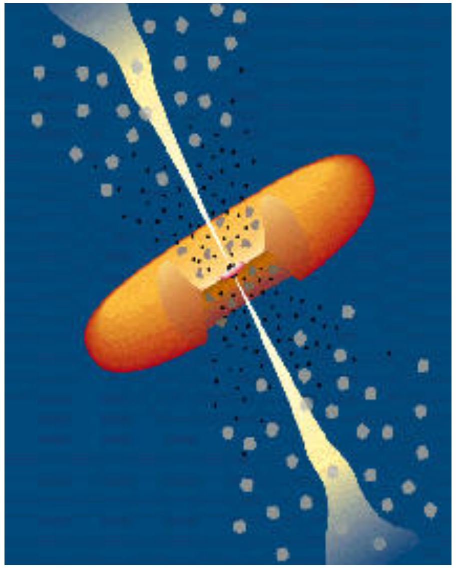

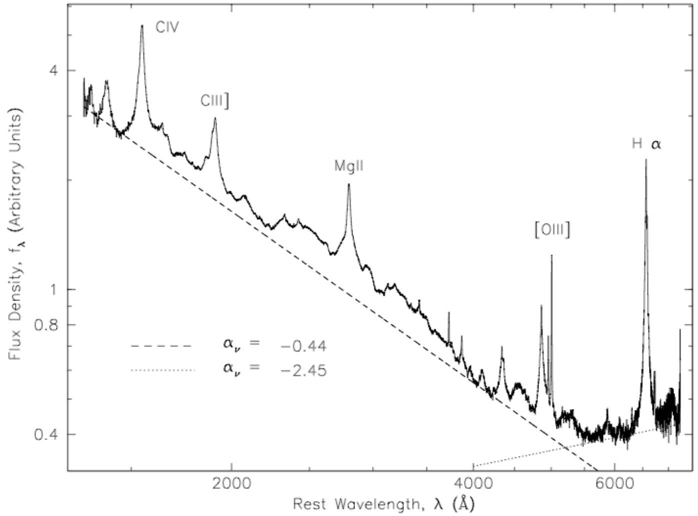

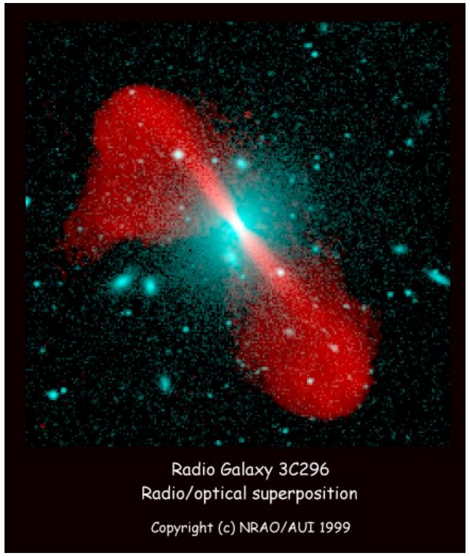

An introduction to Active Galactic Nuclei. 1.

Paolo Padovani, ESO, Germany

- The beginning
- AGN main properties
- The AGN zoo: radio-quiet and loud AGN, Unified Schemes, and relativistic beaming
- AGN masses and physical evolution

It all started fifty years ago ...

3C 273: A STAR-LIKE OBJECT WITH LARGE RED-SHIFT

z = 0.158

By DR. M. SCHMIDT

Mount Wilson and Palomar Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena

THE only objects seen on a 200-in. plate near the positions of the components of the radio source 3C 273 reported by Hazard, Mackey and Shimmins in the preceding article are a star of about thirteenth magnitude and a faint wisp or jet. The jet has a width of 1″–2″ and extends away from the star in position angle 43°. It is not visible within 11″ from the star and ends abruptly at 20″ from the star. The position of the star, kindly furnished by Dr. T. A. Matthews, is R.A. 12h 26m 33·35s ± 0·04s, Decl. + 2° 19′ 42·0″ ± 0·5″ (1950), or 1″ east of component *B* of the radio source. The end of the jet is 1″ east of component *A*. The close correlation between the radio structure and the star with the jet is suggestive and intriguing.

Spectra of the star were taken with the prime-focus spectrograph at the 200-in. telescope with dispersions of 400 and 190 Å per mm. They show a number of broad emission features on a rather blue continuum. The most prominent features, which have widths around 50 Å, are, in order of strength, at 5632, 3239, 5792, 5032 Å. These and other weaker emission bands are listed in the first column of Table 1. For three faint bands with widths of 100–200 Å the total range of wave-length is indicated.

The only explanation found for the spectrum involves a considerable red-shift. A red-shift $\Delta\lambda/\lambda_0$ of 0·158 allows identification of four emission bands as Balmer lines, as indicated in Table 1. Their relative strengths are in agreement with this explanation. Other identifications based on the above red-shift involve the Mg II lines around 2798 Å, thus far only found in emission in the solar chromosphere, and a forbidden line of [O III] at 5007 Å. On this basis another [O III] line is expected at 4959 Å with a strength one-third of that of the line at 5007 Å. Its detectability in the spectrum would be marginal. A weak emission band suspected at 5705 Å, or 4927 Å reduced for red-shift, does not fit the wave-length. No explanation is offered for the three very wide emission bands.

It thus appears that six emission bands with widths around 50 Å can be explained with a red-shift of 0·158. The differences between the observed and the expected wave-lengths amount to 6 Å at the most and can be entirely understood in terms of the uncertainty of the measured wave-lengths. The present explanation is supported by observations of the infra-red spectrum communicated by

Table 1. WAVE-LENGTHS AND IDENTIFICATIONS

λ	$\lambda/1{\cdot}158$	λ_0	
3239	2797	2798	Mg II
4595	3968	3970	Hϵ
4753	4104	4102	Hδ
5032	4345	4340	Hγ
5200–5415	4490–4675		
5632	4864	4861	Hβ
5792	5002	5007	[O III]
6005–6190	5186–5345		
6400–6510	5527–5622		

Oke in a following article, and by the spectrum of another star-like object associated with the radio source 3C 48 discussed by Greenstein and Matthews in another communication.

The unprecedented identification of the spectrum of an apparently stellar object in terms of a large red-shift suggests either of the two following explanations.

(1) The stellar object is a star with a large gravitational red-shift. Its radius would then be of the order of 10 km. Preliminary considerations show that it would be extremely difficult, if not impossible, to account for the occurrence of permitted lines and a forbidden line with the same red-shift, and with widths of only 1 or 2 per cent of the wave-length.

(2) The stellar object is the nuclear region of a galaxy with a cosmological red-shift of 0·158, corresponding to an apparent velocity of 47,400 km/sec. The distance would be around 500 megaparsecs, and the diameter of the nuclear region would have to be less than 1 kiloparsec. This nuclear region would be about 100 times brighter optically than the luminous galaxies which have been identified with radio sources thus far. If the optical jet and component *A* of the radio source are associated with the galaxy, they would be at a distance of 50 kiloparsecs, implying a time-scale in excess of 10^5 years. The total energy radiated in the optical range at constant luminosity would be of the order of 10^{59} ergs.

Only the detection of an irrefutable proper motion or parallax would definitively establish 3C 273 as an object within our Galaxy. At the present time, however, the explanation in terms of an extragalactic origin seems most direct and least objectionable.

I thank Dr. T. A. Matthews, who directed my attention to the radio source, and Drs. Greenstein and Oke for valuable discussions.

It all started fifty years ago ...

1040 NATURE March 16, 1963 VOL. 197

3C 273: A STAR-LIKE OBJECT WITH LARGE RED-SHIFT

By DR. M. SCHMIDT

Mount Wilson and Palomar Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena

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I thank Dr. T. A. Matthews, who directed my attention to the radio source, and Drs. Greenstein and Oke for valuable discussions.

It all started fifty years ago ...

TABLE 1

POSITIONS OF $\boxed{\text{3C 295}}$ Minkowksi 1960

α (1950)	δ (1950)	Frequency (Mc/s)	Reference*
$14^h09^m33^s.4 \pm 1^s.5$	$+52°26'30'' \pm 90''$	178	1
$14^h09^m33^s.2 \pm 0^s.3$	....	960	2
$14^h09^m33^s.3 \pm 0^s.2$	$+52°26'12''.4 \pm 3''$	Optical	3

* The references are as follows:
1. B. Elsmore, M. Ryle, and Patricia R. R. Leslie, *Mem. R. Astr. Soc.*, **68,** 61, 1959.
2. T. A. Matthews, D. Morris, and R. B. Reed, unpublished.
3. T. A. Matthews, unpublished.

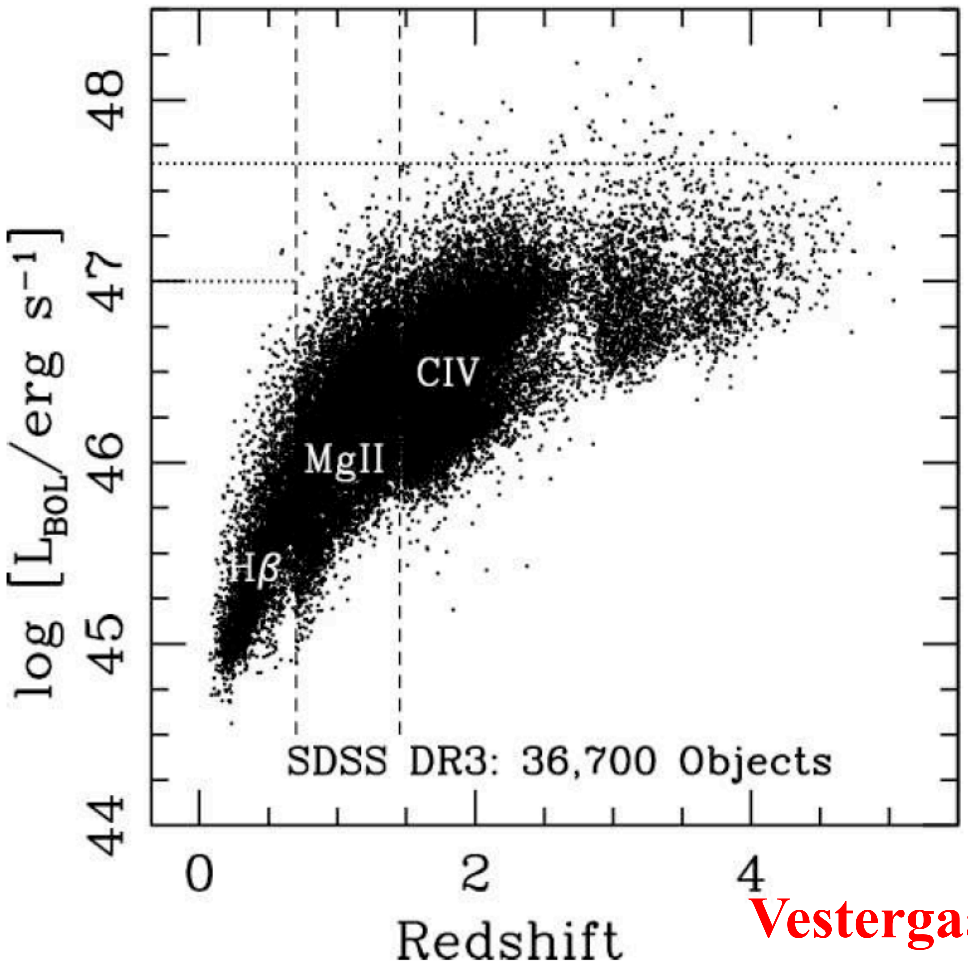
with a redshift $\Delta\lambda/\lambda_0 = 0.243$; the line at λ 5102 as H with $\Delta\lambda/\lambda_0 = 0.244$; and the line at λ 5260 as λ 4226, Ca I, with $\Delta\lambda/\lambda_0 = 0.245$. A redshift of 0.244 is consistent with the brightness of the foreground galaxy, but the interpretation is not beyond doubt.

The emission line in the spectrum of the brightest cluster galaxy is undoubtedly to be interpreted as [O II] λ 3726/29, the most common emission line in the spectra of galaxies. It is by far the strongest line in the spectrum of Cyg A; on a spectrogram on which it would appear as strong as here, none of the other lines would be observable. One might consider the possibility that the [O II] line is hidden by the strongest night sky line [O I] λ 5577 and that the emission line is one of the fainter lines of the Cyg A spectrum—but such an interpretation can be ruled out because it would require the presence of additional lines with observable intensity. The measured wave length of the emission line is 5447.8 ± 0.9; the stated error is the deviation of the two individual values from their mean. On the assumption that the unshifted wave length of the [O II] blend has the value 3727.7 valid for low density (Seaton and Osterbrock 1957), the redshift is $\Delta\lambda/\lambda_0 = 0.4614 \pm 0.0002$.

Using multicolor photoelectric photometry, Baum has derived a redshift of 0.44 ± 0.03 for two galaxies that are probable members of the cluster. This establishes that the galaxy with the strong emission line is indeed a member of the cluster. It is not unusual that the brightest galaxy in a cluster is of outstanding brightness. If the analogy to Cyg A is complete, the galaxy should be double and therefore brighter than the single

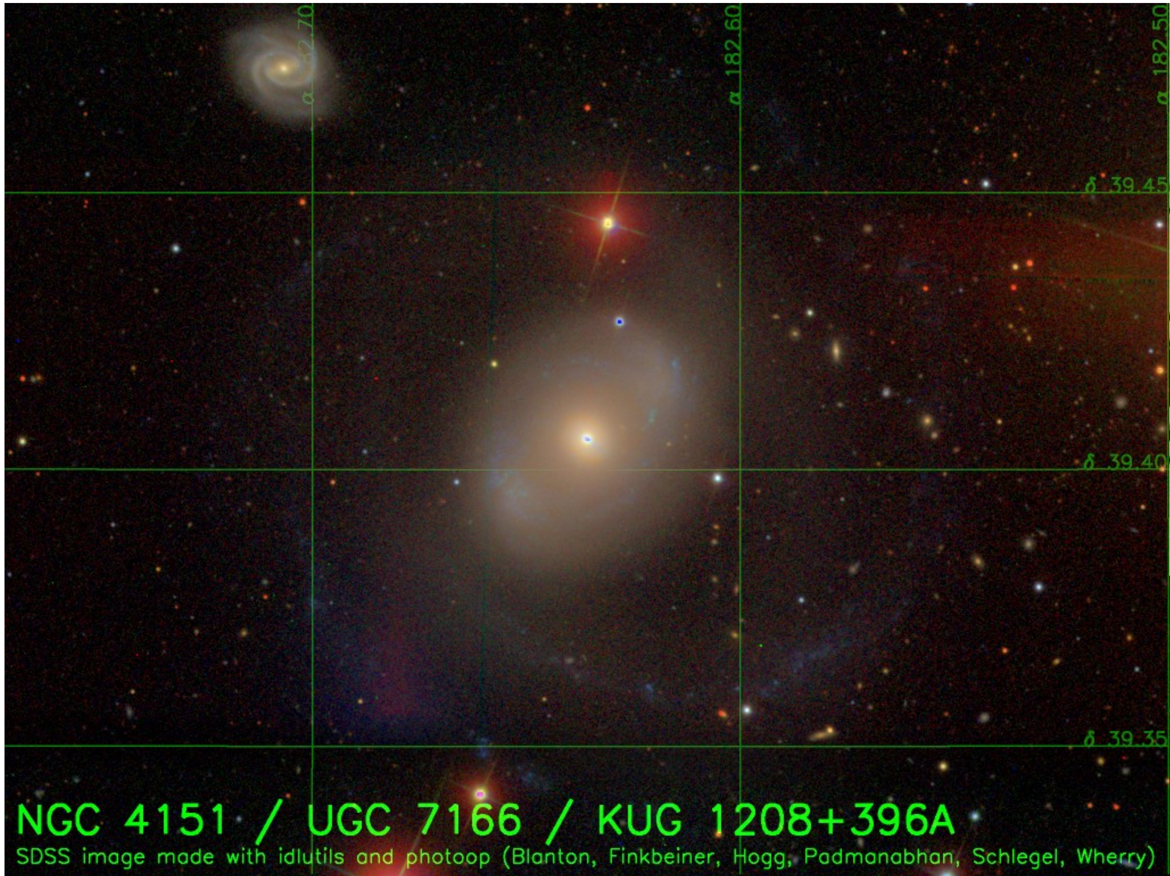
Quasar luminosities

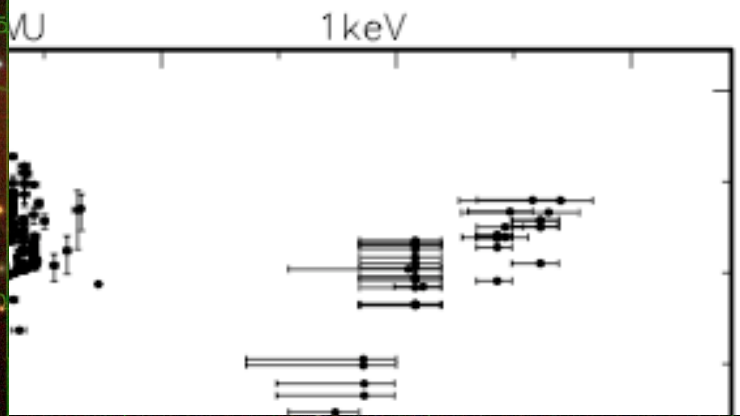
- 3C 273: $L_{bol} \simeq 10^{47}$ erg/s $\simeq 3 \times 10^{13}\ L_{\odot} \simeq$ 1,000 bright galaxies

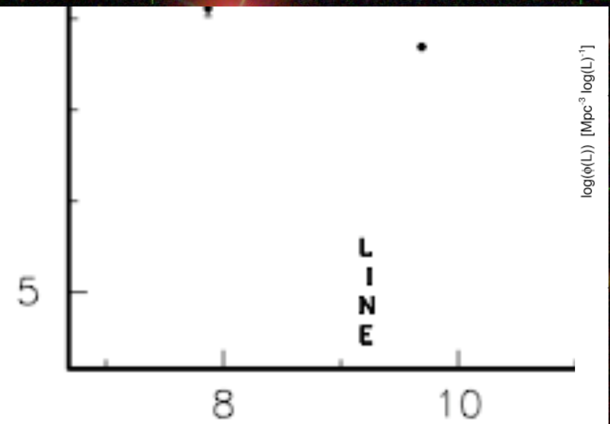


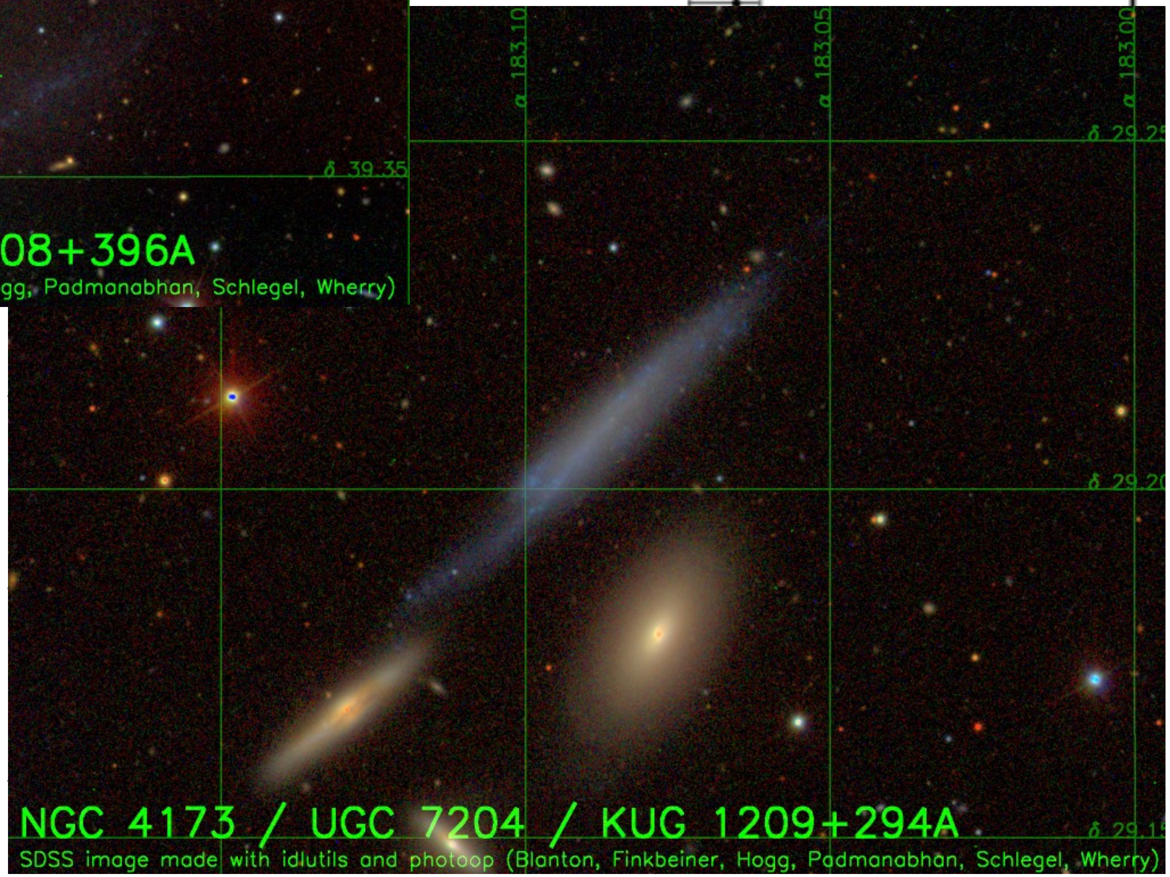
Vestergaard 2009

Nuclei


NGC 4151 / UGC 7166 / KUG 1208+396A
SDSS image made with idlutils and photoop (Blanton, Finkbeiner, Hogg, Padmanabhan, Schlegel, Wherry)

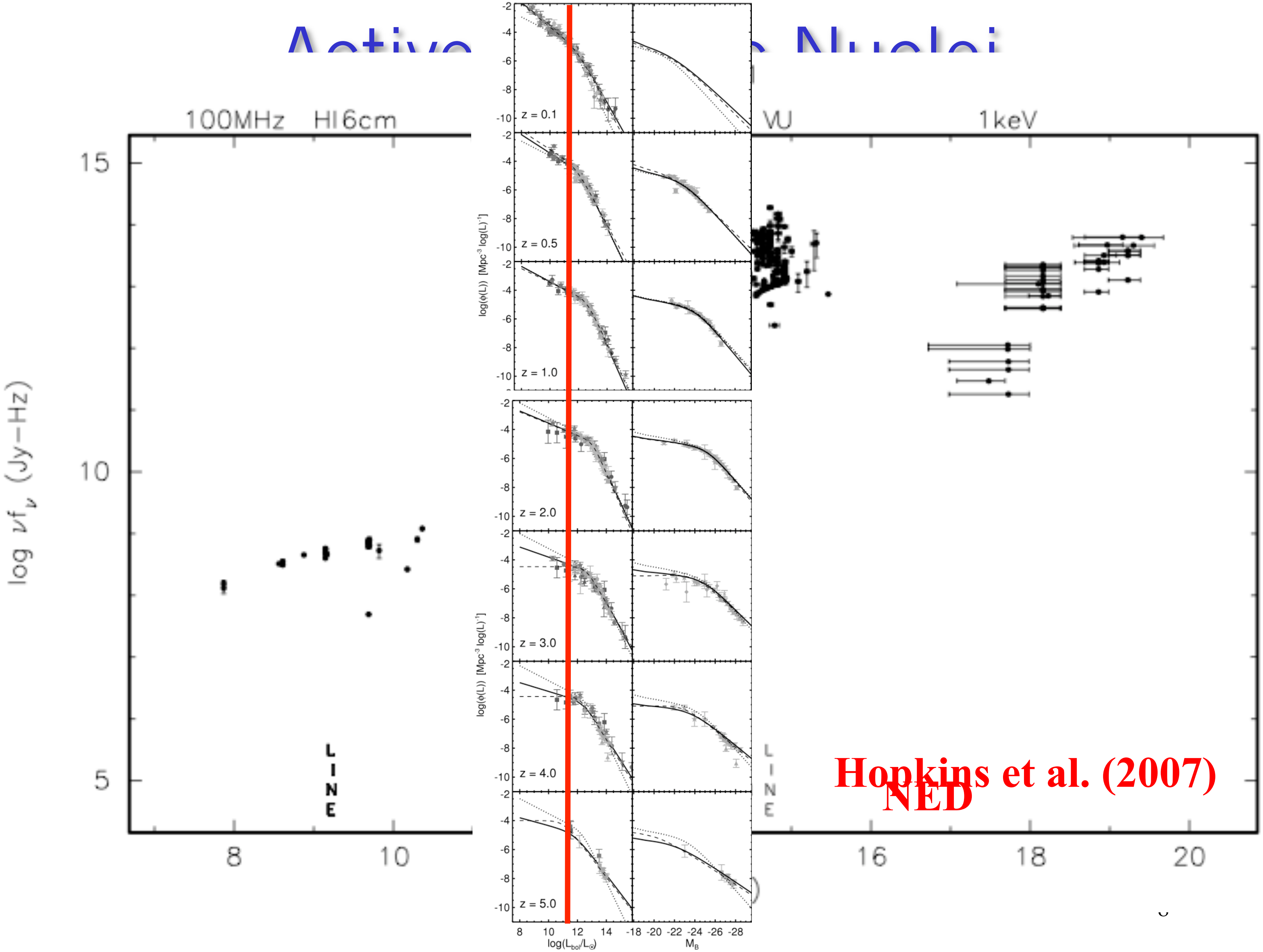

1keV


5
8
10
LINE
log(φ(L)) [Mpc⁻³ log(L)⁻¹]


NGC 4173 / UGC 7204 / KUG 1209+294A
SDSS image made with idlutils and photoop (Blanton, Finkbeiner, Hogg, Padmanabhan, Schlegel, Wherry)

Active Galactic Nuclei

- Quasars belong to the Active Galactic Nuclei (AGN) class
- AGN main characteristics include:
  1. High powers: most powerful "non-explosive" sources in the Universe
     - ✓ visible up to large distances: current record z = 7.1
  2. Small emitting regions: ≈ a few light days (1 lt-day = 2.6 10^{15} cm ≈ 1 millipc); $R \leq c\, t_{var}/(1+z)$
     - ✓ extremely large energy densities
  3. Broad-band emission: from the radio- to the γ-ray band
  4. Strong evolution: higher powers in the past, with peak at z ≈ 2
- AGN phenomenon relatively rare: it affects ≈ 1% of galaxies (at a given time)


100MHz
HI6cm
1keV
log νf_ν (Jy–Hz)
15
10
5
8
10
16
18
20
LINE
z = 0.1
z = 0.5
z = 1.0
z = 2.0
z = 3.0
z = 4.0
z = 5.0
log(φ(L)) [Mpc^{-3} log(L)$^{-1}$]
log($L_{bol}/L_\odot$)
M_B
Hopkins et al. (2007)
NED

AGN energy source

- What could explain the enormous and concentrated powers of AGN?
- Consensus reached (after a while) on supermassive black holes

Gravitational power

$$E_{acc} = \frac{GMm}{R} \qquad L_{acc} = \frac{GM\dot{m}}{R} = \frac{GM\dot{m}}{kR_S} = \frac{GM\dot{m}}{\frac{k2GM}{c^2}} = \frac{c^2}{2k}\dot{m}$$

$$\boxed{L_{acc} = \eta\dot{m}c^2}$$

$\eta \simeq$ 0.06 non-rotating BH
$\eta \simeq$ 0.42 maximally rotating BH
c.f. $\eta \simeq$ 0.007 for Hydrogen burning

$$\dot{m} \cong 2\frac{(L_{bol}/10^{46})}{(\eta/0.1)} M_\odot / yr$$

$$L_{Edd} = 1.3\ 10^{46}(M/10^8 M_\odot)erg/s$$

1. L ≤ L_{Edd} → gives lower limit to BH mass ($M_{3C\ 273}$ > 8 10^8 Mo)
2. L/L_{Edd} measures how close to maximum accretion a BH is

Gravitational power and the Sun

The molecular weight can scarcely go beyond this range *, and for the conclusions I am about to draw it does not much matter which limit we take. Probably 90 per cent. of the giant stars have masses between ½ and 5 times the Sun's, and we see that this is just the range in which radiation-pressure rises from unimportance to importance. It seems clear that a globe of gas of larger mass, in which radiation-pressure and gravitation are nearly balancing, would be likely to be unstable. The condition may not be strictly unstable in itself, but a small rotation or perturbation would make it so. It may therefore be conjectured that, if nebulous material began to concentrate into a mass much greater than 5 times the Sun's, it would probably break up, and continue to redivide until more stable masses resulted. Above the upper limit the chances of survival are small; when the lower limit is approached the danger has practically disappeared, and there is little likelihood of any further breaking-up. Thus the final masses are left distributed almost entirely between the limits given. To put the matter slightly differently, we are able to predict from general principles that the material of the stellar universe will aggregate primarily into masses chiefly lying between 10^{33} and 10^{34} grams; and this is just the magnitude of the masses of the stars according to astronomical observation †.

This study of the radiation and internal conditions of a star brings forward very pressingly a problem often debated in this Section: What is the source of the heat which the Sun and stars are continually squandering? The answer given is almost unanimous—That it is obtained from the gravitational energy converted as the star steadily contracts. But almost as unanimously this answer is ignored in its practical consequences. Lord Kelvin showed that this hypothesis, due to Helmholtz, necessarily dates the birth of the Sun about 20,000,000 years ago; and he made strenuous efforts to induce geologists and biologists to accommodate their demands to this time-scale. I do not think they proved altogether tractable. But it is among his own colleagues, physicists and astronomers, that the most outrageous violations of this limit have prevailed. I need only refer to Sir George Darwin's theory of the Earth–Moon system, to the present Lord Rayleigh's determination of the age of terrestrial rocks from

* As an illustration of these limits, iron has 26 outer electrons: if 10 break away the average molecular weight is 5, if 18 break away the molecular weight is 3. Eggert (*Phys. Zeits.* 1919, p. 570) has suggested by thermodynamical reasoning that in most cases the two outer rings (16 electrons) would break away in the stars. The comparison of theory and observation for the dwarf stars also points to a molecular weight a little greater than 3.

† By admitting plausible assumptions closer limits could be drawn. Taking the molecular weight as 3·5, and assuming that the most critical condition is when ⅓ of gravitation is counterbalanced (by analogy with the case of rotating spheroids, in which centrifugal force opposes gravitation and creates instability), we find that the critical mass is just twice that of the Sun, and stellar masses may be expected to cluster closely round this value.

Eddington 1920

Accretion spectrum

- Simple assumptions:
  - ✓ matter and radiation in equilibrium: thermal radiation → black body emission
  - ✓ most of the emission from deepest part of potential well → single blackbody radiating at T of innermost stable circular orbit (ISCO)
- Matter supposed to have some angular momentum: cannot fall radially → accretion disk

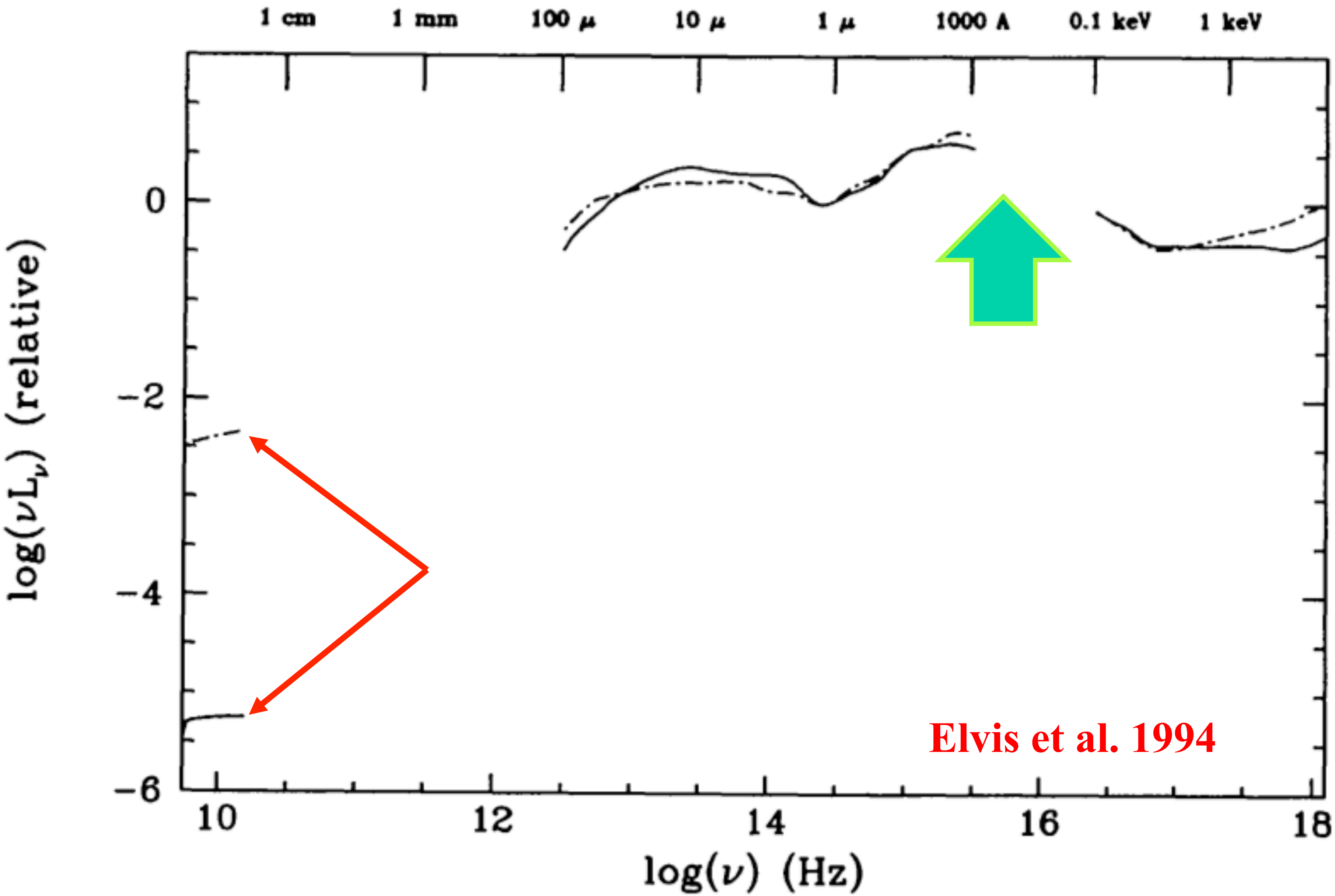
$$L \approx 2\pi\, R_{ISCO}^2 \sigma T^4$$

$$L \approx \left(\frac{2\pi\, R_{ISCO}^2}{R_S^2}\right)\sigma T^4 R_S^2 \qquad R_S^2 \propto M^2 \propto L_{Edd}^2 \Rightarrow$$

$$\boxed{T \approx 10^6 \left(\frac{A_{rad}}{R_S^2}\right)^{-1/4} (L/10^{46})^{-1/4} (L/L_{Edd})^{1/2}\, K}$$

$$T \approx 10^5\, K \rightarrow \lambda_{peak} \approx 300\, A$$

Observed quasar spectra



The AGN Zoo

AGN come in a large (and scary!) number of sub-classes:

Radio-quiet AGN

Type 1 & 2, QSO, QSO2, Seyfert 1, Seyfert 2, Seyfert 1.5, Seyfert 1.8, Seyfert 1.9, Narrow-line Seyfert 1, Liners

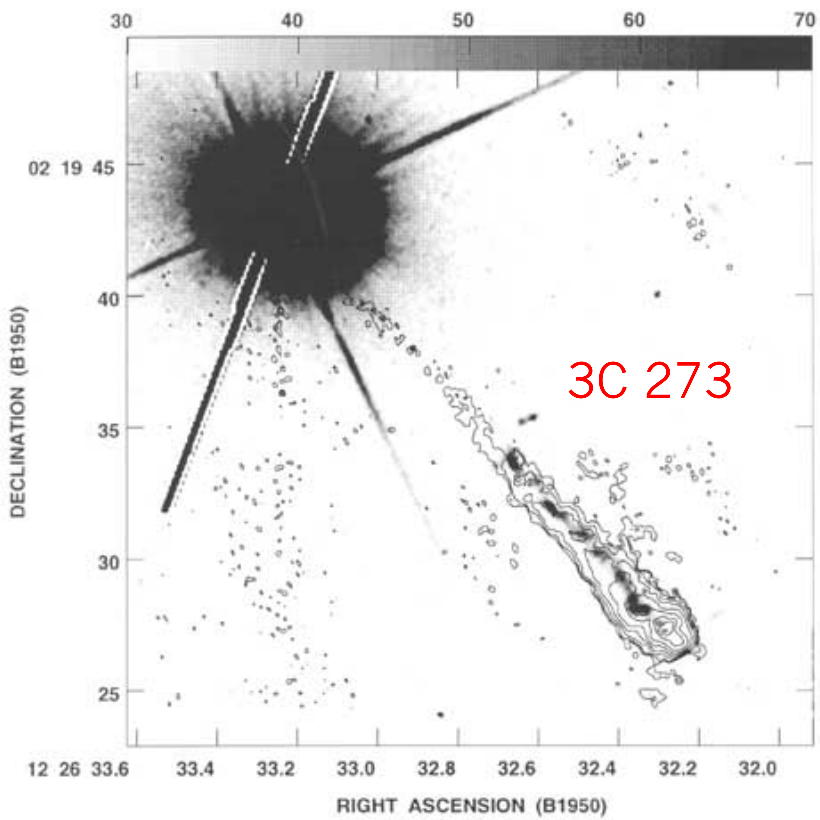
Radio-loud AGN

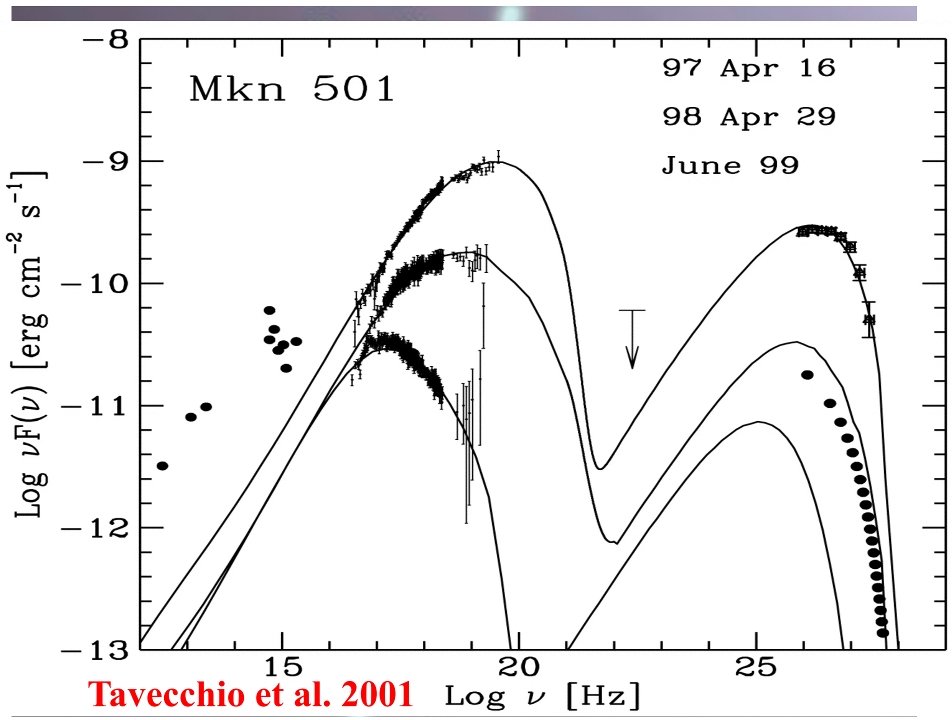
Type 1 & 2, blazars, flat- and steep-spectrum radio quasars, core-dominated, lobe-dominated, optically violent variable quasars, BL Lacertae objects (*high-peaked, low-peaked, radio-selected, X-ray selected*), high- and low-polarization quasars

Radio-galaxies: Fanaroff-Riley I & II, narrow-lined, broad-lined, high-excitation, low-excitation, GHz-peaked

The first quasars

quasar = quasi stellar **radio** source





1965: not all quasars are radio sources

THE EXISTENCE OF A MAJOR NEW CONSTITUENT OF THE UNIVERSE: THE QUASI-STELLAR GALAXIES

ALLAN SANDAGE
Mount Wilson and Palomar Observatories
Carnegie Institution of Washington, California Institute of Technology
Received May 15, 1965

ABSTRACT

Photometric, number count, and spectrographic evidence is presented to show that most of the blue, starlike objects fainter than $m_{pg} = 16^m$ found in color surveys of high-latitude fields are extragalactic and represent an entirely new class of objects Members of the class called here quasi-stellar galaxies (QSG) resemble the quasi-stellar radio sources (QSS) in many optical properties, but they are radio-quiet. The QSG brighter than $m_{pg} = 19^m$ are 10^3 times more numerous per square degree than the QSS that are brighter than 9 flux units. The surface density of QSG is about 4 objects per square degree to $m_{pg} = 19^m$.

The evidence is developed in three parts: (1) Photoelectric photometry shows that a fundamental change occurs in the color distribution of high-latitude blue objects at about $V = 14.^m5$. Brighter than this, the objects fall near the luminosity class V line of the $U - B$, $B - V$ diagram. Fainter than this, 80 per cent of the objects lie in the peculiar region known to be occupied by the quasi-stellar radio sources. (2) The observed integral-count-curve, $\log N(m)$, for objects in the Haro-Luyten catalogue undergoes a profound change of slope between $m_{pg} = 12^m$ and $m_{pg} = 15^m$, steepening and reaching a constant slope for m_{pg} fainter than 16^m. This magnitude interval is the same as that in which the color distribution changes, as discussed above. The slope fainter than 16^m is $d \log N(m)/dm = 0.383$. It is shown that this is the expected value from the theory of cosmological number counts for uniformly distributed objects with large redshifts. (3) Spectra of five of the faint blue objects are similar to spectra of quasi-stellar radio sources Intense, sharp emission lines of forbidden [O III], [O II], and [Ne III], together with very broad (35 Å wide) lines of Hβ, Hγ, Hδ, Hϵ, and [Ne V] are present in two of the five. Two broad emission lines are present in another at λ 3473 and λ 4279, identified as C IV (1550) and C III (1909). The other two objects have featureless spectra with only a blue continuum showing. The redshifts ($\Delta\lambda/\lambda_0$) for the three objects with lines are 0.0877, 0.1307, and 1.2410. The position of the objects in the redshift–apparent-magnitude diagram shows each of the three to be superluminous.

The space density of the quasi-stellar galaxies is estimated to be about 5×10^{-80} QSG/cm^3, which is to be compared with the space density of normal galaxies of about 1×10^{-75} galaxies/cm^3. The ratio, per unit volume, of QSG to QSS is estimated to be 500, which gives a lifetime of the QSG phase as 5×10^8 years if the lifetime of the radio source is 10^6 years.

The objects would seem to be of major importance in the solution of the cosmological problem. They can be found at great distances because of their high luminosity. QSG at $B = 22^m$ are estimated to have a mean redshift of $\Delta\lambda/\lambda_0 \simeq 5$ for a model universe of $q_0 = +1$. At these redshifts, we are sampling the universe in depth to 0.63 of the distance to the horizon (for $q_0 = +1$), and are looking back in time more than 0.9 of the way to the "creation event" in an evolutionary model. Study of the $[m, z]$- and $\log N(m)$-curves using the QSG should eventually provide a crucial test of various cosmological models. But even more important, comparative study of the quasi-stellar galaxies and the intimately connected quasi-stellar radio sources is expected to shed light on the evolutionary processes of the violent events that characterize the two classes.

The radio-quiet – r ny

THE ASTRONOMICAL JOURNAL VOLUME 98, NUMBER 4 OCTOBER 1989

VLA OBSERVATIONS OF OBJECTS IN THE PALOMAR BRIGHT QUASAR SURVEY

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Received 7 April 1989; revised 23 May 1989

ABSTRACT

All 114 objects from the Palomar Bright Quasar Survey (BQS) have been observed using the VLA at 5 GHz (6 cm) wavelength with 18 arcsec resolution. The new radio observations typically reach a level of 0.1 in the ratio R of radio-to-optical luminosity which allow radio emission to be detected from most of the BQS objects. Ninety six (84%) of the BQS were detected as radio sources above a 3σ level of 0.2 mJy, and 75 (82%) of the complete sample of 92 quasars with $M_B < -23$ were detected. There appears to be no difference in the radio properties of AGNs ($M_B > -23$) and quasars ($M_B < -23$). The distribution of radio flux density for the BQS sample appears bimodal. Most of the BQS quasars are "radio quiet" and have a radio flux density close to that of the optical flux density, but 15%–20% are "radio loud" and are much brighter at radio than at optical wavelengths. Only a few percent of the BQS sample overlap radio-selected quasars in the ratio of radio-to-optical flux density. Most of the sources detected with 18 arcsec resolution were reobserved with a resolution of 0.5 arcsec. For the optically selected quasars, we find an increasing fraction of compact sources with increasing redshift. We derive the radio luminosity function, assuming that it is either (a) independent of optical luminosity, or (b) a function of the ratio R of radio-to-optical luminosity. The statistics of radio detections of optically selected quasars in this and in other published studies are equally well represented by the two cases. The radio emission from high-redshift quasars ($z > 0.5$) is dominated by compact components; quasars with $R > 100$ mostly have small redshifts. The distinction between the radio-loud and radio-quiet quasars from this optically selected sample cannot be explained simply by the effects of geometry and relativistic beaming for objects having a fixed ratio of intrinsic radio and optical luminosity.

I. INTRODUCTION

It has long been recognized that only a small fraction, of the order of 10%, of known quasars are strong radio sources (e.g., Katgert *et al.* 1973; Fanti *et al.* 1977; Smith and Wright 1980; Sramek and Weedman 1980). Although this is comparable to the fraction of giant elliptical galaxies that are observed to be strong radio sources (Schmidt 1966), the active nature of quasars has led to considerable discussion about why most quasars appear to be radio quiet. Possible interpretations of the apparent broad distribution of the observed ratio of radio-to-optical flux density include:

(1) **Two Types of Quasars.** There may be two intrinsically different types of quasars (e.g., Moore and Stockman 1984) only one of which becomes a strong radio source.

(2) **Intermittent Activity.** The radio emission from quasars is known to be variable. Quasars may be normally quiescent at radio wavelengths, and are observed as radio sources only during the time of unusual activity. It is unlikely that the kind of variability commonly observed in quasars can explain the wide range of observed radio-to-optical luminosity; known radio-loud quasars typically have a range of flux density which varies by only a factor of 2 or 3 on a timescale of a few years. However, there may be longer periods, of perhaps a hundred years or more, when a quasar becomes bright at radio wavelengths.

(3) **Absorption.** The radio emission from most quasars may be absorbed by an intervening plasma local to the quasar so the radio-emitting region "breaks out" of the obscuring cloud in only a small fraction of quasars (Bolton 1977; Strittmatter *et al.* 1980; Condon *et al.* 1980). Synchrotron absorption may also be important. However, radio searches at short millimeter wavelengths where the opacity is expected to be small do not show any dramatic increase in detections (e.g., Ennis *et al.* 1982; Robson *et al.* 1985).

(4) **Geometry.** The radio emission may be relativistically beamed, and only the small fraction of quasars which are oriented in the appropriate direction are observed as strong radio sources (Scheuer and Readhead 1979).

Many radio studies of optically selected quasars have been carried out to define better the radio luminosity function, to test specific models for the radio emission from quasars, and to establish just how quiet are the radio quiet QSOs.

Our study of the 114 objects in the Palomar Bright Quasar Survey (BQS) (Schmidt and Green 1983) improves on previous searches in several ways:

(1) It is based on an optically complete sample.

[a] The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.
[b] The National Optical Astronomy Observatories are operated by the Association of Universities for Research in Astronomy, under contract with the National Science Foundation.

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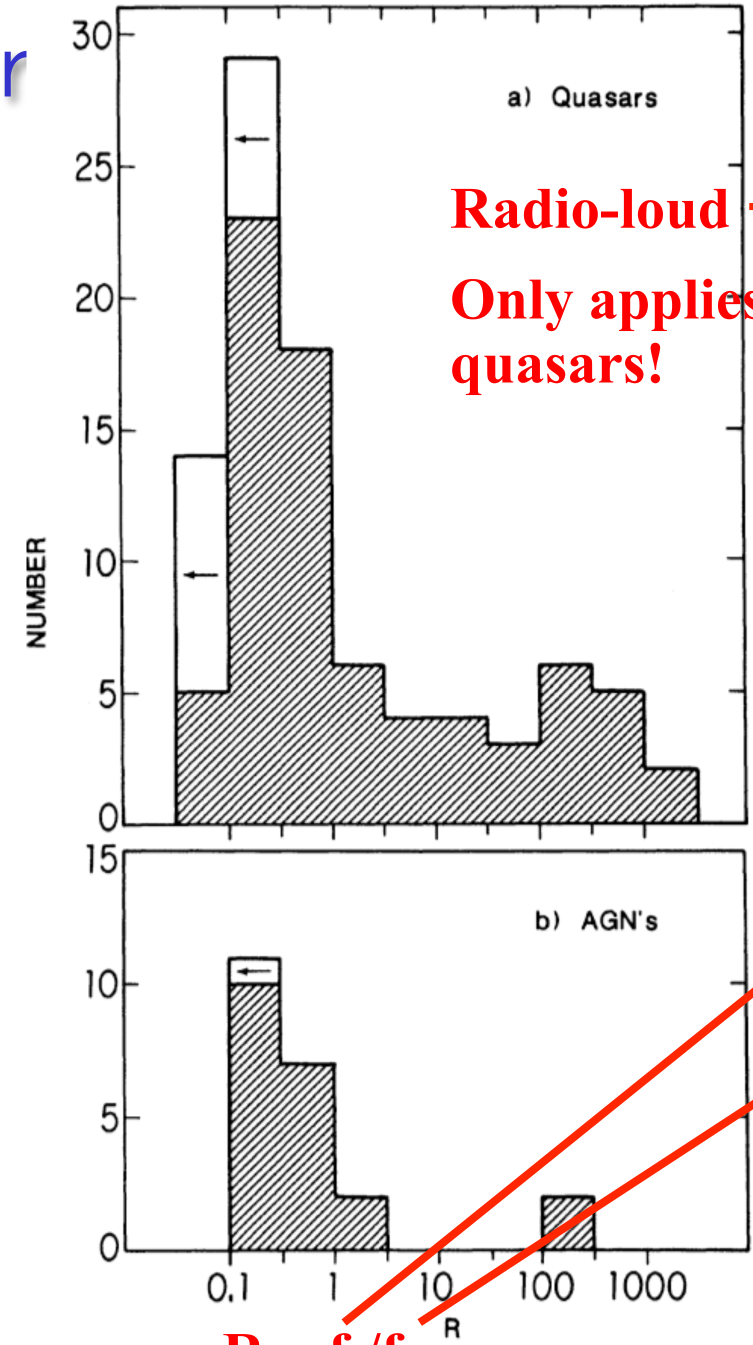
Kellerman et al. 1989



Radio-loud → R > 10

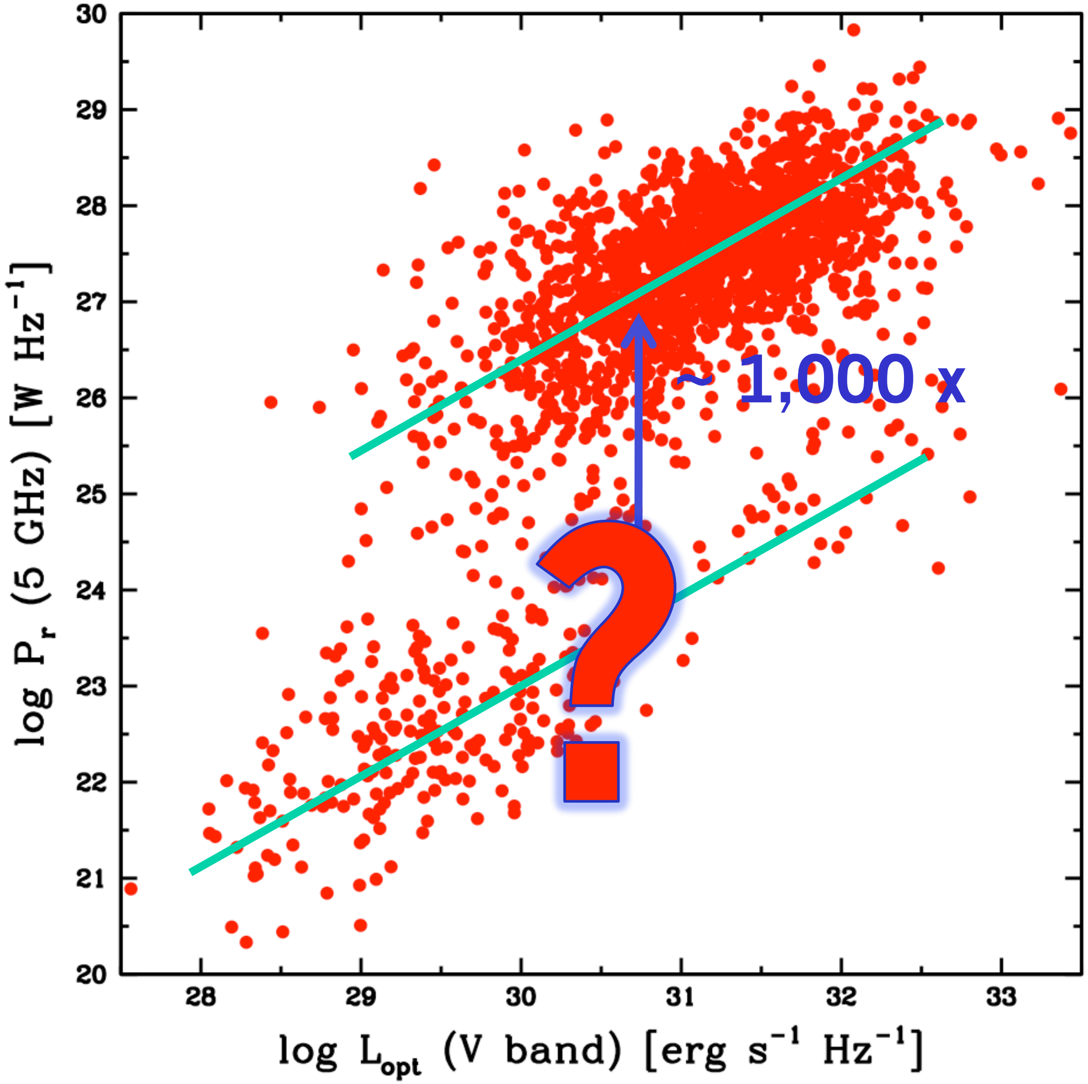
Only applies to quasars!

jet

disc

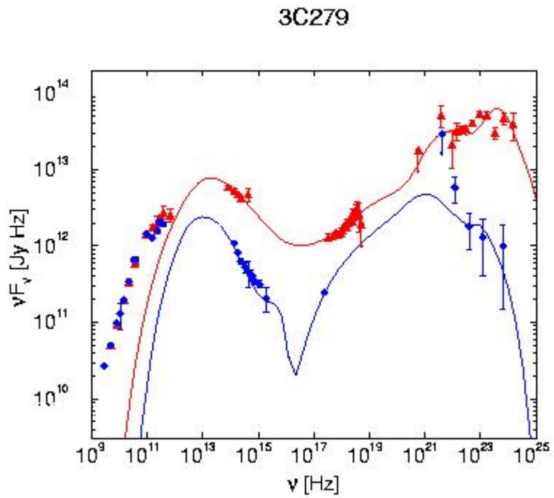
$R = f_r/f_B$

Radio quiet AGN



The radio-quiet – radio-loud distinction

- Radio-loud AGN: most energy non-thermal: powerful relativistic jets (can also have a thermal component [accretion disk])
- Radio-quiet AGN: jets not present or insignificant w.r.t total energy budget → thermal energy dominates



"Seyfert" galaxies

NUCLEAR EMISSION IN SPIRAL NEBULAE*

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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 the other ions show no evidence of wide wings. Some of the lines exhibit strong asymmetries, usually in the sense that the violet side of the line is stronger than the red.

In NGC 7469 the absorption K line of *Ca* II is shallow and 50 A wide, at least twice as wide as in normal spirals.

Absorption minima are found in six of the stronger emission lines in NGC 1068, in one line in NGC 4151, and one in NGC 7469. Evidence from measures of wave length and equivalent widths suggests that these absorption minima arise from the G-type spectra on which the emissions are superposed.

The maximum width of the Balmer emission lines seems to increase with the absolute magnitude of the nucleus and with the ratio of the light in the nucleus to the total light of the nebula. The emission lines in the brightest diffuse nebulae in other extragalactic objects do not appear to have wide emission lines similar to those found in the nuclei of emission spirals.

Many of the spectra of extragalactic nebulae obtained at the Mount Wilson and Lick observatories show one or more emission lines in addition to the usual absorption spectra. In particular, N. U. Mayall[1] finds that 50 per cent of his spectra of spirals show the [*O* II] doublet λ 3727 in emission either in the nuclear region or in the arms. However, only a very small proportion of extragalactic nebulae show spectra having many high-excitation emission lines localized in the nuclei. These emission features are similar to those found in planetary nebulae and are superposed on the characteristic solar-type absorption spectra. Twelve nebulae[2] are now known which probably belong to this unusual class of objects. Most of them are intermediate-type spirals with ill-defined amorphous arms, their most consistent characteristic being an exceedingly luminous stellar or semistellar nucleus which contains a relatively large percentage of the total light of the system. Plate I shows a photograph of NGC 4151, a typical example of this type of nebula.

Probably the earliest spectrographic observation of a member of this unusual class of objects was that of NGC 1068 by E. A. Fath,[3] in which he found five emission and two absorption lines. In 1917, V. M. Slipher[4] found hydrogen lines and the nebular lines N1 and N2 bright in the nucleus of NGC 5236. Shortly afterwards, Slipher[5] made the discovery that the emission lines in NGC 1068 were not monochromatic images of the slit but were small "discs." These findings were confirmed by Campbell and Moore,[6]

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 671.

† Fellow of the National Research Council.

[1] *Lick Obs. Bull.*, **19**, 33, 1939.

[2] NGC 1068, 1275, 2782, 3077, 3227, 3516, 4051, 4151, 4258, 5548, 6814, and 7469.

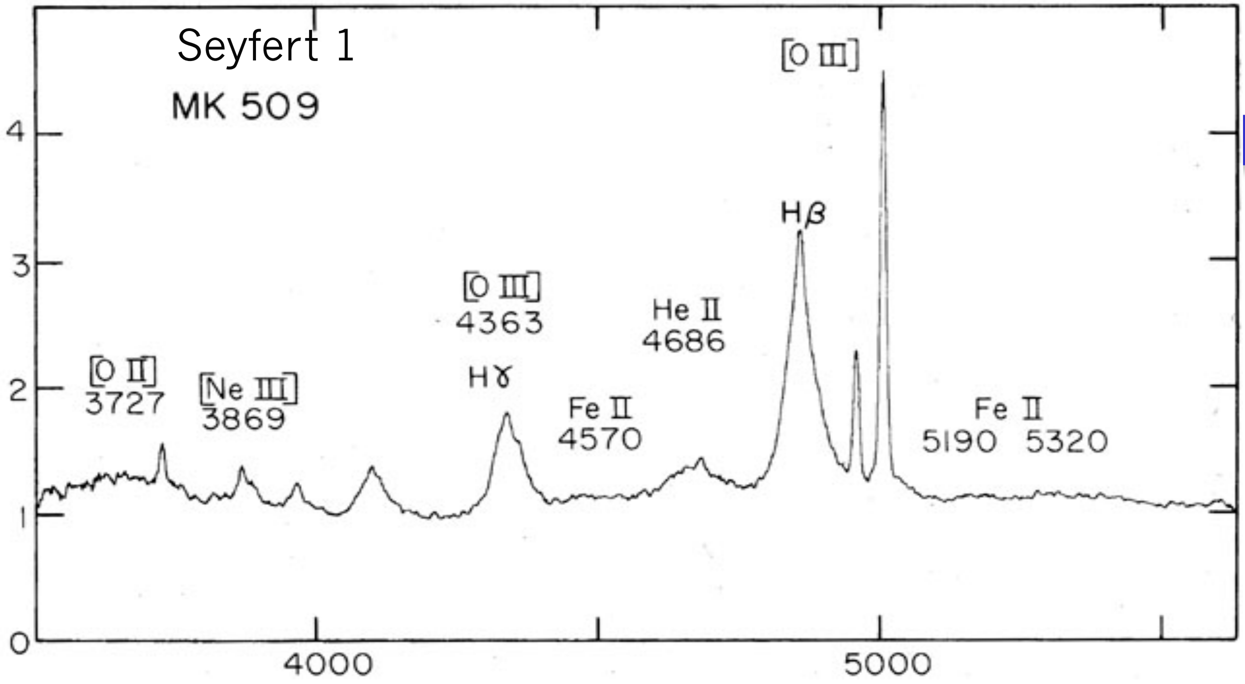
[3] *Lick Obs. Bull.*, **5**, 71, 1908.

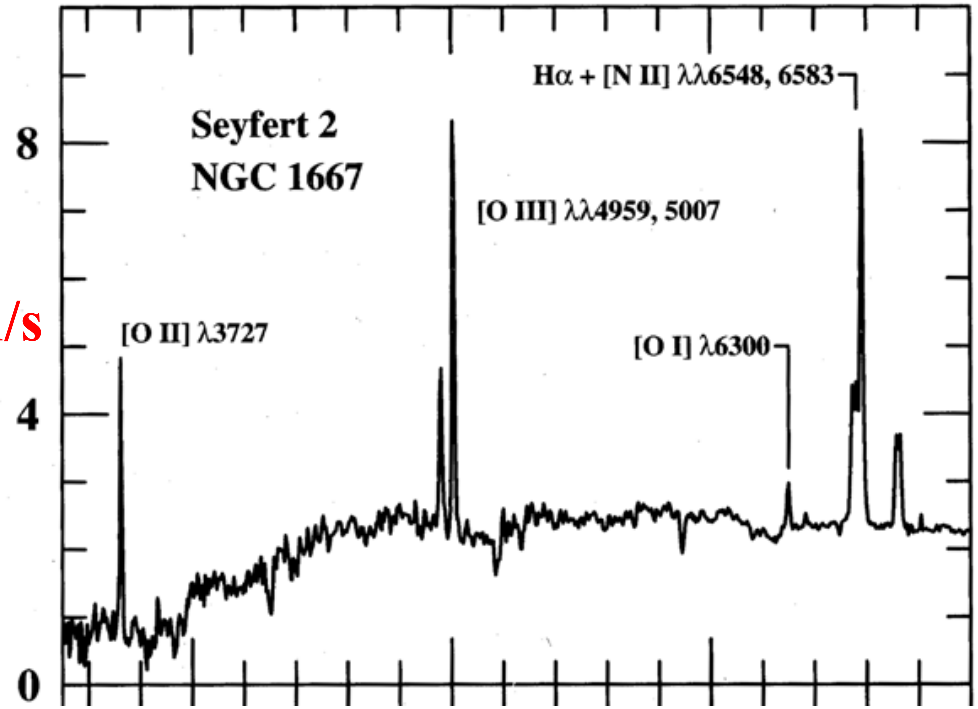
[4] *Pop. Astr.*, **25**, 36, 1917; *Proc. Amer. Phil. Soc.*, **56**, 403, 1917.

[5] *Lowell Obs. Bull.*, **3**, 59, 1917.

[6] *Lick Obs. Pub.*, **13**, 88, 1918.

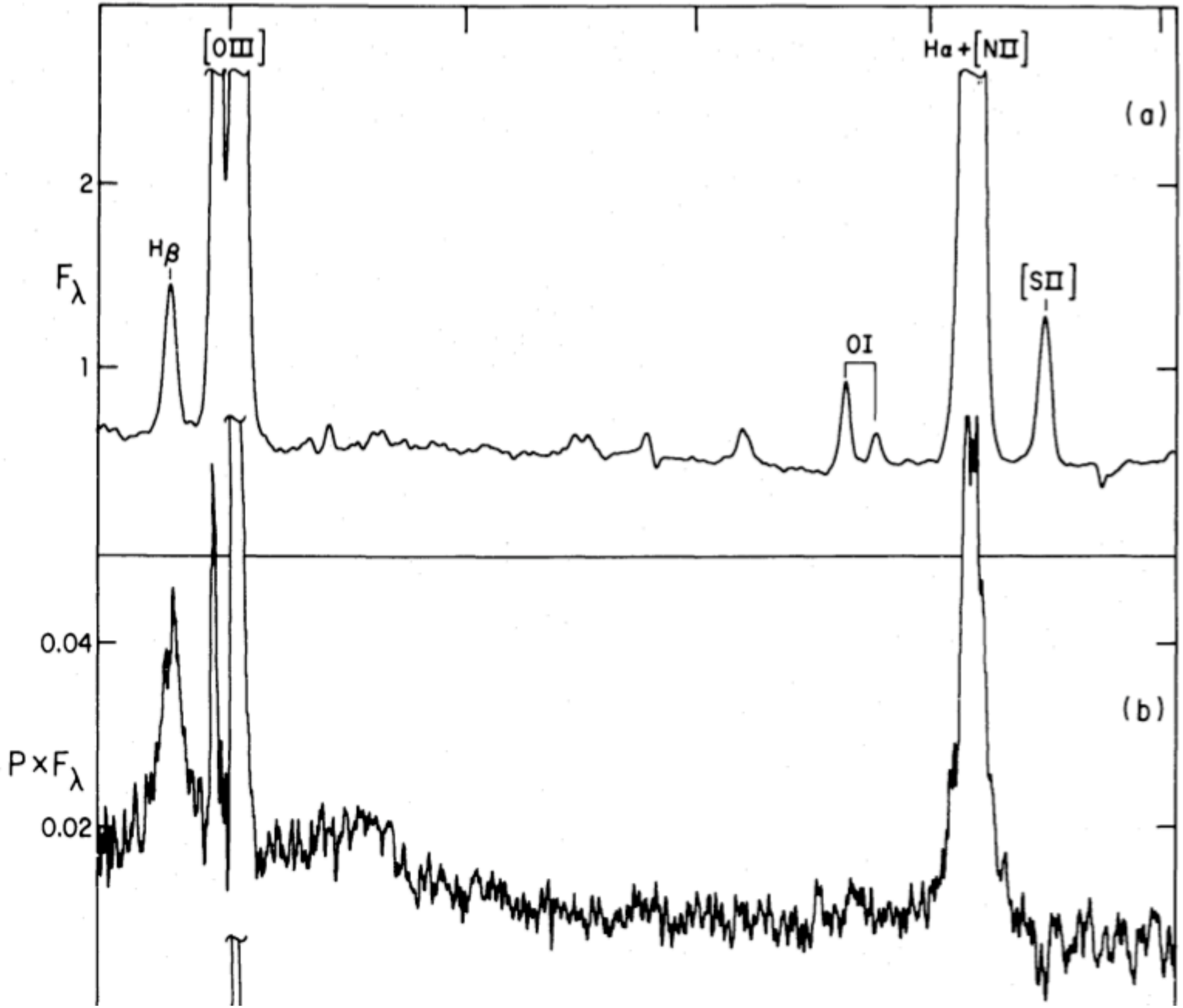
Why th … nction?





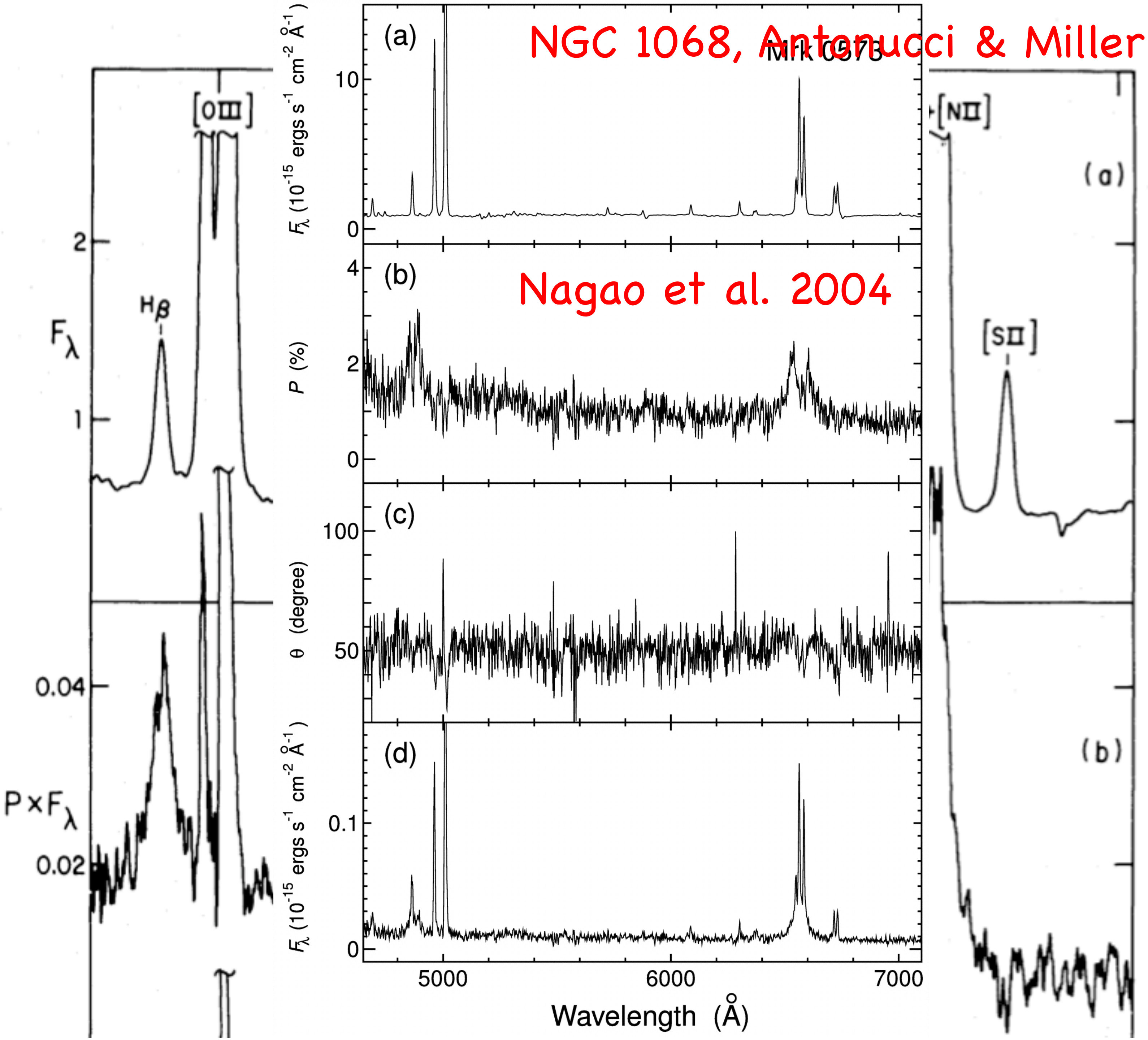
Narrow lines:
FWHM < 1,000 km/s

NGC 1068, Antonucci & Miller (1985)



NGC 1068, Antonucci & Miller (1985)

Nagao et al. 2004



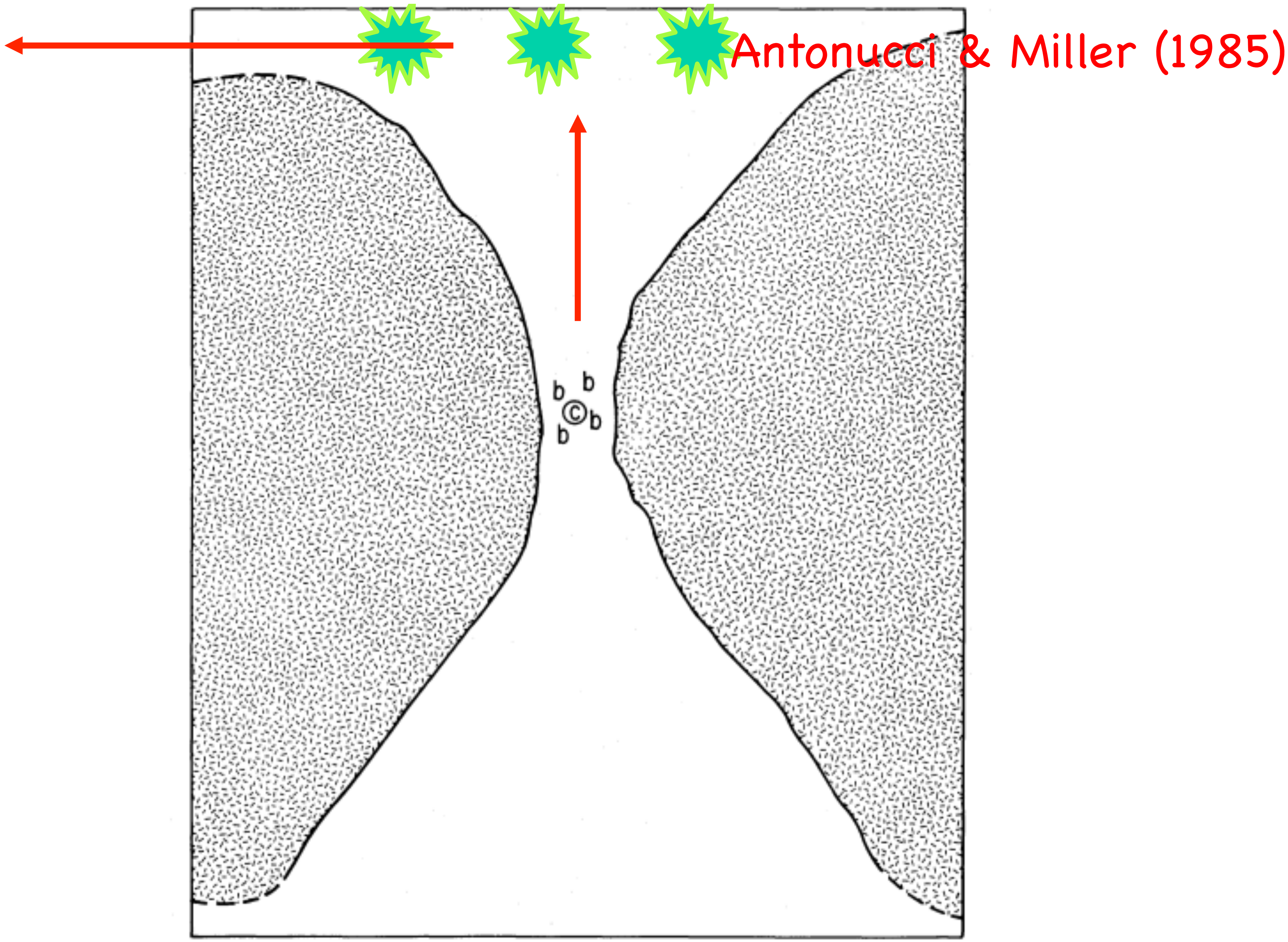
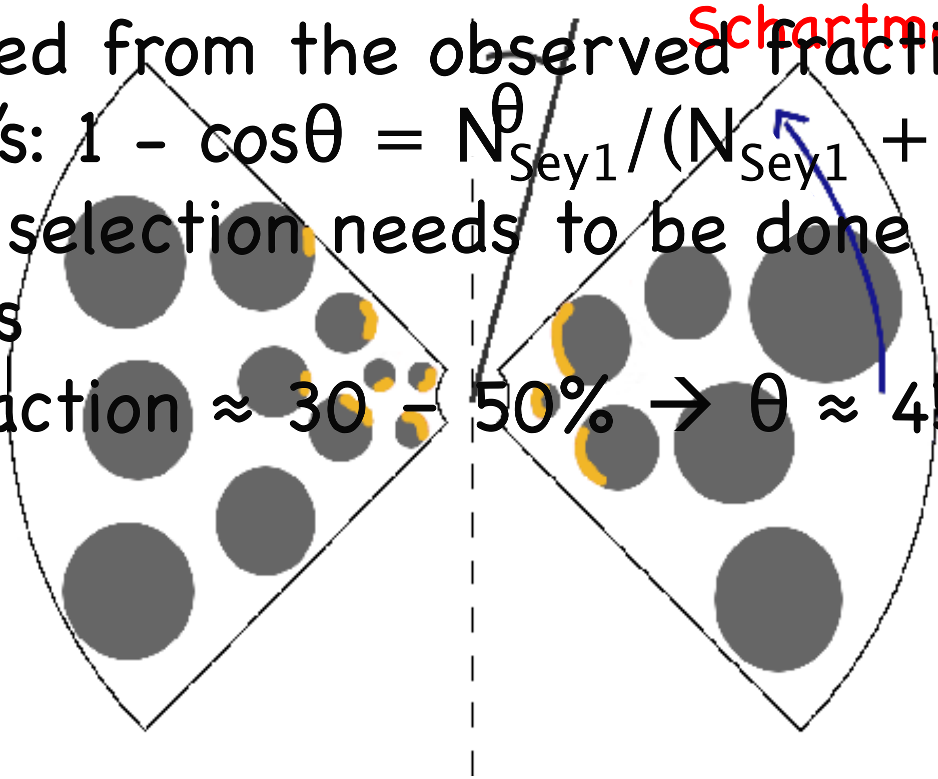


FIG. 5.—Cutaway drawing of a continuum source and broad-line clouds surrounded by a geometrically and optically thick disk. Only photons traveling out along the polar directions can scatter into the line of sight. We would observe a high polarization in the plane perpendicular to the symmetry axis, which we presume to be the radio structure axis.

The “torus” opening angle

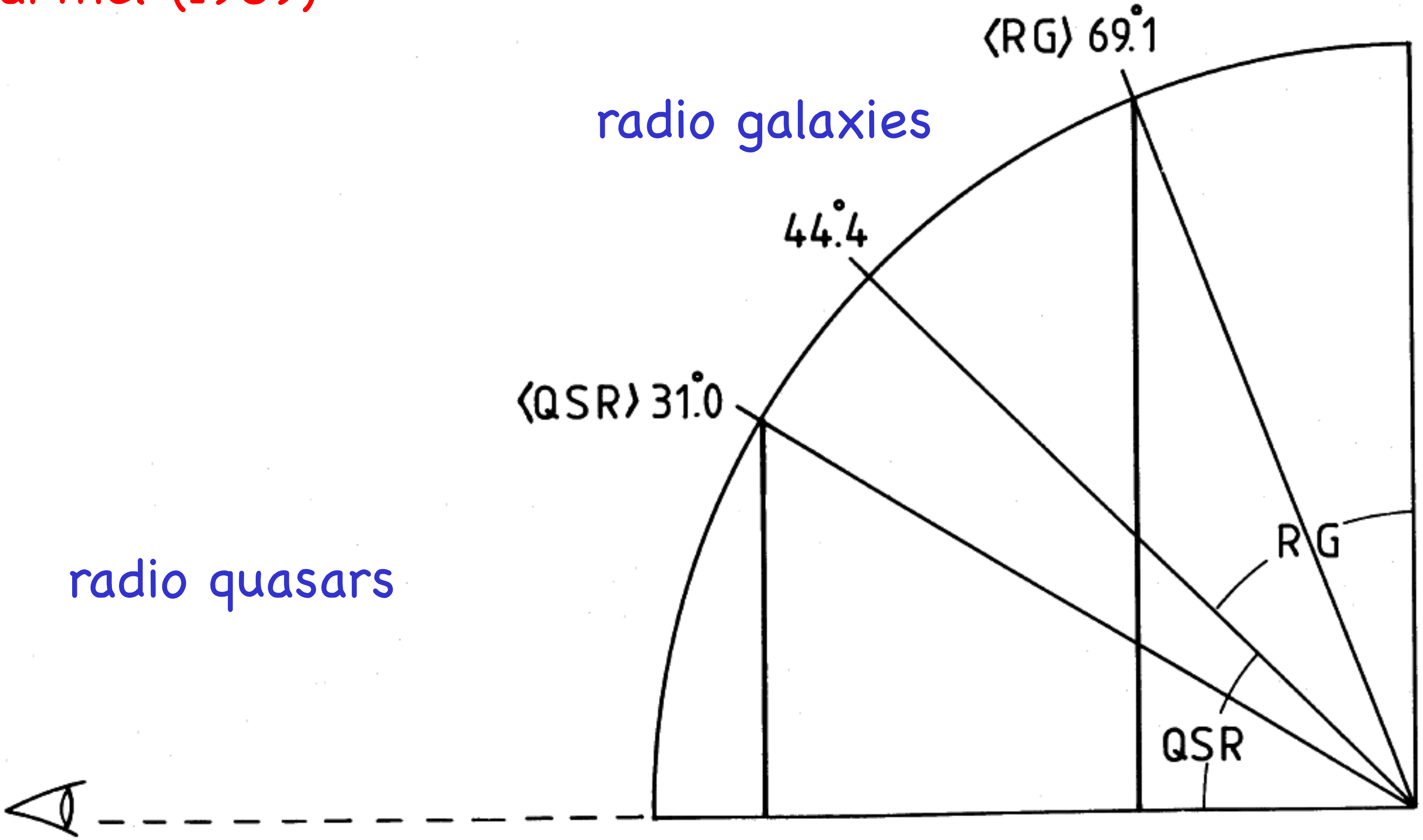
- The fraction of Sey 1's depends on the “torus” half opening angle θ; extreme cases:
  - ✓ θ = 0° → no Sey 1's (covering fraction = 100%)
  - ✓ θ = 90° → all Sey 1's (no torus)
- θ estimated from the observed fraction of Seyfert 1's: $1 - \cos\theta = N_{Sey1}/(N_{Sey1} + N_{Sey2})$
- tricky → selection needs to be done on isotropic properties
- Sey 1's fraction ≈ 30 – 50% → θ ≈ 45° - 60°

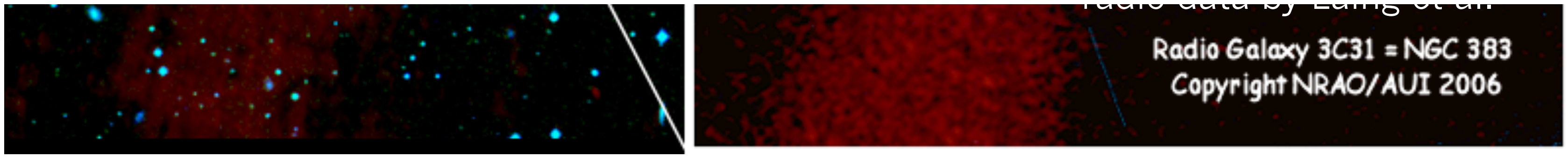


Schartmann et al. (2008)

Radio galaxies and radio quasars

Barthel (1989)





Relativistic Beaming: evidence and effects

$\Gamma = (1 - \beta^2)^{-1/2}$ (Lorentz factor), $\beta = v/c$

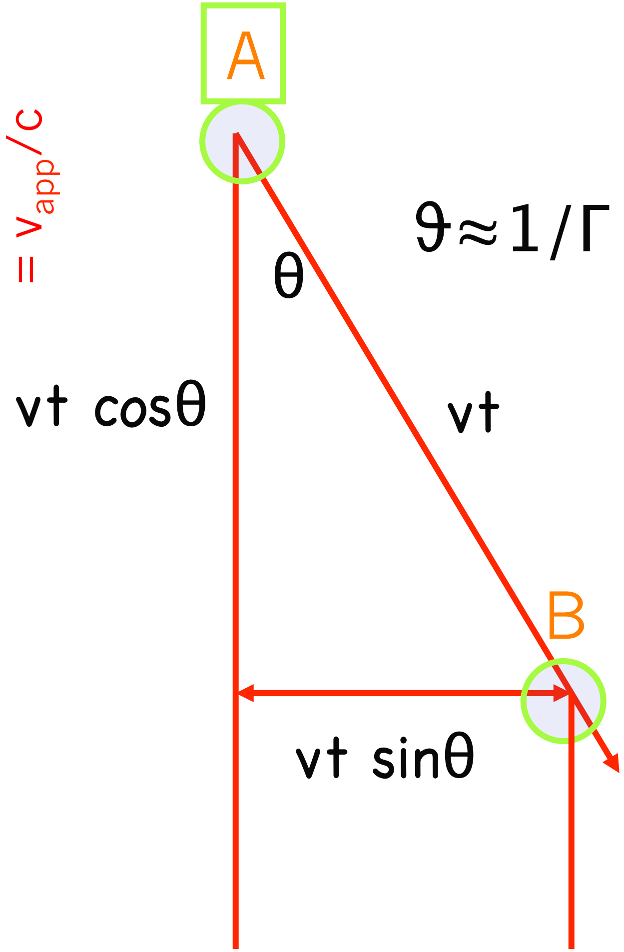
$\delta = 1/[\Gamma(1 - \beta\cos\theta)]$ (Doppler factor)

$\nu_{obs} = \delta\,\nu_{em}$ + I_ν/ν^3 relativistic invariant →

$L_{obs} = \delta^3 L_{em}$ (but energy is conserved); $L_{obs} = \delta^{p+\alpha} L_{em}$, p ~2 - 3

- Strong evidence that jets are relativistic (v ∼ c):
    1. Superluminal motion
    2. Synchrotron self-Compton emission (Marscher et al. 1979)

Superluminal motion



Rees (1966)

$t_A - t_B = t\,(1 - v/c\,\cos\theta)$

$v_{app} = \Delta r/(t_A - t_B) =$

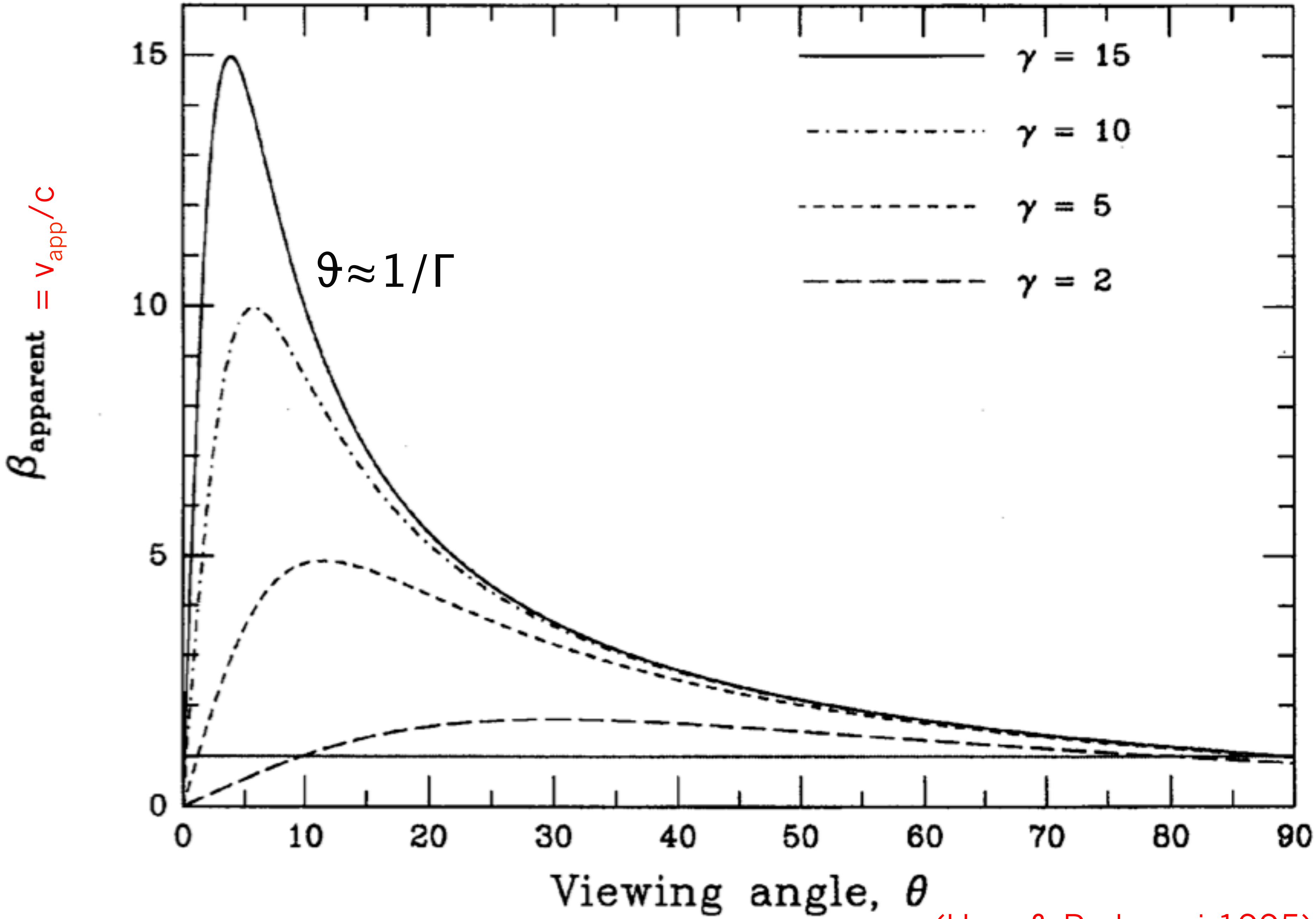
$\vartheta \approx 1/\Gamma$ $\quad v\,\sin\theta/(1 - v/c\,\cos\theta)$

For $v \geq 0.7c$, $v_{app} > c$ for some θ

e.g.,: $v = 0.95c$, $\theta = 18°$, $v_{app} \sim 3c$

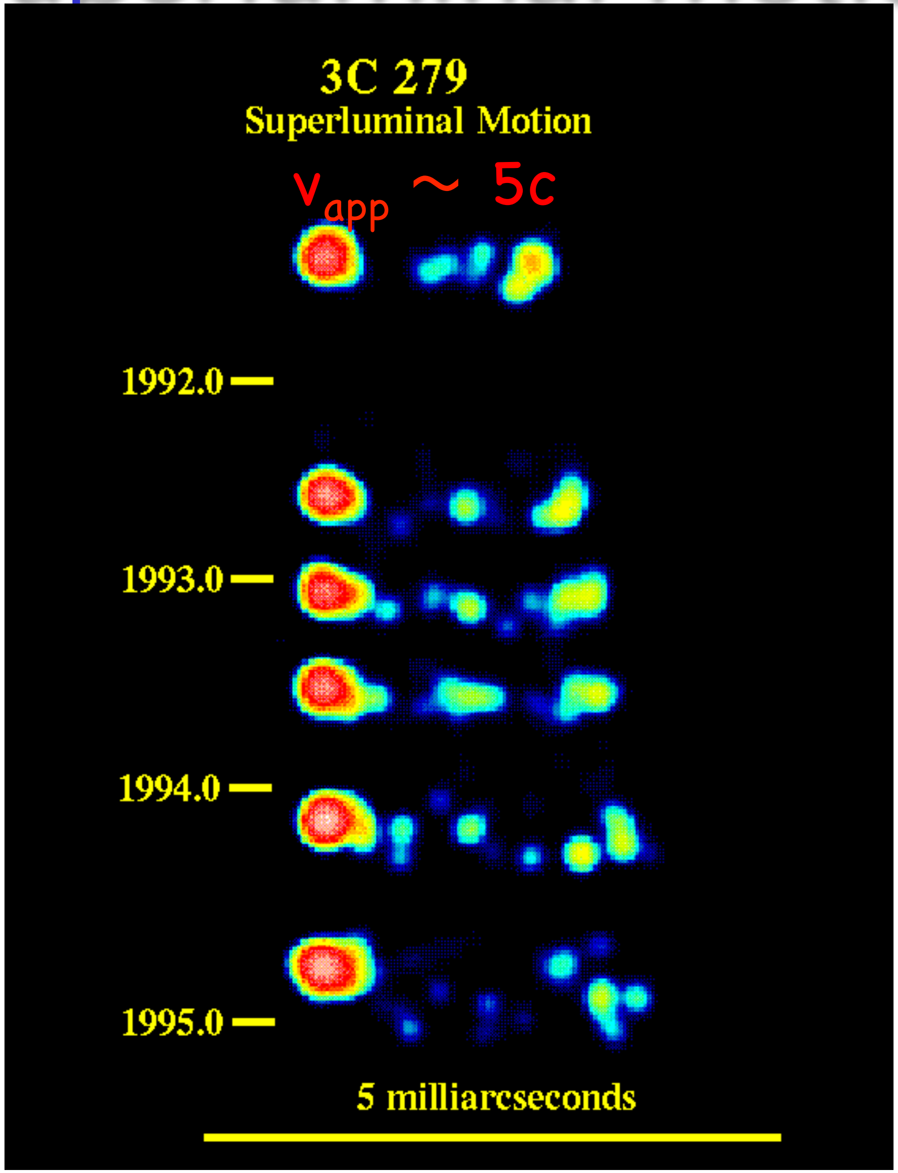
$\Gamma > [(v_{app}/c)^2 + 1]^{½}$

If $v_{app} = 5c \rightarrow \Gamma > 5.1$, $v > 0.98\ c$



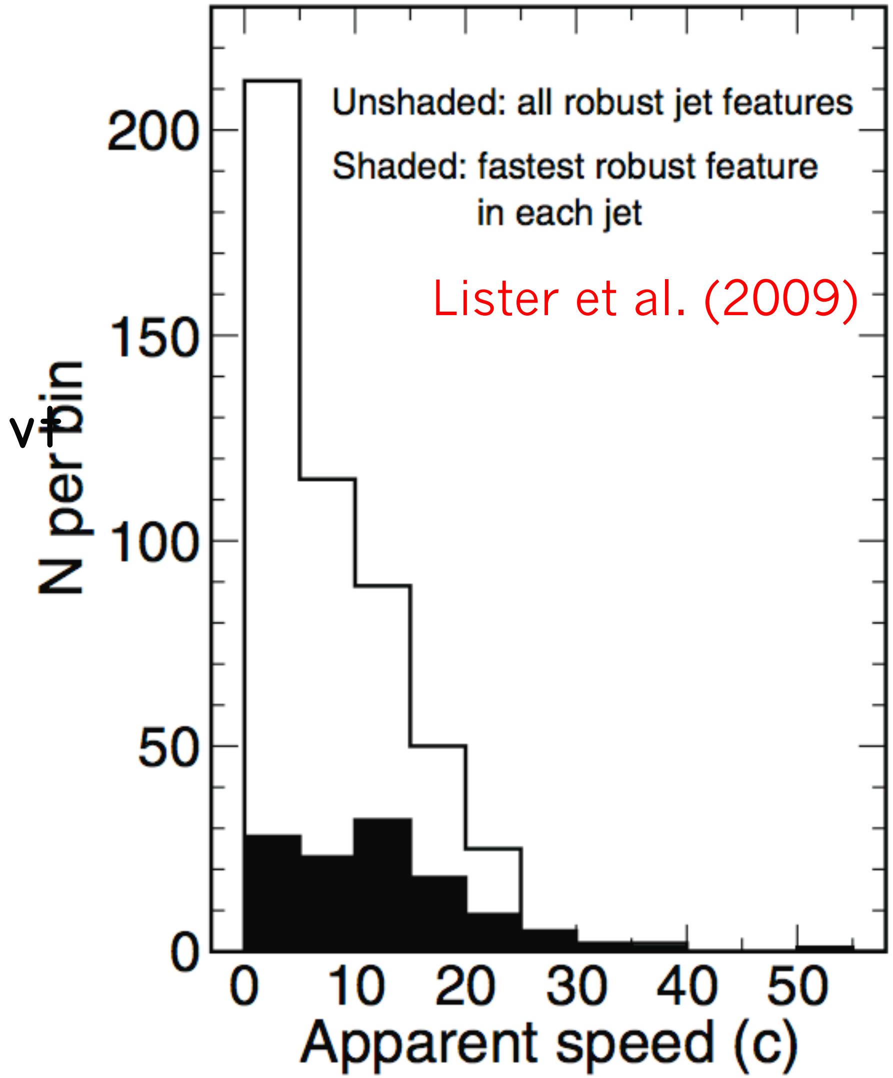
(Urry & Padovani 1995)

Superluminal motion

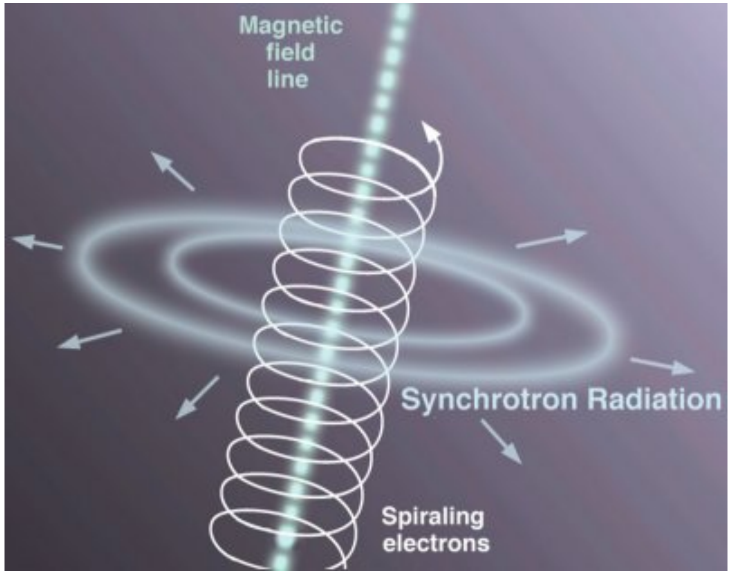


(Wehrle et al. 2001)

Superluminal motion



Synchrotron self Compton basics



$e^- + \gamma_{\text{low-energy}} \rightarrow \gamma_{\text{high-energy}}$

In practice in radio sources:

- $f_{X\text{-ray}}$ is predicted from f_{radio} using the SSC formalism
- $f_{X\text{-ray}}$ is compared to observed values
- turns out that $f_{X\text{-ray,predicted}} >> f_{X\text{-ray,observed}}$
- simplest explanation: assumption of isotropic emission in radio band is wrong → energy density much smaller than we think ($L_{obs} = \delta^3 L_{em}$); lower limit on Doppler factor δ

Relativistic Beaming: evidence and effects

$\Gamma = (1 - \beta^2)$

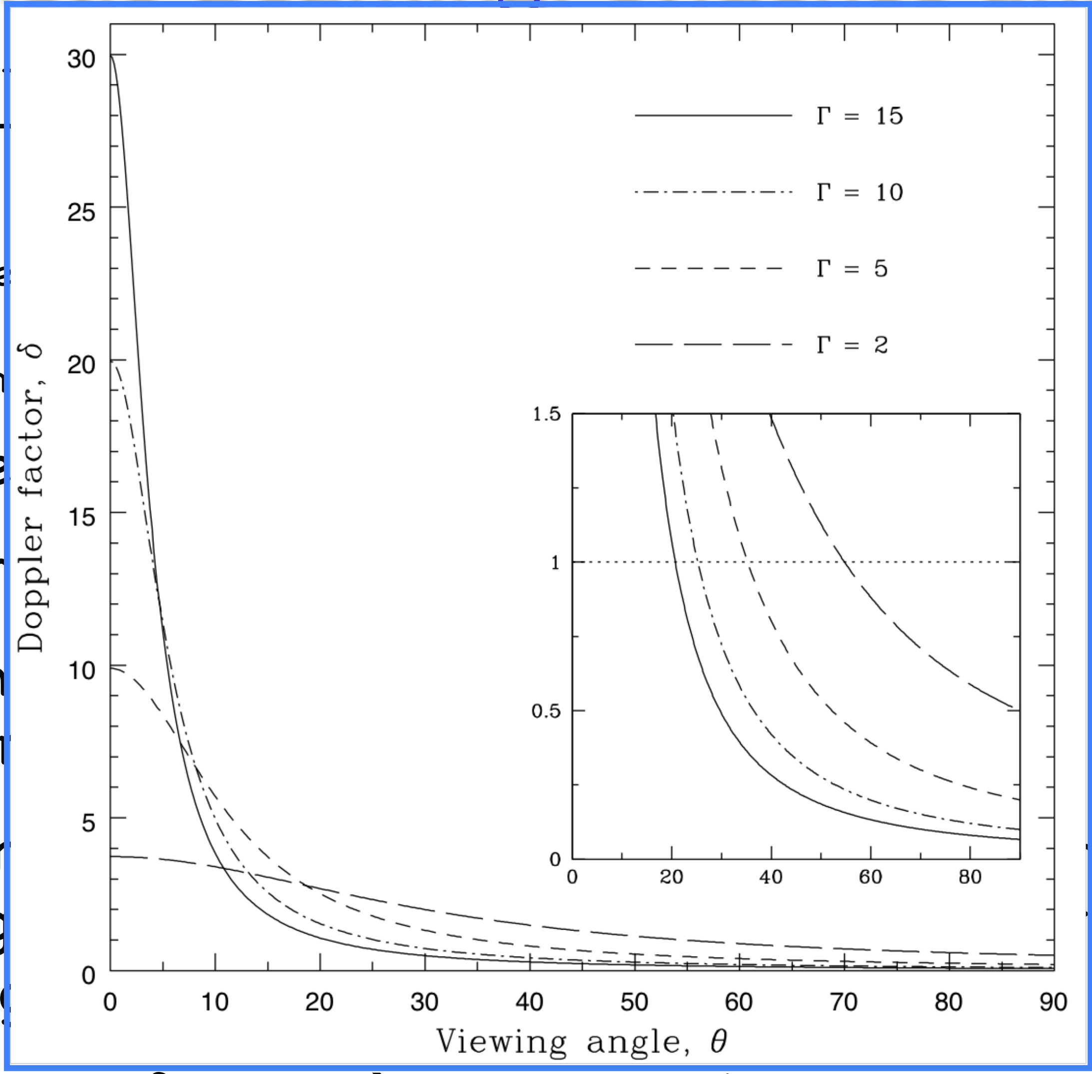
$\delta = 1/[\Gamma$

$\nu_{obs} = \delta \nu_{e}$

$L_{obs} = \delta^3 L_{em}$ ... $_{em}$, $p \sim 2 - 3$

- Strong e ... :

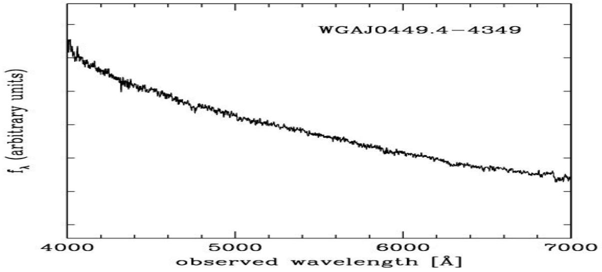
1. Super
2. Synch ... et al. 1979)
   → X-r
3. Power ... i et al. 1992)
   → hig ... h X-rays
   throu ... ssion

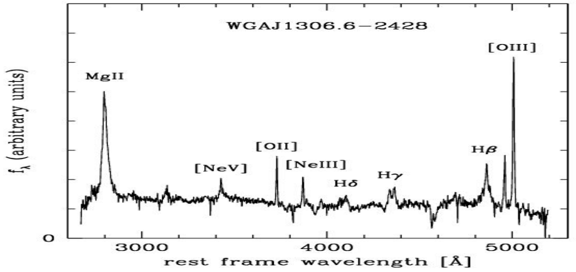


- Large Doppler factors → large speeds + small angles
- Amplification: small θ, $\delta \sim 2\Gamma$ → $\Gamma = 10$, $\delta \sim 20$, $L_{obs} \sim 400$ – 8,000 L_{em}; $\Gamma = 30$, $\delta \sim 60$, $L_{obs} \sim 4{,}000 - 200{,}000\ L_{em}$

Blazar Properties

BL Lacs and Flat-Spectrum Radio Quasars





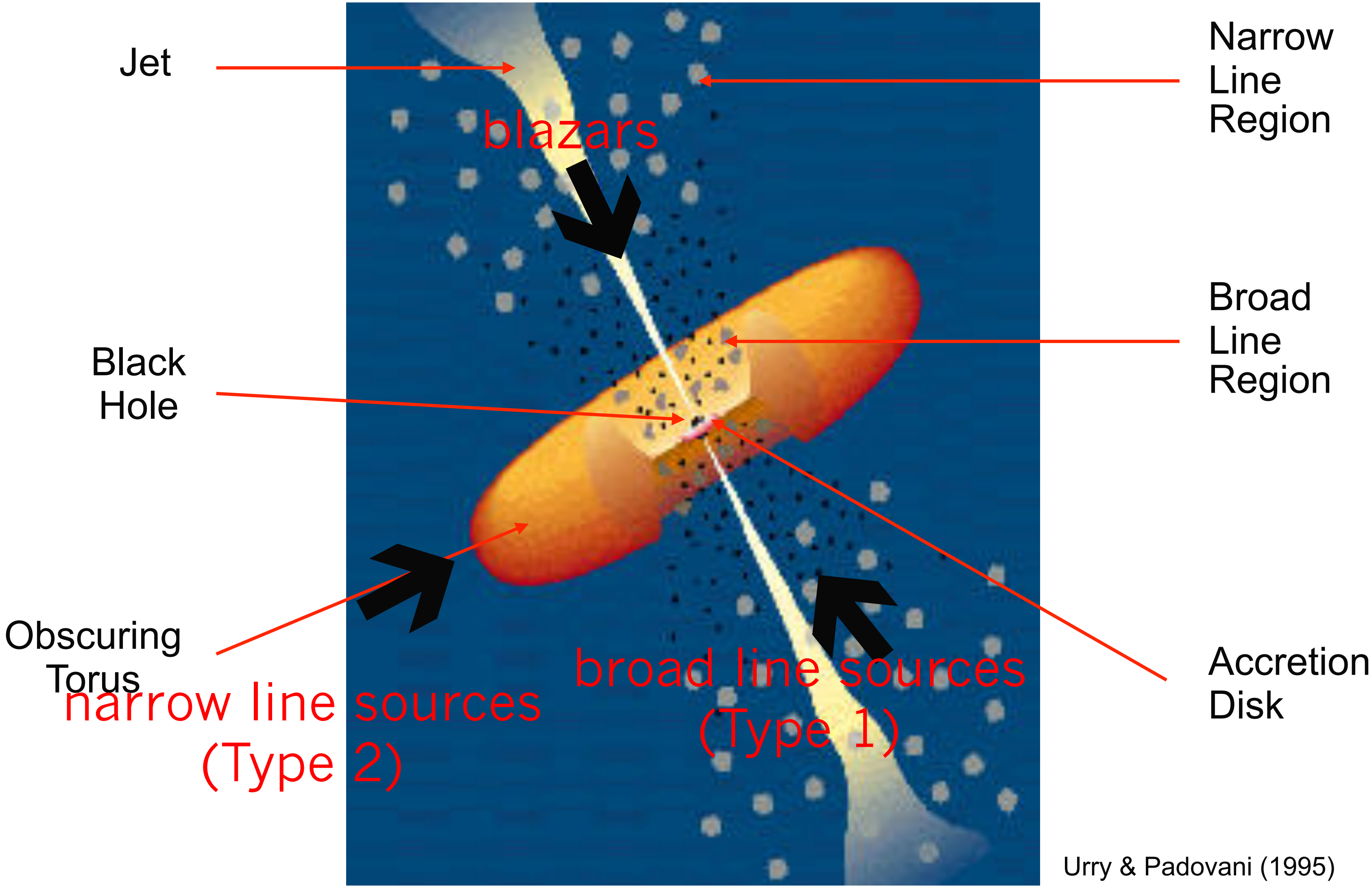
- Smooth, broad, non-thermal continuum (radio to γ-rays)
- Compact, strong radio sources
- Rapid variability (high $\Delta L/\Delta t$), high and variable polariz. (P_{opt} > 3%)
- Strong indications of "relativistic beaming" (e.g., superluminal motion): "fast" jets forming a small angle with the line of sight

Sites of very high energy phenomena:

E_{max} ~ 20 TeV (5 x 10^{27} Hz) and v_{max} ~ 0.9998c

Nature's free accelerators

AGN Unified Schemes



Urry & Padovani (1995)

The AGN Zoo: Unified Schemes

	Type 2		Type 1	
	≈ 40° – 90°	≈ 15° – 40°	< 15°	
Radio-loud	high-excit. RG[1]/FRII[2] →	SSRQ[3] →	FSRQ[4]	blazars
	low-excit. RG[1]/FRI →		BL Lacs	blazars
	≈ 45° – 90°		< 45°	
Radio-quiet	Seyfert 2 →		Seyfert 1	
	QSO 2 →		QSO	

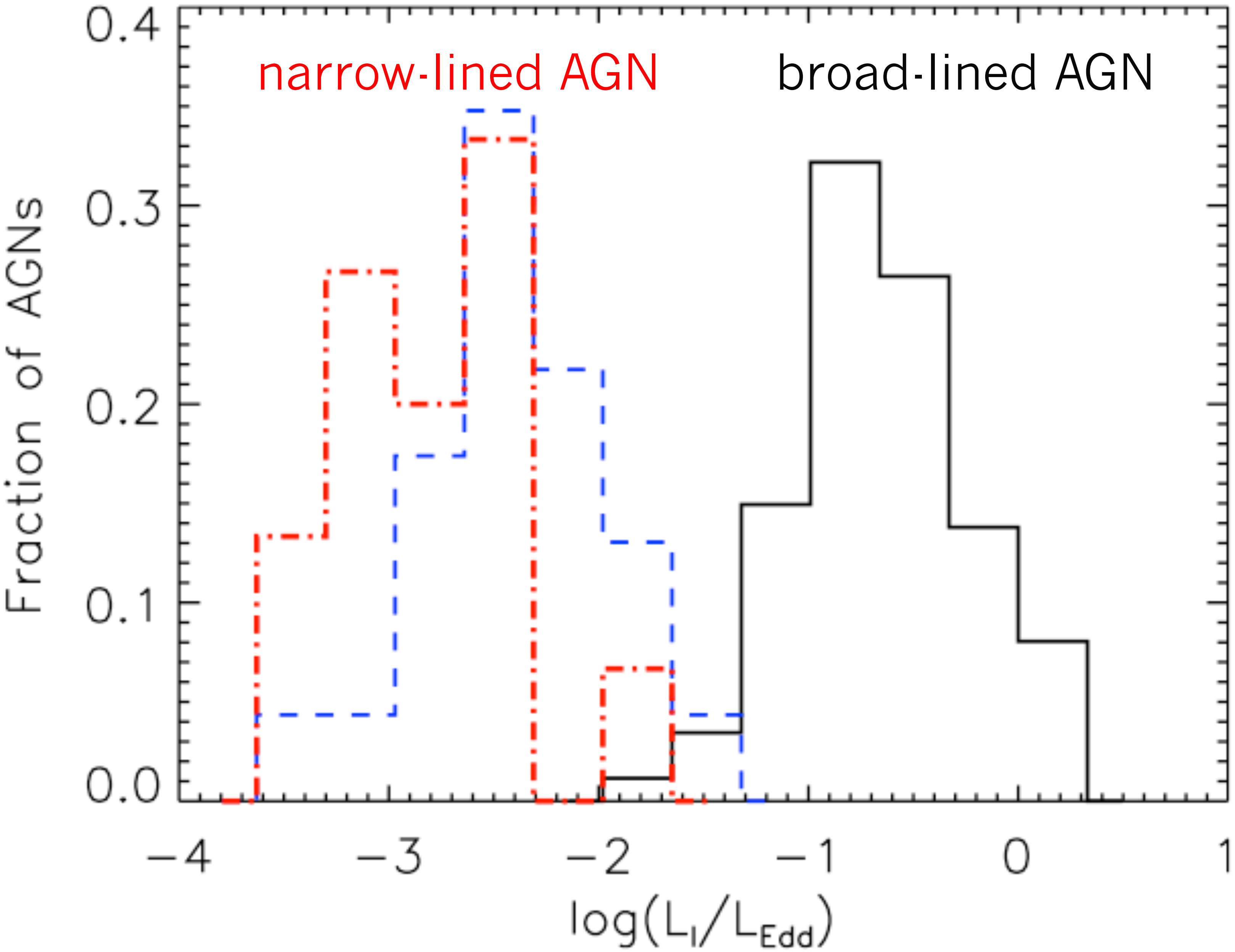
edge-on → face-on

decreasing angle to the line of sight

[1] radio galaxies
[2] Fanaroff-Riley
[3] steep-spectrum radio quasars (<u>also LPQs, lobe-dominated</u>)
[4] flat-spectrum radio quasars (<u>also HPQs, core-dominated, OVVs, ...</u>)

AGN "Really" Fundamental Parameters

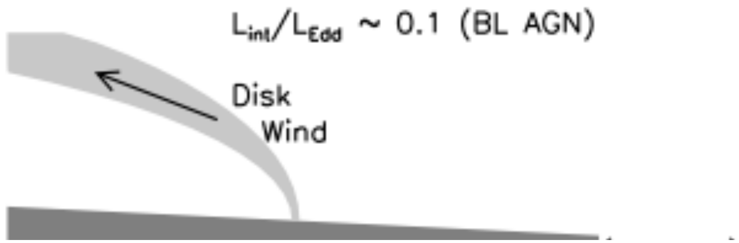
- The full AGN variety can be explained by only three (four?) parameters:
  - ✓ angle; *Seyfert 1 – 2, radio quasars – radio galaxies, etc.*
  - ✓ presence (or lack of) jets; *radio-loud – radio-quiet*
  - ✓ accretion rate: $L/L_{Edd} < 0.01 \rightarrow$ no broad line region or obscuring torus
  - ✓ power (?): opening angle might depend on it

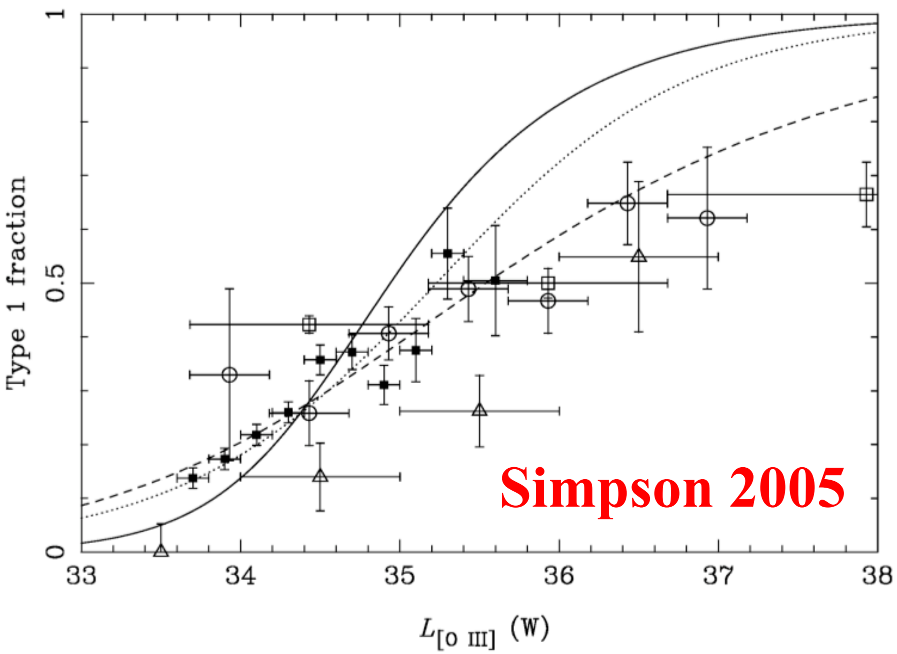


Trump et a

models given in Gilli et al. [136]).

AGN “Really’ Para





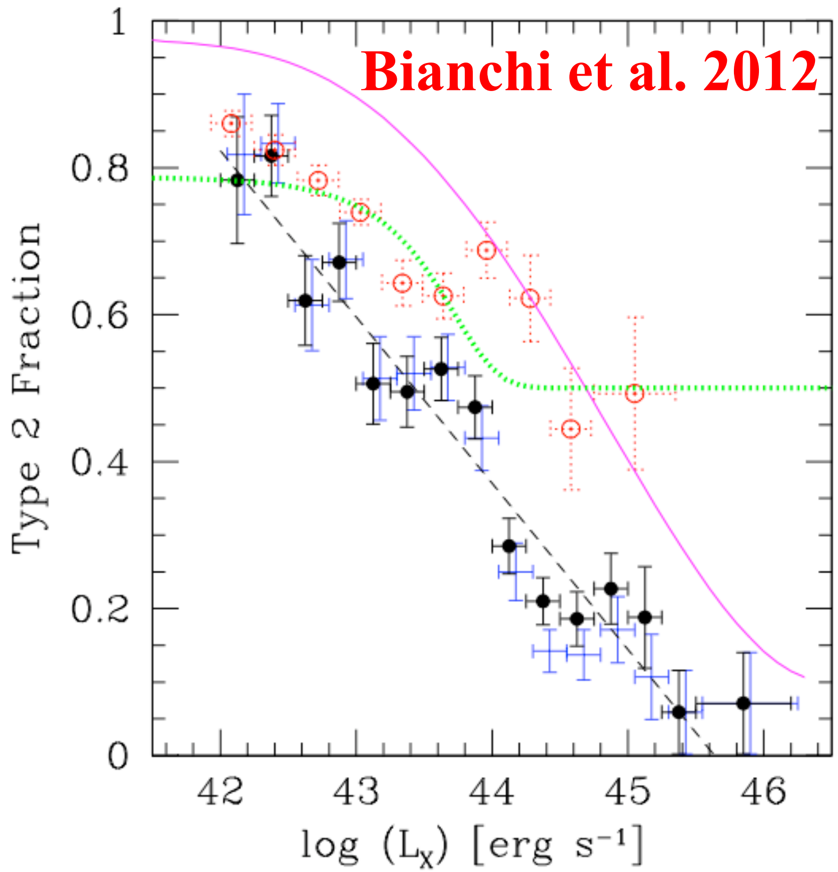


Figure 8: *Fraction of type 2 AGN as a function of X-ray luminosity (from Hasinger [132]). The solid symbols show hard X-ray selected AGN (blue and black symbols illustrate different sub-samples in terms of redshift completeness). The red dotted symbols show optically selected AGN (from Simpson [128]). The magenta line shows the type 2 fraction inferred from the dust covering factor obtained through near/mid-IR observations (from Maiolino et al. [135], note that these include also Compton-thick AGN, which are not present in X-ray samples). The green dotted line shows the expected fraction of Compton-thin type 2 AGN according to the X-ray background synthesis models given in Gilli et al. [136]).*

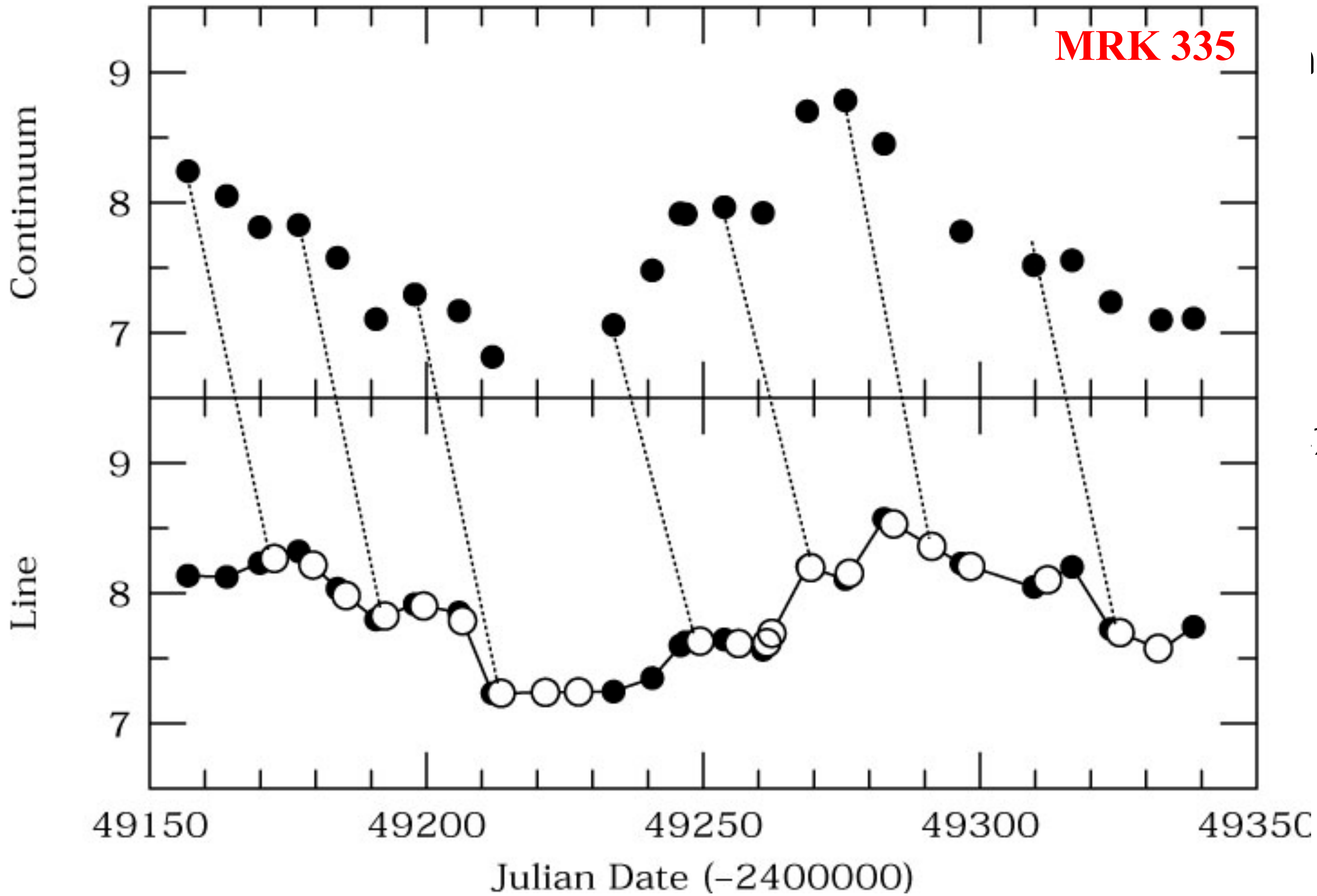
AGN masses

- Estimated through the virial theorem applied to the broad line clouds
- $\langle T \rangle = -\langle U \rangle/2$: $mv^2/2 = GmM/2r \rightarrow M = rv^2/G$
- Two parameters needed:
  - ✓ velocity → from Doppler line broadening
  - ✓ distance → through "reverberation mapping"
- Bound motion *required*: rv^2=const → $v \propto r^{-1/2} \propto \tau^{-1/2}$

$$M = f\frac{rv^2}{G}$$

- Mass range: $10^6 - 10^9$ Mo
- Almost always $L \lesssim L_{Edd}$

AGN masses



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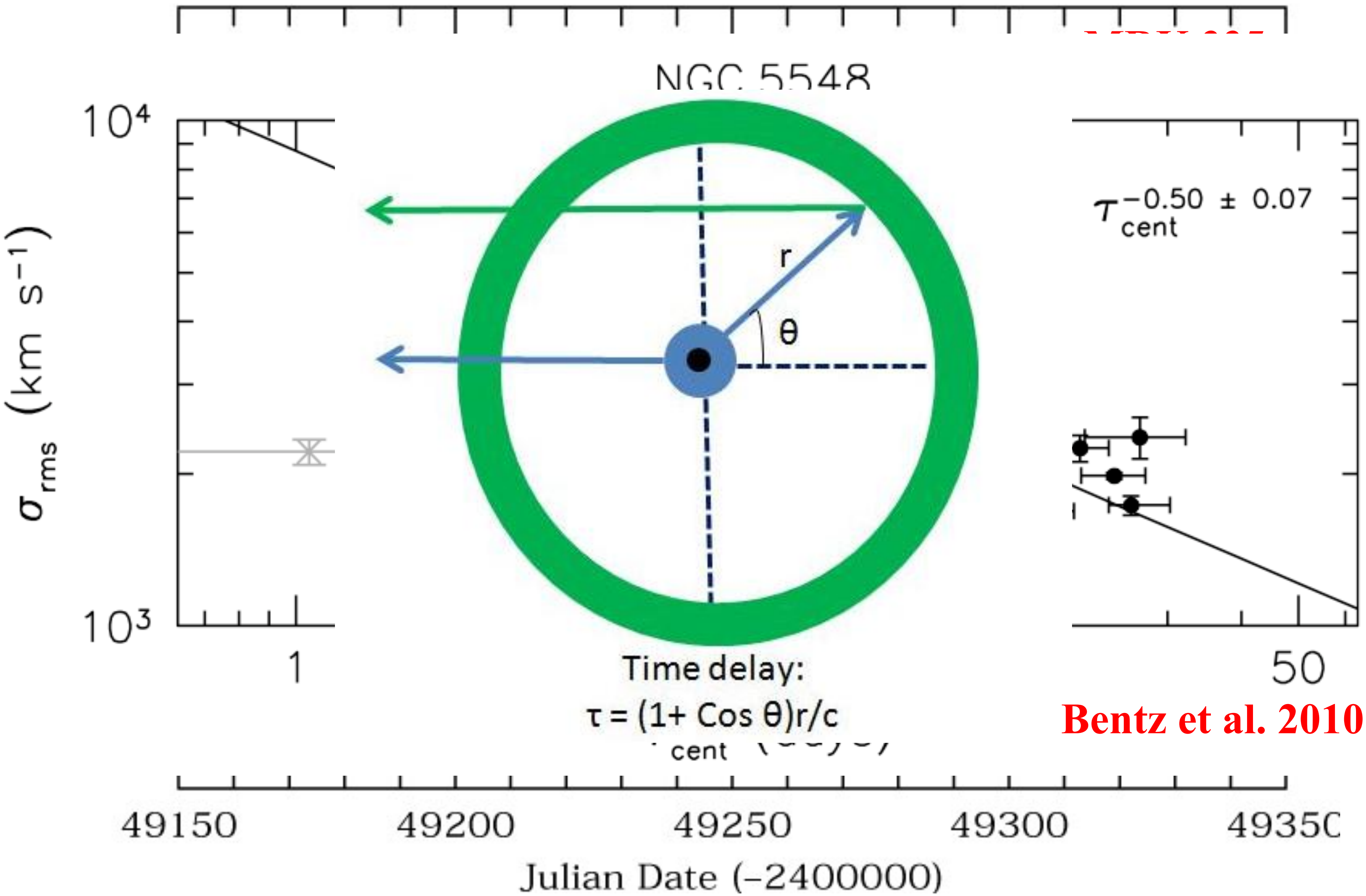
Peterson 2001

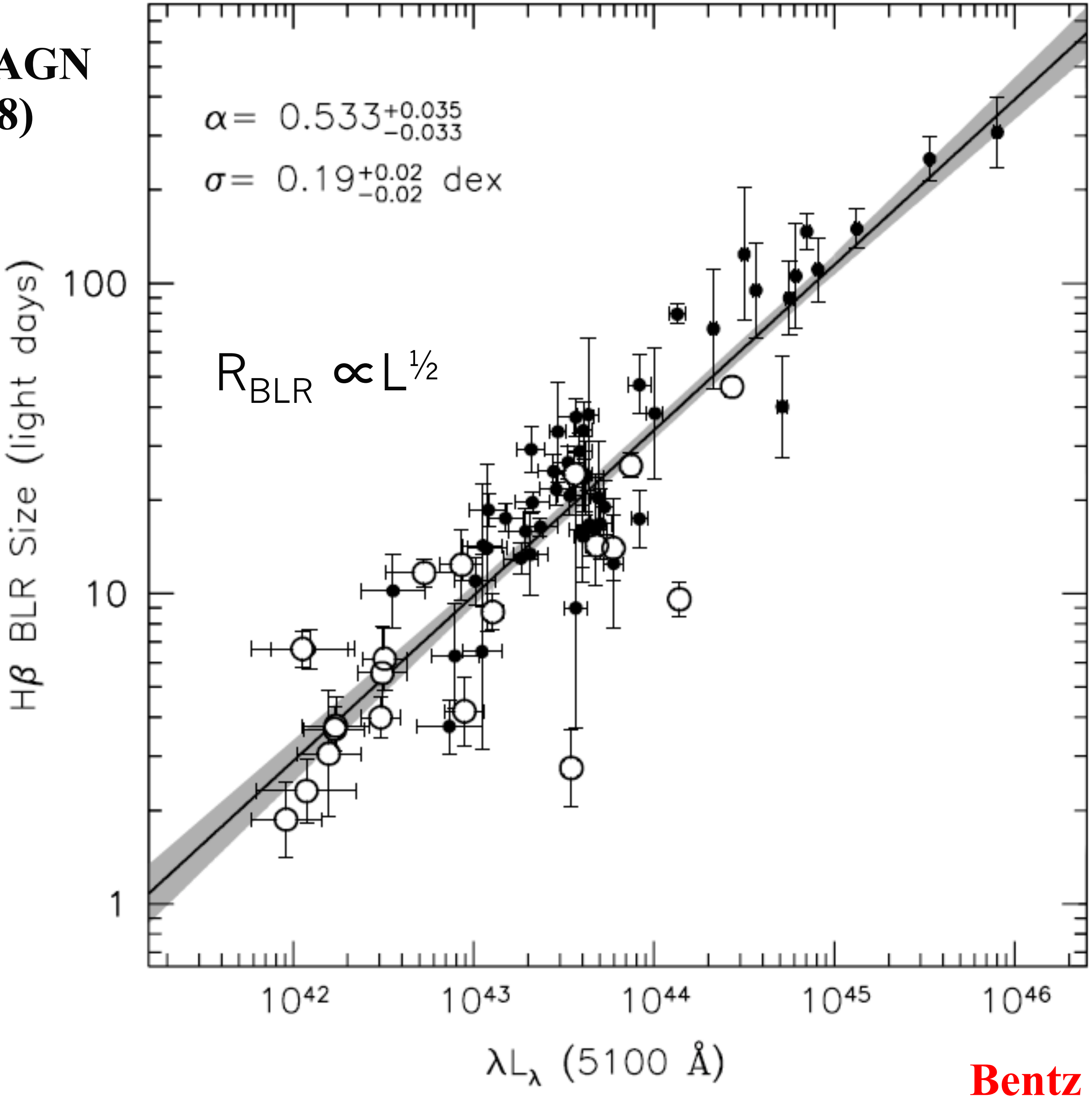
AGN masses



Bentz et al. 2010

Peterson 2001

41 local AGN
($z \leq 0.158$)



Bentz et al. 2013

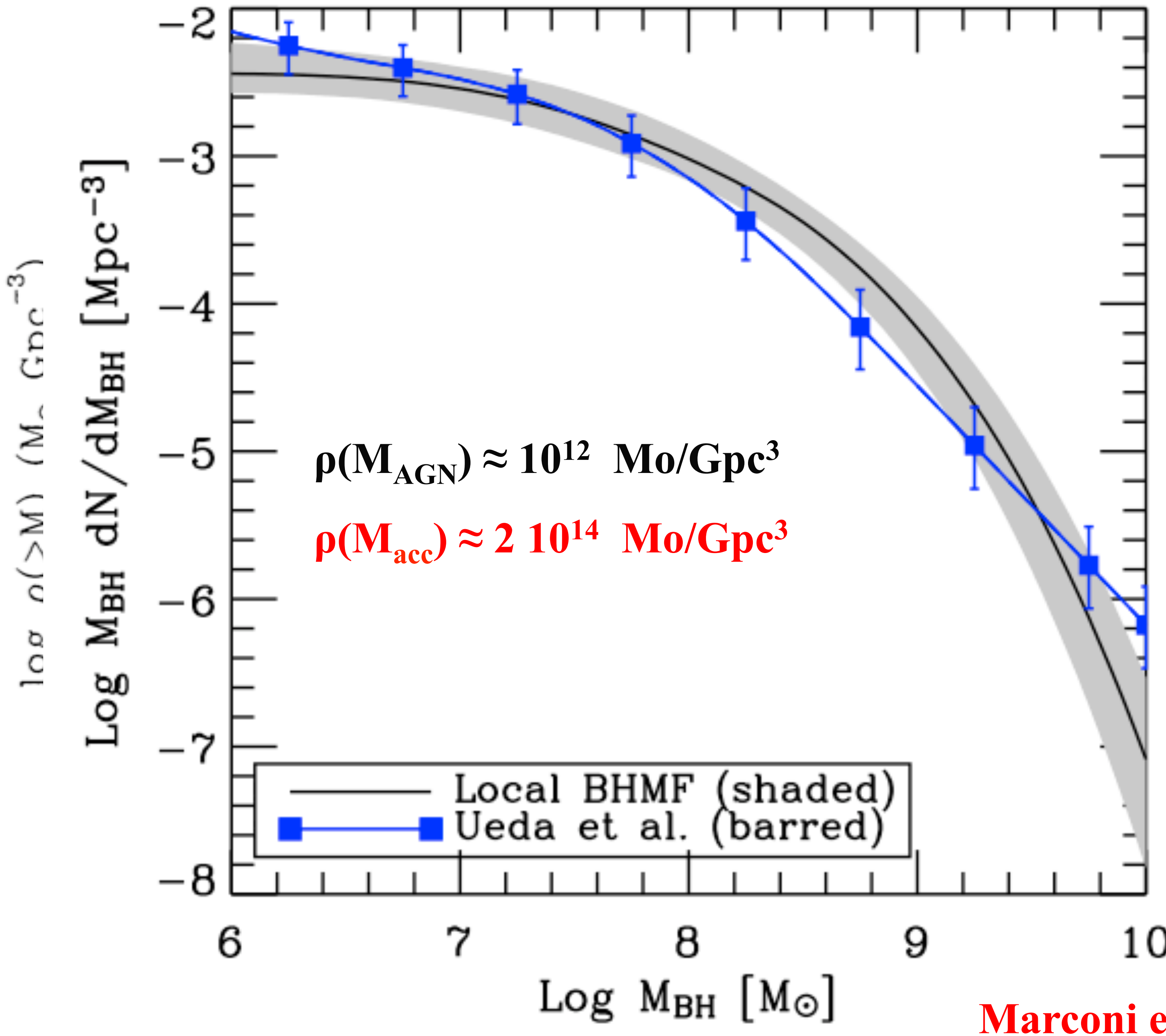
AGN physical evolution. 1.

$$M = \int \dot{m}\, dt + M_i = \frac{(1-\eta)}{\eta c^2} \int L(t)\, dt + M_i$$

$$M \cong 1.6\ 10^9 \frac{(L_{bol}/10^{46})(\Delta T / Gyr)}{(\eta / 0.1)} M_\odot + M_i \quad (L = const.)$$

$$3C273 \qquad M \approx 10^9 M_\odot \;\&\; L_{bol} \approx 10^{47} erg/s \rightarrow \Delta T < 6\ 10^7\ yr$$

- Large AGN samples indicate activity times ≈ a few % of the Hubble time (Cavaliere & Padovani 1989)



2)

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990

Marconi et al. 2004

Things to remember

- *AGN are powered by black holes*
- *Accretion power peaks in the UV band*
- *The radio-loud – radio-quiet AGN distinction reflects different ratios of jet (non-thermal)/disk (thermal) power*
- *The profusion of AGN classes is an illusion (mostly) due to the non-spherically symmetric inner structure of AGN*
- *Know your AGN classes (please!!!)*
- *Jets in blazars are moving close to c and to the line of sight (relativistic beaming)*
- *AGN have been active only for a small fraction of the life of the Universe*
- *Most bright galaxies have been through an AGN phase*