Speed of Light

JHU Advanced Lab

Let each of two persons take a light contained in a lantern, or other receptacle, such that by the interposition of the hand, the one can shut off or admit the light to the vision of the other. Next let them stand opposite each other at a distance of a few cubits and practice until they acquire such skill in uncovering and occulting their lights that the instant one sees the light of his companion he will uncover his own. After a few trials the response will be so prompt that without sensible error [*svario*] the uncovering of one light is immediately followed by the uncovering of the other, so that as soon as one exposes his light he will instantly see that of the other. Having acquired skill at this short distance let the two experimenters, equipped as before, take up positions separated by a distance of two or three miles and let them perform the same experiment at night, noting carefully whether the exposures and occultations occur in the same manner as at short distances; if they do, we may safely conclude that the propagation of light is instantaneous; but if time is required at a distance of three miles which, considering the going of one light and the coming of the other, really amounts to six, then the delay ought to be easily observable. If the

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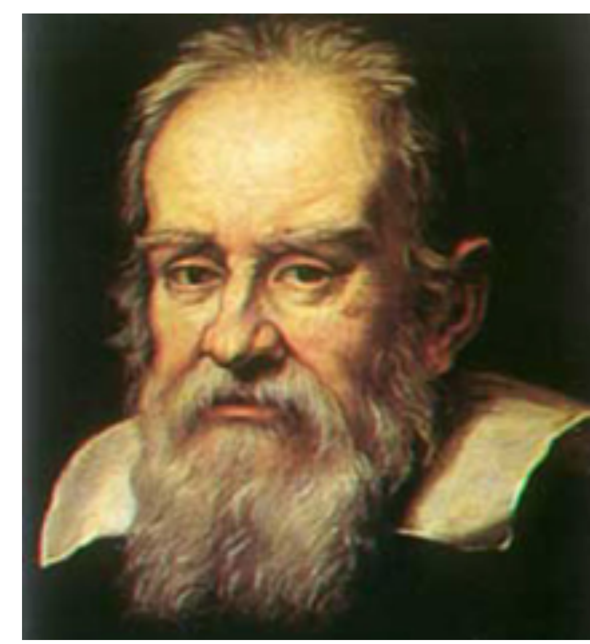
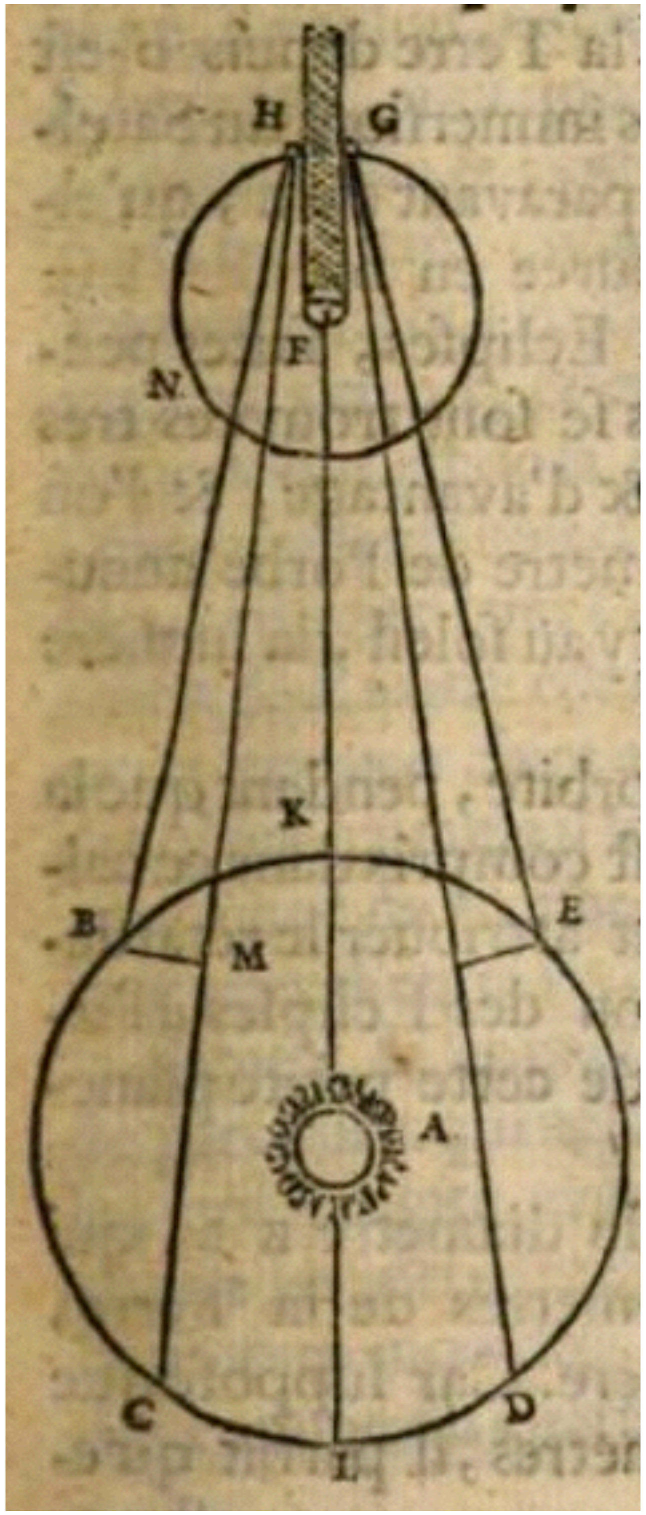
SAGR. This experiment strikes me as a clever and reliable invention. But tell us what you conclude from the results.

SALV. In fact I have tried the experiment only at a short distance, less than a mile, from which I have not been able to ascertain with certainty whether the appearance of the opposite light was instantaneous or not; but if not instantaneous it is extraordinarily rapid—I should call it momentary; and for

from
Dialogues concerning Two New Sciences
by
Galileo Galilei
(1638)



Ole Rømer and the Moons of Jupiter



Rømer measures anomalies in the orbit of Jupiter's satellite, Io. Attributes them to finite speed of light.

(1676)

Rømer

Huygens

If one considers the vast size of the diameter KL, which according to me is some 24 thousand diameters of the Earth, one will acknowledge the extreme velocity of Light. For, supposing that KL is no more than 22 thousand of these diameters, it appears that being traversed in 22 minutes this makes the speed a thousand diameters in one minute, **that is 16-2/3 diameters in one second or in one beat of the pulse, which makes more than 11 hundred times a hundred thousand toises;** since the diameter of the Earth contains 2,865 leagues, reckoned at 25 to the degree, and each each league is 2,282 Toises, according to the exact measurement which Mr. Picard made by order of the King in 1669.

from *Traitée de la Lumiere* by C. Huygens

(1 Toise $\approx$ 2 m): c $\approx$ 220,000 km/s

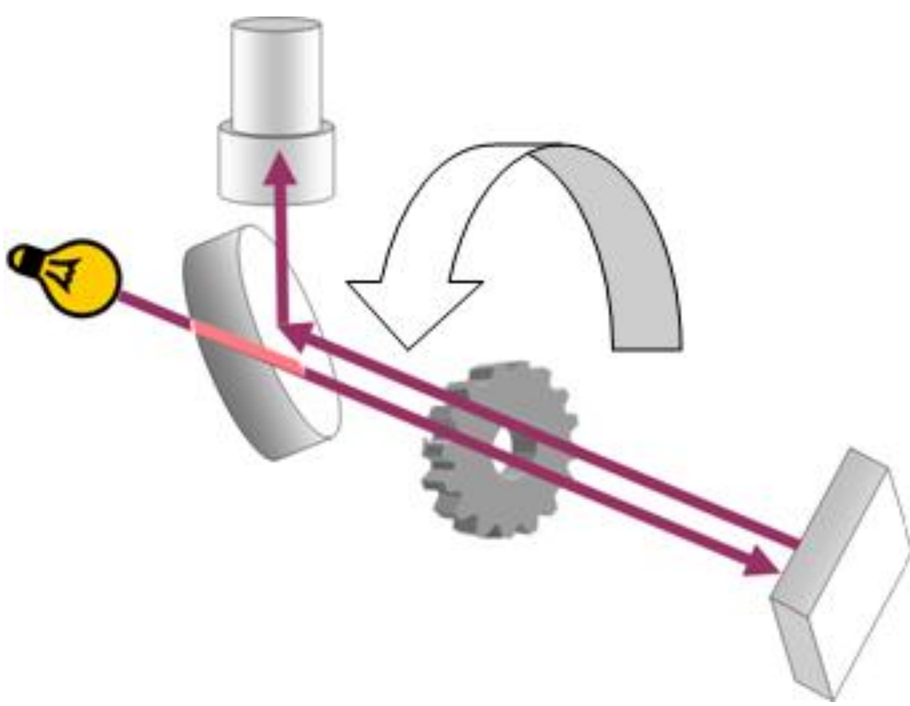
Fizeau-Foucault Measurements

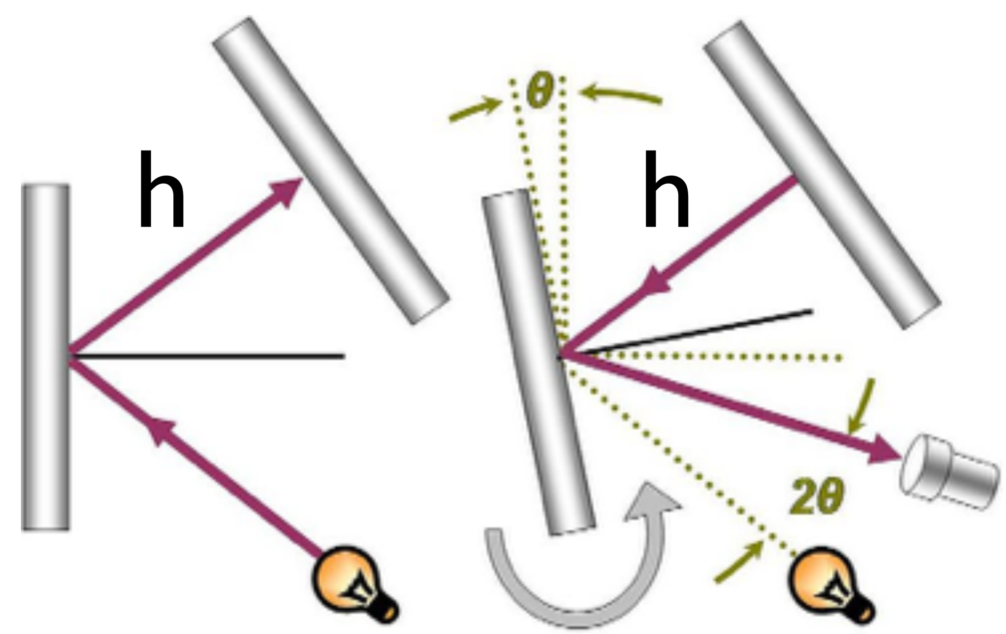
Hippolyte Fizeau

1849 - H. Fizeau uses rotating cogwheel to measure c≈313,300 km/s.

1862 - L. Foucault substitutes a mirror for a cogwheel and estimates c≈298,000 km/s.

Leon Foucault





$$\frac{\theta}{\omega} = \frac{2h}{c} = t \ .$$

20th Century Measurements

1907 - E.B. Rosa and N.E. Dorsey of the National Bureau of Standards (NBS) estimate c using measurements of permittivity and permeability of free space c = 299,781 ± 10 km/s

$$\varepsilon_0 = \frac{1}{\mu_0 c^2}$$

A. Michelson

1926 - Albert Michelson uses improved optics to send beam of light between two mountains (22 miles) using the same rotating mirror technique as L. Foucault. c = 299,796 ± 4 km/s

Michelson's beam launch/return site on Mount Wilson

Frequency-Wavelength Measurements

$$c=\lambda\nu$$

K. Evenson and NIST/NBS Boulder team

1958 - British scientist Keith Froome uses a millimeter-wave interferometer to measure c = 299,792.50±0.1 km/s

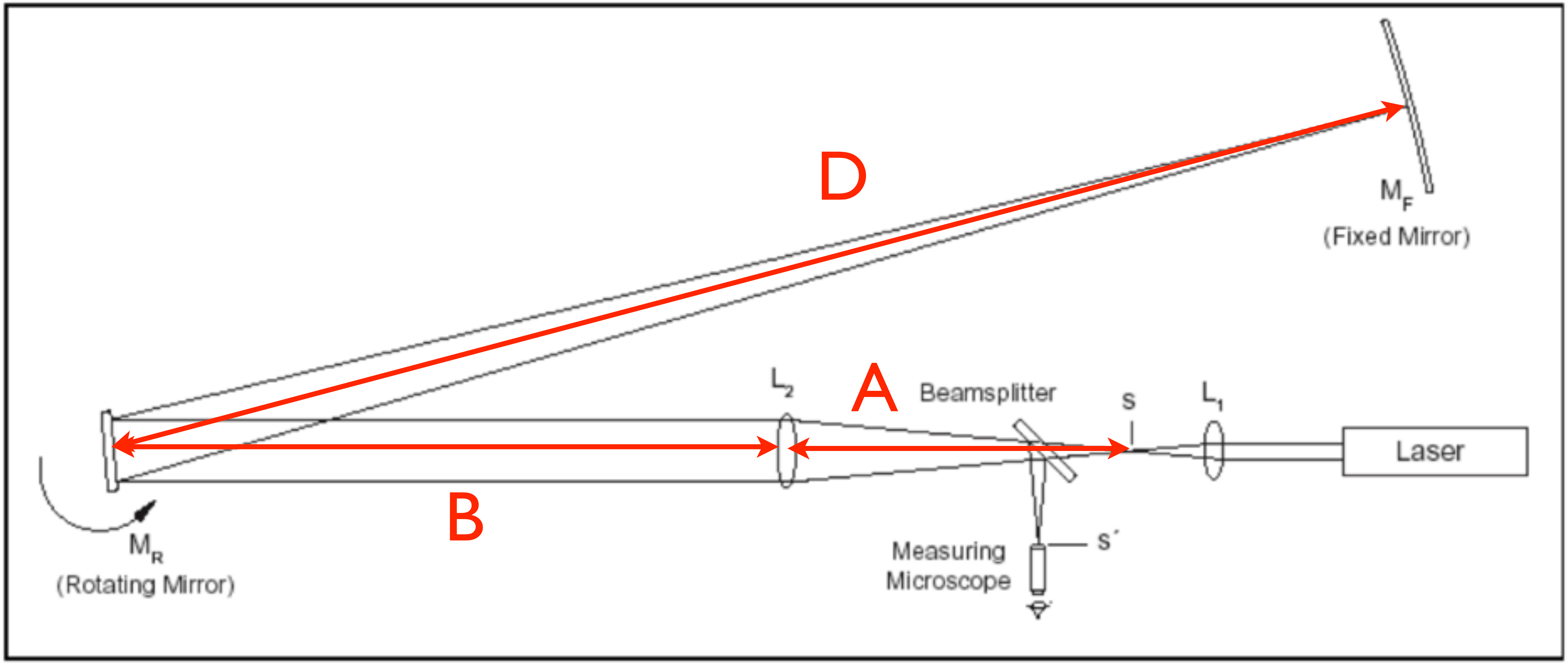
1958 - Ken Evenson and colleagues at NIST/NBS Boulder use an infrared laser interferometer to measure
c = 299,792,456.2 ± 1.1 m/s

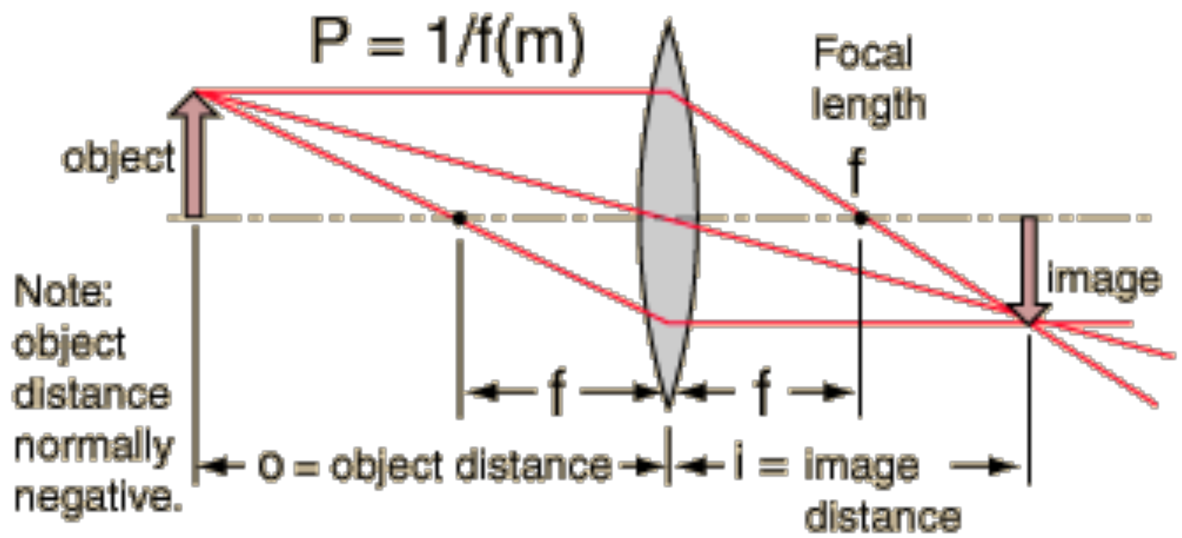
1983 - Meter defined as the distance light travels in 1/299792458th of a second. -- Speed of light "defined".

Experiment and Data

In this lab you repeat the Fizeau/ Foucault/Michelson "time of flight" speed of light measurement.

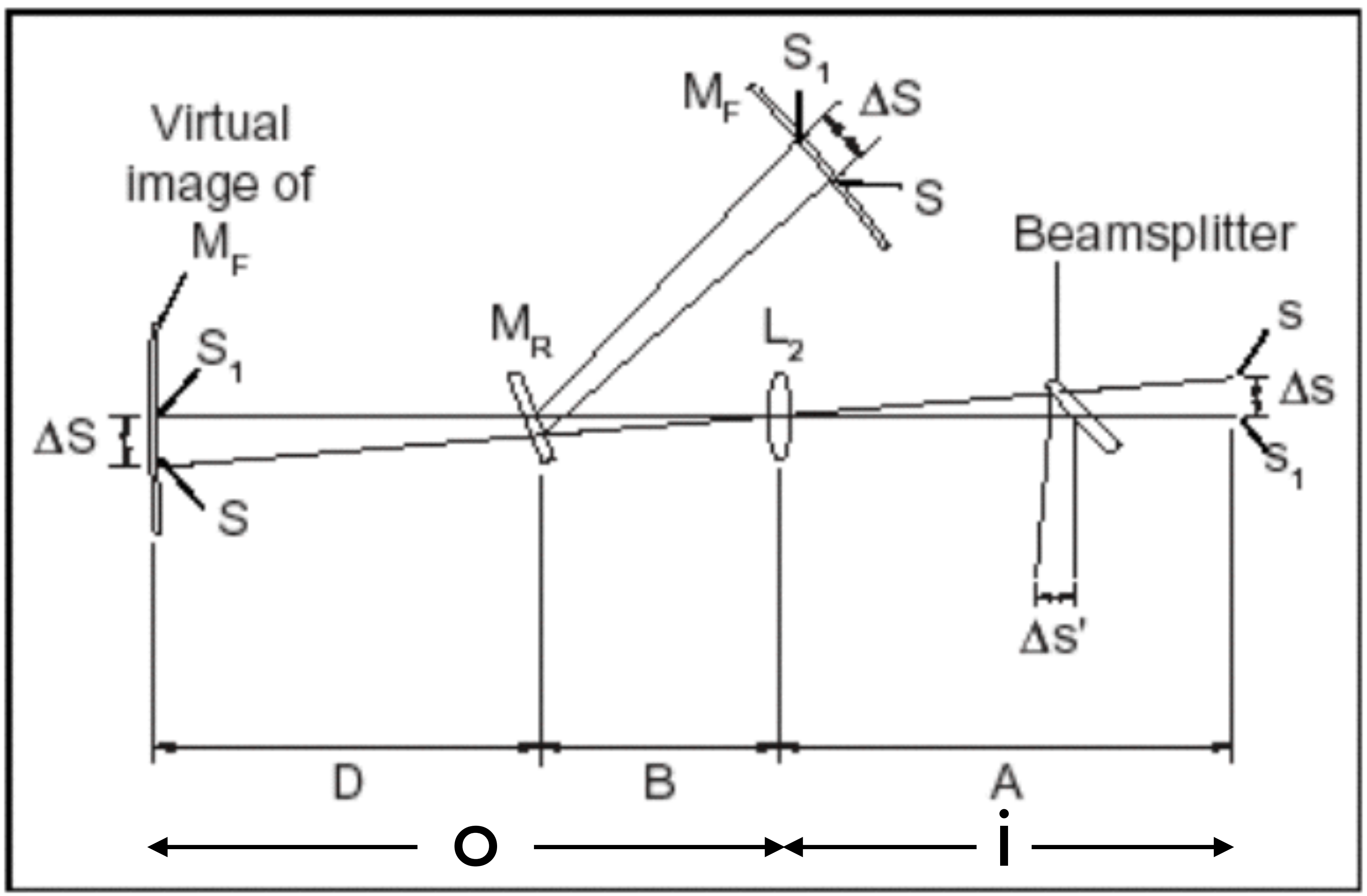
PASCO Speed of Light Apparatus





$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$$

$$\frac{1}{\text{object distance}} + \frac{1}{\text{image distance}} = \frac{1}{\text{focal length}}$$



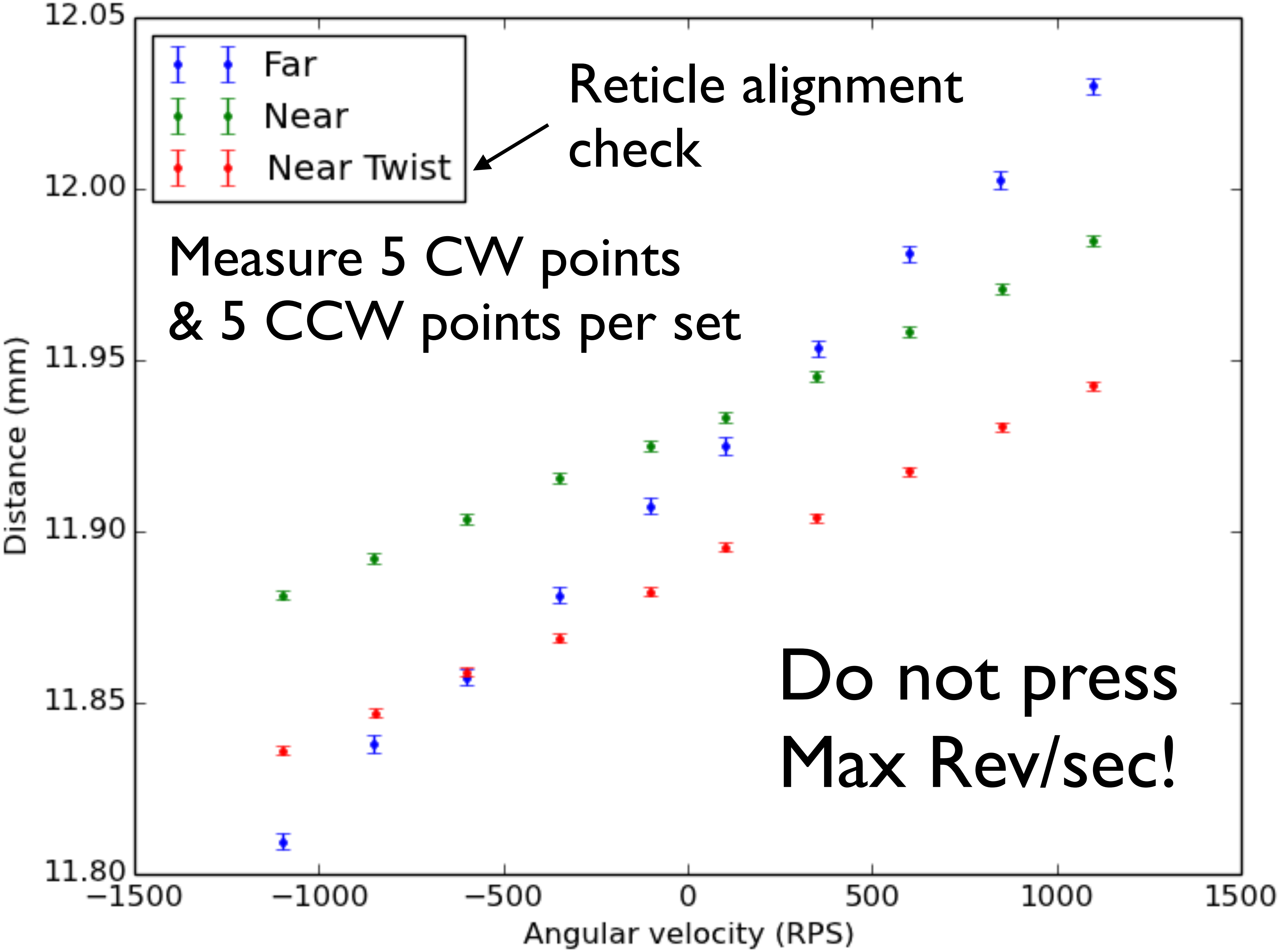
$$\Delta\theta = 2D\omega/c$$

$$\Delta S = D(2\Delta\theta)$$

$$\Delta s = \frac{A\,\Delta S}{D+B}$$

$$\Delta s' = \frac{4AD^2\omega}{c(D+B)}$$

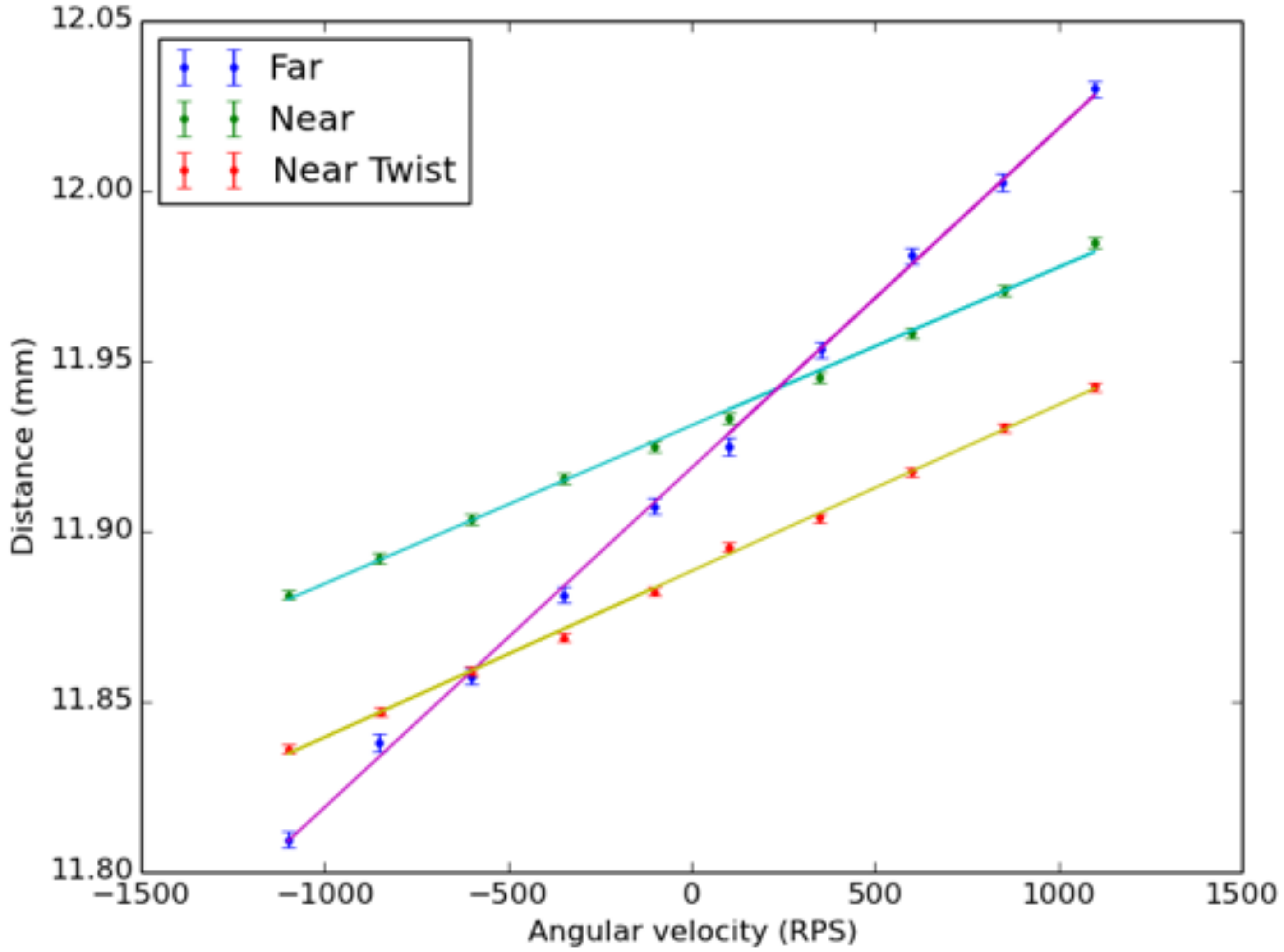
1) At least two people per lab group
2) Take two ‘sets’ of measurements with different D distances.
3) Each person takes both ‘sets’ of measurements.
4) Scatter estimated between group members’ measurements. (may average error across data points in a ‘set’).



For each person, try to obtain measurements at the same angular velocities so that data can be averaged combined and errors in velocity can be neglected.

Data Analysis

1) Linear fits to obtain $\Delta s/\omega$ (and $\sigma_{\Delta s/\omega}$) (also Chi-sq goodness of fit with PTE)



2) Estimate c from

$$c = \frac{4AD^2\omega}{(D+B)\Delta s'}$$

propagating error on $\Delta s/\omega$, A, B, & D.

Bibliography

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C. Huygens, *Traitée de la Lumiere* (1690).

A. A. Michelson, Measurement of the Velocity of Light Between Mount Wilson and Mount San Antonio, *The Astrophysical Journal,* **65**, 1 (1927).

E. B. Rosa and N. E. Dorse, A new determination of the ratio of the electromagnetic to the electrostatic unit of electricity, *Bull. Bur. Stand.* **3**, 605-622 (1907)

Schedule

Week 1:
1) Collect datasets
2) Write Intro and Experiment & Data for Draft One (No Theory Section here)
3) Upload graph of data

Week 2:
1) Linear fitting, error propagation
2) Write Data Analysis for Draft Two

Week 3:
1) Finish up!