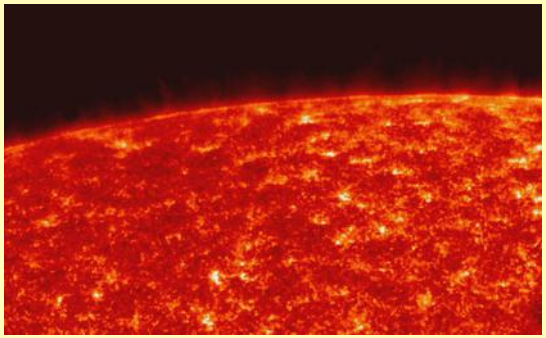
Black Holes

- 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!*

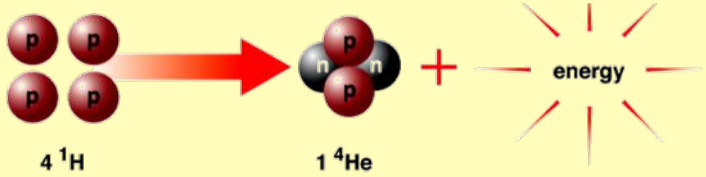


- ***Sun*** contains *~99.9% mass* of **entire** *solar system*

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

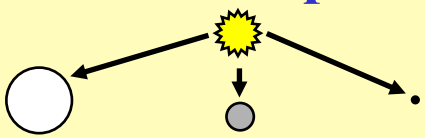
• ***Sun*** has ~ ***5 billion*** more ***H-fusing*** years

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"

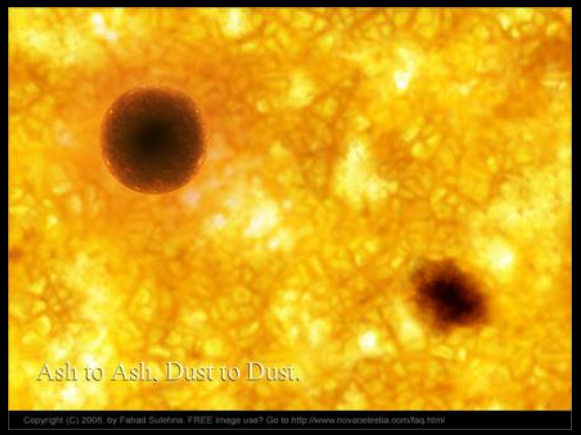


• ***Sun****-like* stars ⇒ ***white dwarf*** *(size of Earth)*
• ***1 tsp*** of ***white dwarf*** = *mass of an elephant*

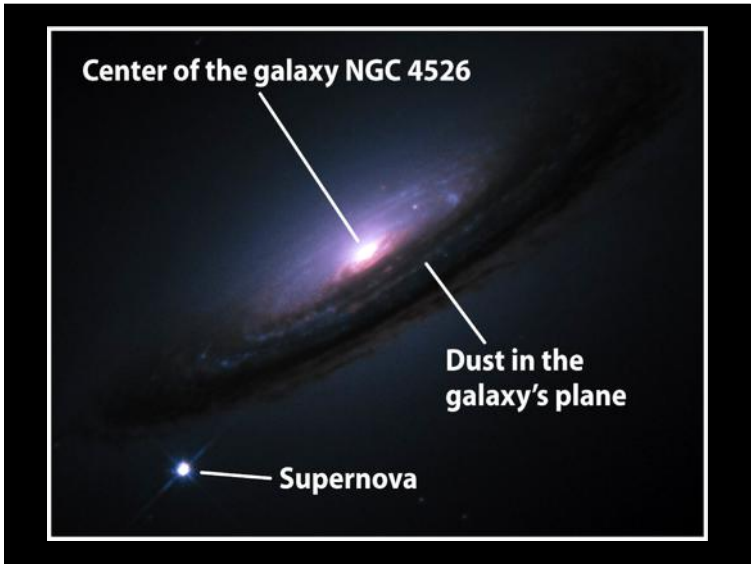
• ***if*** star's core >***1.5*** m_{sun} ⇒ ***neutron star*** *(city size)*
• ***1 tsp*** of ***neutron star*** = *mass of a mountain*

• ***if*** star's core > ***3*** m_{sun} ⇒ ***black hole***

The Earth's Fate…

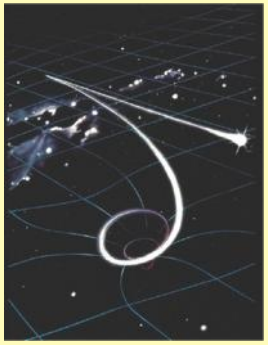


Supernova 1987a



CLICKER: *Our Sun*
(a) is one of the largest stars in the Milky Way
(b) will eventually form a black hole
(c) will eventually run out of hydrogen in its core
(d) will explode in a supernova

Black Holes

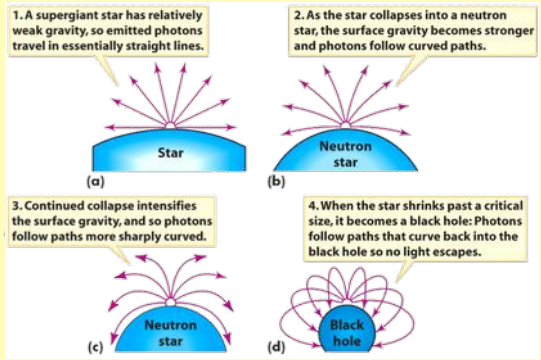


• ***if*** a star's ***core > $3M_{sun}$***,
there is no known force
that can halt its final collapse

• first proposed in 1700's based on *escape speed*; reappeared as *theoretical prediction* of GR

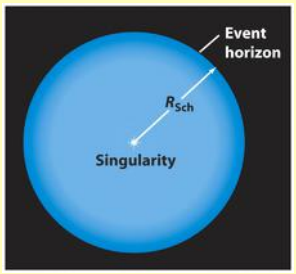
• ***"black hole"*** coined by *J. Wheeler* (1967)

• ***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
DVD: Cosmos-"Warped Space"

Evidence for Black Holes

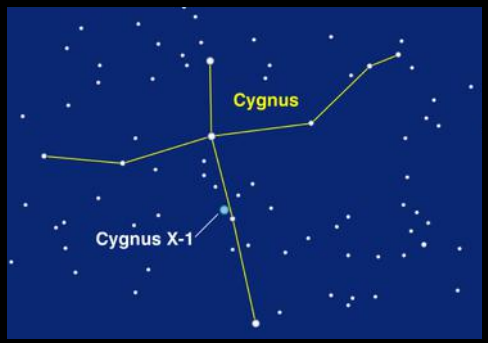
"Extraordinary claims require extraordinary proof."
- Carl Sagan

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

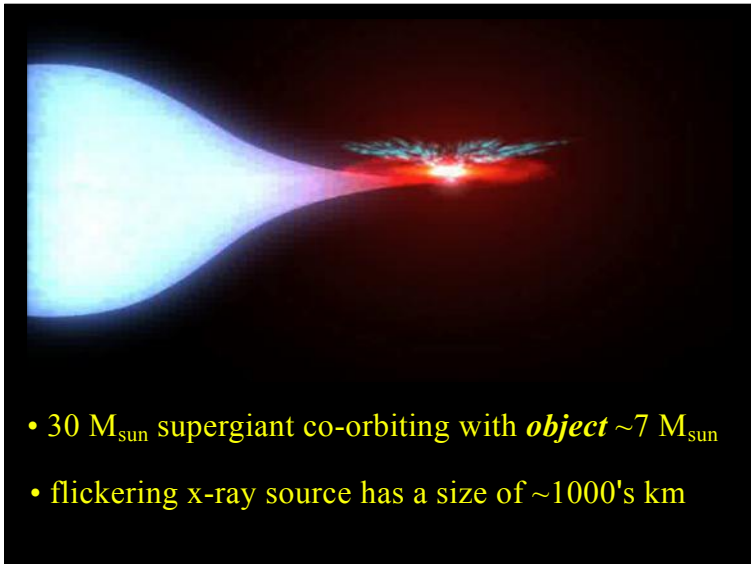
• ***gravitational effects*** on other objects
• ***gravitational lensing*** by the black hole
• ***accretion disk*** emissions

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

Cygnus X-1

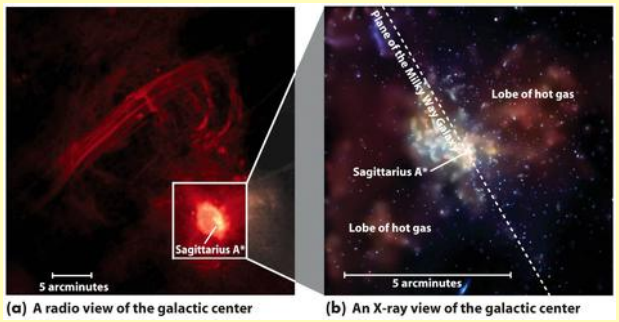


• discovered in 1970 by ***Uhuru X-Ray satellite***



- 30 M_{sun} supergiant co-orbiting with ***object*** ~7 M_{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*
- *$mass_{SgrA*}$ ~* ***3-4 million suns****, diameter < 100 AU*

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

(a) we have directly observed its event horizon
(b) it emits powerful beams of visible light
(c) stars orbit very 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?*

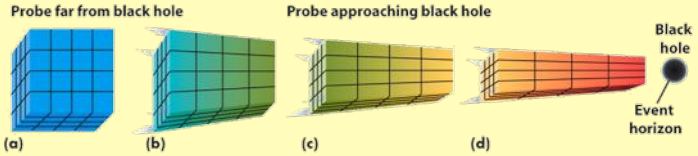
Q: *Do black holes roam around the galaxy, sucking in unsuspecting objects (& possibly people)?*

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

Q: *Do black holes last forever?*

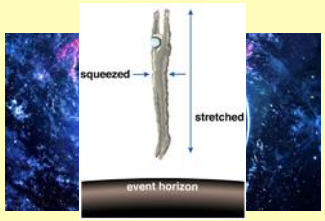
Falling into a stellar BH

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



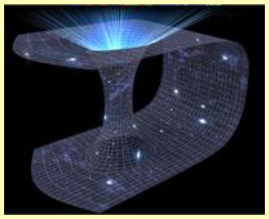
• wavelengths *lengthen* ***(gravitational redshift)***

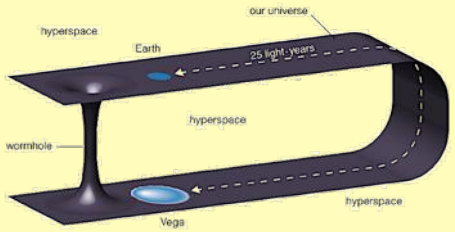
• ***cannot*** *(?)* survive journey to the ***singularity***



"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⇒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***