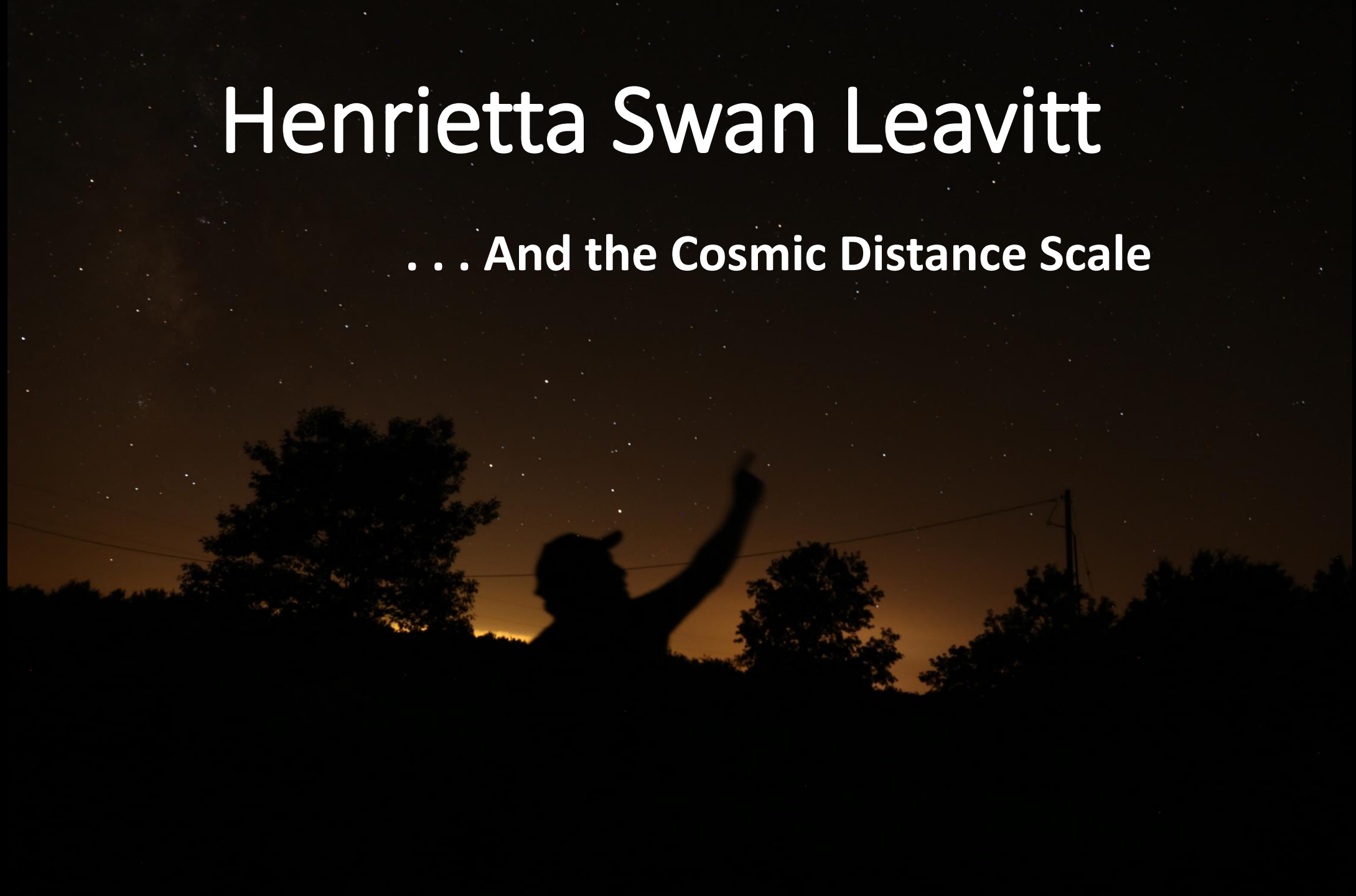
Henrietta Swan Leavitt

. . . And the Cosmic Distance Scale



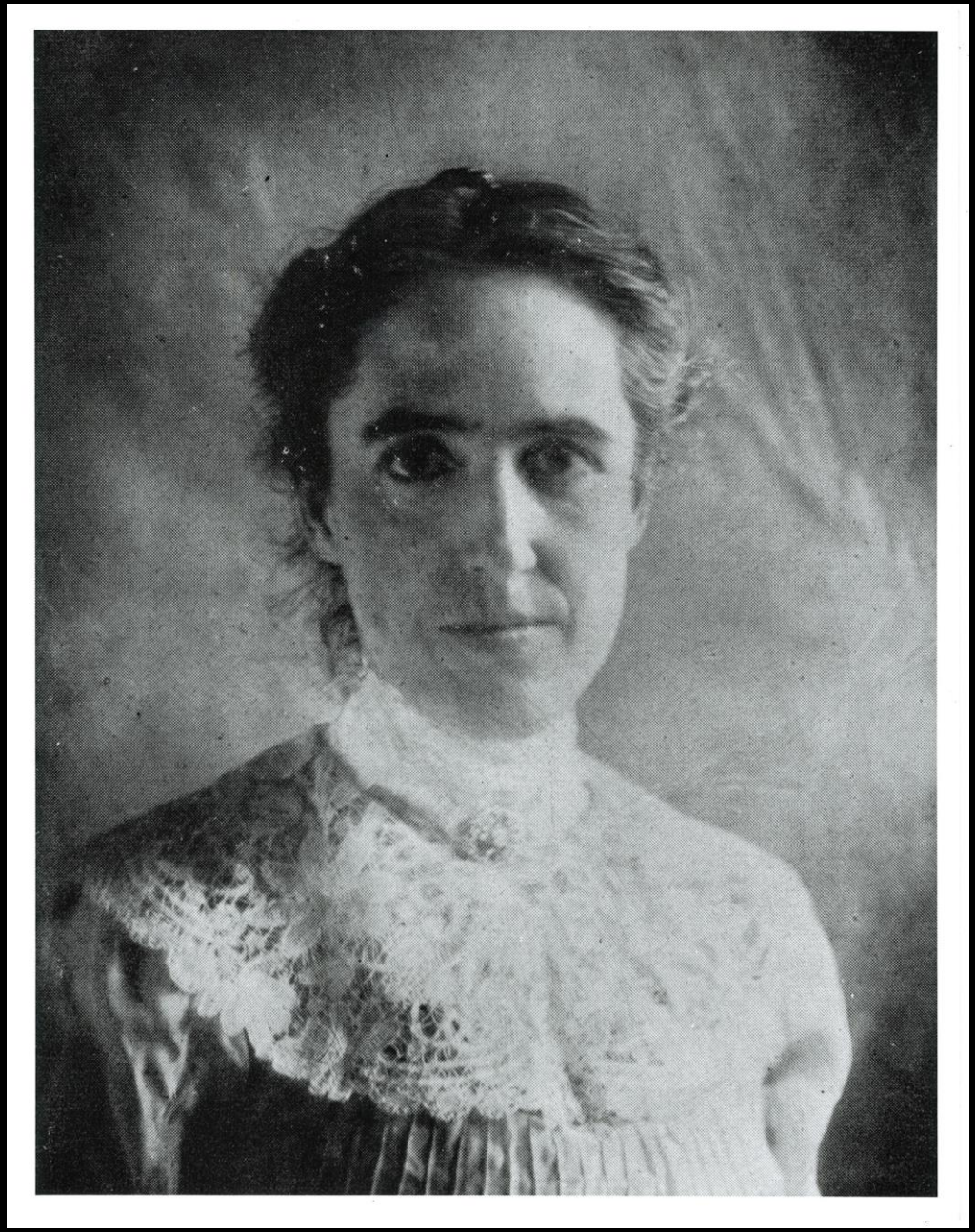
Maria Mitchell

- Co-founder of Association for the Advancement of Women
- Professor, Vassar College (but no college degree)
- Strong advocate for education
- Did navigation calculations for sailors
- Opened own school and allowed non-white students
- 1847 – discovered comet

1877

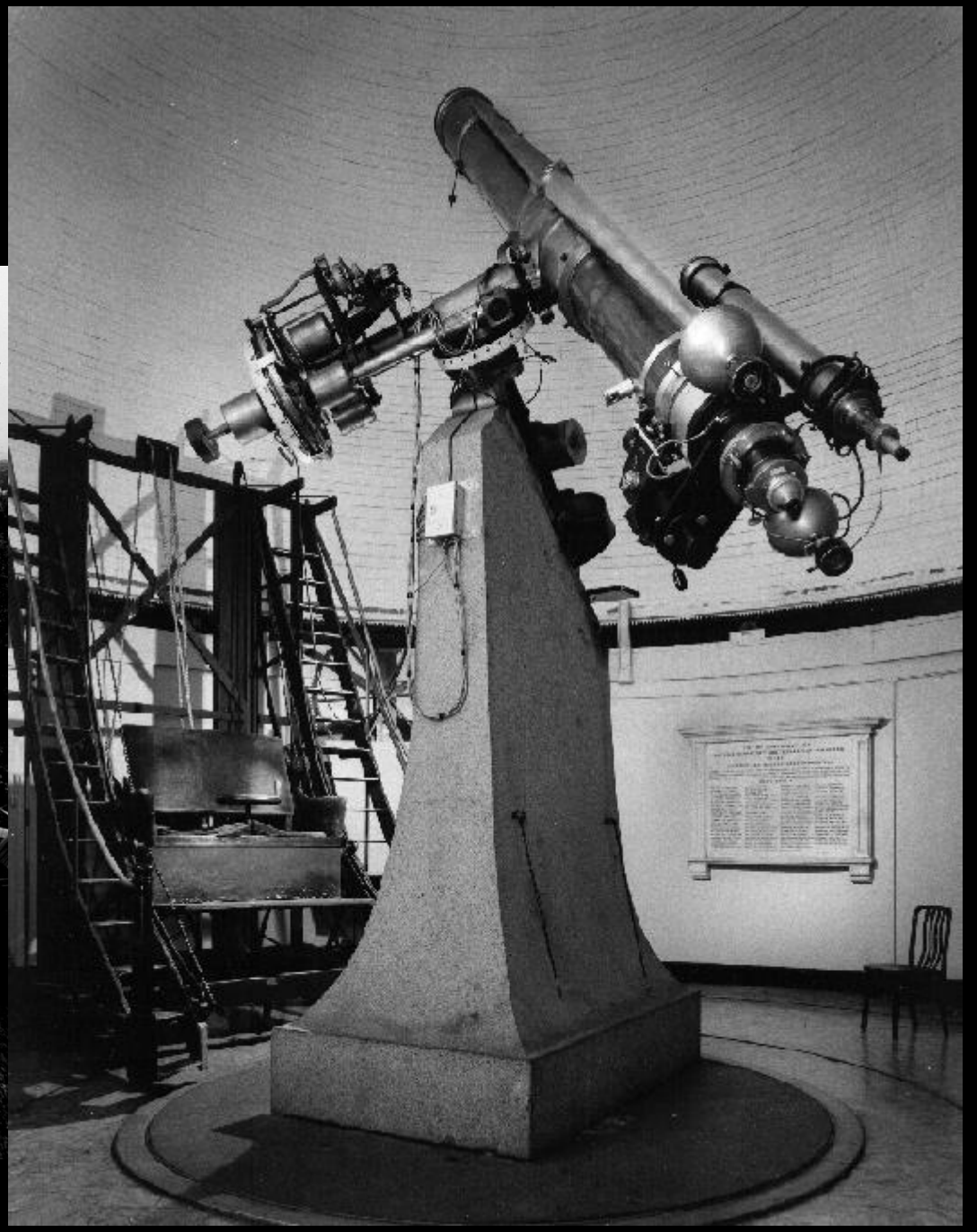
Henrietta Swan Leavitt

- Born: July 4, 1868
- Lancaster, MA
- Oldest of 7 children
- Oberlin College, then Harvard's "Society for the Collegiate Instruction of Women" (later Radcliffe College)
- Graduated 1892



Radcliffe College

Harvard College Observatory



Edward Charles Pickering

- Harvard graduate
- Taught at MIT
- Director of Harvard College Observatory (1877-1919)
- Hired Henrietta as a “computer”

Rev. Angelo Seechi (1818-1878)

Williamina Flemming

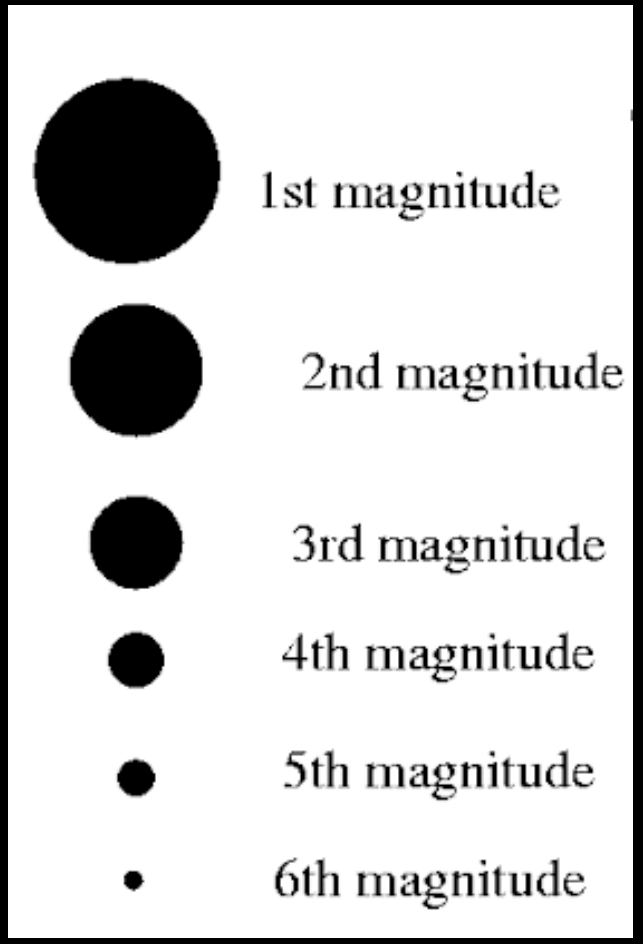
- From Scotland, came to US at age 21.
- School teacher at age 14
- Husband abandoned her & son
- Maid for Pickering (age 23)
- Had skills with numbers & organization

Annie Jump Cannon

- 5 years older than Henrietta
- Suffragist
- From Dover, Deleware
- Wellesley College, MA (physics)

Measuring Light intensity

- "Magnitude System" – set-up 2000 years ago!
- 20 brightest stars . . . ."1st magnitude"
- 2.5x fainter . . . . "2nd magnitude"
- LARGER POSITIVE NUMBER = FAINTER STAR!!



. . . . it's a number line!

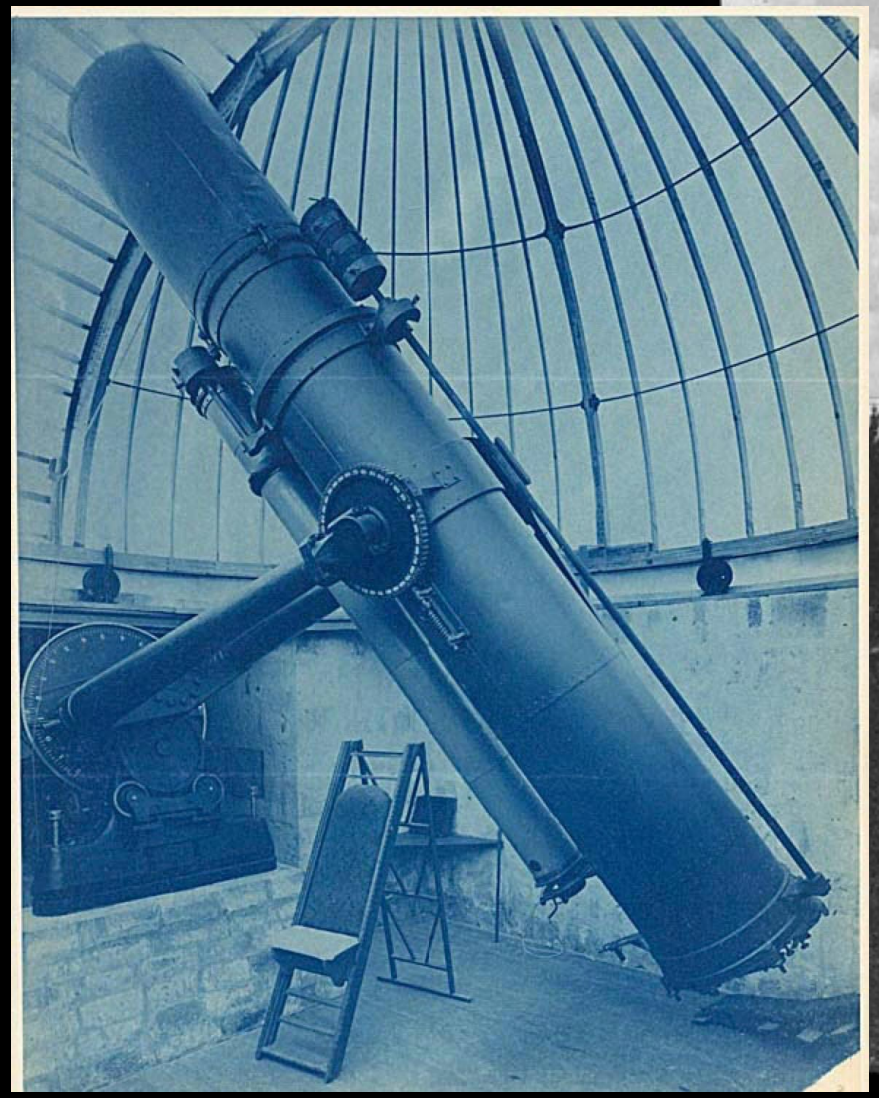
- -26 . . .Sun
- -12 . . .Full Moon
- -4 . . . Venus
- -1.5 . . . Sirius
- 0 . . . Vega
- 1 . . .about 30 stars
- 2 . . .Big Dipper Stars
- 4-5 . . . City limit
- 6 . . . Country limit
- 13 . . . 6-inch telescope
- 14 . . . Pluto
- 23 . . . 200" telescope
- 28 . . . Hubble Telescope

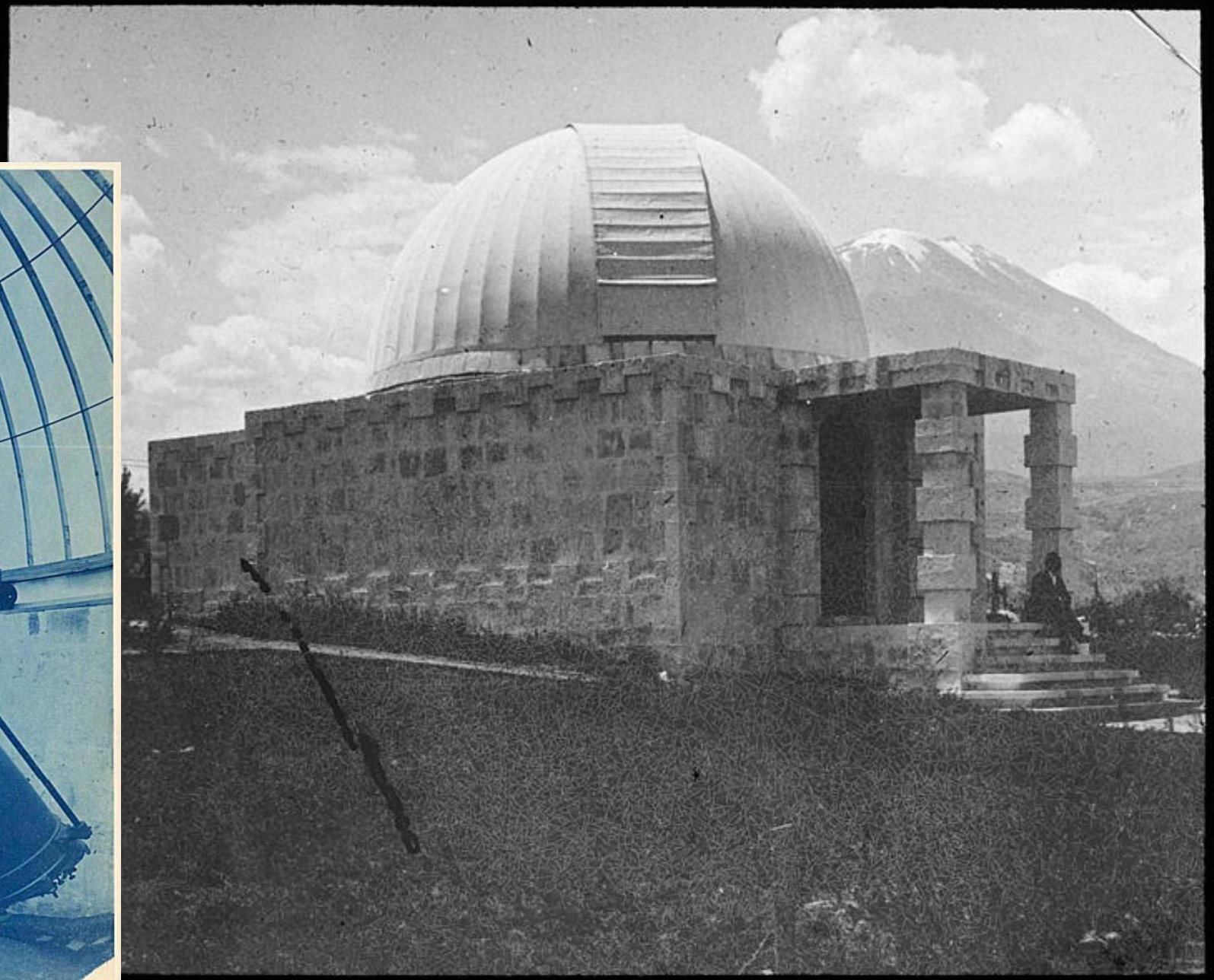

β Aurigæ Dec 1889

HARVARD UNIVERSITY ARCHIVES

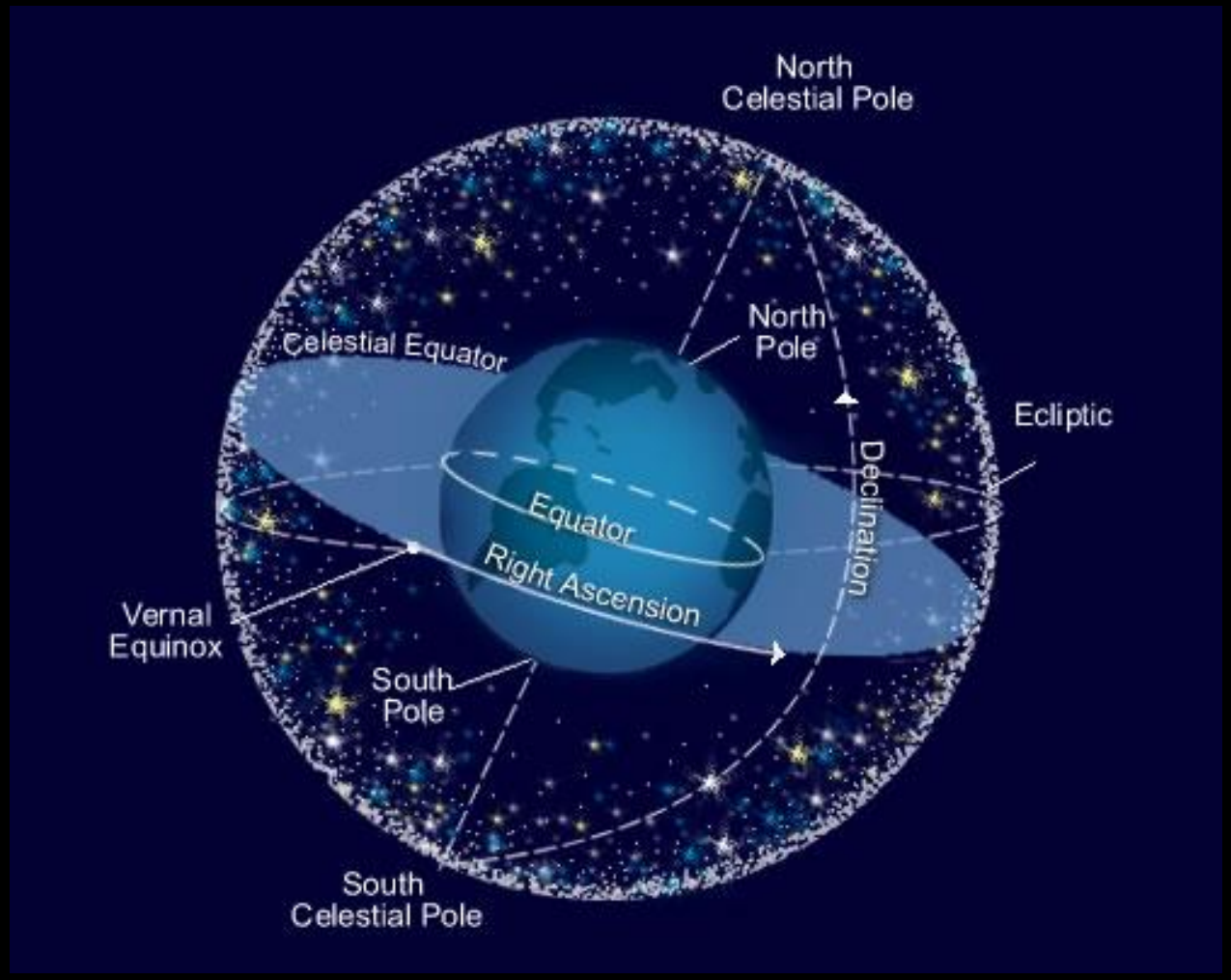
Beloit College (1896)

Arequipa, Peru

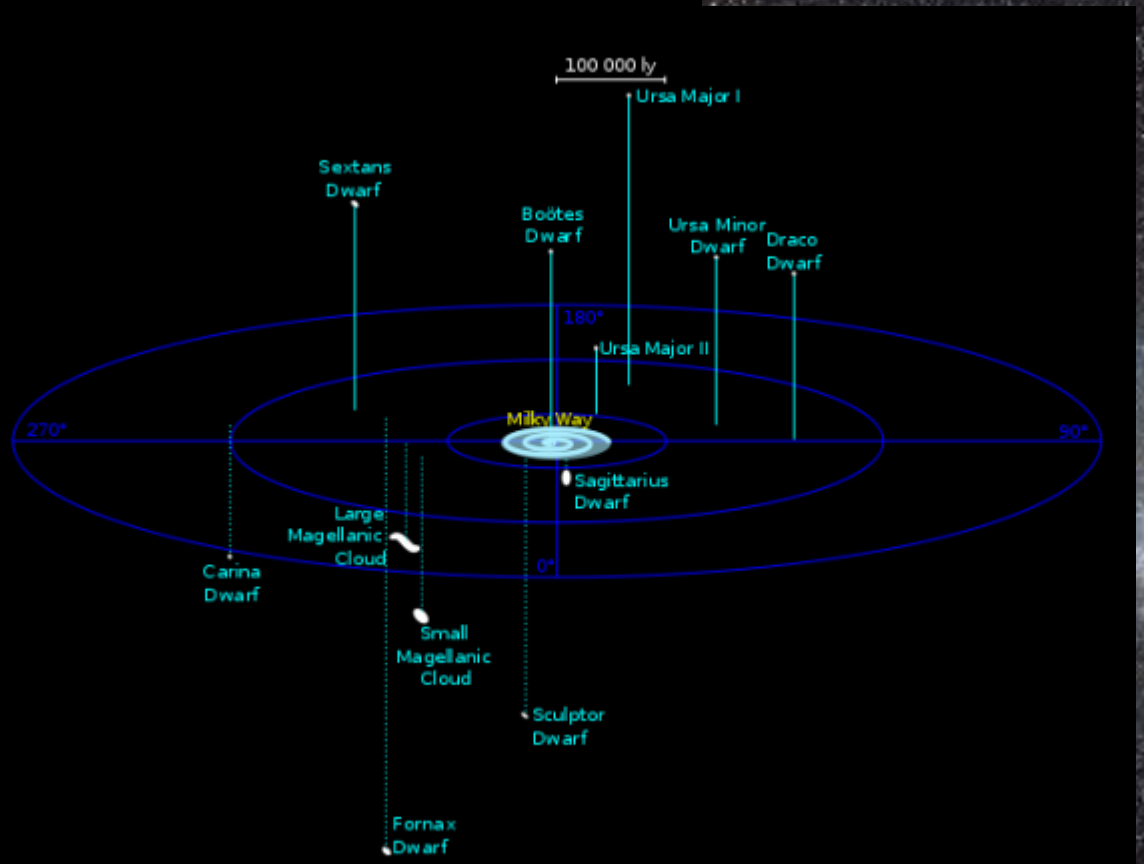




LET'S LOOK AT THE SKY!



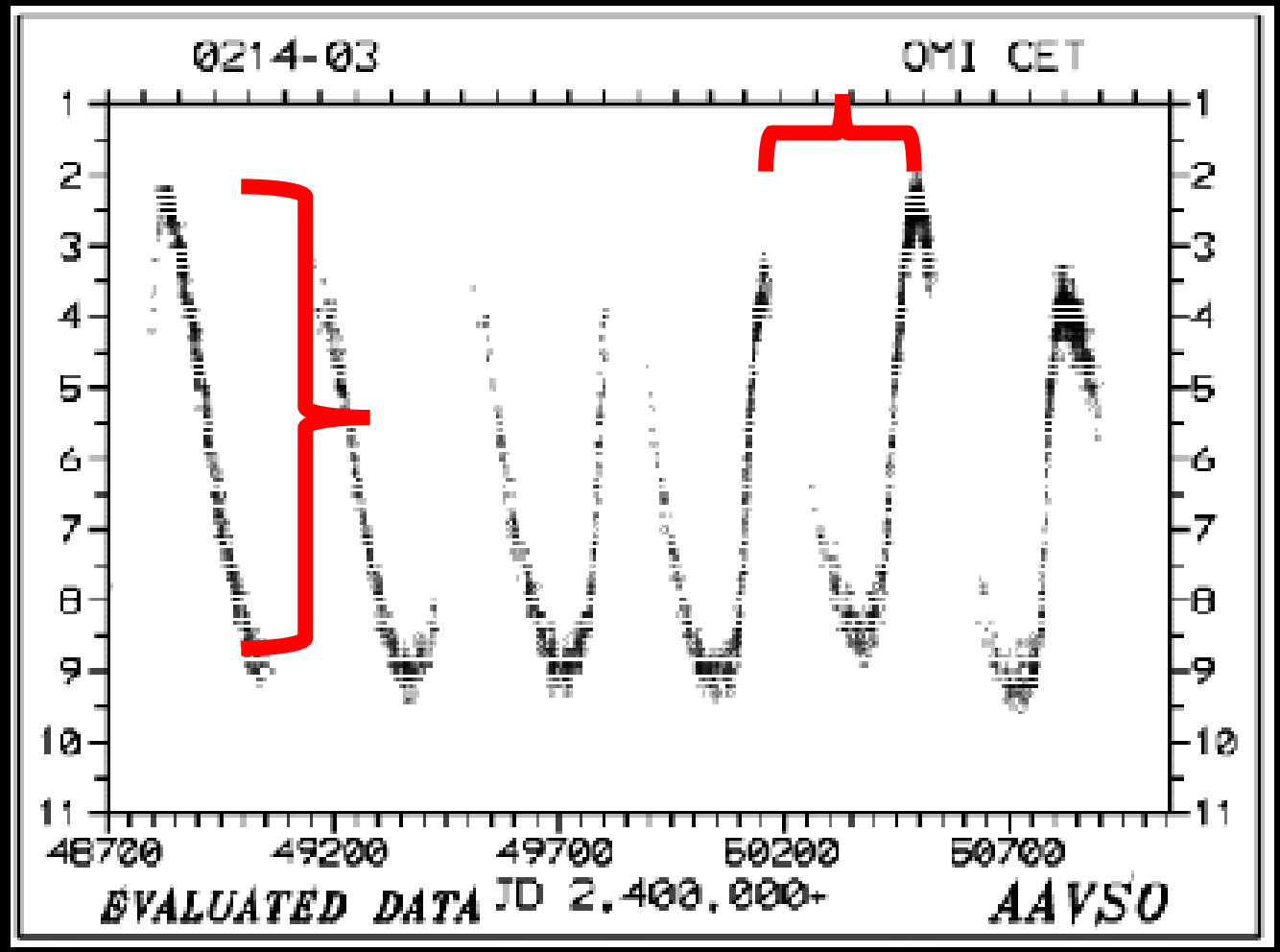
The Clouds of Magellan

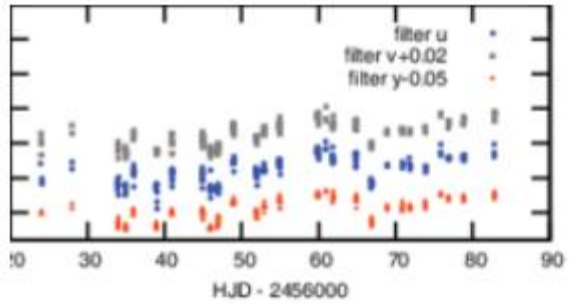


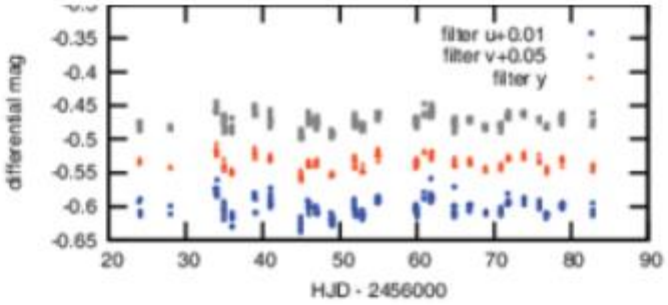
“Variable Stars”

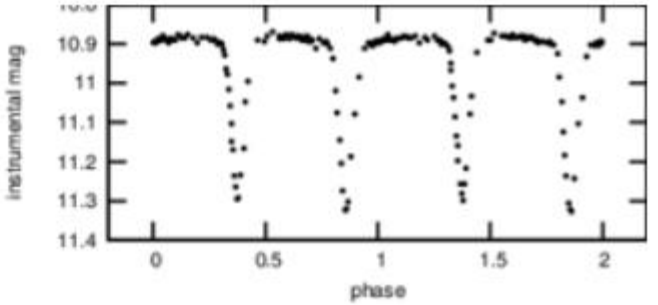
- Stars that change in brightness
- Many types
- AAVSO & role of amateurs
- “Light curves” (magnitude vs time)

“Period”

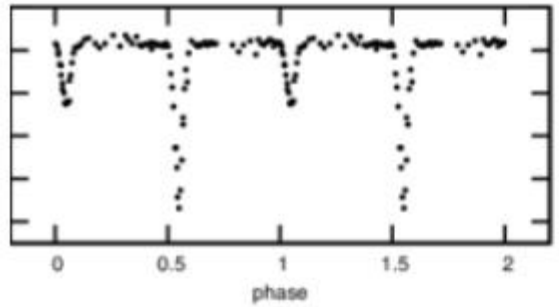




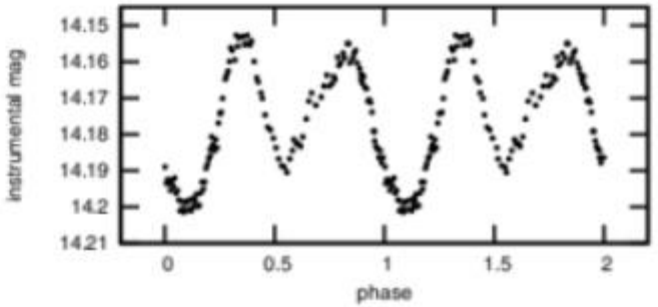




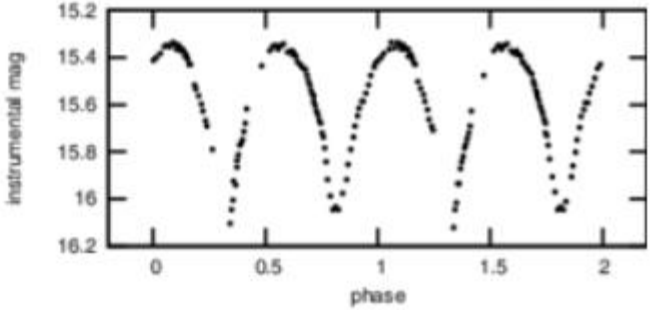
TYC 2139-606-1, period: 1.971320d, type: EA



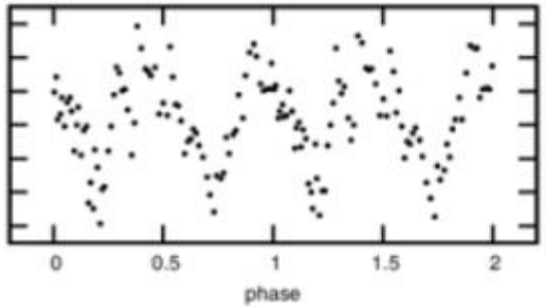
2MASS19450754+2402190, period: 0.846077d, type: ELL



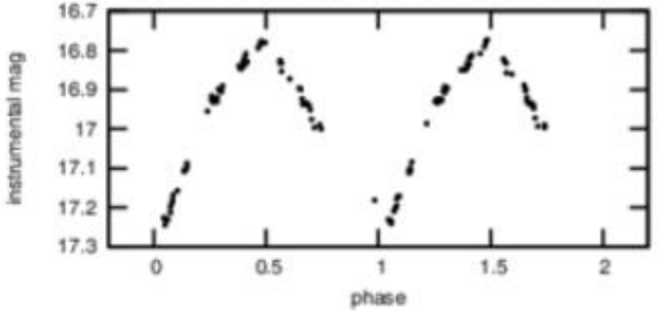
2MASS19460400+2405355, period: 2.392234d, type: EB/EW



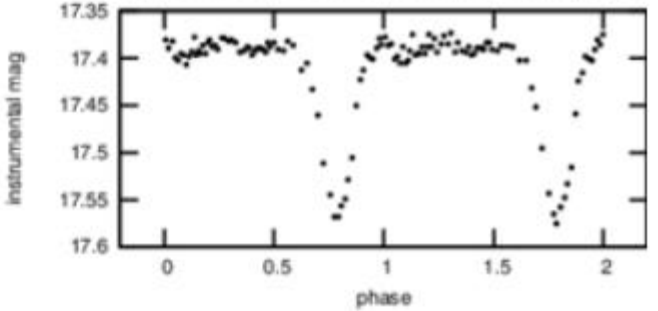
2MASS19444655+2354023, period: 0.620878d, type: EW



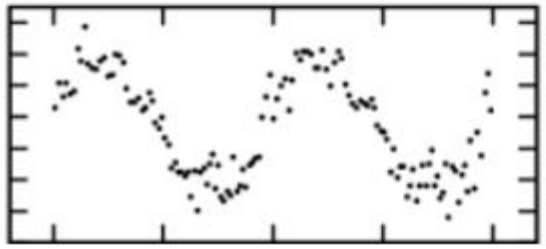
2MASS19445884+2359466, period: 11.199474d, type: ?



2MASS19454587+2356381, period: 0.802226d, type: EA

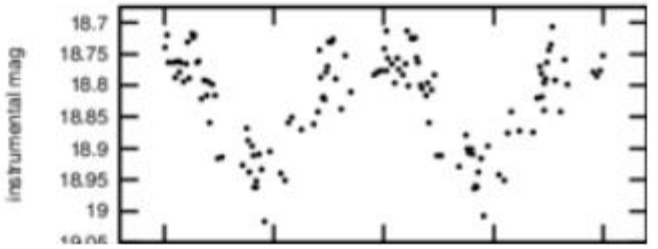


2MASS19460442+2404221, period: 0.147635d, type: DSCT

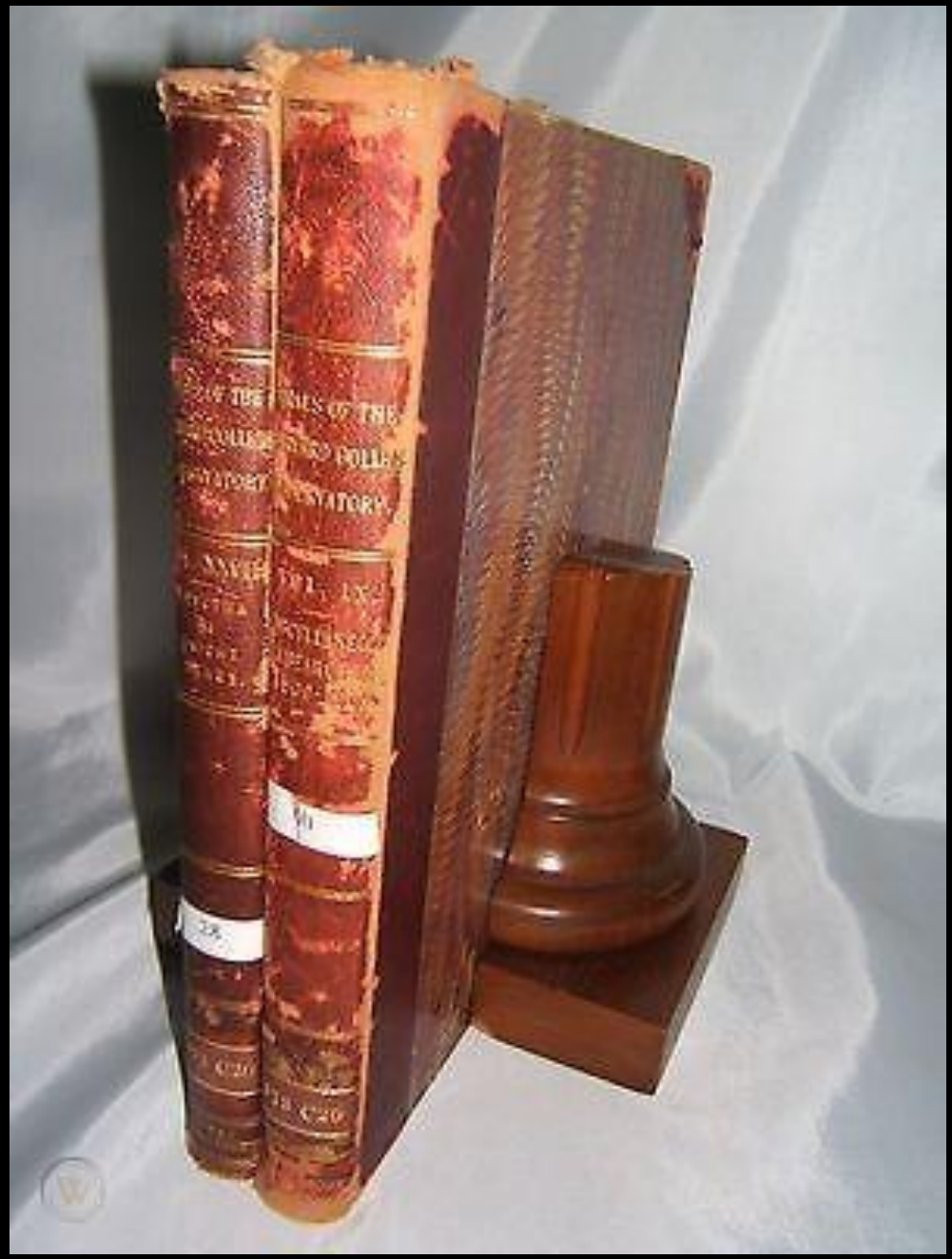


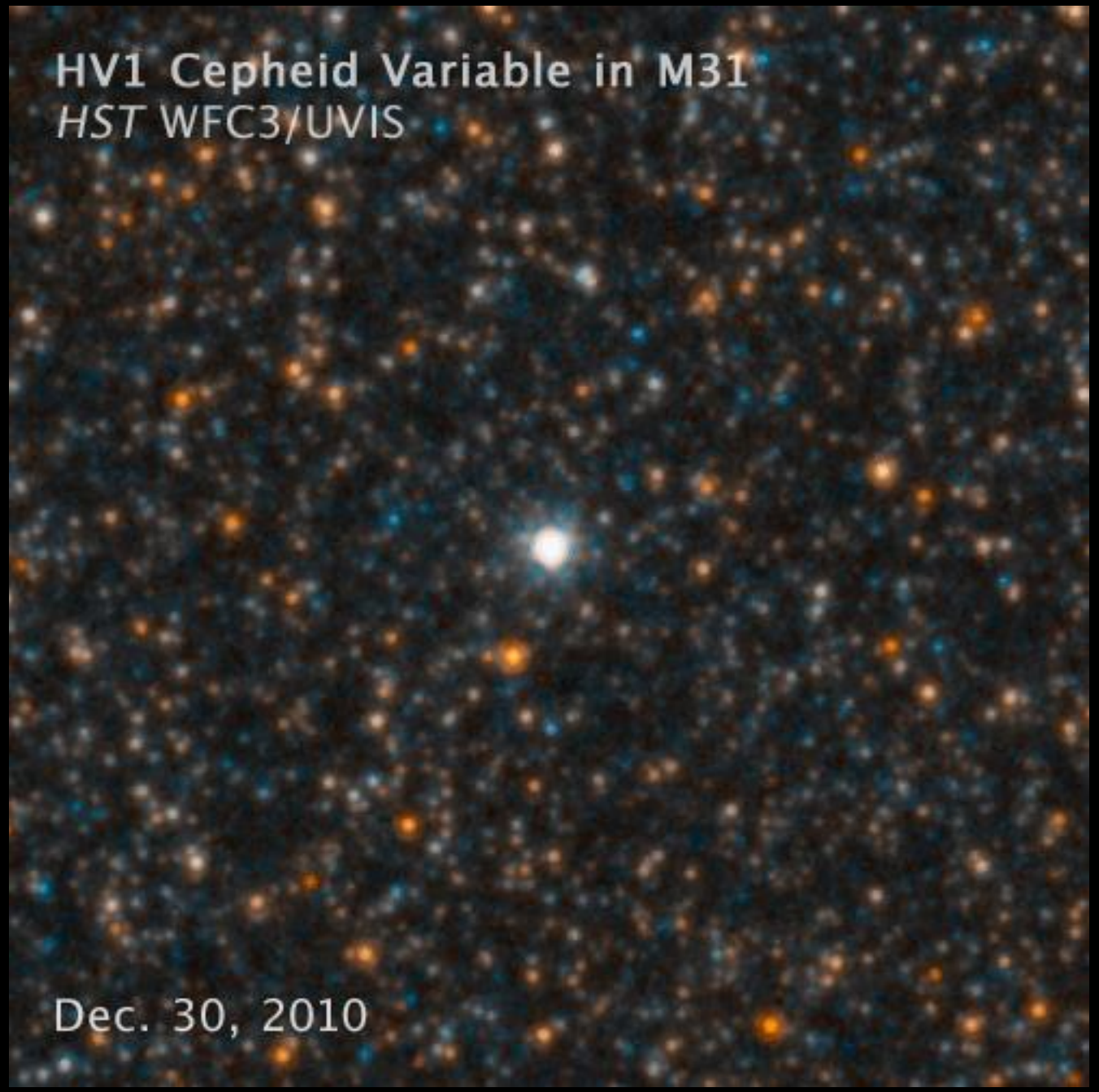
2MASS19444795+2354177, period: 0.395190d, type: EW

2MASS19454095+2348288, period: 2.342110d, type: ?

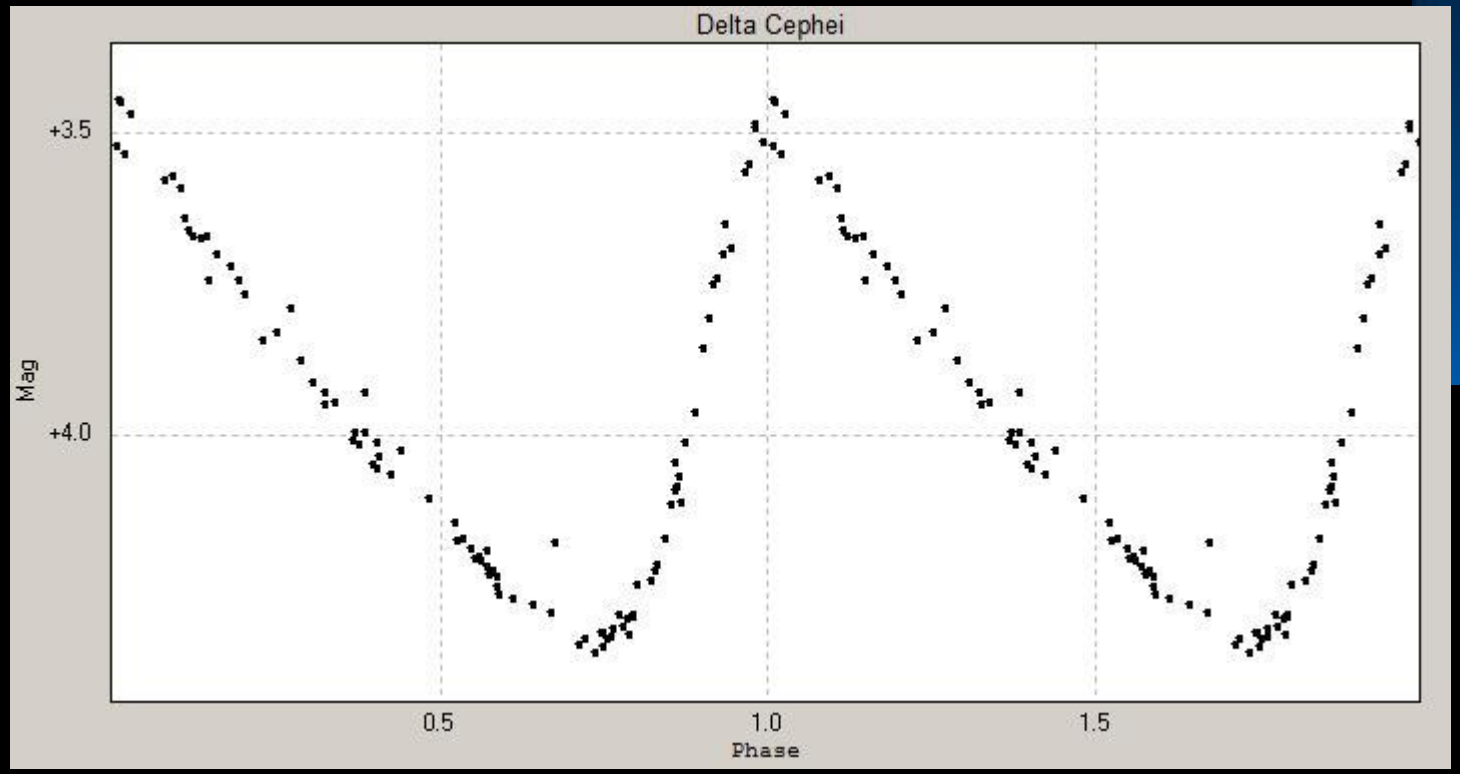


Annals of the Harvard College Observatory




HV1 Cepheid Variable in M31
HST WFC3/UVIS
Dec. 30, 2010

Delta Cephei



"Standard Candles"

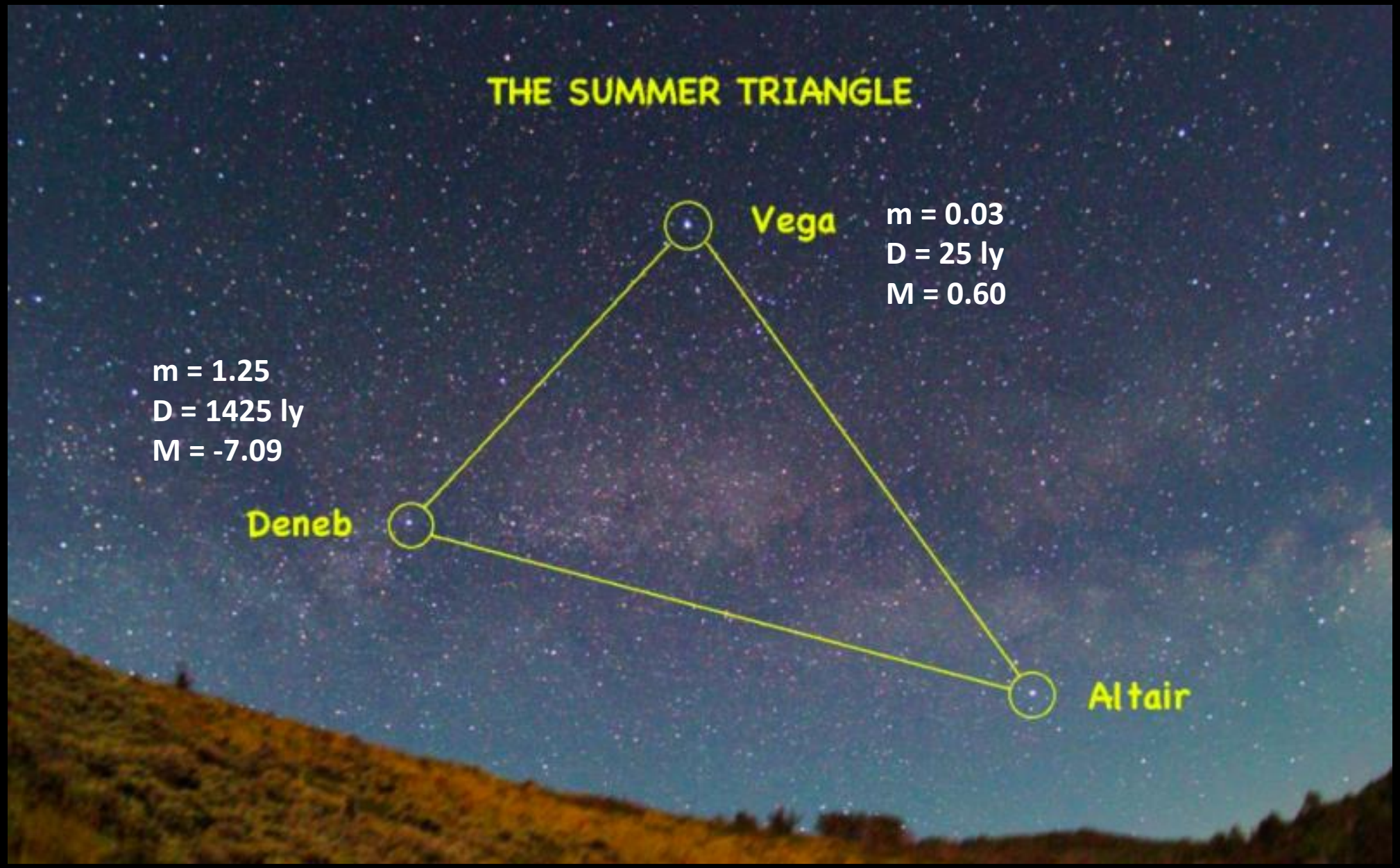
If we know how luminous an object is then we can translate it's apparent brightness into it's distance.

Two types of magnitudes

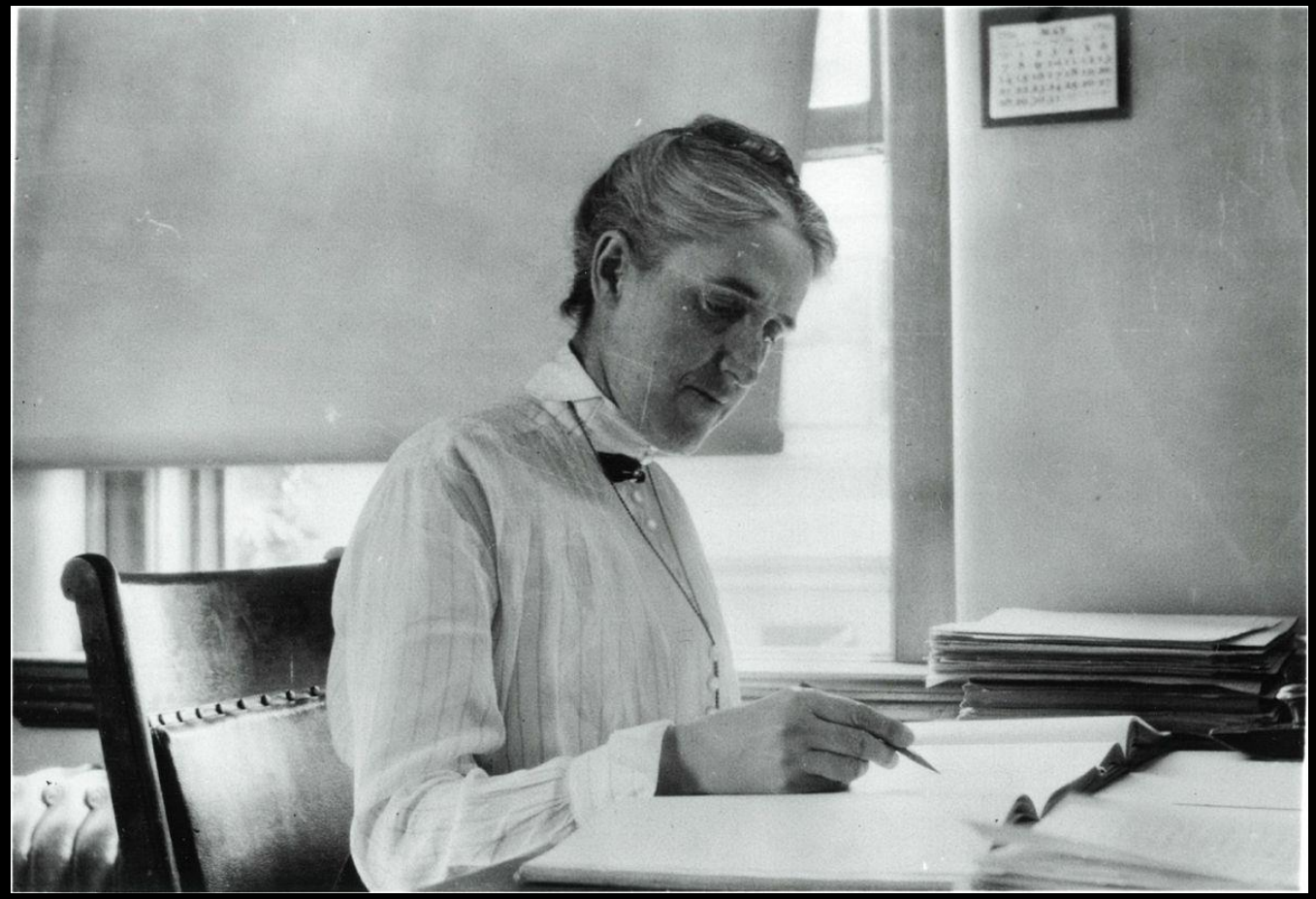
- "Apparent" – how bright an object appears from the Earth (m)
- "Absolute" – how bright the object truly is (M)

Q: How are apparent and absolute magnitude related?

$$\underbrace{m - M}_{\text{"Distance Modulus"}} = 5 \log (\text{dist}/10 \text{ pcs})$$

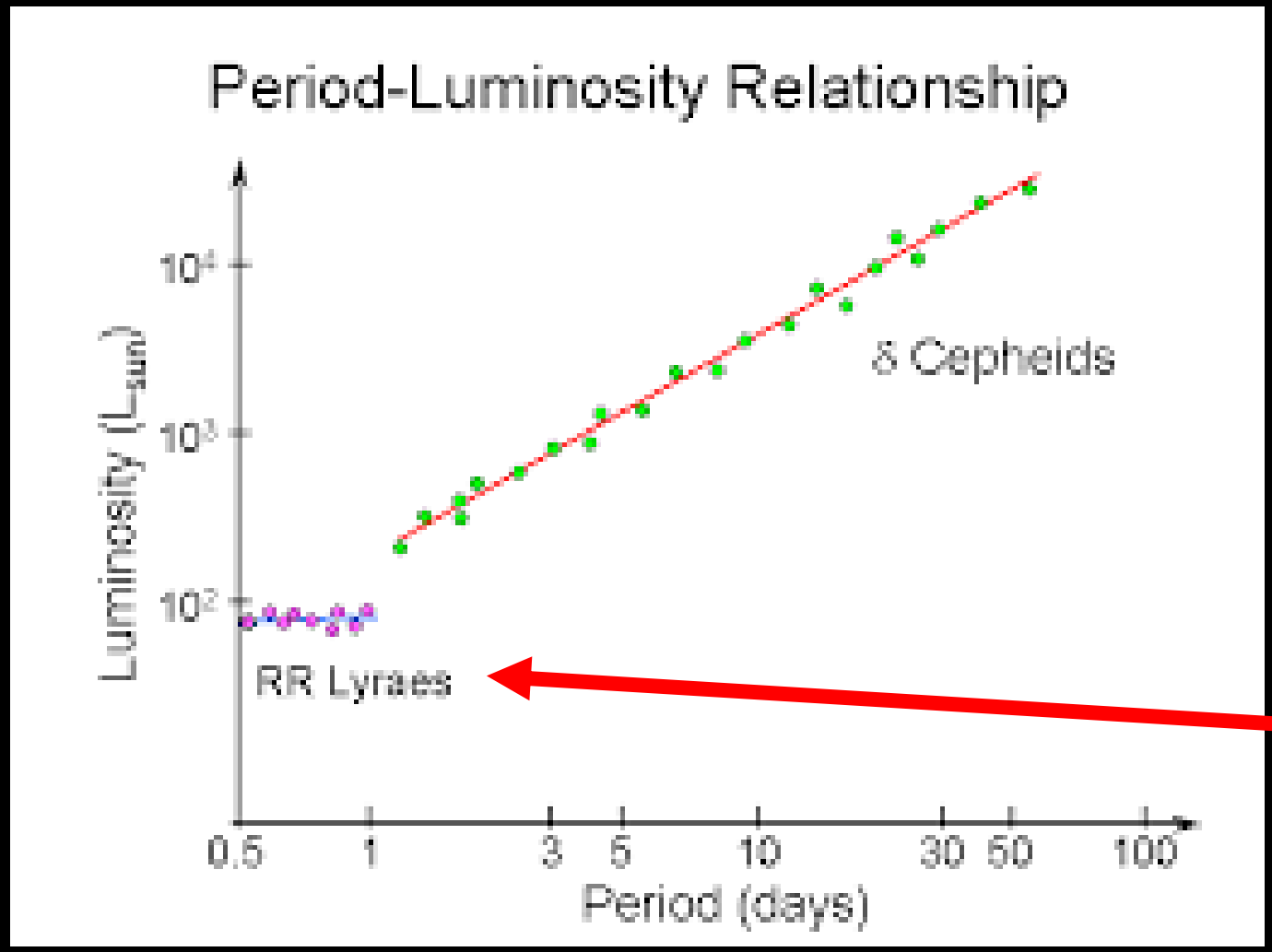

THE SUMMER TRIANGLE
Vega
m = 0.03
D = 25 ly
M = 0.60
m = 1.25
D = 1425 ly
M = -7.09
Deneb
Altair

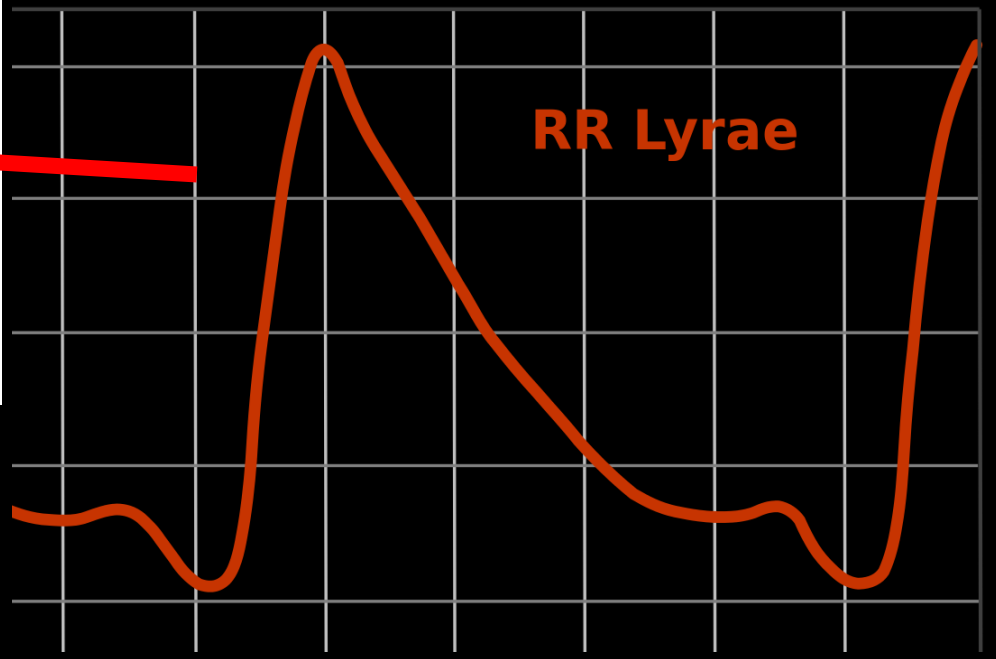
1) All stars in SMC are roughly the same distance
2) So differences in brightness are real differences (not affected by distance)
3) Stars with longer period of variation appear brighter



A straight line can readily be drawn among each of the two series of points corresponding to maxima and minima, thus showing that there is a simple relation between the brightness of the variables and their periods.

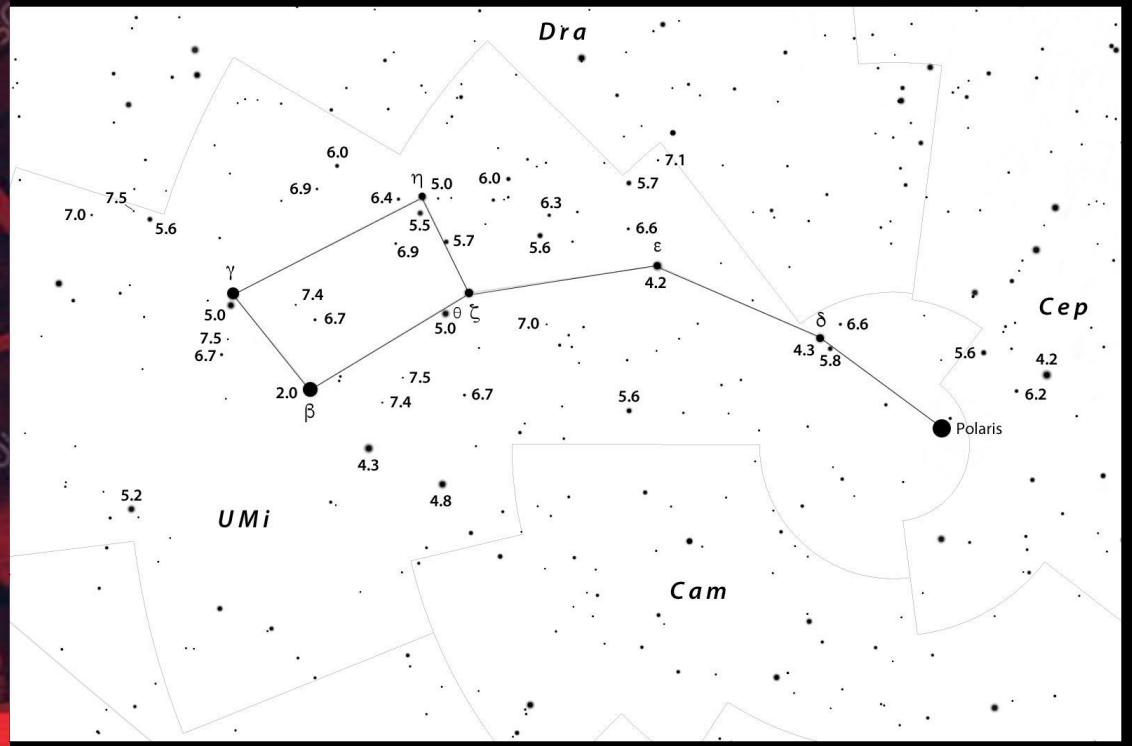
— *Henrietta Swan Leavitt* —


Period-Luminosity Relationship
Luminosity (L_{sun})
10^4
10^3
10^2
δ Cepheids
RR Lyraes
0.5
1
3
5
10
30
50
100
Period (days)

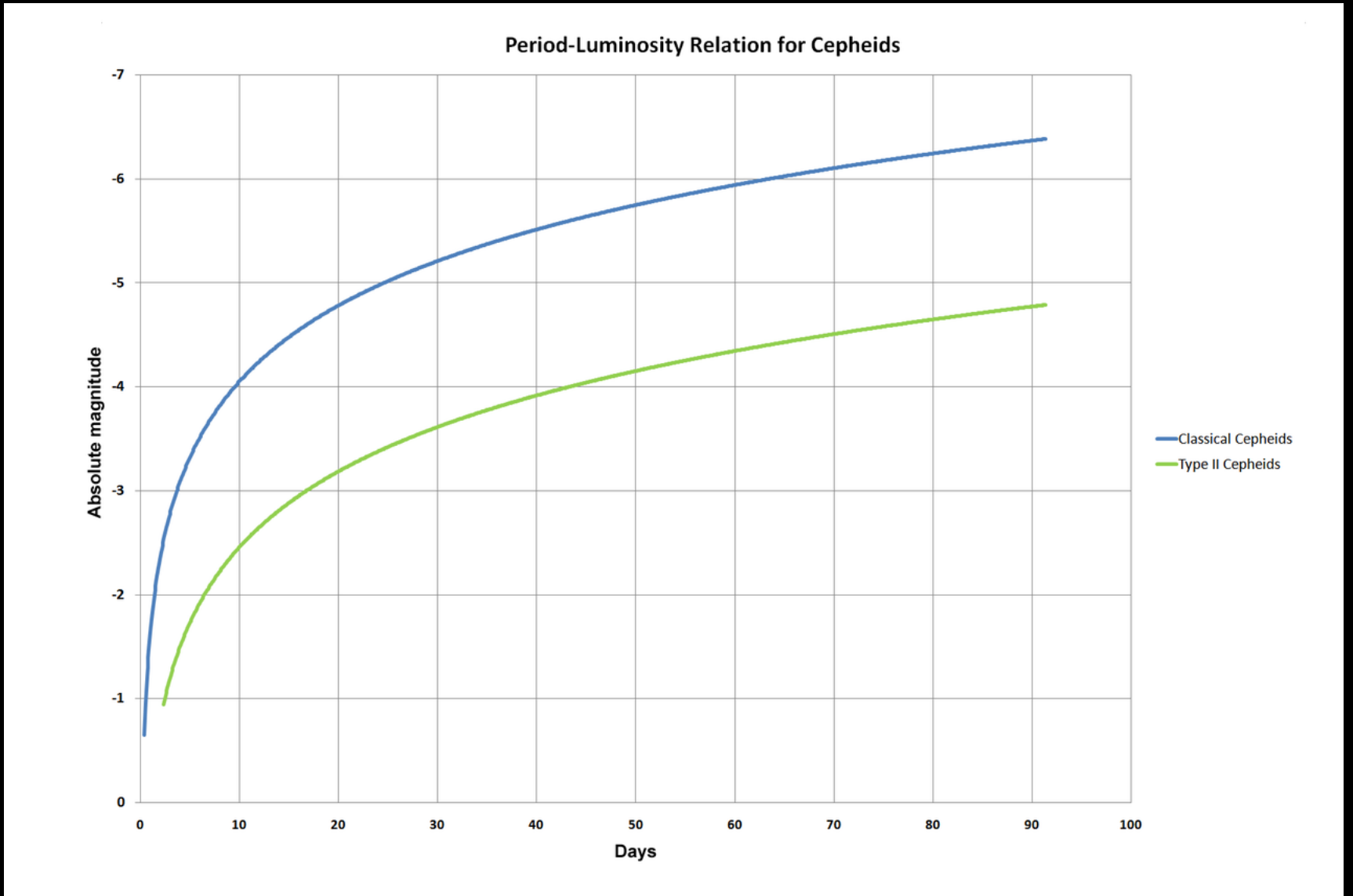

RR Lyrae

RR Lyrae Stars

Mt. Wilson 60” telescope



Period vs luminosity relationship



Harlow Shapley

"[Period/Luminosity Relationship] . . . destined to be one of the most significant results in stellar astronomy!"

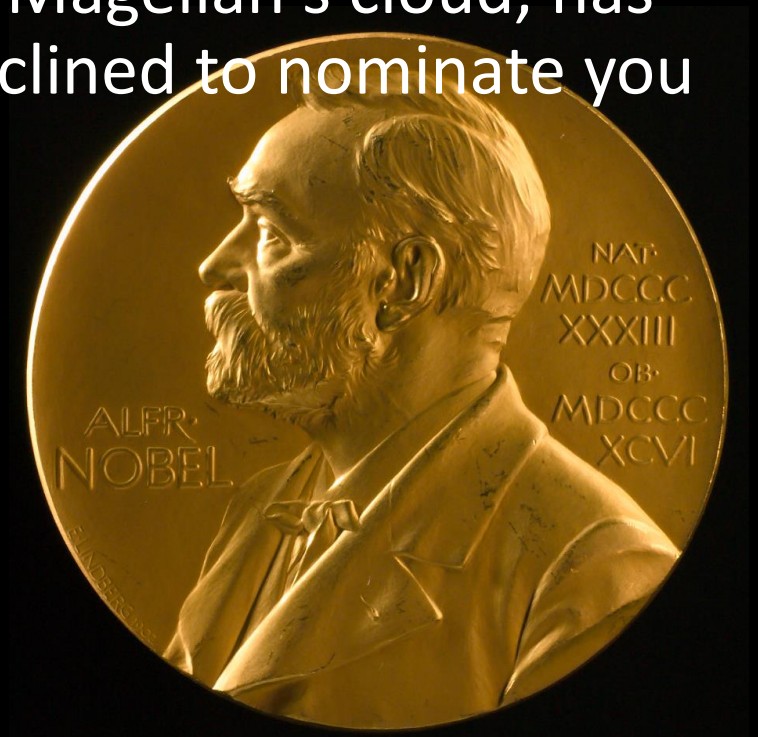
Our Sun

s, represented
, are the
bjects


Altair
Rose Cluster
NGC 6760
NGC 6535
Gumball Globular Cluster
M 14
M 10
NGC 6366
NGC 6539
NGC 6712
The Crucifix Cluster
NGC 6356
M 9
NGC 6235
M 80
Ghost Globular Cluster
NGC 6284
Great Sagittarius Star Cluster
NGC 6553
NGC 6293
NGC 6144
Saturn
Jupiter
M 75
NGC 6316
NGC 6304
Pickering Globular Cluster
NGC 6569
M 54
M 69
NGC 6652
NGC 5824
Specter Cluster
Silver Nugget Cluster
NGC 6139
NGC 5986
Chandelier Cluster
C 81
S

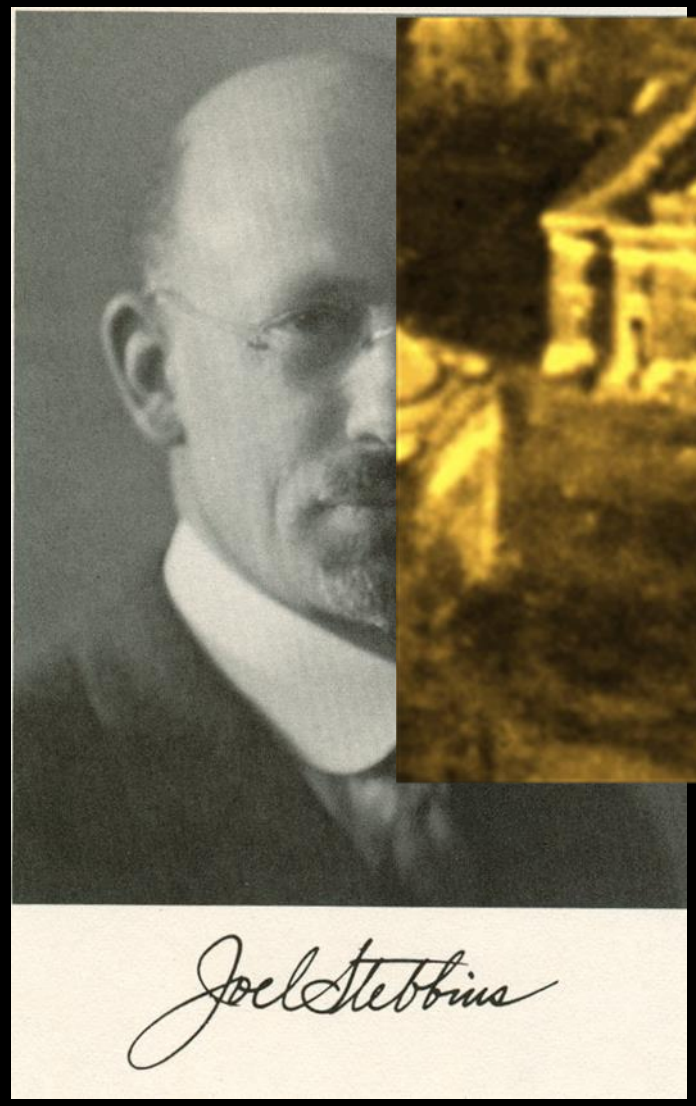
Letter from Gösta Mittag-Leffler (1925)

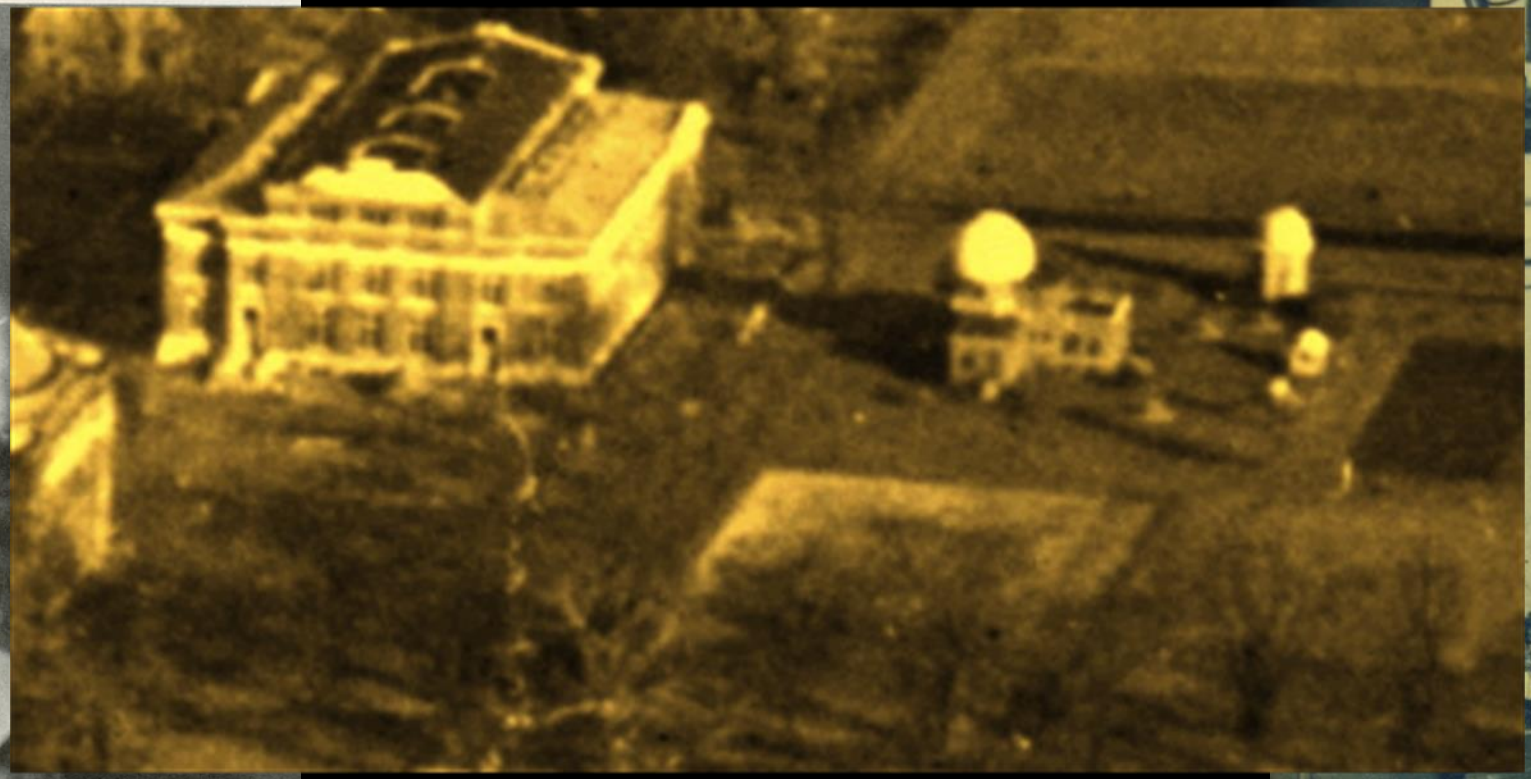
“Honoured Miss Leavitt, What my friend and colleague Professor von Zeipel of Uppsala has told me about your admirable discovery of the empirical law touching the connection between magnitude and period-length for the S Cepheid-variables of the Little Magellan's cloud, has impressed me so deeply that I feel seriously inclined to nominate you to the Nobel prize in physics for 1926 ...”

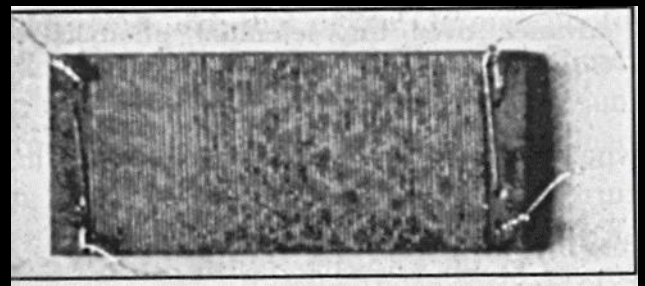


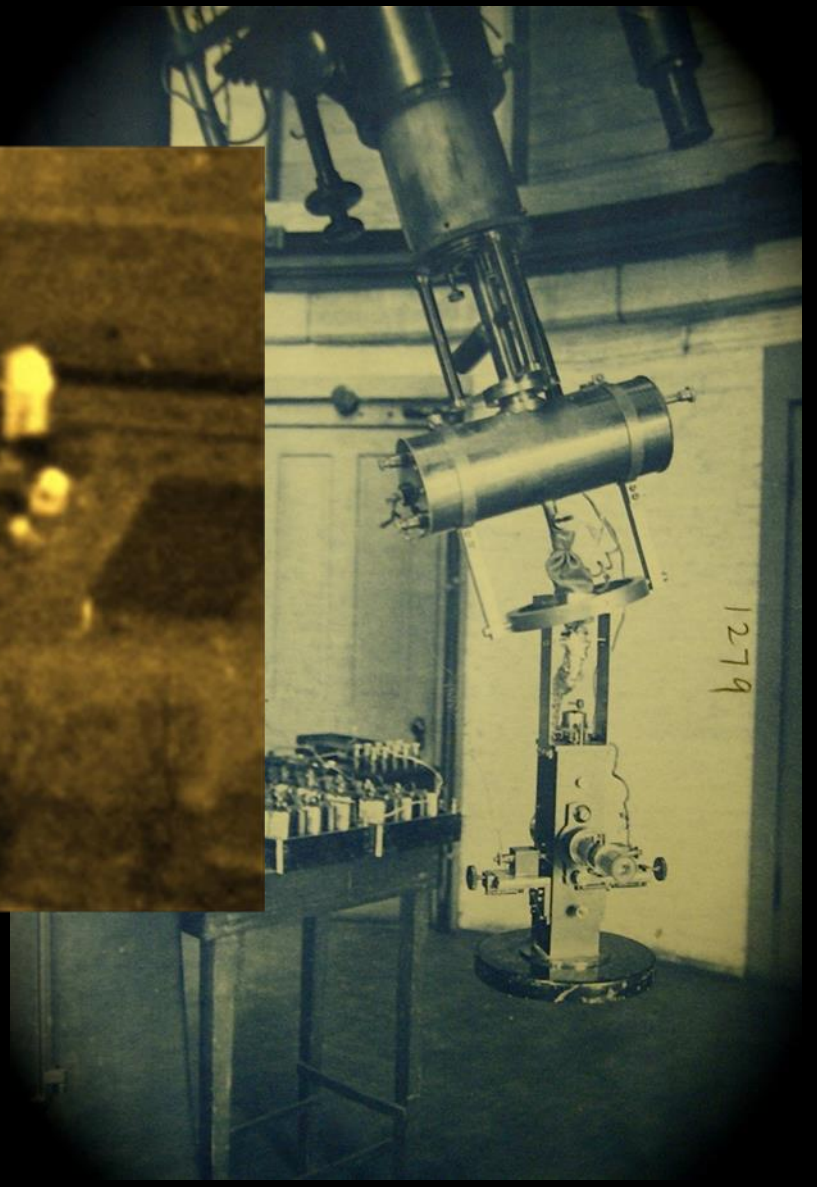

ROSWELL HENRY LEAVITT
BORN OCT. 4, 1871.
DIED JAN. 8, 1873.
MIRA FAY LEAVITT
BORN FEB. 20, 1878.
DIED DEC. 1, 1880.
HENRIETTA SWAN LEAVITT
BORN JULY 4, 1868.
DIED DEC. 12, 1921.
CHILDREN OF GEORGE R.
AND HENRIETTA S. LEAVITT

Photo*electric* Photometry









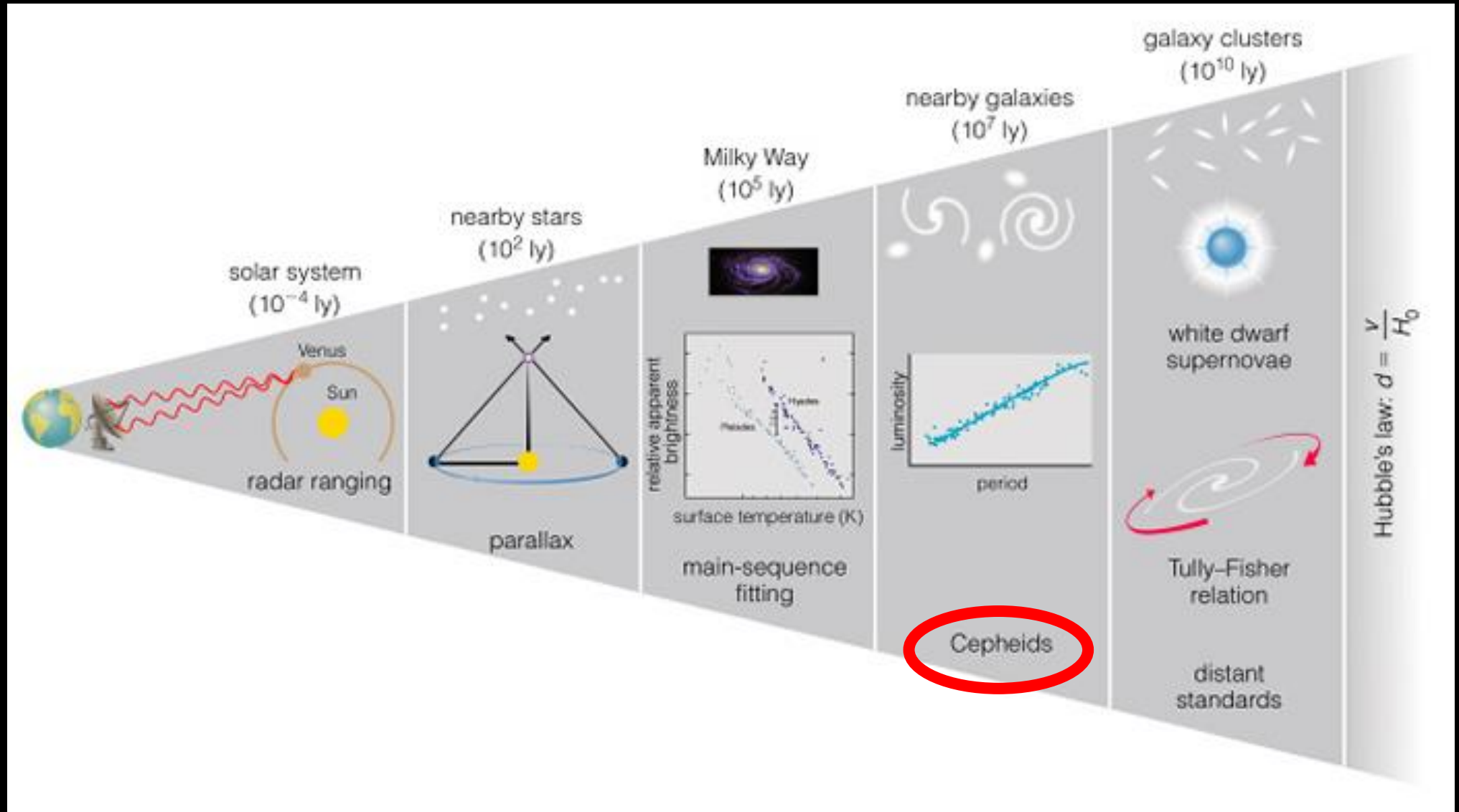
2001: a space odyssey

Lights! Photoelectric Photometer! Action!

In the early 20th century, Illinois astronomer Joel Stebbins and physicist Jakob Kunz conducted pioneering research at the campus Observatory, becoming the first people to use electricity to measure the brightness of stars. This photoelectric cell, a scientific ancestor of modern-day solar panels and digital cameras, was an important component of the photoelectric photometer that made their work possible.

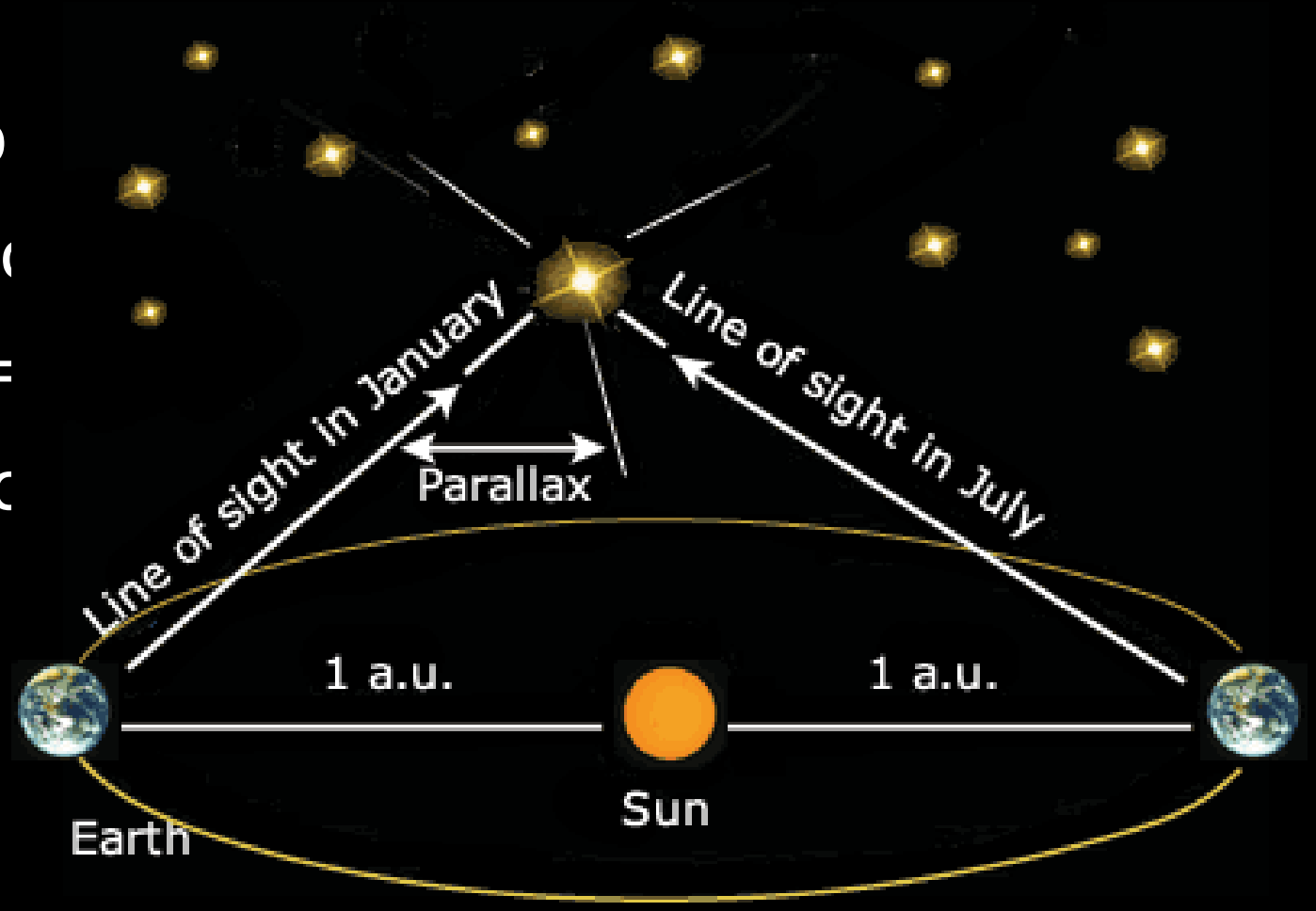
Credit: University of Wisconsin (photoelectric cell)
Illinois Distributed Museum (image of Stebbins)
Bob Zoller (image of Observatory)

Cosmic distance ladder



Parallax . . . A review

- Hold out your thumb
- Only direct measure
- Formula: Distance =
- Units: “parallax-secc
- Closest star?



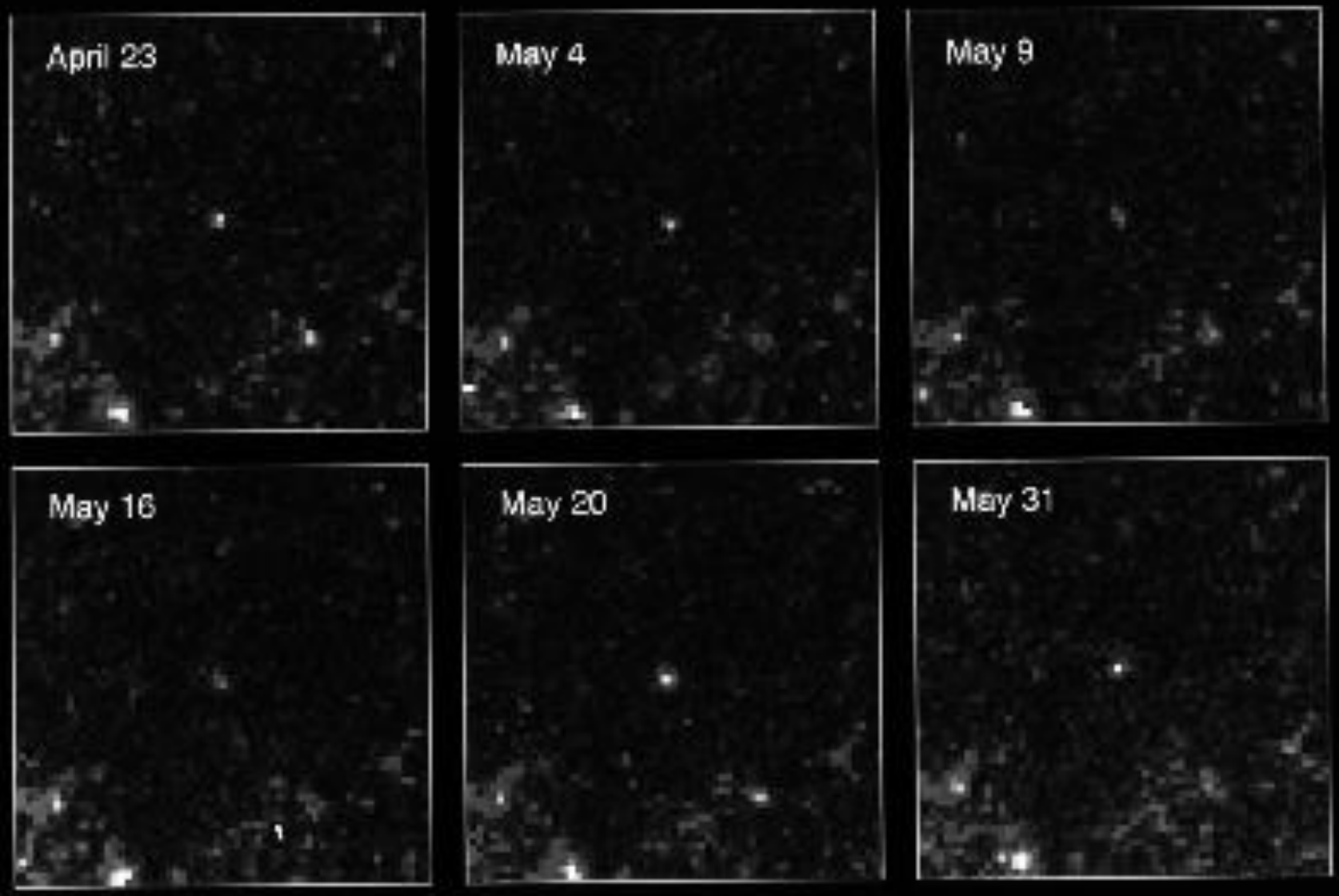
Measuring distances using velocity . ..

- “Chicago is 2.5 hours from here”
- “3 days to get to the Moon”
- 1.3 seconds to get to the Moon
- 8 “light minutes” to the Sun
- 1 “light year” = *DISTANCE* light travels in a year’s time
- 1 light year = 6,000,000,000,000 miles
- 1 parsec = 3.26 light years

So how do we find distances?

- Radar/planetary motions . . . . . .40 AU
- Parallax . . . . . 300 ly (1600 ly with HST)
- Main Sequence Fitting . . . . . .300 kly
- O & B stars . . . . . .32 Mly
- Cepheid Variables . . . . . 94 Mly
- Tully-Fisher relation . . . . . .300 Mly
- Supernova (M= -19). . . . . .650 Mly
- Brightest galaxy in cluster . . . . . .10 Gly

Cepheid Variable Star in Galaxy M100



Hubble Space Telescope · Wide Field Planetary Camera 2

Tully-Fisher Relation (1977)

- The rotation rate is related to the mass of the galaxy
- Mass is related to brightness
- *Large (bright) galaxies spin faster*