Order of Business

1. Homework 1: due Monday
2. Observing poll -- vote was to keep schedule as is
3. Questions?
4. Lecture

Today’s topic: Telescopes
Text: Chapter 6
Parabolic Mirrors

No spherical aberration!

Other worries:
coma
astigmatism
(can also affect spherical mirrors)

comparison images of an **off-axis** star

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Coma  Astigmatism  No Aberrations
Aberration where off-axis point sources appear as “little comets”

Inherent property of paraboloid mirrors (even perfect ones have coma)
Can be minimized by taking less steeply curved paraboloid segment

(larger focal length for constant mirror diameter)

\[ N = \frac{\text{focal length}}{\text{diameter}} \]

f-number: convention: denoted as f/N (or F/N)
Astigmatism

Two different focal lengths:
one for tangential plane & one for sagittal plane

smaller order aberration than coma, symmetric in shape

in front of tangential plane focus  at tangential plane focus  “least confusion”  at sagittal plane focus  behind sagittal plane focus
Hyperbolic Mirrors

No spherical aberration!
No coma!

Still a worry: astigmatism
Telescope Designs -- Prime Focus

Pros: less light loss (fewer optics)

Cons: awkward cramped observing station

Observer in the prime focus cage

Primary mirror

Palomar 200-inch Hale Telescope
Telescope Designs -- Newtonian

Pros:
little light loss (few optics)
great for use with eyepieces (amateur scopes)

Cons:
impractical for use with instruments
Telescope Designs -- Cassegrain

Pros:
compact
long focal length
practical for lightweight instruments

Cons:
coma, astigmatism

MDM 1.3m McGraw-Hill telescope

Pros:
compact
long focal length
practical for lightweight instruments

Cons:
coma, astigmatism

secondary mirror
primary mirror
instrument
Telescope Designs -- Cassegrain Variation 1: Schmidt-Cassegrain

Schmidt corrector plate - corrects spherical aberration

Pros:
compact
long focal length
cheap and simple

Cons:
coma, astigmatism, etc
keep in mind: every time you add another optical component, you lose some light
Telescope Designs -- Cassegrain
Variation 2: Ritchey-Chretien

Pros:
compact
long focal length
no spherical aberration or coma

Cons:
expensive!!

twin 10-m Keck Telescopes

2.4-m Hubble Space Telescope
Telescope Designs -- Gregorian

Pros:
- similar to Cassegrain
- preferable for some applications

Cons:
- less compact than Cassegrain
- more expensive than Cassegrain

8.4-m Large Binocular Telescope
(near-IR secondaries)
Telescope Designs -- Nasmyth or Coude

Pros:
- similar to Cassegrain
- directs light to heavy instruments on stable platforms

Cons:
- less compact than Cassegrain

Thirty Meter Telescope (planned)
Light Gathering Power

Photons collected depends on surface area of primary mirror/lens

Twice the diameter = Four times the light gathering power
Angular Resolution
(oretical limit)

\[
\sin \theta = 1.220 \frac{\lambda}{D}
\]

\(D = \text{diameter of primary}\)
\(\sin \theta = \text{angular resolution in radians}\)

Twice the diameter = Twice the angular resolution
(smaller angles resolved)
Practical Limitations to Diameter of Primary

40-inch Yerkes Refractor
Largest primary lens that can be supported against gravity

now-canceled 100-m
Overwhelmingly Large (OWL) Telescope
(current limit for optical mirrors?)
Solid versus Honeycomb Mirrors

- Simple manufacturing
- Heavy
- Low stiffness

- Weight reduction (up to 80%)
- High stiffness
- Advanced manufacturing

100-inch Hooker Telescope at Mt. Wilson
Largest solid glass mirror

8.4-m Large Binocular Telescope
Largest monolithic mirror to date
Segmented Mirrors

36 hexagonal segments in each of the twin 10-m Keck Telescope mirrors

extremely precise mechanics required to keep mirror shape within specifications

planned for Thirty Meter Telescope (TMT) and 40-m European Extremely Large Telescope (E-ELT)
Meniscus Mirrors

curved, thin glass mirror
(like a giant contact lens)

too thin to support their shape against gravity

very difficult to manufacture
-- glass often cracks during cooling process and easy to break during transport

Four 8.2-m Very Large Telescopes at Paranal Observatory
Multiple Honeycomb Mirrors

25-m Giant Magellan Telescope primary will be composed of seven 8.4-m honeycomb mirrors.
20 tons of glass melting in the mirror oven (GMT mirror 4)
Mirror Materials

Speculum Metal
(alloy of copper and tin)
~1668 to late-1800s
- single material = simple
- low reflectivity (max ~ 60%)
- requires frequent polishing (which also reshapes surface)

Plate Glass
(fused quartz silicates)
1857 to present
- coated with reflective metal for high reflectivity
- recoat possible without surface reshaping
- subject to thermal expansion

Borosilicate Glass (pyrex®)
~1935 to present
- coated with reflective metal for high reflectivity
- recoat possible without surface reshaping
- less subject to thermal expansion
- easier to grind than quartz
Advertisement from May 29, 1948, edition of the Saturday Evening Post
Mirror Materials continued

lithium aluminosilicate glass-ceramic (Zerodur®)
~1968 to present

many benefits similar to borosilicate glass

extremely low thermal expansion

titania silicate glass (ULE® - ultra low expansion)
~1978 to present

benefits similar to zerodur

~zero thermal expansion
**Pros**
Cheap! (~10% glass mirror cost)
Flawless surface

**Cons**
Restricted to zenith pointing only
Usually made with mercury = toxic
Mirror Coatings

Silver
- expensive
- tarnishes quickly

Aluminum
- cheap
- tarnishes less quickly

Gold
- expensive
- unsuitable for optical
## Telescope Mounts

### Altitude-Azimuth or Alt-Az

- **altitude (up-down)** controlled separately from **azimuth (side-to-side)**

  - can be simple = cheap
  - field of view rotates
  - poor match to celestial object sky track

### Equatorial

- **right ascension** controlled separately from **declination**

  - field of view doesn’t rotate
  - matches celestial object sky track

  - less stable for heavy scopes