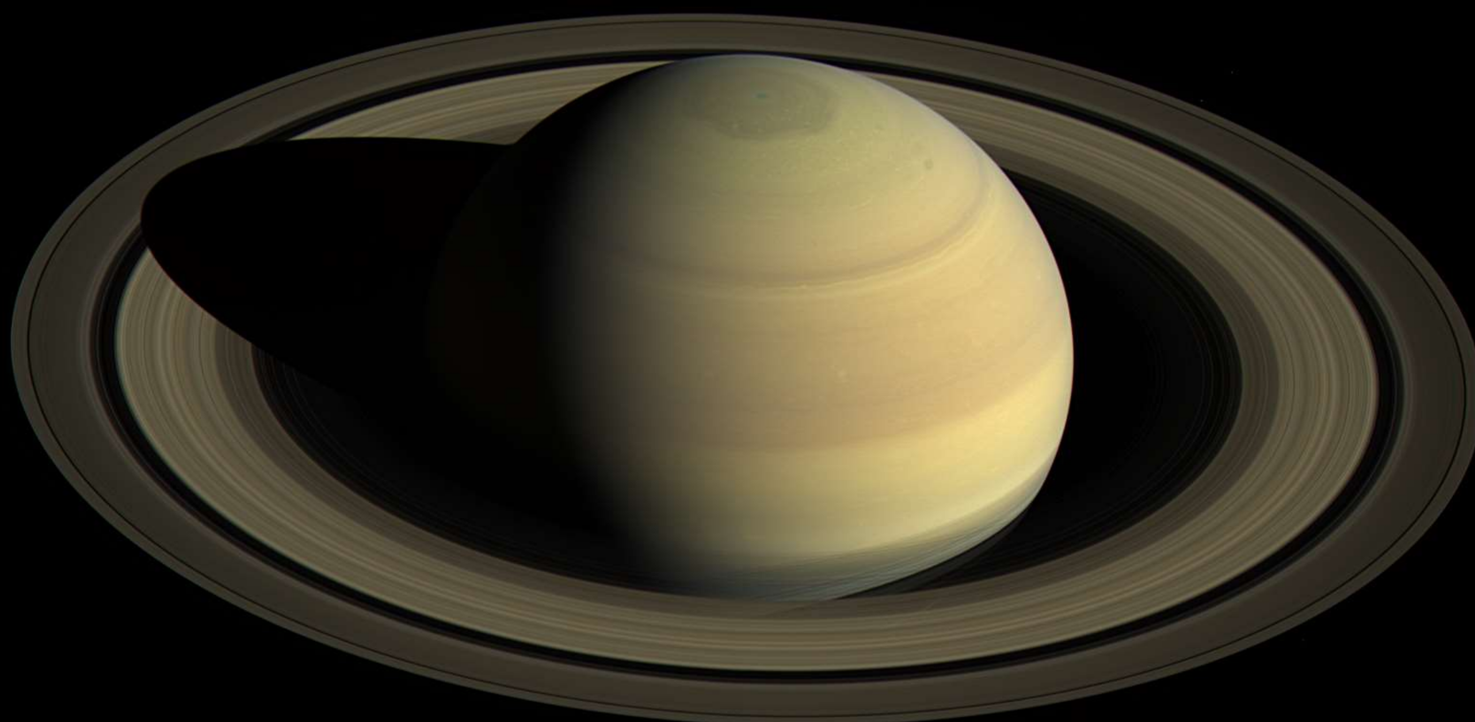
AST 2002
Introduction to Astronomy



A Few Quick Things…

E-mailing me: Must have AST2002 in the subject

Mary Hinkle, Graduate Teaching Assistant:

Office hours: Mon 1:30-3:00pm. PSB 316

My office hours: ~~Mon 3:00-4:00pm. PSB 308~~

~~Tue 3-4 pm. PSB 308~~

I will be in a teleconference next week. Will switch to Wed/Thur at 3 pm.

I will be in DC the week afterwards… Mon-Thur

Will try to get my Graduate student, Amy to cover Mon/Tue on both weeks… also in PSB316

Mid-term results are mostly in today (Best of 2 will count towards final grade)

Final: Friday 27th April. 7am-9:50 am. (on all chapters; ~ 100 questions. 25:25:25:25)

LAST Knights Under the Stars Event – Thursday 19th April

Opportunity to make up the 1% extra credit that was offered (if you haven't been yet, worth 2%) – Last chance for extra credit..

What did we cover last time?

Chapter 14: The Bizarre Stellar Graveyard

14.1. White Dwarfs

- What is a white dwarf?
- What can happen to a white dwarf in a close binary system?

14.2. Neutron Stars

- What is a neutron star?
- How were neutron stars discovered?
- What can happen to a neutron star in a close binary system?

14.3. Black Holes: Gravity's Ultimate Victory

- What is a black hole?
- What would it be like to visit a black hole?
- Do black holes really exist?

14.4. Stars in Close Binaries

- What causes gamma-ray bursts?
- What happens when black holes merge?

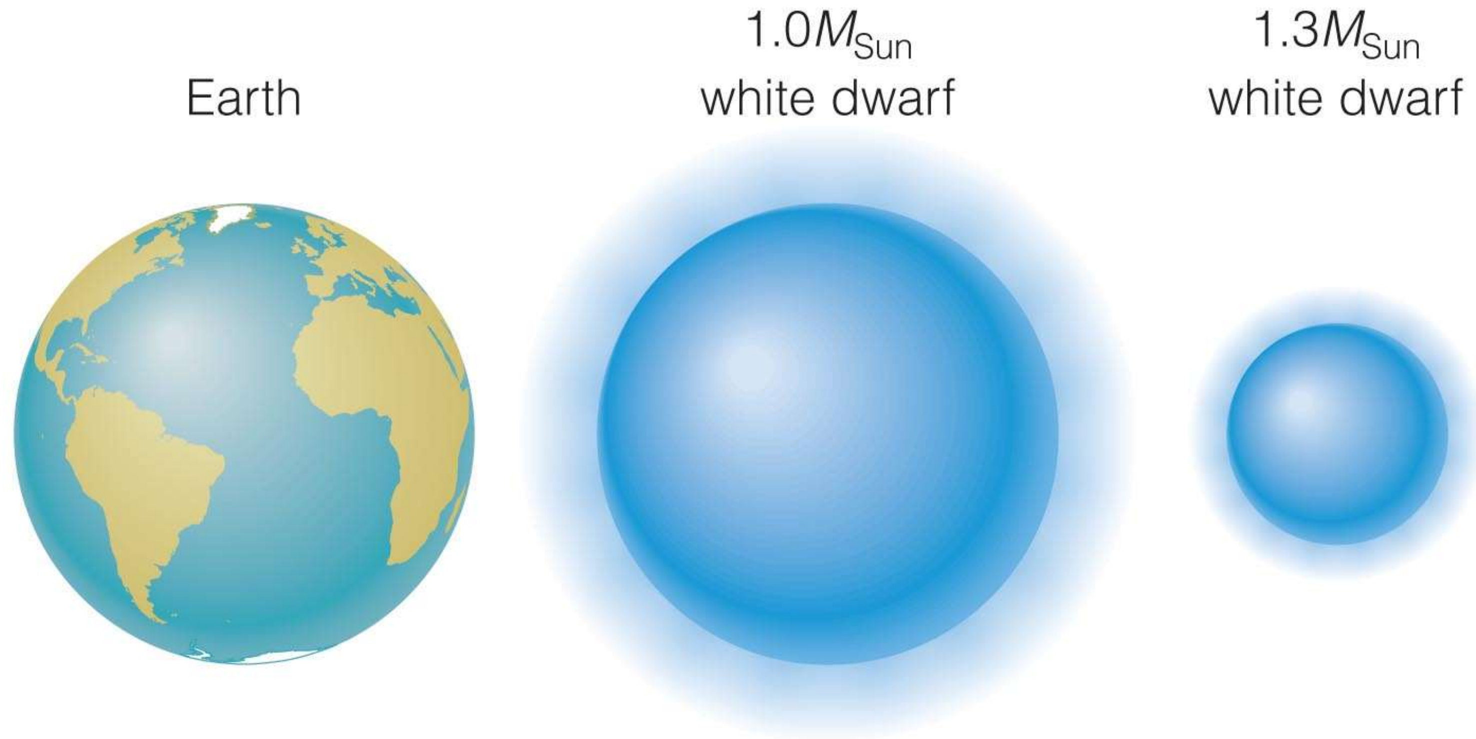
The Fate of Stars Based on Mass

The Ultimate Fate of Stars and Substellar Objects with Different Masses

Initial Mass (Mass of Sun = 1)[1]	Final State at the End of Its Life	
< 0.01	Planet	
0.01 to 0.08	Brown dwarf	
0.08 to 0.25	White dwarf made mostly of helium	
0.25 to 8	White dwarf made mostly of carbon and oxygen	
8 to 10	White dwarf made of oxygen, neon, and magnesium	$< 1.4\ M_{Sun}$
10 to 40	Supernova explosion that leaves a neutron star	$> 1.4\ M_{Sun}$
> 40	Supernova explosion that leaves a black hole	$> 3\ M_{Sun}$

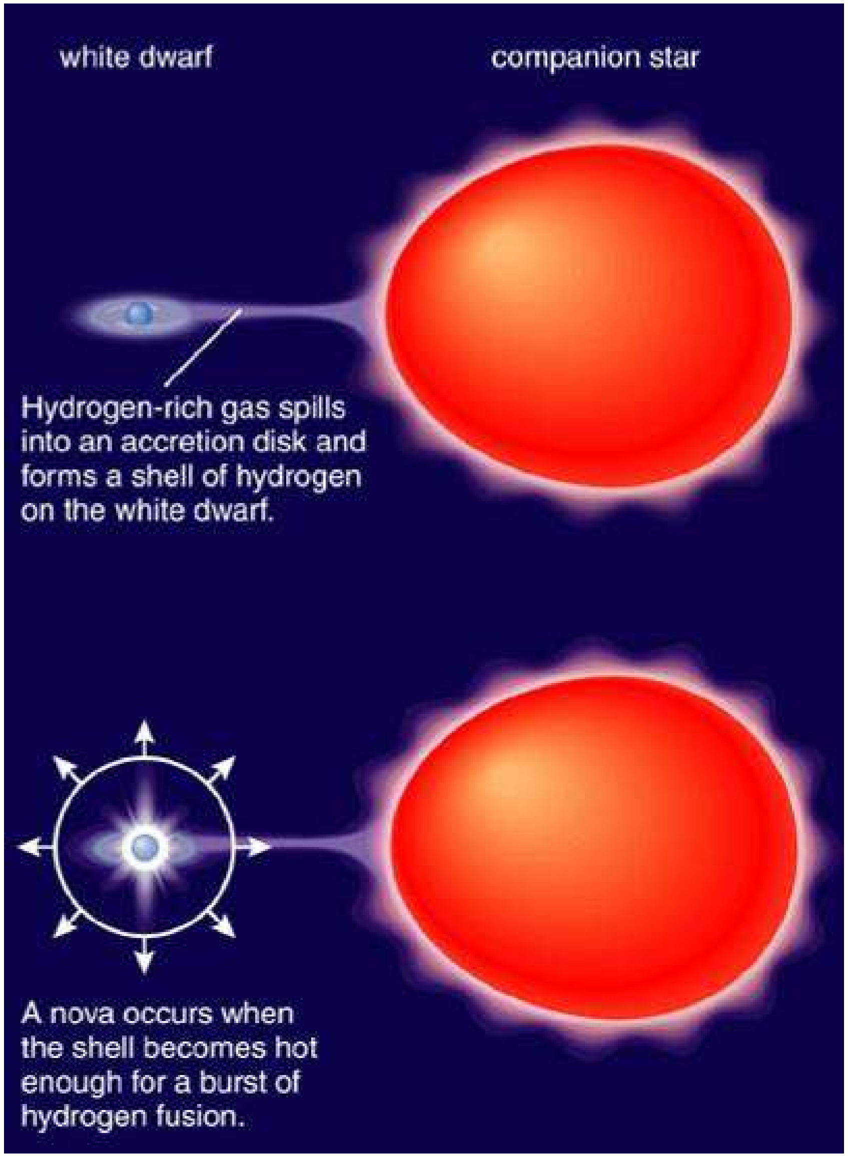
More massive stars lose more mass!

Leaving Behind a White Dwarf…



- White Dwarf's are the remaining cores of low-mass stars
- A 1.0 M_{Sun} white dwarf is about the same size as Earth
- A 1.3 M_{Sun} white dwarf is about half the size of Earth
- *All white dwarfs are supported by electron degeneracy pressure*

What is a Nova?



- Increased brightness up to 100,000 times
- Fades over months to years

What's happening?

1. Hydrogen from a neighboring star gets siphoned into an accretion disk around the white dwarf
2. Friction from the accretion disk causes some hydrogen to decay its orbit and build up mass on the hot white dwarf
3. Once sufficient mass is accreted the shell begins a short burst of hydrogen fusion.

Can occur regularly with ~ hundreds to thousands of years between events…

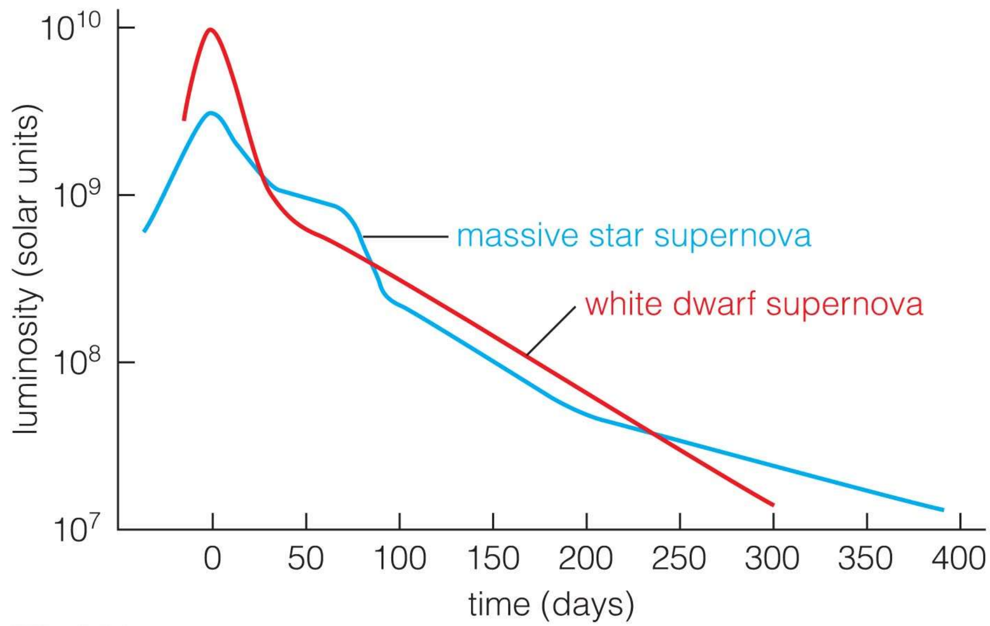
There are Two Types of Supernova

Massive star supernova: (Type II)
Iron core of massive star reaches white dwarf limit and collapses into a neutron star, causing an explosion. Neutron star or black hole remains

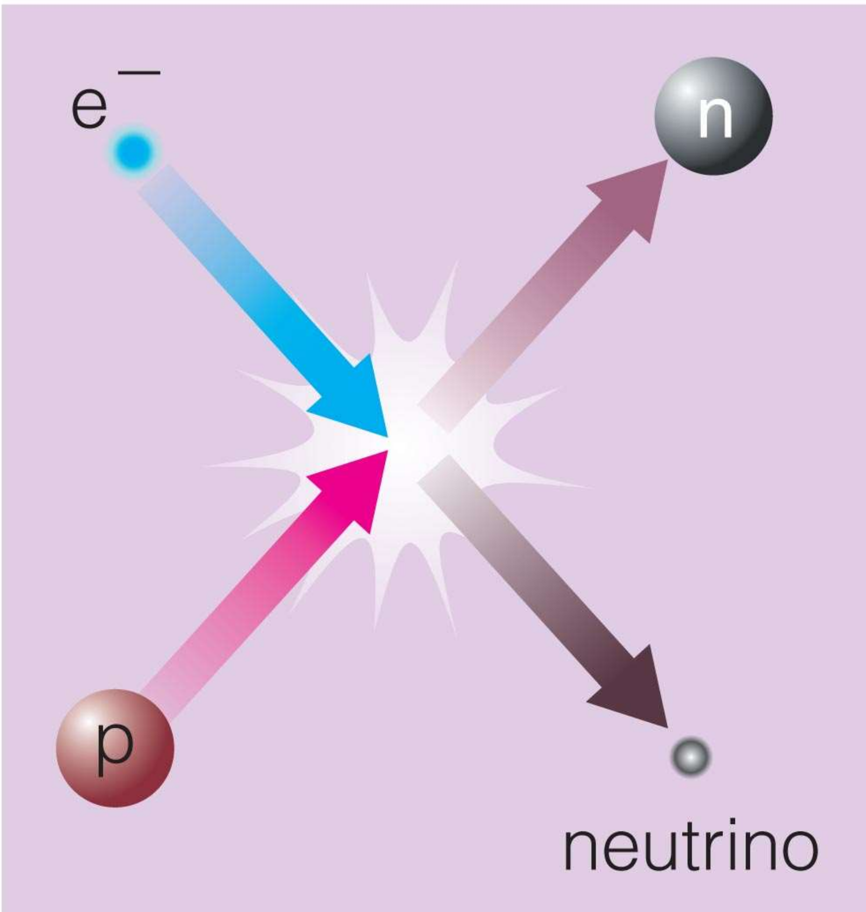
White dwarf supernova*:* (Type 1a)
Carbon fusion suddenly begins as white dwarf in close binary system reaches white dwarf limit, causing a total explosion. Nothing remains

Massive star supernovae have additional heat from radioactive decay from unstable elements formed by the r-process…

White dwarf supernovae are very bright and have similar luminosities
→ Act as a standard candle



What is a Neutron Star?



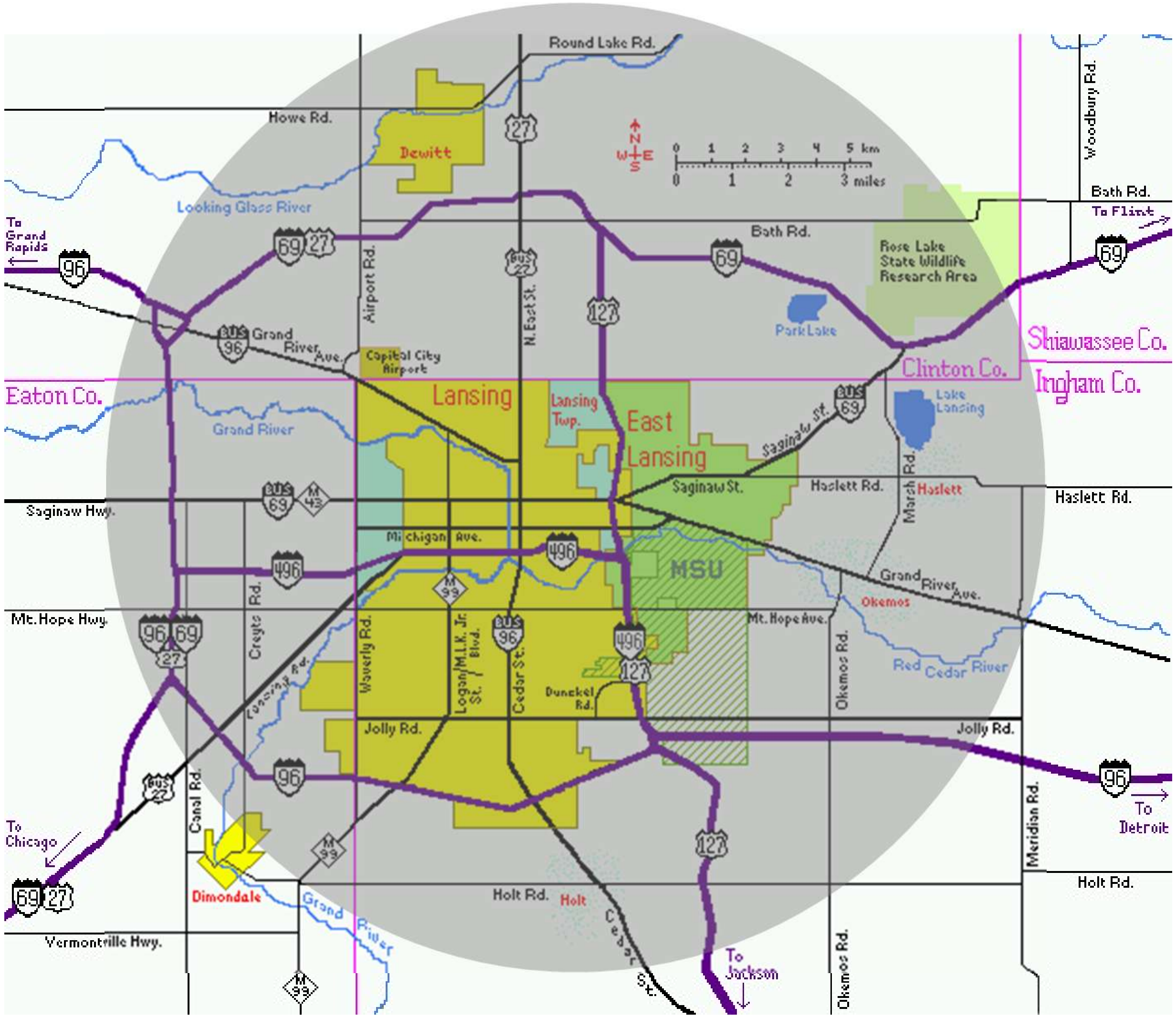
If the pressure within the core of a star exceeds the **electron degeneracy pressure,** electrons and protons recombine to make neutrons and neutrinos.

In a type II supernova, the neutrons may carry away ~10^{46} W of energy…
(more luminous than an entire galaxy)

Neutrons collapse to form a neutron star which is ~ 95% neutrons with some other protons and electrons remaining.

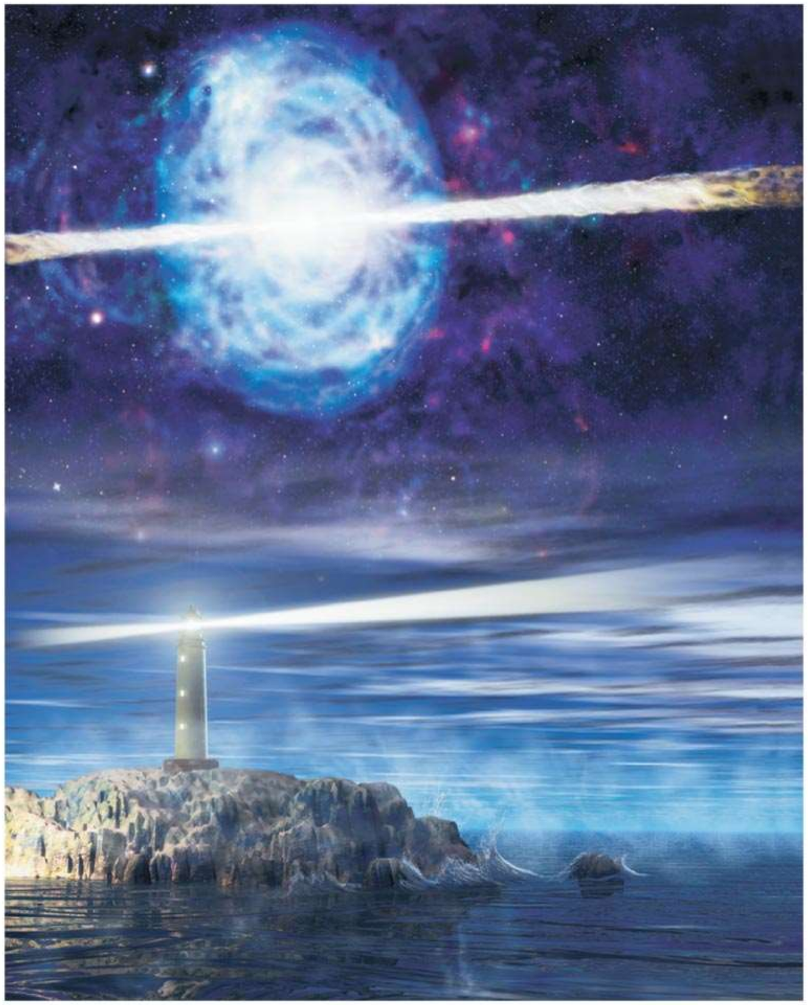
Neutron stars are held from total collapse by **neutron degeneracy pressure**. Neutron star limit ~ 3 M_{Sun}

How Big is a Neutron Star?

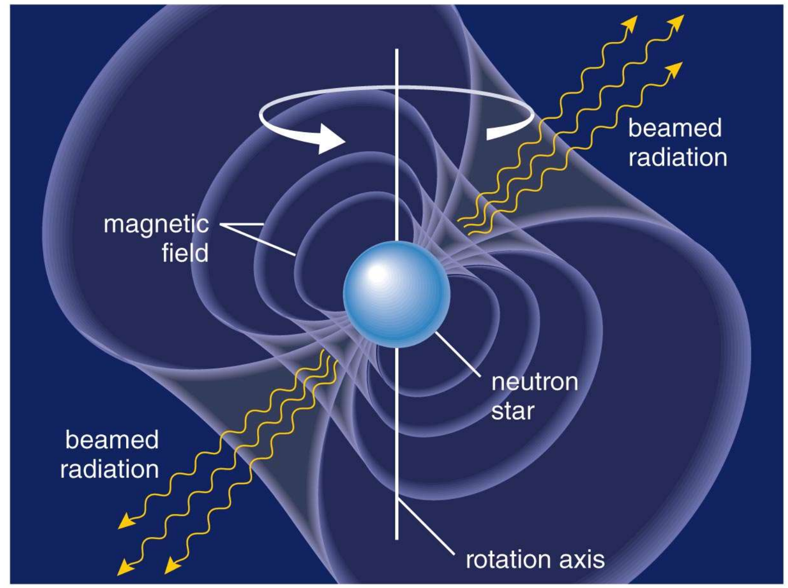


A neutron star is about the same size as a small city… but ~1-3 M_{Sun}

What is a Pulsar?



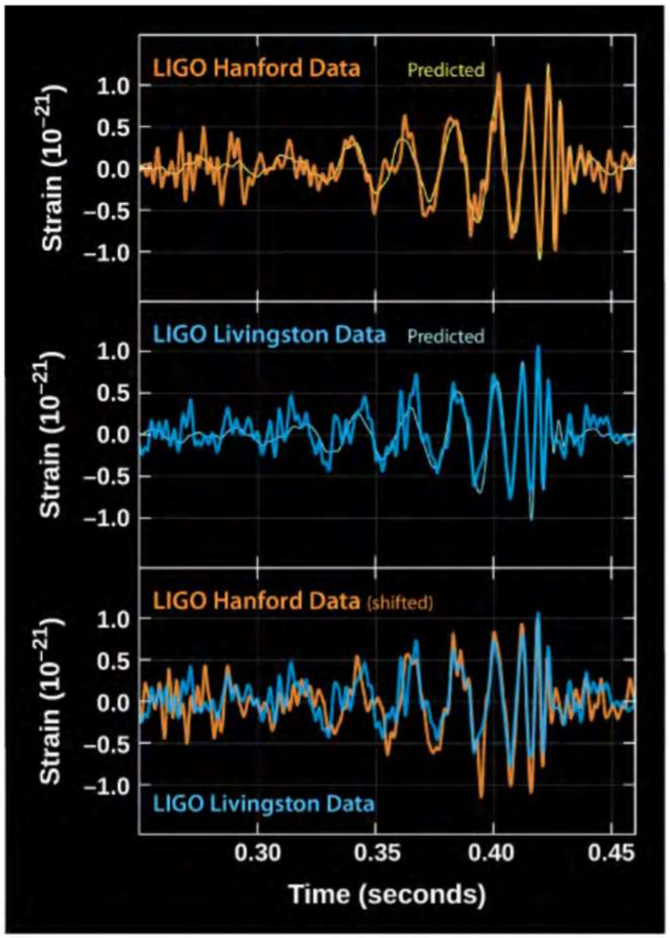
b If the magnetic axis is not aligned with the rotation axis, the pulsar's beams sweep through space like lighthouse beams. Each time one of the pulsar's beams sweeps across Earth, we see a pulse of radiation.



a A pulsar is a rotating neutron star that beams radiation along its magnetic axis.

- The magnetic field from the star is trapped within a very small space…
- Magnetic axis not necessarily aligned with rotation axis…
- Radiation sweeps across the Universe like a lighthouse – observed by Bell.

Detection of Gravity Waves
(from Merging Neutron Stars & Black Holes)



Merger of two black holes 20 and 36 times the mass of the Sun

But Wait, what are Black Holes?

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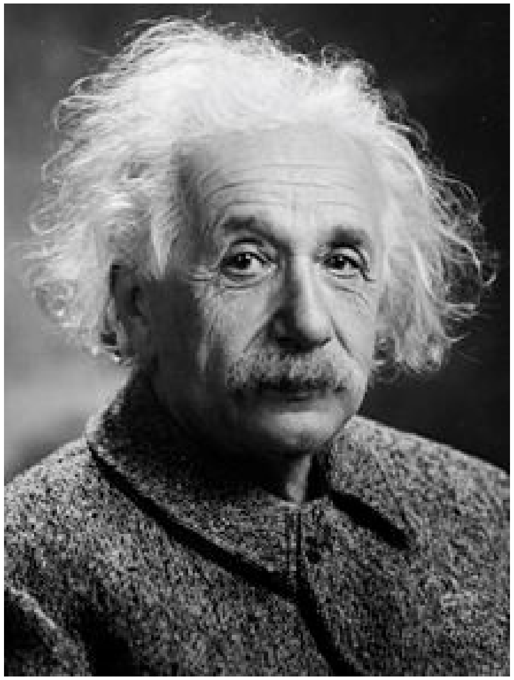
Aside: What is Special Relativity?

The speed of light is constant relative to your reference frame…

1. The laws of nature are the same for everyone
2. The speed of light is the same for everyone

Example for an astronaut…

$E=mc^2$



A few things happen:

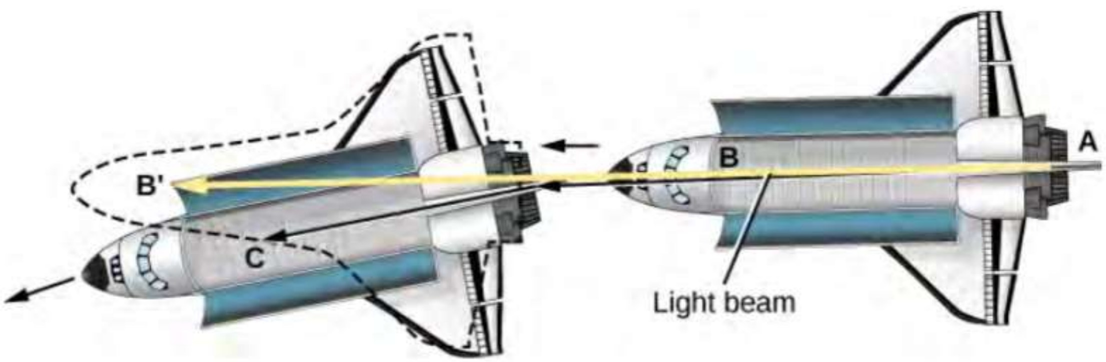
- Mass increases as you go faster
- Size gets compressed as you move faster
- **Time slows down as you go faster**

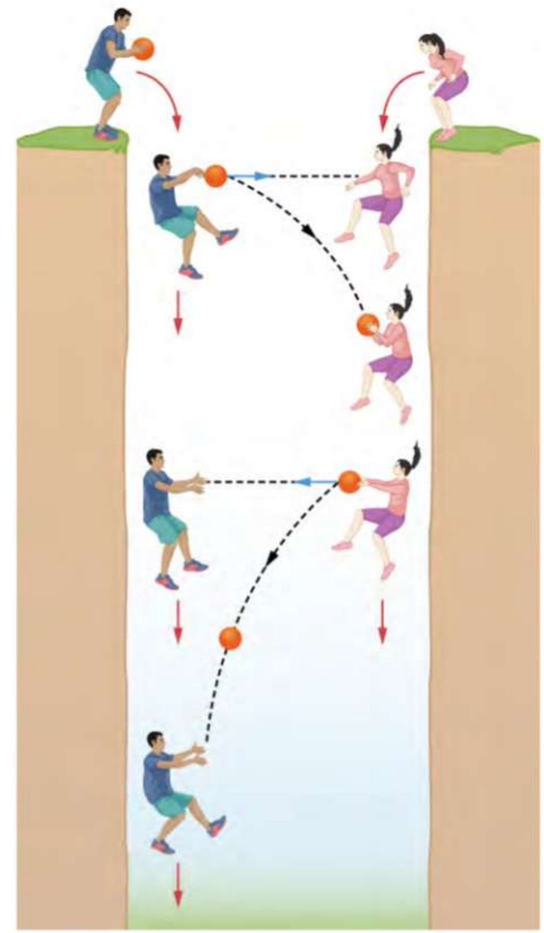
Aside: What is the Equivalence Principle?

It is impossible for us to determine our relative motion:

Example: Being in an elevator, or a plane…

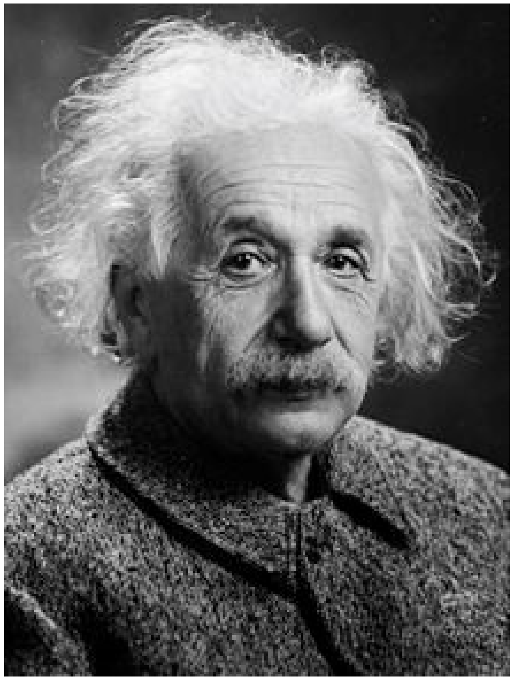
Are we in free fall, or not moving at all?





Gravity must be bending the light, but how?

Aside: What is General Relativity?



Light follows the shortest paths on spacetime (geodesic paths)

Gravity causes spacetime to slow down

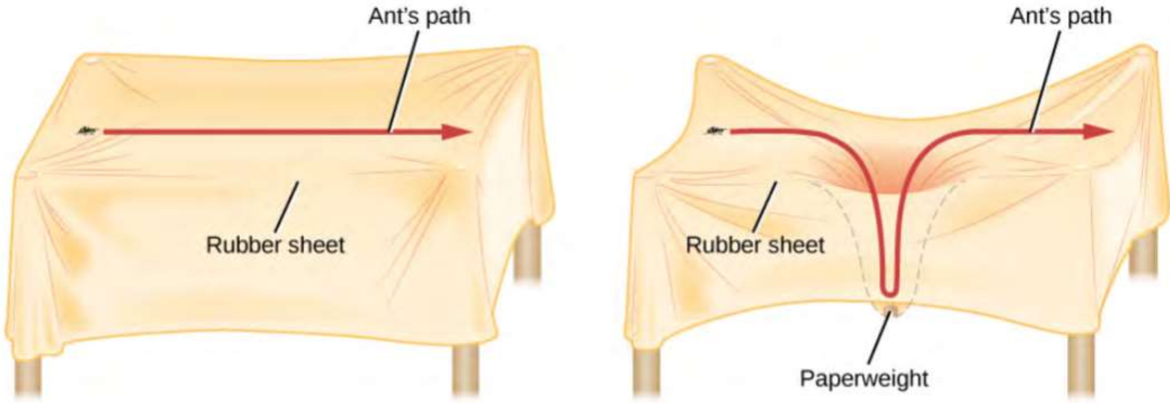


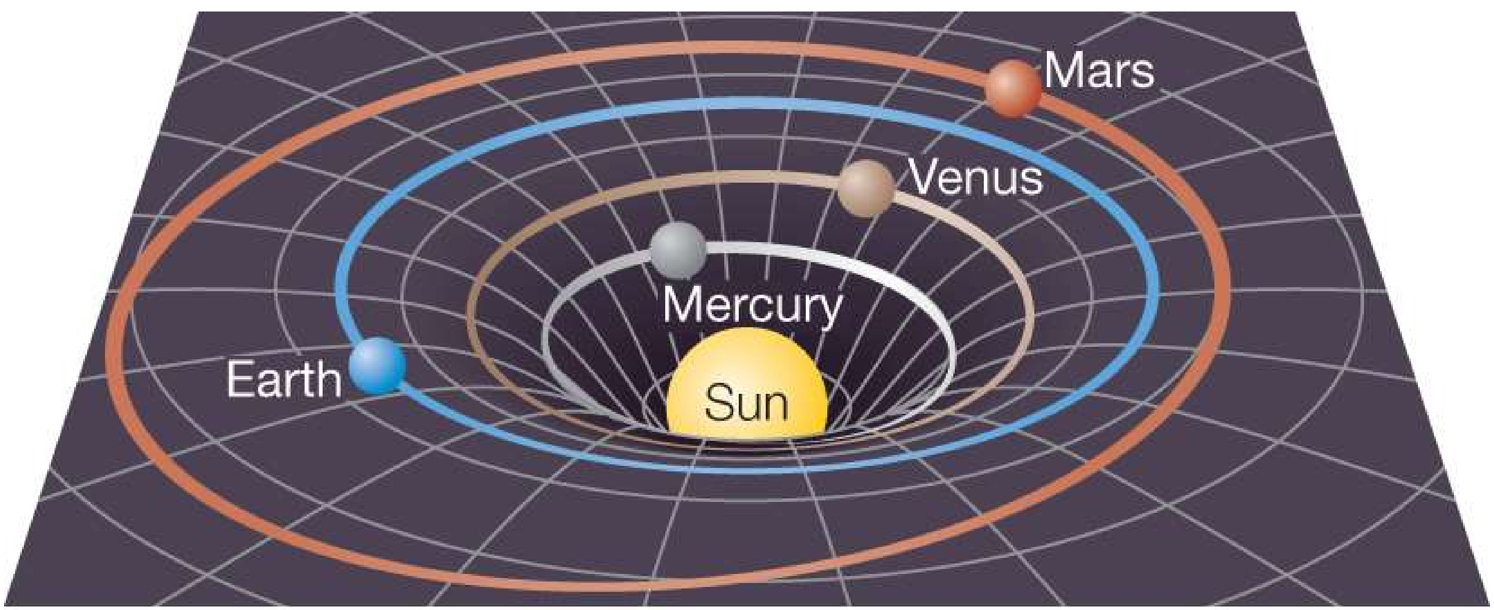
Figure 24.8 Three-Dimensional Analogy for Spacetime. On a flat rubber sheet, a trained ant has no trouble walking in a straight line. When a massive object creates a big depression in the sheet, the ant, which must walk where the sheet takes it, finds its path changed (warped) dramatically.

NEW

More on General Relativity

- Acceleration and gravity are indistinguishable…
- Gravity arises from the curve of spacetime…
- Light follows shortest (geodesic) paths
- Has been proven by putting atomic clocks on high-rise buildings…

The Take-home message: Time slows down near gravitational fields…



Example: GPS Satellites

GPS relies on ~ 24 satellites orbiting Earth, where at any time 4 of them are in line of sight of any position on Earth, allowing accuracy to better than 50 feet.

To judge distance, the satellites have very accurate atomic clocks, but they must be corrected for:

Special Relativity: The satellites are traveling at ~14,000 kilometers per hour… as they approach the speed of light, time slows down. They need to be corrected by ~ 7 millionths of a second per day.

General Relativity: BUT, the satellites are 20,000 kilometers above Earth, where gravity is about four times weaker. According to general relativity, these satellites would tick about 45 millionths of a second faster than they would on Earth.

Overall correction is that they tick ~ 38 microseconds faster than on Earth.

Example: Mercury

Mercury precession should be 531 arcseconds per century but is actually 574 arcseconds per century.

→ Caused many astronomers to search for Vulcan

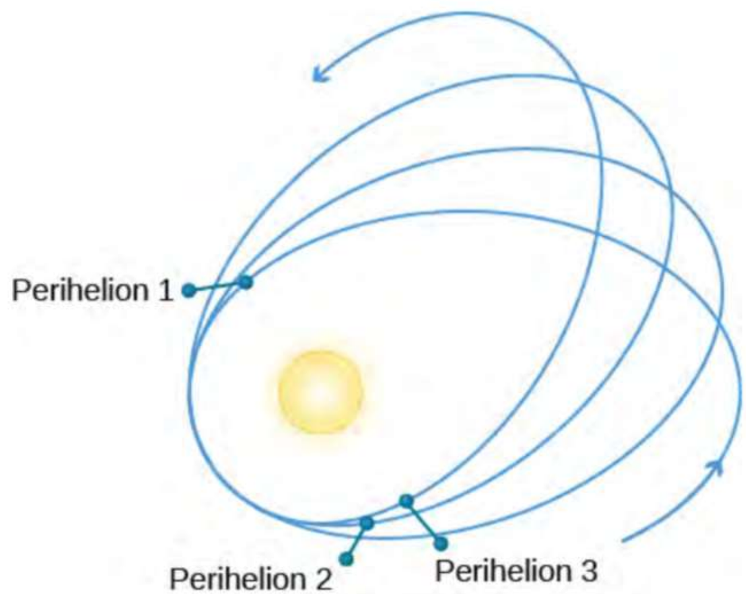
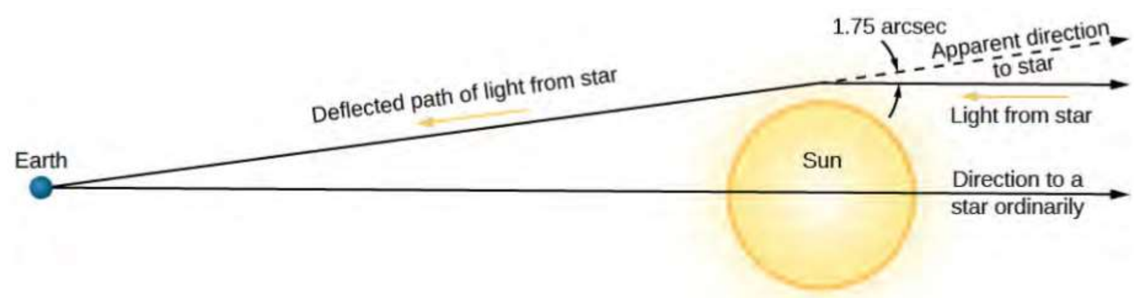


Figure 24.9 Mercury's Wobble. The major axis of the orbit of a planet, such as Mercury, rotates in space slightly because of various perturbations. In Mercury's case, the amount of rotation (or orbital precession) is a bit larger than can be accounted for by the gravitational forces exerted by other planets; this difference is precisely explained by the general theory of relativity. Mercury, being the planet closest to the Sun, has its orbit most affected by the warping of spacetime near the Sun. The change from orbit to orbit has been significantly exaggerated on this diagram.

Example: Bending of Light

Can be observed by comparing night sky 6 months apart from a solar eclipse



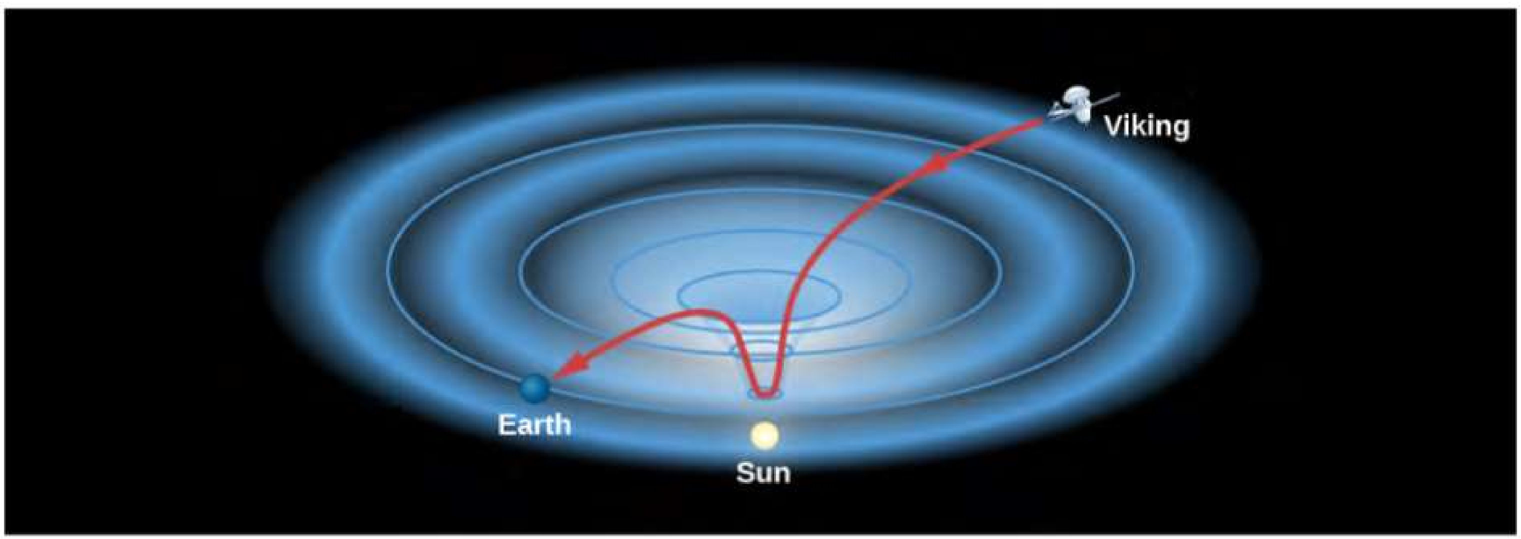
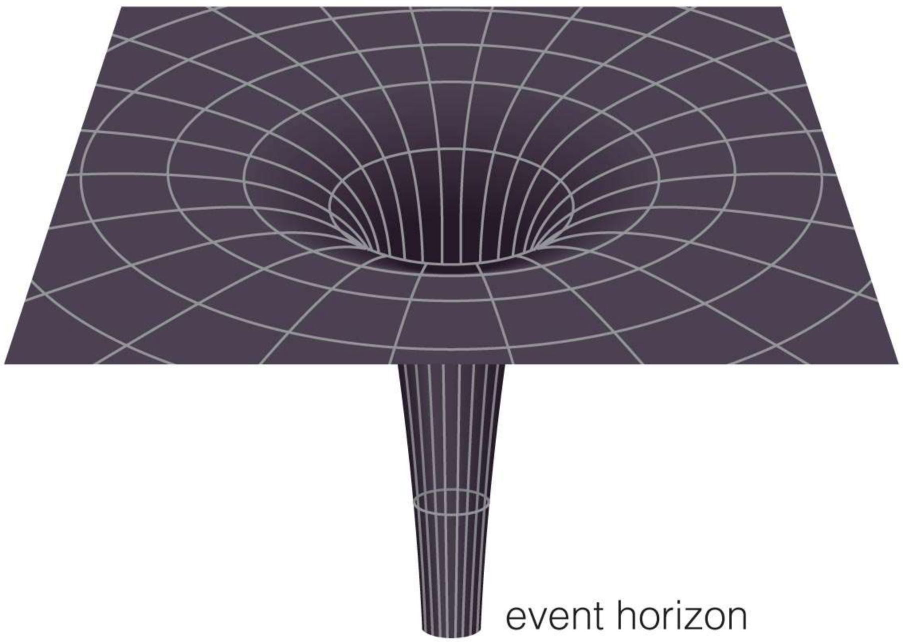


Figure 24.11 Time Delays for Radio Waves near the Sun. Radio signals from the Viking lander on Mars were delayed when they passed near the Sun, where spacetime is curved relatively strongly. In this picture, spacetime is pictured as a two-dimensional rubber sheet.

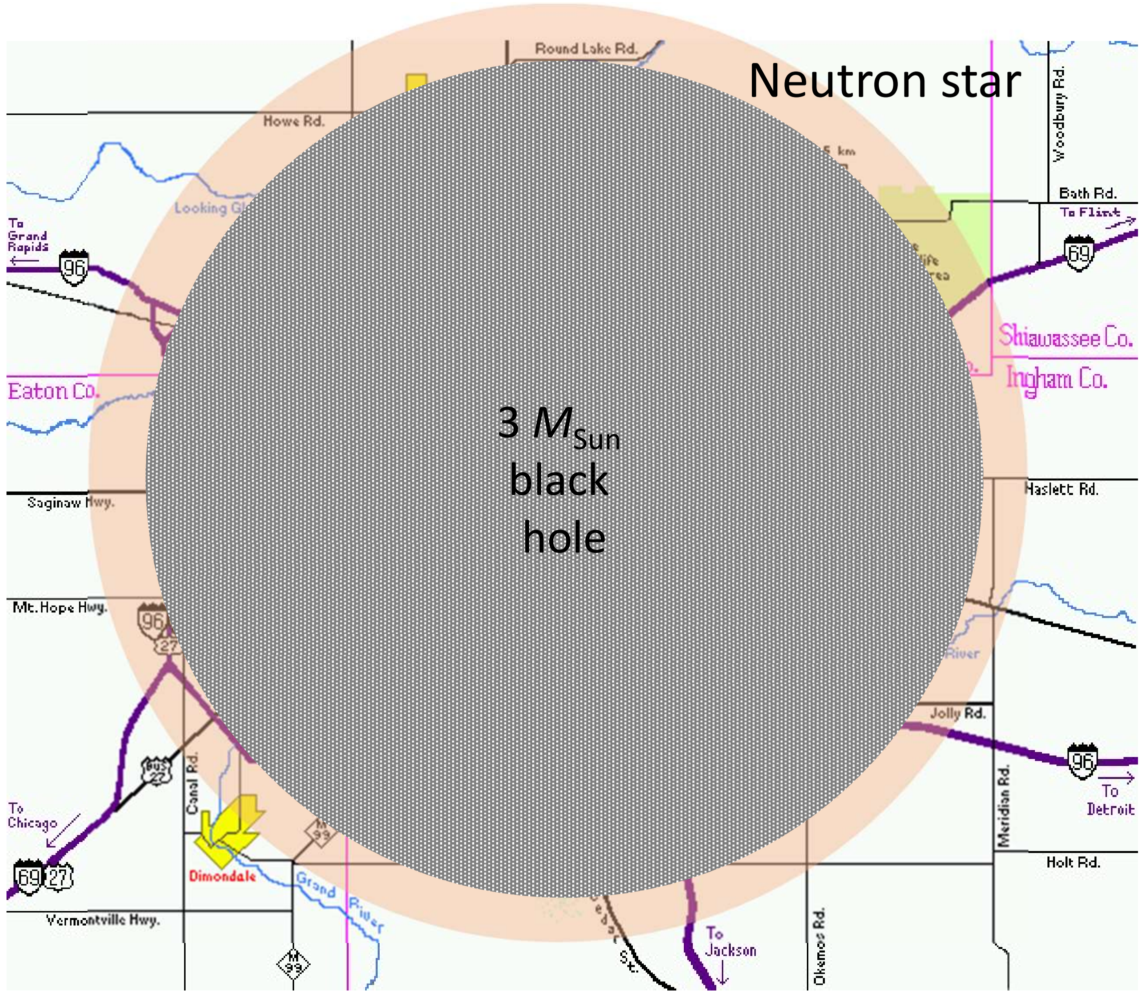
What is a black hole?



c The curvature of spacetime becomes greater and greater as we approach a black hole, and a black hole itself is a bottomless pit in spacetime.

- A ***black hole*** is an object whose gravity is so powerful that not even light can escape it.
- Some massive star supernovae can make a black hole if enough mass falls onto the core.
- Nothing can stop it from collapsing anymore – it becomes an infinitely dense point… a **Singularity.**

How Big is a Black Hole?



The event horizon of a 3M_{Sun} black hole is also about as big as a small city.

NEW

The Surface of a Black Hole

- The "surface" of a black hole is the radius at which the escape velocity equals the speed of light
- The spherical surface is known as the event horizon
- The radius of the event horizon is known as the Schwarzschild radius

$$R_S = 3.0 \times \frac{M}{M_{Sun}} km$$

For the Sun, Rs is about 3 km.

For supermassive blackholes, the size is comparable to that of the solar system… (~ 1000-1000 AU)

What Happens to Light Near a Black Hole?

Schwarzschild radius would be about 3 kilometers for our Sun

Gravity does not change substantially unless you get within about 5 Schwarzschild radii

Blackholes don’t suck!

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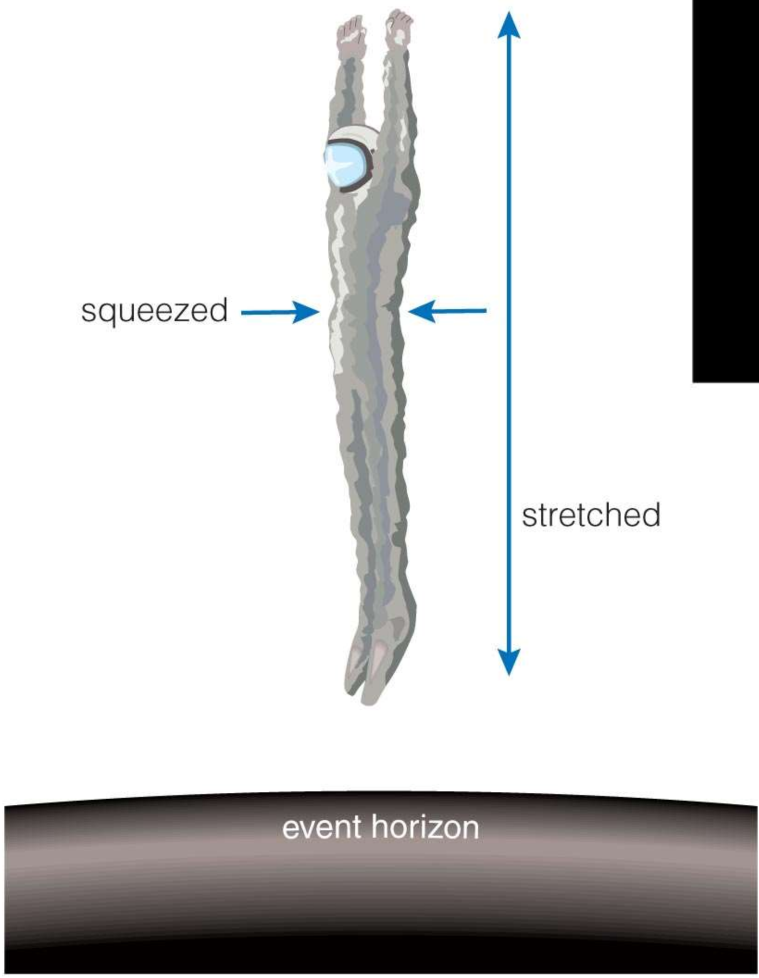
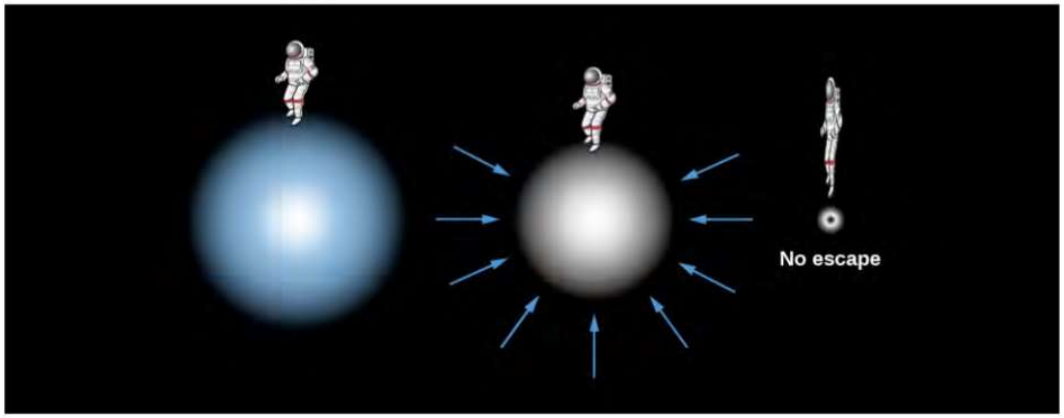
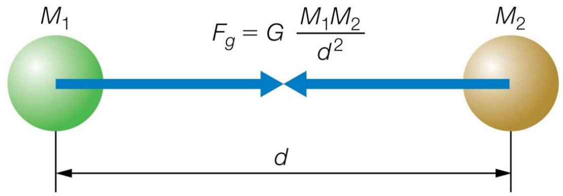
What Happens When you Get Near a Black Hole?





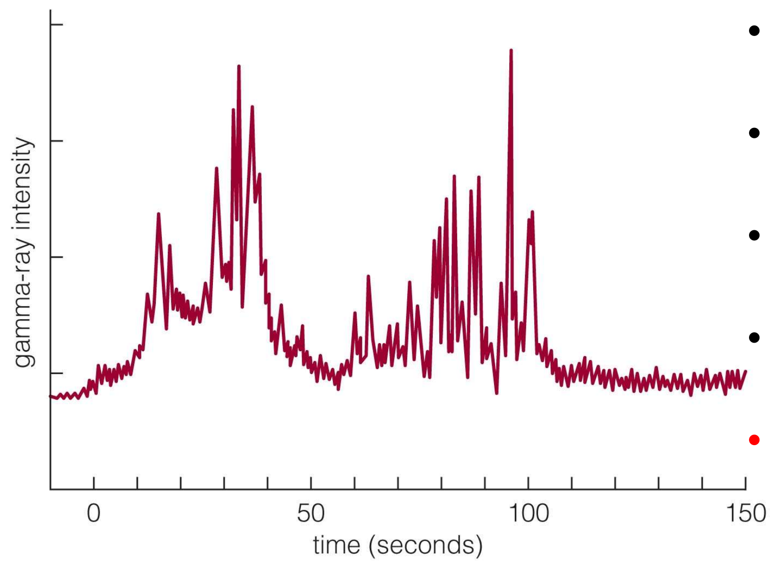
Tidal forces near the event horizon of a $3M_{Sun}$ black hole would be lethal to humans.



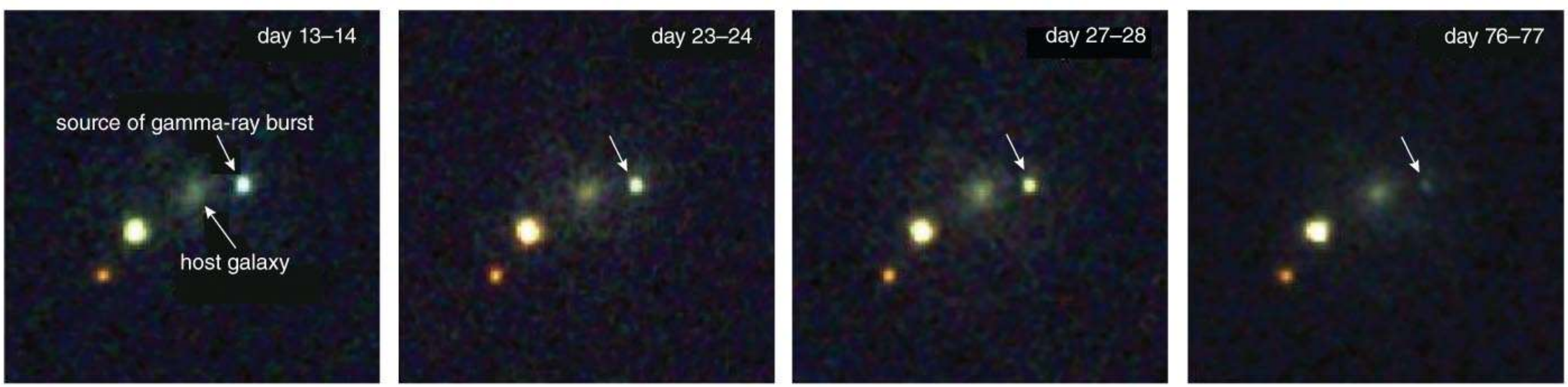
Tidal forces would be gentler near a supermassive black hole because its radius is much bigger. (Gravity differences would be less)

NEW

Gamma Ray Bursts



- Brief bursts of gamma rays coming from space were first detected in the 1960s.
- Observations in the 1990s showed that many gamma-ray bursts were coming from very distant galaxies.
- Observations show that at least some gamma-ray bursts are produced by supernova explosions.
- Some others may come from collisions between neutron stars.
- Can be VERY energetic… some scientists believe were the cause of an extinction event 440 million yrs ago.



What's Next?

Chapter 15: Our Galaxy (Abridged)

15.1. The Milky Way Revealed

- What does our galaxy look like?
- How do stars orbit in our galaxy?

15.2. Galactic Recycling

- How is gas recycled in our galaxy?
- Where do stars tend to form in our galaxy?

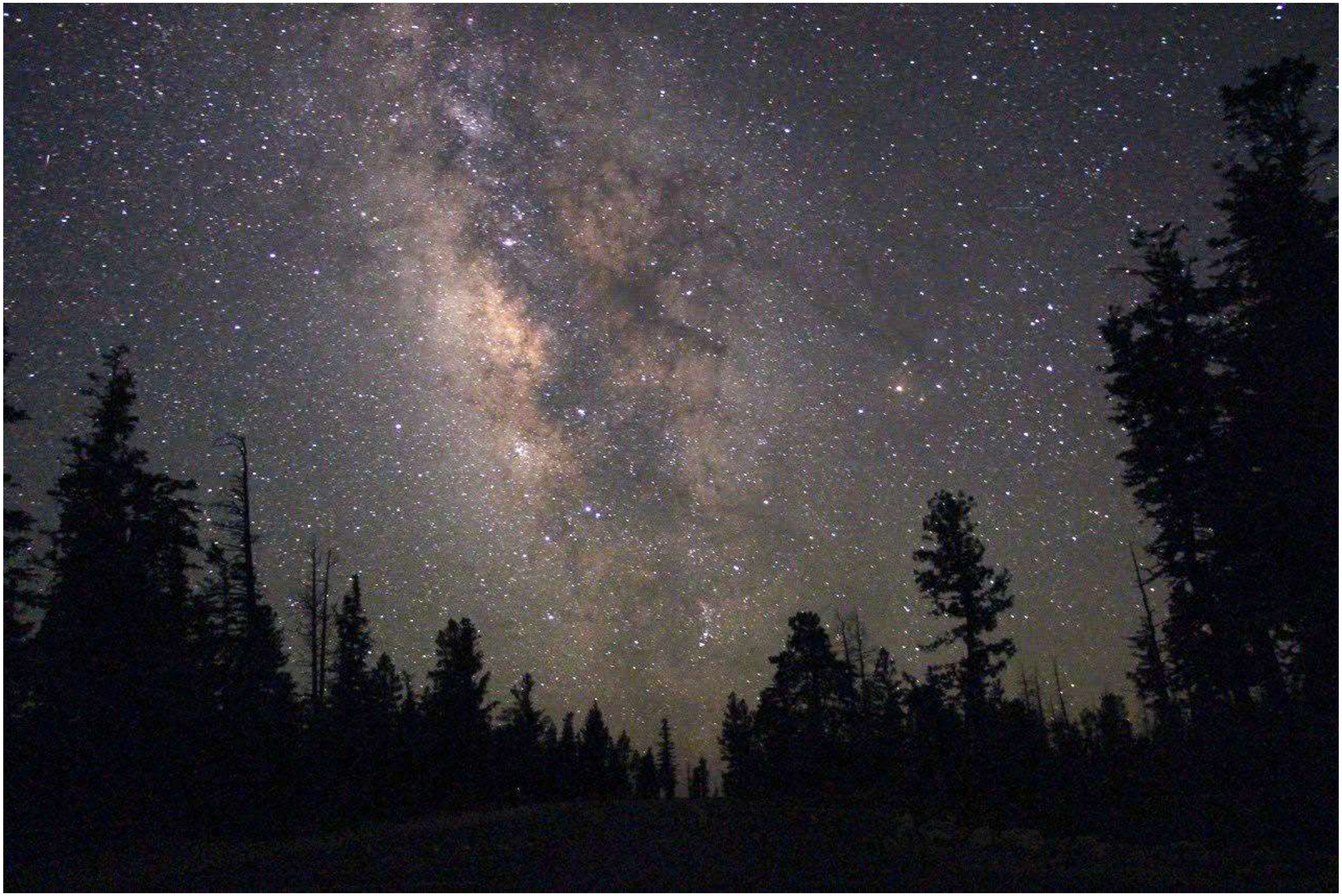
15.3. The History of the Milky Way

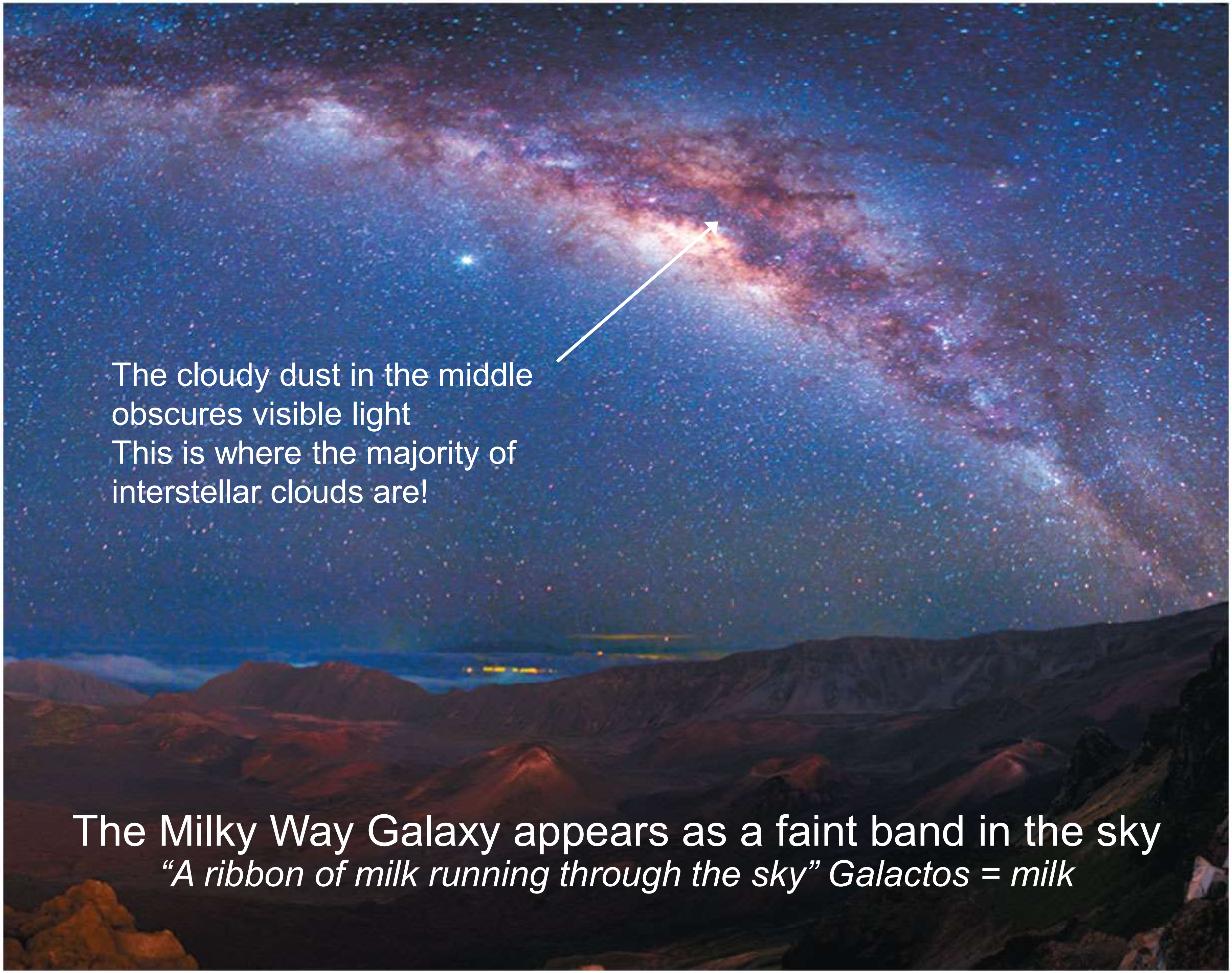
- What do halo stars tell us about our galaxy's history?
- How did our galaxy form?

15.4. The Galactic Center

- What is the evidence for a black hole at our galaxy's center?

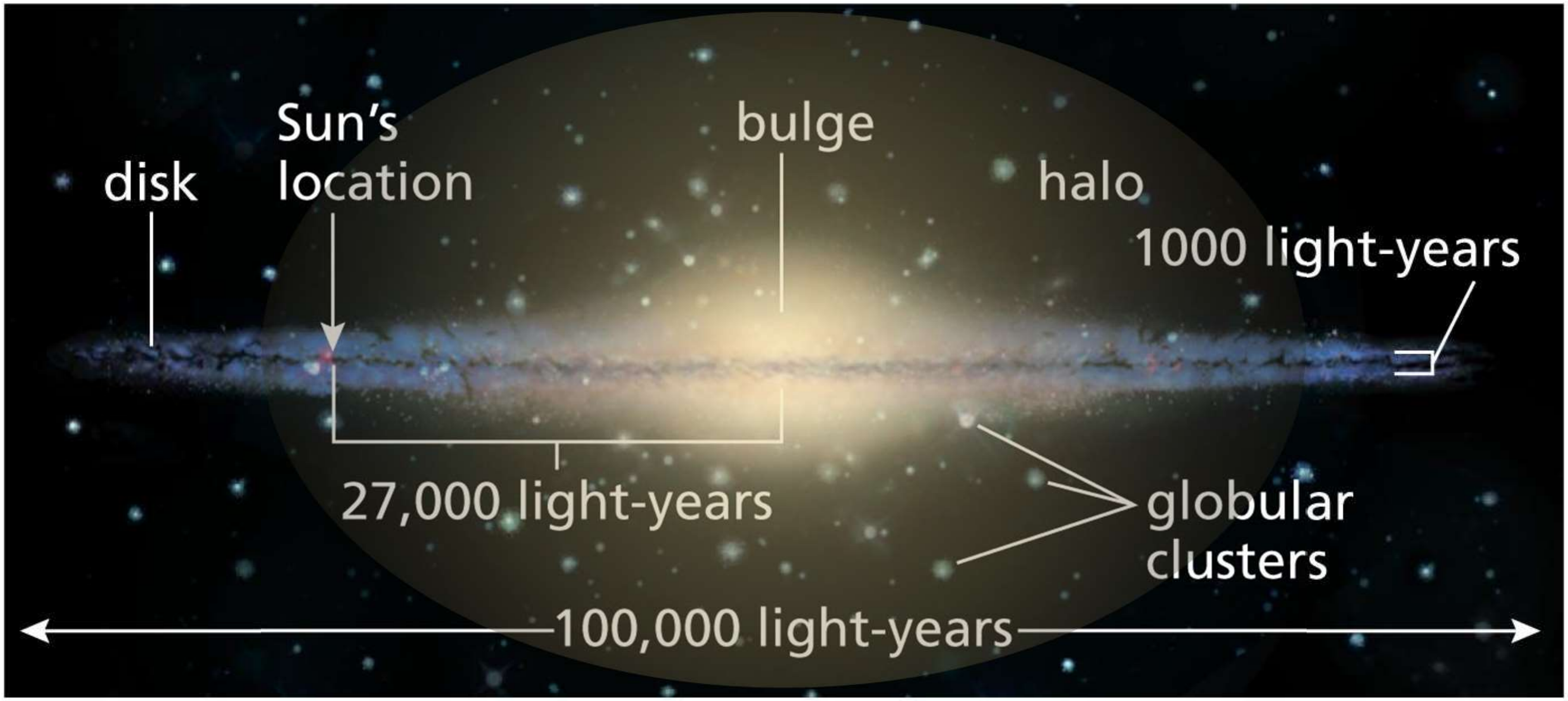
Have you Ever Noticed This?




The cloudy dust in the middle obscures visible light
This is where the majority of interstellar clouds are!
The Milky Way Galaxy appears as a faint band in the sky
"A ribbon of milk running through the sky" Galactos = milk

Edge-on View of the Milky Way*

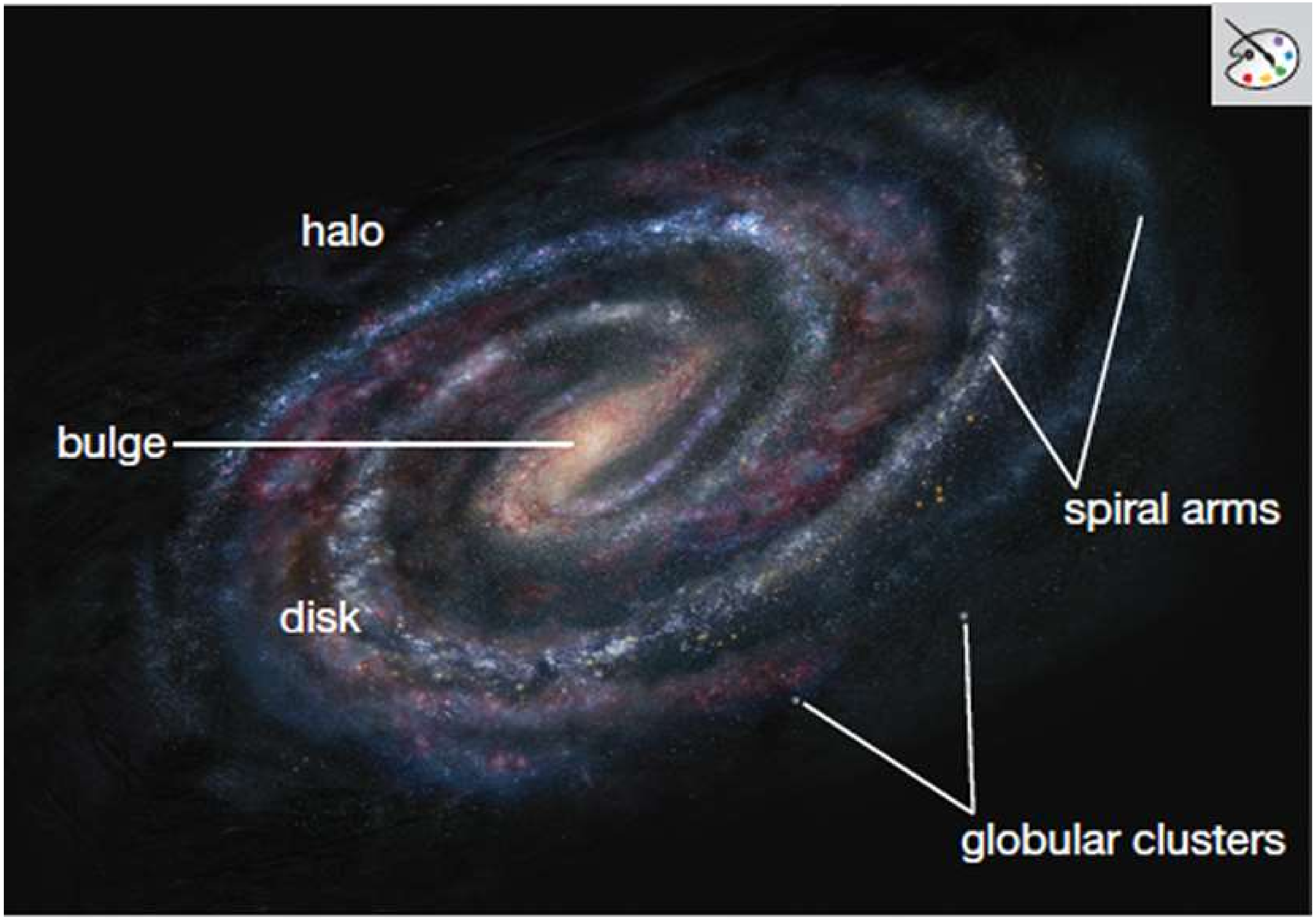
*** - artists impression!!**



b Edge-on schematic view of the Milky Way.

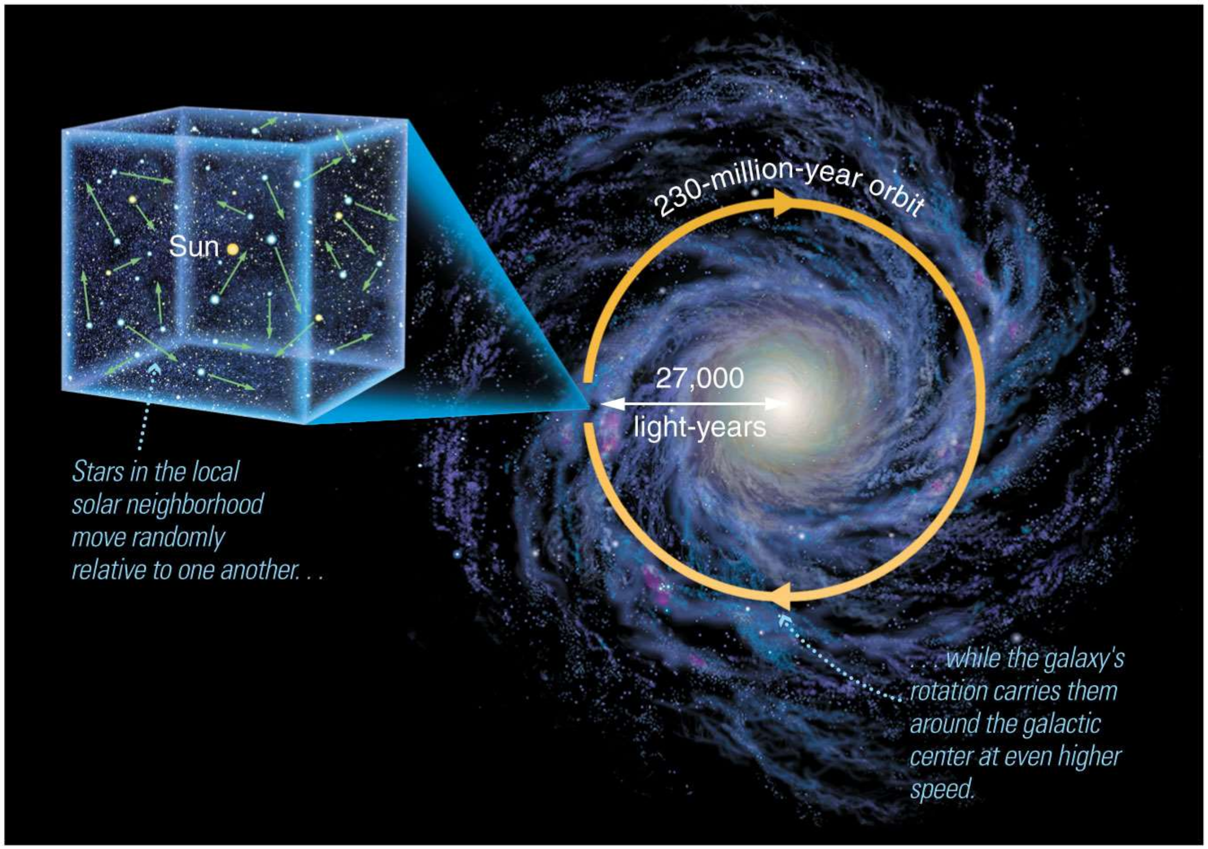
The halo is a ~ circular part surrounding the galaxy… emphasized here…

Outside View of the Milky Way



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

The Sun's Orbit in the Milky Way



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

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

$$M_r = \frac{r \times v^2}{G}$$

Thought Question

What is going to happen to the stars above and below the plane of the disk as they orbit?

A. They will stay in the same position relative to the disk as they orbit

B. The gravity of disk stars pulls them toward the disk, but they fall through it and bob up and down…

C. They would feel less gravity and drift away, but Halo stars knock them back into the disk.

Thought Question

What is going to happen to the stars above and below the plane of the disk as they orbit?

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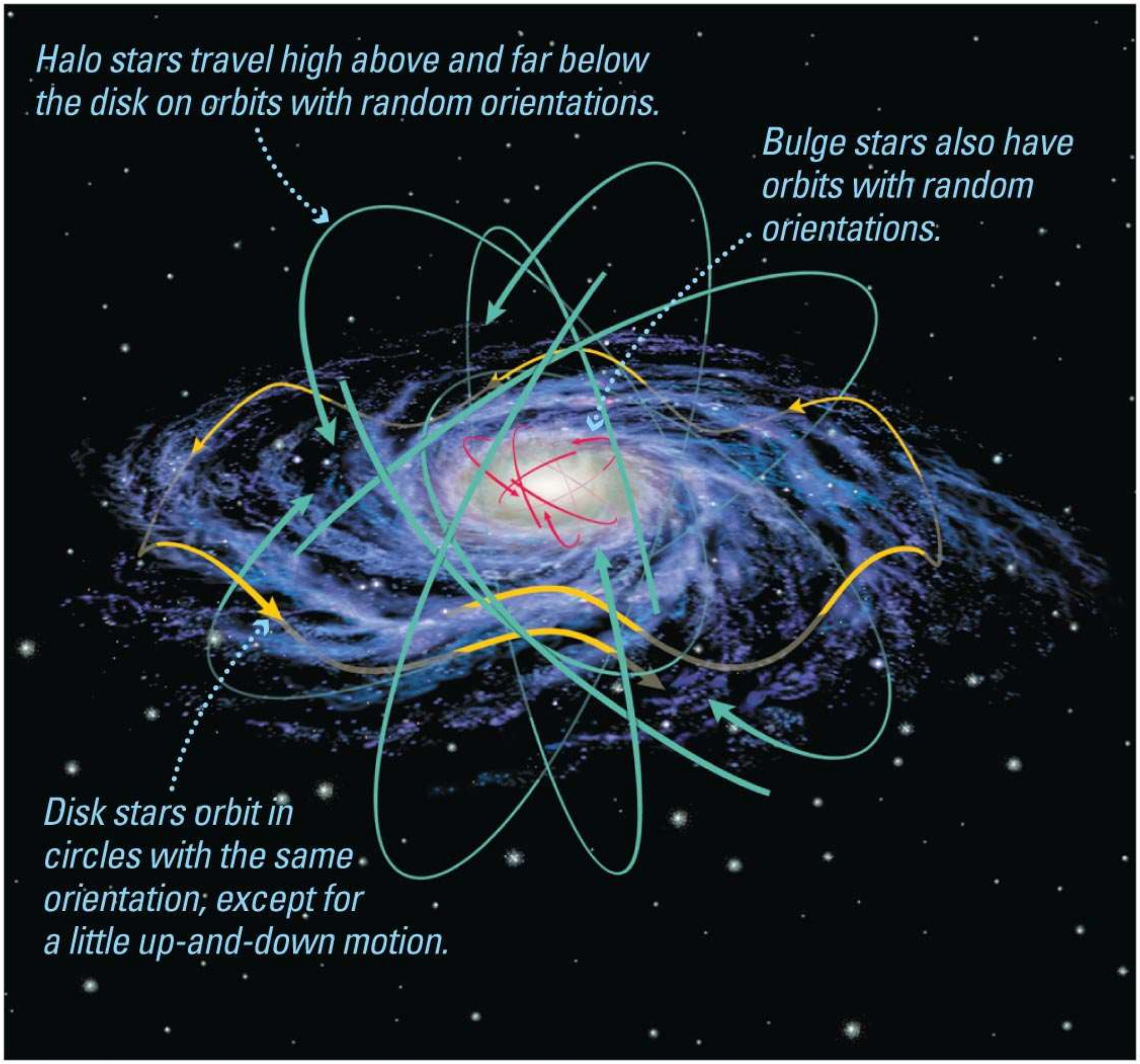
How do Stars Orbit our Galaxy?

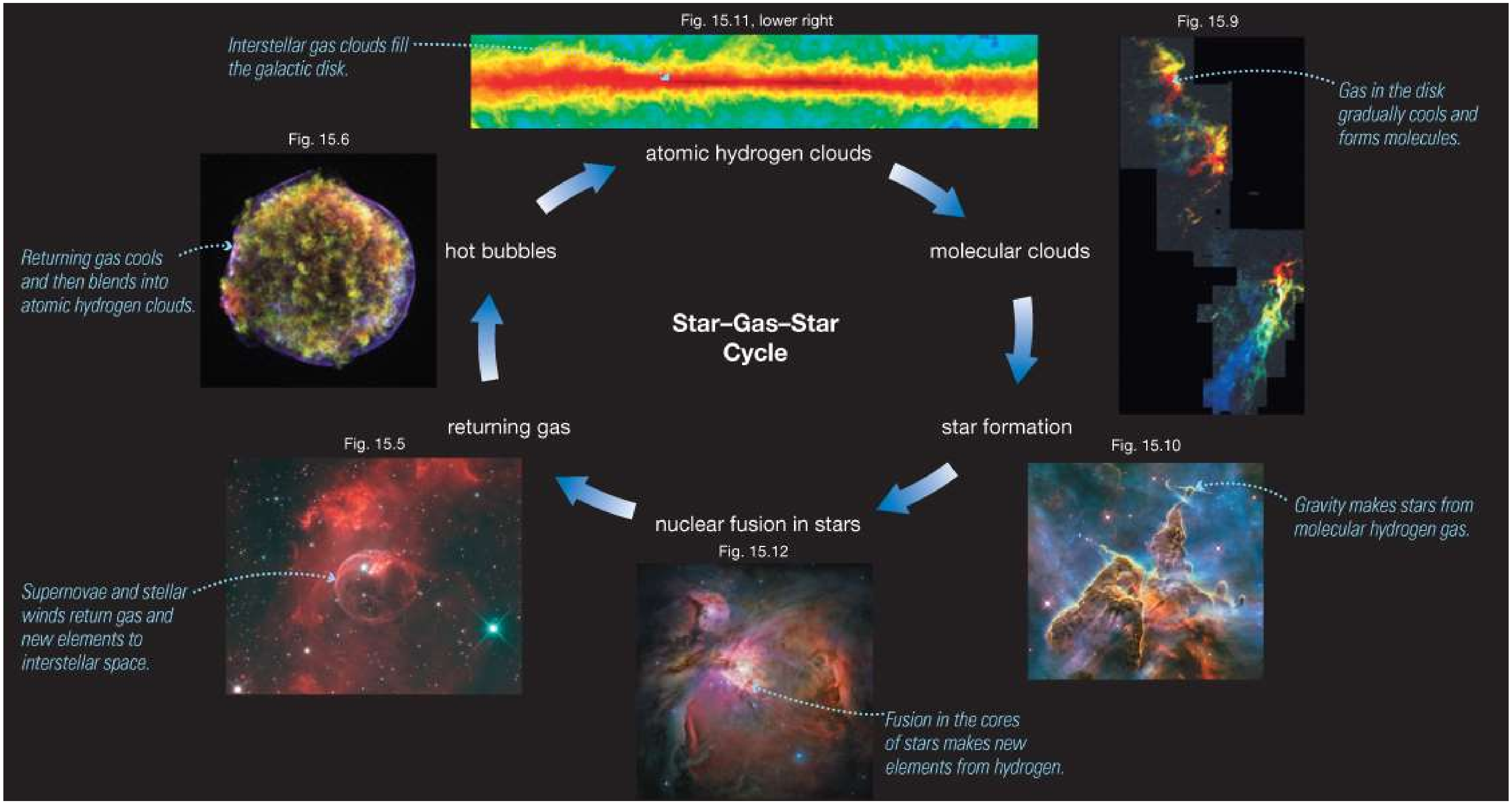


Disk stars have ~circular orbits and bob up and down *(like a merry-go-round), only they travel at the same speed (inner stars circle faster!)*

Halo stars have random orientations

Bulge stars are also have fairly random orientations

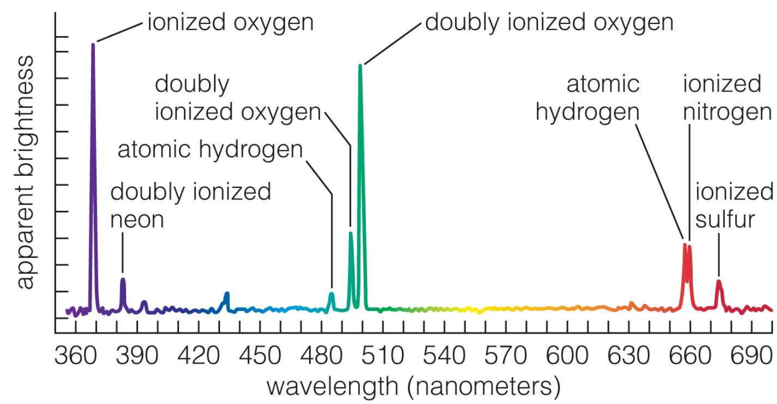
Galactic Recycling



Supernova Remnants

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.

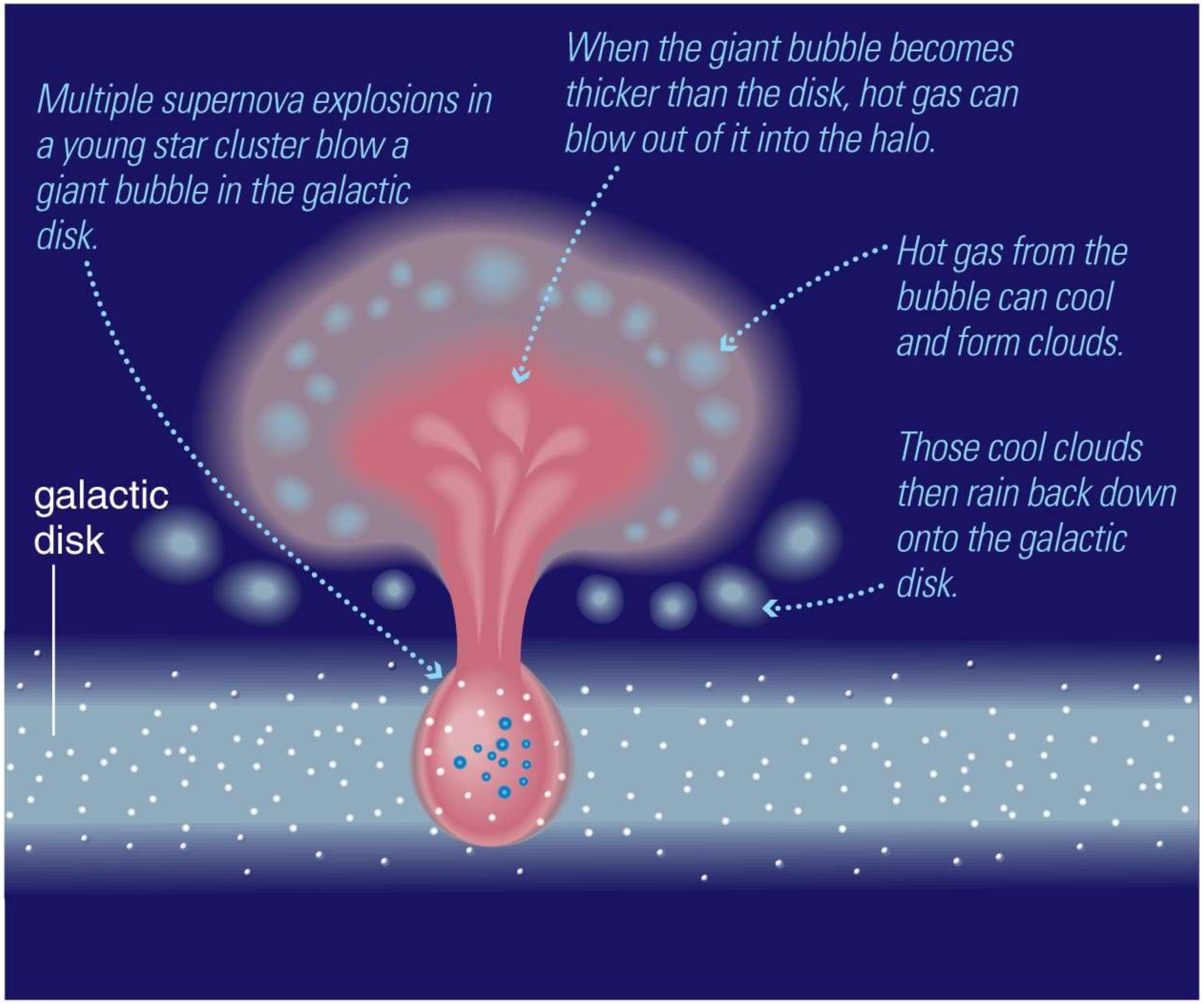
b This Hubble Space Telescope image shows fine filamentary structure in a small piece of the remnant. The colors come from emission lines of the atoms and ions indicated in part c.

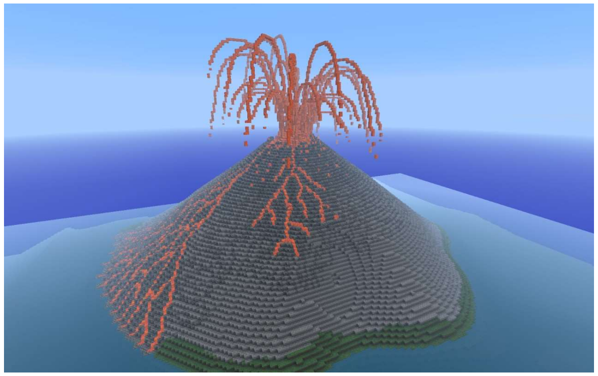


c A visible-light spectrum from the Cygnus Loop shows the strong emission lines that account for the distinct colors in the Hubble Space Telescope image.

These supernova Remnants eventually cool back down and reform clouds

Supernova Bubbles

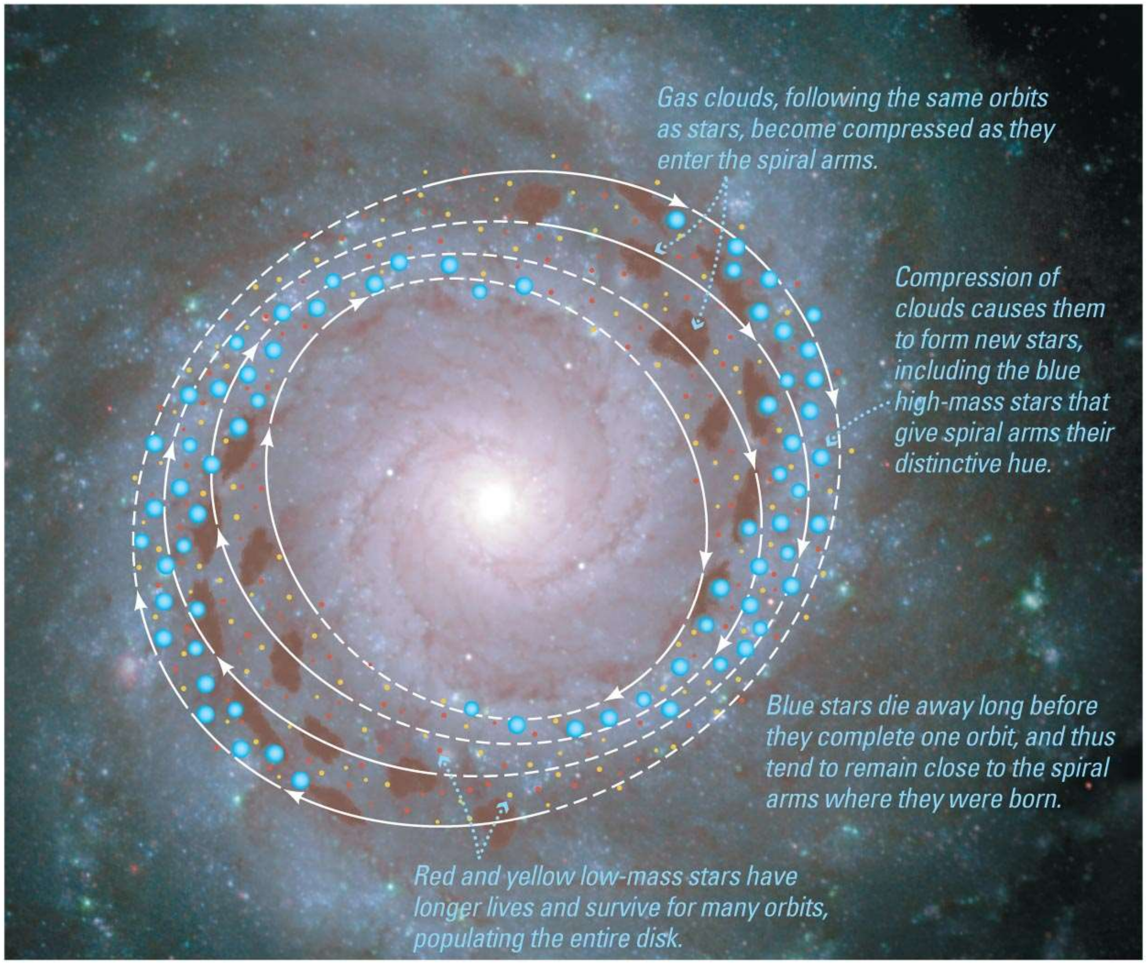




Gas and dust rains back down into the disk, cools and forms new interstellar clouds and stars

How does a Galaxy keep its Spiral?

Remember: The stars orbital velocities are ~ the same, so stars closer will orbit faster



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.

Star Formation Occurs in the Spiral Arms

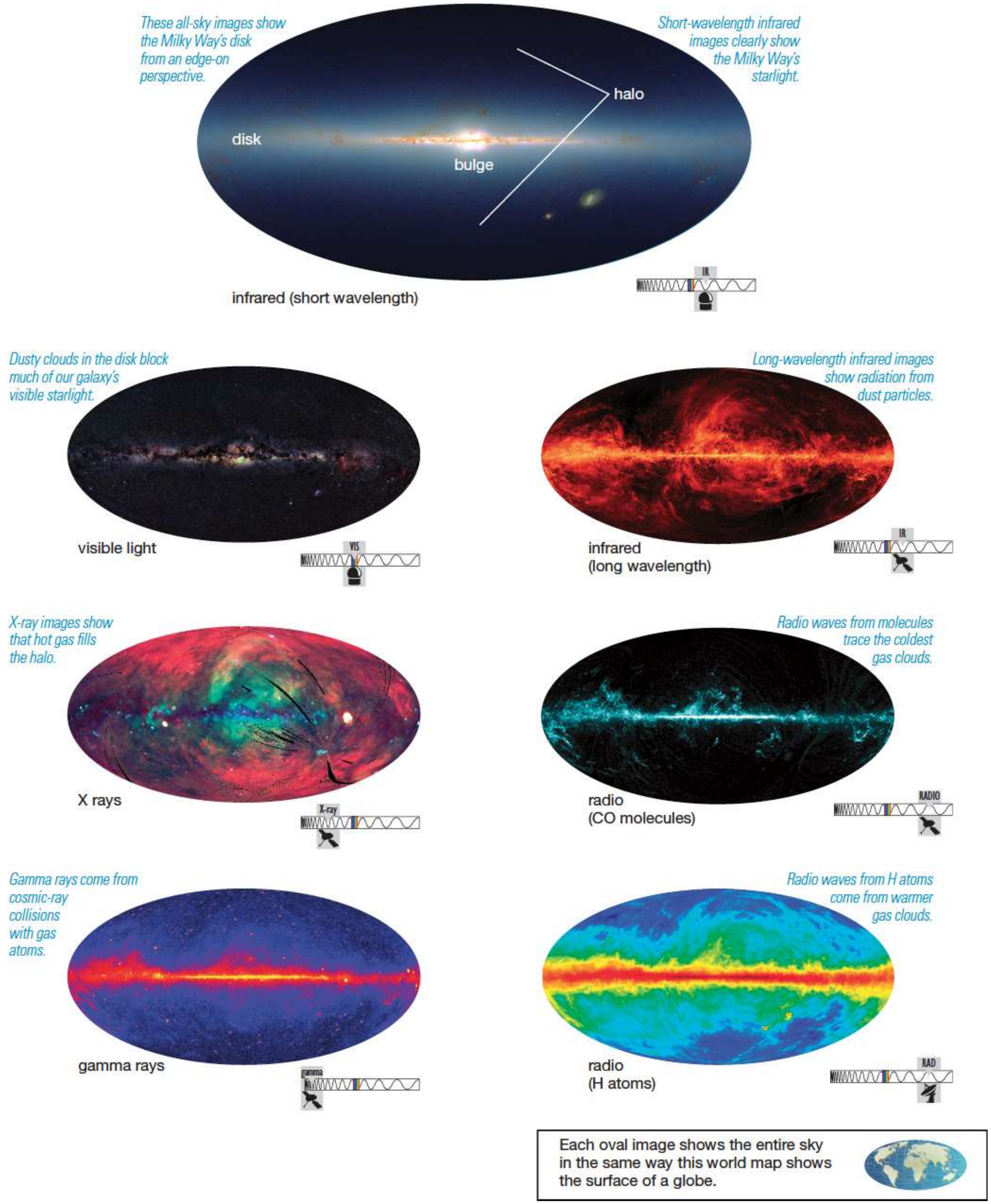
Arms are blue due to the fact there are more young stars there.

The gaps in the spiral are more red as they contain older stars

Red bubbles within the arms are ionization nebulae surrounding the largest young stars

The Galaxy in Different Wavelengths

- Visible – clouds blocks light
- Short IR – reveals those clouds (top)
- Long IR also shows heated dust grains
- X-rays shot hot gas above and below milky way
- CO molecules show where cold molecular clouds are concentrated
- Gamma rays are produced when supernova collide with atomic nuclei in gas clouds
- 21 cm-line shows atomic hydrogen where gas is starting to cool and settle into the disk



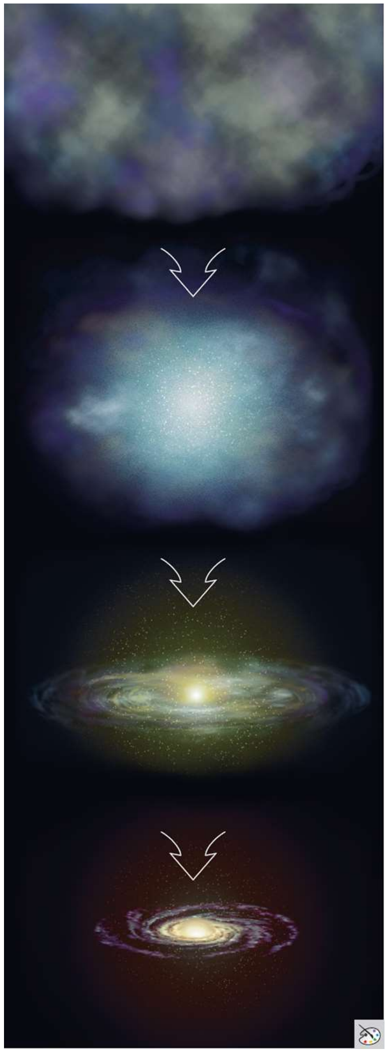
The Formation of the Milky Way

The Stars in different regions reveal the history…

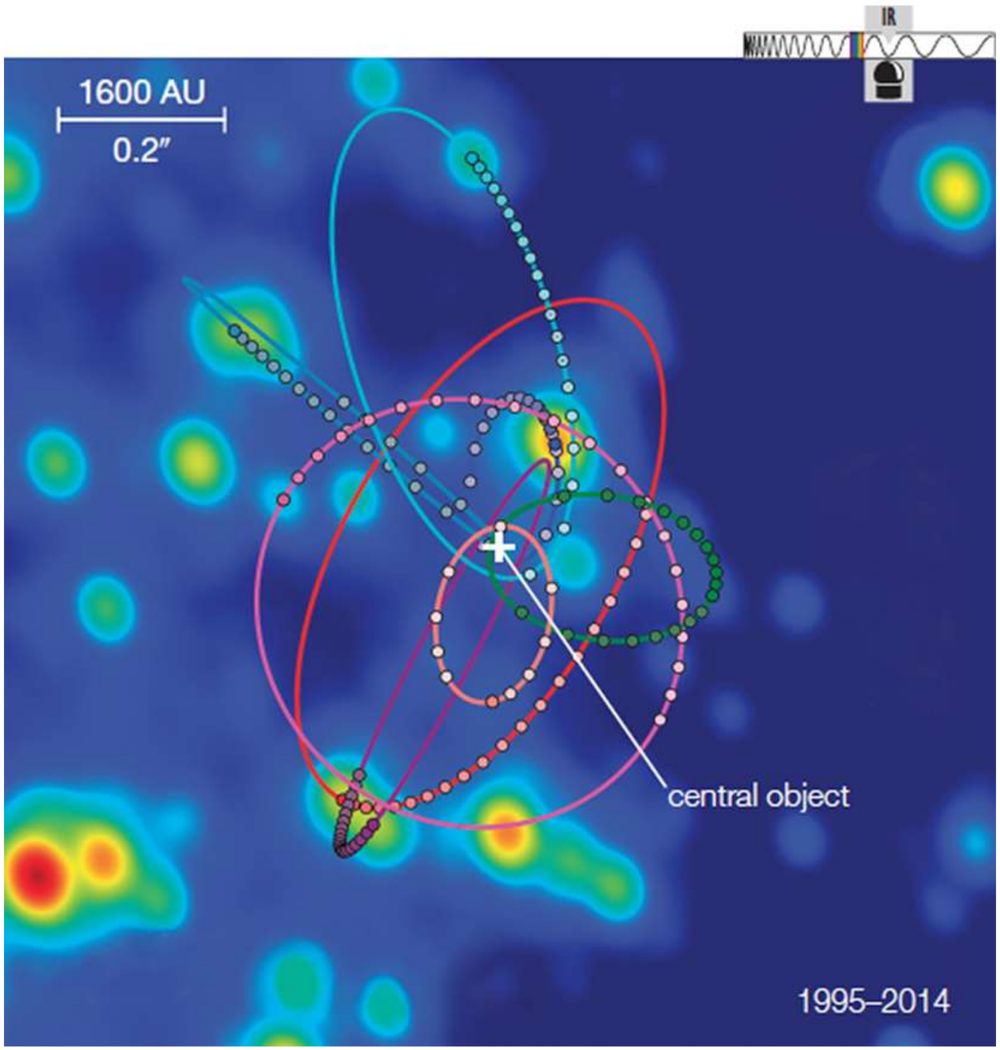
- ***Disk population*** – stars with compositions like the Sun, orbiting near the plane of the galaxy. A mix of young and old stars.
- ***Halo population –*** stars with a scarcity of heavier elements, orbiting at random inclinations to the galactic disk. All older, low-mass stars.

The reason for the difference? The Milky Way's gas has sunk into the disk!

(Also, the milky way probably merged with a few other galaxies in the past too!)



Sgr A* - A Supermassive Black Hole at the Center of our Galaxy



Stars appear to be orbiting something massive but invisible

…

a black hole?

Orbits of stars indicate a mass of about 4 million M_{sun}.

What's Next?

Chapter 16: A Universe of Galaxies (Abridged)

16.1. Islands of Stars

- What patterns do we find among the properties of galaxy's?

16.2. Distances of Galaxies

- How do we measure the distances to galaxies?
- What is Hubble's law?
- How do distance measurements tell us the age of the universe?

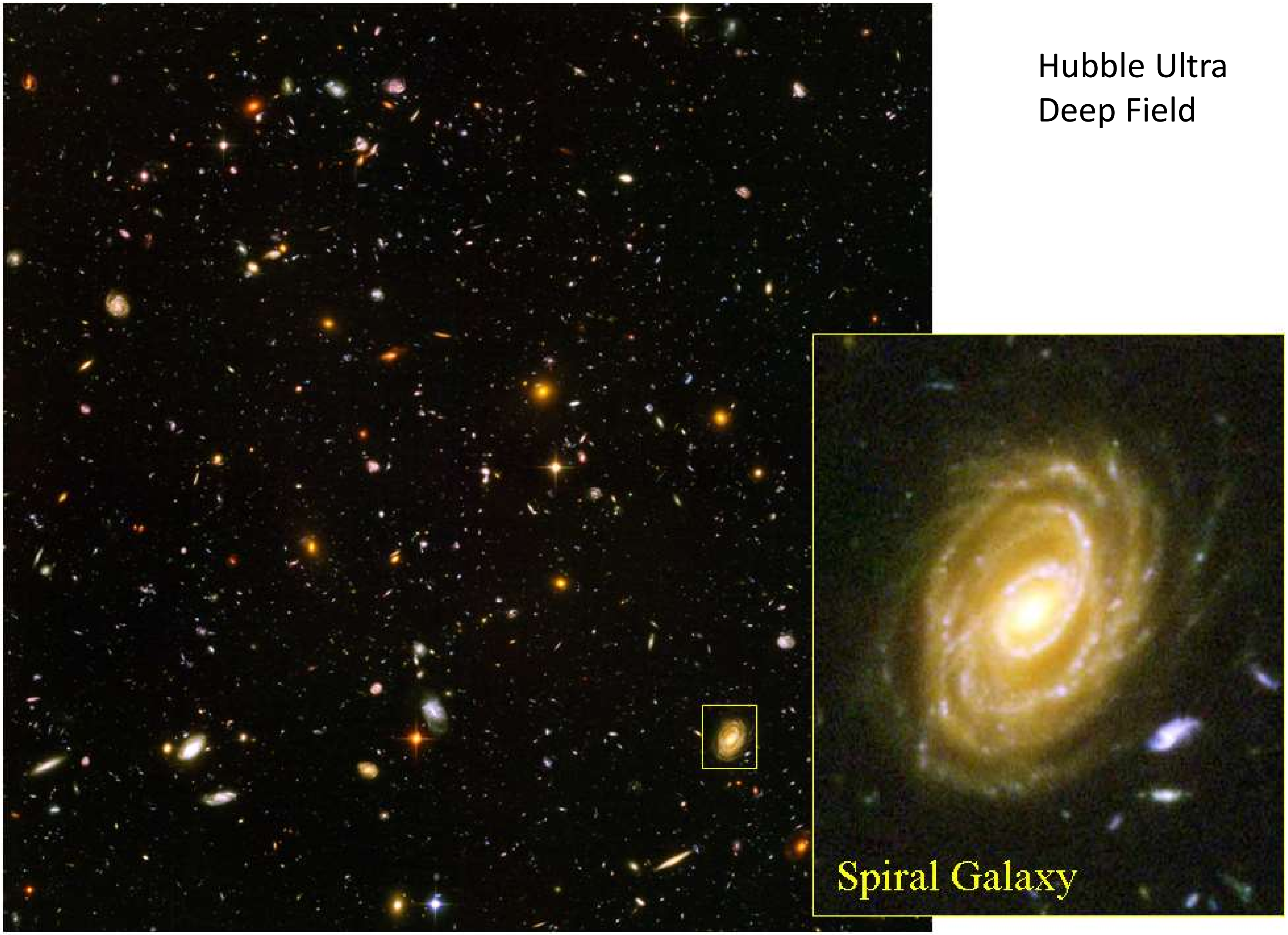
16.3. Galaxy Evolution

- How do we study galaxy evolution?
- Why do galaxies differ?
- How does gas cycle through galaxies?

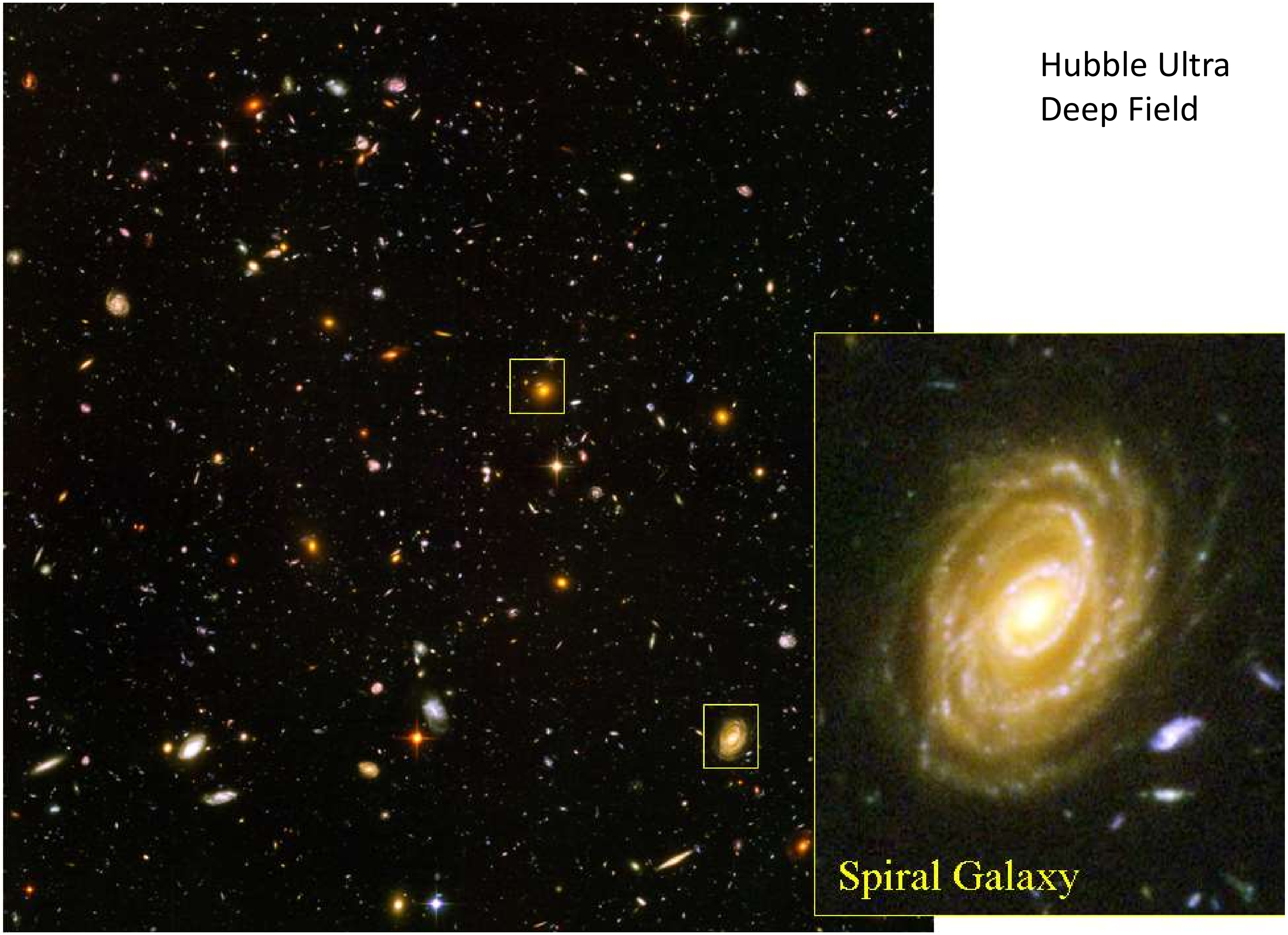
16.4. The Role of Supermassive Black Holes

- What is the evidence for supermassive black holes at the center of galaxies?
- Do supermassive black holes regulate galaxy evolution?

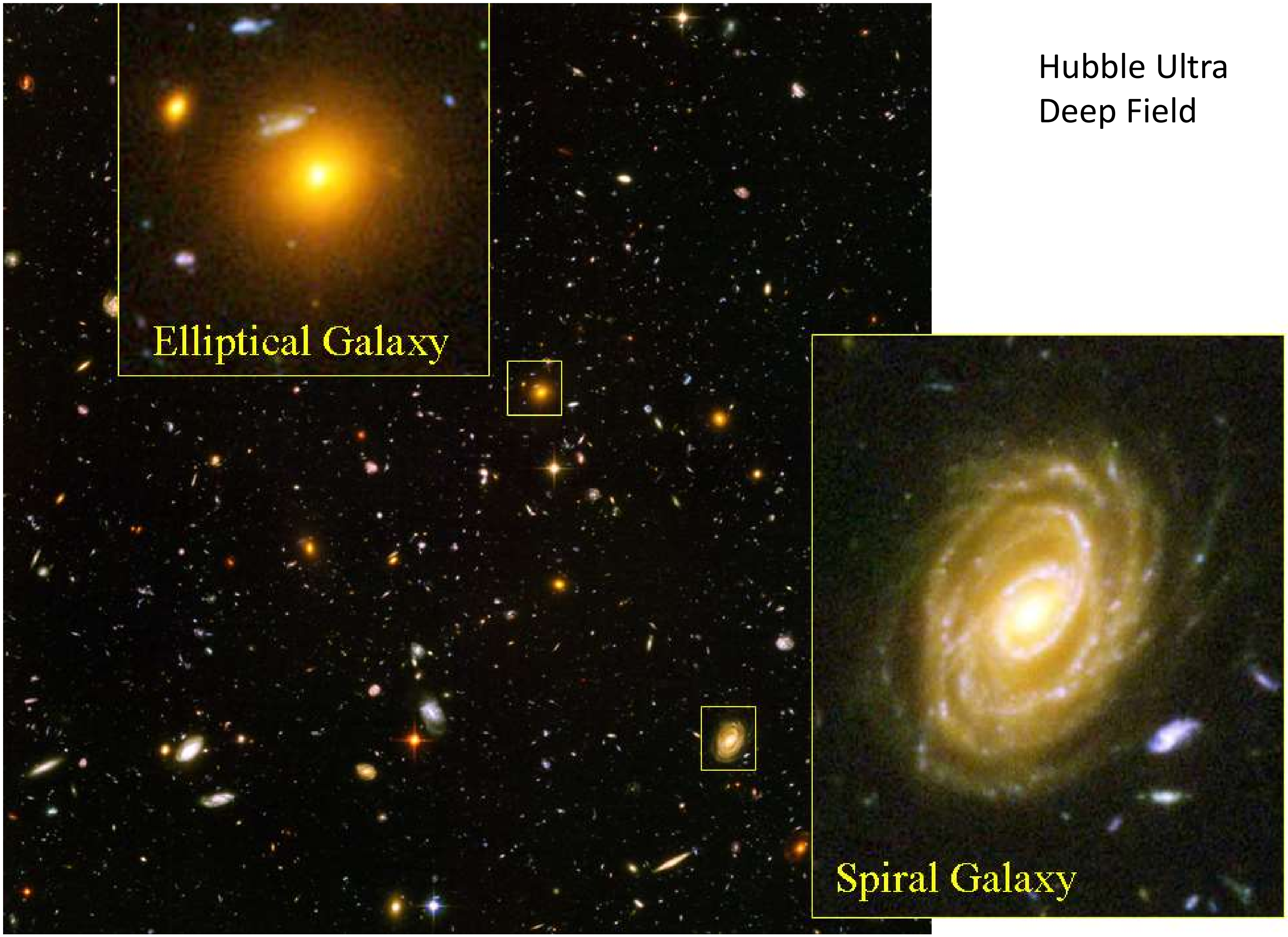
Hubble Ultra Deep Field

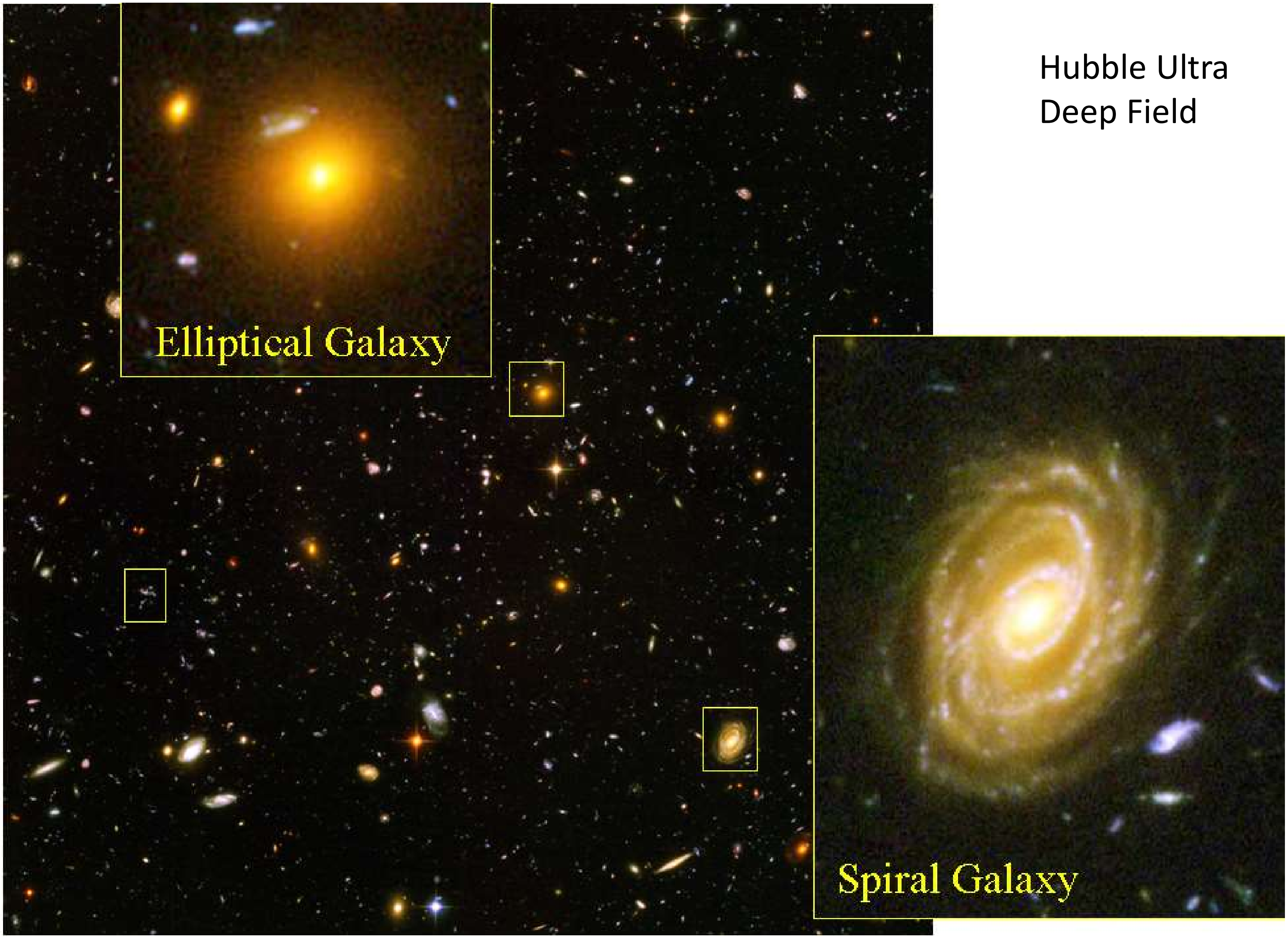


Hubble Ultra Deep Field



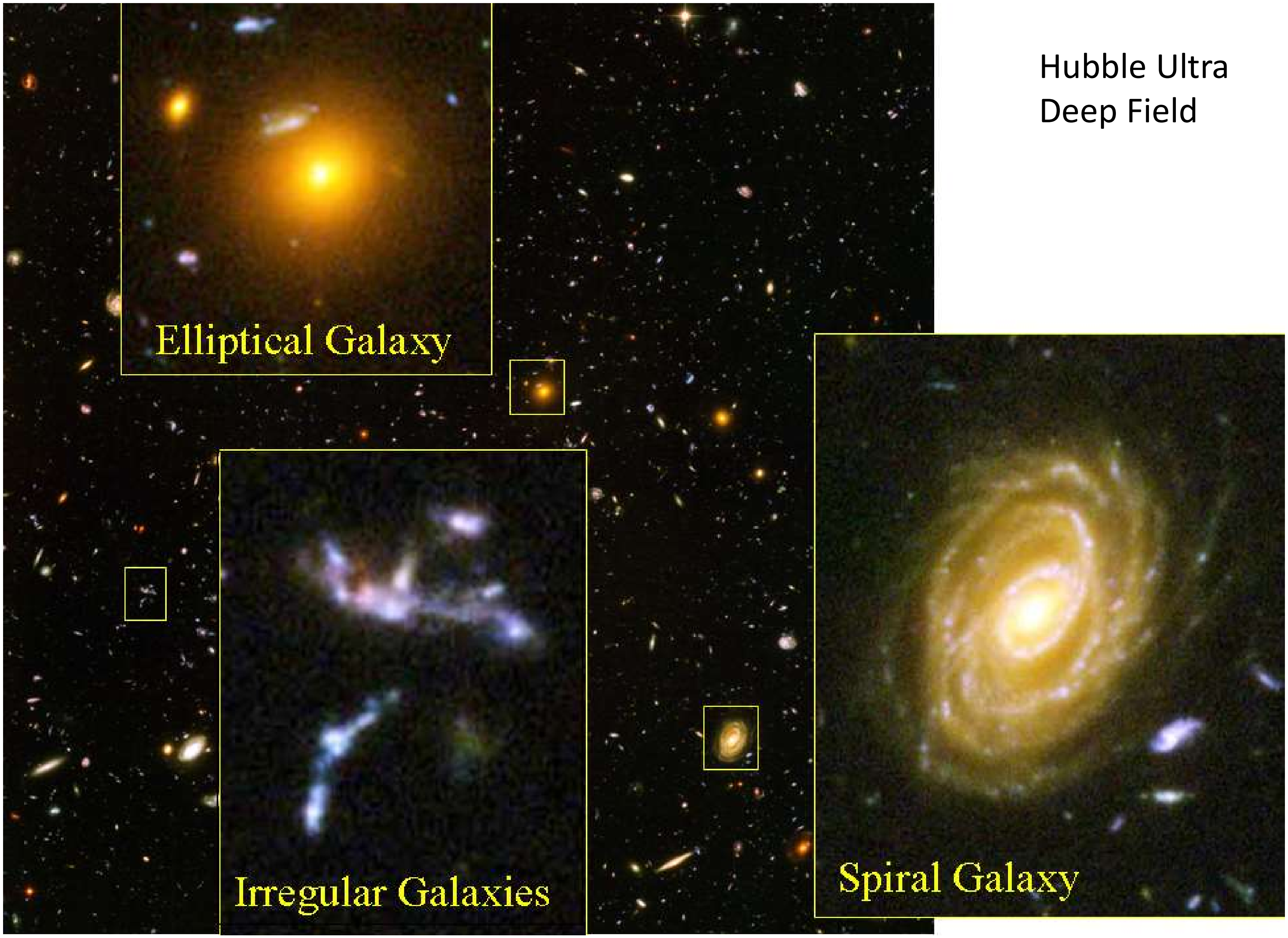
Hubble Ultra
Deep Field





Hubble Ultra
Deep Field

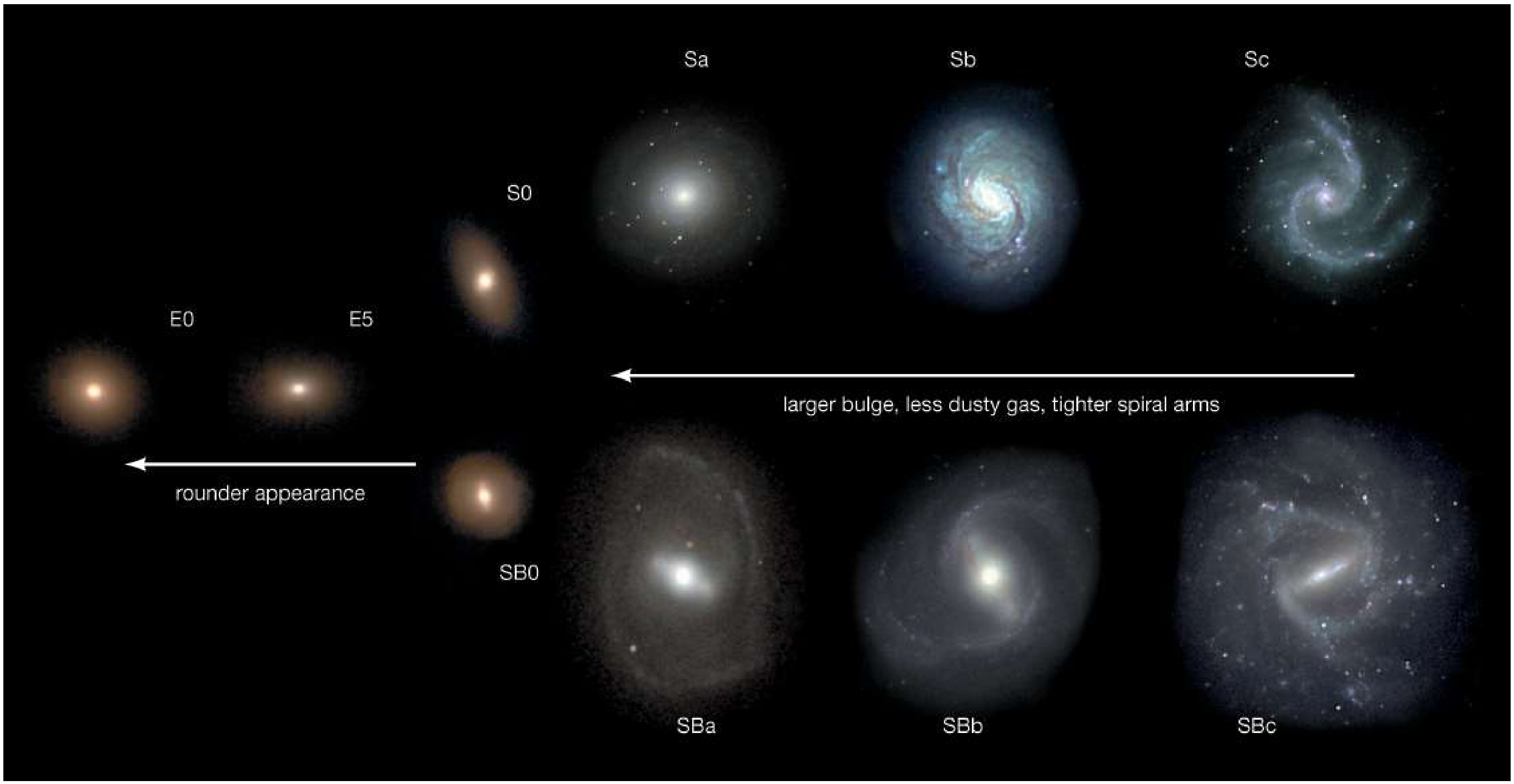
Hubble Ultra
Deep Field

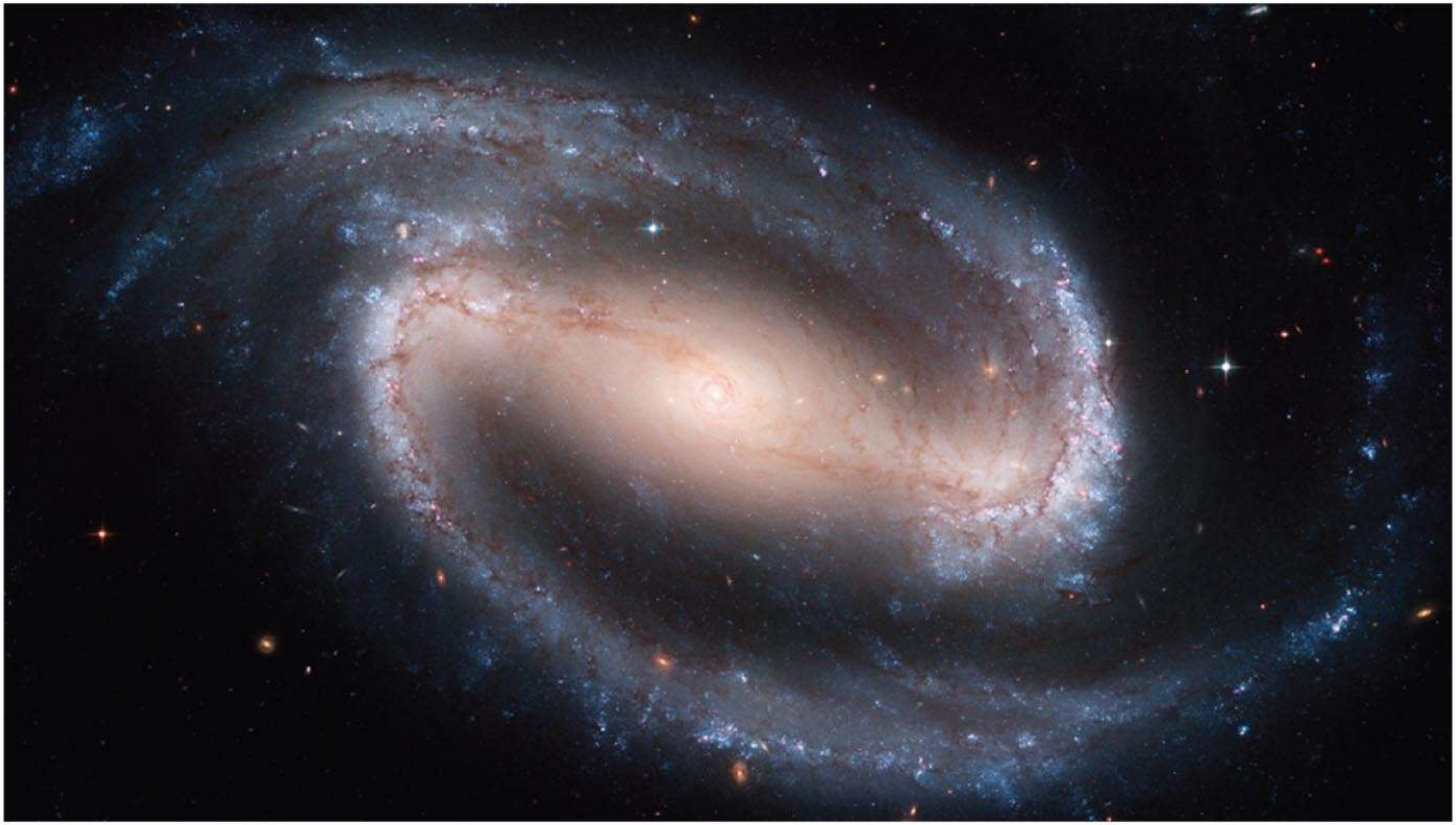


Cosmology – The Study of the Structure and the Evolution of the Universe

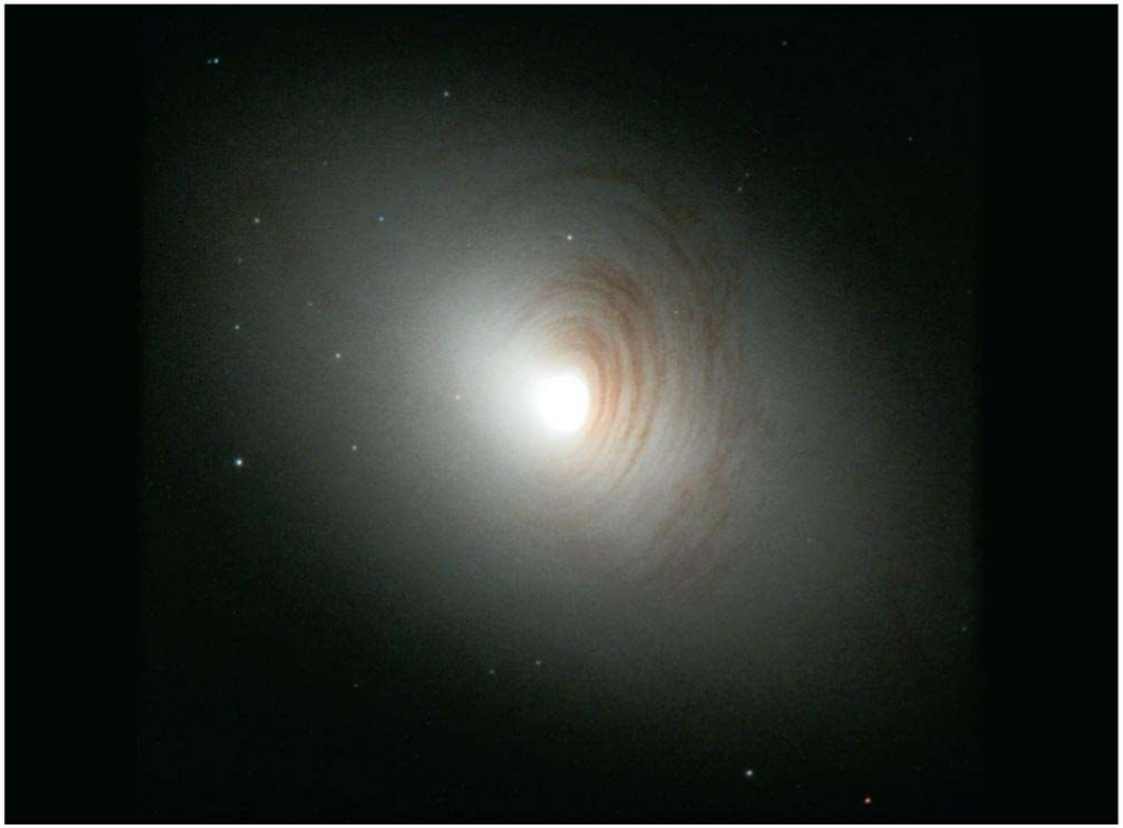
A galaxy's age, its distance, and the age of the universe are all closely related.

What different kinds of Galaxies are there? Hubble's classification system





Barred Spiral Galaxy: Has a bar of stars across the bulge.



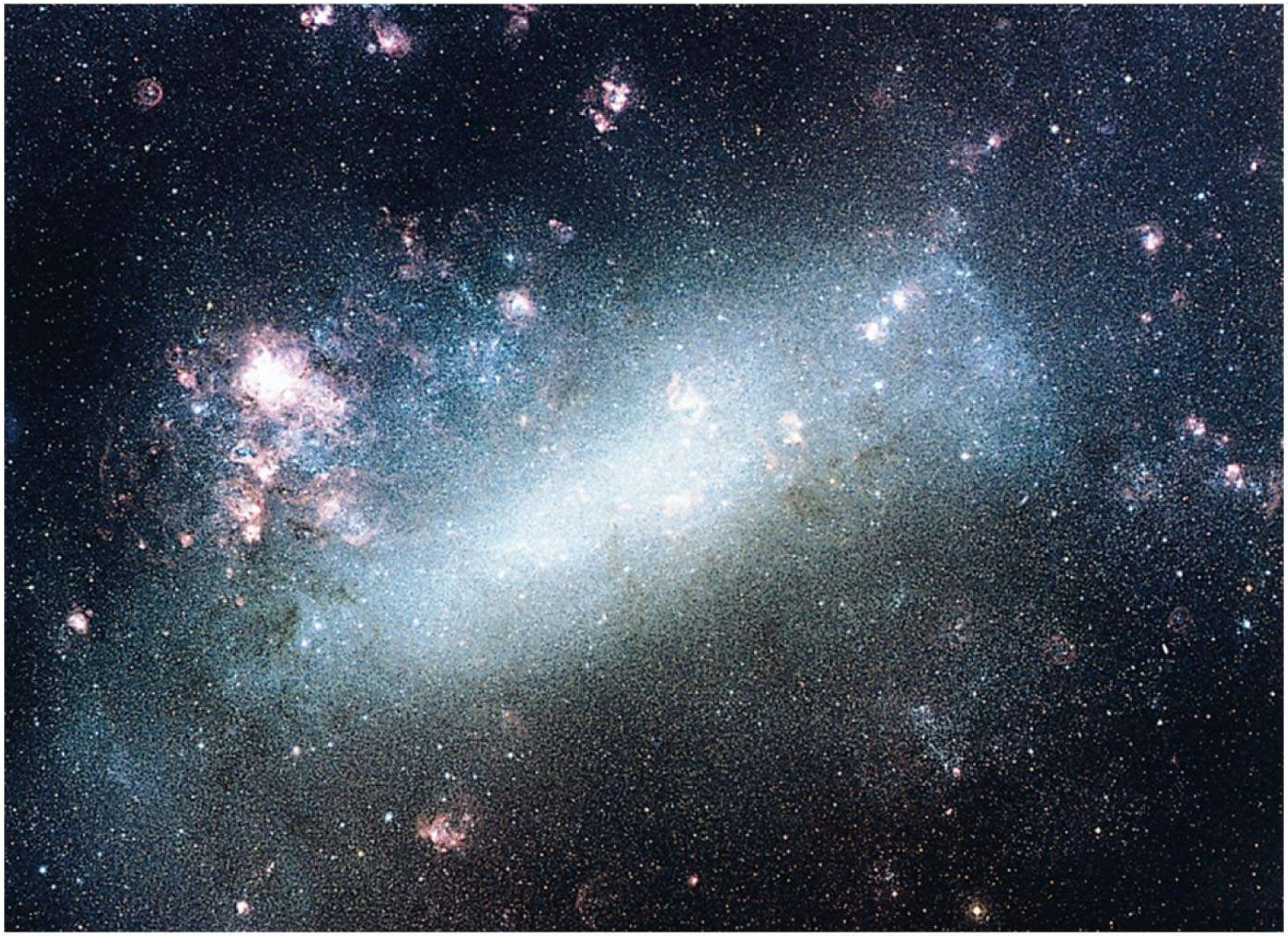
Lenticular Galaxy:

Has a disk like a spiral galaxy but much less dusty gas (intermediate between spiral and elliptical).

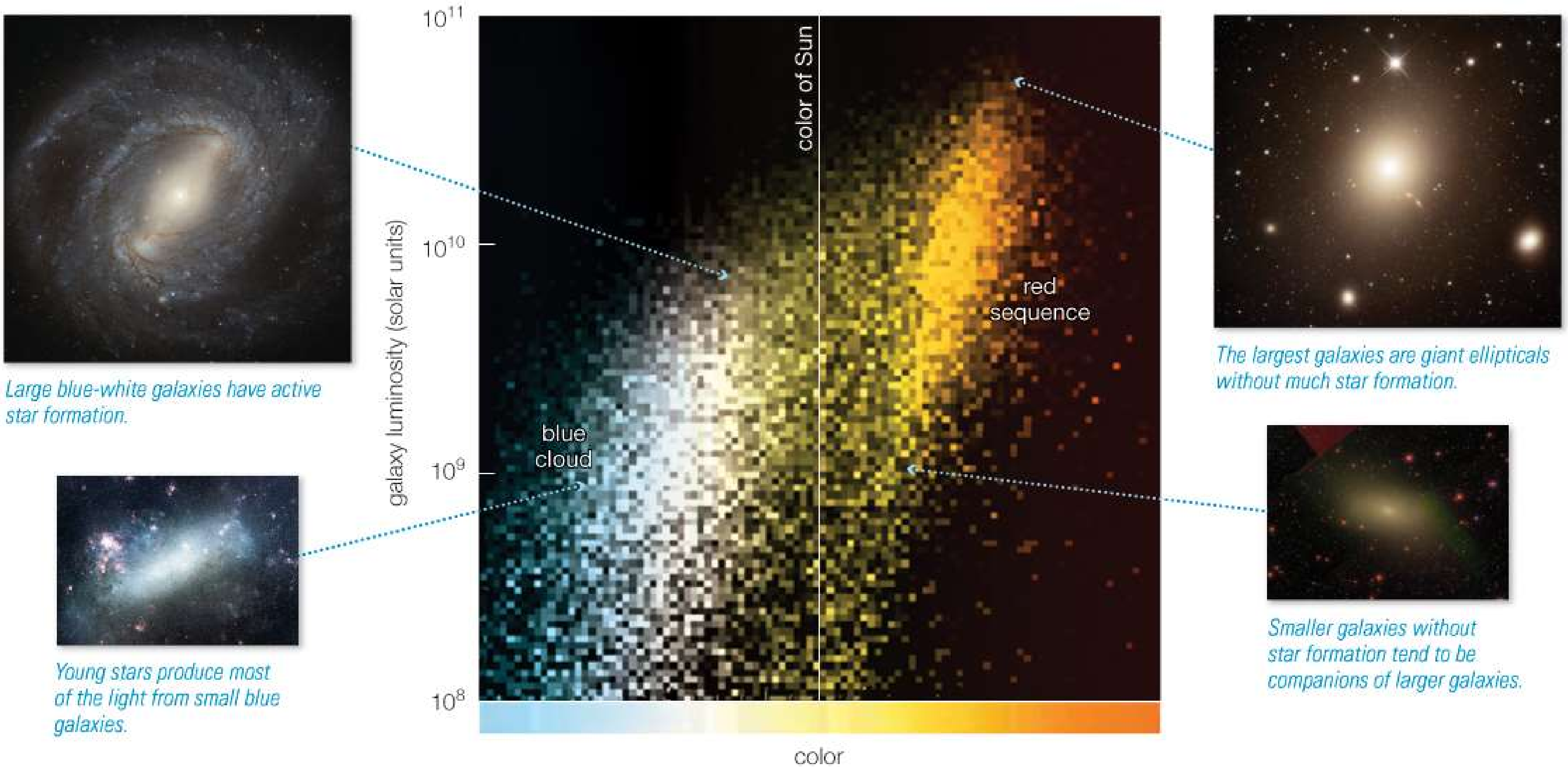
Elliptical Galaxy:

All spheroidal component, virtually no disk component

Red-yellow color indicates older star population.

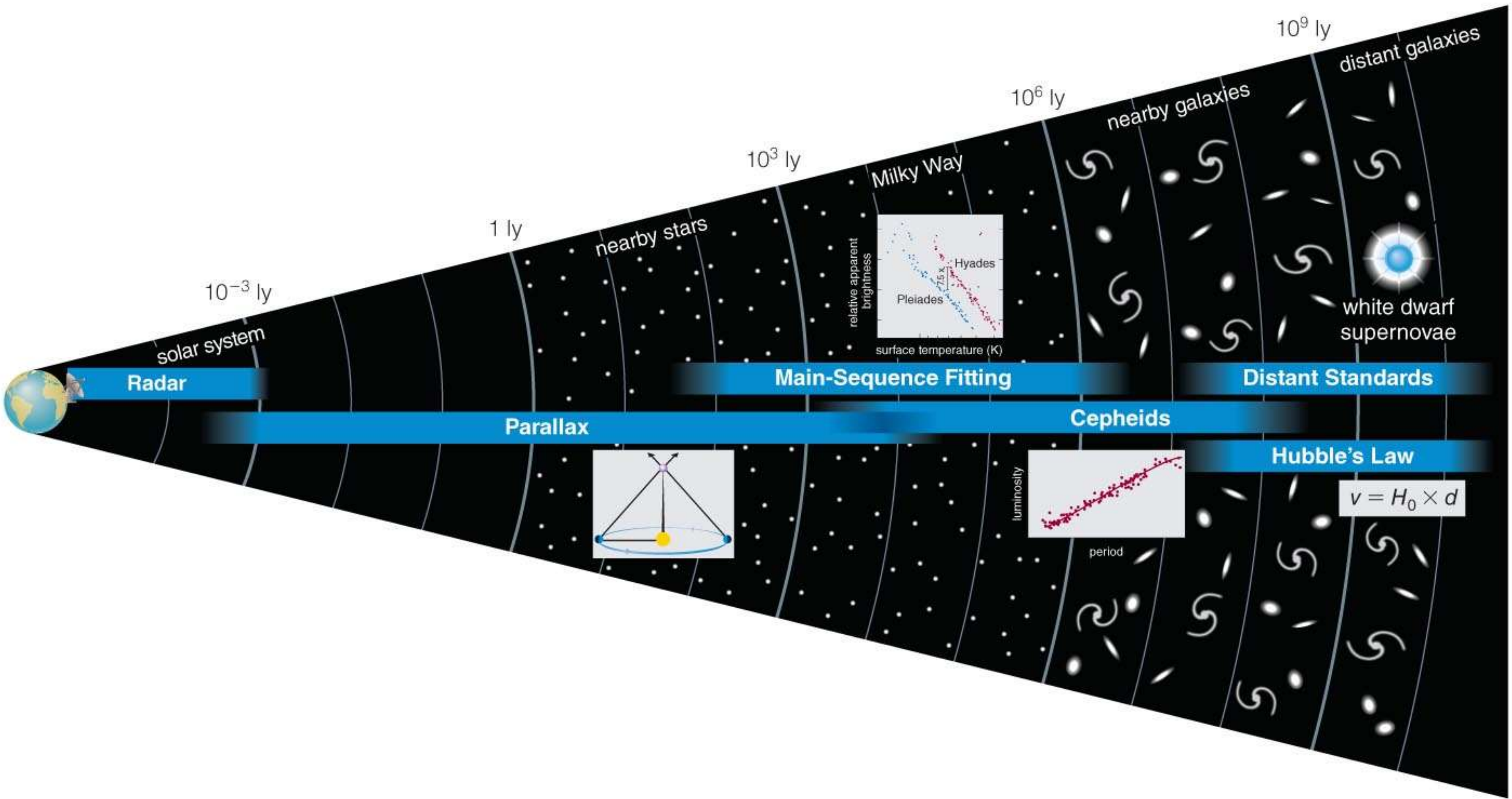


Irregular Galaxy: Neither spiral nor elliptical.
Blue-white color indicates ongoing star formation.

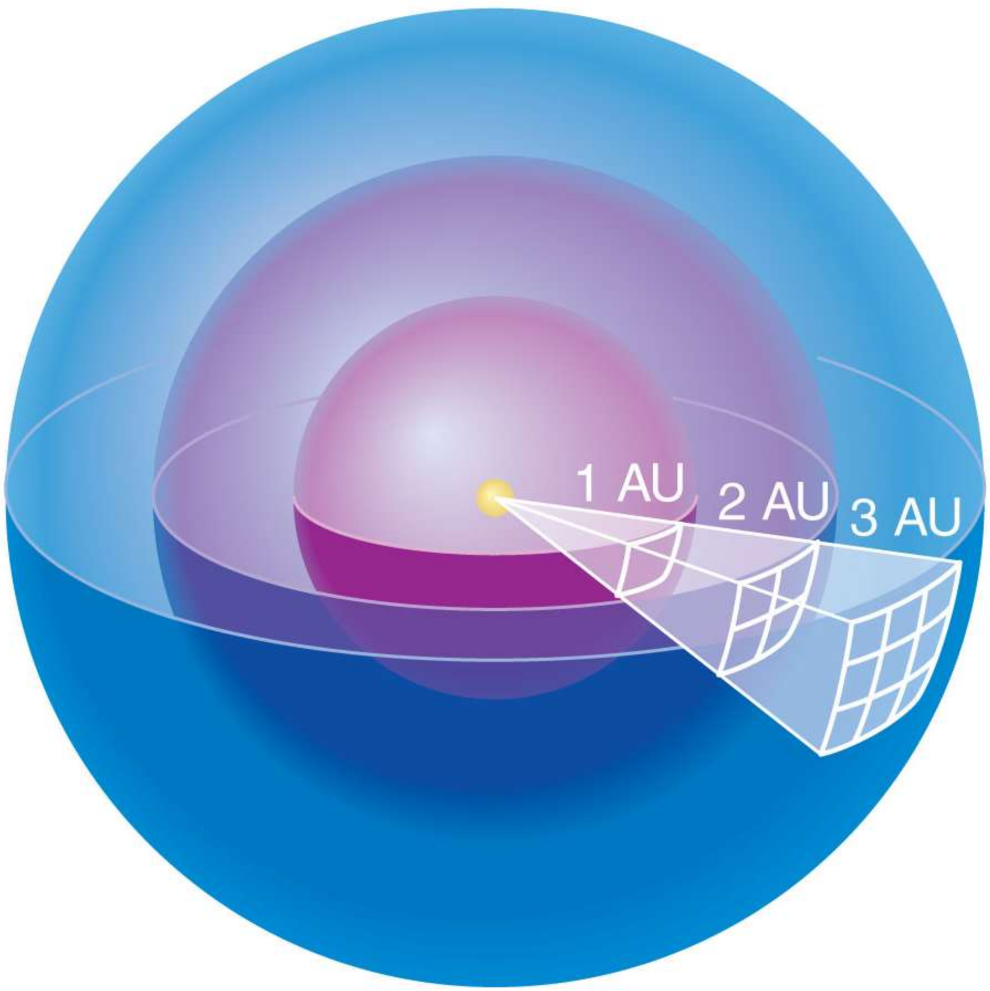


Patterns in color and luminosity

Measuring the Distances of Galaxies



Remember the inverse square relationship?



Luminosity passing through each sphere is the same.

Area of sphere:

$$4\pi\ (\text{radius})^2$$

Divide luminosity by area to get brightness.

What is a Standard Candle?

The relationship between apparent brightness and luminosity depends on distance.

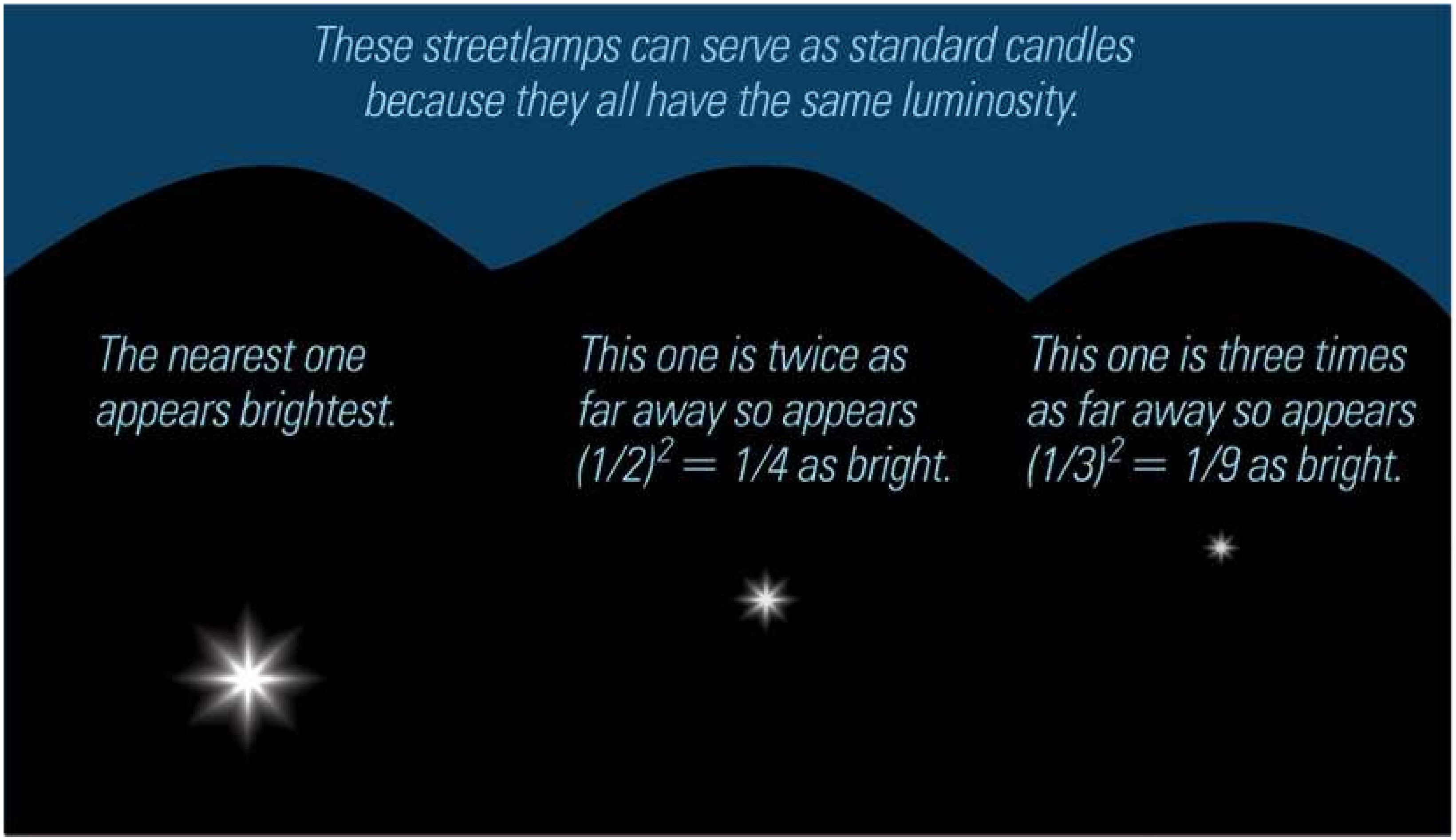
$$brightness = \frac{luminosity}{4\pi(distance)^2}$$

We can determine a star's distance if we know its luminosity and can measure its apparent brightness.

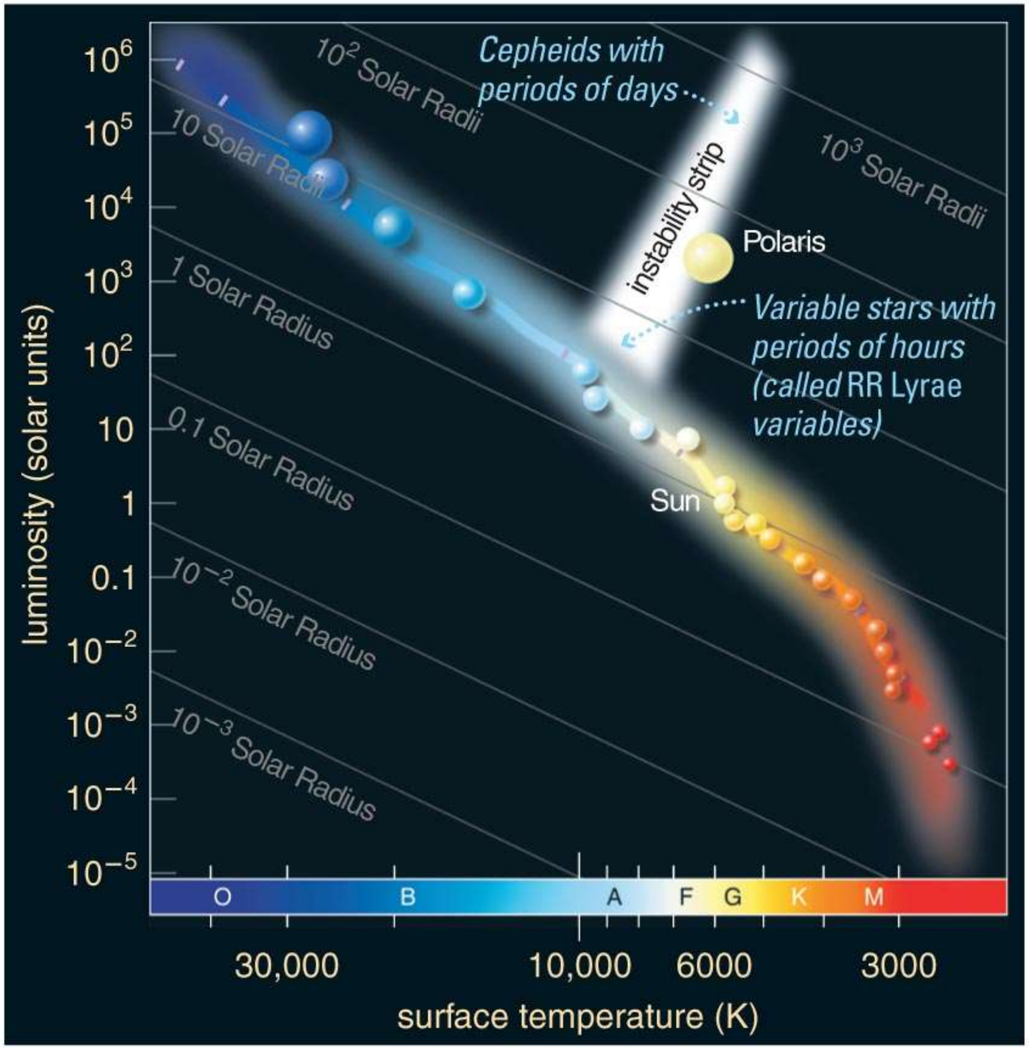
$$distance = \frac{luminosity}{\sqrt{4\pi \times brightness}}$$

A ***standard candle*** is an object whose luminosity we can determine without measuring its distance.

How can we use Standard Candles?



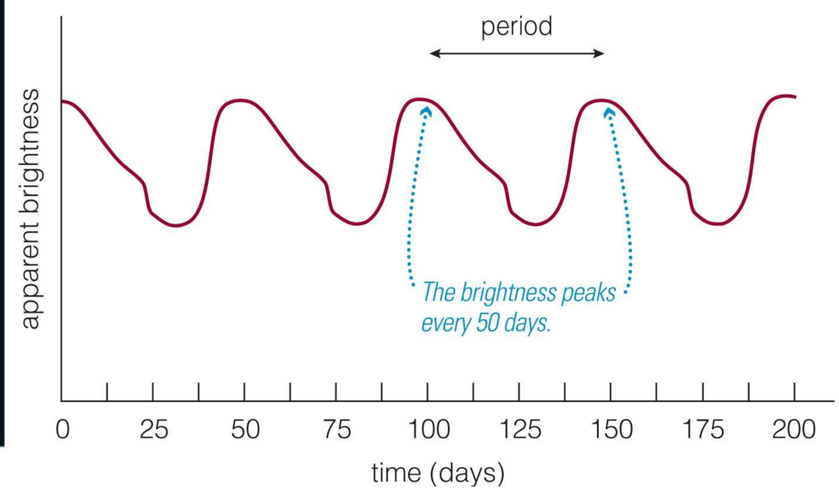
Cepheid stars as standard candles



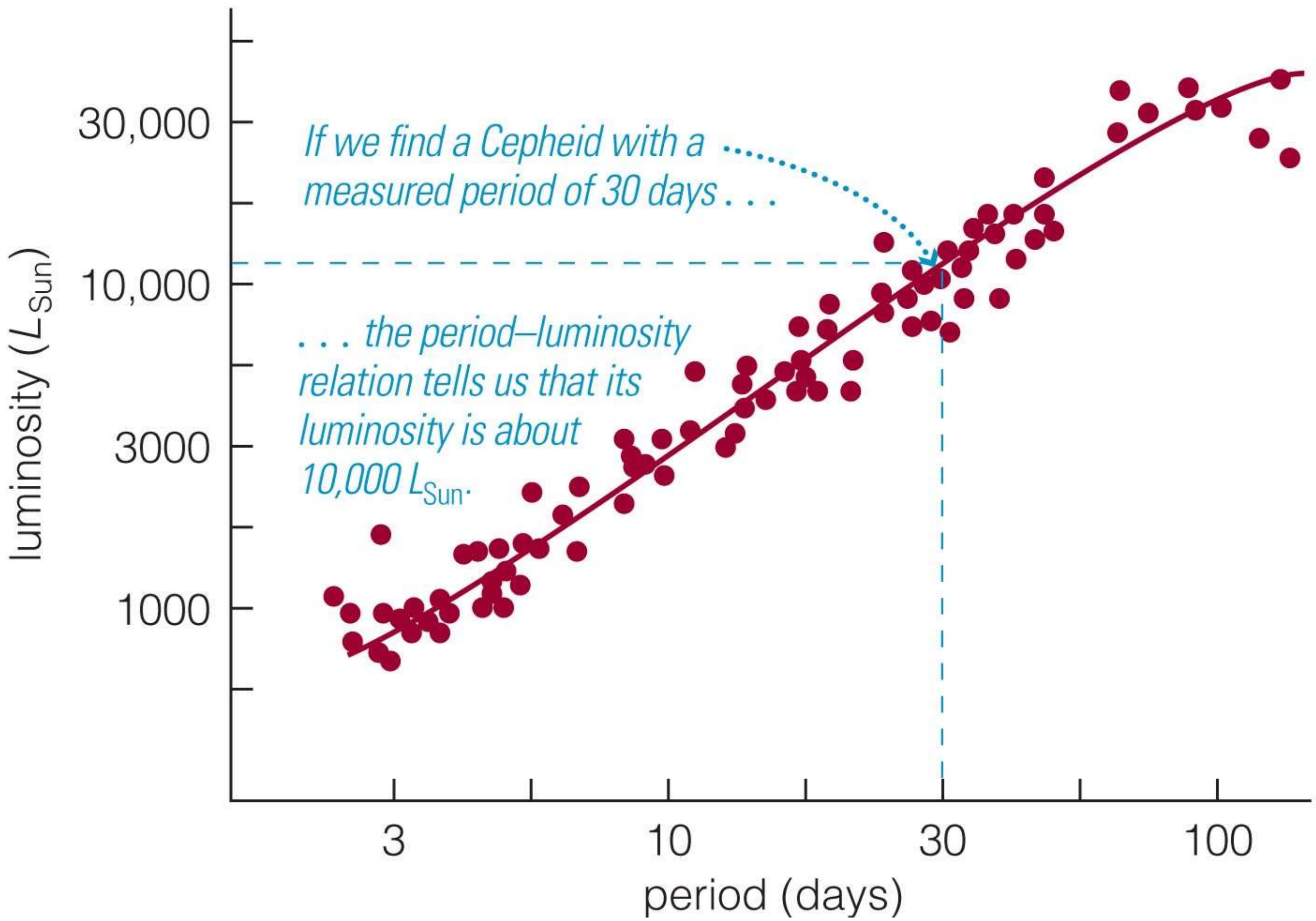
Cepheid variable stars are very luminous.

The variability occurs due to a complex interaction between He^{2+} ←→ He^{+} occurring in the outer layers of the star…

The light curve of this *Cepheid variable* star shows that its brightness alternately rises and falls over a 50-day period.

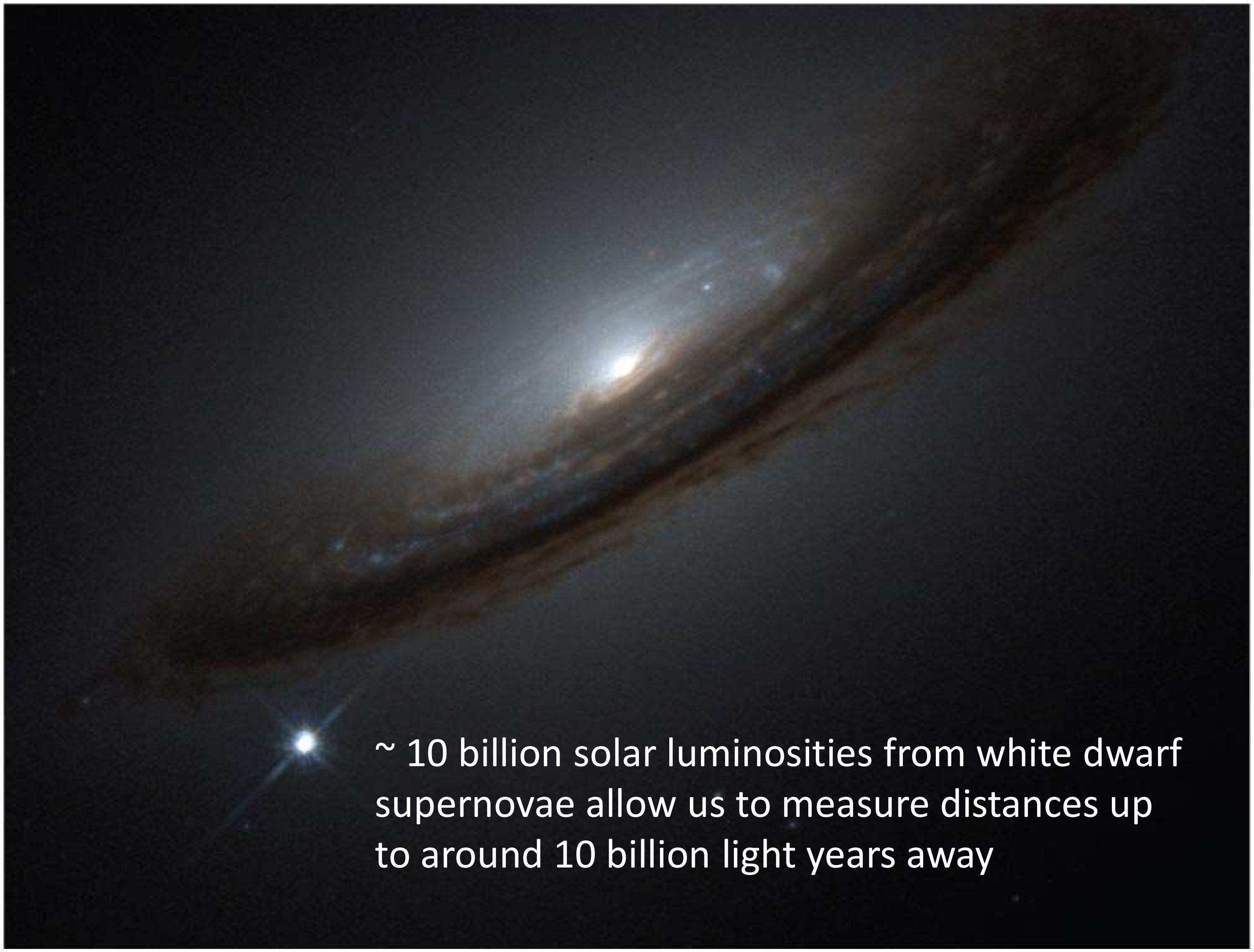


Cepheid stars as standard candles

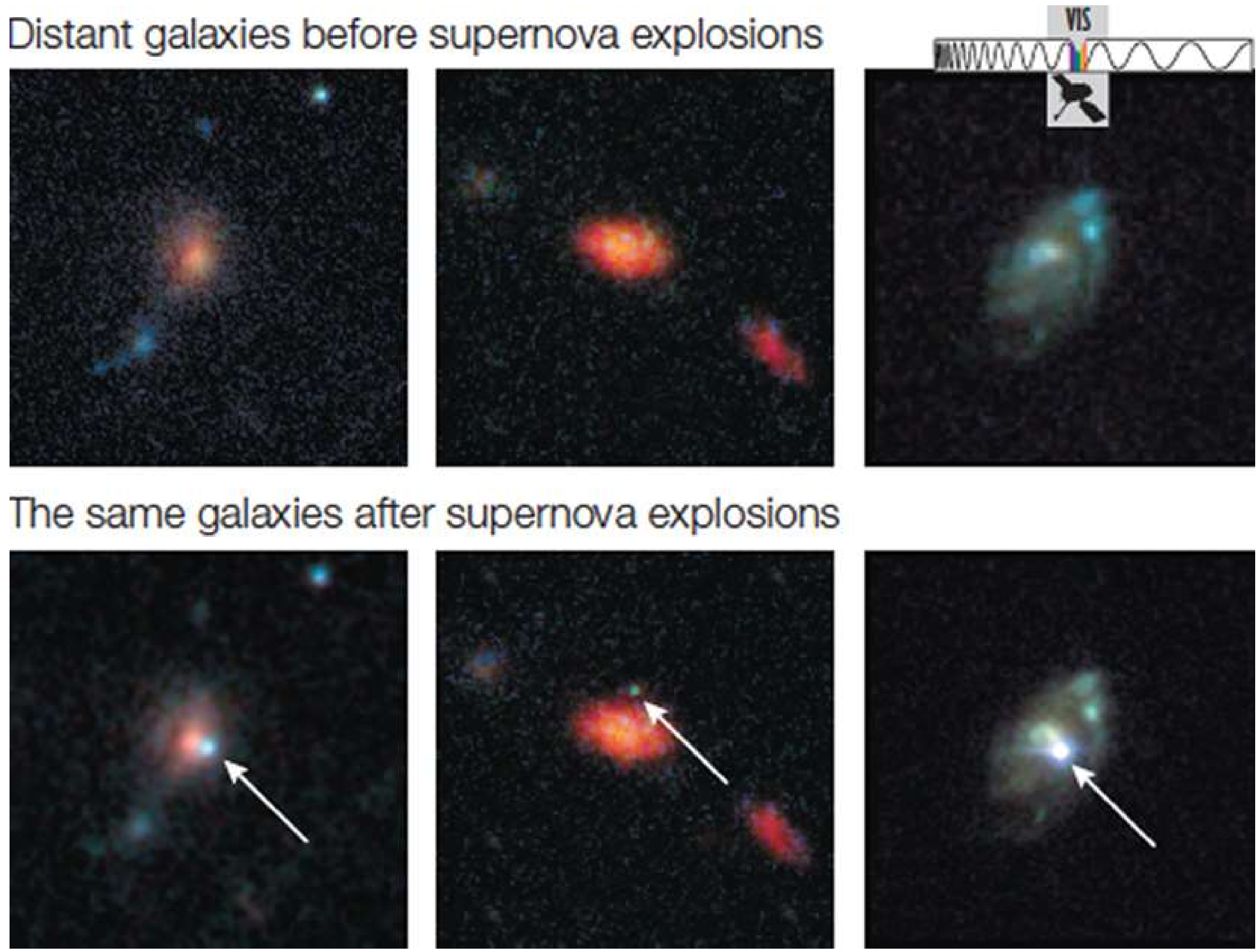


Cepheid variable stars with longer periods have greater luminosities.

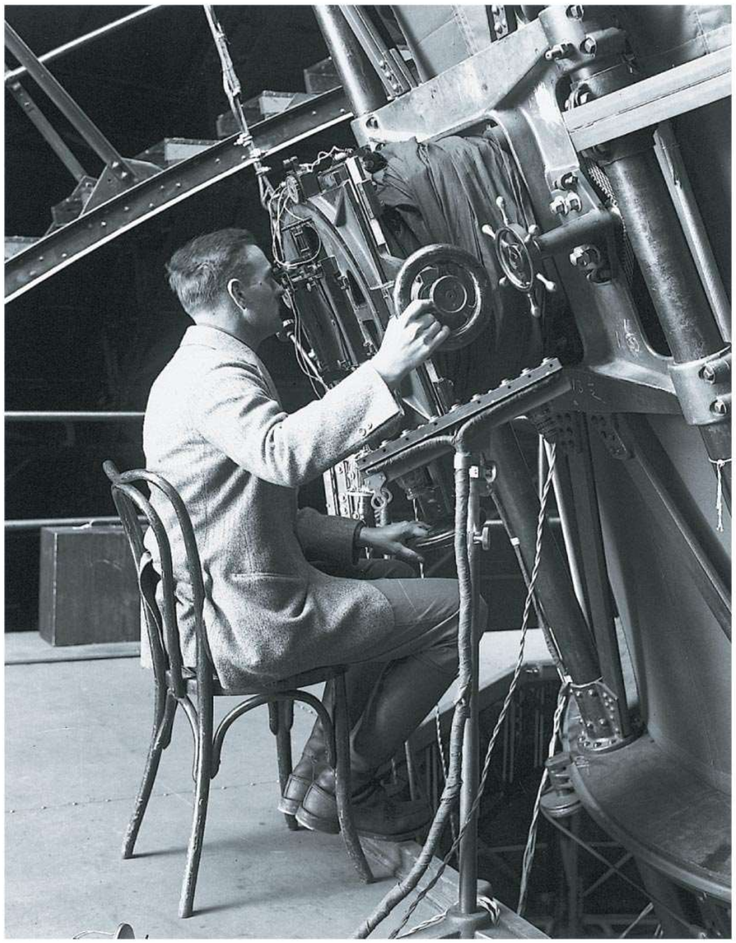
White Dwarf Supernovae as Standard Candles



White Dwarf Supernovae as Standard Candles

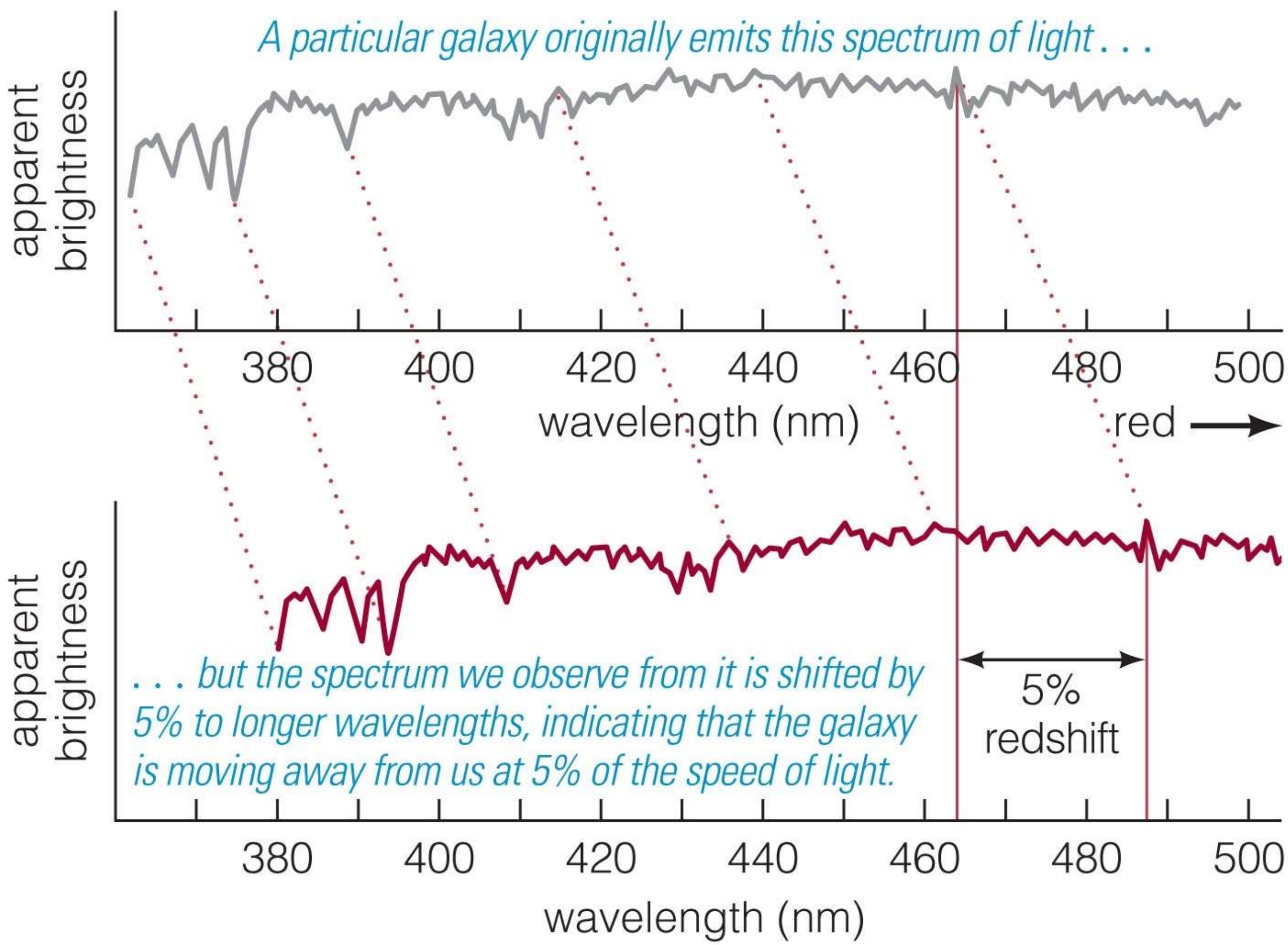


Edwin Hubble & Hubble's Law



- Hubble measured the distance to the Andromeda Galaxy using Cepheid variables as standard candles.
- Hubble also knew that the spectral features of virtually all galaxies are ***redshifted*** ⇒ they're all moving away from us.

Red-Shifting of Galaxies

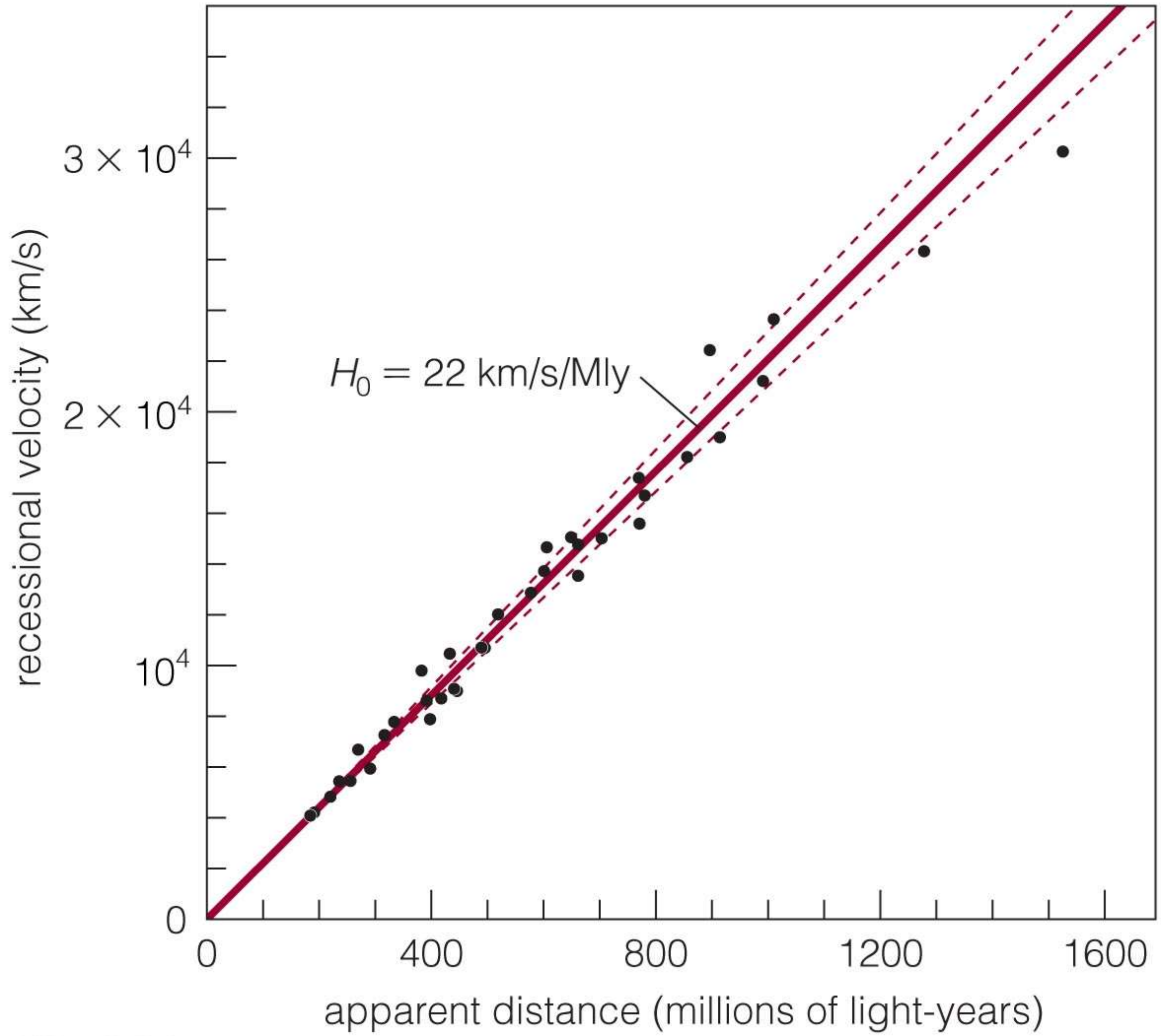


The red-shift of a galaxy tells us of the speed that galaxy is moving away from us.

Galaxies further away seem to be moving faster, as related by Hubble's Law:

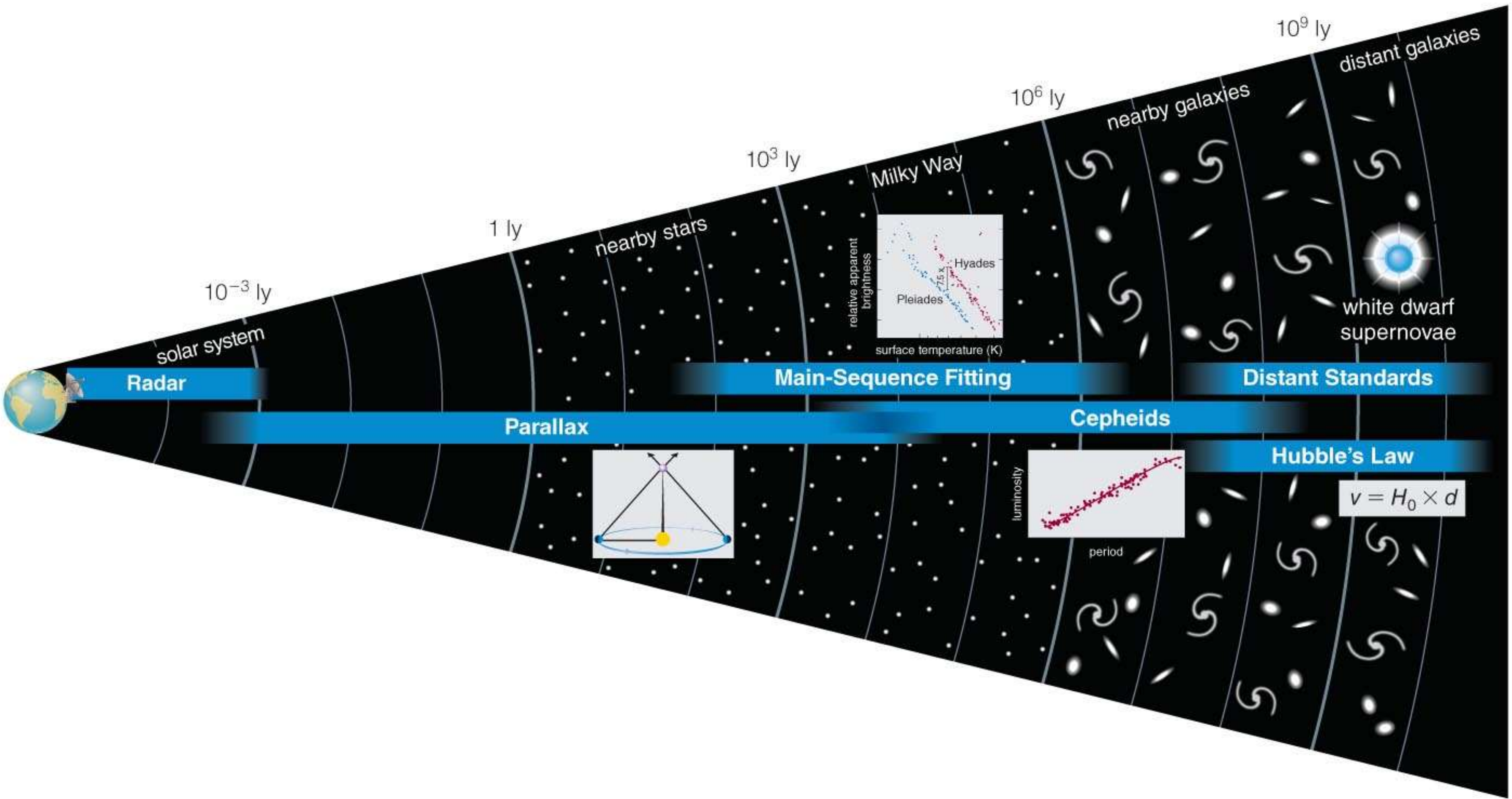
$$distance = \frac{velocity}{H_0}$$

Hubble’s Law



Hubble's law: velocity = H_0 × distance

Measuring the Distances of Galaxies



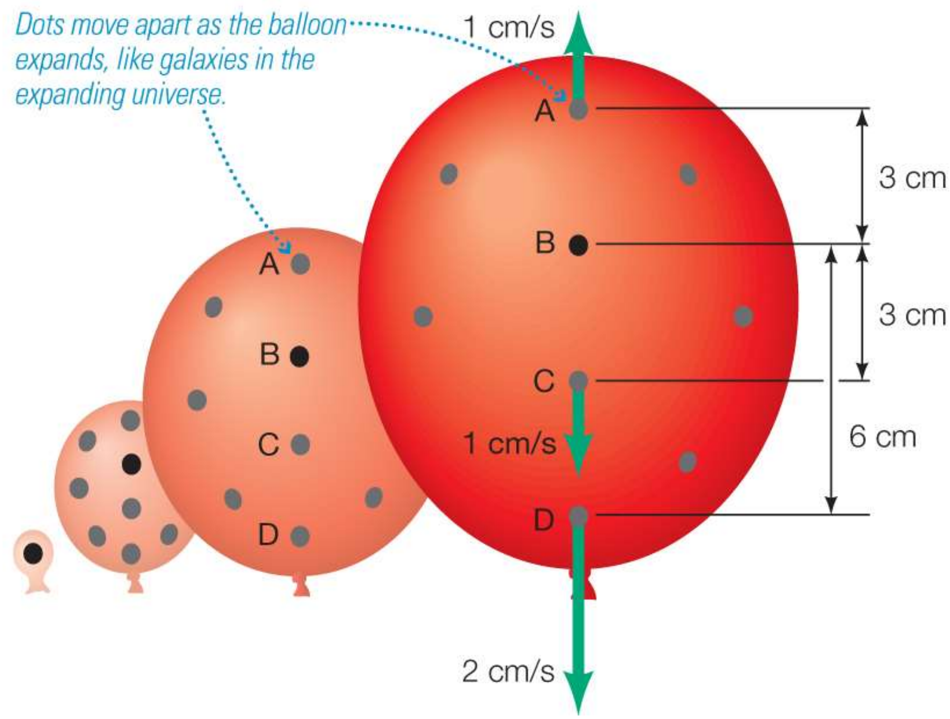
Using Hubble's Law to Constrain the Age of the Universe

The Hubble constant informs us of how the velocities and distances of all galaxies are related… We can therefore use this to work out the age of the universe:

$$Age(s) = \frac{Distance\ (m)}{Velocity\ (m\ s^{-1})}$$

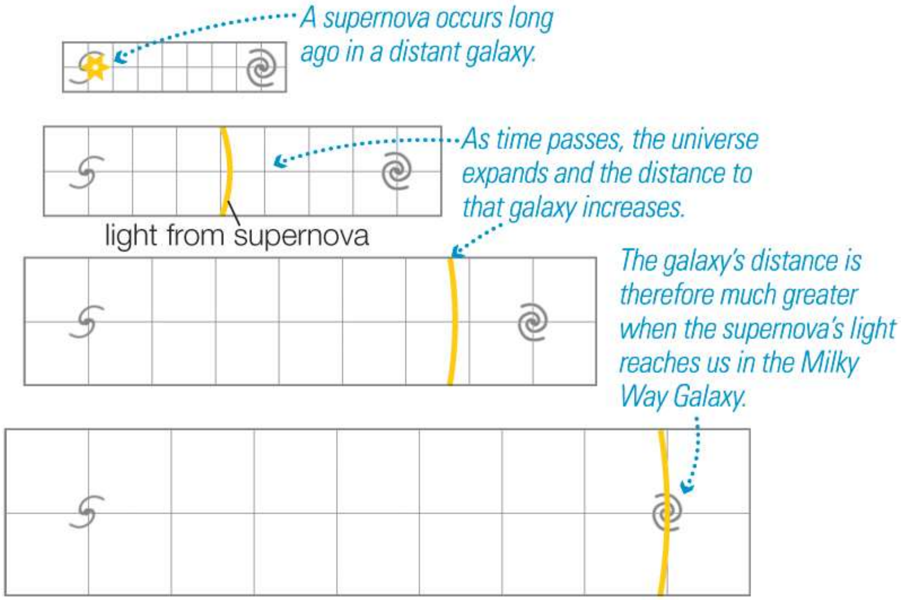
$$\sim \frac{1}{H_0}$$

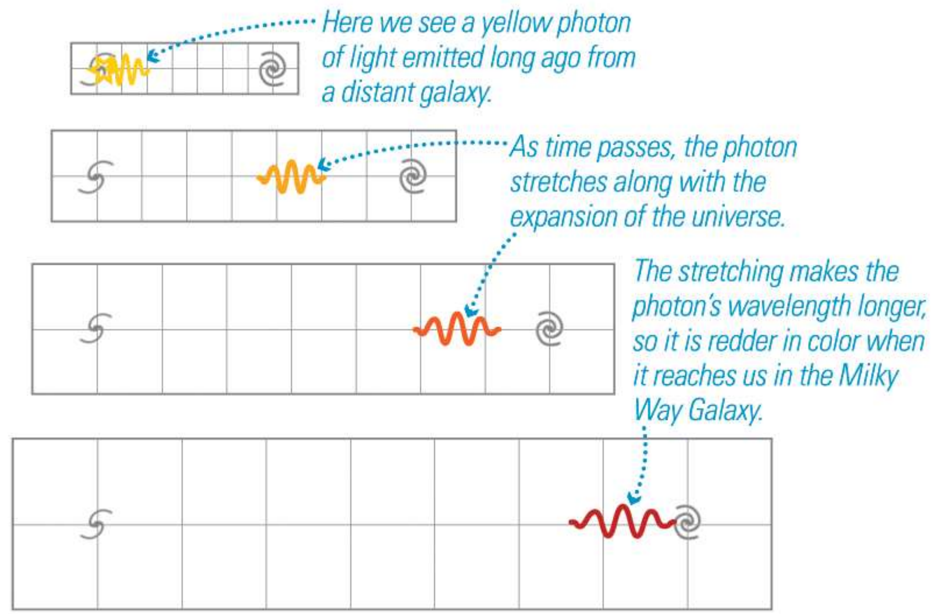
The age of the Universe is determined to be approximately 14 billion years old (assuming the rate of increase is constant, and ignoring local group galaxies)



If galaxies further away from us are moving away at a faster rate, it can only mean that space-time itself is expanding!

Lookback Time and the Cosmological Red-shift





- Distances between faraway galaxies change while light travels. If we observe a galaxy that WAS at a distance of 10 billion light years, it has both moved away from us further, and spacetime has expanded since that point in time… where is it now?
- Astronomers think in terms of ***lookback time*** rather than distance, which is how it appeared when the light reached us. This light will be red-shifted because it is both moving away AND spacetime is expanding between us

End of Todays Lecture