Classification and unification of AGN

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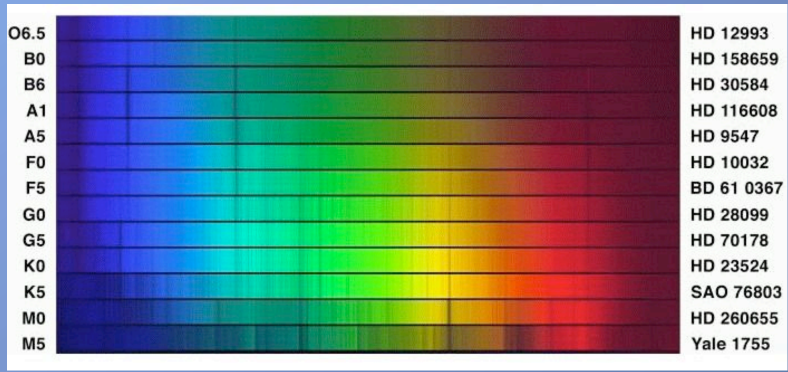
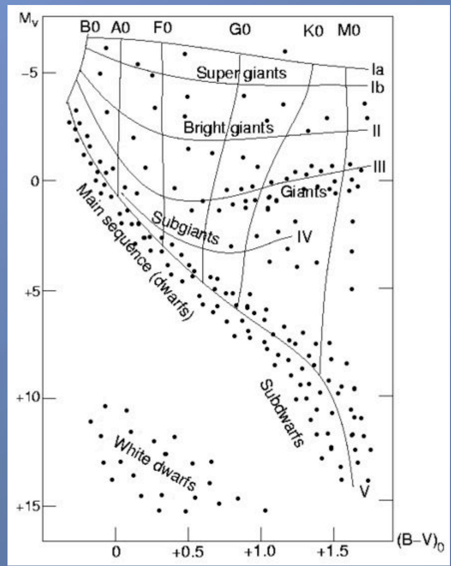
(University of Sheffield)

Stellar spectral classification

- 1863 - 1866: Secchi's first attempts at stellar spectral classification
- 1890 - 1912 Harvard spectral classification sequence developed (Maury, Cannon, Pickering..)
- 1913: Bohr's work on the structure of the Hydrogen atom
- 1920: Saha develops theory of ionization equilibrium in stars
- 1925: Payne-Gaposhkin interprets spectral classification sequence in terms of T variations along the main sequence





Common features of AGN

- High luminosity $(1 - 10{,}000 \times L_{MW})$
- Variability (days to years)
  ➔Compact (light day to light year)
- Ability to produce highly collimated jets
- Long lifetimes (10^3 -- 10^8 yr)

➔ *Most plausible energy generation mechanism is accretion of gas close to a supermassive black hole*

Properties used in classification

- Optical spectroscopic
  - Presence or absence of broad permitted lines
  - Ionization and luminosity of narrow lines
  - Presence of broad absorption lines
- Optical morphology

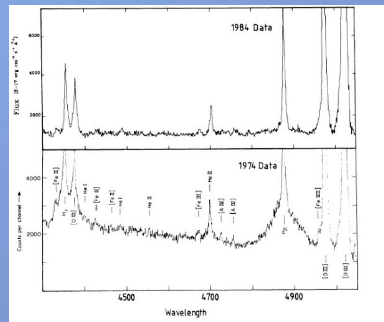
  e.g. Point like or clear galaxy host
- Radio properties
  - Presence of radio jets
  - Radio morphology
  - Radio spectrum
- Variability
- Overall shape of continuum SED from X-rays to radio

Main AGN Classifications

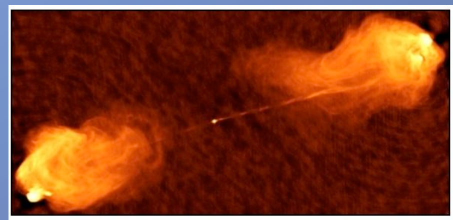
Radio quiet		Radio loud
Radio quiet quasar (RQQ) *Broad absorption line (BAL)* **Seyfert 1** *Sy 1.0.....1.9* *Narrow line Sy 1 (NLS1)*	Type 1	**Radio loud quasar** (RLQ) *Steep radio spectrum (SSQ)* *Flat radio spectrum FSQ)* **Broad line radio galaxy** (BLRG)
Seyfert 2 *NL X-ray galaxy (NLXG)*	Type 2	**Narrow line radio galaxy** (NLRG)
LINER	Type 3	**Weak line radio galaxy** (WLRG)
	Type 0	**BL Lac/Blazar/OVV**
		Fanaroff Riley class I (FRI) **Fanaroff Riley class II** (FRII)

Main divisions in AGN types

- Broad line/narrow line:
  - Seyfert 1/Seyfert 2
  - BLRG/NLRG

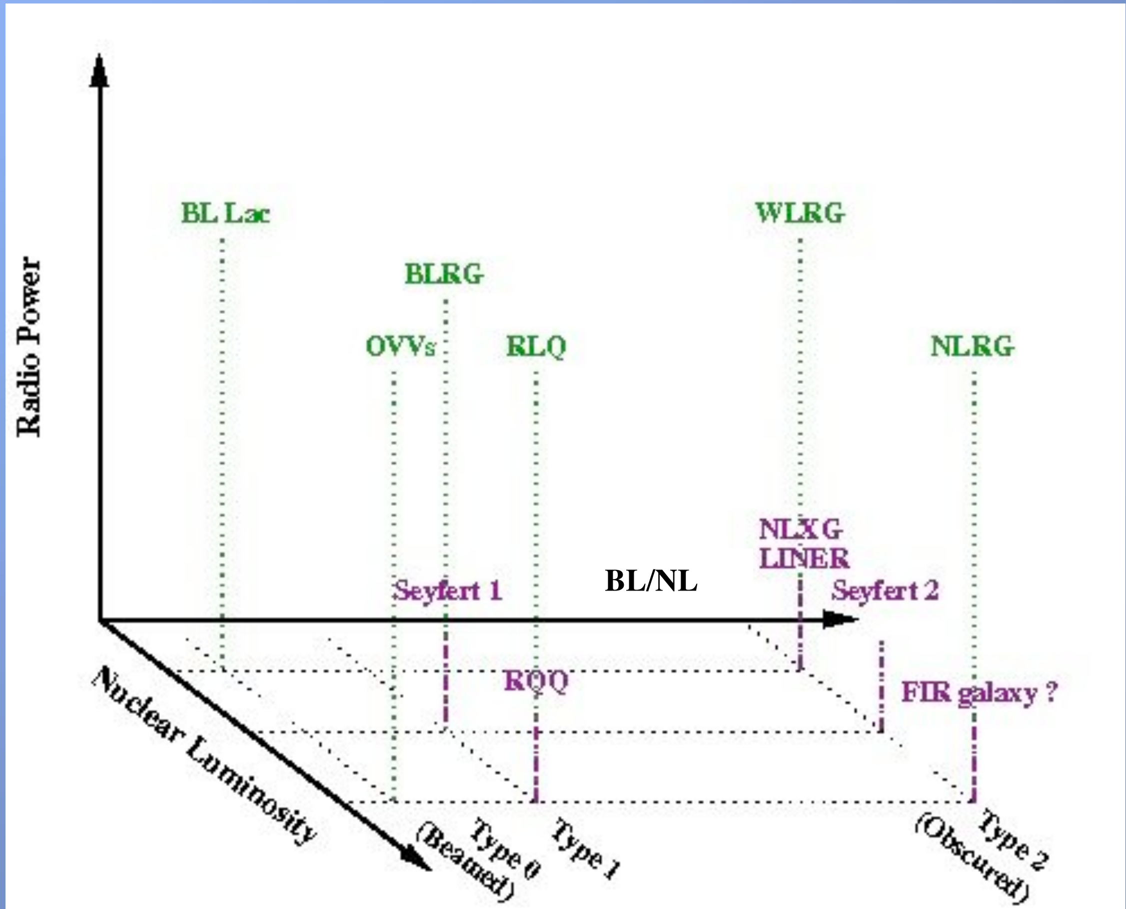


- Radio quiet/radio loud:
  - Seyfert 1/BLRG
  - Seyfert 2/NLRG
  - LINER/WLRG



- Luminosity:
  - RQQ/Seyfert 1
  - RLQ/BLRG

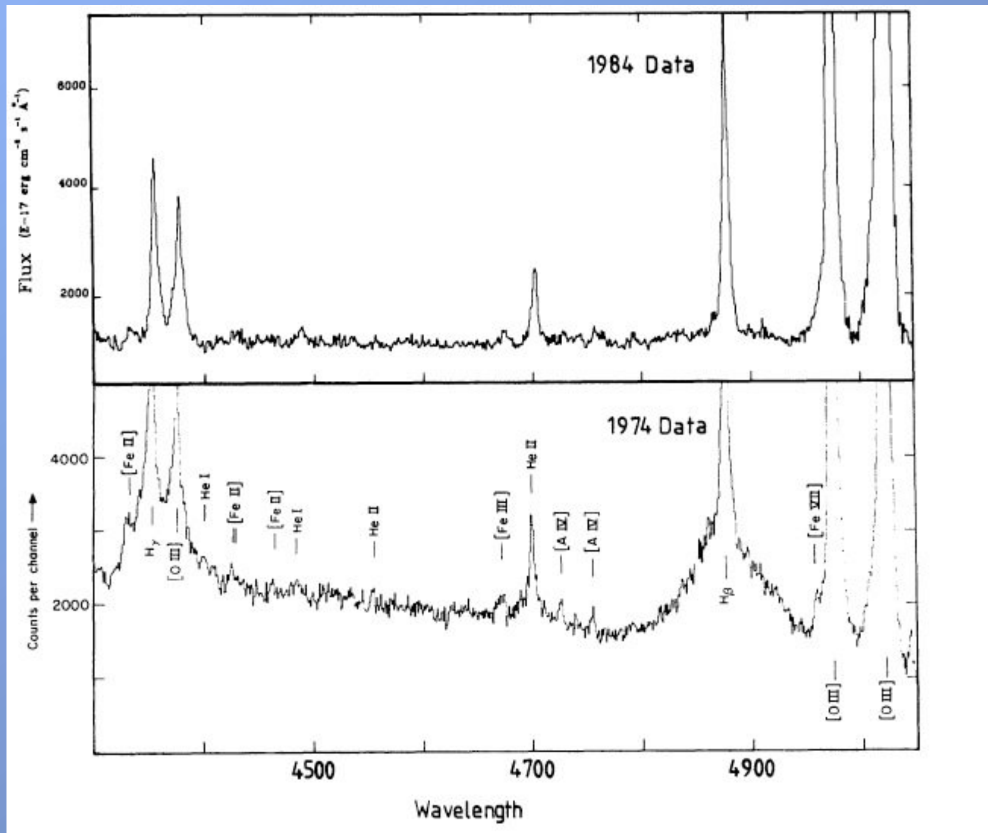
AGN Classification



AGN Classification Difficulties

- Mixing up different methods of classification
- Forcing a continuous range into discrete bins
- Different classifications at different wavelengths, partly reflecting historical and cultural factors
- Classifications change with improved technology/techniques
- The classification of a particular object may change with time, reflecting intrinsic variability

The disappearing Sy1 in NGC4151



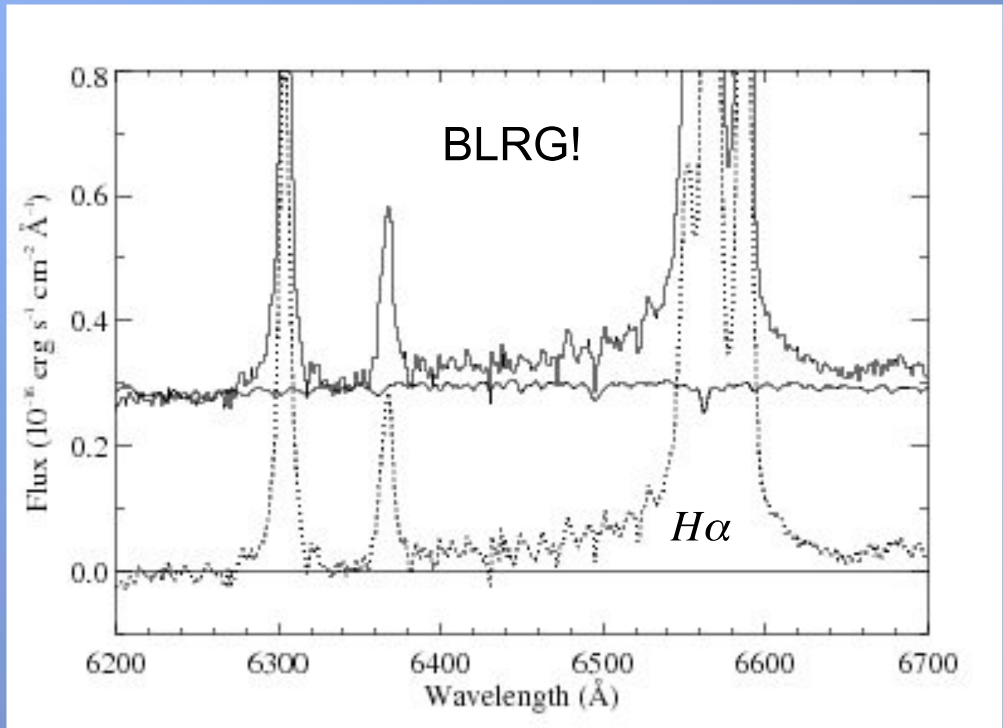
Penston & Perez (1984)

HST detection of quasar host galaxies

Bahcall & Disney (1996)

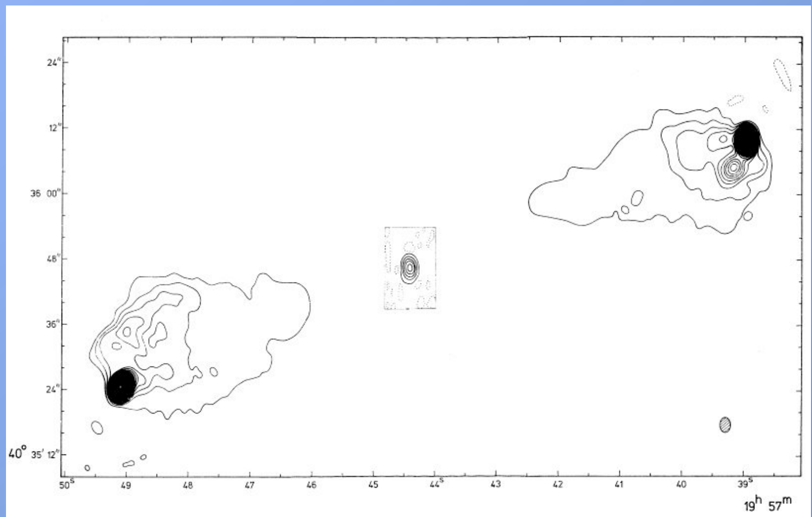
The difficulty with detecting broad lines -- the case of PKS1932-46

PKS1932-46

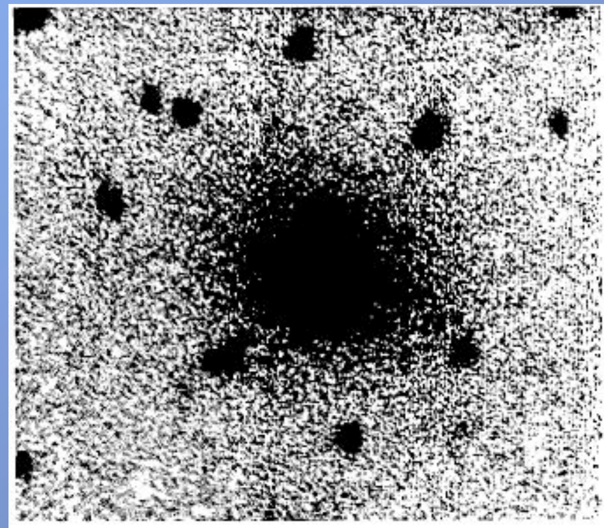


ESO VLT 8m

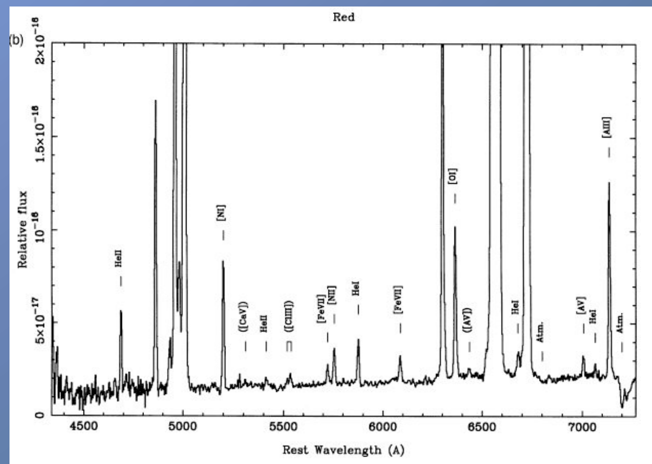
Cygnus A: the archetypal powerful radio galaxy



Radio map (5GHz)
Hargrave & Ryle (1974)



Optical image
Thompson (1984)

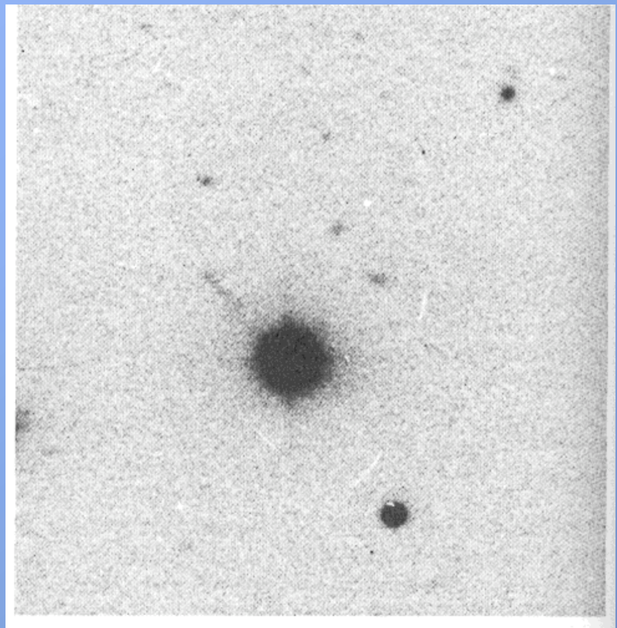


Optical Spectrum
Tadhunter et al. (1994)

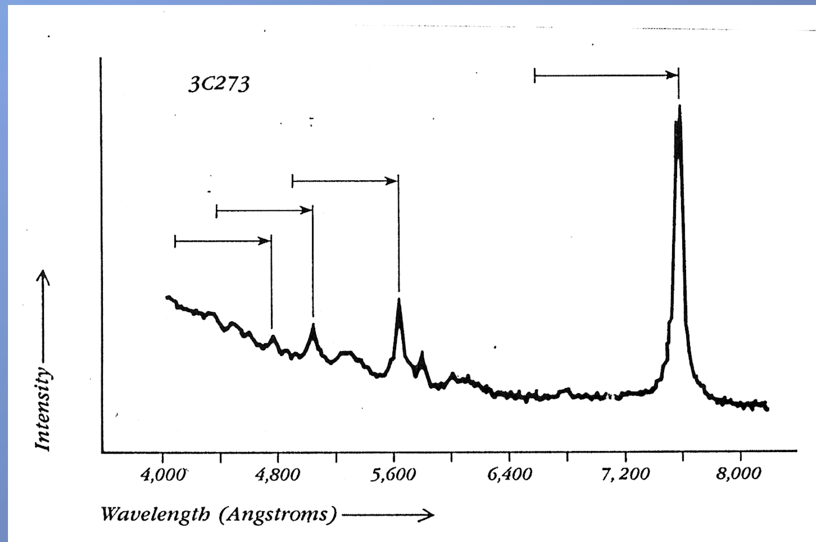
The discovery of the quasar 3C273

(Schmidt 1963)

Optical image



Optical spectrum   z=0.158



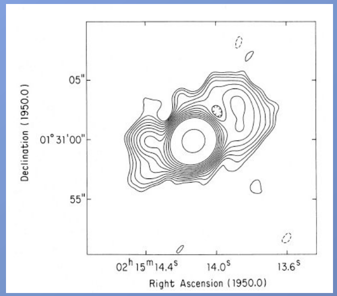
Major types of radio-loud quasars

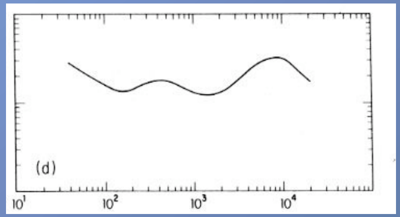
Flat spectrum radio quasar (FSRQ)

* Flat radio spectrum integrated emission
* Core dominated
* Often rapidly variable:

  Optically violent variable (OVV)

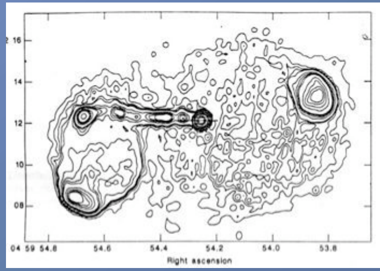
  or Blazar

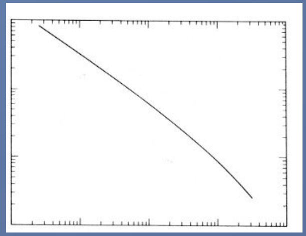




Steep spectrum radio quasar (SSRQ)

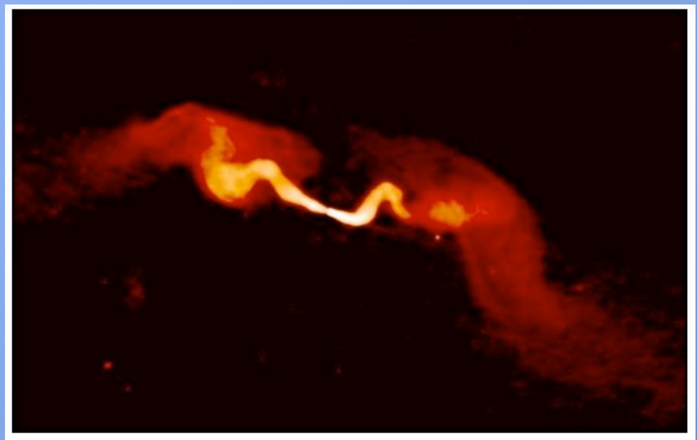
* Steep radio spectrum integrated emission
* Dominated by core and jet emission





FRI/FRII Radio Morphology Classification

Fanaroff-Riley ClassI

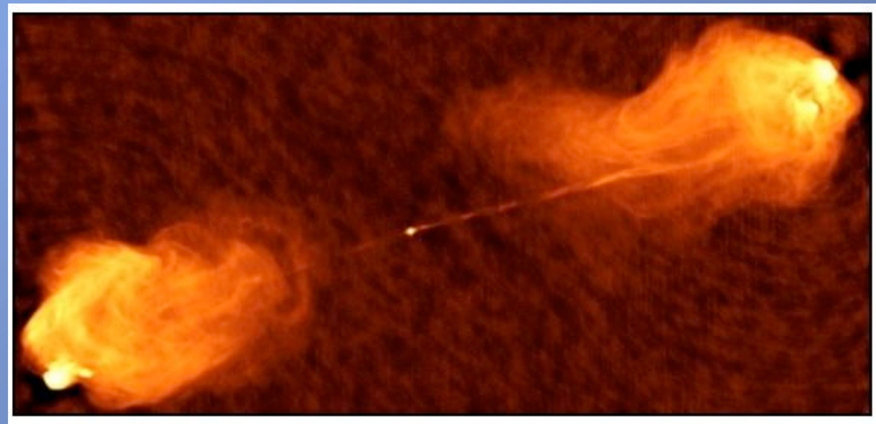


Edge-darkened

$P_{178Mhz} < 5 \times 10^{25}\ W\ Hz^{-1}$

All FRIs classified as WLRG

Fanaroff-Riley ClassII

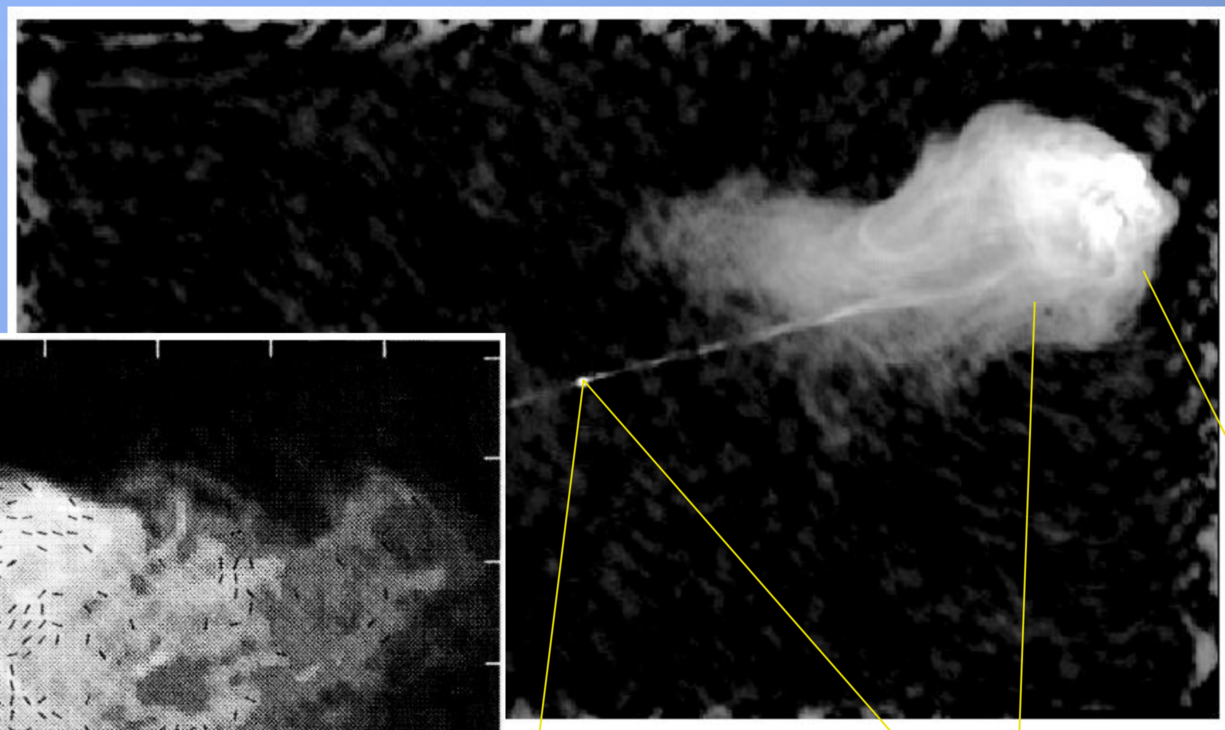


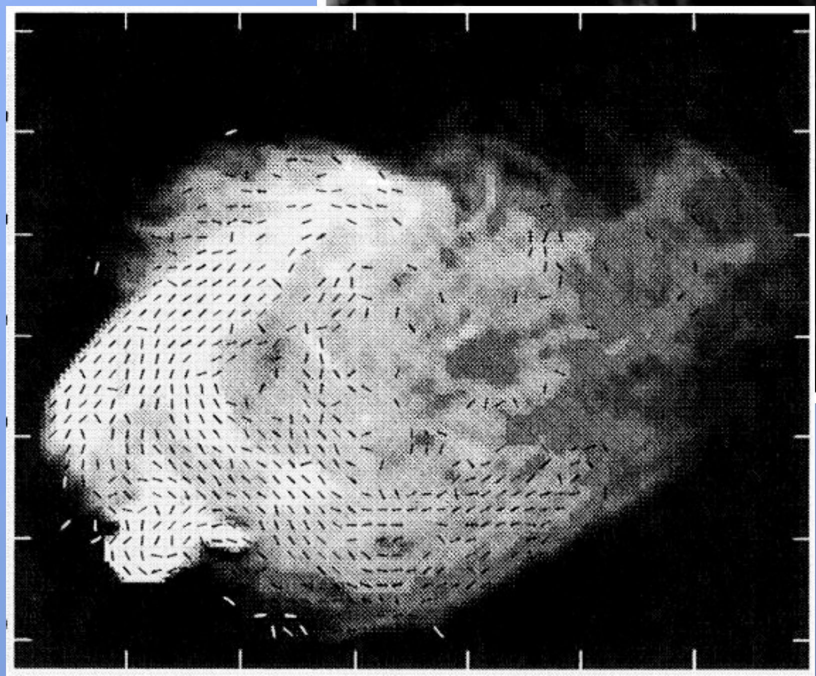
Edge-brightened

$P_{178Mhz} > 5 \times 10^{25}\ W\ Hz^{-1}$

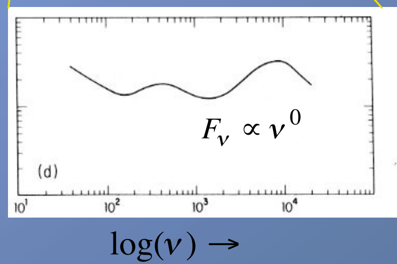
FRIIs mainly classified as NLRG/BLRG/RLQ

Radio properties

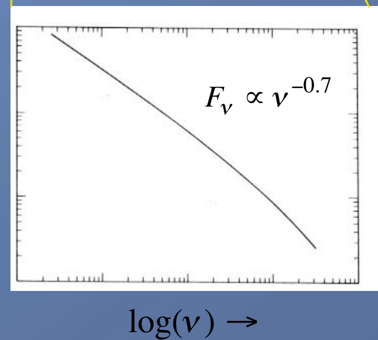




High polarization

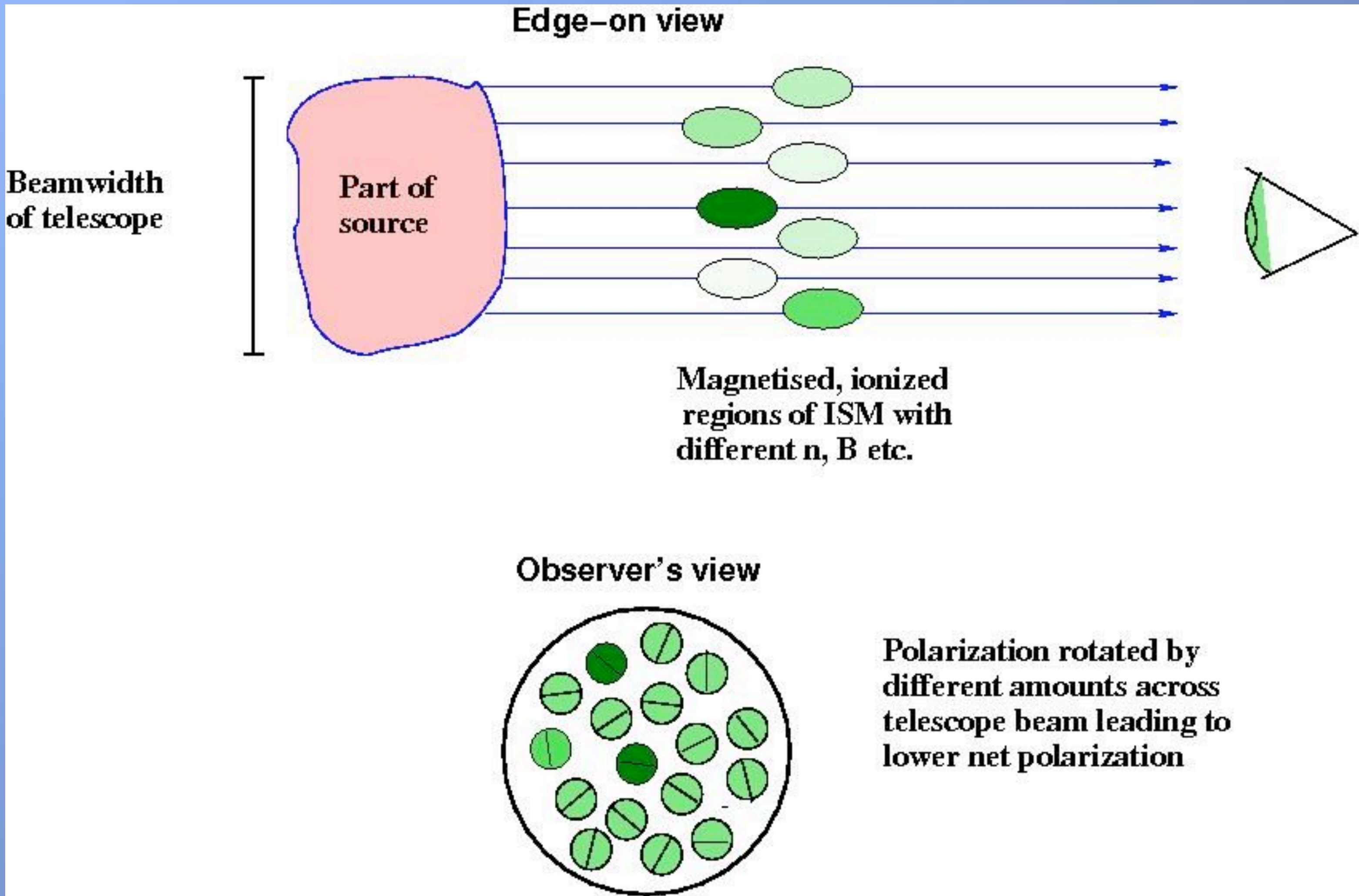


Flat spectrum cores

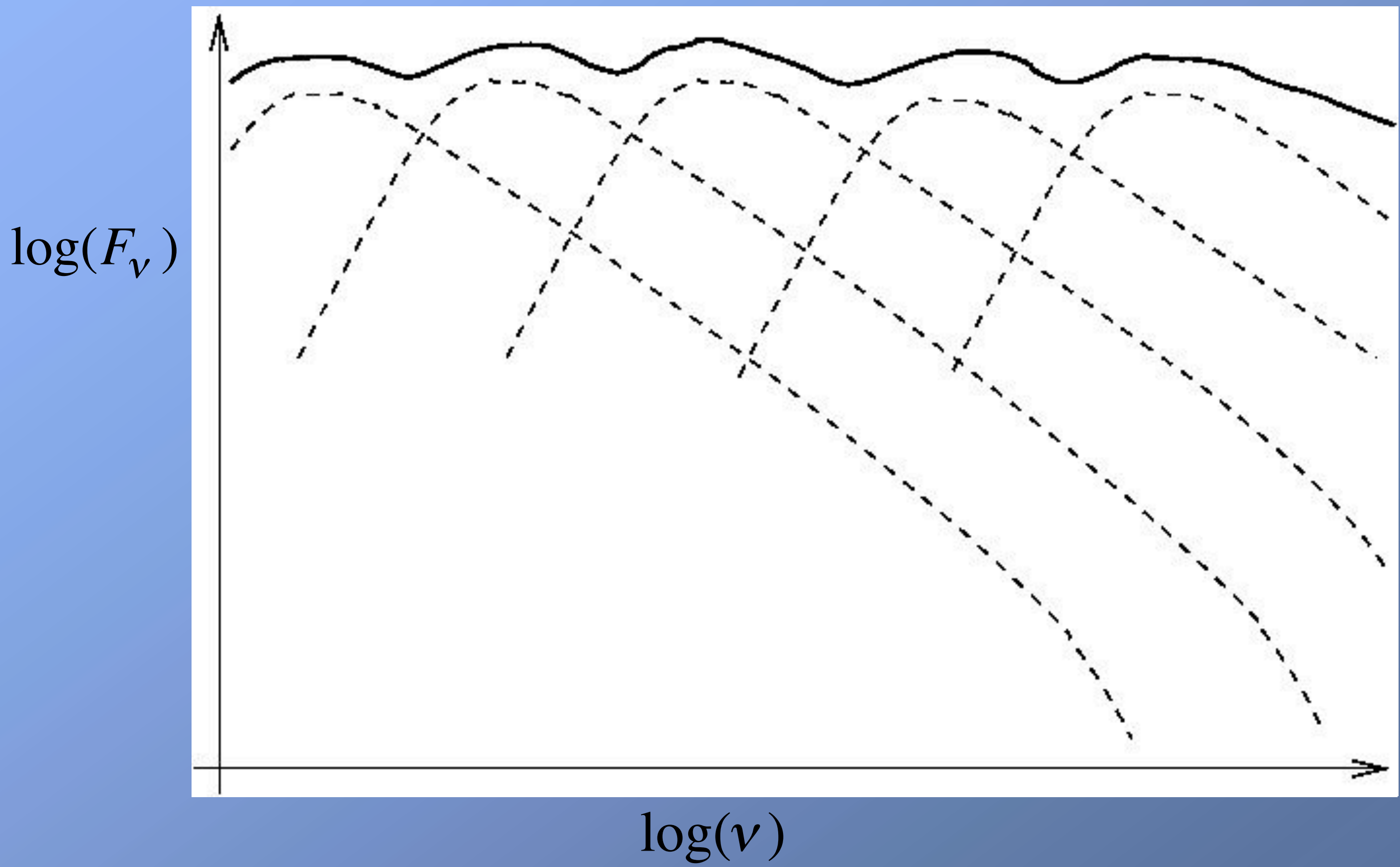


Steep spectrum lobes

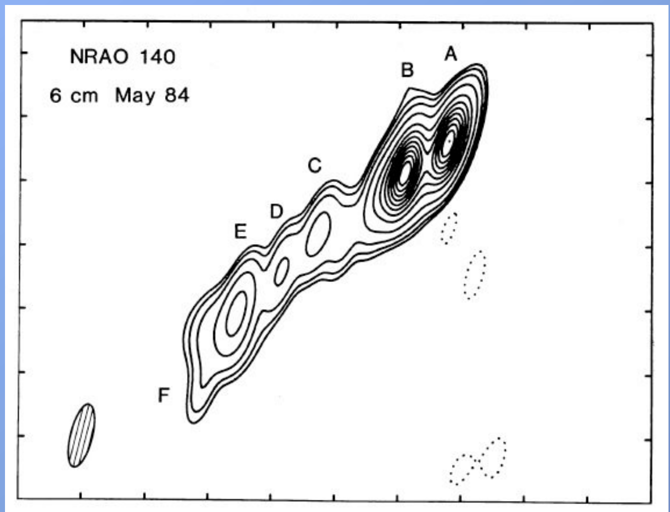
Faraday Rotation and Depolarization

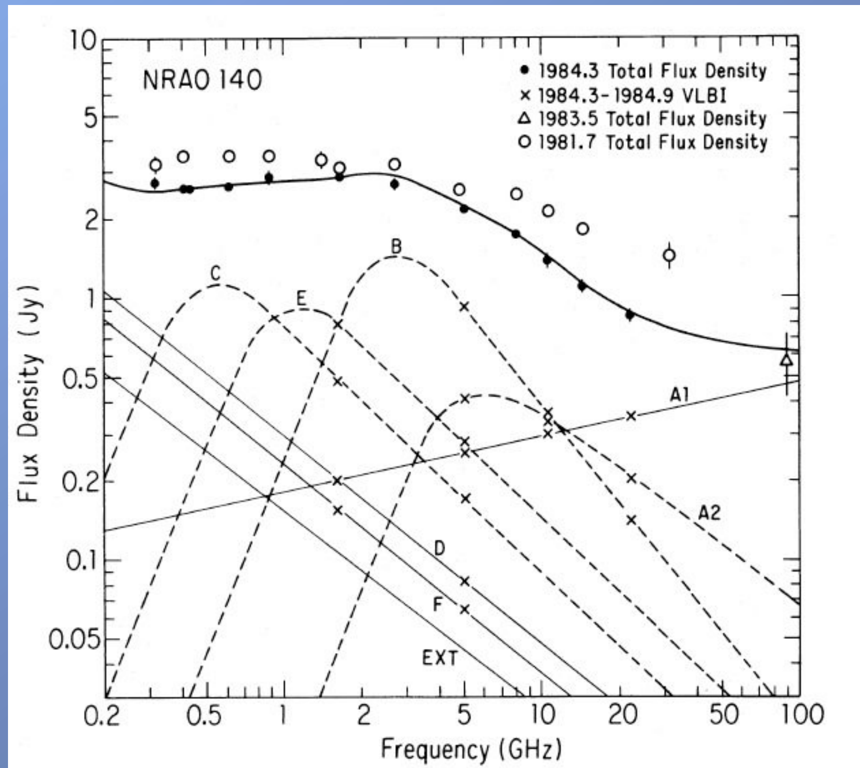


Steep spectrum/flat spectrum components



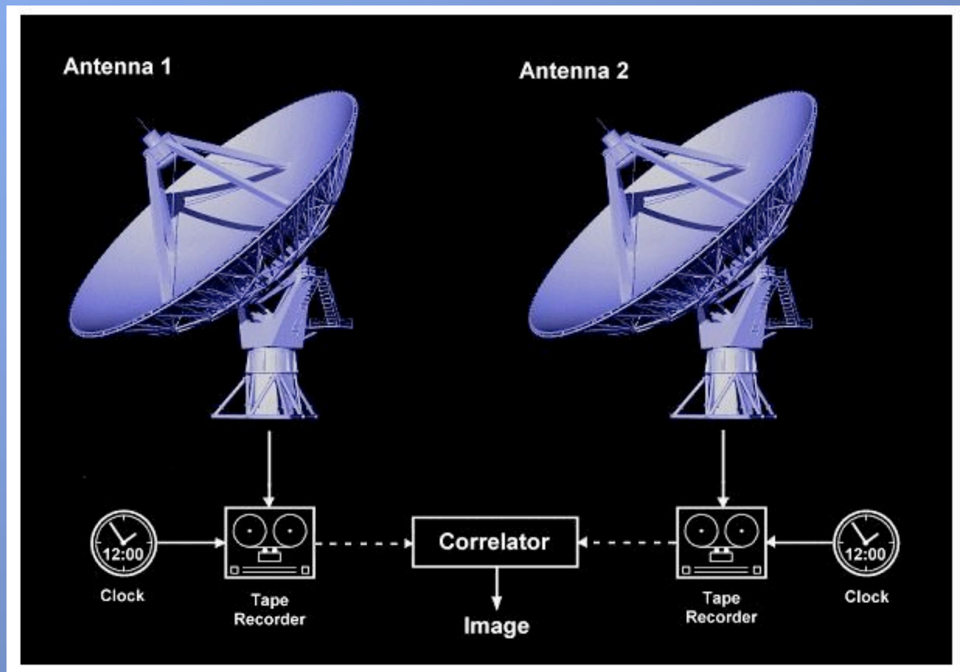
The self-absorbed core in the compact radio source NRAO140





Marscher et al. (1988)

Very long baseline interferometry (VLBI)



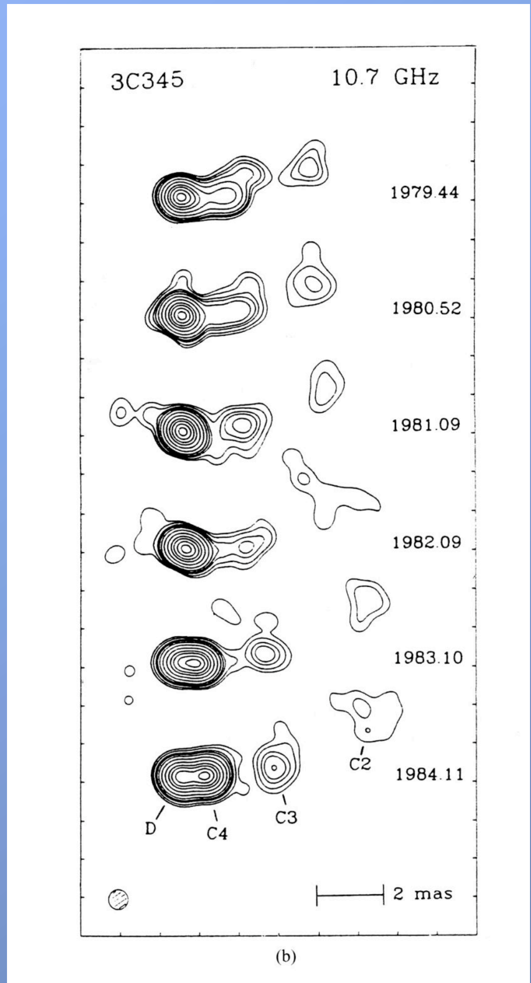
Resolution:

$$\delta\theta \approx \lambda / D$$

$$\lambda_{radio} > 10^5 \lambda_{optical}$$

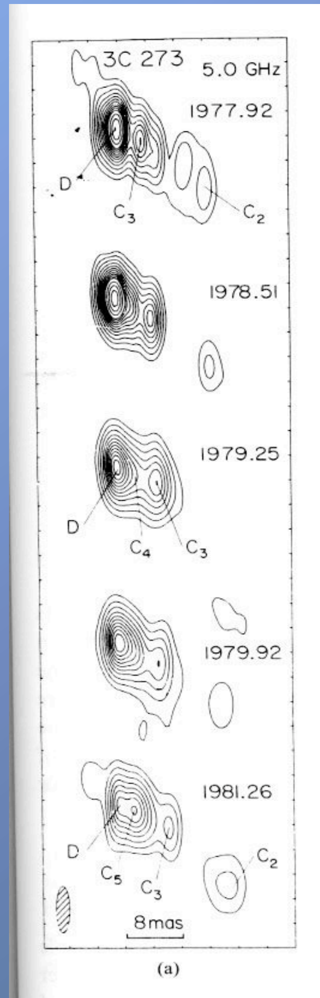
Superluminal motion in radio jets-I

Cohen et al. (1977)



$\beta_{app} \sim 15$

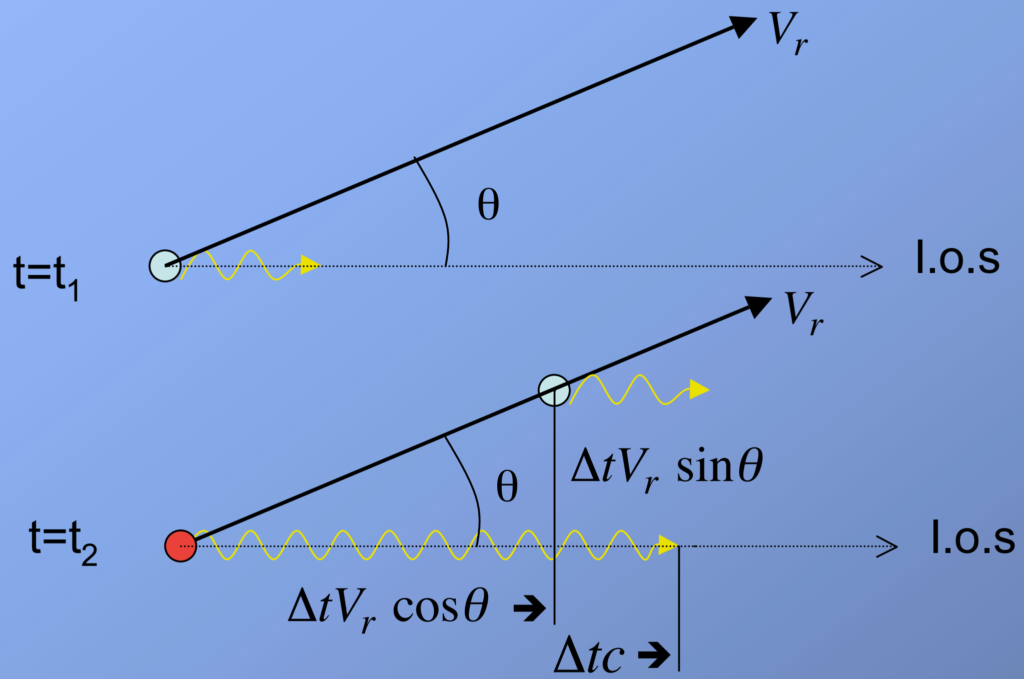
Biretta et al. (1986)



$\beta_{app} \sim 6$

Pearson et al. (1981)

Superluminal motion-II The explanation



Difference in arrival time of photons: $\Delta t' = \dfrac{\Delta t c - \Delta t V_r \cos\theta}{c} = \Delta t\left(1 - \dfrac{V_r}{c}\cos\theta\right)$

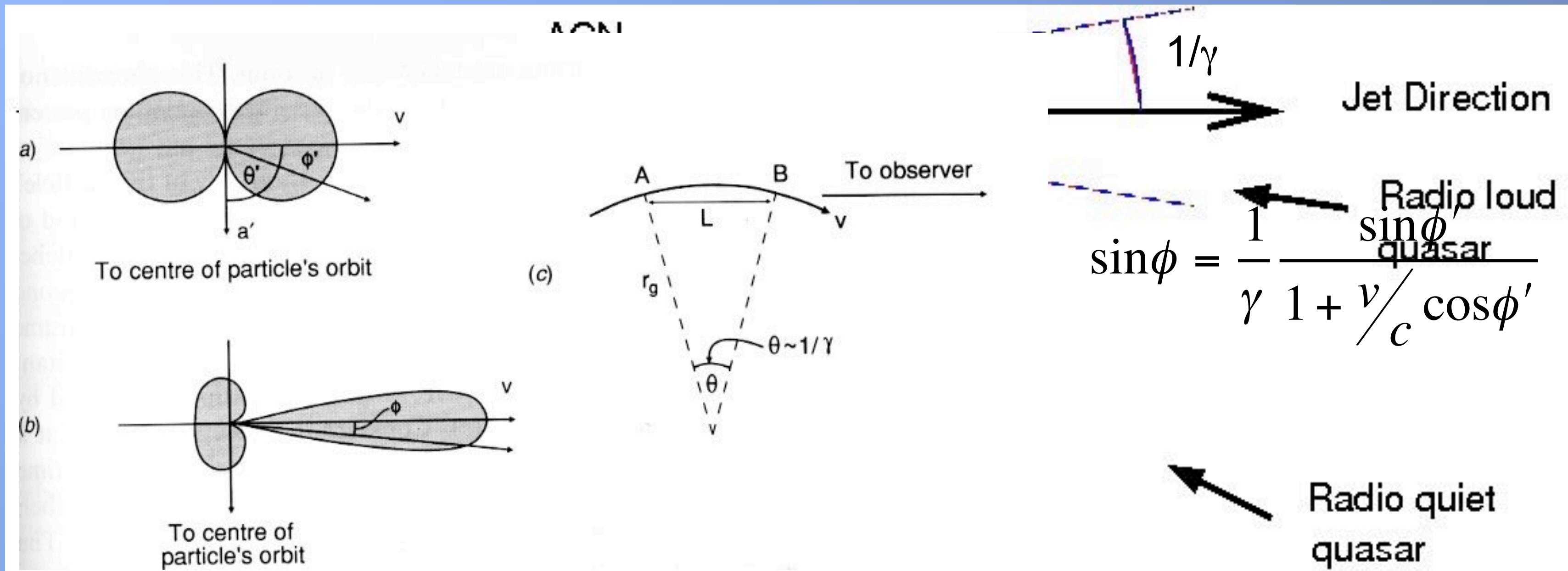
Apparent transverse velocity: $V_{app} = \dfrac{\Delta t V_r \sin\theta}{\Delta t'} = \dfrac{V_r \sin\theta}{1 - \dfrac{V_r}{c}\cos\theta}$

$\beta_{app} = \dfrac{\beta_j \sin\theta}{1 - \beta_j \cos\theta}$

$\therefore\ For\ \ \beta_j \approx 1,\ \theta\ small \Rightarrow \beta_{app} \gg 1$

Apparent superluminal motion is observed when relativistic jets are pointing close to l.o.s.

The first unified scheme based on beaming

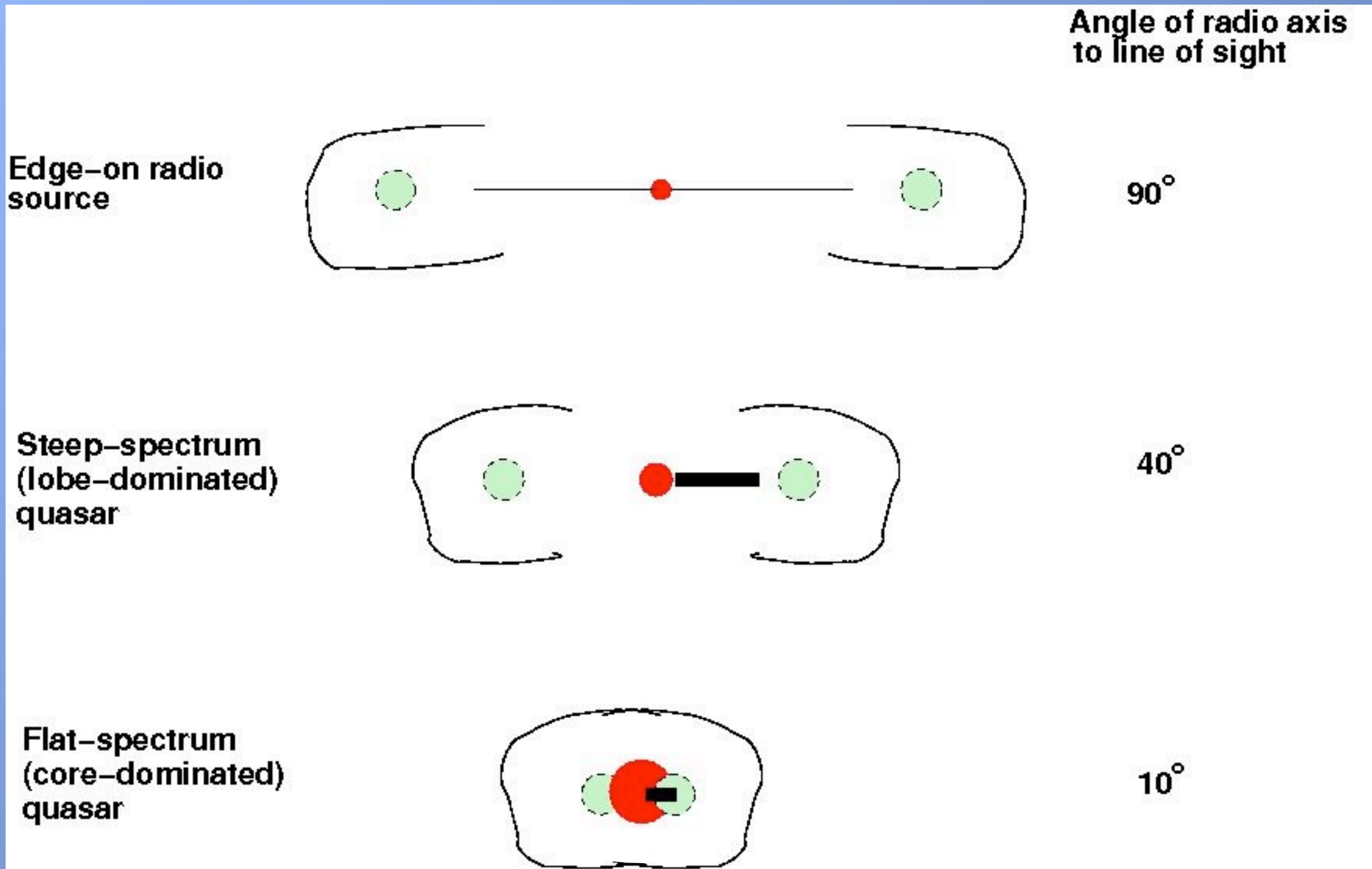


- Radio emission from relativistic jets beamed into narrow cones of width 1/γ

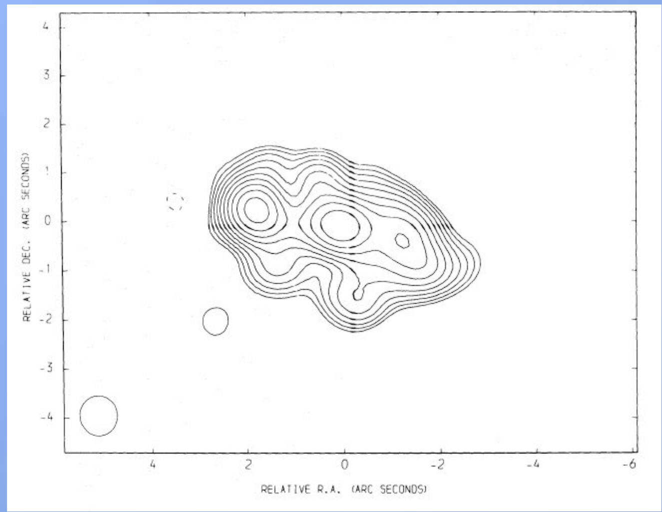
- The object appears as radio-loud or radio quiet quasar depending on whether the observers l.o.s. is inside or outside the cone

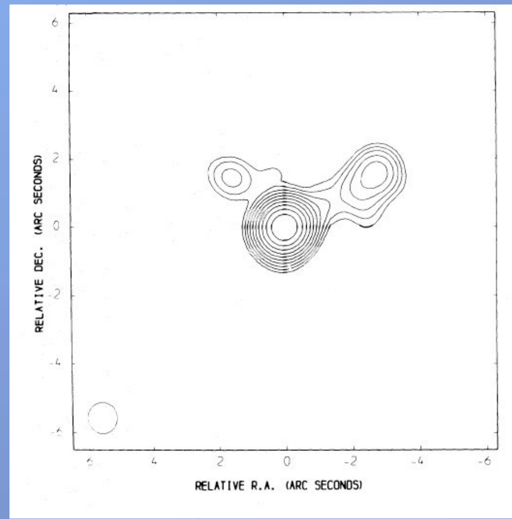
(But not all radio components undergoing relativistic bulk motion!)

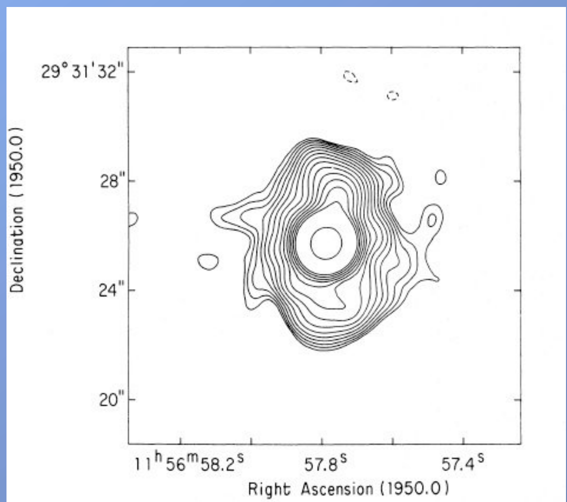
Beaming explanation for the relationship between steep and flat spectrum RLQ

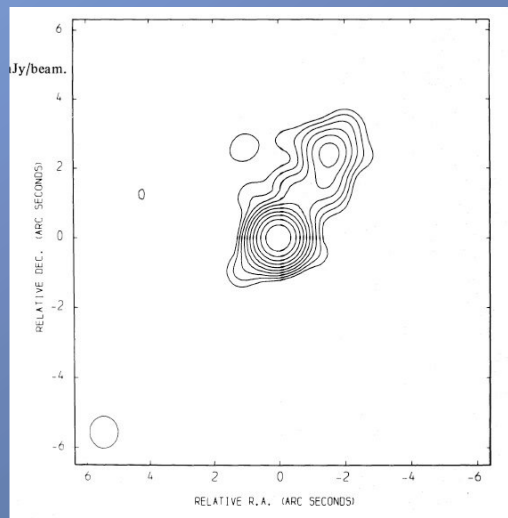


Radio structures of core dominant quasars



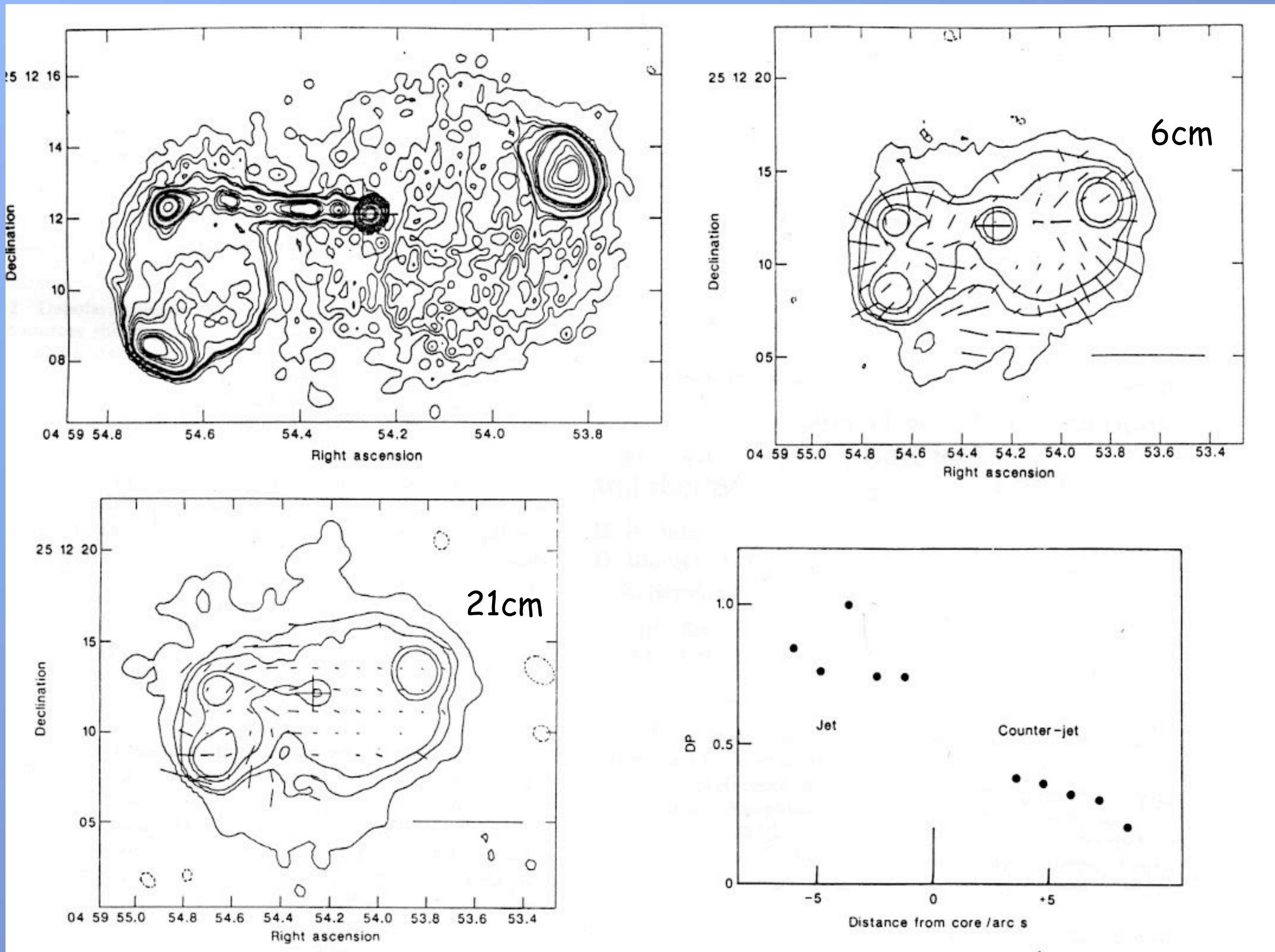






Browne et al. (1982)
Antonucci & Ulvestadt (1985)

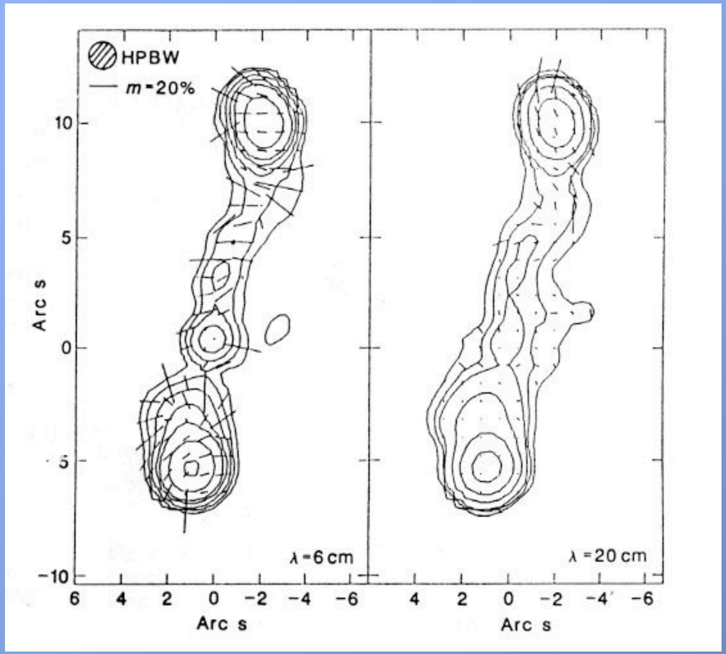
Depolarization asymmetry in quasars-I

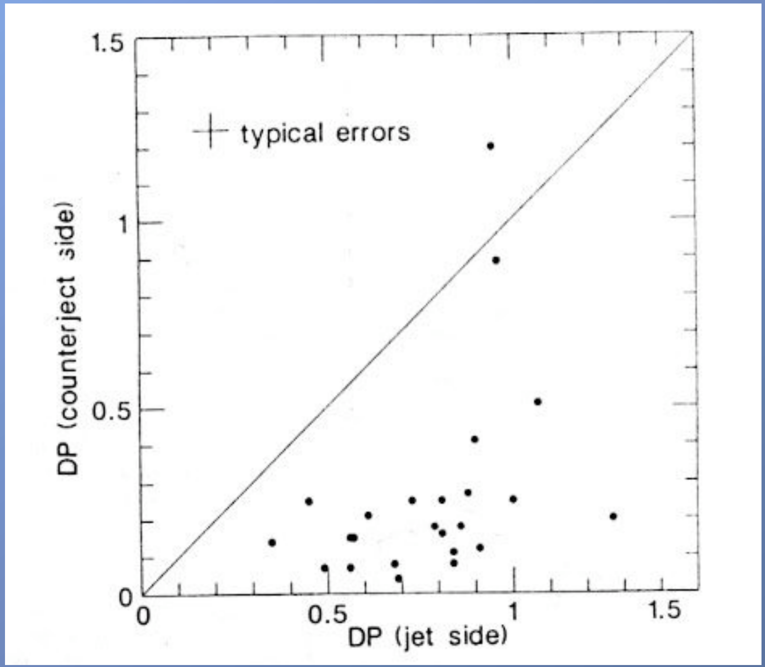


Laing (1988)

$$DP = \frac{P_{21cm}}{P_{6cm}}$$

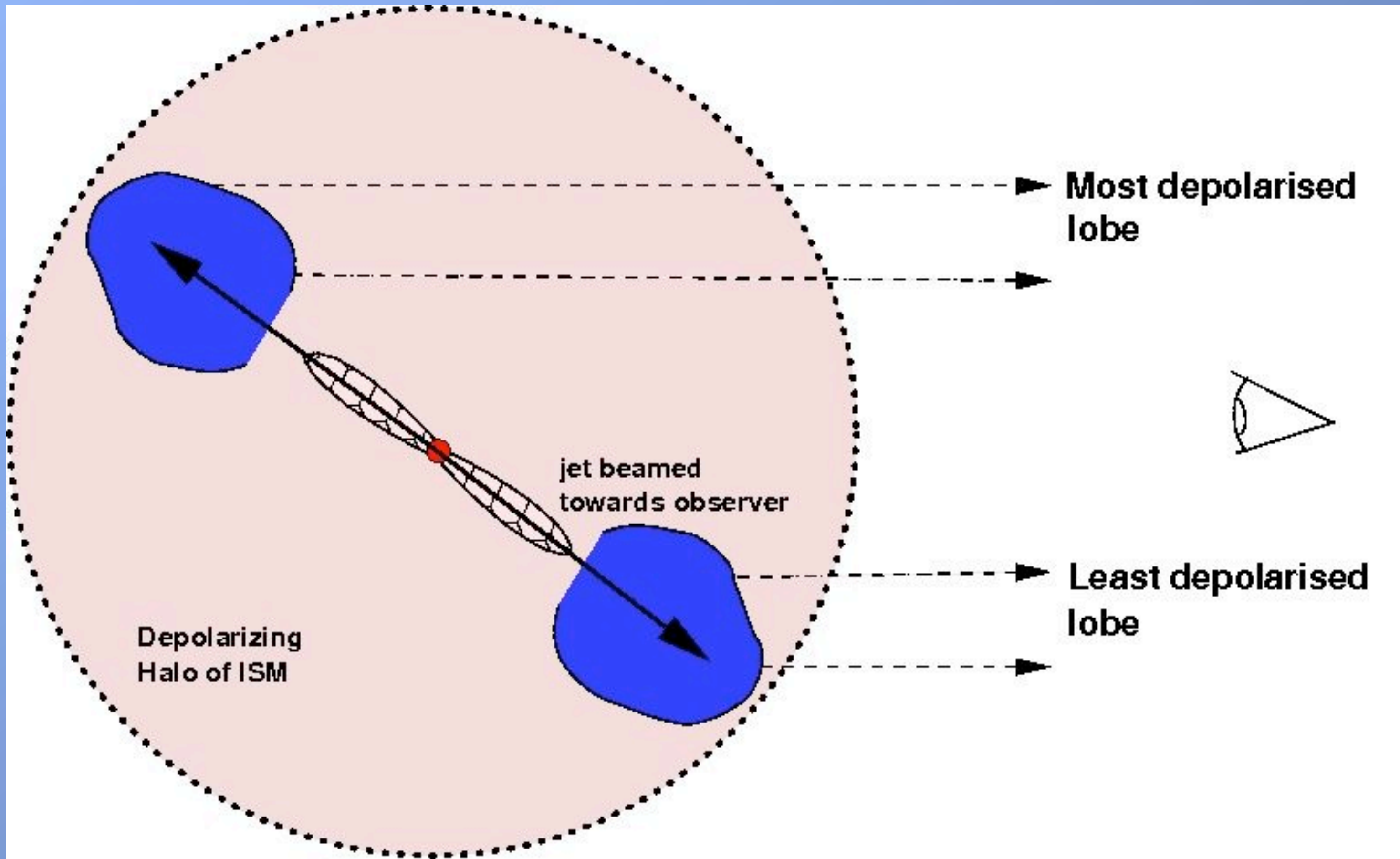
Depolarization asymmetry in quasars-II





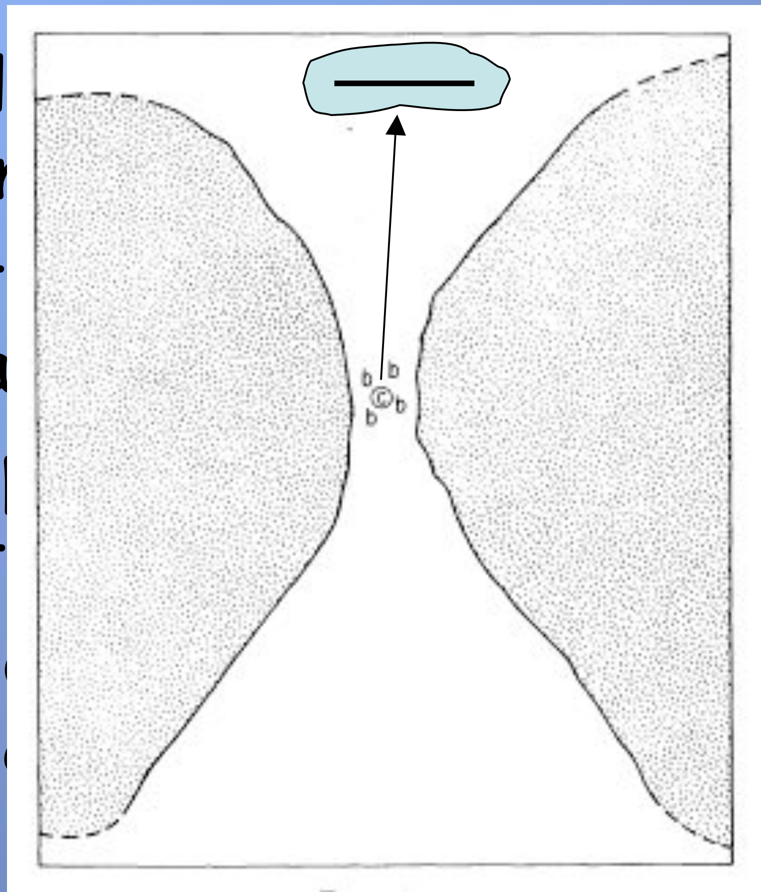
Garrington et al. (1988)

Depolarization asymmetry in quasars - III possible explanation



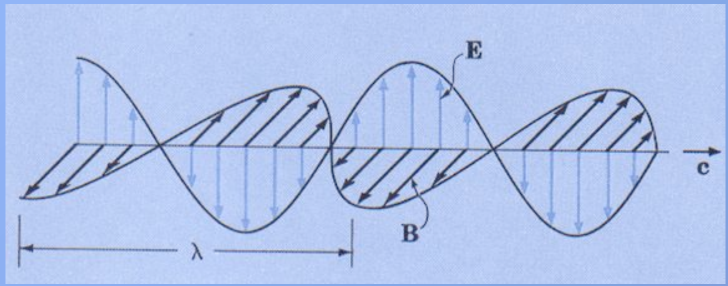
Optical polarimetry of nearby radio galaxies (Antonucci 1982, 1984)

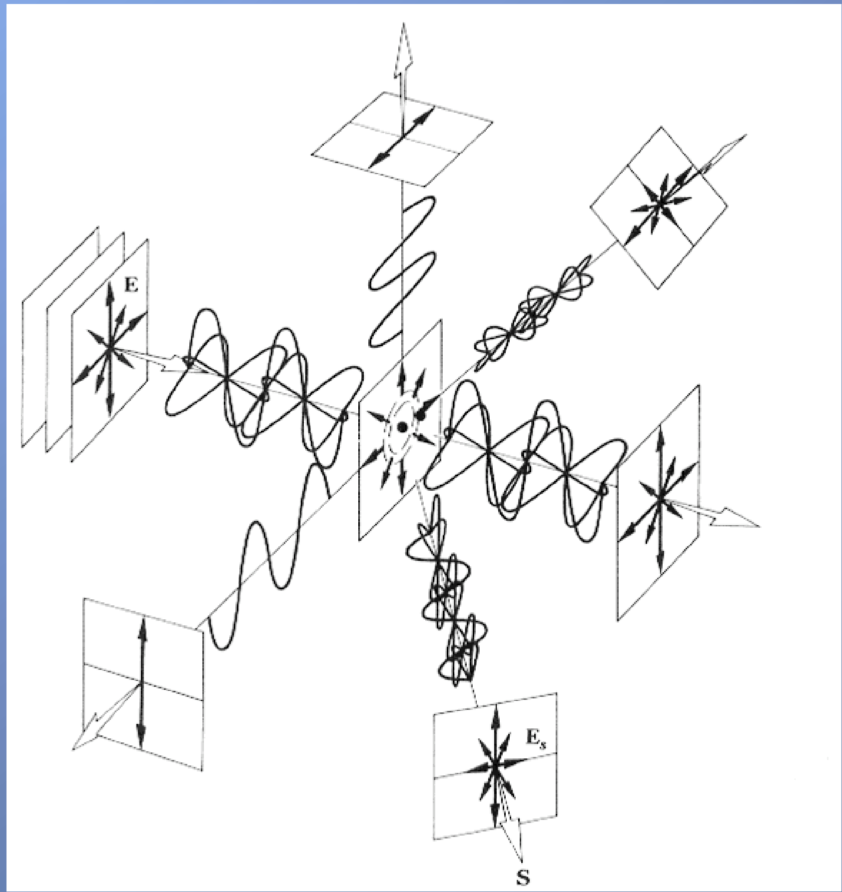
- Radio gal ivity significar
- Polarizat perpendicular to the ra
- Anisotro ely polarizat
- Invoked explain perpendi



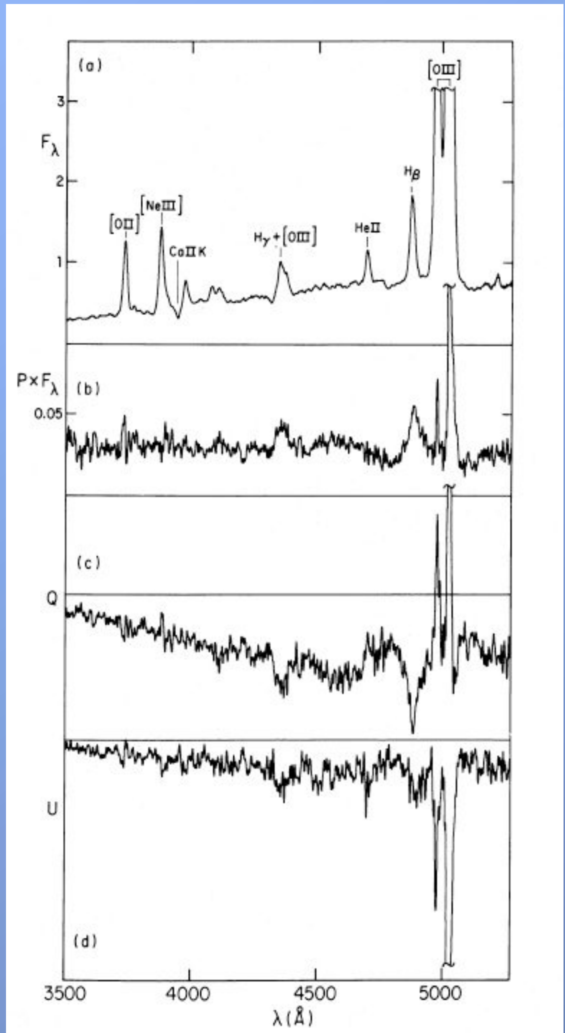
Optically thick obscuring torus

Polarization from scattering





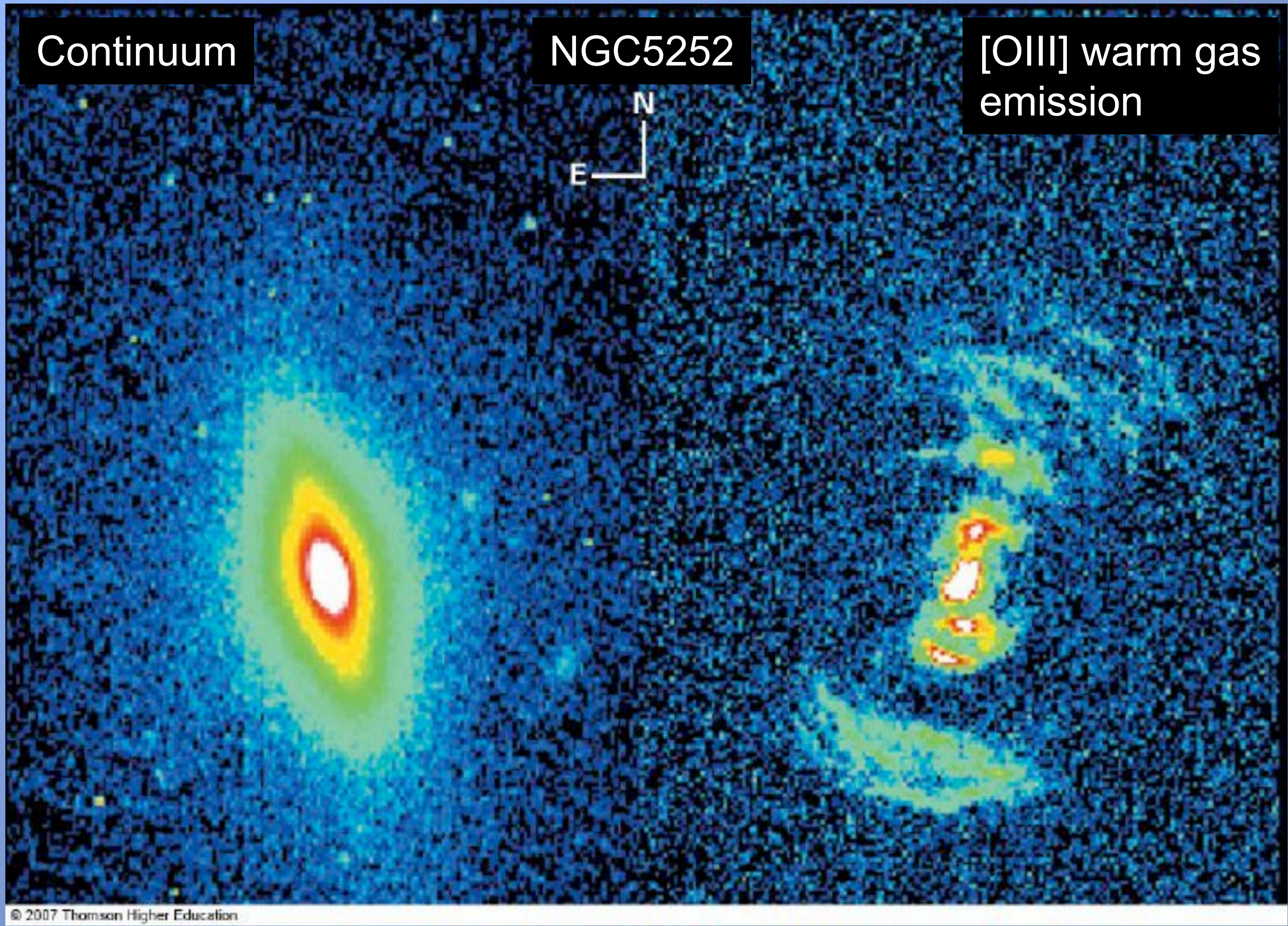
The hidden Sy1 nucleus in NGC1068



Antonucci & Miller (1985)

- NGC1068 appears as a Sy2 in "normal" intensity spectrum
- Broad permitted lines clearly detected in polarized intensity spectrum (scattered light component)
- Provides further evidence that Sy2 contain "hidden" Sy1 nuclei
- Proposed that Sy1 obscured by optically thick torus along our line of sight

Ionization cones in Seyfert galaxies



Tadhunter & Tsvetanov (1989)

Early steps towards unification

Radio - Beaming

- 1977 Cohen et al. discover superluminal motion in RLQ
- 1979 Scheuer & Readhead first unified scheme RLQ/RQQ
- 1982 Orr & Browne unified scheme for core and lobe dominated quasars
- 1988 Laing & Garrington discover depolarization asymmetry in RLQ

Optical/X-ray - Obscuration

- 1982 Lawrence & Elvis highlight evidence for greater X-ray absorption in Sy2 than Sy1
- 1984 Antonucci proposes torus/polar scattering model for radio galaxy polarization
- 1985 Antonucci & Miller detect scattered broad lines in NGC1068
- 1989 Ionization cones detected in Seyfert galaxies

Two main ways of producing anisotropic emission from AGN: beaming in relativistic jets and dust/gas obscuration by an optically thick torus close to AGN; *both will cause the appearance of an object to change with orientation.*

Radio-loud AGN classifications

Torus Obscuration

Radio loud quasar (RLQ)

Steep radio spectrum (SSQ)

Flat radio spectrum (FSQ)

Beaming

Broad line radio galaxy (BLRG)

Narrow line radio galaxy (NLRG)

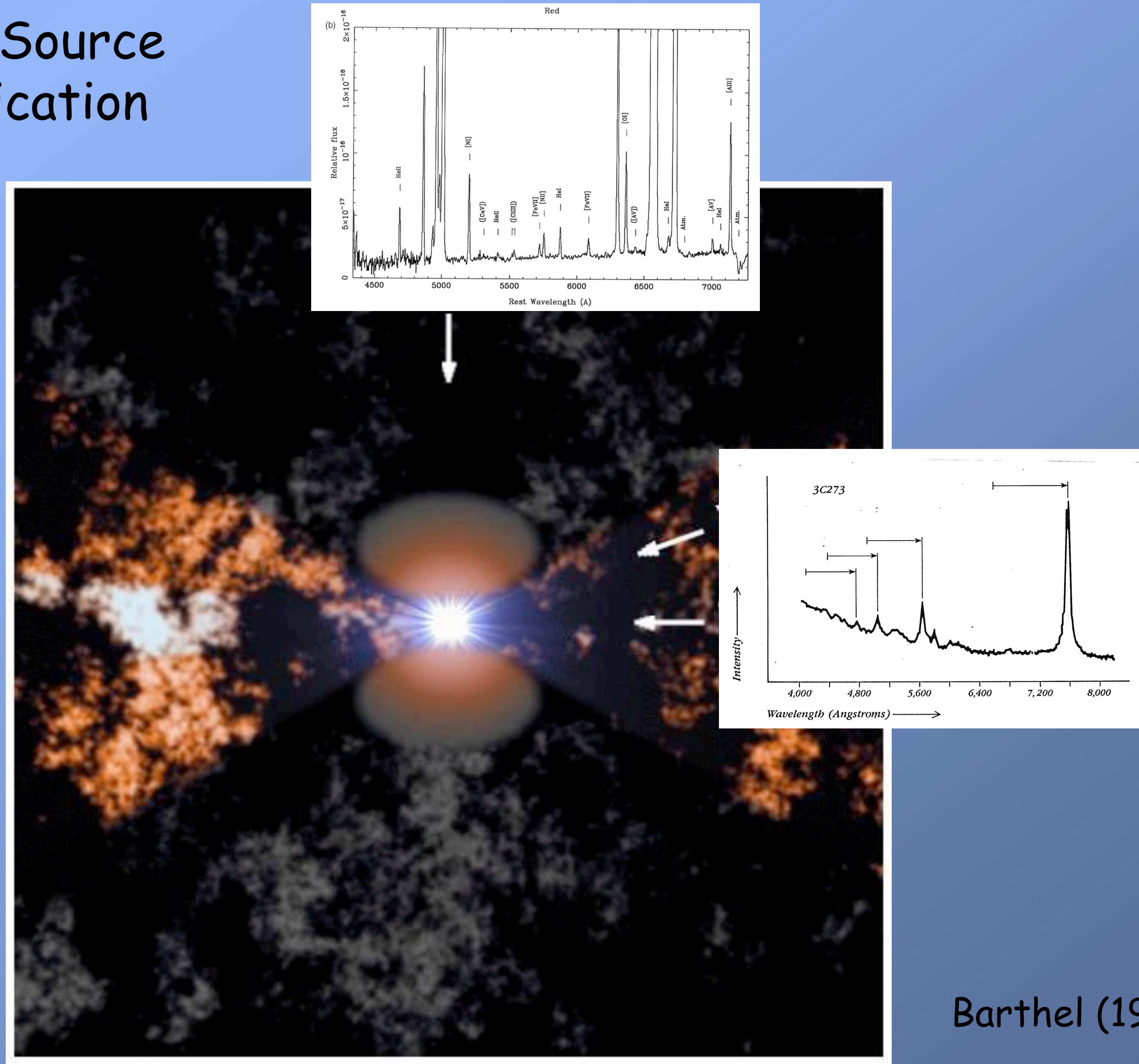
Weak line radio galaxy (WLRG)

BL Lac/Blazar/OVV

Fanaroff Riley class I (FRI)

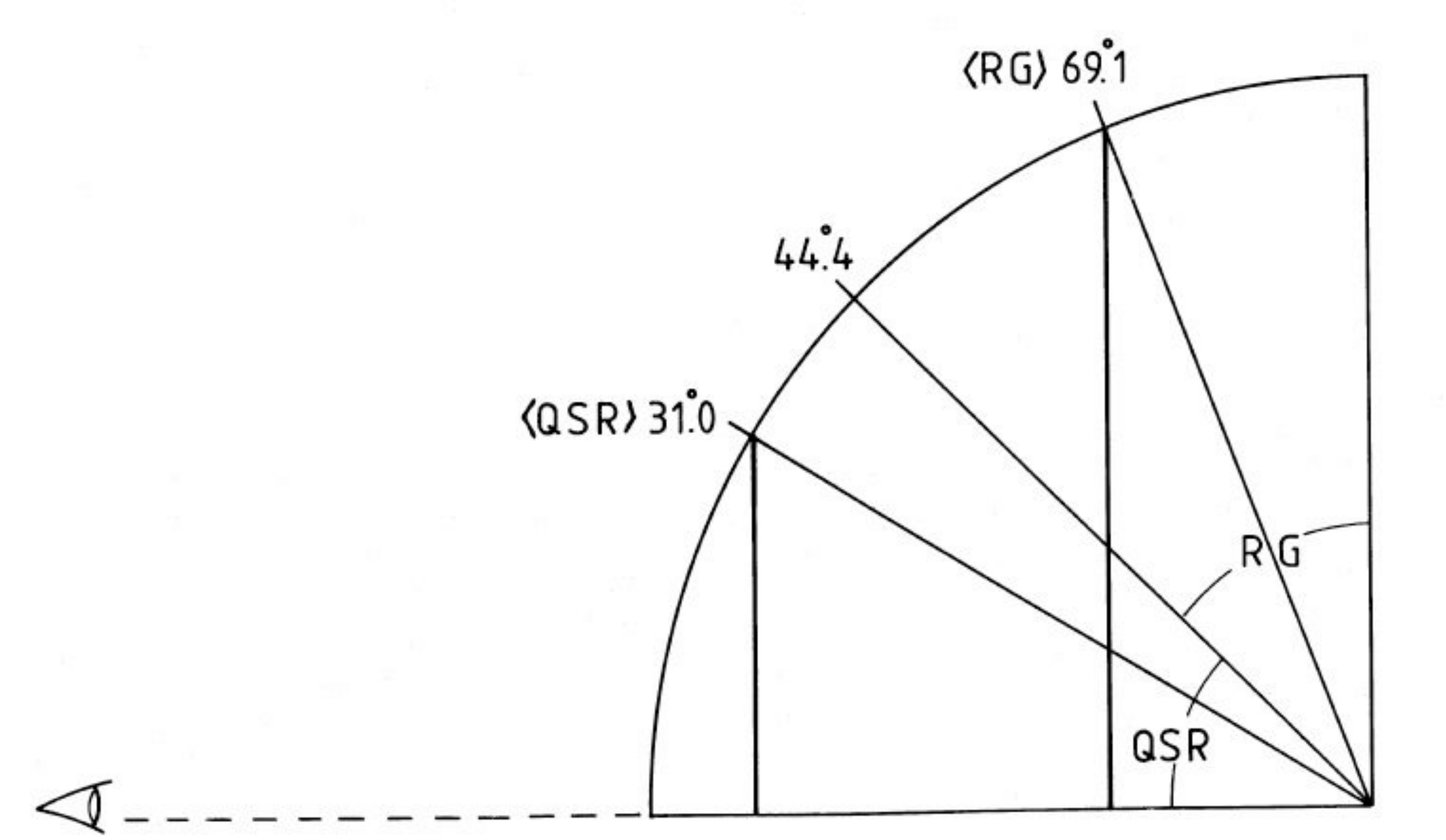
Fanaroff Riley class II (FRII)

Radio Source Unification



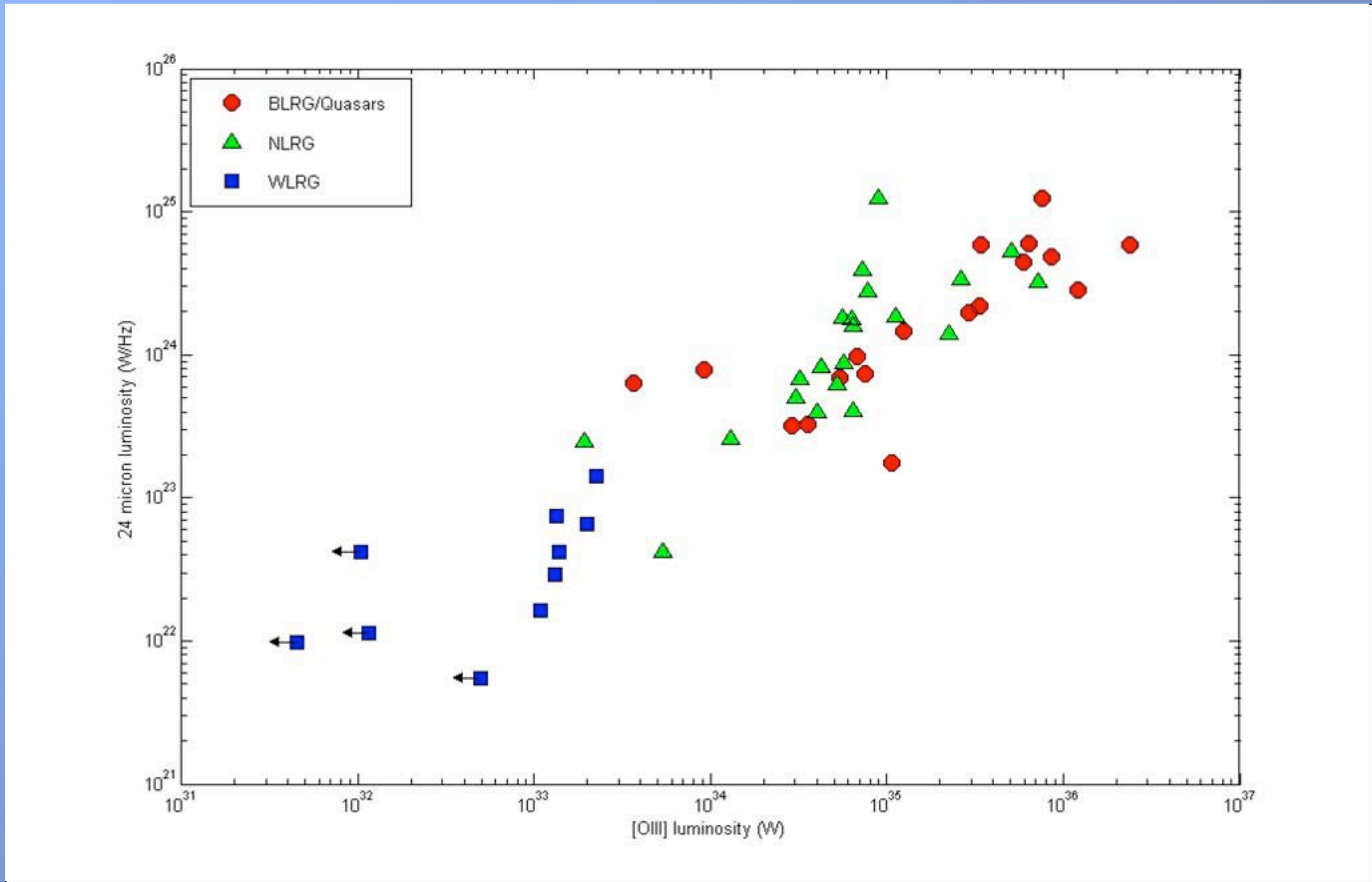
Barthel (1989)

Statistical tests of unification - I
Radio source sizes



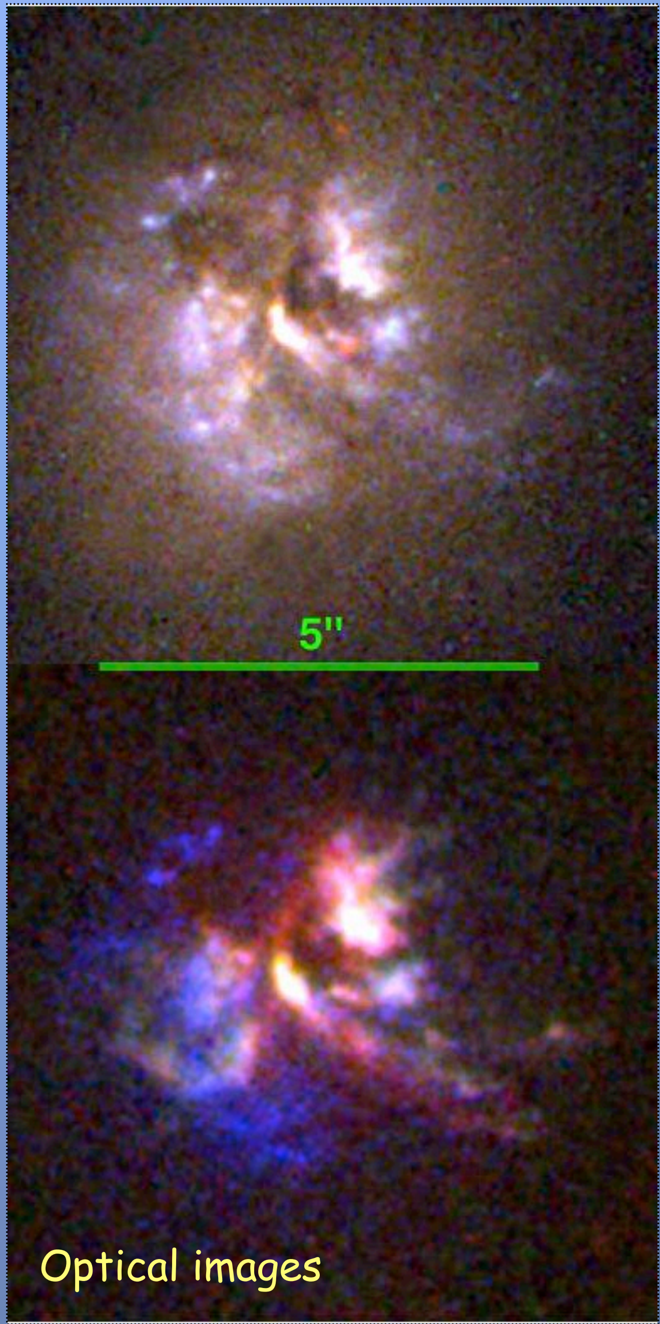
Barthel (1989)

Statistical tests of unification - II
Similarity of isotropic properties



Dicken et al. (1997): 2Jy sample Spitzer data

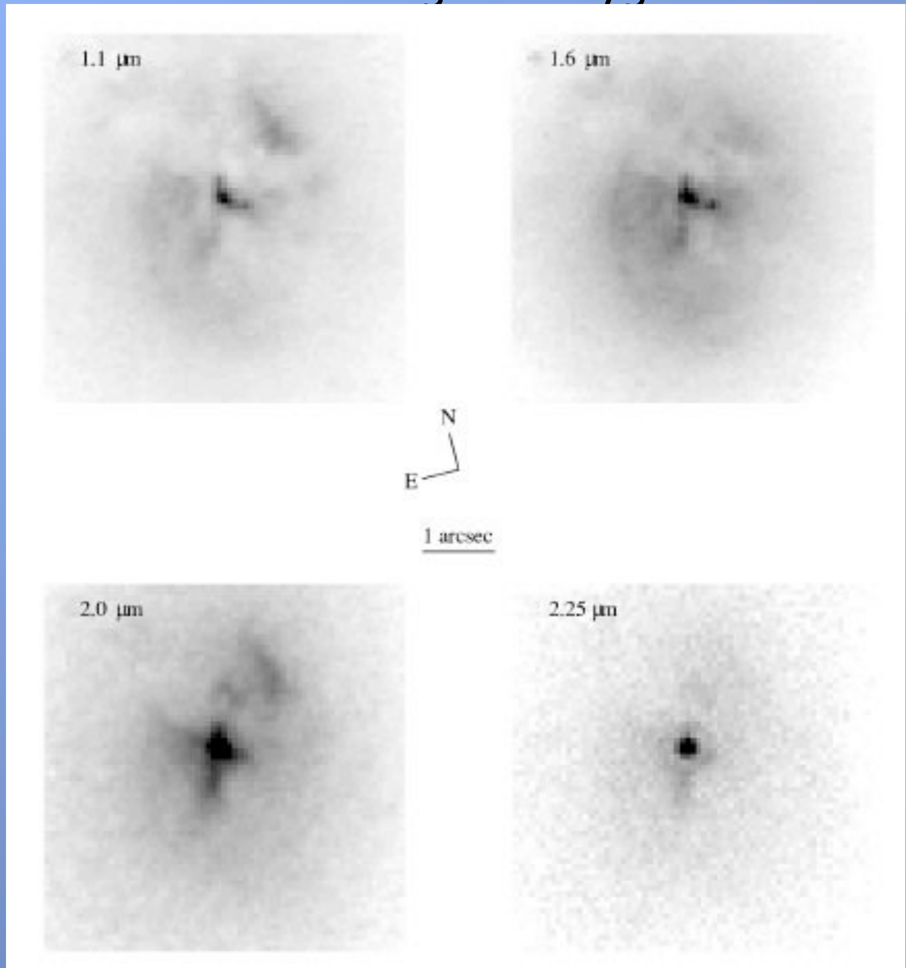
Cygnus A viewed by HST



Jackson et al. (1998)
Fosbury (1999)

Near-IR detection of quasar in Cygnus A

HST/NICMOS images of Cygnus A



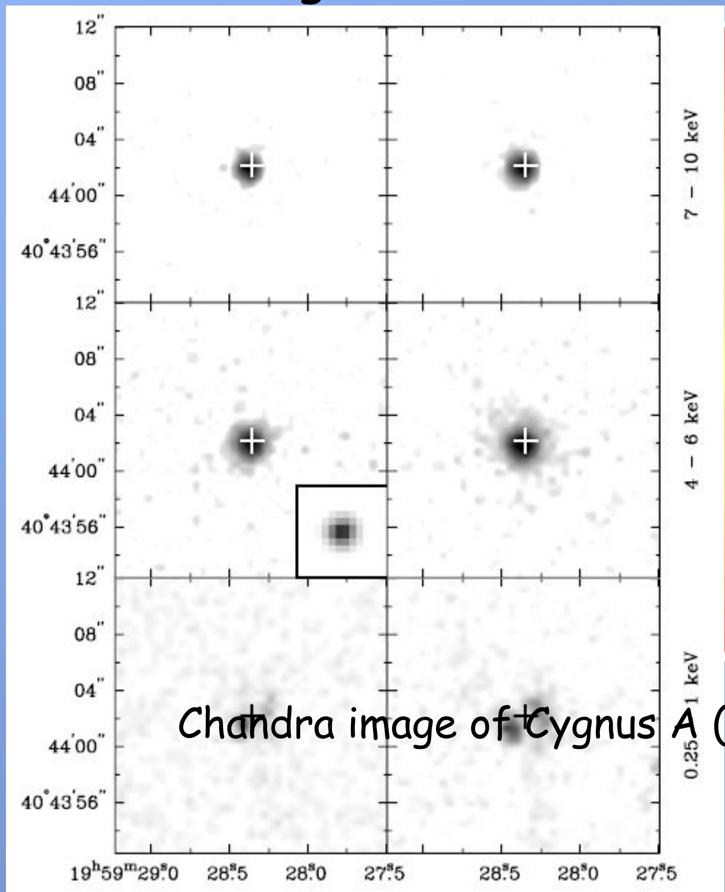
Implied torus extinction:
A_v =70-95 mag.

Tadhunter et al. (1999)

X-ray detection of quasar core in Cygnus A

Chandra images

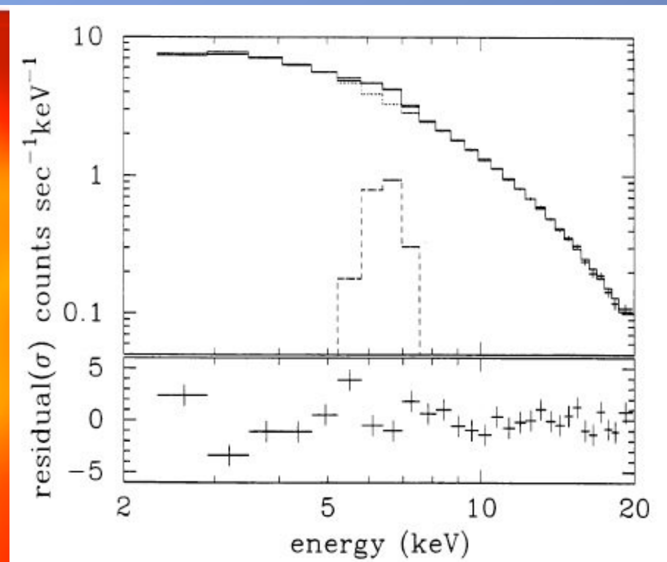
Hard →



← Soft

Young et al. (2003)

Chandra image of Cygnus A (Wilson et al. 2000)

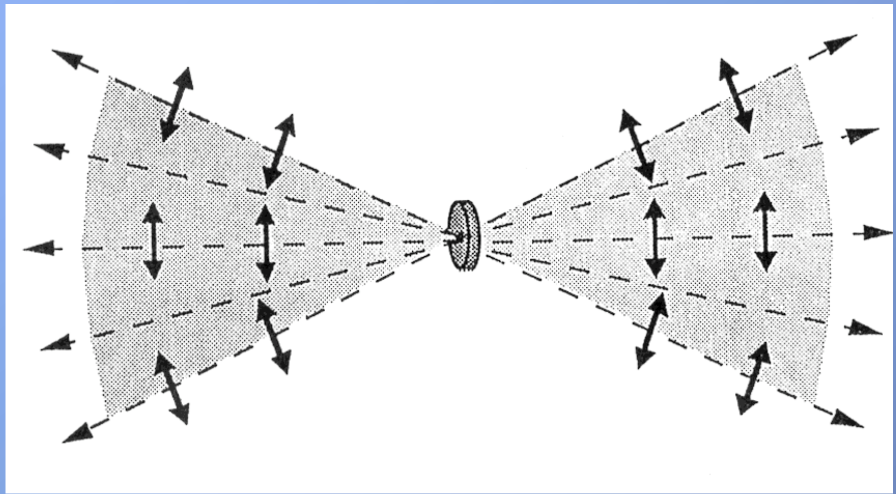


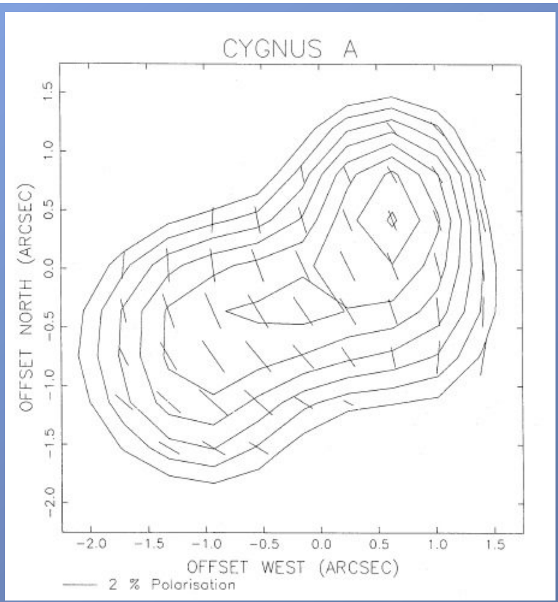
Heavily absorbed power-law required to explain hard X-ray Spectrum (Ueno et al. 1994)

$$L = 5 \times 10^{44}\, erg\, s^{-1},\; N_H > 3.7 \times 10^{23}\, cm^{-2}$$

$$\Rightarrow A_V = 170 \pm 30\, mag$$

Polarimetric detection of quasar nuclei

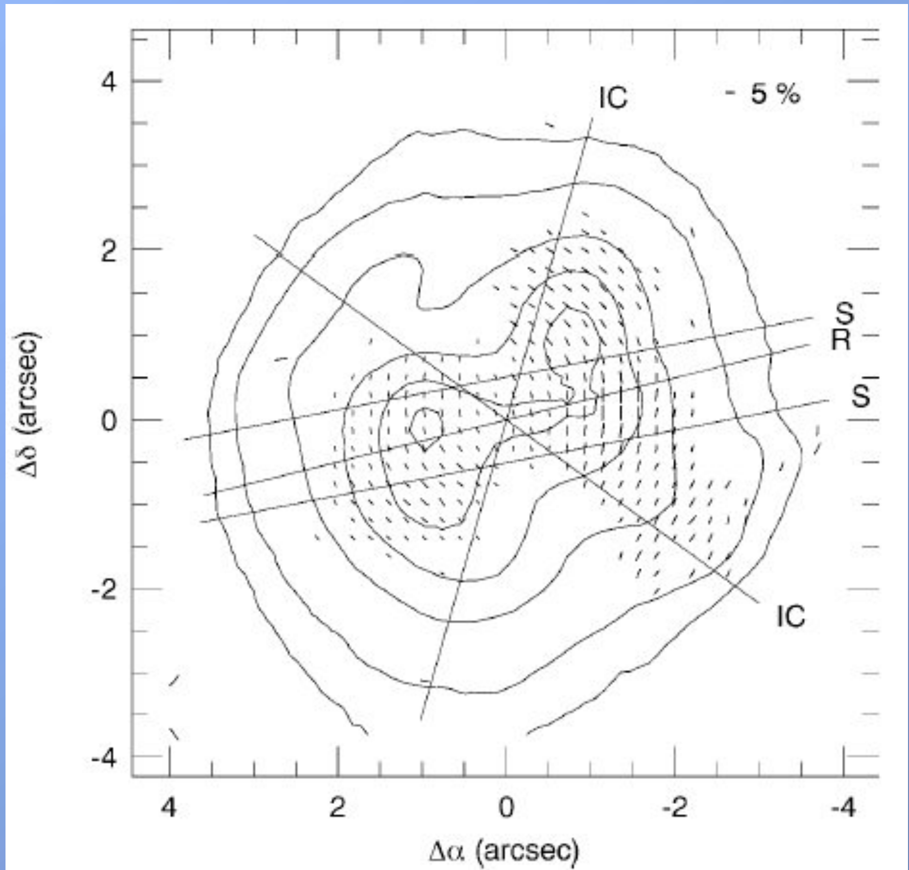


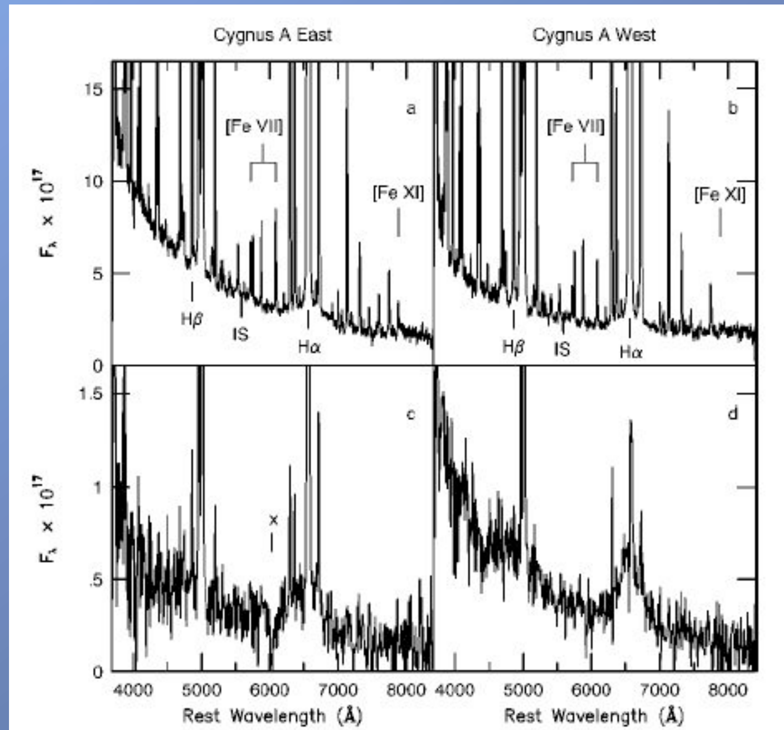


Reflection nebula in Cygnus A

Tadhunter et al. (1990)

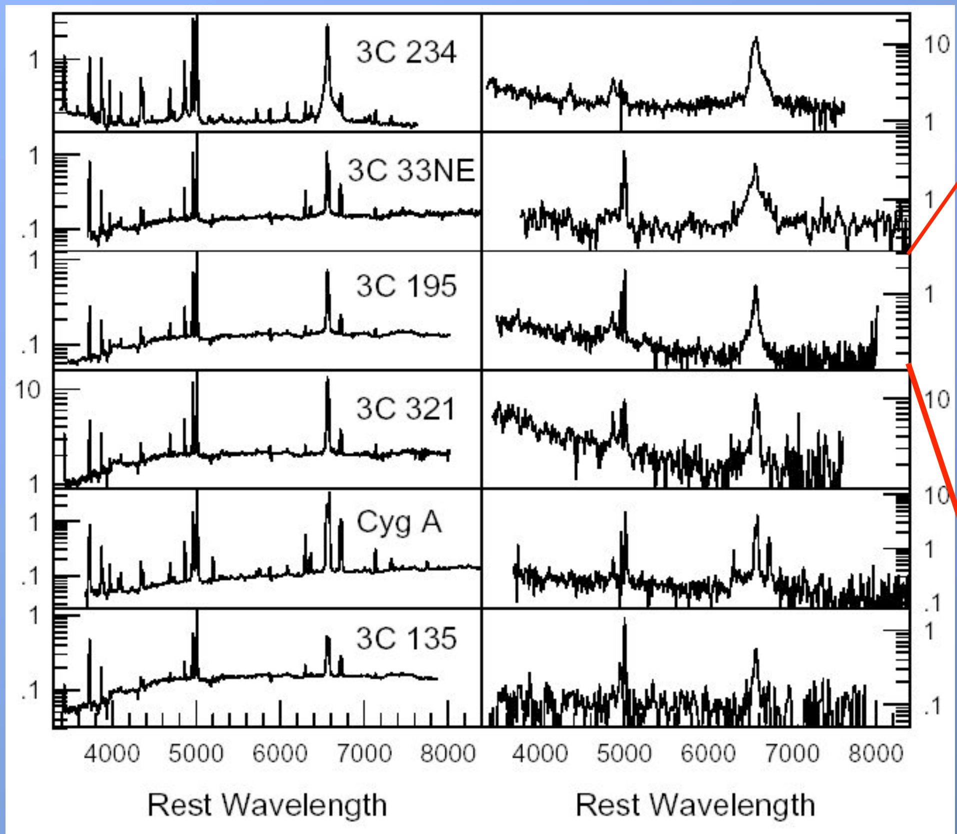
Detection of polarized broad lines in Cygnus A

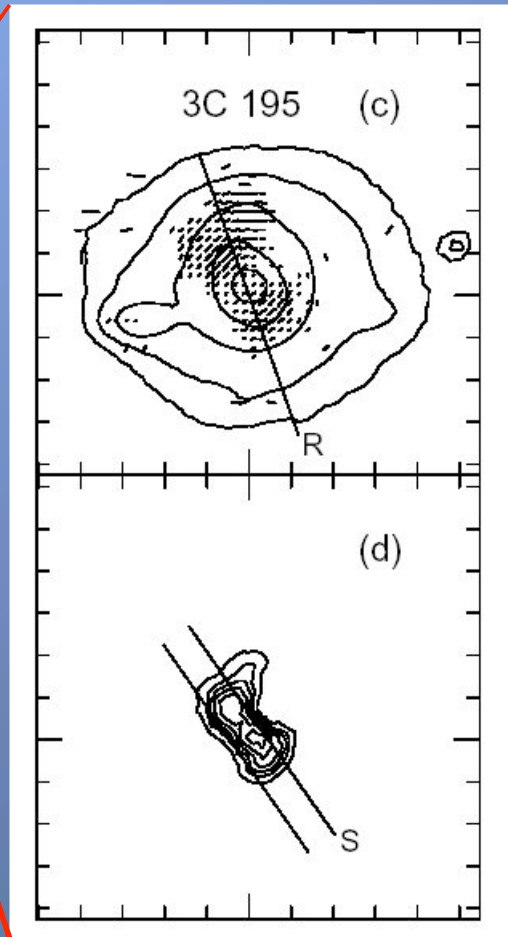




Ogle et al. (1997),
Keck+LRIS

Polarimetry of Low Redshift Radio Galaxies (z<0.2)

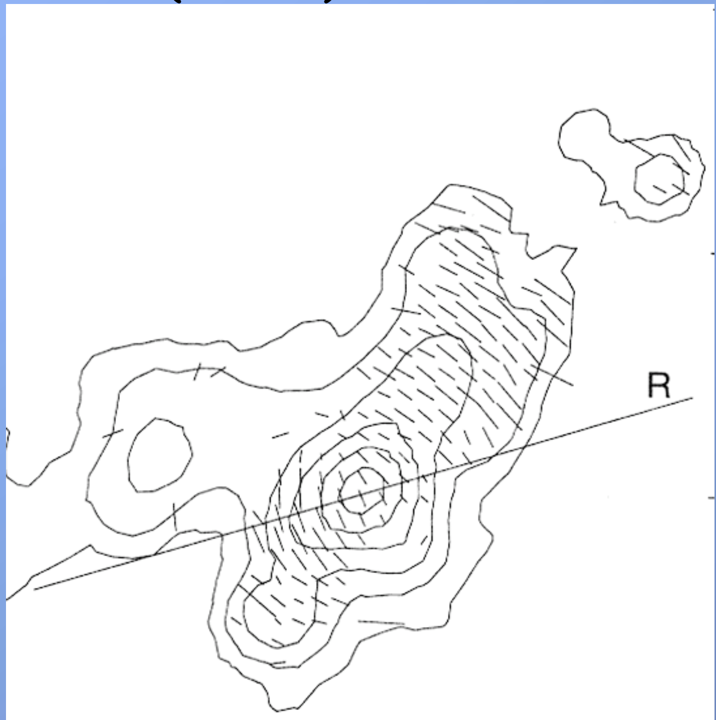




Cohen et al. (1999)
Keck+LRIS

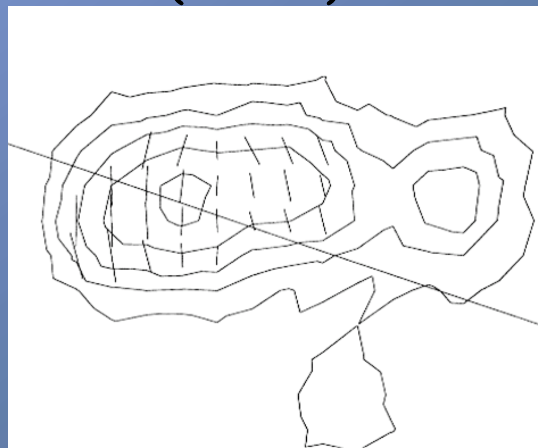
The polarization of distant radio galaxies (0.5 < z < 2.0)

3C265 (z=0.81)



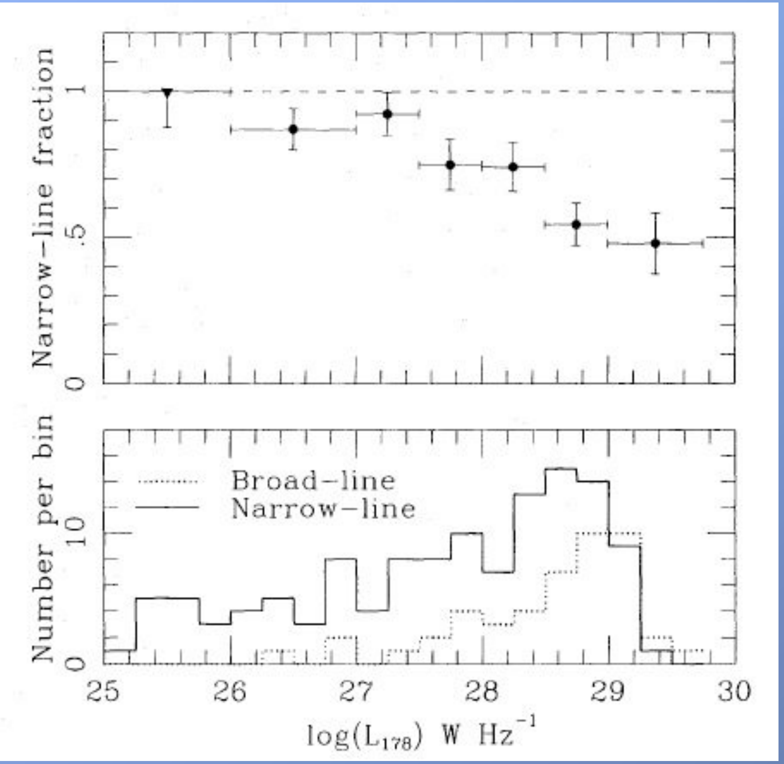
3C277.2 (z=0.76)

3C324 (z=1.20)



Scarrott et al. (1989)
Jannuzi & Elston (1991)
di Serego-Alighieri et a1. (1989)
Tadhunter et al. (1991,2002)
Tran et al. (1995,1998), Dey et al. (1996)

Problems with simple unification - I
Varying quasar fraction with L and z

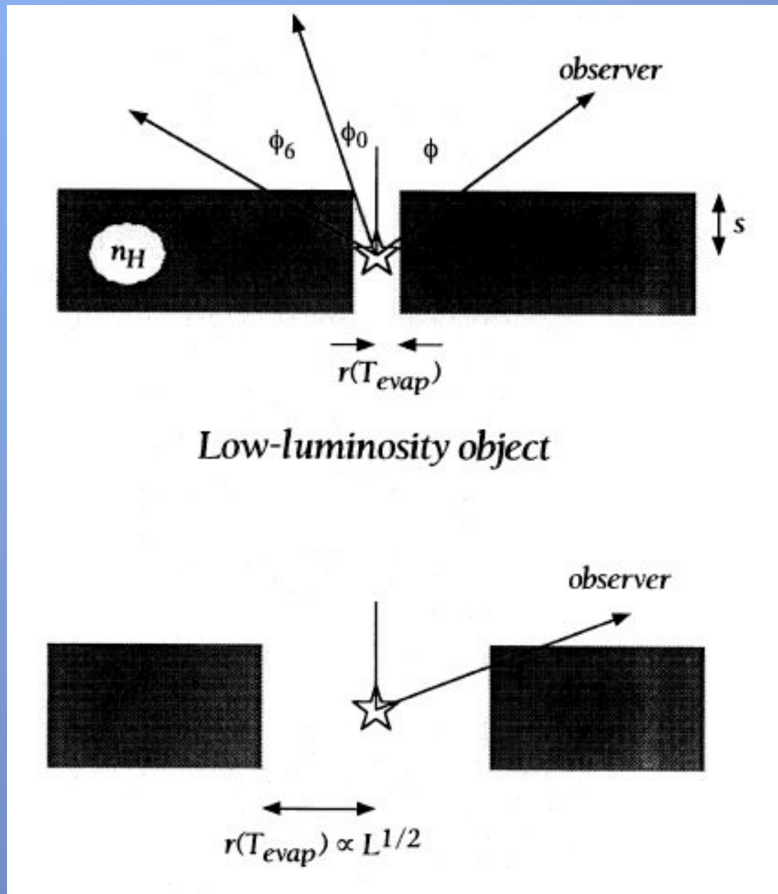


Lawrence (1991)

The fraction of quasars/BLR increases with radio power and redshift. Explanations include:

- Different populations of radio sources at different radio powers
- The properties of the torus change with luminosity (e.g. *receding torus model*: the inner edge of the torus recedes as the quasar become more luminous)

The receding torus model



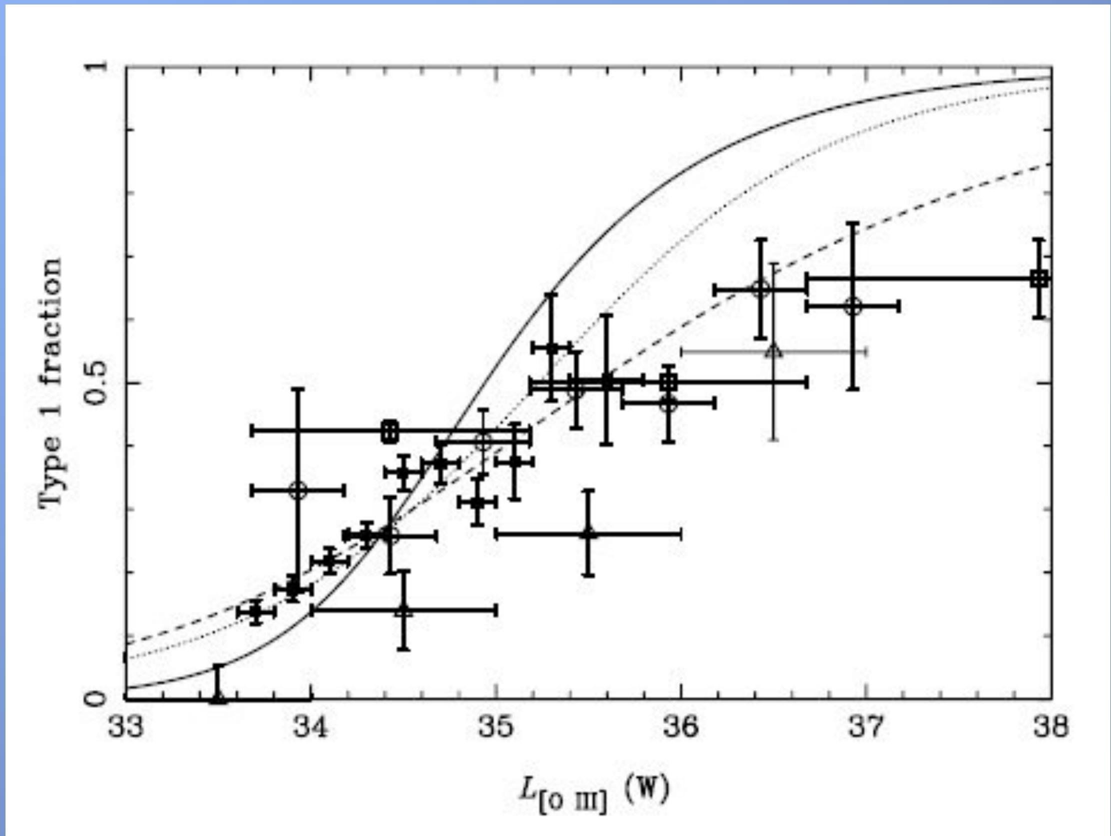
Hill et al. (1996)
Simpson (1998, 2005)

Sublimation radius:

$$\sigma T_s^4 = \frac{L_{bol}}{4\pi r_s^s}$$

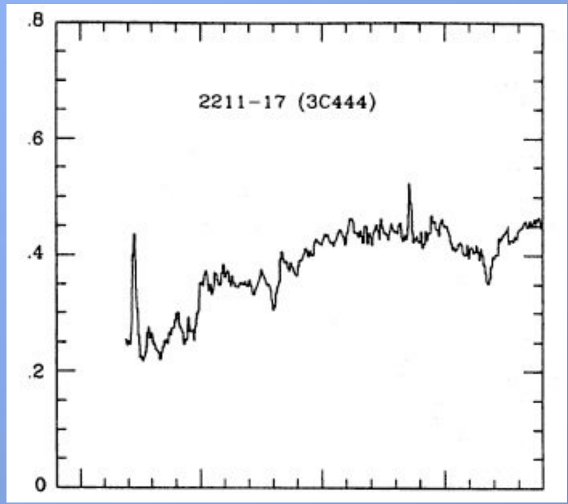
$$\Rightarrow r_s \propto L_{bol}^{0.5} T_s^{-2}$$

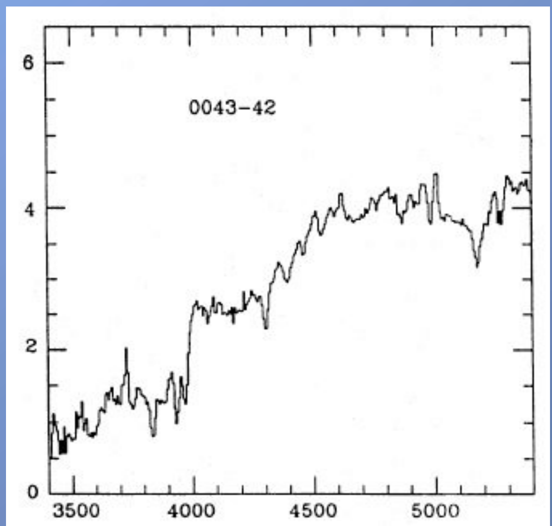
Application of receding torus model to X-ray, optical and radio selected samples of AGN

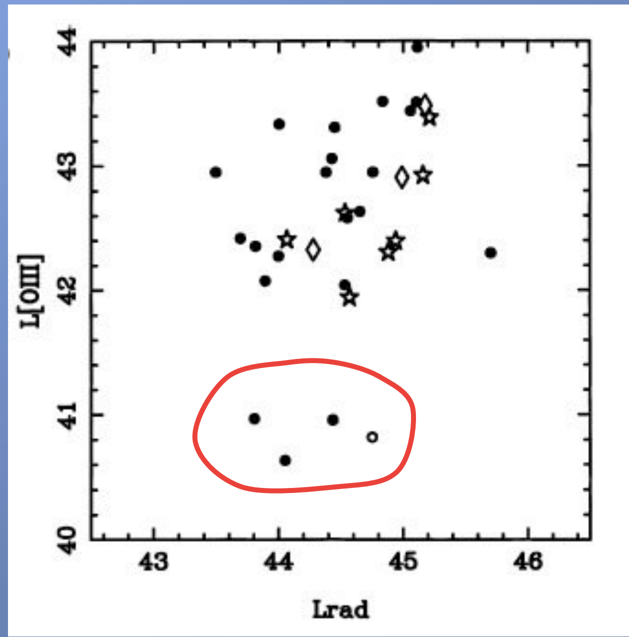


Simpson (2005)

Weak line radio galaxies (WLRG): how do they fit in?

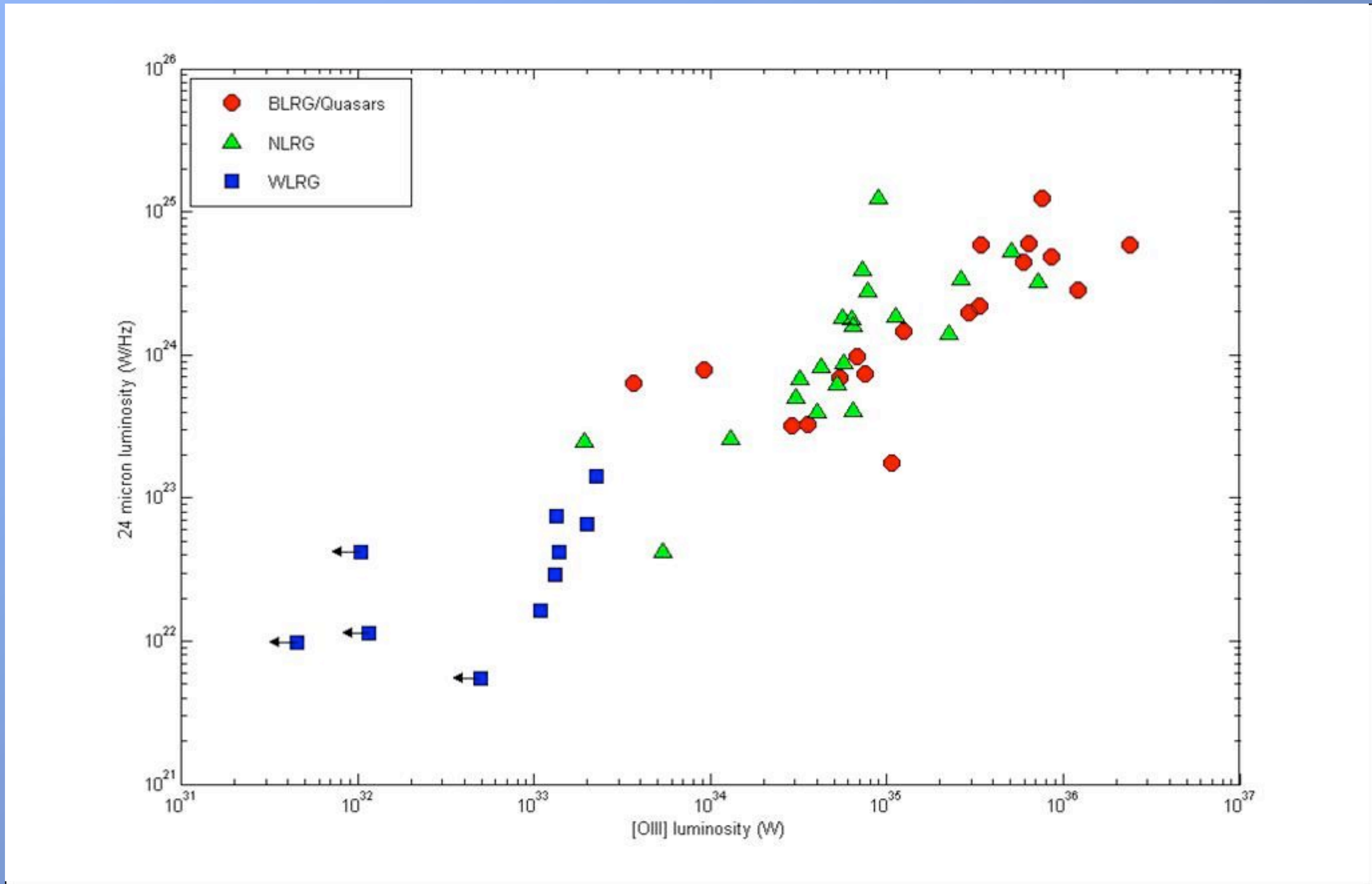






Tadhunter et al. (1993,1998)

Statistical tests of unification
Similarity of isotropic properties



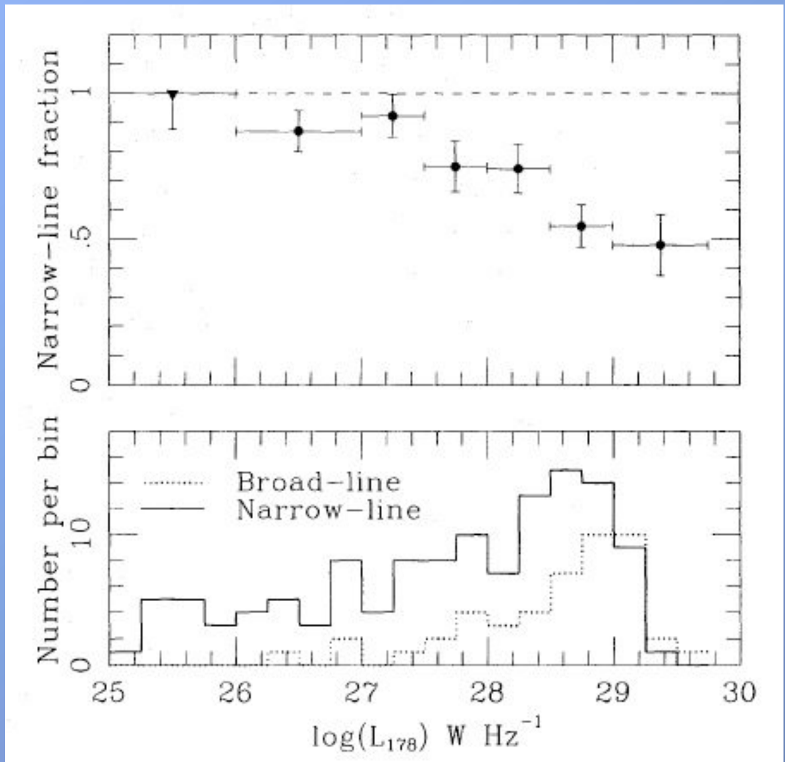
Dicken et al. (1997): 2Jy sample Spitzer data
Tadhunter et al. (2007)

Problems with simple unification - II
How do the WLRG fit in?

- *All* low power FRI radio sources are WLRG
- A minority of FRII radio sources (~10-20%) are WLRG (most are NLRG or BLRG/RLQ)
- Quasar-like broad lines have not been clearly detected in any WLRG
- Unlikely that WLRG have powerful, obscured quasar nuclei because they are also weak in the far-IR

➔It has been proposed that WLRG unify with BL Lac objects, rather than RLQ

Problems with simple unification - I
Varying quasar fraction with L and z



Lawrence (1991)

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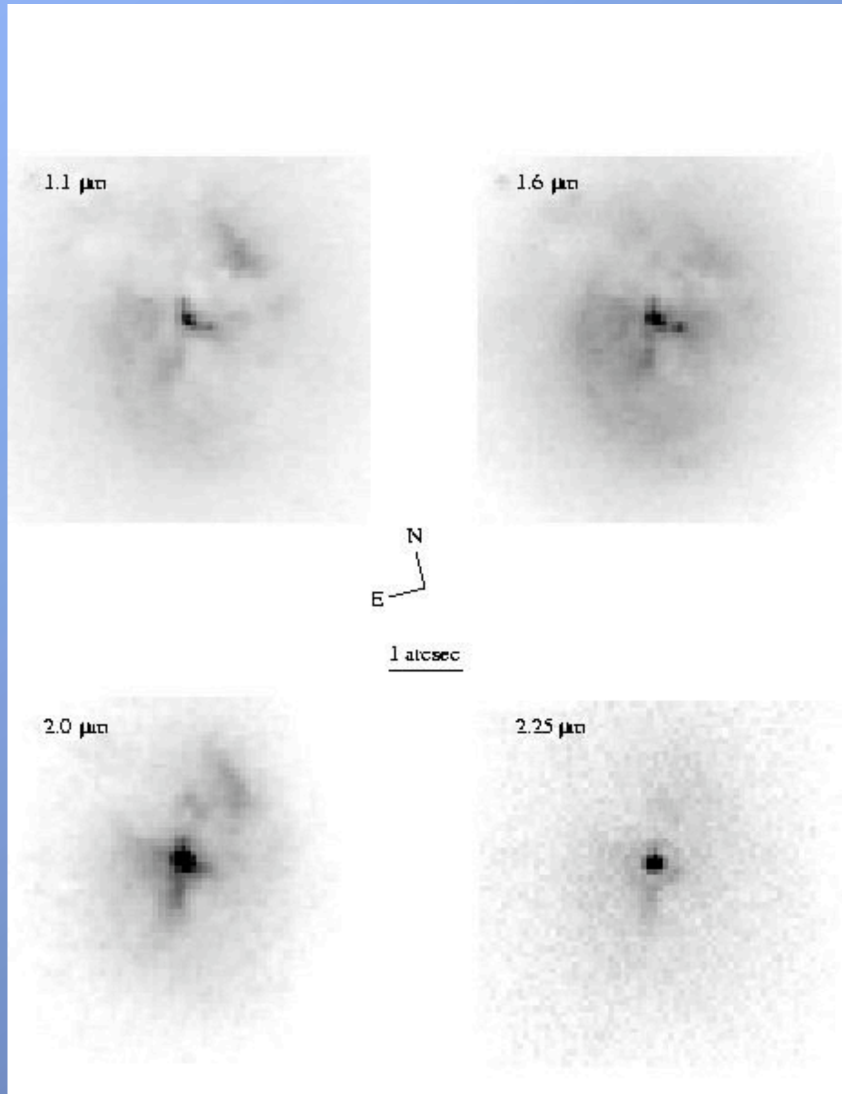
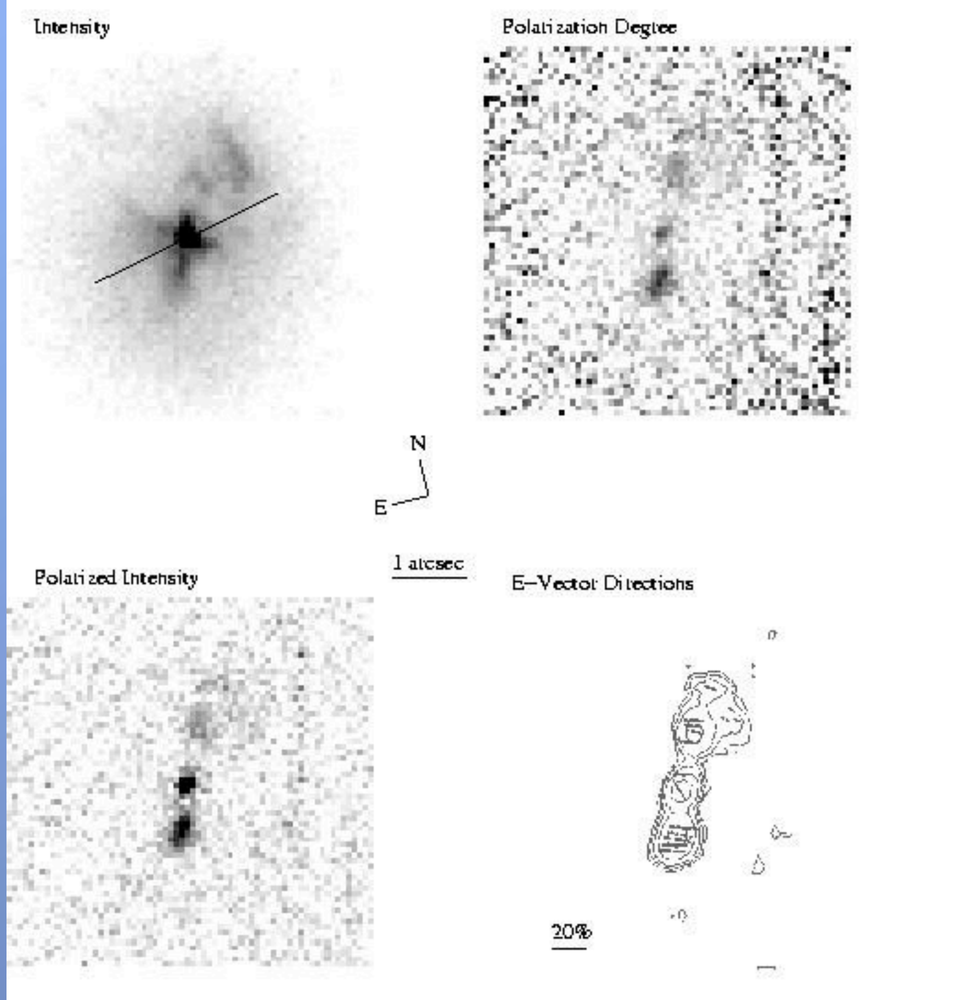
HST/NICMOS Imaging of Cygnus A



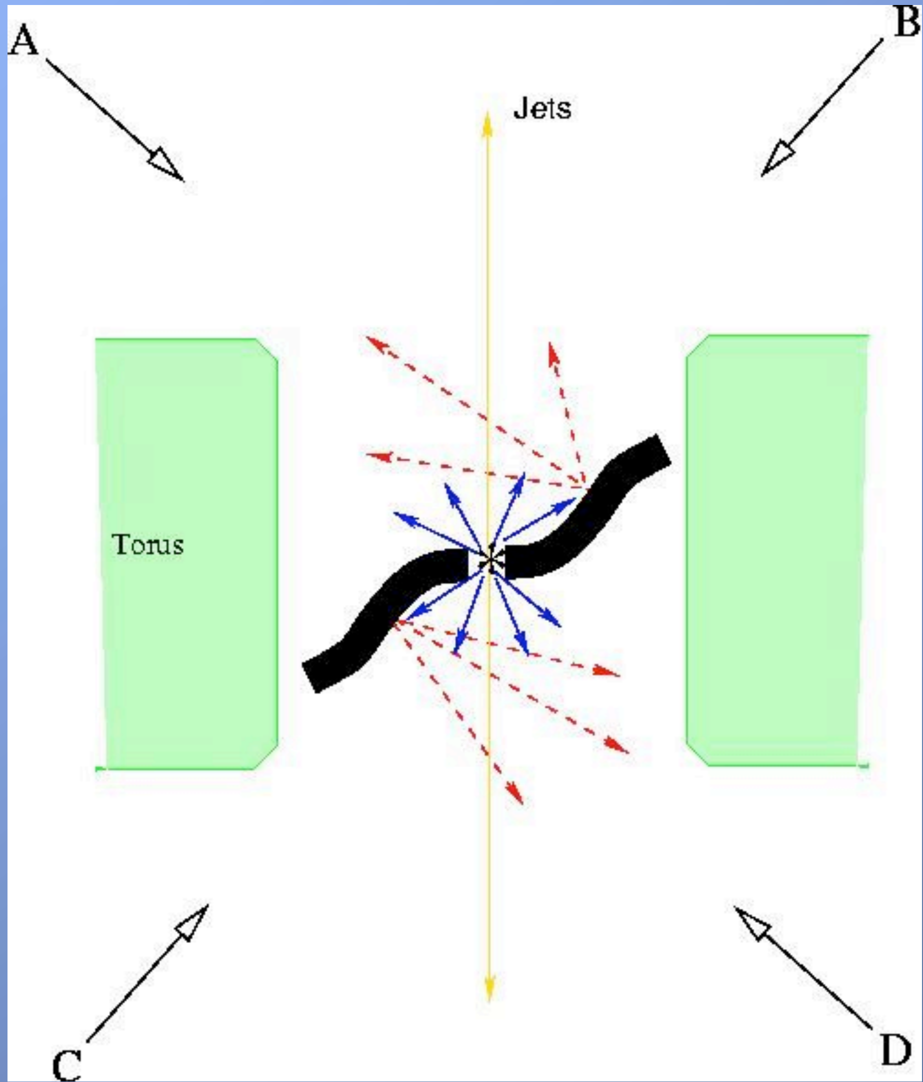
Tadhunter et al. (1999)

Near-IR Polarimetry of Cygnus A

Tadhunter et al. (2000) HST/NICMOS (2.0μm)

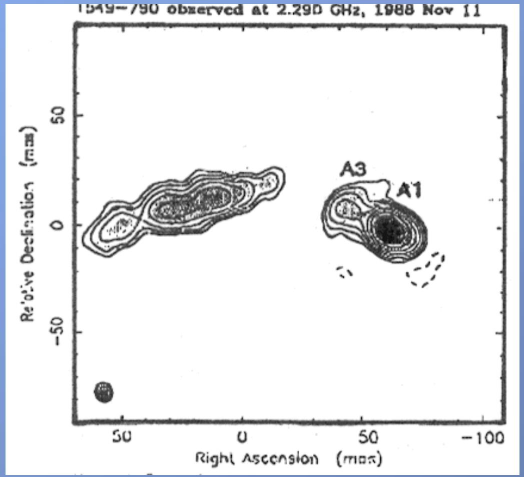


Intrinsic anisotropy in Cygnus A?

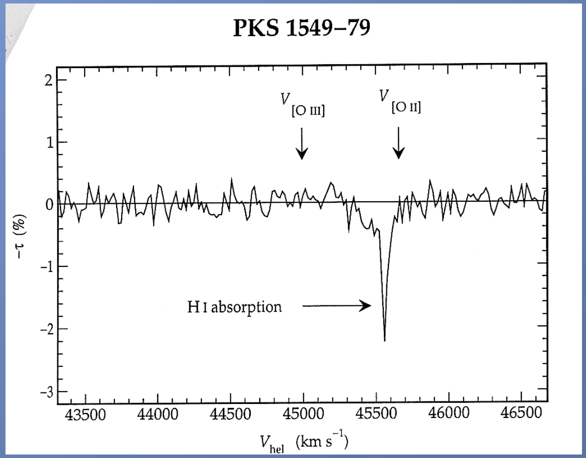


PKS1549-79 (z=0.15): a misfit

- Flat radio spectrum
- One-sided VLBI jet (radius ~420pc)
- Variability
- ULIRG -- as luminous as 3C273 in mid-IR
- Significant HI 21cm absorption

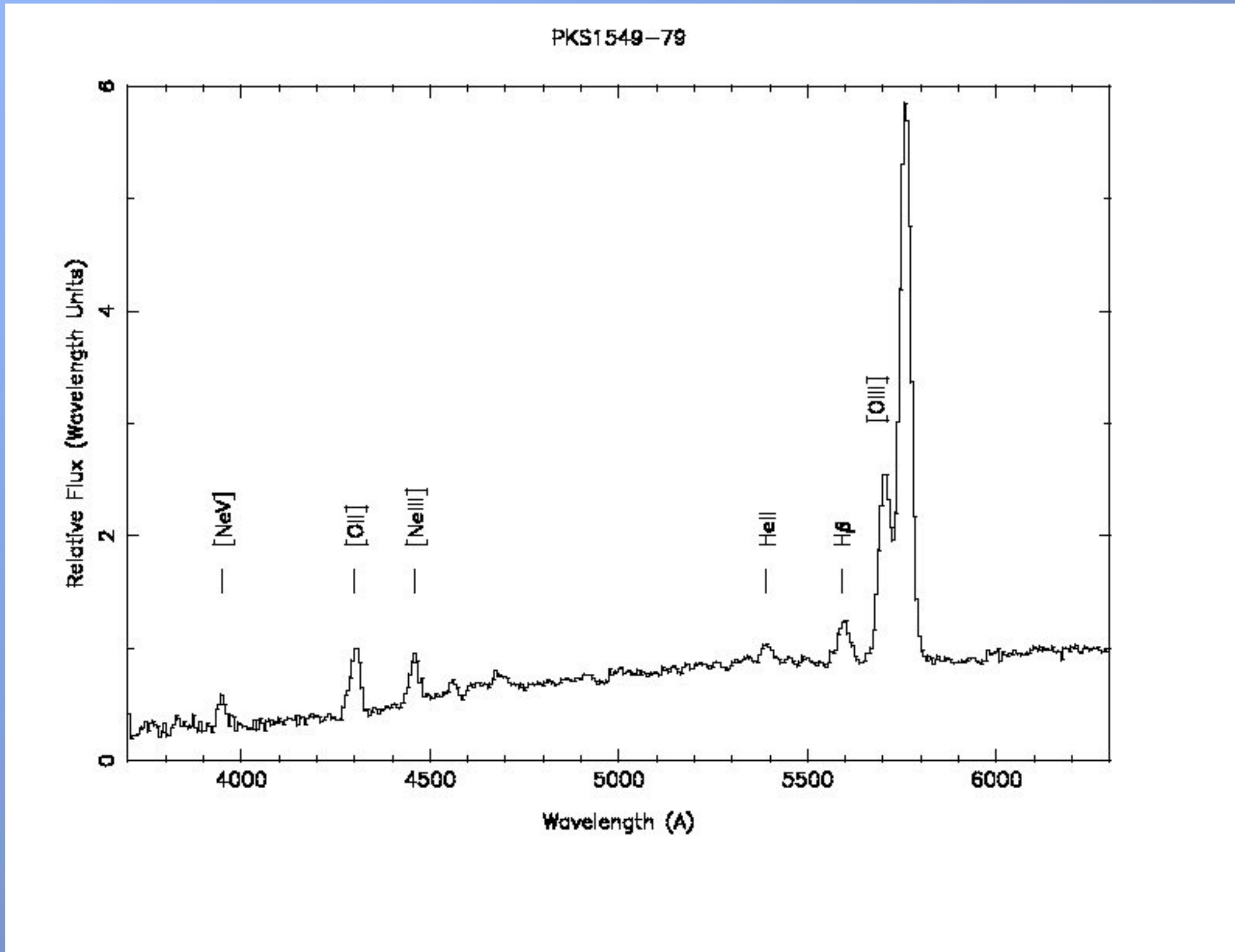


King (1996)



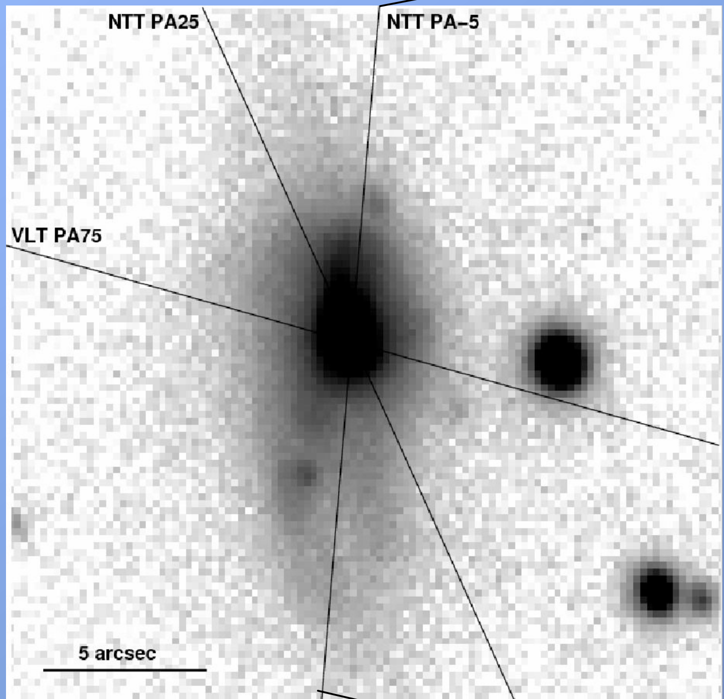
Morganti etal. (2001)

PKS1549-79: Optical Spectrum

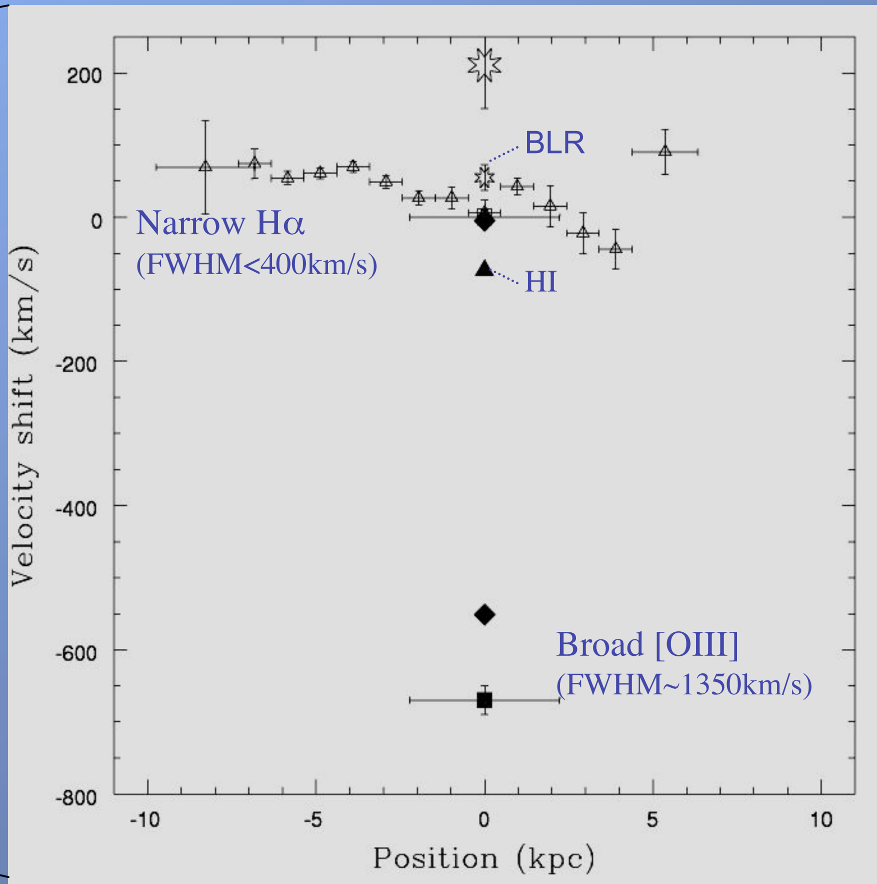


Tadhunter et al. (2001)

Emission line kinematics in PKS1549-79



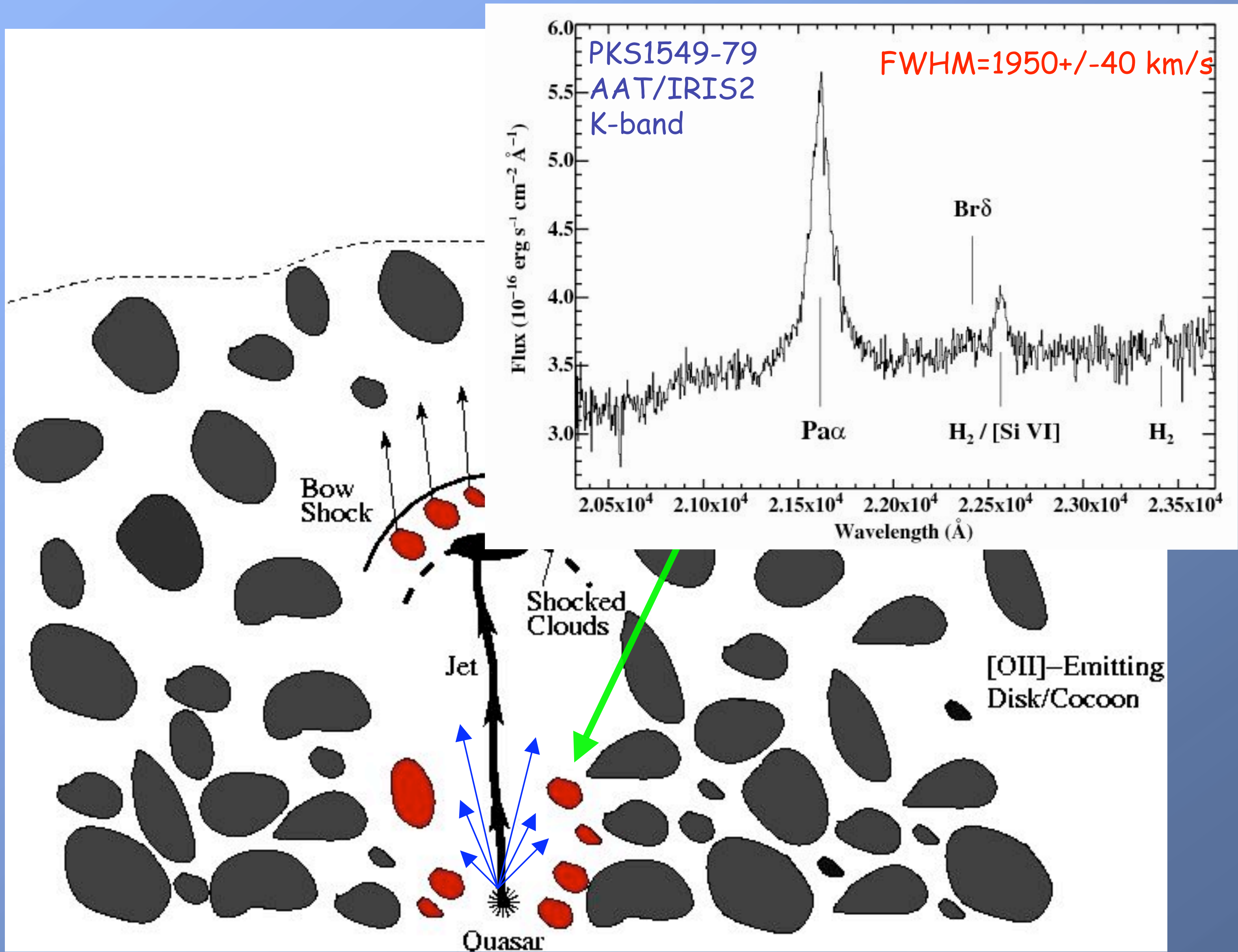
VLT+FORS1
Gunn r



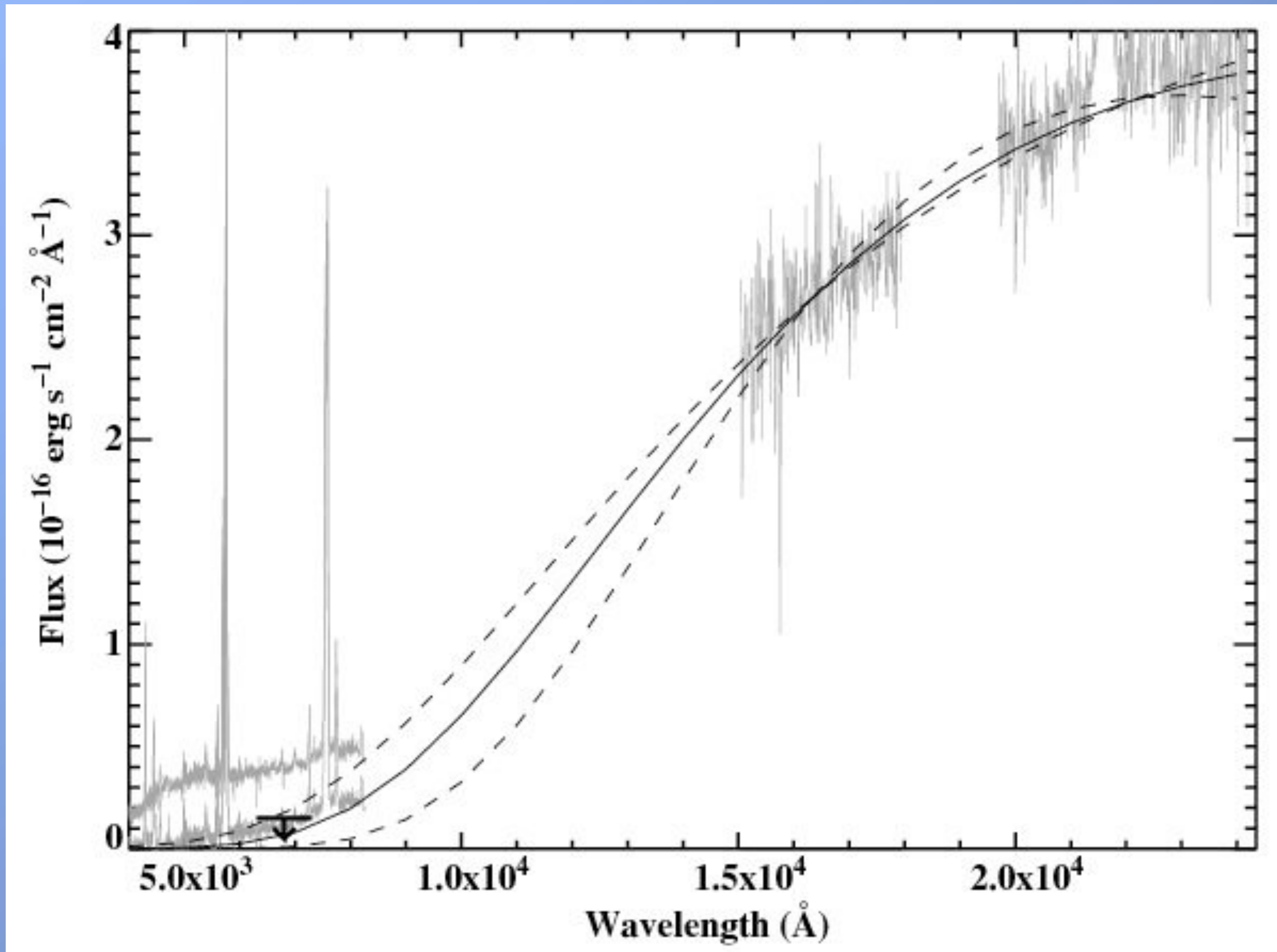
VLT+FORS2

Holt et al. (2006)

The early stages of radio source evolution



Optical/near-IR continuum SED



NTT+
SOFI

VLT+
FORS2

Quasar properties: $-27.56 < M_v < -23.5$ Holt et al. (2006)
$6.4 < A_v < 13.2$

Summary

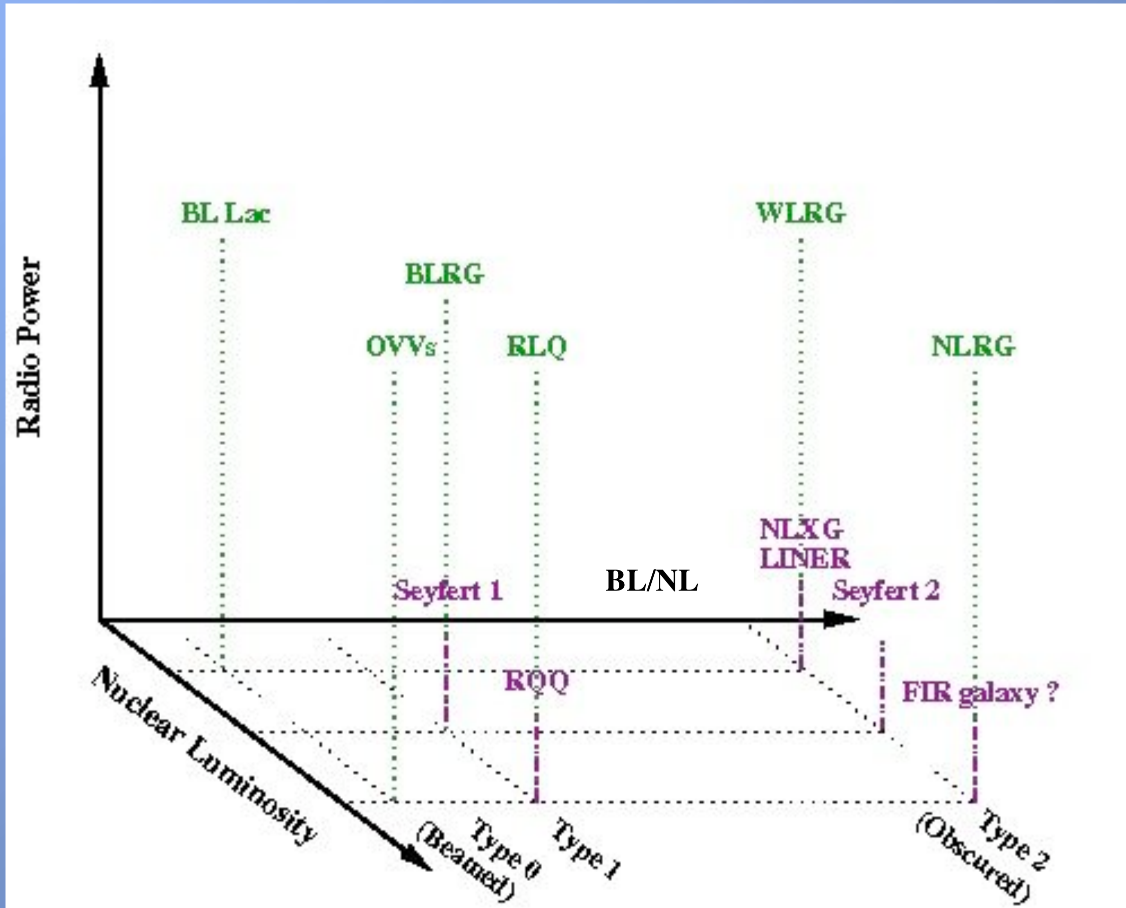
- Simple orientation-based unified schemes (e.g. Barthel 1989) work to first order for radio-loud AGN
- But:

  - the properties of the obscuring material are likely to change with both the luminosity and age of the AGN;

  - require separate schemes for low and high optical luminosity radio-loud AGN;

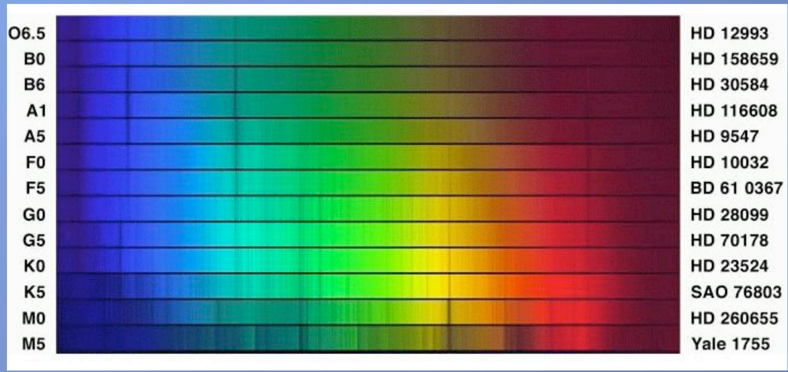
  - we know surprisingly little about the properties of the central obscuring torus!

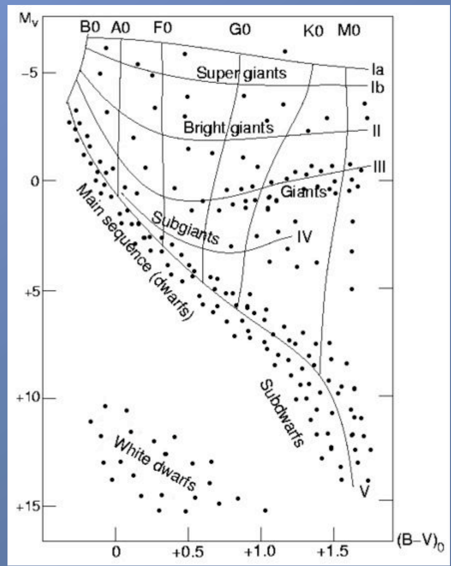
AGN Classification



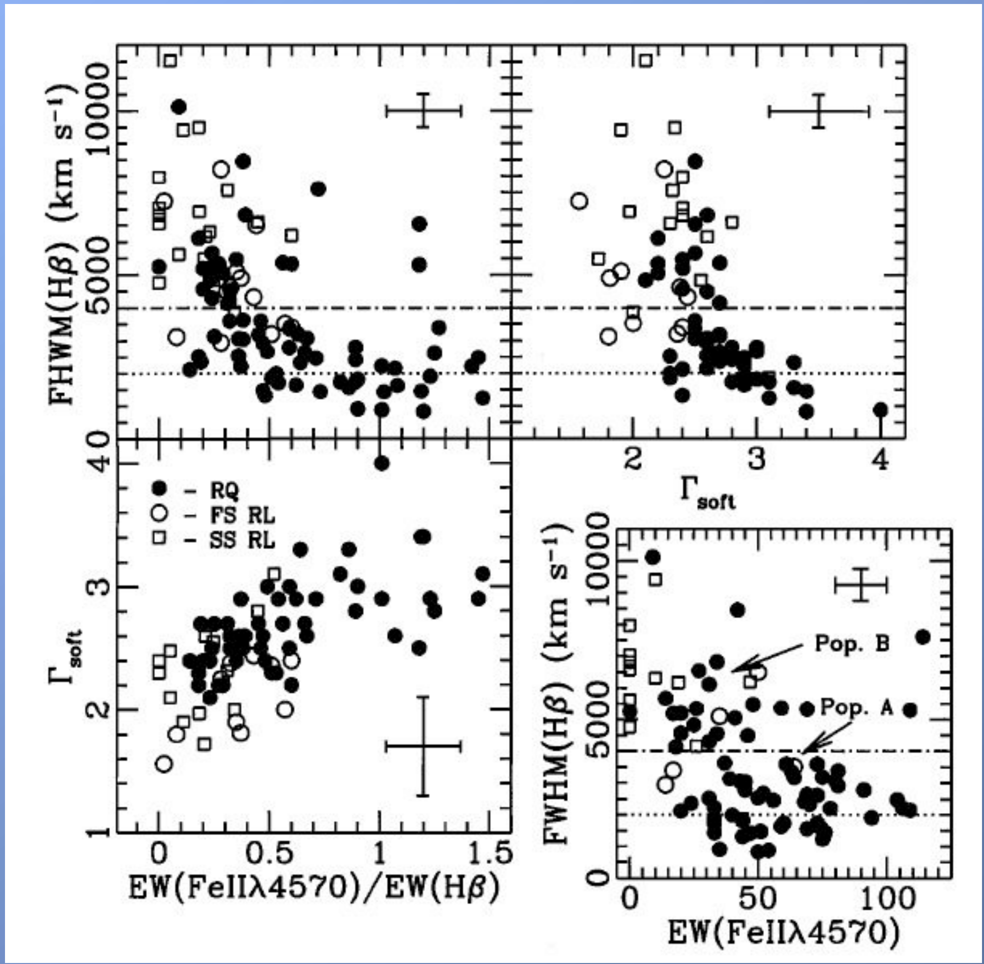
Stellar spectral classification

- 1863 - 1866: Secchi's first attempts at stellar spectral classification
- 1890 - 1912 Harvard spectral classification sequence developed (Maury, Cannon, Pickering..)
- 1913: Bohr's work on the structure of the Hydrogen atom
- 1920: Saha develops theory of ionization equilibrium in stars
- 1925: Payne-Gaposhkin interprets spectral classification sequence in terms of T variations along the main sequence





Towards an HR diagram for AGN?



Sulentic et al. (1999)

AGN: Key questions

- Main power source and accretion physics?
- How are jets formed?
- How is the activity triggered?
- How do normal and active galaxies relate?
- How does AGN activity evolve over cosmic time?
- How is AGN activity linked to galaxy evolution?