
What Stellar Properties would we like to know and Measure?

What would we like to know?

- Distance
- Luminosity
- Temperature
- Mass
- Radius

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Distance is the most basic thing we can measure

How far away is it? Measuring distances

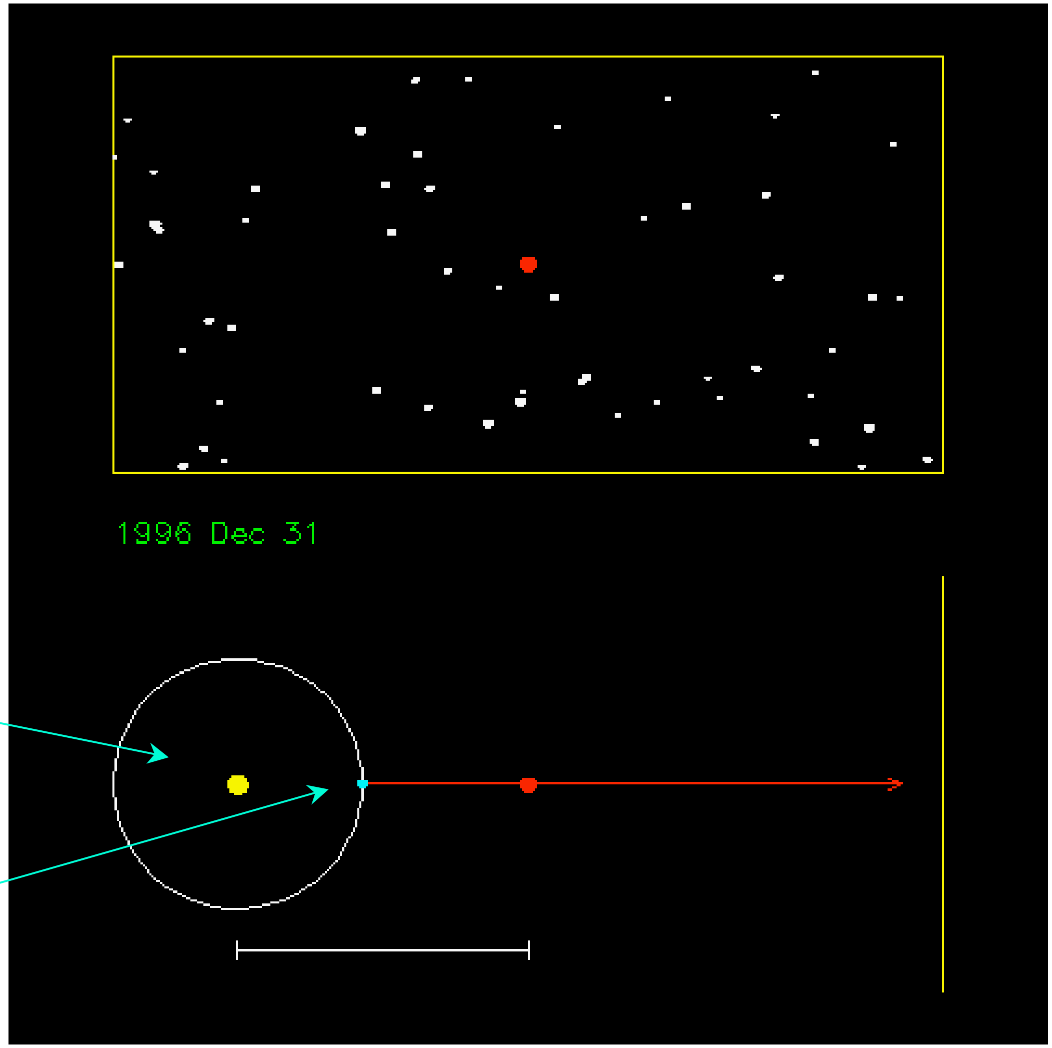
- Nearest star:
  - Our sun is 8 light *minutes* away
- Nearest star other than our sun:
  - 4 light *years* away (300,000 times further)

How do we know this?

Parallax

Red star: nearby

White stars: far away



View from Earth

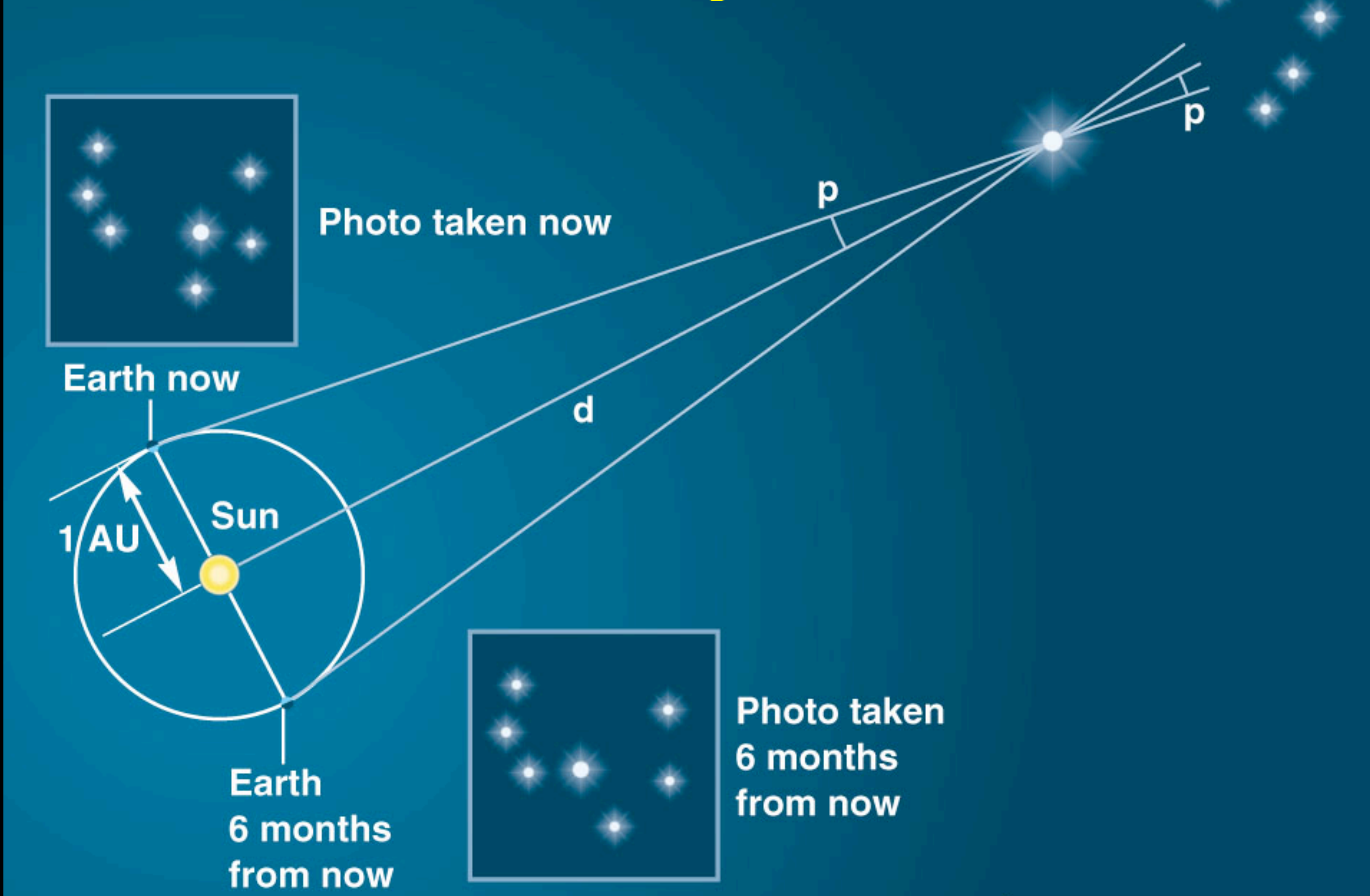
View from above solar system

Sun

Earth

Parallax of stars in Orion

Measuring Parallax



Measuring distances

- Parallax angle ***p*** :
  - 1/2 the change in direction to a star as Earth orbits Sun
- From simple trigonometry, distance ***d*** to star is related to parallax angle ***p*** by

$$d = 1 / p \qquad \text{where } p \text{ is in } \textit{seconds of arc}$$
$$\text{and } d \text{ is in } \textit{parsecs}$$

$$1 \text{ parsec} \approx 200{,}000 \text{ AU} \approx 3.26 \text{ light years}$$

- Star at distance of one parsec has parallax angle of one arcsec

Measuring distances

- Parallax angles are VERY small, so can only be measured for nearby stars
  - Ground-based measurements accurate to ~50 pc
  - Space-based measurements accurate to ~1000 pc
- Nearest star 1.4 pc away (0.7 arcsecs)
- Sirius ~3 pc away (0.3 arcsecs)
- Betelgeuse ~170 pc away (0.006 arcsecs)

We'll encounter many more ways to measure distance, but parallax is the most reliable.

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What is Luminosity (*L*)?

- Total energy emitted per second (Watts)
  - Does *not* depend on distance, but is an intrinsic property of emitting object
    - Sometimes referred to as
      - Absolute magnitude
      - Intrinsic luminosity

Measuring luminosity

- We can *always* measure the apparent brightness of an object (as long as we can see it)

- We can measure its luminosity *if* we can measure its distance (for example using parallax)

Recall another definition: Apparent Brightness

- Energy flux (again in Watts) that we ***receive*** from an object
- Depends on luminosity ***and*** distance – NOT an intrinsic property of emitting object
- Sometimes referred to as apparent magnitude

Apparent Magnitude (m)

- Magnitude scale is *logarithmic*.
  - Difference in magnitude gives brightness ratio
- Difference of 5 mag = factor of 100 in brightness
  - $m_1 - m_2 = 2.5 \log_{10}(L_2/L_1)$
- Difference of 1 mag = $\sqrt[5]{100}$ = 2.5118864…
  - 5^{th} mag star is about 2.512 times *brighter* than 6^{th}
  - 1^{st} mag star is $(2.512)^5 = 100$ times *brighter* than 6^{th}

Absolute magnitude (M)

- Apparent magnitude a star would have ***if*** it were at a distance of 10pc.
- Depends only on intrinsic brightness, so is measure of luminosity.
- Difference of apparent and absolute magnitudes (m-M) depends only on distance **= *distance modulus***

Distance modulus

Let F be the flux (ergs/s/cm^2) we observe from a star, and let F_{10} be the flux we would observe if it were at a distance of 10 pc.

$$\text{m-M} = 2.5\log_{10}(F_{10}/F)$$

But $\quad F_{10}/F = (\text{d}/10)^2$

So $\quad \text{m-M} = 2.5\log_{10}[(\text{d}/10)^2] = 5\log_{10}(\text{d}/10)$

If you know M, measure m, can get distance.
If you know d, measure m, can get luminosity

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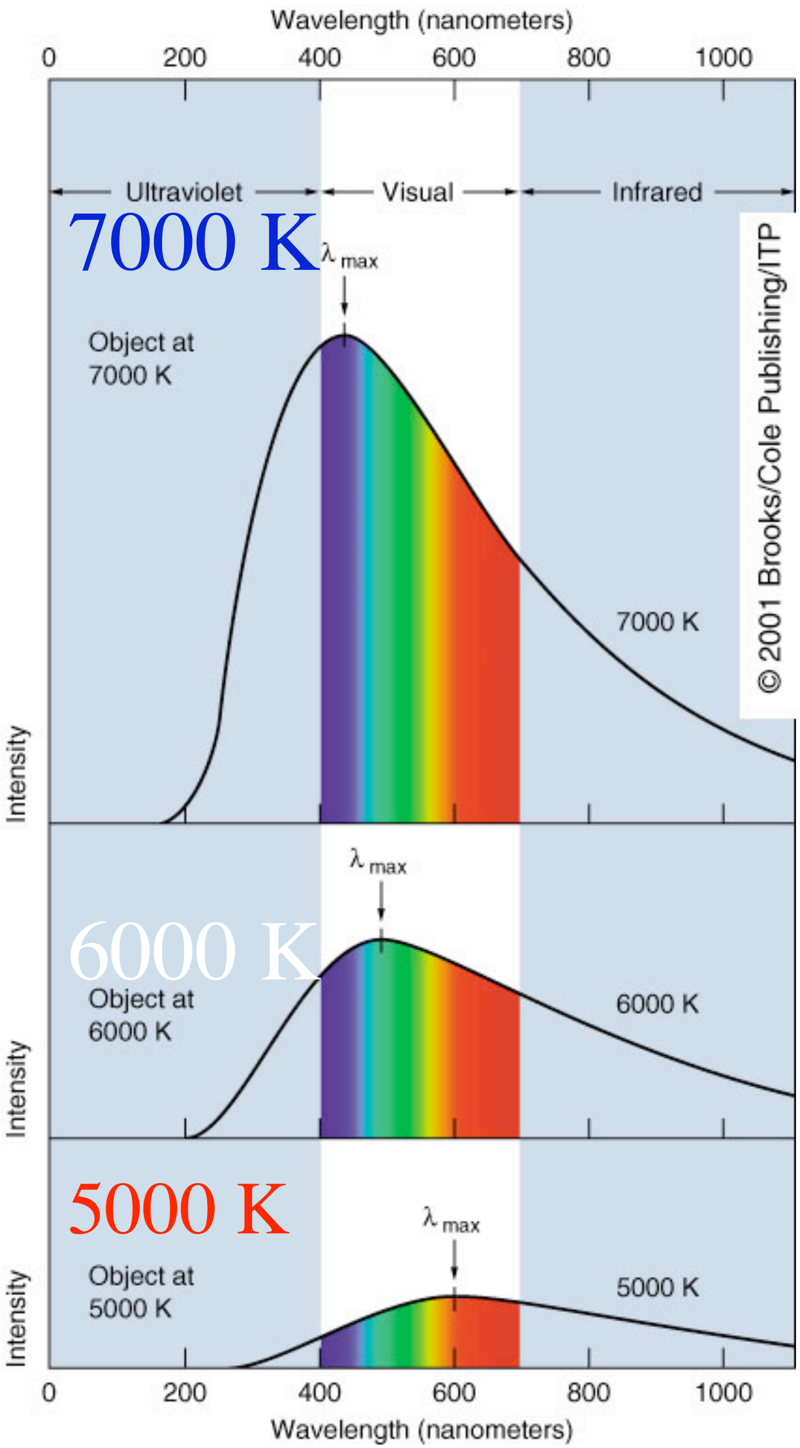
Temperature of a Star

Temperature can be measured either by

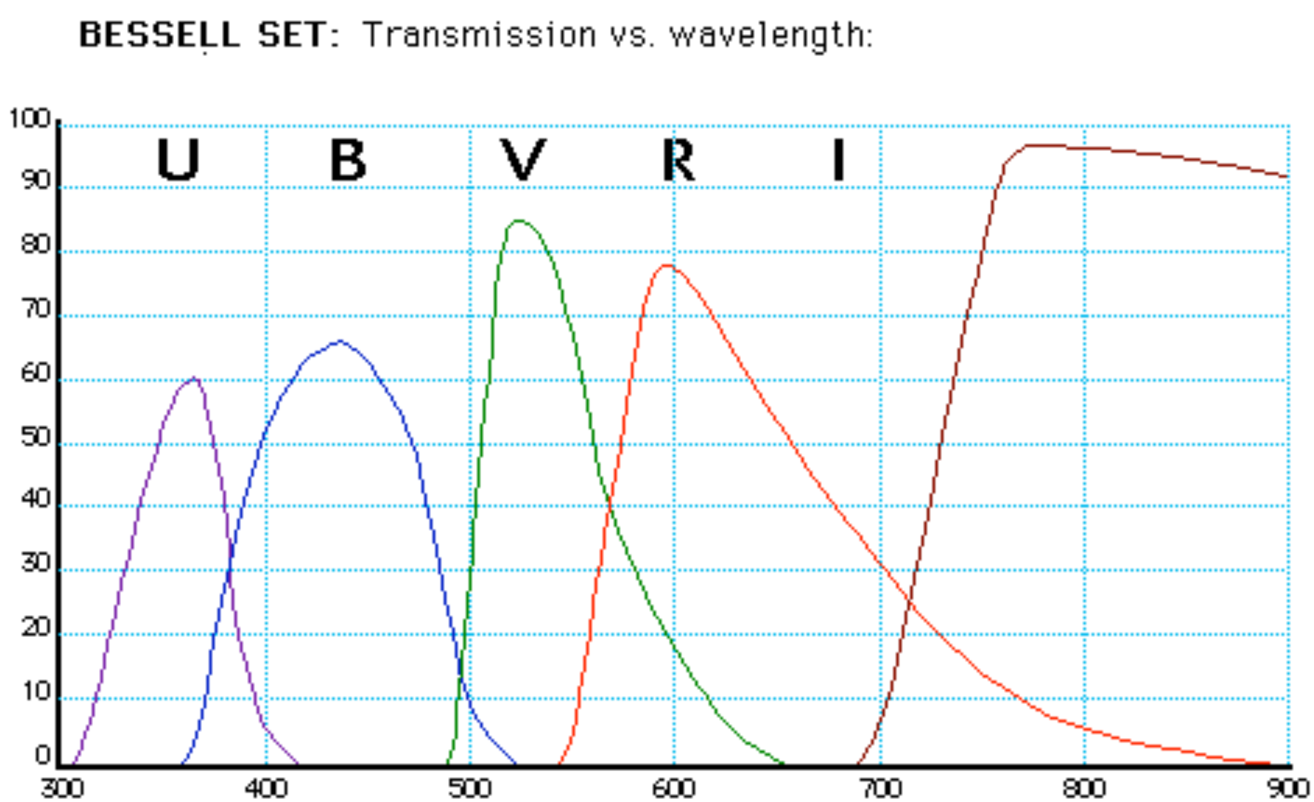
1. Color of star, using black body law:
   - 25,000 K: star looks blue
   - 6,000 K: star looks yellow
   - 3,000 K: star looks red
2. Relative strength of absorption lines in star's spectrum

Black bodies



- 7000 K
  - All colors brighter, but blue is brightest → object looks **blue**
- 6000 K
  - All colors roughly similar in brightness → object **white**
- 5000 K
  - All colors fainter, but red is brightest → object

Broad band filters used to measure brightness of objects at various wavelengths:

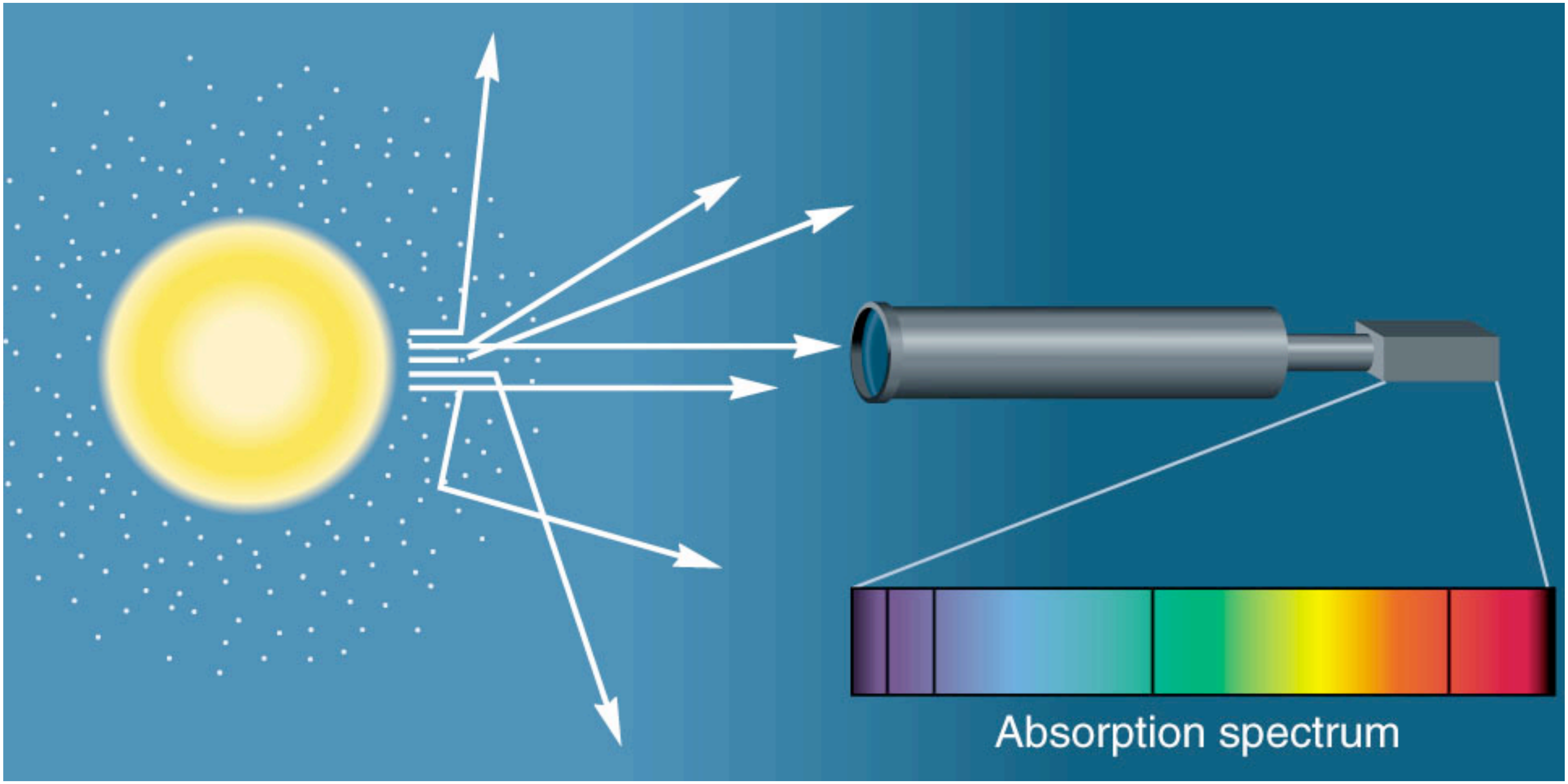


•Wavelength in nm.

Color index

- Can measure magnitude of star at different wavelengths, e.g. U, B, V
- Difference between any two (U-B, or B-V) is called color index - measures T of star
- WARNING: Interstellar dust can preferentially scatter blue light - leads to reddening of starlight, affects color indices, makes objects appear more distant/cooler

Stars have an absorption spectrum



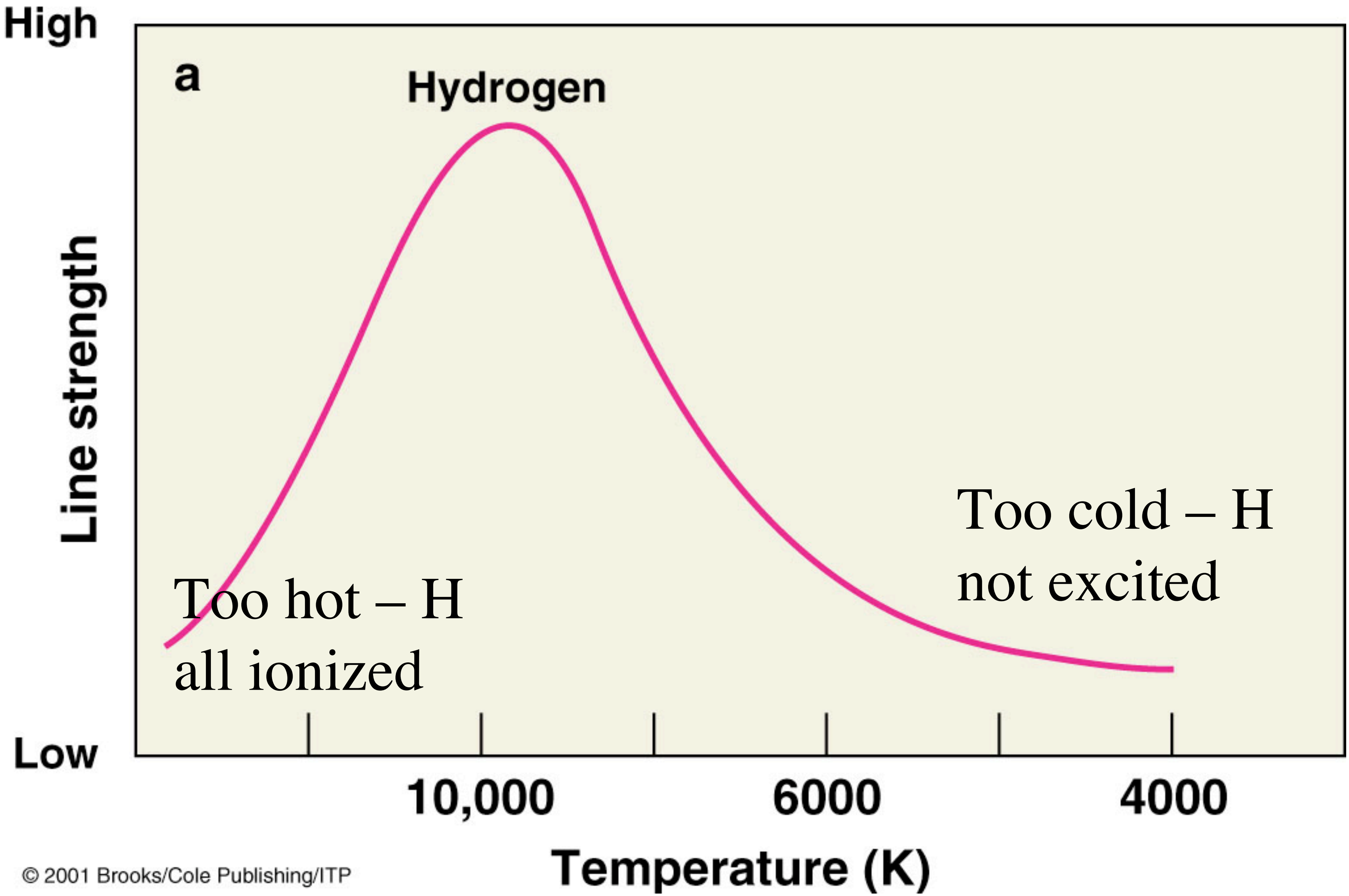
Stellar Absorption Lines

- Strength of absorption lines depends mainly on two things:
  - Abundance of element (see web for spectra of different elements)
  - Temperature of gas

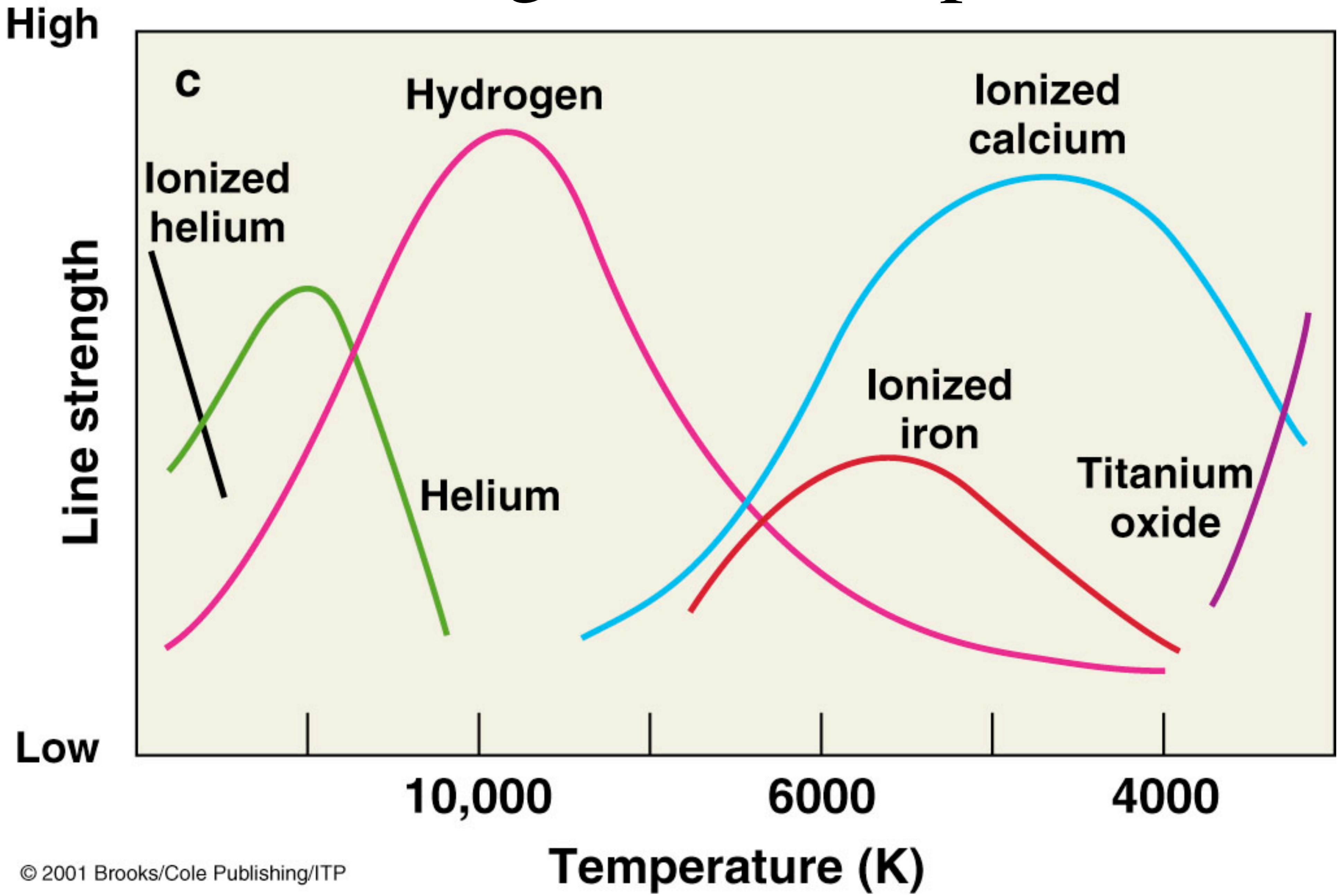
Abundance of Elements in Sun by Mass

- Hydrogen: 73%
- Helium: 25%
- Everything else: 2%
  - Most abundant: C N O Ne Mg Si S Fe
  - In other stars, abundance of "everything else" can be a little higher, or a lot lower

Line Strengths vs Temperature



Line Strengths vs Temperature

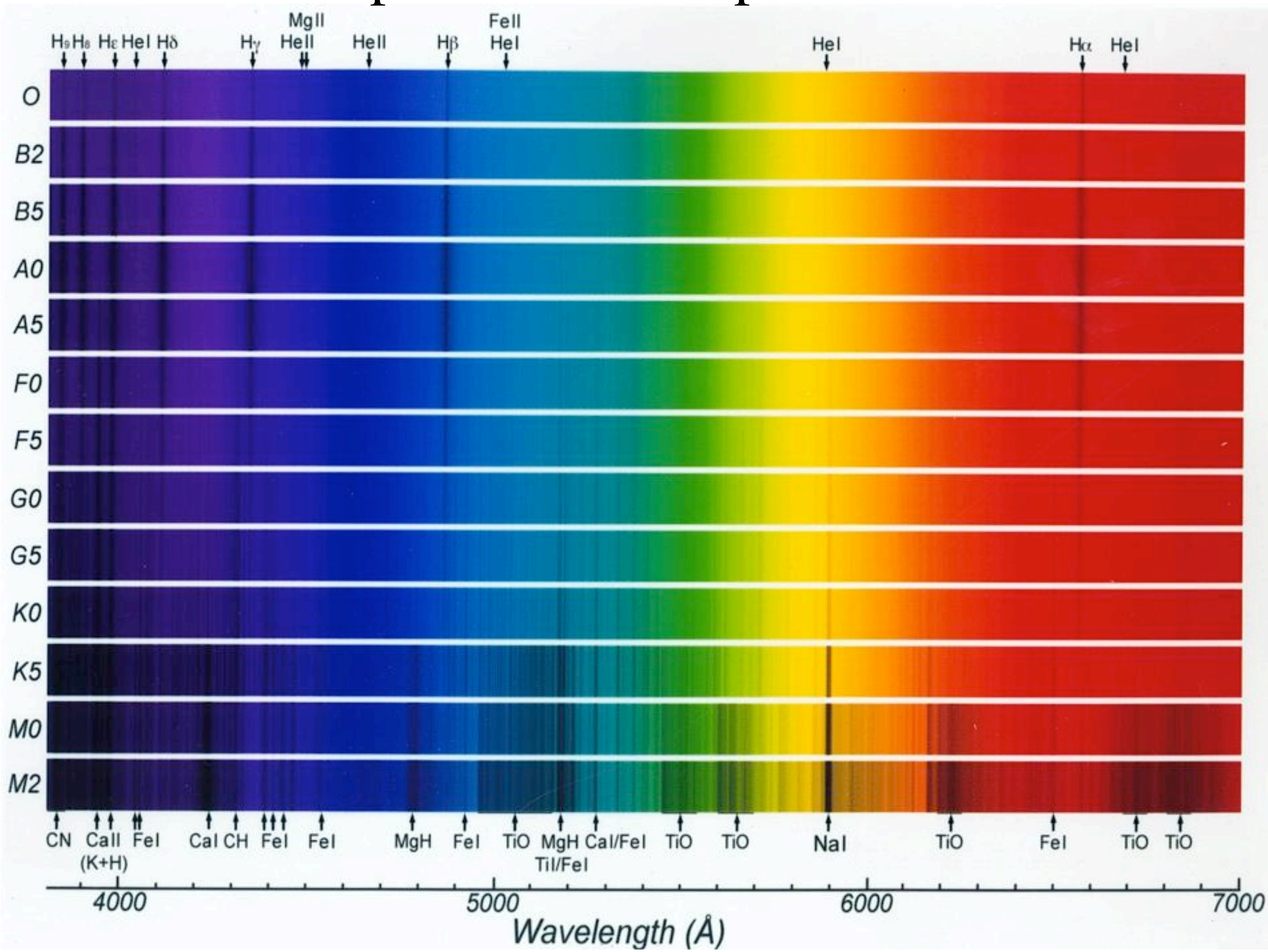


Spectral types

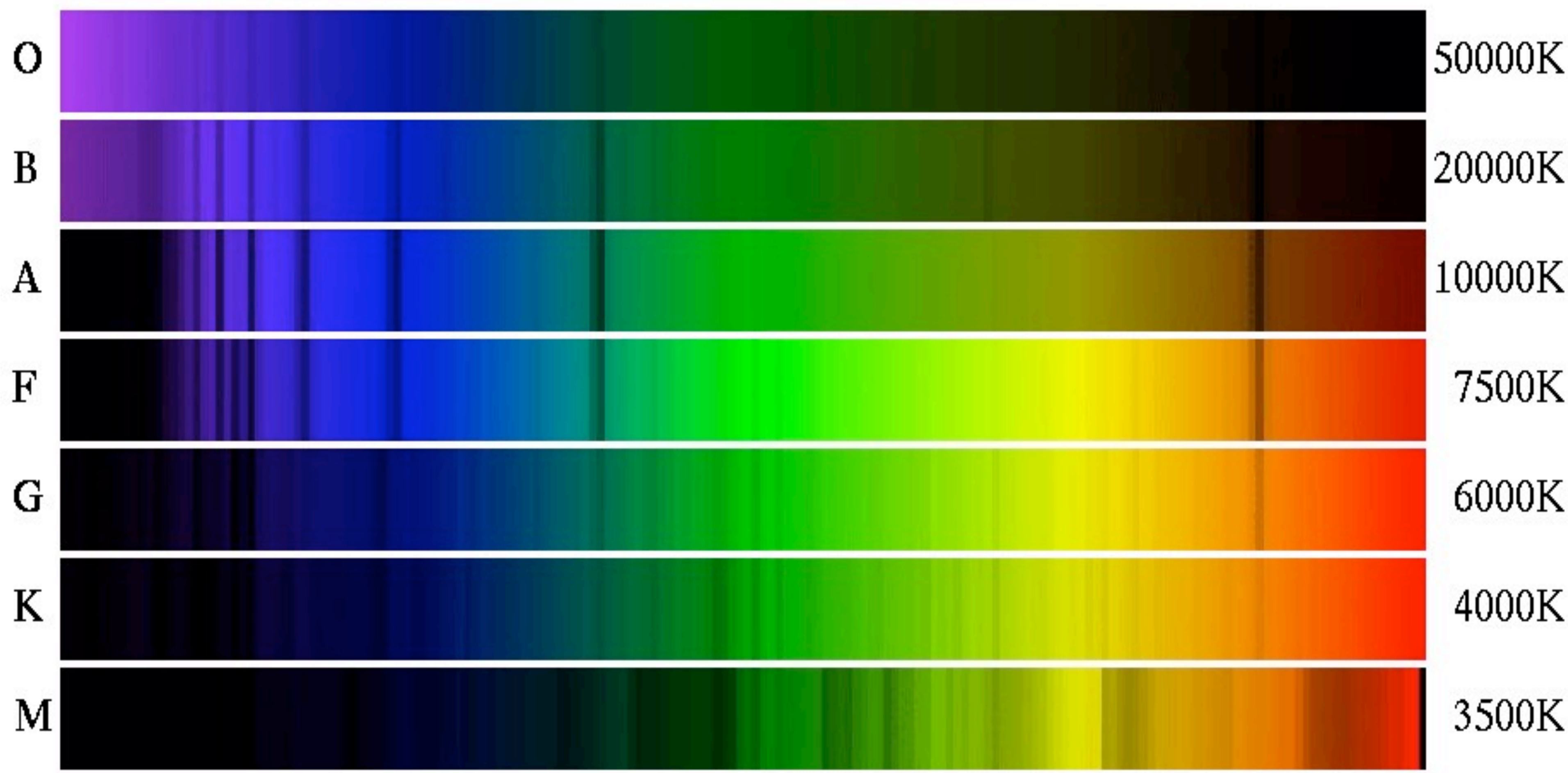
- Astronomers classify stars based on the relative strengths of their absorption lines
- Spectral sequence: O B A F G K M L T
  - type A has the strongest H lines
- Each *spectral type* is further divided into 10 subclasses

  e.g. A0, A1, A2, … , A9, F0, F1, …

Examples of stellar spectra



Spectral Type or *Color* Indicates *Temperature*



Spectral types

- Astronomers classify stars based on the relative strengths of their absorption lines
- Spectral sequence: O B A F G K M L T

Hottest stars — Strongest H lines — Coolest stars

- The Sun's spectral type is G2

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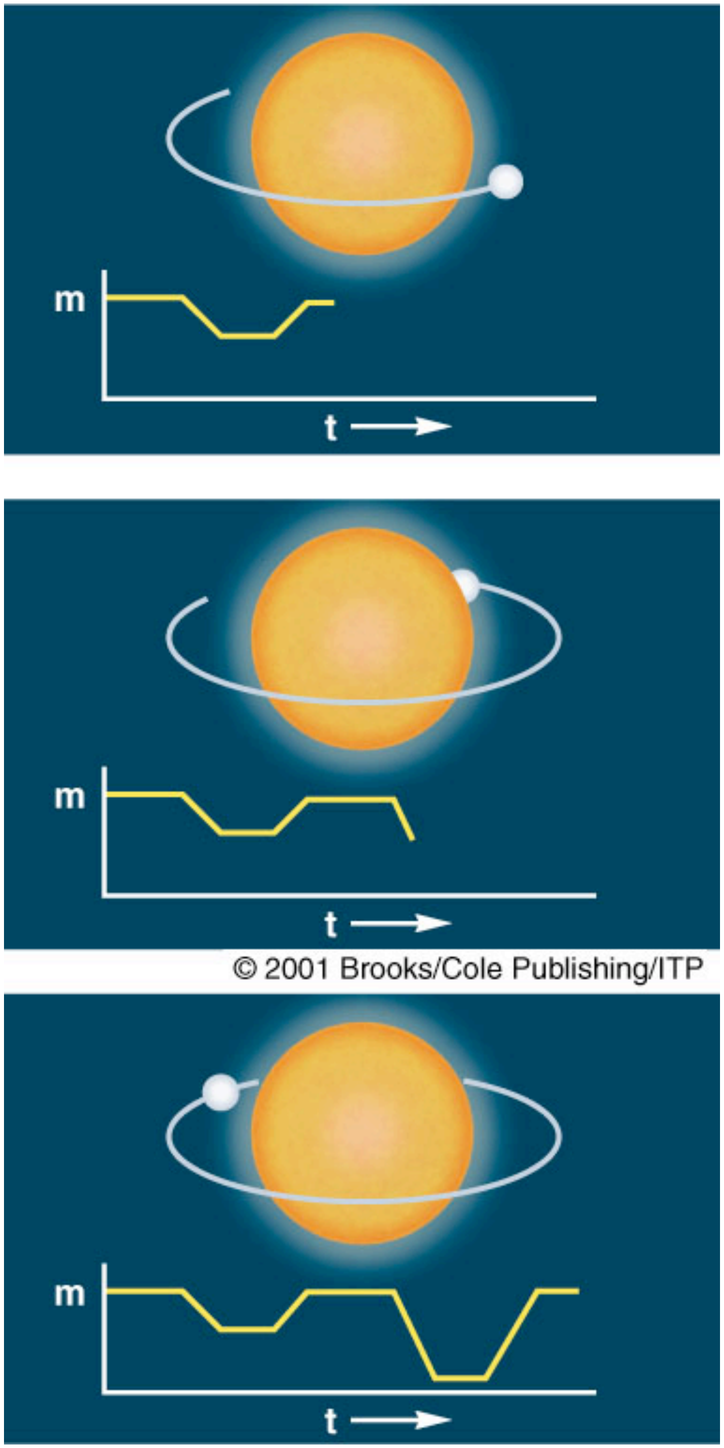
Stellar radii

- Difficult to measure directly for individual stars
- At distance of 1 pc, what is angular diameter of the Sun?
- $D=2*R=2*6.96\times10^{8}$m, $d=3.086\times10^{16}$ m, $\theta=D/d=0.009''$
- Closest star is Proxima Centauri, d=1.3 pc
- Optical/near-IR interferometry useful!



Eclipsing Binaries:
Length of eclipses can also be used to measure radii of stars

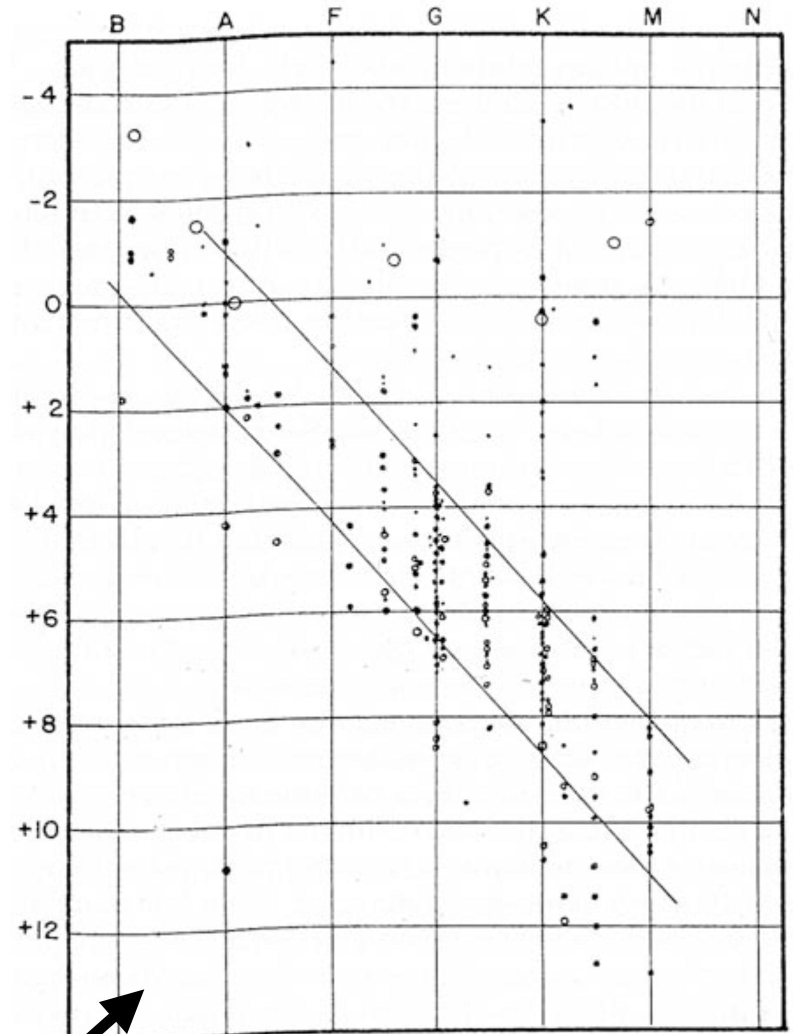
Transiting Planets!

Hertzsprung-Russell Diagram

Ejnar Hertzsprung
(1873-1967)

Henry Norris Russell
(1877-1957)
published diagram

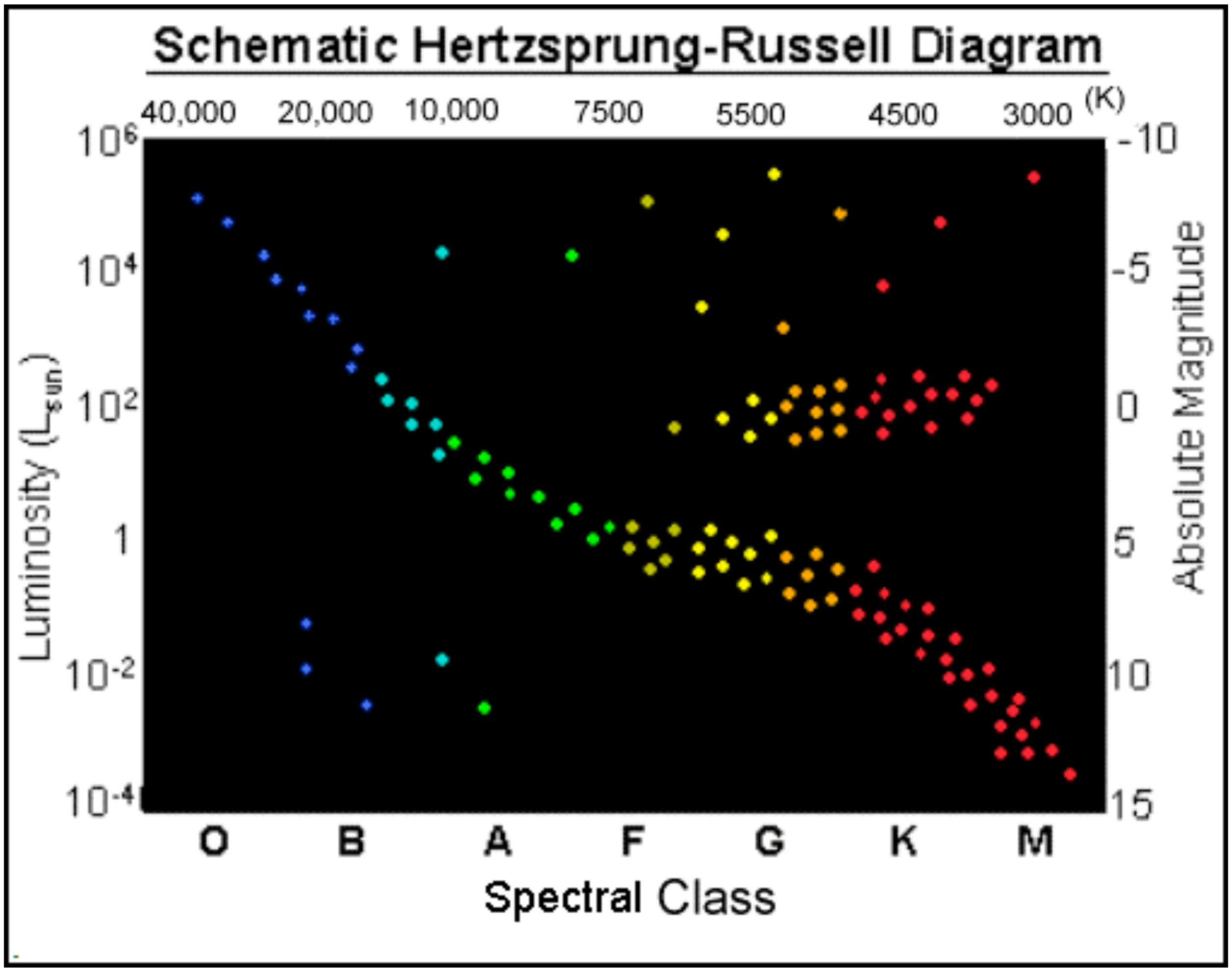
Abs Mag



Spectral Type

Hertzsprung-Russell (HR) diagram

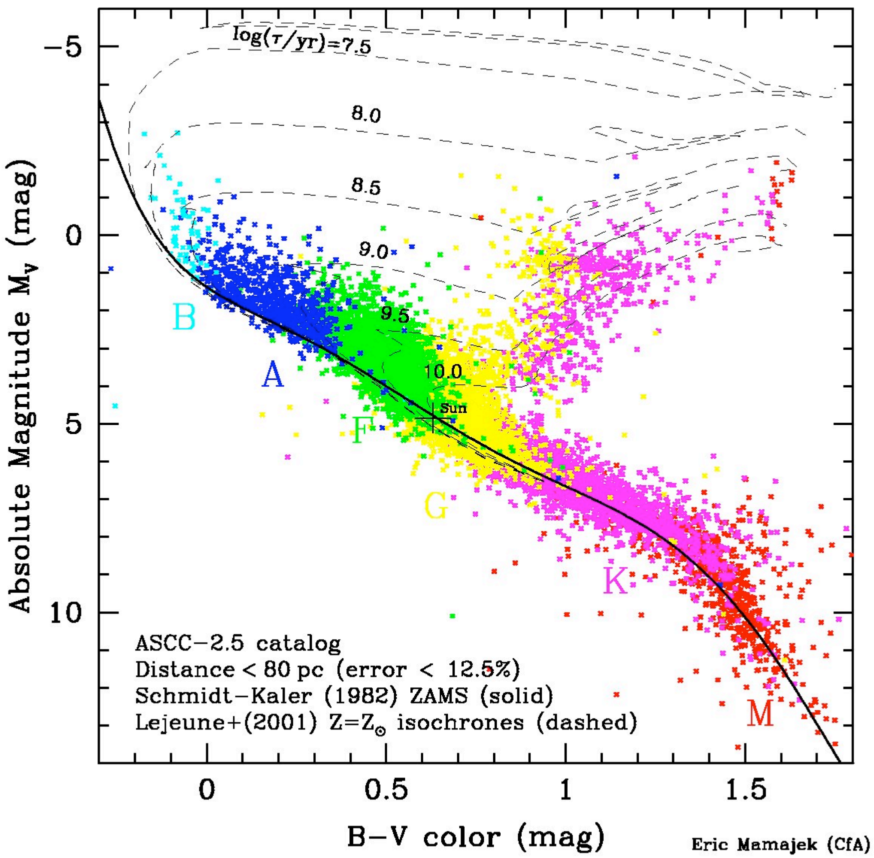
- Plot of luminosity versus temperature
- Most stars lie along a line (*Main Sequence)*



Main sequence stars burn hydrogen to helium in their cores

Hertzsprung-Russell (HR) diagram

- Also, plot of absolute magnitude vs. color
- Most stars lie along a line (*Main Sequence)*



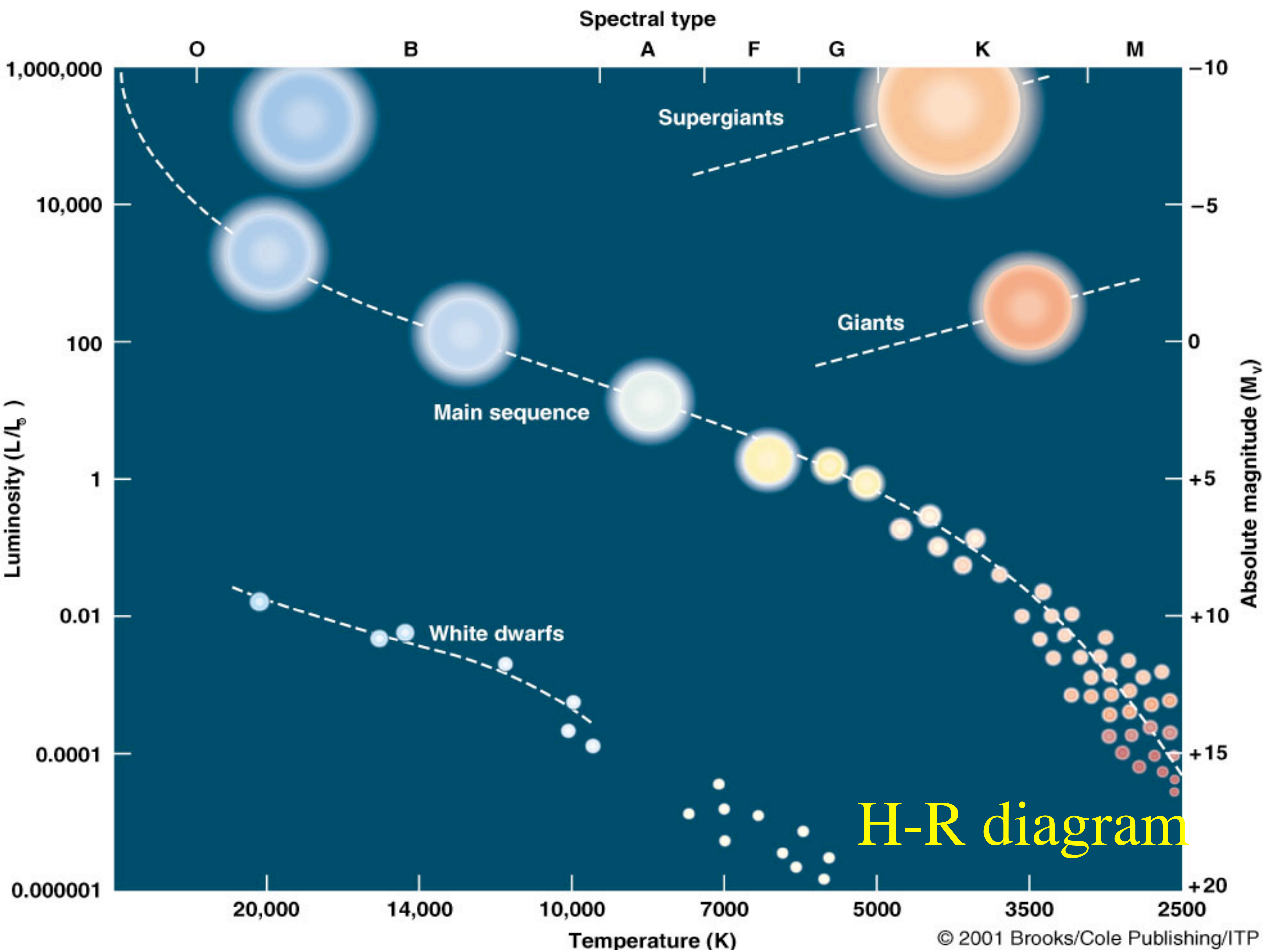
Main
sequence stars
burn hydrogen
to helium
in their cores

Hertzsprung-Russell (HR) diagram

- Plot of luminosity versus temperature
- Most stars lie along a line (*Main Sequence)*
- Stars off the main sequence must have different sizes

$$\frac{L}{L_{sun}} = \left(\frac{R}{R_{sun}}\right)^2 \left(\frac{T}{T_{sun}}\right)^4$$

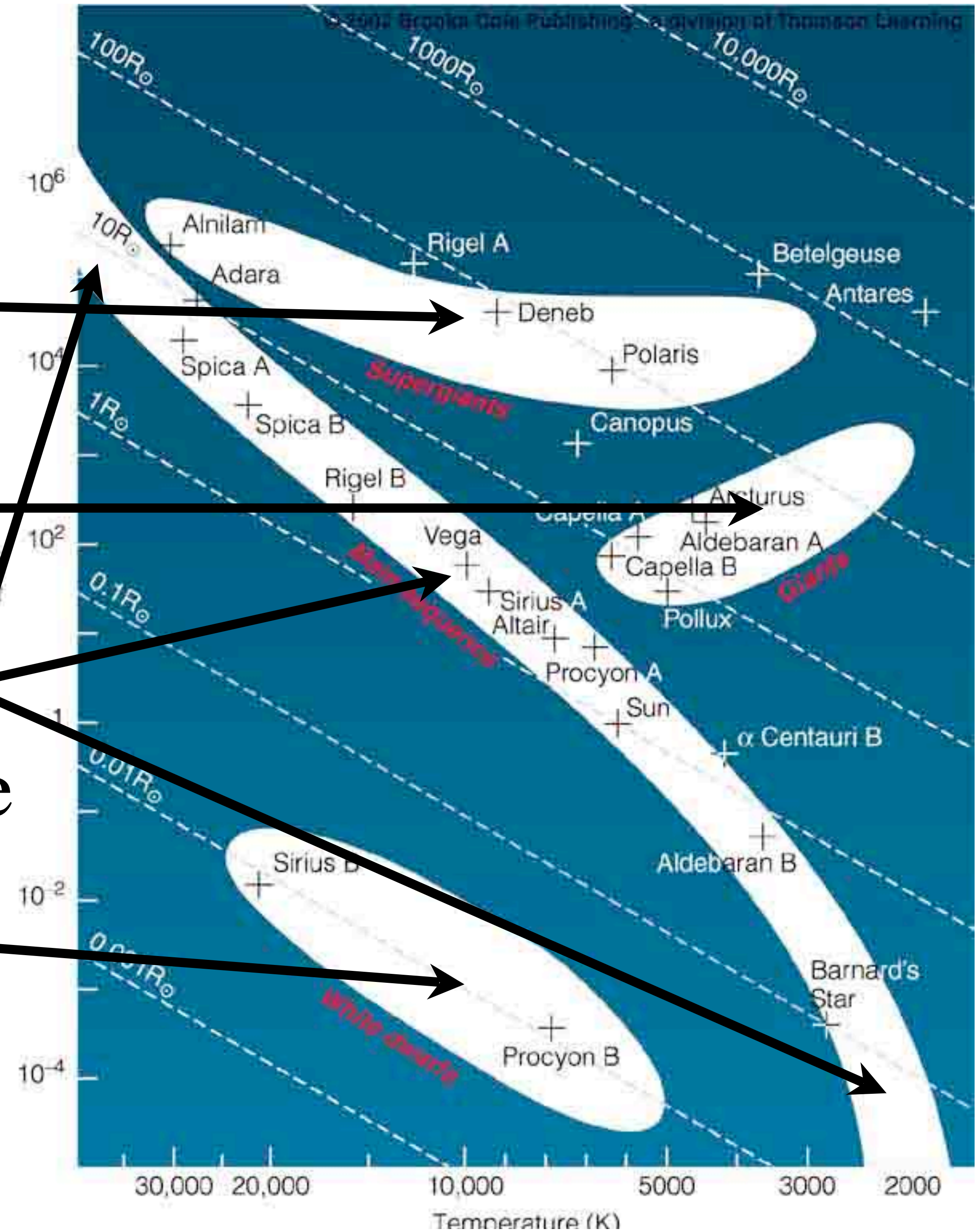
$$R \propto (L/T^4)^{1/2}$$



Spectral type
O
B
A
F
G
K
M
1,000,000
10,000
100
1
0.01
0.0001
0.000001
Luminosity (L/L☉)
−10
−5
0
+5
+10
+15
+20
Absolute magnitude (M_v)
Supergiants
Giants
Main sequence
White dwarfs
20,000
14,000
10,000
7000
5000
3500
2500
Temperature (K)
H-R diagram

HR diagram

- Supergiants
- Giants
- Main Sequence
- White Dwarfs

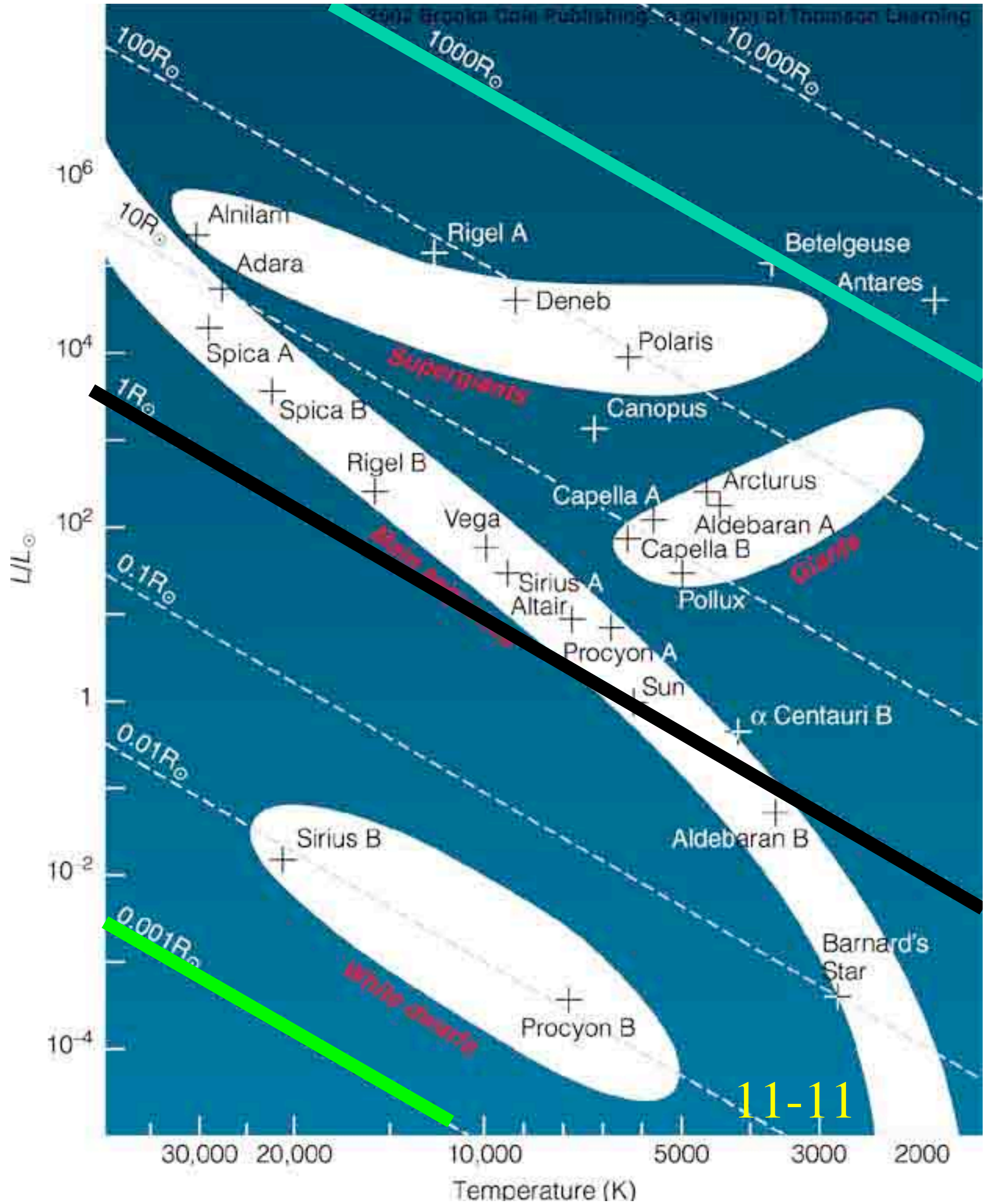


HR Diagram: Stellar Radii

- 1000 R_{sun}

- 1 R_{sun}
  = radius of Sun

- 0.001 R_{sun}

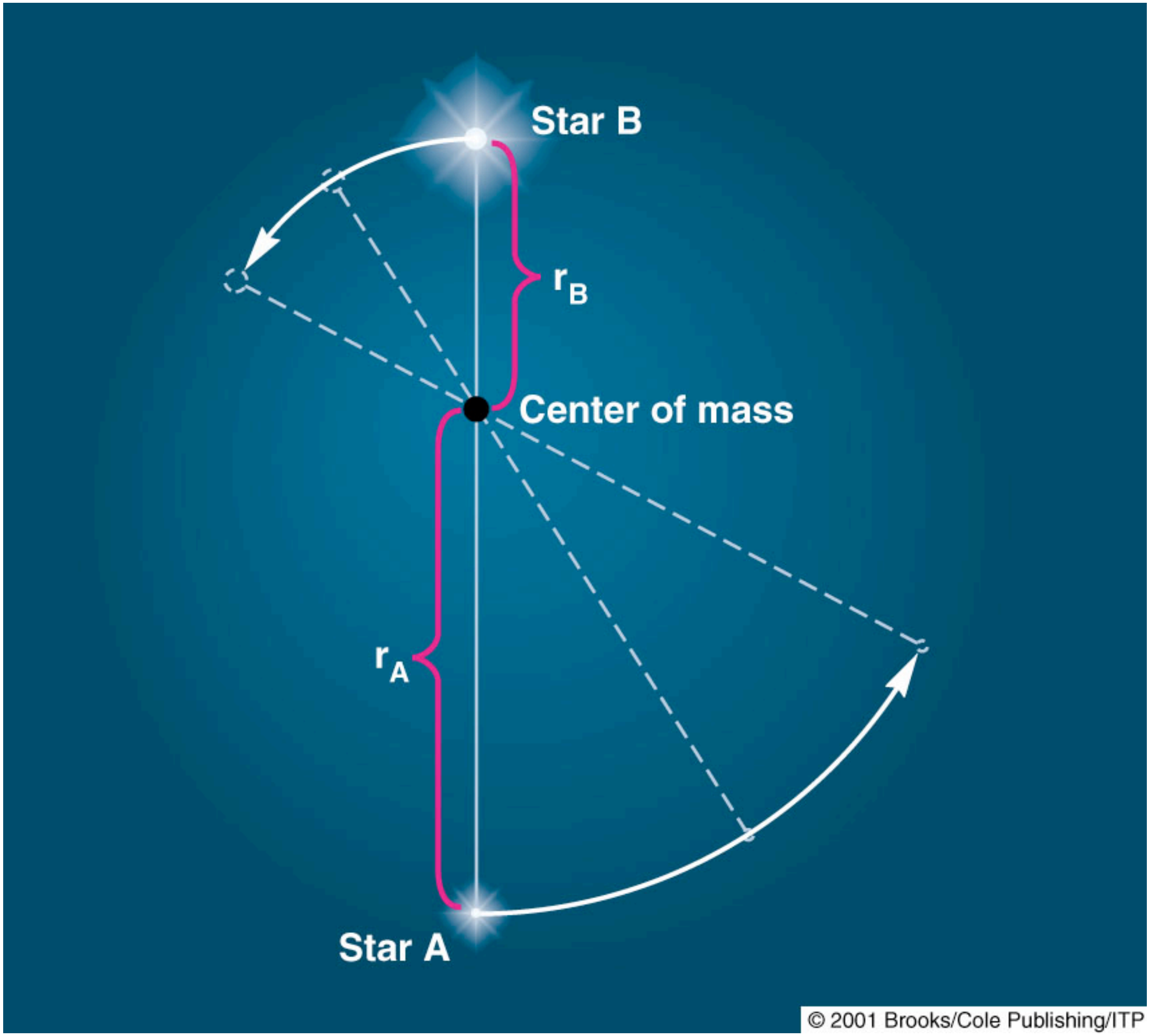


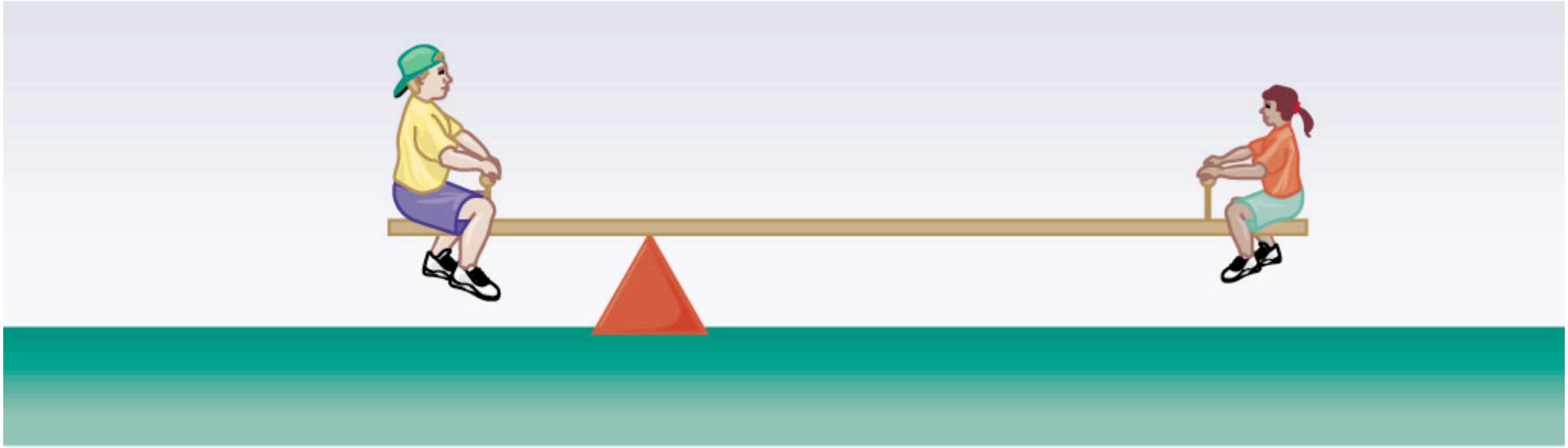
Determining Masses of Stars

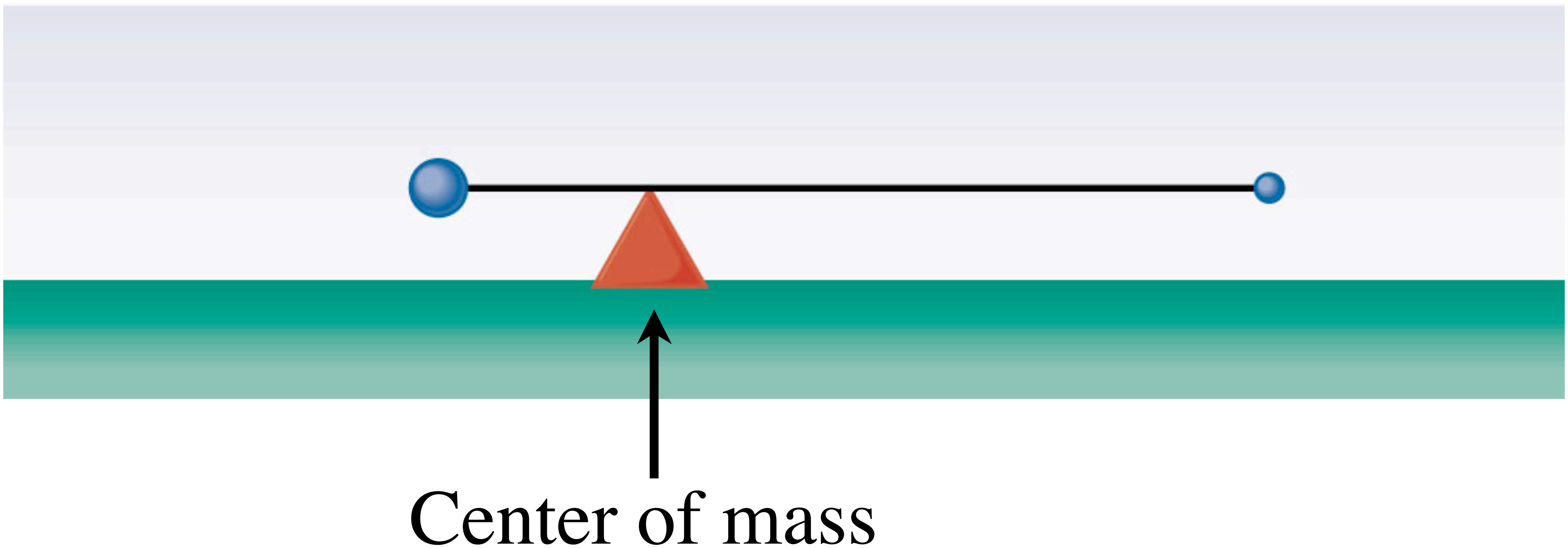
- Observe binary stars; stars that orbit one another
  - Measure:
    - Orbital Period
    - Semi-major axis
  - Apply Kepler's Third Law to get sum of masses $M_1 + M_2 = (4\pi^2 a^3)/(GP^2)$

  (need to know distance to convert separation in angle on sky into length *a*)
  - If both stars visible, and can measure semi-major axis of each orbit, can get individual masses

Recall: Two stars orbit common *center of mass*






Center of mass

Types of binaries

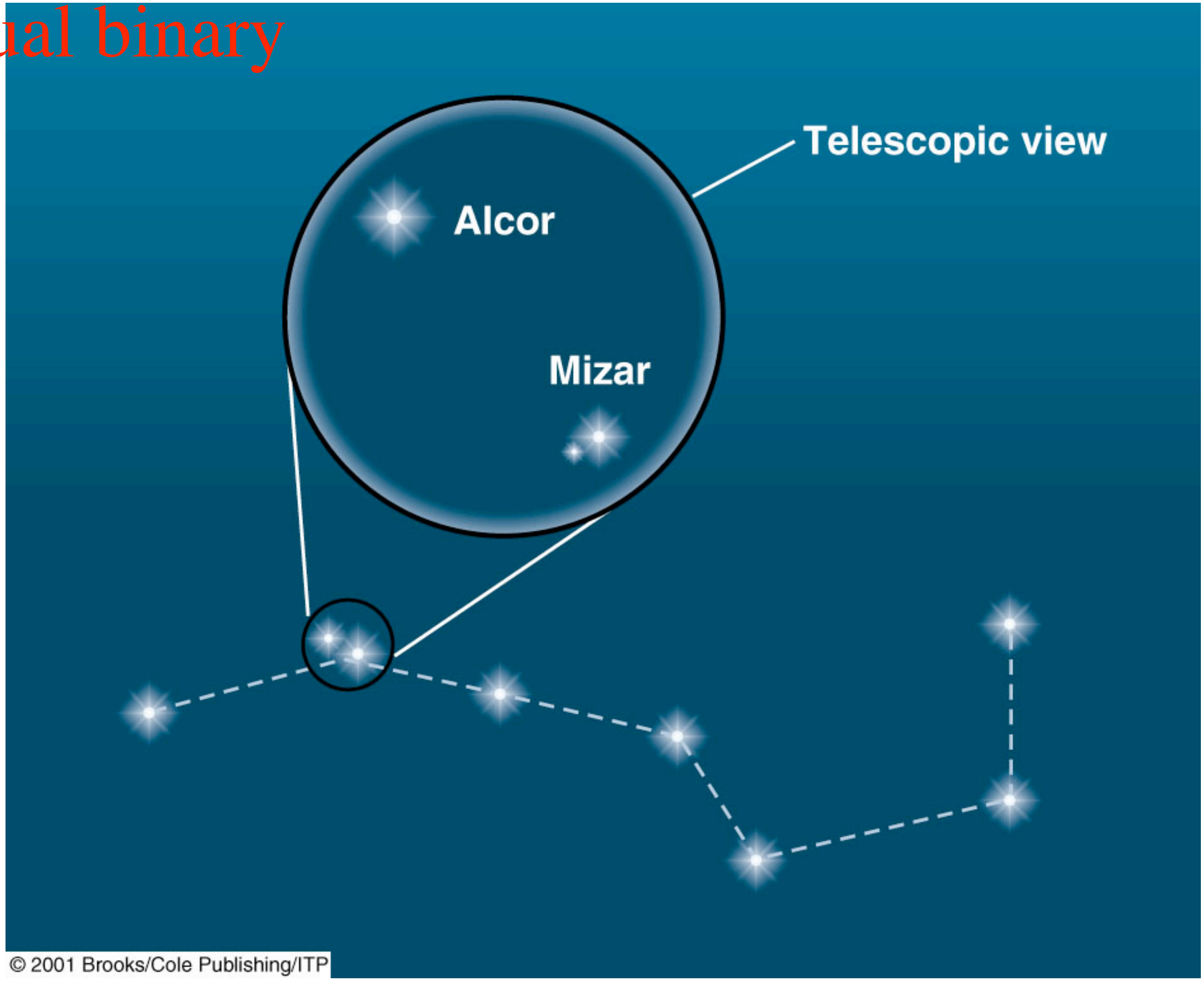
- Visual binary - both stars can be seen to orbit one another (as opposed to optical double)

- Astrometric binary - only one star observed, but unseen component inferred from astrometric wobble of observed star

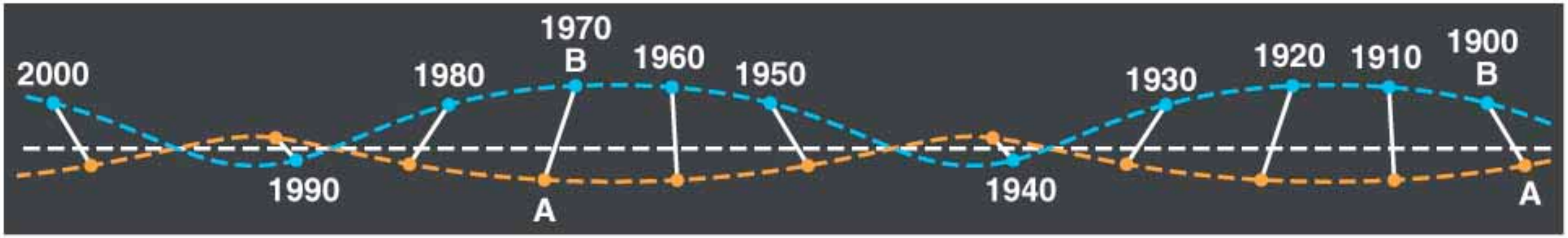
- Spectroscopic binary - two stars too close to resolve separately, but one or two sets of spectal lines seen, Doppler shifted

- Eclipsing binary - two stars eclipse each other

Middle star in handle of Big Dipper is a visual binary



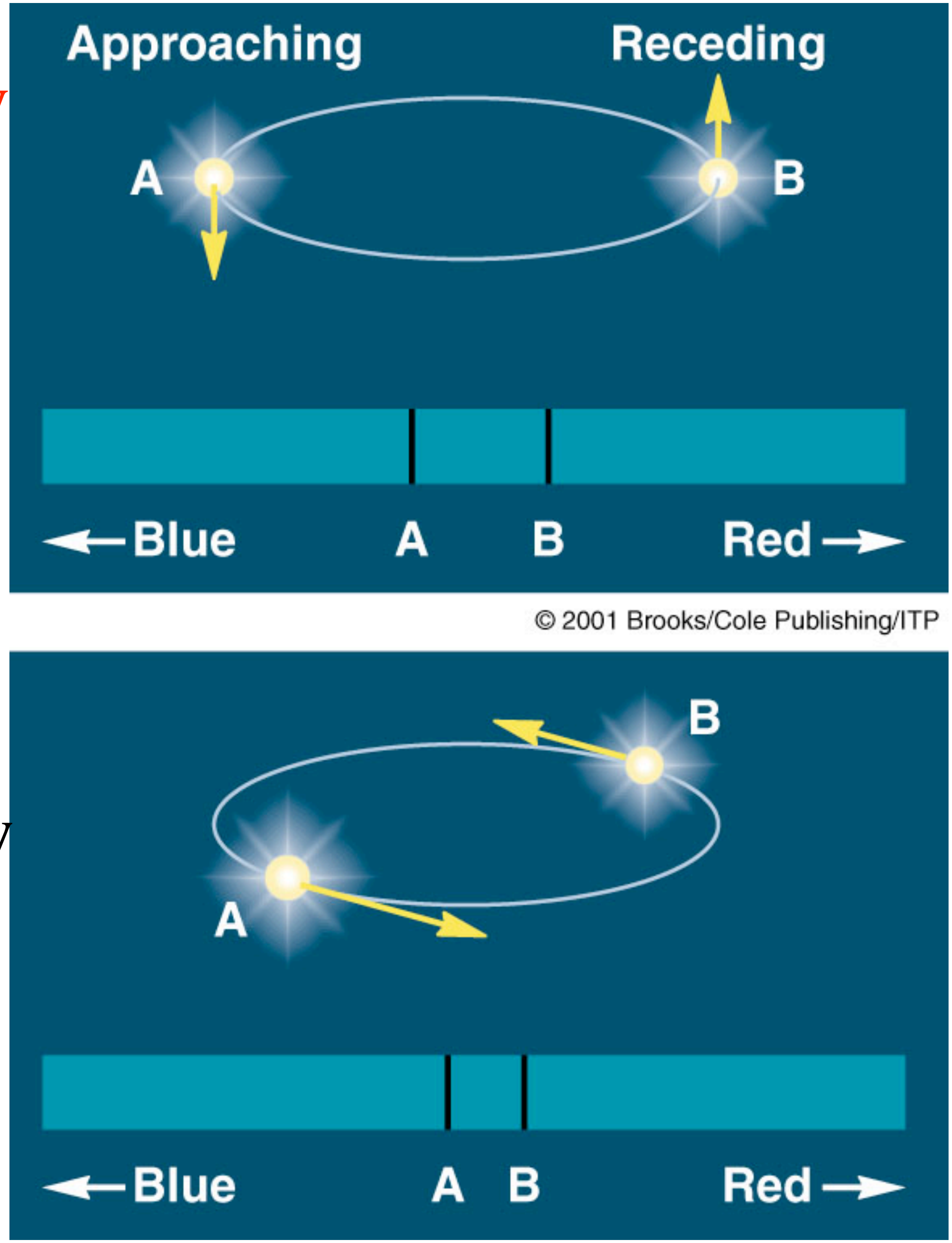
Astrometric binary



Variation of position of Sirius A, relative to background stars, shows proper motion (CM velocity) and orbital motion due to companion, Sirius B

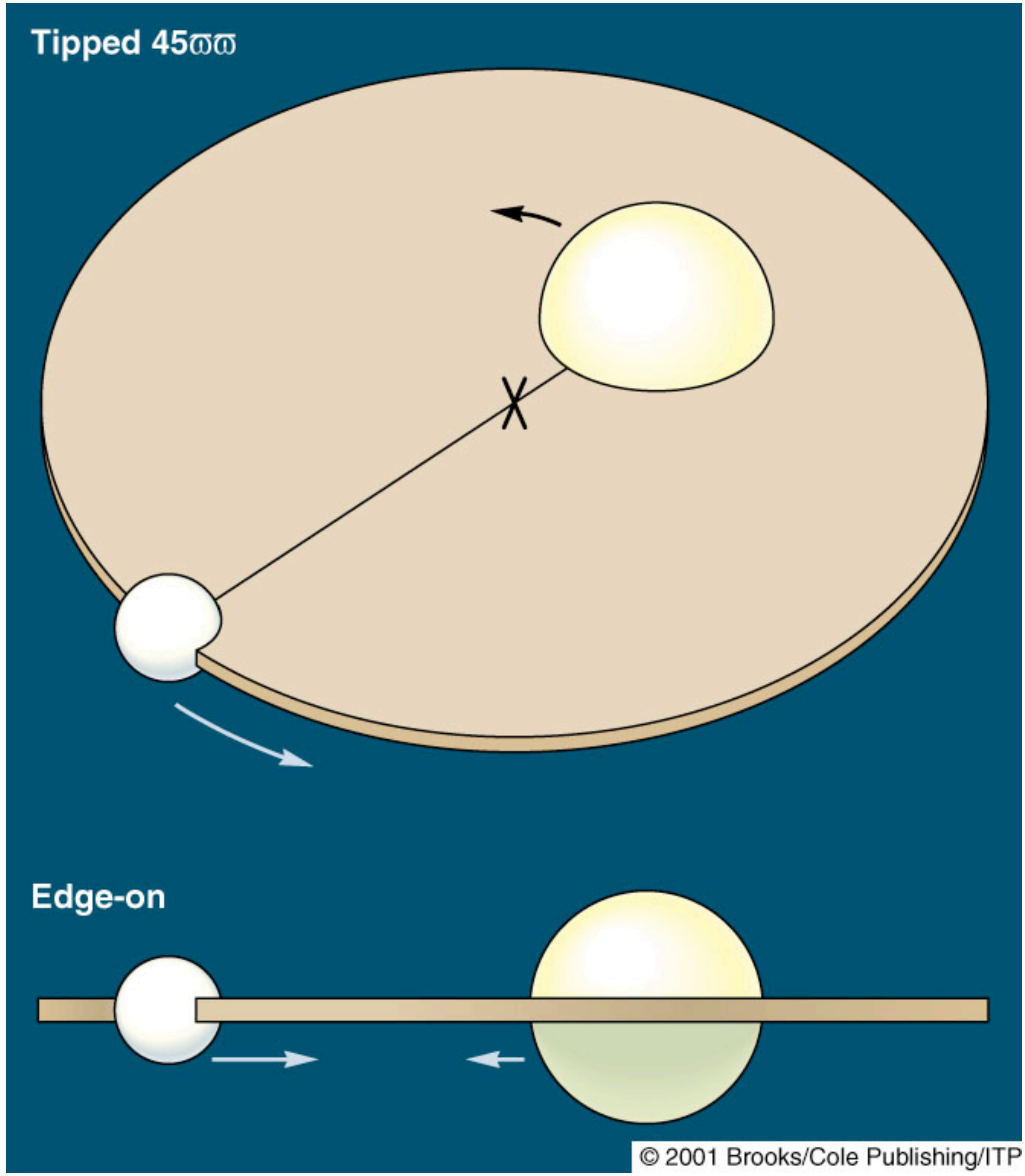
Spectroscopic binary detected by periodic Doppler shifts in spectral lines

(to get full information about masses need to know inclination, *i*)

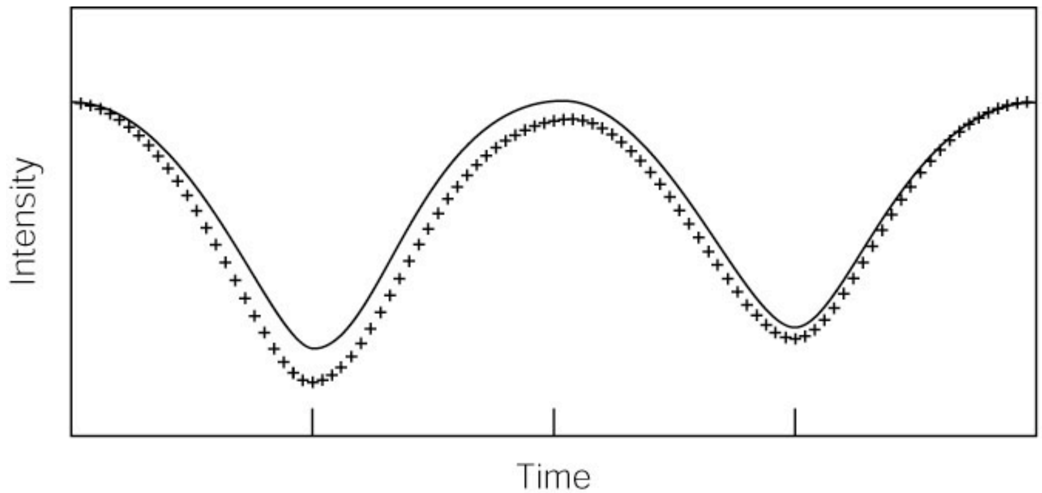


Eclipsing binary

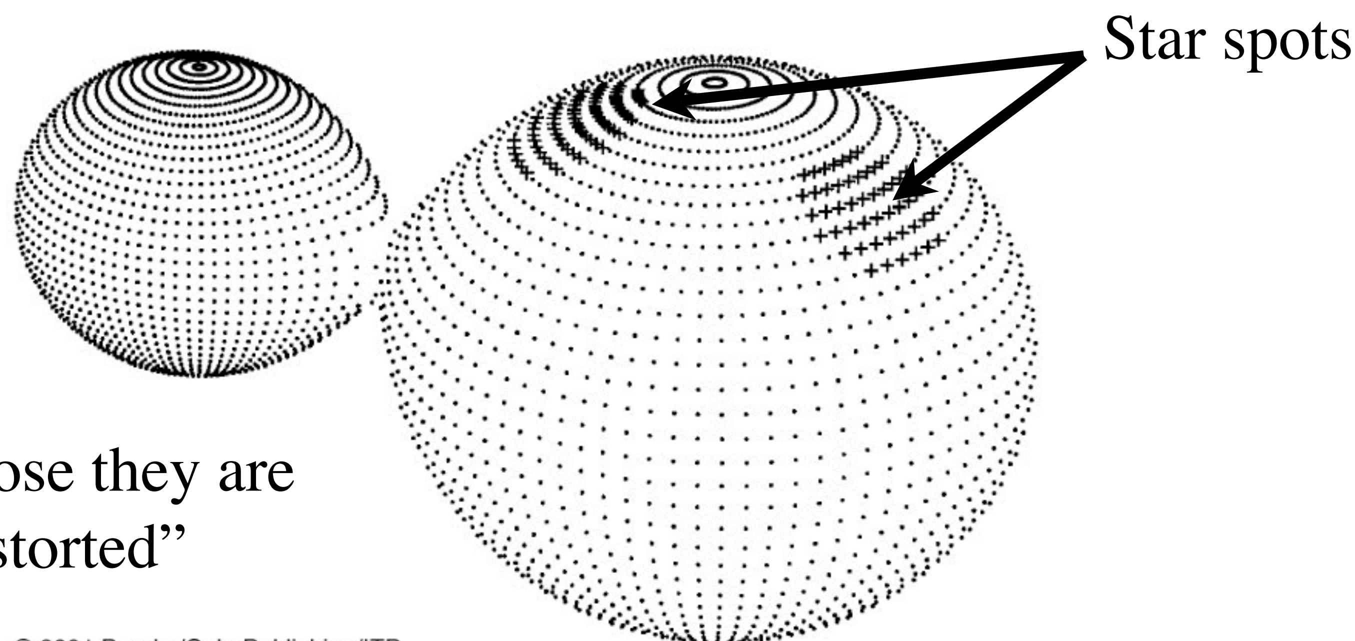
two stars periodically eclipse each other



Details of light curves can be used to infer shapes of stars, presence of star spots

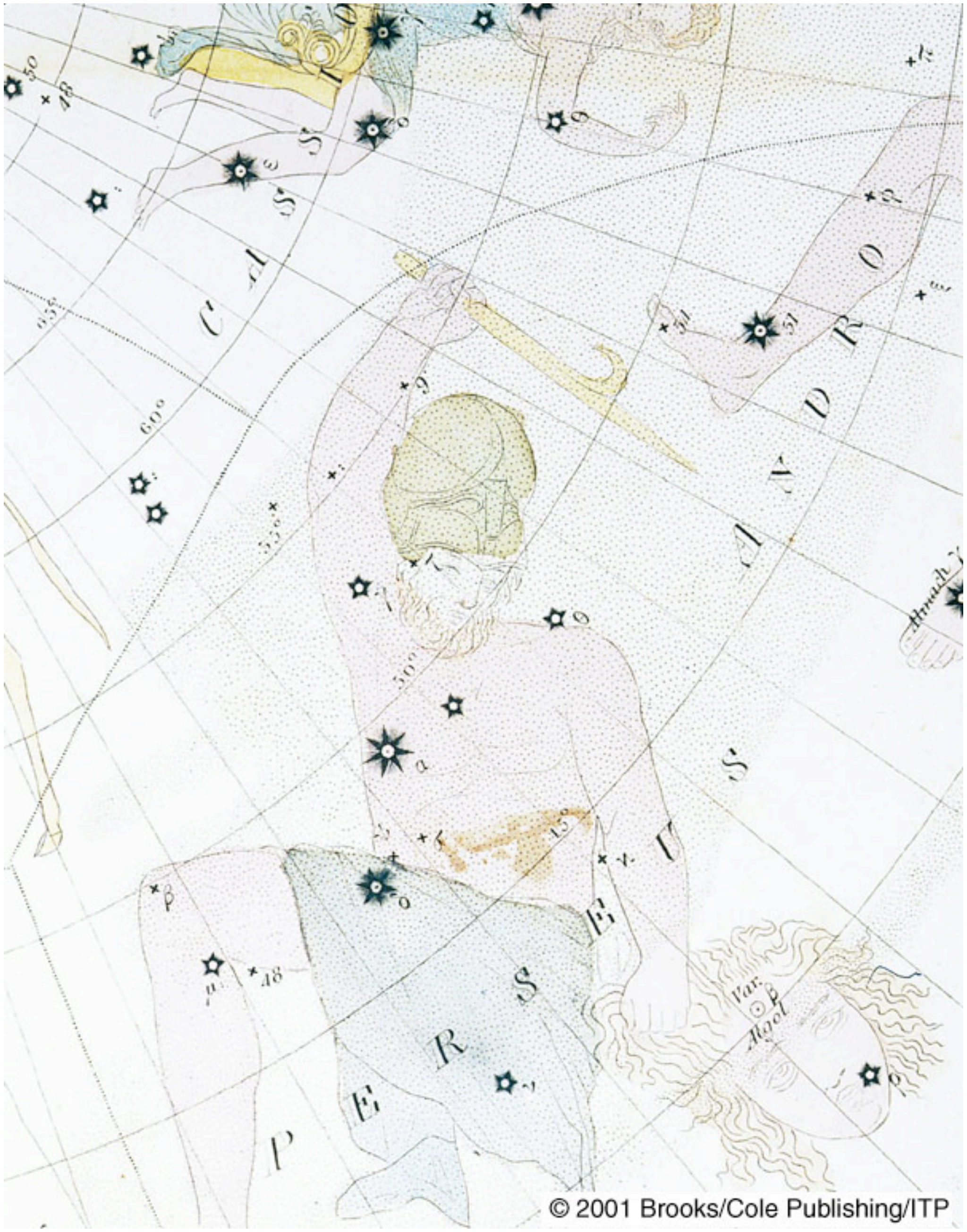


Binary star
VW Cephei

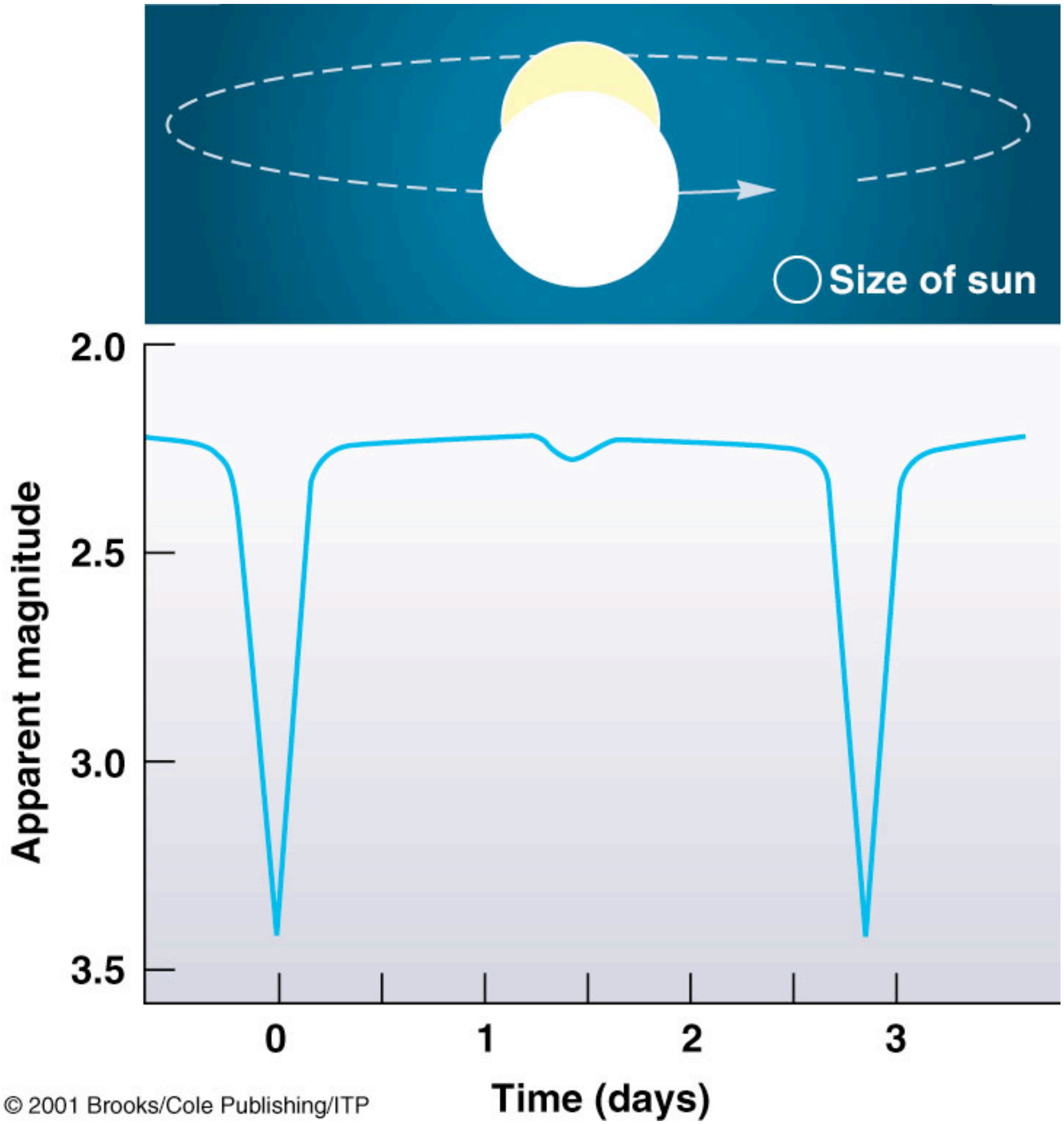


Stars so close they are
"tidally distorted"

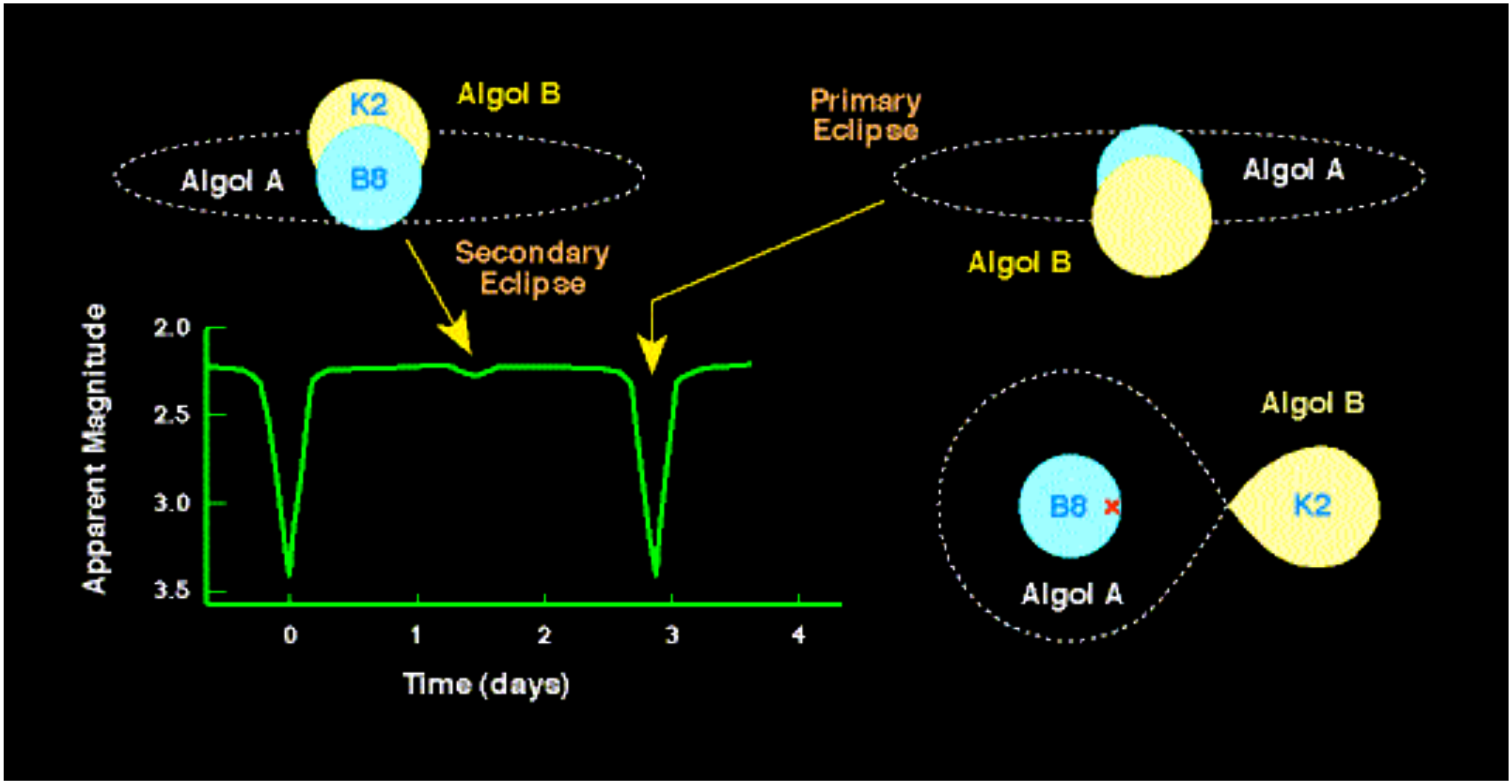
Algol: the demon star



Algol is just an eclipsing binary



Algol: the demon star



•See most light when both stars are visible; primary minimum when cooler star is in front; secondary minimum when hotter star is in front

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Stellar radii

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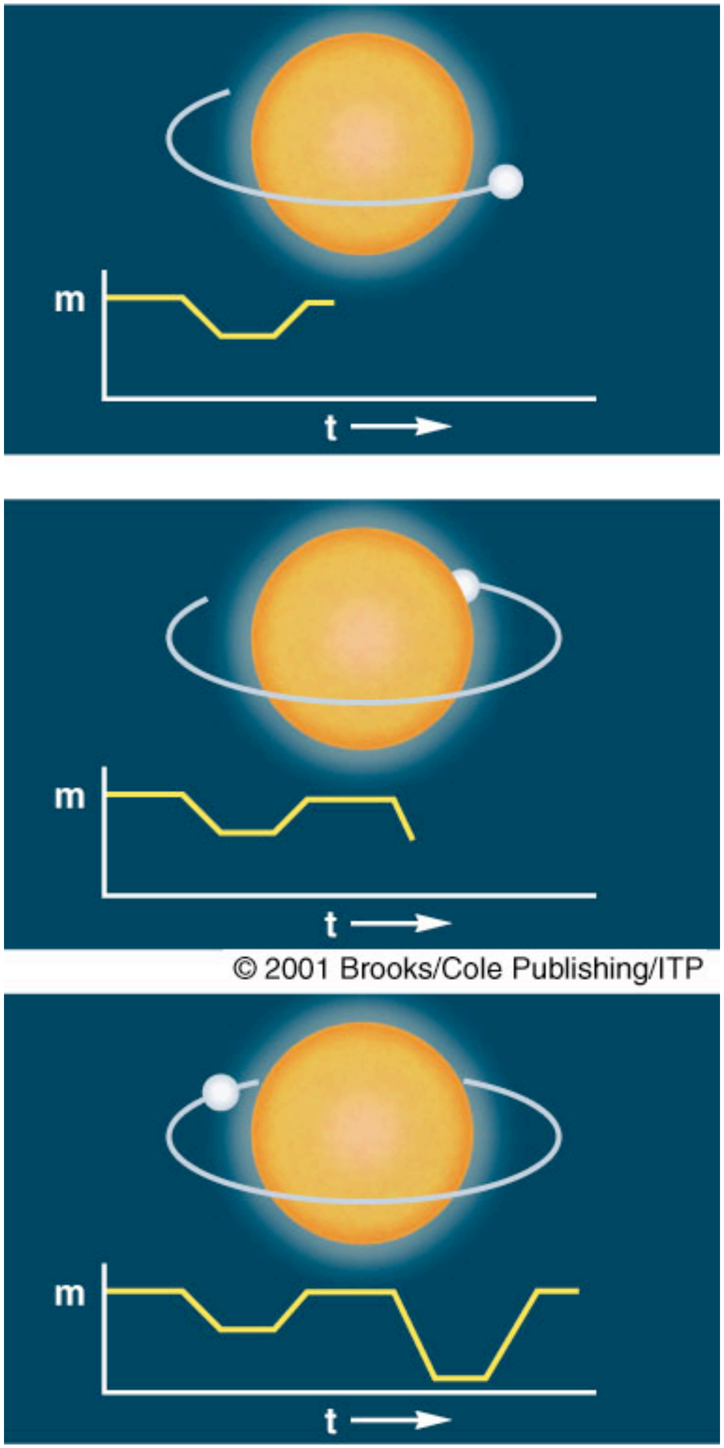

Eclipsing Binaries: Length of eclipses can also be used to measure radii of stars

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