A huge great enormous thing, like — like nothing. A huge big — well, like a — I don’t know — like an enormous big nothing ...

Piglet describes the Heffalump in *Winnie the Pooh* by A.A. Milne
"The most incomprehensible thing about the world is that it is comprehensible." - Albert Einstein
The Story begins with Newton’s discovery of gravity
Escape Speed: For the Earth it is 7 miles per second
Simon LaPlace (1749-1827): Asked what would happen if a mass were large enough so that the escape velocity exceeded the speed of light?
Newton found that gravity is a property of **mass** and **distance** between masses.

It provides the explanation for orbits of the moon and planets.

“Nothing yet. ...How about you, Newton?”
Albert Einstein: Gravity is not a force! It is a curvature in Spacetime!
• General Relativity:
  – theory of gravity
  – successfully describes space around us

• Gravity affects space and time:
  – “invisible hills and valleys”
  – gravity curves space-time
Gravity is due to curvature of space-time
Gravity Around a Black Hole

- The density of a black hole is so great that it "pokes a hole" in space-time.
- The black hole region is separate from the rest of the Universe.
A black hole is an infinite abyss in space-time
The Event Horizon

- The distance from the black hole where the gravity reaches the critical limit is called the Schwarschild radius.
- An imaginary surface at this radius is the Event Horizon.
- Once an object is inside the Event Horizon, no light from it can reach the outside Universe. We can never know what is inside.
What it Looks Like
(artist's illustration)
• What about the radius?
  – Simplest black hole has spherical boundary.
  – Would expect $c = 2\pi r_{bh}$, but not so!

  – Why?

  – Find $r_{bh} \gg \frac{c}{2\pi}$ and not measurable

  • Usually use critical radius $r = r_{cr}$
Inside a Black Hole

- **Tidal forces** would rip you apart before you reached the Event Horizon…
- The Black Hole itself probably has nearly no size at all - it is a "singularity".
- Our **ordinary physical laws do not work** under black hole-like conditions.
How would we detect a black hole?
"It's black, and it looks like a hole. I'd say it's a black hole."
There’s a massive (10^8 solar mass) black hole in here.
The Accretion Disk

- Mass falling into a black hole forms a disk of matter.
- This **accretion disk** swirls into the black hole.
- **Jets** of particles form perpendicular to the disk.
Black Holes: What we Observe

- The disk rotates so fast that one side of it looks **blueshifted** to us and the other looks **redshifted**.
Supermassive Black Holes

- At the center of many galaxies there are giant black holes.
- Their masses are millions of times that of the Sun.
- We think there is one at the center of the Milky Way!
Radio Observation

- Fast-moving gas is seen circling a region at the center of a galaxy.
- Jets have created clouds of heated gas in both directions.
Falling into the hole

How matter might fall into a black hole...

1. Blob of gas breaks off disk to spiral towards event horizon
2. Black hole event horizon
3. Blob leaves disk but does not return to same point in orbit
4. 1000-mile gap

... and the data observed during the event

1. Blob brightens and fades due to gravitational redshift of light
2. Blob dims on far side of event horizon
3. Pulse duration shortens as blob spirals inward and fades
4. Blob disappears as it spirals toward event horizon

Source: STSci
• If same mass squashed to smaller size valley is deeper:
  – you need higher escape velocity
• Can make valley deeper and deeper *till nothing known can escape!*
• This is a **black hole!**
• Stellar black holes
  – Form from gravitational collapse (supernova)
  – Normal star fueled by:
    • nuclear fusion
    • outward pressure balances gravity
  – Healthy star is in static equilibrium

• Thermodynamics vs. Gravity
• Gravitational instabilities
  – fuel at center burns out
  – iron core develops
  – decouples
• Prepare for a black hole visit?
  – Can’t cross event horizon
  – Need powerful ship

• Preparation
  – must ask:
    • are there any black holes out there?
    • what kinds of black holes?
    • hostile/friendly characteristics
– 2) Direct evidence:
  • binary stars
  • accretion and X-rays
    – black hole candidates (BHC)

Conception of a binary star with an accretion disk and a black hole
Official black hole candidate
Cygnus X-1
(14,000 light years away)
Steven Hawking: A Modern Einstein
Wormholes: Passages to another Universe?

Black hole in our Universe

‘White’ hole in another Universe?!