

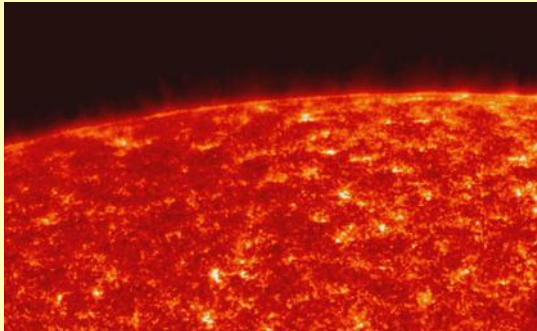
Black Holes



- our Sun (*Sol*) is an *average star*
- like others, it's a big ball of (mostly) *hydrogen (H)*

Stars are large...

- our (average) *Sun* is *~100x larger than Earth!*

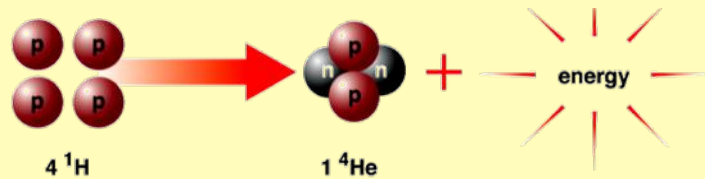


- *Sun* contains *~99.9% mass* of *entire solar system*

How do stars shine?

- can't be *chemical reactions*, eg. "burning"
- if *temperature ~10 million K*, *fusion* converts *hydrogen (H)* into *helium (He)* in a *star's core*

Q: Where have you heard of fusion?



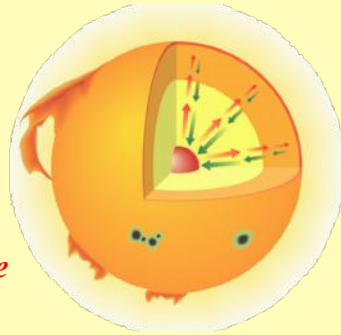
- as a *byproduct*, creates energy! ($E=mc^2$)

Hydrostatic Equilibrium

- during most of a star's lifetime it *fuses H into He in core*

- gravity (inward) & fusion pressure (outward) compete*

- for most of a star's life they are in balance*



When Stars Die...

Mass (M_{\odot})	Surface temperature (K)	Spectral class	Luminosity (L_{\odot})	Main-sequence lifetime (10^6 years)
25	35,000	O	80,000	4
15	30,000	B	10,000	15
3	11,000	A	60	800
1.5	7000	F	5	4500
1.0	6000	G	1	12,000
0.75	5000	K	0.5	25,000
0.50	4000	M	0.03	700,000

- Sun* has ~ **5 billion** more *H-fusing* years

Q: What happens when all the core H is used up?

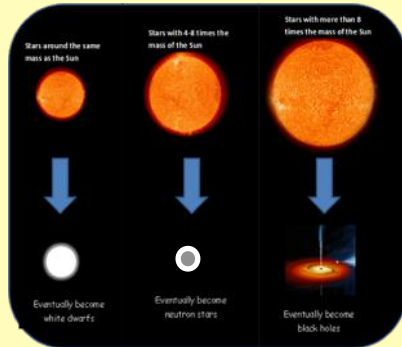
- fusion stops*, and star is near the *end* of its “life”
- gravity is unopposed & collapses the star's core*
- ultimate fate depends on *mass of star*

Stellar “Corpses”

- if star *Sun-like* ⇒ *white dwarf* (size of Earth)
- 1 tsp** of *white dwarf* = mass of an elephant

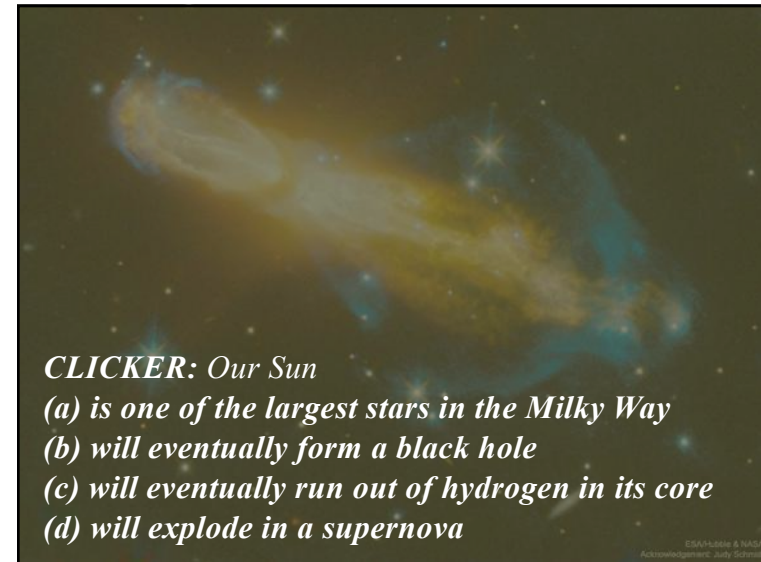
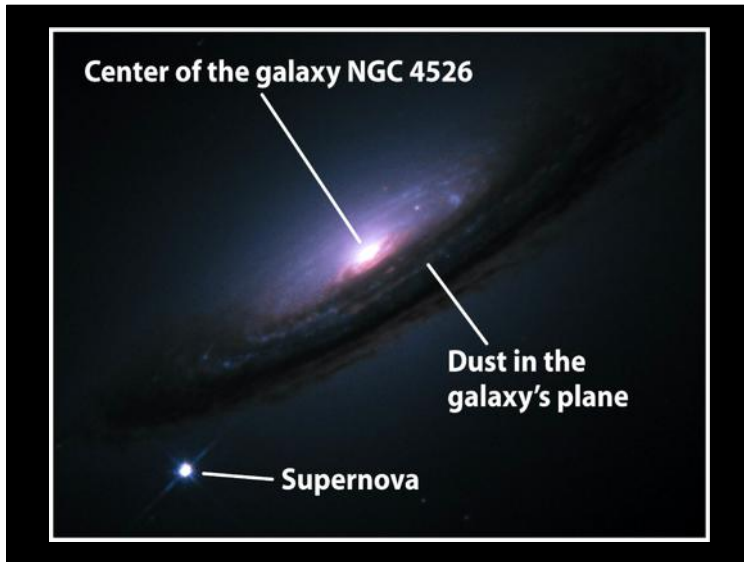
- if star's core $> 1.5 m_{\text{sun}}$ ⇒ *neutron star* (city size)
- 1 tsp** of *neutron star* = mass of a mountain

- if star's core $> 3 m_{\text{sun}}$ ⇒ *black hole*



Supernova 1987a





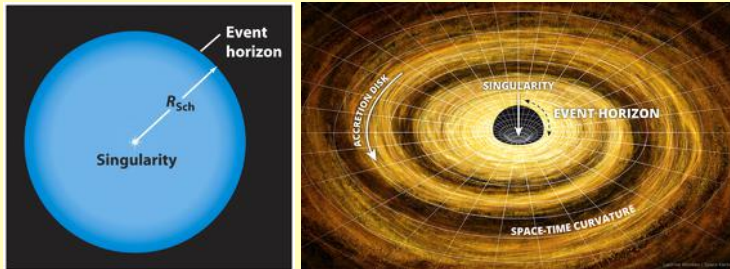
Black Holes

- *if a star's core $> 3M_{sun}$, there is no known force that can halt its final collapse*
- first proposed in 1700's based on *escape speed*; reappeared as *theoretical prediction* of GR
- *"black hole"* coined by *J. Wheeler* (1967)

- *core collapses to a point ("singularity")*
- leaves a *"hole"* in the very fabric of *spacetime*

- *gravity so intense that light cannot escape*

Features of Black Holes



- **event horizon**: visible *boundary* of a **black hole**
- at **event horizon**, the *escape velocity* = c
- an **accretion disk** of *hot, rotating gas* may exist

Evidence for Black Holes

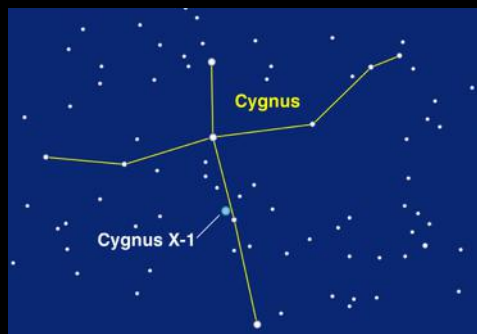
"Extraordinary claims require extraordinary proof."
- Carl Sagan

Q: So how do you look for "nothing"?

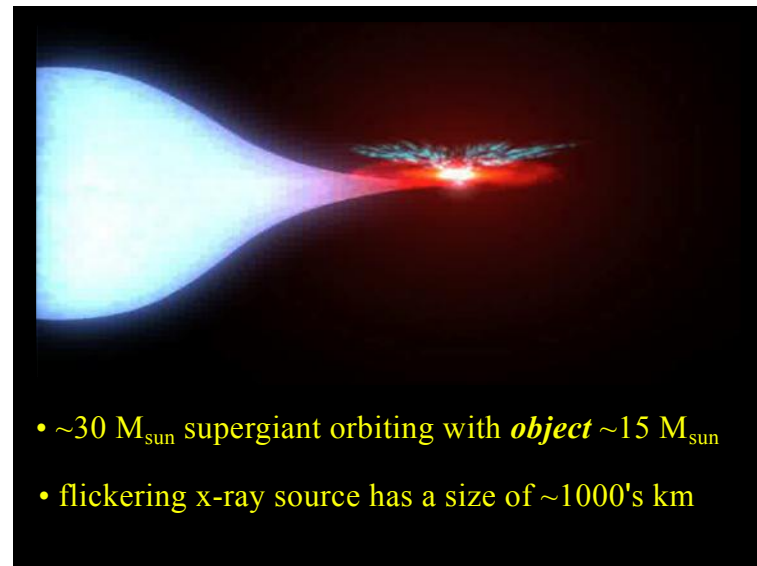
- **gravitational effects** on other objects
- **gravitational lensing** by the black hole
- **accretion disk** emissions

- a **few dozen** candidates found *so far*

Cygnus X-1

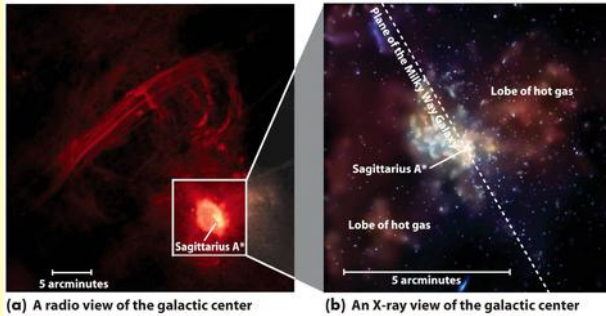


- discovered in 1970 by *Uhuru X-Ray satellite*



- $\sim 30 M_{\text{sun}}$ supergiant orbiting with **object** $\sim 15 M_{\text{sun}}$
- flickering x-ray source has a size of ~ 1000 's km

Center of the Milky Way



- “invisible” **radio & X-ray source** called **Sgr A***
- $mass_{SgrA^*} \sim 3-4$ million suns, diameter < 100 AU



- **M87, elliptical galaxy in Virgo (55 Mly away)**
- **6 billion solar mass supermassive black hole**

***CLICKER:** We believe the center of the Milky Way also contains a super massive black hole because...*

- (a) we have directly imaged it*
- (b) it emits powerful beams of visible light*
- (c) stars orbit incredibly quickly near the center*
- (d) the BH visibly lenses nearby star images*

Black Hole Questions...

***Q:** If our Sun were to become a black hole, would the Earth fly off into space or get sucked in?*

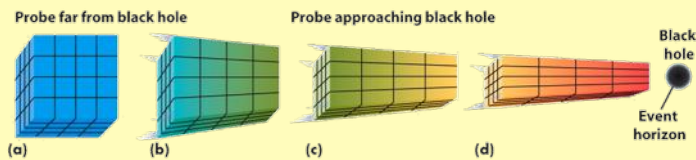
***Q:** Do black holes roam around the galaxy, sucking in unsuspecting objects (& possibly people)?*

***Q:** Could the Sun become a Black Hole? Earth?*

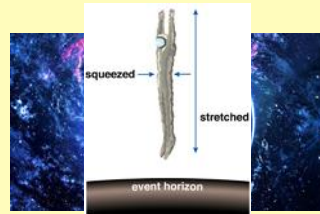
***Q:** Do black holes last forever?*

Falling into a stellar BH

- *time & space distort close to the event horizon*

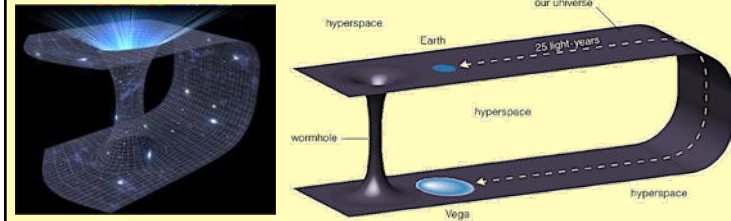


- wavelengths *lengthen* (*gravitational redshift*)
- *cannot* (?) survive journey to the *singularity*

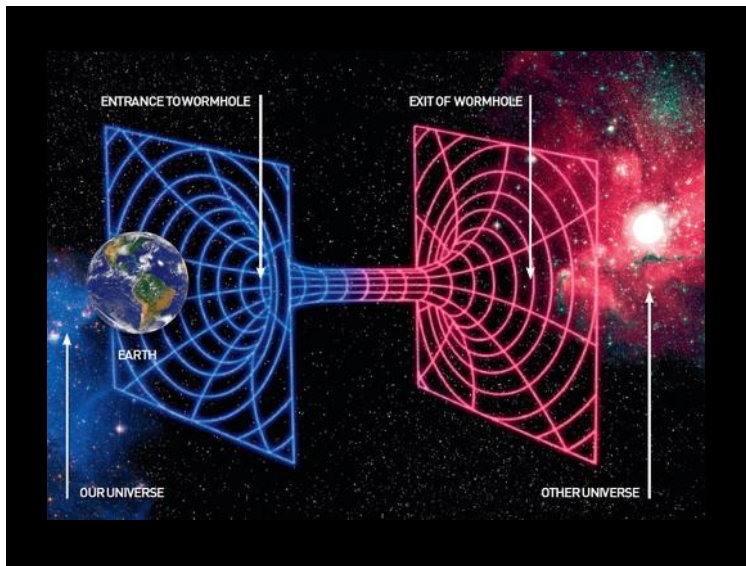


“Wormholes”

- DEMO*: “supra-luminal” motion *is* possible
- 2-D paper *folded* into 3rd dimension



- *wormholes* could connect regions of *our* universe or *parallel* universes by “*folding*” *spacetime*...



Review: Black Holes

- *stars* are born, live for a finite time, & die
- *stars* spends most of their lives fusing $H \Rightarrow He$
- when stars die, result depends on *mass of core*
- *white dwarf, neutron star, black hole*
- *black holes* are *singular points* in *spacetime*
- *spacetime* is so warped even *light cannot escape*
- *black holes* have *strong* influence at *close range*