The History and Basic Properties of Quasars

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Outline

- Discovery and history
- Basic Properties
  - Luminosities
  - Radio Emission
  - SEDs: radio to gamma rays
  - Spectra
  - Masses
  - Taxonomy
  - Conceptual model

References

- Bradley Peterson 1997, “An Introduction to Active Galactic Nuclei” (excellent text)
- Robinson, Schild, and Schucking 1965, “Quasi-stellar Sources and Gravitational Collapse” (Proc. of 1st Texas Symposium)
- 2005 Elba conference on “Superunification of Active Galactic Nuclei,” (current status) http://www.arcetri.astro.it/~agn2005/

History: Quasars

- 1963, Identification of 3C273
  - Work of Schmidt, Hazard, others
  - 3C273 distinctive for its high redshift, inferred luminosity ($100 \times L_{\text{Milky Way}}$), star-like nature
- Quasars: "Starlike objects of large redshift," early definition by Schmidt, still conceptually useful

History: Seyfert Galaxies and Active Galactic Nuclei

- It was later realized that galaxies with bright, compact nuclei showing high-excitation, broad emission lines had been discovered much earlier (e.g., Fath 1908, Seyfert 1943)
- Now understood to be lower luminosity versions of quasars
- Today, “Active Galactic Nuclei (AGN)” refers to the whole class of objects

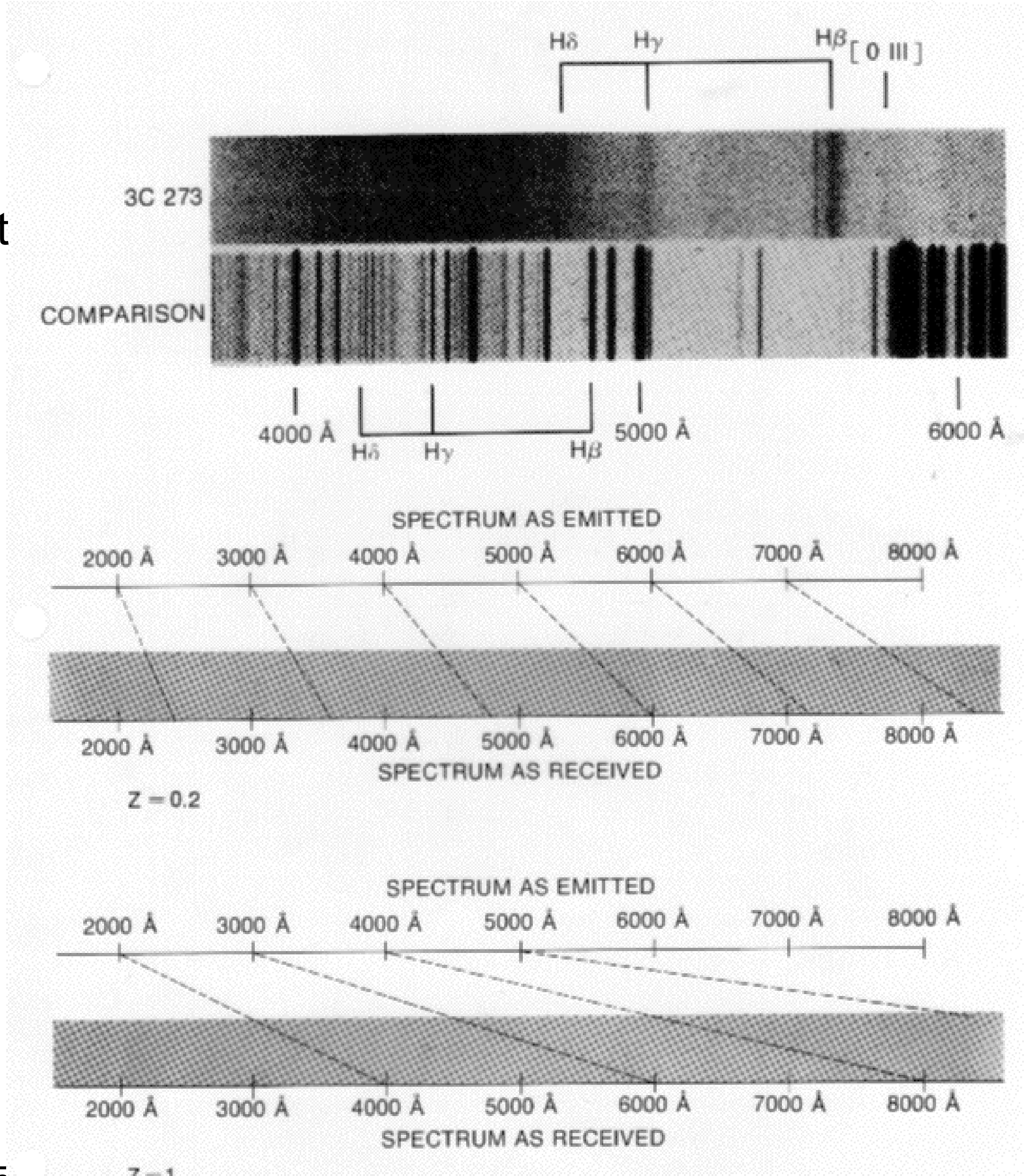
History: Radio Sources

- Discovery of extragalactic radio sources, e.g., Cygnus A (Bolton & Stanley 1948; Baade & Minkowski 1954)
- Recognition of the energy problem, Burbidge (1958-59): up to 10^{60} ergs in radio lobes, far more than could be accounted for by normal sources
- Increasing accuracy of radio source positions, identification of 3C273 from lunar occultation (Hazard, Mackey, Shimmins 1963)

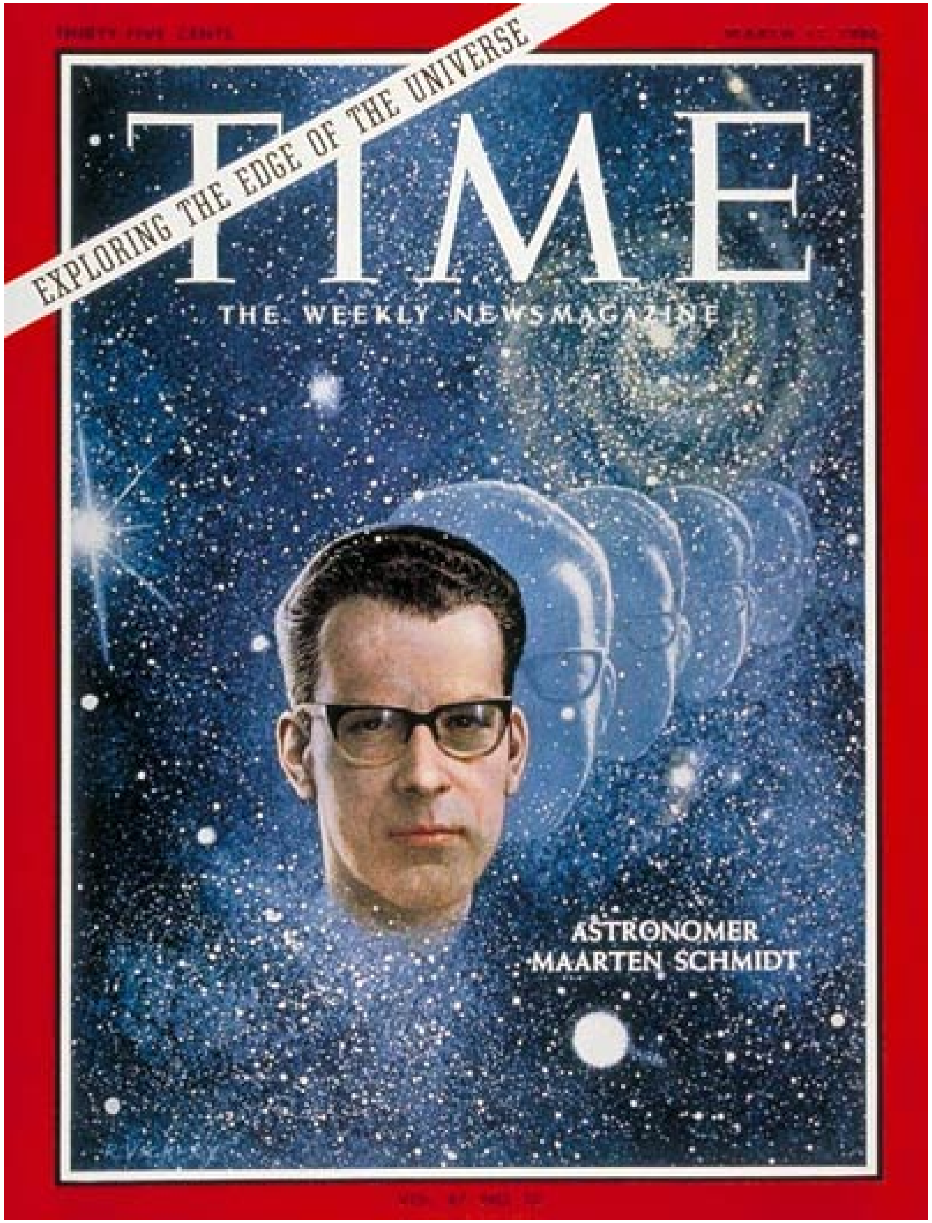
Quasars: The Breakthrough and Mystery

- Schmidt (1963) realizes 3C273 has redshift = 0.16
  - If cosmological, 3C273 has 100× luminosity of Milky Way, but looks starlike
  - Furthermore, Smith and Hoffleit (1963) find it to vary on timescales of months
- Mystery – how to produce so much luminosity in such a small volume?

Spectrum of 3C273 from which its redshift was found (Schmidt)



Time Magazine
1966



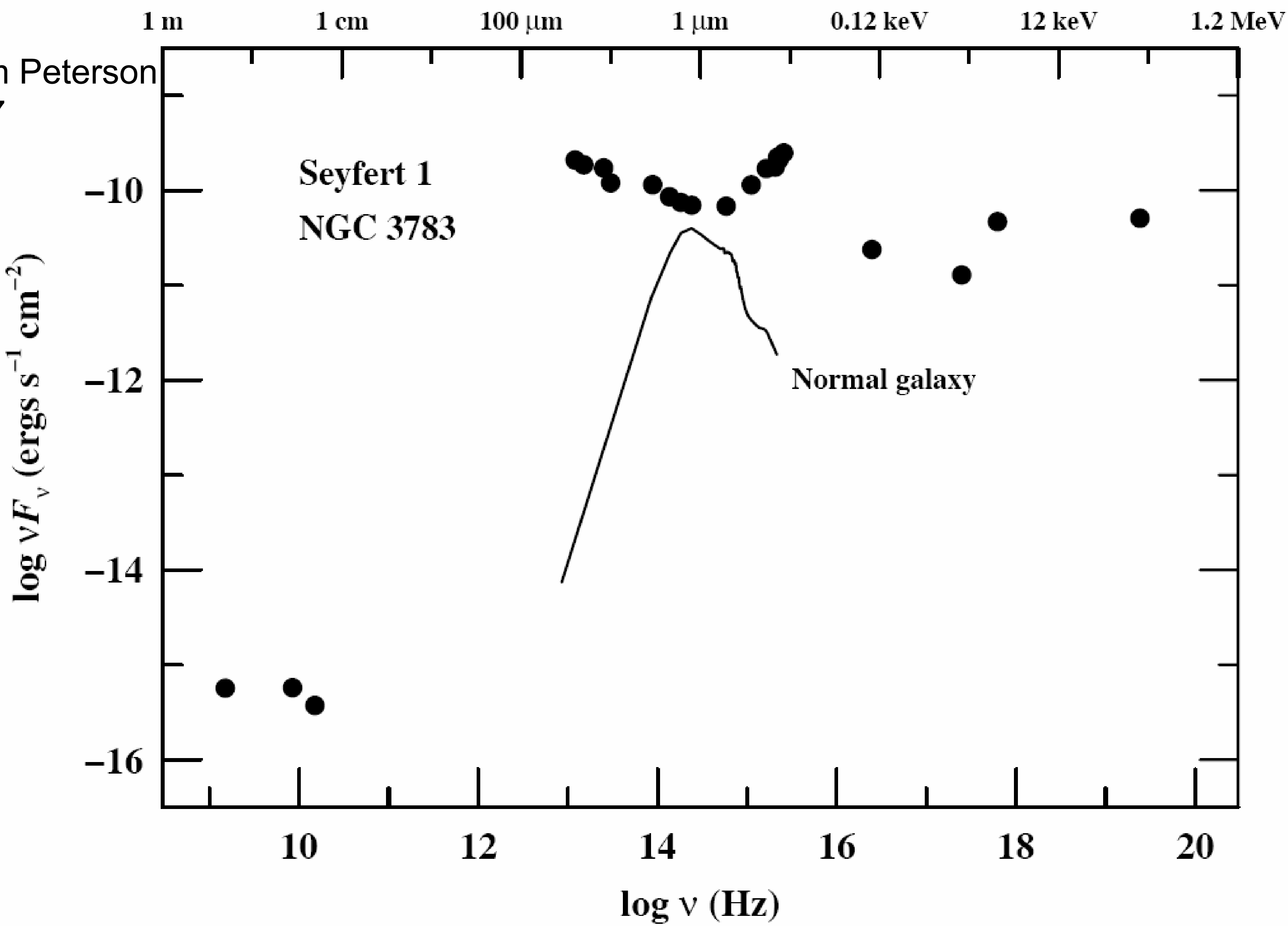
Gravitational Energy to the Rescue

- Thermonuclear reactions in stars are insufficient
- Within the first year Zeldovich & Novikov (1964) & Salpeter (1964) realized that accretion onto a massive compact object could liberate 10% of the rest energy of material falling toward a compact object (today, black hole)

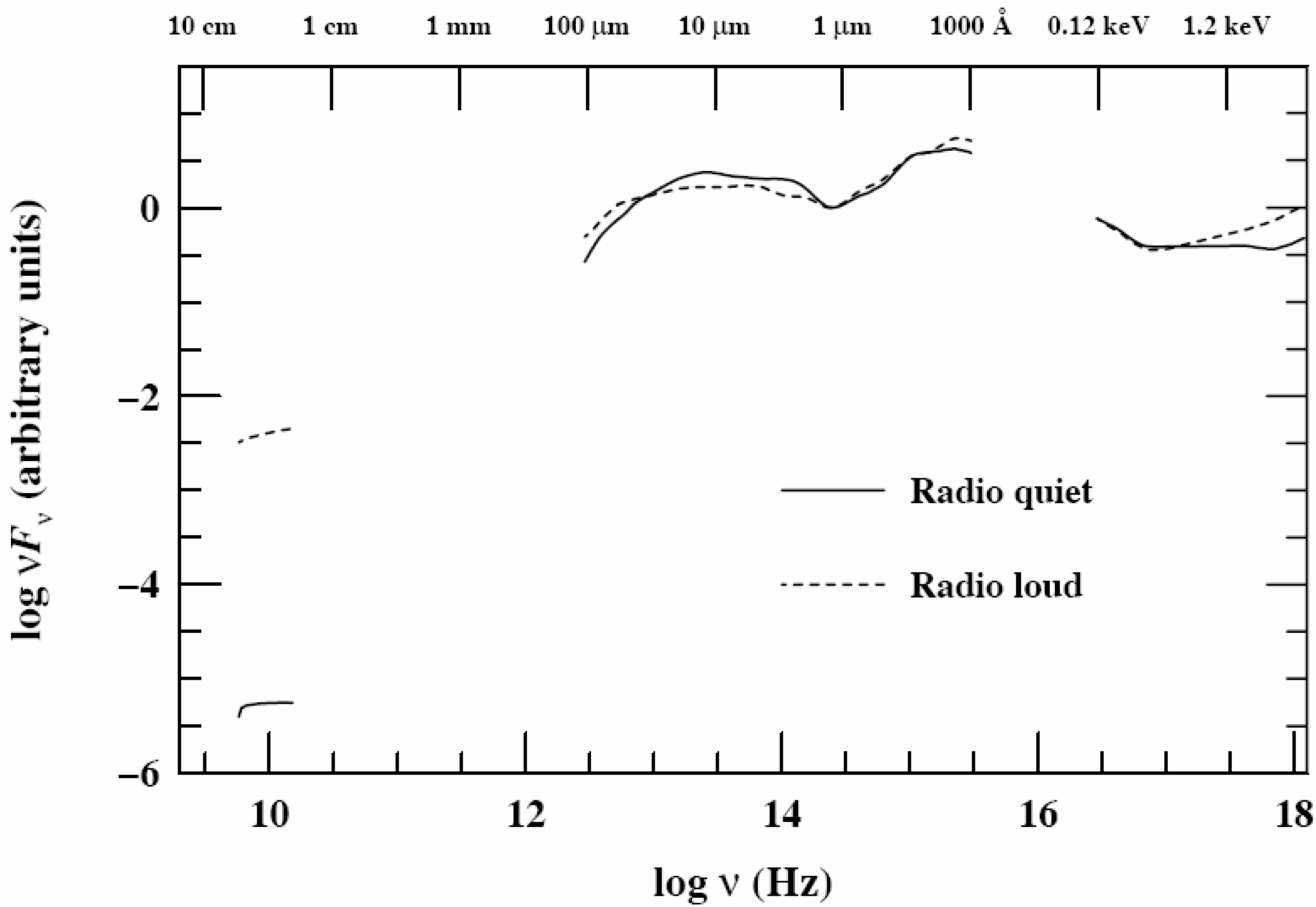
Properties of Quasars

- Schmidt definition (updated to present)
  - Star-like object, sometimes identified with radio source
  - Variable continuum flux (days to months)
  - Large UV flux (compared to most stars)
  - Broad emission lines ($\geq$ 5000 km/s FWHM)
  - Large redshifts ($z \leq 6.4$)
  - X-ray sources (may be the key property)

From Peterson 1997



Spectral Energy Distributions, from Peterson 1997; data from Elvis et al. 1994



From Risaliti & Elvis 2004

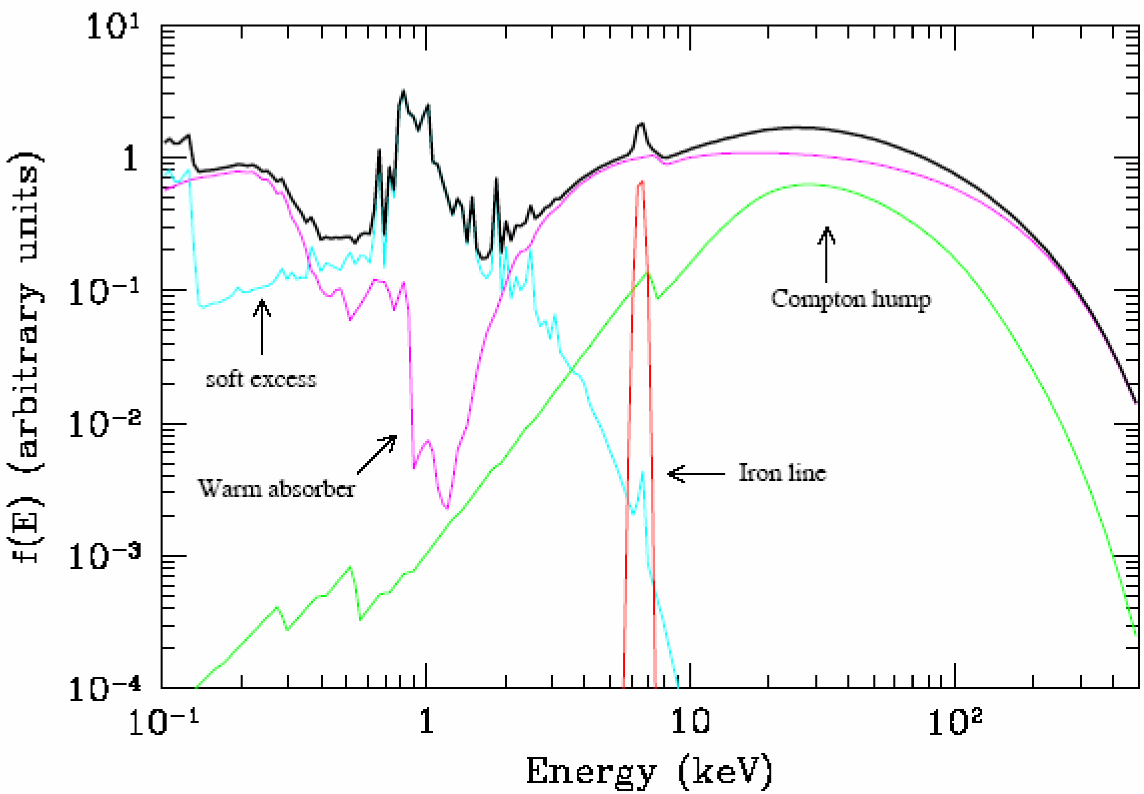
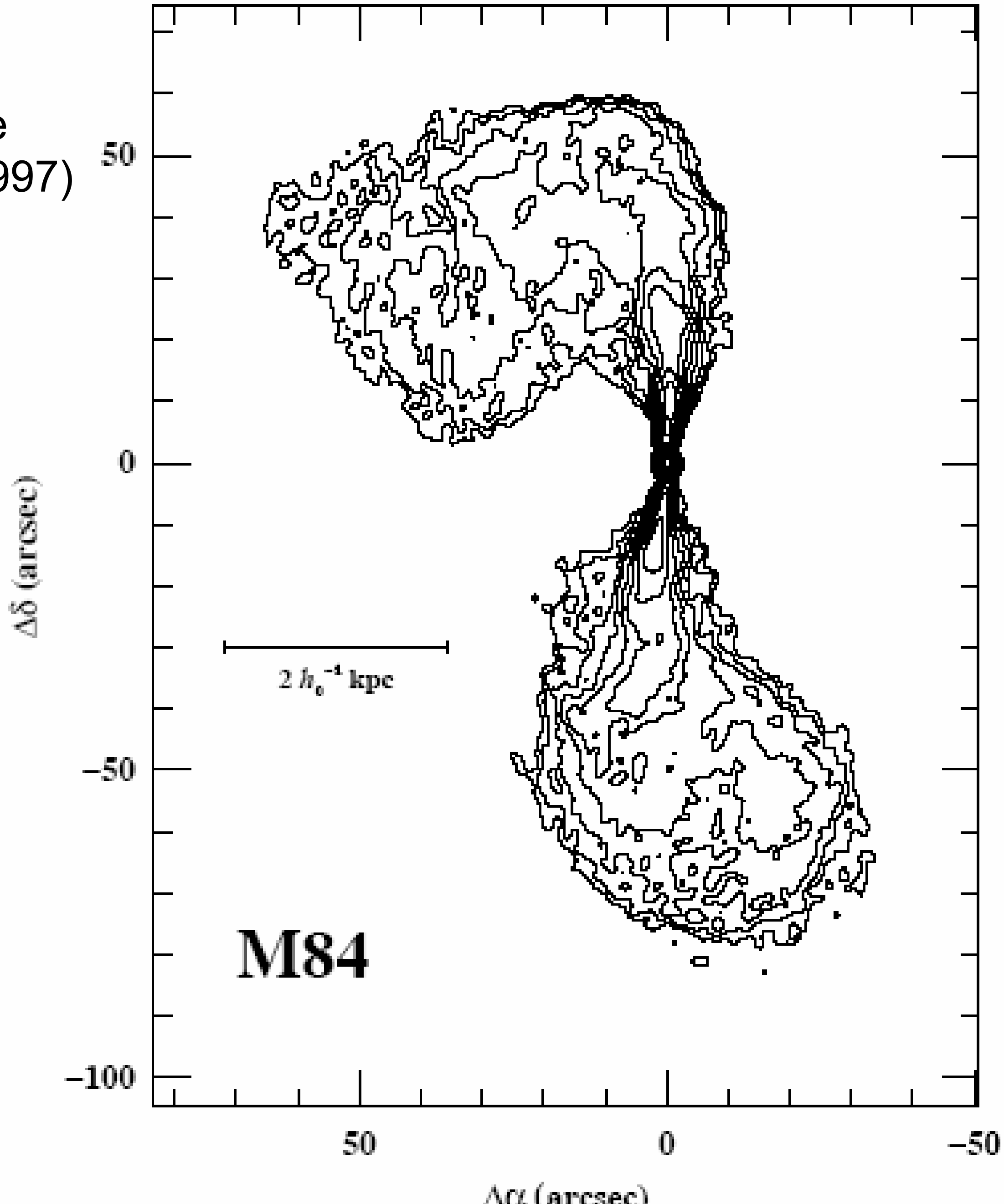
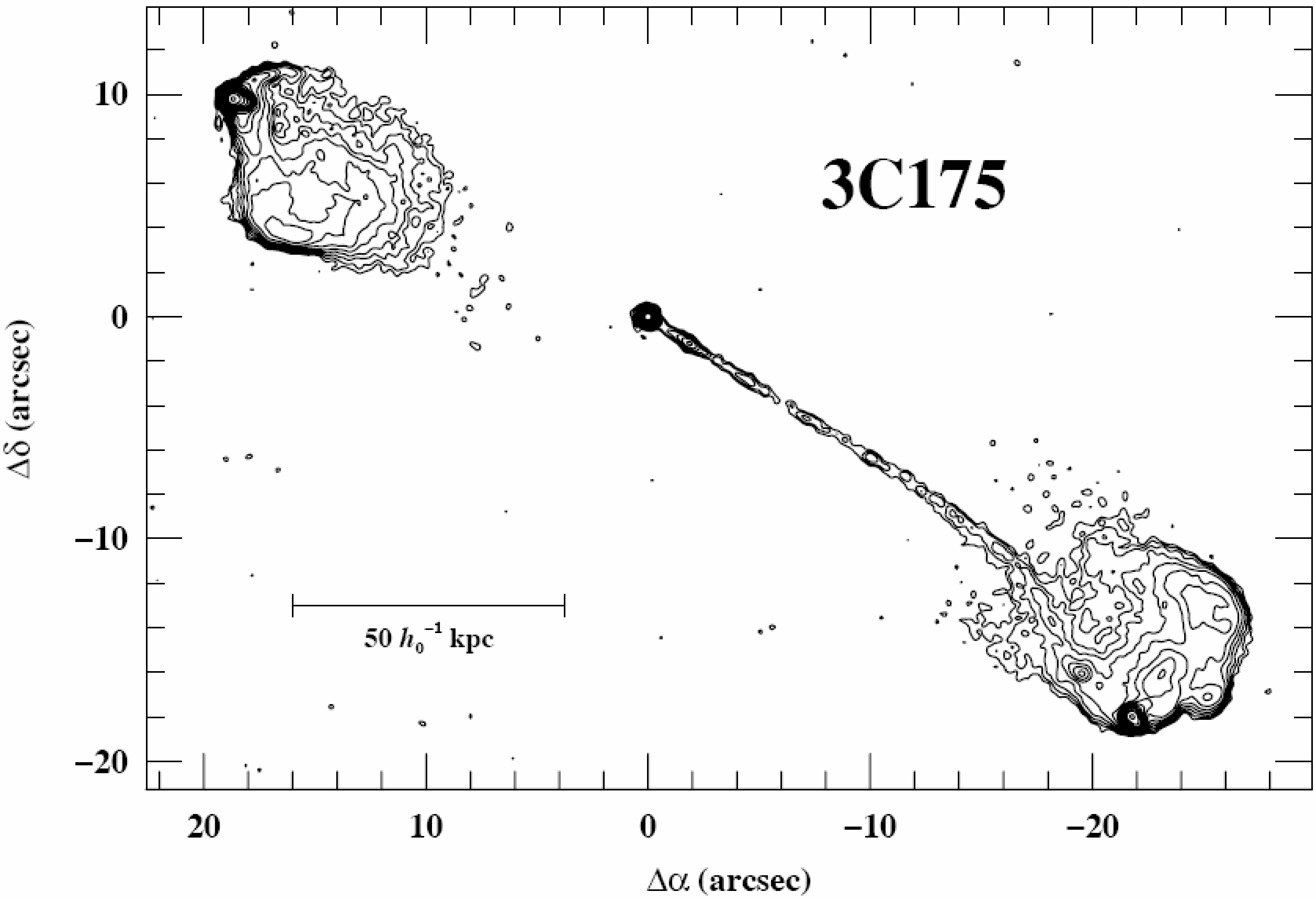


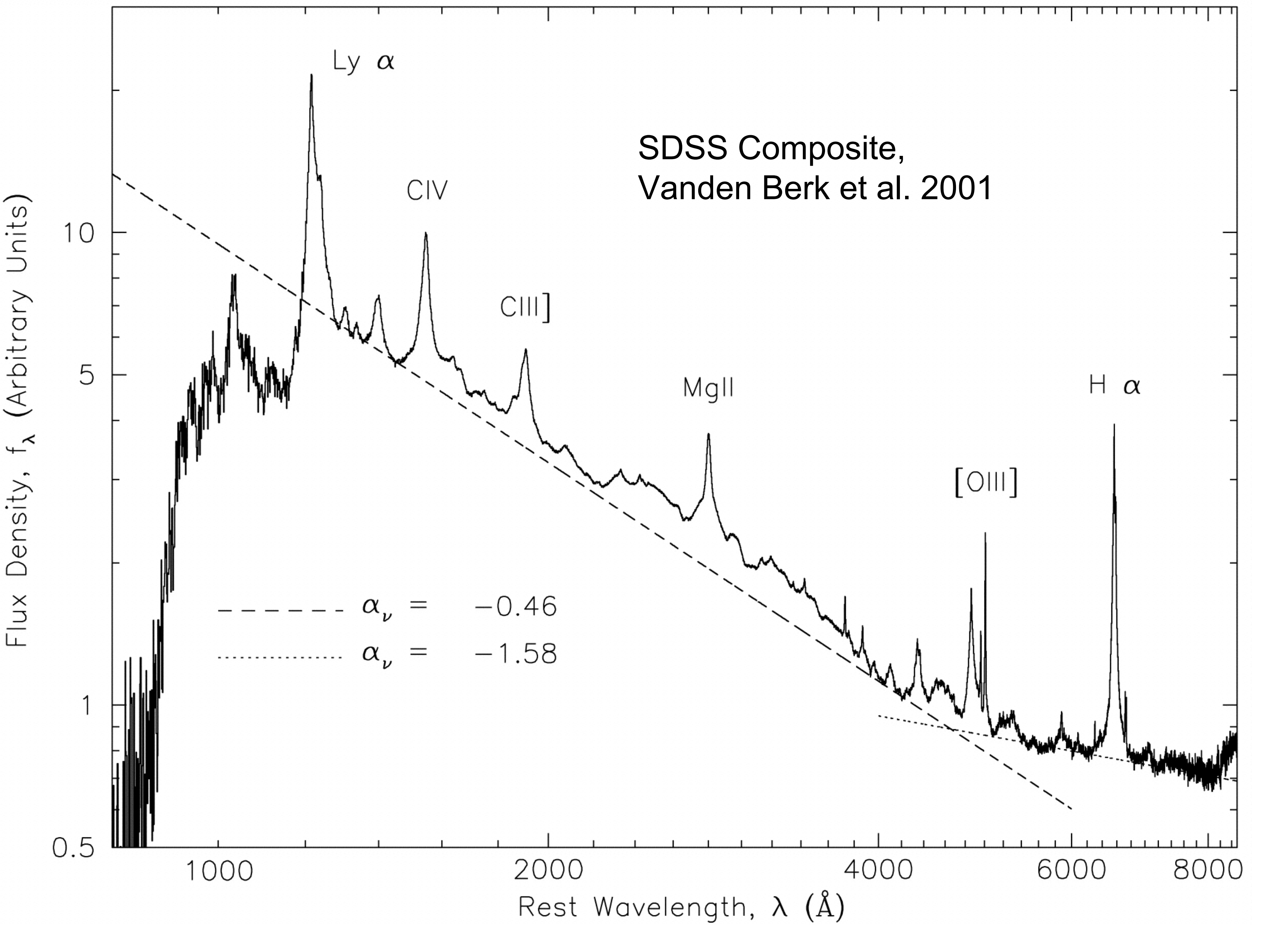
Figure 6.3. Average total spectrum *(thick black line)* and main components *(thin grey lines)* in the X-ray spectrum of a type I AGN. The main primary continuum component is a power law with an high energy cut-off at E$\sim$ 100$-$300 keV, absorbed at soft energies by warm gas with $N_H \sim 10^{21} - 10^{23}$ cm^{-2}. A cold reflection component is also shown. The most relevant narrow feature is the iron Kα emission line at 6.4 keV. Finally, a "soft excess" is shown, due to thermal emission of a Compton thin plasma with temperature $kT \sim 0.1 - 1$ keV.

FRI Radio Source
(from Peterson 1997)

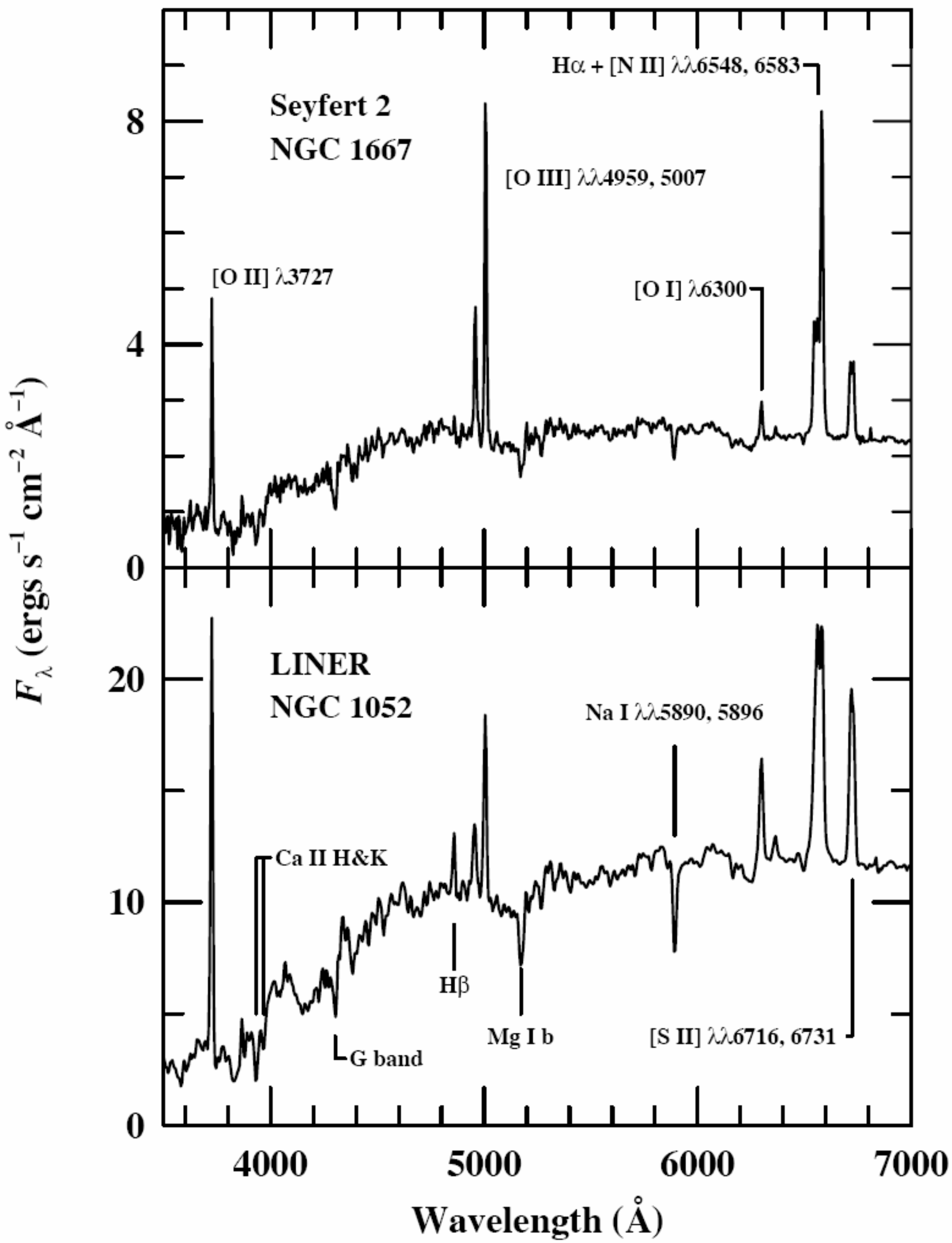


FRII Radio Source, from Peterson 1997




Ly α
CIV
CIII]
MgII
H α
[OIII]
SDSS Composite,
Vanden Berk et al. 2001
Flux Density, f_λ (Arbitrary Units)
10
5
1
0.5
α_ν = −0.46
α_ν = −1.58
1000
2000
4000
6000
8000
Rest Wavelength, λ (Å)

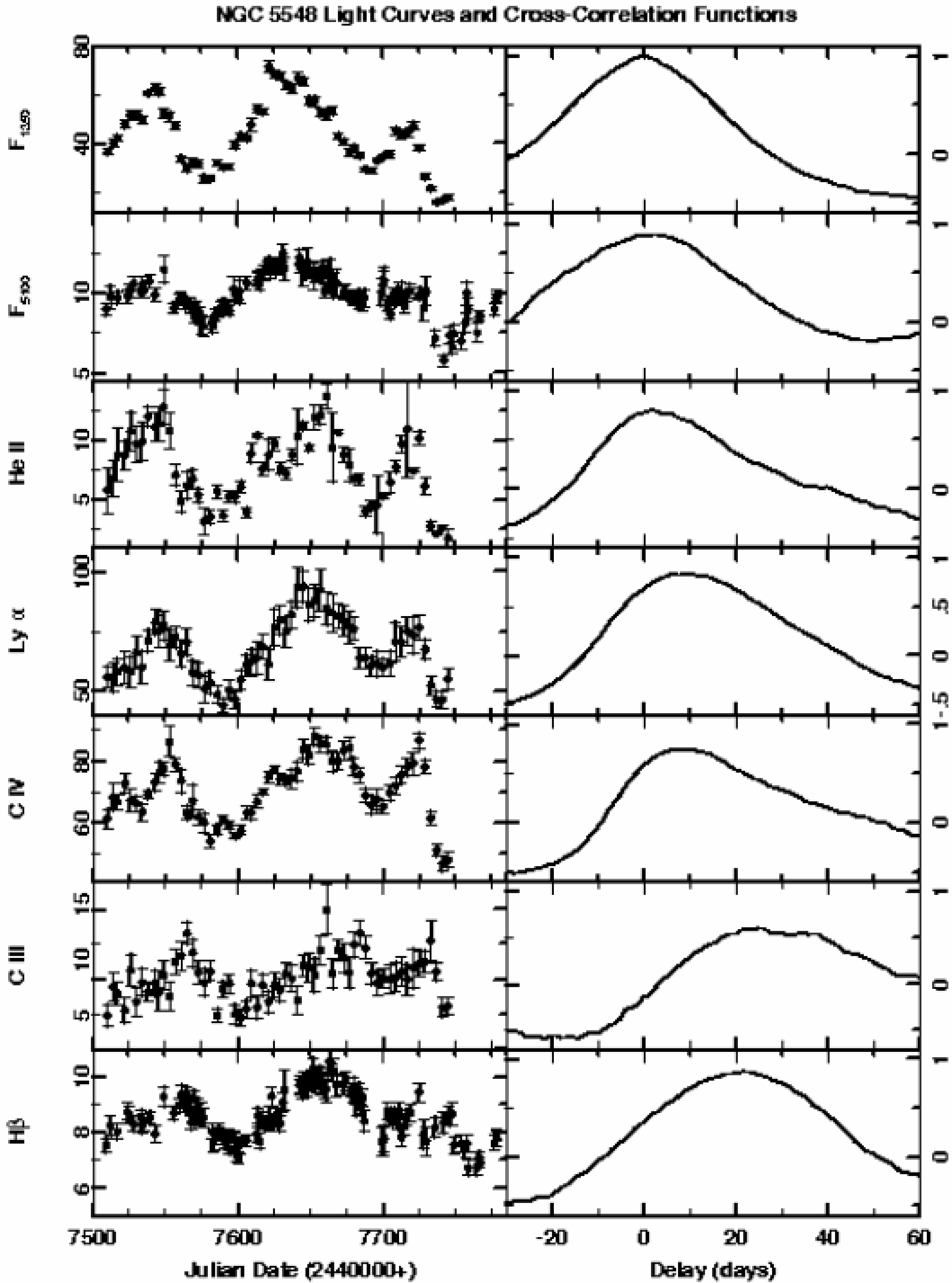
From Peterson 1997



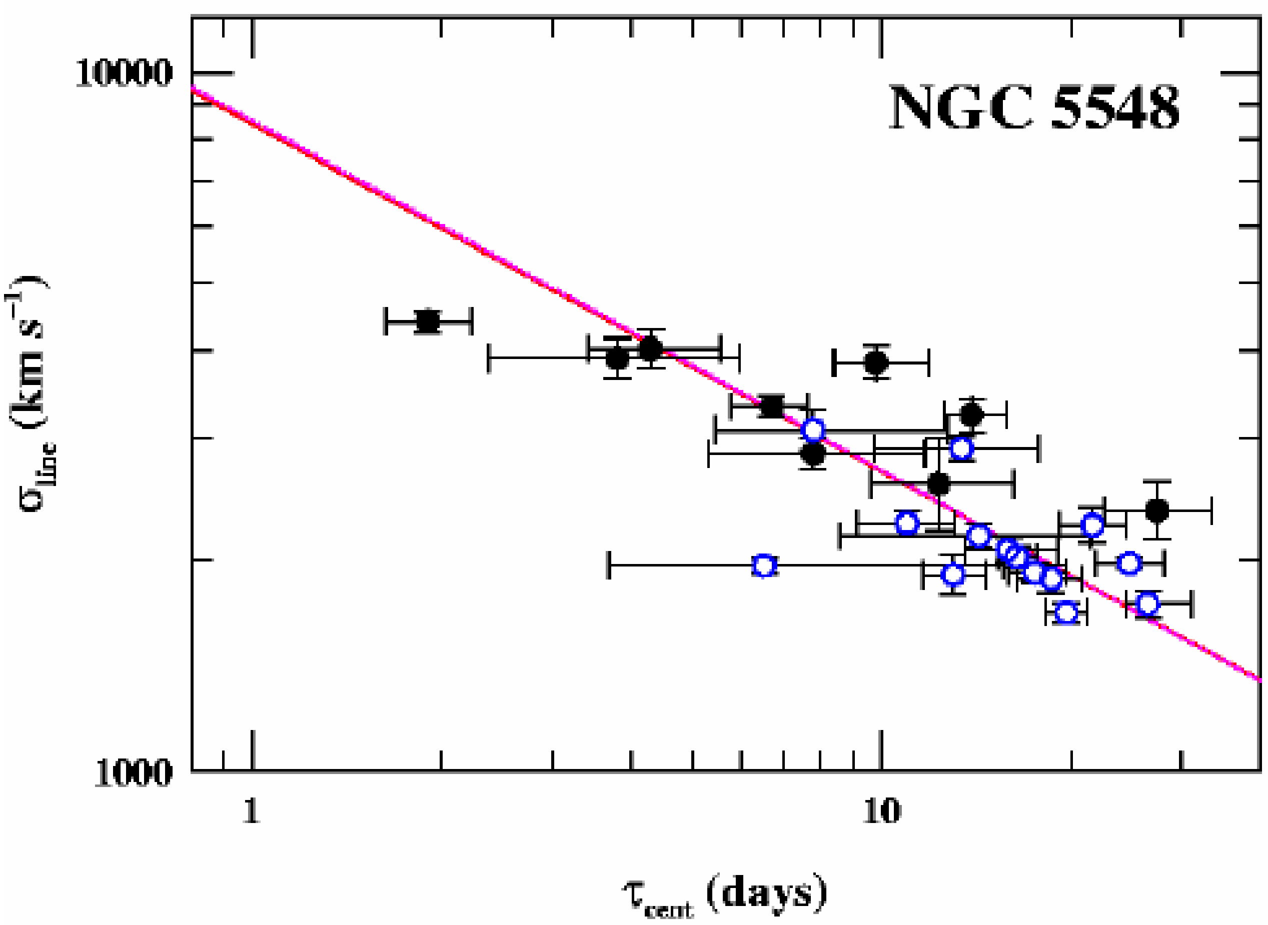
Mass Estimates

- Woltjer (1959), Seyfert Galaxies
  - Applied virial argument, $M \approx v^2 r / G$
  - Leads to values of about 10^9 solar masses
- Peterson (see Elba conference), Reverberation mapping
  - Use "light echo" concept to determine size of emission-line region
  - Combine with spectra and above virial argument
  - Modern values of 10^{7-9} solar masses, depending on the object

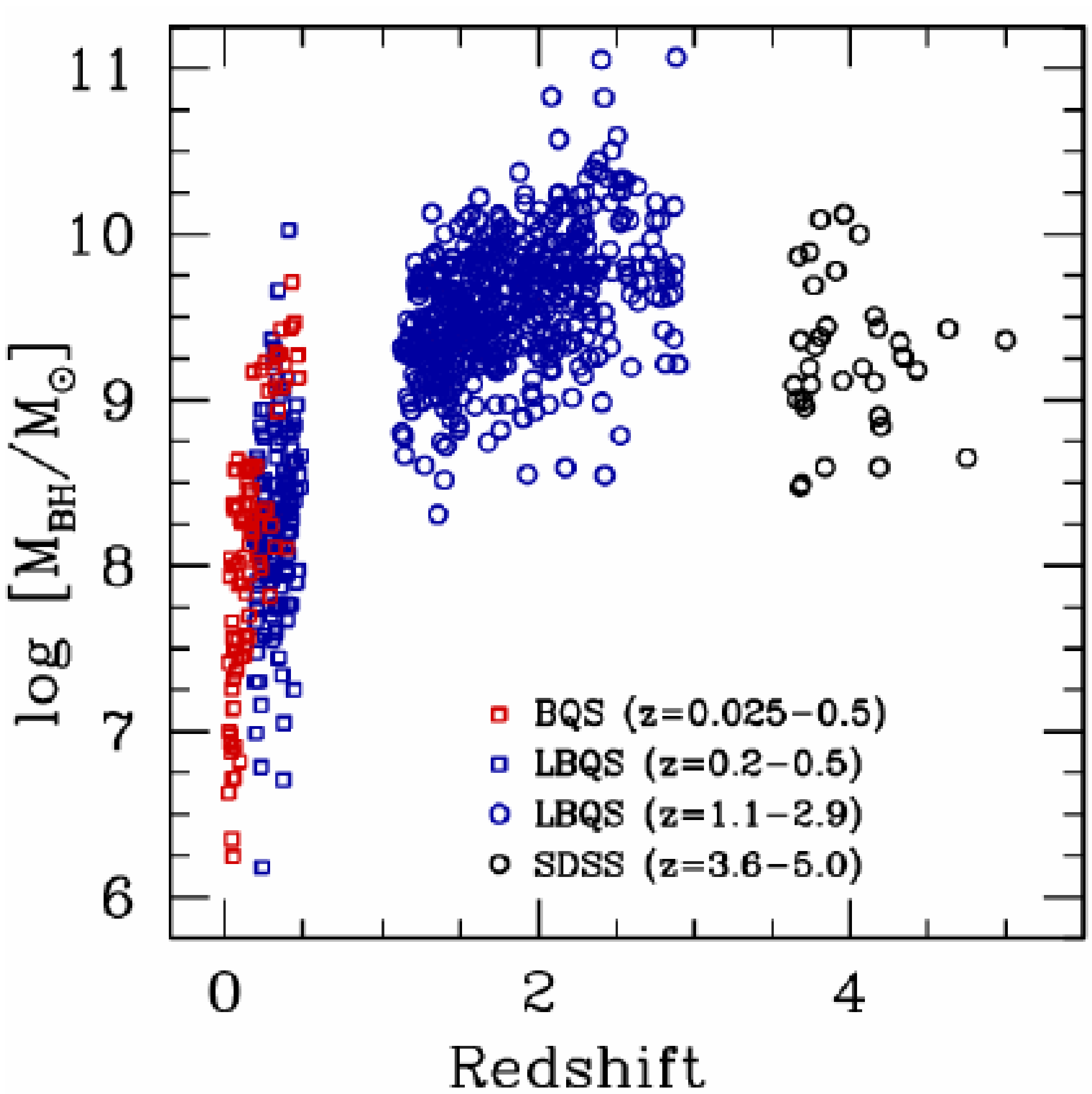
Peterson 2005
Elba conf



Peterson 2005



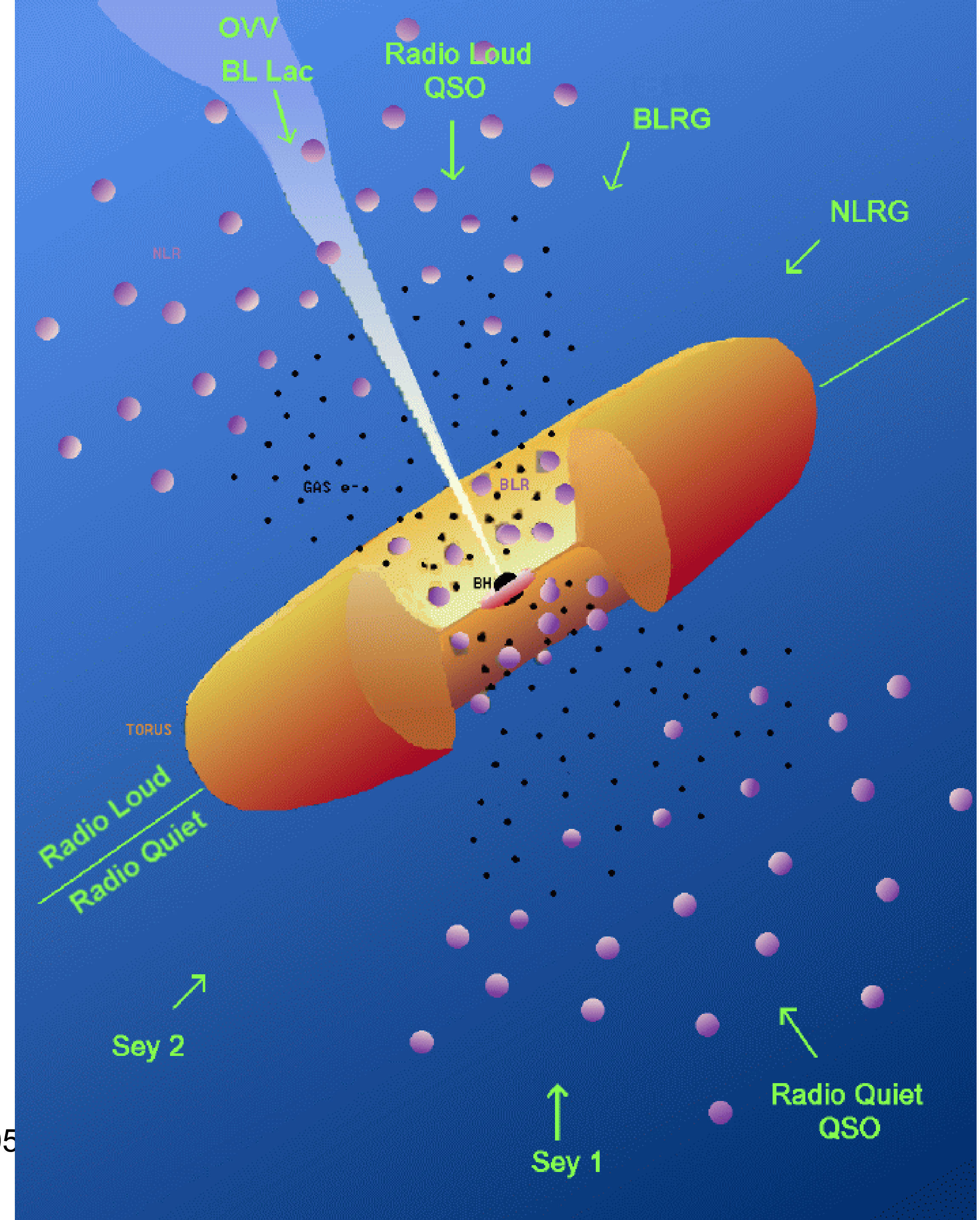
Vestergaard 2005
Elba conf.



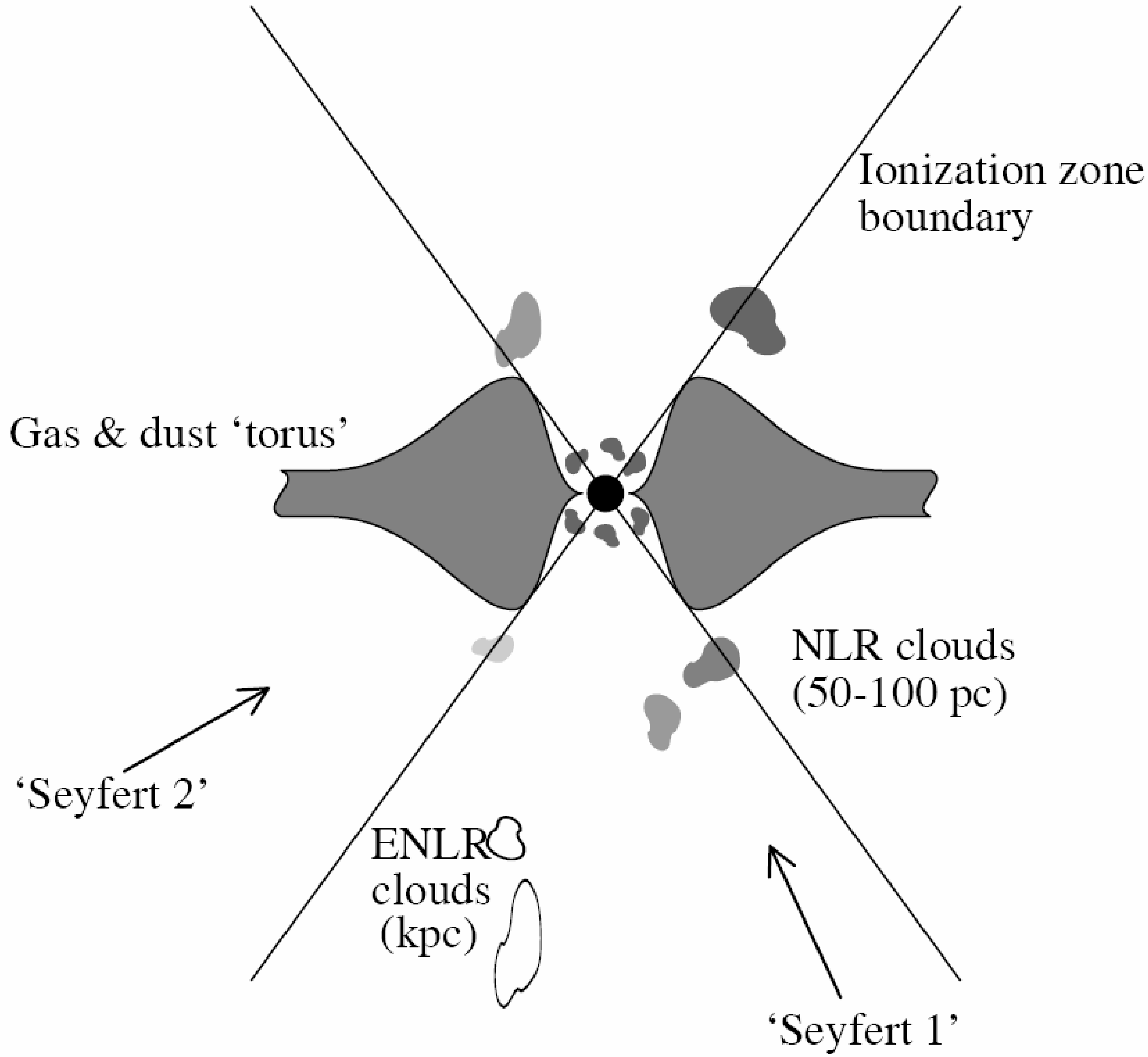
Taxonomy

- AGNs: Objects powered by accretion onto supermassive black holes
- Quasars: AGNs with $M_B < -23$, $L_X > 10^{44}$ erg/s
- Seyfert Galaxies: AGN with lower luminosities than quasars, visible hosts
  - Seyfert 1s: Broad permitted emission lines, narrow forbidden lines
  - Seyfert 2s: No broad permitted emission lines

Schematic model of AGN (Urry & Padovani 1995)



Conceptual model of AGN, from Peterson 1997



Summary

- Advances in radio astronomy led to discovery of quasars
  - even though their radio output is a small fraction of their total luminosity
  - even though radio is at the low end of the electromagnetic energy spectrum, radio emission was produced by the synchrotron mechanism and opened up the field of high-energy astrophysics

- Lessons still valid today:
  - Observations in new wavelength region led to discovery of new phenomena in the universe
  - Accurate positions, observations at other wavelengths needed to identify and characterize the new objects
  - Concurrent advances in theory produced understanding of the nature of the objects

- Discovery of quasars changed our view of the universe
  - Opened up study of distant universe
  - Led to the realization that massive black holes exist in the universe
  - Gravitational energy as source for quasars and all AGNs