Peculiar galaxies: starbursts and AGNs

Peculiar or abnormal galaxies are those which have:

- unusual spectral distributions (i.e. very powerful in radio wavelengths)
- “funny” (unusual) photometric properties or optical appearance

Starburst galaxies

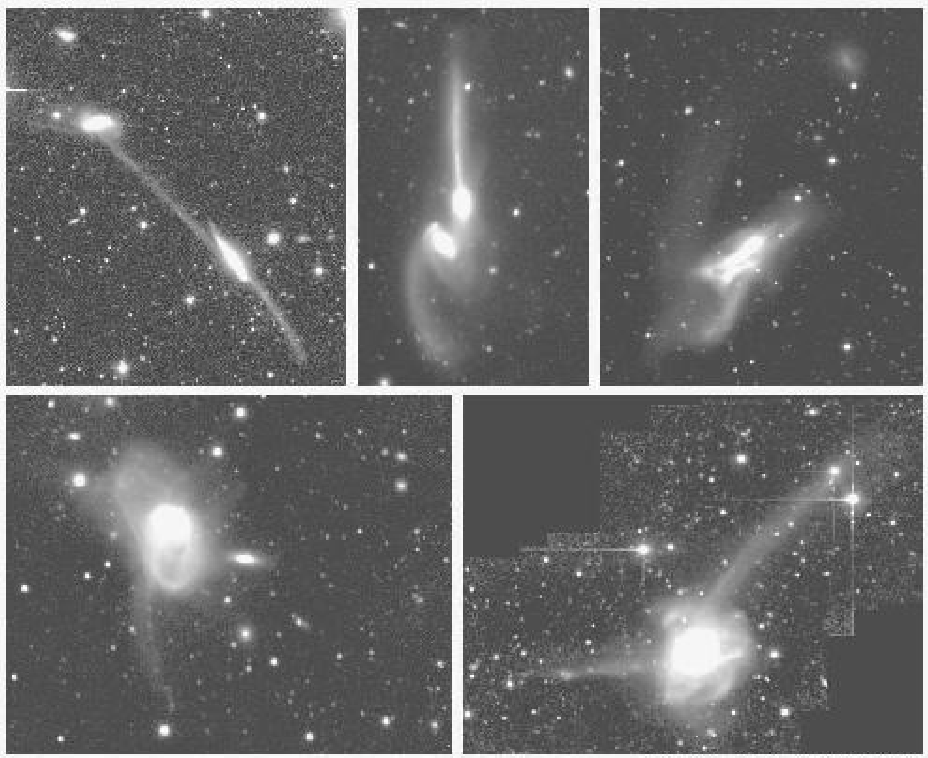
Many funny-looking galaxies show a broader distribution of colours.

Many are bluer, which can be interpreted as due to the presence of a significant population of young stars.

Mostly identified by their optical appearance: jets, ring-like features, tails

Starburst galaxies

Many of the peculiar features can be attributed to interactions or collisions between galaxies



Hibbard & van Gorkom 1996, AJ. 111.655

Quite often the new (or central) object can be fit by an $R^{1/4}$ profile, implying that it may evolve into an E.

The general picture is that one is observing the merging of 2 disk galaxies. The gas in these disks collapses to the centre, and there it is transformed into stars, over a very short timescale (hence the starburst).

Further support interactions trigger starbursts is that these galaxies are also very luminous in the infrared: the young stars light is being re-emitted by dust at those wavelengths.

Active Galactic Nuclei

Many abnormal galaxies contain peculiar point-like sources at their centres; these can be so bright that they outshine the galaxy.

AGNs (or active galactic nuclei) are compact: they show variability on short timescales. They may experience drastic luminosity changes on months-years scales. If ΔT is the time to adjust to a new luminosity and a is the size of the source, then $a \sim c\,\Delta T$, implying that the scale of the source should be much smaller than 1 pc!

There are several classes of AGNs, and they generally divided into radio-loud and radio-quiet.

The various classes of AGNs are: Seyferts, Radio-galaxies, Quasars, ...

Active Galactic Nuclei: Seyferts

Seyfert galaxies are classified into type I and type II

- are radio-quiet
- found in the nuclei of spiral galaxies
- show high-excitation lines

Seyfert I galaxies:

- Show both broad and narrow line emission.
- The narrow lines indicate both permitted and forbidden transitions; implying low density (ionized) gas; the typical widths correspond to velocities of ~ 500 km/s
- the broad lines are only permitted transitions, and hence correspond to higher densities; their widths indicate velocities of 1000 – 5000 km/s

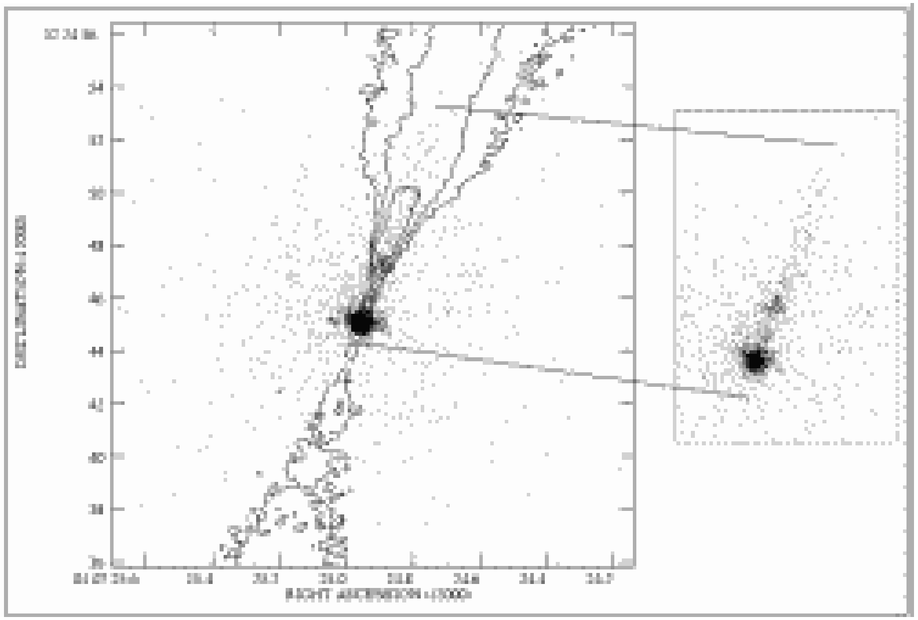
Seyfert II galaxies: (1/3 of pop.)

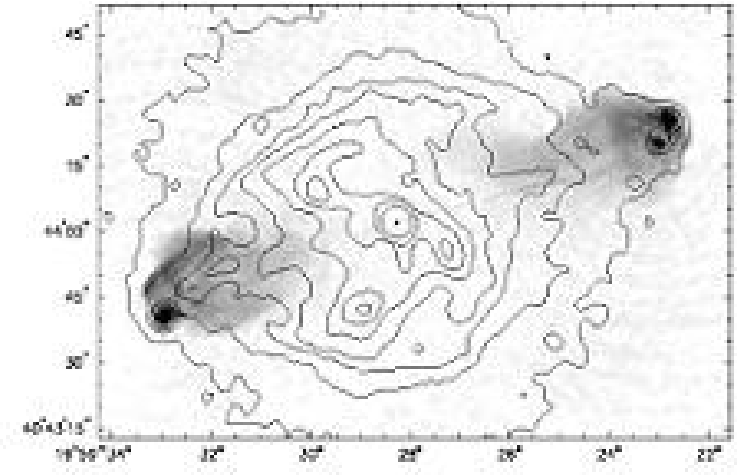
- Only show narrow lines

Radio-galaxies

These galaxies are strong radio sources, and are typically associated to giant elliptical galaxies.

They have a characteristic morphology, which includes a nuclear compact source (bright at higher frequencies), radio lobes (extent from a few kpc to Mpc scales), jet (not always present).





Quasars and QSOs

QSOs (Quasi-Stellar Objects) are
- unresolved point-sources
- strong-emission lines (unlike stars)
- have a broad spectral energy distribution (they are very luminous in almost every band, outshining the host galaxy)
- located at cosmological distances (the Doppler shifts of their lines indicates that they are at high-redshifts, from z~0.1 to z~6)

Quasars (Quasi-stellar radio sources) share the same properties as QSOs but are radio-loud.

Quite often, these objects are called QSOs, and one speaks of radio-quiet or radio-loud QSOs.

Because of the redshift distribution they are cosmologically interesting:
to trace large-scale structure, the chemical enrichment of the intergalactic medium...

The physics behind AGNs

We mentioned initially that the variability observed in the luminosity of AGNs indicates that whatever mechanism is responsible, it must arise from a very compact region.

The paradigm is that the engine of an AGN is a super-massive black hole which is accreting material from its surroundings.

Let us consider a SMBH (point source) surrounded by a highly ionized isotropic distribution of gas, in equilibrium. Any gas particle will suffer from 2 forces: gravity and the radiation pressure force.

The radiation pressure force is produced by the radiation that is emitted by the central object (associated to the SMBH). If this source emits photons of carrying a luminosity L, their momentum is L/c, so an electron at radius r from the source receives momentum $\sigma_e L/(4 \pi r^2 c)$ each second.

Here, σ_e is the cross section of the electron (it is known as the Thomson cross-section: it corresponds to the scattering of radiation by an electron).

Therefore, the radiation pressure force is $\mathbf{F_r} = \sigma_e L/(4 \pi c r^3)\, \mathbf{r}$ (points radially outwards)

while gravity: $\mathbf{F_g} = - GM(m_p + m_e)/r^3\, \mathbf{r}$ (points inwards)

Note that here we have taken the gravitational force on the proton and electron. This is because the electrons cannot move outward unless they take protons with them (electrostatic forces are strong enough to prevent the positive and negative charges from separating).

In equilibrium $\mathbf{F_r} + \mathbf{F_g} = \mathbf{0}$.

Eddington luminosity

This implies that, for the radiation pressure force to equilibrate the gravitational pull from the black hole, the luminosity has to be

$L = 4 \pi G c m_p/\sigma_e M$ or $L = 1.26 \times 10^{38} M/M_\odot$ erg/s

This is the maximum luminosity of a source of mass M powered by spherical accretion. It is known as the Eddington limit.

Essentially the fueling mechanism is the transformation of mass into energy. If the energy that is being released is

$E = \eta m c^2$, where η is the efficiency of the process,

then the luminosity L (energy per dt) is

$L = \eta dm/dt c^2$ where dm/dt is the mass accretion rate [1] and, since L is the transf. of potential gravitational energy/per unit time

$L = GM/r * dm/dt$ [2]

From [1] and [2] we note that the efficiency is $\eta \propto M/r$.
Therefore, the more compact the source, the more effective the process is.

For example, the radius of influence of a black hole can be measured by the Schwarzschild radius R_S, (photons inside this radius cannot escape). and $R_S = 2\ GM/c^2$.

For a particle falling of mass m falling from $r = 5\ R_S$, the change in its potential energy is

$U = GMm/(5\ R_S) = 0.1\ m\ c^2$

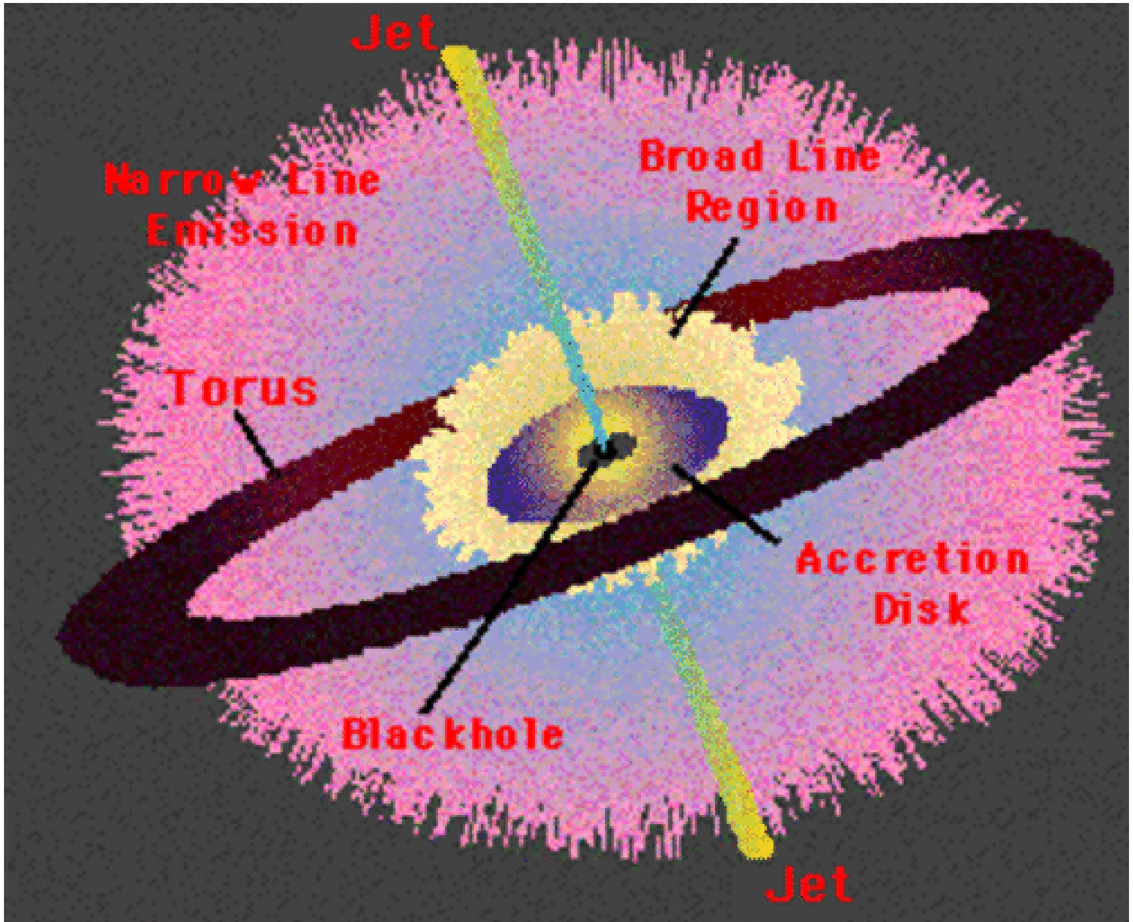
which would imply an efficiency of transforming mass into energy of

$\eta = 0.1$ (for comparison, the efficiency of nuclear reactions in stars is $\eta \sim 0.007$)

The unification scheme

Basic picture: black hole + accretion disk + hot plasma
The gravitational energy released is transformed into heat and luminosity

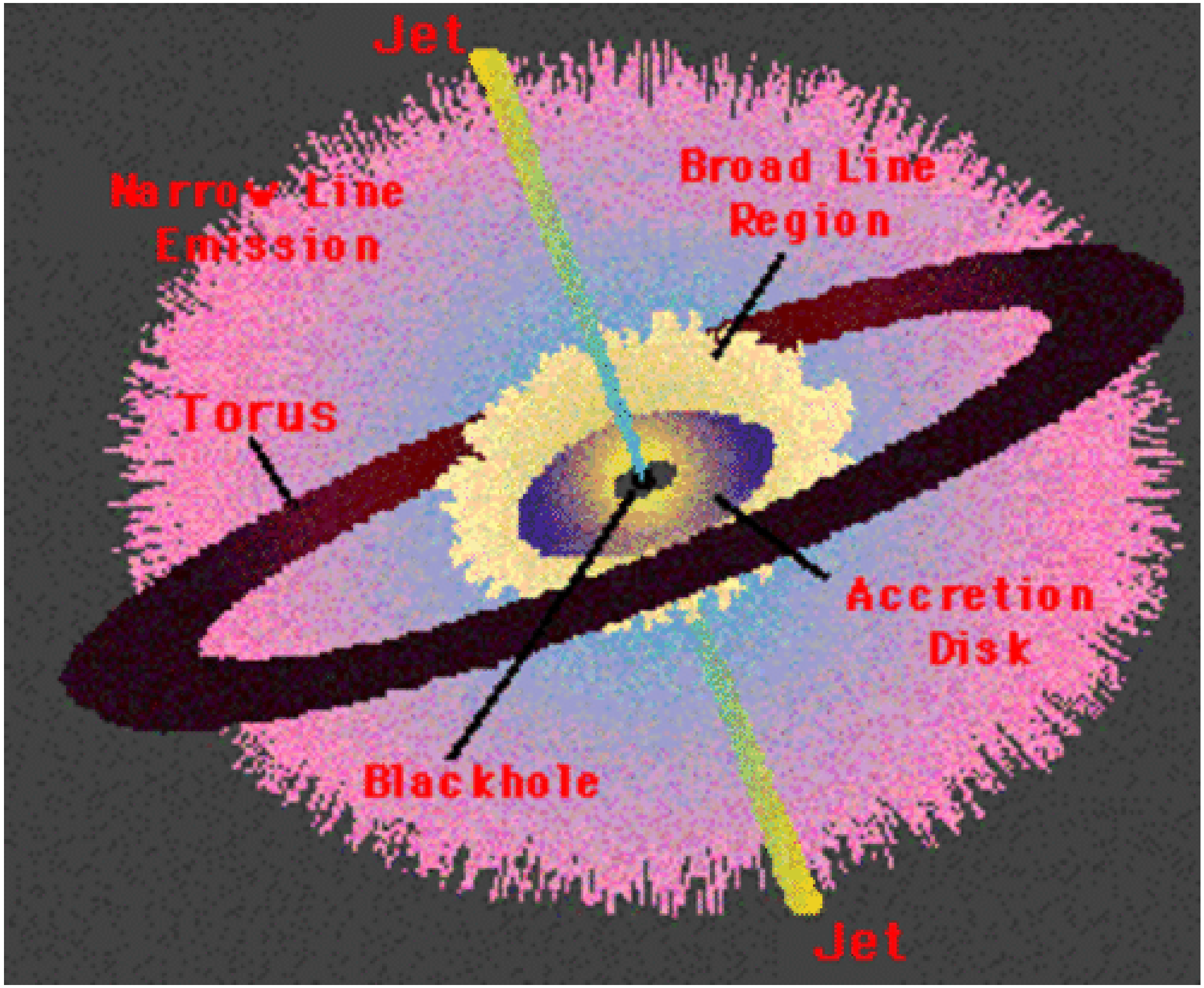
A scheme has been proposed in which the different types of AGNs arise from perspective effects



Seyfert II

Seyfert I

The viewing angle determines what type of AGN will be observed: this is due to the highly anisotropic radiation pattern:
the BLR would be full of clouds moving very rapidly (close to the BH)
the NLR would be located at larger radii and have lower density



Seyfert II

Seyfert I

The unification scheme

This scheme does not explain why some galaxies are radio-loud and why some are radio-quiet. This characteristic will depend on what physical mechanism produces this activity,and it is not clear what this is at the moment.