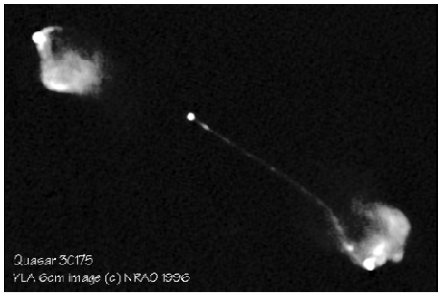
Galaxies AS7007, 2012
Lecture 6: Active galaxies



Outline

- Characteristics of active galactic nuclei
- Variability-size relation
- Supermassive black holes
- Accretion disks
- Eddington luminosity
- Jets and lobes
- Synchrotron radiation
- Superluminal motion

Outline II

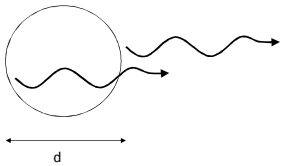
- Different types of active galactic nuclei
  - Quasars
  - Seyfert galaxies
  - LINERs
  - Radio galaxies
  - Blazars
- The unification model
- Quasar host galaxies
- Claims of non-cosmological redshifts
- Quasar Absorption Systems

Characteristics of Active Galactic Nuclei

- High luminosity produced in small region
- Fast variability
- High fraction of polarized light
- Non-thermal spectrum: Not stars!
  - Synchrotron radiation
  - Emission-line ratios→ Ionization source more energetic than hottest known stars

Variability-Size Relation

- Fast variability indicates that the luminosity is produced inside a small region
- Light variations on scales down to 1 hour → size smaller than the Solar system



$$\frac{d}{c} < \Delta t_{\mathrm{var}}$$

Supermassive Black Holes

- Doppler broadened emission lines in AGN indicate gas velocities ~ 10000 km/s
- Line variability time scale (weeks) → size of line-emitting region
- Velocity & size → Mass(<size) & Density, indicating that the gas orbits a SMBH
- Schwarzschild radius:

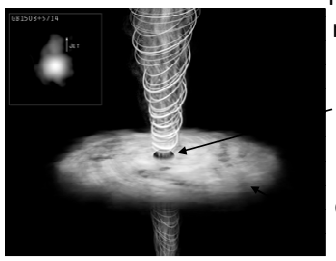
$$R_{\mathrm{S}} = \frac{2GM_{\mathrm{BH}}}{c^2} \approx 3 \times \frac{M_{\mathrm{BH}}}{M_{\mathrm{solar}}} \mathrm{km}$$

Supermassive Black Holes

$$\frac{M_{\mathrm{SMBH}}}{M_{\mathrm{Bulge}}} \sim 0.002 \qquad \frac{M_{\mathrm{SMBH}}}{L_{\mathrm{B_{Bulge}}}} \sim 0.0012 \frac{M_{\mathrm{solar}}}{L_{\mathrm{B_{Solar}}}}$$

- MW has a ~10^6 Msolar mass SMBH, which is expected given its bulge luminosity and mass
- Active galaxies appear to follow the same relations → M_{SMBH} does not determine if a galaxy is active or not

Accretion Disks



Magnetic field channel matter into relativistic jets

SMBH

Angular momentum of infalling material→ matter spirals inward in an accretion disk

Eddington Luminosity

Too high radiation pressure of AGN may overcome inward gravitational force → upper limit on AGN luminosity which still allows material to fall inwards

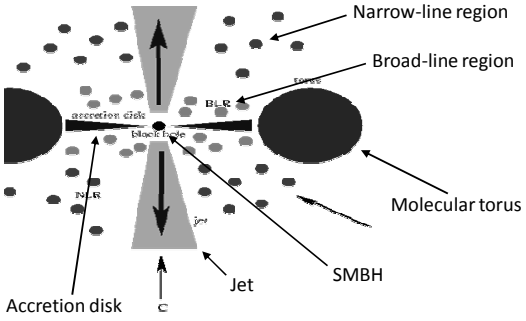
$$L_{\mathrm{E}} \approx 30000 \frac{M}{M_{\mathrm{solar}}} L_{\mathrm{solar}}$$

Note: L_E assumes spherical accretion. Super-Eddington luminosities (a few times L_E) can be produced in accretion disks

Radiation Efficiency

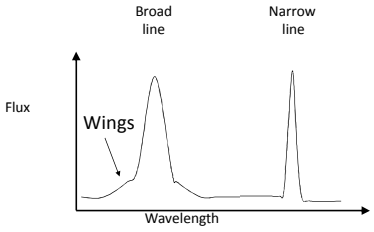
- Mass M falling into a SMBH→ energy Mc^2 added
- Theoretical maximum:
  - 42% of Mc^2 is converted into luminosity
  - The rest increases the SMBH mass
- But typically, ≤10% of Mc^2 is converted into luminosity
- SMBHs in a typical quasar grows with ≥ 1 M_{solar}/yr
- Activity is expected to last for ~ 100 Myr → $M_{SMBH} \geq 10^8$ M_{solar}in faded quasars

The Central Power Source

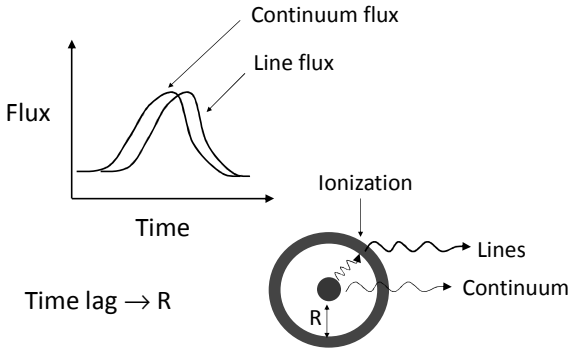


Transitions and Line Profiles

- Forbidden lines (e.g. [OII]3727Å, [OIII]5007) originate in low-density gas ($n_H \leq 10^8$ atoms/cm^3)
- Allowed lines (e.g. Hα, Hβ) originate in more dense gas
- Broad lines, Δv~10000 km/s – Allowed (originate close to the nucleus, in dense medium)
- Narrow lines, Δv<1000 km/s – Forbidden (originate further out, in less dense medium)



Reverberation Mapping

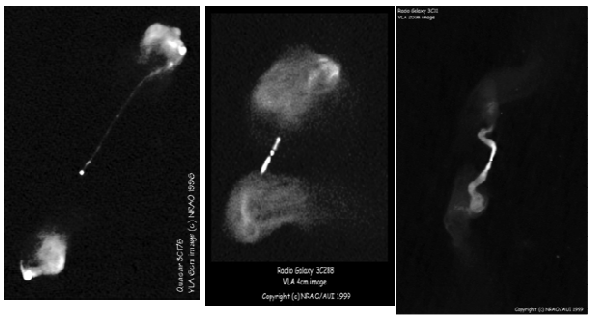


Intermission I: Music from AGN

Dr Fiorella Terenzi

Music from the Galaxies (1991):
Radio waves from the active galaxy UGC 6697 converted into music

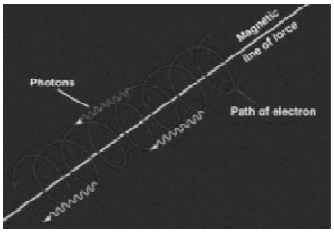
Jets and Lobes



Jets and Lobes

Synchrotron Radiation

- Relativistic electrons spiralling around magnetic field lines
- B=1-10 μG in lobes (same as B close to the Sun)
- B=0.1 G in active cores



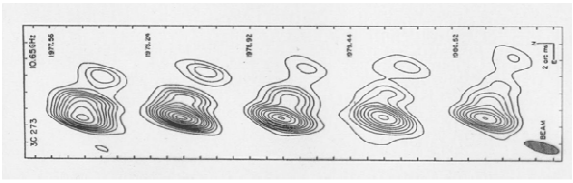
Power-Law Spectrum

$$f_\nu \propto \nu^{-\alpha}$$

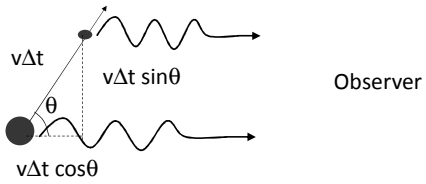
- In radio, due to synchrotron radiation: α=0.7—1.2
- In optical, probably caused by thermal radiation from the accretion disk: α=0—2

Superluminal Motion

- Blobs appear to move outwards at 5-50c



Superluminal motion



$$\Delta t_{obs} = \Delta t(1-(v/c)\cos\theta)$$

In Δt_{obs}, the blob travels v Δt sinθ across the sky, With apparent velocity v_{obs}:

$$v_{obs} = \frac{v\sin\theta}{1-(v/c)\cos\theta}$$

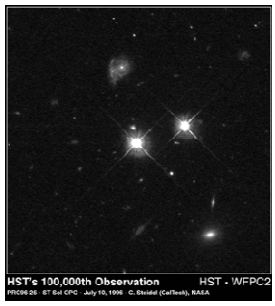
$v \approx c \rightarrow v_{obs} > c$

The number densities of active galaxies at z=0

Type	Number/Gpc^3
Spiral galaxies	~5×10^6
E/S0 galaxies	~ 1×10^6
Seyfert galaxies	~ 1×10^5
Radio galaxies	~ 3×10^3
Quasars	~ 100
Blazars	~ 80

Quasars

- Originally:
  - Quasar = "Quasi-stellar radio source" (radio-loud)
  - QSO = "Quasi-stellar object" (radio-quiet)
- Today: Quasar = Both types

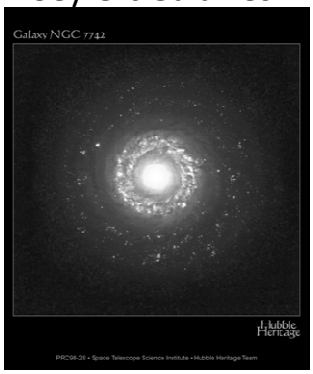


Quasars

- Most luminous of the non-transient objects in the Universe: M_B<-23
- Radio-quiet quasars >10 times more common than radio loud ones
- Both broad and narrow lines

X-ray quasar with jet

Seyfert Galaxies



Seyfert Galaxies

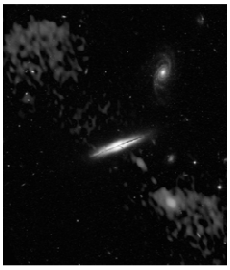
- "Low-luminosity quasars"
- Almost always in S- or S0-galaxies
- Seyfert 1 nuclei
  - Broad lines (allowed) & Narrow lines (forbidden)
  - High optical luminosity
- Seyfert 2 nuclei
  - Narrow lines only, but with wings
  - Low optical luminosity

LINERs

- LINER = Low Ionization Nuclear Emission Line Region
- Low luminosities (lower than Seyfert 2)
- Exhibit lines which do not require very energetic power sources – hot stars sufficient
- Many LINERs are probably starbursts, not genuine AGN

Radio Galaxies

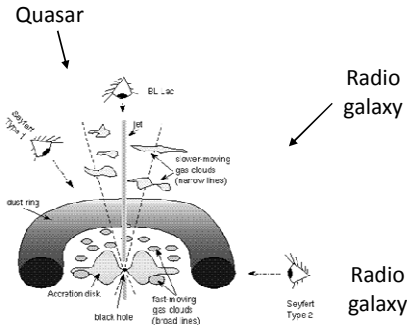
- Milky Way: 10^{30} W in radio
- Radio galaxies $\geq 10^{34}$ W in radio
- Lobes and hot spots
- Always elliptical galaxies



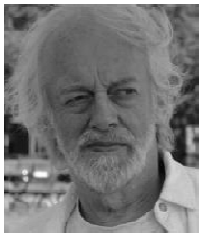
Blazars

- The most rapid and large variations among AGN
- Originally:
  - BL Lac (very weak emission lines)
  - OVV = Optically violent variable (strong emission lines)
- Today: Blazar = BL Lac & OVVs
- *Appear* to be the most luminous objects in the Universe, but this is due to beaming
- Often completely featureless spectrum
  - Emission-lines weak or absent

The Unification Model



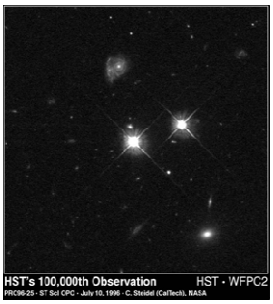
Intermission II: Music from AGN



Professor Nils Bergvall

NGC 4151 (1993):
Rest-frame UV emission-line and continuum variability from the Seyfert galaxy NGC 4151 converted into music

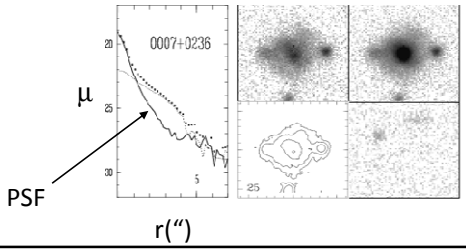
Quasar Host Galaxies



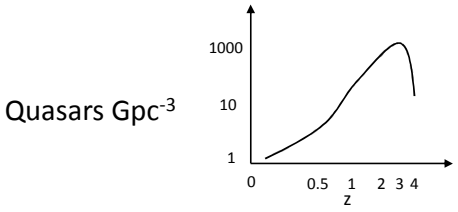
- The AGN of a quasars typically outshines its host galaxy
- To study the host galaxy, one utilizes the fact that the AGN is a point source wheras the host is an extended object

Quasar Host Galaxies

- Point spread function (PSF): Describes how the light of a perfect point source is distributed on the detector (CCD) because of telescope imperfections, diffraction etc.

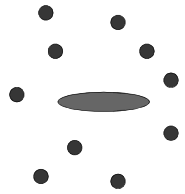


Cosmological Evolution



- At z≈3, bright quasars appear ~1000 times more common than today
- Quasar activity drops at even higher redshifts
- The highest-redshift quasar detected so far has z≈7
- Very challenging to build a SMBH by z=7 (less than 1 Gyr after the Big Bang) – exotic formation channel required?

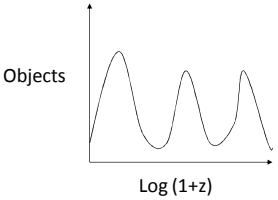
Claims of non-cosmological redshifts I

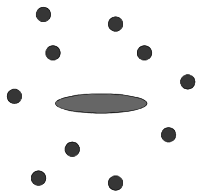


Low-z galaxy surrounded by overdensity of high-z quasars

Low-z galaxy with pairs of high-z quasars (with $z_1 \approx z_2$) aligned along minor axis

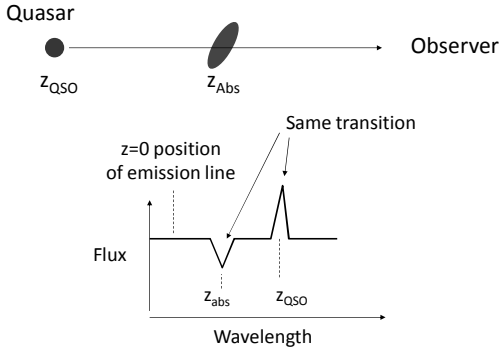
Claims of non-cosmological redshifts II





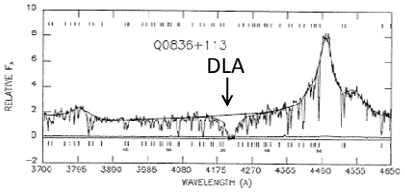
Quasars located close to low-z galaxies show periodicities in redshift distribution

Quasar Absorption Systems



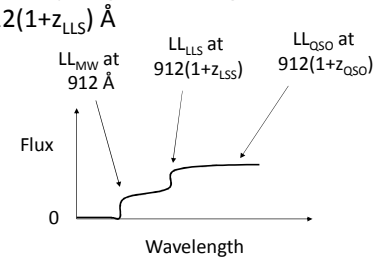
Damped Lyman-Alpha Clouds

- Dense, neutral gas N(HI) ≈ 2×10^{20} cm^{-2}
- Often interpreted as gas associated with intervening galaxies
- Many DLAs are also Lyman-limit systems

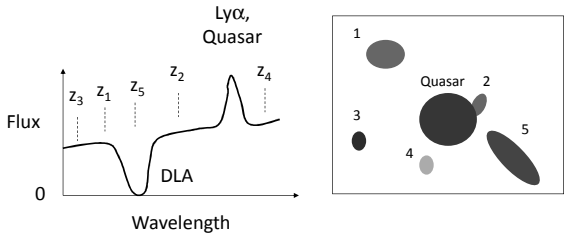


Lyman-Limit Systems

- Dense, neutral gas
- Absorbs hydrogen-ionizing radiation at $\lambda<912(1+z_{LLS})$ Å

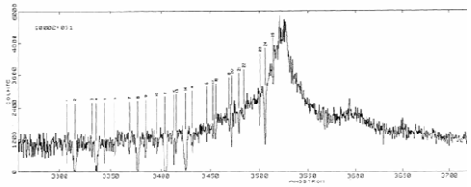


Identifying the Absorber



The Lyman-Alpha Forest

- Low-density, very extended clouds in the intergalactic medium
- Proximity effect:
  - Lyα-forest thinner at $z_{abs}\approx z_{QSO}$
  - Indicates that clouds close to the quasar are photoionized by it



The Gunn-Peterson Test

- If the Universe (the intergalactic medium) is neutral at z_{QSO}, then a strong absorption feature blueward of Lyα in quasars should appear – the Gunn-Peterson trough