STARS

ASTROPHYSICS

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WHAT MAKES SUN -RELATIVELY- STABLE?

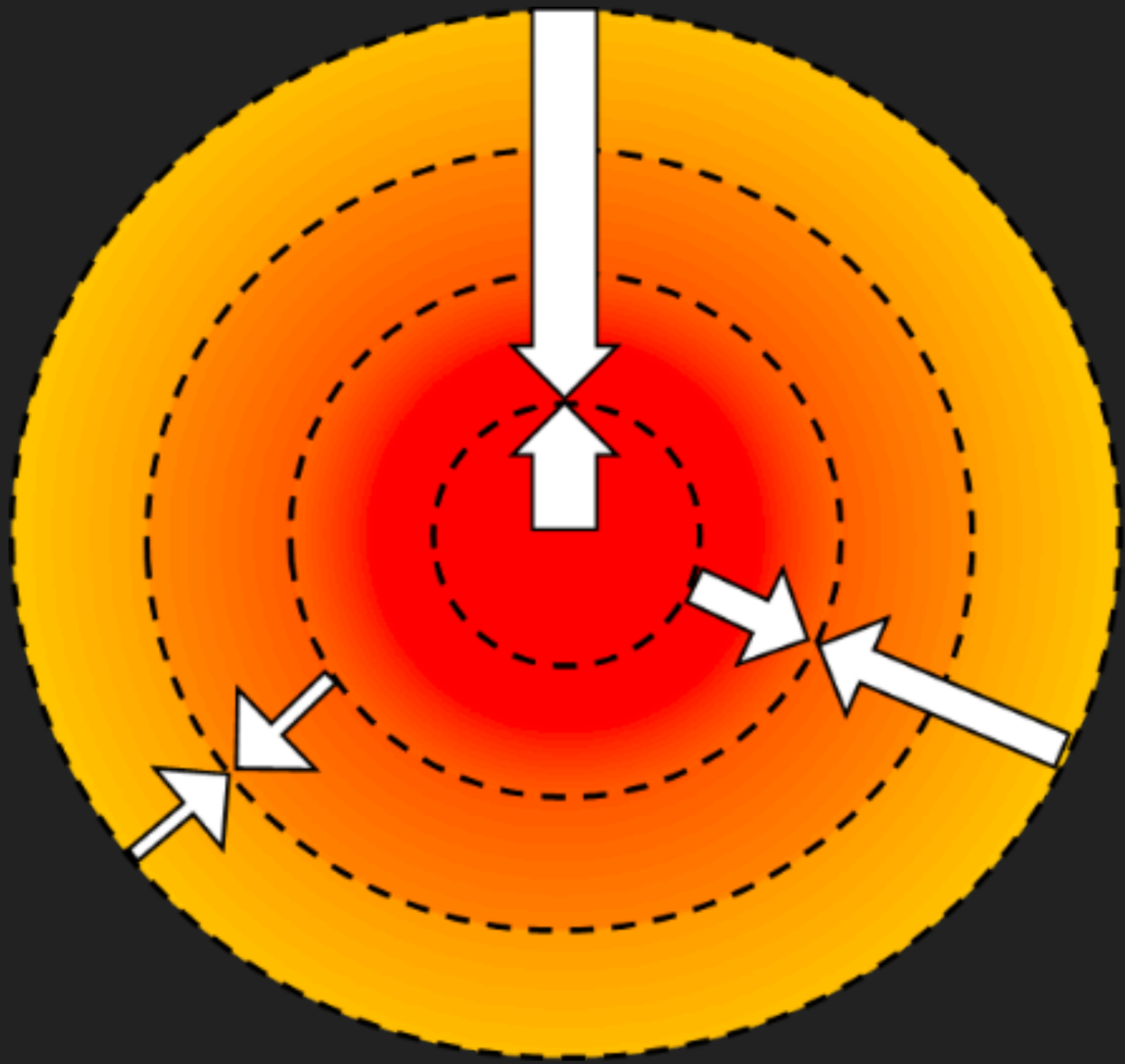
- The structure of a star is a result of
  - a balance of forces,
  - a balance between the energy loss at the stellar surface and energy generation in the core and
  - stationary energy transport between the core and the surface

BALANCE

- Determined by 5 relations or physical concepts:
  - **Hydrostatic equilibrium:** Neither expanding nor contracting; pressure balances the self-gravity
  - **Thermal equilibrium:** Not getting hotter or cooler; the amount of energy generated equals the amount radiated away
  - **Opacity:** How fast the energy is released; the resistance of the solar envelope to the flow of photons.
  - **Energy transport:** How energy is transported from the core to the photosphere (convection or radiation)
  - **Energy production:** Thermonuclear fusion

HYDROSTATIC EQUILIBRIUM

- Neither expanding nor contracting
- Gravitational pull is balanced by differential gas pressure.

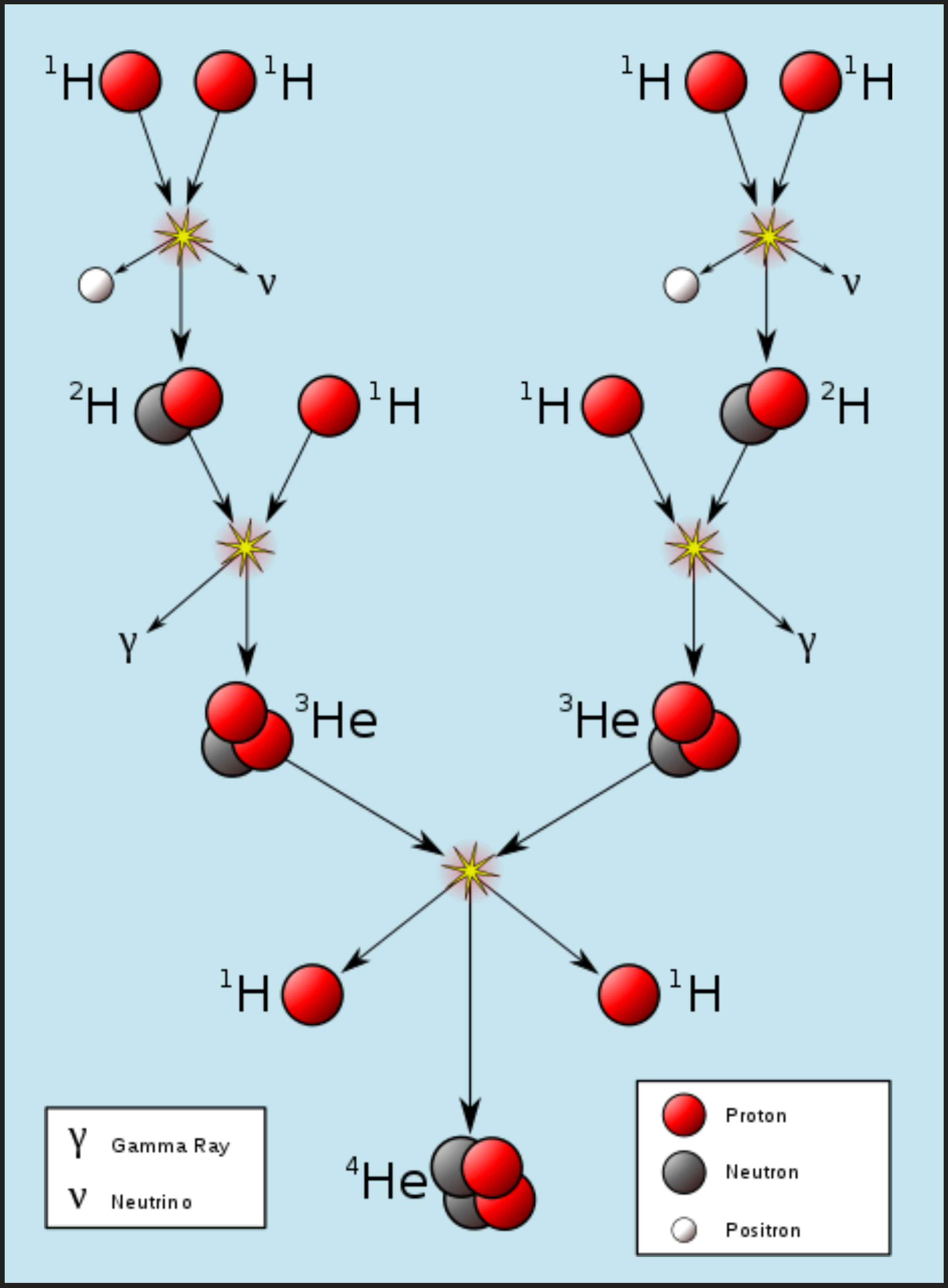


THERMAL EQUILIBRIUM

- Not getting hotter or cooler.
- The energy leakage from any spherical surface within the star is balanced by continuous supply from an internal reservoir.

FUSION

- In fusion, two nuclei of the hydrogen atom (deuterium and tritium isotopes) fuse together.
- Relatively difficult: Both nuclei are positively charged → repel each other.
- Moving extremely fast & collide → fuse & release the energy.



Proton-proton I chain

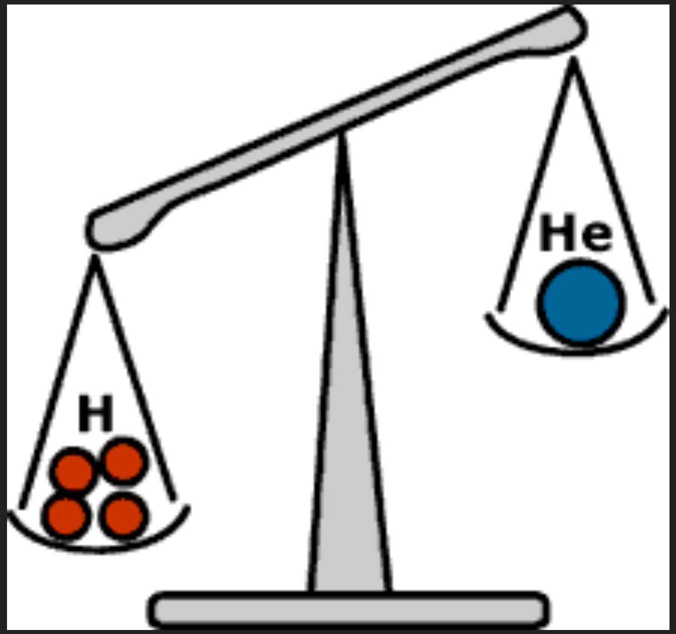
ENERGY PRODUCTION

$$4\ {}^{1}H^{+} \rightarrow {}^{4}He^{2+} + 2e^{+} + 2\nu_{e}$$

- Hydrogen → helium: 0.7% of the mass is changed into energy
  - Einstein's formula $E = mc^2$.
- Mass balance : 4 ^{1}H atoms 6.693 x 10^{-27} kg

  1 ^{4}He atom 6.645 x 10^{-27} kg

  Mass lost : 0.048 x 10^{-27} kg



- Extremely efficient process :
  - Fusing 1 kg of Hydrogen = burning 20,000 metric tons of coal !

THERMONUCLEAR FUSION

THERMO: Needs high temperatures

NUCLEAR: Nuclei of atoms

FUSION: Bring together; combine

- How much Hydrogen must be converted to give solar luminosity ?
  - 600 million tons per second !
- Sounds enormous, but…
- Sun has enough fuel for at least 9 billion years

 How do we know the age of Sun?

APPARENT BRIGHTNESS

- The Sun appears very bright to us because it is much closer than other stars.
- The brightness of a star as it appears from Earth is called its **apparent brightness.**
- The apparent brightness ⬇ α its distance ⬆
- Closer appears brighter
- InterStellarMedium absorbs light

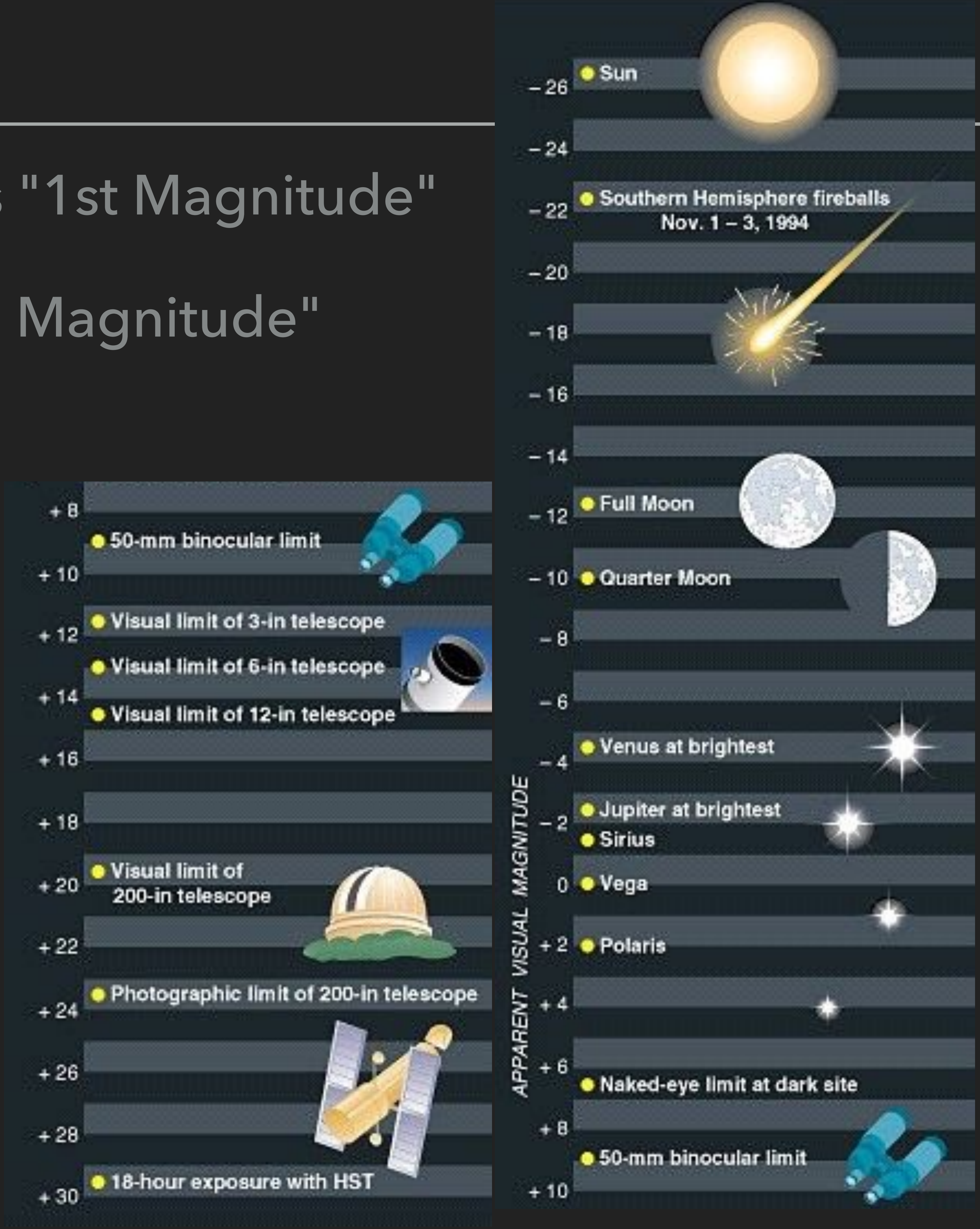
Image credit: Reuters

APPARENT MAGNITUDE

- **Relative apparent brightness** of two stars is measured according to their **apparent magnitude m** on a logaritmik scale.
- Each magnitude change corresponds to a 2,5 factor change in luminosity
- $m_2 - m_1 = 2.5 \log (L_1/L_2)$
- This scale is based on the ability of human eye to judge brightness, which happens to be logarithmic.

MAGNITUDE

- the 20 brightest stars "1st Magnitude"
- the faintest stars “6th Magnitude"
- The Greek astronomer Hipparchus of Rhodes (190-120 B.C.) @129 B.C.



MAGNITUDE SYSTEM

- Pogson (1856) let's make this a standard
  - $m_2 - m_1 = 2.5 \log (L_1/L_2)$

Magnitude	Description	Brightness ratio
1st	The 20 brightest stars	
2nd	stars 2.512 times dimmer than 1st magnitude	
3rd	stars 2.512 times dimmer than 2nd magnitude	6.310 times dimmer than 1st magnitude
4th	stars 2.512 times dimmer than 3rd magnitude	15.851 times dimmer than 1st magnitude
5th	stars 2.512 times dimmer than 4th magnitude	39.818 times dimmer than 1st magnitude
6th	stars 2.512 times dimmer than 5th magnitude	100 times dimmer than 1st magnitude
7th	stars 2.512 times dimmer than 6th magnitude	251.257 times dimmer than 1st magnitude
8th	and so on	

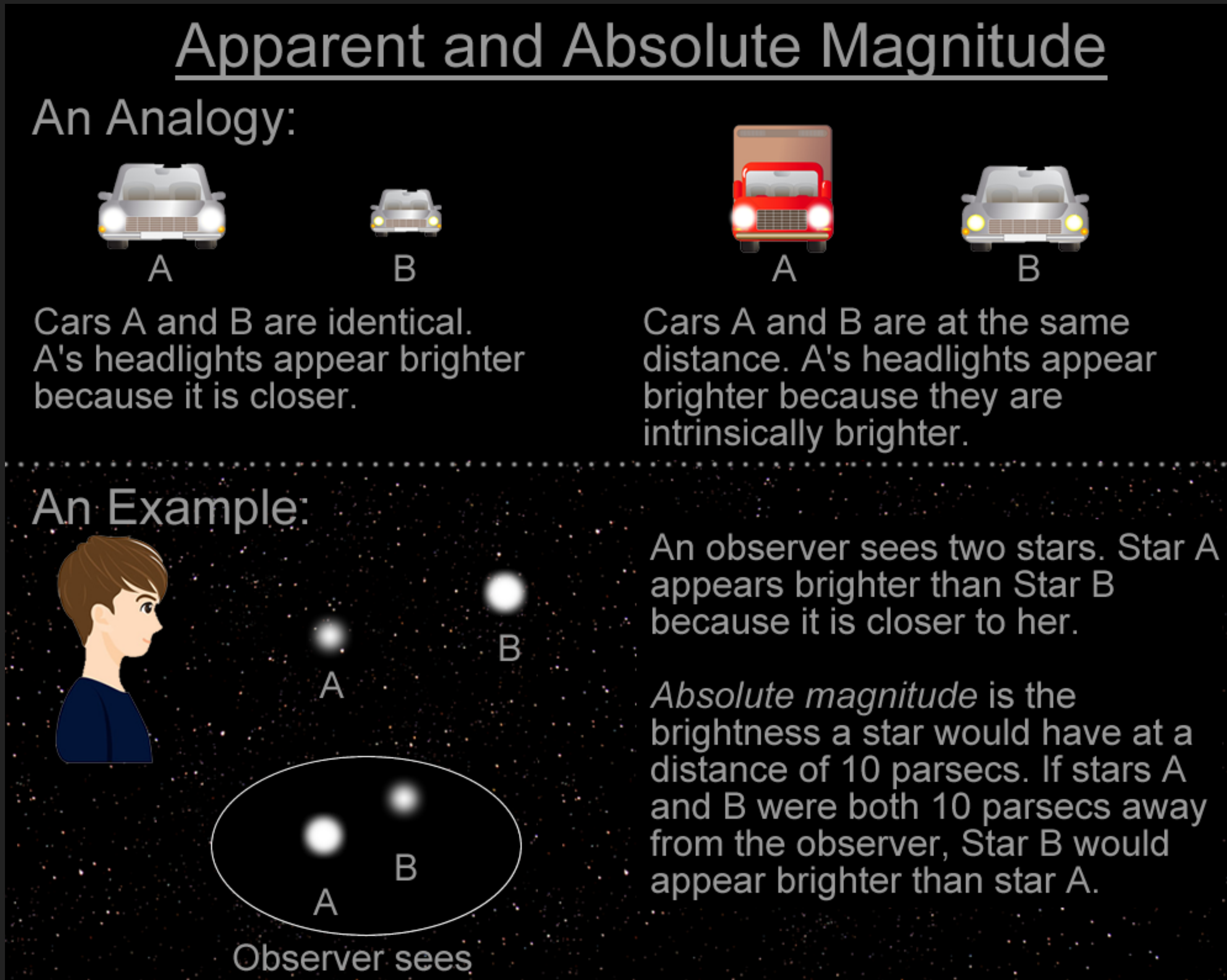
ABSOLUTE MAGNITUDE

- Absolute magnitude is an indicator of **how bright a star really is.**
- You can calculate a star's absolute brightness if you know its **distance** from Earth and its **apparent brightness**.
- Absolute magnitude: how bright it would appear @10 parsec (**par**allax arc **sec**ond)
  - $m - M = 5 \log (d/10)$

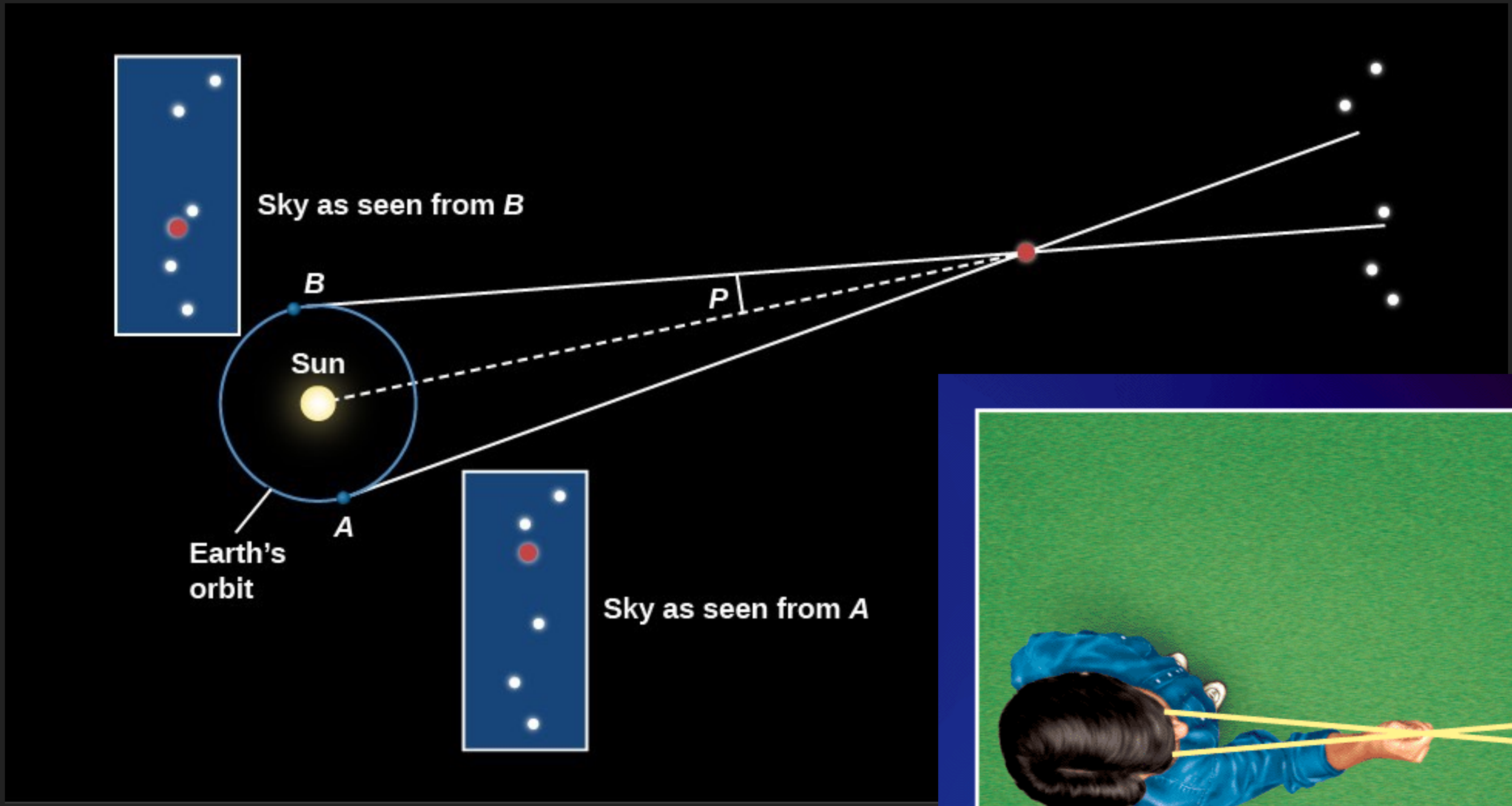
ABSOLUTE MAGNITUDE

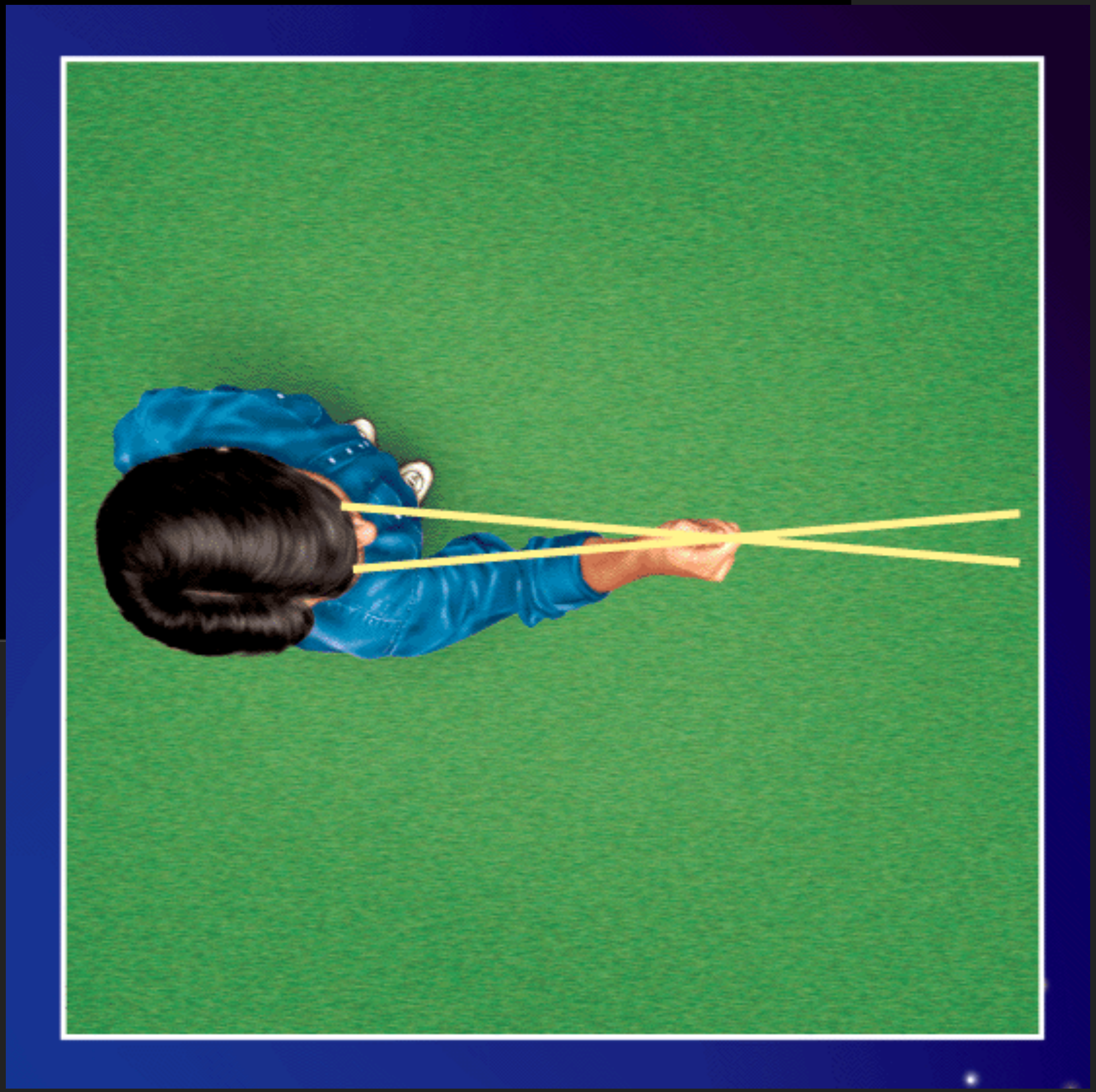
- @10parsec: the Sun 4.85.
- Rigel: -8 mag, nearly as bright as the quarter Moon.
- The red dwarf Proxima Centauri, the closest star to the solar system: 15.6, hardly visible with a 16-inch telescope!
- Absolute magnitude ➡ allows to infer other stellar properties (temperature & mass).
- Absolute magnitudes are always written with a capital M, apparent magnitudes with a lower-case m.

MAGNITUDES

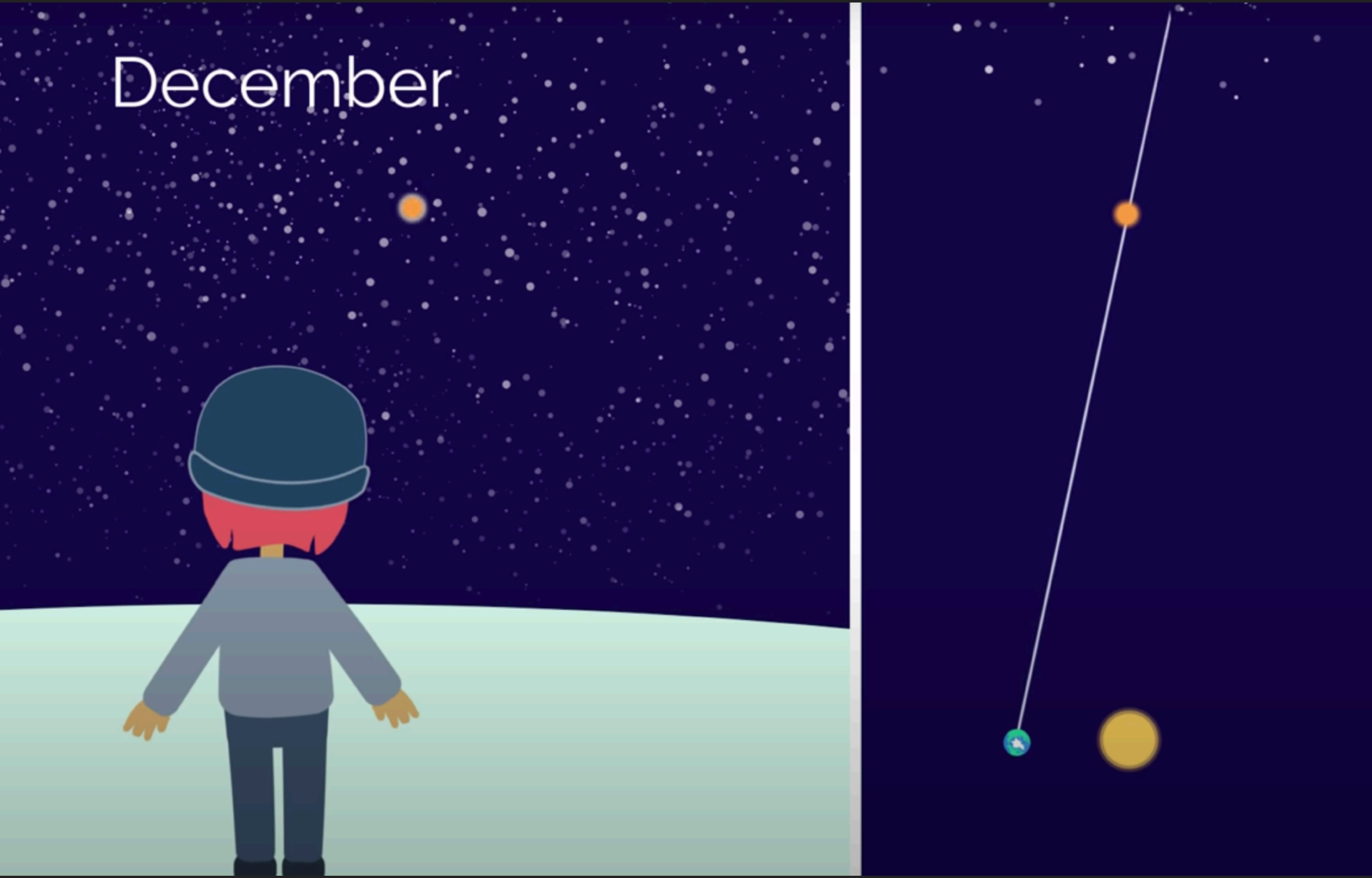

Apparent and Absolute Magnitude
An Analogy:
A
B
Cars A and B are identical. A's headlights appear brighter because it is closer.
A
B
Cars A and B are at the same distance. A's headlights appear brighter because they are intrinsically brighter.
An Example:
A
B
An observer sees two stars. Star A appears brighter than Star B because it is closer to her.
Absolute magnitude is the brightness a star would have at a distance of 10 parsecs. If stars A and B were both 10 parsecs away from the observer, Star B would appear brighter than star A.
A
B
Observer sees

PARALLAX

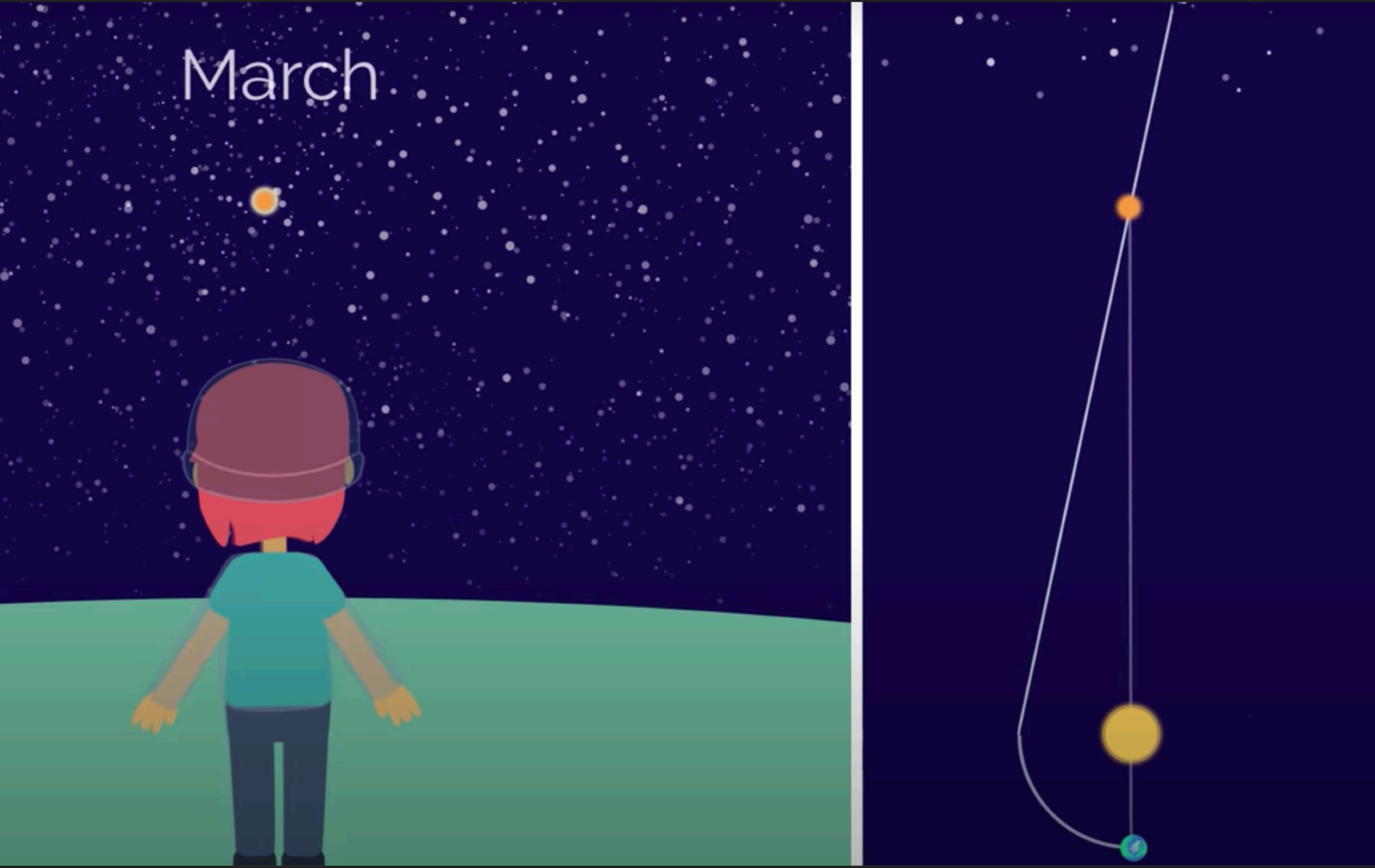




PARALLAX



PARALLAX



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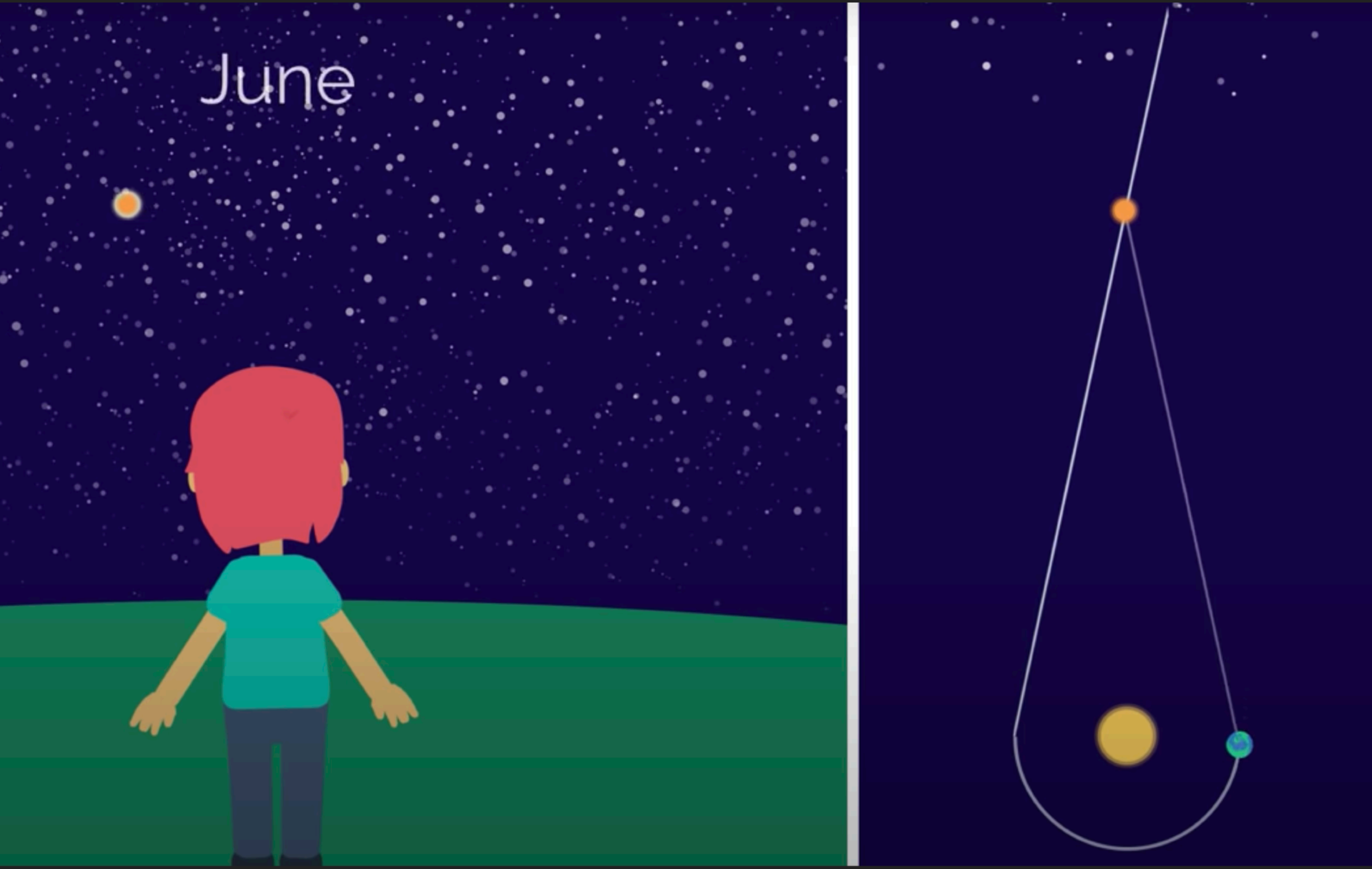

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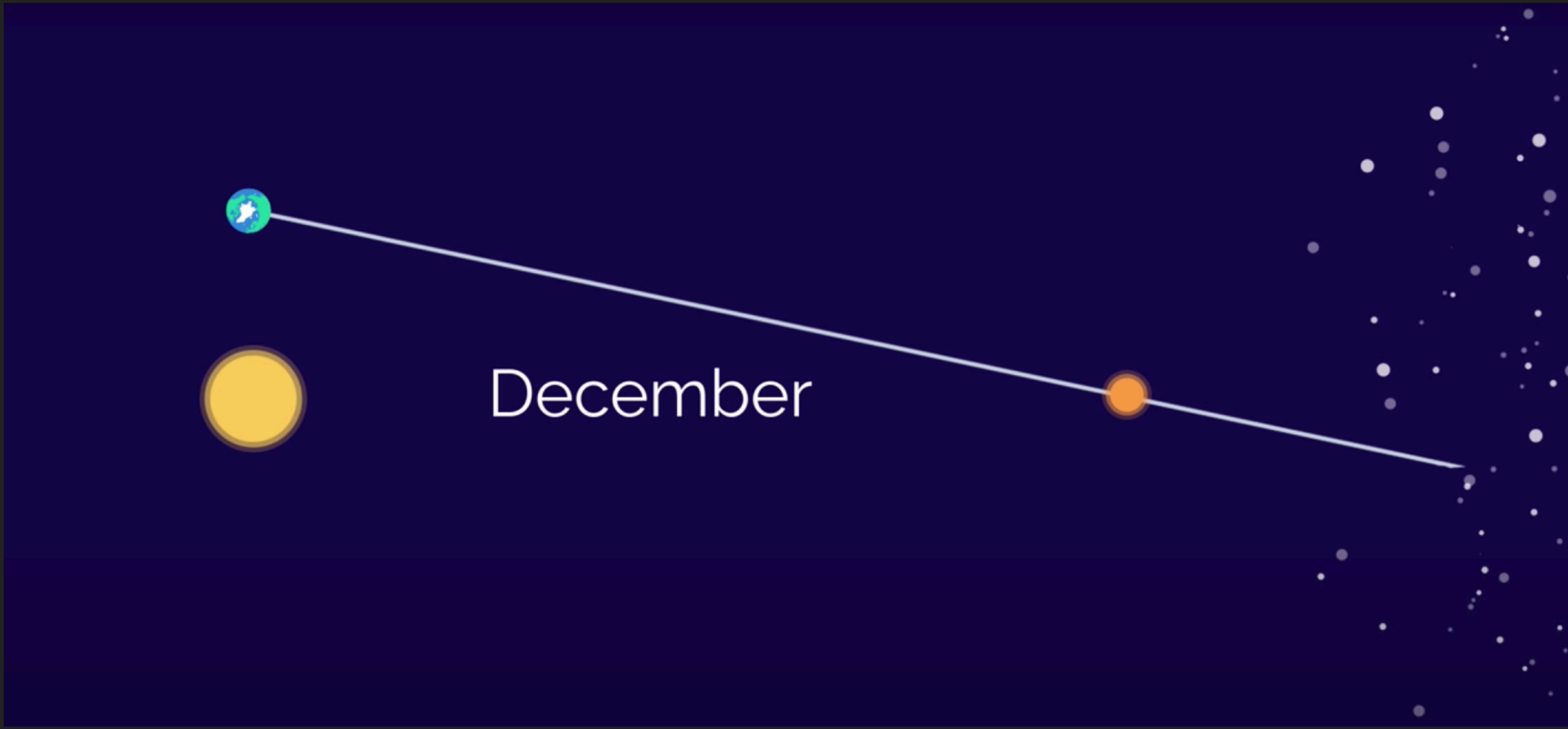

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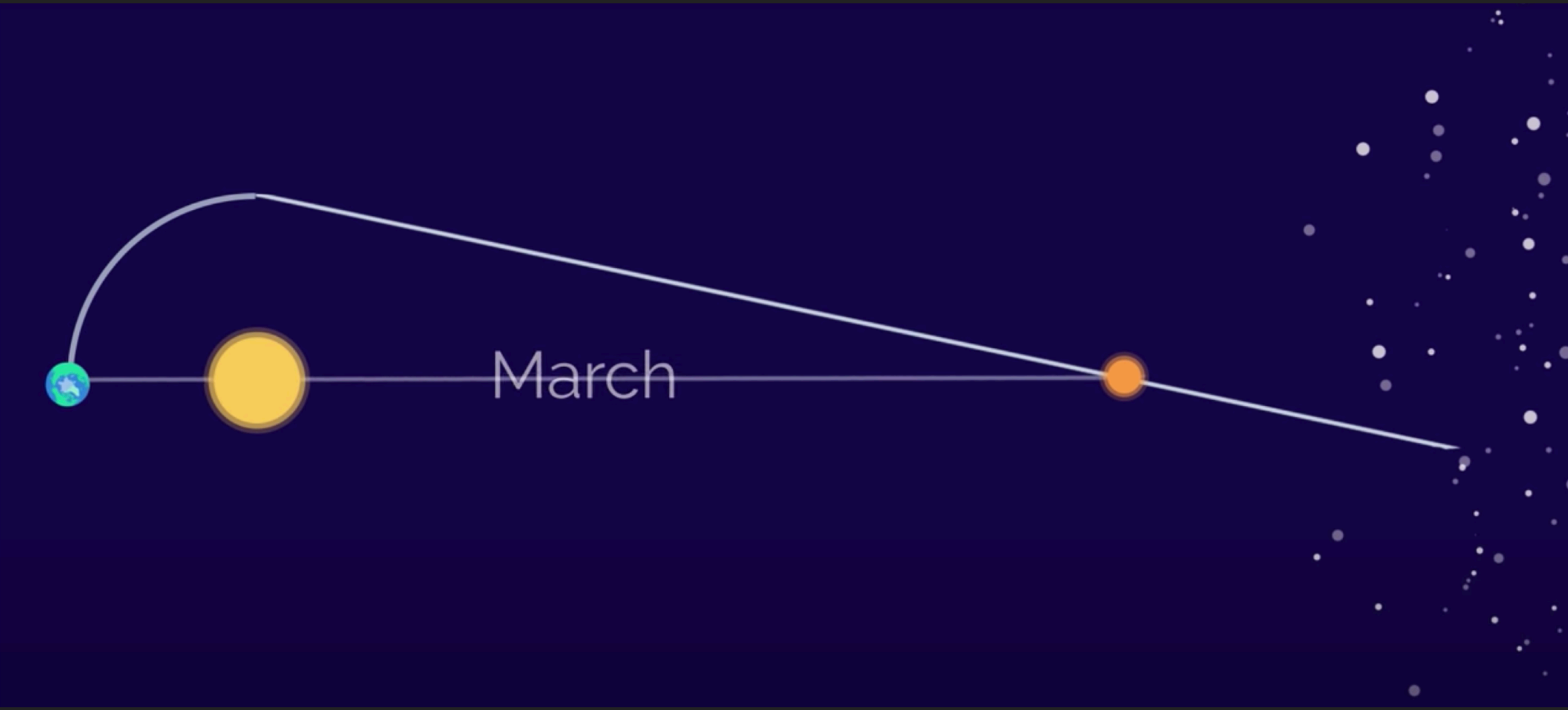

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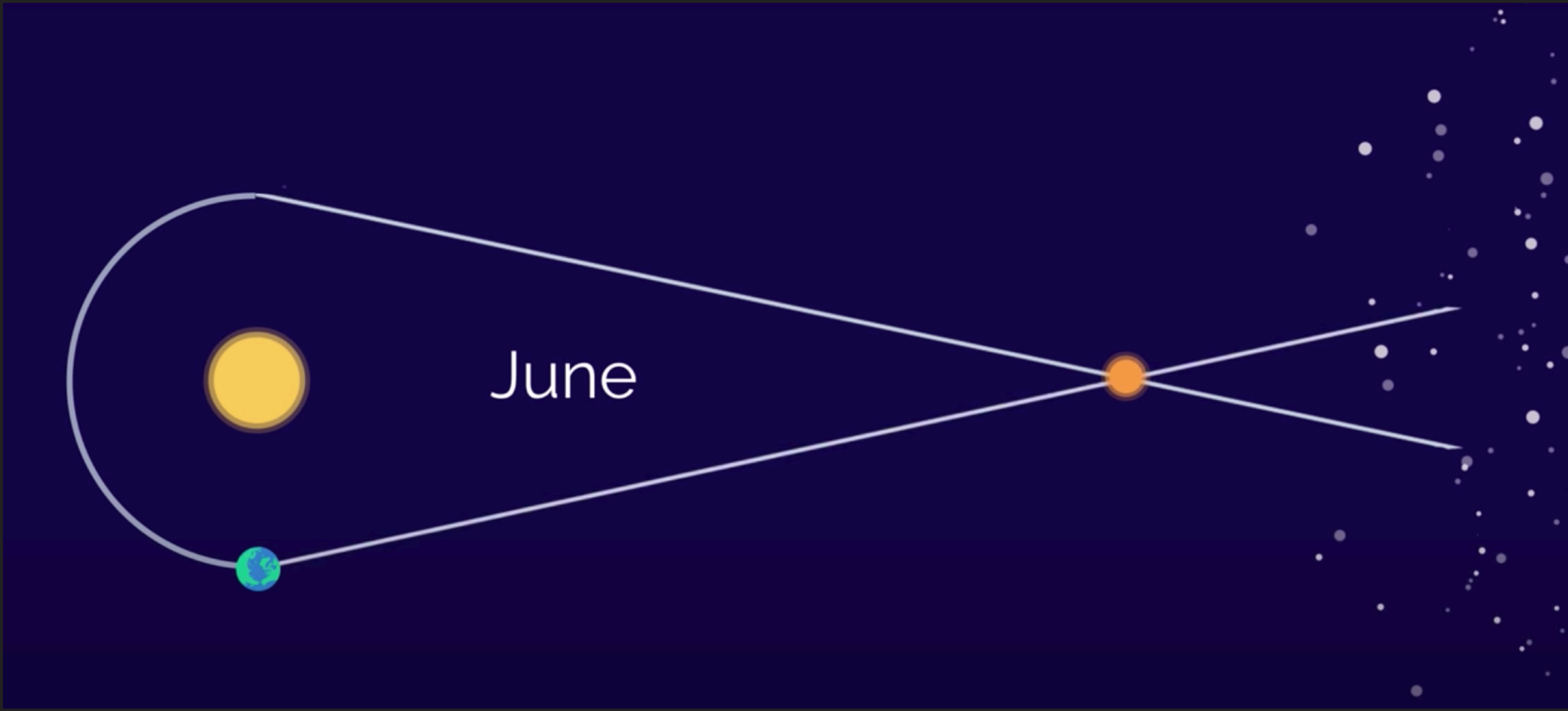
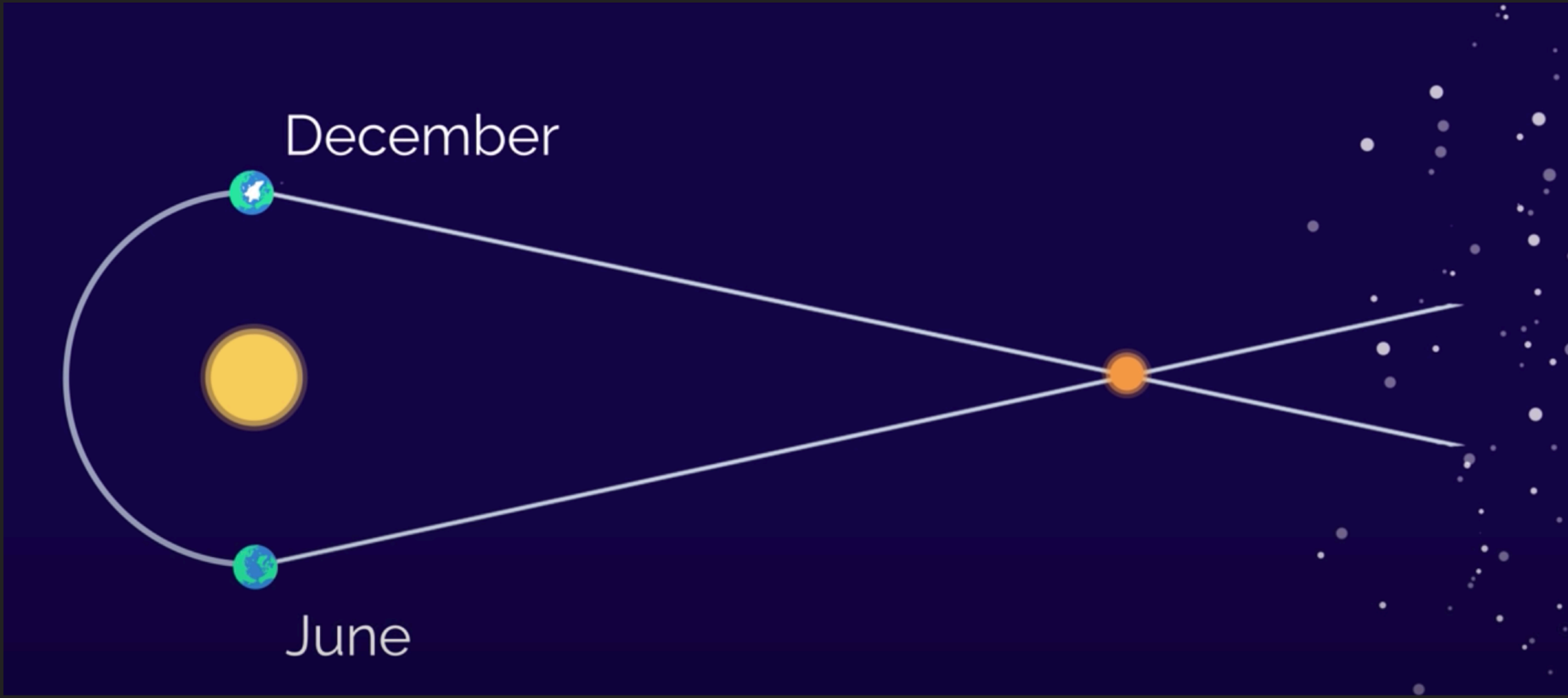
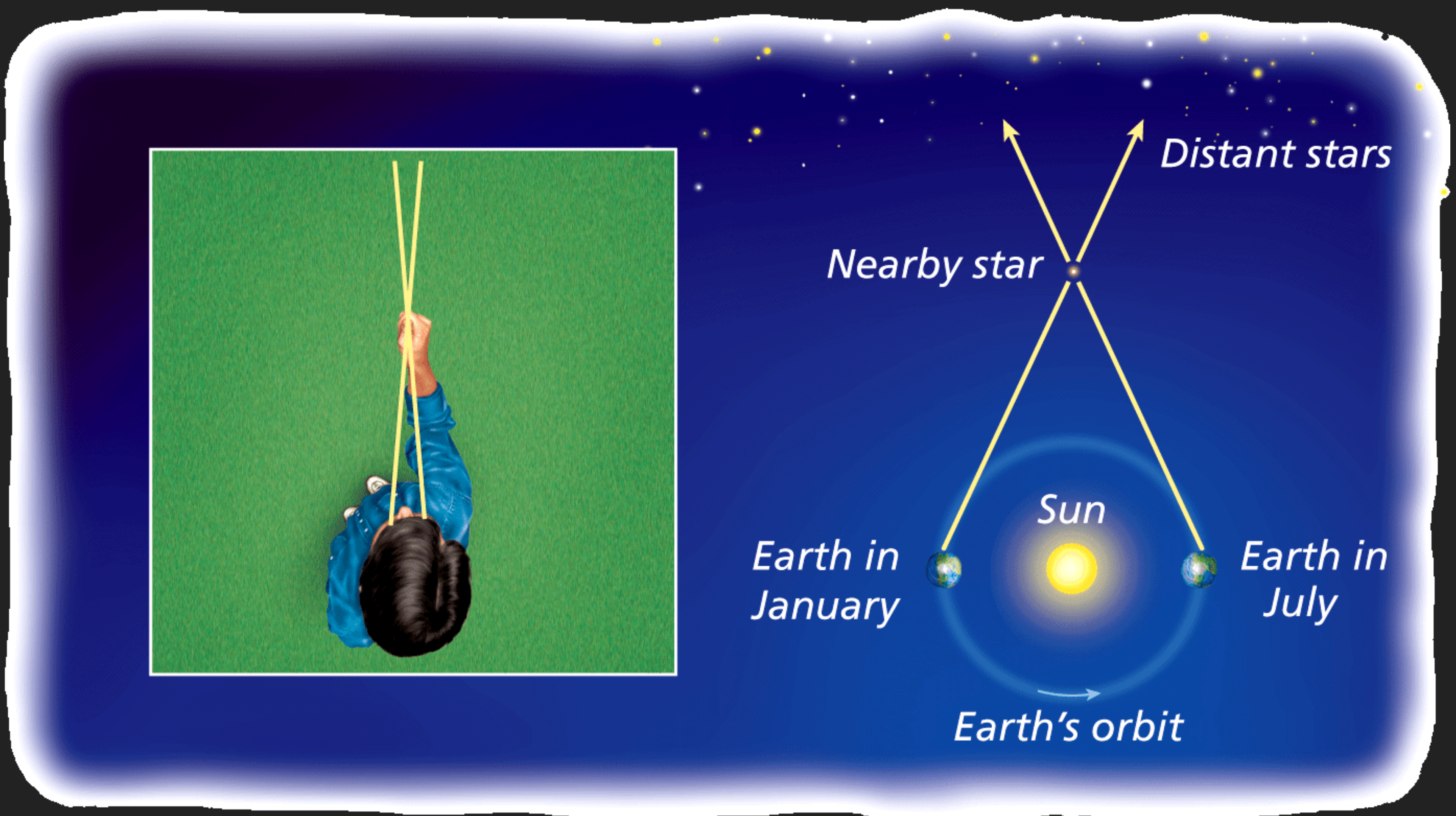


PARALLAX

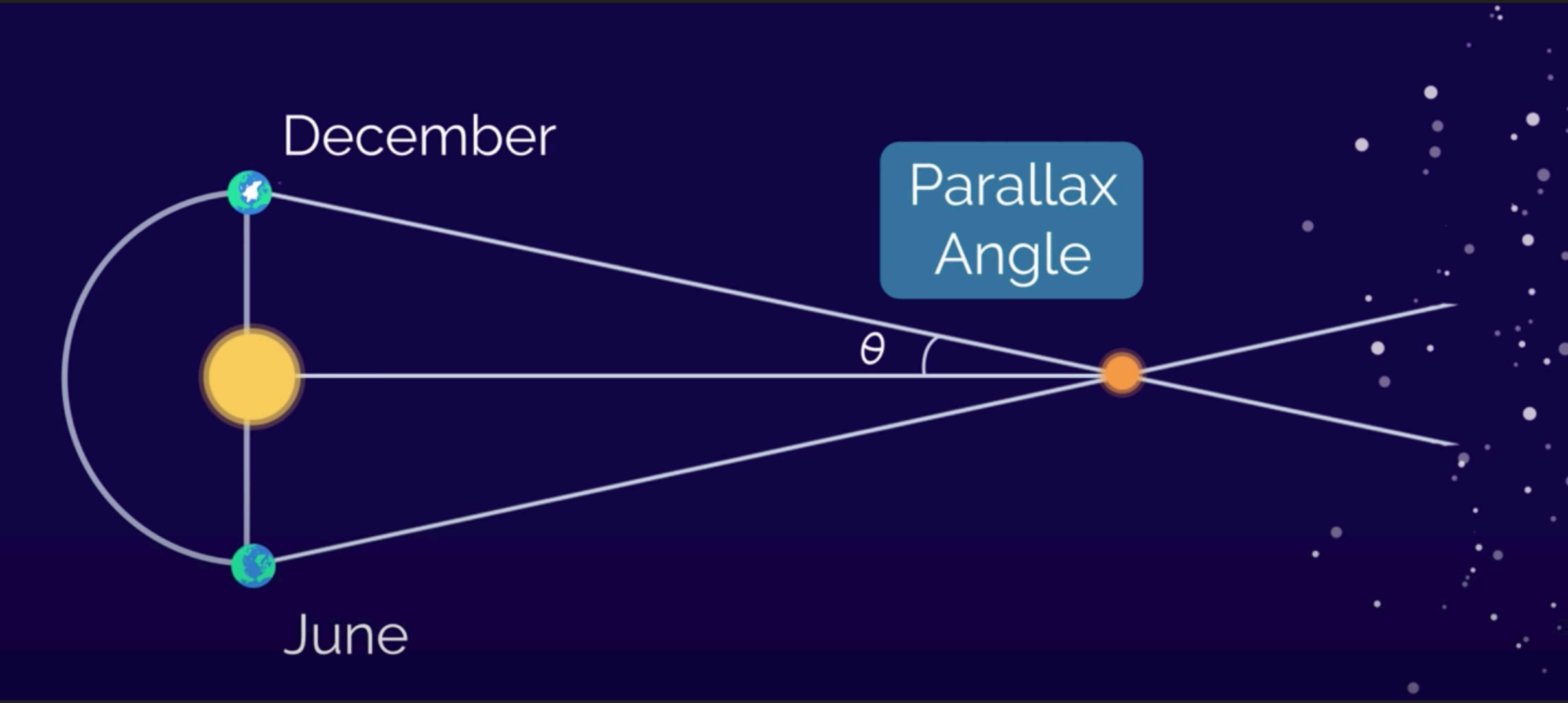


PARALLAX

- Hold your thumb in front of you
  - Look at it, first with one eye, and then with the other.
- The closer a star is to Earth, the greater is its parallax.



PARALLAX



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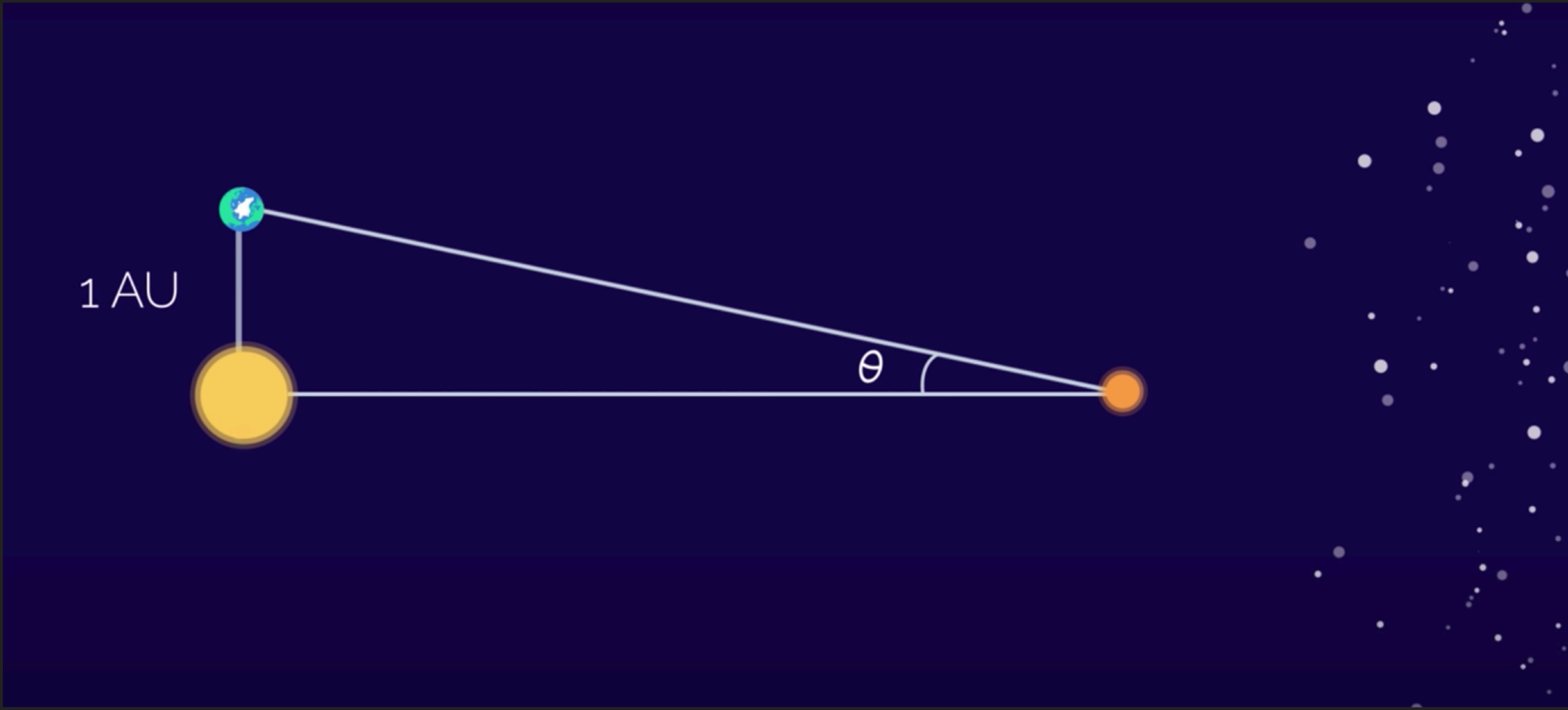
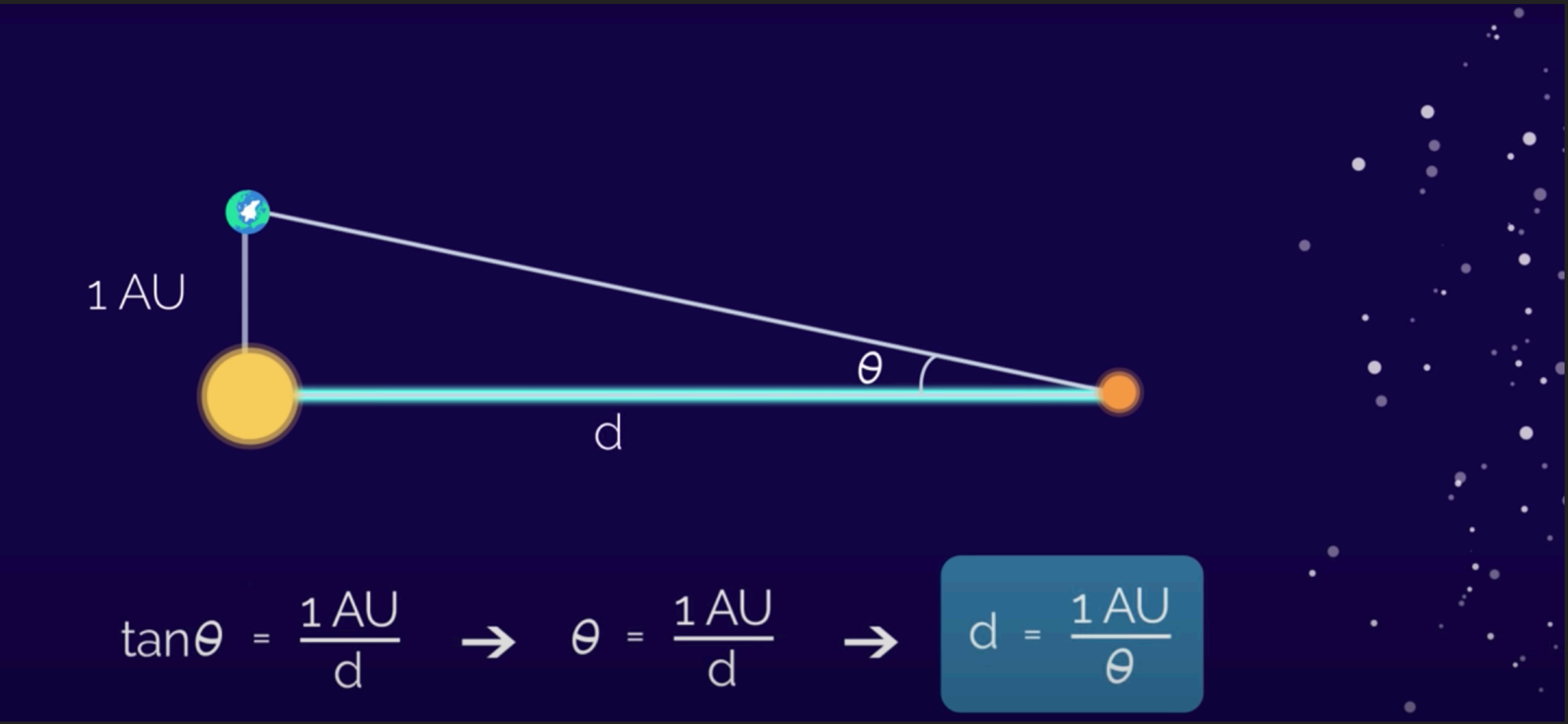
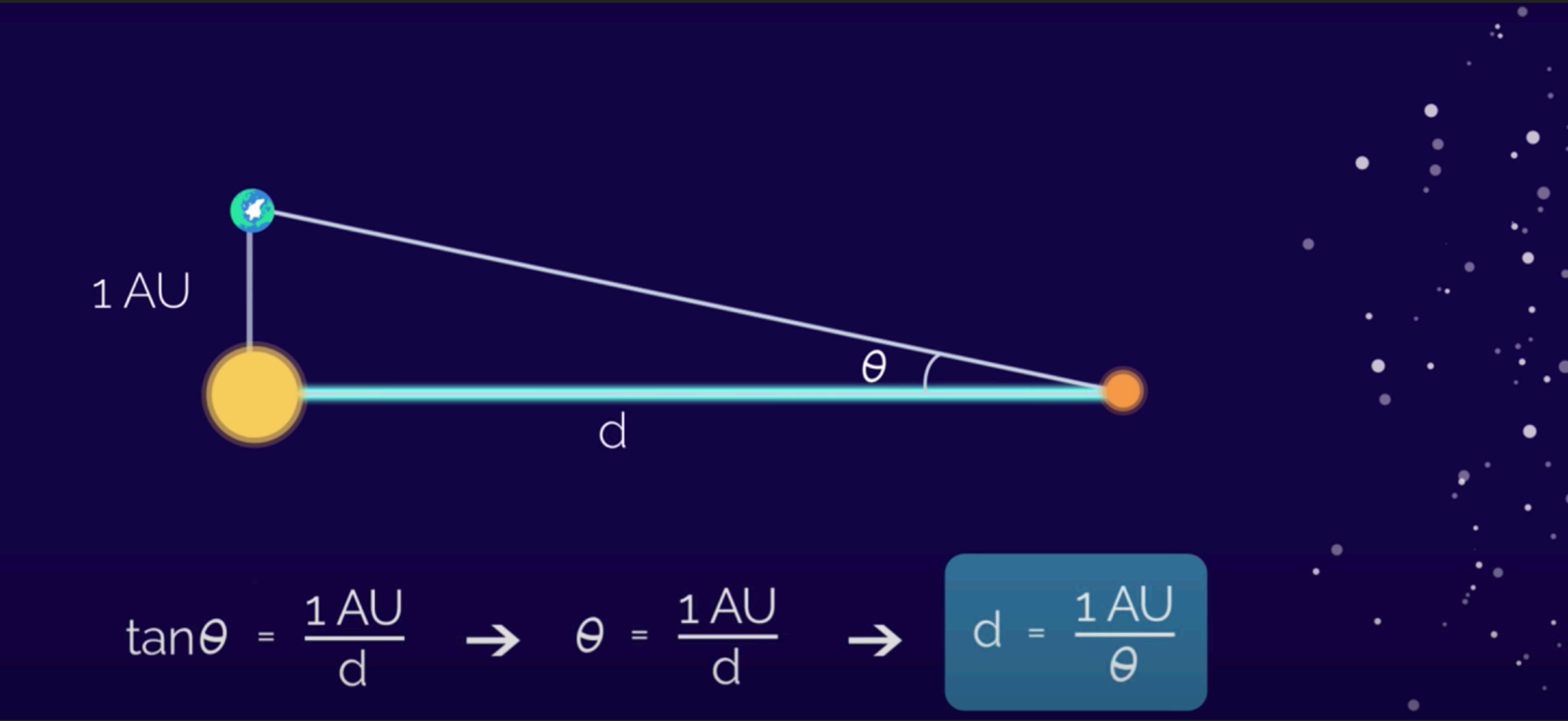


PARALLAX


1 AU
θ
d
$\tan\theta = \frac{1\,AU}{d} \rightarrow \theta = \frac{1\,AU}{d} \rightarrow \boxed{d = \frac{1\,AU}{\theta}}$

PARSEC



- Distance of something/anything that has a parallax angle of 1 arc second.
  - θ = 1arc sec (1/36000°)
  - 1AU ≅149.500.000.000m
- 1 parsec ≅ 3.09 x 10^{16}m
  ≅ 3.26 light years

ABSOLUTE MAGNITUDE

- Absolute magnitude = how bright it would appear if placed at a standard distance of 10 parsecs (parallax arc second) from the viewer.
  - $m - M = 5 \log (d/10)$

LUMINOSITY - BRIGHTNESS

- Luminosity is a measure of the total emitted energy.
  - Depends on the effective temperature

    by the black-body Stefan-Boltzmann law

    as well as on its spherical surface area with radius r
- $L = \sigma T^4 \times 4 \pi r^2$
- Observed brightness of a star depends on its distance does NOT indicate true luminosity.

LUMINOSITY

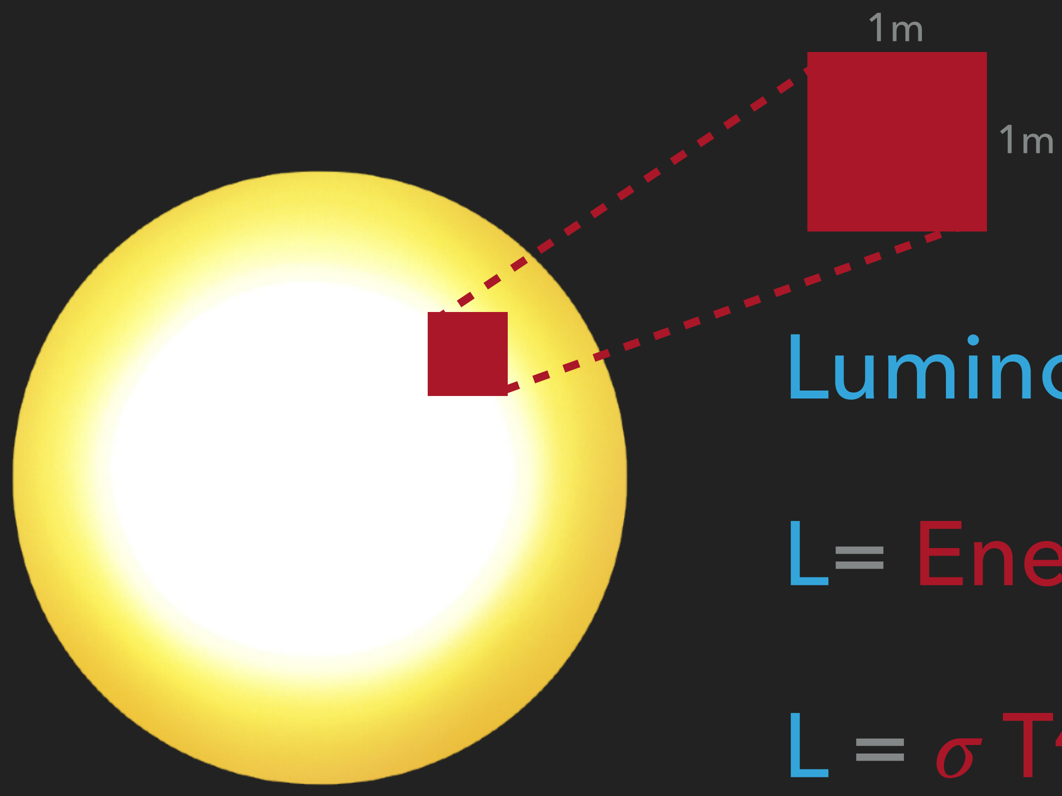
- Total amount of energy radiated by a star per second.
- The absolute magnitude is a measure of the star's luminosity.
- If you measure a star's apparent magnitude & know its absolute magnitude ➡ you can find the star's distance (using the inverse square law of light brightness).
- If you know a star's apparent magnitude and distance ➡ you can find the star's luminosity.
- The luminosity is a quantity that depends on the star itself, not on how far away it is (it is an "intrinsic" property). Luminosity tells you about the internal physics of the star & more important quantity than the apparent brightness.

LUMINOSITY

- A star can be luminous because it is hot or it is large (or both!).
- The luminosity of an object = the amount of energy every square meter produces multiplied by its surface area.
- The amount of energy pouring through every square meter = $\sigma \times$ (object's surface temperature)^4,

  σ : the Stefan-Boltzmann constant.
- Luminosity tightly bounded with the temperature.

LUMINOSITY



1 square meter σT^4

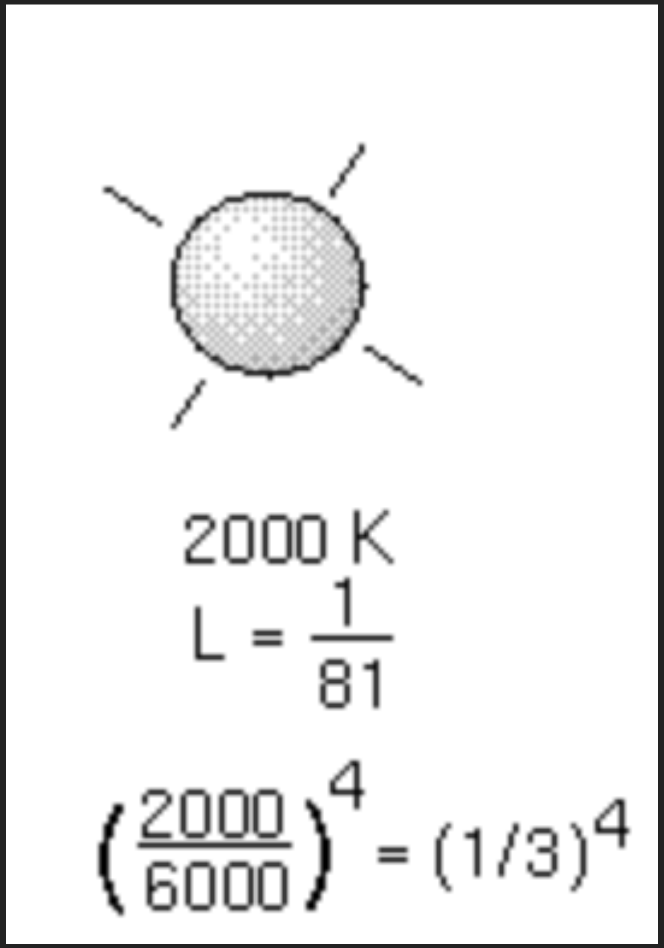
Luminosity = Total energy per second

L= Energy per m² x #of m² on the surface

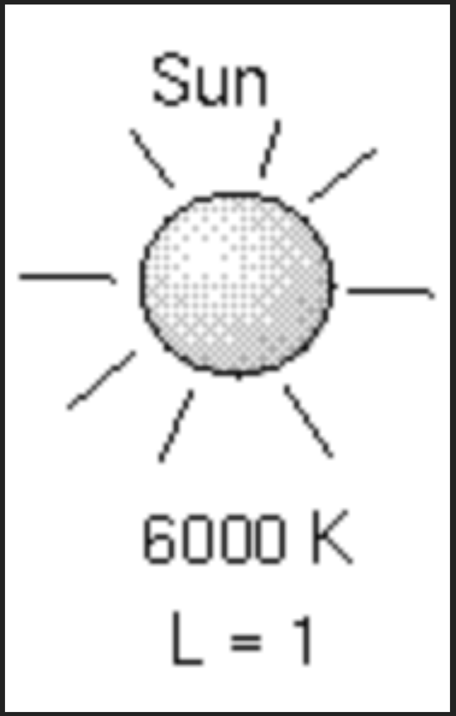
L = σT^4 x Star's surface

$$L = 4\pi R^2 \cdot \sigma T^4$$

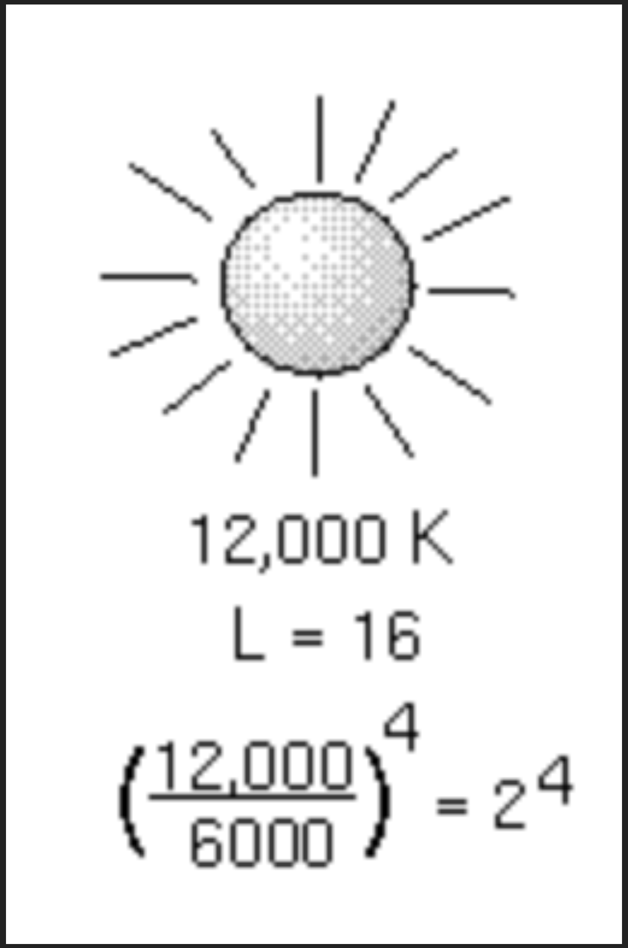
LUMINOSITY



2000 K
L = 1/81
(2000/6000)^4 = (1/3)^4

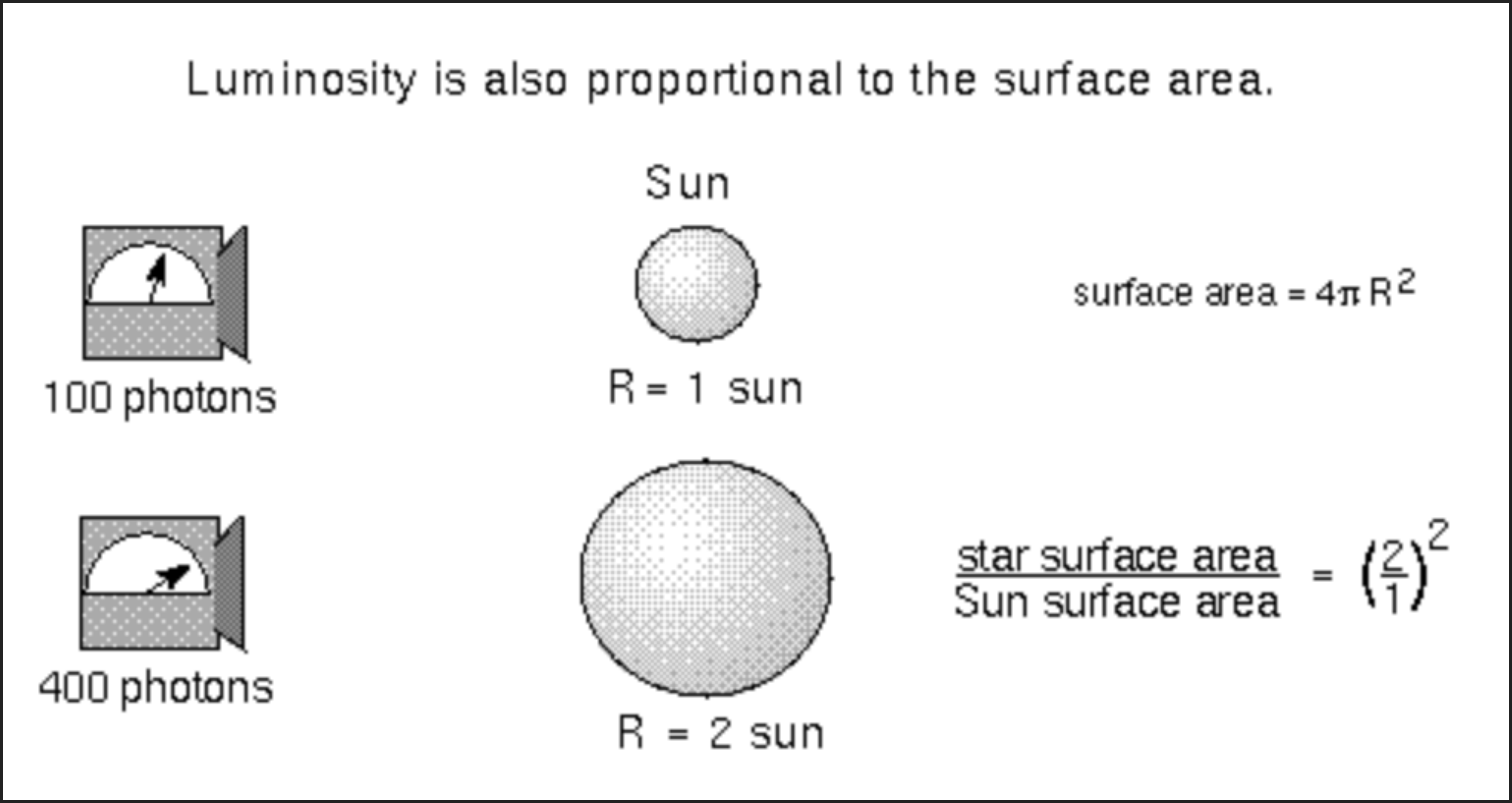


Sun
6000 K
L = 1



12,000 K
L = 16
(12,000/6000)^4 = 2^4

LUMINOSITY

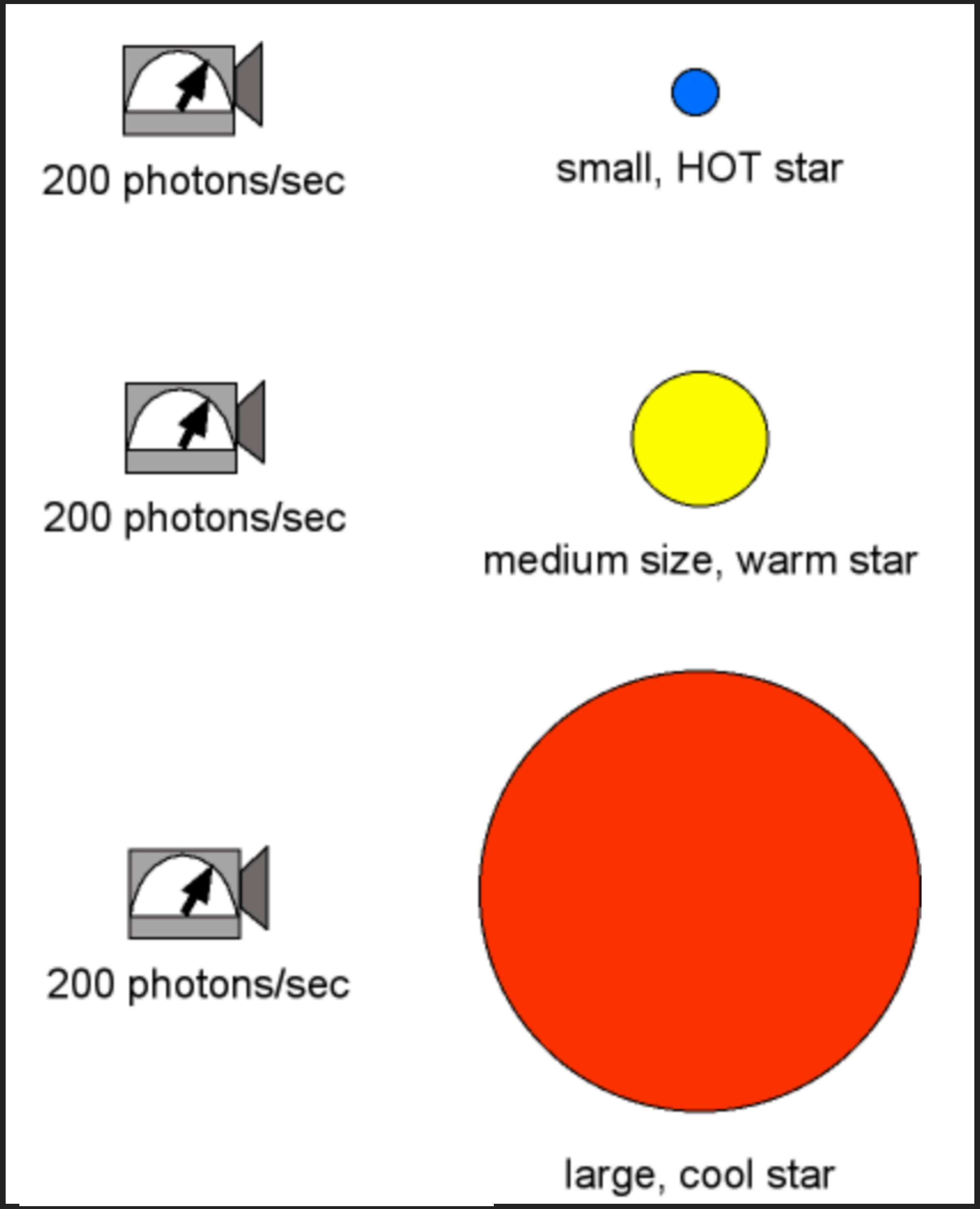

Luminosity is also proportional to the surface area.
Sun
100 photons
R = 1 sun
surface area = 4π R2
400 photons
R = 2 sun
star surface area
Sun surface area
= (2/1)2

LUMINOSITY

A small, hot object

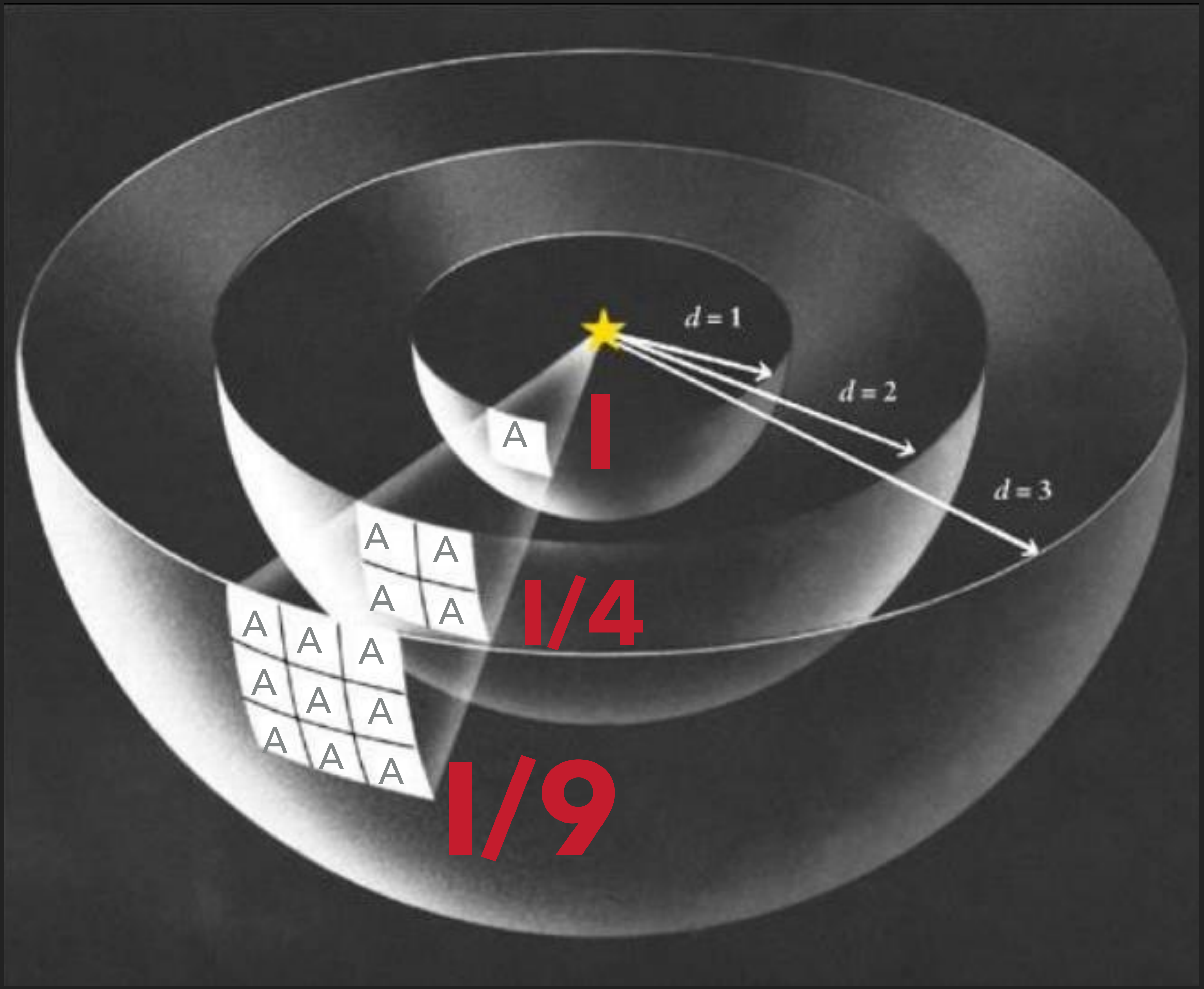
can have the same luminosity

as a large, cool object



FLUX

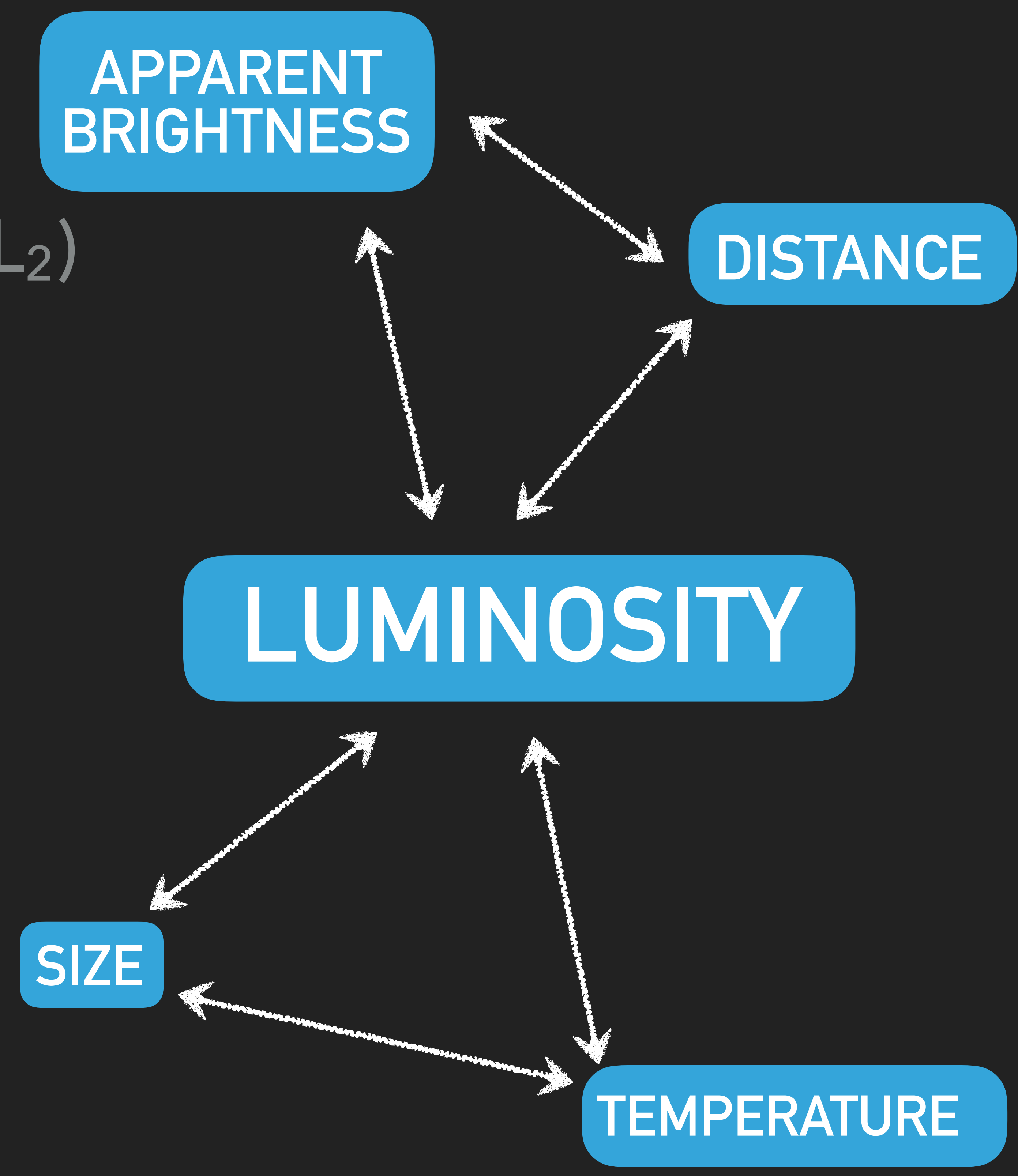
- Total energy released from a star per second per unit area



- How bright we see a star is determined by the FLUX not by the luminosity
- $F = L / 4 \pi d^2$

SUMMARY

- Apparent brightness
    - $m_2 - m_1 = 2.5 \log (L_1/L_2)$
- Absolute magnitude
    - $m - M = 5 \log (d/10)$
- Luminosity
    - $L = \sigma T^4 \times 4 \pi r^2$
- Flux
    - $F = L / 4 \pi d^2$

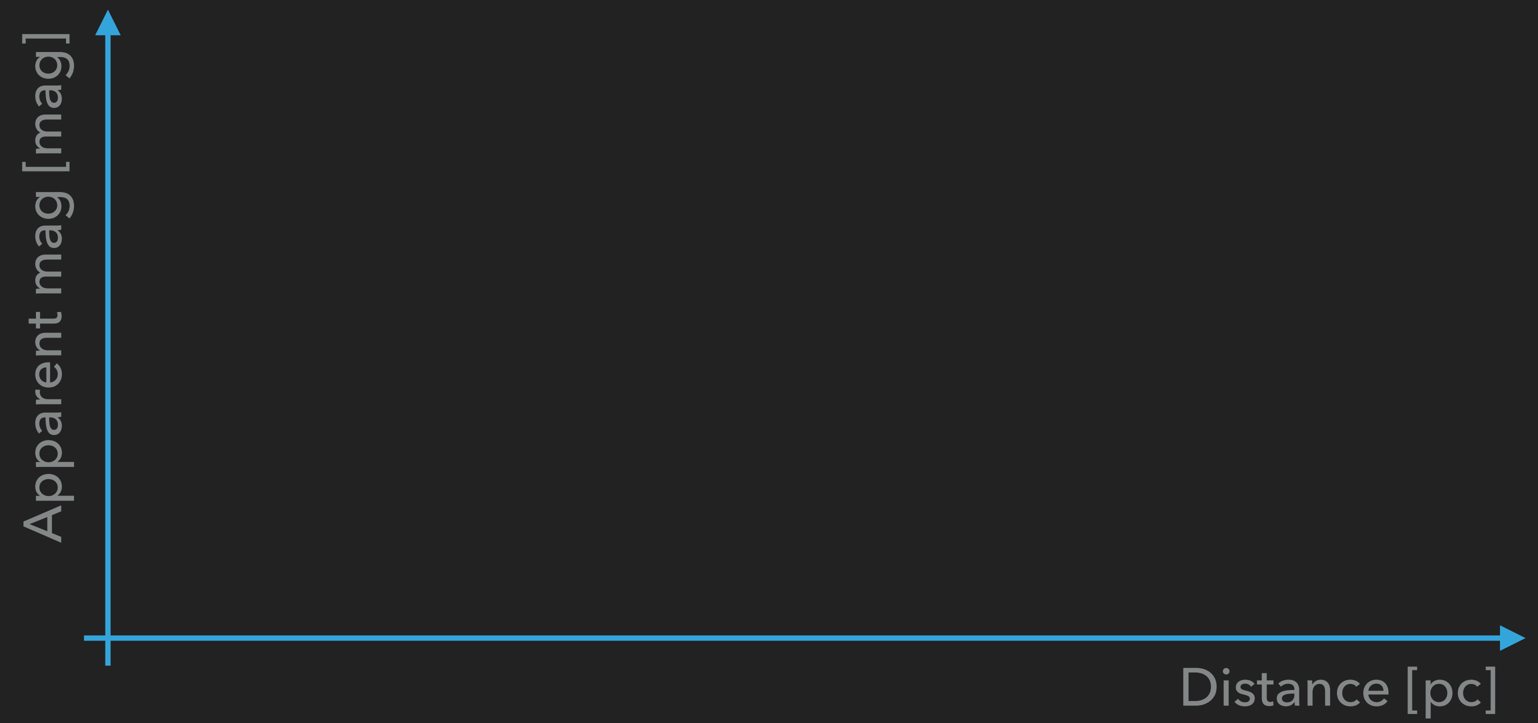


PRACTICE

- How much brighter is a star of 1st magnitude than a star of 5th magnitude?
  - $m_2 - m_1 = 2.5 \log (L_1/L_2)$
  - $L_1/L_2 = 2.5^{(m2-m1)}$

HOMEWORK

- Given an absolute magnitude of 3.0, find the apparent magnitude at a distance of 5pc, 10pc, 15pc, 20pc, 50pc and 100pc.
- Plot these data on distance vs apparent magnitude.



- How far away must the star be to have an apparent magnitude of 5.0?

RESOURCES

- https://spaceplace.nasa.gov/blue-sky/en/
- http://hyperphysics.phy-astr.gsu.edu/hbase/bbcon.html
- https://www.tec-science.com/thermodynamics/temperature/black-body-radiation/
- https://www.tec-science.com/thermodynamics/temperature/plancks-law-of-blackbody-radiation/
- http://hosting.astro.cornell.edu/academics/courses/astro201/kirchhoff.htm
- http://hyperphysics.phy-astr.gsu.edu/hbase/hyde.html
- https://www.webassign.net/ncchem/bohr.html
- https://collection.sciencemuseumgroup.org.uk/objects/co3632/william-herschels-infrared-prism-prism-optical-demonstration
- https://cas.sdss.org/dr6/en/proj/basic/spectraltypes/lines.asp
- https://www.scienceinschool.org/2007/issue4/spectrometer
- http://www.cs.cmu.edu/~zhuxj/astro/html/spectrometer.html
- https://astro.unl.edu/naap/hydrogen/naap_hydrogen_sg.pdf
- https://astro.unl.edu/naap/hydrogen/hydrogen.html
- https://calgary.rasc.ca/stellarmagnitudes.htm
- https://www.youtube.com/watch?v=iwlMmJs1f5o
- https://earthsky.org/space/what-is-a-parsec
- https://www.astronomynotes.com/index.html

RESOURCES

- https://www.nobelprize.org/prizes/themes/how-the-sun-shines-2
- https://sites.ualberta.ca/~pogosyan/teaching/ASTRO_122/lect6/lecture6.html
- https://pages.uoregon.edu/jimbrau/astr122/Notes/Chapter4.html
- https://thecuriousastronomer.wordpress.com/tag/spectra/
- https://www.handprint.com/ASTRO/specclass.html