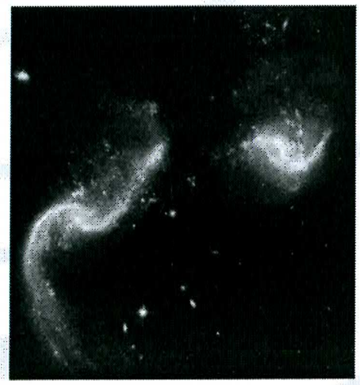
ICRAR International Centre for Radio Astronomy Research

Weighing a galaxy



^ Interacting galaxies seen by the Hubble Space Telescope. Credit: NASA, ESA, the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration, and A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University)

INTRODUCTION

How do astronomers know how much matter is in a galaxy? How do they know dark matter exists? In this project, you will use real galaxy data and make measurements in the same way astronomers do.

GRAVITY

Stars and gas orbit around the centres of spiral galaxies in much the same way as the Earth orbits around the Sun. The more mass a galaxy contains, the faster the orbits have to be. If the orbit is not fast enough, the orbital radius will decrease - just like when a satellite in orbit around the Earth slows for some reason and burns up in the atmosphere.

If in a stable circular orbit, centripetal force mv^2/r needs to be balanced by gravitational force GMm/r^2, where **m** is the mass of the orbiting body (in kg), **v** is its velocity (in m/s), **r** is its radius (in m), **M** is the mass of the galaxy (in kg) and **G** is the Gravitational constant. Therefore:

$$M = rv^2/G$$

ACTIVITY

We will measure the mass of the spiral galaxy NGC 7531 from the following material:

- A hydrogen spectrum of the galaxy: this will enable you to measure the recession velocity of the galaxy (and therefore the distance) and estimate the rotation speed **v**, of the disk.
- An optical or infrared image: this will enable you to measure the angular radius of the galaxy. Together with an estimate of its distance (above), this will allow you to calculate its radius **r**. We will then have everything we need to weigh NGC7531.

HYDROGEN SPECTRUM

You should have a print out of the hydrogen spectrum for a galaxy called NGC 7531 (ask your supervisor if you don't have one.) You should see a 'double-horned' galaxy profile, like the one shown in the presentation.

EXERCISE:

1. What is the mean (average) recession velocity of NGC 7531?

   ~1600 km/s.

2. The Hubble law relates velocity and distance via $v=H_0d$ where H_0 is the Hubble constant.

   a. What is the distance in megaparsecs (Mpc)?

   $v = H_0 d \Rightarrow d = \frac{v}{H_0} = \frac{1600}{75}$ $\quad d = 21.3$ Mpc

   b. What is the distance in metres (m)?

   $d = 21.3 \text{ Mpc} \times 3.09 \times 10^{22} = 65.9 \times 10^{22}$ m

3.

   a. What is the 'velocity width' of the galaxy in m/s? 300 km/s = 300,000 m/s

   b. How is this likely to be related to the rotation velocity (**v**) of the galaxy? Twice the rotation velocity of the galaxy.

   c. Calculate **v**

   $v = \frac{1}{2} \times 300{,}000 = 150{,}000$ m/s.

4. Why are there two peaks in the spectrum?

   Because the galaxy is rotating

Weighing a galaxy

International Centre for Radio Astronomy Research

IMAGE

You should have a print out of the optical image for NGC 7531 (ask your supervisor if you don't have one.) You should see a spiral galaxy shape, like the one shown in the presentation.

EXERCISE:

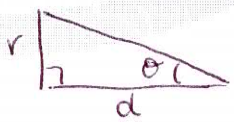
1. Describe the image of NGC 7531.

   Brighter in the centre, two big spiral arms visible

2. Measure its radius in degrees. r = 1.5 boxes   Each box is 2 minutes

   $\therefore r = 3 \text{ minutes} = \frac{3}{60}^{\circ} = 0.05^{\circ}$

3. Use the distance estimated above to calculate its radius in m (hint: use trigonometry).



   $r = d \tan 0.05$

   $= 65.9 \times 10^{22} \times \tan 0.05$

   $= 5.75 \times 10^{20}$ m

4. Finally calculate the mass of NGC 7531 in

   a. kg

   $M = \frac{(r \times v^2)}{G} = \frac{5.75 \times 10^{20} \times (150,000)^2}{6.673 \times 10^{-11}}$

   $= 1.94 \times 10^{41}$ kg

   b. Solar Masses

   $M = \frac{1.94 \times 10^{41}}{2 \times 10^{30}} = 9.7 \times 10^{10} M_{\odot} \approx 100 \text{ billion } M_{\odot}$

CONCLUSION

1. NGC 7531 has an optical luminosity of around 10 billion times the luminosity of the Sun. How does this compare with the mass you have just calculated?

   10 times smaller.

2. How much of the mass you calculated is in the form of stars?

   10 billion solar masses.

3. Is there 'dark matter' in this galaxy? How much?

   Yes. ~90 billion solar masses.

4. Finally, are there any ways to improving the numbers you have just calculated?

   Use more accurate values of constants, measure things exactly using computers and original data.

WELL DONE, YOU'VE JUST WEIGHED ONE OF THE LARGEST OBJECTS IN THE UNIVERSE!