Observational Astrophysics II

Direct imaging
Photometry
Kitchin pp. 187-217, 276-309

Astronomical Imaging

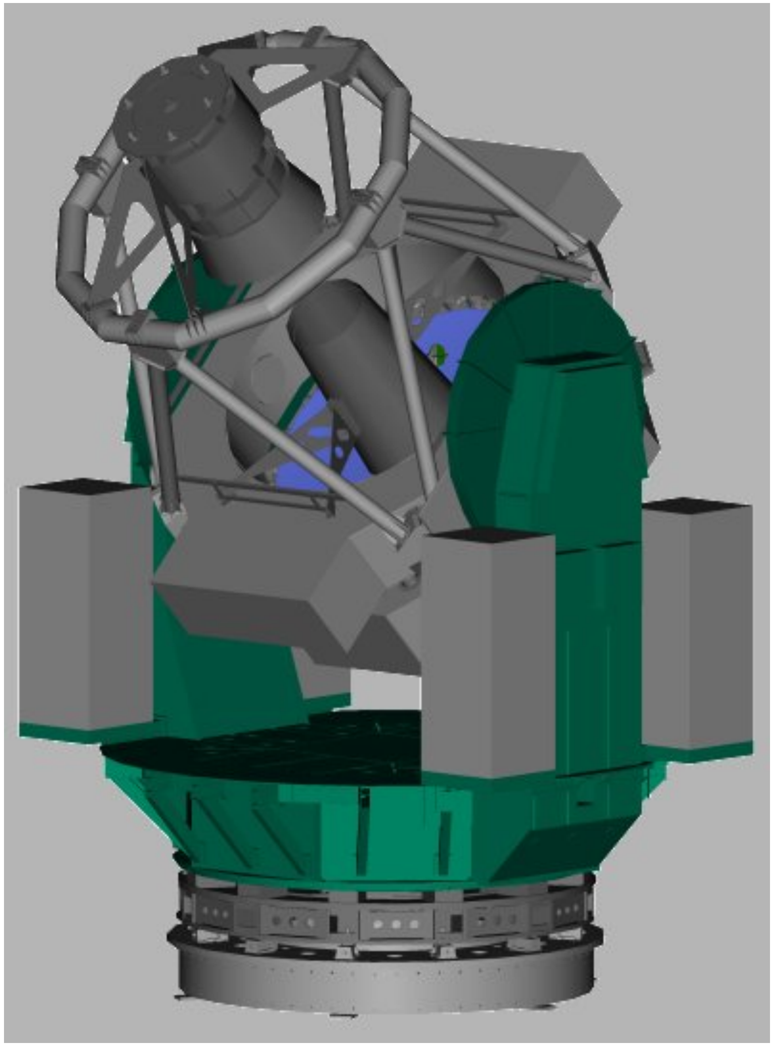
Wide or **Deep**

Specific goal:

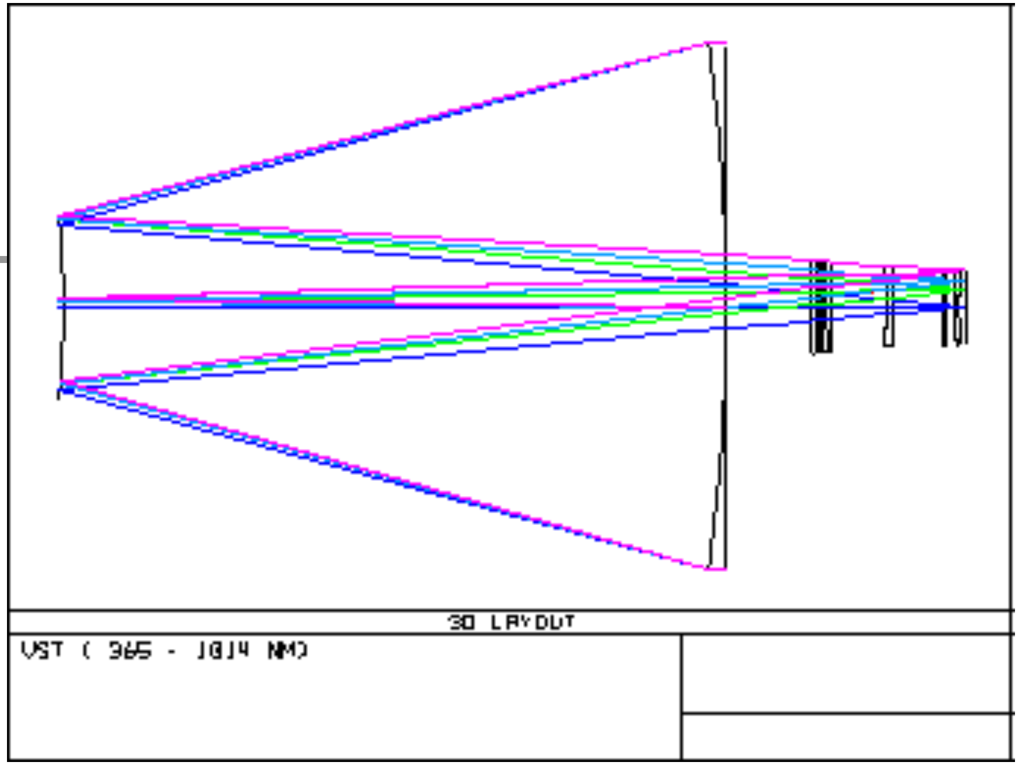
- *As many objects as possible* (e.g. clusters, star-forming regions)
- *As large range of surface brightness as possible* (e.g. galaxies)

Wide Field Imager: VST

- The VST is a 2.6m f/5.5 Cassegrain telescope
- Corrected FoV is 1.5º square with angular resolution of 0.5″
- Focal plane is equipped with a 16kx16k CCD mosaic camera with a 15μ pixel



VST Optics

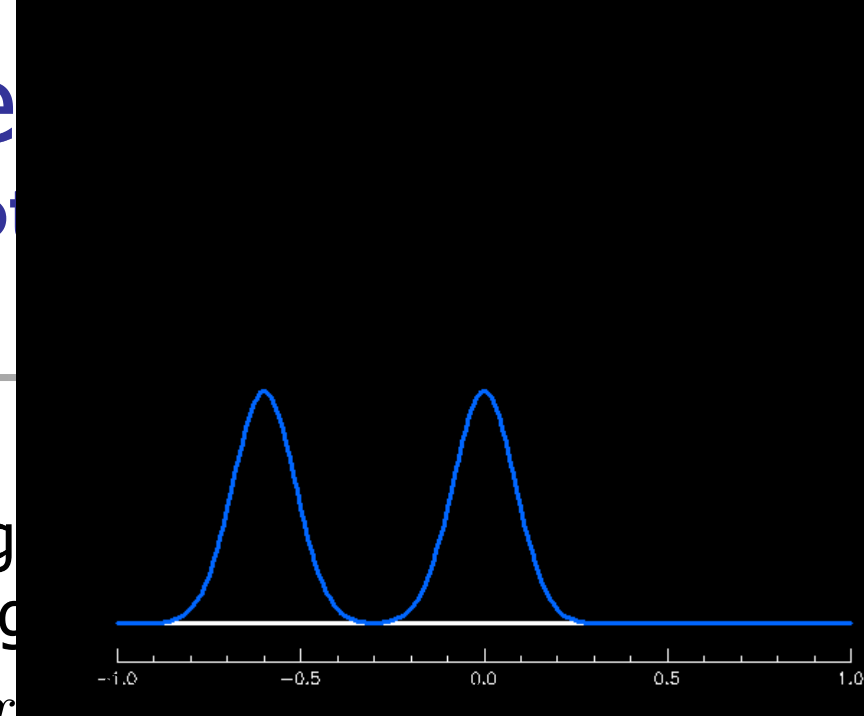


- Optical layout including ADC, field corrector etc.
- Plate scale:
  - focal length=2.6m×5.5=14.3m
  - 1″= π /180º/3600≈5×10^{-6} rad (1 rad ≈ 200000″)
  - Resolution element: 0.5″ ⇒ 0.5 × 5×10^{-6} rad × 14.3m ≈ 35μ

    ≈ 2.3 CCD pixel (nearly perfect Nyquist sampling)

Sampling Theore

(Whittaker-Nyquist-Ko sampling theorem)



The *sampling frequency* must

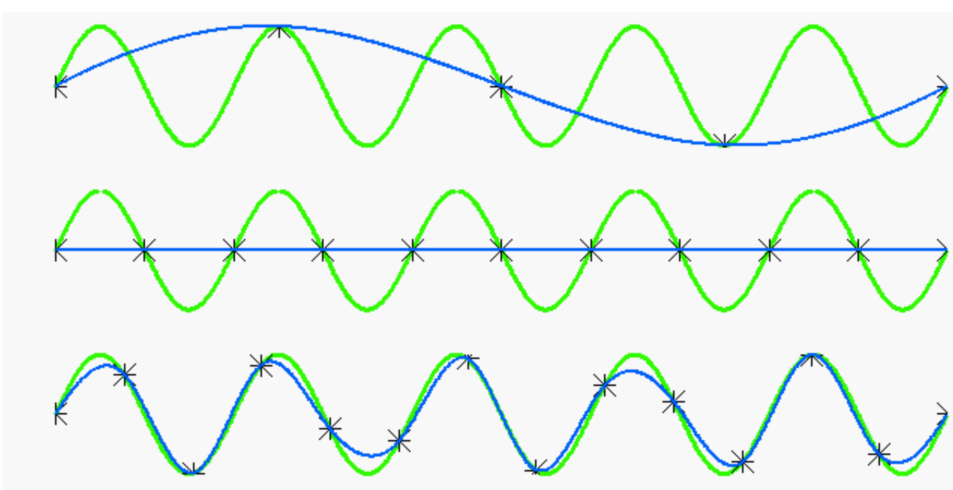
the bandwidth of the input sig

"perfectly" reconstruct the orig

For Gaussian PSF $\propto \exp(-\ln 2x^2/\delta^2) = \exp(-x^2/2\sigma^2)$

with δ =HWHM and 2π/σ - maximum frequency.

Thus FWHM= $2\delta = 2\sqrt{2\ln 2}\,\sigma \approx 2.355\sigma$

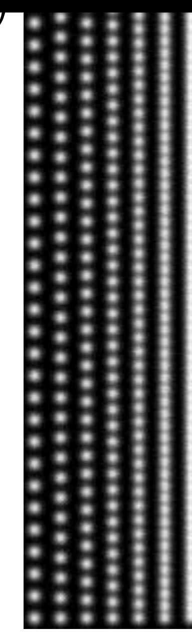


Different samplings:

-Once per period

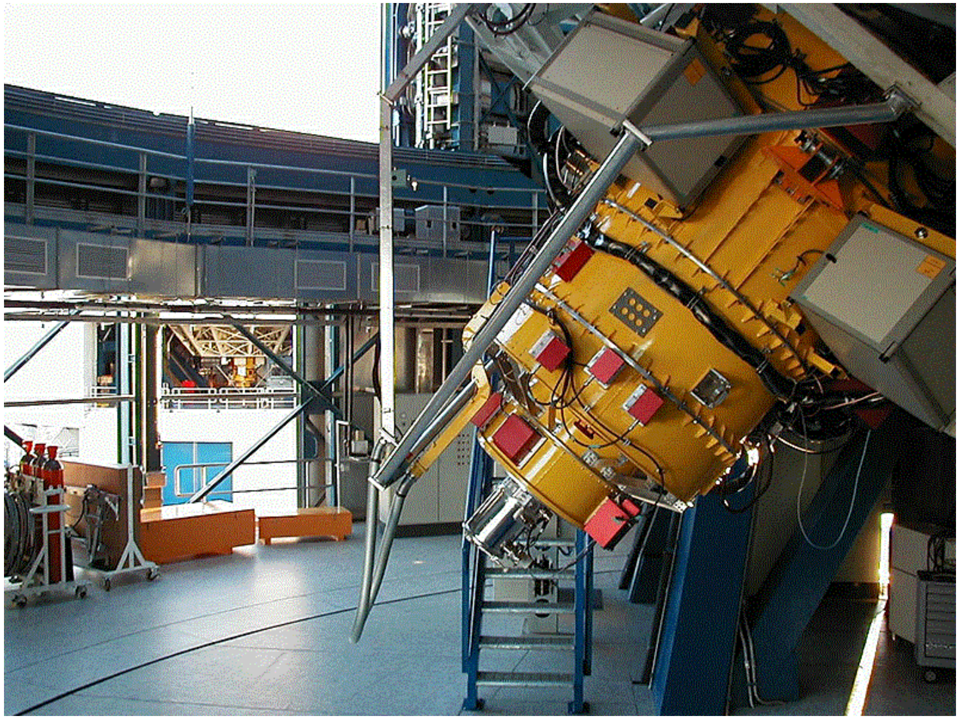
-Twice per period

-Nyquist sampling



Non-dedicated telescope

VLT+FORS

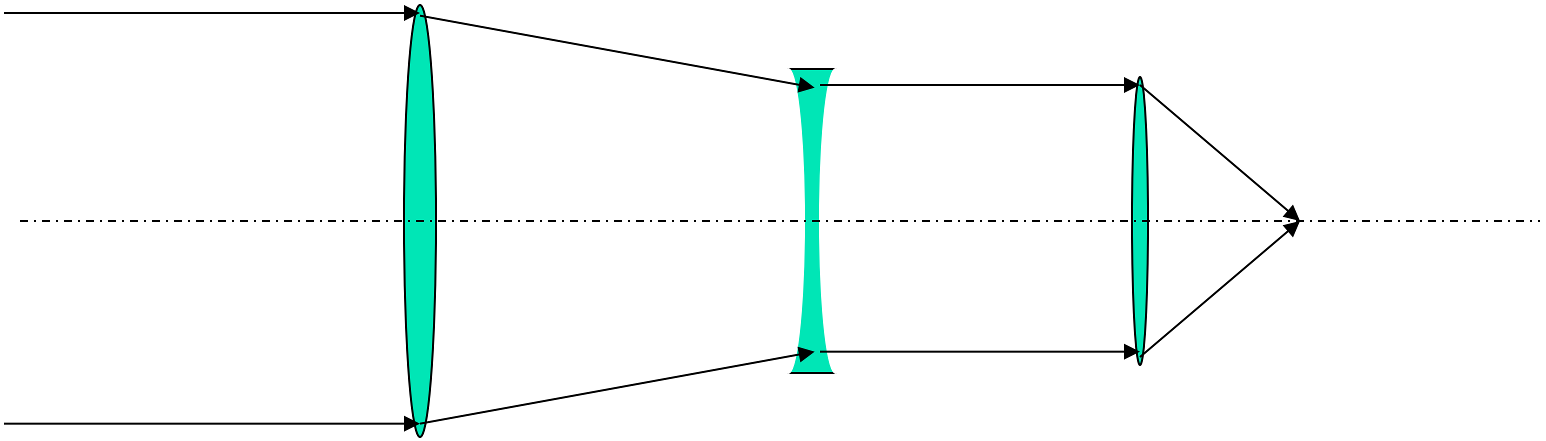


FOcal Reducer/low dispersion Spectrograph

VLT UT (8.2m f/13.4):
focal length=8.2m×13.4=108.8m
Plate scale in Cassegrain:
5×10^{-6} rad × 108.8m ≈ 530μ/arcsec

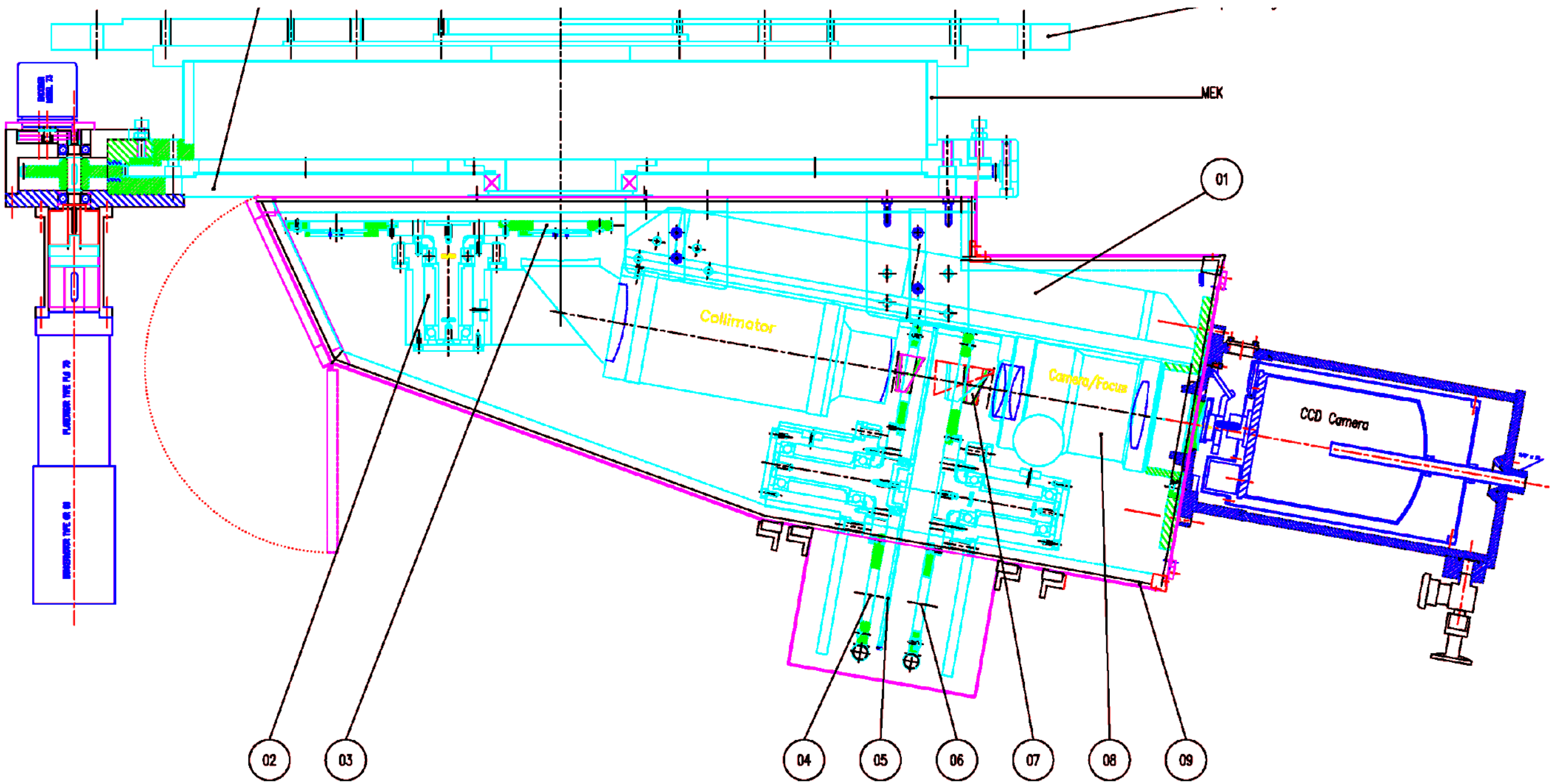
Focal Reducers

- Purpose: adjusting plate scale

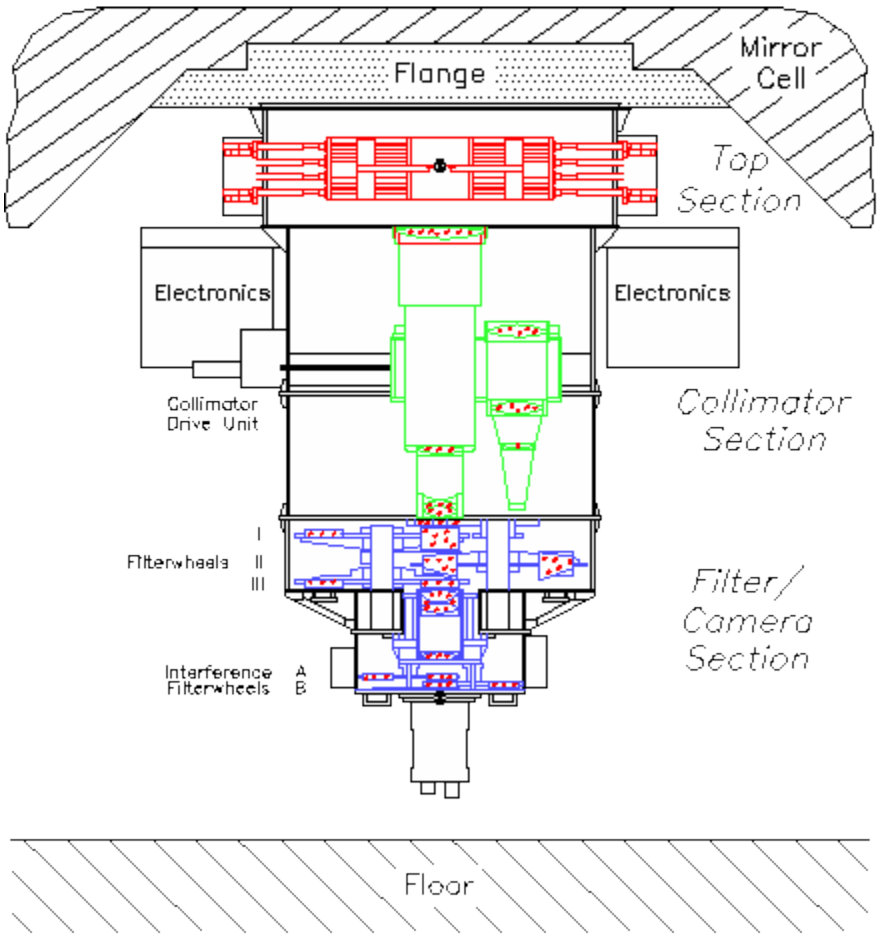


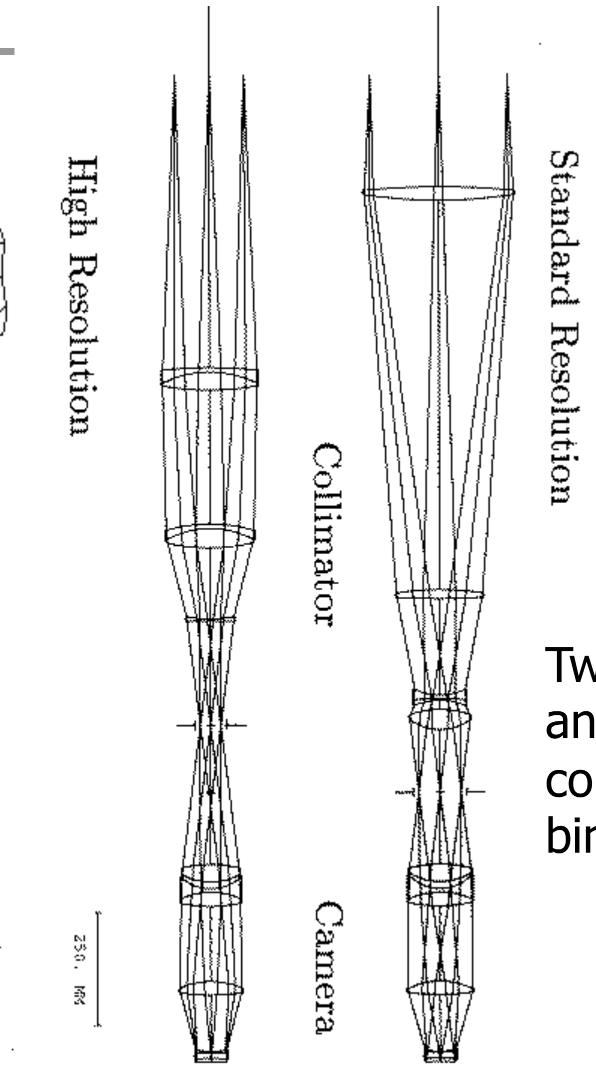
- Side benefits: collimated beam is good for filters

NOT workhorse: ALFOSC



Unconventional instrument: FORS

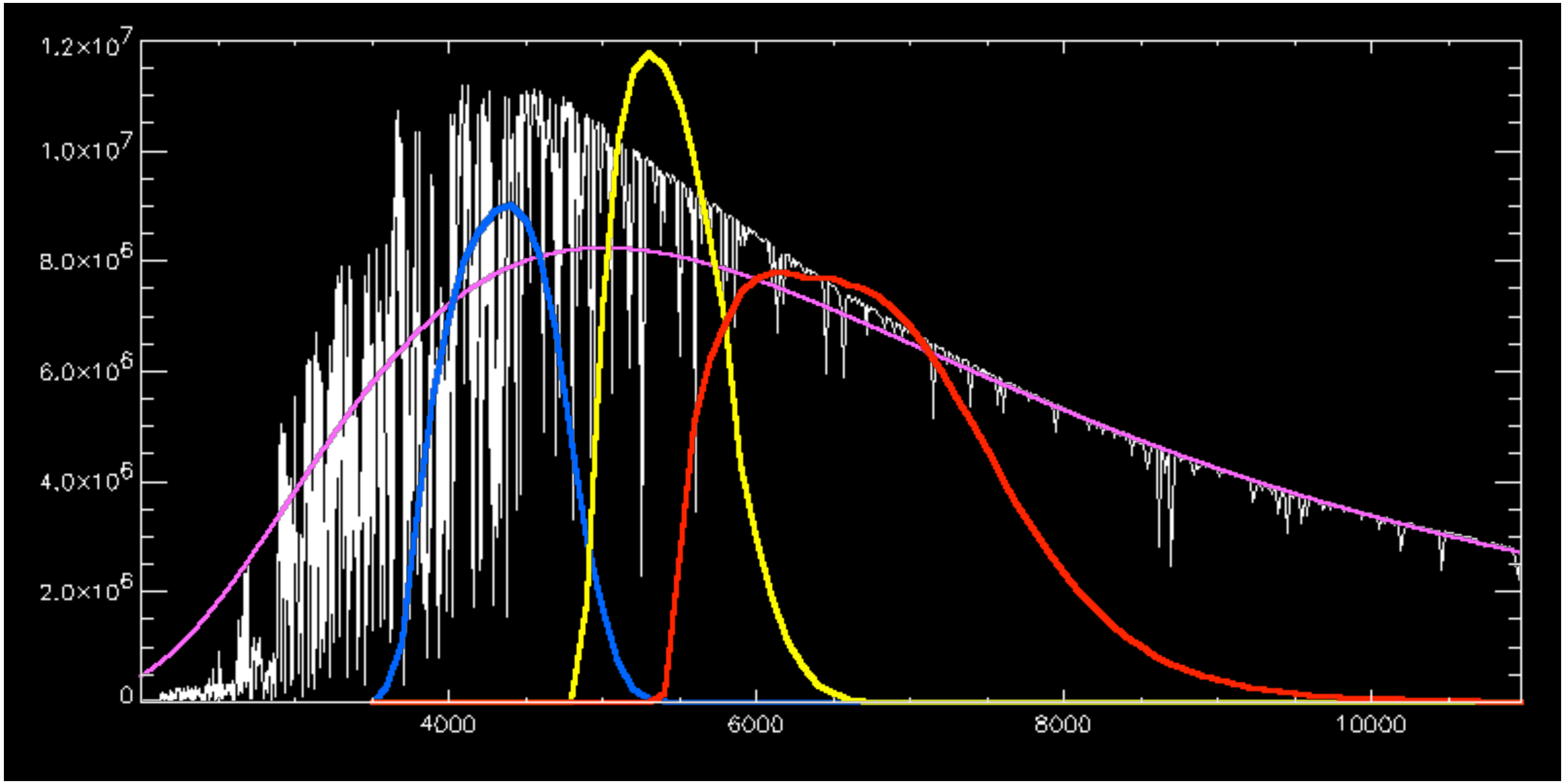




Two resolutions: 0.2" and 0.1" by changing collimators and CCD binning

Filters

- Broad band filters (UBV system, Johnson H.L. & Morgan W.W.: 1953, ApJ, **117**, 313)



Broad-Band Filter Technology

Color absorption glasses:

- *blocking* (high absorption shorter than certain wavelength while highly transparent at longer wavelengths) or
- *bell-curve* (sharp cut-off at shorter wavelength and gradual drop towards longer wavelength)
- Transmission is high, up to 75-90%

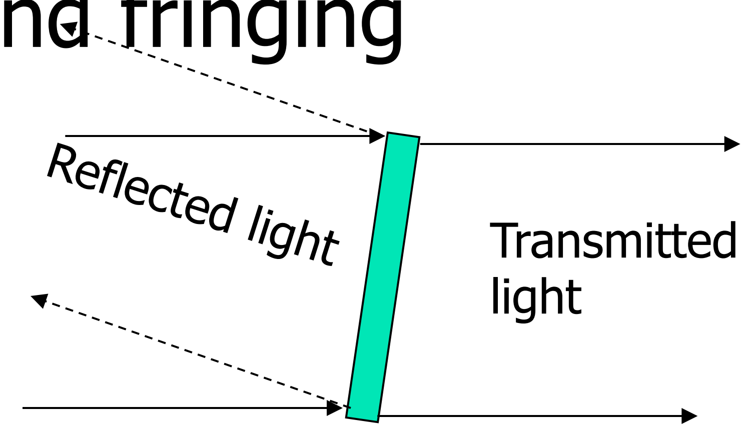
Narrow-Band Filter Technology

Interference coatings:

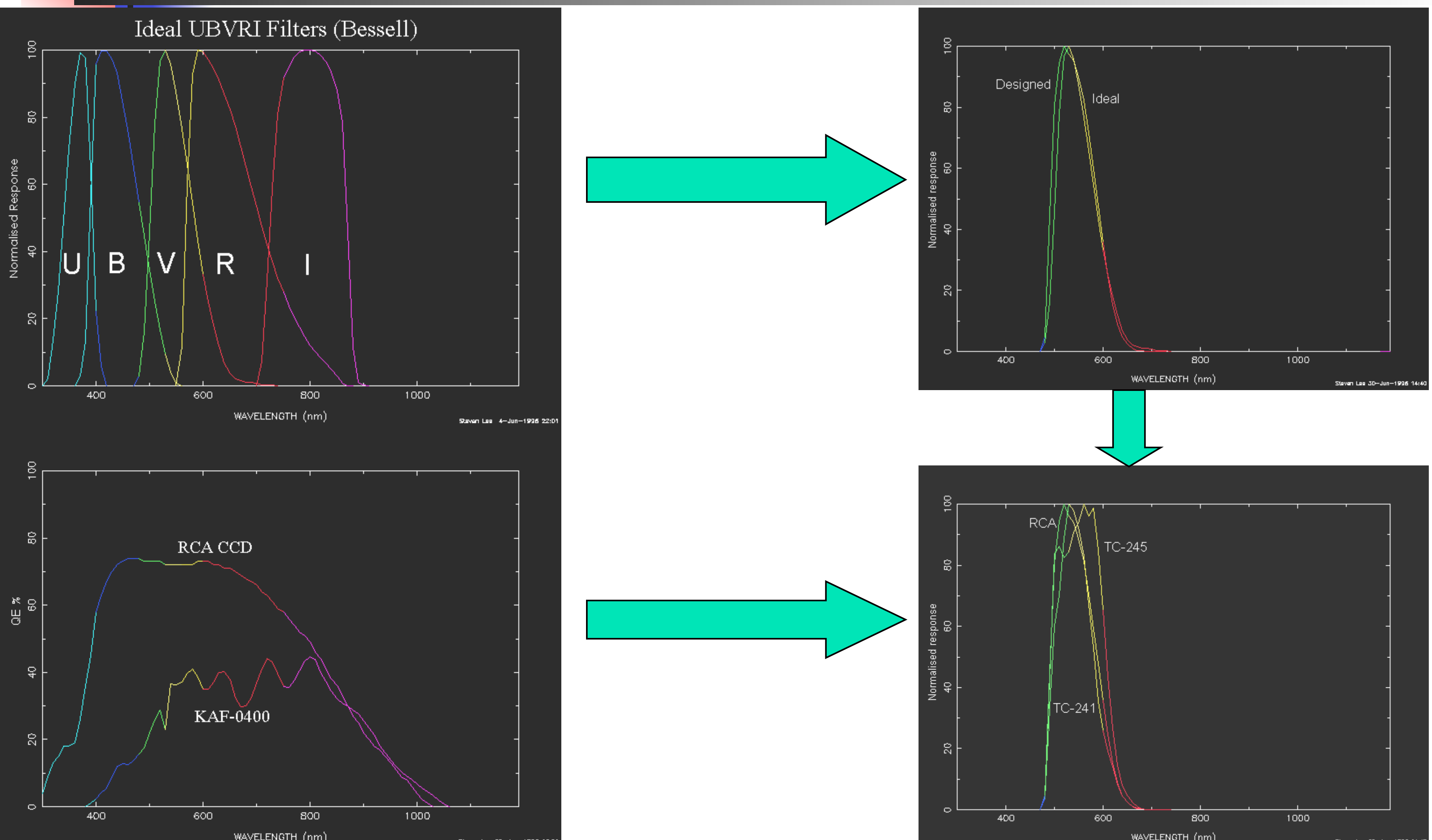
- Multiple (up to 20) dielectric layers producing interference between internal reflections
- Create multiple transparency windows at different wavelengths
- Must be combined with broad-band filters
- Total transmission is low, around 20-40%

Chromatism and other problems

- Filters are best used in parallel beam, otherwise they introduce chromatism
- They also shift focal plane (transparent glass plates)
- Slight tilt is used to avoid ghosts (shift of optical axis) and fringing

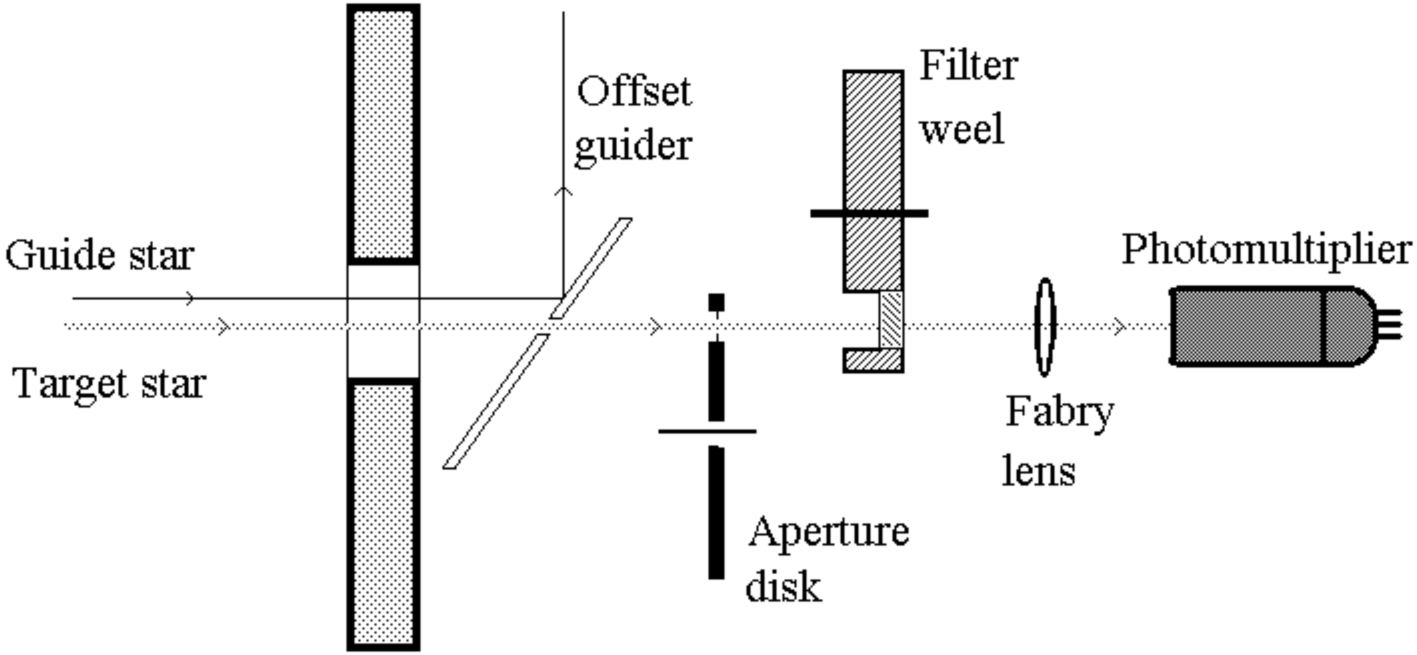


Transmission Function



Photometry

Classical one-channel photometer:



What do we measure and how?

- Magnitudes: $\Delta m_\lambda = -2.5\lg(I_\lambda / I_\lambda^{ref})$
- Filters:

$$\Delta m_V = -2.5\lg\left(a\int_V f^V(\lambda) I_\lambda d\lambda \Big/ b\int_V f^V(\lambda) I_\lambda^{ref} d\lambda \right)$$

- a and b are selected such that Vega will be 0 magnitude in all colors
- Interstellar extinction: objects with the same SED located in different directions and distances will have different magnitudes
(The main source of extinction is the scattering and absorption-heating of the dust particles and their main effect is to "redden" the energy distribution). Color excess:

$$E(\lambda_2 - \lambda_1) = \big(m(\lambda_2) - m(\lambda_1)\big) - \big(m(\lambda_2) - m(\lambda_1)\big)_0$$

More What and How (II)

- The variation of extinction with wavelength is similar for all directions: we measure color excess in one band then scale it to other bands.
- Knowing scaling parameters (in principle) allows to convert apparent magnitudes m to *absolute magnitudes* M. Absolute magnitude is the apparent magnitude of the same object at a distance of 10 parsecs:

$$M_\lambda = m_\lambda - 5\lg d + 5 - A(\lambda)$$

  d is the distance and A is the interstellar extinction, which can be estimated from the color excess in *B*-*V* and scaled:

$$M_\lambda = m_\lambda - 5\lg d + 5 - R_\lambda \cdot E(B-V)$$

More What and How (III)

- Absolute magnitude M_λ does not a measure the total irradiance.
- *Bolometric magnitude* *M(bol)* is defined as the absolute magnitude that would be measured by an ideal bolometer exposed to all of the radiation from an object in space.
- The relation between bolometric magnitude and the absolute magnitude M_{V} requires the knowledge of the bolometric correction *B.C.*:

$$M(bol) = M_V + B.C.$$

- Traditionally *B.C.* for solar-type stars is set close to 0 and it grows for hotter and cooler objects.

Absolute and differential photometry

- Radiation in a given band is affected by the atmosphere, telescope, photometer and detector. All of these must be calibrated.
- Background radiation (sky background) is proportional to the aperture area. *What are the main components of the background?*
- Absolute photometry is done either from space or with absolute calibration e.g. against a black body standard source.

Absolute and differential photometry (cont'd)

- Once absolute measurements are done for a few objects they can be used as standards.
- Differential photometry measures flux difference in a given band between a target and a standard.
- Observations should be close on the sky and in time.
- Classical sequence for a single channel photometry:
  <selecting band>:<standard> - <target> - <standard>

Point source CCD photometry

- Assumption: all point sources have the same PSF.
- Thus we can estimate the correction between small and large apertures using bright sources.
- For faint sources we do small aperture photometry and apply the correction.
- Sky back ground can be estimated from the same image(s).

Point source CCD photometry

- Sky extinction is measured using standard stars.
- Transformation matrix is also made using standard stars, e.g.:

$$V = a \cdot V^{\mathrm{obs}} + b + c \cdot (V - R)$$

and then applied for all the other sources.

CCD Photometry

- Many objects at once (standards and targets)
- Large dynamic range
- PSF is spread over several pixels
- Pixels have different sensitivity and color sensitivity
- Photometry of extended sources

Next time…

Astronomical detectors