Measuring the Speed of Light - The Sequel

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Orwell Astronomical Society (Ipswich)
11th January 2012

Outline

- Recap of last year's workshop
- Is c really constant?
- Neutrinos that break the rules
- The Moons of Jupiter on a spreadsheet
- Mirrors, Prisms, Lasers and Bricks
- Tea break?
- Doing a measurement

Why is the speed of light important astronomically?

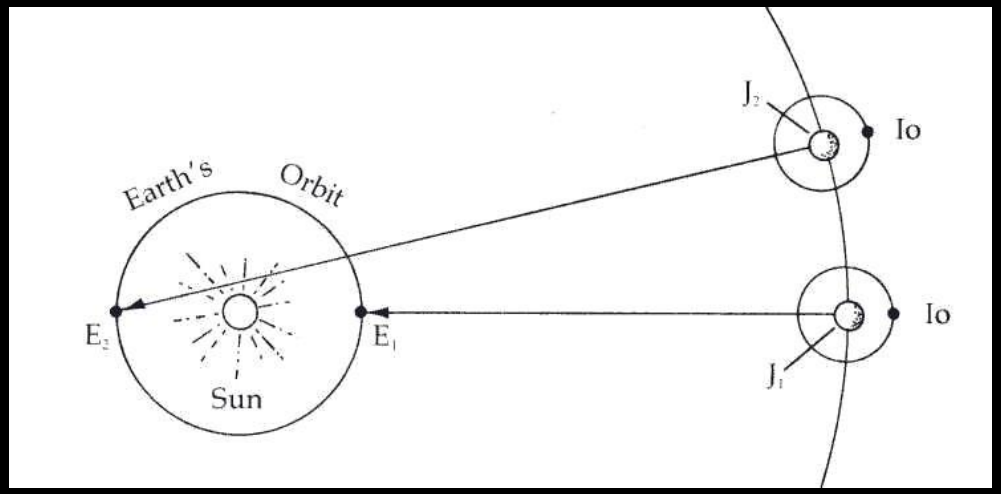
- Key to understanding how what we observe relates to what is actually happening and when
- Led Einstein to his theories of Special and General Relativity which are fundamental to understanding the cosmos

Speed in vacuo:

c = 299,792,458 metres per second

Ole Rømer (~1670)

- Used the orbiting of Jupiter's moon Io (moving into or out of Jupiter's shadow) as a ticking clock
- Having determined the orbital period of Io (the 'clock tick') he argued the ticks would be seen later when Jupiter was further from the Earth

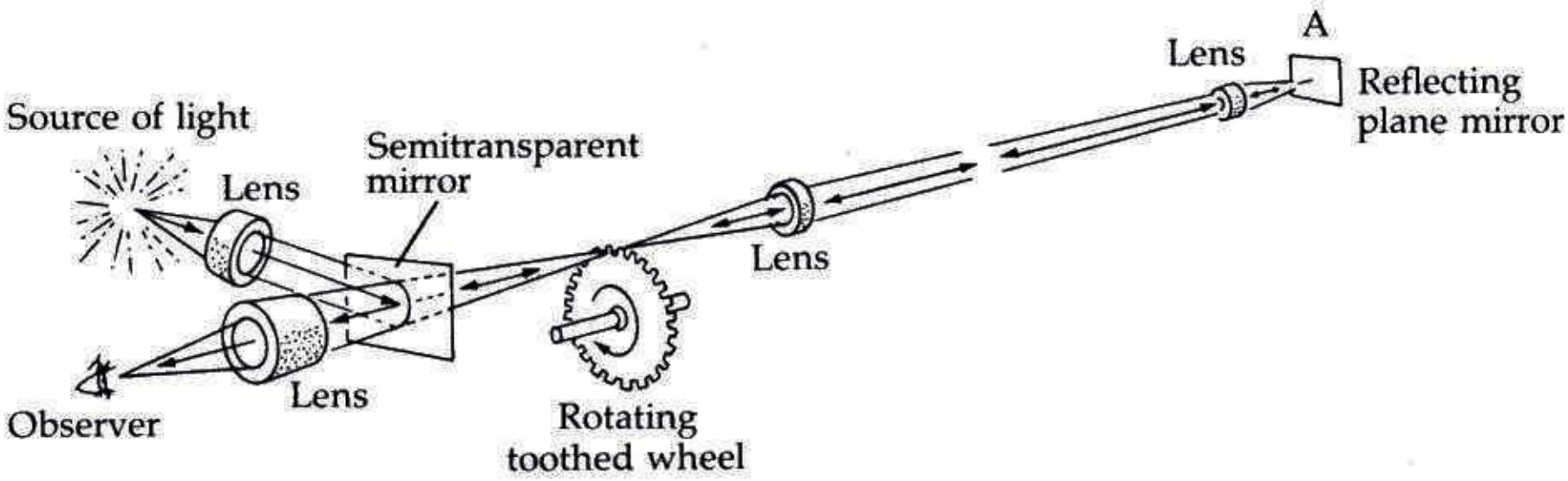


Speed of light =

$$\frac{\text{Earth orbit diameter}}{\text{Maximum tick delay}}$$

Fizeau's toothed wheel

- 1847 – Armand Fizeau measured the speed of light terrestrially
- Spinning toothed wheel passes pulses of light to a distant mirror
- Reflected pulses are blocked upon return if the wheel is spun fast enough



Foucault's rotating mirror

- Originally suggested by Wheatstone in 1834
- Foucault made his measurement in 1860
- Improved by Newcomb (1882) who introduced a multi-faceted mirror
- Further refined by Michelson (1879, 1882, 1929)
- Measurement in vacuo – Pearson and Pease (1931)

Michelson's notebook

Experimental Determination of the Velocity of Light.

Albert A. Michelson
Master, U.S. Navy.

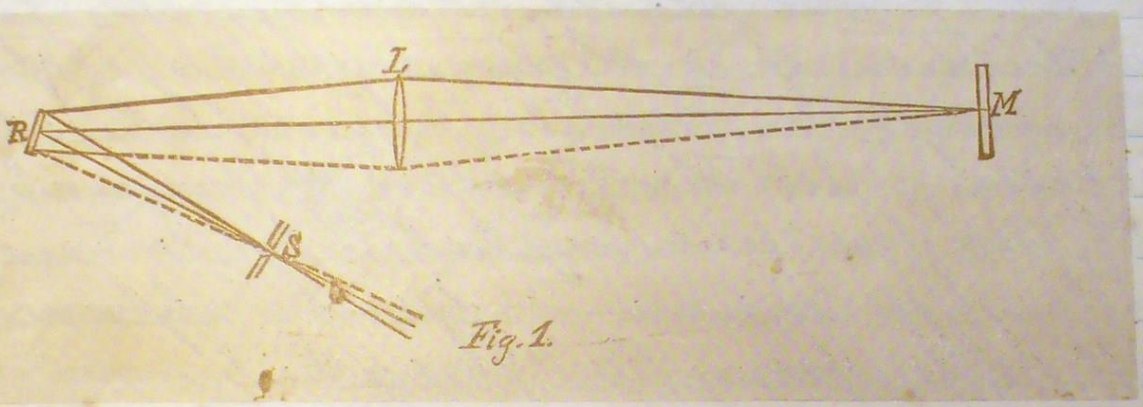


Fig. 1.

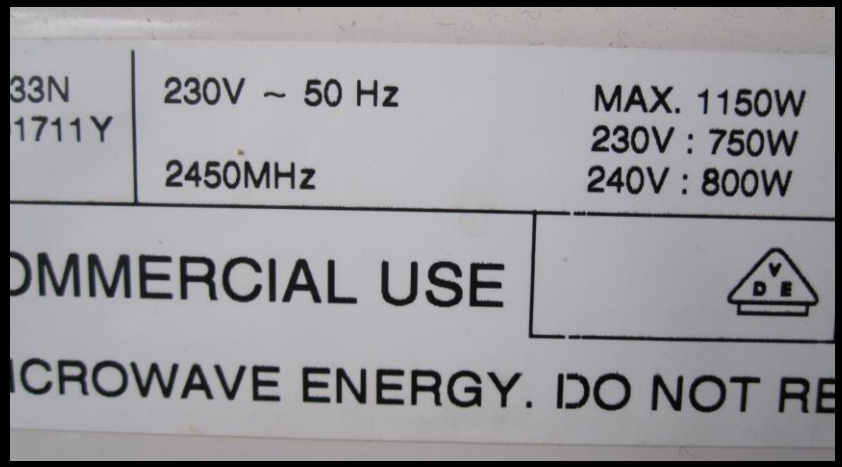
Let S, Fig. 1, be a slit through which light passes falling on R, a mirror free to rotate about an axis at right angles to the plane of the paper; L, a lens of great focal length upon

Methods I tried last year

- Microwave
- Pulsed Laser
- Rotating Mirror

Microwave

- Standing wave in microwave oven produces 2 hot spots per wavelength λ
- Frequency f of microwave oven is 2450MHz



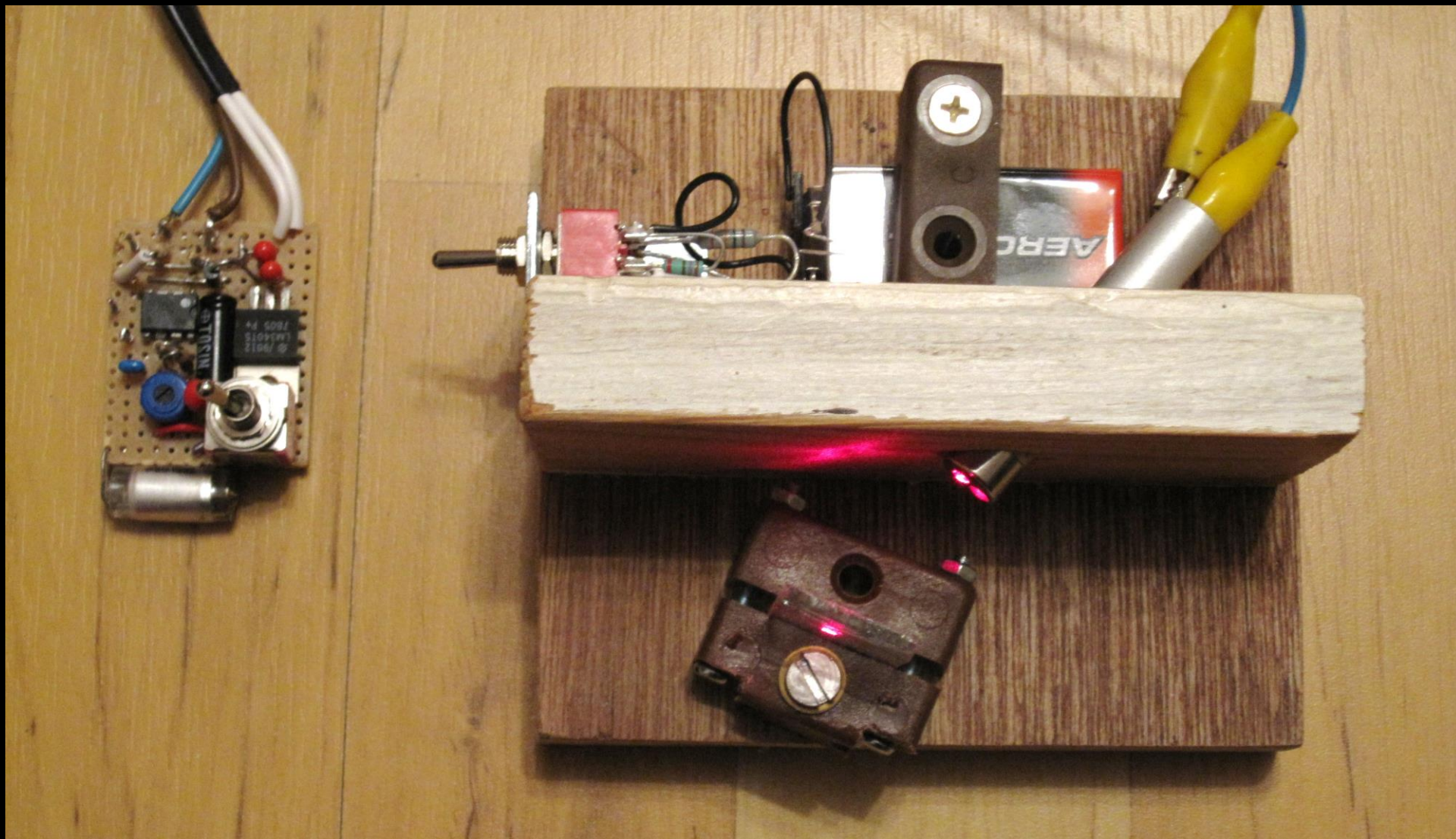
$c = f \times \lambda$

Cheese slices used as hot spot detectors

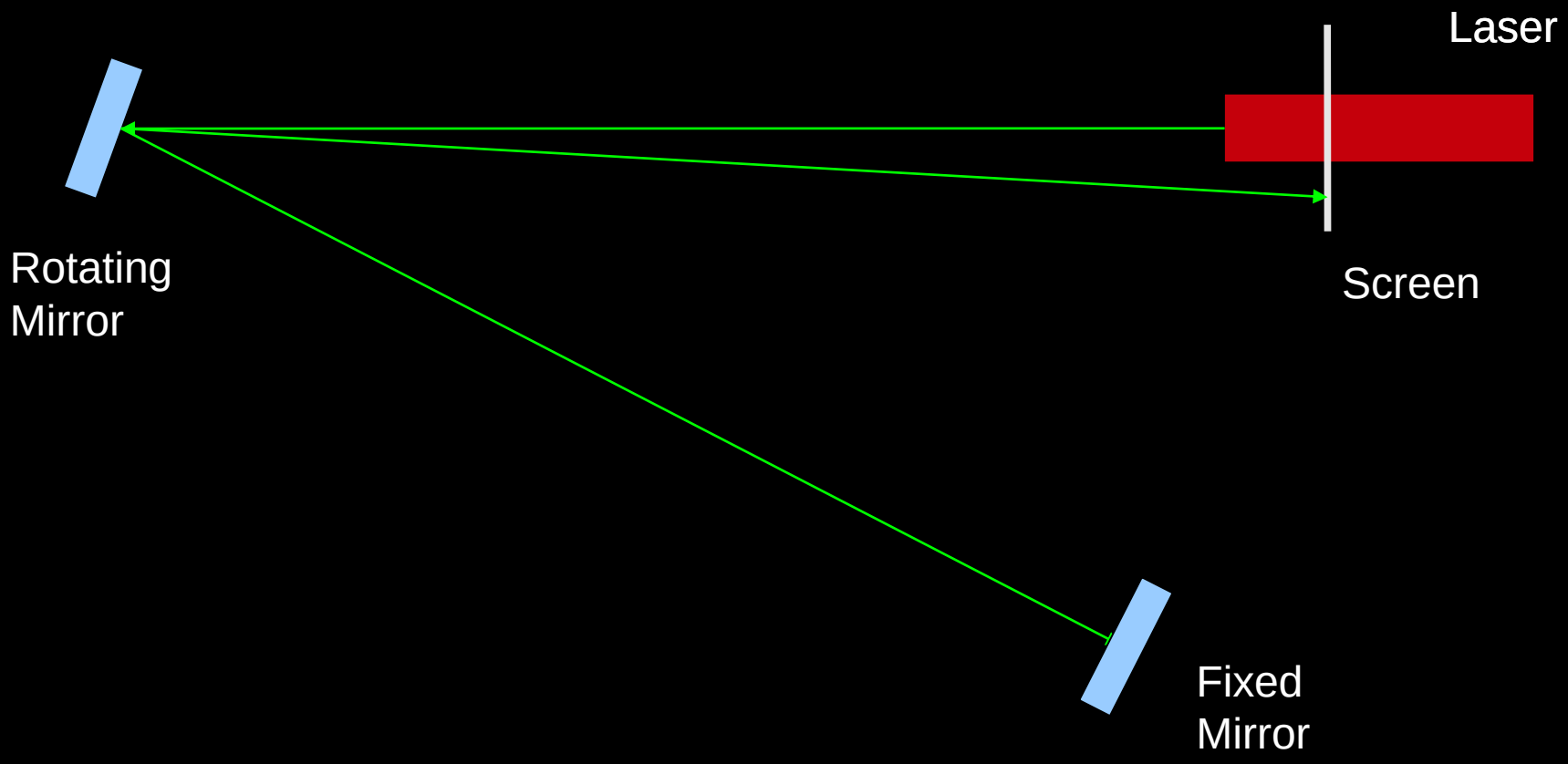
Pulsed Laser

- Laser diode switched on/off at ~100kHz
- Rising edges of light pulses detected by photodiodes and displayed on oscilloscope
- Delay (T) in rising edge observed when long path (P) in place using mirrors
- $c = P / T$
- 30 metre round trip $\rightarrow$ delay of 100nS

Pulsed Laser, Beam Splitter, Reference Photodiode

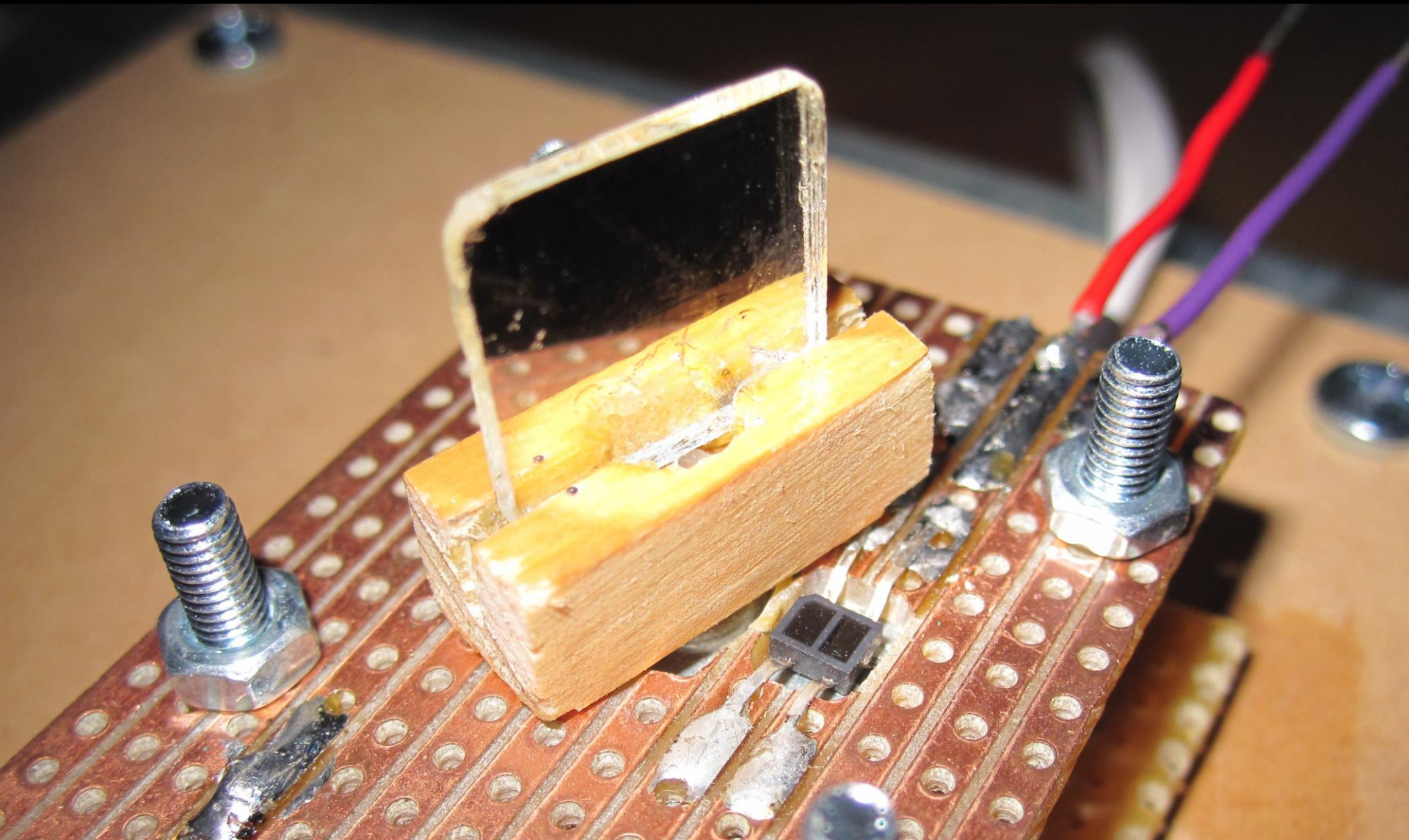


Rotating Mirror Method

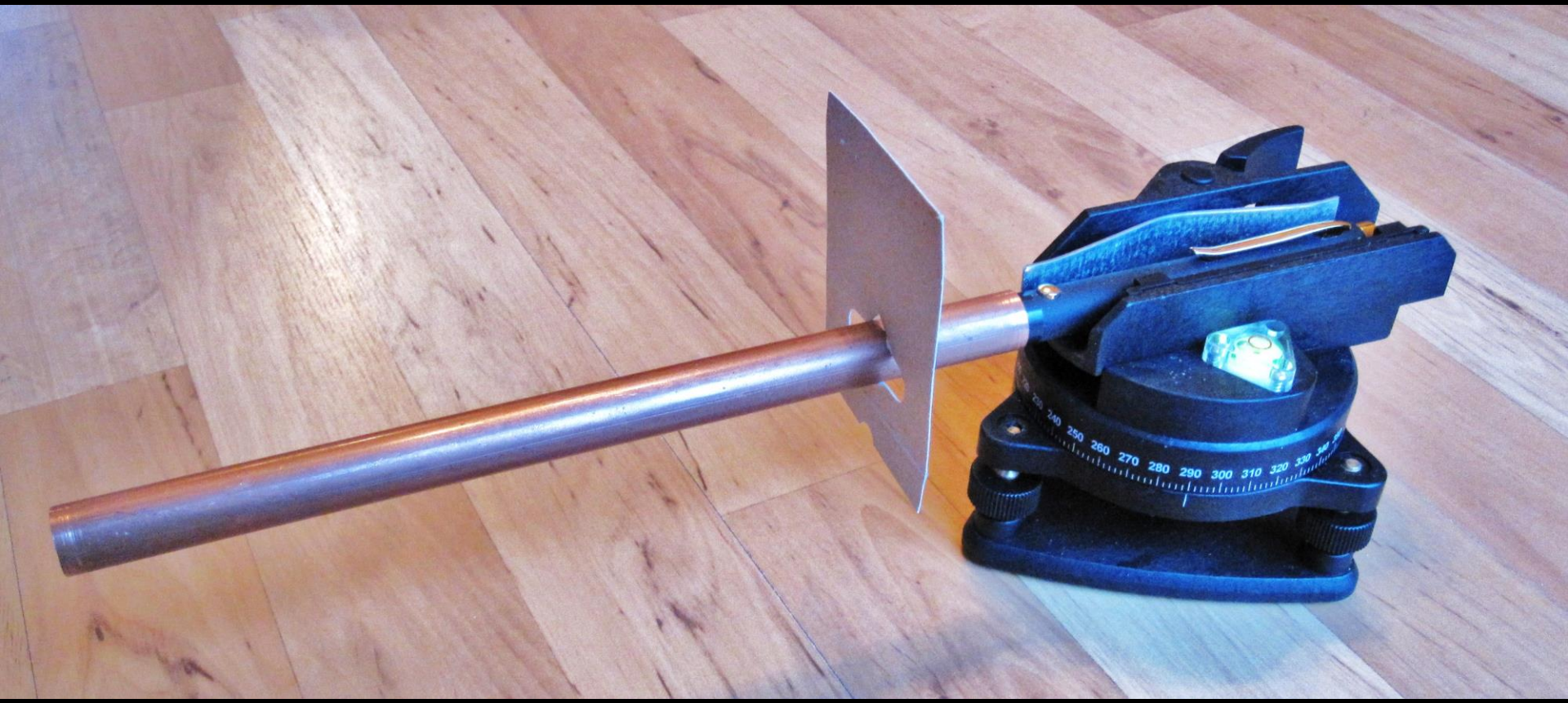


Rotating Mirror

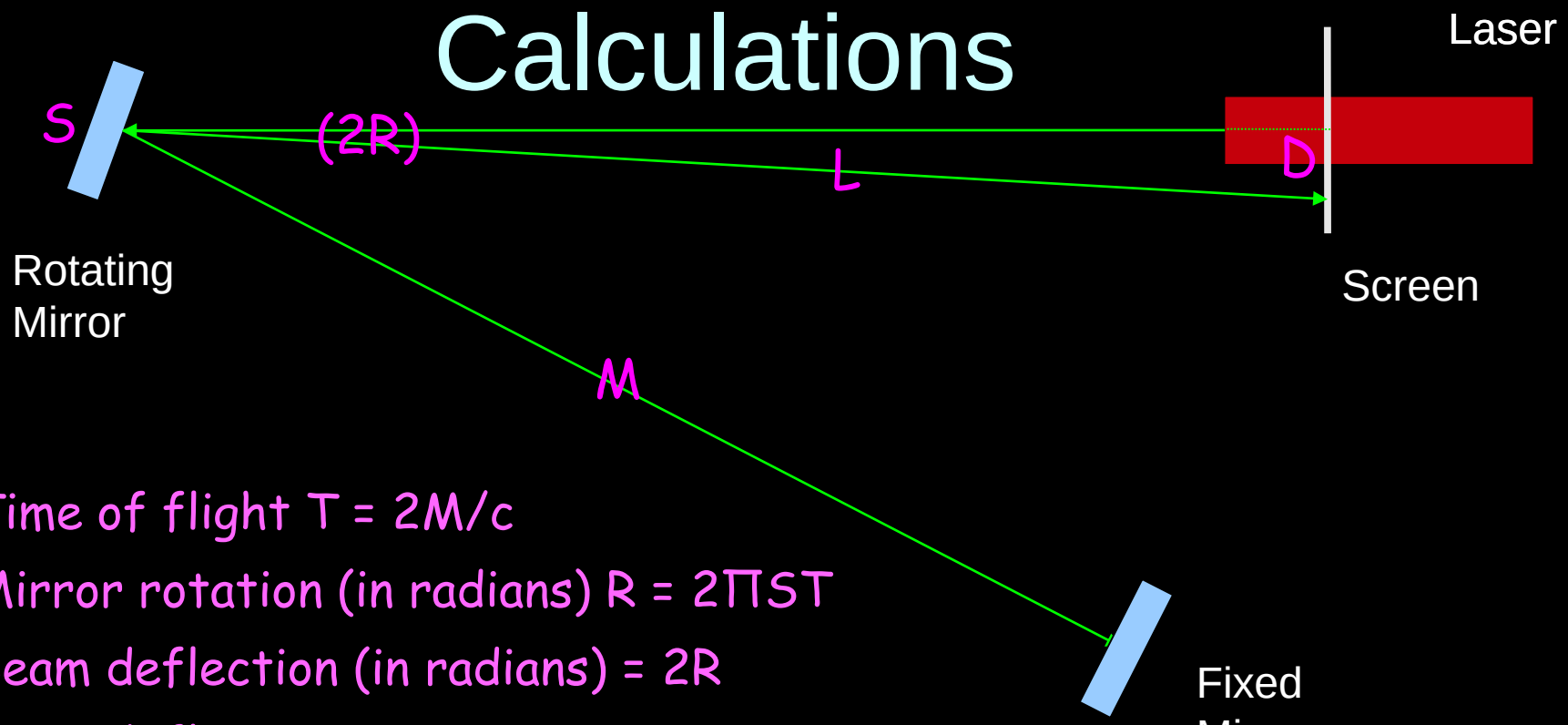
Rotating mirror (~130 rev/s)



Laser and screen



Calculations



Time of flight T = 2M/c

Mirror rotation (in radians) R = 2ΠST

Beam deflection (in radians) = 2R

Beam deflection on screen D = 2RL

Putting it all together: c = 8ΠMLS/D m/s

For initial experiment, expected D to be approx:

$D = \frac{8\Pi x14x14x130}{299792458} \sim 2.1mm$

New this year...

- Is c really constant?
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Is c really constant??

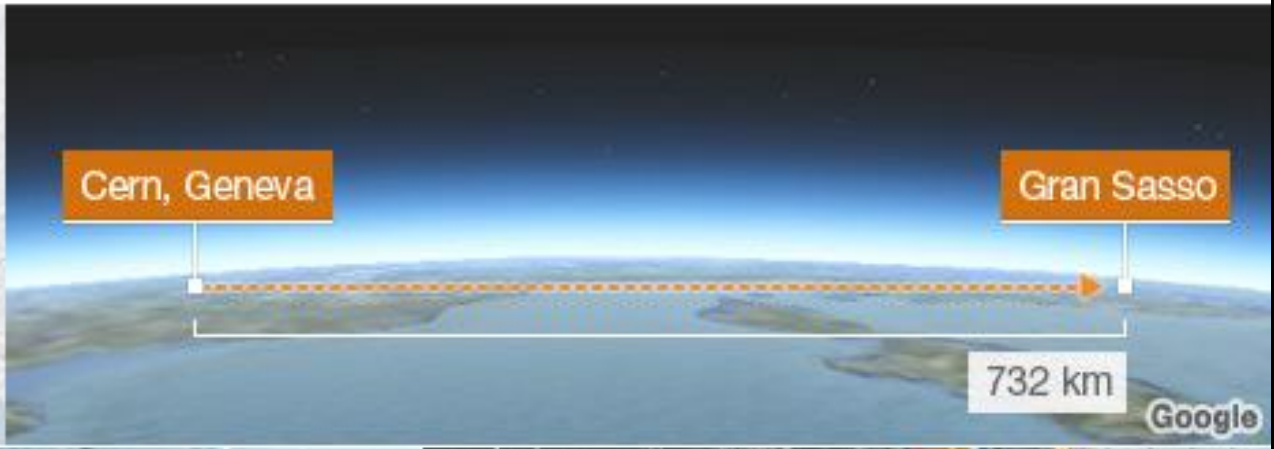
- Light does slow down when passing through matter (Refractive Index)
- If c changed over time, other physical constants must also change
  - e.g. permittivity and permeability of free space - hence charge on an electron, Planck's constant, fine structure constant...
  - hence ratios of spectral lines of distant quasars would have changed – they haven't

Cern test 'breaks speed of light'

0.0024 seconds
time taken by **neutrinos**

0.00000006 seconds
faster than the expected time

732 km
distance travelled through rock

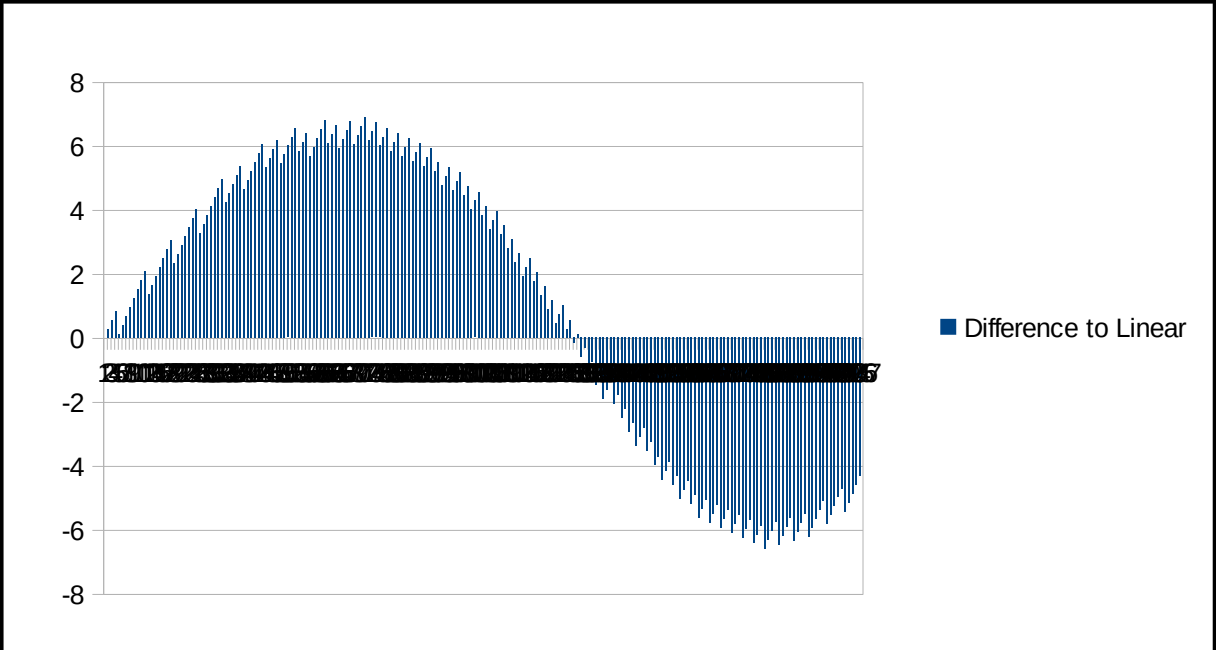


Cern, Switzerland: A beam of neutrino particles is sent through rock towards Italy

Gran Sasso, Italy: Bricks with ultrasensitive covering at underground laboratory detect arrival

Eclipses of Jupiter's moon Io (Rømer's method)

- Eclipse timing predictions for 2011 downloaded from the Internet
- Spreadsheet used to extract deviations of timing from regular 'clock tick'



Observing project

- Record timings of eclipses of Io over a period of up to a year
- Exact timing of an eclipse difficult as each event (start or end of an eclipse) takes 210 seconds to complete
- Eclipse 'starts' are observable for only ~6 months, then eclipse 'ends' for ~6 months
- The full calculations could be quite complex if allowing for:
  - Ellipticity of Earth's orbit
  - Ellipticity of Jupiter's orbit
  - Tilt of Io's orbit
  - Orbital resonances of Jupiter's moons

New equipment built or acquired this year...

- Lasers with variable focus
- Faster and larger rotating mirror
- Mirror rotation speed measurement
- Corner Cube Reflector
- Modified optical path layout

Focussing a red laser

- Saw off the front of a laser pointer/module
- Remove mini lens
- Mount laser at focus of a camera or similar lens with adjustable focus
- Tinker with alignment to get even illumination
- Wide beam (1 to 3 cm) that will focus down to a point at a given distance
- EYESIGHT SAFETY
  - Beware focussed beam
  - Not advised with green laser: strong invisible infra-red content due to internal laser design

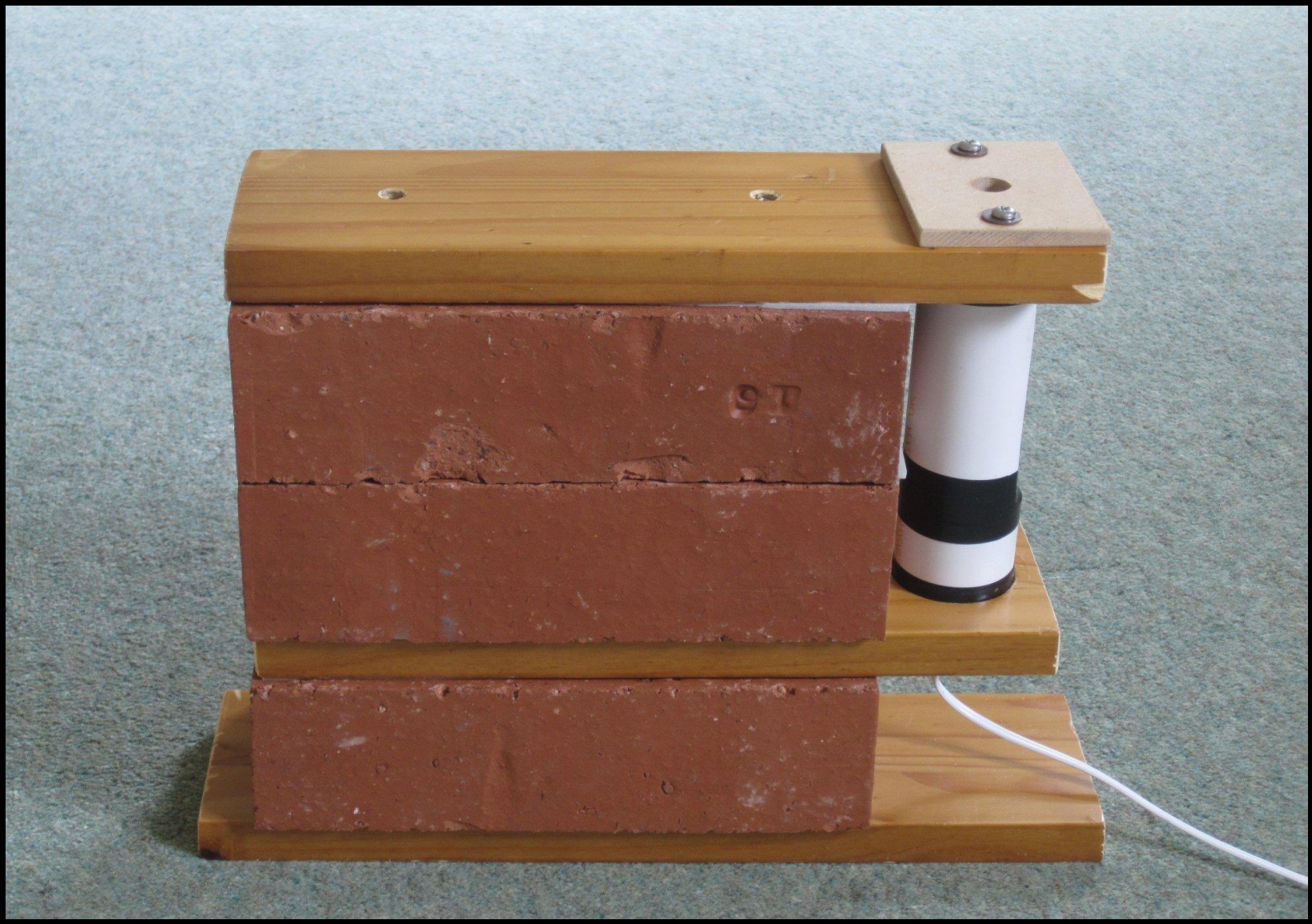
Camera lens with 5mW Red laser

Lens in DIY focuser with 5mW Red laser

5mW Green laser pointer

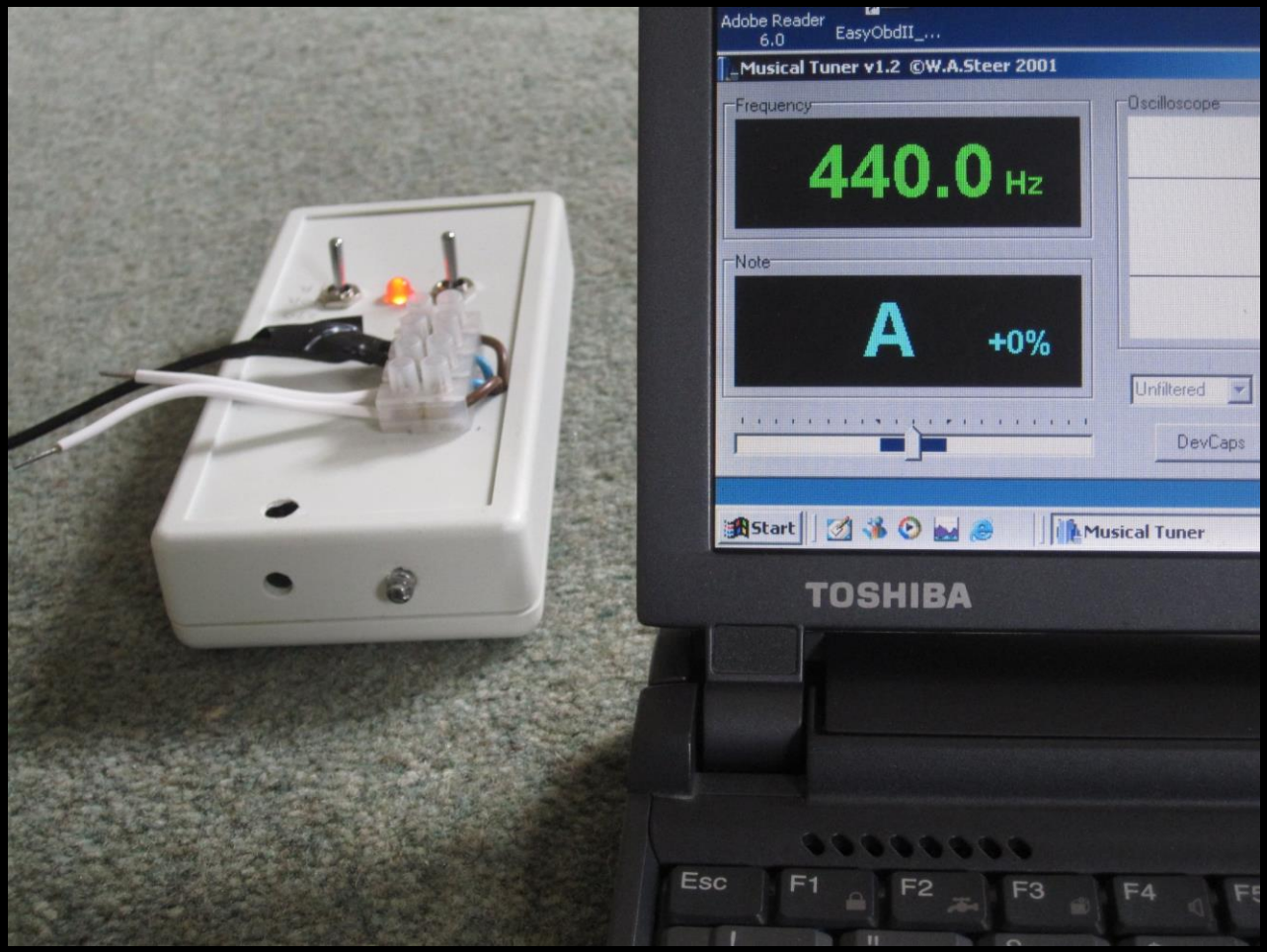
Rotating mirror with motor

Rotating mirror assembly

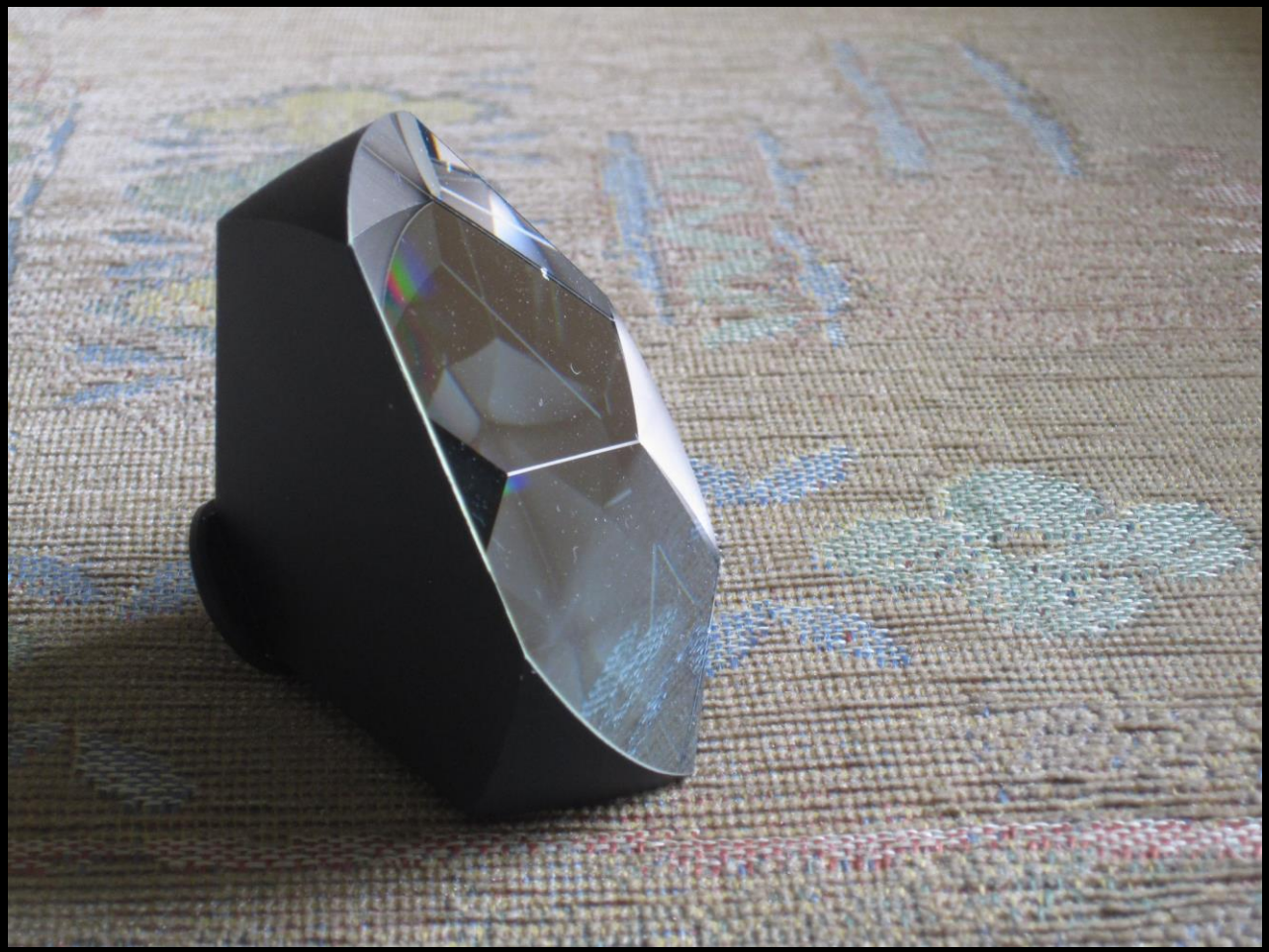


Rotating mirror – business end

Rotation speed measurement – photodiode and frequency counter



Corner Cube reflector



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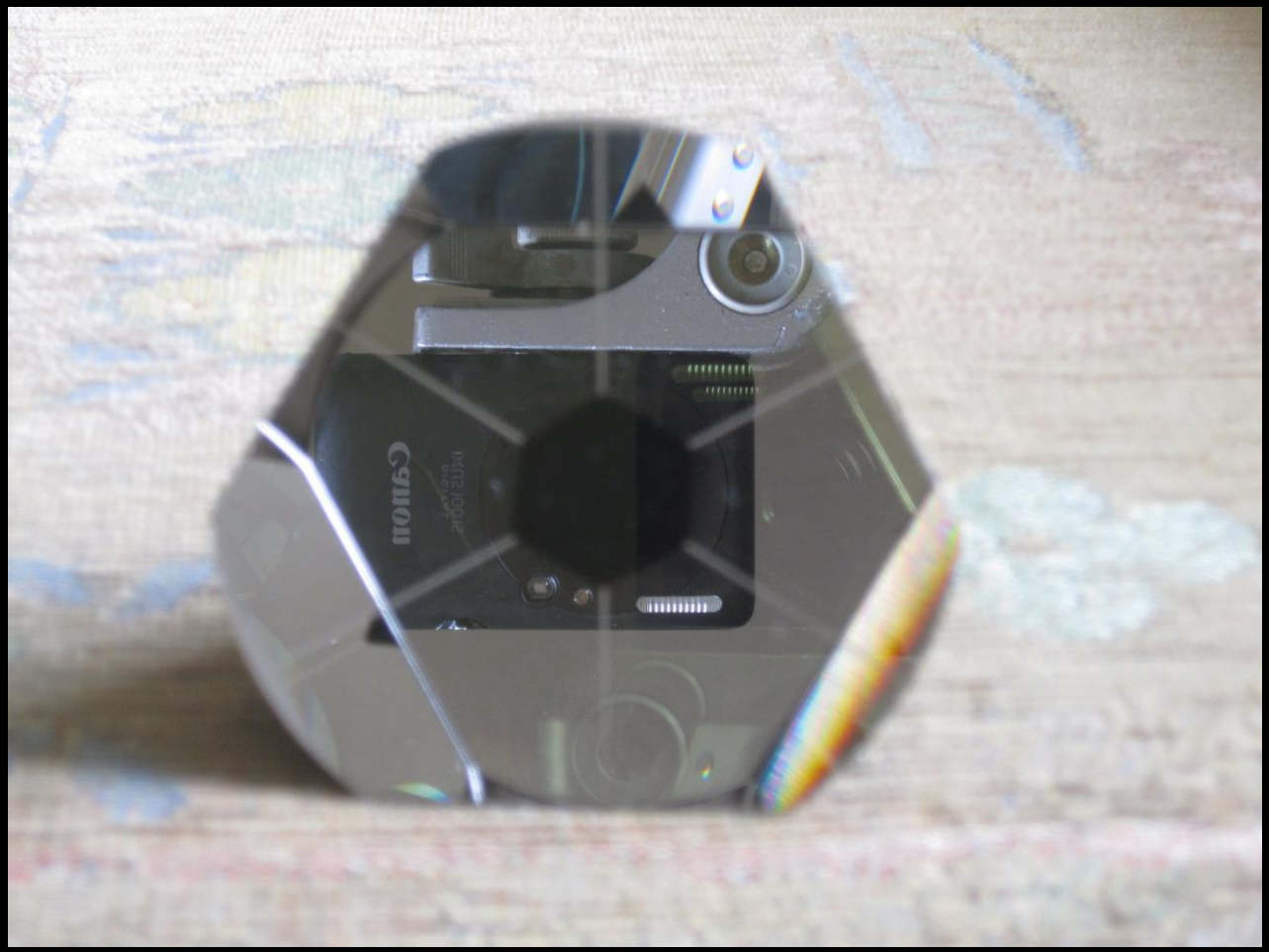
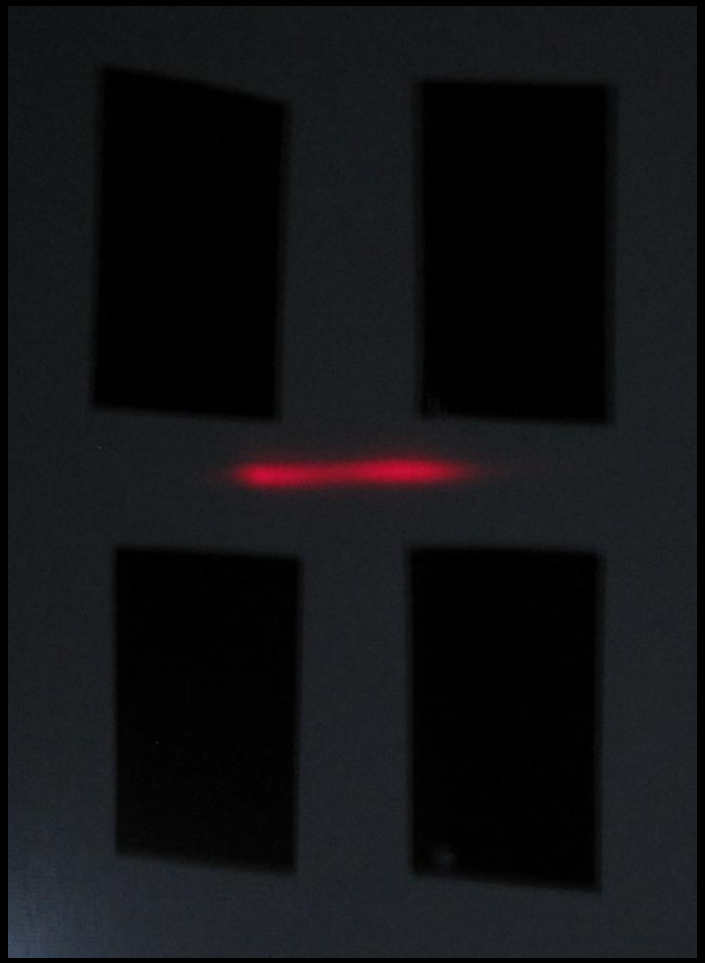
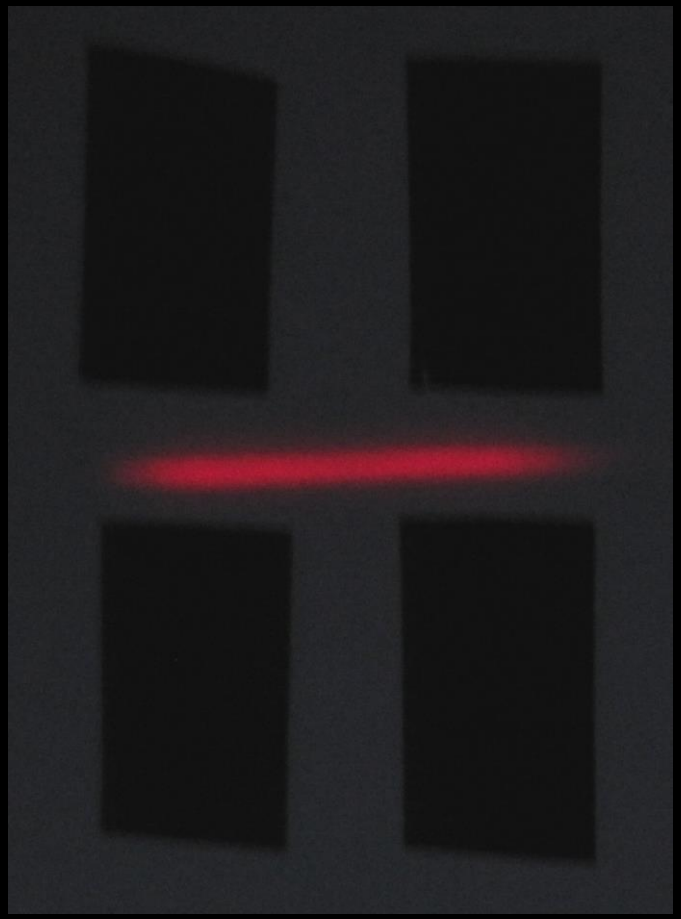


Corner cube



Plane mirror



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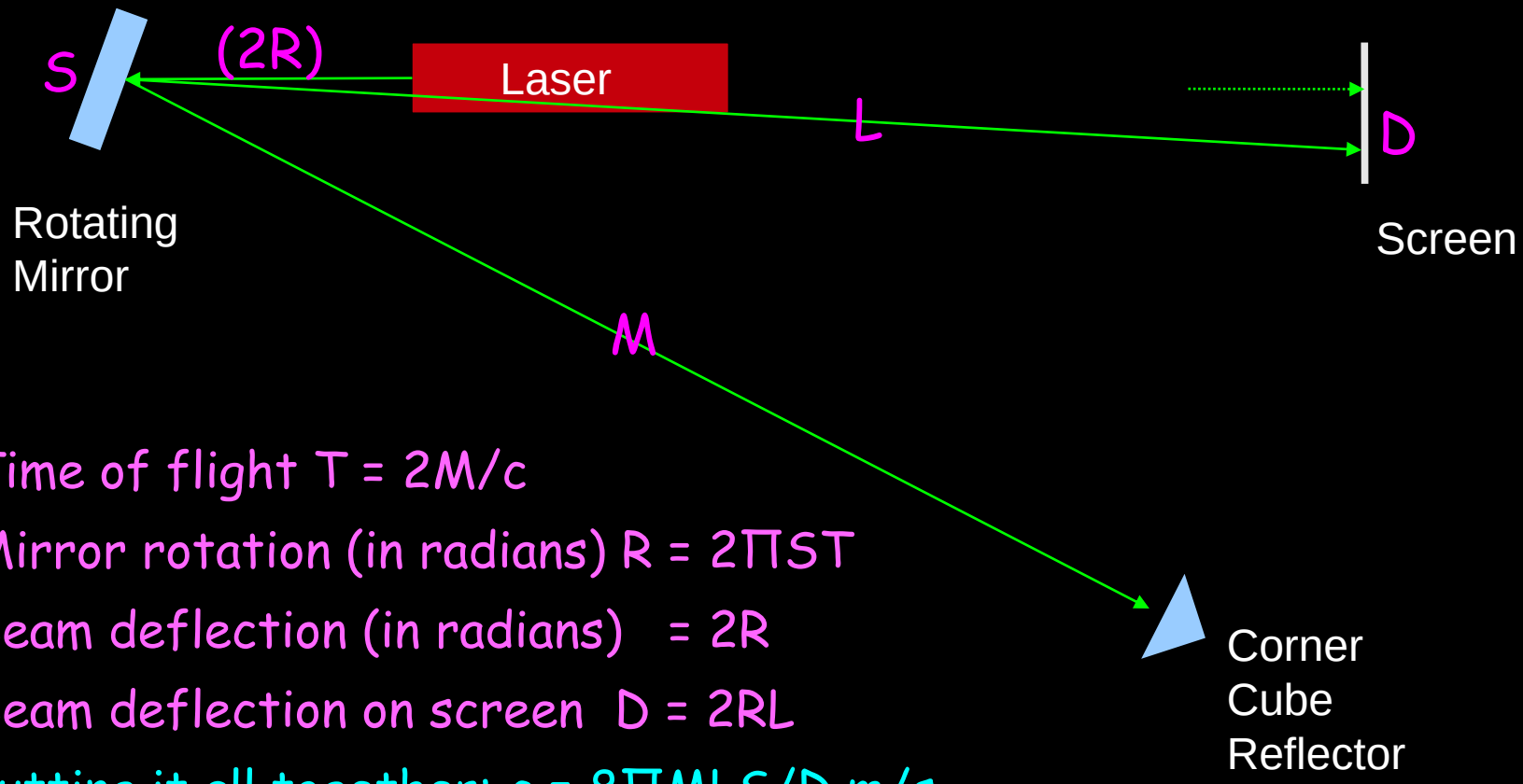

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Mirror rotation (in radians) $R = 2\pi ST$

Beam deflection (in radians) $= 2R$

Beam deflection on screen $D = 2RL$

Putting it all together: $c = 8\pi MLS/D$ m/s

or $D = 8\pi MLS/c$ m

For current experiment, expected D to be approx:

$$D = \frac{8\pi \times 14 \times 14 \times 400}{299792458} \sim 6.6\text{mm}$$

References

A http://en.wikipedia.org/wiki/Speed_of_light
B Relativity and its roots. Banesh Hoffmann. 1983. Scientific American Books. Distributed by W H Freedman & Co
C Geometrical and Physical Optics. R S Longhurst. 3rd Edition 1973. Longman.
D http://en.wikipedia.org/wiki/R%C3%B8mer%27s_determination_of_the_speed_of_light
E Challenges of Astronomy. W Schlosser et al. pp83-87
F http://en.wikipedia.org/wiki/Aberration_of_light
G http://galileoandeinstein.physics.virginia.edu/lectures/spedlite.html
H The Project Gutenberg EBook of Experimental Determination of the Velocity of Light, by Albert A. Michelson
I http://www.magicdave.com/ron/Does%20the%20Speed%20of%20Light%20Slow%20Down%20Over%20Time.html
J The Theory of Relativity. Albert Einstein. 4th Edition 1921. Methuen.

Also - some web urls as given in the notes.

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