The AGN ‘zoo’

Study time: 60 minutes

Summary

In this activity you will make use of an online database of galaxies called NED (NASA/IPAC Extragalactic Database). This database contains a wealth of material – including photometric measurements, spectra, images and maps – of several million galaxies. You will extract spectra and images of some active galaxies which are representative of the types you have met in the course.

This activity will require you to connect to the Internet for the whole session – about 1 hour.

You should have completed Section 3.3 of *An Introduction to Galaxies and Cosmology* before starting this activity.

Learning outcomes

- Use a web browser to gather information from an online database.
- Recognize the different ways of plotting the broadband spectrum of an object and their relative advantages.
- Appreciate how broadband spectra can be used to help distinguish different types of galaxy.

Background to the activity

Astronomers were among the first scientists to see the potential of the World Wide Web not only for exchanging information but for providing access to the many databases of observational results. The NASA/IPAC Extragalactic Database, commonly known as NED, is run jointly by the US National Aeronautics and Space Administration (NASA) and the Infrared Processing and Analysis Center at the California Institute of Technology (Caltech).

Through NED astronomers can access a large amount of observational data about galaxies and access the original research papers in which the data were published.

This site is characteristic of scientific websites designed for professional use in that it is not particularly user-friendly. Consequently you may find that some aspects of this website are difficult to understand. For that reason we will only look at a few of the facilities offered by NED. When you are more confident you could come back and explore further by yourself.

Before starting the activity, make sure you are familiar with how the broadband spectra of galaxies are plotted (*An Introduction to Galaxies and Cosmology*, Section 3.2.2) and the different kinds of flux units (*An Introduction to Galaxies and Cosmology*, Box 3.2).

The activity

- Start up your web browser and connect to the Internet.
- Go to the NED homepage at nedwww.ipac.caltech.edu (You may get a pop-up window asking you to take part in a user survey. If you wish to fill in the form please do so, but if not just close the window and continue.)

- The panel at the bottom of the page gives information about the number of objects in the database.

  ■ How many names are on the database? How many objects?

  ❑ When this activity was written there were 10.5 million names and 7.3 million objects. The numbers may well have changed since then.

  ■ Why are the two numbers different?

  ❑ Some objects have more than one name!

To start with, we are going to look at the spectral energy distributions (SEDs) of some of the types of object you have come across so far in Chapter 3.

The main part of the NED homepage is the table with five columns (labelled 'OBJECTS', 'DATA', 'LITERATURE', 'TOOLS', 'INFO'). Links in the cells of this table take you to different kinds of information.

- In the column headed DATA click on the link Photometry & SEDs. This will take you to a new page headed 'Photometric Data Search Based On An Object Name'.

The first galaxy we will look at is a spiral galaxy called Messier 83 (M83), a type Sc spiral.

- In the box labelled 'Enter object name' type `M83`.
- Leave the next three boxes as they are. (In order, they should read: 'Data as Published and Homogenized (mJy)', 'Error Bars', and 'No Point Labels'.)
- The fifth box allows you to choose either frequency or wavelength units for the horizontal axis (x-axis) of the SED. In S282 we have been using wavelength units, so click on the arrow to the right of the fifth box and select X=log(Wave.)(microns) from the drop-down list. When the SED is plotted it will have a scale on the horizontal axis which is the logarithm of the wavelength in micrometres.
- The sixth box allows us to specify the flux units. For now, select Y=log(Fnu)(W/m2/Hz) from the drop-down list. This will produce a scale on the vertical axis which is the logarithm of the spectral flux density (F_ν) in units of watts per square metre per hertz (W m^{-2} Hz^{-1}).
- The final box should be left as it is ('Fixed data range (for comparisons)').
- Click the Photometry button and wait!

You will now get a long page of data with a graph at the top. Information about each data point and its source is given in the table below the graph. For the purposes of this activity just concentrate on the graph at the top of the page.

  ■ What is the title of the graph?

  ❑ It should say 'Spectral Energy Distribution (SED) for MESSIER 083: 117 Data Points'. This shows that NED has retrieved the data for the correct object (note that the number of data points may be different if the database has been updated since this activity was written).

  ■ What are labels on the horizontal axis (at the bottom) and the vertical axis (to the left)?

  ❑ The horizontal axis is the logarithm of the wavelength (λ) in μm and the vertical axis is the logarithm of the spectral flux density (F_ν) in W m^{-2} Hz^{-1}. So the units are as we requested.

■ Express the wavelength range of the spectrum in metres (to the nearest factor of 10). What part of the spectrum does the graph cover?

❑ On the left, the log of the wavelength is –4, so the wavelength is 10^{-4} μm = 10^{-10} m. On the right, the log is 8, so the wavelength is 10^{8} μm = 10^{2} m. These wavelengths range from X-rays through to radio waves.

The scale on the top of the graph gives us a bit of extra useful information. On the left, ‘1 keV’ tells us that the photon energy is 1 keV, which confirms that these are X-rays. U, V, J, K and L are standard photometric bands (U is ultraviolet, V is visual and J, K and L are near-infrared), while ‘*IRAS*’ refers to the wavelength range of the Infrared Astronomical Satellite which surveyed the sky in 1983. ‘1 mm’ is, of course, in the millimetre-waveband and ‘6 cm’ is at radio wavelengths. ‘HI’ marks the wavelength of the 21-cm spectral line of neutral hydrogen. Finally, ‘100 MHz’ is a radio frequency in the middle of the VHF (FM) broadcast band.

■ Although hard to see, if you look carefully you should be able to see that some of the plotted points have horizontal or vertical bars through them, and some have both. What do they mean?

❑ These are error bars. They tell us the uncertainty in the wavelength or spectral flux density for each measurement.

Now that you understand what the graph is showing, we can start to look at the data itself.

■ This galaxy emits in X-rays and also in radio waves. In which of those two regions does it emit more strongly?

❑ According to this graph, the galaxy emits about 10^{6} times more strongly in radio waves than in X-rays.

If you have read Chapter 3 of *An Introduction to Galaxies and Cosmology* you may be suspicious about this conclusion! And you would be right, because plotting *spectral flux density* does not give us a fair representation of where the galaxy’s energy is being emitted. In Section 3.2.2 of *An Introduction to Galaxies and Cosmology* you learned that we should be plotting $\log(\lambda F_\lambda)$ instead. NED does not allow the option to plot $\log(\lambda F_\lambda)$, but it does let us plot $\log(\nu F_\nu)$ which is exactly the same thing (see Question 1 at the end of this activity).

- To the right of the graph (you may have to use the horizontal scroll bar) are the boxes for changing the plot. Select Y=log(NuFnu)(W/m2) and click on the Plot Again button to get a new graph.

You should now see the same data plotted with $\log(\nu F_\nu)$ (in W m^{-2}) on the vertical axis.

■ How do the X-ray and radio energies compare now?

❑ The galaxy emits about 10^{3} times more energy in X-rays than in radio waves.

This is a truer representation of the importance of different regions of the spectrum.

Finally, look carefully at the part of the SED between the ultraviolet and the 1 mm mark. The first thing that you will probably notice is that at some wavelengths there appear to be many different values of flux density. For instance, in the J-band there is a very wide range flux densities. This illustrates an important point about this database – it is a source of real astronomical data taken over a long time interval. Some of the differences in flux density at a given wavelength could be due to intrinsic variability of the source, but they could also be due to differences in calibration between different observers. This is especially a problem in the near-infrared – where the calibration of some of the older data is rather uncertain – and this, rather than variability of the source, accounts for the scatter in the data in this SED.

Rather than getting too concerned about the spread in the data points at any wavelength, try to view these SEDs as if you had to draw a schematic smooth curves through the data – much in the way as is done in Figure 3.11 of *An Introduction to Galaxies and Cosmology* (the spectrum of NGC 7714).

■ Examine the SED of M83 between the ultraviolet and millimetre wavelengths. How could you describe the shape of the spectrum in this region?

❑ It seems to be double peaked. There is one peak around 1 μm and another around 100 μm.

■ What could be causing these two peaks? What kind of galaxy might this be?

❑ The peak around 1 μm is due to starlight, the peak around 100 μm is probably due to interstellar dust.

In fact, this spectrum is very similar to that of NGC 7714 (*An Introduction to Galaxies and Cosmology*, Figure 3.11). M83 is an example of a *starburst* galaxy.

You may want to save the SED that you generated, so that you can refer to it again, or compare it with those of other galaxies. The simplest way to do this is as follows:

- Right click on the blue area of the SED plot. (Note that if you left click on the plot – a new window will open which zooms in on the part of the spectrum that you have selected.)
- From the menu that appears select the option Save Picture As....
- In the 'Save Picture' dialog box, enter a name for the plot (e.g. 'M83_SED'). The 'Save as type' list box gives two options – you can save the plot either in GIF or BMP format. (It is likely that BMP format would be the most useful since such files can be viewed and edited using the 'Paint' application in Microsoft Windows.)

Of course, you can repeat this process for any SED that you generate using NED.

Next we are going to look at an elliptical galaxy.

■ Given what you know about the composition of elliptical galaxies, what would you expect their SEDs to look like?

❑ Ellipticals have very little gas and dust. We would expect their SED to look like a composite of stellar spectra only.

One of the best known ellipticals is M32, a companion to the Andromeda Galaxy.

- Use your browser's Back button to return to the page called 'Photometric Data Search Based On An Object Name'. This time, enter 'M32' as the object name and select a log(νF_ν) plot with a wavelength scale as before (i.e. select X=log(Wave.)(microns) and Y=log(NuFnu)(W/m2)).
- Click on the Click the Photometry button and you should now see an SED of M32.

This SED has a broad peak in the optical–infrared region and there are no X-ray measurements at all.

■ What do you think the downward pointing arrows in the IRAS and radio parts of the spectrum mean?

❑ They are upper limits. It means that the galaxy has not been detected at that flux density.

This indicates that normal elliptical galaxies such as M32 have stellar spectra with insignificant radiation at very high or very low energies. Unlike M83, there is no detectable emission from dust in this galaxy.

Now we are going to look at a quasar, a type of active galaxy.

- By following similar steps as you used to generate the SED of M32, obtain the SED of the quasar 3C273. To do so, you should enter '3C273' in the object name box on the page called 'Photometric Data Search Based On An Object Name'. Make sure you specify a wavelength scale and a log(νF_ν) plot.

This famous quasar was the first to be discovered. Compare the plot you are now looking at with Figure 3.10 in *An Introduction to Galaxies and Cosmology* – you should be able to see that they are very similar. Looking at the SED produced by NED you may also have noticed a warning message printed on the plot that says 'Data outside fixed range. Plot again using autoscaling.' This means that there are some measurements that fall outside the limits of the wavelength range that has been used. To see all the data, you should re-plot the SED as follows:

The lowest of the five boxes on the right-hand side of the SED provides a choice between 'Fixed data range (for comparisons)' and 'Autoscale data range'. Select the latter option, and press the Plot Again button.

■ In what part of the electromagnetic spectrum is the additional data that is shown on this SED?

❑ The additional data point is at $\log(\lambda/\mu\text{m}) \sim -9$, or $\lambda \sim 10^{-15}$ m. This is an extremely energetic γ-ray.

This SED shows that a substantial part of the total luminosity of 3C 273 is emitted at extremely high photon energies.

Here are some other examples of active galaxies that you might like to inspect and compare. (In each case it may help to save a plot of the SED as described earlier so that you can view several SEDs at once.)

NGC 1068 – a nearby (type 2) Seyfert galaxy.

BL Lac – the original blazar to be discovered

M84 – the radio galaxy pictured in Figure 3.21 of *An Introduction to Galaxies and Cosmology*, which lies in the Virgo cluster.

■ Both M84 and M32 are elliptical galaxies. What is the main difference between their SEDs?

❑ The SEDs are very similar in the visible and near-infrared, but M84 is bright in X-rays and also has considerable radio emission.

The X-ray and radio emission come from the active galactic nucleus. Otherwise their SEDs are similar.

Finally, while you have the M84 plot on the screen, we want to show you how to access more information about specific objects.

- Click on the link to MESSIER 084 in the title of the SED. You will now see a page of information about M84.

The first table contains the position and redshift information. The second table lists the many other designations for M84 from various catalogues and surveys.

At the bottom of the page are links to other databases where more information can be found.

- Scroll back to the middle of the page where there is a small image of the galaxy (this is a negative image with the sky shown as white).
- Click on the `images` link (to the left of the image). It may take a few minutes for the page to finish downloading as the many images amount to a little over a megabyte.

The large table you now see gives information about each of the images in the NED database. It shows a preview image on the left and, among other things, lists the wavelength at which the image was made, the telescope used and a reference to the paper where it was first published. Many of these images use a format called FITS (which stands for 'Flexible Image Transport System') which is in widespread use in the astronomical community but is not supported by web browsers. For example, the second image from the bottom, labelled '285KB FITS image', is very similar to the radio map shown in *An Introduction to Galaxies and Cosmology* Figure 3.21. The table shows it was made with the VLA – the Very Large Array radio telescope in New Mexico.

- Your browser will, however, display images marked 'JPG'. For example, click on the sixth image from the bottom, labelled '45KB JPG image', that is from the 'Einstein_Obs'.

This is a map of X-ray emission from M84, made with the Einstein X-ray Observatory. The X-ray contours are superimposed over a photograph of the galaxy. (NGC 4374 is one of the alternative names for M84, as you can check by looking back at the page of information you downloaded earlier.) You can see that the emission is concentrated on the nucleus of the galaxy which is the source of the energy.

Thus NED provides professional astronomers with a very quick and relatively easy way to review what is known about a particular galaxy, and is an invaluable tool for planning further observations.

There is much more to explore in NED, but we have now finished with the online part of this activity, so you can now disconnect from the Internet.

Question 1

The spectral flux densities F_λ and F_ν are related by the expression

$$F_\lambda = \frac{c}{\lambda^2} F_\nu \qquad (1)$$

(a) Show that the quantity λF_λ is equal to νF_ν.

(b) Show that the units of λF_λ and νF_ν are those of flux density.

Question 2

All the SEDs you have seen here and in Chapter 3 have gaps between the X-ray and near-UV parts of the spectrum, just where the 'big blue bump' is said to be. Can you think why that is?

Answers to questions

Question 1

(a) We multiply both sides of Equation 1 by λ and note that $\nu = c/\lambda$.

$$\lambda F_\lambda = \lambda \frac{c}{\lambda^2} F_\nu = \frac{c}{\lambda} F_\nu = \nu F_\nu$$

(b) Putting the units into SI we find:

For λF_λ m × W m^{-2} m^{-1} = W m^{-2}

For νF_ν Hz × W m^{-2} Hz^{-1} = W m^{-2}

So both quantities have units of watts per square metre, which are the units of flux density.

Question 2

The gaps suggest that measurements have not been obtained in that region, which is known as the extreme ultraviolet (EUV or XUV). You might guess that this part of the spectrum is not observable from the ground, since EUV waves are absorbed by the Earth's atmosphere. That is true but it is not the whole story. Radiation of 10–100 nm is also absorbed by the neutral hydrogen of the interstellar medium and that means our EUV view of the sky is very restricted. Although there are some gaps in the interstellar medium that do allow more distant objects to be seen, it is practically impossible to make useful extragalactic observations in the EUV part of the electromagnetic spectrum.