POV-Ray

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POV-RAY is a program that allows a person to easily render stunning graphics.

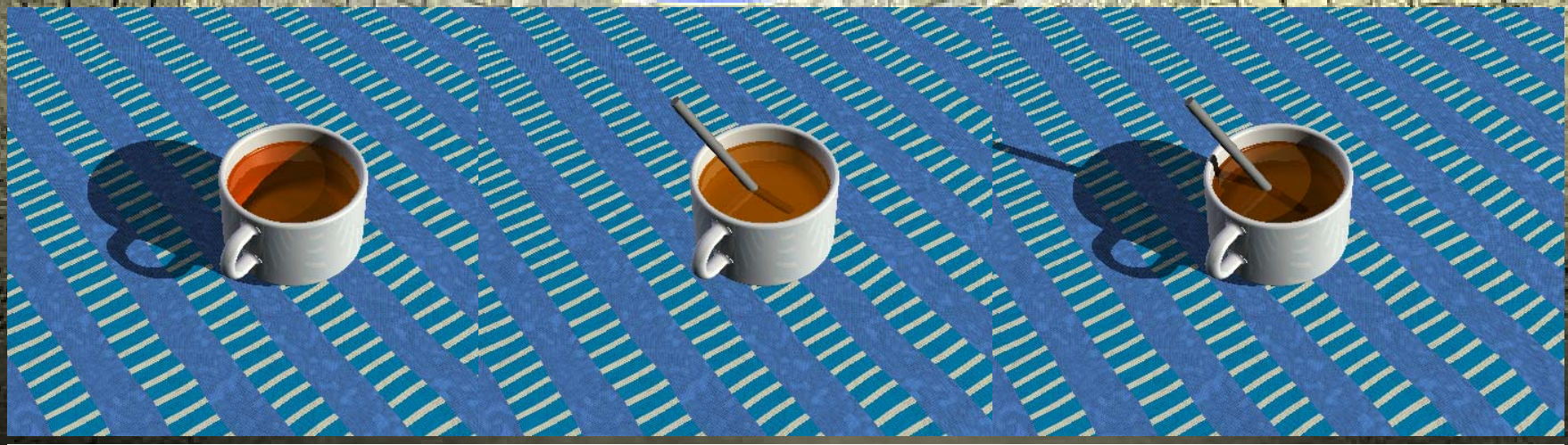
It uses the concept of ray tracing to quickly and efficiently determine how an image will look by following all the rays of light that bounce around the scene and hit the eye.

Objects are defined by the unions and differences of specific geometric shapes, and then instances of these objects are placed within the scene.

How POV-Ray Works

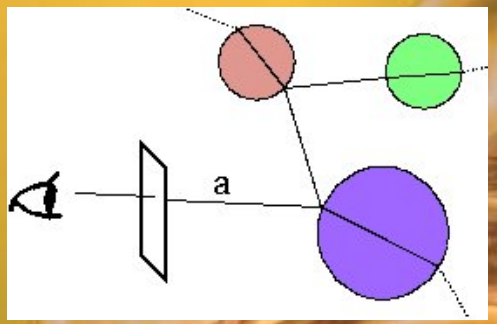
- Programming of images
  - Define objects
    - Combine simple geometric shapes
  - Place instance of objects in the scene
- Rendering and ray tracing
  - Light rays as photons from light source to eye
  - Back-ray tracing from eye to light source is more efficient, practical

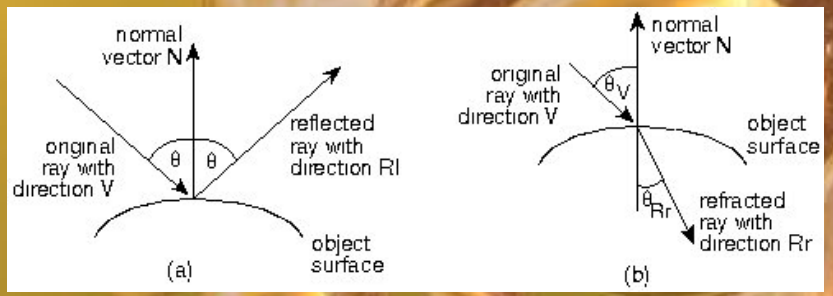
Programming

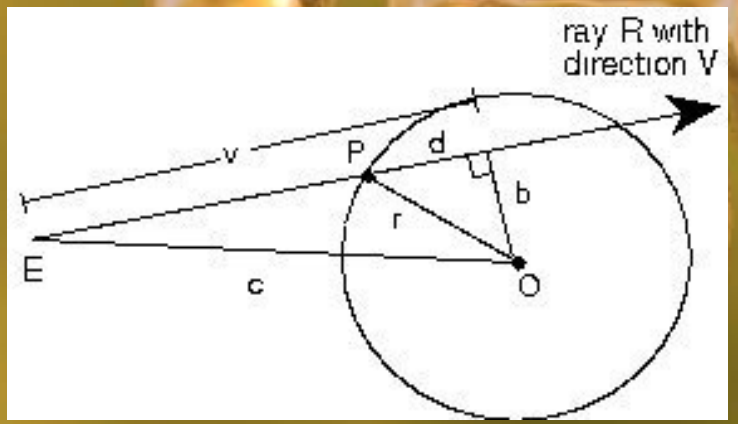


```
light_source {<-140,200,300> rgb <1.0, 1.0, 0.95>*1.5}
light_source {<140,200,-300> rgb <0.9, 0.9, 1.00>*0.8 shadowless}

object {Nappe}

//-----------------------CUP OF TEA
#declare TeaCup =
union {
   difference {
      cylinder {<0,1.2,0>, <0,6,0>, 4.2}
      cylinder {<0,1,0>, <0,6.2,0>, 3.8}
   }

   finish {phong 0.8 reflection 0.1}
   pigment {White}
```

Rendering and Ray Tracing







- Recursive reflection and refraction for multiple objects
- Refraction with Snell's Law:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

- Determination of whether a ray intersects an object
  - Computing d for a sphere:

$$v^2 + b^2 = c^2$$

$$d^2 + b^2 = r^2$$

$$d = \sqrt{r^2 - (c^2 - v^2)}$$

References

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Ray Tracing For the Masses. Rademacher, P. Accessed 19 Nov. 2006. <http://www.cs.unc.edu/~rademach/xroads-RT/RTarticle.html>

Persistence of Vision Ray Tracer. Accessed 19 Nov. 2006. <http://www.povray.org>

All background images are from the POV-Ray Hall of Fame, and can be viewed at http://hof.povray.org.

SOAR Telescope

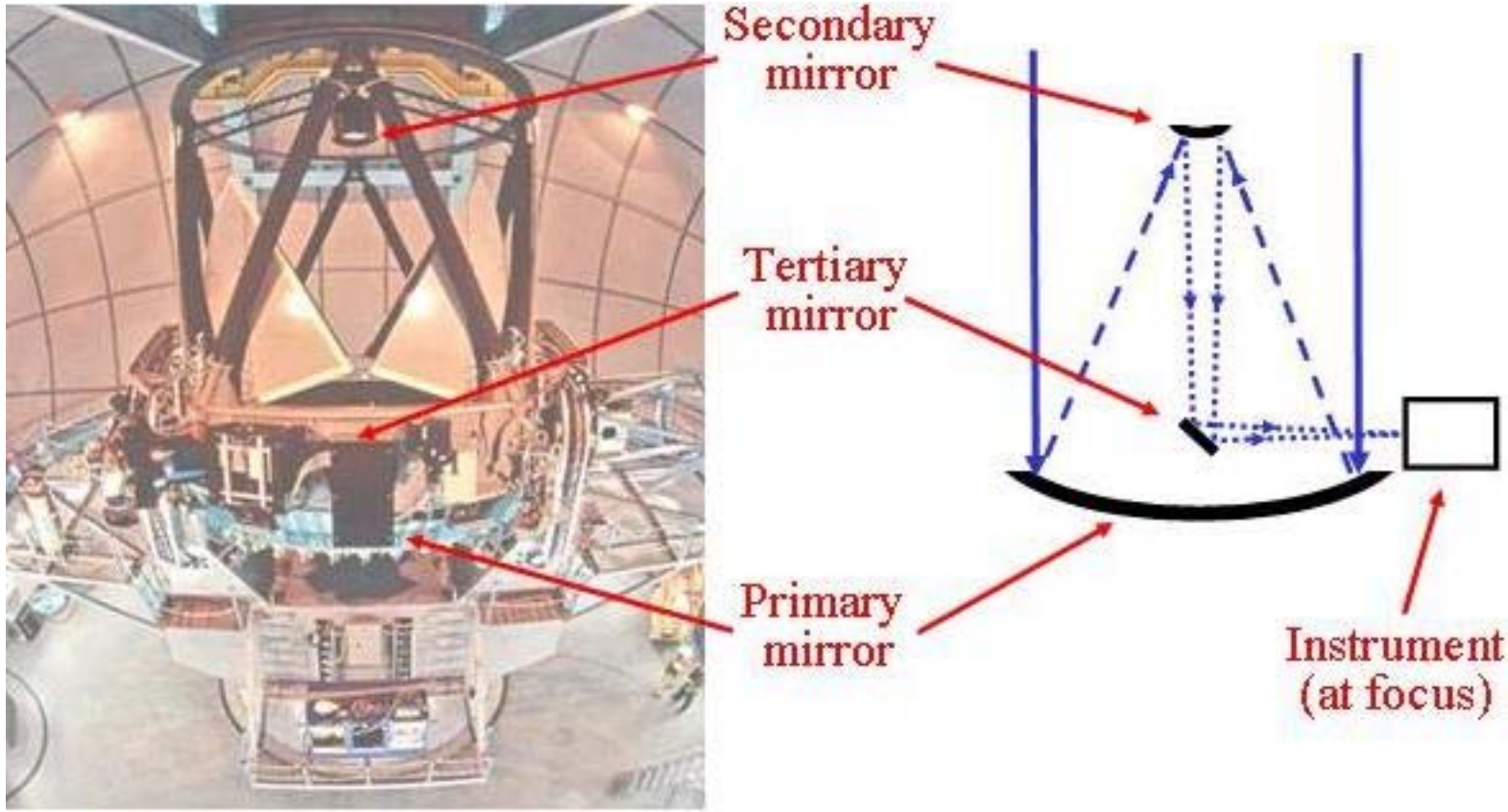
Ashley Dies, Julie Krugler, William Seniura

The Southern Astrophysical Research Telescope is a 4.1m world class telescope, located in La Serena, Chile. SOAR was designed to create some of the sharpest earth-based images. SOAR accomplishes this by using a bevy of instruments that range from the optical to the near infrared.

SOAR Specs

- Located in the Chilean Andes on Cerro Pachon at an altitude of 9000 ft
- 4.1m diameter mirror
- Three mirror optical system with adaptive optics
- Altitude-Azimuth mount
- Instruments mounted around base

Optical Path

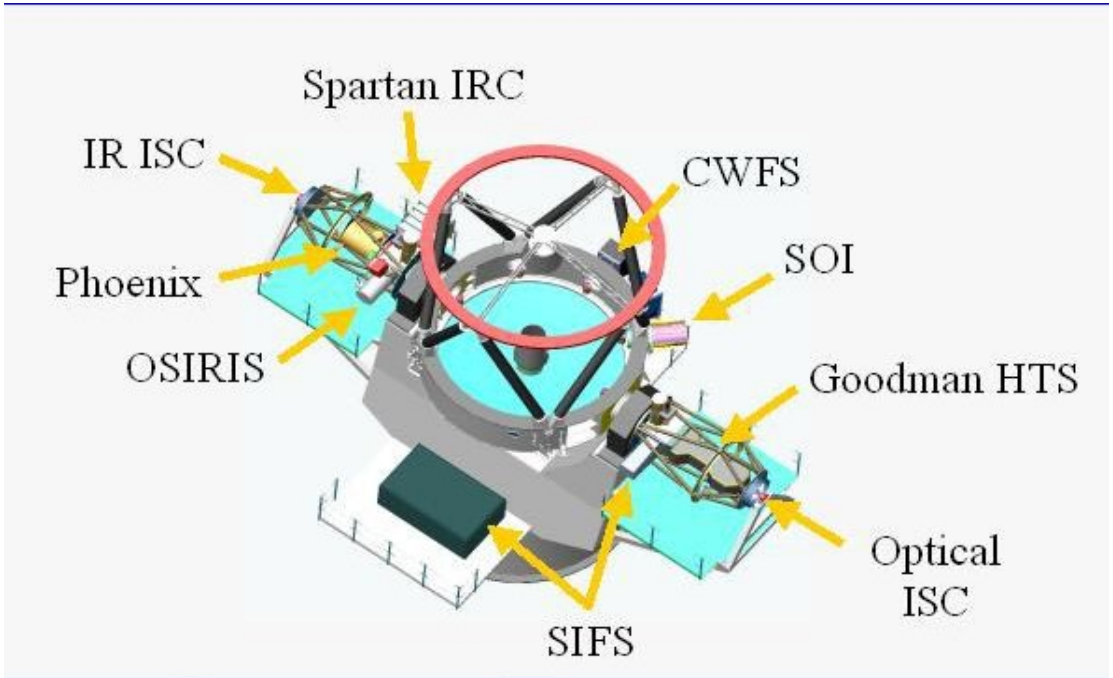


Mirror Equations

- Law of Reflection
  - $\theta_i = \theta_f$
- Mirror Formula
  - $\frac{1}{s_o} + \frac{1}{s_i} = -\frac{2}{R}$
  - $\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}$

Instrumentation and Science

- Instruments mounted around base
- Imagers and spectrograph
- 320 nm to near IR coverage



- First to observe high red shift gamma ray burst
- Carbon Enhanced Metal-Poor Stars
- ZZ Ceti Stars

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- Michigan State University, SOAR Telescope, http://www.pa.msu.edu/soarmsu

- Thomas A. Sebring, Gerald Cecil, & Gilberto Moretto, “The Soar Telescope Project: A Four-Meter Telescope Focused on Image Quality”, http://www.noao.edu/noao/meetings/spie98/gcecil.pdf

Fabry-Perot Interferometer

Daniel Bruder

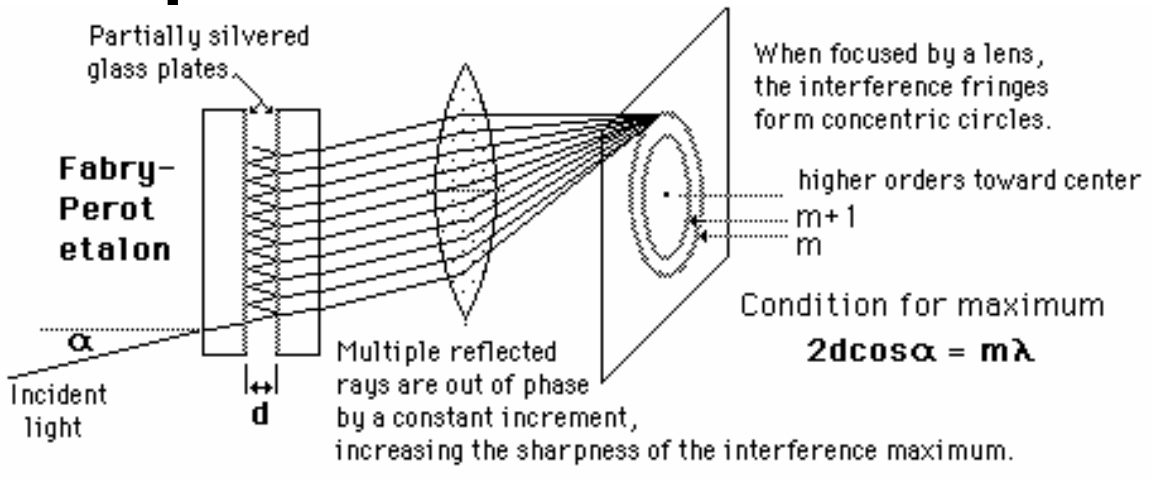
Michael Moulton

Andrew Padgett

The Fabry-Perot Interferometer is an optical devise consisting of two plane, parallel, highly-reflecting surfaces. It uses multiple-beam interference to make very precise measurements of the wavelength of light. Applications include telecommunication, spectroscopy, and lasers.

Qualitative Description

Multiple reflections inside the etalon results in multiple-beam interference, which give sharp and narrow intensities to the fringe pattern on the screen. The transmission of light through the etalon is dependent on the geometry of the etalon (such as d or alpha) and the wavelength of the light. So by varying the geometry, one can determine the wavelength of light.



Another good picture is Figure 9.44a of Hecht, section 9.6.1.

All of the reflections inside the etalon are shifted by the same phase, so they all give the same intensity on the screen. Basically, the Fabry-Perot interferometer exploits the many reflections going on inside the etalon to get a sharp intensities, and hence precise wavelength measurements.

The precise measurement of wavelengths are useful in high-resolution optical spectroscopy (finding the wavelengths of spectral lines). Another use is in a laser resonator, or to examine geometric properties by keeping the wavelength fixed.

Usually, the highly reflective surfaces are semi-silvered or aluminized glass optical flats.

<u>Variants-</u>

•Etalons: The angle of the beam direction is varied.

•Scanning Interferometer: One of the mirrors is moved.

Equations Governing the Fabry-Perot Interferometer

- $T + R + A = 1$
  The sum of the energy transmitted (T), reflected (R), and absorbed (A) must equal unity.

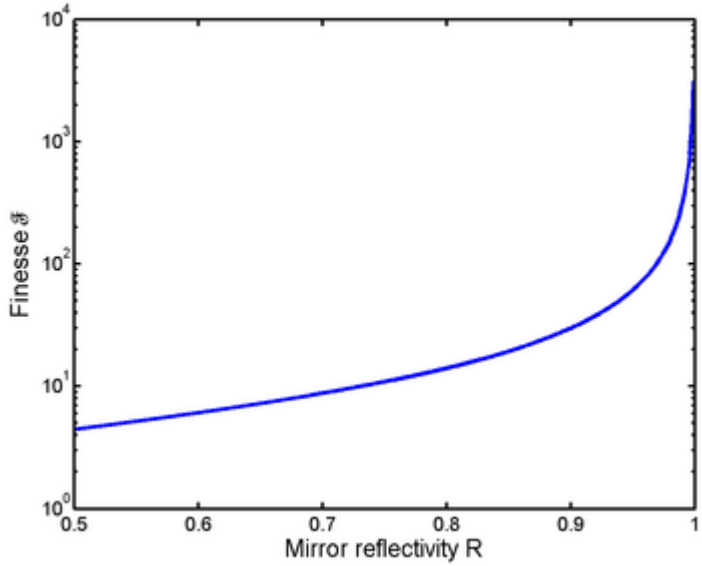
- $(I_t/I_i) = (1 - (A/(1 - R)))^2 Airy(\theta)$
  - The ratio of transmitted to incident irradiance is equal to the absorptance term times the Airy function. The Airy function is $Airy(\theta) = (1 + F\sin^2(\delta/2))^{-1}$.

- $\delta = ((4\pi n_f)/\lambda_0)d\cos(\theta_t) + 2\varphi$ = Phase difference between two successively transmitted waves
  - The factor of 2φ arises from the metallic films covering the two optical flats. It can generally be neglected if the separation between the optical flats, d, is much larger that the wavelength of incident light, λ_0.

- $2d\cos\alpha = m\lambda$
  - Maxima occur when the Airy function is equal to one; this corresponds to a maximum in the transmitted irradiance.

Spectroscopy with the Fabry-Perot Interferometer

- **Lord Raleigh's Criterion**: The interference fringes from a polychromatic light source are "just resolvable" when the combined irradiance of both fringes at their saddle point is $8/\pi^2$ times the maximum irradiance.
- **$\gamma = 4/\mathrm{Sqrt}(F)$**
  - Half-Width, γ, is a measure of the sharpness of the fringes, that is, how quickly the irradiance drops off on either side of a maximum.
- ***R* = $\lambda_0/(\Delta\lambda_0)_{min}$ equals about *F*m**
  - The Chromatic Resolving Power, *R*, is the ratio of the incident wavelength to the least resolvable wavelength difference and is about equal to the finesses times the fringe order, m. The approximation assumes nearly normal incidence.
- ***F* = Finesse = $(\pi*\mathrm{Sqrt}(F))/2 = (\Delta\lambda_0)_{fsr}/(\Delta\lambda_0)_{min}$**
  - The finesse, *F*, is the ratio of the separation of adjacent maxima to their half-width, γ. It also sets a limit on the resolving power because, as you increase the distance between the optical flats, the free spectral range will decrease and the different order maxima will overlap.
  - The coefficient of finesse, $F = 4R/(1-R)^2$, is the same quantity that appears in the Airy equation, where R is the reflectance.



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Compound Optical Microscope

Created by:
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Chris Schlappi
Colby Hollek

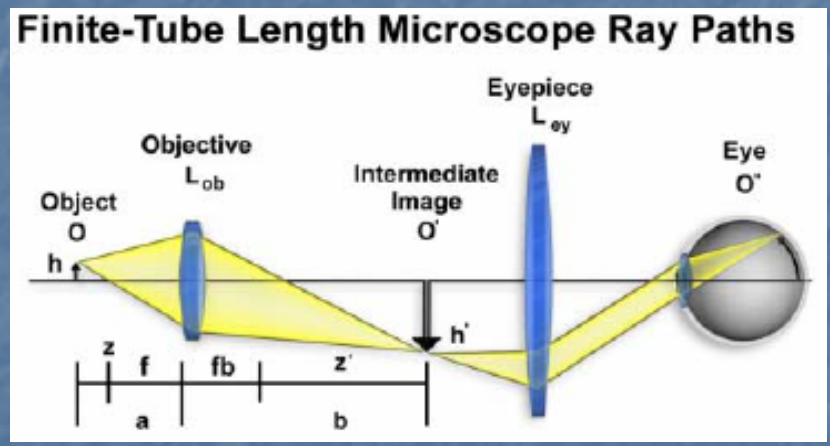
Compound microscopes are designed to enlarge the image of a small object. They do this by capturing as much light as possible using a short focal length objective held close to the object. This produces a real image that is further magnified by an eyepiece that acts like a magnifying glass.

So how does it work?

- A simple magnifier allows you to put the object closer to the eye than you could normally focus; this forms an enlarged virtual image.
- A compound microscope can be thought of as a system of two of these magnifiers.
- Standard tube length is 16cm, this is the image distance of the objective minus f_o (b).
- This is done so that different objectives can be used on the same microscope, making it easier to find what you want to focus on.

Uses

The recent vast advancement of medicinal fields and biology in general, is owed in large extent, to the invention of the optical microscopes.



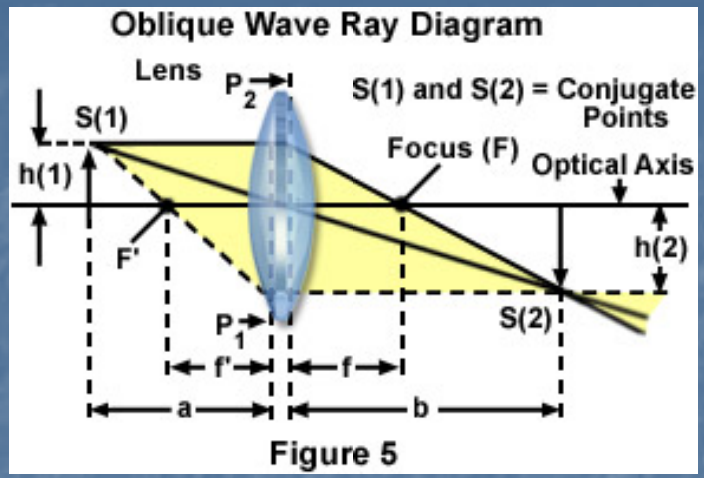
The Basics

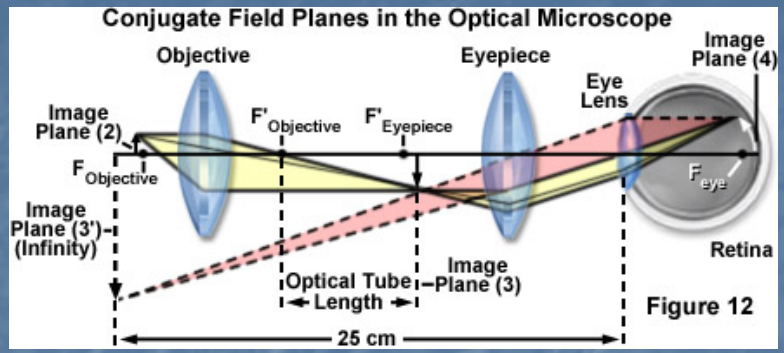
- numerical aperture of an optical system is defined by NA = $n \sin\theta$
- where n is the index of refraction of the medium in which the lens is working, and θ is the half-angle of the maximum cone of light that can enter or exit the lens.
- $r = 1.22\lambda/(NA(obj) + NA(cond))$
- Where r is resolution (the smallest resolvable distance between two objects) and λ is the wavelength

Limitations

- All compound microscopes are limited to a resolution of no smaller than 0.2 micrometer due to diffraction in the system.
- The standard near point of a human eye is taken to be 25.4cm. If this value was smaller we could focus on closer objects, making microscopes more effective.

Magnification



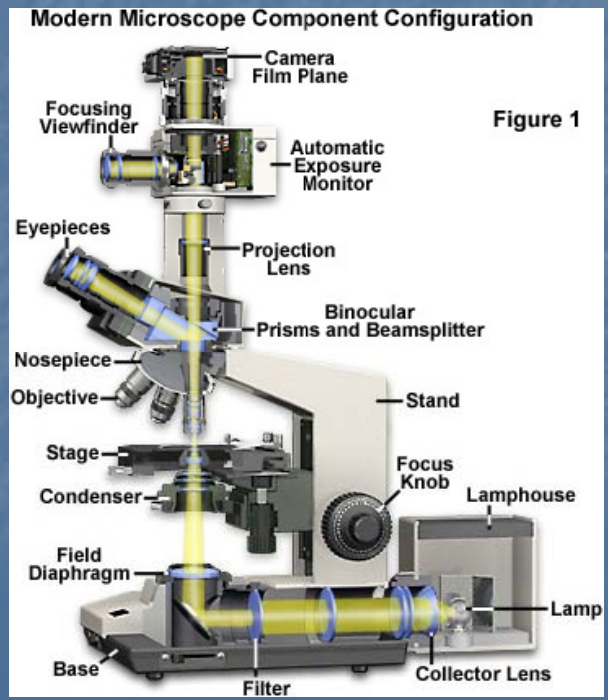


$$1/a + 1/b = 1/f$$

$$M = h(2)/h(1) = b/a$$

$$M = \frac{f_1}{A - f_1}\frac{C - f_2}{f_2}$$

Where A is distance from object to first lens, and C is distance from second lens to image



$$M(p) = f(p)/f(e)$$

Where f(p) is projection lens and f(e) is eyepiece

$$M = (16/-f_o)(25.4/f_i)$$

For standard tube length and near point

References

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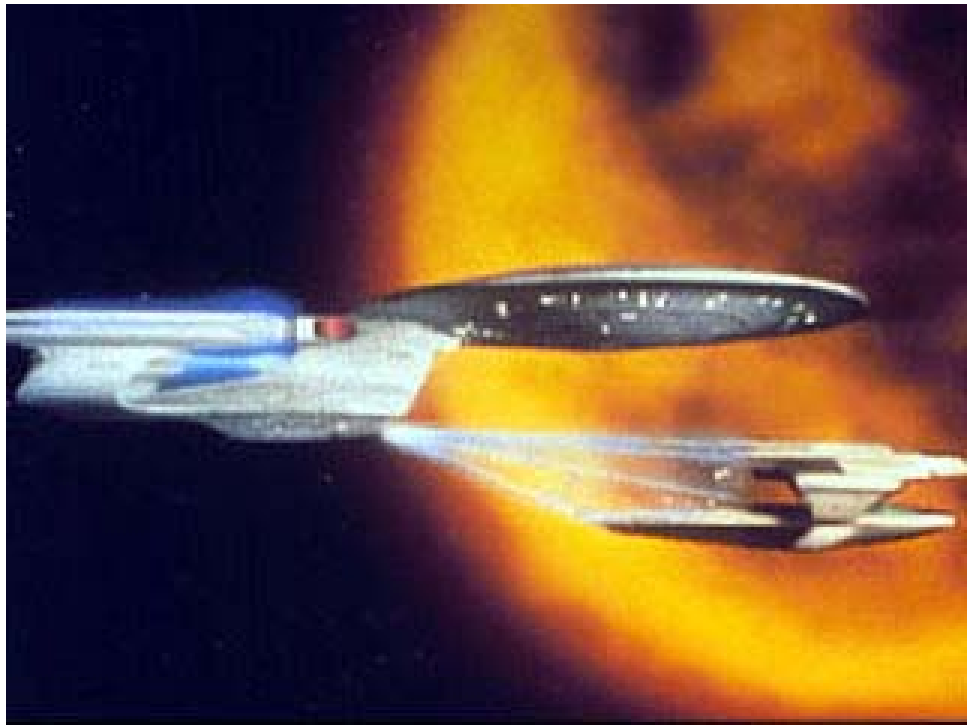
- “Optical Microscope.” Wikipedia. Wikimedia Foundation, Inc. 20 Nov. 2006 <http://en.wikipedia.org/wiki/Optical_microscope>.

OPTICAL TWEEZERS

Zachary DeLand, Amanda Hanson, Erin Nolan



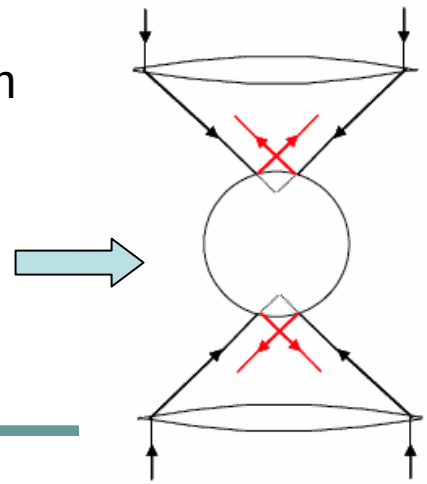
Essentially, they are a microscopic tractor beam, allowing us...

To boldly tweeze where no man has tweezed before!

HOW DO THEY WORK?

- Optical Tweezers use light to physically hold and manipulate very small objects.
- A laser beam is focused by a lens on an object (like micron-sized polystyrene spheres).
- The light reflecting and refracting on the object causes changes in the momentum of the light. By Conservation of Momentum, equal and opposite forces must also act on the sphere.
- These forces trap the object and can be used to move it (like a tractor beam, just smaller ☺)
- These tweezers can move objects as small as an atom

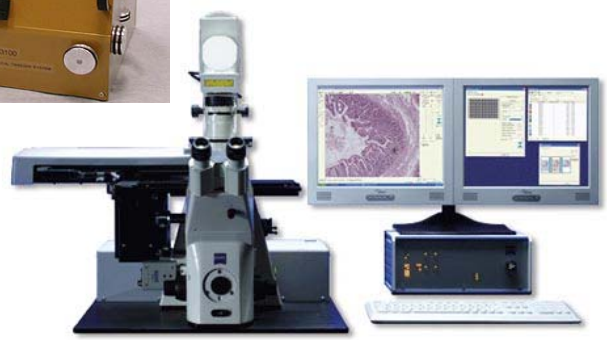
This is a dual beam optical trap – these generate more force than a single beam, but also are a lot more difficult to align. For this reason, single beam traps are preferred when working with beads of diameter less than 1 um



THE REAL THING

Eliot Scientific “entry level” desktop unit, E3100

- 685nm or 785nm near- Gaussian laser source
- 100x oil immersion objective with 1.25 NA



Do-It-Yourself with...

- A microscope w/ a high N.A.
- A dichroic mirror that reflects the appropriate laser wavelength... but transmits visible light.
- A set of IR-blocking filters.
- Two plano-convex lenses.
- More Mirrors.
- A three-axis translation stage attached to a holder for lens.
- A variable attenuator.
- A laser beam expander.
- A momentary shutter.
- A laser suitable for optical trapping.
- A CCD videocamera for the TV port.
- Miscellaneous mechanical pieces

THE MATH BEHIND THE MADNESS

- Momentum of a photon it:

$$\left|\vec{p}\right| = \frac{h}{\lambda} \sim 1 \cdot 10^{-25}\ \mathrm{kg} \cdot \frac{\mathrm{m}}{\mathrm{s}}$$

- Total momentum of the light:

$$\mathbf{P} = \sum_i p_i$$

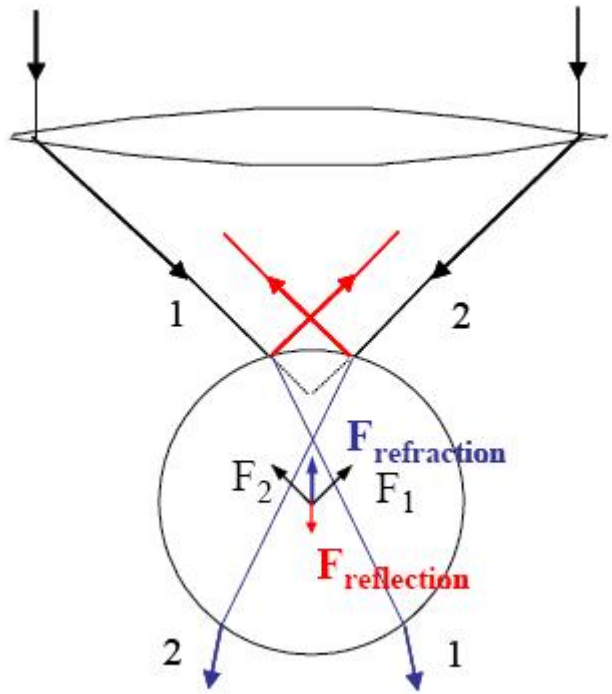
- Momentum flux of light:

$$d\left(\frac{d\vec{\mathbf{P}}}{dt}\right) = \frac{n}{c}\vec{\mathbf{S}}dA$$

- Total Force on Polystyrene Sphere:

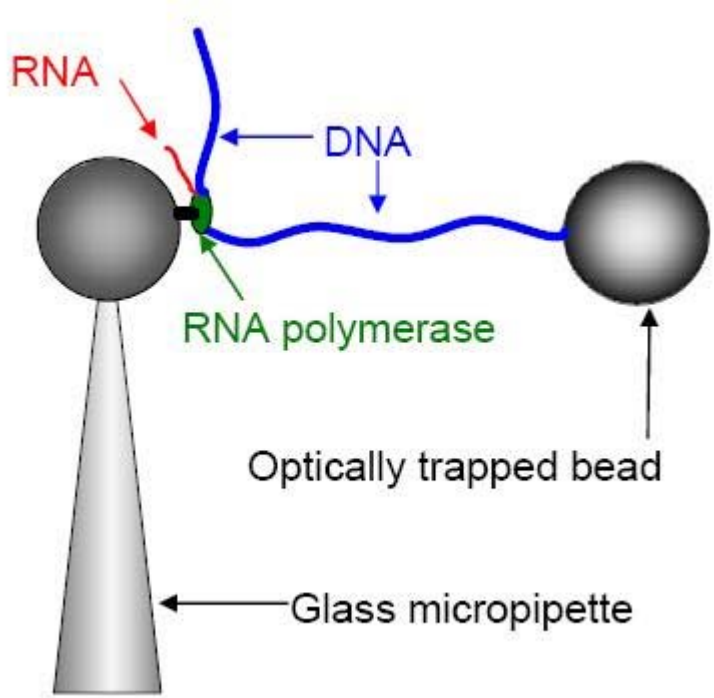
$$\vec{\mathbf{F}} = \frac{n}{c}\iint\left(\vec{\mathbf{S}}_{in} - \vec{\mathbf{S}}_{out}\right)dA < 10^{-12}\ \mathrm{N}$$

- Approximately: $\vec{\mathbf{F}} = -k\vec{\mathbf{x}}$
  - k ~ 50 pN/μm



SO WHY DOES ANYONE CARE?

- Very useful in DNA experimentation
  - DNA can be attached to a sphere and held steady using the tweezers
- Used to determine:
  - Thermodynamic properties of DNA
  - Energetics of DNA-RNA interactions
  - Kinetics of DNA-binding proteins



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