A Brief History of Astronomical Imaging Systems

Oldest “Imaging” Instruments
- circa 1000 CE – 1600 CE
- Used to measure angles and positions
- Included No Optics
  - Astrolabe
  - Octant, Sextant
  - Tycho Brahe’s Mural Quadrant (1576)
    - Star Catalog accurate to 1’ (1 arcminute = 1/60° ≈ limit of resolution of unaided human eye)
  - Astronomical Observatories were built by church as part of European Cathedrals
- (possible subject for course term paper)

Early “Imaging” System
the Mural Quadrant
- Most accurate positions of stars and planets then available
- Used by Johannes Kepler to derive the three laws of planetary motion
  - Laws 1,2 published in 1609
  - Third Law in 1619

Kepler’s Three Laws of Planetary Motion
1. The orbits of planets are ellipses with the Sun at one focus.
2. The line joining the planet to the Sun sweeps out equal areas in equal times as the planet travels around the ellipse, thus the planet travels faster when it is closer to the Sun.
3. The ratio of the squares of the periods (“years”) for two planets is equal to the ratio of the cubes of their semimajor axes.

Optical Instruments, (1609+)
- Refracting Telescope
  - uses lenses to redirect light
  - Invented in 1608
    - Hans Lippershey (1570? – 1619)
  - Early Use in Astronomy
    - 1609, by Galileo Galilei (1564 – 1642)
    - Johannes Hevelius (1611 – 1687)
- Reflecting Telescope
  - Invented ca. 1671
    - Isaac Newton (1642-1727)

Galileo’s Telescopes
- Combination of Two Lenses
  - Objective
    - Two surfaces: flat and convex
  - Eye Lens (Ocular)
    - Two surfaces: flat and concave
- Magnified by 20×

- Spectroscope
  - Invented ca. 1669, also by Newton
Galilean Telescope
- Ray incident “above” the optical axis emerges “above” the axis
- Image is “upright”
- Small Field of View

Keplerian Telescope
- Ray incident “above” the optical axis emerges “below” the axis
- Image is “inverted”

“Refractive Index”
- Denoted by \( n \)
- Measure of ratio of velocity of light in matter to that in vacuum

\[
\frac{c}{v} = n
\]

\( c = \) velocity in vacuum \( \approx 3 \times 10^8 \) meters/second
\( v = \) velocity in medium measured in same units

Sample Refractive Indices
- Vacuum: \( n = 1.0 \)
- Air: \( n \approx 1.00003 \approx 1.0 \)
- Water: \( n \approx 1.33 \)
- Glass: \( 1.71 \leq n \leq 1.46 \)
Lenses Redirect ("Bend") Light by Refraction due to Different $n$

![Diagram of light bending by refraction](image)

Reflected Angles Determined by "Snell’s Law’’

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

$$\Rightarrow \theta_2 = \sin^{-1}\left[\frac{n_1}{n_2} \sin[\theta_1]\right]$$

Problem with Refracting Telescopes: “Optical Dispersion”

- Refractive index $n$ of glass is not constant
- $n$ of glass tends to DECREASE with increasing wavelength $\lambda$.
  - Refracted angles change with wavelength $\lambda$.
- Focal length $f$ of lens tends to INCREASE with increasing wavelength $\lambda$.
  - Different colors “focus” at different distances
  - “Chromatic Aberration”

Optical Dispersion

Chromatic Aberration

- Chromatic aberration is less noticeable for lenses with long focal lengths $f$
Later Methods to Diminish Chromatic Aberration

- Create lens systems from multiple lenses made from different glasses
  - "doublets" or "triplets"
  - Designed so that chromatic aberrations "cancel" for some wavelengths
- Difficult to design and fabricate
- Beyond capability of early optical technicians

“Achromatic” Lenses

- "Achromatic" means “no color”
- Two (or more) lenses with different glasses
  - “Crown”, with smaller $n$
  - “Flint”, with larger $n$

Easy Way to Eliminate Chromatic Aberration

- Don’t use lenses!!
  
  ![Chromatic Aberration Elimination](image)

Newton’s Reflector

- ca. 1671
- 1”-diameter mirror
- no chromatic aberration
  - mirrors reflect all wavelengths at the same angle!

Large Historical Reflecting Telescope

- Lord Rosse’s 1.8 m (6’-diameter) telescope
  - metal mirror, 1845
History of Imaging Sensors

• Eye
  – Limited sensitivity
  – Limited range of wavelengths
  – Images can be “stored” only “by hand” (drawings)

• Image Recording Systems
  – Chemical-based Photography
    • wet plates, 1850 +
    • dry plates, 1880+
    • Kodak plates, 1900+
  – Physics-based Photography, 1970 +
    • Electronic Sensors, CCDs

• Groundbased Infrared Imaging
  – 1856: using thermocouples and telescopes ("one-pixel sensors")
  – 1900+: IR measurements of planets
  – 1960s: IR survey of sky (Mt. Wilson, lead sulfide – PbS – detector)

• Spacebased Infrared Imaging
    • cooled Silicon and Germanium detectors
  – 1989: COBE (Cosmic Background Explorer)

• Airborne Infrared Observatories
  – Galileo I (Convair 990), 1965 – 4/12/1973 (crashed)
  – Frank Low, 12”-diameter telescope on NASA Learjet, 1968
  – Kuiper Airborne Observatory (KAO) (36”-diameter telescope)

• NASA Learjet, 1968
  • 12”-diameter telescope, by Frank Low

• Kuiper Airborne Observatory
  • Modified C-141 Starlifter
  • 2/1974 – 10/1995
  • ceiling of 41,000’ is above 99% of water vapor, which absorbs most infrared radiation
**Stratospheric Observatory for Infrared Astronomy – SOFIA**
- Boeing 747SP
- 2.7-m Mirror (106"

**Spaceborne Observatories**
- “Orbiting Astronomical Observatory” (OAO), 1960s
- “Infrared Astronomical Satellite” (IRAS), 1980s
- Hubble Space Telescope (HST), 1990
- Chandra (Advanced X-ray Astrophysics Facility= AXAF), 7/1999

**History of Imaging Systems for Radio Astronomy**
- Wavelengths $\lambda$ are much longer than visible light
  - millimeters (and longer) vs. hundreds of nanometers
- History
  - 1932: Karl Jansky (Bell Telephone Labs) investigated use of “short waves” for transatlantic telephone communication
  - 1950s: Plans for 600-foot “Dish” in Sugar Grove, WV (for receiving Russian telemetry reflected from Moon)
  - 1960s: 305m Dish at Arecibo, Puerto Rico
  - 1963: Penzias and Wilson (Bell Telephone Labs), "Cosmic Microwave Background"
  - 1980: “Very Large Array” (= VLA) in New Mexico

**Jansky Radio Telescope**
1932

**Very Large Array = VLA**
- 27 telescopes
- 25m diameter
- transportable on rails
- separations up to 36 km (22 miles)

**Large Radio Telescopes**
- 100m at Green Bank, WV
- 305m at Arecibo, Puerto Rico

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http://www.naic.edu/about/ao/telefact.htm
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