Photometry – a Brief Overview

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1. Introduction

Photometry is the part of observational astronomy that deals with measurement of the intensity of radiation from celestial objects. Photometric observations are defined in different wavelength ranges using filters in front of the detector. In the optical wavelength range one speaks of broad band, intermediate band and narrow band photometry when the wavelength intervals are of the order 100 nm, 20 nm and 5 nm respectively. If the resolution is higher one speaks of spectral photometry.

2. Photometric systems

This section refer to Bessell (1992). A light detector, a telescope, a set of colored filters and a method for correction of atmospheric extinction make up a natural photometric system. The standard system is defined by a list of magnitudes and colors measured for a set of typical standard stars. The term ”color” is an abbreviation for ”color index”, which is the difference between the apparent magnitudes in two different spectral regions. The zero point of many color systems is set so that the star Alpha Lyrae (Vega) has zero colors. The purposes with the filters and the resulting color indices are to extract some important features from the stellar spectrum. Thus for example the temperature and metallicity of a star can be obtained from multi color photometry.

The most important of early works of photo electric photometry are the broad band Johnson UBVRI and Kron RI systems, which covered the wavelength region between 310 nm and 900 nm.

Another important filter system is the intermediate band ubvy system by Strömgren. This system was devised to better measure the Balmer discontinuity, the metallicity and temperature of A, B and F stars.

There are many other filter systems available, designed for different stellar types and conditions. For example the DDO system, the uvgr system, the Geneva system, the Vilnius system, the Walraven system and the Washington system can be mentioned.

3. Detectors

One can imagine that early human beings fascinated looked at the stars and other celestial objects with the naked eye already in the beginning of the human evolution. The telescope was first used by Galileo in the 17th century but the eye was still used as detector. And so it was until the end of the 19th century when the photographic film was invented. Astronomers very soon started to use this revolutionizing technique to image different objects. The very interesting history from Galileos small telescope to the large 8 m ground based telescopes and the space telescopes of today is too extensive to describe here.

The photographic film has two main advantages over the eye. Firstly it is possible to integrate light over a much longer time than for the eye. Secondly the film can be stored and used for accurate measurements.

When the development of computers started it soon become interesting to digitize the photographic images to make computer based measurements and manipulations possible. Accurate scanning devices (micro densitometers) were developed for the purpose. The photographic film has a relatively low and non linear dynamic range and saturates for high light intensities and long integration times, which makes accurate photometry difficult also in the digitized images. However the photographic film has been a very powerful tool for astronomers for more than 100 years.

Accurate photometry was usually performed using photo electric detectors. It is only in the last 10 years in the era of integrated silicon electronics a new type of detector, the Charged Coupled Device (CCD), has made a new revolution in the astronomical community. The CCD produces a digital image, is highly linear, has a large dynamic range and, not least important, has a quantum efficiency of 20 % – 80 % depending on wavelength range, to be compared to 2 % – 3 % for the photographic film. Thus the CCD is very well adapted for high precision photometry. A modern CCD typically has a size of 2048^2 pixels, but larger 4096^2 pixels are available. CCDs are small devices and the field of view is typically quite narrow, why photographic film is still used for wide field imaging (for example in Schmidt telescopes). The images from a CCD usually need some basic data reduction such as bias and dark subtraction and flat fielding before scientific use. For long exposure times removal of cosmic ray hits usually is necessary.

4. Different types of photometry

For isolated stars on flat backgrounds in CCD images usually aperture photometry is the most accurate method to obtain the intensity and magnitude of a star. Aperture photometry means that the intensity of the stellar image is integrated over a circular aperture, with a radius of a few times the FWHM of the star. The background is usually estimated from a ring shaped surrounding of the star with large radius. For relatively bright isolated stars magnitude errors smaller than 0.01 magnitudes can be obtained with this method. Standard stars, used as photometric references, are often measured using aperture photometry.

In many images many stars are faint and overlap due to the crowding in the image. Another problem is that the Signal to Noise (S/N) ratio often is low for faint stars. Then different methods for crowded field photometry using PSF-fitting usually performs better than aperture photometry. The Point Spread Function (PSF) is the image of a star (a point light source) on the detector. The PSF is derived from stars in the image, either as an empirical image or by fitting an analytical function to the stellar images. PSF-fitting means that the normalized PSF is fitted to a star in the image to obtain the intensity and magnitude. The positions of the stars are usually obtained with a separate star detection program or simultaneous with the fit. If the stellar field is crowded some programs perform a simultaneous fit of the stars in small groups to make the code more efficient. The background level is estimated from a surrounding of the stars or simultaneous with the PSF fit. The photometric accuracy obtained with PSF-fitting depends on the used program, the crowding and S/N-ratio of the image and on the shape and accuracy of the PSF. If the stars are under sampled, it is usually difficult to use PSF-fitting with good accuracy. There are many photometric packages available that use PSF-fitting (see for example Spännare 1996).

Another problem is when the measured star is located on luminous uneven backgrounds consisting of nebulae or faint stars in galaxies. Then it is usually difficult to obtain a good background level for aperture photometry. Provided that a good PSF and a good model for the uneven background can be obtained PSF-fitting usually performs better. One new method that compares well with other photometry packages has been developed by Spännare (1996).

5. Information obtained from photometry

There is a huge amount of information that can be obtained from multi color stellar photometry. Only a few examples are presented here.

As mentioned in Section 2 the color indices, obtained with photometry with different color filters, give some important spectral information about the stars. For example the spectral class (temperature) of the star and the metallicity can be obtained. By plotting the HR-diagram for the stars in a cluster information about the age and chemical evolution of the cluster can be obtained. The stars in clusters are usually measured using crowded field photometry. By assuming a relatively constant absolute magnitude for supergiant stars in galaxies a value of the Hubble constant can be obtained. The velocity of the galaxy relative to earth can be obtained from the red shift in the spectrum of the stars. The distances to different objects can be obtained from photometry together with some additional information. For example the distance to the open cluster Hyades can be obtained with the convergence point method and the distances to nearby galaxies by measuring the apparent magnitudes and the period of variable stars (such as Cepheids) and knowledge about the period-luminosity relation. The measurement of supergiant stars or Cepheids in galaxies are typical situations which require good models of the luminous backgrounds.

6. This work

Some projects in progress at Lund Observatory deal with chemical evolution of globular clusters and the Hubble constant, the latter program through investigations based on supergiant stars in galaxies. This has prompted the development of the computer program POLYFIT, for photometry of stars on luminous uneven backgrounds. The program is evaluated and compared to some other photometry packages in this thesis.

References

M. S. Bessell, 1992, In: Stellar Photometry – Current Techniques and Future Developments, IAU Colloquium 136, p 22, eds. C.J. Butler and I. Elliott

S. Spännare, 1996, Photometry of Stars on Uneven Backgrounds, this thesis