Lecture 8 : Merger relics and active galaxies

1 Merger relics

It is possible that polar ring galaxies are results of accretion of matter. They usually show a S0 galaxy with a perpendicular ring of material of gas and stars. It is thought that the accreted companion ends up in the disc of the primary, and occasionally the accreted gas can enter a polar orbit. Although most inclined orbits are unstable, those close the perpendicular plane are thought to be stable. Age estimtes of the stars in the rings of a few Gyr show that rings are stable.

Some elliptical galaxies show low surface brightness shells in them. It appears that about half of all field ellipticals and about a third of all field S0 galaxies have shell or arc like features. The shell boundaries are very sharp and often the shell radii on the opposite sides alternate. The shells usually contribute to about 10-20% of the total luminosity and are generally bluer, with color indices similar to disc stars.

It was originally thought to be the result of merger of a small spiral onto a pre-existing ellipticals, but now it is also thought that major mergers between spirals can also be the origin. Stars change their orbits depending on their new energy, after the perturbation. The sharp edges are formed as stars reach apocentre and turn around, which is a slow process. Stars with slightly higher energy then come up to replace them, and they get abit further. The shells therefore move out as stars of different energy populate them. Number of shells therfore increase with age of the system and one can estimate the age since merger from their number. The shell spacing can be a probe of the dark matter halo potential.

Starburst galaxies, or their nuclei, often show signs of a recent and transient increase of SFR by as a large factor (~ 50 typically). They are usually diagnosed from (1) high infrared to blue luminosity ratio, (2) large Balmer-line luminosity and equivalent width, (3) rapid gas consumption timescale from gas mass and SFR (M_g/SFR) and (4) strong radio continuum emission. Many of them are associated with interacting and merging galaxies.

Some very luminous galaxies which have a lot of dust content emit most of their power in far-IR, which are called **Ultra-luminous infrared galaxies (ULIRGs)** (with $L_{FIR} > 10^{12} L_\odot$). It is difficult to ascertain if most of their luminosity is due to starburst or AGN phenomenon. The compact (flat0-spectrum) radio source may indicate AGN whereas there is some diffuse radio emission that can come from star forming nuclei. Condon & Broderick (1988, AJ, 96, 30) have introduced a ratio of radio to far-IR flux densities as a diagnostic, based on the fact that powerful AGNs are usually more radio-loud.

The mergers certainly fuel the **active galactic nuclei** (see below) but simulations still do not have high enough resolutions to say much on this. If some gas reaches the central black hole it can trigger the AGN activity. There is however an angular momentum barrier for the gas, which must be lost in the accretion disc. The images of neighbourhood of some Seyfert galaxies suggest that they are undergoing strong interactions.

We will now discuss the active galaxies in some detail over the next lectures.

There are many abnormal galaxies which contain point-like sources at their centres. These sources are called **Active galactic nuclei (AGN)**. It is possible for an AGN to be so bright as to outshine the whole surrounding galaxy. Yet there are reasons to believe that they must be very small in size, which we will discuss shortly. It therefore seems to be a source of light that is very different from what we have been so far concerned with in this course.

2 Zoo of active galaxies

The first indication of the existence of AGNs came from a study of the nearby spiral NGC 1068. Its spectrum seemed to have a number of bright *emission* lines, unlike the typical spectra of galaxies with only absorption features. Around 1943, Carl Seyfert alerted the community with a list of a dozen such galaxies which had broad and bright emission lines.

Objects like this are now called **Seyfert galaxies**. They are categorized into Seyfert 1 or 2 type galaxies. **Seyfert 1** galaxies have very broad emission lines, including allowed transitions (HI, HeI, HeII) and relatively narrower forbidden lines (e.g., O[III]). The large widths mean that allowed lines originate from sources with speeds of a few thousand km/s, while the forbidden lines correspond to speeds of order $\sim$ 500 km/s. **Seyfert 2** galaxies have only narrow (permitted and forbidden) lines, with characteristic speeds of $\sim$ 500 km/s. All the spectra of course show a continuum, that probably comes from a central source. The continuum level of Seyfert 2 is generally lower than that of Seyfert 1. There are some galaxies which have characteristics of both and are dubbed to be of type 1.5.

Seyfert 1 and 1.5 galaxies are known to be prolific X-ray emitters, much more than Seyfert 2, which perhaps means that there is some absorbing material in Seyfert 2. The X-ray emission is also very variable, with time scales ranging from days to hours.

Seyfert galaxies comprise only about a few tenths of a percent of all field galaxies. Since Seyfert's early work, a number of other types of AGNs have been classified. Markarian, for example, did a survey (1978) of galaxies which were unusually UV bright. We now know that this is due to AGNs. They are called **Markarian galaxies**. There are also galaxies resembling Seyfert 2 type but with forbidden lines mostly from low ionization species. These are called **Low-Ionization nuclear emission-line regions (LINERS)**. They are fairly common and found in about 80% of all Sa and Sb galaxies.

Radio observations are particularly important for active galaxies. Cygnus A was the first radio source that was idenfied with an elliptical galaxy by Baade and Minkowski (1954). There are now a number of detailed catalogues of powerful radio sources, like 3C catalog from Cambridge, and its successors. These sources are generally called **radio galaxies**. About 2/3 of them are associated with elliptical galaxies.

With the advent of radio interferometers, one has been able to study the structures of radio galaxies in more detail. Nearly all radio galaxies have two diffuse radio-bright regions, called **radio lobes**, which are often situated roughly symmetrically on opposite sides of a compact central source. These lobes are most prominent in low frequencies, for which the central source is dim. The nuclear source stands out at higher frequencies. Detail images also show that the lobes are connected to the nuclear source by thin and collimated structures, called **radio jets**. Sometimes, e.g. for M87, the jet is also seen in optical. We will discuss radio galaxies in more detail later.

Positions of some radio sources coincide with unresolved point sources rather than elliptical galaxies. These star-like sources are called *quasi-stellar radio sources (quasars)*. Spectrum of a quasar 3C 273 taken by Schmidt (1963) showed that it looked similar to that of a Seyfert 1, with emission lines, only redshifted by $z = \delta\lambda/\lambda = 0.16$. The similarity with Seyfert galaxies mean that they are perhaps their distant counterparts, with the redshift arising from expansion of the universe. They are so distant that the angular sizes are comparable to the region of their nuclei blurred by seeing. The nuclei therefore outshines the stellar light from the host galaxy and they appear to be point-like objects.

There are also **quasi-stallar objects (QSO)**, which are often called *radio-quiet quasars*, which are not strong radio sources. They are very similar to type 1 Seyferts, and in general such objects with $M_v < -23$ are called QSOs.

Then there are **BL Lacertae (BL Lacs)** objects that are unresolved optically and which can vary in luminosity by an order of magnitude in less than a month.

Their spectra are very non-thermal with power law behaviour without any emission or absorption lines. They are also very strong radio sources, compact in angular size and with strong variability. Radio observations show strong linear polarization, perhaps due to magnetic fields. We now know that the host galaxies are normal elliptical galaxies, from spectroscopy.

BL Lacs are now grouped into a closely related category called the **blazars**. This group also contains a class of AGNs called **optically violently variable quasars (OVV)**, which are in many respects similar to BL Lacs—they are strong radio emitters, vary in brightness by large factors on timescales of weeks and their radio and optical emissions are strongly polarized. But OVVs possess the broad optical emission lines that are characteristic of quasars.

A comprehensive catalogue of QSOs is that of Hewitt and Burbidge (1993) with 7315 objects in it. These compilations show that for every radio-loud AGN there are about 20 radio-quiet AGNs. It also seems that BL Lacs comprise only about 1% of the total population.

The bolometric luminosities of quasars range from $1-^{45}$ to more than 10^{48} erg/s, a typical value being 5×10^{46} erg/s. This implies that a typical quasar is more than a thousand times luminous than our Milky Way. A typical AGN spectrum spans many decades of frequency than a sharply peaked blackbody curve of a star, for example. It is clear from the spectrum that non-stellar processes are responsible for radiation from AGNs. Quasars are very blue compared to other objects in the sky, with a typical colour of $U-B \sim -0.5$ and $B-V \sim 0.4$. The blue colour comes from the ultraviolet bump between 10^{14} and 10^{16} Hz, which is a distinctive feature of all quasars.