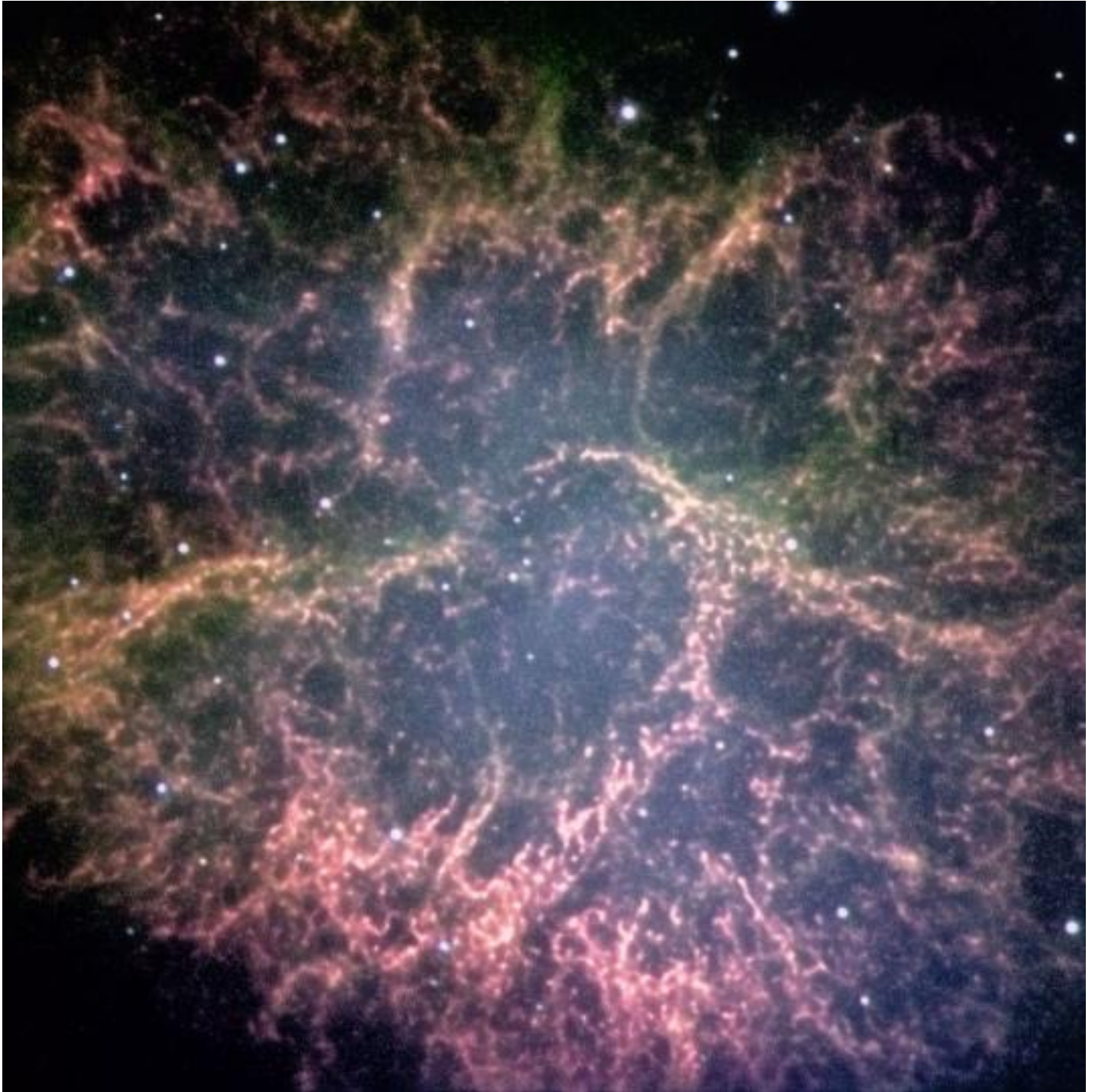

Ancient Cosmic Explosions

Activity Guide

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Introduction

In this project you will study LCOGT observations of supernova remnants to measure how fast they are expanding and calculate how long ago the supernova explosion occurred.

Materials

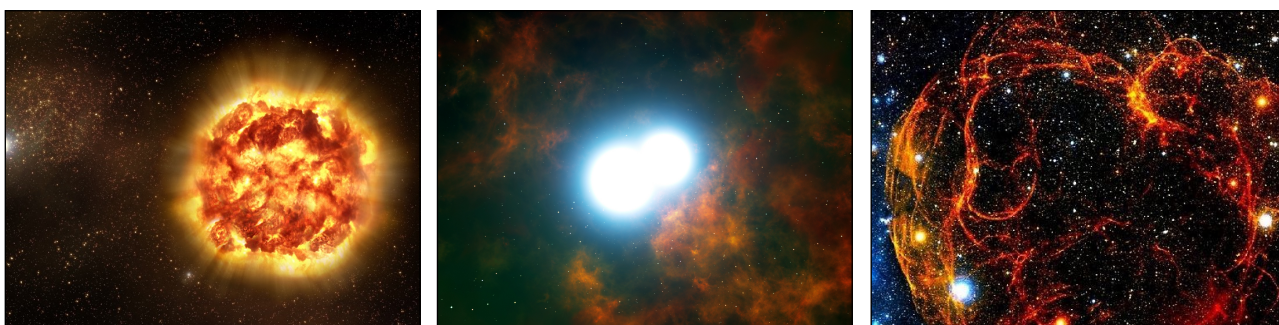
- FITS file of a supernova remnant
- A computer with ds9 image editing software installed

Background Science

Supernovae

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. Supernovae release more energy in a single instant than the Sun will produce in its whole lifetime! If the nearest massive star, Betelgeuse in the constellation Orion, were to go supernova it would (for a short time) be brighter than the full moon, even though it's much further away!

There are two main types - Type Ia and II. Type II are the explosions of very massive stars with mass greater than 8 times the mass of the Sun. Type Ia are the explosions of stars similar in mass to the Sun, which have a binary companion and become unstable.



In order these images show an artist's impression of a Type II supernova, a Type Ia supernova and the Spaghetti Nebula supernova remnant. Credit: ESO

Type II -These are caused by massive stars that 'live fast and die young', using up all of their hydrogen and helium fuel in only a few million years — thousands of times faster than the Sun burns its fuel. When the fuel supply is exhausted the star must burn heavier and heavier elements until, finally, when it can do no more to

keep itself alive, the inner parts of the star collapse to form a neutron star or black hole, and the outer parts are flung off in an explosion we call a **supernova**.

Type Ia - These happen when a star similar in mass to the Sun reaches the end of its life as a white dwarf star - a hot, dense core. If this hot core has a binary companion star (two stars orbiting around a common centre of mass), the white dwarf will pull matter from the companion star onto its surface, until it becomes unstable and explodes as a supernova. Type Ia supernova can also be caused by two white dwarfs merging to the same end.

Supernova Remnants

No matter whether it is a Type Ia or Type II supernova, the enormous explosions from these stars ejects material into the surroundings at very high velocities, sweeping up the surrounding interstellar 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.

Supernova remnants are studied at many different wavelengths from optical light to X-rays. Different things are happening in different wavelengths; when we observe in, say the X-ray, we are looking at the bits of the shell that are much hotter than the bits shining in the optical.

In this activity we will concentrate on the **optical** emission that comes from the interaction between the outward moving shell and the interstellar material that surrounds the supernova. The material is compressed and heated to **10 thousand degrees Kelvin**. In the optical we can see the shocks caused by the expanding material as it sweeps outwards at high velocities. Using the H-alpha filter we will specifically see hydrogen gas.

Cassiopeia A

Cassiopeia A is the brightest radio object in the sky so it is very well studied (and very beautiful)! It exploded about 300 years ago. It is around 11,000 light years away and is about 8 arcmin across. It was a Type II Supernova i.e. it was formed by the explosion of a massive star.

E0102 72:

E0102-72 is a supernova remnant located in a nearby dwarf galaxy called the Small Magellanic Cloud.

symbol	description	value
KE	kinetic energy of shell	10^{44} J
density	density of surroundings	10^{-21} kg m ⁻³
D	distance to the supernova	Find this value on the web

Summary of Terms

Preparation

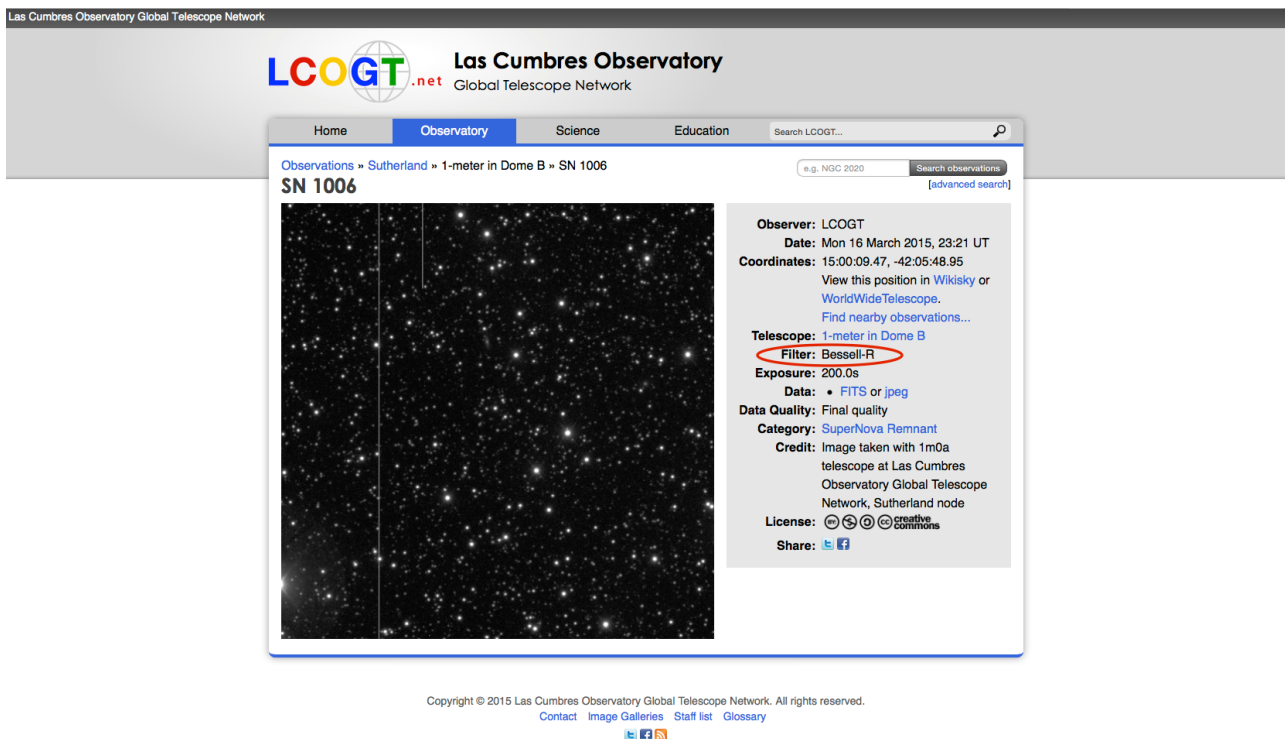
In this project you will choose one of the following supernova remnants to study with the final goal of using observational data to calculate its expansion velocity and its age.

1. Cassiopeia A (Cas A),
2. E0102-72

You can either use observations from the LCOGT data archive or make your own observations. If you are using images from the LCOGT data archive visit:

<http://lcogt.net/observations>

Use the search bar to find images of the supernova remnant you have chosen. Find an image taken using the red (R-band) or H-alpha filter. Once you have clicked on an image the filter will be listed on the right-hand menu.



The screenshot shows the LCOGT website interface. At the top, there is a navigation bar with 'Home', 'Observatory', 'Science', and 'Education'. Below this is a search bar with the text 'Search LCOGT...'. The main content area shows a search result for 'SN 1006'. On the left is a large image of a star field. On the right is a metadata sidebar with the following information:

- Observer: LCOGT
- Date: Mon 16 March 2015, 23:21 UT
- Coordinates: 15:00:09.47, -42:05:48.95
- View this position in Wikisky or WorldWideTelescope.
- Find nearby observations...
- Telescope: 1-meter in Dome B
- Filter: Bessell-R (circled in red)
- Exposure: 200.0s
- Data: • FITS or jpeg
- Data Quality: Final quality
- Category: SuperNova Remnant
- Credit: Image taken with 1m0a telescope at Las Cumbres Observatory Global Telescope Network, Sutherland node
- License: CC BY-NC-SA
- Share: [social media icons]

At the bottom of the page, there is a copyright notice: 'Copyright © 2015 Las Cumbres Observatory Global Telescope Network. All rights reserved.' and a footer with 'Contact', 'Image Galleries', 'Staff list', and 'Glossary'.

Just go to the webpage and type in the name of the supernova remnant you want, click on the relevant thumbnail and select 'FITS' from the right-hand options bar. Be aware that the red filter may be listed as 'Bessell-R'.

If you are taking your own observations, please note that these objects are very faint and require long exposure times. The table below provides information on the exposure time needed for each object and which filters to use.

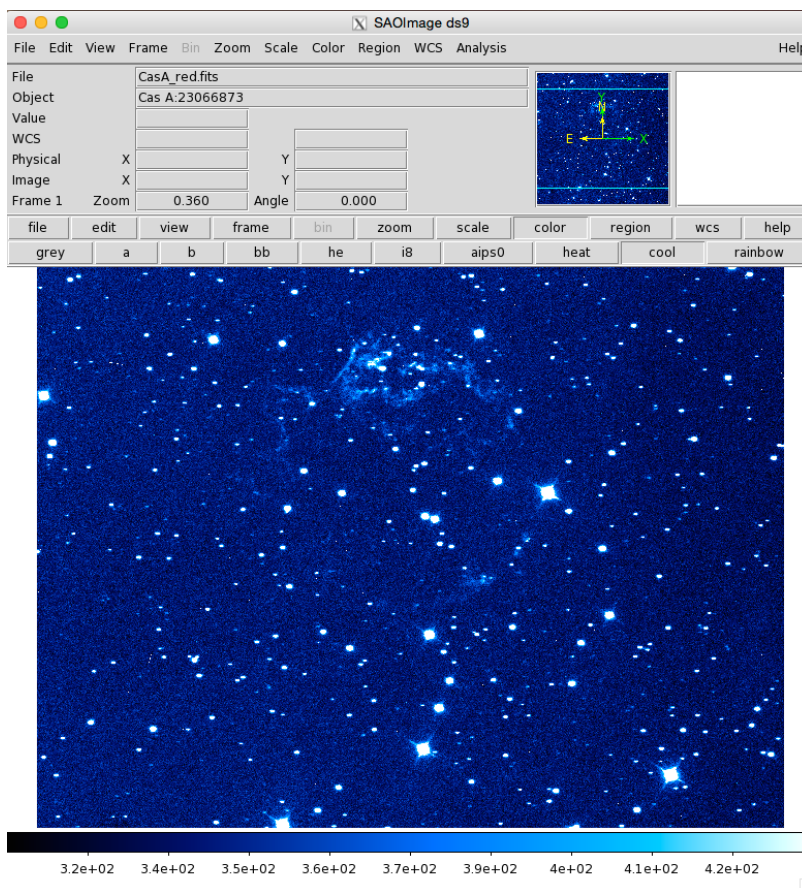
A full guide to observing with LCOGT can be found online at:
<http://lcogt.net/files/OnSkyGuide.compressed.pdf>

	R-band (s)	H-alpha (s)
Cas A	120	120
E102-72	200	200

Instructions

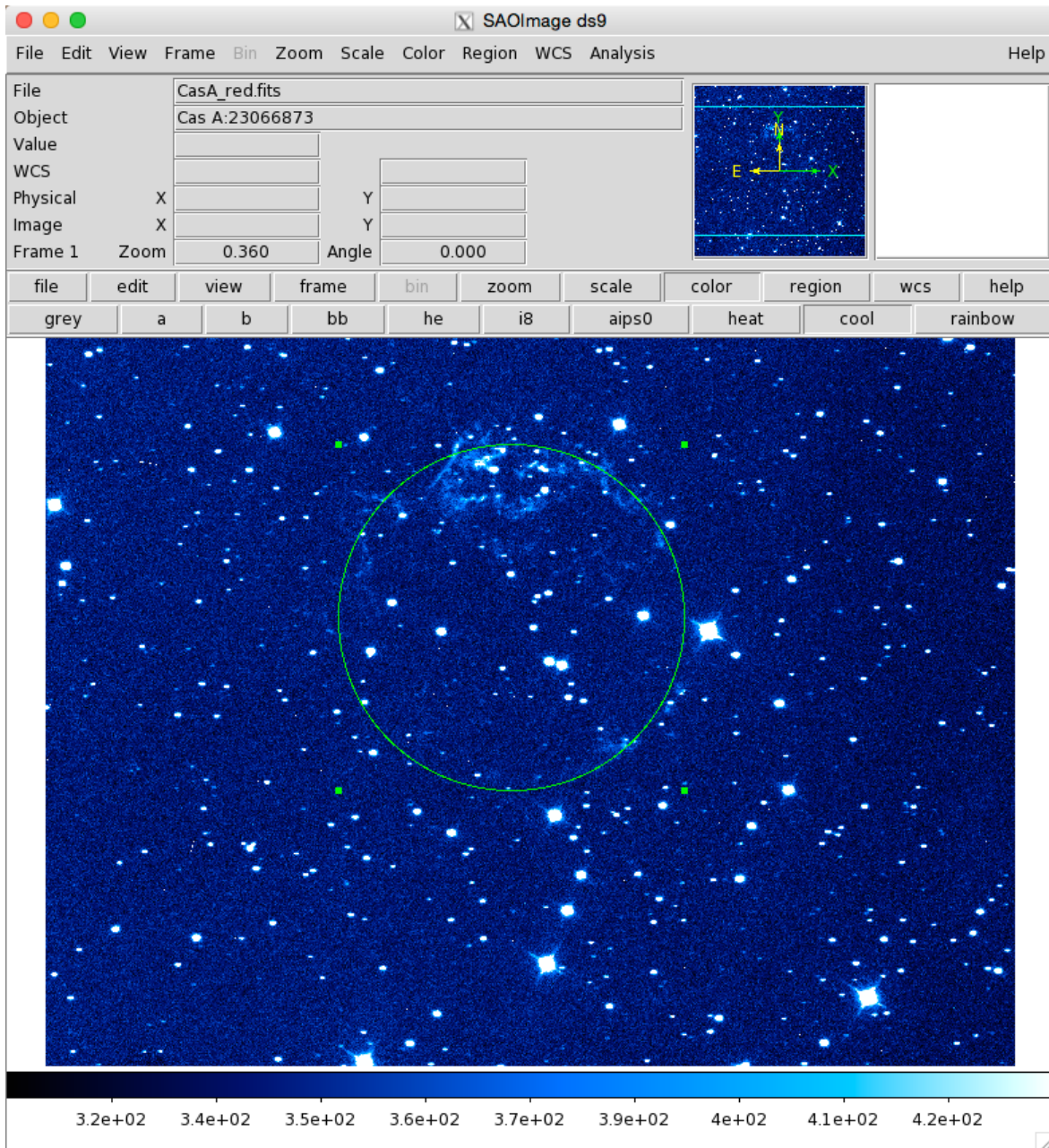
1. Start ds9 and open the supernova remnant FITS file you have chosen to work with.
2. Your image may appear black to begin with, try out different options in the toolbars. You are looking for an image that shows as much of the supernova remnant's details as possible.

This image of Cas A is shown demonstrating the following DS9 settings:
scale > linear > 99%,
colour > cool

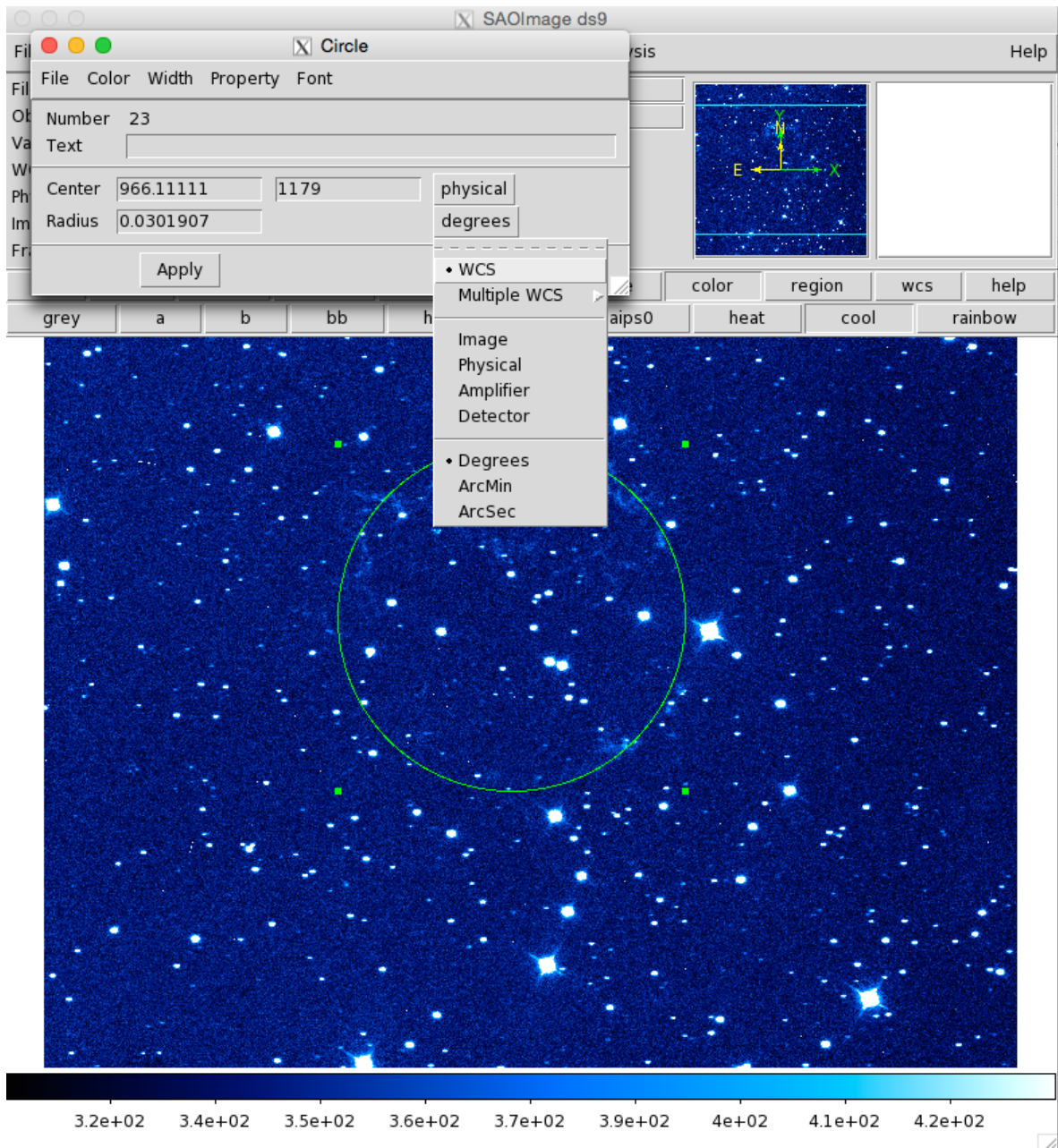


You will now determine the diameter of the remnant by placing a circle over the shell. This will tell you the angular size of the remnant.

2. Go to **Region > Shape > Circle**
3. Draw a circle over the supernova, marking out the shape of the shell. Aim to be as exact as possible.



4. Go to **Region > Get Information**
5. A box will appear showing the centre co-ordinates of the circle.
6. Next, click on the box marked **physical** next to the Radius values. Select **WCS** and choose the type of units you want - degrees. The example below shows the radius = 0.0301 degrees.



7. Using your radius values, calculate and write down your radius and diameter in degrees below:

Radius in degrees =

Diameter in degrees =

Now that you know the diameter of your supernova remnant, you will calculate the age of the supernova remnant and find out when the source star exploded.

Now that you have the radius, you will need to calculate the distance to your supernova in **metres**.

- Calculate the distance to your supernova in metres and note your result in the table below. Remember that **1 light year = 9.5×10^{15} m**.

Name	Distance (light years)	Distance (metres)
Cas A	10,200	
E102-72	190,000	

- The next step is to work out the size of the shell. Do this using the equation below:

$$d = D \tan (\theta)$$

D = distance to remnant **in metres**

d = diameter of remnant **in metres**

θ is the angle on the sky **in degrees**

- Begin by calculating the angle on the sky for your supernova. This will be your radius from step 7, but you will need to convert your radius from degrees into radians: $360 \text{ deg} = 2\pi \text{ rad}$ or $1 \text{ deg} = 0.0174 \text{ rad}$. Note your result on the table below.
- Next calculate the diameter of your supernova remnant and use this value to calculate the radius: $0.5 \times \text{diameter}$. Note down your results in the table below.

Name	θ degrees	Diameter (m)	Radius (m)
Cas A			
E102-72			

- Now that you have the physical radius, you can work out the volume of your supernova remnant, a figure that will allow you to work out its **mass**. Where V is **volume** and the R is the **radius** in metres. Use the equation:

$$V = (4/3) \pi R^3$$

Enter your result into the table on the following page.

In this table you will also find a value for **density**. Remember that density is a measure of how much mass is in a given volume. For example, the density of water is 1000 kg m^{-3} , whereas the same volume of iron or lead will be much heavier. Lead is 10 times denser than water.

During the initial collapse and rebound of the star's core when a supernova occurs, the outer layers of the star's material are ejected, yet most of the gas in a supernova remnant is not from the star but is collected afterward. As the remnant expands, it sweeps up the surrounding interstellar medium, material which builds up around the edge of the shockwave. The volume through which the remnant has expanded and the density of the interstellar medium can be used to calculate the mass of the remnant.

In the space between the stars, the density of material is very low - there isn't much out there! In fact, the average density in space is about **1 x10⁻²¹ kg m⁻³**! This is the density value we will be using in the calculations for our supernova remnant.

13. With a value for both density and volume you can calculate the mass of your supernova remnant:

$$\text{Mass} = \text{density} \times \text{volume}$$

Enter your result into the table below.

Name	Volume	Density (kg m ⁻³)	Mass (kg)
Cas A		1 x10 ⁻²¹ kg m ⁻³	
E102-72		1 x10 ⁻²¹ kg m ⁻³	

14. The next step is to calculate the velocity of the material in your supernova remnant. A typical supernova explosion will eject about **10⁴⁴ Joules** of energy into the surroundings. This is the value you will use for kinetic energy. Use the following equation, where M is mass:

$$v = (2 \text{ K.E. } / M)^{1/2}$$

Velocity = _____

15. The final step is to calculate the age of your supernova. You can do this using the distance to your supernova remnant and its expansion velocity:

$$\text{Time} = \text{distance} / \text{velocity}$$

The distance here is actually the **size of the remnant** (i.e. the distance the shell has travelled since the explosion) using the radius in question 7, and time is actually the **age of the remnant**. Your result will be in seconds, convert it to years and note down your result below.

Note: this assumes that the exploding material has been travelling outwards at a constant speed, and that the mass has been constant.

**Age of your supernova remnant = _____
years**

Congratulations, you just calculated the age of a real supernova remnant!