Lecture 11 : Active galaxies (III)

0.1 The unified scheme for AGNs

There have been many attempts to build an unified picture of the different types of AGNs. The basic idea is that only a few underlying physical properties might account for the large range of AGN characteristics. There are indeed some interesting patterns between the behaviours of different types of AGNs. In a way the present state of our understanding is like the state of chemistry just prior to the discovery of the periodic table.

One essentially posits that there is only one type of AGN. The observed variety arises from two degrees of freedom : (1) Dust opacity ,which produces the distinction between Type 1 and 2 Seyferts; (2) Viewing angle of a relativistic jet, which produces the distinction between Type 1 AGN and blazars.

The scheme for unifying the radio-quiet AGNs says that Seyfert 2 may also have a BLR but it is obscured from view in some directions by a torus of dense gas and dust that girdles the continuum source and the BLR. Looking down the axis of the torus, we can see right into the BLR and the accretion disc. If we see it edge-on, the torus obscures our view of the BLR and the galaxy looks like a Seyfert 2. The torus also blocks ionizing photons from reaching the NLR in some directions, thereby explaining the cone-shaped NLRs that are sometimes seen.

This idea got an enormous boost when Antonucci & Miller (1985) found broad lines in the polarized light in NGC 1068, a Seyfert 2 galaxy, and suggested that the continuum and the broad line photons are being scattered into the line of sight. Interestingly, the Seyfert 2 galaxies have a hard X-ray spectrum, which can be explained saying that the torus absorbs the low energy X-rays from the centre in these galaxies.

Apart from this, the arguments in favour of the unification schemes are:

- The continuum is stronger in Sy1 than in Sy2—torus absorption (Lawrence 1987).
- The optical-UV continuum flux required to explain NLR of Sy2s is much larger than that seen directly—anisotropic absorption around the continuum source (Binette, Fosbury and Parker 1993).
- NLRs are cone-shaped (Evans et al 1994, e.g.)–ionizing continuum radiation collimated by torus.

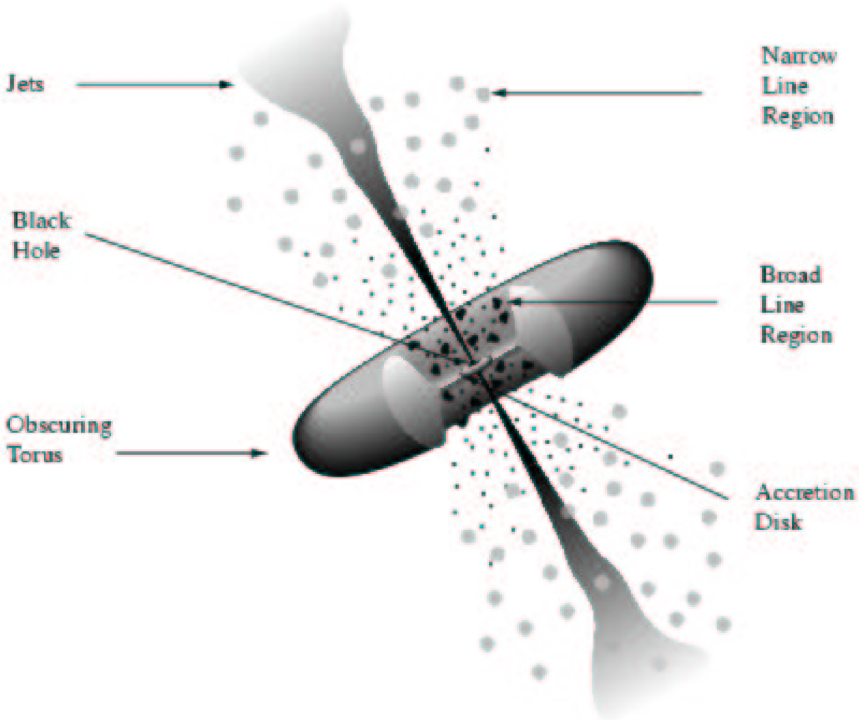

Figure 1: Schematic diagram of unification scheme for radio-quiet AGNs.

- Variability differs between Seyfert types—the continuum of Sy2s do not vary much (Lawrence 1987)—core is not directly seen and sacttering averages the variability.

There are some arguments against this scheme though. (1) Firstly no torus has been observed as yet, but that is perhaps due to the difficulty of such an observation; (2) some Seyferts change type rapidly; (3) the torus in NGC 1068 does not seem to reradiate in mid-IR as expected (Cameron 1993); (4) NGC4151 is a Syfert 1 although the line of sight is outside the opening angle of the NLR cone (Evans et al 1994), and so on. Perhaps orientation is not the only story.

There are similar unification schemes for radio-loud AGNs. One scheme unifies FR2 galaxies with radio-loud quasars (Barthel 1994), and another unifies FR1s with BL Lac objects (Urry and Padovan 1994). In the first scheme

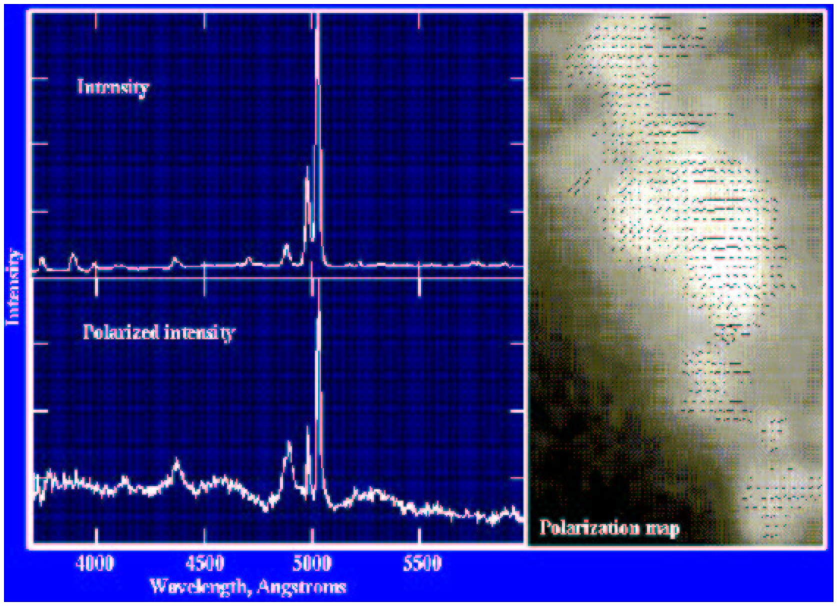

Figure 2: The spectrum of the polarized (i.e, scattered) light from NGC1068 shows broad emission lines.

one says that the parent population is FR2 galaxy, and it looks like a radio-loud quasar when viewed end-on because the radio jets become more prominent due to Doppler boostin, the lobe separation is foreshortened and the optical core dominates the host galaxy, and one can see the BLR. In the second scheme the parent population is FR1 galaxies, which have many common properties with BL Lac obhects—their host galaxy morphology, optical emission line widths etc. When the jet is pointed towards us, we find it as a BL Lac object because the Doppler boosting is large and we find a point source that swamps the parent galaxy.

1 X-ray and γ-rays from AGNs

The X-ray spectra in the range of 2-20 keV in general has a power law of index ~ 0.7. The standard model for decades have been to inject monoenergetic relativistic electrons into a region filled with soft photons. The electrons would produce gamma rays through inverse Compton scattering, which would produce pairs from photo-photon interaction, which would then lead to a pair cascade, with lower energy particles. It has also been suggested that there is a component from Compton scattering of X-rays from from the accretion disk (Zdziarski et al), although there are problems with the model.

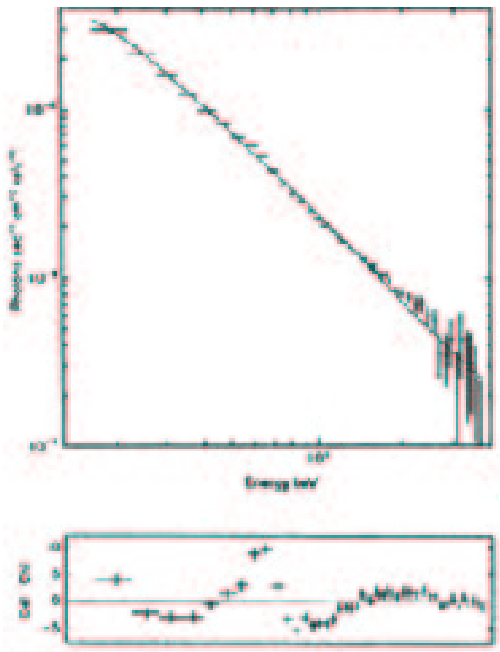

Figure 3: Ginga observation, the power law fit and the residual.

Detail data from Ginga have shown that there are some features superposed on the smooth power law spectra, like an Fe emission line at 6.4 keV and a dip in 7-10 keV range and another excess above 12 keV. These are now thought to arise from reprocessing of the incident radiation from the central hard X-ray source. The emission line has been explained with the help of fluroscence from an accretion disc, after X-ray photons impinge on it, and the the dip with the help of absorption from the edge of the disc and the excess with Comptonized radiation.

An interesting observation was provided by ASCA of the Seyfert 1 galaxy MCG-6-30-15, where the 6.4 keV iron line is gravitationally redshifted because of the strong gravity in the accretion disc region.

Recently the Compton Gamma ray Observatory has detected gamma rays from about a dozen AGNs, which also happened show superluminal motion implying that beaming is important. The gamma rays is thought to arise from the pair plasma in the jet, but details are still not clear.

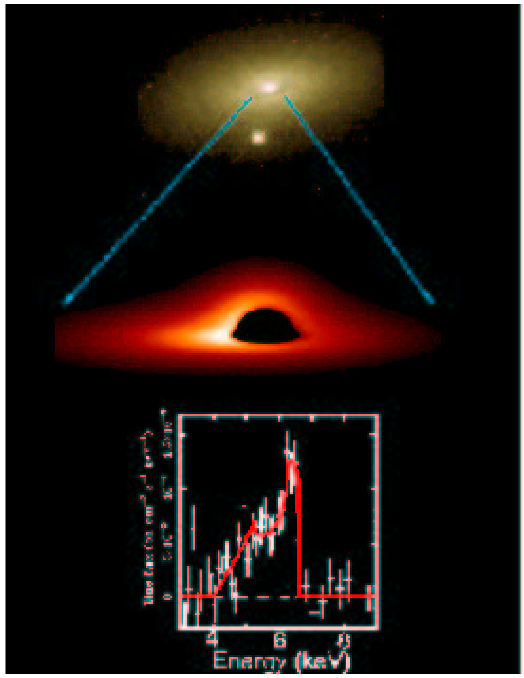

Figure 4: The top image is the optical picture of MCG-6-30-15. The middle image is an artist's conception of the inner part of the accretion disc that produces the iron line. The iron line emission is redshifted by the combination of Doppler and gravitational redshift.

2 Schematic structure of AGNs

- We then find that AGNs are powered by accretion into supermassive black holes ($10^6 - 10^9 M_\odot$). This provides high efficiency of conversion of energy and also satisfies the requirement of small physical size.

- Emission from the accretion disc at different radii explains the radiation at different wavelengths, from optical, through UV to soft X-ray (few keV) continuum, as well as the iron line at 6.4 keV (fluroscence).

- Broad emission line region is photoionized by this continuum radiation. It has a size from a few light-days to light-months, with clouds of density $\geq 10^9$ cm^{-3}. Higher ionization lines come from smaller radii.

- Narrow emission line region is also photoionized, with a size of $101 - 3$ pc, with densities $\leq 10^7$ cm^{-3}.

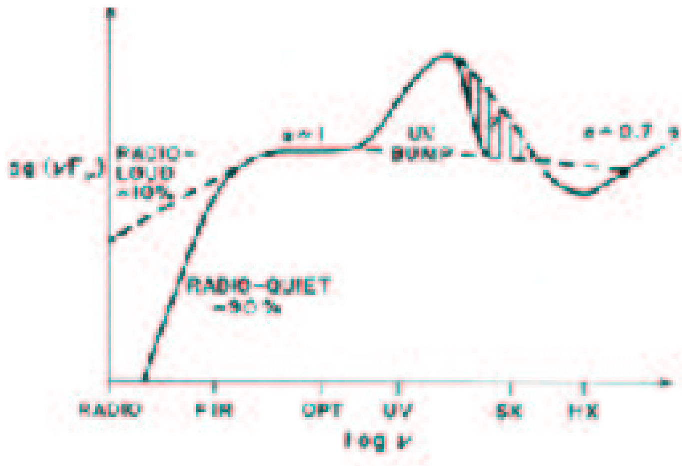

Figure 5: A theorist's spectrum of AGN.

3 Evolution of quasars

Quasars are so bright that they can be observed from a large distance (or redshift), which allows us to determine the evolution of quasars, their space density, and their luminosity function, with time. One usually measures these characteristics in units of the *comoving volume*. If one measures the density of quasars in a volume of 1 cubic mega parsec in the present day universe, one then also measures the density at high redshift in a volume *which would have expanded to 1 cubic mega parsec today*, and one then would have measured the density in the same comoving volume. One essentially factors out the expansion of the universe by this.

Firstly, the number counts, say in radio, clearly shows that there has been evolution. In other wavelengths like the optical, source count of objects is mostly populated by Galactic objects, but in radio, the most luminous objects are extragalactic objects. For any set of sources with constant space density, in a flat universe, one expects that the number of sources above a given flux S is given by $N(>S) \propto S^{-3/2}$. This plot from Windhorst et al (1993) shows the number counts (normalized by the Euclidean expectation; with a slope 2.5 because the differential

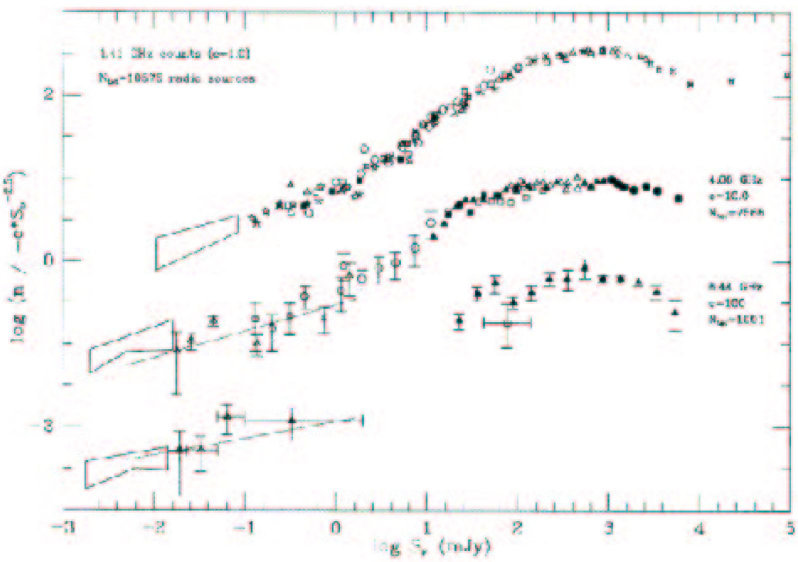

Figure 6: Source count for radio sources.

counts, and not integral counts, are plotted here), shows that there are departures. There is a rise from very high fluxes to lower values, but then there is a strong drop as one goes fainter. At faint levels, one encounters radio emission from normal galaxies and starbursts (the dregs of the universe!). The number density of radio sources therefore rises with lookback time but then the growth dies down.

The luminosity function of quasars however contain more information and one may want to study the evolution of this function with redshift. In a large sample of quasars whose luminosities and redshifts have been determined, one associates with each quasar (labelled i) a comoving volume (depending on its redshift z and the bin-size Δz), $V_{co,i} = c\frac{dt}{dz}dz \times (d_A \times (\mathrm{solid\,angle}))^2$. Here d_A is the angular diameter distance at z. The luminosity function at that redshift is then,

$$\frac{dn}{dL} = \Sigma_i^N \frac{1}{\Delta L V_{co,i}}, \tag{1}$$

where ΔL is the width of the luminosity bin. Of course, this will depend on the cosmological parameters. But the most worrying aspect of this exercise is correction due to redshift if one wants to compare luminosity in a given band. One needs to build an 'average' spectrum to do this k-correction, and uncertainty in this would introduce errors in the luminosity function.

The most recent luminosity functions in visible wavelengths from 2dF survey show that (1) the high luminosity AGNs were about a hundred times at $z = 2$ than today, (2) the difference between the brightest quasar and the weakest Seyfert galaxies is around four decades in luminosity, and that (3) the shape of the luminosity function remains a steep power law at high end, becoming shallower at low luminosity. SDSS survey has given us the statistics at higher redshifts. It is clear that there is a dramatic rise in number density of quasars from now to $z \sim 2$ which then declines at $z > 3$.

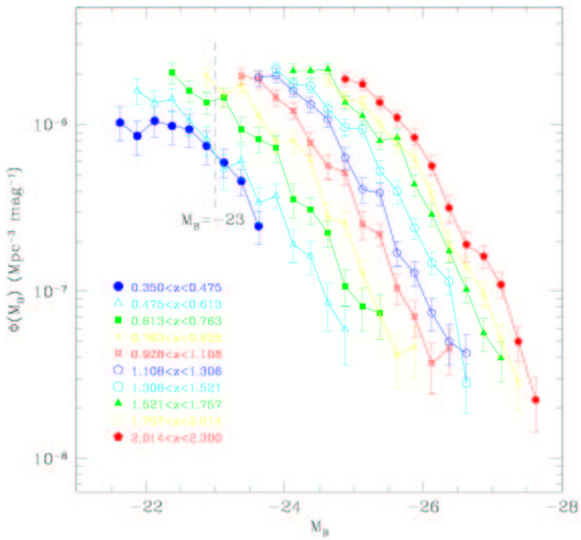

Figure 7: Luminosity function from 2dF survey (Boyle et al 2000).

The luminosity function of radio-loud objects also tell similar stories (Dunlop and Peacock 1990). Divided into flat and steep spectrum sources (that is, core or lobe dominated objects), luminosity functions of both classes evolve strongly between now and $z = 2.5$, although that of steep spectrum sources seems to have evolved more than that of flat spectrum sources. The X-ray luminosity function also has a similar qualitative picture.

There has been a long debate on how to interpret the evolution in LF, whether to parameterize it as density evolution or as luminosity evolution in time. It is clear that there have been evolution in both the number density and the characteristic luminosity. For example, the characteristic luminosity seems to have evolved as $\propto (1+z)^3$ between now and $z \sim 2.5$. The number density of very bright quasars, say, with $M_B < 23$ mag (3 mag brighter than L_* of field galaxies), has increased from 120 Gpc^{-3} at present to about 3.2×10^4 Gpc^{-3} at $z = 2$.

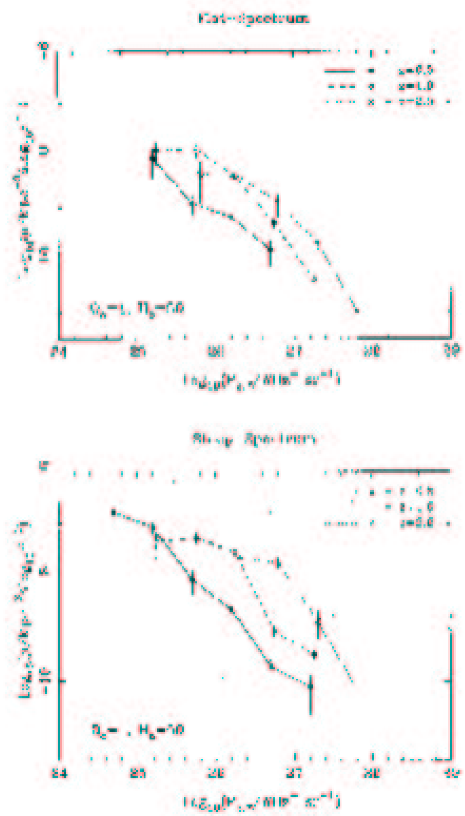

Figure 8: Luminosity function of radio galaxies.

There have been many attempts to understand this evolution in the context of structure formation theories of cosmology. One has the mass function of collapsed objects (say, the Press-Schechter mass function) collapsing at a given redshift z, denoted by $dN(M,z)/dM$. One then finds a rate of formation of objects as $d^2N(M,z)/dMdt$. Quasars are assumed to be active for a duration t_q, and one assumes that every galaxy goes through a quasar phase for this duration. If a galactic mass M_l corresponds to the lower limit that it must have to produce a given luminosity L, then the number density of quasars at redshift z would be,

$$N_Q(>L,z) \sim \int_{\max[t(z)-t_q,0]}^{t(z)} \int_{M_l}^{\infty} \partial dN(M,z)/\partial t dM dt \,, \tag{2}$$

where $t(z)$ refers to the cosmic age at z (Efstathiou & Rees 1988). Variations of this theme have been attempted and there is a general agreement with the data,

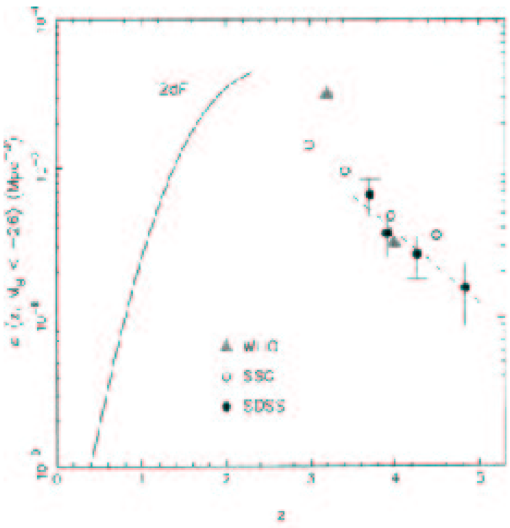

Figure 9: Evolution of number density of QSOs.

which shows that there have been generations of QSOs in the past and that all galaxies have passed through a QSO phase at some time or other.

Estimate the present mass density of supermassive black holes in the universe (dead-quasars)