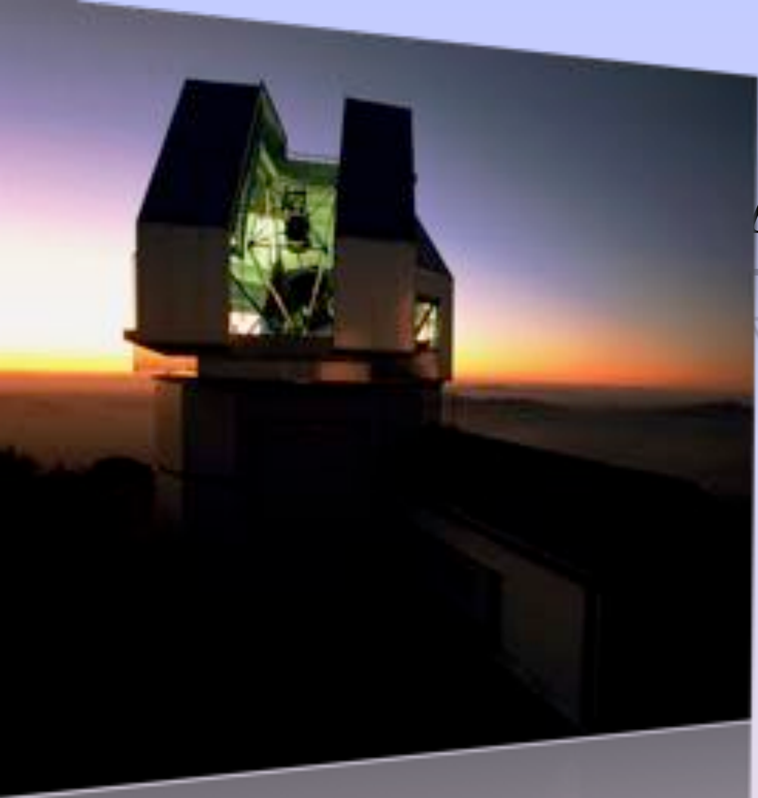


Astro 500

Techniques of Modern Observational Astrophysics

Matthew Bershady
University of Wisconsin

Find values for WIYN & SALT instr.:

- Detector gain, read-noise, system efficiency
  - WIYN
    - WHIRC
    - Bench Spectrograph
    - MiniMo
    - OPTIC
    - ODI
  - SALT
    - SALTCAM
    - RSS

What did you find?

Assignment:
- Work in pairs
- Tabulate information
- Assess availability, ease of access
- Bring to class to present

Homeworks

- Show your work
- Cite your sources
- Make your write-up neat and organized
  - I can't grade it properly if I don't know what's going on.
- Wikipedia is not a peer-refereed source.
  - If you use a result from wikipedia, show the derivation – *make sure wikipedia is correct!*

Telescopes & Optics

Outline

- Defining the telescope & observatory
- Mounts
- Foci
- Optical designs
- Geometric optics
- Aberrations

Conceptually separate (Mounts, Foci, Optical designs)

Critical for understanding telescope and instrument capabilities and preliminary instrument design (Optical designs, Geometric optics, Aberrations)

Essential for detailed instrument design *and* for evaluating data. (Aberrations)

Telescopes as Facilities

- The Observatory: far more than telescope
  - Opto-mechanical and thermal control
  - Acquisition & guiding
  - Telemetry and sensing
  - Instrumentation and instrument interfaces (ports)
  - Software for telescope and instrument control
  - Technical support and maintenance
  - Data storage and transfer
  - Software pipelines for data reduction and analysis
  - Environment for observer and operator
  - Personnel management, technical and scientific leadership

Telescopes: broader relevance

- Telescopes are examples of optical systems serving as cameras, i.e., producing images from sources at infinity (collimated light).
- Spectrographs and re-imaging systems essentially use variants of these systems as collimators and cameras.

Telescopes

- What parameters define telescopes?
  - Collecting Area (A)
  - FOV (Ω)
  - Image Quality
  - Cost
  - Throughput
  - Spectral range
  - Plate scale/Magnification
  - Pointing/tracking

(Collecting Area, FOV, Image Quality, Cost:) *highly* coupled

Telescopes as cameras

Telescopes

We will focus on optical/IR telescopes;
Most of this parameter space is relevant for
light collection at other wavelengths.

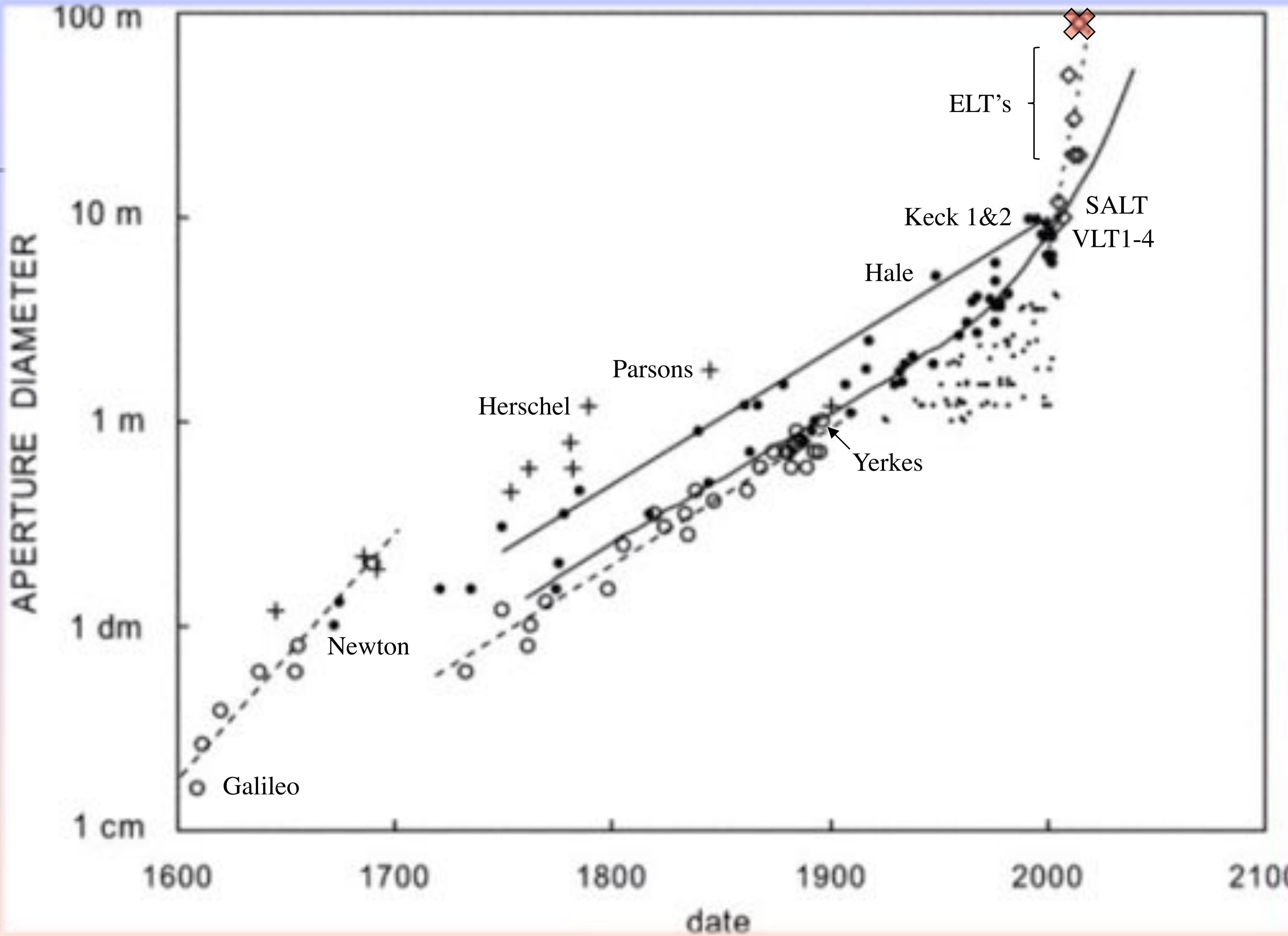
Examples of Telescopes

- Refracting
  - o Galilean (1609)
  - o Keplerian (1611)
- Reflecting (4x harder to make!)
  - o Newtonian (1672)
  - o Gregorian (1673)
  - o Cassegrain (1668)
  - o Ritchey-Cretien (1927)

Why?

- Catadioptric
  - o Schmidt (1931)
  - o Maksutov (1944)
- Multi-mirror
  - o MMT (1977)
  - o Keck (1992)
  - o HET (1996), SALT (2005)
  - o all ELT's (2014+)

Trends to larger collecting area, but more compact in mounting and focal-ratio (speed).



Credit: R. Racine

Telescope Mounts

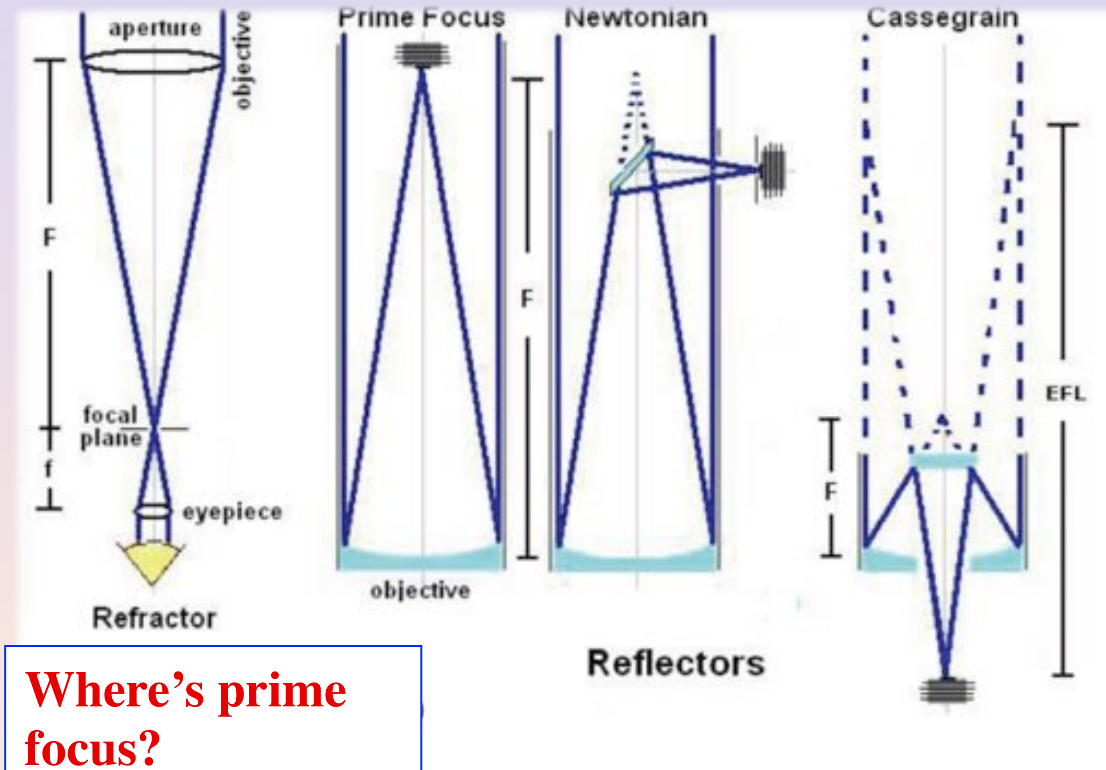
- Equatorial — Easiest for tracking
  - German (Yerkes)
  - English Yoke or English Cross ← Best for flexure, but pointing limitations
  - Fork (Shane 3m)
  - Horseshoe (CTIO & KPNO 4m) ← Best compromise
- Alt-Az (Altitude-Azimuth) — Most compact but requires computer control; has field rotation
  - 3.5-4.5m: ARC, WIYN, ARC, SOAR
  - 6.5-10m: Keck, VLT, Subaru, LBT, MMT, Megallan (MMT — First: 1977)
- Transit — Cheapest but limited sky coverage (40%)
  - Arecibo (radio)
  - LMT - liquid mirror telescope
- Transit-Azimuth — Cheap and up to 70% sky coverage
  - HET, SALT

Telescope Foci

- Prime
- Newtonian
- Cassegrain

What's the difference?

- Folded Cassegrain
- Nasmyth
- Coude

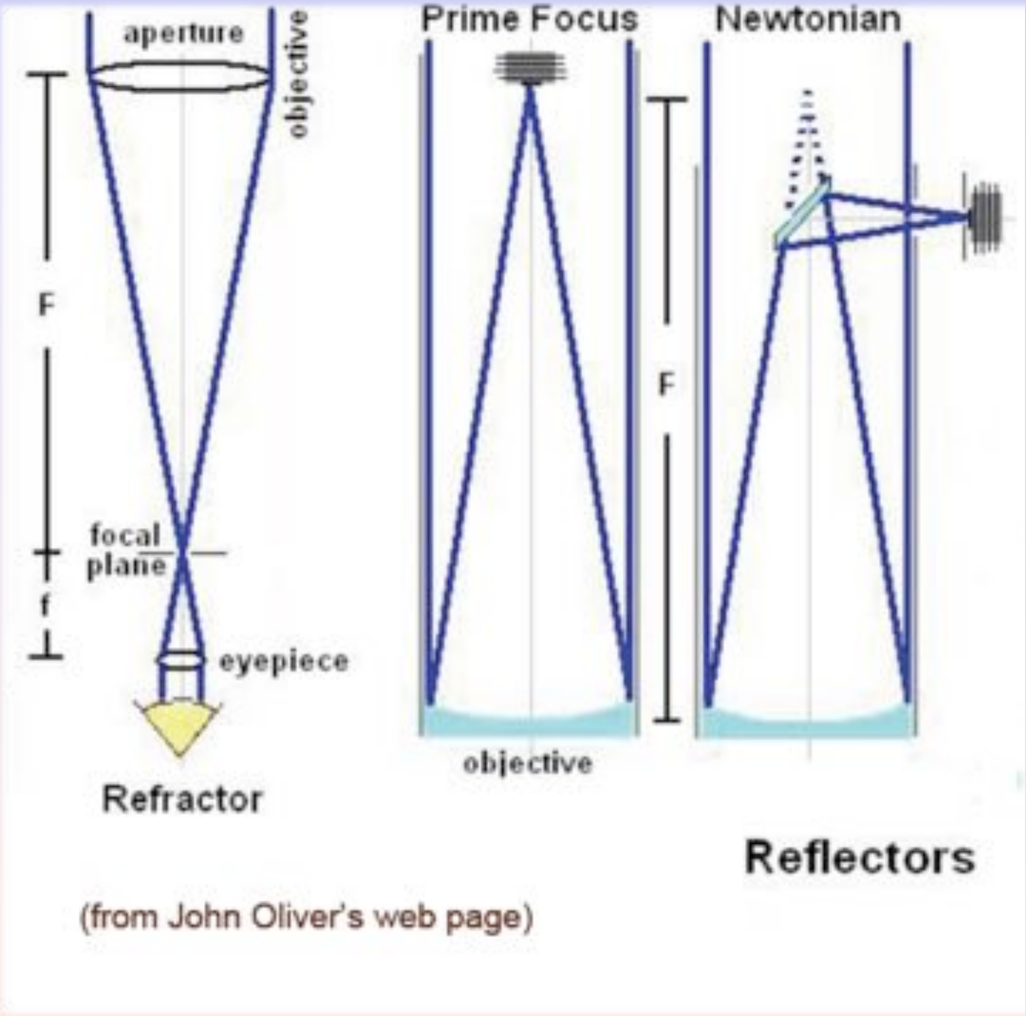


Where's prime focus?

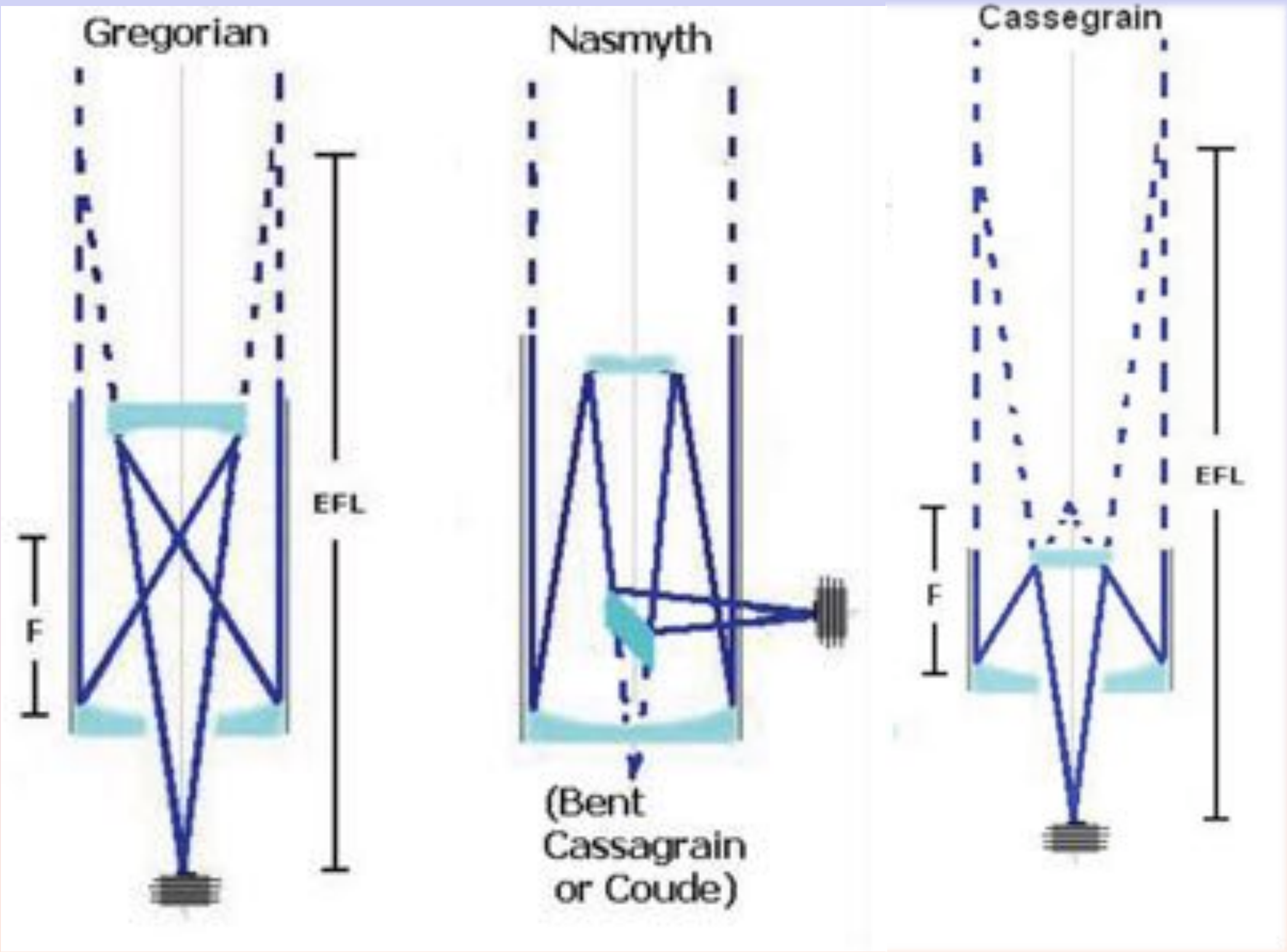
Types of Telescopes

Category	**Primary**	**Secondary**	**Corrector**	**Name**	**Principal Aberrations**
Singlet lens	Spherical			refractor	spherical + chromatic
Singlet mirror	Paraboloid mirror			Newtonian	coma + astigmatism
Doublet mirrors	Paraboloid	Hyperbaloid		Cassegrain	coma
	Hyperbaloid	Hyperbaloid		Ritchey-Chertien (RC)	astigmatism (twice Cassegrain field)
	Parabaloid	Ellipsoid		Gregorian	field curvature
	Ellipsoid	Spherical		Dall-Kirkham	
	Ellipsoid	Ellipsoid		Aplonatic Gregorian (AG)	best images but large obstruction
Multiplets	Spherical		Aspheric lens or achromate doublet	Schmidt	v. wide field
	Spherical	Hyperbaloid	Aspheric lens	Schmidt-Cassegrain	“
	Spherical	Spherical	Spherical meniscus lens	Maksutov	“
	Spherical		4-mirror asphere	HET, SALT	Low cost

Singlets

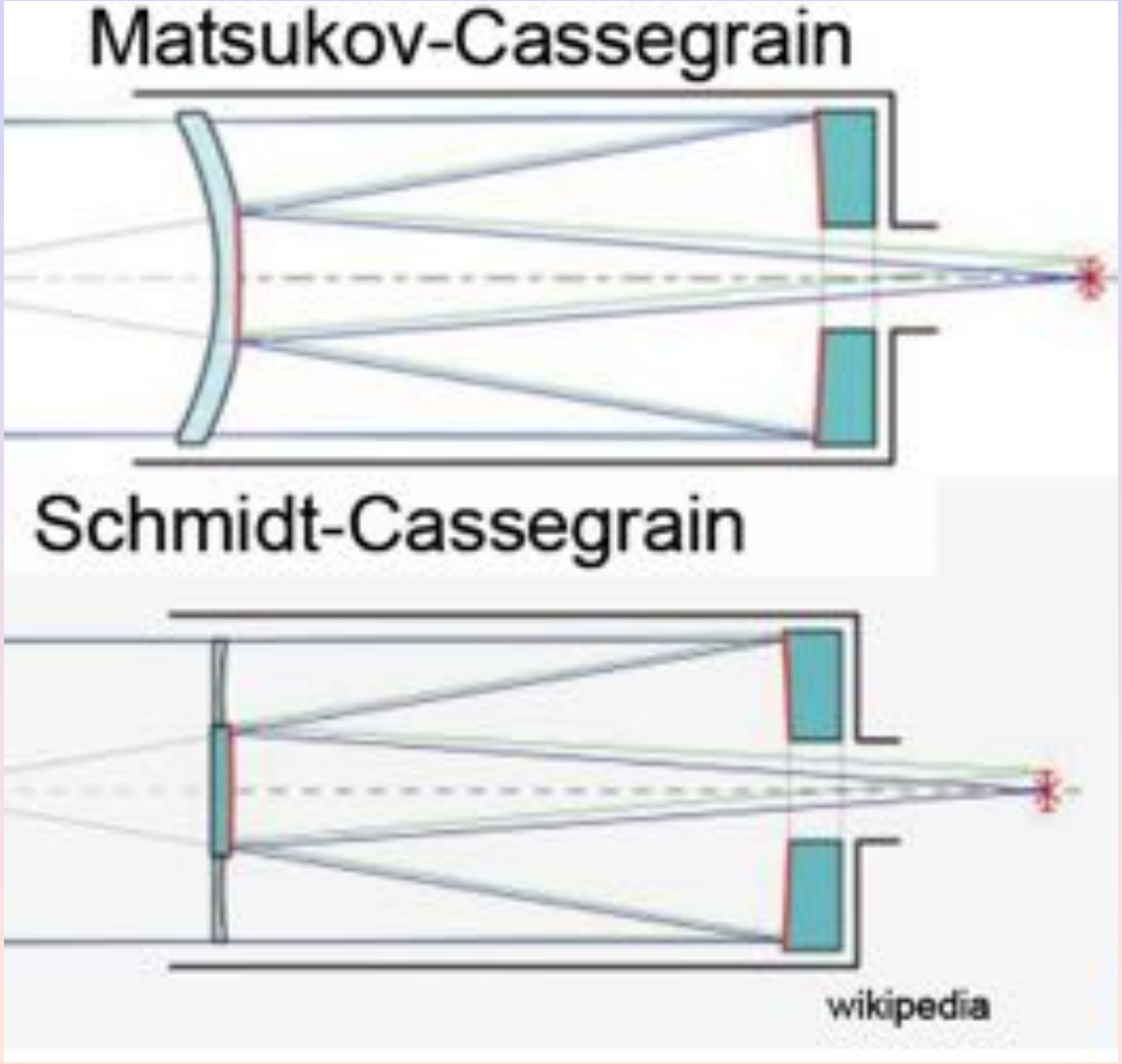

aperture
objective
F
focal plane
f
eyepiece
Refractor
Prime Focus
Newtonian
F
objective
Reflectors
(from John Oliver's web page)

Doublets



Gregorian
EFL
F
Nasmyth
(Bent
Cassagrain
or Coude)
Cassegrain
EFL
F

Multiplets: Catadioptrics



Spherical Primary

Why different designs?

- Trade-offs primarily between cost, desired field of view (at given image-quality) and collecting area.
- Image-quality and field-of-view concern aberrations.
- 6 principal aberrations:

Radial

- Chromatic — Lenses only

- Spherical
- Coma
- Astigmatism

The Big 3

Off-axis

- Distortion
- Field curvature

Not strictly aberrations

Optics

- Geometric Optics
  - Reflection
  - Refraction
  - Thin lens
  - Spherical optics
  - Conics
  - Stops
  - Pupils
  - Chief rays
  - Marginal ray
  - System design
  - Telescope summary

Where we're headed

- Aberrations
  - Chromatic
  - Spherical
  - Coma
  - Astigmatism
  - Distortion
  - Field curvature

Reading

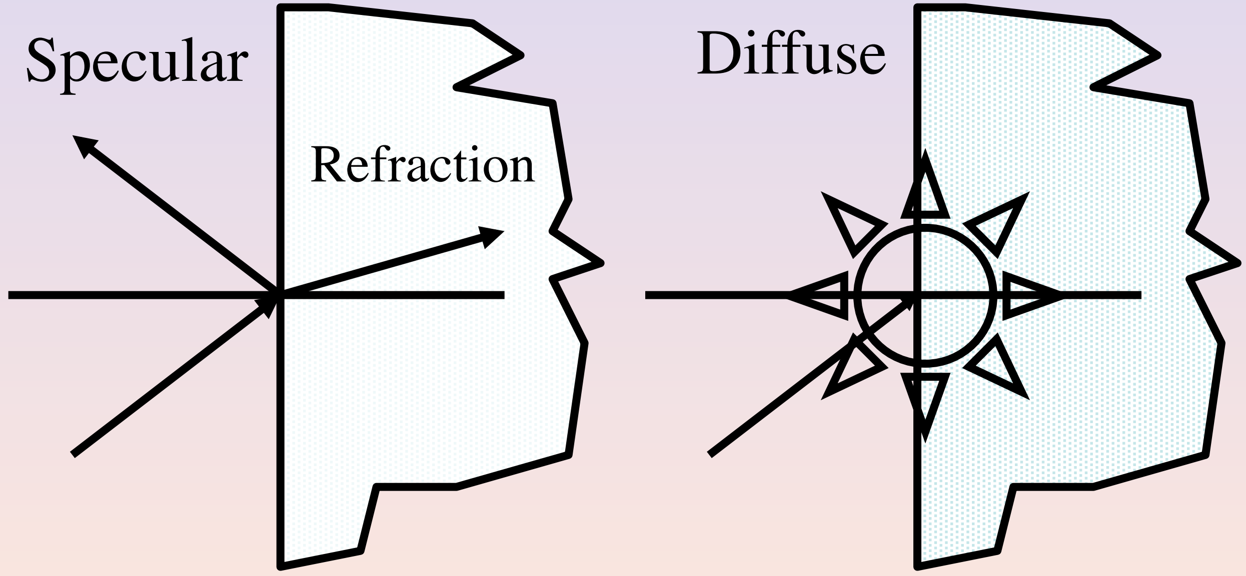
- Walker - ok place to start
- Schroeder - ferocious, but very rigorous and remarkably general and complete
- McLean - fairly complete, but missing basics

➢ *Recommend*:

1. Start with Walker to get an overview
2. Pick up McLean *and* a basic optics book (e.g., Meyer-Arendt, "Introduction to Classical and Modern Optics") and work out quoted results; return to Walker to reconcile results and nomenclature.
3. Then hit Schroeder's text running to go to expert level.

Some Everyday Concepts

- Specular and Diffuse Reflection
- Refraction

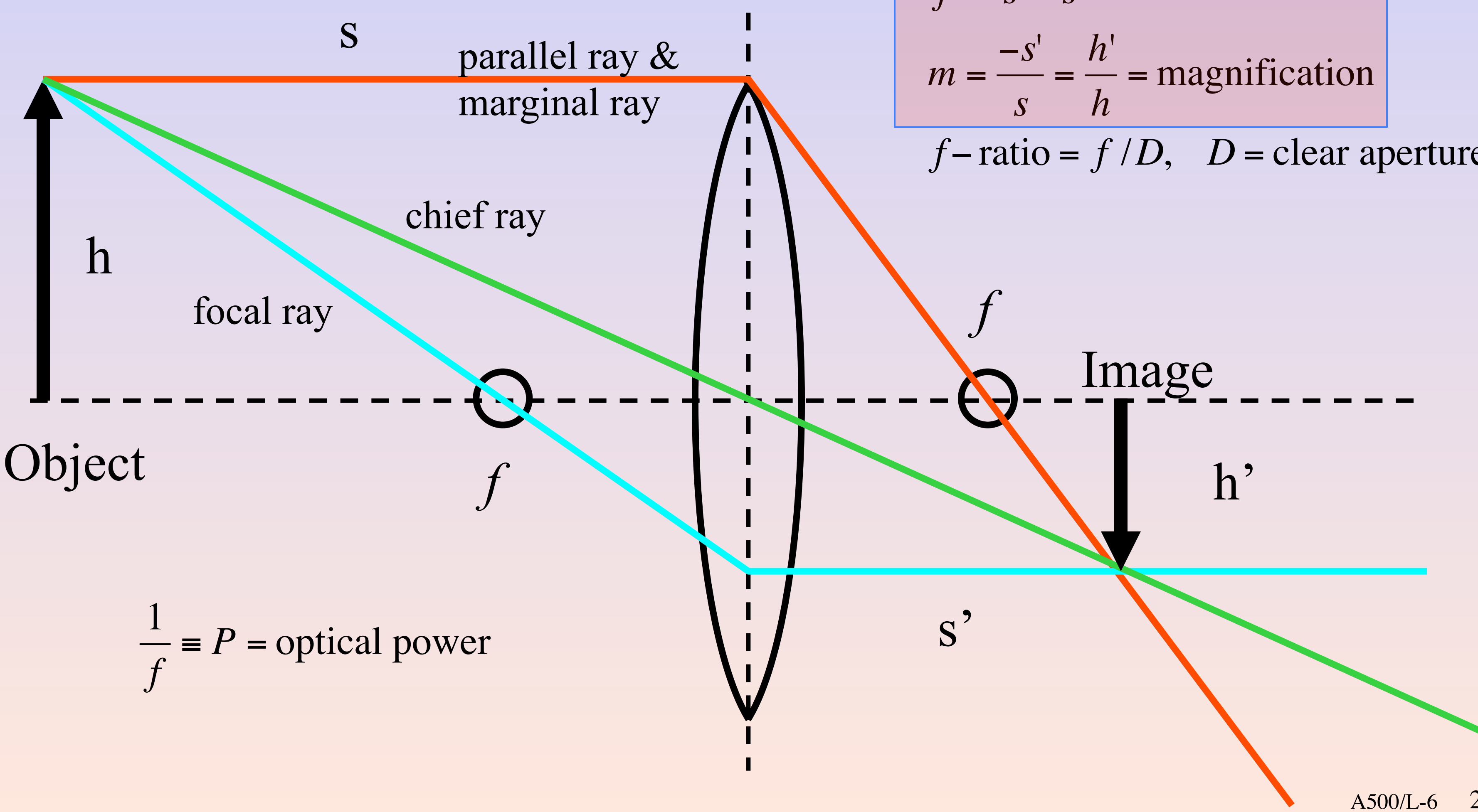


The Thin Lens

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$$

$$m = \frac{-s'}{s} = \frac{h'}{h} = \text{magnification}$$

$$f-\text{ratio} = f/D, \quad D = \text{clear aperture}$$



$$\frac{1}{f} \equiv P = \text{optical power}$$

The Thin Lens

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$$

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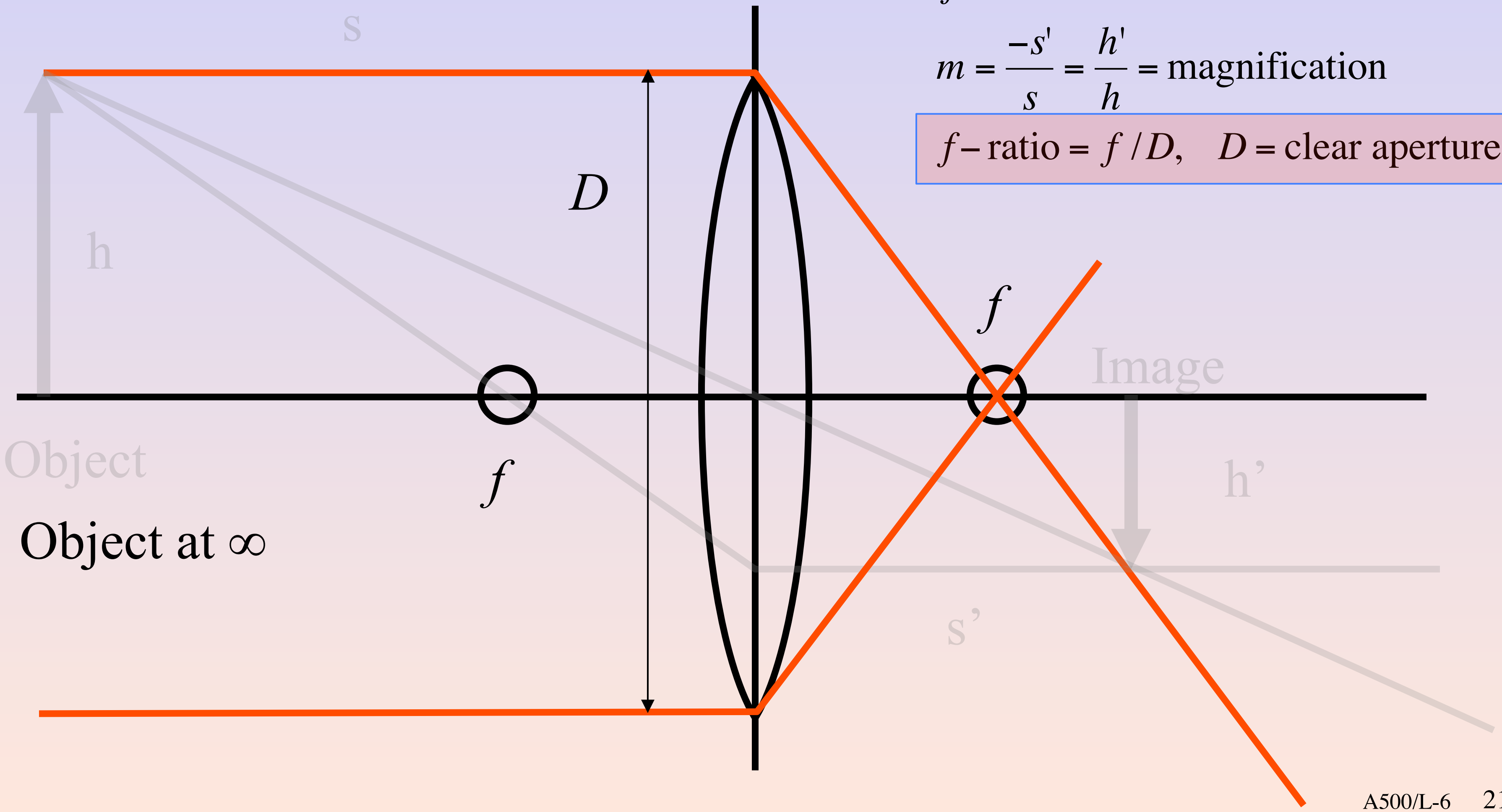
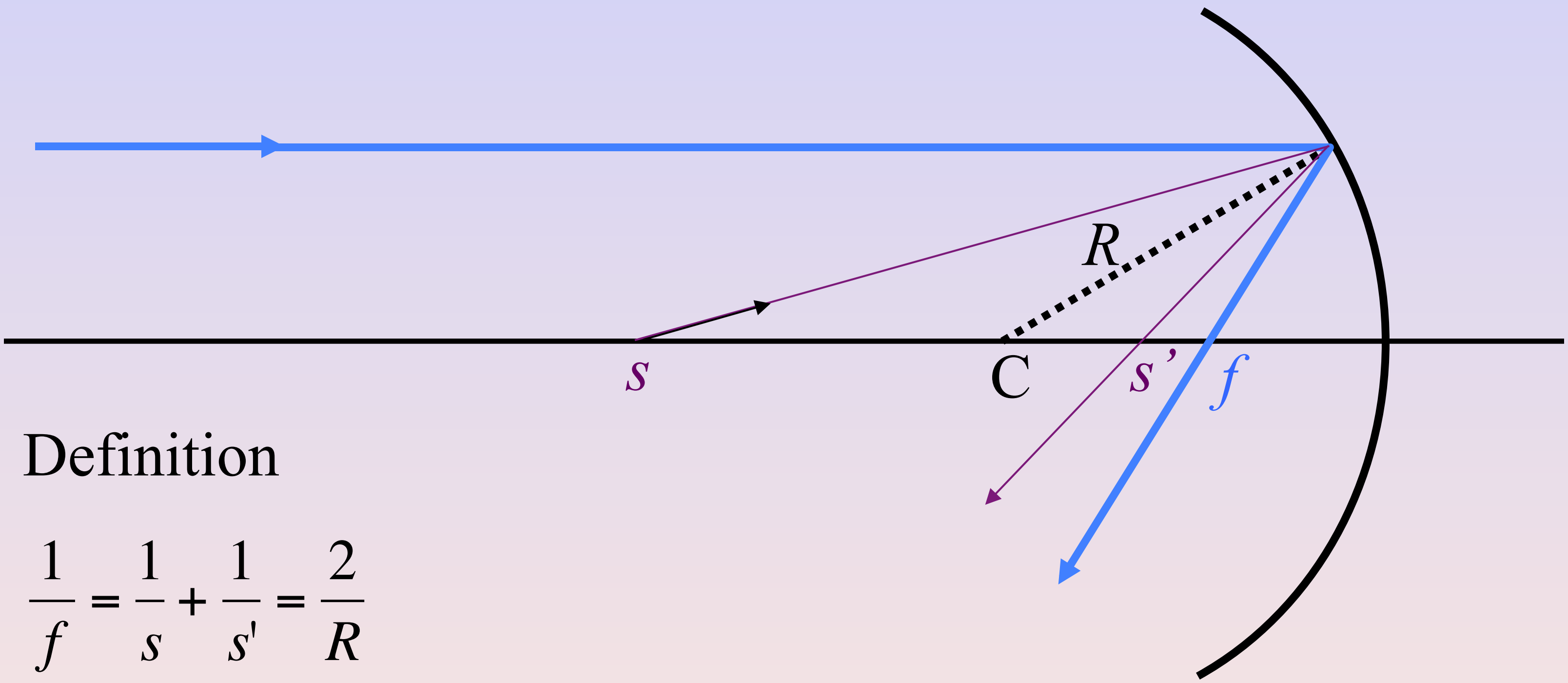


Object at ∞

Spherical Optics

Focal Length Defined



Definition

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'} = \frac{2}{R}$$

Object at Infinity $\quad \frac{1}{s'} = \frac{1}{f} \qquad \frac{1}{s'} = \frac{2}{R}$

$f = R/2$ is referred to as the *paraxial* focal-length

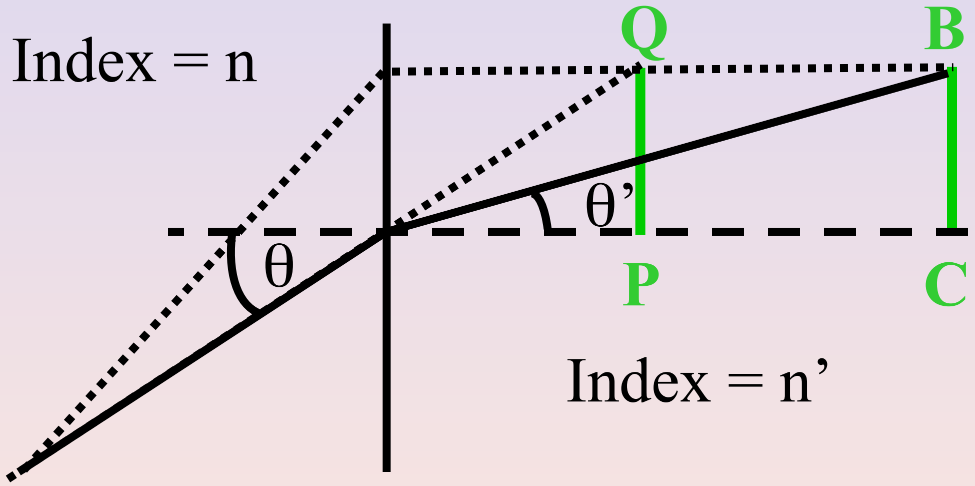
Snell's Law

$$n \sin\theta = n' \sin\theta'$$

n and *n'* depend on λ

$$\frac{1}{V} = (n_F - n_C)/(n_D - 1)$$

= dispersive power



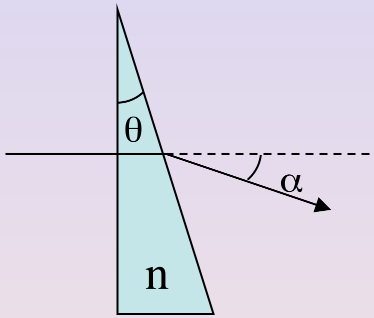
F,D,C: solar-spectrum Fraunhofer lines (486, 589, 656 nm).

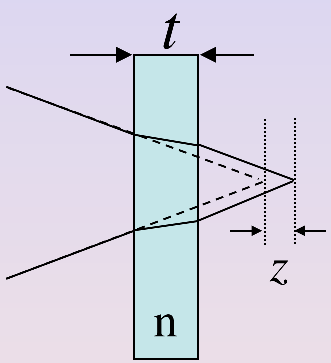
V vs n is called a glass table.

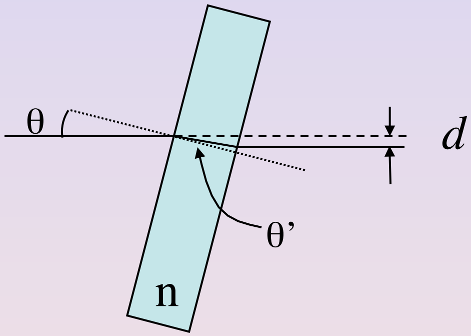
Fermat's principle: least time

An Aside: Implications of Snell's Law

$$\alpha \approx (n-1)\theta \qquad z \approx \frac{(n-1)t}{n} \qquad d \approx t\sin\theta\left(1-\frac{\cos\theta}{n\cos\theta'}\right)$$



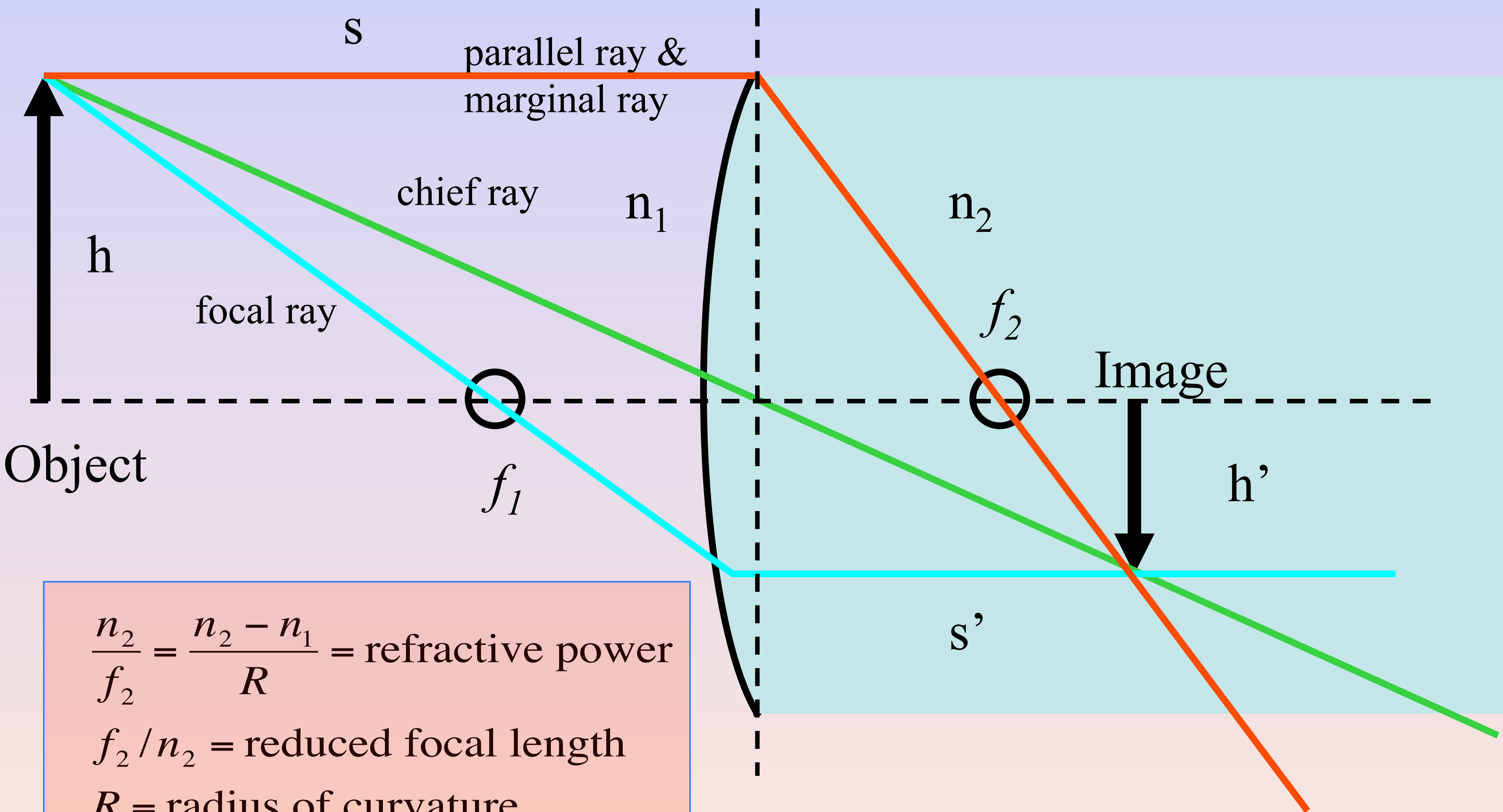




Impact of wedges and and plane parallel plates on an optical beam

If beam is converging, astigmatism introduced. Can be eliminated with wedge.

The Thick Lens

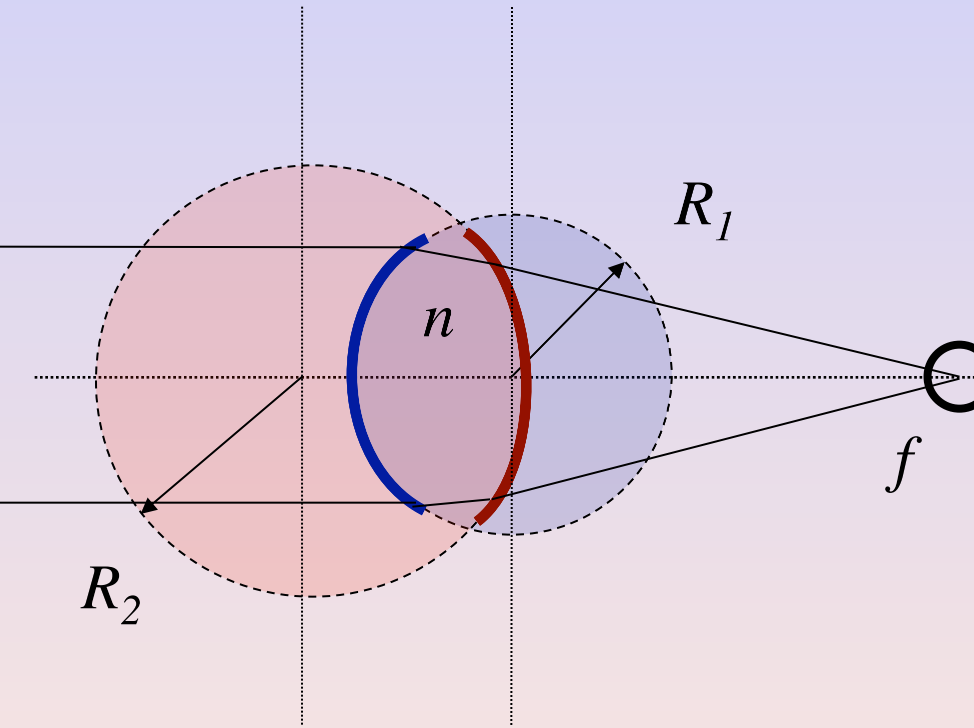


$$\frac{n_2}{f_2} = \frac{n_2 - n_1}{R} = \text{refractive power}$$

f_2 / n_2 = reduced focal length

R = radius of curvature

Optical Power, *P*



Two surfaces

- separation *d*
- index *n*

$$P \equiv \frac{1}{f} = P_1 + P_2 - \frac{d}{n} P_1 P_2$$

Two-surface spherical lens in air or vacuum

- R_1, R_2 radii of curvature
- R>0: center of curvature behind lens

Lensmaker's formula:

$$P = \frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{d(n-1)}{nR_1R_2}\right]$$

units : dioptor (m^{-1})