Run 4469 Col 2 Field 436

Active Nuclei and Their Host Galaxies

Rich Kron
Hands-On Universe Teacher Resource Agents Workshop
August 2005, Yerkes Observatory

taxonomy: Seyfert galaxies and quasars

connecting properties of the surrounding galaxy to the central nucleus:

- galaxies with active nuclei are relatively luminous
- host galaxies tend to be barred spirals

1943 Astrophysical Journal, 97, 285

NUCLEAR EMISSION IN SPIRAL NEBULAE*

CARL K. SEYFERT†

ABSTRACT

Spectrograms of dispersion 37–200 A/mm have been obtained of six extragalactic nebulae with high-excitation nuclear emission lines superposed on a normal G-type spectrum. All the stronger emission lines from λ 3727 to λ 6731 found in planetaries like NGC 7027 appear in the spectra of the two brightest spirals observed, NGC 1068 and NGC 4151.

Apparent relative intensities of the emission lines in the six spirals were reduced to true relative intensities. Color temperatures of the continua of each spiral were determined for this purpose.

The observed relative intensities of the emission lines exhibit large variations from nebula to nebula. Profiles of the emission lines show that all the lines are broadened, presumably by Doppler motion, by amounts varying up to 8500 km/sec for the total width of the hydrogen lines in NGC 3516 and NGC 7469. The hydrogen lines in NGC 4151 have relatively narrow cores with wide wings, 7500 km/sec in total breadth. Similar wings are found for the Balmer lines in NGC 7469. The lines of the other ions show no evidence of wide wings. Some of the lines exhibit strong asymmetries, usually in the sense that the violet side of the line is stronger than the red.

In NGC 7469 the absorption K line of *Ca* II is shallow and 50 A wide, at least twice as wide as in normal spirals.

Absorption minima are found in six of the stronger emission lines in NGC 1068, in one line in NGC 4151, and one in NGC 7469. Evidence from measures of wave length and equivalent widths suggests that these absorption minima arise from the G-type spectra on which the emissions are superposed.

The maximum width of the Balmer emission lines seems to increase with the absolute magnitude of the nucleus and with the ratio of the light in the nucleus to the total light of the nebula. The emission lines in the brightest diffuse nebulae in other extragalactic objects do not appear to have wide emission lines similar to those found in the nuclei of emission spirals.

I. THE OBSERVATIONAL MATERIAL

The present investigation is an intensive study of six of the brightest extragalactic nebulae showing emission bands in their nuclei (Table 1). Of these six, special emphasis was placed on the three having the brightest nuclei, NGC 1068, 3516, and 4151, because

TABLE 1*

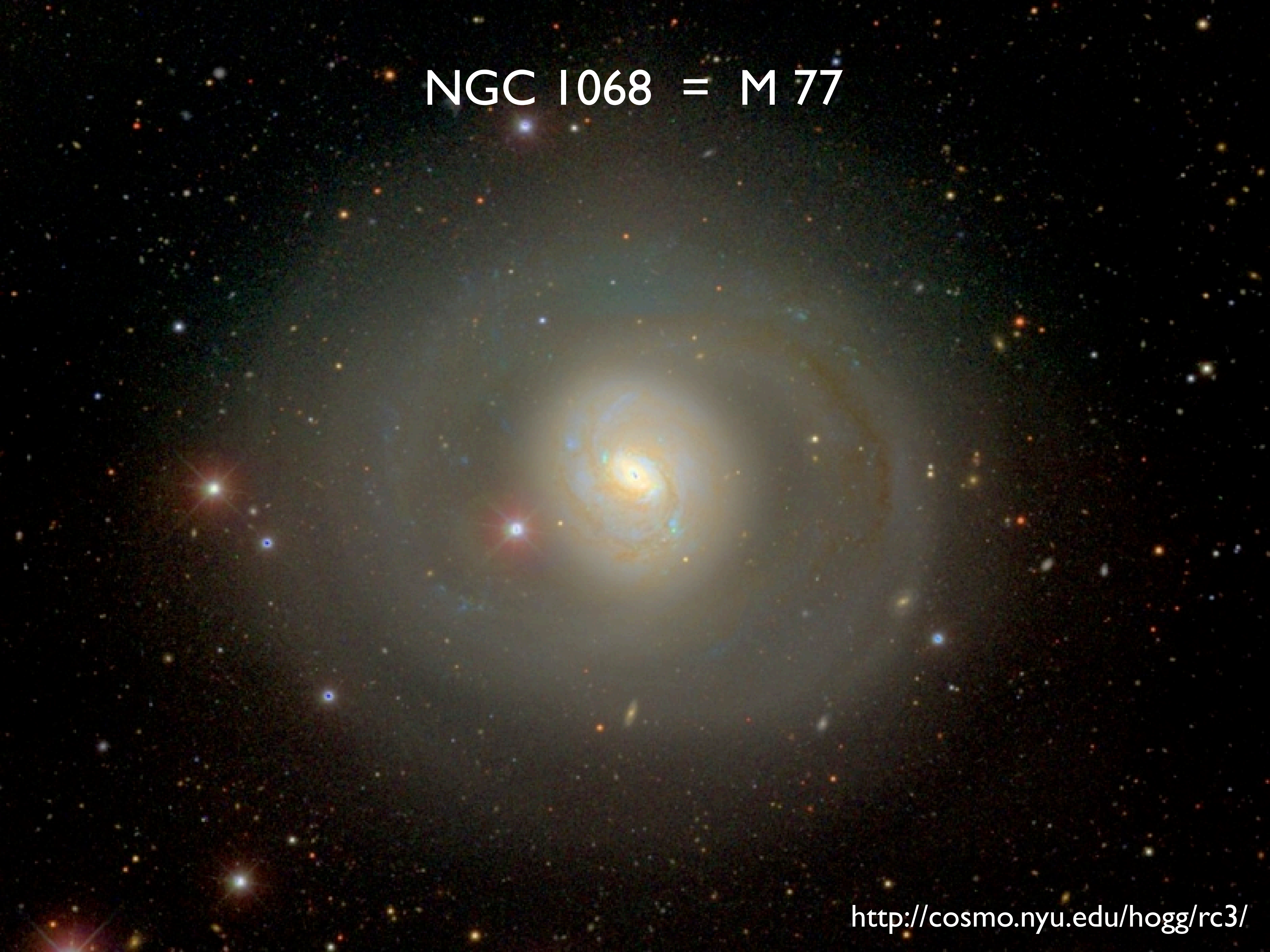
EMISSION SPIRALS OBSERVED

NGC	1950 R.A.	1950 Dec.	Type	m_{total}	$m_{nucl.}$	Spect.	Modulus	No. of Plates
1068	$2^h40.1$	− 0° 14	Sb	10.0	13.0	G3	26^m0	17
1275	3 15.6	+41 18	E:	13.0	15.5	G3	30.0	4
3516	11 3.4	+72 50	Sa	12.2	13.7	G2:	28.5	6
4051	12 0.6	+44 48	Sb	11.7	14.0	G2	26.0	4
4151	12 8.0	+39 41	Sb	11.2	12.0	G2	26.0	12
7469	23 0.7	+ 8 36	Sa	13.0	14.3:	G0:	29.8	2

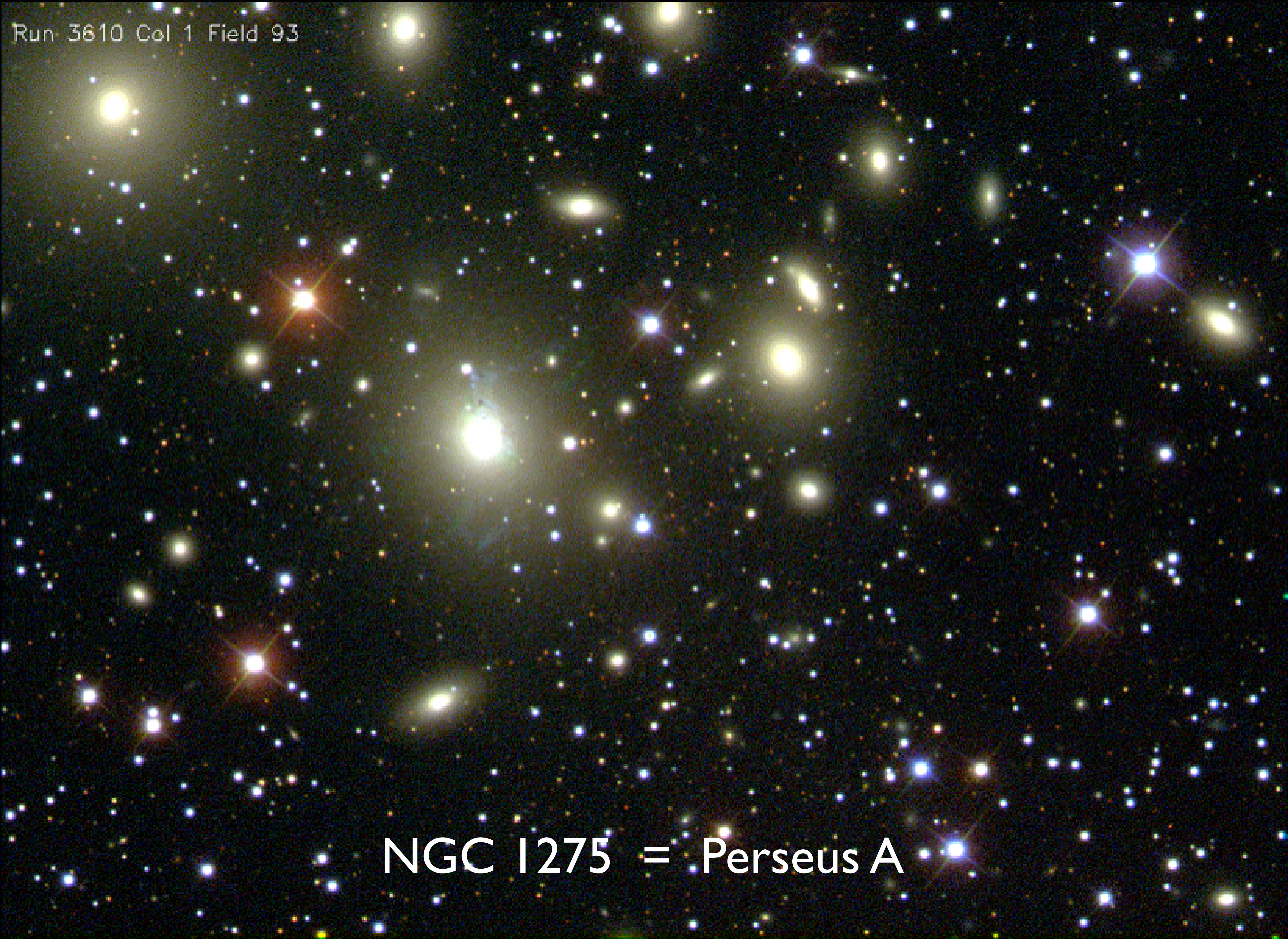
* The total apparent photographic magnitudes are from the *Shapley-Ames Catalogue of External Galaxies* (*Harv. Ann.*, **88**, 43, 1932). The apparent magnitudes (photographic) of the nuclei were estimated from short-exposure plates, taken in series with selected areas. The distance moduli are new determinations derived from magnitudes of resolved stars in the arms (NGC 1068), radial velocity (NGC 1068, 3516, 7469), or from association with recognized clusters or groups (NGC 1275, 4051, 4151). The plates used for determinations of nuclear magnitudes and most of the data for computing the distance moduli were supplied by E. P. Hubble. The spectral types were determined by M. L. Humason.

it was possible to observe them with higher dispersion than could be used on the fainter objects.

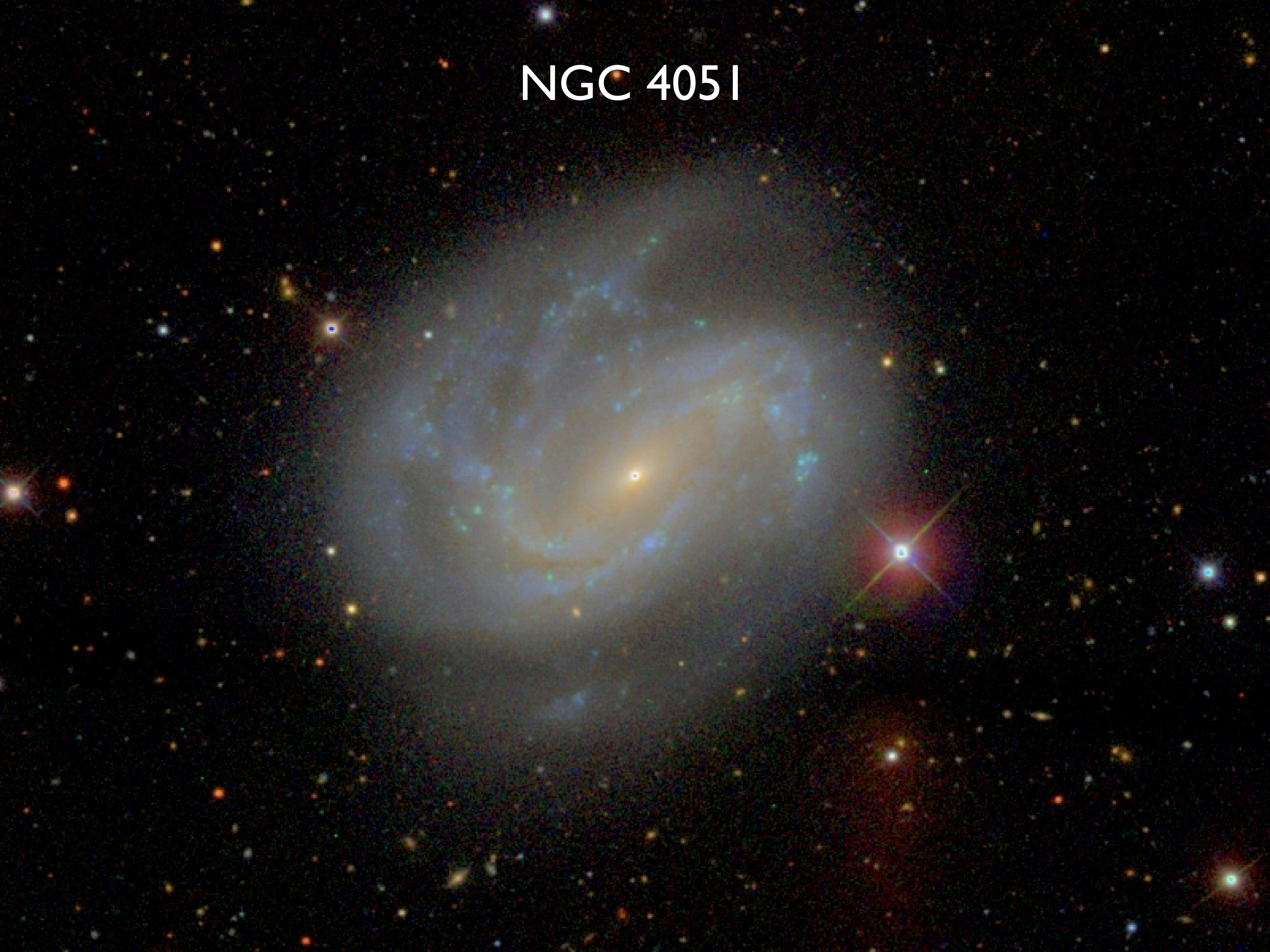
NGC 1068 = M 77

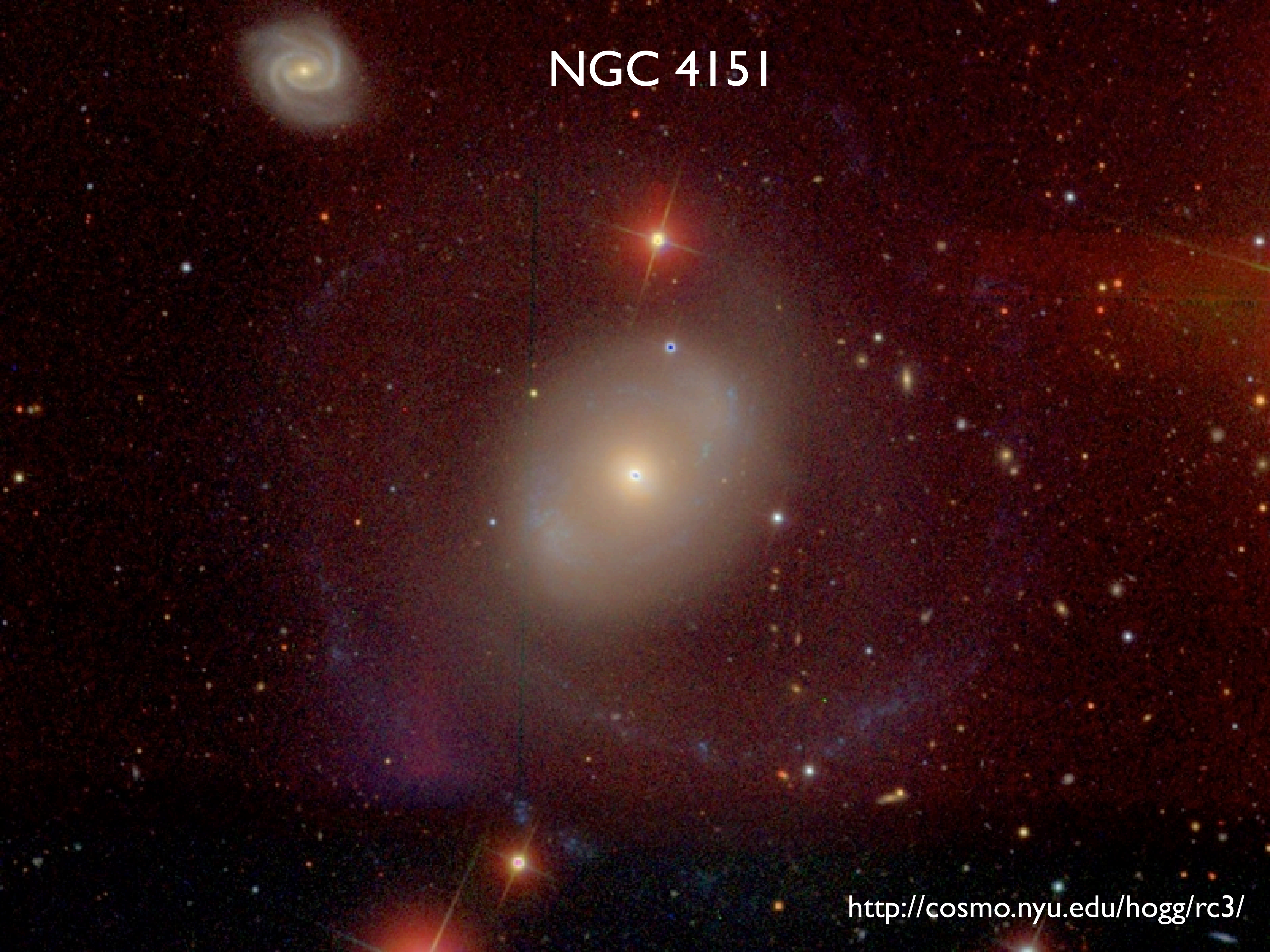


http://cosmo.nyu.edu/hogg/rc3/

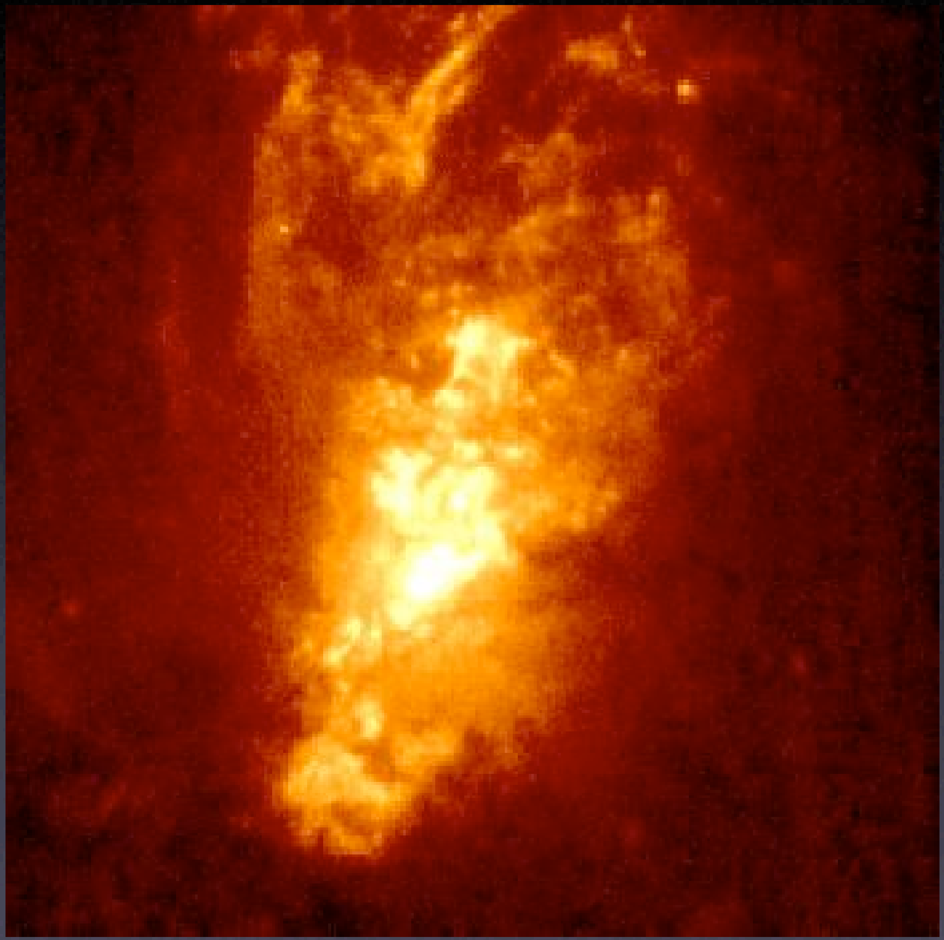


NGC 1275 = Perseus A


NGC 4051

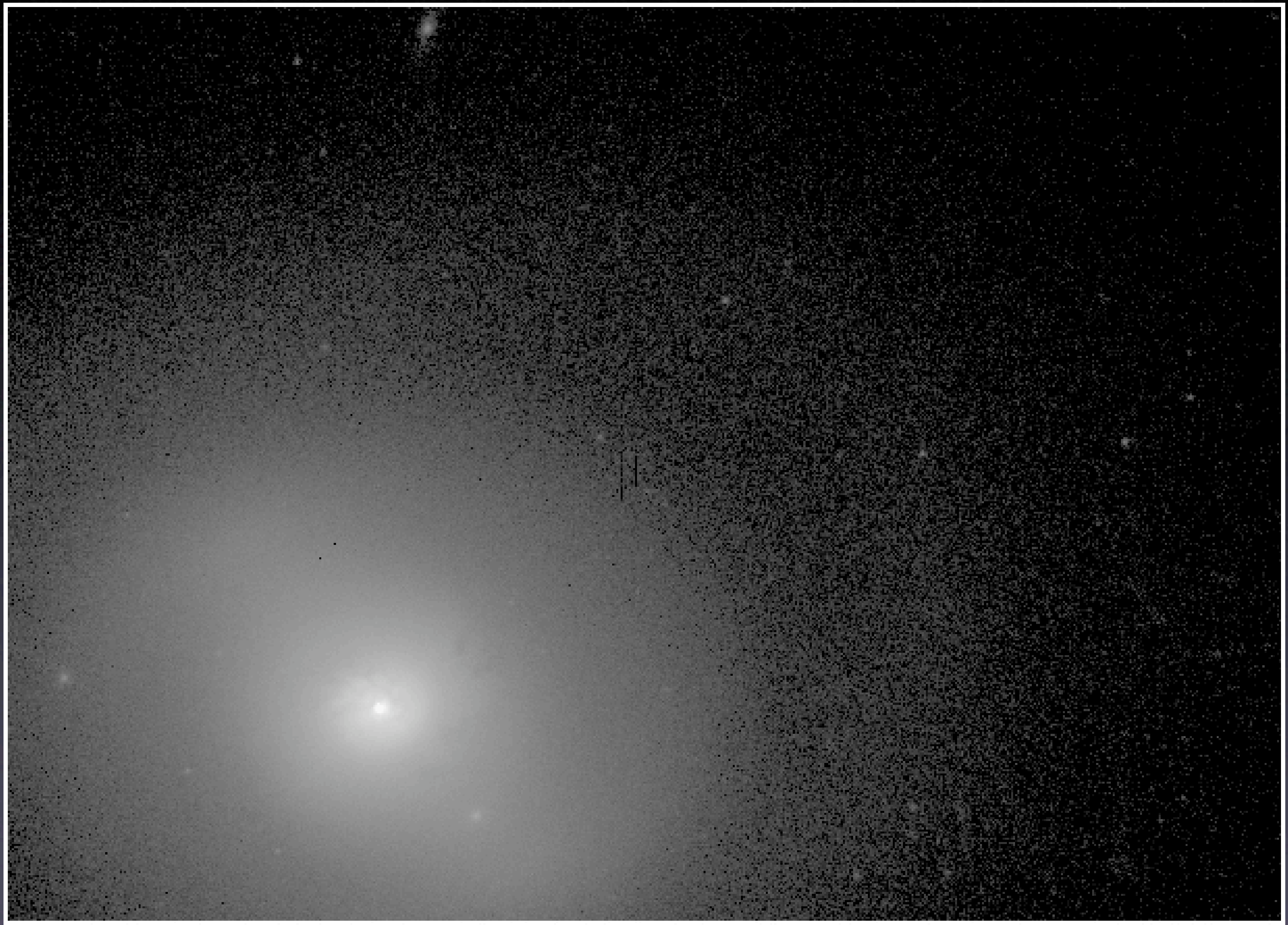

NGC 4151
http://cosmo.nyu.edu/hogg/rc3/

NGC 1068 (HST)

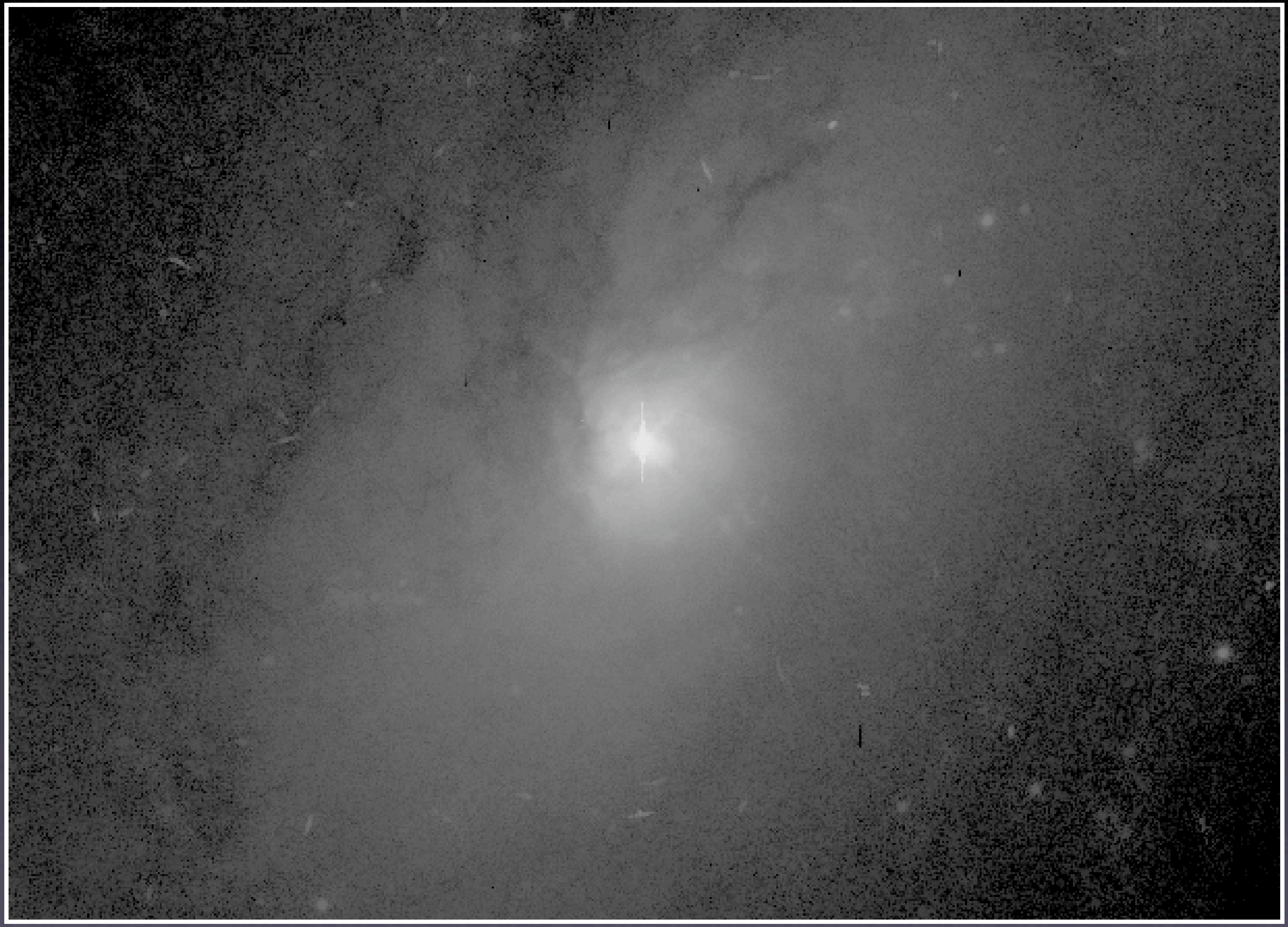


NGC 1275 (HST)

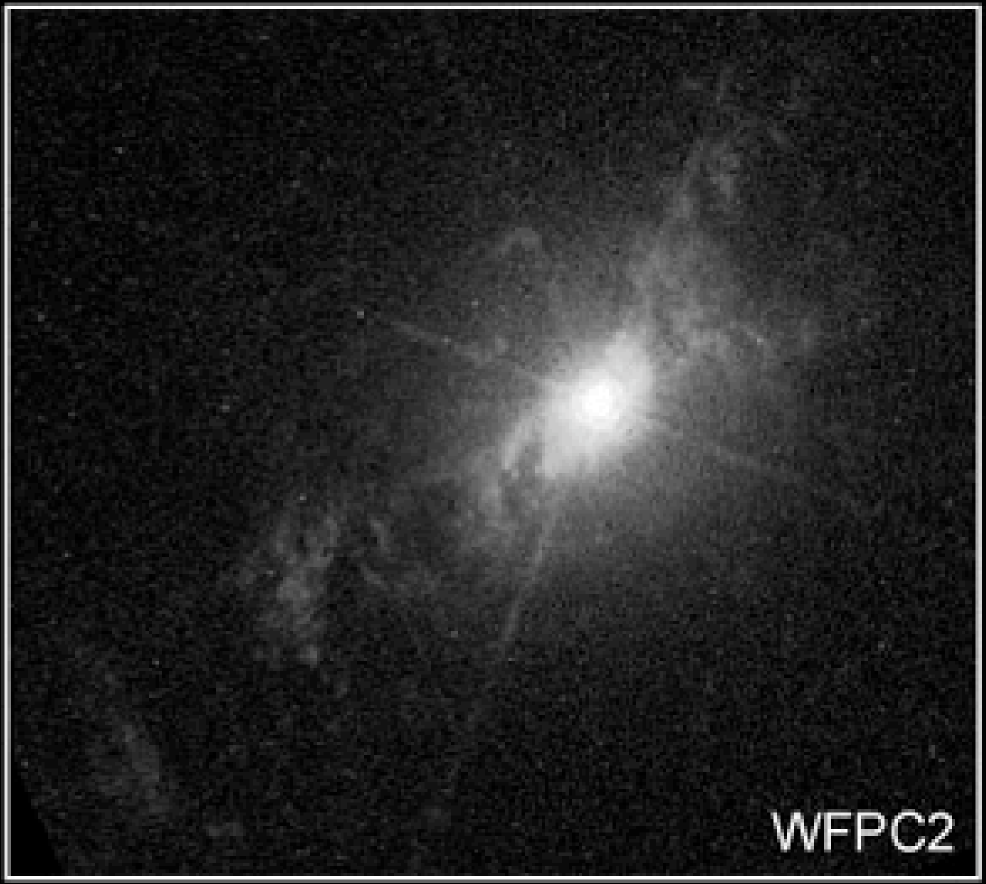
NGC 3516 (HST)

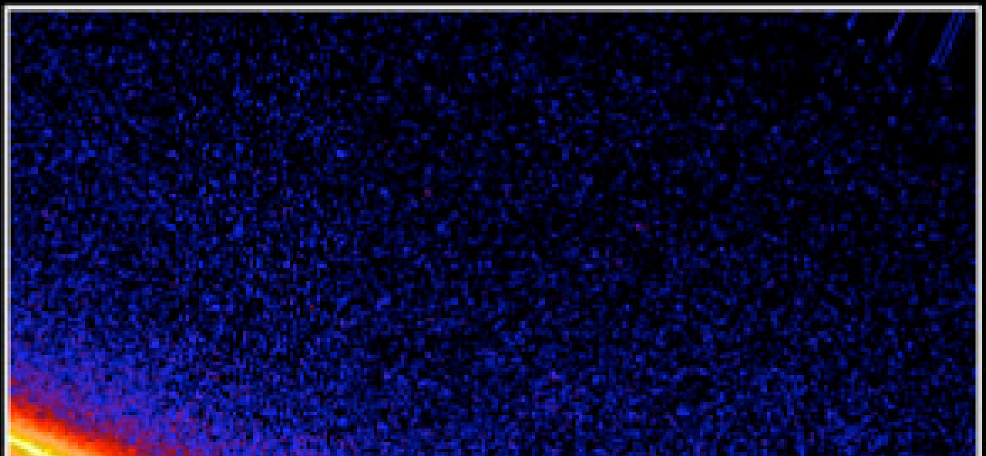


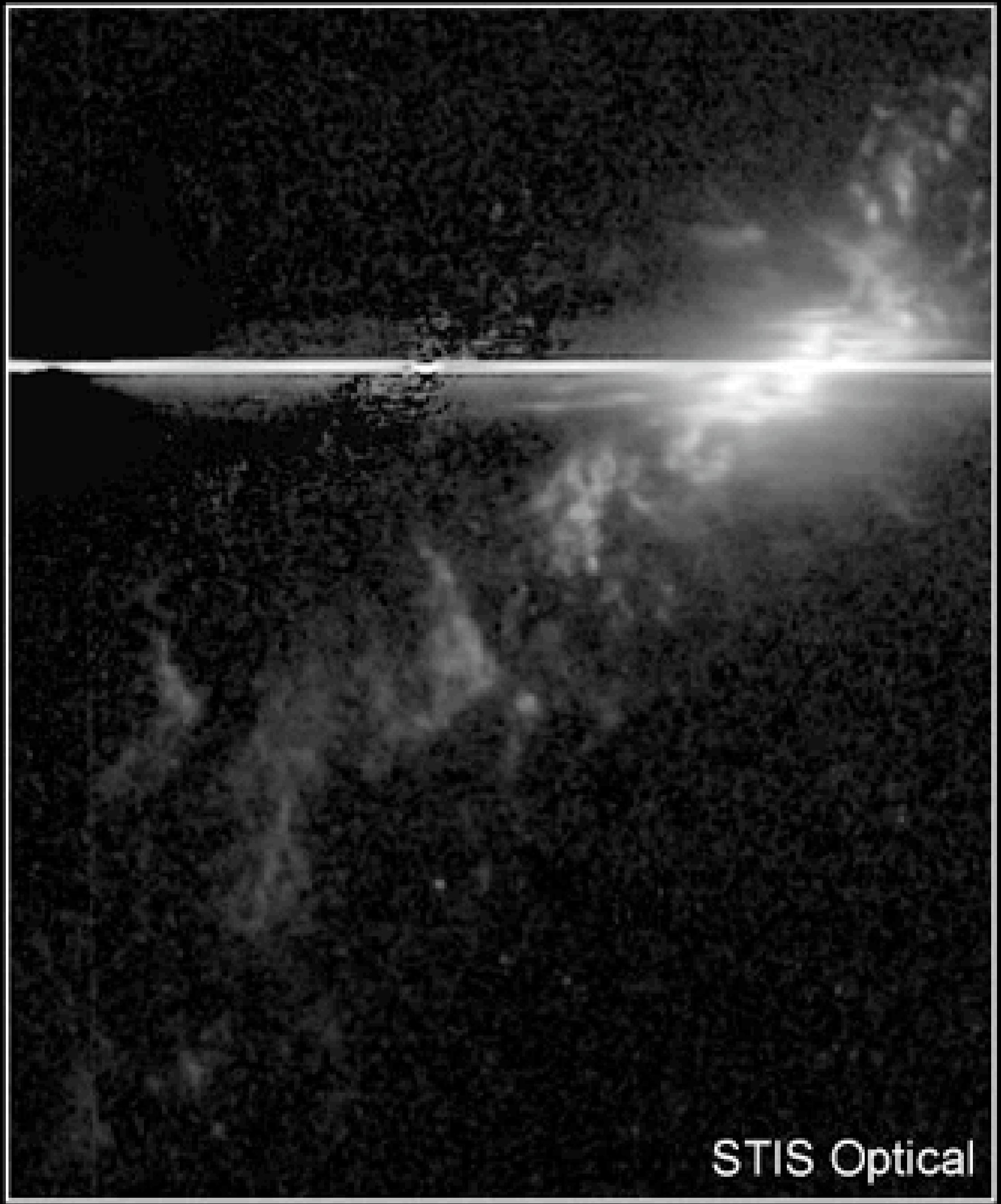
NGC 4051 (HST)



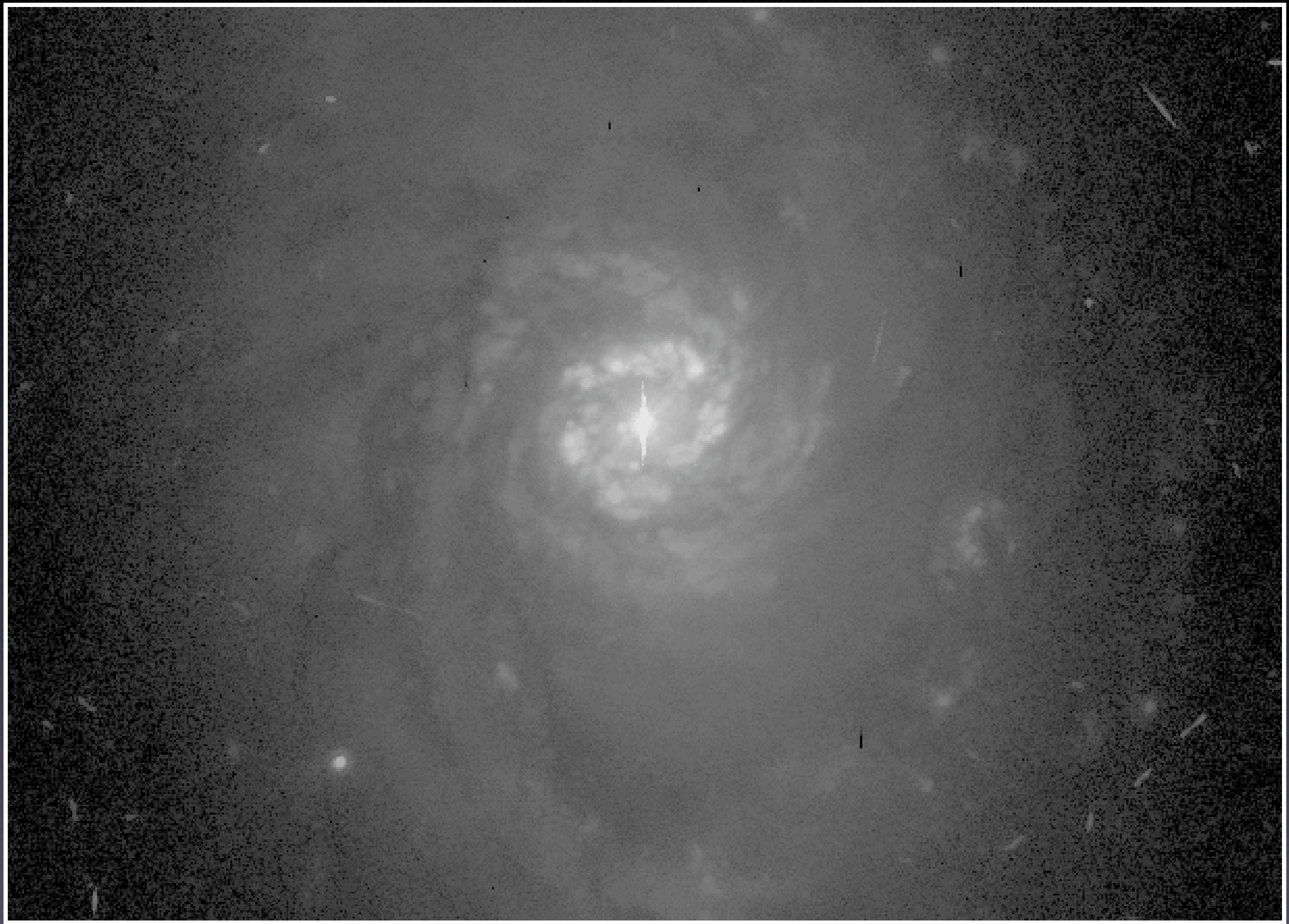
NGC 4151 (HST)







NGC 7469 (HST)



Seyfert galaxy nuclei are tiny:

$M_{bh} = 3 \times 10^7 M_{sun}$

$R_s = 2 G M_{bh} / c^2 = 0.6$ AU

$R_{accretion} \sim 10 R_s = 6$ AU $=$ 50 light-minutes

compare to:

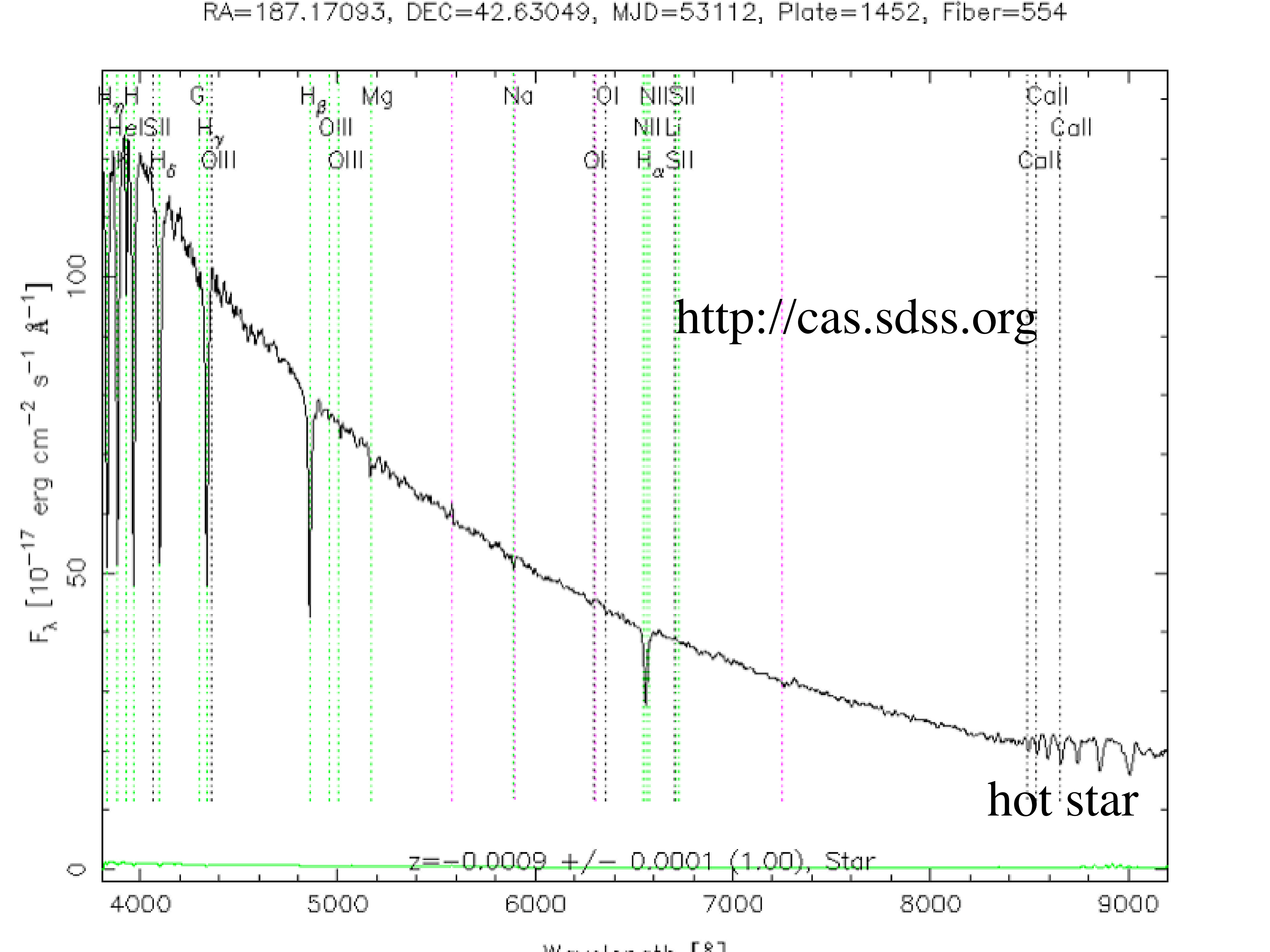
diameter of a galaxy ~ 70,000 light-years

image: α, δ, magnitude, color, size, shape

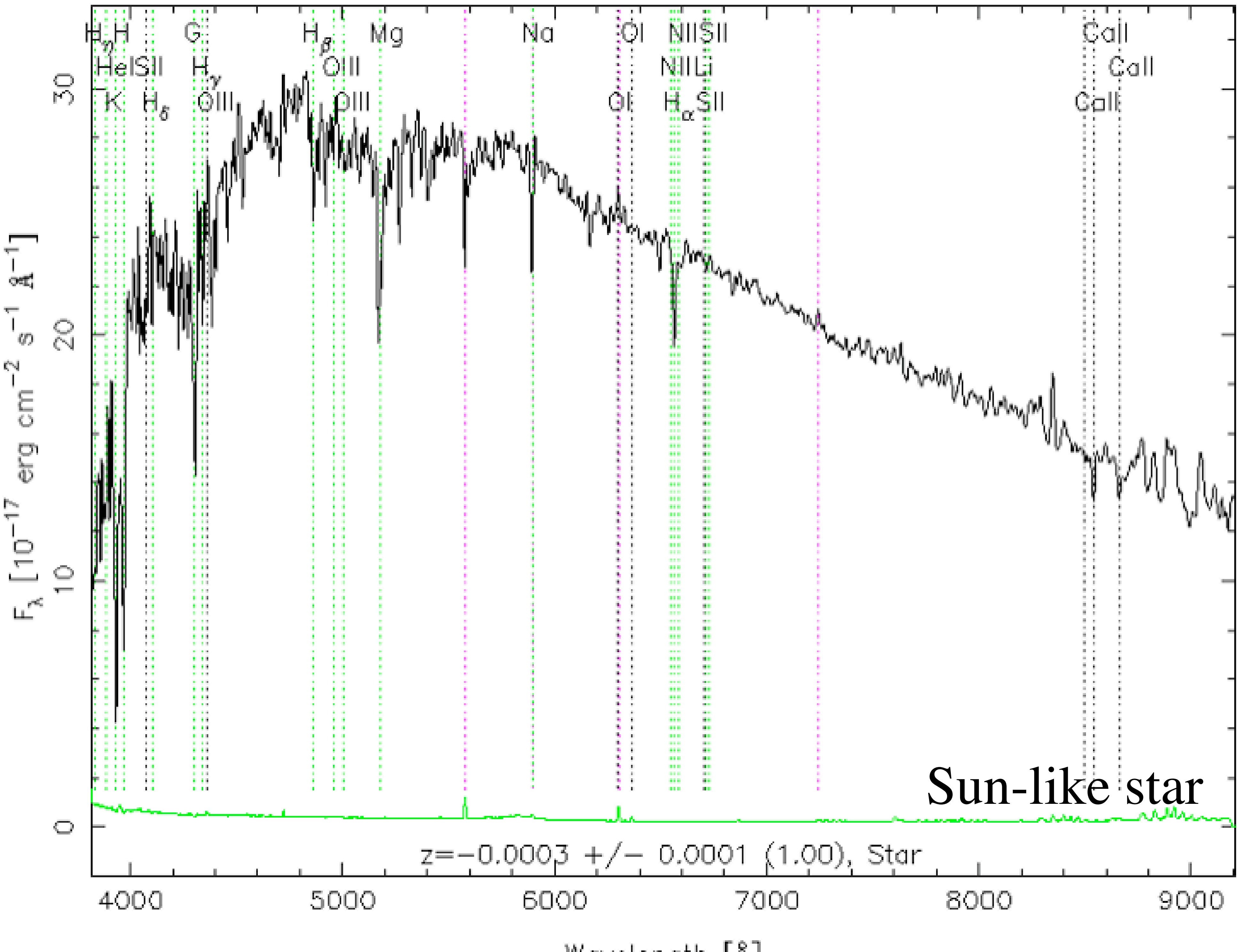
spectrum: profiles of absorption and emission lines, shape of continuum

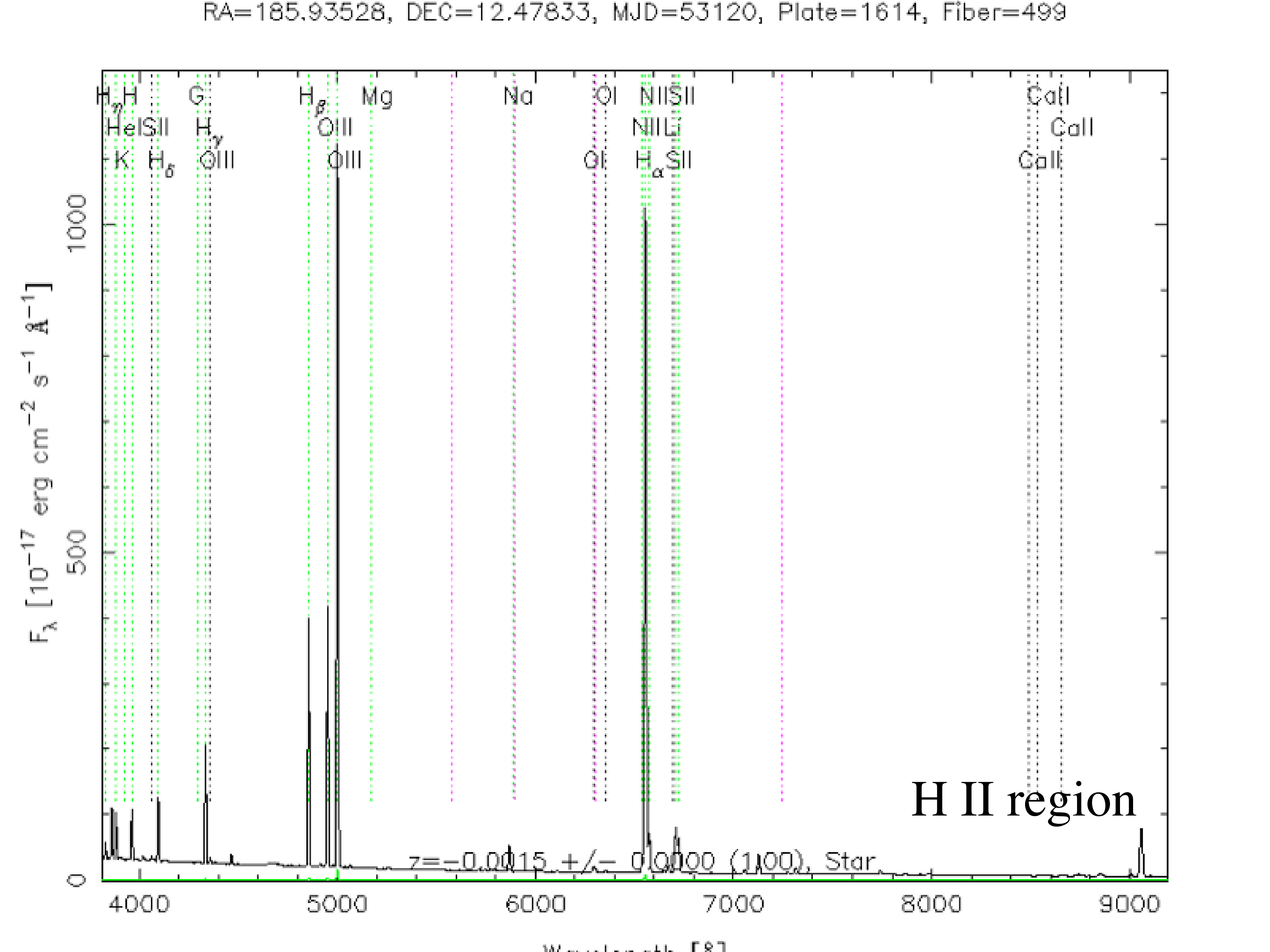
Spectra yield detailed physical diagnostics:

stars: temperature, surface gravity, chemical abundances
galaxies: rate of star formation, mass in stars, total mass, chemical abundances in both gas and in stars
Seyferts: density, temperature, velocity, and ionization structure of the emitting gas


RA=187.17093, DEC=42.63049, MJD=53112, Plate=1452, Fiber=554
http://cas.sdss.org
hot star
z=-0.0009 +/- 0.0001 (1.00), Star
F_λ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
Wavelength [Å]

RA=187.74074, DEC=44.18579, MJD=52821, Plate=1371, Fiber= 10



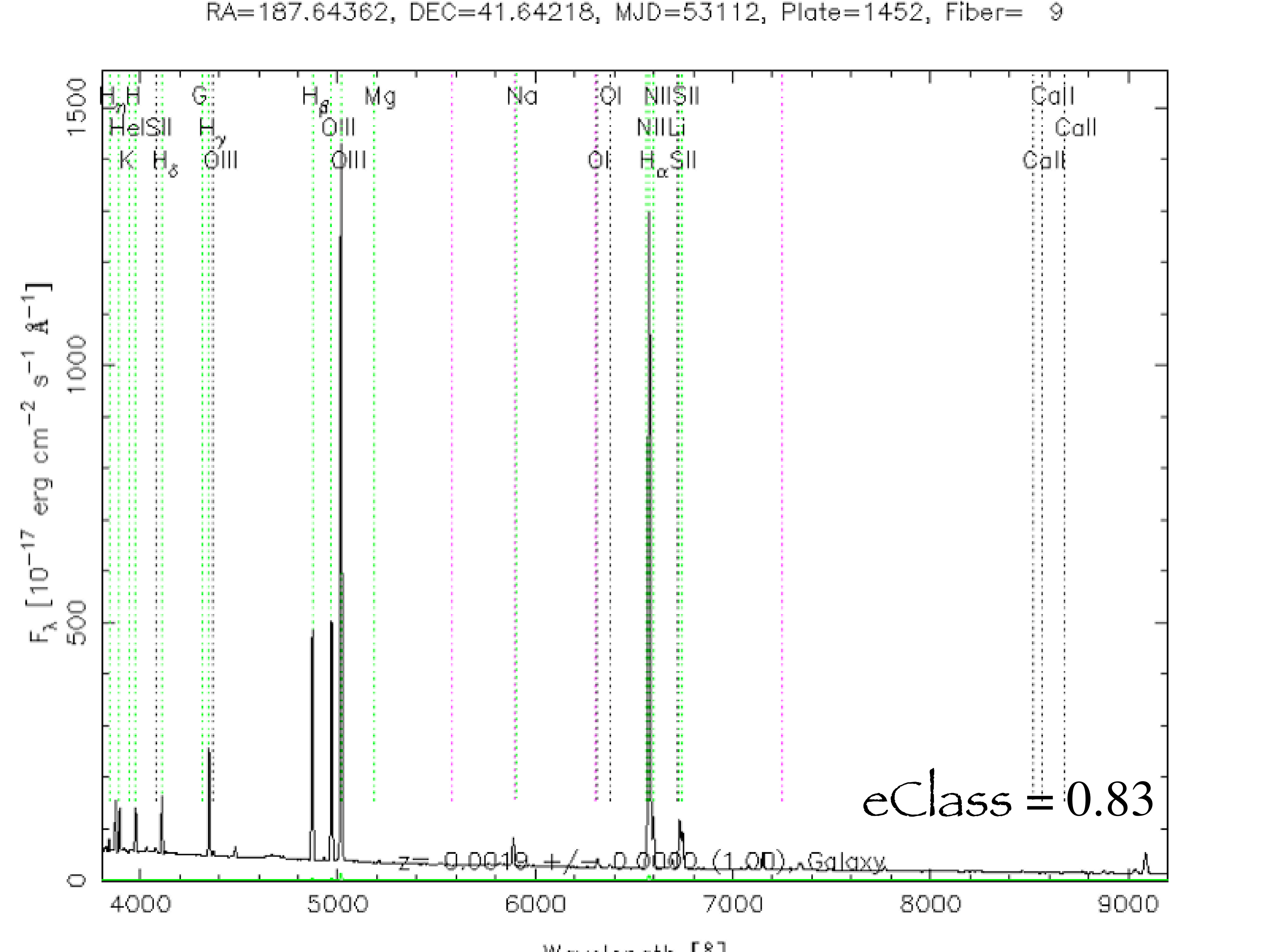

RA=185.93528, DEC=12.47833, MJD=53120, Plate=1614, Fiber=499
Hη H
HeI SII
K Hδ
G
Hγ
OIII
Hβ
OIII
OIII
Mg
Na
OI
OI
NII SII
NII Li
Hα SII
CaII
CaII
CaII
z=-0.0015 +/- 0.0000 (1.00), Star
Fλ [10^-17 erg cm^-2 s^-1 Å^-1]
0
500
1000
4000
5000
6000
7000
8000
9000

H II region

Spectral types of bright stars visible now:

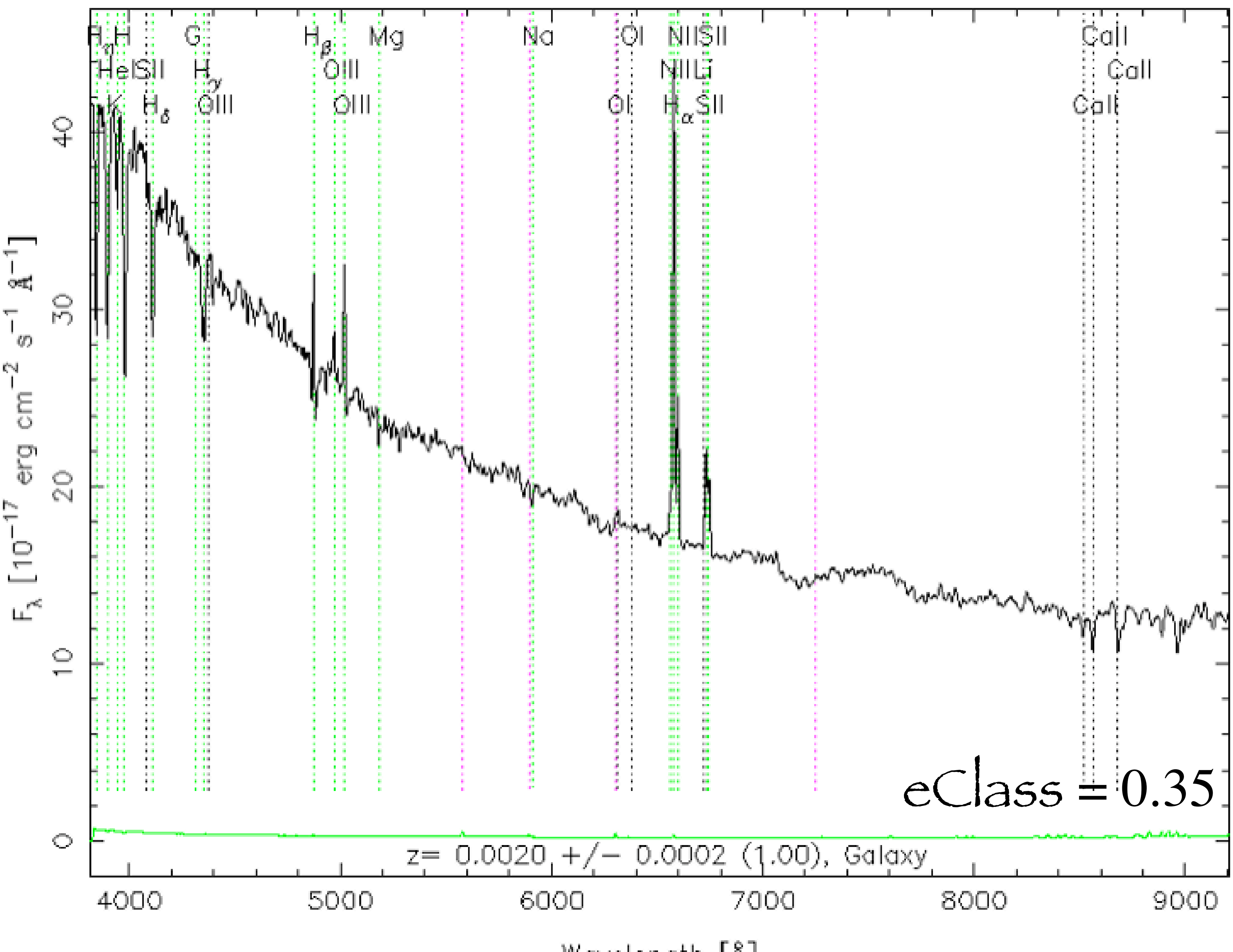
γ Peg	B2 IV
Vega	A0 V
Deneb	A2 I
Altair	A7 V
μ Peg	G8 III
Arcturus	K1.5 III
Antares	M1.5 I
β Peg	M2 II-III

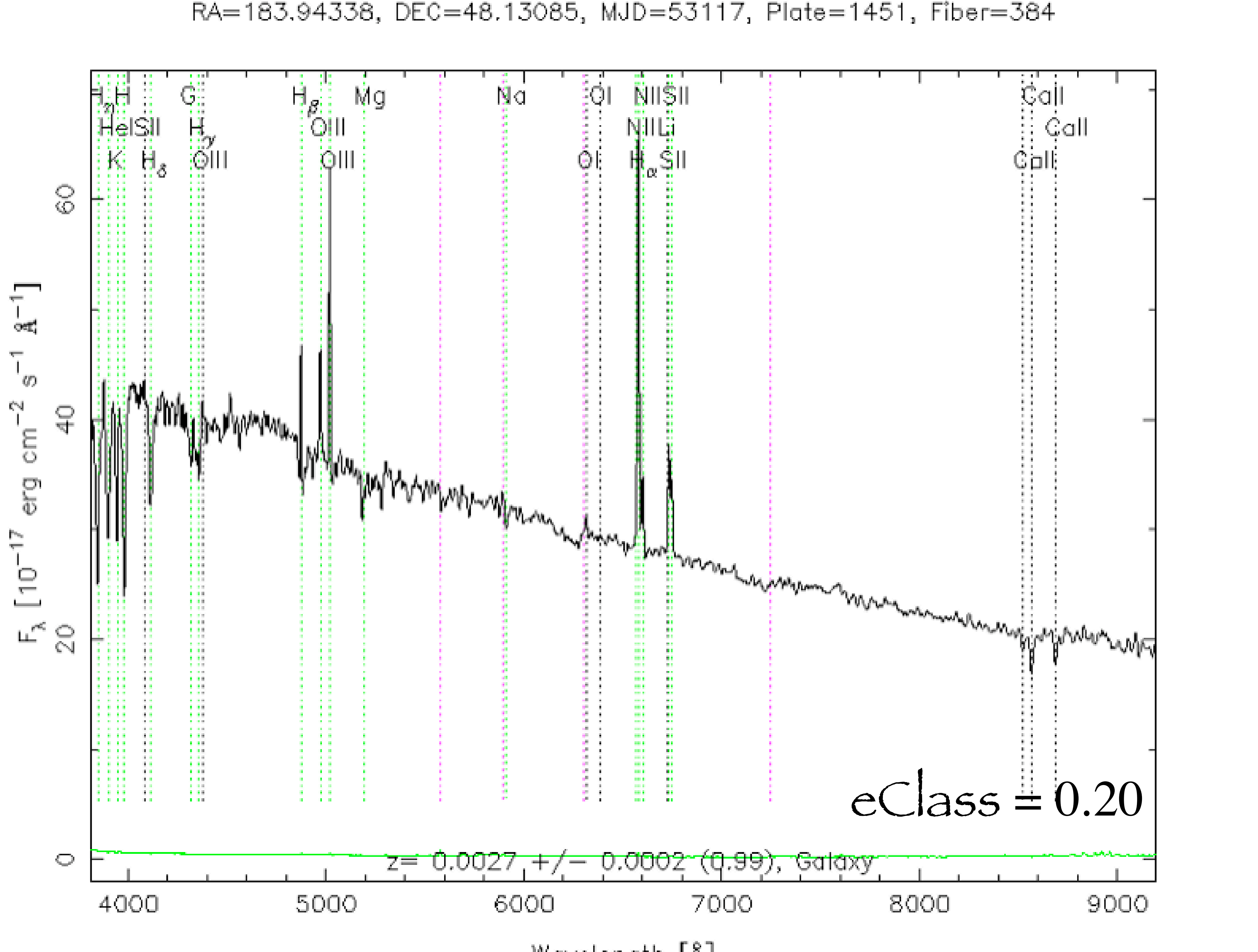
expect spectra of galaxies to look like:
"A" + "K" + "emission" in some proportion

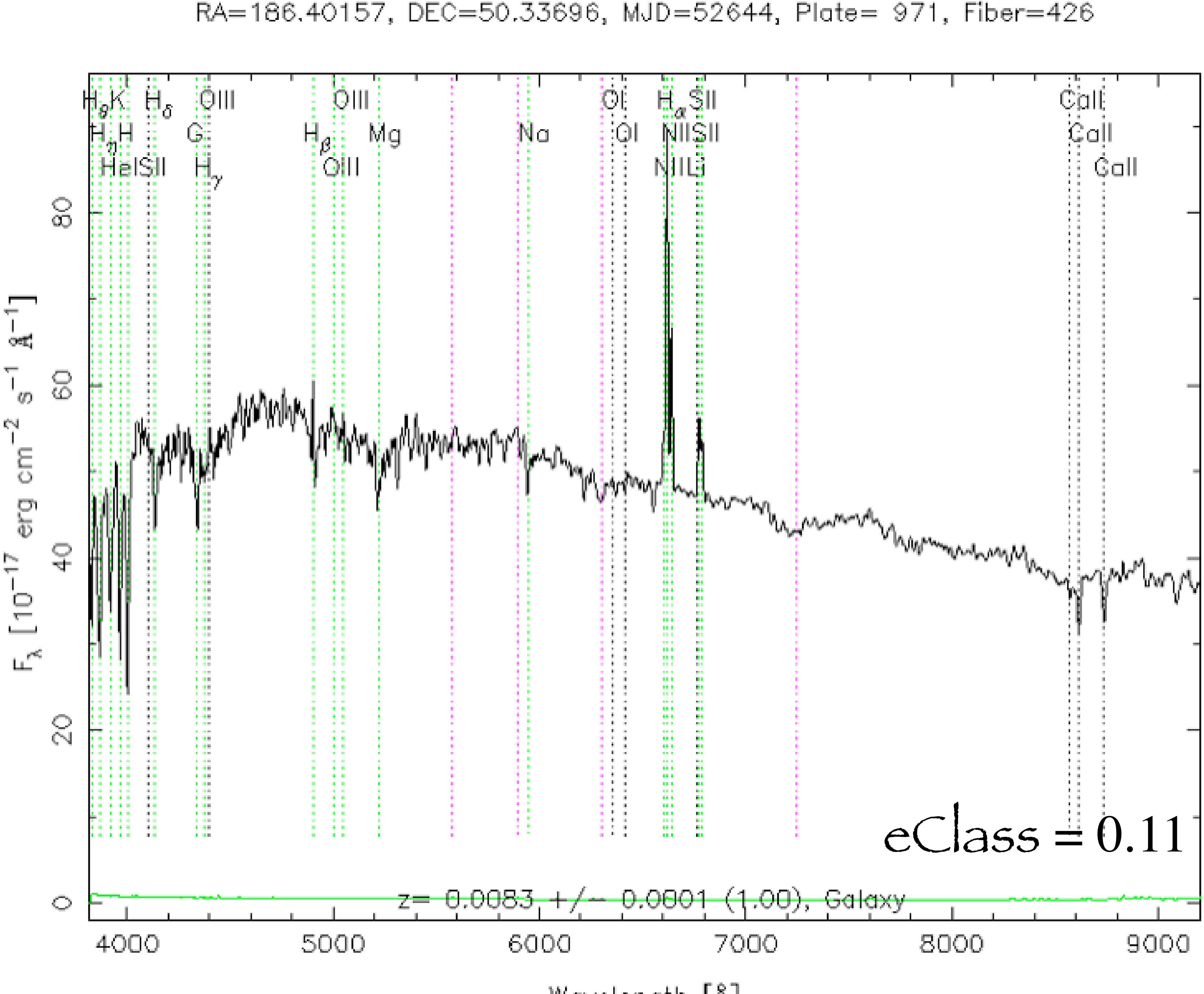


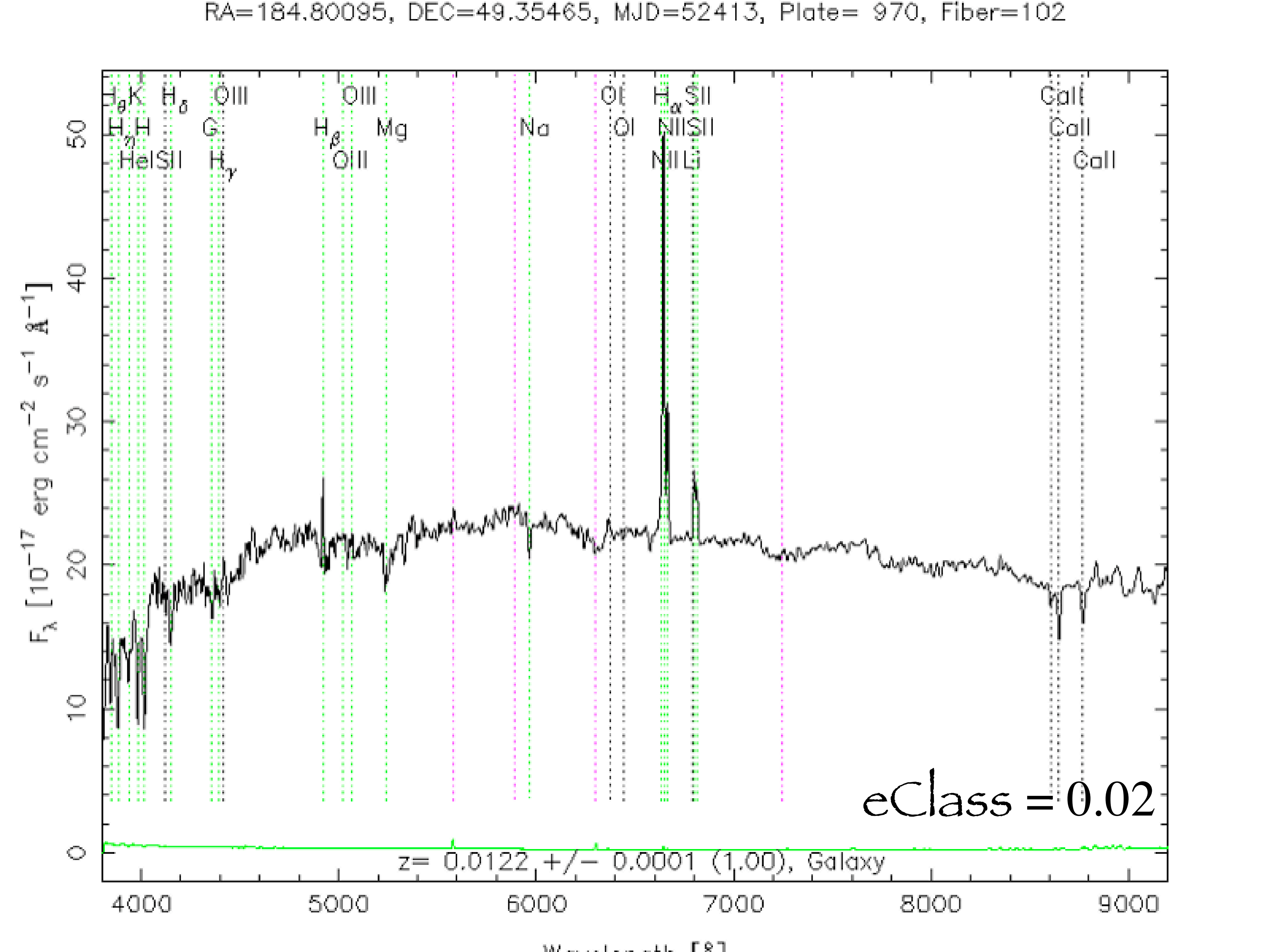
RA=187.64362, DEC=41.64218, MJD=53112, Plate=1452, Fiber= 9
F_λ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
0
500
1000
1500
4000
5000
6000
7000
8000
9000
z= 0.0019 +/- 0.0000 (1.00) Galaxy
eClass = 0.83

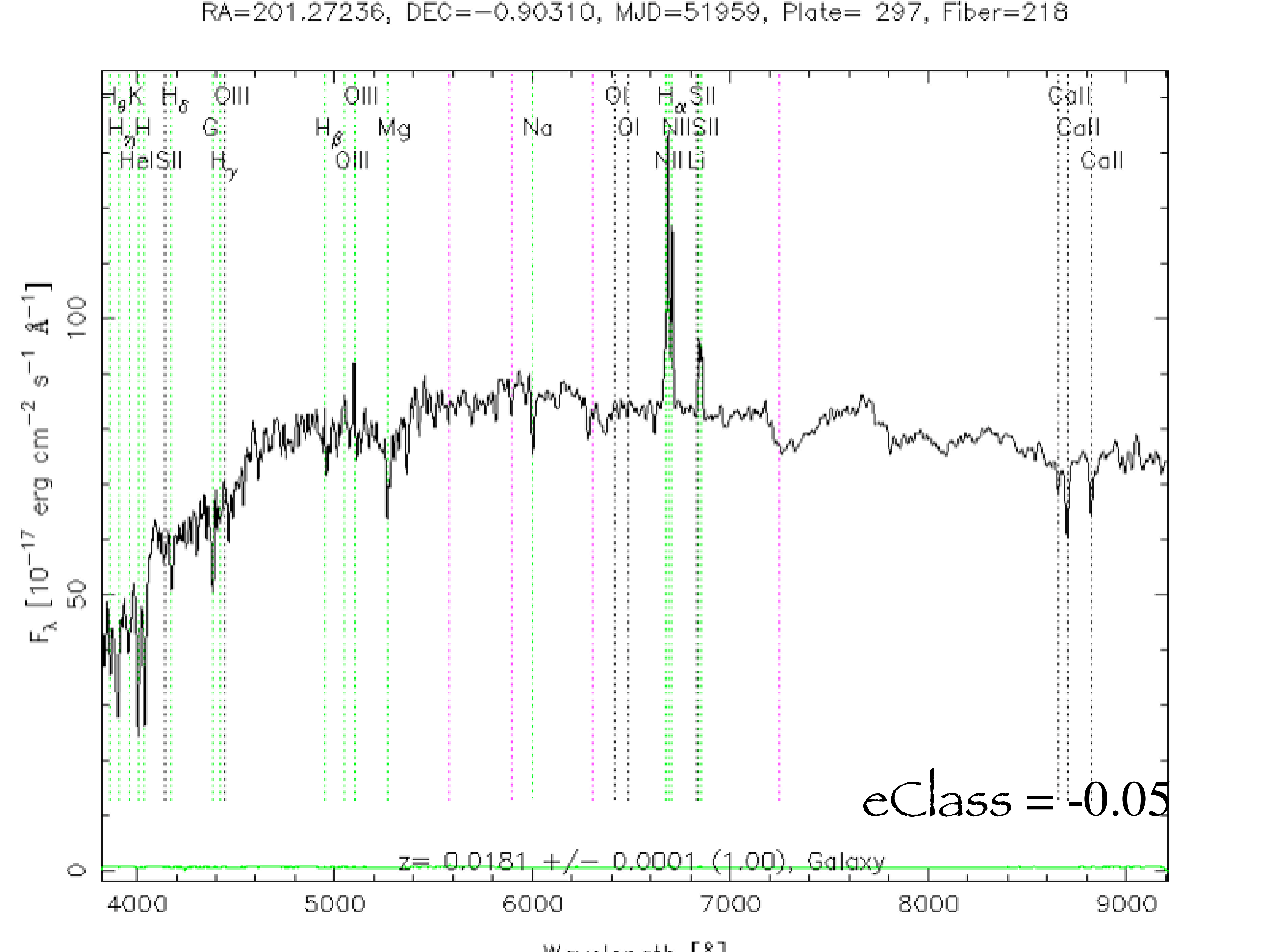
RA=181.43164, DEC=50.55525, MJD=52442, Plate= 969, Fiber=509

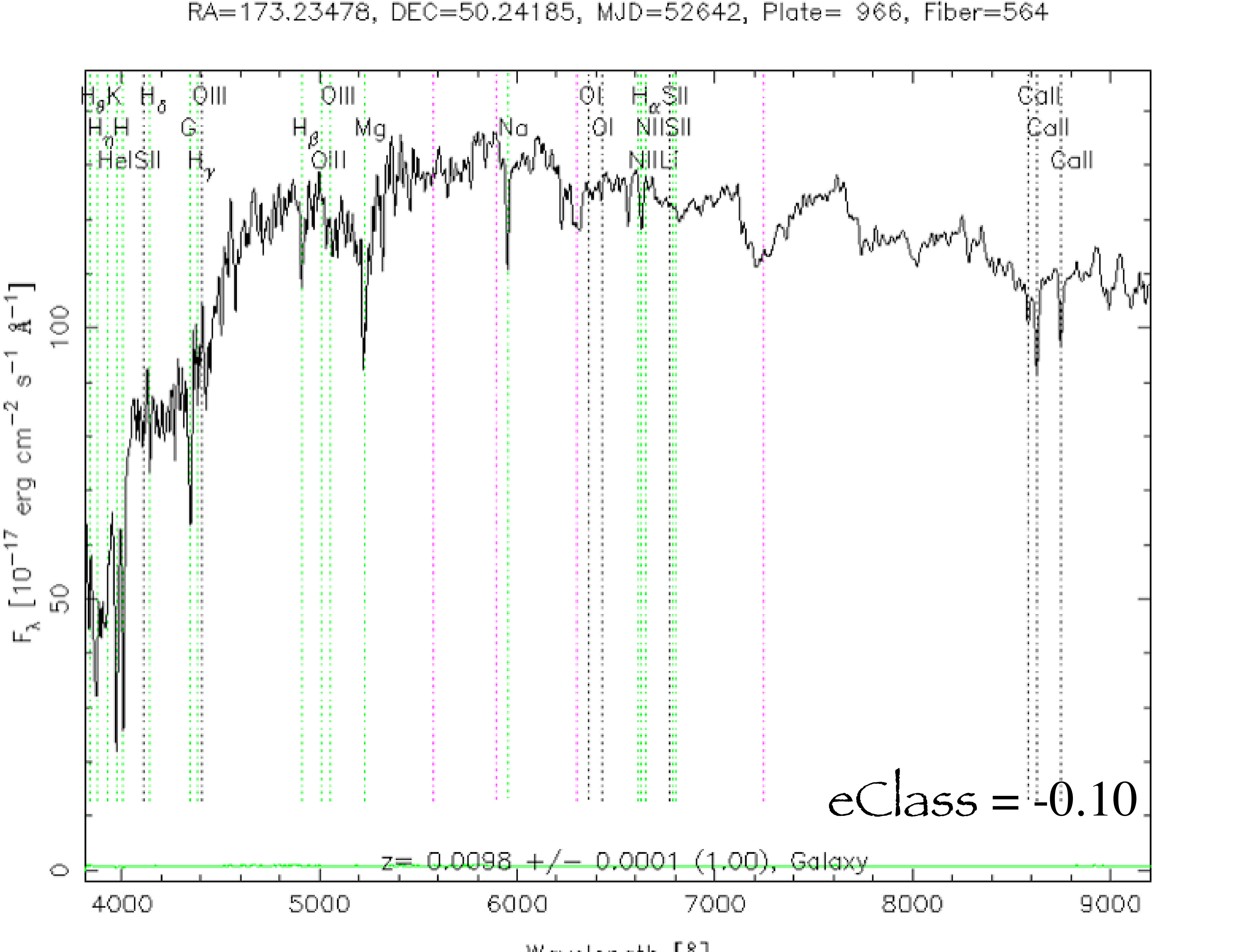


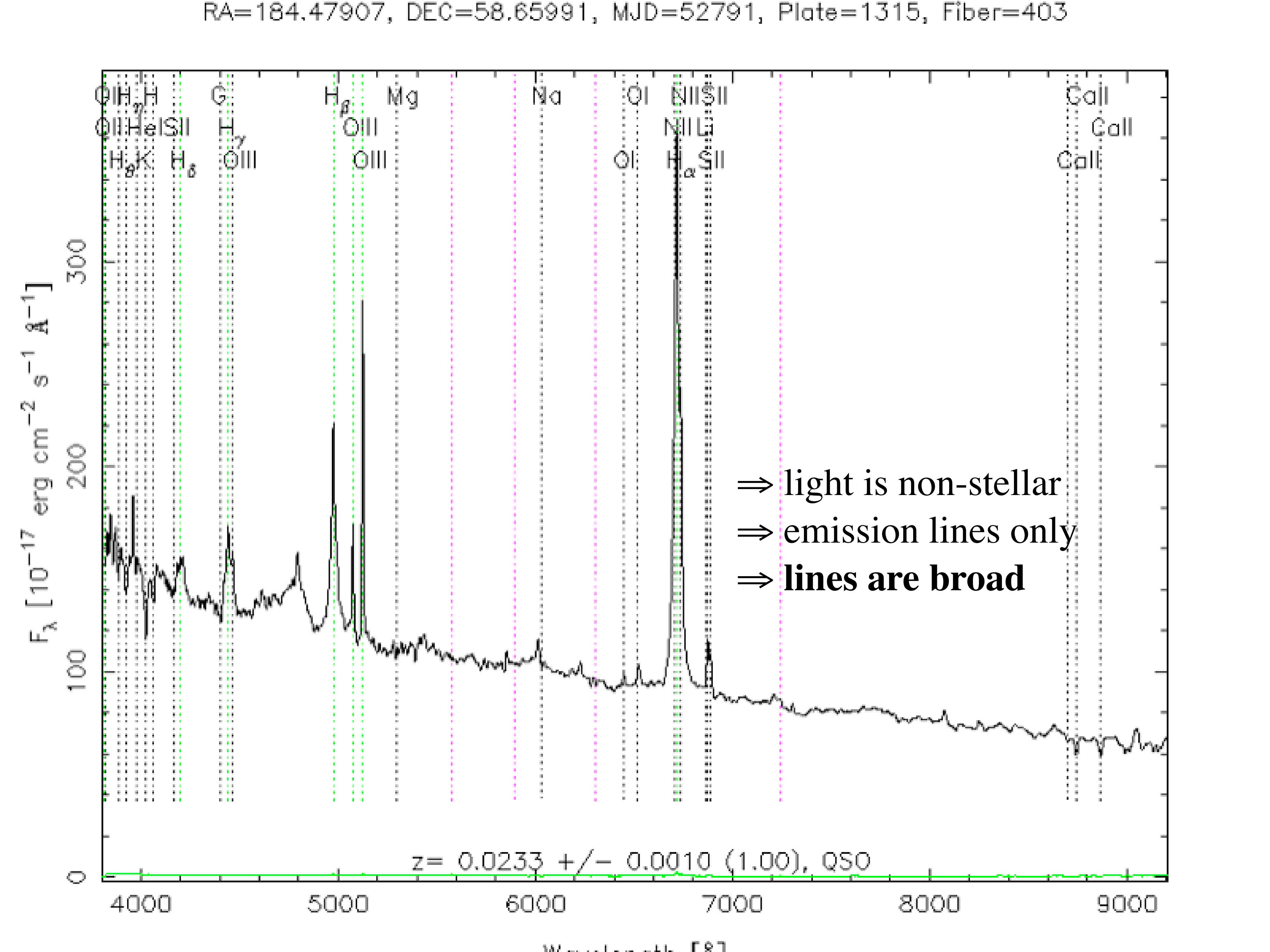

RA=183.94338, DEC=48.13085, MJD=53117, Plate=1451, Fiber=384
F_λ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
0
20
40
60
H_η H
HeI SII
K
H_δ
G
H_γ
OIII
H_β
OIII
OIII
Mg
Na
OI
OI
NII SII
NII Li
H_α SII
CaII
CaII
CaII
eClass = 0.20
z= 0.0027 +/- 0.0002 (0.99), Galaxy
4000
5000
6000
7000
8000
9000


RA=186.40157, DEC=50.33696, MJD=52644, Plate= 971, Fiber=426
H_ϑK
H_ηH
HeISII
H_δ
OIII
G
H_γ
H_β
OIII
OIII
Mg
Na
OI
OI
H_αSII
NIISII
NIILi
CaII
CaII
CaII
F_λ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
0
20
40
60
80
4000
5000
6000
7000
8000
9000
z= 0.0083 +/- 0.0001 (1.00), Galaxy
eClass = 0.11


RA=184.80095, DEC=49.35465, MJD=52413, Plate= 970, Fiber=102
F_λ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
0
10
20
30
40
50
4000
5000
6000
7000
8000
9000
H_θ K
H_η H
HeI SII
H_δ
G
H_γ
OIII
H_β
OIII
OIII
Mg
Na
OI
OI
H_α SII
NII SII
NII Li
CaII
CaII
CaII
z= 0.0122 +/- 0.0001 (1.00), Galaxy
eClass = 0.02


RA=201.27236, DEC=−0.90310, MJD=51959, Plate= 297, Fiber=218
Hθ K
Hη H
HeI SII
Hδ
G
Hγ
OIII
OIII
Hβ
OIII
Mg
Na
OI
OI
Hα SII
NII SII
NII Li
CaII
CaII
CaII
F_λ [10^−17 erg cm^−2 s^−1 Å^−1]
0
50
100
4000
5000
6000
7000
8000
9000
z= 0.0181 +/− 0.0001 (1.00), Galaxy
eClass = -0.05

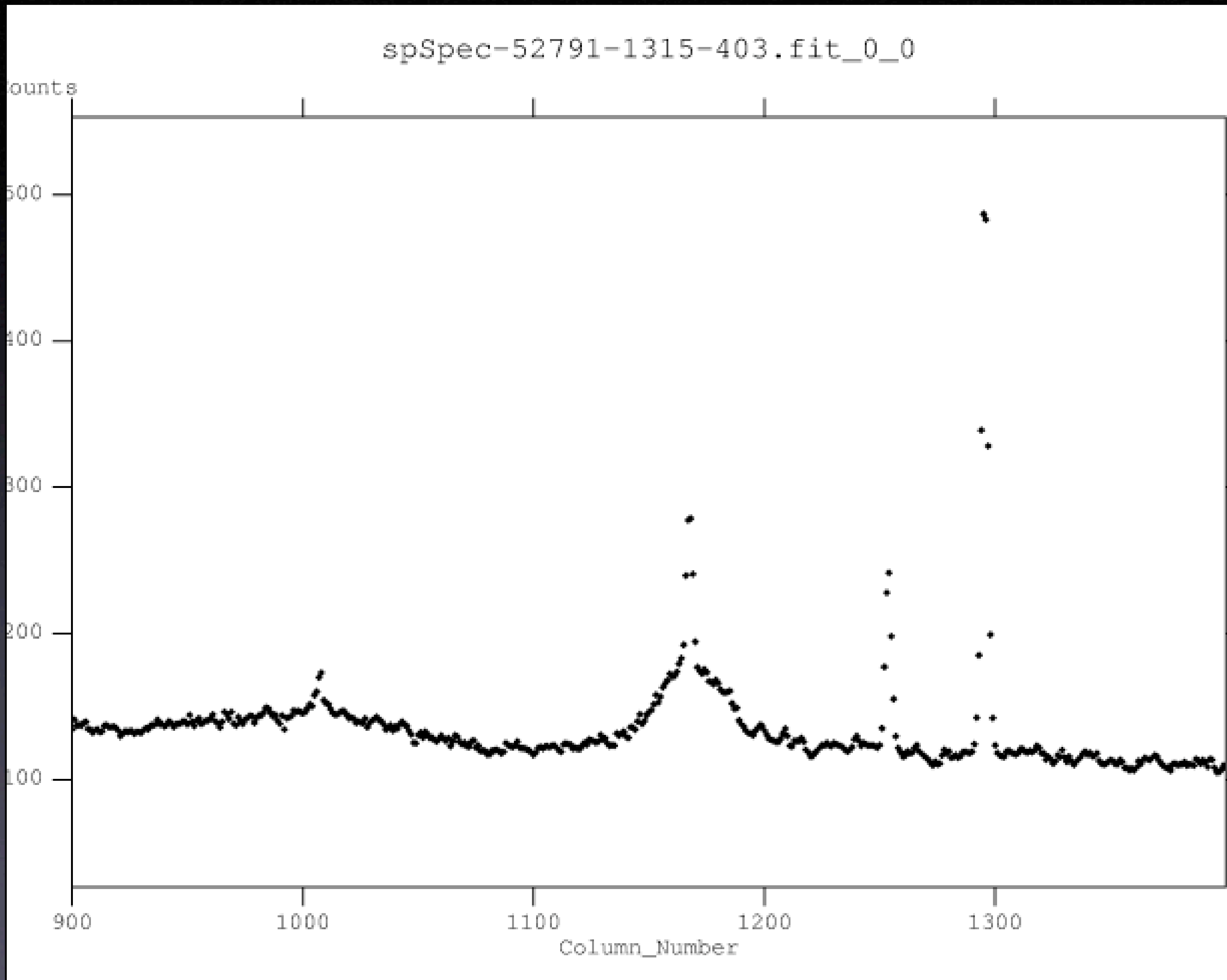

RA=173.23478, DEC=50.24185, MJD=52642, Plate= 966, Fiber=564
Hδ
OIII
OIII
OI
Hα SII
CaII
G
Hβ
Mg
Na
OI
NIISII
CaII
HeISII
OIII
NIILi
CaII
F_λ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
eClass = -0.10
z= 0.0098 +/- 0.0001 (1.00), Galaxy
4000
5000
6000
7000
8000
9000
0
50
100



⇒ light is non-stellar

⇒ emission lines only

⇒ **lines are broad**


spSpec-52791-1315-403.fit_0_0
Counts
500
400
300
200
100
900
1000
1100
1200
1300
Column_Number

Hβ oxygen

physical model: central supermassive black hole accreting gas

⇒ broad emission lines in the spectrum indicate high Doppler shifts

if the thing outshines the surrounding galaxy, we call it a *quasar* or *QSO* (1963)

otherwise, we call it a *Seyfert galaxy* (1943)

Significance of line width:

SDSS spectroscopic resolution ≈ 150 km/sec

escape velocity from the Milky Way ≈ 450 km/sec

⇒ any line in a galaxy broader than this must be due to something interesting!

Quantifying the line profile:

SDSS software detects lines (absorption and emission) and fits a Gaussian to the line profile.

The parameters are in the `specLine` database:

height (10^{-17} erg sec^{-1} cm^{-2} Å^{-1}); + = em, - = abs
sigma (Ångstroms)
continuum (10^{-17} erg sec^{-1} cm^{-2} Å^{-1})

Measures of line strength:

equivalent width

(parameter called ew in the `specLine` database):

$$\text{ew} = (\sqrt{2\pi} \times \text{sigma} \times \text{height})/\text{continuum}$$

(units are Ångstroms; + is emission, - is absorption)

line flux $= \sqrt{2\pi} \times \text{sigma} \times \text{height}$

(units are 10^{-17} erg sec^{-1} cm^{-2})

Other names for/kinds of sources:

BL Lac objects
quasi-stellar radio sources
radio galaxies (Type I and Type II)
ultraluminous infrared galaxies
Type 1 Seyferts
Type 2 Seyferts
Type 1.7 (and so on) Seyferts
N galaxies
etc., etc.

$\Rightarrow$ *active galactic nuclei*, or *AGN*

An AGN is an extragalactic source that emits non-stellar radiation from a small volume.

All of these objects may be fundamentally related to each other, differing by how the energy emerges (e.g., some are radio-loud, some are radio-quiet). Dust may surround the galaxy nucleus such that radiation is beamed in special directions (e.g. the rotation axis of the accretion disk). Many things are going on close to the black hole (magnetic fields, jets of relativistic particles, X-ray reflection), and the geometry is likely to be complex.

SDSS adopts a practical definition of an AGN: at least one line must have a full-width at half-maximum (FWHM) broader than 1000 km/sec. These are identified by the specClass parameter,

specClass = 3 (or 4)

to convert from sigma in Ångstroms to FWHM in km/sec:

$$\text{FWHM} = c \times [(2.354 \times \text{sigma}) / \lambda]$$

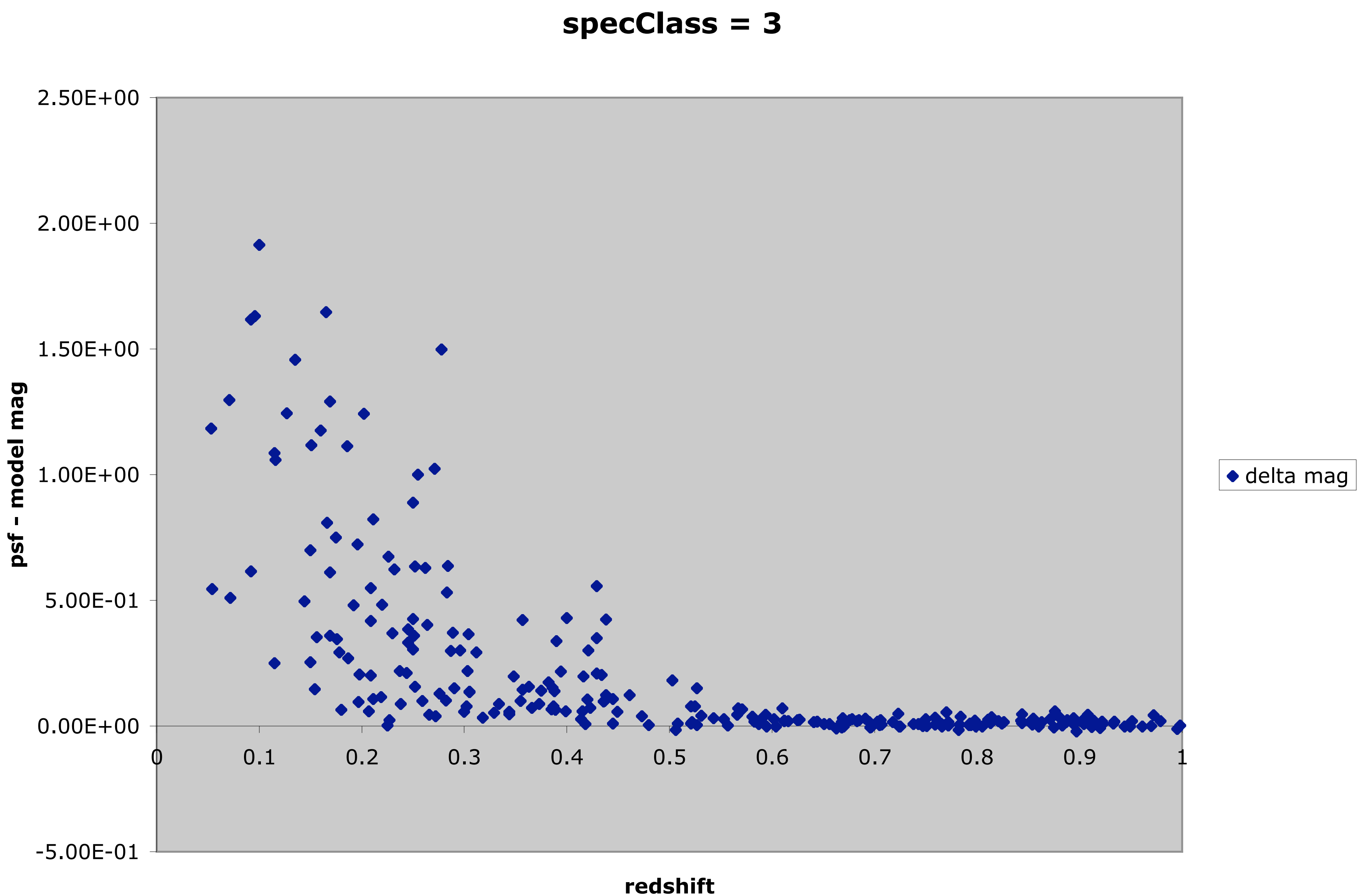
This classification does not depend on what the thing looks like, or any other photometric parameter.

Exercise 1: explore specClass = 3 image structures with respect to redshift

"image structure" will be quantified by the fraction of the light in the nucleus:

(point-spread function = *psf*)

```
SELECT z, psfmag_r, modelmag_r

FROM SpecPhoto

WHERE specClass = 3 and
ra > 170 and ra < 180 and dec > 40 and dec < 50
```



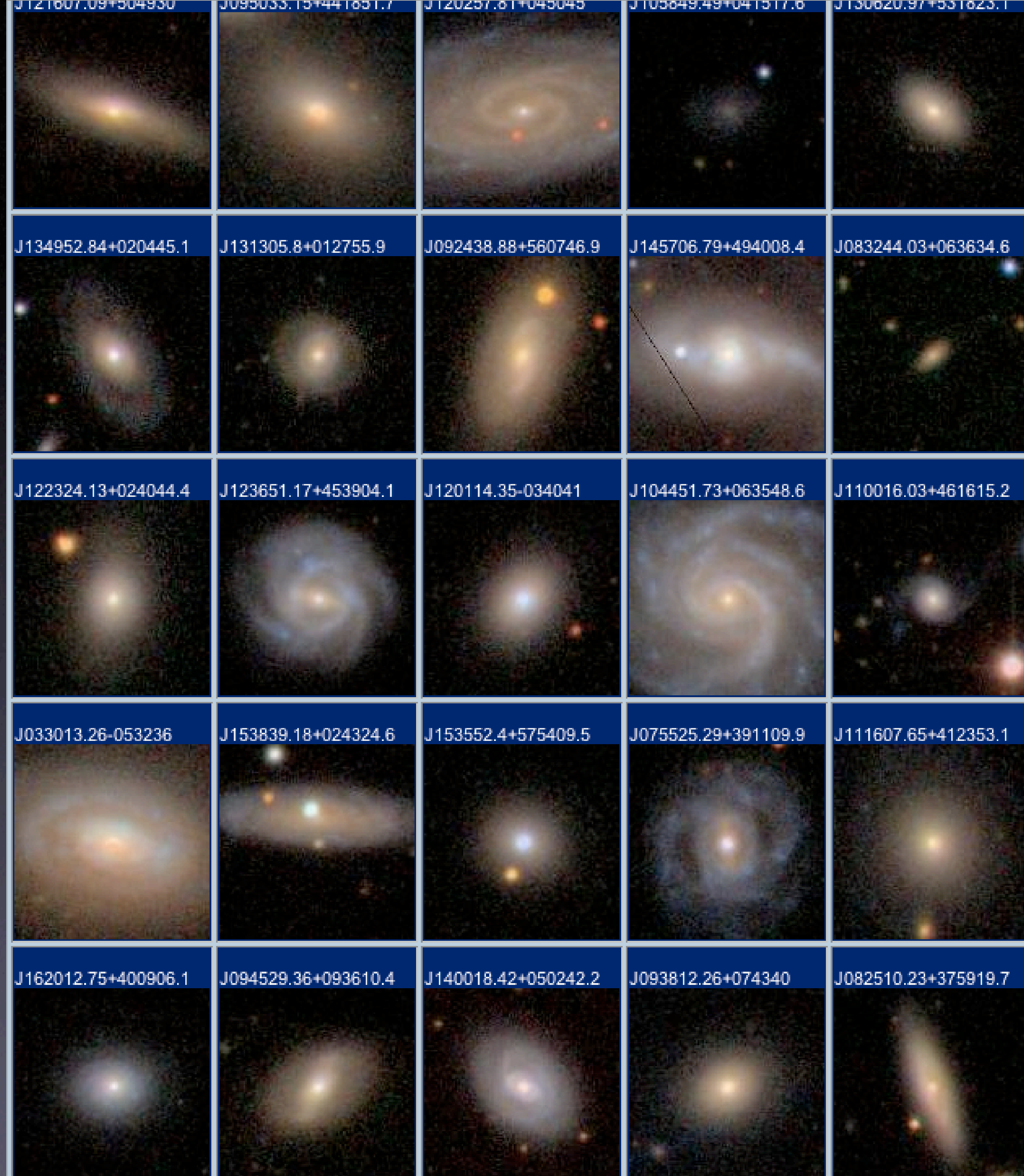
Seyferts quasars

Exercise 2: show that the host galaxies of AGN's are relatively luminous

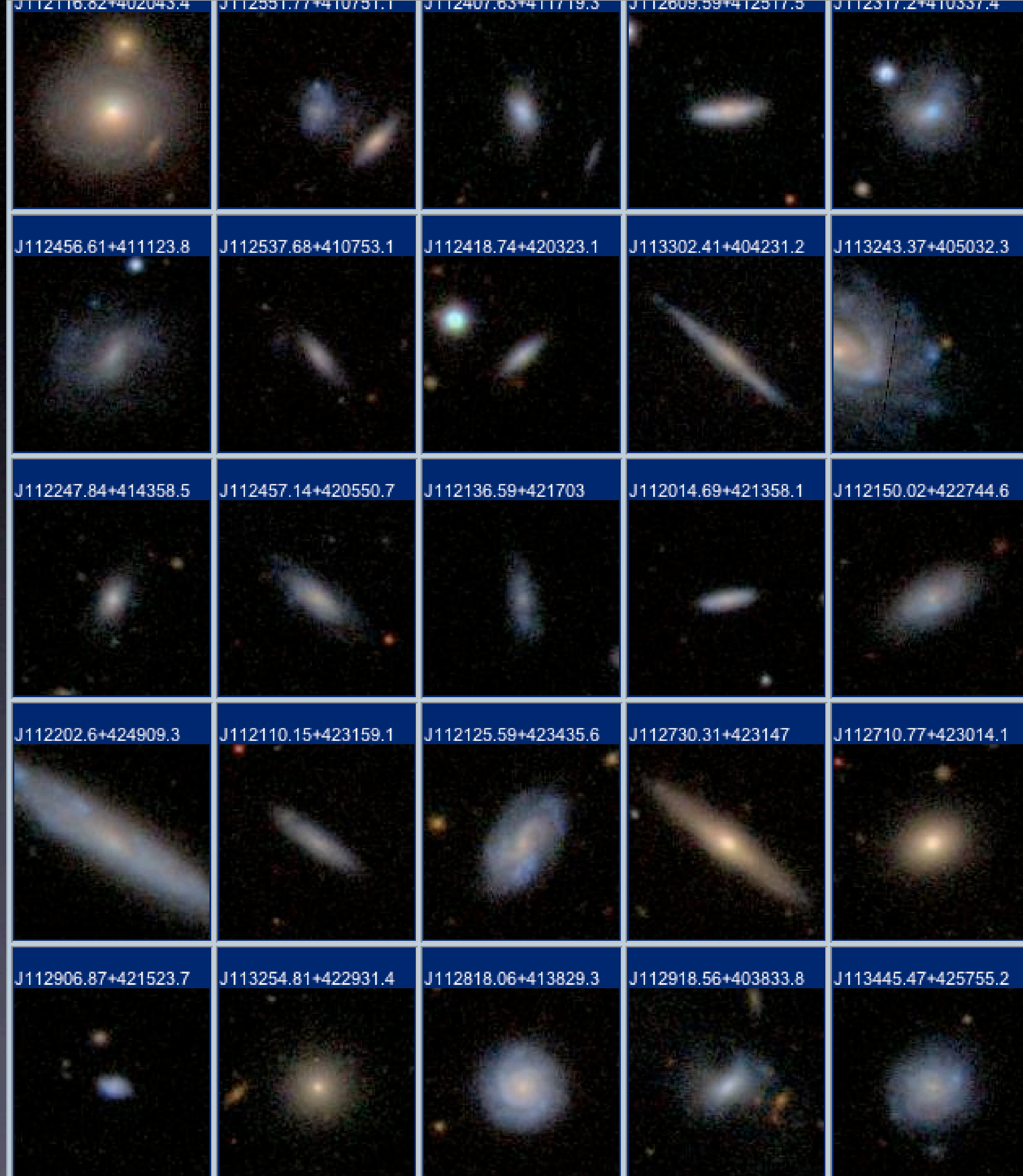
```
SELECT S.z, S.ra, S.dec, P.fibermag_r, P.modelmag_r

FROM specobj as S, photoObj as P

WHERE S.specClass = 3 and
P.specobjid = S.specobjid and
P.modelmag_r < 17.77 and
S.z > 0.01 and S.z < 0.035
```

Similar query for a control sample of normal galaxies (specClass = 2), adding restriction to 10 square degrees of sky

specClass = 3

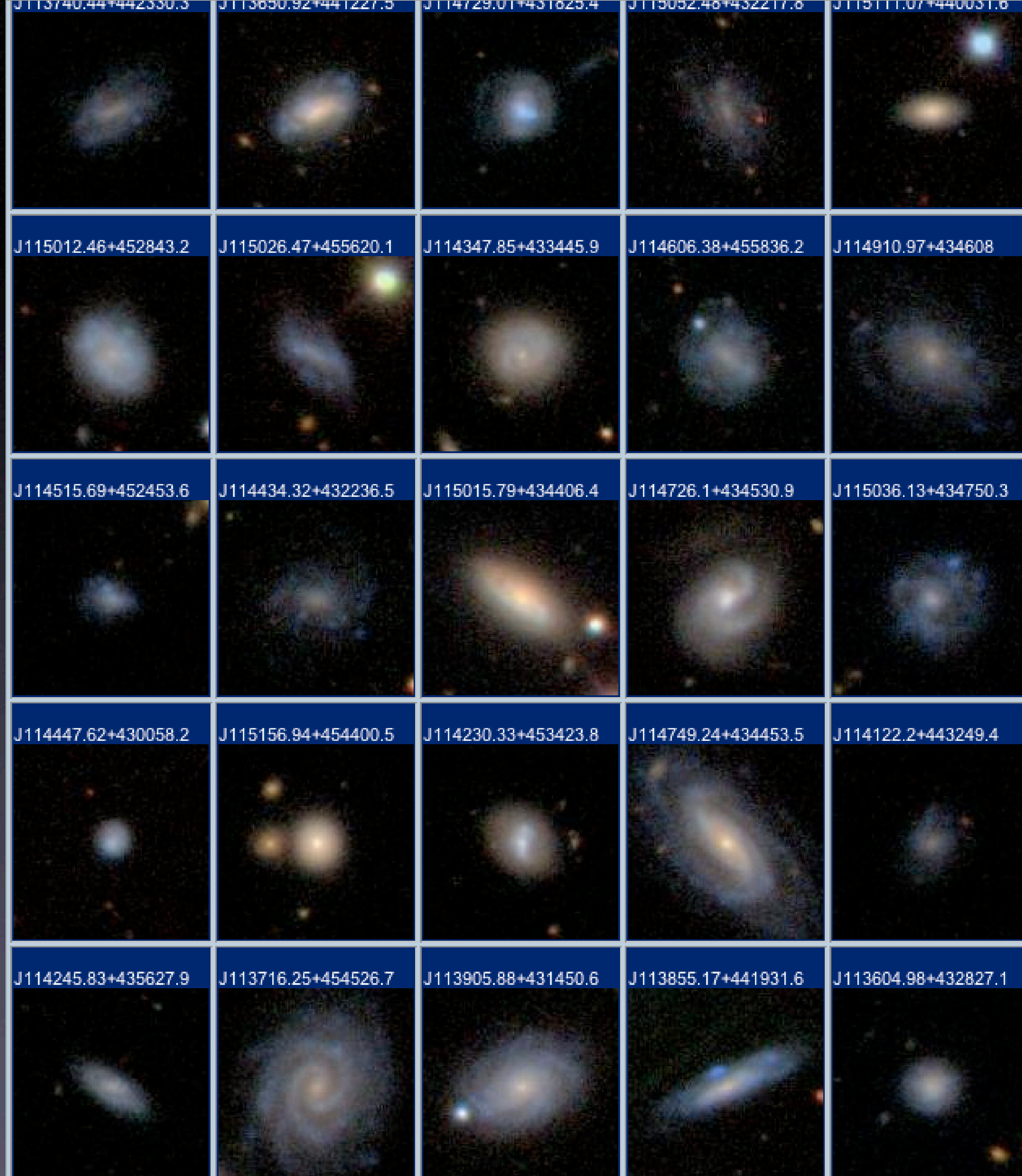

J134952.84+020445.1
J131305.8+012755.9
J092438.88+560746.9
J145706.79+494008.4
J083244.03+063634.6
J122324.13+024044.4
J123651.17+453904.1
J120114.35-034041
J104451.73+063548.6
J110016.03+461615.2
J033013.26-053236
J153839.18+024324.6
J153552.4+575409.5
J075525.29+391109.9
J111607.65+412353.1
J162012.75+400906.1
J094529.36+093610.4
J140018.42+050242.2
J093812.26+074340
J082510.23+375919.7

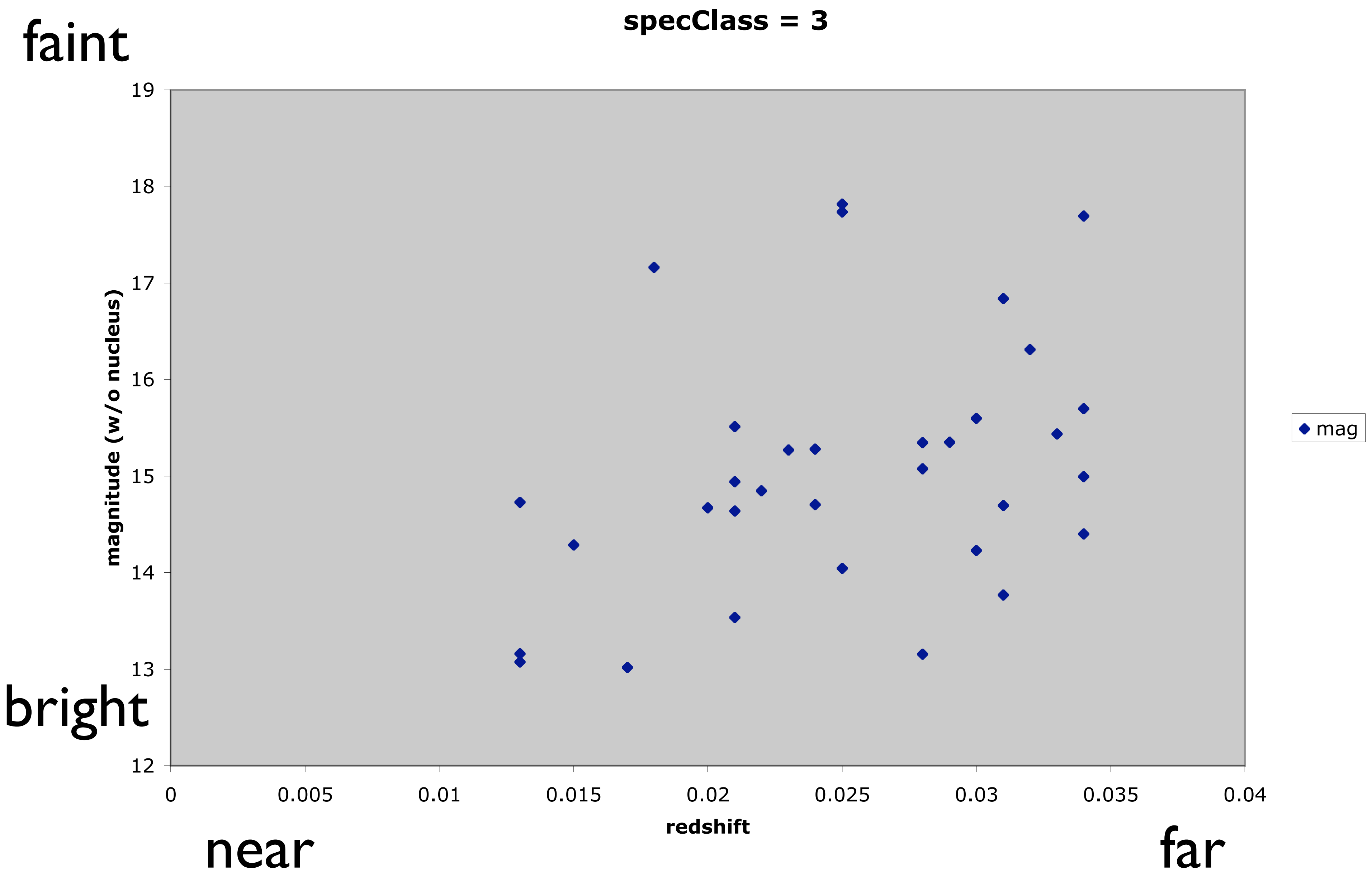
specClass = 2

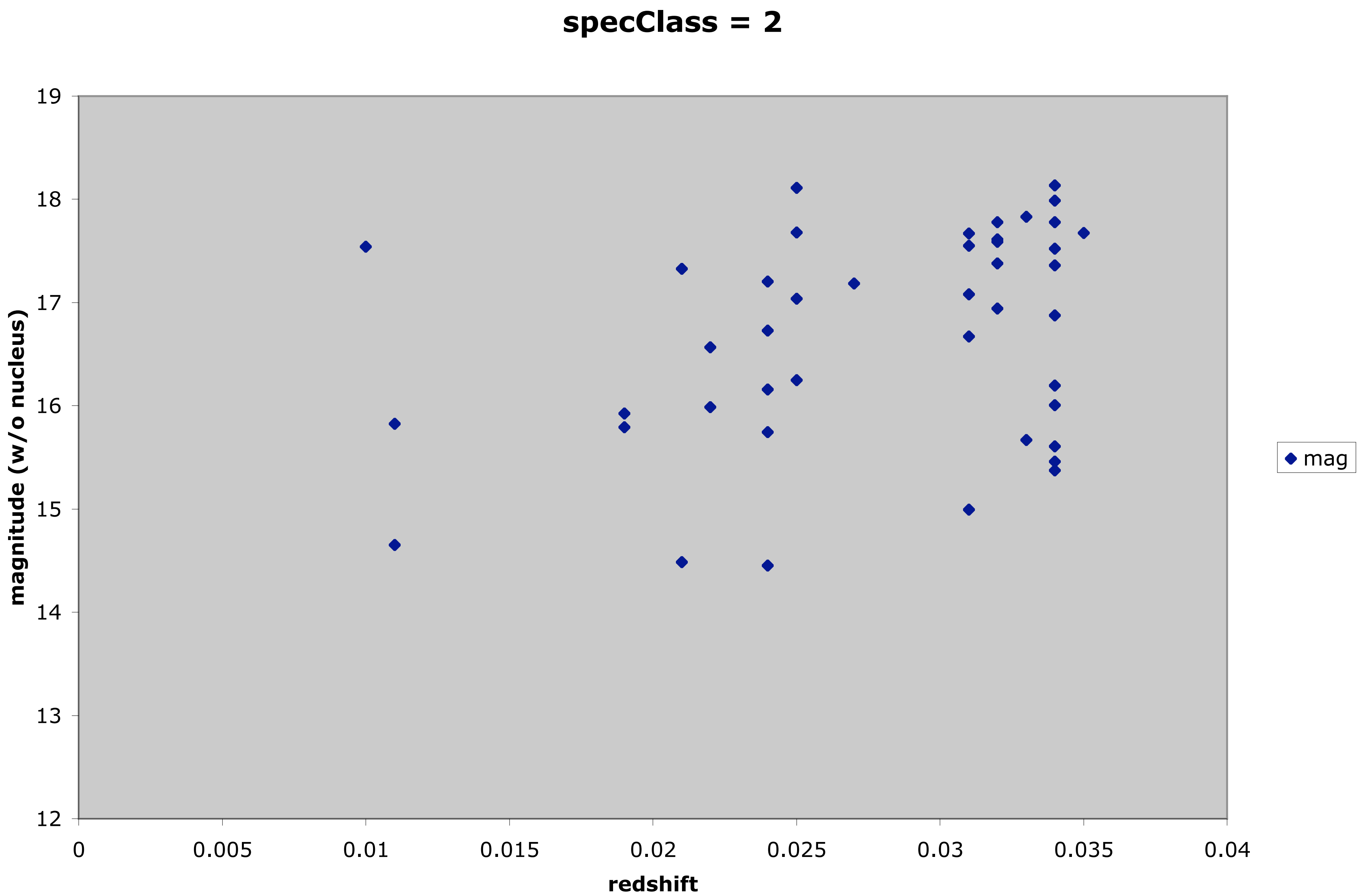


J112456.61+411123.8
J112537.68+410753.1
J112418.74+420323.1
J113302.41+404231.2
J113243.37+405032.3
J112247.84+414358.5
J112457.14+420550.7
J112136.59+421703
J112014.69+421358.1
J112150.02+422744.6
J112202.6+424909.3
J112110.15+423159.1
J112125.59+423435.6
J112730.31+423147
J112710.77+423014.1
J112906.87+421523.7
J113254.81+422931.4
J112818.06+413829.3
J112918.56+403833.8
J113445.47+425755.2

specClass = 2


J115012.46+452843.2
J115026.47+455620.1
J114347.85+433445.9
J114606.38+455836.2
J114910.97+434608
J114515.69+452453.6
J114434.32+432236.5
J115015.79+434406.4
J114726.1+434530.9
J115036.13+434750.3
J114447.62+430058.2
J115156.94+454400.5
J114230.33+453423.8
J114749.24+434453.5
J114122.2+443249.4
J114245.83+435627.9
J113716.25+454526.7
J113905.88+431450.6
J113855.17+441931.6
J113604.98+432827.1


specClass = 3
faint
bright
magnitude (w/o nucleus)
19
18
17
16
15
14
13
12
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
redshift
mag
near
far


specClass = 2
magnitude (w/o nucleus)
19
18
17
16
15
14
13
12
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
redshift
mag

Exercise 3: show that the host galaxies of AGN's are often barred spiral galaxies

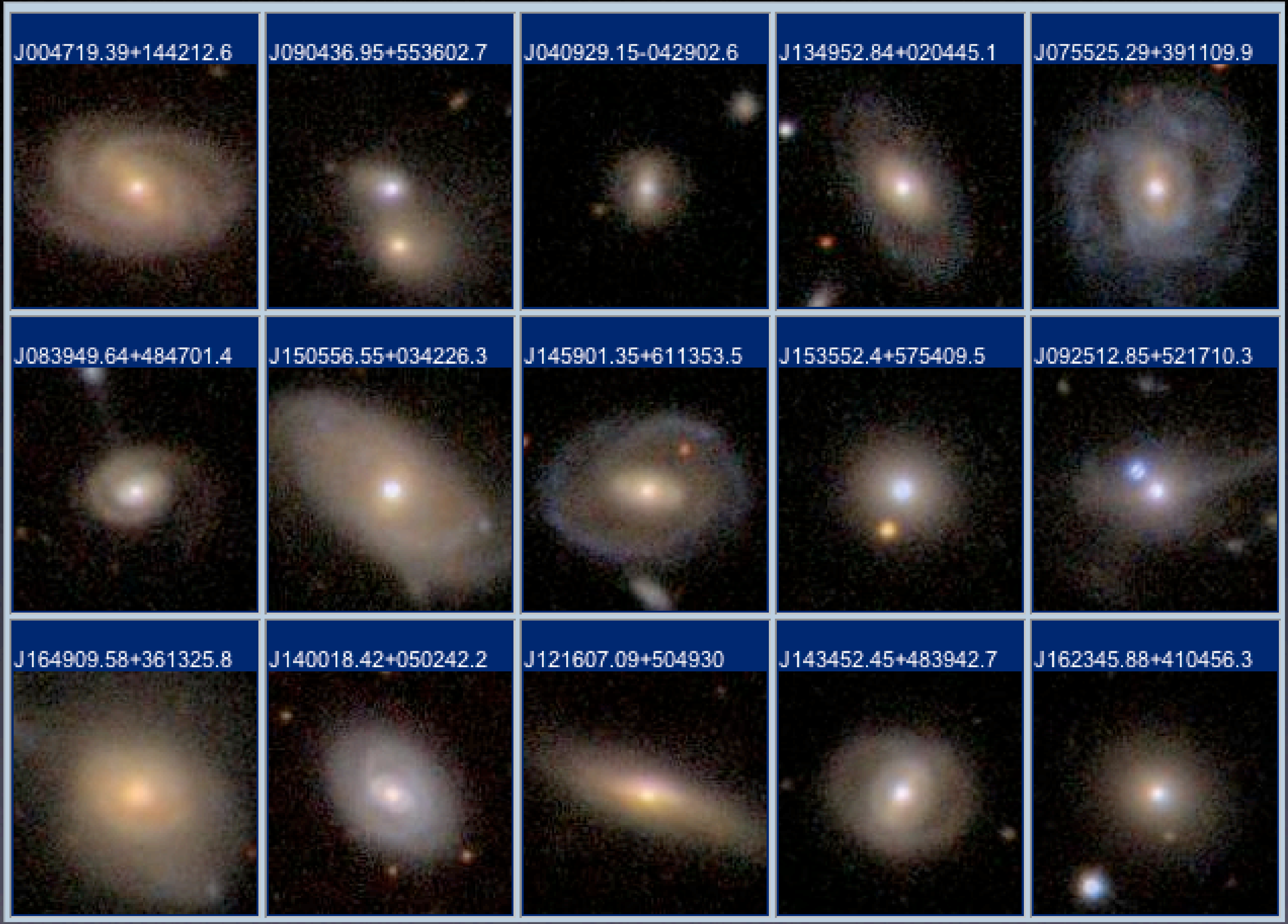
```
SELECT S.z, S.ra, S.dec,
L1.continuum, L1.height, L1.sigma

FROM specobj as S, specline as L1

WHERE S.specClass = 3 and
S.z > 0.01 and S.z < 0.02 and
L1.specobjid = S.specobjid and
L1.lineID = 6565 and
L1.category = 2 and
L1.height > 6 and
(2.507 * L1.height * L1.sigma) > 850
```


J120114.35-034041
J033013.26-053236
J095033.15+441851.7
J080538.66+261005.4
J094529.36+093610.4
J145706.79+494008.4

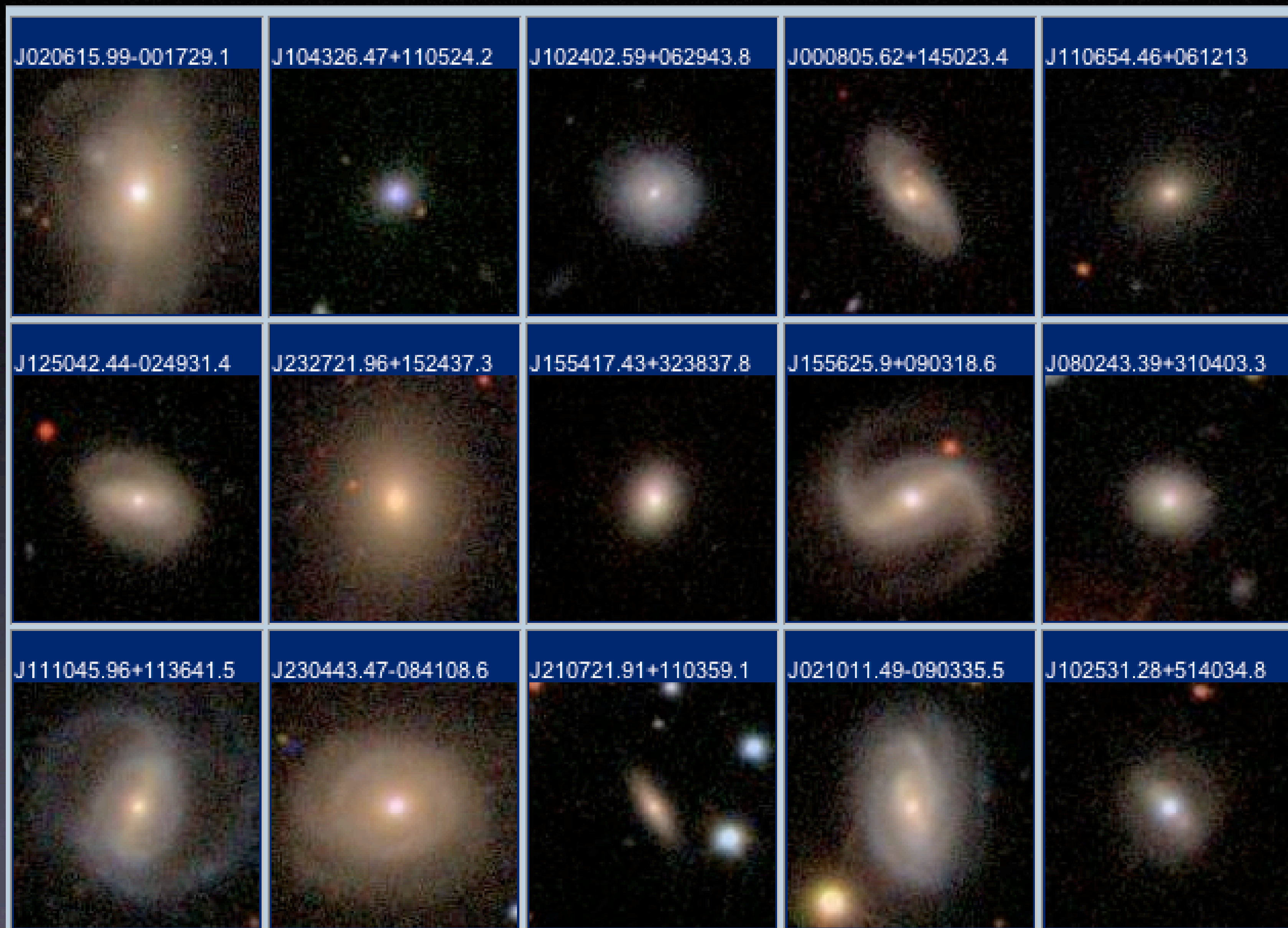
$0.01 < z < 0.02$


J092438.88+560746.9
J122324.13+024044.4
J131305.8+012755.9
J120257.81+045045
J082510.23+375919.7
J111857.68+580323.5
J104451.73+063548.6
J112536.16+542257.1
J130620.97+531823.1
J162012.75+400906.1
J093812.26+074340
J121754.97+583935.6
J111607.65+412353.1

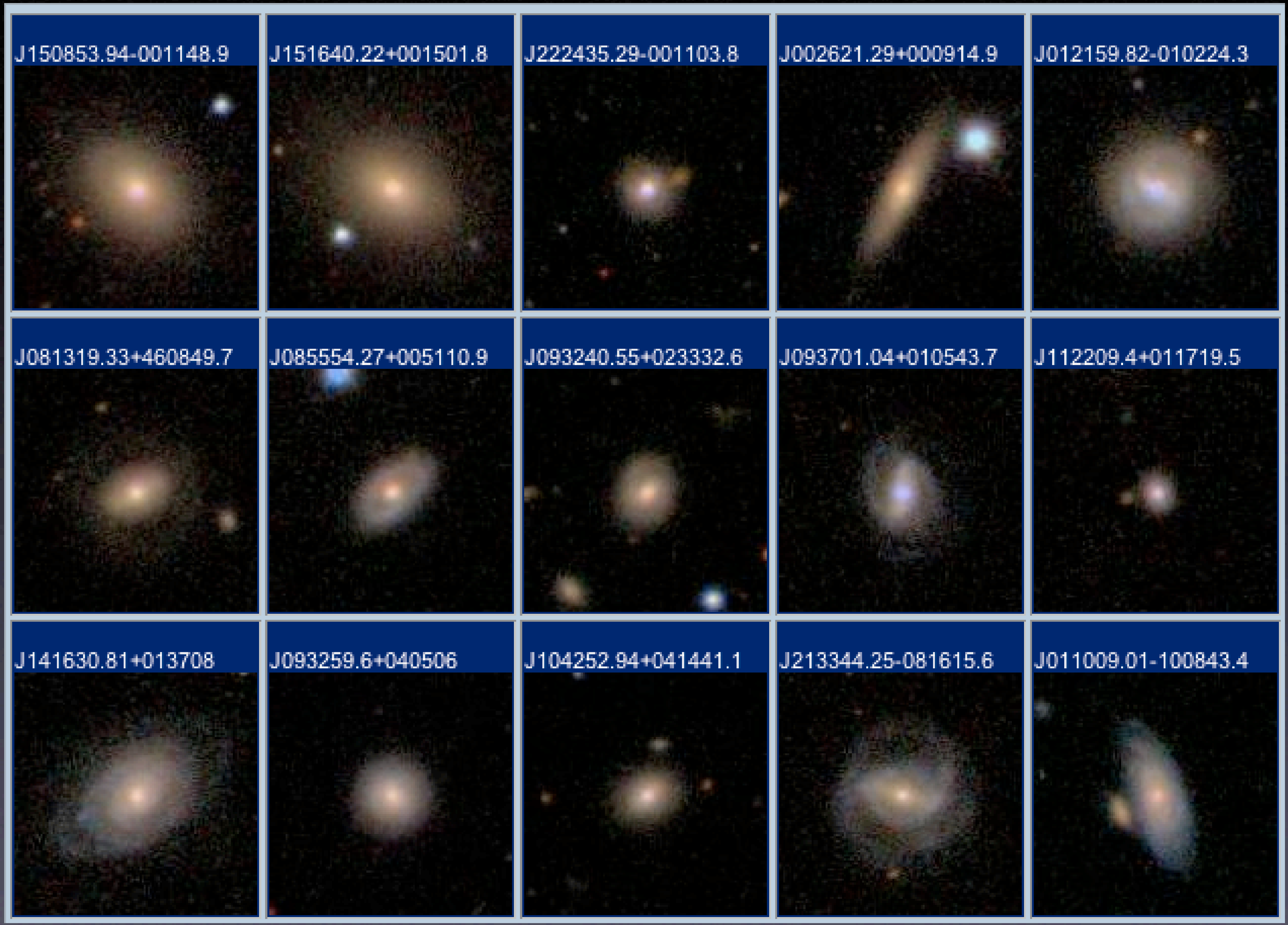
$0.02 < z < 0.03$


J004719.39+144212.6
J090436.95+553602.7
J040929.15-042902.6
J134952.84+020445.1
J075525.29+391109.9
J083949.64+484701.4
J150556.55+034226.3
J145901.35+611353.5
J153552.4+575409.5
J092512.85+521710.3
J164909.58+361325.8
J140018.42+050242.2
J121607.09+504930
J143452.45+483942.7
J162345.88+410456.3

$0.03 < z < 0.04$


J020615.99-001729.1
J104326.47+110524.2
J102402.59+062943.8
J000805.62+145023.4
J110654.46+061213
J125042.44-024931.4
J232721.96+152437.3
J155417.43+323837.8
J155625.9+090318.6
J080243.39+310403.3
J111045.96+113641.5
J230443.47-084108.6
J210721.91+110359.1
J021011.49-090335.5
J102531.28+514034.8

$0.04 < z < 0.05$


J150853.94-001148.9
J151640.22+001501.8
J222435.29-001103.8
J002621.29+000914.9
J012159.82-010224.3
J081319.33+460849.7
J085554.27+005110.9
J093240.55+023332.6
J093701.04+010543.7
J112209.4+011719.5
J141630.81+013708
J093259.6+040506
J104252.94+041441.1
J213344.25-081615.6
J011009.01-100843.4

$0.05 < z < 0.06$


J095939.52+003512.1
J115205.88-033015.9
J171550.49+593548.7
J173107.87+620026
J021257.59+140610.1
J035107.59-052637
J084025.51+033301.7
J094057.19+032401.2
J102148.9+030732.2
J145047.19+033645.3
J163631.28+420242.4
J165612+422553.6
J165408.15+392533.3
J001335.38-095120.9
J225051.71-085456.8

$0.06 < z < 0.07$

z range	No. gals
0.01 - 0.02	6
0.02 - 0.03	13
0.03 - 0.04	23
0.04 - 0.05	31
0.05 - 0.06	45
0.06 - 0.07	63

Exercise 4: check whether line flux or line width correlates with morphology

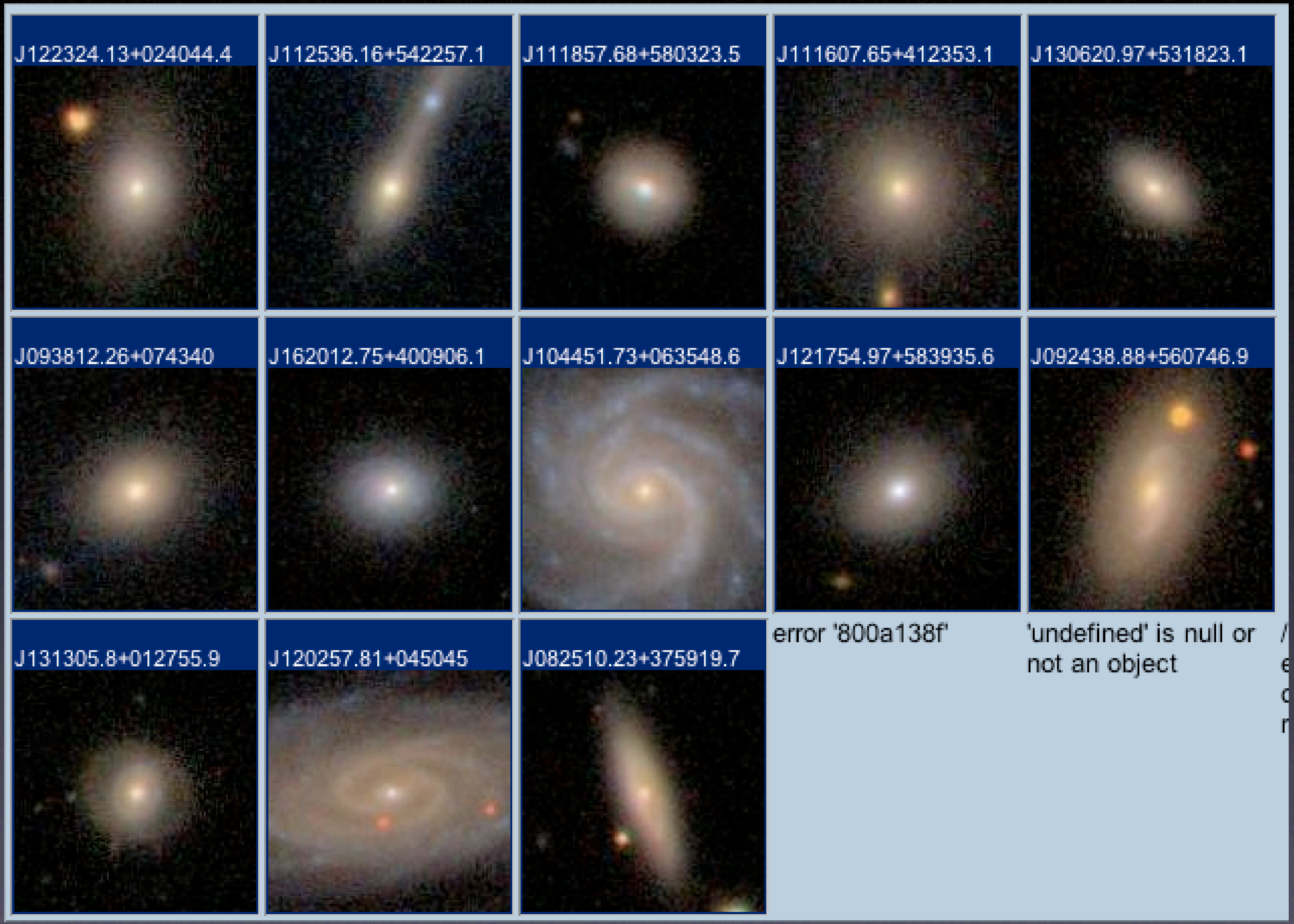
```
SELECT S.z, S.ra, S.dec,
L1.continuum, L1.height, L1.sigma

FROM specobj as S, specline as L1

WHERE S.specClass = 3 and
S.z > 0.02 and S.z < 0.03 and
L1.specobjid = S.specobjid and
L1.lineID = 6565 and
L1.category = 2 and
L1.height > 6 and
(2.507 * L1.height * L1.sigma) > 850
```

Your SQL command was:

```
select S.z, S.ra, S.dec,
L1.continuum, L1.height, L1.sigma

from specobj as S, specline as L1

where S.specClass = 3 and
S.z > 0.02 and S.z < 0.03 and
L1.specobjid = S.specobjid and
L1.lineID = 6565 and
L1.category = 2 and
L1.height > 6 and
(2.507 * L1.height * L1.sigma) > 850
```

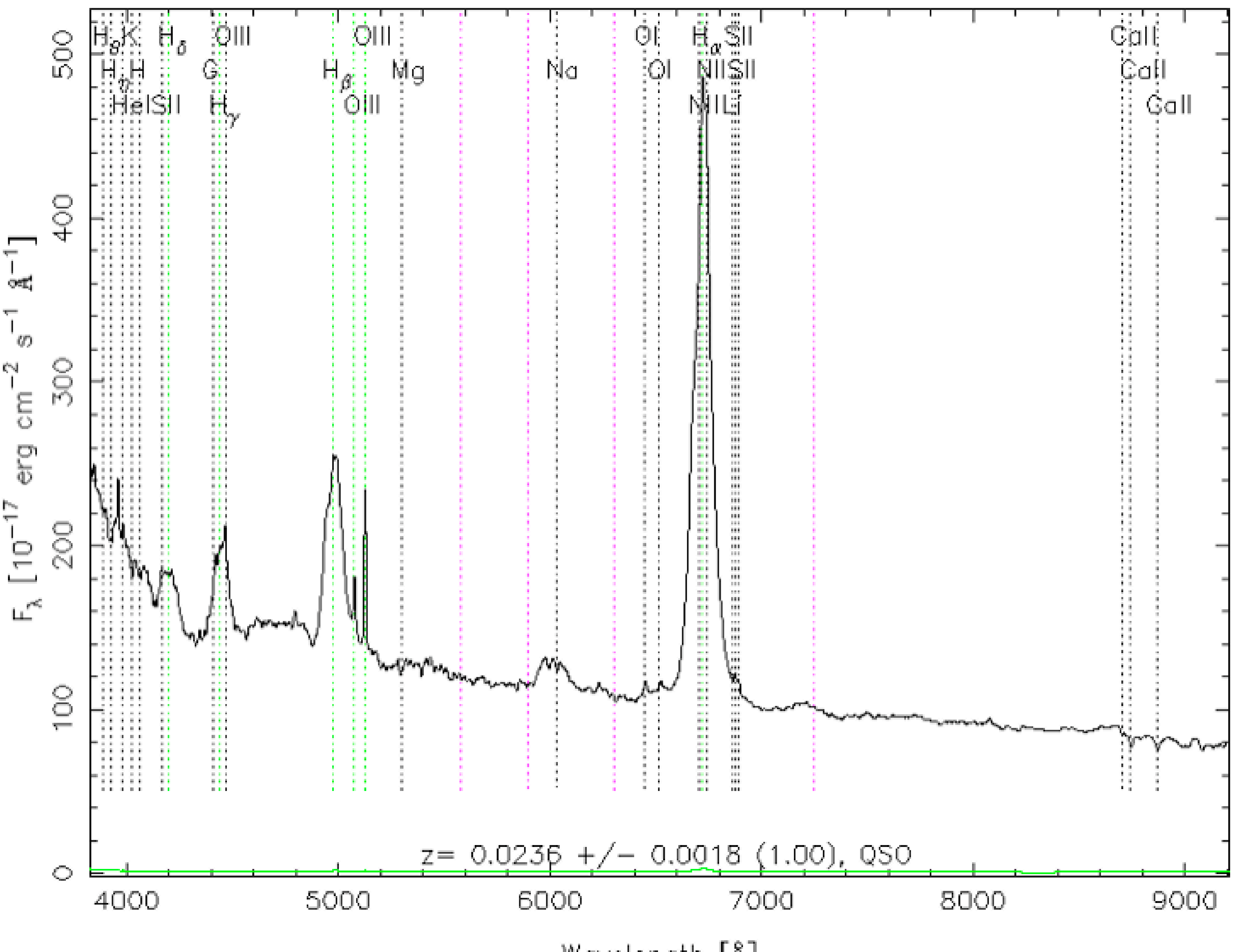
z	ra	dec	continuum	height	sigma
0.028	161.21555	6.596852	64.448	121.225	12.465
0.029	198.2742	1.465541	48.516	55.088	17.106
0.025	141.16204	56.12972	61.155	148.123	7.609
0.021	169.03189	41.398105	63.694	76.096	46.604
0.021	180.7409	4.84585	20.044	25.54	22.264
0.024	185.85057	2.679011	105.932	359.524	40.106
0.021	171.40069	54.382555	85.506	226.579	27.498
0.021	126.29263	37.98882	39.878	105.84	4.099
0.028	245.05315	40.15172	59.938	180.315	9.976
0.022	144.5511	7.727792	103.537	82.802	30.882
0.023	184.47907	58.659912	91.101	298.09	4.074
0.028	169.74037	58.056554	58.018	157.344	25.042
0.024	196.58738	53.306444	58.177	19.621	149.996

ordered by strongest line to weakest

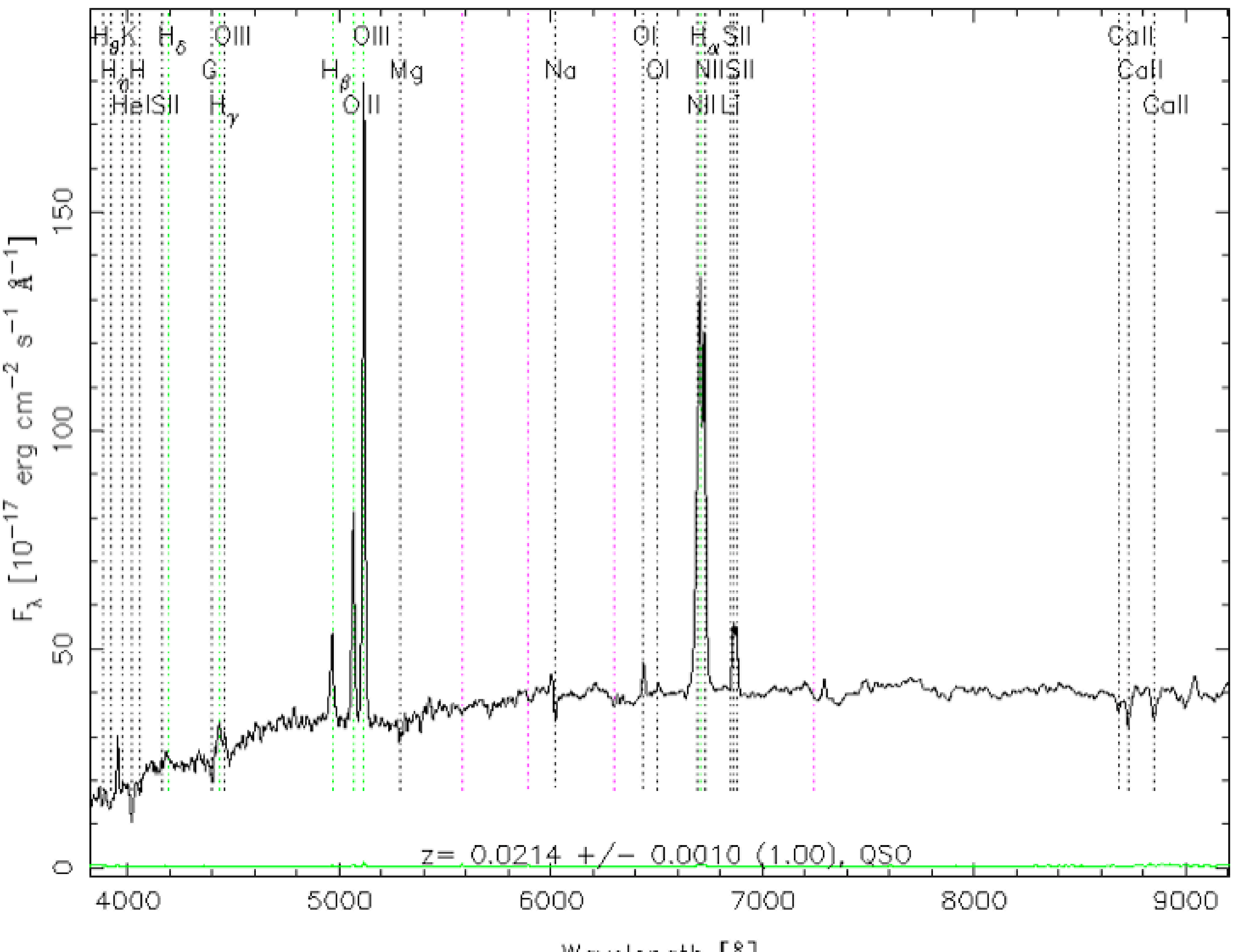


0.02 < z < 0.03

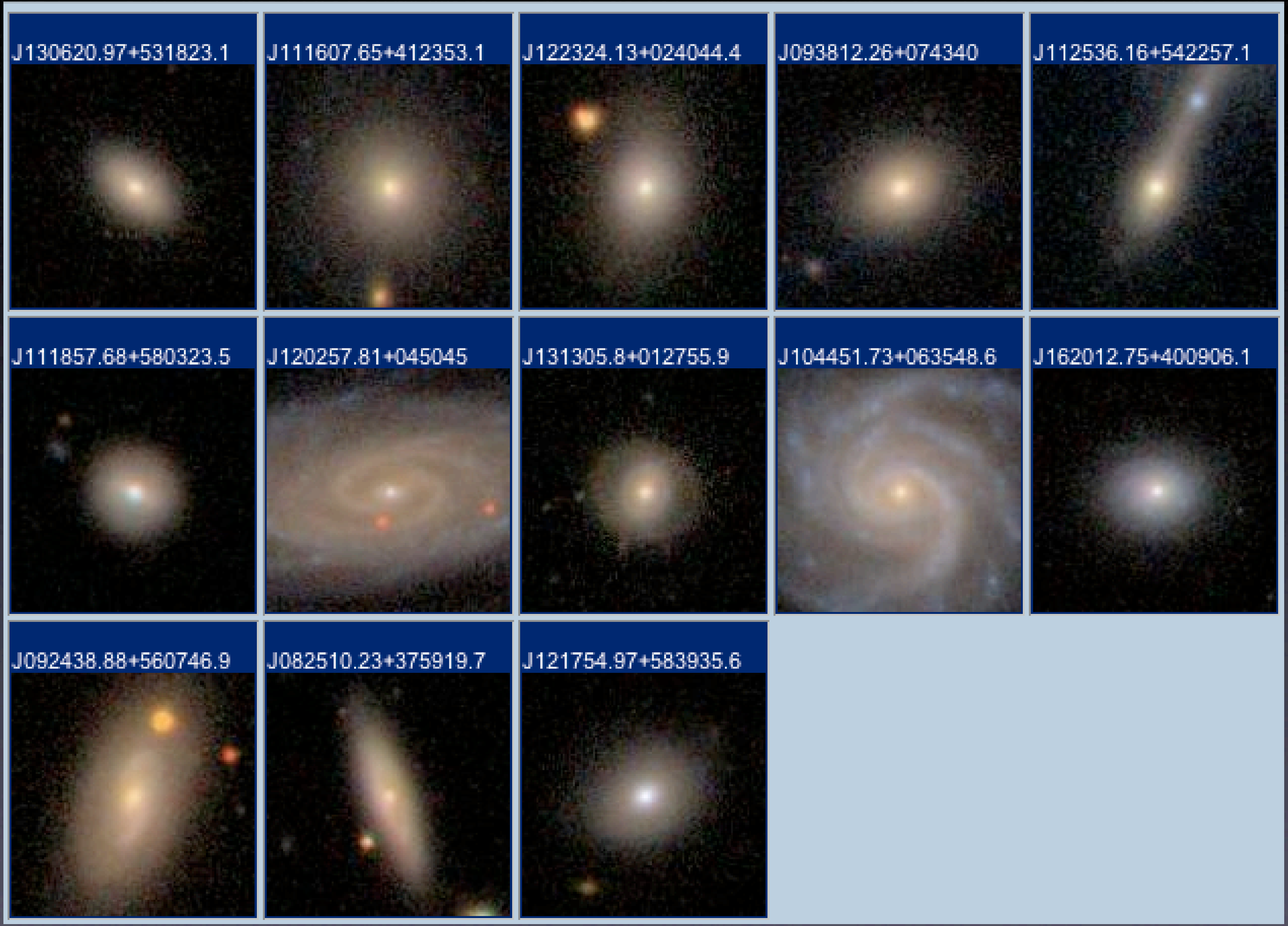
RA=185.85057, DEC= 2.67901, MJD=52283, Plate= 519, Fiber=487



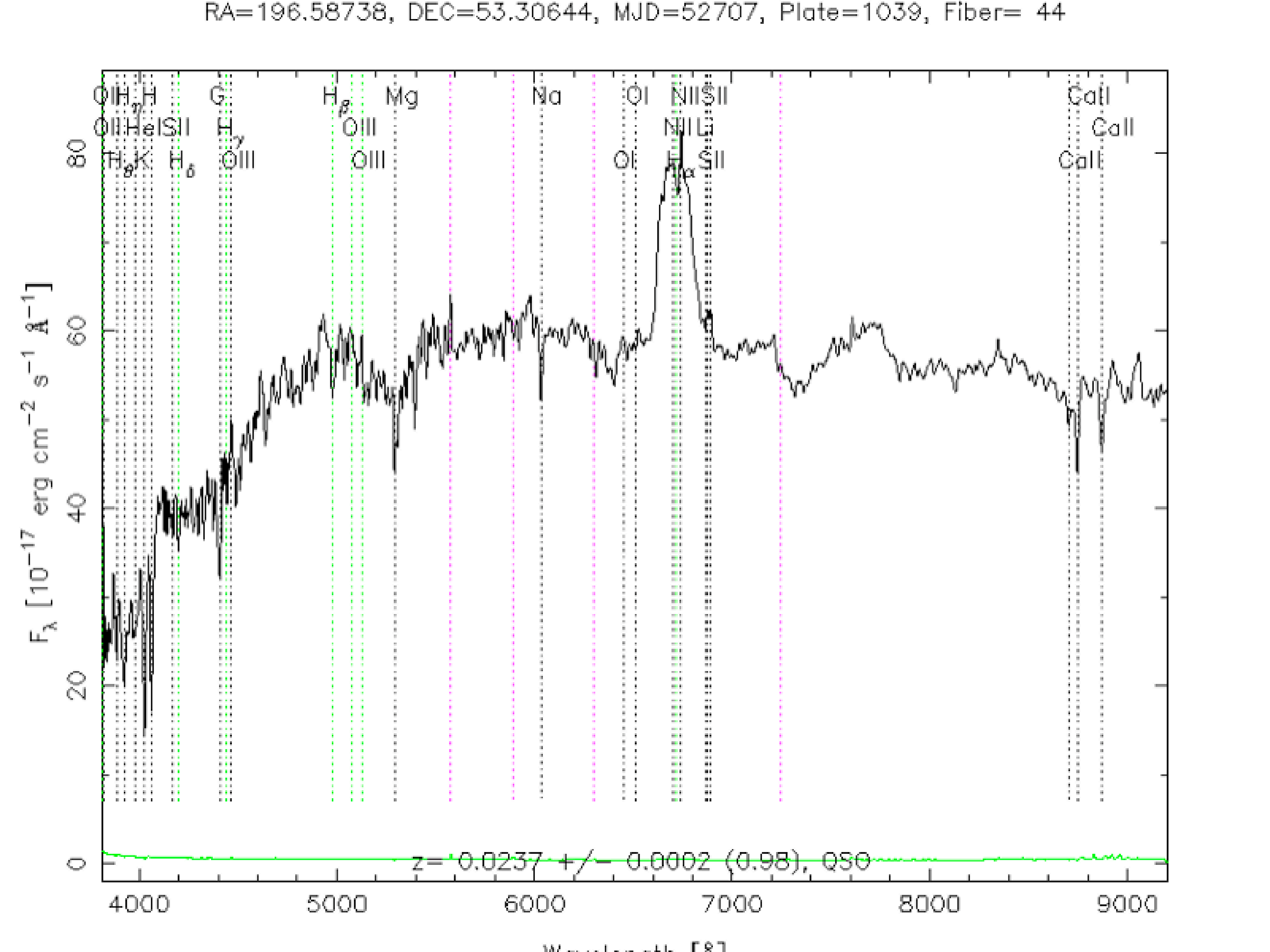
RA=126.29263, DEC=37.98882, MJD=52589, Plate= 893, Fiber=628



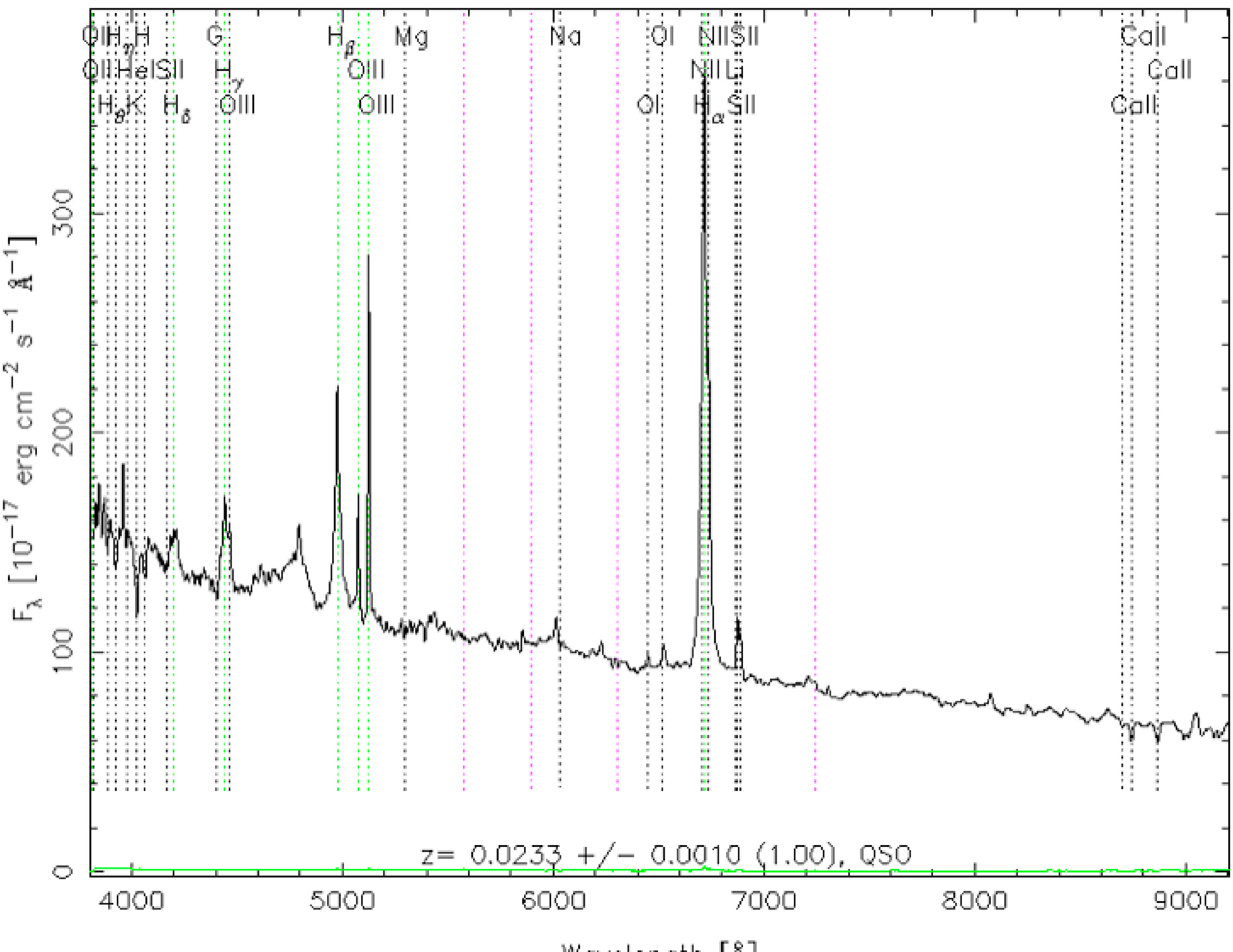
ordered by widest line to narrowest

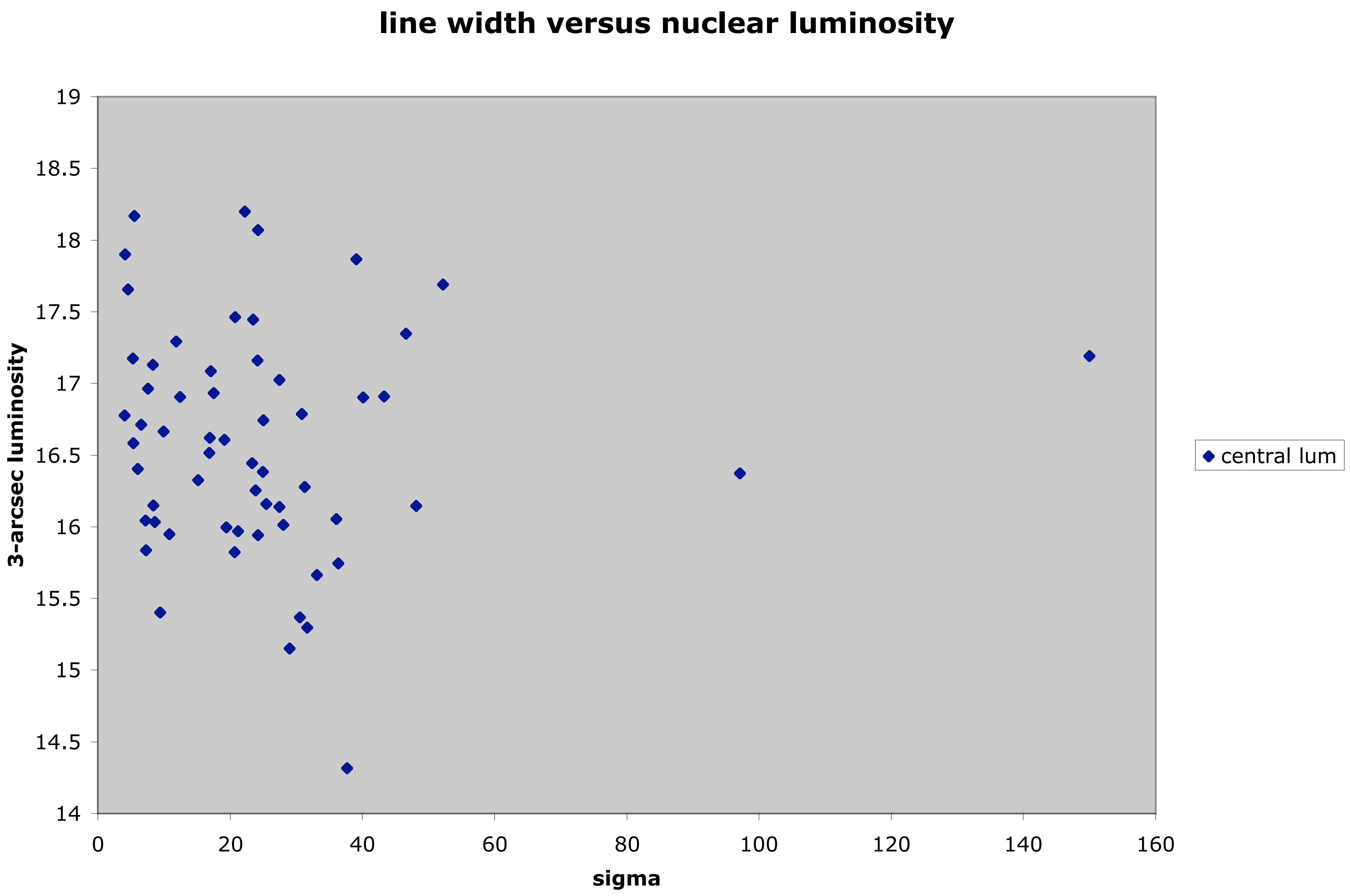


$0.02 < z < 0.03$


RA=196.58738, DEC=53.30644, MJD=52707, Plate=1039, Fiber= 44
z= 0.0237 +/- 0.0002 (0.98), QSO
Wavelength [Å]
F_λ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
OII H$_\gamma$ H
OII HeI SII
H$_\theta$ K
H$_\delta$
G
H$_\gamma$
OIII
H$_\beta$
OIII
OIII
Mg
Na
OI
OI
NII SII
NII Li
H$_\alpha$ SII
CaII
CaII
CaII
0
20
40
60
80
4000
5000
6000
7000
8000
9000

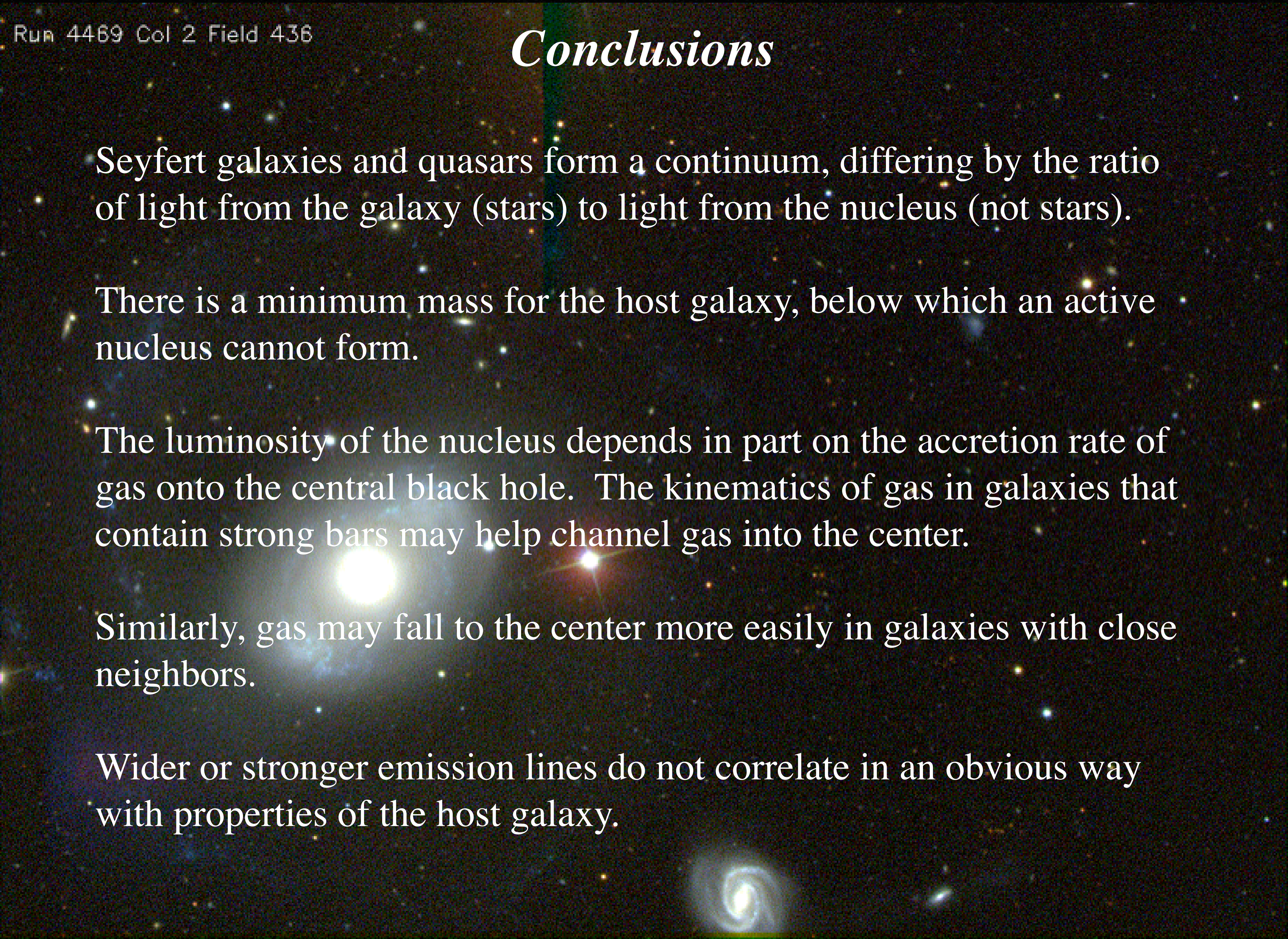
RA=184.47907, DEC=58.65991, MJD=52791, Plate=1315, Fiber=403




line width versus nuclear luminosity
19
18.5
18
17.5
17
16.5
16
15.5
15
14.5
14
3-arcsec luminosity
0
20
40
60
80
100
120
140
160
sigma
central lum

Exercise 5: explore frequency of tidal disturbances from nearby galaxies among AGN sample

Exercise 6: explore orientation frequency of galaxy disks (are galaxies harboring AGN more often face-on?)



Conclusions

Seyfert galaxies and quasars form a continuum, differing by the ratio of light from the galaxy (stars) to light from the nucleus (not stars).

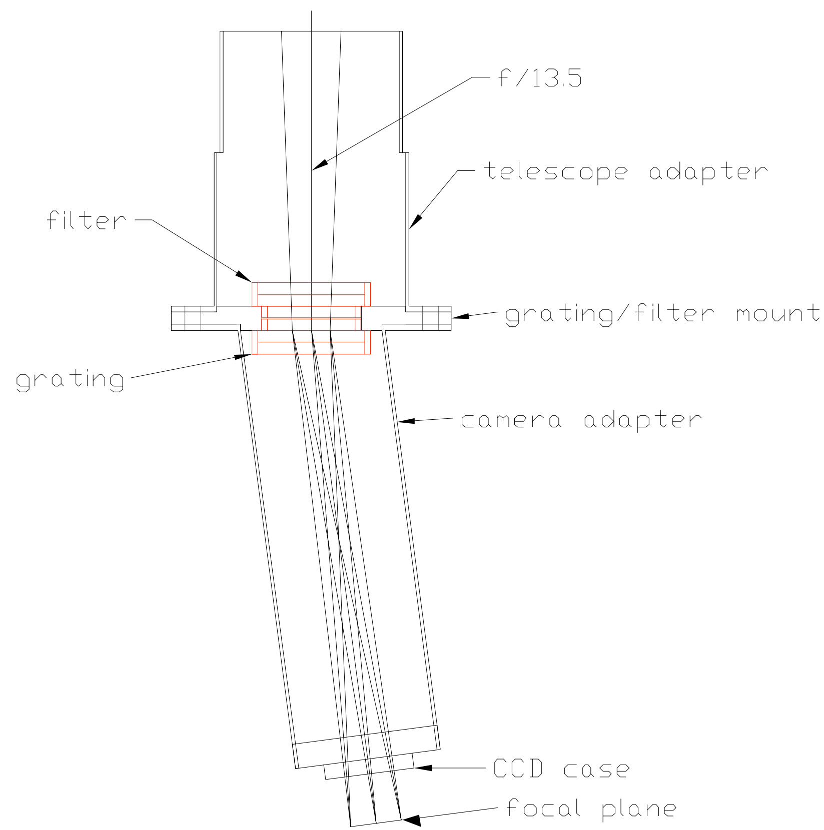
There is a minimum mass for the host galaxy, below which an active nucleus cannot form.

The luminosity of the nucleus depends in part on the accretion rate of gas onto the central black hole. The kinematics of gas in galaxies that contain strong bars may help channel gas into the center.

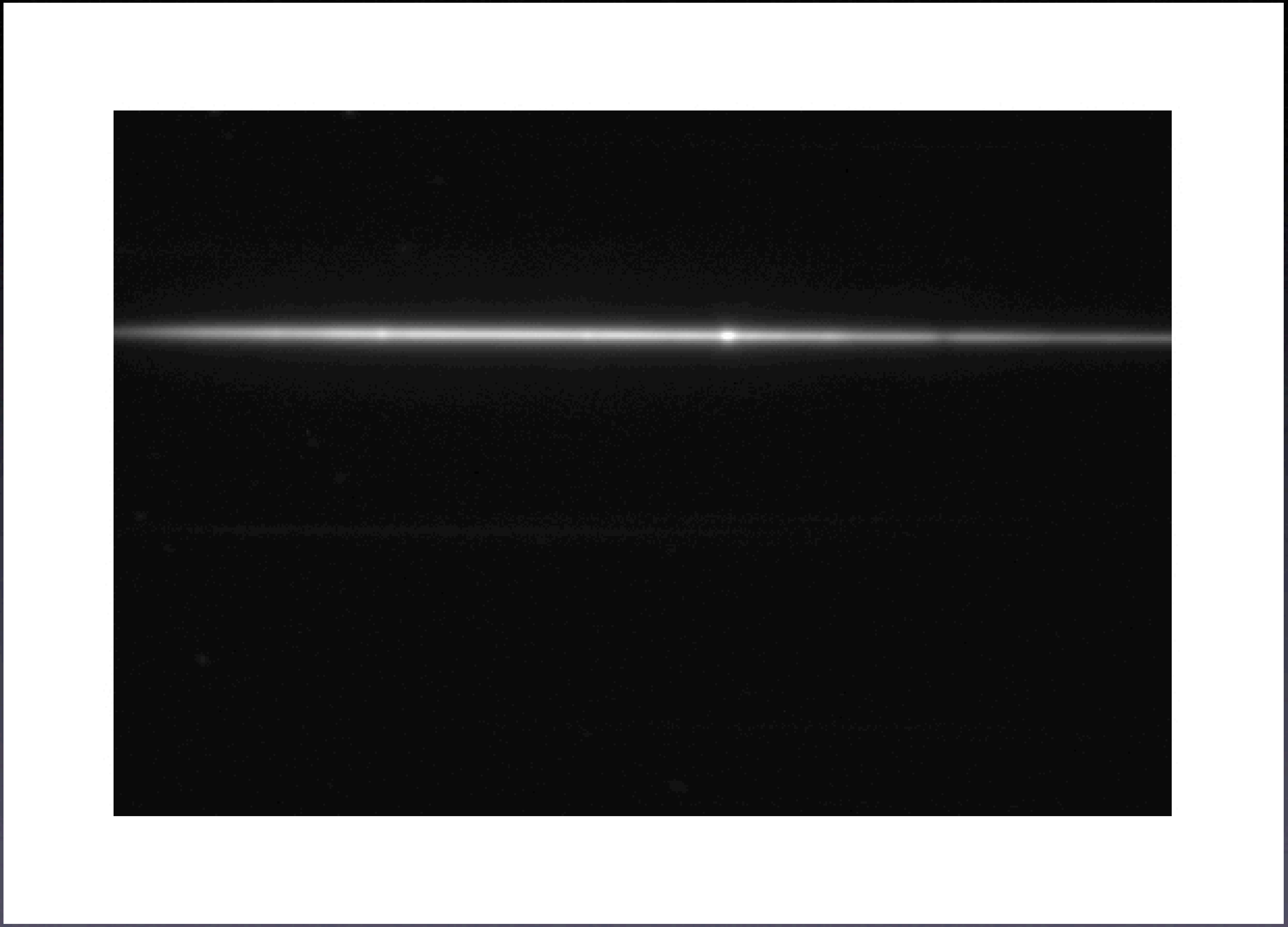
Similarly, gas may fall to the center more easily in galaxies with close neighbors.

Wider or stronger emission lines do not correlate in an obvious way with properties of the host galaxy.

transmission grating in converging beam - "slitless spectroscopy"



P Cygni (Yerkes 24-inch)



Spectroscopy with optical fibers