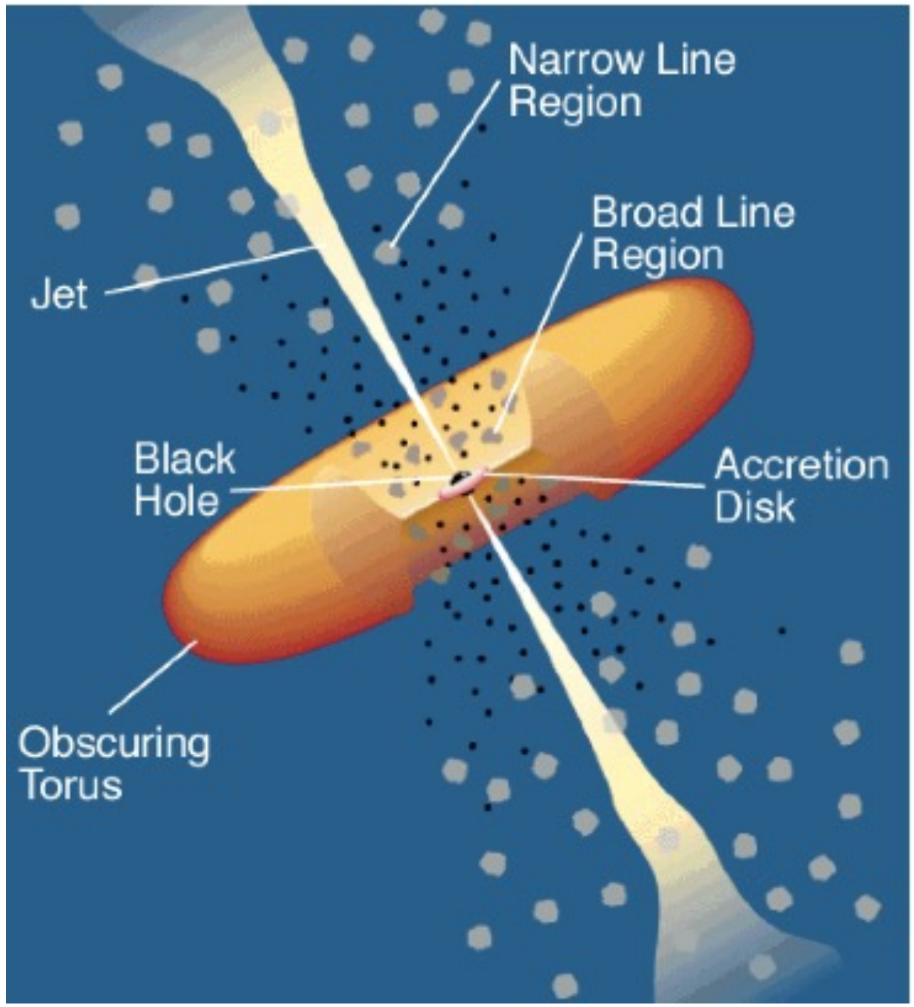
Astronomy 537



Lecture 21: Active Galactic Nuclei III

Key concepts:

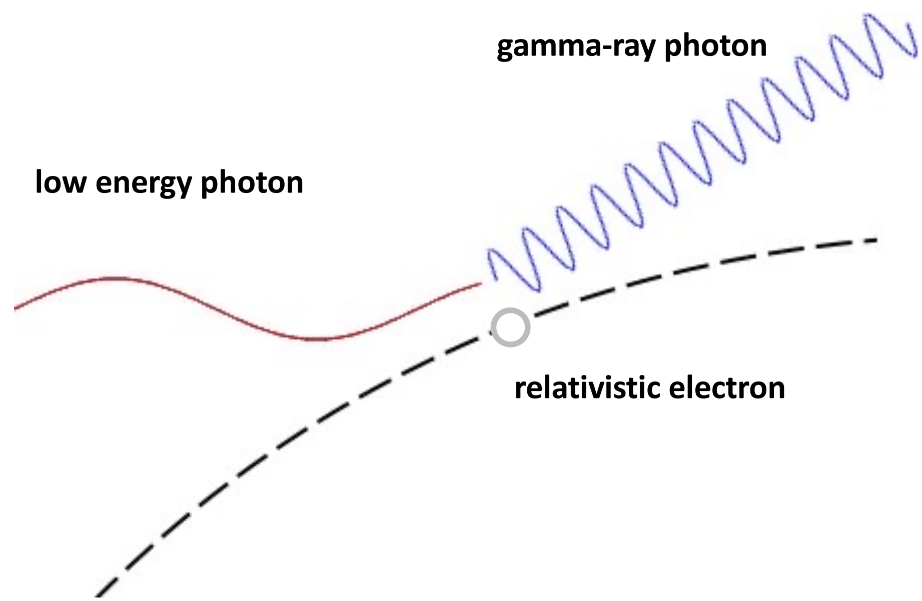
Spectral Energy Distributions

Unified scheme

Superluminal motion

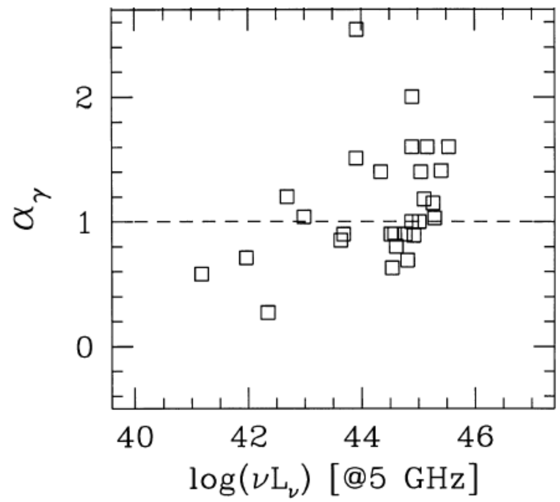
Inverse Compton Scattering in AGN

- synchrotron radio emission originates from relativistic electrons that can upscatter photons to high energy
  - some connection between radio and gamma-ray properties is expected!
  - observationally, all gamma-ray AGNs are radio loud, unlike most X-ray QSOs

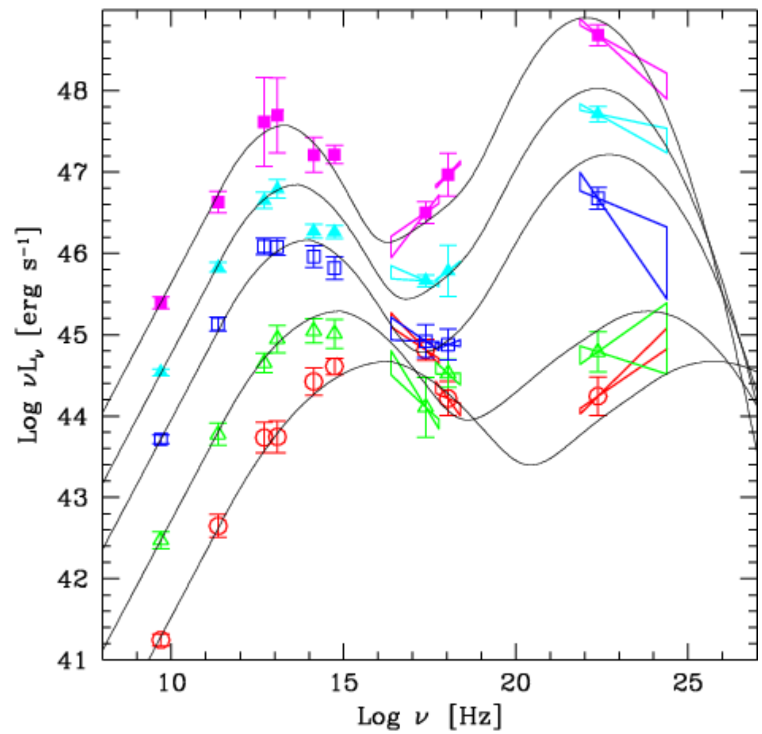


Background

- the blazar sequence was originally devised on the basis of the radio luminosity
- See Muecke et al. etc

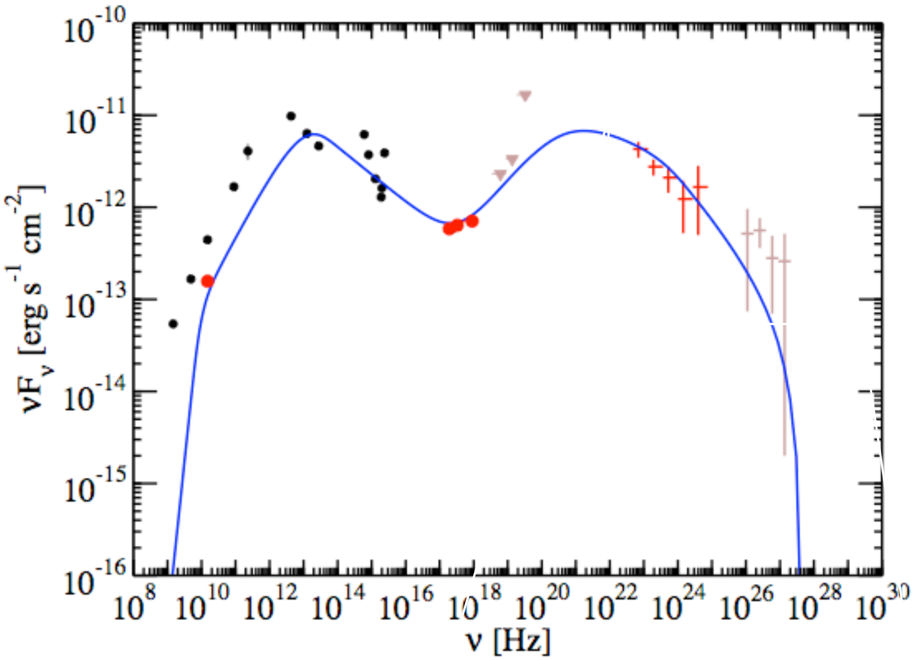


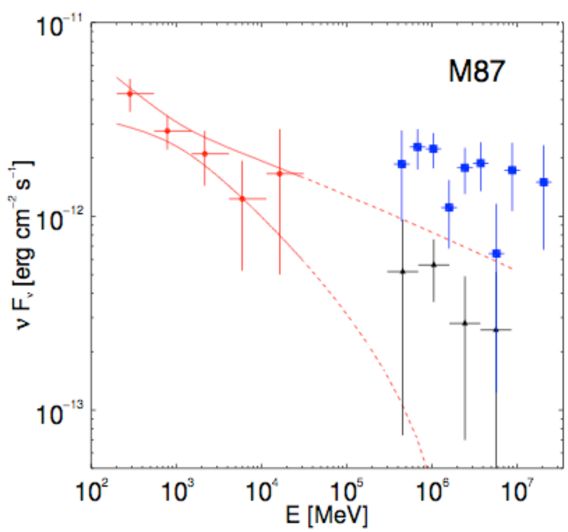
Fossati et al. (1998)

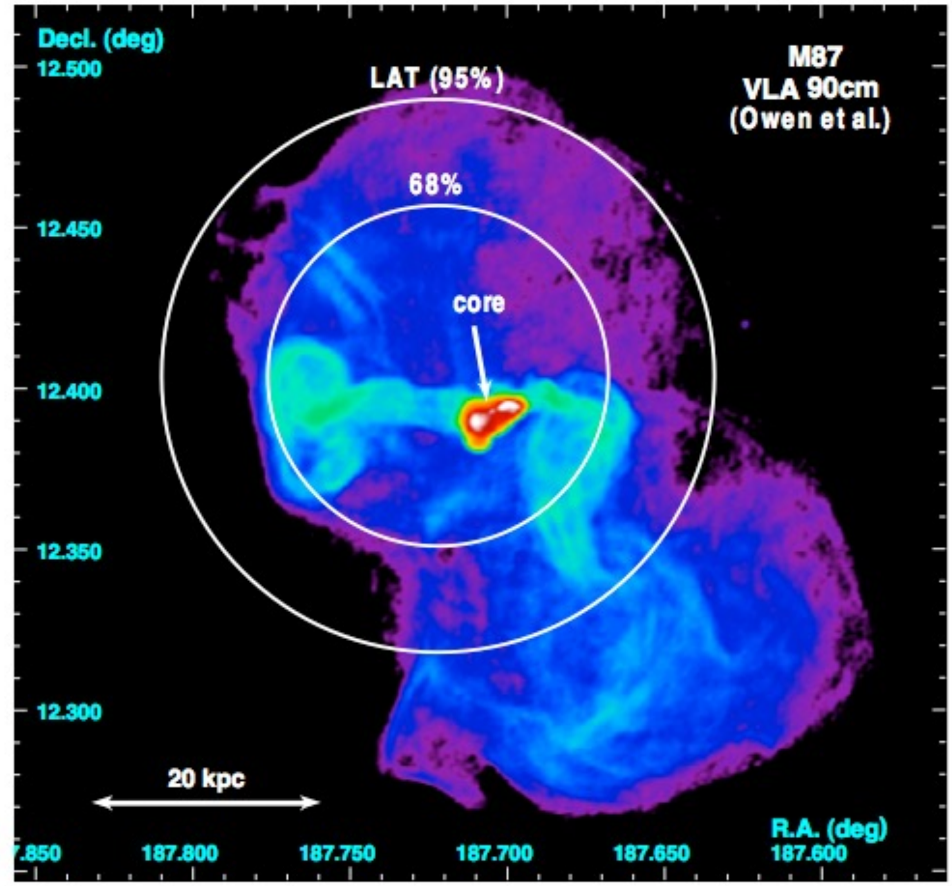


Donato et al. (2001)

M87

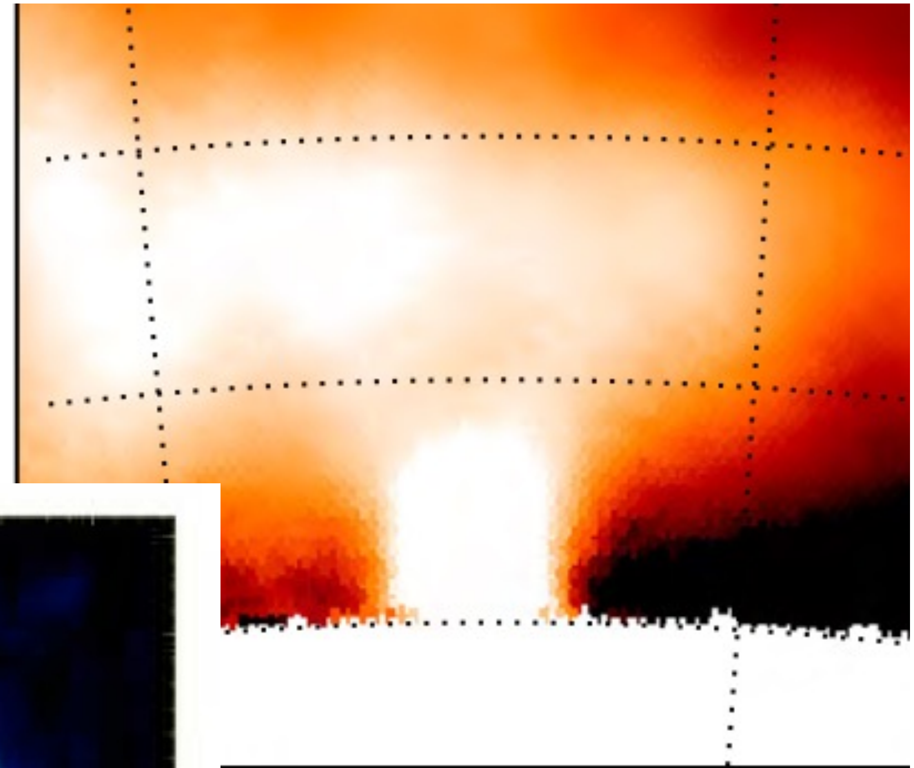




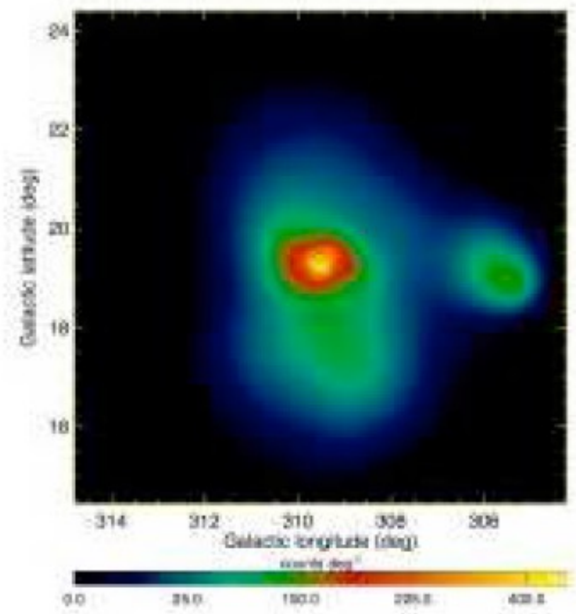


Abdo et al. (2009)

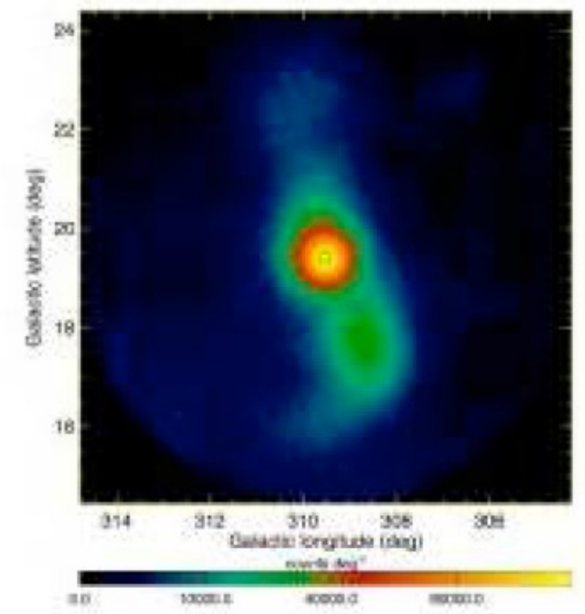
Cen A



LWA1 (74 MHz)



Fermi (>200 MeV)



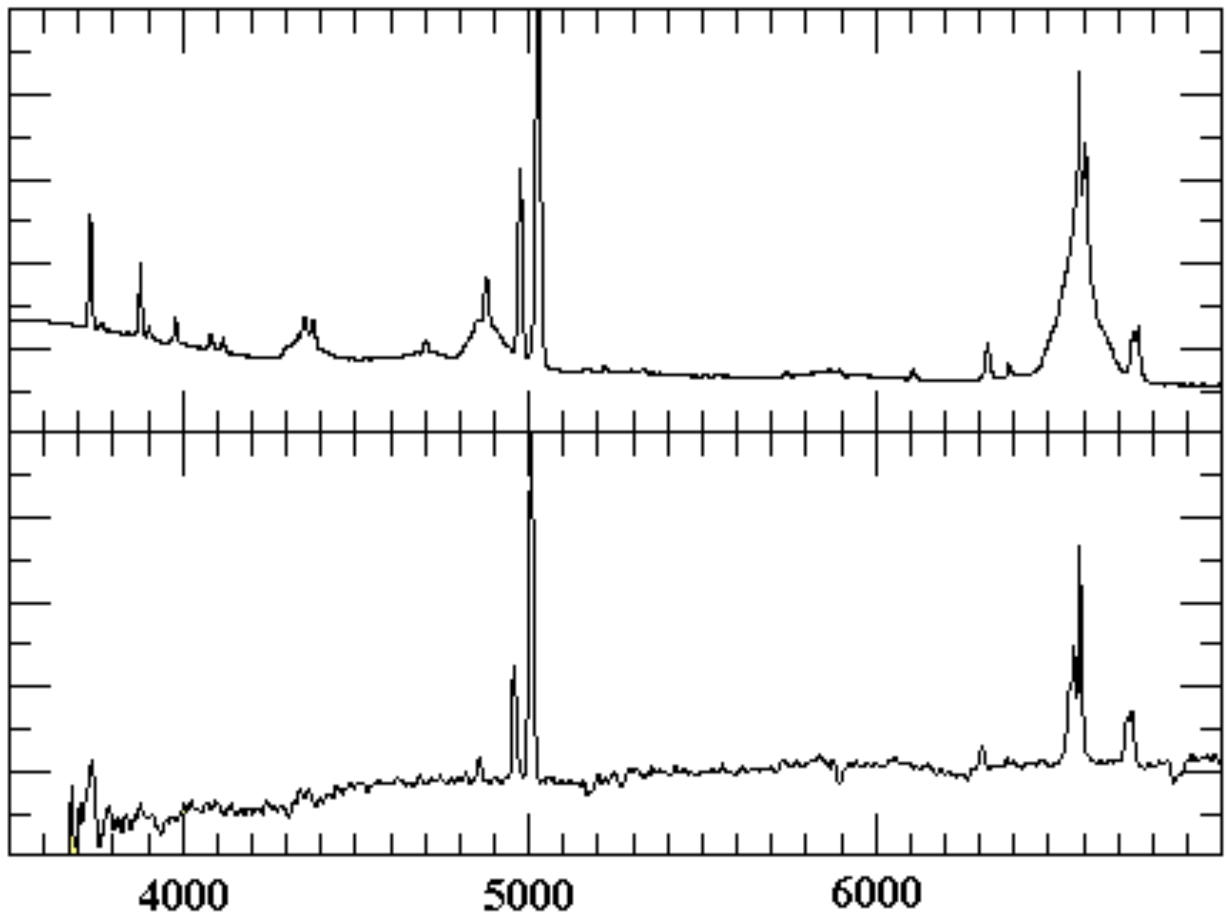
WMAP (20 GHz)

Abdo et al. (2009)

Dowell et al. 2016

Summary of AGN classes

- Seyferts
  - Type I and II: broad and narrow emission lines
  - weak radio emision
  - X-ray emission
  - Spiral host galaxie
  - Variability



Summary of AGN classes

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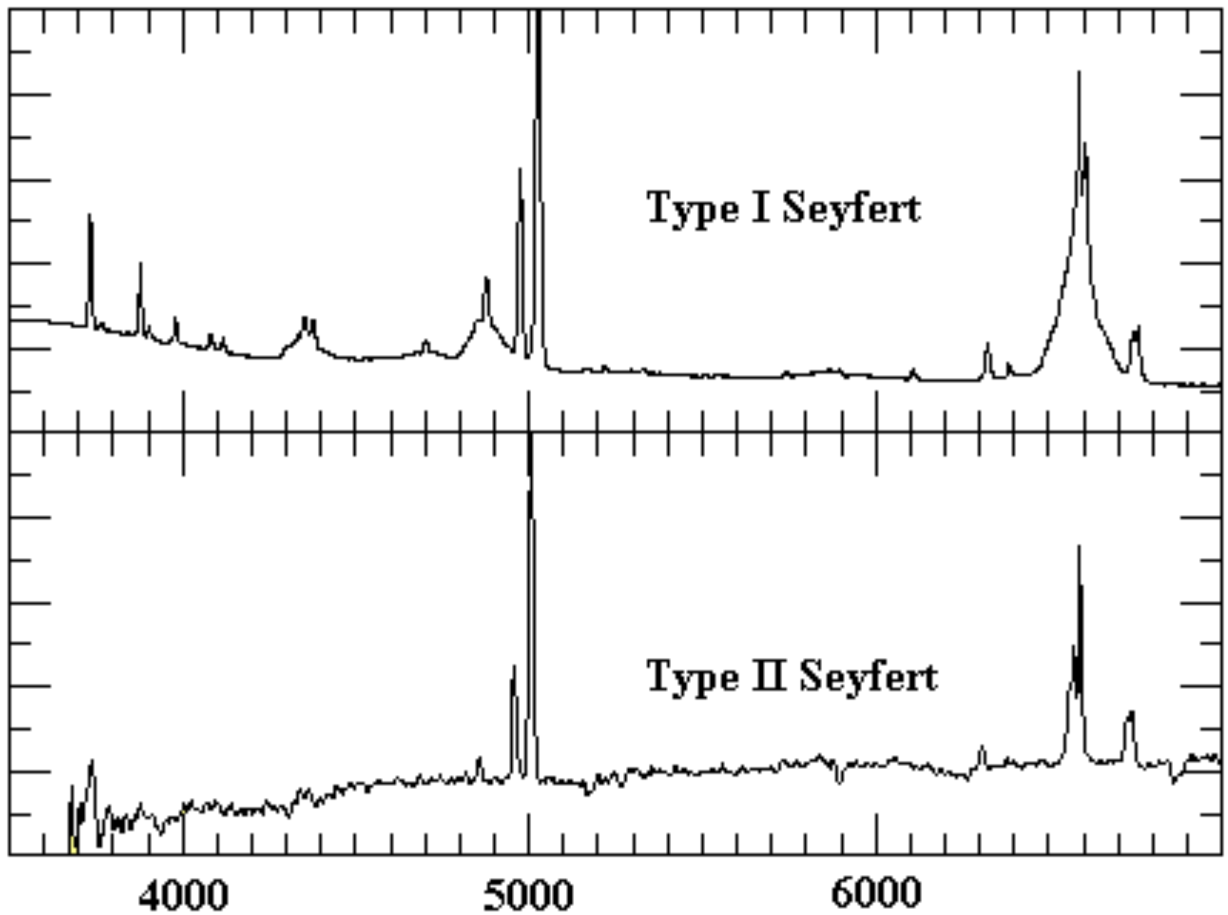
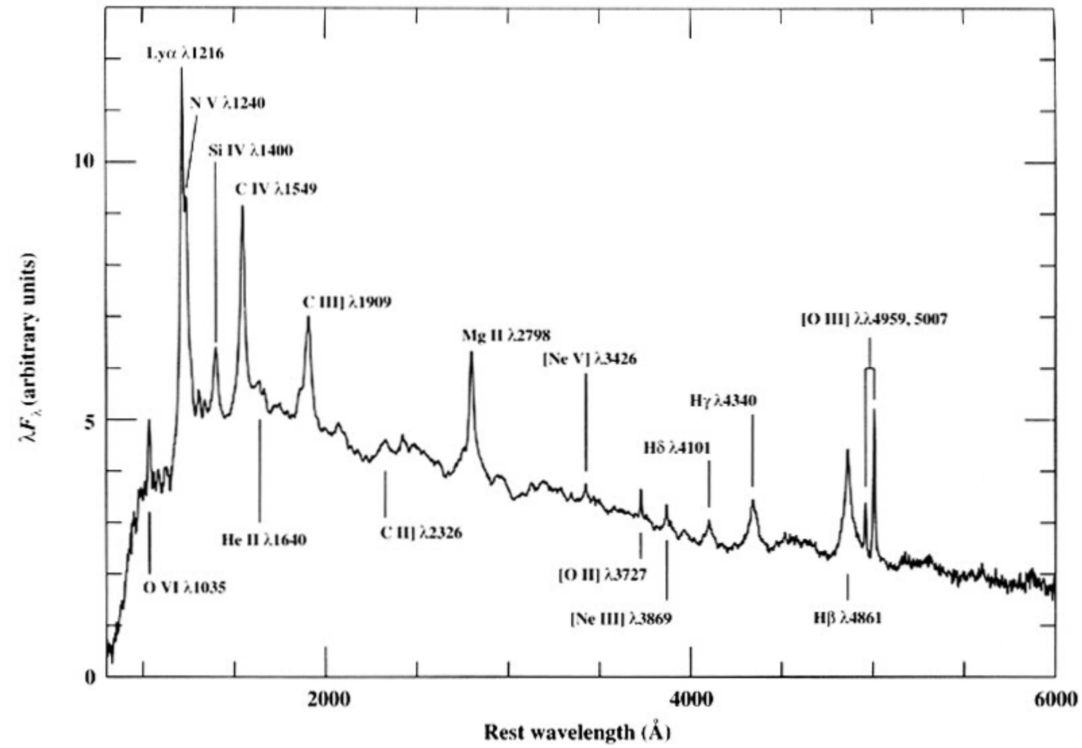
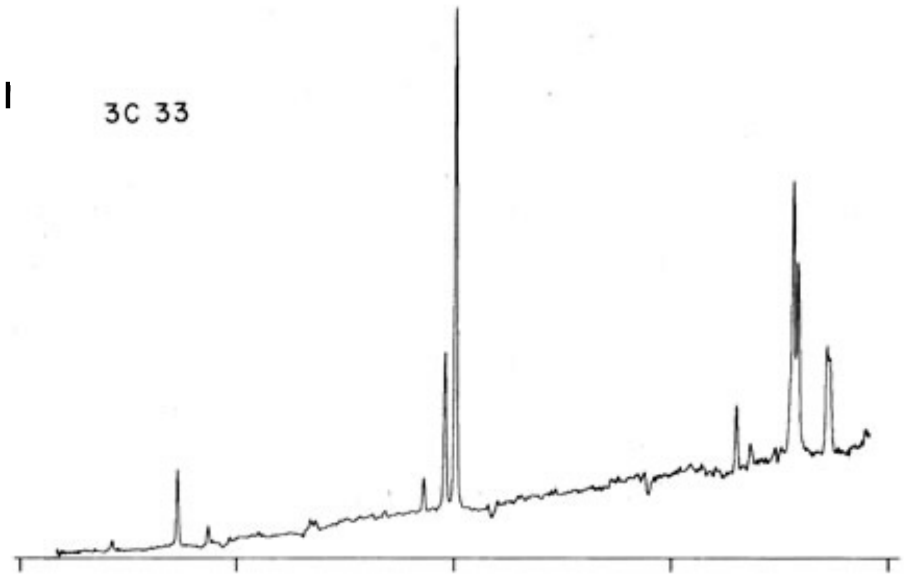
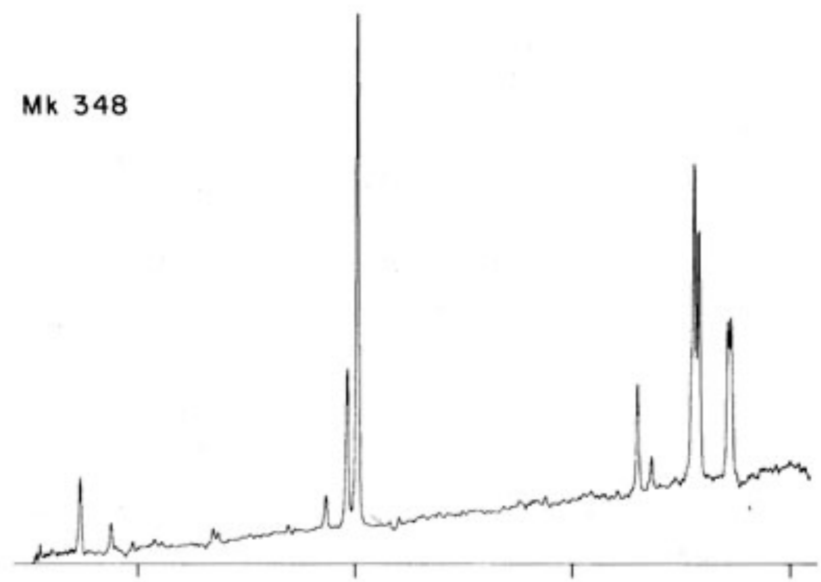


- Quasars
  - Radio loud
    - broad and narrow emissior
    - Strong radio emission
    - Some polarization
    - FRII morphology
    - Variability
  - Radio quiet
    - broad and narrow emissior
    - weak radio emission
    - weak polarization
    - Variability

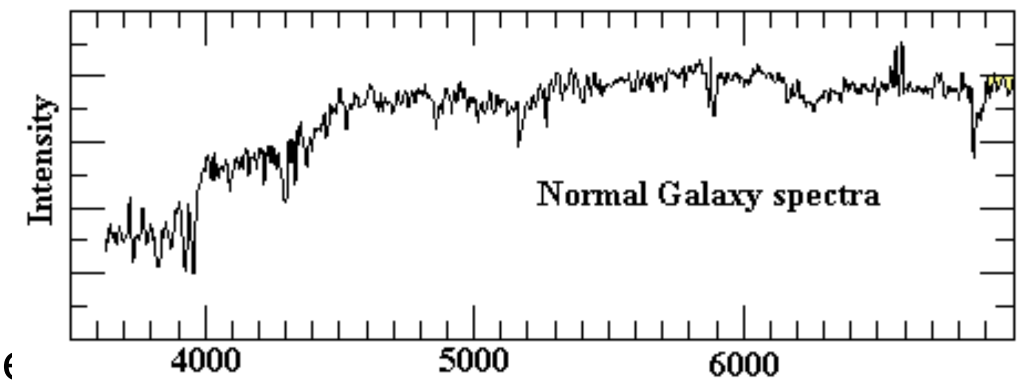


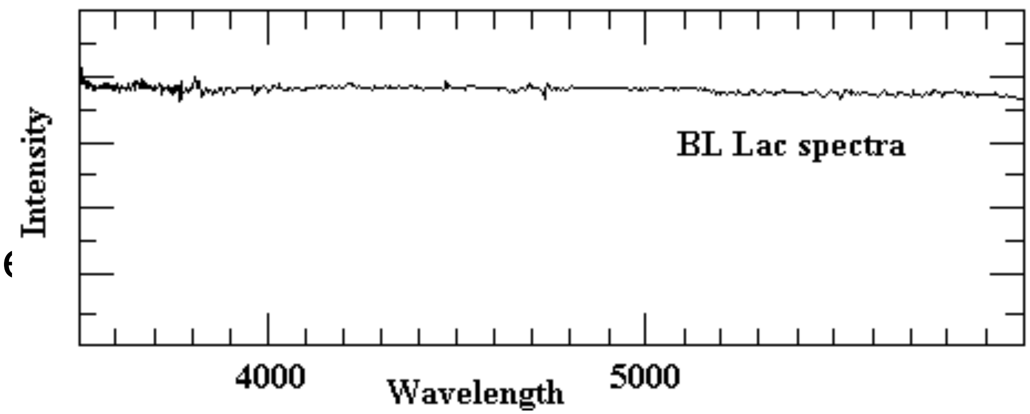
- Radio galaxies
  - BLRG
    - broad and narrow emission li
    - strong radio emission
    - FRII morphology
    - weak polarization
    - Elliptical host galaxies
    - Variable
  - NLRG
    - narrow emission line only
    - strong radio emission
    - FRI and FRII morphologies
    - no polarization
    - Elliptical host galaxies
    - No variability



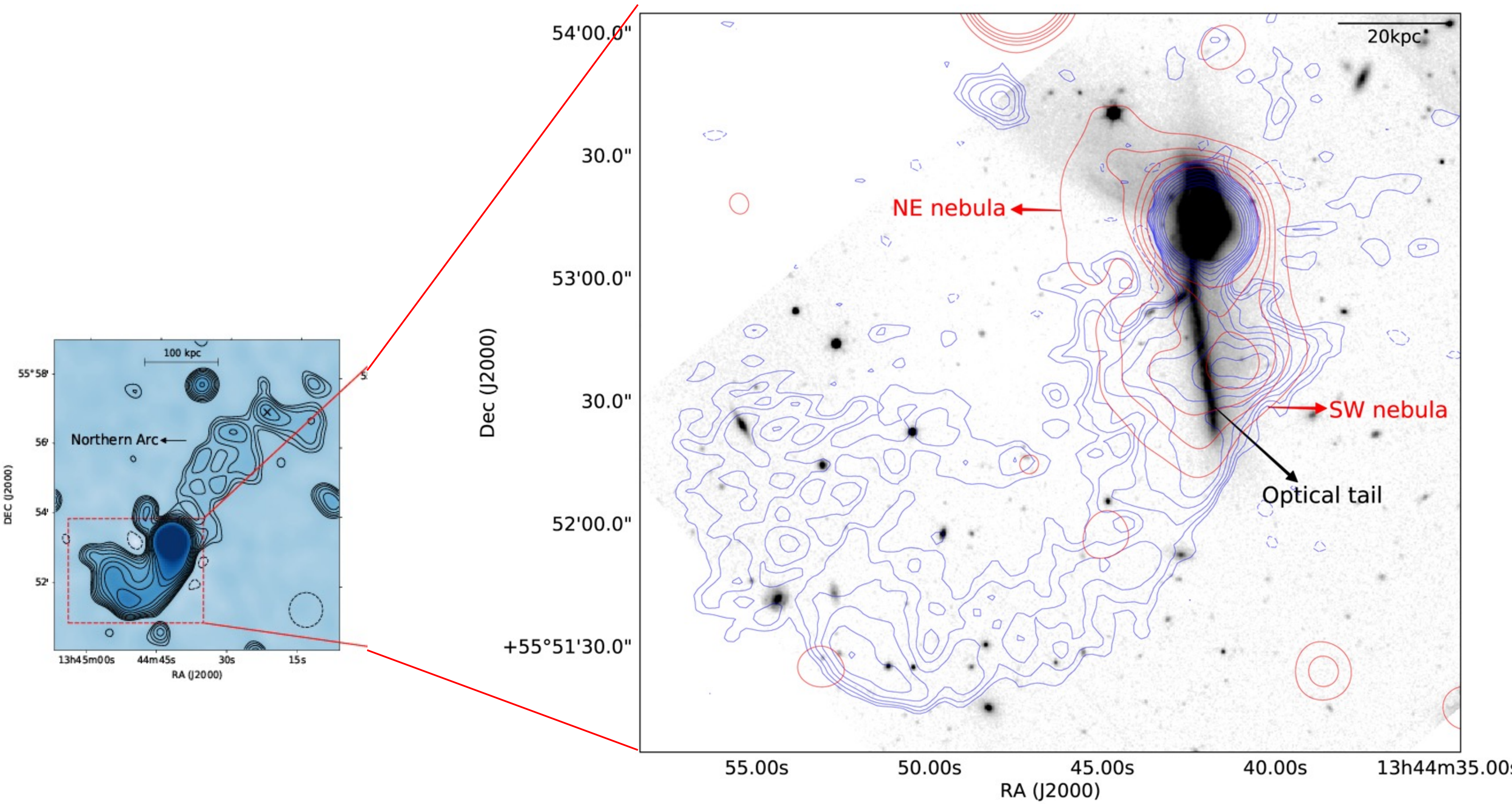


- Blazars
  - BL Lacs
    - almost no emission lines
    - strong radio emission
    - strong polarization
    - 90% have elliptical host galaxie
    - Strong variability
  - OVV quasars/ FSRQs
    - broad and narrow emission line
    - strong radio emission
    - strong polarization
    - Strong variability
    - Much more luminous than BL Lacs





- ULIRGs
  - Possibly dust-enshrouded quasars
  - Alternatively a starburst phenomena



Mrk 273 optical (greyscale), 144 MHz radio (blue) and X-ray (red) from Kukreti et al. 2022

Distinguishing AGN

Seyferts are separated from HII regions (which also produce emission lines by photoionization by stars) by *line ratios.*

Common criterion for Seyferts:

[OIII] 5007 / Hbeta >3

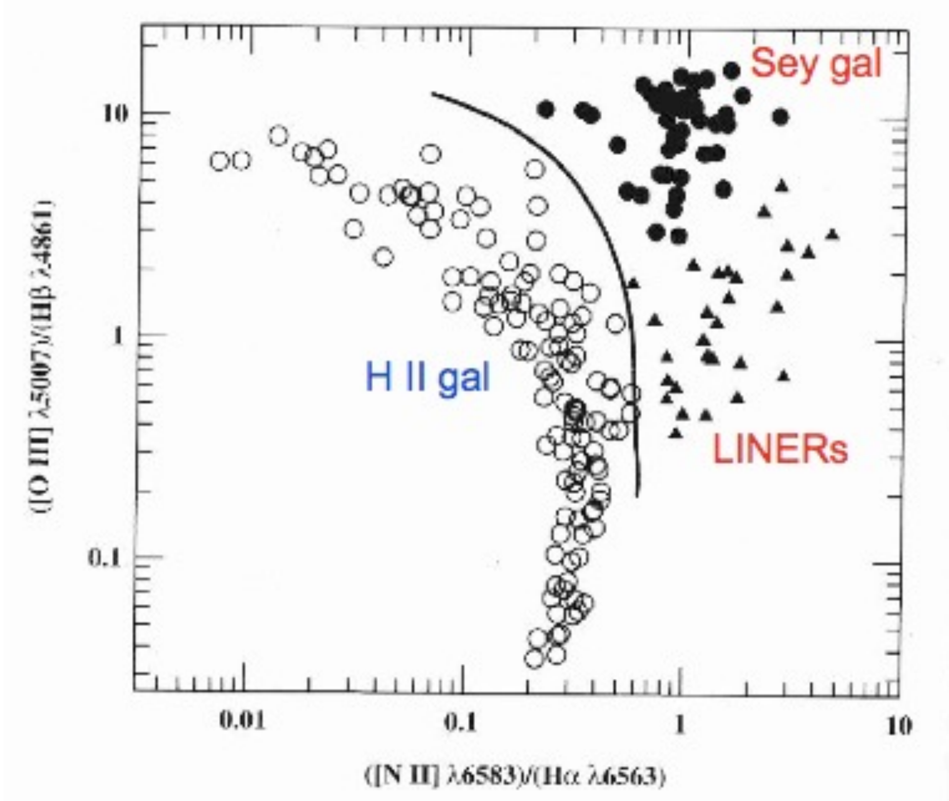
This requires a relatively hard, non-stellar ionizing continuum.

Problem: reddening can affect line ratios.

Solution:

a) Use line ratios of lines which are very close in wavelength (same reddening dependence)
b) Use two sets of widely separated lines (line ratio depends on continuum shape)

LINERs have lower ionization levels that Seyferts, but higher than HII regions.

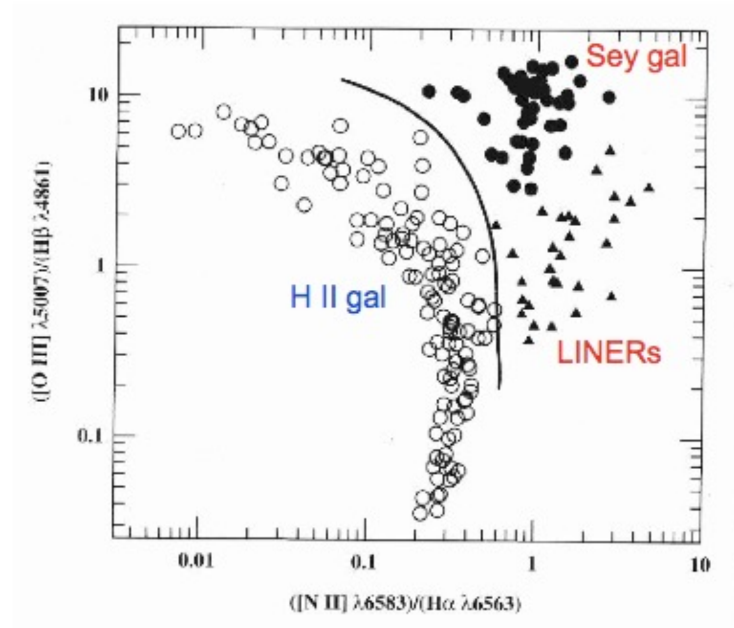


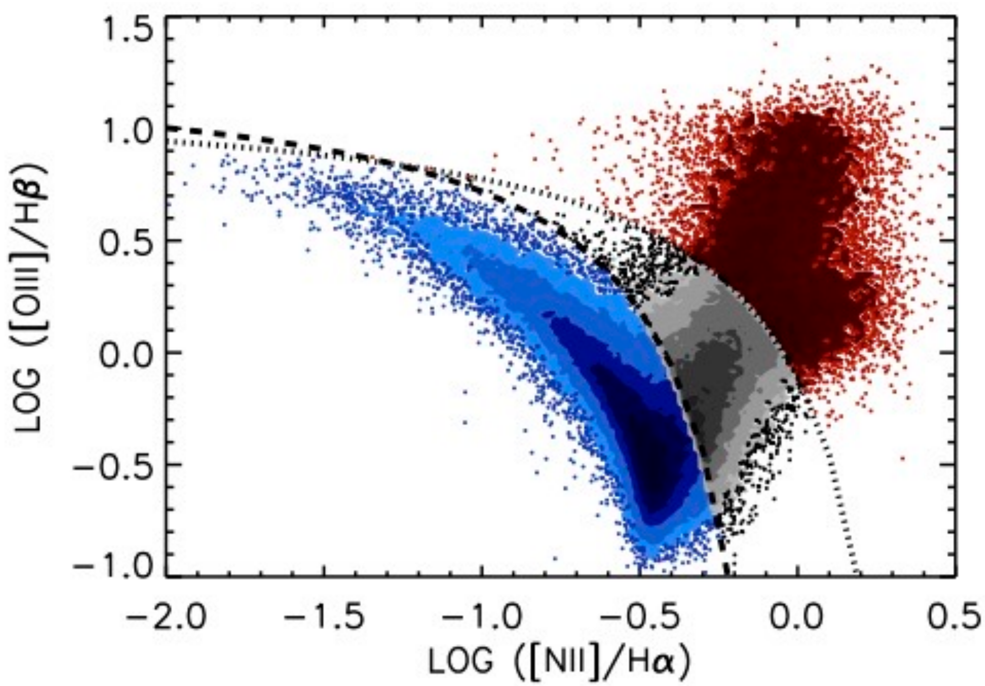
AGN diagnostic diagram

Baldwin, Phillips & Terlevich 1981:
BPT-diagram

The BPT diagrams are used to distinguish between hard and soft radiation.

This is ascribed to non-stellar or stellar activity, respectively.





Active Galactic Nuclei - General Summary

- Emission that cannot be attributed to stars
- Occur both in spirals and E/S0s (Sy/Quasars, distinguished mostly in the amount of energy emitted)
- Emit energy comparable, or larger than all the stars in the host galaxy over a wide range of wavelengths, sometimes including the radio
- Can show linear structures (jets/lobes/hotspots) in the radio (and jet in the optical) of the order of ~ Mpc

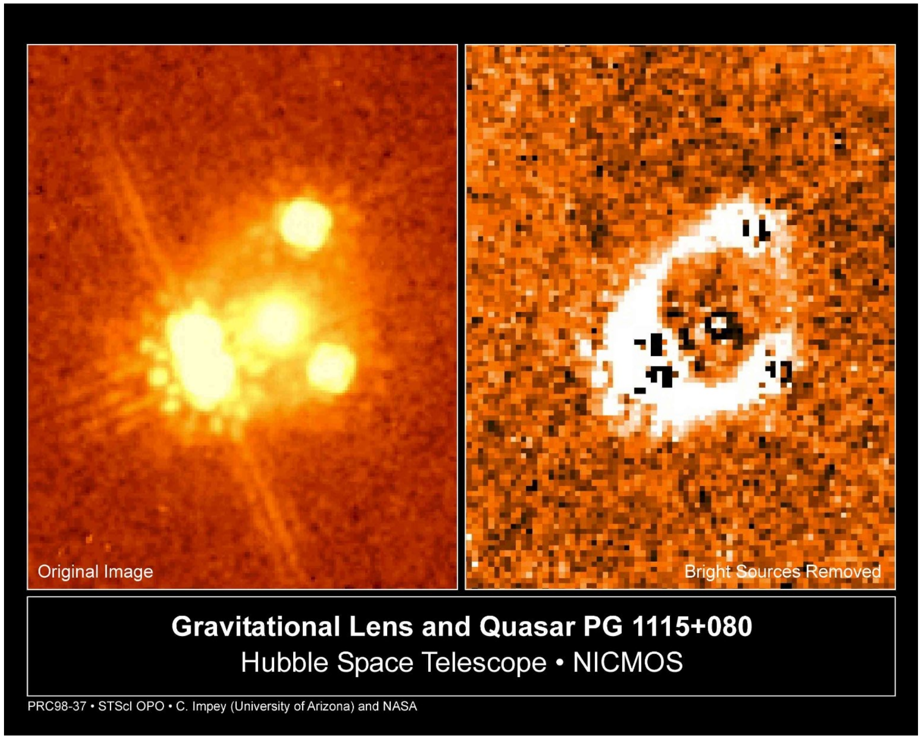
- AGN show strong broad emission lines. Combined with small emission region this indicates a *high concentration of mass.*

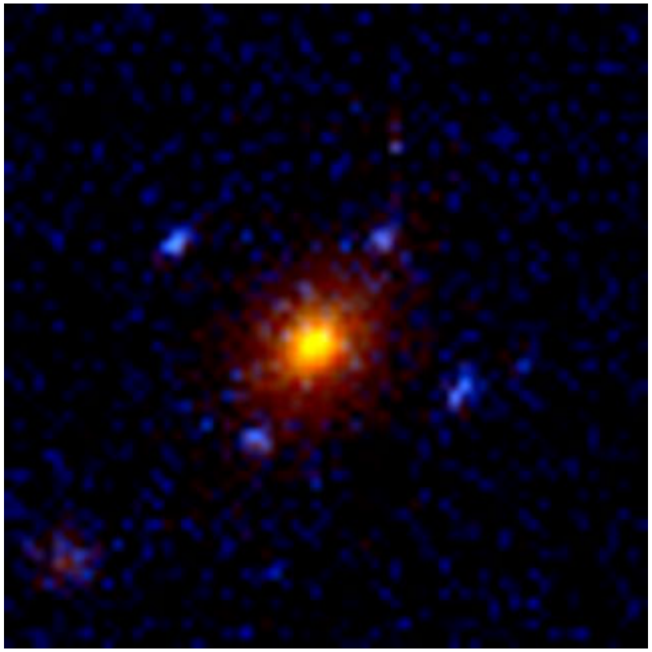
- AGN come in many shapes and forms, not always with a clear connection.

- Are often highly variable, supporting a small central engine

Why are AGN interesting?

a) For studying black hole physics
b) Studying high energy physics
c) Background sources on cosmological scales
    a) Lyman alpha forest in optical spectra (absorbing gas in walls? IGM information)
    b) Gravitationally lensed by clusters, can get Hubble constant from time delay

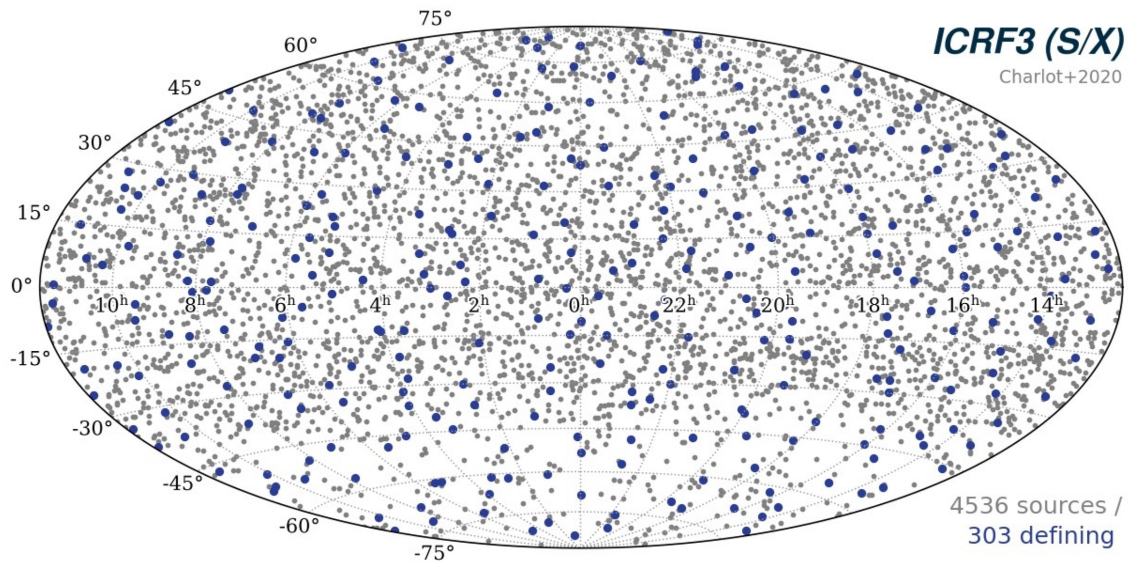




c) background radiation to detect absorption lines in host galaxies at large redshifts

d) produce cosmic background radiation, e.g. X-ray wavelengths

d) Use radio cores as cosmic reference points for fixed coordinate systems – This is the International Coordinate Reference Frame



e) History of the Milky Way: have all galaxies been an AGN at some point? Are they still?

How can we bring all AGN types into a single framework?

- We will "postulate" a standard model for the structure of AGN

- Different types result from different viewing angles
  - and perhaps some different physical conditions
  - we need to remove the aspect-dependency to determine this!

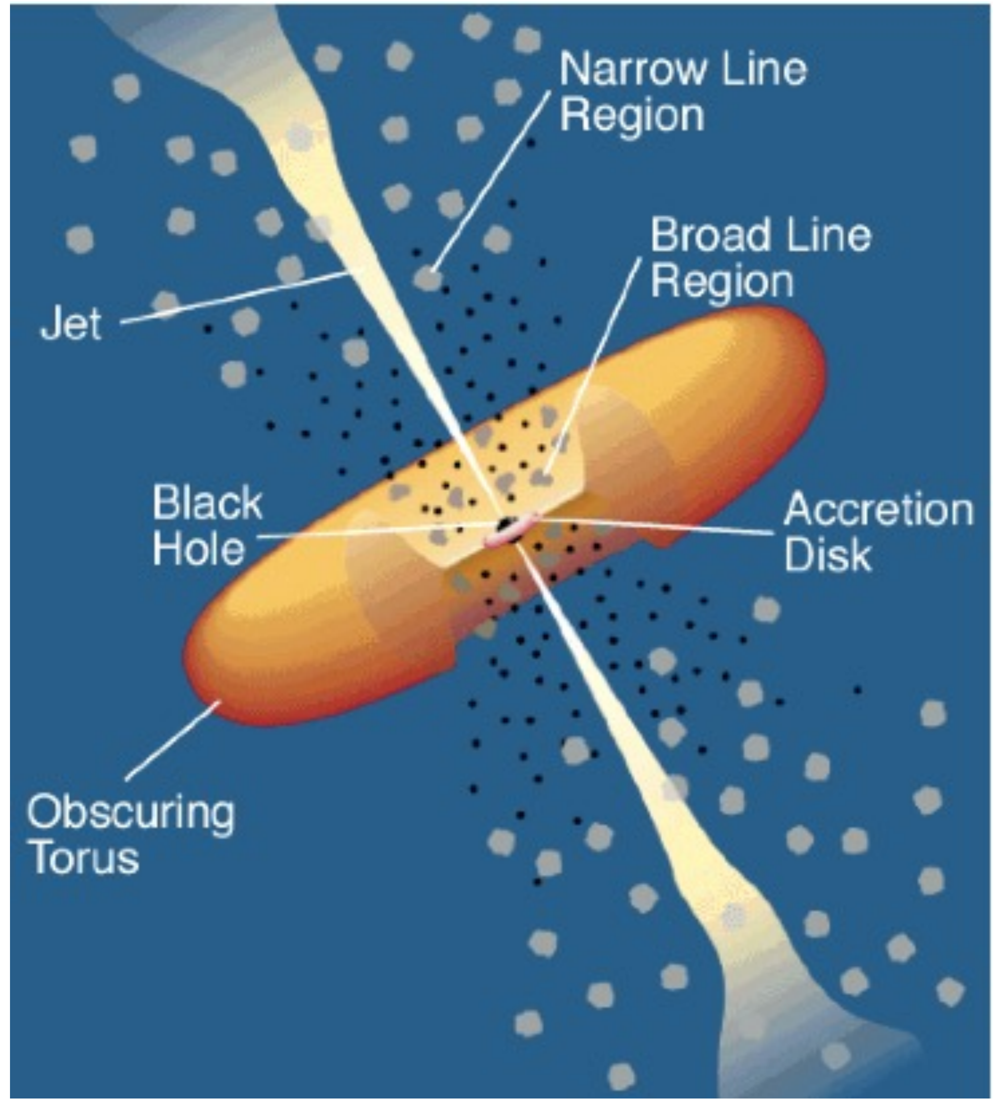
- We call this *unification.*
  - What are the evidence for unification?

The Unified Model for AGN

- Radio galaxies, quasars, QSOs, Seyferts, Blazars etc are *the same type* of objects viewed from different angles

- The center of the galaxy is a supermassive black hole surrounded by an accretion disk, clouds of gas and a dusty torus.

- The energy output is ascribed to accretion of material onto the black hole



The Standard Model of AGN

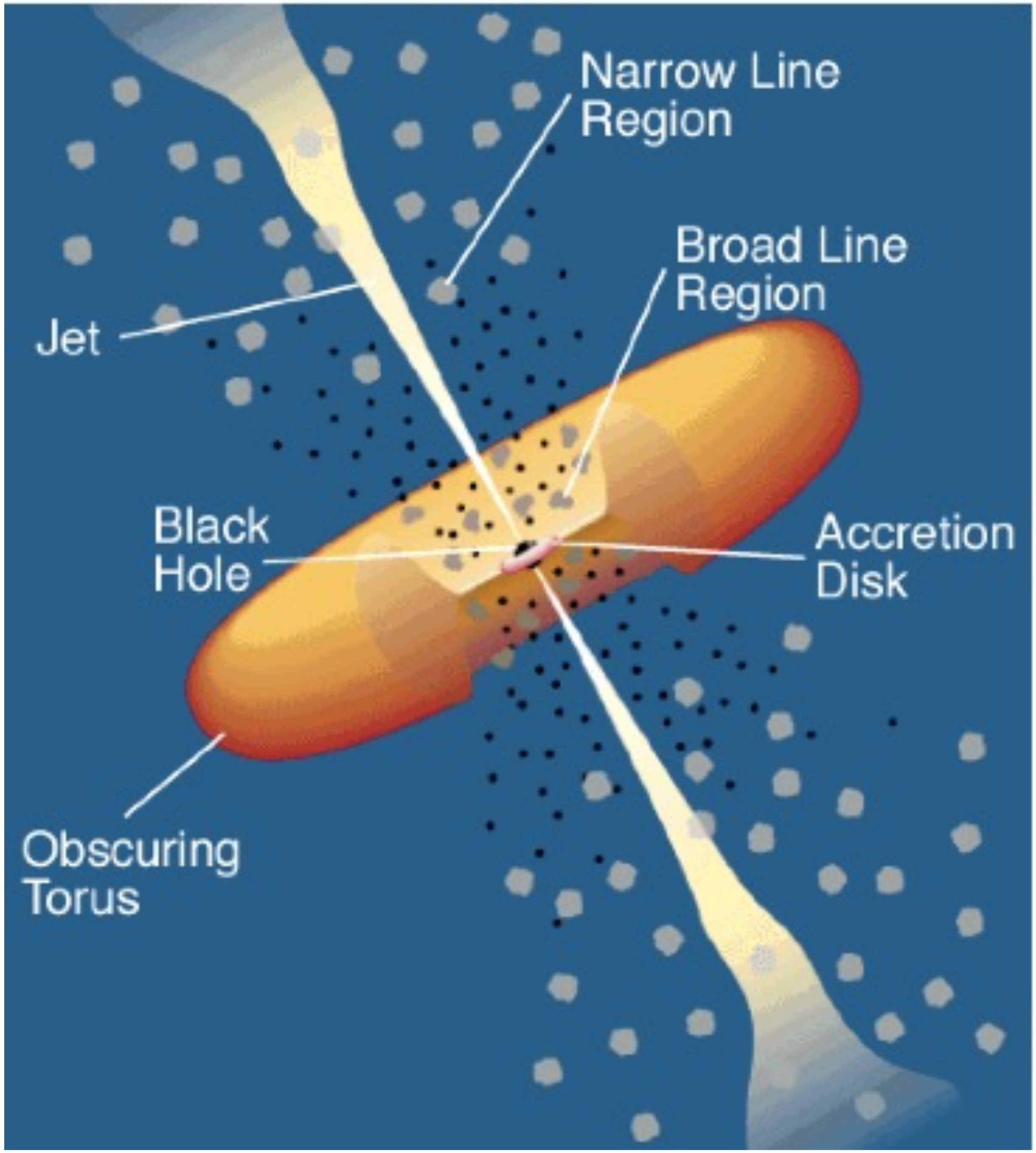
Components:

- Accretion disk
  - $r \sim 10^{-3}$ pc, $n \sim 10^{15} cm^{-3}$, $v \sim 0.3c$

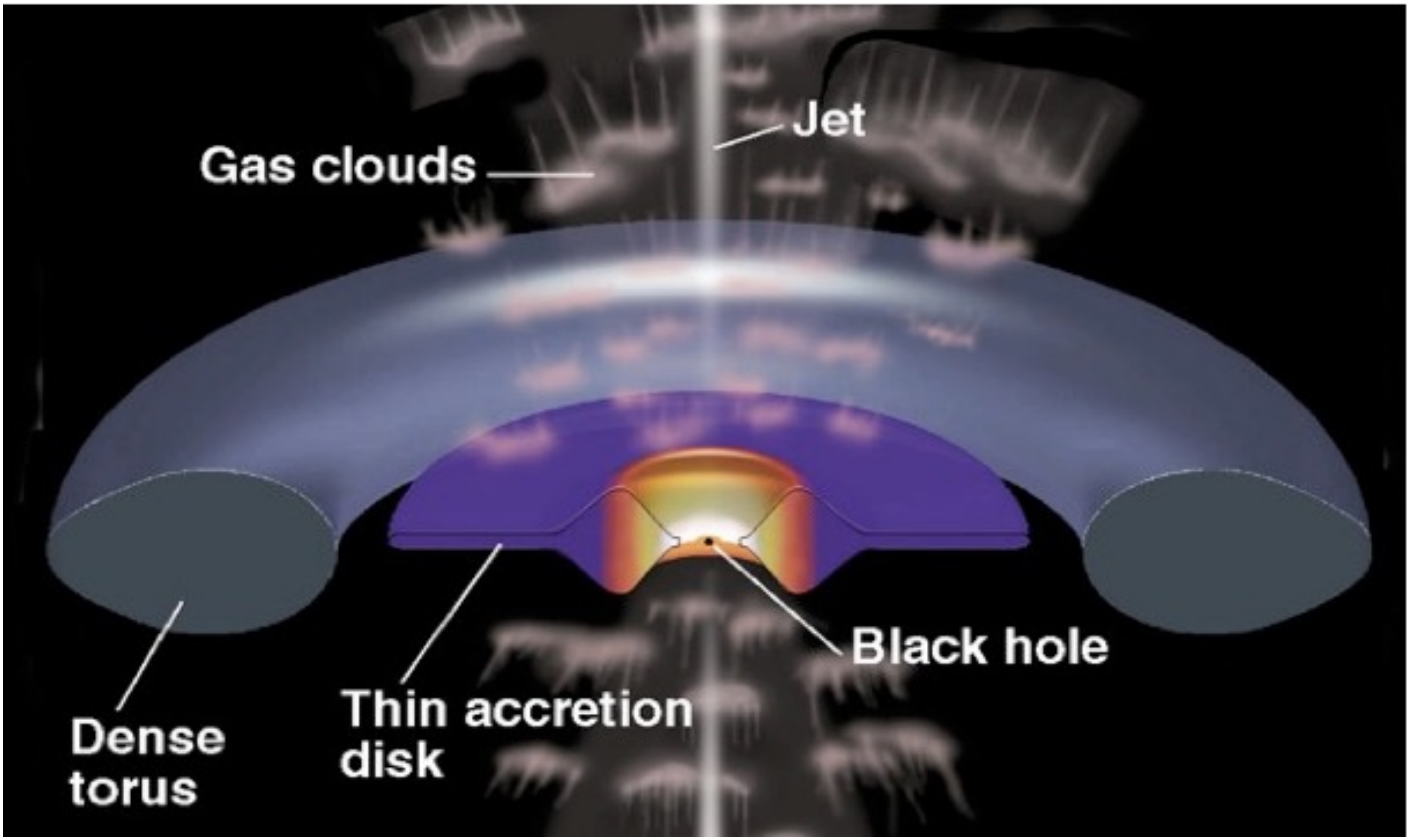
- Broad Line Region (BLR)
  - $r \sim 0.01$-0.1 pc, $n \sim 10^{10}$ cm^{-3}, v~ a few 10^3 km/s

- Narrow Line Region (NLR)
  - $r \sim 10$-1000 pc, $n \sim 10^3$-$10^6 cm^{-3}$, v~a few 100 km/s

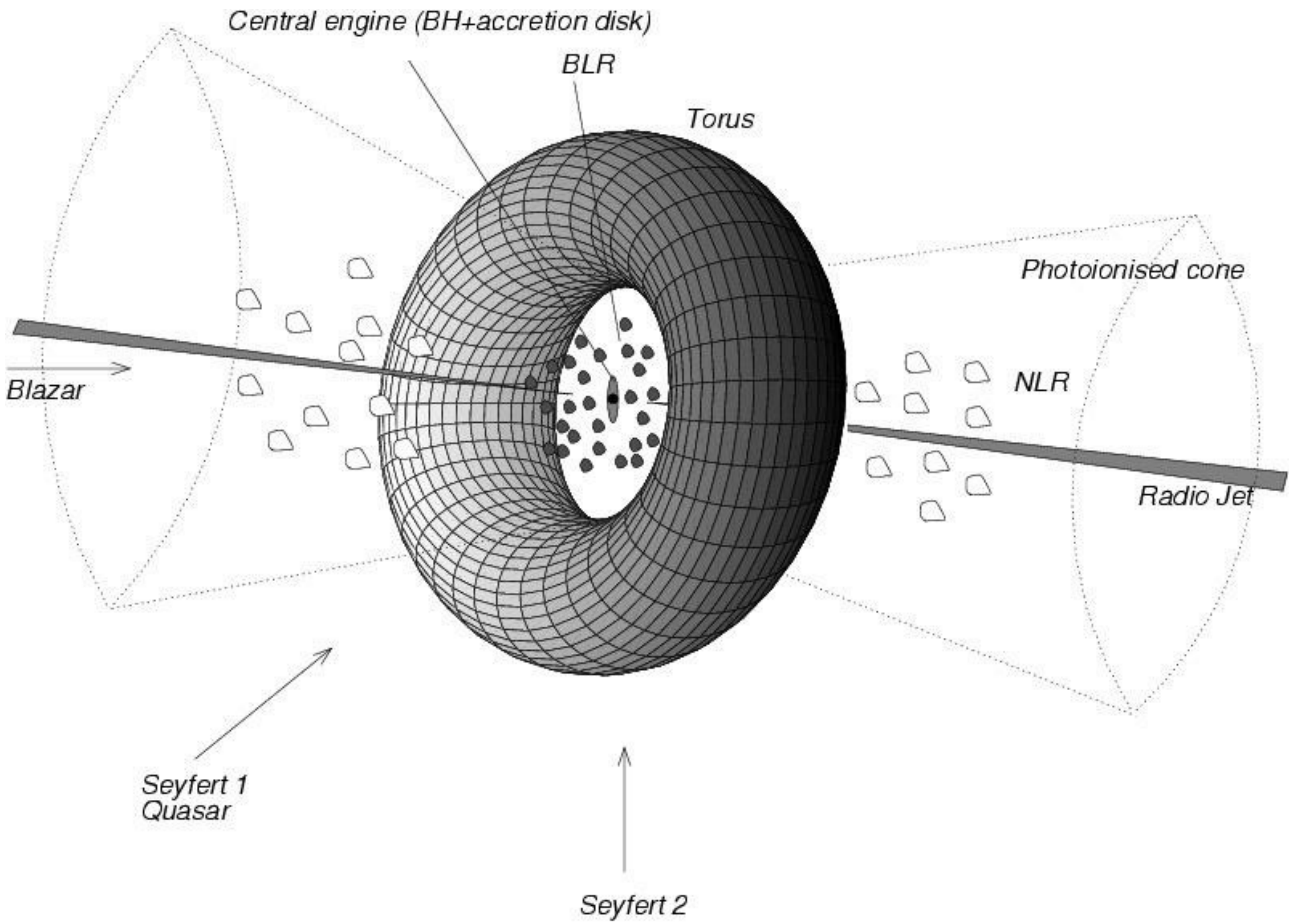
- Torus (Thick Obscuring Region required by Unification Systems)
  - $r \sim 1$-100 pc, $n \sim 10^3$-$10^6 cm^{-3}$


Narrow Line Region
Broad Line Region
Jet
Black Hole
Accretion Disk
Obscuring Torus

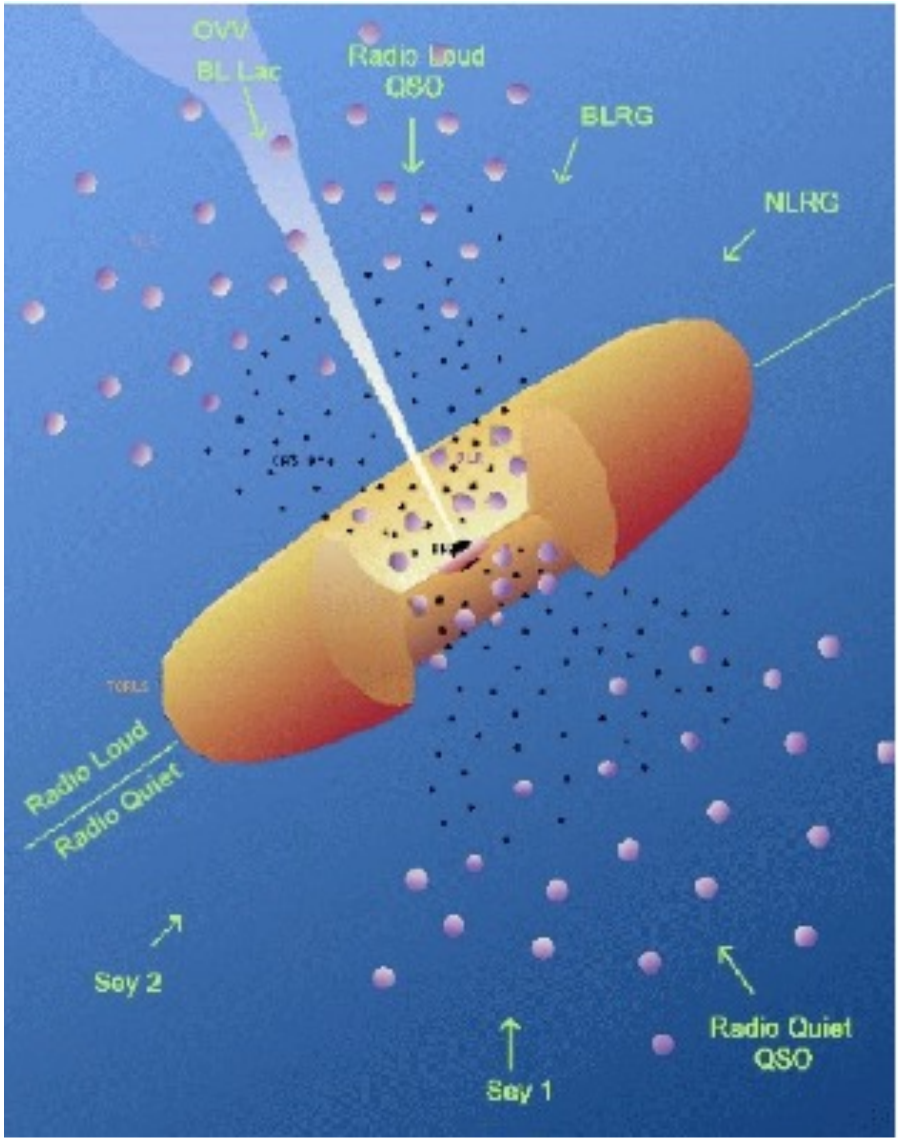
Model for the central region: SMBH, surrounded by accretion disk containing infalling material. If conditions are right, the AGN may possess a magnetically confined jet (the source of radio emission).



Effects of orientation



Unification of AGN

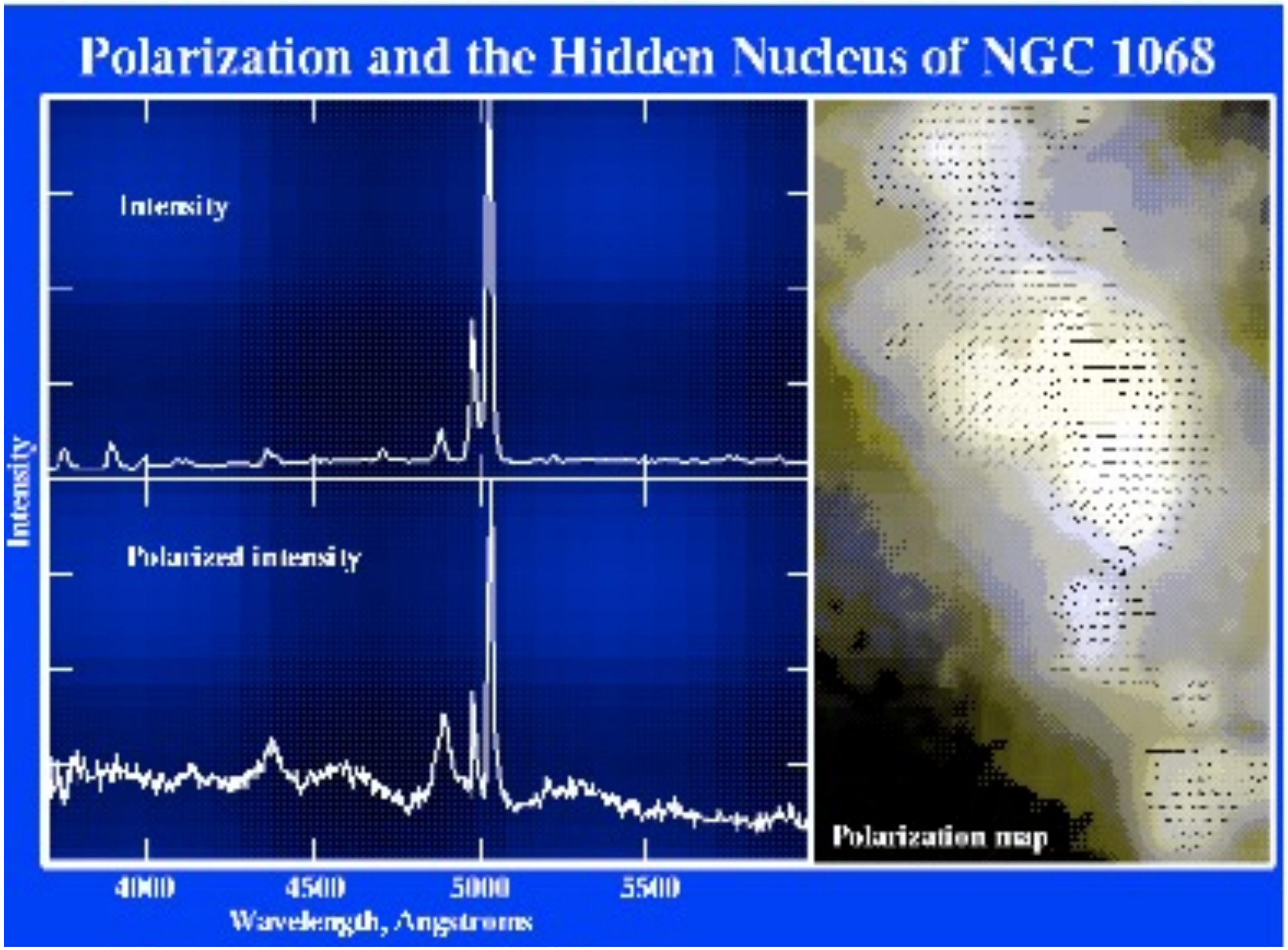


	Face-on	Edge-on
Radio-quiet	Sy1	Sy2
	QSO	
Radio-loud	BL Lac	FRI
	BLRG	NLRG
	Quasar	FRII

Proposed by Rowan-Robinson in 1977, and became a popular model in the mid-80s.

Support for unification

1. Hidden emission lines: Some Sy2s show broad lines in polarized light.

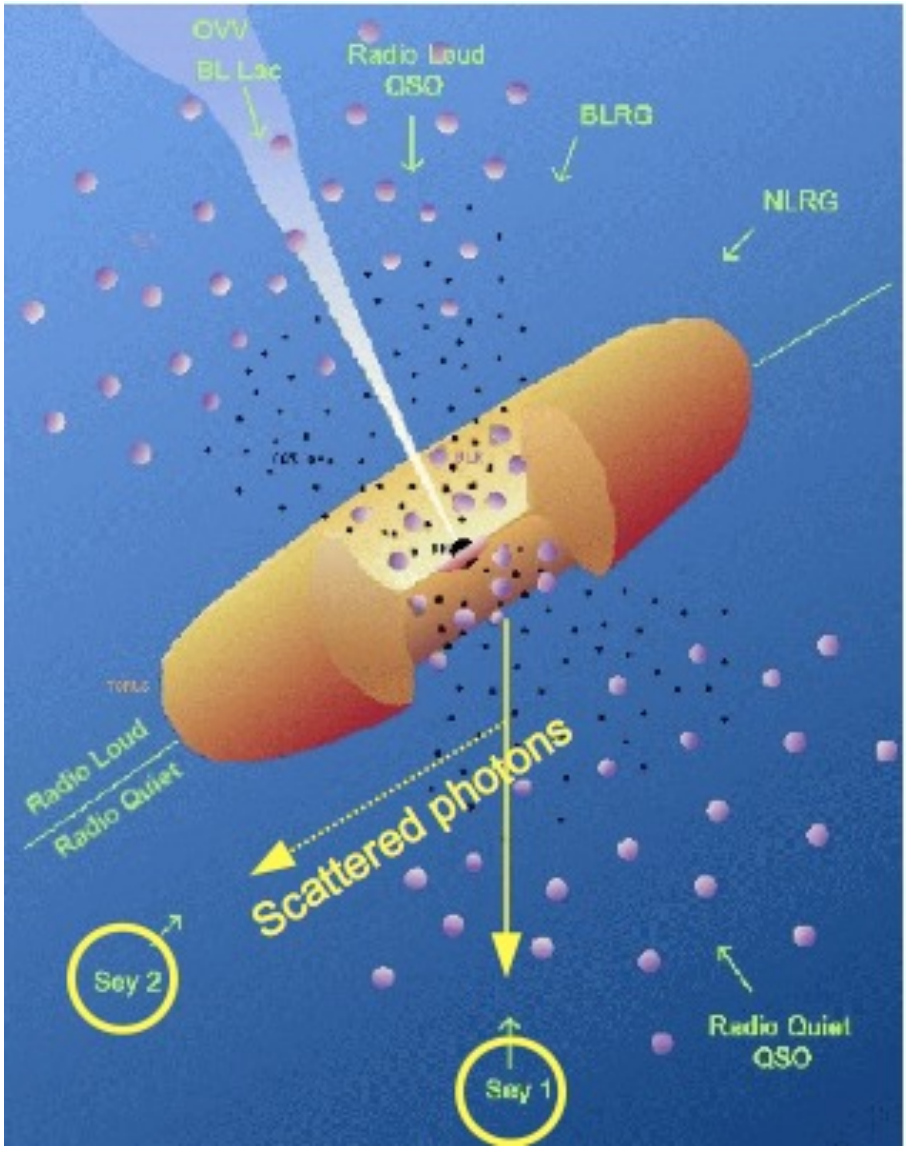


Electrons scatter photons from the BLR near the nucleus toward the observer.

The dusty torus shields the direct line-of-sight to the nucleus.

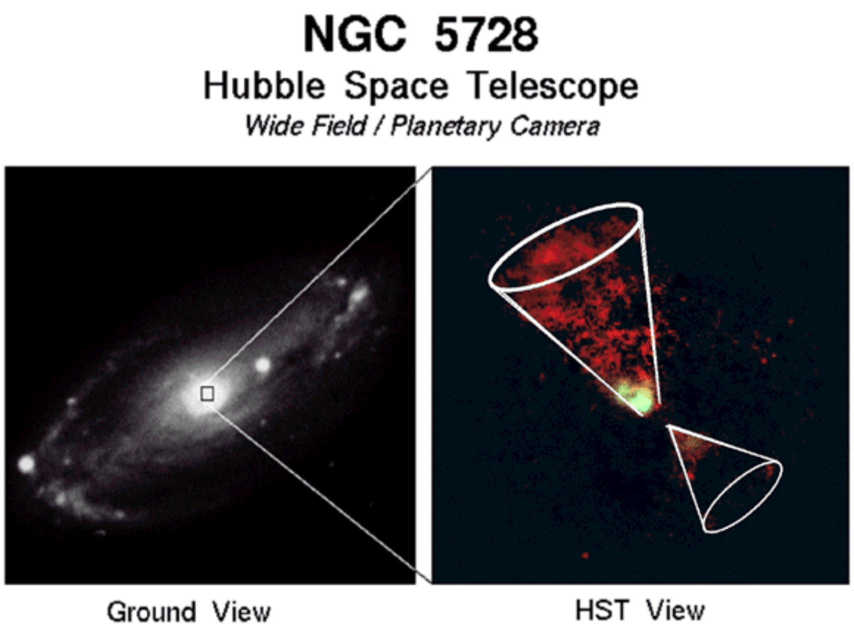
Thus, an Sy2 looks like an Sy1 in polarized emission!

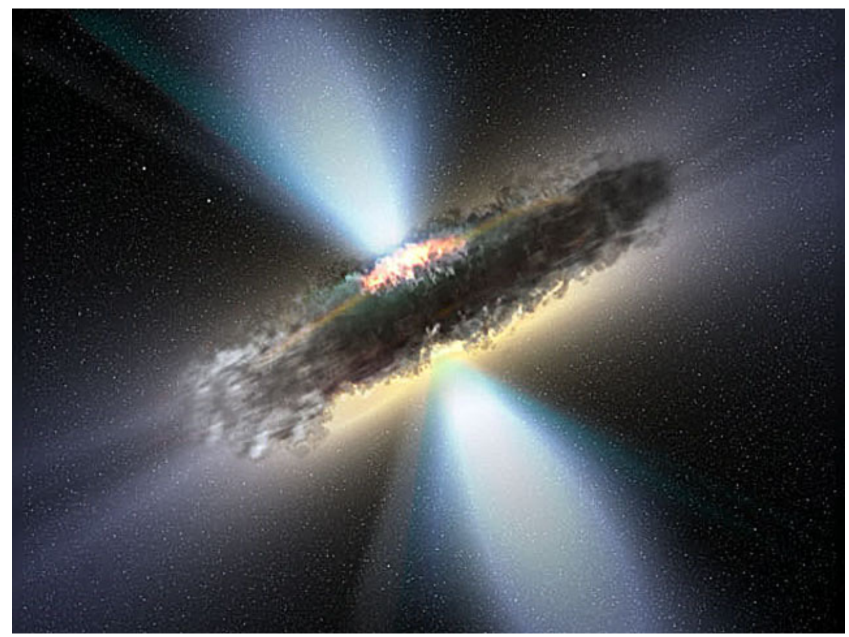
Some NLRGs also behave as Sy2s, showing hidden broad lines.



Support for unification:

2. Ionization cones: The UV emission arises in the accretion disk, illuminating gas in the galaxy. Emission can only escape in a cone, shaped by the torus.



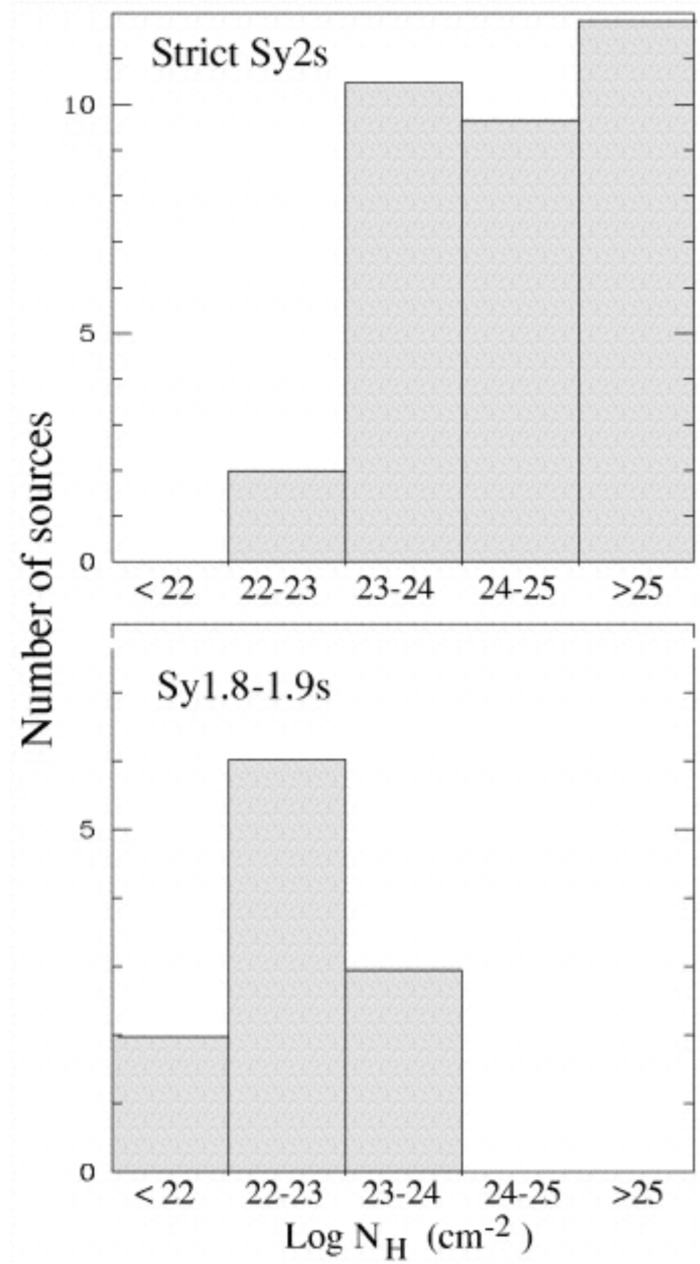


Support for unification

3. IR and N_H excess: The column of neutral H absorbing soft X-rays emitted by the nucleus is associated with dust in the torus. This provides an estimate of the dust content, and the corresponding attenuation.

Sy2s have the largest absorbing column densities: X-rays suppressed below 10 keV.

Sy2s also have colder IR colors than Sy1s: Explained if the torus is partially thick at mid-IR wavelengths.



Risaliti et al 1999

Support for unification:

4. Quasar host galaxies: RLQs have same hosts as FRII radio galaxies.

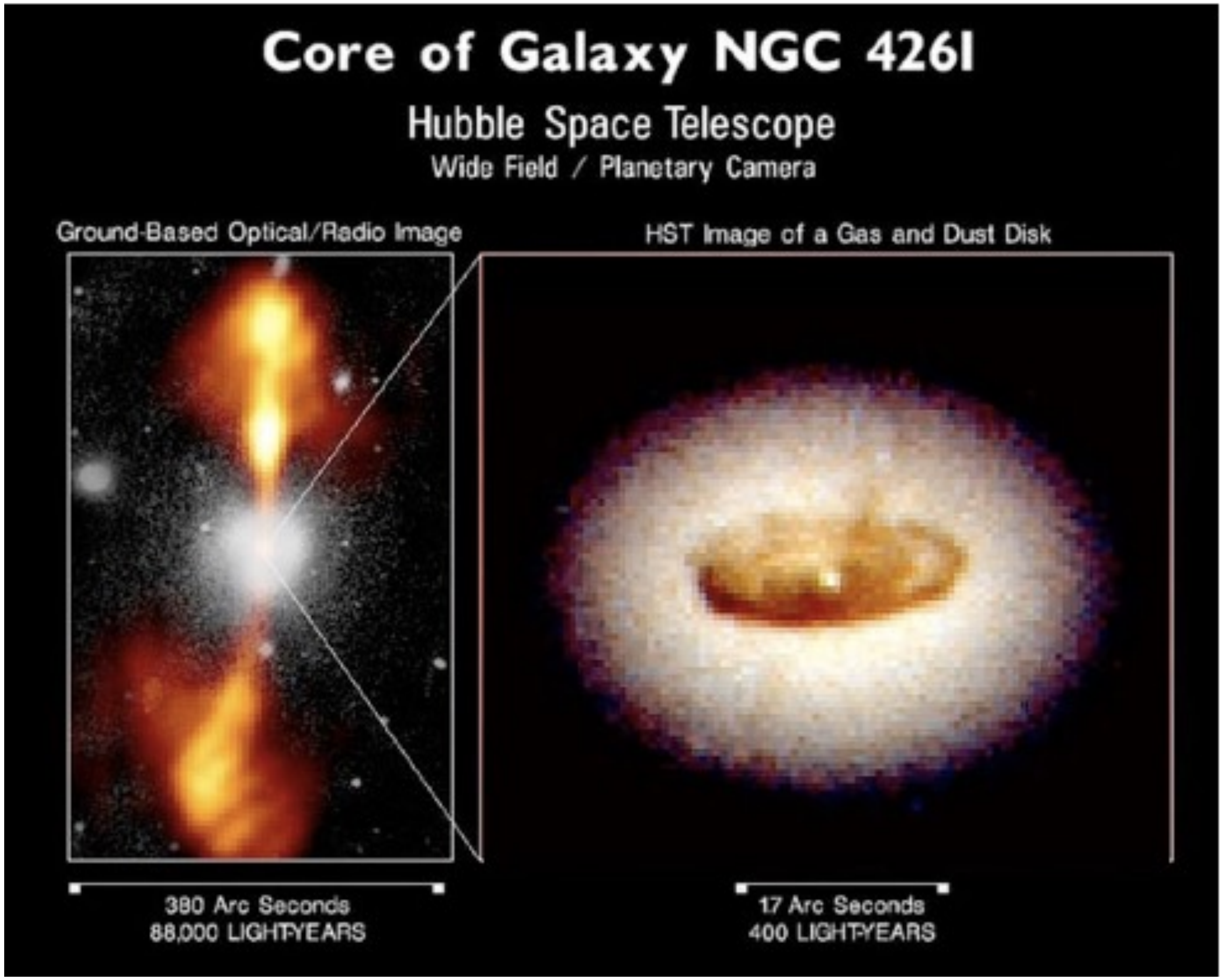
5. Number counts: a simple relationship is expected between number of RLQs and FRIIs based on the obscuring angle of the torus.

6. Environments: RLQs and FRIIs occupy similar environments: poor cluster/groups.

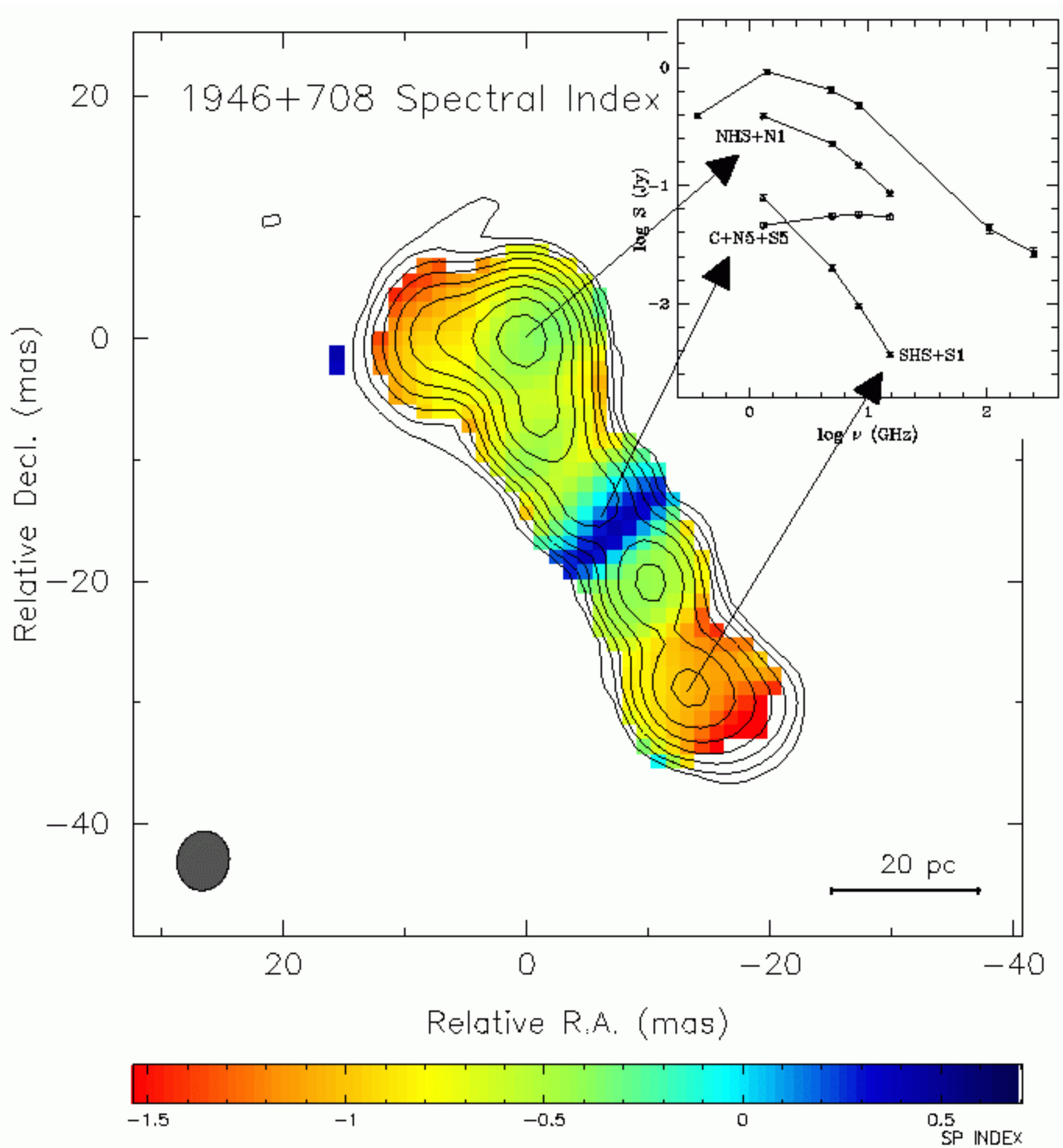
Blazars and FRIs appear to have the same host galaxies

Support for unification:

7. Direct imaging of torus



Free-free absorption in 1946+708



Peck & Taylor (2001)

Spectral index map from 1.3/5 GHz VLBI observations

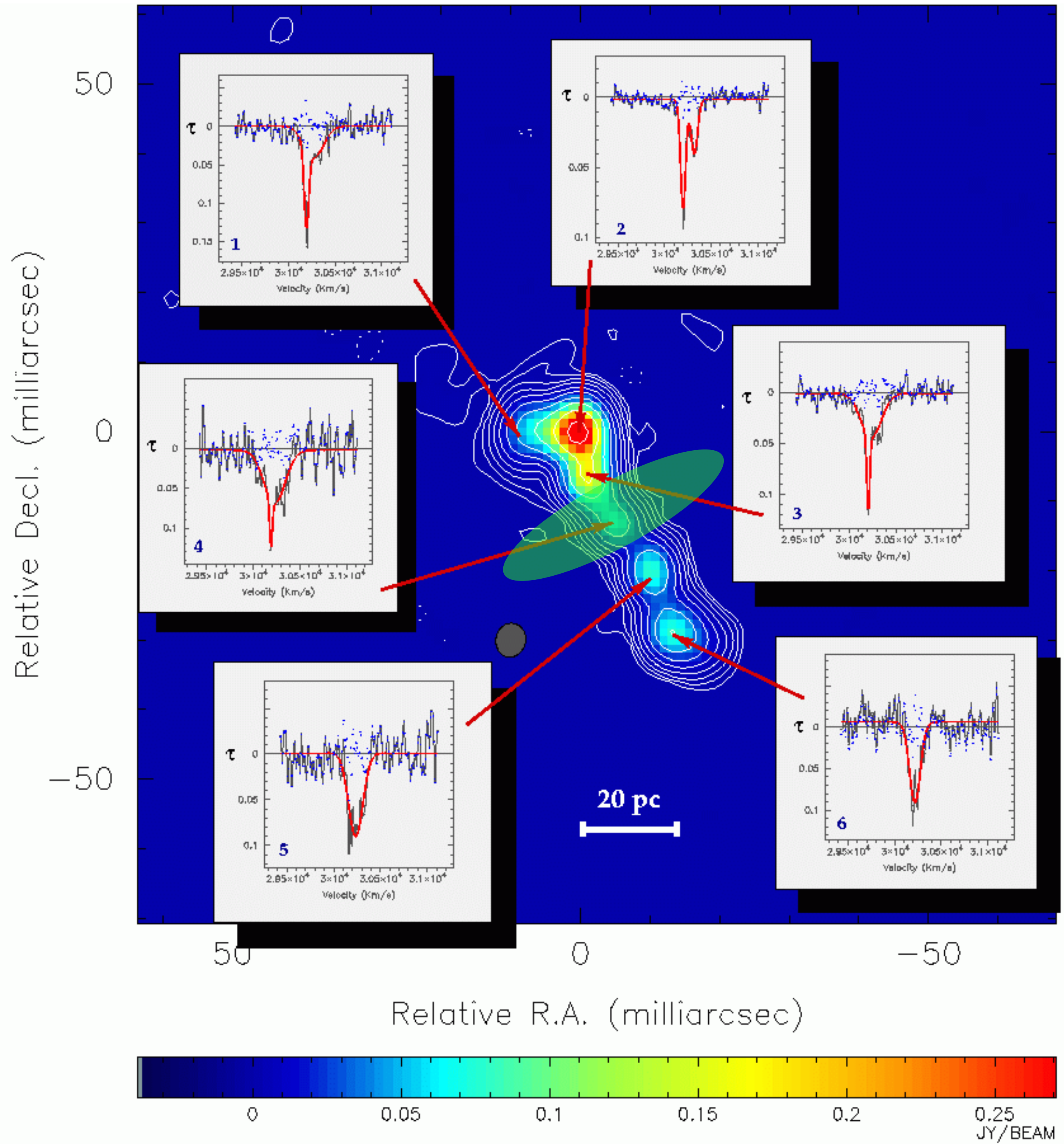
HI absorption in 1946+708

Peck & Taylor (2001)

"Global" VLBI observations

core:

M ~ 10^8 M_{sun}

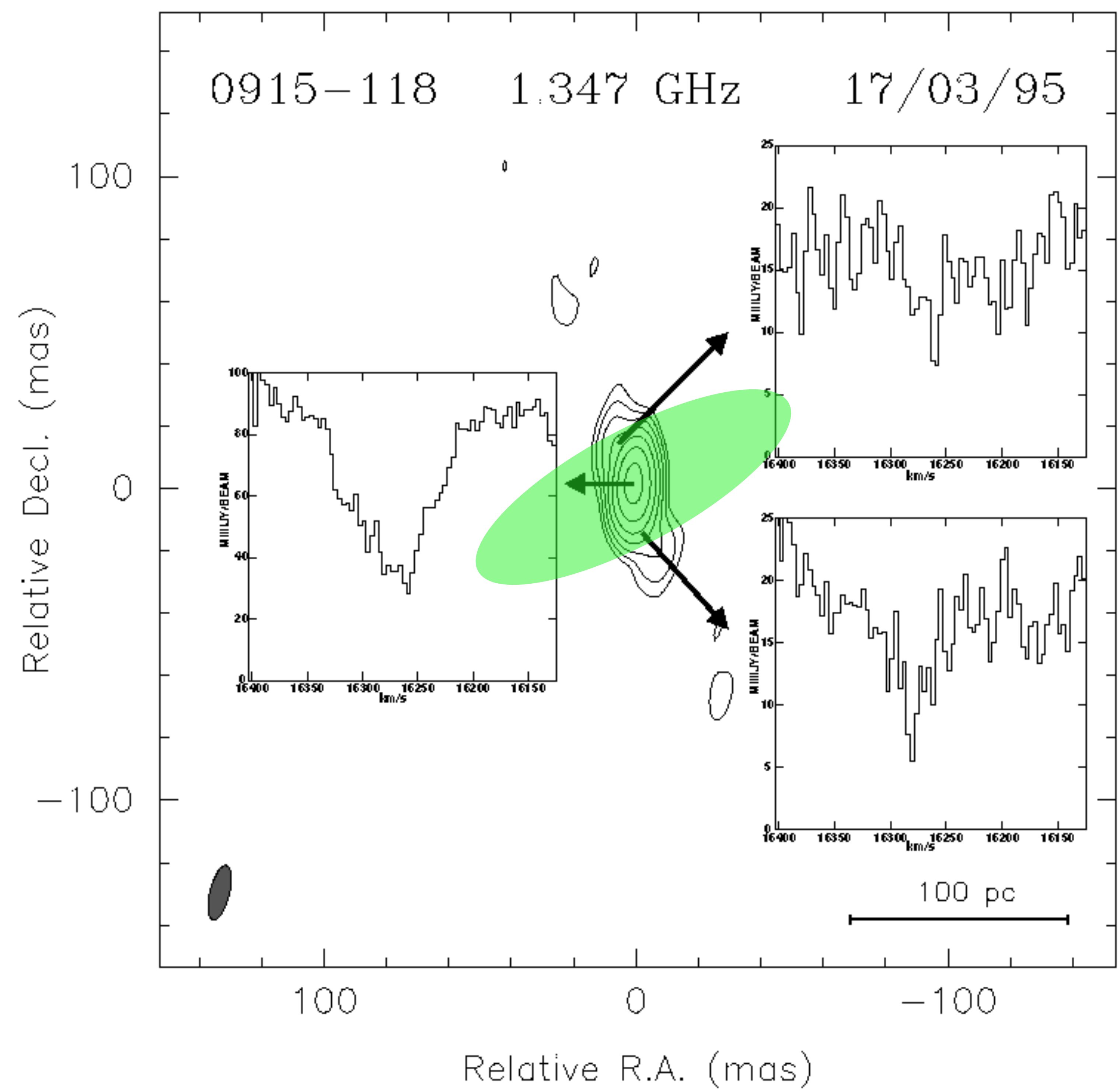


Hydra A

Taylor (1996)

core:

M ~ 2 x 10^7 Msun



NGC 4258

- Considered best evidence of a supermassive black hole
- Can estimate central mass
- Can estimate distance to host galaxy

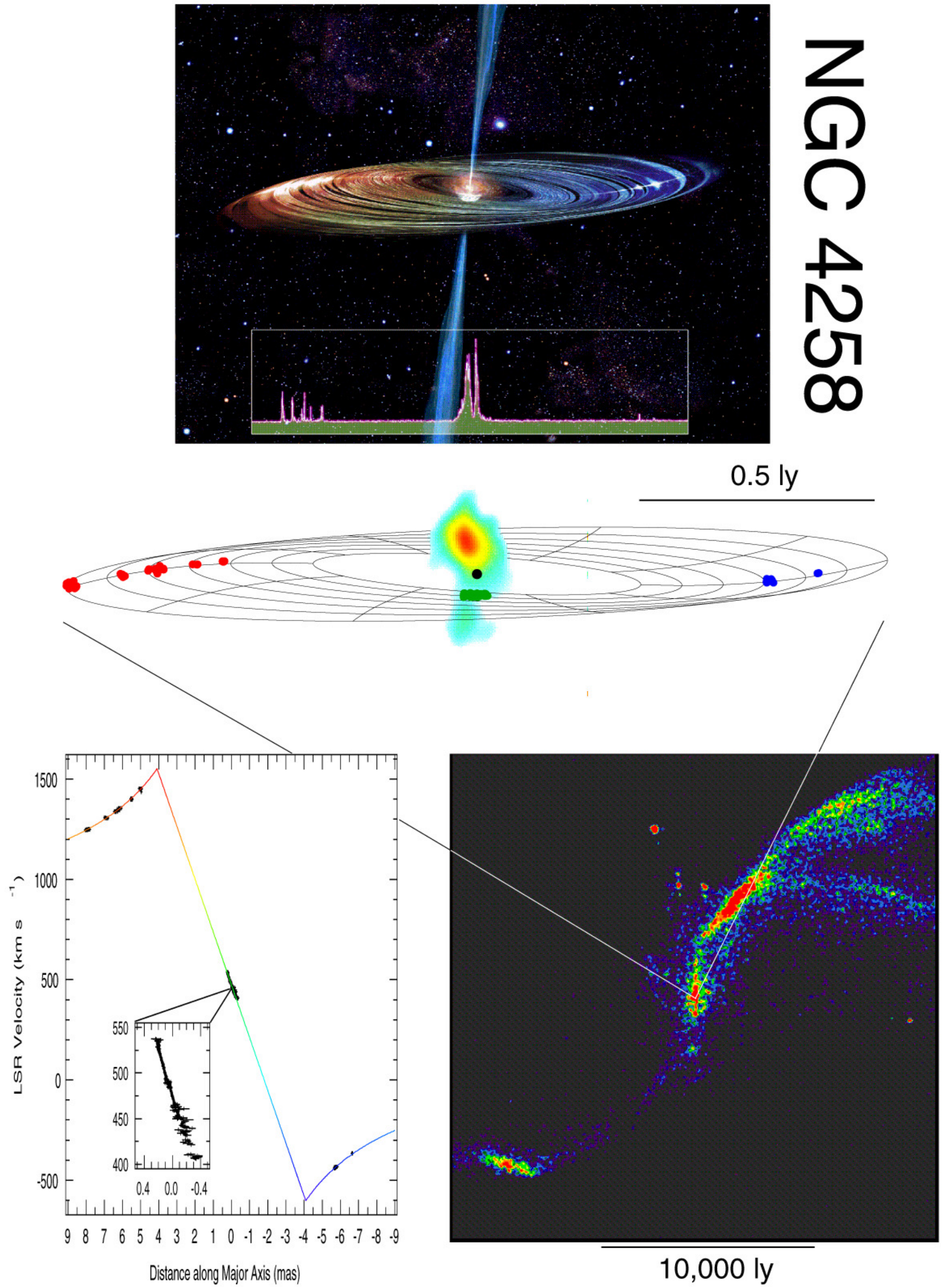
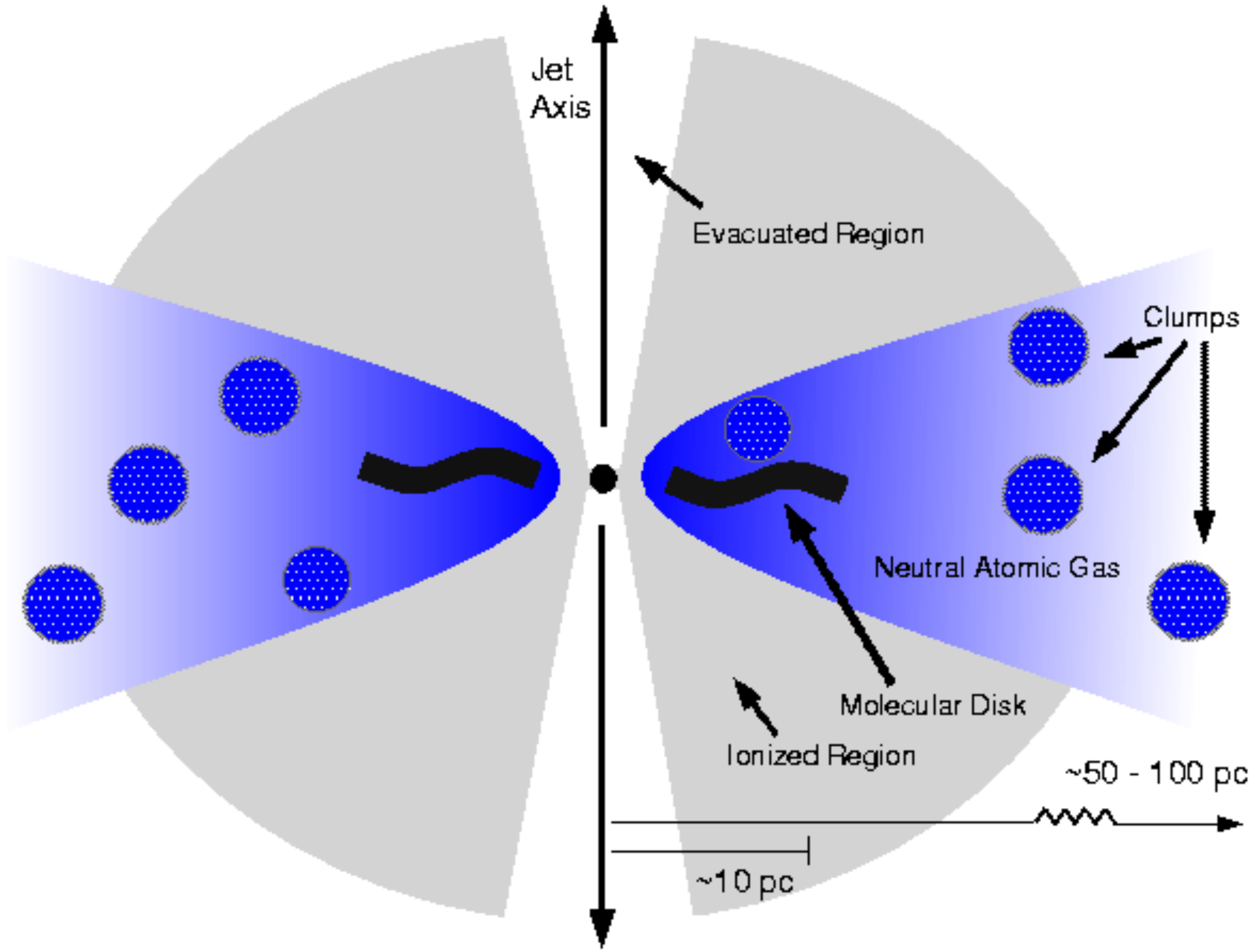
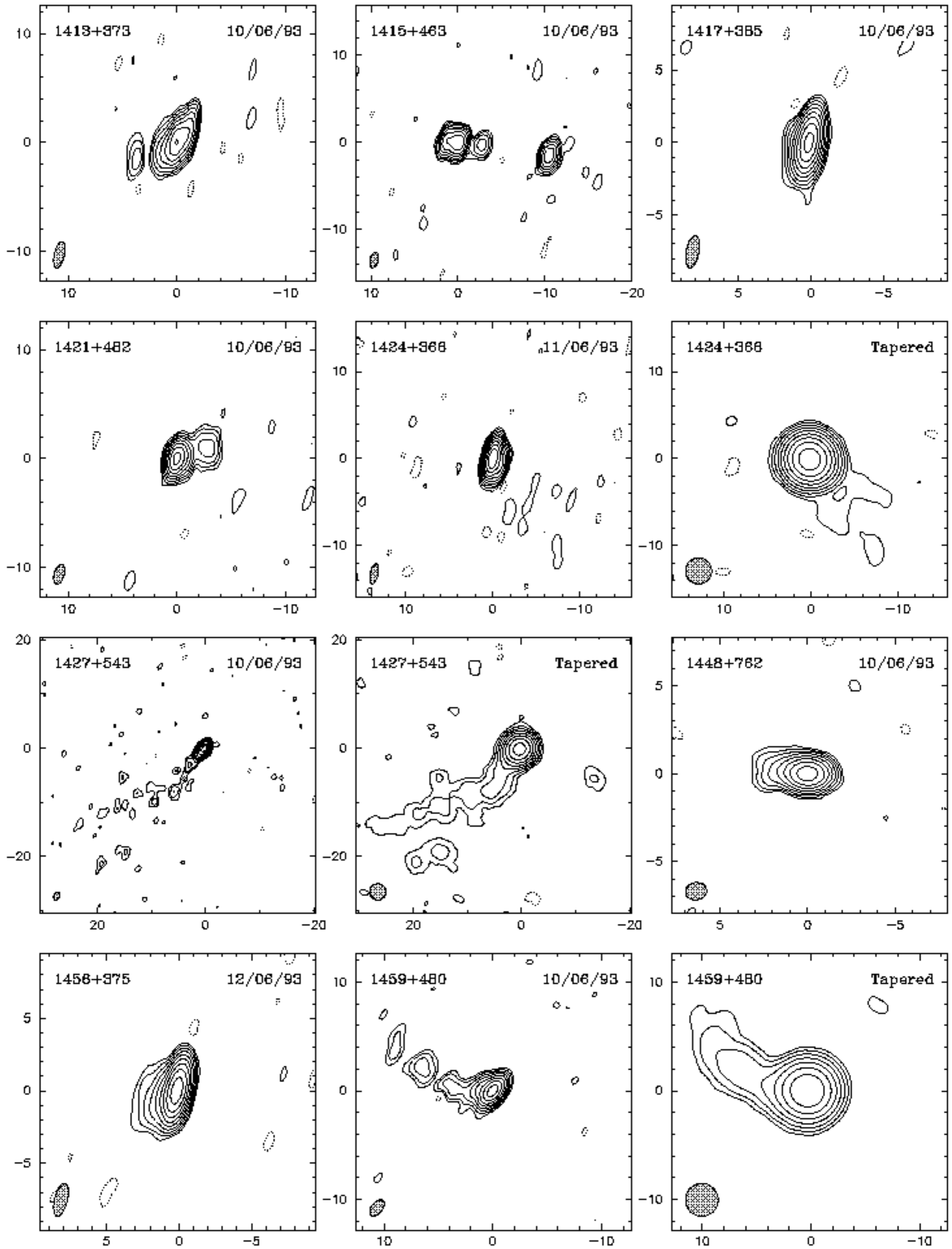


image courtesy Lincoln Greenhill
(see Miyoshi et al 1995
Herrnstein et al 1999)


Jet
Axis
Evacuated Region
Clumps
Neutral Atomic Gas
Molecular Disk
Ionized Region
~50 - 100 pc
~10 pc

VLBA Images At 5 GHz



30 pc

Superluminal motion

Pearson et al. 1981

constant expansion observed at

rate = $\Delta\theta$/year = 0.76 ± 0.04 mas/year

$z = 0.158$ so $D \approx 940$ Mpc

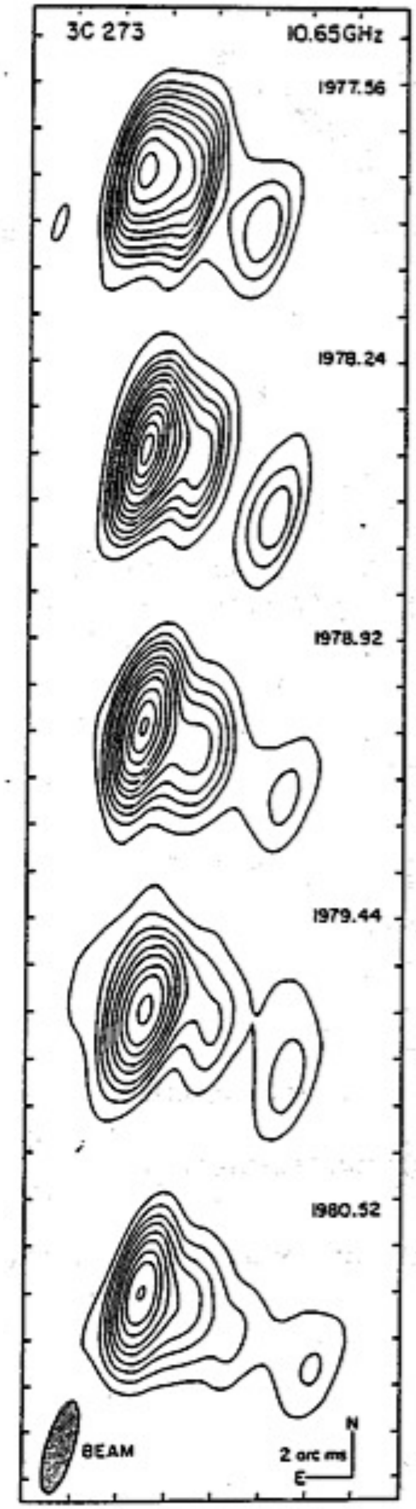
assuming $H_0 = 50$ km sec^{-1} Mpc^{-1}.

1 mas = 10^{-3} arcsec = 4.85×10^{-9} radians

$d = D\Delta\theta$ so the apparent transverse velocity, or rate = d/year

= 10 lt-years/year

= 10 c [!!]



- **Worksheet:** Superluminal motion. Consider a radio source with a jet that makes an angle ϕ to the line-of-sight to the Earth. At time $t=0$ a component emits radio emission that we detect at time $t_1 = 0 + D/c$ where D is the distance to the source. At some later time $t=t'$ we observe again at time $t_2 = t' + (D - x)/c$ and see that the component has moved. The jet has an intrinsic velocity v so the component moves a distance $vt'\cos\phi$ in the x direction and $vt'\sin\phi$ in the y direction. Derive the projected velocity in the y direction and show that it can be greater than c.

Journal Class

- **The search for Population III: Confirmation of a HeII emitter with no metal lines at z=10.6**
- Maiolino, R. et al. 2026

Discussion leader: **Sara Stamer**

Note: To encourage discussion everybody must pose at least one question during the group discussion

Velocity Structures

Evidence for limb brightened jet morphology on the parsec scale
is present in some FR I radio galaxies:
1144+35, Mkn 501, 3C 264, M87, 0331+39…….