Hertzsprung-Russell Diagram Simulation

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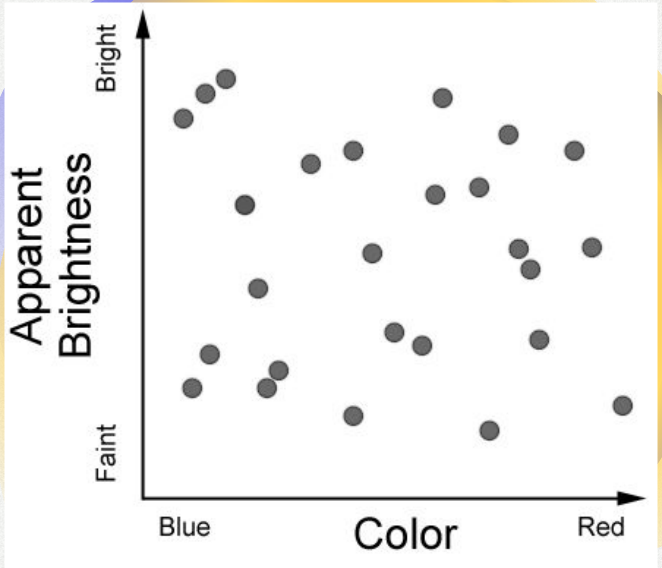
01

Background Information



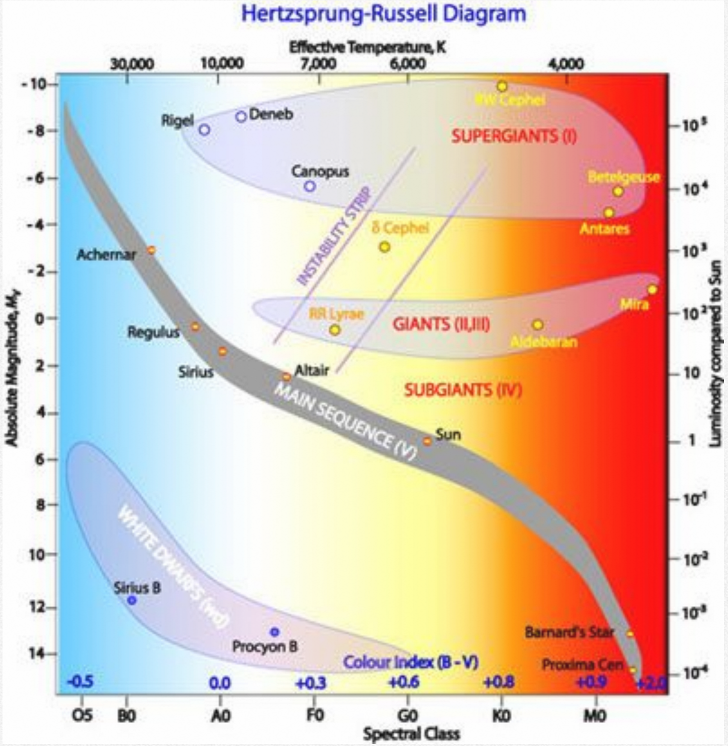
H-R Diagrams

Used to **study the stellar evolution** of stars based off of their **initial mass**

Allows us to observe its **internal structures and how its energy is produced**.

Theoretical Diagrams:
Model Temperature Vs Luminosity

Observational Diagrams:
Model Spectral Type (color) Vs Absolute Magnitude



Allows astronomers to know a star’s age and internal structures based off of its position on the graph

Stages of Evolution

Main Sequence

Runs diagonally across diagram from top left to bottom right

Most stars are found here. About 90% of a star's lifespan will be in the main sequence

Greatest variation in temperature and luminosity amongst stars

Giants

Found at top right above the main sequence

Stars here are very big and bright, but not as hot as they could have once been

Supergiants are predicted to Supernova

Giants are predicted to turn to dwarf stars

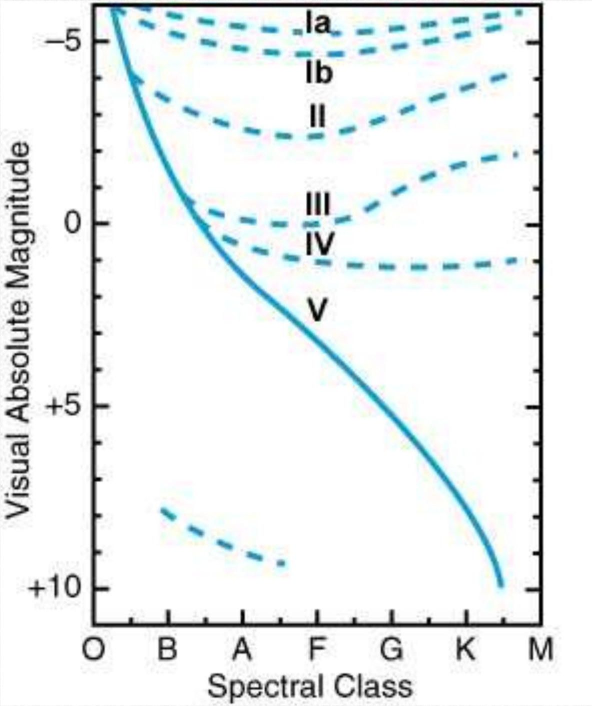
Dwarfs

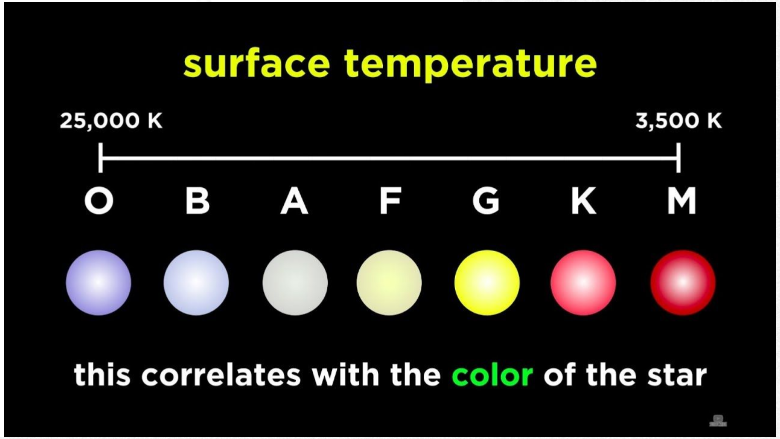
Occur when stars shed their outer gas layers

Very hot, but not very bright as they're so small

Dwarfs eventually burn out and "die"

Spectral and Luminosity Classes





Stars of the same classes tend to show the same evolutionary behavior.

You will sometimes see a spectral class of VI/D and SD.

These categorize dwarf stars

02 Methods and Techniques

Equations

Initial Mass Function

$$\frac{dn}{dM} = kM^{-2.35}$$

n = number of stars
M = mass
k = local stellar density (0.14)

Mass Luminosity Relation

$$\frac{L}{L_\odot} \approx 0.23\left(\frac{M}{M_\odot}\right)^{2.3} \qquad (M < 0.43M_\odot)$$

$$\frac{L}{L_\odot} = \left(\frac{M}{M_\odot}\right)^{4} \qquad (0.43M_\odot < M < 2M_\odot)$$

$$\frac{L}{L_\odot} \approx 1.4\left(\frac{M}{M_\odot}\right)^{3.5} \qquad (2M_\odot < M < 55M_\odot)$$

$$\frac{L}{L_\odot} \approx 32000\frac{M}{M_\odot} \qquad (M > 55M_\odot)$$

Data Collection

We downloaded our stellar evolution models from the publicly available **MESA Isochrones & Stellar Tracks (MIST)** dataset.

For simplicity, we downloaded models that assume the following parameters:

1. v/vcrit=0.0
2. [Fe/H]=+0.00

There was missing data between the star ages that the model provided, so we needed to linearly interpolate to fill in the gaps.

See this link for the model downloads:
http://waps.cfa.harvard.edu/MIST/model_grids.html

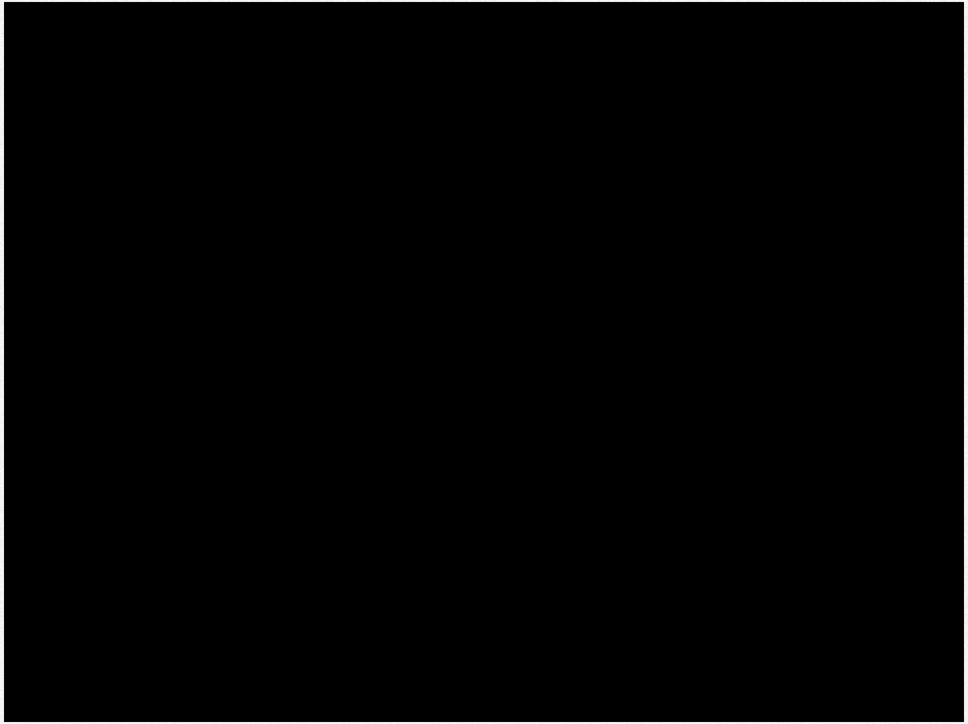
Sample Code

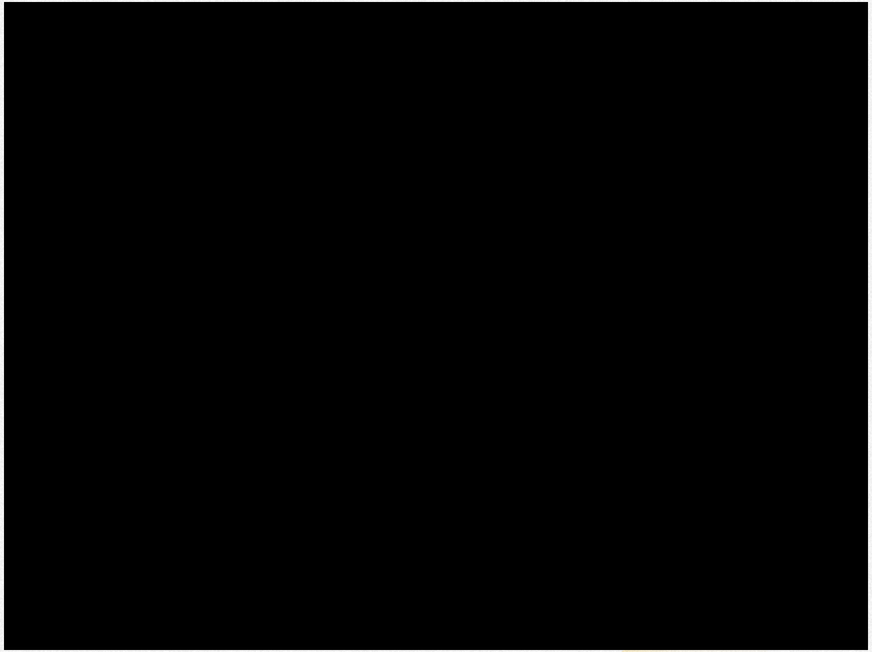
```python
def mass_luminosity_relation(masses):
    """
    Use a for loop to loop through array of masses, then use the conditions
    above (with if statements) in order to compute the right luminosity in units
    of solar luminosity L_sun.
  ***M is in solar masses***
    """
    output = []
    for M in masses: #appends L of M
        if M < 0.43*const.M_sun:
          output.append(0.23*(M/const.M_sun)**2.3*const.L_sun)
        elif M>0.43*const.M_sun and M<2*const.M_sun:
          output.append((M/const.M_sun)**4*const.L_sun)
        elif M>2*const.M_sun and M<55*const.M_sun:
          output.append(1.4*(M/const.M_sun)**3.4*const.L_sun)
        else:
          output.append(32000*(M/const.M_sun)*const.L_sun)
    return output
```

```python
# Initilize writer
metadata = dict(title='2D animation', artist='Matplotlib')
writer = FFMpegWriter(fps=24, metadata=metadata, bitrate=200000)

## SAVE AS MP4 ##
fig, ax = plt.subplots(figsize=(5,5))

with writer.saving(fig, "test2.mp4", dpi=200):
    for log_star_age in log_ages:
        ax.clear() # first clear the figure

        ax.set_xlabel('log Temperature [K]')
        ax.set_ylabel('log Luminosity [L_sun]')
#         ax.set_title(f"Age of Star: {abbreviate(int(np.exp(log_star_age)))} years")
        ax.set_title("Age of Star: {:.0e} years".format(np.exp(log_star_age)))

        star_age = np.exp(log_star_age)
        data = get_data_for_age(eeps, star_eep_idxs, star_age)

        Teffs, Ls, Ms, Rs = parse_data_dict(data)
        ax.scatter(Teffs, Ls, s=10**Rs, c=Ms, alpha=0.1)
        ax.invert_xaxis()

        plt.draw()
        plt.pause(0.005)

        writer.grab_frame() # save the current frame to mp4
```

We didn’t end up using the Mass Luminosity Relationship, as it was implemented in the data set.

Iterations of our Simulation





03 Findings and Results

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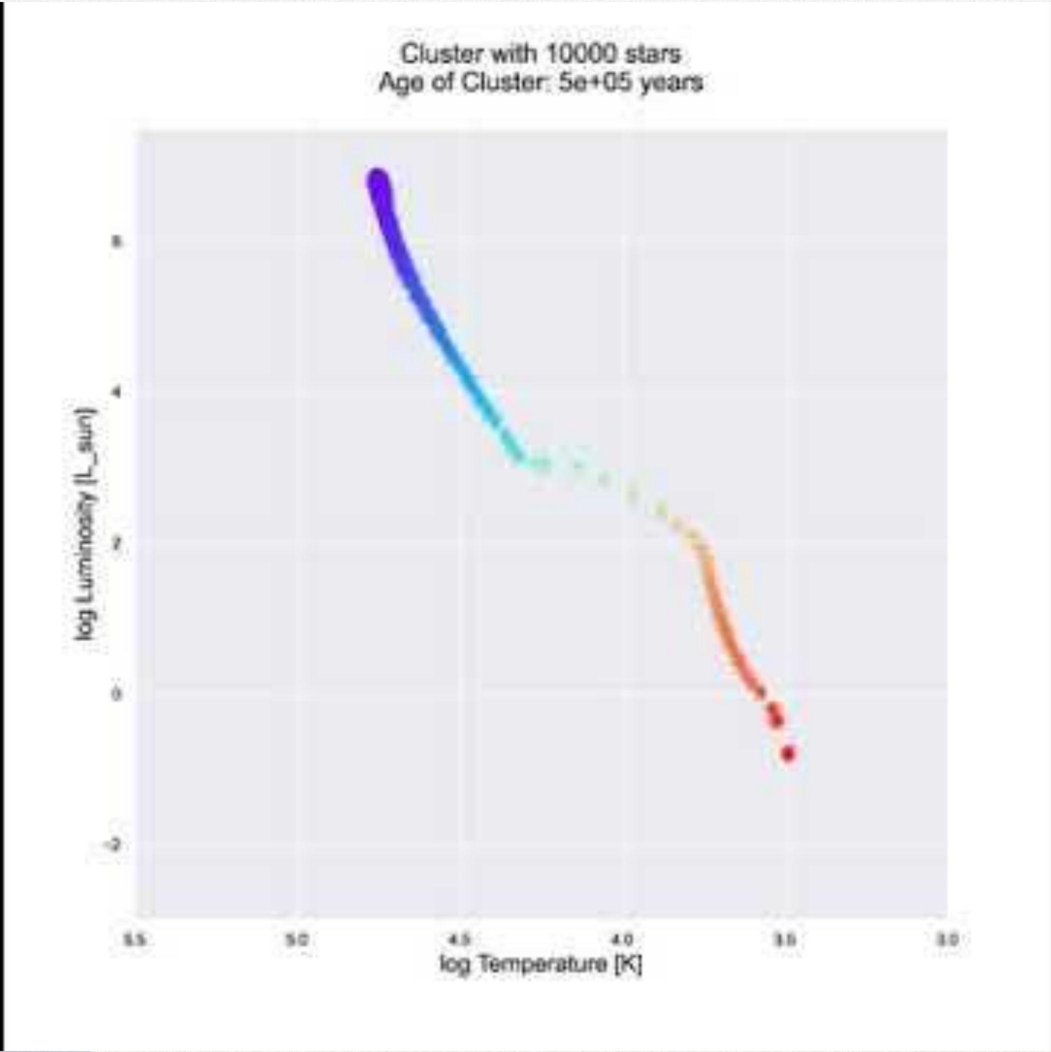
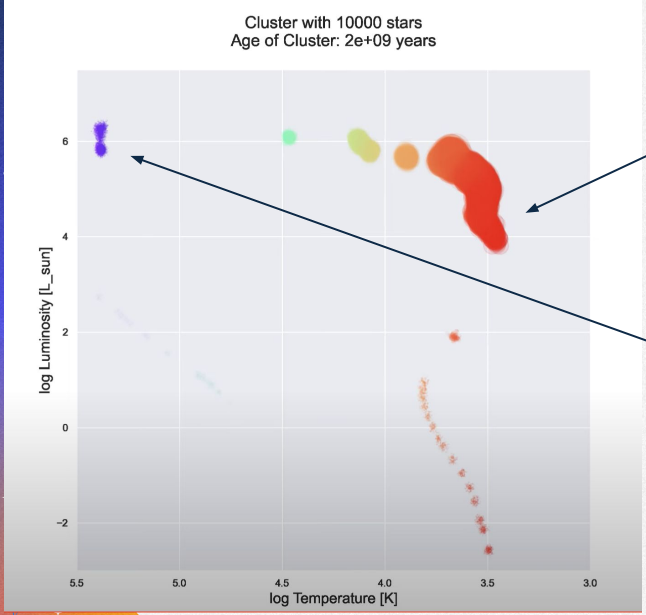

Cluster with 10000 stars
Age of Cluster: 5e+05 years
log Luminosity [L_sun]
log Temperature [K]
4.5
4.0
3.5
3.0

The simulation shows how astronomers can use HR diagrams to predict how stars will evolve over time.

The Sun is a class G2 main sequence star that is predicted to expand to a red giant and then a dwarf star.



In the simulation, you will notice that there is a group of stars that seemingly remain as O class main sequence stars. We believe that this is an error in the data and would not be there in a simulation of actual stars.

04 References and Citations

Articles/Texts:

https://en.wikipedia.org/wiki/Mass%E2%80%93luminosity_relation

https://en.wikipedia.org/wiki/Initial_mass_function#cite_note-6

https://en.wikipedia.org/wiki/Stellar_density

http://waps.cfa.harvard.edu/MIST/model_grids.html