Astronomical Techniques

Lecture 3

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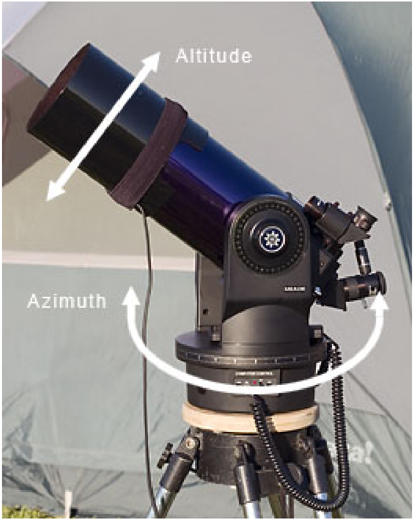
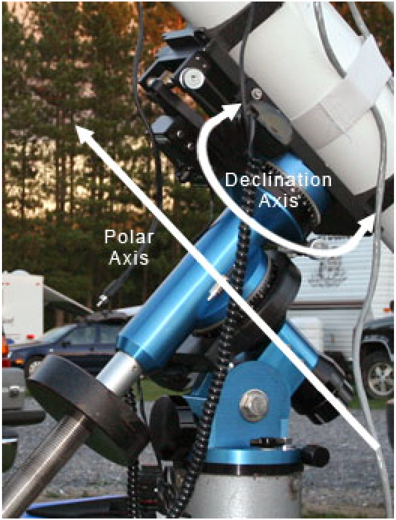
Assignment 1

Altazimuth mount

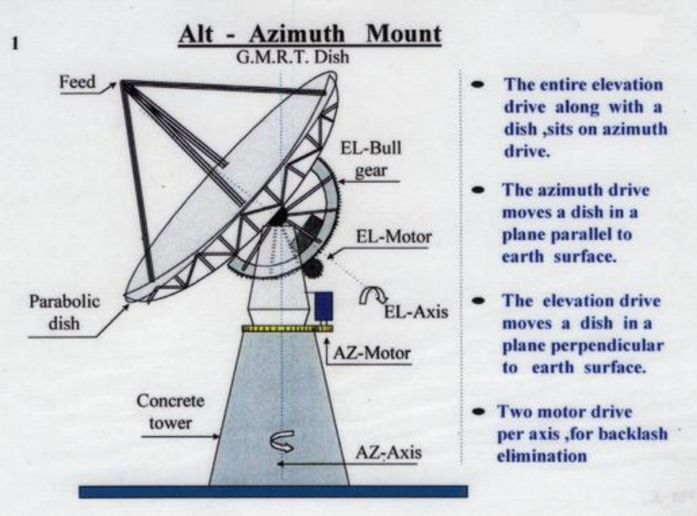


Dobsonian mount

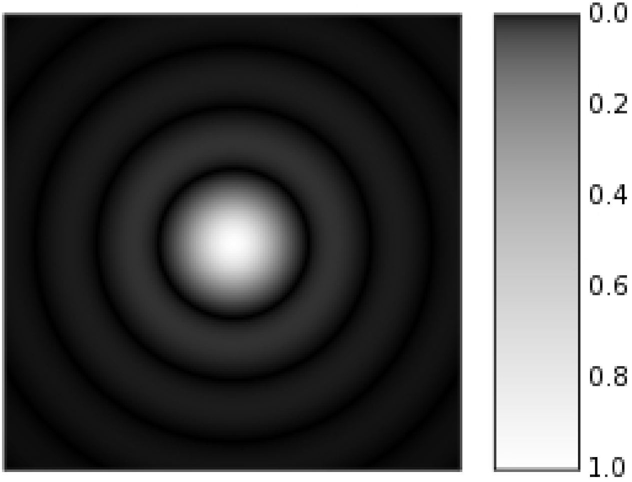
Equatorial mount



Most modern telescopes use altazimuth mounts



Fundamental limit on resolution - diffraction (Airy disk)



$\sin \alpha_n = m_n \lambda / D$

Effects of the atmosphere on incoming radiation

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- atmospheric turbulence affects wavefronts

Refraction and dispersion

Refractive index η of air at sea level at 15 degrees Celsius:

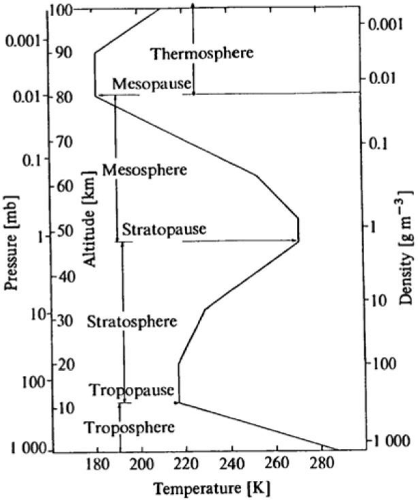
$$(\eta - 1) \times 10^8 = 8342 + \frac{2.4 \times 10^6}{130 - \lambda^{-2}} + \frac{1.6 \times 10^4}{40 - \lambda^{-2}}$$

where λ is in microns.

- changes position, important in high resolution (eg. adaptive optics) observation
- because $\eta = f(\lambda)$, refraction corrections depend on zenith angle and λ (called *chromatic* refraction correction.

Green flash

Temperature/Pressure/Density in the lower atmosphere



Sources of atmospheric attenuation

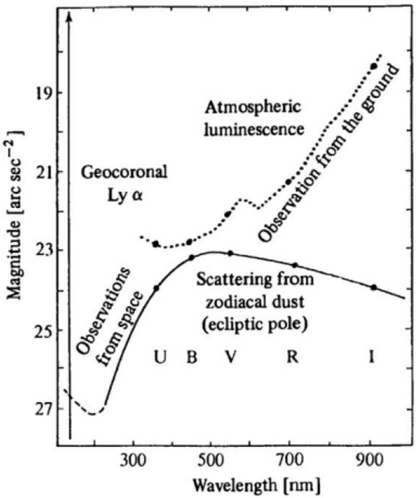
- molecular: rotational, rotational-vibrational, electronic
- atomic: electronic

atomic and molecular physics allows for the calculation of absorption coefficients and cross-sections of the various transitions for the various atmospheric species. Telluric bands can severely affect infrared spectroscopy.

Sources of atmospheric emission

- flourescense (airglow) at $\sim$100 km altitude caused by
  - recombination of ions which were photoionized by the sun during the day
  - luminescence caused by cosmic rays striking the upper atmosphere
  - chemiluminescence caused mainly by oxygen and nitrogen reacting with hydroxyl ions at heights of a few hundred kilometers.
- below 60 km, atmosphere is dense enough that collisions are frequent to keep it in local thermodynamic equilibrium, therefore thermal emission.

Emission dependence on wavelength



Advantage of space based optical observatory!

Question

Why is thermal emission from the atmosphere not much of a concern at optical wavelengths?

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has contributions from

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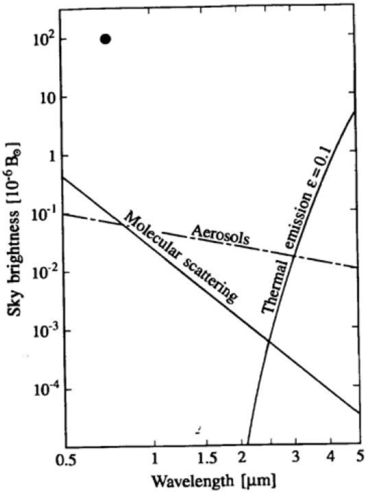
1. air molecules cause elastic scattering of photons (Rayleigh scattering) $\propto \lambda^{-4}$
2. aerosols - content and concentration depends on winds, industrial pollution, volcanic eruptions, and is therefore very difficult to model. Particles are much larger than molecules. So, Mie theory applies. For details see: *Light scattering by small particles* by van de Hulst.

Question

Telescope time allocation commitees like to give dark time to optical observations and bright time to infrared observations. Why?

Scattering dependence on wavelength



Daytime observations at sub mm. wavelengths routine.

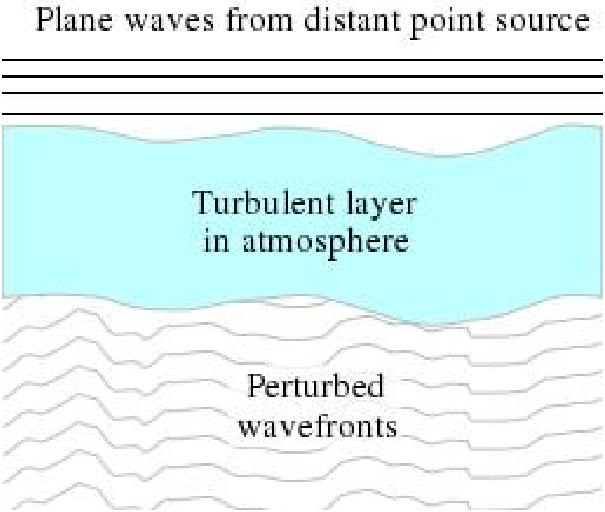
Modeling atmospheric absorption and emission - MODTRAN

The MODTRAN5 software (developed by the US airforce in collaboration with a private company) is the state-of-the-art atmospheric band model radiation transport model. The software implements a correlated-k algorithm which facilitates accurate calculation of multiple scattering. This permits MODTRAN5 to act as a 'true Beer-Lambert' radiative transfer code, with attenuation/layer having a physical meaning. More accurate transmittance and radiance calculations will greatly facilitate the analysis of hyperspectral imaging data. The other major addition to MODTRAN has been to provide sets of Bi-directional Radiance Distribution Functions (BRDFs) that permit the surface scattering to be other than Lambertian. The combination of correlated-K and BRDFs has greatly improved the scattering accuracy, as has the implementation of azimuthal asymmetries.

The turbulent sky as seen by the Infrared Sky Camera

Show video

Effect on plane wavefronts

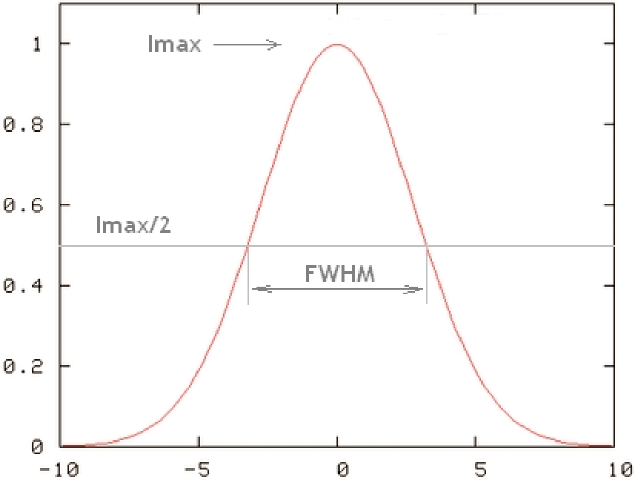


characterised by Fried parameter r_0 (5-20cm) and timescale t_0. Details gory - Kolmogorov (1941) theory of turbulence.

Question

Plot telescope resolution versus telescope size if Fried parameter is r_0
In adaptive optics systems r_0 determines the spacing between actuators and t_0 the frequency of wavefront correction.

Gaussian like Point Spread Function

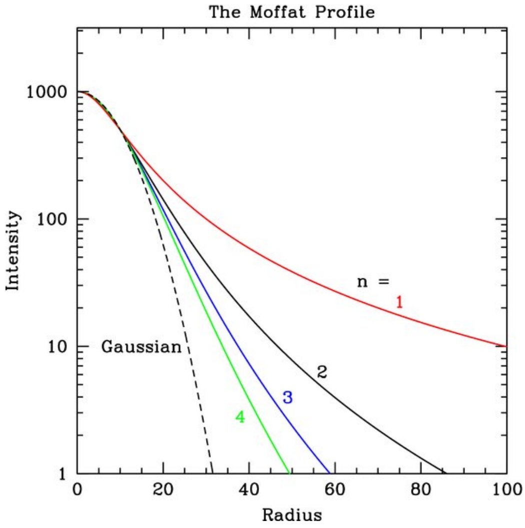


The Moffat function for nuclear source and PSF

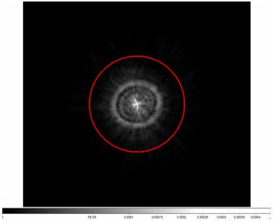
$$\Sigma(r) = \frac{\Sigma_0}{[1 + (r/r_d)^2]^n}$$

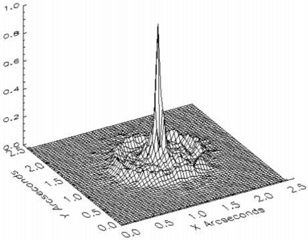
r_d is related to FWHM and n=4.765 (for ground based observations)Why?. For $n \to \infty$ it becomes a Gaussian.

The Moffat profile



The Point Spread Function - Diffraction





How large is the atmospheric deterioration?

At Mauna Kea, where the 10 m Kecks are located the median FWHM of the see ing disc is 0.8 arcsec at 500 nm. How does this compare with the Airy disk for this telescope?

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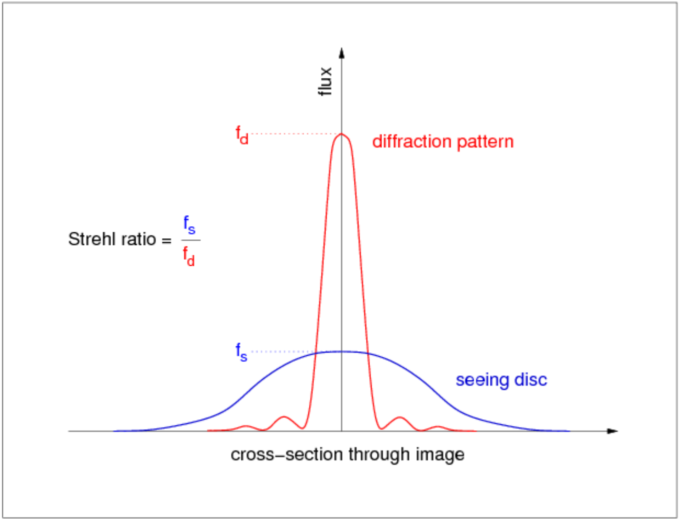
Therefore, Adaptive Optics!

How adaptive optics works

Show video

How to quantify improvement due to adaptive optics?



Parent Distributions

Measurement of any physical quantity is always affected by uncontrollable random ('stochastic') processes. These produce a statistical scatter in the values measured. The parent distribution for a given measurement gives the probability of obtaining a particular result from a single measure. It is fully defined and represents the idealized outcome of an infinite number of measures, where the random effects on the measuring process are assumed to be always the same ('stationary').

Systematic versus stochastic

In general, the effects of systematic errors are not manifested as stochastic variations during an experiment. In the lab, for instance, a voltmeter may be improperly calibrated, leading to a bias in all the measurements made. Examples of potential systematic errors in astronomical photometry include a wavelength mismatch in CCD flat field calibrations, large differerential refraction in Earth's atmosphere, or secular changes in thin clouds.
The statistical infrastructure we will discuss in this course here does not permit an assessment of systematic errors. Those must be addressed by other means.

But systematics can be important - high precision, low accuracy

The primary mirror for the Hubble Space Telescope was figured with high precision (i.e. had very small surface features much smaller than a wavelength of light), but it was inaccurate in that its shape was wrong.

The central problem

How to make accurate flux measurements with a precision or SNR appropriate to the scientific goals given the practical constraints?

Non-stochastic effects on number of photons received

per unit time, per unit area, from a unit solid angle of sky per unit wavelength/frequency

- *Interstellar extinction* depends on dust grain column density in direction of source
- *Atmospheric extinction* depends on total atmospheric path length ($\propto \sec Z$, where Z is the angular distance to the zenith)
- *Atmospheric refraction* Prismatic effect of differential refraction for $Z > 0$ causes elongation/chromatic separation of sources
- *Atmospheric turbulence* (seeing) Causes blurring and jitter of images
- Absorption/scattering by optical surfaces Reflecting and refracting surfaces and transmitting media destroy a fraction of photons incident on the telescope aperture.

The discussion today focuses on UVOIR observations made with detectors based on the photoelectric effect.

Major contributors to stochastic noise

1. Photon noise
2. Background noise
3. Measuring process noise
4. Other sources of noise