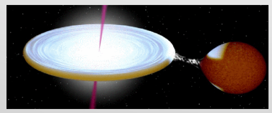
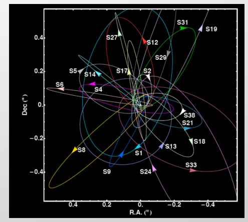
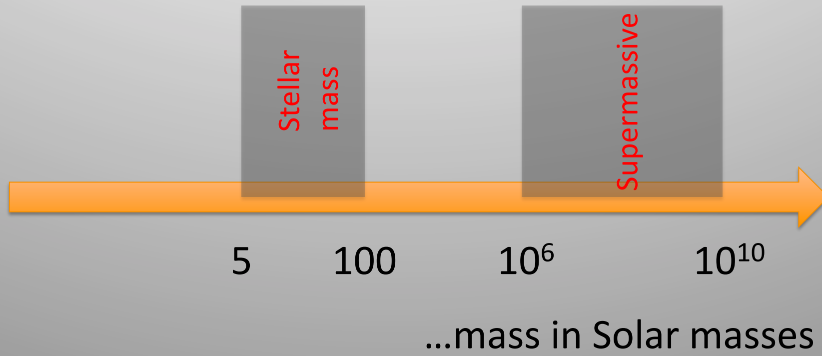
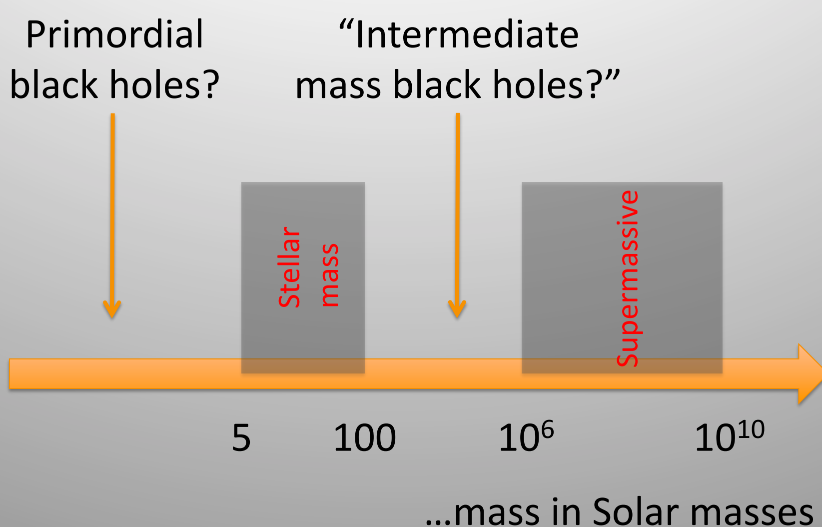
Black Hole Masses









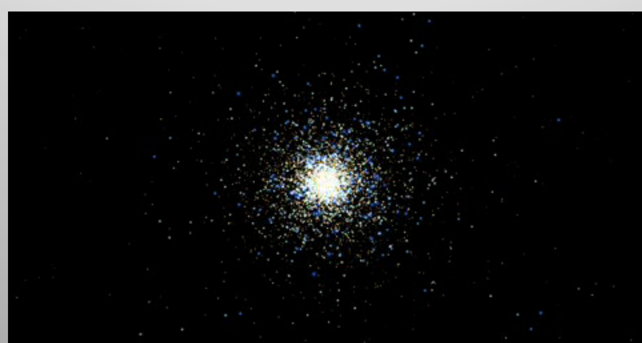
Intermediate mass black holes

Suggested new class of astronomical black holes with masses $10^3 - 10^4$ Solar masses

No *established* formation mechanism, but could form:

- accretion on to pre-existing stellar mass black hole
- supermassive black hole "seed" that fails to grow

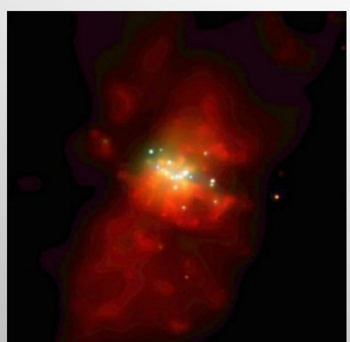
Idea: an IMBH might form in young clusters of stars… massive stars sink to the center, form a *very* massive star, collapse to black hole



movie: Simon Portegies Zwart

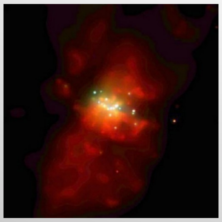
Where to look?

- binary systems
- centers of star clusters (young ones, globular clusters)
- centers of galaxies (dwarf galaxies?)
- in halos of massive galaxies



"Ultra luminous X-ray sources" (ULXs)

- see X-ray sources in some external galaxies that are brighter than stellar mass X-ray binaries
- scaling luminosity, could be 10^3 Solar mass BHs
- are these IMBHs?

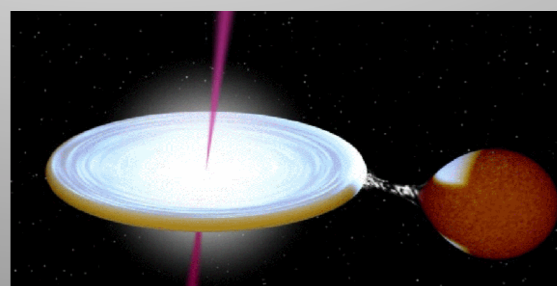


"Ultra luminous X-ray sources" (ULXs)

look along jet or outflow

IMBHs: maybe

Alternative: regular X-ray binaries that seem bright due to beaming



Low mass black holes

Cannot form any black hole with mass below ~2 Solar masses from astrophysical processes in the present day Universe

→ lower mass objects are absolutely stable as neutron stars, white dwarfs, planets, asteroids, comets etc… no need for an energy source

Early Universe was very dense (denser than a present day neutron star)

If it was also sufficiently "lumpy", regions could have collapsed to form ***primordial*** black holes

Mass depends on when they collapsed:

- 10^{-5} s – about Solar mass
- 1 s – about 10^5 Solar mass

Constraints on the Universe at t ~ minute from helium abundance, so hard to make hyper massive black holes

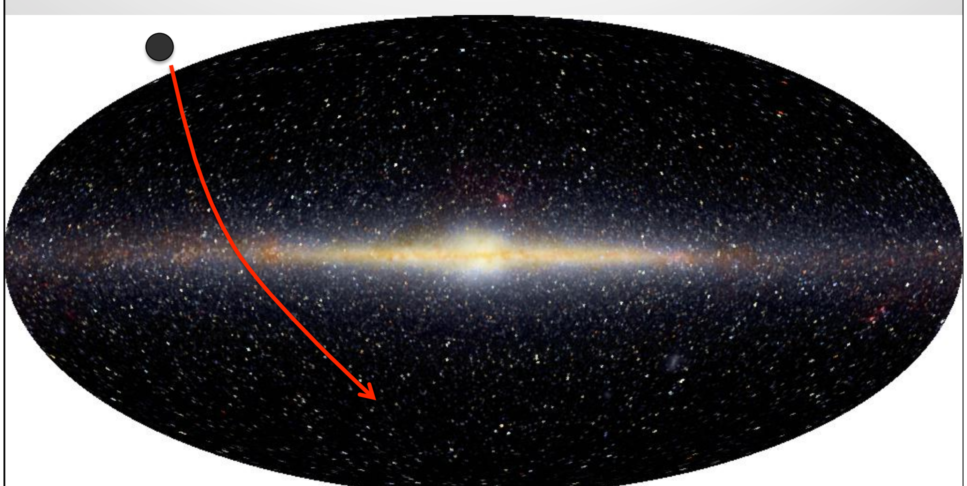
BUT earlier formation, and much lower masses, are in principle possible

Detecting primordial black holes

10^{11} – 10^{12} kg – would be evaporating via Hawking radiation at current epoch… detectable as gamma-ray flashes?

10^{-3} – 10^{2} Solar masses – gravitational lensing

10^{5} Solar masses – gravitational effects?



…too many would "thicken" the Milky Way disk beyond what is observed

No evidence for primordial black holes

Can rule out primordial black holes of many masses being highly abundant (e.g. abundant enough to constitute all the dark matter)

Best understanding of very early Universe does not suggest PBH formation would occur

…BUT we don't know for sure

How small can a black hole be?

No hair theorem: black holes of all masses are just scaled up / down versions with same properties

Limit: black hole whose Schwarzschild radius is the same as the quantum mechanical uncertainty in the position…

How small can a black hole be?

$$E = \frac{hc}{\lambda}$$

Photons with energy E have wavelength λ

Apply to matter: put $E = mc^2$ and set the wavelength equal to the scale of a black hole:

$$\lambda = \frac{Gm}{c^2}$$

…and solve for m

How small can a black hole be?

$$mc^2 = \frac{hc^3}{Gm} \Rightarrow m = \sqrt{\frac{hc}{G}}$$

This is the *Planck mass* – 5 x 10^{-8} kg

Mass or energy scale on which gravity and quantum mechanics are equally important

Collide particles at this energy, expect to form (very short lived) black holes

How large is this energy?

About 10^{15} times larger than attained in the LHC

With *known* physics, don't expect there to be any chance of making black holes in the lab