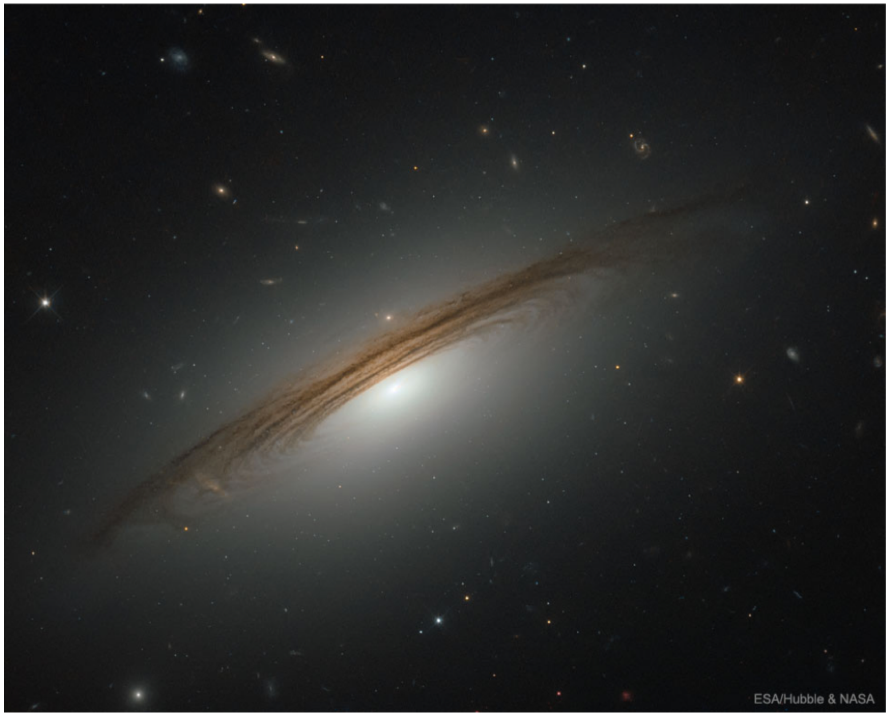
[12] The Milky Way (3/8/18)

Upcoming Items

1. Read Ch. 19.2–19.3 for next class and do the self-study quizzes.
2. Also read darkmatter.pdf in Files->derivations
3. Advance notice: please read probability.pdf, then read statistics.pdf (Files->derivations) for next Thursday
4. Homework #3 due next Tuesday, March 13.

APOD 3/7/17: UGC 12591 (rapidly rotating galaxy)

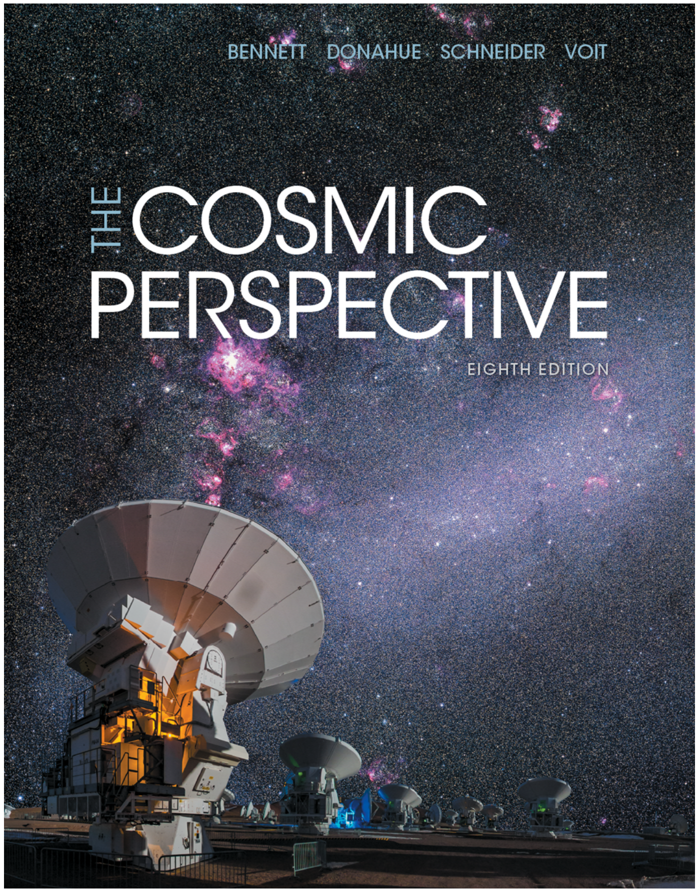


LEARNING GOALS

Ch. 19.1

For this class, you should be able to…

- … *describe the main differences between disk stars and halo stars and the primary reason for these differences;*
- … *explain how the rotation curve of the Milky Way is measured and use the result to predict the orbital speed as a function of orbital distance for objects in the galaxy.*



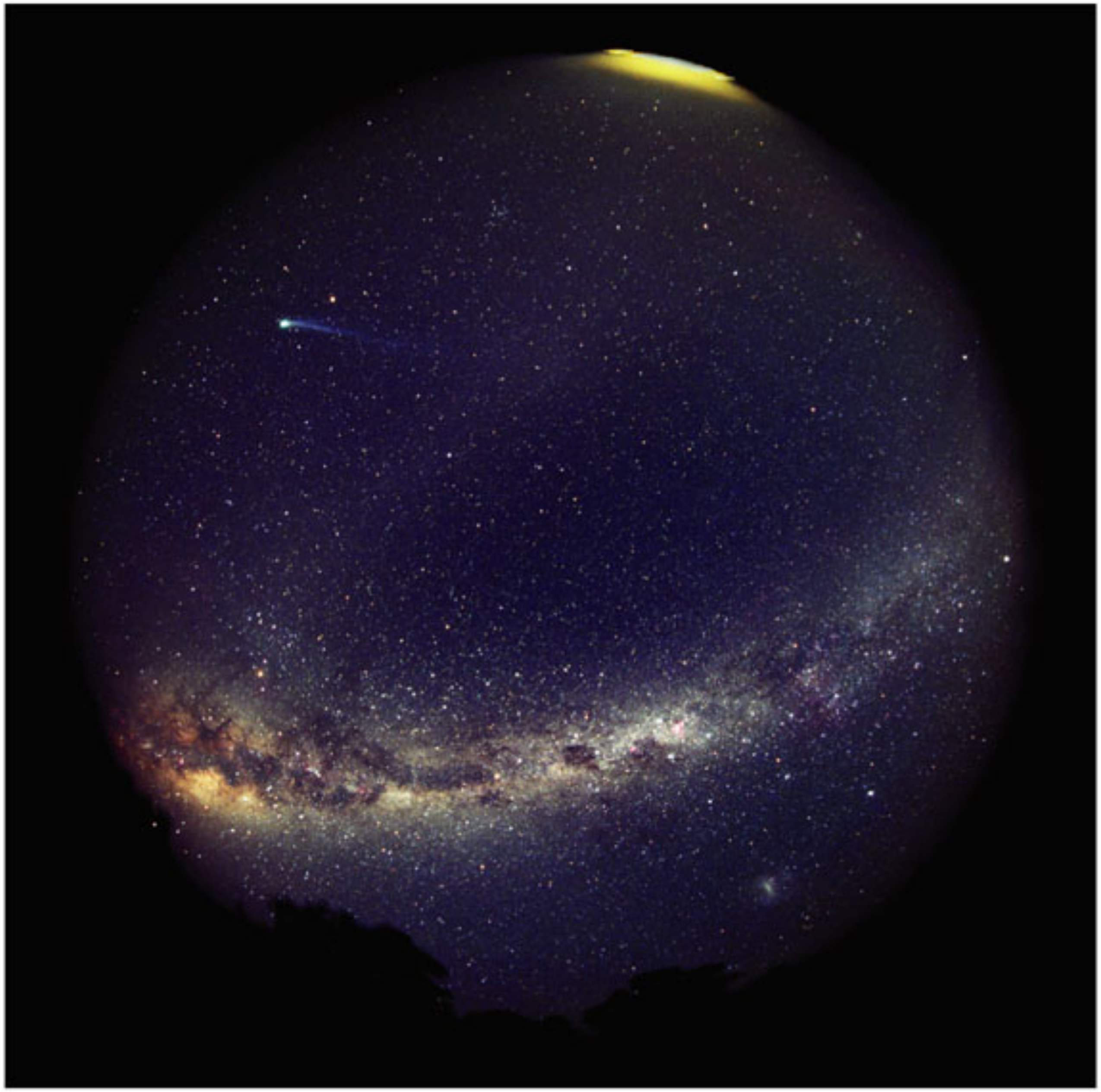
Results of Midterm #1

- Class average was 101/150=68%
- Toughest exam you've had so far, but not out of the ordinary for this course
- Remember: we will curve the final letter grade at the end of the course; thus even if you didn't do as well as you'd hoped, it's not a big deal
- Problem #5 presented the most trouble. In particular, the use of calculus here was not clear to many, and this was also true of the similar use of calculus in Homework #1
- Let's go over some of the relevant principles; this technique is very useful in astrophysics!

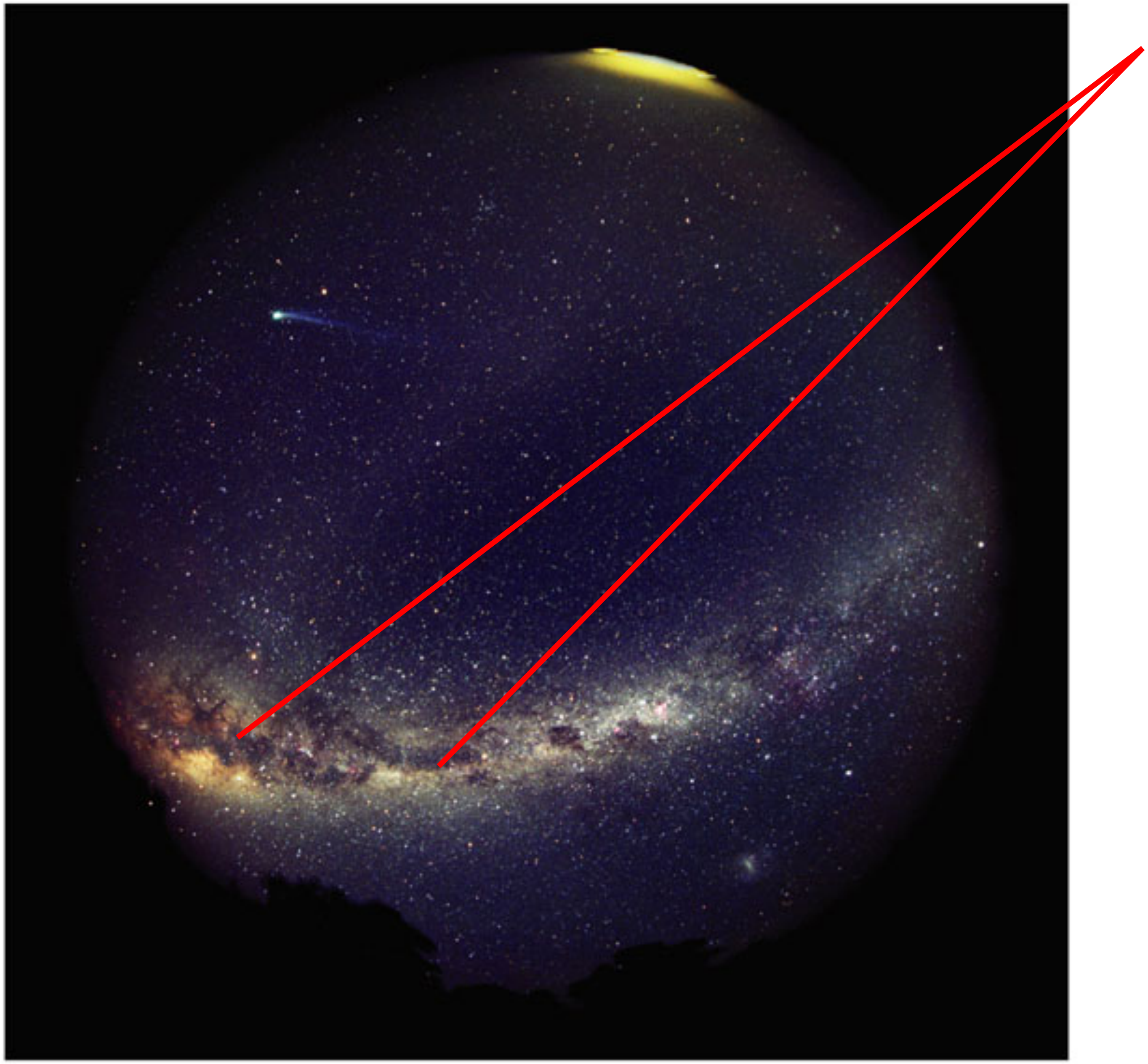
Any astro questions?

The Milky Way

- **The disk:** We live in the disk of a (barred) spiral galaxy, about halfway out from its center. Disk is ~30 kpc across.
  - Disk material rotates in an orderly way.
  - Present-day star formation happens here (Population I stars).
  - Neutral hydrogen gas is concentrated in **spiral arms** in the disk…more about this next class.
- **The halo:** The disk is surrounded by a spherical halo of very old stars (many in globular clusters) and dark matter.
  - Halo (Pop. II) stars have random orbits about the galactic center.
- **The central bulge:** There is a spherical concentration of old stars, also with random orbits, at the center of our galaxy. At the very center is a supermassive black hole…



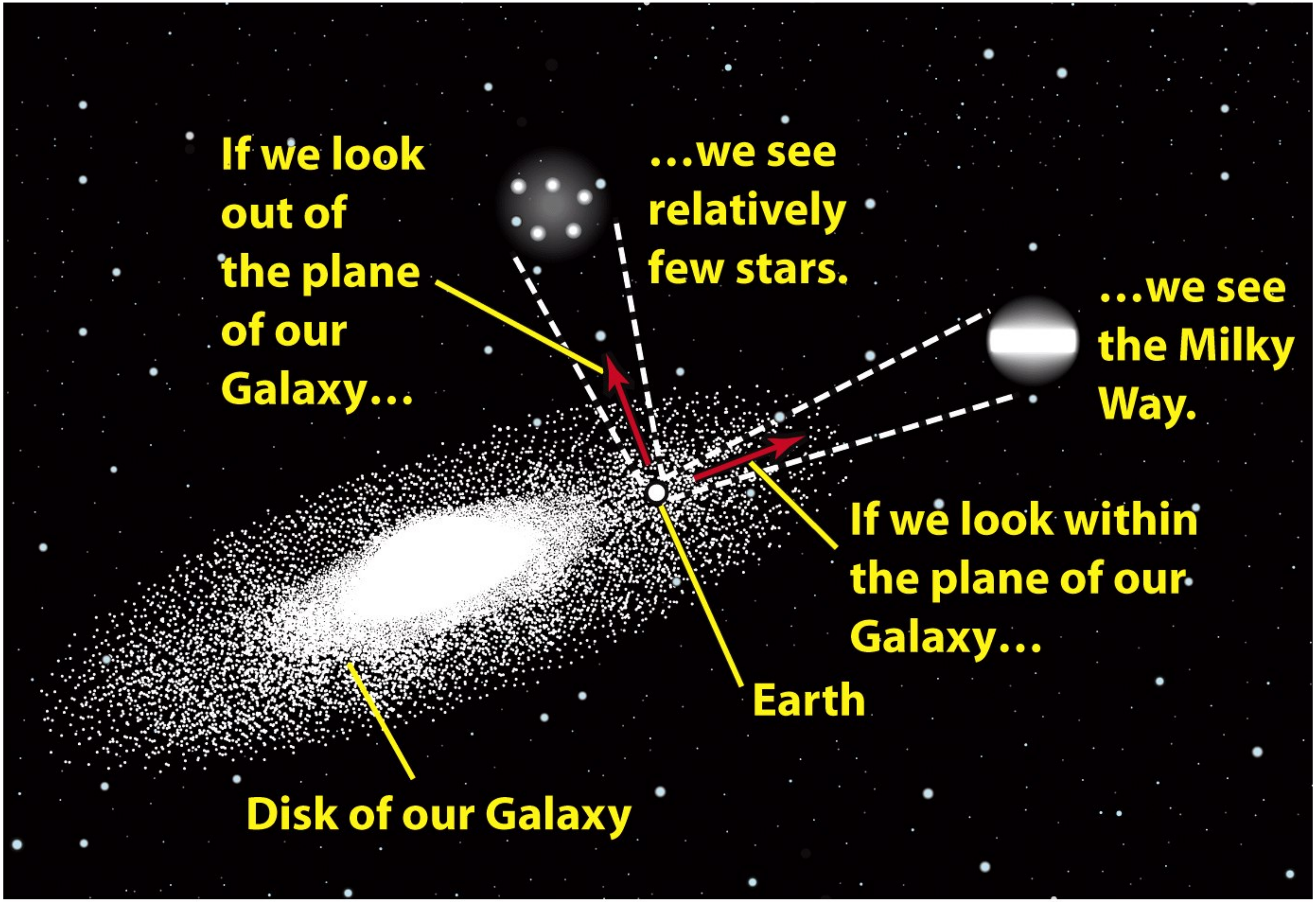
The Milky Way galaxy appears in our sky as a faint band of light.

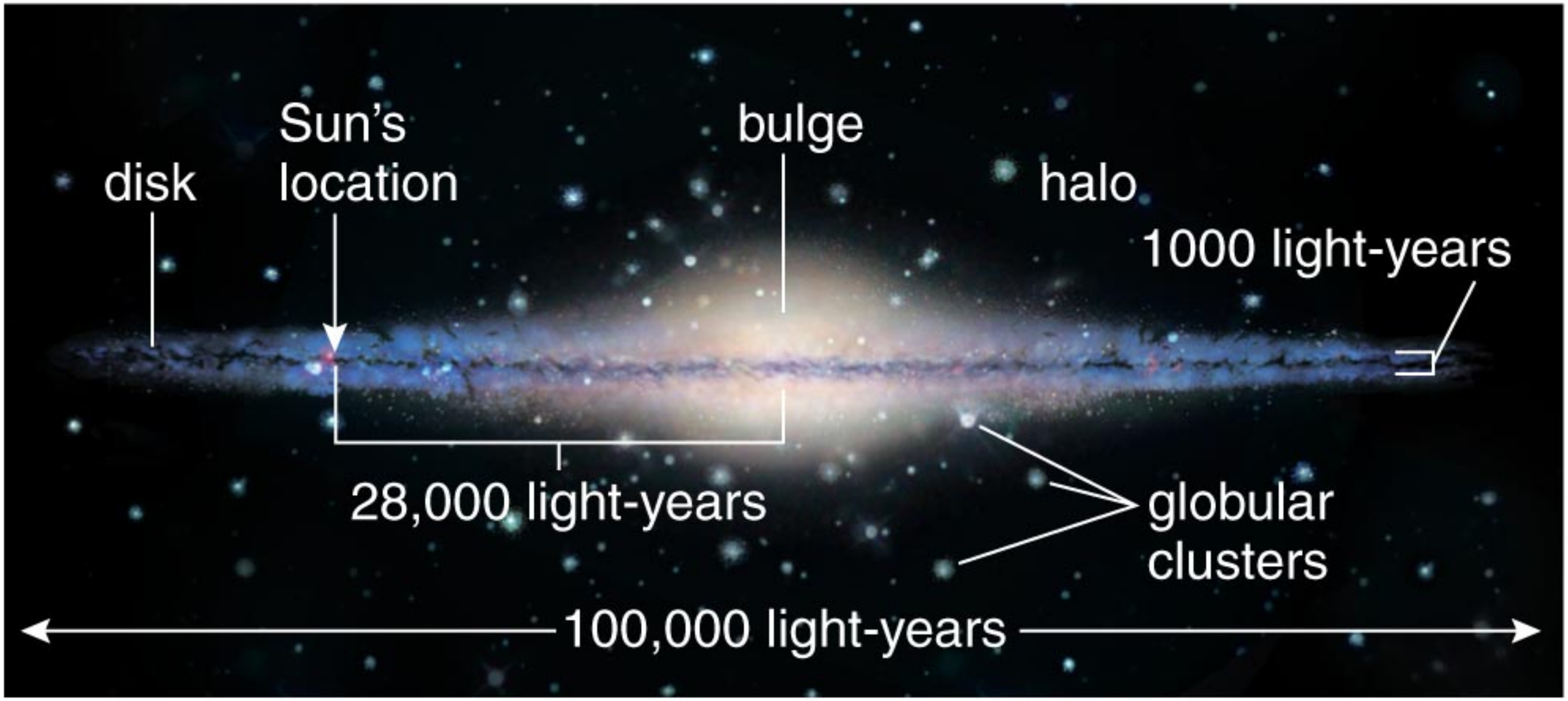


Dusty gas clouds obscure our view because they absorb visible light.

This is the ***interstellar medium*** that makes new star systems.

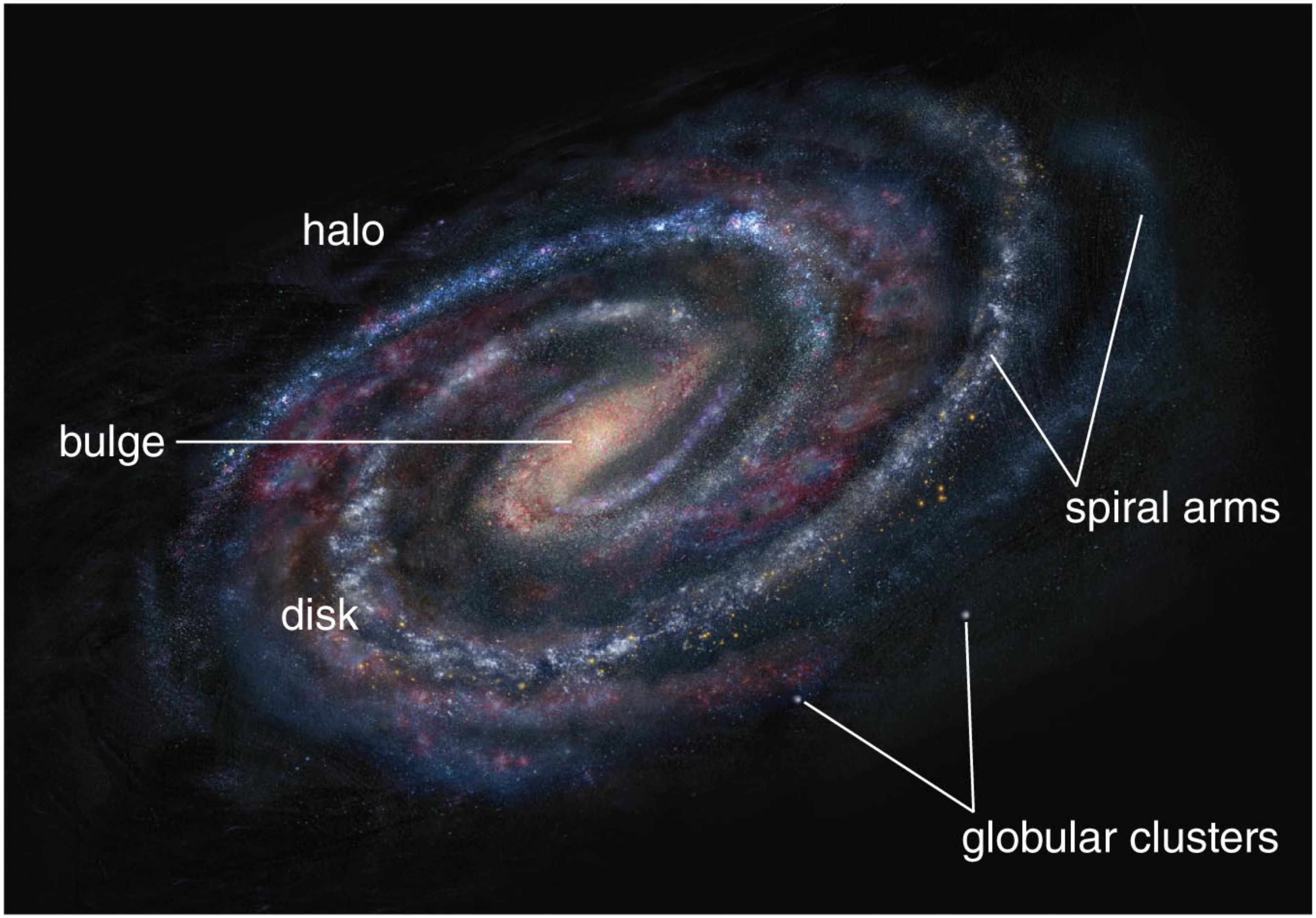
All-sky View


If we look out of the plane of our Galaxy…
…we see relatively few stars.
…we see the Milky Way.
If we look within the plane of our Galaxy…
Earth
Disk of our Galaxy



We see our galaxy edge-on from the *inside*.

Primary features: *disk*, *bulge*, *halo*, *globular clusters*.



If we could view the Milky Way from above the disk, we would see its spiral arms.

Group Q: Why is the MW ~flat?

- Our galaxy is a spiral, and like other spirals it is largely flat
- What does this tell us about how it might have formed?
- Thinking about later: there are many other galaxies (called "ellipticals") that are more like balls than flat
- How might their histories have been different?

Anatomy of the Milky Way

- The disk
  - Approximately 30 kpc diameter (center is 8 kpc away).
  - Very thin, only ~300–600 pc thick.
  - Contains stars of all ages, including young stars (“Population I”).
  - Contains significant amounts of dust and gas.
- The bulge
  - Thick (oblate spheroid), few kpc in diameter.
  - Contains almost exclusively old stars (Population II).
  - Contains most of the stars in the galaxy!
  - Very little dust or gas.
- The halo
  - Very extended (> 100 kpc diameter) spherical region.
  - Contains very old stars (Population II).

Stellar Populations

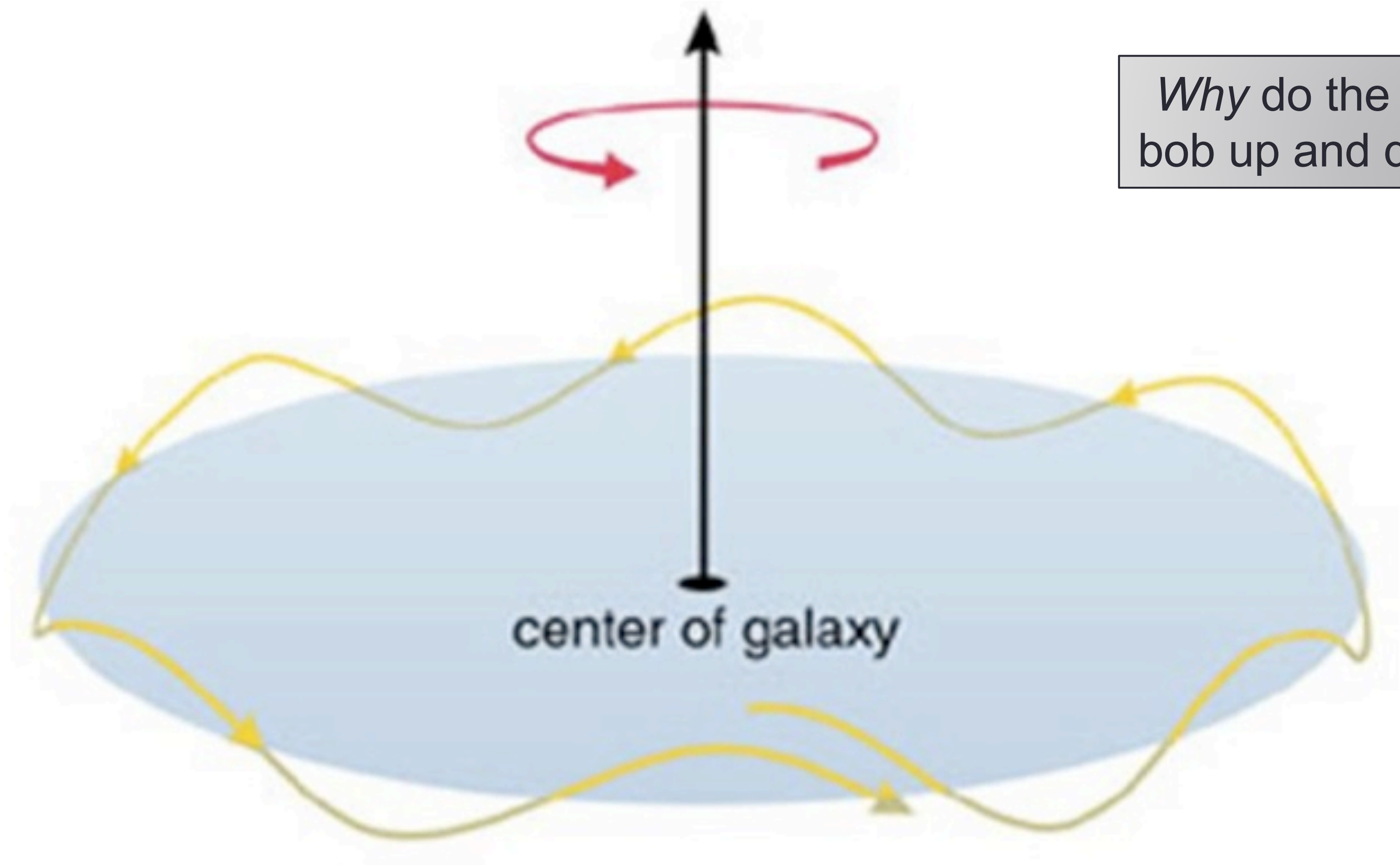
- Population I
  - Found in the disk of the galaxy.
  - Stars of multiple ages, including the youngest stars.
- Population II
  - Found in the bulge and the halo.
  - Exclusively very old stars (older than Pop. I stars).
- Population III
  - The theorized first stars, likely all gone by now.

Which of these images shows mostly disk (not halo) stars?

A. Left image only.
B. Right image only.
C. Both images.
D. Neither image.

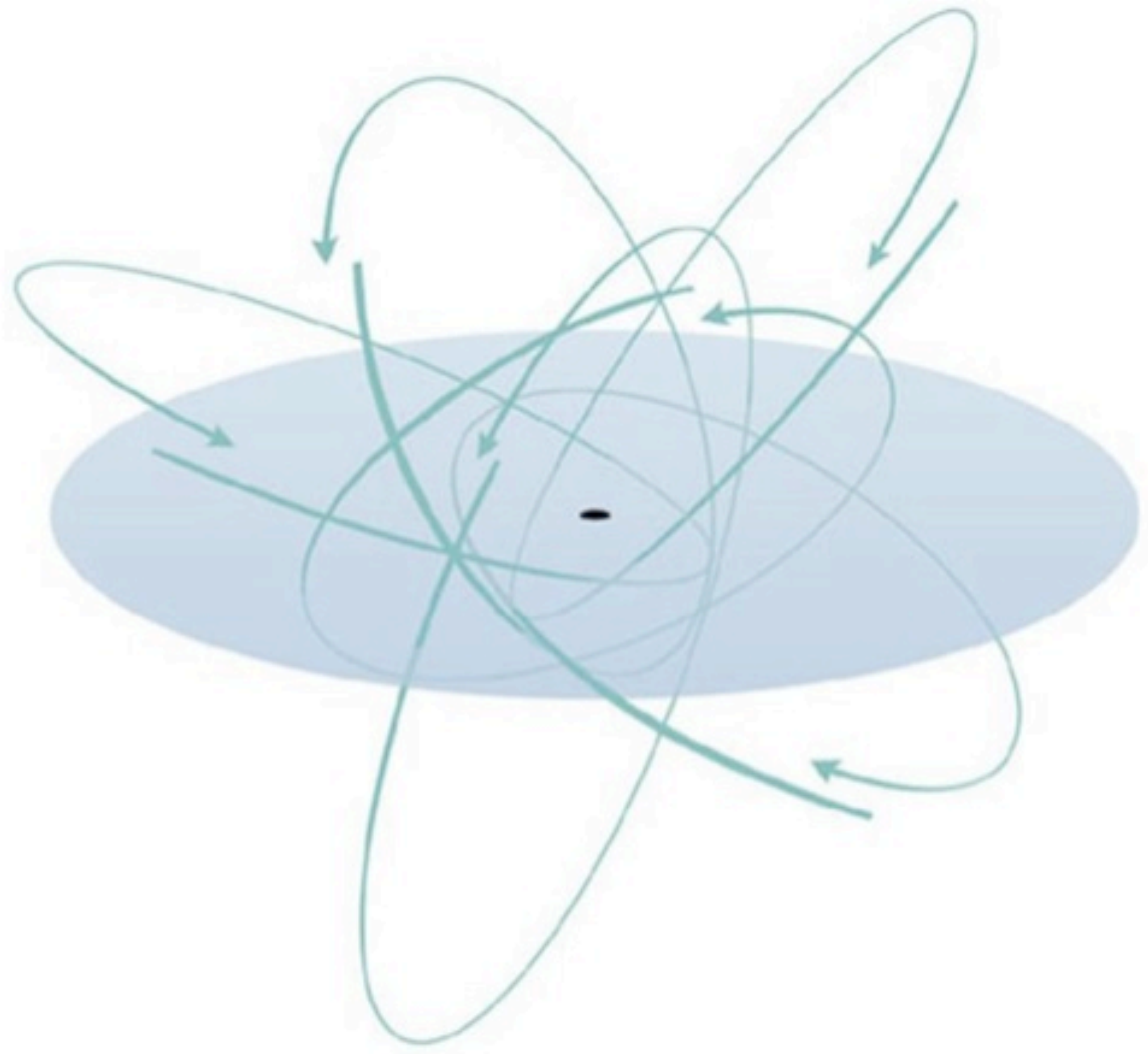
Stellar Dynamics in the Milky Way

- Gravity reigns supreme: each star moves purely under action of gravity.
  - Gravitational field created by everything **else** in galaxy!
- In the disk…
  - All stars (+ dust, gas) are orbiting in approximately circular paths; same direction in approximately the same plane.
  - Across much of the disk, orbital speeds in range 200–250 km/s.
  - At location of Sun, orbital period is approximately 250 Myr.
- In the bulge and the halo…
  - Stellar orbits have no preferred direction or plane.
  - Orbits can depart dramatically from circles.



Why do the stars bob up and down?

Stars in the disk all orbit in the same direction with a little up-and-down motion, like perturbed planetary orbits.



Orbits of stars in the bulge and halo have random orientations, like stars in a star cluster.

Using Motion to Probe Galaxy Mass

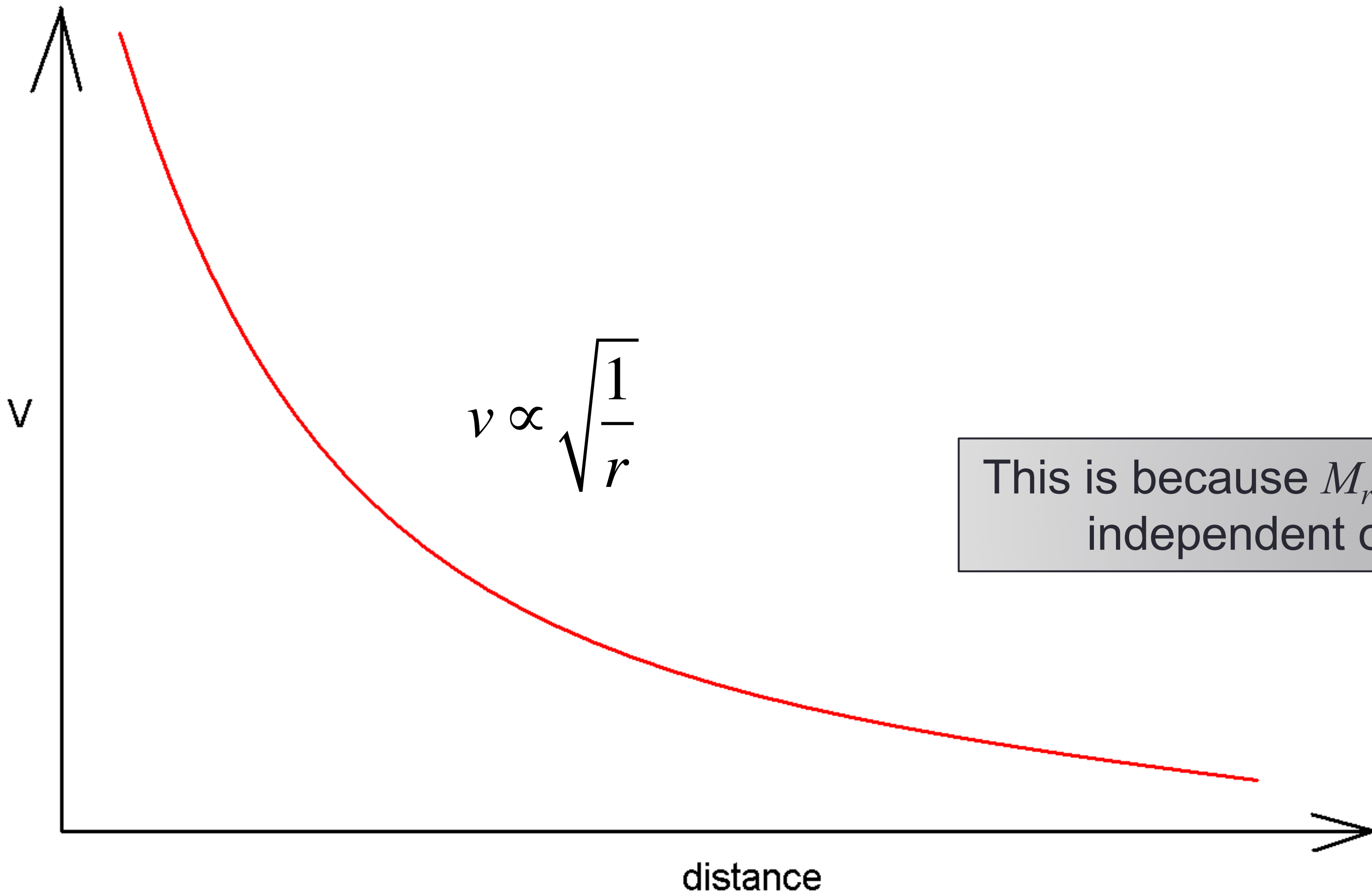
- Star & gas motion in the galaxy is determined by gravity.
- If we assume a ***spherically symmetric*** mass distribution, then gravity field at radius r is as if all of the mass interior to r is compressed to a point at the center (Gauss' law). And the exterior mass doesn't contribute at all!
- So for circular orbits in the disk,

Centripetal acceleration → $$\frac{v^2}{r} = \frac{GM_r}{r^2},$$ ← Newton's law of gravity

M_r = mass inside radius r $$\therefore v = \sqrt{\frac{GM_r}{r}} \text{ or } M_r = \frac{rv^2}{G}.$$ ← The orbital speed "law"

- By measuring $v(r)$, we can deduce M_r.

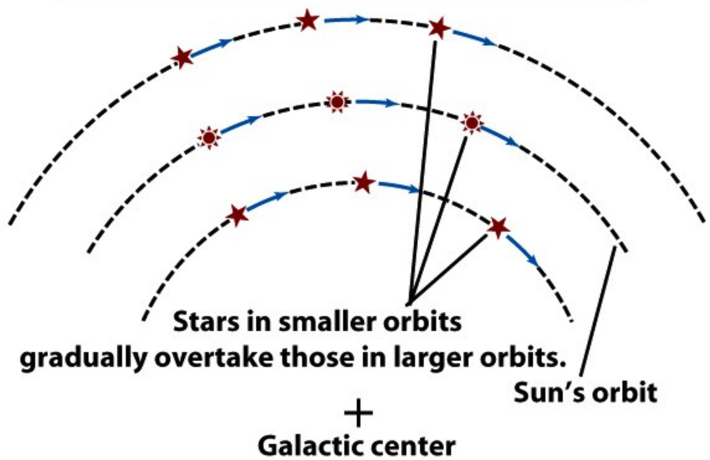
Velocity dependence on radius for a *planet orbiting the Sun…*



$$v \propto \sqrt{\frac{1}{r}}$$

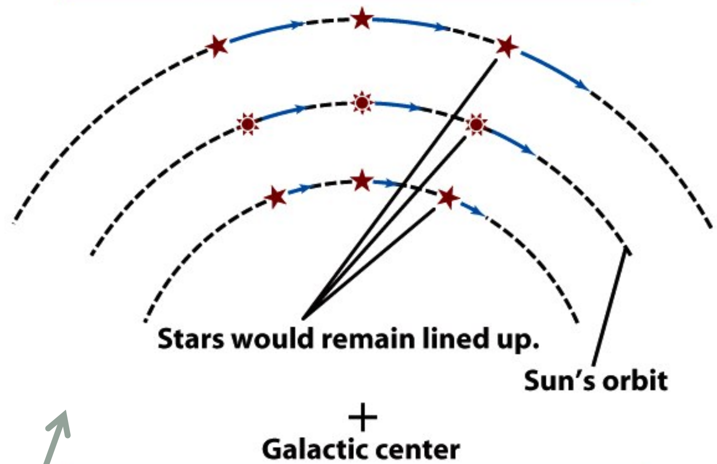
This is because M_r = 1 $M_\odot$, independent of r.

(a) The orbital speed of stars and gas around the galactic center is nearly uniform throughout most of our Galaxy.



v = constant ➔ $M_r \propto r$

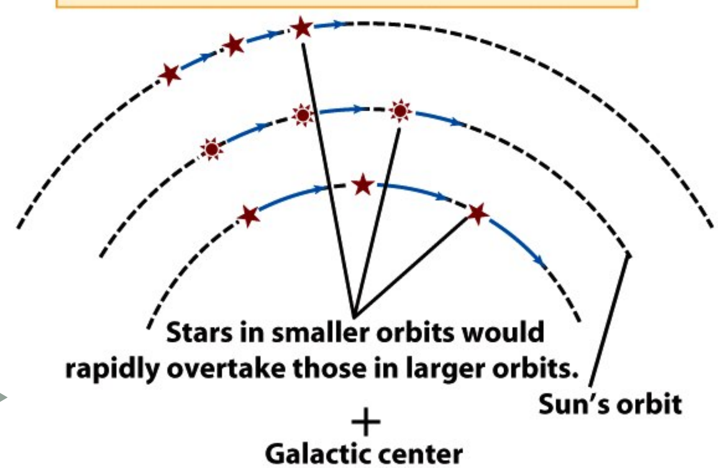
(b) If our Galaxy rotated like a solid disk, the orbital speed would be greater for stars and gas in larger orbits.



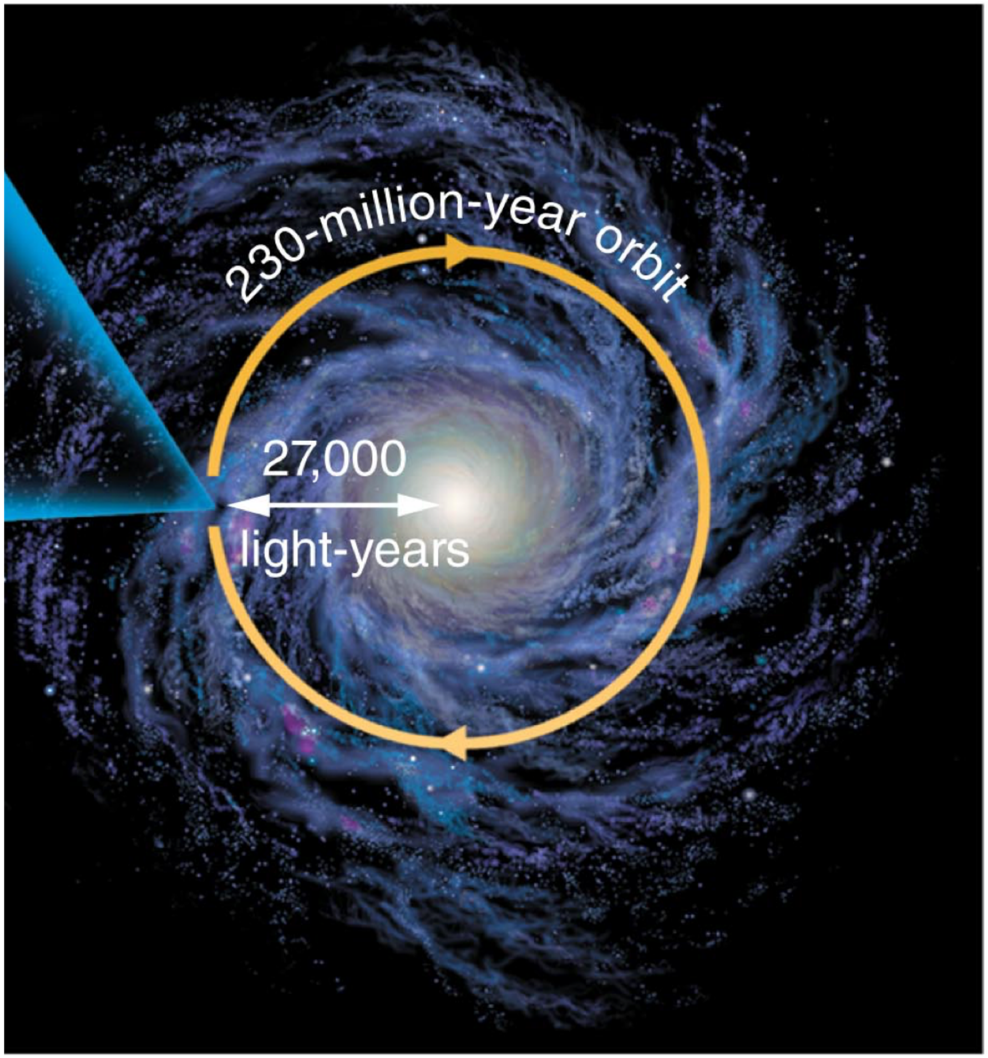
$v \propto r$ ➔ $M_r \propto r^3$

(constant density)

(c) If the Sun and stars obeyed Kepler's third law, the orbital speed would be less for stars and gas in larger orbits.

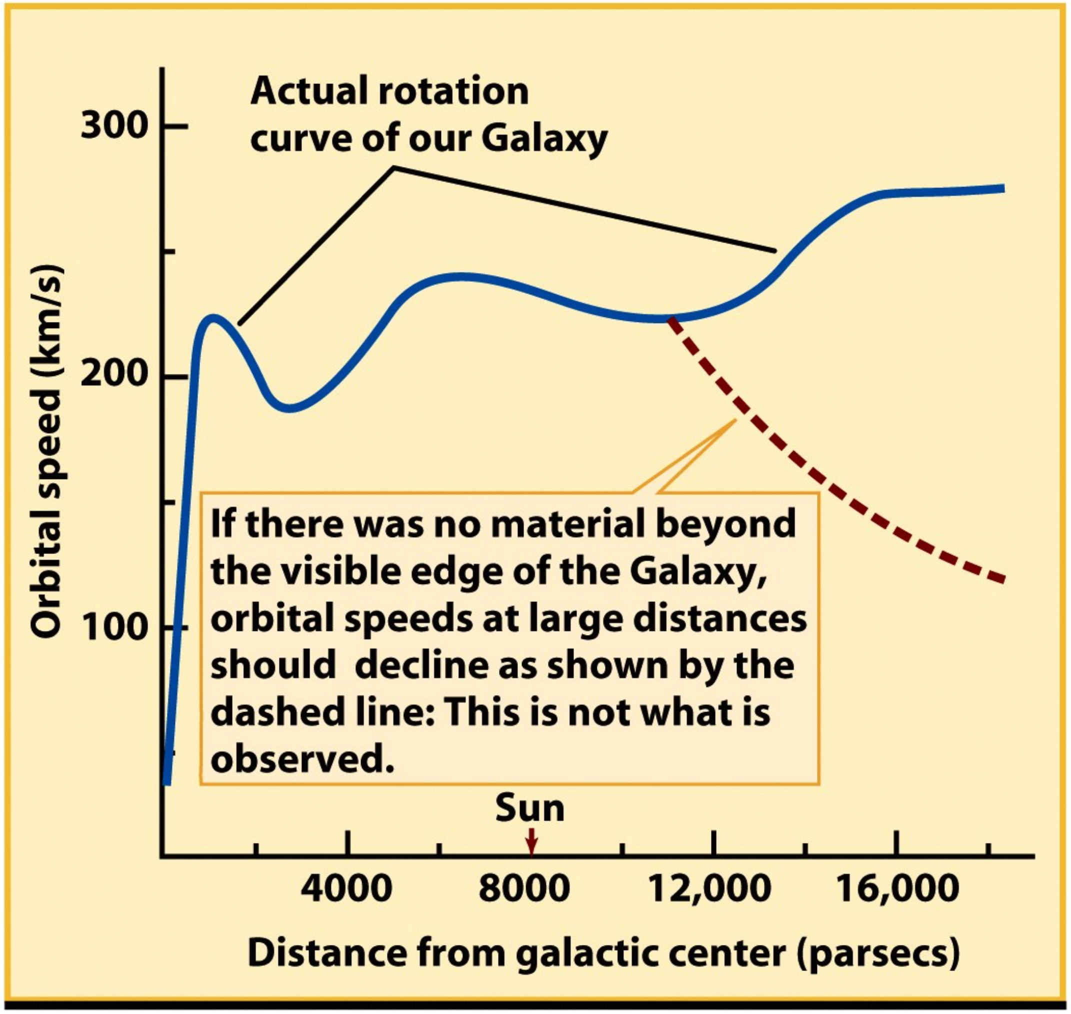


$v \propto 1/r^{1/2}$ ➔ M_r = constant



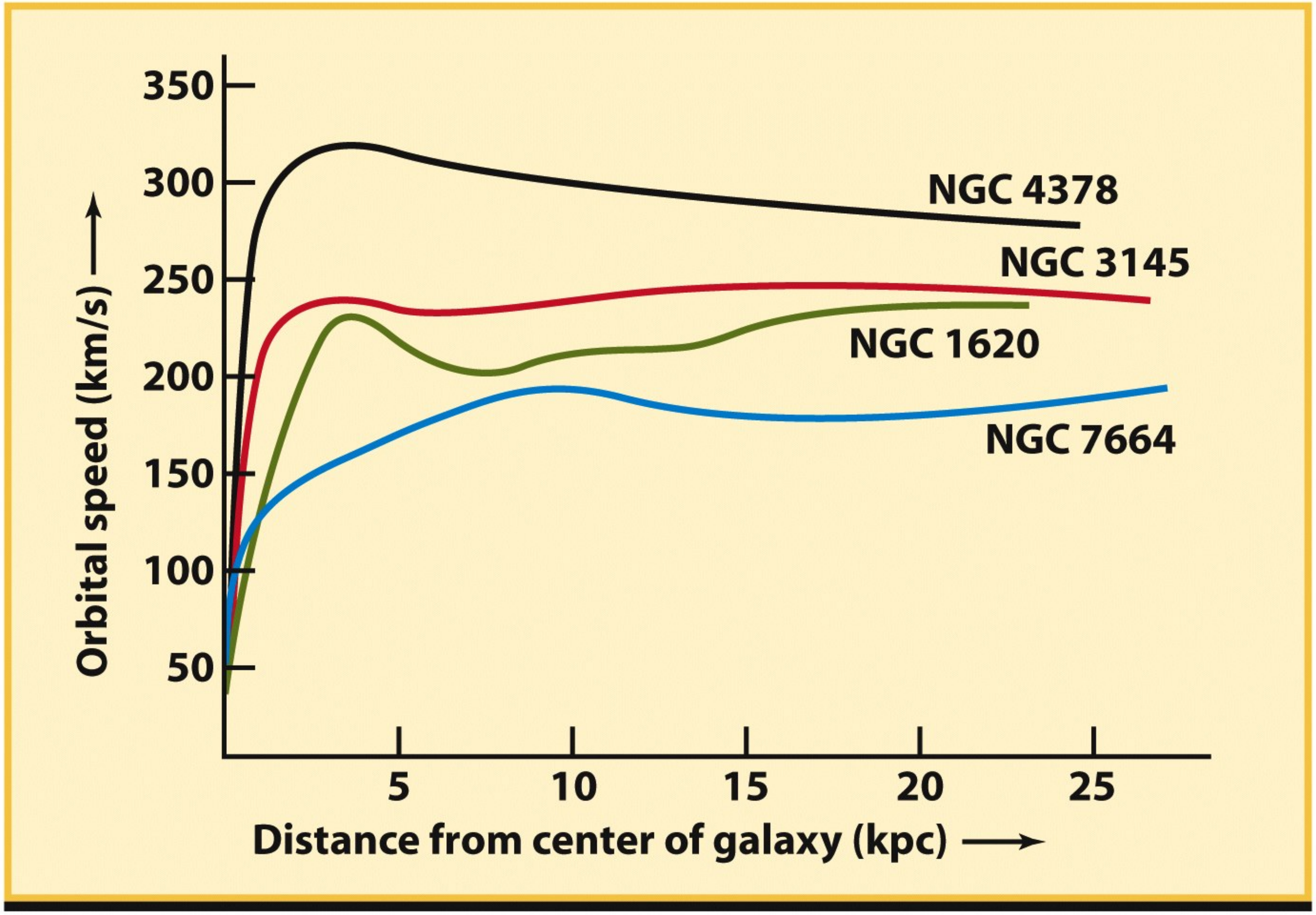
The Sun's orbital motion (radius and speed) tells us mass within the Sun's orbit:

$$1.0 \times 10^{11}\ M_{\odot}$$



- The Milky Way's rotation curve is flat(ish), implying $M_r \propto r$, even beyond the visible disk: invisible matter?!

Other spiral galaxies also have flat rotation curves…



Preview: Dark Matter

- The outer regions of galaxies are revolving too quickly relative to the mass that we see.
- So, we conclude that one of two things must be true:
  1. There's something strange about how gravity works for systems as large as galaxies and/or accelerations as small as those relevant for stars orbiting the galaxy.
  2. There's a lot of matter in a form that we do not see: ***dark matter***. Since there's evidence for this on larger scales as well, this is the favored hypothesis. We'll talk about the nature of dark matter later…