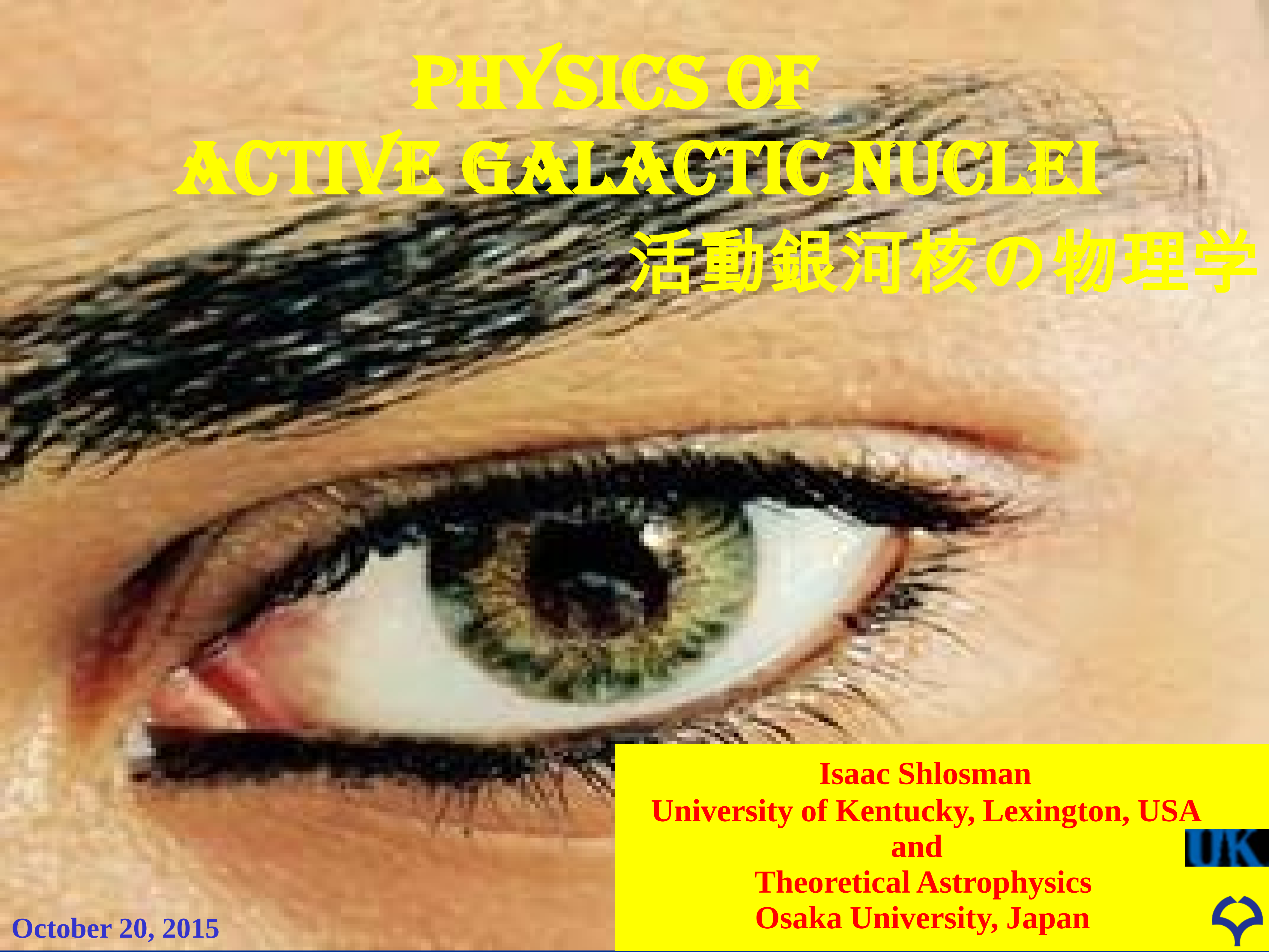


PHYSICS OF ACTIVE GALACTIC NUCLEI

活動銀河核の物理学

Isaac Shlosman
University of Kentucky, Lexington, USA
and
Theoretical Astrophysics
Osaka University, Japan

October 20, 2015

Physics of
Active Galactic Nuclei
活動銀河核の物理学

History, Taxonomy and Detection

Supermassive Black Holes and Accretion Processes

AGN: Inflows and Outflows

AGN and Host Galaxies: Fueling and Feedback

Formation and Evolution of AGN

LECTURE 1:
HISTORY, TAXONOMY AND DETECTION OF ACTIVE GALACTIC NUCLEI

Historical notes and definitions

Observations and classification

Emission and absorption lines

Radio-quiet and radio-loud objects

Broad-band continuum → constraints

Unification of AGN

AGN: HISTORY, TAXONOMY AND DETECTION

First spectroscopy of spiral nebulae, including NGC1068, by Edward A. Fath (1880-1959): detected nebular emission lines and was awarded Ph.D.
(21 citations, starting 61 yr later!)

UNIVERSITY OF CALIFORNIA PUBLICATIONS
ASTRONOMY

1909

E.A. Fath

LICK OBSERVATORY BULLETIN

NUMBER 149

NGC 1068: strong emission lines with width of few x 100 km/sec !

THE SPECTRA OF SOME SPIRAL NEBULAE AND GLOBULAR STAR CLUSTERS.*

The matter producing the lines, bright or dark, must be assumed to lie between the source of continuous radiation and the observer. Hence we conclude this source to be surrounded by a gaseous envelope, of physical condition varying in the different nebulae and corresponding to the various spectra obtained. The only celestial bodies of this type with which we are acquainted are the stars.

Fig. 3. SPIRAL NEBULA, N. G. C. 1068

AGN: History, Taxonomy and Detection

Sir James H. Jeans in 1929:

The centres of the nebulae are of the nature of singular points,' at which matter is poured into our universe from some other and entirely spatial dimension, so that to a denizen of our universe, they appear as points at which matter is being continually created…

AGN: History, Taxonomy and Detection

Jansky working at the Bell Telephone Laboratories, conducted a study of the sources of static affecting trans-Atlantic radio communications. Using a rotatable antenna and a short-wave receiver operating at a wavelength of 14.6 m, he systematically measured the intensity of the static arriving from all directions throughout the day. From these records, he identified three types of static: (1) static from local thunderstorms, (2) static from distant thunderstorms, and (3) "a steady hiss type static of unknown origin". The latter seemed to be somehow associated with the Sun (Jansky 1932).

AGN: History, Taxonomy and Detection

ApJ 97, 28 (1943)
6 galaxies

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.

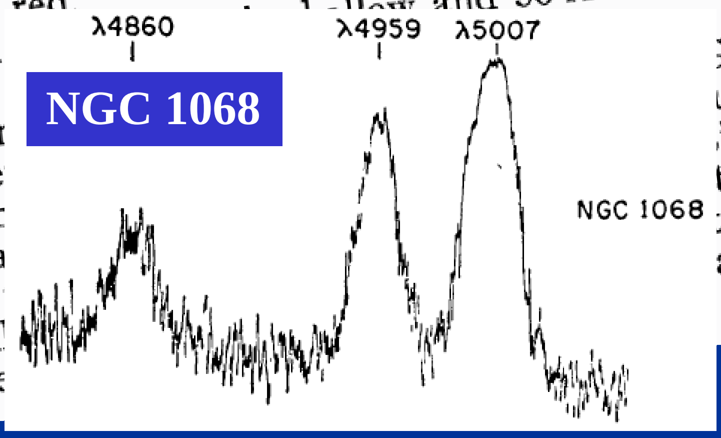
Apparent relative intensities of the emission lines in the six spirals were reduced to true relative intensities. Color temperatures of the continua of each spiral were determined for this purpose.

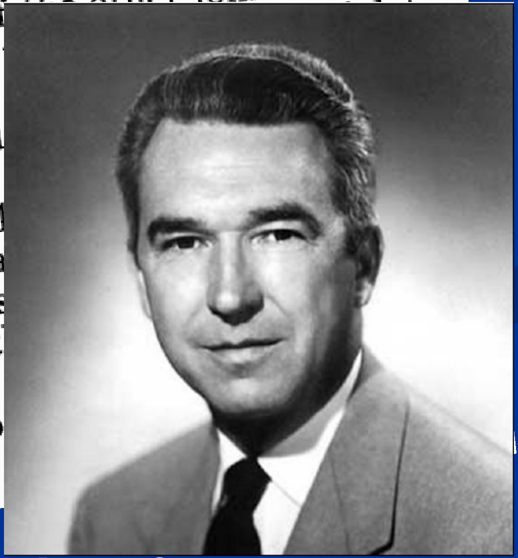
The observed relative intensities of the emission lines exhibit large variations from nebula to nebula. Profiles of the emission lines show that all the lines are broadened, presumably by Doppler motion, by amounts varying up to 8500 km/sec for the total width of the hydrogen lines in NGC 3516 and NGC 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 ... other ions show no evidence of wide wings. Some of the lines exhibit strong asymmetries, usually in ... side of the line is stronger than the red ... llow and 50 A wide, at l...

In NGC 7469 the absorption K ... GC 1 ... normal spirals.

Absorption minima are found in ... uiva ... 4151, and one in NGC 7469. Evide ... ions ... these absorption minima arise fro ... th t ...

The maximum width of the Ba ... , of ... the nucleus and with the ratio of ... app ... lines in the brightest diffuse nebul ... lines similar to those found in the ...



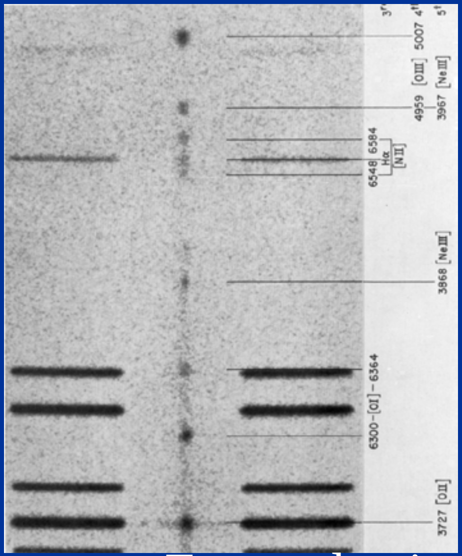


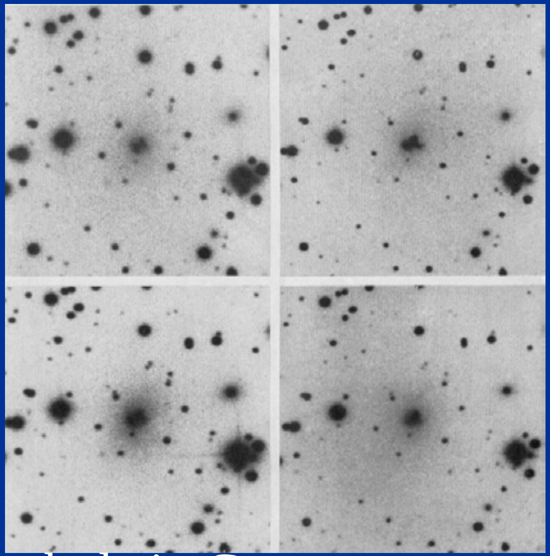
Carl Seyfert (1911-1960)

AGN: History, Taxonomy and Detection

Reber (1944): detection at 160MHz of Cyg-A
Bolton (1948): first radio identification of point sources (other than Sun!),
including Cas A, Crab,
Cygnus A, Cen A, M87, etc. at 100 MHz (not extragalactic!)
Baade & Minkowski (1954): optical identification of Cas A,
Cyg A (distorted morphology)
emission lines of [NV], [OIII], [NeIII], [OI], [NII], Hα → width 400 km/s
distance of 31 Mpc for H_0 = 540 km/s/Mpc
1950-60's: radio catalogs by Cambridge (*e.g.* 3C)

John Bolton





Extragalactic nebula in Cygnus

L(radio)~ 8×10^{42} erg/s

L(opt) ~ 6×10^{42} erg/s

Radio emission: first distinguishing sign of AGN!

AGN: HISTORY, TAXONOMY AND DETECTION

THE THEORETICAL EXPLANATION OF RADIO EMISSION

INTRODUCTORY LECTURE by

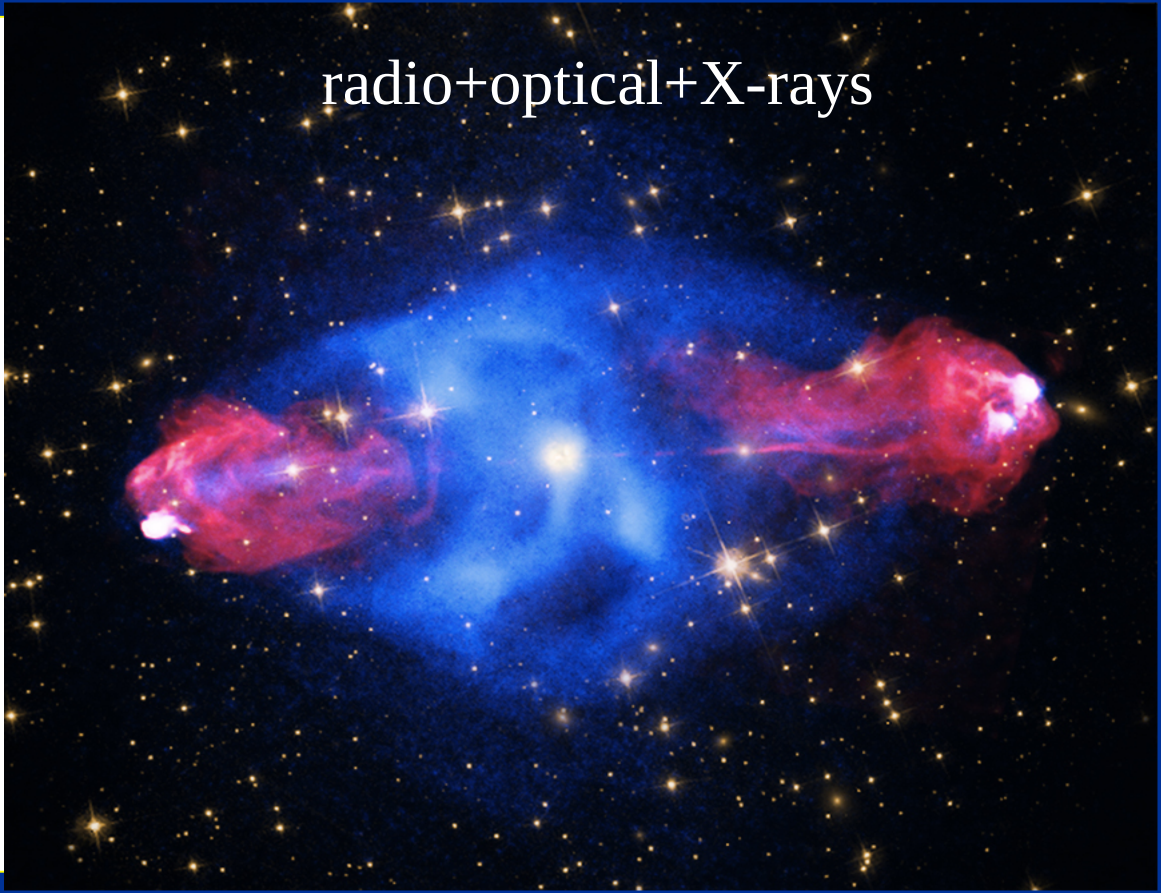
1959

G. R. BURBIDGE

Yerkes Observatory, Williams Bay, Wisconsin, U.S.A.

* Footnote:

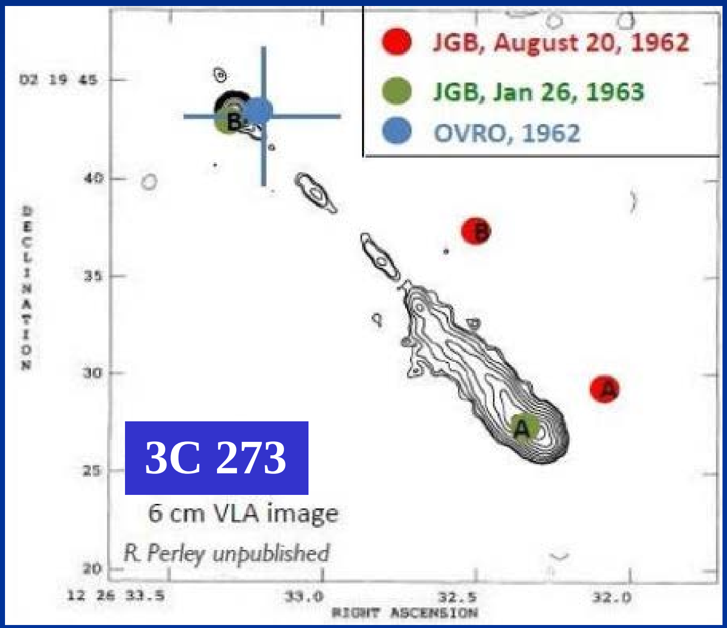
In my opinion, the term "synchrotron radiation " to describe cosmic radio emission should be avoided. It was first used by physicists interested in this phenomenon, which has been a source of trouble in accelerating electrons in synchrotrons. To continue to use a laboratory term in connection with astronomical phenomena does not appear very sensible. Some authors in the U .S.S.R. have used the term "magnetic bremsstrahlung." However, I would like to suggest the term "acceleration radiation," which has the advantage of more closely describing the phenomenon itself.

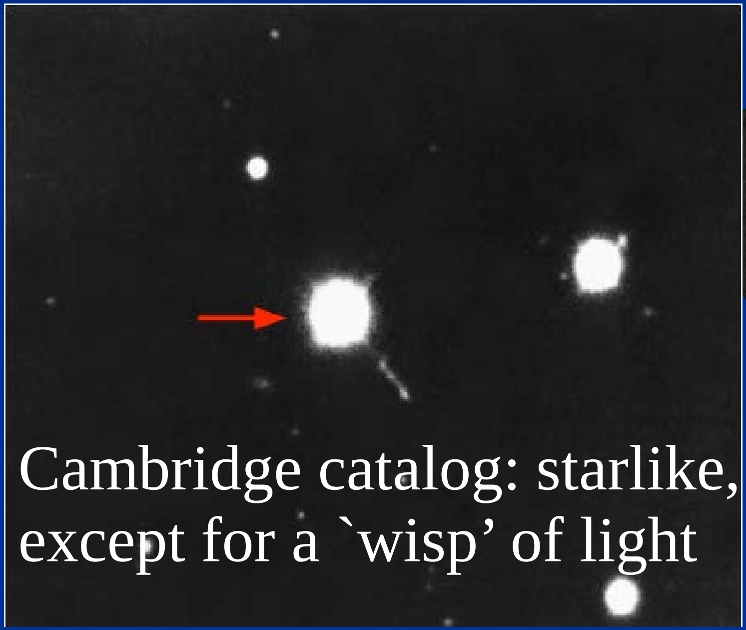


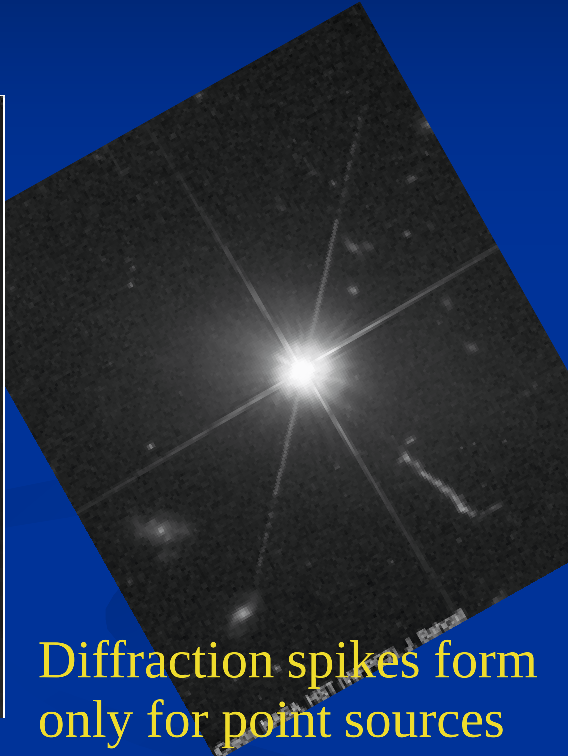
Synchrotron radiation in double lobed galaxies: $E \sim 10^{60}$ erg

AGN: HISTORY, TAXONOMY AND DETECTION

3C 273 --- one of the strongest extragalactic radiosources, was first catalogued in 1959. Its 13th magnitude optical counterpart was observed (at least!) as early as 1887







Diffraction spikes form only for point sources → quasar is star-like

A 6-cm image of 3C 273 obtained with the VLA. Red dots show the location of components A and B as reported to Maarten Schmidt by John Bolton in a letter dated 20 August 1962. Green dots show the location of components A and B as reported by Bolton in his 26 January 1963 letter to Schmidt. The blue point with error bars represents the then-unpublished OVRO interferometer position.

lunar occultation of 3C 273
→accurate position
(Hazard et al. 1963)

DETECTION OF QUASISTELLAR OBJECTS: QUASARS

EMISSION NUCLEI IN GALAXIES

1959

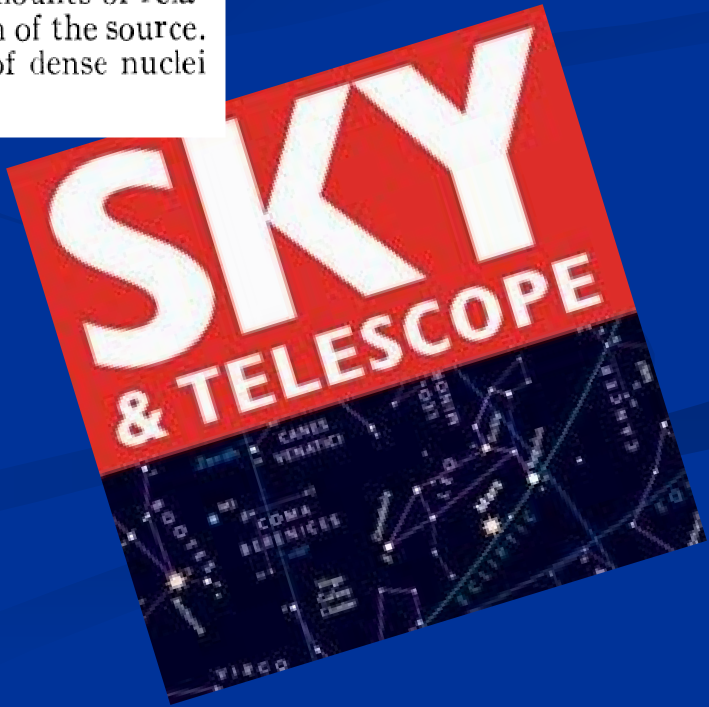
L. WOLTJER*
Yerkes Observatory, University of Chicago
Received February 16, 1959

ABSTRACT

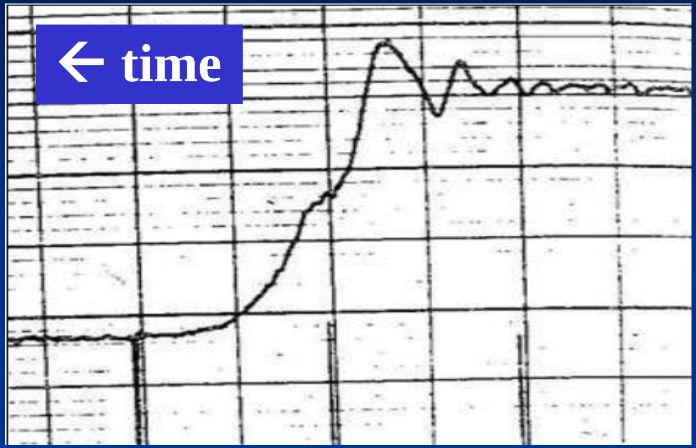
Some galaxies which show wide emission lines in the spectra of their nuclei are discussed. It is shown that, on statistical grounds, the nuclear emission must last for several times 10^8 years at least. The nuclei are extremely narrow, of the order of 100 parsecs, and, if a normal mass-to-light ratio applies, extremely massive. The width of the emission lines, which indicates velocities of a few thousand kilometers per second, is probably due to fast motions, circular or random, in the gravitational fields of the nuclei. The high star density in the nuclei may provide a source of excitation. In the nucleus of our own Galaxy the radio source Sagittarius gives evidence of strong magnetic fields and large amounts of relativistic particles. A mass of a few times 10^8 solar masses is needed to prevent disintegration of the source. The Andromeda Nebula has a nucleus with a somewhat smaller mass. The occurrence of dense nuclei may be a common characteristic of many galaxies.

Timescale of Seyfert Activity $\sim 10^8$ yr ← 1% of galaxies are Seyferts and nuclear mass $\sim 10^{8-10}\ M_\odot$

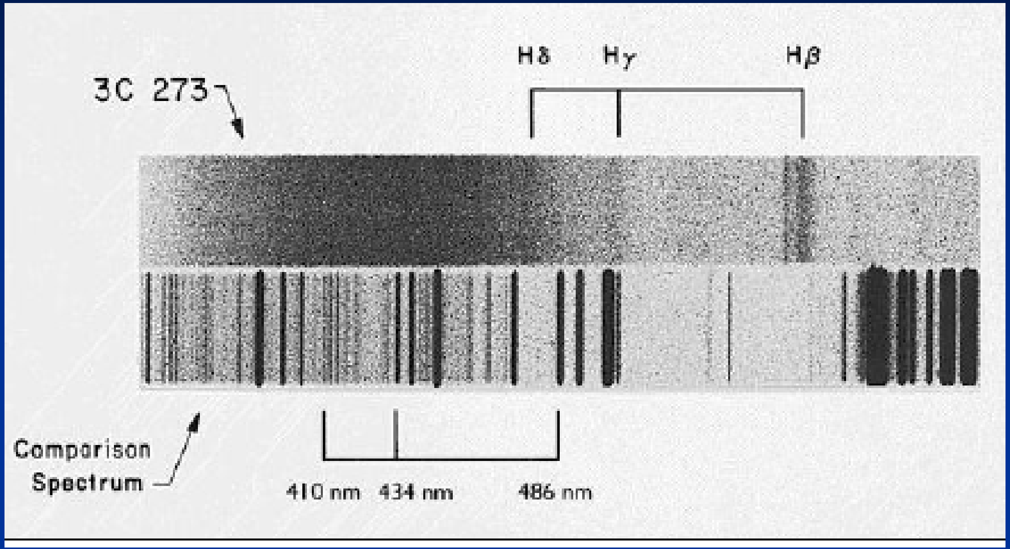
Sky and Telescope Editor (1961):
There is a "remote possibility that it may be a distant galaxy of stars" but "general agreement" that it is "a relatively nearby star with most peculiar properties."



DETECTION OF QUASISTELLAR OBJECTS: QUASARS

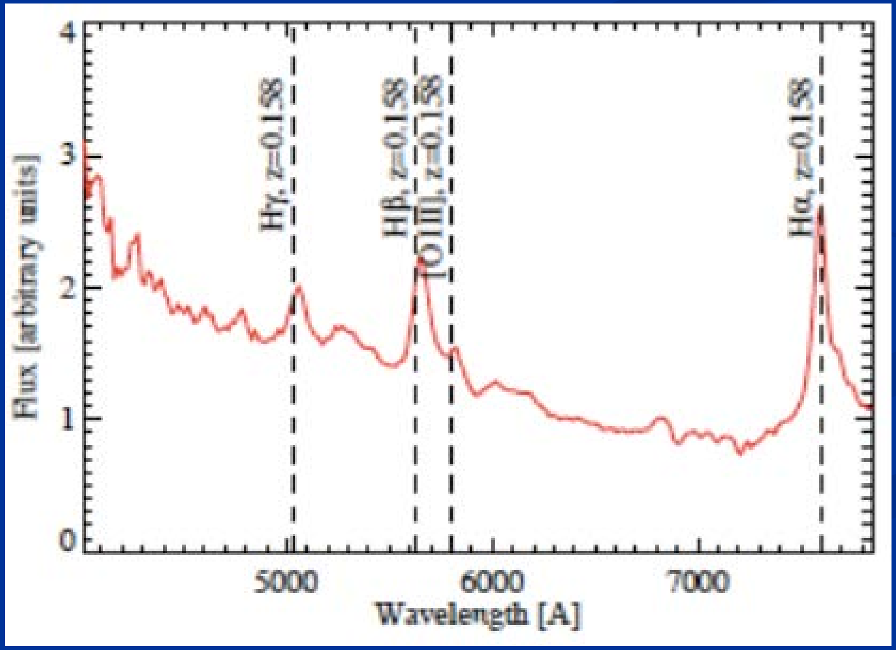


Moon occultation of 3C 273
on August 5 1962 at 410 MHz
(Hazard, Mackey & Shimmins 1963)

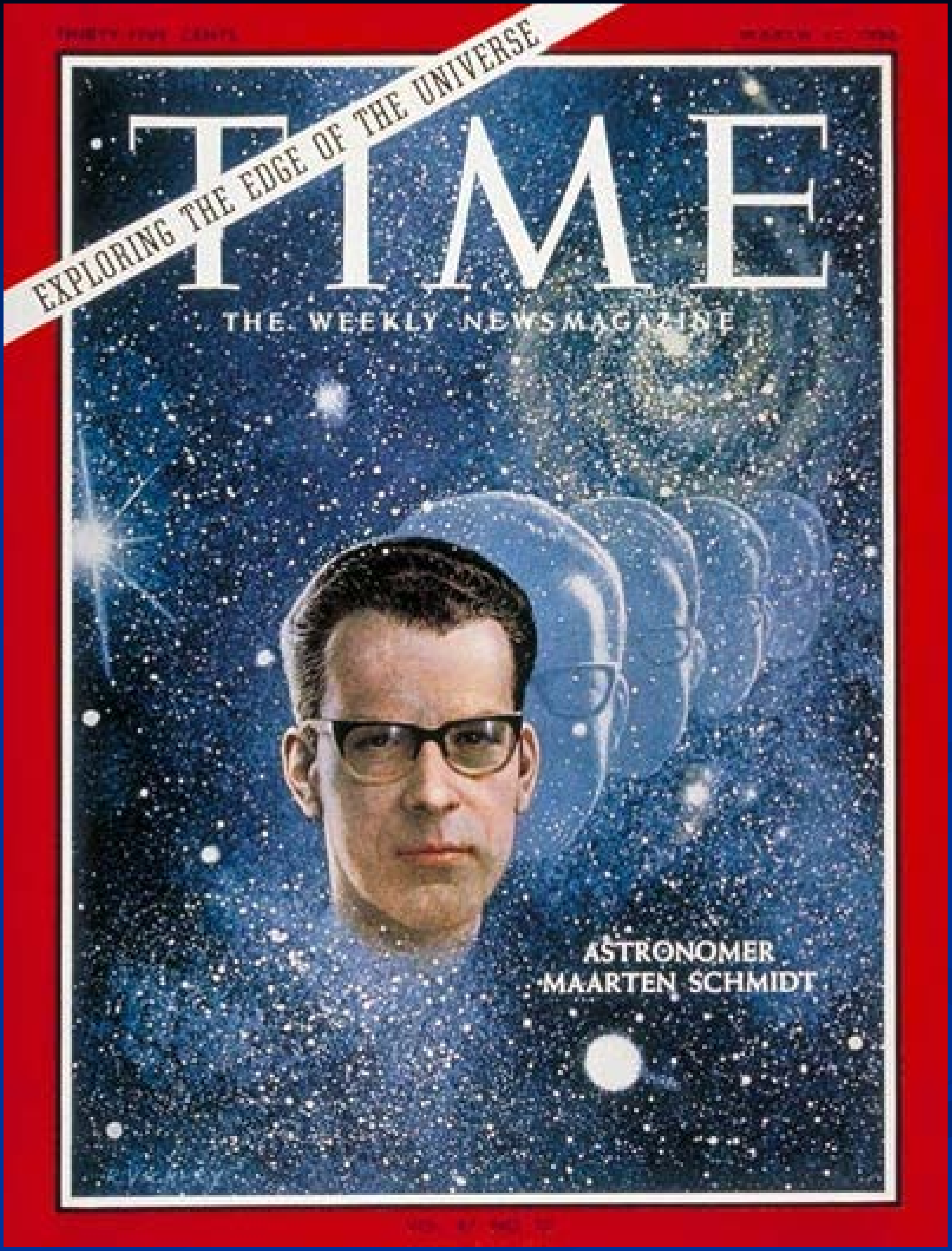


Maarten Schmidt (1963) & spectrum of 3C 273 with 200” Palomar (z=0.158): February 5, 1963

The 64-m Parkes Radio Telescope



QUASARS



Maarten Schmidt | Mar. 11, 1966

QUASARS

What made 3C 273 at z=0.158 so special?

$$z = \frac{\Delta\lambda}{\lambda_0}$$

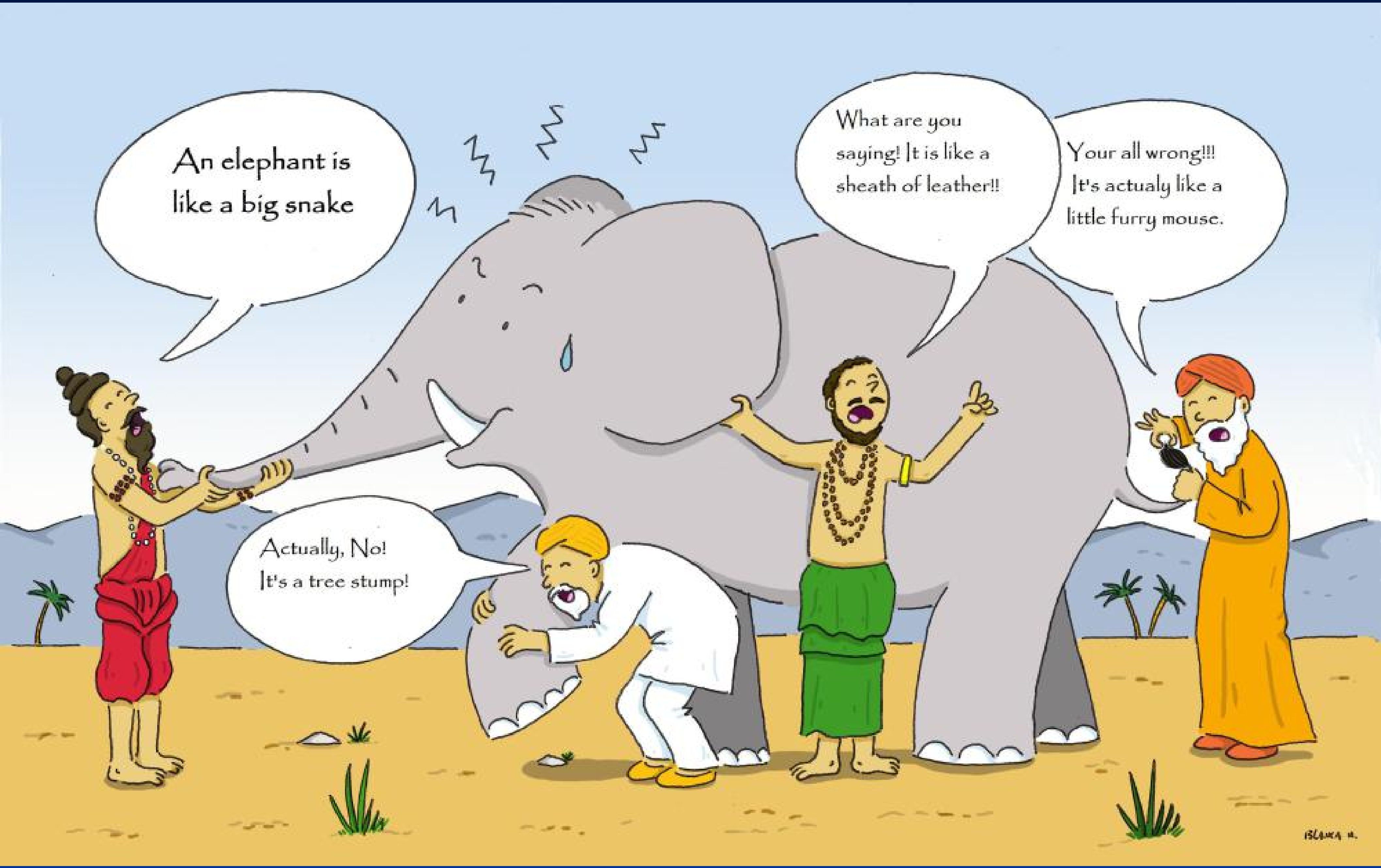
$$d = \frac{cz}{H_0} \simeq 470h^{-1}\,\mathrm{Mpc}$$

$$m - M = 5\log(d/pc) + 5$$

$$m_B = 13.1\,\mathrm{mag} \;\Rightarrow\; M_B = -23.3 + 5\log h^{-1}$$

Absolute magnitude very massive galaxies!

AGN: TAXONOMY

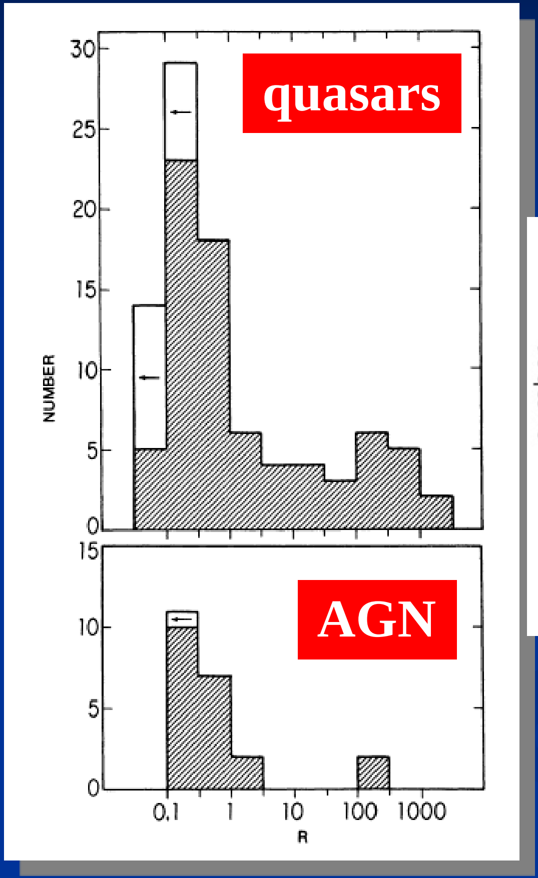


Blind men and elephant (Indian) parable

Active Galactic Nuclei (AGN): The Zoo

AGN: TAXONOMY

Kellerman et al. (1989)



$R = f_{radio} / f_{optical\text{-}UV}$

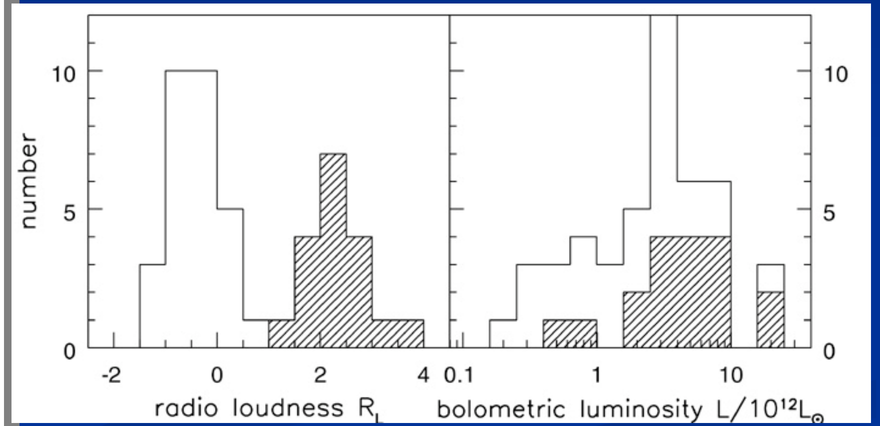
Radio-quiet

~90% of luminous AGN

Seyfert Galaxies ($M_B > -23$)
Type 1 and Type 2
Quasars ($M_B < -23$)
Type 1 and Type 2
LINERS: Low-ionization nuclear emission-line region galaxies

Radio-loud

~10% of luminous AGN



$R_L = \log(L_{radio}/L_{opt})$

Radio galaxies
Broad-line radio galaxies (BLRGs)
Narrow-line radio galaxies (NLRHs)

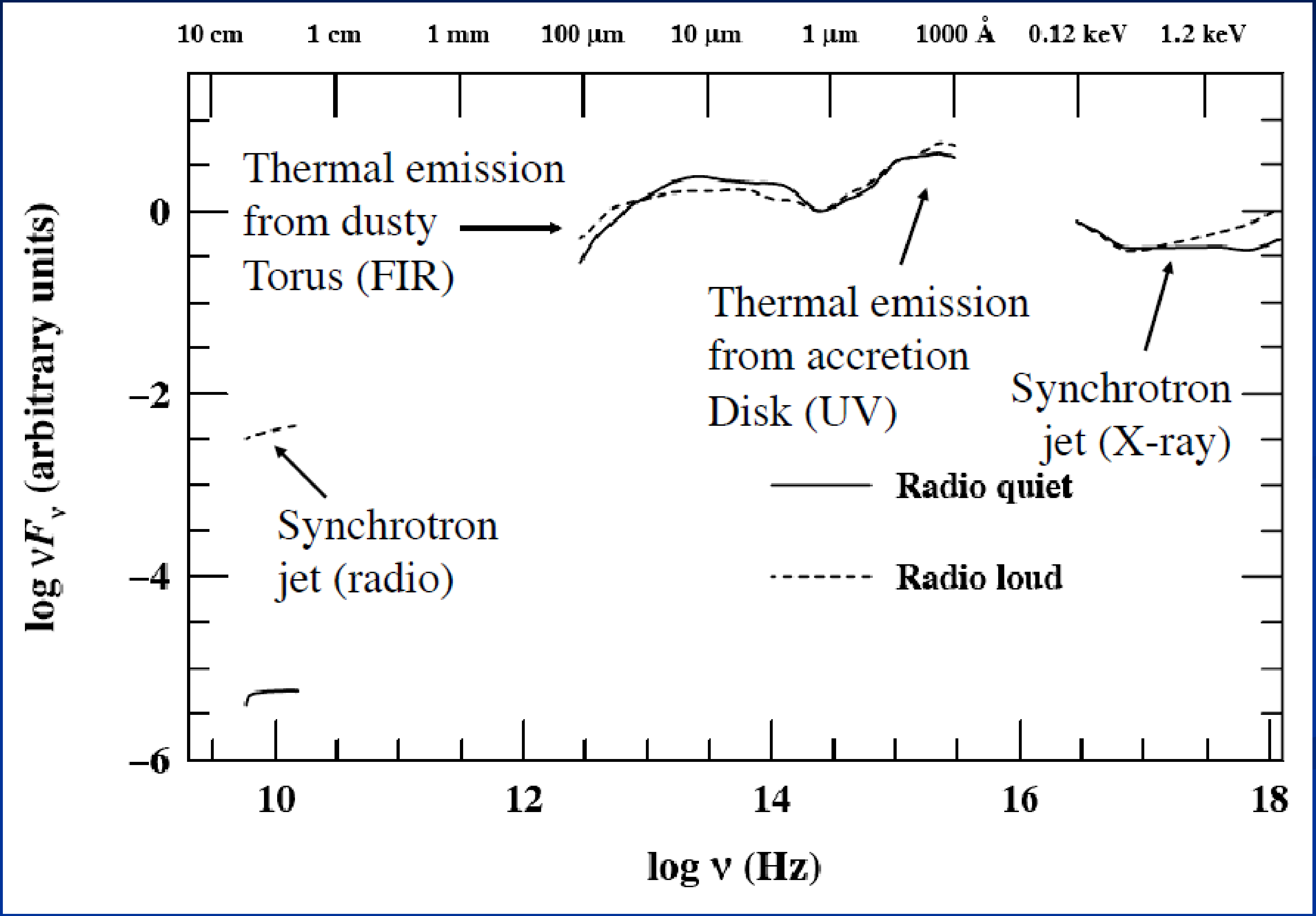
Blazars
BL Lacs
OVVs: Optically violently variable quasars
Radio-loud quasars

AGN: (More Complete) Taxonomy

3-D classification: spectral type, radio properties, luminosity

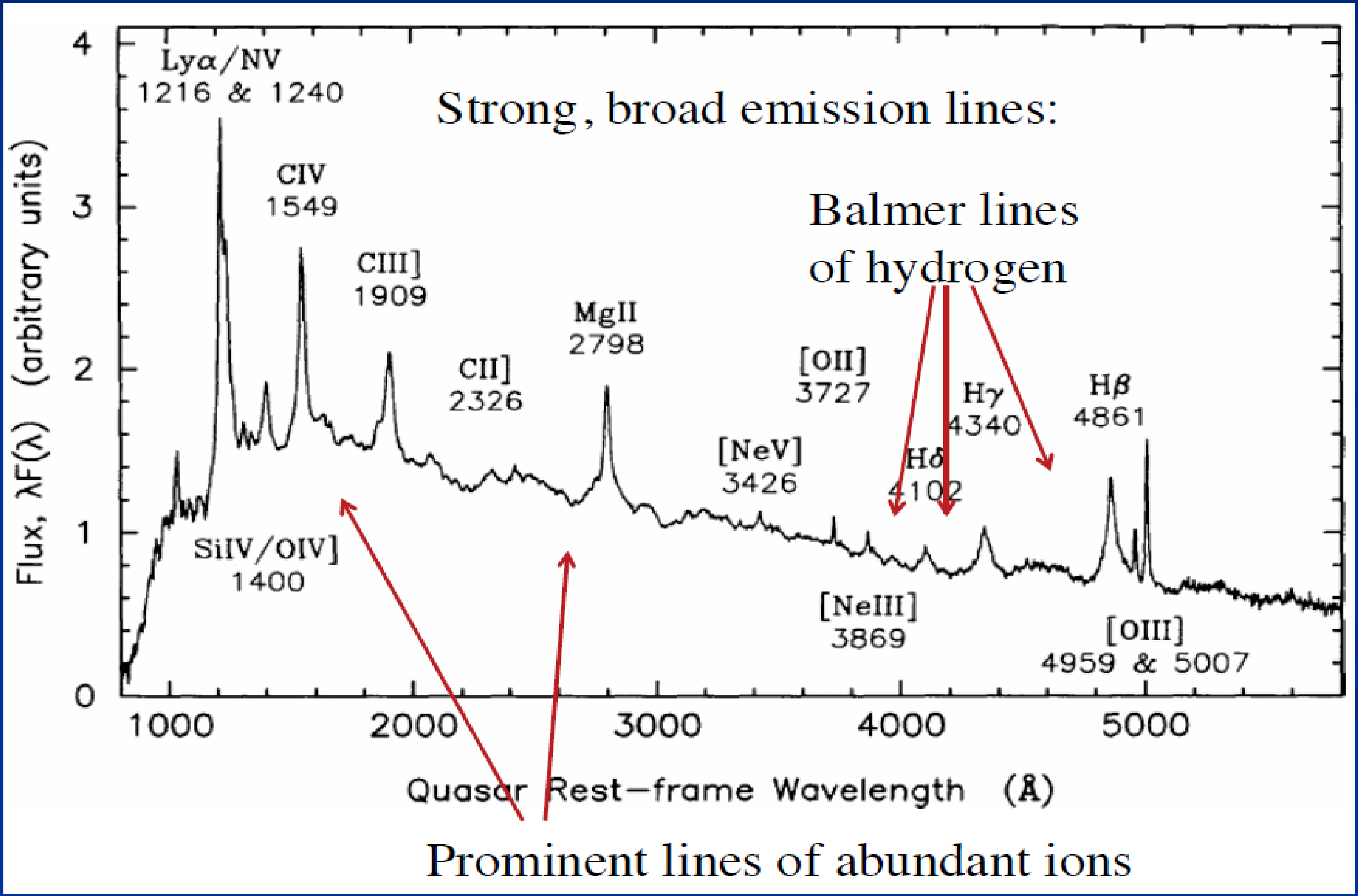
NAME	SPECTRAL TYPE	RADIO-LOUD?	LUMINOSITY
Seyferts	1, 1.2, 1.5, 1.8, 1.9, 2.0	No	Moderate
Quasars	1, 2	No	High
LINERS	1, 2	Yes/No	Low
BLRGs	1	Yes	Moderate
NLRGs	2	Yes	Moderate
Radio-loud quasars	1, 2	Yes	High
FR Is	1	Yes	Low
FR IIs	1, 2	Yes	Low/High
Blazars	0	Yes	Low/High

AGN: Broad-band Spectrum



AGN: Emission Lines

❖ UV/optical spectrum of quasars



Explanations to Taxonomy

Quasars: quasi-stellar

Seyferts: host galaxy visible, but has a bright nucleus

type 1 --- narrow+broad emission lines)

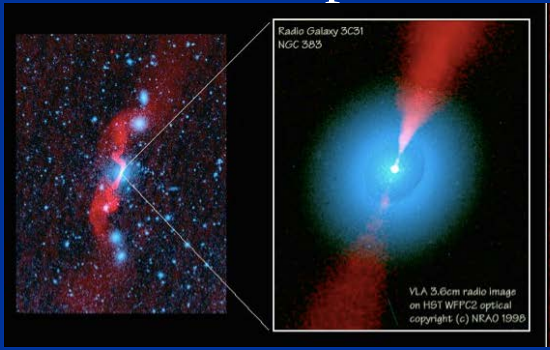
type 2 --- only narrow lines (but look in a polarized light….)

LINERS: host galaxy visible, not so bright nucleus, low excitation lines visible

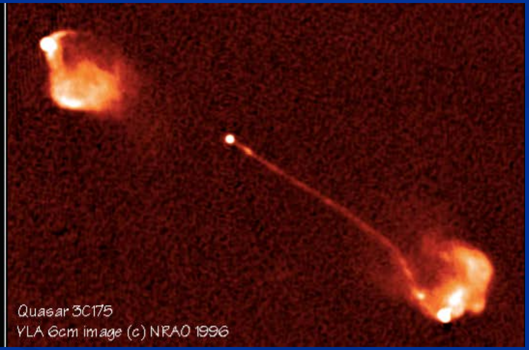
Radio galaxies:

FR II --- powerful collimated jets with hotspots (Fanaroff & Riley 1974)

FR I --- less-powerful, less-collimated, no hotspots



3C 31 (FR I)



3C 175 (FR II)

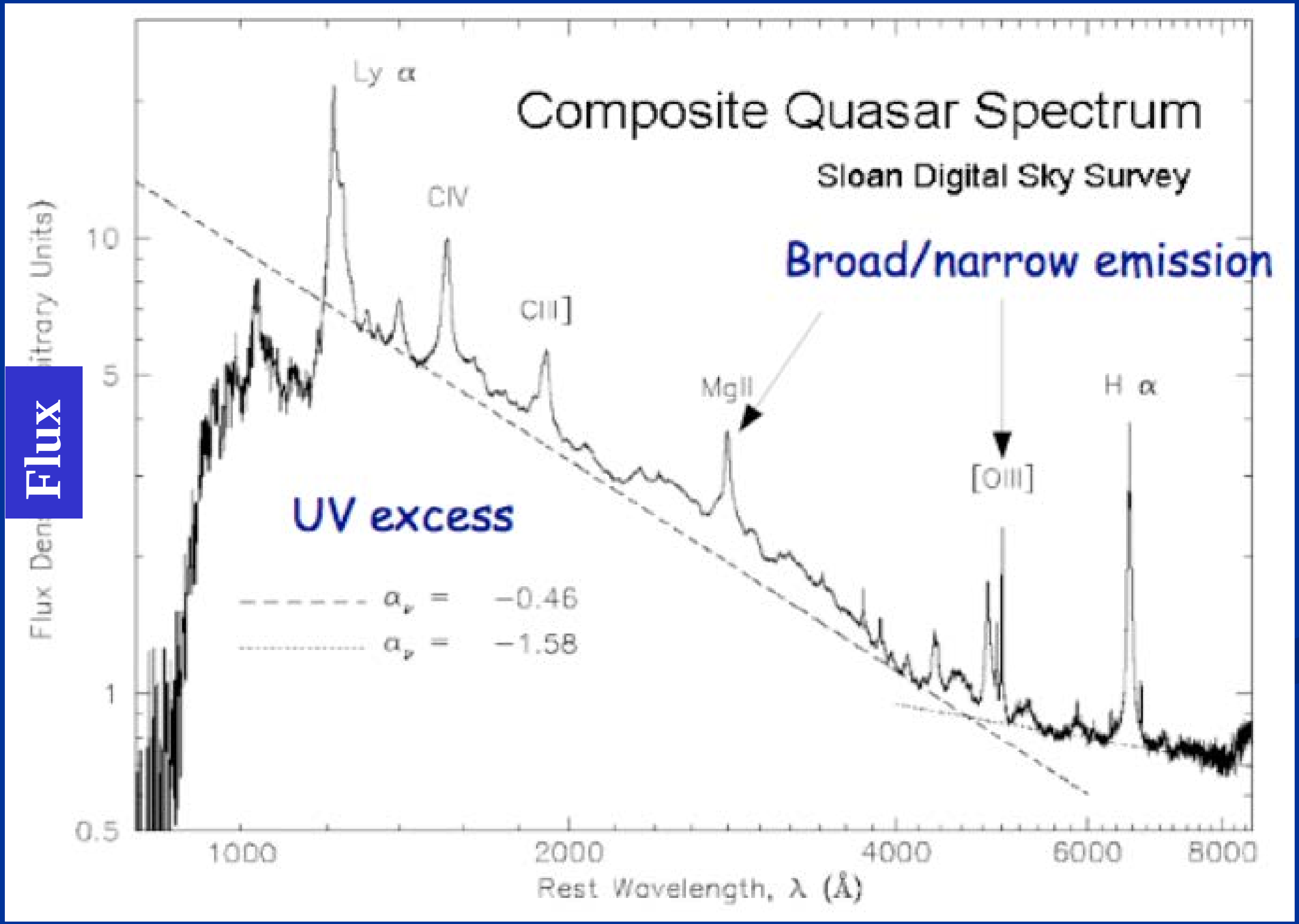
Blazars, BL Lacs: core-dominated, flat-spectrum quasars, with significant non-thermal radiation forming SED

About 30-40% of all galaxies show signs of AGN! (Ho et al. 1995)

Explanations to Taxonomy

- Quasars $M_B < -23$, strong nonthermal continuum,
  broad permitted emission lines → ~10^4 km/s
  narrow forbidden emission lines → ~$10^{2\text{-}3}$ km/s
  Radio quiet (RQQ): elliptical or spiral host galaxies
  Radio loud (RLQ): ~10% of all quasars, elliptical hosts

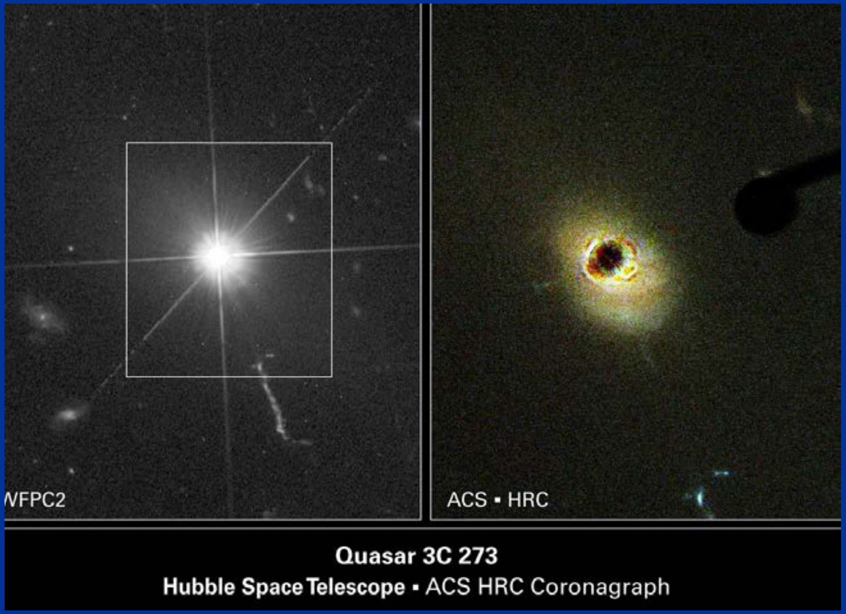
Emission lines!



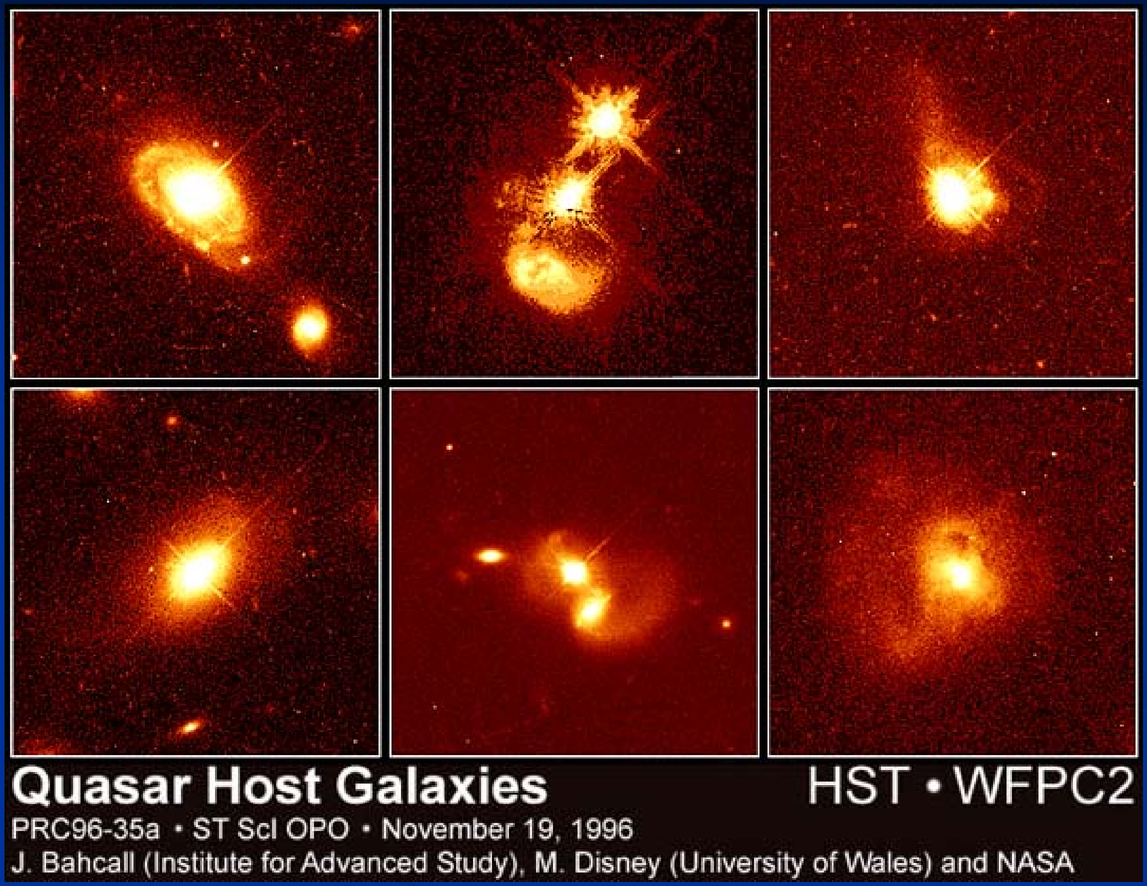
Composite quasar optical/UV spectrum

EXPLANATIONS TO TAXONOMY

❖ Quasars: host galaxies



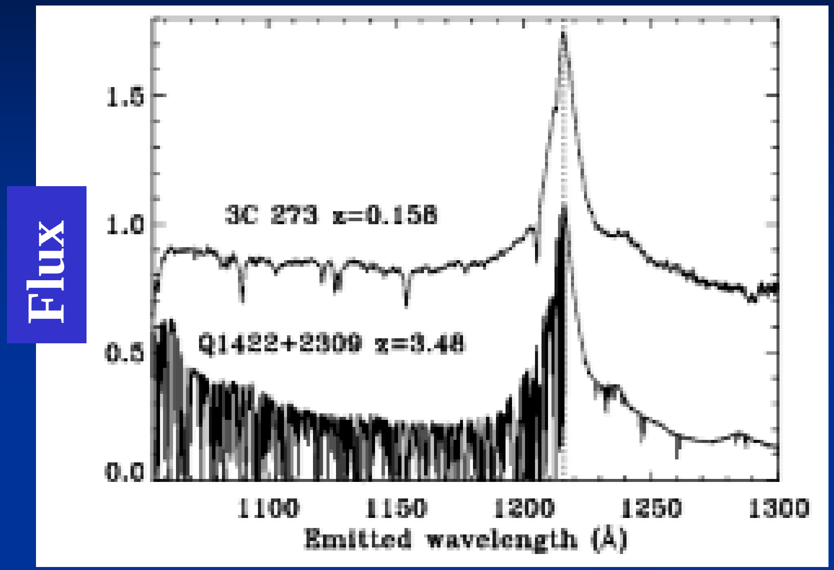
Subtracting the star-like quasar image
→ underlying galaxy



Some quasars are found in colliding and distorted galaxies, but not all!!

EXPLANATIONS TO TAXONOMY

❖ Quasars: spectra and Lyman α forest



Quasars and Lyman α forest

Some spectral features are not associated with quasars
→ narrow absorption lines are formed in intervening galaxy halos between us and quasars

⬇

Redshifts of these absorption lines ≤ quasar redshift

→ occurs as Lyman α absorption (this is the lowest excitation level for hydrogen gas found in these galaxy halos

→ can be used to measure extent of galaxy halos and map out large scale structure in the universe

EXPLANATIONS TO TAXONOMY

- Quasars Broad Absorption Lines (BAL) Quasars (always blue-shifted) : normal quasars seen at a particular angle along the l.o.s. of intervening, fast-moving material (?) → 10% of quasars

WINDS ! Outflows with v ~ 0.2c !

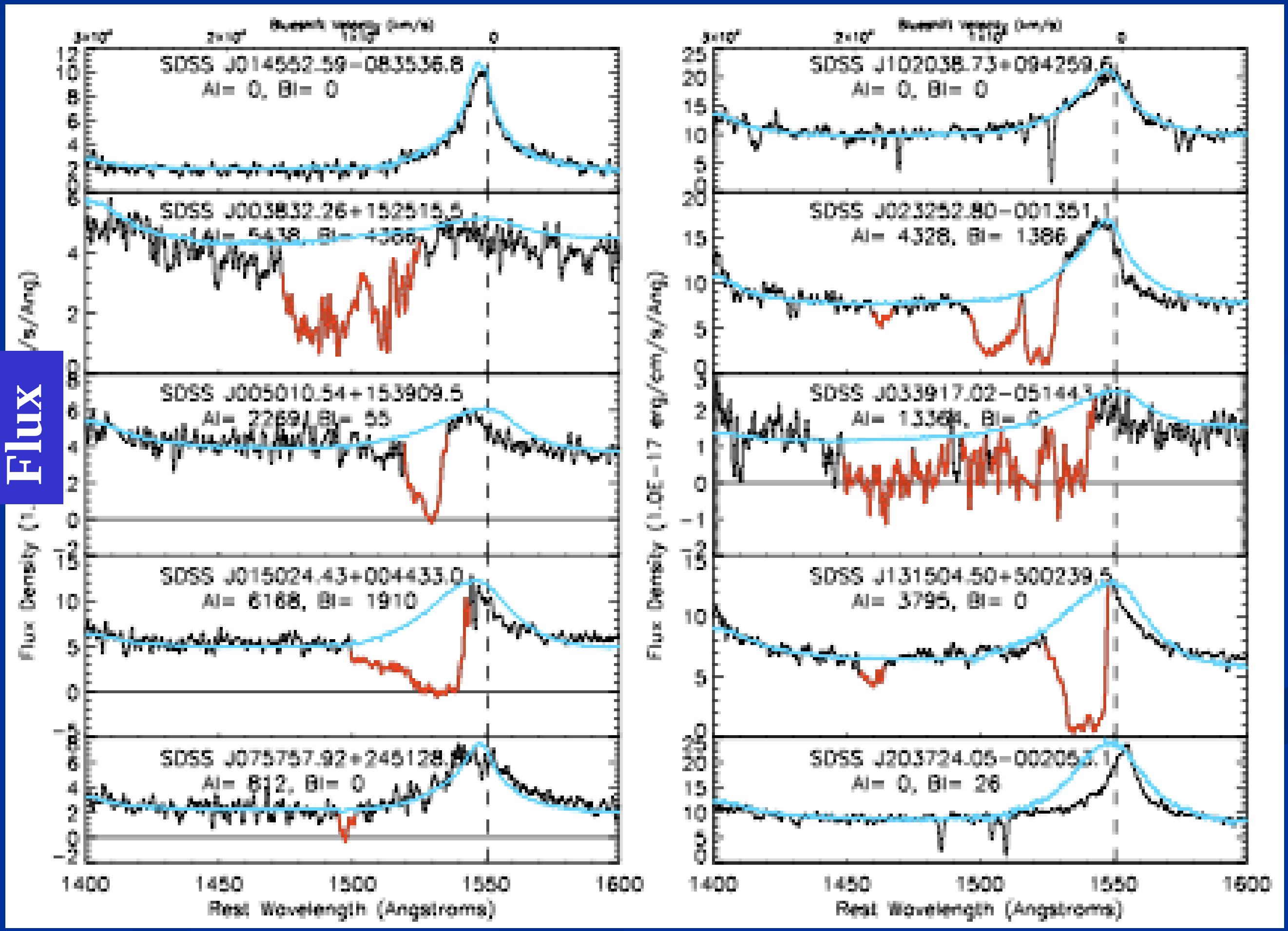
High-ionization (HIBAL):
Lyα, N V, Si IV, C IV

Low-ionization (LOBAL):
Al III, Mg II

blue-shifted absorption lines!

Trump et al. 2006

Flux



7 BAL QSOs (red throughs), 2 non-BAL QSOs

Explanations to Taxonomy

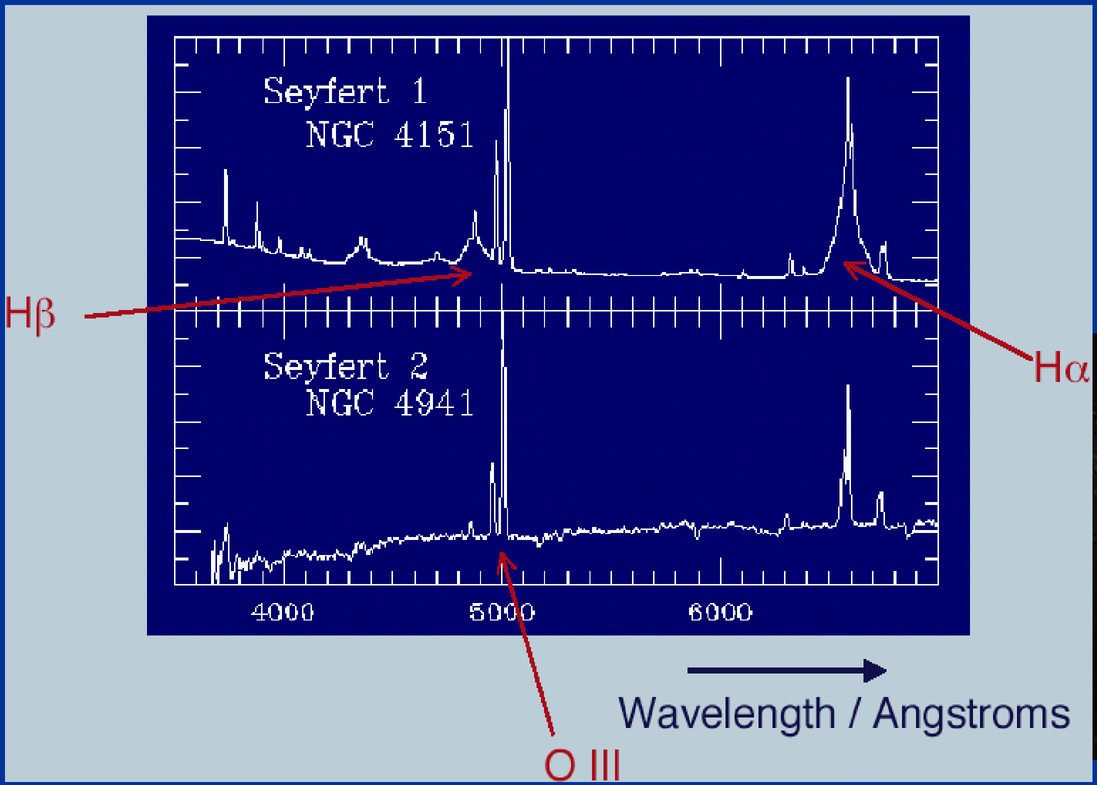
- Seyfert galaxies

  Type 1: two sets of emission lines

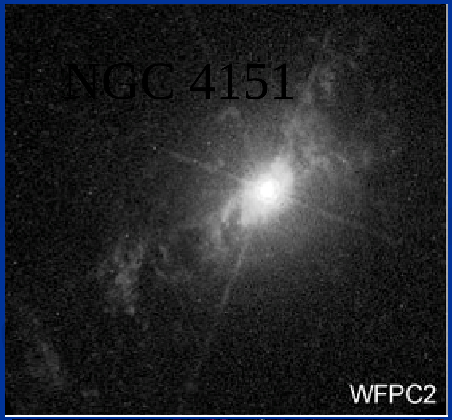
  → narrow emission lines with FWHM of few x 100 km/s produced by a narrow emission line region (NLR)

  → broad emission lines with FWHM of few x 1000 km/s produced by a broad line emission region (BLR)

  Type 2: only narrow emission lines, but….



NGC 4151 (Sy 1)



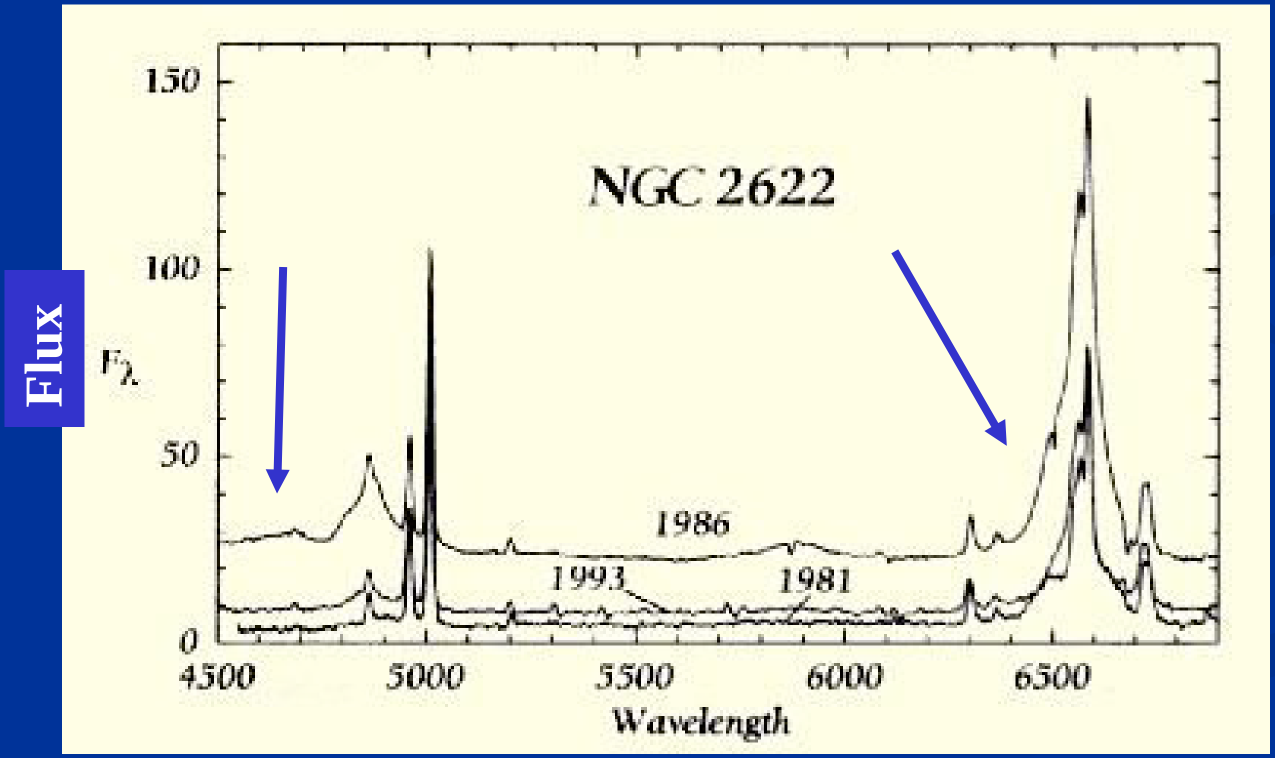
NGC 1275 (Sy 1.5)

Circinus (Sy 2)

EXPLANATIONS TO TAXONOMY

- Seyfert galaxies

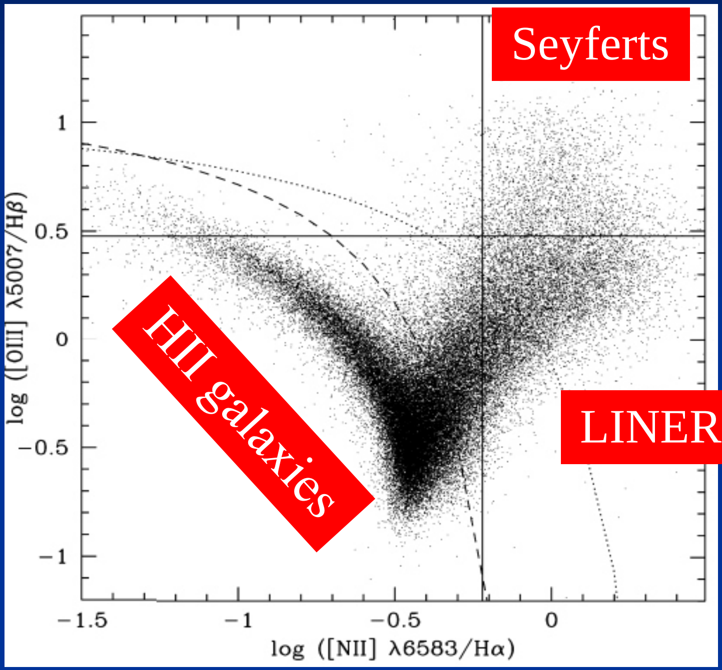
Sy 1.x (1.9, 1.8, ...): defined by the width of the Hα and Hβ lines
Narrow line (NL) Sy 1: subclass of Sy 2 with X-ray excess and optical Fe II in emission



But the classification for a specific object can change with time, due to AGN variability!

EXPLANATIONS TO TAXONOMY

❖ LINERs: Low-Ionization Narrow-Line Region galaxies



LINERs are found in nearly all nuclei of bulge-dominated galaxies

They appear to be the weakest in the AGN zoo

Characterized by

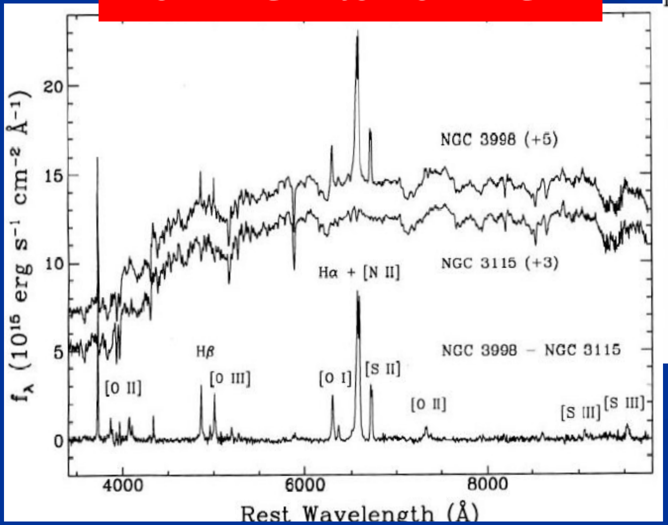
[O II] +3727Å / [O III] +5007Å ≥ 1

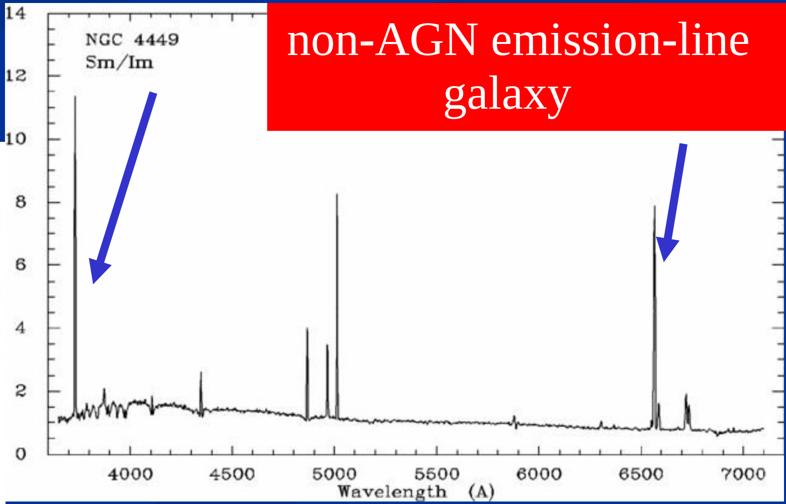
[O I] +6300Å / [O III] +5007Å ≥ 1/3

--- classification line

— extreme starburst

M104 Sombrero galaxy (LINER)





EXPLANATIONS TO TAXONOMY

❖ LINERs: Low-Ionization Narrow-Line Region galaxies

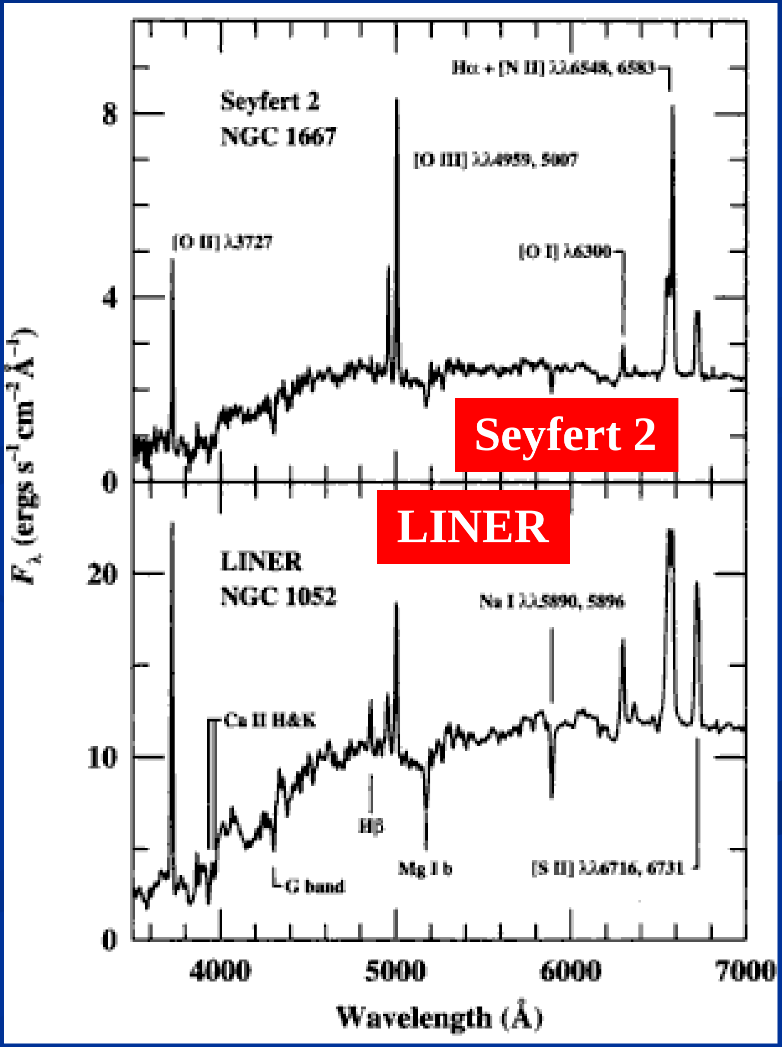
Narrow, low-ionization emission lines

Weak non-thermal continuum

Emission comes from either a low-luminosity AGN or from shocks and winds from a starburst

Hosts galaxies are typically spirals

LINER: [OIII]/Hβ less prominent than in Sy 2
Strong [OI]6300A and [NII]6548,6583A

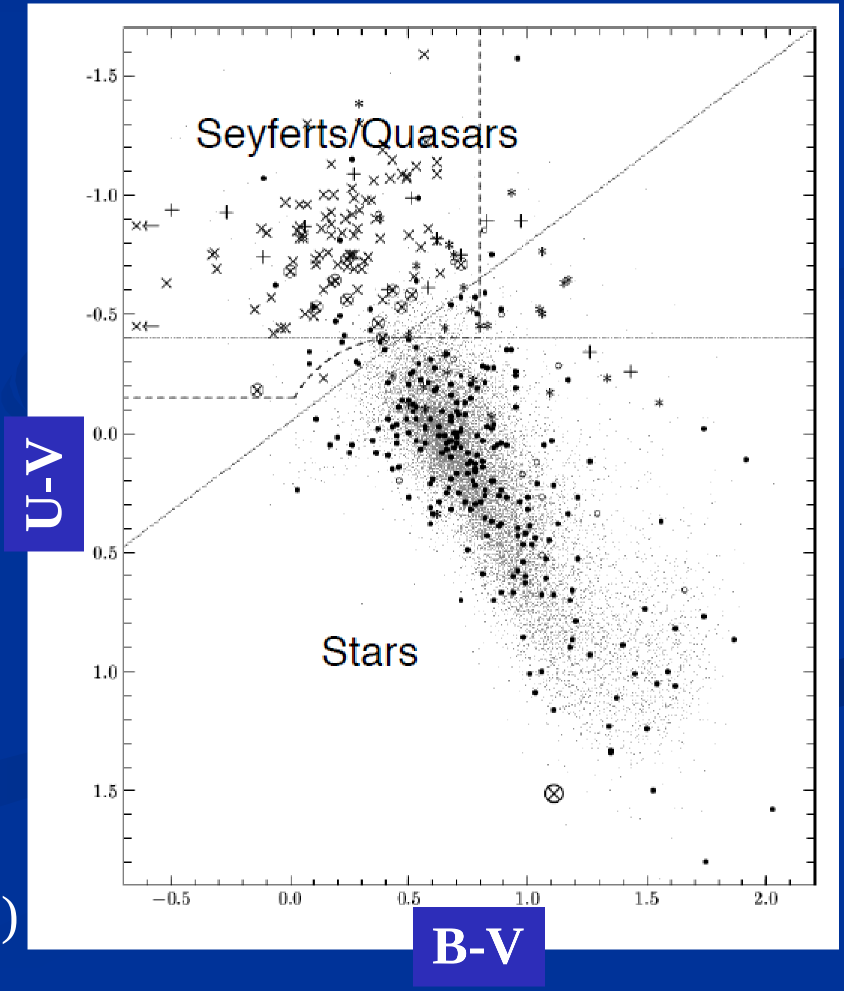


EXPLANATIONS TO TAXONOMY

❖ Quasars, Seyfert galaxies and stars

UV excess in quasars and Seyferts:

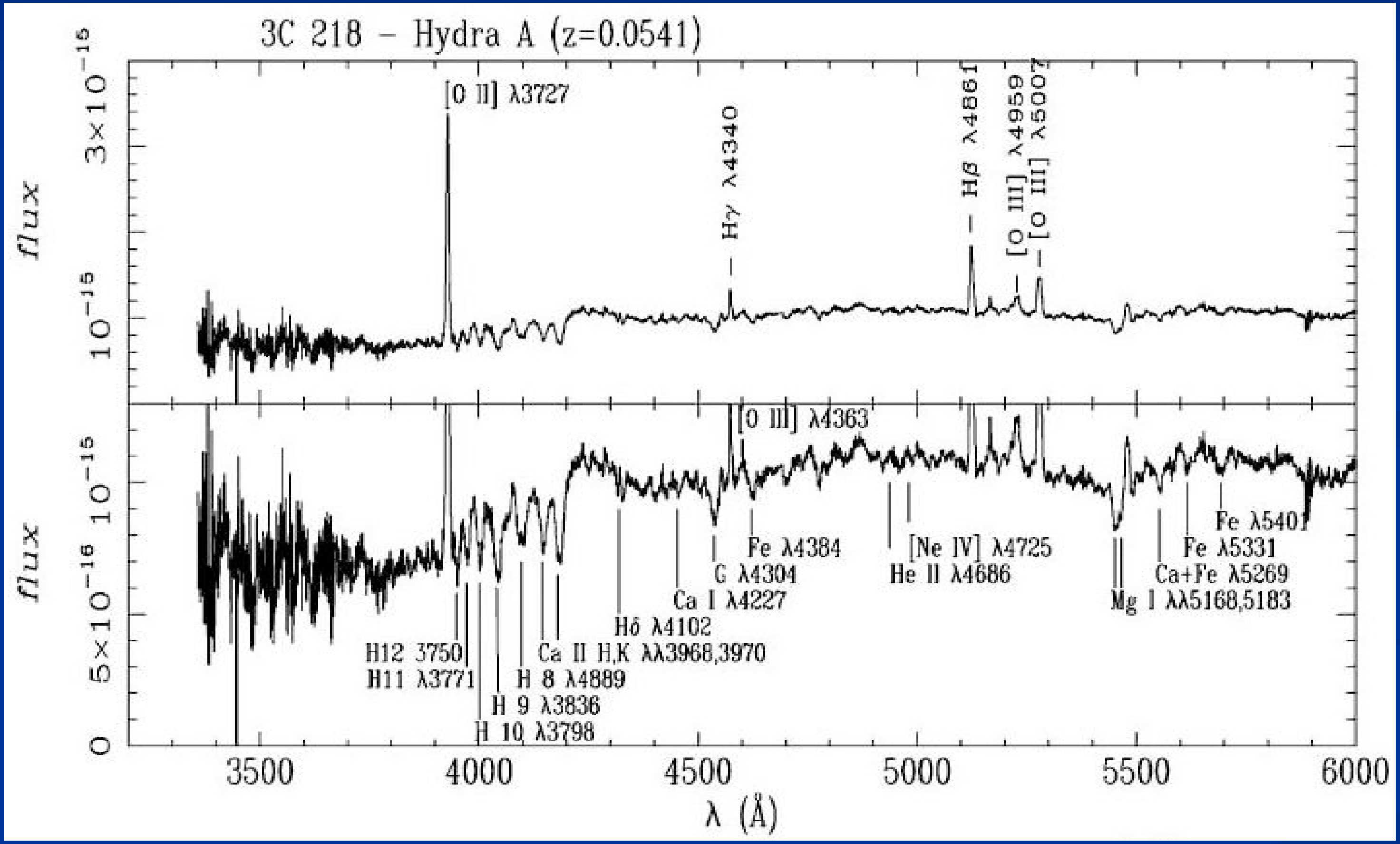
Quasars and Seyferts often have unusually blue colors compared to stars: bluer than most A stars!
→ quasars have flat spectra in U—B band

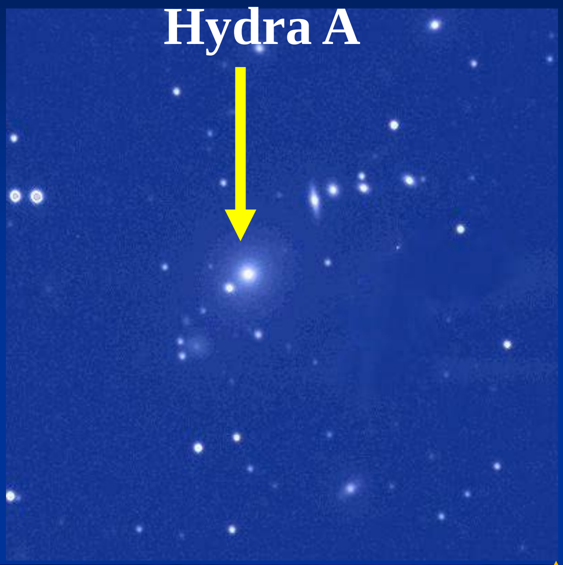


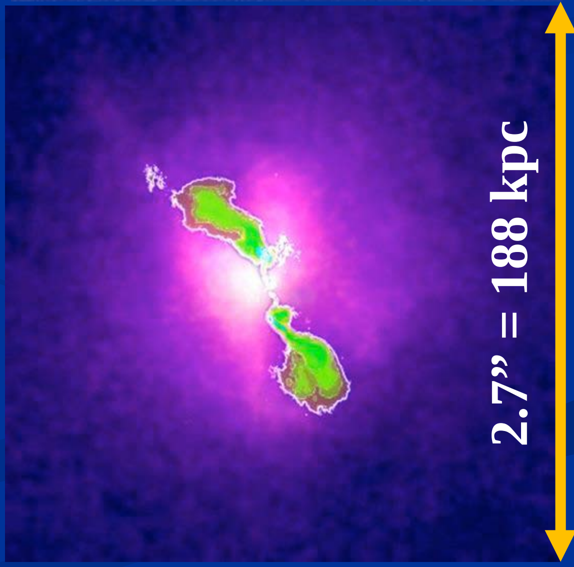
Brunzendorf & Meusinger (2002)

Explanations to Taxonomy

❖ Radio galaxies: strong radio sources associated with giant elliptical galaxies, with optical spectra similar to Seyfert Type 1 and 2







Sub-classification according to optical spectra:
NLRG = narrow-line radio galaxy
BLRG = broad-line radio galaxy, with optical spectra similar to Sy 2 and Sy 1

Explanations to Taxonomy

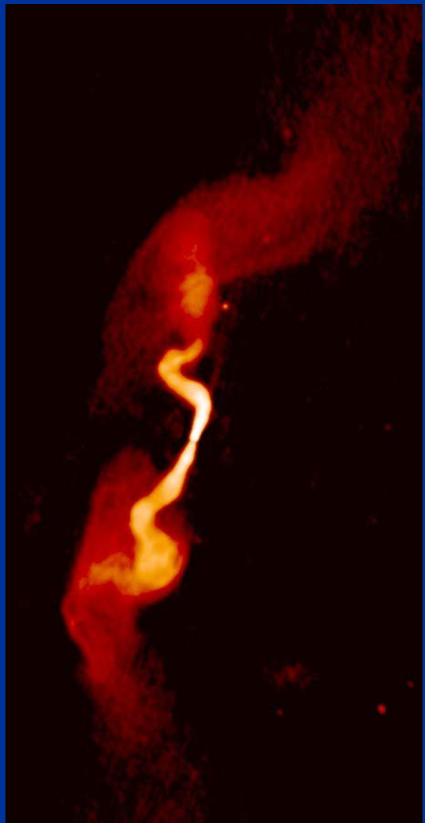
- Radio galaxies: FR Is and FR IIs — radio morphology: measured by the ratio of the distance between the two brightest spots and the overall size of the radio image: FR I with $R<0.5$ and FR II with $R>0.5$

FR Is: weaker radio sources that are bright in the center and fainter toward the edges

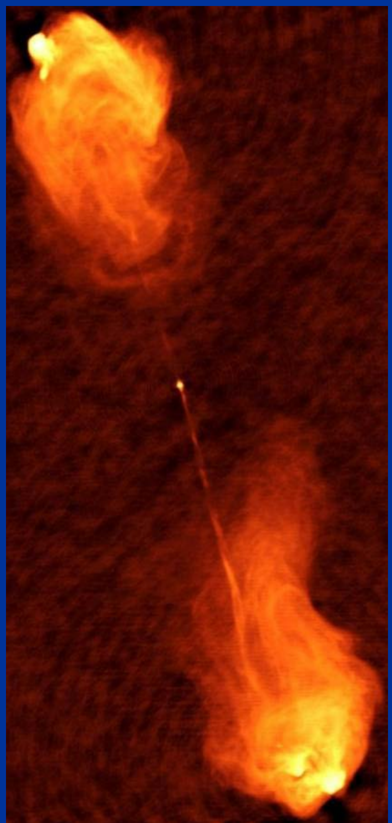
FR IIs: limb-brightened

transition at $L_{1.4\,\mathrm{Ghz}} = 10^{32}$ erg/s/Hz

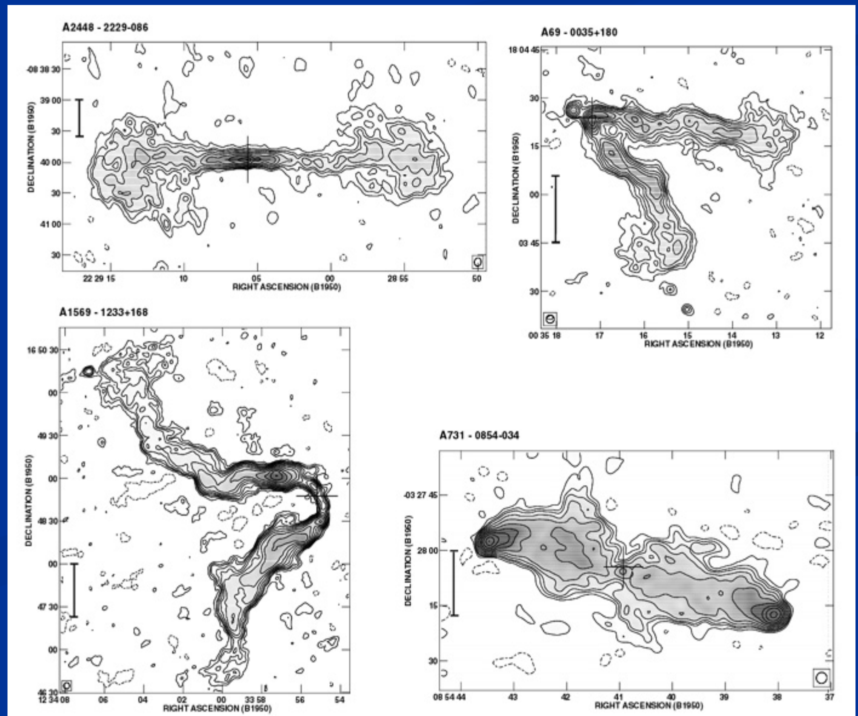
FR I - 3C 449



FR II - 3C 47



Doppler boosting!



EXPLANATIONS TO TAXONOMY

❖ Blazars:

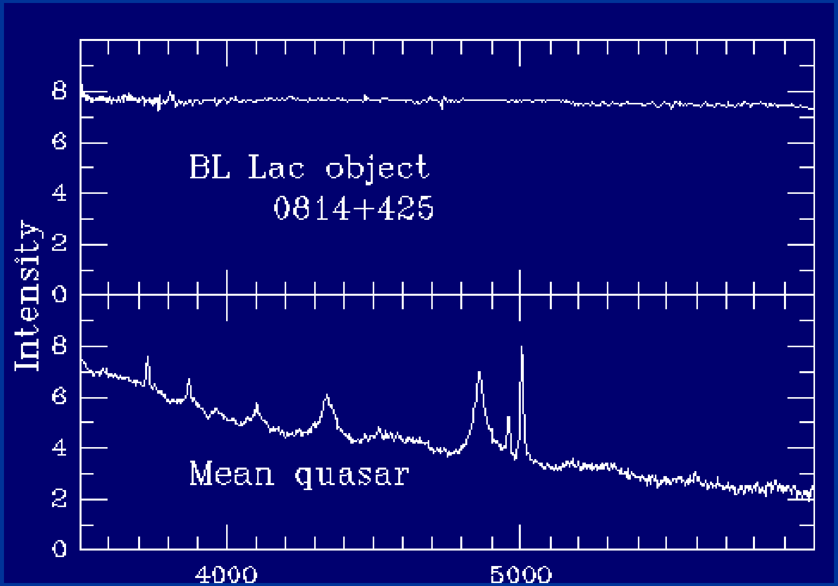
Strongly variable, highly polarized nonthermal continua (up to TeV), weak/absent emission lines, hosts: faint ellipticals

Variability faster and higher amplitude than normal quasars and Seyferts

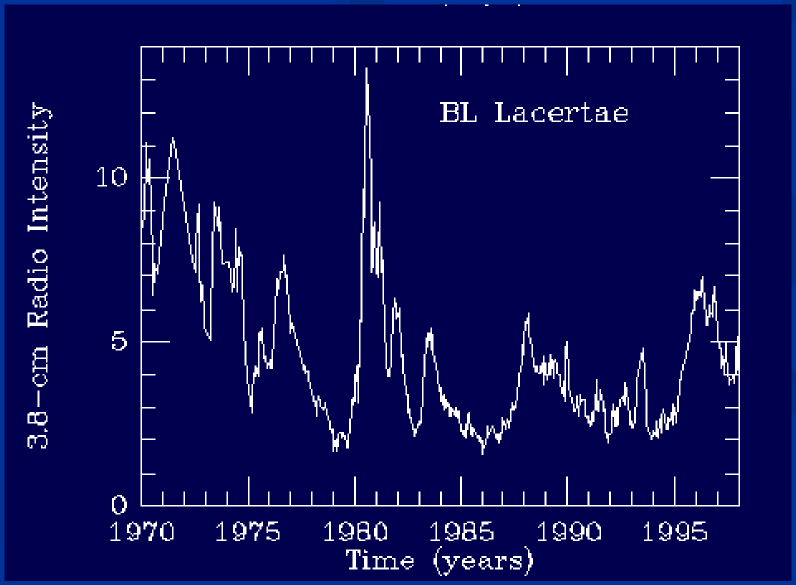
BL Lac - high polarization, emission lines have low equivalent width→ strong relativistically beamed jets along l.o.s

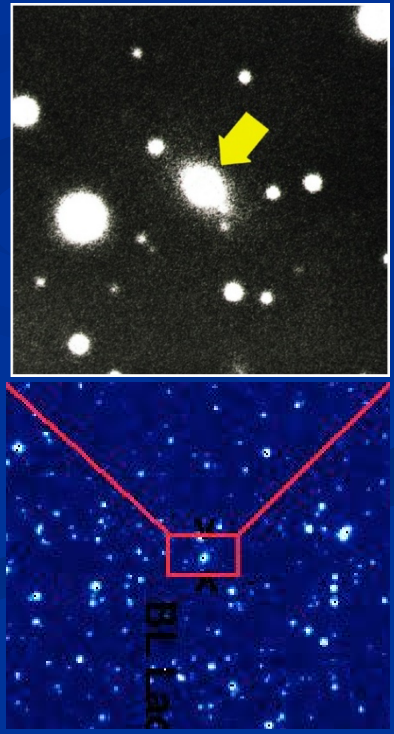
OVVs (Optically Violent Variables) - lower polarization, emission line EW decreases as continuum brightens, variability >0.1 mag on ~day, much stronger on longer times

Spectrum



Light Curve



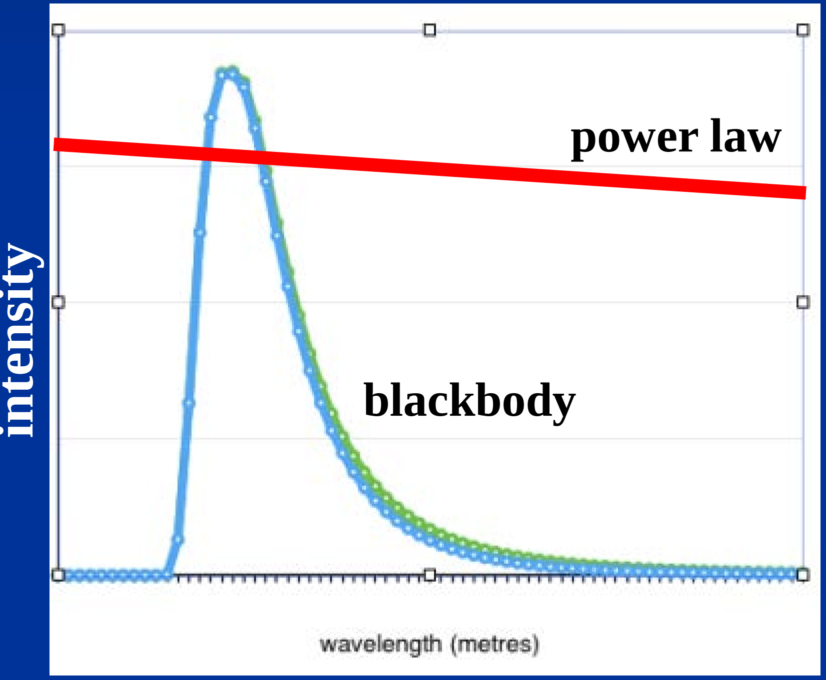


BL Lac

AGN: OBSERVATIONS

❖ Spectral energy distributions (SEDs):

AGN show emission in all astrophysically relevant wavelengths

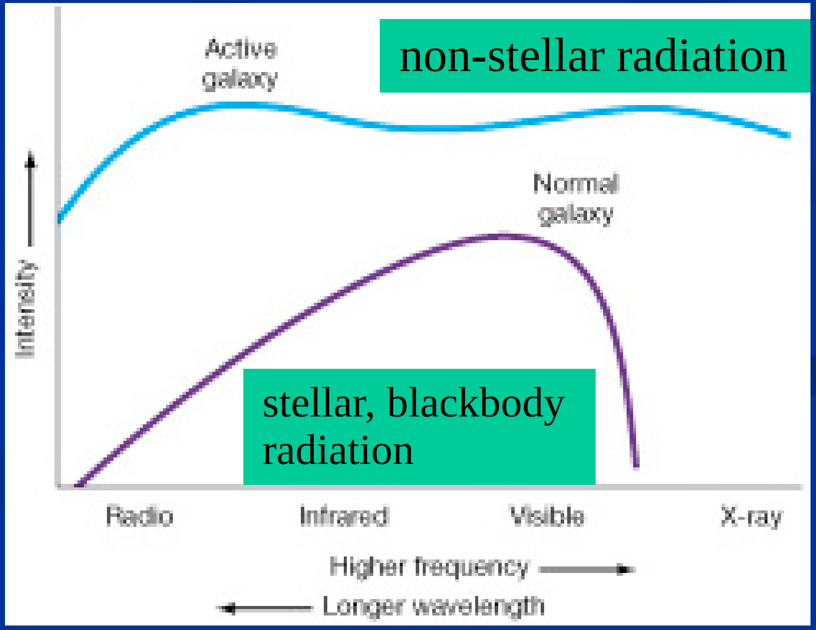


Power law *vs* blackbody SEDs

Power law $F_\nu = C\nu^\alpha$ → nonthermal!!

Typical values for quasars $-1 < \alpha < 0$

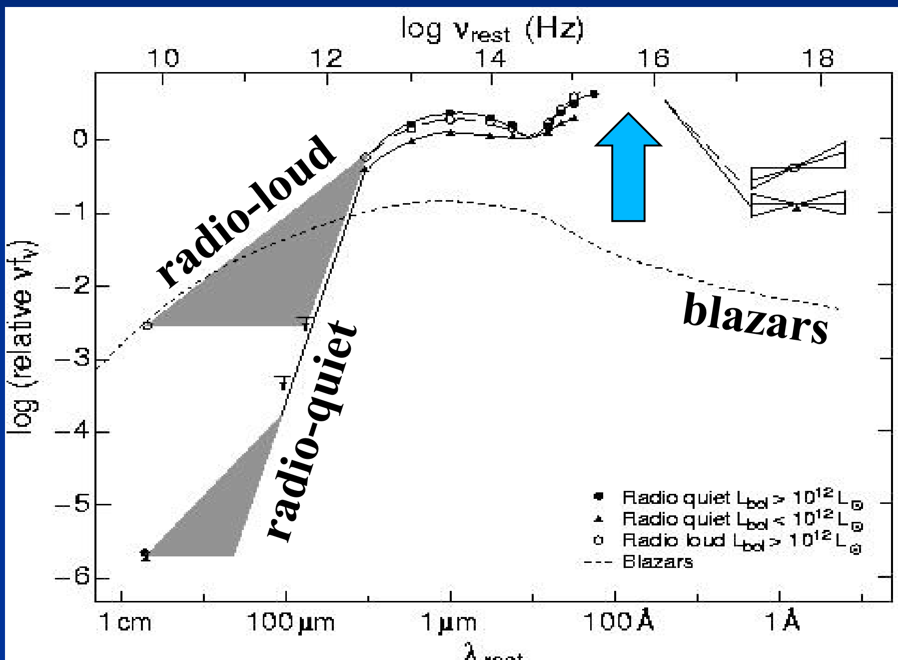
$\nu F_\nu \simeq \mathrm{const}$ → equal energy per logarithmic frequency interval (per decade)



AGN: OBSERVATIONS

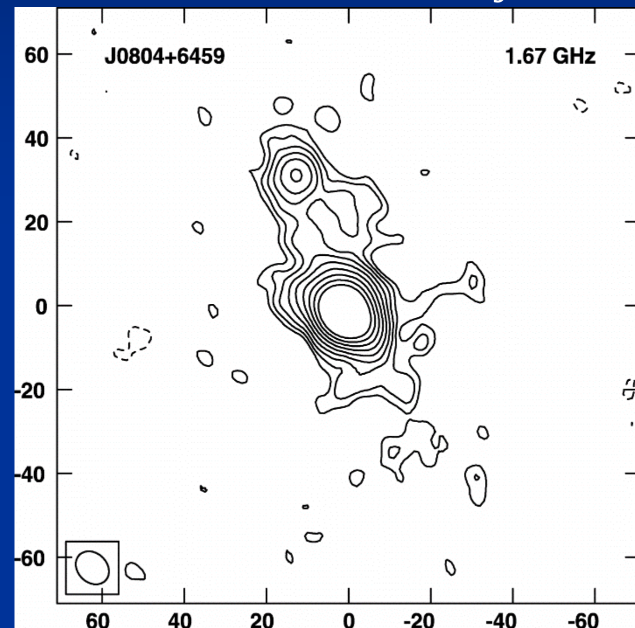
- ❖ Bi-modality: do radio-quiet quasars have jets?

Comparing SEDs of radio-quiet and loud QSOs



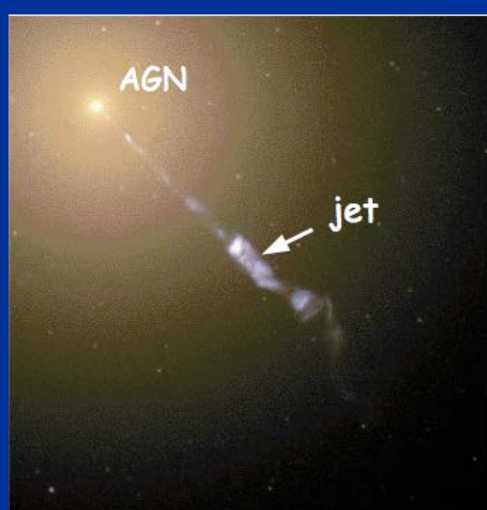
Elvis et al. 1995

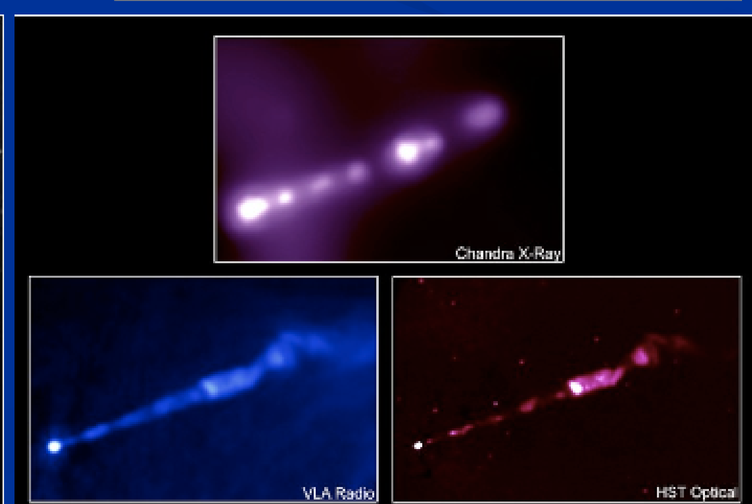
Radio emission from jets?



Ulvestad et al. 2005

Recent VLA observations:
weak jet-like outflows in RQQs
(Leipski et al. 2006)

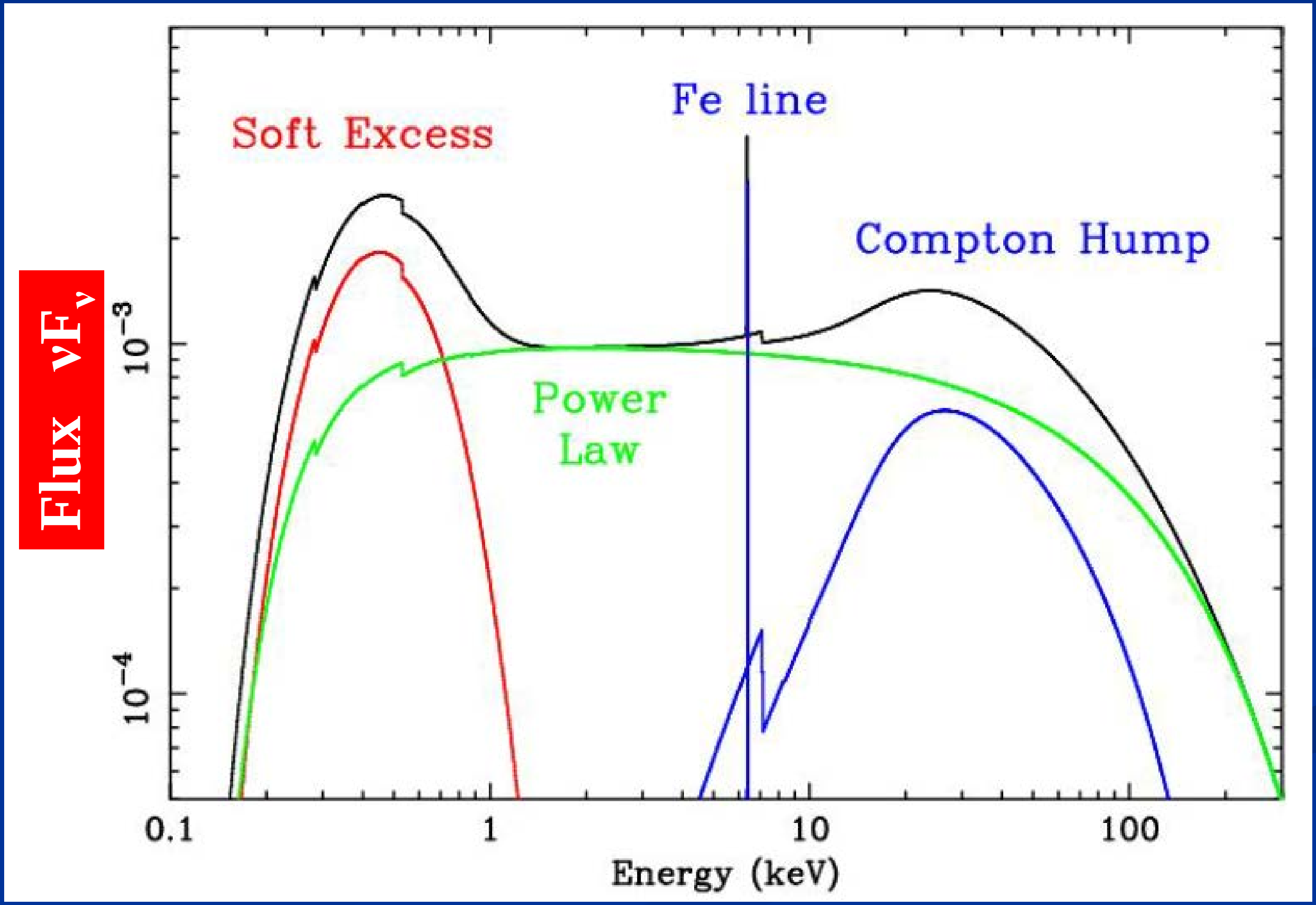




First detection
of optical jet in M87
by Curtis (1913) !!

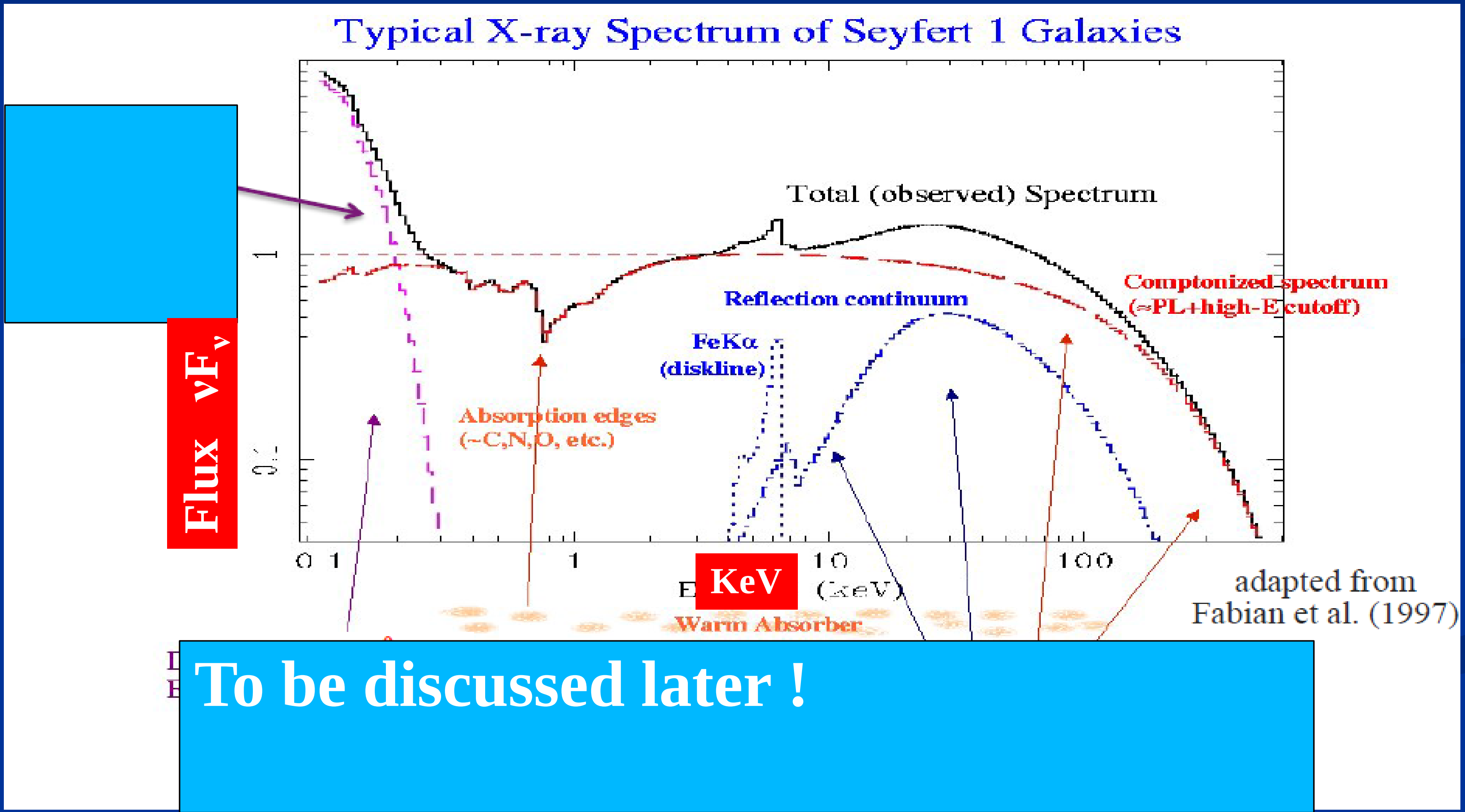
AGN: OBSERVATIONS

- X-ray bands



AGN: OBSERVATIONS

- X-ray bands



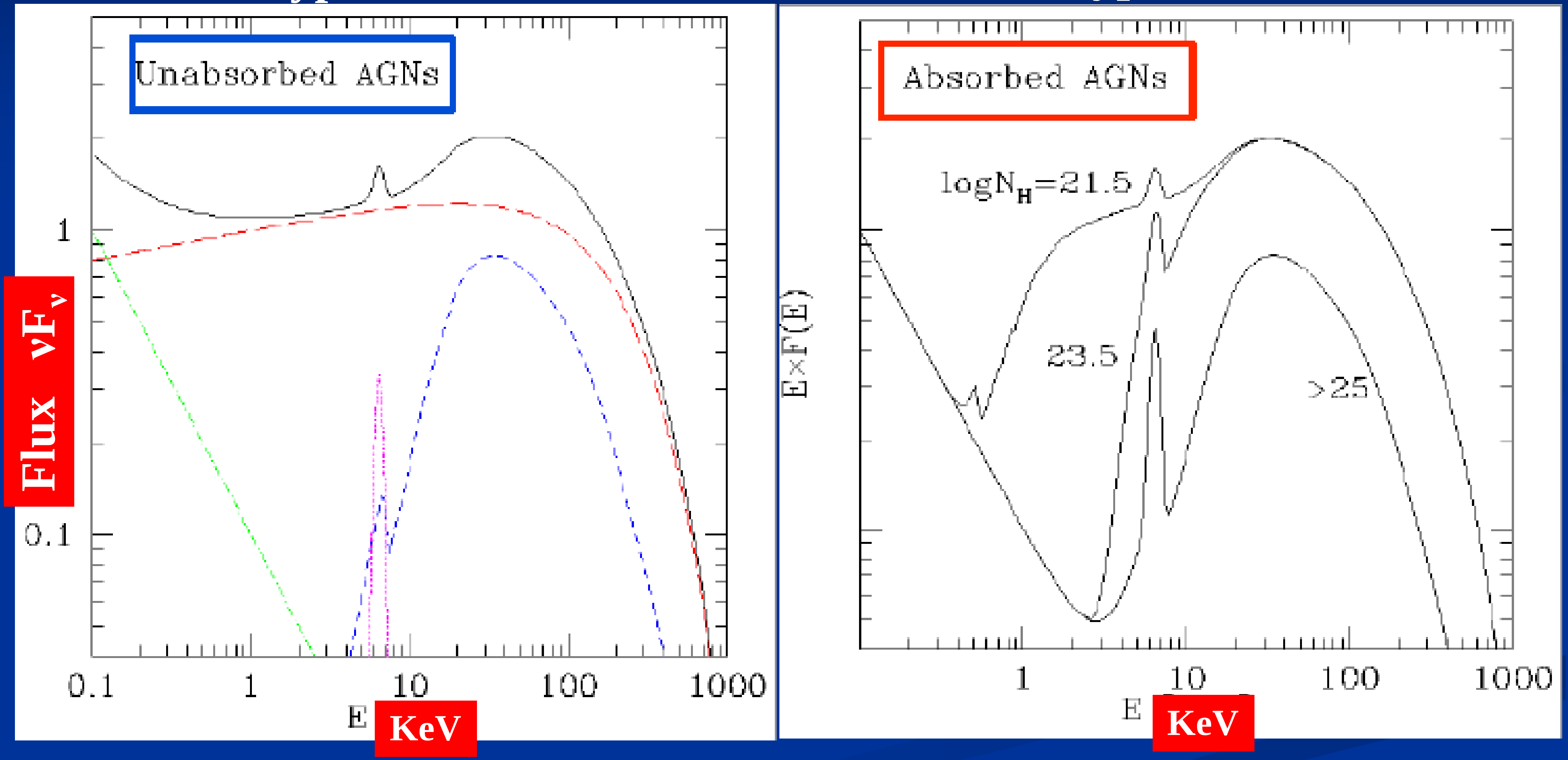
To be discussed later !

Haardt et al. 1994

AGN: OBSERVATIONS

- X-ray bands

Type 1 AGN　　　　Type 2 AGN



Type 2 can be easily missed not only in optical surveys but partly in X-ray surveys !

AGN: OBSERVATIONS

❖ Energetics

3C 273

$$z = \frac{\Delta\lambda}{\lambda_0}$$

$$d = \frac{cz}{H_0} \simeq 470 h^{-1}\,\mathrm{Mpc}$$

$$m - M = 5\log(d/pc) + 5$$

$$m_B = 13.1\,\mathrm{mag} \quad \Rightarrow \quad M_B = -23.3 + 5\log h^{-1}$$

Milky Way galaxy: -19.7 → 30 MW

$$L = 2 \cdot 10^{46}\mathrm{erg/sec} = 5 \cdot 10^{12} L_\odot$$

THE AGN ZOO: OBSERVATIONS

❖ Energetics: quasar variability

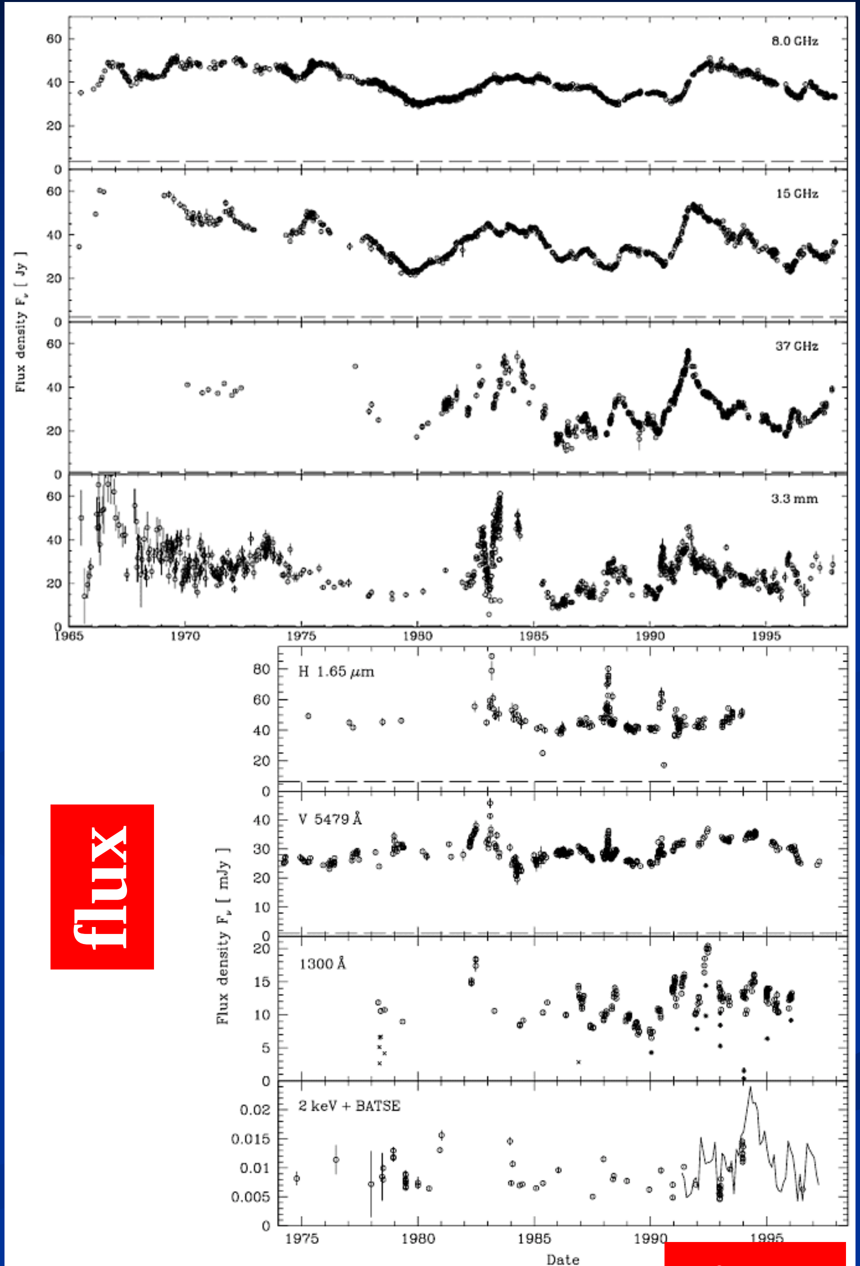
Quasars are variable in every wavelength and emission lines:
timescale → days to months

Sizes of emission regions in AGN:
light-days --- light months

$$L = 2 \cdot 10^{46} \mathrm{erg/sec} = 5 \cdot 10^{12} L_{\odot}$$

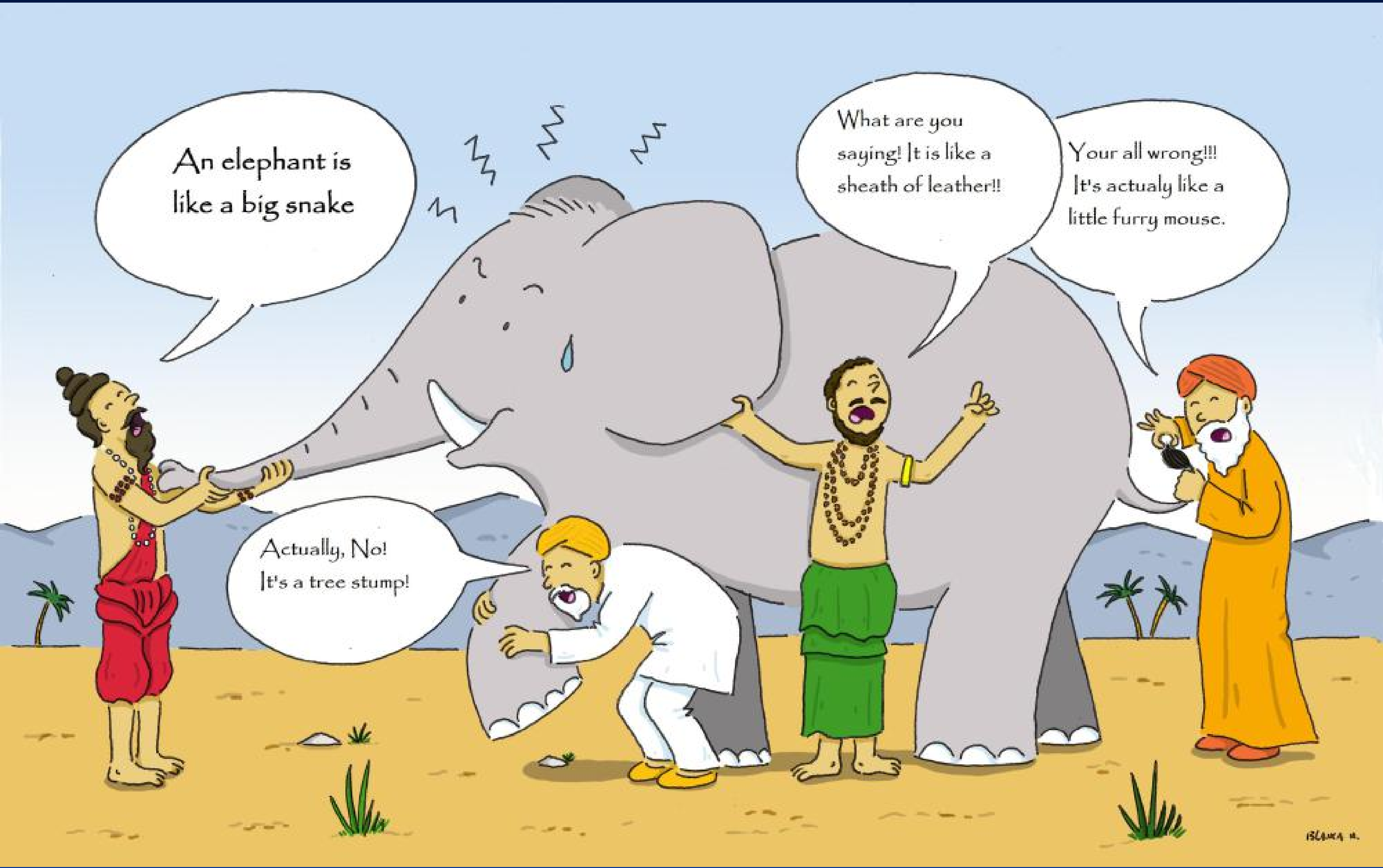
Luminosity of 30 MWs squeezed into ~ light days (!!) ~ 2×10^{10} km → Solar System

WHAT OBJECT(S) CAN BE RESPONSIBLE ?



30 years of multi-wavelength observations of 3C273
Astron. Astrophys. Suppl. Ser. 134, 89-101
M. Türler et al. 1998 July 28 http://obswww.unige.ch/3c273/

AGN: COMMON GROUNDS?

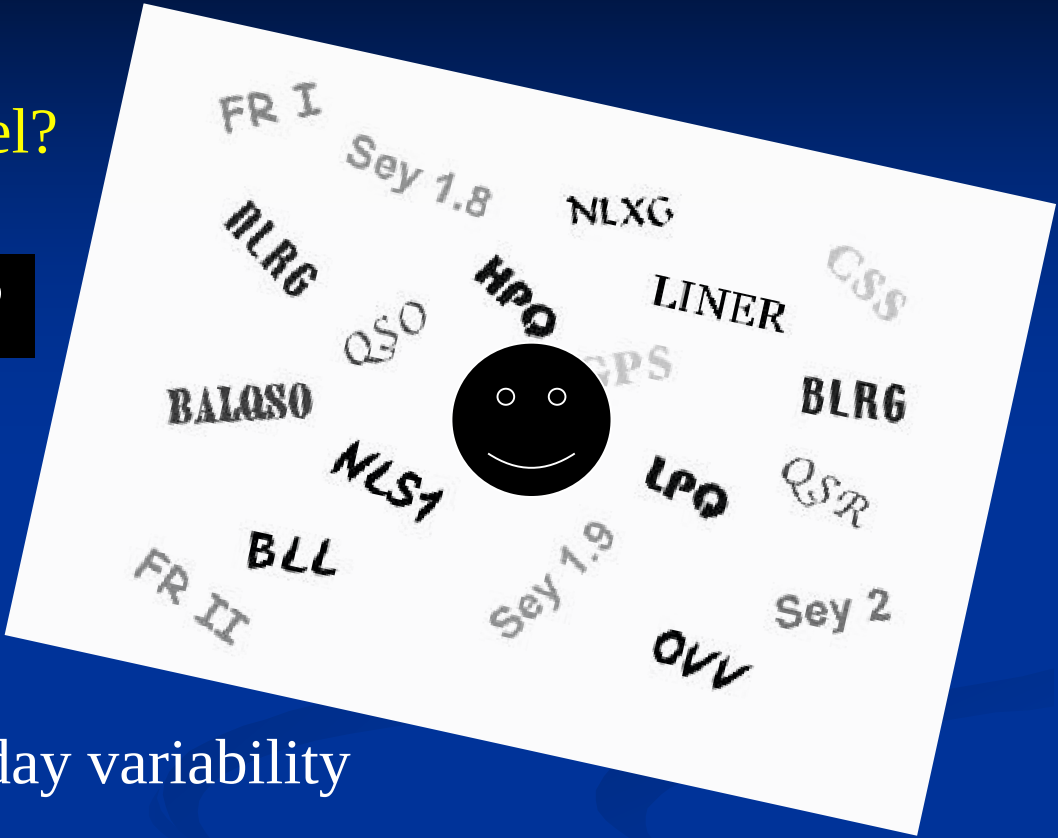


Blind men and elephant (Indian) parable

WHAT POWERS AGN?

- The central engine → standard model?

What object(s) could these be ?



Ultra-high compactness: from ~ light day variability

Ultra-high luminosity $L \sim 10^{40-48}$ erg/s → $10^{6.5-14.5} L_{\odot}$

Only supermassive black holes (SMBHs) have these properties

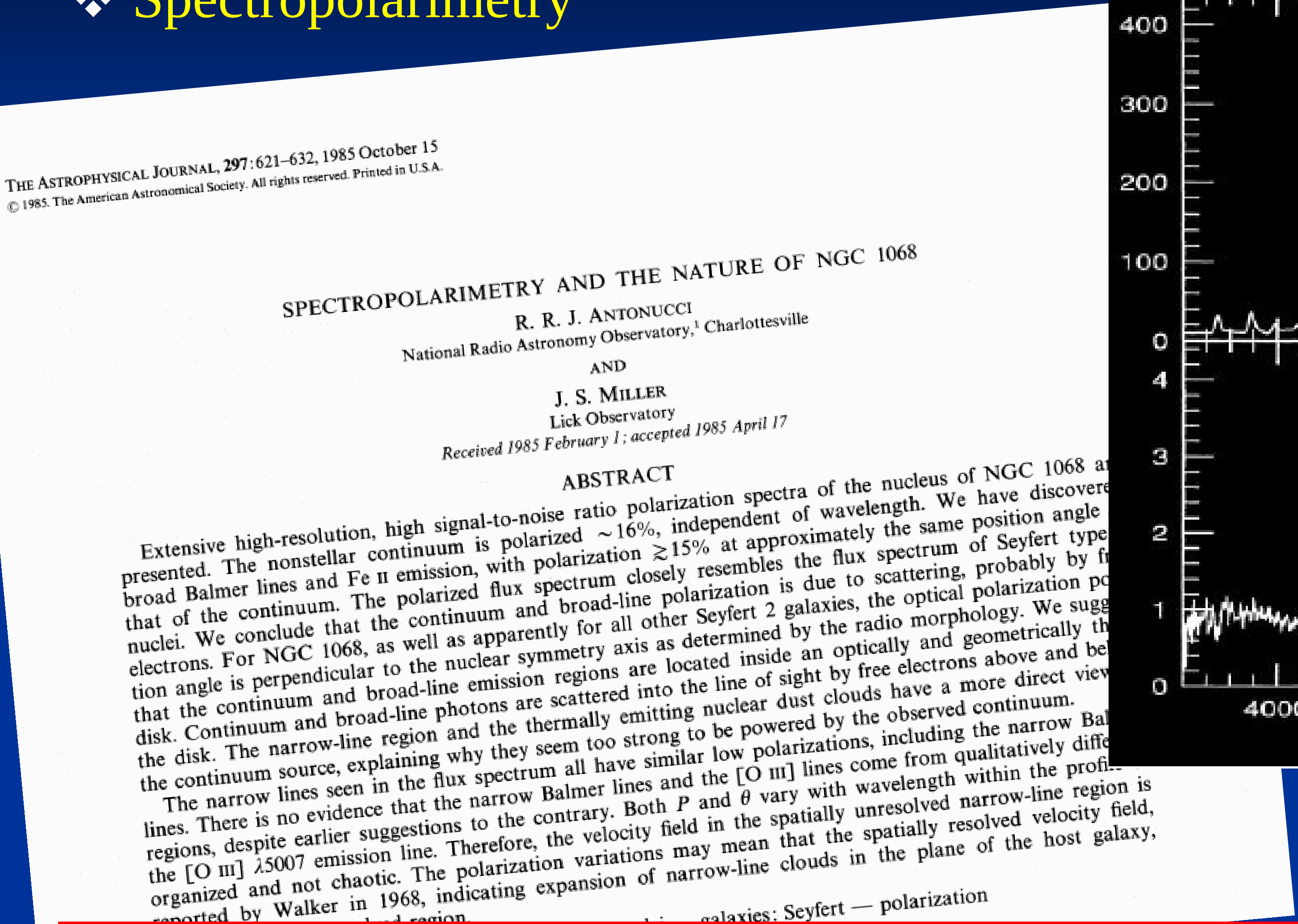
Additional arguments in favor of SMBHs in AGN include a long list of issues → this is the subject of remaining talks !

THE AGN ZOO: UNIFICATION?

"Why are we being held here?"

THE AGN ZOO: UNIFICATION?

- Spectropolarimetry



THE ASTROPHYSICAL JOURNAL, 297:621–632, 1985 October 15

SPECTROPOLARIMETRY AND THE NATURE OF NGC 1068

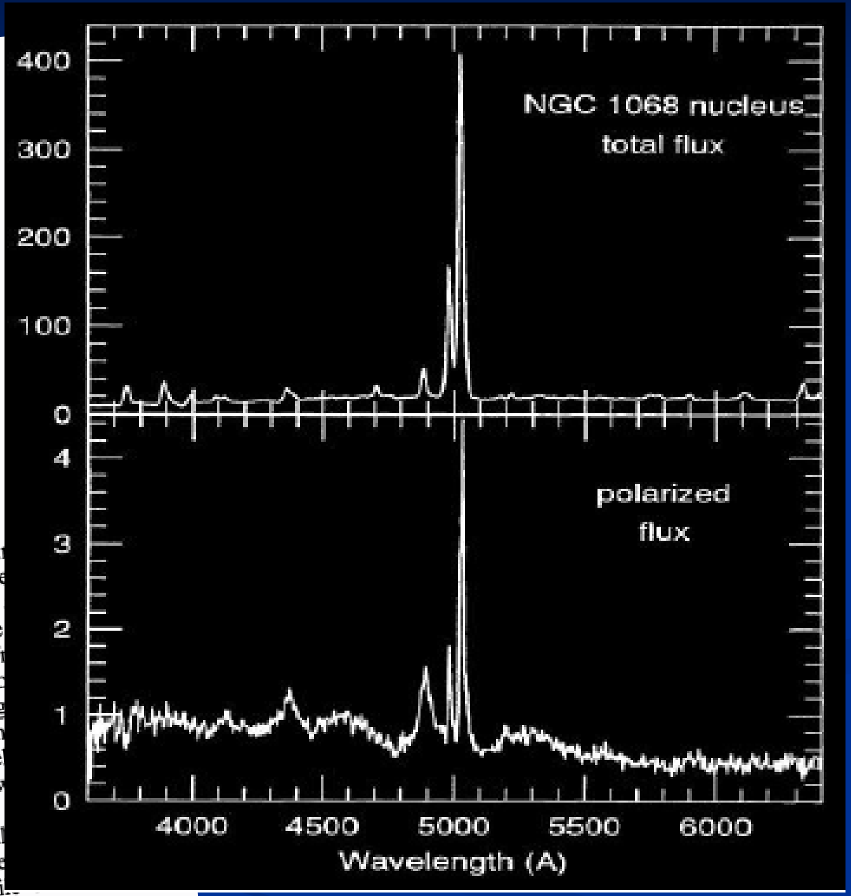
R. R. J. ANTONUCCI
National Radio Astronomy Observatory,[1] Charlottesville
AND
J. S. MILLER
Lick Observatory

Received 1985 February 1; accepted 1985 April 17

ABSTRACT

Extensive high-resolution, high signal-to-noise ratio polarization spectra of the nucleus of NGC 1068 a
presented. The nonstellar continuum is polarized ~16%, independent of wavelength. We have discovere
broad Balmer lines and Fe II emission, with polarization ≳15% at approximately the same position angle
that of the continuum. The polarized flux spectrum closely resembles the flux spectrum of Seyfert type
nuclei. We conclude that the continuum and broad-line polarization is due to scattering, probably by f
electrons. For NGC 1068, as well as apparently for all other Seyfert 2 galaxies, the optical polarization p
tion angle is perpendicular to the nuclear symmetry axis as determined by the radio morphology. We sugg
that the continuum and broad-line emission regions are located inside an optically and geometrically th
disk. Continuum and broad-line photons are scattered into the line of sight by free electrons above and be
the disk. The narrow-line region and the thermally emitting nuclear dust clouds have a more direct view
the continuum source, explaining why they seem too strong to be powered by the observed continuum.
The narrow lines seen in the flux spectrum all have similar low polarizations, including the narrow Ba
lines. There is no evidence that the narrow Balmer lines and the [O III] lines come from qualitatively diffe
regions, despite earlier suggestions to the contrary. Both P and θ vary with wavelength within the profi
the [O III] λ5007 emission line. Therefore, the velocity field in the spatially unresolved narrow-line region is
organized and not chaotic. The polarization variations may mean that the spatially resolved velocity field,
reported by Walker in 1968, indicating expansion of narrow-line clouds in the plane of the host galaxy,

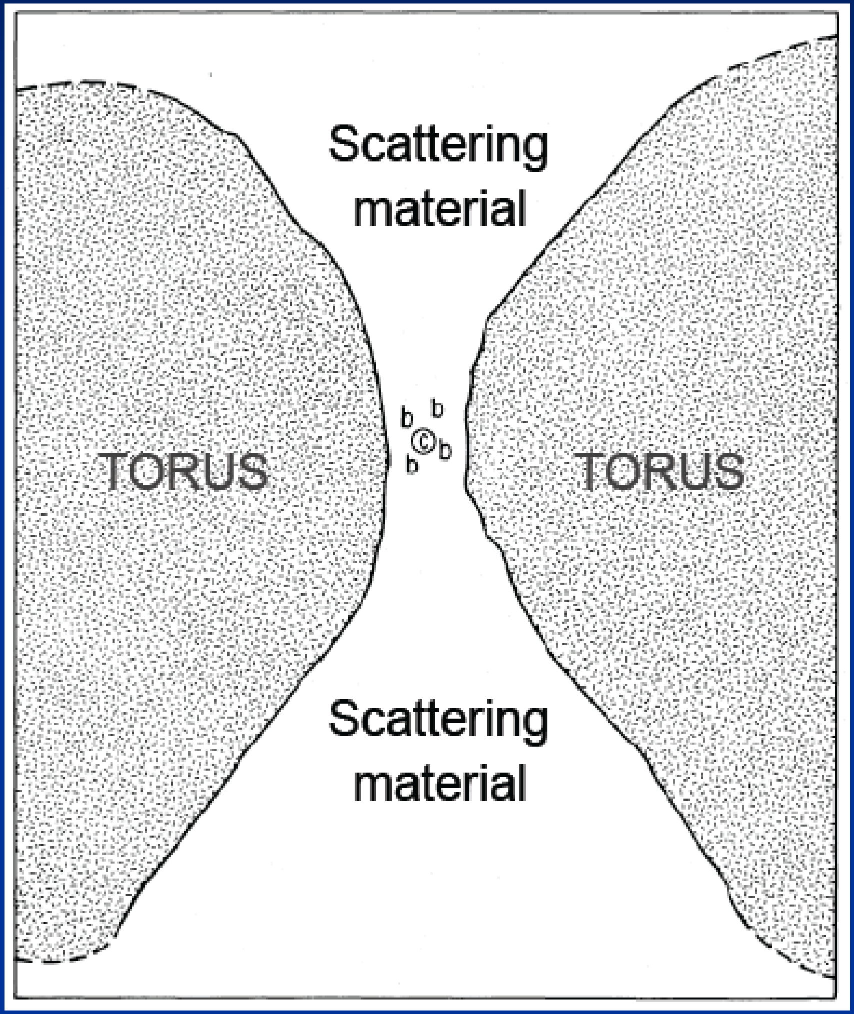
galaxies: Seyfert — polarization



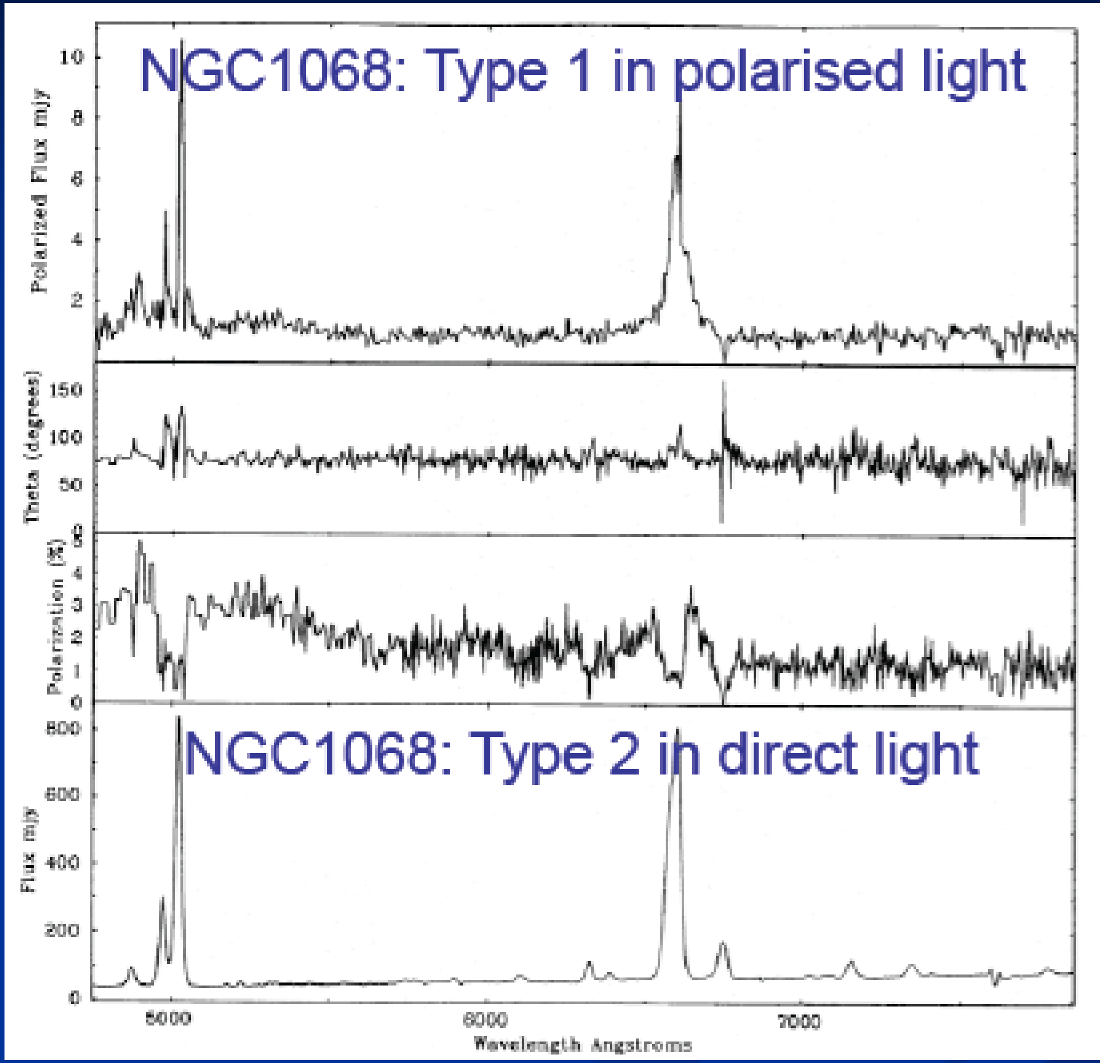
Sy 2 galaxy NGC 1068 observed in polarized light showed a Sy 1-type polarized spectrum. The observed properties could be explained by reflection of a hidden Broad-Line Region (BLR) into the line-of-sight

THE AGN ZOO: UNIFICATION?

❖ Spectropolarimetry



Antonucci & Miller 1985

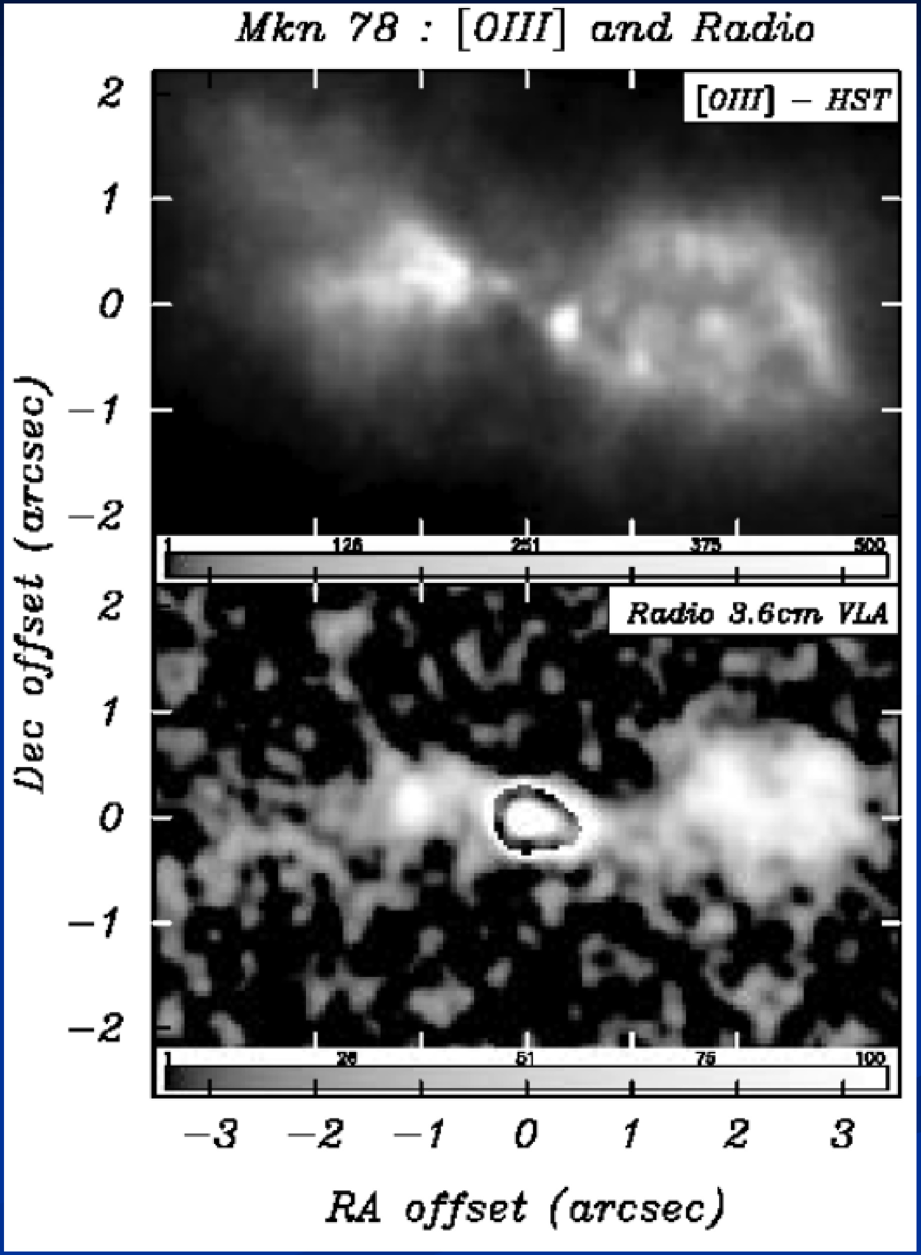


Hidden type 1 AGN in type 2 AGN (but not in all!)

Anisotropy in AGN for radiation propagation!

THE AGN ZOO: OBSERVATIONS

❖ Ionization cones from AGN



Additional evidence for anisotropy
in AGN: ionization cones
in narrow emission-line region (NRL)

These cones are aligned with the radio jets
(if present) → toroidal obscuration

From spectropolarimetry and ionization cones→ central source of radiation
and anisotropic radiation field

THE AGN ZOO: UNIFICATION?

❖ Attempt to make order in this mess

Obscured — **Seyfert 2** — **Type 2** quasar or radio galaxy

Unobscured — **Seyfert 1** — **Type 1** quasar or radio quasar

Viewed directly down the jet — **Blazars**

Power

Many Type 2 AGN are hidden but can contribute to the X-ray background

There are some low L unobscured AGN with no broad line lines…
(explain later!)

THE AGN ZOO: UNIFICATION!

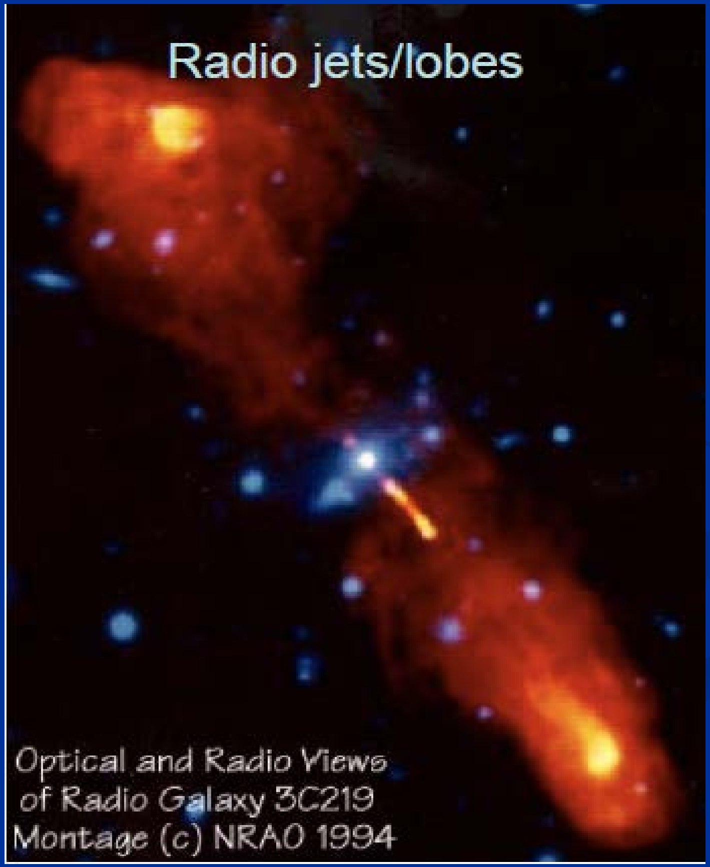
❖ Another attempt to make order in this mess

Radio-loud versus radio-quiet

Relate the radio-loudness to the angular momentum (J) of AGN

high spin → radio jets which are source of radio emission
low spin → no jets → no powerful radio emission

Can jets be powered by rotational energy from AGN??



THE AGN ZOO: UNIFICATION!

❖ Another attempt to make order in this mess

If angular momentum (J) in AGN is so important,
where do AGN get their angular momentum ?

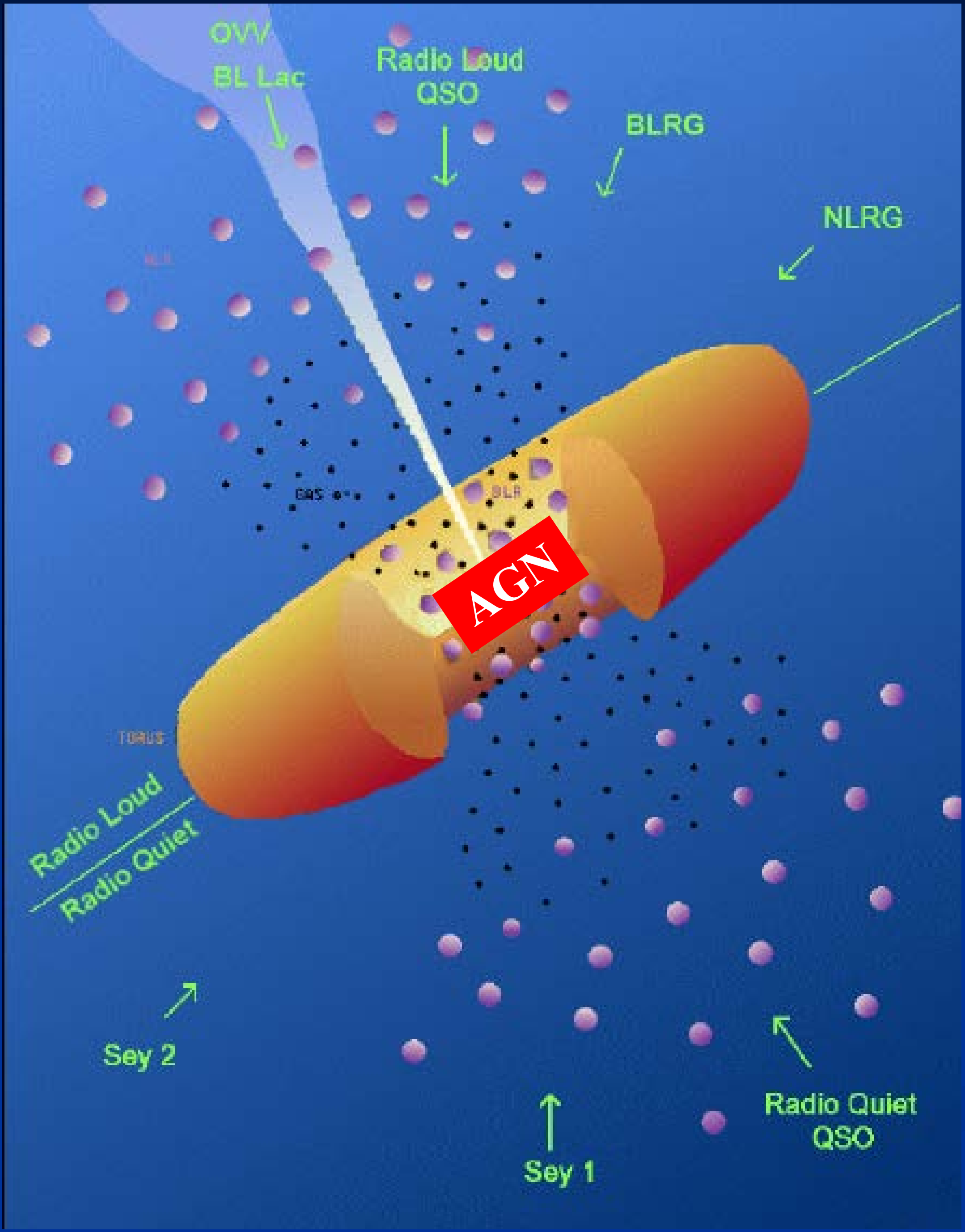
accretion process?
mergers with other AGN (when their host galaxies merge)?

ACCRETION: growth of small objects into a massive object by gravitationally attracting more matter

Because the AGN must be very compact → gravitational wave signals detectable by LISA or LIGO

This would also explain why powerful radio sources favor giant elliptical galaxies as host and galaxy cluster environment!
(Remember: large Ellipticals maybe merger products)

THE AGN ZOO: UNIFICATION!



Another attempt to unify AGN:

All the observational appearances of AGN are aspect-dependent

There are clear benefits of this scheme, BUT (a big BUT!) it does not explain or unify all the AGN

For example, we still don't know difference between the radio-quiet and radio-loud AGN in this unification…

Padovani & Urry 1995

CONCLUSIONS FOR LECTURE 1

- Active Galactic Nuclei (AGN) is a diverse class of objects which appears to have a single unifying source of energy to be discussed in the next lecture.
- The observed characteristic properties of AGN may reflect the diverse options of how the injected energy finds its way out of the object, depending on the environment.
- The emerging unification of AGN as a class of objects must be yet proven to be *only* aspect-dependent. In addition to `aspect-dependency', various factors can be important and determine additional relevant physics.
- The relevant physics of AGN is not yet fully understood. It involves both the central engine of AGN, transfer of the outflowing energy (radiative and mechanical), as well as the ultimate question of what fuels this spectacular activity.