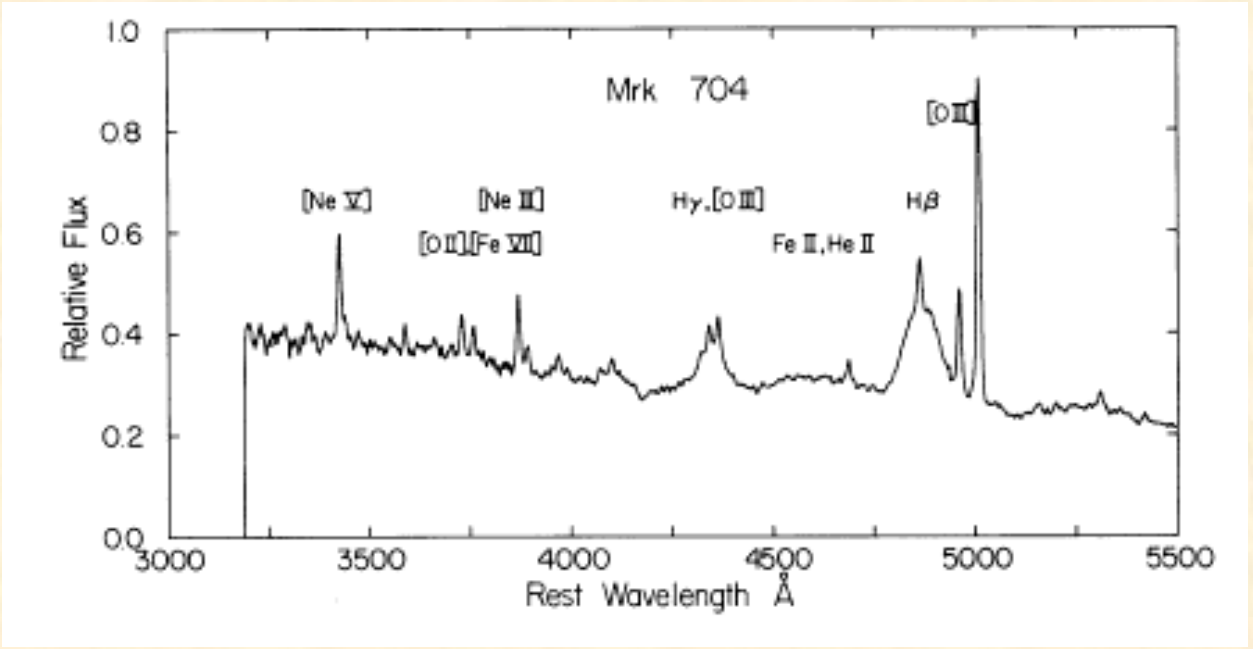
AGN Family

- Classification
- AGN Types
- Interpretation



AGN Classification

AGN have been classified in the past on the basis of:

- Appearance of their optical spectra (Sey 1 vs. Sey 2)
- Luminosity (Seyfert → Quasar)
- Radio Power (Radio Loud vs. Radio Quiet)
- Morphology (FR I vs. FR II; host galaxy type)
- A number of other properties

Ultimately, we want a more physical description, e.g.:

- Black hole mass (M)
- Luminosity (L)
- Eddington Ratio ($L/L_{Edd} \sim L/M$)
- Etc: black hole spin, environment, evolutionary state, …

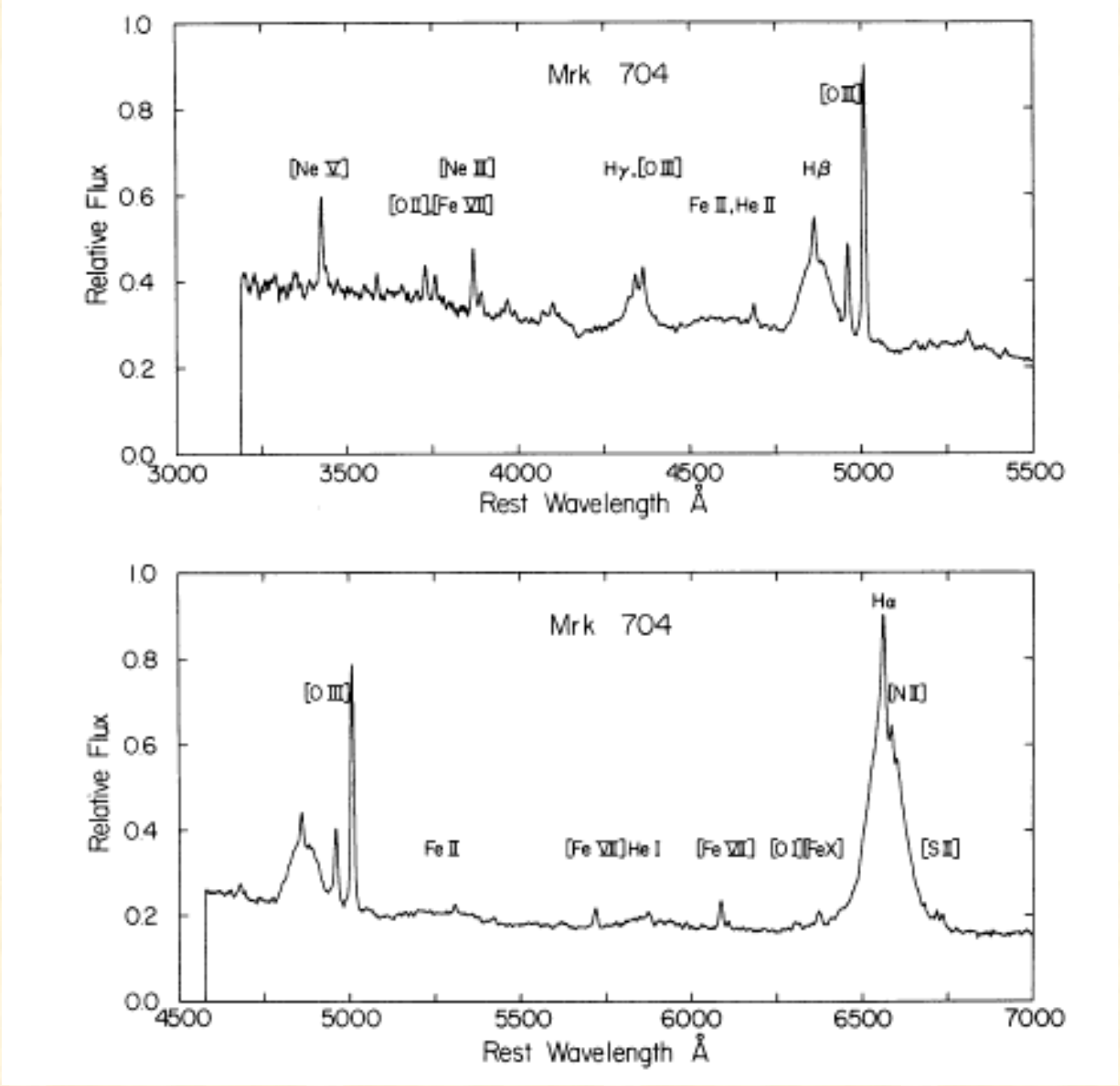
Seyfert Galaxies

- 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 has many 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}) from 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 →Unified model

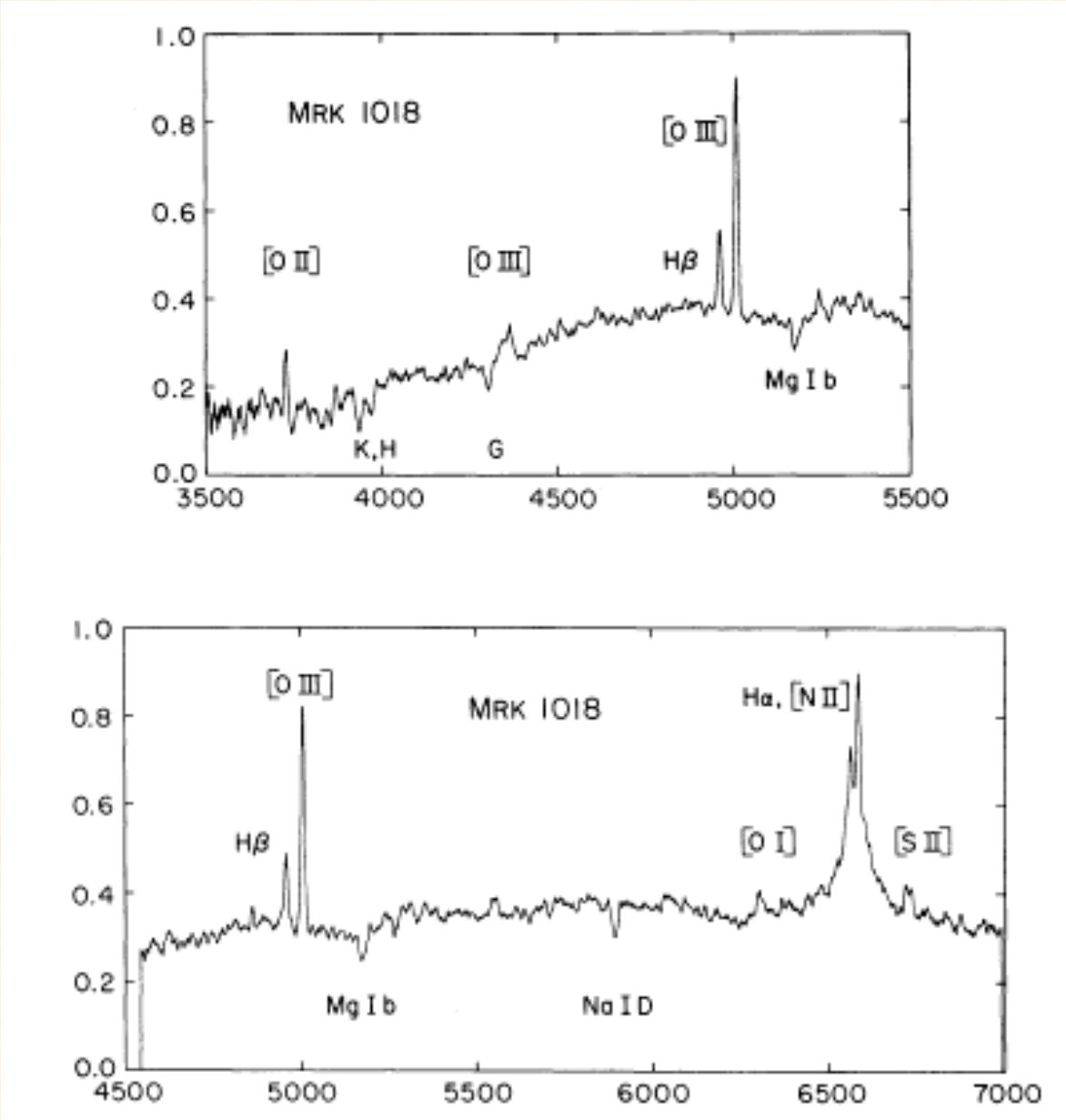
- Additional Osterbrock types:
  - Seyfert 1.5: narrow permitted components are easily seen
  - Seyfert 1.8: weak broad Hα and Hβ
  - Seyfert 1.9: only weak broad Hα detectable
  - Narrow-line Seyfert 1 galaxies (NLS1s) (not Seyfert 2s!)
    - FWHM (BLR) = 800 – 2000 km/sec
    - Strong Fe II (high density region like other BLRs)
    - strong excess below 1 –2 keV and rapid X-ray variability
- Seyferts are weak radio sources (radio blobs rather than jets)
- Usually strong X-ray sources at E > 2 keV

  - Seyfert 2 galaxies are often weak in soft X-rays (E < 2 keV), due to absorption by a large column of gas (e.g., the torus)
- Seyfert host galaxies are almost always spirals.
- "Changing-look AGN": a small fraction (~0.4%) of Seyferts change type (1 ⇔ 1.5 ⇔ 1.8 ⇔ 2) over years to decades.
  - mostly changes in ionizing flux (e.g., variable accretion), but some could come from changing obscuration (e.g. torus clouds) (Ricci+ 2023)

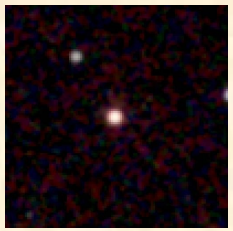
Seyfert 1.5 - BLR+NLR



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
MRK 1018
[O III]
Hα, [N II]
Hβ
[O I]
[S II]
Mg I b
Na I D
4500
5000
5500
6000
6500
7000

Quasars

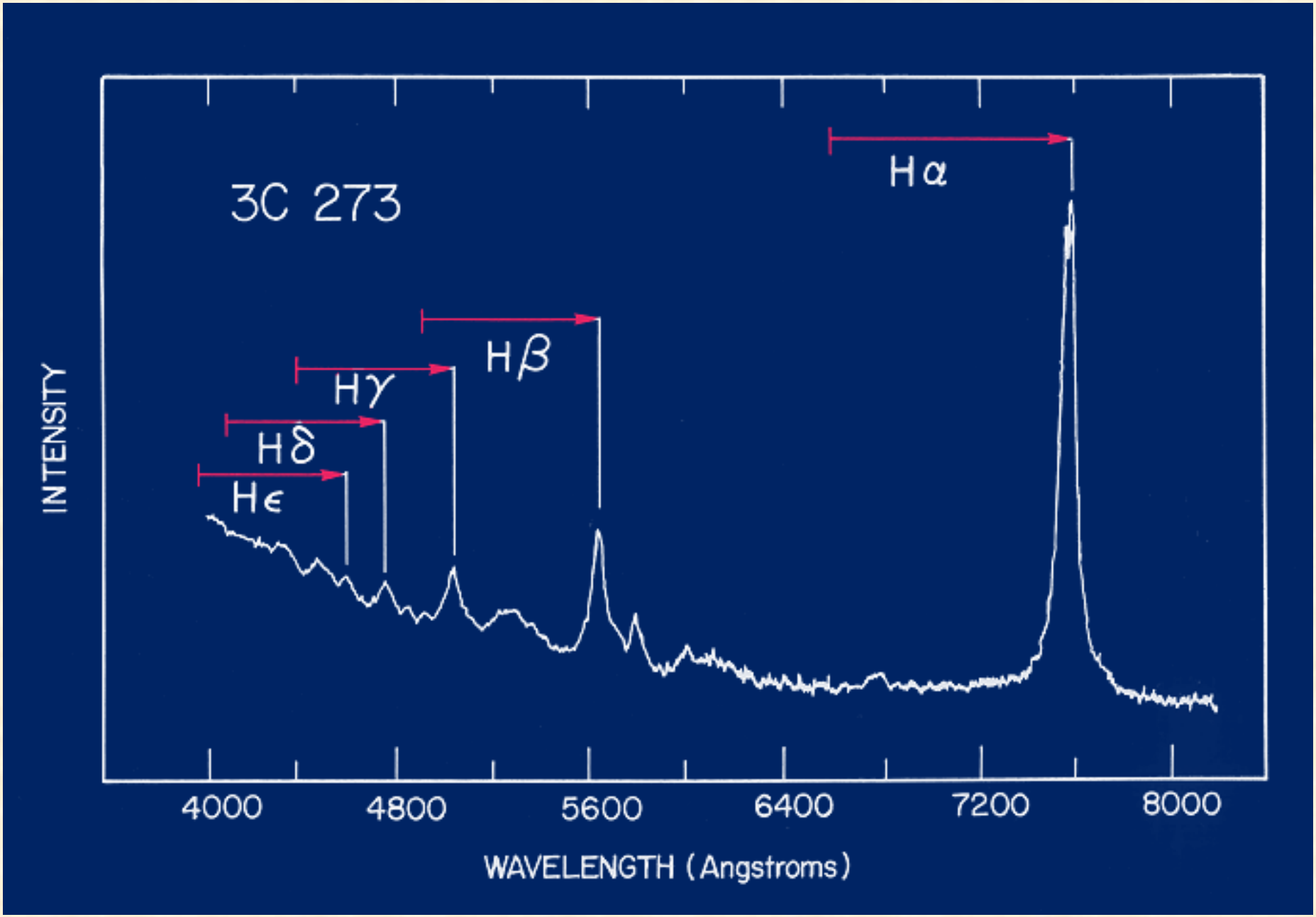


- At redshifts z = 0.1 to ~ 7.6
- Higher luminosities than Seyferts: L = 10^{45} – 10^{47} ergs s^{-1}
- Quasars (quasi-stellar radio sources): discovered first by radio surveys, emission-line spectra revealed high redshifts
- QSOs (quasi-stellar objects): discovered optically from their strong blue continua, broad emission lines, X-ray flux, etc.
  - The terms "quasars" and "QSOs" have become interchangeable; now we use radio–loud quasars (RLQ) and radio-quiet quasars (RQQ)
  - Radio loud: R = νF_ν(6 cm)/ νF_ν(4400 Å) ≥10
  - Only 5 - 10% of all quasars are RLQ
- Quasars have spectra like Seyfert 1 galaxies, but

  - stellar absorption features not easily detected

  - narrow-lines tend to be weak
- Type 2 quasars (no broad lines) have also been detected

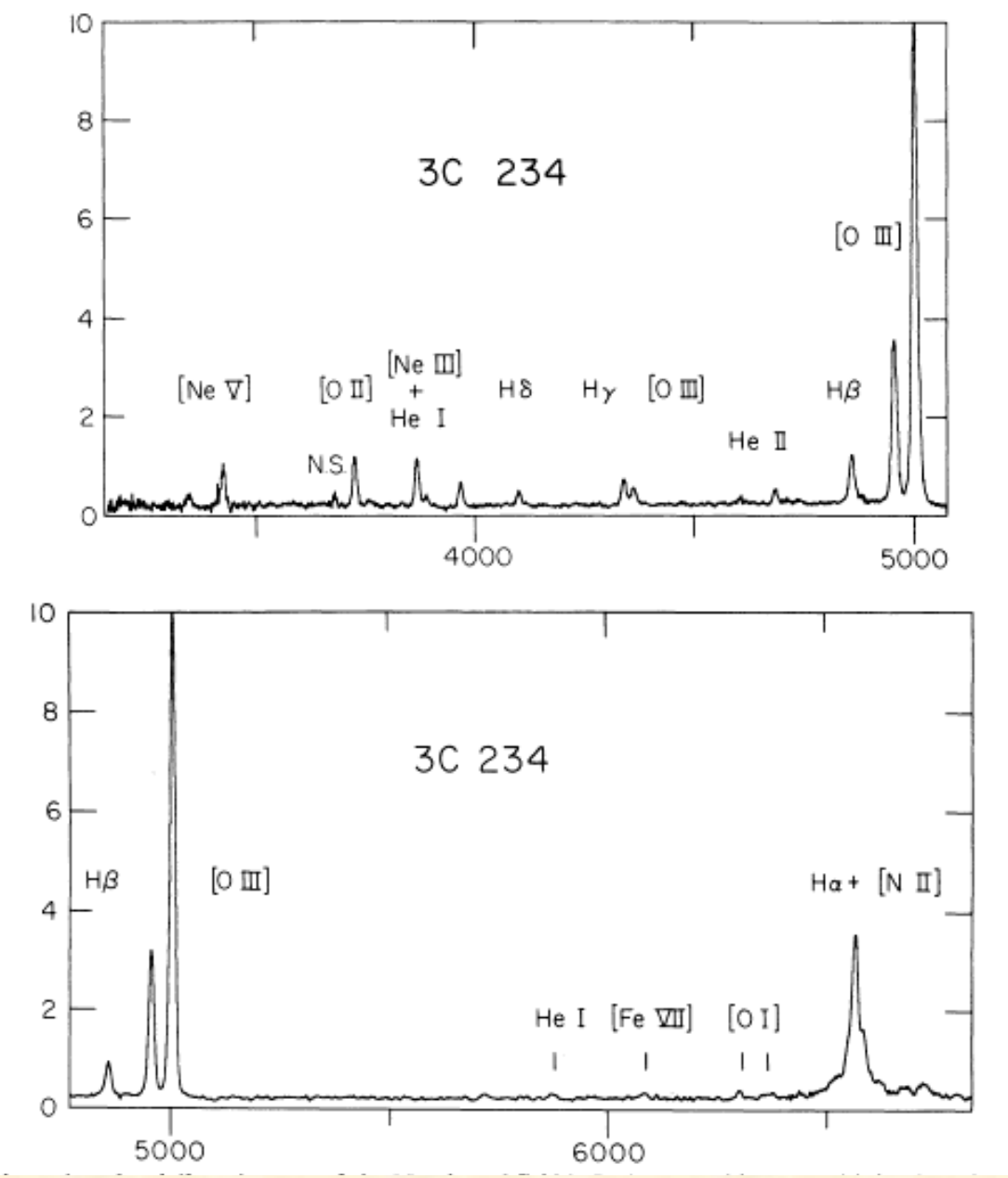
Quasar Spectrum



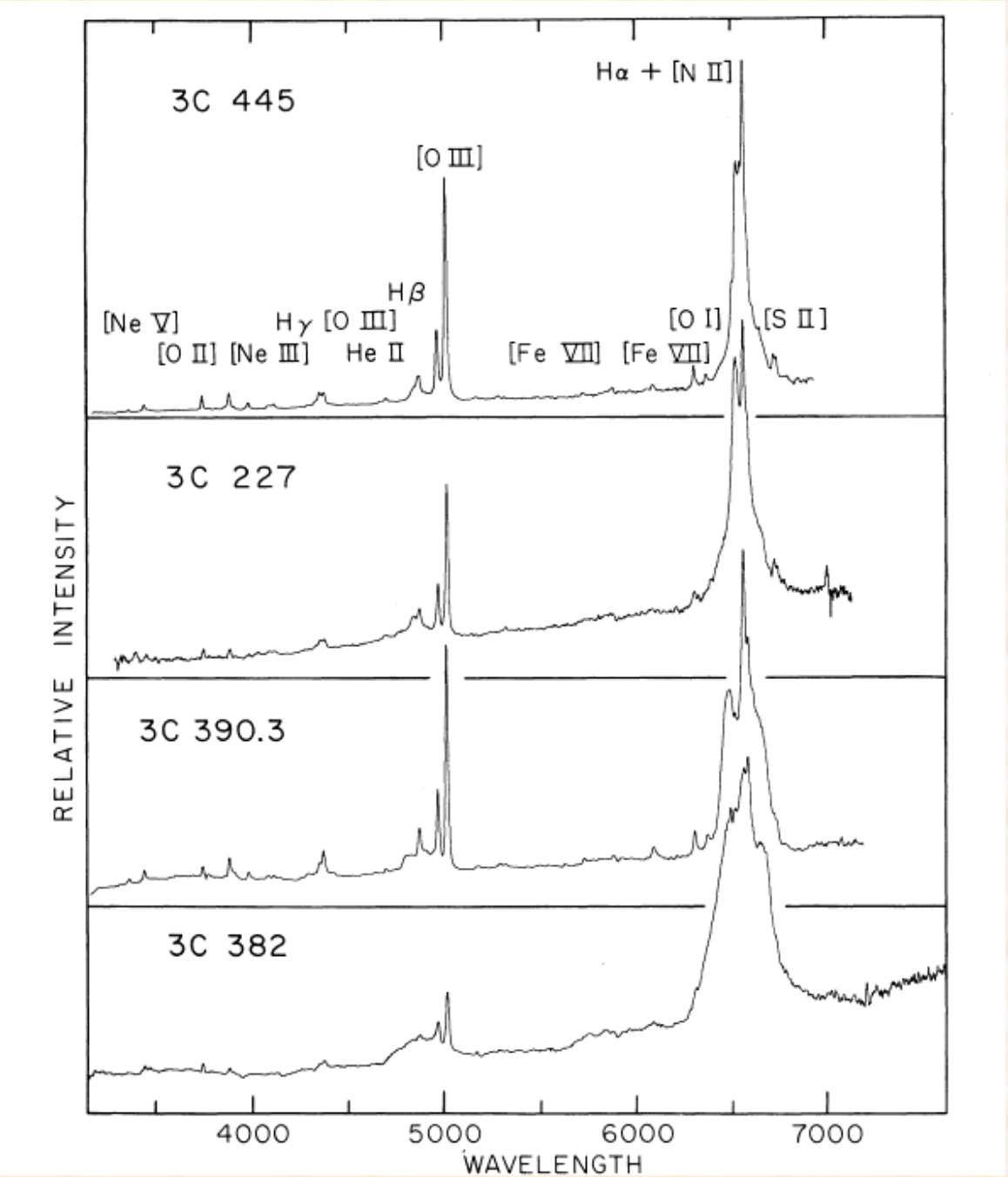
Radio Galaxies

- Low-luminosity analogs of RL quasars
  (Seyferts are low-luminosity analogs of RQ quasars)
- Characterized by compact radio core, lobes, and (often) jets
  1. FR I: lower luminosity; bright in center and weak toward edges
  2. FR II: high luminosity; brighter at edges
  3. Dividing line: $L_\nu = 10^{32}$ ergs s^{-1} Hz^{-1}
- 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. Hα/Hβ ratios higher (steeper Balmer decrement)
- Narrow-line radio galaxies (NLRG): optical spectra are essentially identical to Seyfert 2s

NLRG


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

BLRG


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

Blazars

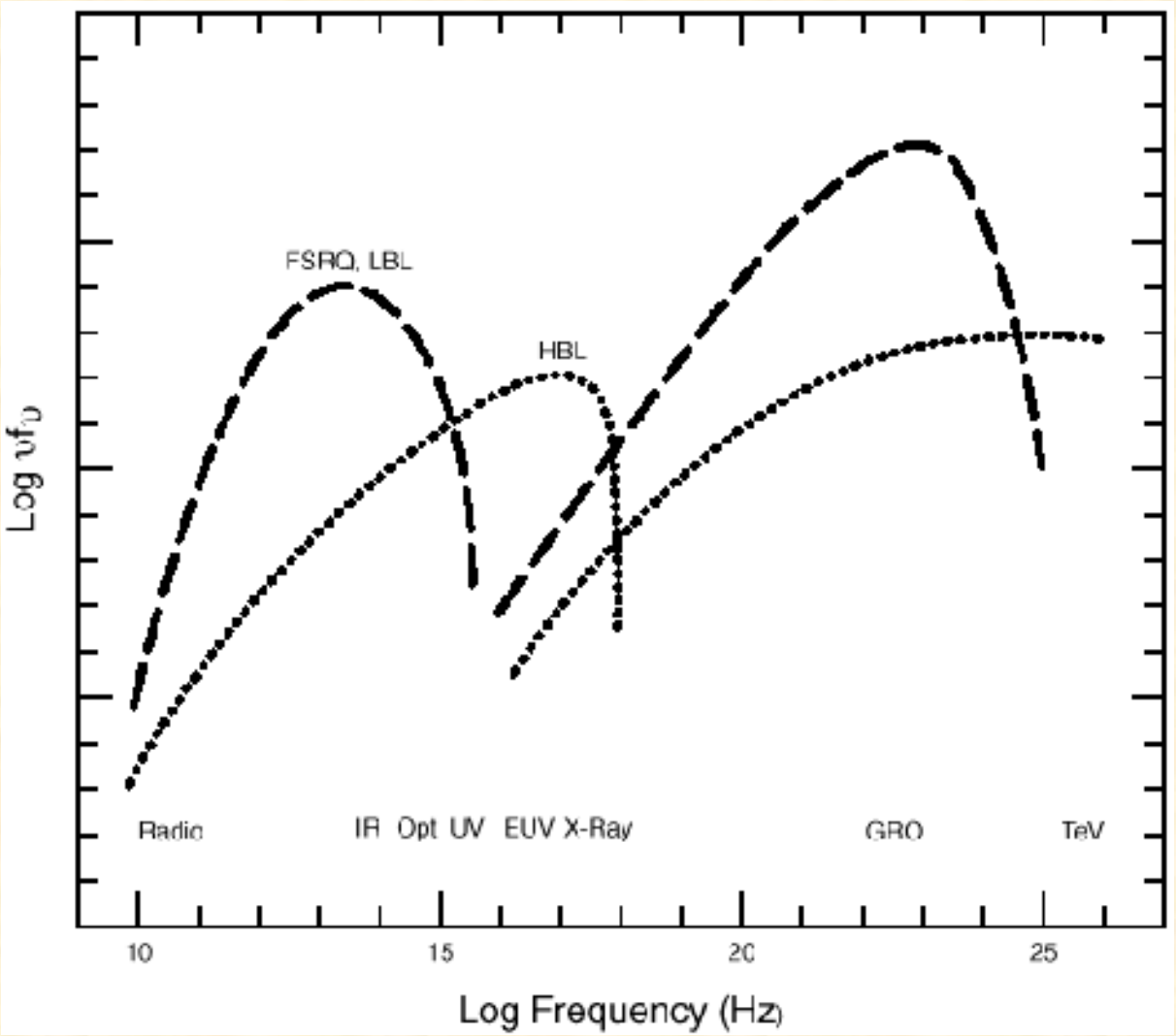
- Defined by 1) strong variability (time scales one day or less) from radio to X-rays and high polarizations (1 – 4 %)
- Moderate to strong radio sources (radio loud)
- Two classes:

  1) BL-Lac objects: no strong emission or absorption lines
  - likely beamed FR Is

  2) Optically-violent variables (OVVs): highly polarized, variable, but have broad emission lines like quasars
  - likely beamed FR IIs
- 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:
  - High-frequency BL Lacs (HBLs): synchrotron peak in X-rays (or XBLs)
  - Low-frequency BL Lacs (LBLs): synchrotron peak in radio (or RBLs)

Blazar SEDs (Urry 1998)

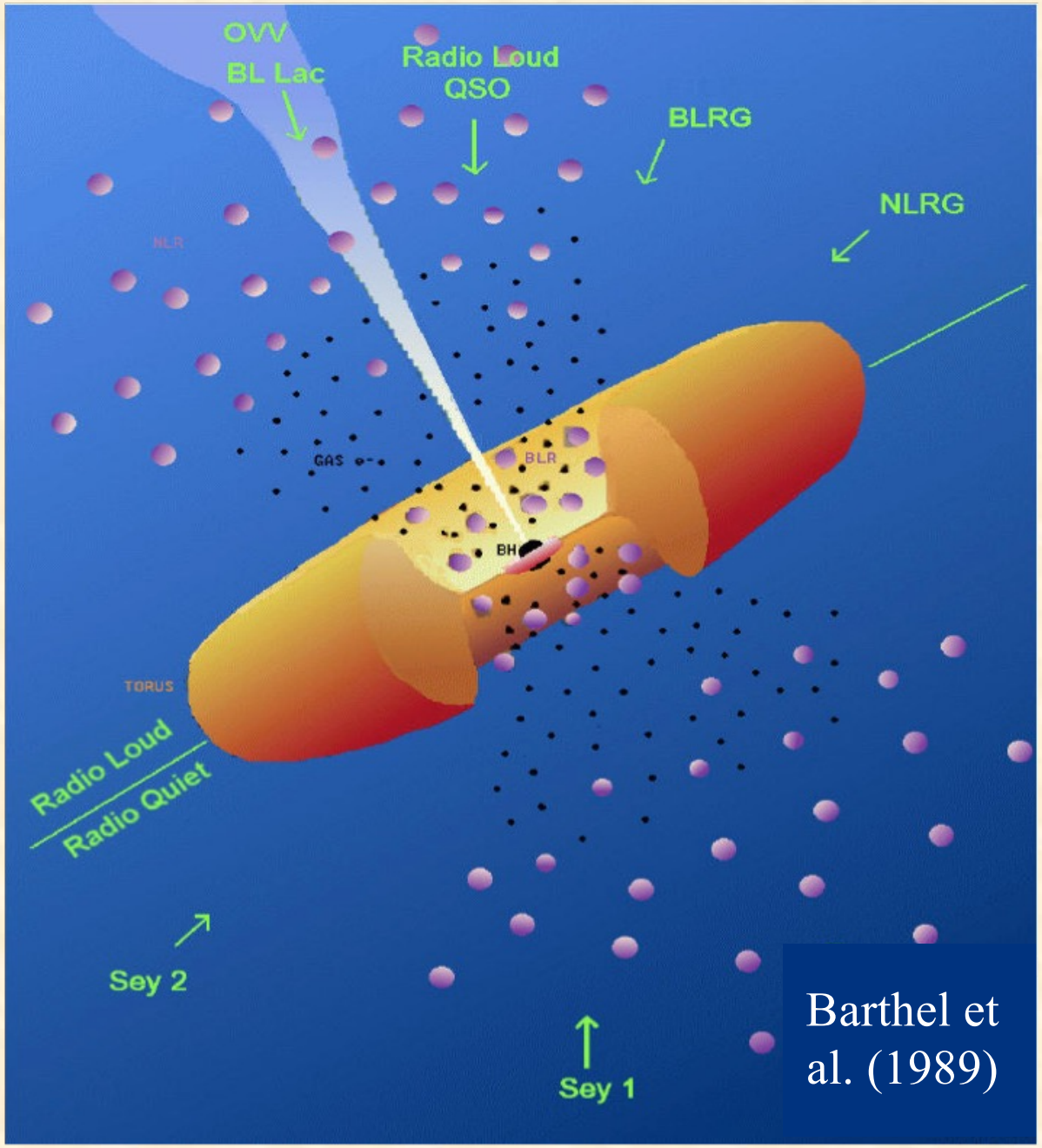
Synchrotron ⋮ Inverse Compton



Inverse Compton Models:

- Synchrotron Self Compton (SSC)
- External Compton (EC): seed photons from accretion disk, BLR, Cosmic Microwave Background (CMB), etc.

Radio Galaxy Unification



FR IIs:
OVV, RLQSO, BLRG, NLRG

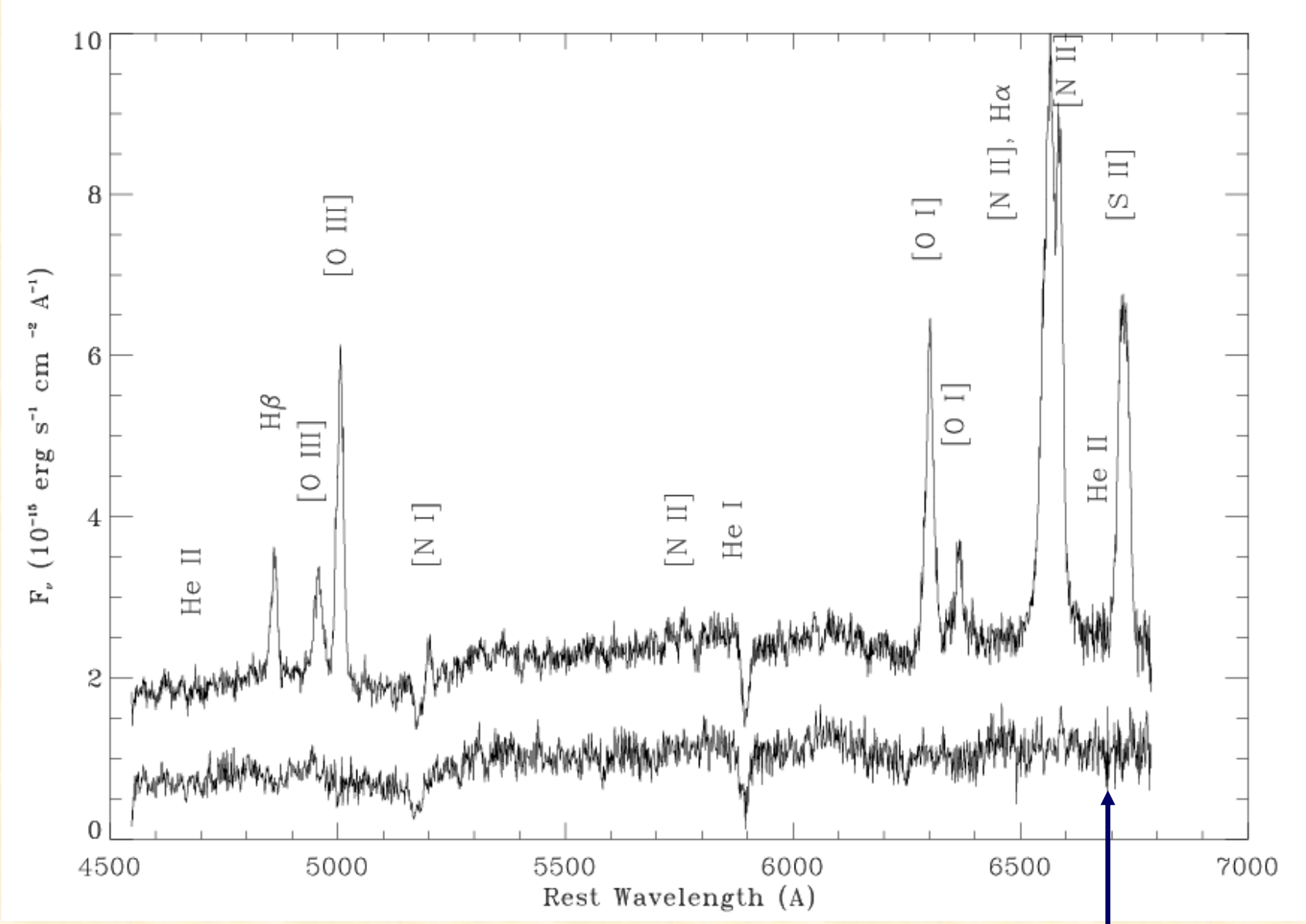
FR Is:
BL Lac, WLRG, (weak-lined radio galaxy)

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
- Current evidence shows that most LINERs are AGN

  (previous explanations include very hot stars and shock heating)
- About 1/3 of all luminous galaxies (including Ellipticals) contain LINERs!
- Broad Balmer emission detected in ~20% (type 1 LINERs)
- LINERs are more radio-loud than Seyferts
- There are some transition objects, which may a combination of starbursts (H II galaxies) and AGN

LINER (NGC 1052)



normal galaxy

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, p. 310)

Mike's Highly Biased View (MHBV)

AGN Optical Luminosity →

Radio ←Power

dwarf Sey 1	NLS1	NLQ1?	
LINER 1	Seyfert 1	RQQ 1 (QSO1)	Face-on
WLRG (FR I)	BLRG (FR II)	RLQ 1	

Radio ←Power

dwarf Sey 2	NLS2?	NLQ2?	
LINER 2	Seyfert 2	RQQ 2 (QSO2)	Edge-on
WLRG2?	NLRG (FR II)	RLQ 2	

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

Parameters :

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

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

3) Orientation

Recent additions to the AGN family

- XBONGS: X-ray Bright Optically Normal Galaxies
  - X-ray luminous, optically obscured BLR and NLR?
  - Optical AGN emission diluted by bright starlight?
  - Unidentified galaxy group or cluster with X-ray emitting gas?
  - Likely a mixture of all of the above. (Kim+ 2023, ApJ, 955, 56)
- Hot DOGs: Hot Dust-Obscured Galaxies
  - Obscured AGN, highly luminous AGN in IR, enshrouded by dust (Eisenhardt+ 2012, ApJ, 755, 173)
- LRDs: Little Red Dots (Mathee+ 2024, ApJ, 963, 129)
  - Compact red distant galaxies discovered by JWST ($z = 4 – 8$)
  - Unusual V-shaped spectrum lacking emission at ~1 micron
  - Broad emission lines, little or no X-ray emission
  - Dust-enshrouded AGN? Pop III stars?
- Most of these are likely evolutionary stages of AGN.