Photometry in Astronomy

What is photometry and what is it useful for?

The word **photometry** derives from the Greek words 'photo', meaning **light,** and 'metron', meaning **measure**. It is the process of measuring the **intensity** or **brightness** of an astronomical object by adding up its total output of light.

When a telescope collects incoming light from a star, the light is focused onto a tiny microchip inside a **charged-coupled device** (CCD). This microchip consists of a large grid of light sensing, picture elements called **pixels**. When light falls onto a pixel the atoms within the pixel **release electrons** and the pixel becomes charged, this process is called **photoionization**.

The number of **electrons** that are released by the pixel is **proportional** to the number of incoming **photons**. At the end of the exposure, the number of electrons in each pixel is counted and read by a computer as **counts** or **intensity.** We use this to determine the object's **apparent magnitude** (see "Calculating Magnitudes" worksheet).

The brighter the star, the more electrons are released from the pixels and therefore the higher the counts or intensity.

However, there are a few complications…

When you look up at the night sky, the stars will appear as little pin-points of light. But turbulence in the Earth's atmosphere makes the positions of stars appear to change slightly over time – this is why we see stars "twinkle". When you take an image with a telescope and camera, you typically use an exposure of tens of seconds or minutes to collect more light in the image. During this time, the twinkling of the stars causes their light to smear and the result is that each star appears more like a fuzzy disc rather than a distinct point on the image. This effect is referred to as **seeing.** Figure 1 shows the same stars in two different images. Figure 1a shows an example of good seeing and Figure 1b shows an example of bad seeing.

Figure 1 – Examples of good and bad seeing.
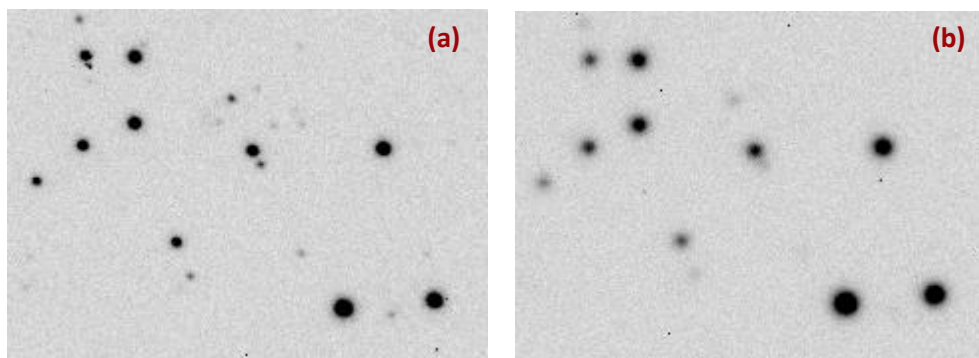
In order to account for the effect of seeing and to be sure we are measuring ALL of the light from a star, we must make sure that **all of the light** within this fuzzy disc is measured.

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Aperture Radius

So how do we make sure we measure the total light from the star?

As the stars in our images are more-or-less circular in shape, we use a circle to surround the star and count the pixel values (the number of electrons that have been released) in each pixel within this area.

It is important to first decide on the most appropriate size of this circle within which we measure the star's intensity. The radius of this circle is called the **aperture radius**.

If we use an aperture radius that is too large, we will measure too much **background light** in the image. Also, if the star is near to another object, e.g. a galaxy, then the light from the galaxy will contaminate the light from the star. On the contrary, if we use a radius that is too small, we will not measure all of the light emitted from the star.

The importance of this is illustrated in Figure 2, where the red circle represents the aperture radius.

Here you can see the aperture on the left is too small and does not cover the entire star. However the aperture on the right is too big and encompasses a lot of background sky.

Figure 2 – Changing the aperture radius size.
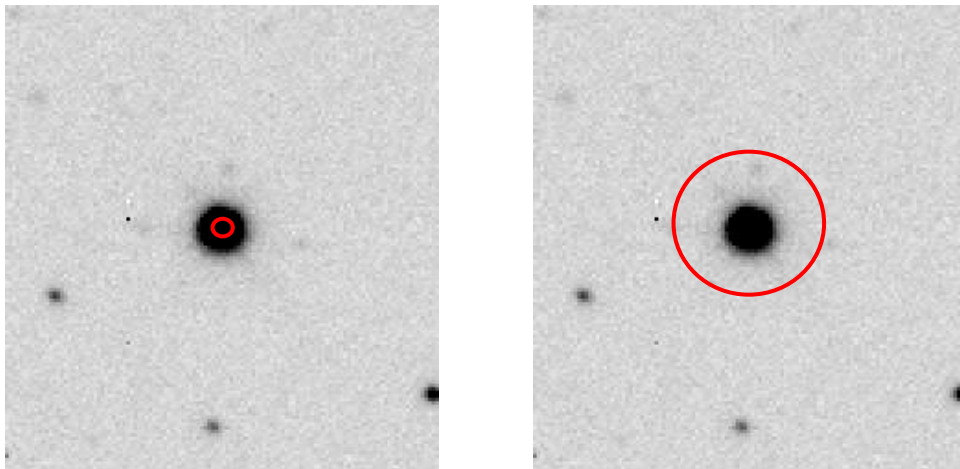
Instrumental Magnitude

The 'Calculating Magnitudes' worksheet shows us how the magnitudes of astronomical objects are measured and calculated.

The CCD cameras used with telescopes measure the incoming light from an object (usually a star) which can be used to derive its magnitude. However, telescopes and CCDs are **not uniform** which means that the magnitude that is calculated will depend on the instruments that are used.

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This value is referred to as the instrumental magnitude; this value can only be used to compare the brightness of objects in the same image. A more useful value is the apparent magnitude; this is a calibrated value that accounts for the instrumental influences and can be used in comparison with objects across different images and taken with different telescopes.

There are also additional factors external to the CCD that will cause the number of counts to vary slightly across images. As a result the star could appear to be changing in brightness.

We have already mentioned the effects of seeing, can you think of any other factors that might cause these variations?

You may have acknowledged that these variations can be seen due to factors such as changes in **weather**, the **phase of the Moon** and the **angle of the telescope** (how much atmosphere it looks through).

All of these will influence how many photons fall onto the pixels within a CCD and therefore how bright the star is measured to be. The measurements need to be corrected for these effects.

To do this we use **comparison stars**. These are stars that have been measured to establish that they are reliable, non-variable stars. Comparison stars appear in the same field of view as your target object and therefore will be affected in the same way by the factors discussed.

So, by measuring a number of comparison stars as well as your target object in each image, any variations that the comparison stars display can be attributed to environmental factors/seeing effects and can be used to correct the measurements of your target object. You are then able to obtain the **apparent magnitude** of the star and determine its **true variability**.

FITS Files

Your **phone** or **camera**, like telescope cameras, also have CCDs in them and will take photographs that are formatted as **jpeg images**. However, photometry is typically performed on FITS files. This stands for **Flexible Image Transport System** and uses a **digital format**.

FITS files are commonly used in astronomy due to their ability to store data. They hold much more information than jpegs and were specifically designed for scientific data.

Some of this extra information is stored in the **FITS Header** and will include details such as the coordinates, the date of observation and the telescopes that were used.

Software

There are many **free software packages** that have been developed for carrying out photometry. Two of these are listed below, with the accompanying link to where you can download them.

Makali'i: https://makalii.mtk.nao.ac.jp/

SalsaJ: http://www.euhou.net/index.php/salsaj-software-mainmenu-9

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If you have performed photometry before, you may wish to use an alternative, however instructions on using both of these two packages are provided.

Uses of Photometry

So once we've performed our photometric measurements, what can we do with the data?

One particular application of photometry is the study of stars that display variations in their brightness, known as **variable stars.** Photometric measurements can be used to generate a **light curve** that illustrates how these stars **change in brightness over time**.

We can also use photometry to look for **exoplanets**. An exoplanet is a planet outside of our Solar System, orbiting another star. By measuring the light output from this star over a period of time, we may see changes (depending on the angle of inclination as illustrated in Figure 3). When there is a periodic drop in the light, it is an indication that there is something in our line-of-sight towards the star, blocking (or partially blocking) our view of the star. This could be an exoplanet. However, this method will only work for transiting exoplanets with respect to our view from Earth. If the exoplanet does not follow an orbit that passes between our line-of-sight on Earth and its star, we will not detect this drop in light output, this is illustrated in Figure 3.

Figure 3 – An exoplanet transit across its star (left) and a non-transit exoplanet (right) with the resulting light output that is measured from Earth.
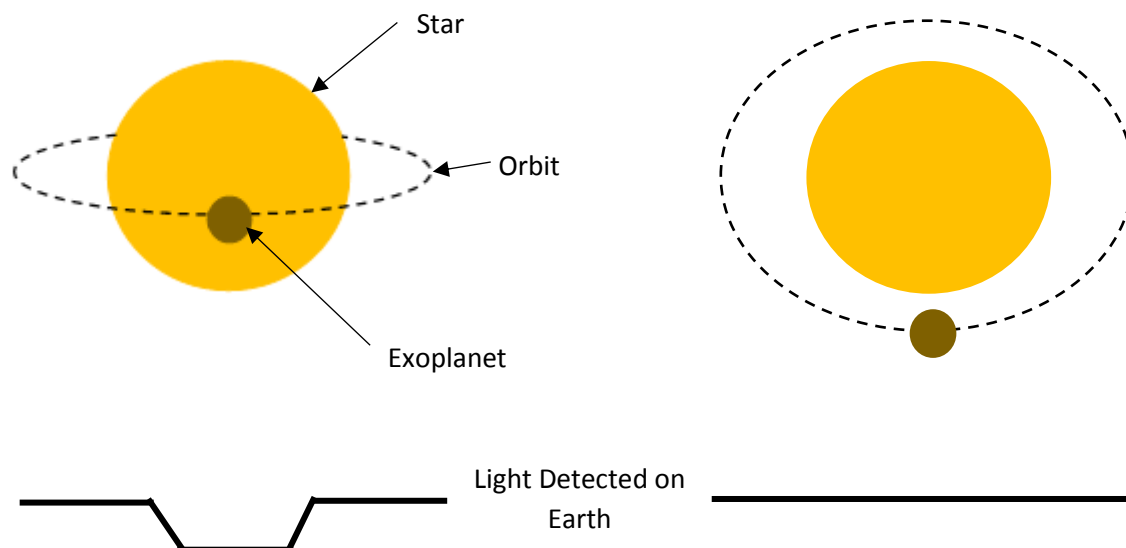
The shape of the light curve of a star with an exoplanet transiting across it will appear different to a variable star or an eclipsing binary (a system involving two stars where one star periodically passes in front of and blocks the light from the other star, due to the angle at which the system is viewed). Therefore different shaped light curves indicate different causes of variability. For more details on this see the 'Variable Stars and Light Curves' worksheet.

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Astronomers also generate catalogues from various different **astronomical surveys** containing positions and photometry for all stars that have been observed. These catalogues may contain information for millions of stars (a billion, for Gaia) and are used in many different scientific studies.

If you want to check your understanding of photometry in astronomy, see **Quick Quiz 4**.

Differential Photometry

The activities that accompany these worksheets guide you through carrying out differential photometry. This involves observing a target object (a supernova) and a number of comparison stars at the same time, using the same instruments and filters. From our observations we can calculate a **differential magnitude** by subtracting the average magnitude of the comparison stars from the magnitude of the target object.

This is perhaps the most straight-forward method of performing photometry. The comparison stars are measured and used to cancel out the instrumental effects in the measurements. We can then use this to investigate how the magnitude of the target object varies over time by plotting measurements in a light curve.

To have a go at carrying out photometry, see the photometry worksheets.

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