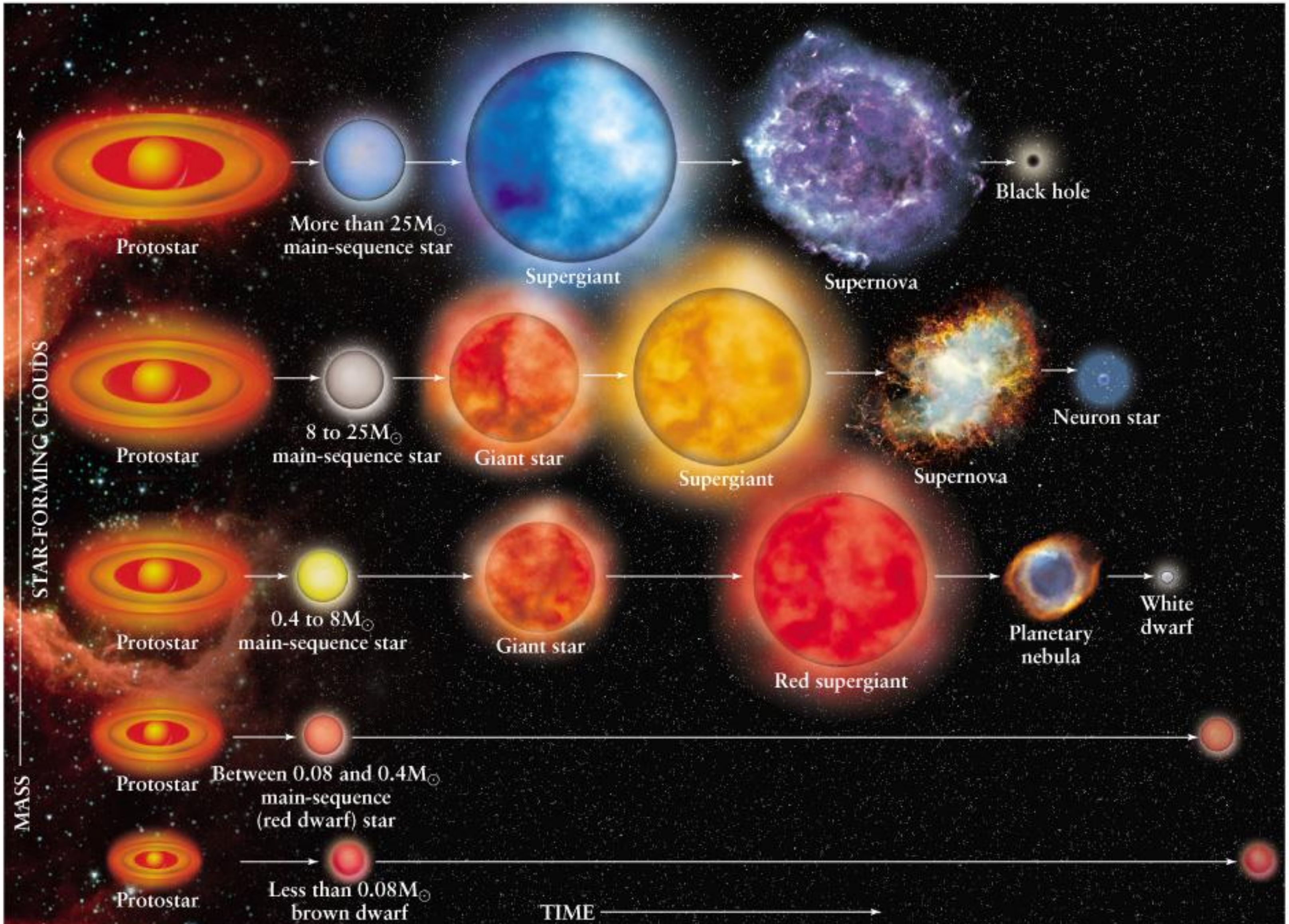
Fate of Stars

INITIAL MASS	Final State
relative to Sun’s mass	
M < 0.01	planet
.01 < M < .08	Brown dwarf (not true star)
0.08 < M < 0.25	not Red Giant→ White Dwarf
0.25 < M < 12	Red Giant→White Dwarf
12 < M < 40	Supernova: neutron star
M > 40	Supernova: black hole

2017: Some very massive stars go directly to a Black Hole without a supernova. Postulated for a while as the number of massive stars seems greater that the number of SN remnants. A BH has been detected without a SN remnant, which seems to confirm this. Some WD can become SN by acquiring mass from companion star

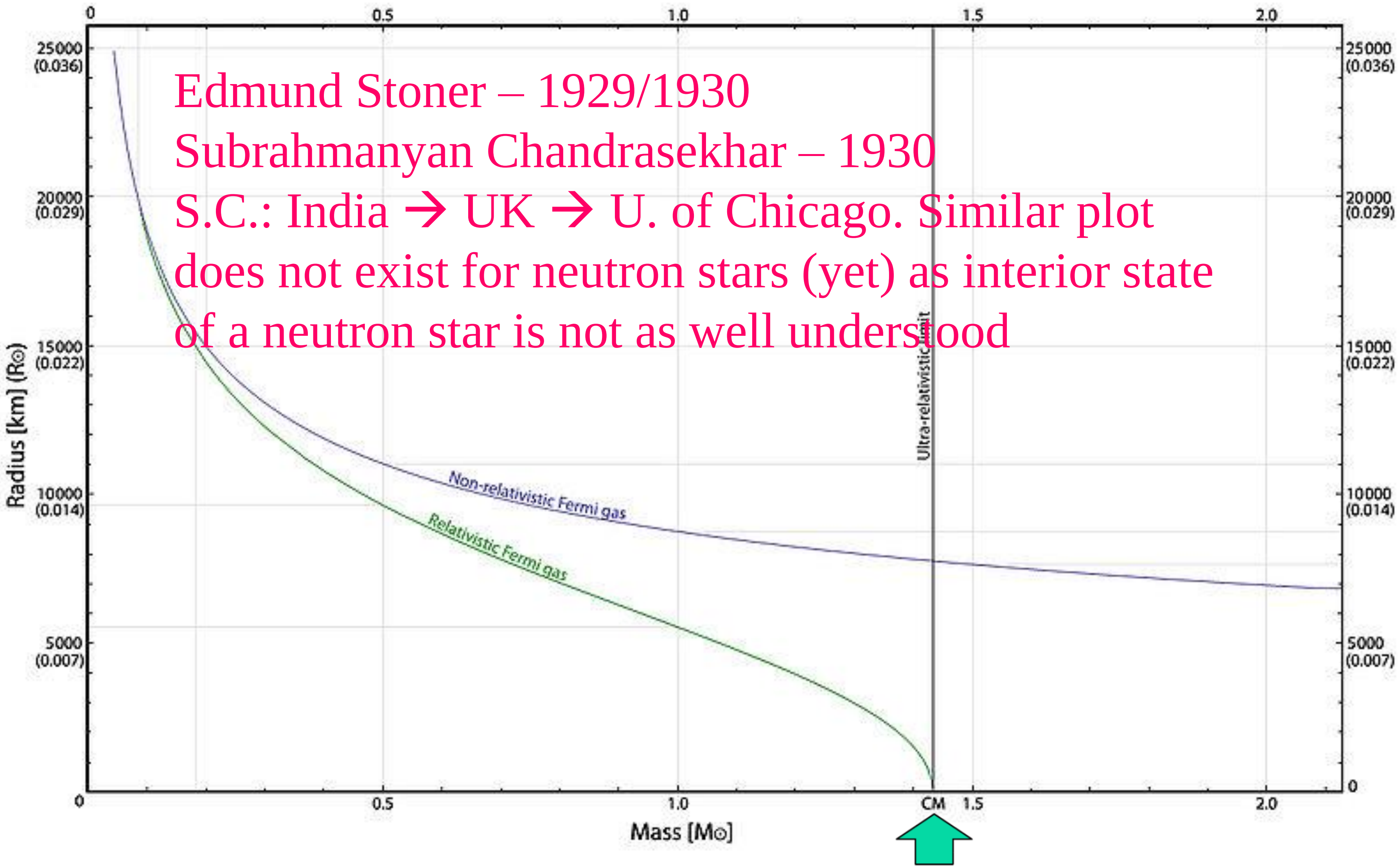
Star Life Cycles - Summary



Surface Gravity → Black Holes

- force of gravity in neutron star is resisted by degenerate neutrons
- If Mass(NS) > about 3xMass(Sun), neutron star collapses into **BLACK HOLE** whose radius approaches 0.
- In many massive Type II supernovas, the core that collapses has enough mass that a Black Hole is produced by the supernova.
- For very, very massive stars, their cores collapse into a black hole without a supernova (the gravity is so large that essentially everything is sucked into the BH)

WD or NS: Mass vs Radius



Edmund Stoner – 1929/1930

Subrahmanyan Chandrasekhar – 1930

S.C.: India → UK → U. of Chicago. Similar plot does not exist for neutron stars (yet) as interior state of a neutron star is not as well understood

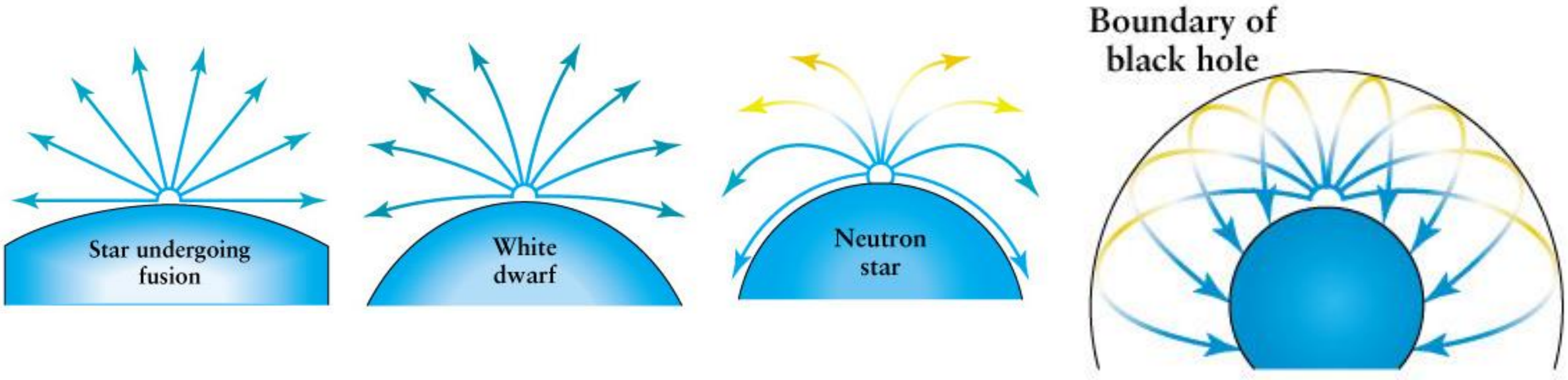
Chandraseker limit at 1.4 Mass Sun for White Dwarves

BLACK HOLES - history

- Predicted by many back to 18th Century. Real effort followed Einstein's General Theory of Relativity in 1915 with early work by S. Chandrashenkar in the 1930s but rejected by many including A. Eddington.
- from Wikipedia "Chandrasekhar's work presaged the discovery of black holes, which at the time seemed so absurdly non-physical that Eddington refused to believe that Chandrasekhar's purely mathematical derivation had consequences for the real world. History clearly proved Eddington wrong, but his motivation remains a matter of some controversy. Chandrasekhar's narrative of this incident, in which his work is harshly rejected, portrays Eddington as rather cruel, dogmatic, and racist." Chandrasekhar was an Indian living in 1930's England, had to move to the US where discrimination patterns were/are different
- 1939 Robert Oppenheimer ("father" of WW II atom bomb work) worked out with Tolman and Volkov the approximate neutron star mass limit → collapses into black hole

BLACK HOLES

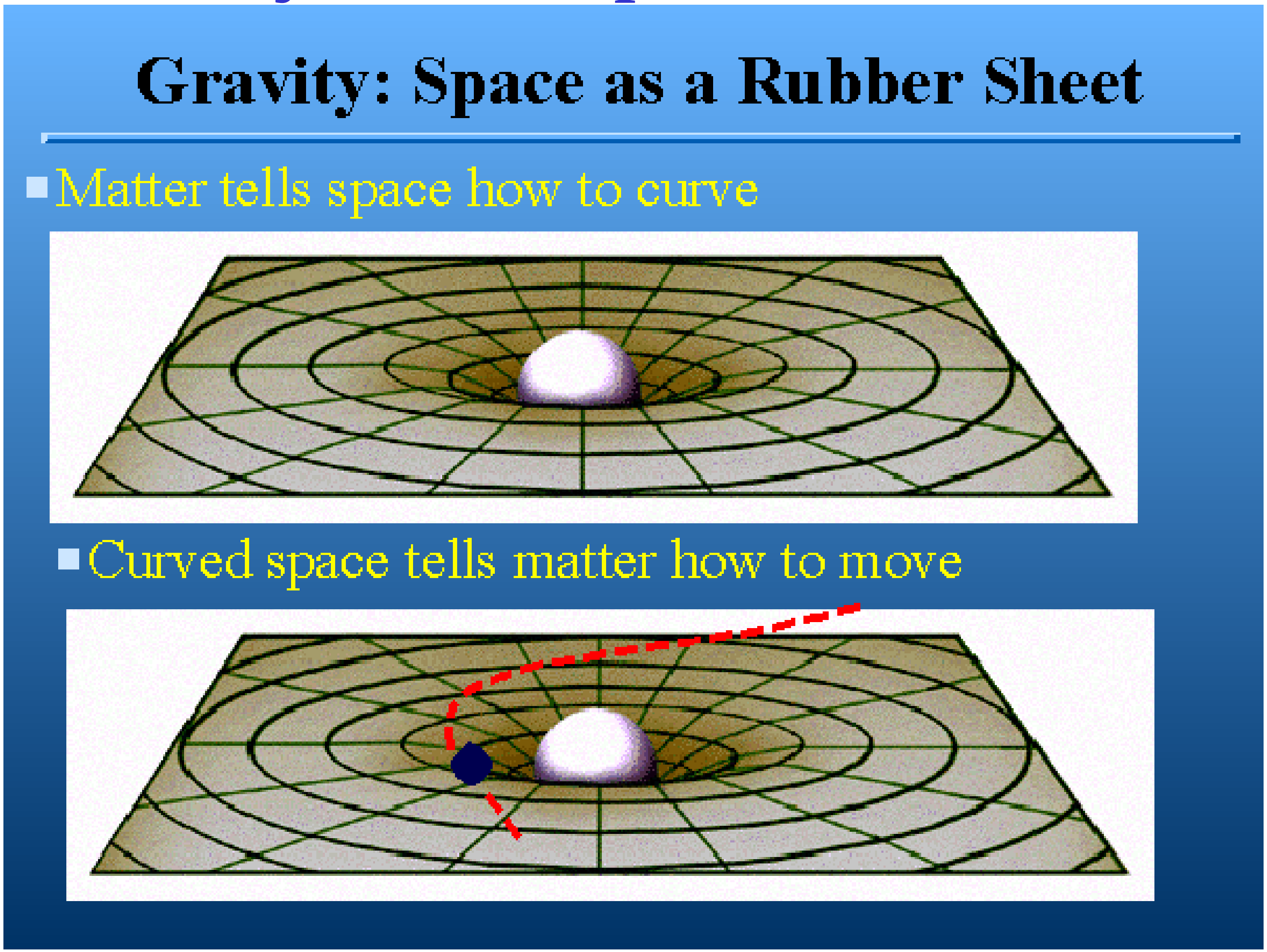
- very small radius with mass >3x Mass(Sun) (and can be much, much more massive)
- so much gravitational force that not even light can escape --- escape velocity is greater than the speed of light. Larger Mass and/or smaller radius increases
- Non-Einstein escape velocity = sqrt(2gR) =sqrt((2GM)/R)



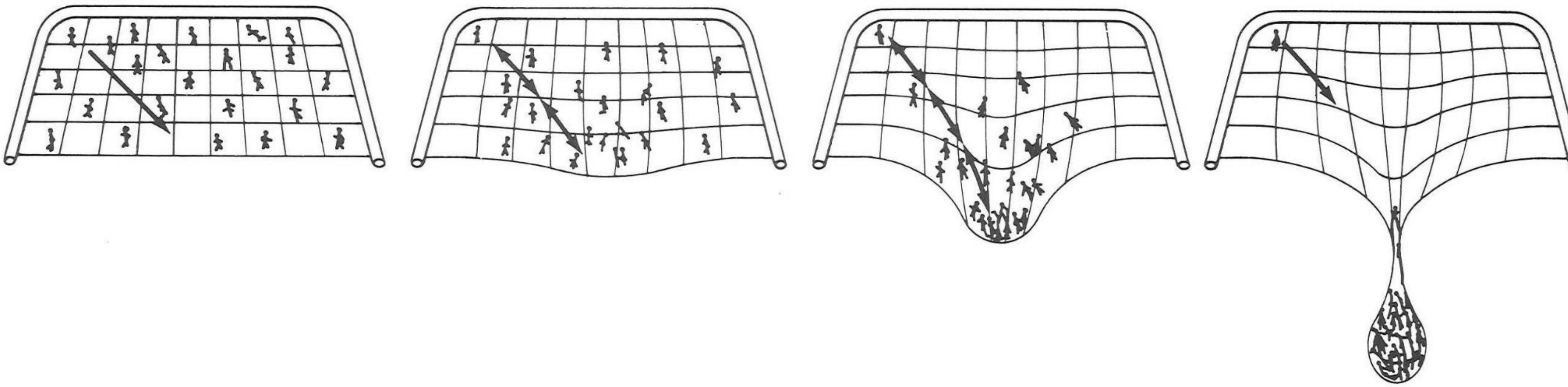
BLACK HOLES II

- clearly "normal" matter can't escape surface but why light??
- classical (Newton) gravity has force = Gm_1m_2/r^2. As mass(photon) = 0, and photon=light, then gravity should not effect
- But Einstein (in General Relativity) showed that light is bent by large gravitational fields, and has been observed by light bending near a star (like our Sun) or a galaxy
- photons travel along space-time lines → curved near massive objects → near Black Hole light from BH is "trapped" → nothing can escape gravity's pull

Gravity bends space-time 2D

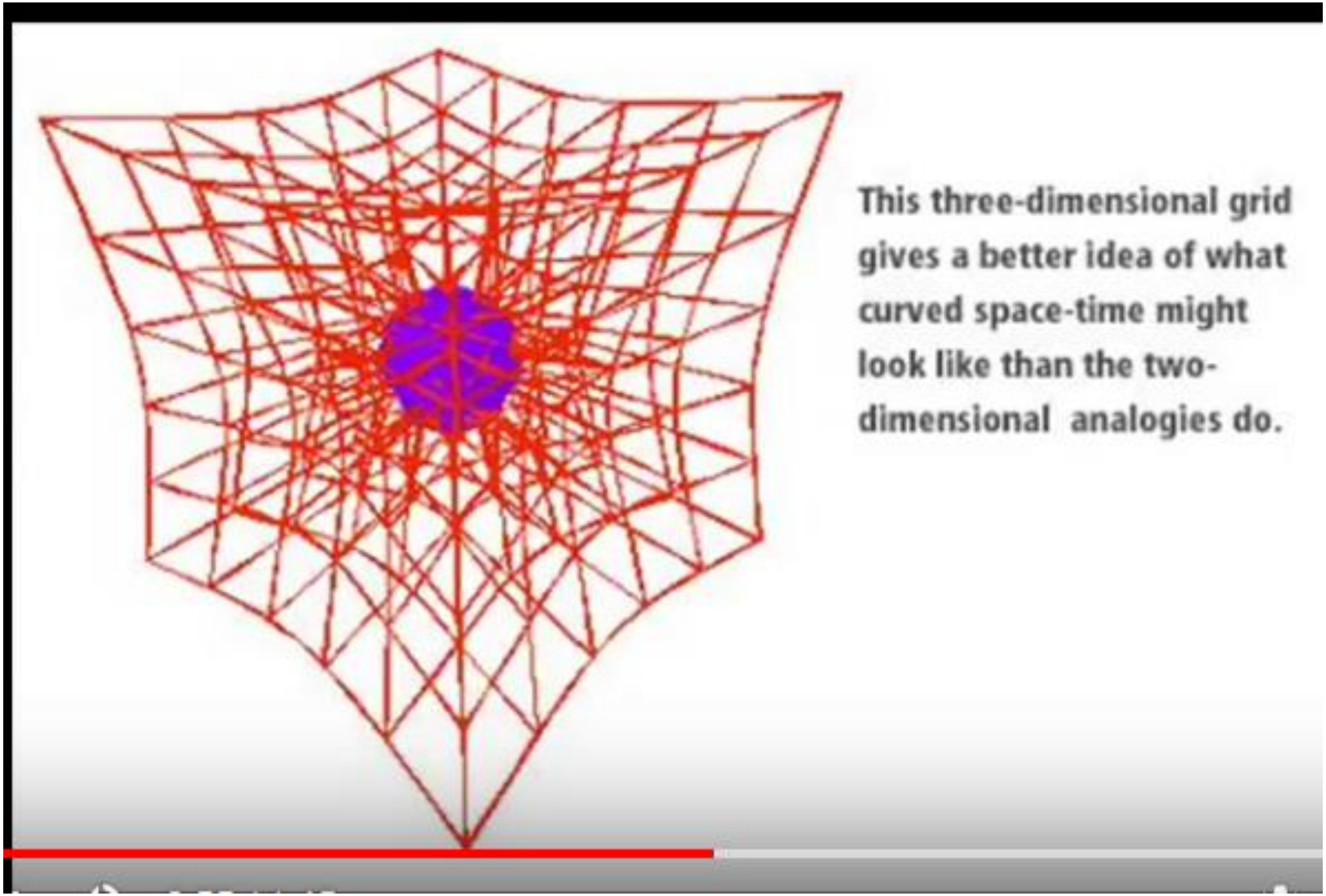


People on a rubber sheet analogy

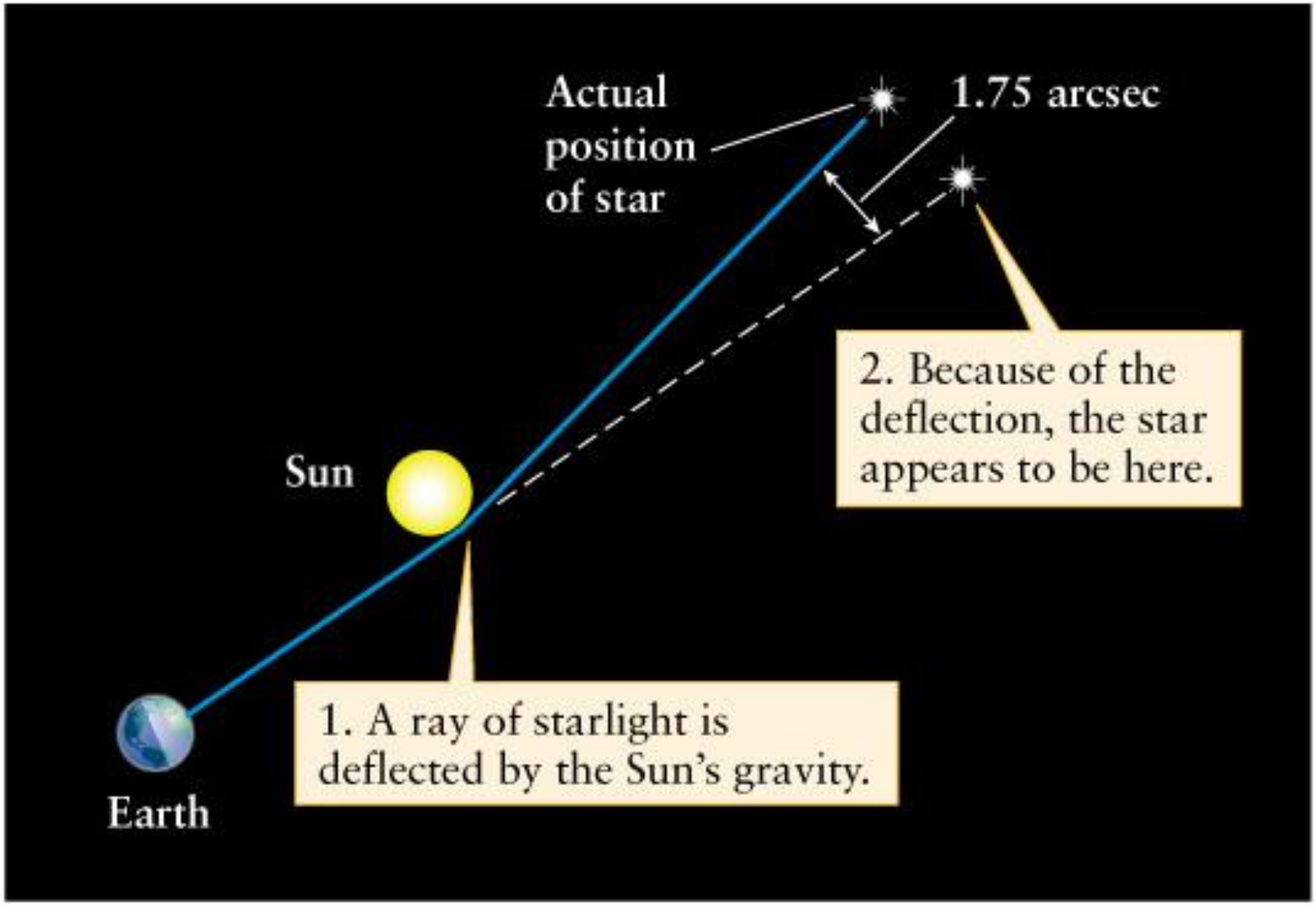


Let say you have people spread out on a rubber sheet. But then they are all drawn to a point (for example they are NIU faculty and there is free food and drinks at a campus event). As they move to the point, the rubber sheet becomes deformed. If the deformation is great enough, the people are trapped and can't get back to the undistorted rubber sheet. In a black hole, gravity is causing the "distortion" in space and trapping everything, including light, near the black hole. From textbook Astronomy Today.

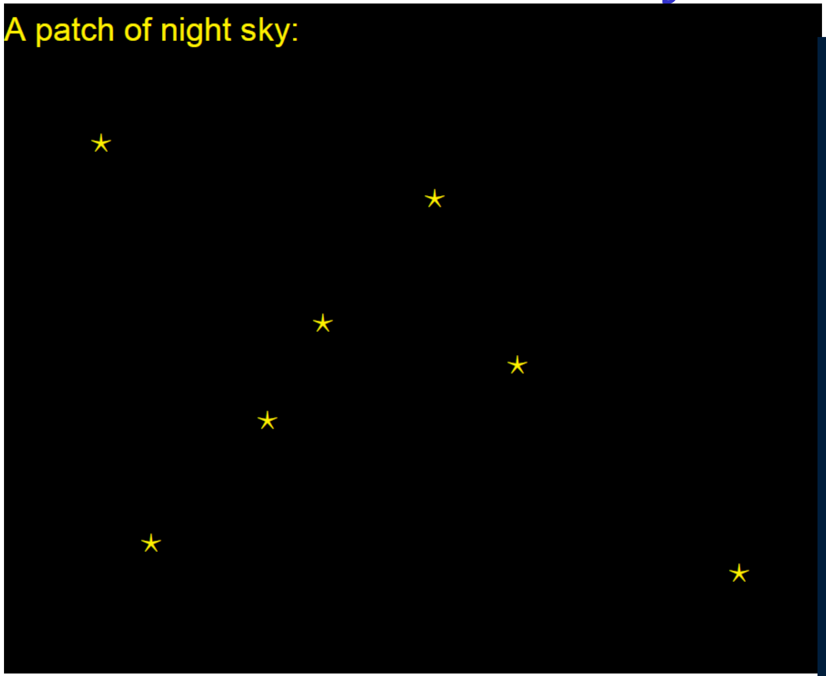
Gravity bends space-time 3D

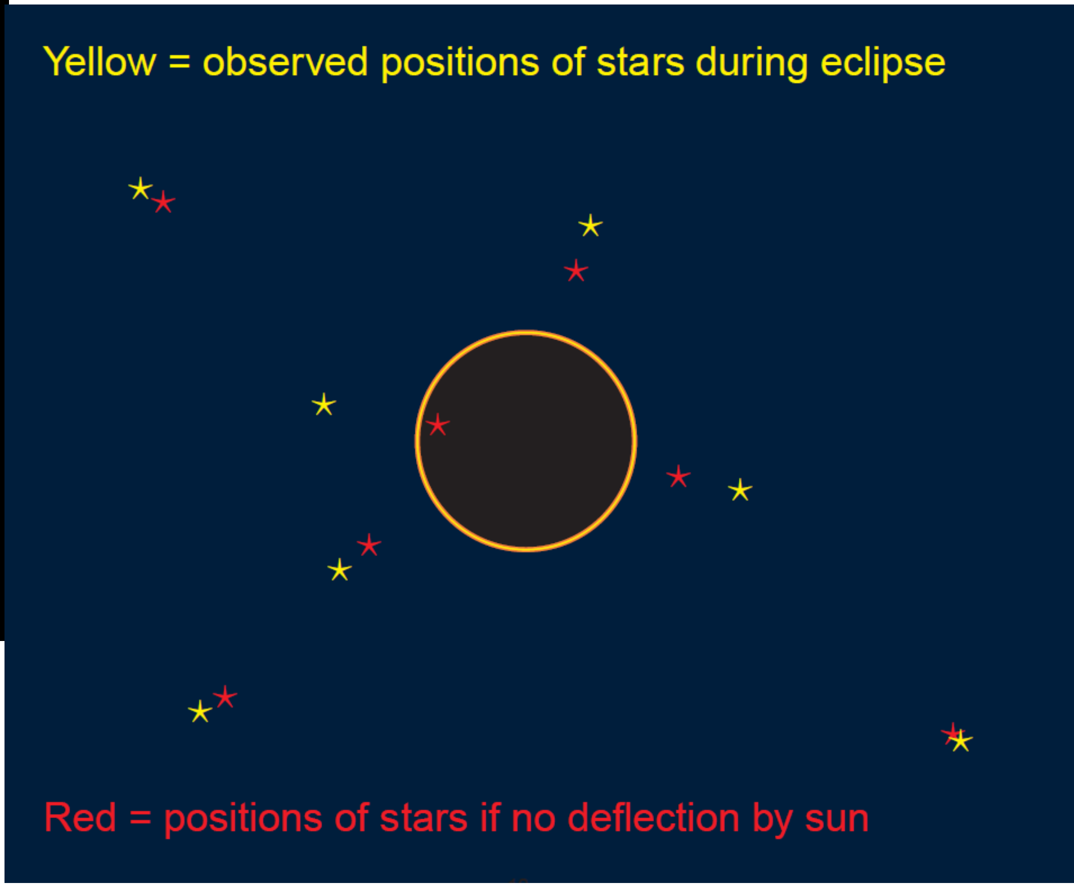


Gravity bends space-time near Sun



Gravity bends the path of light

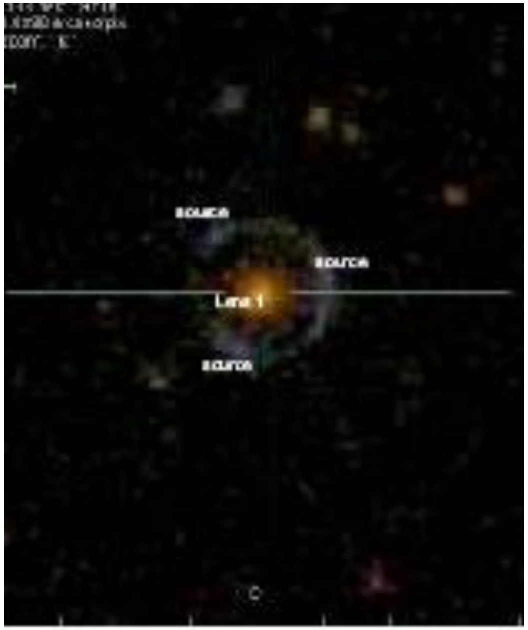


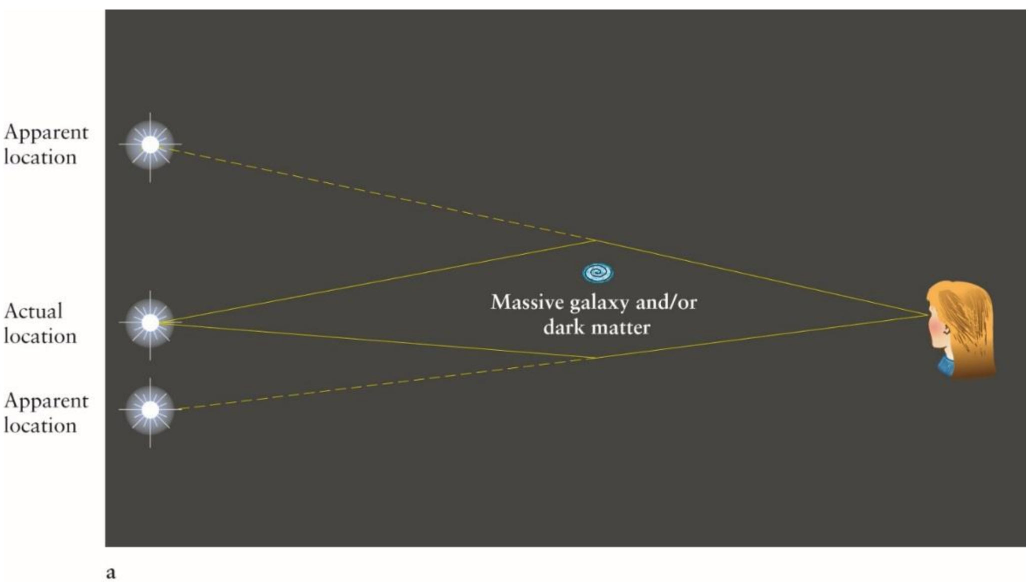


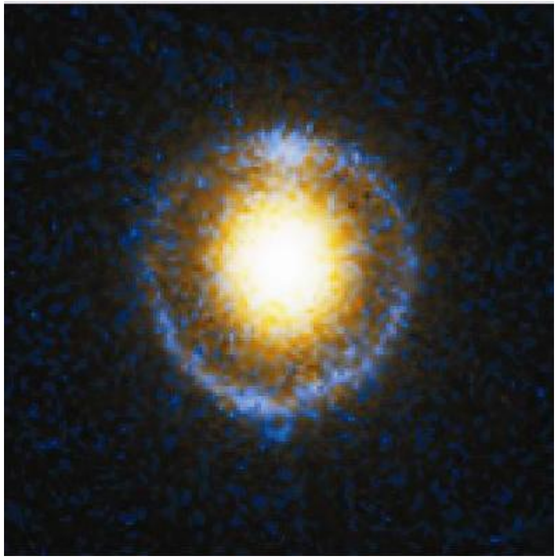
First confirmation of Einstein prediction made in 1919 during solar eclipse (Arthur Eddington and others though Eddington may have fudged his data)

Gravity bends space-time/light - Galaxy

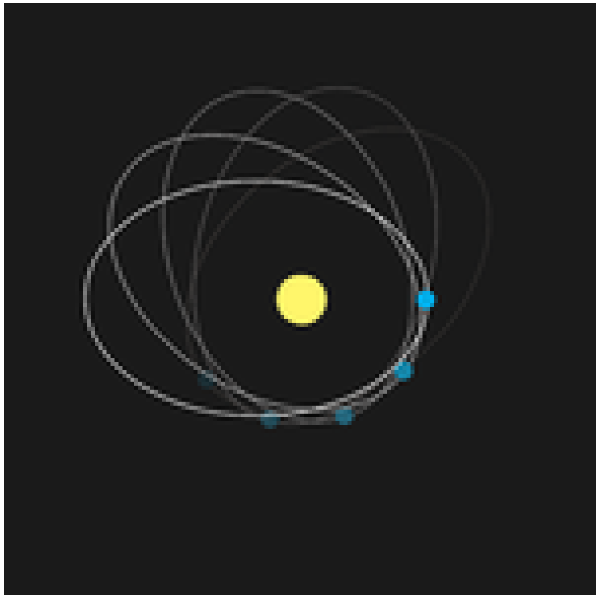
Einstein lens. Nearer galaxy bends light from another galaxy further away giving ring (figure on right from NIU student theses of M. Wiesner and D. Kubik, below from book). Measures mass of closer galaxy

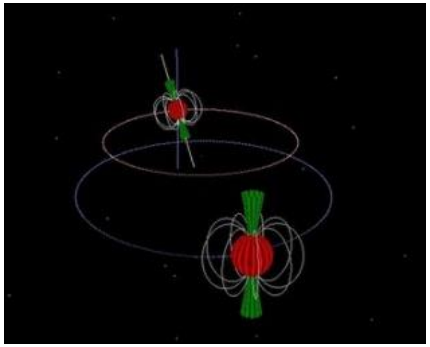


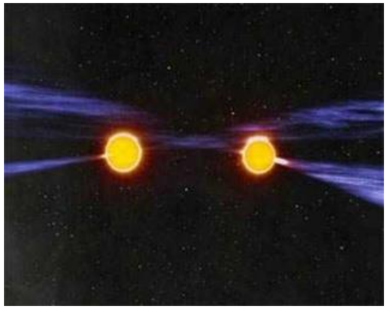




Gravitational Force: Newton vs Einstein



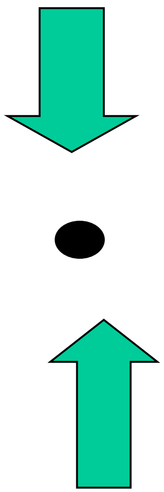




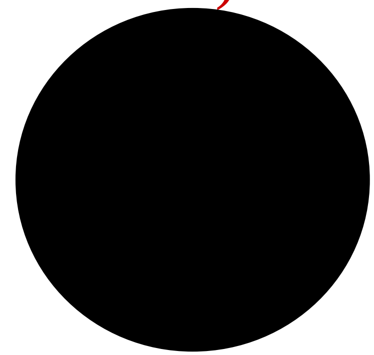
For large mass or short distances, the gravitational force from Newton is modified by Einstein's theory. See in the "precession of the perihelion" of Mercury's orbit around the Sun, or in orbits of 2 neutron star systems (1993 Nobel Prize). Don't need to know. Links on course web page

BLACK HOLES III

- Black holes can keep accumulating mass…including "colliding" Black holes. Very massive (million times mass Sun) at center of many galaxies



Matter falls into BH → it grows (and grows and grows)



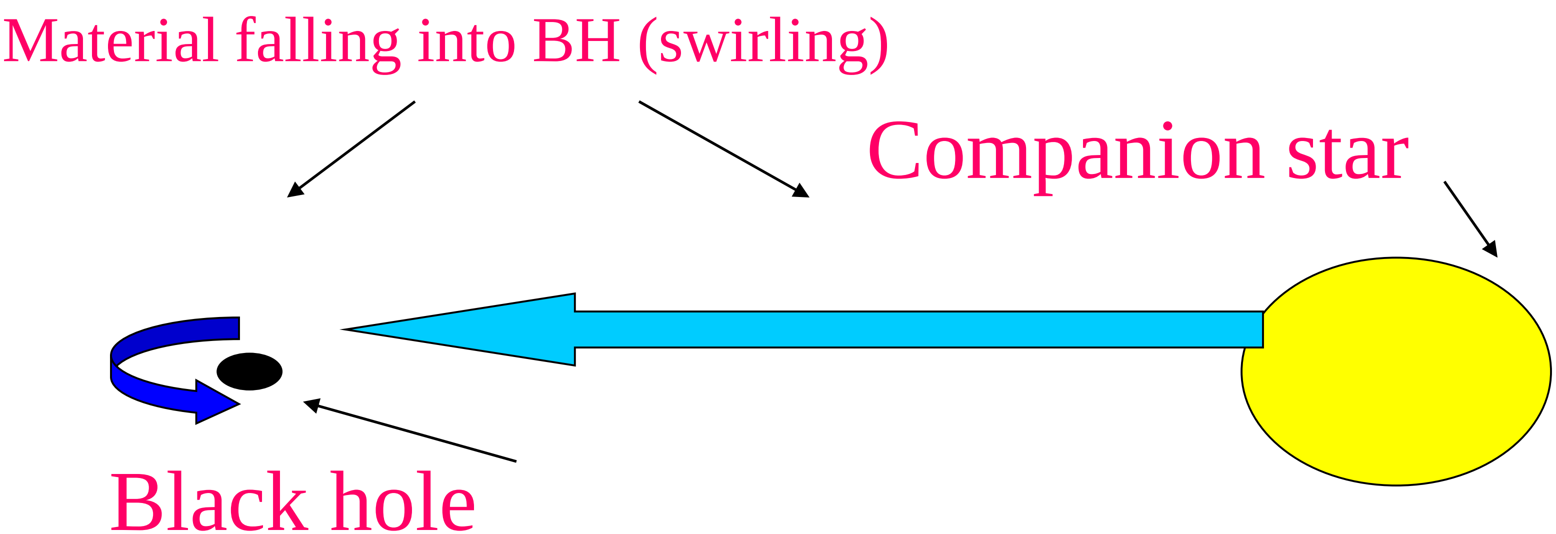
Millions (billions) of years later

About 100 million black holes in Milky Way galaxy with about 10 million with masses more than 30 times the Sun, and a supermassive 1 million times the Sun's mass at the galaxy center

Matter falling in can also heat up and produce light

Observing Black Holes

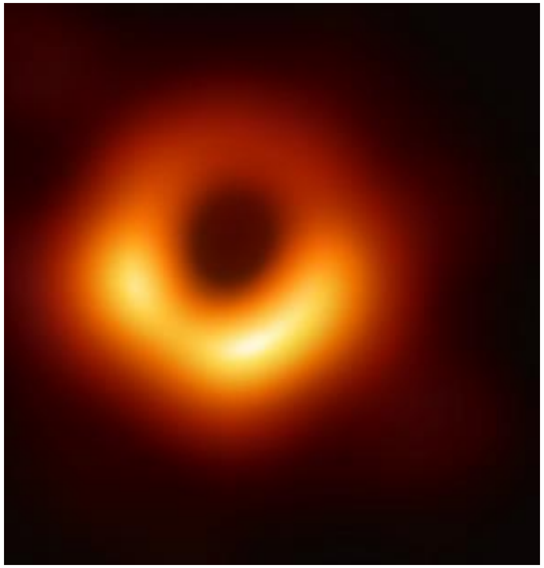
- See directly using Event Horizon Telescope (2019)
- observe radiation from hot matter falling into black hole. See video on course web page. Not all blackholes will have matter falling into them
- observe orbit of normal star around “unseen” companion. Gives mass and if > 3xmass(Sun) then assume black hole (if smaller may be neutron star)



Observing a Black Hole

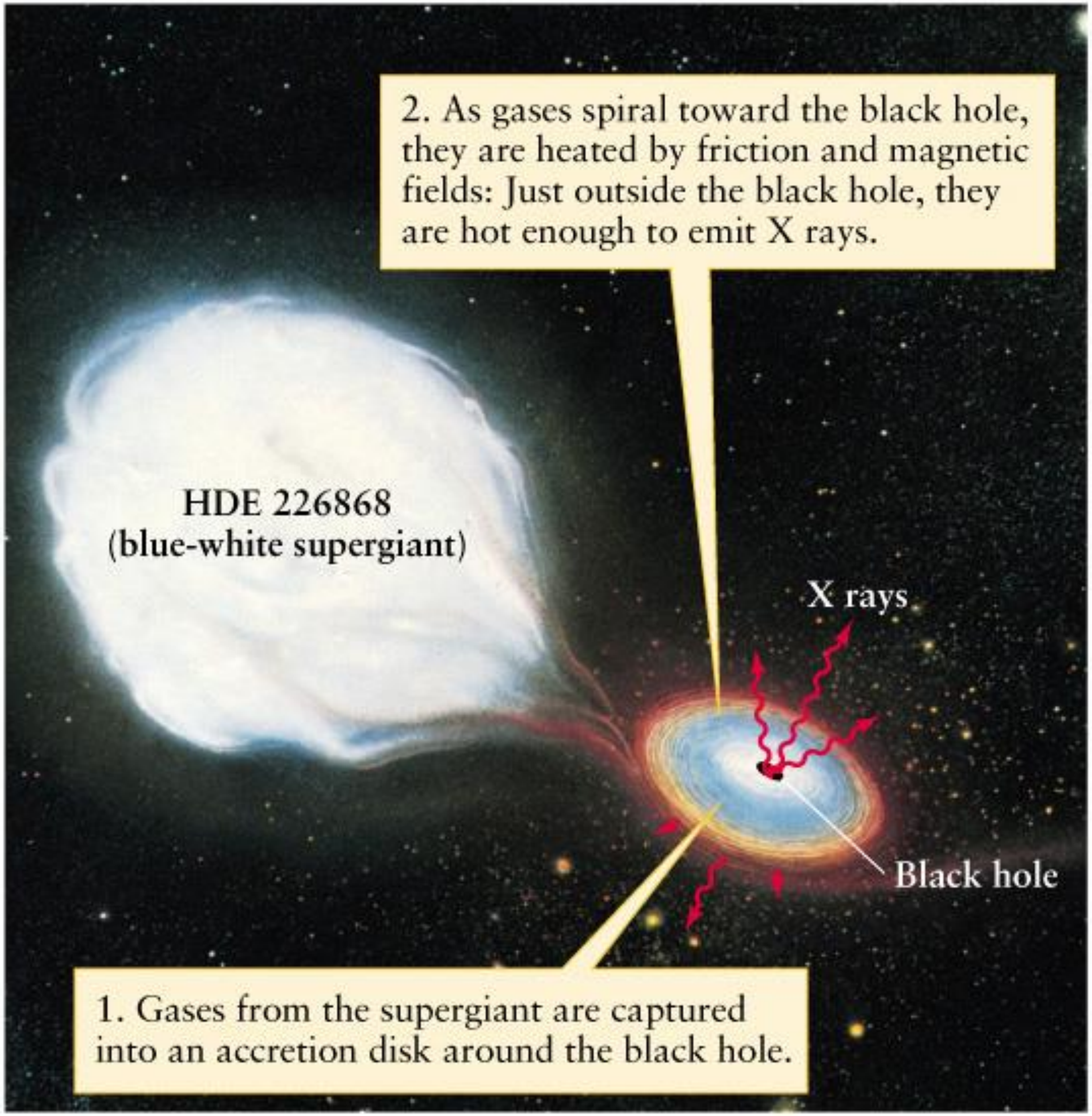
- In 2019 an image of a black hole was released. It used 1.3 millimeter photons (microwaves) from data collected over 4 days in 2017
- Event Horizon Telescope team: 8 radio telescopes combined: 2 in Hawaii, 2 in Arizona, 1 each in Chile, Mexico, Spain, and the South Pole Telescope. The "size" of the combined telescope was then "Earth size" giving a 40 micro arcsecond angular resolution (roughly the size of the date on a quarter if seen from 3000 miles away)
- Telescopes also had to remove atmospheric

effects (see lecture 8) to see the image.



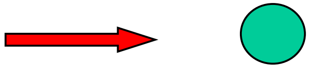
- Image shows light from hot gases falling into

a black hole in galaxy M87 55 million
Light years away. The "ring" probably tilted
Giving brighter on bottom of image


2. As gases spiral toward the black hole, they are heated by friction and magnetic fields: Just outside the black hole, they are hot enough to emit X rays.
HDE 226868
(blue-white supergiant)
X rays
Black hole
1. Gases from the supergiant are captured into an accretion disk around the black hole.

BLACK HOLES IV

- perhaps new physics but lack quantum theory of gravity. Items like wormholes, breaks/tunnels in space-time, other dimensions….



Enter at one Black Hole, exit at another