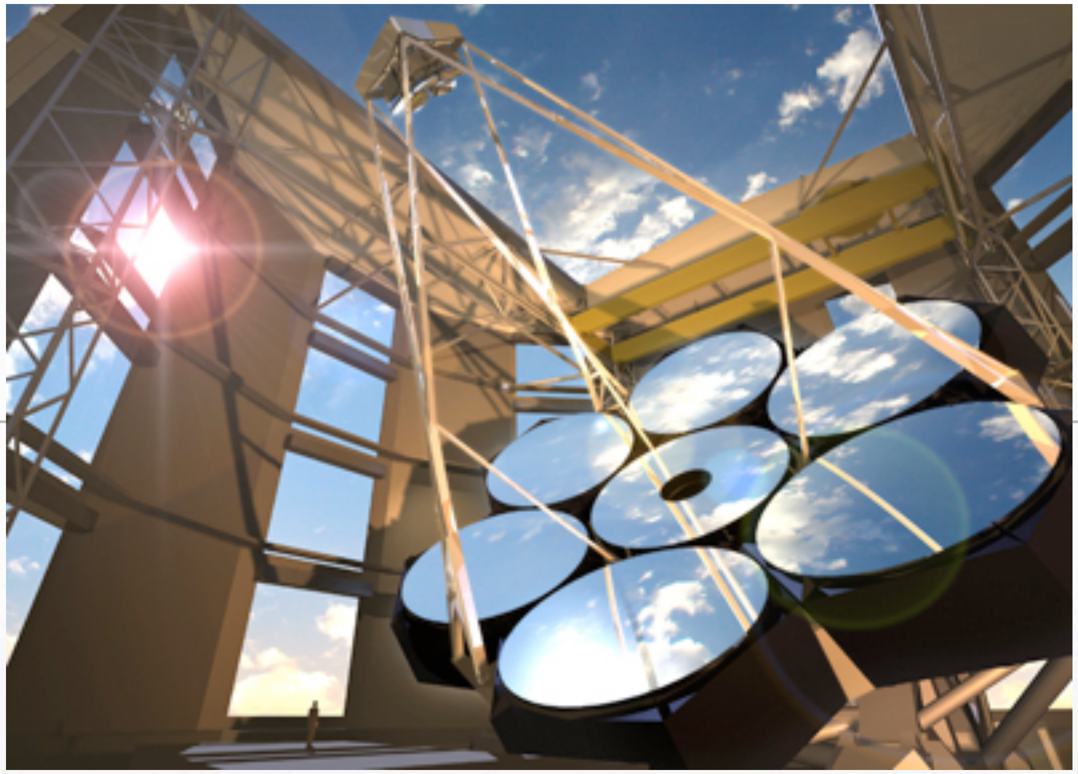
Optical Telescopes



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Princeton Astrophysics

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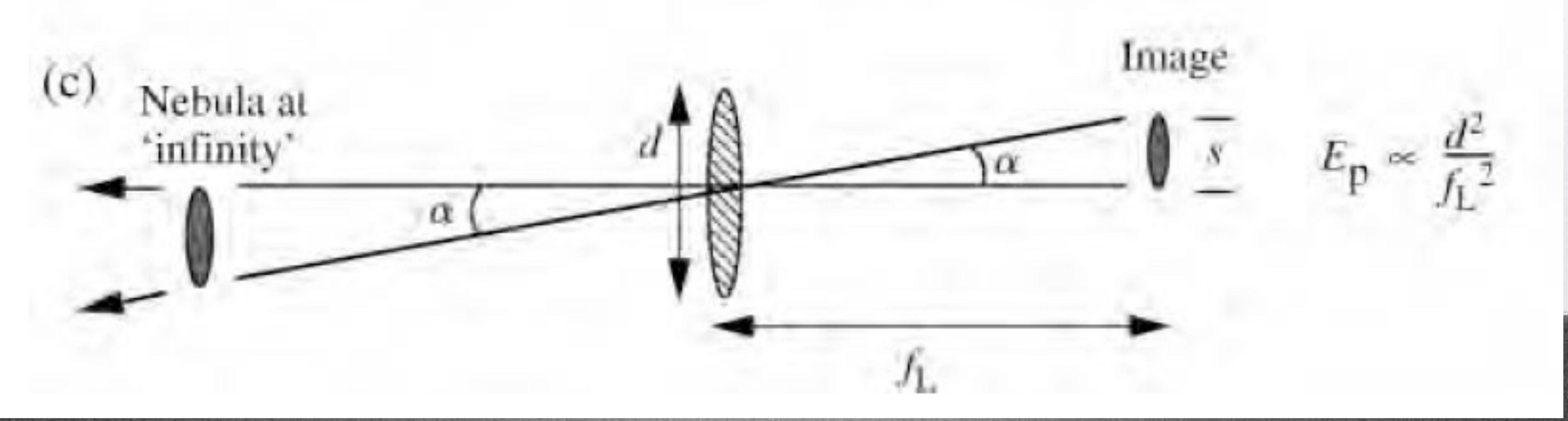
Outline

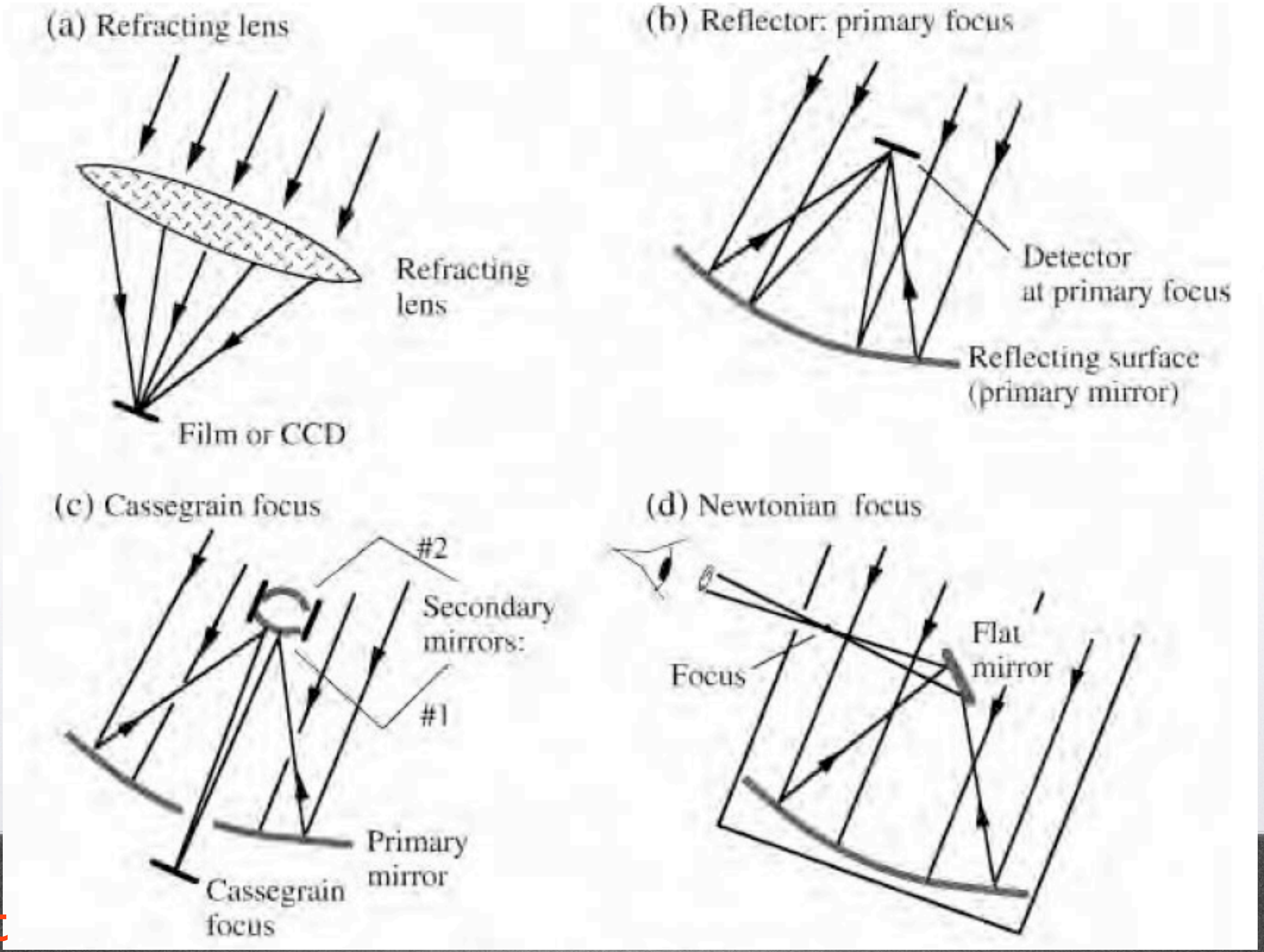
- Telescope Overview
- Two-Mirror Reflecting Telescopes
  - Cassegrain
  - Gregorian
  - Ritchey-Chretien
- Auxiliary Optics & Correctors
- Catadioptric Telescopes/Cameras
  - Classical Schmidt
  - Schmidt-Cassegrain
- Examples: Subaru, Keck, APO

Optical Systems: Basics

- Focal length $\longleftrightarrow$ plate scale: angle imaged onto unit length
  - Lick 3m: f_L=15.2m, P_s=14"/mm
- Energy per unit time onto single pixel: $$E_p \propto \left(\frac{d}{f_L}\right)^2$$
- $E_p \longleftrightarrow$ "speed"
- Notation: focal ratio = "f/R" (e.g., f/3 means focal ratio of 3)
- Slower optics: greater magnification, angular resolution
- Faster optics: shorter exposure time
  - better for wide-field surveys



Designs

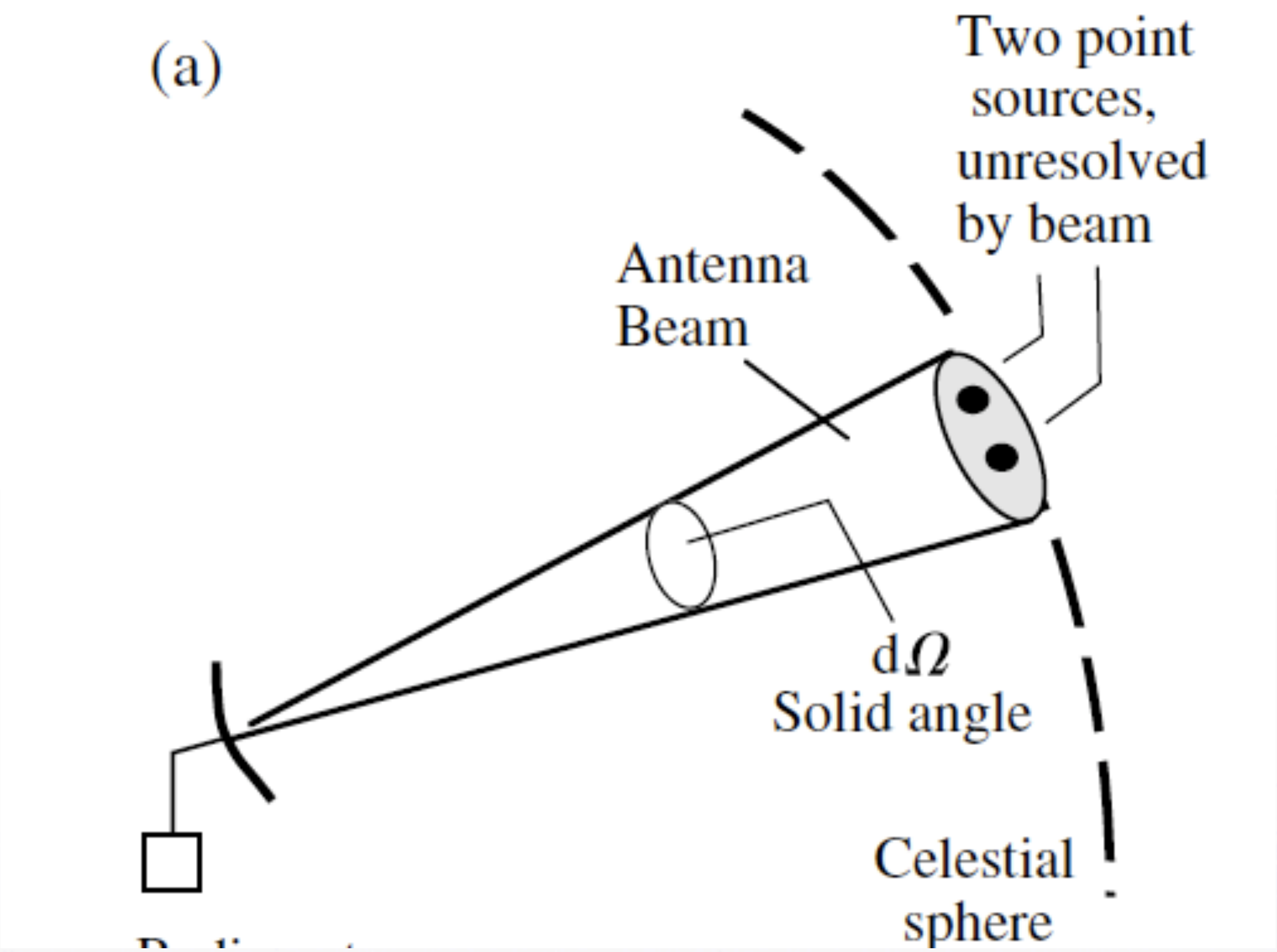


(a) Refracting lens
Refracting lens
Film or CCD
(b) Reflector: primary focus
Detector at primary focus
Reflecting surface (primary mirror)
(c) Cassegrain focus
#2
Secondary mirrors:
#1
Primary mirror
Cassegrain focus
(d) Newtonian focus
Flat mirror
Focus

Important Quantities

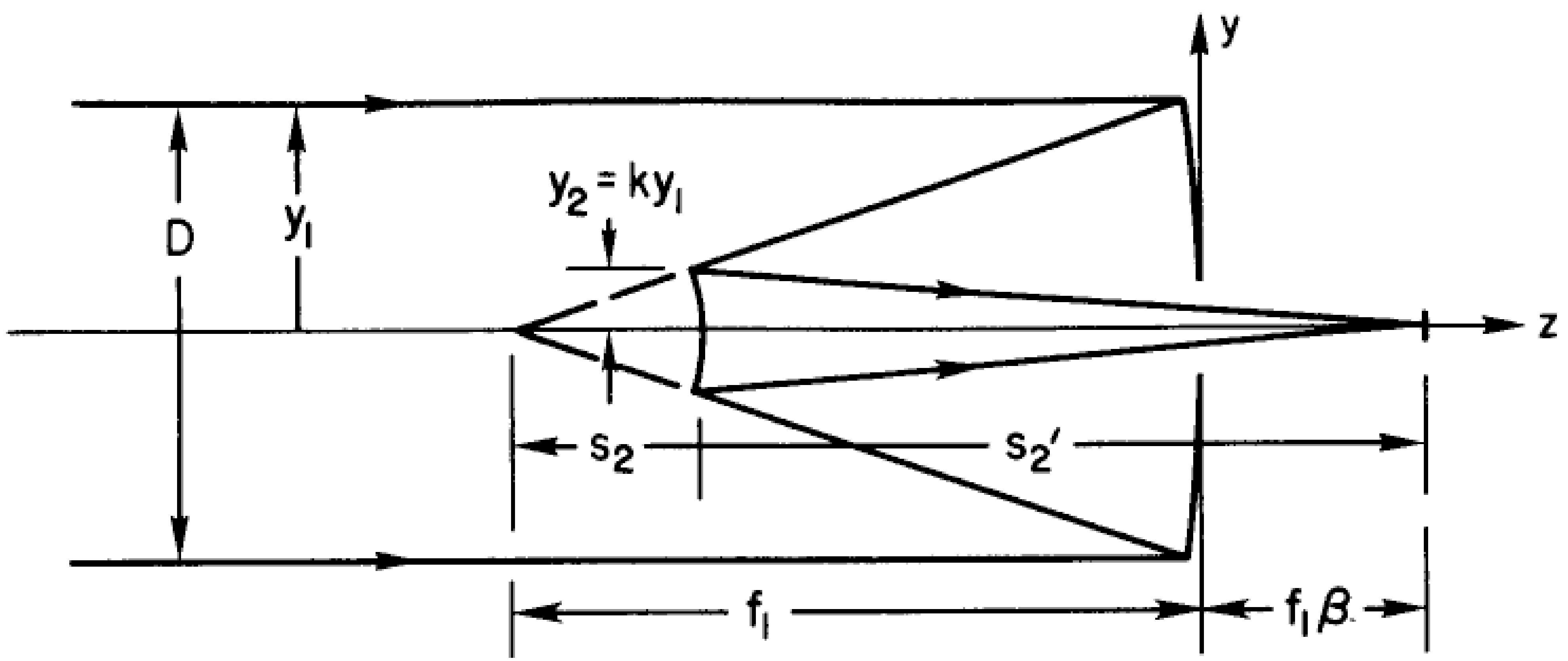
- Diameter of primary mirror: light collecting power
- Telescope scale: $f_{eff} = f_1 m$
- Back focal distance
- Design parameters:
  - Radii of curvature of mirrors
  - Separation between mirrors
- f_l limited by technology: choose *m* to get desired scale
- Mirror separation: compromise between longer/less blocked light vs. shorter/more blocked light
- How to focus: move secondary mirror

Other Quantities



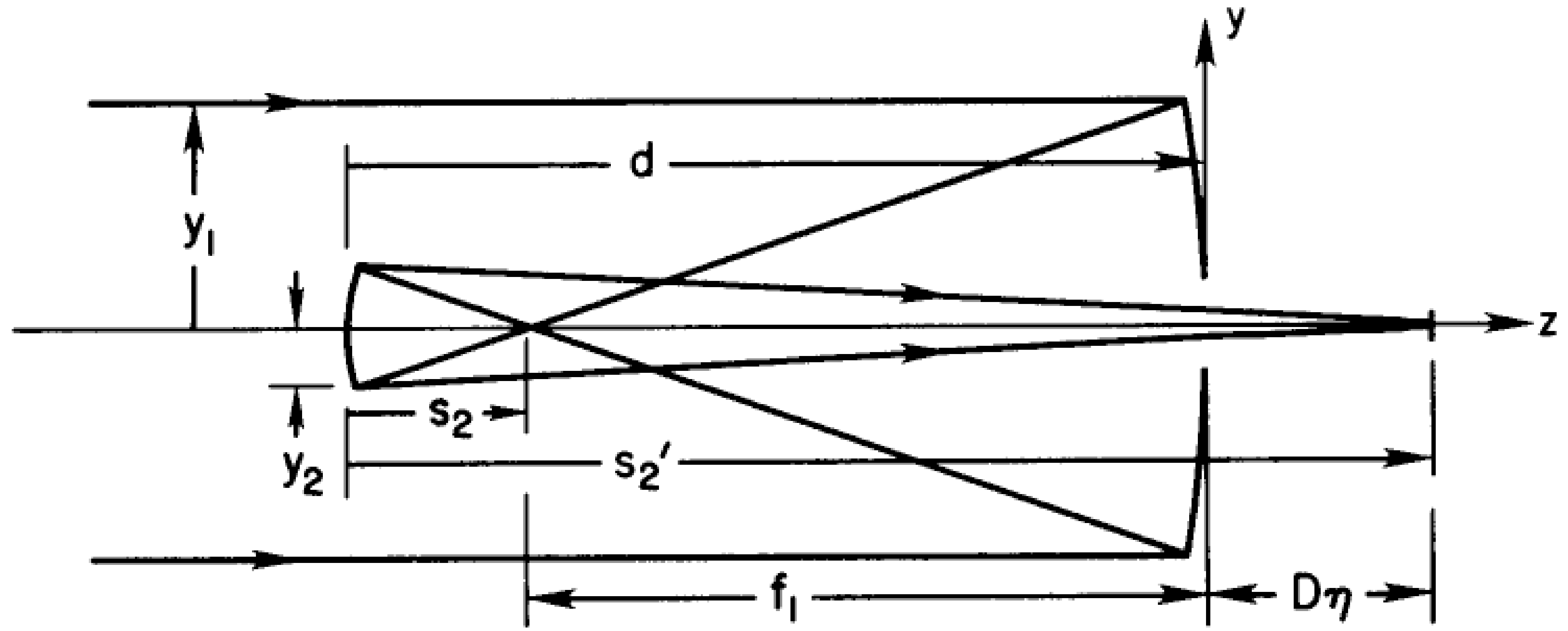
- Beam: portion of sky observed at a time by a given pixel
- PSF: distribution of deposited energy in image plane in response to a point source (map of single-pixel beam shape)

Reflectors: Cassegrain



- Parabolic primary; hyperbolic secondary
- Correct for spherical aberration w/ secondary (*classical*)
- Dominated by coma (over astigmatism)
- Limited to small fields (O(<10') for 1" seeing)

Reflectors: Gregorian



- Parabolic primary; prolate ellipsoidal secondary
- Again, correct for spherical aberration w/ secondary
- Same coma and astigmatism as Cassegrain
- Only difference: smaller image surface curvature (negligible given small field size)

Reflectors: Ritchey-Chretien

- *Aplanatic*: optical system w/ zero spherical aberration and coma
- Ritchey-Chretien: aplanatic Cassegrain
- Choose shapes of primary+secondary to leave only astigmatism
  - Two hyperbolic mirrors
  - Also, aplanatic Gregorian: two ellipsoidal mirrors
- RC: larger astigmatism compared to CC at same f/R
  - AG: smaller than CG at same f/R
- Location of stop does not affect astigmatism
- RC: most popular choice today for big optical telescopes

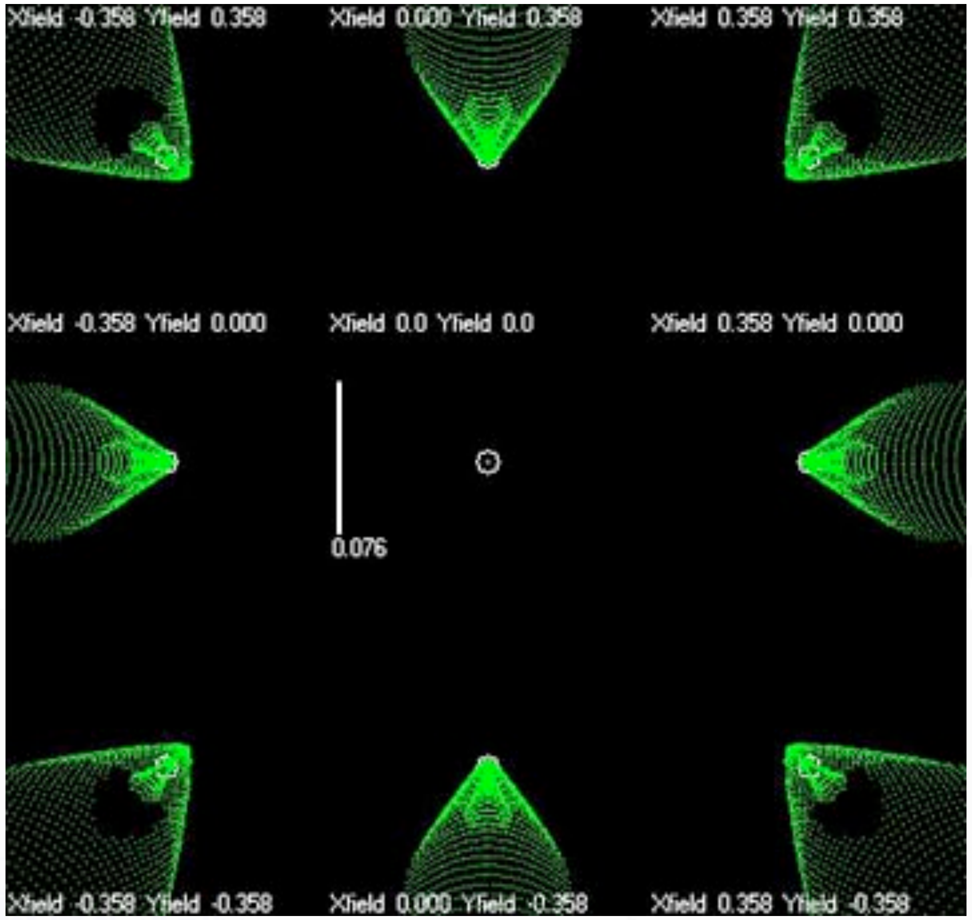
Reflectors: Comparison

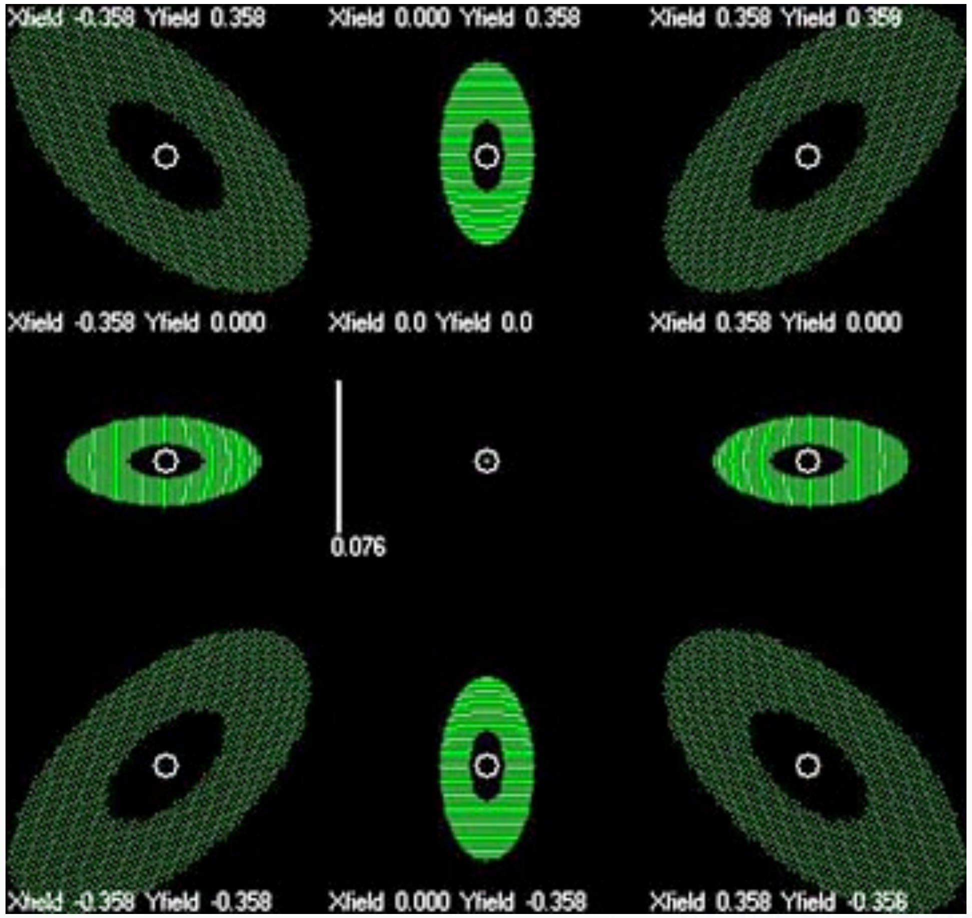
- Cassegrain is significantly shorter for same primary mirror
  (Gregorian would need faster primary to have same physical length)

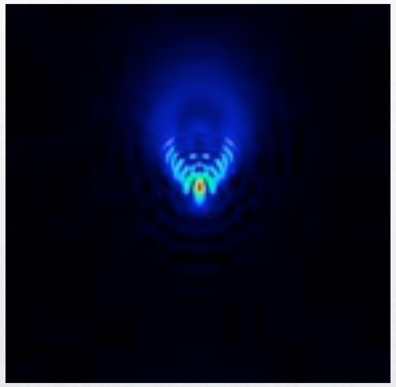
$$\text{secondary–focal surface distance} = mkf_1$$

- Cassegrain needs smaller secondary to get all light from primary
- Aplanatic Gregorian generally gives best optical quality
- Design considerations favor RC overall though
  - Symmetric images (astigmatism only)
  - Large field
  - Shorter than AG; obstructs less light

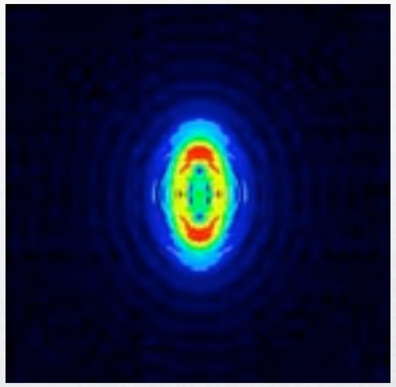
Reflectors: why RC?



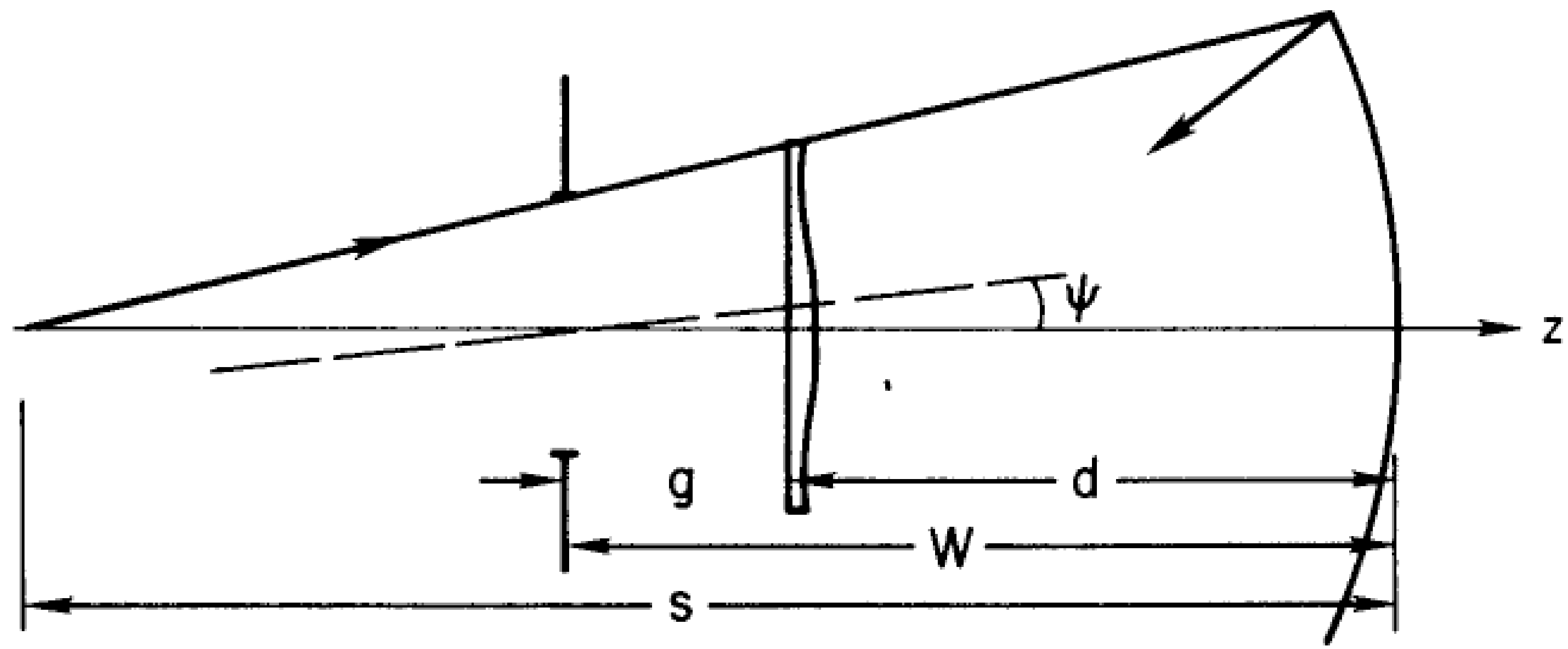




- Center: on-axis (note Airy disk); others: outer edges of field
- PSF off-axis (at edge of 2 in. diameter field -- corresponds to 0.7162°)



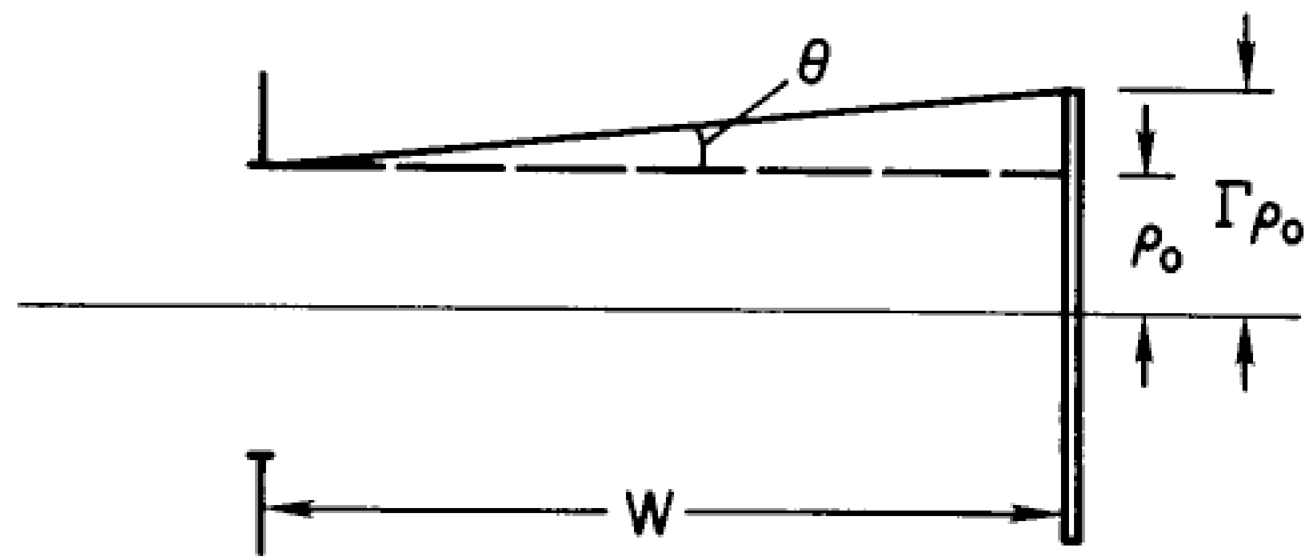
Catadioptric Telescopes: Schmidt



- Catadioptric: full-aperture refracting element corrects spherical aberration
- Locate plate and aperature stop to give zero coma and astigmatism (to third order)
- Attain good wide-field imaging

Schmidt Telescopes/Cameras

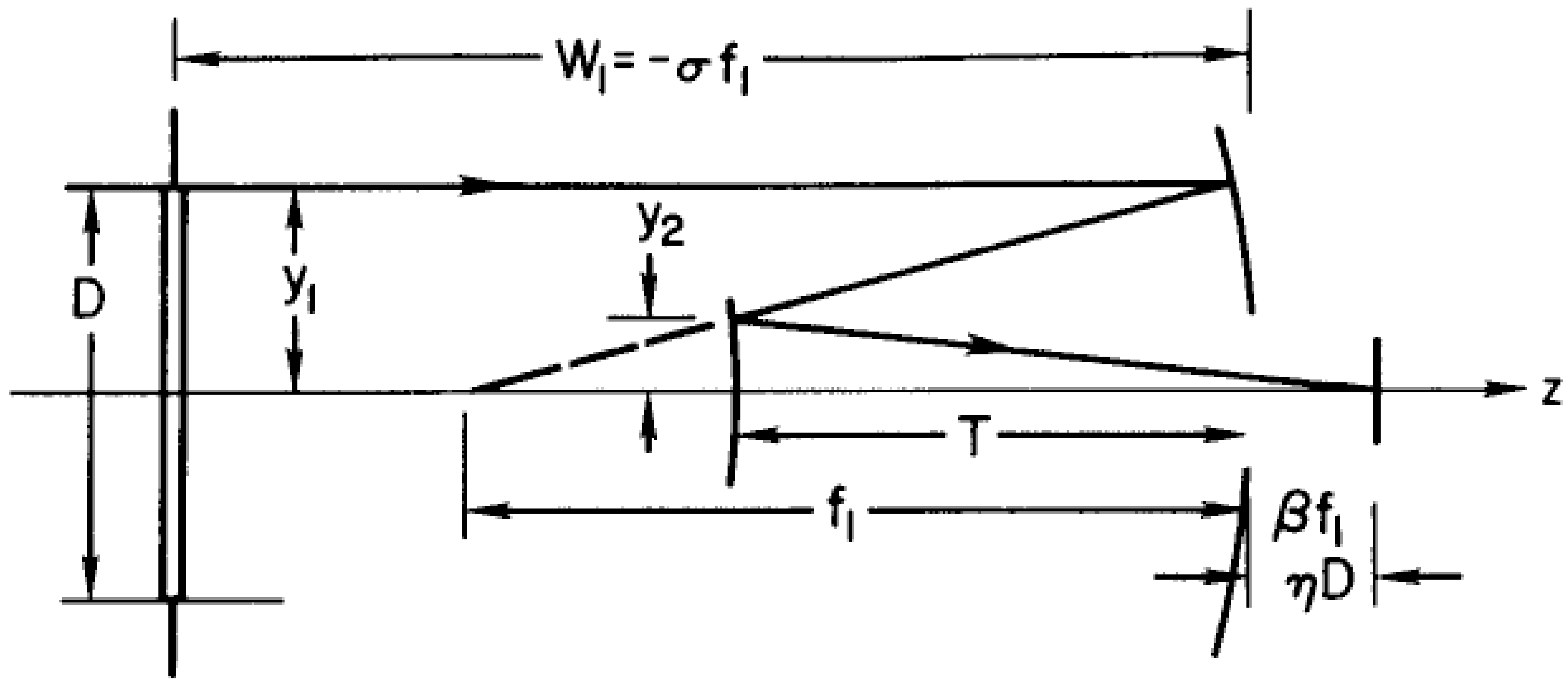
- Key: aspheric plate
  - To minimize chromatic effects: locate stop/exit pupil as near corrector as possible
  - Otherwise need larger plate



- Why Schmidt?:
  - Relative simplicity: only two large optical elements
  - Good choice if aperture of >1m is required
  - Smaller chromatic aberration of apsheric corrector compared to other types

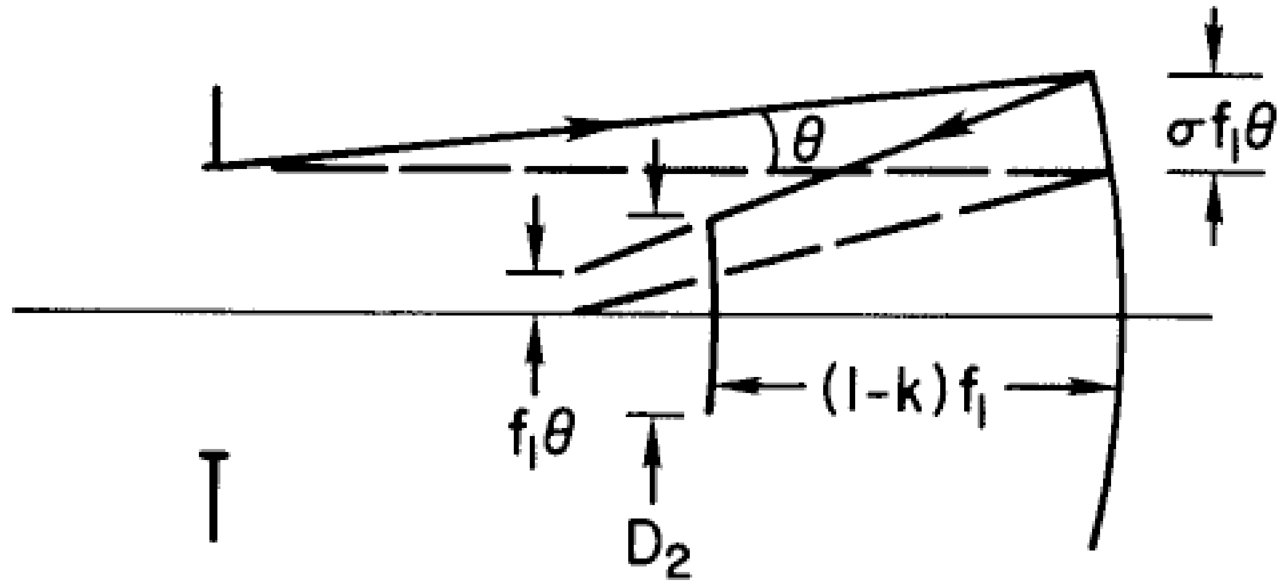
- Short focal length-> fast

Catadioptric: Schmidt-Cassegrain



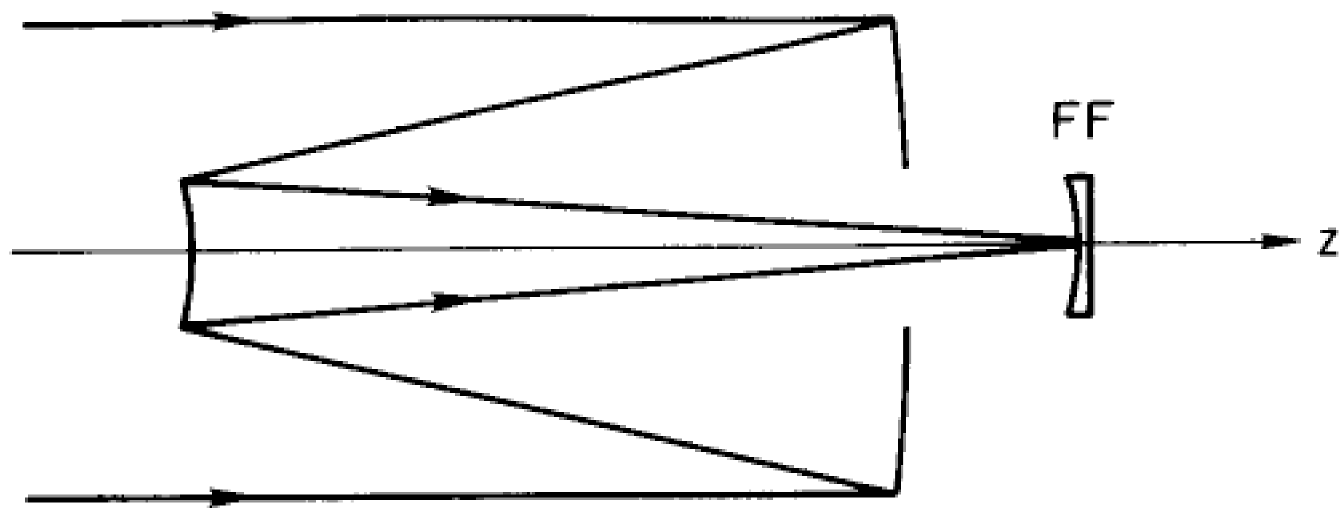
- Aspheric corrector in collimated beam ahead of primary mirror
- Leaves free parameters for mirror design for other corrections
- Note shift of aperture stop from primary to corrector

Schmidt-Cassegrain



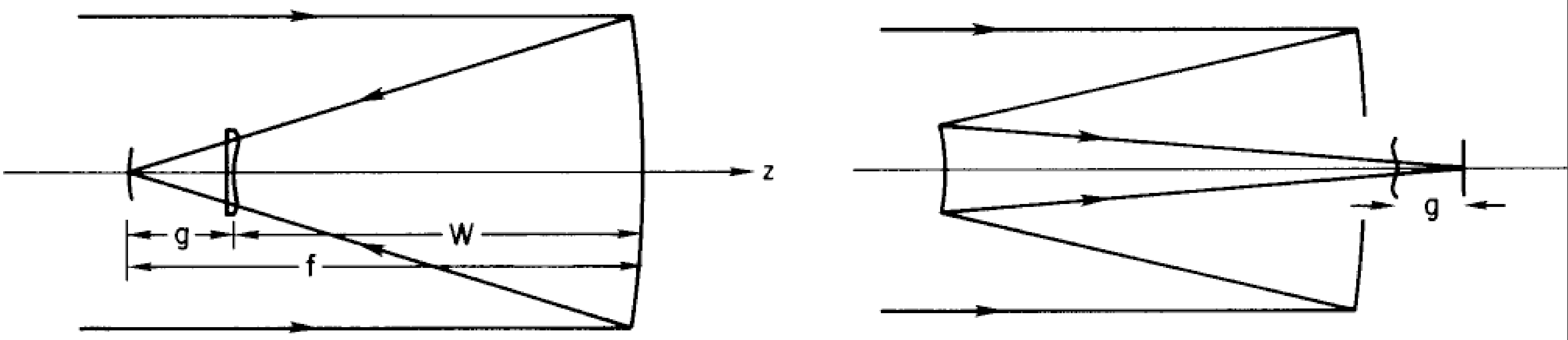
- Different stop location means secondary size changes
- SC types:
  - Flat-field anastigmatic SC: zero astigmatism/coma/spherical aber.
  - SC with spherical mirrors (including aplanatic SC)
  - Compact SC with spherical primary (popular for amateurs)
- Main issue: chromatic aberration (large compared to standard Schmidt)--displacing stop from corrector makes it worse

Auxiliary Optics



- Field lens: element placed at or near image plane
- Field-flattener: flattens a curved image surface
  - Does change system aberrations slightly
- Ex.: Ritchey-Chretien w/ FF
- Can also use in Schmidt, but introduces larger aberrations

Correctors

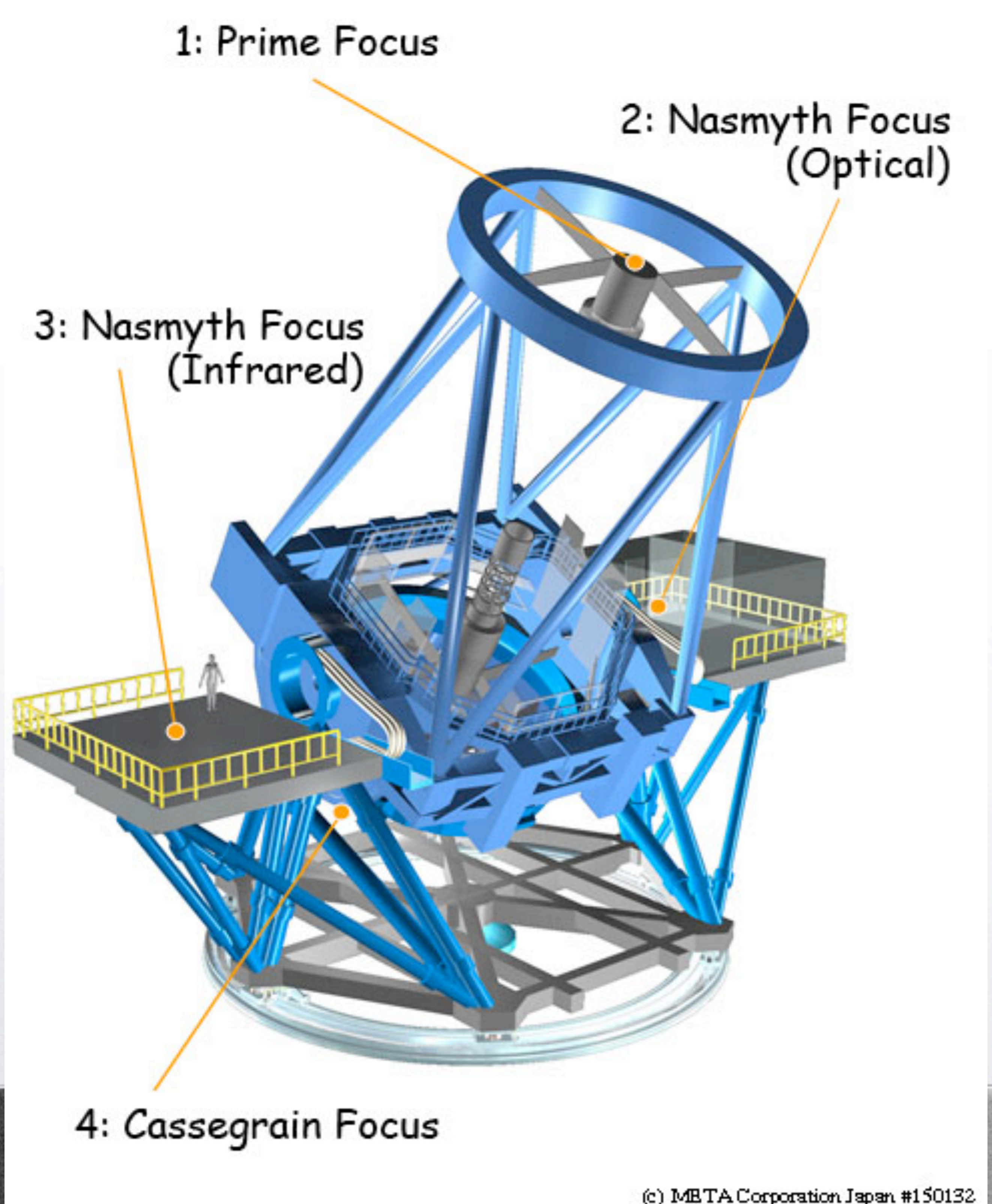


- Prime focus correctors (when needing smaller focal ratio)
  - Aspheric plates
  - Wynne triplets
- Cassegrain focus correctors
  - Aspheric plates (Gascoigne) -- remove astigmatism
  - Modified Ritchey-Chretien (e.g., Las Campanas 1.0m, 2.5m)

Other Sources of Aberrations

- Misfigured or imperfect optics
- Misalignments: leads to constant coma over the field (dominates over astigmatism)
- Mechanical/support problems -- distortion of mirror shape, alignment of mirrors (one reason for alt-az mount)
- Chromatic aberration in cameras/spectrographs
- Seeing

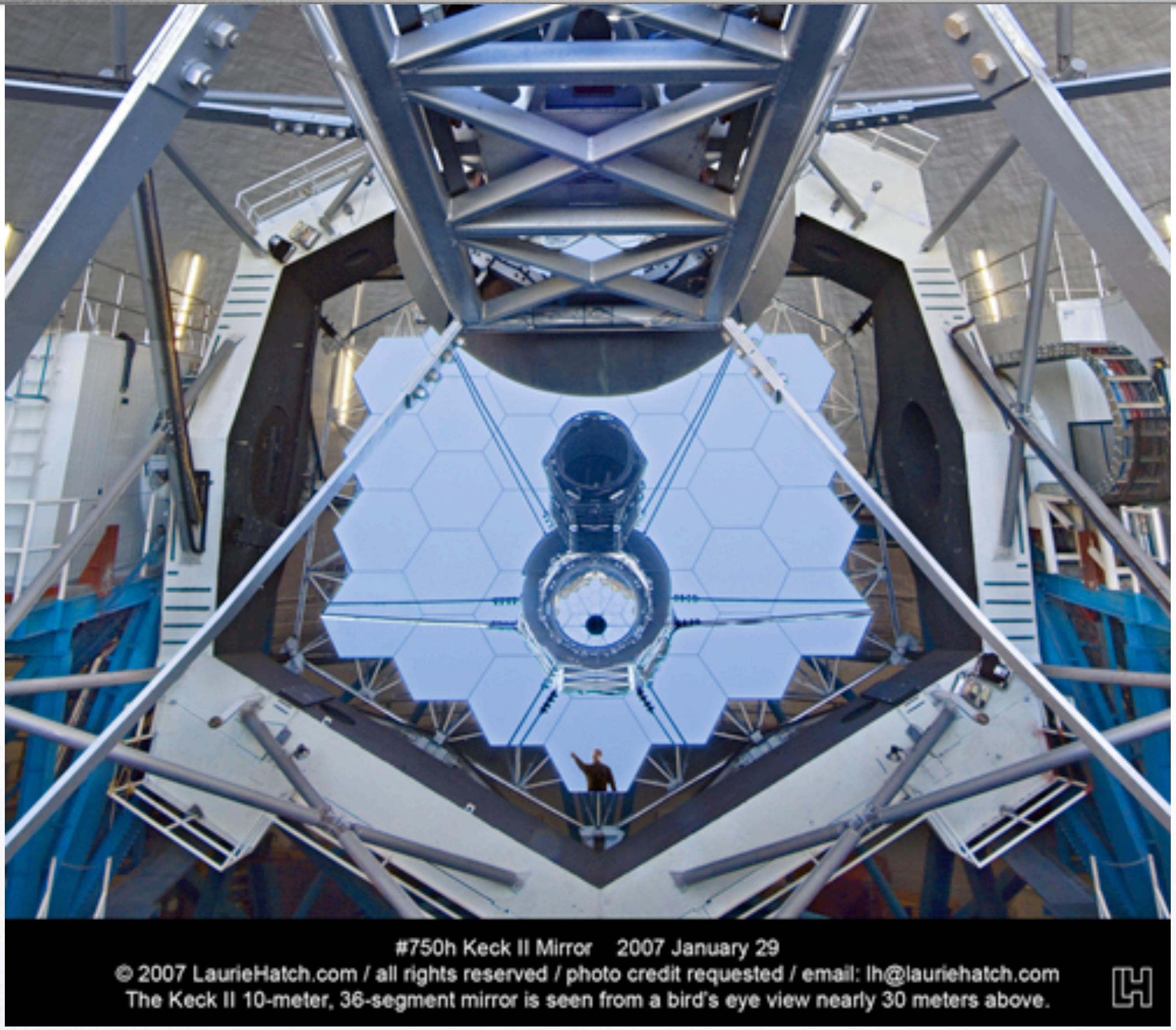
Subaru

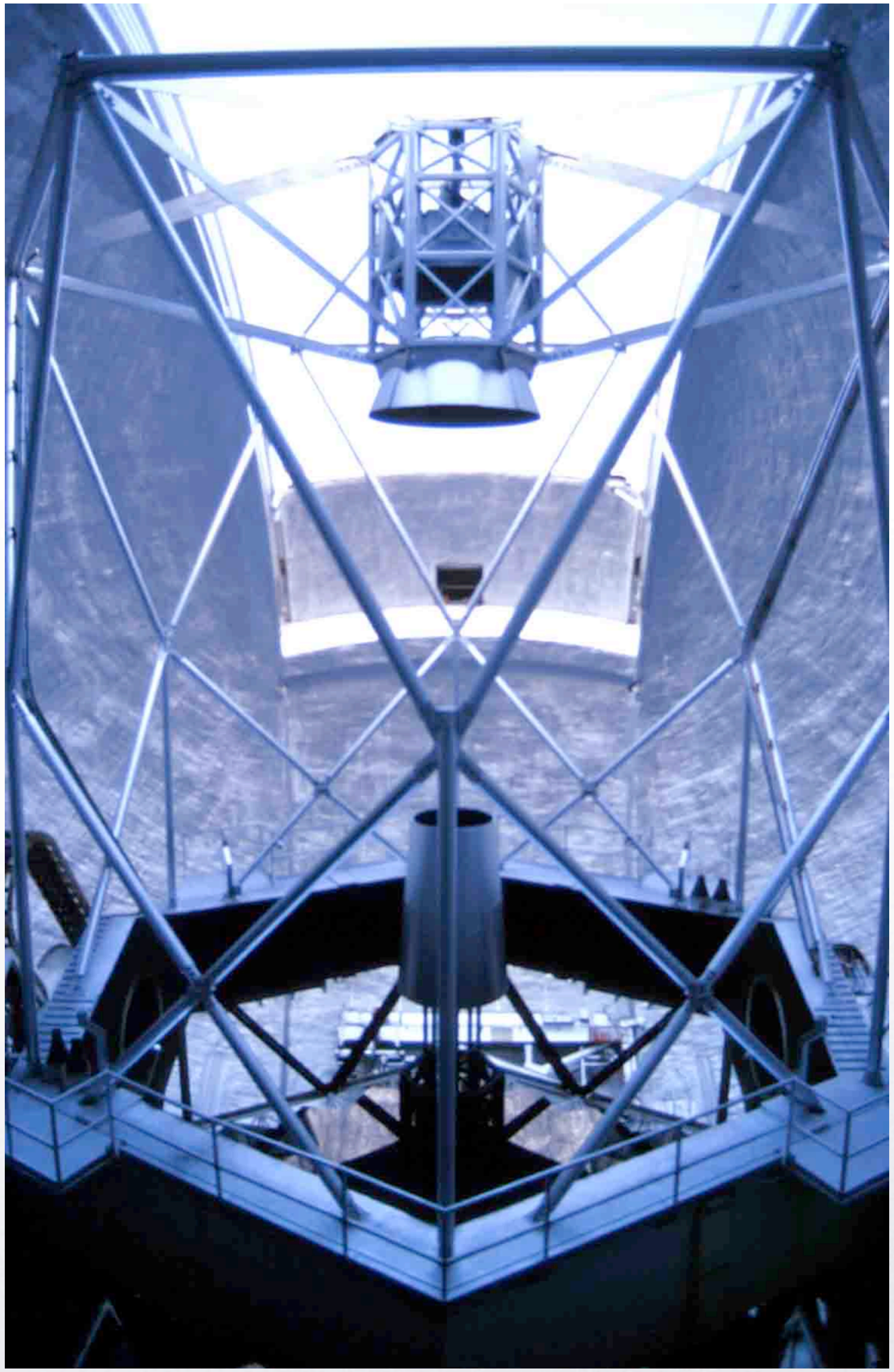


- 8.2m primary (f/1.83)
- ~1.3m secondary
- Ritchey-Chretien
- Can place instruments at prime focus!
- Optical/IR

http://www.subarutelescope.org/Introduction/telescope.html

Keck

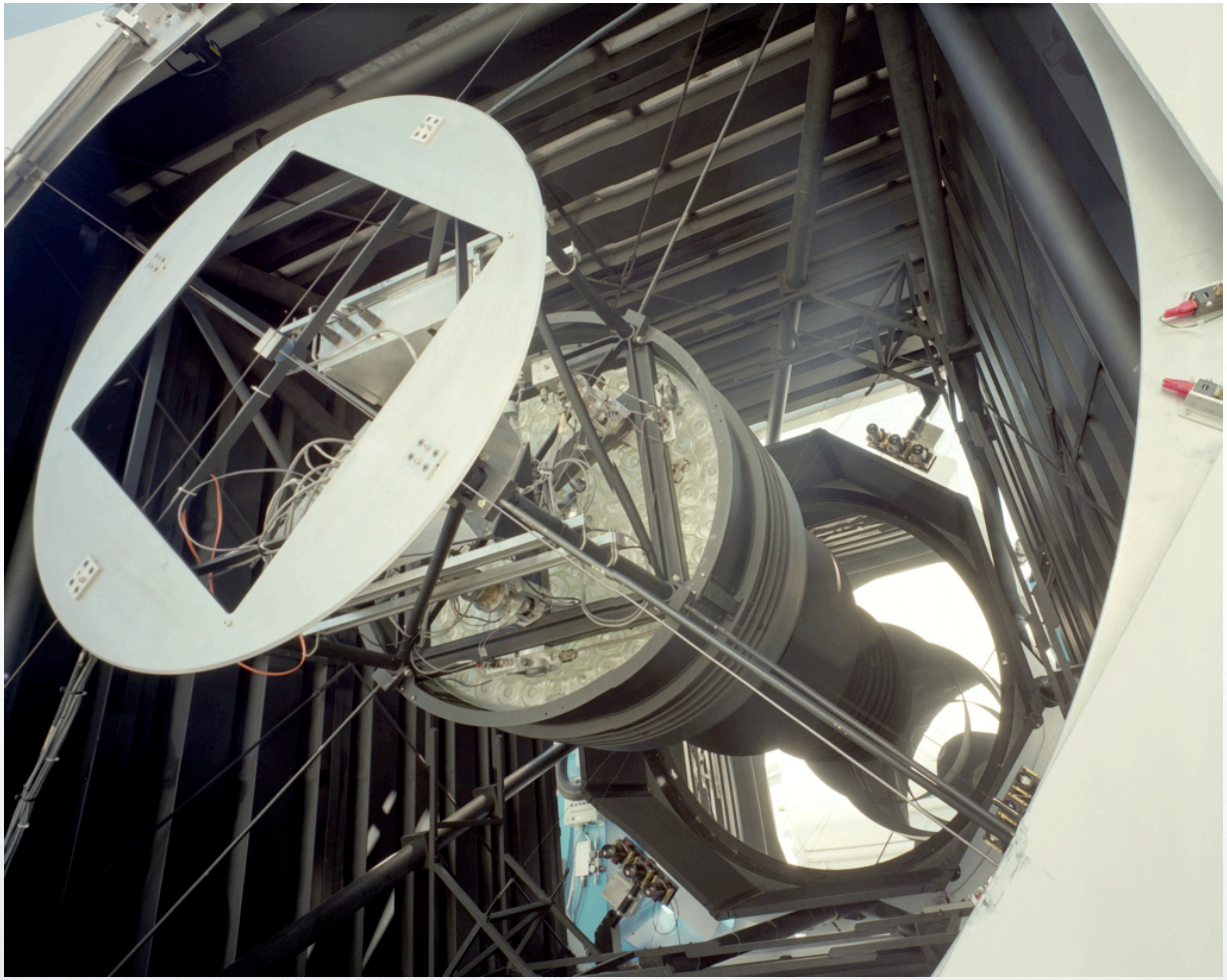




- 10m primary (36 segments, f/1.75)
- Ritchey-Chretien + AO
- Optical/IR

http://keckobservatory.org/gallery/album/C6

Apache Point Observatory 2.5m



- Ritchey-Chretien
- 2.5m primary (f/5 tot.)
- 1.8m secondary
- Two corrector lenses: 3° distortion-free FOV
  - Gascoigne astigmatism corrector
  - Highly aspheric corrector
- CCD camera
- Fiber-fed double spectrographs

Gunn et al. (2006)

Summary

- Many ways to reduce different aberrations, increase FOV
- Most popular today: Ritchey-Chretien
  - Astigmatism-limited field
  - Smaller facilities required
  - Can modify further to reduce astigmatism, flatten image plane

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