

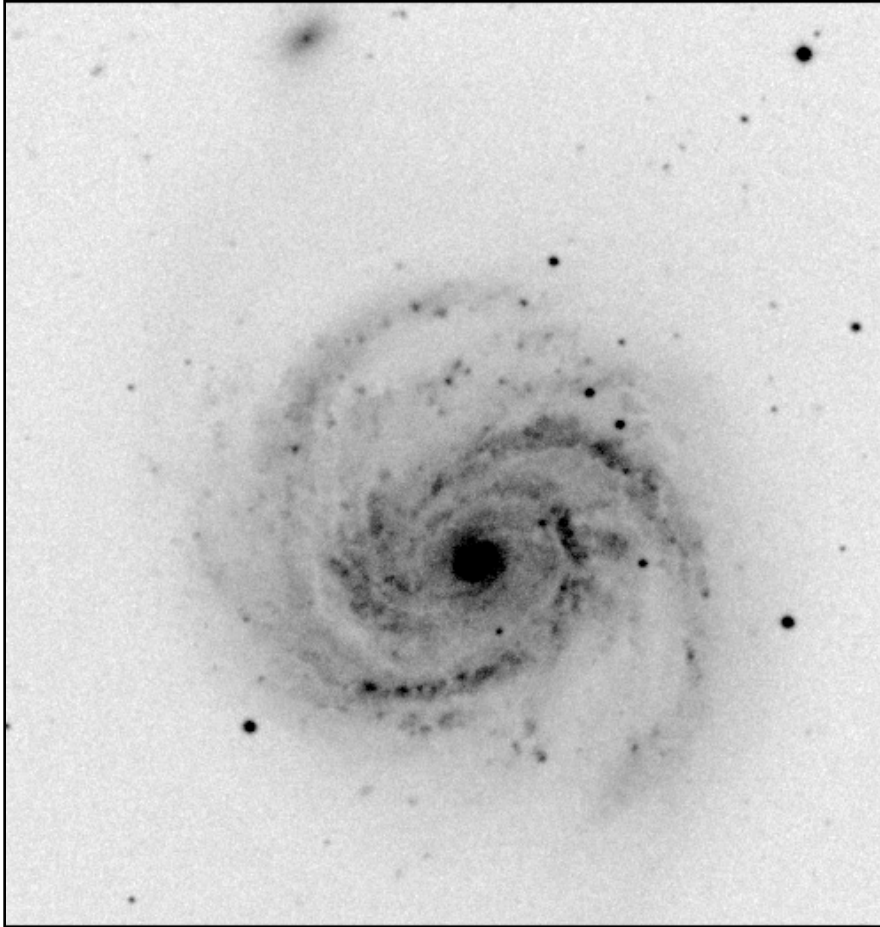
Spiral Galaxies:

Density Waves



Spiral Arms

Defining feature of spiral galaxies - what causes them?



Observational clues:

Seen in disks that contain gas, but not in gas poor S0 galaxy disks.

Defined mainly by blue light from hot massive stars, thus lifetime is \ll galactic rotation period

When the sense of the galactic rotation is known, the spiral arms almost always trail the rotation

Differential Rotation of Galaxian Disks

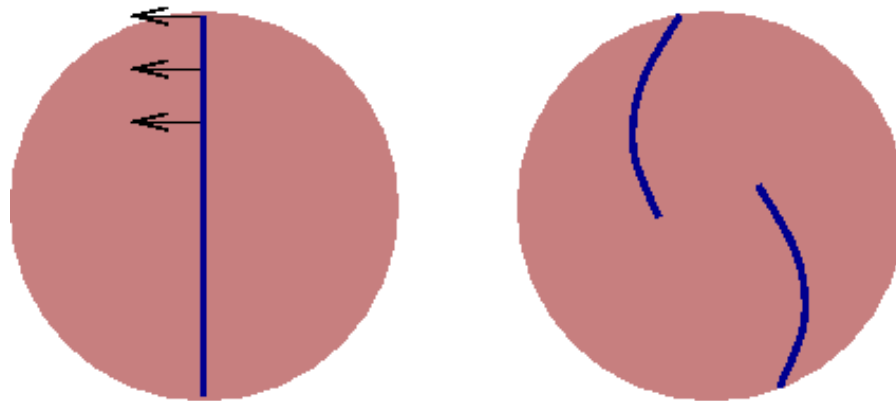
First ingredient for producing spiral arms is differential rotation.

For galaxy with flat rotation curve:

$$V(R) = \text{constant}$$

$$\text{Angular velocity} \longrightarrow \Omega(R) = \frac{V}{R} \propto R^{-1}$$

Any feature in the disk will be wrapped into a trailing spiral pattern due to differential rotation:

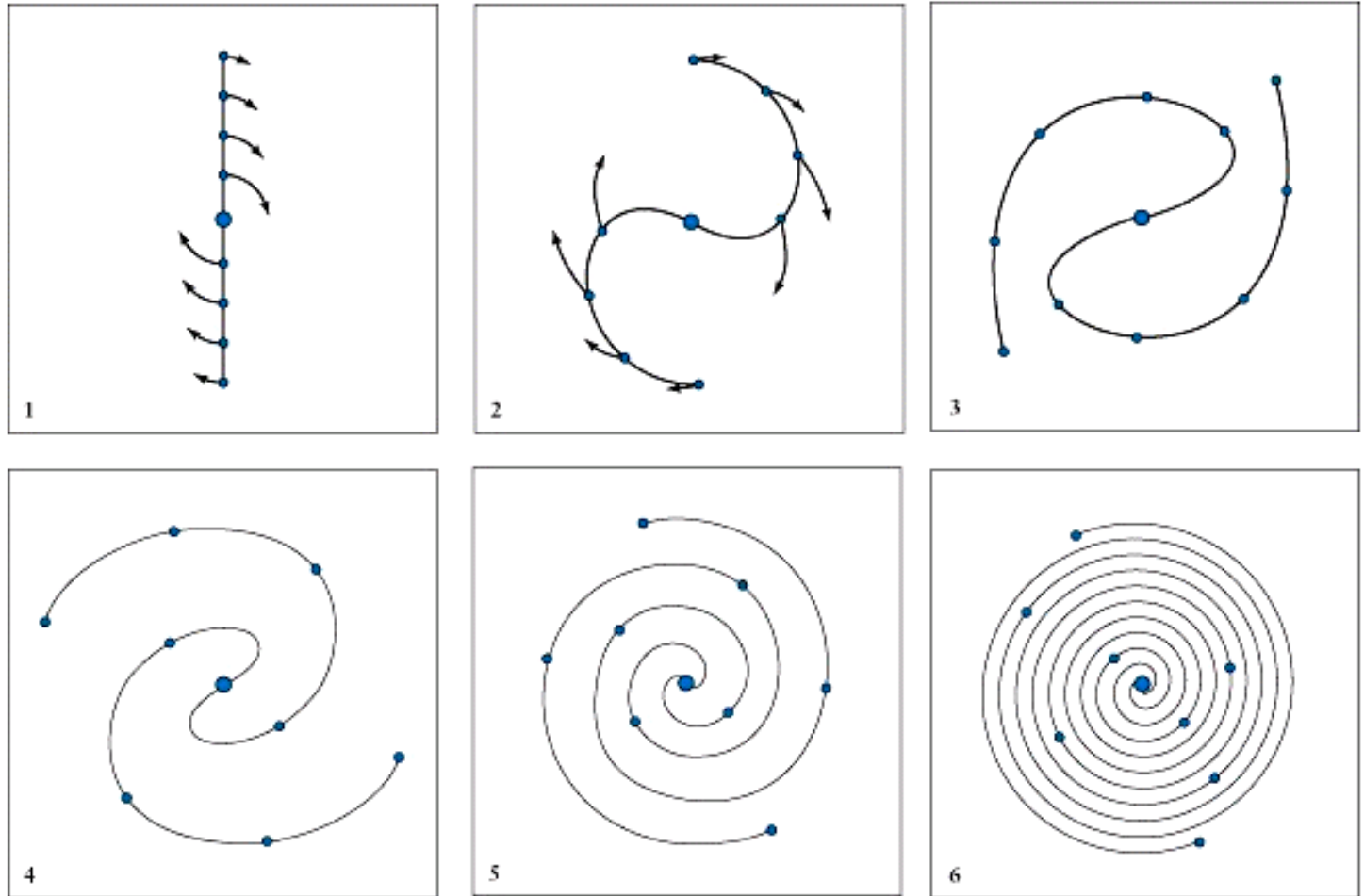


Tips of spiral arms point *away* from direction of rotation

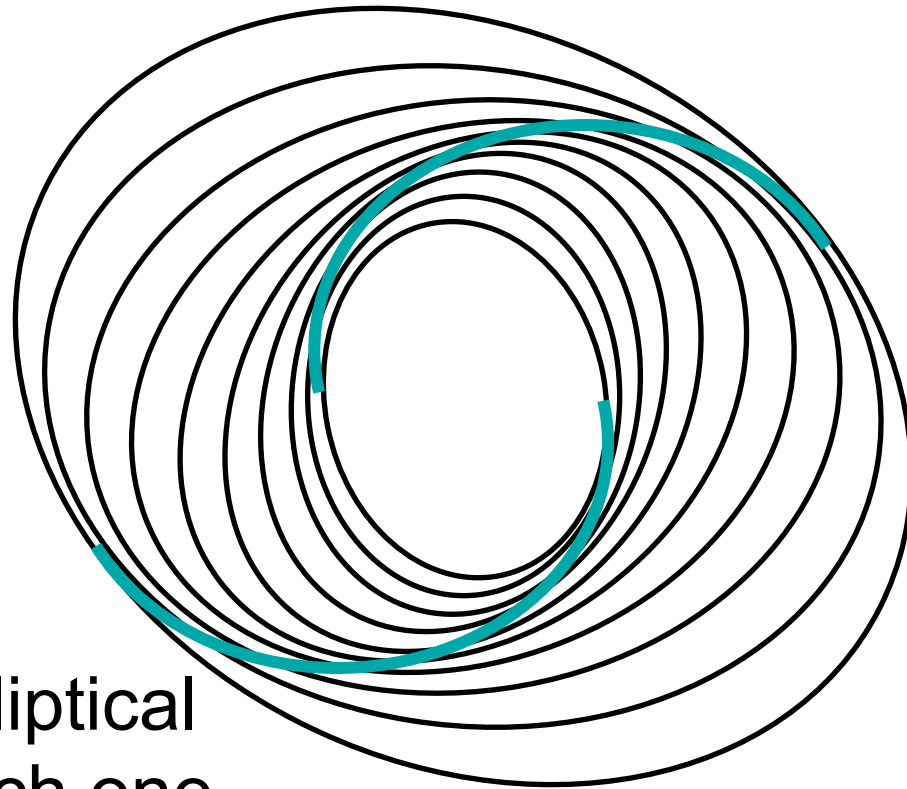
The Winding Dilemma

Due to differential rotation, stars near the galactic center don't need to travel far to circle the galaxy, but stars further out can take a long time to go around. An initial line of stars will be drawn out into a spiral:

But this is not why galaxies have spiral arms!



Orbit Crowding Schematic



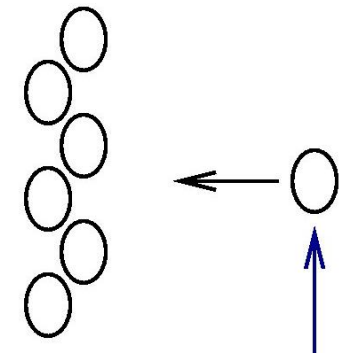
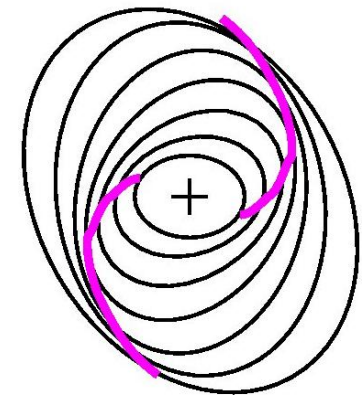
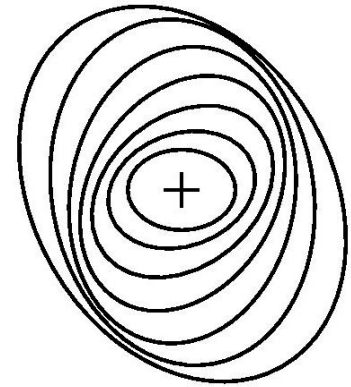
Nested Elliptical
Orbits, each one
slightly rotated.

Density Wave Theory

- Spiral arm patterns must be persistent. Density wave theory provides an explanation: the arms are density waves propagating in differentially rotating disks
- Spiral arm pattern is amplified by resonances between the epicyclic frequencies of the stars (deviations from circular orbits) and the angular frequency of the spiral pattern
 - Spiral waves can only grow between the inner and outer *Linblad resonances* ($\Omega_p = \Omega - \kappa/m$; $\Omega_p = \Omega + \kappa/m$) where κ is the epicyclic frequency and m is an integer (the # of spiral arms)
 - Stars outside this region find that the periodic pull of the spiral is faster than their epicyclic frequency, they don't respond to the spiral and the wave dies out
 - Resonance can explain why 2 arm spirals are more prominent
- We observe resonance patterns in spirals

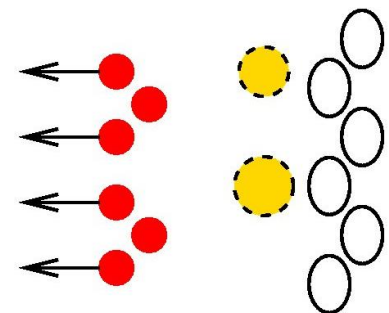
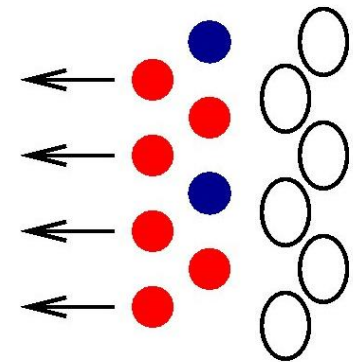
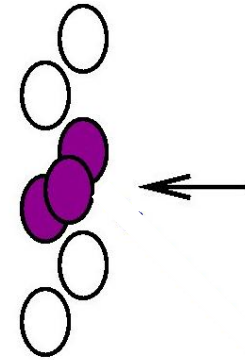
Spiral Density Waves

- The orbits in spiral galaxies are not quite circles – they are ellipses. These ellipses are slightly tilted with respect to each other.
- Thus there are regions of slightly higher density than their surroundings. The higher density means higher gravity.
- Objects (such as a gas cloud) will be attracted to these regions and will drift towards them.



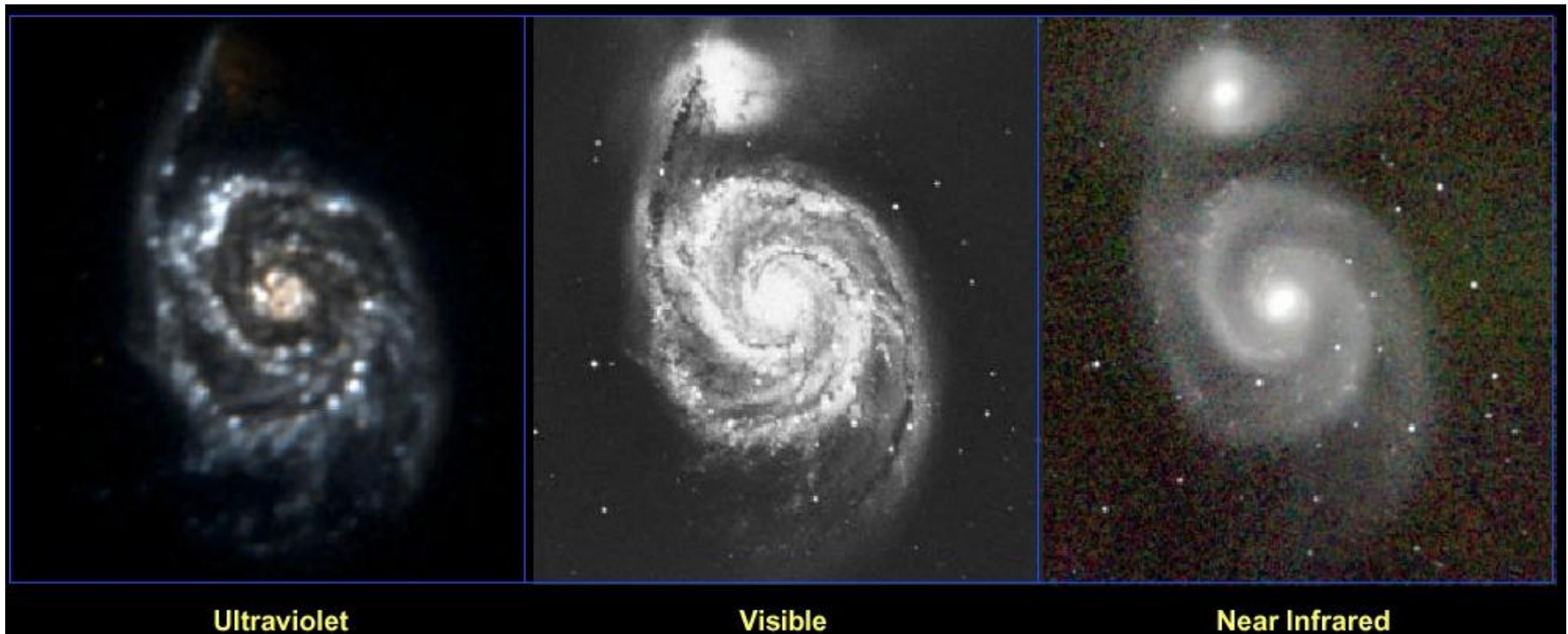
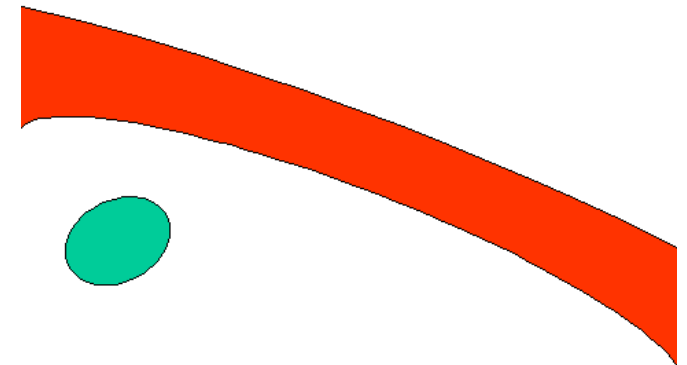
Spiral Density Waves

- When the gas cloud collides with other gas clouds, stars will be formed. (This is where most of the galaxy's star formation takes place.)
- Many of the stars will be faint, red main sequence stars, but some will be bright blue OB stars. These stars will continue to drift through the region.
- The OB stars don't go far before they explode. The brightest (and bluest) of a galaxy's stars will never be far from the spiral arm where they were born.

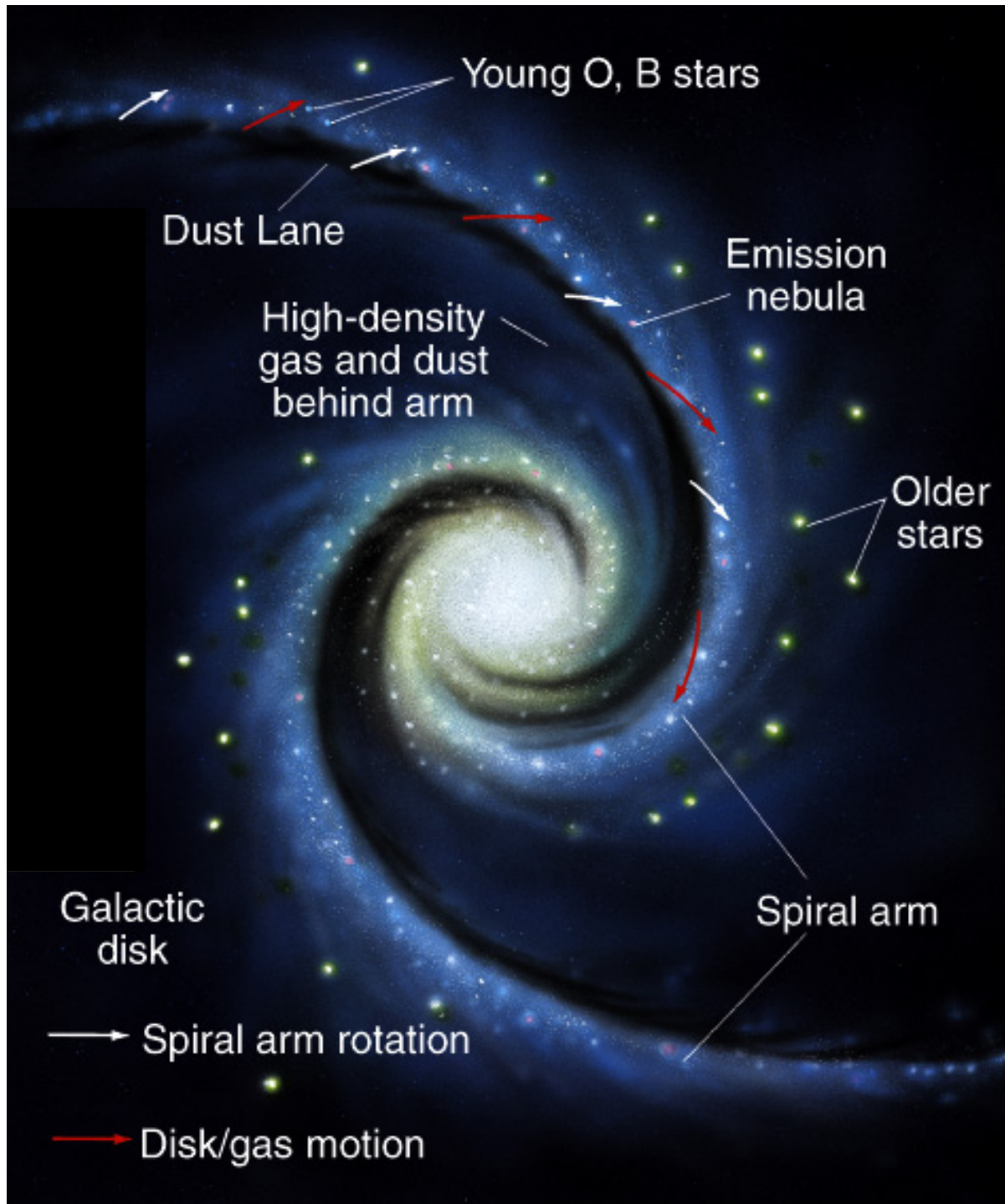


Spiral Density Waves

Since all the bright blue stars die before leaving the spiral arm, the **spiral density waves** must show up better at ultraviolet wavelengths.



The Density Wave Theory





Density Wave Theory Summary

- Spiral arms are waves of compression that move around the galaxy and trigger star formation
- Star formation will occur where the gas clouds are compressed
- Stars pass through the spiral arms unaffected
- This theory is successful in explaining the properties of spiral galaxies
- Two outstanding problems with it:
 1. What stimulates the formation of the spiral pattern?
Tidal interactions?
 2. What accounts for the branches and spurs in the spiral arms?

Star Formation in Spiral Arms

- Spiral density wave creates spiral arms by the gravitational attraction of the stars and gas flowing through the arms
- Even if there was no star formation, there would be spiral arms - but star formation makes them more prominent
- This can explain the so-called “*grand design*” *spirals*
- Star formation can *self-propagate* in a differentially rotating disk, e.g., as supernova shocks compress neighboring molecular clouds
- Self-propagating star formation may be responsible for the branches and spurs in the spiral arms, or disks without evident spiral density waves (the so-called *flocculent spirals*)

Next:

Elliptical Galaxies

