The First Three Minutes
Meeting 2

Peter Fisher

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Meeting 2 – Before the First Three Minutes

- Discussion of I Introduction: the Giant and the Cow
- Break
- Redshift and measuring redshift
- Before ”The First Three Minutes”
    - The Great Debate
    - How far to Andromeda? Measuring distances in astronomy
        - Parallax
        - The Cepheids and Henrietta Swan Leavitt
        - Cepheids in the Milky Way and Andromeda
    - The Mt. Wilson 100 inch telescope

I Introduction

Early History of the Universe

Grows exponentially with t.

- 10^{-34} s - Inflation – Guth (1980) – “rolling” of inflaton to minimum energy causes 86 doublings of size of the universe, 7 x 10^{22} increase in size
- 10^{-12} to 10^{-5} s – Quark-gluon plasma
- 10^{-5} to 1 s – nuclear matter forms, $p\bar{p}$, $n\bar{n}$ annihilation
- 1 s - neutrinos fall out of equilibrium, stream away
- 1-10 s – e^+e^- annihilation starts – γ/N ratio 10^9
- 10 – 14 s – ^{3}H, ^{3,4}He, and ^{7}Li begin to form
- 3 m – 3m46s – ^{2}D, ^{3}H, ^{3,4}He, and ^{7}Li form

Grows as $t^{1/2}$

- 34 m - e^+e^- annihilation ends
- 47,000 y – Matter energy density greater than photon energy density
- 377 ky - neutral hydrogen, CMB emitted
- 200 My – first stars and galaxies form

Grows as $t^{2/3}$

- 9.8 Gy – Dark energy begins to drive expansion
- 13.8 Gy - Now

Grows exponentially with t.

All of Einstein on one slide

Postulates of Relativity

1. Laws of physics are the same in all observers moving at constant velocity w.r.t. each other
2. Speed of light is maximum speed of energy transmission, same in all frames
3. Acceleration is the same as gravity (Equiv. Princ.)

Cosmological Principles

1. Universe the same at every point (homogeneity)
2. Universe looks the same in every direction (isotropy)

5 m Break

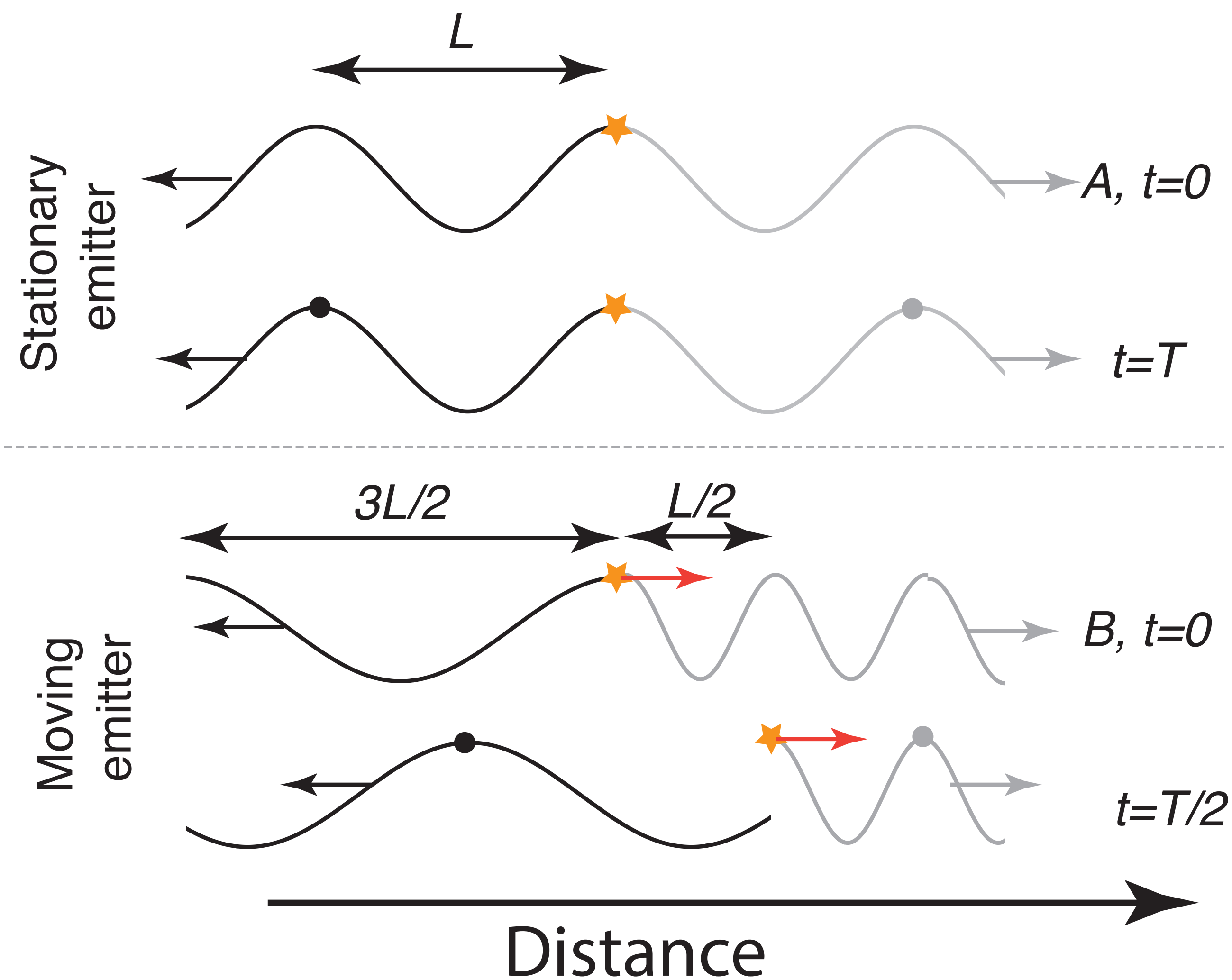
Redshift

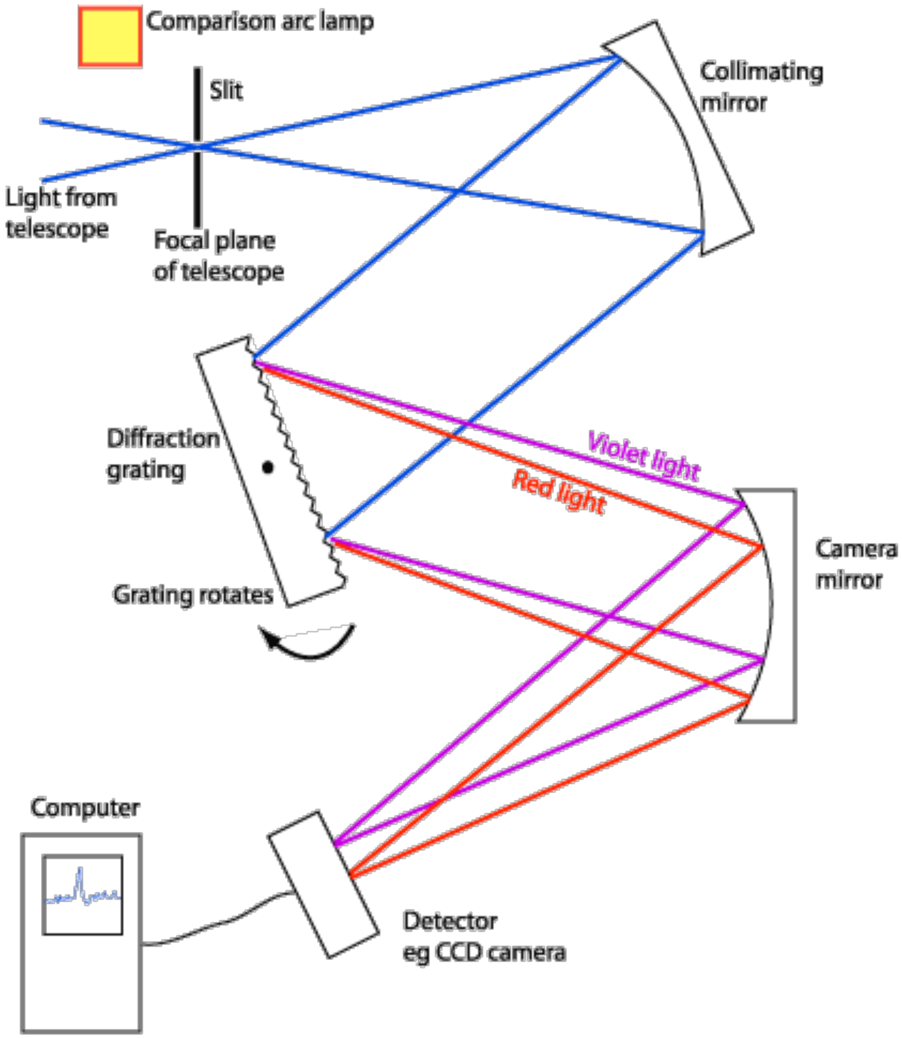
A moving emitter stretches light behind it, compresses light in front of it

Like Doppler shift for sound, but relativistic

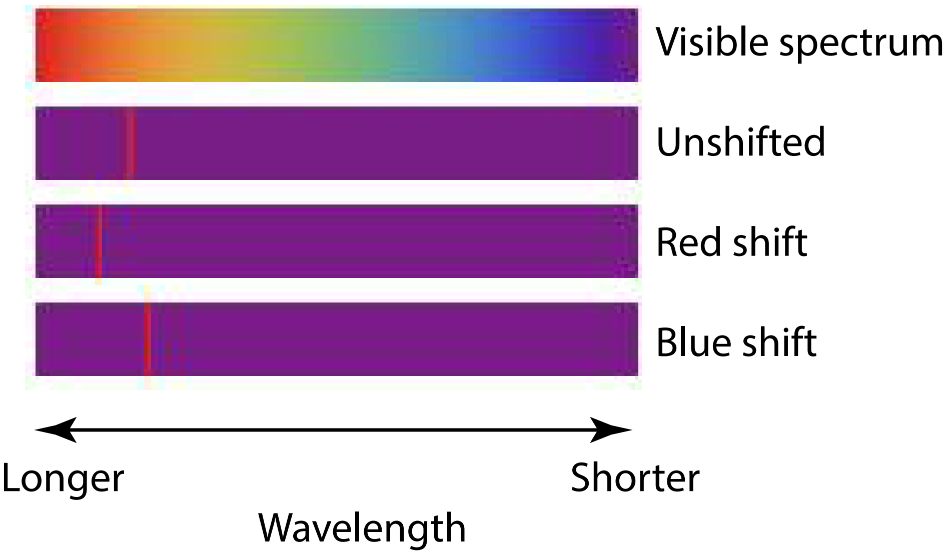
Measure wavelength from moving emitter (star) and compare with stationary emitter in lab

Exoplanets: measure 1 m/s





A Schematic Diagram of a Slit Spectrograph



Measure line from an atomic transition (usually) with. Spectrograph

Diffraction grating or a slit splits light into colors

Need to block off light except from source

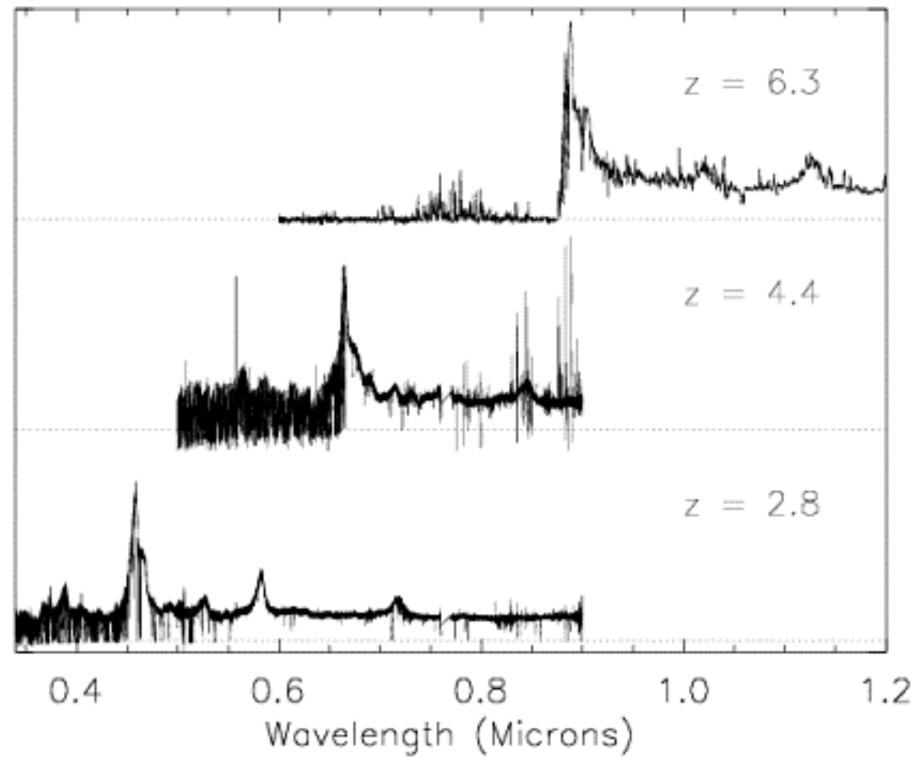
Example: Folded port Infrared Echellette (FIRE) – Rob Simcoe, Magellan Telescope

Spectra from quasars at different redshifts

Same spectral features

z is fractional change in wavelength

z	a	v/c	Time Since start of Universe
0.	1.	0.	13.8 Gyr
1.	0.5	0.6	4.89 Gyr
2.8	0.26	0.87	1.87 Gyr
4.4	0.19	0.93	1.1 Gyr
6.3	0.14	0.96	0.701 Gyr
10.	0.091	0.98	0.379 Gyr

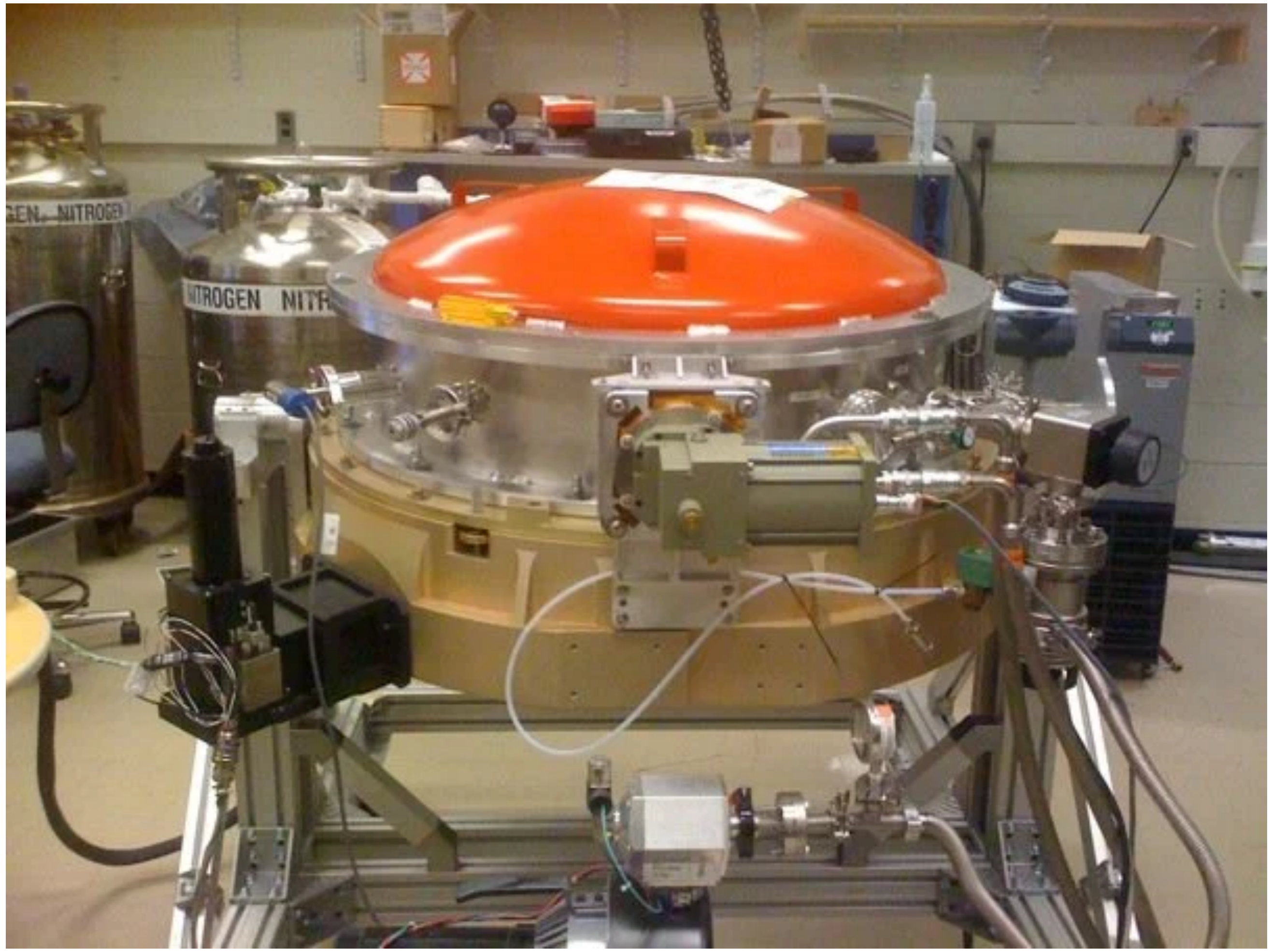


Violet

Red

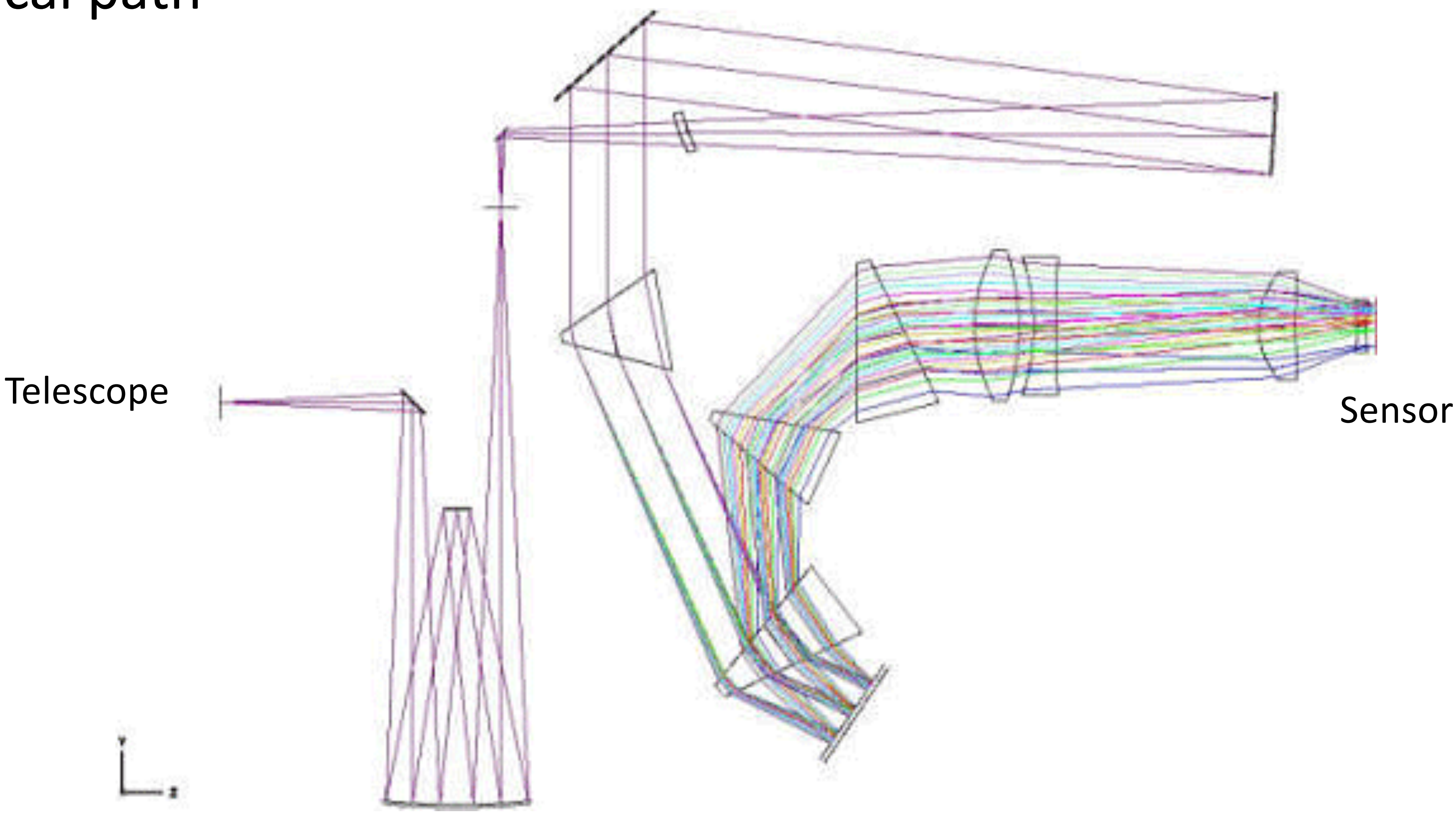
Wavelength at source 0.123 um

Folded Port
Infrared
Echellete
(FIRE)



Magellan 8 m telescope in Chile

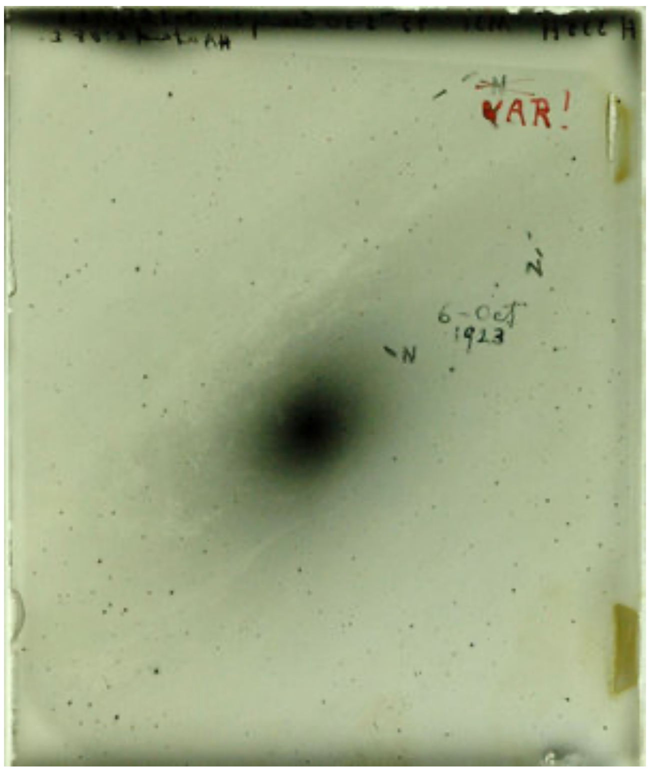
Optical path



The Great Debate (1920)

The Milky Way as seen from La Silla Observatory, Chile

``Nebula'' (German), "Foggy" (English)



1920:
Our solar system is located in a plane of stars called the Milky Way

Many diffuse nebula had been observed. What were they?

Plate from Hubble, Mt. Wilson 100'' of Andromeda

The Great Debate

Smithsonian Museum of Natural History, April 26, 1920

Hebber Curtis (Lick Observatory): Nebula are Island Universes – large collections of starts far outside the Milky Way.

Harlow Curtis (Mt. Wilson Solar Observatory): Nebula are gas clouds inside the Milky Way.

Need to measure distance to Andromeda.

Hubble, Leavitt and the start of the distance ladder

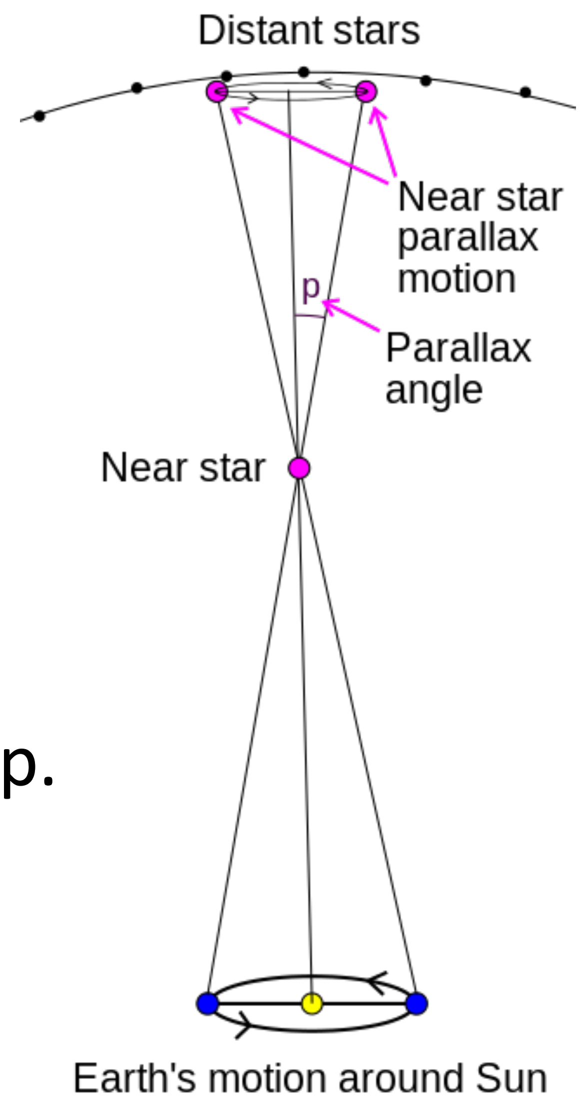
- Parallax method could measure to 1,000 ly
- Cepheid Variable stars' peak luminosity varied with period. Cepheid's are abundant and bright enough to observe at long distances.
- Parallax used to calibrate nearby Cepheids luminosity as a function of period
- Cepheids in Andromeda: measure period to find luminosity, measure luminosity on Earth to find distance.

Stellar Parallax Method

During the course of a year, the Earth orbits the Sun, causing the position of a nearby star to shift relative to more distant stars.

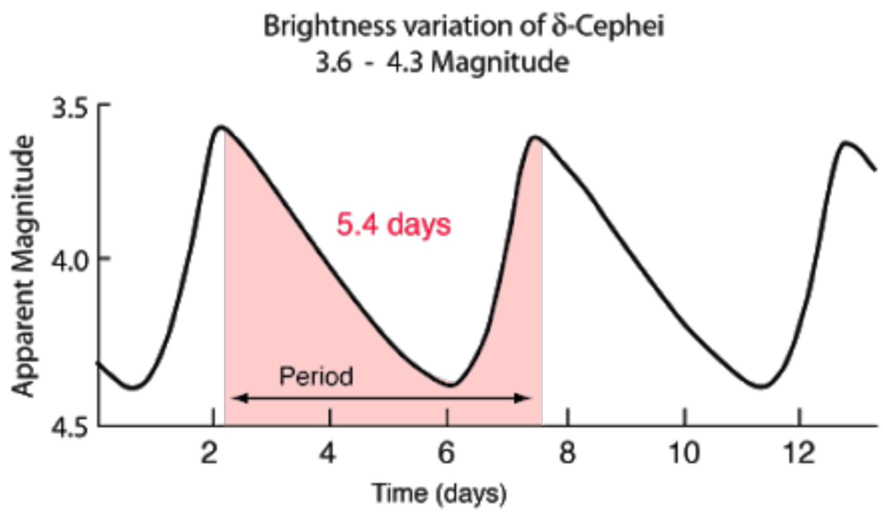
Equal triangles gives D distance as 1 AU/p.

Can measure up to 1 kly.



Calibration of Cepheids

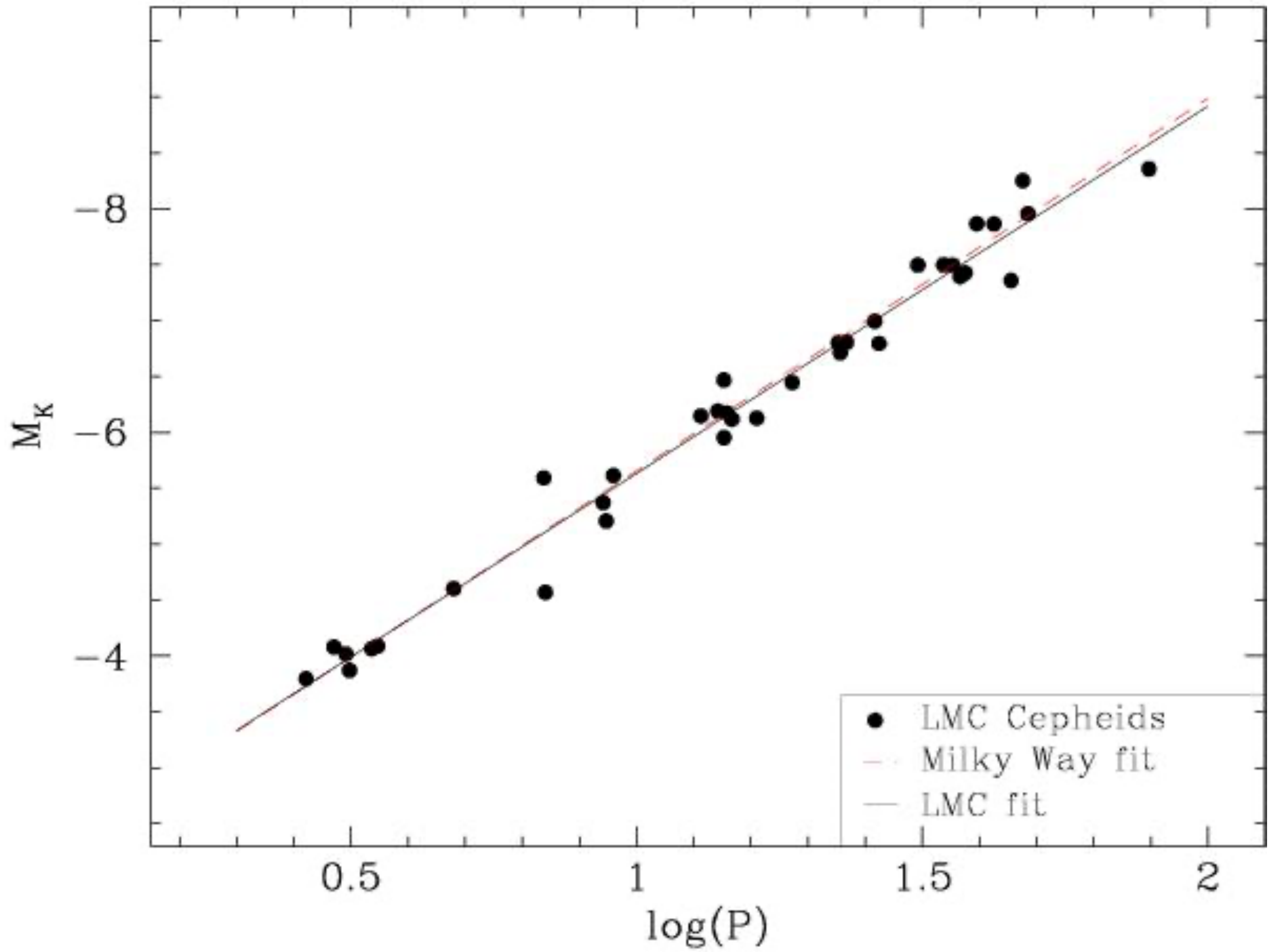
Luminosity, total light emitted, related to period.



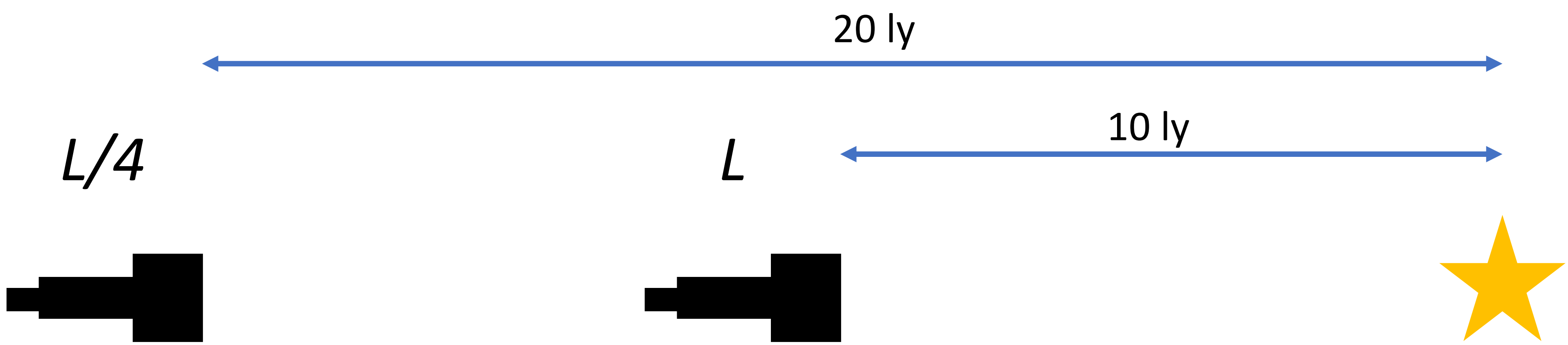
Studied Cepheids in the Small Magellanic Cloud, 160 kly from Earth, all same distance

Henrietta Swan Leavitt – Harvard Observatory

6.25x brightness increase



3 days 10 days 30 days 100 days



Light from a star spreads out as it travels away from the star

Far telescope collects ¼ as much light at the near telescope, twice as far away

If you know how much light a star emits (luminosity) and measure how much you collect in a telescope, you can find the distance to the star.

Leavitt called a star with known light output a “Standard Candle”, the name stuck

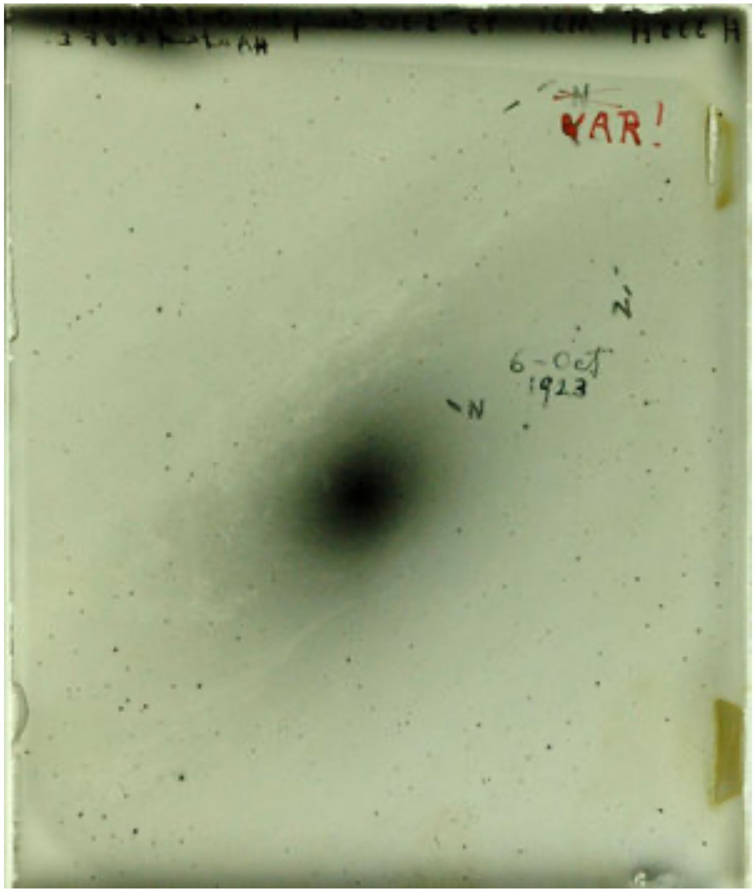
Distance to Andromeda

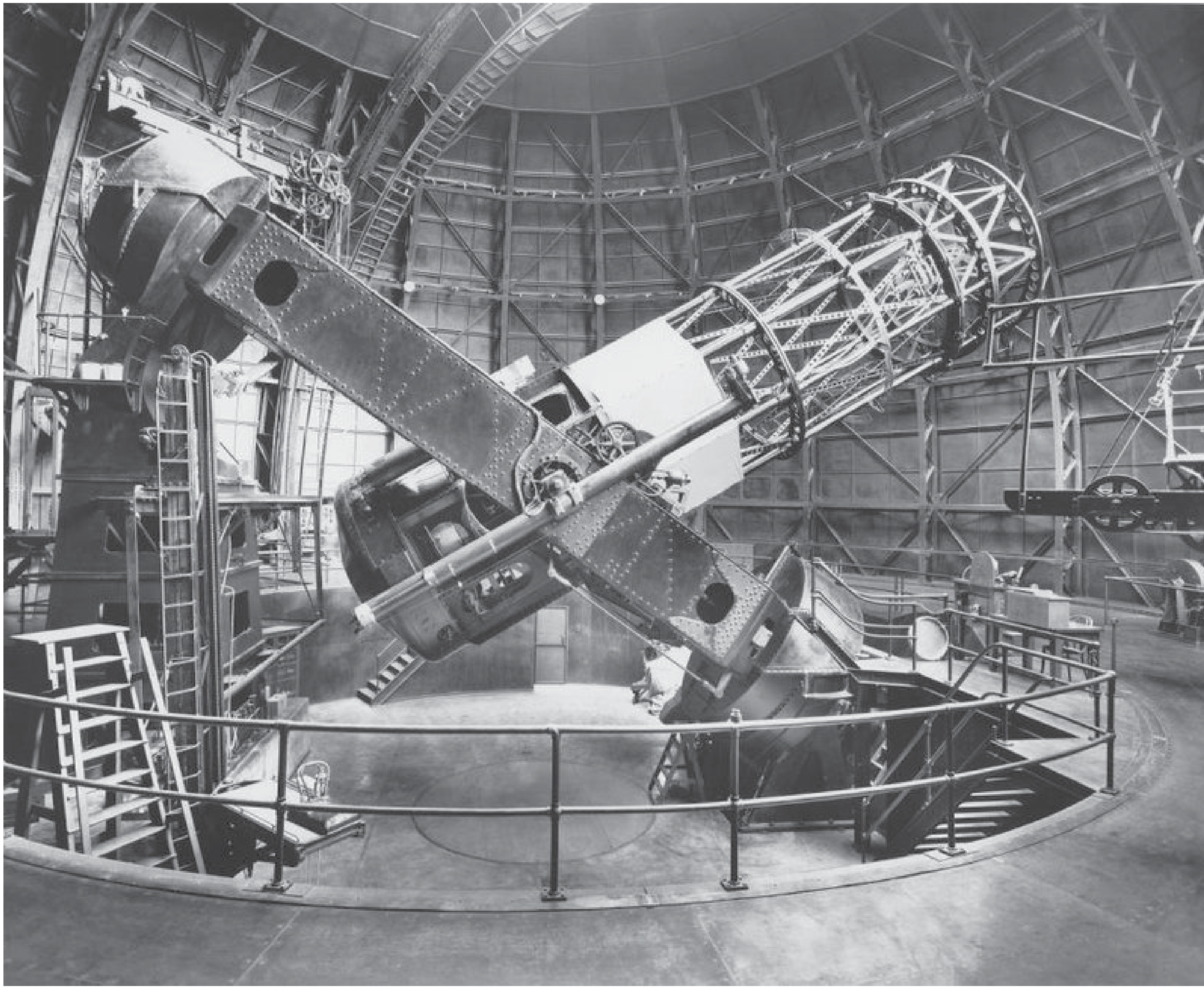
Leavitt studied Cepheids in the LMC and found period luminosity relation

Hertzsprung used parallax to find the distance to several Cepheids in the Milky Way, allowing Leavitt to calibrate their luminosity.

Hubble found Cepheids in Andromeda and measured their period. He then used Leavitt's law to find their luminosity and used measured the light collected in the Hooker telescope to find the distance to Andromeda, 900 kly…

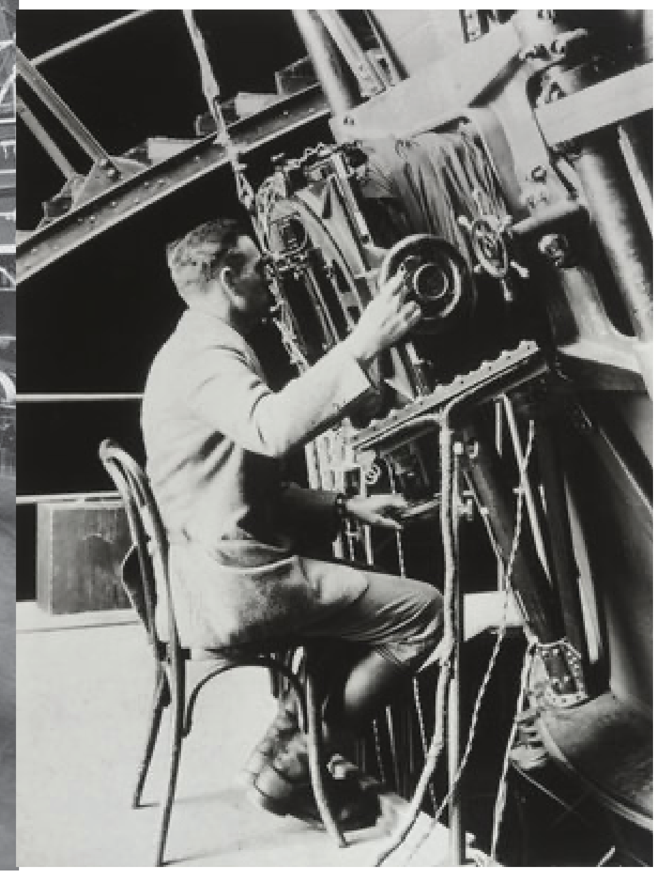
…actual distance is 2.5 Mly.





Hooker 100” telescope

Edwin Hubble



Edwin Hubble