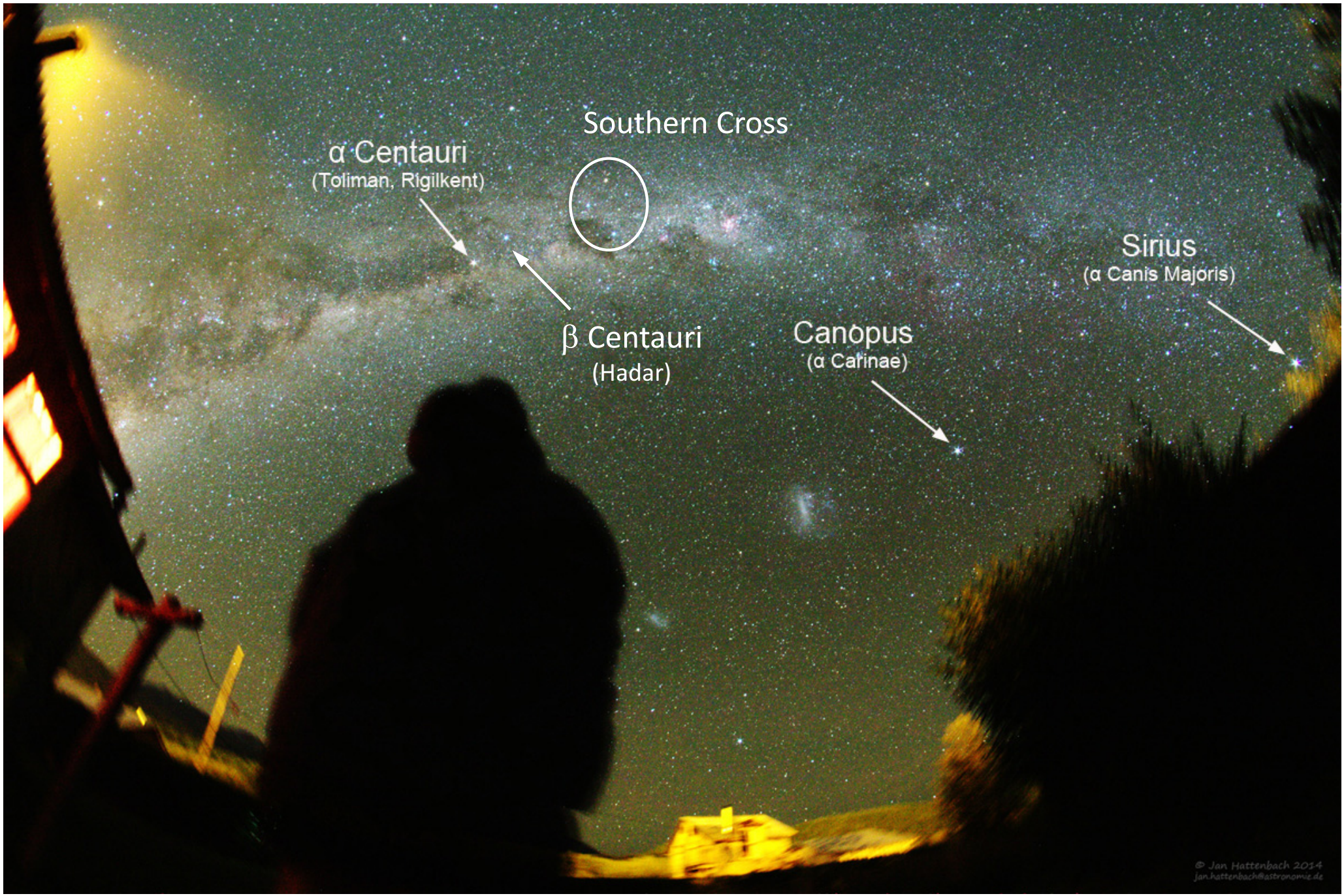
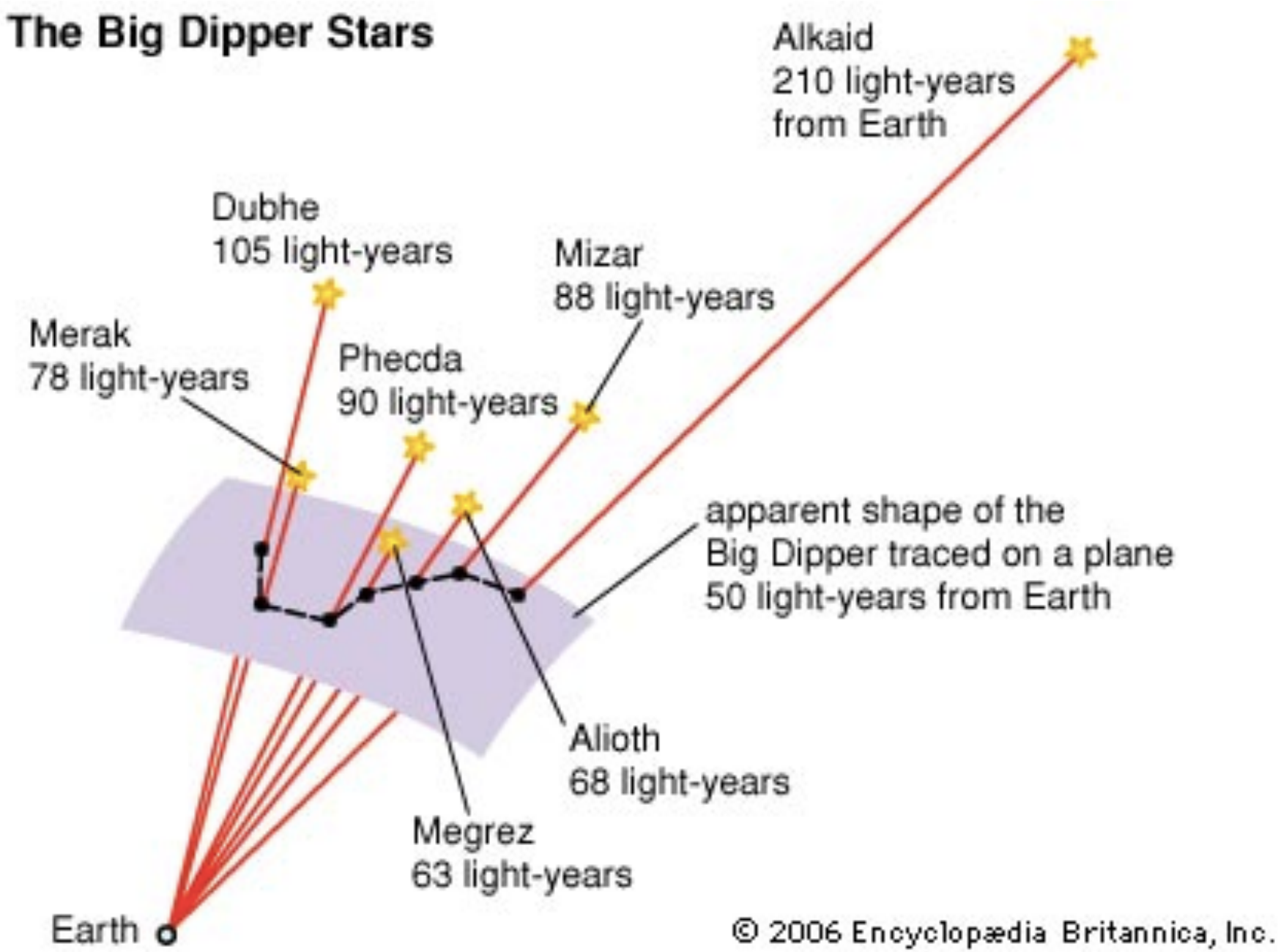
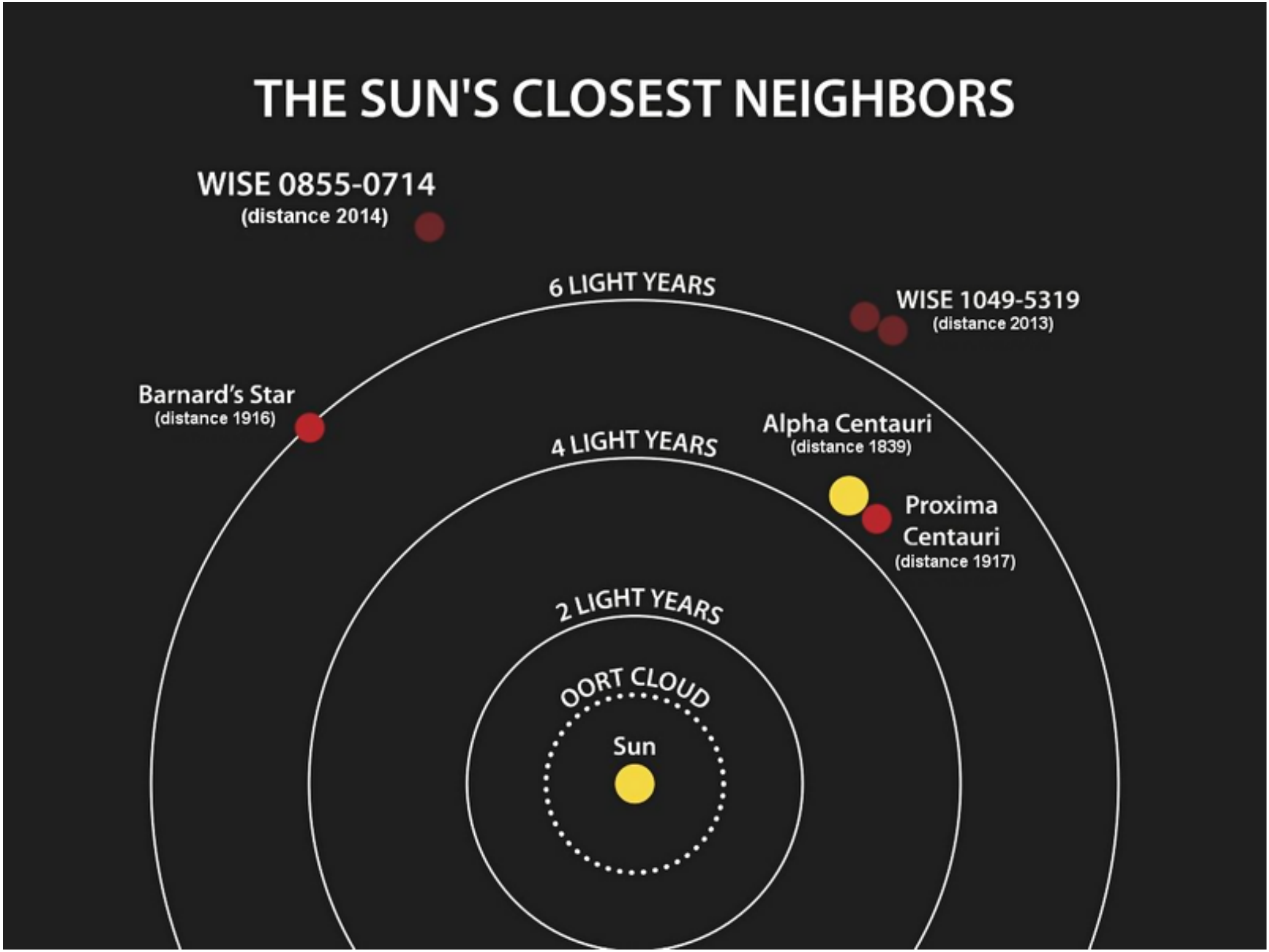
Distances and Brightness

Learning Objectives

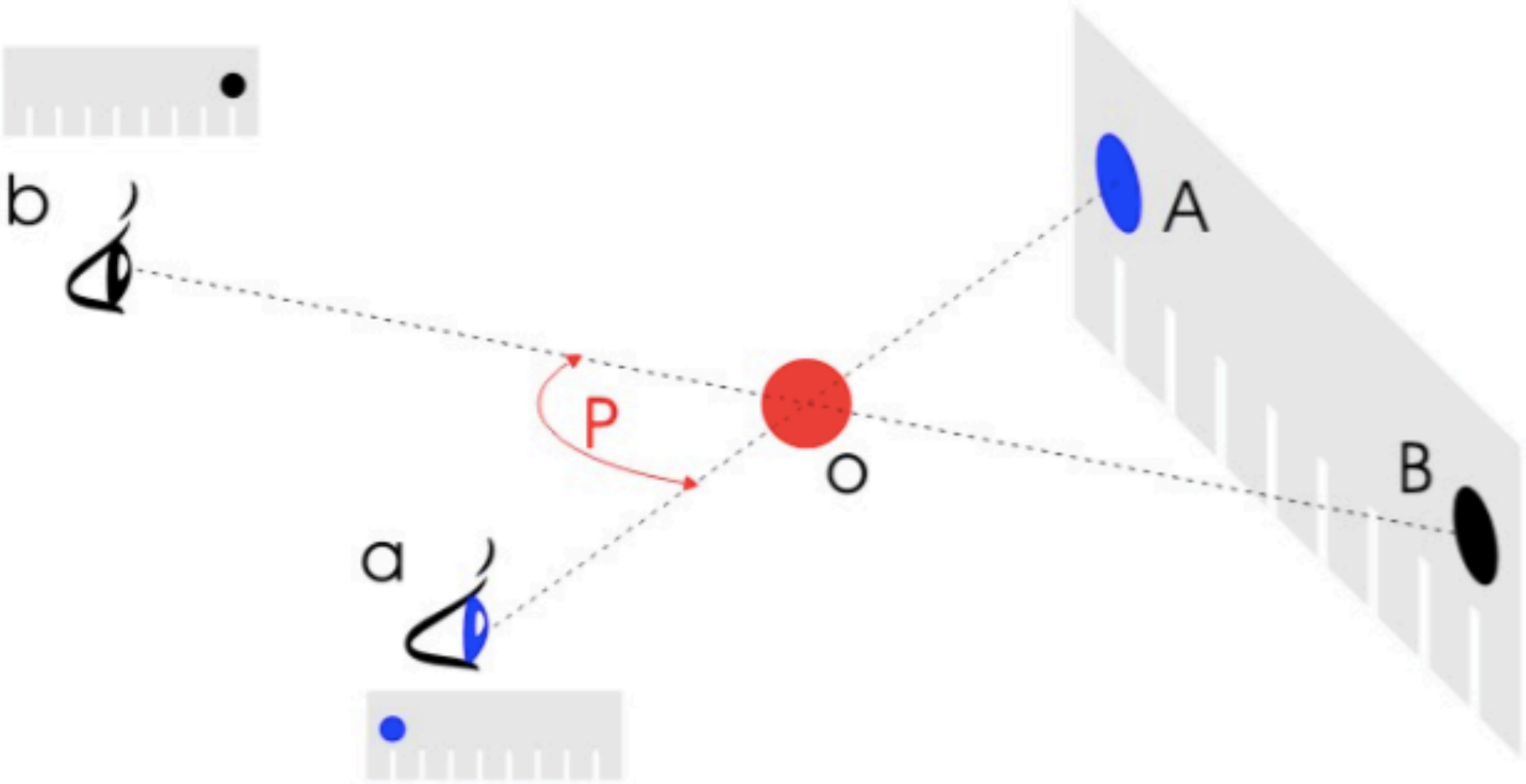
- The invisible 3rd dimension in the sky: depth (distance) and how we measure it;
- Distance ladder and its first step: parallax;
- Familiarity with combining magnitudes;
- Stellar motions: true and apparent.


Southern Cross
α Centauri
(Toliman, Rigilkent)
β Centauri
(Hadar)
Canopus
(α Carinae)
Sirius
(α Canis Majoris)
© Jan Hattenbach 2014
jan.hattenbach@astronomie.de

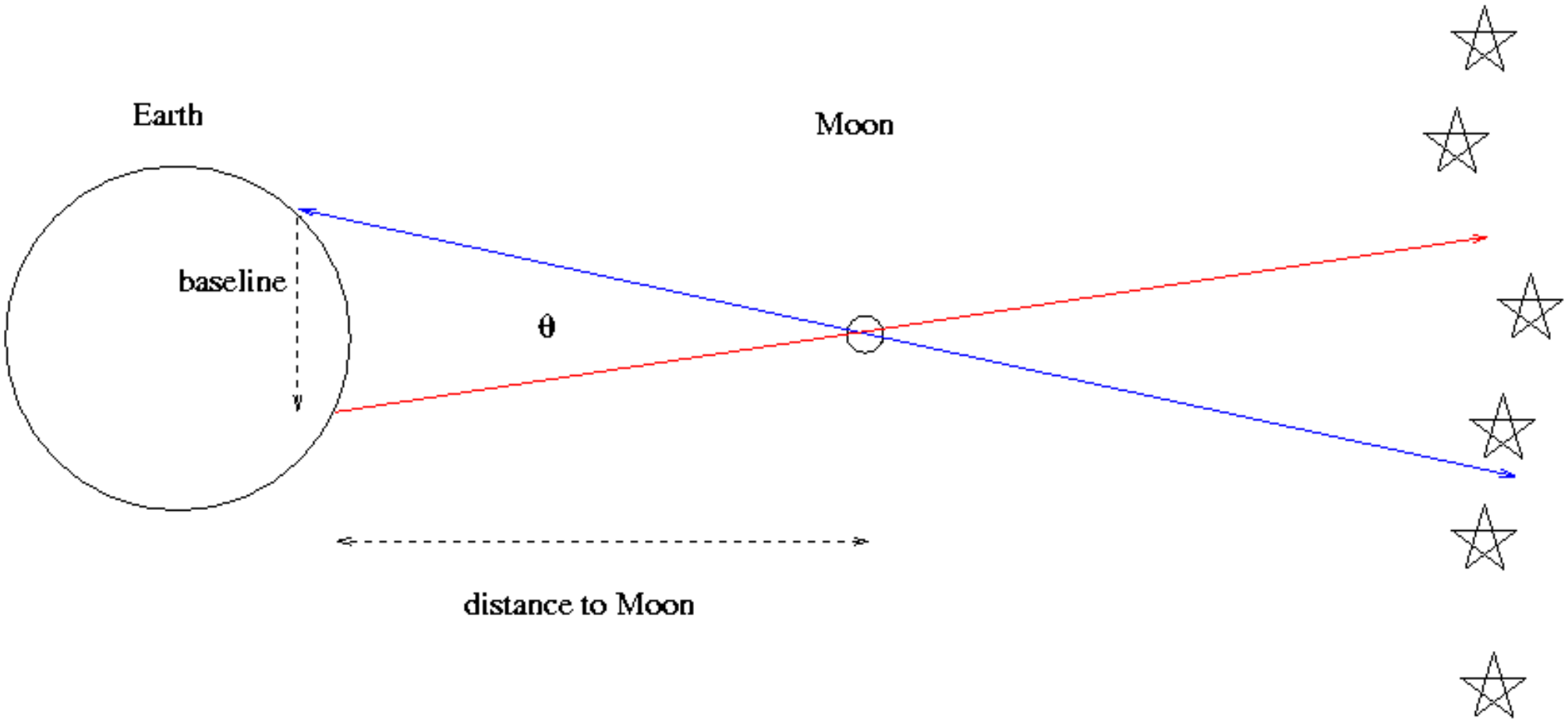

The Big Dipper Stars
Alkaid
210 light-years
from Earth
Dubhe
105 light-years
Mizar
88 light-years
Merak
78 light-years
Phecda
90 light-years
apparent shape of the
Big Dipper traced on a plane
50 light-years from Earth
Alioth
68 light-years
Megrez
63 light-years
Earth
© 2006 Encyclopædia Britannica, Inc.


THE SUN'S CLOSEST NEIGHBORS
WISE 0855-0714
(distance 2014)
6 LIGHT YEARS
WISE 1049-5319
(distance 2013)
Barnard's Star
(distance 1916)
4 LIGHT YEARS
Alpha Centauri
(distance 1839)
Proxima
Centauri
(distance 1917)
2 LIGHT YEARS
OORT CLOUD
Sun

Parallax



Motion Parallax


Earth
Moon
baseline
θ
distance to Moon

Lunar Parallax

Lunar Parallax Demonstration Project - Update 2004 October 28

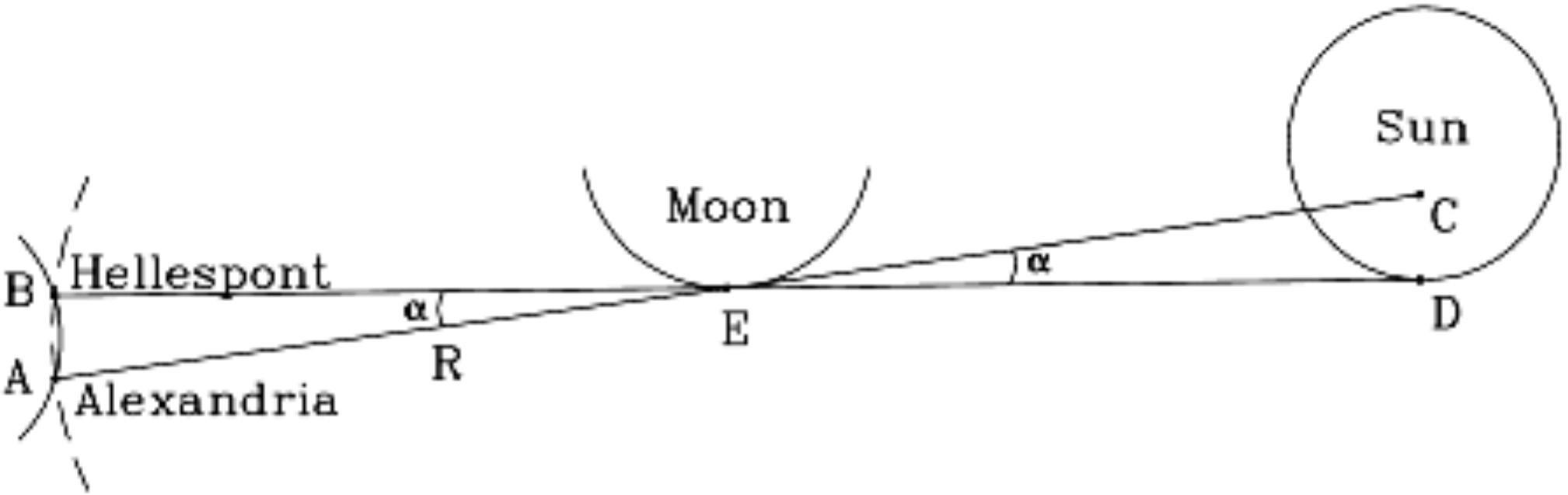
http://www.DigitalSky.org.uk/lunar_parallax.html

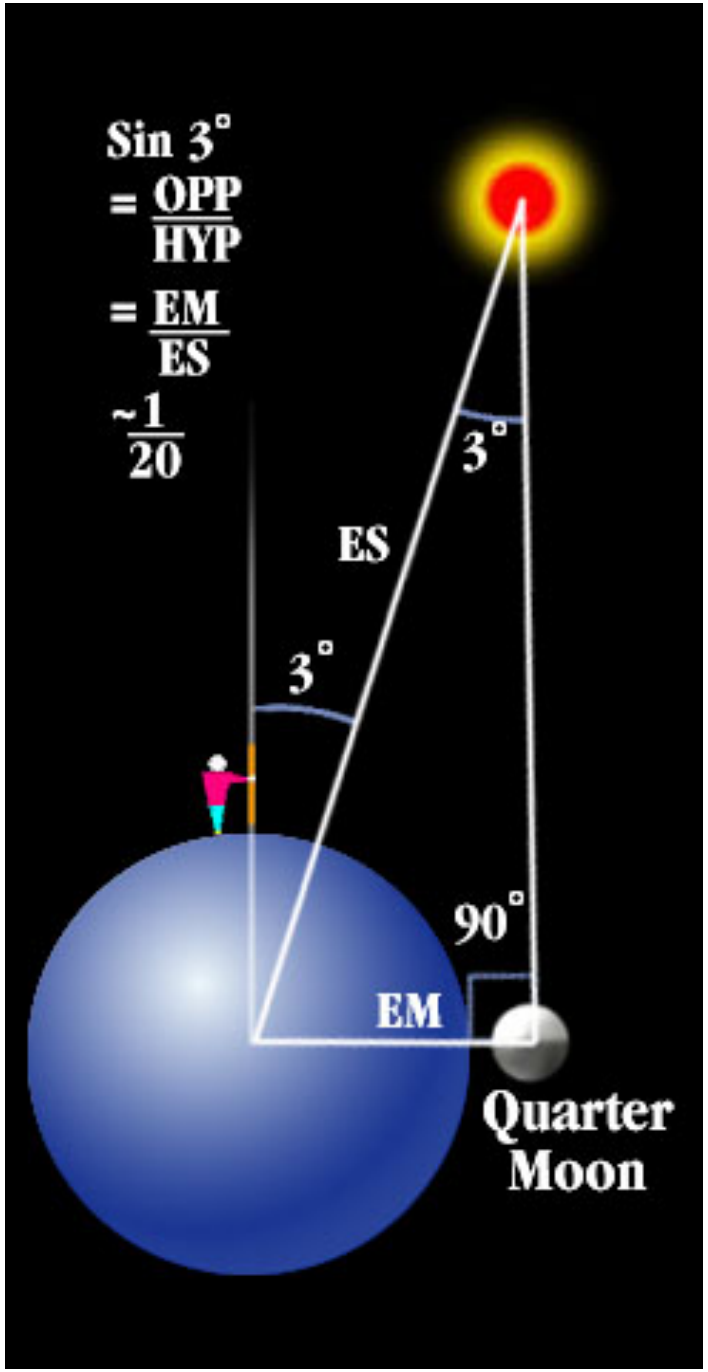
Upper Moon - Gerardo Addiego
Lower-left-hand Moon - Pete Cleary
Background stars, lower-right-hand Moon and image composition - Pete Lawrence

Pete Lawrence,
Selsey, UK

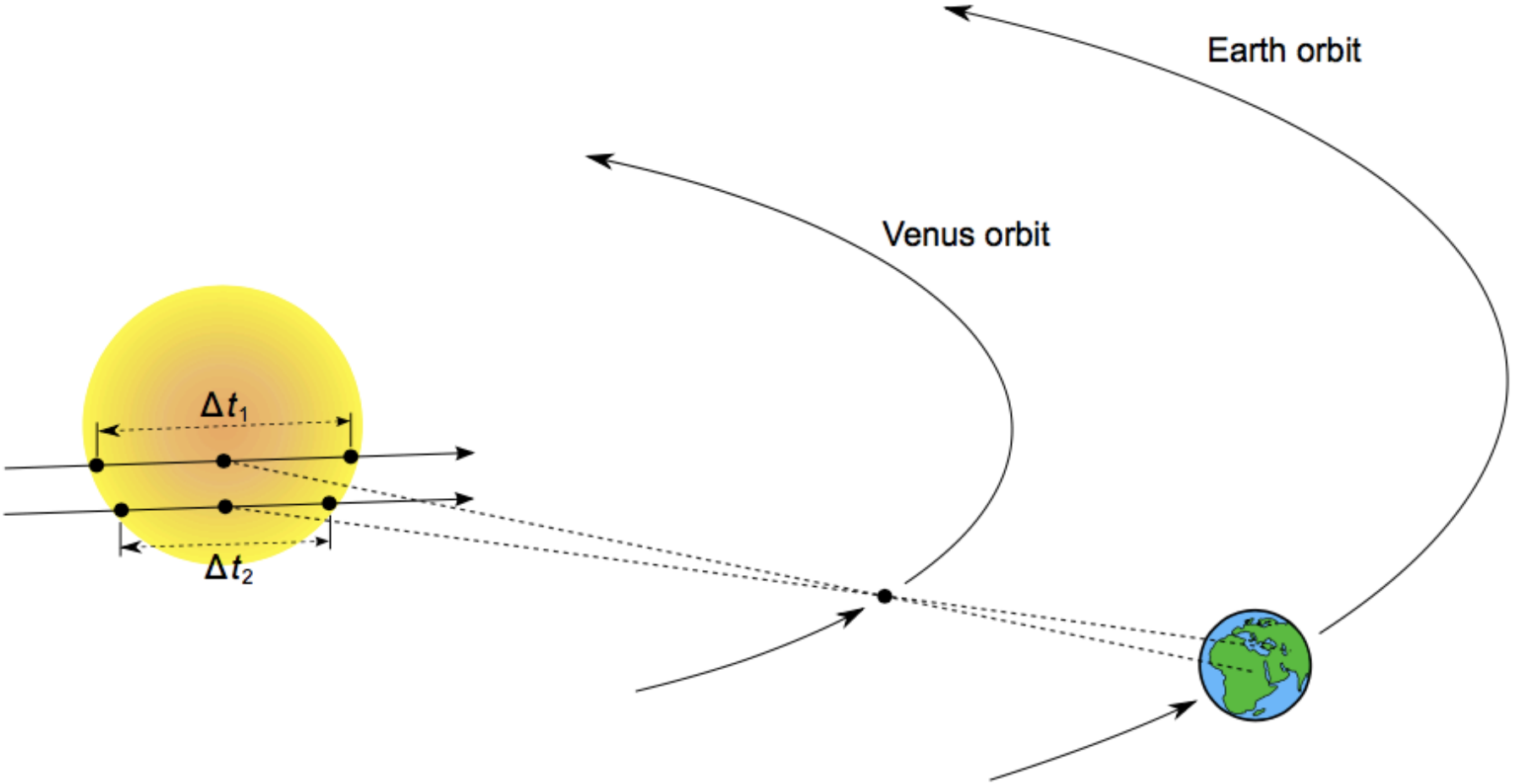
Location A

Location B



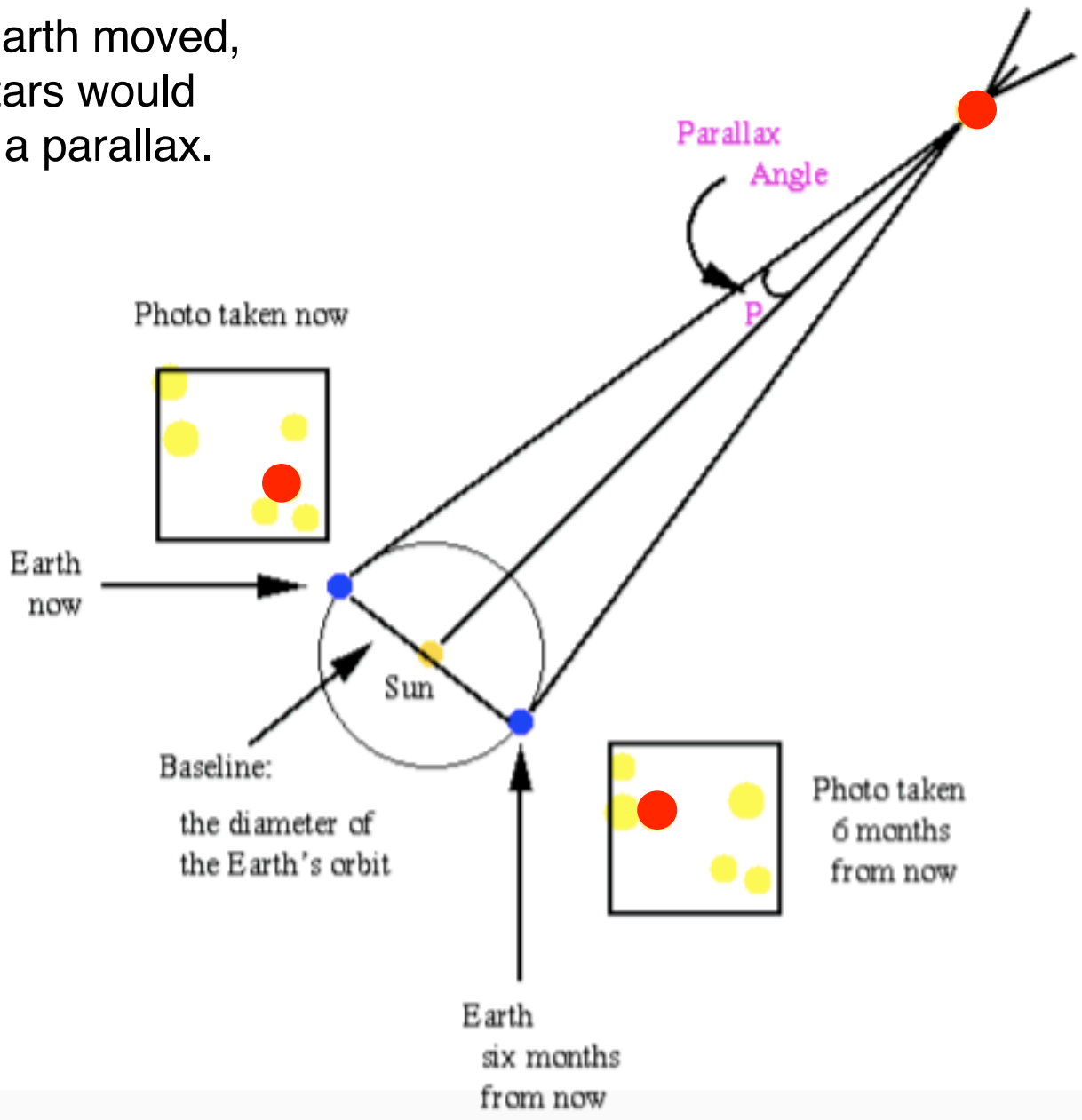

Sin 3°
= OPP / HYP
= EM / ES
~1/20
3°
ES
3°
90°
EM
Quarter Moon

Distance to the Sun

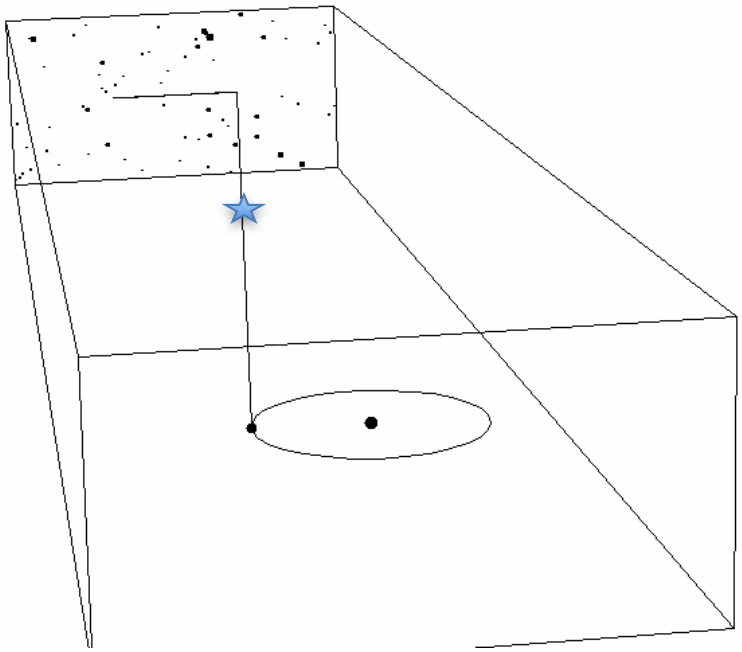


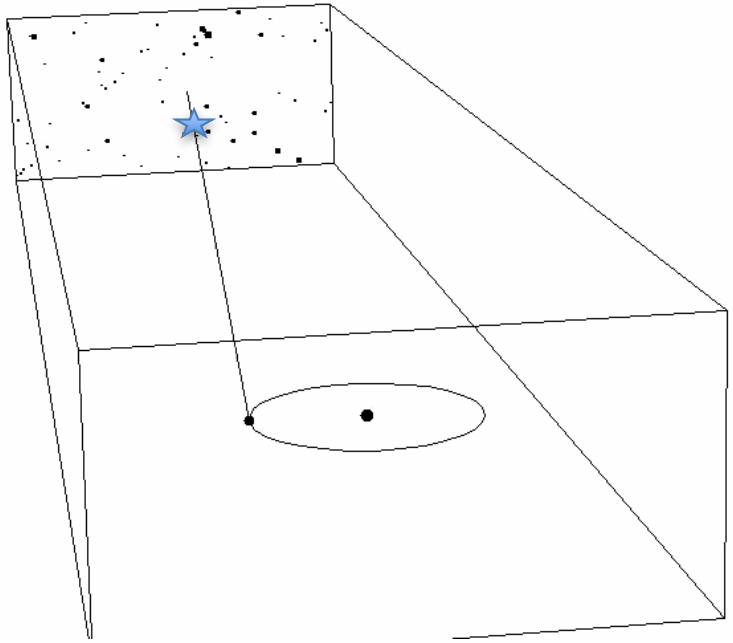
Annual Parallax

If the Earth moved, the stars would show a parallax.



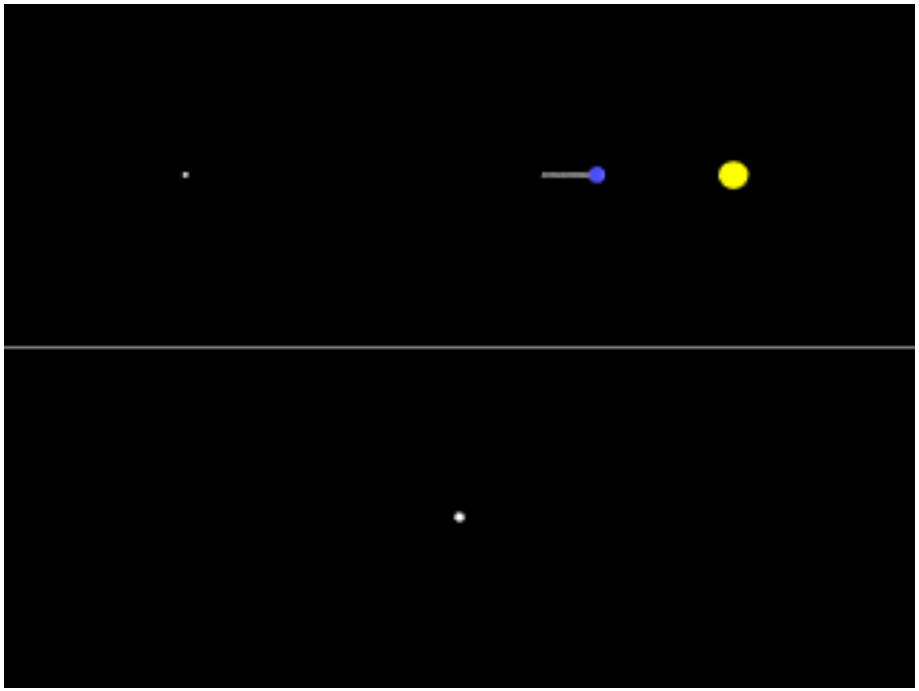
Annual Parallax





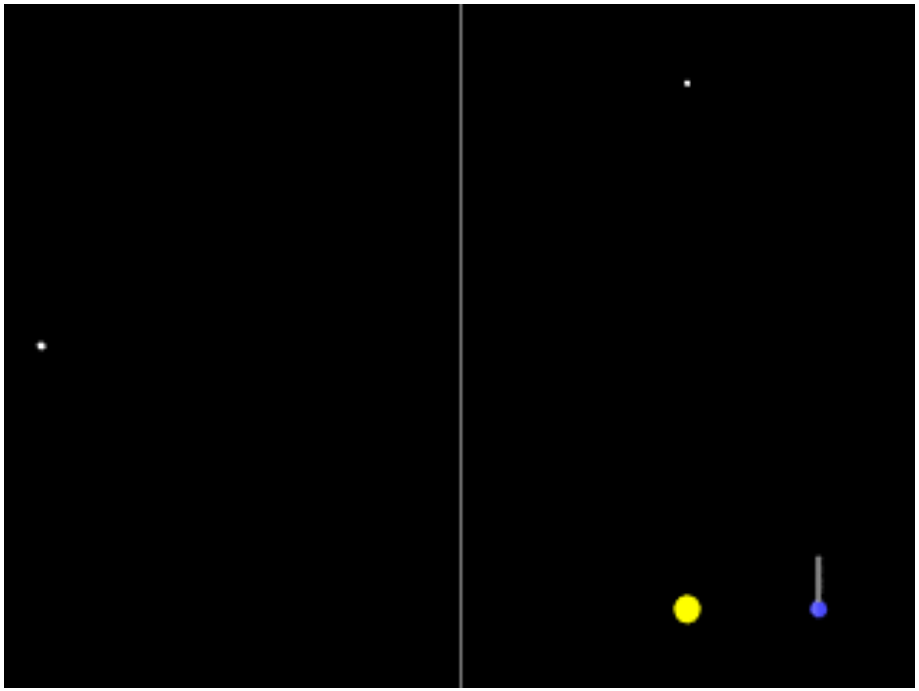
Annual Parallax – Star at Ecliptic

A LINE!

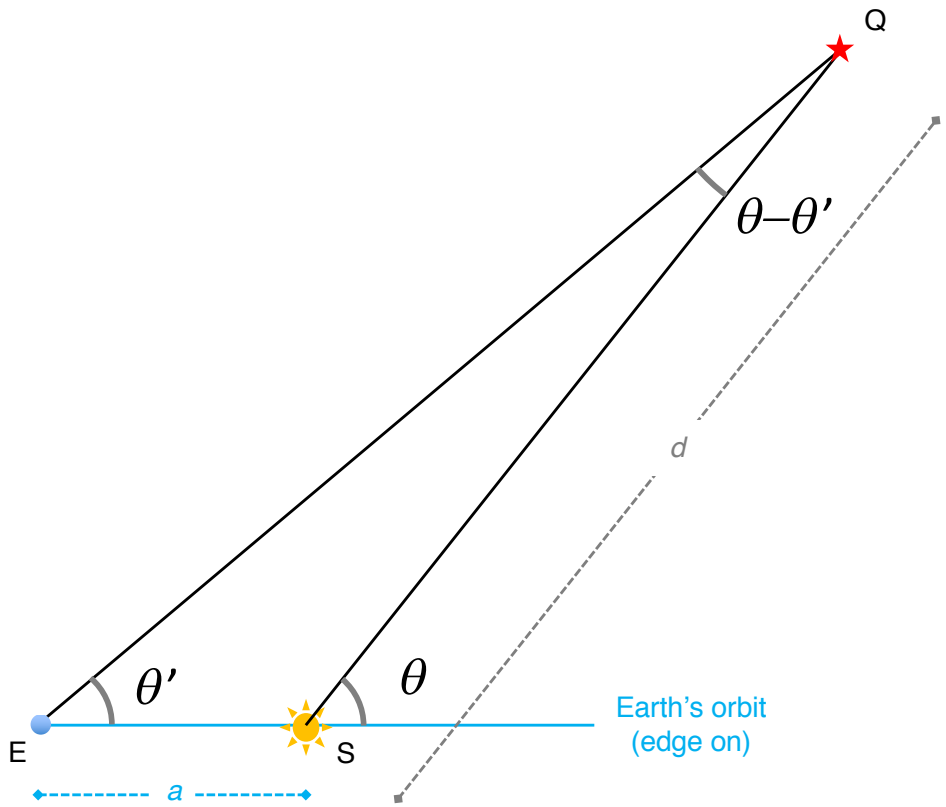


Annual Parallax – Star at Ecliptic Pole

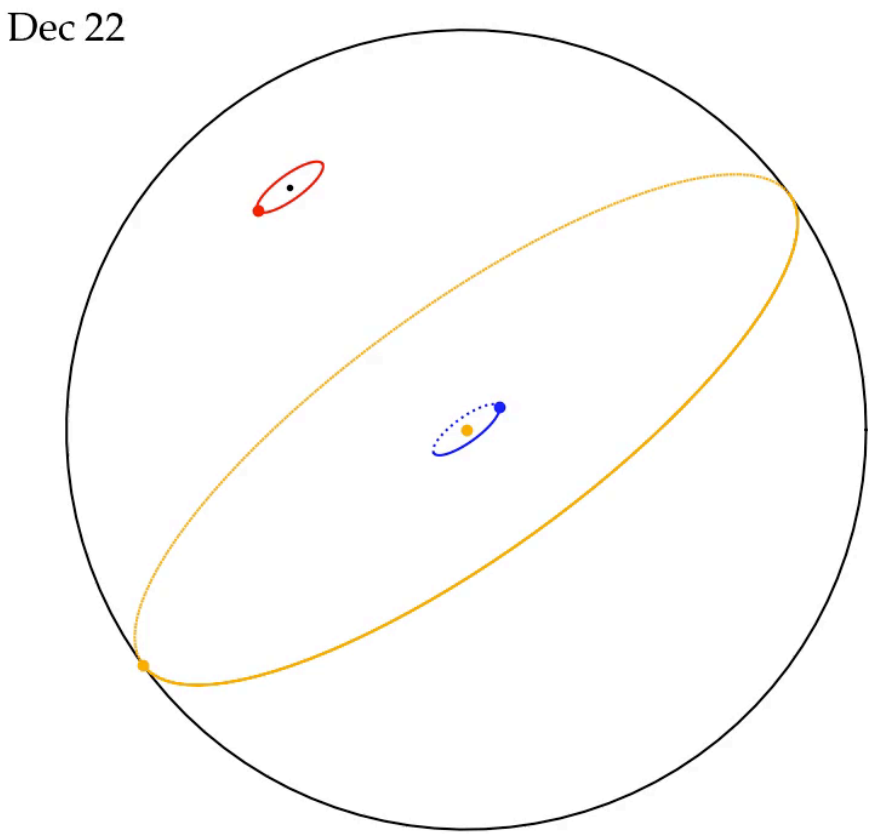
A CIRCLE!



Annual Parallax – star at arbitrary ecliptic latitude

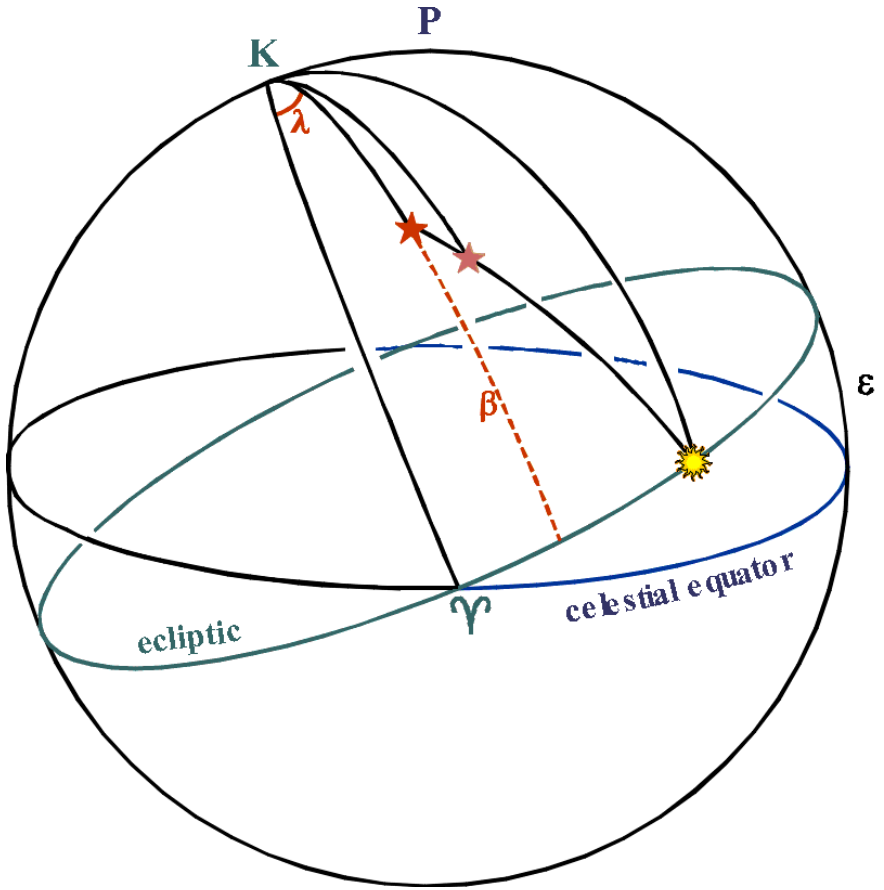


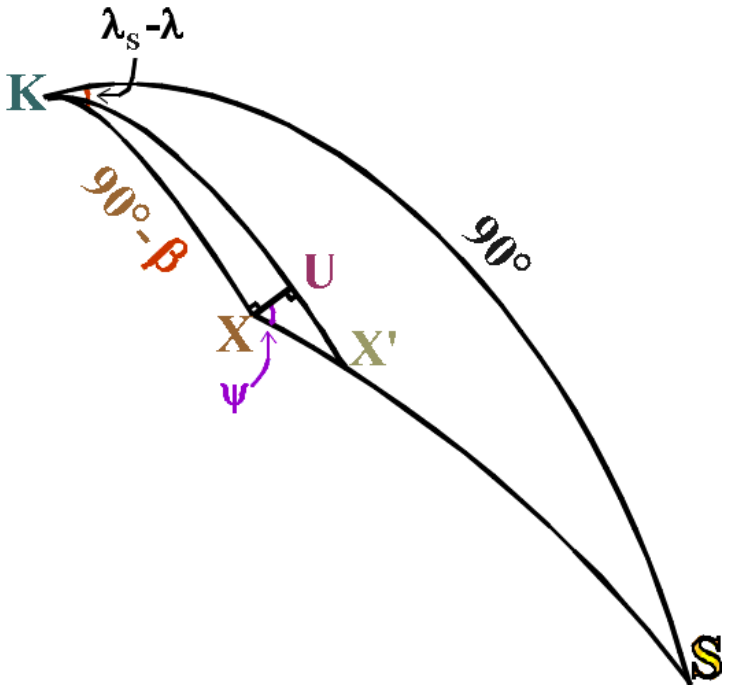
Annual Parallax



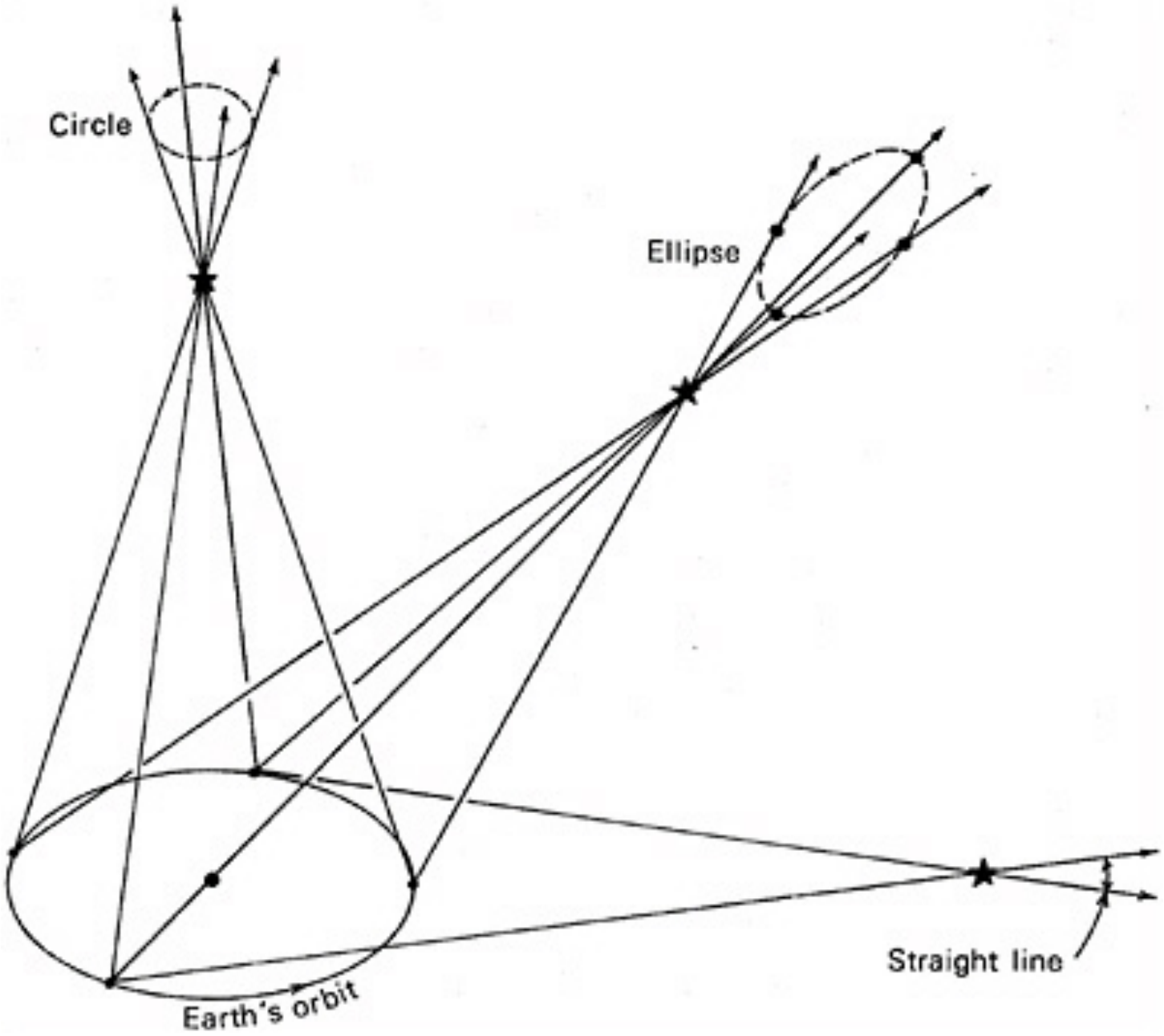
. Earth
. Sun
. Star's shifted position
. Star's true position

- The shift follows the Sun's apparent motion
- The shift is along the line connecting the Sun and the star

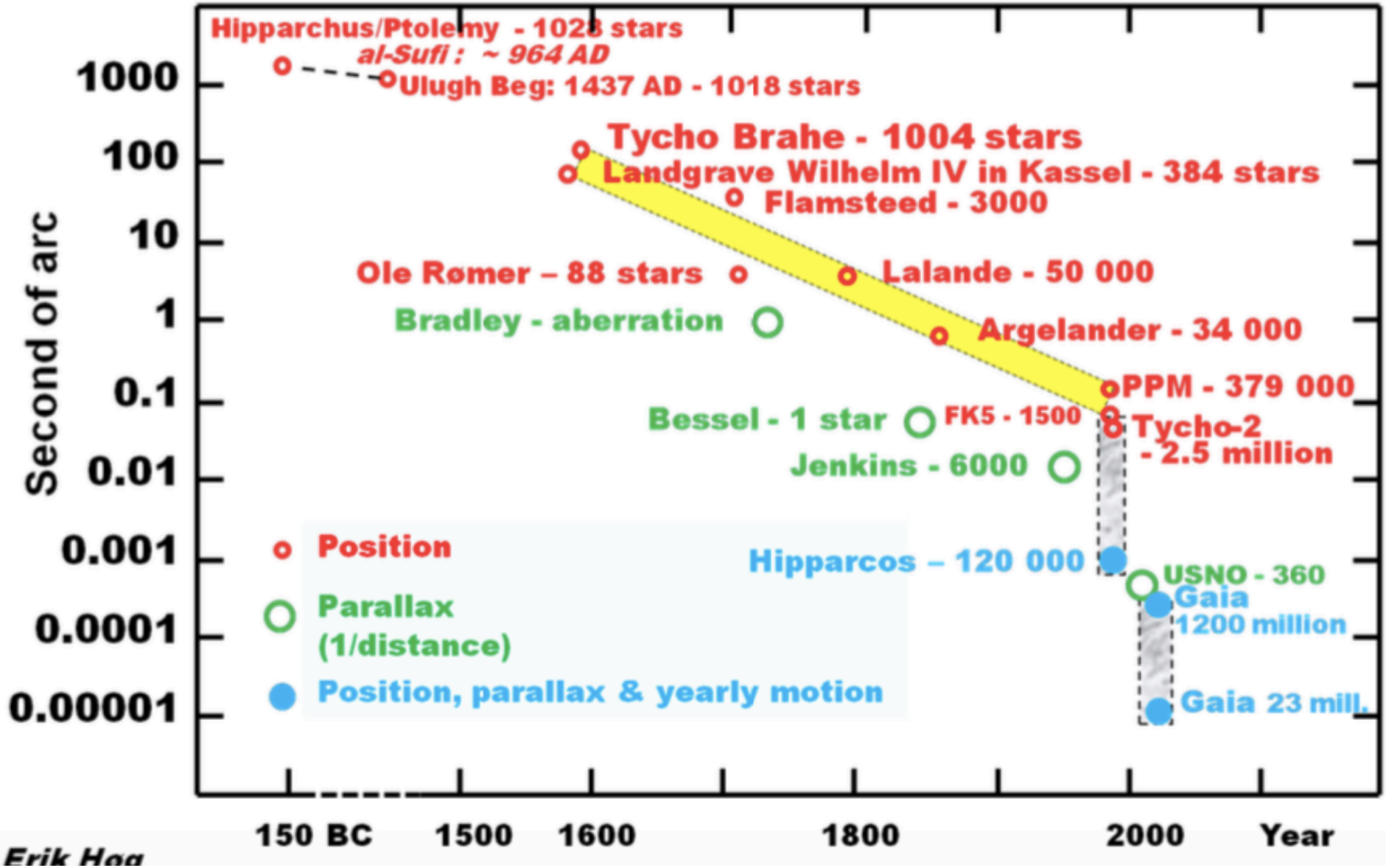

P
K
λ
β
ε
ecliptic
♈
celestial equator


λS -λ
K
90°-β
90°
U
X
X'
ψ
S

Parallax



Astrometric Accuracy during 2000 Years

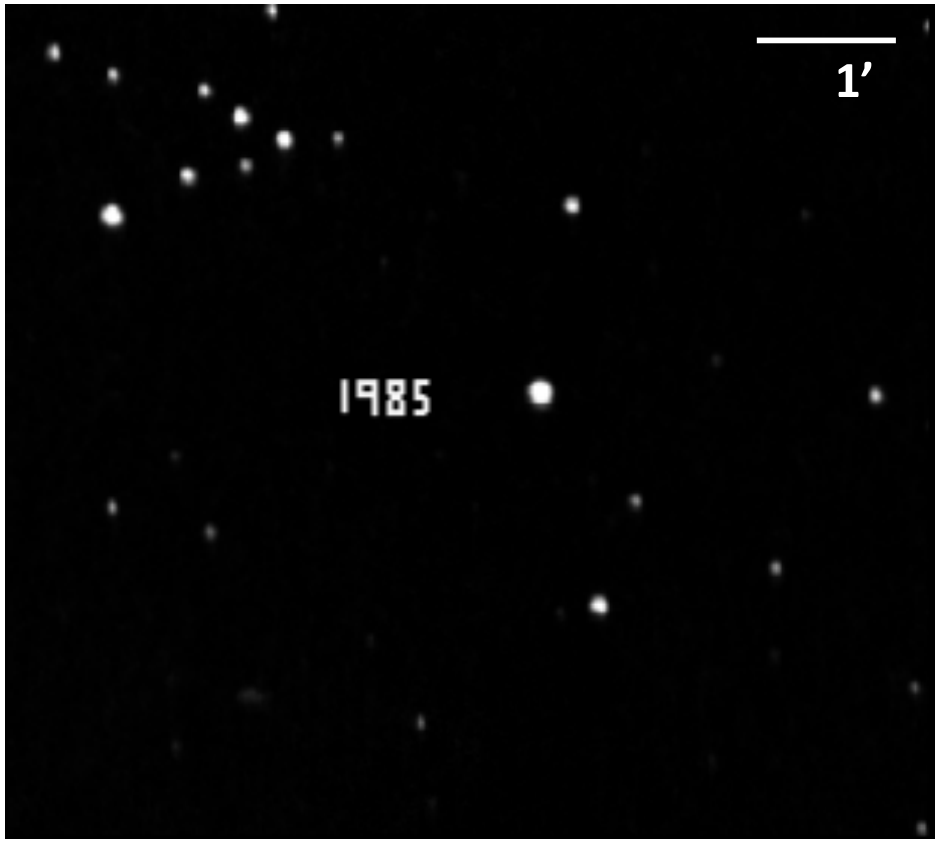


Erik Høg

End of Class 1 of parallax (Sept 3rd, 2019)

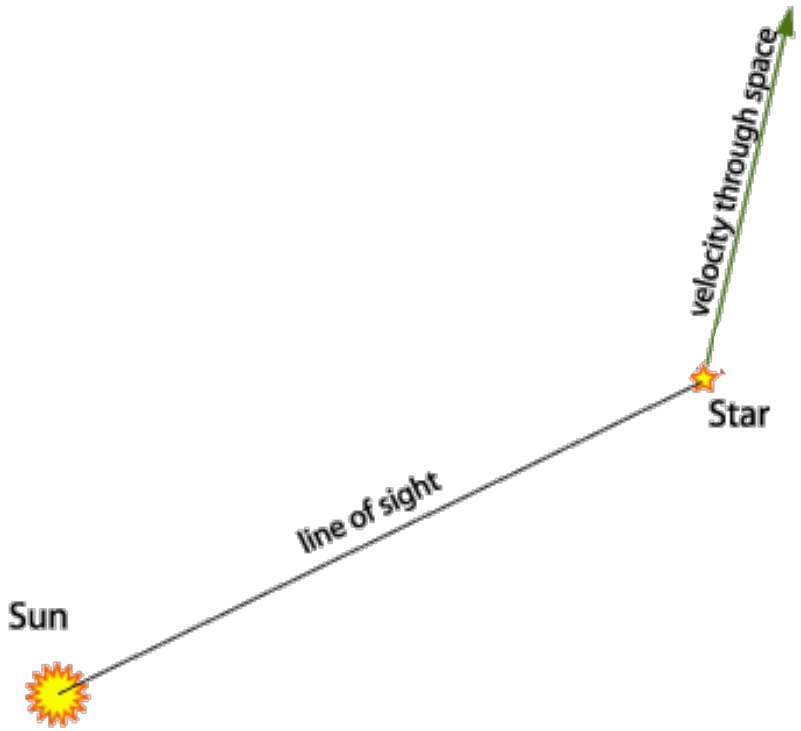
What didn't work: going through the elliptical was beyond the point.
I could have solved an exercise or gone through the other types of parallax.

Proper Motion

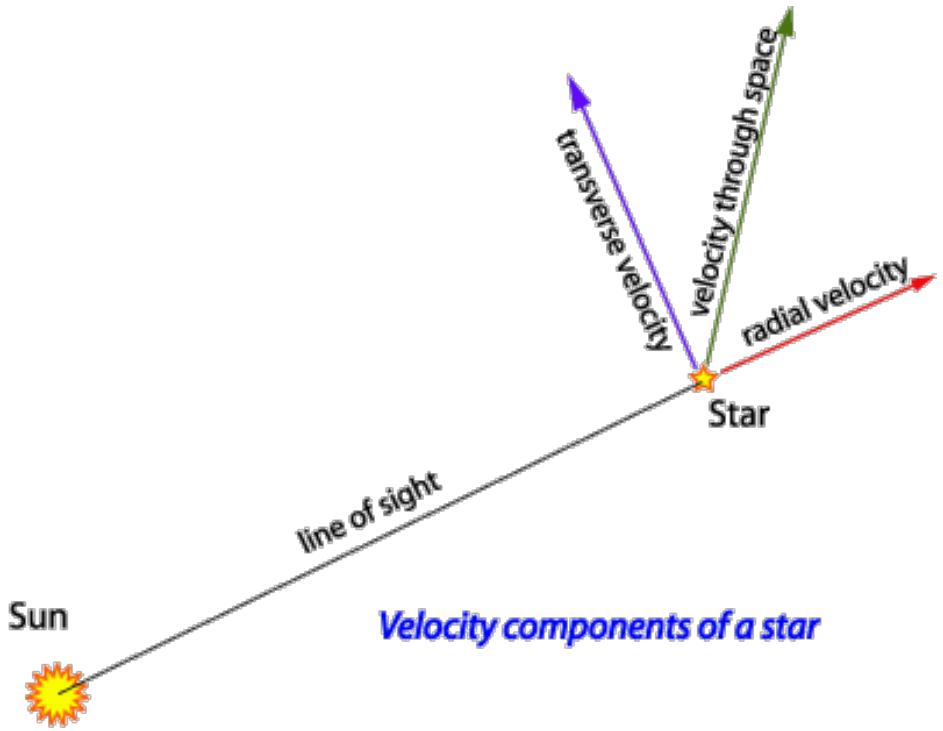


Barnard's Star

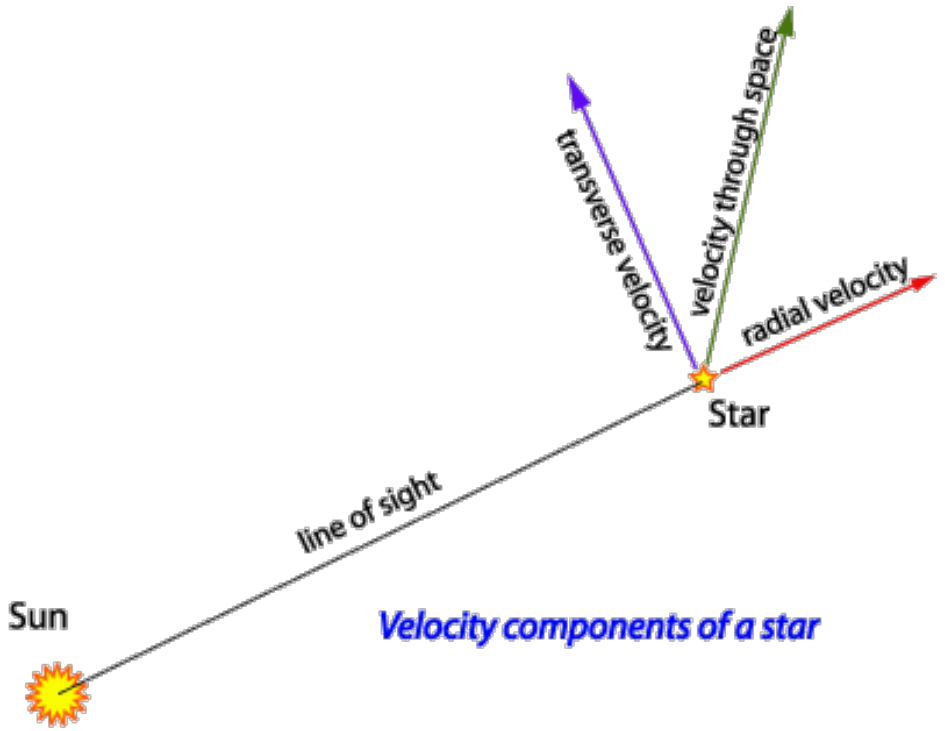
How do we measure proper motion?



Stellar velocity components

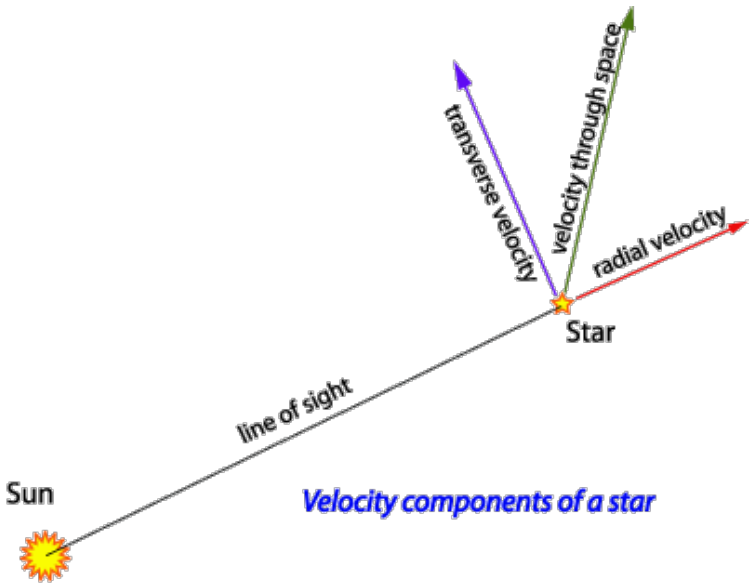


Stellar velocity components



We see the *transverse velocity* as a star's "*proper motion*", which changes its position in the sky.

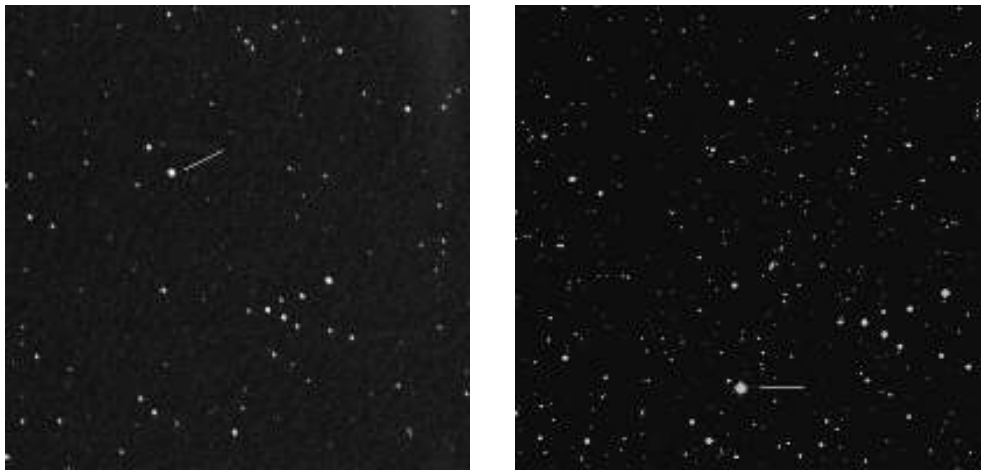
Stellar Motions



Proper motion *is measured in* ***arcsec per year****.*

Typical proper motion: 0.1 ”/yr

Barnard's star

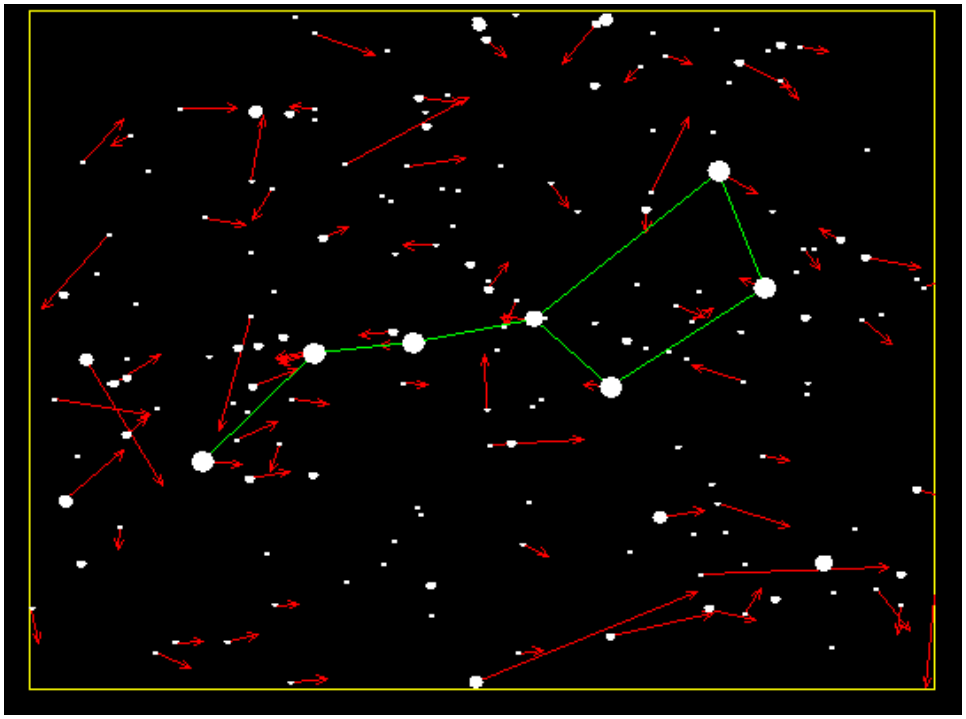


1950 2000

Largest proper motion - **10.3 ”/yr**
(crosses half the moon in a human lifetime)

Stellar Motions

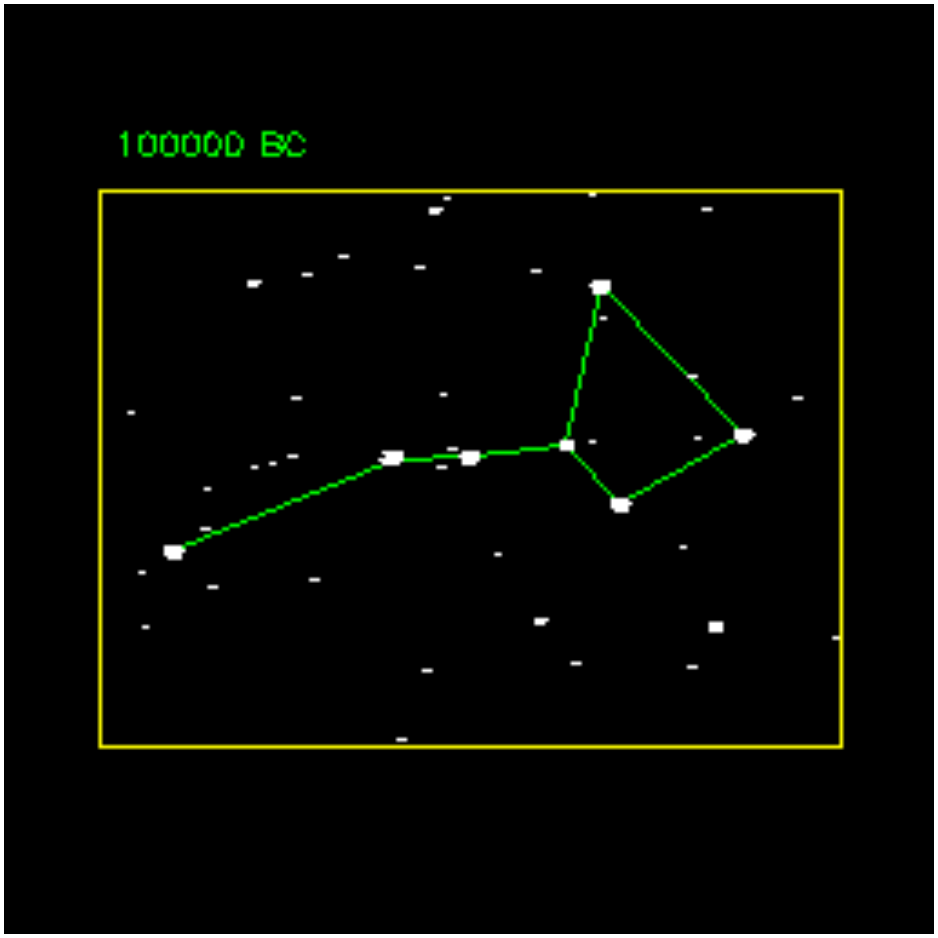
Proper motions of stars at the vicinity of the Big Dipper



Constellations change over time

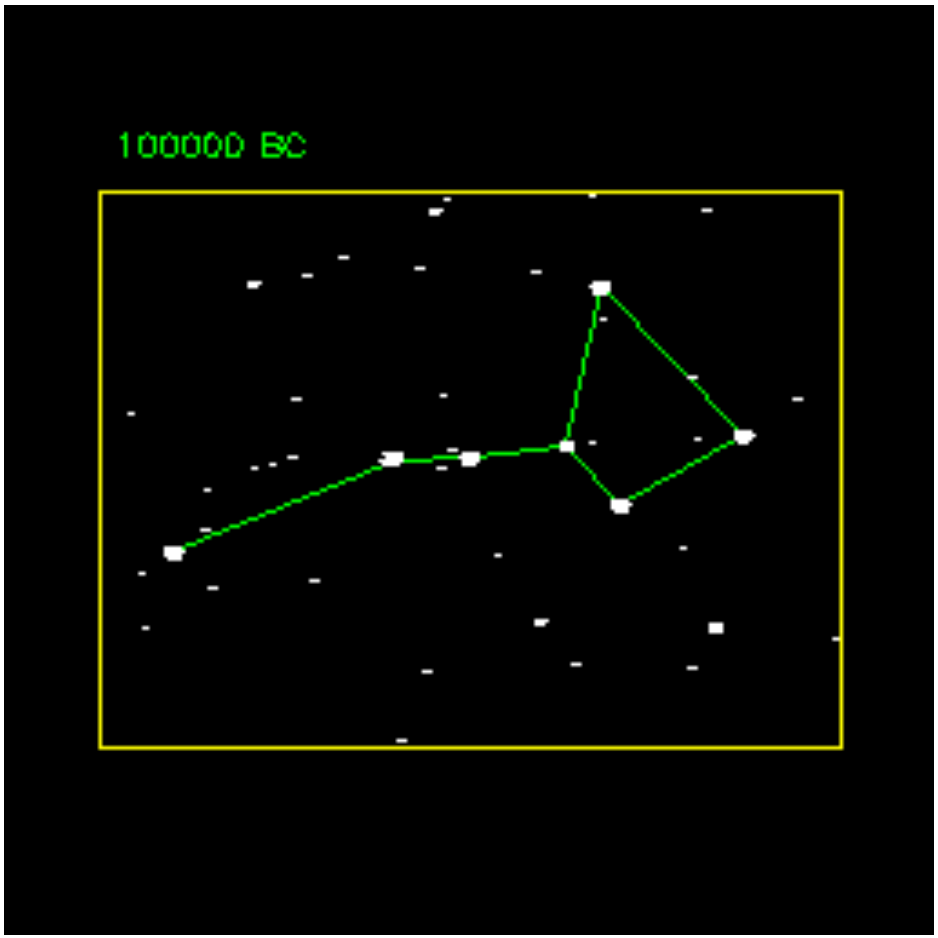
Stellar Motions

Constellations change over time

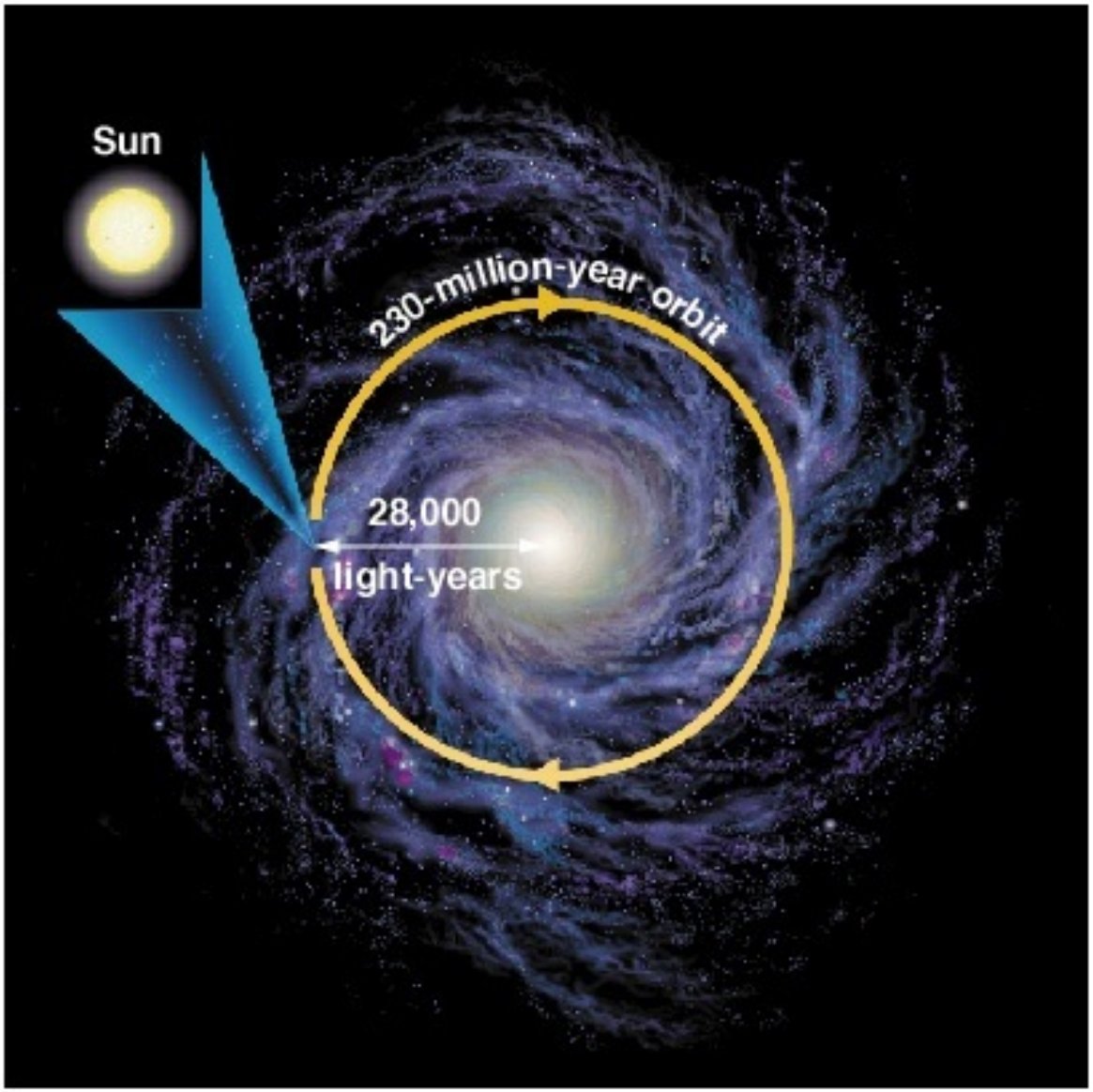


Stellar Motions

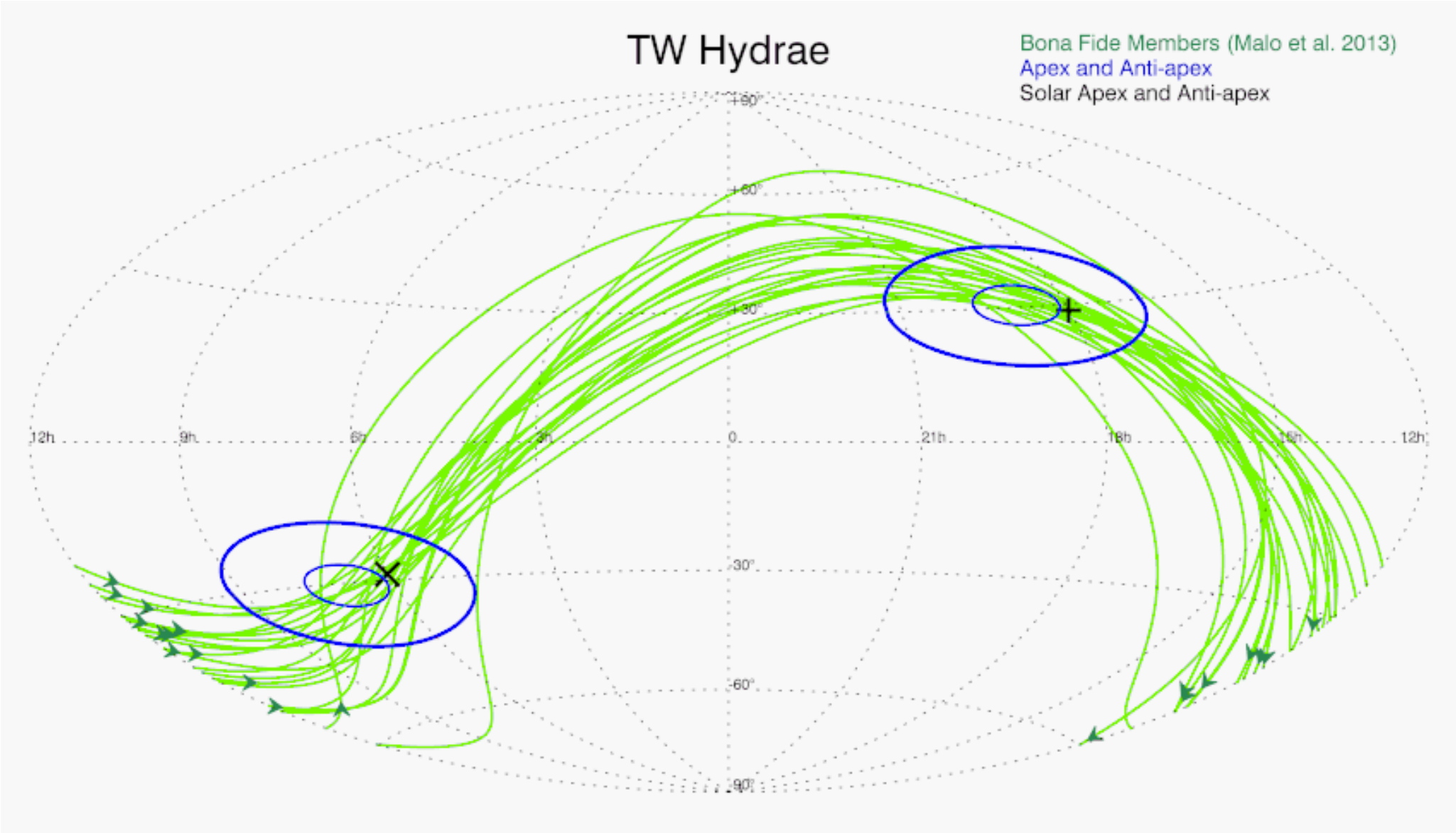
Constellations change over time



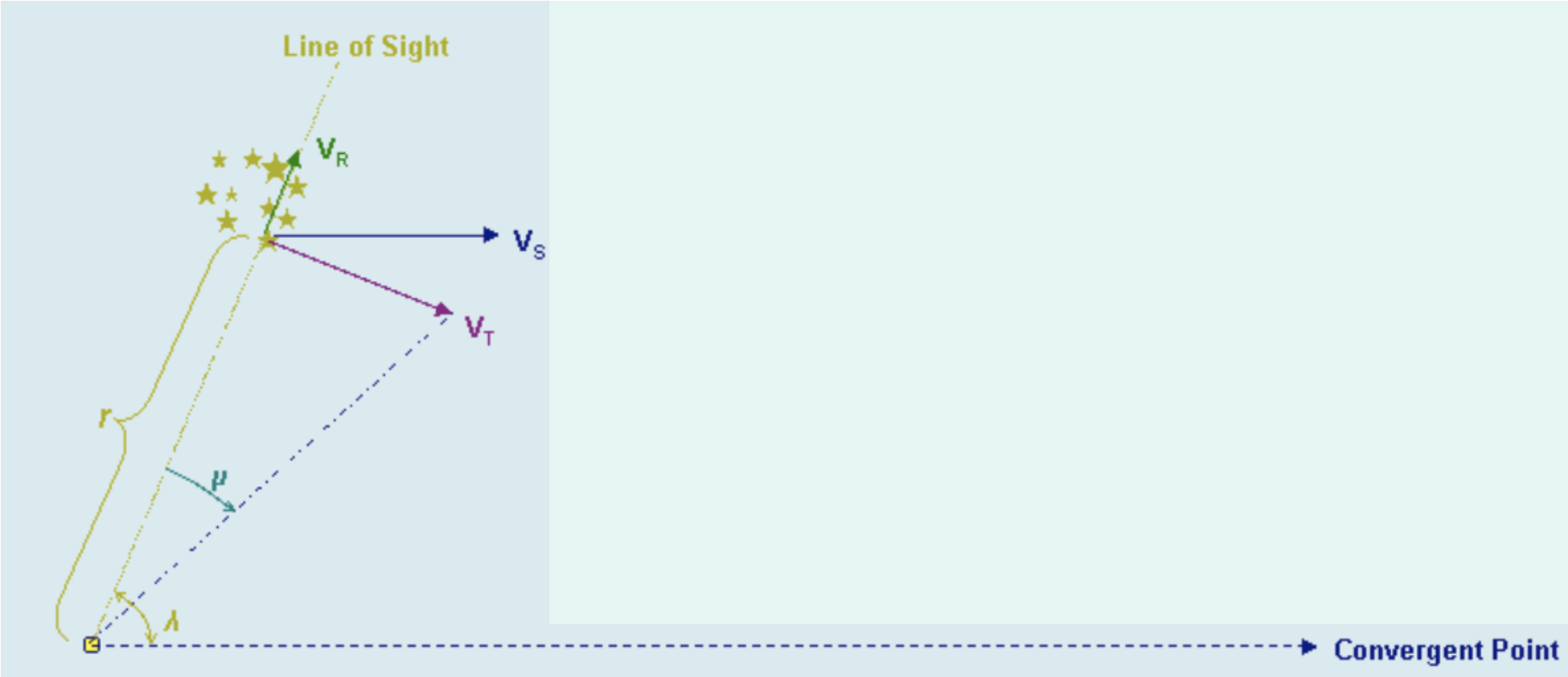
Solar Orbit



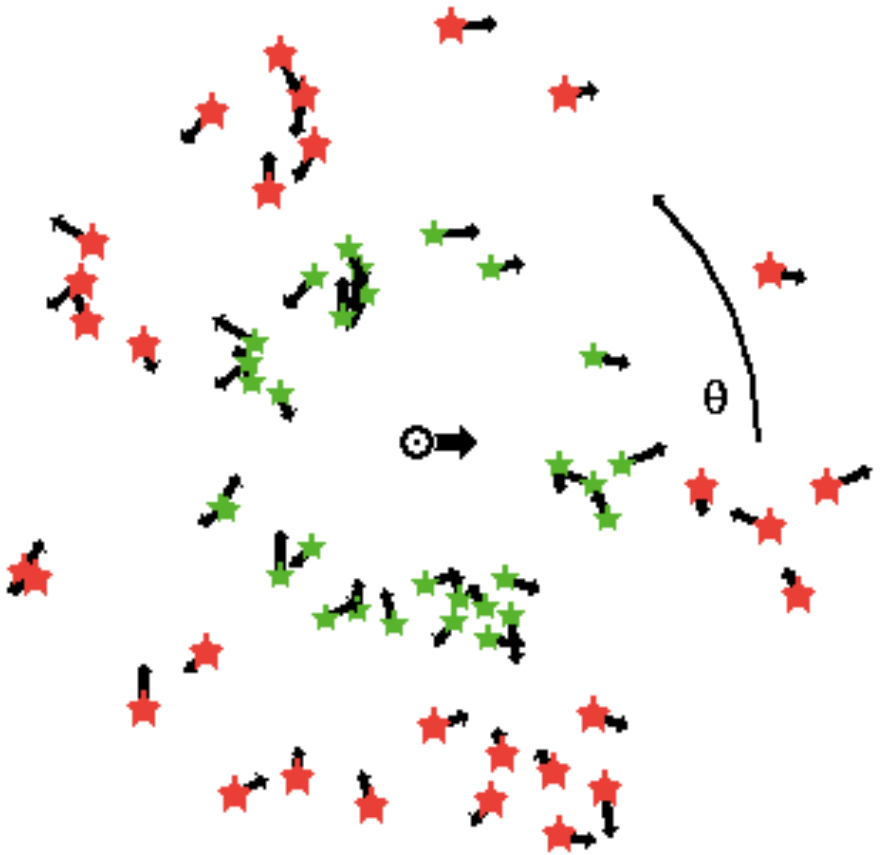
Solar Apex and Anti-Apex



Moving Cluster Parallax



Secular Parallax



Magnitudes

Hipparchus or Ptolemy (sources vary) thought it a good idea to come up with the following scheme :

- The brightest stars we see are of **first magnitude**
- Stars not so bright are of **second magnitude**
- The faintest stars we can see are of **fifth magnitude**

Magnitudes

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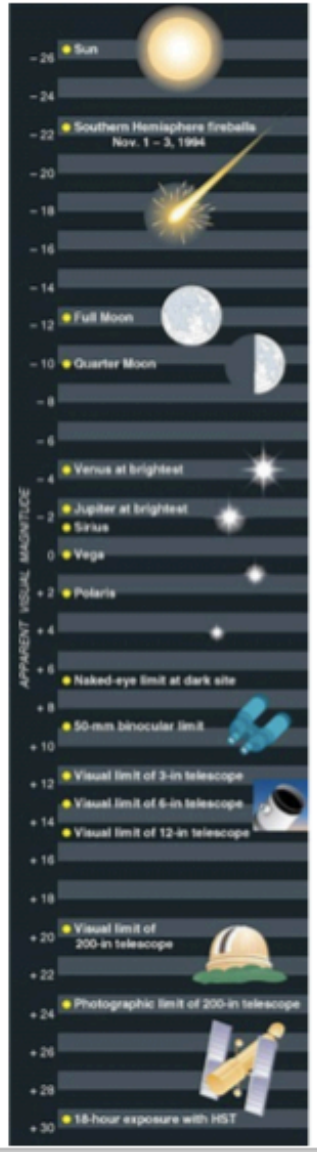
- The faintest stars we can see are of **fifth magnitude**

Bright – Magnitude 1
Dim – Magnitude 5

The scale is **reverse**.
(It's a ranking system)

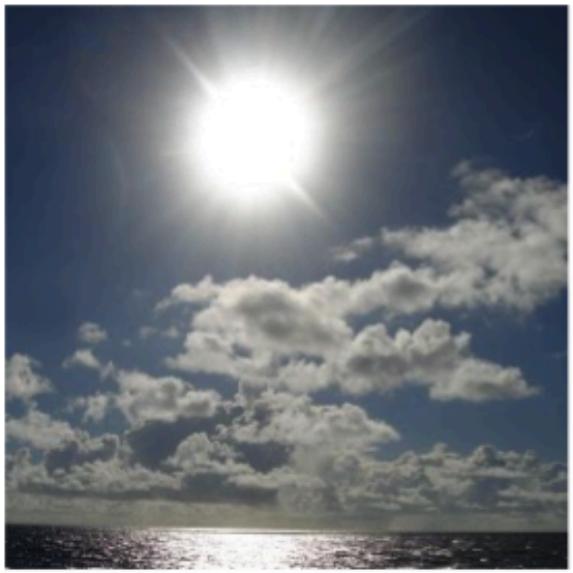
Magnitude

Energy



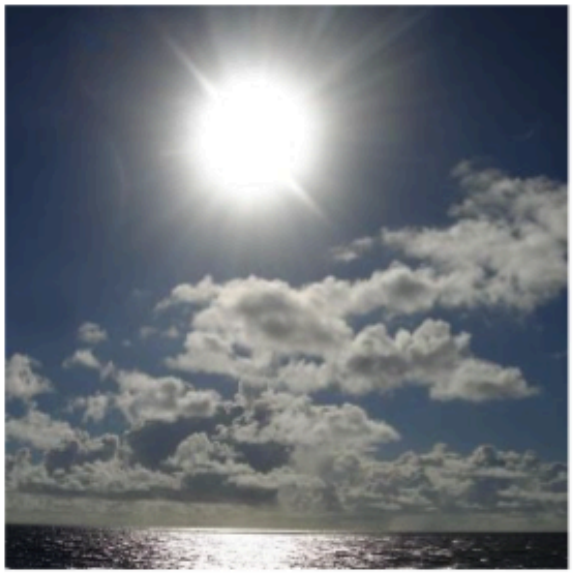
-26	Sun	2.5 x 10^{10}
-22		6 x 10^{8}
-18	Comet	1.6 x 10^{7}
-12	Full Moon	6 x 10^{4}
-10	Quarter Moon	10^{4}
-4	Venus at brightest	40
-2	Jupiter at brightest	6
0	Vega	1
2	Polaris	0.158
6	Naked-eye limit at dark site	0.004
9	50mm binocular limit	2.5 x 10^{-4}
11	Visual limit of 3-in telescope	4 x 10^{-5}
13	Visual limit of 6-in telescope	6 x 10^{-6}
15	Visual limit of 12-in telescope	10^{-6}
20	Visual limit of 200-in telescope	10^{-8}
24	Photographic limit of 200-in telescope	2.5 x 10^{-10}
30	18-hour exposure with HST	10^{-12}

The Moon is 500,000 times dimmer than the Sun as seen from Earth



Yet one can read with nothing but moonlight

The Moon is 500,000 times dimmer than the Sun as seen from Earth

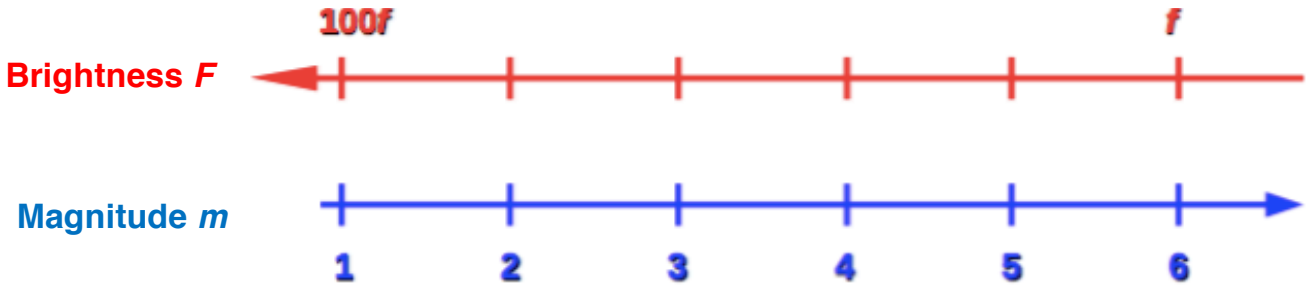


Yet one can read with nothing but moonlight

Because of the huge DAY-NIGHT constrast,
our eyes evolved to adapt to a WIDE RANGE in brightness

Magnitudes

A difference of five magnitudes amounts to a factor 100 in brightness



Magnitudes

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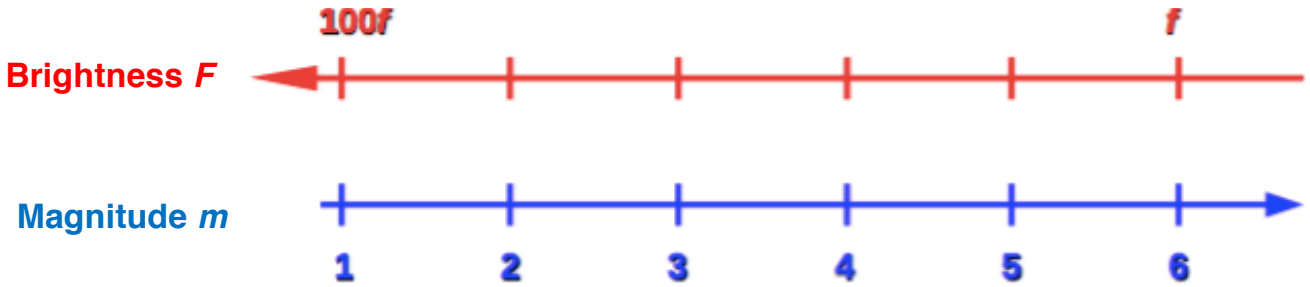
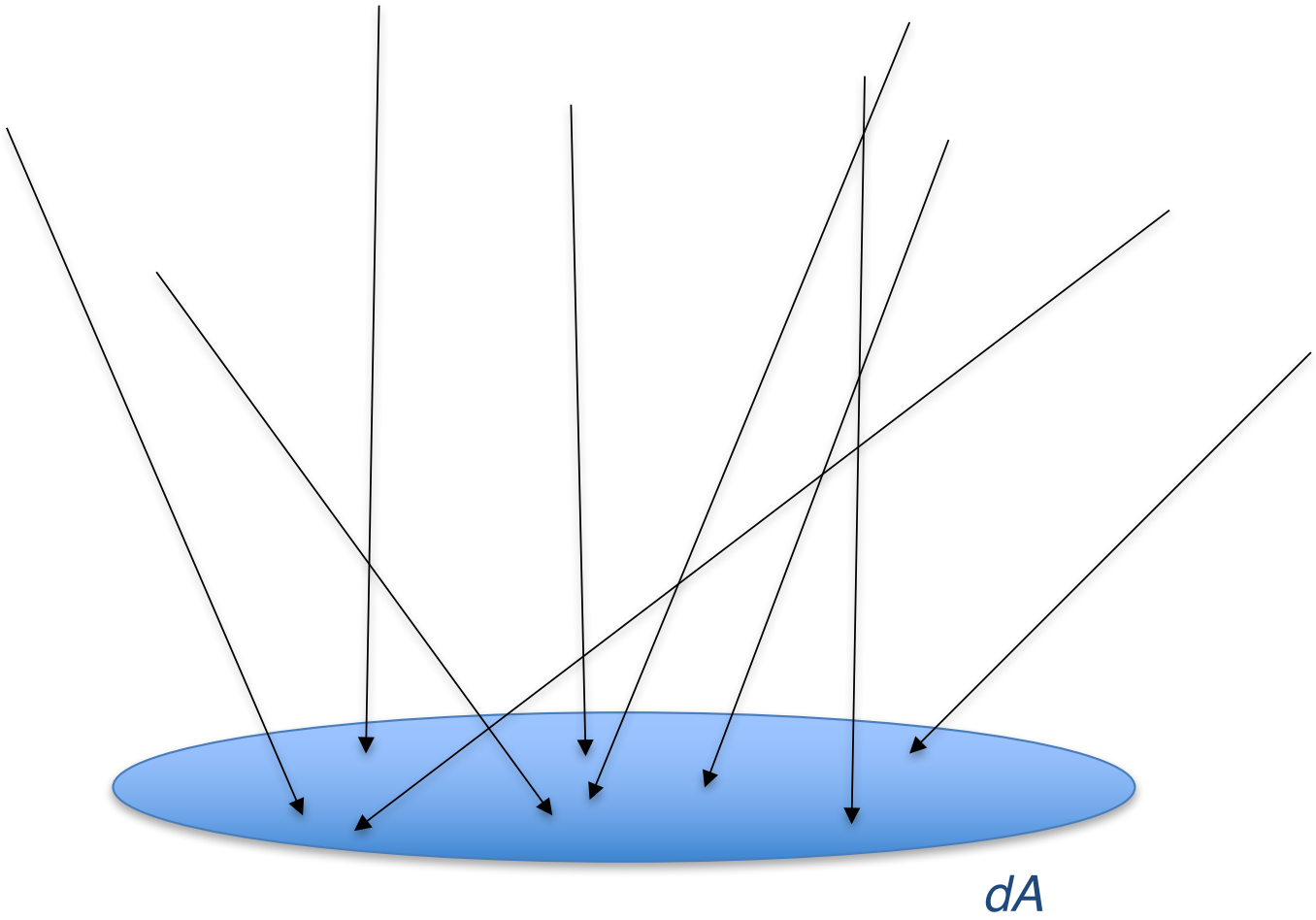
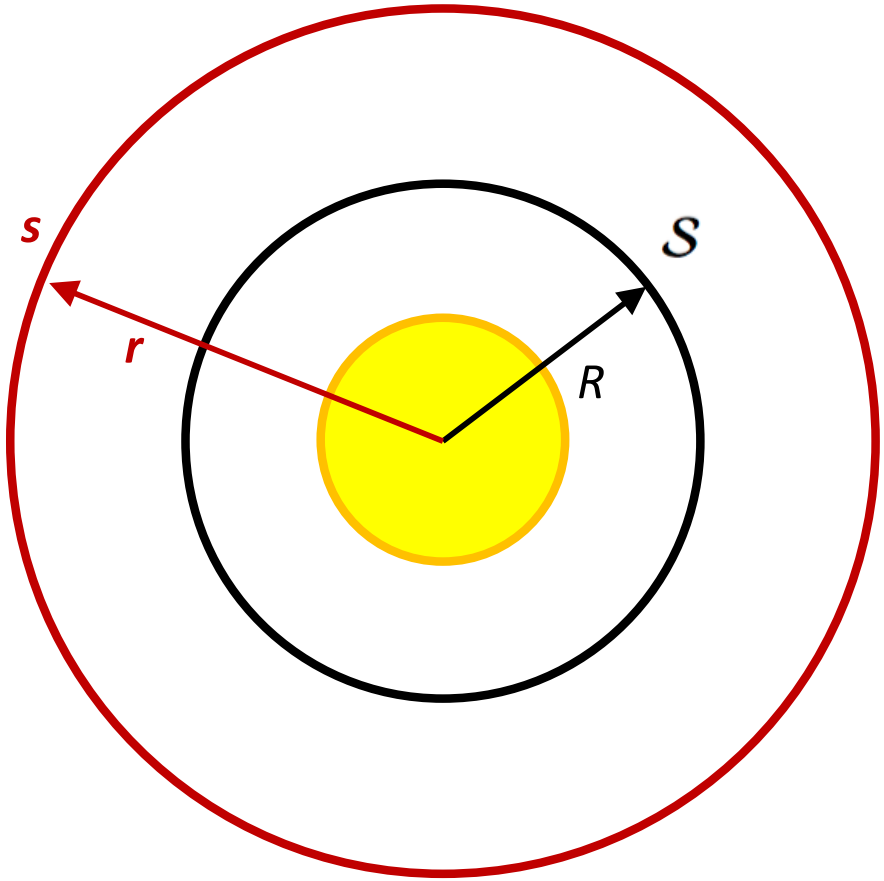


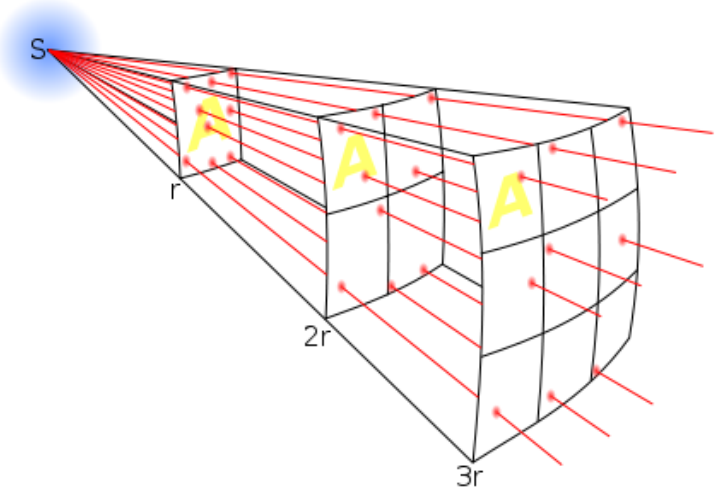
$$m = -2.5 \log F + C$$

- *m* - What Hipparchus came up with
- *F* - What has physical meaning
- *C* - Constant that makes the two systems match

The system is defined so that the magnitude of VEGA is zero


dA

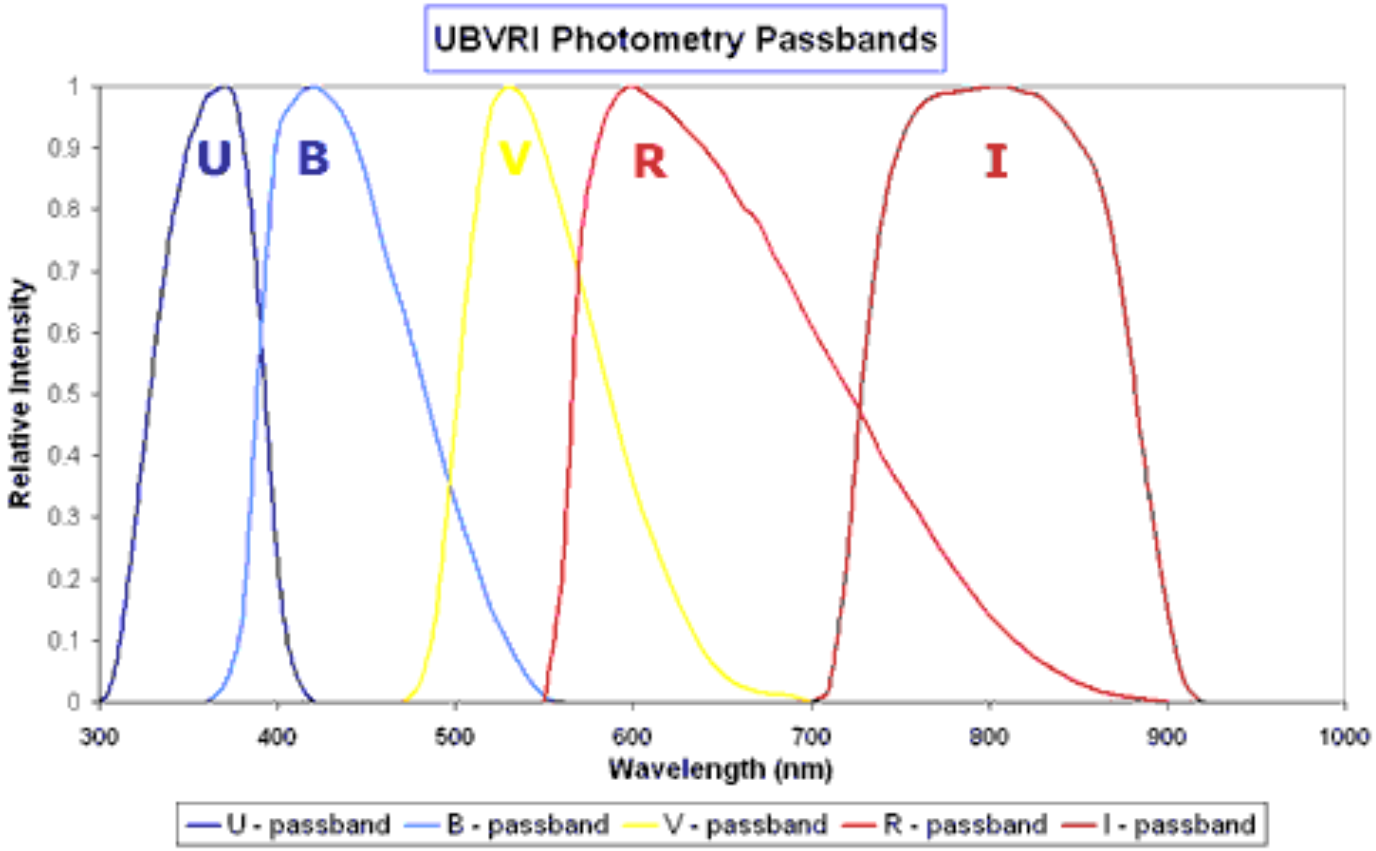

s
r
S
R

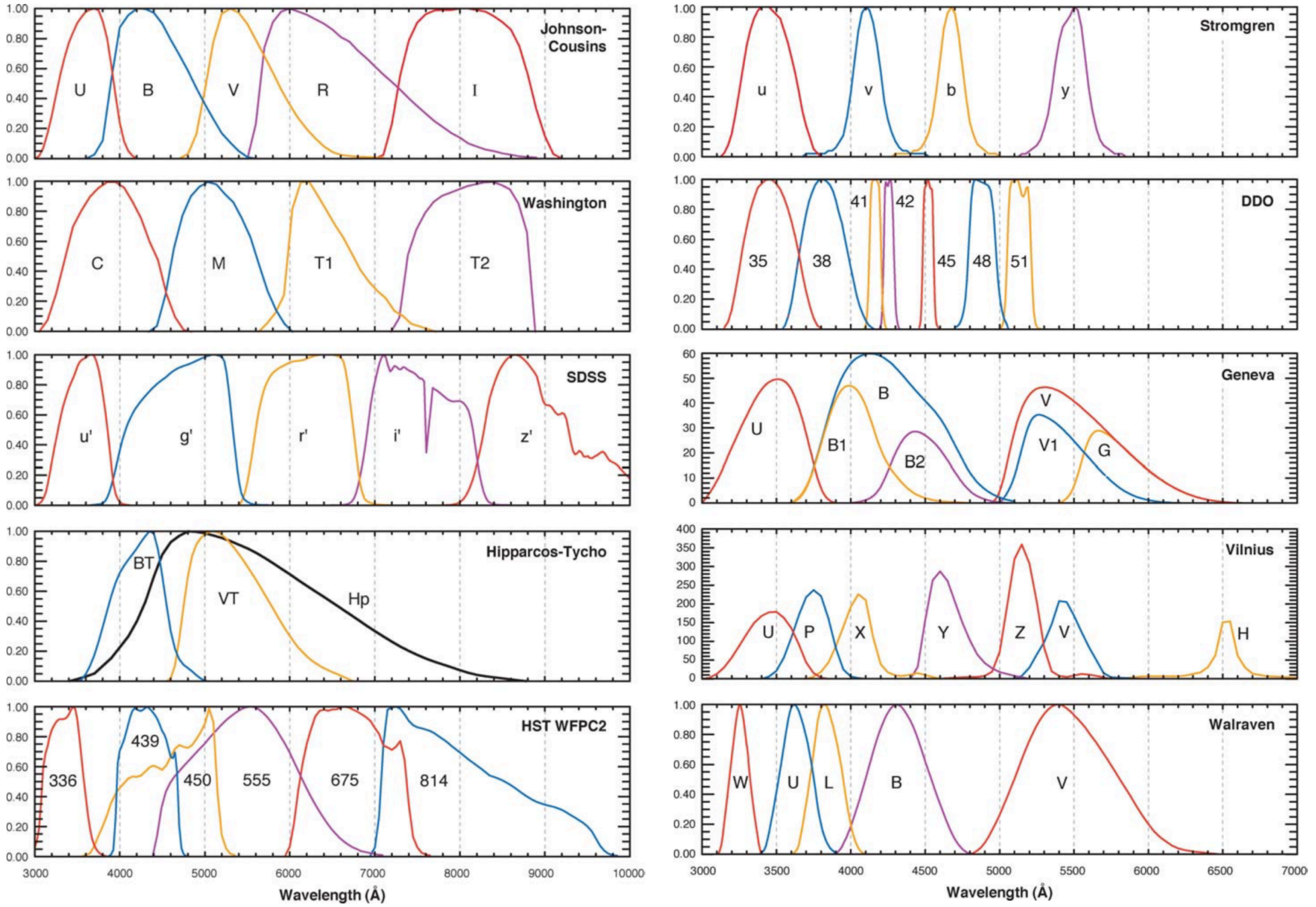


$$F \propto 1/r^2$$

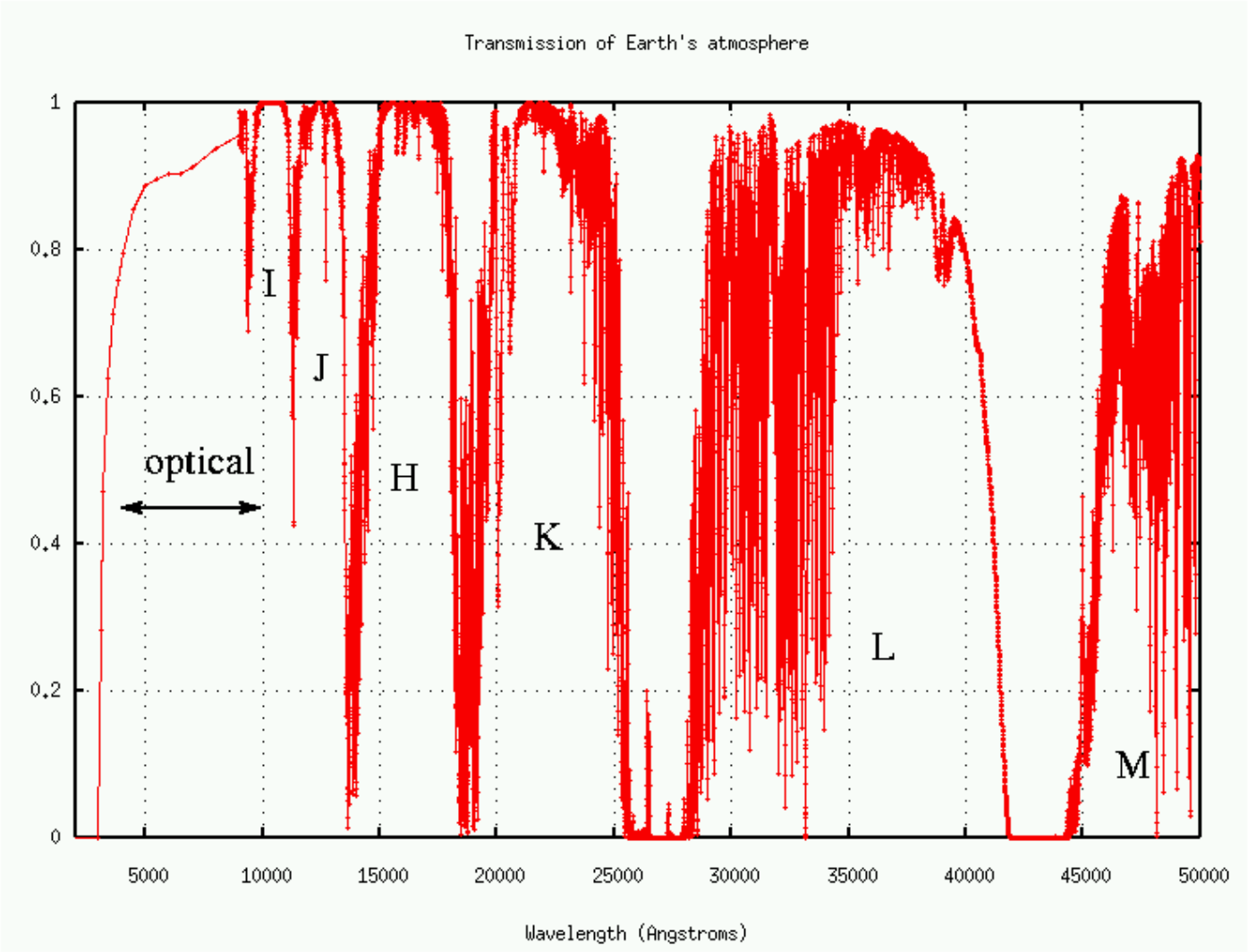
As distance increases, the same energy spreads through a larger area

Johnson UBVRI photometric filters

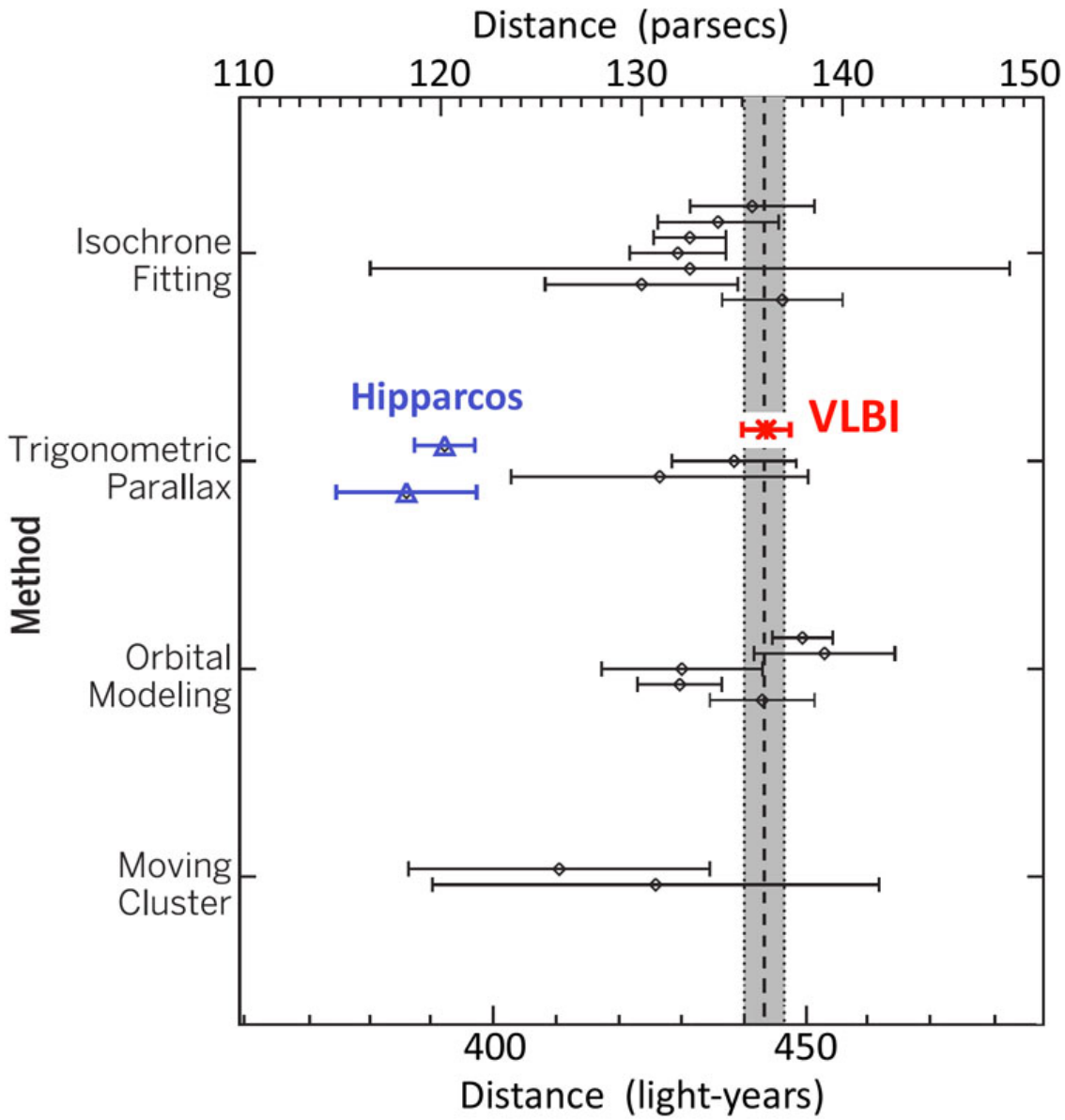



Johnson-Cousins
U
B
V
R
I
Washington
C
M
T1
T2
SDSS
u'
g'
r'
i'
z'
Hipparcos-Tycho
BT
VT
Hp
HST WFPC2
336
439
450
555
675
814
Wavelength (Å)
Stromgren
u
v
b
y
DDO
35
38
41
42
45
48
51
Geneva
U
B
B1
B2
V
V1
G
Vilnius
U
P
X
Y
Z
V
H
Walraven
W
U
L
B
V
Wavelength (Å)

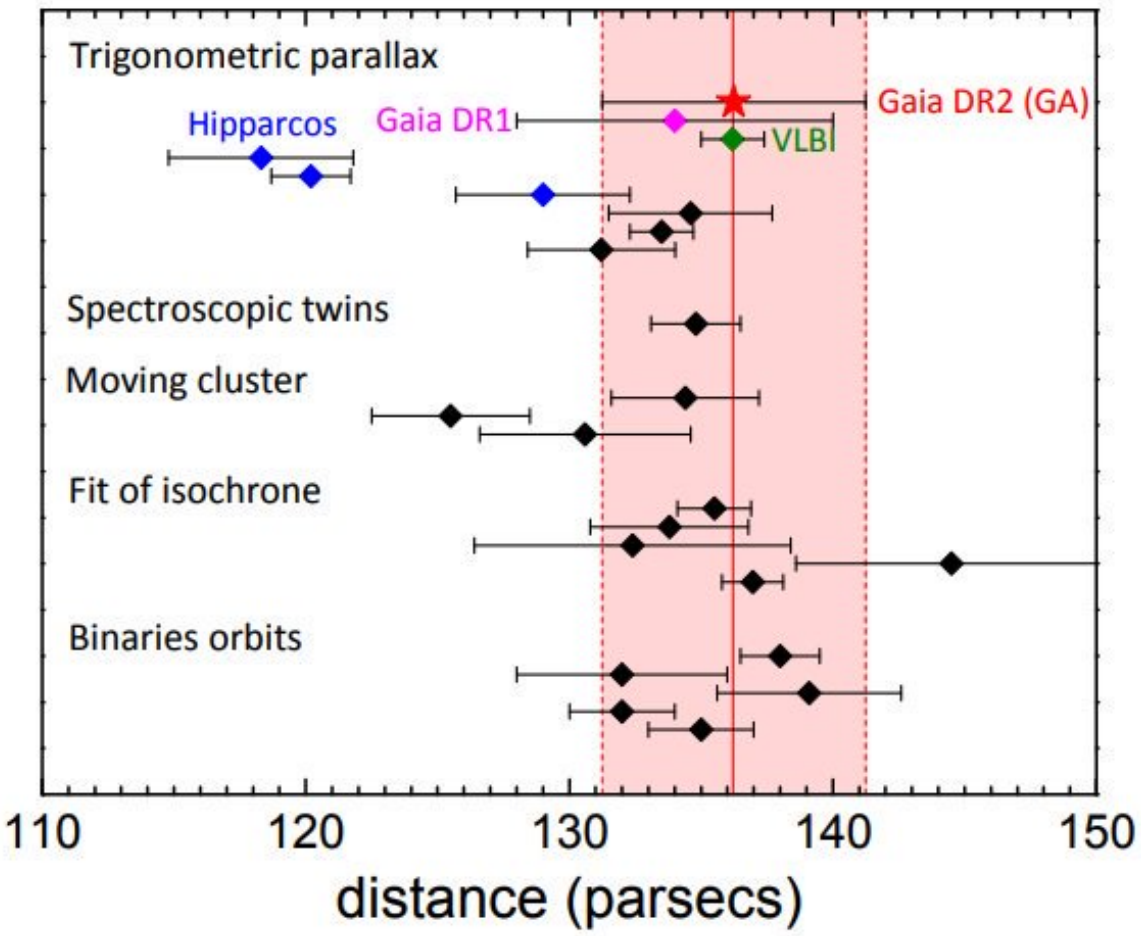
Infrared filters

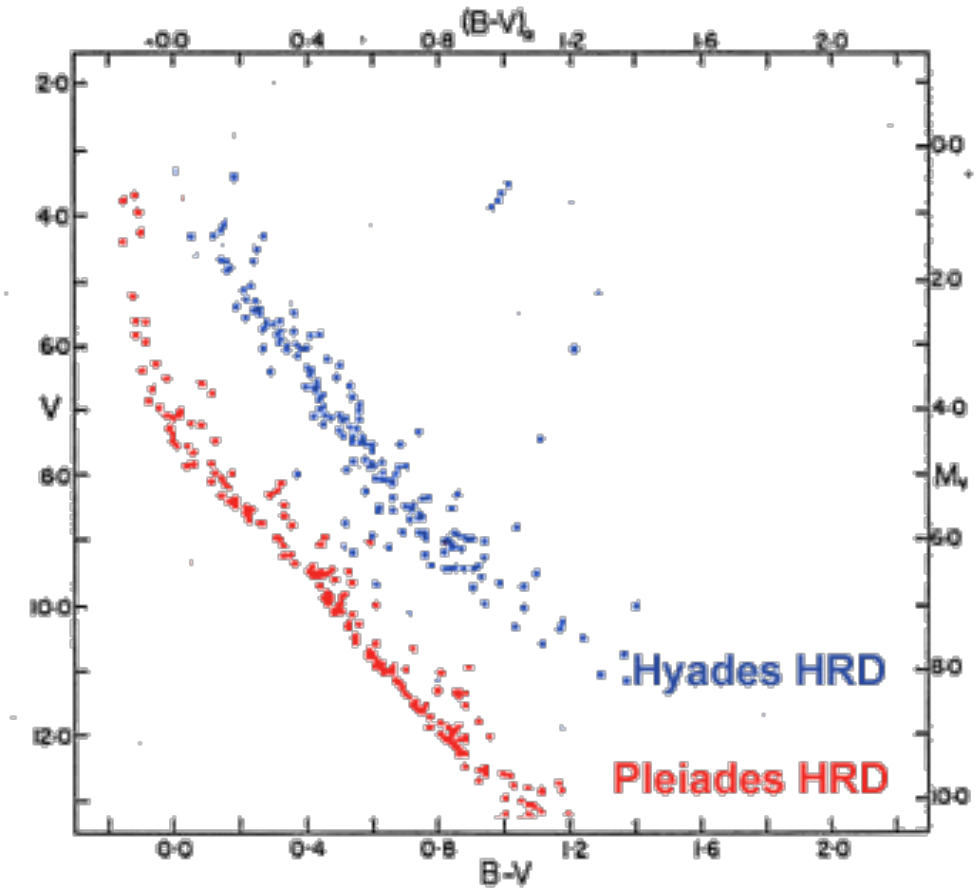


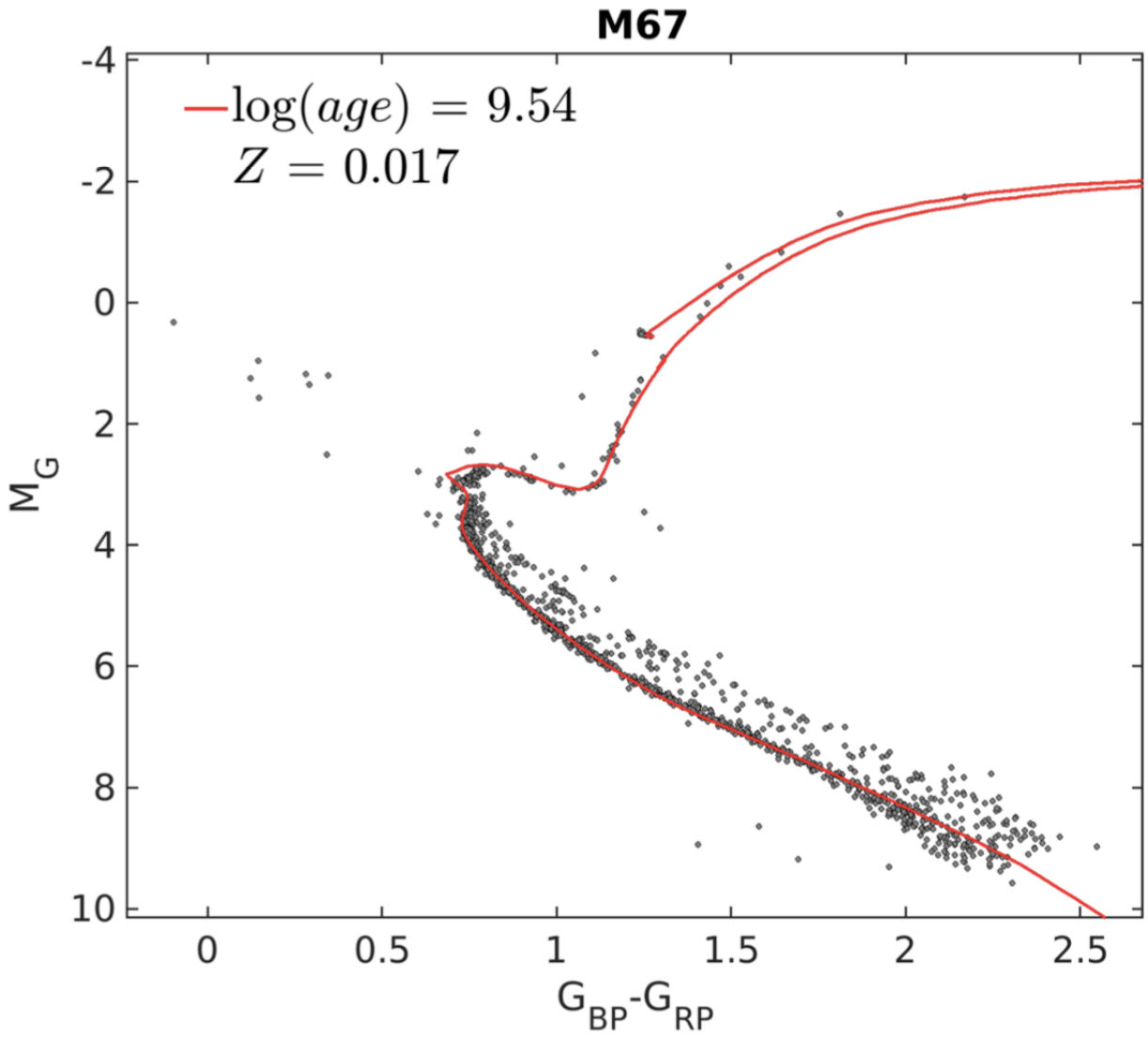
The Distance to the Pleiades



The Distance to the Pleiades




(B-V)o
-0·0
0·4
0·8
1·2
1·6
2·0
2·0
4·0
6·0
8·0
10·0
12·0
V
Mv
-3·0
-2·0
-1·0
0·0
1·0
2·0
3·0
4·0
5·0
6·0
7·0
8·0
9·0
10·0
Hyades HRD
Pleiades HRD
0·0
0·4
0·8
1·2
1·6
2·0
B-V


M67
log(age) = 9.54
Z = 0.017
M_G
G_BP-G_RP
-4
-2
0
2
4
6
8
10
0
0.5
1
1.5
2
2.5

The Andromeda galaxy is visible in the night sky as a diffuse cloud of 4th magnitude ($V = 3.44$, where V stands for magnitude in the visible waveband.)

(a) Several ways to estimate the distance to Andromeda agree on the value of $\approx 780\,\mathrm{kpc}$. Show that the absolute magnitude of the Andromeda galaxy in the same band is $M_V \approx -21$.

(b) Assume that the radiation coming from Andromeda is all due to solar-like stars ($M_{V,\odot} = 4.83$). How many stars are there in the Andromeda galaxy according to this approximation?