Quasars and AGN

- **Goals:**
  - What are quasars and how do they differ from galaxies?
  - What powers AGN’s.
  - Jets and outflows from QSOs and AGNs
- **Discovery of Quasars**
  - Radio Observations of the Sky
    - Reber (an amateur astronomer) built the first radio telescope in 1936.
    - Strong radio emission was detected from the Sgr A, Cas A (Galactic) and Cyg A (extragalactic). Identified as star-like.
    - Cyg A has strong emission lines and lies at a redshift $z=0.057$ (220 Mpc for $H_0=75$ km s^{-1} Mpc^{-1}). cyg A has 10^7x radio luminosity of our galaxy.
    - Schmidt (1963) showed that some of the radio stars were not in our own Galaxy (for 3C 273) - quasi-stellar radio sources (quasars). Now denoted as QSOs (radio bright and radio quiet).

High Redshift Objects

– Relativistic Redshifts

- **Redshifts of quasars have been measured up to z=5.01. Using the standard redshift relation we have to explain velocities greater than the speed of light!**
- **We move back to special relativistic form for redshift. It is not a linear equation.**

$$\frac{\lambda-\lambda_0}{\lambda_0}=z=\sqrt{\frac{c+v}{c-v}}-1$$

- **λ: wavelength observed**
  λ_0: restframe wavelength
  v: apparent velocity
  z: redshift
  c: speed of light
- **As $v\rightarrow c$ redshift $\rightarrow \infty$**
- **For the highest redshift QSO (z=5.01) the increase in the wavelength of the Hα emission line is a factor of 6.01 (656.2 nm → 3.94 μm).**
- **The apparent recessional velocity is**

$$\frac{v}{c}=\frac{(z+1)^2-1}{(z+1)^2+1}$$

- **For z=5.01 v is 95% of the speed of light.**

– Luminosities of QSOs

- From the distance modulus and the redshift distance relation we can calculate the luminosities of QSOs.
- QSO 3C 273 has a luminosity of 10^{40} W or $2.5 \times 10^{13}\ L_{\odot}$. Our Galaxy has a luminosity of 10^{37} W. QSOs are amongst the brightest objects in the sky.
- Radiation in not thermal (i.e. a blackbody spectrum). The spectrum of a QSO has a power law form from synchrotron radiation (acceleration of relativistic electrons).

$$f_{\nu} \propto \nu^{-2.7}$$

- f_{ν}: flux per unit frequency
  ν: frequency
- The strong emission lines come from the ionization of rapidly moving clouds of Hydrogen.
- The non-thermal spectrum seen in QSO spectra is indicative of the spectra seen from black holes.
- QSOs are powered by massive black holes at the center of a galaxy (<u>host galaxy</u>).

– Variability of QSOs

- QSOs vary on time scales of a few days, weeks and months.
- This limits the possible size of a QSO.
- Imagine a QSO 1 yr across (0.36 pc).
- If the QSO luminosity varies instantaneously then the light from the part of the QSO closest to the observer would arrive 1 year before the light from the furthest part of the QSO.
- A sudden flash of light would appear as a slow rise and fall in intensity over the course of a year.
- Variations on the time scale of a day mean that the QSO must be less than 200 AU.
- QSOs must be small and massive to produce a large amount of energy and vary over a short time period.

- Bridging the gap between QSOs and galaxies.
  - QSOs are 1000x brighter than normal galaxies why are there not intermediate luminosity galaxies?
  - There are. A class of galaxies called Seyferts (I and II).
  - These galaxies have bright compact nuclei (Active Galactic Nuclei - AGN) and have luminosities from 10^{36}-10^{38} W.
  - They make up approximately 10% of luminous spiral galaxies (this number is not certain).
  - They tend to have weak radio emission.
  - Some Elliptical galaxies also have strong radio emission (radio galaxies). They tend to have jets of high energy particles (from the center of the galaxy) emitting synchrotron emission.
  - These jets produce radio lobes on either side of the Elliptical galaxy (e.g. Centaurus A).

Powering AGNs

– Massive black holes as central engines

- Lynden-Bell (1968) suggested than supermassive black holes might power AGNs.
- The luminosity that a black hole can output through accretion of matter is given by the Eddington limit.

$$L_{Edd} = 30{,}000\left(\frac{M}{M_O}\right)L_O$$

- L_{Edd}:Eddington luminosity
  M: Mass of black hole
- For luminosities $L>L_{Edd}$ the radiation pressure will stop material accreting onto the black hole.
- For QSOs 3C 273 $L=3\text{x}10^{13}\ L_{\odot}$. If this is the Eddington limit (the smallest black hole that can produce this luminosity) then the black hole mass $M=10^{9}\ M_{\odot}$.
- Supermassive black holes may have been observed in the Andromeda Galaxy (M31) where rapidly rotating stars surround the core of the galaxy (suggest $10^{7}\ M_{\odot}$ system within 5 pc of the galaxy center.

– Density of supermassive black holes

- Supermassive black holes are not hard to create - they do not require a massive star or supernovae.
- Using simple Newtonian arguments we can estimate the density of matter in a supermassive black hole.
- The density of matter is given by

$$\rho = \frac{3M}{4\pi R^3}$$

- The mass of a black hole is related to its Schwarzschild radius by

$$R = \frac{2GM}{c^2}$$

- Substituting for the radius we can estimate the relation between density and mass of a black hole.

$$\rho = \frac{3c^6}{32\pi G^3 M^2}$$

- For a “normal” black hole $M=10M_\odot$ the density is 10^{17} kg m^{-3} (1/5th density of a neutron star).
- For a supermassive black hole with $M=10^9$ $M_\odot$ the average density is only 10 kg m^{-3} (10x density of air).