Plan of Lecture
The Unified Model and Lensing

Review of exam.

Types of active galaxies.

Unified model of active galaxies.

Gravitational lensing and applications.

Second Exam

Tougher than first.

- **Average 109/150 (73%).**

Overall happy with performance.

- **Recognition of wrong answers.**
- **Good job on quantitative questions.**
- **No widespread misunderstandings.**

Types of AGN

In the decades following Schmidt's realization about quasars, many AGN varieties were discovered.

Distinguished by various properties:

Narrow or broad lines.

Amount of radio emission.

Shape of radio spectrum.

Degree of polarization.

Inferred luminosity.

Features in optical spectrum.

Rapidity of variation.

Are these really intrinsically distinct objects?

The Unified Model

In the 1980s, a consensus arose about how to bring all the types together.

In this "unified model", all AGN have several things in common.

Supermassive black hole in center.

Accretion disk.

Torus of gas and dust.

The main difference is *orientation*. Are we looking through the hole or side of torus?

If through hole, see deep into gravitational well.

Broad lines.

If side, see more distant, slowly-moving gas.

Narrow lines.

A Matter of Spin

What about the jets?

Here, the unified model points towards black hole spin.

- **Magnetic fields in disk thread hole.**
- **Twisted around by spacetime.**
- **Outflow along rotational pole.**
- **Relativistic speeds.**

Maybe slowly rotating BH don't have jets.

- **Still a matter of controversy.**

If jet is pointed nearly at you, get blazar.

- **Many relativistic effects!**

Measuring Spin, Part 1

Mass comes from orbital measurements. How about spin?

Effect is in dragging of spacetime.

Only significant near hole.

As always, can turn to spectroscopy.

Inner shell of iron.

Fluorescence.

Highly ionized, near hole.

Breadth and character of line indicate rotation and general relativistic effects.

Some holes rotate fast!

Measuring Spin, Part 2

Another way to measure spin comes from timing.

Innermost stable circular orbit: $r = 6GM/c^2$ for nonrotating hole, less for rotating.

Maximum stable frequency.

If higher frequency is seen, indicates spin.

Quasi-periodic oscillations.

Seen in stellar-mass black holes.

Not yet in AGN.

Much current discussion about what the spin *should* be.

Beyond the Unified Model

In addition to AGN themselves, people have suggested links with other objects.

Some early galaxies have a lot of luminosity, but it comes out mainly in the infrared.

Ultraluminous infrared galaxies.

How does this happen?

IR emission means obscuring dust.

AGN at center?

Or maybe burst of star formation?

In any case, the predominance of bright AGN at early times suggests that most have exhausted their fuel.

Fossil black holes!

Gravitational Lensing

Like anything else, light follows the curve of spacetime.

Passes distance r from mass M.

Total deflection $\Delta\theta \approx 4GM/c^2$.

Weak gravity limit.

Twice Newtonian value.

Different photons follow different paths, depending on how close they come to masses.

Can see two images!

Even if you can't see two images, lensing can increase the number of photons that get to you from source.

Brightens object.

More on Gravitational Lensing

Surface brightness is conserved.

Brighter means bigger image!

Might see more detail.

If you see two images, they traveled different paths.

Different distances.

Time delay.

Gravitational radius $r_g = GM/c^2$ enters in many ways.

E.g., time delay $\sim r_g/c \sim 5\mu\mathrm{s}(M/M_\odot)$**.**

Image separation is arcseconds for galaxies, microarcseconds for stellar-mass lenses.

Application: Microlensing

Let's return to dark matter in our galaxy. What is it?

Maybe dim stars, planets in halo?

One way to find out: monitor millions of background stars, look for signs of lensing.

MACHO, EROS, OGLE, AGAPE.

Lensing objects are low-mass.

Can't see two images or delay.

Can see achromatic brightening.

Many examples; not enough for DM.

Find planets with $P_{\rm orb} < 3$ days!

Application: Quasars

In 1979, QSO 0957+561.

Two quasars 6" apart.

Same spectra, redshift.

Binary quasar, or lensed?

Spectra aren't completely identical; different paths, different absorption.

Crucial test: correlated variability.

Seen! Delay is ~ 420 **days.**

Several other examples seen.

However, these are relatively uncommon.

Magnification Bias

In principle, the fraction of quasars lensed could tell us about cosmological parameters.

Cosmological constant!

If high, more multiple imaging.

However, in a magnitude-limited sample we have a bias.

Lensing increases flux.

Makes easier to see.

Fraction of lensed quasars goes up.

Therefore, to do this right, you need to apply uncertain corrections.

At this time, more promising to do detailed models of individual sources.

Galaxies can make many images.

Summary

Many properties of AGN are explained by the unified model.

Line of sight.

Spin of black hole.

Gravitational lensing can create multiple images and time delays.

Challenge: how far is the focal point for light just grazing the limb of the Sun?