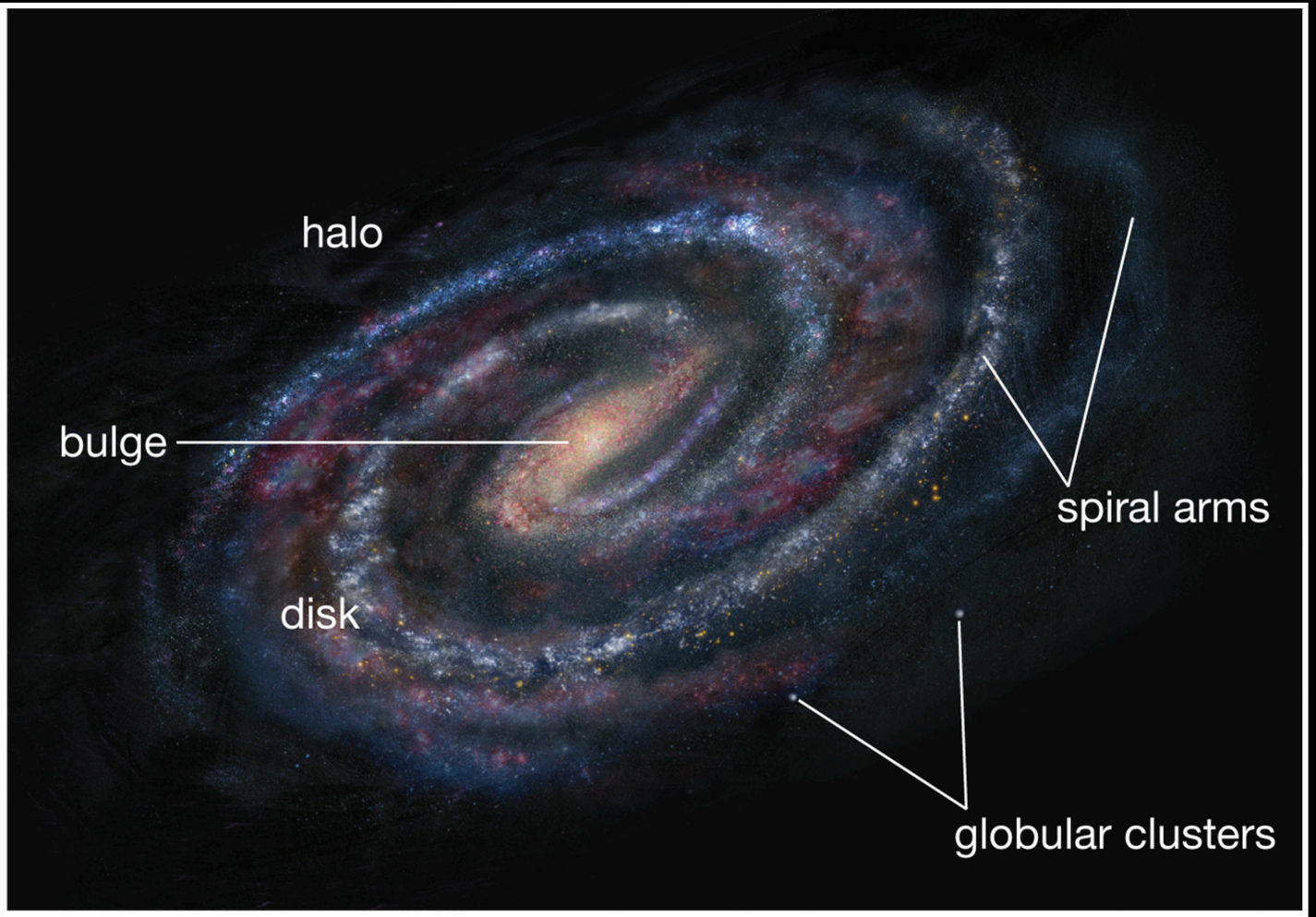
ASTR-3301: Extragalactic Astronomy

Lecture #8: Complete Map of the Milky Way

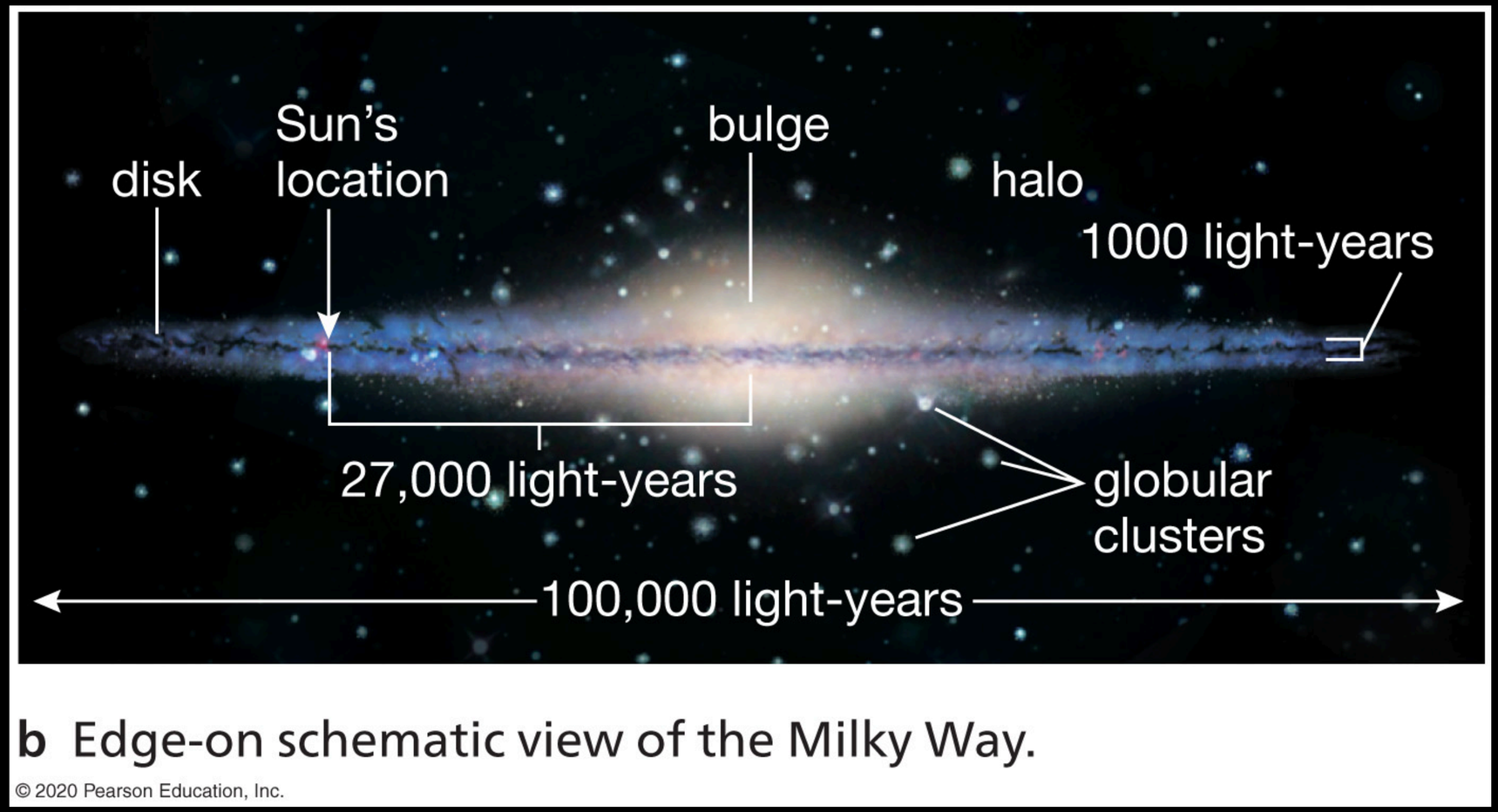
The Milky Way



a Artist's conception of the Milky Way viewed from the outside.

The Milky Way is a spiral galaxy, if seen from outside, we would see spiral arms that make up the galaxy's disk

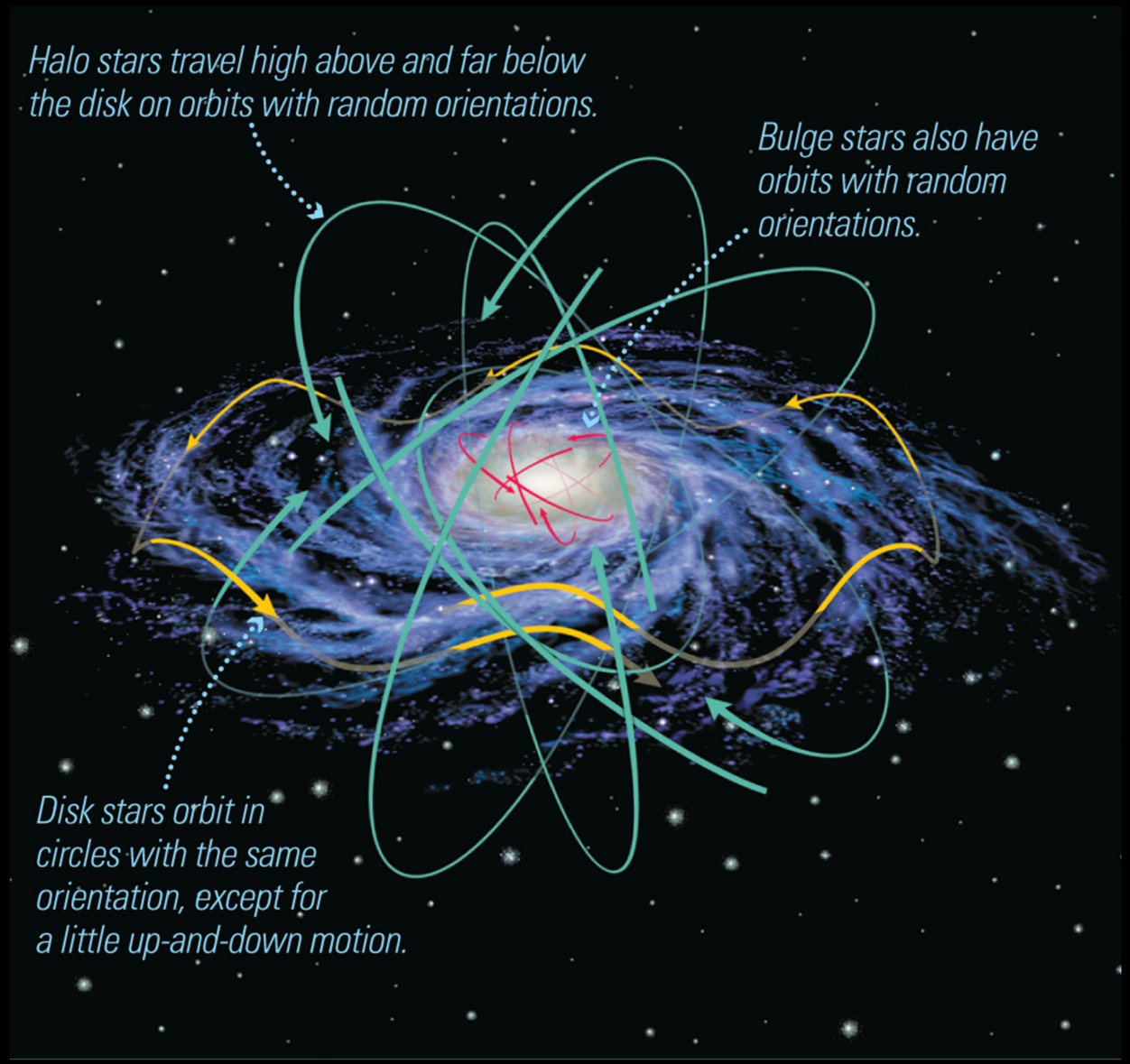
The Milky Way



b Edge-on schematic view of the Milky Way.

Schematic from an edge-on orientation. Primary features: bulge, disk, halo

The Milky Way



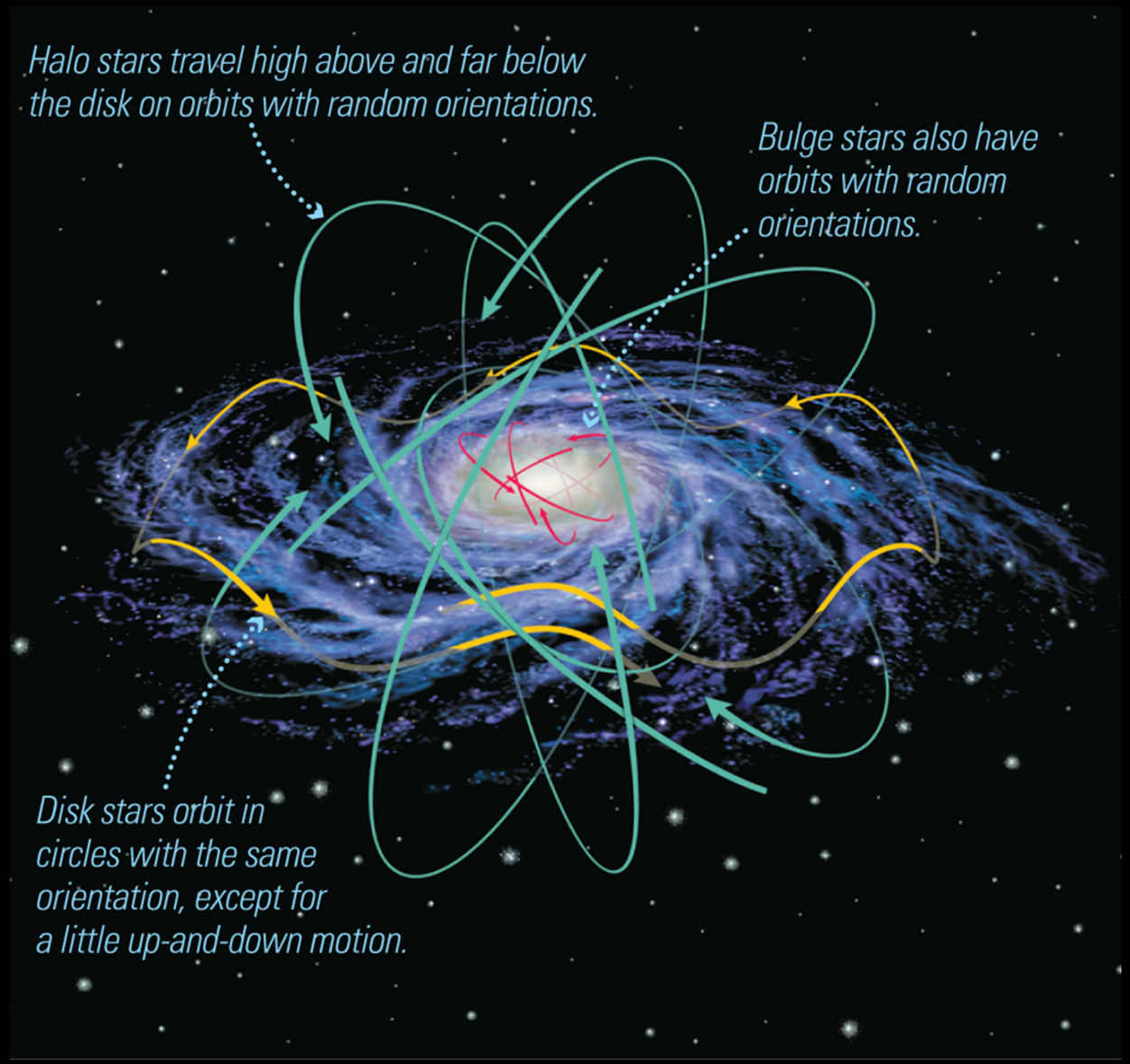
Stars and gas that populate the disk:

- mostly orbit in the same direction

- have elliptical orbits

- mostly stay in the same plane as the disk with some up and down motion

The Milky Way



Stars that populate the bulge and halo:

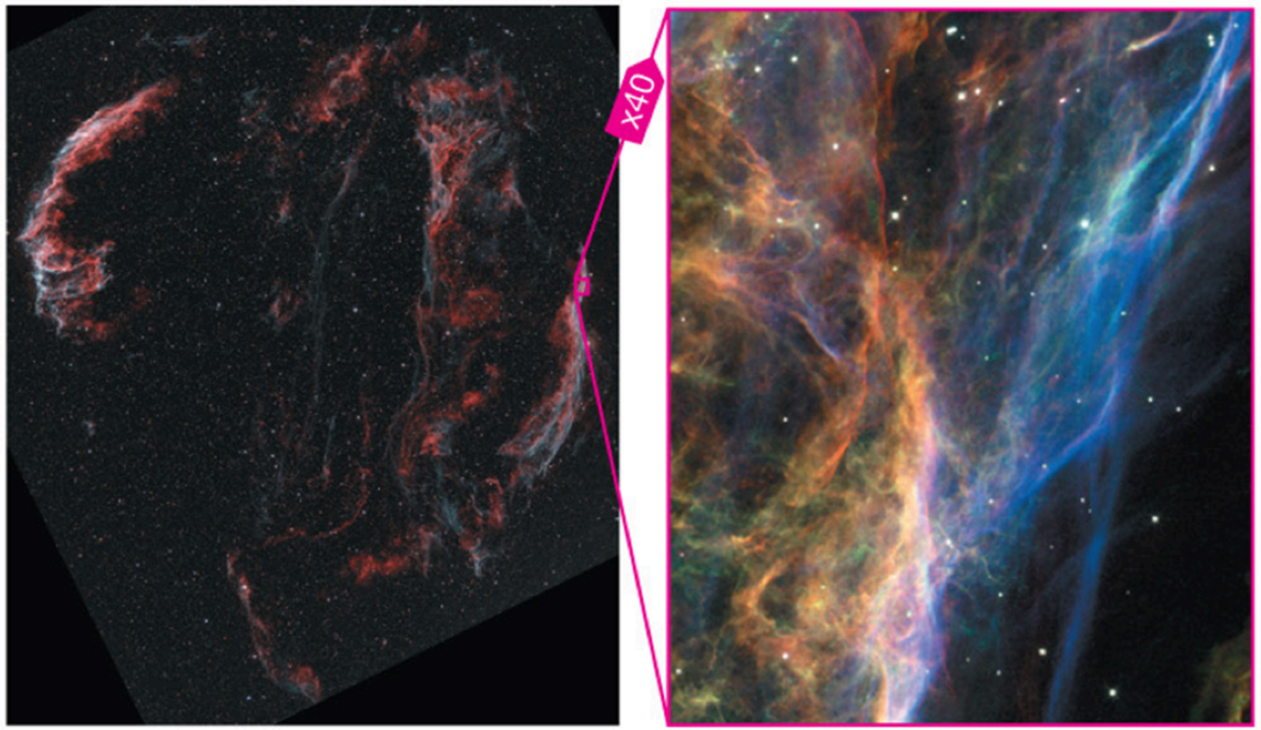
- have random orbit orientations

- millions to billions of stars with random orbits make that area look ~spherical

The Milky Way

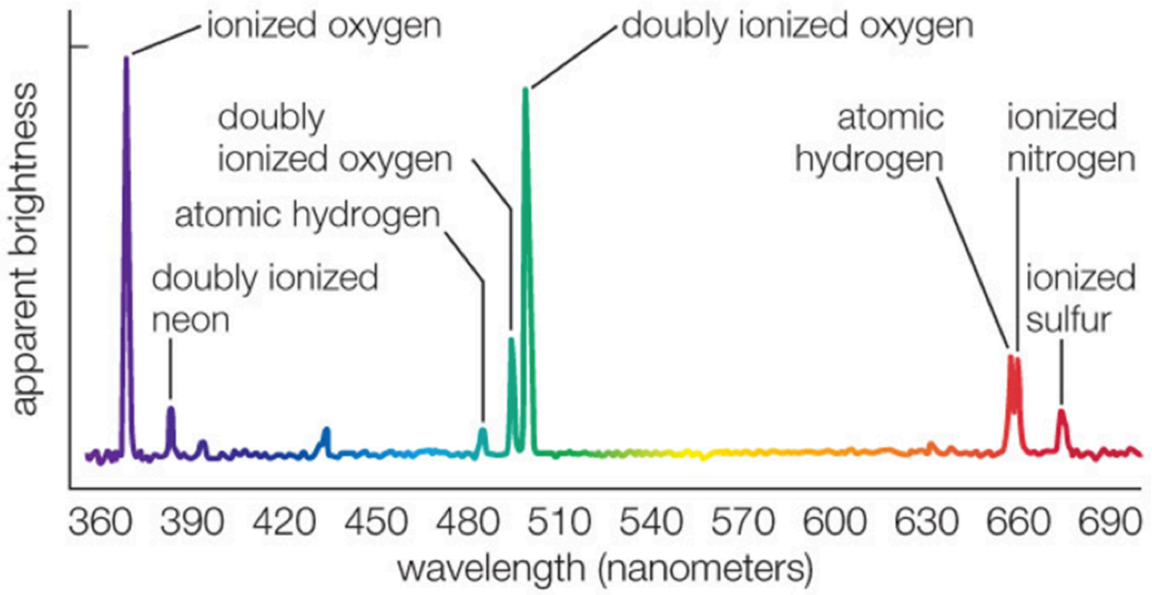
High mass stars emanate strong winds that create bubbles of hot gas in the interstellar medium (ISM): the composition of the space between stars

The Milky Way



a This visible-light image shows the entire supernova remnant, which is about 130 light-years across and spans an angular width in our sky six times that of the full Moon.

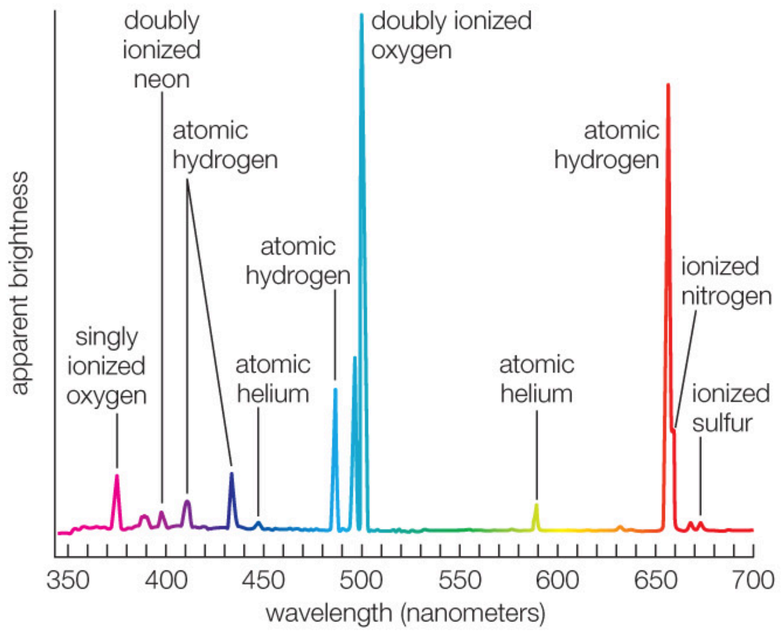
b This Hubble Space Telescope image shows fine filamentary structure in a small piece of the remnant. The colors come from emission lines of the atoms and ions indicated in part c.



c A visible-light spectrum of the Cygnus Loop shows the strong emission lines that account for the distinct colors in the Hubble Space Telescope image.

Star Forming Regions

a A Hubble Space Telescope photo of the Orion Nebula, an ionization nebula energized by ultraviolet photons from hot stars.



b A spectrum of the Orion Nebula. The prominent emission lines reveal the atoms and ions that emit most of the light. Through careful study of these lines, we can determine the nebula's chemical composition.

<u>Ionization nebulae</u> are found around short-lived high mass stars -> shows active star formation

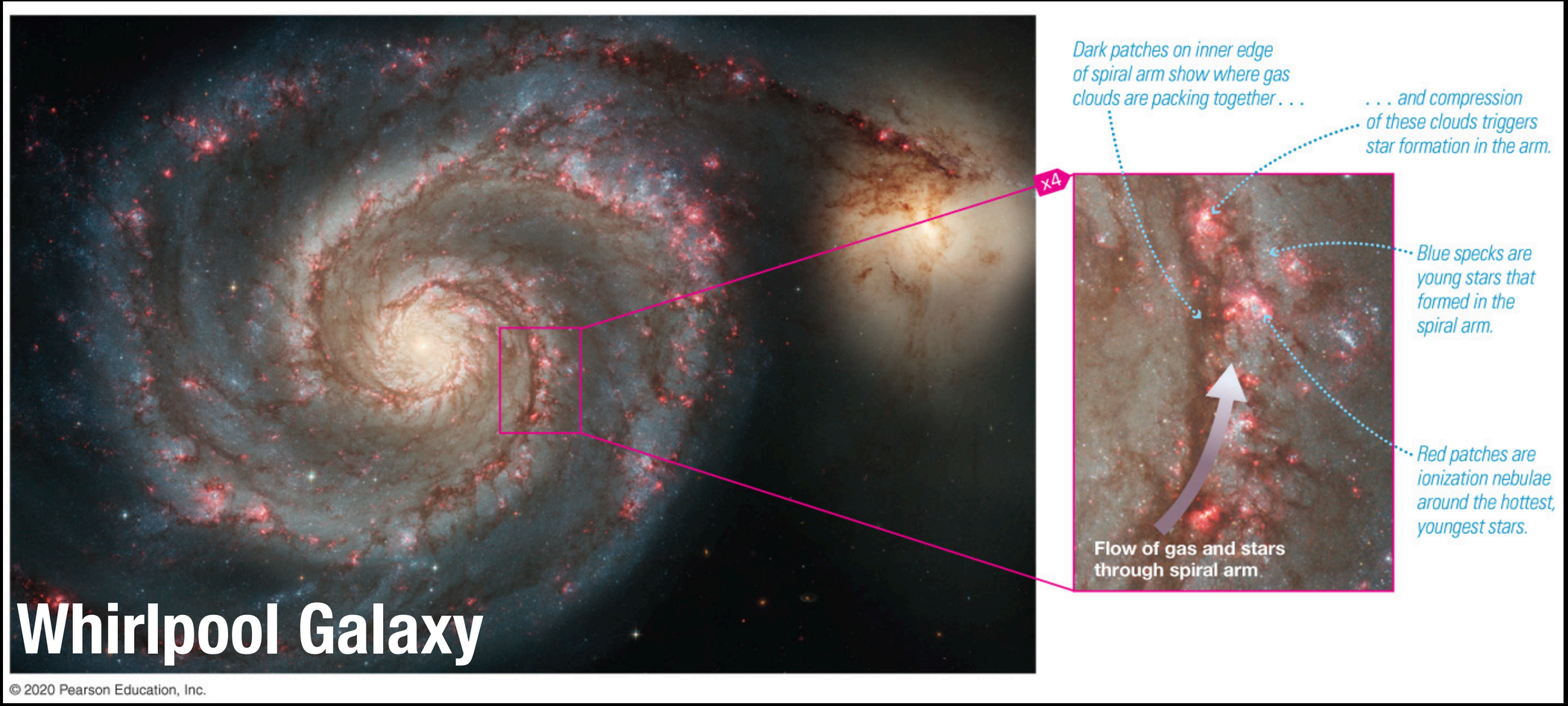
Star Forming Regions

Halo: no ionization nebulae, no blue stars

⇒ no star formation

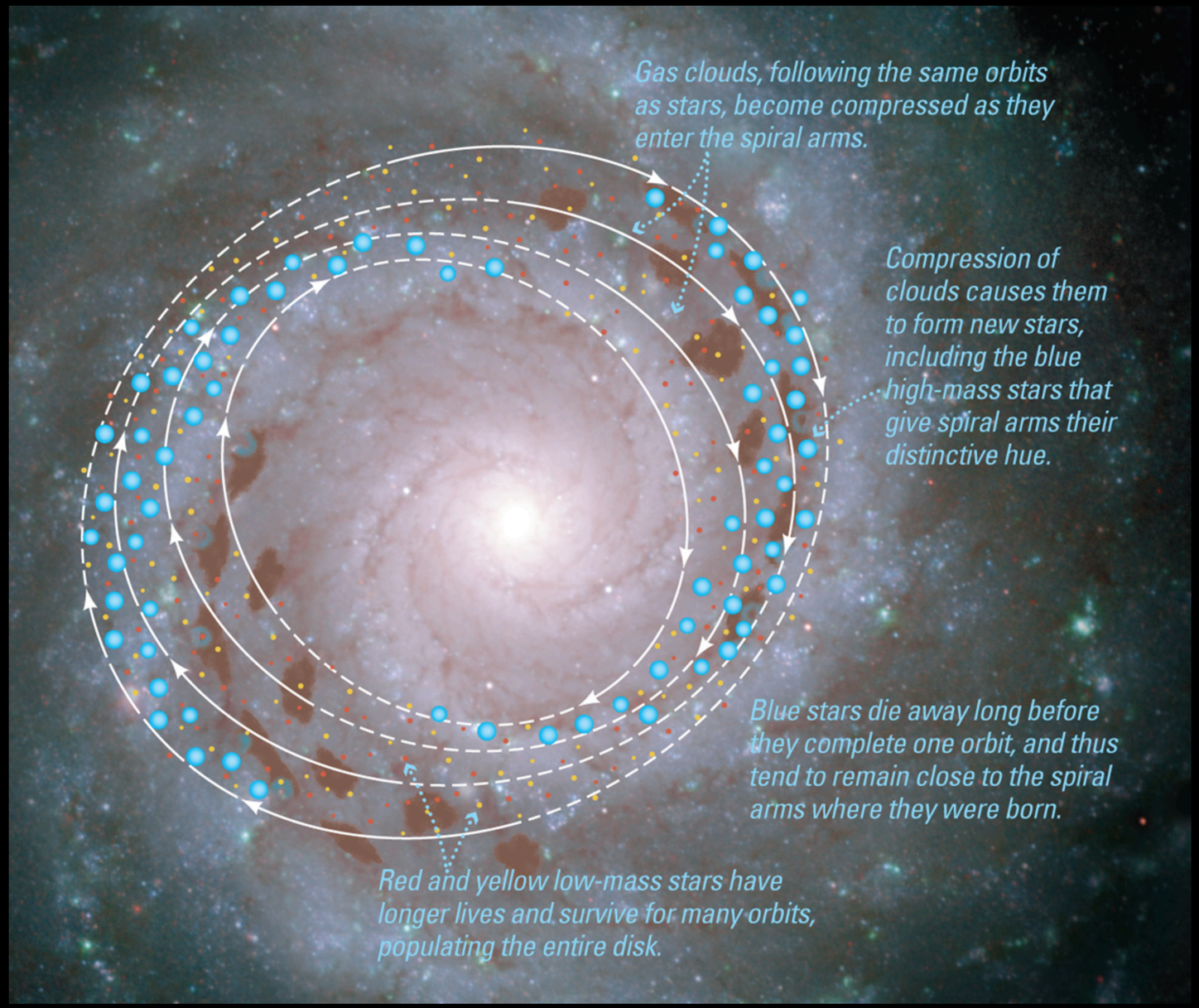
Disk: ionization nebulae, blue stars ⇒ star formation

Star Forming Regions



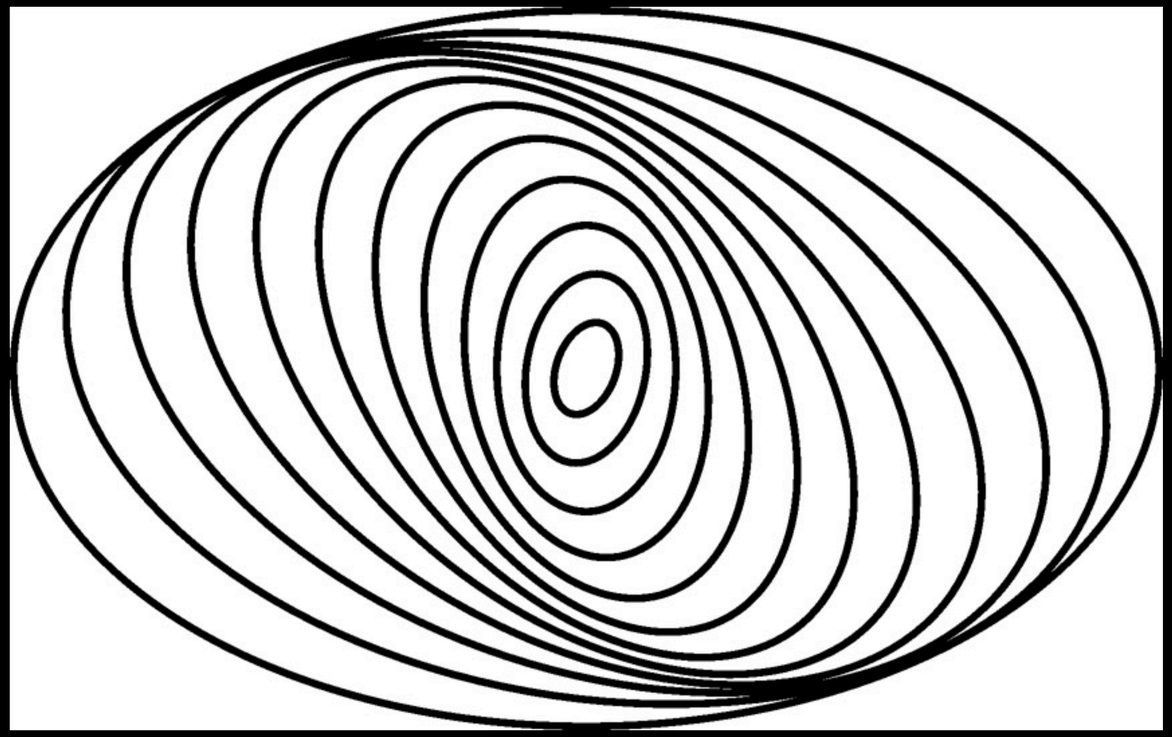
The arms of spiral galaxies are the star-making factories

Spiral Arms



Spiral arms are not “physical” parts of a galaxy, they are overdense regions of gas and stars

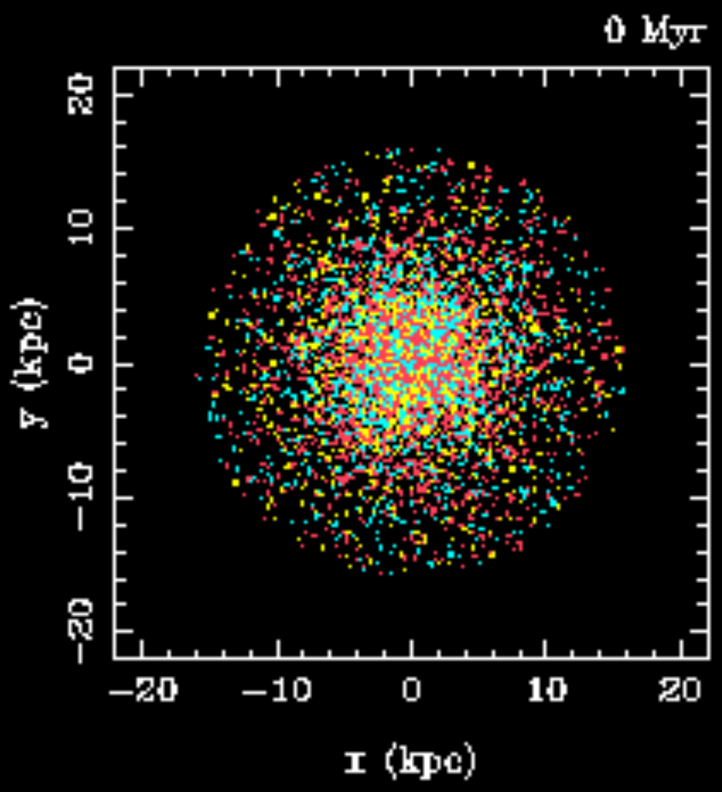
Spiral Arms



Prevailing theory: Density Waves

Because all gas and stars are orbiting the center of the Milky Way in ellipses, a lot of randomly-placed ellipses cause areas of overlap

Spiral Arms

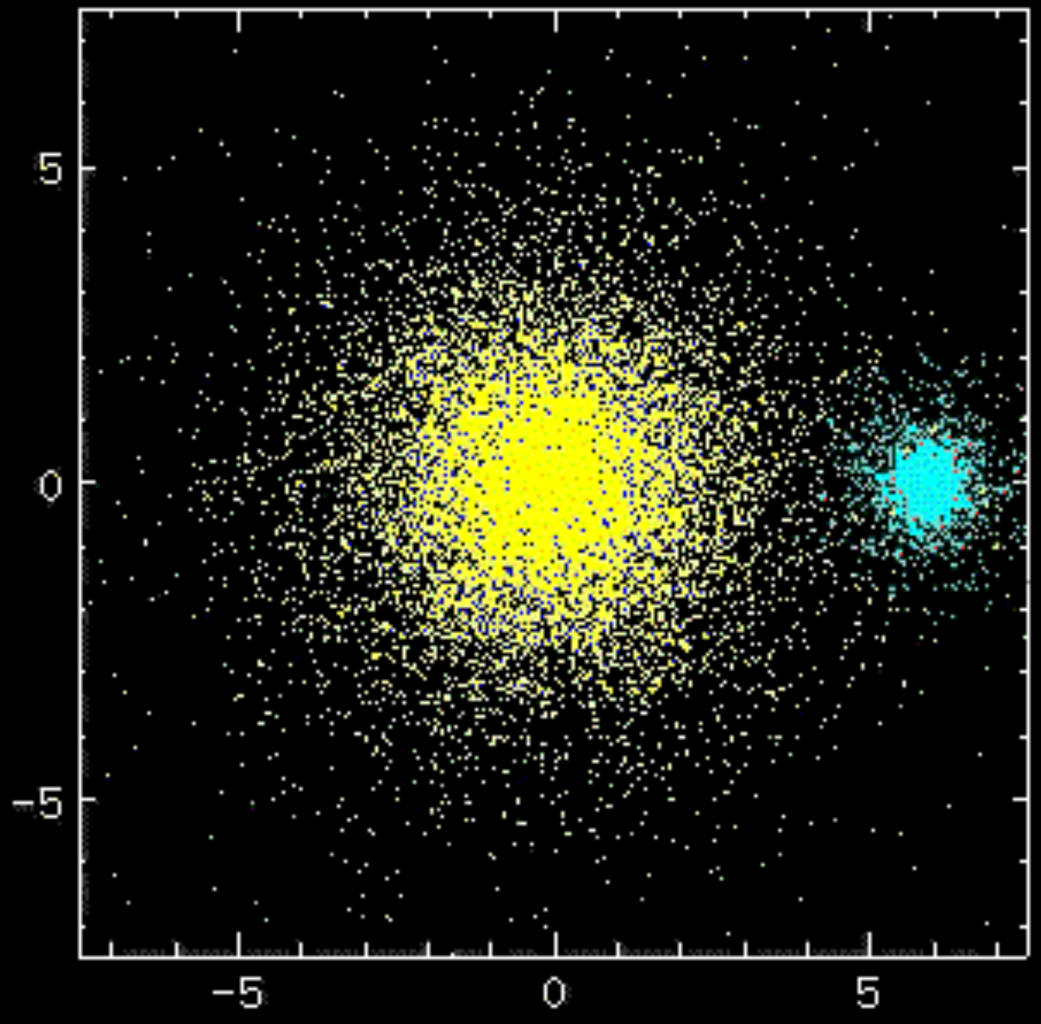


Example: spiral pattern changing over time just from star orbit shapes

-> spiral pattern changes over really long periods of time

Gif links: http://ircamera.as.arizona.edu/NatSci102/NatSci/lectures/spiralarms.htm

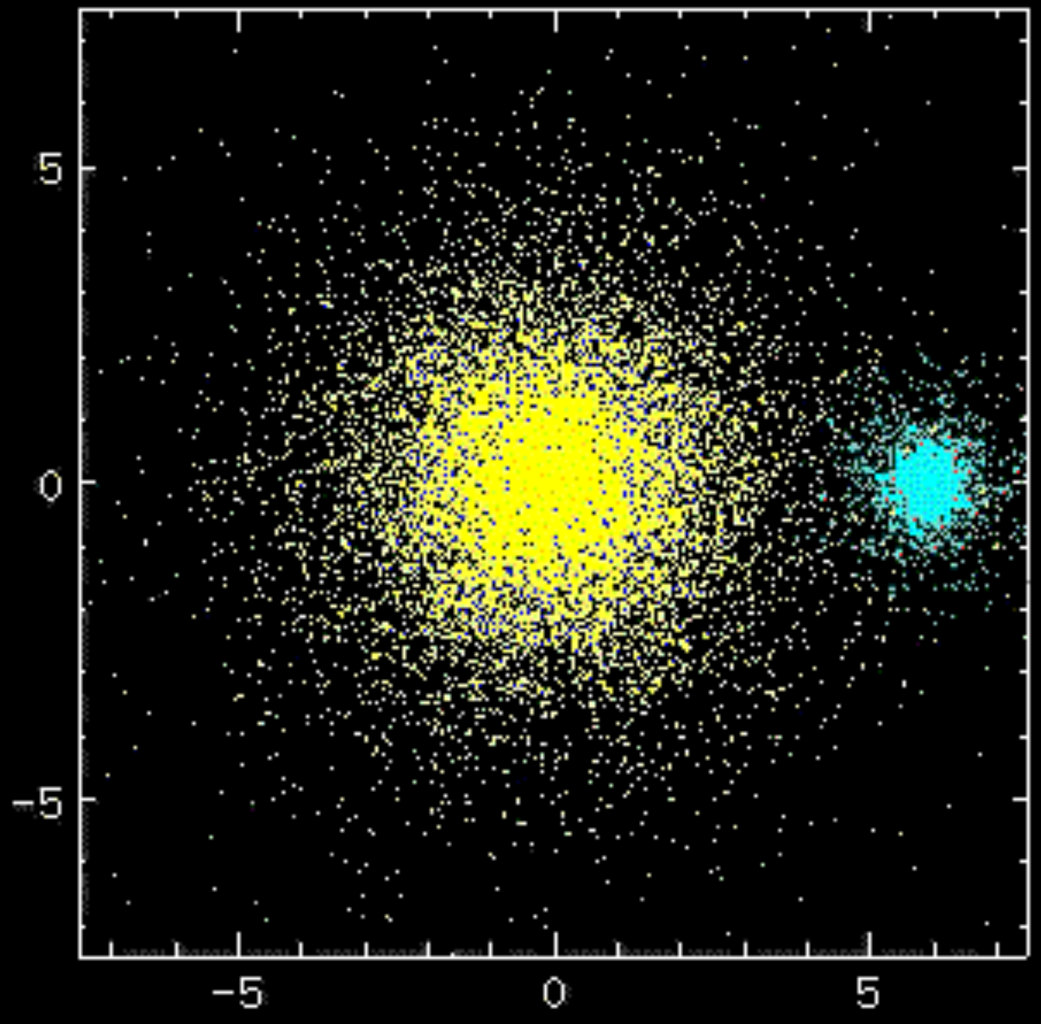
Spiral Arms



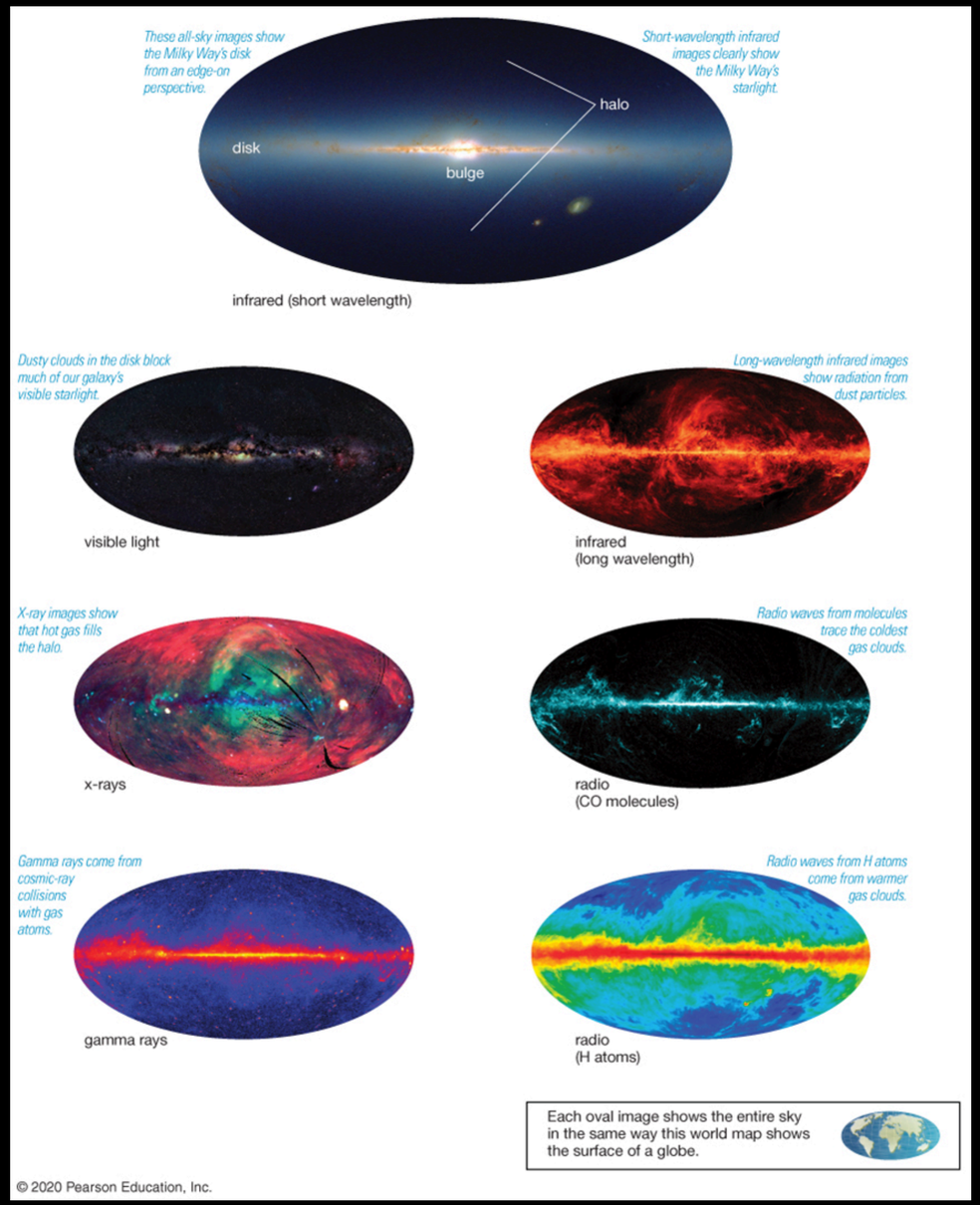
Gravity from an interacting galaxy can also induce a spiral arm pattern by disrupting stars' orbit shape

Gif links: http://ircamera.as.arizona.edu/NatSci102/NatSci/lectures/spiralarms.htm

Spiral Arms

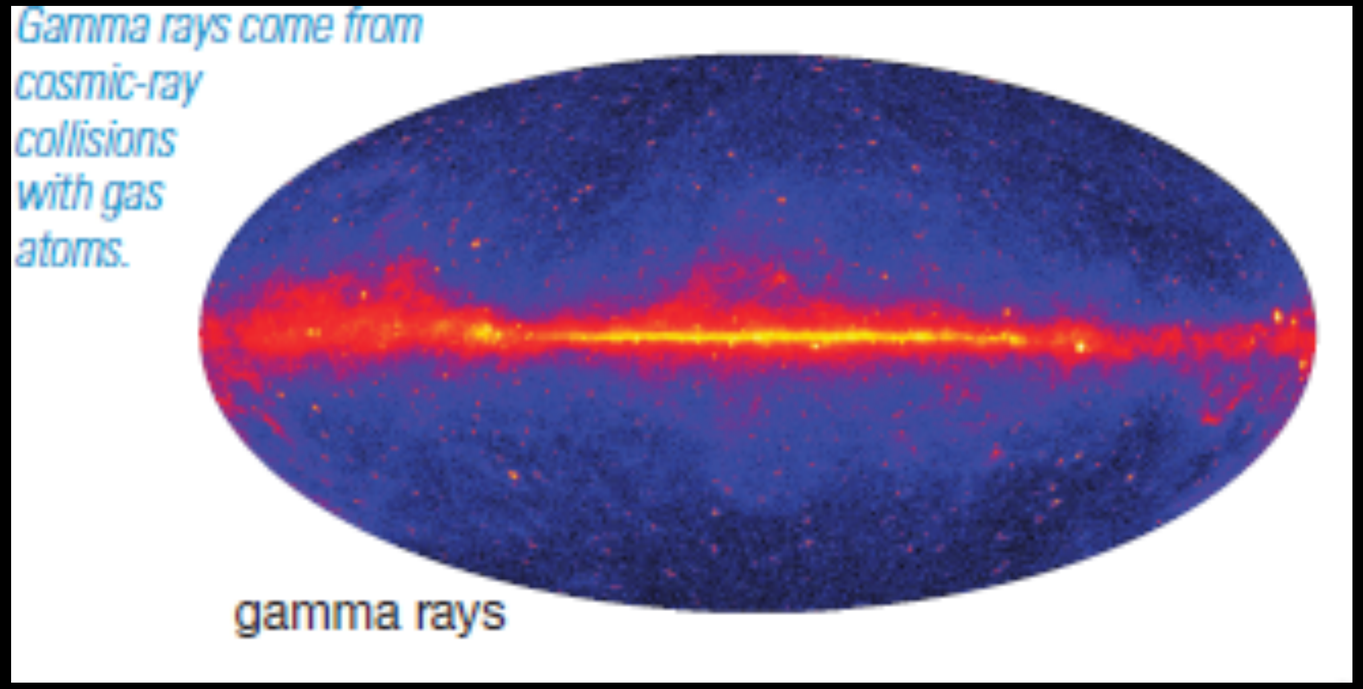


The Milky Way on the EM Spectrum



We observe the Milky Way on every wavelength regime on the EM spectrum

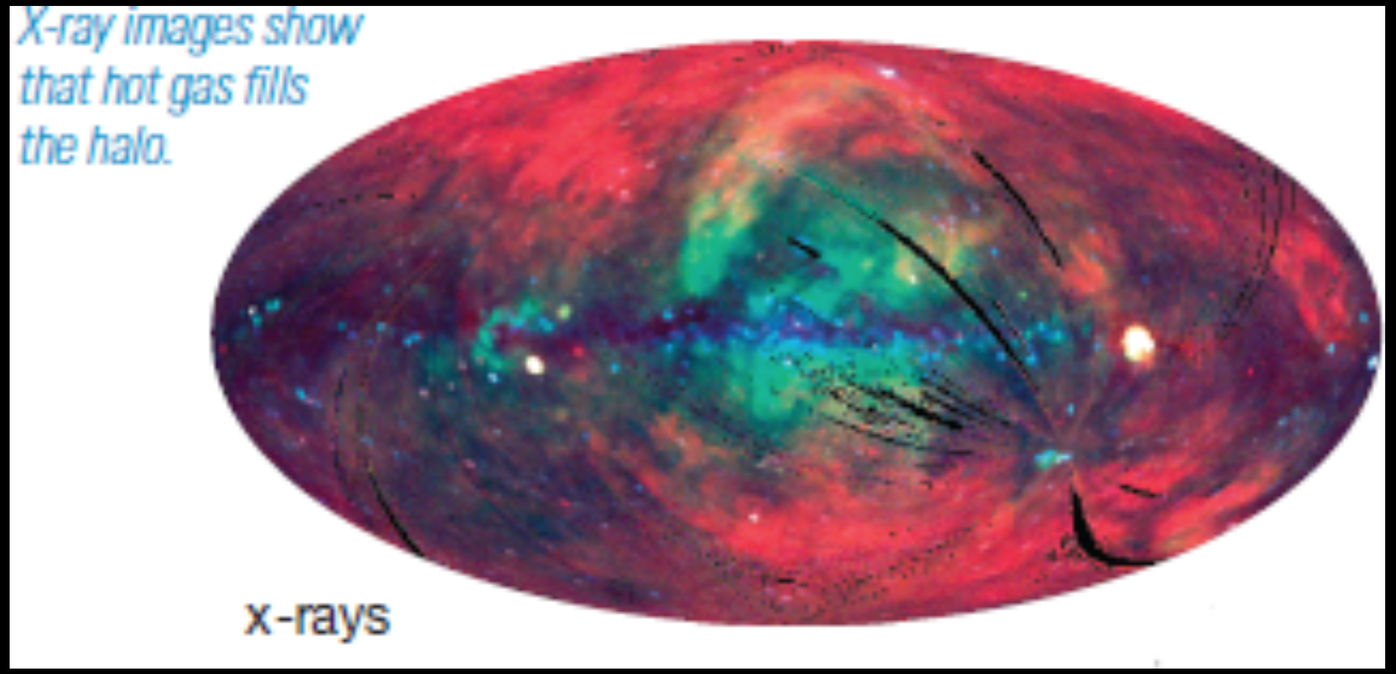
The Milky Way on the EM Spectrum



Gamma Rays

Gamma rays ($\sim 10^8$ K) are emitted from cosmic rays from supernovae colliding with atomic elements in gas clouds

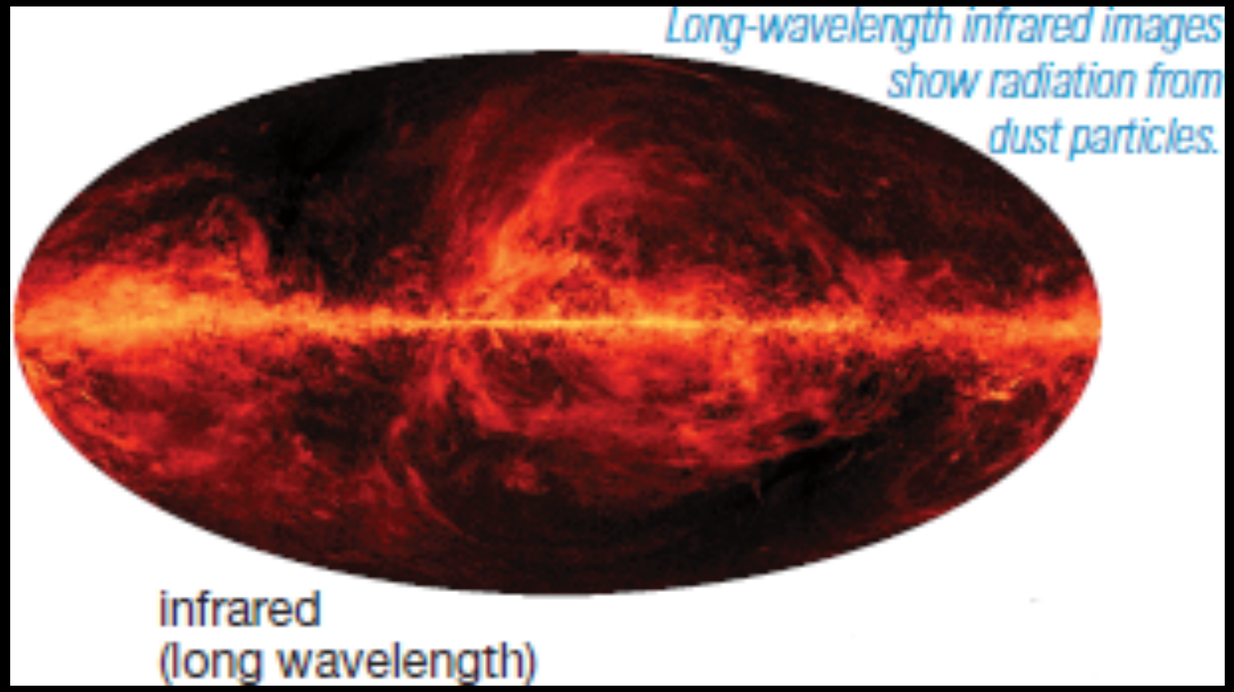
The Milky Way on the EM Spectrum

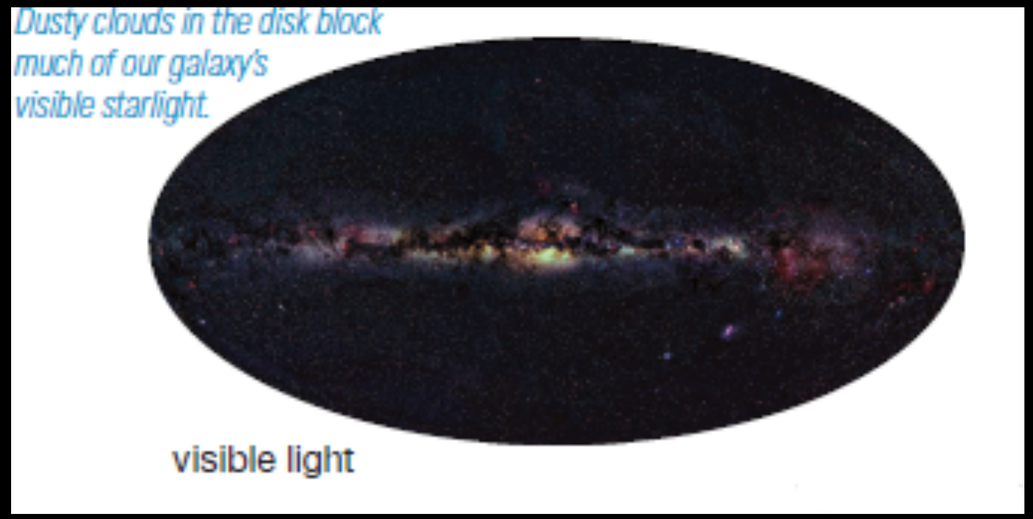


X-Rays

X-Rays are the high-powered photons (~10^7 K) emitted mostly from supernovae remnants -> reveals hot gas above and below the disk

The Milky Way on the EM Spectrum

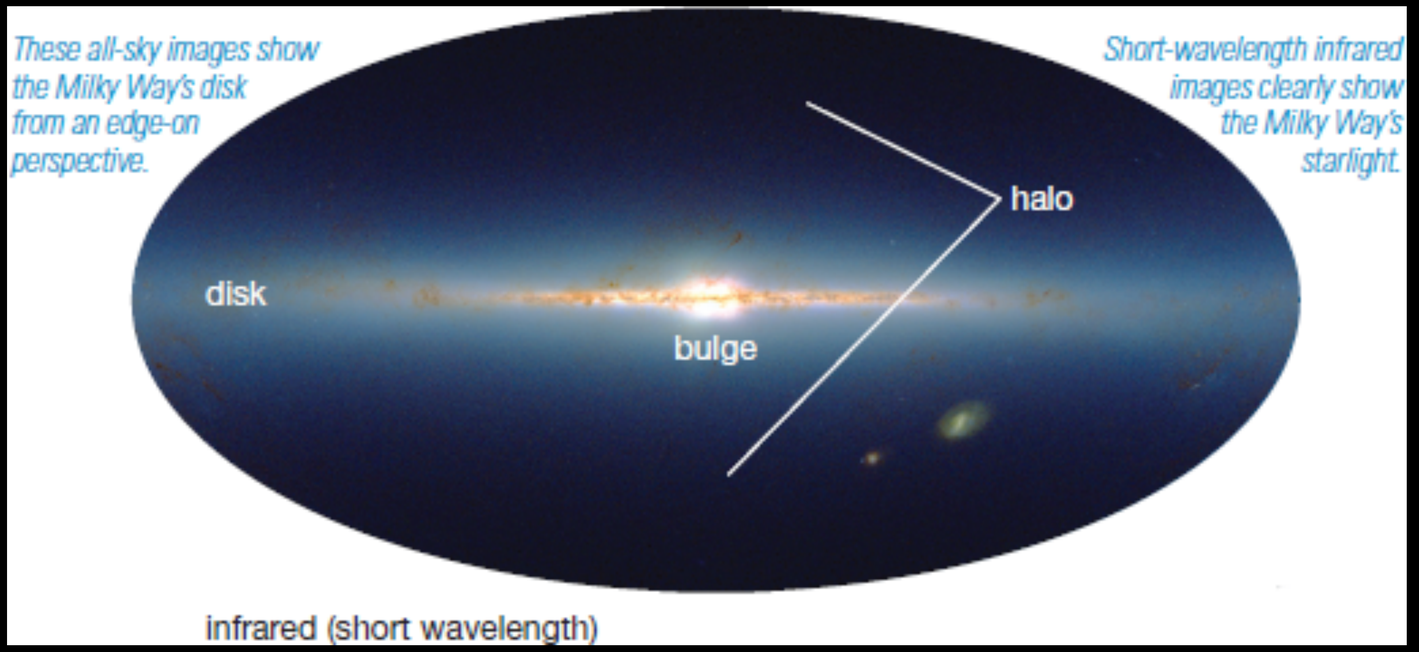




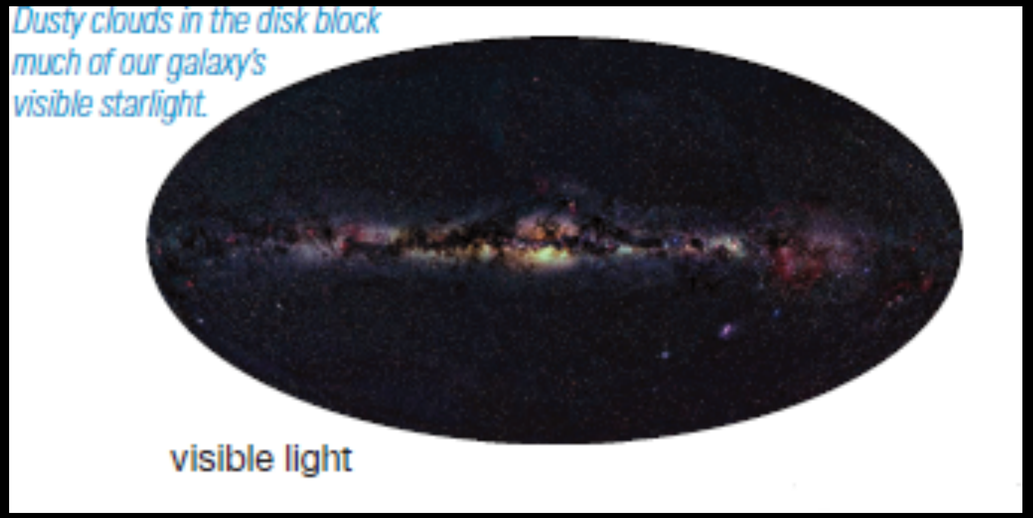
Infrared

IR (~10^3 K) traces heat, which means it shows where stars are being formed

The Milky Way on the EM Spectrum

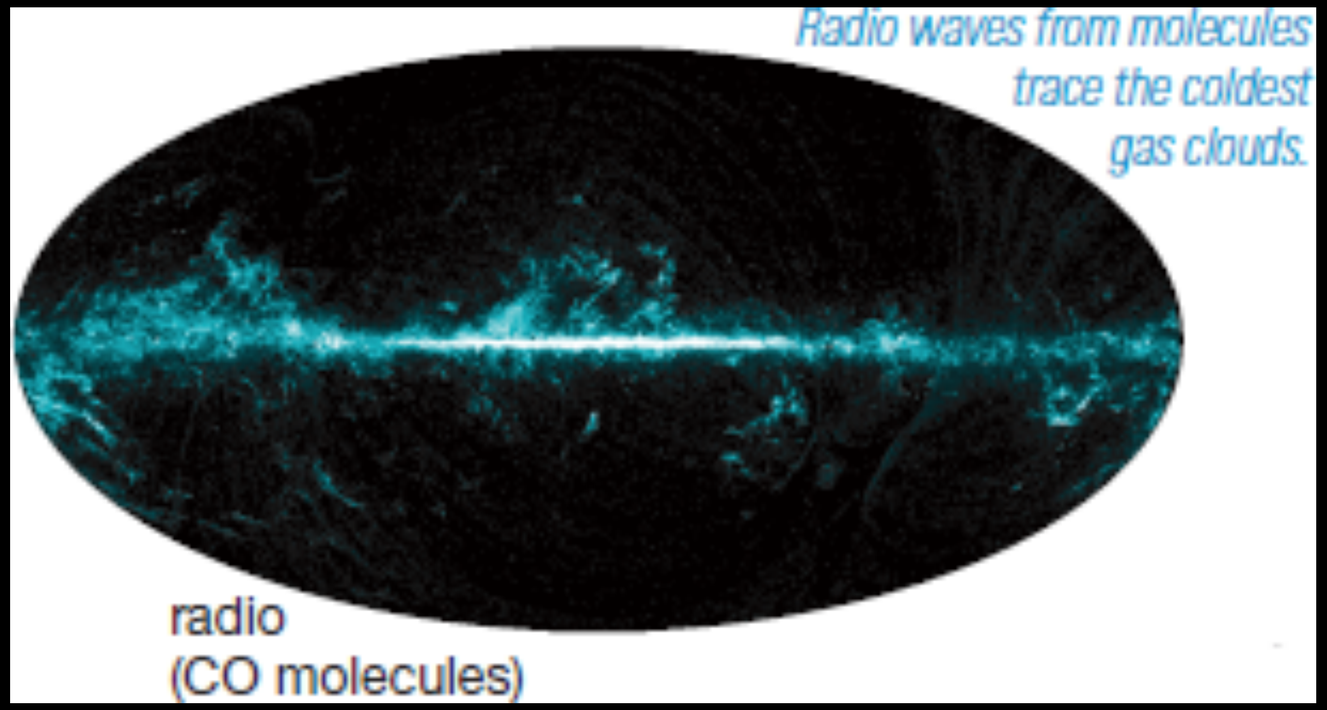


IR also reveals stars whose visible light is blocked by gas clouds which make them hidden in the optical. Why?



Longer wavelengths than optical, can penetrate farther

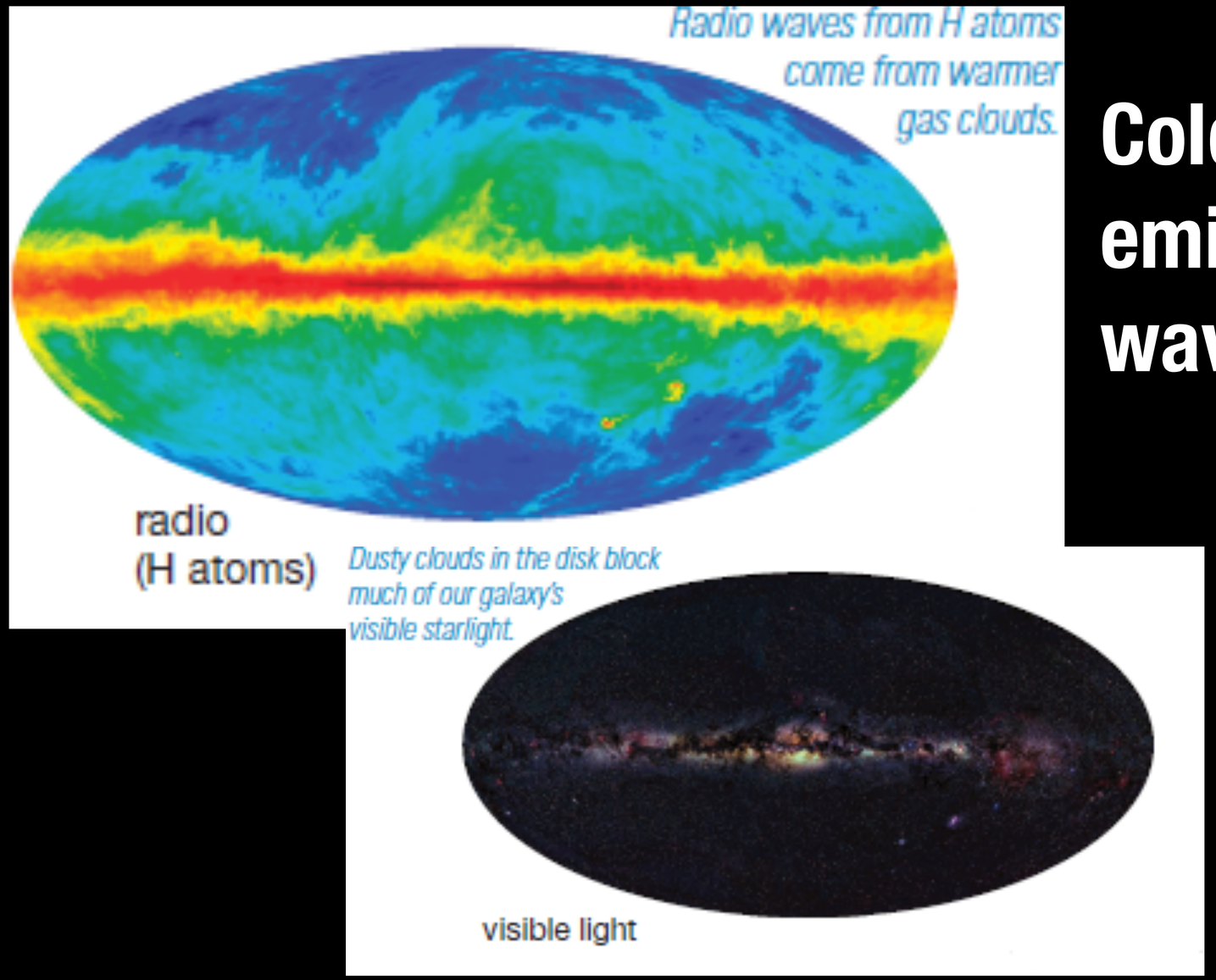
The Milky Way on the EM Spectrum



Radio

Cold carbon monoxide (CO; ~10^2 K) emits in the radio -> shows where molecular clouds are

The Milky Way on the EM Spectrum

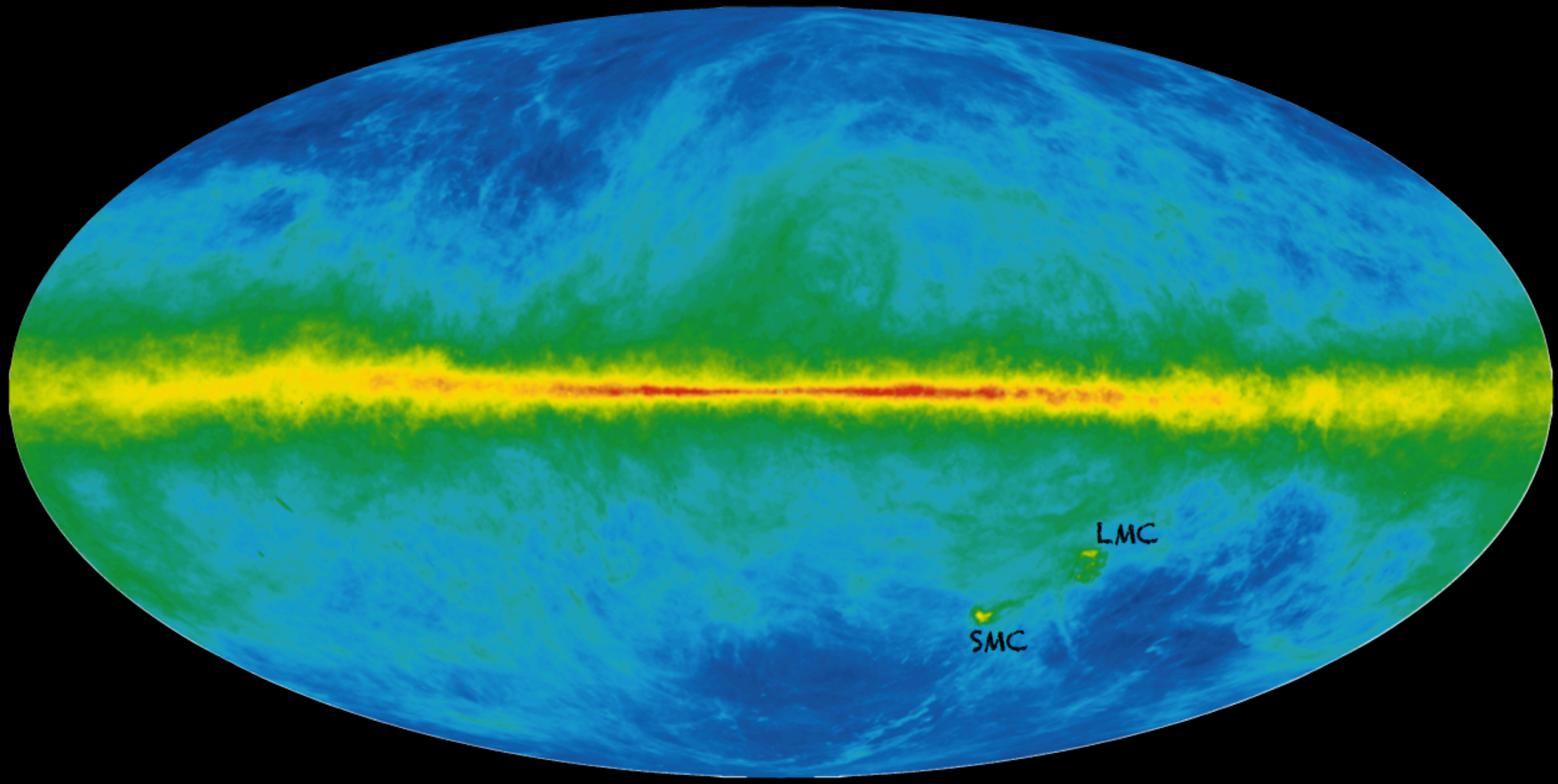


Radio

Cold atomic H (HI; ~10^1-10^2 K) emits in the radio at 21cm wavelength

Most abundant element means HI 21cm is one of <u>the</u> dominant sources of emission in gas-dominated galaxies (including MW)

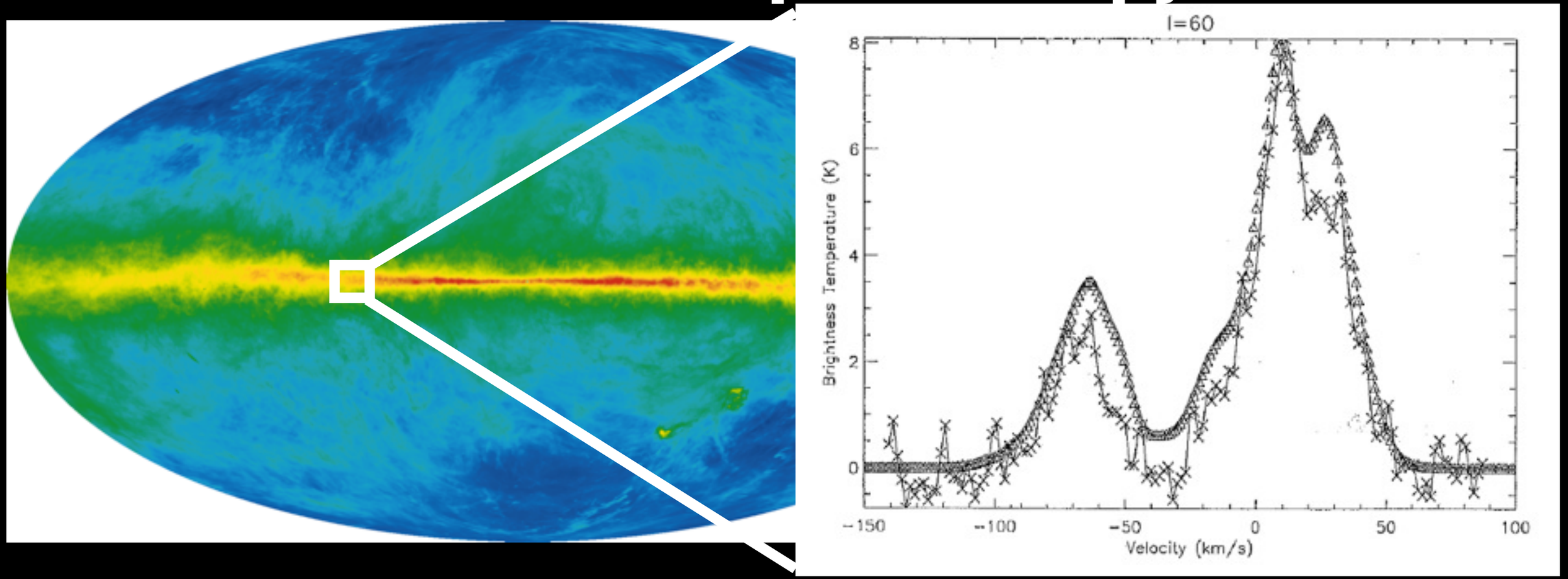
HI 21cm Emission



- colored patches map detection of 21cm emission from the MW; disk has highest concentration -> how the rest of the disk of the MW is mapped

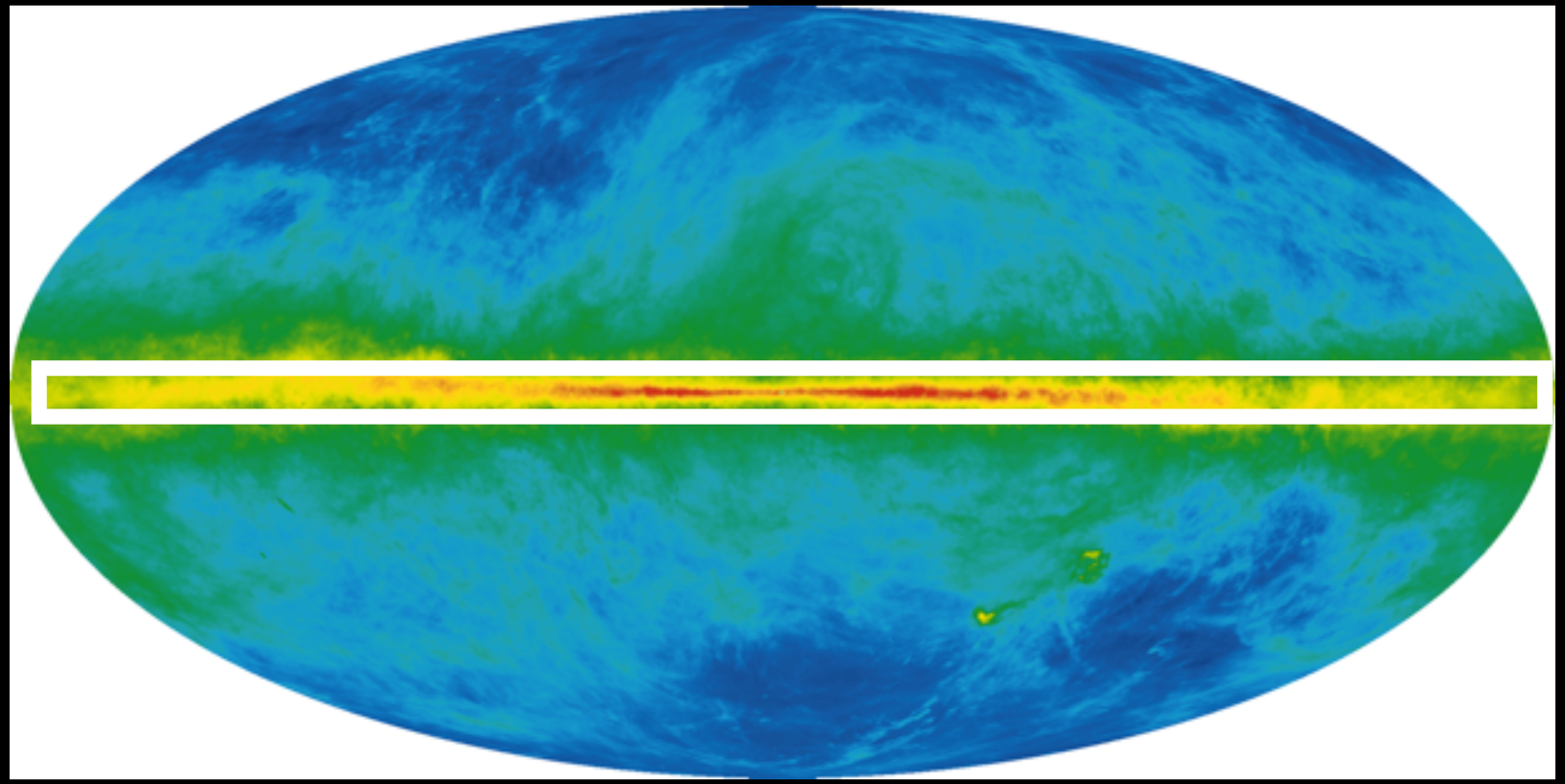
- also traces HI clouds in the ISM as well as the Large and Small Magellanic Clouds

HI 21cm Spectroscopy



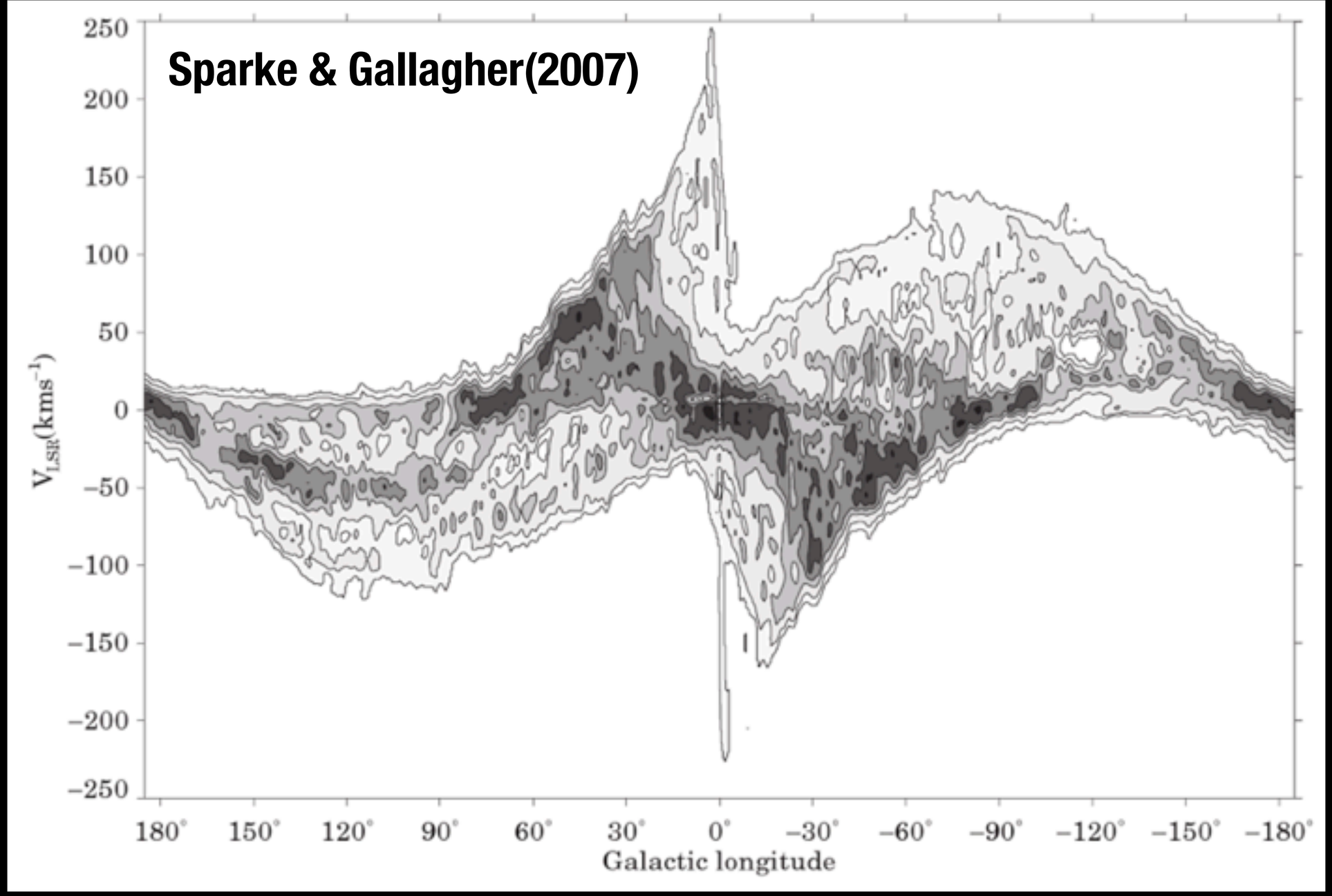
More useful: Spectroscopic analysis. HI emission has a very specific λ, we can detect the radial velocity (motion along the line of sight of the observer) of the emitting gas by measuring its redshift or blueshift relative to its rest wavelength (λ= 21cm)

HI 21cm Spectroscopy



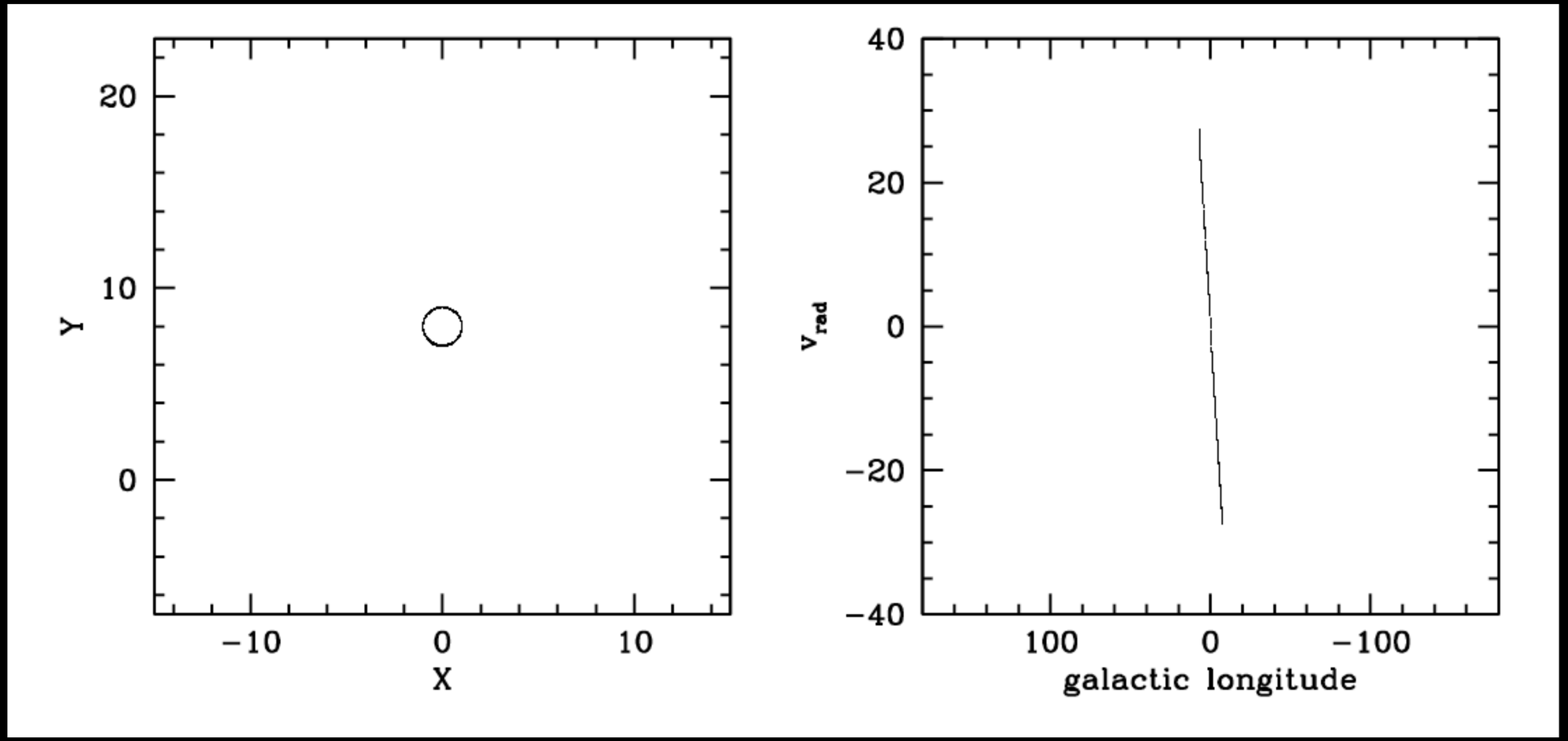
HI 21cm is optically thin: probability of photons getting absorbed is very low. Not the same for warmer emitters (especially optical)

So: we're able to map the entirety of the disk using 21cm radiation because we can detect it ~everywhere in the disk (can't do it with warmer emitters, some are blocked or absorbed)



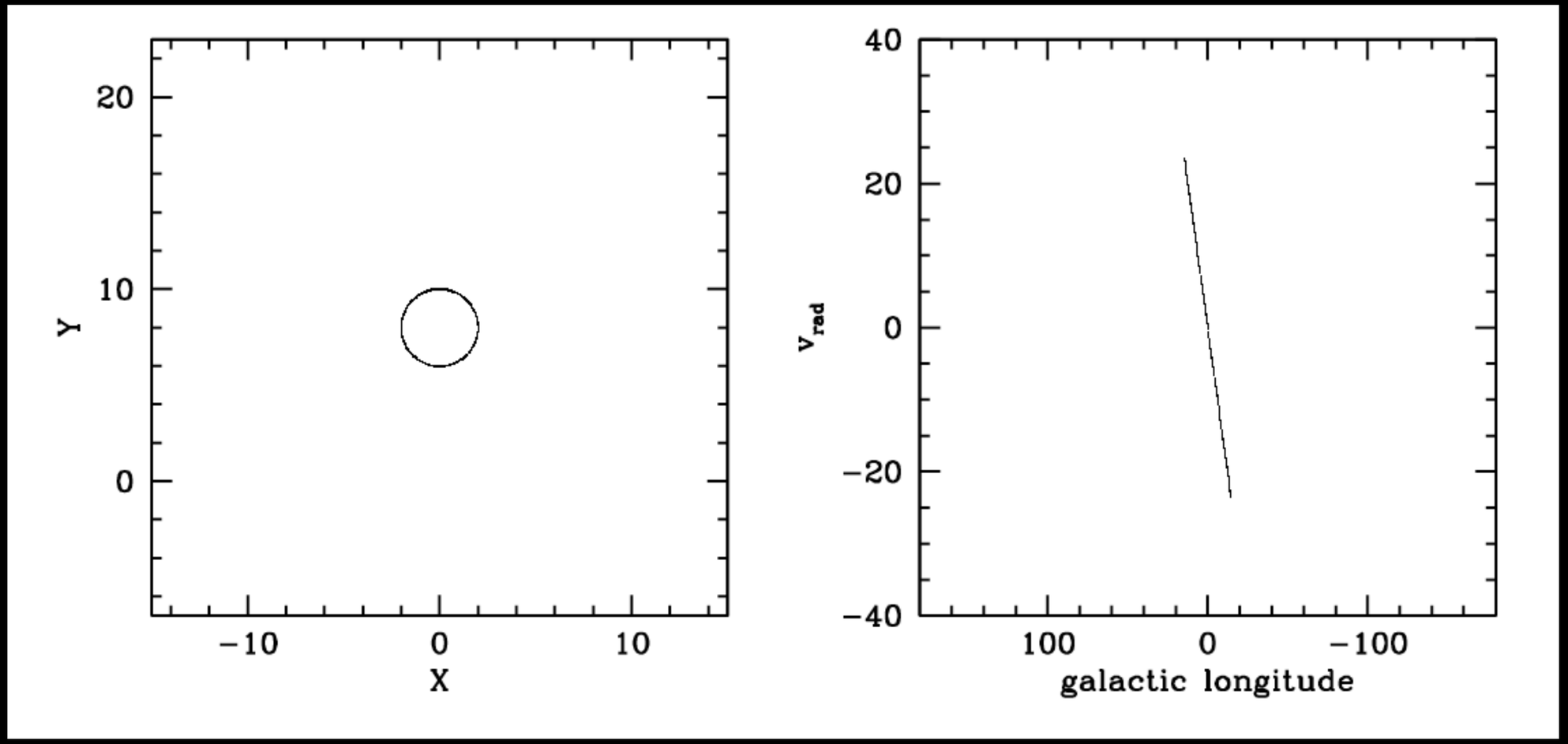
What does this graph tell you?

Simplified Differential Rotation



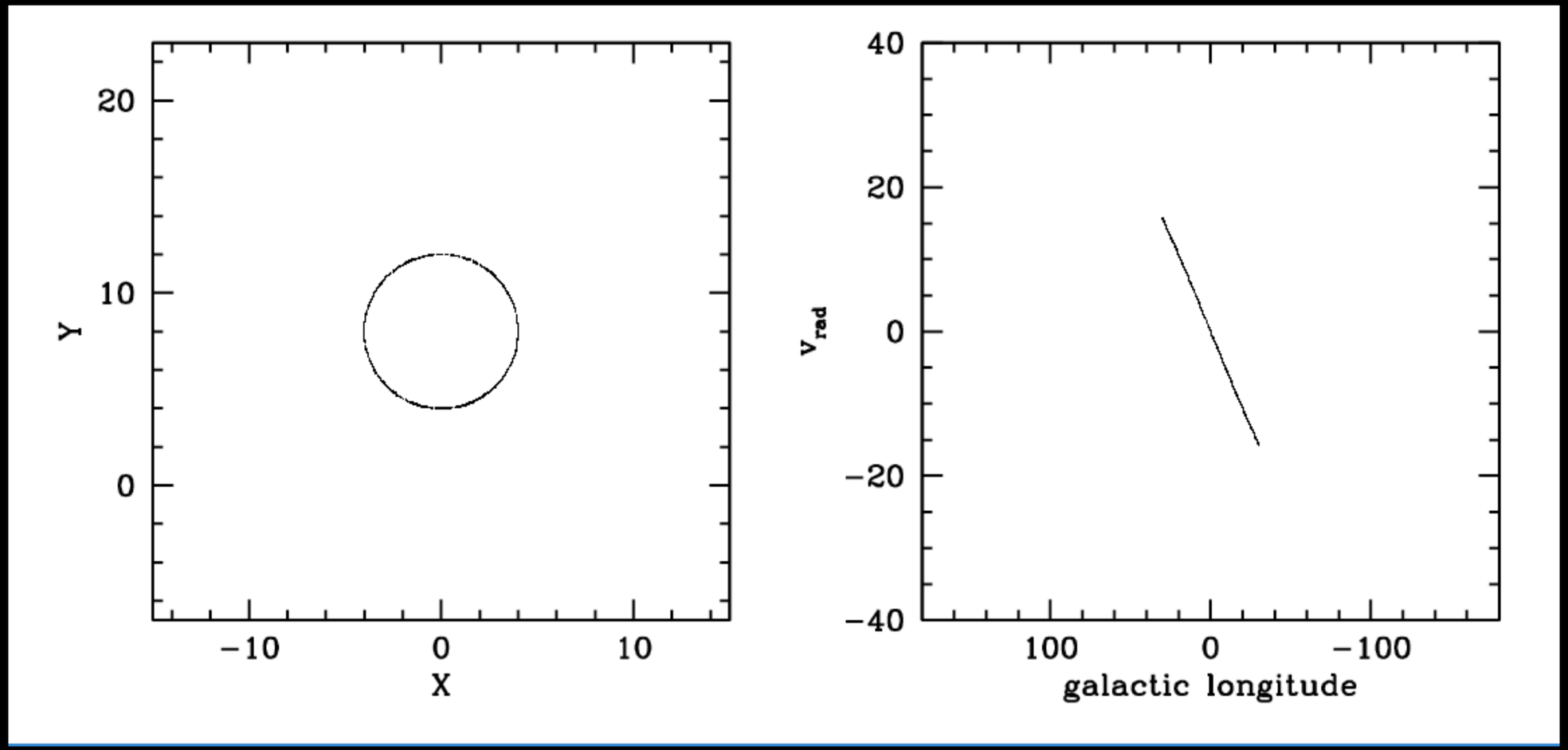
Left: test gas particles lying on a circle of radius R = 1 Kpc observed relative to a point (at X=0,Y=0) denoting the location of the Sun. Right: observed radial velocity as a function of Galactic longitude for these test particles.

Simplified Differential Rotation



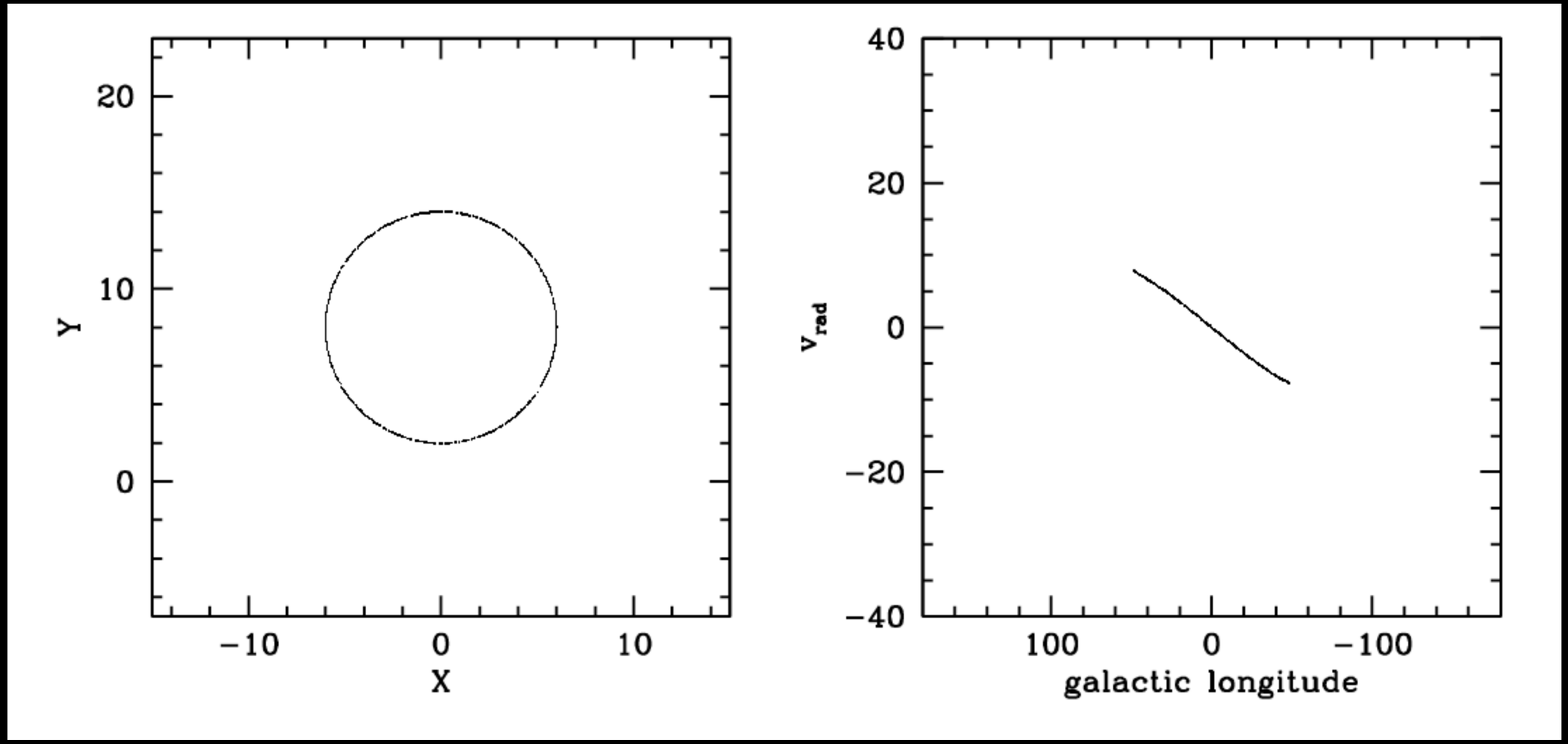
Same as previous plot, but now for gas particles at R = 2 kpc

Simplified Differential Rotation



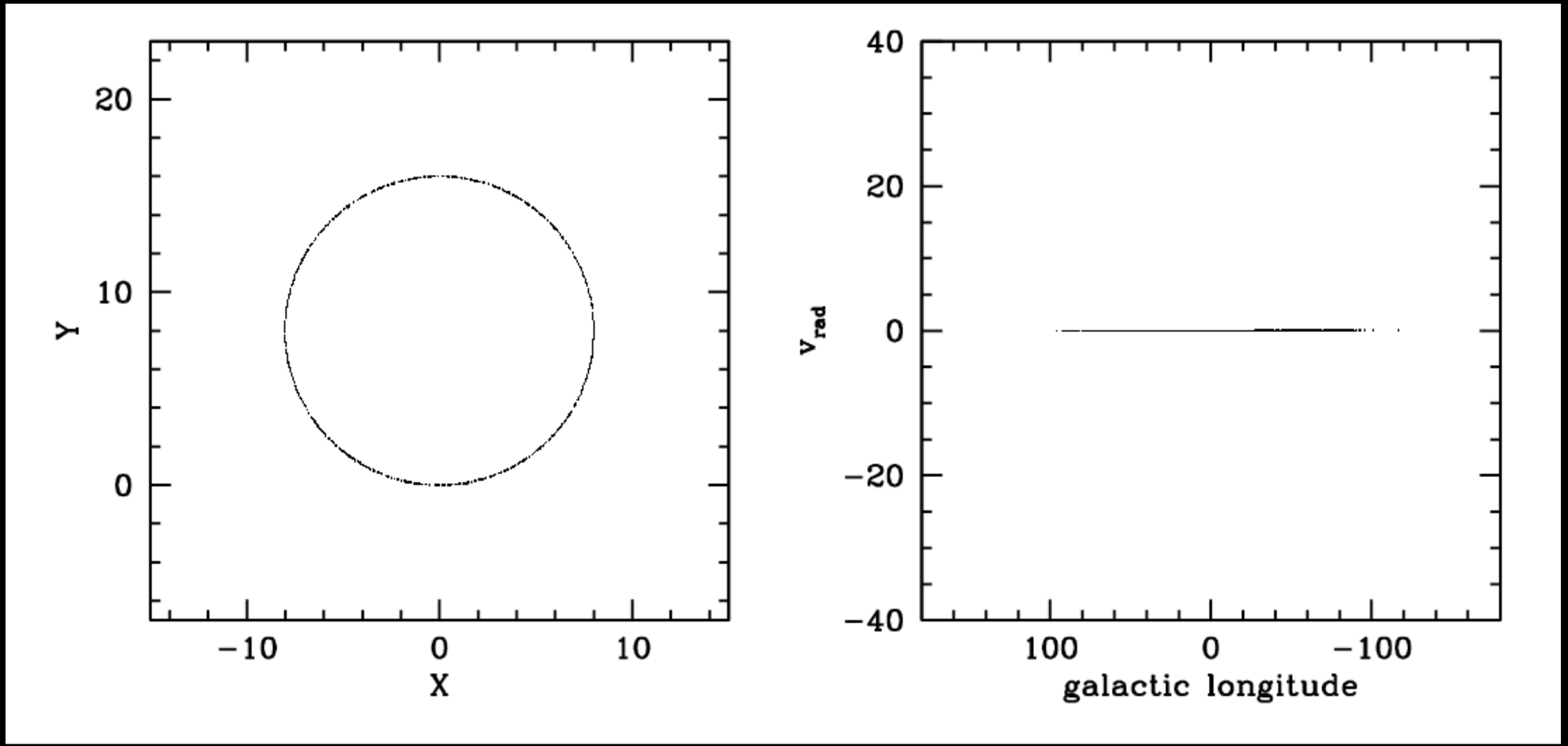
Same as previous plot, but now for gas particles at R = 4 kpc

Simplified Differential Rotation



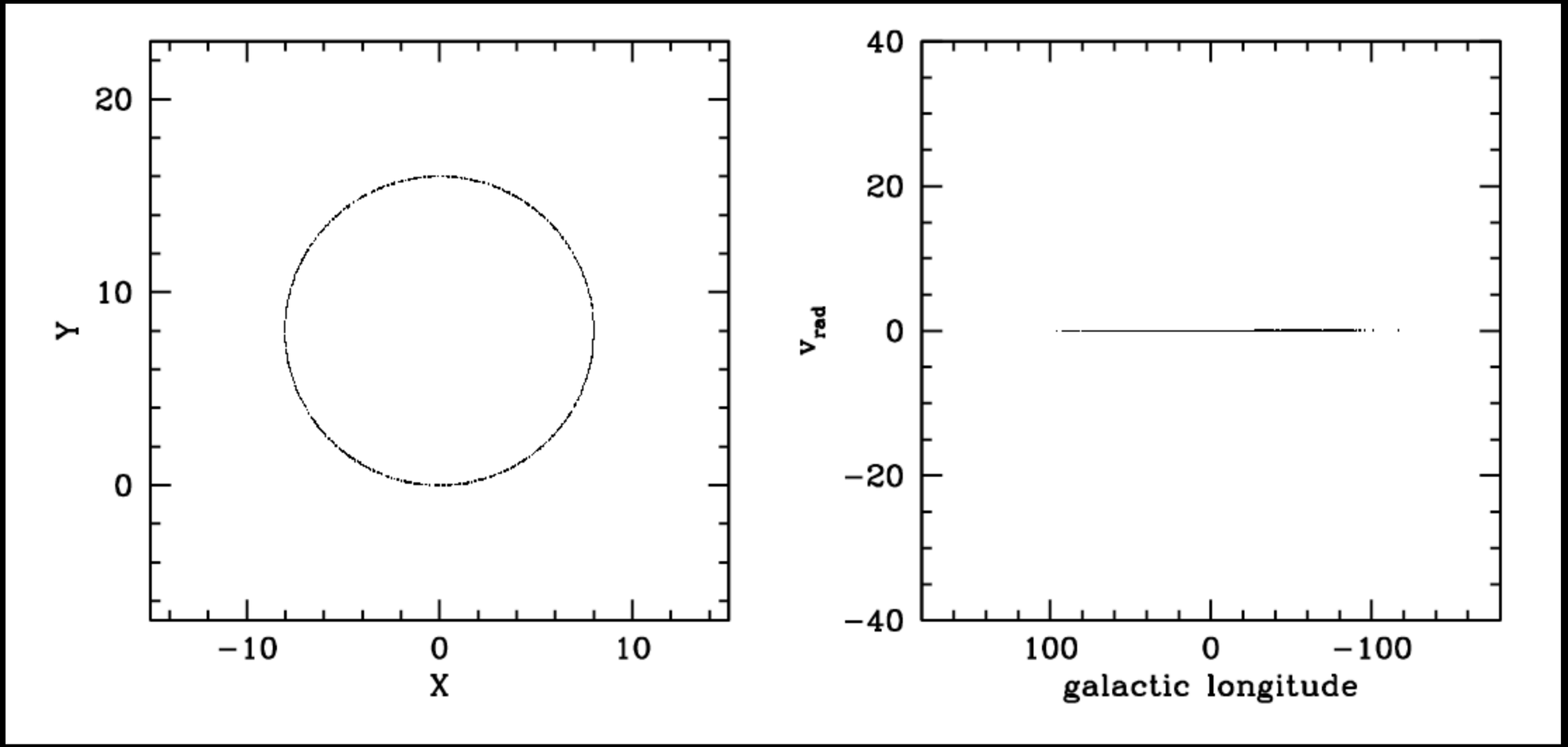
Same as previous plot, but now for gas particles at R = 6 kpc

Simplified Differential Rotation



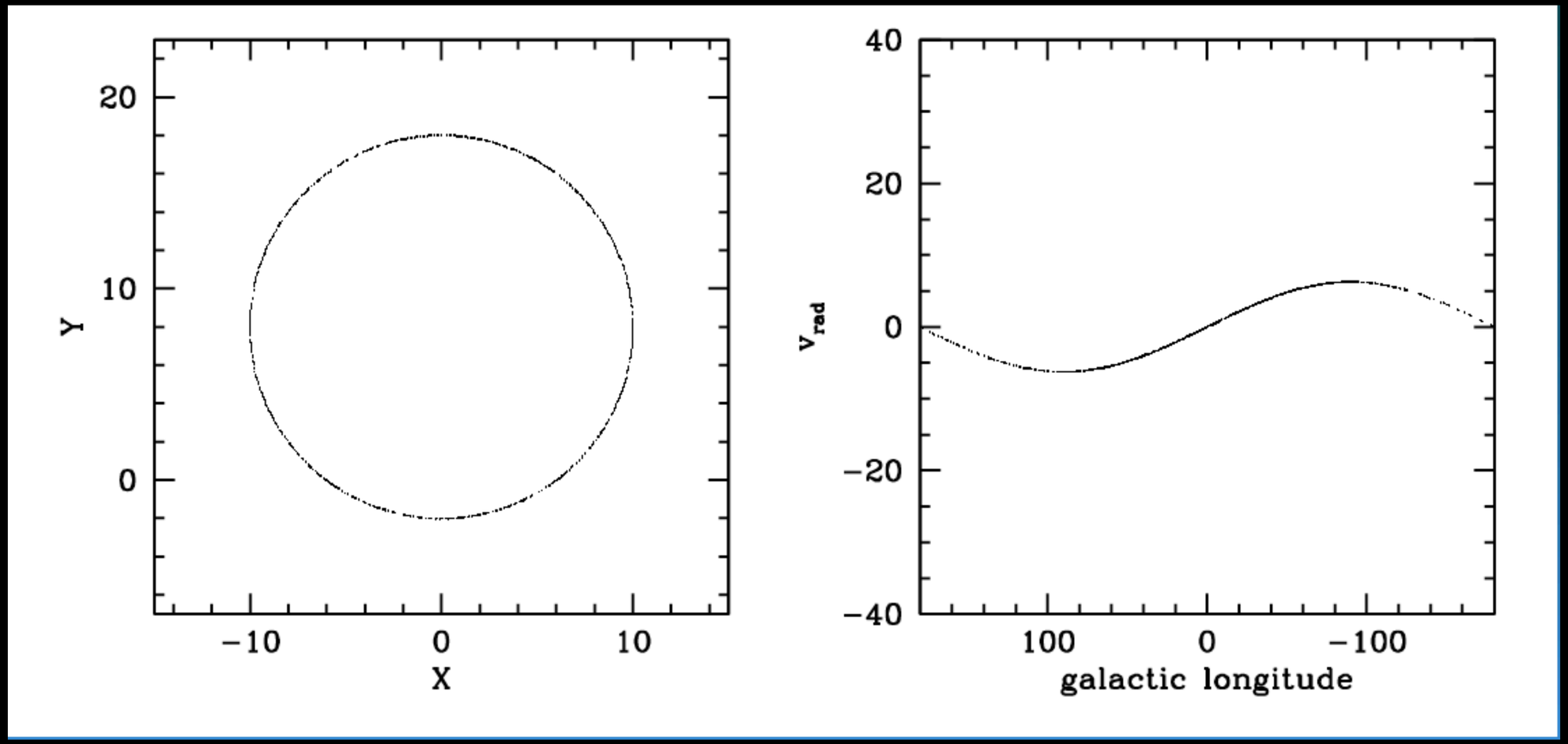
Same as previous plot, but now for gas particles at R = 8 kpc. Why are no radial velocities detected?

Simplified Differential Rotation



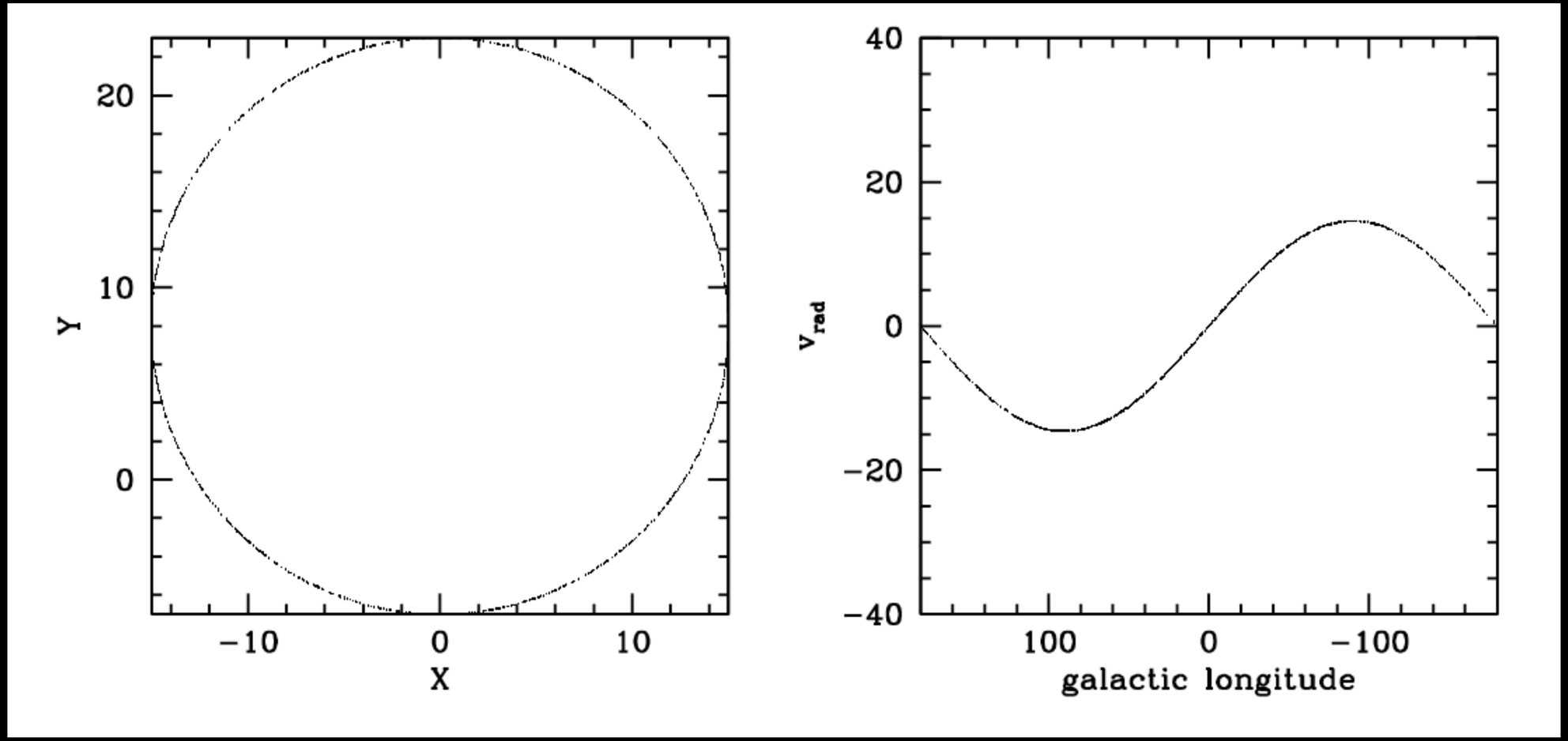
These particles are located on the Solar circle (same distance from the Galactic center as the Sun). In this simplified example (uniform distribution, perfectly circular orbits, etc), all particles move with the Sun at the same rotation speed, so no relative motion is detected (close enough to reality)

Simplified Differential Rotation



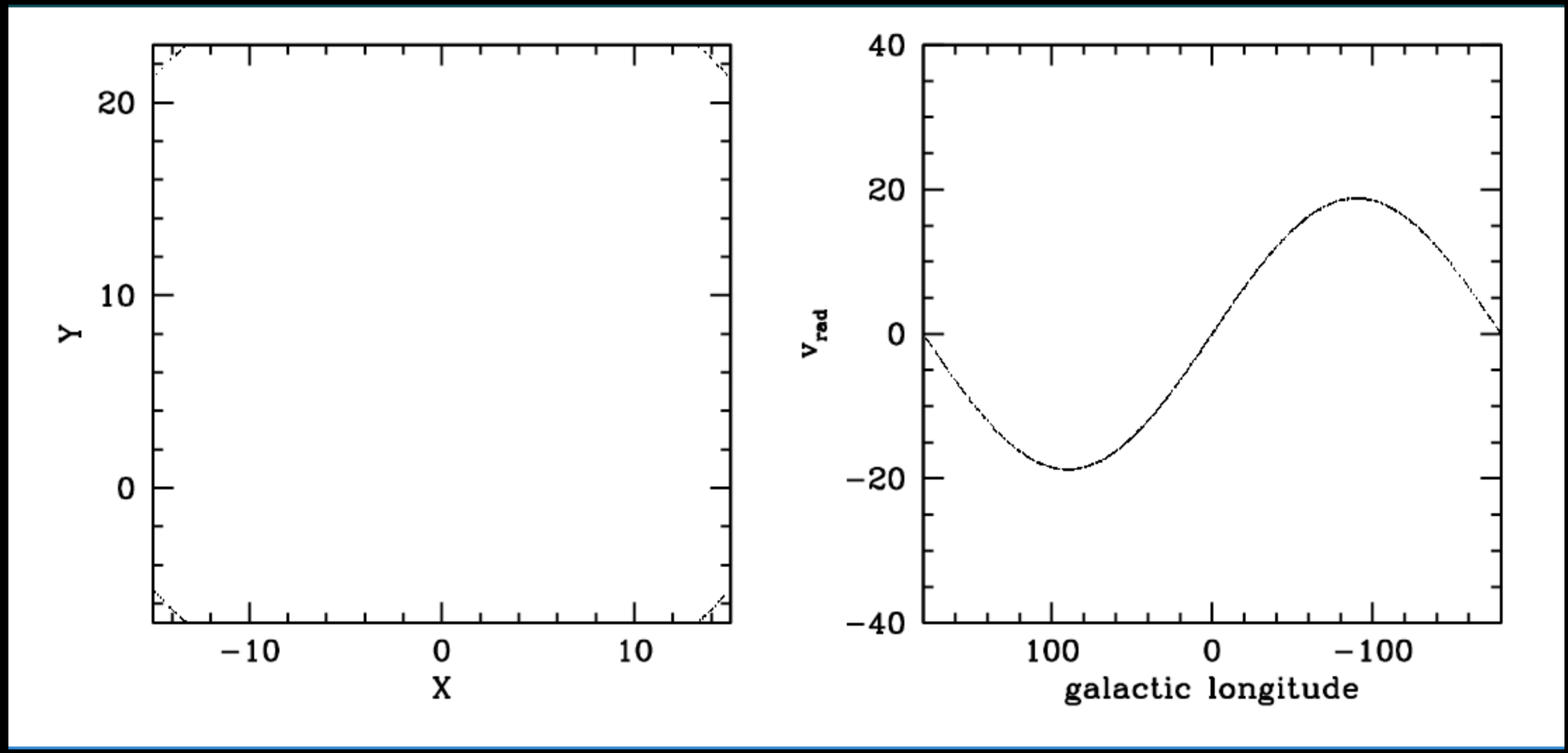
Same as previous plots, but now for gas particles at R = 10 kpc. What does this graph tell you?

Simplified Differential Rotation



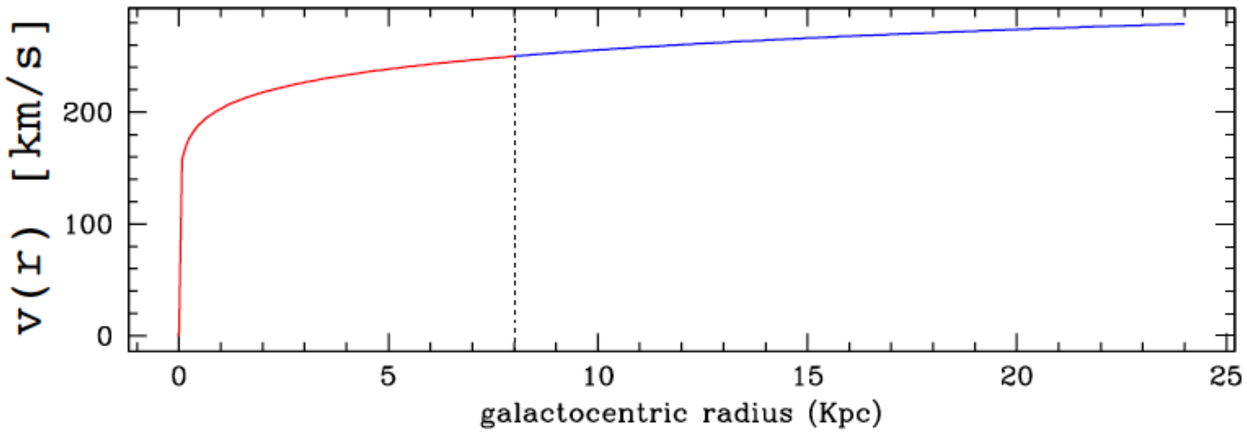
Same as previous plots, but now for gas particles at R = 15 kpc

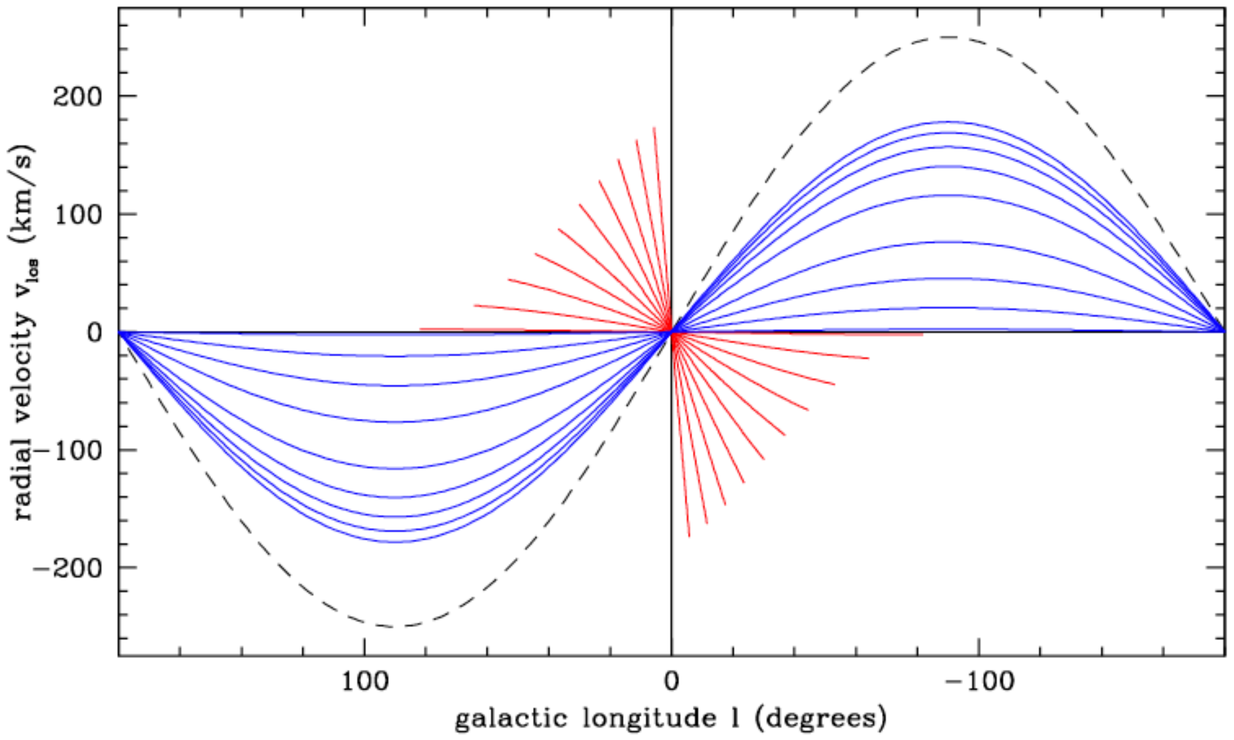
Simplified Differential Rotation



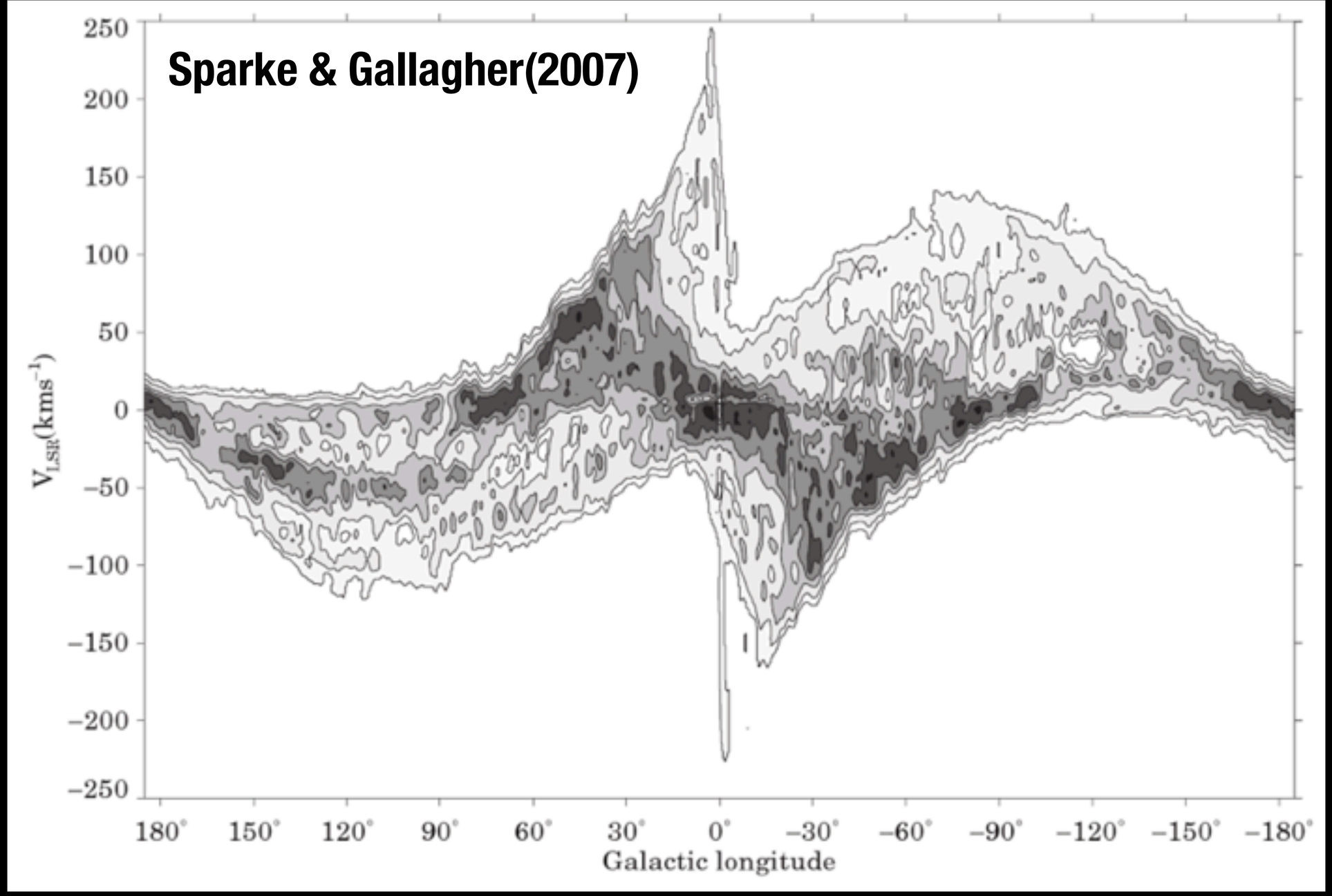
Same as previous plots, but now for gas particles at R = 20 kpc

Simplified Differential Rotation



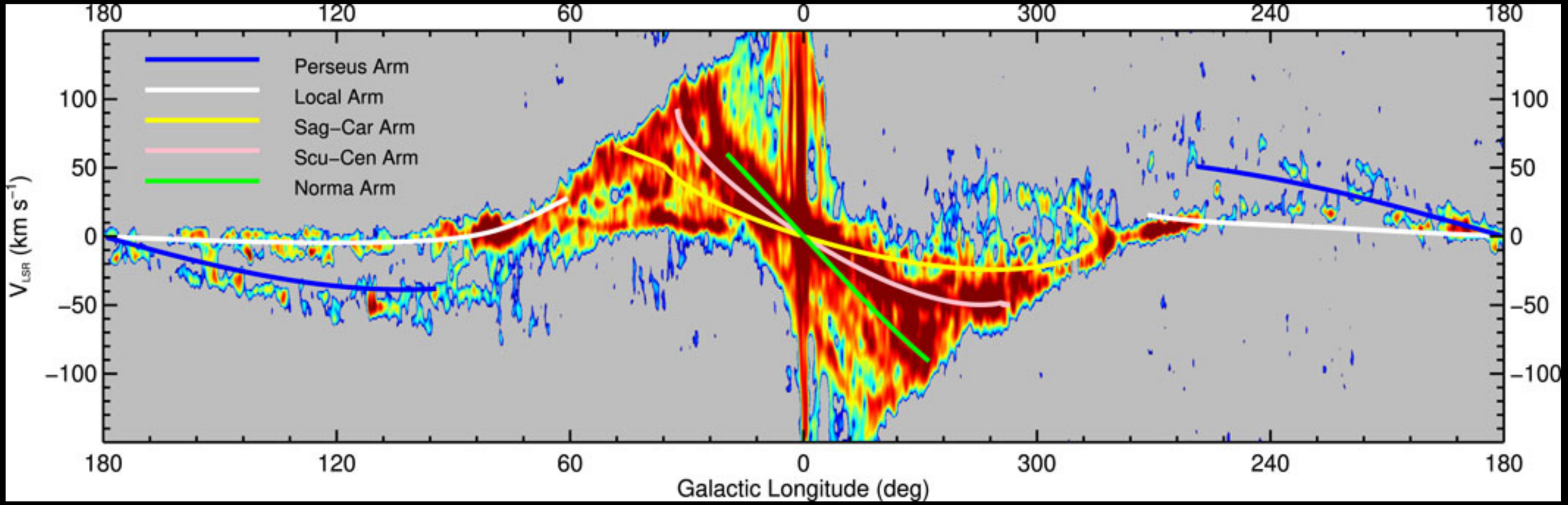


All together: emission for gas particles orbiting along circles at different distances from the Galactic center. Those with orbits inside the Solar circle are shown in red, those outside in blue.



What are the over-dense regions?

HI 21cm Spectroscopy



Those are the arms of the MW! (over-dense regions of gas compared to regions in-between spiral arms)