

Stars

The spectra of SS433

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Introduction

SS433 is a binary star system which consists of a massive, hot star and a compact object (a small, dense object at the end of a star's life, such as a neutron star or black hole), orbiting around a common centre of mass. As material from the star falls towards this compact object, an accretion disk forms. This disk radiates at a variety of wavelengths, from the optical to the X-ray part of the electromagnetic spectrum. It can't handle all the material that flows from the companion star, so it ejects most of the gas as jets of material at speeds of around quarter the speed of light at right angles to the plane of the disc. The diagram below, produced by Rob Hynes (<http://www.astro.soton.ac.uk/~rih/>) shows how this binary star system may look.

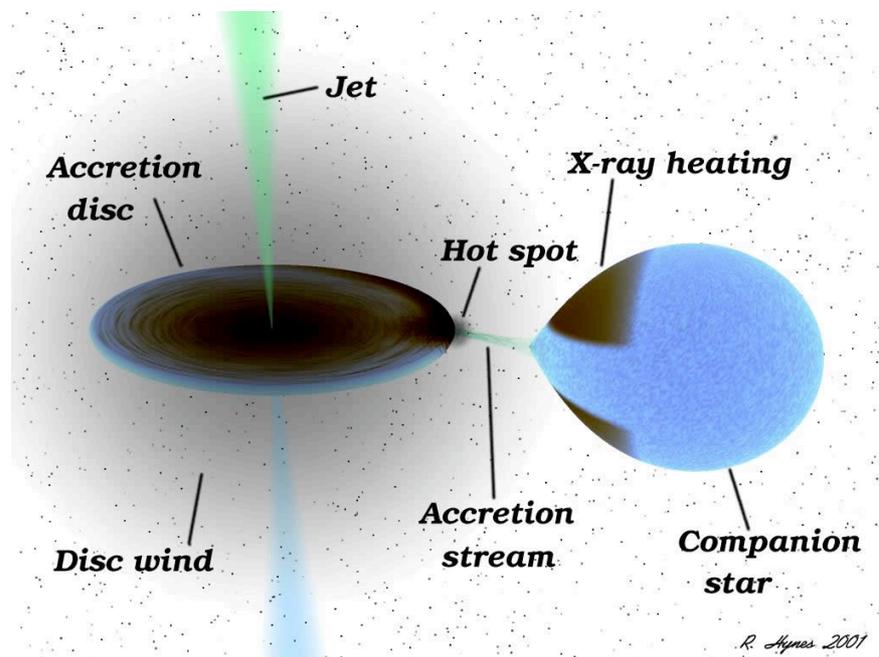


Fig. 1. How the SS433 binary star system may look

The Discovery

The binary system SS433 was discovered by an American astronomer, Larry Kruminaker in the 1970's. Originally named 'K16', Kruminaker found this object during his summer job, when he spent hours looking at spectra of stars on photographic plates (much like the one in Fig 2 below). He was looking for stars which had particularly bright Hydrogen Alpha emission lines on the spectra, but came across an object which had a wider than average emission line for Hydrogen gas. After naming it K16, Kruminaker published his findings in an astronomical journal in 1975 and left the data until he could find a bigger telescope.

In the meantime, two other astronomers from Case Western University, Bruce Stephenson and Nick Sanduleak came across K16 when they were compiling a list of objects with emission lines in their spectra. Being the 433rd object in their catalogue, they renamed the object SS433, which is the name by which it is now known.

The mysterious SS433 Spectral Lines

The first optical spectral lines of SS433 were obtained by two UK astronomers, Paul Murdin and David Clark who found that together with the very broad H-alpha emission line, there were also other lines on its spectrum which couldn't be identified with any known chemical elements!

This puzzle came to the attention of the American astronomer Bruce Margon, who began taking and studying more spectra of the SS433 system. He found that the unidentified lines were actually pairs of lines, with one line shifted to the blue part of the spectrum (blueshift) and the other line shifted to the red (redshift).

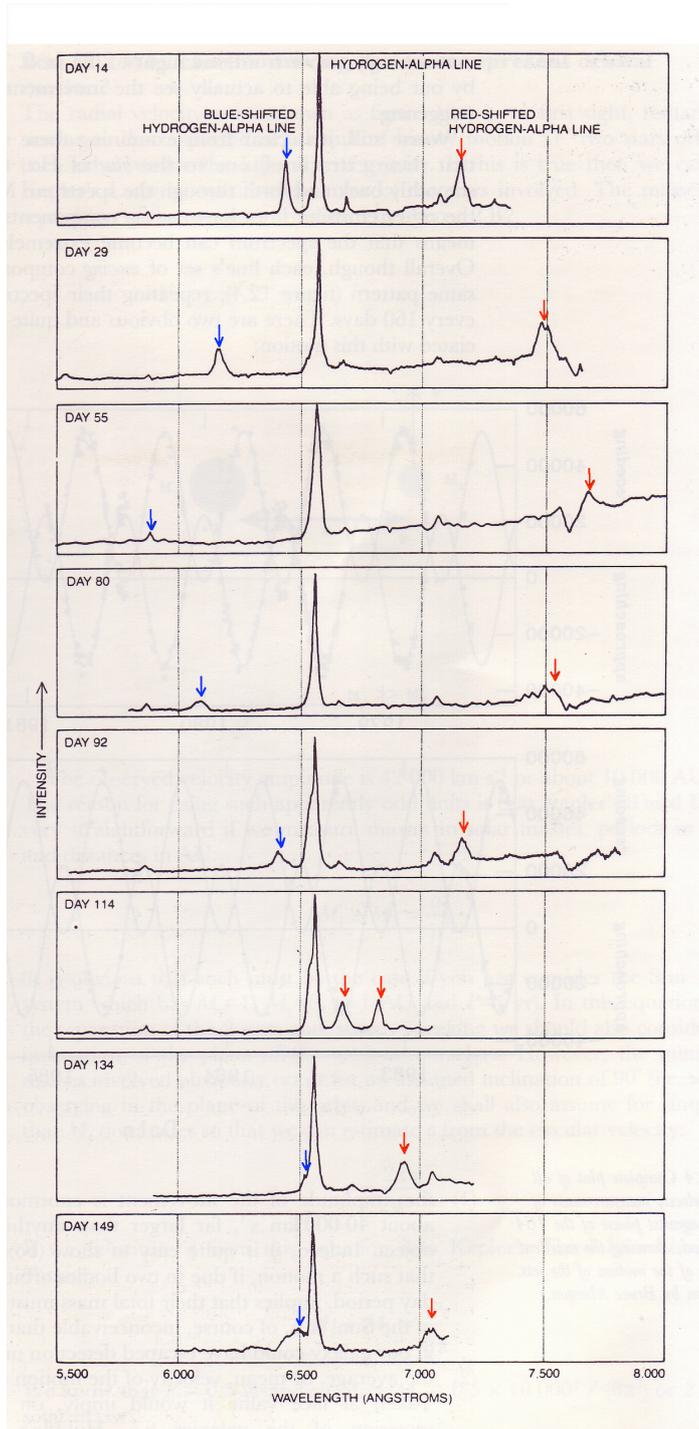


Fig. 2. Optical spectra of SS433 taken over a 5 month period (Bruce Margon).

The large peak at the centre of the spectrum is the stationary Hydrogen Alpha emission line. The pairs of Hydrogen Alpha lines which have been blue and red shifted are shown by the blue and red arrows respectively.

These lines move over the 5 month period as can be seen in the diagram. Towards the end of this period, both pairs of Hydrogen Alpha lines become redshifted as they move towards the red end of the spectrum.

Redshift, z , is defined as the ratio of the change in wavelength, $\Delta\lambda$, to the wavelength, λ_0 , as measured in the laboratory. It is given by:

$$z = \Delta\lambda/\lambda_0 = \lambda - \lambda_0/\lambda_0 \quad (1)$$

and if $v \ll c$ (v = speed of the source of the radiation, c = speed of light in a vacuum), then:

$$z = \Delta\lambda/\lambda_0 \approx v/c \quad (2)$$

If v is approaching c , the speed of light, then equation 2 would not be valid - the effects of special relativity would have to be taken into account, but this is beyond the scope of this worksheet, so we will assume that $v \ll c$ for the following questions.

If the value for z is negative, the source is moving towards the observer (i.e. its light is blue shifted). A positive value of z implies that the source is moving away from the observer - its light is redshifted.

The H-alpha lines of SS433 shift on a periodic basis every 164 days.

1. From equation 1, show that:

$$1+z = \lambda/\lambda_0$$

2. Describe with the help of a diagram how the H-alpha emission line is generated.

3. From Fig.2. it can be seen that the blue shifted H-alpha line is at its highest blue shift around Day 55. At this point its measured wavelength is approx. 5860 Å. The rest wavelength of H-Alpha is 6560 Å.

a). Explain what is meant by the term 'blue shift'.

b). Using equation 1 above, calculate the blue shift of this line at the point of its highest blue shift.

b). Using equation 2 and your answer above, calculate the velocity at which the source is travelling at this point (the speed of light, c is $3 \times 10^8 \text{ms}^{-1}$). Give your answer in terms of both a fraction of the speed of light, and in ms^{-1} .

4. From Fig.2. it can be seen that the red shifted H-alpha line is at its highest red shift around Day 55 also. At this point its measured wavelength is approx. 7700 Å. The rest wavelength of H-Alpha is 6560 Å.

a). Explain what is meant by the term 'red shift'.

b). Using equation 1 above, calculate the red shift of this line at the point of its highest red shift.

b). Using equation 2 and your answer above, calculate the velocity at which the source is travelling at this point (the speed of light, c is $3 \times 10^8 \text{ms}^{-1}$). Give your answer in terms of both a fraction of the speed of light, and in ms^{-1} .

It is now generally accepted by astronomers that the Doppler shifted pairs of lines seen in SS433 are due to two jets of gas travelling in opposite directions from the centre of the accretion disc, as shown in Fig. 3 below.

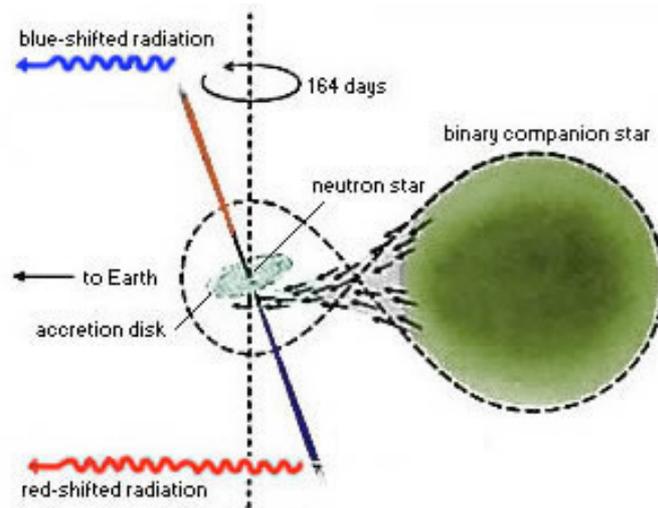


Fig. 3. The SS433 binary system.

As can be seen, the two jets are emitted from the disk of material surrounding the compact object (which may be a neutron star) at opposite angles, so that one jet appears to be blue shifted whereas the other jet appears red shifted. The jets also precess about an axis every 164 days. This is the reason for the shifting of the line pairs in the emission spectrum - as the jets move about this axis their position with respect to the Earth changes from pointing towards the Earth to away from Earth. Thus light from these jets change from being blue shifted to red shifted as this happens. Occasionally the two jets both appear to be red shifted even though one of the jets may actually be travelling towards us! This is due to an effect known as the '*relativistic Doppler shift*' - it occurs when the velocity of an object (such as the jet in this example) are large fractions of the speed of light. This is beyond the scope of this worksheet so will not be explained in more detail here. If you would like to read more about the effects of special relativity, then a detailed explanation can be found at:

<http://www.howstuffworks.com/relativity.htm>

The home of SS433

SS433 lies in the Supernova Remnant (SNR) W50. Supernovae are the violent explosions of stars occurring at the end of their lives. On average, one supernova goes off every 50 years or so in our Galaxy. The enormous explosion from these stars, ejects material into the surroundings at very high velocities, sweeping up the surrounding gas into a shell or a giant bubble. This is known as a **supernova remnant**. The ejected material and the swept-up compressed gas are very hot. The shell (or bubble) shines at different wavelengths, mainly in the X-ray, optical and radio. Below is a radio image of the supernovae remnant W50 with SS433 at approximately its centre.

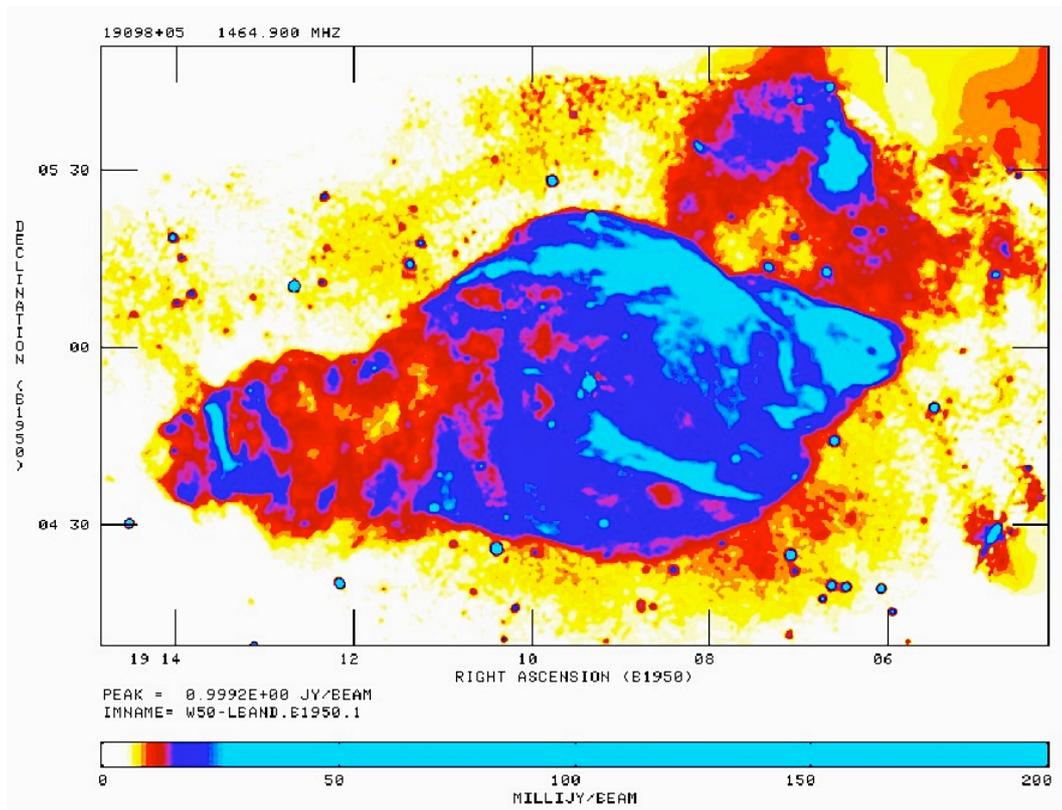


Fig. 4. A radio wavelength image of part of the supernova remnant W50. The binary system SS433 is thought to be located near the centre of this shell-like object. In this colour inverted image, bluer regions in the image are where the radio wave emission is more intense, redder regions are where it's less intense. Image courtesy of NRAO/AUI

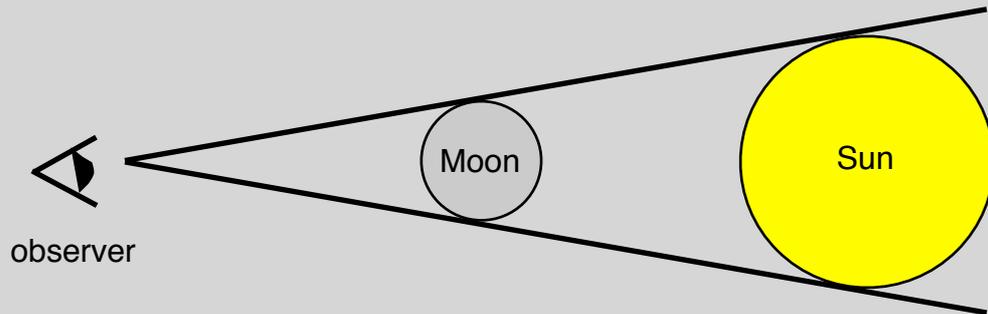
Astronomers often talk about angular sizes of objects when they describe objects in the Universe, as it is much easier to measure the size of objects as they appear in the sky rather than their real physical size. The angular size (θ in arcseconds) of the SNR W50 in the above diagram is about 2 degrees. This can be converted into a physical size (D) using the following formula if the distance, d , to the remnant is known (D and d should be in the same units):

$$D = \frac{\theta d}{206265} \quad (3)$$

Angular Size

If you look at the Sun and the moon in the sky, they appear to be approximately the same size - that is, they have the same angular size.

However, we know that the Sun is very much larger than the moon - its diameter is about 400 times larger than the Moon's. So why do they appear the same size in the sky? This is because the angular size of an object depends on both the object's actual size and its distance from the observer, as shown in the diagram below.



So, although the Sun is clearly much larger than the Moon, it is also much further away, thus it has the same angular size on the sky.

Thus, if two objects have the same angular size in the sky, they are not necessarily the same physical size. One of them may be larger but further away.

5. a). Explain in your own words, the difference between angular size and linear/physical size.

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- b). The angular size of W50 is 2 degrees. Using this information and the information below, calculate the angular size of W50 in arcseconds.

$$1 \text{ degree} = 60 \text{ arcmins}$$

$$1 \text{ arcmin} = 60 \text{ arcseconds}$$

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c). W50 is approximately 17,930 light years away. Using equation (3) above and taking care to use the correct units, calculate the physical size of W50 in light years.

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d). What is the physical size of W50 in km and pc? (*Hint: 1 light year = 9.46×10^{12} km; 1 pc = 3.26 light years*)

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e). Assume that SS433 lies at the centre of W50. Using your value for the physical size of W50 in km from above, calculate how far SS433 is from the edge of W50 (in km).

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f). Astronomers found that the jets of SS433 travel at speeds of 78×10^3 km/s. From the equation:

$$\text{Speed} = \text{Distance} / \text{Time}$$

and using your answer to 5 (e) above, calculate how long it will take for a jet from SS433 to reach the edge of W50 in both seconds and years (*Hint: 1 year = 31,556,926 seconds*)

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