Stellar Evolution: Low & Intermediate Mass Stars

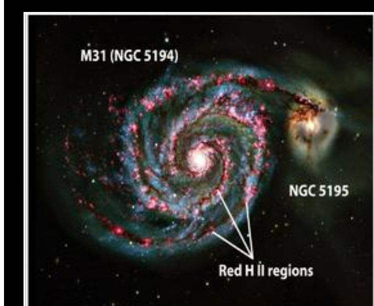
Stellar Evolution

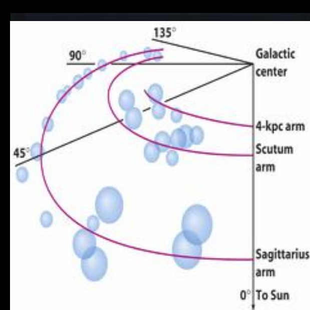
• even *hot, fast burning stars* live *millions of years*

• they ***seem*** unchanging, but stars ***evolve*** *through specific stages in their lifetimes*

Q: *During a human lifetime we observe only one billionth of the lifetime of many stars… so how do we decipher the life story of the stars?*

Dark Molecular Clouds

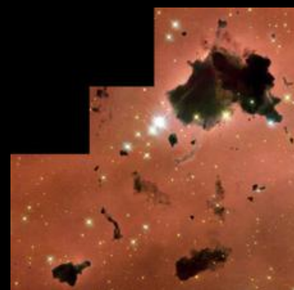




• *"warm" atomic H (HI) throughout the galactic disk*
• *cold, dark molecular clouds* of H_2 *in the disk*

GON: Emission nebula

Nebulae

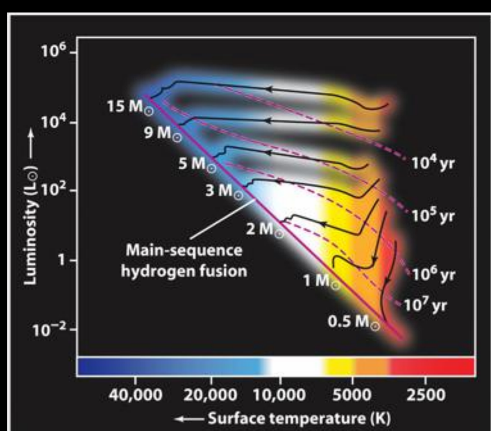


- ***Trifid (M20)***: dark regions lie within *HII region*

Protostars

- ***before*** sustained *nuclear reactions* occur in ***core***
- *within cold gas clouds*, ***contraction*** converts *gravitational potential energy* into *thermal energy*
- ***protostar*** is **too opaque** to radiate thermal energy away quickly, so *interior heats up*
- *thousands of years*: *surface* temp *thousands of K*

Protostar to MS times

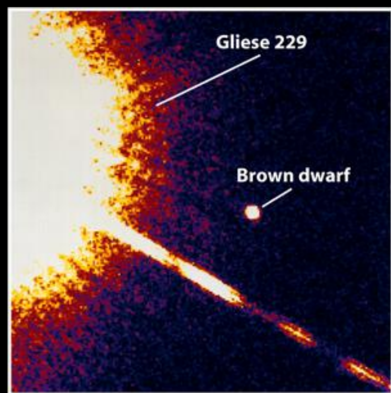


A Star is Born

- ***core*** temperature & density **increase** with time
- ***fusion*** begins *when* ***core*** reaches ***10 million K***
- for ***Sun****-like star*, may take ***100+ million years***
- a ***main-sequence, H*** *burning star* is born!
- some ***protostars*** *do* ***not*** *have enough mass*
- core ***cannot*** reach *10 million K*
- *dense balls of gas* (***not*** *stars*) called ***brown dwarfs***

(eg) Jupiter, Gliese 229 companion (*19 ly, Lepus*)

Gliese 229 (infrared)



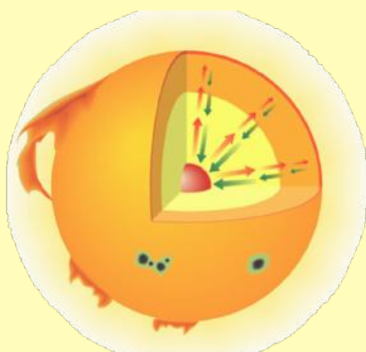
CLICKER: What ***stops*** a star's grav collapse?

(a) *solidification of its core*
(b) *an intense stellar wind*
(c) *the rapid rotation of the protostar*
(d) *nuclear reactions in its core*

Hydrostatic Equilibrium

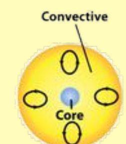
• ***gravity*** pulls ***inward***, ***fusion pressure*** pushes ***outward***

• for ***main sequence they are in balance***



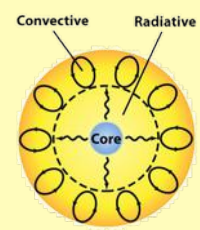
Low Mass Stars

• ***core* H *fusion*** via ***proton-proton chain***



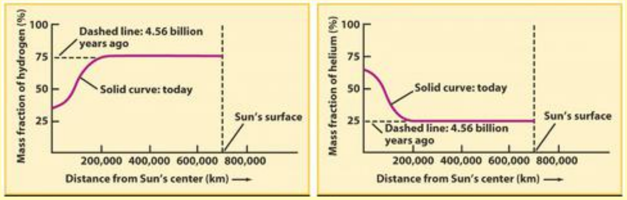
• ***energy transport*** based on ***density***, ***temp***

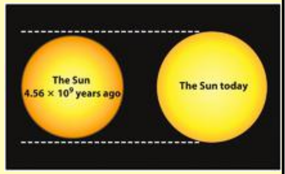
• *our Sun* is ***1 solar mass*** ($1M_\odot$)



• ***low mass***: $0.08M_\odot \Rightarrow 4M_\odot$
• ***intermediate mass***: $4M_\odot \Rightarrow 8M_\odot$
• ***high mass***: $8^{+}M_\odot$

• ***major differences*** in *evolution, lifetime & death*





- ***star*** *depletes* ***H***, creates ***He***
- *fewer* particles, ***lower*** pressure, so ***core*** *contracts*
- ***envelope*** *expands* - *why?*
- ***eventually*** core *runs out* of ***H***
- ***fusion rate*** (& thus ***lifetime***) depends on ***mass***

table 21-1 Approximate Main-Sequence Lifetimes

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

The main-sequence lifetimes were estimated using the relationship $t \propto 1/M^{2.5}$ (see Box 21-2).

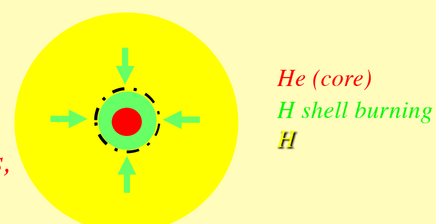
- ***Sun*** has ~ ***5 billion main-sequence*** years left

Q: *What happens when* ***all H*** in ***core*** *gets* ***used up?***

- ***fusion stops***; ***outward*** fusion pressure ***ceases***
- ***end*** of ***main sequence lifetime***
- ***gravity*** **collapses** ***core***

Shell Burning

- as ***core*** collapses, ***H*** *outside of* ***core*** falls *inward*
- ***H*** in *shell* around ***core*** will ***fuse***
- ***core*** collapse *slows,* but does ***not*** stop



- ***shell fusion rate*** may ***exceed*** *MS fusion rate*

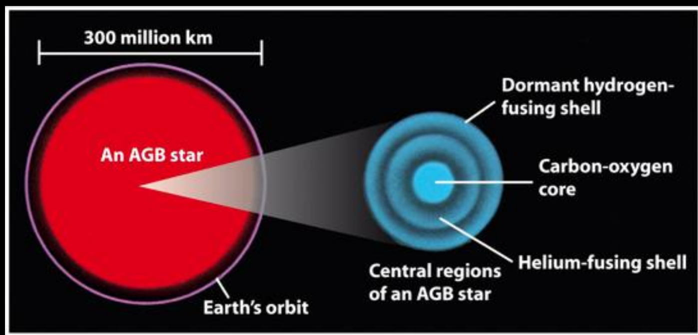
Q: *What happens to* ***envelope*** *&* ***L*** *of star?*

- ***envelope*** *expands* hugely; *enhanced* ***solar wind***
- ***Red Giant*** phase
- ***very*** *low mass stars* ***do not evolve further***
- in others, ***core*** *temperature* reaches *100 million K*
- fuse ***He*** ⇒ *carbon* (***C***) & *oxygen* (***O***) (***triple-α***)

Q: Why is ***temperature*** so high for ***He*** fusion?

- ***hydrostatic equilibrium*** *restored*
- ***envelope*** *cools* somewhat *& contracts*

Low Mass Stellar Interior



***CLICKER:** Why are Red Giants "red"?*

(a) ***decreased*** energy flux at the star's surface
(b) ***scattering of blue light*** by enhanced envelope
(c) ***increased*** surface temperature
(d) ***contraction*** & ***cooling*** of the star's envelope

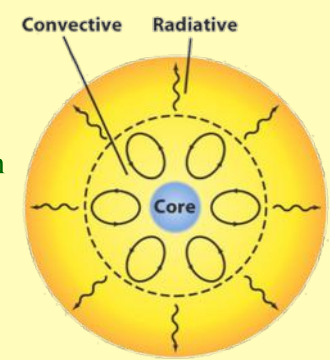
***Q:** What happens when all **He** in core is used up?*

• *low-mass stars **never** reach **core*** temp needed to fuse ***C**, **O** (600 million K)*

• collapse *heats **core***, causes ***He** shell burning*
• series of *thermal pulses* drive ***envelope** expansion*
• *dredge up* ***C*** from ***core***: ***"star stuff"***

• ***envelope*** swells into a ***Red Giant*** again
• ***core*** undergoes *final collapse*

Intermediate Mass Stars

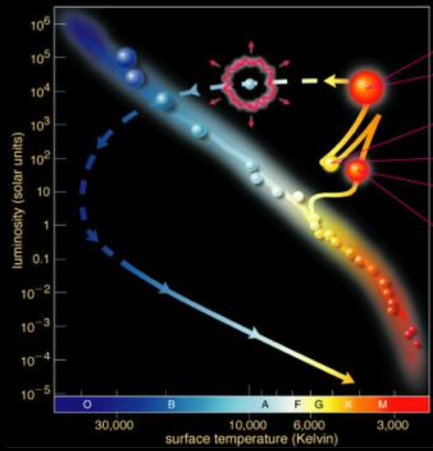


• ***fusion*** via ***CNO cycle***
• ***C**arbon, **N**itrogen, **O**xygen*
• *catalysts* for ***He*** production

• fusion ***more vigorous***
• *shorter* lifetime

• ***evolution*** proceeds as for *low mass stars*

Low/Int Mass Evolution



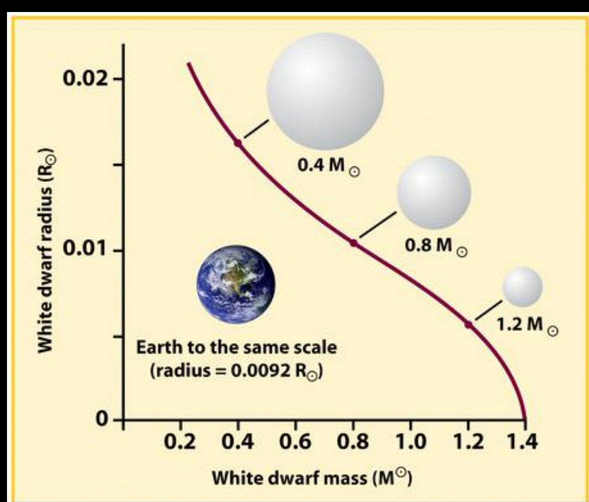
Death of Low & Intermediate Mass Stars

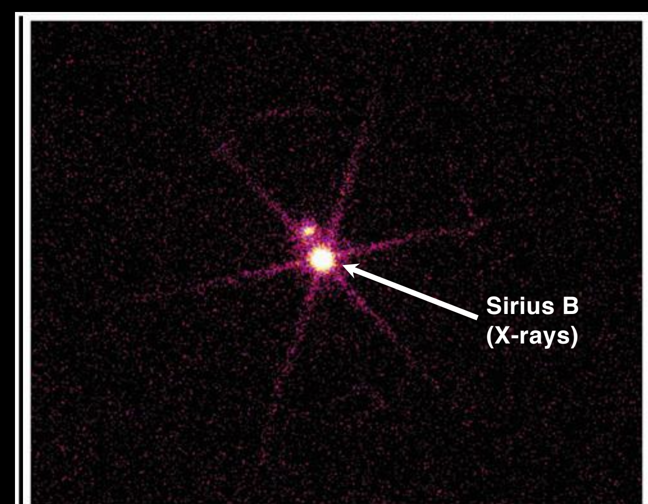
- ***no fusion***: ***core*** collapses to *size of Earth*
- high ***density***; *1 tsp ~ mass of an elephant*

Q: *What stops the **core** collapse?*

- ***electron degeneracy pressure***
- results from ***Pauli Exclusion Principle***
- **electrons *cannot*** be *close* **&** *share properties*

- ***hot core*** called a ***white dwarf***
- eventually *cools*, *crystallizes*: ***black dwarf***





• if *wd* has companion, things can *get interesting…*

• *added mass could exceed* ***Chandrasekhar Limit***

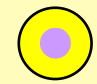
• **Type Ia Supernovae (~10^{10} $L_\odot$)**

"Planetary" Nebulae

• *expanding* ***envelope*** of a *dying low/int mass star*

• ***envelope*** is *heated*, *ejected*

• *initially* ~20 km/s

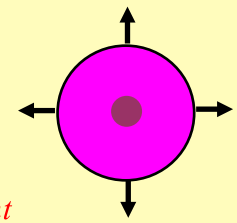


• as ***core*** is *exposed*:~ 1000 km/s

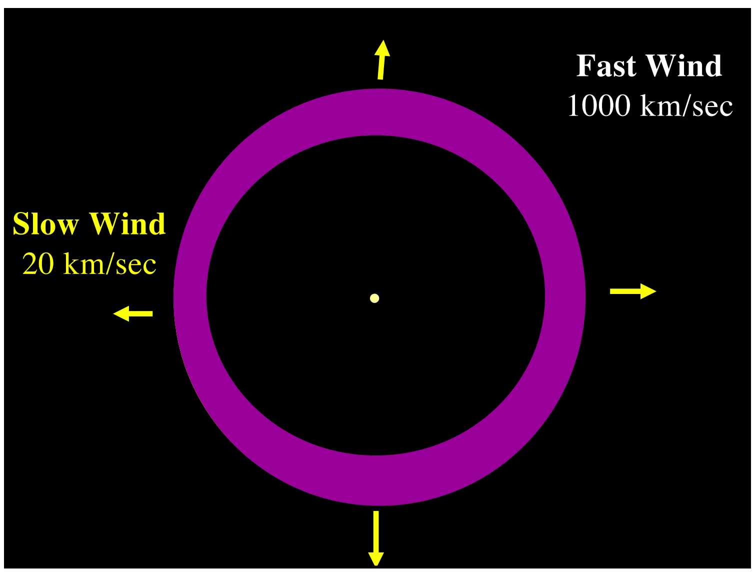
• *fast wind* acts as ***'snowplow'***

• *compresses* gas, creates *shell*

• ***"wind blown bubble"***



• *UV* from ***white dwarf*** heats shell, which *re-emits visible light*

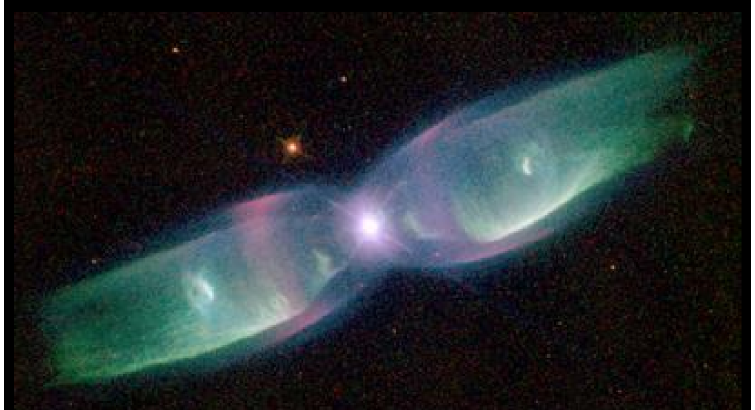


Ring Nebula (*Lyra*)

Helix Nebula (*Aquarius*)

Cat's Eye Nebula (*Draco*)

Butterfly Nebula (*Ophiuchus*)



Butterfly Nebula (*Scorpius*)