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
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***

<table>
<thead>
<tr>
<th>NGC</th>
<th>1950</th>
<th>Type</th>
<th>$m_{\text{total}}$</th>
<th>$m_{\text{nucl.}}$</th>
<th>Spect.</th>
<th>Modulus</th>
<th>No. of Plates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R.A.</td>
<td>Dec.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1068</td>
<td>$2^h40.1$</td>
<td>$-0^\circ14$</td>
<td>Sb</td>
<td>10.0</td>
<td>13.0</td>
<td>G3</td>
<td>26$^m0$</td>
</tr>
<tr>
<td>1275</td>
<td>3 15.6</td>
<td>+41 18</td>
<td>E:</td>
<td>13.0</td>
<td>15.5</td>
<td>G3</td>
<td>30.0</td>
</tr>
<tr>
<td>3516</td>
<td>11 3.4</td>
<td>+72 50</td>
<td>Sa</td>
<td>12.2</td>
<td>13.7</td>
<td>G2:</td>
<td>28.5</td>
</tr>
<tr>
<td>4051</td>
<td>12 0.6</td>
<td>+44 48</td>
<td>Sb</td>
<td>11.7</td>
<td>14.0</td>
<td>G2</td>
<td>26.0</td>
</tr>
<tr>
<td>4151</td>
<td>12 8.0</td>
<td>+39 41</td>
<td>Sb</td>
<td>11.2</td>
<td>12.0</td>
<td>G2</td>
<td>26.0</td>
</tr>
<tr>
<td>7469</td>
<td>23 0.7</td>
<td>+8 36</td>
<td>Sa</td>
<td>13.0</td>
<td>14.3:</td>
<td>G0:</td>
<td>29.8</td>
</tr>
</tbody>
</table>

*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 1068 (HST)
NGC 1275 (HST)
Seyfert galaxy nuclei are tiny:

\[ M_{bh} = 3 \times 10^7 \, M_{\text{sun}} \]

\[ R_s = 2 \frac{G \, M_{bh}}{c^2} = 0.6 \, \text{AU} \]

\[ R_{\text{accretion}} \sim 10 \, R_s = 6 \, \text{AU} = 50 \, \text{light-minutes} \]

compare to:

diameter of a galaxy \sim 70,000 \, \text{light-years}
image: $\alpha$, $\delta$, 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
Sun-like star
Spectral types of bright stars visible now:

\[\begin{array}{ll}
\gamma\text{ Peg} & \text{B2 IV} \\
\text{Vega} & \text{A0 V} \\
\text{Deneb} & \text{A2 I} \\
\text{Altair} & \text{A7 V} \\
\mu\text{ Peg} & \text{G8 III} \\
\text{Arcturus} & \text{K1.5 III} \\
\text{Antares} & \text{M1.5 I} \\
\beta\text{ Peg} & \text{M2 II-III} \\
\end{array}\]

expect spectra of galaxies to look like: “A” + “K” + “emission” in some proportion
eClass = 0.35
$eClass = 0.20$

$\text{RA}=183.94338, \text{DEC}=48.13085, \text{MJD}=53117, \text{Plate}=1451, \text{Fiber}=384$
RA=186.40157, DEC=50.33696, MJD=52644, Plate= 971, Fiber=426

eClass = 0.11
RA=184.80095, DEC=49.35465, MJD=52413, Plate=970, Fiber=102

eClass = 0.02
RA=201.27236, DEC=-0.90310, MJD=51959, Plate= 297, Fiber=218

$eClass = -0.05$
$e\text{Class} = -0.10$

RA = 173.23478, DEC = 50.24185, MJD = 52642, Plate = 966, Fiber = 564
- light is non-stellar
- emission lines only
- lines are broad
$H\beta$  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 $\approx 150$ km/sec

escape velocity from the Milky Way $\approx 450$ km/sec

$\Rightarrow$ 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:

- \text{height} \ (10^{-17} \text{ erg sec}^{-1} \text{ cm}^{-2} \text{ Å}^{-1}); \ + = \text{em}, - = \text{abs}
- \text{sigma} \ (\text{Ångstroms})
- \text{continuum} \ (10^{-17} \text{ erg sec}^{-1} \text{ cm}^{-2} \text{ Å}^{-1})
Measures of line strength:

**equivalent width**

(parameter called \( \text{ew} \) in the specLine database):

\[
\text{ew} = \frac{\sqrt{2\pi} \times \text{sigma} \times \text{height}}{\text{continuum}}
\]

(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.

⇒ 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, \( \text{specClass} = 3 \) (or 4)

\[
\text{FWHM} = c \times \left[ \frac{2.354 \times \text{sigma}}{\lambda} \right]
\]

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
specClass = 3

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
$\text{specClass} = 3$
specClass = 2
specClass = 2

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<tr>
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<th>J113650.92+441227.5</th>
<th>J114729.01+431825.4</th>
<th>J115052.48+432217.8</th>
<th>J115111.07+440031.6</th>
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<th>J114347.85+433445.9</th>
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<th>J115015.79+434406.4</th>
<th>J114726.1+434530.9</th>
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<tr>
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<th>J115156.94+454400.5</th>
<th>J114230.33+453423.8</th>
<th>J114749.24+434453.5</th>
<th>J114122.2+443249.4</th>
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<td><img src="image18" alt="Image" /></td>
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<td><img src="image20" alt="Image" /></td>
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<th>J114245.83+435627.9</th>
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<td><img src="image24" alt="Image" /></td>
<td><img src="image25" alt="Image" /></td>
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</tbody>
</table>
specClass = 3

- **faint**
- **bright**

**Redshift (near, far)**

**Magnitude (w/o nucleus)**
specClass = 2

Magnitude (w/o nucleus) vs. Redshift

- X-axis: Redshift
- Y-axis: Magnitude (w/o nucleus)

The graph shows a scatter plot of magnitude versus redshift for objects with a specific classification.
**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
$0.01 < z < 0.02$
$0.02 < z < 0.03$
$0.03 < z < 0.04$
$0.05 < z < 0.06$
<table>
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<tr>
<th>J095939.52+003512.1</th>
<th>J115205.88-033015.9</th>
<th>J171550.49+593548.7</th>
<th>J173107.87+620026</th>
<th>J021257.59+140610.1</th>
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<th>J094057.19+032401.2</th>
<th>J102148.9+030732.2</th>
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<th>J165408.15+392533.3</th>
<th>J001335.38-095120.9</th>
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<td><img src="image14.jpg" alt="Image" /></td>
<td><img src="image15.jpg" alt="Image" /></td>
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</tbody>
</table>

$0.06 < z < 0.07$
<table>
<thead>
<tr>
<th>$z$ range</th>
<th>No. gals</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01 - 0.02</td>
<td>6</td>
</tr>
<tr>
<td>0.02 - 0.03</td>
<td>13</td>
</tr>
<tr>
<td>0.03 - 0.04</td>
<td>23</td>
</tr>
<tr>
<td>0.04 - 0.05</td>
<td>31</td>
</tr>
<tr>
<td>0.05 - 0.06</td>
<td>45</td>
</tr>
<tr>
<td>0.06 - 0.07</td>
<td>63</td>
</tr>
</tbody>
</table>
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:

```sql
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
```
ordered by strongest line to weakest

0.02 < z < 0.03
ordered by widest line to narrowest

0.02 < z < 0.03
line width versus nuclear luminosity

sigma

3-arcsec luminosity

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