Episode 701: Observing stars

What we know about the Universe comes from observations which rely on the radiation and (to a lesser degree) particles which reach us on Earth.

Summary

Discussion: What is astronomy? (10 minutes)

Student activity: Reviewing current knowledge. (30 minutes)

Discussion: How do we know? (10 minutes)

Demonstration: A line spectrum. (20 minutes)

Demonstration: Further spectral types. (20 minutes)

Discussion: A stellar poem. (10 minutes)

Discussion:

What is astronomy?

Students will have heard of several different terms that you want to disentangle at the start:

- Astronomy is, broadly speaking, the observation of the motion and distribution of celestial objects.
- Astrophysics is the application of physics to astronomy.
- Cosmology is the study of the Universe as a whole, its origin, development and fate.
- Space science is concerned with space exploration, including putting people in space.
- Astrology is an attempt to predict the future based on the positions of the stars and planets. Scientists regard this as mumbo-jumbo, but you may have to be sensitive to students' personal or religious views.

Naked eye observation of the night sky can reveal up to 8000 objects, mostly stars, the Moon and various 'nebulae'. On closer inspection the nebulae are either diffuse dust clouds or galaxies that have a definite shape (spiral, elliptical etc). Repeated observation reveals the 'wandering stars' now known as the planets (5 are visible to the naked eye). If you are lucky you may observe the odd comet.

Because the speed of light is finite and we see all the light entering our eye at the same time, the further away its source, the father back in time it is being observed.

With the naked eye we can see out to about a distance of 2×10^{18} km corresponding to light that has been travelling for ~ 200,000 years (so the distance ~ 2×10^{5} light years). In other words, we are seeing back in time for up to 200,000 years ago (NB even looking in a mirror you see yourself as you were a split second ago!).

Student activity:

Reviewing current knowledge

Find out what your students already know (or think they know) by asking them to assess a number of statements about astronomy.

TAP 701-1: What do you know about cosmology?

Discussion:

How do we know?

All our information about astronomical objects in the Universe beyond our solar system is gleaned by analyzing the electromagnetic radiation they emit or absorb. Visible light is of course a small part of the total spectrum. A useful analogy is a fraction of an octave compared to the range of a concert grand piano.

Temperature, relative speed to Earth, rate of spin, orbital speed (and hence mass), and what they are made from can all be deduced by analysis of their electromagnetic radiation.

Knowing what stars ‘are’, that those twinkling pin points of light have a structure, and that our Sun is made of the same stuff as down here on Earth had a similar intellectual impact as the change from the geocentric to the heliocentric model of the 17th century known Universe.

Some elements were first discovered ‘out there’ before being found ‘down here’ on Earth. For example, helium was discovered in 1895 in the spectrum of the Sun, and so was named after Greek word for the Sun (Helios).

Demonstration:

A line spectrum

It’s worth repeating for emphasis that our knowledge about astronomical bodies is coded in the ‘light’ they emit. All we can measure is the colour (i.e. wavelength λ) of the ‘lines’ in the spectra and the intensity at each wavelength.

There are three categories of spectra: continuous, band and line. Line spectra are subdivided into emission and absorption spectra.

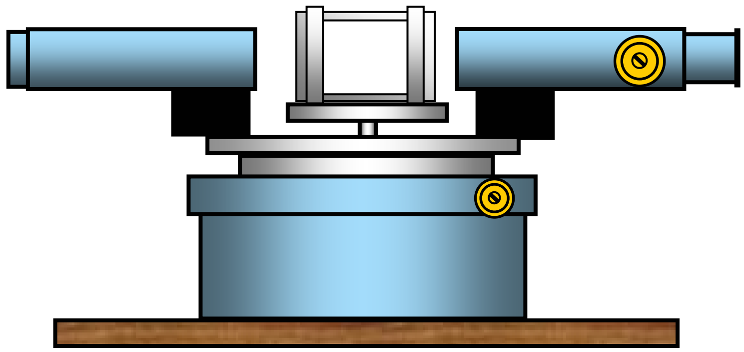
Start with a demonstration of the sodium (Na) spectrum. View a sodium lamp using either an optical spectrometer or hand-held spectroscopes. Students should see a clear set of differently-coloured spectral lines, with (apparently) random spacing.

Now discuss: Why do we observe spectral ‘lines’? Each ‘line’ is an image of the slit in the spectrometer (if you have an optical spectrometer indicate it to the students).

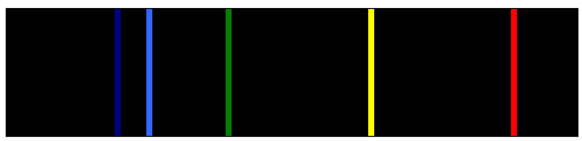
(To emphasise this, you could show that a circular laser beam and a grating gives a series of circular diffracted *spots*. A ‘laser line’ parallel to the grating slits gives a series of lines. (A laser line is also the commercial name for a useful and cheap DIY item used to give a line of light for setting tiles horizontal etc.)

Safety

Remember that a class 2 laser can be used with the simple warning ‘Do not stare down the beam.’ Other lasers require precautions.



Each atom has a *unique* line spectrum, a sort of ‘bar code’ that is used to identify each atomic constituent.



For each line the spectrometer determines the wavelength λ, hence f (= c/λ), hence the energy *difference* between two energy levels in the atom from $\Delta E = hf$. (Refer to the relevant lessons, or flag forward to that section of your specification.)

A quite common misapprehension is that the line spectrum is the energy level diagram ‘turned on its side’.

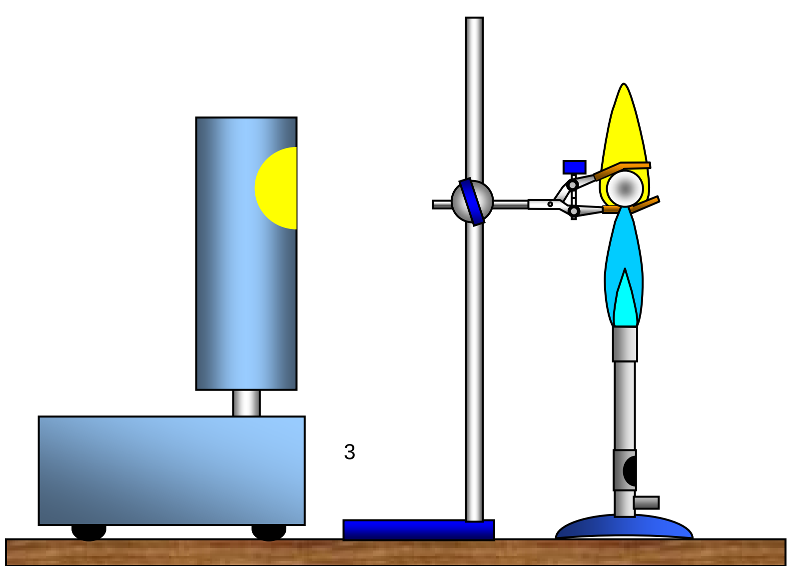
Episode 501: Spectra and energy levels

Because of the high stellar temperatures many atoms become ionized, (at the centre of a star atoms are totally ionized). It is common to see a spectrum due to partially ionized atoms rather than that of just a neutral atom. This is particularly true of sodium and calcium. Only in the coolest stars will the spectrum of only neutral atoms be present.

Demonstration:

Further spectral types

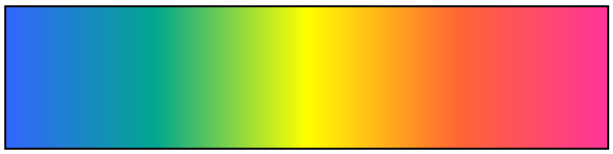
Demonstrate an emission spectrum using a spectrometer. Simply look at a Bunsen flame into which you sprinkle salt.



Demonstrate an absorption spectrum using a spectrometer – position a white light source so that it shines through a cloud of sodium atoms – arrange the light beam above a Bunsen flame into which you sprinkle salt.

Now show the band spectrum from the hydrogen molecules in a hydrogen discharge tube (or similar). It's also worth looking at the historically important Balmer series from the atomic hydrogen.

Finally, look at the continuous spectrum from a white light source.



Your students may wish to see examples of spectra used to classify star types. These are available at:

http://antwrp.gsfc.nasa.gov/apod/ap010530.html

TAP 701-2: How to set up a spectrometer

Discussion:

A stellar poem

The poem by G M Minchin sums up nicely the story so far, and provides an opportunity to mention how some of the scientific assumptions have changed over the last hundred years or so.

It was written before the source of stellar energy (nuclear fusion) was known, so a star's death was thought to be due to collision. Stars were just assumed to have planetary systems (extra-solar planets were not actually discovered until 1995), and light although known to travel at a finite speed was assumed to need an ether in which to propagate.

To finish this episode, discuss the sort of evidence that can be gleaned from spectra. It should be evident that we can deduce the chemical compositions of stars, as well as interstellar dust and gas. You can add that spectra can also tell us about the following:

- Relative quantities of different elements
- Brightness
- Temperatures
- Movement – Episode 702: Red shift

TAP 701-3: POEM by G M Minchin

TAP 701- 1: What do you know about cosmology?

Everybody knows something

Many people have a great interest in cosmology – and already know a lot about it. But what they know may be disorganised - and self contradictory. This activity will help you find out how much you already know about this topic.

You will need

- ✓ copies of statements about cosmology on card
- ✓ a large card with the headings ‘Agree’, ‘Disagree’, ‘Don’t know’

What you have to do

You will probably learn most by working in groups – your teacher will organise this. You will be given a set of statements about cosmology.

1. Read each statement in turn.
2. Discuss with your partners whether or not you agree with the statement.
3. Put the statement cards in a pile under the appropriate headings. Use the 'Disagree' heading when the whole group thinks that the statement is incorrect. If the members of the group disagree about the statement then classify the statement as a 'Don’t know'!

   Finally, your teacher will discuss your decisions with you: be prepared to defend them.

Outcome

1. You will have a good idea about what you already know and what you still have to learn about cosmology.

Practical advice

This activity is the kind of activity that students usually find interesting and often leads to some spirited discussions. It will also give the teacher an idea of how well-informed the students are, and so help in planning future lessons and activities. Cosmology is a popular topic and some students will have read a great deal and have at least a good, if superficial, general knowledge. If they do ‘know everything’ then subsequent lessons may be able to concentrate more on how this knowledge is obtained by astronomers.

Introduce the topic briefly, without giving too much away. You might simply give a very brief résumé of how people’s ideas about the Universe have changed over time, for example, from the Babylonian idea of an island supported by elephants on the back of a tortoise to a round Earth surrounded by crystal spheres with stars merely holes through which the outermost element of fire was to be seen.

Prepare copies of the statements, each on a separate slip of paper or card, and number them to aid later identification. You might decide to use a subset of the statements, to save time or to match your knowledge of the students' abilities and interests. Divide the class into groups of three or four students and explain the task – to agree on the statements, or not, and place them into two piles accordingly. If they can't agree one way or the other, or simply don't know, they should put the statement card into a 'Don't know' pile.

Allow about 15 minutes for this group discussion – or longer if discussions are fruitful. But consider that it might be a waste of time to allow unsubstantiated argument to go on too long.

Finally, summarise the outcome as a simple 'straw poll' under the three headings.

Raise the question: what evidence is there for or against the statements on the cards? Answering this will provide the programme for the rest of the topic.

Statements for the activity

(delete items or add your own if you wish):

The Universe was created about 5000 years ago.

The Universe was created about 14 billion years ago (14 x 10^9 years).

On average, the Universe is a vacuum, with about one hydrogen atom to every 10 cubic metres of space.

The Universe is expanding.

The Universe began as a very small point and then exploded with a 'big bang', so creating matter, energy, space and time.

When we look into the night sky, without the aid of a telescope, we can see about 5000 stars.

The solar system is at the centre of an expanding Universe.

Astronomers have measured the movements of the stars we can see in the night sky and shown that they are all moving away from us.

Galaxies are huge collections of many hundreds of millions of stars.

The Universe is eternal and has always been the same as it is today.

The Universe is infinitely large.

New stars are being created today.

Stars don’t stay bright forever, eventually they will ‘die’ and stop radiating.

The Universe will keep on expanding forever.

Eventually the Universe will stop expanding and start collapsing back to a point.

The most common element in the Universe is hydrogen.

When you see a star through a telescope it might no longer be there.

External References

This activity is taken from Advancing Physics, chapter 12, 10E

TAP 701- 2: How to set up a spectrometer

Important: NEVER LIFT A SPECTROMETER BY ITS “ARMS”

A Focusing

- Adjust the eye piece so you can see the cross-hairs with a relaxed eye
- Focus the telescope on infinity (i.e. an object a long way away).

The telescope is now set to receive and focus parallel light.

- Adjust the collimator to as to see sharp image of slit. The collimator is now providing parallel light.
- Adjust the slit so that just enough light gets through to give an easily visible ‘line’.

B Aligning the grating

The grating must be at right angles to the parallel light from the collimator.

‘Proper’ method

(If data being taken)

- Before inserting the grating, set the telescope at 90 degrees to the collimator.
- Insert the grating so that it *reflects* light from the collimator into the telescope. It must then be at 45 degrees to the light beam.
- Turn the grating 45 degrees so that it is now at 90 degrees to the collimator. Clamp the grating turntable.
- Re-set the telescope to see an image of the slit.
- Note the telescope vernier reading (this is the zero reading from which all diffraction angles can be measured).

‘Quick’ method

(For making qualitative observations)

- Line up the telescope at 90 degrees to the collimator
- Insert the grating by eye at 90 degrees to the collimator.
- Locate a diffracted beam using the telescope.
- Slowly twist the grating and find the position when the diffracted beam has the smallest angle of diffraction. Clamp the grating table.

[The light from the collimator now ‘sees’ the grating slits at their full width, which gives the smallest diffraction angle: $d \sin\theta = n \lambda$, thus $\sin \theta \propto d^{-1}$, maximum ‘d’ gives minimum $\sin \theta$ and hence the smallest θ.]

External reference

The picture is taken from Resourceful Physics

TAP 701- 3: POEM by G M Minchin

Distant scintillating star,
Shall I tell you what you are?
Nay, for I can merely know
What you were some years ago.

For the rays that reach me here
May have left your photo-sphere
Ere the fight of Waterloo –
Ere the pterodactyl flew!

Many stars have passed away
Since your aether-shaking ray
On its lengthy journey sped –
So that you perhaps are dead!

Smashed in some tremendous war
With another mighty star –
You and all your planets just
Scattered into cosmic dust!

Strange, if you have vanished quite.
That we still behold your light,
Playing for so long a time
Some celestial pantomime!

But, supposing all is well,
What you're made of, can I tell?
Yes, 'twill be an easy task
If my spectroscope I ask.

External reference

Published in *Nature*, 14th April 1898