Plan of Lecture

Superclusters and Active Galaxies

The large scale structure of the universe.

Quasars and their discovery.

Active galaxies.

Supermassive black holes.

Large Scale Structure

Even a cluster is small compared to the universe.

~ 1 **Mpc vs.** ~ 4 **Gpc!**

What does the universe look like on larger scales?

Clusters are often grouped into *superclusters*.

Dozens of clusters.

Spread over tens of Mpc.

There are also large structures: filaments and voids in the distribution of galaxies.

These tend to border *voids* of very few galaxies.

Like soap bubbles!

Clues to structure formation.

Other Probes

Optical observations of the distribution of galaxies are biased.

Only things emitting visible light!

What other methods could we use?

If there distant sources of light, we could look at absorption from them.

Equivalent of absorption nebulae.

In addition, we could use gravitational lensing to map out the true mass distribution.

What sources might suffice?

Distant, bright, pointlike.

The Discovery of Quasars

As radio astronomy grew in the 1940-1960 period, various strange sources were seen.

In 1960, Sandage discovered an optical “star” at the position of the radio source 3C 48.

Series of emission lines.

Couldn’t be identified.

Maybe just one weird example?

No: starlike counterpart to 3C 273.

Also had strange lines!

In 1963, Maarten Schmidt had a “Eureka!”

Lines positioned like hydrogen’s.

But, all shifted!

Equivalent redshift z=0.158.

3C 48: z=0.367.

The Nature of Quasars

More than 10^4 quasars are known.

Large-scale surveys see many more.

Redshifts up to $z \approx 6.5$!

Only about 10% are strong radio emitters.

Their great distances imply incredible luminosities.

$L \approx 10^{46}$ **erg s^{-1} is common.**

Energy is spread over whole EM spectrum.

Very unlike stars.

Some similar objects vary on short timescales.

Hours or even minutes!

What could explain all this?

Ejection From Galaxies?

Starting in the 1960s, a small but vocal group dissented from the "distant quasar" hypothesis.

Halton Arp, Fred Hoyle, etc.

Arp pointed out that many quasars appear close to galaxies on the sky.

But, different redshifts!

If unassociated, why are they nearby?

Arp suggests the quasars were *ejected* from galaxies.

Fits in with Hoyle's cosmology: steady state, no Big Bang.

How can this be tested?

More Clues

Observations in the last ~decade have found faint galaxies around quasars.

Same redshift as quasars.

Therefore, quasars are the bright centers of some galaxies.

What about Arp's observations?

Partly coincidence (projection).

Partly gravitational lensing.

Some of the emission lines from quasars are very broad.

Width: $\sim 10^4$ **km s**$^{-1}$**.**

These are amazingly fast; what could produce such motion?

Active Galaxies

Quasars are dramatically brighter than normal galaxies.

Are there intermediates?

Carl Seyfert discovered one type in 1943.

Spiral galaxies.

Bright, compact nuclei.

Rapid, intense, variation.

Called Seyfert galaxies.

Some ellipticals are called *radio galaxies*.

Strong radio emission.

M87: Heber Curtis, 1918!

Linear or lobe features.

These and other types are collectively known as *active galaxies*.

Superluminal Motion

For some active galaxies, one can see “blobs” of emission.

Over years, one can measure the proper motion of these blobs.

Transverse to line of sight.

From galaxy redshift, get distance; from distance, angular motion, get blob speed.

One problem: the inferred transverse speed often exceeds the speed of light!

Is distance measured incorrectly?

Is special relativity wrong?

No, this is a projection effect.

Predicted from other phenomena!

Requirements for Models

The phenomenon of active galaxies requires a model to explain many observations.

High luminosities.

Broad spectral distribution.

High speeds from lines.

Rapid variability.

Superluminal motion.

Presence in many galaxies.

The rapid variability requires that the emitting object be small.

Variability time T.

Object size $\lesssim cT$.

$<$ size of solar system!

Supermassive Black Holes

In 1968, Donald Lynden-Bell made a suggestion.

"Central engines" are black holes!

Supermassive, $M \sim 10^6 - 10^{10}\, M_\odot$.

Gas in the vicinity can be attracted to the black hole.

Spirals in.

Friction with itself.

Releases energy.

Can release $\sim 10\%$ of the mass-energy of the matter.

Most released close to hole.

Compact and bright.

Can a black hole emit an arbitrarily high luminosity this way?

The Eddington Luminosity

Assume accretion and emission are both spherically symmetric.

Consider a particle in the flow.

Attracted by gravity.

But, pushed outwards by radiation.

At low fluxes, gravity wins.

But, eventually the flux gets high enough to offset gravity.

No more accretion possible!

Accretion is self-limiting.

Under normal circumstances, the limit is just $L_E \approx 3 \times 10^4 L_\odot (M/M_\odot)$.

How could it be violated?

Effects of Black Holes on Galaxies

Supermassive black holes are low-mass compared to their host galaxies.

$\sim 2 \times 10^{-3}$ **of bulge mass.**

Therefore, the gravitational influence is small.

But what about other influences?

One general scenario suggested to explain the $M - \sigma$ relation is as follows:

Galaxy starts off mostly gas.

SMBH starts forming.

Luminosity grows, blows gas out.

Black hole stops accreting.

Stars don't form as much.

Therefore, BH might influence galaxy formation!

Effects of Black Holes on Clusters

Now let's return to cooling flows.

Recall: heating process needed.

Chris Reynolds (UMd) and others have worked on the following idea:

Active galaxy in cluster core.

Jets spew out hot gas.

Gas is mixed into cluster.

Voila! Heating accomplished.

Looks promising, but full 3-D simulations have yet to be done.

Summary

Clusters are often grouped in superclusters.

Filaments, sheets, voids.

Quasars and other active galaxies are energetic and violent.

Supermassive black holes explain evidence.

SMBH can have big effect on environment!

Challenge: what is the largest structure ever seen in the universe?