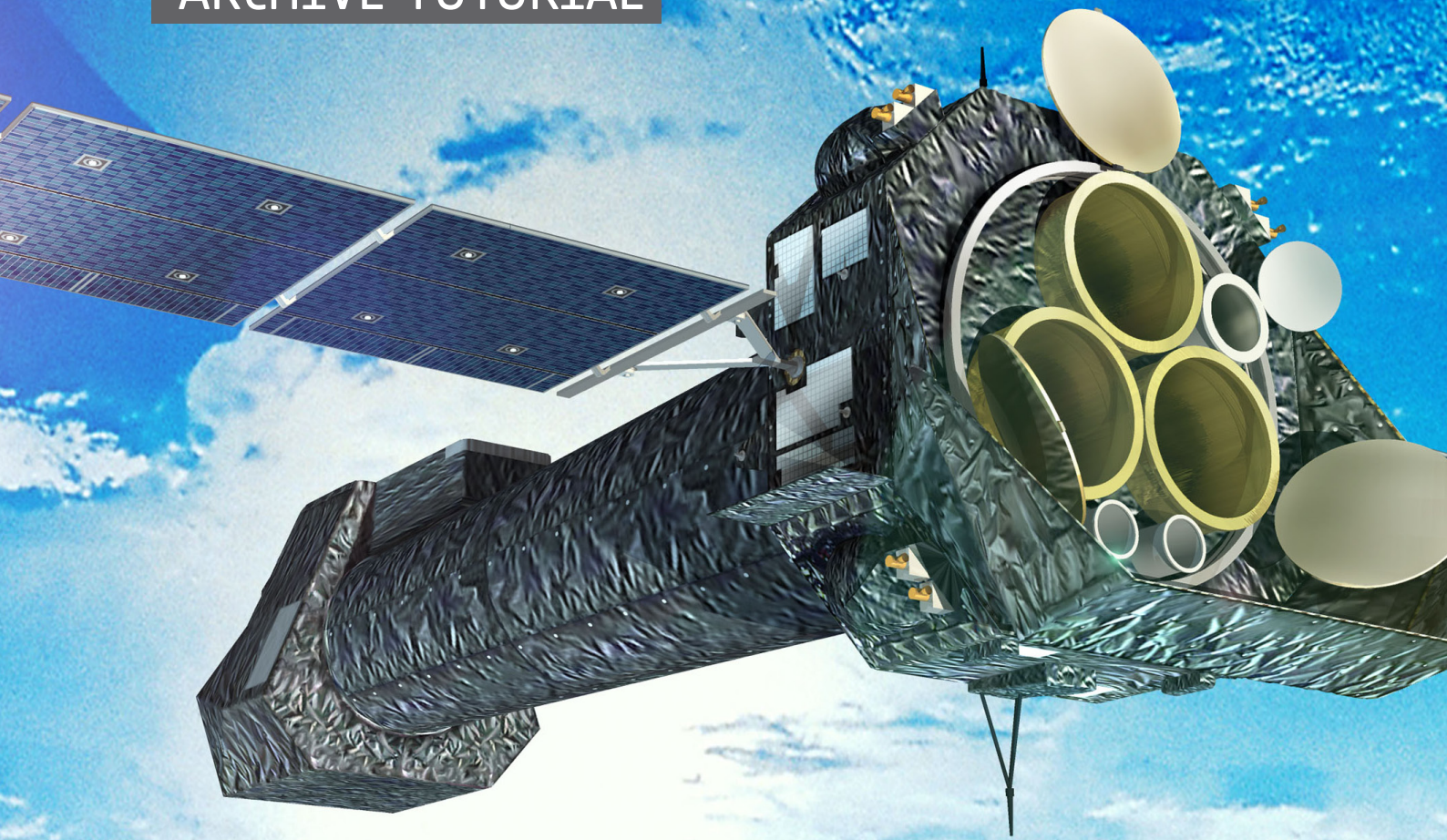


→ **MERGING GALAXIES**

**A XMM-NEWTON &
HUBBLE SPACE TELESCOPE
ARCHIVE TUTORIAL**



SCIENCE ARCHIVES AND VO TEAM



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This is an image of a pair of merging galaxies: the Antennae galaxies. During the course of the collision, billions of stars will be formed.

Image Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)-ESA/Hubble Collaboration

PART 1

In Part 1, the tutorial will explain how to measure the distance between two supermassive black holes contained within an extragalactic object NGC 6240. NGC 6240 is made up from two spiral galaxies which are merging, pulled together by their cumulative gravitational forces. Next, the mass of one of the supermassive black holes will be calculated.

Therefore, in the background a number of subjects will be covered to introduce the main topics used in the tutorial:

- NGC 6240
- Black Holes
- Merging Galaxies
- Cosmological Concepts
- Spacecraft (data from which are used in this tutorial).

Then, the experiment will be explained step by step. The tools used will be the XMM-Newton Science Archive and Aladin. Some basic calculations will be made in order to determine the distance between the supermassive black holes and the mass of one of the black holes.

Finally, conclusions will be made about the performed experiment and some additional activities will be provided.



BACKGROUND

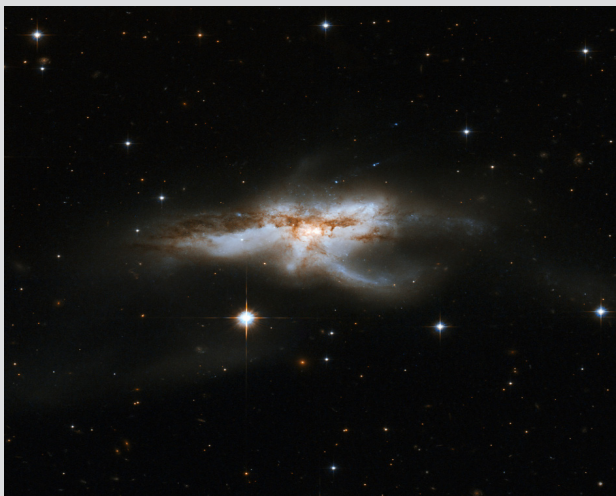
→ NGC 6240

NGC 6240 is the object that will be studied in this tutorial.

NGC 6240 is a remnant of a galaxy collision between two spiral galaxies. Both were similar in size to the Milky Way.

This merged body has two supermassive black holes at its centre, and around them a vast quantity of gas which is forming new stars at an immense rate. The two black holes are spiralling towards each other and ultimately may become one even larger black hole.

The merging of the galaxies has also generated substantial infrared emission from dust heated by newly forming stars and by the Active Galactic Nuclei (AGN). As there is so much infrared emission the system is extremely luminous (10^{12} solar luminosities), and therefore is known as a (Ultra)-Luminous Infrared Galaxy ((U)-LIRG). NGC 6240 is located in the Ophiuchus (which means Serpent-Bearer) constellation, a mere 98 Mpc or around 3.2×10^8 light-years from the Milky Way.



↑ This is an image of the galaxy merger NGC 6240. The shape of this combined-galaxy is clearly very irregular. NGC 6240 is the product of two Milky Way sized spiral galaxies and it is predicted to become an elliptical galaxy. Theories also state that the supermassive black holes from each of the galaxies will eventually collide.

As, with respect to the size of the observable Universe, NGC 6240 is nearby to our own galaxy, it provides an opportunity to easily witness a galaxy collision. Even so, collisions are surprisingly common, although it is difficult to get an exact estimate; NASA's Hubble Space Telescope found results implying between 5% to 25 % of galaxies were merging. It is expected that the Milky Way will eventually collide with the Andromeda galaxy - our closest spiral galaxy, in about 4 billions years.

→ BLACK HOLES

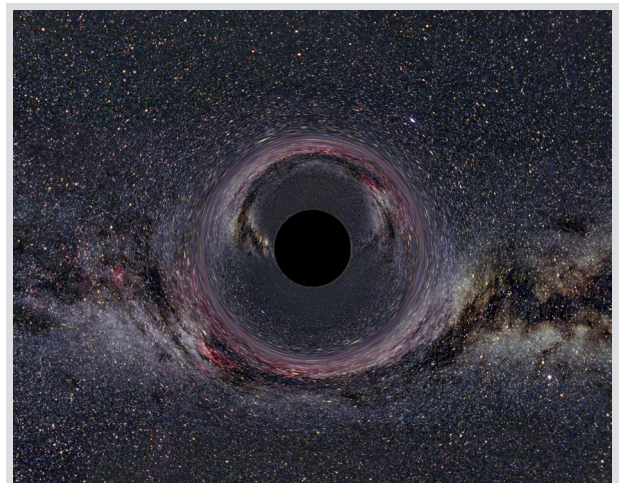
NGC 6240 contains two supermassive black holes. But what exactly are they?

A black hole is an object that has sufficient mass in a small enough volume so that nothing can escape its huge gravitational pull beyond a certain point. This distance is known as the **Schwarzschild Radius**, and after this even light is swallowed: Which is why they are known as black holes. We cannot directly see them as no light is emitted from within the Schwarzschild Radius.

Everything that enters the Schwarzschild Radius of the black hole is squashed into its singularity at the centre; which is believed to be an infinitely small point with infinite density.

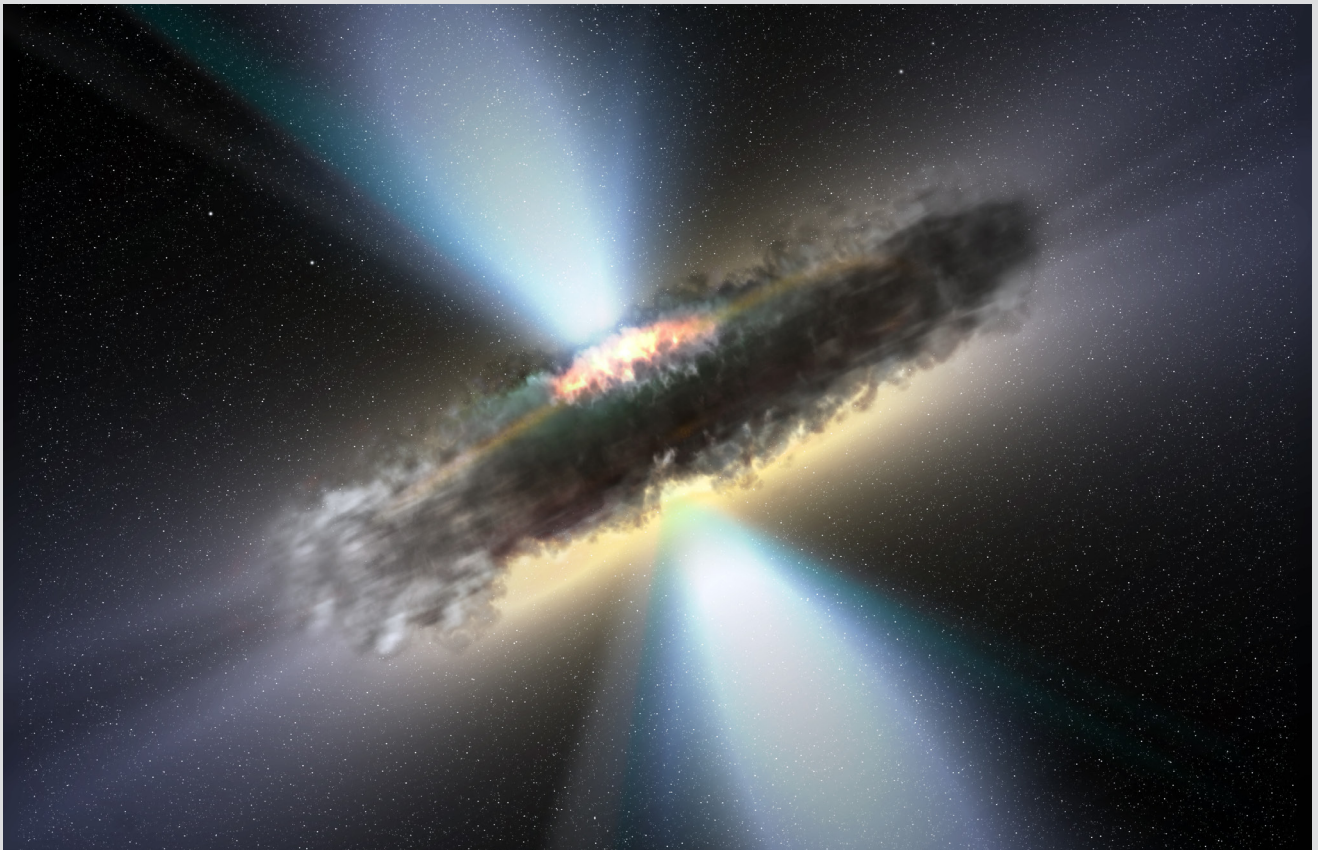
Although it is not possible to see a black hole directly, astronomers are aware of their existence and some of their properties due to their influence on the material in their vicinity. For example, the mass of a black hole can be calculated using the orbital velocity of the material travelling around it.

So far, two types of black holes have been observationally confirmed: Stellar-mass black holes, which are just a few times more massive than our Sun and supermassive black holes. Supermassive black holes can have masses ranging from millions to billions of times the mass of the Sun.



↑ This is a computer simulated image of a black hole with mass ten times the mass of the Sun, as seen from a distance of 600km with the Milky Way in the background. The light from the Milky Way has been bent due to the relativistic gravitational effect of the black hole.

Image: Ute Kraus, Institute of Physics, Universität



↑ An artist's depiction of the accretion of a thick ring of dust into a supermassive black hole. The accretion produces jets of gamma rays and X-rays.

Credit: ESA / V. Beckmann (NASA-GSFC)

Supermassive black holes have masses which can be as large as small galaxies. The Milky Way has a supermassive black hole in the centre, which approximately has the mass of 4 million Suns!

Some black holes have accretion discs surrounding them, which are made from material in orbital motion as it falls into the black hole. As the matter gets closer to the black hole it is compressed, its speed increases and it gains energy. The difference between the speeds, in comparison to distance from the black hole, is large and this generates a substantial friction in the disc. This heats the matter, causing it to emit thermal radiation. The frequency of the radiation is dependent on the heat of the matter, which in turn is dependent on the distance to the black hole. Consequently stellar mass black holes emit mainly X-rays, whereas supermassive black holes emit more towards the UV wavelength range.

Another important feature of a black hole is whether it rotates or not. Rotating black holes are formed from rotating stars through the conservation of angular momentum. They are known as 'Kerr' black holes. The amount spin of the black changes the size of the Schwarzschild Radius.

→ AGN

An Active Galactic Nucleus (AGN) is the compact area at the innermost part of a galaxy which has a vast luminosity over some or all of the electromagnetic spectrum in comparison with the rest of the galaxy. They are actually the most luminous sources the Universe.

As the emission from the AGN is so bright (it can outshine billions of stars) it can only be caused by something that can generate enormous amounts of energy. Accretion onto a black hole is such a mechanism; it has an efficiency of 10%, which seems small, but is in fact a very powerful way to produce energy.

There are many different types of AGN, which are mainly categorised according to their brightness and what type of electromagnetic radiation they emit. The main distinction is 'Radio Loud' and 'Radio Quiet' which represent 10% and 90% of AGN respectively. 'Radio Loud' describes objects such as Radio Galaxies and Blazars, whereas AGN galaxies such as Seyferts and Starbursts are 'Radio Quiet' objects.

Although the Milky Way contains a supermassive black hole, it does not contain an AGN as there is not enough matter currently accreting onto the black hole.

→ MORE ON MERGING GALAXIES

It has been found that galaxies often merge due to their small separation in comparison with their size. There is a huge cumulative gravitational pull of each galaxy towards the other which causes them to merge.

However, whilst galaxies are merging, stars or star systems (like the Solar System) do not actually collide, as the distances between them are too great. Many stars or star systems may be thrown off into space or their orbits completely changed. This results in most of the stars having complex orbits and moving in random directions, which is one of the reasons merged galaxies become irregular or peculiar eventually becoming elliptical.

In the merging process of two galaxies, large amounts of gas and dust are directed towards the central region, and are compressed. This induces active star formation. Galaxies with high rates of star formation are known as 'starburst' galaxies. The new stars, along with the Active Galactic Nuclei, heat up the surrounding dust which then emits huge amounts of infrared radiation. Such galaxies are known as (Ultra)-Luminous Infrared Galaxies (U)-LIRGs.

Once the galaxies have fully converged and much of the gas and dust is used up, a red-looking elliptical galaxy is formed and there is very little star formation. To see simulations of galaxies merging, including the Milky Way and Andromeda, visit the following links:

General:

<http://www.youtube.com/watch?v=DPvCdU6cepY>
http://www.youtube.com/watch?v=_F1GiqPdbx8
<http://www.youtube.com/watch?v=q2h42UTqINc&NR=1>

Milky Way vs Andromeda:

<http://www.youtube.com/watch?v=Cd9cBlvfjow>



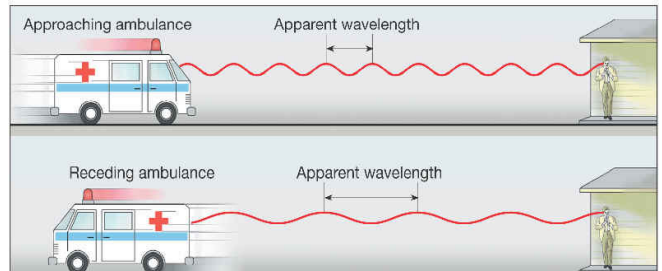
→ An image from the Hubble Space Telescope of the galaxy merger NGC 3256.

Credit: NASA, ESA, the Hubble Heritage (ST-ScI/AURA)-ESA/Hubble Collaboration, and A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University)

→ COSMOLOGICAL CONCEPTS

REDSHIFT

As objects move away from us, the light waves or sound waves appear to become longer. This effect can be observed by listening to the sound of an ambulance rushing past; the sound pitch gets lower as it travels away. This is the wave stretching and elongating in relation to you. This is known as the Doppler Effect.

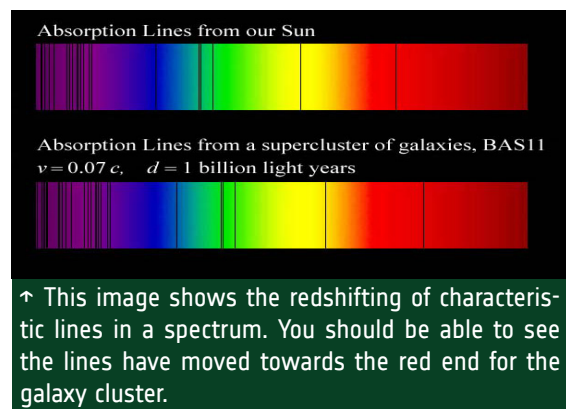


↑ An illustration to show how the Doppler Effect changes the appearance of wavelengths.

The same thing happens with light. One of the most interesting places this effect is seen is from the light received from extragalactic objects: In 1929 Edwin Hubble discovered that the Universe is expanding; each point (on a large scale) in the Universe is moving away from those around it.

This expansion also increases with distance, so that the further away an object is from us, the faster it is travelling. Therefore, for objects further away from the Earth the light waves appear longer and stretched. In the optical range, we see longer wavelengths as being more red, which is why this effect is known as 'redshift'. It is given the symbol 'z'.

As this effect increases with separation, it is a useful tool for astronomers and cosmologists to estimate distances to objects. For example, by taking a spectrum from a distant star, the characteristics in the spectrum can be compared with that from the Sun; and the amount of change in the wavelength can be measured.

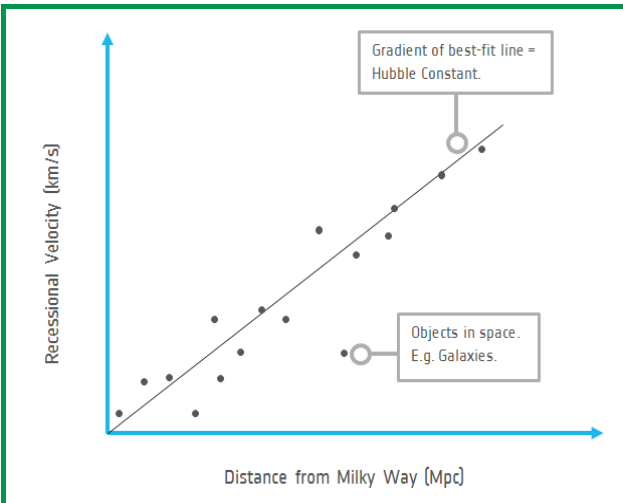


↑ This image shows the redshifting of characteristic lines in a spectrum. You should be able to see the lines have moved towards the red end for the galaxy cluster.

HUBBLE'S CONSTANT

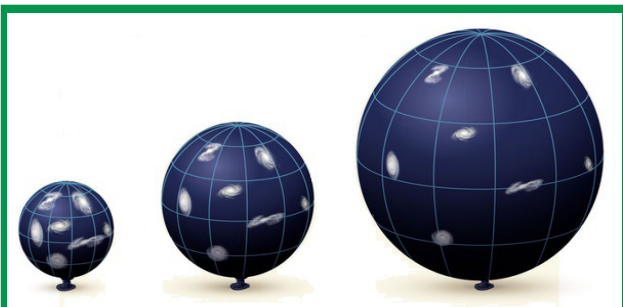
The concept of redshift tells us the Universe is expanding; and that objects further away are receding faster than those closer. Hubble's Constant gives us the rate at which these objects are moving as a function of distance.

This recessional change, although measured with respect to the Milky Way, is the expansion of the whole Universe when measured on a large scale. The Milky Way is also flying through space; for an observer in the distance it would seem like we were speeding away too. This is one of the most important and easily visible pieces of evidence for the 'Big Bang' model of the Universe. However it should be noted that the force of gravity can overcome this expansion, so that galaxies can form and even merge!



↑ This plot illustrates how scientists calculate the value of Hubble's Constant.

The Hubble Constant is usually given in units of kilometers per seconds per Megaparsecs: km/s/Mpc. Generally, the numerical value adopted for Hubble's Constant (H) is 75 km/s/Mpc, although there is some debate of this value and it can be taken between 100 and 50 km/s/Mpc. This is because there is uncertainty in the methods used to measure Hubble's Constant.



↑ An analogy to describe the expansion of the universe; imagine galaxies on the surface of a balloon which is being blown-up.

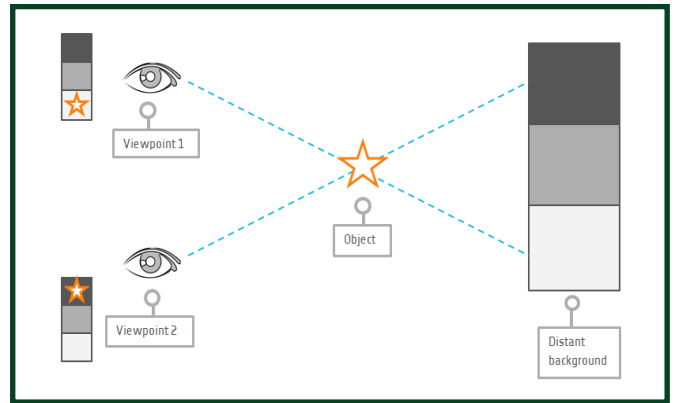
ASTRONOMICAL UNITS

Astronomical units have been created to more easily describe the vast distances between objects in the Universe.

We have already mentioned one of these: the parsec. The parsec is defined to be a parallax of one arcsecond. One parsec is the distance from the Sun to an object which has a parallax angle of one arcsecond.

Firstly, what does 'a parallax' actually mean?

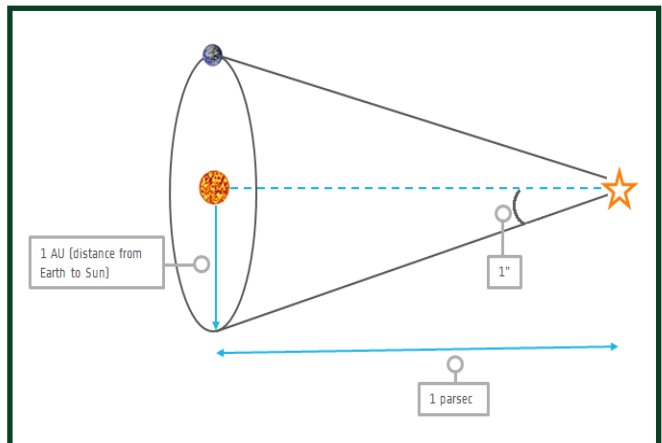
Parallax is the difference in the perceived position of an object along two different lines of sight.



Try exploring this idea by holding a pen up at arms length, with a fixed point in the background. Now open and close each eye in succession. You should be able to see the pen moving relative to the background. This is parallax, and it is a concept astronomers use to calculate distances. By measuring the perceived movement of an object at different times of the year, trigonometry can be used to estimate a distance to the object.

Secondly, what is an arcsecond?

The parallax of an object is bigger the closer it is, therefore for things very far away, the change in angle is very small. This is why astronomers often use arcseconds, which are defined to be 1/3600th of a degree, or around 0.00028 degrees. One arcsecond is written as 1".



→ OBSERVATIONS WITH XMM-NEWTON



↑ An artist's impression of XMM-Newton in space.

As was previously stated, the accretion emission around supermassive black holes is better studied in the X-ray range of the electromagnetic spectrum. Thus, to gain information about these phenomena it is important to observe them in the X-ray frequency range. The Earth's atmosphere blocks X-rays and therefore observations must be taken from space. The X-ray data used in this tutorial comes from ESA's XMM-Newton; an X-ray space observatory.

XMM-Newton is the biggest scientific satellite ever built in Europe, its telescope mirrors are amongst the most powerful ever developed in the world, and it has extremely sensitive cameras suitable for imaging and spectroscopy. The satellite launched in 1999 and is still in operation today (2013).

There are two types of instruments aboard XMM-Newton, which takes X-ray, ultraviolet and optical images. XMM-Newton also performs X-ray spectroscopy, which will be explained later in this tutorial.

Firstly, there is the **European Imaging Camera (EPIC)**. It is composed of three detectors and takes X-ray images of even very weak X-ray signals. Therefore it is a useful device for investigating objects extremely far away.

The Reflection Grating Spectrometer (RGS) obtains spectra from the incoming X-ray radiation to study the physical conditions of the particular source being observed.

Finally, there is the **Optical Monitor (OM)** which is an optical/ultraviolet telescope. It looks at the same sources as the X-ray instruments simultaneously to help scientists by providing additional data about a source.

→ OBSERVATIONS WITH THE HUBBLE SPACE TELESCOPE

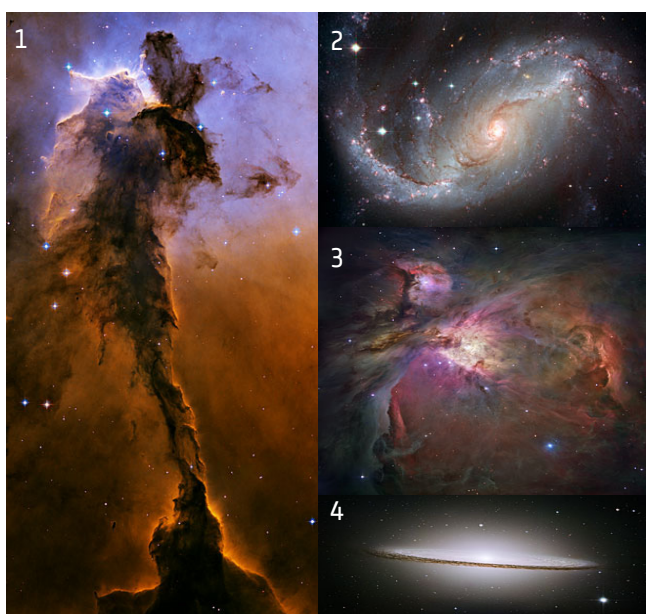


↑ An artist's impression of the Hubble Space Telescope

In this tutorial, images in the optical and near infrared from the Hubble Space Telescope (HST) will be used, although the HST also observes in the ultraviolet.

The HST can image with very high resolution as it avoids the distortion and background which results from the Earth's atmosphere. Because of this, it has achieved extremely deep views into space and time and has led to many interesting discoveries, including more accurately determining the value of the Hubble Constant.

The HST is a NASA/ESA/STScI (Space Telescope Science Institute) project. It orbits the Earth at 600km above the surface and outside Earth's atmosphere. It has taken more than 1 million observations. There have also been more than 9,400 scientific papers published using HST data.



↑ A few of the incredible images taken by HST. 1. Eagle Nebula 2. NGC 1672 3. Orion Nebula 4. Sombrero Galaxy



○ THE EXPERIMENT

→ THE AIM

The aim of Part 1 of the tutorial is to explore data about the galaxy-merger NGC 6240. Subsequently, the distance between the two supermassive black holes will be calculated. Moreover, the mass of one of the black holes will also be determined.

→ USING THE ARCHIVE TO EXPLORE THE GALAXY MERGER NGC 6240

Tools Used

XMM-Newton Science Archive (XSA): This archive provides simple and flexible access to data from the XMM-Newton mission.

Aladin: This is an interactive program providing access to sky atlases which can be used to visualise astronomical images.

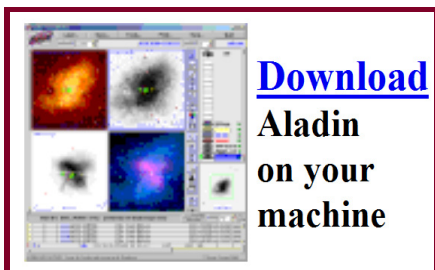
Opening the Archives and Loading Data

To begin, it is necessary to open both the XSA and Aladin.

XSA can be opened from here: <http://archives.esac.esa.int/xsa>

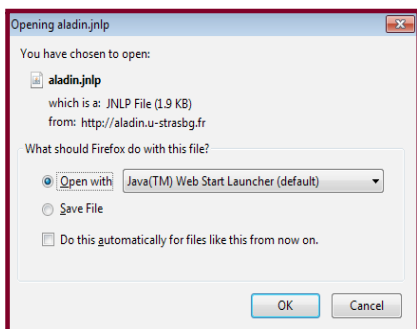
To open Aladin, go to: <http://aladin.u-strasbg.fr/>

Next, click on the 'Download' link



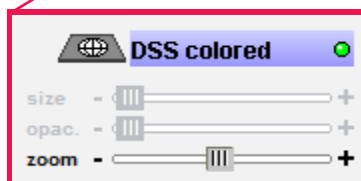
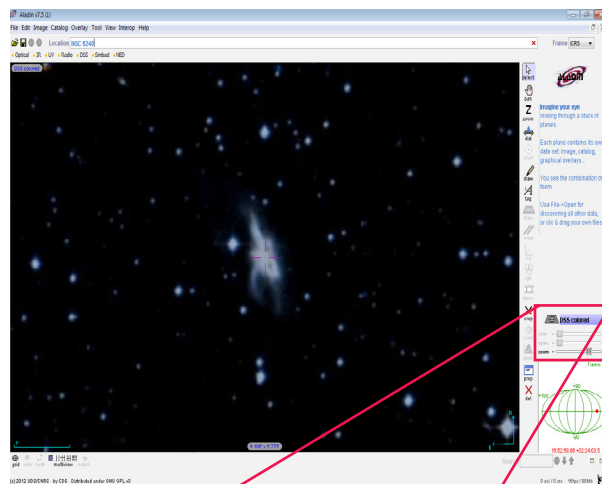
Then click on the Aladin Webstart link. A new window called 'Opening aladin.jnlp' should open. Make sure 'Open with' is selected and then click 'OK'. If a security window appears, click 'Run'.

Web Start:
(java installer)

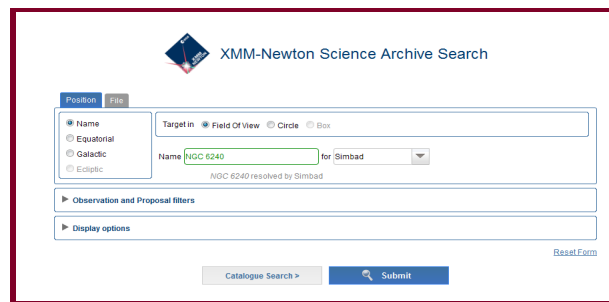


Now both Aladin and the XSA should be open. Initially, go to Aladin and in the bar at the top called 'Location' type **NGC 6240** and click 'Enter'.

This should load a picture of the galaxy merger from the Digital Sky Survey (DSS). This is an optical image of the whole sky. By using the zoom function in the bottom right hand corner it is possible to see this.



Now go back to the XSA. In the search bar under 'Name', type NGC 6240 and click 'Submit'.



This will load the Observation IDs and the corresponding data, presented in tabular format. For NGC 6240 there should be 8 in total.

Firstly there are some features it is useful to be aware of. For example, the magnifying glass image: By clicking on this a window is opened with the extra data.



Details for Observation 0101640601

Obs. ID	0101640601
Revolution	413
Target	NGC 6240
Exposures	3 EPIC, 11 OM, 2 RGS

Proposal Abstract

GT-Redshift surveys of extragalactic IRAS sources have revealed a class of Ultraluminous IRAS Galaxies (ULIRGs). The proposed XMM observations of ULIRGs will allow us to (i) precisely determine the intrinsic X-ray column density of neutral hydrogen and warm absorbers and to compare this with the IR-optical reddening, (ii) compare the relative amounts of the soft and hard flux to further deconvolve the relative contributions from the starburst- and black hole accretion processes in ULIRGs, (iii) search for iron line emission.

Show Quality Report

↑ An example of a window which opens after clicking on the magnifying glass next to one of the observations. 'Summary' gives general information about the observation, 'Exposures' has the images taken for the observation, and 'Publications' lists papers published which used the data from the observation.

To hide this from view, click on the window with the green arrow in the top left-hand corner, as can be seen in the image above.

Another feature to note is the button labelled 'Columns', by clicking on this it is possible to hide certain columns in the table by deselecting the ticked boxes next to the relevant data. By clicking 'Clear' all the columns are deselected; this is useful if only a few columns are required.

Column selection

- Obs.ID
- EPIC
- RGS
- Target
- RA
- Dec
- PA
- Rev
- Distance

Select All Clear OK

To apply the choices, click 'OK'. This will close the window 'Column selection' as seen above.

Click on the picture for **Obs ID 0101640601**, under the column heading 'EPIC'. This should open up a new window called 'Postcard Preview'.

Postcard Preview

Once this is open, click on the 'Send Image to' button, and then on the Aladin link.

This will bring up a new window called 'SAMP Hub Security'. For more information about the SAMP Hub, click on the blue 'i' circular image in the top right-hand corner of the postcard preview window. To continue sending the data to Aladin, authorise the connection by clicking on 'Yes'.

SAMP Hub Security

The following application, probably running in a browser, is requesting SAMP Hub registration:

Name: XSA
Origin: http://nxsa.esac.esa.int

If you permit this, it may be able to access local files and other resources on your computer.

You should only accept if you have just performed some action in the browser, on a web site you trust, that you expect to have caused this.

Do you authorize connection?

No Yes

Go to Aladin to see if the image has sent. Return to the XSA and click 'Close' on the window shown below. It should be possible to continue using the interactive tables. This will not have closed anything in Aladin. If the image has not been sent properly try repeating the process.

image successfully sent

More help here Close

Finally by clicking on the 'Obs ID', for example **Obs ID 0101640601**, this opens a new tab with particular results for this observation.

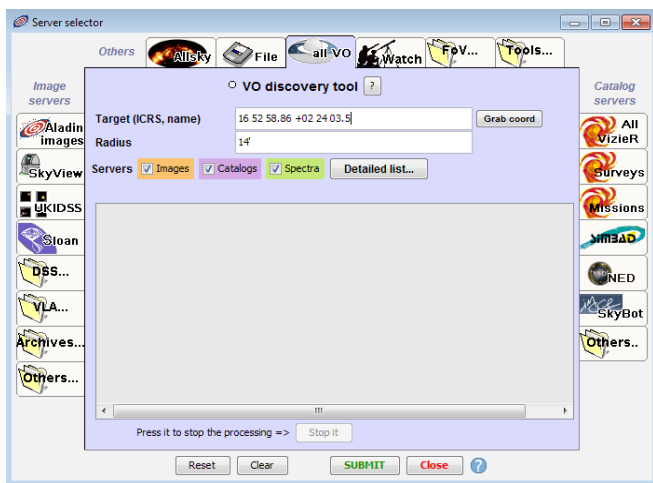
Do this, and then click on the tab labelled '**EPIC SOURCE CAT (48)**'.

ObsID	RA	Dec	Pos.Err	Det.MI	Det.Count	TotalRate	TotalProcRate	EPIC.HRT	EPIC.HR2	EPIC.HR3	EPIC.HR4	EPIC.QualityFlag	PM Tot.Count	PM Tot.Count
0101640601	16h 52m 58.29s	+02° 24' 03.5"	0.9	102	0.000	1.10E-13	2.00E-14	0.00	0.07	-0.12	-0.12	#####	0.024	0.0
0101640601	16h 52m 52.64s	+02° 02' 32.3"	1.9	8	0.007	1.20E-14	1.30E-14	-0.14	0.10	-0.19	-0.02	#####	0.086	20.2
0101640601	16h 52m 53.79s	+02° 17' 38.46"	1.9	10	0.009	2.20E-14	1.20E-14	0.09	-0.10	-0.07	#####	0.003	19.1	
0101640601	16h 52m 52.26s	+02° 01' 08.59"	1.9	7	0.012	0.70E-14	5.70E-15	0.06	-0.00	-0.03	#####	0.042	19.0	
0101640601	16h 52m 53.89s	+02° 02' 25.12"	0.9	122	0.000	0.80E-14	1.70E-14	0.00	0.24	-0.43	0.15	#####	0.059	79.3
0101640601	16h 52m 58.69s	+02° 07' 25.12"	2.1	15	0.006	4.90E-14	3.56E-14	0.06	0.74	-0.45	-0.23	#####	0.029	6.7
0101640601	16h 52m 58.52s	+02° 07' 24.92"	1.4	18	0.009	2.00E-14	1.01E-14	-0.00	0.00	0.45	-0.08	#####	0.029	6.7

Now, click on the button 'Send table to'. Then select the Aladin link. Once again, if the window called 'SAMP Hub Security' opens authorise the connection and send the data to Aladin, by clicking 'Yes'.

Now move to Aladin. On the image it should be possible to see a number of small circles. Each circle is an X-ray source, like stars and galaxies, within the image.

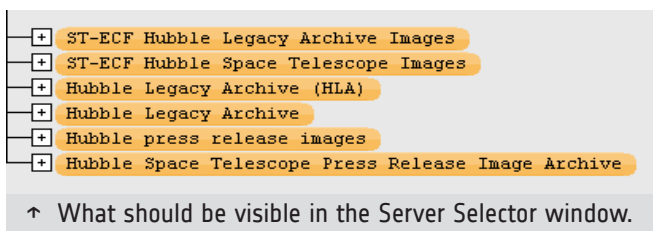
The final images to load into Aladin are from the **Hubble Legacy Archive**. To do this, on the Aladin window, click on 'File' and then 'Load from the Virtual Observatory'. This will open a new window called 'Server Selector'.



On the line with 'Servers' deselect 'Catalogs' 'Spectra'. Then click on 'Detailed List'.



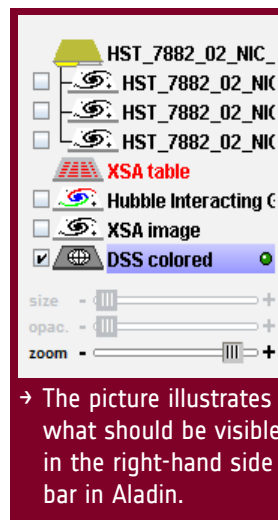
By doing this, another window will open called 'Server List'. As can be seen there is a lot of servers to retrieve data from! In the box at the top called 'Filter' type 'Hubble'. Next to this box, click 'Go'.



Then, after making sure that only the 'Image Servers' are selected, click on 'Submit'. Finally, click 'Close' to close the window.

In the Server Selector window there is a list of types of Hubble data. Firstly, under 'Hubble press release images' select the box named 'Hubble Interacting Galaxy NGC 6240 2.9' x 3.0'. To see this, click on the plus next to the title to expand the data tree and tick the box next to this. Click Submit

Once this has been selected, go under the 'ST-ECF Hubble Legacy Archive Images' by clicking on the relevant plus sign again, and then select 'HST_7882_02_NIC_NIC2_F215N' by ticking the relevant box and clicking Submit. Wait for the images to load.

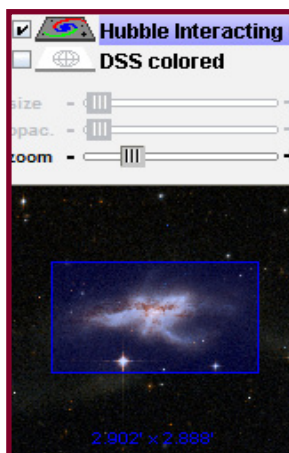


→ The picture illustrates what should be visible in the right-hand side bar in Aladin.

Using Aladin to Interact with the Images

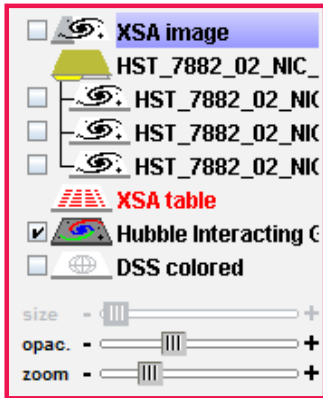
Aladin has a number of useful features for interacting with and investigating astronomical images. We will explore some of these here.

Firstly, select the Hubble Press Release Image to get an idea of what the galaxy merger looks like. Do this by selecting the box next to the name on the table on the right hand side (as pictured above).

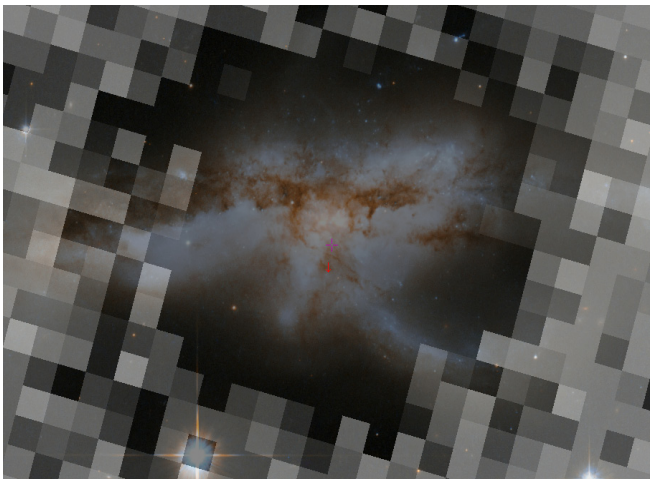


There is clearly a bright section in the middle of the galaxy merger, producing a vast amount of light. To compare this to the X-ray image produced by XMM-Newton, firstly left click and drag the label 'XSA image' to the top of the list.

Then, click on the label 'XSA image' so that it is highlighted, without deselecting the checked box in the Hubble image. Now it should be possible to use the 'opac' slider on the 'XSA image'. This is the opacity, or transparency of the image, and can be used so that two images can be seen at the same time.



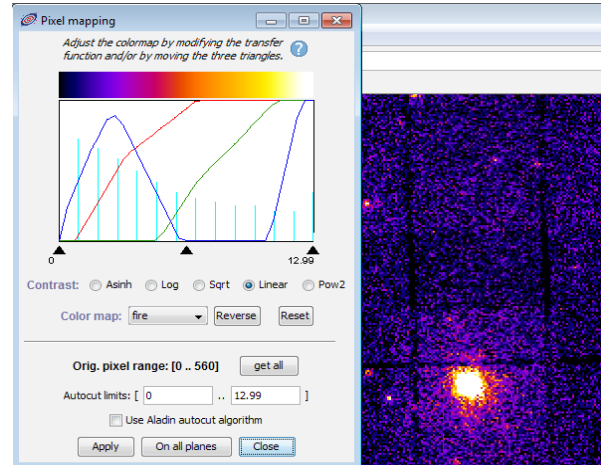
If you slide the opacity up it should be clear that the black region on the XSA image corresponds to the galaxy merger. **Although the area is black, this actually implies a large X-ray signal from this part.** Which was expected. If you aren't sure about this, try reading the background section again.



↑ The spatial resolution of the X-ray image is much lower than the press release image!

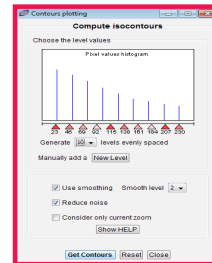
To make it clear that the dark region in the X-ray image is in fact where **most** of the signal is coming from, the pixel appearance can be changed. Firstly select the XSA image fully by clicking in the box next to the label.

Then, down the right hand side there is a button called 'Pixel'. Click on this and a new window will open called 'Pixel Mapping'. Try different settings on the 'Color map' drop-down menu, and clicking on 'Reverse', to reverse the colours.

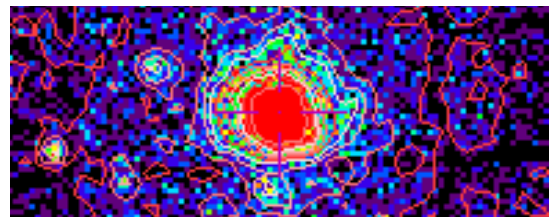


When you are happy with the colour mapping of the image, click on 'Apply' and then 'Close'.

For another way to see where most of the pixel output comes from, try plotting contours. This is like a geographical map. The contours show the regions with increased pixel counts, much like in a geographical map where the contours show increase from ground height.



Increase the number of levels by picking a higher number in the drop down box, in the 'Generate _ levels evenly spaced'. Then click 'Get Contours'. To remove this layer, go to the list on the right-hand side and right click on the label, then select 'Delete'.



↑ An example of the contours plotted in the centre of the XSA image.

Try exploring what these features can do and what information it is possible to gain from the images.

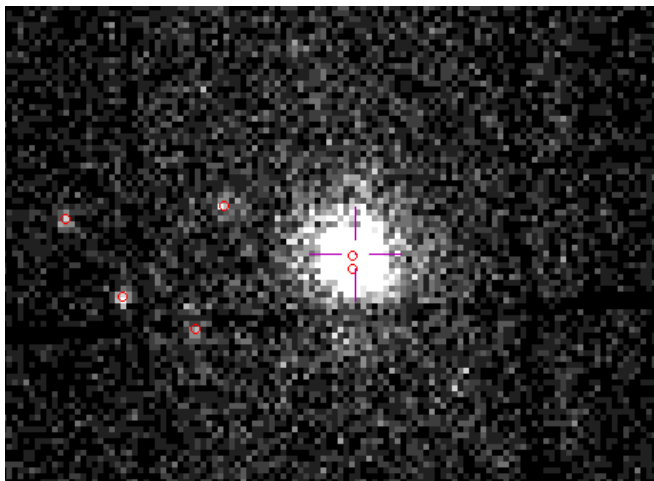
Calculating the Distance Between the Supermassive Black Holes

As was explained in the background section, the galaxy merger NGC 6240 contains two supermassive black holes. After exploring the data it may be clear that there are two sources.

We also saw that NGC 6240 was producing intense X-rays, which could imply that it contains black hole-like sources. Now we will calculate the distance between the two black holes.

Firstly, use the 'Pixel Mapping' to return the XSA image back to 'gray' (remember that the XSA image must be highlighted when clicking on the 'Pixel' button). It does not matter if is reversed or not.

Now drag the 'XSA image' label on the list, by right clicking and dragging, under the 'XSA table' label. This is so it is possible to see where the XSA detects objects.



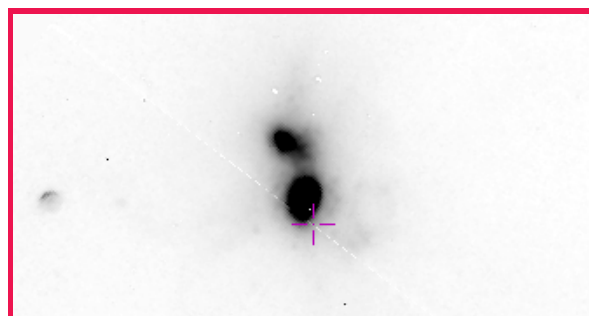
↑ Can you see the two circles in the centre of this image? This means that the XSA has data implying there are two objects here. These are not necessarily the black holes.

Despite this, the resolution of the XSA image is not high enough to see that there are two supermassive black holes at the centre of the galaxy merger. Therefore it will be necessary to use the image 'HST_7882_02_NIC_NIC2_F215N' where the resolution is much higher.

To begin investigating the separation of the black holes select 'HST_7882_02_NIC_NIC2_F215N' by ticking the box next to the relevant label. There should be three images loaded under a folder icon. Select the last, or the one with two clear sources.



Now select the distance (dist) icon.



↑ This is the near infrared (2.15×10^{-6} m) image. Make sure the image on your screen is the same. To edit the colours or reverse them, use the 'Pixel Mapping' function under the 'Pixel' button.

Next, left click on the centre on one of the black holes, and holding down the left click, drag the mouse to the centre of the other black hole. Release the mouse; Aladin should display an arrow between the two black holes. If you have made a mistake press the delete button on your keyboard.

You should also see a number corresponding to the length of the arrow. This is the distance in arcseconds, which were explained in the background section.

In this image, 1 arcsecond = 470 parsecs.

→ Use this to calculate the distance in parsecs between the two black holes. Next change this to light years and km using the conversions given below.

$$1 \text{ Parsec} = 3.26 \text{ light years}$$

$$1 \text{ light year} = 9.46 \times 10^{15} \text{ m}$$

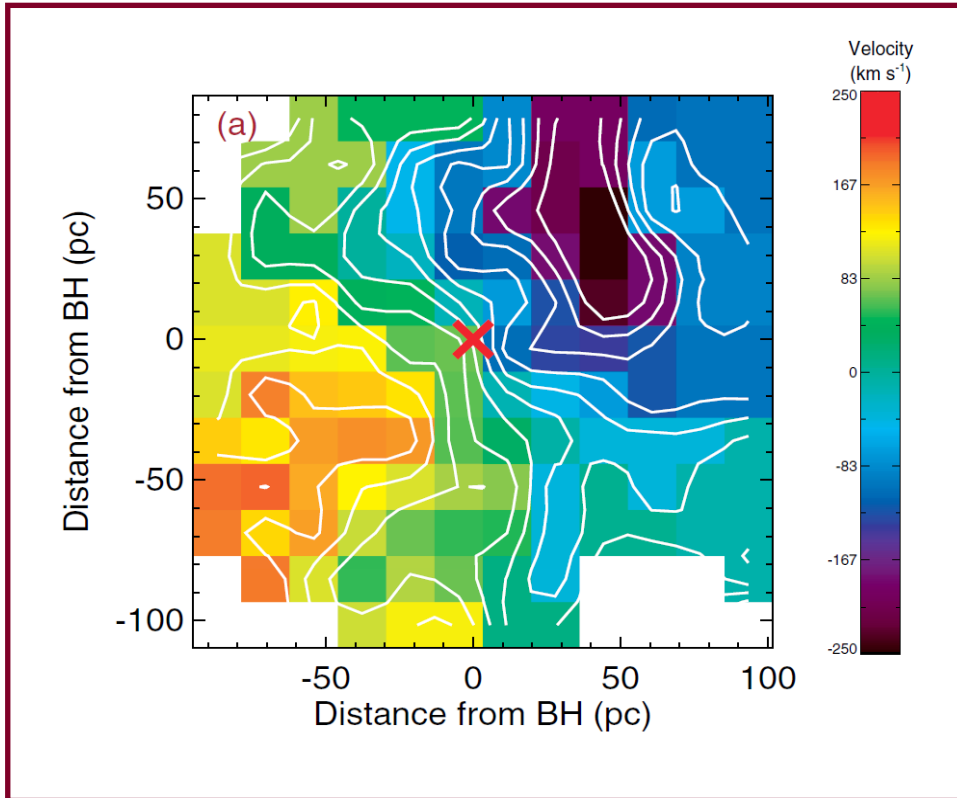
→ Finally compare these distances you have found to some of these standard astronomical distances.

Distance from Sun to the centre of the Milky Way: 8.3 ± 0.34 kpc

Distance to the closest galaxy, the Canis Major Dwarf Galaxy: 25,000 light years

Distance to Andromeda: 2.4×10^{19} km

The answers to all numerical questions can be found at the back of this booklet.



→ This is a velocity field diagram for one of the black holes in NGC 6240. The different colours represent the velocities of the material. The black hole is indicated with the red cross in the middle of the diagram. By choosing a point on the diagram it is possible to find the distance from the black hole, and the velocity of the material. The region close to the black hole is being analysed so the influence on the surrounding matter has negligible influence from the other black hole.

Diagram credit: 'Mass of the Southern Black Hole in NGC 6240 from Laser Guide Star Adaptive Optics' Medling, A. et al. ApJ, 743:32, Article 1, 10 pp. (2011).

Calculating the Mass of One of the Supermassive Black Holes

The next task is to calculate the mass of one of the supermassive black holes.

Firstly consider the plot above, taken from a scientific paper which calculated the mass of the southern black hole in NGC 6240.

Now pick a distance from the black hole (the red cross in the picture) and look at what velocity this corresponds to. Write these two values down in the table below.

Trial No.	Distance (r)	Velocity (v)
1		
2		
3		

To calculate the mass of the black hole, use the following equation. Make sure all your units are the same - note in the plot above the distance is in parsecs and the velocity is km/s.

$$\text{Mass} = \frac{(r \times v^2)}{G}$$

G = Gravitational constant = $6.67 \times 10^{-11} \text{ m}^3/\text{kg/s}^2$

Write down what you calculate the mass of the black hole to be.

Now repeat the process and see how close your two answers are. Try taking an average.

Compare this to the mass of the Sun. How many Suns would it take to replicate the mass of this black hole?

Mass of the Sun = $2 \times 10^{30} \text{ kg}$

Mass Trial 1	Mass Trial 2	Mass Trial 3	Average

→ CONCLUSIONS

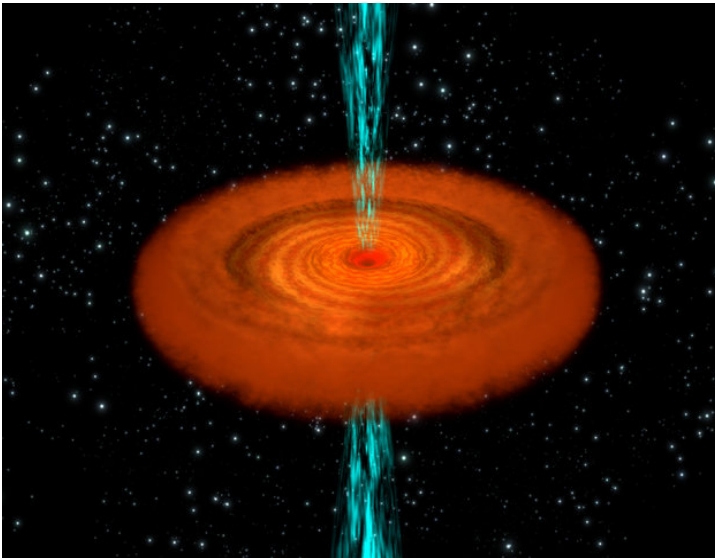
In Part 1, firstly some background was covered to introduce some of the main concepts which were used in the experiment.

In the experiment the XSA and Aladin were used to look at some of the data from the extragalactic object NGC 6240. Using this data, the distance between the two supermassive black holes contained within the galaxy-merger was measured. The distance was then compared to some standard cosmological distances to put it in context.

Finally, the mass of one of the supermassive black holes was calculated, using data from a scientific paper about NGC 6240. This mass was compared to the mass of the Sun.

As can be seen, it is possible to use simple data analysis techniques and equations to find out information about extragalactic objects in the Universe!

→ ADDITIONAL ACTIVITIES



↑An artist's impression of a galaxy containing a supermassive black hole powering a rare type of quasar called a BAL quasar. XMM-Newton has been surprised by a BAL quasar from which it has detected a higher number of X-rays than thought possible. The observation gives new insight into the powerful processes shaping galaxies during their formation and evolution.

→ Calculate the Schwarzschild Radius for the mass of the black hole previously determined. Remember, the Schwarzschild Radius is defined to be the radius around an object if all its mass were squeezed together to the point at which even light could not escape its gravitational pull.

This is the equation to calculate the Schwarzschild Radius for a non-rotating black hole:

$$R_s = \frac{2GM}{c^2}$$

c = Speed of light = 3×10^8 m/s

M = Mass of the black hole

G = Gravitational constant = 6.67×10^{-11} m³/kg/s²

→ Now do the same for the Sun - using the mass given on the adjacent page. How do these values compare?

→ Determine the required mass of a black hole that has a radius the size of Neptune's orbit: Neptune is the outermost planet in the Solar System.

Radius of Neptune's orbit, at furthest point = 30.10 AU

1 AU = 1.50×10^{11} m



↑ This is an image of the 'Mice Galaxies' or NGC 4676. They are two spiral galaxies, around 290 million light years away. Otherwise known as NGC 4676, the pair will eventually merge into a single giant galaxy in the constellation Coma Berenices.

PART 2

In Part 2 of the tutorial the Spectral Energy Distribution (SED) of the extragalactic object NGC 6240, which is a pair of merging spiral galaxies, will be investigated. Its form will be evaluated to see if it fits the model of a standard starburst galaxy, or (Ultra)-Luminous Infrared Galaxy. Next, it will be explained how to use observed emission lines on a spectrum in comparison to their rest wavelength values to calculate the redshift.

Therefore, in the background two more subjects will be covered to introduce the new concepts used in this part of the tutorial:

→Spectra

→Spectral Energy Distributions (SEDs)

Then the experiment will be explained step by step. The tools used will be VOSpec and the XMM-Newton Science Archive. Next, the form of the Spectral Energy Distribution of NGC 6240 will be discussed and subsequently, some basic calculations will be made in order to calculate the redshift of the galaxy-merger.

Finally, some conclusions will be made concerning the performed experiment, and some additional activities will be provided.



BACKGROUND

→ SPECTROSCOPY

As was previously stated, XMM-Newton includes a spectroscopic instrument. That is, some of the exposures taken are spectra. When using the archive previously you may have noticed the spectral images alongside the CCD images when searching for NGC 6240.

Spectrometers, in general, are used to disperse light into its component wavelengths. For example, shining a white light through a prism produces a rainbow. This technique can be used by astronomers to investigate the emission and absorption lines in spectra.

Emission and Absorption

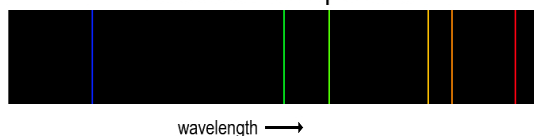
So what are emission and absorption lines?

Both arise due to light interacting with atoms. Remember, light can also be thought of in terms of tiny packets of energy, called photons.

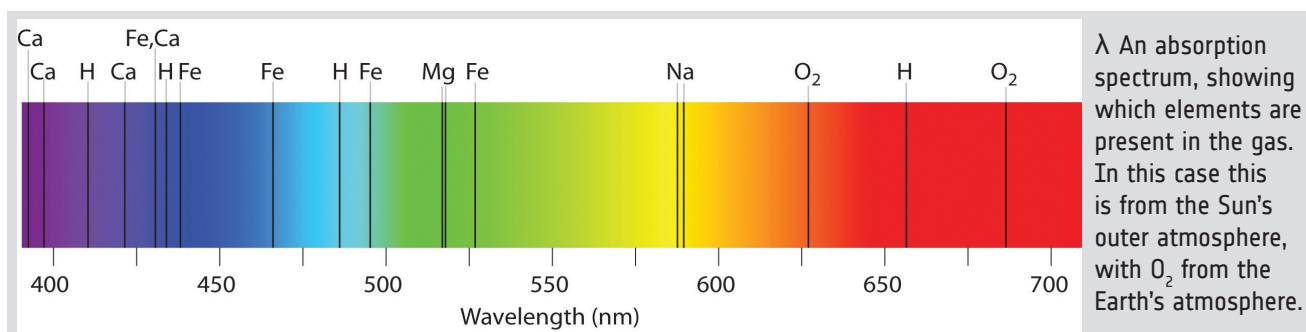
Absorption lines are produced when photons collide with an atom, causing the photon to transfer its energy to an electron, which then moves to a higher orbit around the nucleus of the atom. The photon is absorbed; and the corresponding wavelength of light is no longer seen!

Emission lines are when an electron in an atom moves down an orbit to a lower energy. The energy is emitted as a photon, which again is perceived as light at a particular wavelength.

Emission Line Spectrum



Atoms from different elements have unique energy levels and therefore only emit or absorb photons of certain energies, or wavelengths of particular length. Therefore, depending on what is observed in an object's spectra, it is possible to tell what it is made from and its physical properties such as temperature, density and motion.



→ SPECTRAL ENERGY DISTRIBUTIONS

One way in which spectra can be particularly useful to astronomers is in terms of a Spectral Energy Distribution (SED).

Many astronomical objects emit over the full range of the electromagnetic spectrum. For example, galaxies. However, different types of galaxies emit more or less flux at particular wavelengths. By inspecting the amount of flux compared to the wavelength at which the light is emitted, galaxies (or other astronomical objects) can be classified. This distribution of energy with respect to wavelength is the Spectral Energy Distribution (SED).



↑ Galaxy imaged in many different wavelengths.
Image: <http://www.sedfitting.org>

A SED may also be plotted in terms of frequency rather than wavelength. These units are related through the following equation:

$$\text{Frequency} = \frac{\text{Speed}}{\text{Wavelength}}$$

For electromagnetic radiation the speed is constant; the speed of light (c).

Moreover, the 'amount of light' is quantified as spectral flux density F , which is the rate of energy passing through a given surface area, per unit wavelength.

This is a difficult concept. Try thinking of it like this: Imagine pushing playdough through a tube; the amount of playdough passing through the end of the tube per second is the 'playdough flux'.



THE EXPERIMENT

→THE AIM

The aim of Part 2 of this tutorial is to continue considering the evidence used to determine what kind of object NGC 6240 is. This will be done by considering the form of the spectra and Spectral Energy Distribution of the galaxy merger. Then the spectra will be used to calculate the redshift of the galaxy.

→ INVESTIGATING THE SED OF NGC 6240

More Evidence for NGC 6240 Consisting of Two Merging Galaxies
 Although in the last section we assumed that NGC 6240 was the merging of two spiral galaxies containing two supermassive black holes, as this happens over billions of years it is not possible to witness first hand. Therefore, it is vital to explore more of the reasons why astronomers have concluded this is a galaxy merger.

Scientists have to find as much evidence as possible to confirm or disprove a theory. Therefore it is a very important process to understand.

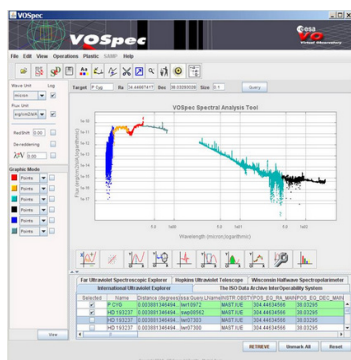
Tools Used

VOSpec: This is an ESA Virtual Observatory tool, which makes it possible to perform multi-wavelength analysis and provides easy access to spectra.

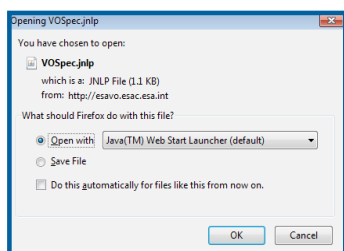
XMM-Newton Science Archive (XSA): This archive provides simple and flexible access to data from the XMM-Newton mission.

Firstly, to open VOSpec, go to:
<http://www.sciops.esa.int/index.php?project=SAT&page=vospec>

Then, on the VOSpec homepage, click on the picture of the VOSpec tool. Or, click on the link 'Webstart' under the 'Download' section.

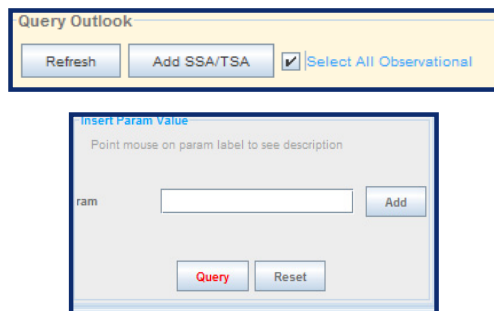


Once this has been done, a new window should open called 'Opening VOSpec.jnlp'. Make sure 'Open with' is selected, and then click 'OK'.

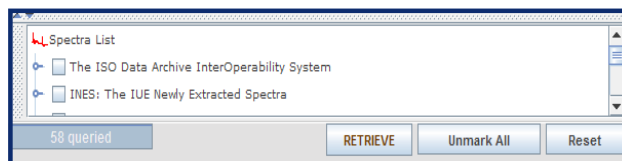


Now VOSpec should be open. In the box along the top named 'Target' type in NGC 6240 and in the box named 'Size' enter **0.1 (degrees)**. Then click on 'Query'.

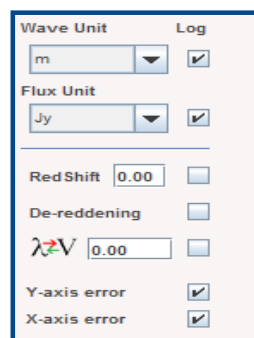
Again, a window should open called 'Server Selector'. Through this spectra can be downloaded from online catalogues. Tick the box for 'Select All Observational' and then click on the red 'Query' button, to the right.



In the 'spectra list', scroll down until you see 'NED Multicatlogue Photometry Service' (NED = NASA/IPAC Extragalactic Database). Tick the box next to this label and then press on 'RETRIEVE' below.



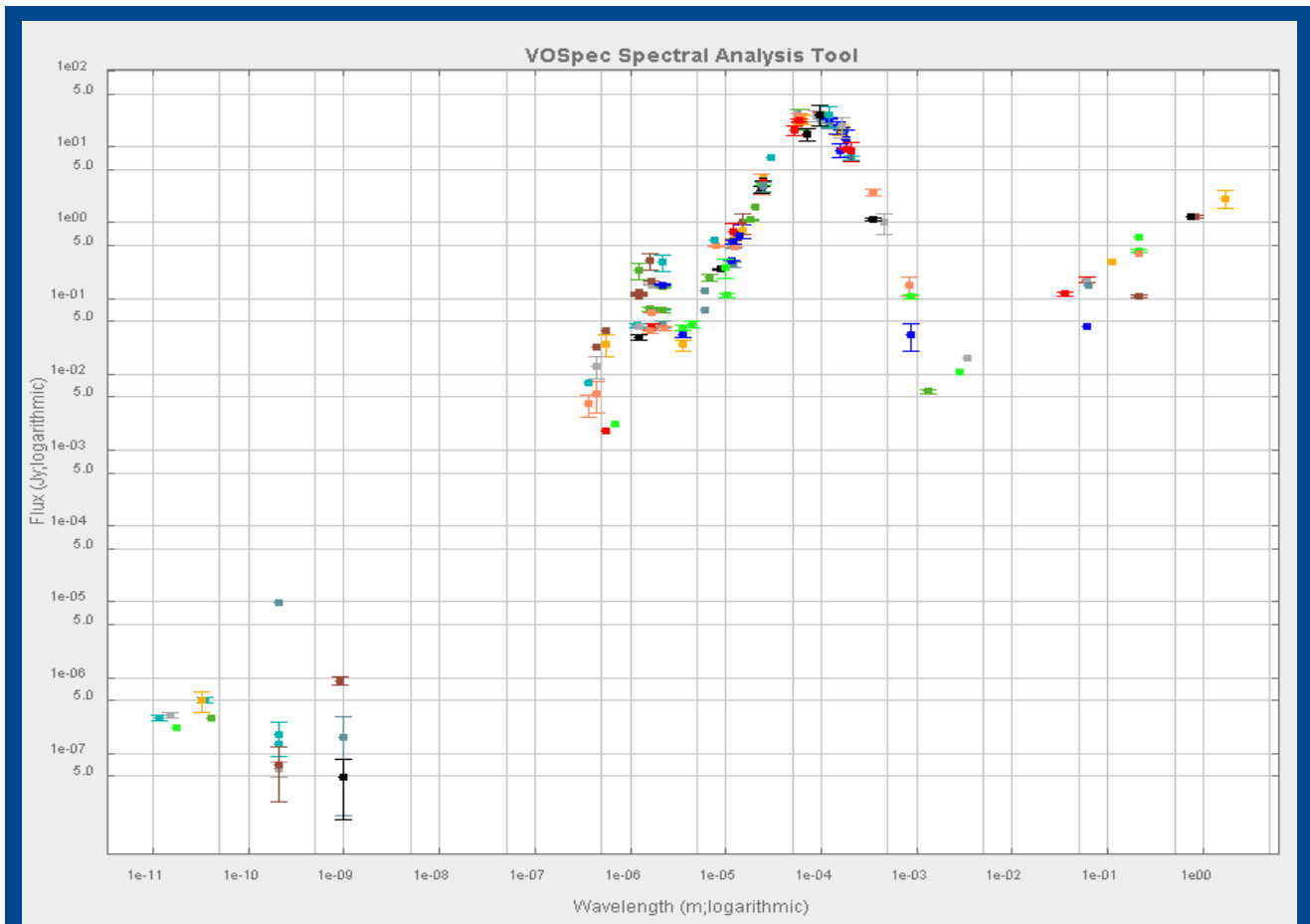
An SED with many coloured points should have loaded in the plot area. At the right-hand side change the 'Wave Unit' to meters (m) in the dropdown selection. **What wavelengths does the plot correspond to in the electromagnetic spectrum?**



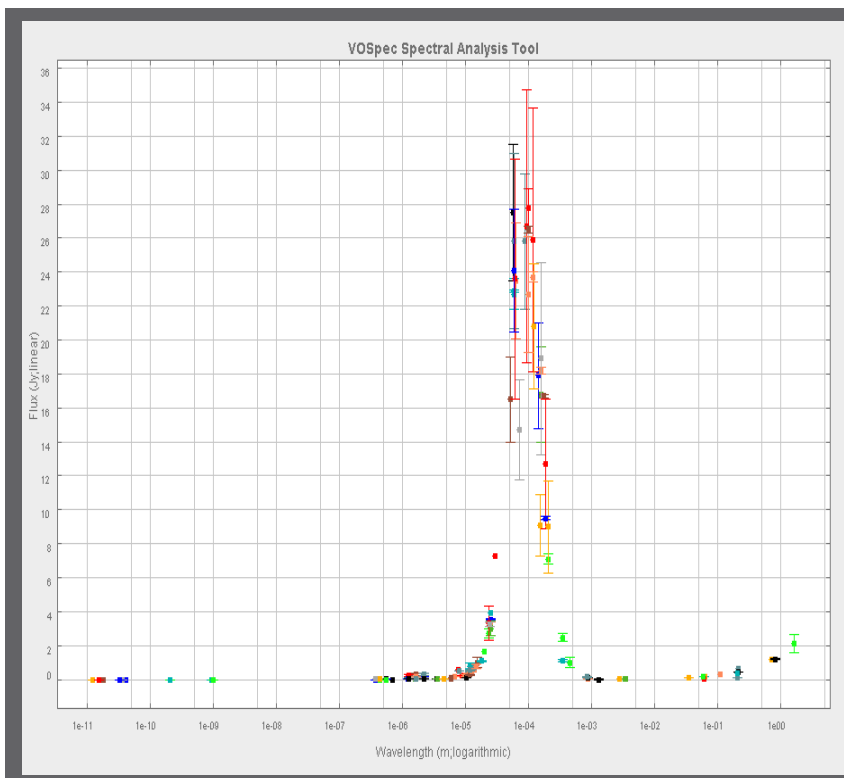
You may also have noticed that the boxes under 'log' are ticked. This means that the graph is plotted in a logarithmic scale. Often this makes the data easier to read on a plot. Try unclicking the logs to see what the graph looks like.

Finally, the spectral flux density unit, here just called 'Flux Unit' is the **Jansky (Jy)**. This is used a lot by astronomers and represents 10^{-26} watts per square metre per hertz.

To increase the size of the plot, click on the arrow in the blue square button. This should open a new window with the graph.



↑ The SED plot of NGC 6240 actually shows data from low energy gamma-rays to radio waves. The strong peak is in the infrared range. This shape is characteristic of a starburst galaxy / ULIRG.



→ Deselect the 'log' for the flux. By doing this the peak in the infrared becomes extremely clear. As was explained in the background section of Part 1, galaxy mergers are characterised by being UltraLuminous Infrared Galaxies (ULIRGs), as they contain vast amounts of dust which absorbs the ultraviolet light being emitted by newly formed stars, and reradiates it in the infrared wavelength range.

→ Therefore by investigating the spectrum, evidence has been found for NGC 6240 being a possible merging of two galaxies. This exercise should illustrate how important spectral analysis is to astronomers.

Employing Spectral Analysis to Calculate Redshift

Redshift increases the wavelength emitted by an object. Therefore a spectrum can be used to estimate the redshift of the object, by comparing the observed emission lines to their rest values. This is what will be done here.

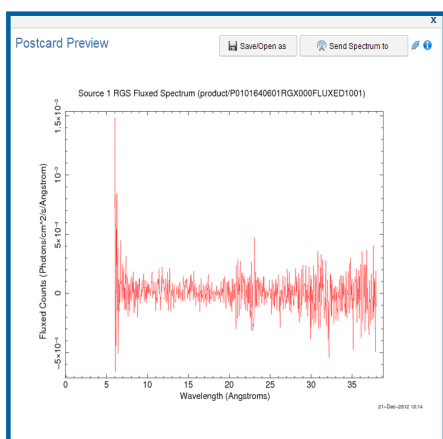
Firstly, keep the spectrum generated in VOSpec open. Or, if you have closed it, repeat the process above to reproduce it.

Now, go back the XSA archive. You should have the search results for NGC 6240 open. If not, click on the 'SEARCH' tab at the top of the webpage, and research NGC 6240, by typing this in the box called 'Name' and click 'Submit'.

With the search results open (called 'Observations'), you should be able to see that there are spectra taken by XMM-Newton of the galaxy merger. These are in the column 'RGS' and are plotted in red.

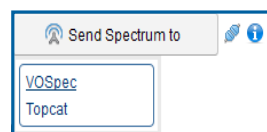
Obs.ID	EPIC	RGS	Target
0101640101		N/A	NGC 6240
0101640501	N/A	N/A	NGC 6240_RGS.OM
0101640601			NGC 6240
0147420201			NGC 6240
0147420301			NGC 6240
0147420401			NGC 6240
0147420501			NGC 6240
0147420601			NGC 6240

Click on the first spectrum, which corresponds to the 'ObsID' 0101640601. This should have opened up the spectrum in the 'Postcard Preview' view.



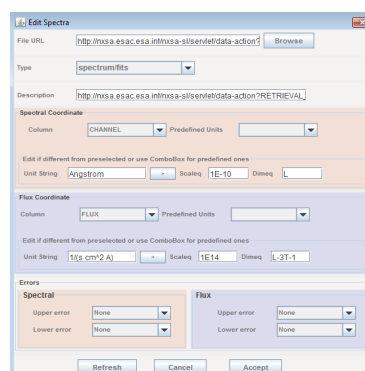
We are going to send this to VOSpec to see how the data collected by XMM-Newton compares with that in VOSpec. By doing this the new spectrum will be overlaid on the 'NED Multicatalogue Photometry Service' spectrum that should still be open.

To send the spectrum to VOSpec, look at the 'Postcard Preview' and click on the button 'Send Spectrum to' and then the link



If SAMP has disconnected, which might be the case, a window may open called 'SAMP Hub Security'. To authorise the connection and continue sending the spectrum to VOSpec, click 'Yes'. For more information about SAMP connections, click on the 'i' in the blue circle next to the 'Send Spectrum to' button in the 'Postcard Preview'.

Now move on to VOSpec. Another window should be open called 'Edit Spectra'. Do not change the options. Click 'Accept'. The new spectrum should be clearly plotted.

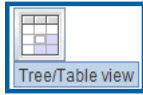


Where does it lie on the spectrum and what does this tell us about the wavelengths XMM-Newton was performing spectroscopy at?

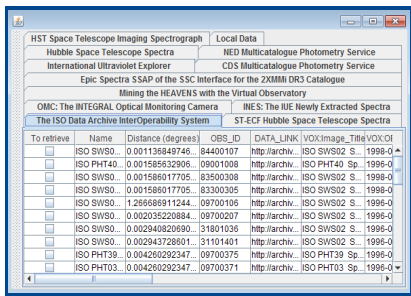
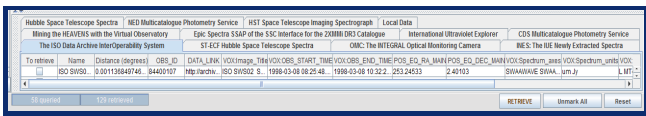
You should be able to tell that, as was expected, the XMM-Newton spectrum is in the X-ray range.

Firstly, consider the form of the XSA spectrum that was loaded. There is a lot of 'noise'; variation is apparent in the flux. This makes it much more difficult to tell if any spectral lines are present. Therefore, we will check other ranges of wavelengths to see if there is less variation at other points.

To load more spectra on top of the current spectra it will be easier to put the spectra options in table view. Therefore click on the 'table button' above the plot. The spectra options should then change to a tabular view.



To make the table more accessible left click on the edge by the side of the options; then drag. The spectra table should then be separate from the main VOSpec window.

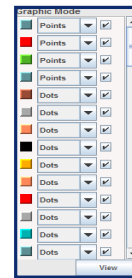


Under the tab 'The ISO Data Archive InterOperability System' (ISO - Infrared Space Observatory) select the spectrum called 'LWSO1' (There is only one of these!)

Under the tab 'International Ultraviolet Explorer' select all three spectra. Finally, go back to the main VOSpec window and click 'Retrieve'.

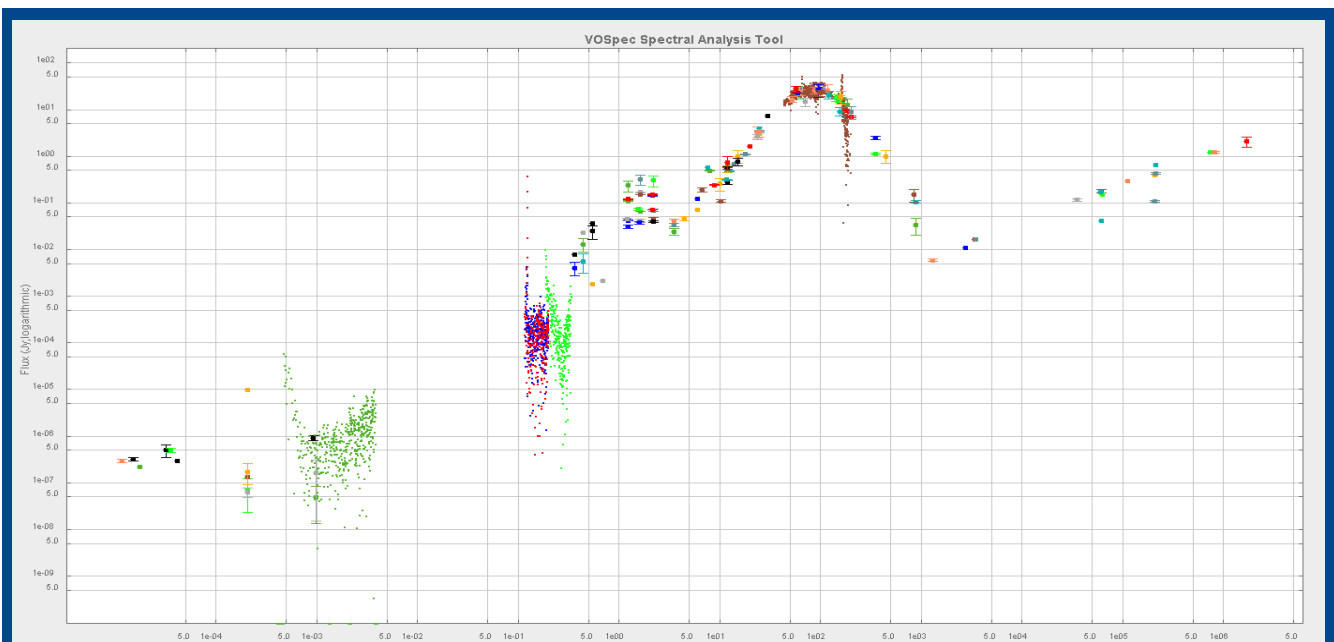
To find the redshift, spectral lines from the object need to be found and compared with their rest wavelengths. It should be clear from the plot that the infrared spectrum has the least amount of variation. Therefore 'ISO LWSO1 spectra' will be used.

To show this data only, either, look at the colour which the data is plotted in. Then down the left-hand side under 'Graphic Mode' click on the relevant coloured box and corresponding to 'points' in the dropdown box. Thus, only this data should be showing.



Or, another way, is to click on 'Unmark All' at the bottom. Then, go to the tables of the spectra, and go back to the tab 'The ISO Data Archive InterOperability System' and once again select LWSO1. Next, go back to the main VOSpec page and click 'Retrieve'. The ISO data should now only be plotted.

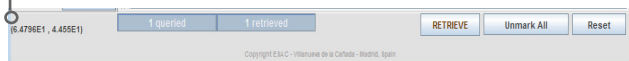
Once you have only the ISO data plotted, click on the dropdown menu next to the relevant data colour under 'Graphic Mode'. Select 'Lines', this will make the element emission lines easier to see.



↑ This is what you should see in VOSpec with all the spectra plotted. The green dots towards the left-hand side is the spectrum sent from the XSA.

Can you see the two most dominant emission lines? They are highlighted in the picture below. To begin, make sure the 'log' box for the wavelength is unchecked.

Hover the mouse over these lines to find the wavelength, which can be found in the bottom left-hand corner of the VOSpec screen. The first value is the x-axis number, which is the wavelength.



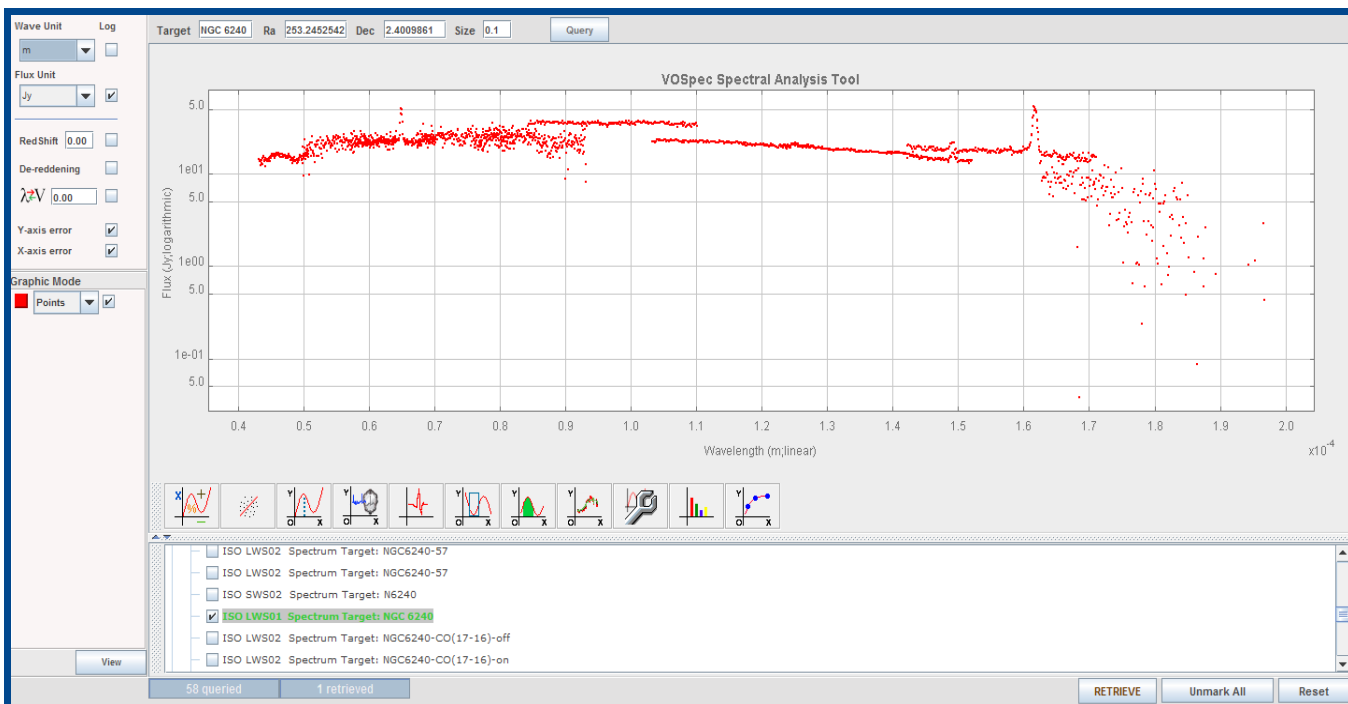
Alternatively, just read the values straight from the plot each time.

Whatever method you use, remember to do it from the centre of the peak, for the most accurate results.

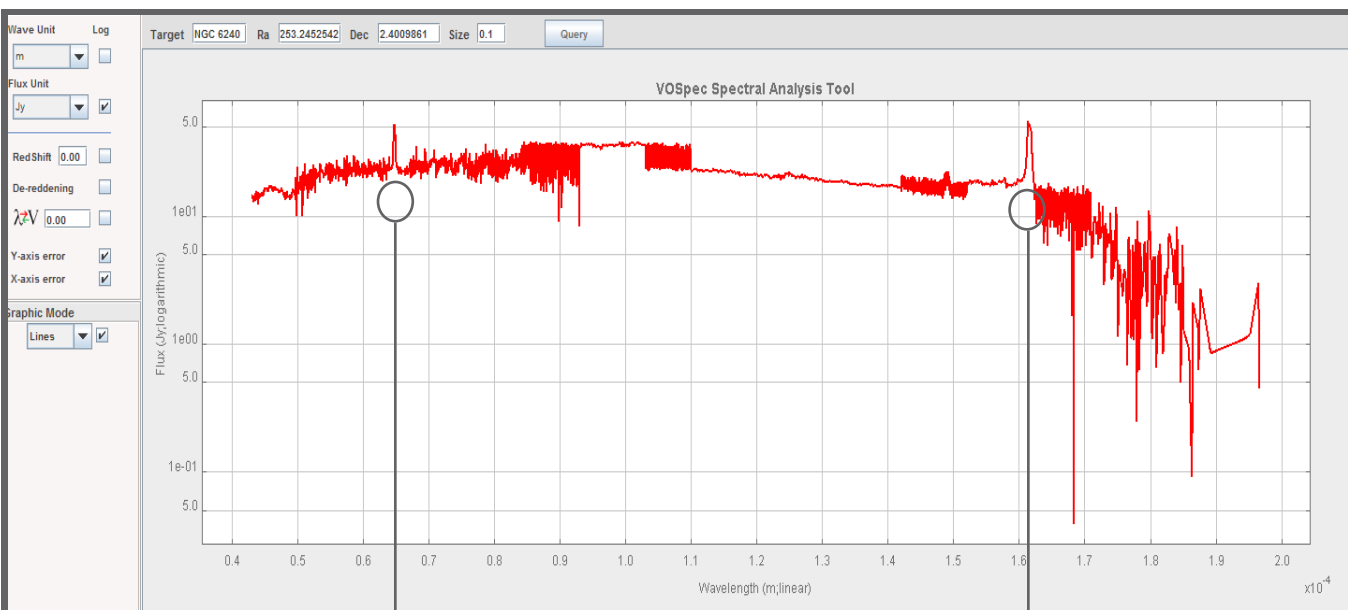
To zoom into the peak, left click on the plot and drag the box over the peak. To undo this, click on the button with a picture of a magnifying glass with a cross next to it.



These are the 'observed' wavelengths; the wavelengths that are detected have been red-shifted. This means they have been stretched from their original, or 'rest' wavelengths.



↑ Here you can see that only the ISO LWS01 Spectrum has been selected. It is initially in points; it is clear it is not easy to see where the emission lines lie when the data is plotted like this. To change this, go to 'Graphic Mode' and select 'Lines'. Moreover, make sure the 'log' function for wavelength is deselected.



↑ The plot using the ISO data, which should have been produced in VOSpec. The two dominant lines are highlighted here.

Therefore, to calculate the redshift the 'rest' wavelengths are needed. The line at the smaller wavelength is [OI], which is Oxygen. The longer wavelength is [CII] and this is Carbon.

The 'rest' wavelengths of these are $63.187 \times 10^{-6} \text{ m}$ and $157.7409 \times 10^{-6} \text{ m}$ respectively.

Emission Line Element	Observed Wavelength of Emission Line

→ Now use these values, along with the values you found from the spectrum in VOSpec in the following equation to calculate the redshift, do this for both the Oxygen and Carbon lines and then take an average:

$$z = \frac{(\lambda_{observed} - \lambda_{rest})}{\lambda_{rest}}$$

λ = Wavelength

→ Use the Hubble-redshift relation stated below and your value for the redshift to calculate the distance to the galaxy.

$$\text{Distance} = \left(\frac{c}{H} \right) \times z$$

c = Speed of light = $3 \times 10^8 \text{ m/s}$
 H = Hubble's Constant = 75 km/s /Mpc

→ Finally compare these distances you have found to some of these standard astronomical distances.

Distance from Sun to the centre of the Milky Way:
 $8.3 \pm 0.34 \text{ kpc}$

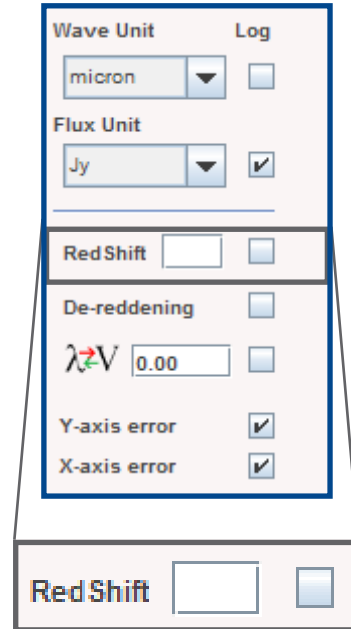
Distance to the closest galaxy, the Canis Major Dwarf Galaxy: $25,000 \text{ light years}$

Distance to Andromeda: $2.4 \times 10^{19} \text{ km}$

The answer for all numerical problems can be found at the back of this tutorial booklet.

Finally, it is possible to adjust the wavelengths shown on the spectrum so that they show the correct values.

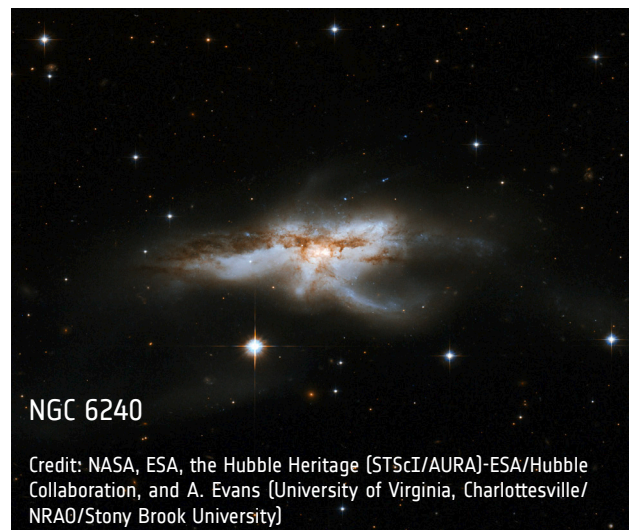
This is done by entering the redshift, which VOSpec then uses to adjust the wavelengths it is displaying. Therefore, go to VOSpec and look at the left-hand side panel. It should be possible to see two boxes labelled RedShift.



In the larger box, type in the redshift you calculated. Then tick the smaller box next to this.

Did you notice the spectrum shift? The wavelengths should have changed. Zoom in on the emission lines again. **What values do they have?**

If you have determined the redshift correctly, they should match the **rest wavelengths** stated on the previous page.



→ CONCLUSIONS

In Part 2 initially some extra background was covered, relevant to the continuation of the tutorial and the experiment.

The experiment consisted of the evaluation of the SED of NGC 6240. It took the form of an Ultra-Luminous Infrared Galaxy, which was what was expected. It was also noted that NGC 6240 corresponded to a starburst galaxy; one which is producing new stars at a high rate. Again this helped to confirm that it is in fact a pair of merging galaxies. Then, using spectroscopic techniques; studying emission lines from particular elements, a redshift of the galaxy was calculated. Using the redshift, and Hubble's constant, a distance to the galaxy could be estimated.

→ ADDITIONAL ACTIVITIES

- Repeat Part 2 of the experiment for an object named 'Arp 220'
- What can you tell about the spectrum of Arp 220? Compare it to the spectrum of NGC 6240. What kind of object do you think Arp 220 is?
- Firstly the redshift of Arp 220 will be calculated, then the element which corresponds to the emission line will be determined by using the method explained below:

Load the 'ISO LWSO1' spectrum of Arp 220 into VOSpec. There should be three available; use the **first one** in the list. Make sure the 'log' function is deselected for wavelength, and put the units in meters.

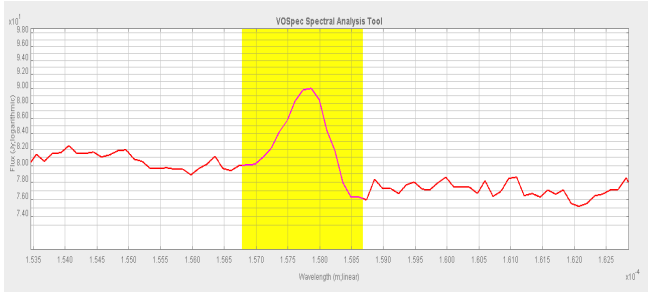
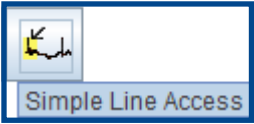
Can you see any obvious emission or absorption lines?

The emission line you will use to calculate the redshift is the most prominent emission line towards the right-hand side of the spectrum. It is around $1.6 \times 10^{-4} \text{ m}$. If you aren't sure, an image with it highlighted is provided in the Numerical Solutions section of this booklet.

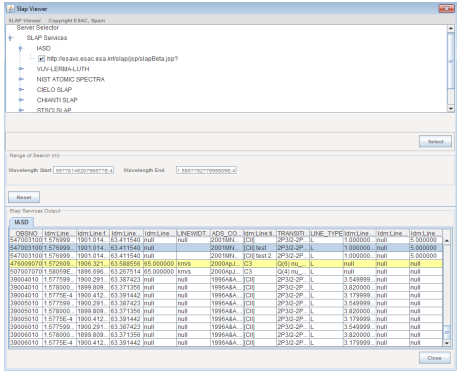
Zoom in on the emission line by left-clicking and dragging, so a blue box encloses the whole of the peak. Read off the value of the wavelength at the top of the line. To undo the zoom, click on the bottom with the picture of the magnifying glass on it.

The value of the rest wavelength of the emission line is $1.577 \times 10^{-4} \text{ m}$. Use the equation on the adjacent page to calculate the redshift. Enter it into the 'RedShift' box on the left-hand side and make sure the box is ticked. The spectrum should shift. Does the peak now approximately match up with the value $1.577 \times 10^{-4} \text{ m}$. If it doesn't, try the calculation again.

Finally, to find out the element which produced this emission line, use the 'SLAP' service. Click on the button called 'Simple Line Access'. This searches databases of elements' wavelengths. Then, highlight the emission line by left clicking and dragging the mouse over the peak.



A new window should open called 'Slap Viewer'. Select the box under 'IASD' named '<http://esavo.essac.esa.int/slap/jsp/slapBeta.jsp?>' Then press 'Select'. The window should load a list of elements and wavelengths in the box at the bottom.



Go back to VOSpec and hover the mouse over the peak of the emission line. What element is displayed? This is the element that produced the emission line.

→ NUMERICAL SOLUTIONS

→PART 1

The distance between the black holes shown on Aladin should have been around **1.75 arcseconds**. It should not be any larger than 2.25 or smaller than 1.25 arcseconds.

Using the fact that **1 arcsec = 470 parsecs** (ONLY APPLICABLE TO THIS GALAXY IMAGE) this gives a distance of **~822 parsecs**. This gives **~2681 light-years** and **~2.54 x 10¹⁶ km**.

This means it is ~10x smaller than the distance from the Sun to the centre of the Milky Way.

It also is less than ~10x smaller than the distance from the Earth to the nearest galaxy; you may have noticed that we are actually closer to the nearest galaxy, Canis Major, than we are to the centre of our own galaxy the Milky Way!

Furthermore it is ~100x smaller than the distance to Andromeda.

Although these show that the distance is smaller than the comparison cosmological distances, it does illustrate that the black holes in NGC 6240 are still very far apart, and it will be an extremely long time before they could collide.

The mass of one of the supermassive black holes should have been calculated at around **2 x 10³⁹ kg**.

The paper the plot was taken from estimates the upper limit as **2 x 10³⁹ kg** and the lower limit as **1.74 x 10³⁹ kg**.

This can then be used to show that it would take around 10⁹ Suns to make this black hole; this is around 1 billion Suns!

→ADDITIONAL ACTIVITIES

The Schwarzschild Radius for the black hole should have been calculated at around **2.96x10¹²m** or **2.96x10⁹ km**.

The Schwarzschild Radius for the Sun is about **2964.4 m**. Or only **2.96 km**! You should see that as the mass of the Sun is one billion times smaller, the radius should be too, as they scale linearly with each other.

A black hole with the radius the same as Neptune's orbit would have a mass of **3.05 x 10³⁹ kg**. Compare this with the mass and Schwarzschild Radius of the black hole in NGC 6240. They are very similar! Therefore we can see that the black hole in NGC 6240 is extremely large.

→If you are feeling comfortable with the equations used in this part of the tutorial, why not try and calculate some other masses or Schwarzschild Radii? For example, how many of **you** would it take to create a black hole just 1m in radius? Or how big would **your Schwarzschild Radius** be if you were compressed enough to create a black hole?

→Another interesting activity would be to estimate the velocity of the material that would be orbiting a black hole the same size as the one in the center of the Milky Way - try different distances from the black hole to see how the speeds vary.

→ PART 2

The line which corresponds to OI (Oxygen) should have been found to be at around $6.474 \times 10^{-5} \text{ m}$. This produces a redshift of ~ 0.0247

The line which corresponds to CII (Carbon) should have been found to be around $1.616 \times 10^{-4} \text{ m}$. This produces a redshift of ~ 0.0244

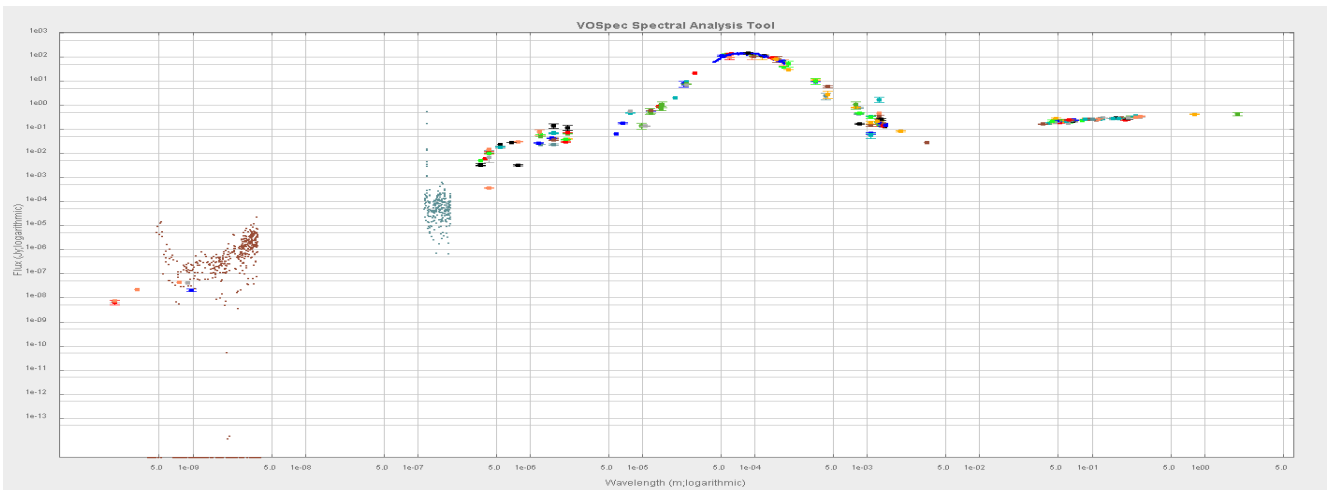
Therefore, the average redshift is **0.0246**.

Using the Hubble-Distance redshift relation this gives a value of **98.4 Mpc** (Mega-parsecs) which is $9.84 \times 10^7 \text{ parsecs}$, or **98,400 kpc**, or $3.2 \times 10^8 \text{ light-years}$, or $3.03 \times 10^{21} \text{ km}$.

Therefore it is $\sim 10,000x$ further away in comparison to the distance from the Sun to the centre of the Milky Way. This also shows it is $\sim 100x$ further away than the closest spiral galaxy Andromeda.

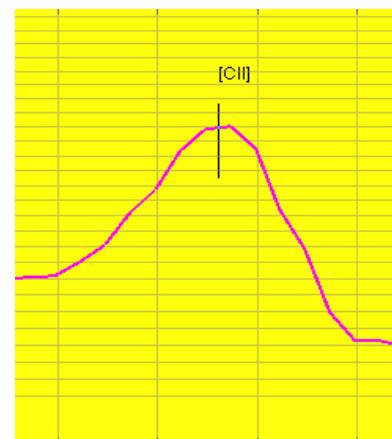
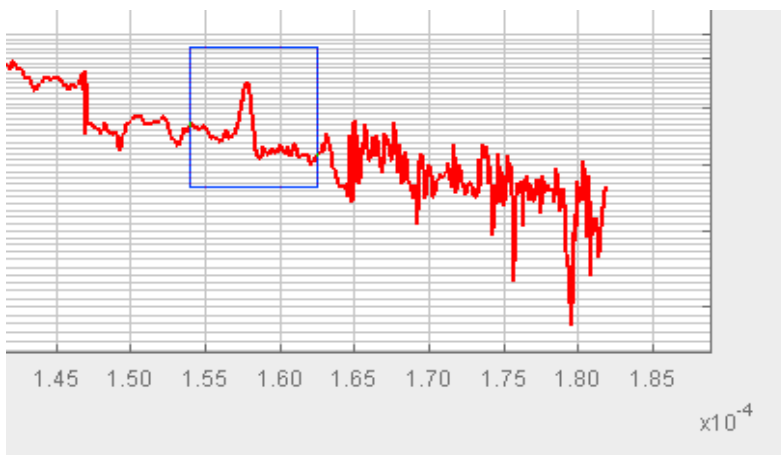
→ ADDITIONAL ACTIVITIES

The spectrum of **Arp 220**, with the same data sources as in Part 2 experiment.



This is very similar to the spectrum produced for NGC 6240. **This is because Arp 220 is in fact a starburst ULIRG. It is believed to be the result of a collision between two galaxies.**

The redshift calculated should be around **0.018126**.



The element which produced this emission line should have been found to be **[CII] which is Carbon**. Why not try finding out more information about Arp 220?



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