Calibration

February 1, 2024

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Instrumental Sensitivity & Calibration

Useful references

- Adam Block, *Deep sky imaging: workflow 1* in Rob Gendler (ed.) 2013, *Lessons from the masters* (New York: Springer), 159–192
- Ralph Bohlin et al. (2014), PASP 126, 7111B (HST master collection)

HII regions NGC 7635 (left) and NGC 7538 (right), LRGB (Mees Observatory image)

Flux calibration

Finally, the images need to be multiplied by the factor that converts DNs to physical units.

- The basis for this conversion: observations, interleaved with your target-object observations, of at least one standard star: one set of stars
  - which cover the sky and a useful range of magnitudes
  - which are monitored to ensure that they are not variable
  - whose flux density is traceable to laboratory standards with high precision and accuracy, and thus **for which $f_0(\lambda)$, in physical units, is known.**
- A good choice are the Vega-like A0V standards for almost all observations.
  - Same magnitude at all visible wavelengths
  - Essentially no absorption lines except for the hydrogen recombination spectrum

Flux calibration

- If you are observing with an Hα filter, your choices are
  - (preferably and easily) to add observations of another standard star without significant hydrogen absorption, such as a K giant (e.g. ξ Draconis, K2III)
  - (even more easily) to build your own chain of secondary calibrators from the later-type stars detected in your Hα image
- Either way,
  1. Select and observe standards near your target, or at least covering a similar range of zenith angle on the same night (in every filter that you are using, of course)
  2. Correct them for atmospheric attenuation
  3. Measure their DNs — mean and standard deviation — in each filter
  4. Scalar-multiply all target frames by the appropriate f_0/DN ratio

Where do the zero-points come from?

The flux or flux density for zero magnitude,

$$f_0 = \int_{\text{filter}} \tau(\lambda) F_\lambda(\lambda)\, d\lambda \qquad \text{or} \qquad F_{\lambda 0} = \frac{\int_{\text{filter}} \tau(\lambda) F_\lambda(\lambda)\, d\lambda}{\int_{\text{filter}} \tau(\lambda)\, d\lambda}$$

of a standard star like Vega (flux density F_λ in a given filter), is one form of the zero point for a photometric system.

Zero points are, in turn, built from a network of calibrations that took decades to get extremely precise and accurate.

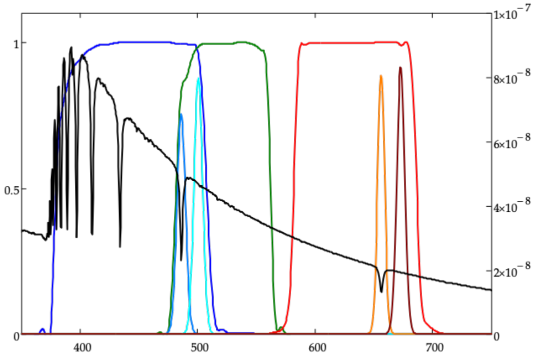
- Observation of laboratory light sources and bright standard stars with the same telescope and intruments (usually by Bev Oke).
- Detailed spectra of the bright standards.
- Fits of detailed stellar-absorption models to the spectra (usually by Bob Kurucz).

See the CALSPEC database for the calibration data in use on the HST.

Zero points for Mees Camera #2

On the Vega = 0 magnitude scale, using the CALSPEC spectrum and the transmission spectra of the seven filters that we will use for photometry.

- Fluxes given for the spectral-line filters, as this is the output normally desired for spectral-line images.
- For those filters, f_0 turns out to be close to $F_{\lambda 0}(\lambda_0)\Delta\lambda\sqrt{\pi/4\ln 2}$, which indicates that the narrowband filter profiles are essentially gaussian.
- For broadband filters, take the flux to be the product of $\Delta\lambda$ and $F_{\lambda 0}$ if need be.



Filter	Wavelength λ_0 [nm]	Bandwidth $\Delta\lambda$ [nm]	Flux density $F_{\lambda 0}$ [erg/s/cm^2/nm]	Flux f_0 [erg/s/cm^2]
B	442	128	6.18×10^{-8}	
Hβ	486.1	8.5	1.76×10^{-8}	9.84×10^{-8}
[OIII]	500.7	8.5	4.67×10^{-8}	4.22×10^{-7}
G	521	80.5	4.10×10^{-8}	
R	633	101	2.32×10^{-8}	
Hα	656.3	7.0	1.76×10^{-8}	1.31×10^{-7}
[SII]	670.0	8.0	1.92×10^{-8}	1.63×10^{-7}

Flux calibration

Conveniently placed in M 42 is V1073 Ori, a 9.50 magnitude A0V star. One night, we measured

$$B = 7.28 \times 10^4 \text{ DN/s}$$
$$G = 7.89 \times 10^4 \text{ DN/s}$$
$$R = 7.12 \times 10^4 \text{ DN/s}$$

for V1073 Ori. What flux conversion factors should we use for that night's RGB frames of M 42?

This is a special circumstance: we do not need to measure atmospheric absorption because V1073 Ori and M 42 are always observed in the same frame, **and there is negligible difference in** $\sec z$ **and absorption within each frame.**

Flux calibration

If the signal (current DN values) is actually in original DNs divided by exposure time, scalar multiply the B, G, and R frames by the factors

$$f = \frac{F_{\lambda 0}(\lambda_0)\Delta\lambda}{\text{signal}}$$

$$f_B = \frac{(6.18 \times 10^{-8})\,(10^{-9.50/2.5})\,(128)}{7.28 \times 10^4}\ \text{erg/s/cm}^2\text{/DN} = 1.72 \times 10^{-14}\ \text{erg/s/cm}^2\text{/DN}$$

$$f_G = \frac{(4.10 \times 10^{-8})\,(10^{-9.50/2.5})\,(80.5)}{7.89 \times 10^4}\ \text{erg/s/cm}^2\text{/DN} = 6.63 \times 10^{-15}\ \text{erg/s/cm}^2\text{/DN}$$

$$f_R = \frac{(2.32 \times 10^{-8})\,(10^{-9.50/2.5})\,(101)}{7.12 \times 10^4}\ \text{erg/s/cm}^2\text{/DN} = 5.22 \times 10^{-15}\ \text{erg/s/cm}^2\text{/DN}$$

Since M 42 is an HII region, every pixel without a star has a flux equal to the sum of the spectral line fluxes spanned by the broadband filters.

When and how to calibrate

Taking calibration data:

- **Dark and bias**: Every six months or so. Most recently around February 2024
- **Flat fields**: Every night, if possible
- **Standard stars**: 2–3 times during the night
- **Atmospheric opacity**: From stars in the images frames; no additional observation required

Use CCDStack
Use IDL or Python

The actual calibration happens during data reduction, not while observing:

- **Apply dark, bias, flat field correction**: Every frame, before alignment
- **Remove hot and cold pixels**: Frame by frame, before alignment
- **Measure zenith optical depth**: From stars in target frames, before normalization
- **Apply atmospheric correction and/or normalize**: Right before transient removal
- **Remove transients**: Frame by frame, after normalization and before averaging
- **Flux calibration**: Last step, after averaging calibrated and aligned frames