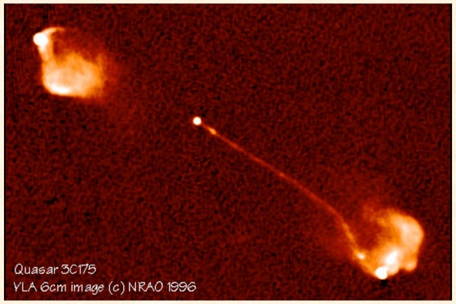
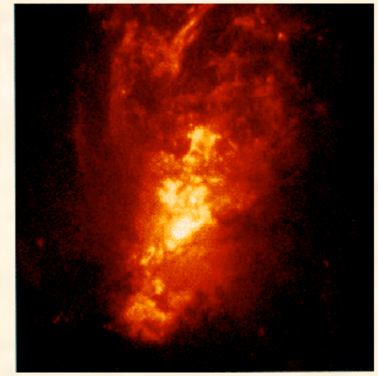
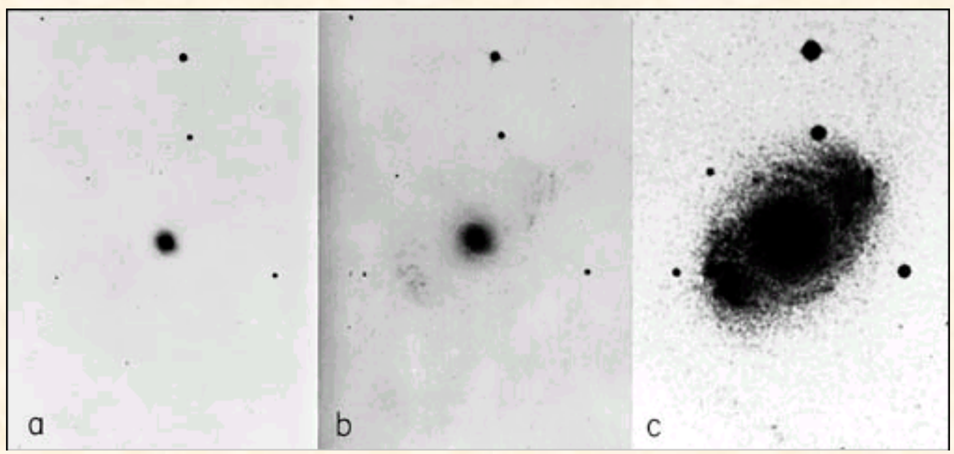


Introduction to AGN



- General Characteristics
- History
- Components of AGN
- The AGN Zoo



AGN – What are they?

Active galactic nucleus – compact object in the gravitational center of a galaxy that shows evidence for a strong nonstellar continuum

AGN are characterized by:

- High luminosity
- Continuum radiation over a broad λ range – radio to γ-rays
- Rapid variability (time scales of days or even hours)

AGN tend to have:

- Unusually blue colors / strong UV excess
- Emission lines with significant widths ($\geq$ 300 km/sec)

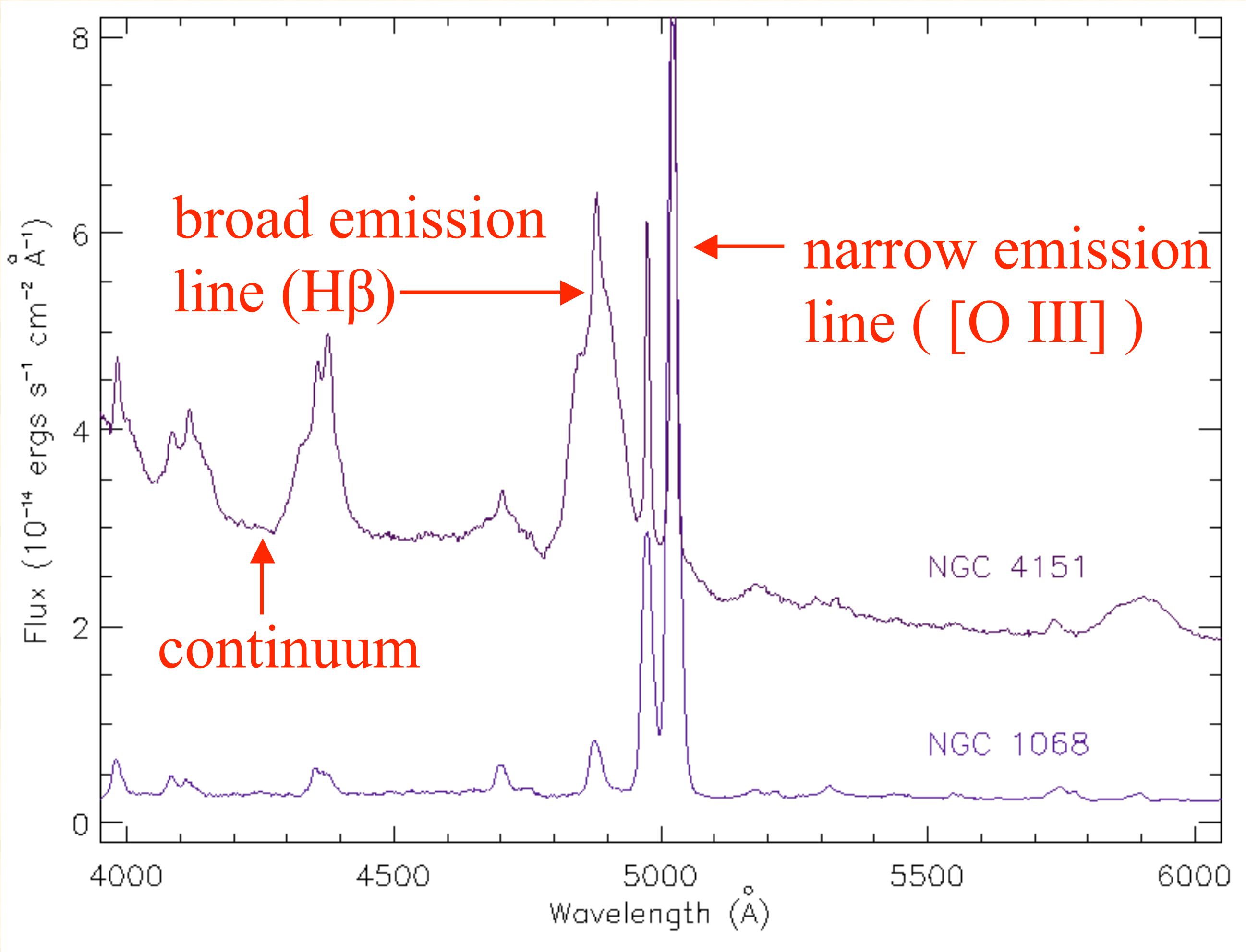
Basic problem:

- What physical mechanism generates so much luminosity ($L_{bol} > 10^{43}$ ergs s^{-1}) in such a small volume (radius < 10 light days?)

A Brief History of AGN

- E.A. Fath (1908): discovered strong emission lines in the spiral "nebula" (now galaxy) NGC 1068
- C.K. Seyfert (1943, ApJ, 97, 28) obtained high dispersion spectra of 6 spiral galaxies with high excitation nuclear emission lines
  - NGC 1068, 1275, 3516, 4051, 4151, 7469
  - broad emission lines (5000 km/s) attributed to Doppler motions
- Various radio surveys (1950s; 3C, PKS, etc.) discovered sources identified optically as quasi-stellar radio sources (quasars)
- M. Schmidt (1963) realized that broad lines in the quasar 3C 273 were redshifted nebular lines ($z = 0.158$)
- Eventually, it was realized that quasars (and optically discovered QSOs) are distant, high-luminosity analogs of Seyfert galaxies
- Khachikian and Weedman (1974) defined two types of Seyferts:
  - Seyfert 2s: narrow permitted and forbidden emission lines
  - Seyfert 1: same lines as Seyfert 2s plus broad permitted emission lines

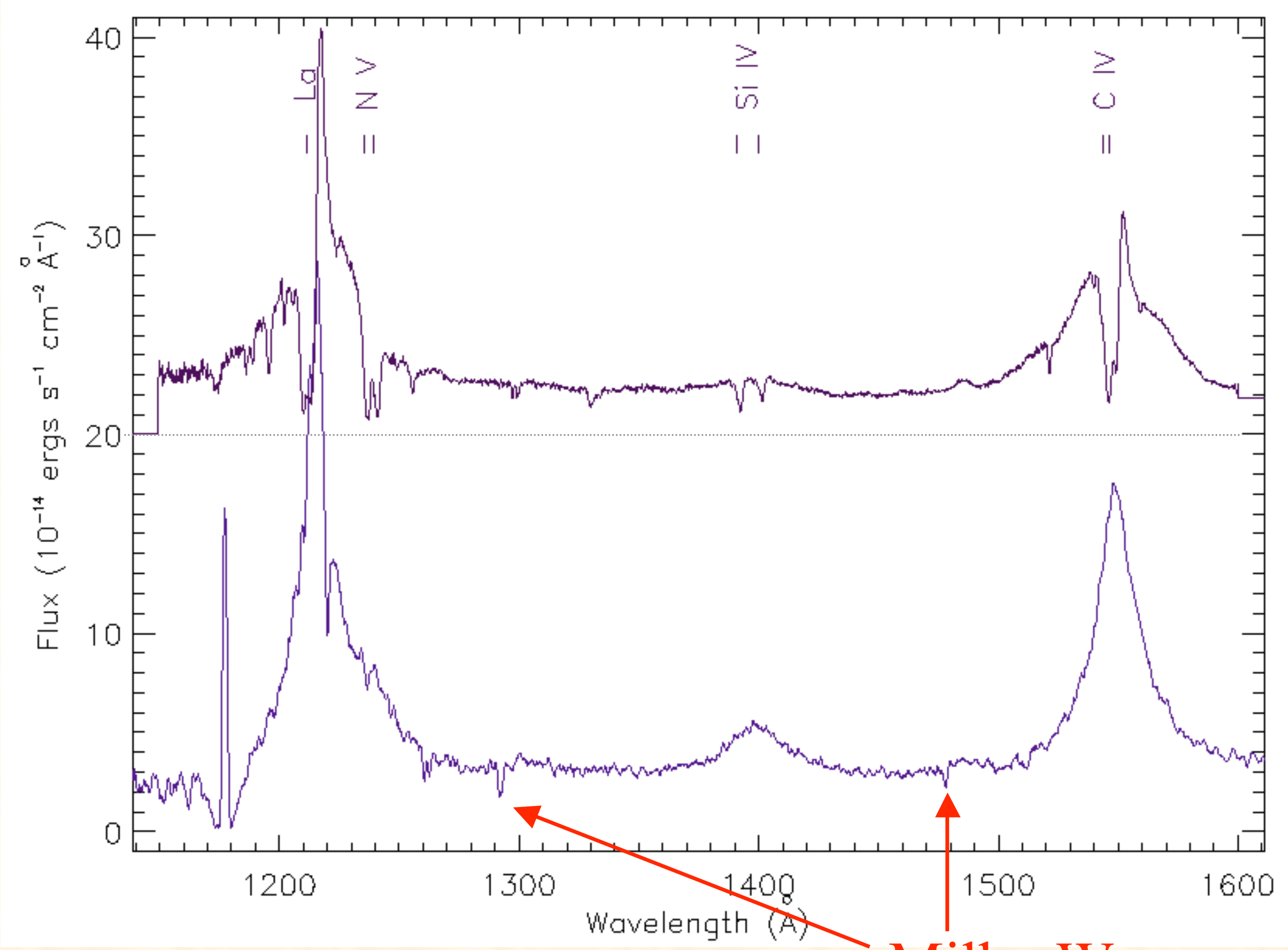
Optical Spectra of Seyfert Galaxies
(HST/FOS spectra)



Seyfert 1

Seyfert 2

Mass Outflow in Seyfert 1 Galaxies (HST UV Spectra)



NGC 4151
Intrinsic absorption

Akn 120
No intrinsic absorption

Milky Way absorption

Observed Spectral Components of AGN
(and probable physical components)

Spatially Unresolved:

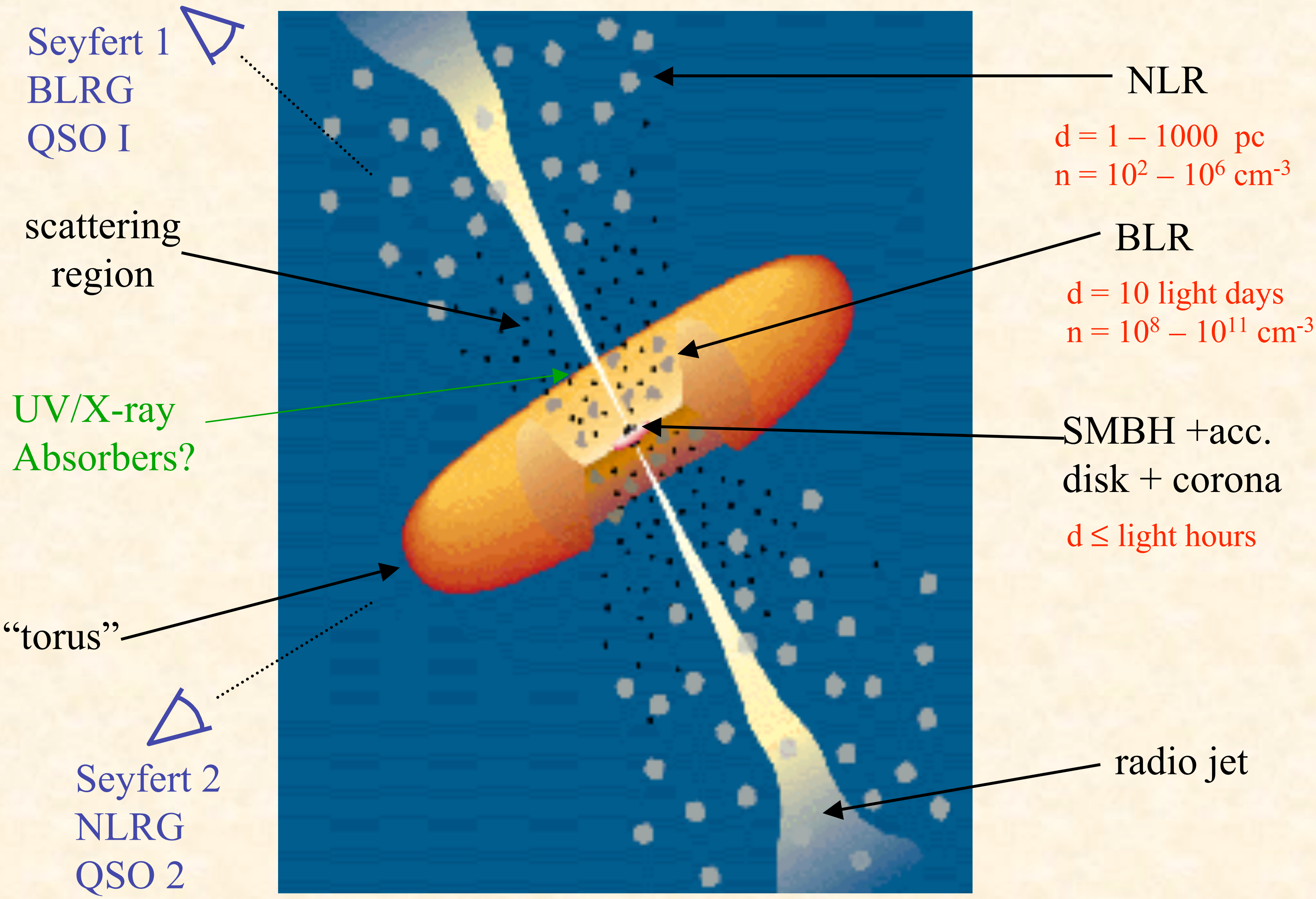
- Optical/UV/soft X-ray continuum → accretion disk
- Hard X-ray continuum (E > 1 keV) → hot X-ray corona
- IR thermal emission → dusty torus (or wind?)
- Broad emission lines → broad-line region (BLR)
- Intrinsic UV/X-ray absorption lines → mass outflow

Spatially Resolved:

- Narrow emission lines → narrow-line region (NLR)
- Ionized gas in the host galaxy → extended narrow-line region (ENLR)
- Radio synchrotron radiation → radio jets/lobes

Drum roll, please →

“Unified Model” of AGN



The AGN Zoo

- Classified according to the appearance of their optical spectra, luminosity, radio power:
- Seyfert galaxies (including subtypes)
- Broad-line radio galaxies (BLRG)
- Narrow-line radio galaxies (NLRG)
- Quasi-stellar radio sources (quasars)
- Quasi-stellar objects (QSOs or radio-quiet quasars)
- Blazars: BL Lac objects and Optically Violent Variables (OVVs)
- Low-ionization nuclear emission-line regions (LINERs)
- Ultraluminous IR galaxies (ULIRGs) – most are starburst galaxies, but a minority may be AGN
- Where does it stop? – evidence for very mild activity in the vicinity of the Milky Way’s SMBH

Seyfert Galaxies

- Nucleus - absolute blue magnitude: $M_B > -21.5$ (to distinguish from quasars)
- $L_{Bol} = 10^{43} - 10^{45}$ ergs s^{-1}
- "Classic" Seyferts: $z < 0.1$ (SDSS discovered higher z Seys.)
- Broad permitted lines (FWHM = 800 - 8000 km s^{-1}) from BLR
- Narrow permitted and forbidden lines (FWHM = 200 - 500 km s^{-1}) NLR
  - Seyfert 1: both BLR and NLR, strong nonstellar continuum
  - Seyfert 2: only NLR, weak continuum (mostly stellar)
- Spectropolarimetry (Antonucci 1985) shows hidden BLR in some Seyfert 2s:
  - Balmer lines scattered into the line of sight by electrons and/or dust $\rightarrow$ Unified model

- Additional Osterbrock types:
  - Seyfert 1.5: narrow permitted components are easily seen
  - Seyfert 1.8: weak broad Hα and Hβ
  - Seyfert 1.9: only weak broad Hα detectable
  - Narrow-line Seyfert 1 galaxies (NLS1s) (not Seyfert 2s!)

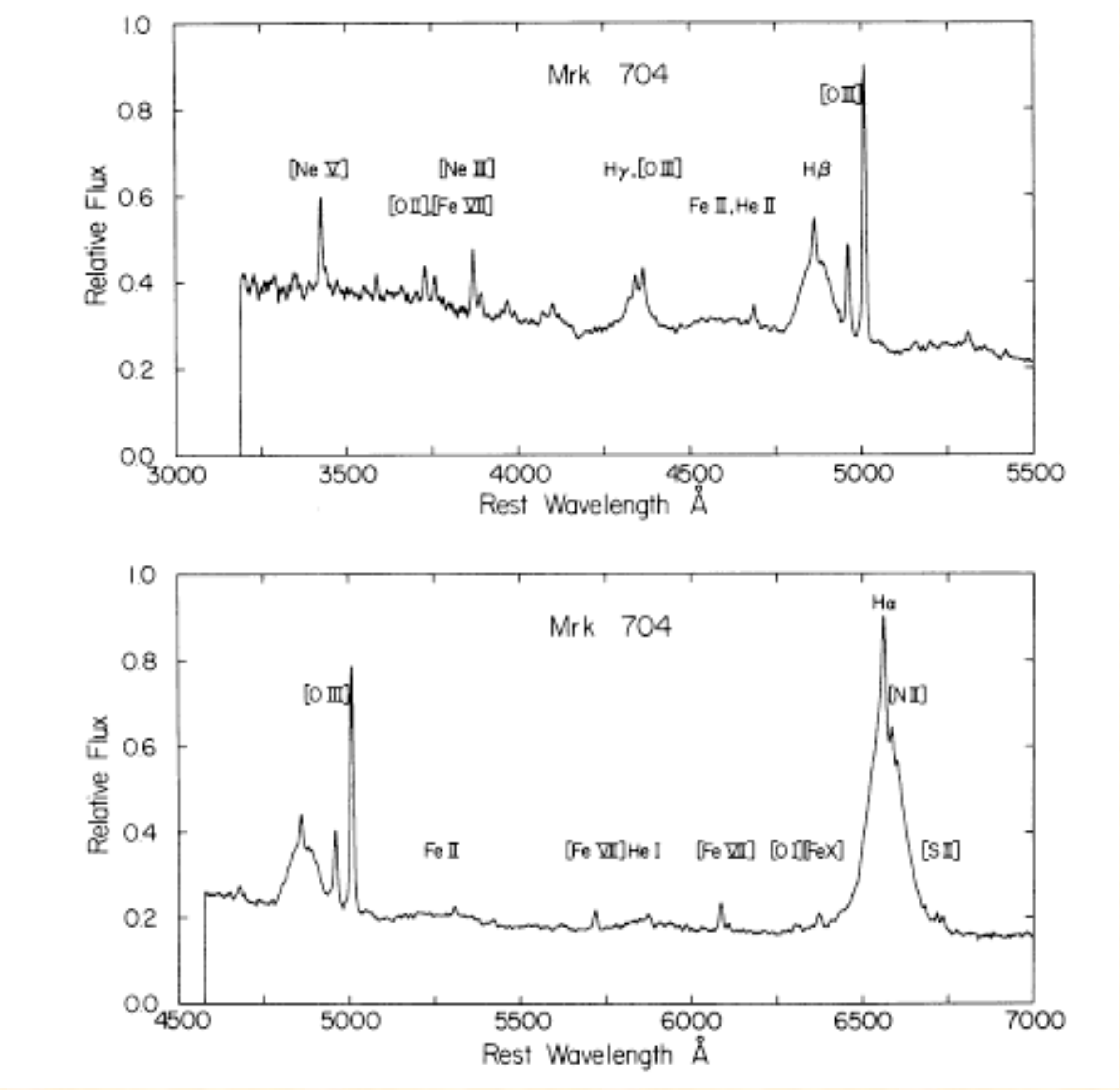
    FWHM (BLR) = 800 – 2000 km/sec

    1) strong Fe II (high density region like other BLRs)

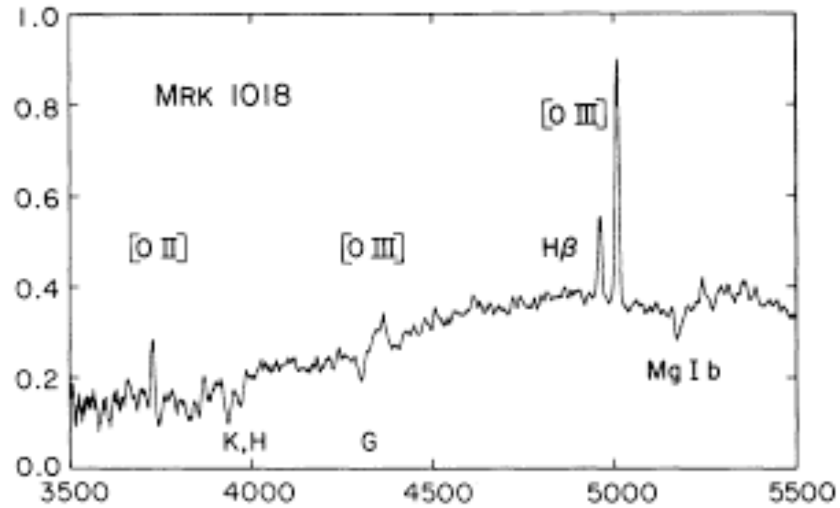
    2) strong excess below 1 –2 keV and rapid X-ray variability
- Seyferts are weak radio sources (radio blobs rather than jets)
- Strong X-ray sources at E > 2 keV

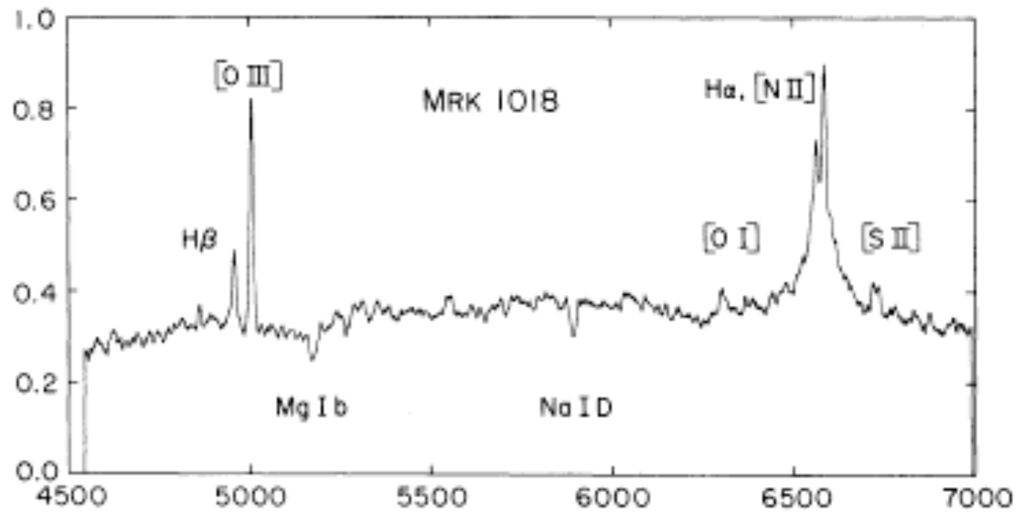
  - Seyfert 2 galaxies are weak in soft X-rays (E < 2 keV), due to absorption by a large column of gas (torus?)
- Seyfert host galaxies are almost always spirals
- Most well-known Seyferts are NGC galaxies or Markarian galaxies (strong UV excess in objective-prism surveys)

Seyfert 1.5 - BLR+NLR

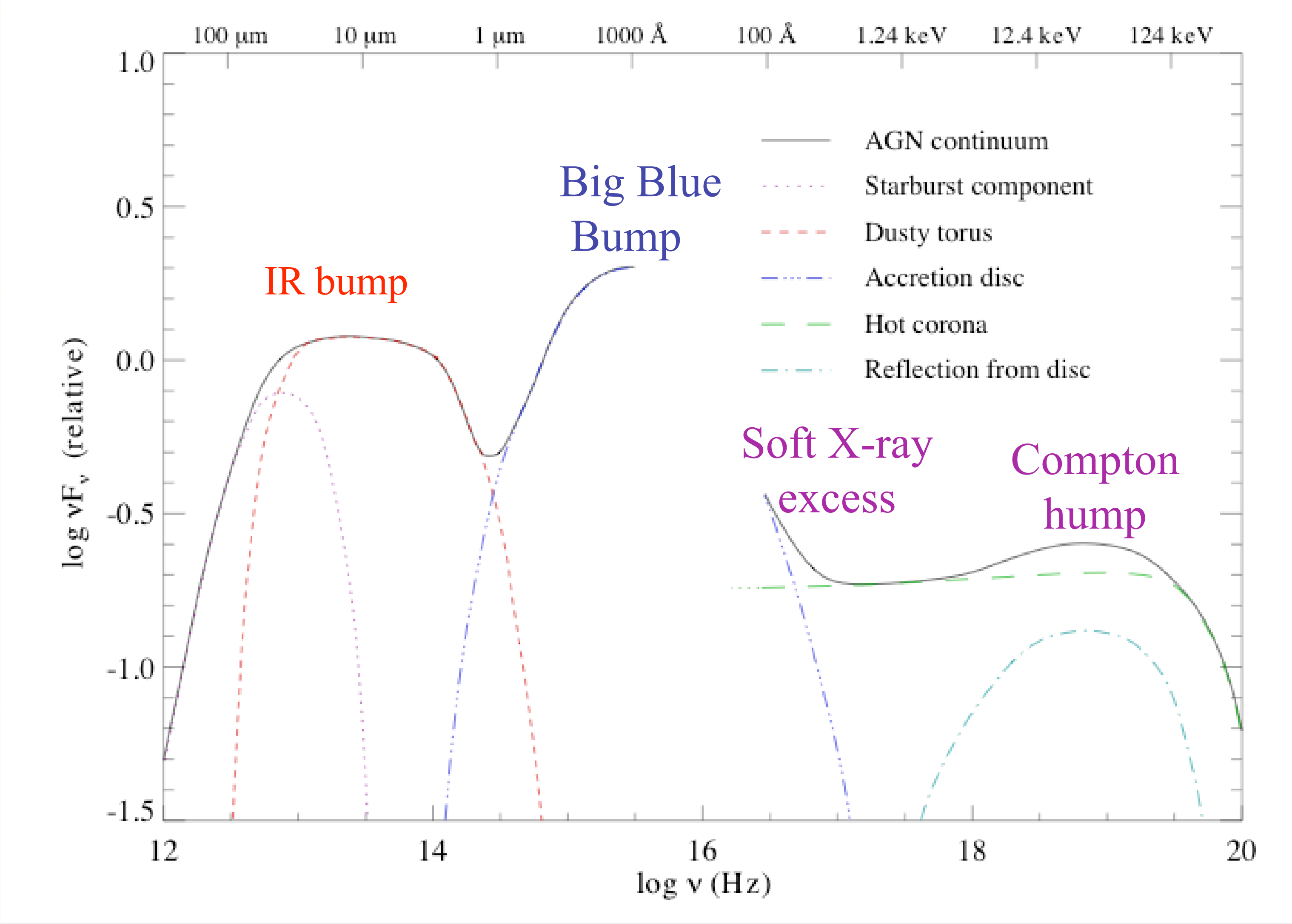


Seyfert 1.9


MRK 1018
[O III]
[O II]
[O III]
Hβ
Mg I b
K,H
G
1.0
0.8
0.6
0.4
0.2
0.0
3500
4000
4500
5000
5500


[O III]
MRK 1018
Hα, [N II]
Hβ
[O I]
[S II]
Mg I b
Na I D
1.0
0.8
0.6
0.4
0.2
0.0
4500
5000
5500
6000
6500
7000

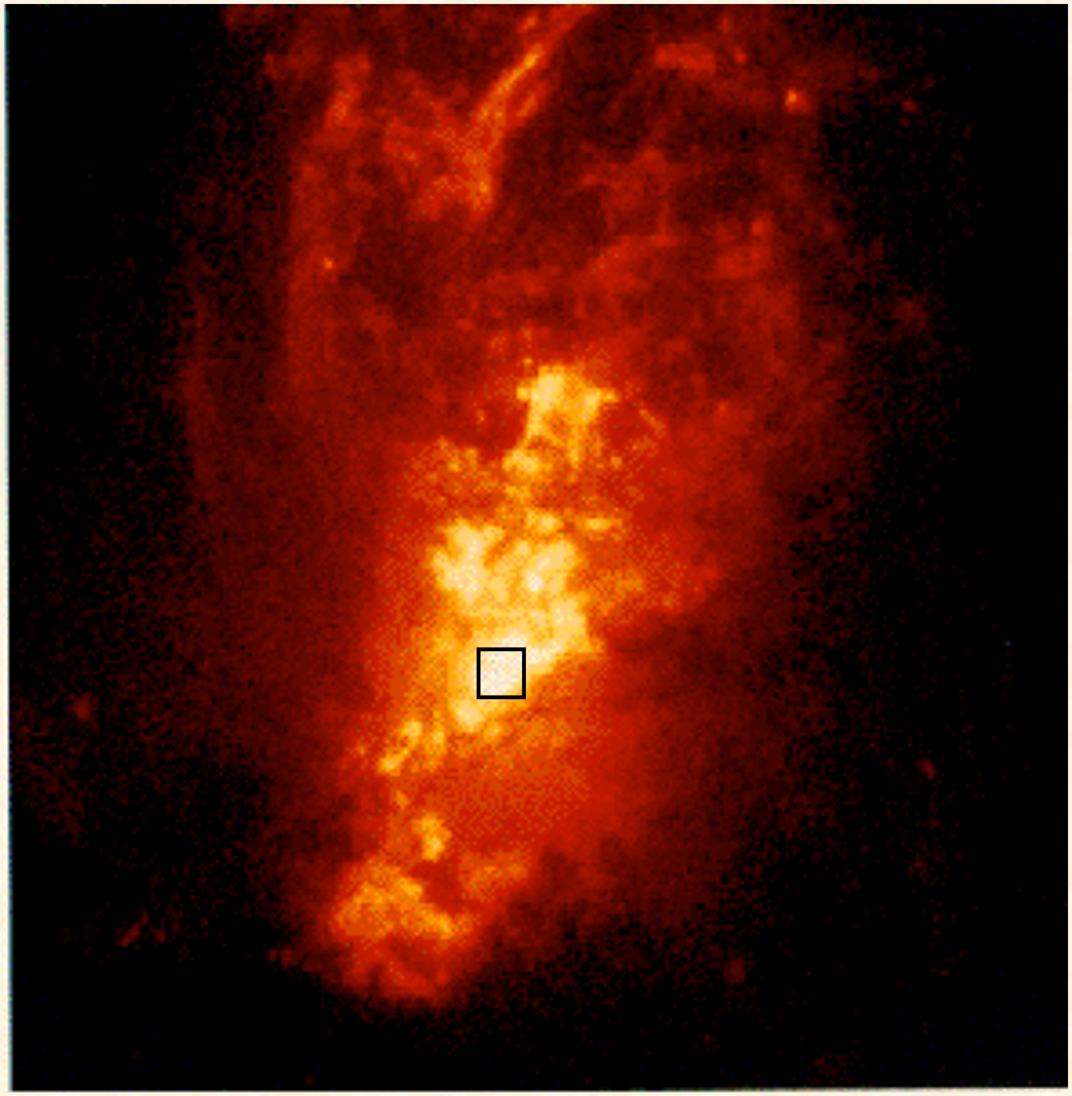
Schematic Continuum SED for Seyferts



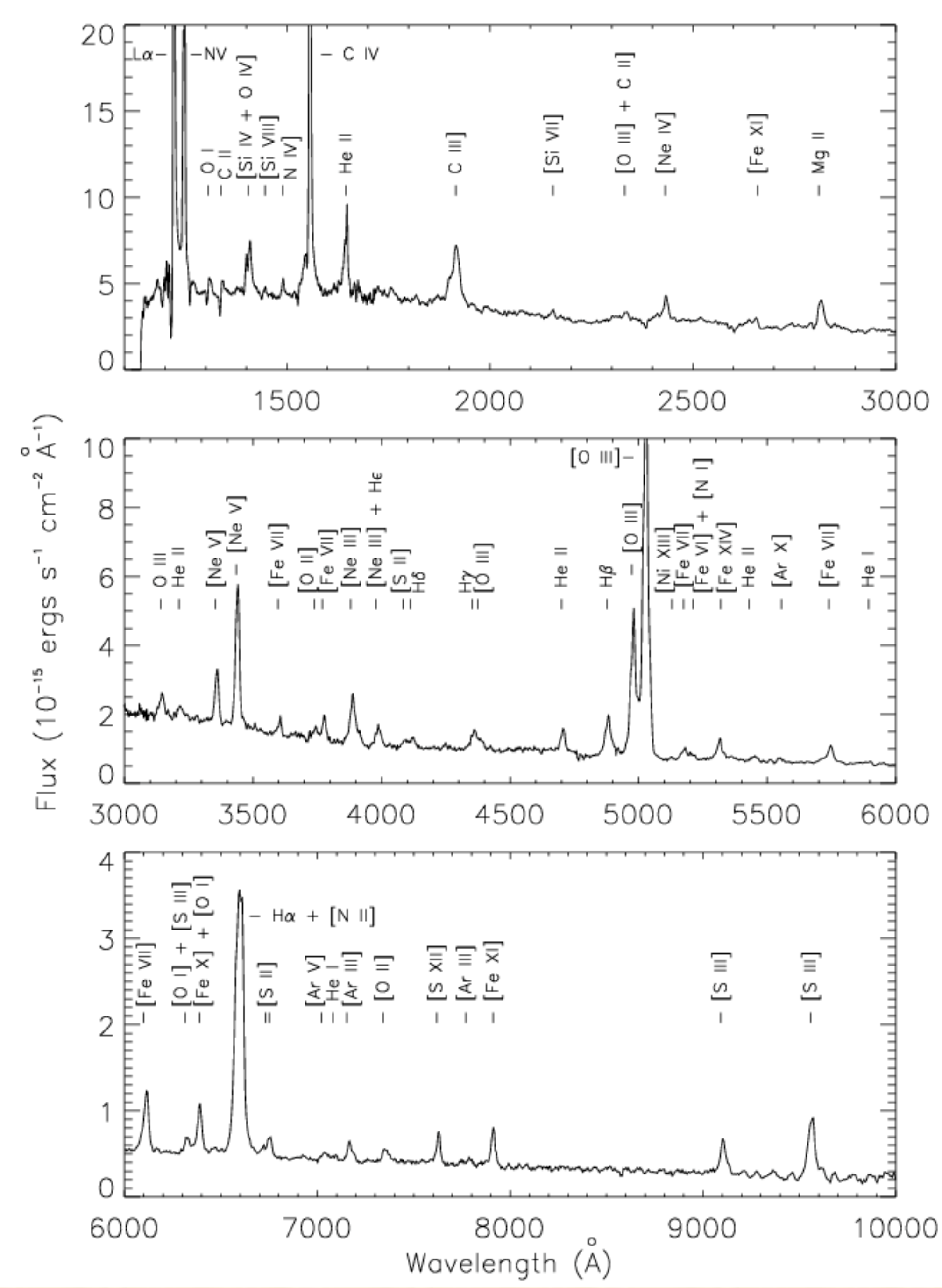
- strong ionizing continuum in EUV/X-rays

Seyfert 2

NLR in NGC 1068 (HST [O III] image)



7.0"
(500 pc)



NGC 1068

- bright knot in NLR
- huge range in ionization (O I to [S XII])
- requires X-ray photoionization

Quasars

- Higher luminosities than Seyferts: $L = 10^{45} - 10^{47}$ ergs s^{-1}
- At redshifts $z = 0.1$ to ~ 6
- Quasars (quasi-stellar radio sources): discovered first by radio surveys, emission-line spectra revealed high redshifts
- QSOs (quasi-stellar objects): discovered optically from their strong blue continua, broad emission lines, X-ray flux, etc.

  - the terms "quasars" and "QSOs" have become interchangeable; often we use "radio –loud" or "radio-quiet" quasars

  - Radio loud: $\nu F_\nu(6\ \text{cm}) / \nu F_\nu(4400\ \text{Å}) \geq 10$

  - Only ~5% of all quasars are radio-loud
- Quasars have spectra like Seyfert 1 galaxies, but

  - stellar absorption features not easily detected

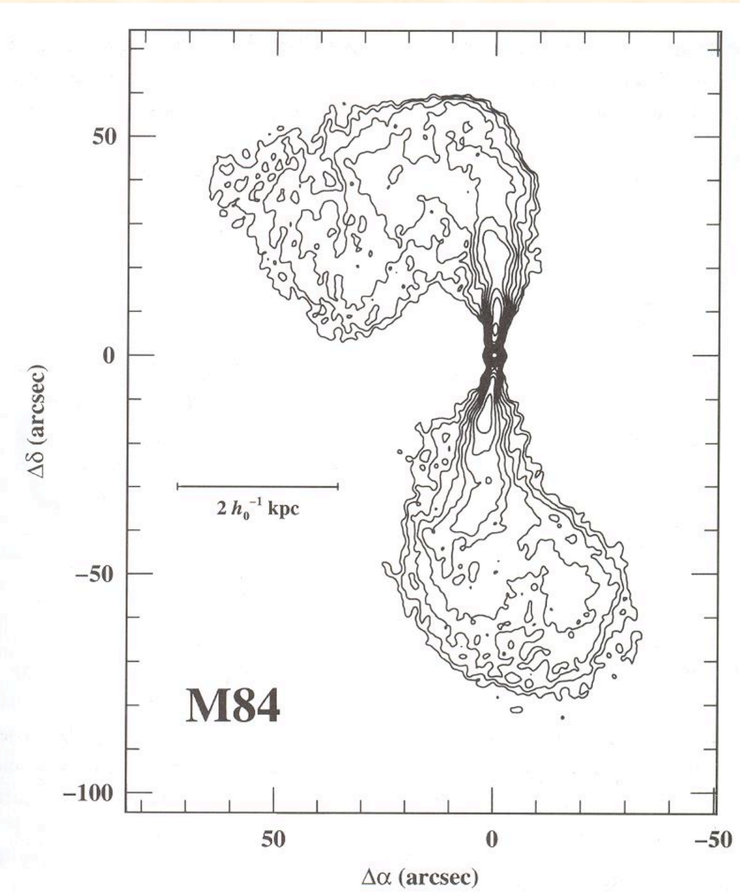
  - narrow-lines tend to be weak
- A number of type 2 quasars (no broad lines) have recently been detected.

Radio Galaxies

- Low-luminosity analogs of RL quasars (Seyferts are low-luminosity analogs of RQ quasars)
- Characterized by compact radio source, lobes, and (often) jets
  1. FR I: lower luminosity; bright in center and weak toward edges
  2. FR II: high luminosity; lobes brighter at edges
  3. Dividing line: $L_\nu = 10^{32}$ ergs s^{-1} Hz^{-1} at 1.4GHz
- Radio galaxies with emission lines are similar to Seyferts, but are typically found in giant ellipticals (E or cD)
- Broad-line radio galaxies (BLRG): similar to Seyferts 1s, but
  1. Balmer profiles are broader and more flat-topped
  2. Fe II emission is weaker
  3. $H\alpha/H\beta$ ratios higher (steeper Balmer decrement)
- Narrow-line radio galaxies (NLRG): optical spectra are essentially identical to Seyfert 2s

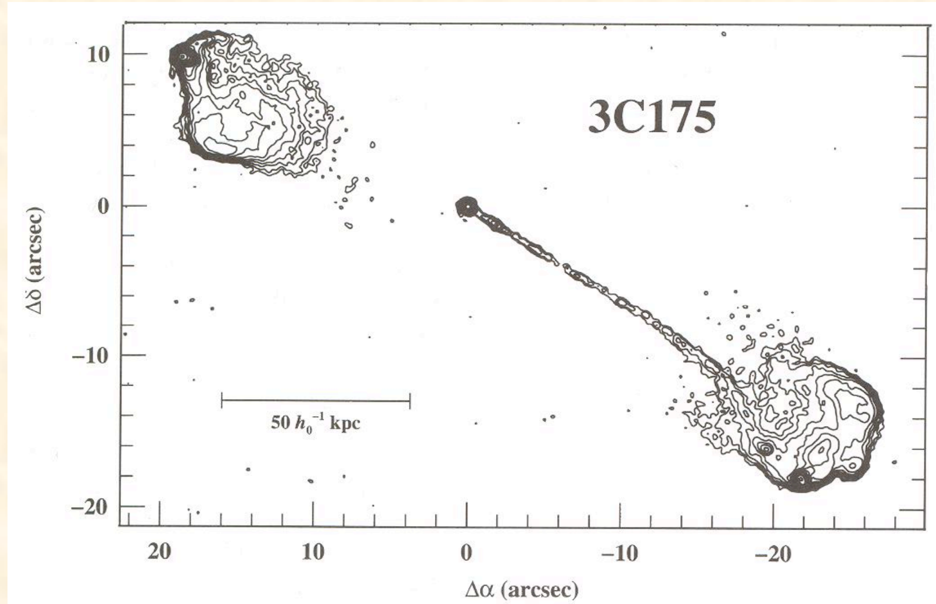
Fanaroff-Riley (FR) Types

FR I

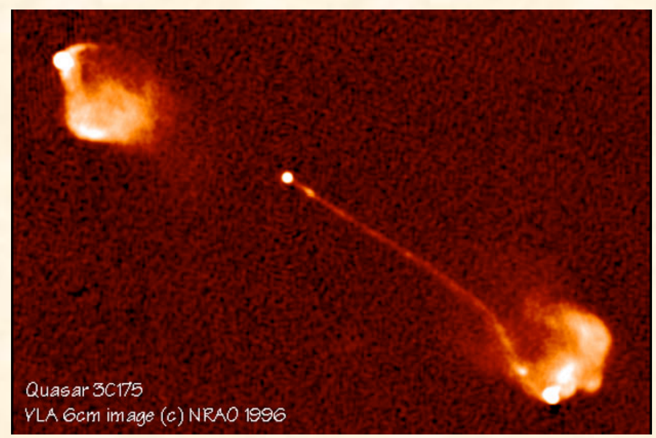


(Peterson, p. 11)

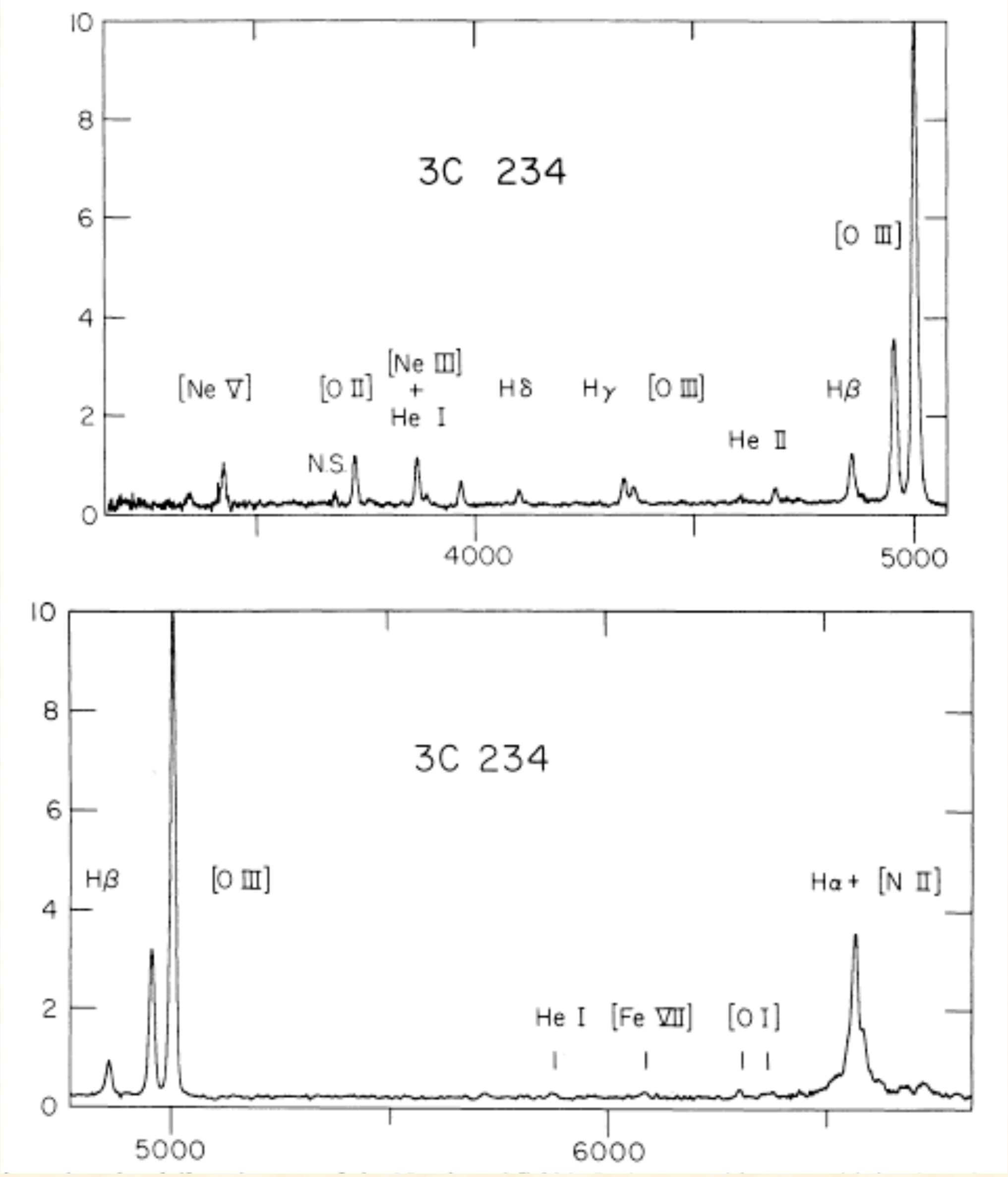
FR II



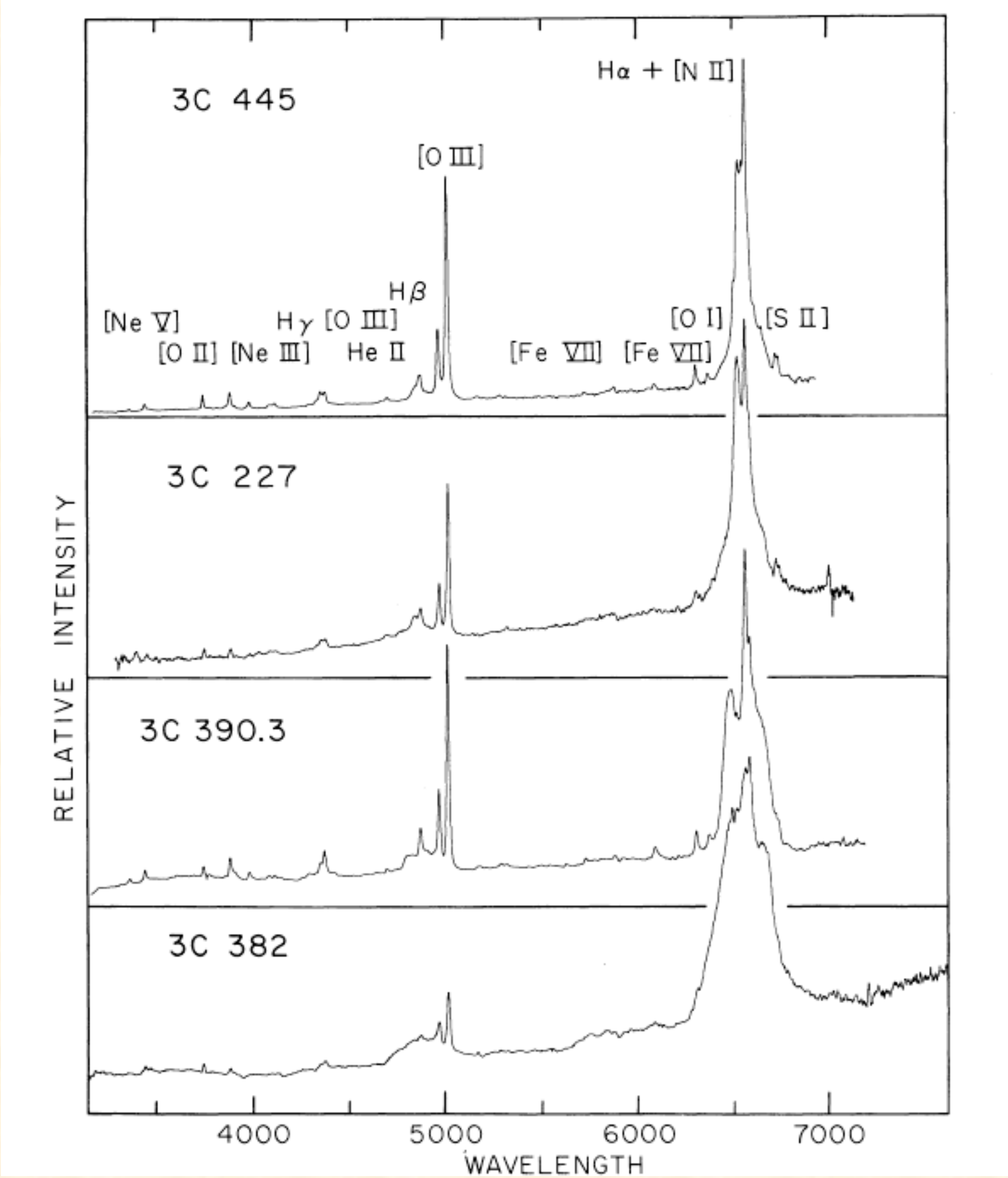
(Peterson, p. 12)



NLRG


3C 234
[Ne V]
[O II]
N.S.
[Ne III]
+
He I
Hδ
Hγ
[O III]
He II
Hβ
[O III]
4000
5000
3C 234
Hβ
[O III]
He I
[Fe VII]
[O I]
Hα + [N II]
5000
6000

BLRG


3C 445
Hα + [N II]
[O III]
Hβ
[Ne V]
Hγ [O III]
[O I]
[S II]
[O II] [Ne III]
He II
[Fe VII] [Fe VII]
3C 227
3C 390.3
3C 382
RELATIVE INTENSITY
4000
5000
6000
7000
WAVELENGTH

Blazars

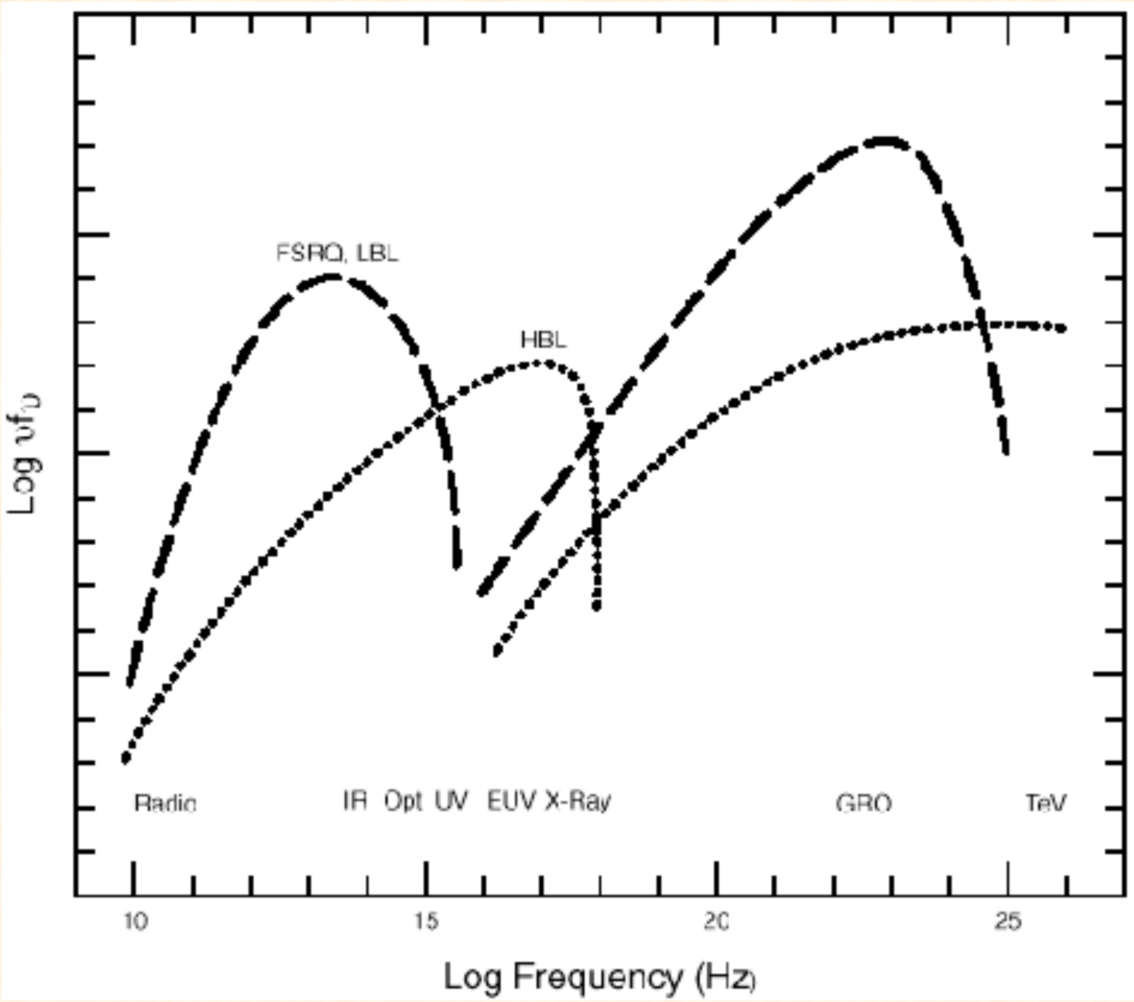
- Defined by 1) strong variability (time scales one day or less) from radio to X-rays and high polarizations (1 – 4 %)
- Moderate to strong radio sources (radio loud)
- Two classes:

  1) BL-Lac objects: no strong emission or absorption lines

  2) Optically-violent variables (OVVs): highly polarized, variable, but have broad emission lines (aka FSRQ or flat-spectrum radio quasars)
- Continuous spectra are less complicated than those of quasars – likely synchrotron radiation plus Compton "upscattering"
- Interpretation: relativistically beamed jets close to our line of sight (overwhelms other emission components)
- Two types of BL Lacs:
  - X-ray BL Lacs (XBLs): synchrotron peak in X-rays
  - Radio BL Lacs (RBLs): synchrotron peak in radio

Blazar SEDs (Urry 1998)

Synchrotron | Compton



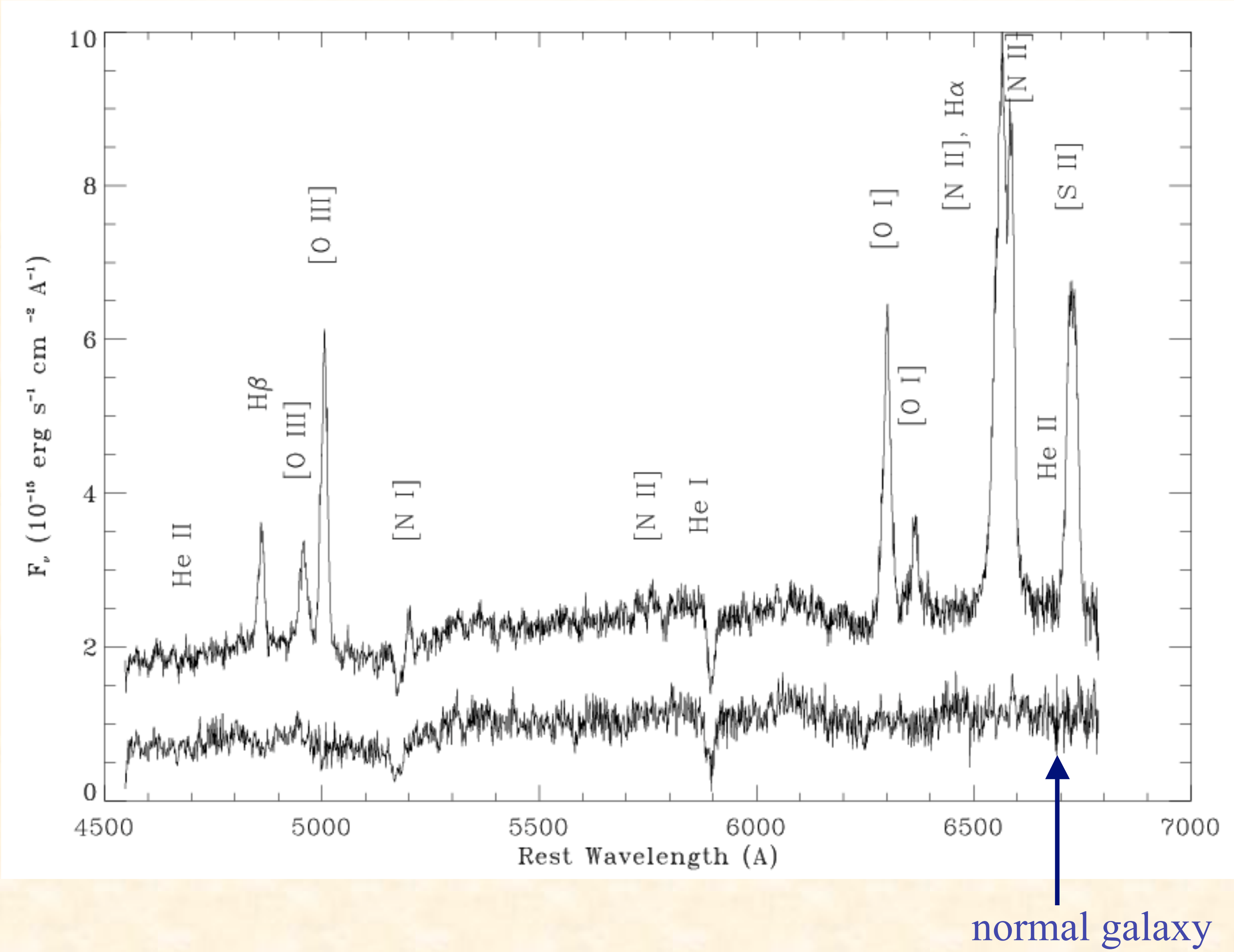
LBL: low-frequency blazars (or RBL)
HBL: high-frequency blasars (or XBL)

LINERS

- Low-ionization nuclear emission-line regions (LINERs) (Heckman 1980)
- Strong low-ionization lines like Seyferts: [O I], [S II], [N II]
- However, high-ionization lines are weak (e.g., [O III]/Hβ < 3)
- Lower luminosities than Seyferts: $10^{39} – 10^{42}$ ergs s^{-1}
- Difficult to detect against background of host galaxy
- Recent evidence shows that most LINERs are AGN

  (previous explanations include very hot stars and shock heating)
- About 1/3 of all luminous galaxies contain LINERs!
- Broad Balmer emission detected in ~20% (type 1 LINERs)
- LINERs are radio-loud (for their optical luminosities)
- There are some transition objects, which may be H II galaxies or a combination of H II/ AGN

LINER (NGC 1052)



AGN – Approximate Space Densities (Local)

Type of Object	# per Mpc^3
Field galaxies	10^{-1}
Luminous spirals	10^{-2}
LINERs	3×10^{-3}
Seyfert galaxies	10^{-4} (~1% of spirals)
Radio galaxies	10^{-6}
Radio-quiet quasars (QSOs)	10^{-7}
Radio-loud quasars	10^{-9}

(Osterbrock & Ferland, p. 327 - modified)

Mike's Highly Biased View (MHBV)

AGN Optical Luminosity →

Radio Power ↓

dwarf Sey 2?	NLS2?	NLQ2?	
LINER 2	Seyfert 2	QSO 2	Edge-on
WLRG2?	NLRG (FR II)	Quasar 2	

Radio Power ↓

dwarf Sey 1	NLS1	NLQ1?	
LINER 1	Seyfert 1	QSO 1	Face-on
WLRG (FR I)	BLRG (FR II)	Quasar 1	

↓ ↓ ↓

BL Lacs	OVV (FSRQ)	OVV (FSRQ)	Pole-on

Parameters :

1) Luminosity ($\dot{M}$)

2) Radio Power ($\dot{M}$/M?)

3) Orientation