# Today

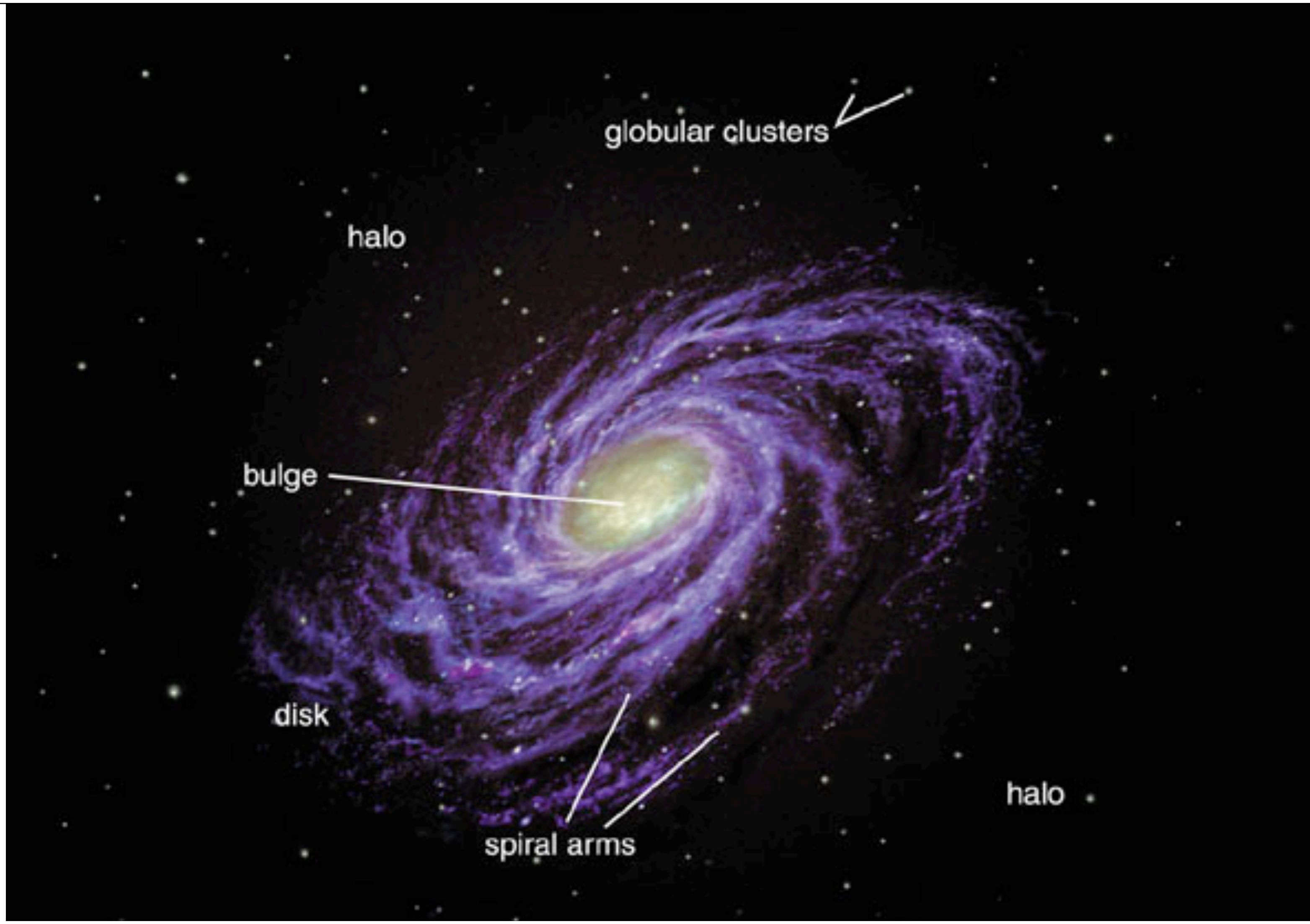
- The Milky Way
  - Galactic Structure
  - The Interstellar Medium
  - Star Formation
  - Stellar Populations

# Extra credit (2 points)

- What would happen to the orbit of the Earth if the Sun were suddenly turned into a black hole with the same mass as the Sun?
- Be sure to include your name and section number
- You may consult your notes, but do not communicate with anyone else

# Student Evaluations are Open

- CourseEvalUM will be open for student evaluations Nov 29 through Dec 14
- https://www.courseevalum.umd.edu
- Please do respond: I really do want to know what I did poorly or well, as does my department
- High response rate is important to our department
- Thanks!




Our Milky Way: the view from above the disk

# MW Misconception #1

- How do you think we took that photograph of the Milky Way?

# MW Misconception #1

- How do you think we took that photograph of the Milky Way?
- Answer: we didn't! We are *in* the Milky Way galaxy, and would have to move tens of thousands of light years to get such a view
- All "images" of our Milky Way are either artist's conceptions or photographs of other galaxies *similar* to the Milky Way

# MW Misconception #2

- What is the size of the Milky Way?

MIB

# MW Misconception #2

- What is the size of the Milky Way?
- Many people confuse it with solar system
- Answer: a galaxy is *much* bigger than our solar system, or a collection of a few stars!
- If the solar system out to Pluto were a basketball, the main disk of the MW would extend to twice the diameter of Earth!

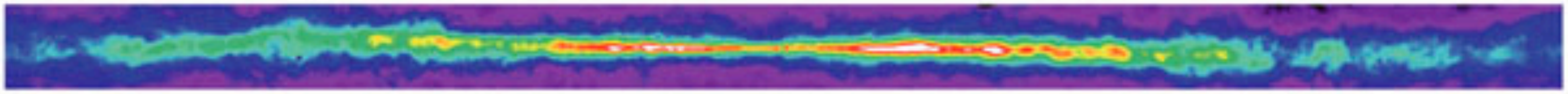
# Galactic Structure

- Stars ~80% of mass
  - DISK ~80% of stars
  - BULGE ~20% of stars
- Gas ~20% of mass
  - atomic gas ("H I") ~2/3 of gas
  - molecular gas ($H_2$) ~1/3 of gas
  - hot, ionized gas ("H II")
- Dust
  - between stars
  - mostly in spiral arms & molecular clouds

**INTERSTELLAR MEDIUM**

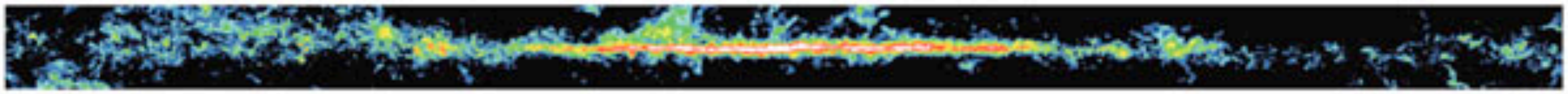
# Multi-wavelength Milky Way

radio (21 cm)
HI gas



**a** 21-cm radio emission from atomic hydrogen gas.

radio (CO)
molecular gas



**b** Radio emission from carbon monoxide reveals molecular clouds.

far-IR
dust

**c** Infrared (60–100 μm) emission from interstellar dust.

near-IR
stars

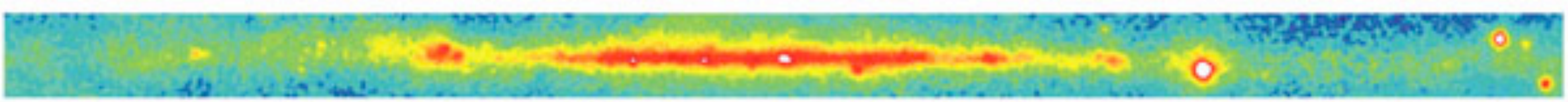
**d** Infrared (1–4 μm) emission from stars that penetrates most interstellar material.

Optical
stars & dust

**e** Visible light emitted by stars is scattered and absorbed by dust.

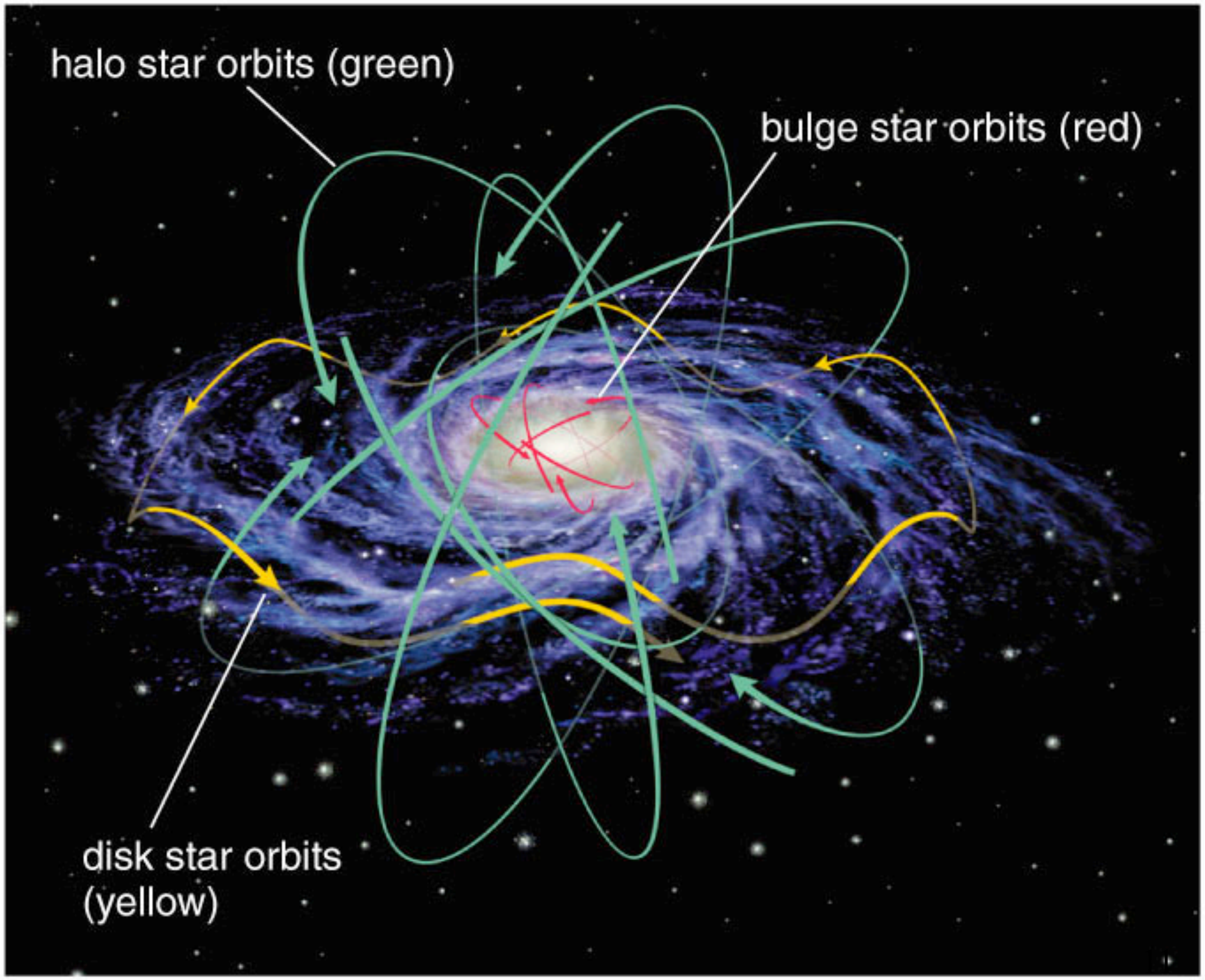
X-ray
hot gas

**f** X-ray emission from hot gas bubbles (diffuse blobs) and X-ray binaries (pointlike sources).



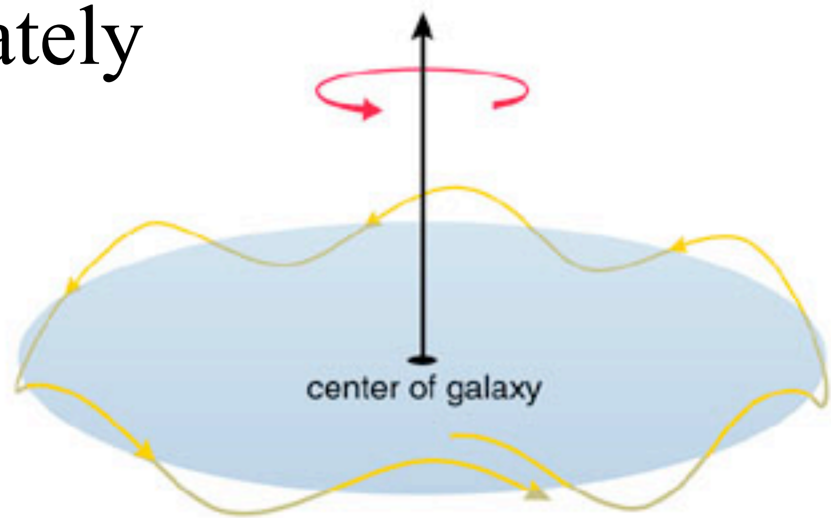
**g** Gamma-ray emission from collisions of cosmic rays with atomic nuclei in interstellar clouds.

# Stellar orbits

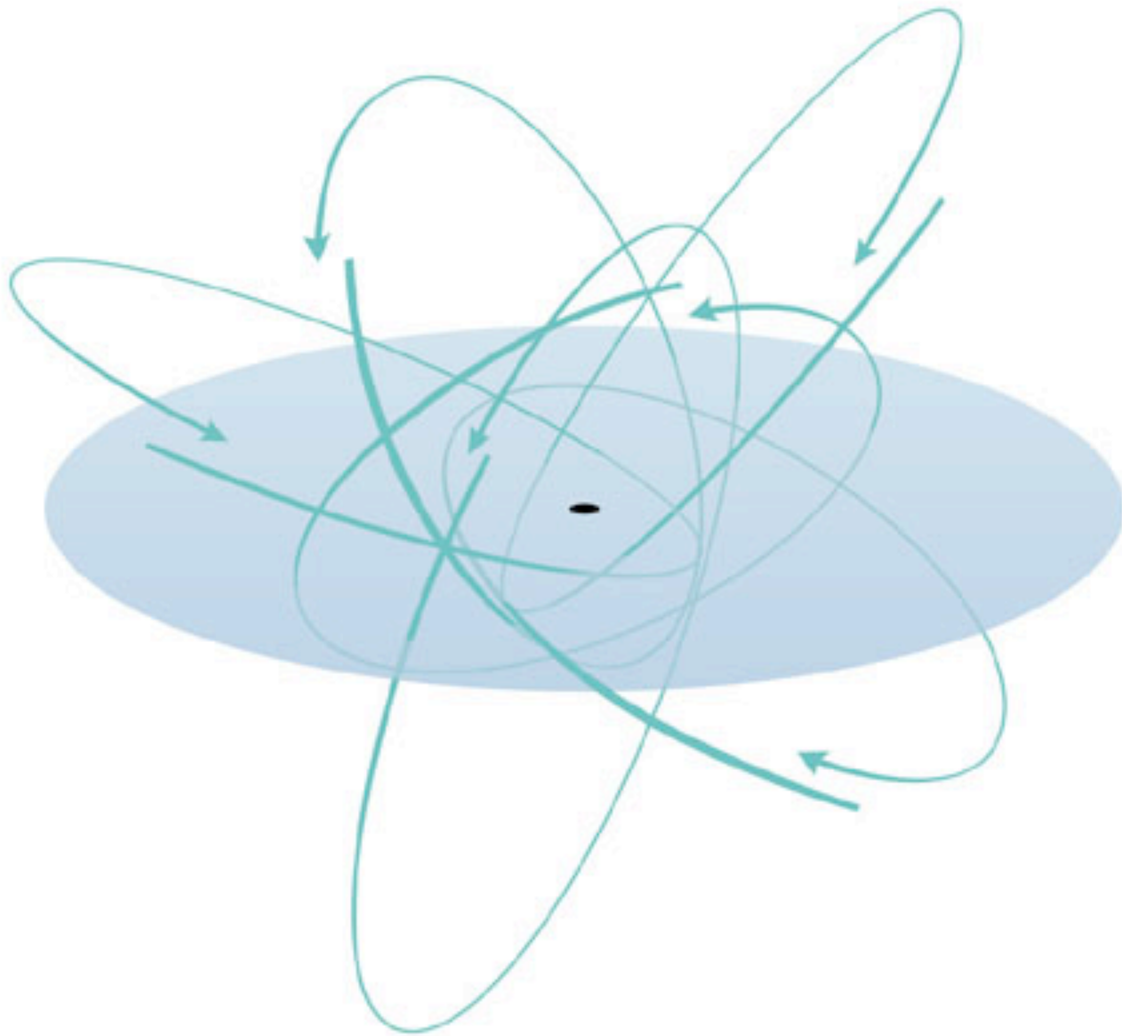


# Disk

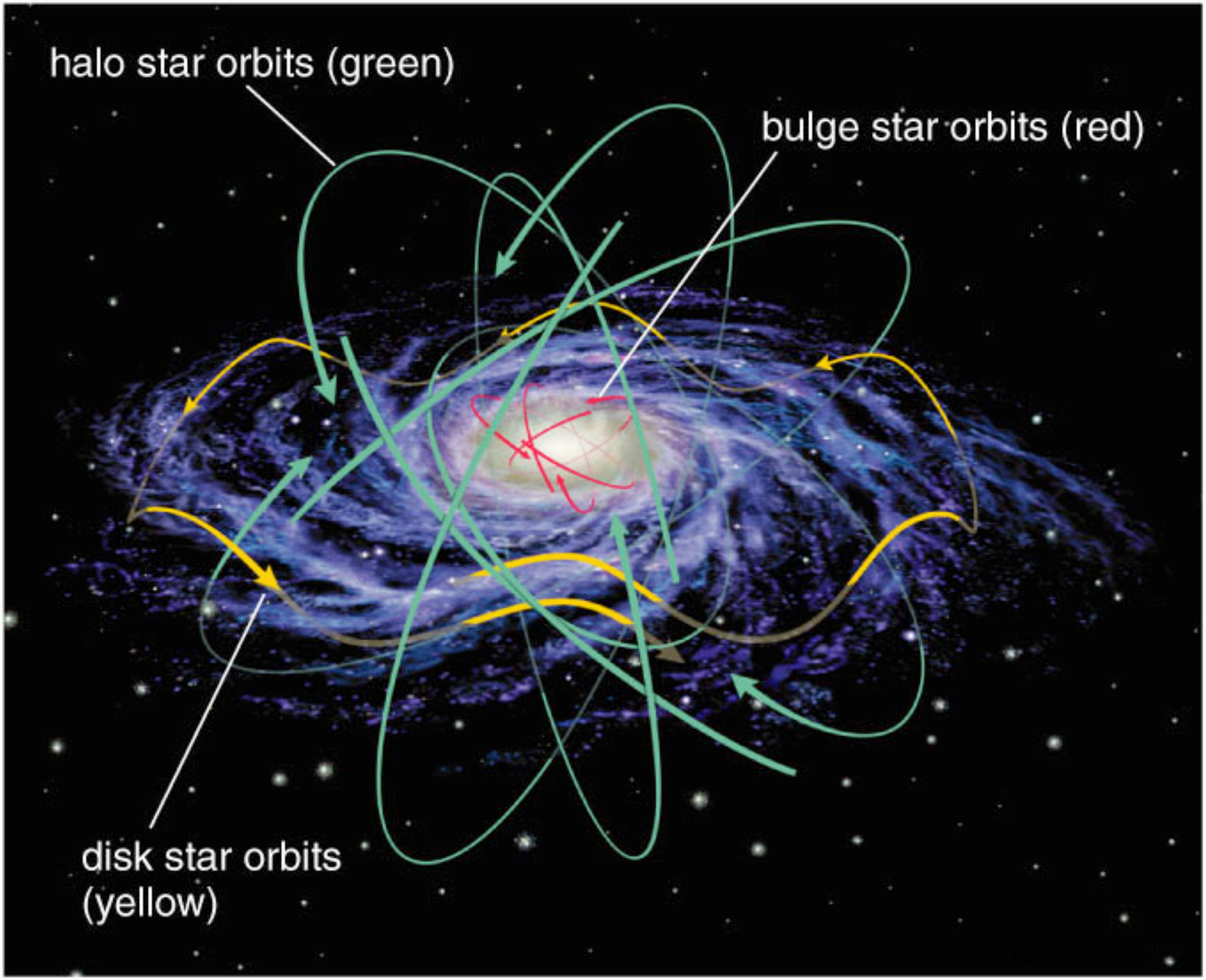
- Most stars are in the disk (2D)
- Disk stars have approximately circular orbits
- Disk stars orbit in same direction
- Individual stars oscillate slightly in the vertical direction (perpendicular to the disk), giving the disk a finite thickness

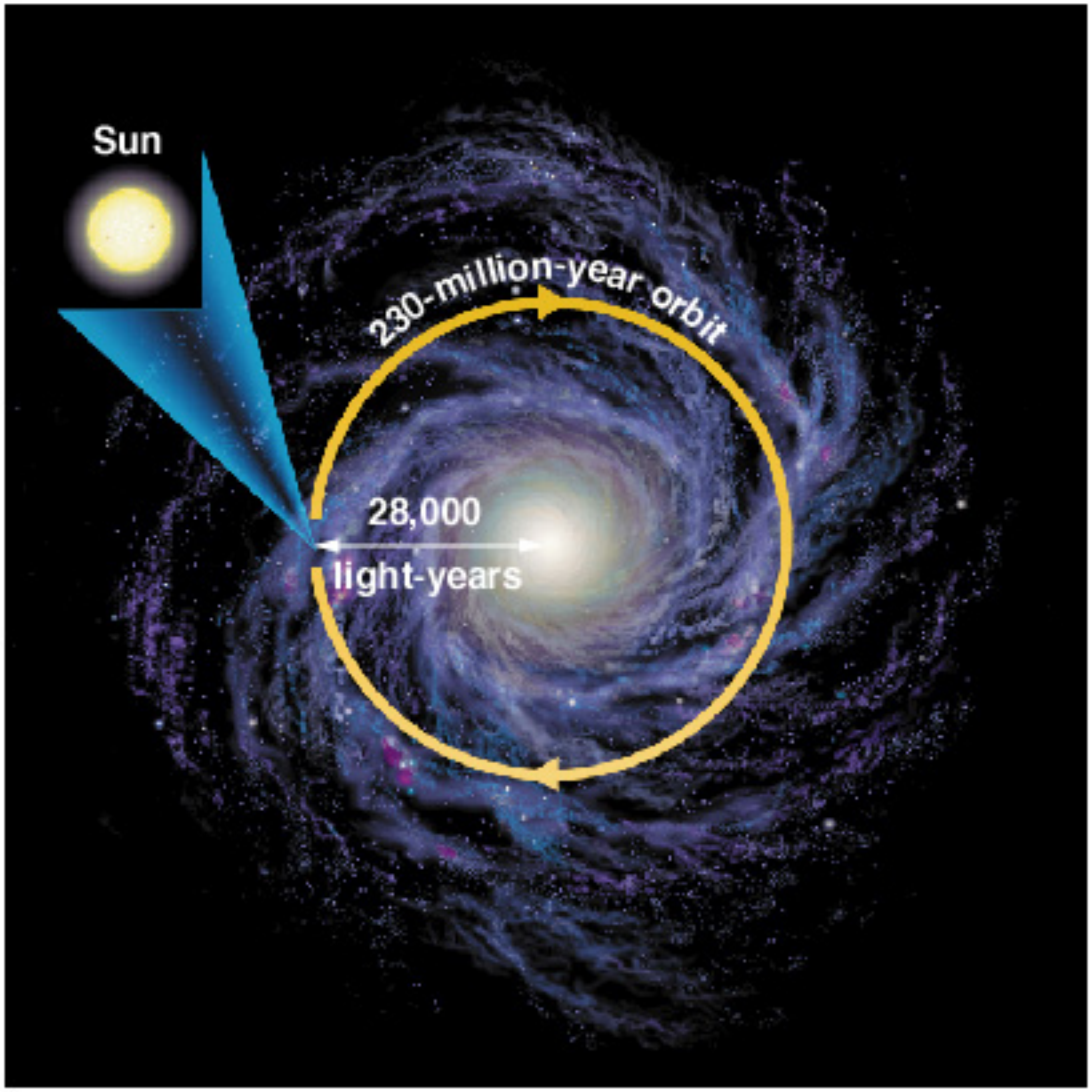


# Bulge & Halo



- Bulge mass < 20% of disk
- Halo fraction small ~1%
- Bulge & halo stars have elliptical orbits
- Bulge & halo stars orbit with random orientations; fill out 3D structure


halo star orbits (green)
bulge star orbits (red)
disk star orbits
(yellow)






Sun's orbital period is about 230 million years.

In 4.5 billion years, it has completed over 19 orbits.

# Mass of our Galaxy

How can we measure the mass of our galaxy?

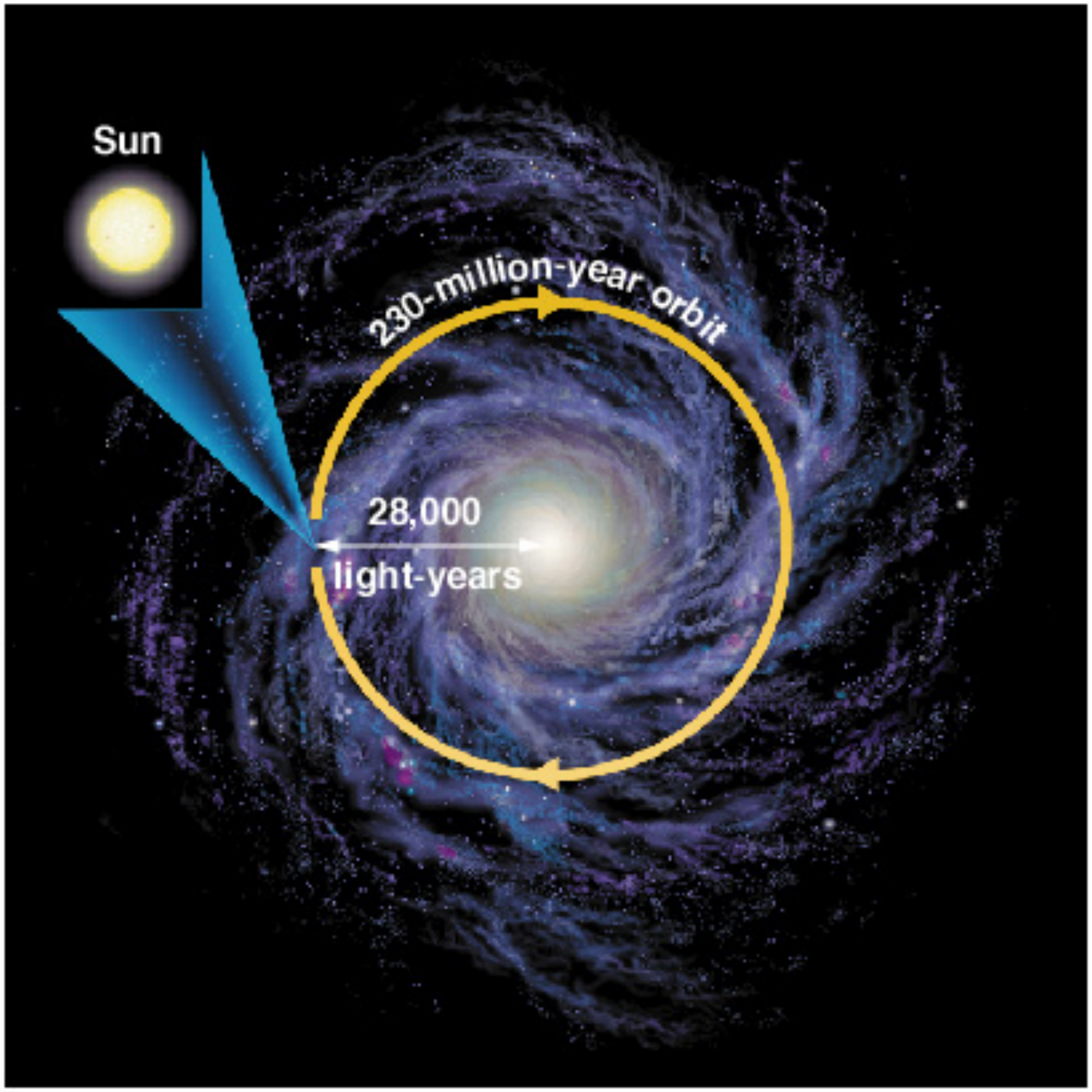
A. Using the speeds of stars, their distance from the MW center, and Newton's laws

B. Using full orbits and Kepler's laws

C. By extrapolating dark matter properties

D. By measuring the light from our galaxy

E. I don't know

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Sun's orbital motion (radius and velocity) tells us mass within Sun's orbit:

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

# Orbital Velocity Law

$$V^2 = \frac{GM}{R}$$

measure circular velocity and radius

solve for mass: $$M = \frac{V^2 R}{G}$$

- The orbital speed (*V*) and radius (*R*) of an object on a circular orbit around the galaxy tell us the mass (*M*) enclosed within that orbit.

stars and gas: $$M \approx 6 \times 10^{10}\ M_{sun}$$

# Relation of Milky Way components

radio (21 cm)
HI gas

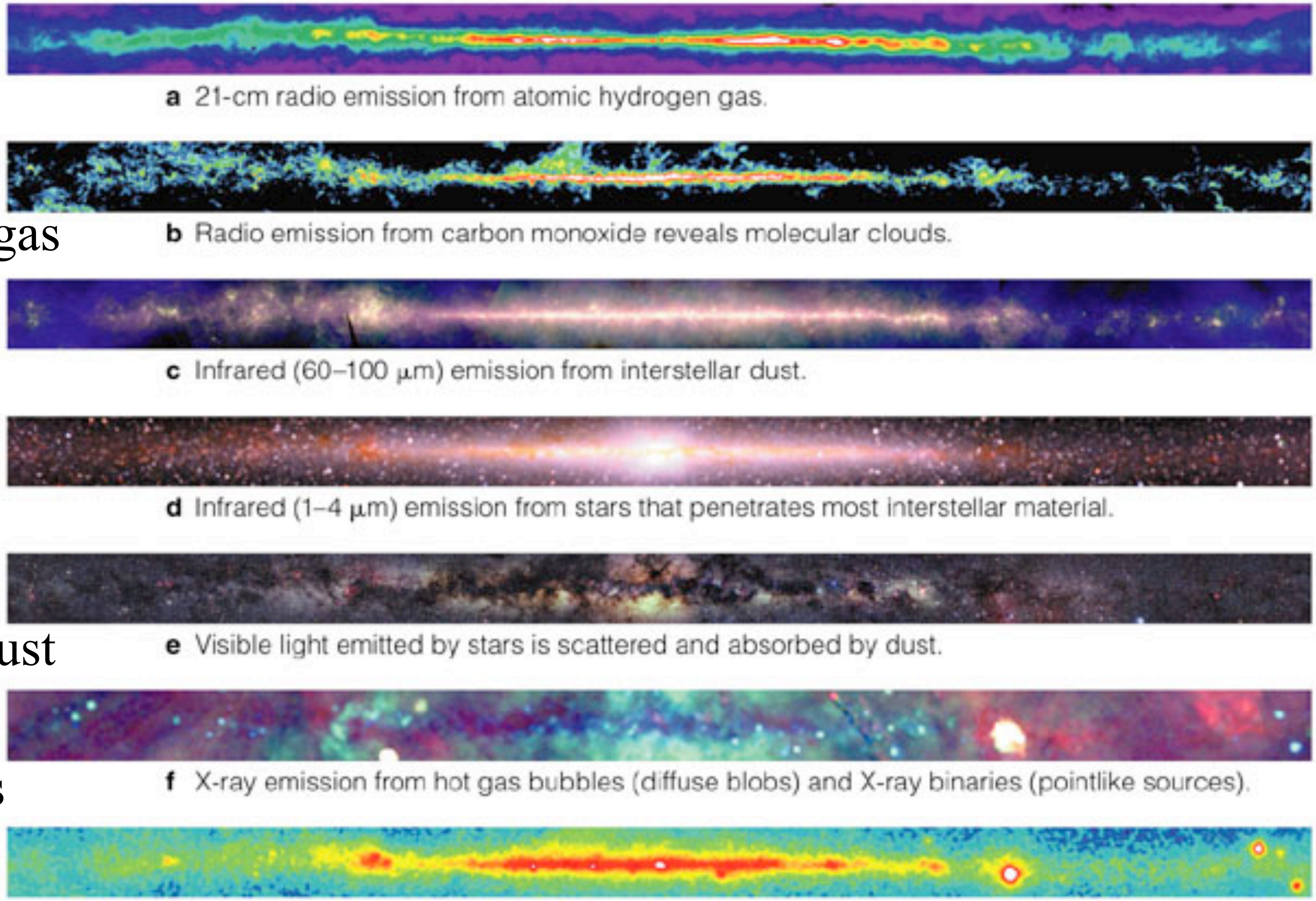
radio (CO)
molecular gas

far-IR
dust

near-IR
stars

Optical
stars & dust

X-ray
hot gas



a 21-cm radio emission from atomic hydrogen gas.

b Radio emission from carbon monoxide reveals molecular clouds.

c Infrared (60–100 μm) emission from interstellar dust.

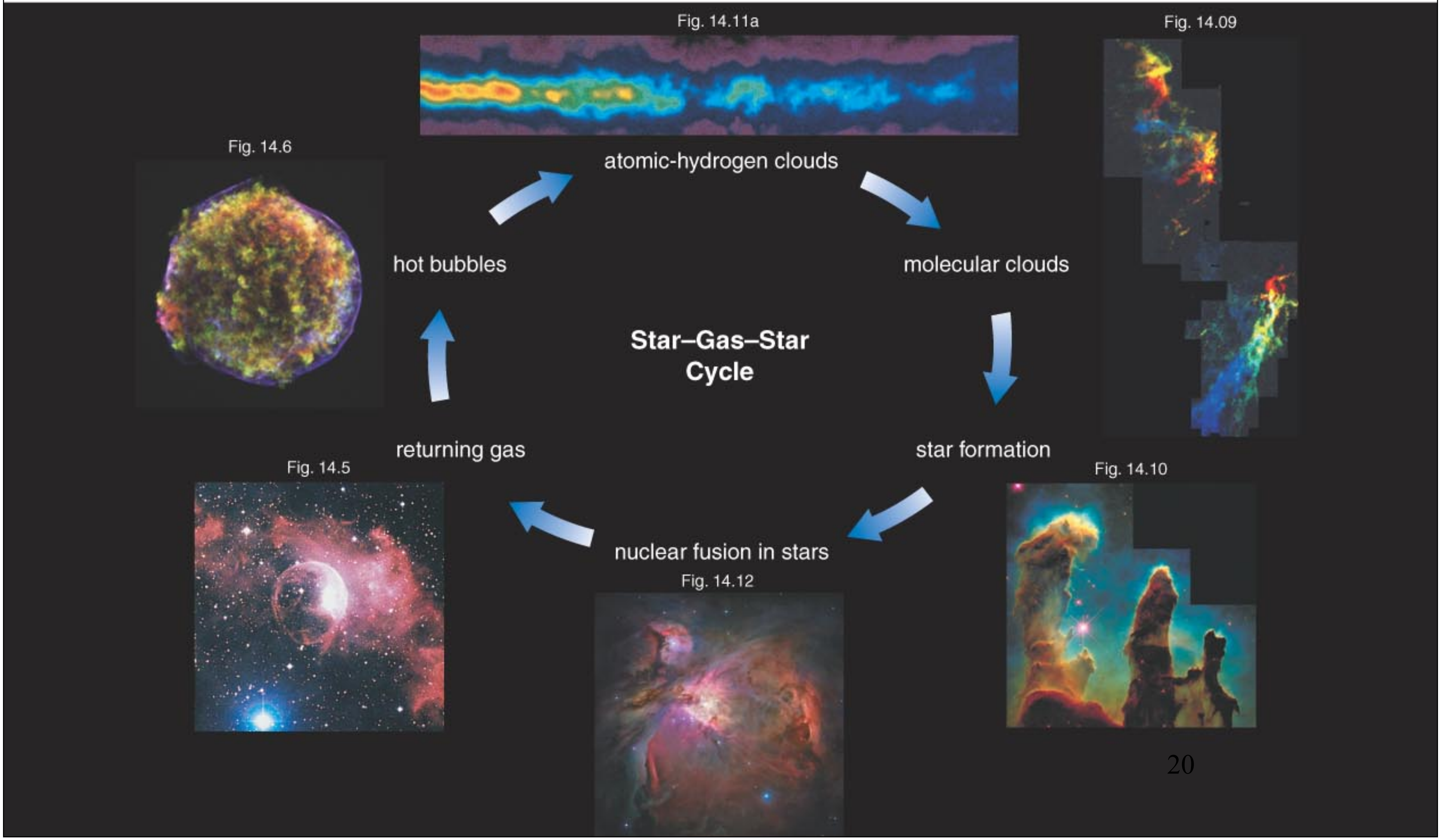
d Infrared (1–4 μm) emission from stars that penetrates most interstellar material.

e Visible light emitted by stars is scattered and absorbed by dust.

f X-ray emission from hot gas bubbles (diffuse blobs) and X-ray binaries (pointlike sources).

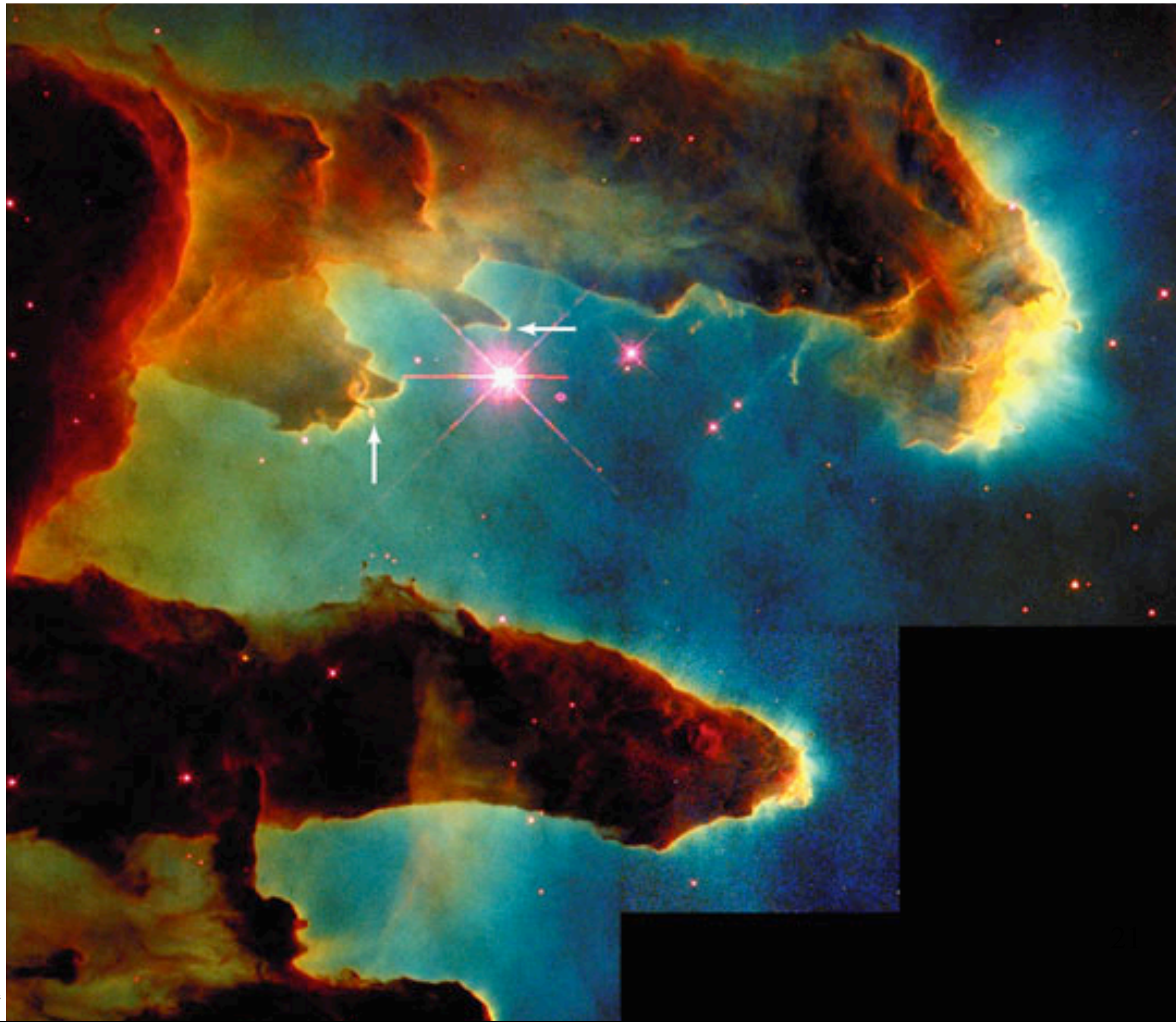
g Gamma-ray emission from collisions of cosmic rays with atomic nuclei in interstellar clouds.

# Gas recycling in our galaxy



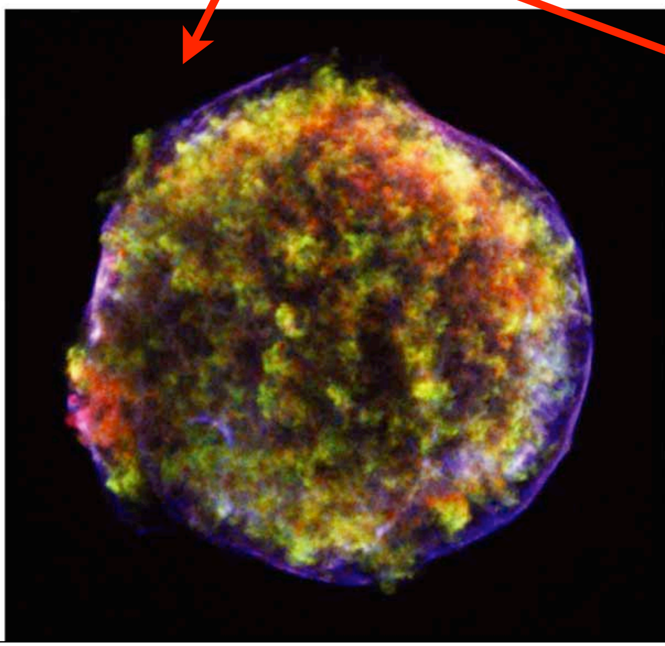
# Gas recycling

- Stars form in cold molecular gas clouds



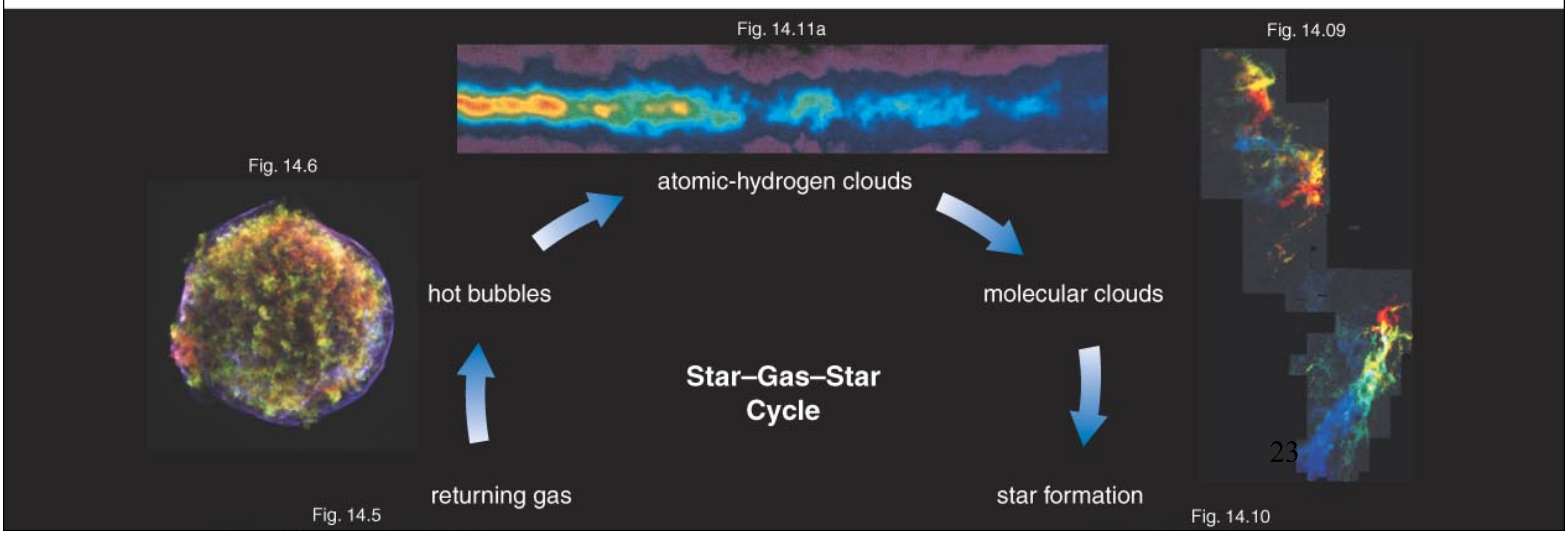
# Gas recycling

- Stars form in cold molecular gas clouds
- High mass stars explode
  - return processed gas to interstellar medium
  - heat surrounding gas
    - Supernova bubbles
    - Ionized gas (H II regions) [hot stars emit UV radiation]



# Gas recycling

- Stars form in cold molecular gas clouds
- High mass stars explode
- Hot gas cools
  - First into "warm" atomic gas (H I), then
  - into "cold" molecular gas ($H_2$) in dusty places (~30 K)



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- Hot gas cools
  - First into "warm" atomic gas (H I), then
  - into "cold" molecular gas ($H_2$) in dusty places
- Stars form in cold molecular gas clouds

Note: recycling is inefficient. Some mass locked up in remnants.

# How long will MW last?

Could the MW live indefinitely, with new stars forming, living, and dying for eternity?

A. Yes, gas will simply be recycled forever

B. Yes, new gas is created all the time

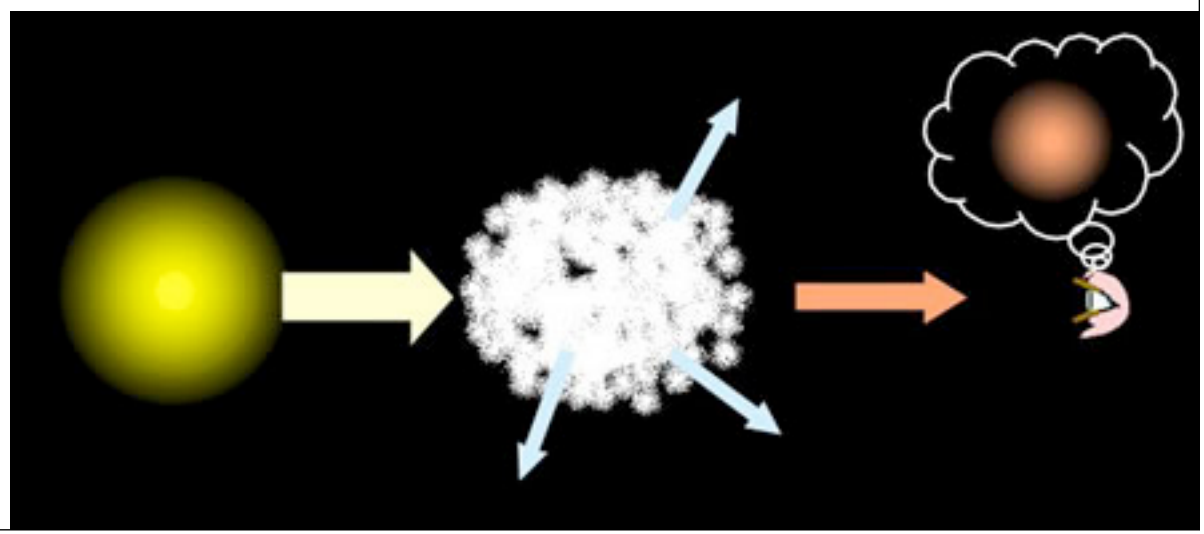
C. No, matter is gradually locked up in remnants

D. No, conversion of H to He, He to C, etc. means stars can't perform fusion forever

E. I don't know

# The Effects of Dust

- Interstellar dust
  - small grains in space
  - scatters star light passing through it
- Dims light
- Reddens it



# The Effects of Dust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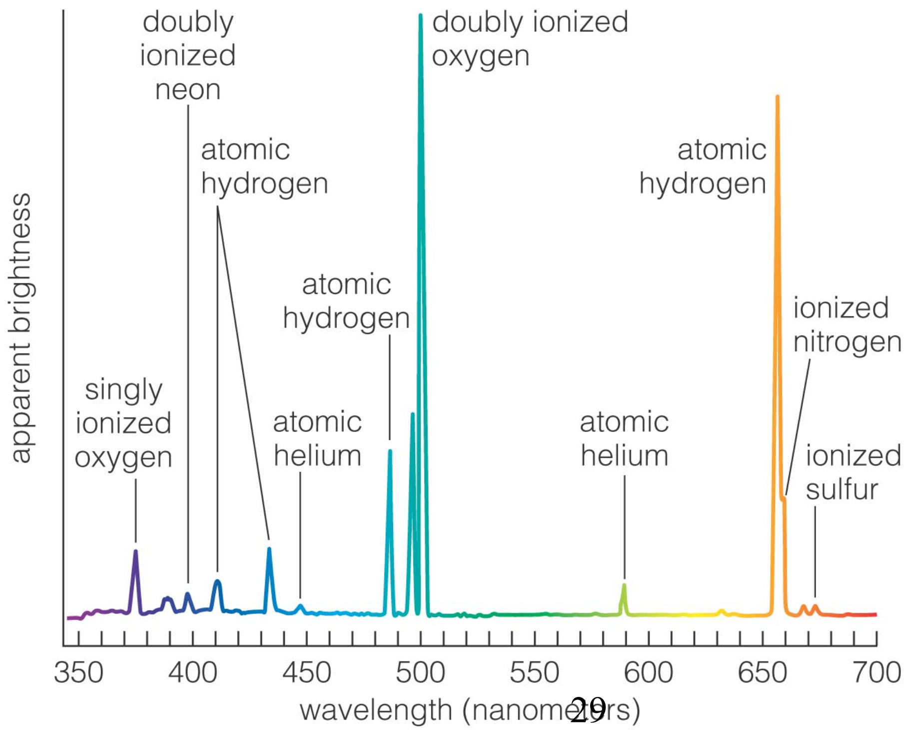
- Interstellar dust
  - small grains in space
  - scatters star light passing through it
- Dims light
  - blocks some light
  - stars appear fainter than they otherwise would
- Reddens
  - preferentially scatters blue light
  - light that gets through is redder than it started

# Various Nebulae

# H II Regions

***Ionization nebulae*** are found around short-lived high-mass stars, signifying active star formation.



***Reflection nebulae*** scatter the light from stars.

Why do reflection nebulae look bluer than the nearby stars?

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Why do reflection nebulae look bluer than the nearby stars?

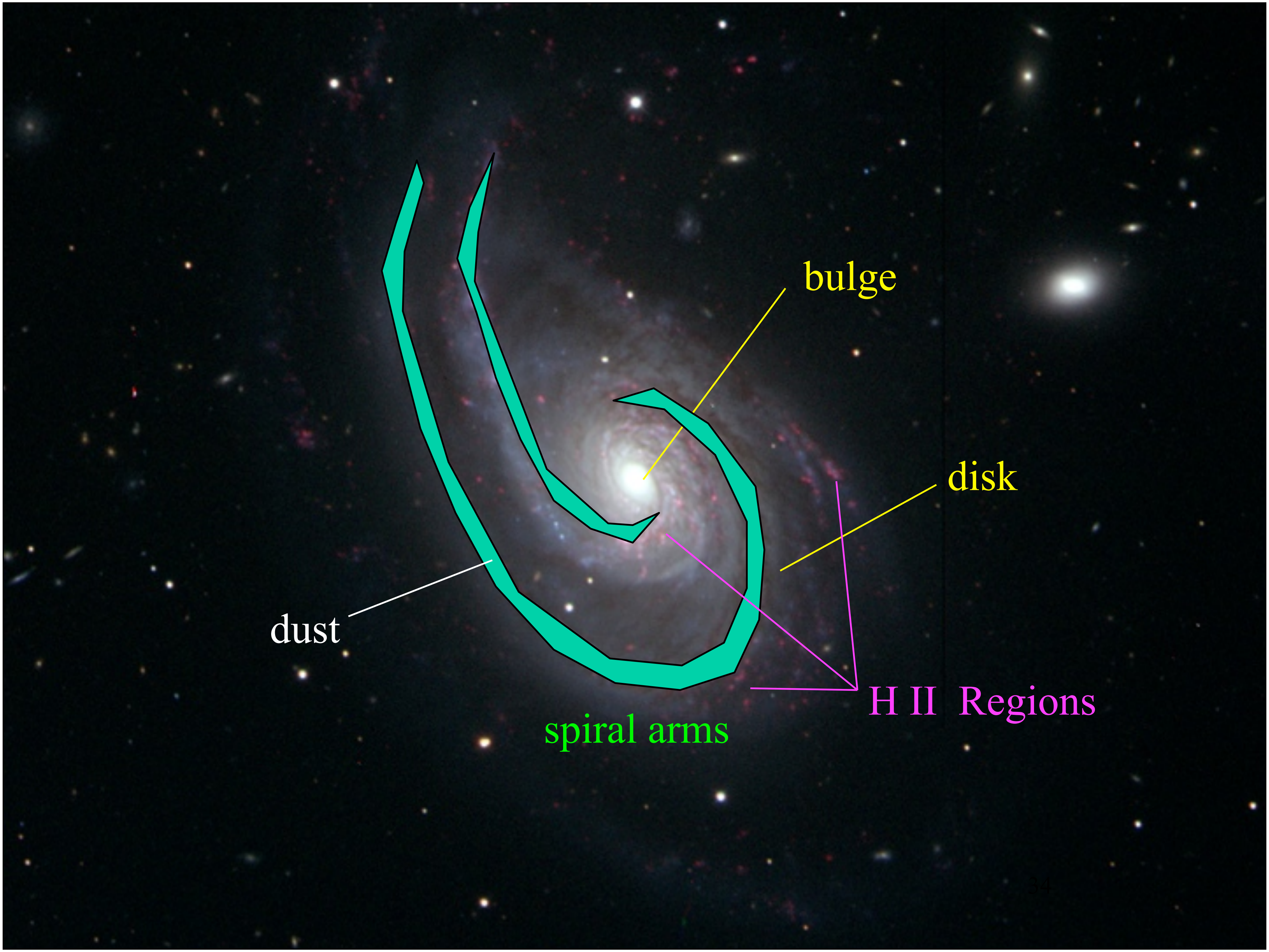
For the same reason that our sky is blue!


Spitzer

What kinds of nebulae do you see?

# Star formation

- Stars form in molecular clouds
- Molecular clouds contain a lot of dust
- Most star formation occurs in spiral arms


bulge
disk
dust
H II Regions
spiral arms

# MW Misconception #3

- Spiral arms must be where the matter is, so why don't they wind up very tightly over the ~50 orbits they have performed?

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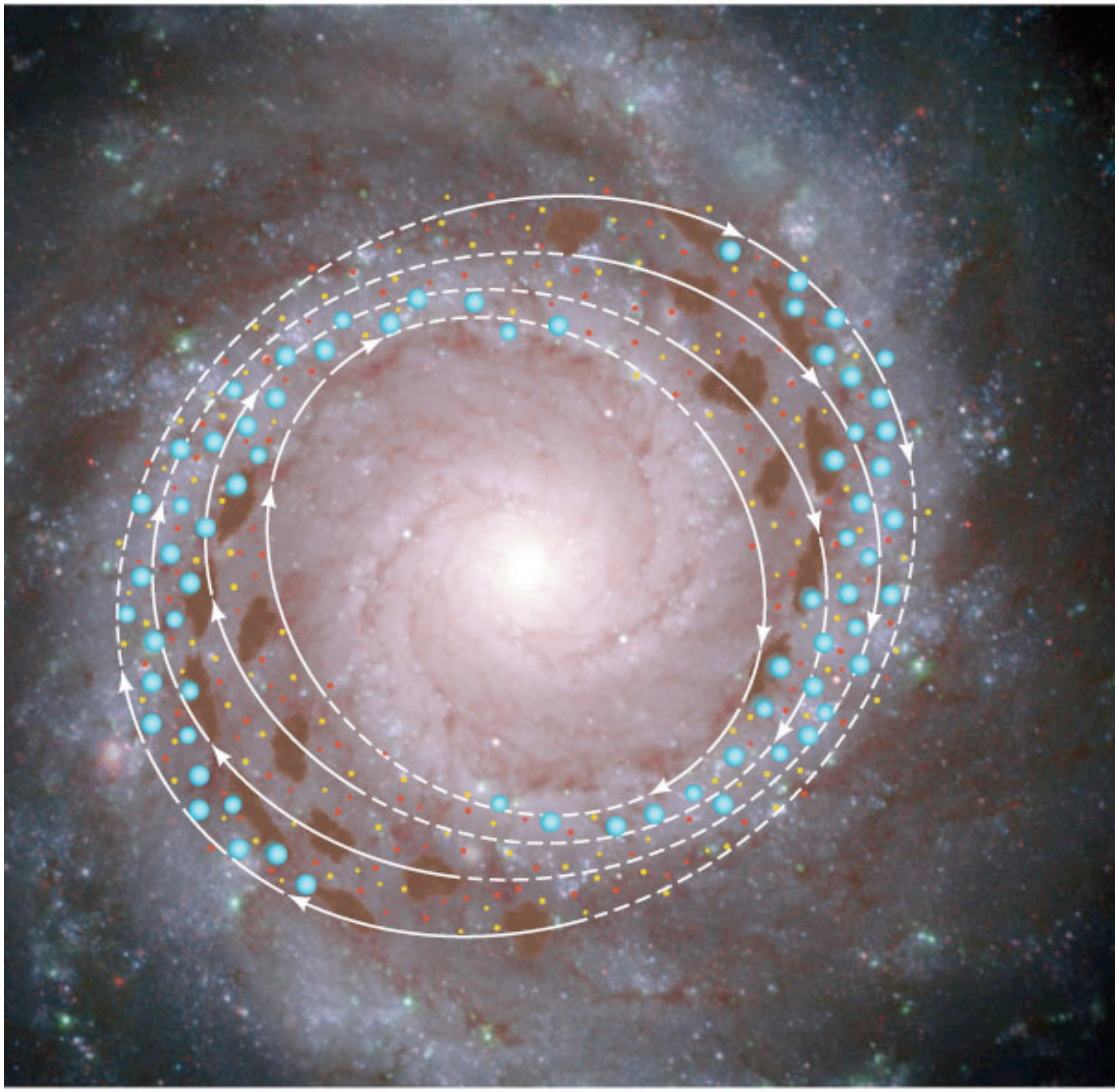
- Spiral arms must be where the matter is, so why don't they wind up very tightly over the ~50 orbits they have performed?
- Answer: spiral arms are *not* persistent density enhancements! Instead they are the sites of active star formation; these last for times less than one orbit.



Spiral arms are waves of star formation:

1. Gas clouds get squeezed as they move into spiral arms.

2. The squeezing of clouds triggers star formation.

3. Young stars flow out of spiral arms.

# Stellar Populations

- **Population I**
  - circular orbits in plane of disk
  - mix of ages
    - young, newly formed OB stars
    - old stars (& everything in between)
  - metal rich, like sun (~2% mass in "metals")
  - recall: "metal" means element heavier than He
- **Population II**
  - elliptical orbits of all orientations
  - old stars only
  - metal poor in halo (~0.2% metals)