The Dark Side of Galaxy Evolution : Coursework Assignment

Having completed the lecture series, you should now be in a position to do some basic analysis on real galaxy optical data and assess their major properties. This exercise consists of a combination of optical photometry (which you will perform yourself) and HI spectroscopy (for which the measurements have been provided). The goal is to analyse a sample of 25 galaxies. For each one you will need to measure and/or obtain the following properties : apparent magnitude (in the g and i bands), absolute magnitudes, position on the colour-magnitude diagram (it is sufficient to state whether you think the galaxy is on the red or blue sequence or in the transition region), morphology, HI mass-to-light ratio, and HI deficiency. The easiest way to report these findings is via a table (a template is provided of which you may create your own copy, or you may find it more convenient to reproduce in Excel or other spreadsheet software).

For each galaxy, you should also record if you see any evidence of any unusual interactions. Write a short description (1 or 2 sentences maximum) of anything you see that you think indicates some environmental effect the galaxy is experiencing and why. To help you, the template table contains a hyperlink to the SDSS and NED for each galaxy. Consulting NED can be useful for a literature search to see if any unusual features have been previously reported, but *do not* go overboard : many galaxies have appeared in thousands of papers, and if you can't see anything unusual in the data, chances are that trawling through the literature won't reveal anything. There's no need to spend more than a few minutes checking for interesting papers, unless you want to !

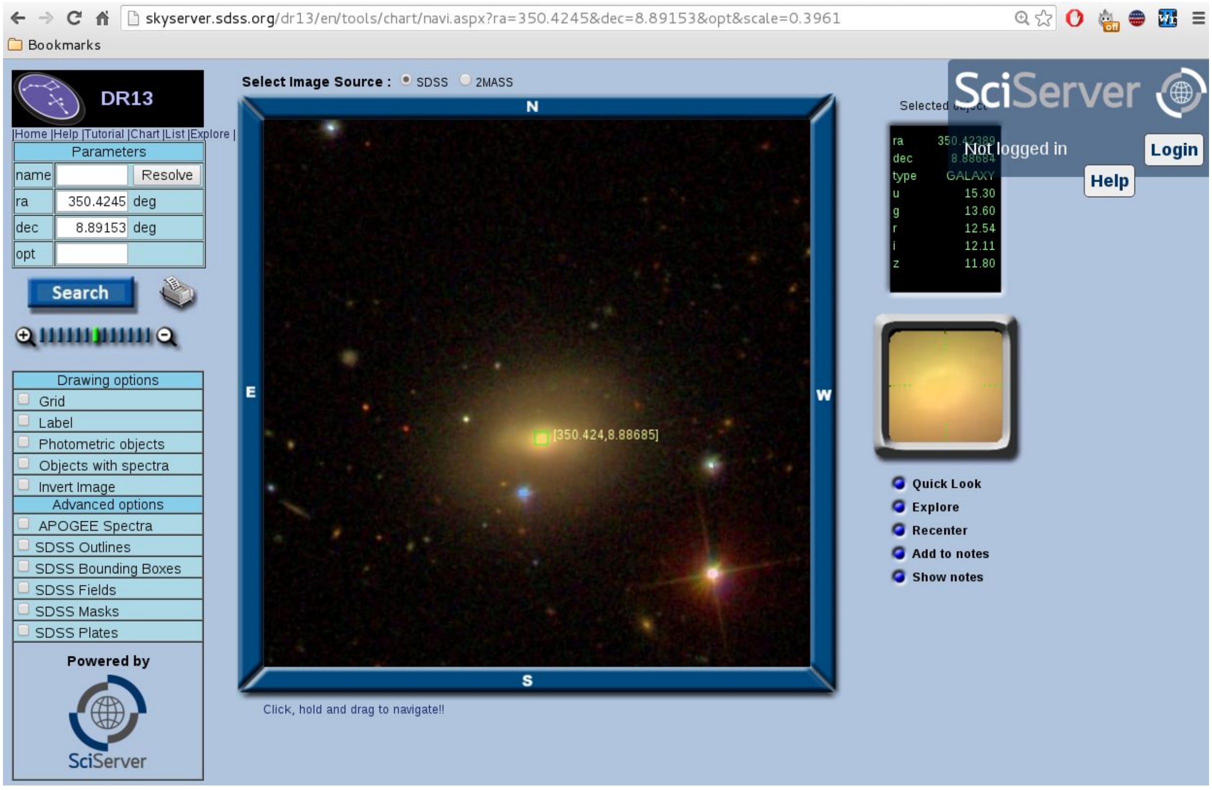
The complete set of *g* and *i* band FITS files, along with the HI spectra and data files, are provided as a zip file for download.

Some galaxies in this sample were detected by an HI survey and have been given a fake name (e.g. "Galaxy 01"). For these cases, the links in the table take you the coordinates of the HI. You will then need to decide for yourself which (if any) of the visible optical galaxies are associated with the HI. From the SDSS navigate tool, click on any object you think might be the counterpart (it will be within the default field of view and should be near the centre), then hit the "Explore" button on the right. From there, you can access NED (via the lower left of the screen) to get specific data about that object. In particular, check if the velocity matches that of the HI - but remember, not every object has an optical redshift measurement. Once you've decided which galaxy you think is the optical counterpart, find its common name using NED and add it to the name column.
Hints : For most cases this should be very straightforward. A FEW cases are ambiguous or may not even have an optical counterpart at all - there is no need to attempt photometry for these objects.
For comparison, a few galaxies have been included which do not have HI detections. These galaxies are listed in the table using their name from a common catalogue.

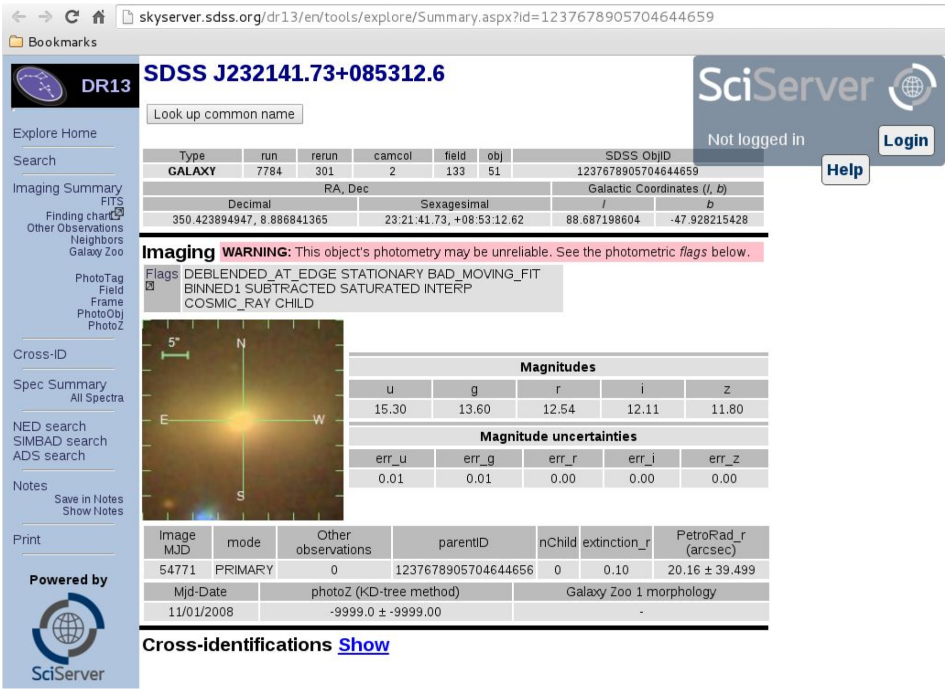
All of the equations you will need are in the course notes. The following pages contain a detailed guide to using *ds9* and *funtools* to do the photometry. Remember, you will need to use NED to get the extinction corrections for the magnitudes. These should be applied to your apparent magnitudes you record in the table. You can also (sometimes) find the morphological type in NED but do not take these too strictly as they are somewhat subjective.

A worked example

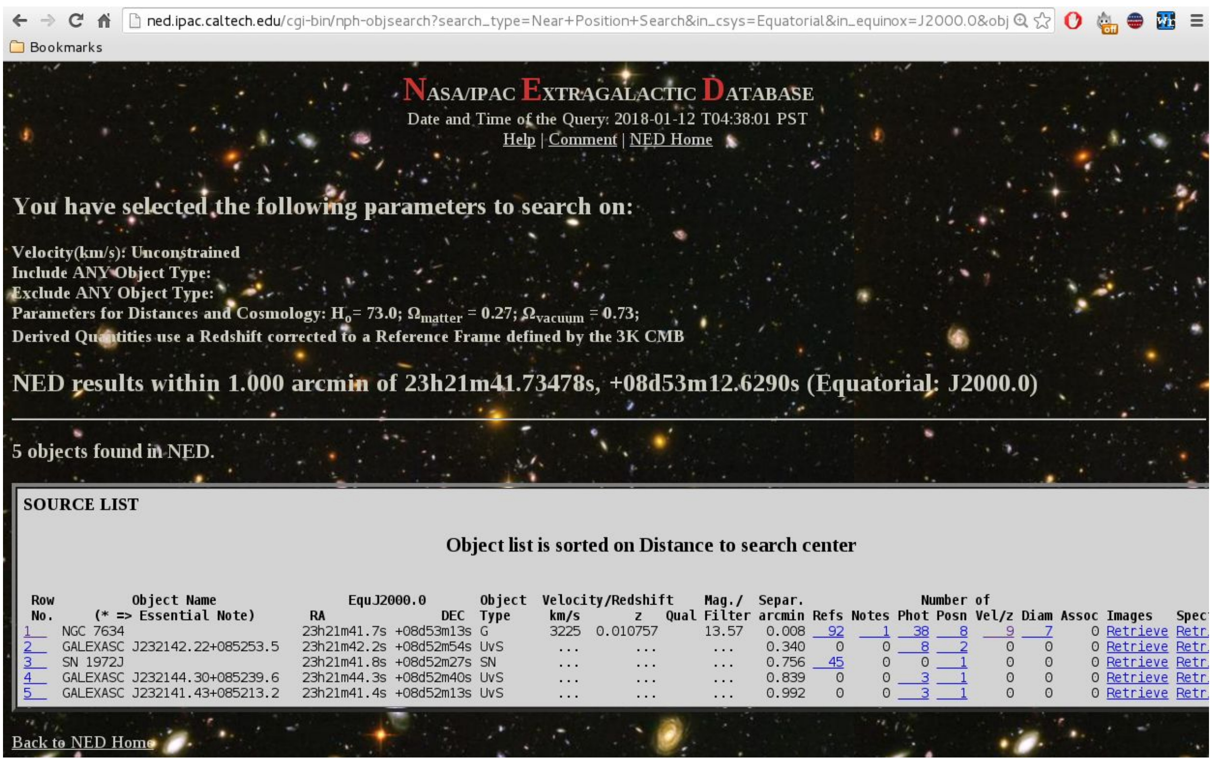
Clicking on the following link will reveal something like this :



The link displays the SDSS image of a region centred on the coordinates of an HI detection. In this case only a single bright galaxy is visible, and it's near (but not exactly at) the centre of the image, so we can be extremely confident that it's associated with the HI. Just to check, click on the centre of the galaxy. A green square should appear. On the right three panels are shown : at the top, some basic information about the source (in this case correctly identified as a galaxy but often not; don't trust the magnitude estimates given below); the middle shows a close-up of the selected region; the lower section contains various other buttons. Click on "explore"here, which should give :

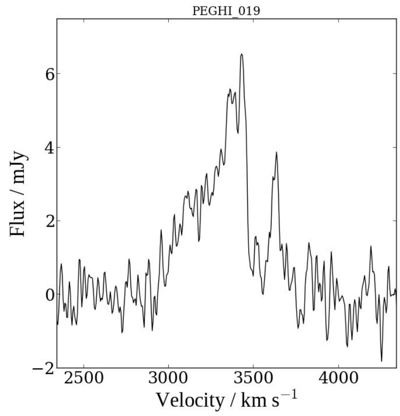


For other objects you might see something slightly different if they have an SDSS spectrum, but we don't really need anything from here. Instead, click the "NED search" button in the left panel and you should get :

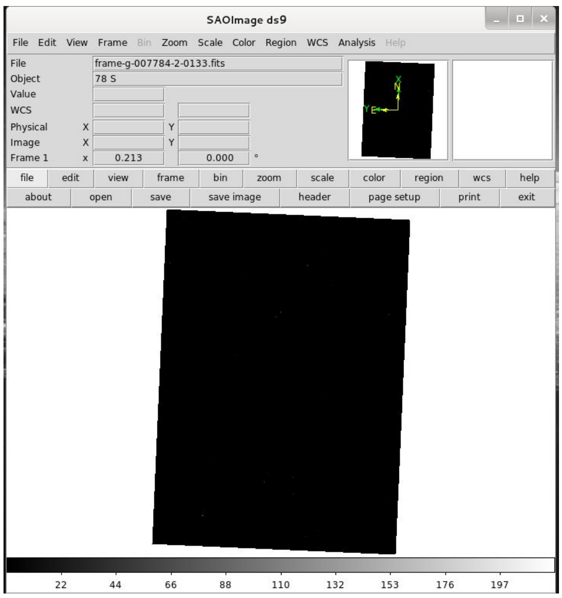


You can see that there are several objects found in this region (the NED search is limited to 1' - you can change this by altering the "radius" parameter at the very end of the address bar), which are listed in order of proximity to the search centre. Only one object is given the "G" (galaxy) object type, which is the one closest to our supplied coordinates. Also, this object has an NGC (New General Catalogue) number, as we expect most bright galaxies to do (the others, apart from the SN (supernova) object, all have automated catalogue measurements, meaning they're likely to be much fainter). This already makes it overwhelmingly likely that it's the first object in the list that's associated with our HI detection.

The best test we can possibly have to ensure that we've really picked the optical counterpart is to compare the optical and HI redshifts. Check the HI measurements [here](#) - the "line centre" parameters reveal the velocity is about 3340 km/s, whereas the redshift reported from NED is 3225 km/s. The difference of 115 km/s is a little high - we might typically expect < 50 km/s. But this galaxy is a little unusual - it's an early-type, and so the kinematics of the HI can be expected to be a bit weird. And indeed, if we actually look at the HI spectrum, we see it's clearly unusual. It has two peaks, but one of them is very lopsided and it doesn't resemble the classical double horn (a.k.a. "Batman") shape at all. So it's a safe bet that this galaxy really is the optical counterpart of our HI detection.

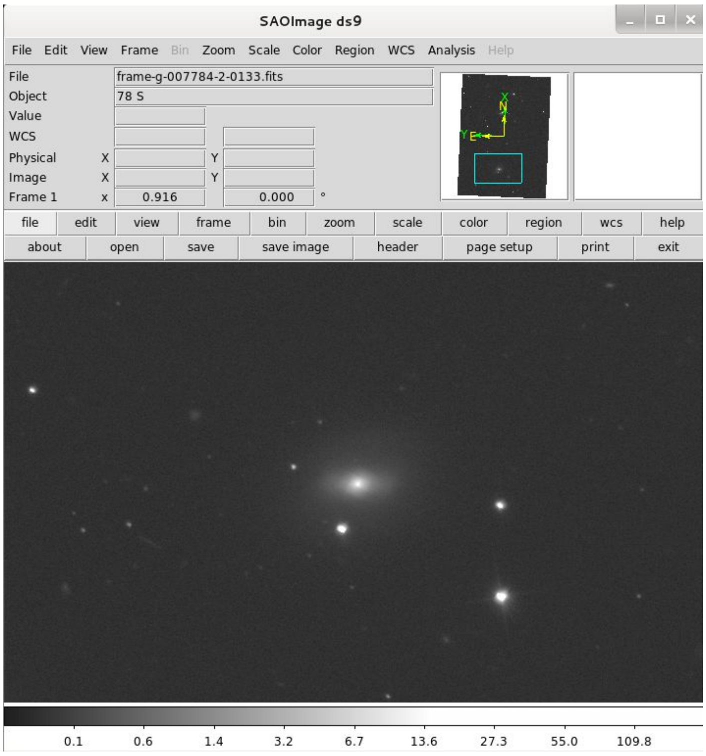


Now we can start to do photometry. Open the *g* band FITS file in ds9. To make it easier to navigate, hit "Zoom" ***in the top banner*** and then "Align" from the drop-down menu. This will orient the image in the same standard convention as shown in the SDSS browser, though the field of view will not necessarily be the same. As a starting point, it's also helpful to choose "Zoom -> Zoom to fit frame", which will zoom out such that the entire field of view is visible.



The default image will be black with perhaps a very few white dots. This is because the default colour scale is not suitable for our purposes. A much better result is obtained using "Scale -> Log". You can refine this further using the percentage cuts in the same drop-down menu, and right-clicking and dragging will adjust the contrast more strongly. All these procedures do is alter the display - they do not change the data itself.

You can reposition the centre of the image by middle clicking, and zoom using the mouse wheel. You can also zoom using the options in the Zoom menu (top banner), which also has the "Pan Zoom Rotate" option at the bottom for really fine control.



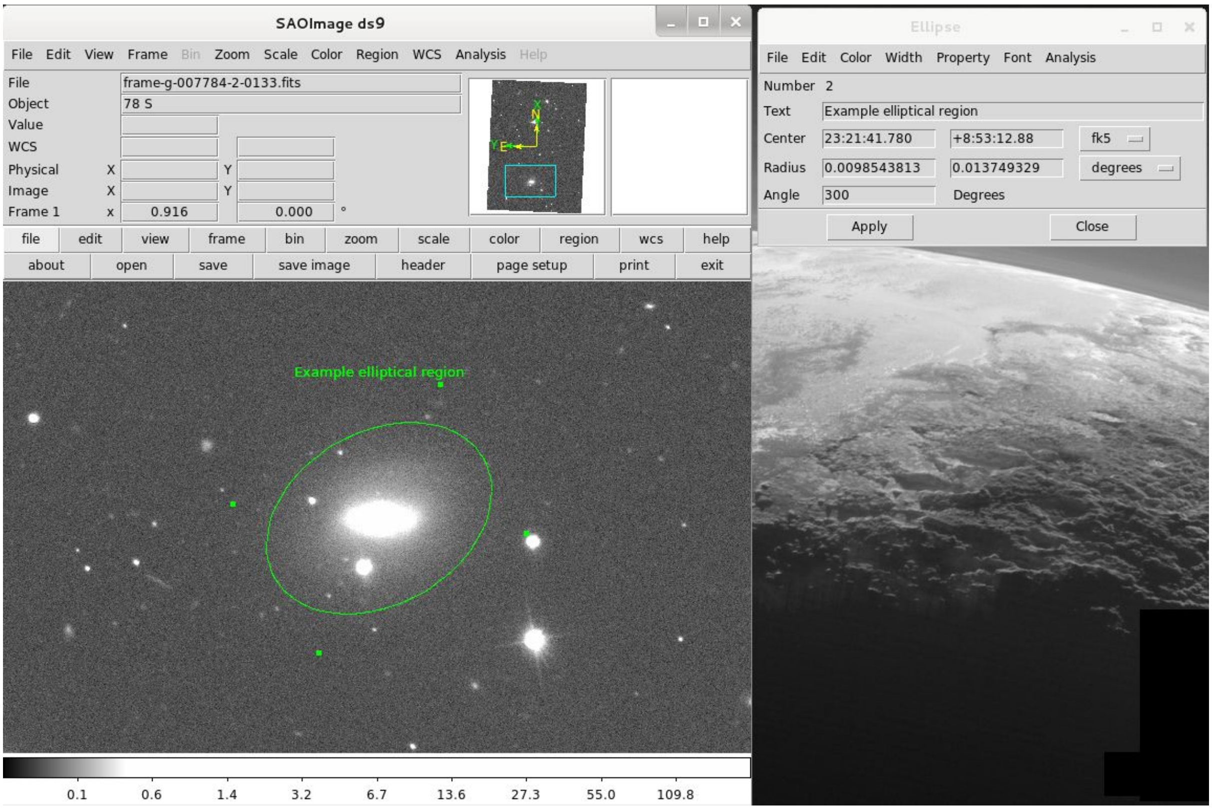
Once you've located your target galaxy, you need to define a region to measure it (see the lecture 2 course notes). By default, left clicking will place a circular region. If you do this accidentally, you can get rid of it in a number of ways :

- Left click inside it to select it, then hit either the delete key on the keyboard or go to "Region" (in the middle banner, not the top menu) and choose "delete". Note that both of these options will just delete the region without prompting you if you're sure.
- From the middle banner, choose "Region" and then "Delete all". Don't do this if you have any regions you want to keep !

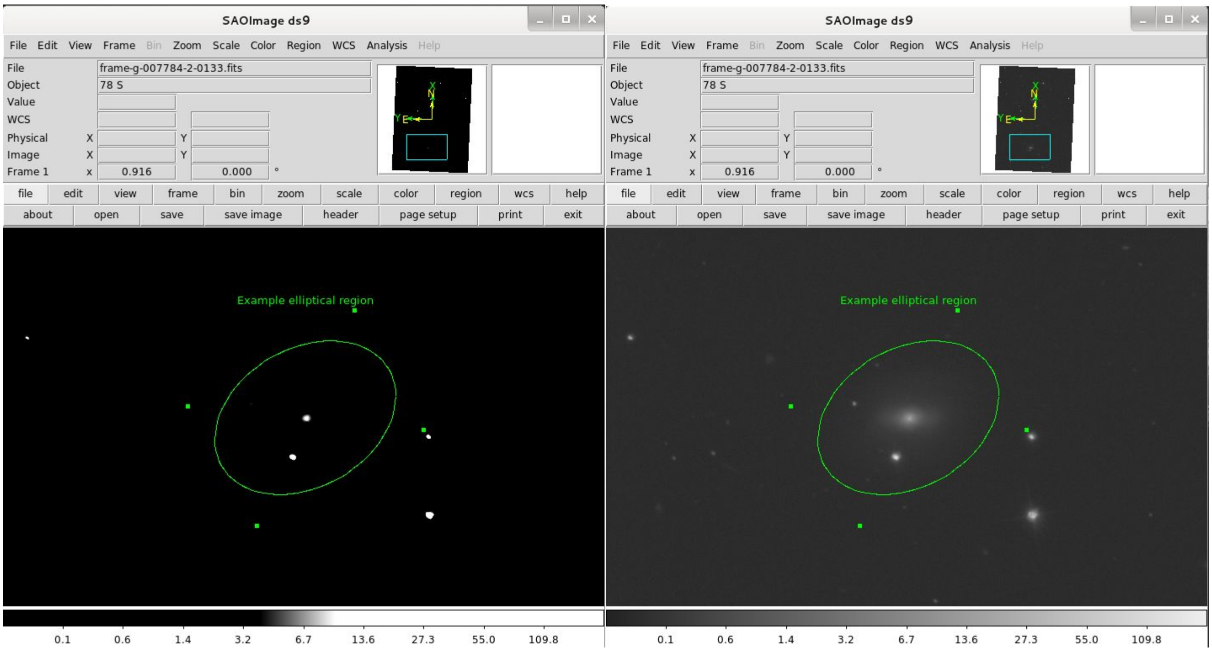
Try and get into the habit of clicking the middle button/wheel instead of the left one, to avoid having to delete unnecessary regions all the time.

A circular region would be adequate for basic photometry in this case. But we'll get a slightly more accurate estimate if we use an ellipse. To create an elliptical region, go to the top banner's Region button and choose Shape -> Ellipse. Then left click and drag to define the region as before. Note that with an ellipse, moving the mouse will define both its vertical and horizontal size. Just release the button to accept the region. If you need to reposition it, left click anywhere within the region and drag it to where you need it.

You'll probably need to rotate the ellipse to get a better fit. Double left-click inside it to bring up its Property box. In here you can set the position angle. You might then need to resize the region, which you can do by clicking and dragging on any of its four green control points. You can also choose how the coordinates are displayed with the drop-down menus on the right. If you want, you can add some text to label the region in the main display window.

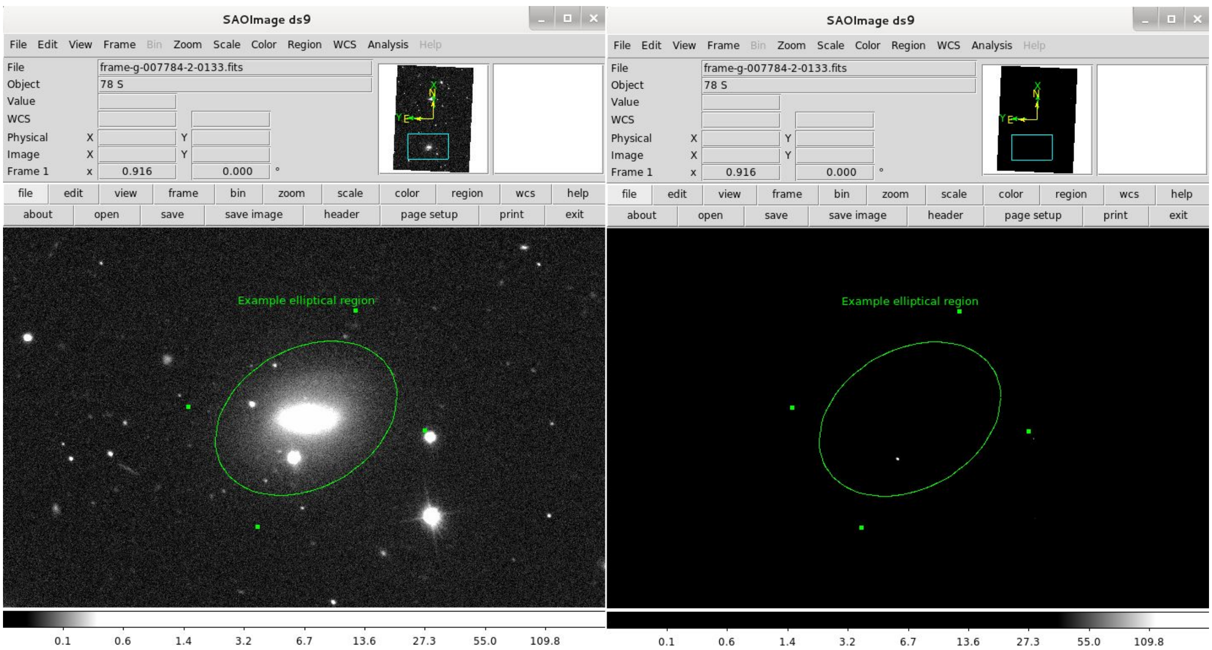


Note that the Property box also allows you to change the colour and thickness of the region's line, which can be helpful making regions more clearly visible if you have a very bright source. Remember to play around with the contrast by dragging the right mouse button to accurately see where the source ends ! See the course notes for more details, but the easiest way to understand this is to test it yourself : watch what happens to the colour bar as you move the mouse (while holding the right button) vertically…



Moving the mouse vertically downwards restricts the colour range to almost black-white (left), giving a very high contrast but making it difficult to see fine details; moving the mouse vertically upwards (right) expands the colour range to give a full greyscale, making some features easier to see but lowering the contrast and making edges harder to detect.

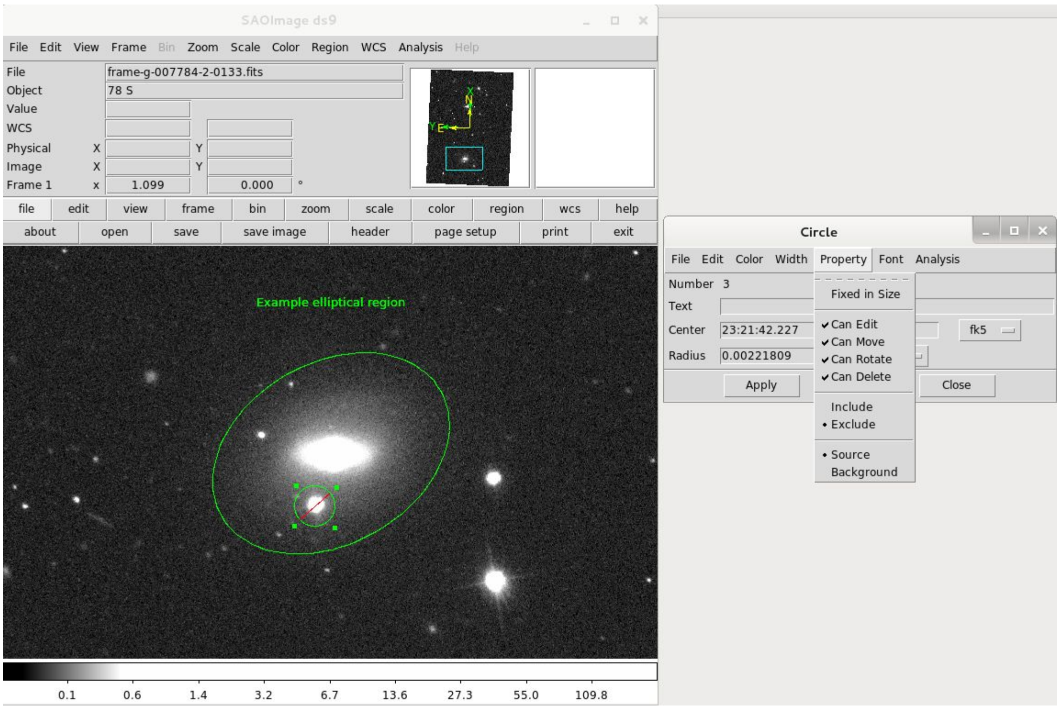
… and horizontally :



Moving the mouse left places the maximum colour level (i.e. white) at a lower flux level, making faint features easier to see but saturating bright features (left image).. Moving it right places the maximum colour at a higher flux level, making faint features harder to see but giving more dynamic range within bright structures (right image).

By default, the region created will have all the properties set to simply integrate the flux within it. However, you may need to mask any overlapping sources that would contaminate the measurement.

Foreground stars can be masked using circular apertures (and perhaps a couple of boxes if they show bright diffraction spikes); other galaxies usually require circles or ellipses. Regardless of shape, to create a mask you need to set the following properties :

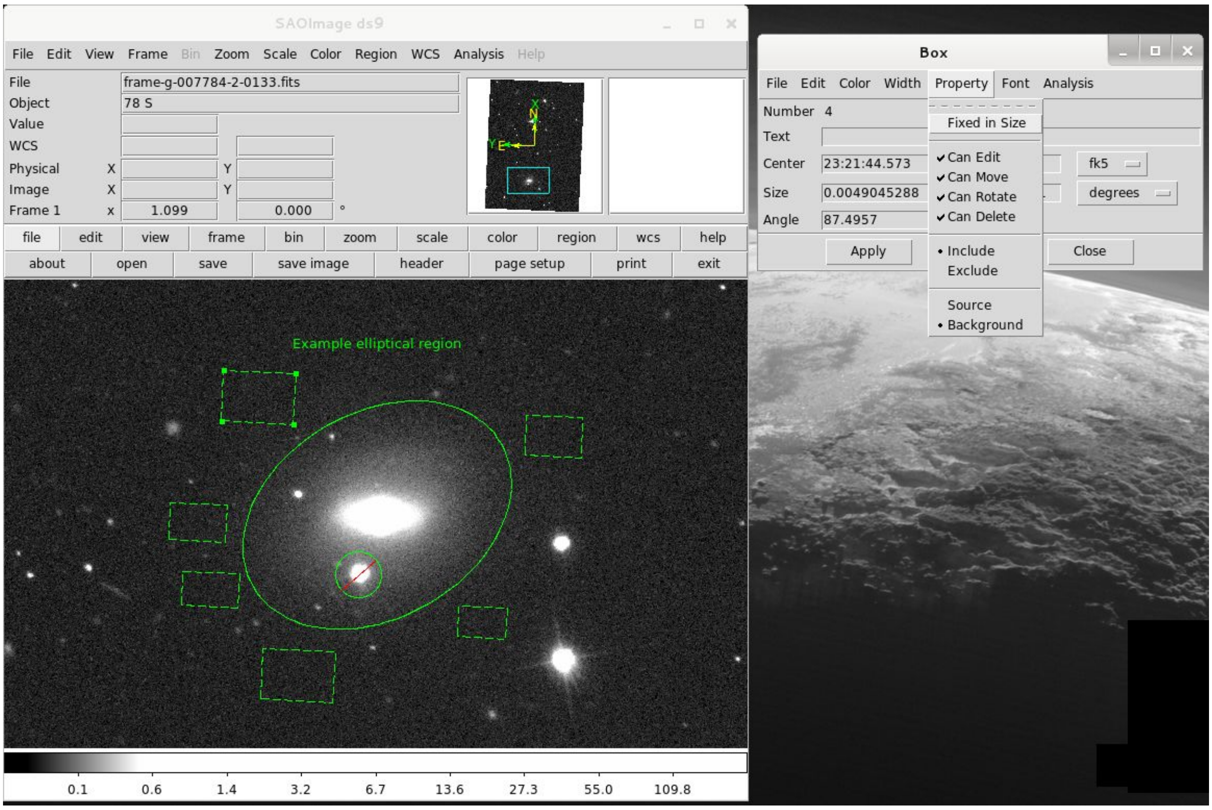


The region will then have a red strikethrough line in the main display, as shown.

Often, regions can overlap so it can be hard to select the one you want if you need to alter its properties. In this case, for example, if we left click inside the circular mask within the elliptical source aperture, we might select the source region by mistake. If we're lucky we'll be able to click inside the part of the region which doesn't overlap with the source, but often, as above, this isn't possible. Pay attention to the control points which are visible - they indicate the region you've got selected, as well as the name as the most recently-opened Property window. If in doubt, close all Property windows and double-click on the region you want again. If you can't select the region you want, use the Region menu (either top or middle banner) and choose "Back" or "Move to back" to move the selected region behind the overlapping regions. You should then be able to select the region you want.

The last set of regions you need to create define the background. These will be used to estimate the background level, which is then subtracted from the source region to give you an accurate measure of the total flux. For SDSS data, the background level is generally close to zero anyway, so this step is just a refinement. For other data sets this can be much more critical.

Background regions are not something you want to spend very long with, so the easiest solution is probably to use box shapes. Set them to define the background with the following settings in their Properties box (note their dashed outline in the main display) :



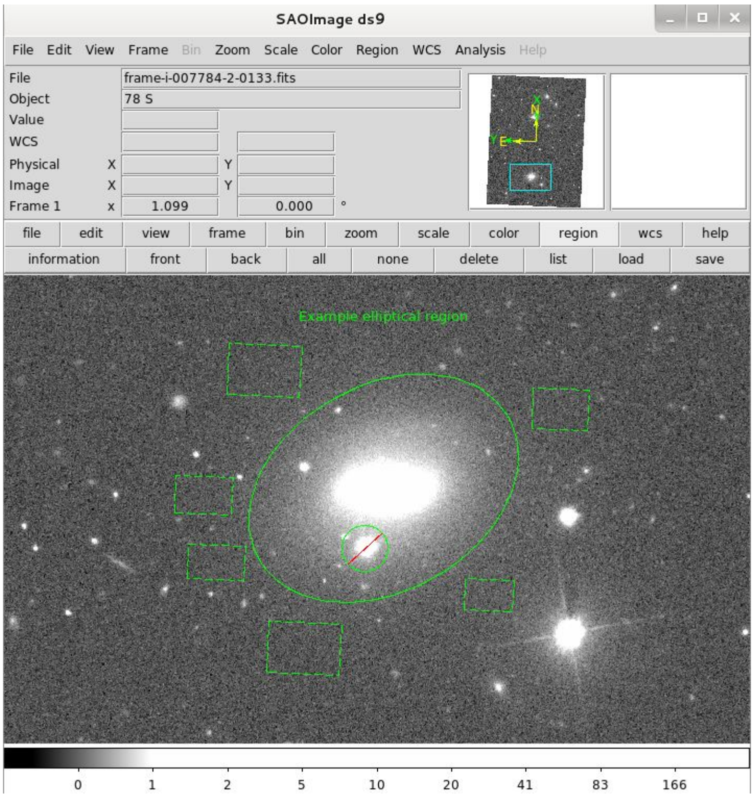
This is a quick, crude example. In reality I'd probably make the source region a bit bigger, mask at least three or four additional things within it, and probably add a couple more background boxes.

To avoid having to set these for all the regions, first create one background region, then duplicate it using the top Edit menu (Copy-Paste, as normal, but note that the usual ctrl+c ctrl+v keyboard commands *might* not work !). Of course you can also use this to quickly mask multiple objects.

When done, get the net counts via Analysis -> Funtools -> Counts in regions, as demonstrated in the second lecture.

The final essential step is to save your regions to a file. Either use the top banner "Region -> Save Regions" or the middle banner "Region -> Save". Save it in the directory where you have the FITS file stored. You might want to give it a file name corresponding to the waveband you've been working with - we'll see why in a moment. Once you've chosen the name, you'll be given a small prompt. The default options of the file format "ds9" and "fk5" are fine. The region file created will save ALL your regions, included those that aren't selected.

Saving the regions makes it very much easier to do a repeat analysis on the second waveband to get colour information. Load the other FITS file ("File -> Load") then the regions ("Region -> Load region", either top or middle banner). In this case we get :



In this example I started with the *g* band and then loaded the final regions onto the *i* band FITS file. Since the galaxy looks very similar in each band, this saves having to recreate the region from scratch. So we get the second waveband photometry almost - but not quite - for free. They're not quite identical, so we may need to resize some regions, move others, delete a few and add a few new ones. In practise, for the majority of cases these adjustments are very minor and often not necessary at all. In the above example, we see quite a few more things within the source region that probably need to be masked (likely red globular clusters that are barely visible in the *g* band but show up more clearly at the longer *i* wavelengths). For these I'd create another, smaller mask region, then just create copies for each thing I wanted to mask. I probably wouldn't change the source or background regions at all.

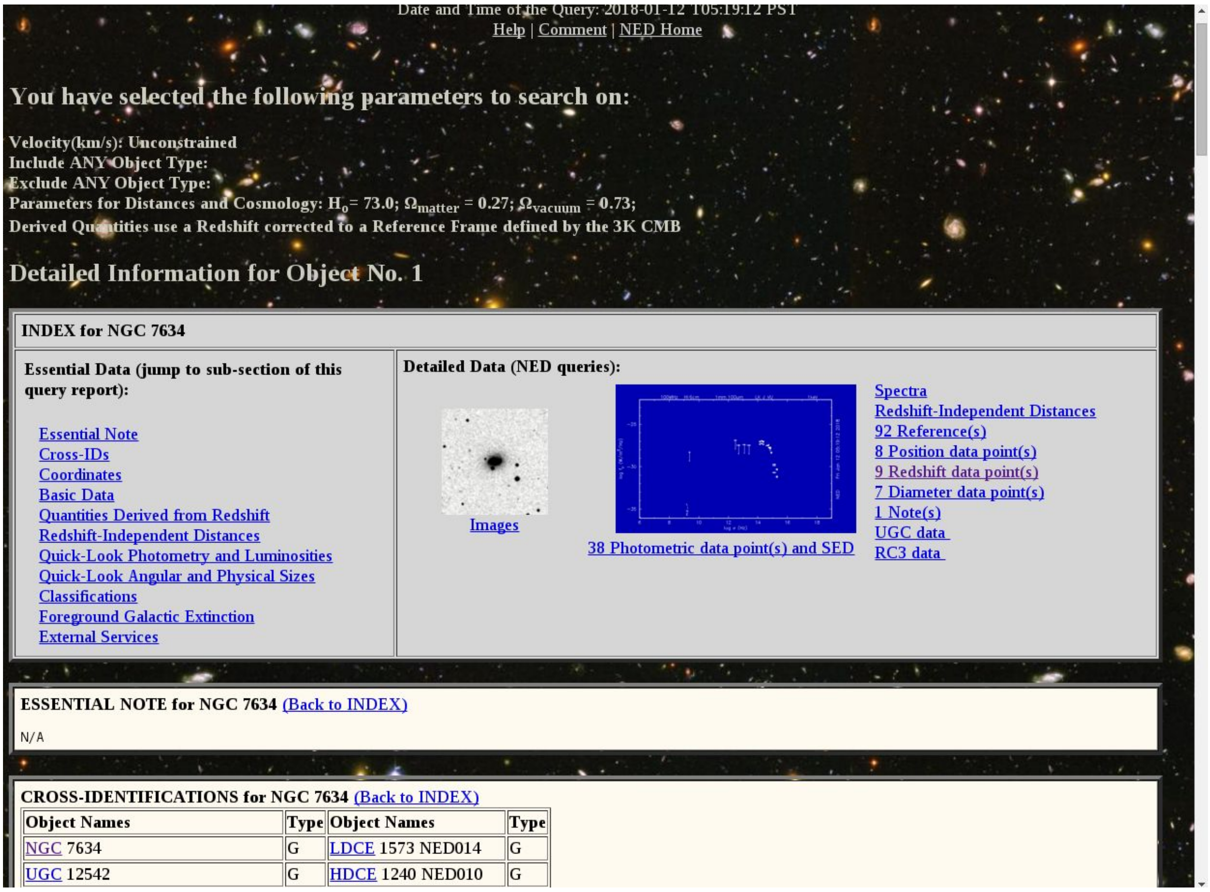
For the purposes of estimating the size of the galaxy, use the source regions from the *g* band. If you use an elliptical aperture, choose the largest "Size" value from the Property box. Make sure you get the right coordinates to use for the equation given in the course notes to convert angular to physical size.

That's really all there is to it. A few other tips :

- You can smooth the image to improve sensitivity using the "Analysis -> Smooth" (or better, "Smooth Parameters") menu. This only affects the image display, so won't change the photometric results.
- Using a different colour scheme than the default greyscale can help reveal features that might be hard to see, but can make it more difficult to decide where a source begins and ends. Experiment using the colour menus.
- To very precisely define the displayed flux range, use the "Scale -> Scale parameters" menu to enter numerical values.

- If you want to save an image of what you've done (e.g. to compare with others or so that you can quickly check later without having to open the FITS file), using the "File -> Save image" option to save as a standard image file.
- Is the galaxy clearly visible in the RGB image but hard to find in the FITS file ? Create a region in ds9 and open its Property menu. From here you can enter the RA and Dec using the values from the SDSS window (just switch the coordinates from sexigesimal to degrees).

Finally, you might find it useful to consult NED for more detailed information about the object. In our example, if we clicked on the "1" next to NGC 7634 in the previous NED screenshot, we'd get this :



Mostly this should be self-explanatory. "92 References" takes you to a list of all the papers which have mentioned this object. "9 Redshift data point(s)" gives you more information about how the velocity was obtained. Scrolling down, "Cross-identifications" gives you names of the object from other catalogues. These can give you clues to the environment. For example, "VCC" means the object is in the Virgo Cluster Catalogue (but check the distance, and remember that the Virgo cluster itself (as opposed to objects in the Cluster Catalogue !) is at ~15-32 Mpc); "HCG" means it's a Hickson Compact Group.

Further down, most things should be self-explanatory. For consistency, don't use the "distance independent redshift measurements" (if available). Instead, calculate the distance by assuming the galaxy is in pure Hubble flow with H_0 = 71 km/s. Use the HI redshift where available in preference to the optical measurement.