Contents

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.

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

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

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)))

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)

-

$$\frac{\Delta\lambda}{\lambda} = \frac{v_{rad}}{c}$$

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

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

2.6

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

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

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

2.9 Double NSs & BHs

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

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*

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 I SNe
  - Type I SNe
  - Type II SNe
- due to the fact that Type I SNe and Type I SNe are stripped cores, it is incredibly likely that they result from binary systems
- We may also observe both Type I SNe and Type I SNe in WR, however, we have **not** yet
- WD SNe (section 0.1) *require* some sort of mass transfer process
- The companion donor can be either a standard star (SD), or another WD (DD)

2.12 Weird stars

- Blue stragglers
- Barium

3 Orbits and masses of spectroscopic binaries

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

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

3.5 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, which they are distinguished from by the presence of hydrogen
- Denoted as WNh

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

[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

- 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

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

4 Roche equipotential

[5]

- 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
-

0 Misc

0.1 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

[5] I have a ridiculous amount of notes and a whole essay written about this, so notes here Wil be pretty light

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. 1

Chandrasekhar limit Maxium mass of a WD, $\sim 1.4M_\odot$ 7

DD *Double Degenerate*, donor as well as accretor are WDs 5, 7

edge limit detonation A WD SNe trigged by accreted H/He on the suface which sends a shockwave into the star, trigging runaway fusion. 7

GWR gravitnal wave radiation.
Process of stars losing angular momentum through the radiation of gravitnal waves 7

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. 1

MSP Milisecond Pulsar.
A pulsar with a spin period $\sim$ 30ms 5

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 2

Recylced Pulsar A pulsar which obtained its rapid spin through accretion. Has weaker magnetic fields then newly formed NSs 5

SD *Single Degenerate*, donor is a normal star, accretor is WD 5

Type I SNe A SNe **without** hydrogen in its spectra
Generally standard candles. They are thermonuclear explosions of carbon-oxygen WDs. See section(0.1) 5

Type I SNe A SNe **without** hydrogen and with helium in its spectra.
Caused by collaspe of the naked helium core star. 5

Type I SNe A SNe **without** hydrogen or helium in its spectra.
A star where both the hydrogen and helium envelopes have been fully stripped. 5

Type II SNe A SNe **with** hydrogen in its spectra
generally found in galaxies with high star formation rate. Likely caused by core collaspe 5

WNh Very massive stars with strong stellar winds, leading to spectra very similar to that of WRs, but with with hydrogen emission 6

WR Wolf-Rayet star.
A star so massive (generally more than $\sim 25M_{\odot}$) that it sheds its hydrogen layer due to stellar wind. It may also shed its helium layer as well. 5, 6