Understanding the Lives of Stars
Stars are big balls of hot gas in a container. In many ways just like a jar of hot gas in the lab. We can understand changes they make over time using three tools:

1. the ideal gas law
2. gravity
3. nuclear fusion reactions

We will start with number 3.
tool #3, nuclear fusion reactions
require high temperatures and pressures
heavier atoms require every higher temperatures
all stars fuse H to He
stars of about $0.5 \, M_{\odot}$ stop with H fusion
they never become red giants
stars of above $0.5 \, M_{\odot}$ fuse He to C
some like our Sun stop there
other more massive stars fuse heavier atoms
more about that later
now tool #2, gravity

every star's life is controlled by a battle between
pressure & gravity

weight of a star's matter pushes down on stuff below
creates the pressure = force/area

if the pressure is balanced, things are static
if not balanced stuff below is forced to be smaller
if pressure below is higher, outer layers pushed up

since gravity depends on distance from center
weight & thus pressure by gravity is less

goes on until a new static situation results but. . . .
tool #2, gravity
but there is a complication:
gravitational potential energy (gPE)
when a gas is pushed outward
it gains gPE and it temperature drops
when a gas is pulled inward
it loosees gPE and it temperature rises
remember class demo
so if pressure below is higher, outer layers pushed up
weight is less & temperature drops
Now tool #1 the ideal gas law

Let's look at the parts in this equation
starting on the right

T is the Kelvin temperature of star region you consider

R is the gas constant—you can ignore it

n is the number of moles in the region

remember Avogadro?

No? Here is a reminder
one mole = $6.02 \times 10^{23}$

Here, take my number. Of course its $6.02 \times 10^{23}$! I’m Amedeo Avogadro. Ha! Get it? Its my number.

Avogadro-chemist, mathematician... ladies man
now on the left

V is the volume of star region you consider
P is the pressure in that region

let's apply this idea to our Sun, a main sequence star
our Sun

in the core $4 \text{H} \rightarrow 1 \text{He} = \text{energy}$

the number of moles in the core goes down

if $PV = nRT$ applies and the right side drops, the left must too

pressure can't really fall so the volume does but $gPE$ makes the core a littler hotter speeding up the fusion reactions

extra fusion energy pushes up the top layers; result

Sun is more luminous but larger and cooler
so far everything mentioned is a slow process
when the H runs out completely, things happen faster

no H in core means source of pressure is gone
the $PV = nRT$ balance is upset
the P drops & so does V but now gPE to heat the core
the core shrinks and heats but
the star's outside expands and cools yet is more luminous
then something interesting kicks in right outside the original contracting core (yellow) it is now hot enough for H fusion
Sun goes up the red giant branch (RGB) in the HR diagram
Sun has an inert He core + H fusing shell process goes on until core is hot enough for He fusion Then . . . .
Sun shrinks, outside is hotter, but less luminous
Sun is now on the horizontal branch of the HR diagram
has a He fusion core making C & O
and a H fusing shell making He

Eventually the He fuel in the core runs out and the process repeats in a sense . . . .
w/no He fuel core contracts again
Sun expands again on the outside
Up the second red giant branch,
    the AGB in the HR diagram
Inside there is an inert C & O core
    surrounded by a shell of fusing
    He inside a shell of fusing H
this core is never reaches C fusion temperatures
thermal pulses drive away the outer layers
they for a planetary nebula
core becomes a white dwarf