Plan of Lecture

Black Holes

History of black holes.

Properties of black holes.

Detecting black holes.

Types of black holes.

History of Black Holes

In 1784, John Michell suggested:

Stars have escape velocity.

Speed of light is finite.

Biggest stars might be dark!

Michell based his ideas on Newton's concept of gravity.

He would have thought:

Rocket could land and take off.

Light would move away, fall back.

Modern concepts are different.

History of Black Holes, Part 2

In 1915, Einstein published the final version of general relativity.

In 1916, Karl Schwarzschild found a solution to Einstein's equations.

If $R < 2GM/c^2$, funny things happen...

Not clear that such things could really exist.

Chandrasekhar proved upper mass limit to white dwarfs.

Still disbelief about BH (including by Einstein), because of misunderstandings.

Cleared up in 1957, but do they really exist?

Event Horizons

Let's go back to some black hole properties.

The most important feature is the *event horizon*.

This is the "point of no return"; once inside, nothing can escape.

$R = 2GM/c^2$.

Not a surface!

Unlike what Michell thought, once inside event horizon you can't make *any* outward progress.

Event horizon does *not* necessarily kill you.

Tidal forces only.

Infinite at *singularity*.

No Hair

An isolated black hole is the simplest macroscopic object in the universe.

Only three properties:

Mass, spin, electric charge.

In practice, electric charge is negligible (significant amounts would neutralize).

Black holes are therefore mathematically elegant.

However, there are many effects associated with BH...

Light Bending

In weak fields, gravity bends light slightly.

Near BH, a lot!

Photon could *orbit* **at** $r = 3GM/c^2$**!**

Looking close to BH, could see multiple images of individual stars.

At particular angles, very bright because of light bending.

Called a caustic.

Bright ring called a "glory".

Frozen Star?

This is the effect that confused Einstein.

Say you watched someone fall into a black hole.

Redshift increases without limit, so time seems to slow down.

Would the person hover just outside the event horizon?

No! Matter of perspective.

The person feels no slowdown.

Even you see light fade fast.

Equivalence principle: to you, locally, everything seems normal.

No frozen surprised aliens around BH!

Frame Dragging

What happens when a black hole rotates?

Nearby spacetime rotates!

Back to the rubber sheet: spin a ball, the sheet gets twisted.

If you drop a particle straight in to a rotating BH (equatorial plane), the particle deflects then goes in.

There is a region *outside* the horizon that forces everything to rotate.

Called the ergosphere.

Can extract energy from rotation!

A nonequatorial orbit will precess.

Hawking Radiation

Consider a perfectly isolated black hole.

The black hole will eventually evaporate by sending off particles!

The particles do *not* come from inside the event horizon.

Virtual quantum pair arises.

BH gravity makes real.

One particle ejected to infinity.

BH loses energy, hence mass.

Probably unobservable: takes $\sim 10^{65}(M/M_\odot)^3$ yr to fully evaporate!

Detecting Black Holes

All these predicted effects are wonderful. But things that go down BH never come up, so how could we see them?

Accreting Black Holes

Despite being one-way gates, black holes power the most luminous persistent sources in the universe.

Consider a BH accreting gas.

From star or ISM.

BH is small, so the gas won't hit it directly.

Angular momentum!

The gas forms an accretion disk.

The gas-gas friction releases energy as the gas spirals closer.

This can release $\sim 5 - 30\%$ of Mc^2!

Dynamical Effects of Black Holes

Even a nonaccreting BH can be seen by its effect on nearby stars.

Stars move in response to other masses.

If a star moves faster than it should, extra mass is around!

Looking at lots of stars allows estimate of mass.

This is seen in our Galactic center and elsewhere.

Types of Black Holes

Two types of black holes have definitely been detected.

Stellar-mass ($M \sim 5 - 20\, M_\odot$).

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

There is growing evidence for an intermediate-mass class ($M \sim 10^{2-5}\, M_\odot$), but not conclusive.

Some speculation of mini black holes produced in early universe.

Small enough for Hawking radiation?

However, no evidence at all for mini-BH.

Summary

Black holes have an event horizon.

Not a physical surface.

One-way ticket!

Only mass, angular momentum play a role for BH.

We see them by their indirect influence.

Stellar-mass and supermassive BH are known, but others likely exist.

Challenge: what would happen if a mini black hole hit the Earth?