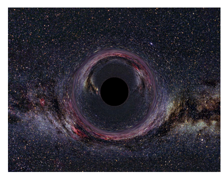
3. Black holes

- A black hole is a region of curved and warped spacetime from which nothing, not even electromagnetic radiation can escape.
- They were first considered at the end of the 1700's by, e.g., Laplace on the basis of Newtonian gravity.
- $v_{escape}=(2GM/r)^{1/2} \rightarrow r_{BH} = 2GM/c_{escape}^2$
- GR predicts black holes as singularities in spacetime.
- Karl Schwartzschild in 1916 found a solution of the GR field equations that characterizes a black hole.
- It has an event horizon as a mathematically defined surface that defines the location of no return.
- Black holes are like black bodies. The event horizon even emits radiation depending on the temperature according to quantum field theory . T α 1/M! That radiation however is miniscule for black hole stellar masses and larger masses.

- With the discovery of neutron stars black holes started to be considered as possibly real objects.
- The term "black hole" was first mentioned by the journalist Ann Ewing in 1964 and then brought to the scientific community by John Archibald Wheeler in 1967.
- There are four different mass ranges for black holes: 1)micro BH, 2)stellar BH, 3)intermediate mass BH, 4)supermassive BH

Micro black holes

- Shortly after the Big Bang the universe was dense enough so that regions of space could fit within its own Schwarzschild radius. But rapid growth prevented the universe to collapse into a singularity. Remnants of this scenario are micro black holes or primordial black holes. Such black holes would have masses larger that 10^{15} g. Less massive black holes would have evaporated already.

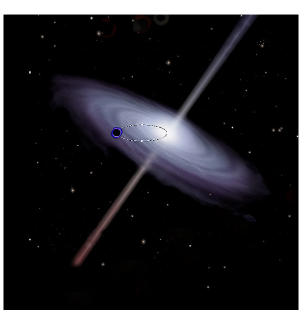


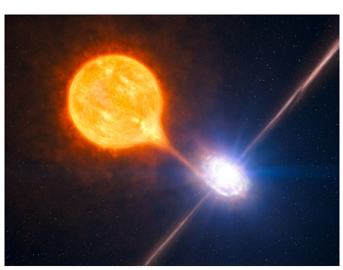
Stellar mass black holes

- Stellar mass black holes are formed through the core collapse of a massive star with about $M>25M_{sol}$. The mass of the resulting black hole is between 3 and ~30 M_{sol}. Gamma ray bursts are candidates where such black holes are formed.
- Only ~15 are known but a few 100 Mill may exist in our Galaxy.
- Stellar black holes can be observed in binary systems where accretion of matter generates x-ray emission.

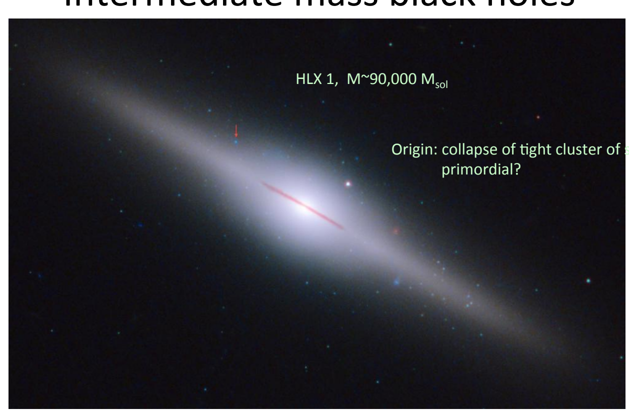
Cyg X-1 (most famous stellar BH)

- Cyg X1, 14.8±1 M_{sol}, P_{orb}=5.6 d, d=6-8 kly.





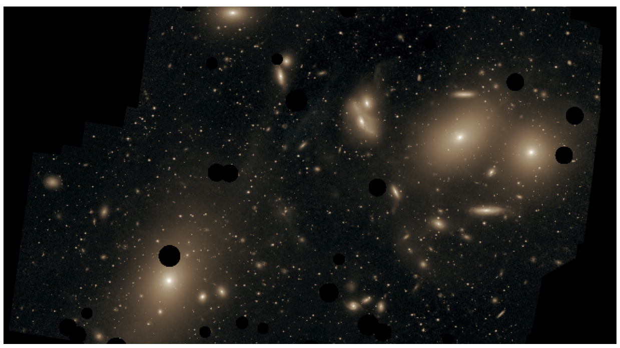
Intermediate mass black holes



Supermassive black holes

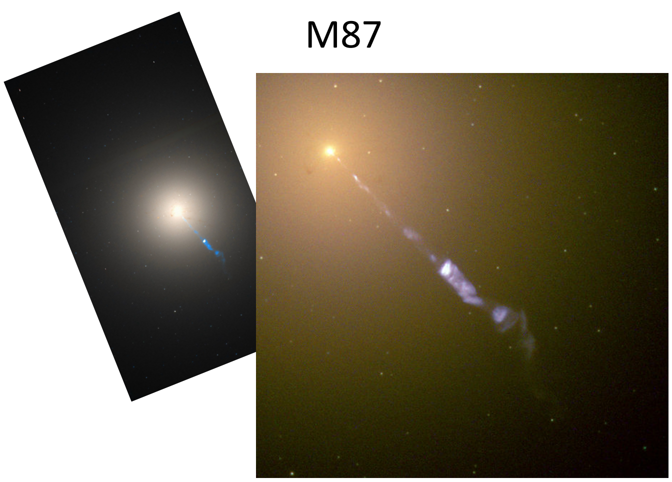
- Supermassive black holes may have originated from many stellar black holes.
- They grew in mass through accretion of ambient medium.
- Every galaxy has a supermassive black hole in its center.
- M between 10^6 and 4 x 10^9 M_{sol}
- Often jets emanate along the spin axis of the black hole with relativistic velocities that appear superluminous when shooting toward us.

M87 in the Virgo cluster

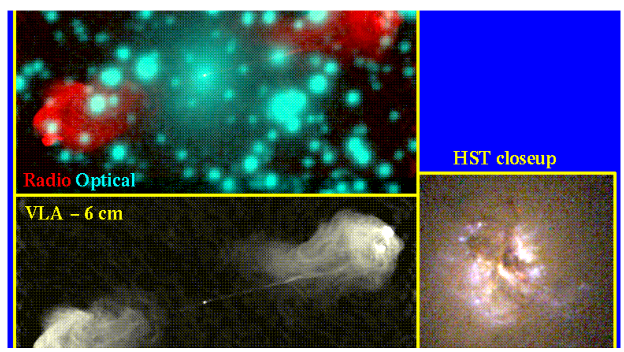


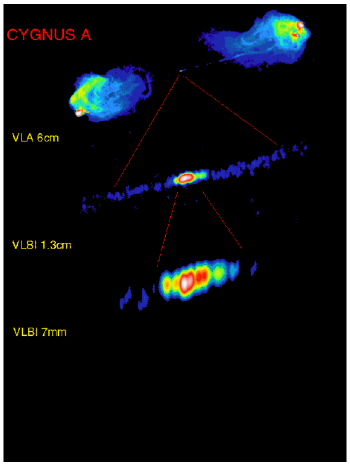
Gas falling into the center of M87

M87



The radio galaxy Cyg A





The center of our Galaxy, Sgr A*

- M=4.1 Mill M_{sol} to fit into Uranus' orbit
- Dormant
- Evidence that it was very active 2,000,000 Mill years ago

Event horizon

- Event horizon given by the Schwarzschild radius: $r_s = 2GM/c^2$
- R_s =3 km, for $M=M_{sol}$
- R_s =1.2 x 10^7 km, for M=4 x 10^6 M_{sol}
- R_s =1.2 x 10^{11} km, for M=4 x 10^9 M_{sol}
- Event horizon could be mapped with mm- VLBI. Sgr A* is 8 kpc = 2.5 x 10^{17} km away. Angular radius of R_s =0.5 x10^{-10} rad = 10 micoarcseconds. With a VLBI array at 1 mm wavelength and 10,000 km baseline→ angular resolution: 1 x 10^{-10} rad! Black hole resolved!