STELLAR PHYSICS

MIDTERM REPORT

YASH SANJAY SAWANT

MENTOR - Adarsh Madur

OVERVIEW

Stellar physics is the branch of astrophysics that focuses on the study of stars. It involves the exploration of the physical properties, structure, evolution, and behavior of stars using principles from physics, astronomy, and other related fields.

HOWEVER ALERT WE ARE ANTIQUITY REMAINS AN UNKNOWN UNANTICIPATED GALAXY

Gravity has a huge role in astronomy due to unimaginably high masses of heavenly bodies . Stars try to fight back gravity but gravity always succeeds. Stars are formed in the dense regions of huge gas clouds. The matter collapses on itself, releasing the loss in gravitational potential energy as kinetic energy. This kinetic energy manifests in the form of temperature and pressure of the gas, slowing down the collapse of mass. But this kinetic energy keeps leaking due to radiation and the core collapses further.

After a certain mass is accumulated the core becomes hot enough for nuclear fusion (H-H fusion to give He) to start. This nuclear fusion maintains the temperature (and hence pressure) of the star and a state of quasi-static equilibrium is reached. Every star spends almost its entire life in this stage : burning H in the core. This is called main sequence period. Only the core of the star is hot enough for nuclear reaction to take place.

After a few billion years the core is running low on fuel, the core starts to collapse. Now the shell just surrounding the core becomes hot enough for fusion. During this process the outer layers of the star expand (a lot!, I literally mean it !!)
After a certain time, the core becomes hot enough for the He + He = C fusion reaction. But this doesn’t sustain the core for long as the amount of He is small. Now the processes become complex....

Let's explore how it happens!!

CONTENTS:

Solving a star involves some complex differential equations.
Some standard notation is used :
r- distance from the center of the star.
m = m(r) - the mass inside a sphere of radius r centered at the center of the star.
R - radius of the star.
M - total mass of the star.
ρ= ρ(r) - density at that position.
l = l(r) - the luminosity (energy coming out per unit time) at distance r from the center.
L - total luminosity of the star.
P = P(r) - total pressure at r.
Pgas - pressure due to gas.
Prad - radiation pressure.
T = T(r) - temperature at r.
Note that is to be interpreted as ‘of the order of’, that is, it indicates order of magnitude.

CHAPTER 1

BASICS:

It is the longest and most stable period in a star's life, during which it fuses hydrogen into helium in its core, releasing an enormous amount of energy in the process. The main sequence stage is characterized by a delicate balance between the inward gravitational force and the outward pressure generated by nuclear fusion.

It can be described in 4 basic stages

1) Conservation of mass (loss in mass due to radiation is very insignificant)
2) Conservation of energy
3) Hydrostatic equilibrium
4) Energy transport equation

1.1 <u>CONSERVATION OF MASS</u>

Let R and r be the radius of the star and distance of a point from center of the star respectively. Let M, m = m(r, t) and = (r, t) be the total mass of star and mass inside a shell of radius r and density at r respectively.
v is the radial velocity at a distance r from the center.

$$dm = 4\pi r^2(\rho dr - \rho v dt)$$

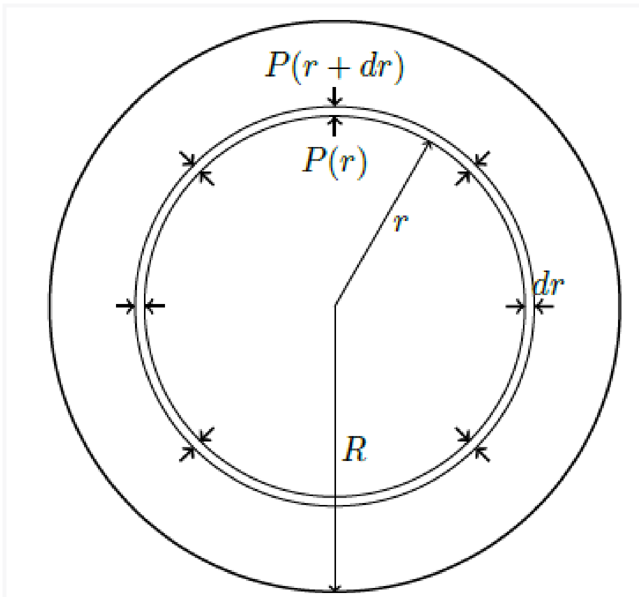
$$\boxed{\frac{\partial m}{\partial r} = 4\pi r^2 \rho v}$$

$$\frac{\partial m}{\partial t} = -4\pi r^2 \rho$$

1.2 Hydrostatic Equilibrium

In the core of a star, gravity acts as a force that tries to compress the stellar material inward. This compression leads to an increase in pressure within the star. On the other hand, the energy generated by nuclear fusion processes in the core creates an outward pressure that counteracts gravity.

Since the star is in an equilibrium (on average), the net force on a element at r with thickness dr and subtending a solid angle dΩ at the center must be zero.



$P = P(r,t)$ denotes the pressure at distance r from the center.

$$\frac{Gm\,dm}{r^2} = d\Omega\, r^2 (P(r) - P(r+dr))$$

$$dm = \rho\, d\Omega\, r^2\, dr$$

Therefore,

$$\boxed{\frac{\partial P}{\partial r} = -\rho g}$$

where g is the local acceleration due to gravity.

1.3 Virial Theorem

The virial theorem is a fundamental principle in physics that relates the average kinetic energy and potential energy of a system in equilibrium. It has various applications in different fields, including astronomy, astrophysics, and statistical mechanics.

In the context of astrophysics, the virial theorem is often used to study the equilibrium and stability of stellar systems, such as star clusters and galaxies. It provides a way to estimate the total mass or gravitational potential energy of a system based on its observable properties.

The virial theorem states that in a system of particles (such as stars) in equilibrium under the influence of gravitational forces, the average kinetic energy of the particles is related to the average potential energy by a specific factor. Mathematically, the theorem can be expressed as:

$$2K + U = 0$$

where K represents the total kinetic energy of the system, U represents the total potential energy, and the factor of 2 arises from the average nature of the theorem.

This equation implies that the average kinetic energy of the system is negative and equal in magnitude to half of the average potential energy. In other words, the system is in a state of equilibrium when the sum of twice the kinetic energy and the potential energy is zero.

The virial theorem provides important insights into the stability and properties of astrophysical systems. For example, in a star cluster, the theorem can be used to estimate the total mass of the cluster based on the measured velocities of its member stars. It can also be applied to study the dynamics of galaxies and galaxy clusters.