Stellar mass black holes

Maximum mass of a neutron star is unknown, but is probably in the range 2 - 3 M_{sun}.

No known source of pressure can support a stellar remnant with a higher mass - collapse to a **black hole** appears to be inevitable.

Strong observational evidence for black holes in two mass ranges:

Stellar mass black holes: M_{BH} = 5 - 100 M_{sun}

- produced from the collapse of very massive stars
- lower mass examples could be produced from the merger of two neutron stars

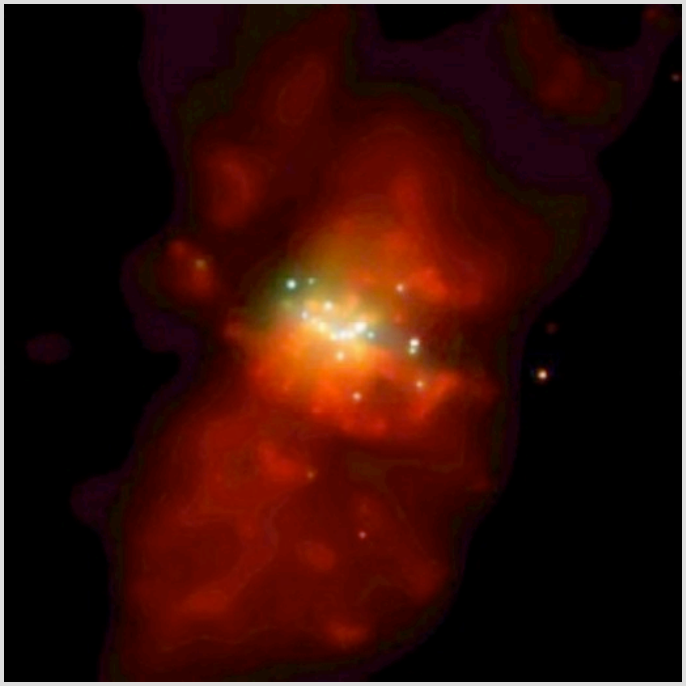
Supermassive black holes: $M_{BH} = 10^6 - 10^9$ M_{sun}

- present in the nuclei of most galaxies
- formation mechanism unknown

Other types of black hole could exist too:

Intermediate mass black holes: $M_{BH} \sim 10^3\ M_{sun}$

- evidence for the existence of these from very luminous X-ray sources in external galaxies ($L \gg L_{Edd}$ for a stellar mass black hole).
- `more likely than not' to exist, but still debatable



Primordial black holes

- formed in the early Universe
- not ruled out, but there is no observational evidence and best guess is that conditions in the early Universe did not favor formation.

Basic properties of black holes

Black holes are solutions to Einstein's equations of General Relativity. Numerous theorems have been proved about them, including, most importantly:

The `No-hair' theorem

A stationary black hole is uniquely characterized by its:

- **Mass M**
- **Angular momentum J**
- **Charge Q**

} Conserved quantities

Remarkable result: Black holes completely `forget' how they were made - from stellar collapse, merger of two existing black holes etc etc…

Only applies at **late times**. Immediately following formation, black holes can have extra structure.

Astrophysical black holes are highly unlikely to have any significant charge. Interesting cases are then:

Q=0, J=0: **Schwarzschild black hole**

Spherically symmetric. Most important property - existence of an **event horizon** at a radius:

$$R_s = \frac{2GM}{c^2} \quad \text{(Schwarzschild radius)}$$

No matter, radiation, or information can propagate outwards through this radius.

For $M_{BH} = 7\ M_{sun}$: $R_s = 20$ km - very similar to the size of a neutron star. Unless we can measure the mass, hard to observationally distinguish between stellar mass black holes and neutron stars…

Q=0, J and M arbitrary: **Kerr black hole**

Axisymmetric solution - hole has a preferred rotation axis.

Define the amount of angular momentum via a dimensionless **spin parameter**:

$$a = \frac{cJ}{GM^2}$$

Maximum angular momentum of a Kerr black hole corresponds to a spin parameter a = 1. Cannot spin a Kerr hole up beyond this limit.

For comparison, $J_{sun} = 1.6 \times 10^{48}$ g cm^2 s^{-1}, M = 2 x 10^{33} g, so for the Sun a = 0.185.

Event horizon □ $\frac{GM}{c^2}$ as a tends to maximal value.

Stellar mass black holes in mass transfer binaries are the best studied systems. Show many very complex phenomena.

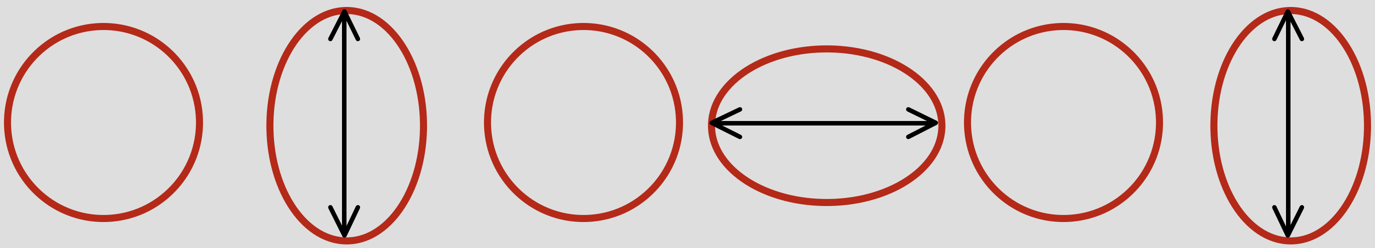
Best hope for studying fundamental physics of black holes is probably to observe **gravitational radiation** as they either form, or as pre-existing black holes in a binary merge.

Axisymmetric systems do not emit gravitational radiation (e.g. pulsars, or Kerr black holes) at all, so need to look for:

- inspiral or merging of black hole binaries
- merger of neutron stars (binary pulsar will merge in a few hundred million years, so we know for certain such events occur)
- signals from black hole formation in core collapse supernovae - **if** the collapse is not axisymmetric…

Gravitational waves from neutron star mergers propagate away at the speed of light - not absorbed by anything.

Pass through the Solar System, effect is to compress space in one direction while expanding space in the perpendicular direction:



Effect is very small - a neutron star merger at d = 100 Mpc produces a fractional distortion of space $\sim 10^{-23}$ at Earth. Two masses 4 km apart oscillate with an amplitude of $\sim 10^{-18}$ cm, much smaller than the size of an atomic nucleus.

Just before merger, frequency of the wave is ~kHz.

Pair of large laser interferometers have been built in Hanford and Livingstone to try to detect high frequency gravitational waves - primarily from merging neutron star and black hole binaries (also maybe supernovae).

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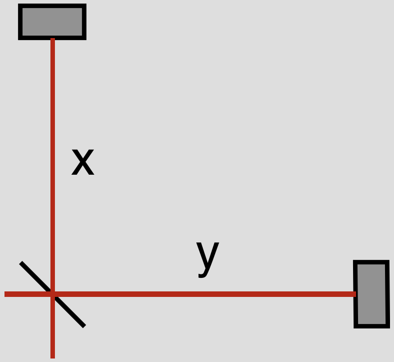

Measure changes in (x-y) with time as wave passes.

Sensitivity attained so far is not good enough to detect any astrophysically plausible sources…