Contents

Chapter 1

Paper Notes

1.1 'Elusive hot stripped helium stars in the Galaxy' [1]

1.1.1 Stripped Helium Star Properties

- nondegenerate He-cores of which retained a $\lesssim 1 M_{\odot}$ hydrogen-helium envelope. This chemical abundance is formed by numerous aspects
  - the retreat of an H-burning convective core in MS
  - Mixing!
  - Mass loss during RLOF
  - Stellar wind from a post RLOF remnant
- Masses of $(1-7)M_{\odot}$
- None have been identified
- Most are lower mass ($\gtrsim 2M_{\odot}$)
- Their formation is heavily constrained by runaway RLOF
- Likely progenitors of both hydrogen-poor and hydrogen-rich core-collapse SNe, occurring when their CO core exceeds $\approx 1.4 M_{\odot}$
- stars with mass $\lesssim 2M_{\odot}$ with hydrogen-depleted envelopes are sdO/B-type subdwarf and stripped stars with mass $\gtrsim 7M_{\odot}$ are Wolf-Rayet stars. This gap is believed to be filled with HeS stars
-

1.1.2 Case B RLO

"At solar metallicity $Z = Z_{\odot}$ this results in the formation of a system with a He white dwarf component, if the ZAMS donor mass is $\lesssim 2.5M_{\odot}$ or a hot ($\log(T_{eff} \lesssim 4.4)$) stripped helium star (HeS) component, if the donors ZAMS mass is higher and the mass-loss by its stellar wind does not prevent RLOF"

Chapter 2

General Notes

2.1 Misc

2.1.1 WD SNe

- This, simply-ish put, is caused by because a WD cannot reach hydrostatic equilibrium. A pressure increase does **not** lead to increase and radius, and thus cooling, instead, it just increases heat, and thus fusion, quickly getting out of hand. Can b trigged if the Chandrasekhar Limit is crossed, as well as if a layer of H/He on top entities, called a edge limit detonation or "sub-Chandrasekhar" explosions.

- In DD systems the WDs must have a small separation, causing GWR to shrink the separation until merger $\rightarrow$ SNe

2.1.2 Pauli Exclusion Principle

The property of matter that two identical particles with half integer spins (fermions) cannot occupy the same quantum state.

> https://en.wikipedia.org/wiki/Pauli_exclusion_principle
> "In a poly-electron atom it is impossible for any two electrons to have the same two values of all four of their quantum numbers, which are: n, the principal quantum number; ℓ, the azimuthal quantum number; $m\ell$, the magnetic quantum number; and ms, the spin quantum number. For example, if two electrons reside in the same orbital, then their values of n, ℓ, and $m\ell$ are equal. In that case, the two values of ms(spin) pair must be different. Since the only two possible values for the spin projection $ms$are +1/2 and -1/2, it follows that one electron must have ms= +1/2 and one ms= -1/2. "

This means that in systems of very dense matter, the system ***cannot reach homogeneity***, and thus will actually have a inherent pressure. This pressure can prevent collapse due to gravity in various high dense objects (compact objects in astro).

Chapter 3

Physics of Binary Star Evolution Notes [2]

3.1 Intro

Importance of binaries

- Plays a key role in the evolution of massive stars
- first presumed to exist because of Algol Type stars. These stars were explained with mass transfer
- Mergers are a key source of strongest GW rad, GrBs, and have r-process elements. (i.e. in Kilonova)
- Likely cause of SNe Ia, Ib, Ic (SN with a lack of hydrogen in their spectra)
- cause of low-intermediate mass stars with odd chemical compositions, ex. barium stars.

3.2 Visual binaries and the universal validity of the laws of physics

3.2.1 Visual binaries

- Visual binary → two in proximity through a telescope
- Physical → gravitonalty bound orbits
- Optical → happen to be close together in the sky
- Visual binaries have longer orbits
- the proof of physical binaries (and not just coincidence) was proved in 1767 by John Michell
- Shows that Newton's law of gravity applied outside just our solar system

3.2.2 Astrometric Binaries

Wide binaries

- Binaries where one of the stars is too faint to directly observe
- Can still be detected by the following Proper Motion of the visible component
- Center of mass moves along, star orbits this center, showing a periodic wiggle in its apparent motion (I wonder how this can be muddled with and/or separated from parallax. I'm guessing they are in different planes?? (next graphic helped(it wiggles slightly due to yearly parallax, however, the proper motion is much greater and over a much longer duration, so it sort of just becomes "noise" relative)))

3.2.3 Spectroscopic Binaries

Spectroscopic Binaries

- A binary which is determined to be a binary due to its spectra
- double-lined binary (SB2) → when both sets of spectral lines can be observed redshifting and blueshifting
- single-lined (SB1) → when only set of spectral lines can be observed redshifting/blueshifting
- this is due to Doppler shifting when one of the binaries is relativistically coming towards us and the other away
- Doppler shift ($\Delta\lambda$) can be related to the radial velocity (the component of the velocity on our line of sight)
-
$$\frac{\Delta\lambda}{\lambda} = \frac{v_{rad}}{c}$$

3.2.4 Eclipsing Binaries

Binaries where one star passes in front of the other at some point during its period

- A partial eclipse will happen if
-
$$\sin(\phi) < \sin(\phi_0) = \frac{R_1 + R_2}{a}$$
- where inclination i is defined as the angle between the orbital plane and the plane of the sky $\rightarrow \phi = 90° - i$ and a is the orbital radius
- and a total eclipse will occur if
-
$$\sin(\phi) < \sin(\phi_1) = \frac{R_1 - R_2}{a}$$
- We assume that the angles between line of sight and orbital planes are random, the probability of having an angle between 0 and ϕ_0 is the fraction of the surface area of the half sphere between the pole and the circle at an angle ϕ_0 from the pole, which is equal to $2\pi(1 - \cos(\phi_0))$. While the area of the half sphere is 2π[1]. Thus, the probability of having an eclipse is
-
$$\mathcal{F}_{eclipse} = (1 - \cos\phi_0)$$
- Assuming ϕ_0 small
-
$$\sin\phi \simeq \phi_0 \simeq \frac{(R_1 + R)_2}{a}$$
- due to series expansion[2]
-
$$\cos\phi_0 \simeq 1 - \frac{(R_1 + R_2)^2}{2a^2}$$
- Thus
-
$$\mathcal{F}_{eclipse} = \frac{(R_1 + R_2)^2}{2a^2}$$
- Because $R_1 + R_2 < a$, eclipses are most likely for either dwarf stars with a very close orbital radius, or wide binaries where at least one star is a giant

[1] Try this myself and verify that this makes sense
[2] for sure do this at some point

3.2.5

- It is possible for a spinning WDs to show variation (but not pulses) in star brightness
- This is because of the magnetic fields on WDs causing bright spots
- Pulsation can be determined by the density

Novae/CVs

- Caused my mass transfer onto a WD
- WD shell goes SN, causing Novae
- Standard candle
- Has a variation called dwarf Novae
- caused by instability in the accretion disk
- much weaker

3.2.6

- Brightest sources of x-rays were found to be CV accreting systems

3.2.7

- The first NS star XrB
- Regular periodicity of with increase of x-ray emission
- Caused by the NS being obscured by the larger star

3.2.8 First BH XrB

- Discovered x-ray source with nearby supergiant
- Falls into two classes
- HMXBs and LMXBs
- determined by the mass of the acceptor with respect to the donor
- x-ray emission called by infilling matter
- $\frac{GMm}{R} = .01mc^2$[3]
- much much much more efficient than any fusion reactor on earth
- values as high as $.42mc^2$
- Common in Globular clusters

[3] Shockingly simple eq

3.2.9 Double NSs & BHs

- Proved by GW detection
- Detections are dominated by DBHs
- DNSs formed through lower mass binaries

3.2.10 MSPs

- Generally remnants of LMXBs
- Systems with MSPs generally have WD partners
- Mass-transfer through evolution, or through orbital momentum loss through or GWR
- The NS is greatly accelerated through accretion
- Old NSs which evolved through this process are called *Recylced Pulsars*

3.2.11 Results of evolution in binaries

- SNe caused by the death of stars more massive than $\sim 8M_\odot$
- SNe types
  - Type I SNe
  - Type Ib SNe
  - Type Ic SNe
  - Type II SNe
- due to the fact that Type Ib SNe and Type Ic SNe are stripped cores, it is incredibly likely that they result from binary systems
- We may also observe both Type Ib SNe and Type Ic SNe in WR star, however, we have **not** yet
- WD SNe (section 2.1.1) *require* some sort of mass transfer process
- The companion donor can be either a standard star (SD), or another WD (DD)

3.2.12 Weird stars

- Blue stragglers
- Barium

3.3 Orbits and masses of spectroscopic binaries

3.3.4

This is generally all math that I either know from astro classes, or is so specific id need to revisit it to use anyway

$$\frac{L}{L_\odot} = \frac{M}{M_\odot}^{3.5}, M > 1.3M_\odot$$

3.3.5 Very massive stars

- Most massive has $L \sim 10^{L}_{\odot}$
- Because of the high ($\sim 50000k$) temps, they have strong stellar wind, and thus very similar spectra to WR star, which they are distinguished from by the presence of hydrogen
- Denoted as WNh

3.3.6 Stuff that screws up rad vel curves

- Rad Vel curve must be off due to a difference in eccentricity values derived from the rad curve and the light curve
- Rotation effect
  - when the stars are eclipsing the rotational Doppler shift can be added (if the half spinning away from us is obscured) or subtracted to the shift, leading to different rad velocity measurements. This is called the Rossiter-McLaughlin effect. [4]
- presence of gas streams
  - wow they could have said literally anything about what a gas stream is in this case
  - im guessing it means some sort of flow of mass coming off of the binaries, maybe in accretion, maybe in jets???
- reflection effect
- heating effect
  - Both the reflection and heating effect are caused by that the stars will cast light on each other, both heating and causing reflection
- deformation effect
  - the above effects cause the curve to be shifted from the c.m., leading to wonky radial vel curves
- this is actually pretty important when it comes to HMXBs and properly measuring NS and BH masses

[4] This is actually a super neat and intuitive process which i feel like the book just sorta skips and doesnt explain, maybe wanna write out/make some graphics bout this sometime

3.3.7 Interacting binaries

- $> 70\%$ of massive o-type stars are members of binaries so close that they'll exchange mass or merge before either star explode as a SN

the rest of this section follows the "way too niche of math to write down" thing

3.4 Roche equipotential

I have a ridiculous amount of notes and a whole essay written about this, so notes here will be pretty light

---

- This is some black magic mathmathmatic reasoning
- Co-rotating binaries with have a tidal bulge that can be 'easily' calculated
- also love the seemingly kinda personal rant about how the RL diagram is actually wrong, then provides a diagram which is way less intuitive

3.4.1 Mass transfer Galore

- Mass transfer through L_1 does not majority effect angular momentum, however, transfer through L_2 does, causing a shrinkage in separation, and typically mergers
- Different ways of modeling the transfer, depending on how you treat angular momentum with respect to the transfer
- Orbit widens if the donor is less massive then accreter, and shrinks if the donor is more

3.4.2 Types of RLO

- Conservative Roche lobe overflow
- Mass loss from a circumbinary disk

3.4.3 General Notes

- Mass transfer onto NS and BH are limited by the Eddington Limit
- However, mass transferred off of the donor is at the rate of the evolution of its envelope. (Thermal Timescale)
- mass transfer off of the donor is much greater (2 to 4 orders of magnitude) then the maximum accretion rate thus, the bulk of the mass will be "blown away"
- if more than half of the total mass of the binary system is lost in a SN, the system will become unbounded
- What on earth is a applegate mechanism
- and what is gravitational quadrupole coupling
- 'im pretty sure its just when the oblateness of the star various from some convection stuff, which causes the period to variation causing period variations

3.4.4 Stability Criteria

- Depends on the response of the star losing mass as well as the RL
- more likely to detect it if the mass transfer is stable
- orbit always expands for $q < 1$ and always shrinks when $q = 1.28$
- Depends on whether the donor contracts or swells upon starting to transfer mass
- Donors with radiative envelopes (Case A RLO) or slightly convective envelopes (early Case B RLO) will typically either shrink or stay the same radius
-

3.4.5 Tidal Evo

- Grav interaction will cause Tidal Bulges to form
- If rotation of the stars is not synced with orbital motion, the movement of the bulges will cause friction, thus dissipating the KE of the star.
- If the orbit is eccentric, the effect is greater in magnitude
- This leads to the orbit becoming perfectly circular
- Happens faster in systems with closer separations
- Tempature can heavily effect orbtial eccentrictiy based on convection rates

3.4.6 CE

- Trigged by unstable runaway mass transfer
- companion star is engulfed in the envelope of the donor
- the companion moving through this envelope causing friction, thus reducing angular moment, thus shrinking orbit
- In some cases the envelope is ejected, and if it isnt, it leads to merger
- Likely progenitor of some planetary nebulae
- Very hard to predict due to unstable nature
- Onset is caused by runaway RLO, Darwin instability, or the expansion of the accreting star

Stages of CE

- loss of co-rotation
- plunge-in
- Slow spiral-in
- Envelope Ejection

CE ejection

- Whether not the envelope will be ejected is dependent on how good the system is at converting the GPE into KE, this added KE can then eject the envelope
- This can be described as the efficiency α_{CE} of converting orbital energy ΔE_{orb}
- $$E_{bind} = \alpha_{CE} \Delta E_{orb}$$
- Ability to eject a CE depends heavily on the evolutionary status of the donor at the onset of CE
- Separation post CE ejection is about 100-1000x smaller than at Onset
- $$E_{bind} \equiv -\frac{GM_{donor}M_{env}}{\lambda R_{donor}}$$
- λ various heavily on stealer mass and evolutionary status
- For low max systems the envelopes of the donors are typically ejected, as $|E_{bind}|$ is typically quite small
- Many HMXBs with NSs will not survive CE and hence DNS mergers are rare, although these do theoretically form Thorne-Zytkov objects
-

3.8 Evolution of single stars

F

3.8.1 Why stars do stuff[5]

- A globe of monatomic gas without energy sources and in HSEq follows
-
$$2E_{th} + E_{pot} = 0$$
- E_{th} is given by
-
$$E_{th} = \frac{3}{2}Nk\bar{T} = \frac{3}{2}M(\mathcal{R}/\mu)\bar{T}$$
- Where N is the partcile number in the star, k is the boltzman constant, M is the mass of the globe $\mathcal{R} = ak/m_h$, the ideal gas constant, μ is the mean particle mass, in units of m_h of the hydrogen atom
- E_{pot} is given by
-
$$E_{pot} = -\alpha GM^2/R$$
- Where R is stellar rad, G is grav const, and α is a constant of proportionality of order unity, which depends on the density distribution of the star.
- From substitution, we find that
-
$$\bar{T} = \alpha(\frac{GM}{R})(\frac{\mu}{3\mathcal{R}})$$
- This is import because it shows that internal temp is only depended on the stellar radius, increasing when the star shrinks
- Energy loss is given by
-
$$E_{tot=E_{th}+E_{pot}} = \frac{1}{2}E_{pot} = -\alpha\frac{GM^2}{2R}$$
- This shows that as E_{tot} decreases the radius of the star must decrease
- However, as shown by $\bar{T}$,as the star contracts the internal temp increases
- This means as the star (or cloud of gas) radius heat away, it actually gets hotter, leading to more radiation, and thus more shrinking
- This applies to the star from the moment it is a gas to the end of its life as BH, NS, WD, etc

[5] trying to focus on some of the math here, cause while i conceptually understand it, the math is really neat

- These equations work well for antibiotic index of $\gamma = C_p/C_V = 5/3$, which is great for globes of ionized hydrogen and helium. However, generalized forms can be found with eqs 8.6-8.8
- if $\gamma \leq 4/3$, the star **cannot** reach HSEq, and thus must collapse or explode
- Stars of very high mass have very high luminosites, which mean their interior pressure is dominated by photon gas, which has $\gamma = 4/3$. This sets an upper limit for the mass of a star, also called the Eddington (Luminosity) Limit

3.8.2 Stellar Timescales

There are three timescales for single star evo that are relevant for binary stellar evo

Dynamical Pulsation timescale

Theorem 3.8.1 – Dynamical-Pulsation-timescale

$$\tau_{dyn} = \frac{R}{c_s} \simeq 50\text{min} \left(\frac{\bar{\rho_\odot}}{\bar{\rho}}\right)^{1/2}$$

Where $\bar{\rho}$ is the mean mass density.

This is the timescale of how long it takes for a start to restore a perturbation of its HSEq. This can be defined as the time it takes for a sound way with velocity c_s to cross the stellar radius

Thermal/Kelvin-Helmholtz timescale

Timescale of how long it takes for the star to react to fusion rate not being equal to the radiative energy loss. This is import with pre-main sequence contraction and after the stars fuel has been used

Nuclear timescale

Time it takes for a star to use all of its available fuel

3.8.3 High mass evolution $M \geq 12 M_\odot$

- Leave behind a collapsing iron core, which creates a NS or BH
-

3.8.4 Low mass stellar evolution $M \leq 8 M_\odot$

- The degenerate mass in the core of the star heavily effects fusion
- For electron degenerate gas, the pressure only depends on the density (and not on the temperature)
- This means that this degenerate gas ignites, it has no way of stabilizing itself, leading to a ‘flash’, where it all ignites rapidly.

- This will only stop when the temp reaches a point where the ideal gas is able to also do fusion, at which point the star can actually expand and cool
- "In stars with $M < 2.3M_{\odot}$, the core becomes degenerate during hydrogen shell burning, and when $M_{he} \approx .47M_{\odot}$, the helium ignites with a flash, the temp rises to $\approx 10^9$K, and the degeneracy is removed"
- This is not violent to actually disrupt the star
- In stars with mass $2.3m_{\odot} < M \lesssim 8M_{\odot}$ they instead ignite carbon in a flash. This is strong enough to disrupt the star (albeit rarely)
- However, it is more likely for the star to eject its helium envelope due to helium-shell burning as well as the instability of the RSG stage, leaving behind a CO WD.
- Because of this CO ignition is rare.

Mass limit at $\sim 1.2M_{\odot}$

- When hydrogen is exhausted in the star, the star contracts. This causes it to drift sharply left on the HR diagram, until the hydrogen-shell begins fusion causing it to have drift slowly upward and to the right on an HR diagram
-

Mass limit at $\sim 1.5M_{\odot}$

- Masses less than $\sim 1.5M_{\odot}$ have convective outer envelope and ones higher are radiative.
- This convective envelope creates a magnetic field, this magnetic field can cause magnetic breaking, leading to stars of this mass range having slower spins

3.8.5 Stars in the range of $8 - 12M_{\odot}$

- Not very well is known about evolution in this range
- Generally, the carbon in the ore will ignite and leave a degenerate ONeMg core
- This happens after they eject their hydrogen envelope, but in binaries this envelope is lost through mass transfer
- This means that the ONeMg core will grow to the Chandrasekhar Limit, at which point it will then collapse, creating NS and SN explosion
- Might also result in Type I SNe

3.8.6 Effects of wind mass loss, metallicity, and rotation

- If a star has very fast spin, the helium in the core can get mixed into the whole star, preventing the star from becoming a giant, instead leading it towards becoming a WR star[6]. This can happen with stars with of low of mass as $15M_{\odot}$, as compared to the typical progenitor mass of $\sim 25M_{\odot}$
- Non-rotating stars can become much more massive

[6] This is cool as shit. Blender star my beloved

3.8.7 Final Evo of stars in the range of $1 - 8M_{\odot}$

- Unstable pulsing
- Very strong stellar winds
- If they're low enough mass, ($< 8M\odot$), they can become WDs before carbon ignition

3.8.8 Final Evolution and core collapse of stars more massive than $8M\odot$

Between 8 and $\sim 10 - 12$

- When the core approaches the Chandrasekhar Limit thus begins the onset of core collapse
-

Used Papers

[1] L. Yungelson et al. “Elusive hot stripped helium stars in the Galaxy - I. Evolutionary stellar models in the gap between subdwarfs and Wolf-Rayet stars”. en. In: *Astronomy & Astrophysics* 683 (Mar. 2024). Publisher: EDP Sciences, A37. ISSN: 0004-6361, 1432-0746. DOI: 10.1051/0004-6361/202347806. URL: https://www.aanda.org/articles/aa/abs/2024/03/aa47806-23/aa47806-23.html (visited on 11/18/2025).

[2] Thomas M. Tauris and Edward P.J. van den Heuvel. *From Stars to X-ray Binaries and Gravitational Wave Sources*. Princeton: Princeton University Press, 2023. ISBN: 9780691239262. DOI: doi:10.1515/9780691239262. URL: https://doi.org/10.1515/9780691239262.

Glossary

Algol Type Type of eclipsing binary with properties similar to the Algol system. It appears paradoxical because the more evolved star has a smaller mass, explained by mass transfer. 6

antibiotic index Also called a heart capacity ratio. A very very very simplified and abstract defenition is how much a gas will expand when heated. `https://en.wikipedia.org/wiki/Heat_capacity_ratio` 17

Case A RLO RLO during donor hydrogen core burning (Meaning mainsequence) [1] 14

Case B RLO This is where the donor star is *post* hydrogen core burning. Ex. hydrogen *shell* burning [1]
See 1.1.2 for more info 14

Chandrasekhar Limit Maxiumum mass of a white dwarf, approx $M \approx 1.4M_{\odot}$
This is support be electron degeneracy pressure 4, 18, 19

Conservative Roche lobe overflow RLO where the total mass and angular momentum remain constant. Is an example of Huangs *slow mode* 13

DD *Double Degenerate*, donor as well as accretor are WDs 4, 10

degenerate Matter which is under the effects of degeneracy from the Pauli Exclusion Principle. This is very commonly seen in neutron stars, as degeneracy pressure is what keeps them from collasping.
3

Eddington (Luminosity) Limit The uper limit of the mass of a star, defined as $3.2 \times 10^4 \left(\frac{M}{M_{\odot}}\right) L_{\odot}$ 17

Eddington Limit $\dot{M}_{Edd} \simeq 1.8 \times 10^{-8} M_{\odot}\mathrm{yr}^{-1}$ For NS
Maxium rate of mass transfer onto a NS or BH 13

edge limit detonation A WD SNe trigged by accreted H/He on the suface which sends a shockwave into the star, trigging runaway fusion. 4

GWR gravitnal wave radiation.
Process of stars losing angular momentum through the radiation of gravitnal waves 4

Kilonova A merger of either a NS+NS (DNS) binary or a NS+BH binary. Results in a bright signal resulting from the rapid decay the the NS material. Results in a peak brightness around 1000x that of a standard nova, hence the name. Likely a standard candle. 6

magnetic breaking the process of a star magnetic field binding with the winds (or gas, etc), causing the stars spin to slow due to consv of ang momentum 18

Mass loss from a circumbinary disk Ejected mass from mass transfer/winds a ring orbiting the system (a circumbinary disk).
Refered to by Huang as an *intermediate mode*. Due to tidal interactions these rings "extract" angular momentum from the system 13

MSP Milisecond Pulsar.
A pulsar with a spin period $\sim$ 30ms 10

ONeMg Fill this in later hopefully. Pretty sure it just means Oxygen, Neon and Magnesium? 18

Pauli Exclusion Principle See 2.1.2 21

photon gas A 'gas-like' collection of photons. This means that they have a tempature, pressure, and entropy.
They are most common in black-body equilibrums. https://en.wikipedia.org/wiki/Photon_gas 17

Proper Motion The motion of a star in the sky relative to more distant stars. Allows us understand the velocity of a star relative to the earth 7

Recylced Pulsar A pulsar which obtained its rapid spin through accretion. Has weaker magnetic fields then newly formed NSs 10

RSG Red-supergiant
Supergaint stars with a spectral class of M or K 18

runaway RLOF Unstable RLOF mass transfer which leads to eventual mergers 3

SD *Single Degenerate*, donor is a normal star, accretor is WD 10

Thermal Timescale 13

Type I SNe A SNe **without** hydrogen in its spectra
Generally standard candles. They are thermonuclear explosions of carbon-oxygen WDs. See section(2.1.1) 10, 18

Type Ib SNe A SNe **without** hydrogen and with helium in its spectra.
Caused by collaspe of the naked helium core star. 10

Type Ic SNe A SNe **without** hydrogen or helium in its spectra.
A star where both the hydrogen and helium envelopes have been fully stripped. 10

Type II SNe A SNe **with** hydrogen in its spectra
generally found in galaxies with high star formation rate. Likely caused by core collaspe 10

WNh Very massive stars with strong stellar winds, leading to spectra very similar to that of WRs, but also with hydrogen emission. These have ejected their outer shells of hydrogen, and show distinct He and/or C emission, buta also is still doing H fusion in the core 11

WR star Wolf-Rayet star.
A helium star of mass They are genally so massive (typically more than $\sim 25M_{\odot}$) that it sheds its hydrogen layer due to stellar wind. It may also shed its helium layer as well. 10, 11, 18

ZAMS Zero age main sequence This is a star which is has literally just started on the main seqeunce. Hence 'zero-age' 3