

Introduction to Optical Observations

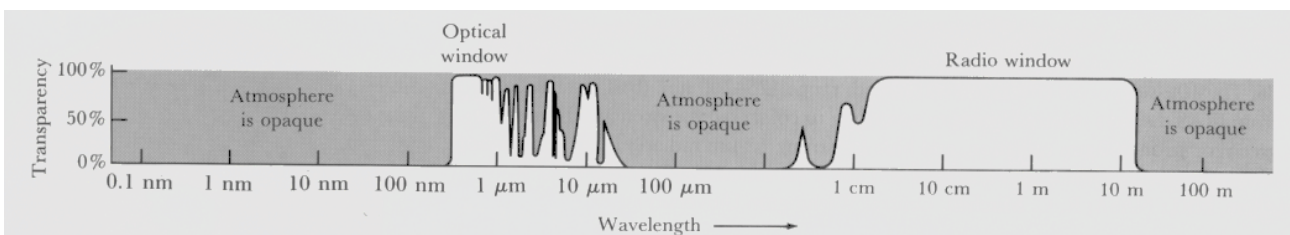
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The optical regime

- $\lambda \sim 300 - 900 \text{ nm}$.
- $\nu \sim 3 \times 10^{14} - 1 \times 10^{15} \text{ Hz}$.
- Photon energy $\sim 1 \text{ eV}$.

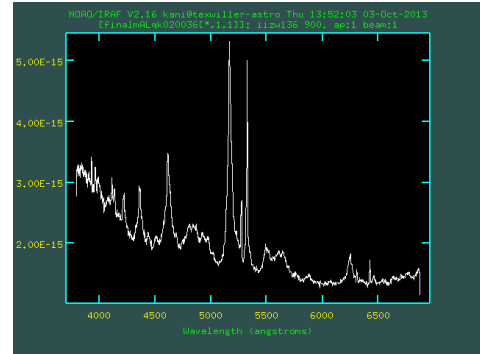


Optical techniques

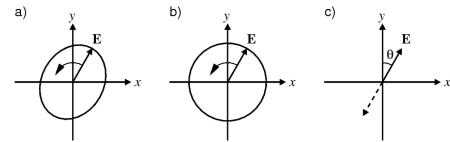
Imaging : Find out object structure, new objects (surveys), positions of objects (astrometry), target brightness (photometry), etc.



Spectroscopy : Find out the energy distribution of the object and/or brightness variations.

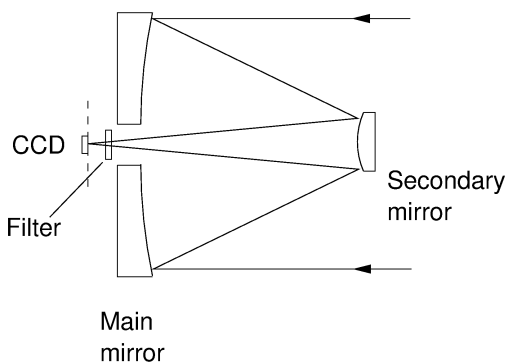


Polarimetry : Find out the polarization state of object light.

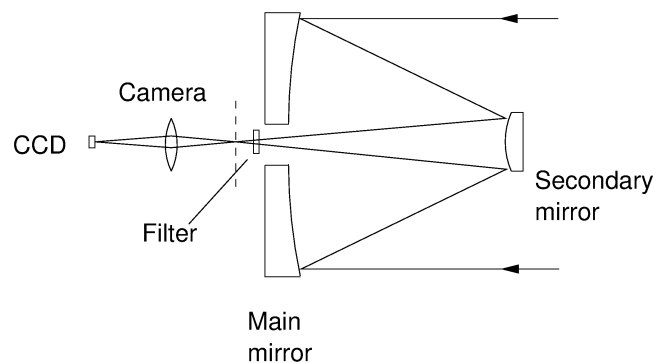


Imaging

Use the telescope to collect light and focus it onto the *focal plane* (dashed line below).

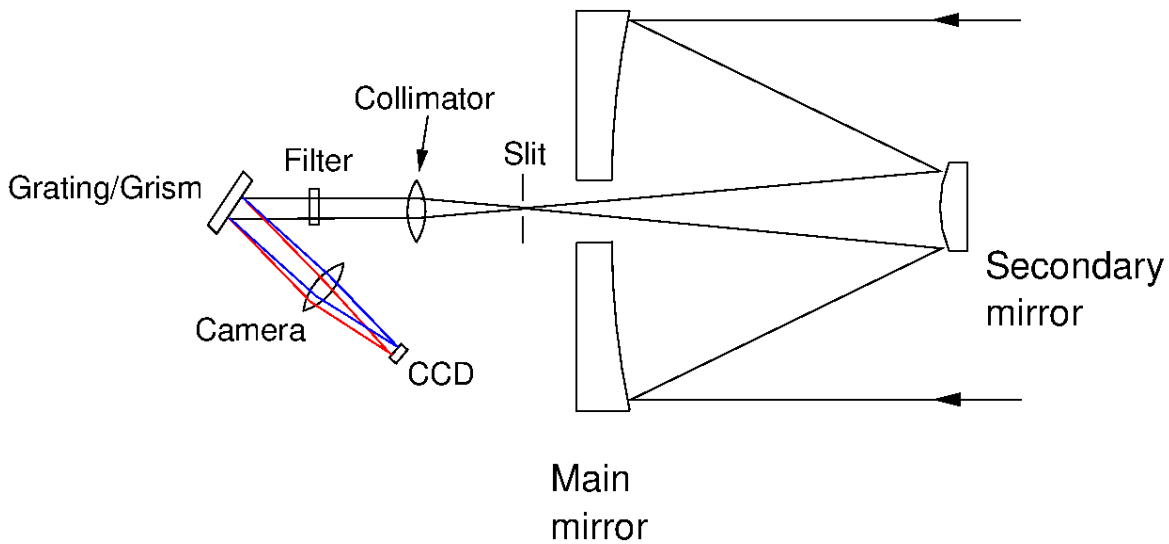


CCD directly at focal plane,
e.g. StanCam @ NOT.



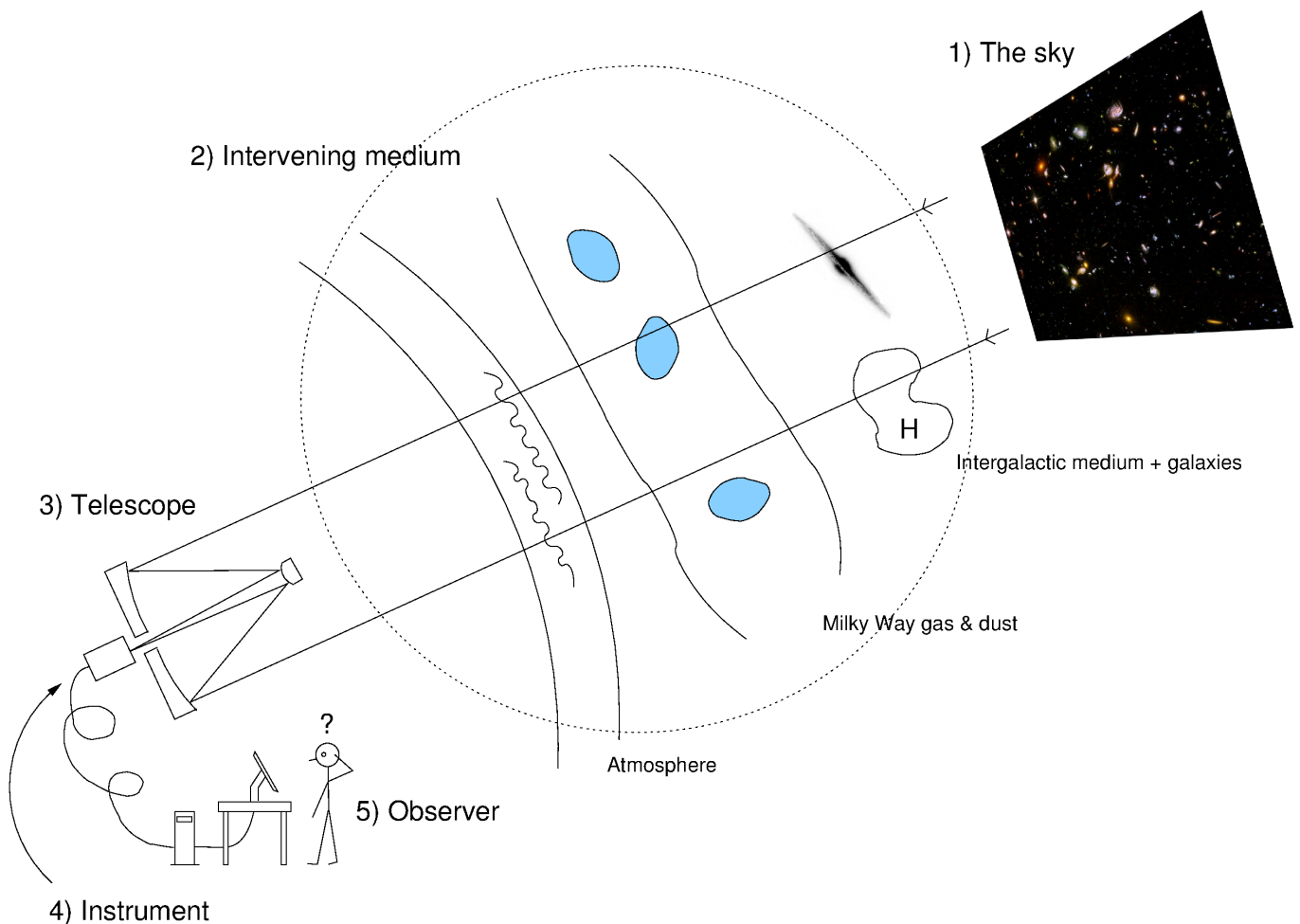
Re-imaging optics (camera),
e.g. ALFOSC @ NOT.

Spectroscopy



- Collimator:** Make the rays parallel.
- Filter:** Remove unwanted wavelengths.
- Grating:** Disperse the light into colors.
- Camera:** Re-image the rays onto the CCD.

From target to observer



1) The sky

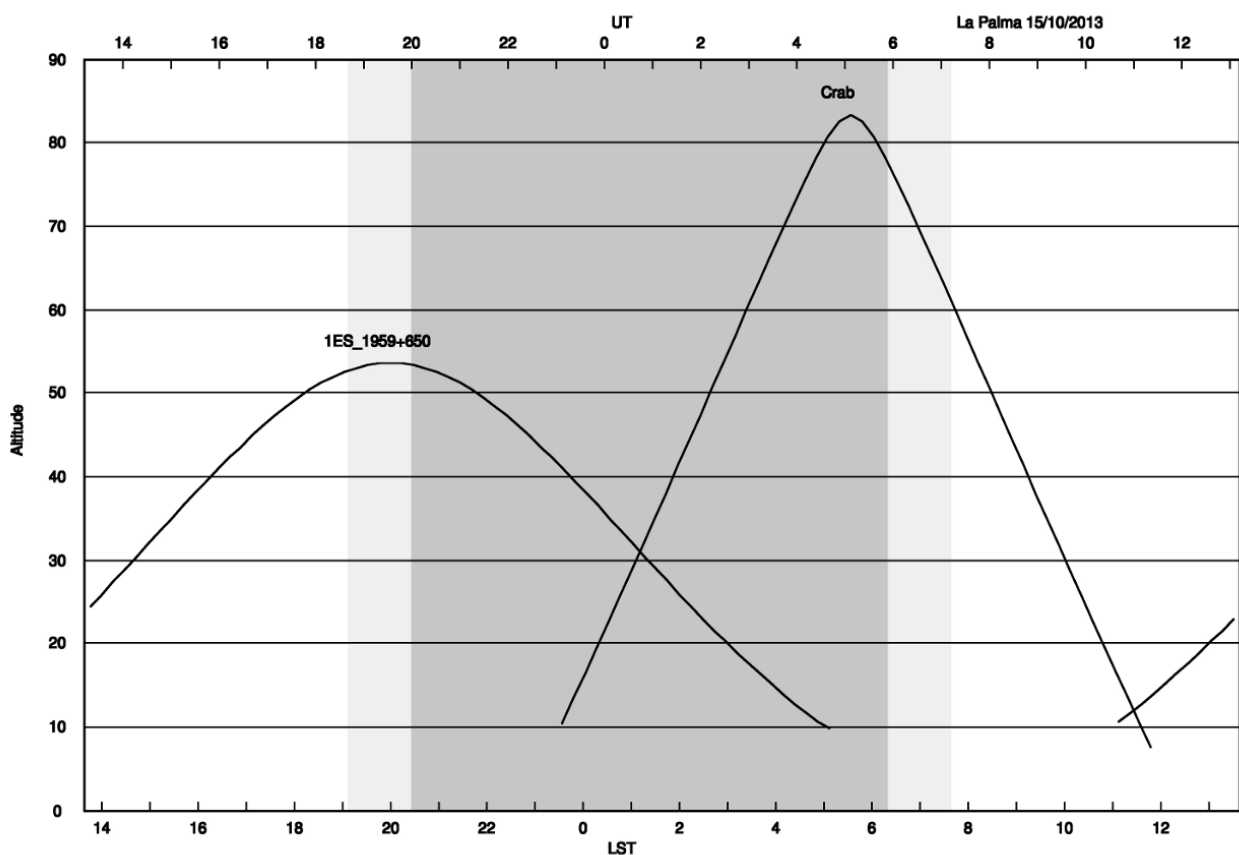


- Targets rise from the East, reach the highest point in South and set to the West. Exception: circumpolar targets, which never set.
- As the night advances, progressively higher right ascensions become visible.
- Local Siderial Time (LST) gives the RA currently at meridian (South).
- **During the year** different RA ranges are visible during the night. This means that a given target is visible during part of the year only.

Preparations before observations (or even before applying)

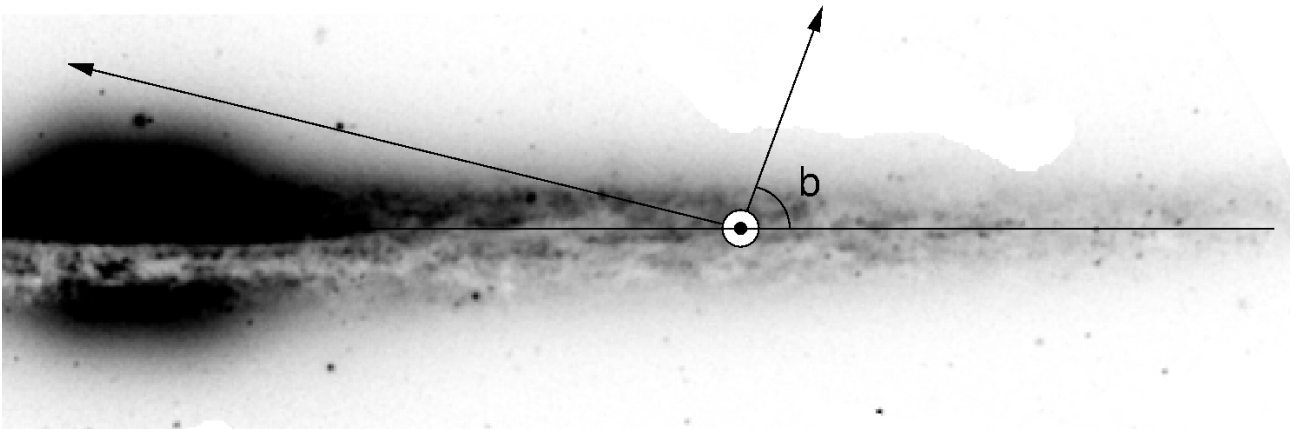
- Make a list of target coordinates, selecting only targets which are visible during the time of year your observations are scheduled.
- Make a *visibility plot* of your targets.
- Check for possible Moon influence (e.g. Stellarium).
 - Dark time: < 4 days from new moon.
 - Grey time: 4-10 days from new moon.
 - Bright time: close to full moon.

Visibility plot

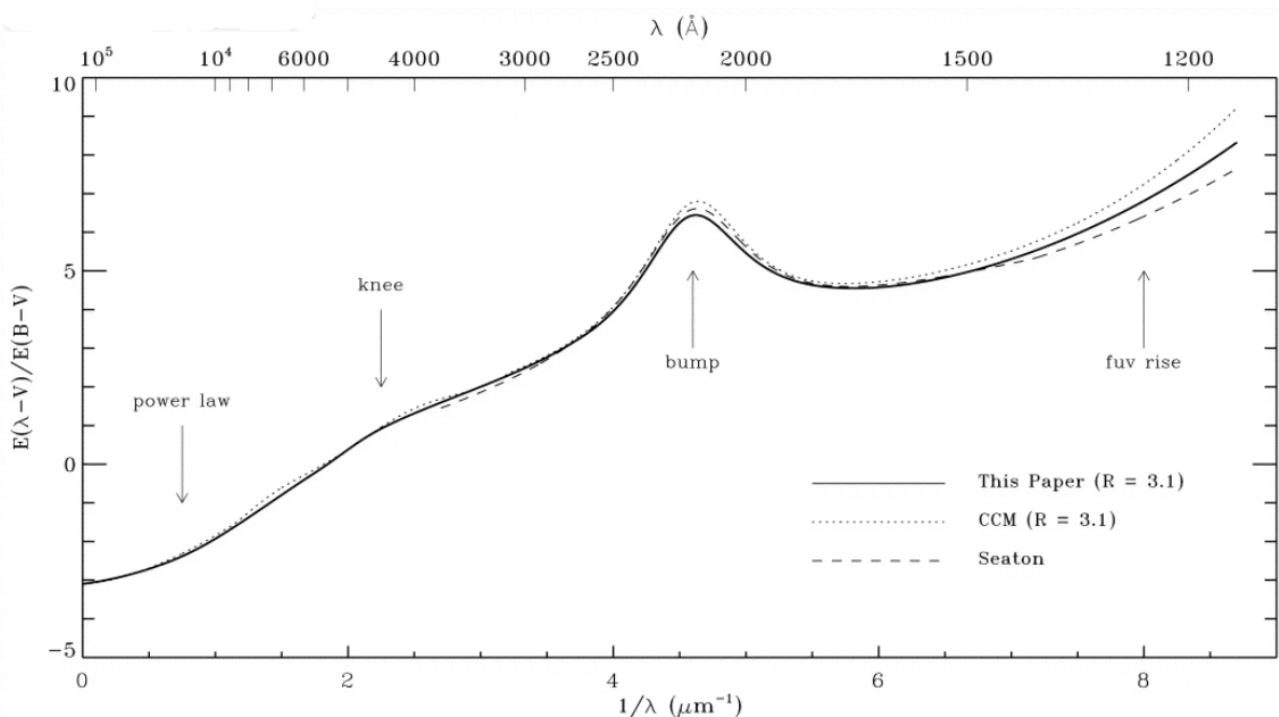


2) Intervening medium: The Galaxy

- The gas and dust in the Milky Way disk absorb light of extragalactic targets. This is called *galactic extinction*.
- The extinction is strongest at small galactic latitudes b and decreases towards the direction perpendicular to the plane (high b). The extinction is not smooth, but very patchy and irregular.



- Galactic extinction is a very strong function of wavelength with blue wavelengths more strongly absorbed \rightarrow targets appear fainter and “redder” than what they truly are.



2) Intervening medium: Atmosphere

The atmosphere

- a) generates the unpredictable phenomenon called weather
- b) absorbs and scatters light
- c) refracts incoming light rays
- d) increases the background due to emission and scattering
- e) decreases resolution due to turbulence.

The strength of most effects depends on the zenith distance z and wavelength λ .

a) The weather

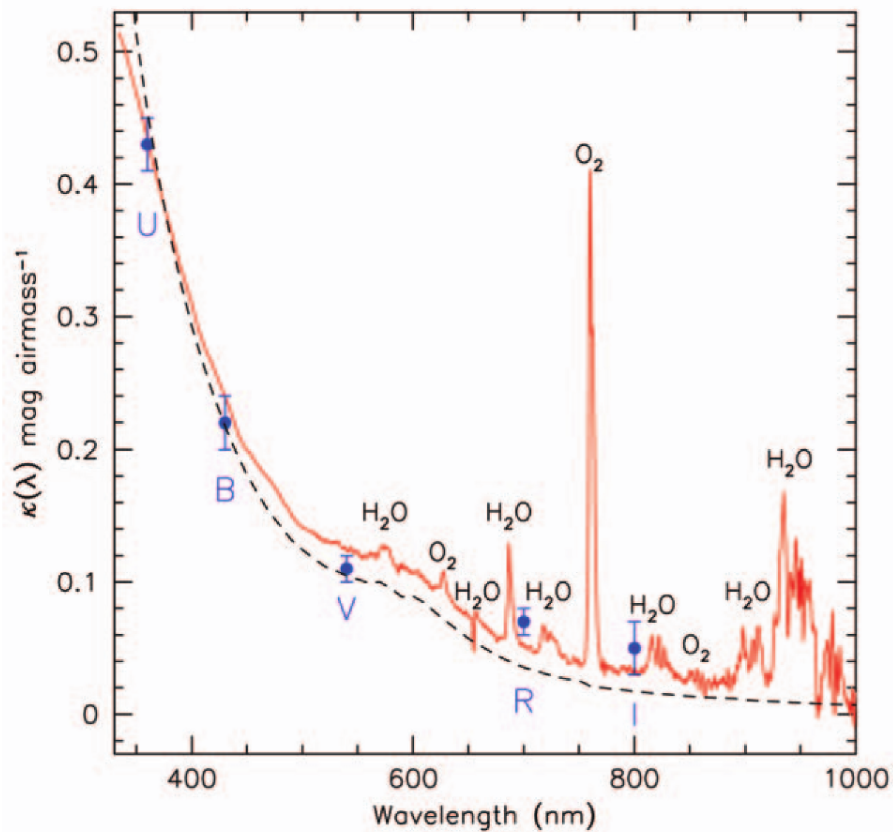
Ground-based astronomy is on the mercy of the weather, since observations are impossible e.g. through thick clouds.

Photometric weather = no clouds or dust in the air, i.e. the transparency of the atmosphere is stable.

Even on clear nights observations may be impossible due to limits set by the observatory for relative humidity, wind, dust and temperature.

Humidity	Wind	Dusty Wind	Temperature
> 90% - Close telescope	12 m/s - Close sideports and lower hatch	10 m/s - Close sideports and lower hatch	If the humidity is > 90% and the temperature is < 0° C close telescope and do not open until all ice has melted on the outside of the dome.
After 20min < 90% the telescope can be reopened.	15 m/s - Observe down wind	12 m/s - Close telescope	
	20 m/s - Close telescope		

b) Absorption and scattering: λ -dependence



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Absorption and scattering: z -dependence

The absorption and scattering by the atmosphere causes the target to appear fainter, which is called *atmospheric extinction*.

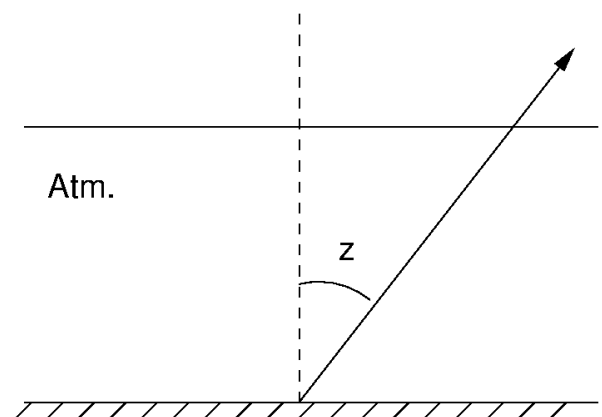
When expressed in magnitudes the extinction is

$$A_\lambda = k_\lambda * X,$$

where k_λ is the *extinction coefficient* and X is the *airmass*, which can be computed from

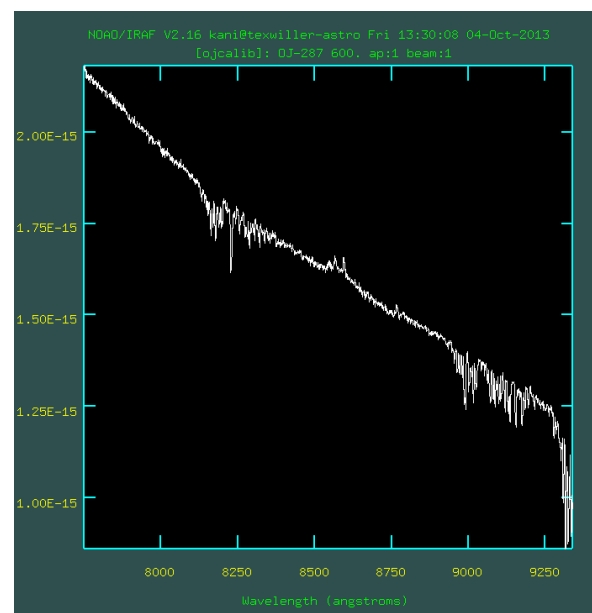
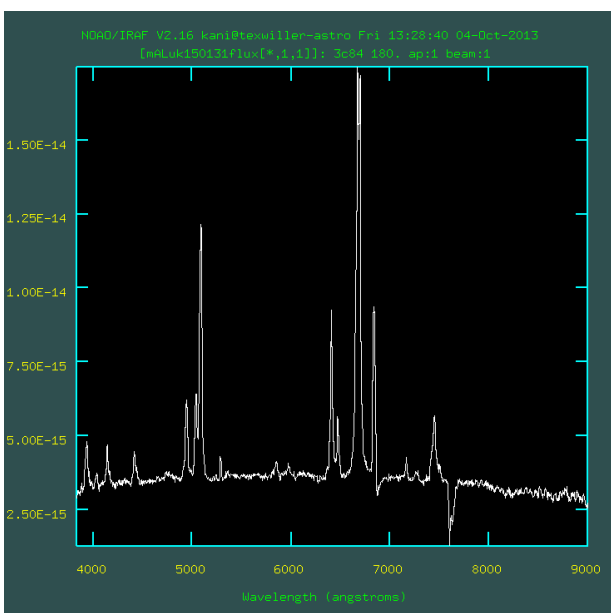
$$X = 1 / \cos z$$

in the plane parallel atmosphere approximation.



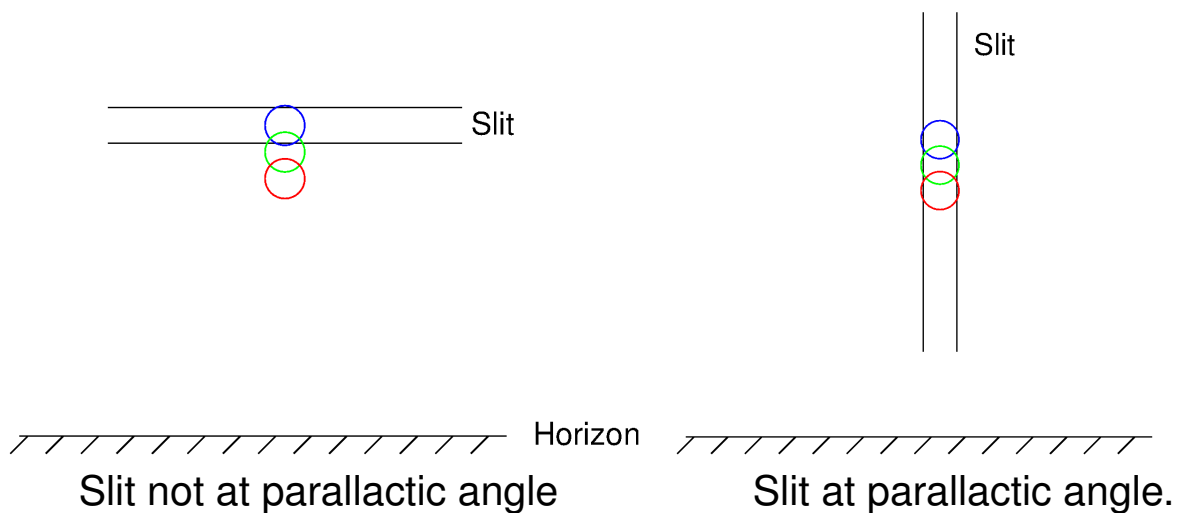
- Airmass $X = 1.0$ corresponds to the airmass at zenith. Therefore, k_λ gives the extinction at zenith in magnitudes.
- Typical values for UBVRI filters at high altitude observatories: $k_U = 0.45$, $k_B = 0.22$, $k_V = 0.10$, $k_R = 0.07$, $k_I = 0.05$.
- At airmass $X = 2.0$ ($z = 60^\circ$) there is twice as much atmosphere between the target and the observer than at zenith. Observations should generally be done above $X = 2$, if possible.

Atmospheric absorption effects in spectra



c) Atmospheric refraction

- Causes mainly problems for spectroscopy in the form of *slit losses*, which stem from the fact that bluer wavelengths are more strongly refracted.
- Can be avoided by placing the slit in the *parallactic angle*, i.e. perpendicular to the horizon.



d) Background due to emission and scattering

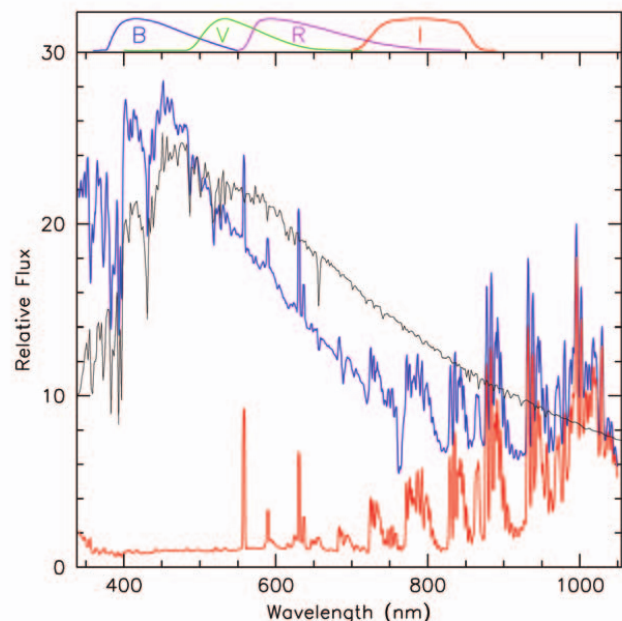
The atmosphere

- emits light (airglow) and
- scatters terrestrial lights (light pollution) and moonlight, increasing the background and producing spectral artifacts.

Red: night sky spectrum in dark conditions (no Moon).

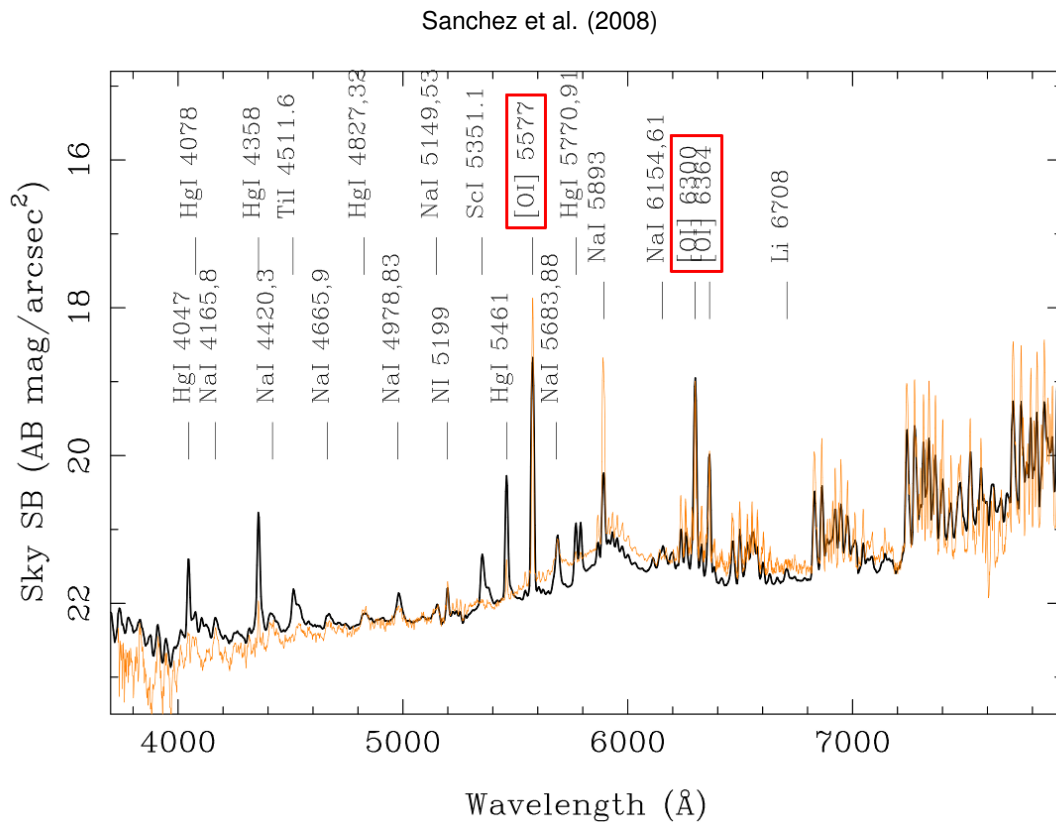
Blue: night sky spectrum with full Moon on the sky.

Black : spectrum of a Solar type star.



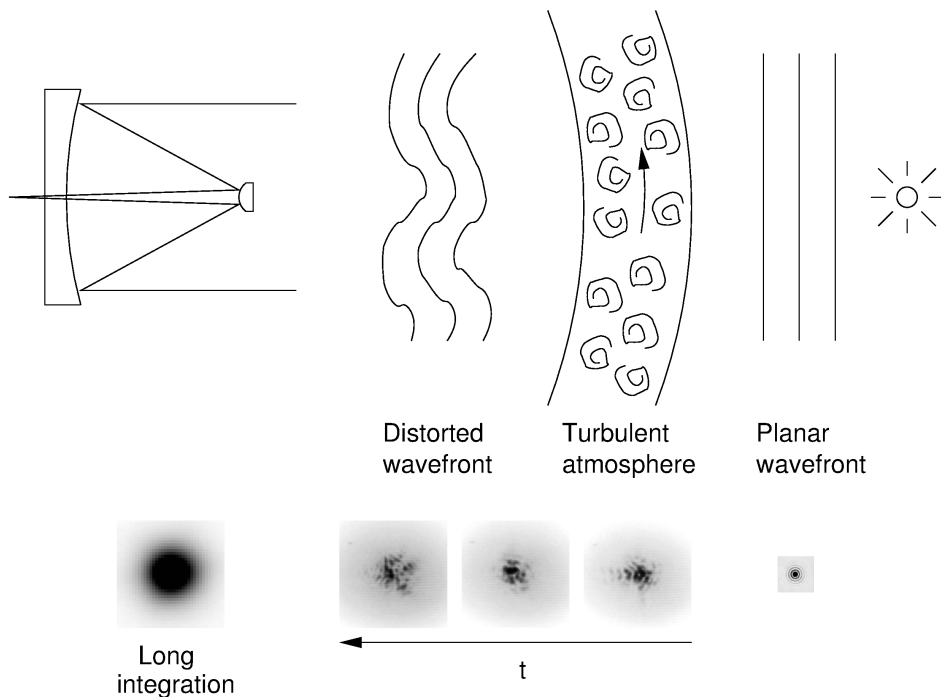
Pollution lines (Calar Alto)

Red = natural lines, rest of the labeled lines are pollution.



e) Atmospheric turbulence

Turbulence in the atmosphere creates phase errors into the incoming wavefront → object image is distorted.



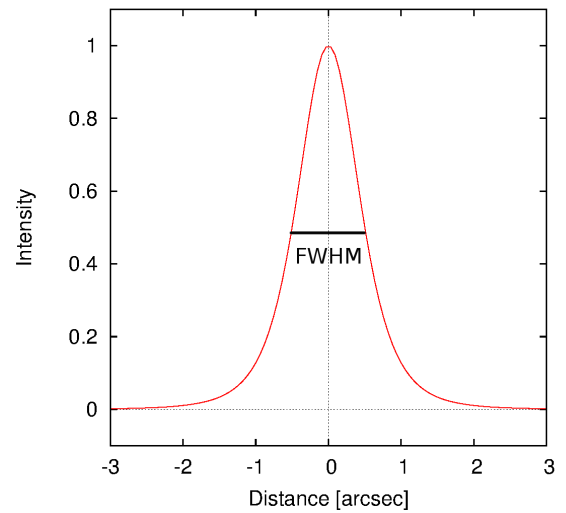
Seeing

- A long integration (long wrt the turbulence time scale) results in a broadened light distribution.
- This broadening is measured from the apparent width of point sources (e.g. stars) in the image (=seeing).
- Seeing is measured as the full width at half maximum (FWHM) of a point source.
- Typical seeing values:

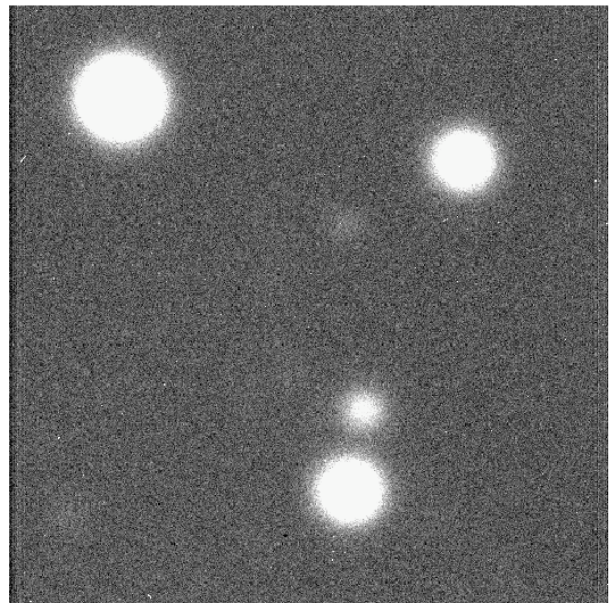
HST: 0.05"

NOT: 0.4"-0.9"

Tuorla: 2.5" - 5"



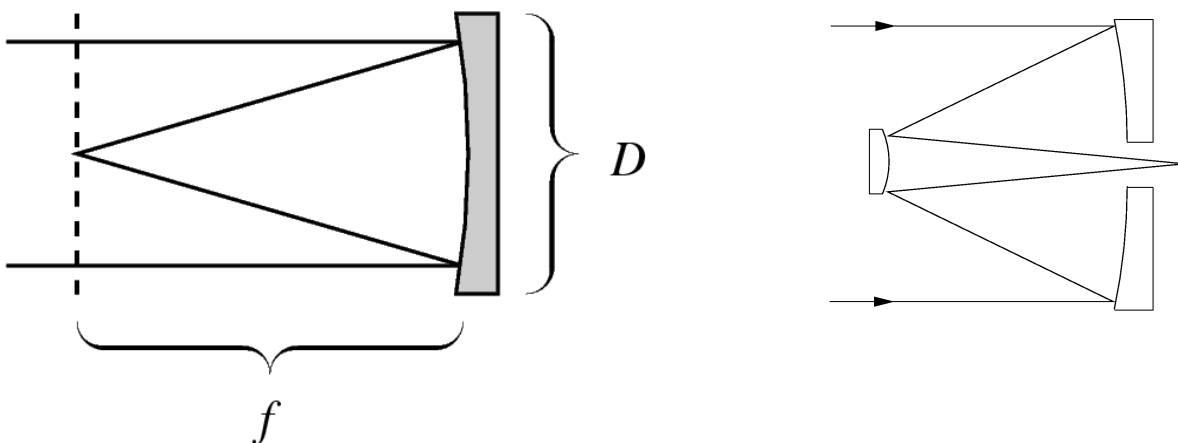
Seeing matters!



- The 2-dimensional shape of a point source in an image is called the *point spread function* (PSF).
- The PSF tells how a point source looks through the telescope.
- Observed image is a result of *convolution* of the “true” image by the PSF:

$$Obs(x, y) = True(x, y) * PSF(x, y)$$

3) The telescope



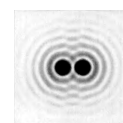
- Light gathering power $\propto D^2$

- Resolution = $1.22\lambda/D$, set by diffraction

NOT, V-band (550 nm): 0.054" but atmosphere limits to $> 0.4''$

- Focal ratio = f/D (e.g f/11)

- Pixel scale ("/pix.) = $205265 * \frac{d_{pix}}{f}$, d_{pix} = pixel size.



4) The instrument

- Processes and records the incoming light, but also adds random variations, i.e. *noise*, to the images.
- In addition to instrumental noise, the image always contains *photon noise*, which cannot be avoided.
- A fundamental rule of observational astronomy:

Plan the observations in such a way that the noise is dominated by photon noise, not by instrumental noise.

In the first case the data are said to be *photon noise limited* (=good) contrary to e.g. *read noise limited* data (=bad).

Photon noise

Imagine a perfect detector, which records every photon hitting it and adds no noise to the signal.

If the detector records n photons, then for “large” n (>a few tens) the standard deviation of n is \sqrt{n} .

Thus the true photon rate is with 68% probability in the interval $(n - \sqrt{n}, n + \sqrt{n})$.

Photon noise gives the fundamental lower limit of noise in any image.

Signal to noise

The *signal to noise* (S/N) is a measure of data quality.

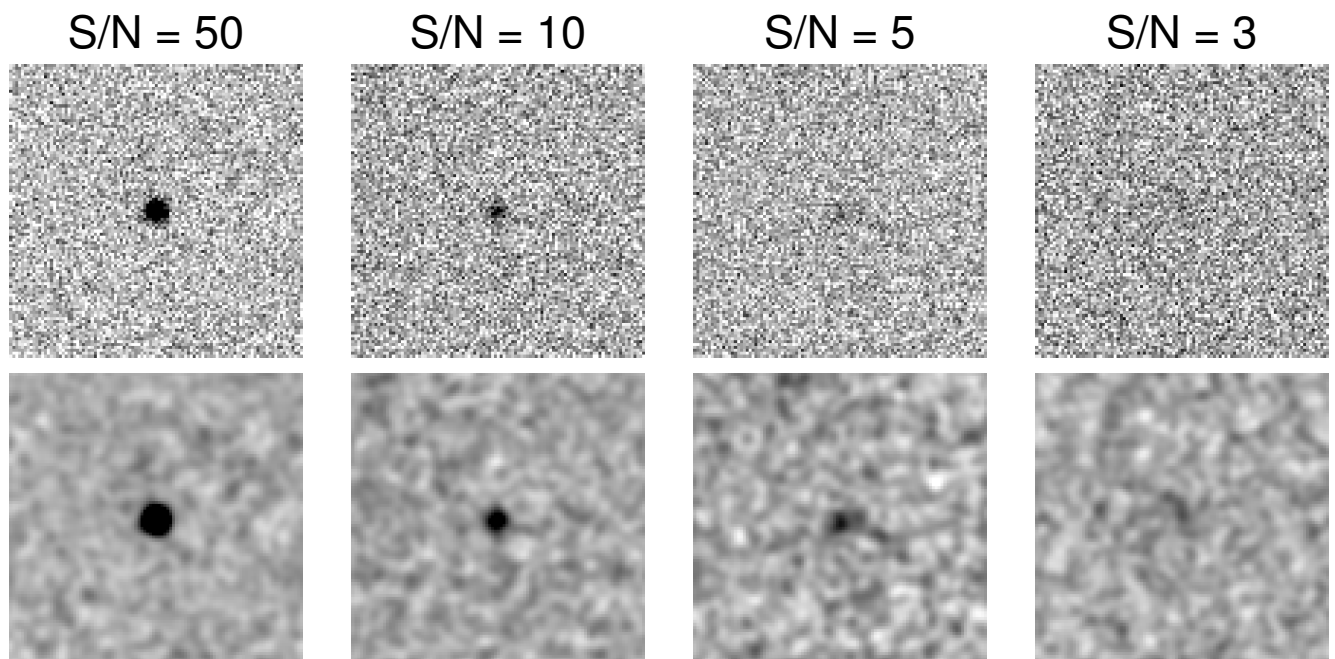
$$\frac{S}{N} = \frac{\text{observed signal}}{\text{noise}}$$

$S/N > 3$ is generally required to claim detection, but $S/N > 5$ is a safer limit.

In the case of perfect detector $S/N = \frac{n}{\sqrt{n}} = \sqrt{n}$.

Before observations there should be an idea of required S/N and the observations should be planned so that this S/N is reached.

S/N examples



Computing S/N depends on the situation, but if

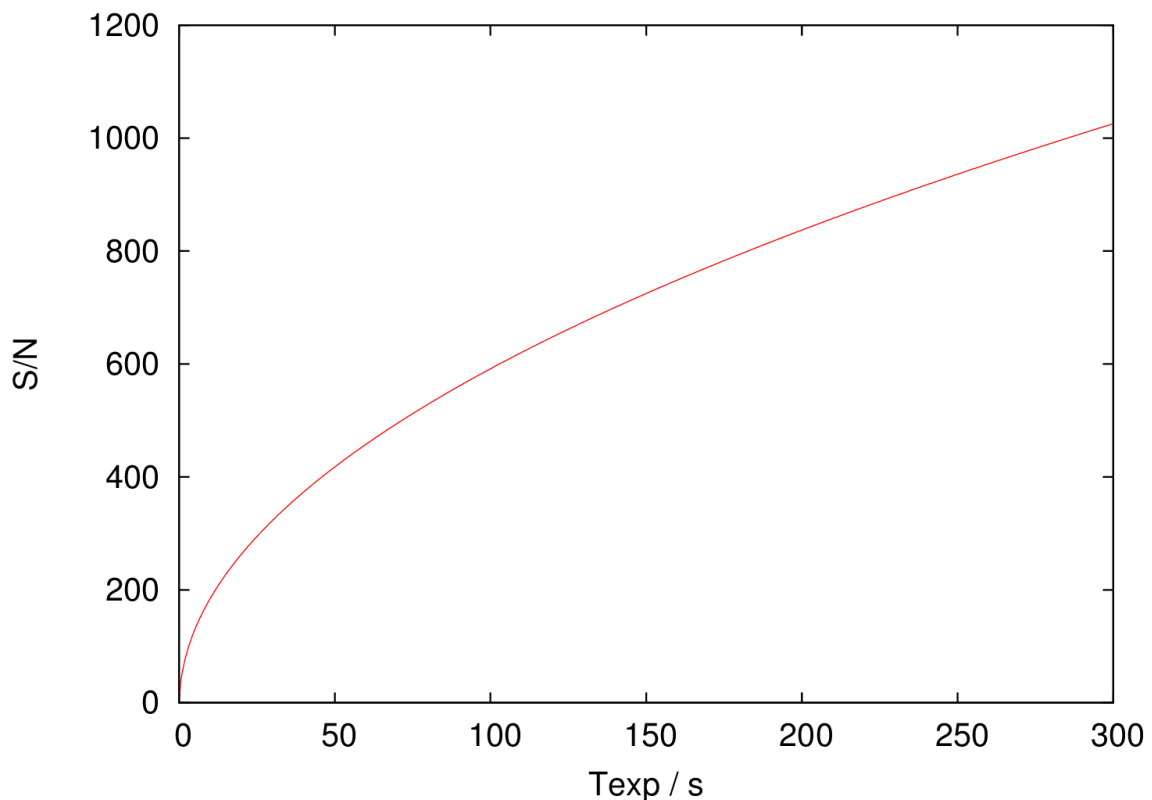
- the signal is obtained by summing the signal of M pixels with n_i photons in pixel i and
- the standard deviation of n_i in pixel i is σ_i

then

$$\frac{S}{N} = \frac{\sum_{i=1}^M n_i}{\sqrt{\sum_{i=1}^M \sigma_i^2}}$$

Note that in the case of perfect pixels ($\sigma_i = \sqrt{n_i}$) we get $S/N = \sqrt{\sum n_i}$.

S/N example: aperture photometry



Proposal/planning phase:

- Choose the telescope & instrument most suitable for your science case.
- Estimate the required S/N and determine the required exposure time to reach that with given telescope and instrument.
- Make a visibility plot of your targets and plan the observations so that targets are observed high in the sky.

When observing:

- The weather is unpredictable. Be ready to change the plan during the night.
- Expose long enough for the data to be photon noise dominated.