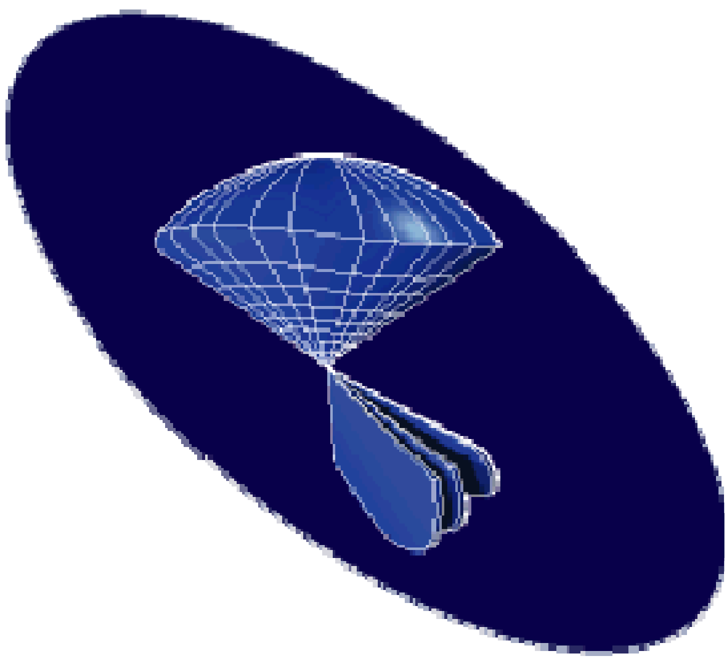
Sloan Digital Sky Survey II

Project Execution Plan



Version 1.2

Revised
May 14, 2008

Preface

This Project Execution Plan (PEP) was prepared by the Sloan Digital Sky Survey-II for the National Science Foundation in compliance with the Programmatic Terms and Conditions of the Cooperative Agreement AST-0443905 (effective date 1 July 2005) awarded to the Astrophysical Research Consortium. It concerns the cost, schedule, product goals, management structure, education and public outreach, metrics, and other aspects of the project. It supersedes the SDSS-II Management Plan that was provided to the NSF on 13 July 2004 (and in a slightly updated form on 17 February 2005). This version (v1.2, 14 May 2008) of the PEP is subject to change according to requests from the SDSS Oversight Group within the NSF Division of Astronomical Sciences. Although this document was prepared for the NSF, it will serve as an official reference for all aspects of the project, including activities not funded by the NSF.

Submitted 14 May 2008
Richard Kron, PI
Director, SDSS-II

Revision Log

Rev.	Date	Revision
1.0.1	11/29/05	Updated Figures 1.1, 1.2, and 1.3 to reflect organizational changes.
1.1	08/09/06	Removed “draft” qualifier from the document. Updated organization charts for observing systems (Fig. 4.2), observatory support (Fig 4.3), data processing (Fig. 4.4), and data distribution (Fig 4.5).
1.2	05/06/08	Changed last day of observing to July 14, 2008. Combined DR7 and DR8 into one public release(DR7) Updated organization charts for observing systems (Fig. 4.2), observatory support (Fig 4.3), data processing (Fig. 4.4), and data distribution (Fig 4.5). Updated Appendix E to reflect revised closeout plan. Updated Appendix F Figures F.1.

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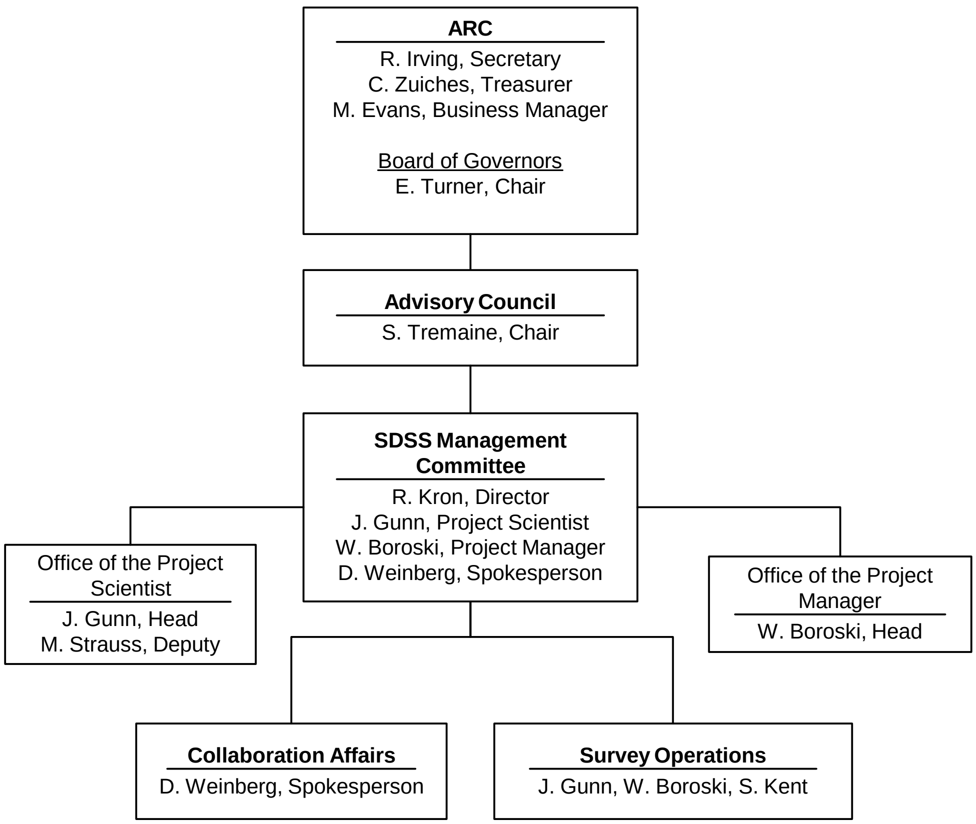
Appendices

1. ORGANIZATIONAL STRUCTURE

This section describes the management of the Sloan Digital Sky Survey (SDSS-II) under the auspices of the Astrophysical Research Consortium (ARC). It describes the roles and responsibilities of ARC, the ARC Board of Governors, the Advisory Council, the Director, the Project Scientist, the Scientific Spokesperson, and the Project Manager. It also describes the roles and responsibilities of other senior personnel serving in key positions within the project.

The flow of accountability from the Board through the Advisory Council to the Director, and then to the Project Scientist, the Project Manager, and the Spokesperson is shown in Figure 1.1.

Figure 1.1. Organization Chart for ARC / SDSS-II Management



1.1. The Astrophysical Research Consortium

The Astrophysical Research Consortium (ARC) was created to provide the faculty, staff, and students from its member institutions access to modern astronomical equipment for their research and educational programs. ARC owns and operates the Apache Point Observatory (APO) near Sunspot, New Mexico. The ARC-managed facilities at APO consist of a 3.5-m general-purpose telescope and its instruments; and the telescopes, instruments, and ancillary support systems developed for the Sloan Digital Sky Survey (SDSS).

The resources for operating ARC facilities have been provided by participating institutions and private, federal and international sources. The ARC Secretary, Ron Irving, the ARC Treasurer, Carol Zuiches, and the ARC Business Manager, Michael Evans, administer the funds received by ARC. ARC disburses some of these funds to the participating institutions through formal agreements and the remainder through contracts managed directly by ARC. New Mexico State University, an ARC member, manages the operations at APO for ARC. The ARC Business Manager directly administers large contracts with vendors when it is advantageous to ARC.

Oversight of ARC operations is the responsibility of the Board of Governors, hereafter the Board. The institutions that constitute the Board are the University of Chicago, the University of Colorado, the Institute for Advanced Study, Johns Hopkins University, New Mexico State University, Princeton University, and the University of Washington.

Two members represent each institution on the Board and the members are drawn from active scientists and senior university administrators. The Chair of the Board is Dr. Edwin Turner of Princeton University. The Board directly oversees the 3.5-m telescope program but created the Advisory Council to advise the Board on matters related to the SDSS, in view of the large scale of the SDSS program and the very large number of institutions participating in that program.

1.2. The Advisory Council

The Board has delegated the oversight and management of SDSS-II to the Advisory Council. The Acting Chair of the Advisory Council is Dr. Scott Tremaine of the Institute for Advanced Study.

Institutional membership on the Advisory Council is granted to those ARC institutions that make significant cash or in-kind contributions toward the operation of SDSS-II. Non-ARC institutions become full participants through Memoranda of Understanding (MOU) with ARC. Each Participating Institution may appoint one voting member to the Advisory Council.

Advisory Council actions are governed by the Principles of Operation-II (PoO-II). The PoO-II is approved by the Board.

1.3. The Directorate

The Board delegates to the Director the executive authority for the operation of SDSS-II. To this end, the Director is responsible for organizing and directing all aspects of the Survey, including the appointment of key personnel. The Director is responsible for ensuring that the available resources are effectively applied toward the scientific goals described in the PoO-II.

1.3.1. The Director

The Board, taking into consideration the recommendation of the Advisory Council, appoints the Director for a fixed term. The Board appointed Richard Kron of The University of Chicago and Fermilab as the Director for a 3.5-year term beginning July 1, 2005. He has arranged for reduced teaching responsibilities such that he can devote essentially full time to the project.

The Director is responsible for preparing the SDSS-II Project Execution Plan and submitting it to the Advisory Council for approval. He leads the preparation of funding proposals for the operation of the Survey. ARC submits these proposals to federal agencies and philanthropic institutions and the Director serves as the Principal Investigator for these proposals. He is responsible for drafting, for concurrence by the Advisory Council and approval by the Board, the Memorandum of Understanding with any new Participating Institution.

The Director submits both an annual budget and a total budget for the completion of the Survey to the Advisory Council. These budgets include all funds and in-kind services needed for the operation of the Survey, including the acquisition, processing, archiving, and distribution of data to the collaboration and general public. The Advisory Council transmits the Director's budgets along with its recommendations to the Board for approval.

The Director is responsible for implementing financial controls within the project. He is assisted by the Project Manager and ARC Business Manager. The Director approves all expenditures above $3000. The Director and ARC Business Manager approve all computer purchases in accordance with ARC corporate policy. The Project Manager tracks expenditures against the approved budget and advises the Director of financial status and performance.

The ARC corporate office, under the general supervision of the ARC Treasurer, assists the Director and Project Manager with the preparation of the annual budgets and quarterly progress reports. The ARC Business Manager provides quarterly Revenue and Expenditure Reports to the Director, Project Manager, and Advisory Council to show expenditures and obligations compared to the annual budget.

1.3.1. Management Committee

The Management Committee provides a forum for the discussion and framing of issues that require action by the Director and/or Advisory Council. The Director, the Project Scientist, the Project Manager and the Spokesperson constitute the Management Committee; the Director is the Chair. It examines and acts on all issues that have a broad impact on the Survey. When the resolution of an issue requires the approval of the Advisory Council or the Board, the Management Committee reviews the matter and formulates a recommendation for action by the Advisory Council.

1.3.2. Project Scientist

The Director has appointed James Gunn of Princeton University as the Project Scientist. The Director has delegated to the Project Scientist the responsibility for providing the overall quality assurance for the Survey and ensuring its scientific integrity. The Project Scientist monitors the performance of all systems and evaluates the scientific impact of proposed changes to hardware, software, and operating plans. The Project Scientist tracks the progress made on the development of critical new hardware and software systems (i.e., for SEGUE and for Supernova, as well as final photometric calibration) before they can be certified as meeting the science requirements. He is responsible for assuring the Director that the performance of all systems will meet the scientific goals of the Survey.

The Deputy Project Scientist, Michael Strauss of Princeton University, assists the Project Scientist in the implementation of his responsibilities. The Deputy Project Scientist is responsible for definition and documentation of the science requirements for all aspects of SDSS-II. The Project Scientist and his deputy are responsible for developing and coordinating tests of the scientific integrity of SDSS-II data, comparing the results of these tests with the requirements, and suggesting action to address concerns where these requirements are not being met and the science goals of the project might be compromised.

The Deputy Project Scientist chairs a weekly phone conference of software developers and SDSS scientists. These meetings include discussion of testing of new software, priorities for effort, and coordination of data releases to the collaboration and the public.

1.3.3. Project Manager

The Director has appointed William Boroski of Fermilab as Project Manager. The Project Manager assists the Director in the performance of his responsibilities. The Project Manager is responsible for developing and maintaining project schedules. He is responsible for preparing annual and cost-to-complete budgets for consideration by the Director and the Project Scientist prior to their submission by the Director to the Advisory Council. He is responsible for tracking project expenditures against the approved budget and reporting them, together with any deviations from the approved budgets, to the Director on a timely basis. He is responsible for preparing annual and quarterly reports that are distributed to the Advisory Council and the funding agencies.

The Project Manager oversees day-to-day operations associated with Survey Operations. He coordinates the engineering effort at APO with the efforts of the engineering groups at the Participating Institutions and the requirements of the observing program. He coordinates the software effort at the Participating Institutions with the requirements of the data processing and distribution programs. He identifies resources at the Participating Institutions when additional resources are needed to meet schedules.

The Project Manager is responsible for informing the Director and the Project Scientist of the state of compliance of Survey Operations with survey metrics. The Project Manager is responsible for developing and maintaining the project schedule and determining the schedule performance of Survey Operations. The Project Manager is responsible for negotiating and managing the institutional work agreements. The Project Manager maintains the list of new work requests until each new project is approved, assigned, and integrated into the overall project plan; or rejected based on the lack of sufficient justification.

1.3.4. Scientific Spokesperson

The Director has delegated the management of the affairs of the SDSS-II collaboration to the Scientific Spokesperson. He has also delegated to the Spokesperson the primary responsibilities for representing the Survey to the scientific community and for raising the visibility of the Survey within the astronomy and physics communities. Accordingly, the Spokesperson oversees the publication of scientific, technical, and data release papers. The Spokesperson is also charged with promoting the collective scientific productivity of the SDSS-II Collaboration.

The Spokesperson is elected by a majority vote of the collaboration. In the event the Spokesperson resigns or becomes unable to serve, the Director will appoint an acting Spokesperson. David Weinberg of Ohio State University was elected spokesperson .

1.3.5. External Advisory Committees

The Director may form ad hoc external Advisory Committees to provide him with advice on the capabilities of the Survey to acquire and process data and to distribute the archived data products to the Collaboration and general astronomy community. These committees will review the effectiveness of observing operations, data processing, and the distribution of data and make recommendations for improvement if survey operations do not meet the expectations of the sponsors. The members of these committees will consist of scientists (primarily astronomers), engineers, and computer professionals with experience in large projects, and who are not engaged in the Survey.

1.4. Survey Operations

The Director has formed Survey Operations to provide an organization to manage the operation of the Survey. The organization chart for Survey Operations is shown in Figure 1.2. Survey Operations consists of four technical groups – Observing Systems, Observatory Operations, Data Processing, and Data Distribution. It also includes Project Teams organized around specific scientific interests and issues. The Heads of the technical groups and the Project Teams advise the Management Committee on matters related to operations.

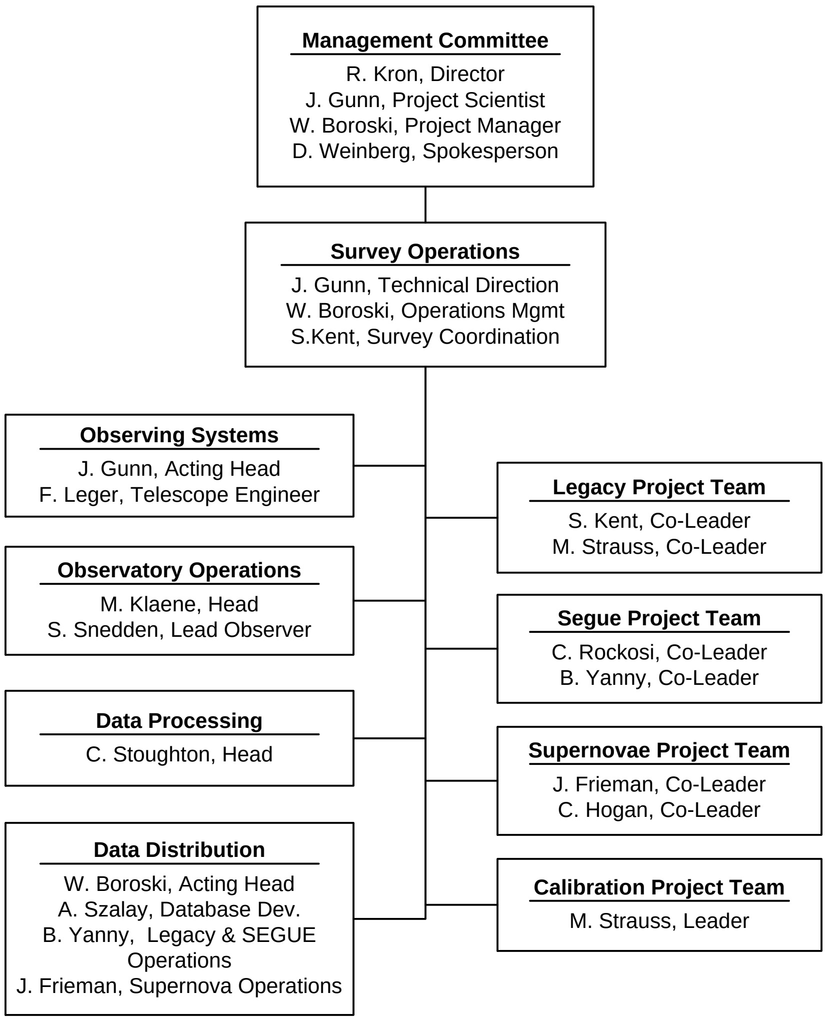
The Director appointed the Acting Head of Observing Systems, the Head of Data Processing, the Head of Survey Coordination, the Acting Head of Data Distribution, and the Project Team Leaders. ARC appointed the Site Operations Manager, Mark Klaene, who oversees Observatory Operations and whose assigned duties at APO are broader than just the SDSS-II.

The Project Scientist is responsible for setting the technical direction and goals of the technical groups and for reviewing the level of observatory support to assure that it is sufficient for the proper execution of the Survey. He sets priorities when the goals of the groups are in conflict.

The Project Manager is responsible for overseeing day-to-day operations of the various project components, planning the general application of resources on an annual basis, and reacting to immediate needs of the survey. The survey operations work plan is coordinated through a weekly teleconference chaired by the Project Manager. The participants in the weekly conference include the Project Scientist, Head of Survey Coordination, Site Operations Manager, Lead Observer or representative, Telescope Engineer, and key personnel at the APO site and participating institutions.

The Head of Survey Coordination provides the strategic and tactical direction of the observing program, tracks survey progress, and generates monthly observing plans. The Head of Survey Coordination also provides direction for the off-mountain efforts related to the fabrication of plug plates for spectroscopy. Stephen Kent is the Head of Survey Coordination. Stephanie Snedden is the Deputy Head of Survey Coordination; she is also the Lead Observer. The Lead Observer is responsible for scheduling the observing staff and implementing the monthly observing plans.

Figure 1.2. Organization Chart for Survey Operations



1.4.1. Observing Systems

The Observing Systems group is responsible for maintaining the Observing Systems in an operational state throughout the observing phase of operations. The Observing Systems consist of the 2.5-m telescope, the CCD imaging camera, the dual spectrographs, the 2.5-m instrument change system, the equipment for plugging spectroscopic plates, the Photometric Telescope (PT) and its instruments, and the data acquisition system for both telescopes (which now includes the mountaintop Supernova computing system). The group is responsible for maintaining and improving the software used to operate the telescopes and instruments (the Observers' Programs) and the data acquisition equipment at APO. In addition, it is responsible for implementing incremental improvements that will increase the efficiency of these subsystems. Finally, it is responsible for assuring that the aforementioned systems can meet the Science Requirements. The Acting Head of Observing Systems is James Gunn.

1.4.2. Observatory Operations

Observatory Operations are carried out under the direction of the APO Site Operations Manager, Mark Klaene. APO provides all of the basic services and facilities to the technical groups that are needed to carry out their work at the site. APO provides and trains the observing staff that carries out the observations for the Survey. The Site Operations Manager is responsible for providing the observer team with office and laboratory space, onsite and offsite computer networks, and desktop computing. The Site Operations Manager is responsible to ARC for the safe conduct of all activities at the Observatory. The APO Safety Officer, Mark Klaene, provides safety oversight for all activities at APO, establishes the qualifications for all people to engage in various tasks while working at the Observatory, and maintains their training records. In order to fulfill this responsibility, APO provides the safety training for staff engaged in activities at the Observatory.

1.4.3. Data Processing

The Data Processing (DP) group is responsible for processing data for the Legacy, SEGUE, and Supernova Surveys. Data processing operations occur at Fermilab, Princeton, and APO. The Head of the DP group is Chris Stoughton.

The Fermilab members of the DP group, with the support of facilities and people from the Fermilab Computing Division, are responsible for processing Legacy imaging and spectroscopic data, SEGUE imaging data, and Supernova imaging data, and data from the PT. They are responsible for all software and computer systems used to process data at Fermilab.

The Princeton members of the DP group are responsible for processing SEGUE spectroscopic data. They are also responsible for the software and hardware systems used to process data at Princeton.

Supernova data are processed primarily at APO by members of the SN data processing team. This group is responsible for the operation and maintenance of software and hardware used to process SN data at APO.

As a whole, the DP group is responsible for archiving the data and making the files available to the Collaboration, in accordance with the requirements for the specific surveys. The DP group is responsible for assuring that the quality of the data in the Operational Database and the Science Archive meets the Science Requirements. Weekly quality assurance (QA) teleconferences are held with members of the DP group, the Project Scientist, the Project Manager, the Lead Observer, the Telescope Engineer and others to review and discuss data quality matters. The forum ties together QA activities at the observatory with data processing QA activities and facilitates the prompt identification and resolution of problems should they arise. It also facilitates the development of new tests and procedures to continuously improve the effectiveness of the QA program.

Weekly teleconferences, chaired by the Deputy Project Scientist, Michael Strauss, review the state of data processing software, discuss the results of ongoing tests of the processed data, and provide a forum for setting priorities to meet survey requirements. This forum is also used to plan work needed to support future data releases.

1.4.4. Data Distribution

The Data Distribution (DD) group is responsible for all software and computer systems that are used to distribute the SDSS data to the collaboration and general astronomy community. Data distribution activities are coordinated by William Boroski.

Distribution of Legacy and SEGUE data to the Collaboration and public is via a web interface. There are three primary access tools: the Data Archive Server (DAS), the Catalog Archive Server (CAS), and the SkyServer. The DAS enables direct access to files in the survey archive. The CAS enables efficient searches in the database of derived parameters. The SkyServer provides a user interface designed to promote education and outreach and provide the general public with easy access to the data archive. These tools have some overlap in their functionality, but are otherwise complementary.

The CAS and SkyServer were developed by the Database Development Group at JHU, and Jim Gray of Microsoft. Alex Szalay of JHU is Head of the Database Development Group. The Database Development Group is responsible for maintaining and improving the CAS and SkyServer to support the prompt distribution of data to the collaboration, astronomy community, and general public. The group is responsible for fully documenting the CAS and SkyServer and assisting with their deployment and use by the Data Distribution Operations Group at Fermilab. The Database Development Group is also responsible for hosting a mirror site of the most current data release, which provides a high degree of data integrity by hosting the data archive at two geographically distinct sites.

The DAS was developed at Fermilab by the DP group. The Data Distribution Operations Group, located at Fermilab, is responsible for loading and maintaining the DAS. The Data Distribution Operations Group is also responsible for setting up and managing a CAS/SkyServer production system at Fermilab, with assistance from JHU. The Data Distribution Operations Group is responsible for loading data files into the CAS, verifying data integrity, and making the CAS and SkyServer interface available for collaboration and public access in accordance with the data distribution schedule. The Data Distribution Operations Group is also responsible for supporting and maintaining the machines, disk drives and network devices used to support the DAS and CAS. Brian Yanny of Fermilab is Head of the Legacy & SEGUE Data Distribution Operations Group.

Weekly teleconferences review the state of the Legacy and SEGUE data access tools, coordinate development and implementation work, and provide a forum for setting priorities and planning work to meet data distribution requirements.

Distribution of Supernova data to the Collaboration and public is via several web-accessible databases and a DAS. One database holds imaging data and GIF versions of image cut-outs that are used to identify SN candidates. A second database holds SN candidates and the corresponding data that help determine the likelihood that a candidate is a Type Ia. An instance of the DAS will be used to provide data files (object catalogs and corrected frames) to the Collaboration and public. Work on the Supernova data distribution systems is being performed at Fermilab under the direction of Chris Stoughton. The Fermilab group is responsible for developing, maintaining and documenting the systems used to host and serve SN data.

As is the case with SDSS data releases, SDSS-II participants may wish to establish informal web sites to host SDSS-II data, but ARC takes no responsibility for these sites.

1.4.5. Project Teams

A number of Project Teams undertake efforts that assist survey operations. These efforts include the design of target-selection algorithms, the specification of required calibrations, monitoring pipeline outputs for quality assurance of the data, optimizing the sequence of observations for the end-game, and writing technical papers. The Project Teams also serve as centers of expertise to advise on matters of the optimal observing strategy, necessary systems or software development, analysis software, the specific content of periodic data releases, and other matters related to operations.

The Project Team Leaders are appointed for the duration of the SDSS-II survey by the Director, in consultation with the Management Committee. Stephen Kent and Michael Strauss are co-leaders of the Legacy Project Team. Constance Rockosi and Brian Yanny are co-leaders of the SEGUE Project Team. Joshua Frieman and Craig Hogan are co-leaders of the Supernovae Project Team. Michael Strauss is leader of the Calibration Project Team.

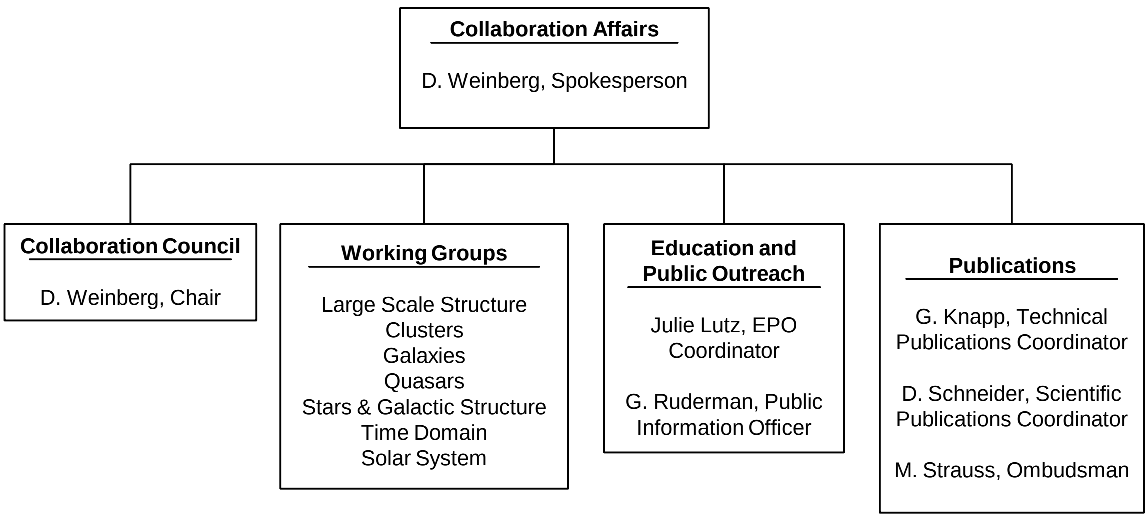
Participants in the SDSS-II are encouraged to join Project Teams of interest to them. It is understood that with the exception of Project Team Leaders, Project Team members have no specific responsibilities with respect to survey operations.

1.5. Collaboration Affairs

The Collaboration consists of scientists from the Participating Institutions. Its membership also includes scientists from non-participating institutions who have earned data access rights through their contributions to survey infrastructure; and external collaborators who provide expertise on specific projects.

The Collaboration provides opportunities for its members to exchange information and ideas freely, thereby assisting the pursuit of their individual research goals. Collaboration Affairs was formed to accomplish these goals. The organization chart is shown in Figure 1.3.

Figure 1.3. Organization Chart for Collaboration Affairs



The Spokesperson is responsible for organizing Collaboration Affairs, chairing the Collaboration Council, and nominating the Technical Publications Coordinator, the Scientific Publications Coordinator, and the Ombudsman. A major responsibility of the Spokesperson is to create a healthy collegial environment in which the pursuit of the scientific goals of the Survey can flourish. Special attention is paid to the mentoring of postdocs and graduate students, and to rules governing graduate student theses involving Survey data. The principles guiding the work of the Collaboration are spelled out in the PoO, Publications Policy, and similar documents. As required, the Spokesperson is responsible for proposing and/or revising collaboration-specific policies for approval by the Management Committee and the Advisory Council.

The Spokesperson arranges for the organization of presentations at the meetings of professional societies, in the course of discharging his responsibilities for representing the Survey to the scientific community and for raising the visibility of the Survey within the astronomy and physics communities. He consults CoCo on these matters and brings them to the attention of the Management Committee. The Publications Office provides the Collaboration with a means to oversee the preparation of technical and scientific publications.

The Spokesperson, with the help of CoCo, solicits offers from Participating Institutions to hold Collaboration meetings at roughly six-month intervals. The organization and agenda for each meeting is the responsibility of the local organizing committee. The agenda and special events are reviewed and approved by the Spokesperson in consultation with the CoCo.

1.5.1. Collaboration Council

The Collaboration Council (CoCo) assists the Spokesperson in the management of Collaboration Affairs. It provides advice to the Spokesperson on all Collaboration matters, including recommendations for policies on publications, scientific representation, and science projects. The membership consists of one person from each Participating Institution who is appointed by the member of the Advisory Council from that institution. In addition, one of the External Participants is elected by the External Participants to serve on CoCo. The Spokesperson generally serves as the Chair of CoCo.

The Chair of CoCo is responsible for ensuring that CoCo meets regularly to discuss matters pertaining to the health of the Collaboration and to advise the Spokesperson.

CoCo is responsible for reviewing proposals for science projects that include external collaborators. External collaborators bring special expertise to a particular project and the capacity to enable the project so that its results can be published in a timely way. In exchange for their assistance, external collaborators are given access to the data appropriate for the specific project and become eligible for authorship on that research.

CoCo is responsible for organizing and conducting the election of the Spokesperson.

1.5.2. Working Groups

The Working Groups facilitate the work on the science goals of SDSS-II. The Collaboration and the Working Groups are organized to allow individual scientists a great deal of freedom in pursuing their scientific projects. For example, any participant may join in any project. Working Groups were formed to address specific topics, including large scale structure, clusters, galaxies, quasars, stars and Galactic structure, time domain, and solar system. The Director, on the recommendation of the Project Scientist and the Spokesperson, may create a new Working Group or dissolve an existing one. The Spokesperson is responsible for providing a charge to each of the Working Groups and to review their activities from time to time. The Working Group chairs are appointed for the duration of the survey by the Director, based upon recommendations from the Spokesperson.

1.5.3. Education and Public Outreach

The principal goal of the SDSS-II Education and Public Outreach (EPO) effort is to make the discoveries, data, and methods of the SDSS-II intelligible and interesting to a broad audience of non-scientists. To realize this goal, we are creating a new position called SDSS-II EPO Coordinator. Dr. Julie Lutz has agreed to serve in this capacity. She will review the current suite of EPO efforts already underway and assemble them in creative ways, identifying strengths around the Collaboration that may be put together for an even greater benefit.

The Public Information Officer handles press releases and communication with the news media. The Spokesperson is responsible for providing the Public Information Officer with the scientific and technical information that will be distributed in press releases and other communications with the media. The Public Information Officer is responsible for coordinating and organizing the work of the Public Information Officers at the other Participating Institutions in order to assure that the interests of all of the Survey sponsors are properly served.

1.5.4. Publications Office

The Spokesperson oversees the Publications Office, which provides a means to disseminate scientific results in draft form to the collaboration. This enables review of the scientific content of draft papers.

The Scientific Publications Coordinator and the Technical Publications Coordinator are appointed for the duration of the SDSS-II survey by the Spokesperson. The Spokesperson maintains a web page on www.sdss.org listing all published papers and papers approved for publication in refereed journals. These papers include papers posted on astro-ph and conference proceedings. A separate, internal web page, accessible only to the Collaboration, is maintained for work in progress prior to its acceptance for publication. Policies and procedures for the publications are posted on www.sdss.org.

The Ombudsman is appointed by the Spokesperson for the duration of the SDSS-II survey. The Ombudsman is responsible for resolving conflicts that arise on matters related to publications when they cannot be resolved by the authors, the Publications Coordinators, or by the Spokesperson.

2. BASELINE PROJECT DEFINITION

2.1. Cost

The SDSS-II baseline cost estimate is shown organized by WBS in Table 2.1.

Table 2.1. SDSS-II Cost Estimate

1.0	Survey management	$1,629K
2.0	Survey operations	
	2.1. Observing Systems	$ 2,552K
	2.2. Observatory operations	$ 5,174K
	2.3. Data processing	$ 2,390K
	2.4. Data distribution	$ 1,451K
	2.5. ARC support for operations	$ 207K
	Survey Operations sub-total	$ 11,774K
3.0.	New Development	
	3.1. SEGUE development	$ 369K
	3.2. Supernova development	$ 258K
	3.3. Photometric calibration	$ 146K
	3.4. Data acquisition system upgrade	$ 241K
	New Development sub-total	$ 1,013K
4.0.	ARC Corporate Support	$ 179K
5.0.	Public Outreach	$ 0K
6.0.	Management Reserve	$ 305K
TOTAL		$ 14,900K

The SDSS-II WBS is discussed in Section 3. WBS elements 1, 2, and 4 constitute the core aspects of running the survey; the cost estimate for these sections is based on the experience gained during the past four years of SDSS-I operations. In preparing the cost estimate for SDSS-II, each cost element in each section was carefully scrutinized. We reviewed staffing needs in each section; as a result, the size of the staff supporting SDSS-II operations will be slightly less than that employed for SDSS-I. We also reviewed the budget for travel, materials, supplies and observatory operating expenses, and made reductions where possible without impacting safety, equipment protection, data quality, or operating efficiency.

WBS element 3 captures the work and budget associated with new development. The development budget is based on the level of support required to develop the software and systems necessary to achieve the science objectives of the survey. The development budget can be broken down as follows:

1. The SEGUE development budget provides salary support for 4 FTEs to develop the data reduction and distribution software for the SEGUE program. The SEGUE budget also provides $70K for data processing and distribution hardware and an additional $17K for travel and other miscellaneous expenses.

2. The Supernova development budget provides salary support for 2.5 FTEs to develop the hardware and software systems to process and distribute Supernova data. The Supernova budget also provides $70K for data processing and distribution hardware, and an additional $15K for travel and miscellaneous expenses.

3. The Photometric Calibration budget provides salary support for 1.8 FTEs to finish the development and testing of the calibration software, compare results to externally calibrated data, and develop the means for integrating the calibration into the production data processing operation. The budget also provides an additional $4K for travel and miscellaneous expenses associated with this work.

4. The data acquisition system (DA) upgrade is necessary to address obsolescence and reliability issues present in the current system. Some critical components of the DA system are obsolete and no longer available. In addition, there are hardware problems in the existing system with the potential to seriously impact observing operations. The DA upgrade budget provides 1.15 FTEs of salary support for computer professionals to upgrade system hardware with current technology and port existing code onto the new platform. The budget provides $105K for hardware replacements and $10K for travel to install and commission the improved system.

The $14.9 million budget approved by the Advisory Council provides for development, operations, and close-out costs for the three-year Survey. In addition, The Ohio State University (OSU) and the American Museum of Natural History (AMNH) are contributing "additional services" with a combined value of $390K. Ohio State is building a new spectrometer for the Supernova survey, a contribution valued at $200K. The American Museum of Natural History is undertaking a range of educational programs valued at $190K. These efforts will occur at the two respective sites and were added to the project after the original budget had been prepared and approved. Therefore, the value of these “additional services” is not included in the $14.9 million budget.

WBS element 6, Management Reserve, holds the project contingency fund. The level of contingency is deemed to be too low at 2% of the project cost. As described in Section 11, Contingency Management, we have raised additional funds from the institutional partners that will be applied as additional contingency. These additional funds are not included within the $14.9 million budget.

2.2. Schedule

The observing systems at Apache Point Observatory will be operated full time from 1 July 2005 through 14 July 2008 for SDSS-II data collection. ("Full time" means useful for the project goals, and thus bright moon time is not used. We also require down time in the summer for aluminization and other critical maintenance.)

Data are processed and made available to the SDSS-II Collaboration as soon as they are calibrated (Data Archive Server) and as soon as they are loaded into the database (Catalog Archive Server and SN databases). The new SEGUE spectroscopic pipeline is not required to be fully implemented until July 2006. When it is fully implemented, we will reprocess the SEGUE plates obtained up to that time and reload the databases.

Public releases of Legacy and SEGUE data will be made by 1 July 2007 (DR6), and by 1 December 2008 (DR7). DR6 will consist of all imaging data obtained up to 1 July 2006, and all spectroscopic data within that same footprint. DR7 will consist of all data that can be routinely handled and that can be calibrated, even data that do not meet SDSS-II data-quality standards (such data will be so identified).

The corrected frames from the Supernova survey will be made publicly available much faster: frames taken in September of each season will be available in a bulk release around 31 October, and so on. Good candidates for Type Ia supernovae will be publicly announced within days of discovery to enable maximum benefit from follow-up spectroscopy.

In the fourth quarter of each calendar year, an expense summary will be prepared for that year and a budget request for the following year will be presented to the Advisory Council for approval, and subsequent approval by the ARC Board of Governors. Quarterly and annual reports will be prepared for the Advisory Council, A.P. Sloan Foundation, and NSF.

2.3. Data Product Goals

Legacy: Complete the acquisition of photometric imaging data for the region defined by Stripe 10 through Stripe 37. The area yet to be completed is estimated to be about 200 square degrees. Complete the acquisition of spectroscopic data for galaxies and quasars for tiles within this same footprint, using the same targeting algorithms and quality criteria as for SDSS-I. The number of additional tiles necessary to complete the coverage is estimated to be approximately 500, or equivalently about 240,000 galaxy spectra and about 32,000 quasar spectra. The data products (images, photometric parameters, spectra, and spectroscopic parameters) will be the same as for SDSS-I.

SEGUE: Obtain photometric imaging data of the stripes depicted at http://home.fnal.gov/~yanny/fut/layout.html, a network comprising a total of about 3500 square degrees of imaging data. Obtain spectroscopic data for stars within 200 tiles depicted at the same site. Each tile has two plates, each targeting 600 stars. 135 of the tiles will uniformly probe the Milky Way at all accessible longitudes and latitudes, and 65 will sample specific directions, such as well-calibrated open clusters. The bright plate selects to $r = 17.8$ (S/N per pixel > 30), and the faint plate selects to $r = 20$ (S/N per pixel > 10). There are 11 targeting categories for stars, based on color and magnitude, applied uniformly across the sky. For all stars measured with S/N per pixel > 22.5, radial velocities will be accurate to at least 7 km/sec (1 sigma, $g-r > 0.5$) or 11 km/sec ($g-r < 0.5$). For stars with S/N per pixel > 22.5, measures of Teff, log g, and [Fe/H] will be accurate to 150K, 0.5 dex, and 0.3 dex, respectively (1 sigma). These atmospheric parameters will be included in the standard catalogs.

Supernova: During each of three 90-day campaigns, obtain light curves for Type Ia supernovae in 300 square degrees of Stripe 82 useful for constraining cosmological parameters. To be considered useful, each light curve should have at least one observation before peak, at least 7 data points with S/N > 5 in one filter, at least one point with S/N > 10 in each of three bands, and a good fit of the data to a template light curve. Early identification of likely Type Ia candidates, based on available colors and magnitudes, will be publicly announced to enable timely follow-up with other telescopes. The survey products will be these early announcements; the calibrated light curves (each with derived distance modulus, extinction, and SN intrinsic color); calibrated spectra and redshifts where available; and the corrected frames and object catalogs for all of the scans.

2.4. Science Outcome Goals

Legacy: The goal of Legacy is to complete the photometric and spectroscopic coverage of the North Galactic Cap to create a contiguous map of 7700 square degrees. In so doing, the contiguous volume of the galaxy redshift survey will be substantially increased, and the surface-to-volume ratio will be substantially decreased, which will enhance the resolution in k-space of the galaxy power spectrum, as well as the precision of higher-order measures of galaxy clustering. The improvements in the measurement of the power spectrum will constrain the nature of inflationary fluctuations as modified through the epoch of matter-radiation equality. The improvement in the measurement of the baryonwiggle amplitude will constrain the ratio of Omega_b to the total mass density, while the measured wavelengths constrain the geometry (and hence Omega_lambda) and the Hubble constant. Another test of inflationary models comes from the higher-order statistics, which place limits on non-Gaussian primordial fluctuations.

A globally calibrated, filled survey of the North Galactic Cap enables the photometry of an object in one part of the sky to be compared to another 100 degrees away to an accuracy of 1%. This capability allows the measurement of the galaxy power spectrum on the largest scales via photometric redshifts.

SEGUE: The goal of SEGUE is to unravel the structure, formation history, kinematical and dynamical evolution, chemical evolution, and dark matter distribution of the Milky Way. These results will form a basis for our knowledge of the formation of the Milky Way Galaxy and be a cornerstone for our understanding of galaxy formation processes in general. The data will make possible the discovery of all major halo substructures visible in the Northern hemisphere, including relic streams from merger events. Low Galactic latitude imaging and spectroscopy enable studies of the metal-rich Galactic thin disk, the vertical structures of the thin and thick disks, the disk-halo interface, and the warping and flaring of the Galactic disks.

Supernova: The SN Ia Hubble diagram will be populated with 40 to 70 supernovae in each of three redshift bins spanning the range $0.05 < z < 0.35$. These distances and redshifts will measure the cosmic scale factor with a precision of 0.02 mag in distance modulus in each redshift bin, which will constrain the equation of state parameter w in conjunction with priors from other surveys. The Supernova survey will control systematics by virtue of the uniformly calibrated, well characterized photometric system; by achieving dense sampling of the light curves in multiple bands; and by including extensive spectroscopic follow-up. Such control of systematics will allow study of the color/peak brightness/decline-rate relationship and to search for any second parameters. The survey will obtain rest-frame u-band template data needed for the interpretation of samples obtained with space missions. The survey will discover and select for spectroscopic follow-up rare supernova types based on their colors, including for example type Ibc hypernovae thought to be associated with gamma-ray burst sources.

2.5. Survey Priorities and Monitoring Survey Progress

The three surveys are interleaved with each other: Legacy and SEGUE are both conducted in the Spring, and SEGUE and Supernova are both conducted in the Fall. This interleaving enables us to use the telescope effectively throughout the year. In the following we outline the constraints that result in an unambiguous observing plan for a given season.

Almost all of the Legacy imaging is completed; hence the competition between Legacy and SEGUE in the Spring is mostly for spectroscopic observations, which are obtained in non-photometric conditions. If conditions are photometric, we will obtain any remaining Legacy imaging as the top priority. If no Legacy imaging area is available and conditions are photometric, then we will conduct SEGUE imaging. If all of the imaging has been completed for both Legacy and for SEGUE, then photometric time will be used to complete spectroscopy for Legacy and for SEGUE, in that order.

If conditions are spectroscopic, we will give Legacy top priority but allow also for some SEGUE spectroscopy. This will be done by declaring, at the beginning of each observing season, a conservative goal for the number of Legacy plates. At the beginning of the next season, the number of Legacy plates in the goal can be adjusted up or down according to the actual performance in the previous season. SEGUE is then given all remaining spectroscopic time in the Spring season. By such parallel scheduling of plates, we can take best advantage of the sidereal time range of the plate inventory. If Legacy is running behind schedule as of the last season, Spring 2008, all of the spectroscopic time potentially useful to Legacy will be given to Legacy. The SEGUE stripes and tiles are prioritized, so that at the end of the survey, we will have obtained data in the highest-priority directions in the sky.

As a concrete guide to the expected rate of obtaining new spectroscopic plates, we use the past history of progress in SDSS-I. The projections derived from past performance are detailed in the "Schedule for the Three-Year Baseline Plan for SDSS-II Operations" (included as Appendix A) and provide the fundamental mechanism for tracking survey progress (just as we have done in SDSS-I). The Three-Year Baseline Plan allocates 993 hours for Legacy, which would be sufficient to yield 550 plates if the rate of obtaining plates is like that of SDSS-I. We actually need only 500 plates to finish Legacy, but as always are at the mercy of the weather.

In the Fall observing season, September, October, and most of November are allocated to the Supernova survey, where imaging is attempted even in spectroscopic conditions. The right ascension range of the Supernova survey is from 20 h to 4 h; whenever this area is not accessible for at least 1.5 hours at an hour angle of less than 3.25 h, the time is given to SEGUE (e.g., the ends of the nights later in the Fall). Since the Supernova science goals can be met without sampling every night within a string of clear nights, there will be opportunities for additional time to be given to SEGUE (for either imaging or spectroscopy, depending on the needs, and what the weather permits).

Progress can and will be monitored more frequently than every year, of course. Internal reviews are undertaken every dark run by the Head of Survey Coordination and by the Project Teams. The interaction of these operations groups, with the Management Committee's oversight, allows the observing plan for the next dark run to be formulated, taking into account any relevant factors. Moreover, the SDSS-II Director will report actual progress with respect to the adopted Three-Year Baseline Plan on a quarterly basis. These written reports, together with regular reports presented by the Director at Advisory Council and Executive Committee meetings, will ensure that the Participating Institutions are informed and have an opportunity to advise the Director with respect to the general plan for subsequent observations and the prioritization amongst the three surveys in this plan.

2.6. Achievable Metrics

We will monitor the progress of the three surveys with respect to a projection (the Three-Year Baseline Plan) based on past average rates (as we have done in SDSS-I). For Legacy and SEGUE, progress will be measured according to the data quantity (square degrees and number of spectra) that meet the data quality criteria. The basic metric for the Supernova survey is the number of rapidly announced Type Ia supernovae.

Data quantity itself does not fully address whether we are making adequate progress on meeting the scientific goals described above. In addition to the data-volume metrics, we will also undertake periodic analyses that will provide scientific evaluation, as follows:

Legacy: A scientific goal that lends itself to a useful metric is to improve the resolution in k-space in the galaxy power spectrum by some significant factor by the end of the SDSS-II Survey (14 July 2008) with respect to the end of SDSS-I (1 July 2005). We will track progress by simulating yet-to-be-obtained data with an adopted tiling pattern and adopted order in which the tiles are obtained. These simulations will quantify the progress based on this scientific criterion and will provide a basis for choosing between different possible observing sequences as a hedge against much-worse-than-average weather or a serious system failure. We will undertake a science review of the Legacy progress after each observing season, i.e. in July 2006 and again in July 2007.

SEGUE: To realize the scientific goals of SEGUE, we need to sample the entire sky visible from Apache Point Observatory with stripes and tiles separated by 10 to 20 degrees. By doing so, no detectable stream will avoid being identified, and the key structural components of the Milky Way will be adequately sampled. The required number of spectroscopic target stars in each direction (tile), $N \sim 1200$, is determined by the need to measure the radial velocity distribution and other population characteristics as a function of both distance and stellar type.

It is important to note, however, that SEGUE is very much an exploratory project, and we do not know in any detail what we will find. The design makes use of the best interpretation we have been able to muster of the existing very incomplete data, and the specification of scientific metrics is essentially impossible. We can and will measure progress vis-à-vis the baseline we have proposed, which when complete will allow substantial progress in all the scientific areas which SEGUE addresses.

We will undertake a science review of the SEGUE progress in July 2006 and again in July 2007. At these reviews, we will address specifically the progress towards constraining halo sub-structures on various scales, and progress on constraining the parameters describing the major Galactic components: halo, thick disk, and thin disk.

Supernova: Most of the scientific goals depend on the number of high-quality light-curves for Type Ia supernovae. We adopt as a metric the number of good Type Ia light curves found sufficiently early that follow-up spectroscopy can be undertaken. The criteria for "good" described above yield a precision in the peak brightness of about 15% per supernova. Our projections suggest a discovery rate of at least 50 such light curves per season. After the end of the first season (Fall 2005), we will evaluate whether the achieved rate is on track, and if not, we will devise a plan to address the shortfall. We will conduct a second review at the end of the Fall 2006 season.

3. WORK BREAKDOWN STRUCTURE

The SDSS-II Work Breakdown Structure (WBS) is organized to identify the effort, deliverables, and services necessary to meet project objectives. It is also used to identify organizational and individual responsibilities and integrate project scope, cost, and schedule. Table 3.1 presents a top-level view of the WBS. Appendix B contains a more detailed version. The WBS is also maintained online on www.sdss.org.

The WBS organizes work and cost into six areas: Survey Management, Survey Operations, New Development, ARC Corporate Support, Education and Public Outreach, and Management Reserve. Subsequent sections describe the work and costs captured in each area.

Table 3.1. SDSS-II Top-Level Work Breakdown Structure

1.0	Survey Management		
	1.1	ARC Administration	
	1.2	Office of the Director	
	1.3	Office of the Project Scientist	
	1.4	Office of the Project Manager	
	1.5	Office of the Scientific Spokesperson	
2.0	Survey Operations		
	2.1	Observing Systems	
		2.1.1	Technical Support at APO
		2.1.2	Off-mountain Technical Support
		2.1.3	Plug-plate Production
		2.1.4	ARC Support for Observing Systems
	2.2	Observatory Operations	
	2.3	Data Processing	
		2.3.1	Data Processing Operations
		2.3.2	Software and Data Processing Support
	2.4	Data Distribution	
		2.4.1	Data Distribution Operations
		2.4.2	Data Archive Development and Support
	2.5	Survey Coordination	
	2.6	ARC Support for Survey Operations	
		2.6.1.	Additional Scientific Support
		2.6.2.	Observers' Research Fund
3.0	New Development		
	3.1	SEGUE Project Development	
	3.2	Supernova Project Development	
	3.3	Photometric Calibration	
	3.4	Data Acquisition System Upgrade	
4.0	ARC Corporate Support		
5.0	Education and Public Outreach		
6.0	Management Reserve		

3.1. Survey Management

Survey Management encompasses all activities associated with the management and oversight of the project. Descriptions of the roles and responsibilities of each position mentioned below can be found in Section 1, Organizational Structure.

<u>WBS element 1.1: ARC Administration</u>

Captures the work and costs associated with corporate duties performed by the ARC Secretary, ARC Treasurer, and ARC Business Manager. The budget supports a fraction of the salary for the Business Manager and provides a modest amount for administrative support, travel, and office supplies. The budget and scope of work are established under ARC agreements SSP-221 and 234.

<u>WBS element 1.1.2: Office of the Director</u>

Captures the work and costs associated with the work performed by and for the Director. The budget provides for partial salary support, as well as travel and office supply costs. The budget and scope of work are established under ARC work agreement SSP-267.

WBS element 1.1.3: Office of the Project Scientist

Captures the work and costs associated with work performed by the Project Scientist and his Deputy. The budget provides partial salary support for the Project Scientist, as well as travel and office supply costs incurred by the Project Scientist and Deputy. The budget and scope of work are established under ARC work agreement SSP-246.

WBS element 1.1.4: Office of the Project Manager

Captures the work and costs associated with the work performed by and for the Project Manager. The budget provides for salary, travel, teleconference, and office supply costs. The budget and scope of work are established under ARC work agreements SSP-248.

WBS element 1.1.5: Office of the Scientific Spokesperson

Captures the work and costs associated with the activities of the Spokesperson. The budget provides for the cost of administrative support, travel, and supplies needed by the Spokesperson to carry out the duties of this office and is established under ARC agreement SSP-246. The salary of the Spokesperson is provided as an in-kind contribution by his or her host institution and is not included in the cost estimate for the SDSS-II project.

This WBS element also captures the work and costs associated with activities under the direction of the Spokesperson, including Collaboration Affairs and Public Affairs. The budget for Collaboration Affairs provides for technical page charges and travel expenses incurred by Working Group Chairs. The budget for Public Affairs provides for the cost of renting and staffing exhibit booths at American Astronomical Society (AAS) meetings and travel support for SDSS-II speakers invited by the Spokesperson to present SDSS-II results at AAS meetings. An active presence at AAS meetings provides an effective way to distribute current information about the project to the astronomy community. The budget is established under ARC agreement SSP-291.

3.2. Survey Operations

Survey Operations is by far the largest of the top-level work elements and encompasses all activities associated with the day-to-day operation of the project, including Observing Systems, Observatory Operations, Data Processing, Data Distribution, and Survey Coordination. The following sections describe work activities and costs associated with these major elements.

WBS #2.1: Observing Systems

A roll-up level WBS element that captures all of the work and costs associated with maintaining and supporting the equipment that enables the collection of data at APO. This includes the 2.5-meter telescope, the photometric telescope, the imaging camera, the two multi-fiber spectrographs, the data acquisition system, and all ancillary equipment associated with their operation. It also includes the tasks required to fabricate the spectroscopic plug plates, ship them to APO, provide storage until they are used, and prepare them for spectroscopic operations at APO. It also includes the tasks for unplugging observed plates and transferring them to long-term storage.

WBS #2.1.1: Technical Support at APO

A group of technical personnel stationed at APO provide the first line of support and maintenance for the telescopes, instruments, and ancillary systems. The group includes the Telescope Engineer, an instrument specialist, one mechanical technician, one electronics technician, two plug-plate technicians, and a clerical support person. Work performed by the group includes on-going maintenance and support, and when necessary the design and implementation of improvements to meet operational needs and requirements. The budget provides salary support for the group. It also provides for the cost of machine shop services, materials, supplies, and travel incurred by the group. The budget and scope of work are established under ARC work agreements SSP-235 and SSP-242.

WBS #2.1.2: Off-mountain Technical Support

Many of the hardware systems and software applications in use at APO were developed and delivered by individuals working at Participating Institutions. These individuals possess in-depth knowledge and expertise of the systems they built and delivered and are occasionally called upon to assist the site technical staff with troubleshooting, or to implement upgrades as necessary to address obsolescence or similar concerns. The budget provides partial salary support for personnel at Fermilab, Princeton, The University of Washington, Los Alamos National Laboratory, and the U.S. Naval Observatory, as well as funds for materials, supplies and travel required by these individuals to support on-going operations. The budget and scope of work are established under ARC agreements SSP-231, 232, 242, 257, and 258.

WBS #2.1.3: Plug-Plate Production

The aluminum plug plates used for spectroscopic observations are fabricated in the Physics Shop at the University of Washington. This WBS element captures the work associated with producing the plug plates, including management and oversight of the manufacturing operation, plate drilling by machine shop personnel, post-production quality assurance inspections, and plate shipment to APO. The budget provides salary support for the individuals involved in plate production. The budget also covers the cost of materials, expendable supplies (e.g. drill bits), and shipping. The budget and scope of work are established under ARC work agreement SSP-231

WBS #2.1.4: ARC Support for Observing Systems

Larger procurements associated with Observing Systems are frequently managed directly by the ARC Business Manager, since it is often more cost-effective for him to place these large orders directly. Examples of on-going procurements paid directly from the ARC corporate account include the annual aluminization of the primary mirror for the 2.5-m telescope. The budget is established under ARC work agreement SSP-291.

WBS #2.2: Observatory Operations

This WBS element captures the work and costs associated with staffing and maintaining the observatory at the level required to sustain survey operations over the 3-year observing period. This WBS element also contains the work scope and schedule for upgrades to the observatory infrastructure when required to maintain effective operations. The budget provides for technical and observing staff salaries, building and grounds maintenance, utilities and consumables, and other related services. The budget and scope of work are established under ARC agreement SSP-235.

WBS #2.3: Data Processing

This roll-up WBS element captures the work and costs associated with processing and calibrating data for the Legacy, SEGUE and Supernova projects. During observing operations, the following types of data are recorded: 2.5-meter imaging data, 2.5-meter spectroscopic data, and PT calibration data. Work associated with data processing is separated into two components: activities associated with production data processing operations; and activities associated with the maintenance and support of data processing pipelines and calibration software.

WBS #2.3.1: Data Processing Operations

This WBS element captures the work and costs associated with routine data processing operations. SDSS-II data processing operations occur at three locations: Fermilab, APO, and Princeton University.

The Fermilab Data Processing Team has primary responsibility for processing Legacy imaging and spectroscopic data, SEGUE imaging data, and Supernova imaging data. The budget and scope of work are established under ARC work agreement SSP-240.

The Princeton Data Processing Team has primary responsibility for processing SEGUE spectroscopic data. The budget and scope of work are established under ARC work agreement SSP-238.

The University of Chicago Data Processing Team has primary responsibility for processing imaging data collected for the Supernova Survey at APO shortly after the data are acquired, which allows for the rapid identification and dissemination of candidate SN objects. The budget and scope of work are established under ARC work agreement SSP-239.

WBS #2.3.2: Software and Data Processing Support

This WBS element captures the work and costs associated with maintenance and support of data processing pipelines. Work activities include responding to problems encountered during routine operations; fixing bugs; adding improvements to accommodate hardware or operating system changes; and making code enhancements to improve operational efficiency.

On-going maintenance and support is provided by the institutions that developed the pipelines, namely Princeton, the University of Chicago, and the U.S. Naval Observatory.

Princeton provides support for the Photometric Pipeline, which is used to reduce imaging data from all three projects. Elements of the Photometric Pipeline include SSC (Serial Stamp Collection), PSP (Postage Stamp Pipeline) and Frames. Princeton provides support for the spectroscopic pipeline, SpecBS, which is used to reduce SEGUE spectroscopic data. Princeton maintains pipeline quality analysis code and diagnostics and provides scientific analysis, software development, and observing support to the photometric calibration effort. The budget and scope of work are established under ARC work agreement SSP-238.

The University of Chicago (UC) provides support for the spectroscopic pipeline, Spectro 1D, which is used to reduce Legacy spectroscopic data. UC maintains quality analysis code in support of Spectro 1D pipeline automation at Fermilab. UC also provides on-going maintenance and support for the hardware and software used to process imaging data for the Supernova survey. The budget and scope of work are established under ARC work agreement SSP-239.

The U.S. Naval Observatory (USNO) maintains the astrometric pipeline (ASTROM) and provides limited support for the maintenance of the Operational Database. USNO monitors the performance of the ASTROM pipeline and makes modifications as required to meet the Science Requirements. USNO will continue to provide the project with the best available astrometric catalogs for use in the pipeline as they become available. The budget and scope of work are established under ARC work agreement SSP-257.

WBS #2.4: Data Distribution

This roll-up WBS element captures the work and cost associated with developing and implementing the file systems, databases, and hardware to distribute SDSS-II data to the collaboration and general public. Work associated with data distribution is separated into two components: activities associated with production data distribution operations; and activities associated with the development and support of the databases used to host and serve data.

WBS #2.4.1: Data Distribution Operations

Production data distribution operations take place at Fermilab. Data from the Legacy and SEGUE projects are incrementally loaded into the Data Archive Server (DAS) and Catalog Archive Server (CAS) on an annual basis, in accordance with the approved data release schedule. Data from the Legacy and SEGUE projects are incrementally loaded into the Runs Database (RunsDB) and made available to the collaboration on a more frequent basis. Data from the Supernova project are loaded onto fileservers and into databases and made available to the collaboration and general public in accordance with Supernova Survey data dissemination plans. The budget provides for salaries, travel, computer hardware, and supply costs and is established under ARC work agreements SSP-240 and SSP-268.

WBS #2.4.2: Data Archive Development and Support

This WBS element captures the work and cost associated with developing the databases, user interfaces, and other tools required to access data from the Legacy, SEGUE, and Supernova projects.

Data from the Legacy and SEGUE surveys will be distributed through the DAS, CAS, and Runs DB. Access to data in the CAS and Runs DB will be via the SkyServer and CasJobs interfaces. Fermilab provides development, documentation and maintenance support for the DAS. The budget and scope of work are established under ARC work agreements SSP-240. The Johns Hopkins University (JHU) provides development, documentation and maintenance support for the CAS, CasJobs, SkyServer, and RunsDB. Upgrades and enhancements are made as required to support data model changes, and database product and operating system upgrades. The budget and scope of work for JHU are established under ARC Agreement SSP-237.

Data from the Supernova Survey will be distributed through a series of databases currently under development at Fermilab. During operations, Fermilab will provide development, documentation and maintenance support for these databases. The budget and scope of work are established under ARC agreement SSP-240.

<u>WBS #2.5: Survey Coordination</u>

This WBS element captures the work associated with planning and executing the observing strategy for the Survey. This includes the development of strategy planning tools that are used to determine the optimum time(s) when specific regions of the survey area should be imaged and when specific spectroscopic plug plates should be exposed. The budget for Survey Coordination is included in the SSP budgets that also support data processing and distribution at Fermilab (SSP-240) and observatory operations at APO (SSP-235).

<u>WBS #2.6: ARC Support for Survey Operations</u>

This roll-up WBS element captures the cost of additional support activities associated with Survey Operations. The funds for these items are held in an ARC corporate account and administered by the ARC Business Manager. The budget is established under ARC agreement SSP-291.

<u>WBS #2.6.1: Additional Scientific Support</u>

Funds are set aside here to cover the cost of scientific support that may be needed on an occasional basis. When a need for additional support is identified, a scope of work is defined and cost estimate prepared and submitted to the SDSS Director for consideration and approval. Once approved, a written agreement describing the scope of work and budget is established between ARC and the institution, and the funds to support the work are allocated from the ARC Corporate budget to that institution. Funds are also set aside here to provide support to the Project Teams (primarily in the form of travel expenses); and to cover personnel replacement costs.

<u>WBS #2.6.2: Observers' Research Fund</u>

Funds are set aside here to cover the cost of professional development activities for the observing staff, such as travel to participating institutions to participate in collaborative science projects, and travel to conferences to maintain and improve technical skills.

3.3. New Development

A small number of new development efforts are required to achieve the scientific and operational goals of the Legacy, SEGUE, and Supernova surveys. WBS element 3.0 captures the work and costs associated with new development work. The following sections identify the WBS sub-elements associated with specific development activities and provide a brief description of the work associated with each.

3.3.1. SEGUE Survey Development

<u>WBS #3.1: SEGUE Survey Development</u>

A roll-up level WBS element that captures all of the work and costs associated with new development work for the SEGUE Survey. The budget provides salary support, as well as funds for data processing hardware, travel and miscellaneous supplies. The budget and scope of work are established under ARC agreement SSP-140.

WBS #3.1.1: SEGUE Survey Planning and Coordination

Work includes the development of science requirements, survey strategy, and quality assurance (QA) programs for the SEGUE project. Deliverables include a science requirements document, the baseline 3-year SEGUE observing plan, and a QA program for verifying the quality of SEGUE imaging and spectroscopic data shortly after acquisition at APO; and after data processing operations at Fermilab and Princeton.

WBS #3.1.2: SEGUE Target Selection

Work includes the refinement of target selection algorithms and the completion of target selection code. The deliverable is a production version of the SEGUE target selection code that meets SEGUE science requirements and programmatic goals.

WBS #3.1.3: Very-low-latitude Target Selection and Data Processing Analysis

Work includes generating a list of SEGUE cross-scans for possible inclusion into the observing program; and developing and implementing target selection algorithms for open cluster and Sagittarius stream plates. Deliverables include the list of cross-scans and very-low-latitude target selection algorithms.

WBS #3.1.4: Refined Derived-Parameters Determinations and Theory/Simulations

Work includes determining and quantifying various parameters to assess data quality and determine how well SEGUE data compares with theoretical models and predictions. The detailed WBS contains the full list of deliverables to be completed.

WBS #3.1.5: Calibrations/Catalogs of Spectroscopy of Stars of Known Metallicity

Work includes designing and observing globular and open cluster plates in order to assemble a catalog of stars with known metallicity, gravity, and effective temperature, for use in refining atmospheric parameter measuring code. The deliverable is a catalog of SEGUE stars of known metallicity.

WBS #3.1.6: SEGUE Data Processing Software Development

Work includes the development and refinement of data processing pipelines to meet SEGUE data processing requirements.

- The Spectro-1D pipeline will be modified to incorporate the most recent ELODIE catalog of known star templates.
- The Spectro-2D pipeline will be modified to 1) generate outputs that are co-added and wavelength calibrated; 2) output non-sky subtracted spectra; and 3) include rebinning and smoothing operations for spectra vs. signal-to-noise.
- A Stellar Atmosphere Parameter pipeline will be developed to compute stellar atmosphere parameters, incorporate proper motions, and outputting data in flat file format.
- The photometric pipeline, Photo, will be modified to incorporate DAOPHOTO/DoPhot-style PSF fitting, in order to reduce the load on the Photo deblender when processing crowded-field data.

Deliverables include production versions of these pipelines checked into the CVS code repository following procedures common to the project.

WBS #3.1.7: SEGUE Data Distribution Development

Work includes the incorporating SEGUE data model changes into the DAS and CAS schemas; developing procedures for outputting SEGUE data in DAS-style flat file format; and modifying the CAS to include a indexed look-up table containing the new SEGUE parameters. Deliverables include an updated data model containing SEGUE parameters, a procedure for generating DAS-style files, and a modified production-ready CAS that accommodates SEGUE data.

WBS #3.1.8: SEGUE Technical Papers

Work includes writing technical papers documenting the SEGUE target selection process and stellar parameter techniques. The deliverables are published papers.

3.3.2. Supernova Survey Development

WBS #3.2: Supernova Survey Development

A roll-up level WBS element that captures all of the work and costs associated with new development work for the Supernova Survey. The budget provides salary support, as well as funds for data processing and distribution hardware, travel and miscellaneous supplies. The budget and scope of work are established under ARC agreements SSP-139 and 140.

WBS #3.2.1: Supernova Survey Planning and Coordination

Work includes the development of science requirements, survey strategy, hardware and software development plans, and quality assurance (QA) programs for the Supernova Survey. Deliverables include a science requirements document, the baseline 3-year Supernova observing plan, and a QA program for verifying the quality of Supernova imaging data shortly after acquisition at APO, and also after data processing operations.

WBS #3.2.2: Supernova Survey Computing Hardware Implementation

New computing hardware is required to process Supernova data at APO and Fermilab, and to host the Supernova Survey public archive at Fermilab. This WBS element captures the work and costs associated with specifying, purchasing, installing and testing the new computer systems. It also captures the work and cost of replacing and relocating the Uninterruptable Power Supply (UPS) units used at APO, to accommodate the additional thermal loading imposed by the new data processing hardware.

WBS #3.2.3: Supernova Survey Software Development for 2.5m Survey Operations

Work includes the development and refinement of data processing pipelines and other software tools to meet the data processing and analysis requirements of the Supernova Survey.

- Software scripts will be developed to automate data processing pipeline operations at APO.
- Software tools will be developed to monitor SN detection efficiency and test the accuracy of SN photometry.
- The Frame Subtraction pipeline will be modified to incorporate an improved re-mapping algorithm between search and template frames; improved characterization of noise properties in subtracted images; and improved masking of artifacts.
- Co-added template frames for Stripe 82 will be developed to reach the required depth of the SN search.
- I-band frame subtraction will be implemented for all processed frames as a part of normal operations.
- Veto catalogs, an Objects database, and a SN Candidates database will be developed to support SN observing and analysis operations.
- Target selection code will be developed that incorporates color-color and color-mag pre-selection criteria using models and color/magnitudes of nearby SN, real-time light-curve fitting and estimated current magnitude.
- A web interface for target selection will be developed. The interface will include improved finding charts and consolidation of information on candidate objects.
- A public version of the SN candidate web server will be developed to allow easy and rapid access to candidate SN by astronomers external to the collaboration.

Deliverables include production versions of these pipelines, software tools, and databases. Where possible and pertinent, software code will be checked into the CVS code repository following procedures common to the project.

WBS #3.2.4: Software Development for Follow-up Observations

Work includes the development of software tools and databases to support follow-up observations.

- A database will be developed to hold information on follow-up candidates and observed objects.
- Observing tools will be developed to determine if sufficient spectroscopic signal-to-noise levels have been obtained and to perform on-the-fly SN typing and redshift determination.

- Software tools will be developed that incorporate improved galaxy spectroscopic subtraction for improved SN typing.
- Software tools will be developed for reducing auxiliary imaging data obtained from other sources, such as the NMSU 1-meter telescope and the 3.5-m telescope instrument, SPIcam.
- A framework will be developed for inter-calibrating imaging data obtained from the 2.5-m, 1-m, and 3.5-m telescopes at APO.

Deliverables include production versions of these tools, checked into the CVS code repository following procedures common to the project.

WBS #3.2.5: Software Development for Supernova Off-mountain Analysis

Work includes the development and testing of the SN Photometry Pipeline, which will compute precision aperture and PSF photometry; and the development of improved calibrations of Stripe 82 objects and images based on multiple observations.

WBS #3.2.6: Supernova Survey Database Development

Work includes the development and implementation of data archives and databases for the dissemination of repeat imaging scans and supernova data to the collaboration and general public. Deliverables include an archive of repeat imaging scans and a database containing supernova data.

WBS #3.2.7: Supernova Survey Technical Papers

Work includes writing technical papers documenting the Supernova Survey target selection process and data processing and analysis techniques. The deliverables are published papers.

3.3.3. Photometric Calibration

WBS element 3.3 captures the work and costs associated with new development work associated with the Photometric Calibration effort. Planned work activities include integrating ubercalibration software and calibration outputs into the imaging data reduction process; testing for statistical structure and systematics; developing a post-calibration process that will apply improved calibration outputs to the existing, standard “factory” data processing outputs; developing software and a process to deliver flat-field data to the DP factory in a timely fashion after cross-scan calibration; and analyzing various forms of spectrophotometric data to provide the best possible constraints on the AB corrections. The detailed WBS for photometric calibration work is being developed. The planned budget provides salary support, as well as a modest level of funds for travel and miscellaneous supplies.

3.3.4. Data Acquisition System Upgrade

WBS element 3.4 captures the work and costs associated with upgrading the existing data acquisition (DA) system. The upgrade is required to mitigate obsolescence concerns, as the original DA was built and delivered in 1995 and many critical components are no longer available. In addition, the upgrade incorporates improvements to provide 1) faster on-mountain access to the data by the Supernova data processing system and on-the-mountain QA analysis tools; and 2) a more cost-effective means of transferring data from APO to Fermilab and Princeton for Legacy and SEGUE data processing.

WBS #3.4: Data Acquisition System Upgrade

A roll-up level WBS element that captures all of the work and costs associated with the DA Upgrade. The budget provides salary support for technical staff working on the upgrade, and funds to cover the cost of new DA hardware and travel to APO to implement and commission the new system. The budget and scope of work are defined under ARC agreement SSP-161.

WBS #3.4.1: DA Upgrade Planning

Work includes developing the functional specifications for the new DA, as well as testing and commissioning plans.

WBS #3.4.2: DA Hardware Procurements

Work includes specifying, procuring, installing, and testing new computer hardware associated with the upgrade. Planned procurements include the following:

- Motorola MVME5500 PowerPC single-board computers to replace obsolete Motorola MVME162 boards.
- Motorola IPMC712 SCSI interface modules, to maintain backward compatibility.
- Dual-process Linux computer to replace the existing "host" computer, which has become obsolete and very costly to maintain.
- Two dual-processor Linux fileservers to stage data prior to transfer to data processing sites.
- Upgraded networking hardware.

WBS #3.4.3: DA Software Development

Work includes porting existing code to run on the new PowerPC boards and Linux operating system platform. Software packages requiring modification include the following:

- The low-level DA code that acquires data from the instruments and writes it to disk for subsequent processing (astroda, astroline, archiver).
- The xOP programs used by the observers to control and communicate with the telescopes and instruments (IOP, SOP, and MOP)
- The code that controls telescope motion (MCP).
- The code that acquires and logs telescope and instrument performance data (TPM).
- The various software packages that serve as observing tools during operations (e.g., watcher, tccmon, mopdb, webserver, etc.)

WBS #3.4.4: DA Upgrade Testing at Fermilab

Work activities include resurrecting the DA test stand at Fermilab, upgrading the test stand with the new hardware, installing the modified software, and running simulated test data through the system to bench-test performance and verify that the new DA system is functioning properly and is ready for installation, testing and commissioning at APO.

WBS #3.4.5: DA Upgrade Activities at APO

Work includes installing the new DA computer hardware at APO, upgrading and reconfiguring network connections, testing broadcast functionality under the new configuration, and performing preliminary tests prior to full system commissioning.

WBS #3.4.6: DA Upgrade Commissioning

Work includes testing the new DA hardware and modified software on the production systems at APO. Preliminary testing will involve taking test data with the imaging camera and spectrographs to verify system operation and data integrity. Advanced testing will involve full system tests with the telescope and instruments on the sky, collecting data following standard operating procedures.

WBS #3.4.7: Final As-built Documentation

Work includes updating existing system documentation and operating procedures to reflect the changes made by the upgrade project. Documentation web pages will be updated as appropriate. Software will be checked into the CVS code repository following established procedures.

3.4. ARC Corporate Support

WBS element 4.0 captures the cost of financial audits, insurance, Advisory Council meetings, external project reviews, etc. The corporate support budget is managed by the ARC Business Manager.

3.5. Education and Public Outreach

Education and public outreach activities and costs are captured under WBS element 5.0. Sub-elements capture the work and costs associated with the work of the EPO Coordinator and Public Information Officer (PIO). The budget provides for partial salary support, travel and modest office supply expenses.

3.6. Management Reserve

Management reserve funds are treated as a line item in the budget and captured under WBS element 6.0. Management reserve funds are held in an ARC Corporate account and managed and controlled by the SDSS Director. Management reserve is used to cover the cost of unanticipated but required expenses that arise during the course of survey operations. Management reserve funds are allocated only after it is clear that costs cannot be covered by adjusting priorities, postponing procurements, or rearranging work.

4. OPERATIONS AND MAINTENANCE

4.1. Survey Operations

Survey Operations includes the Observing Systems, Observatory Operations at Apache Point Observatory (APO), Survey Coordination, Data Processing, and Data Distribution. The data flow through Legacy Survey Operations is shown in Figure 4.1. There are slight variations in the data flow for SEGUE (i.e., spectroscopic data are transferred to Princeton for processing) and Supernova (i.e., data are initially processed at APO). These, and other key aspects of day-to-day operations and maintenance, are described in the following sections.

4.1.1. Observing Systems

Observing Systems captures the work and costs associated with the equipment that enables the collection of data at APO. This includes the 2.5-meter telescope, the photometric telescope, the imaging camera, the two multi-fiber spectrographs, the data acquisition system, and all ancillary equipment associated with their operation. It also includes the tasks required to fabricate the spectroscopic plug plates, ship them to APO, provide storage until they are used, and prepare them for spectroscopic operations at APO. It also includes the tasks for unplugging the plates and transferring them to long-term storage. Work activities for Observing Systems fall into two categories: maintenance/repair and improvements. A hierarchical system is used in the WBS to identify the engineering, fabrication, implementation, and maintenance tasks necessary to maintain the telescopes, instruments, data acquisition system, and ancillary support systems at the level required to achieve survey goals.

The Head of Observing Systems directs the work of the Observing Systems organization and is responsible for ensuring that the observing equipment and systems meet the Science Requirements and operational needs of the survey. A preventive maintenance program has been established to ensure system reliability. A spares inventory will be maintained through the end of survey operations to ensure system availability. A configuration management program has been implemented to manage improvements in a controlled manner and ensure maintainability. A quality assurance program tracks system performance. The SDSS Problem-Reporting Database is used to report and track safety concerns and equipment problems.

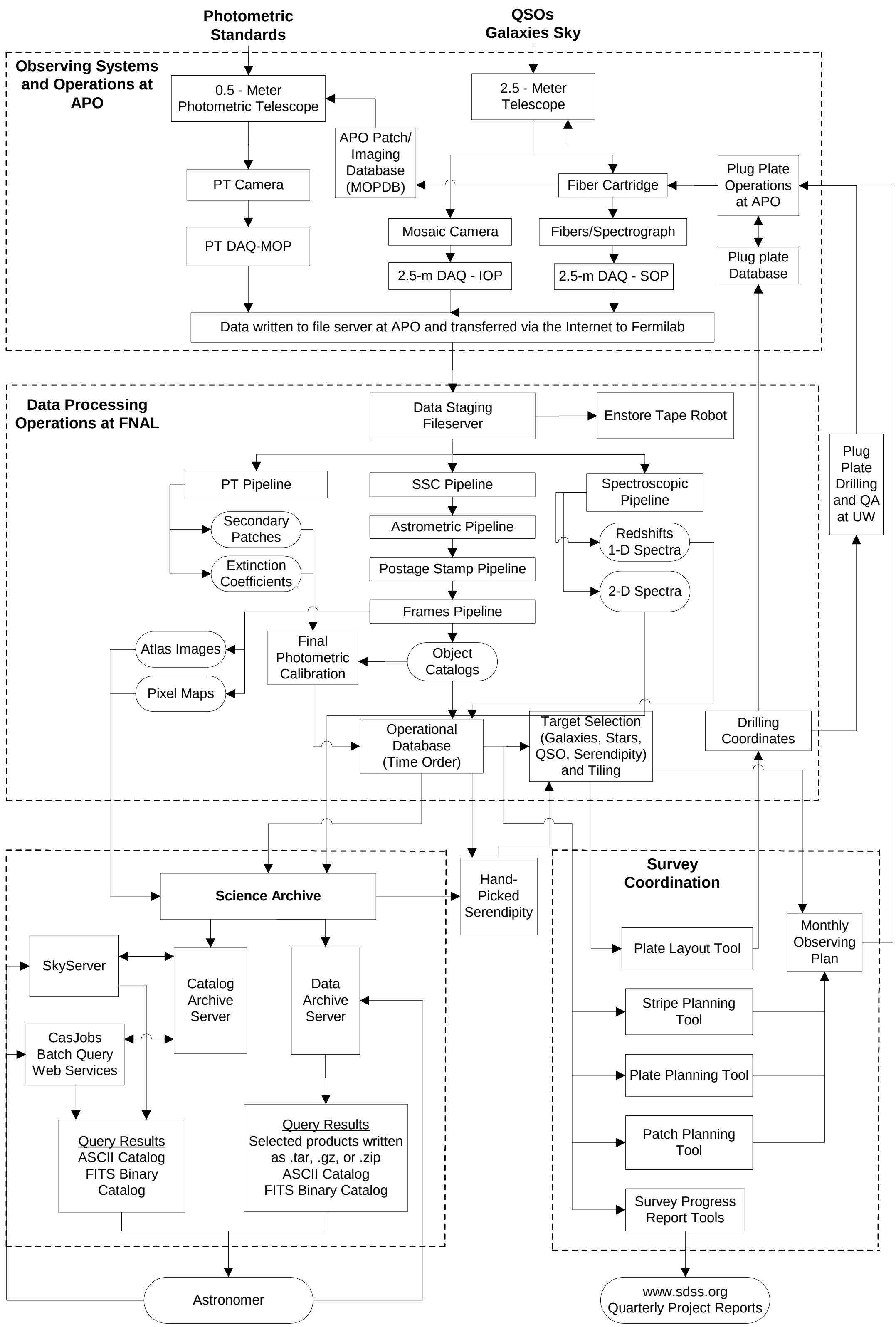
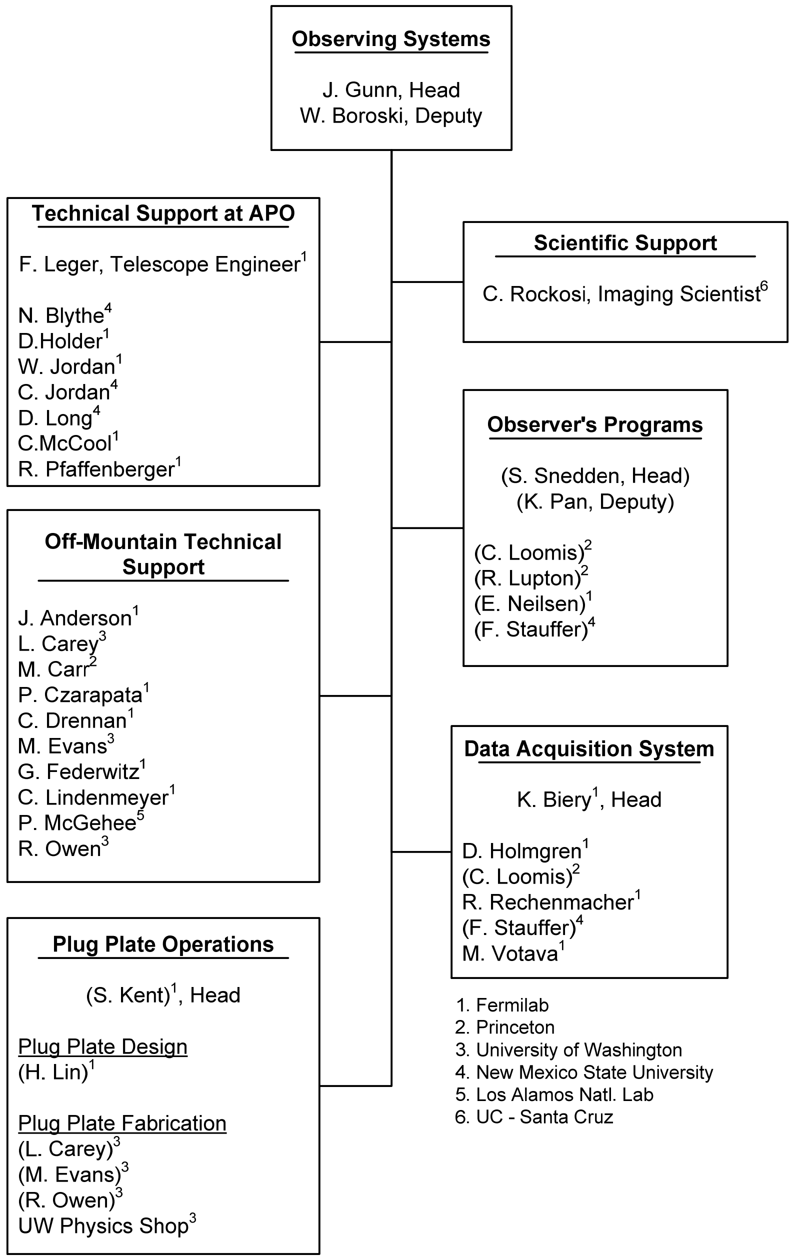


Figure 4.1. Data Flow for Legacy Survey Operations.

Figure 4.2 presents the organization chart for Observing Systems. The Telescope Engineer and staff shown in the "Technical Support at APO" box comprise the group responsible for maintaining the telescope and instrument systems. They are also responsible for plug plate operations at APO.

Figure 4.2. Organization Chart for Observing Systems



The Off-Mountain Technical Support box defines the personnel that work part-time for the SDSS and to whom specific projects are assigned. These projects produce deliverables that are implemented and tested at APO by the Off-Mountain Technical Support staff in close coordination with the Technical Support at APO staff. Once tested and implemented, the responsibility for maintaining and repairing these deliverables is given to the Technical Support at APO staff.

The individuals shown in the Observers' Programs box are responsible for maintenance and improvements to the software programs that operate the telescopes and instruments at APO. As these individuals reside at several institutions, the Observers' Programs box defines a coordination mechanism. For example, Princeton developed portions of the Observer's programs, including the focus loop, parameter watcher, Imaging Observers' Program (IOP), Spectroscopic Observer's Program (SOP). Princeton also developed the Motion Control Processor (MCP) and the interlocks graphical display. Princeton will provide support to maintain these systems through the three-year observing period; the major responsibility for IOP and SOP has been transferred to Fermilab, with Princeton providing consulting support on an as-needed basis. Additional details are provided in Section 4.1.1.3.

The individuals shown in the Data Acquisition System box are responsible for maintenance and improvements to the data acquisition system at APO. Fermilab built and installed the DAQ system at APO and is responsible for its maintenance through the end of the survey. Fermilab personnel routinely answer urgent questions from observers during the night and provide consultation during the day to the APO technical staff that provide the first level of maintenance and support to the DAQ. Additional details are provided in Section 4.1.1.4.

4.1.1.1. Telescopes and Instruments

Observing Systems includes the telescopes, instruments, and ancillary systems at APO that are used to acquire SDSS data. Maintaining system reliability is critical to our ability to meet the observing efficiency specification for equipment uptime.

The Telescope Engineer is responsible for scheduling the re-aluminization of the telescope mirrors, including removal of the mirrors and preparation for shipping, and reinstallation into the telescopes after aluminizing. The Site Operations Manager coordinates aluminizing schedules with the Telescope Engineer, secures vendors for the aluminizing work, oversees transport of the mirrors to and from the vendor, and oversees the actual aluminizing process.

The Head of Observing Systems has delegated the maintenance and repair of Observing Systems to the SDSS Telescope Engineer. He is assisted in performing maintenance and repair work by the technical staff at APO. When work cannot be handled by the on-site staff, the Head of Observing Systems works with the Project Manager to assign work to off-site specialists according to skill needs and availability. The specialists include the people who built and commissioned the various systems at APO and who are available to assist with problems on an on-call basis.

Princeton University built and delivered the imaging camera and its mechanical and support systems, the detector systems for the spectrographs and the Photometric Telescope, the cryogen and temperature control systems for all of the instruments, the flat-field and wavelength calibration systems for the spectrographs, throughput monitoring systems for the optical surfaces, and software for the Fiber Mapper. Princeton is maintaining these systems during operations as required to meet the Science Requirements. Princeton also provides technical support for other telescope-related tasks as needed.

The University of Washington provides technical support to maintain and upgrade as necessary the Telescope Control Computer, the 2.5-m telescope guiding system, and telescope optical support and control systems, and provides technical support for other areas on an as-needed basis.

Los Alamos National Laboratory (LANL) provides technical support for the maintenance of the Telescope Performance Monitor (TPM), which monitors, displays, and archives telescope engineering and thermal data.

The U.S. Naval Observatory provides technical support for the maintenance and repair of the camera hardware and firmware for the imaging, spectroscopic, and PT systems. USNO also provides documentation support for these systems.

The Japan Participation Group (JPG) provided the CCDs for the imaging camera. The CCDs are JPG property on loan to ARC for the duration of the survey. JPG engineers and scientists contributed to the fabrication of electronic components and systems for the imaging camera. They built and installed a 50 Å resolution monochrometer to measure, through the corrector plate and filter, the sensitivity of every CCD on the imaging camera. They designed, built and installed the flat field system for the Photometric Telescope. The JPG provides operations, engineering, and maintenance support for these systems as needed. They will periodically calibrate the imaging camera using the monochrometer.

4.1.1.2. Plug Plate Operations

In addition to the telescopes and instruments, Observing Systems includes the activities associated with the fabrication of the spectroscopic plug plates and their subsequent use in spectroscopic observations. The Head of Survey Coordination is responsible for coordinating and overseeing all activities associated with target selection, generation of drill files, drilling schedules, and inventory control at APO. In addition, the Head of Survey Coordination is responsible for providing the observing staff with tools and observing plans sufficient to ensure that the spectroscopic observing goals of the survey are met. To help achieve these goals, the Head of Survey Coordination has developed the Plug-Plate Database, which tracks the location of and information on each plate fabricated and prepared for observing. The database also provides the observers with information needed to determine when specific plates should be selected for observing, and keeps track of which plates have been observed.

The Head of Observing Systems is responsible for plug plate operations at APO, which includes ensuring that adequate facilities exist at APO to meet the storage requirements requested by the Head of Survey Coordination, and that an adequate staff and facilities exist at APO to prepare plates for nighttime observing. The Head of Observing Systems has delegated the day-to-day management of APO plug plate operations to the SDSS Telescope Engineer.

Plate production begins with the delivery of plug-plate blanks to the University of Washington, where the blanks are inspected to verify conformance to specifications. On a monthly basis, target selection code is run at Fermilab on processed imaging data, thereby enabling the selection of stars, galaxies, quasars, and other objects that will be observed in the spectroscopic survey. The resulting drill files are posted on the Internet and subsequently downloaded at the University of Washington. These drill files instruct a numerically controlled milling machine at the University of Washington to drill holes in the spectroscopic plug plates that correspond to the selected objects in the sky and to engrave each plate with a unique ID number. After machining, each plate is sanded to dull the finish and remove burrs, and then thoroughly cleaned and rinsed. The cleaned plates are then inspected for conformance to design, in accordance with the plug plate QA program. The QA program is in place to monitor the quality of plug-plate production, with the complete set of QA records maintained at the University of Washington. After passing inspection, the plates are packaged and shipped to APO for storage, plugging and observing. The shipping method is chosen based on the required delivery schedule and the ability to track the shipment.

The fiber plugging cycle begins after the drilled plates are received at APO. The plates are inspected for shipping damage and cleanliness by the APO plugging staff, logged in the plug plate database, and stored in the staging facility until they are ready to be plugged. Each morning during an observing run, the plugging staff receives instructions from the observing staff denoting which plates were successfully observed during the previous night and can be unplugged, and designating which plates need to be plugged for the coming night. When the observations for a plate have been declared complete, the observed plate is unplugged, removed from the fiber cartridge, and returned to the appropriate storage system. New plates are retrieved from the storage system, loaded into fiber cartridges, and plugged with optical fibers. Once plugged, the cartridge/plate assembly is scanned by the Fiber Mapper, which correlates fiber number with position on the plate. Once mapping is complete, the cartridge is placed in the storage rack in preparation for spectroscopic observation. Relevant information is loaded in the SDSS plug-plate database throughout the fabrication, plugging, and storage process. APO maintains on-site storage and staging facilities for approximately 300 plates and contracts for off-site facilities for long-term storage of the remaining plates.

Typically target selection is run on recently acquired imaging data, followed by the creation of the drill files used to fabricate the plug plates for subsequent observing periods. The University of Washington shop is capable of fabricating approximately six plates per day, or a peak capacity of 120 plates per month; however, drilling runs rarely exceed 50 plates. The driving requirement for the number of plates drilled per run is that spectroscopic observations should not be limited by an inadequate inventory of plates at APO.

The plug plate cycle was designed to achieve a one-month turn-around from the time that imaging data are collected at APO, to the time that plates drilled from that data are ready for observing at APO. While we have demonstrated this capability, it does strain the system and we do so only when necessary. Our process is designed so that weather is the only uncontrolled element in the schedule.

4.1.1.3. Observers' Programs

Observing Systems includes the Observers' Programs, which are used by the observers to control the telescopes and instruments. The Observers' Programs include the Imager Observer's Program (IOP), the Spectroscopic Observers' Program (SOP), and the Photometric Telescope Observer's Program (MOP). IOP provides the observer's interface to the systems used in imaging operations (telescope, imaging camera, and DAQ). SOP provides the observer's interface to the systems used in spectroscopic operations (telescope, multi-fiber spectrographs, and DAQ). MOP provides the observer's interface to the Photometric Telescope. The Observers' Programs are maintained by the staff shown in the Observer's Programs box in Figure 4.2.

4.1.1.4. Data Acquisition System

Observing Systems includes the Data Acquisition System (DAQ) at APO, which consists of the hardware, and software programs that collect data from the instruments and send the data to Fermilab for subsequent data processing. The DAQ system consists partially of U.S. Government-owned property on loan to ARC for the duration of the survey. A spares plan has been established for the DAQ system and spare components procured to ensure that an adequate supply of critical parts is available to keep data acquisition activities on-line. Fermilab is responsible for specifying and maintaining the on-site spares inventory and is assisted by the APO site staff. Fermilab also manages commercial hardware and software support contracts for DAQ system components. The DAQ is maintained by the staff shown in the Data Acquisition System box in Figure 4.2.

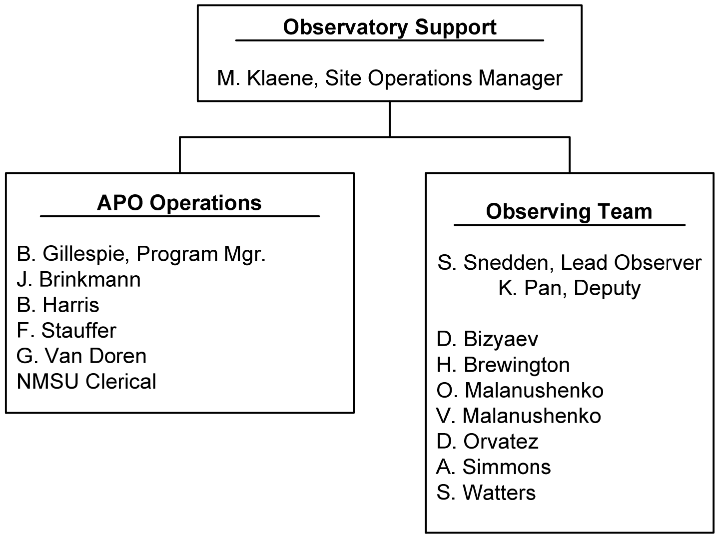
4.1.2. Observatory Operations

Observatory Support captures the work and costs associated with staffing and maintaining the observatory at the level required to sustain survey operations over the 3-year observing period. The organization chart for Observatory Support is shown in Figure 4.3.

APO site management provides managerial and administrative support for observatory operations. The APO Site Operations Manager is responsible for staff recruitment and training, budget, and procurements. These activities are developed in concurrence with the SDSS Director and Project Manager to ensure that SDSS needs are met. APO implements procedures to ensure data quality and consistency through the 3-year observing period. The SDSS Problem-Reporting Database is used to report and track safety issues and system problems. The Site Operations Manager provides status reports to the Project Manager and has implemented programs for publishing night and day site activity logs.

APO provides a staff of Observers for the 2.5-m telescope. One observer has been appointed the Lead Observer and another Deputy Lead Observer. The Lead Observer is responsible for preparing the schedule and activities of the observing staff. The Lead Observer is also responsible for interfacing with the technical staff to ensure good communication between management, technical, and observing personnel. The Lead Observer works with the Head of Survey Coordination to prepare monthly observing plans and is responsible for the execution of those plans. The Deputy Lead Observer assists the Lead Observer in these responsibilities and assumes them in the Lead Observer's absence.

Figure 4.3. Organization Chart for Observatory Support



The observing staff is responsible for the safe and efficient use of the telescopes and instruments to collect data that meet the survey requirements. They develop and use documented procedures that ensure data quality and uniformity; and they implement and use performance metrics to track observing efficiency and performance against goals. Short, on-line QA analyses are done to verify data quality: data passing these tests are forwarded for processing. The observing staff publishes observing logs to document observing activities and records problems in the SDSS Problem-Reporting Database.

APO provides technical personnel to the Telescope Engineer to assist him in the preparation of the 2.5-meter and Photometric Telescopes for daily operation. APO provides cleaning procedures for the optics and assist with the cleaning of the optics. They perform routine maintenance and repair activities when requested. APO also maintains the instruments that monitor seeing and weather conditions, including the Cloud Camera, the DIMM, and the instruments on the meteorological tower.

APO maintains the ARC-provided real property and equipment necessary to support data collection activities at the observatory. APO maintains ARC-provided facilities and equipment necessary to operate and maintain the instruments, including vacuum equipment and a Class-100 clean room for maintenance and repair activities associated with the SDSS imaging camera. APO maintains the site telecommunication system and all on-site SDSS computer systems and associated spare parts. These consist of Fermilab-provided DAQ systems as well as ARC-provided instrument and telescope control computers. APO also maintains the basic site services and facilities necessary to carry out operations in an efficient manner. Critical equipment and sub-systems have been placed on Uninterruptible Power Supplies and an automatic backup diesel generator is available for emergencies.

The APO operations staff maintains the site facilities, roads, grounds, and housing used by visitors working on SDSS activities at APO. A small machine shop at APO is outfitted with tools and equipment suitable for performing small machining jobs. Larger machining jobs are done under contract with local shops. Fermilab provided the machine tools in this shop and will maintain these tools through the 3-year observing period.

4.1.3. Survey Coordination

Survey Coordination captures the work associated with planning and executing the observing strategy for the Survey. This includes the development of strategy planning tools that are used to determine the optimum time(s) when specific regions of the survey area should be imaged and when specific spectroscopic plug plates should be exposed. These tools are critical to achieve efficient observing operations and to meet survey performance goals.

The start and end dates for each monthly observing run during the 3-year observing period, as well as the summer shutdowns for planned maintenance, are published on the SDSS website (www.sdss.org). Defining and publishing the dates for observing runs and shutdowns allows for the efficient planning and scheduling of resources and the identification of bright times during which engineering and maintenance work can be integrated with observing activities.

The Head of Survey Coordination is responsible for creating detailed monthly observing plans for the Observers based on and prioritized according to the Three Year Baseline Plan. The Head is responsible for tracking survey progress against the detailed metrics in the Baseline Plan for each of the three surveys and adjusting observing priorities as necessary to ensure that the plan is achieved.

The Head of Survey Coordination is responsible for developing and implementing survey planning and strategy tools to ensure efficient survey operations and measure observing performance. The Head is responsible for coordinating the steps in the production of plug plates, from target selection to plate inventory at APO. This includes scheduling and oversight of target selection, determining the number of plates required per drilling run, overseeing the generation and delivery of drill files to the UW, and overseeing plate delivery to APO. The Head of Survey Coordination is responsible for maintaining the on-line plug plate database, which tracks the location and observing status of all plug plates.

The Lead Observer serves as the Deputy Head of Survey Coordination and is responsible for implementing the monthly observing plans at APO. The Deputy Head is responsible for developing the planning and tracking tools necessary to efficiently conduct observing operations at APO. The Deputy Head is responsible for implementing a tracking system to log and monitor observing performance against the established baseline plan.

4.1.4. Data Processing

Data processing activities include all work associated with the development and maintenance of the data processing pipelines, and the organization, operation, and maintenance of the data processing "factory" at Fermilab. The organization chart for Data Processing is shown in Figure 4.4.

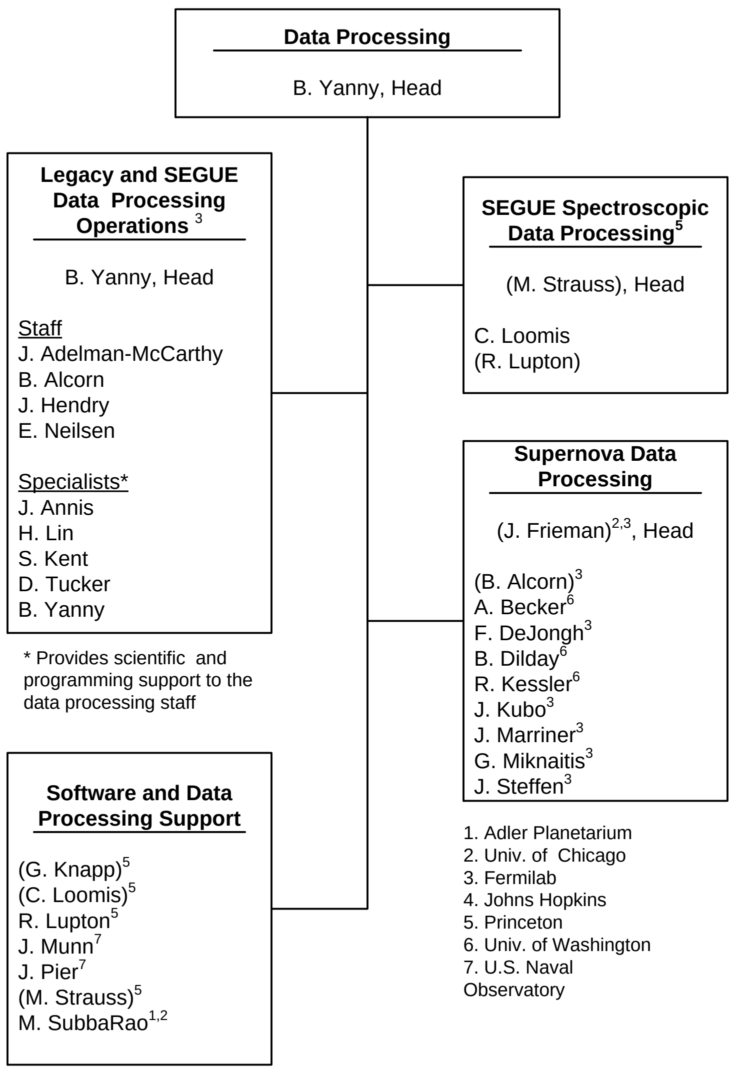
Most SDSS data processing is carried out by members of the Fermilab Computing Division Experimental Astrophysics Group (EAG), using Computing Division facilities. Other sites for data processing are Princeton University (SEGUE spectroscopic processing) and APO (real-time processing of the Supernova data).

During observations, imaging, spectroscopic, and photometric telescope data are written in real time to removable disk and staged for transmission to Fermilab via high-speed internet connection. The disk serves as backup until the data have been validated and stored on the Enstore tape robot at Fermilab.

Data processing operations at Fermilab run in a "factory" production mode. Under the Head of Data Processing, the goal of the Data Processing Team at Fermilab is to process new imaging data within two weeks after it is collected and to process spectroscopic data within one day of acquisition. When necessary, selected imaging runs can be processed in less than one week.

Once received at Fermilab, each type of data is processed by its own set of pipelines. Photometric Telescope data are processed through MTpipe, which defines the primary network of photometric standards, calculates extinction and color terms, and produces calibrated secondary patches. Imaging data are processed through the imaging pipelines, which produce catalogs of calibrated objects, corrected frames, and atlas images. Object lists from individual imaging runs are merged together and targets selected for subsequent spectroscopic observations. Using the target selection data, drill files are designed for use in the fabrication of the spectroscopic plug-plates. Results from target selection, and the corresponding drill files, are loaded into the Operational Database and made available via the Internet for plate drilling at the University of Washington and plugging and mapping operations at APO. Spectroscopic data are processed through the spectroscopic pipelines to produce calibrated spectra, identifications, redshifts, and other spectral parameters. Data from special runs are processed on an as-needed basis to obtain calibration files (electronic calibrations, CCD positions, etc.) or check the imaging and spectroscopic data. After each stage of processing, the results are loaded into the Operational Database. Data quality is verified and checked in summary form to determine which segments of data are ready for the next stage of processing. Global tests are performed on calibrated outputs. Problems and their solutions are tracked in the SDSS Problem-Reporting Database to allow trending analysis on system performance.

Figure 4.4. Organization Chart for Data Processing



The full set of processed data is stored temporarily on disk and permanently archived in an online tape robot. A facility is provided to access the tape robot and disks at Fermilab so members of the SDSS-II Collaboration have ready access to these files. As the cost of disk continues to decline, the intent is to place essentially all of the processed data on disk in the future. This will allow efficient use of the Data Archive Server at Fermilab by the collaboration and the astronomy community. Portions of the processed data that meet Survey requirements are also loaded in the various data servers for use by the collaboration and community.

All of the software used in the data processing operation is controlled by the CVS configuration management system. The introduction of new versions of data processing code into the production operation is done under the direction of the Head of Data Processing. Upgrades of the pipelines are implemented only when it is established that a pipeline does not meet Survey requirements. Aside from the development of the SEGUE and Supernova pipelines, efforts now consist of responding to bugs and change requests in the SDSS Problem-Reporting Database to correct problems and improve operating efficiency.

The Head of Data Processing at Fermilab directs the efforts of the data analysts who carry out routine operations. The EAG scientists support them by diagnosing problems and implement solutions when they are encountered. This team processes data through the pipelines, performs QA checks, archives the processed data, stuffs the appropriate files of processed data in the Operations Database and the other data servers, and prepares the processed data for export to the data distribution servers. They rely on the support from the Computing Division for computer hardware maintenance, operating system maintenance, networking, and tape handling. Fermilab provides the support necessary to maintain all Fermilab-provided computer systems for data processing and distribution. Computer hardware and operating systems are monitored and problems repaired as they arise by personnel from the Fermilab Computing Division as part of its normal support function for elements of the Fermilab experimental program.

Maintenance of data processing pipelines at Fermilab includes fixing bugs; adding improvements to accommodate hardware or operating system changes; and making code enhancements to improve operational efficiency. Bug fixes and improvements will be made as necessary to meet Survey requirements and/or improve operational efficiency. Fermilab also provides scientific analysis of the photometry to verify that scientific goals are met.

Princeton provides support for the maintenance and improvement of the Photometric Pipeline to meet the Survey requirements. This includes SSC (Serial Stamp Collection), PSP (Postage Stamp Pipeline) and Frames. Princeton develops and maintains pipeline quality analysis code and diagnostics and works jointly with Fermilab to maintain and improve the Spectro 2D pipeline, *idlspec2d*. Princeton is responsible for coordinating the development of *idlspec2d* and the SEGUE 1D pipeline, *spec1d*. Princeton also provides scientific analysis, software development, and observing support to the photometric calibration effort.

The U.S. Naval Observatory (USNO) maintains the astrometric pipeline (ASTROM) and provides support for the maintenance of the Operational Database. USNO monitors the performance of the ASTROM pipeline and makes modifications as required to meet the Science Requirements. USNO will continue to provide the project with the best available astrometric catalogs for use in the pipeline as they become available.

4.1.4.1. SEGUE Data Processing

Image processing for SEGUE will, in the first instance, be the same as Legacy image processing at Fermilab. It is expected that some frames in crowded regions will not be processable through PHOTO in its current form. In some regions, PHOTO will run, but the outputs may not be reliable because image crowding may have affected the determination of the point-spread function.

Approximately 44 of the 200 SEGUE spectroscopic tiles have Galactic latitude less than 15 degrees; these fields are, of course, the most likely to suffer from image crowding (as well as having large reddening and large gradients in the reddening). To enable reliable spectroscopic tiling of these regions, additional work will be needed to validate, and perhaps correct, the PHOTO outputs. This work will be undertaken by members of the SEGUE Project Team. Possible ways to obtain accurate photometry in crowded fields include correction to PHOTO outputs at the catalog level; running a separate pipeline in the crowded fields designed for that purpose; and modifying the code that determines the point-spread function in PHOTO.

To design the spectroscopic plates for these regions, not only does the photometry have to be reliable, but the target-selection algorithm has to be in place. Because the stellar population is different at low latitudes, and because significant reddening interferes with the reliability of the standard target selection, the target-selection algorithm for latitudes lower than 15 degrees will be a modified version of the target-selection algorithm that is run uniformly in the remainder of the SEGUE survey. The target-selection algorithm for the low-latitude fields will be made final by the SEGUE Project Team by early Spring 2006 so that plates can be ready when the Milky Way is up.

The target-selection algorithms for both high and low latitude will be automated and will be run at Fermilab. Simple QA checks will be run based e.g. on the number of candidate stars in each of the targeting categories. From this point forward, plate design will follow the standard (Legacy) process.

Currently, SEGUE data processing uses the standard (Legacy) v4 version of the Spectro 2D pipeline, *idlspec2d*. SEGUE plates are processed at Fermilab through *idlspec2d_v4* and the Spectro 1D pipeline, *spectro1D_v5_7_7*, in the same way as for Legacy plates. The calibrated spectra are then further reduced with non-automated code that ultimately yields the atmospheric parameters log g, Teff, [Fe/H], and an independent measure of reddening, with the associated errors. These parameters are available to the Collaboration in flat files, but not yet in the CAS.

This current procedure will be upgraded and refined as follows. The improved spectro 2D pipeline, *idlspec2d_v5* will be implemented, which features better sky-subtraction in the red part of the spectrum, as well as including other important enhancements such as access to individual exposures and access to the specific sky spectrum subtracted from a given object spectrum. All SEGUE plates will be processed through *idlspec2d_v5* and the SEGUE 1D pipeline, *spec1d*, at Princeton University. The SEGUE Spectroscopic Data Processing team there will run the pipelines, perform QA checks, and make the output files easily accessible, all with the CVS versioning procedures common to the rest of the project.

Meanwhile, the atmospheric parameter code will be further developed, led by Michigan State University, such that the code can run in a fully automated way on the outputs of the Princeton SEGUE pipeline. Michigan State University is also responsible for devising a plan for independently checking the derived atmospheric parameters.

The Johns Hopkins University will provide for the addition of the new spectroscopic parameters in the CAS, perhaps by adding a new table. Finally, Fermilab will load the SEGUE spectroscopic data and derived parameters into the DAS and the CAS. Fermilab will also be responsible for ensuring that tiling/target-selection documentation exists for each plate.

4.1.4.2. Supernova Data Processing

The Supernova Survey relies on rapid data processing through a series of pipelines to identify candidate supernovae, enabling follow-up on other telescopes for spectroscopic confirmation and photometric follow-up in other passbands. The SN Survey uses 2.5m data taken on the celestial equator, stripe 82, from September 1 to November 30.

Initially, the 2.5m imaging data are copied from the data acquisition host computer to a dedicated SN compute cluster that resides at APO. The data are processed through the PHOTO reduction pipeline through the stage of producing corrected frames (e.g., sky-subtracted, de-biased, astrometrically calibrated, with masking for bright stars, cosmic rays, etc.). The corrected g, r, i frames are used as input for the frame-subtraction pipeline, which differences these search frames from template images of the same region, detects objects in the difference images, and measures their PSF magnitudes. Catalog information about these objects is stored in a database on the compute cluster at APO. The next stage of processing, called doObjects, operates at the catalog level; it correlates positions of detected objects in the different passbands, weeding out fast-moving objects (e.g., asteroids) and also applies a veto around the positions of previously cataloged stars and variables. For the resulting list of interesting objects, cut-out images in the search, template, and difference images are made. These pipelines (PHOTO, frame-subtraction, and doObjects) are launched with shell scripts by a member of the SN team, and monitor scripts are used to keep track of their progress and to flag failures that may need human intervention to fix a bug in a pipeline.

Within 24 hours of the time the data are acquired, the images, along with the catalog information for each object, are transferred over the Internet to Fermilab and placed in the main database. Gif versions of the cut-outs are made, and the resulting information for objects in each night's data is available for manual inspection through a web interface. SN team members perform the manual inspections, one person for each column of data per night, on a rotating schedule that allows us to keep up with the flow of data. These team members generally scan several hundred objects per night of data; typically 10% of those have images consistent with being SN candidates and are flagged as such by the inspectors. The results of the scanning are automatically fed into a database of SN candidates, which is web-accessible. The SN candidates then go through further processing: for each candidate, all extant information is fed into a program that fits the data to SN template light-curves (for different SN types, redshifts, and levels of extinction) and that also uses available host galaxy information from historical SDSS imaging (e.g., spectroscopic or photometric redshift, galaxy type, offset between galaxy and SN candidate, etc.) to yield an "observability" index for each candidate; this number summarizes the joint likelihood that the candidate is a Type Ia and that it can be spectroscopically confirmed. This information, all in the database, is used by the SN team to select candidates for spectroscopic and photometric follow-up on other telescopes.

All SN candidates, once flagged as such by the manual inspectors, are subject periodically to "forced photometry" which aims mainly to measure u and z magnitudes (i.e., it carries out u, z frame subtraction in those regions) and to see whether the object may have been present at faint levels in imaging runs prior to first detection. Forced photometry is also undertaken periodically for u, g ,r, i, z over the entire time series to obtain measurements that are reduced with a common centroid.

Candidate SNe that are spectroscopically confirmed are announced via IAU circulars. A publicly accessible webpage with basic information on SDSS-II SNe is currently available at http://sdssdp47.Fermilab.gov/sdsssn/snlist.php. It is anticipated that this site will be augmented with additional information and extended to candidates not yet spectroscopically confirmed. In addition to the processing of frames at APO through PHOTO, all data will be reprocessed at Fermilab within one month of data collection in the standard production environment. We will provide the data files (object catalogs and corrected frames) on that time scale using a separate DAS interface.

4.1.5. Data Distribution

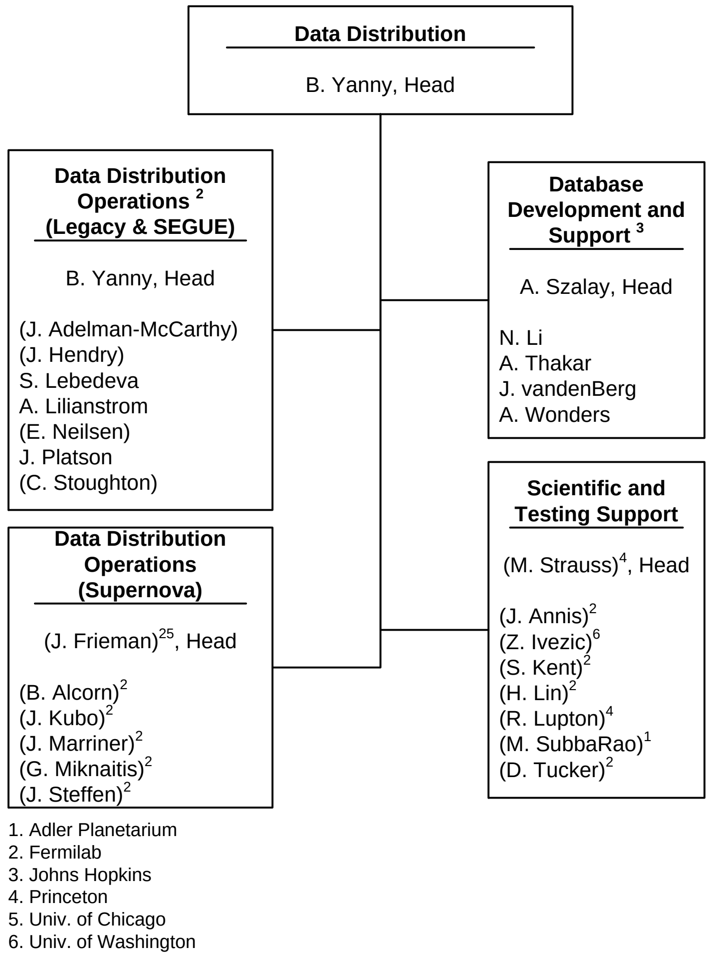
The organization chart for Data Distribution is shown in Figure 4.5. Fermilab will host the SDSS-II data distribution system and make SDSS-II data available to the Collaboration and general public. The SDSS-II data distribution system is an extension of the SDSS data distribution system. The schedule for data releases is defined in Table 4.1. Fermilab will work with JHU and other institutions and individuals working on data distribution to meet these release dates.

Table 4.1. Data Release Schedule

	Scheduled Release Date
Data Release 5	1-Jul-2006
Data Release 6	1-Jul-2007
Data Release 7	31-Oct-2008

Each data release will contain all of the survey quality data acquired in the observing season immediately preceding the scheduled release. The time between the end of the data acquisition period and the data release date will be spent processing and calibrating the data; loading the data into the appropriate databases; and verifying data quality and integrity. Where possible, modifications will be made to correct problems identified in the data. If it turns out that a problem will significantly delay a data release, the problem will instead be documented in the data release notes and a correction applied in the subsequent release. The data for the Supernova survey must be treated differently because the survey is more generally a time-domain survey: we will release the imaging frames as quickly as possible given the available resources.

Figure 4.5. Organization Chart for Data Distribution



The SDSS-II data distribution system consists of the following:

- Data Archive Server;
- Catalog Archive Server database, SkyServer front-end interface, and CasJobs;
- Web pages that provide access to and describe the SDSS-II data archive;
- Computer hardware to support and serve the archive to the SDSS-II collaboration and general astronomy community.

Brian Yanny serves as SDSS-II Head of Data Distribution Operations. He is responsible for coordinating the efforts of Fermilab staff who carry out SDSS-II data distribution operations.

Fermilab data distribution responsibilities include:

- Configuring and expanding the Data Archive Server to accommodate new data;
- Providing systems support for the hardware required to support the Data Archive Server;
- Defining and implementing a backup strategy for the Data Archive Server;
- Performing regular data integrity inspections of the Data Archive Server;
- Loading data into the Catalog Archive Server, in close coordination with JHU;
- Assembling documentation necessary to support the use of the data archive by the collaboration and the community, and using the documentation to develop web-based documentation pages;
- Operating a helpdesk to support public data releases.

The Data Archive Server provides the capability to download data to storage at the user's institution for subsequent use. The Catalog Archive Server provides access to the full object catalog and enables the user to carry out complex queries over all of the output quantities of the photometric and spectroscopic pipelines, plus the calibration parameters used in the processing. These queries are enabled through a tool using a language similar to standard SQL, but with some astronomy-specific extensions. Both the Data Archive and Catalog Archive servers rely on a commercial object-oriented database. The SkyServer is built in the Microsoft Windows environment, using Microsoft's SQL Server database, and offers an interactive web-based interface that provides an integrated navigation of both images and the catalog. It provides access to the full object catalog, with redshifts and spectral lines, and a full set of color images in compressed (JPEG) format, plus GIF images of all of the spectra. The SkyServer was jointly developed as a separate project by the Microsoft Bay Area Research Center (BARC) and JHU, with the goal of developing an interface that would provide easy-access to the SDSS data by the K-12 audience and the general public. Its features are sufficiently powerful that it is also of considerable use to astronomers.

The Catalog Archive Server and Data Archive Server, and the preparation of the data releases with these products, is carried out by groups at Johns Hopkins and Fermilab, under the direction of the Head of Data Distribution. Johns Hopkins is responsible for developing, loading and testing the CAS and responding to problems. Fermilab is responsible for developing, loading and testing the DAS and responding to problems. Fermilab is also responsible for preparing the data products for loading into the DAS and CAS. The Collaboration is responsible for validating the data that can be accessed by these servers and providing feedback to the data processing and distribution teams through the SDSS Problem-Reporting Database.

The Fermilab Core Servers and Infrastructure (CSI) group will support and maintain the computing hardware associated with the production Catalog Archive Server (CAS) system. The Fermilab Database Systems (DBS) group will assist with CAS loading and will administer and support production deployment and use of the CAS, and its SkyServer front-end, by the Collaboration and general public.

The CSI group will support SDSS-owned hardware used on the Fermilab network to load and deploy the CAS database and SkyServer front-end. This hardware utilizes the Microsoft operating system (OS). The CSI group will provide support for 29 servers: SDSSSQL001-SDSSSQL024, and SKYSERVER2-SKYSERVER6. These servers will reside in the 1st floor computer room of the Feynman Computing Center (FCC). Over time, new servers will be purchased to replace obsolete machines. The total number of servers to be maintained at any given time is not expected to exceed 30. The SDSS-II team will work with the CSI group to develop a plan and schedule for the purchase and replacement of aging machines.

Specific CSI functions and responsibilities include the following:

1. Coordinate all support activities with SDSS-II and DBS points of contact to avoid operational problems on the servers.
2. Perform OS installation, patching, capacity planning and configuration of CAS data servers and web servers.
3. Coordinate system maintenance and hardware installations.
4. Monitor and analyze system performance.
5. Provide remedial OS support for covered systems and be the first contact for system problems. The support will be 24x7 for systems serving the current data release to the public. All other systems will be supported 8x5.
6. Arrange remedial hardware maintenance with a commercial service. CSI will coordinate maintenance and repairs with the commercial maintenance provider.
7. Manage supported OS software licenses and software maintenance agreements.
8. Advise and assist in identifying and maintaining appropriate security for the mission of the database systems.
9. Advise and assist the project with all network support issues.

10. Advise and assist the project with the implementation of procedures and/or mechanisms to redirect database users to a copy of the current public release spinning at the Johns Hopkins University, should the database cluster at Fermilab be offline for unexpected reasons.

DBS will be responsible for loading, administering and maintaining the CAS database system. Specific responsibilities and functions include the following:

1. Appoint a full-time database administrator (DBA) to manage and oversee production CAS operations at Fermilab. The DBA will serve as the principal point of contact with the SDSS-II Project Manager and the CSI group on CAS system issues.
2. Provide management and maintenance services to ensure the integrity of data and applications software on the CAS servers.
3. Provide day-to-day management and oversight for the operation of the CAS servers.
4. Participate in the design and specification of the production database hardware system at Fermilab.
5. Maintain and as necessary update the SDSS-II Production SkyServer Hardware Plan in coordination with the SDSS-II Project Manager and CSI group.
6. Install MS SQL Server and SDSS-II database software programs onto new hardware and configure as required.
7. Configure the database system and manage user accounts in a manner that ensures compliance with the Fermilab Security Program Plan.
8. Install and update software patches as appropriate.
9. Test and verify new database software versions as they are delivered from JHU and implement new versions into the production operation in accordance with production schedules.
10. Load new data into the databases, develop and participate in testing efforts to validate loaded data and prepare databases for use by the collaboration and general public in accordance with the data release schedule.
11. Develop and implement quality control checks into the production operation as appropriate to ensure data integrity.
12. Set up and implement an effective data back-up and recovery system.
13. Implement effective on-call and system performance monitoring systems to promptly identify and respond to database software problems.
14. Document the database loading operation and update procedures as appropriate to reflect changes in setup procedures and techniques.

As close to 100% uptime as possible will be maintained on SDSS and SDSS-II CAS servers serving the current data release to the public.

4.2. New Development

4.2.1. SEGUE Development Work

For SEGUE, software-related development includes:

- Finish the development of the target selection code by refining the algorithms for the eleven targeted object categories, and validate the code based on empirical data;
- Develop software tools to monitor and verify data quality during operations;
- Refine derived-parameter determinations and theory/simulations, such as computing and verifying photometric parallax information; and incorporate into reduction software as appropriate;
- Develop a catalog of stars of known metallicity, gravity, effective temperature, etc. for use in refining the atmospheric parameter measuring code;
- Revise the spectroscopic pipeline (Spectro-1D) to incorporate the most-recent ELODIE star templates to improve fitting algorithms for pipeline radial velocities and star-typing;

- Revise the spectroscopic pipeline (idlspec2D) to output continuum subtracted spectra and non-sky-subtracted spectra, and to include outputs that are co-added and wavelength calibrated;
- Develop stellar atmosphere parameter code;
- Develop code to package new spectro parameters into uniform flat file format for collaboration use.
- Modify existing DAS and CAS data distribution software to accommodate SEGUE data;
- Modify the existing photometric pipeline (PHOTO) to process imaging data taken in crowded fields.

New hardware will be required to process SEGUE spectroscopic data and to serve SEGUE data to the collaboration and general public. For spectroscopic data processing, a dual-processor high-end PC, outfitted with sufficient memory and disk space and running Linux, will be implemented. Additional disk space will be added over time as the volume of data increases. For data distribution, three dual-processor database servers, with sufficient disk space, will be implemented to load and serve data to the collaboration and public.

Work is underway on many aspects of the SEGUE development task list. None of the work impedes the start of SEGUE observing.

4.2.2. Supernova Development Work

For the Supernova project, software and software-related work involves the following:

- Install a data processing system at Apache Point Observatory to perform next-day reductions on newly acquired data;
- Modify the photometric pipeline (PHOTO) as necessary to meet the processing-time requirements on the APO reduction system;
- Modify the Frame-Subtraction pipeline to implement an improved remapping algorithm between search and template frames; to improve subtracted image noise characterization, to implement better re-sampling methods; and other improvements.
- Develop software scripts to automate data processing;
- Develop a Supernova Candidates Database;
- Implement i-band frame subtraction for all SN candidates;
- Refine target selection code by developing color-color and color-magnitude pre-selection criteria using models and color/magnitudes of nearby SN;
- Develop frameworks and tools for follow-up observations;
- Develop pipelines for off-mountain data analysis;
- Develop databases to serve SN data, and repeat imaging data and/or catalogs, to the collaboration and general public.

Sufficient elements were in place by 1 September 2005 to enable the start of the Supernova survey at that time.

4.2.3 Photometric Calibration

Work on the photometric calibration effort is all analysis and software related. No new hardware is required to support this work. Over the course of the survey, we anticipate finishing the Apache Wheel code, comparing calibration results to externally calibrated data, and developing the software required to integrate new calibration outputs into the factory data processing operation. We will also analyze data processing output to verify and quantify the quality of the final calibration.

5. SAFETY, ENVIRONMENT, AND HEALTH

Policies for safety, environment, and health for SDSS-II are derived from the institutions where the work is performed, namely Apache Point Observatory (APO), Sunspot, New Mexico; Fermi National Accelerator Laboratory (Fermilab), Batavia, Illinois; and The University of Washington, Seattle, Washington. Data are acquired at APO. Data are processed at and distributed from Fermilab. Spectroscopic plug plates are drilled in the Physics Department machine shop at the University of Washington.

New Mexico State University (NMSU) operates APO for the Astrophysical Research Consortium (ARC) and employs many of the resident staff. The applicable NMSU policies are generally derived from and accountable to OSHA guidelines and regulations, and are documented at the following locations:

- http://www.nmsu.edu/~safety/
- http://www.apo.nmsu.edu/Site/usersguide/finalsafety.htm

The APO Site Operations Manager, Mark Klaene, is responsible to ARC for the safe conduct of all activities at the Observatory. Mark Klaene also serves as the APO Safety Officer, and provides safety oversight for all activities at APO, establishes the qualifications for all people to engage in various tasks while working at the Observatory, and maintains their training records. In order to fulfill this responsibility, APO provides the safety training for staff engaged in activities at the Observatory. To ensure the adequacy of the site safety program, external safety officers are called upon to perform periodic site audits.

Operations at Fermilab are conducted according to Department of Energy policies, which can be found online at the following locations:

- http://www-esh.fnal.gov/pls/default/esh_home_page.html
- http://www.fnal.gov/directorate/Policy_Manual.html#Section_3
- http://www-esh.fnal.gov/FIESHM_Plan/IESHM_011404.pdf

Some of the on-site staff at APO are employees of Fermilab. These individuals comply with both Fermilab and NMSU/APO policies and observe the stricter of the two policies, in cases of conflict or non-overlap.

Plate-drilling operations are conducted according to the University of Washington Physics Department's policies, which can be found online at the following locations:

- http://www.phys.washington.edu/safety.htm
- http://www.ehs.washington.edu/

6. CONFIGURATION MANAGEMENT AND CHANGE CONTROL

6.1. Technical Projects

In the course of conducting the survey, it may happen that a limited set of improvement projects must be executed to bring performance into compliance with survey requirements. The work in each of these tasks is organized as a separate project with well-defined deliverables and schedules. The responsibility for completing each project is assigned to a specific individual. Problems with existing systems are identified by members of the scientific and technical staff and filed in the SDSS-II Problem-Reporting Database. Problems are then discussed in the appropriate project teleconference and an individual is given an action to resolve it. If the resolution requires the definition of a new project, it is submitted to the Project Scientist or Project Manager for consideration and approval. New project requests may be submitted in the form of change-requests filed in the Problem-Reporting Database or through e-mail messages to the Project Scientist or Project Manager. The Project Manager consults with the Project Scientist to determine if the new project is necessary and if deemed so, the Project Manager works with the appropriate individuals to develop a cost and schedule estimate. Once the cost and schedule estimate is prepared, it is reviewed against the current budget and schedule to consider if, when, and by whom the work will be done. New project requests with an estimated cost in excess of $3K are submitted to the Director for approval before they are incorporated into the WBS and work plan.

An important element of the approval process is to prioritize new work against the existing plan. The following criteria are used to prioritize new projects:

1. Projects that are required to mitigate a serious personnel safety concern receive the highest priority and are assigned and integrated into the schedule as soon as possible. These projects will interrupt operations if continuing operations is judged unsafe. As of this writing, there are no outstanding safety projects to complete. However, periodic external safety reviews, which are arranged by the APO Site Operations Manager to ensure a safe work environment, may uncover the need for additional work. If one of these reviews reveals a problem that is accepted by the APO Site Operations Manager, it will be incorporated in the WBS.

2. Projects that address serious equipment protection issues or are needed to maintain the availability of critical systems are given second highest priority. Priority 2 projects may cause the suspension of normal operations if it is judged that serious damage to observing systems could occur if operations continued.

3. Projects that will bring a system or sub-system into compliance with science requirements, or with functional performance requirements flowing from approved science requirements, receive third priority.

4. Work that is necessary to improve the efficiency, reliability, or robustness of a system, sub-system, or procedure is ranked fourth in priority. Such work is undertaken to achieve and/or maintain operating uniformity and/or efficiency goals.

After new projects are approved, they are prioritized and assigned to an organization and individual, added to the WBS, and integrated into the project schedule. Institutional budgets are adjusted to fund a new project whenever the new project reflects a change in the scope of work that was defined in the original agreement between the institution and ARC. Funding for new projects must come from within the approved annual operating budget, either by postponing planned lower priority work, or by tapping the management reserve that is controlled by the Director. The latter will occur only when the funds required for new work cannot be re-distributed amongst the allocated institutional budgets.

6.2. Software Configuration Control

All software used in mission-critical production operations, from observing to data processing to data distribution, is under version control. All production software is stored in a source code control system and tagged with a unique version number. The source code control system is discussed in Section 6.3.1.

The version of software used in production is under the control of the individual responsible for the project area in which the software is used (e.g., Observing, Data Processing, and Data Distribution). Production version upgrades are made infrequently and in consultation with survey management.

Changes to production software packages are kept to a minimum to provide for stable, reliable operations and consistent data products. Changes are limited to only those required to fix critical bugs, meet survey science requirements, or improve operational efficiency. The Problem-Reporting Database, described in Section 6.3.3, is used to identify and track approved software changes or improvements. Software bugs filed as Critical/High indicate a problem serious enough to negatively impact operations or adversely affect data quality. These problems are typically addressed promptly by the developer and implemented into production as quickly as possible. Other, less critical bugs are discussed during weekly project teleconferences and agreements reached regarding which bugs and/or change-requests will be worked on, and on what time scale. The decision to work on a particular bug or implement a particular improvement is in general made jointly by survey management, the developer, and the group who will receive and implement the modified code. When a developer has completed the agreed-upon modifications, the code is checked into the code repository and the recipient operations group notified that the code is ready to test. The developer will typically provide the recipient group with instructions for testing and validating the improved code, and will often participate in the testing and analysis process. Once a new code version is successfully tested and validated, it is declared current by the production group and placed into production use.

6.3. Configuration Management Tools

6.3.1. Source Code Control System

All of the software used in mission-critical applications is stored and tracked in a source code control system. The system in use is CVS (Concurrent Version System). Each software package is stored as a separate module in the central source code repository located on a computer at Fermilab. The CVS system allows for the creation of a stable release of a software package by creating a branch in the repository for that software module. Branches are typically tagged with a version number and only bug fixes for this version of the software module are made on this branch. After a few test and bug fix cycles on this branch, a stable version of the software module should develop. Meanwhile, enhancements and ongoing development of the software module can continue in the mainline of the repository. The branch and the mainline are periodically merged by the developer so that the bug fixes make it into the enhanced operations version of the software module.

6.3.2. Product Database

CVS works well when tracking changes to flat ASCII files such as source code, but is awkward to use for tracking compiled binary sources or for switching between different versions of software packages. For this task, a Fermilab-developed database and tracking tool called UPS (Unix Products Services) is used. In the UPS system, each software package/module is called a product. All products in the UPS are cataloged in a simple ASCII database and are stored in a special Unix file partition (/p). Each product has a sub-directory in the /p partition, where several complete versions of each product can be stored. This database makes it straightforward to switch between different versions of a product and to track the software dependencies for products.

6.3.3. Problem Reporting Database

All Problem Reports (PRs) for both software and hardware are tracked using a Web-based Problem Report System called the SDSS-II Problem-Reporting Database (GNATS). PRs in the database can be classified as critical, serious or non-critical. Critical-high software bugs are defined as a problem that prevents telescope operations, adversely affects our ability to take good quality data efficiently, or makes reducing or releasing the data impossible. All critical-high bugs are fixed immediately and the fixes are tested right away. Serious bugs are problems or bugs in important telescope commands or operational tools, but for which there is a known work-around. Serious bugs are discussed in the appropriate forum (e.g., functional-area or project-specific teleconferences such as Survey Operations, SEGUE, or Supernova) and decisions made on which bugs will be addressed and on what time scale. This discussion and negotiation occurs between the developer and operations group who will be responsible for installing and validating the modified code.

7. SYSTEM INTEGRATION, COMMISSIONING, TESTING, AND ACCEPTANCE

System integration, commissioning, testing, and acceptance are activities that relate primarily to new development. A large portion of all of the SDSS-II systems were developed and tested under SDSS-I. Nonetheless SDSS-II does have a number of development tasks. These are:

- Upgrade to the mountaintop data-acquisition system (DA), including both hardware and software.
- Software development for SEGUE, e.g. target-selection algorithms and pipeline code for stellar atmospheric parameters.
- Software development for Supernova, e.g. pipeline frame-subtraction code and code for rapid evaluation of good candidates based on the light curve and colors.
- New computing hardware to support data processing and data distribution for SEGUE and for Supernova.
- Development and implementation of code for final photometric calibration.

We have already made significant progress on all of these tasks; here we describe relevant procedures for each.

7.1. Mountaintop Data Acquisition System

The design, installation, and integration of this system are already complete, since the summer shutdown (July/August 2005) afforded an opportunity to make the transition to the upgraded system with minimal loss of observing time. The DA affects the imaging system, the spectroscopic system, and the Photometric Telescope; it also interfaces to the mountaintop Supernova computing system. As of this writing, we are taking data and thus in testing mode. Developers at Fermilab are in close communication with the daytime APO staff and the Observers, who are doing the on-the-sky testing. During this critical time, there are daily teleconferences between Fermilab and APO to identify problems and to formulate specific plans for resolving them.

An important supplement to these verbal discussions is the Problem-Reporting Database (which is extensively used by the SDSS-II for the whole survey). Problems of any nature can be posted by any of the involved people, and made visible to all of the individuals with skills that may be applicable. Even problems that are already solved are posted so that there is a record. The database includes fields for which system encountered the problems, who is assigned responsibility for resolving the problem, who is assigned responsibility for testing, what the test was, and whether the problem was closed (which in effect comprises "acceptance").

The Project Manager and the Project Scientist oversee the general project integration and testing. In the case of the DA, a primary criterion for acceptance is whether the new system and the old system give the same outputs for the same inputs; so far we have determined that this is the case.

7.2. SEGUE Software Development

SEGUE has a dozen spectroscopic target categories and is thus relatively complex. We have conducted observations for SEGUE since the Fall of 2004 to test preliminary versions of the target-selection algorithm and other aspects of SEGUE observations.

A timely convergence on the final target-selection code is obviously critical. On the other hand, since it is relatively easy to reprocess the spectroscopic data, we are under less time pressure to make the needed upgrades to the SEGUE spectroscopic pipeline, and we will do so over the coming year.

Both the target-selection code and the modified spectroscopic processing code require the active involvement of scientists: the issues require scientific judgment, the process is iterative, and it is often hard to optimize the balance of applied effort versus scientific benefit. Our method for software design, integration, commissioning, testing, and acceptance takes advantage of the close working relationship of the SEGUE scientific team, operating in a research environment. For example, it is essentially a research project to determine if the pipeline outputs are producing the right values, and the right errors, for stellar effective temperatures. While in principle the testing could be done by a project-supported individual with specific responsibilities, in practice we take full advantage of the large, diverse group SEGUE scientists, which yields a much deeper skill mix and allows for multiple checks.

The development of the code is partly done by project-supported people with designated responsibilities, and partly by scientists volunteering time. The various tasks are in the SEGUE WBS and are tracked by the Project Team Leaders and Project Manager. The Project Scientist oversees whether the actual performance of the systems are meeting the SEGUE goals as stated in the proposal.

7.3. Supernova Survey Software Development

The methods for developing the new systems needed for the Supernova survey mirror the methods for SEGUE, namely, there is a coherent team of scientists working on elements of the Supernova WBS (coding, integration, and testing). Some of the more junior scientists are supported by the project and so have designated responsibilities, and other more senior scientists are contributing effort. Communications are extensive, via frequent teleconferences and via mail lists. The process enables a very broad base of scientists to be involved and to make tangible contributions.

Because of the time-critical nature of the Supernova survey, the computing is done at APO. A prototype of the mountaintop hardware and software system was implemented in the Fall of 2004 and successfully obtained test data. The remaining work relates to upgrading the Fall 2004 systems to handle more data from more filters faster. These upgrades have already been made, in time for the start of the survey on 1 September 2005. Commissioning, testing, and final acceptance are ongoing, now with on-the-sky data. The evaluation of the data and of the pipeline outputs is again essentially a research effort, involving the same people who developed the systems.

7.4. New Computing Hardware for Data Processing and Distribution

Additional machines and disks are needed to process and stage data obtained by SDSS-II. However, the work is incremental to the current computing environment at Fermilab, and we have already designed the needed infrastructure to expand the systems, based on similar increments needed to move from one SDSS-I data release to the next. The systems are managed by the Computing Division at Fermilab, a large infrastructure from which we are well supported. Testing of the integrity of the databases will be done in the same way we test the current SDSS data. For these reasons, for this development work we have not devised any new plans for integration, commissioning, testing, and acceptance.

7.5. Final Photometric Calibration

The photometric calibration effort involves analysis and software development; no new hardware is required. Over the course of the survey, we will finish the Apache Wheel code, compare calibration results to externally calibrated data, and develop the software required to integrate the new calibration outputs into the factory data processing operation. We will also analyze the data processing output to validate the final calibration. This is clearly a longer-term project, and we have remaining organizational work to accomplish in terms of assigning tasks (there may be new hires). For SDSS-I, much of the testing of the photometry was done by astronomers interested in minimizing the systematics in the survey for large-scale structure studies; we expect a similar level of involvement by scientists in the testing for SDSS-II.

8. QUALITY ASSURANCE AND QUALITY CONTROL

This section describes the procedures used to insure that the quality of the data distributed to the consortium and ultimately to the public are of the high quality defined in the survey requirements; and to rectify failures to meet those requirements.

8.1. Introduction

For surveys of the kind of SDSS as originally conceived and in the three-pronged continuation in SDSS-II, strict control on the quality of the data is crucial. The data sets are so large and the details of the data acquisition and processing so removed from the end user of the data that the data are essentially useless unless there are well-defined minimum standards they must meet. It is also very useful for the end user to have accurate, well-understood metrics by which data which do meet survey requirements and is released can be sorted by various criteria of excellence for especially demanding projects. Meeting these desired things is the aim of the Quality Assurance (QA) program.

The QA procedures for SDSS-II are a natural outgrowth of what we began in the original survey but will be extended in ways which are driven by the requirements for the new scientific thrusts and by new capabilities enabled, for example, by the new data acquisition system.

In essentially every aspect of the survey, the QA exercise can be divided into two parts, by no means completely separable but useful for organization and description. First, tests need to be made on the raw data as they come off the telescope to make sure, to the extent possible, that the observing conditions are suitable and, more importantly, that the instruments are behaving properly. Second, more sophisticated tests can be and need to be done on the data after processing both to refine the assessment of the quality of the input data and to assess the quality of the reductions. The thing we wish to prevent above all is that data are compromised by some (perhaps subtle) problem with the telescope or instruments and this condition is not caught for some considerable period of time, possibly invalidating all the data for that period and necessitating re-observing or, in the worst case, de-scoping the survey.

The QA procedures are quite different for the spectroscopy and the imaging, and we will discuss them separately.

8.2. Imaging QA

The imaging QA begins on the mountain with the real-time data acquisition system. Several basic things are checked, including the bias levels and read noise of the CCDs, the FWHM of the images on all the CCDs, the sky levels on all the CCDs, and the form of the TDI flat fields. The read noise is checked against historical data and serious deviations are flagged. Biases are taken every imaging night and the levels and profiles are compared with historical data; again significant deviations are flagged. The sky levels vary a great deal, of course, but excessive levels caused by, for example, auroral activity, and misbehaving sensors can easily be found. Many of these checks are performed automatically and are flagged on a display maintained by a sophisticated piece of monitor software called Watcher.

There is a FWHM limit of 1.6 arcseconds for imaging, and it must be photometric. The decision to switch to imaging during a night is motivated by seeing measurements by the differential image motion monitor (DIMM), anecdotal evidence from the other telescopes on the site (primarily the 3.5-meter), the output of the 10-micron all-sky cloud camera, and, of course, by the observers' experience with the weather at the site. Often the observing will *begin* with imaging, motivated by the weather patterns. In any case, once an imaging run is underway, there is real-time feedback from real-time analysis of the image FWHM for stars automatically chosen from each CCD, and sensors with discrepant image sizes are flagged on Watcher. The Watcher display in this case is an array of boxes on the screen arrayed like the CCDs in the camera, with the sensor identification and the current FWHM displayed. The boxes are green if the FWHM is satisfactory, red if not; the green-red go/nogo theme is maintained for all of the displays. The transparency is evaluated in a rather indirect way by looking at the variance in the image obtained by the all-sky thermal infrared camera. This is calculated every five minutes, and there is a simple threshold set for satisfactorily photometric conditions; this has worked very well in practice. At the same time, the 0.5-meter robotic photometric telescope observes primary standards periodically, and a running photometric solution is maintained by real-time software from these observations.

At the end of the night, therefore, there is reasonable assurance that the data taken are OK from these simple tests, and in only a few instances have we been fooled. In each of these cases, very little data was lost, and the causes were sufficiently bizarre that it was decided that it was not cost-effective to test for their presence as a standing procedure.

When the data are processed at Fermilab, a quite sophisticated QA suite is applied, and the outputs of these tests are made available both to the consortium and to the public when the data are released. There are two QA programs, runQA and matchQA. The former is a set of self-contained tests for the imaging run in question; the second compares the reductions for the run in question with others which overlap it on the sky. There is a fair amount of redundancy in the SDSS imaging due to stripe overlap, repeated data at the beginnings and ends of incomplete scans, oblique calibration scans , and, of course the multiple scans of the southern equatorial stripe, and as a result this is a very powerful test.

The runQA suite uses the fully calibrated outputs of the photometric pipeline to perform a series of powerful checks on the integrity of the data. These include the following tests:

1. Uniformity of the sky background from column to column, corrected for expected gradients due to elevation differences across the field.

2. Uniformity and values of 4 "principal colors" chosen as linear combinations of the 4 SDSS colors in which the stellar locus is especially narrow in some restricted SDSS color range. This test is especially powerful in determining photometric quality.

3. Agreement of PSF and canonical aperture magnitudes. This test is very sensitive to how well the PSF is determined.

4. Astrometry. Agreement of the astrometric positions of the USNO UCAC stars on the photometric frames with the astrometric solutions.

5. Flat fields. This test looks at the constancy of the principal colors across each set of CCDs in a dewar. Since the swath of one dewar is only 13 minutes of arc, it is expected that they should be constant in the mean across that swath. Errors in flatfielding show up as variations in the colors.

6. Seeing. The FWHM is evaluated as a function of time for each CCD in each column, and problematic areas in which the seeing is bad or is changing rapidly (which condition nearly always confuses the PSF determination) are found and flagged.

7. Finally, a composite quality index for each field in the run is evaluated and displayed.

The matchQA tests allow a much deeper analysis, and include external photometric errors from direct comparison of two runs on the same part of sky for galaxies, stars, and comparison of the rms differences with the calculated errors. Object classification is also compared, so the star-galaxy separation as a function of magnitude in particular can be evaluated, and errors can be analyzed as a function of CCD column as another sensitive test of the flat-fielding.

In SDSS-II a new calibration technique called ubercalibration, in which all of the data with its overlaps is treated in one very large least-squares problem to determine corrections to run zero points and flat-fields, will be used. Preliminary tests using significant fractions of the whole data set show that photometric errors in most bands can be brought to under one percent with this technique, and the u band to of order two percent. Object-by-object comparison of these results with the conventionally calibrated photometry will also be an end-to-end QA tool. It is likely that a sizeable fraction of the calibration errors at present are due to uncertainties in the 0.5-meter photometric telescope transfer patch photometry brought about by uncertainties in the flatfielding, especially in the u band. The ubercalibration scheme is aided by the input of special "Apache Wheel" data taken on photometric nights with the telescope scanning at approximately seven times its normal rate with 4 by 4 pixel binning. Most of these data are taken with the scans roughly perpendicular to the normal survey stripes, so the calibration errors from stripe to stripe, which normally are poorly controlled, can be controlled. In addition, the rapid scanning gives leverage over very large angular scales, again which are poorly controlled using the normal techniques.

It is worth mentioning here a couple of near-failures, both of which were caught by visual inspection. On one run in the spring of 2001 a set of wide, diffuse stripes were noticed in the data. After consideration of possible cosmic sources, it was decided that the cause had to be instrumental, and careful inspection and head-scratching revealed that a change of configuration in the electronics in the mirror cell had left an uncovered LED which at just the right rotator angles could shine onto the camera corrector at a very oblique angle. We, like many other observing facilities, have had a fair share of trouble with LEDs, which are ubiquitous parts of some very large fraction of purchased equipment. This was the only camera problem so caused, but the spectrographs have had a rash of them. The second was a soft power-supply failure which injected noise into the CCD data stream in one dewar. The noise was not of sufficient amplitude to trigger read-noise thresholds, but was coherent and very damaging. This was found by inspection of the data and quickly diagnosed and repaired; in both cases there was an element of luck involved. In the second case it might be argued that such things can be found by full-up Fourier analysis of a bias frame or even a data frame with some preprocessing, but we had neither the processor or programmer resources to pursue this course. Visual inspection we felt in any case to be better, since a human can find troubles any narrowly focused piece of software cannot.

One of the limitations of on-mountain imaging QA has been the very old and slow computer hardware associated with the real-time data acquisition system. The problems with the old system were sufficiently severe that, though it gathered data quite robustly, interfering with it even to the extent of pulling over a frame for careful inspection was chancy. The data are continually displayed, and the displays are sufficient for gross evaluation, but not for anything even slightly subtle. The new system, which is now installed and undergoing commissioning under fire, is of order a hundred times faster. The data are archived on the Unix side of the system (the DA itself is a VME system running VxWorks), which makes them available at once for whatever analysis is desired. We hope in the near future to run a stripped-down version of the Fermilab QA tools in near-real-time on the mountain, which we could not have even considered before.

One of the observers, is tasked with supervising and evaluating the on-mountain QA efforts and maintaining historical records against which modern data can be compared. He conducts periodic phone meetings attended by the mountain staff, the Fermilab staff, and the project scientist, to assess the QA effort and to discuss QA problems. It is his job to inspect the imaging and spectroscopic data visually and report any anomalies.

8.3. Spectroscopic QA

The volume of spectroscopic data is much smaller than imaging data, and the limitations of obtaining it and working on it in near-real-time much less severe. From the beginning, a reduced-capability “quick-look” spectroscopic reduction pipeline called SoS (Son of Spectro) has been run on the mountain as soon as the data are obtained. Detailed tests at the beginning of each run are performed to determine the general health of the spectrographs, and the calibration images for each plate are analyzed for correct positioning, focus, and uniformity of focus. Problems with stray LED light in the dome (and, we are embarrassed to say, occasionally in the spectrographs themselves) have been so pervasive that excessive flux in the red LED part of the spectrum is specifically analyzed for.

Since the spectrographs obtain data on objects for which we have photometry, the comparison of the spectroscopic signal with that expected in the synthesized photometric bands is a powerful end-to-end sensitivity test. Since spectroscopic observations are taken generally under conditions of poorer seeing and/or poor transparency, a real-time evaluation of signal-to-noise is necessary to gauge exposure times and to determine the number of exposures (never less than three, but sometimes under poor conditions as many as six) required. SoS provides this as well, and so is an indispensable observing tool as well as a QA tool.

As the survey has progressed, tests have been added to cover problems as they have arisen; the red LED test above is an example, as well as a more recent problem, in which incorrect serial data transfer caused obvious visual havoc with the frames but diagnosing the problem was considerably less obvious. A simple analysis of the bit patterns in the data turned out to be a good diagnostic, and it was implemented. Such things as strong gradients in the photometric comparison between the synthesized magnitudes and the photometric ones, which are indicative of various problems with tracking, scale, and focus, are made.

When the data for a plate have been analyzed by SoS, one-dimensional spectra are produced which can be displayed by the observers, and so quick sanity checks to see whether supposed galaxies look like galaxies, quasars like quasars, etc, are made.

This is carried farther when the final reductions are made at Fermilab, where more extensive visual checking and more refined photometric checking are done.

It is unfortunately true that the spectroscopic QA, while perhaps even more thorough than that for the imaging, is much more poorly documented. This is partly justified by the fact that the QA for the imaging is enormously complex and must encompass a very large number of variables which affect the data quality. For spectroscopy, the criteria are basically that the CCDs are working properly, the spectrographs are in focus, and one has enough photons.

Again, there have been gotchas through the course of SDSS-I, caused by relatively subtle failures. Again in many of these cases an element of luck was involved in finding them and a lot of detective work in diagnosing them, but the data loss has been very small. As the survey has moved into a steady production mode and the personnel both at the mountain and at Fermilab have become more experienced, the incidence of problems not caught or not correctly or ambiguously diagnosed by the interpretation of SoS outputs has decreased.

For the last phase, QA on the full reductions, a great deal of use has been made of the fact that there are two independent pipelines which take the one-dimensional calibrated spectra produced by the first part of the spectroscopic pipeline (spectro2d) and attempt to do photometry and classify the spectra astrophysically. The second pipeline is run at Princeton and is really optimized for stellar spectra, though it classifies everything, as does the official pipeline run at Fermilab. Comparisons of the independent (there is not a line of code or detailed algorithm in common) classifications for all spectra show that agreement in classification and radial velocity is at the 98 percent level, which we consider astonishing. Even better, the two percent of the objects in which there are substantial disagreements consist almost entirely, on the one hand, of objects for which the signal-to-noise is too low to make any intelligent classification, and on the other, delightfully weird juxtapositions or new kinds of weird objects which neither code knew about. Indeed, the class of “failures” in this comparison has been the source of a significant amount of serendipitous science with the survey.

In SDSS-II, the stellar spectra for SEGUE will be reduced for analysis and distribution by the Princeton pipeline, and the Legacy data by the Fermilab pipeline, as before, though both pipelines will continue to reduce all the data, as always, so the comparisons can continue to be made.

For the SEGUE stellar spectra, there is another step which currently is not terribly well defined. The spectra will be analyzed to determine stellar parameters, such as effective temperature, surface gravity, and as many composition parameters as we can reliably obtain given the kind of star and the signal-to-noise in the spectrum. These parameters will be part of the SEGUE data releases. We are currently doing this analysis with prototype code, but the final pipeline code is not yet written and even the algorithms for a number of fussy quantities, primarily reliable error estimates for many of the derived quantities, do not yet exist. We are also currently gathering data on our system for a large number of stars for which accurate parameter determinations from high-resolution spectroscopy exist, so that we have a set from which we can determine accurate external errors. Once these data and algorithms are in hand, the QA becomes relatively straightforward. Repeat observations of fields and/or plate overlaps will allow us to assess internal errors, and very occasional revisits of standards, probably primarily cluster fields, will allow us to assess the stability of external errors. It is likely that the analysis pipeline will evolve fairly strongly as the project progresses; very little work of this sort using spectra of the (fairly low) resolution, (quite high) quality, (very broad) wavelength coverage, and good spectrophotometric calibration that characterize ours has been done before. We are already achieving levels of internal accuracy sufficient to do the proposed science, but the general feeling is that we can, and will, likely do much better. The pipeline is in any case so tightly tied to the scientific interests of the SEGUE team that it must be allowed to evolve simply to keep it maintained. Controlling the development in the sense of maintaining a system sufficiently stable for reliable data releases will be a challenge, but we have a lot of experience with precisely this issue, and do not expect this one to be more difficult than similar ones in other areas.

9. EDUCATION AND PUBLIC OUTREACH

The principal goal of the SDSS-II Education and Public Outreach (EPO) effort is to make the discoveries, data, and methods of the SDSS-II intelligible and interesting to a broad audience of non-scientists. Desirable outcomes include improving science literacy in the US and fostering underrepresented groups to consider careers in science and engineering. To realize this goal, we are creating a new position called SDSS-II EPO Coordinator. Dr. Julie Lutz has agreed to serve in this capacity.

The SkyServer will continue to be developed as the public portal to SDSS-II data, including tools for accessing the data, documentation on how to use the tools, and suggestions for projects to undertake with the data. In consultation with teachers and amateur astronomers, we will improve the user-friendliness for users with relatively little astronomy background and/or experience with manipulating large databases. We will consider organizing workshops on SkyServer and on SDSS science for educators at various SDSS locations. We will explore ways to provide ongoing support for users who have been through the training.

The sdss.org site is intended to serve the public as well as the Collaboration. At this Web site, the public can obtain background information about the project; images of hardware and of astronomical objects; a small number of demonstrations using imaging and spectroscopic data; the Picture of the Week with its popular-level caption; the publication list; and information that gives a sense of how the project is run and how the Collaboration works. To determine how best to improve the site, and how to call more attention to it, we will need to learn who is using it (for example by soliciting information via registration). Two specific ideas for additions to the site are profiles of scientists working on the project, and popular-level abstracts of the research papers.

The SDSS-II partnership includes the American Museum of Natural History (AMNH) and its Rose Center for Earth and Space. Several efforts will be undertaken by the AMNH to publicize SDSS-II science. For example, a video documentary feature story will be created about SDSS science. SDSS data will be incorporated into the Museum's *Digital Universe* database, which has grown to become a virtual universe, now supplemented with distance estimates for all objects from SDSS photometric and spectroscopic measurements. Moreover, SDSS data will also be featured in a future Space Show for viewing by Hayden Planetarium audiences as well as at national and international dissemination venues. Finally, astronomy activity carts, staffed by trained explainers, will offer Internet access and numerous hands-on, participatory experiments and demonstrations illustrating the different ideas presented. The AMNH will incorporate SDSS information and data into this menu of astrophysics education activity.

The position of Public Information Officer (PIO) established in SDSS-I will continue into SDSS-II. This position is held by Gary Ruderman, a free-lance writer. He coordinates the production of press releases and press conferences with the PIO's at the respective participating institutions. He helps with activities associated with AAS meetings (e.g. the SDSS exhibit booth). He handles enquiries from the press, and provides an interface between the project and media (e.g. film crews at APO).

We intend to establish a repository of documentation for SkyServer educator workshops (e.g. how-to manuals) and other useful EPO materials, such as PowerPoint files of public presentations. Such a repository of documents will help SDSS institutions and others to conduct similar workshops and public presentations. The success of educator workshops depends partly on the level of ongoing support for the participants; ideas for how to continue to engage the participants at some later time will also be documented.

Many SDSS institutions have undergraduates using SDSS data for research projects, or follow-up research derived from SDSS data. We plan to track undergraduate research projects related to SDSS. A Web site can document these projects, publicize them, and perhaps enable students from different institutions to work together.

In addition to these various outreach directions, a number of SDSS-II institutions (and individuals not at SDSS-II institutions) have been conducting outreach programs in one way or another that use SDSS data.

These efforts range from popular talks to relatively ambitious teaching programs involving schools or networks of teachers (such as the Collaboratory at Northwestern University). It is expected that these grass-roots efforts will continue to grow.

The SDSS-II EPO program will include all of these elements as building blocks. The EPO Coordinator has the responsibility to review the building blocks and attempt to assemble them in creative ways, identifying strengths around the Collaboration that may be usefully put together for an even greater benefit.

In addition to the efforts of the EPO Coordinator, we will consider enlisting the help of a K-12 teacher with a strong interest in astronomy. In so doing, we would add an important perspective that we do not already have within the project.

In summary, the position of SDSS-II EPO Coordinator includes the following tasks:

1. Ascertain what SDSS-related EPO programs are going on currently at the partner institutions. Seek advice from those who are doing the projects and others with an interest in EPO as to how coordination and communication should occur.
2. Let Collaboration members know what is going on in SDSS EPO programs via a Web page attached to sdss.org. This Web page would include documentation of EPO projects, PowerPoint presentations for popular talks, etc.
3. Look for common elements, themes and interests among the SDSS EPO activities. Once these are identified, the EPO Coordinator can facilitate the production of some materials that might be generally useful to Collaboration members, for example by creating a template for conducting workshops and providing subsequent support for educators who would like to learn how to use SkyServer.
4. Organize an EPO session at Collaboration meetings so SDSS scientists and engineers can share their projects and interests.
5. Advise Collaboration scientists and engineers on EPO logistics, e.g., how to recruit educators for a workshop, funding opportunities, dealing with national/state science standards and high-stakes testing, informal education groups that might be interested in SDSS, etc.
6. Help to publicize the sdss.org Web site, SkyServer and other SDSS EPO programs by writing articles for the National Science Teachers Association, Astronomy Education Review, etc.

10. RISK ASSESSMENT AND MANAGEMENT

Projects with the scope and complexity of the SDSS-II Survey must be carefully assessed to identify areas containing a high degree of risk. Risks may be associated with internal factors such as inadequate operations planning, equipment failure, complications associated with new development work that has never been done before, poor cost estimates, and the loss of key personnel. Risks may also be associated with external factors including weather and changes in economic conditions that impact the ability of participating institutions to meet financial and personnel resource commitments. The failure to identify and properly manage these risks may result in cost overruns, schedule slippages, and inadequate technical performance.

The key elements of a comprehensive risk assessment and management program include risk identification and analysis, implementation of risk minimization and contingency plans, and an appropriate level of contingency reserve. For SDSS-II, the WBS has been used to help identify risks associated with specific elements of the project. The following sections identify potentially serious risks by project area and discuss strategies for minimizing these risks. Contingency reserve and management is discussed in Section 11.

Survey Management

Survey Management comprises the activities of key project personnel, including the Director, Project Scientist, Project Manager, Spokesperson, and ARC Business Manager. The primary risk associated with Survey Management is the departure of one of these individuals, which could result in the loss of critical scientific and technical skills, and institutional knowledge. The risk is minimized by a steady dialogue and the continuous sharing of information between these individuals.

Withdrawal of a financial commitment from an invested partner is very unlikely because we have obtained formal letters with explicit pledges. Even if an institution were to withdraw, the impact would be small because of the large number of participating institutions. More serious (but still very unlikely) would be the withdrawal of one of the partners contributing essential operational resources. This risk is minimized by successfully meeting Survey milestones and goals, and maintaining good communication with each institutional partner to remain aware of changing conditions that may impact future involvement.

Observing Systems

Observing Systems includes all of the equipment and systems used to acquire data at APO. It also includes the personnel responsible for maintaining, repairing, and where necessary, improving these systems. A complete description can be found in Section 3.

With the exception of the upgraded data acquisition system and the newly-implemented Supernova Survey data processing computers, all of the equipment and systems associated with Observing Systems have been in place for several years and were used to acquire data for the SDSS Survey. During the preparation of the SDSS-II work plan and cost estimate, we considered system performance and reliability over the past 5 years of operation, and the impact of aging and obsolescence, in our technical risk assessment. The results of this assessment, and our plans for minimizing risk, are as follows:

1. 2.5m and 0.5m Telescopes

   Risk Assessment: The telescopes are in good operating condition. Potential risks going forward include critical component failure (*e.g., drive amplifiers, motors, bearings, encoders, mirror control and support systems, etc.*), component obsolescence, damage to optics, and the loss of institutional knowledge.

   Risk Minimization Plan: A strong preventive maintenance program and a spare parts inventory system were put in place during SDSS-I operations, resulting in average system uptime of 96% over the past three years. The PM program and spare parts system will continue to be used for SDSS-II. Moreover, in preparing for SDSS-II operations, the spare parts inventory was reviewed and additional components purchased as necessary to provide adequate sparing for three additional years of operation. With regard to optics, protecting telescope optics is a very high priority. Procedures have been developed and vetted and are in place for handling telescope optics. In addition, all optics handling operations are performed under the direct supervision of the Telescope Engineer. To protect against the potential loss of institutional knowledge over time, we are cross-training site technical staff and improving system documentation.

2. Telescope Instruments (*Imaging Camera, Fiber-feed Spectrographs, PT CCD*)

   Risk Assessment: All instruments are in good operating condition and should remain operational through the 3-year extension. Potential risks going forward include the loss of an instrument due to a lightning strike or other electrical surge, loss of a CCD, component obsolescence, and accidental damage during maintenance and repair.

   Risk Minimization Plan: The threat of lightning strikes or other electrical surges is mitigated through the use of Uninterruptable Power Supplies and isolation transformers that isolate the instruments from line power; comprehensive grounding connections for the telescope enclosure; and the use of opto-isolator circuits to eliminate copper wire connections from penetrating the enclosure shell. The loss of a CCD in the imaging camera array would be problematic, as we have minimal spare CCDs and the time and effort to install, calibrate and properly test a replaced CCD would significantly impact the project schedule. Obsolescence concerns are addressed by maintaining suitable replacement components in the spare parts inventory at APO. All work on the imaging camera is done under the direct supervision of the Project Scientist. All maintenance and repair work performed on the spectrographs and PT CCD is performed by site technical staff under the direction of the Project Scientist. In his absence, work is directed by the Imaging Scientist. The Project Scientist and Imaging Scientist built the imaging camera and the cameras for the spectrographs and continuously monitor their health during operations. If critical errors occur with the imaging camera that prevent the acquisition of survey-quality data, the Project Scientist, Imaging Scientist, and technical support staff travel to the observatory to make emergency repairs. The site technical staff responds to critical errors with the spectrographs and PT CCD. Less-critical problems are addressed on an annual basis during the scheduled summer shutdown.

3. Cartridge-Handling and Plug-Plate Measuring Equipment

Risk Assessment: Cartridge-handling equipment includes the hardware used to handle the spectrograph fiber cartridges in the APO plug-plate lab and move the cartridges to and from the telescope. Plug-plate measuring equipment includes systems such as the Fiber-Mapper, which maps the location of optical fibers in a specific plug-plate. All equipment and systems are in good operating condition. Risks going forward include premature equipment failure and component obsolescence.

Risk Minimization Plan: A preventive maintenance plan is in place to maintain the condition of this equipment. The PM program allows us to monitor the condition of equipment over time and to take corrective action as necessary to replace and/or repair components showing signs of wear and premature aging. The risk of component obsolescence is minimized by maintaining a suitable supply of spare parts.

4. Data Acquisition System

Risk Assessment: The DA system acquires data from the various instruments and prepares it for transfer to Fermilab, Princeton, and the SN data processing system at APO for subsequent processing and analysis. The DA system was delivered and commissioned in 1995. Many of the board-level components are obsolete and no longer available, and the current spares inventory is insufficient to replace all of the obsolete components. In addition, the host computers used by the observers to interface with the telescopes, instruments, and DA system are obsolete and costly to maintain.

Risk Minimization Plan: In preparation for the SDSS-II Survey, the DA system has been upgraded with new components and the existing DA software has been ported to run on the new components. In addition, the existing host computers have been replaced with more powerful and less costly Linux computers and existing software has been ported to run on the new operating system. The upgrade will result in a substantially more reliable, maintainable, and cost-efficient system. In addition to providing for the upgrade itself, the upgrade budget included funds to procure an adequate level of spare components.

5. Plug-Plate Production Operations

Risk Assessment: Plug-plate operations include plate design at Fermilab and plate fabrication in the UW Physics Shop. Risks include the loss of institutional knowledge and the loss of machine tools and facilities at UW due to an environmental catastrophe (e.g., earthquake or building fire) or machine tool breakdown.

Risk Minimization Plan: During operations, one individual at Fermilab is responsible for running the target selection code and generating the drill files used to fabricate plug plates. However, others in the Fermilab data processing group know how to perform this operation; therefore, risk is minimized through cross-training and redundant knowledge. A short-term loss of production capabilities in the UW Physics Shop would most likely be caused by a problem with the large drilling machine used to fabricate plates, or in the large Coordinate Measuring Machine (CMM) used to make quality control measurements on finished plates. Based on past experience, it is not likely that either of these machines would take more than a few weeks to repair (the limitation being replacement parts availability), so we do not expect to lose more than one drilling run due to a serious machine breakdown. It should be noted that in the past five years of operation for SDSS-I, no drilling runs were lost due to a machine tool failure. Notwithstanding, the short-term loss of fabrication facilities is minimized by maintaining a sufficient backlog of plates that have already been drilled and shipped to APO for observing. For the Legacy Survey, a sufficient backlog of plates exists. For the SEGUE Survey, we are still drilling plates in a just-in-time mode, so a loss of fabrication facilities could result in a short-term shortage of SEGUE plates. A catastrophic failure caused by environmental conditions would be addressed by re-locating plate fabrication to Fermilab or a commercial machine shop. The limitation is finding a fabrication facility with a drilling machine large enough to handle the ~1-m diameter plug-plates.

On an annual basis, the Project Manager brings together the members of the technical staff to review system performance during the previous year, identify areas of concern regarding the on-going condition of systems and equipment, and identify equipment or systems requiring improvement to maintain operational or science requirements. Work is prioritized using the Risk Priority Matrix shown in Table 10.1. The matrix ranks projects based on the probability of an event or failure occurring, against the potential impact (cost and schedule) to the project. The result of the assessment and planning exercise is a prioritized work plan for the coming year. The exercise also provides a forum for the identification and discussion of new risks that arise during the course of operations.

Table 10.1. Risk Priority Matrix

		Potential Impact		
		High	Medium	Low
Probability	High	HIGH	HIGH	LOW
	Medium	HIGH	MEDIUM	LOW
	Low	MEDIUM	LOW	LOW

Observatory Operations

Observatory Operations includes the observatory site infrastructure and the staffing and resources required to maintain the observatory at the level necessary to sustain operations. Potential risks include environmental conditions that could permanently damage facilities (e.g., forest fire, building fire, lightning strike, etc); poor management practices that violate agreements with federal and state agencies (e.g., activities and actions that violate conditions in the agreement with the National Forest Service (NFS) for operating the observatory on Forest Service property); and poor management or work practices that result in serious personnel injury or environmental damage that result in a shutdown of site operations.

To minimize the risk associated with forest fires, the Site Operations Manager has on several occasions obtained permits from the NFS and cleared timber away from observatory buildings and telescope enclosures. Increasing the distance between the forest and site structures provides a modest buffer zone around the site. In addition, the National Forest Service occasionally clear-cuts areas near the observatory to eliminate dead-fall and remove diseased trees and excess brush. These materials are disposed of through controlled burns conducted by the NFS.

To minimize personnel risks associated with lightning strikes, the Site Operations Manager has implemented procedures that require personnel to remain indoors during severe weather. In addition, visitor guides available at the observatory warn visitors to take cover in the event of severe weather.

To minimize lightning risk to site infrastructure, a lightning protection upgrade was completed in 2000. The upgrade was in response to recommendations from an external review committee charged by the Site Operations Manager with reviewing the status of lightning protection measures in place at the time. The upgrade helped ensure that electrical systems were properly isolated and grounded. Follow-up work included replacing the site telephone system to eliminate copper wires from running through walls and into sensitive areas; installing ground cables on all buildings and telescope enclosures; improving the grounding of the 2.5m telescope; and subscribing to an early-lightning-detection and warning system.

To maintain a good working relationship with the NFS and preclude complaints, the Site Operations Manager works closely with the NFS to ensure that any and all site work is performed in accordance with NFS requirements and guidelines, and that all necessary work permits are obtained before work commences.

To minimize risks associated with poor management or work practices, all work is performed at APO in conjunction with the APO Site Safety Plan. The plan defines personnel responsibilities and accountabilities; identifies applicable codes, agencies, and inspection procedures; and outlines requirements and procedures for performing work in a safe and responsible manner. Front-line supervisors are responsible for ensuring that all work done under their direction is performed in a safe manner and in accordance with the Site Safety Plan. Additional information is provided in Section 5.

Data Processing

Data processing includes the activities and systems associated with processing and calibrating data for the Legacy, SEGUE, and Supernova Surveys. Potential risks include outputting substandard data due to inadequate quality control measures; schedule delays due to inadequate configuration control, data re-processing, and equipment failures; and loss of institutional knowledge.

Data outputs from the three Surveys must be carefully inspected to ensure that the data meet the scientific goals for each Survey, as failure to promptly and properly assess and verify data quality may have serious cost and schedule impacts. To minimize this risk, quality control measures are implemented at the observatory and at various steps in the data processing process, as discussed in Section 8.

Configuration control is necessary to maintain data consistency and maximize the use of data processing resources. In order to meet schedule requirements, data must be processed and calibrated in a production manner. This requires limiting changes to only those required to meet the approved science objectives and achieve the level of efficiency necessary to meet schedule requirements. Code changes and improvements require testing and validation, which consume resources. Moreover, if a change is of significant consequence, proper implementation may require the re-processing of existing data. Implementing and validating code changes, and re-processing data, consume resources and have the potential to impact project schedule and cost. To minimize these risks, configuration control measures have been put into place, as discussed in Section 6.

To minimize schedule risk due to equipment failures, we have built redundancy into the systems used for data processing at Fermilab, Princeton, and APO. Data is processed using arrays of computers; if one computer fails, data processing will continue, albeit at a slightly slower pace until the faulty machine is replaced. Data are stored on hard drives configured in Redundant Arrays of Inexpensive Disks, or RAID arrays. Through the use of redundancy, RAID arrays offer increased data security, improved fault tolerance, and improved data availability.

To minimize risks associated with the loss of institutional knowledge, we cross-train personnel and update system documentation as processes change. We also work to automate many of the data processing operations, which in addition to improving operating efficiency, serves as a form of process documentation. Finally, data processing operations are managed by a core group of scientists who participated in SDSS-I operations and have indicated they will remain in their current roles through the 3-year extension.

10.5. Data Distribution

Data distribution includes the activities and systems associated with preparing and loading processed data onto fileservers and into databases, and serving the data to the collaboration and general public. Potential risks include loading and distributing faulty data; failure to meet data release deadlines due to inadequate configuration control; failure to meet release deadlines and system availability requirements due to equipment failures; and loss of institutional knowledge.

As with data processing, sound quality control processes are required to ensure data integrity prior to and after loading the data into databases and onto file servers in preparation for data distribution. Loading faulty data means wasted time, as the data has to be reloaded once problems are discovered downstream in the loading and preparation process. Distributing faulty data is bad for any number of reasons. To minimize these risks, quality control processes will be built into the production data distribution operations. In addition, we have imposed a three-month minimum window between the date a specific data release is made available to the collaboration, and the date it is made available to the general public. This provides a three-month period in which collaboration members use the data and identify problems. Depending on the nature of a given problem, we either fix the problem in the data or document its existence in the data release documentation. The three-month evaluation period helps ensure the quality of released data products.

Configuration control is necessary to minimize schedule risks associated with mismatched data models. When changes are made to data processing code and the data model, and those changes are not properly propagated into the data distribution operation, problems inevitably occur during the data loading process. To minimize schedule risk, configuration control measures to manage data model and database schema changes have been implemented.

To minimize risks associated with equipment failures, we have built redundancy into our data distribution systems. All fileservers are configured with RAID arrays. Multiple copies of each data release are spinning on different machines. In the case of the CAS and SkyServer, to avoid a catastrophic failure at a single site, we have mirror copies spinning at Fermilab and JHU.

To minimize the loss of institutional knowledge, we cross-train individuals, automate processes, and strive to keep process documentation updated.

10.6. New Development

New development work associated with the SDSS-II Survey is discussed in Section 3.3. Risk is typically higher on new development work, as there is greater uncertainty in the actual work to be done and amount of effort required. To minimize these risks, the scope of work and cost estimate associated with each area of new development was prepared in consultation with the Project Team Leaders, individuals who have done similar work in the past, and the individuals who would be performing the work. A WBS was prepared for each development project to outline major deliverables and specify individual tasks at a reasonable level of detail. The WBS was then used to develop a cost estimate and budget for the work, and a schedule against which to track performance. The WBS for new development work is discussed in Section 3.

The Project Manager is responsible for developing and maintaining the WBS for new development work, in consultation with the Project Team Leaders. He is also responsible for tracking performance against the work plan and for working with the Project Team Leaders to make adjustments as necessary to ensure that development work is completed on time and within the approved budget.

11. CONTINGENCY MANAGEMENT

The original project budget included only 2% for contingency (Management Reserve). Fortunately, since scientific interest in SDSS-II remains high, we have had the opportunity to expand our original partnership, and thereby raise additional funding to expand further the project's scientific and outreach goals. At the same time we take the opportunity to allocate some of this additional external funding to rectify the previously inadequate contingency reserve, restoring it to a level better matched to best management practice. We will start the SDSS-II with a cash Management Reserve of approximately 8% of the original project budget.

The remaining additional cash will be available to pursue new projects (New Projects Fund), an example of one such possibility being support for designated tasks associated with Education and Public Outreach. If at any time the project suffers an emergency where the Management Reserve proves to be insufficient, then the remaining cash in the New Projects Fund can be tapped for this purpose. Conversely, if in later years it appears that holding a smaller Management Reserve is acceptable, then cash can be moved from the Management Reserve to the New Projects Fund. In any case, we do not intend to start new projects with major expenditures early in the project, to ensure sufficient balance to address potential large unforeseen expenses.

Prior to the submittal of each year's budget request to the Advisory Council, the Management Committee will assess any likely demands in the coming year on spending from the Management Reserve, based on an evaluation of the status of the project infrastructure and any other issues that are relevant. This assessment forms the basis for the proposed level of the Management Reserve that is part of the annual budget request.

Separately, the Management Committee will also consider the merits and priorities for activities that could be funded from the New Projects Fund. Based on that review, it makes a recommendation to the Advisory Council for specific expenditures. This recommendation also appears in the budget request, and requires the approval of the Advisory Council because any such funded activity represents an extension of the scope of work for the SDSS-II.

The above process ensures that the Advisory Council can monitor the level of the contingency, and can take an active role in the design and approval of extensions to the scope of work. It also provides for flexibility in the best allocation of resources as the survey progresses.

12. FINANCIAL MANAGEMENT AND BUSINESS CONTROLS

12.1. Institutional Work Agreements

Funding for the SDSS-II has been obtained from federal, private, and international sources. These funds are administered by the ARC Business Manager and disbursed to the institutions performing work for the project through formal work agreements known as Sky Survey Projects (SSPs). Appendix C lists the current set of formal work agreements, organized by institution.

Each agreement defines the General Conditions under which work will be performed and allowable costs will be reimbursed. Each agreement defines the performance period and reporting requirements, and includes a description of the work to be accomplished (the scope of work) and a budget to support that work. The scope of work and budget are determined through a negotiation with the Project Manager and the institutional contact responsible for managing the SSP; the latter is referred to as the SSP Manager.

SSP work agreements are revised annually as part of the annual budget preparation and approval process. Once the budget for the next fiscal year is approved, the SSP agreements are formally amended by the ARC Business Manager to reflect the approved budget and any changes in work scope. The amendments typically occur in the fourth quarter of the calendar year.

12.2. Cost Control Structure

The work plan is organized by WBS as discussed in Section 4. Work tasks are distributed amongst the participating institutions based on logistics, skill requirements, and resource availability. The WBS structure has many branches, some of which extend out seven levels. Tracking costs to such low levels is unnecessary and would require a complicated accounting structure. To preclude this, the project budget is organized into a Cost Control Structure (CCS) that has a one-to-one mapping of the WBS, to level 3. Level 4 of the CCS corresponds to the SSP work agreements with participating institutions. This allows costs to be tracked at the level at which work is assigned to the participating institutions and defined through the formal work agreements. The SDSS-II CCS is shown in Appendix D.

12.3. Budget Preparation Process

The baseline cost estimate for the SDSS-II Survey was prepared using a bottoms-up approach that took advantage of the experience gained during the past five years of SDSS-I operations. The cost estimate takes into account all known tasks required to complete development work and operate the SDSS-II Survey. In preparing the budget, specific responsibilities and deliverables were provisionally assigned to groups at the participating institutions. In consultation with the Project Manager, these groups then determined resource requirements and developed cost estimates and schedules for their tasks. In most cases, personnel costs are based on current salaries of the individuals who will actually do the work, as many of these people have been working on the SDSS project for the past several years. In those instances where work has not been assigned to a specific individual, personnel costs have been estimated by using the average salary for the appropriate job classification at the institution where the work will likely be assigned. Time estimates for routine operations and maintenance tasks were based on the experience obtained in the past five years of operations. Procurement, fabrication, and installation costs for new work were based on solicited quotations or careful estimates based on prior experience. Cost estimates for the individual tasks in the WBS were incorporated into the SDSS-II CCS and provisionally assigned to an SSP.

The baseline cost estimate was presented to the Advisory Council and approved as the baseline budget for the 3-year Survey. The baseline budget is shown in Section 2. On an annual basis, the Project Manager is responsible for preparing a revised cost estimate for the 3-year Survey that takes into account actual expenses incurred and the current cost-to-complete forecast. The Project Manager is also responsible for preparing the annual operating budget for the coming year for consideration by the Director. The Project Manager prepares the annual budget in consultation with the SSP managers, taking into account the work plans and anticipated needs for the coming year. The budget includes all funds and in-kind services needed for the operation of the Survey. The Director reviews the proposed annual and cost-to-complete budget with the Project Manager and adjustments are made as necessary to balance work needs with available resources.

12.4. Budget Approval Process

The ARC fiscal year coincides with the calendar year. In the fourth quarter of each year, the Director submits the proposed annual operating budget for the coming year, as well as the revised cost-to-complete budget, to the Advisory Council for consideration. During the budget presentation, the Director reviews cost performance against the approved budget for the period just ending, and presents the request for the new budget. The Advisory Council transmits the Director's budgets along with its recommendations to the ARC Board of Governors for approval.

12.5. Expenditure Approvals

The Director is responsible for implementing financial controls within the project. He is assisted by the Project Manager and ARC Business Manager. The Director approves all expenditures above $3000. The Director and ARC Business Manager approve all computer purchases in accordance with ARC corporate policy. The Project Manager tracks expenditures against the approved budget and advises the Director of financial status and performance.

12.6. Cash Flow Management

The ARC corporate office, under the general supervision of the ARC Treasurer, receives and administers project funds received from federal, private, and international sources. The ARC Business Manager works with the Project Manager to prepare cash flow forecasts and Sources and Uses of Cash statements. The Business Manager provides quarterly Revenue and Expenditure Reports to the Director, Project Manager, and Advisory Council to show expenditures and obligations compared to the annual budget and cost-to-complete forecast. The Business Manager reviews invoices for accuracy and pays the invoices from the appropriate funding source. For example, only expenses included in the approved NSF budget plan are paid for from NSF funds.

12.7. Cost Performance Reporting

Cost performance is formally tracked with respect to the approved budget by the Project Manager, Director and Advisory Council.

On a quarterly basis, each SSP Manager submits a progress and budget report to the Project Manager that describes the work completed in the preceding quarter, work planned for the coming quarter, actual costs incurred in the preceding quarter, and a revised forecast for the remainder of the calendar year. Since institutional transaction reports from some of the participating institution financial systems tend to lag actual expenses by as much as two months, the Project Manager and the ARC Business Manager consult with departmental budget officers to obtain accurate forecasts. The Project Manager uses information from the SSP Managers and budget officers to track and report on performance against the budget.

On a quarterly basis, the Project Manager is responsible for preparing a quarterly financial report that tracks cost performance. The financial report is included in the quarterly progress report that is provided to the Advisory Council, funding sponsors, and SSP Managers. The financial report compares the actual expenses of each institution against the plan for the quarter, based on the input received by the SSP Managers. By reviewing quarterly SSP progress and budget reports, the Project Manager is able to assess cost performance and understand the cause of significant deviations from the baseline plan. When significant deviations occur or are forecast, adjustments are made in the overall plan and forecast for the remainder of the year to ensure that critical work is completed and the project remains within the approved budget. When new work is added to the baseline plan, the work is either funded by allocating undistributed contingency or by eliminating other planned work that is of lower priority.

On an annual basis, cost performance is formally reviewed by the Advisory Council in conjunction with the Director's budget request for the next fiscal year. The Director or Project Manager presents to the Advisory Council a report on the cost performance for the period just ending, noting significant discrepancies and highlighting any changes that may impact future financial performance.

12.8. Management Reserve

Management reserve funds are held in an ARC corporate account and controlled by the Director. Management reserve funds are used to cover the cost of unanticipated but required expenses that arise during the course of survey operations. Management reserve funds are allocated only after it is clear that the costs cannot be covered by adjusting priorities, postponing procurements, or rearranging work. Any use of management reserve funds is reported in the Quarterly Progress Report and noted by the Director to the Advisory Council during the annual budget review process.