Active Galactic Nuclei: An Overview

Seminar

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Outline

- AGN - Definition & Characteristics
- How do we detect them?
- Classification …
- Unification model
- Observational survey
- Summary

Black Hole

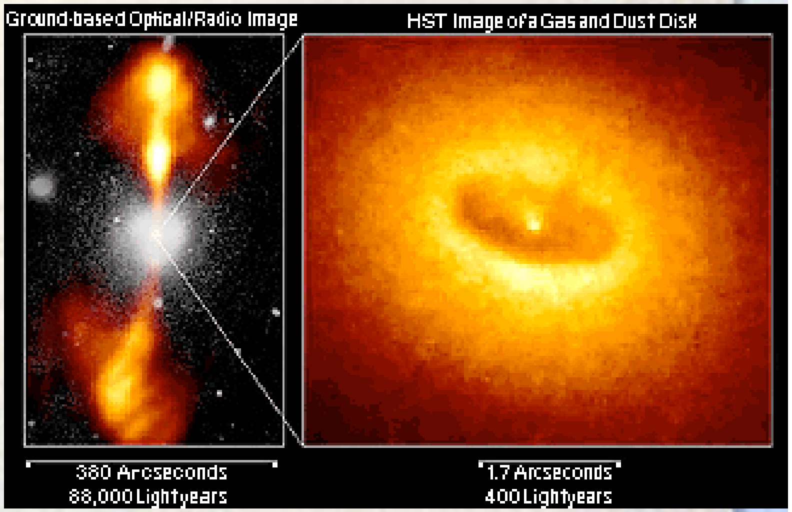
- An object smaller than its Schwarzschild radius
  - r_{Sch} (Sun) = 3 km
  - r_{Sch} (Earth) = 9 mm

$$r_{Sch} = \frac{2GM}{c^2}$$

- Supermassive (SMBH) at the center of AGN
  - $M_{BH} > 10^6\ M_{\odot}$
- How do we detect a SMBH?
  - Broad emission lines
    - Large velocity of gas
    - Gravitationally redshifted lines
  - Relativistic bulk motion in radio jets
  - Large velocity of stars toward the region of BH
  - Power emitted can be 10^{48} erg s^{-1} $\Rightarrow$ ~40% efficient accretion to convert rest mass into energy

What are AGN?

- A galaxy nucleus which shows evidence for accretion onto a supermassive black hole
- Active nucleus ⇒ Central region radiates more energy than all the stars in the whole galaxy
  - Seyferts: $10^{10} – 10^{11}\ L_{\odot}$
    $L_{Sy} \approx 10^{44}$ erg s^{-1}
  - Quasars: 10 – 1000 x brighter
    $L_{QSO} \approx 10^{46}$ erg s^{-1}



- Very high bolometric luminosity
  - Not normal evolution of stars
  - Release of gravitational energy by accretion onto SMBH
- Observed up to large distances

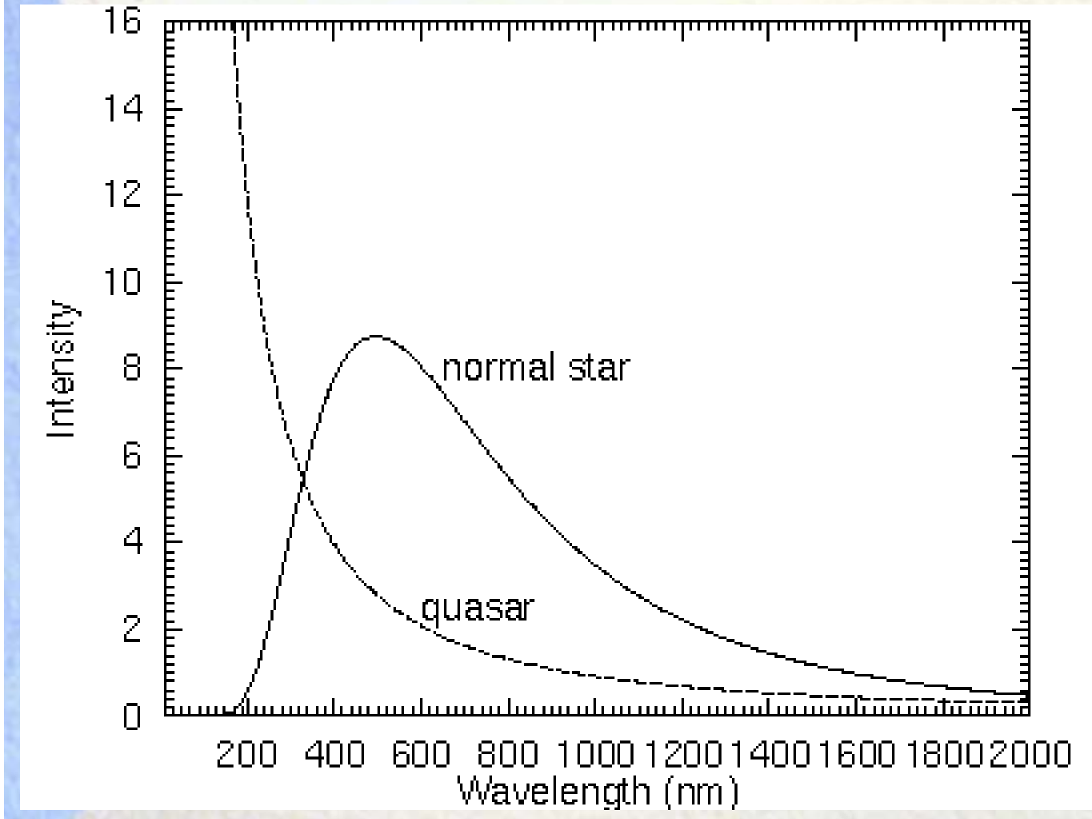
Units

- 1 pc (parsec)
  $= 3.26$ light-years
  $= 3.09 \times 10^{18}$ cm
  $= 2.06 \times 10^{5}$ a.u.

- Mass of Sun = $M_{\odot} = 1.99 \times 10^{33}$ g

- Luminosity of Sun = $L_{\odot} = 3.83 \times 10^{33}$ erg/s

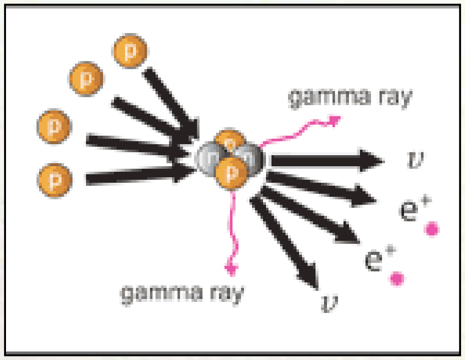
AGN has Non-Thermal Spectrum



- Luminous in the X-rays, UV, visible, IR, radio wavebands
- The spectrum looks like the synchrotron radiation from charged particles spiraling around magnetic field lines at relativistic speeds

Energy Comparison

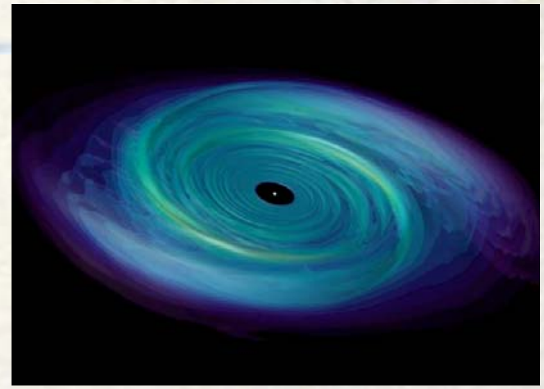
Nuclear Fusion



$$\Delta E_{nuc} = 0.007 mc^2$$

- H ⇒ He
- $\Delta E_{nuc} \sim 6\times10^{18}$ erg g^{-1}

Gravitational Accretion



$$\Delta E_{acc} = E_{grav\ P.E.} = \frac{GMm}{R}$$

- In a neutron star with
  - R ~10 km
  - M ~M$_\odot$
- $\Delta E_{acc} \sim 10^{20}$ erg g^{-1}

Eddington Limits for a BH

- For stability, inward gravitational force must exceed outward radiation force
- Eddington Luminosity: Upper limit to the luminosity of a BH of given mass

$$F_{rad} \le F_{grav}$$

$$\frac{\sigma_e L}{4\pi r^2 c} \le \frac{GMm_p}{r^2}$$

$$L_{Edd} = \frac{4\pi G c m_p}{\sigma_e} M$$

$$= 1.26 \times 10^{38} (M / M_{\bullet}) \text{ ergs/s}$$

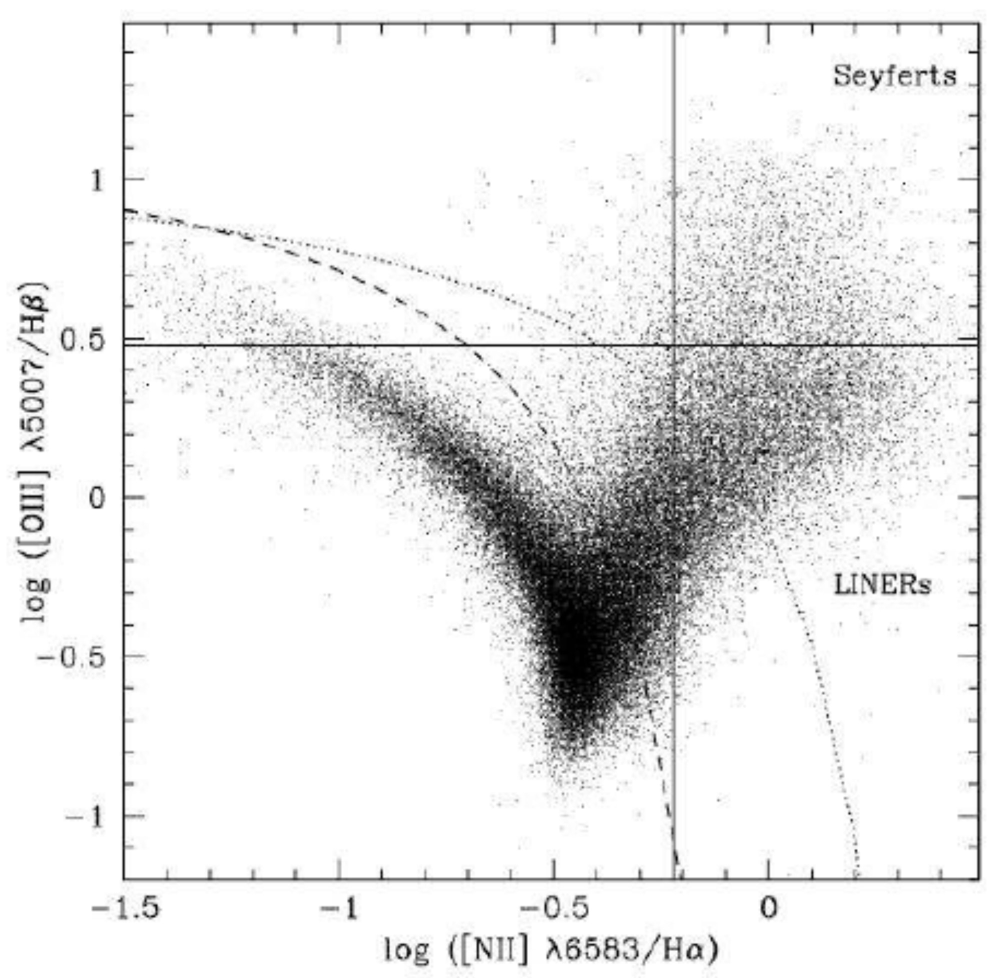
- $M = 10^9 \ M_{\odot} \Rightarrow L_{Edd} = 10^{47}$ erg/s
- Eddington Accretion Rate: Mass accretion rate required to shine at L_{Edd}
- Maximum accretion rate for mass M

$$\dot{M}_{Edd} = \frac{L_{Edd}}{\eta c^2}$$

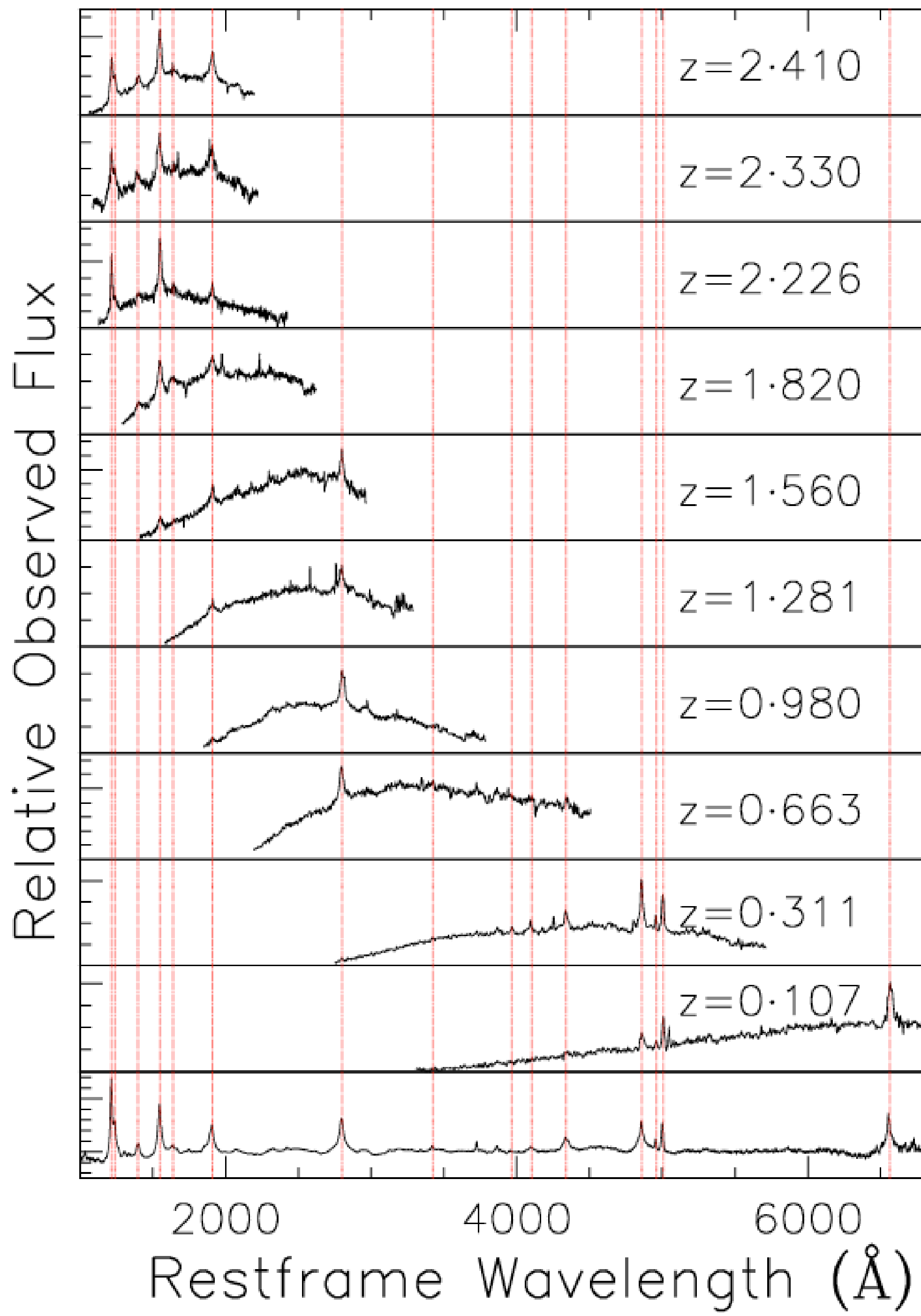
$$\approx 1.4 \times 10^{18} (M / M_{\bullet}) \text{ g/s}$$

AGN Detection: Spectroscopy

- How do we see AGN?
- Emission line ratio diagram
- BPT diagram (Baldwin, Phillips & Terlevich 1981) [OIII]/Hβ vs. [NII]/Hα
  - Non-stellar $\Rightarrow$ AGN
  - Separated from stars



55757 galaxies from SDSS. Lines separate starburst activity & AGN (type II at low-z). Kauffmann et al. (2003, MNRAS).



- **Primary detection mechanism: Observation of spectral lines**
- Determine redshift

AGN Classification

- Many different types …
  - Primarily based on observations
  - Theory try to explain these by the **Unification model of AGN**

- Seyferts -- low-luminosity AGN: Sy-1, NLS1, Sy-2
- Quasars, QSO, BALQSO
- Radio galaxies: BLRG, FRI, FRII
- Blazar, OVV, GPS, CSS, LINER

Seyfert Galaxy

- Low-luminosity AGN

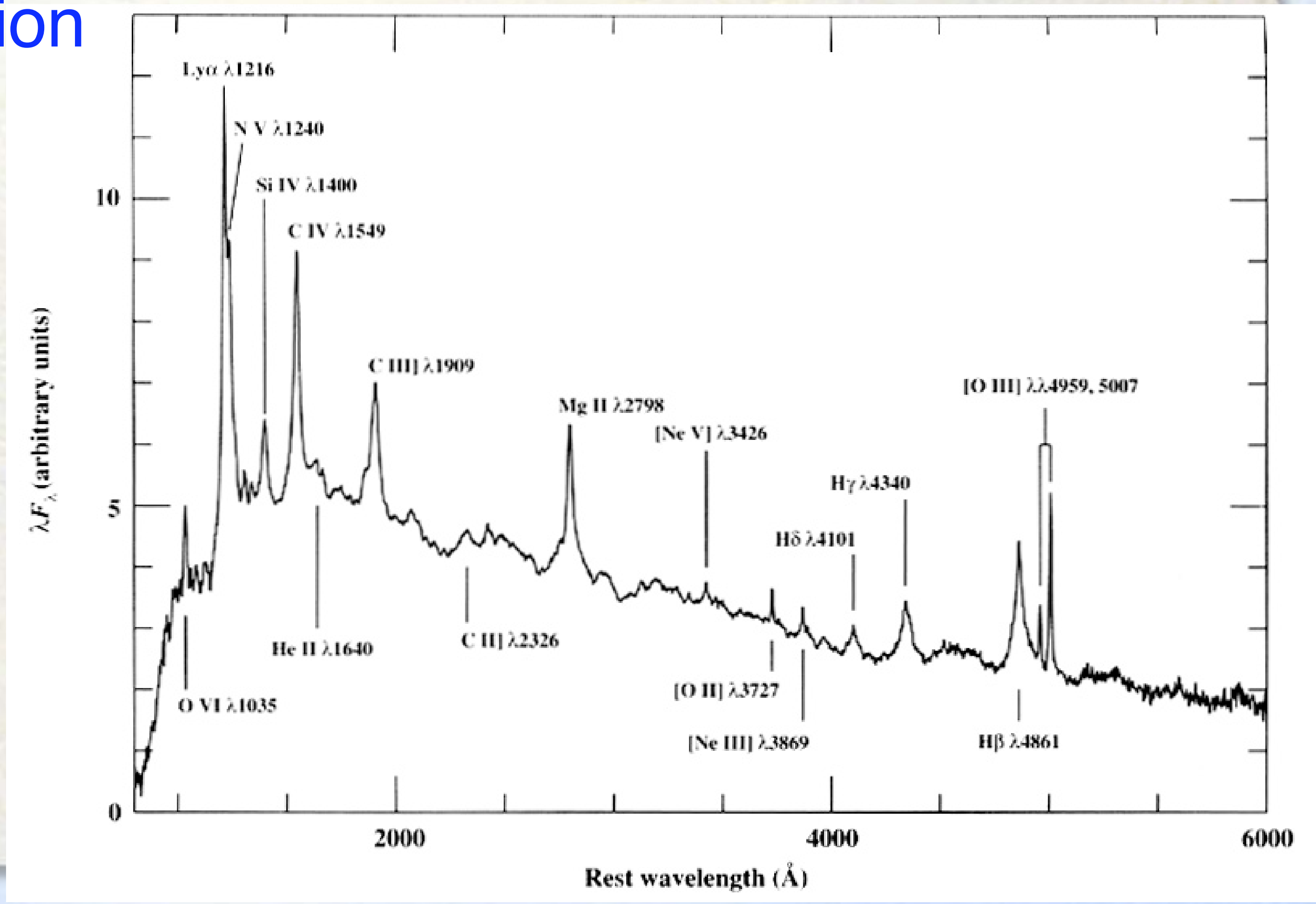
- Emission lines from highly ionized gas (Carl Seyfert 1943)
- Usually spiral galaxy

- Subtypes: depending on the width of the optical emission lines
  - Sy-I : broad permitted lines & narrow forbidden lines
    - NLS1 : optical Fe II in emission & X-ray excess
  - Sy-2 : narrow emission lines

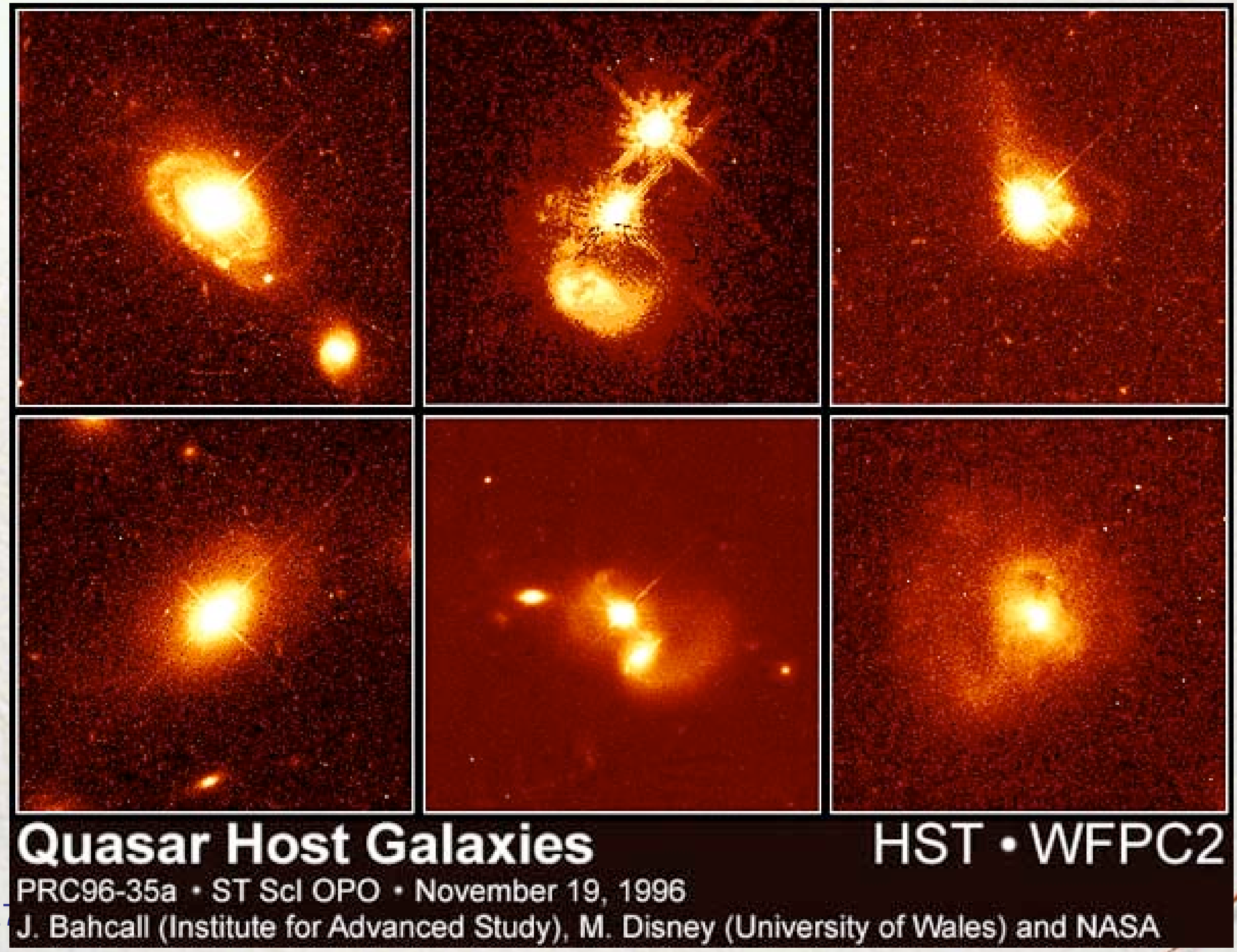
Quasars

- Quasars = Quasi-Stellar Radio Source
- QSO = Quasi Stellar Object
- Very high luminosity (10^{12}–10^{13} $L_{\odot}$) coming from a star-like region

Composite Quasar Spectra



Optical Image of Quasars

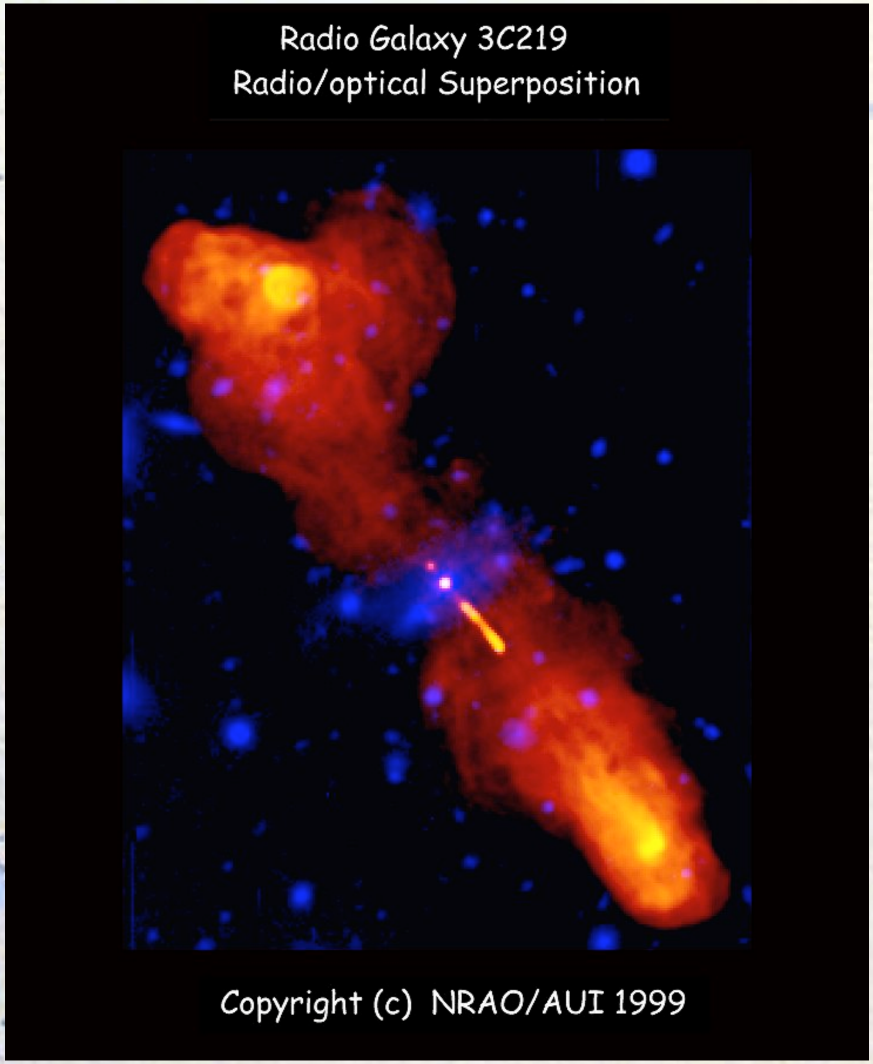


Quasar Subclasses

- 2 types based on radio-loudness:
  - Radio-loud, RL QSO : 5-10 % of quasars
  - Radio-quiet, RQ QSO
  - Dividing power, $P_{5GHz} \approx 10^{24.7}$ W Hz^{-1} sr^{-1}

- BAL QSO = Broad Absorption Line QSO
  - QSO with deep blue-shifted absorption lines, resonance lines of C IV, Si IV, N V
  - Observed in rest-frame UV
  - At $z \geq 1.5$, 10% of observed population

Radio Galaxy



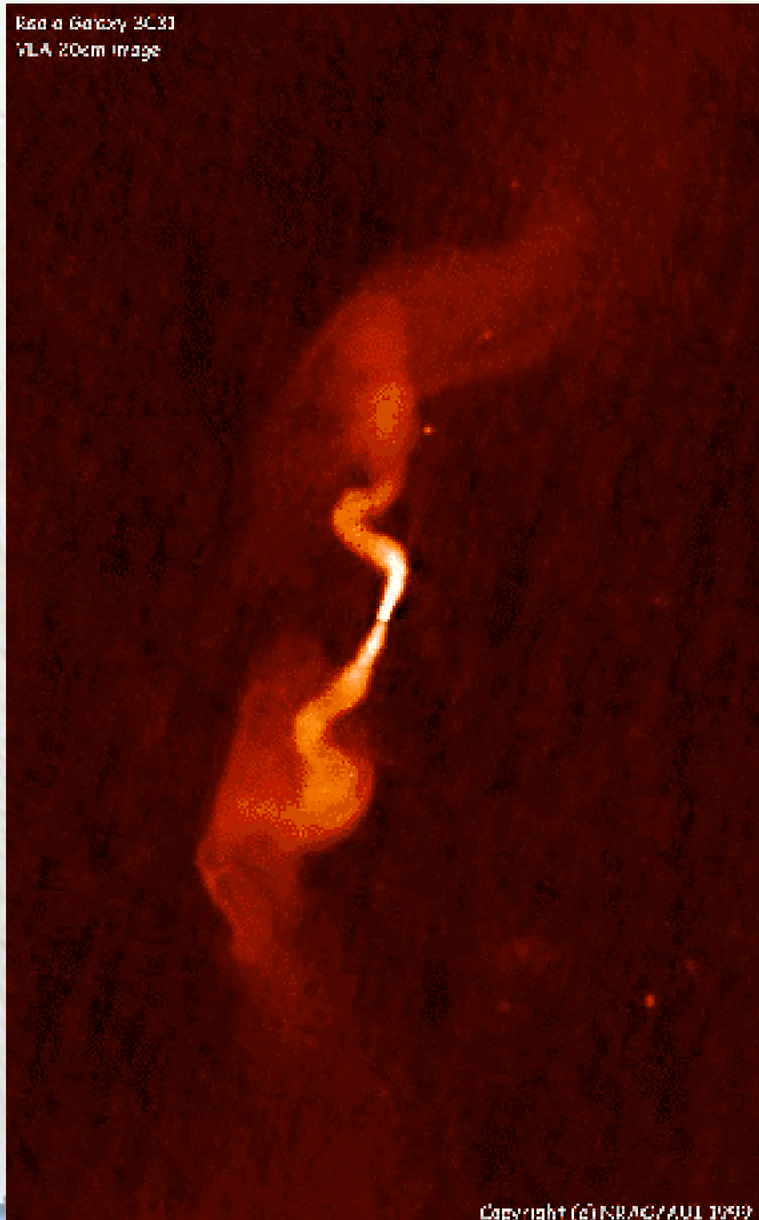
- Strong radio emission, extending over 100s of kpc - Mpc
- Optical spectra similar to Seyferts
- Mostly hosted by giant elliptical galaxies

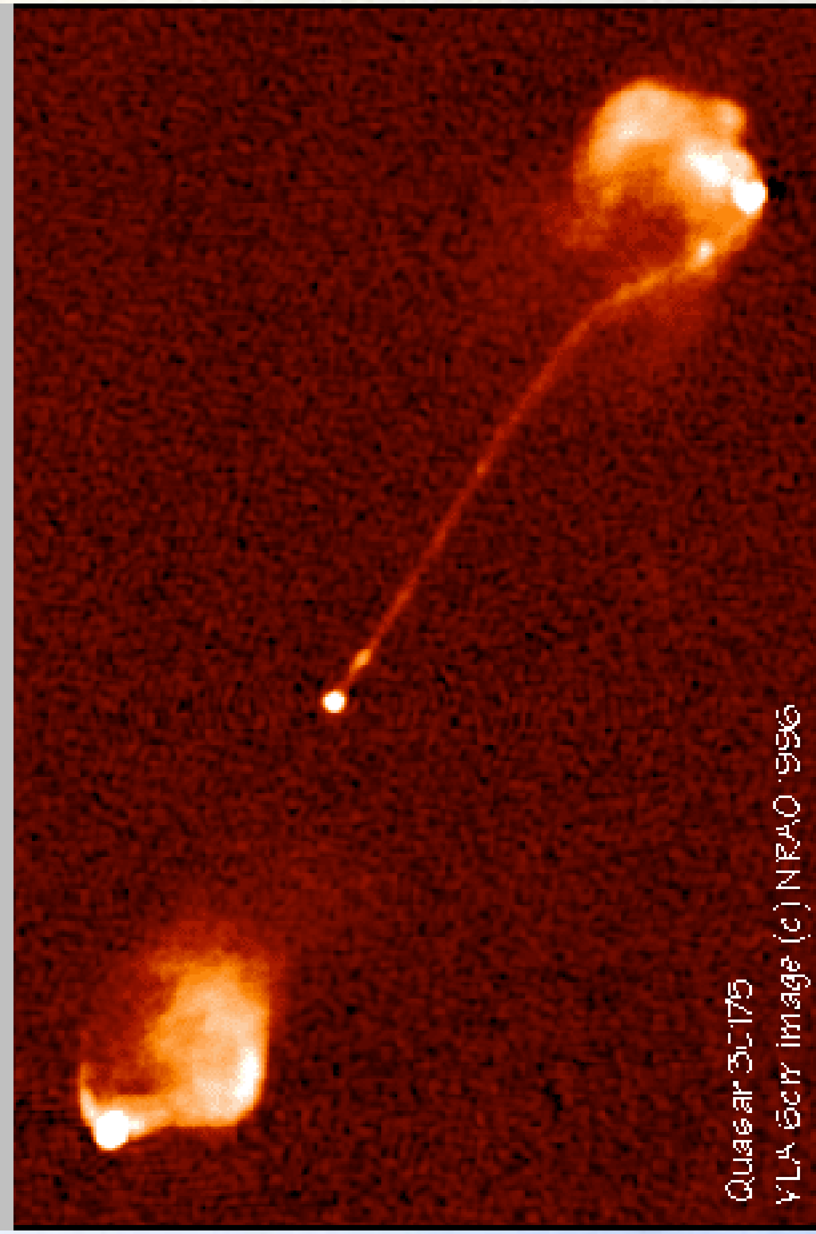
Sub-classes of Radio Galaxies

- Optical spectra
  - NLRG : narrow-line (~ Sy 2)
  - BLRG: broad-line (~ Sy 1)
- Spectral index ($F_\nu \sim \nu^{-\alpha}$) at ν=1 GHz
  - Steep or flat from α=0.4
- Radio morphology (Fanaroff & Riley 1974): ratio of distance between 2 brightest spots and total size
  - FR I : ratio < 0.5
  - FR II : ratio > 0.5

FR-I

FR-II


Radio Galaxy 3C31
VLA 20cm image
Copyright (c) NRAO/AUI 1999

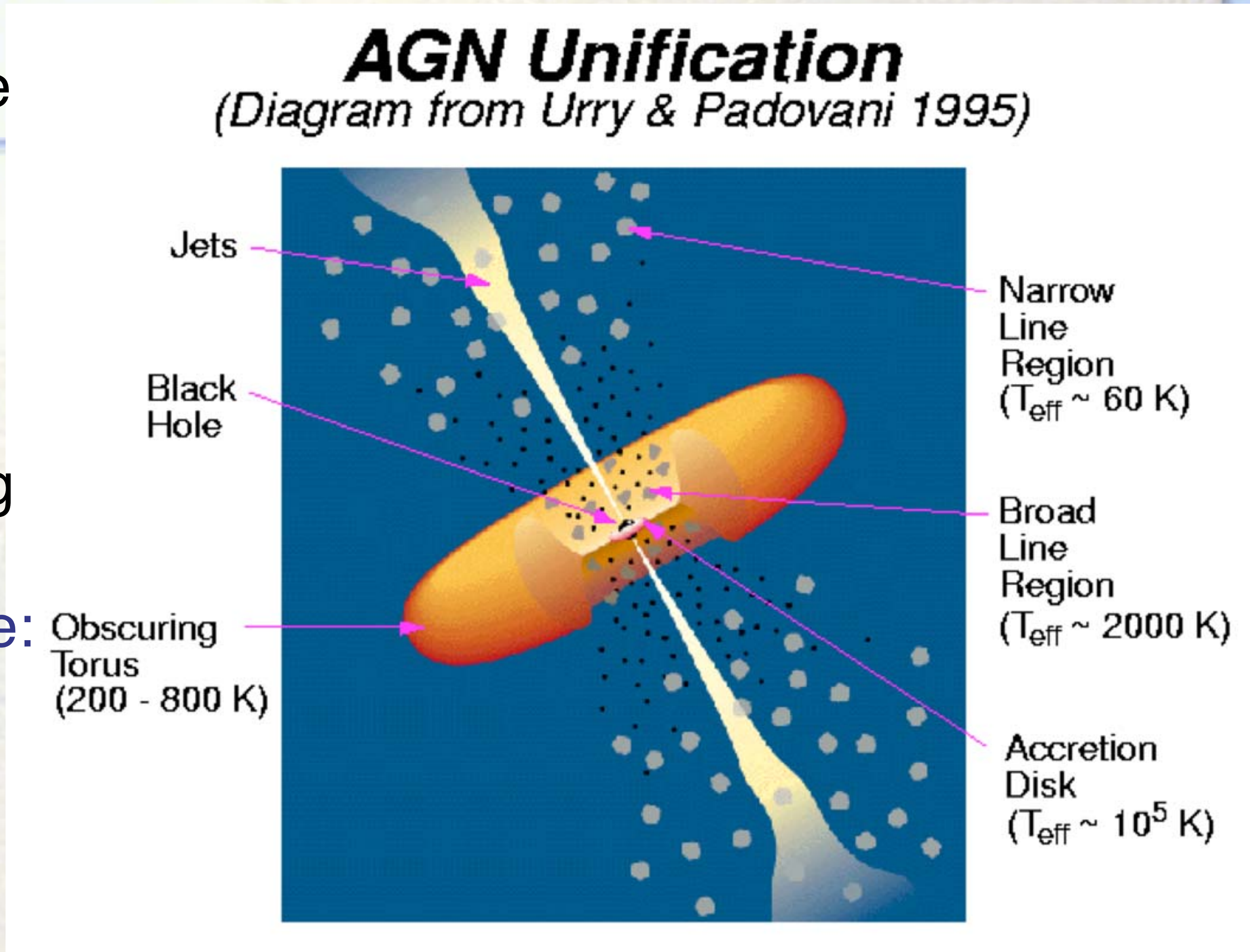

Quasar 3C175
VLA 6cm image (c) NRAO 1996

Some Other AGN

- LINER = Low-Ionization Narrow-Line Region
  - Weak AGN
- BL Lacs : star-like, very weak emission line, highly variable & polarized continuum
- Blazars = BL Lacs + OVV (optically violent variable) QSOs
  - Relativistic beaming of jet toward our line of sight

Unified Model of AGN

- All classes have same internal structure
- We observe differently because of different viewing angles
- Unified structure:
  - Central SMBH
  - Accretion disk
  - Dust torus
  - Pair of jets coming out on opposite sides



Superluminal Motion (apparent)

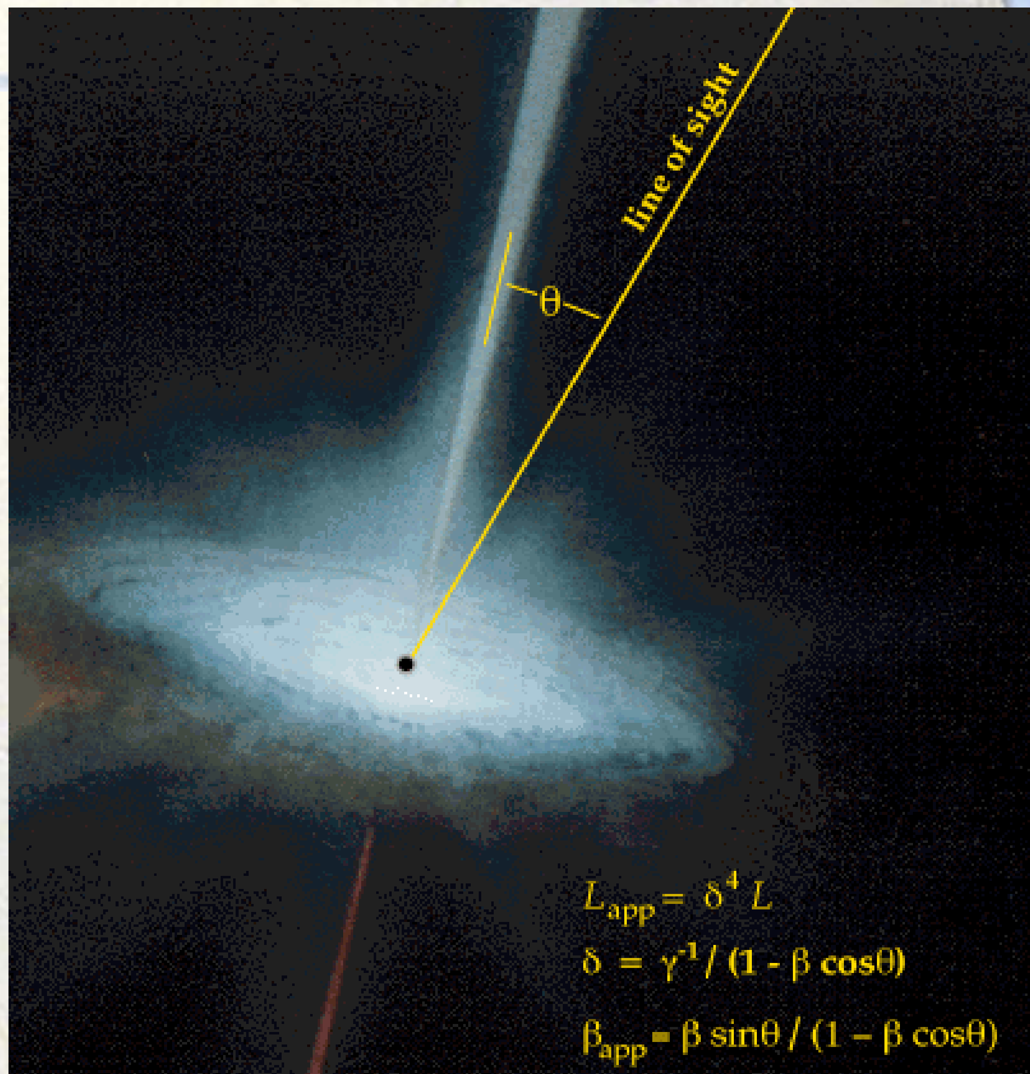
- Seen in some radio sources and blazars
- Due to bulk relativistic motion in jet along the line-of-sight to the source

$$\beta = \frac{v}{c}$$

$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$

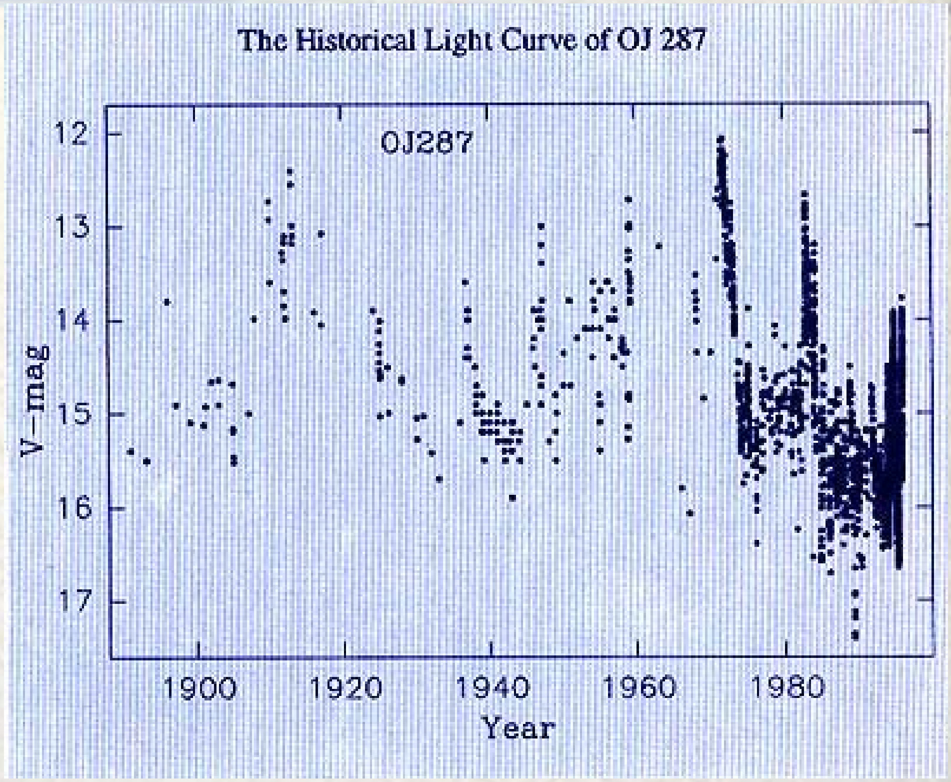
$$\beta_{app} = \frac{\beta \sin\theta}{1-\beta\cos\theta}$$

$$\beta_{app}^{\max} = \beta\gamma$$



Variability

- Blazars, BL Lac - highly variable
- Broad-line AGNs (Sy1, QSO, BLRG) are variable
- Timescale of variability
  - Longterm : years
  - Intraday : days
  - Microvariability: seconds
- E.g.: Longterm Variability
  - OJ 287 (blazar)

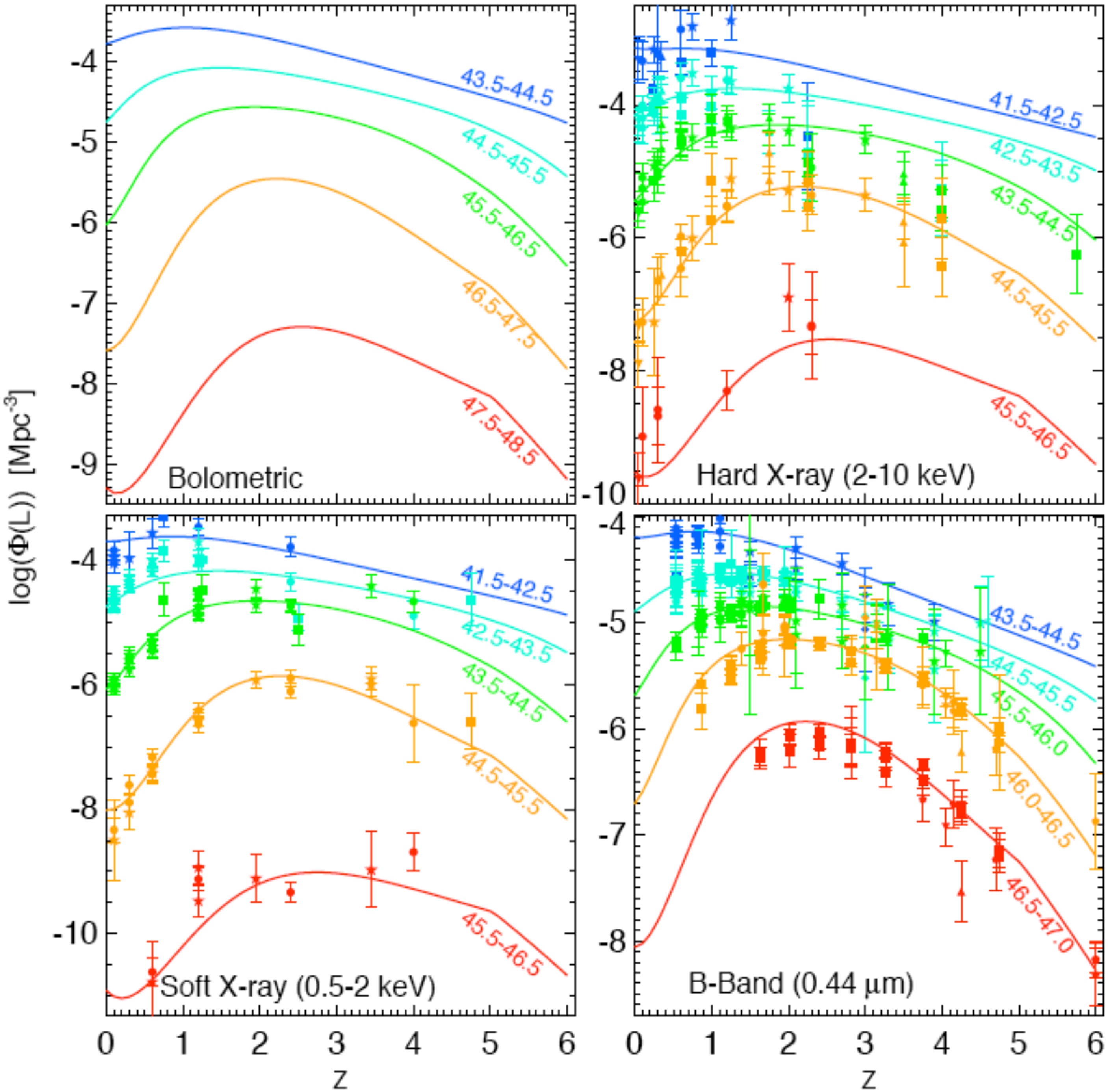


Space density of AGN

- Luminosity function: number of AGN per unit comoving volume, per unit luminosity

- Space number density in the local Universe
- AGNs : $1.0 \times 10^6 \ h_0^3 \ \mathrm{Gpc}^{-3}$
- All galaxies
  - Spirals : $1.5 \times 10^7 \ h_0^3 \ \mathrm{Gpc}^{-3}$
  - Ellipticals : $1.0 \times 10^7 \ h_0^3 \ \mathrm{Gpc}^{-3}$

$\Rightarrow$ AGNs are rare

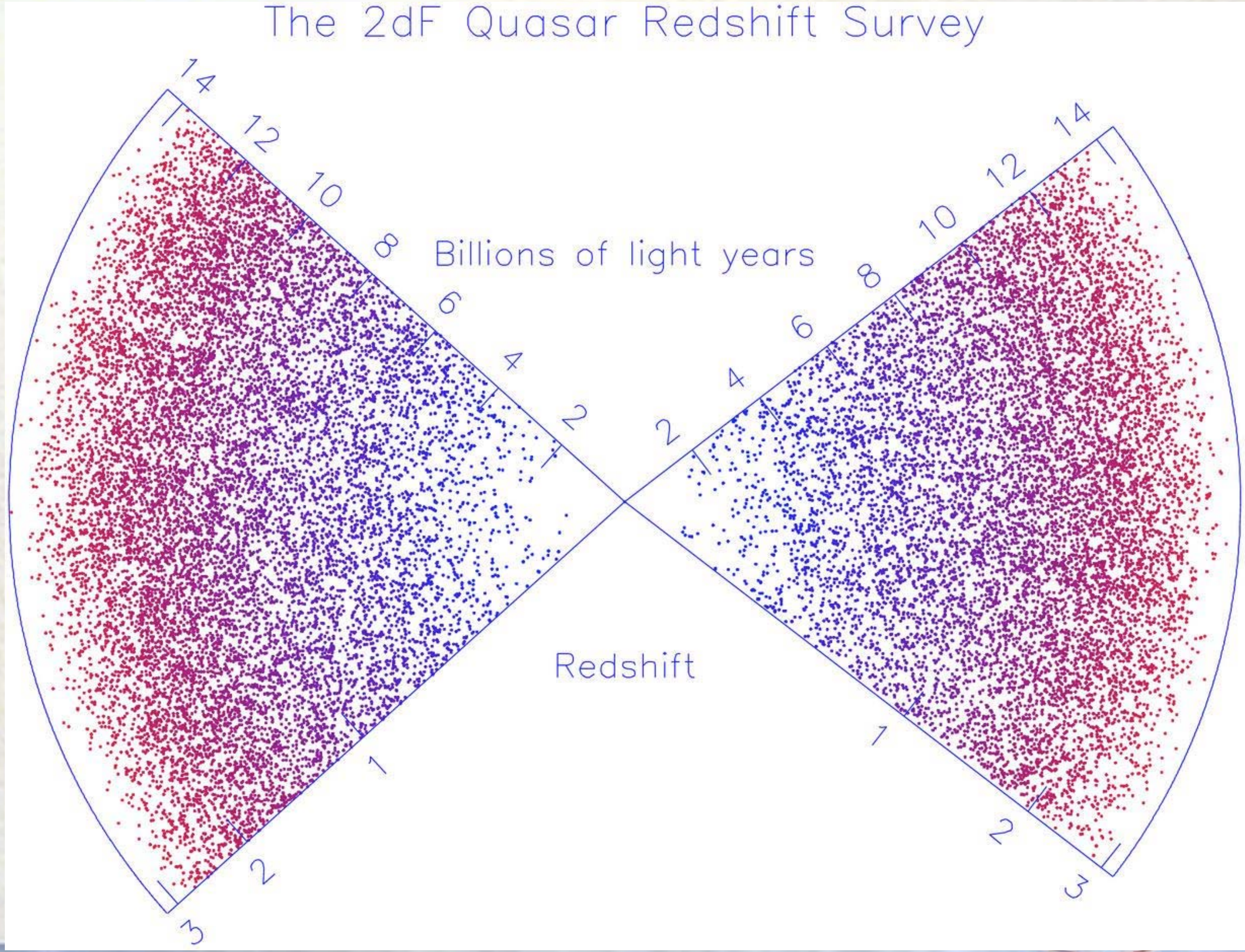


- Hopkins et al (2007, MNRAS)
- Total number density of quasars in various luminosity intervals
- Density of low-L AGN peaks at low-z

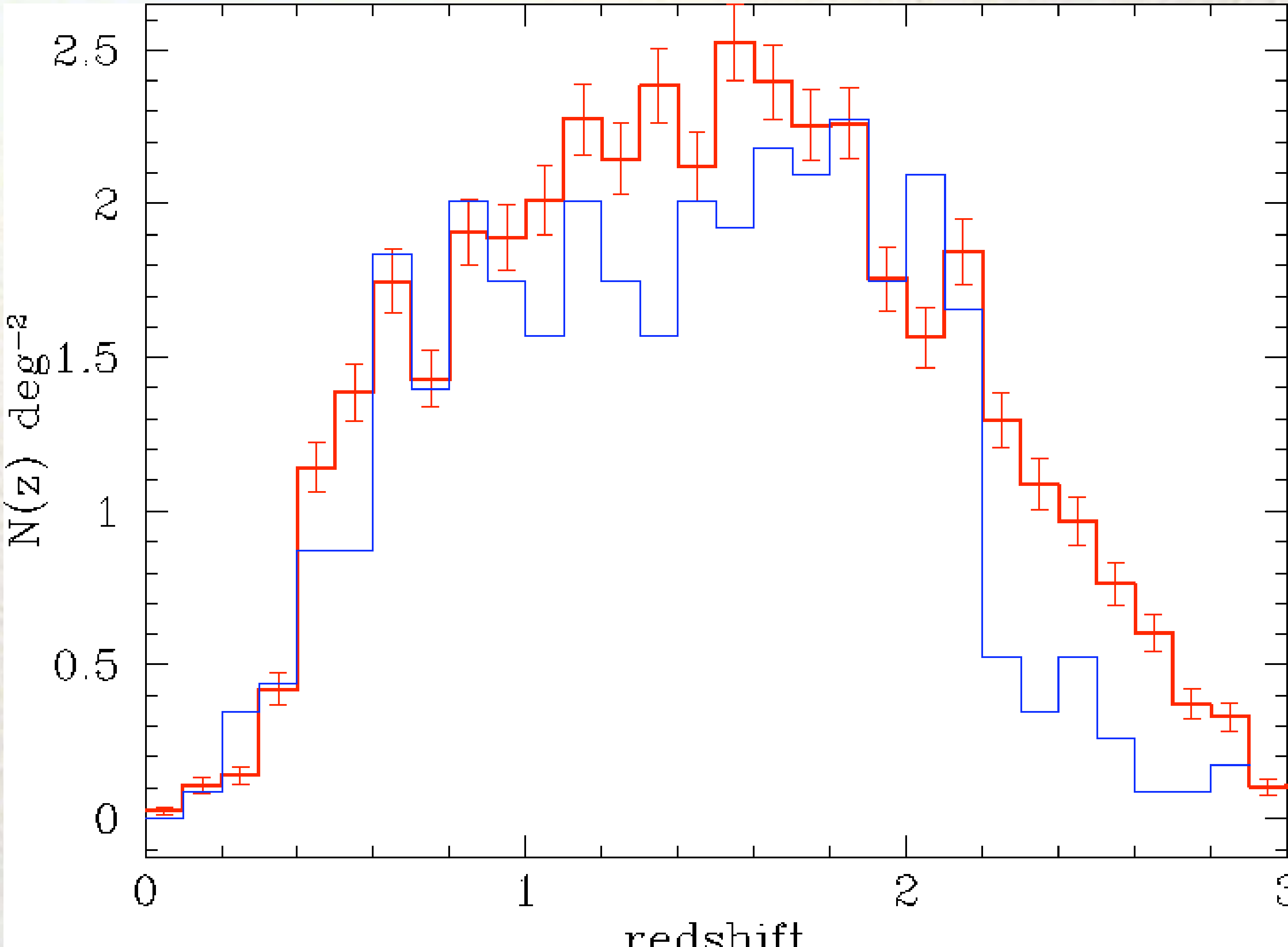
Lifetime

- AGN lifetime --- Time for which SMBH accretes matter and radiates energy
- $T_{AGN} \sim 10^7 - 10^8$ yrs
- Few observations show evidence of multiple AGN activity
  - Duty-cycle
- Gas accretion and BH fueling is a self regulated process during galaxy formation and growth

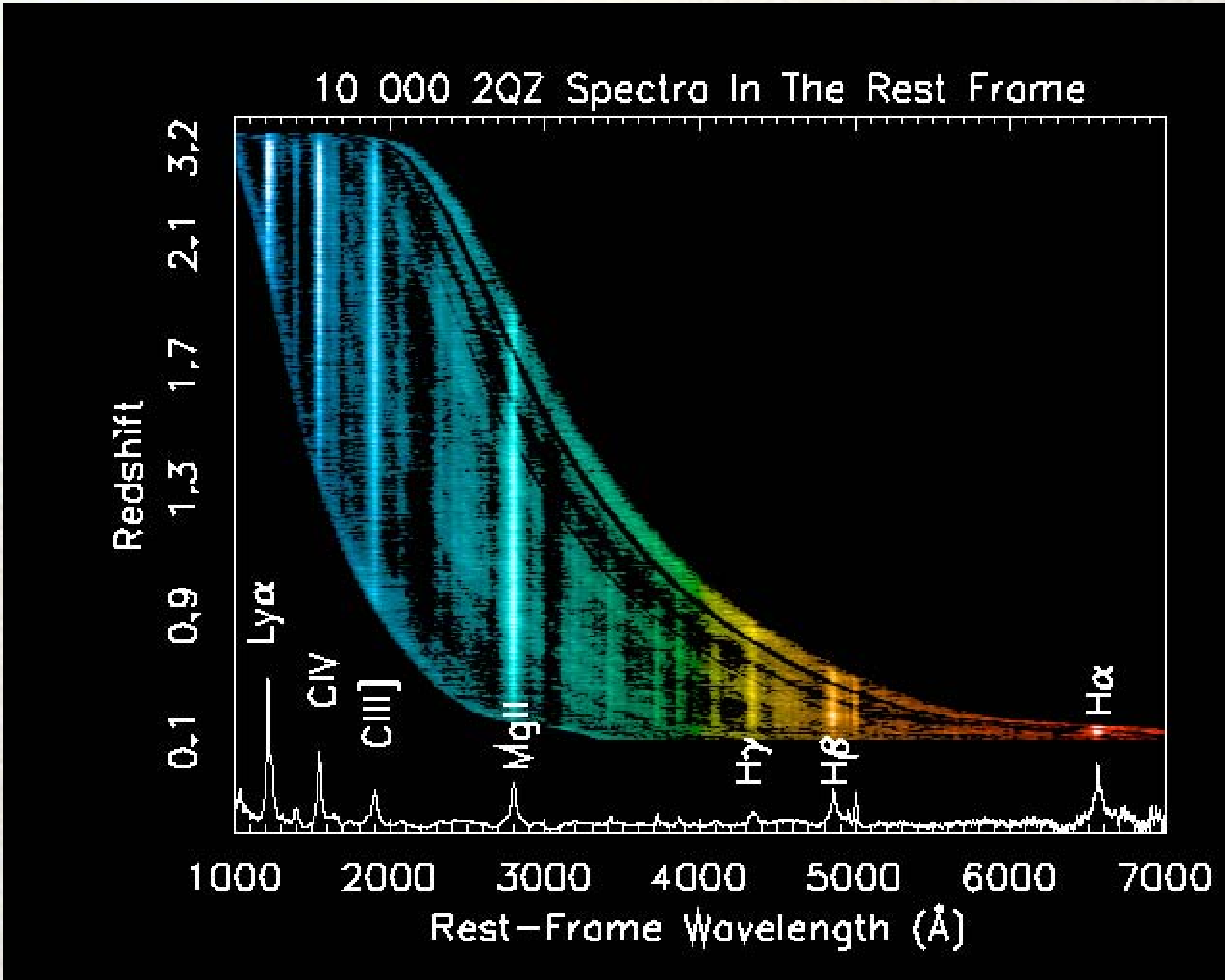
Quasar Survey
2QZ (2dF QSO redshift survey)



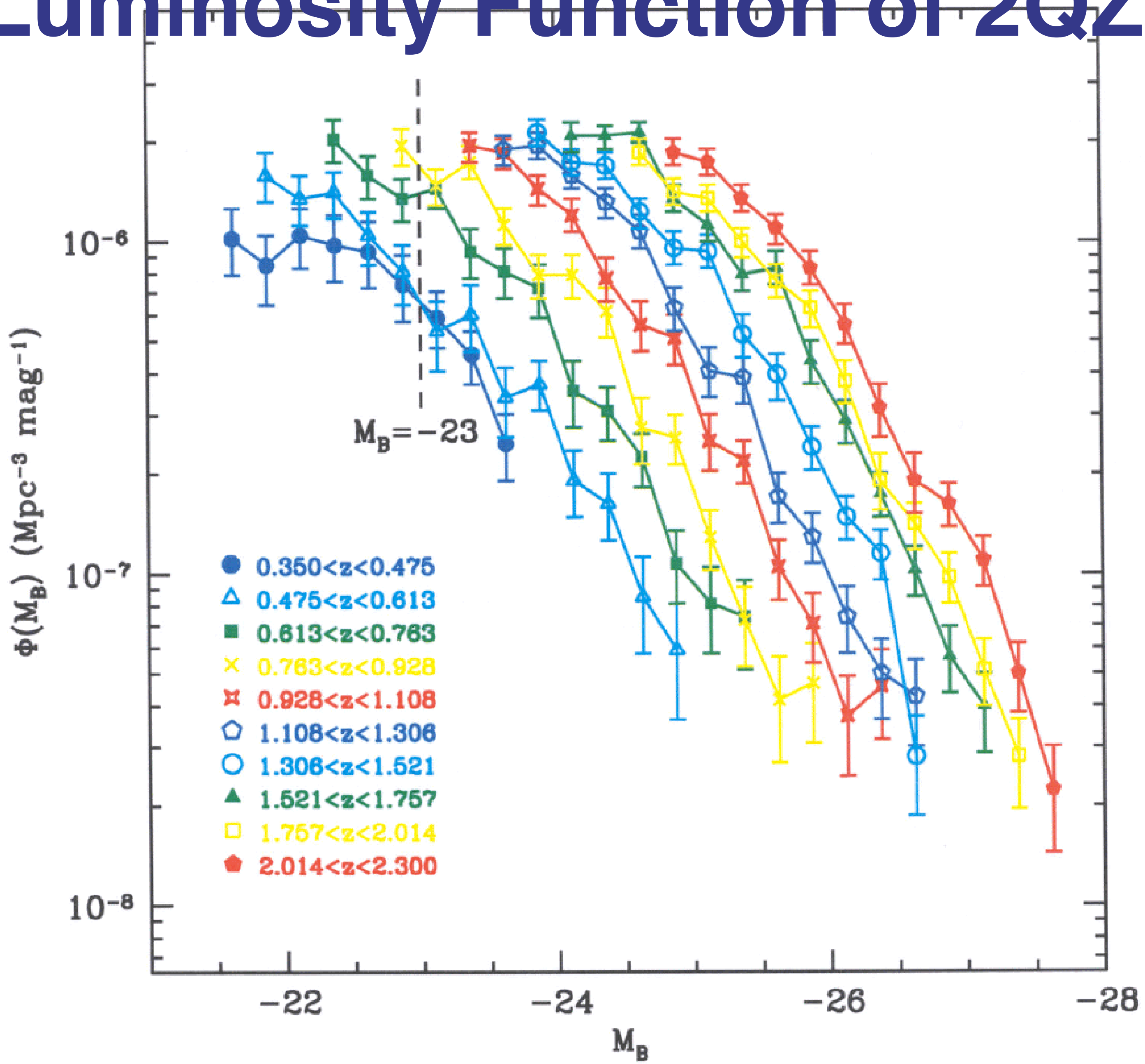
Number vs. Redshift Relation



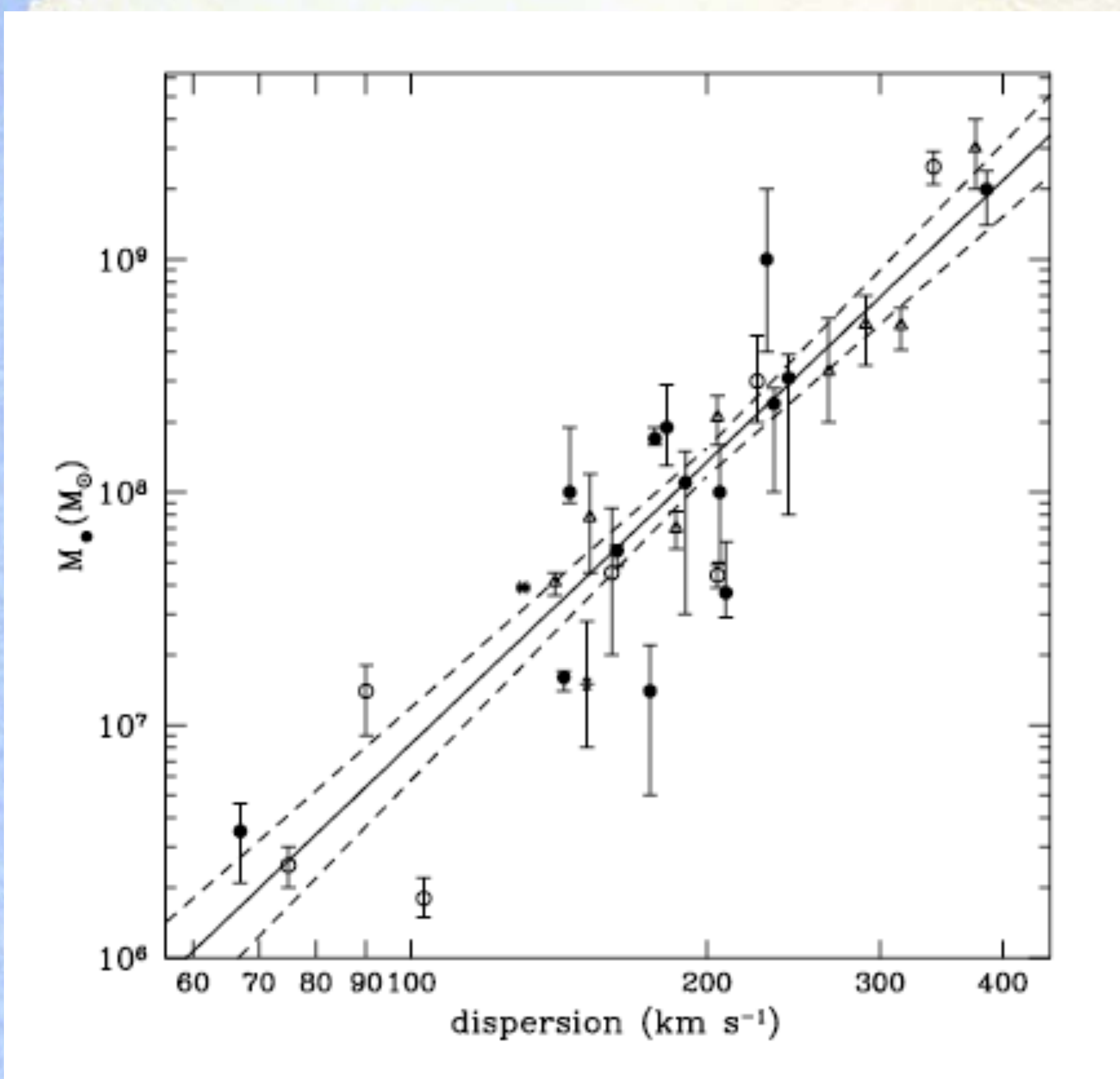
Composite Spectra



Optical Luminosity Function of 2QZ



BH-Galaxy Correlations from Observations



- Tight relation between BH mass and galaxy bulge mass/velocity dispersion

⇒ formation of BHs and galaxy bulges must be related

Evolution & Cosmology

- Spatial distribution of AGN --- clustered toward high density regions of the Universe
  - Quasars are also strongly clustered as galaxies
- AGN feedback required to resolve some problems in galaxy formation models
- Observe --- BH-galaxy correlations
  - Co-evolution of galaxies & central SMBH in the cosmological scenario

Is Milky Way an AGN?

- BH at center, located at SgrA*
  - Has a mass of 3.7 x 10^6 $M_\odot$
  - Size is smaller than the solar system
- No accretion activity
- NOT AGN

References and Research in India

- Books:
  - "An introduction to AGN" -- Brad Peterson (Ohio State univ.)
  - "Quasars and AGN" -- A. Kembhavi & J. V. Narlikar (IUCAA)
- Theoretical and observational research
- IUCAA, IIA, RRI

Summary

- SMBH at centers of active galaxies radiate huge amounts of energy $\Rightarrow$ AGN
- Detected spectroscopically
- Unification model for different classes
- AGN feedback plays important role in formation of galaxies and cosmology

- Can we link up the cosmologica l evolution of the AGN population to the build up of galaxies over time?