[Techniques of Observational Astronomy AST3722C]

The Effect of the Earth's Atmosphere

Introduction

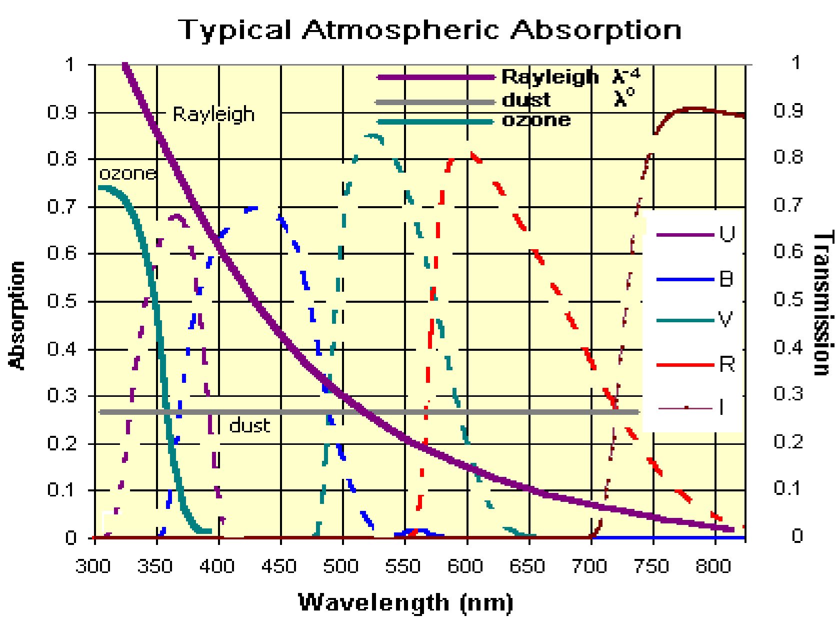
Ground based astronomy is heavily influenced by the Earth's atmosphere. In addition to the interruption of observations by clouds, the atmosphere affects the wavelengths that can be observed, the resolution that can be achieved, the accuracy of position and brightness measurements, and it introduces lines (both absorption and emission) into spectra.

Absorption and Scattering

Extinction

Absorption and scattering in the Earth's atmosphere is usually called (by astronomers) extinction. There are three main sources:

1. molecular scattering: This is Rayleigh scattering and thus goes as 1/lambda^4
2. scattering by dust and aerosol particles (haze): essentially wavelength independent
3. molecular band absorption: Ozone cuts off the UV, oxygen and H2O bands show up in the IR beyond 7000Å



The plot shows typical curves for Rayleigh, dust, and ozone absorption as well as the passbands for the frequently used U (ultraviolet), B (blue), V (visual), R (red), and I (infrared) astronomical filters. The actual amount of absorption depends on how much atmosphere is in the beam (airmass). Note that in the blue and especially in the ultraviolet the potential for loss is very high. Ultraviolet observations from low altitude observatories are usually not useful. Note also that the absorption in the V (yellow-green region of the spectrum), and the R and I , is dominated by aerosols independent of wavelength.

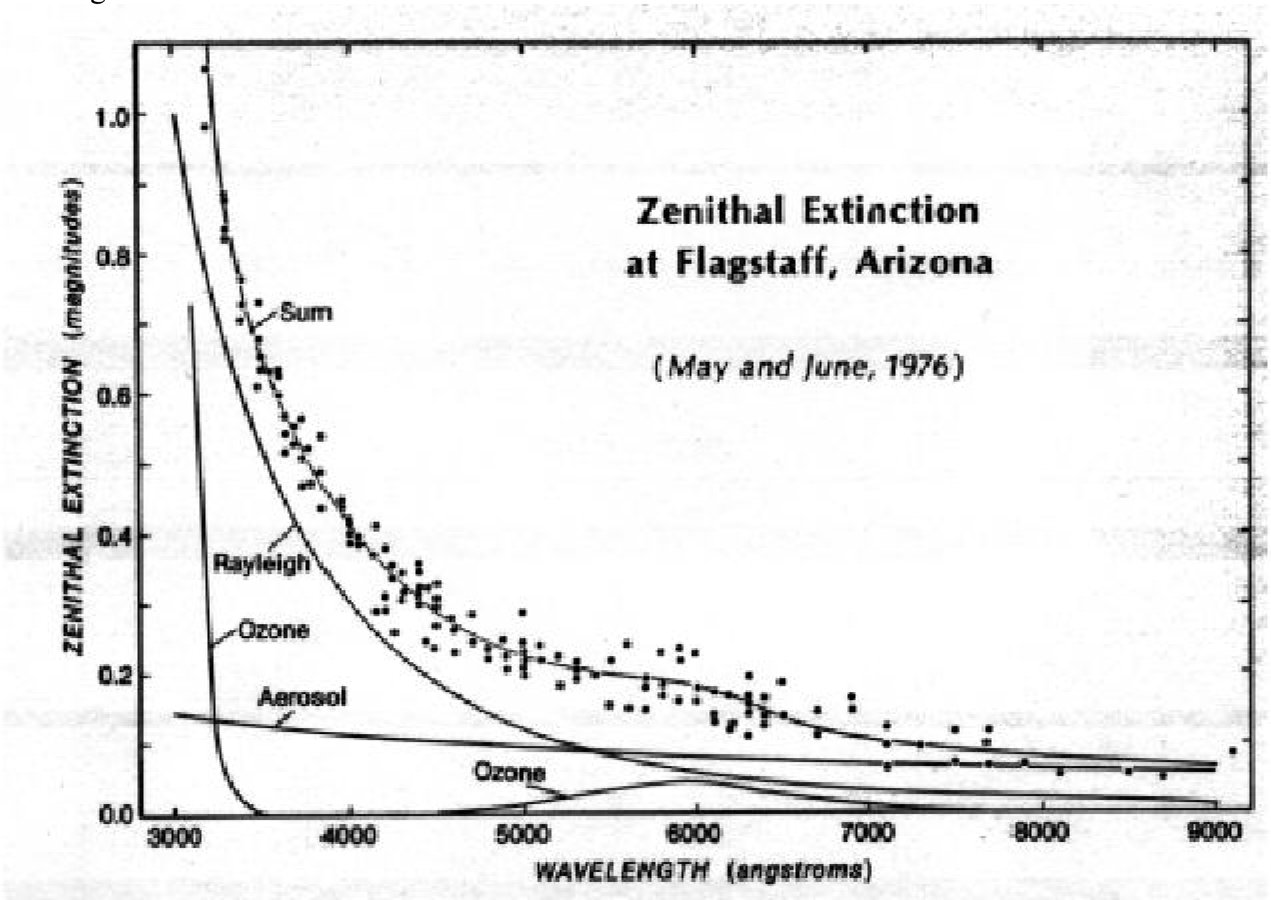
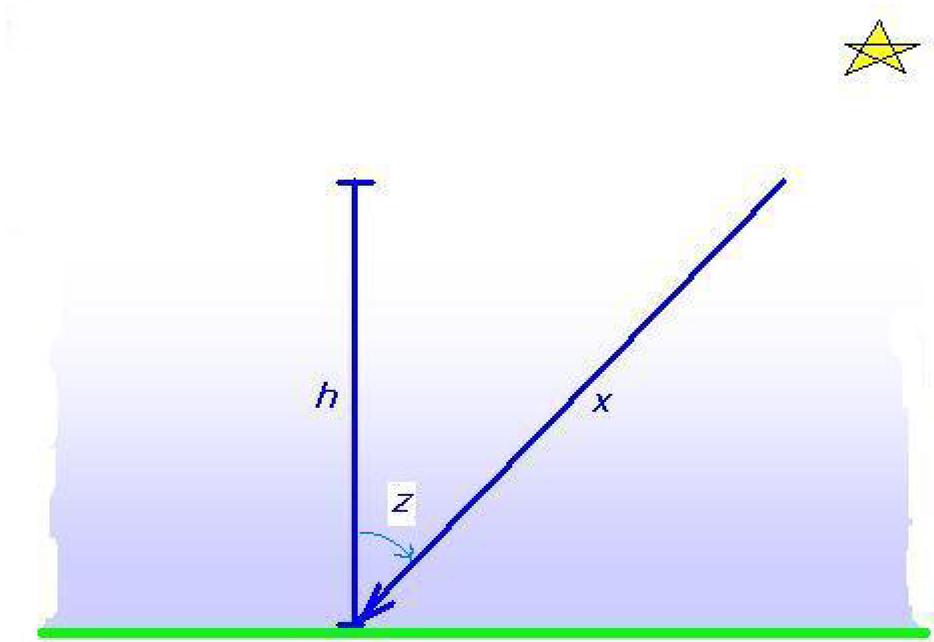


Figure 18.1: Extinction at Flagstaff, showing components of extinction. (from "A New Absolute Calibration of Vega" Sky and Telescope Oct 1978)

Typical extinction at the zenith (magnitudes per airmass):

Site	U	B	V
Kitt Peak National Obs.	0.50	0.25	0.15
Rosemary Hill Obs.	0.69	0.38	0.22



Airmass

When we look at a star, the total extinction will be a function of the atmosphere through which we are observing. For a first approximation we will assume a plane parallel stratified atmosphere. The total path length x is usually computed in units of the path length at the zenith h (the airmass). For a plane parallel atmosphere, the relation is $x=h$ *secant(z)*, usually termed "secZ", where z is the zenith angle or zenith distance. The thickness h can be set to unity ("one airmass" at the zenith) so $x=sec(z)$. The plane parallel approximation is sufficient for most purposes for z < 60°. Beyond 75° it is necessary to use a more accurate model. Romanishin gives an approximation formula (where z is the apparent, not true, zenith distance):

X = secz - 0.0018167 (secz - 1) - 0.002875 (secz - 1)** 2 - 0.0008083 (secx - 1)**3

Refraction

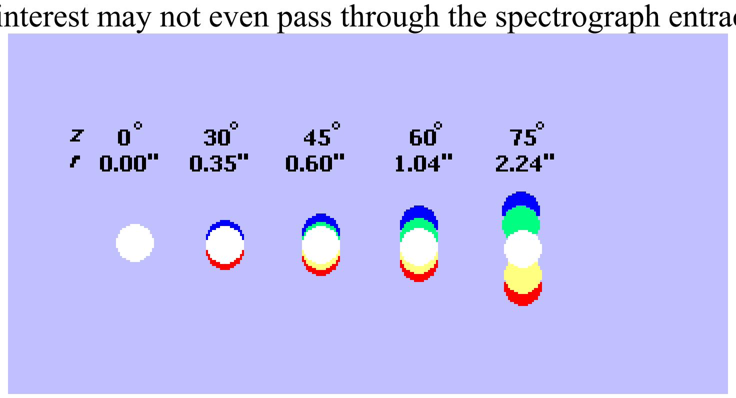
The atmosphere refracts (bends) the path of light rays passing through it. This has the effect of changing the direction at which the telescope must be pointed (usually a minor effect), and causing objects (especially point sources such as stars) to change rapidly in apparent size and location ("seeing" and "scintillation"). Assuming a plane-parallel stratified atmosphere, each layer with a differing index of refraction, uniformly increasing towards the surface, we can use Snell's Law to find the angle of refraction, r, to be approximately $r = 60.4 \tan z_{tr}$ where z_{tr} is the true zenith distance. The apparent zenith distance can be found by $z_{ap} = z_{tr} - r$. Note that the effect of refraction is to reduce the apparent zenith distance as one looks closer and closer to the horizon. The result that a setting object appears to slow down in its diurnal motion as it sets (thus setting two or more minutes later than might be expected) and an extended object (e.g. the sun or moon) will appear flattened when viewed near the horizon.

This image also illustrates the effect of dispersion which may result in the "green flash" visible for a brief instant at the upper limb of the sun.

Second Order Effects of the Atmosphere

Dispersion

Dispersion is the variation in refraction as a function of wavelength. A star viewed at a large zenith distance may appear elongated by this effect. The figure illustrates what may be seen where z is the zenith angle and r is the seperation between the blue and red images (the assumed star size here is 1"). Clearly this effect can become a problem for astrometry (position measurement) as well as spectroscopy where some of the wavelengths of interest may not even pass through the spectrograph entrace aperture.



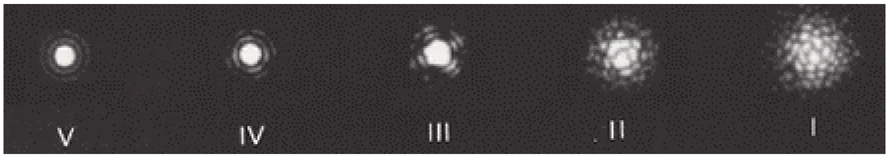
Tracking Rate

Because refraction is a function of zenith distance, a star's diurnal motion will vary with time. For precise tracking telescopes must compensate for this variation. Edward Skinner King developed an algorithm for such compensation which results in the King Tracking Rate:

$$K = 1436.07 + 0.40\left[\frac{\cos\phi(\cos\phi\cos\delta + \sin\phi\sin\delta\cos t)}{\cos\delta(\sin\phi\sin\delta + \cos\phi\cos\delta\cos t)^2} - \cot\phi\tan\delta\cos t\right],$$

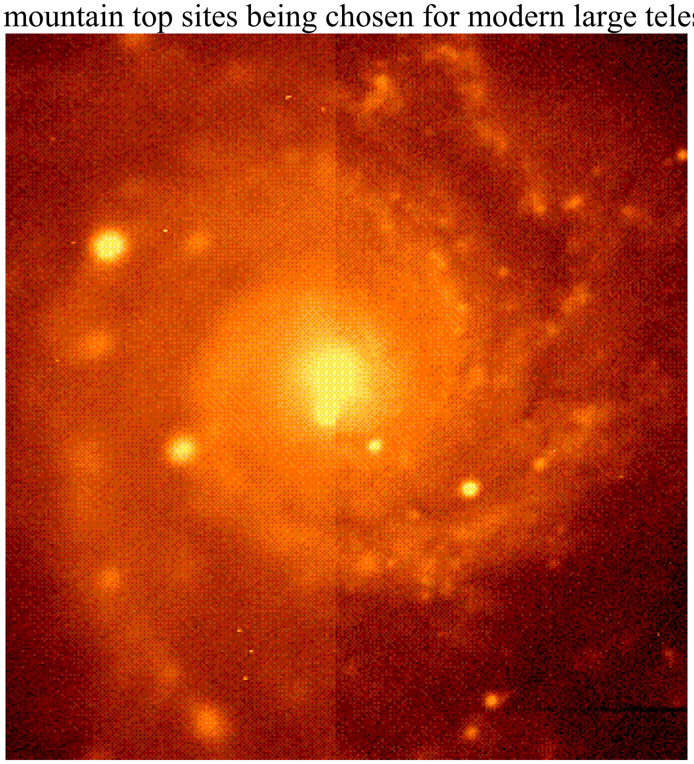
where *K* is the tracking rate in minutes of (solar) time per revolution, δ is the declination, ϕ is the latitude, and *t* is the hour angle.

Seeing and Scintillation

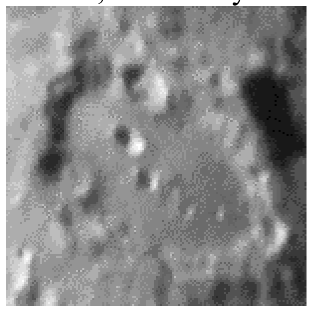


The Earth's atmosphere is not, of course, a quiescent plane-parallel ideal region. It is, in fact, a turbulent mix of gasses, always in motion. Because the index of refraction varies with tempurature and pressure motions in the atmosphere result in variations in refraction of the light passing through. This results in rapid fluctuations in the apparent brightnesses of stars (scintillation), and motions in the apparent positions or variations in the apparent sizes of stars (seeing).

This image of a swimming pool illustrates the effect of ripples (equivalent to density variations) on the transmission of light. The effects of seeing and scintillation ultimately limit the resolution of conventional ground based telescopes and are the reason for carefully selected mountain top sites being chosen for modern large telescopes.



A demonstration of the effects of astronomical seeing, the atmospheric turbulence which is the bane of most kinds of optical observations from the ground. This frame compares M74 (NGC 628) as observed on night with different seeing blurs. Improved seeing leads to a dramatic increase in the detectability not only of starlike objects (mostly bright clusters and associations in M74), but to greatly improved resolution of fine detail such as dust structures. (Photo from Bill Keel, University of Alabama)



A movie of the crater Clavius showing the effect of seeing. This image is © Philipp Salzgeber

Another set of notes on seeing
Here is a site that predicts seeing in North America

References

Henden et al., *CCD Photometry*, April 11, 1999; Ch. 4 (on class CD-ROM)
Romanishin, *An Introduction to Astronomical Photometry Using CCD's*, August 23, 2000; Ch. 7-10, 18 (on class CD-ROM)

Interesting Links

Many interesting atmospheric effects (rainbows, halos, etc.) are illustrated and discussed at a site run by Les Cowley

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