

# Galaxy rotation

# In this talk...

- How do galaxies rotate
- What is a rotation curve
- How do we measure galaxy rotation
- How do we measure baryonic galaxy mass
- What rotation curve does this give

# Rotation in galaxies



# Rotation in galaxies

## Spiral galaxies

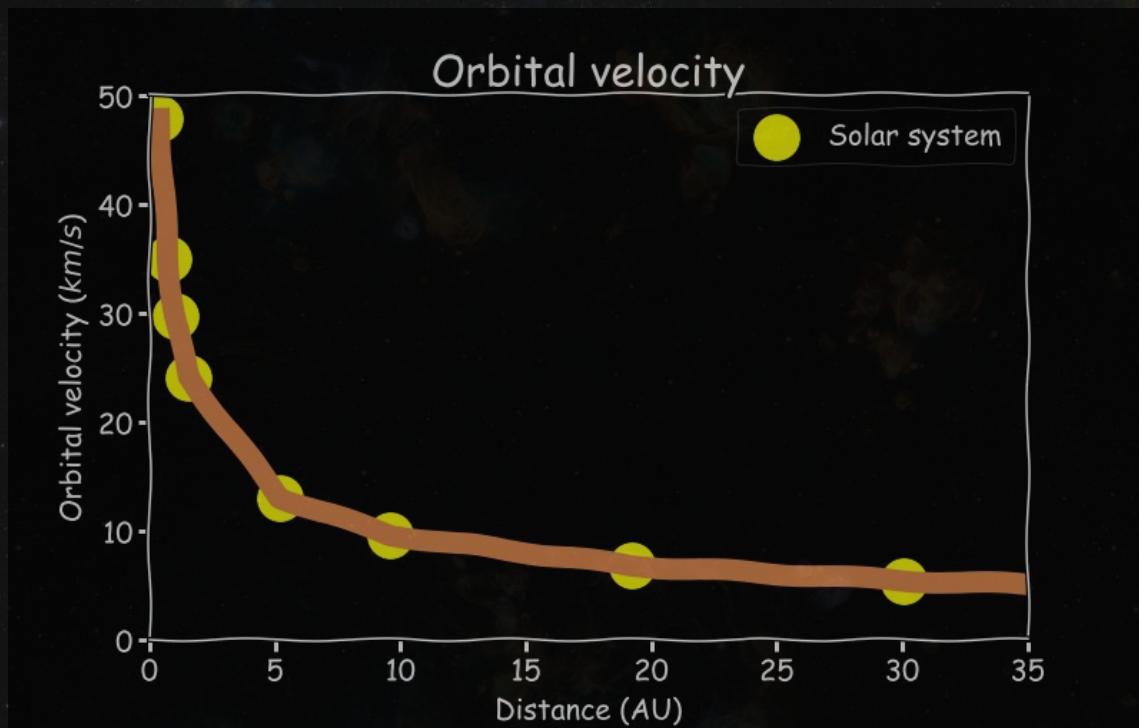
Spiral galaxies spin like a plate or pizza, but different parts spin with different velocities.

The bright areas are stars and gas, which can be observed directly with telescopes.

Mass is spread out over a large area. Very dense in the core, less dense further and further out



# Rotation in galaxies



## Rotation curves

Orbital velocity as a function of distance from centre.

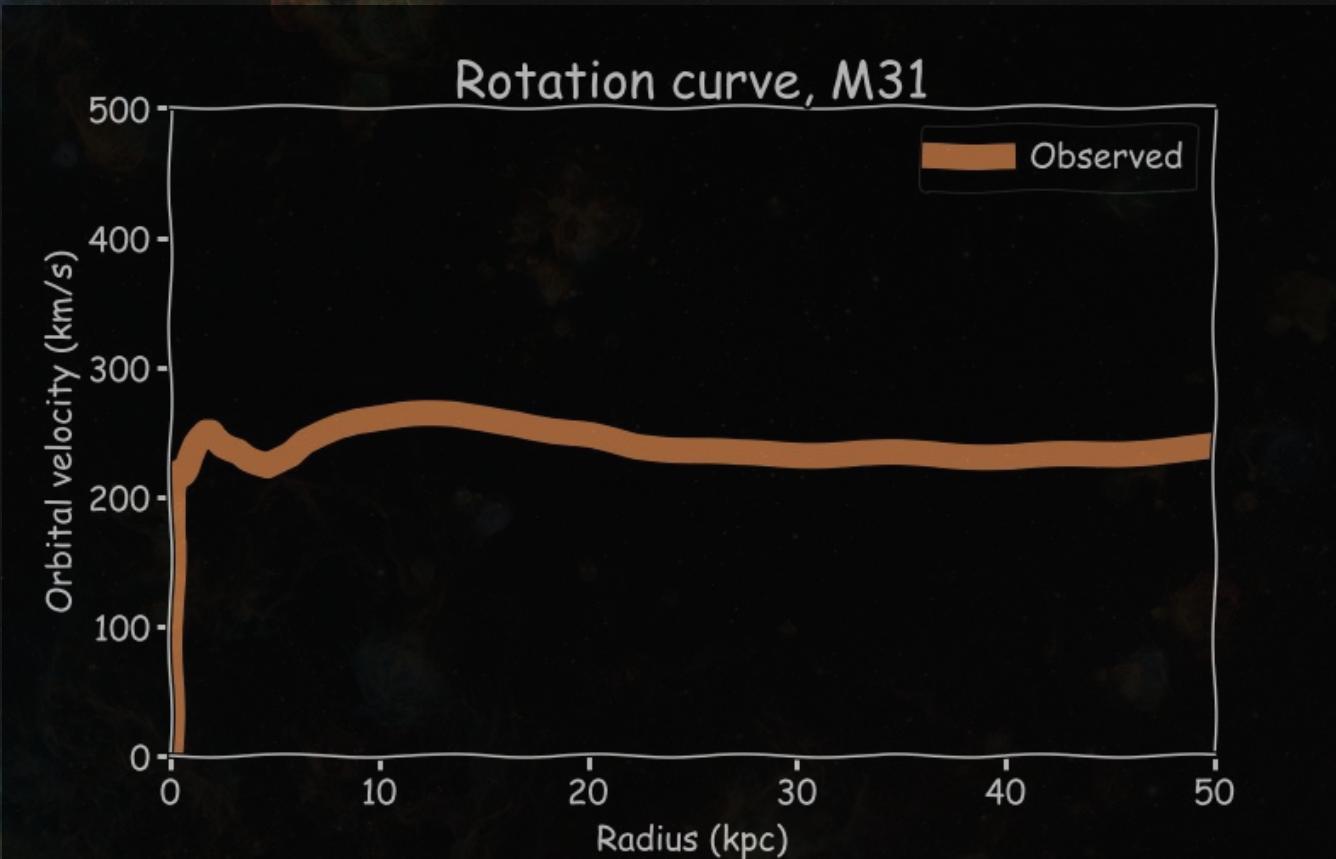
We have done this in the Kepler notebook.

Sun as central mass



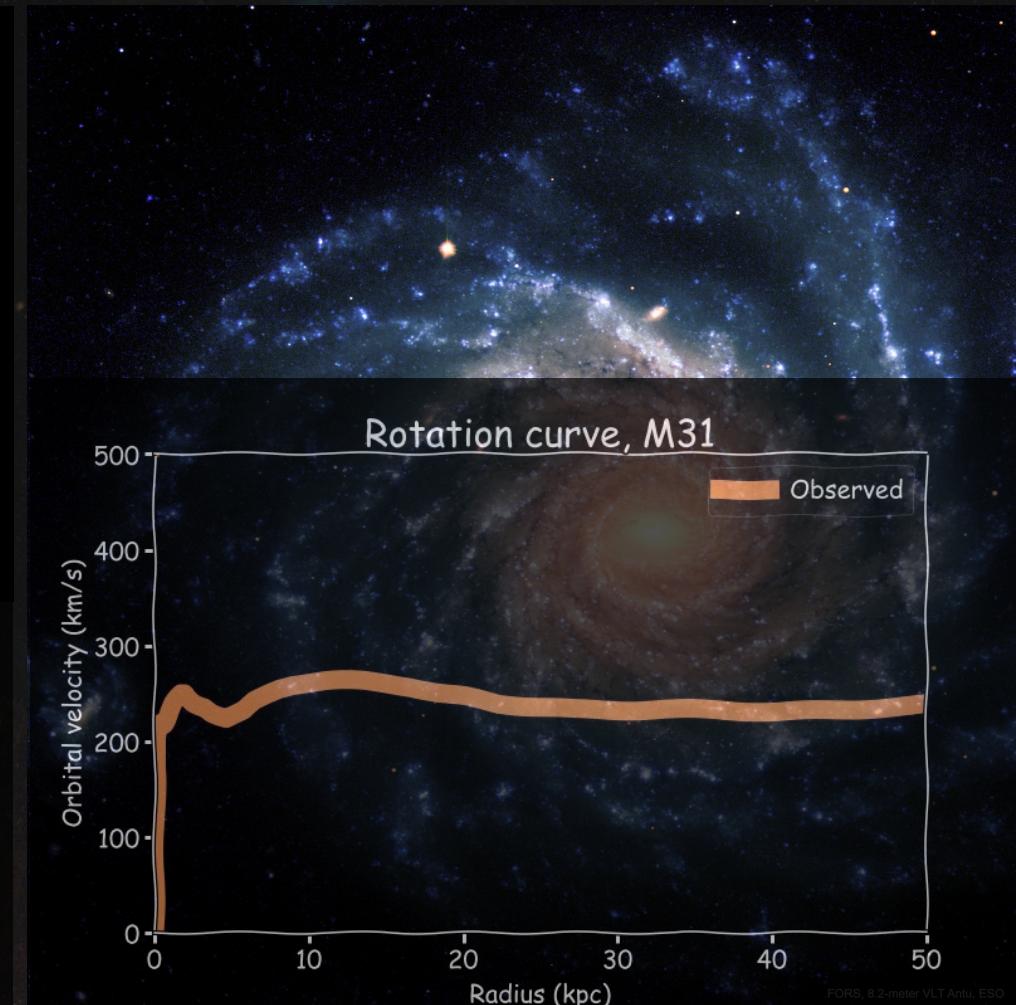
# Rotation in galaxies

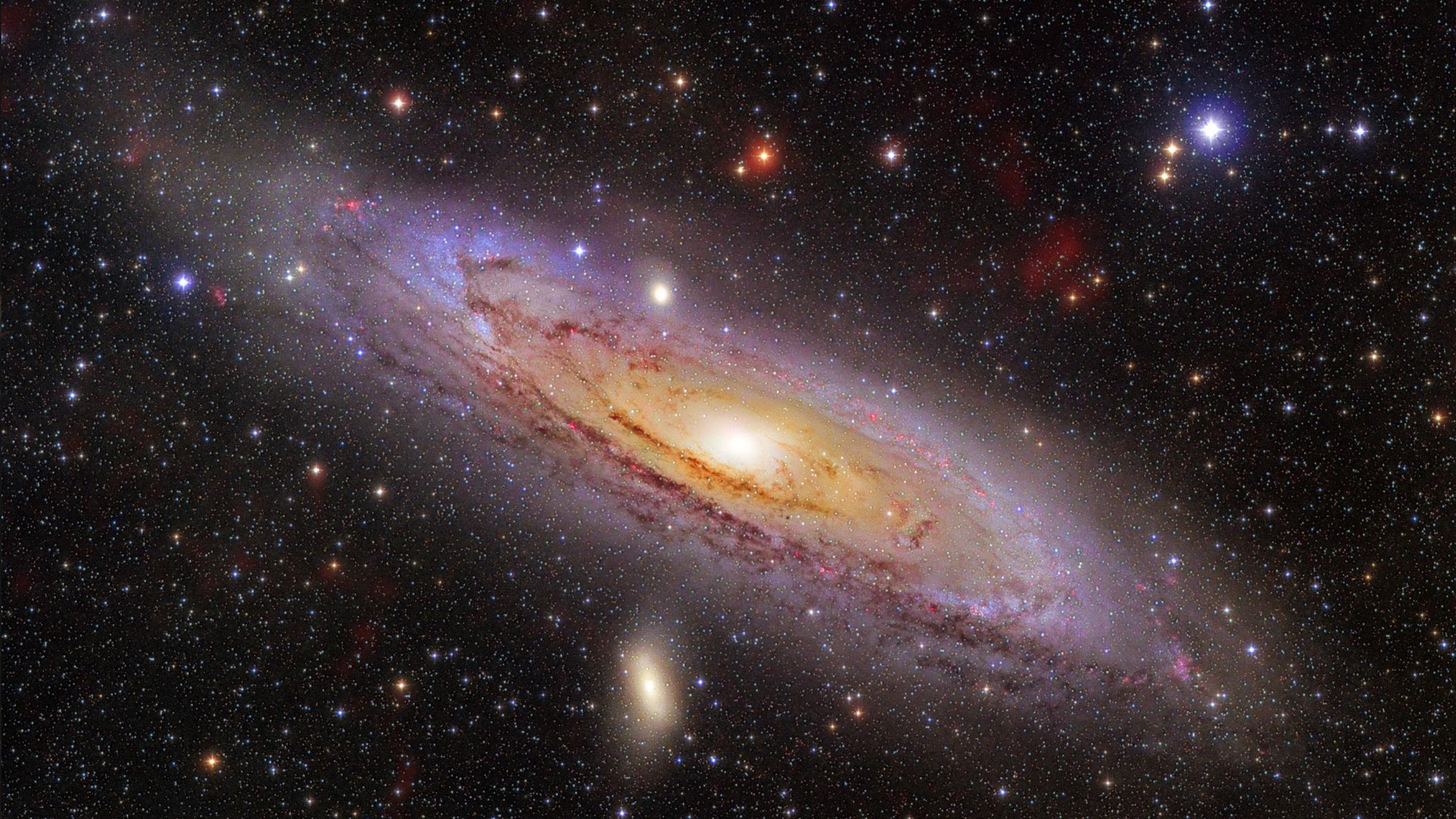
## Rotation curve for a galaxy



How is this different to the rotation curve for the solar system?

# Rotation in galaxies





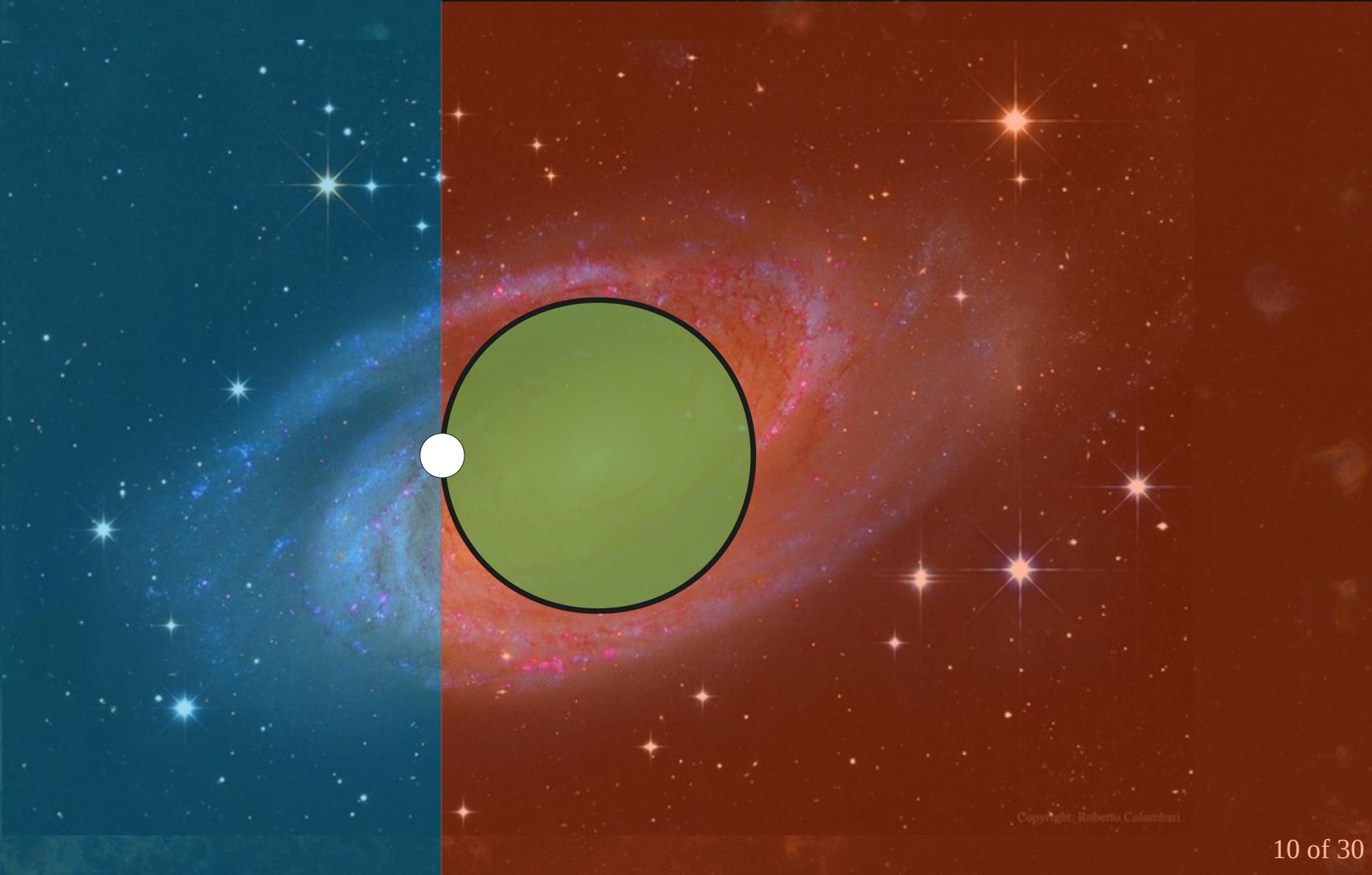
## However...

We have only worked with a single mass – the mass of the Sun or a star at the centre.

A galaxy is spread out over an area. This raises questions:

- The force that decides the orbit is the gravitational force. How does the spread out mass affect this?
- What mass should we use in our equation? Can we even use the same equation?

The answer is surprisingly simple



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## How to measure mass in galaxies

Astronomers can't measure mass directly...

We have two methods:

- 1) Measuring the orbital velocity of stars and gas and use the orbital velocity equation to find the mass
- 2) Measuring the light of the galaxy, which consists of only of light from stars and gas and since we know how bright one star is, we can infer the total mass (Mass-luminosity relation)

$$v^2 = \frac{GM}{r}$$

$$M \propto L^\alpha$$

## Spectral lines

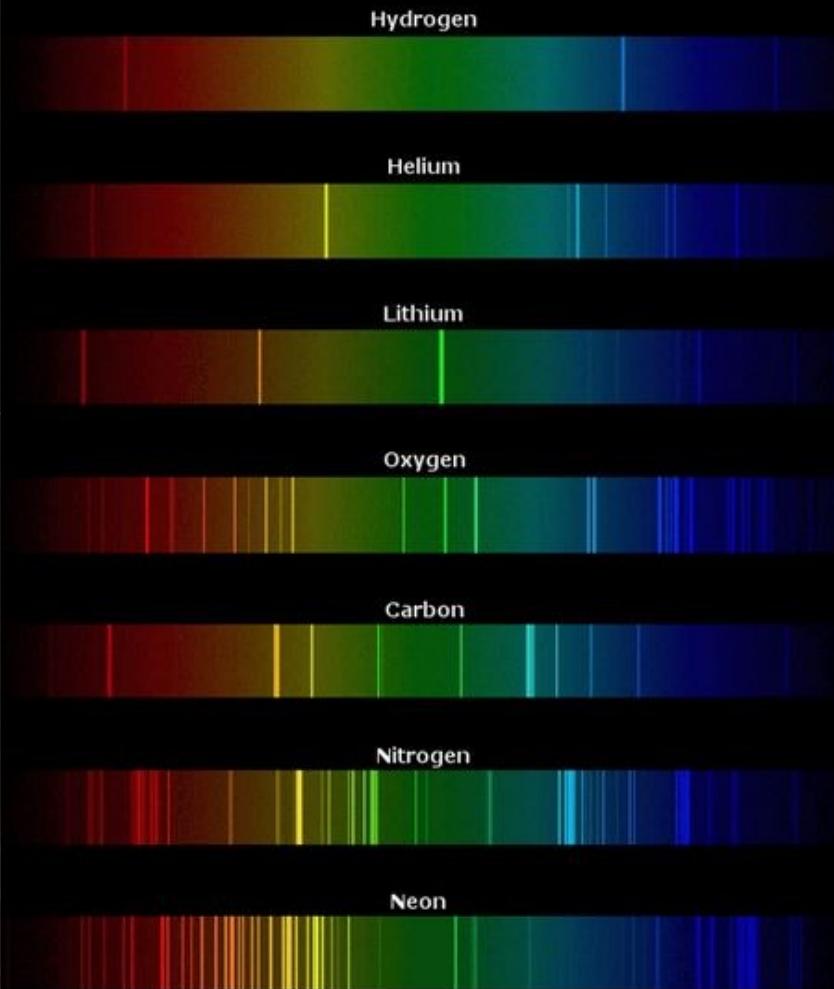
The unique fingerprints of elements

Each element has its own set of *spectral lines*. Spectral lines are located at very specific wavelengths/energies.

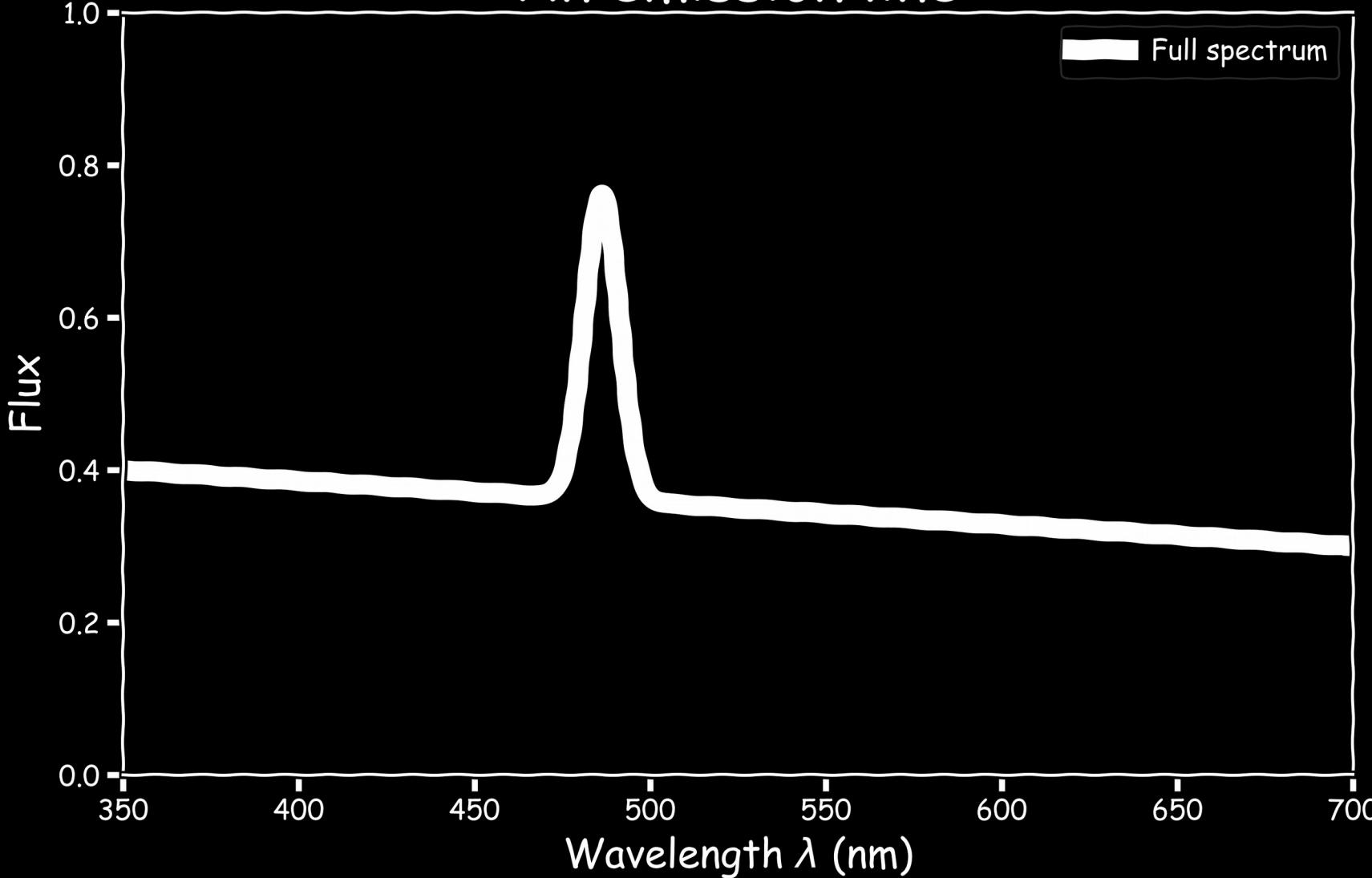
If there is a lack of light where the spectral line is, light has been absorbed. This is called an absorption line.

If there is an excess of light where the spectral line is, extra light has been added. This is called an emission line.

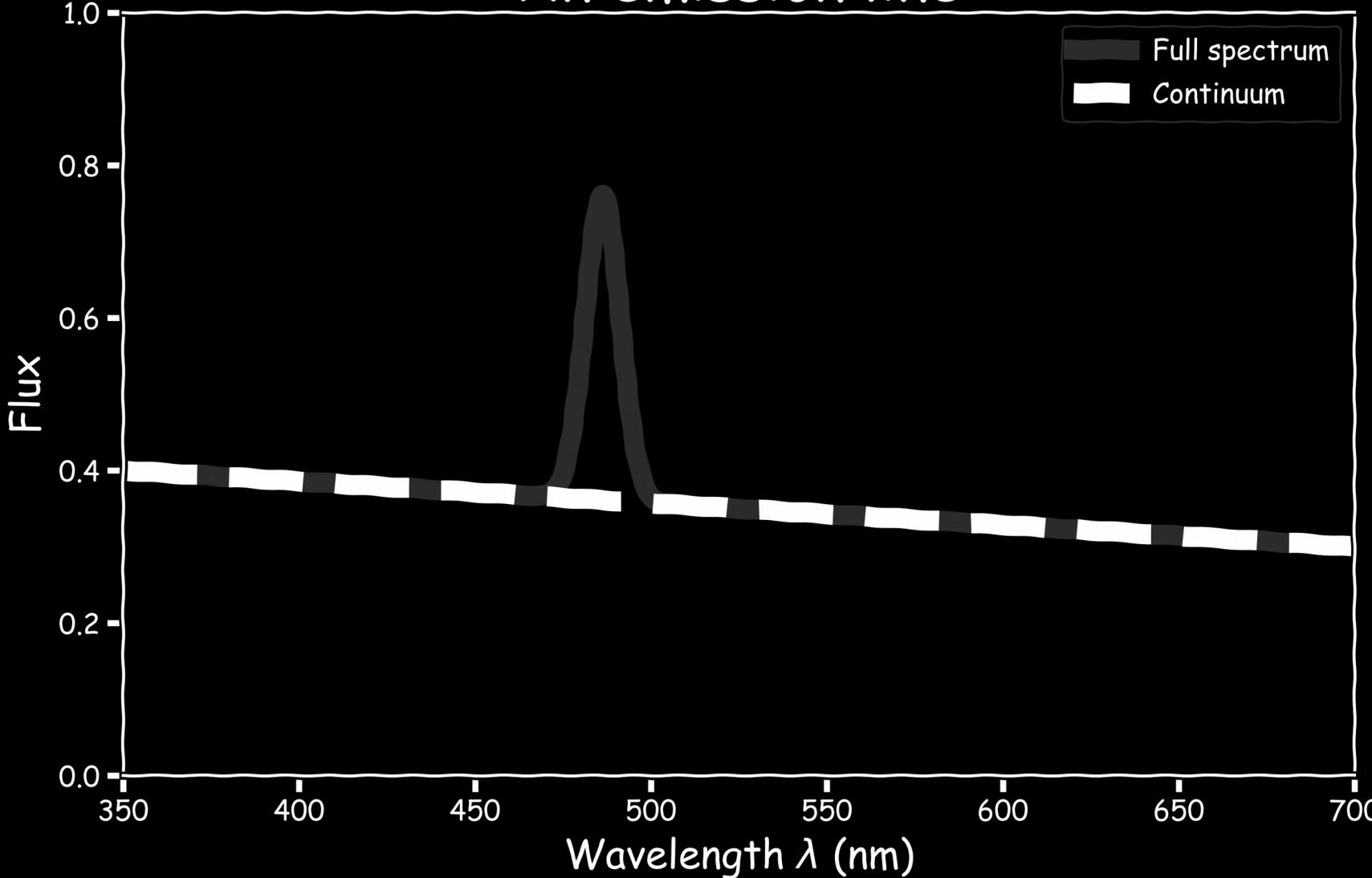
Samples of Emission Spectra



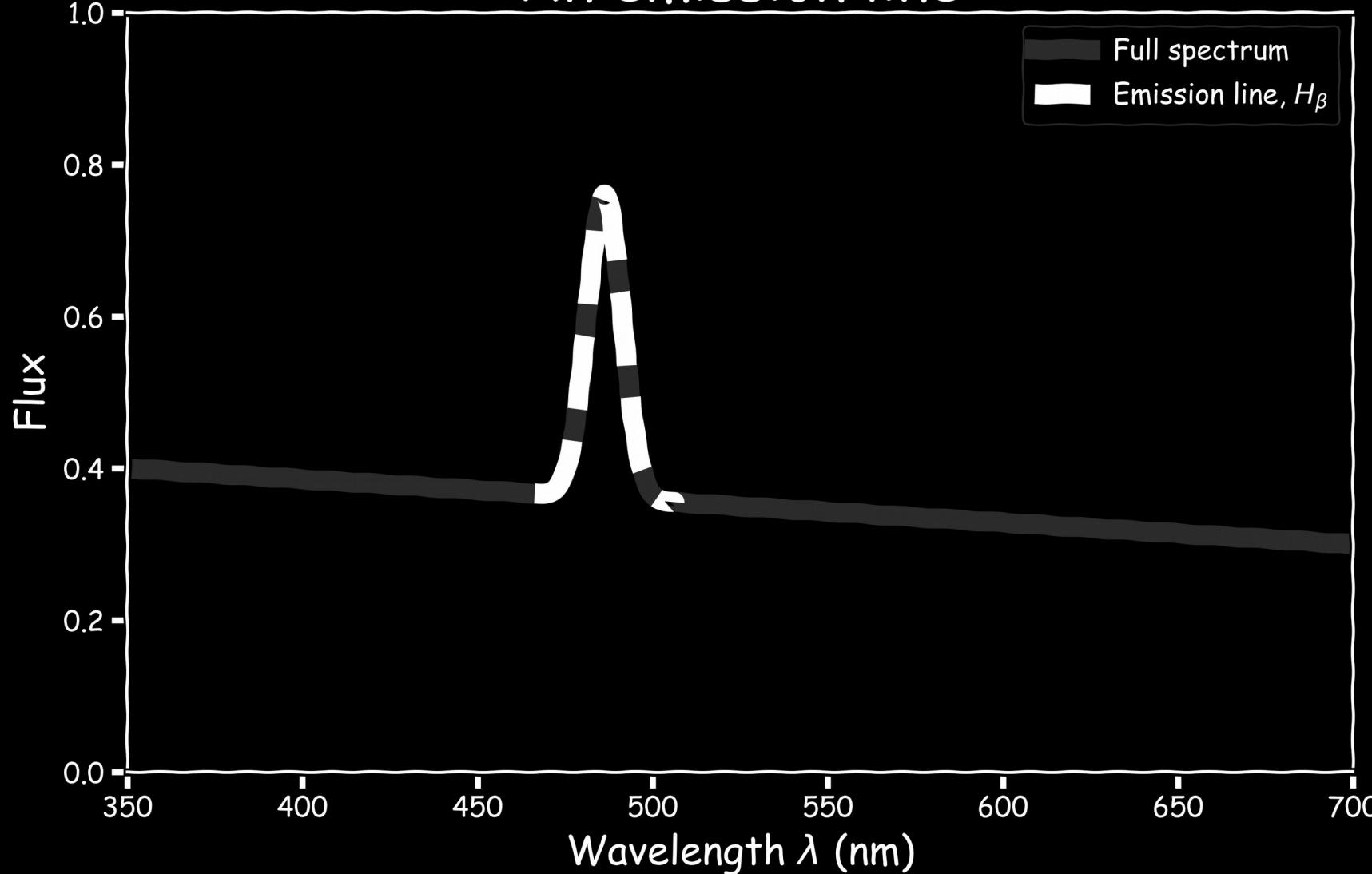
# An emission line



# An emission line



# An emission line



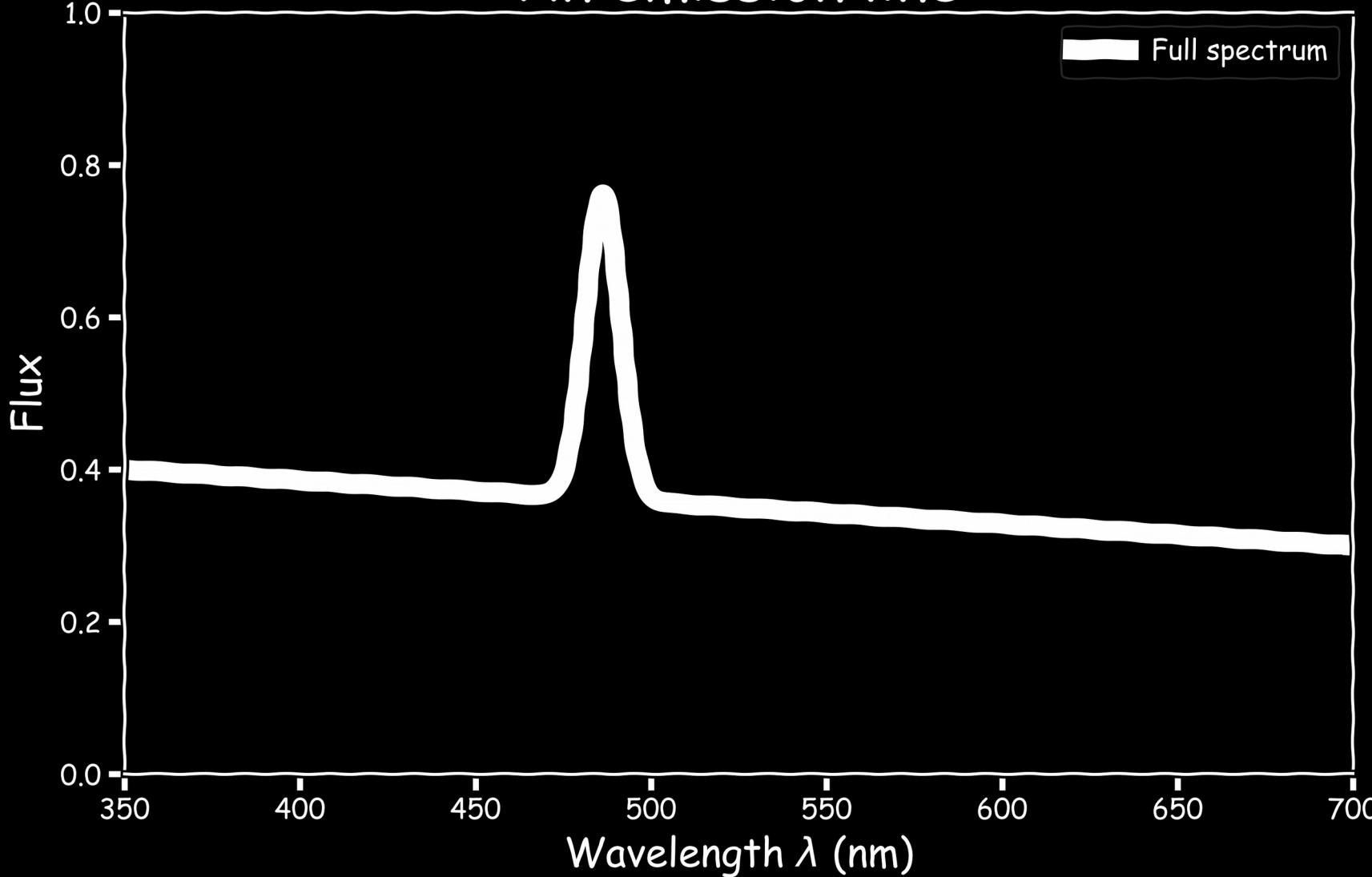
## Doppler redshift

Objects emitting light while moving have their light *doppler shifted*. The light emitted is more or less energetic depending on the motion of the emitter.

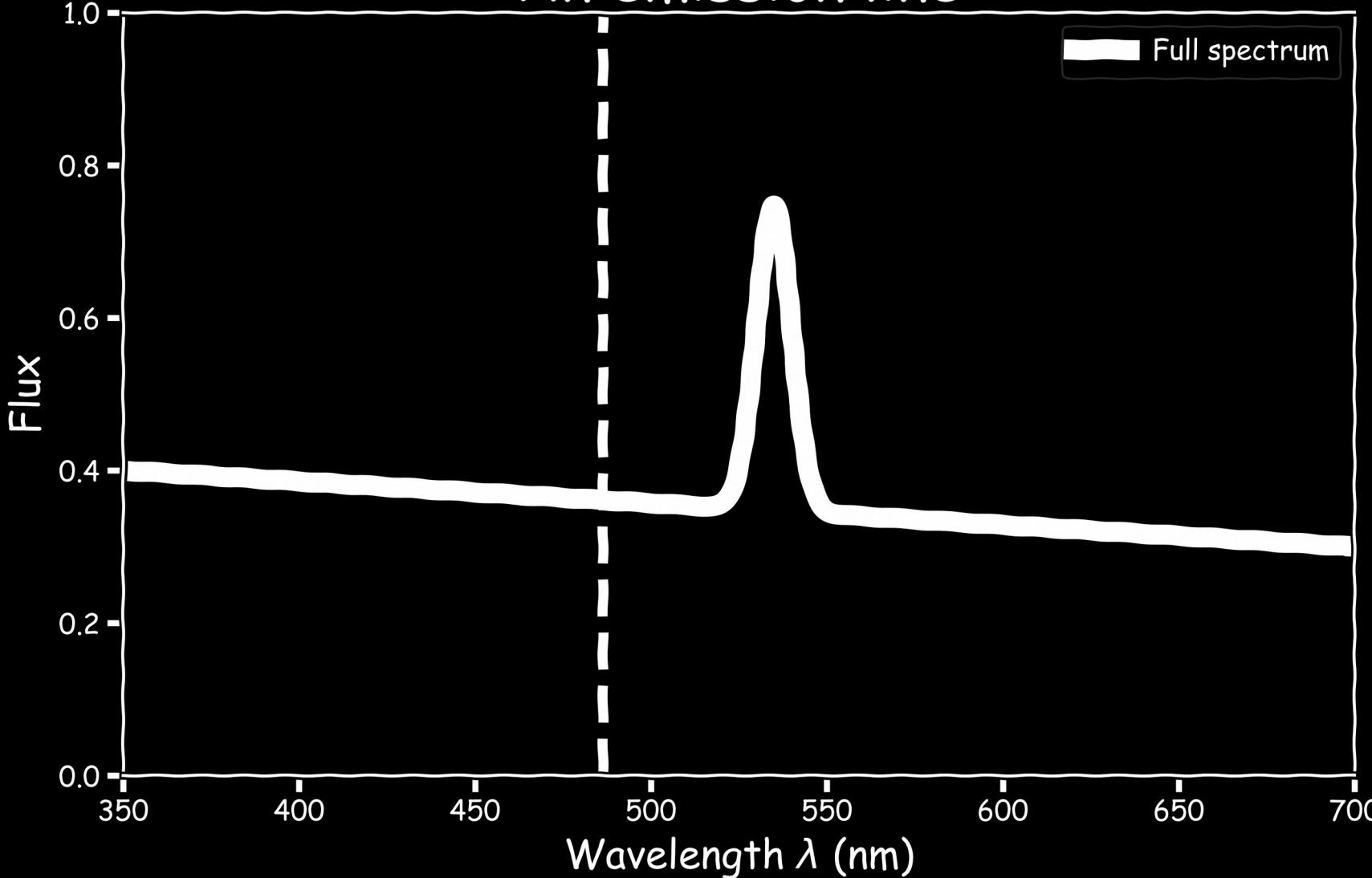
$$z = \frac{v}{c}$$

$$z = \frac{\lambda_{obs} - \lambda_{emit}}{\lambda_{emit}}$$

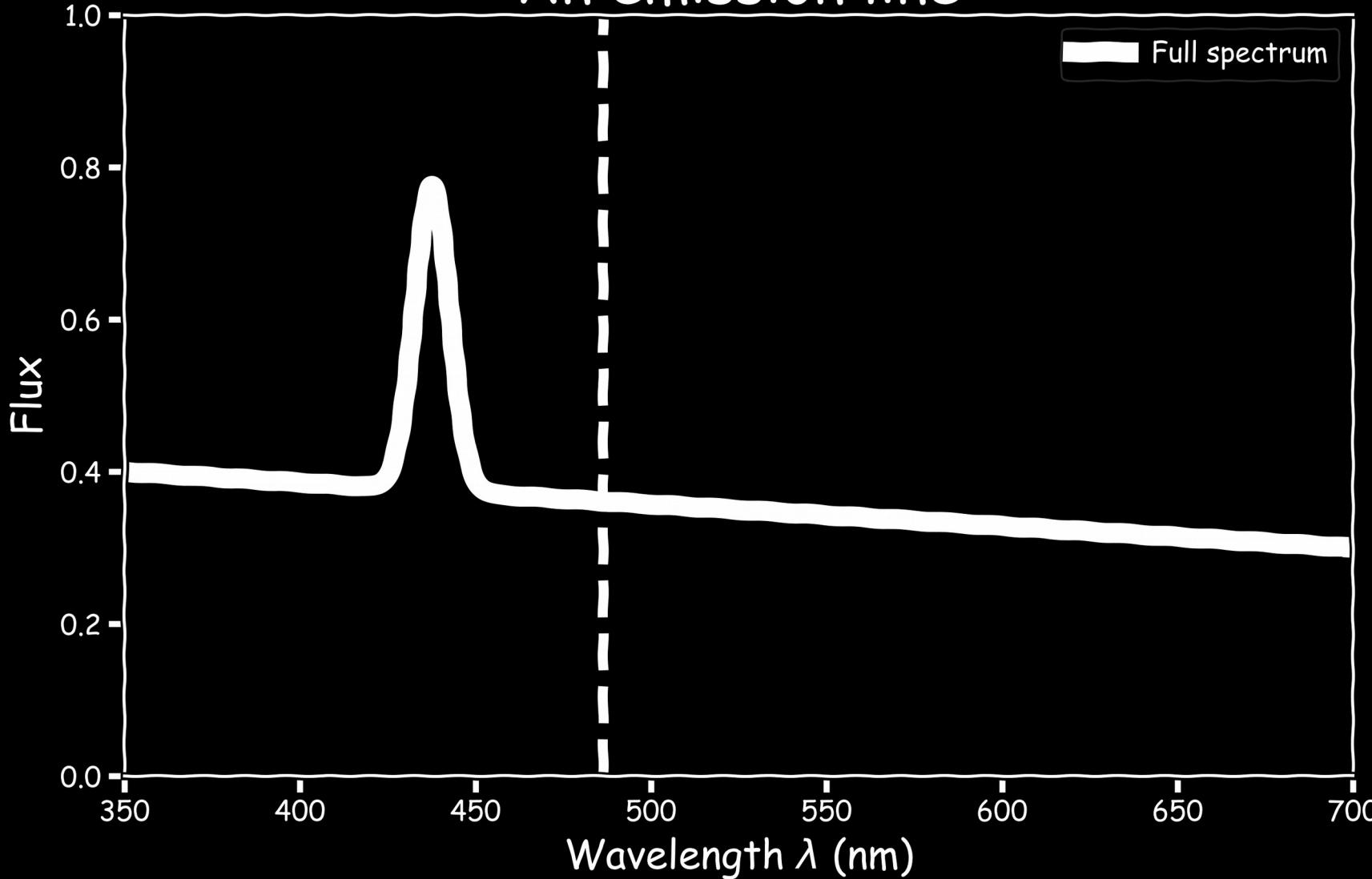
# An emission line



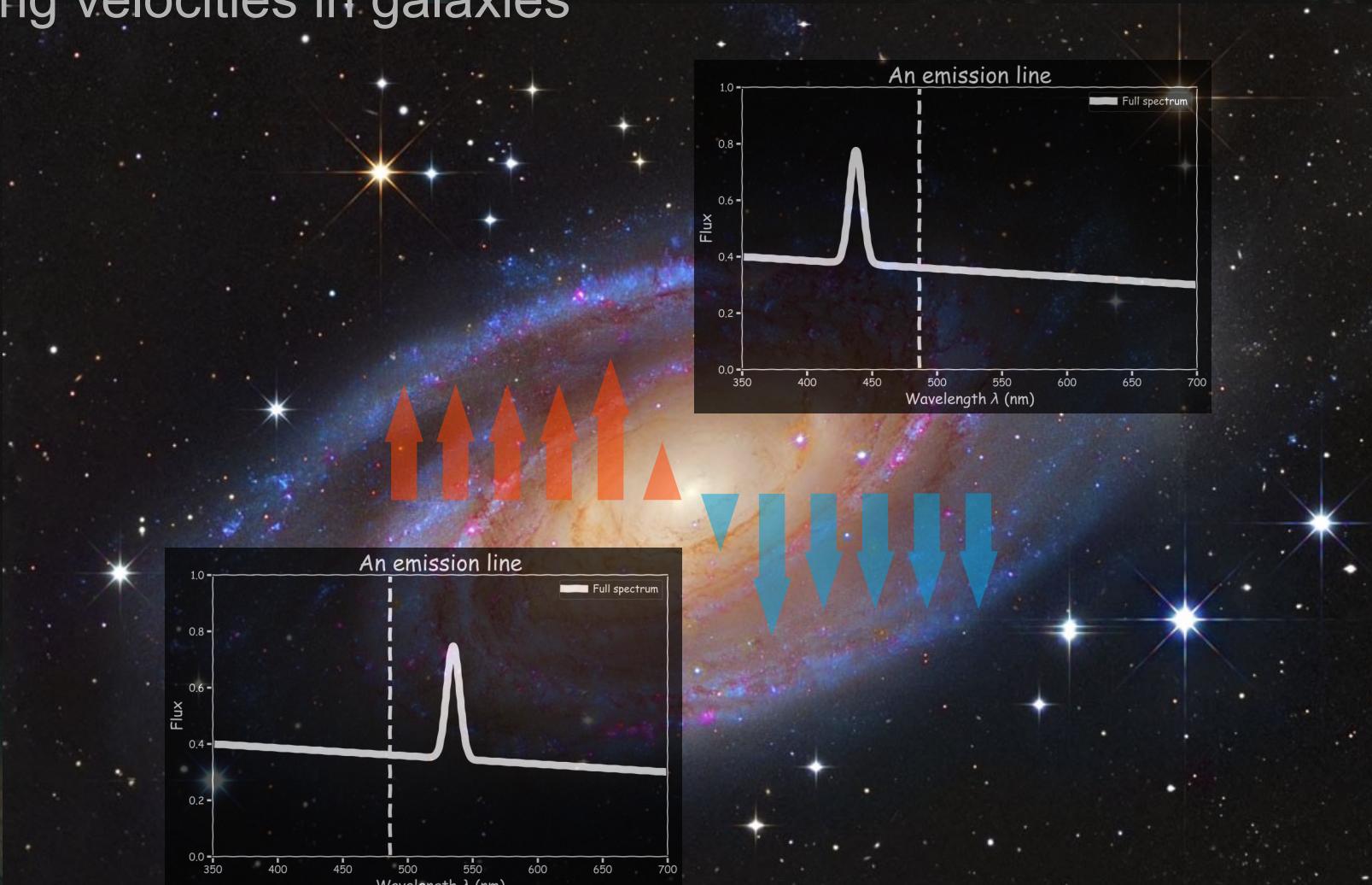
# An emission line



# An emission line



# Measuring velocities in galaxies

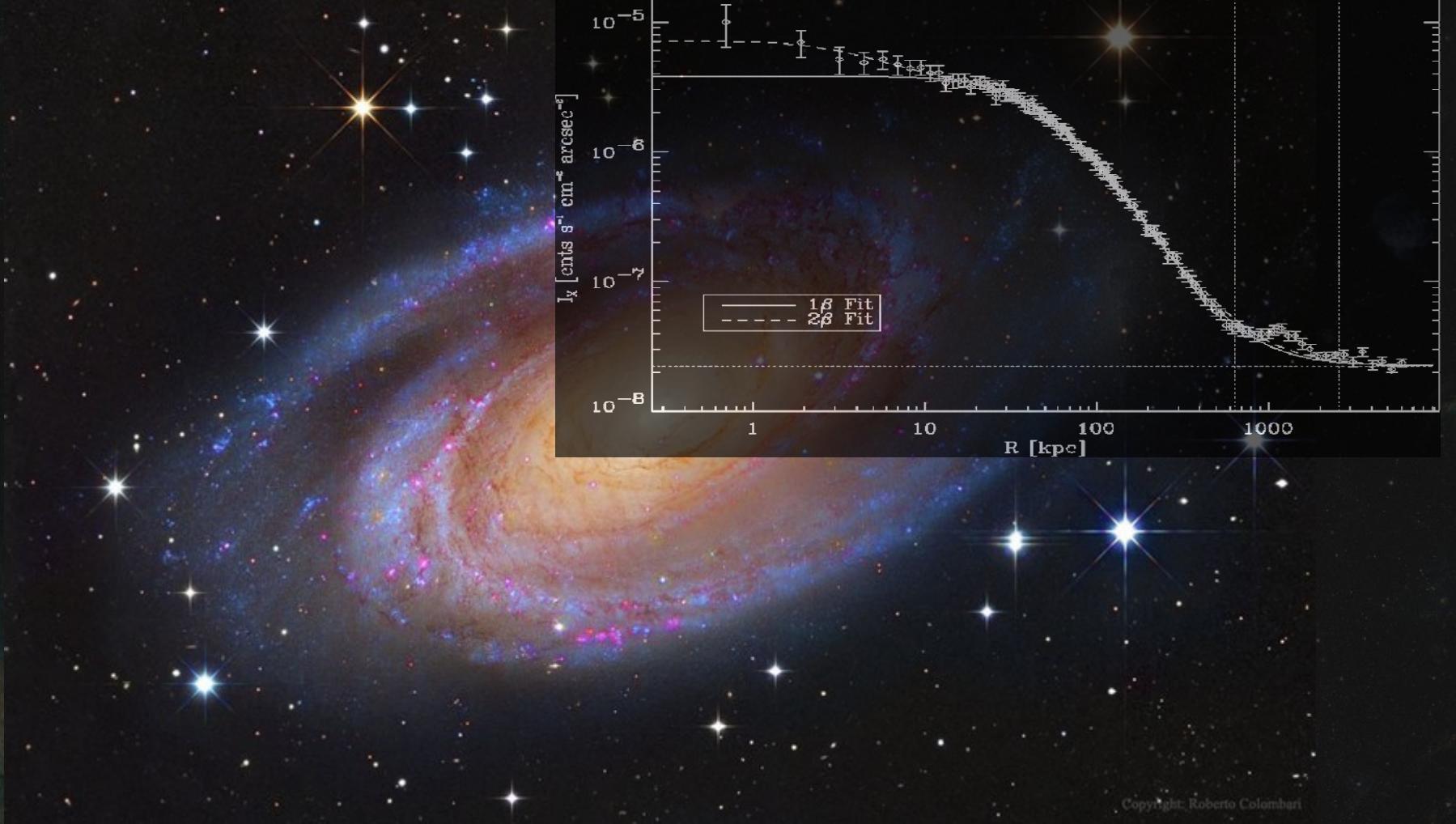


# Enclosed mass from surface brightness

From surface brightness, you can get an estimate of mass in each part of a galaxy.

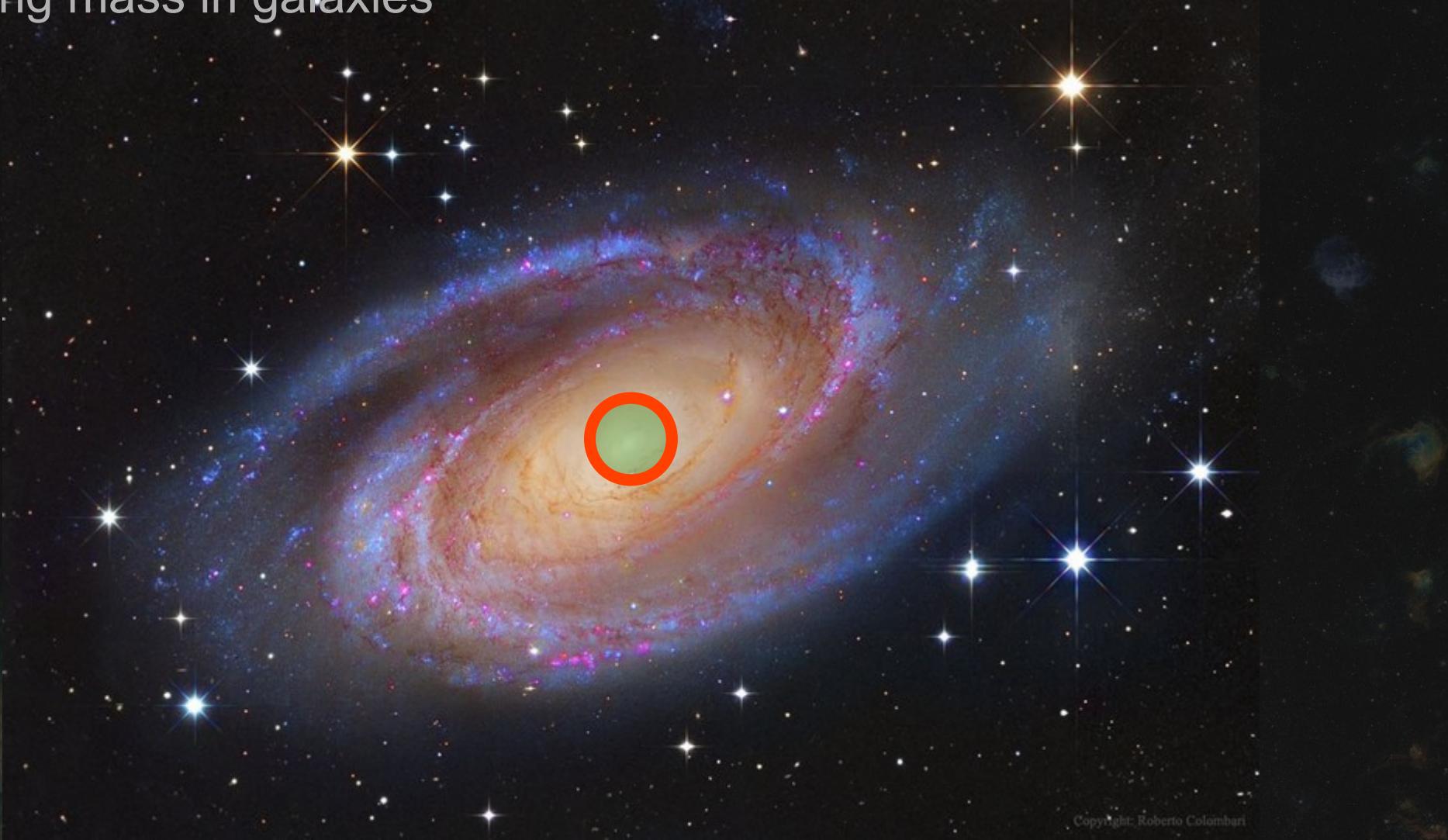
The enclosed mass is the sum of all mass inside of the orbit.

# Measuring mass in galaxies



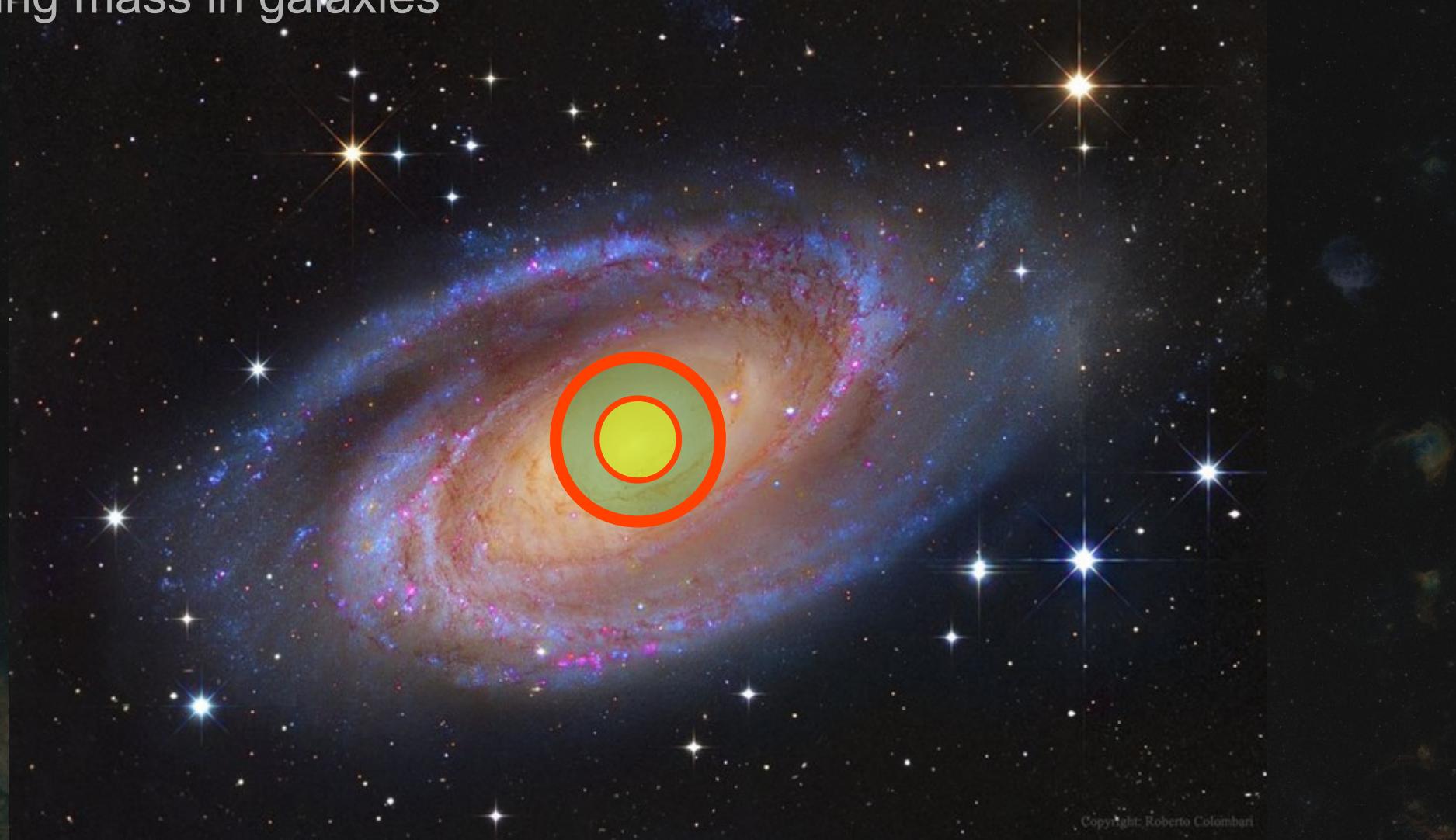
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# Measuring mass in galaxies



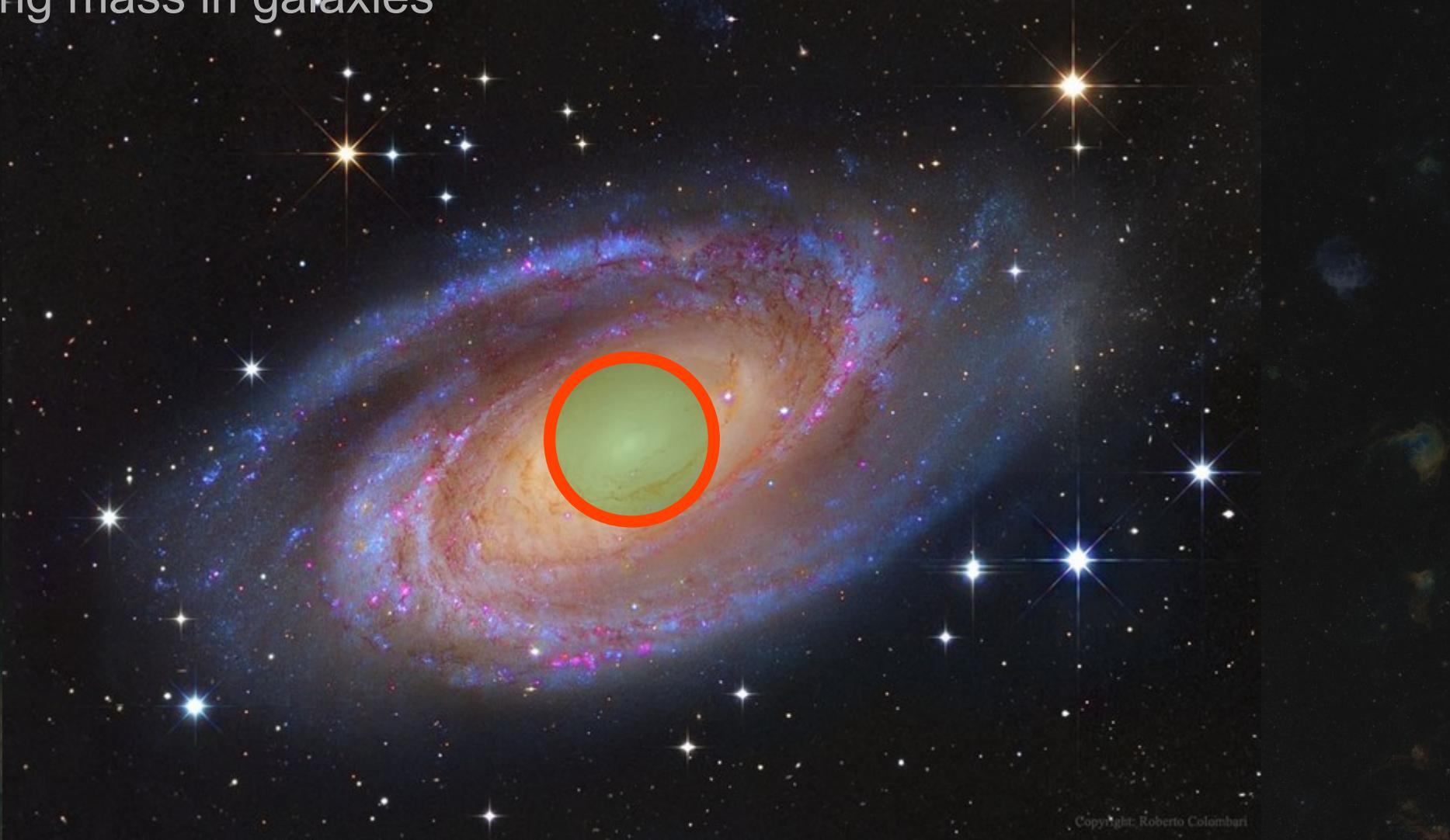
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# Measuring mass in galaxies



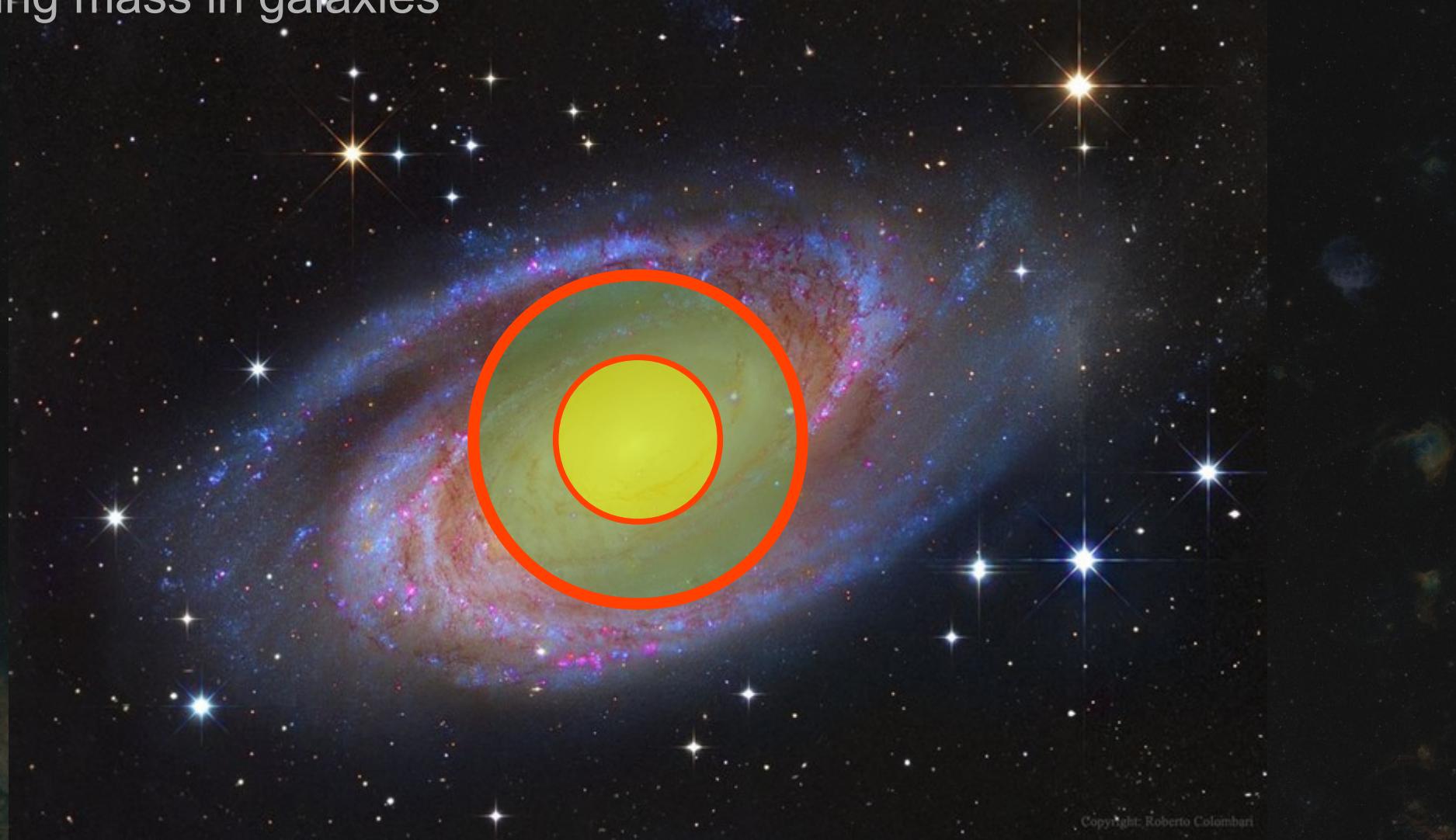
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# Measuring mass in galaxies



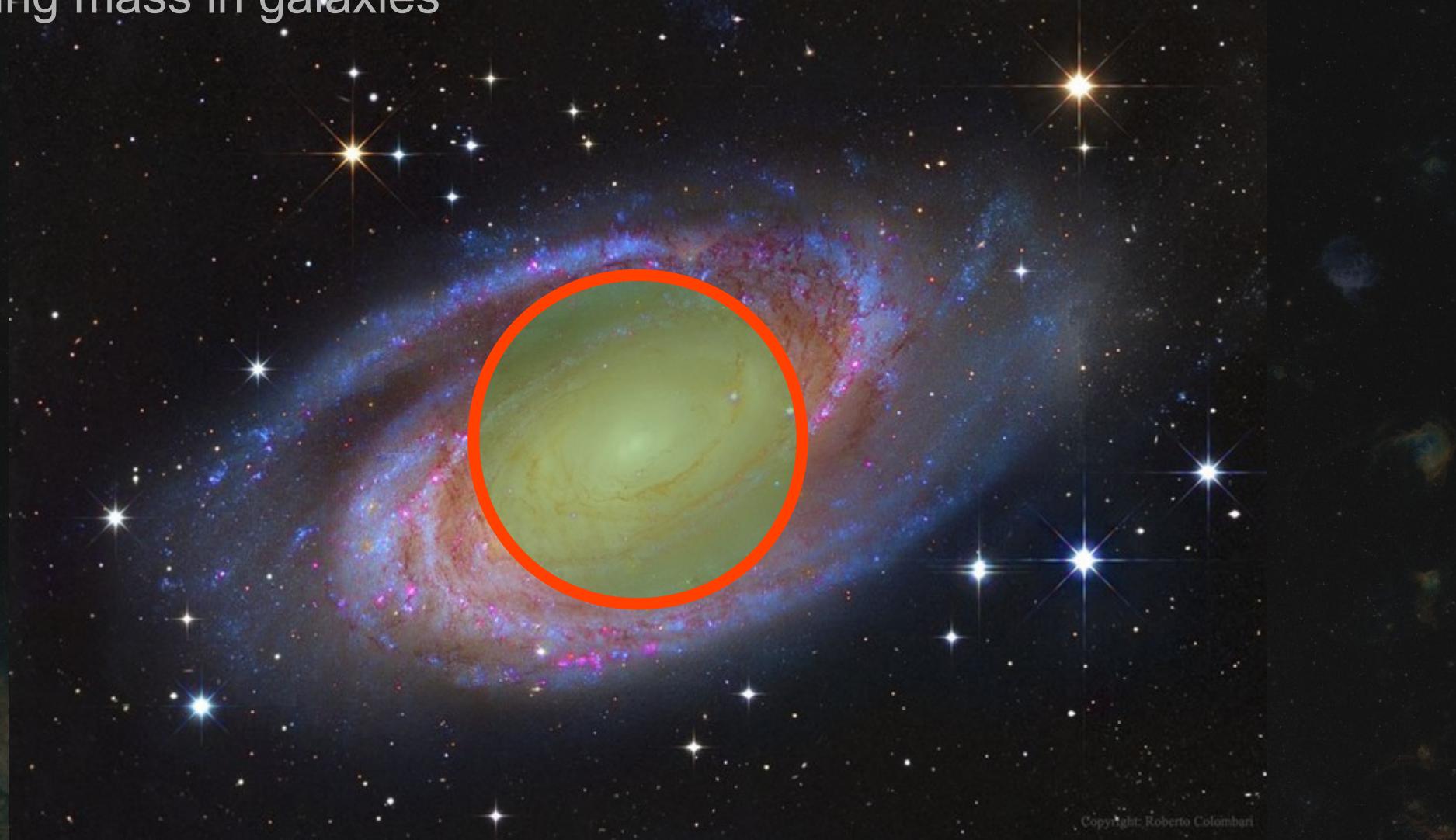
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# Measuring mass in galaxies

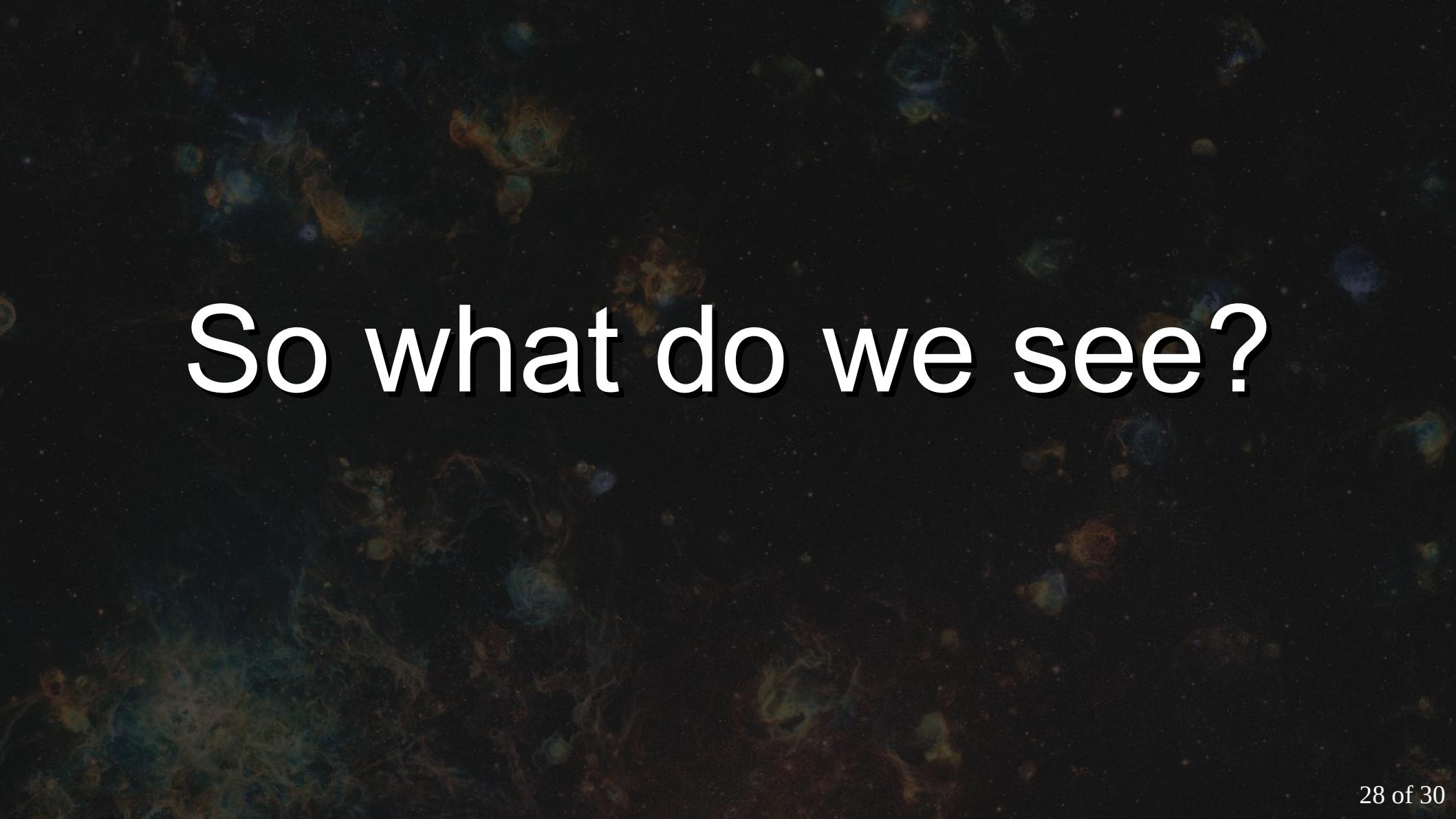


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# Measuring mass in galaxies

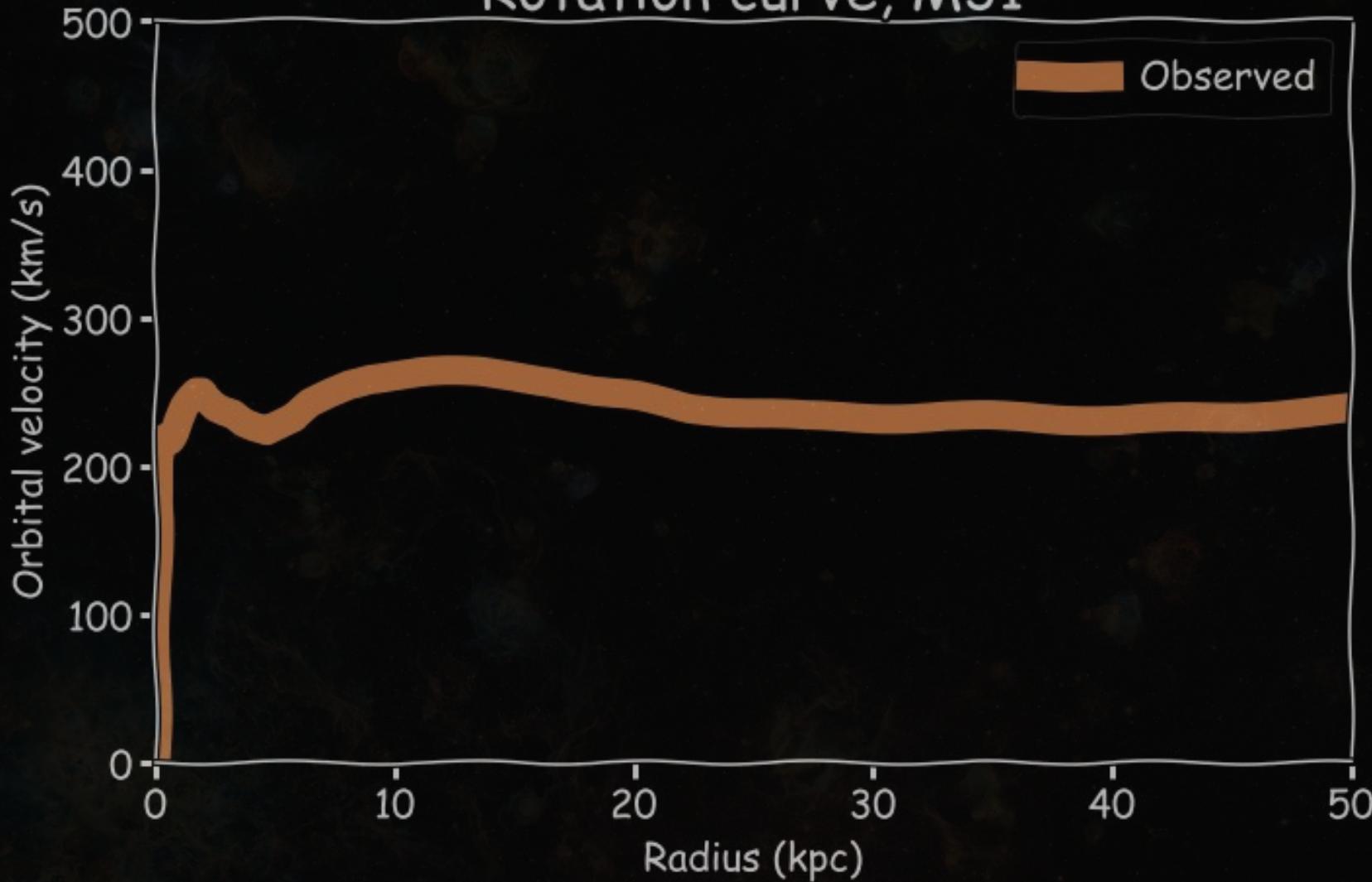


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So what do we see?

# Rotation curve, M31



# Rotation curve, M31

