UNIT 3:

DISTANCES (2nd part). QUASARS

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ACTIVITY

LIGHT CURVE OF A QUASAR

OBJETIVES

This activity aims to familiarize students with the brightness measurements in astronomical images, deepening in the use of the tools provided by the image analysis software. In addition, it seeks to show how to recognize and identify celestial bodies in the images with the help of a star map of the area where the objects to be studied are located. For this purpose, we will use a series of images of a quasar obtained by the Liverpool Telescope and we will study the variation of its brightness.

INSTRUMENTS AND EQUIPMENT

For this practice we are going to use a selection of images of a quasar, specifically 3C454.3, taken over a period of several months and obtained with the Liverpool Telescope of the Roque de los Muchachos Observatory. These images are contained in the *QUASAR* folder of our web page **www.iac.es/peter**. For their processing we will use the *Peter_soft* program, which can also be downloaded and installed. The most used tool of this program will be the brightness measurement.

METHODOLOGY

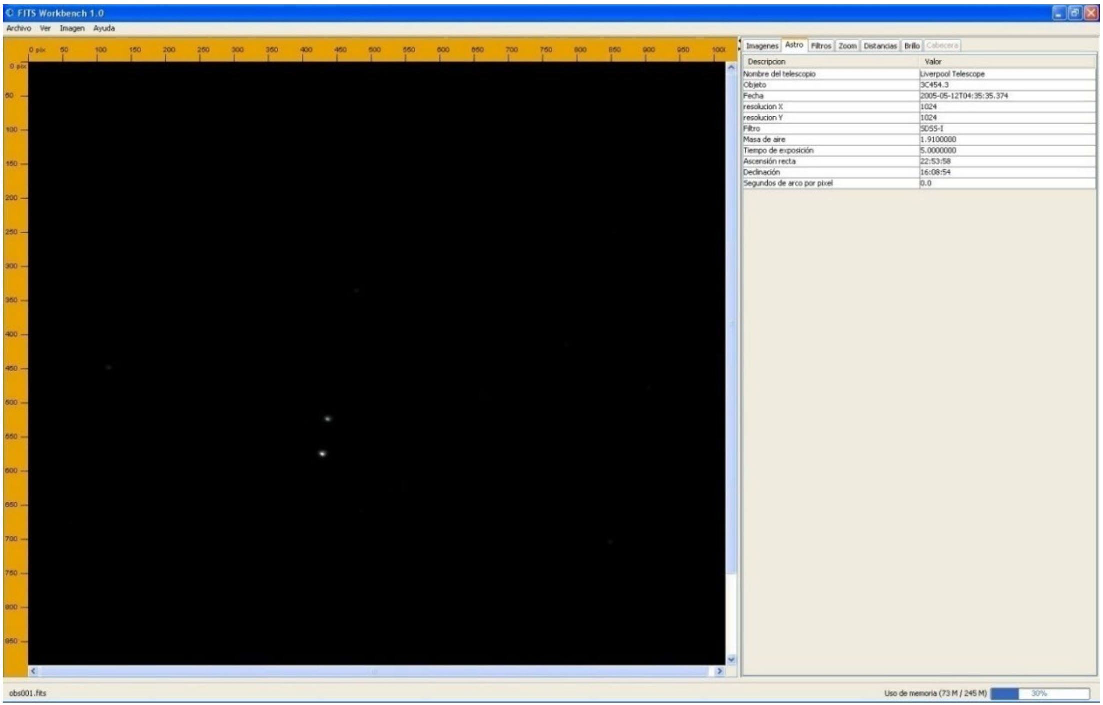
First we will download the image set and examine each of them, identifying the object to be studied and the comparison stars. Then, we will obtain an estimate of the brightness of each of these objects. Finally, we will plot the difference in brightness between the quasar and the comparison star to study the variability of the quasar.

PROCEDURE

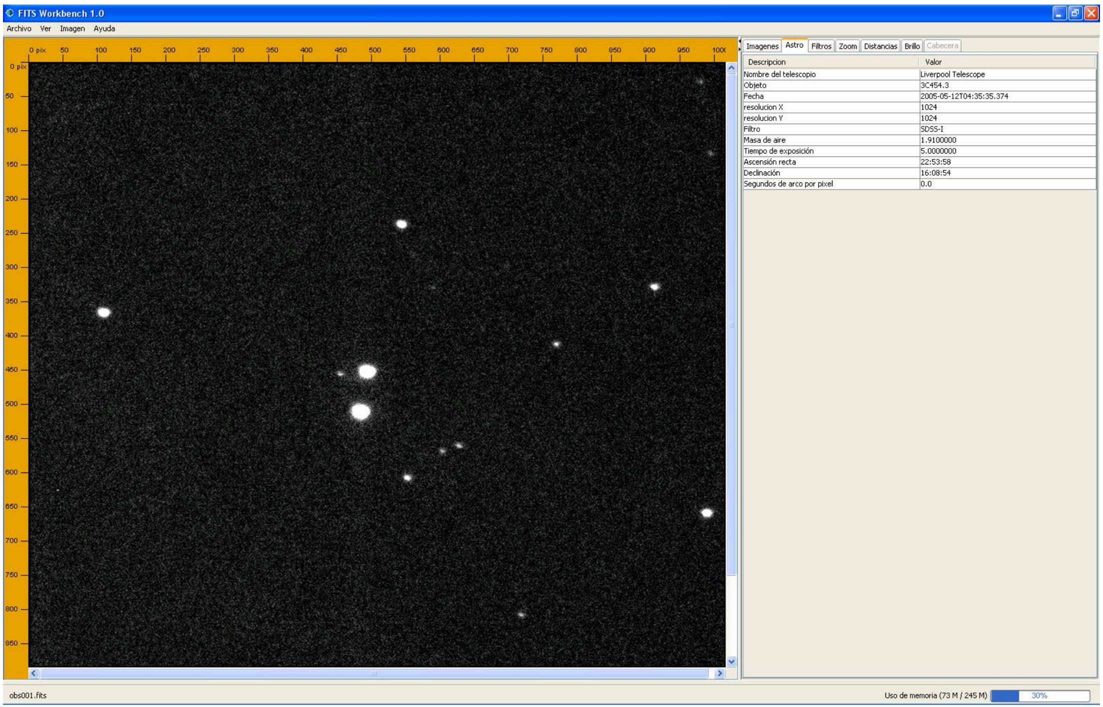
Open the images and identify the quasar

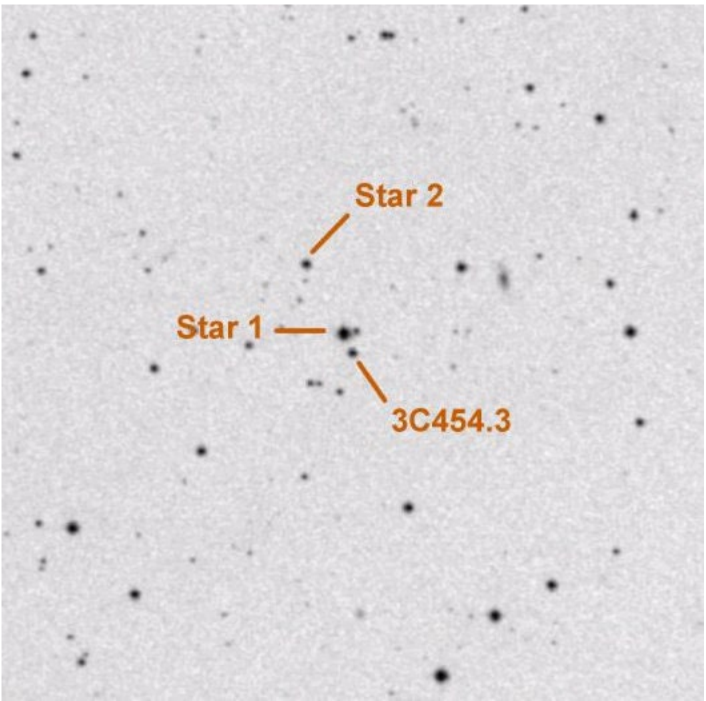
En primer lugar, procederemos a descargar y descomprimir en el disco duro el archivo *U3_imagenes_quasar.zip*, donde se encuentran todas las imágenes del cuásar que vamos a estudiar. Posteriormente, ejecutaremos el programa de análisis de imagen *Peter_soft* y abriremos las imágenes a estudiar de una en una.

Once the images are loaded into the program, we can obtain information about each of them in the *ASTRO* tab, for example, date and time when the image was taken. This data, together with the brightness of the celestial bodies to be studied, is what we will need to complete our practice.



Using the zoom and filters, we will improve the visualization of the image in order to find the quasar we want to study. To locate it, we will use a sky chart of the area of the sky where 3C454.3 is located, in which we have marked the position of the quasar and two non-variable stars ('Star 1' and 'Star 2') that will serve as reference stars.





Sky chart of the area of the sky where the quasar 3C454.3 is located

It is very important to make sure that we have located the quasar without any doubt, because if we make a mistake in this, all subsequent measurements will be incorrect. For example, in the image above we have to realize that the field is rotated 180º on the vertical axis with respect to the celestial chart, that is, it is its mirror image. If in any of the images we have doubts when locating the quasar, it is preferable to discard that image and not take it into account.

Watch out! Images obtained with a telescope usually have the same orientation, but this does not always have to be the case. Some telescopes have a mount that, when taking images of the same region of the sky, their orientation changes depending on the position of the telescope. This is the case of the Liverpool Telescope and the series of images of the quasar 3C454.3 we are studying. Keep this in mind when looking for the quasar in each of the images.

If you look at the three images above, the field has rotated, so you have to compare the position of the bright objects in the image until you correctly identify the quasar and the reference stars 1 and 2 before measuring their brightness. We repeat: if in doubt it is better to discard the image.

How the quasar brightness changes

Each of the images was taken at a different time. We are going to measure the brightness of the quasar in each of them to see how it changes over time. But we have a small complication: the brightness we measure can go up or down for other reasons than just the quasar processes: small changes in the Earth's atmosphere or in the camera from one day to the next can make the whole image a little brighter or a little darker. Therefore, in addition to measuring the brightness of the quasar, we will also measure the brightness of the reference stars. The brightness increases or decreases in the image will also affect these stars and through them we will be able to measure them so that they do not affect our results.

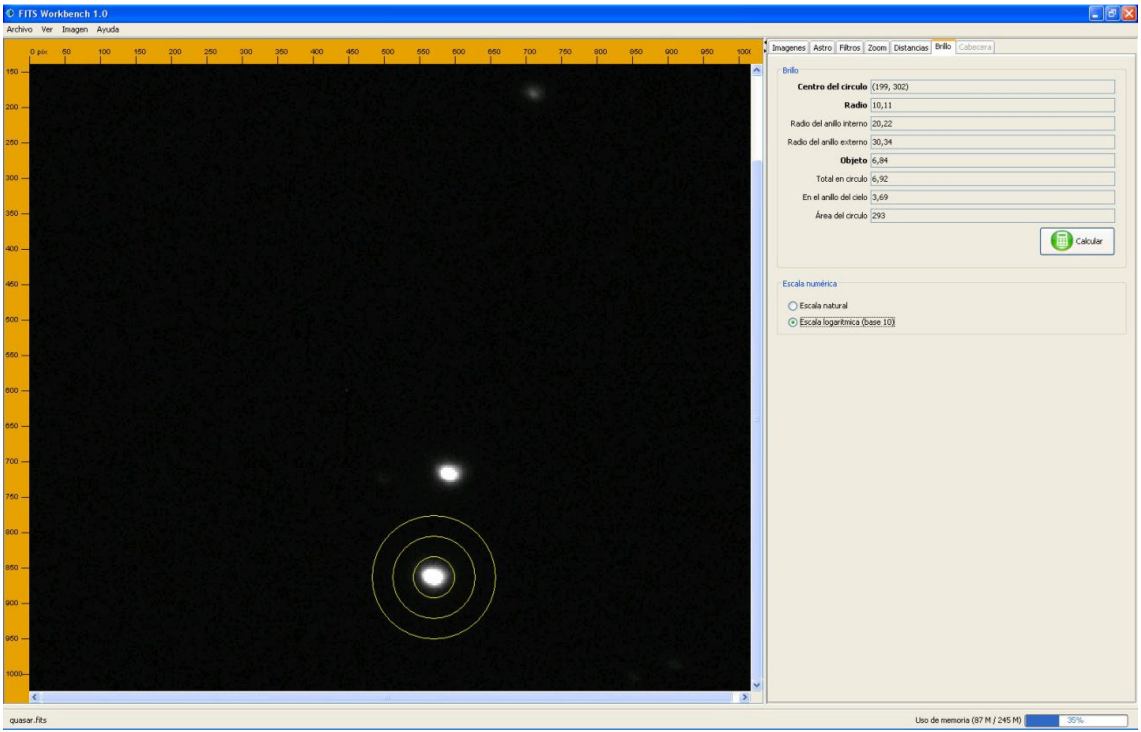
The method is as follows: we open an image, locate the quasar and the reference stars. We measure the brightness of the quasar and one of the reference stars, the one we choose. We write down the values and repeat the same operation with the next image, until we have a table of data that we can use to observe the changes.

Measuring the brightness of the quasar and the comparison stars

In a CCD camera what we have is a series of light sensors placed in a grid. These sensors receive photons during the exposure time and then send an electrical signal indicating how much light they have captured. We call each of these sensors a pixel. The brighter the object, the more photons each pixel collects.

The light from our object, be it a star or a quasar, is spread over several pixels around a point. What we have to do is to add up how many photons have been received in all the pixels that form the image of each of the objects: the quasar and the two reference stars. To do this, we must tell the program which pixels we want to sum.

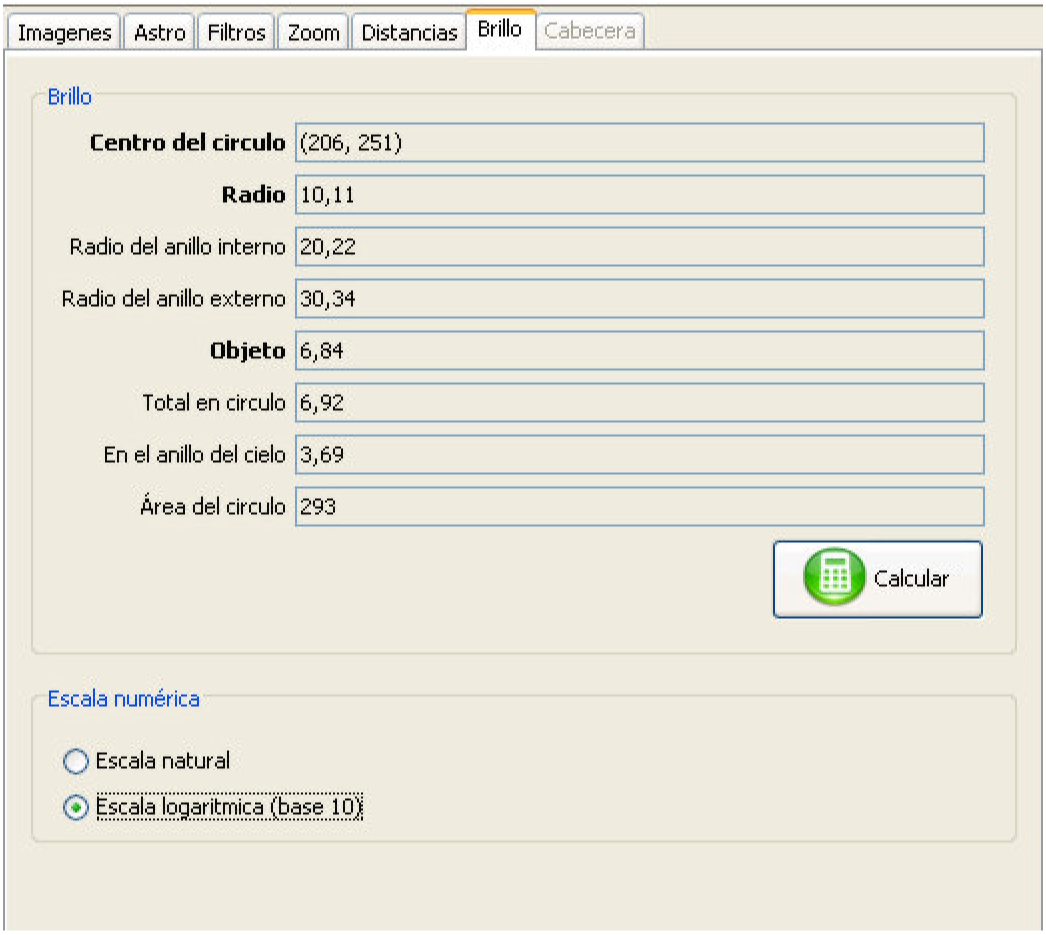
We select the tool *Brillo* (Brightness), then we click with the left mouse button on the center of the object and move at the same time. We see that three circles are formed.



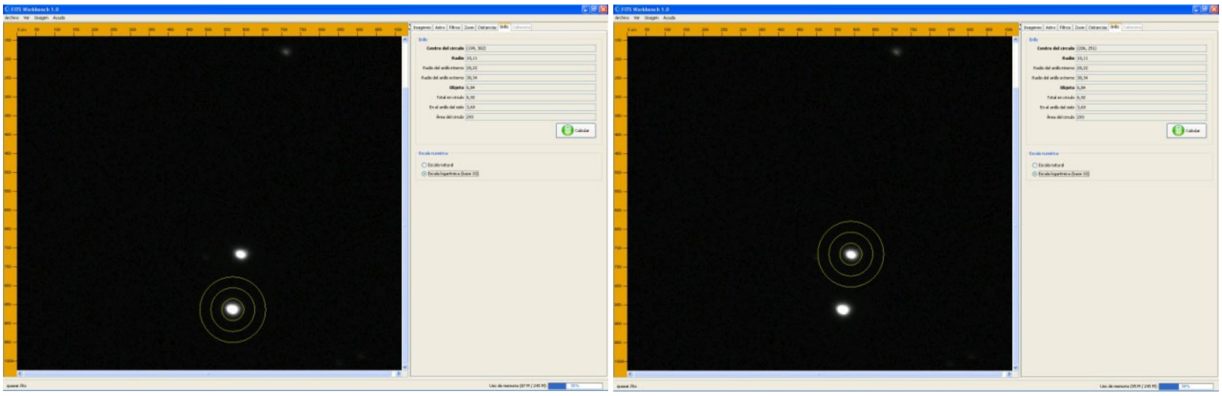
The first circle, the smallest one, is the one we must match with the pixels we want to add. We should not make the circle too big or too small, but adjust it as much as possible to the size of the object. We can zoom in on it to see it better.

What do the other two circles do? They will serve to subtract the background brightness. Apart from the photons coming from the object, the camera also receives photons coming from the sky background and from the thermal noise of the camera itself, and they will be added to the light we count in our object. That is why we want to know how many they are and subtract them from the total calculation.

The other two circles draw an area of sky around the star and calculate what is the background brightness in that region in order to subtract it. Don't worry, you don't have to do the calculation, the program does this operation by itself. Your job is to point out where the quasar or star is, size the circles as you think is most appropriate and press Calculate. The program will tell you the brightness of the object (subtracting the light coming from the sky background).



The counts can be obtained in two different scales: natural scale (you will get thousands or millions of counts) or logarithmic scale (in base 10) like the one you see in the image above. You can use the one you want, but **the scale must always be the same** in all the images. It is also advisable to **always use the same radius** in each of the images.



The astronomical technique we are using is called **photometry**. It consists of measuring the brightness of celestial objects in a certain range of the electromagnetic spectrum. In our case, if you look at the *ASTRO* tab, all the images have been obtained with the same filter, SDSS-i, which corresponds to a wavelength range between 6930 and 8670 *Angstroms*.

When you analyze the reference star, you will see its brightness changes. It is not that it is a variable star, but that every night and at every moment the image may be affected by different conditions. For example, there may be cirrus clouds (high clouds) or dust in the atmosphere that night; even the different height of a star above the horizon produces changes in the measure of its brightness. The latter is due to the different path that the star's light has to take as it passes through our atmosphere, which you can see with the Sun: when you see it on the horizon at sunset, doesn't it seem to shine much less brightly than at noon?

Therefore, the measurement of the brightness of an object by itself is not useful if we do not compare it with some reference. Hence, we need to obtain the brightness of the quasar and the reference star in each image. By making a quotient between the two and plotting it for each date, we can check how the quasar brightness changes over the weeks. What we are doing is **differential photometry**, that is, studying the variation in brightness of our quasar with respect to a fixed brightness star that serves as a reference.

Image	Date and time	Brightness of 3C454	Brightness of reference star	**Quasar brightness / Star brightness**
Obs001				
Obs002				
Obs003				
Obs004				
Obs005				
Obs006				
Obs007				
Obs008				
Obs009				
Obs010				
Obs011				
Obs012				
Obs013				
Obs014				
Obs015				
Obs016				
Obs017				
Obs018				
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Obs036				
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Obs041				
Obs042				

Obs043				
Obs044				
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Obs046				
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Obs048				
Obs049				
Obs050				
Obs051				
Obs052				
Obs053				
Obs054				
Obs055				
Obs056				
Obs057				
Obs058				
Obs059				
Obs060				
Obs061				
Obs062				
Obs063				
Obs064				
Obs065				
Obs066				
Obs067				

Now, just plot the last column against the dates and you will see how the brightness of the quasar has changed over time.

Do you observe how it decreases? Is this decrease constant? Do you see if there is any periodicity in the decrease of brightness?

For further information, visit our website: **www.iac.es/peter**

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