Lecture notes 19: Active Galaxies

In 1944 an radio amateur, using self built equipment, picked up signals from three source in the night sky: from the center of the Milky Way, Sagitterius A; from a supernova remnant Cassiopeia A; and from an unknown source Cygnus A. The latter region of strong radio emission was ?rst optically identi?ed in 1952 by Walter Baade and Rudolph Minkowski using the giant 200-inch re?ector at Mount Palomar Observatory to be a faint dust-lane elliptical galaxy (3C 405). At the time this was the most distant galaxy known with a red shift $z = 0.057$, equivlent to 220 Mpc. The luminosity of the radio emission is some 10^7 the radio luminosity of a normal galaxy.

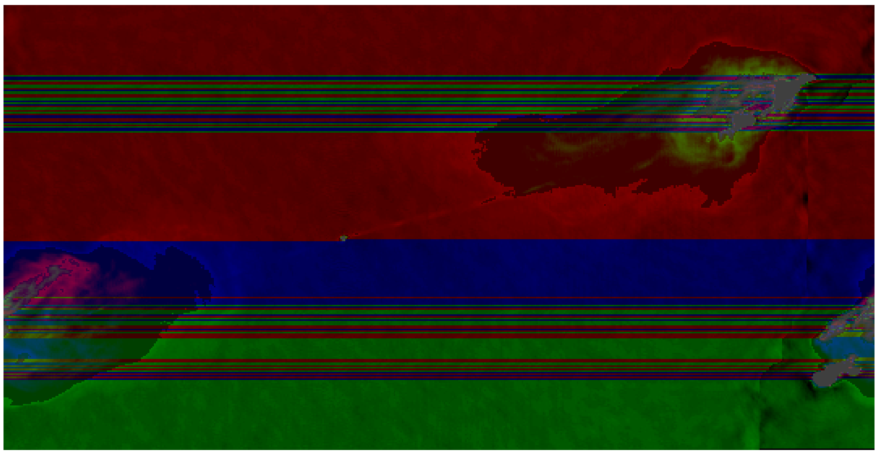

Figure 1: This image is a radio map (at a wavelength of 6 cm) of the powerful radio galaxy Cygnus A, produced from observations at the Very Large Array by John Conway and Philip Blanco in March 1994. The 2 x 1 arcminute image shows Cygnus A?s famous double radio lobes, spanning over 500,000 light years, which are fed by jets of energetic particles beamed from the compact radio core between them. The giant lobes are formed when these jets are slowed down by the tenous gas which exists between galaxies.

Quasars and QSO?s

Some years later another radio lound object, 3C 273, was discovered. It?s optical counterpart was steller-like, but with a jet protruding. The spectrum of this ?star? was unique showing strange emission lines indicationg energetic processes. The red shift was also very large $z = 0.158$ indicating a distance of 660 Mpc, much to far away to be a star.

In 1960 Alan Sandage discoverd 3C 48 a radio source with an optical counterpart that looked like a star, but with a redshift $z = 0.367$ or a distance of

1200 Mpc.

All of these objects are examples of **quasars**, from *quasi-stellar radio sources*. Also radio quiet quasars have been discovered, these are also known as as **QSO?s** (quasi-stellar objects). In total 10% of quasars are radio loud, 90% radio quiet. There are now 10 000 quasars known with red-shifts $z = 0.06 ? 5.8$. Most quasars are at $z > 0.3$, *i.e* at distances greater than 1000 Mpc.

Redshift $z > 1$ does not mean that $v > c$. In cases where $z > 0.1$ we must use the equations of relativity: Imagine a source at rest relative the observer that releases light spanning $N\lambda_0$ in time t_0 such than $N\lambda_0 = ct_0$. A source moving with velocity v will during the same duration release the same number of wavelengths $N\lambda$ over time t. In this case these waves are spread over a distance $N\lambda = ct + vt = (c + v)t$. Dividing these relations by each other and remembering that time dilation is given by $t = \gamma t_0$, where $\gamma = \frac{1}{\sqrt{1-v^2/c^2}}$ we ?nd

$$\left(\frac{\lambda}{\lambda_0}\right)^2 = [1 + (v/c]^2 \gamma^2 = \frac{(1 + v/c)}{(1 ? v/c)} \tag{1}$$

This gives

$$\frac{\lambda}{\lambda_0} = \sqrt{\frac{1 + v/c}{1 ? v/c}} \equiv 1 + z \tag{2}$$

It has now become clear that quasars are (very) luminous galactic cores. The luminosity of quasars ranges $L_{\text{quasar}} = 10^{38} ? 10^{42}$ W. Their spectra are dominated by non-thermal radiation and emission lines indicative of energetic processes with line widths indicating velocities of up to 10 000 km/s.

Radio quiet quasars (QSO?s) are observed to associated with spiral galaxies while the radio loud quasars are found in elliptical galaxies. A large percentage of quasars have close lying neighbors, seem perturbed in some way, or seem strange in some way. Note also that there are very few near lying quasars.

Seyfert and radiogalaxies

Seyfert galaxies are named for Carl K. Seyfert who in 1943, described them as their central regions having peculiar spectra with notable emission lines. They also have very luminous and dynamical cores. 10% of the brightest galaxies are Seyferts and there are roughly 700 known. The luminosity lie in the range $10^{36} ? 10^{38}$ W. There is also some (weak) radio emission and some Seyferts are colliding pairs og galaxies.

Radio galaxies are elliptical galaxies with strong radio emission, this emission often comes in two lobes as shown in ?gure ?? that are 5?10 times the size of the galaxy. The radio emission is synchrotron radiation, indicative of very high speed electrons in a strong magnetic ?eld. These type of galaxies are found near the center of rich clusters. The luminosities lie in the region $10^{36} ? 10^{38}$ W. One well known example is Centaurus A, which is an elliptical galaxy in collision with a spiral galaxy.

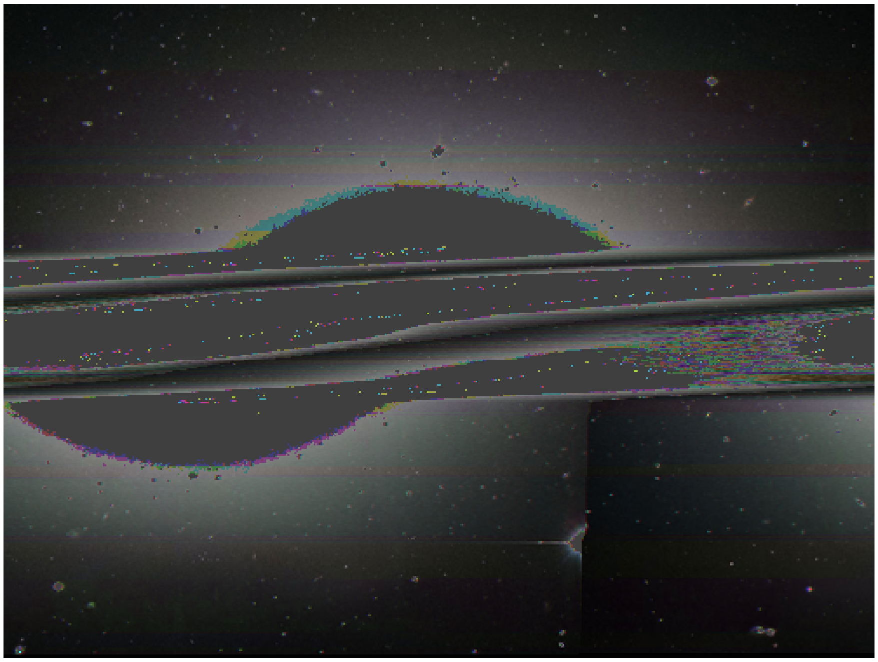

Figure 2: The Sombrero galaxy (M104), a Seyfert galaxy with very luminous dynamic cores. M104 is numerically the ?rst object of the catalog which was not included in Messier?s originally published catalog. However, Charles Messier added it by hand to his personal copy on May 11, 1781, and described it as a ?very faint nebula.? It was Camille Flammarion who found that its position coincided with Herschel?s H I.43, which is the Sombrero Galaxy (NGC 4594), and added it to the o cial Messier list in 1921. This object is also mentioned by Pierre Mchain as his discovery in his letter of May 6, 1783. William Herschel found this object independently on May 9, 1784. Credit: www.seds.org (the text), STScI and NASA.

BL Lacerta objects are star like and show no spectral lines. They are elliptical galaxies with luminous cores, sometimes also known as ?blazars?. They show rapid rotations in their cores with timescales on the order of a few years which means that their cores are small, no larger than ct.

Supermassive black holes

Supermassive black holes were proposed as a uni?ed explanation for all active galactic nuclei (AGN?s) by Donald Lyndon Bell in 1968. These objects are perhaps less strange than one would suppose, the density of mass M contained inside a Schwarschild radius

$$\rho \quad M/V \quad \frac{M}{4\pi R_{Schw}^3/3} \quad \frac{3c^6}{32\pi G^3 M^2} \quad \frac{1}{M^2} \tag{3}$$

falls rapidly with increasing mass and is approximately 0.1? that of water for a black hole of mass 10^9 M_S.

The radiation arises as material rids itself of angular momentum as it descends towards the black hole through an accretion disk. The Eddington limit, set so that the radiation pressure of a compact source does not rip the source itself apart, is

$$\frac{L_{Edd} = 30\,000(M}{M_S)L_S} \tag{4}$$

which gives 10^9 $M_S$for a luminosity corresponding to that of 3C 273. An accumulation of 1 ? 10 M_S/yr gives a supermassive black hole in 10^6 to 10^9 years.

There are many indirect indications that supermassive black holes are common: Motions near the core of the Milky Way and in the Andromeda galaxy, in the core of the giant elliptical M87 - which also shows a jet out of its core, and the galaxy NGC 4261.

The general idea is as follows:

1. Friction caues material to fall towards the black hole and heating of the inner edge of the accreation disk.

2. The infall stops as a result of the conservation of angular momentum.

3. A pressure increase in the inner part of the disk causes material to be shot out perpendicular to the disk in two jets.

4. A magnetic ?eld is induced that helps to collimate the out?ow jets.

Di erent ?types? of AGN?s are due di erent host galaxies or di erent viewing angles. There are no nearlying quasars as most of the potential fuel has been used up by the time of our Universal epoch. However, collisions between galaxies can give new fuel to a sleeping black hole and thus revive it.