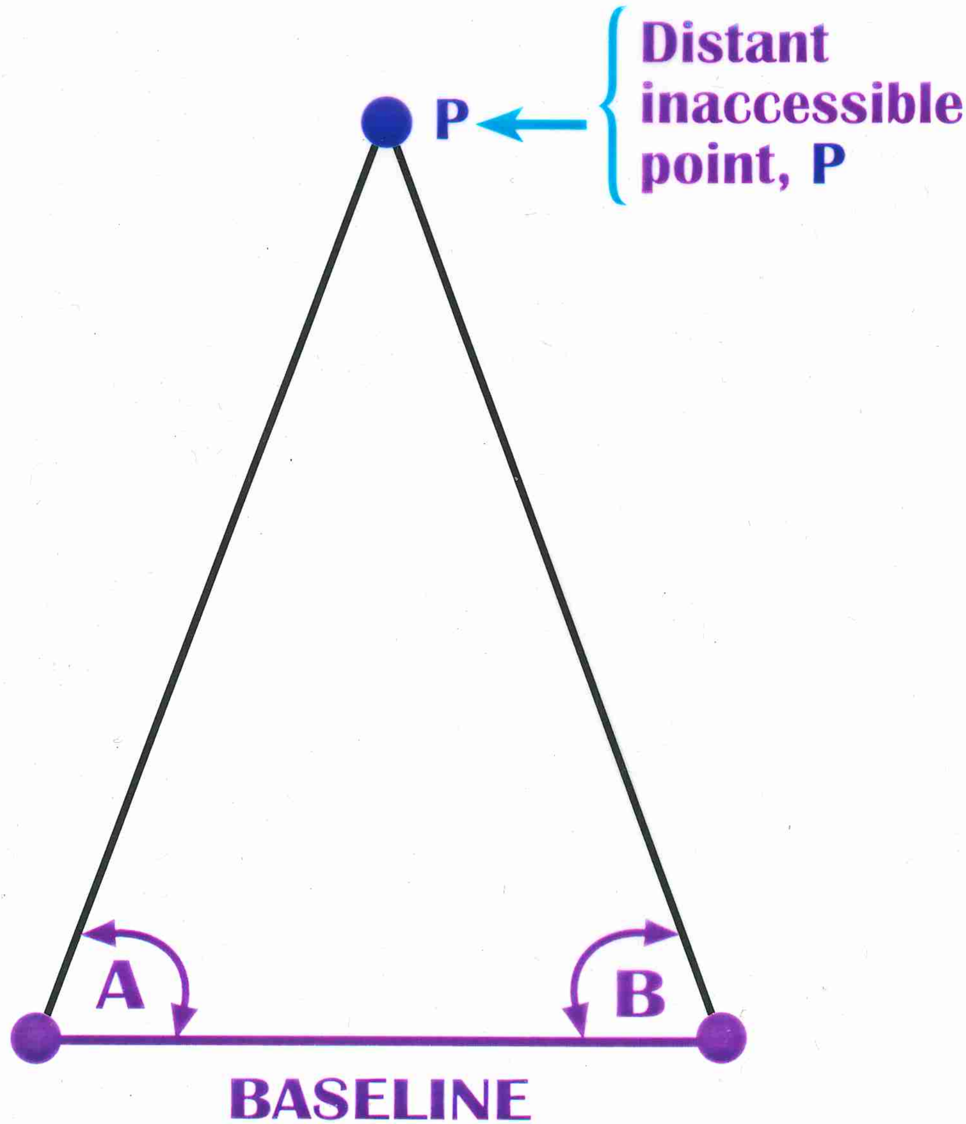
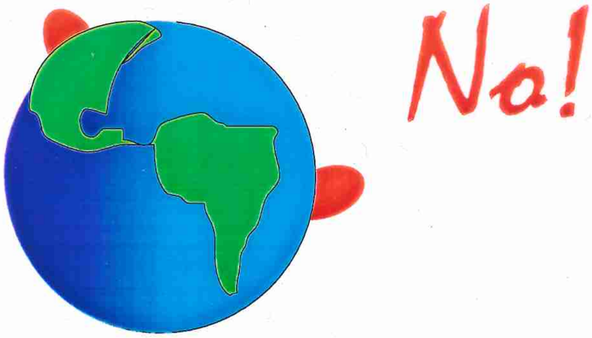
SURVEYOR'S METHOD

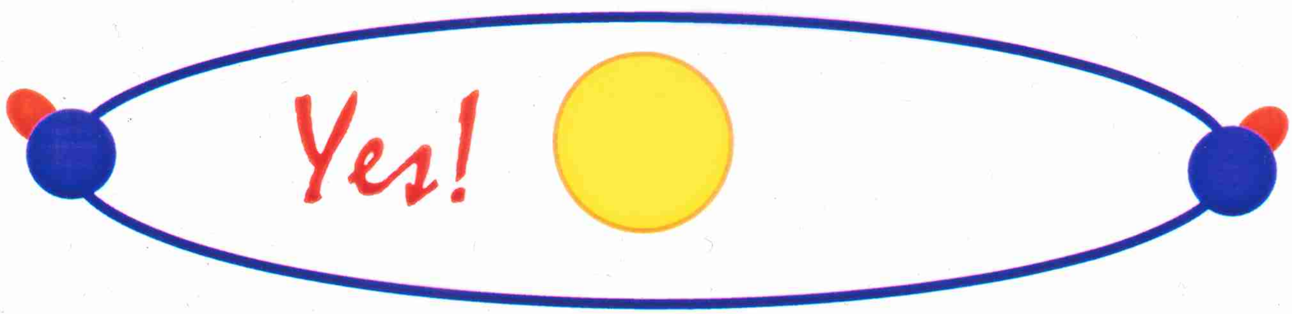


- Measure baseline
- Measure angles A and B
- Construct the *unique* triangle: then, you know distance to P

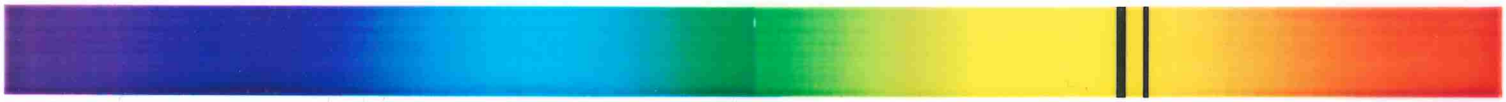
Distances to Stars?

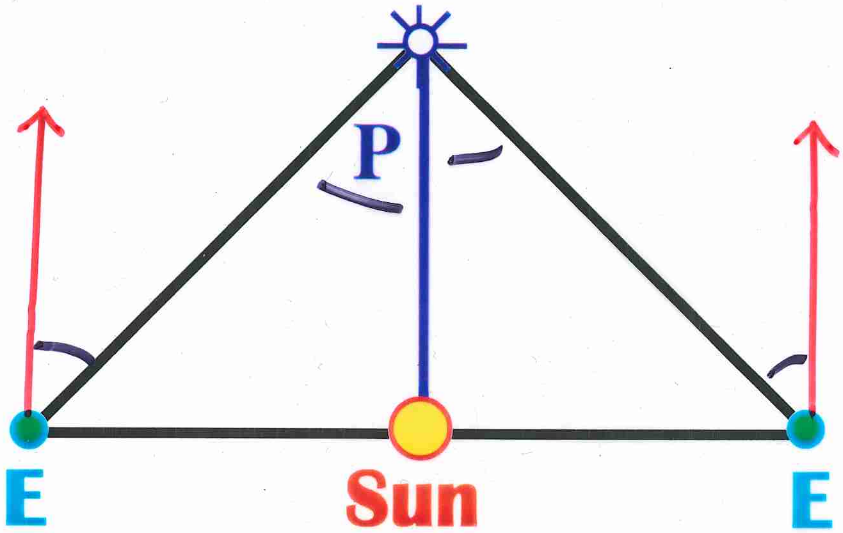
Distances » Earth's size

1. 

2. 

Distances still » Earth-Sun distance but method works for nearest 100–1000 stars





P = Parallax = 1/2 (the angle at star)

Distance in parsecs

$$= \frac{1}{\text{Parallax (in seconds of arc)}}$$

1 parsec	**= 3 1/4 light years**
	= 206, 265 A.U.

Abbreviations

1 parsec	**= 1pc**
1000 pc	**= 1 Kpc**
1,000,000 pc	**= 1 Mpc**

HIPPARCHOS!

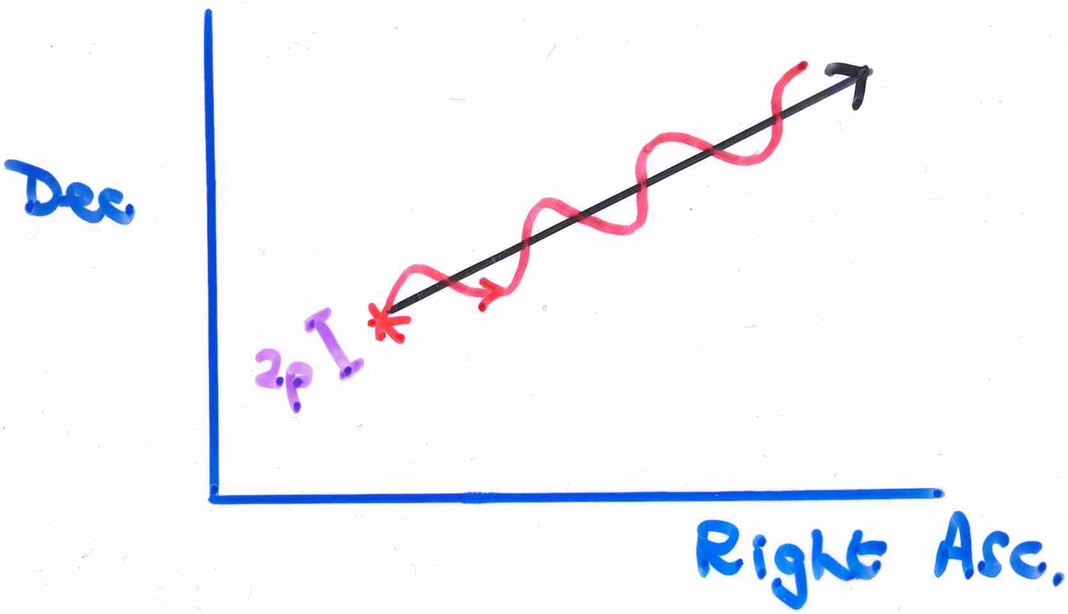
TELESCOPE IN SPACE

→ MUCH MORE ACCURATE PARALLAXES

- WHY MORE ACCURATE?
- WHY IS THE GAIN IN ACCURACY IMPORTANT?

PARALLAX DETAILS

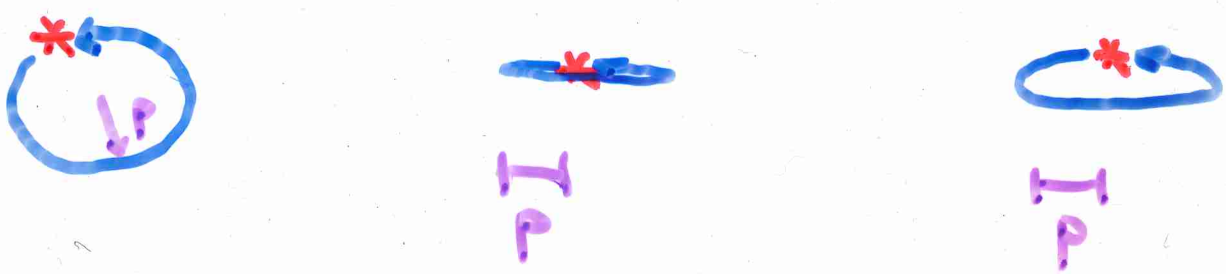
① STAR MOVES RELATIVE TO SUN



② SHIFTS DUE TO PARALLAX depend on * position rel. to ECLIPTIC

[FOR NO *–☉ MOTION]

AT ECLIPTIC POLE | ON ECLIPTIC | INTERMEDIATE POSITION



CIRCLE | LINE | ELLIPSE

What is the distance in parsecs of a star with a parallax of $0\overset{\prime\prime}{.}2$?

$$d\,[\text{in pcs}] = \frac{1}{p\,[\text{in }''\text{arc}]}$$

$$= \frac{1}{0.2} = 5\ \text{pc}$$

Two stars have parallaxes of $0.^{\prime\prime}1$ (A) and $0.^{\prime\prime}05$ (B), respectively.

Which star is closer to us, and by what factor?

If the stars are equally luminous, how much brighter will the nearer one appear than the farther one?

A is closer; larger parallax is twice as close.

$$\text{Brightness} \propto \frac{\text{Luminosity}}{\text{Distance}^2}$$

$$\frac{B_A}{B_B} = \frac{L_A}{L_B}\left(\frac{D_B}{D_A}\right)^2$$

$$= 1 \qquad \left(\frac{20}{10}\right)^2$$

$$= 4$$

Three stars of equal absolute luminosity are at distances of 1, 2, and 10 pc.

If the second star has a brightness of 1 unit, what are the brightnesses of the others?

STARS	a	b	c
L	1	1	1
d (pc)	1	2	10
B	?	1	?

$$\frac{B_a}{B_b} = \frac{L_a}{L_B}\left(\frac{d_b}{d_a}\right)^2$$

$$= 1 \left(\frac{2}{1}\right)^2 = 4$$

$$\frac{B_c}{B_b} = \frac{L_c}{L_b}\left(\frac{d_b}{d_c}\right)^2$$

$$= 1 \left(\frac{2}{10}\right)^2 = \frac{1}{25}$$

What are the apparent luminosity (brightness) ratios of the following pairs?

	L_1	D_1	L_2	D_2
a	10	10	25	10
b	5	5	50	100
c	1	1/2	1/4	1/3

L = Absolute Luminosity
D = Distance

TRY THIS AT HOME!

Star A has a parallax of $0''.2$ and B a parallax of $0''.04$. Star B appears 3 times as bright as Star A.

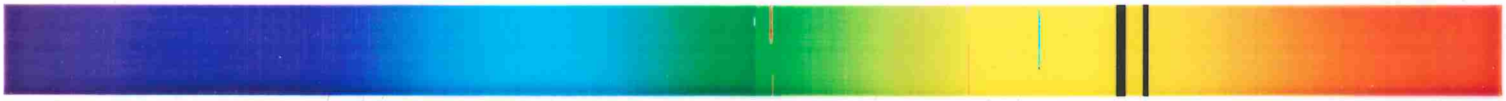
Which of the stars is more luminous (*absolute luminosity*) and by how much?

AND THIS ONE!

Two stars are observed to have the same parallax and the same brightness. One is red and the other is blue.

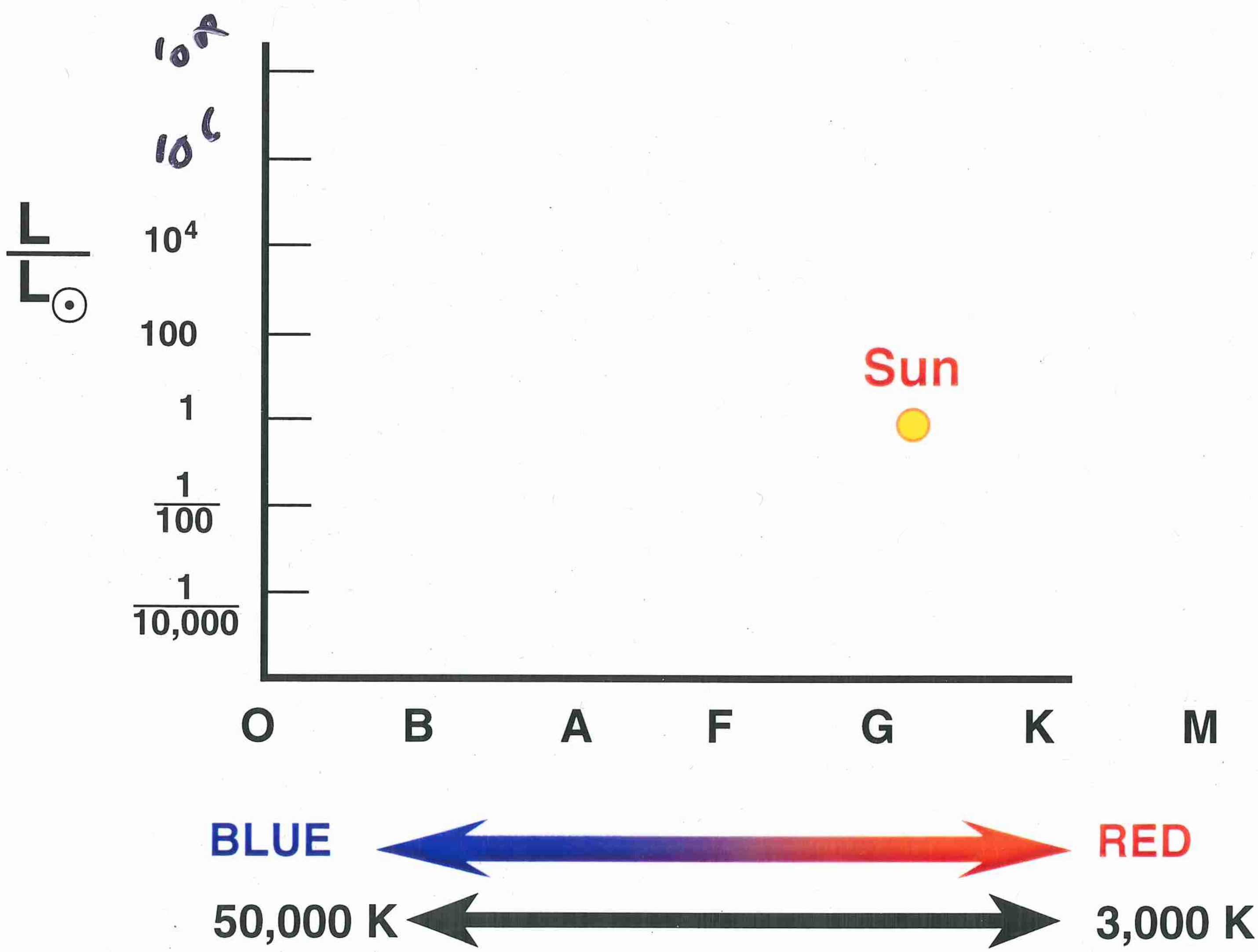
Which star is larger?

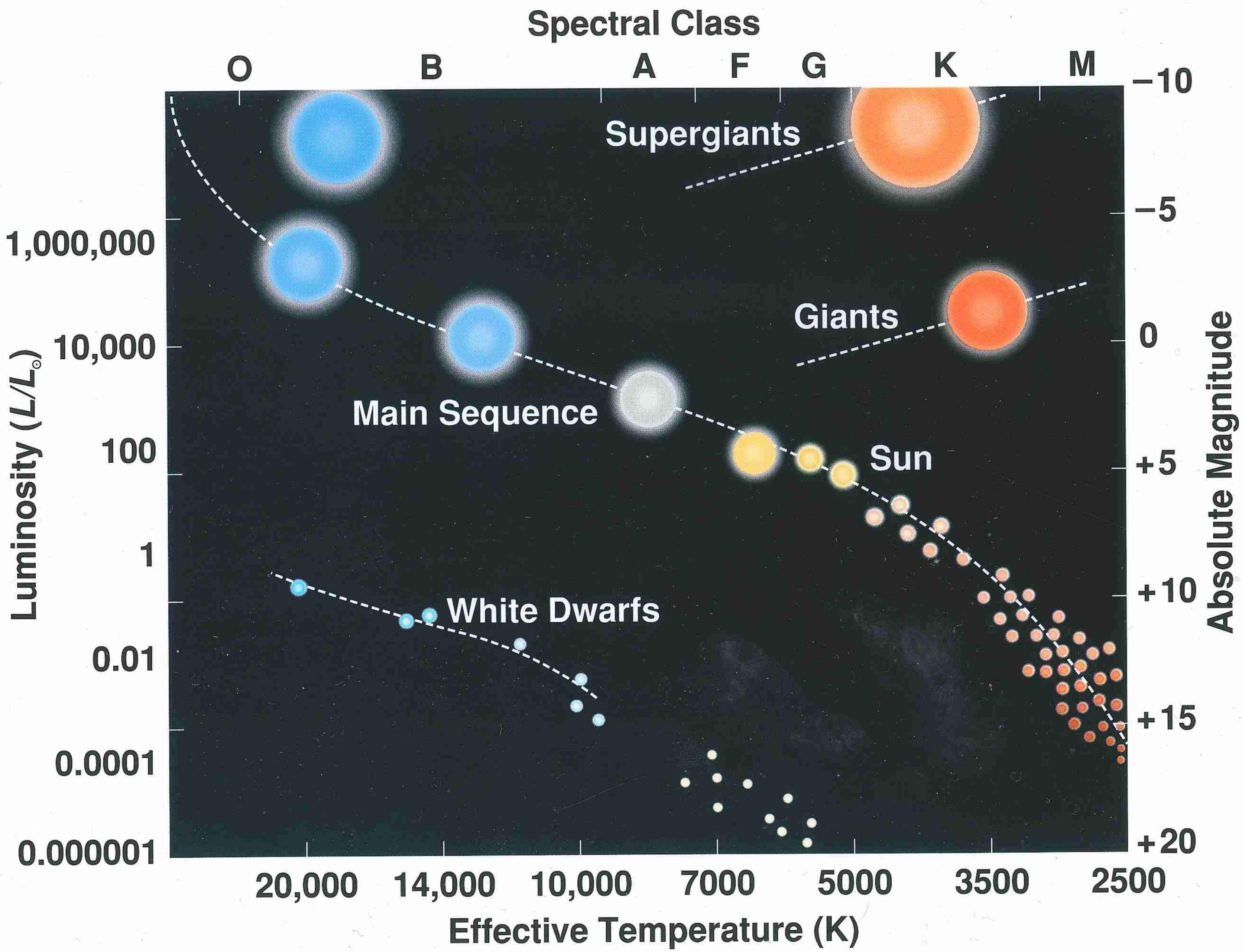
1. Same parallax → same distance.
2. 1 + same brightness → same absolute L
3. red → cool ∴ low L per unit area
   blue → hot ∴ high L per unit area
4. 2 + 3 → red star larger area than blue star



Hertzsprung-Russell Diagram

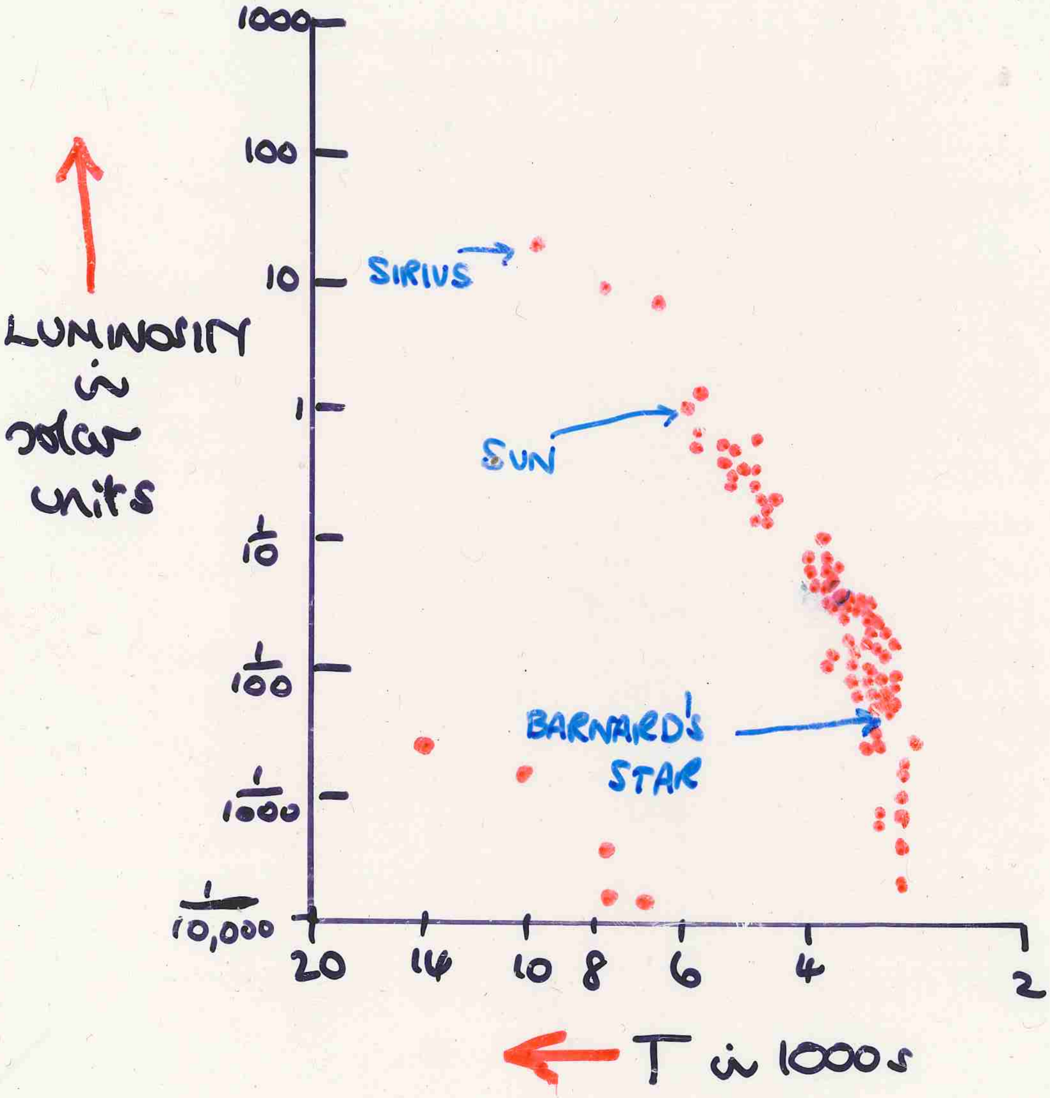
Luminosity plotted against
- Spectral Type
- Color
- Temperature



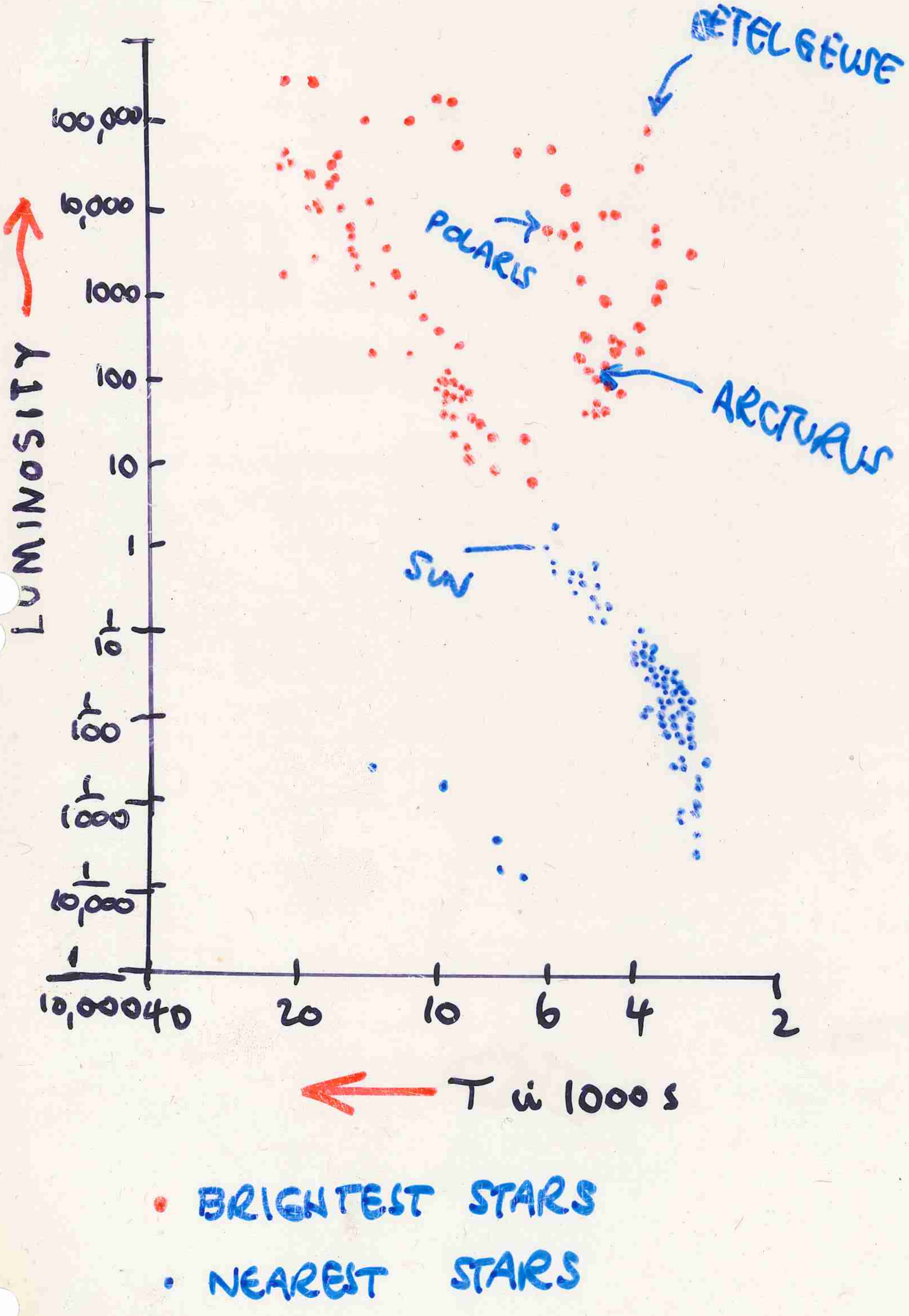


H-R diagram—different types of stars

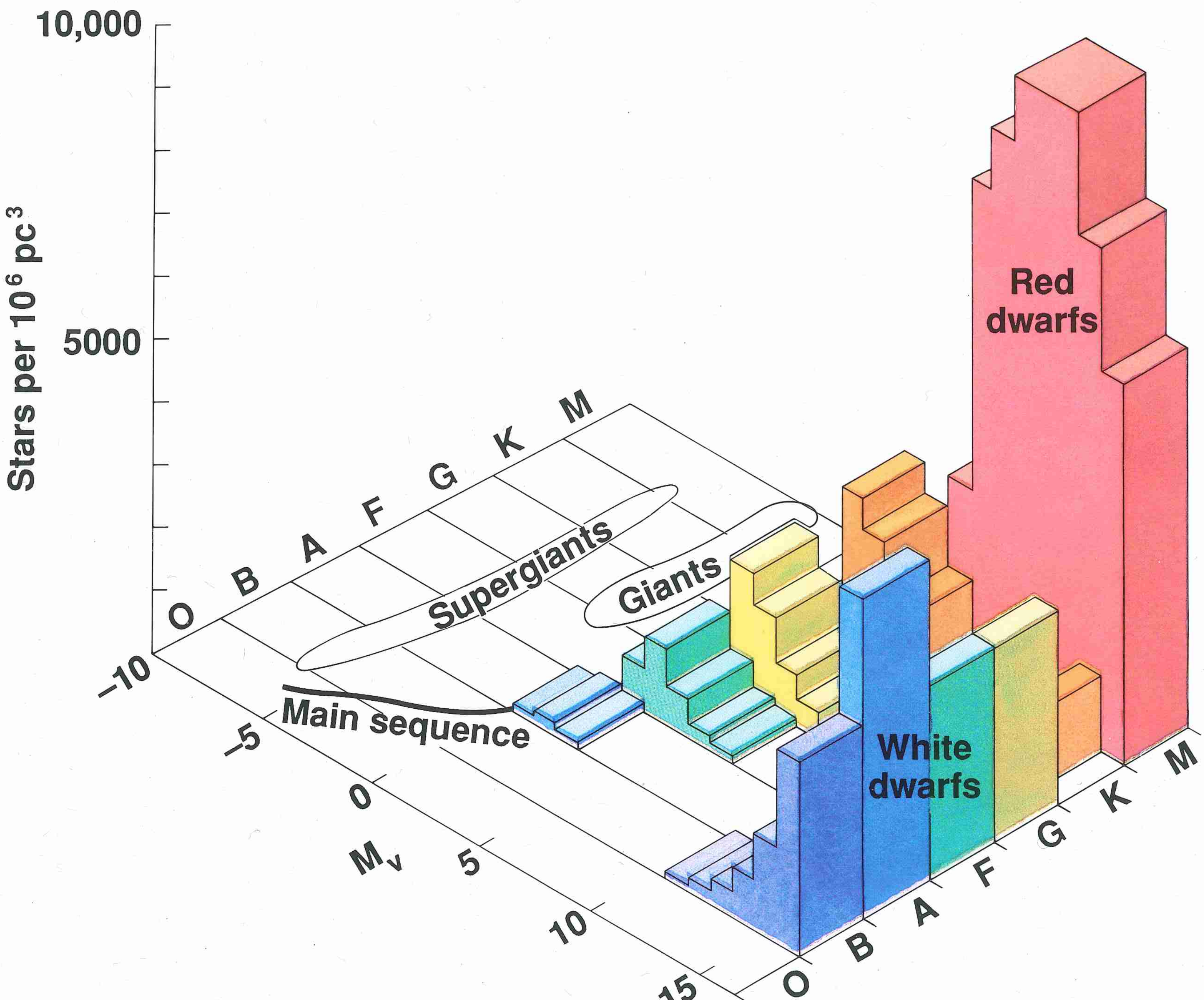
Hartmann/Impey: The Cosmic Journey, 5th ed., Fig. 17-2; Hartmann: The Cosmic Voyage, 1992 ed., Fig. 17-1



HR-diagram for nearby stars.



LUMINOSITY
100,000
10,000
1000
100
10
1
1/10
1/100
1/1000
1/10,000
1/10,000
BETELGEUSE
POLARIS
ARCTURUS
SUN
40
20
10
6
4
2
T in 1000 s
BRIGHTEST STARS
NEAREST STARS



Histogram—H-R diagram

Seeds: Horizons, 1995 ed., Fig. 8–24; Foundations of Astronomy, 1994 ed., Fig. 9–17

STELLAR CENSUS

[SEEDS p.172+ FIG 8.24]

* RESULTS DEPEND ON SELECTION CRITERIA.

FOR SOLAR NEIGHBORHOOD:

- MOST COMMON? M DWARFS
- WHICH STARS PROVIDE MOST OF BLUE LIGHT? THE FEW O/B STARS
- WHICH ... RED LIGHT? THE FEW RED GIANTS & SUPERGIANTS
- WHAT KIND OF STARS HAVE MOST OF THE MASS? M DWARFS: EACH OF LOW MASS BUT LOTS OF THEM

* WHY ARE RED GIANTS COMMON AMONG THE BRIGHTEST STARS BUT NOT AMONG NEAREST STARS?

BETELGEUSE

$L \sim 20{,}000\, L_\odot$ $\qquad$ $T \sim 3000\,K$

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

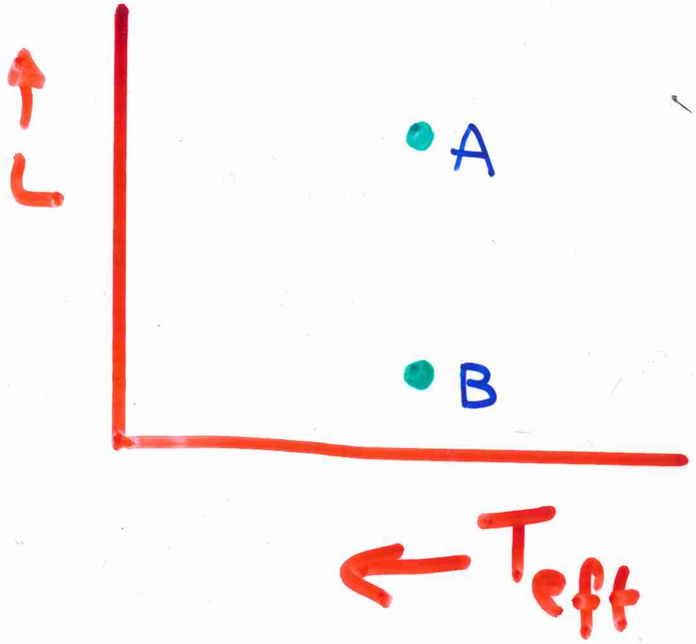
$$\left(\frac{R}{R_\odot}\right)^2 = \frac{L/L_\odot}{(T/T_\odot)^4}$$

$$= \frac{20{,}000}{(3000/6000)^4} = \frac{20{,}000}{(1/2)^4}$$

$$= 20{,}000 \times 16 = 320{,}000$$

$$R = \sqrt{320{,}000}\, R_\odot = 565 R_\odot$$

$$\simeq 2\,AU$$



NOW, $L \propto R^2 T^4$

THEN, $\frac{L_A}{L_B} = \frac{R_A^2}{R_B^2}$ as $T_A = T_B$

$\therefore \quad R_B^2 = R_A^2 \frac{L_B}{L_A}$

$$R_B = R_A \sqrt{\frac{L_B}{L_A}}$$

* NOW COMPARE SIRIUS A AND B

SIRIUS A AND B

SIRIUS A : $L \sim 30 L_\odot$

B : $\sim 0.003 L_\odot$

$$\frac{R_B}{R_A} \approx \sqrt{\frac{L_B}{L_A}} \approx \sqrt{\frac{0.003}{30}}$$

$$\approx \sqrt{0.0001} \approx \sqrt{10^{-4}}$$

$\approx 10^{-2} \approx 0.01$, if we ignore fact that A is slightly hotter than B.

MASS, RADIUS, AND DENSITY

$$\text{DENSITY} = \frac{\text{MASS}}{\text{VOLUME}}$$

$$\rho = \frac{M}{\frac{4\pi}{3}R^3} \propto \frac{M}{R^3}$$

SUN HAS AVERAGE DENSITY OF

$1.4\ \text{gm/cm}^3 \approx$ WATER

WHITE DWARF (SIRIUS B)

$R \sim 0.01 R_\odot$

$m \sim 1 m_\odot$

$$\rho \propto \frac{m}{R^3} \sim 10^6 \cdot \frac{m_\odot}{R_\odot^3}$$

$$\sim 10^6 \rho_\odot$$

$\sim$ million gm/cm^3 !!

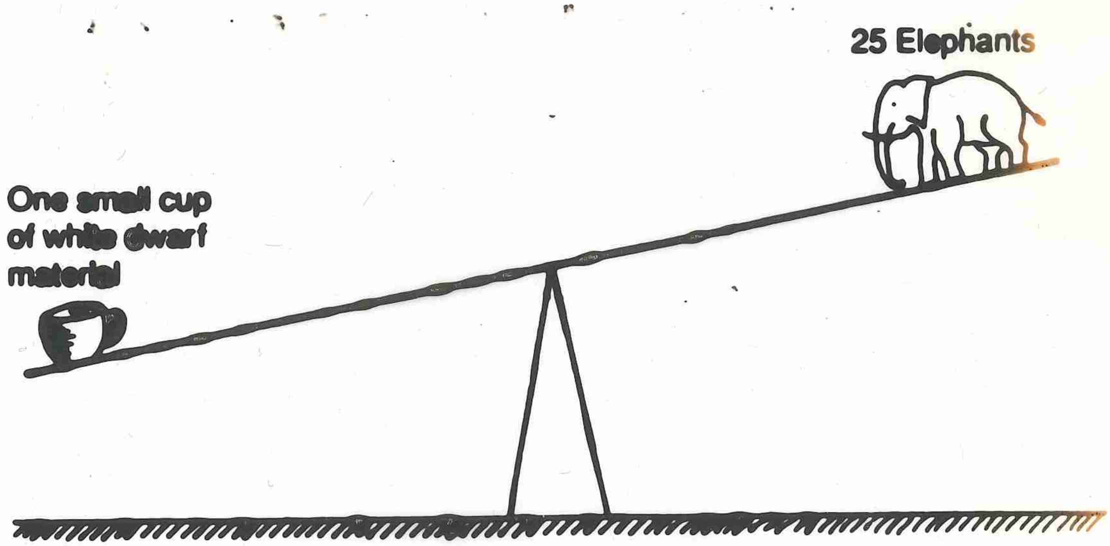


Fig. 2.9 Schematic drawing whose main purpose is to make you remember that white dwarfs are very dense!

RED SUPERGIANT (BETELGEUSE)

$$R \sim 1000 R_\odot$$

$$m \sim 10 m_\odot$$

$$\rho \propto \frac{10 m_\odot}{(1000 R_\odot)^3}$$

$$= \frac{10}{10^9} \frac{m}{R_\odot^3}$$

$$= \frac{1}{10^8} \rho_\odot = 10^{-8} \rho_\odot$$

ON AVERAGE, BETELGEUSE HAS DENSITY LOWER THAN THAT REPRESENTED BY BEST VACUUM ON EARTH

	WHITE DWARF	RED SUPERGIANT
MASS	$\sim 1 M_\odot$	$\sim 10 M_\odot$
RADIUS	$\frac{1}{100} R_\odot$ (RADIUS OF EARTH)	$1000 R_\odot$ (EARTH'S ORBIT AROUND SUN)
DENSITY	$10^6 \times$ WATER	$10^{-8} \times$ WATER

NOT THE MOST EXTREME

NEUTRON STARS

BLACK HOLES

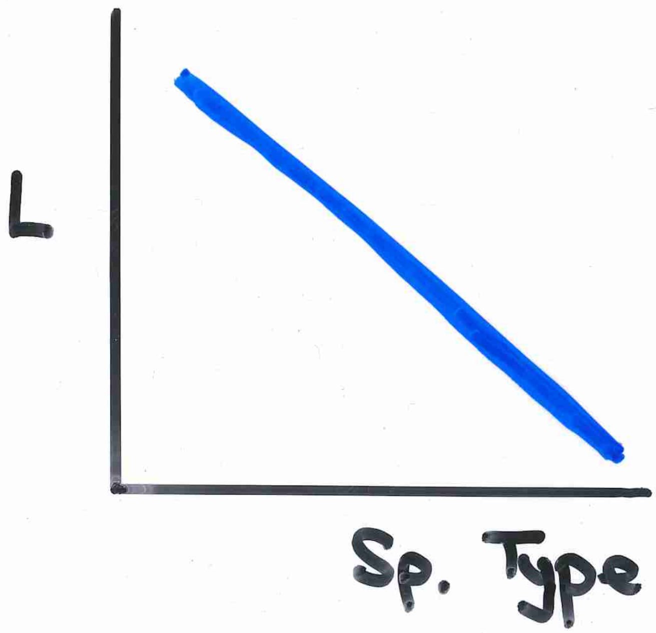
MUCH LARGER RADIUS

= UNLIKELY / IMPOSSIBLE

GASES NOT RESTRAINED BY STAR'S GRAVITY

HR DIAGRAM & DISTANCES TO STARS : METHOD OF SPECTROSCOPIC PARALLAX.

BASIC IDEA

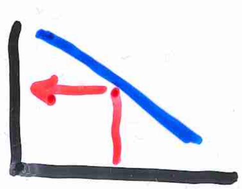


- MAIN SEQUENCE from STARS WITH ACCURATE TRIGONOMETRICAL PARALLAXES
  ≡ GOOD CORRELATION OF L WITH SPECTRAL TYPE
- IDEA! CORRELATION TRUE FOR ALL MAIN SEQUENCE STARS
- OBSERVE A STAR'S SPECTRUM TO GET SPECTRAL TYPE

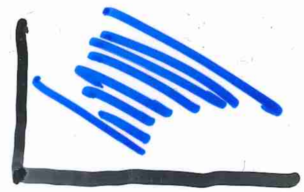
- IF NOT LUMINOSITY CLASS V → GIVE UP!
- IF CLASS V, LOOK UP L FROM CORRELATION

COMBINE THIS L AND OBSERVED BRIGHTNESS TO GET DISTANCE

KEY: MAIN SEQUENCE IS NARROW



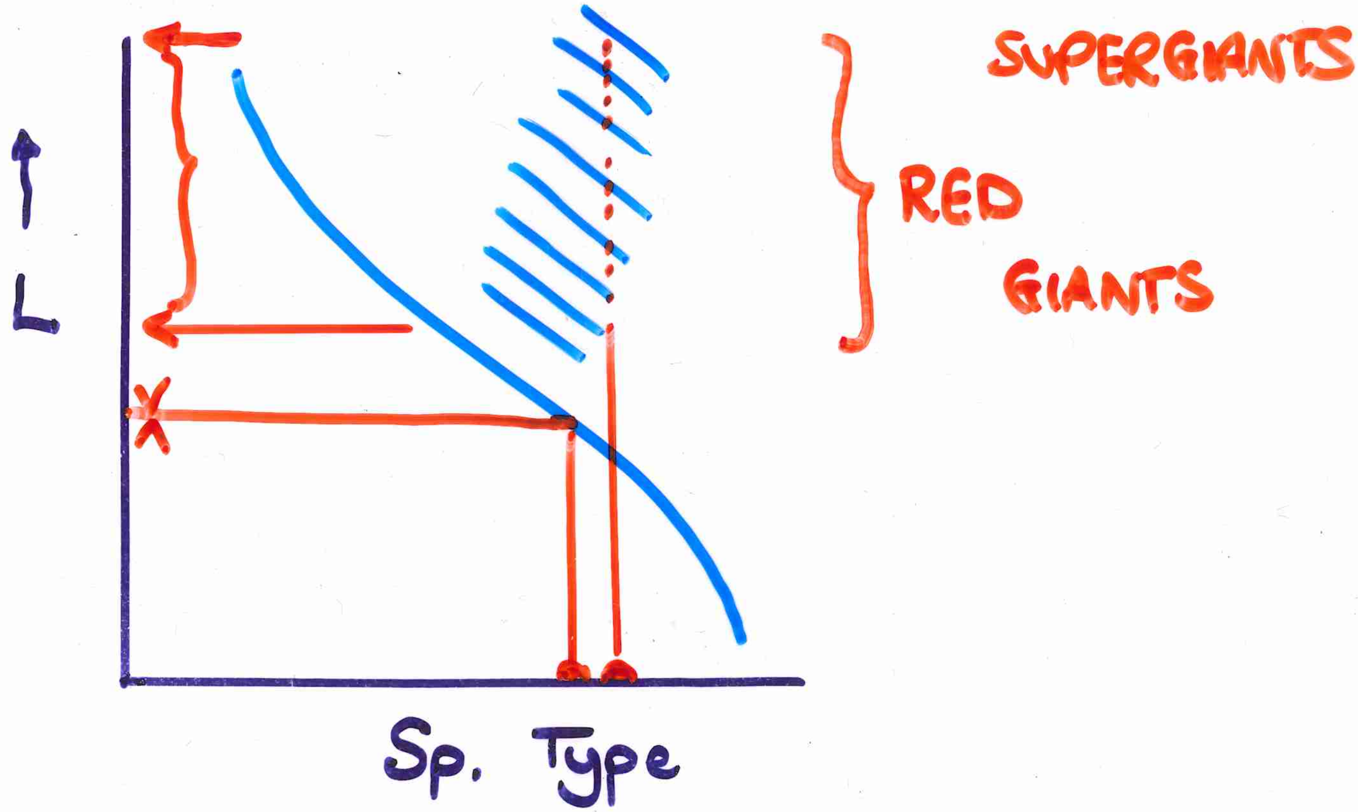
ok !



not ok!

WE KNOW WHY MAIN SEQUENCE IS NARROW BUT NOT CRITICAL TO OPERATION OF METHOD.

WHY ARE SPECTROSCOPIC PARALLAXES OF GIANTS AND SUPERGIANTS INACCURATE ?

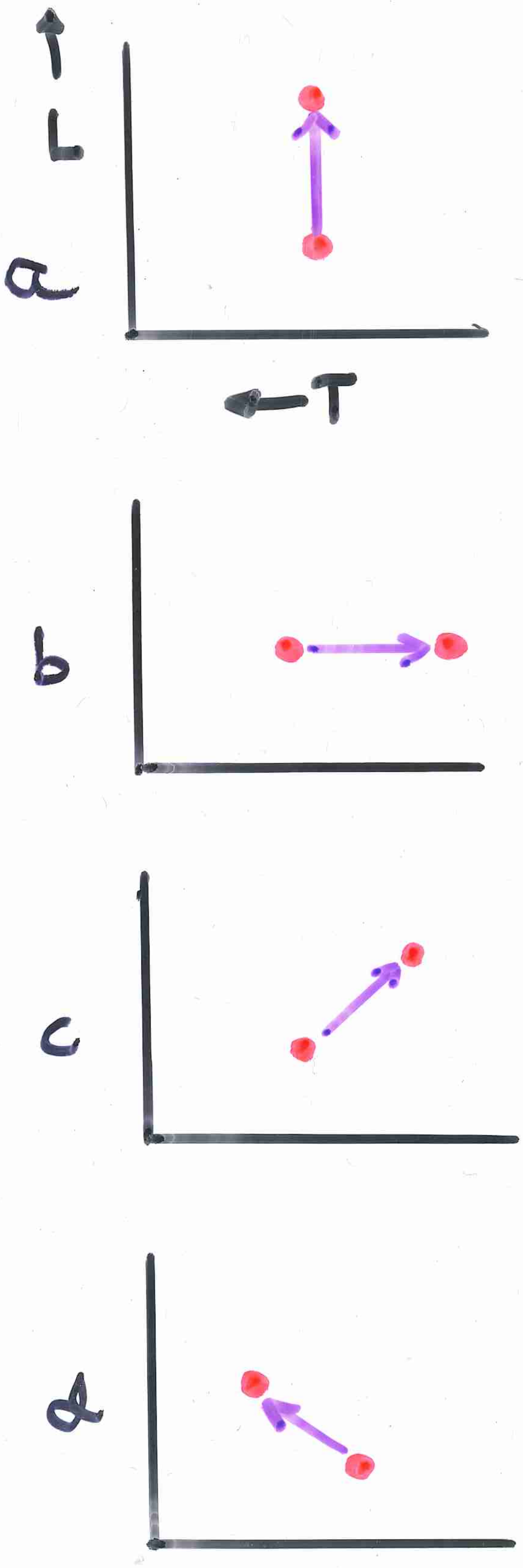


LUMINOSITY CLASSIFICATION (I, II, III, IV) helps but uncertainty remains.

AN EXERCISE

IS THIS STAR GETTING
- LARGER
- SMALLER
- NOT CHANGING

?



KEY to ANSWER is

$$L \propto R^2 T^4$$

For a, there is NO change of T but L increases. therefore, R must increase as L increase:

$L \propto R^2$ for constant T

Red Giants/Supergiants

Why red?

Why giant/supergiant?

White Dwarfs

Why white?

Why dwarf?