# AGA0414
# Photometry 2

Prof. Alessandro Ederoclite

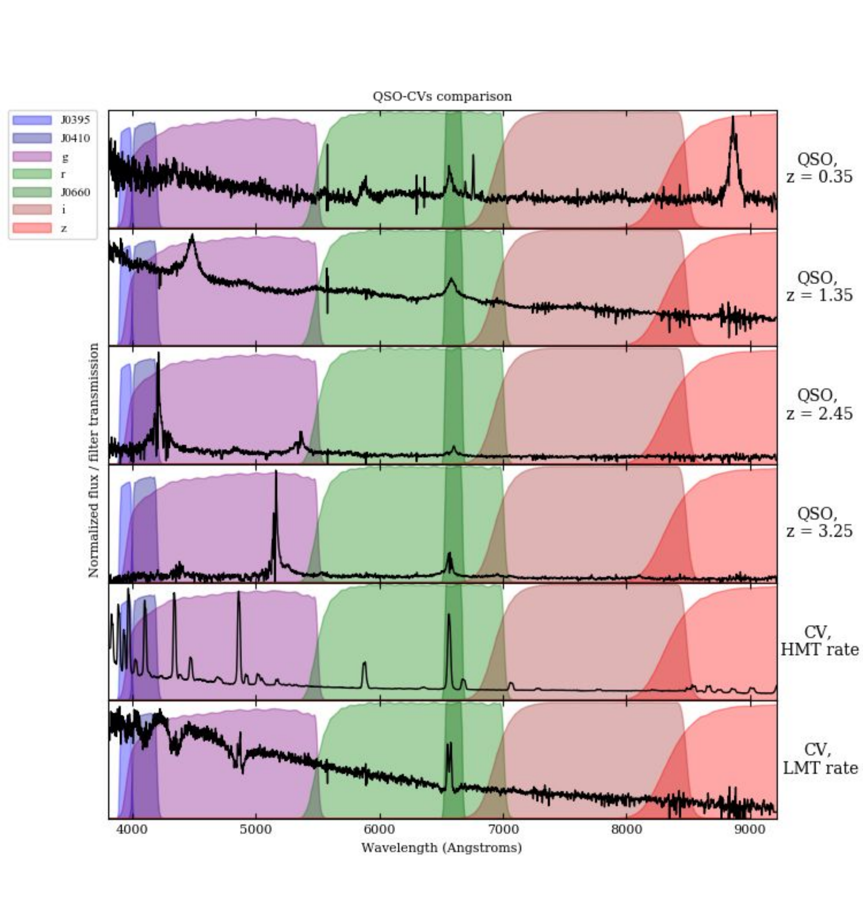
# What's in a magnitude...

Convolution of the filter of an object with a filter.

Convolve: ∫ f(v) T(v) dv

In fact, it's the transmission of the whole system: optics (mirrors and lenses; gold does not reflect bluer than 6000Å), filter, and detector (CCDs only detect light between 3000 and 10,000Å).

https://pysynphot.readthedocs.io/en/latest/



# (Unfortunate) definition of magnitude

Defined by Ptolemy/Hipparchus: bright stars “first magnitude” and faint stars “sixth magnitude”.

We said that the response of the human eye is logarithmic.

Pogson (1856) quantified this relation:

$$mag_1 - mag_2 = -2.5 \log(f_1/f_2)$$

$$\Delta mag = 5 \rightarrow f_1/f_2 = 100$$

<u>All magnitude measurements are relative!</u>

# First, it was Vega

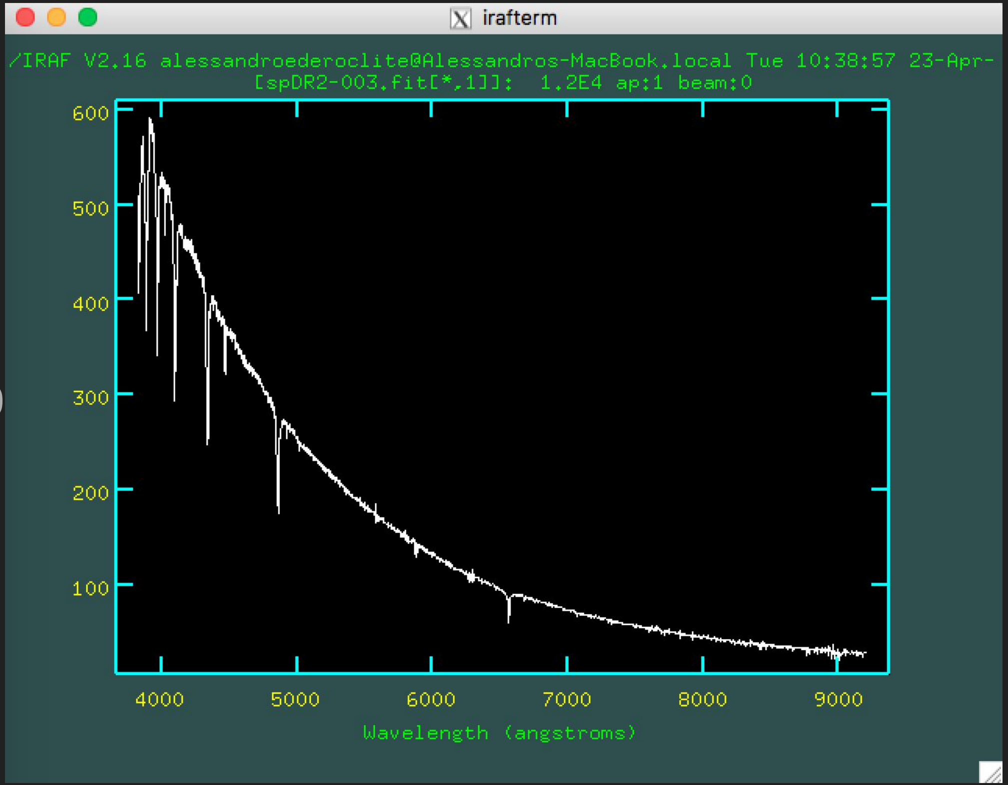
By definition:

- U-B = 0
- B-V = 0

By the way, Vega, by definition, had V=0.0

These colours are valid for any A0 star.

Turns out, that Vega has V=0.03



# Then we started using flux

Optical astronomers use $f_\lambda$ [ergs $cm^{-1}$ $Å^{-1}$ $s^{-1}$]

Radio astronomers use $f_\nu$ [ergs $cm^{-1}$ $Hz^{-1}$ $s^{-1}$]

Luckily: $f_\nu = ( \lambda^2 / c ) f_\lambda$

Oke (1974) and Oke & Gunn (1983) defined AB magnitudes

$$mag_{AB} = -2.5 \text{ Log } f_\nu - 48.6$$

Useful because it relates to a physical quantity. Hard because $f_\nu$ strictly relates to its source and its filter.

# Caveat! SDSS

The magnitudes in the SDSS catalogue are inverse hyperbolic sine magnitudes!

https://www.sdss.org/dr12/algorithms/magnitudes/#asinh

$m = -2.5/\ln(10) * [\mathrm{asinh}((f/f_0)/(2b)) + \ln(b)]$

Asinh Softening Parameters

| Filter | $b$ | Zero-flux Magnitude [$m(f/f_0 = 0)$] | $m(f/f_0 = 10b)$ |
|---|---|---|---|
| $u$ | $1.4\times10^{-10}$ | 24.63 | 22.12 |
| $g$ | $0.9\times10^{-10}$ | 25.11 | 22.60 |
| $r$ | $1.2\times10^{-10}$ | 24.80 | 22.29 |
| $i$ | $1.8\times10^{-10}$ | 24.36 | 21.85 |
| $z$ | $7.4\times10^{-10}$ | 22.83 | 20.32 |

Excercise:

Show how asinh magnitudes differ from AB magnitudes in a range between 18 and 24.

# … but we measure counts on a CCD!

$\gamma$ -> $e^-$ -> counts

All this relations are linear!

So we can actually write:

$$mag_1 - mag_2 = -2.5 \log ( counts_1 / counts_2 )$$

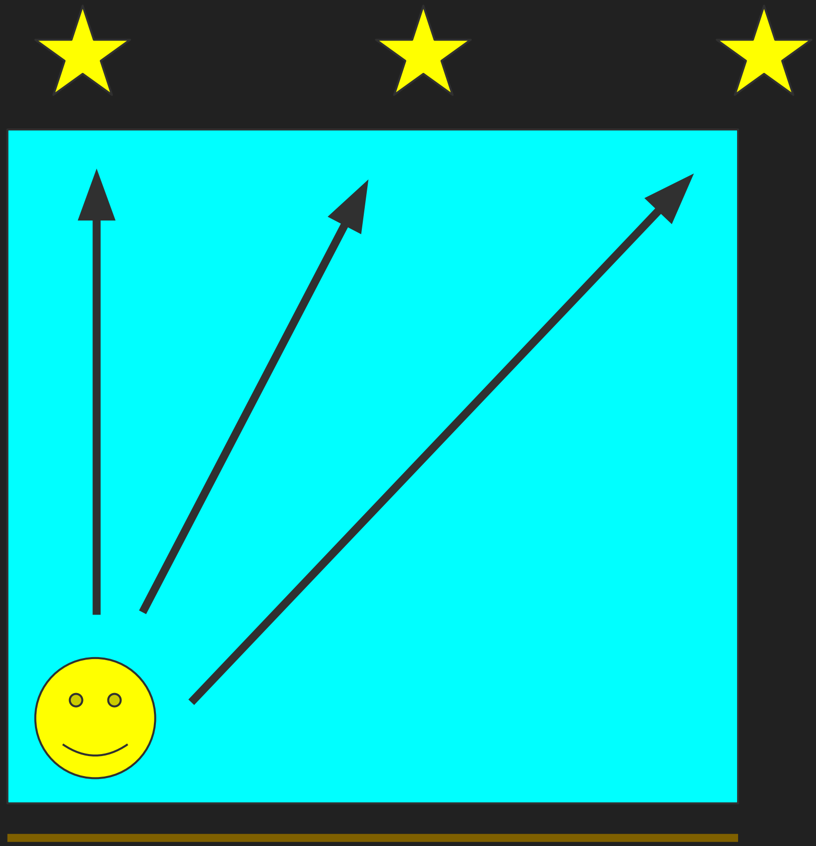
(note that it should be "$counts_i$ / exposure time" but it cancels out if it is a single exposure)

# The role of the atmosphere

The further from zenith, the more atmosphere is between the observer and the star.

Airmass Z = sec

*k* is the “extinction coefficient” of the atmosphere. It measures the exctinction (in units of magnitudes) per unit of airmass.



# Bouguer's Law

I measure a star of known brightness at different airmass:

$mag_0 = mag_z + k * \sec Z$

THIS DEPENDS ON FILTER!

How does this affect different wavelengths?

Stars get "redder" with increasing airmass

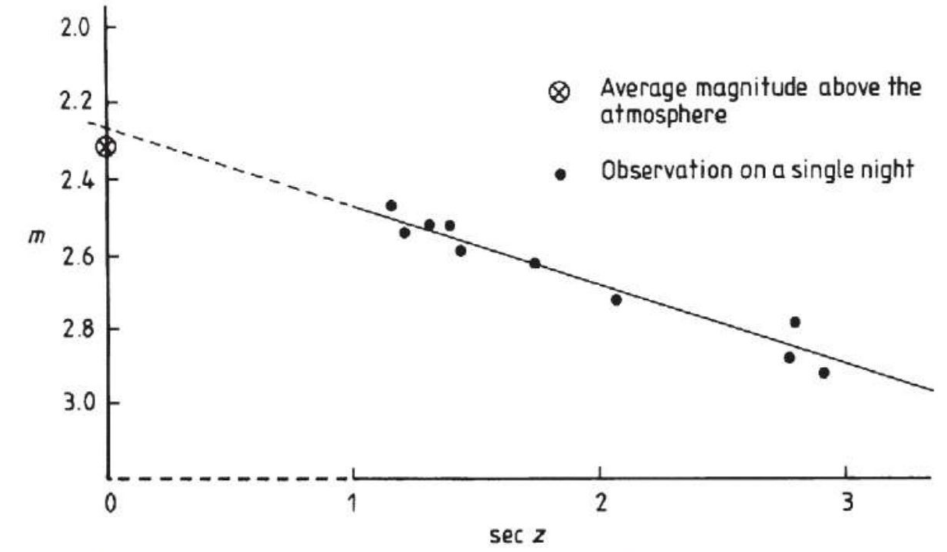
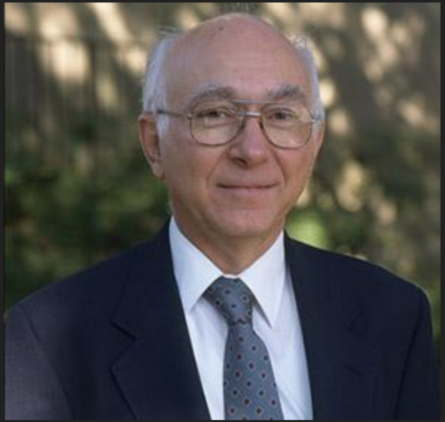


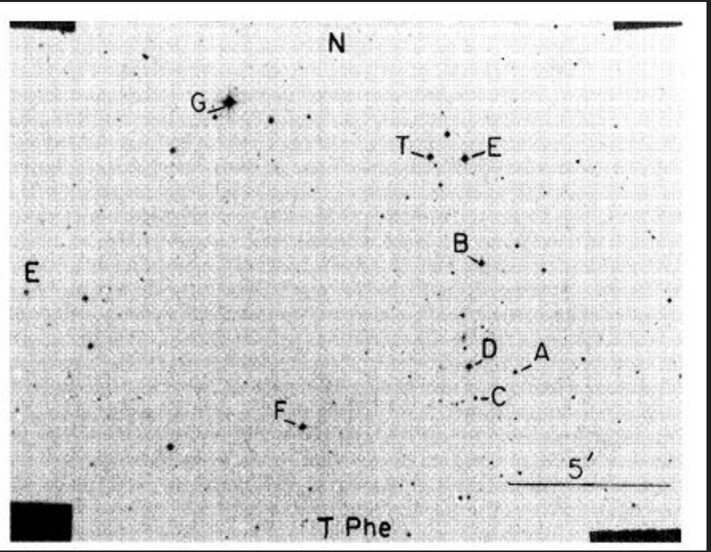

**Figure 3.2.5.** Schematic variation in magnitude of a standard star with zenith distance

# Landolt's Fields

In fact, usually we measure a whole field of stars. The main standard fields have been identified by Arlo Landolt https://en.wikipedia.org/wiki/Arlo_U._Landolt

An astronomer is really famous once his papers are not cited but taken for granted as basic astronomical knowledge.





# Colour terms

The Bouger’s Law gives you the zeropoint and the extinction coefficient for your filter.

Yet, you still have to get the colour-terms:

$(U\ B\ V\ R\ I)_{calibrated} = C\ (U\ B\ V\ R\ I)_{instrumental}$ + Zeropoints

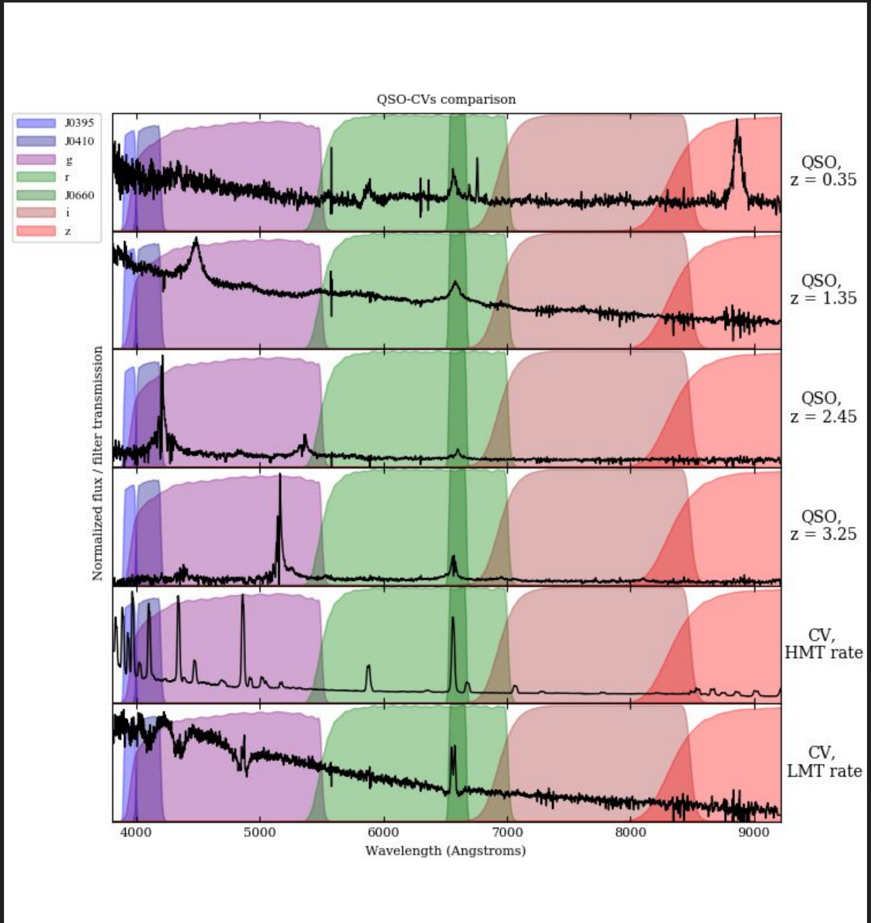
Where “C” is a matrix; normally you do not have to take care of all the elements

If the filters were always identical, there would be no need for colour terms.

Plus, a calibration tends to work for one type of object: the more generic, the less precise.

# Another way to calibrate

If you have calibrated spectra in your field of view (and you trust the calibration of your spectra) and you have the response of your system, you can convolve these spectra by your filter response.



# Good practice

As a rule of thumb, I noticed that papers which have “CCD photometry” in the title are often very very careful about data.

E. g. https://arxiv.org/abs/2004.10902

**WIYN [5] Open Cluster Study LXXX: HDI CCD *UBVRI* Photometry of the Old Open Cluster NGC 7142 and Comparison to M67**

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Calibrate between different systems (e.g. Johnson to SDSDS) is really hard.

E. g. [https://arxiv.org/abs/2004.05605](https://arxiv.org/abs/2004.05605) (which I thought it was just impossible)

Bridging the Ultraviolet and Optical Regions: Transformation Equations between *GALEX* and *UBV* Photometric Systems

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# Absolute Magnitude vs. Apparent Magnitude

The magnitudes we observe are “apparent” ones.

An apparently faint star may just be a very far away bright star (or…? ;-) )

We define **“absolute magnitude” the magnitude of a star as if it was at a standard distance of 10 parsecs**.

$M = m + 5 \log d[pc] + 5$

<u>This is an incomplete version of an absolute magnitude!</u>

Distance modulus: $M - m = 5 \log (d/10pc)$

# Parallax

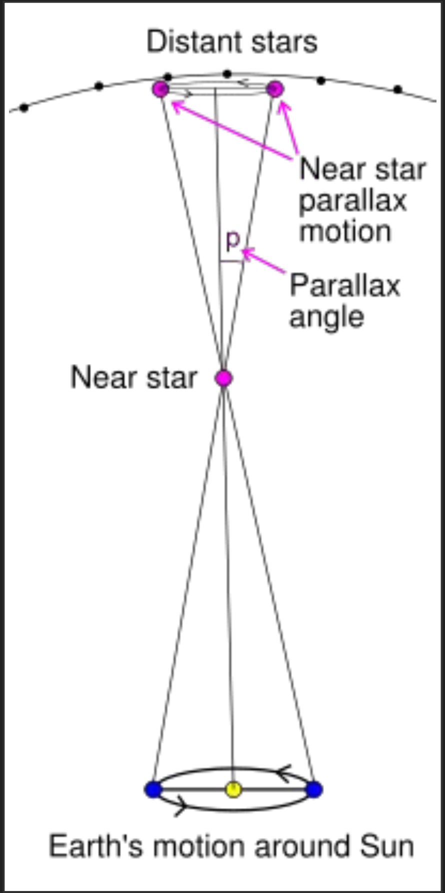
π = 1arcsec

corresponds to

206265 astronomical units

1 parsec

d[pc] = 1 / π(arcsec)



# Interstellar extinction

The universe is full of gas and dust.

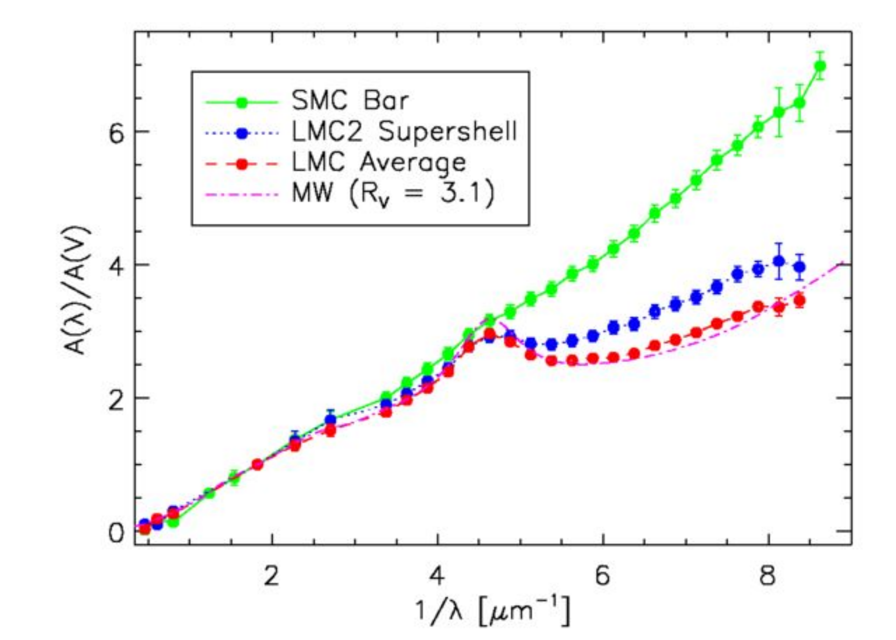
How does this gas and dust affect starlight?

Light gets absorbed and reddened!

$R_V = A_V / E_{B-V}$

The complete expression of "absolute magnitude" (note dependence on λ) is:

$M_\lambda = m_\lambda + 5 \log d[pc] + 5 + A_\lambda$




https://en.wikipedia.org/wiki/Extinction_(astronomy)

# Exercises

- Can you demonstrate that $f_\nu = ( \lambda^2 / c ) f_\lambda$ ?
- Can you calibrate the images that I passed you for the photometry exercise?
- Read Section 2 of https://arxiv.org/abs/2004.10902
- Read Section 1 of https://arxiv.org/abs/2004.05605