Spiral structure in disks

Types of spirals:

Grand design: 2 well-defined, symmetric spiral arms.

Flocculent: spiral arm "fragments", not continuous

Multiple arms: 3, 4, etc

Barred spirals


M81 (Adam Block)

Spiral structure in disks

Types of spirals:

Grand design: 2 well-defined, symmetric spiral arms.

Flocculent: spiral arm “fragments”, not continuous

Multiple arms: 3, 4, etc

Barred spirals

Spiral structure in disks

Types of spirals:

Grand design: 2 well-defined, symmetric spiral arms.

Flocculent: spiral arm “fragments”, not continuous

Multiple arms: 3, 4, etc

Barred spirals


NGC 5054 (Michael Sidonio)

Spiral structure in disks

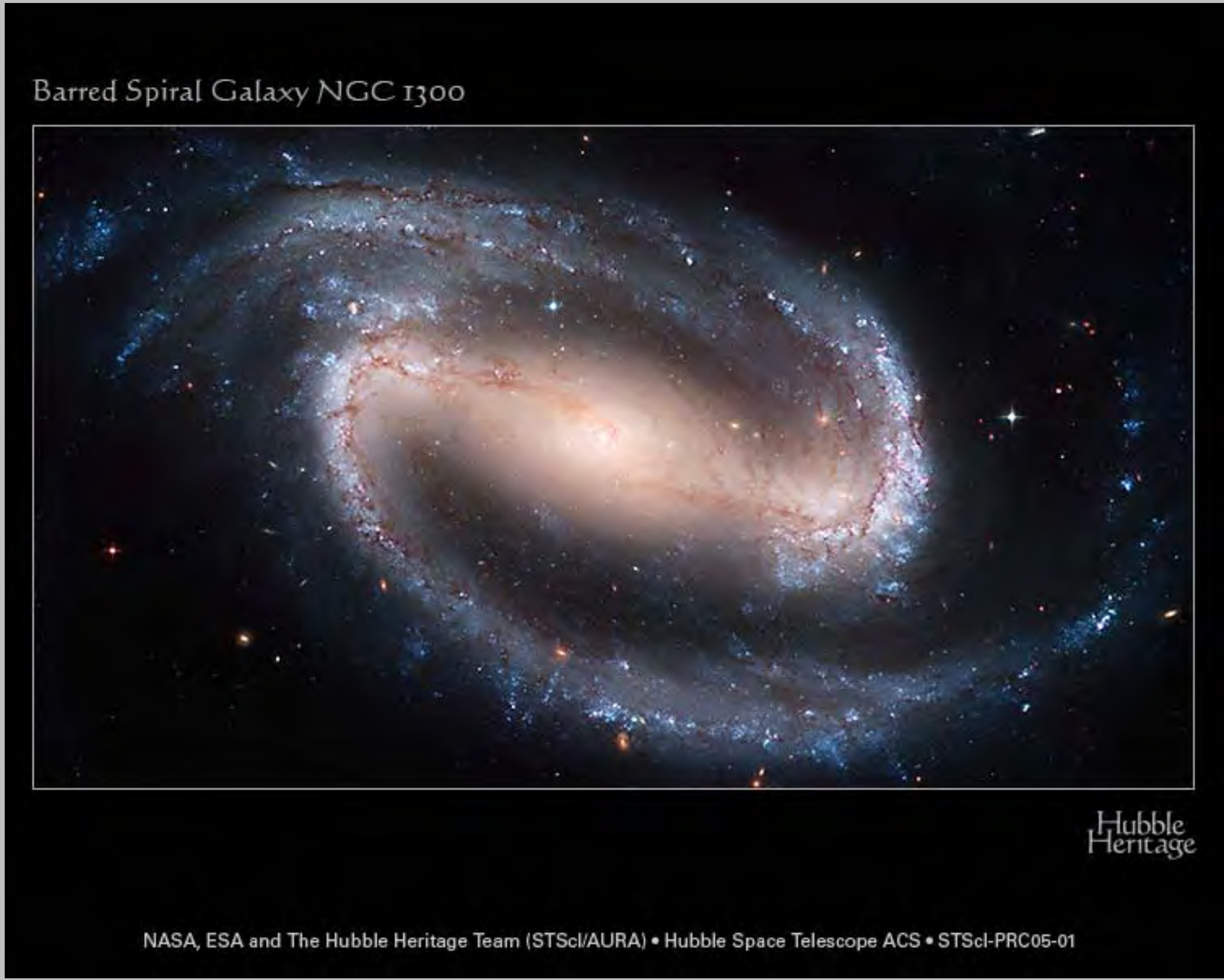
Types of spirals:

Grand design: 2 well-defined, symmetric spiral arms.

Flocculent: spiral arm “fragments”, not continuous

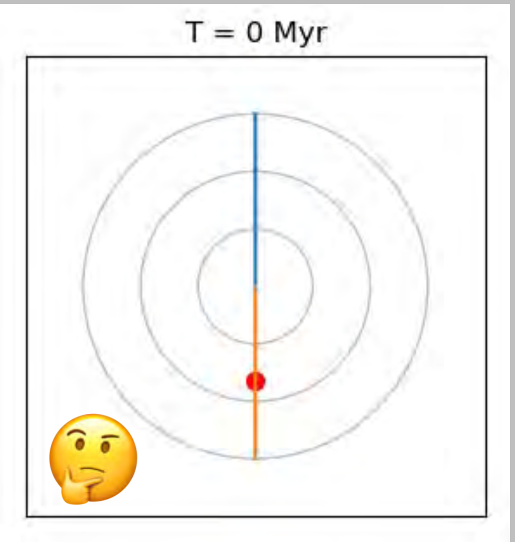
Multiple arms: 3, 4, etc

Barred spirals: arms coming off a central bar



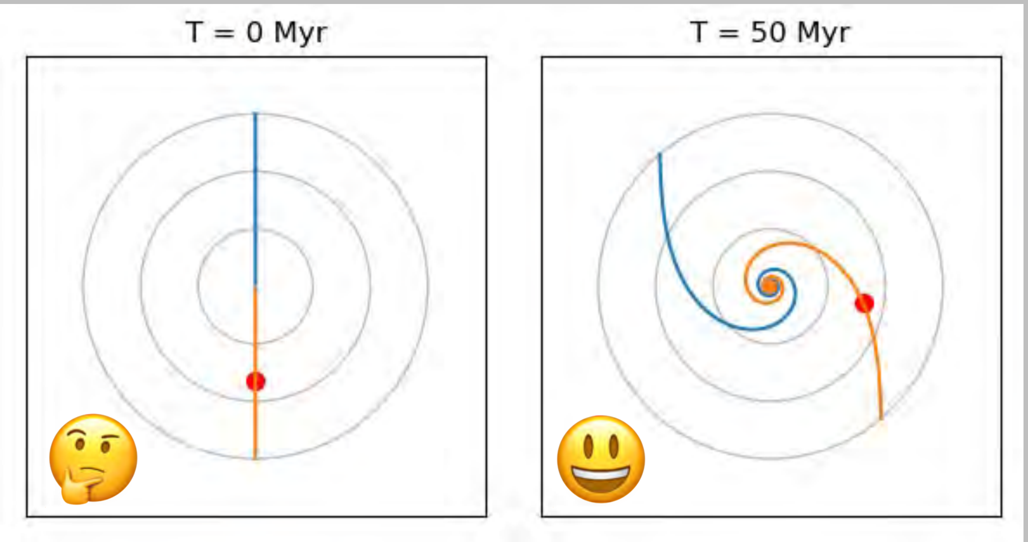
Making spiral arms

Imagine making a linear “ridge” of stars and letting it orbit around the galaxy. What happens over time?



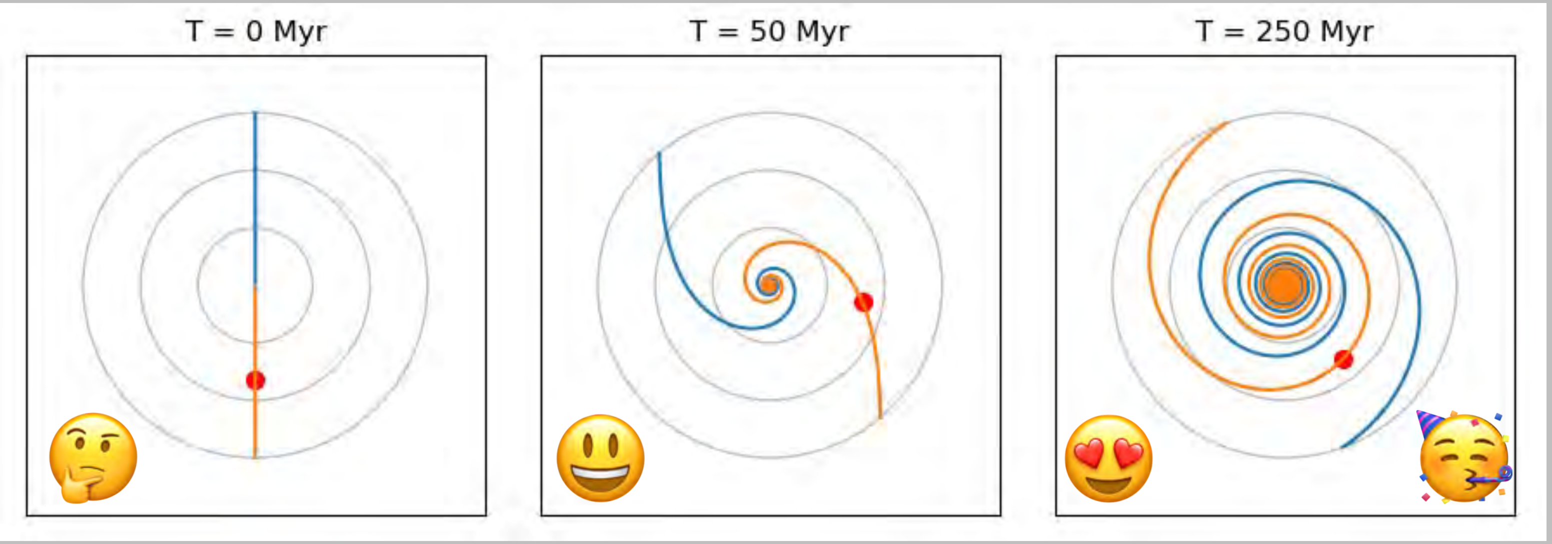
Making spiral arms

Imagine making a linear "ridge" of stars and letting it orbit around the galaxy. What happens over time?



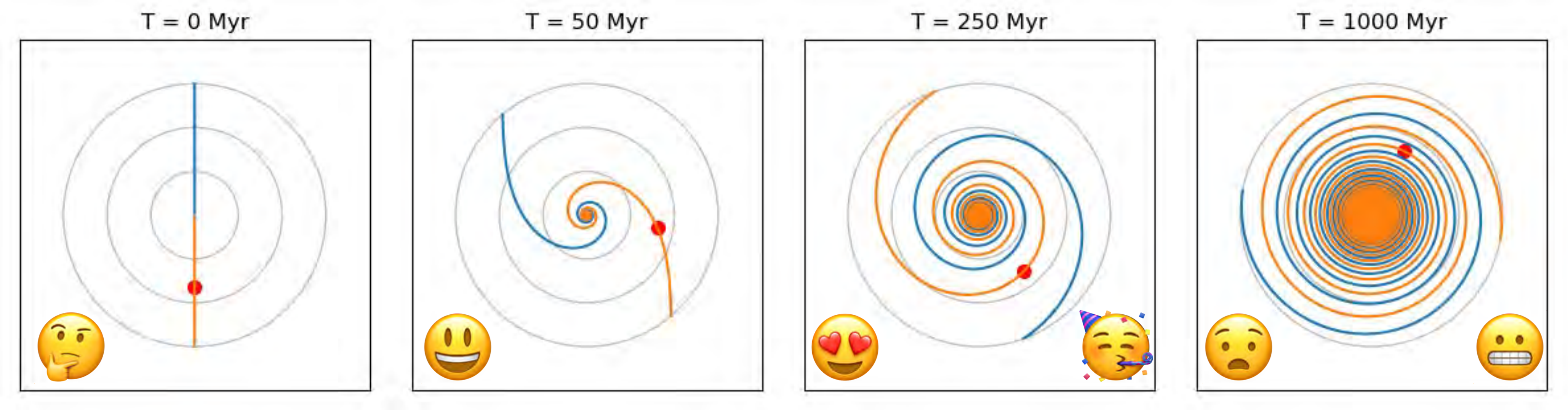
Making spiral arms

Imagine making a linear “ridge” of stars and letting it orbit around the galaxy. What happens over time?



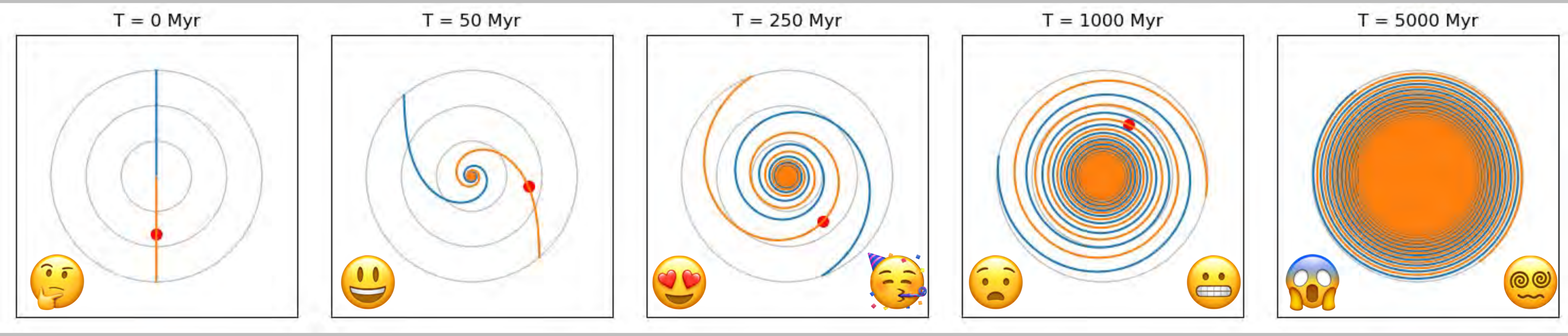
Making spiral arms

Imagine making a linear "ridge" of stars and letting it orbit around the galaxy. What happens over time?



Making spiral arms

Imagine making a linear "ridge" of stars and letting it orbit around the galaxy. What happens over time?



The winding problem

Galaxies do not rotate like a solid object – since $V_c(R)$ is roughly constant with radius , the orbital time is short in the inner disk and long in the outer disk. This means any physical structure will wind up very quickly and be sheared away.

What would the rotation curve have to look like for this not to be a problem?

Orbital time is $T = \frac{2\pi R}{V_c(R)}$ so if the orbital time needs to be the same at all radius, then $V_c(R) = \frac{2\pi R}{T} \sim R$

"Solid Body Rotation"
Not what galaxies do!

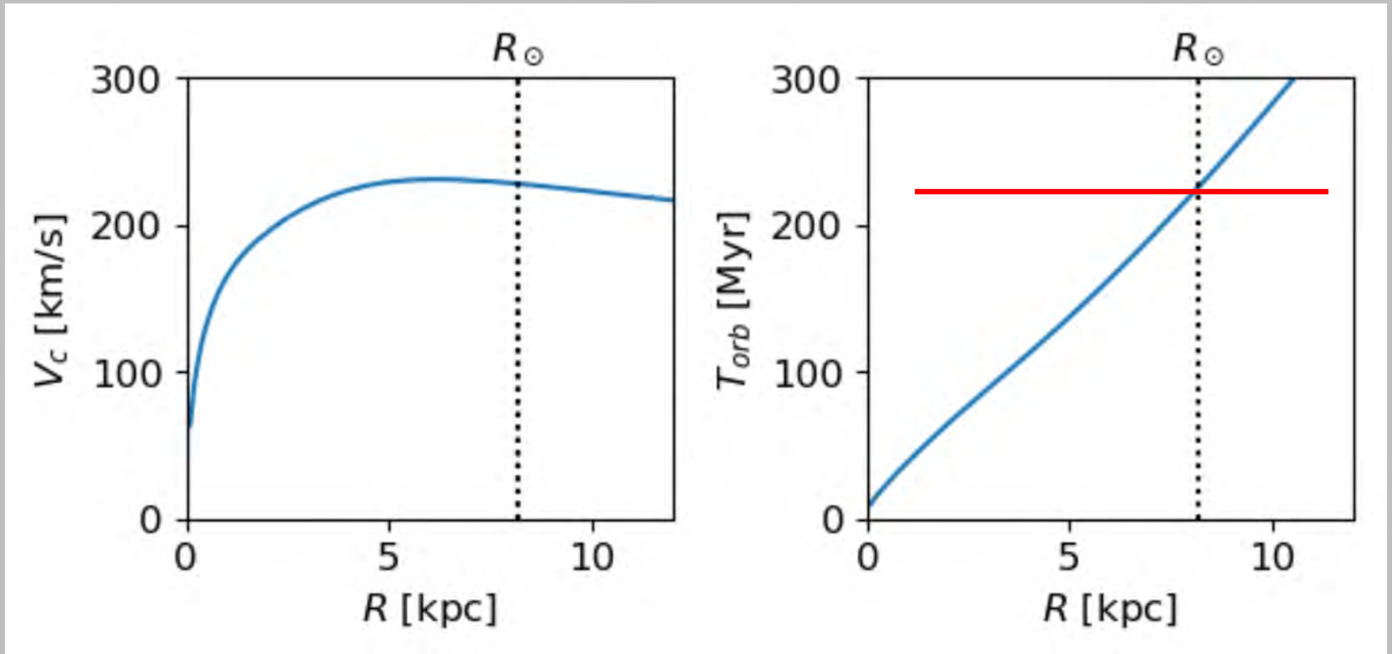
Spiral Density Waves

Spirals cannot be physical structures orbiting coherently for long timescales. Instead, they are density waves moving through the disk. What is a density wave?

A traffic jam is an example of a density wave. Cars move in and out of the jam at a different speed than the jam itself moves.

Spiral Density Waves in Disk Galaxies

In a galaxy a density wave is moving compression of gas and stars that travels with a fixed *angular* rate that is different from the circular velocity. This gives it an orbital time that doesn't change with radius. Look at the Milky Way's rotation:



Co-rotation is where the stars and spiral wave move at the same velocity, and is very close to the Sun's orbital radius.

⇒ Inside co-rotation, stars orbit faster than the wave and "catch up" to the spiral arms.

⇒ Outside co-rotation, stars orbit more slowly than the wave, and the arms "sweep past" them.

Spiral Density Waves in Disk Galaxies

Think of a star orbiting inside co-rotation. As it nears the arm, the extra mass of the arm pulls it forward into the arm, speeding the star up.

As it leave the arm, the extra mass of the arm pulls back on the star, slowing it down.

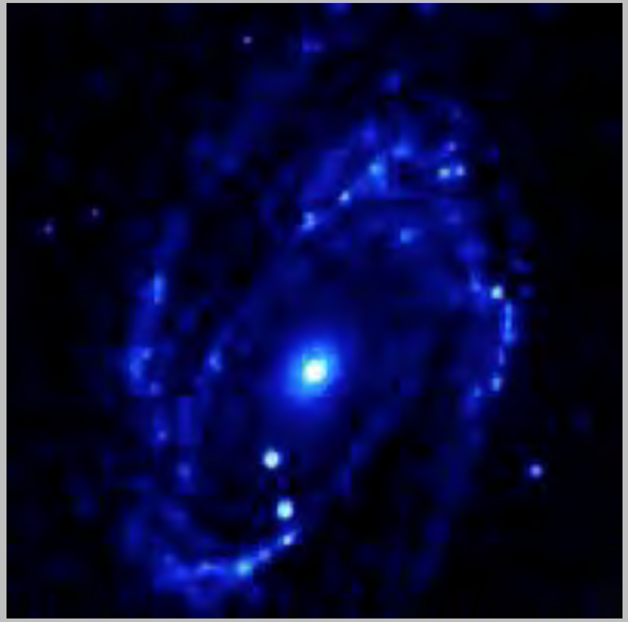
So the star spends more time in the arm, adding to the arm's mass and density. The spiral wave is sustained by this "self-gravity" as it moves through the disk.

But stars can easily move in and out of arms. What happens to the interstellar gas in the disk?

- **Collisions**: unlike stars, gas collides together in arms and is shocked, compressing the gas and driving star formation.

- **Ambient density**: the overall mass density inside arms is greater than outside them, so clouds are closer to gravitational collapse and can form stars.

⇒ ***Increased efficiency of star formation in spiral arms!***



Barred spirals

If the conditions are right, the self-gravity of the disk can be so strong that the galaxy forms a bar.

The density wave perturbation is so strong that it “traps” stars inside the wave. Stars begin to move radially along the wave rather moving on circular orbits. ⇒ linear bar structure

What are those conditions?

1. High disk surface density

If the overall density of the disk is high, its self-gravity is very strong and the density of the wave grows very quickly. A bar forms and strengthens.

2. Slowly rising rotation curve

A slowly rising rotation curve mimics solid body rotation: $V_c(R) \sim R$

In this case, the wave and the stars rotate at the same speed so stars can get more easily “trapped” inside the wave, strengthening it.

Both these conditions can happen in the inner disks of bright galaxies!

But what starts the spiral density wave to begin with?

Any kind of non-axisymmetric perturbation can seed a wave, after which the disk self-gravity can amplify it into spiral arms.

- Galaxy interactions?
- Galaxy bars?
- Irregular lumps of mass in the disk?