STARS

WHAT ARE STARS?

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LEARNING OUTCOMES

- Describe stars and their properties
- Describe how stars are classified according to their colours
- Describe how physical properties of stars, including mass, radius, temperature and luminosity are deduced from observations
- Describe and understand the HR diagram, it's purpose and how it relates to stellar evolution
- Describe how main sequence stars of low and high masses produce energy

OUTLINE

- What is a star
- Properties of stars
- Observational properties
- Stellar colors
- Luminosity
- Distance calculations (reminder)
- The HR diagram
- Combining temperature and luminosity
- Measuring stellar mass
- Measuring stellar age
- HR diagram and stellar evolution
- Hydrogen fusion in low mass stars
- Hydrogen fusion in high mass stars
- Explaining the HR diagram

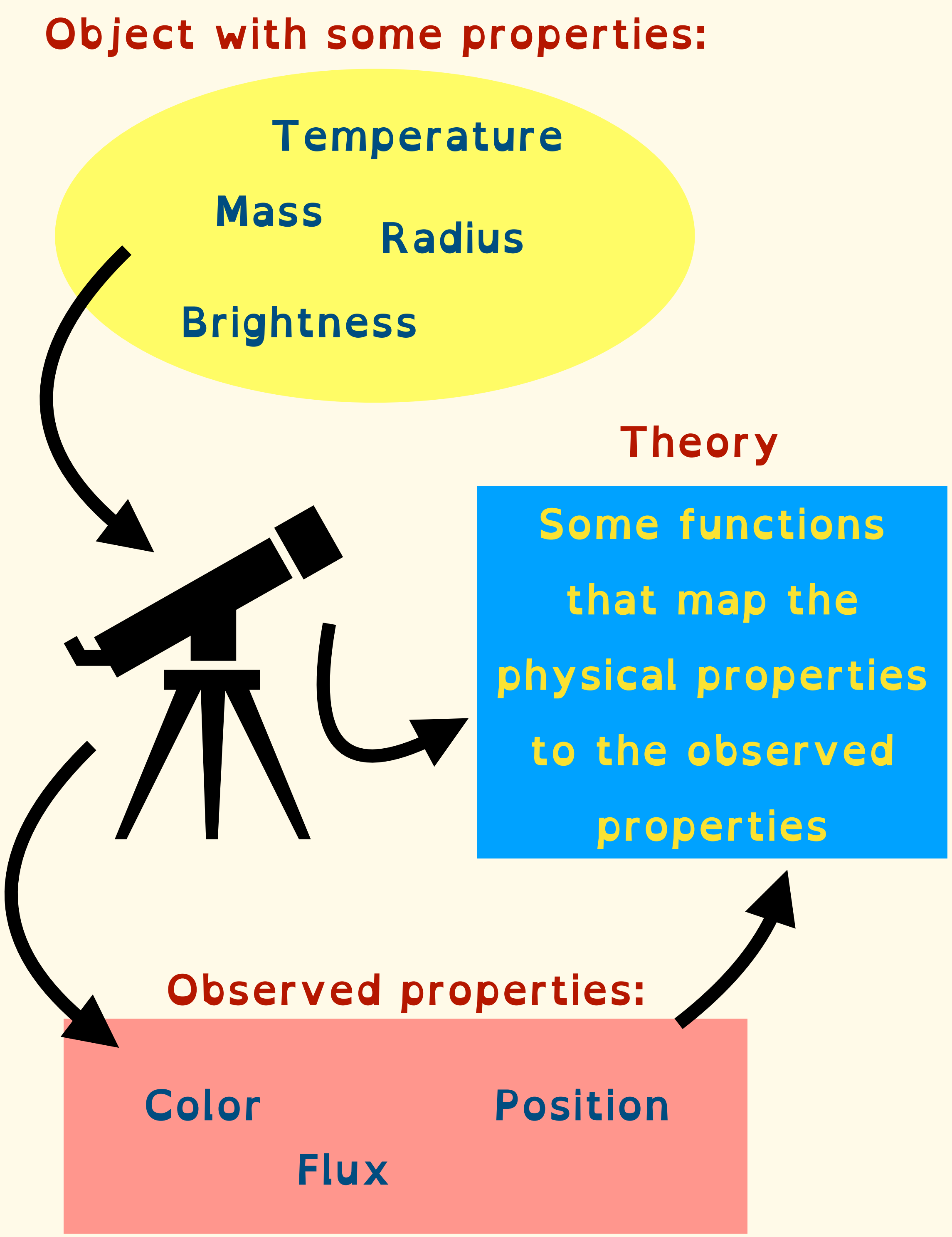
WHAT IS A STAR?

- Luminous ball of gas held together by gravity
- Does not collapse under its own weight due to radiation pressure provided by nuclear fusion reactions in the core of the star
- The Sun is the nearest star to Earth
- Stars are the factories that produce all the elements that make up life (and more), and help drive the evolution of galaxies across cosmic time

Disclaimer: The Sun is not flat, we checked

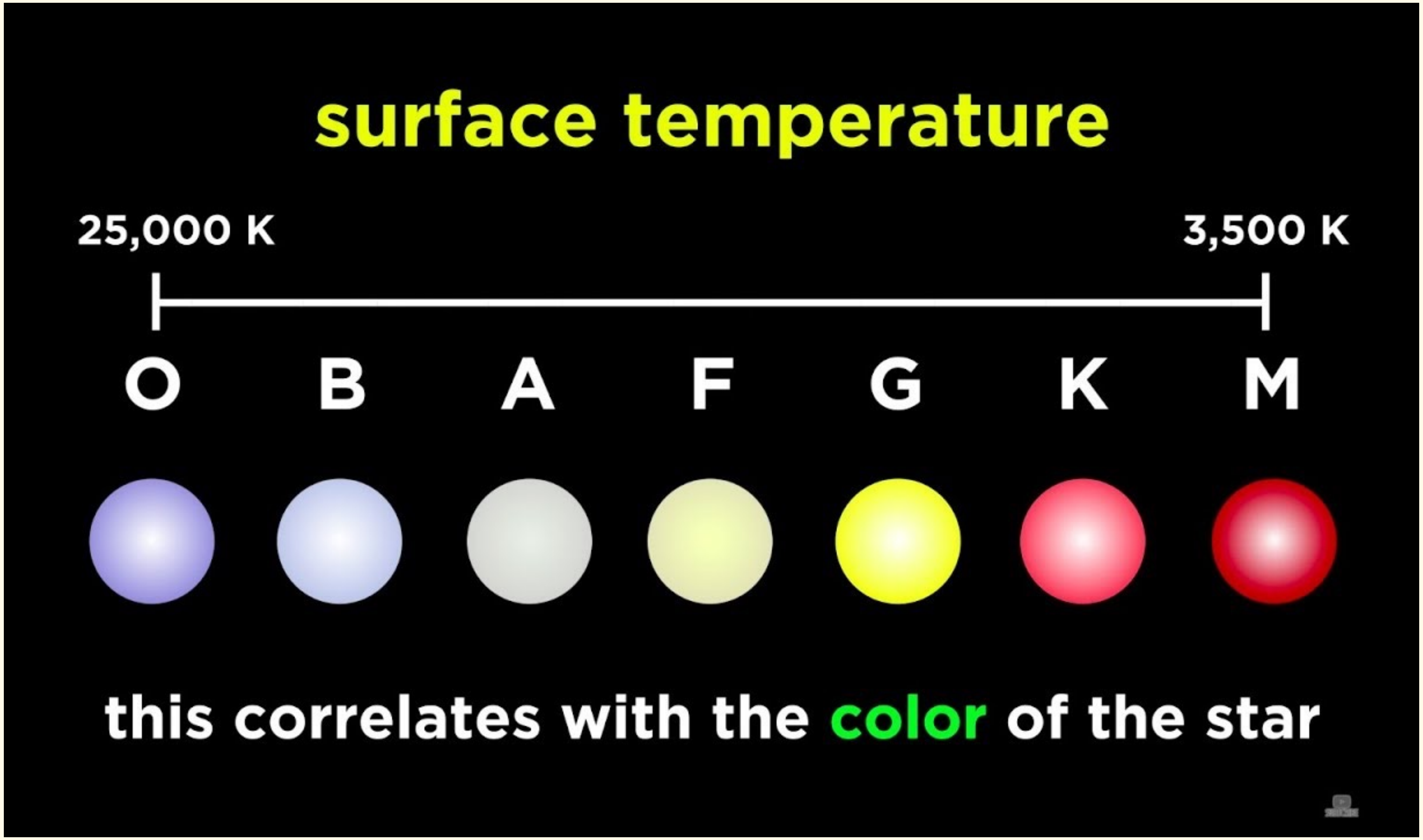
PROPERTIES OF STARS

- Observable properties: Observed brightness, colour, position relative to other stars
- Physical properties: Mass, distance from Earth, intrinsic brightness, temperature, radius
- Physical laws (or ways of modelling reality) can help us convert between observable properties and physical properties



OBSERVATIONAL PROPERTIES OF STARS

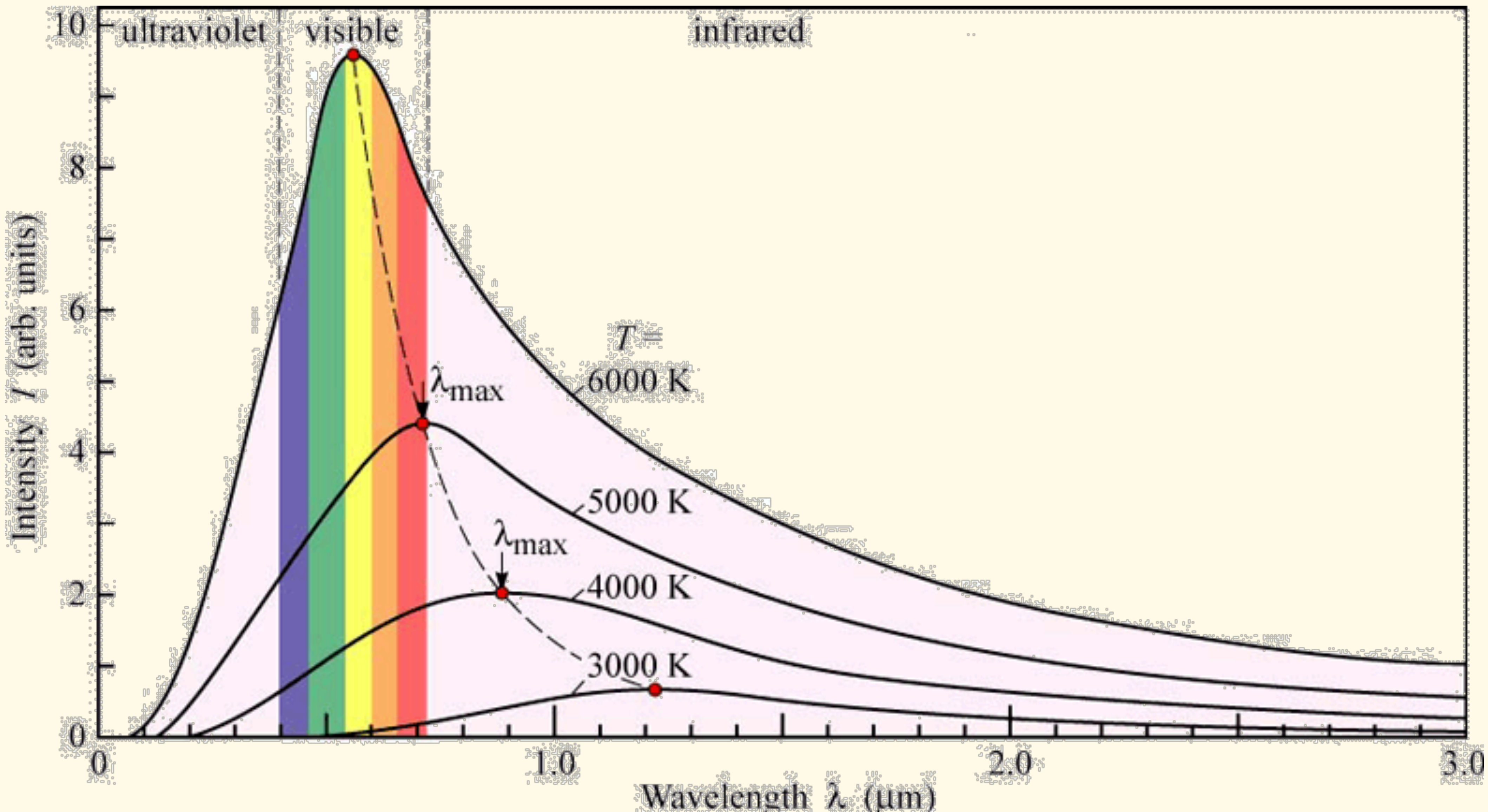
- Harvard classification: developed by Annie Jump Cannon
- Cecilia Payne demonstrated that this is actually a sequence in temperature



A few good mnemonics for this, I personally like 'Old Bob Always Favours Green Ketchup More'

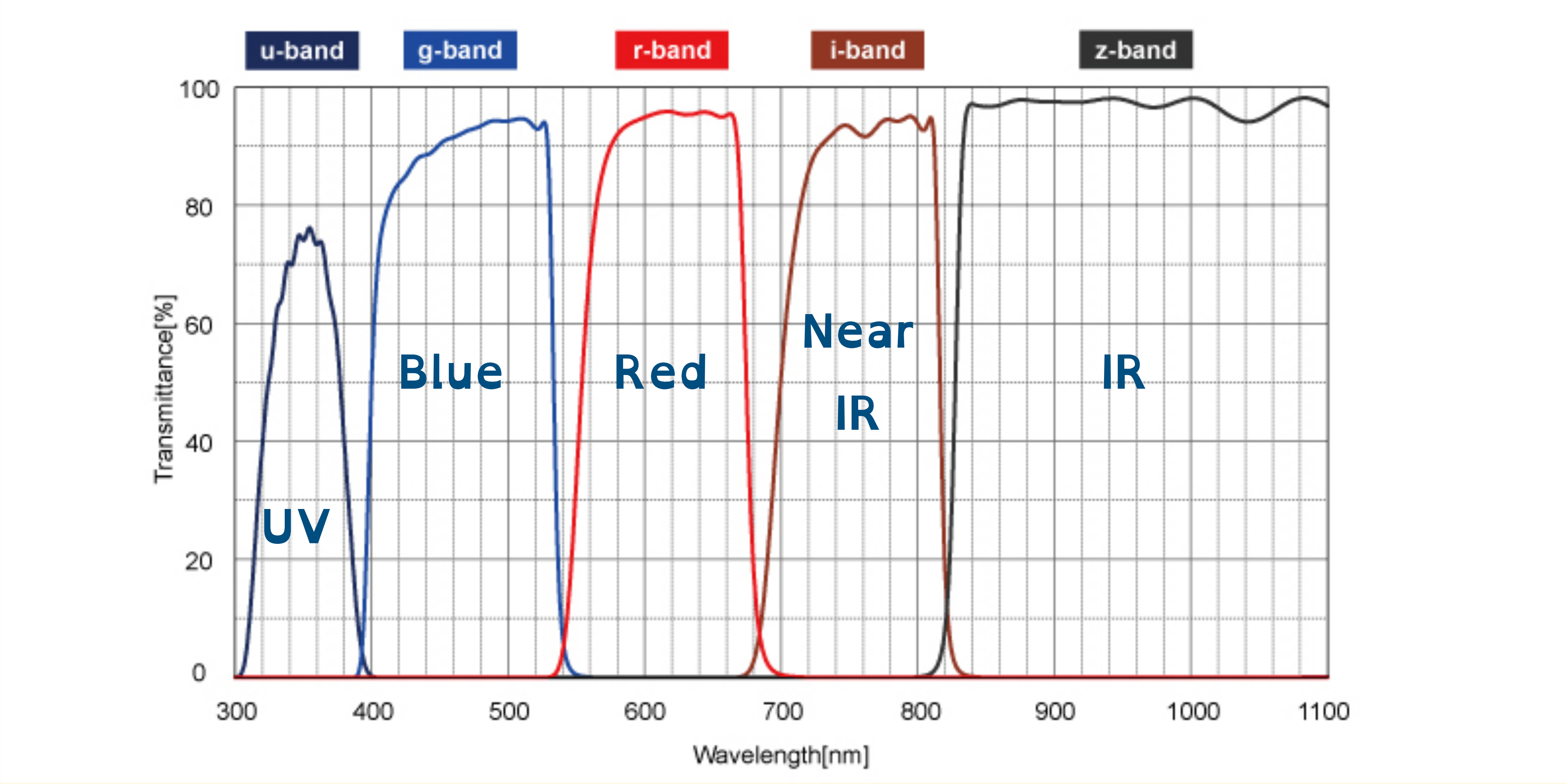
BLACKBODY SPECTRUM

- Blackbody, or thermal radiation is emitted by any object where the emitter is in thermal equilibrium with its surroundings (no energy flow to or from object).
- Usually this is conceptualised as the emission from an object that absorbs all radiation that falls on it.
- The blackbody spectrum has a characteristic shape that is determined solely by the temperature of the object doing the emitting.



HOW TO MEASURE COLOURS OF STARS

- Coloured filters are used to find out how bright stars are in certain coloured bands
- This is ‘photometry’



MEASURING STELLAR LUMINOSITY

- Telescopes measure flux:

Flux = no. of photons emitted from source / area / time

- Want to know the luminosity of something:

Luminosity = no. of photons emitted by source / time

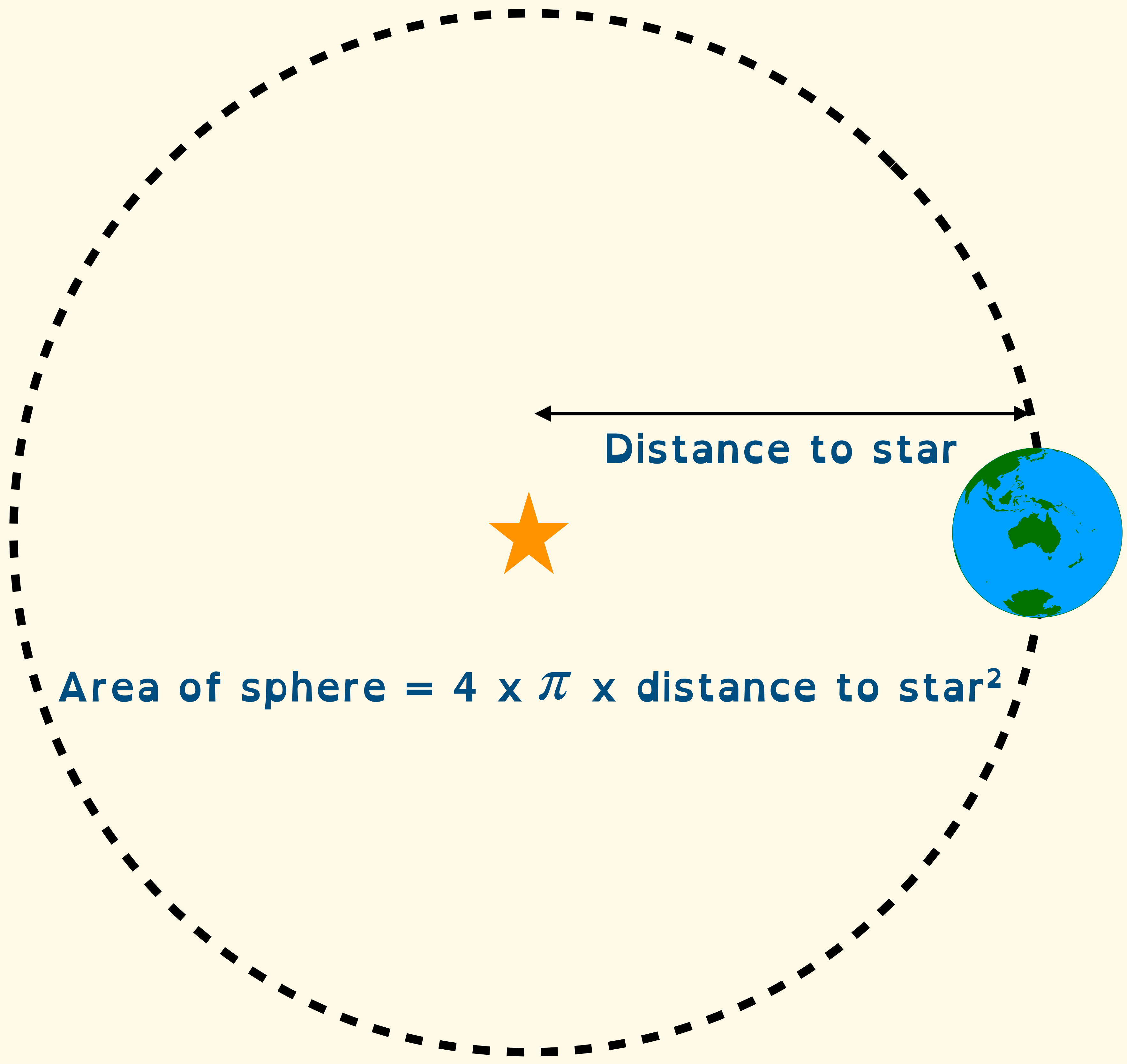
Luminosity = Flux x area

- If a star emits light isotropically in all directions, then

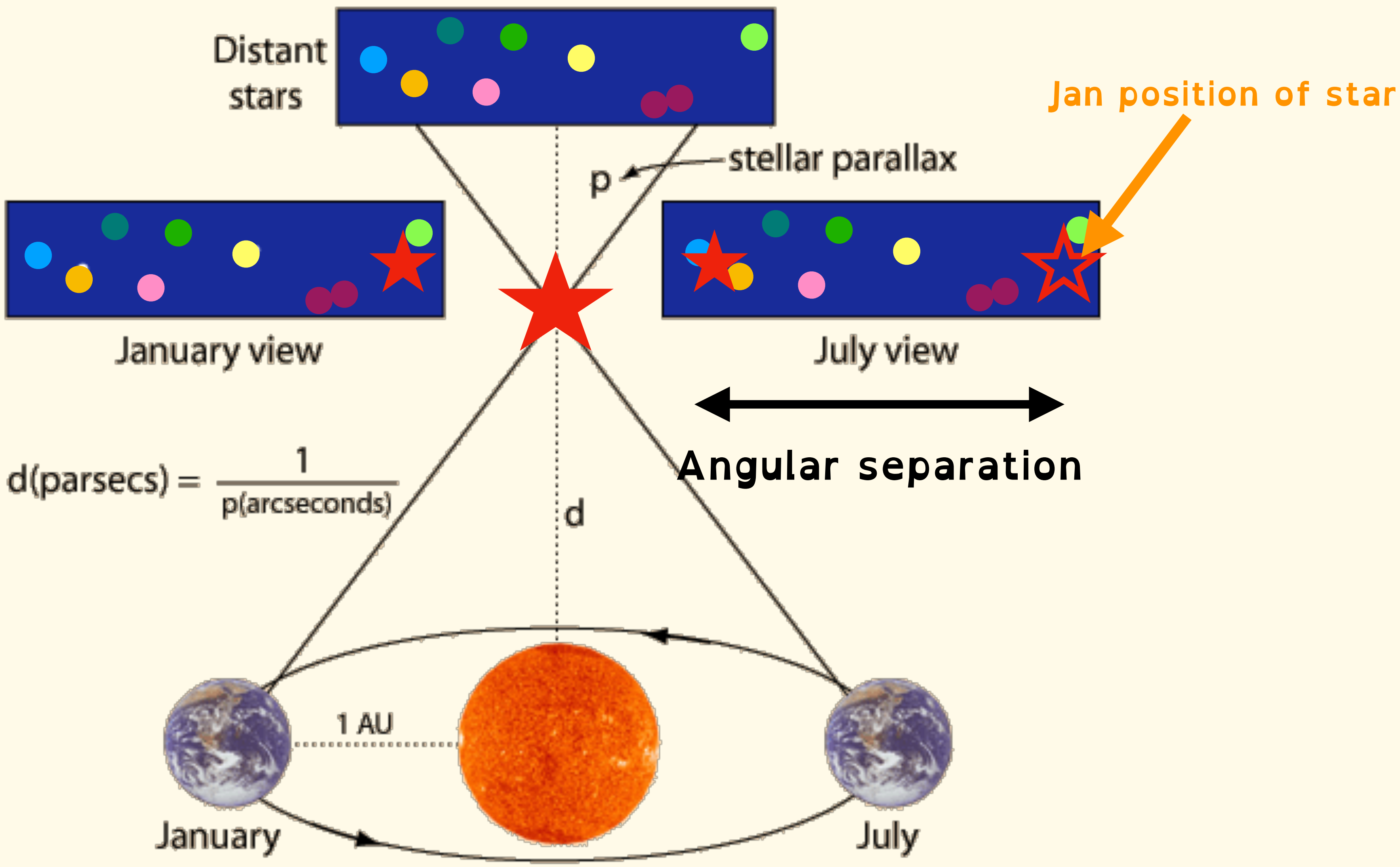
Luminosity = Flux x (4 x π x distance to star^2)

Area of a sphere centred on the star emitting light

MEASURING STELLAR LUMINOSITY

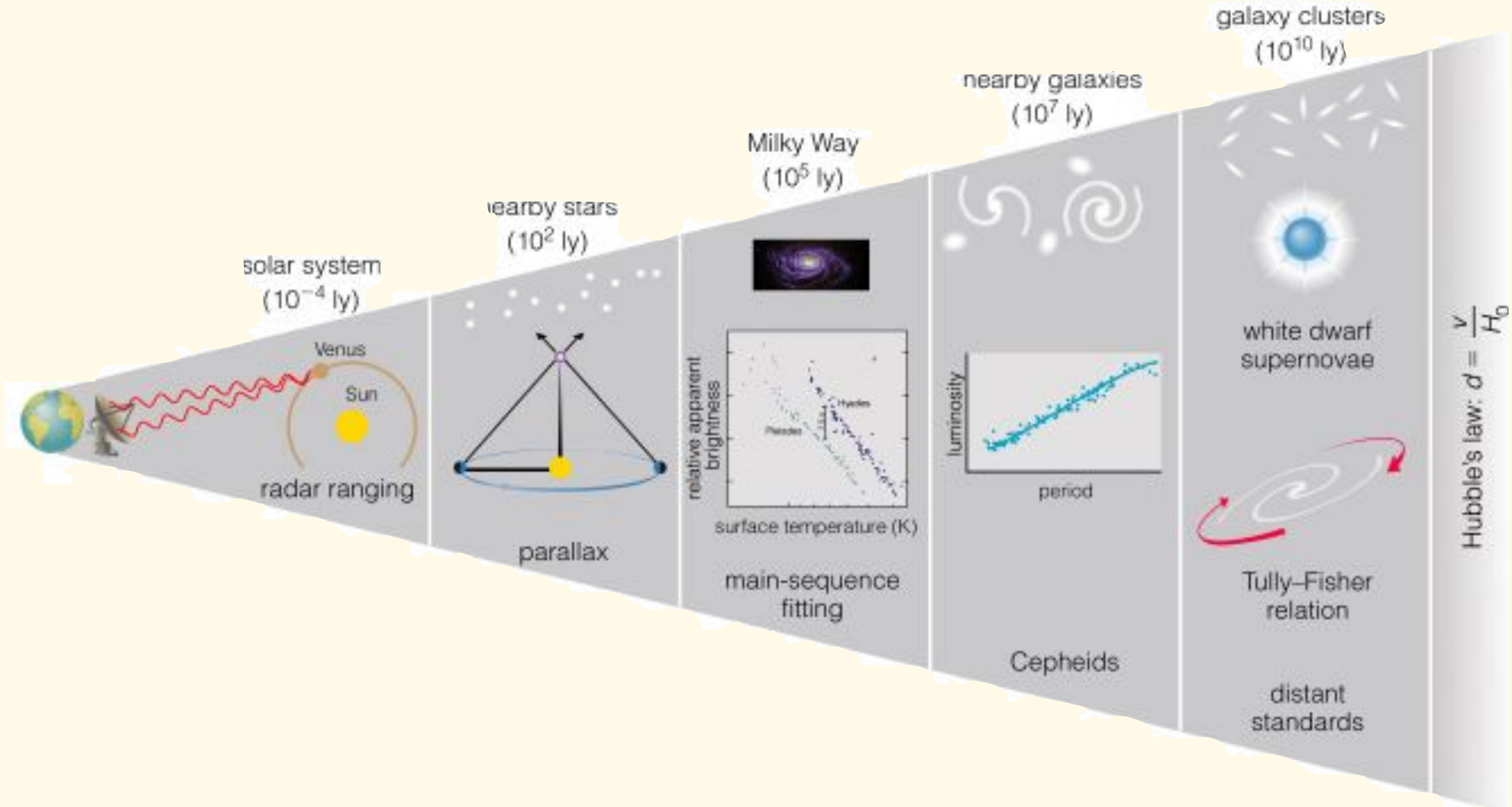


PARALLAX - MEASURING THE DISTANCE TO STARS



- Measure distance to nearby stars using parallax
- Take images of the same area of sky 6 months apart
- Use the apparent angular difference in location of stars to measure distance (as distance between Earth and sun is accurately known)
- Allows us to measure the luminosity of stars

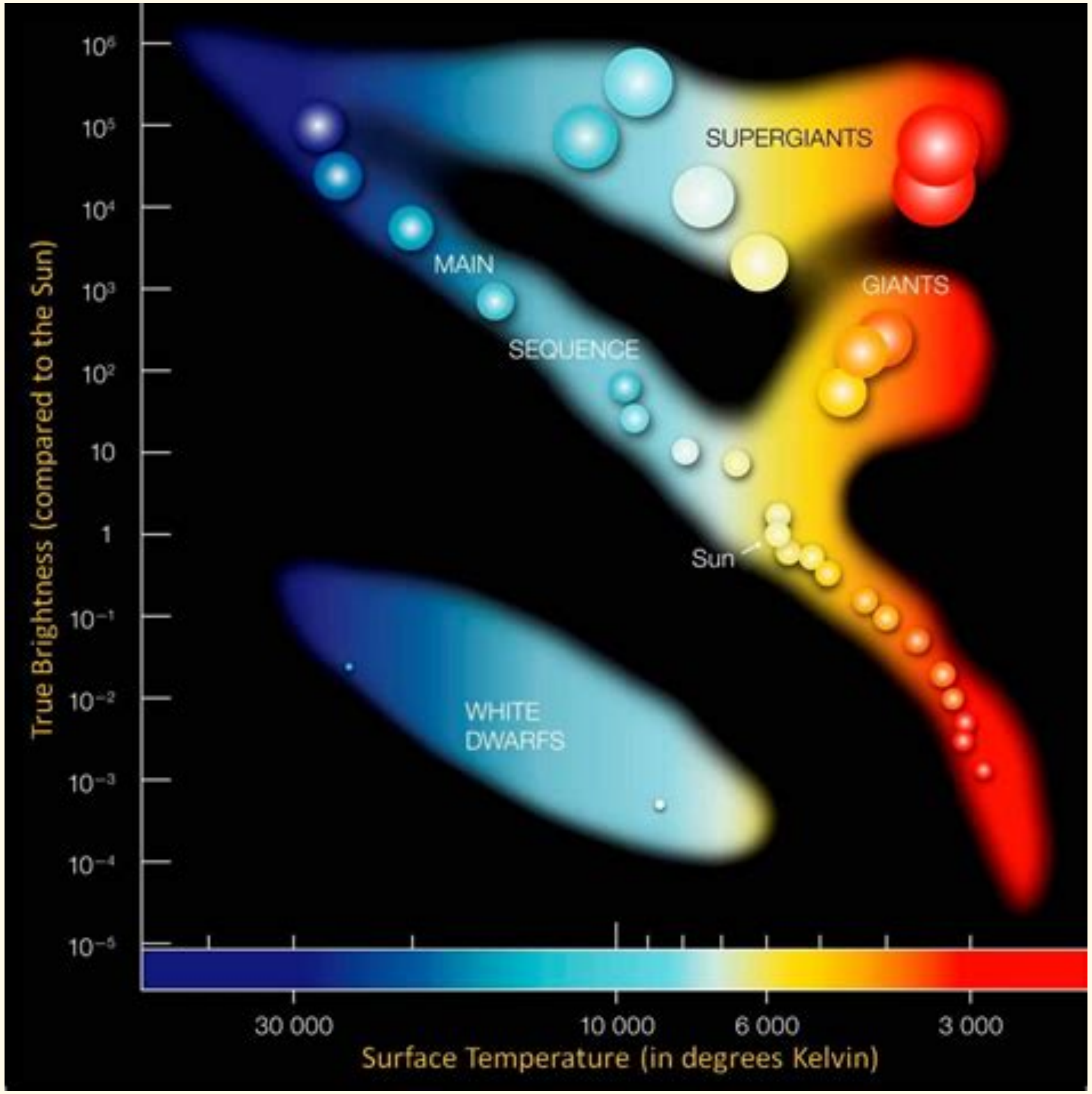
REMINDER: COSMIC DISTANCE LADDER



- For more distant stars, we can use the cosmic distance ladder to estimate distances

THE HERTZPRUNG-RUSSELL DIAGRAM

- A diagram that shows how the colour (i.e. temperature) and luminosity of observed stars are related



- Stars tend to occupy certain regions
- 1910: discovered by Ejna Hertzsprung (Denmark) and Henry Russell(USA)
- A major step towards understanding of stellar evolution

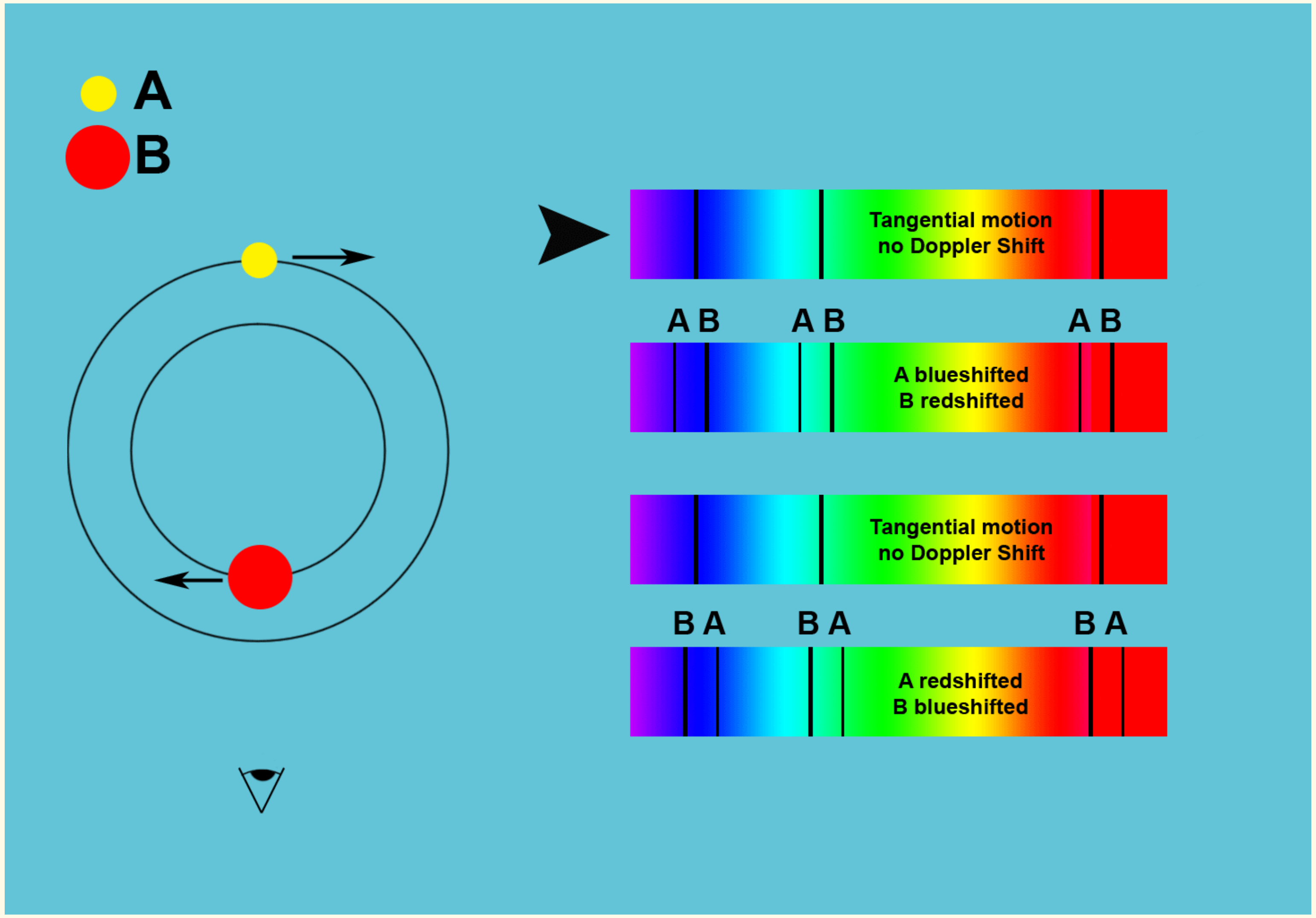
COMBINING TEMPERATURE AND LUMINOSITY

- Once we know the temperature and luminosity of a star on the main sequence, we can usually determine a few other properties of the star, for example it's mass and radius
- The mass of the star can be derived from its colour.
- The radius can then be derived from the principle that pressure outwards from the nuclear reactions inside the star must balance the force of gravity inward due to it's mass

Class	Color	Mass (solar masses)	Radius (solar radii)
O	Blue	>16	>6.6
B	Blue-white	2.1 - 16	1.8 - 6.6
A	White	1.4 - 2.1	1.4 - 1.8
F	Yellow-white	1.04 - 1.4	1.15 - 1.4
G	Yellow	0.8 - 1.04	0.96 - 1.15
K	Light orange	0.45 - 0.8	0.7 - 0.96
M	Orange-red	0.08 - 0.45	<0.07

MEASURING STELLAR MASS

- Knowing the mass and radius of a star are important as this tells us how a star will evolve
- Can estimate mass and radius from position on the HR diagram (colour and luminosity)
- Can also use stars in binaries (e.g. spectroscopic binaries) to calculate mass more accurately



MEASURING STELLAR MASS

- Once you know the radial velocity, can use Newton's and Kepler's laws to calculate mass
- For stars that are not in binaries, use the empirical mass-luminosity relation to calculate:

Luminosity of star

Luminosity of the sun

$$\frac{L}{L_\odot} = \left(\frac{M}{M_\odot}\right)^{3.5}$$

Mass of the star

Mass of the sun

STELLAR AGE

- How long a star lives depends on it's initial mass (called the 'zero age main sequence' or ZAMS mass
- How a star ends it's life also depends on it's ZAMS mass
- Recall that mass is related to temperature (observed as colour)
- Hotter stars burn through fuel faster, and live shorter lives

Main sequence lifetime

Lifetime of the sun

$$\frac{t_{\mathrm{MS}}}{t_{\odot}} = \left(\frac{M}{M_{\odot}}\right)^{-2.5}$$

Mass of the star

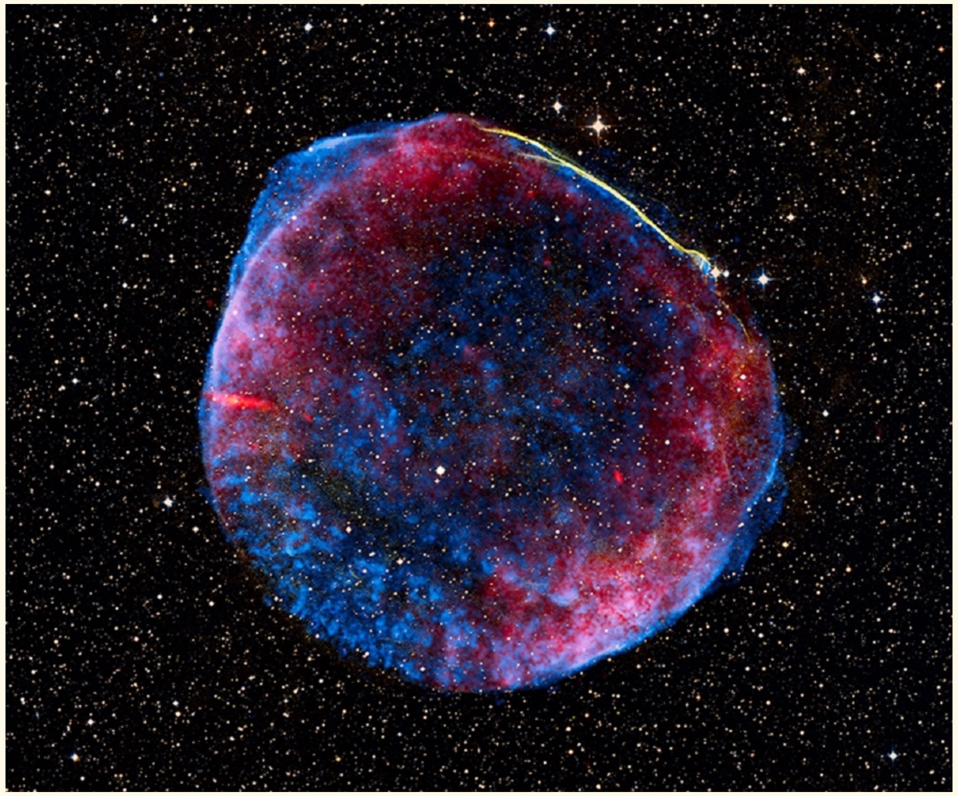
Mass of the sun

HR DIAGRAM AND STELLAR EVOLUTION

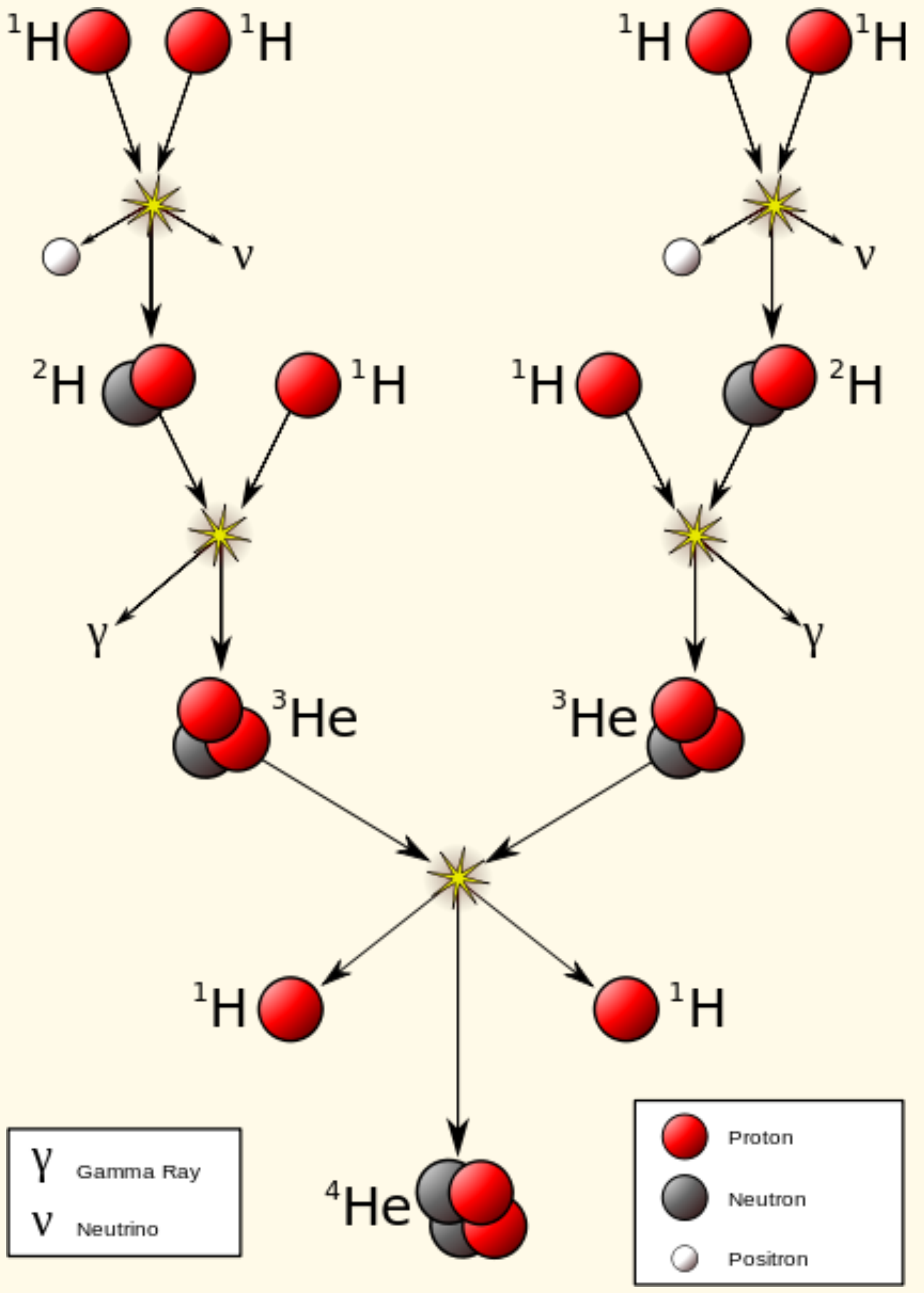
- Around 1912, speculations were that stars might evolve along the tracks of the HR diagram.
  - E.g., from a red giants to a dwarf star, and then move down the Main Sequence?
- One big question was: what converts gravitational energy to radiation?
- 1926 Arthur Eddington predicted:
  - Nuclear fusion could be the source of stellar energy
  - Stars may be made of mostly hydrogen
  - Dwarf stars stay on Main Sequence most of their lifetime
- 1930-1940s: laboratory nuclear fusion of hydrogen isotopes was accomplished, nuclear fusion in stars was understood.
- 1954: Fred Hoyle predicted creation of heavy elements during the evolution and supernova explosion of a star

ENERGY PRODUCTION AND NUCLEOSYNTHESIS

- The stars are the source of all the chemical elements.
- After the Big Bang, the universe was made up of mostly hydrogen, a tiny amount of helium and even tinier amounts of lithium
- The stars can convert hydrogen into heavier elements
- This process is called 'nucleosynthesis'
- Stars drive the chemical evolution of the universe

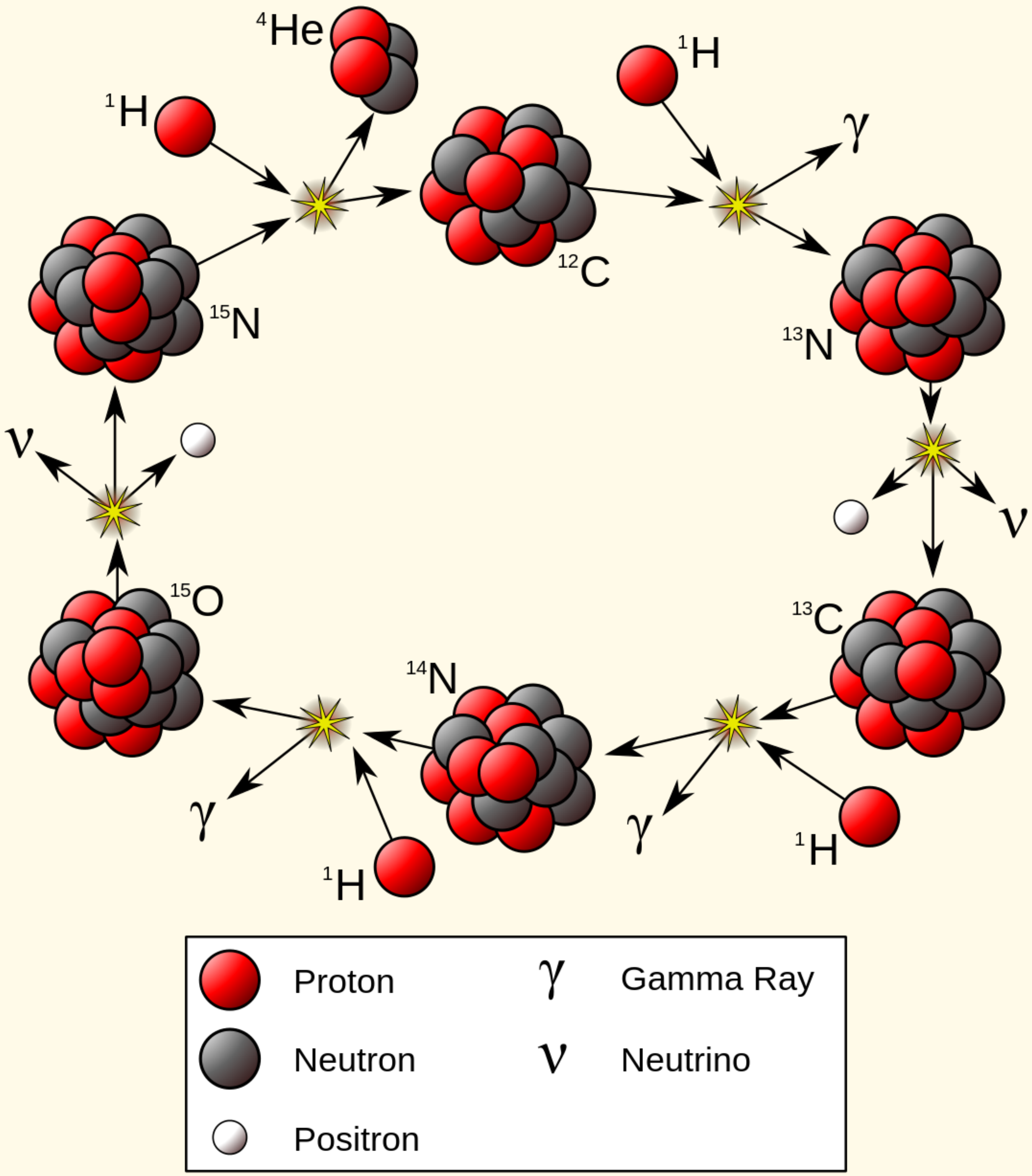


HYDROGEN FUSION



- Source of energy for main sequence stars with masses < 1.5 solar masses
- Light is initially in the form of gamma-rays
- These gamma-rays scatter off particles inside the sun and lose energy
- Eventually are emitted at IR, optical and UV wavelengths
- It takes ~20,000 yrs for a photon to reach the surface of the sun from its core

CNO CYCLE AND HIGH MASS STARS



- Source of energy for main sequence stars with masses >1.5 solar masses
- Catalytic reaction
- Gets more efficient at higher and higher temperatures, so dominates in high mass (hotter) stars

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