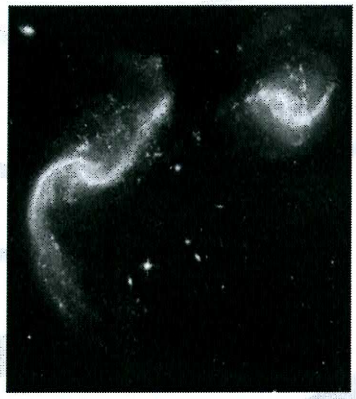
International Centre for Radio Astronomy Research

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.

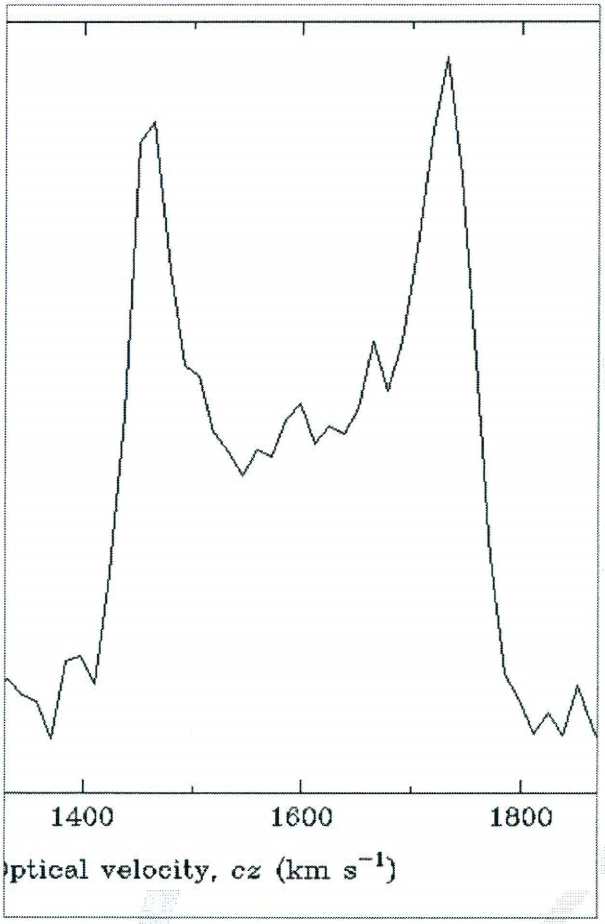
If in a stable circular orbit, centripetal force $\mathbf{mv^2/r}$ needs to be balanced by gravitational force $\mathbf{GMm/r^2}$, where **m** is the mass of the orbiting body (in kg), **v** is its velocity (in m/s), **r** is its radius (in m), **M** is the mass of the galaxy (in kg) and **G** is the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

$$\mathbf{M = rv^2/G}$$

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 estimate the rotation speed **v**, of the galaxy's disk.
- Its radius **r**. We will then have everything we need to weigh NGC7531!



HYDROGEN SPECTRUM

To the left is a zoomed in section of the hydrogen spectrum for a galaxy called NGC 7531. You can see more closely the 'double-horned' shape, like the one shown in the presentation.

EXERCISE:

1.

a. Use a ruler to measure the 'velocity width' of the galaxy

1750 − 1450 km/s = 300 km/s

b. Convert this answer into m/s instead of km/s

300 km/s × 1000 = 300,000 m/s

c. The velocity width of the galaxy is twice the rotational velocity at the edge of the galaxy (**v**). Calculate **v**

V = 150,000 m/s

2. Why are there two peaks in the spectrum?

Because the galaxy is rotating/spinning

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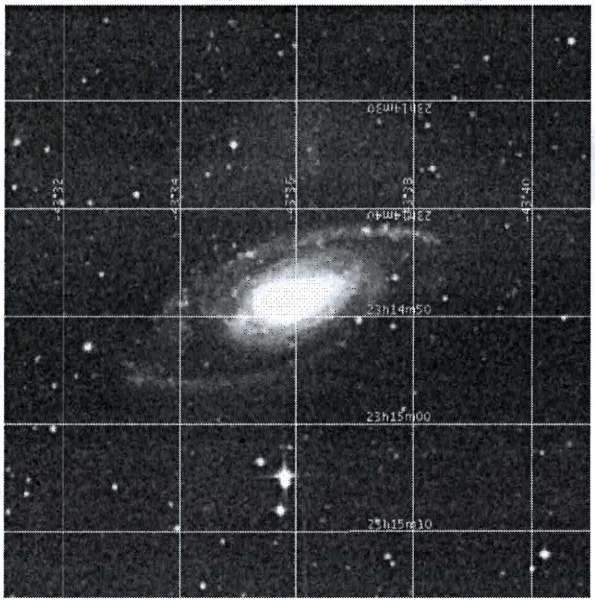

IMAGE

To the left is an optical image of NGC 7531. Can you see a spiral galaxy shape, like the one shown in the presentation?

EXERCISE:

1. Describe the image of NGC 7531.

Brighter in the center
two big spiral arms visible

2. Measure its radius in degrees. If 1 degree = 11.5×10^{21} m, what is that in metres? 1.5 boxes wide (radius)

Each box is 2 minutes. r = 3 minutes

$r = \frac{3}{60}^{\circ} = 0.05^{\circ} = 0.05 \times 11.5 \times 10^{21}$ m

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

3. Finally, calculate the mass of NGC 7531 using the formula on the first page and putting in your values for its radius (**r**, make sure you use the one in m) and its rotation velocity (**v**)

a. in kg

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

$v = 150,000$ m/s

$M = \frac{(r \times v^2)}{G} = \frac{5.75 \times 10^{20} \times (150000)^2}{6.673 \times 10^{-11}}$

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

b. in Solar Masses

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

CONCLUSION

1. How many Suns would it take to make up NGC7531's mass? (hint how many Solar Masses are in NGC7531?)

9.7×10^{10} (100 billion)

2. NGC 7531 is around 10 billion times brighter than the Sun, which means you need 10 billion Suns to make up NGC 7531's brightness. How does this compare with the number of Solar Masses you have just calculated?

10 times smaller

3. How much 'extra' mass is there?

90 billion suns

4. Is there 'dark matter' in this galaxy? If so, how much?

Yes! 90 billion suns worth

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