Observational Techniques In Astronomy

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Chapter 1

Introduction and Terms

1.1 RA/Dec co-ordinate system

We have two requirements for a co-ordinate system:

- The system needs to be well defined
- Everyone needs to use the same one to allow for collaboration

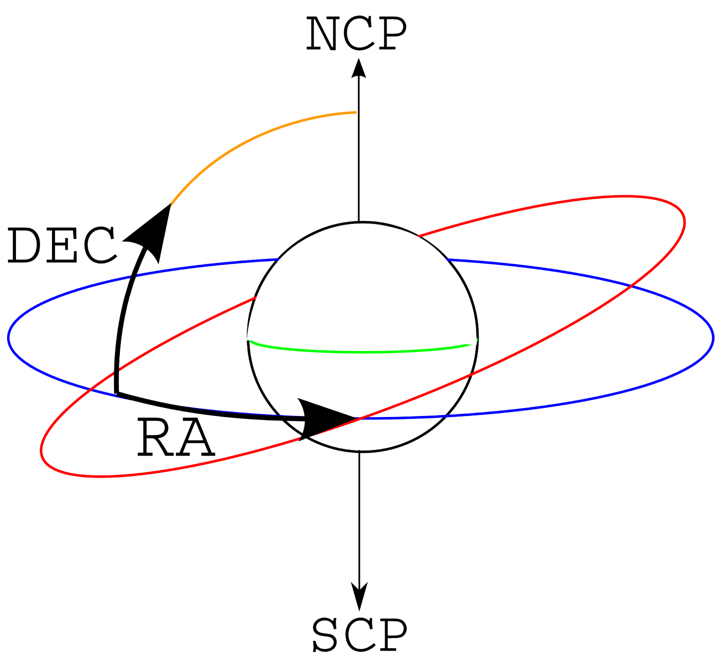


Figure 1.1: Red:Ecliptic, Blue:Celestial Equator, Green:Equator

A Siderial Day is the time between stars crossing the same line in the sky. This is an absolute earth day with respect to the stars - not the Sun! It is approx 23h56m long.

Example If a star with RA = 100° crosses a stationary telescope eyepiece at 11pm and another appears in the eyepiece an hour later, what is the RA of the second star?

Earth rotates once in 24h, so in 1h rotates 15°. Therefore the telescope now points at first star +15° = 115°!

Example Two stars seen in an image:

$$\alpha_1 = 117.397^\circ, \quad \delta_1 = 22.393^\circ$$

$$\alpha_2 = 117.384^\circ, \quad \delta_2 = 22.390^\circ$$

What is the separation in arcseconds?

Because the declination difference changes depending on the RA of each, we find that the distance is:

$$\Delta^2 = (\alpha_1 - \alpha_2)^2 \cos^2\left(\frac{\delta_1 + \delta_2}{2}\right) + (\delta_1 - \delta_2)^2$$

This gives us the distance $\Delta = 44.5$ as.

1.2 Fluxes and Magnitudes

Flux is luminosity corrected for distance:

$$F = \frac{1}{L}(4\pi r^2)$$

We define magnitude as a relative scale that is dependent on the fluxes of two objects. Normally, Vega is taken as the standard.

$$m_a - m_b = -2.5 \log\left(\frac{F_a}{F_b}\right)$$

With the naked eye, it is possible to see a maximum of 6th magnitude stars.

Example The star RR-Lyrae ranges in magnitude from 7.1 to 7.8 in 8 hours. What is the relative increase in brightess?

$$m_1 - m_2 = -2.5 \log\left(\frac{F_a}{F_b}\right)$$

$$10^{2.5(m_2 - m_1)} = \frac{F_1}{F_2} = 1.91$$

Example A binary star comprises two stars, a and b, with a brightness ratio of 2. We see them as unresolved, and the total magnitude is 5. What is the magnitude of each star?

Let's begin by pretending we have a reference star with flux F_0 and magnitude 0. We also know that the fluxes of the stars sum to make the flux of the binary system.

$$m_{a+b} - 0 = -2.5 \log\left(\frac{F_a + F_b}{F_0}\right)$$

Now, we can find F_0 in terms of the fluxes of the stars using $m_{a+b} = 5$:

$$100(F_a + F_b) = F_0$$

Again using the magnitude equation, we find m_a:

$$m_a - 0 = -2.5 \log \left(\frac{F_a}{F_0} \right)$$

Substituting in:

$$m_a = -2.5 \log \left(\frac{1}{100(1 + \frac{F_b}{F_a})} \right) = 5.44$$

We repeat for $m_b = 6.19$.

1.2.1 Absolute magnitude

Asbolute magnitude (M) is found by 'placing' the stars 10 pc away and 'measuring' it's magnitude. We do this mathematically with:

$$M = m + 5 \left(1 + \log \left(\frac{d}{10} \right) \right)$$

1.3 Geometrical Optics

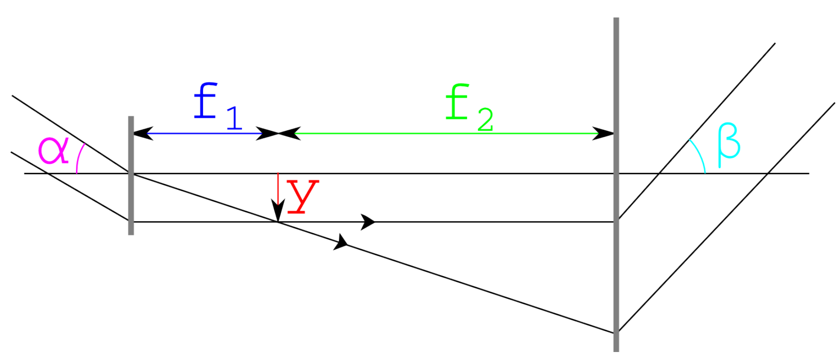
This is the thin lens equation for convex (converging) lenses:

$$\frac{1}{f} = \frac{n-1}{R_1} + \frac{n-1}{R_2}$$

For concave lenses, we have that:

$$\frac{1}{f} = \frac{-2}{R}$$

Example A gun sight is designed to view a distant object at 9x magnification. If the overall length, L, is 10 cm, suggest values of f_1 and f_2 where the cross-hair should be placed.



We have that:

$$\tan\alpha = \frac{y}{f_1} \approx \alpha$$

$$\tan\beta = \frac{y}{f_2} \approx \beta$$

$$f_1 + f_2 = 10 \text{ cm}$$

Since the image is at infinity, we define an angular magnification:

$$M = -\frac{\beta}{\alpha}$$

We know that:

$$\beta = -9\alpha$$

And as such we can find taht:

$$\frac{\alpha}{\beta} = \frac{f_2}{f_1}$$

and that $f_2 = 1$ cm, $f_1 = 9$ cm.

1.3.1 f-ratio

The f-ratio is the focal length over the diameter: f/D. Telescopes with a low f ratio, e.g. $f/1$, are faster (they take less time to collect the same amount of light on the sensor).

1.3.2 Effective focal length

The effective focal length is the focal length of the whole compound lens system if they were replaced with a single large lens. We always give telescope sizes in diameters rather than in radii.

1.3.3 Refracting and reflecting telescopes

Even though the discussion this far has been on refracting telescopes, they are seldom used. This is because refracting telescopes need a very long focal length to be abberation-free, and large lenses are very difficult to make as well as support. Reflecting telescopes, however, are more common because it is easier to design them and they are much 'faster'. We must make the mirror in a reflecting telescope *parabolic* rather than circular to prevent abberation.

1.3.4 The plate scale

We define the plate scale as:

$$\frac{\mathrm{d}\theta}{\mathrm{d}s}.$$

From the small angle approximation:

$$s = f\theta$$

The plate scale gives us the number of arcseconds per milimeter that is observed on the detector.

Example: We want a field of view of 1'x1'. We have an 8m telescope with a detector of 128x128 px, with each pixel being 100 μm across.

1. What is the plate scale in arcseconds/mm?
2. What should the focal length be to achieve this plate scale?

1. The physical size of the detector:

$$128 \times 100 = 12.8 \text{ mm}.$$

   As such we have the plate scale:

$$\frac{\mathrm{d}\theta}{\mathrm{d}s} = \frac{60}{12.8} = 4.7 \frac{"}{\text{mm}}.$$

2. From above:

$$\frac{\mathrm{d}\theta}{\mathrm{d}s} = \frac{1}{f}\, rightarrow\; f = 43.9 \text{ m}.$$

1.3.5 Limitations

We are not really limited by the number of pixels that we can have on a detector, we can have pretty much as many as we want now. However, we are limited by the defraction limit of the telescope. When we take an image of a point source through a circular apeture, we get an airy disk: With small telescopes, it is hard to resolve individual points that are close together

because the airy disks overlap.

Rayleigh's Criterion sates that we can resolve two objects if the primary maximum of one overlaps with the first maximum of the other.

For circular apetures, the angular resolution is:

$$\theta_{dl} = \frac{1.22\lambda}{D}$$

Example: What are the basic properties of an $f/10$, 10" telescope?

- Focal length:
$$F/\# = \frac{f}{D} \;\rightarrow\; 10 \times 10 \times 2.54 = 254\text{cm}$$
- Plate scale:
$$\frac{\mathrm{d}\theta}{\mathrm{d}s} = \frac{1}{f} = \frac{1}{254} = 0.22\,^{\circ}/\text{cm}$$
- Light gathering power compared to eye:
$$\text{LGP} = \frac{25.4^2}{0.12^2} = 4.4 \times 10^4$$
- Resolving power:
$$\theta = 1.22\frac{\lambda}{D} = 0.5\text{"}$$

1.4 The Atmosphere and Detectors

The atmosphere is a right pain. It causes:

- Absorption
- Refraction and dispersion
- Emission
  - Thermal
  - Rayleigh scattering
  - Flourescent emission
- Turbulance (twinkle)

1.4.1 Correcting for atmospheric absorption

We have that:
$$m_{corr} = m_{obs} - A_\lambda \sec z$$
Where A_λ is the number of air volumes you're looking through, and z is the angle with respect to straight up.

1.4.2 Atmospheric refraction

This is what causes the 'green flash'. The angle that the light is refracted by, r, is given by:
$$r = (n-1)\tan(z)$$
Where z is the same as above. This means that any object that is not directly above us shows a spectrum (n varies by colour).

1.4.3 Atmospheric emission

We see very bright emission lines from OH in the upper atmosphere, as they transfrom between rotational and vibrational energy levels. These are mainly in the infa-red, however we really want to look in the IR - so we just ignore it and build telescopes anyway. Most of the IR comes from the heat of the telescopes themselves and as such we need to keep them very cool. We want to observe in the IR because it allows us to see through the dust in the center of our galaxy.