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?

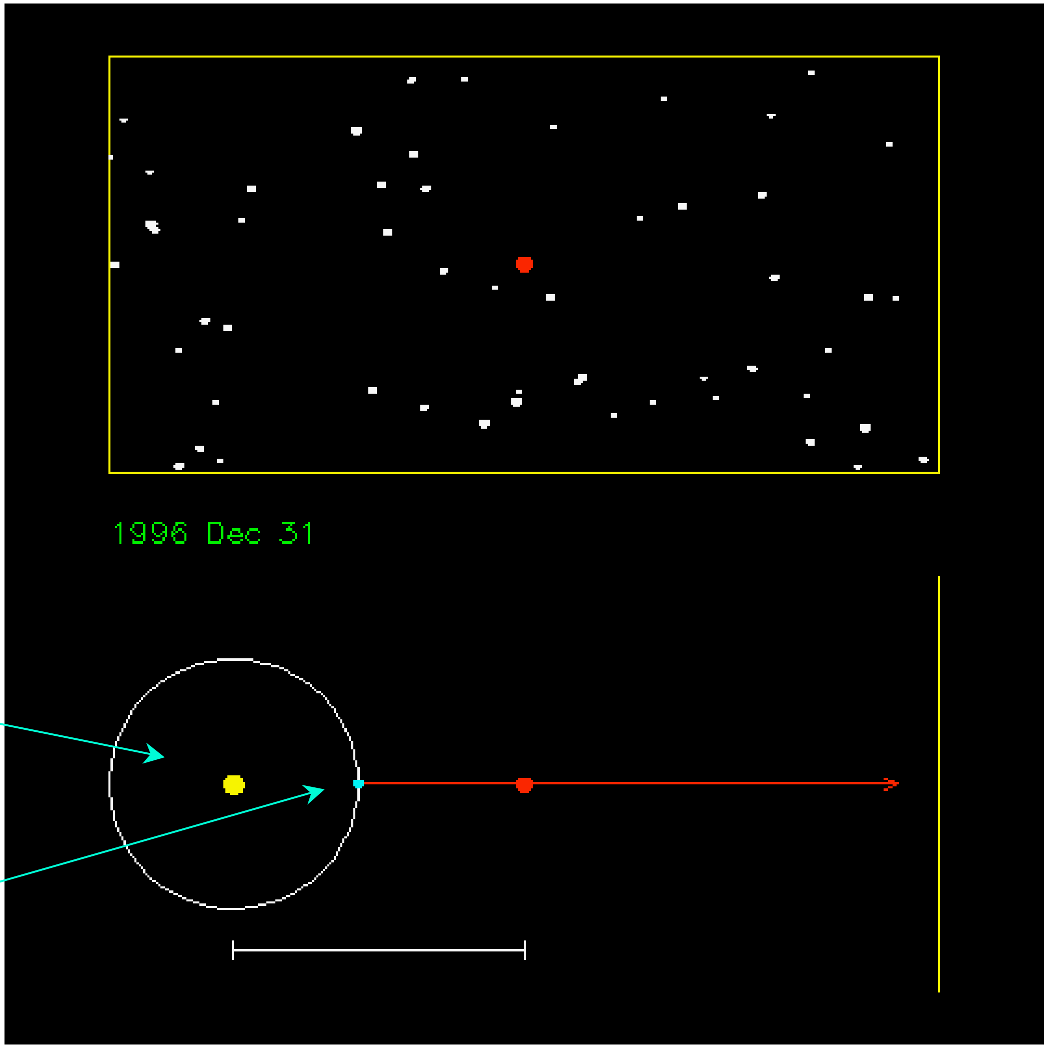
Parallax

Red star:
nearby

White stars:
far away

Sun

Earth

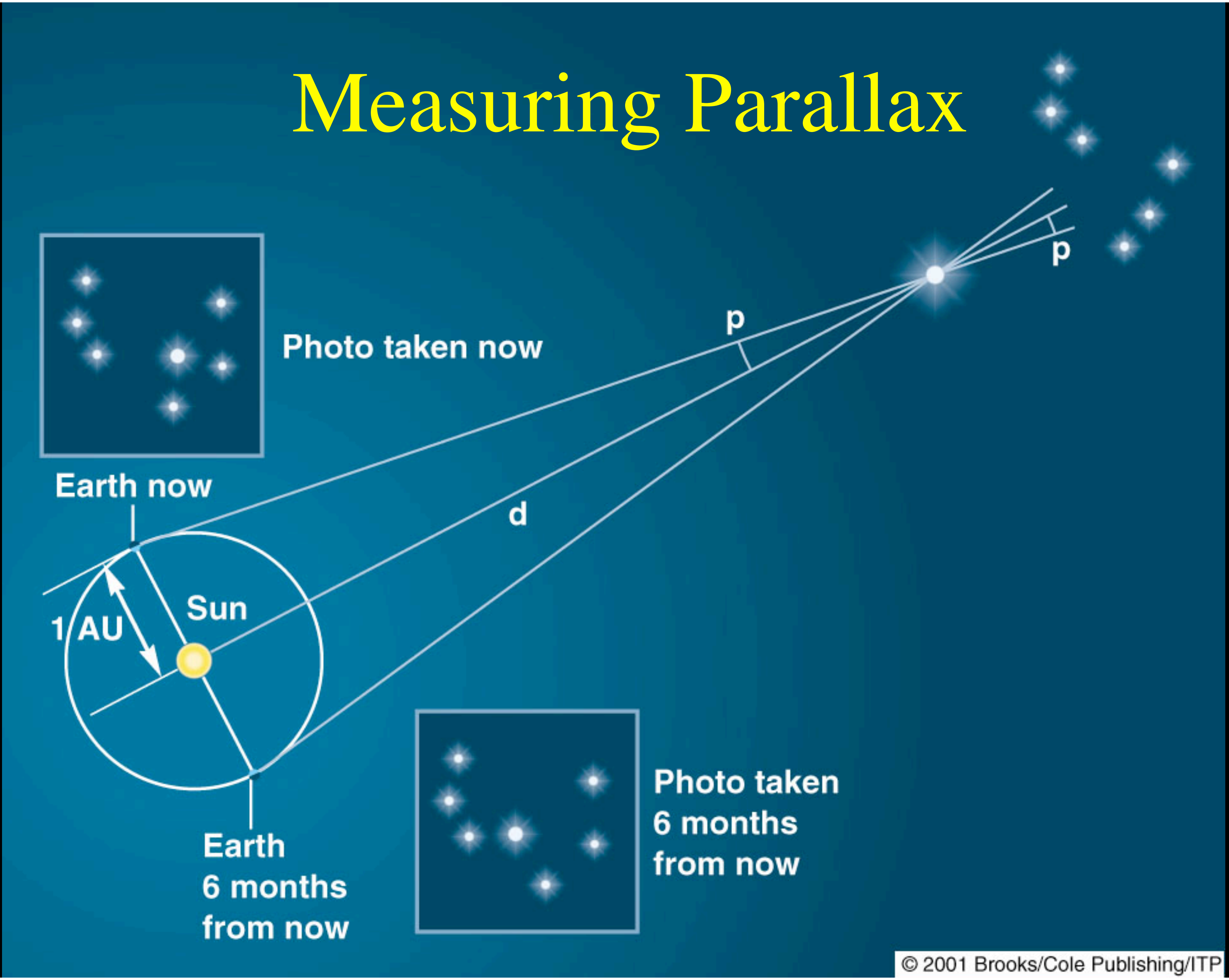


View
from
Earth

View
from
above
solar
system

Parallax of stars in Orion

Measuring Parallax



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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.

What would we like to know?

- Distance
- Luminosity
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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…
  - 5th mag star is about 2.512 times *brighter* than 6th
  - 1st mag star is $(2.512)^5 = 100$ times *brighter* than 6th

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.

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

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

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

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

What would we like to know?

- Distance
- Luminosity
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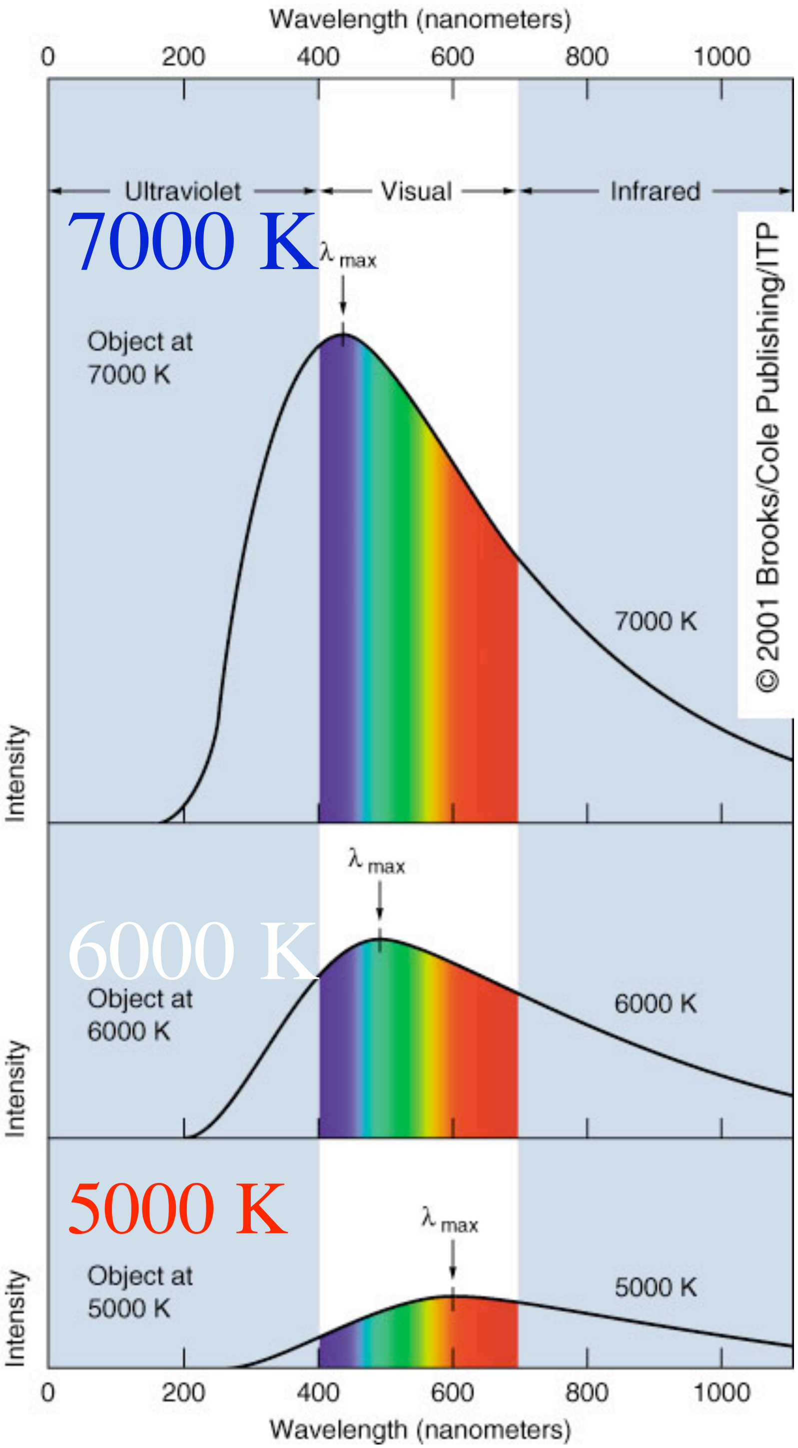
Temperature of a Star

Temperature can be measured either by

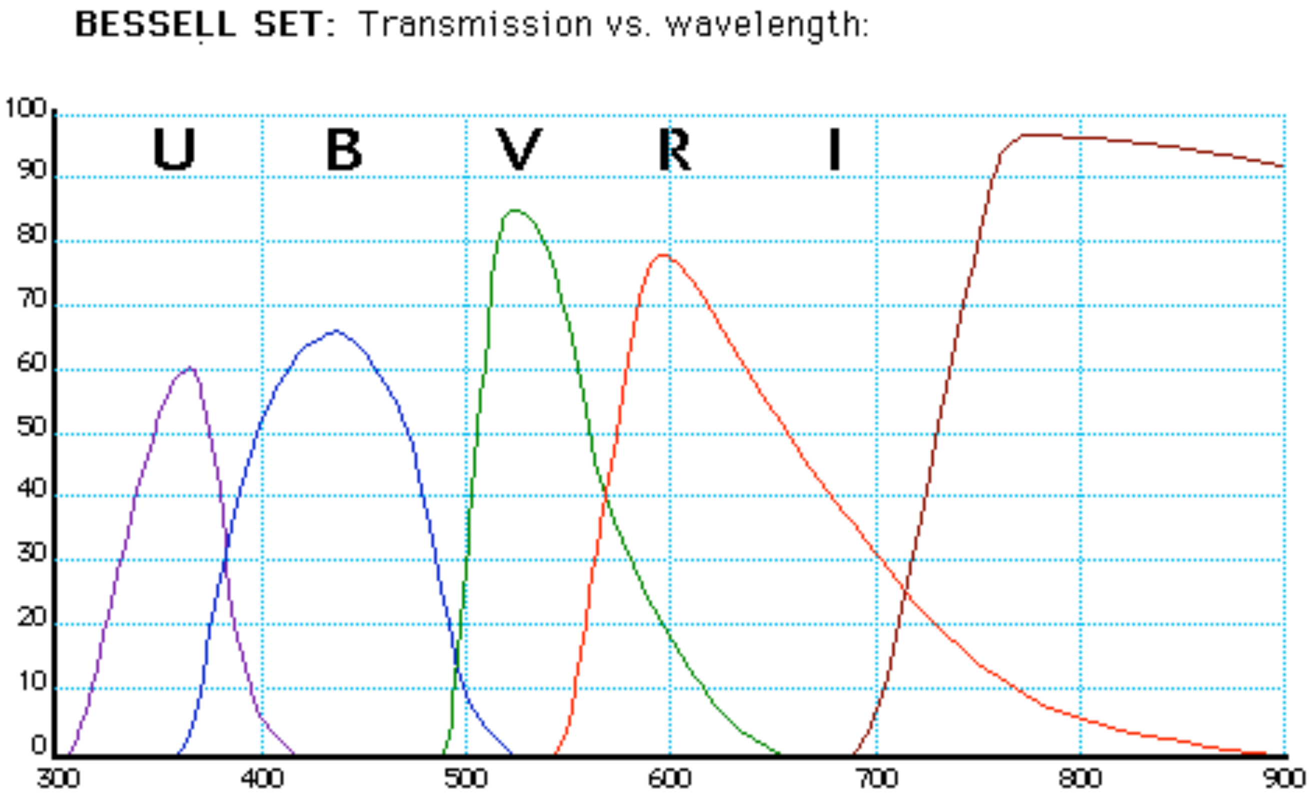
1. Color of star, using black body law:
    - 25,000 K: star looks blue
    - 6,000 K: star looks yellow
    - 3,000 K: star looks red
2. Relative strength of absorption lines in star's spectrum



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:

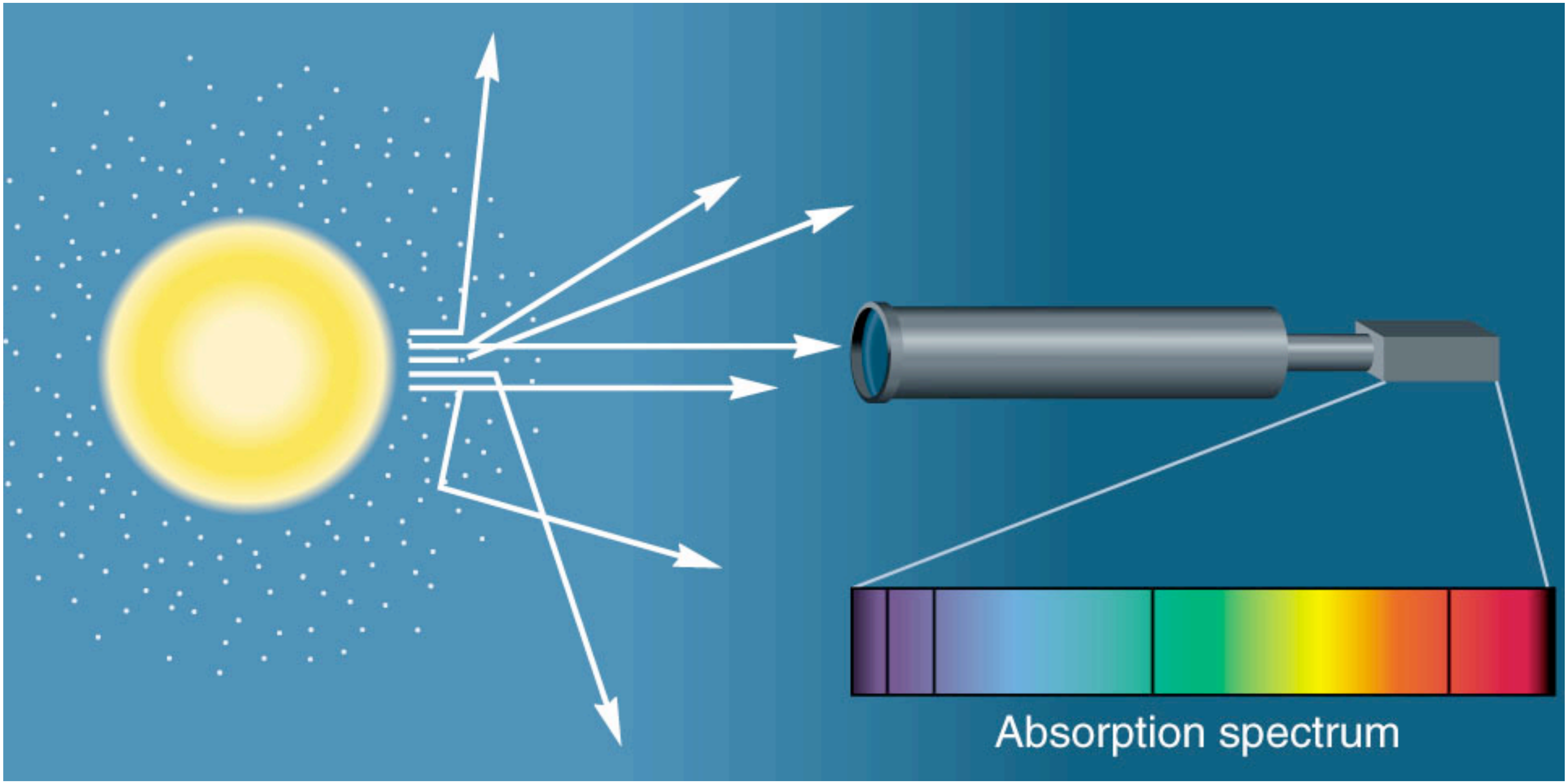


- Wavelength in nm.

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



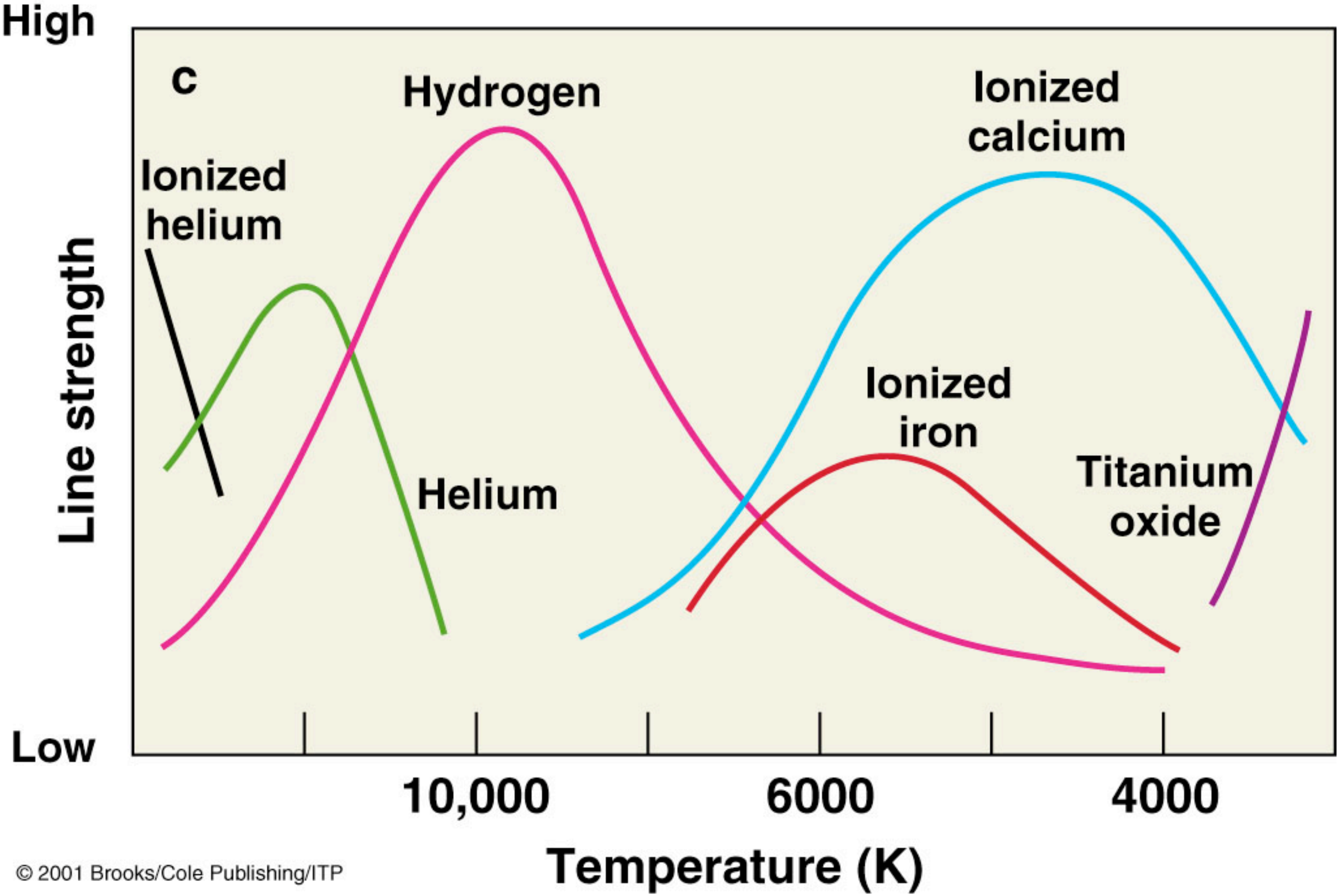
Stellar Absorption Lines

- 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



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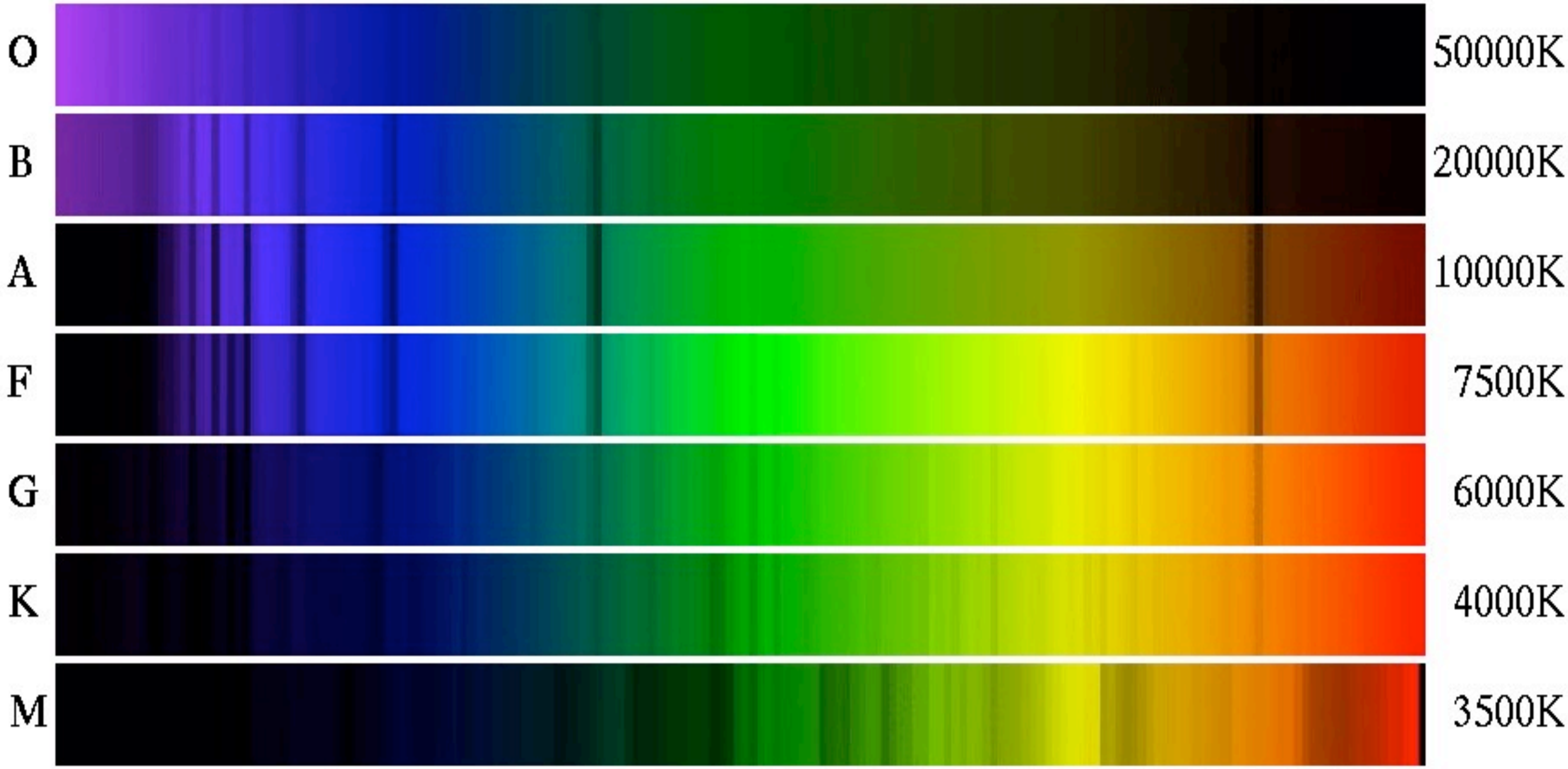
Spectral types

- 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, …

Spectral Type or *Color* Indicates *Temperature*



Spectral types

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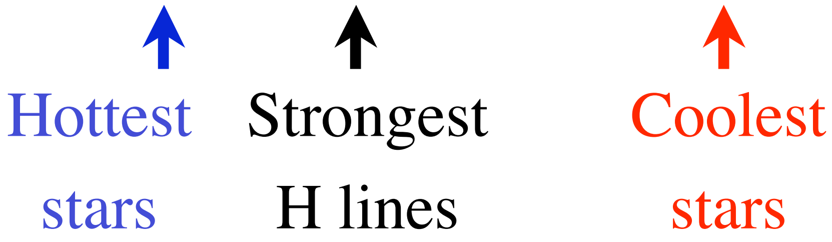

Hottest stars

Strongest H lines

Coolest stars

- The Sun's spectral type is G2

What would we like to know?

- Distance
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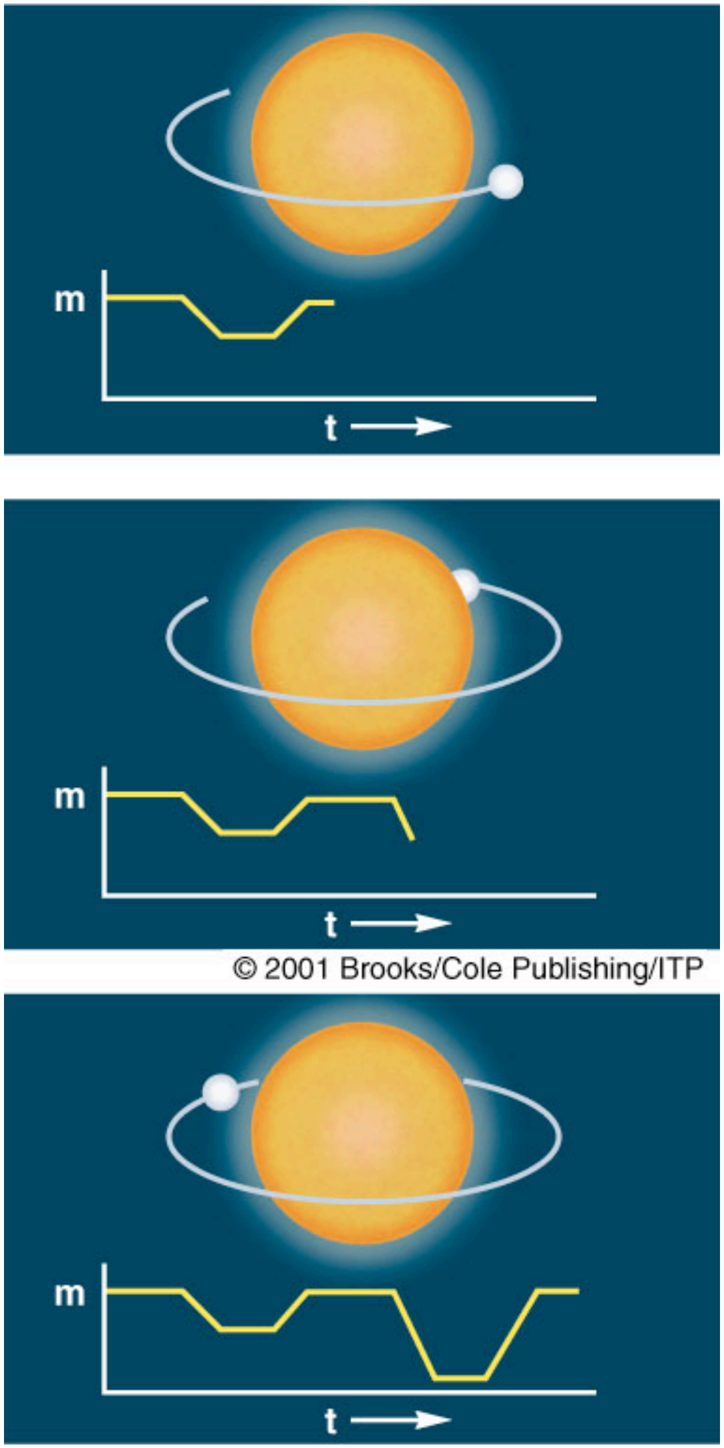
- Radius

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!



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

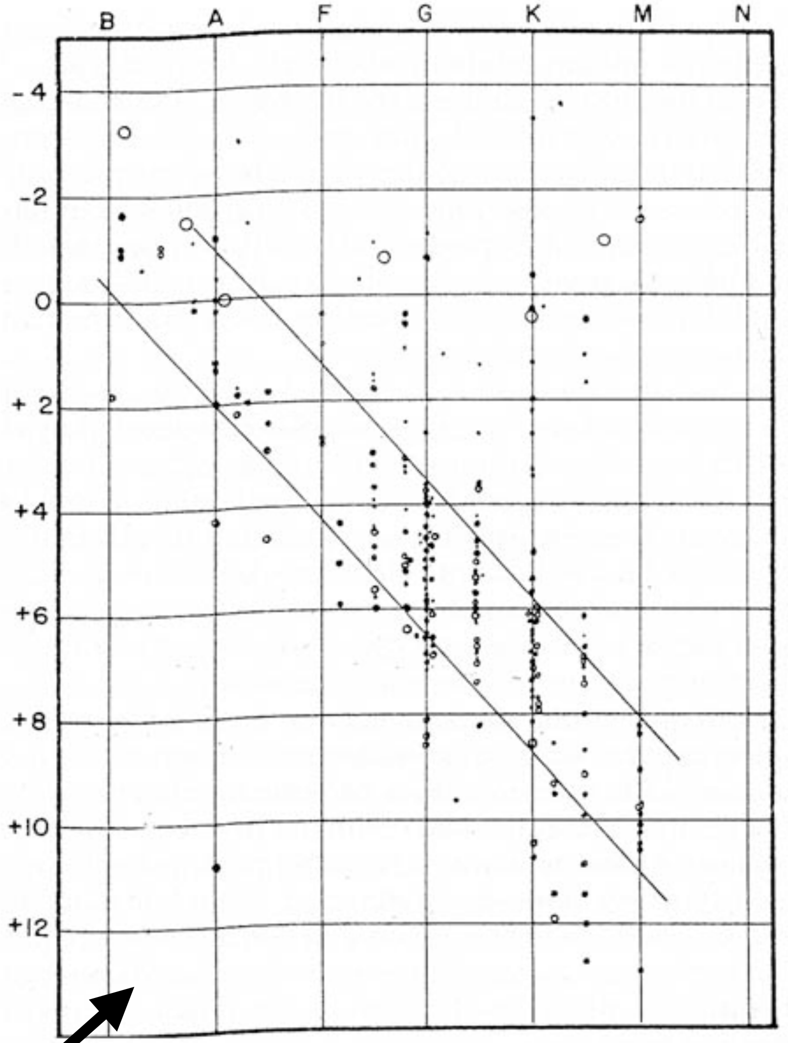
Transiting Planets!

Hertzsprung-Russell Diagram

Ejnar Hertzsprung
(1873-1967)

Scanned at the American Institute of Physics

Henry Norris Russell
(1877-1957)
published diagram

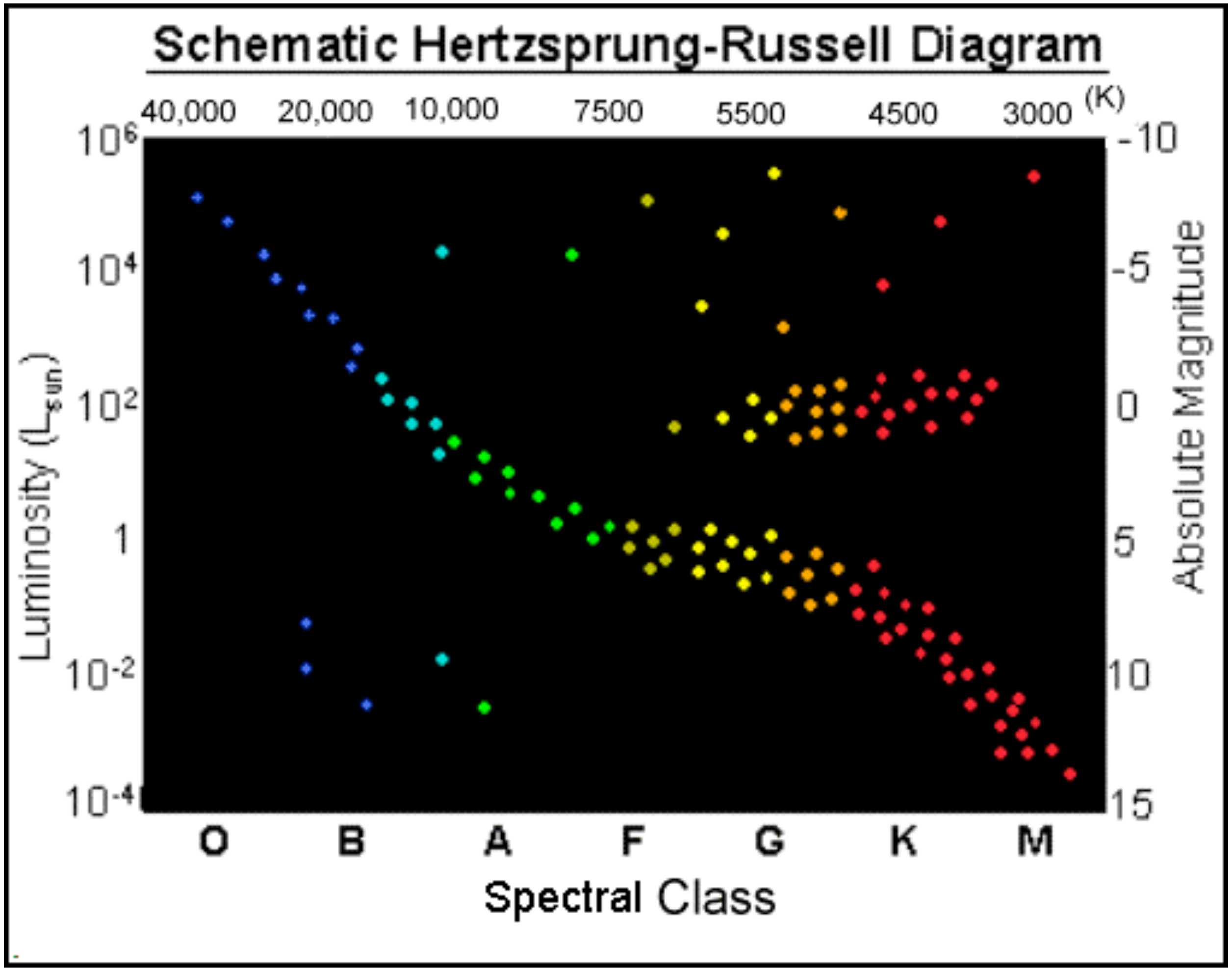


Abs Mag

Spectral Type

Hertzsprung-Russell (HR) diagram

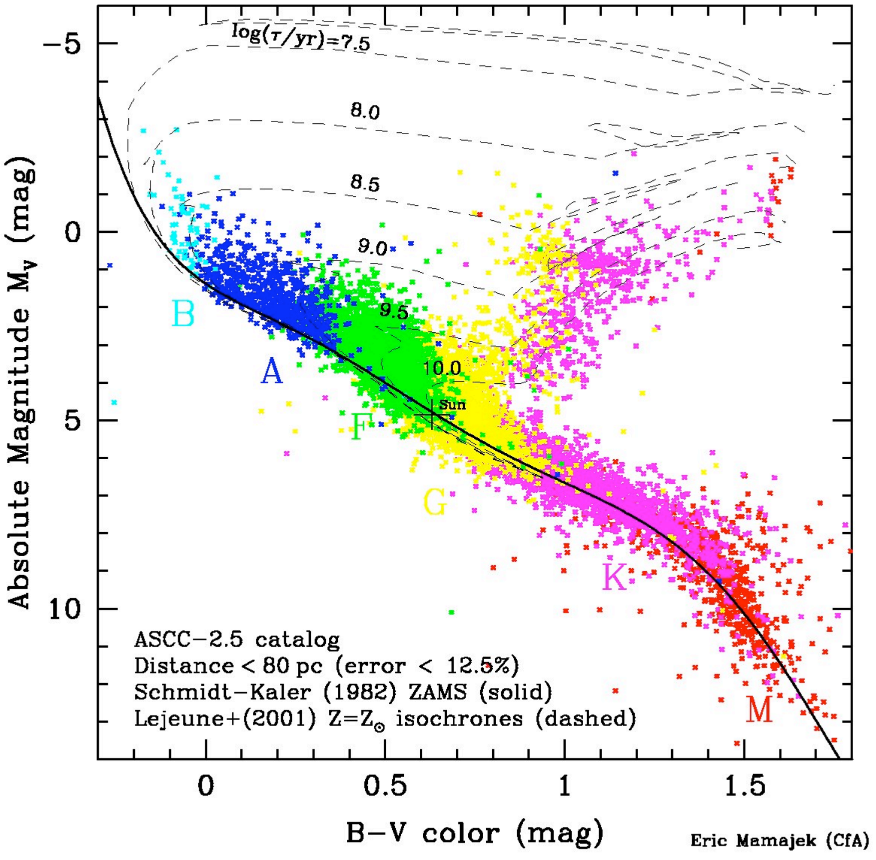
- Plot of luminosity versus temperature
- Most stars lie along a line (*Main Sequence)*



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)*



Eric Mamajek (CfA)

Main
sequence stars
burn hydrogen
to helium
in their cores

Hertzsprung-Russell (HR) diagram

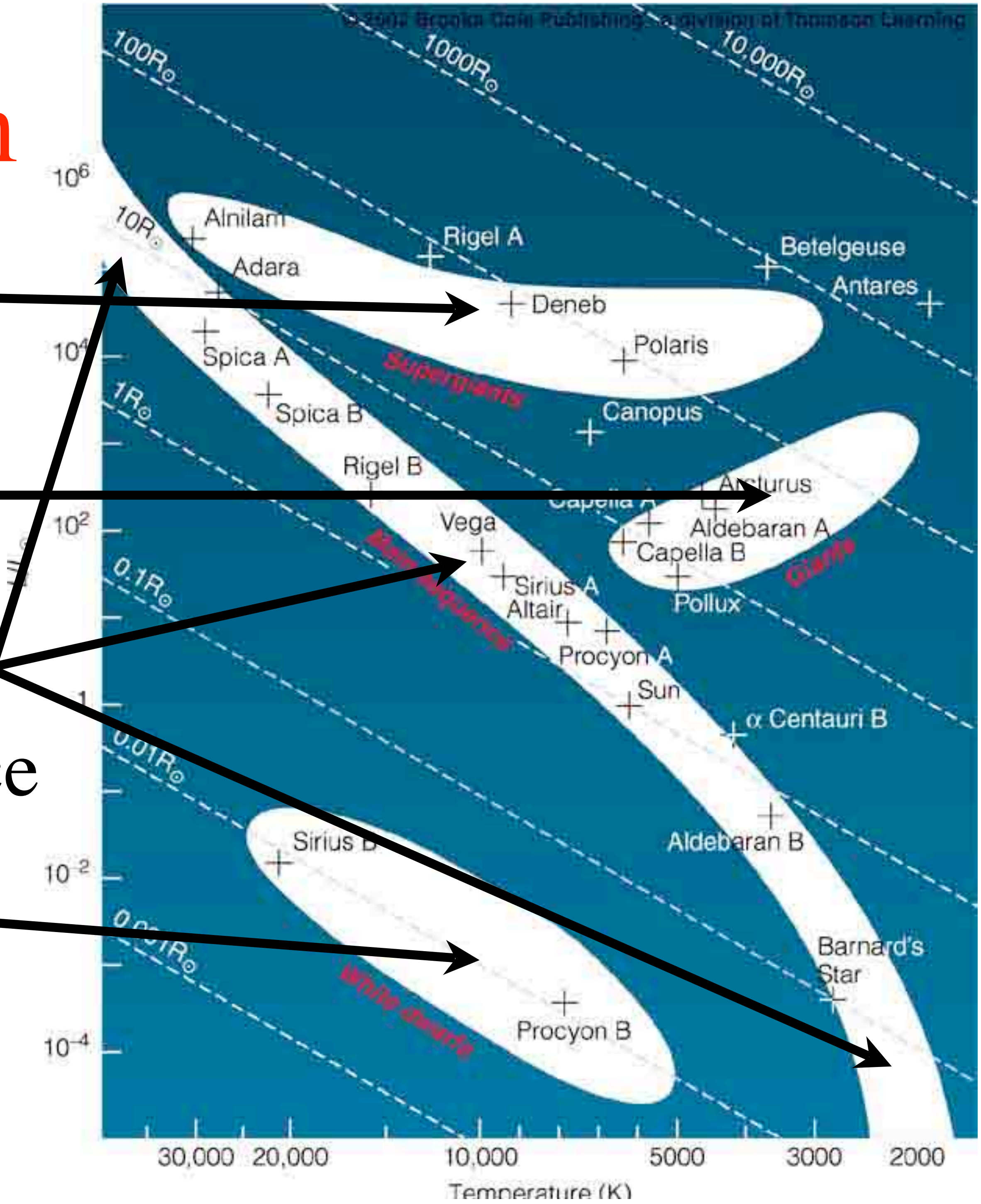
- Plot of luminosity versus temperature
- Most stars lie along a line (*Main Sequence)*
- Stars off the main sequence must have different sizes

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

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

HR diagram

- Supergiants
- Giants
- Main Sequence
- White Dwarfs

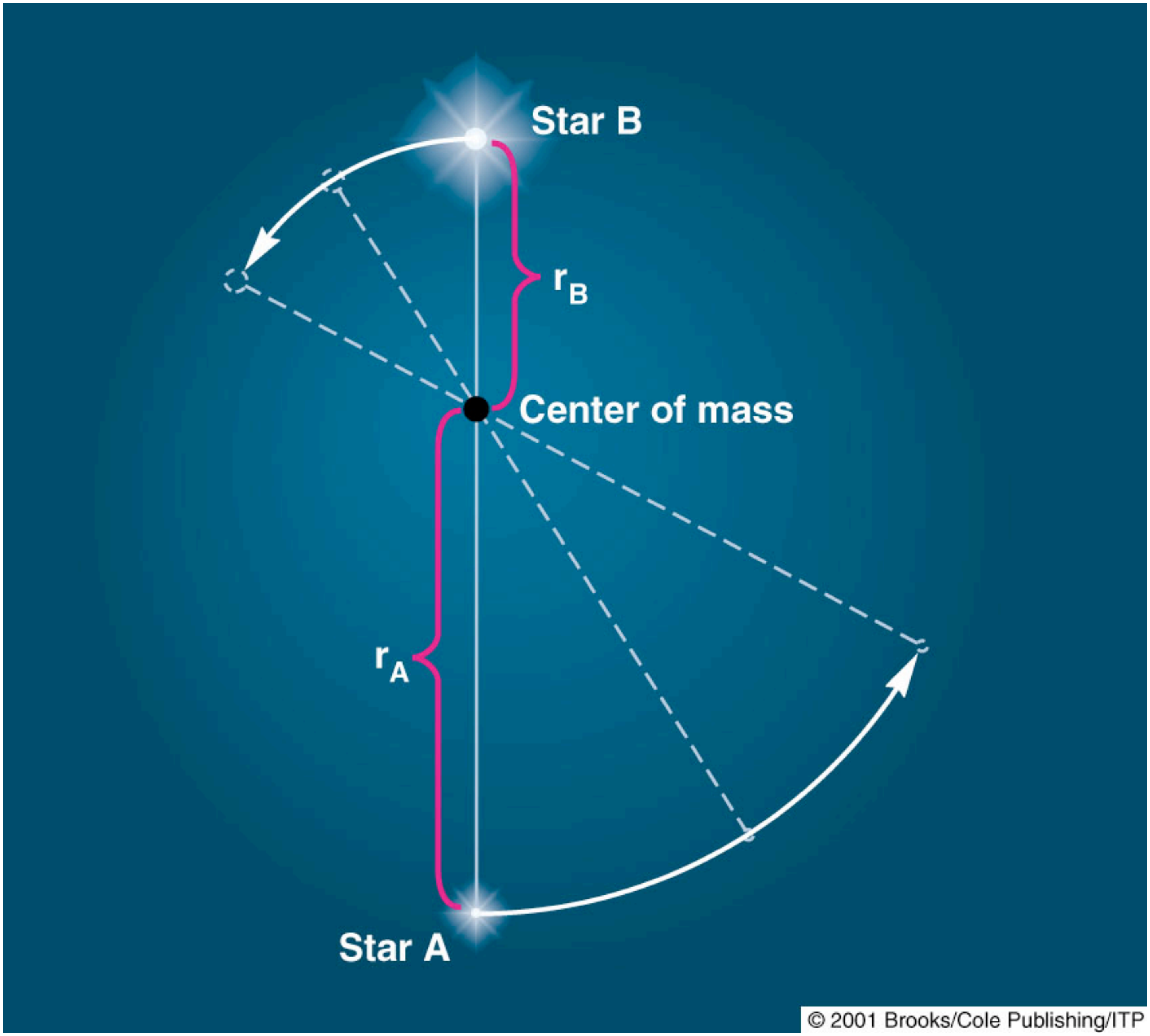


Determining Masses of Stars

- 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*



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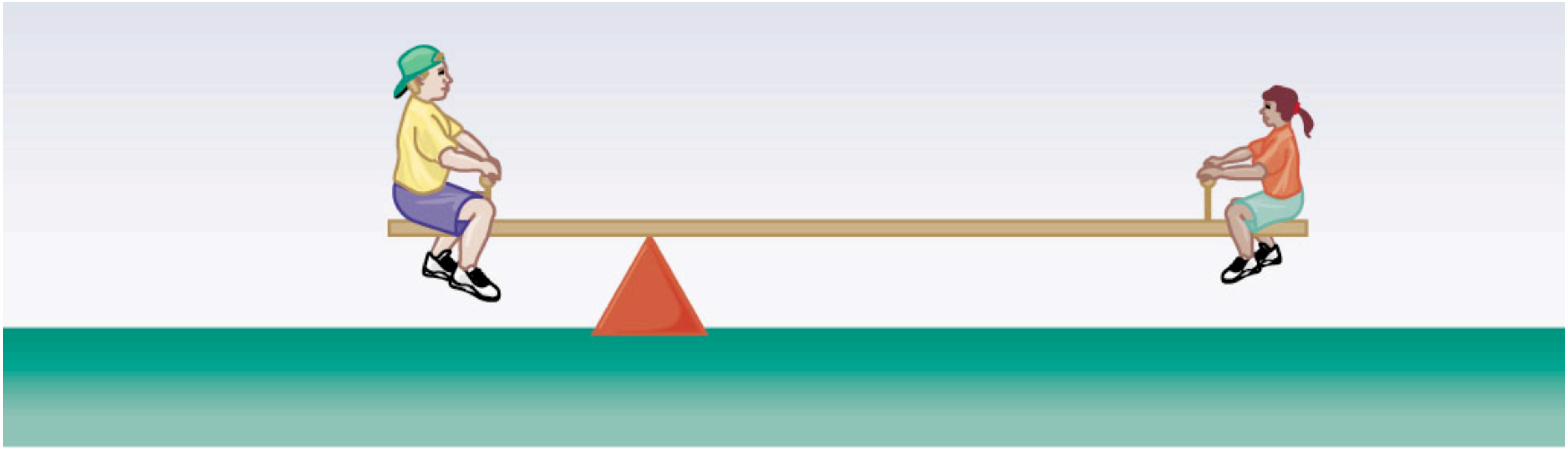

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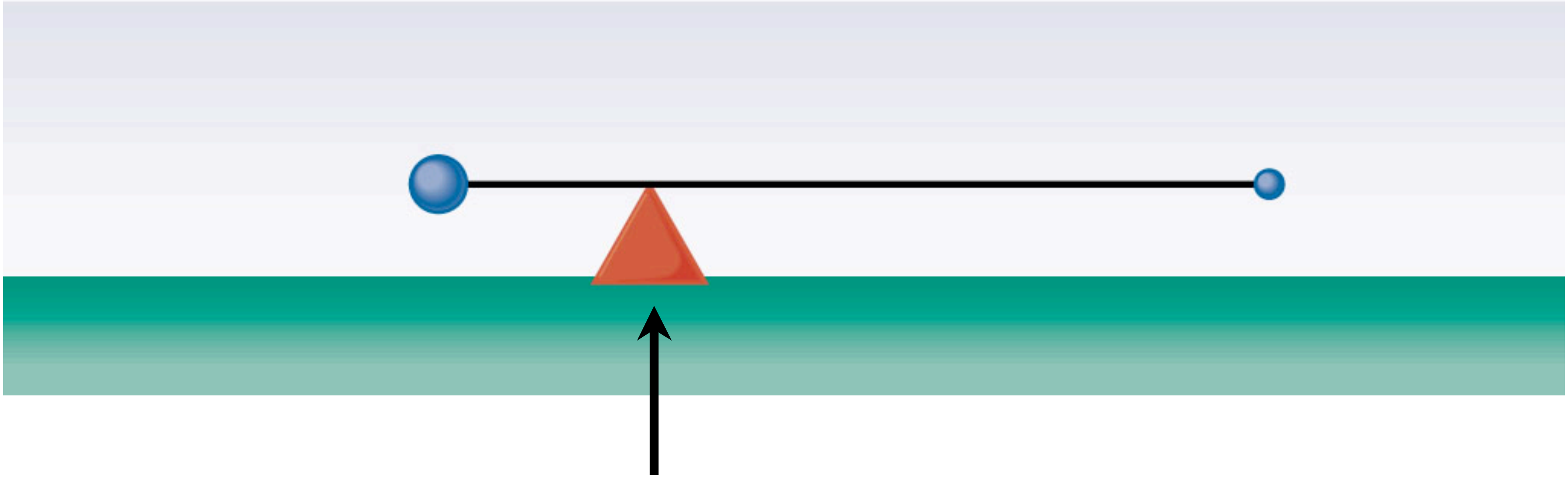


Center of mass

Types of binaries

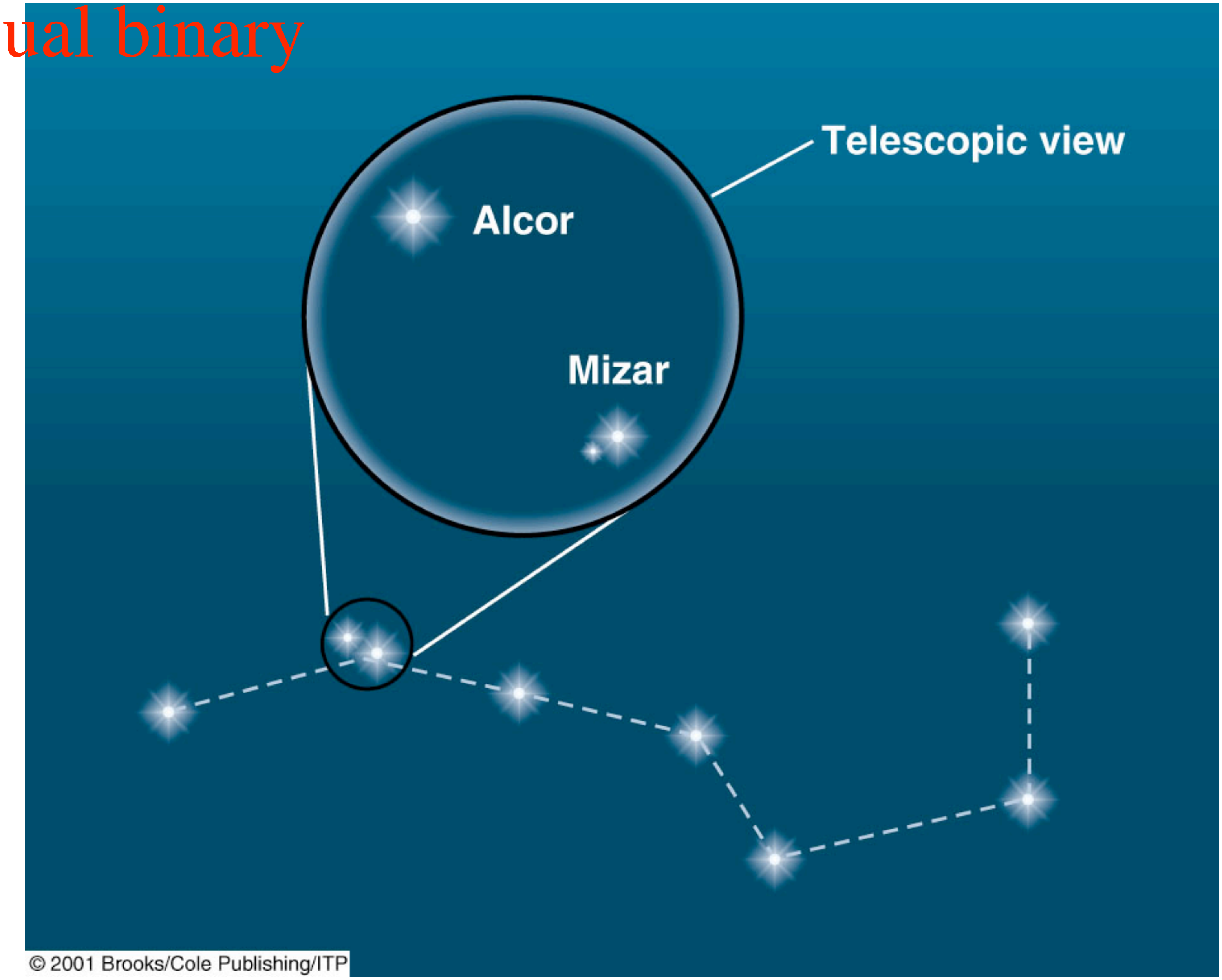
- Visual binary - both stars can be seen to orbit one another (as opposed to optical double)

- 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



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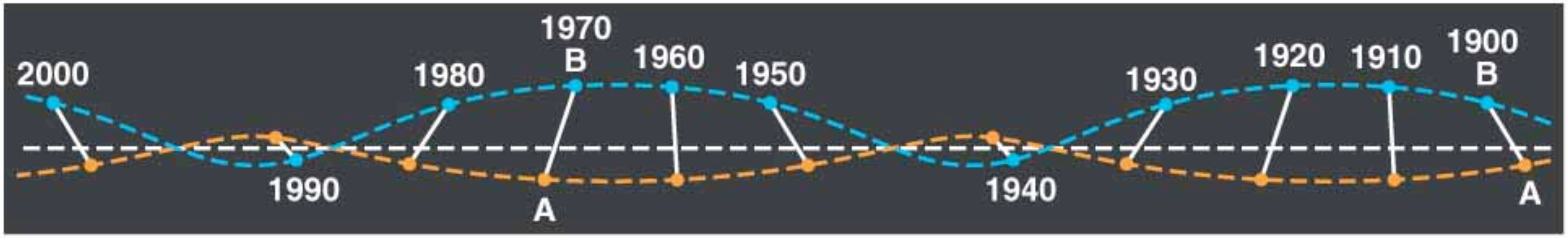
Astrometric binary



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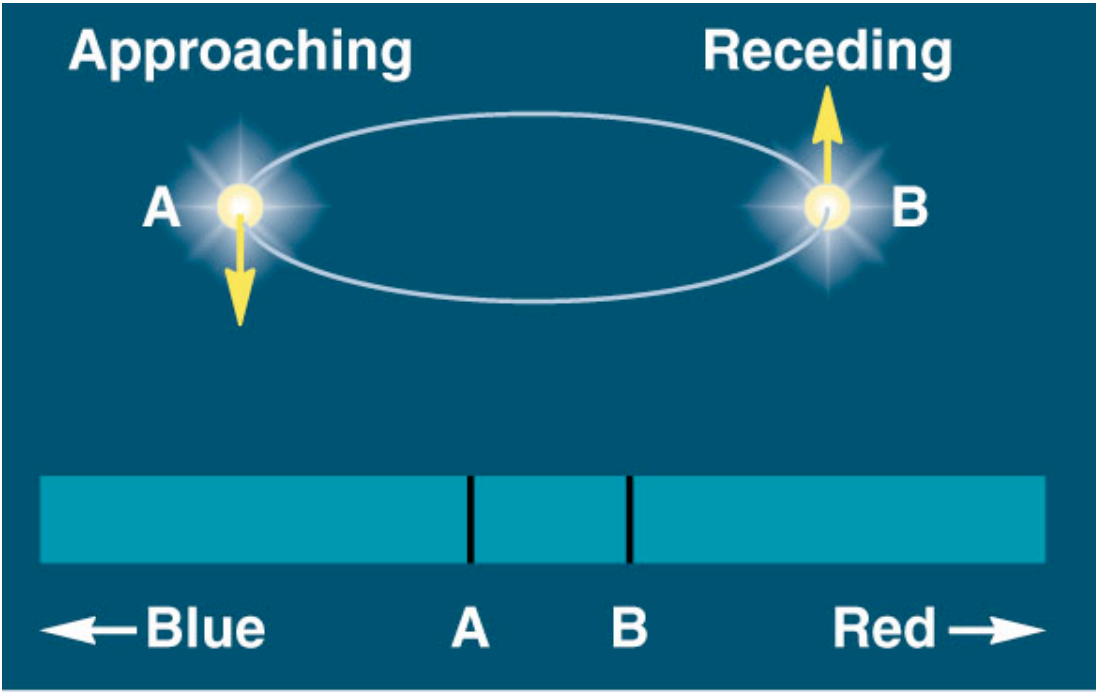
Variation of position of Sirius A, relative to background stars, shows proper motion (CM velocity) and orbital motion due to companion, Sirius B

Spectroscopic binary detected by periodic Doppler shifts in spectral lines

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



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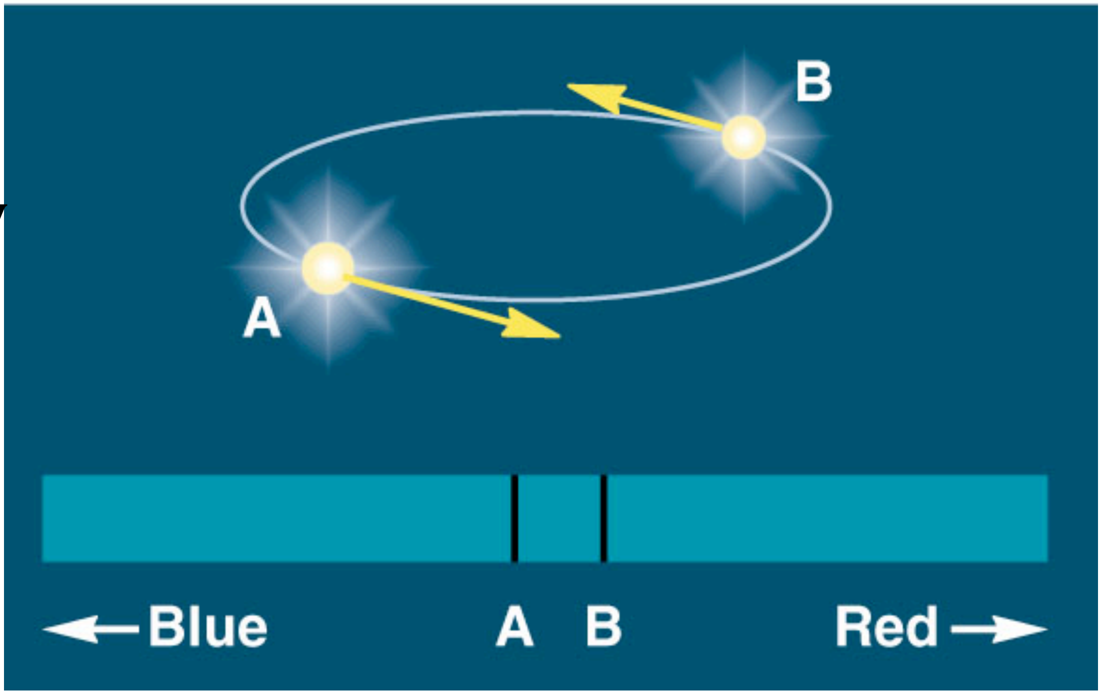
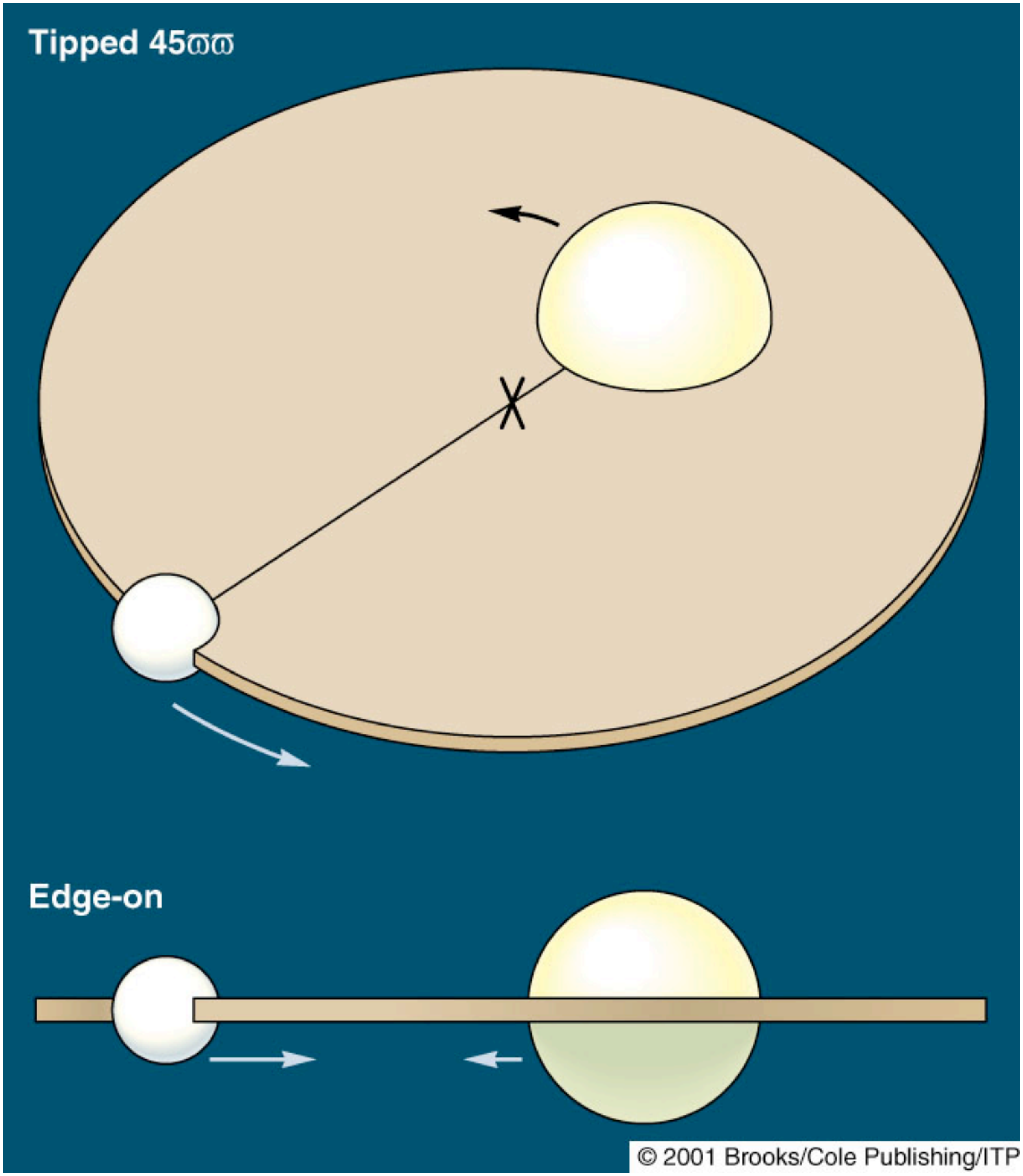


Eclipsing binary

two stars periodically eclipse each other



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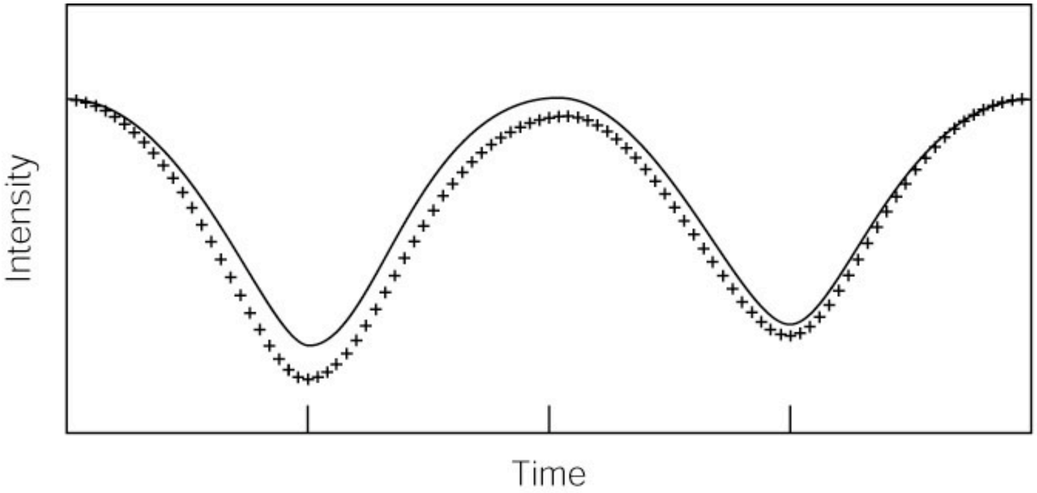
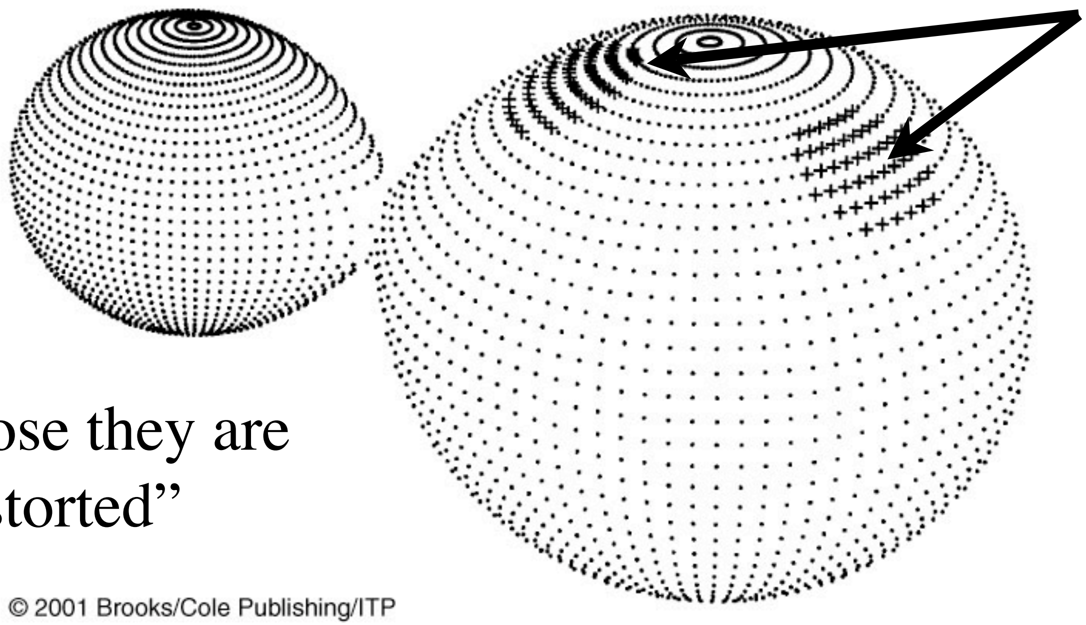
Details of light curves can be used to infer shapes of stars, presence of star spots



Binary star
VW Cephei

Star spots



Stars so close they are
"tidally distorted"

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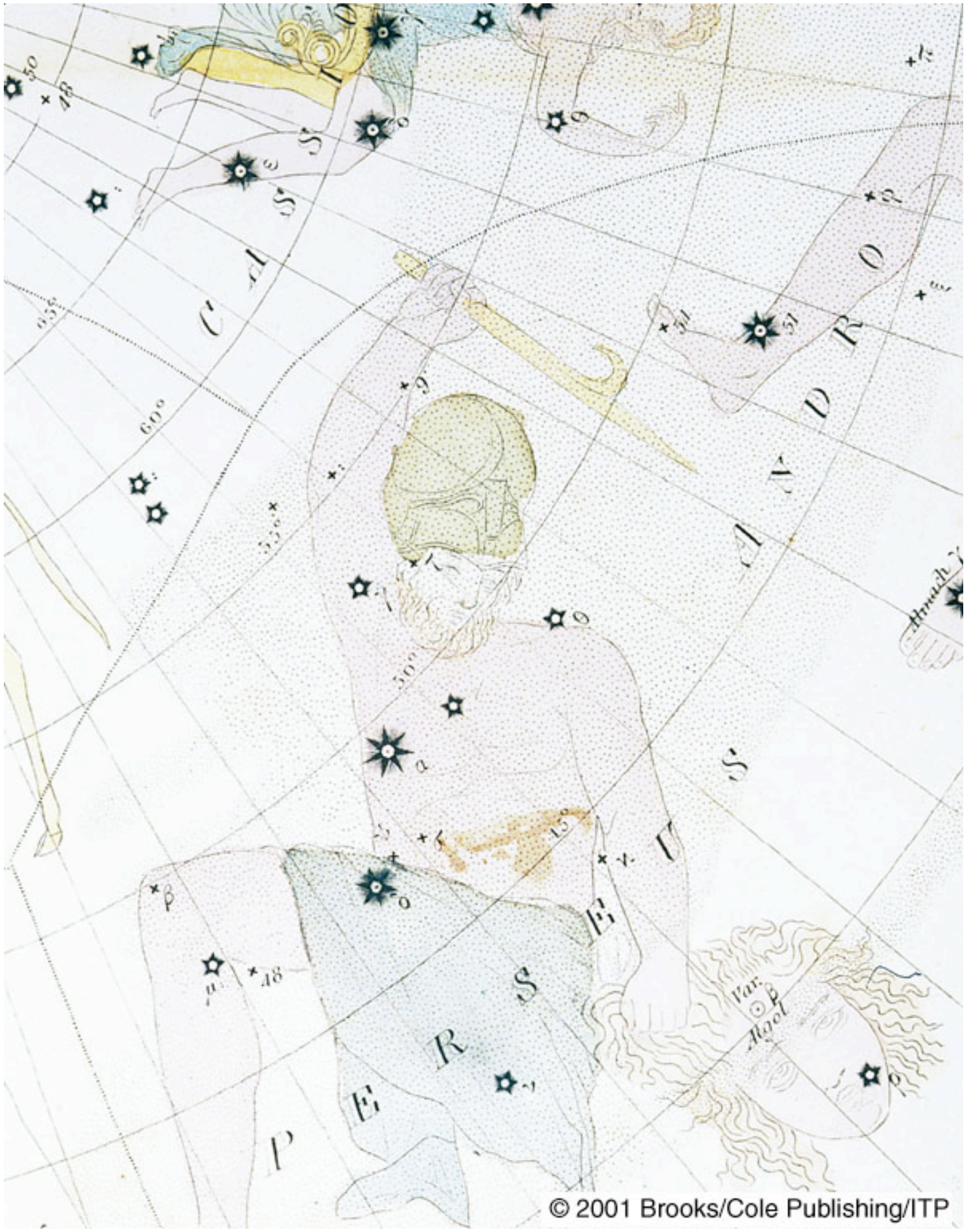
Algol: the demon star



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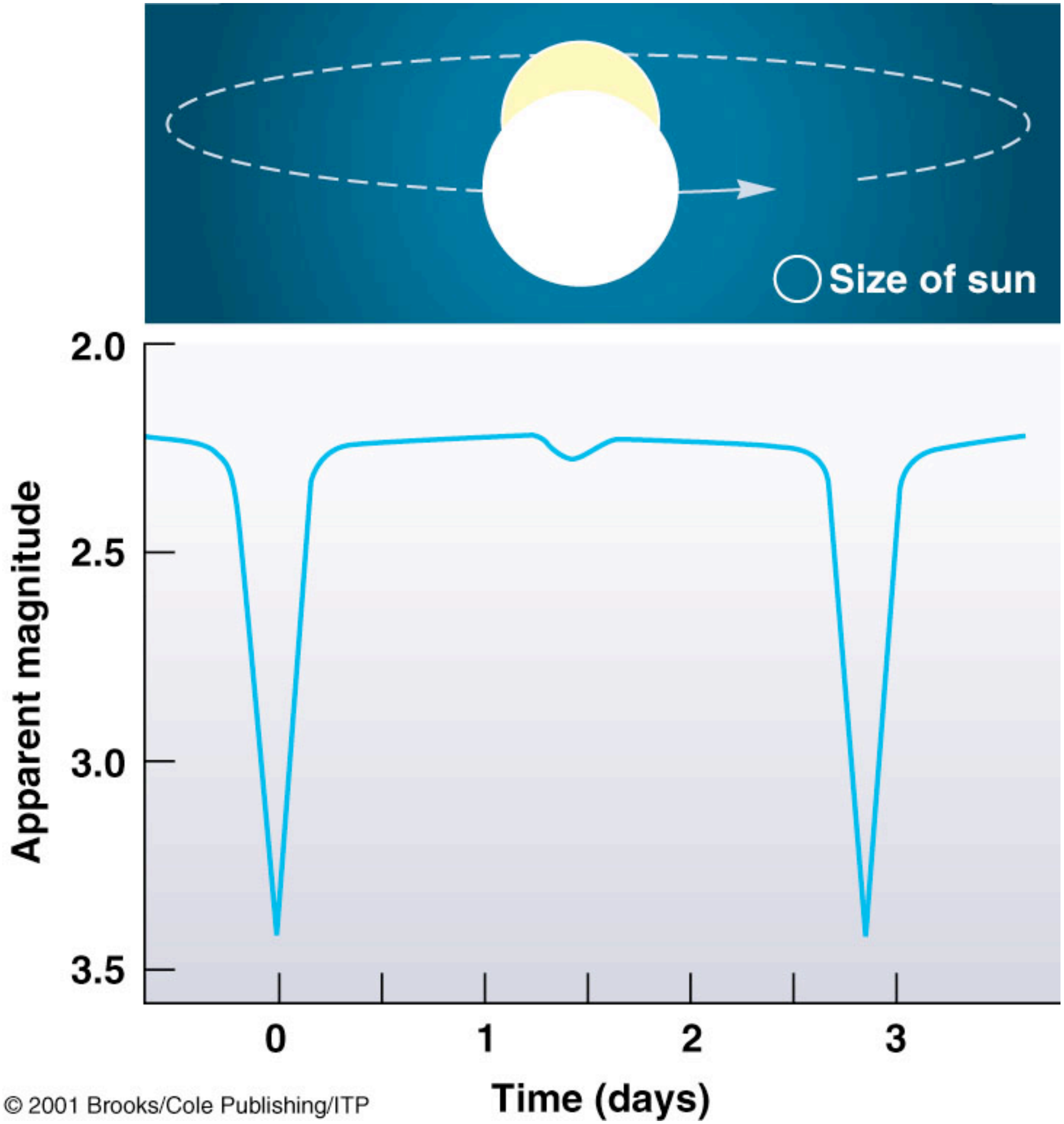
Algol is just an eclipsing binary



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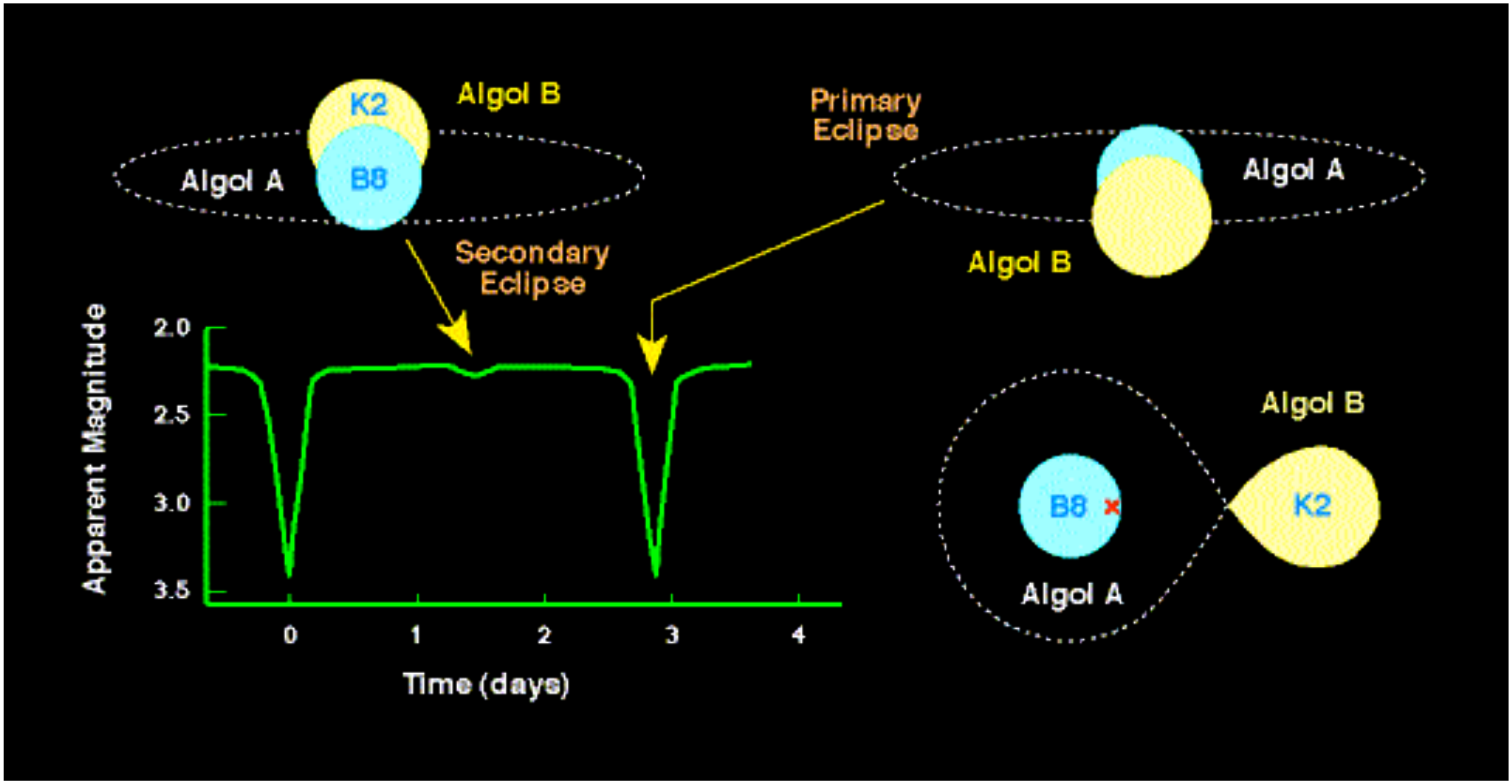
Algol: the demon star



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

What would we like to know?

- Distance
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- Radius

Stellar radii

- Difficult to measure directly for individual stars
- At distance of 1 pc, what is angular diameter of the Sun?
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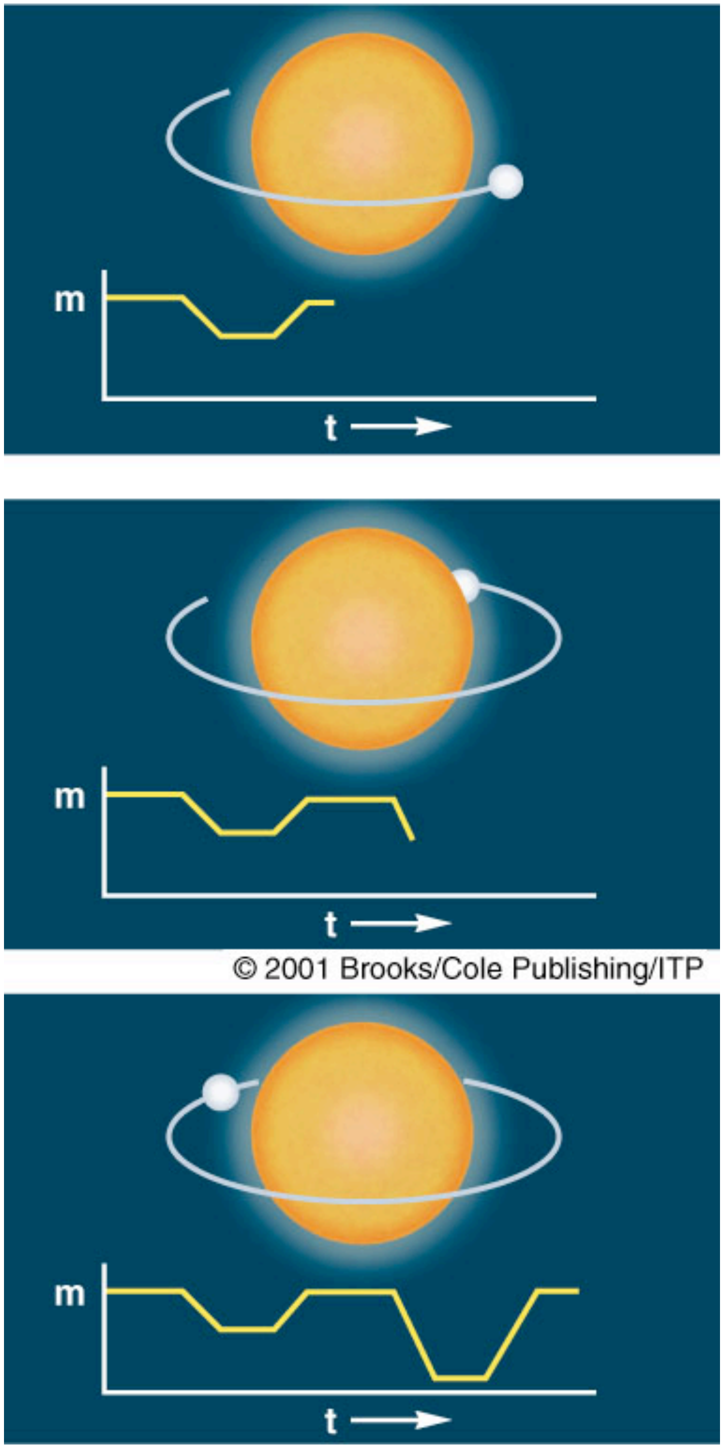

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Eclipsing Binaries: Length of eclipses can also be used to measure radii of stars

Transiting Planets!