Observational Astrophysics
11. Spectrophotometry

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Spectrophotometry is the practice of doing absolute flux calibration of the spectrum. A lot of science that can be done with spectra does not require flux calibration (e.g. radial velocities, chemical abundances). There are, of course, other applications that require spectra in physical units (energy per unit time, per unit area, per unit wavelength) instead of just counts per second (e.g. accurate stellar temperatures, population synthesis of galaxies, distances to supernovae Ia).

Spectrophotometric fluxes require spectroscopic data that is obtained and processed with similar observational techniques used to acquire photometric data. As we discussed regarding photometry, one needs to be concerned here with the atmospheric extinction (as a function of wavelength) and the response functions of the instrumentation (telescope + spectrograph + detector).

One will then need to observe spectrophotometric standard stars, stars for which we assume the flux is known to high precision, to be able to model the effects of the atmosphere and the instrumentation. It is also common, however, to skip the observations of standards and instead of deriving the atmospheric extinction of the night, just assume a mean extinction law of the observation site. This approach will of course limit the absolute accuracy of your calibration (to $\sim$ 20%, typically), although the internal precision (in the comparison between stars observed during the same run) can be better.

Spectrophotometric observations for high-precision work need to be conducted when the sky conditions are photometric. The aperture used for the observations is usually wide, to include all light from the source without slit losses. The resolving power thus achieved is usually R $\sim$ 100-1000. Note however, that if the seeing is varying during the night (and even during the observation of one source), then the resolving power obtained will also be changing.

1 Read this text

To read details about flux calibration and standards, including also a bit of information about work on gamma ray, X-ray, submillimeter, and radio see Deustua et al. (2013)[1].

[1] https://link.springer.com/referenceworkentry/10.1007%2F978-94-007-5618-2_8

2 Summary of concepts

- As we mentioned before, to tie physical units to astronomical observations in an absolute sense, one needs to use laboratory reference standard sources and detectors (see Section 3 for references where you can find some related discussion and further references to explore). Ideally, one would need to observe the standard source using the telescope and detector in the same way that the science source is observed. Some of the history in calibrating Vega fluxes to physical sources is discussed in Megessier (1995)[2]. Sirius has also been suggested and used as primary standard, particularly in the infrared, as way to mitigate problems with the debris disk of Vega (Engelke et al. 2010)[3].

- An alternative as absolute flux calibrators are pure hydrogen white dwarfs. The atmospheres of such stars are believed to be simple enough that models are accurate to 1–2%, over certain wavelength ranges. The fundamental spectrophotometric calibration of the Hubble Space Telecope is based on three such stars (Bohlin 2007)[4].

- In practice, Vega and Sirius are too bright to be observed with large telescopes. They also might not cover all sky positions needed for the observations. Secondary "faint" standards have thus been defined and tied to the primary standards. A list of papers where spectrophotometric standards can be found is given in Section 3 below.

- Ideally, the observation of the standard stars should be done before and after the science target, at similar airmass and at the same region of the sky.

- For details of observing strategies and data reduction, it is perhaps good to have a look at some papers describing such work, as for example Krisciunas et al. (2017)[5] and the series about the spectrophotometric calibration of the *Gaia* data (Altavilla et al. 2015; Pancino et al. 2021)[6].

3 Additional reading

A review of the concepts, techniques, observations, and data for spectrophotometry above the atmosphere with the HST in mind is given in Bohlin et al. (2014)[7].

Some practical details for dealing with telluric lines when doing flux calibration can be found in Bessell (1999)[8].

A review about the calibration of spectroscopic data from space telescopes, including wavelengths from X-ray to infrared and a solar observations, can be found in Pauluhn et al. (2015)[9]. This

[2] `https://ui.adsabs.harvard.edu/abs/1995A%26A...296..771M/abstract`

[3] `https://ui.adsabs.harvard.edu/abs/2010AJ....140.1919E/abstract`

[4] `https://ui.adsabs.harvard.edu/abs/2007ASPC..364..315B/abstract`

[5] `https://ui.adsabs.harvard.edu/abs/2017PASP..129e4504K/abstract`

[6] `https://ui.adsabs.harvard.edu/abs/2015AN....336..515A/abstract` and `https://ui.adsabs.harvard.edu/abs/2021MNRAS.503.3660P/abstract`

[7] `https://ui.adsabs.harvard.edu/abs/2014PASP..126..711B/abstract`

[8] `https://ui.adsabs.harvard.edu/abs/1999PASP..111.1426B/abstract`

[9] `https://ui.adsabs.harvard.edu/abs/2015A%26ARv..24....3P/abstract`

reference also discusses calibration of primary standards against laboratory sources and provide additional references where more information on this topic can be found.

A detailed discussion about the problems limiting the accuracy of spectrophotometry calibrations can be found in Ivănescu et al. (2021)[10].

Lists of standards stars can be found in (and references therein): Oke & Gunn (1983)[11], Stone & Baldwin (1983)[12], Baldwin & Stone (1984)[13], Oke (1990)[14], Hamuy et al. (1992, 1994)[15], Stritzinger et al. (2005)[16], Gregg et al. (2006)[17], Falcón-Barroso et al. (2011)[18], Bohlin et al. (2019)[19], Pancino et al. (2021)[20].

There is a project called "NIST Stars", that aims to create a catalog of standard stars whose flux is traceable radiometric calibration sources with accuracy better than 0.5%, see `https://www.nist.gov/programs-projects/nist-stars`.

References

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[11] `https://ui.adsabs.harvard.edu/abs/1983ApJ...266..713O/abstract`
[12] `https://ui.adsabs.harvard.edu/abs/1983MNRAS.204..347S/abstract`
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[17] See `https://ui.adsabs.harvard.edu/abs/2006hstc.conf..209G/abstract` for the paper and `https://archive.stsci.edu/prepds/stisngsl/` for the database.
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