ASTR-1010: Astronomy I
Course Notes
Section VI

Dr. Donald G. Luttermoser
Department of Physics and Astronomy
East Tennessee State University

Edition 2.0

Abstract

These class notes are designed for use of the instructor and students of the course ASTR-1010: Astronomy I taught by Dr. Donald G. Luttermoser at East Tennessee State University.

VI. Optics and Telescopes

A. Atmospheric Windows

1. The Earth's atmosphere is transparent in 2 different regions of the E/M: visual and radio. As such, these 2 regions are called the **visual window** and the **radio window**.

2. The Sun's peak radiation falls within the visual window (at 5200 Å in the yellow part of the spectrum).

3. Evolution and the visual window: our eyes have evolved to *see* the visual window with its peak reception being coincident with the same wavelength as the Sun's peak flux.

B. Optical Ground-Based Telescopes

1. Refractors.

a) Size of telescope determined by D = diameter of the objective (*i.e.*, front lens).

b) Magnification: $M = f_{\rm obj}/f_{\rm eye}$, where $f_{\rm obj}$ is the focal length of the objective lens and $f_{\rm eye}$ is the focal length of the eyepiece.

c) The objective lens **refracts** light to a focus.

d) Photons of different λ's focus at different points $\Longrightarrow$ **chromatic aberration**.

i) This can be corrected by making a lens multicomponent with different types of glass and different shapes (convex in association with a concave lens).

ii) Once corrected, such a lens is called an **achromatic lens**.

2. Reflectors.

a) Size: D = diameter of the primary mirror located at the back of the telescope.

b) Magnification: $M = f_{\rm prim}/f_{\rm eye}$.

c) The primary mirror **reflects** light to a focus.

d) There are 4 primary types of reflecting telescopes.

e) The shape of the primary must be precise to minimize **coma** and **spherical aberration**.

i) A perfectly spherical mirror will <u>not</u> focus parallel lights rays (from an object very far away) at the same point from over all the surface $\Longrightarrow$ however, **parabolic** mirrors will focus parallel light to a single point.

ii) One overcomes this spherical aberration by either grinding the mirror to parabolic shape or including a corrector plate at the front of a reflecting telescope with a spherical mirror $\Longrightarrow$ Schmitt-Cassegrain telescope.

iii) Parabolic mirrors can suffer from coma (*i.e.*, teardrop shape to a point source near the edge of the field of view) if their field of view is too large.

3. The **light bucket** concept (*i.e.*, how many photons it collects) is the most important thing about a telescope, <u>not</u> its magnifying power!

4. There are 3 powers to a telescope:

a) **Light-gathering** power (LGP) between two telescopes (labeled A and B in the equation below):

$$\frac{(\mathrm{LGP})_A}{(\mathrm{LGP})_B} = \frac{D_A^2}{D_B^2}. \qquad \text{(VI-1)}$$

b) **Resolving** power:

$$\alpha = 2.1 \times 10^5 \left(\frac{\lambda}{D}\right) \text{ arcsecs}, \qquad \text{(VI-2)}$$

$\Longrightarrow$ note that the Earth's atmosphere sets an upper limit of about 1".

c) **Magnifying** power:

$$\begin{aligned} M &= \frac{f_{\mathrm{obj}}}{f_{\mathrm{eye}}} \qquad \text{(for a refractor)} \\ M &= \frac{f_{\mathrm{prim}}}{f_{\mathrm{eye}}} \qquad \text{(for a reflector)} \end{aligned} \qquad \text{(VI-3)}$$

$\Longrightarrow$ least important power.

Example VI-1. Compare the light-gathering power and the resolving power of a 3" and the 200" telescope at 5000 Å (note that 1" = 2.54 cm and 1 Å = 10^{-8} cm).

$$\frac{(LPA)_{200}}{(LPA)_3} = \frac{(200\text{ in})^2}{(3\text{ in})^2} = \frac{40,000}{9} = 4400.$$

$$\begin{aligned} \alpha_{200} &= 2.1 \times 10^5 \left(\frac{5000\text{ Å } \times 10^{-8}\text{ cm/Å}}{200\text{ in} \times 2.54\text{ cm/in}}\right) \text{ arcsecs}, \\ &= 2.1 \times 10^5 \left(\frac{5000 \times 10^{-5}\text{ cm}}{5.08 \times 10^2\text{ cm}}\right) \text{ arcsecs}, \\ &= 2.1 \times 10^5\ (9.84 \times 10^{-8}) \text{ arcsecs}, \\ &= 0.021 \text{ arcsecs}, \end{aligned}$$

$$
\begin{aligned}
\alpha_3 &= 2.1 \times 10^5 \left(\frac{5000 \text{ Å } \times 10^{-8} \text{ cm/Å}}{3 \text{ in} \times 2.54 \text{ cm/in}} \right) \text{ arcsecs,} \\
&= 2.1 \times 10^5 \left(\frac{5000 \times 10^{-5} \text{ cm}}{7.62 \text{ cm}} \right) \text{ arcsecs,} \\
&= 2.1 \times 10^5 \; (6.56 \times 10^{-6}) \text{ arcsecs,} \\
&= 1.4 \text{ arcsecs,}
\end{aligned}
$$

5. **New Technology Telescopes** (NTT) have recently come on line.

a) **Multi-mirrored** (or multi-segmented) telescopes have been built. Allows for very large mirrors to be built $\Longrightarrow$ 10 m Keck telescope now the biggest on Earth.

b) **Adaptive optics** telescopes correct for the Earth's atmosphere *smearing* of images (remember the 1" upper limit in resolution). **Seeing** is a term used to indicate how good the angular resolution is on the sky. Adaptive optics allows for subarcsecond seeing from the ground.

C. Radio Telescopes

1. These telescopes are ground-based and observe radio waves instead of visible light.

2. Disadvantages:

a) Need a large telescope to collect enough photons to detect astronomical objects.

b) Need a whole array of telescopes to match the angular resolution of optical telescopes $\Longrightarrow$ **radio interferometer** — the VLA is an example of these types of telescopes.

3. Advantages:

a) Radio waves penetrate interstellar dust and gas → can see to the center of the Galaxy.

b) The Earth's atmosphere does not degrade the angular resolution of radio waves.

D. Space Telescopes

1. These telescopes are needed to detect regions in the E/M spectrum that do not make it to the ground.

2. Some of the more famous space telescopes:

a) Hubble Space Telescope (HST): UV, optical (telescope limited resolution), and near-IR; imaging and spectroscopy.

b) International Ultraviolet Explorer (IUE): UV spectroscopy — a very successful NASA program (it lasted 18 years even though it was designed for a 3 year lifetime).

c) Einstein: X-ray imaging and photometry.

d) Chandra: X-ray imaging and spectroscopy (this telescope was called the Advanced X-ray Astronomical Facility, or AXAF, prior to launch).

e) Infrared Astronomical Satellite (IRAS): IR imaging and photometry.

f) Spitzer (called the Space InfraRed Telescope Facility (SIRTF) prior to launch).

g) Solar and Heliospheric Observatory (SOHO): Solar imaging and spectroscopy at X-ray, UV, and visual bands; solar wind detectors; monitoring solar oscillations.

E. Instruments Used on Telescopes

1. Photographs/cameras: records positions and colors of stars, galaxies, etc. Not used much anymore.

2. CCD (Charged-coupled devices): the electronic analogy to the photo.

3. Photometers: counts the number of photons received per second.

4. Spectrographs: breaks white light into its component colors.

5. Polarimeters: send the astronomical light through a polarizing filter before recording the image. This is done to see if the astronomical object is emitting polarized light.