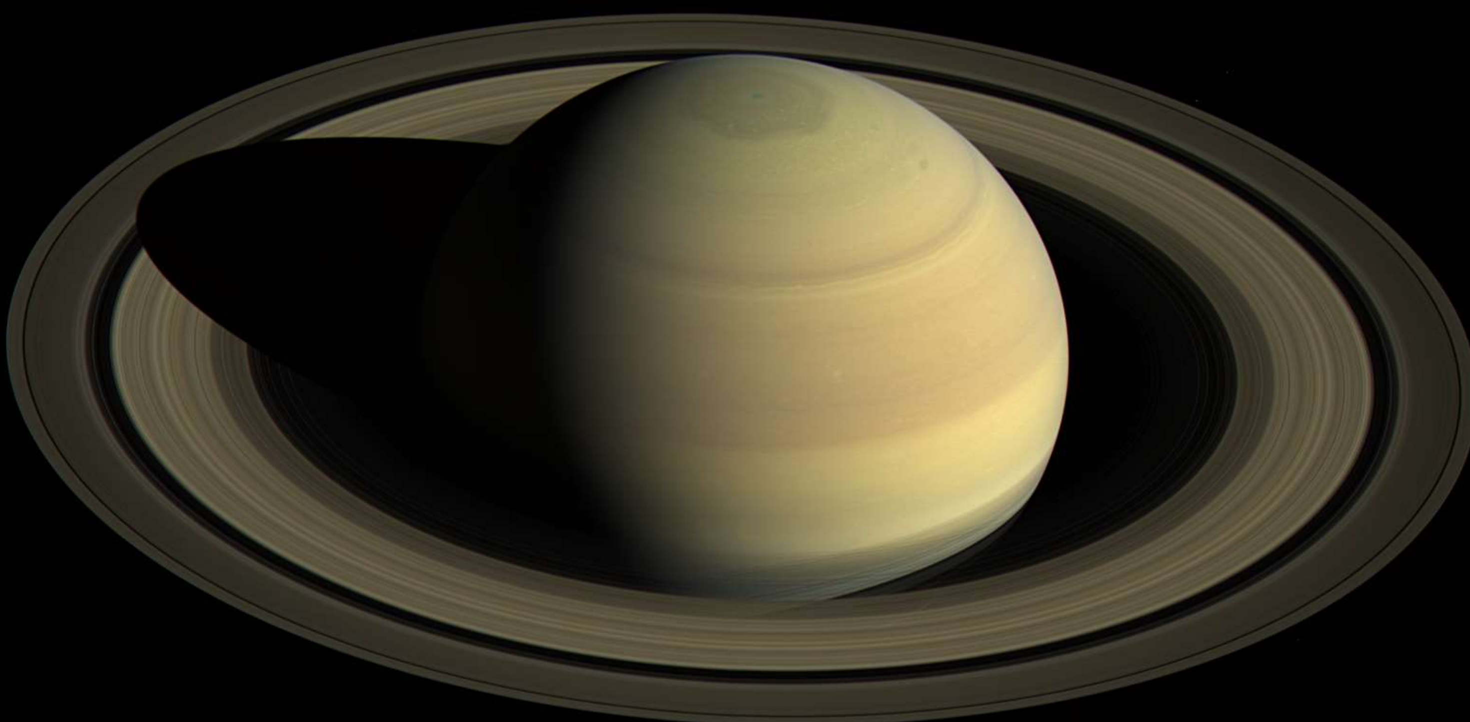
AST 2002
Introduction to Astronomy



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

Curved Mid-term results are out on webcourses...

Homework is also out (next slide)

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..

Homework (Revised) & Evaluations

There are 3 homework sets on Webcourses:

- HW # 2 is on Chapters 1-5, 15 questions, due April 27th at midnight
- HW # 3 is on Chapters 6-9, 12 questions, due April 27th at midnight
- HW # 2 is on Chapters 10-13, 12 questions, due April 27th at midnight
- The Syllabus quiz has been re-opened and will be available until April 27th at midnight
- HW #1 has been re-opened and will be available until April 27th at midnight

Each quiz is worth 2%. The syllabus will be worth 1% and there will be a bonus 1% for putting up with the 'lack' of homework throughout this course…

Evaluations of the Course & Instructor are available on Webcourses – Please fill out this week!

What’s Did We Cover Last Time?

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

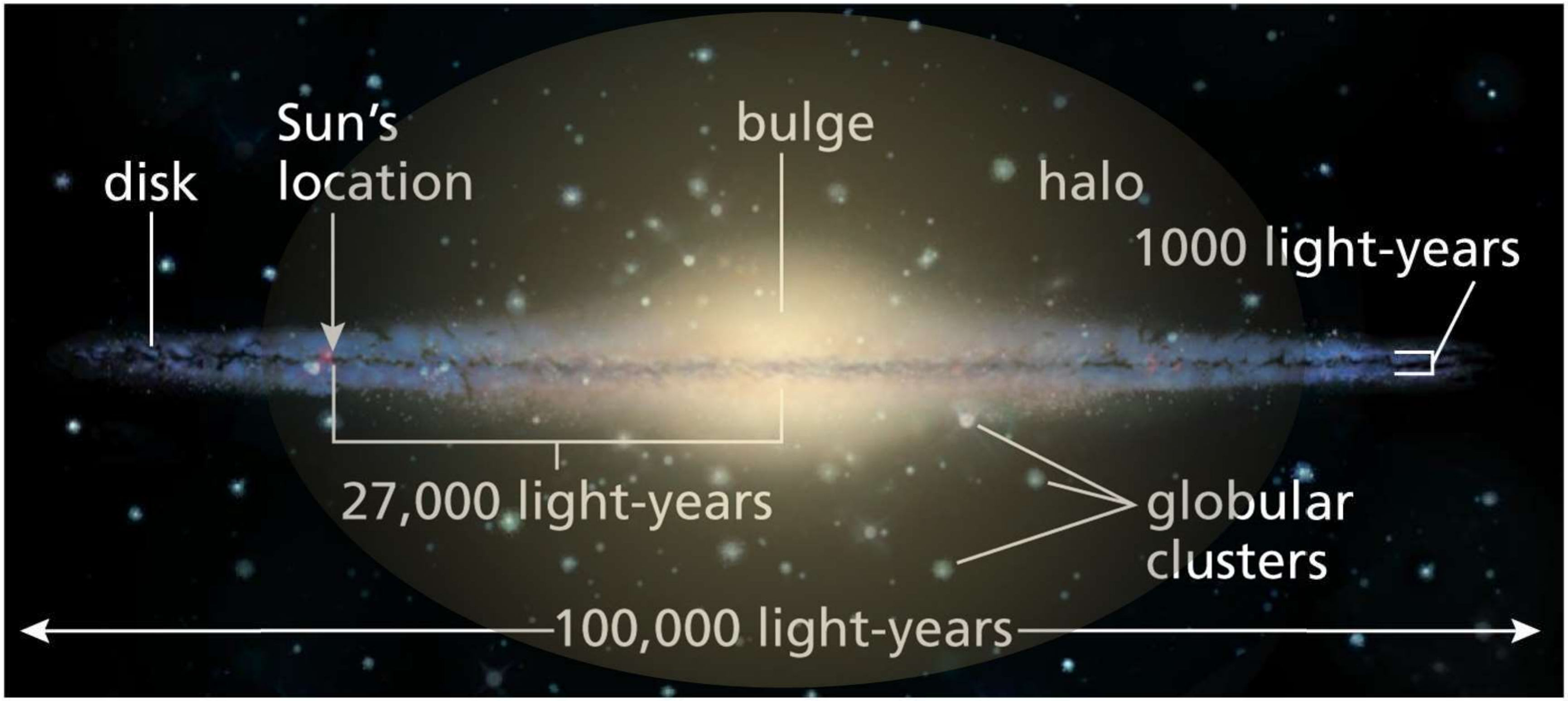
- What do halo stars tell us about our galaxy’s history?
- How did our galaxy form?

15.4. The Galactic Center

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

Edge-on View of the Milky Way*

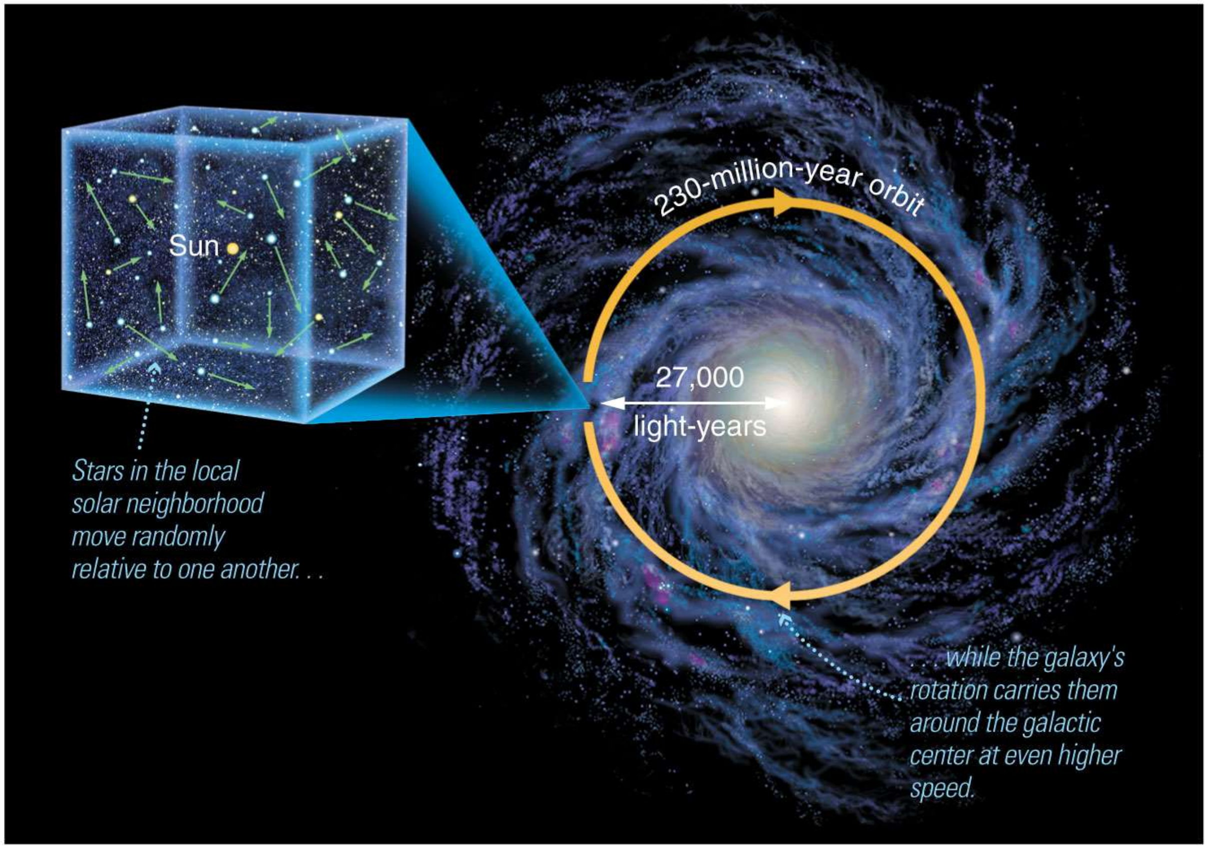
*** - artists impression!!**



b Edge-on schematic view of the Milky Way.

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

The Sun's Orbit in the Milky Way

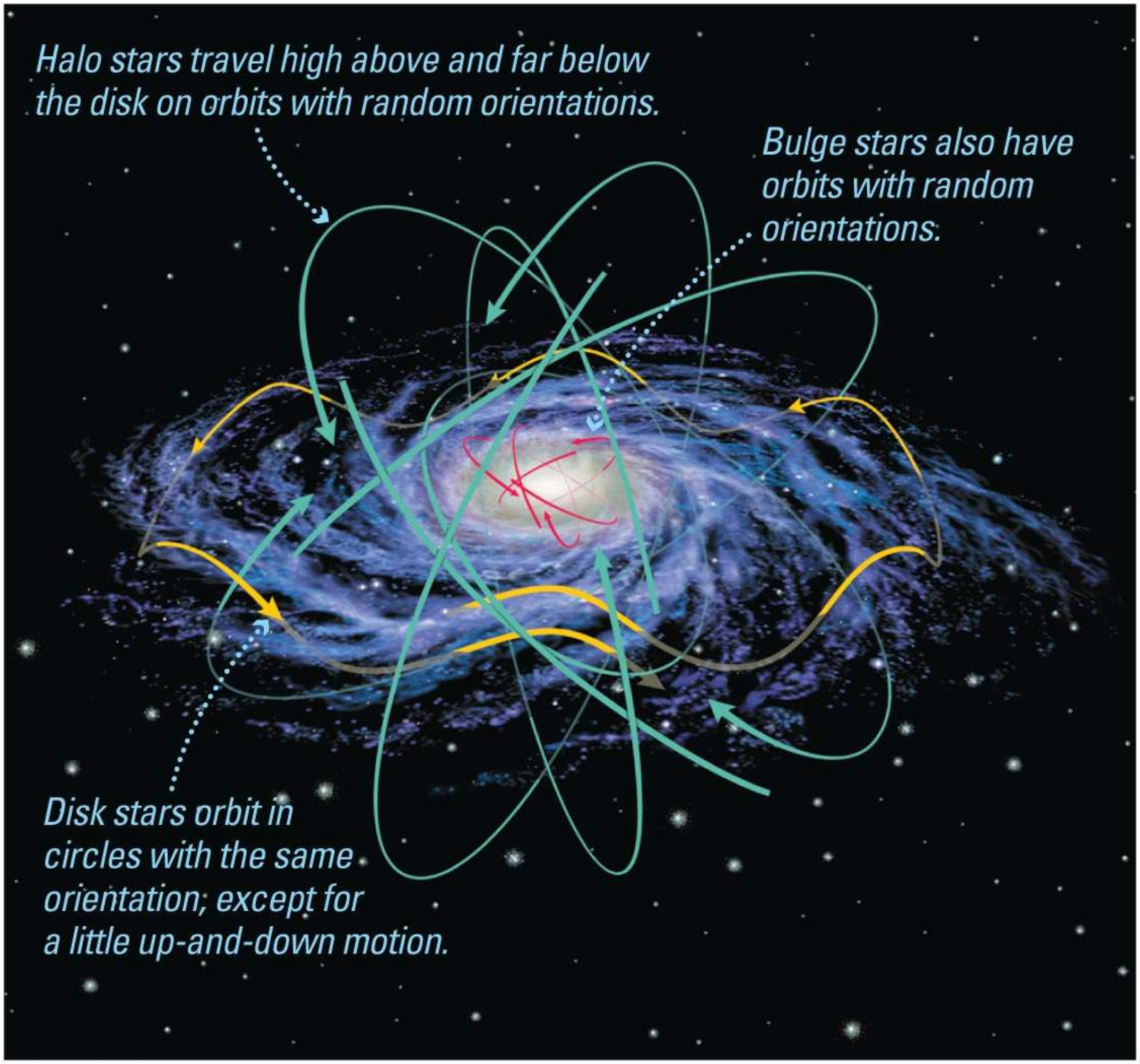


Sun's orbital motion (radius and velocity) tells us mass within Sun's orbit:

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

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

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

Star Formation Occurs in the Spiral Arms

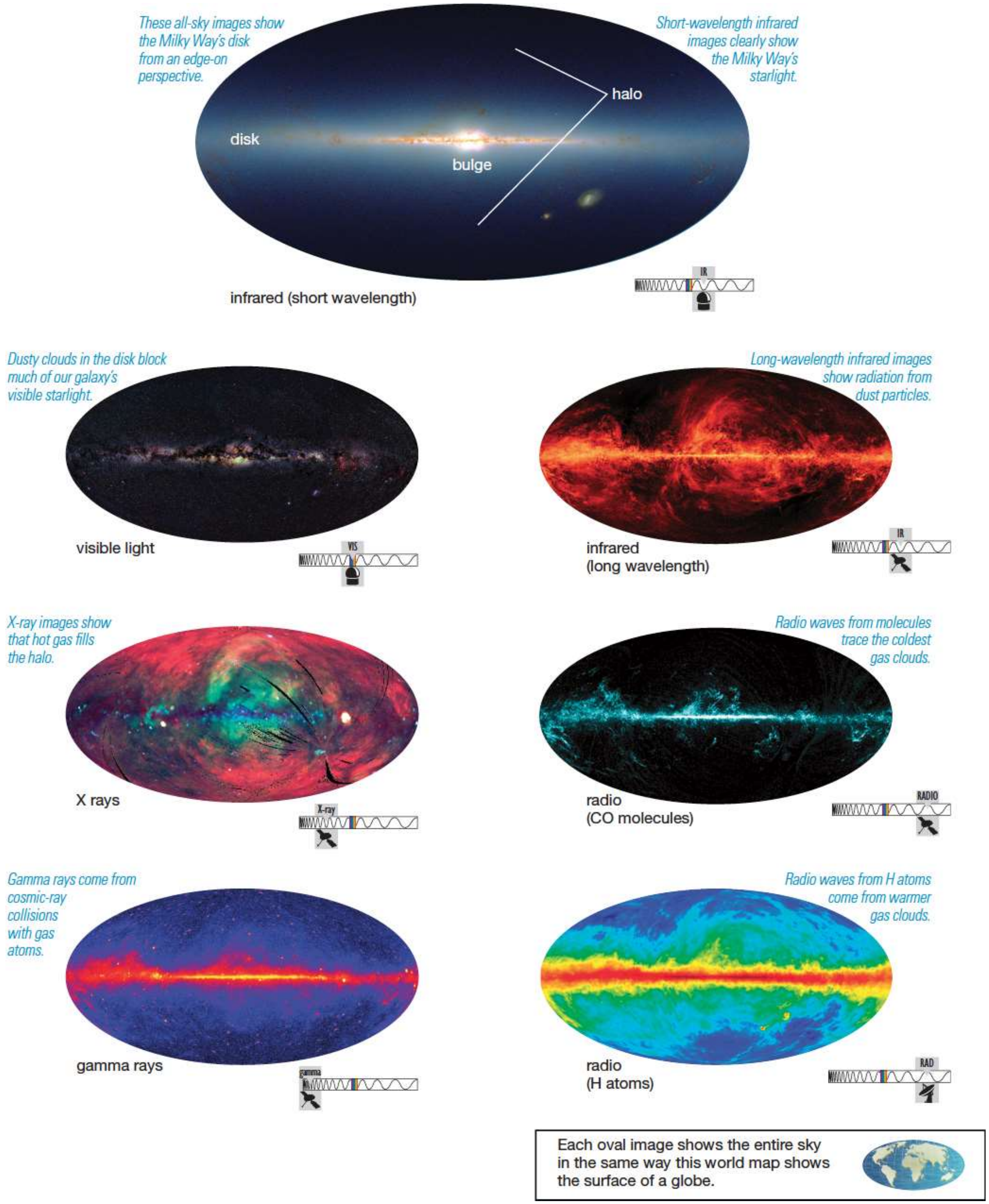
Arms are blue due to the fact there are more young stars there.

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



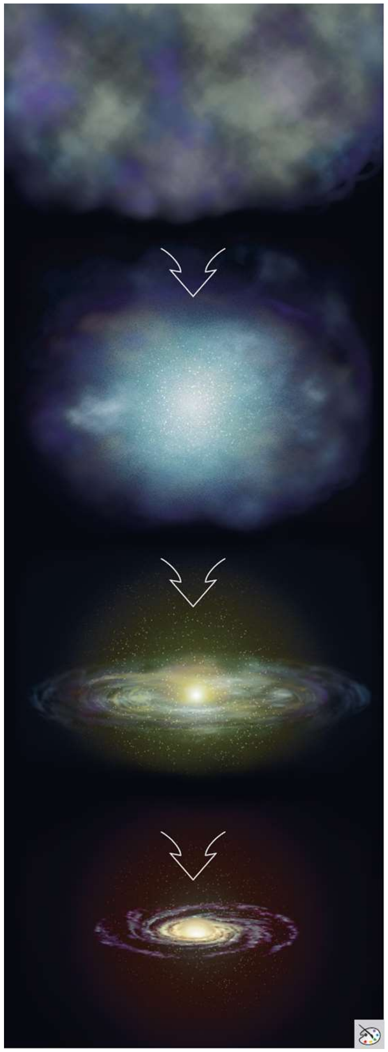
The Formation of the Milky Way

The Stars in different regions reveal the history…

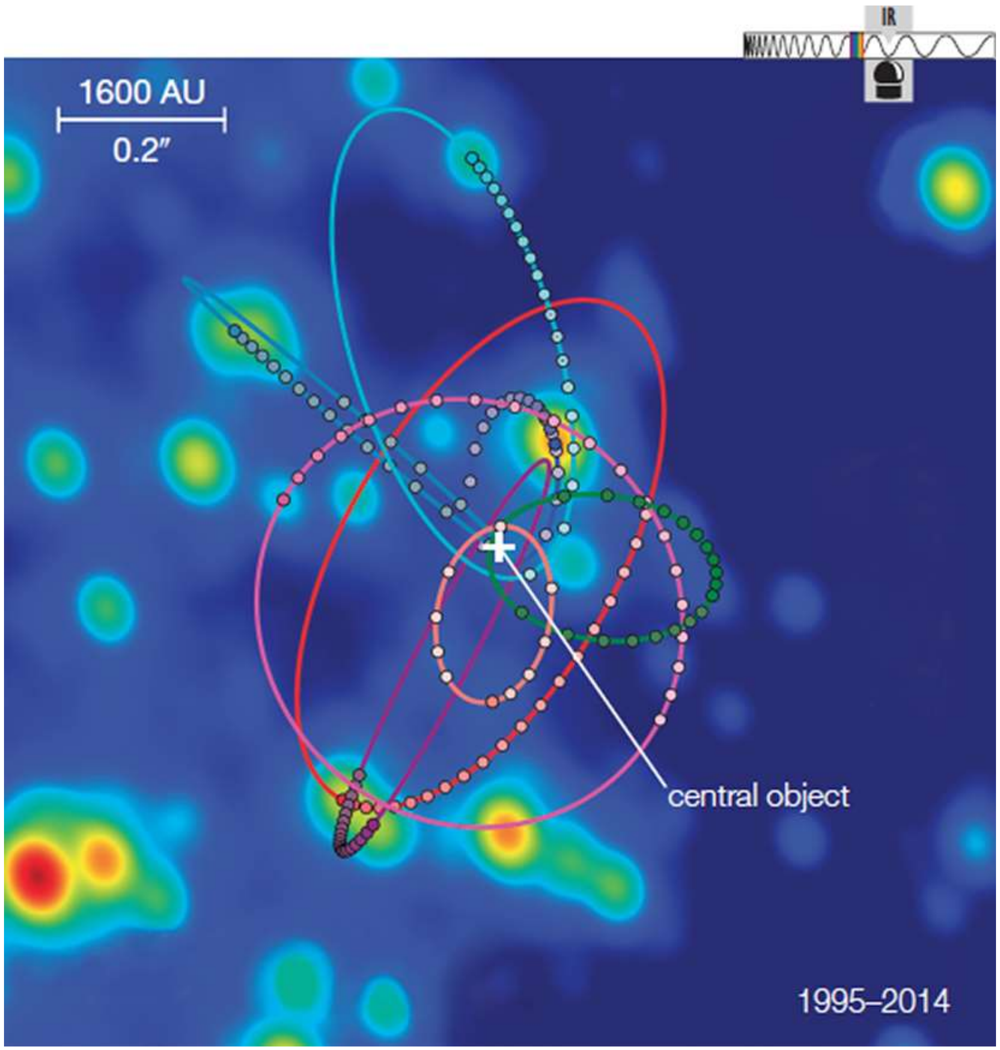
- ***Disk population*** – stars with compositions like the Sun, orbiting near the plane of the galaxy. A mix of young and old stars.
- ***Halo population –*** stars with a scarcity of heavier elements, orbiting at random inclinations to the galactic disk. All older, low-mass stars.

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}.

iClicker Question

Is the iClicker useful???

A. Yes, I love it… it really helps me learn (or not fall asleep)

B. No, get rid of it… it's a waste of time/money

C. The idea is good, but the instructor didn't seem to know how to use it…

D. It probably would have been fine if no students were using the REEF mobile app

E. The idea is good… but perhaps a different (free?) version should be used…

What Else Did We Cover Last Time?

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?

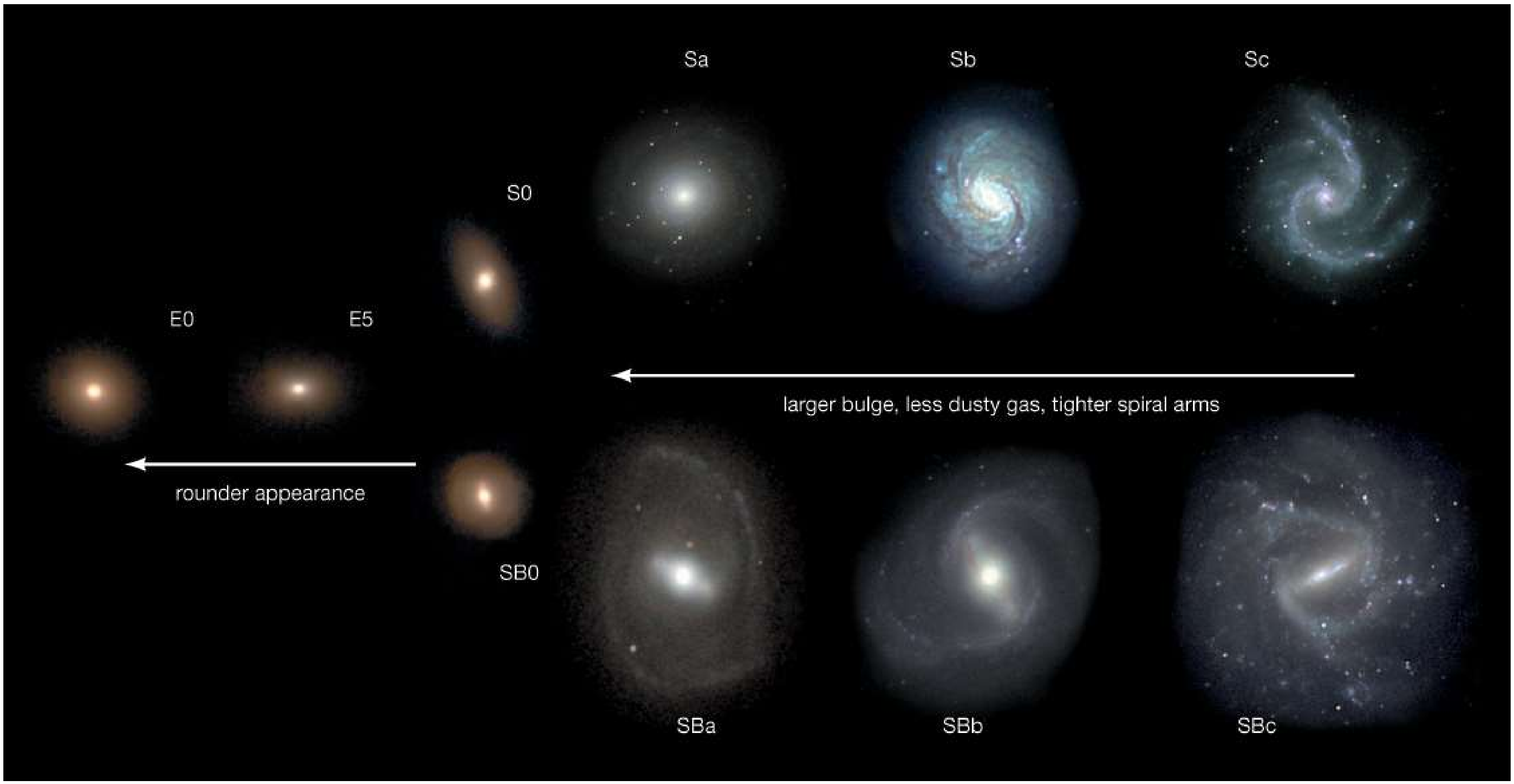
16.4. The Role of Supermassive Black Holes

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

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.

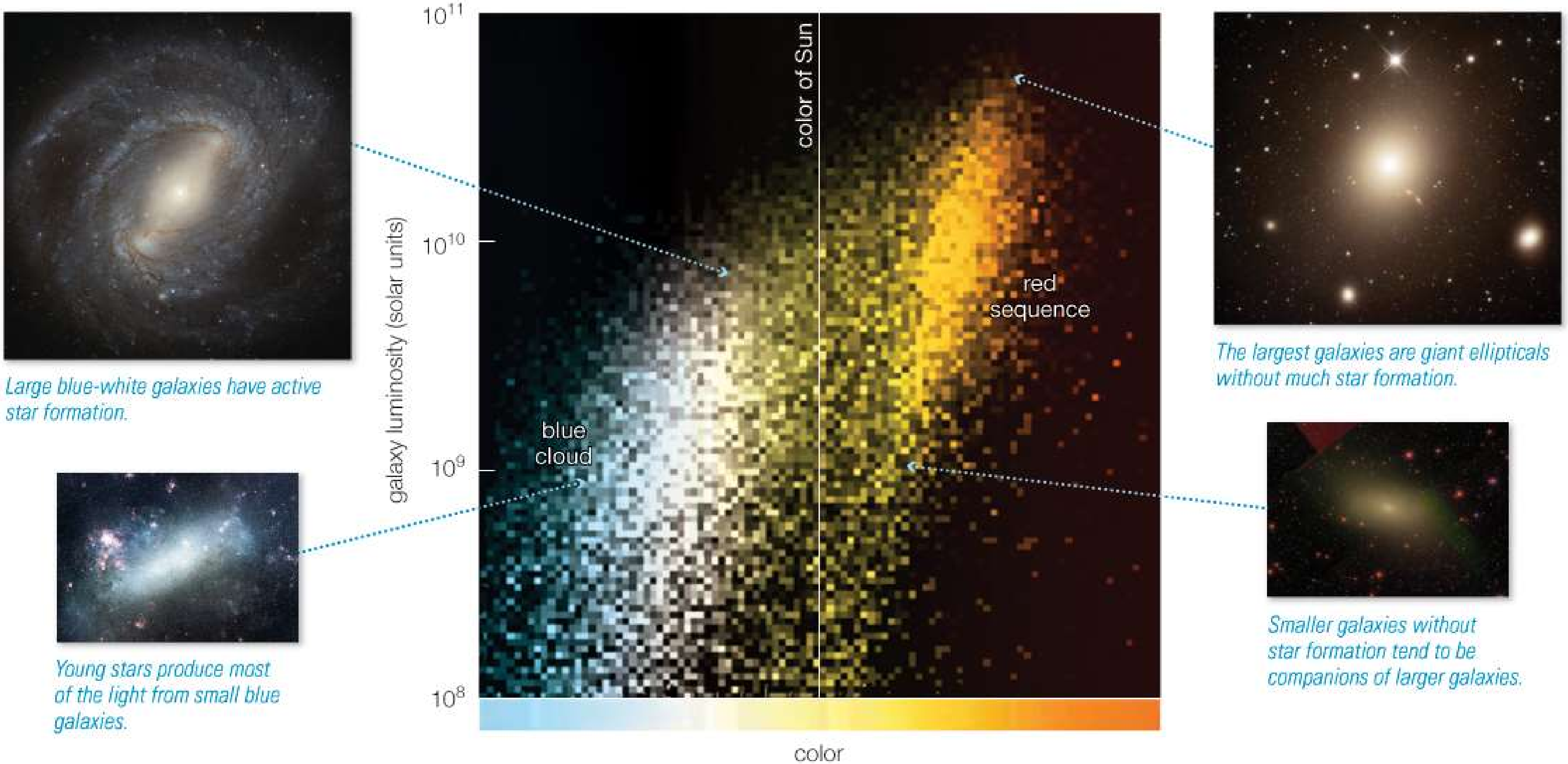
What different kinds of Galaxies are there? Hubble’s classification system



Elliptical Galaxy:

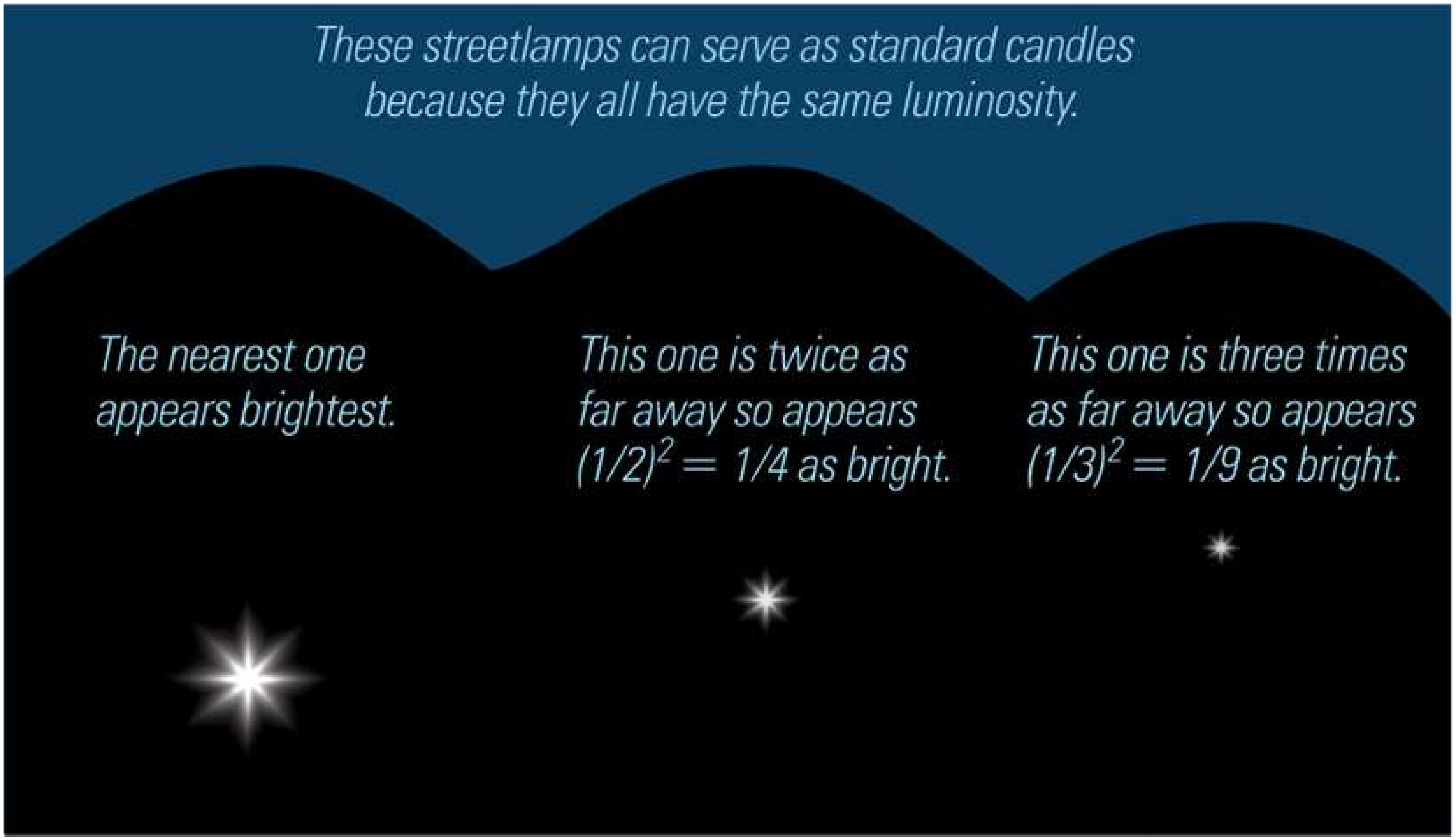
All spheroidal component, virtually no disk component

Red-yellow color indicates older star population.

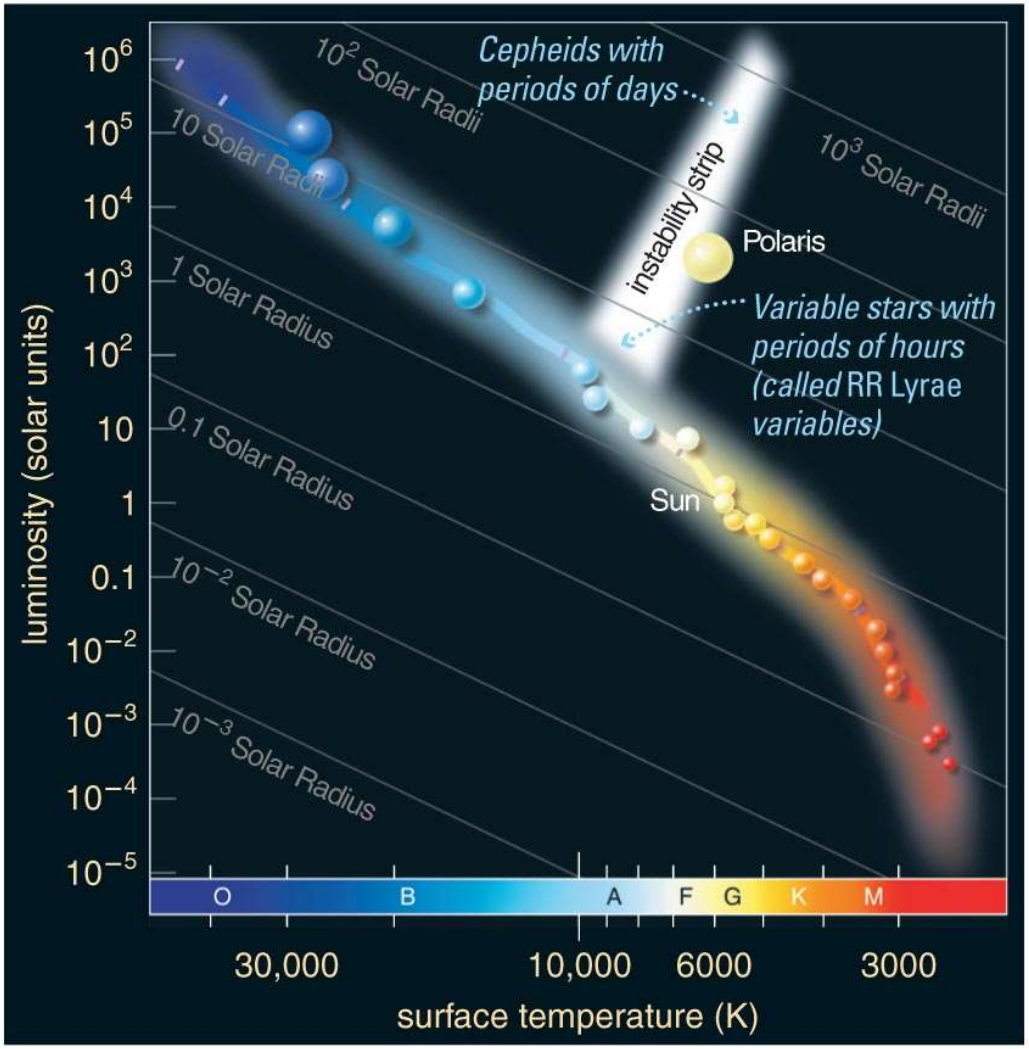


Patterns in color and luminosity

How can we use Standard Candles?



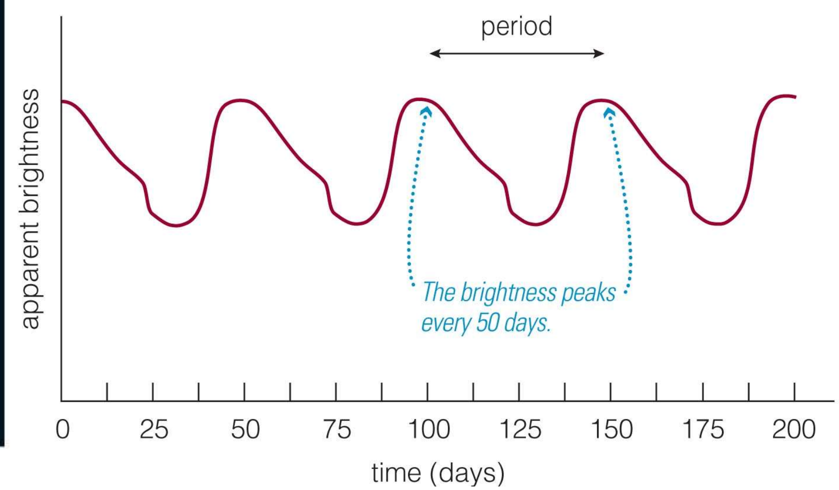
Cepheid stars as standard candles



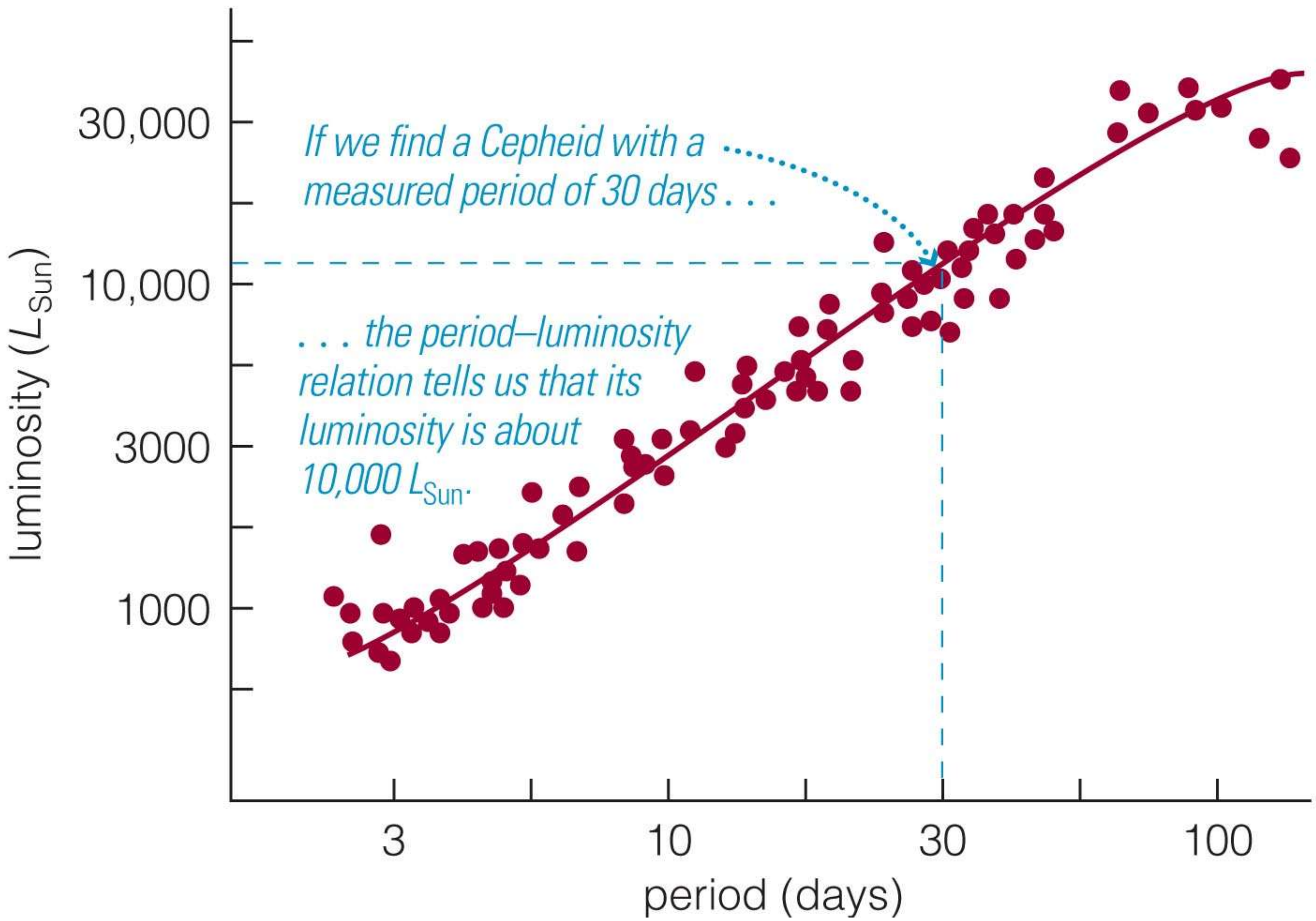
Cepheid variable stars are very luminous.

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.

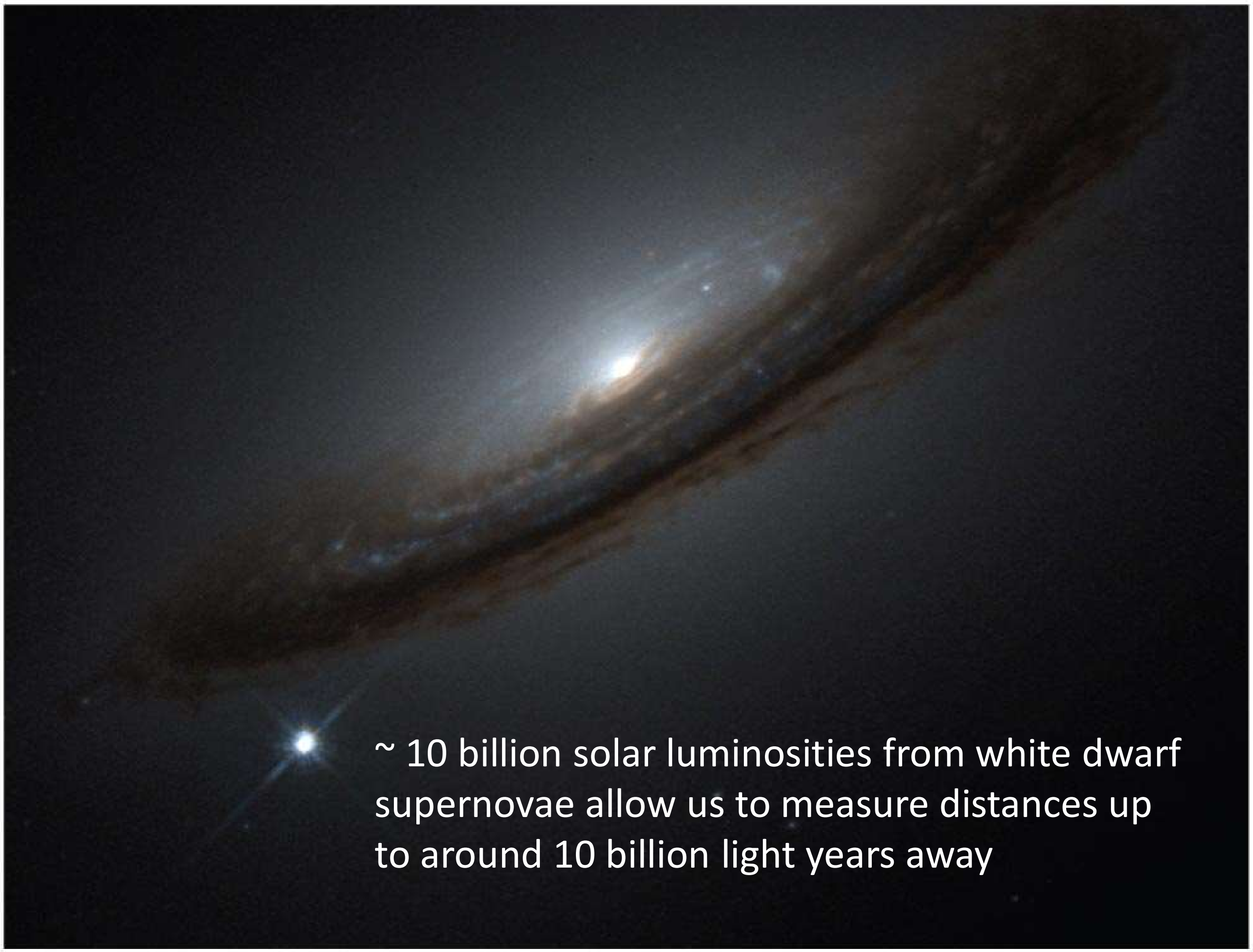


Cepheid stars as standard candles

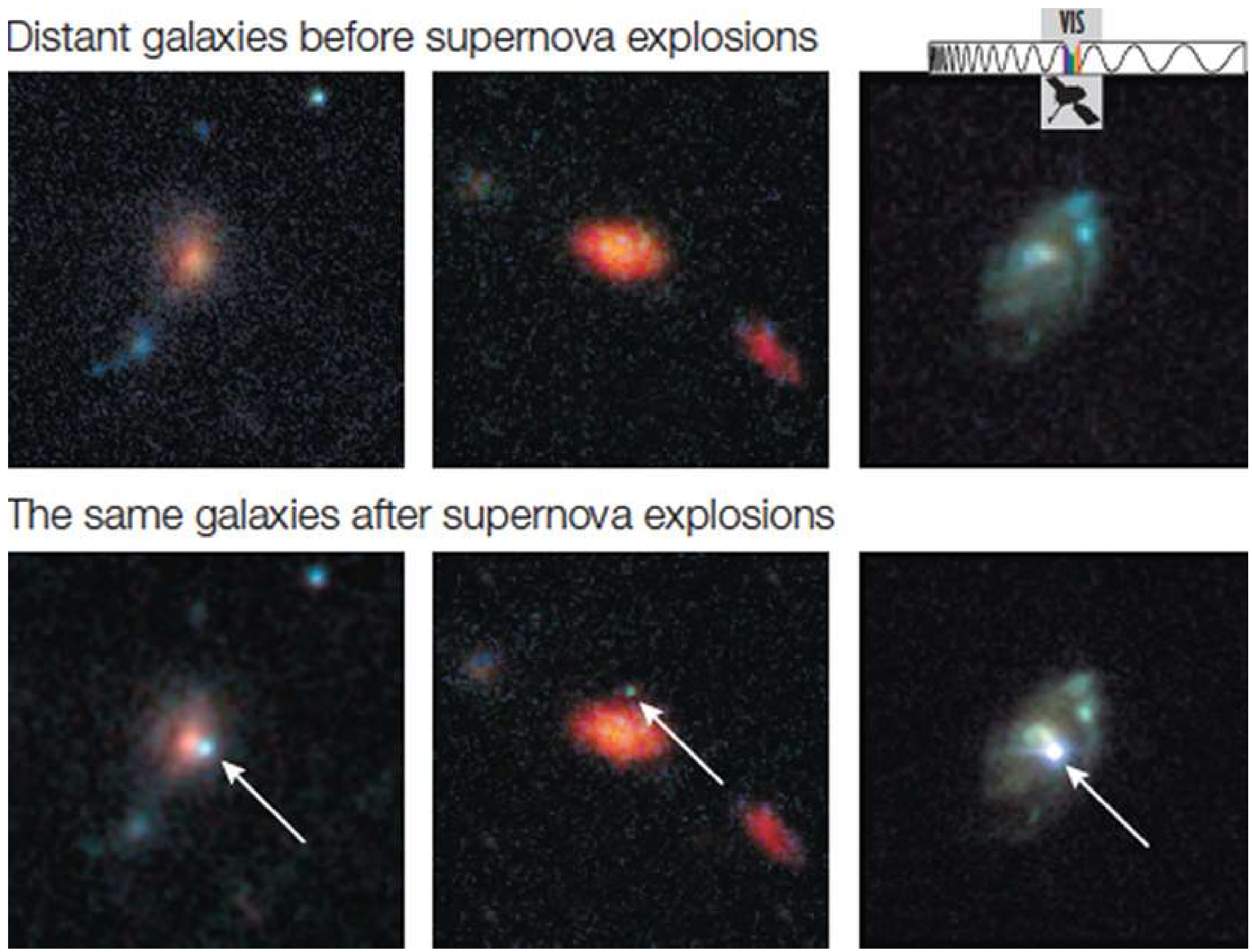


Cepheid variable stars with longer periods have greater luminosities.

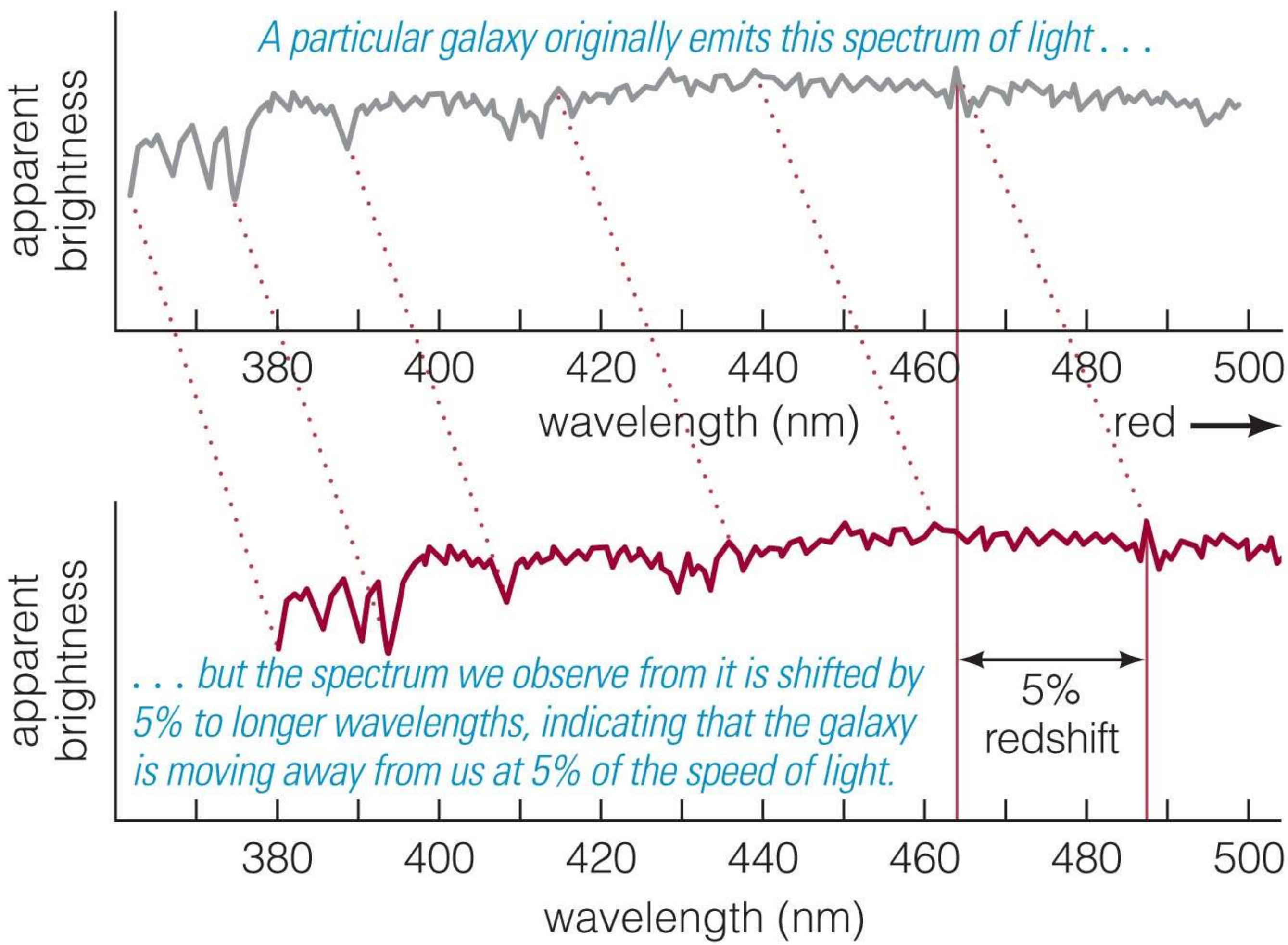
White Dwarf Supernovae as Standard Candles



White Dwarf Supernovae as Standard Candles



Red-Shifting of Galaxies

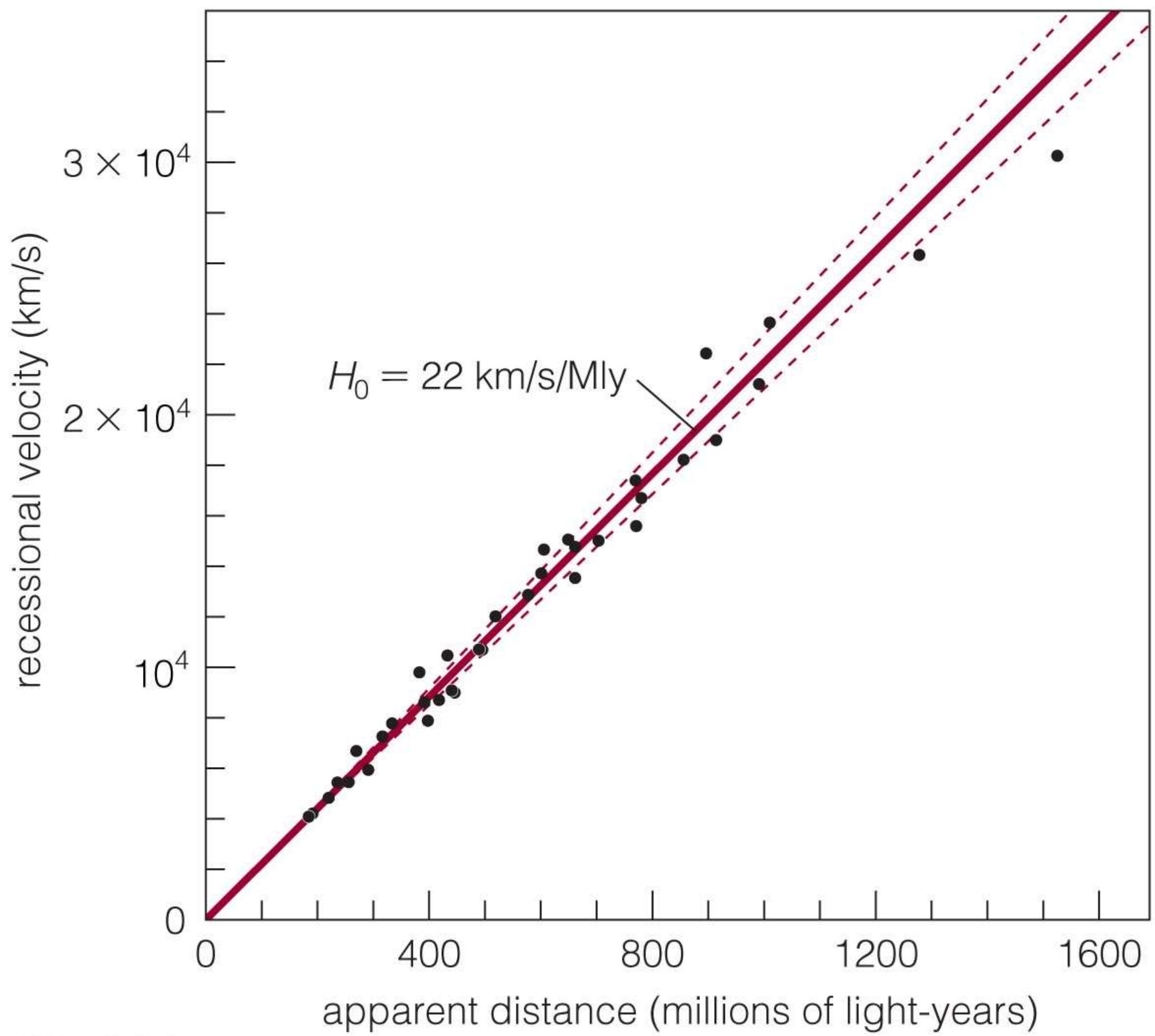


The red-shift of a galaxy tells us of the speed that galaxy is moving away from us.

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

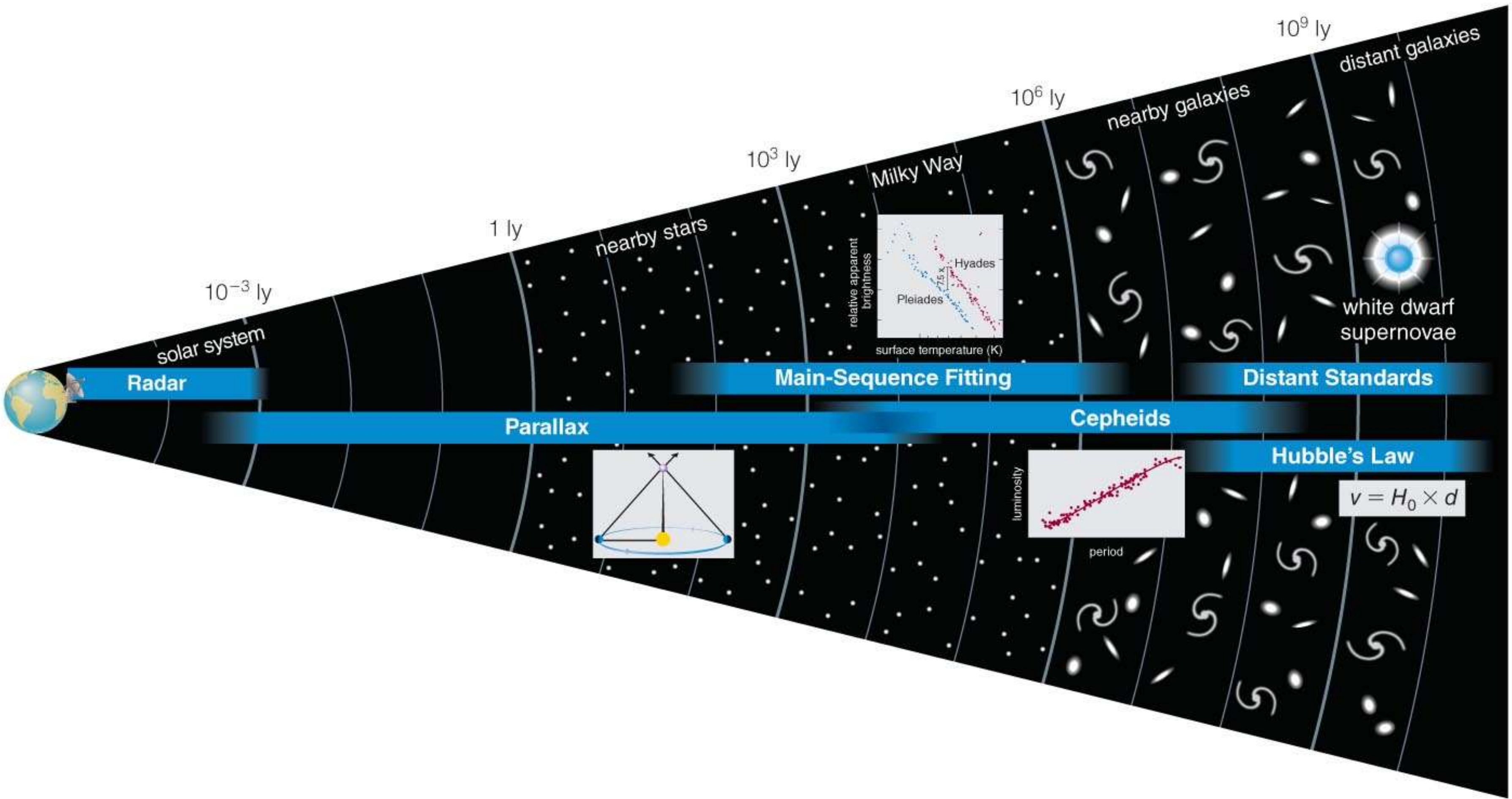
$$distance = \frac{velocity}{H_0}$$

Hubble's Law



Hubble's law: velocity = $H_0 \times$ distance

Measuring the Distances of Galaxies



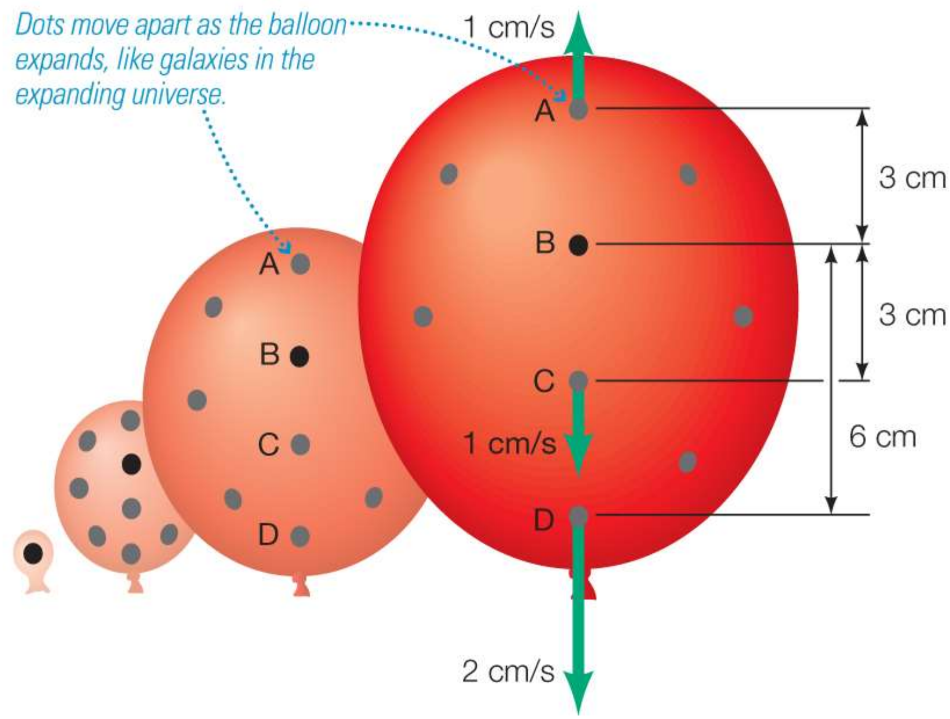
Using Hubble's Law to Constrain the Age of the Universe

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:

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

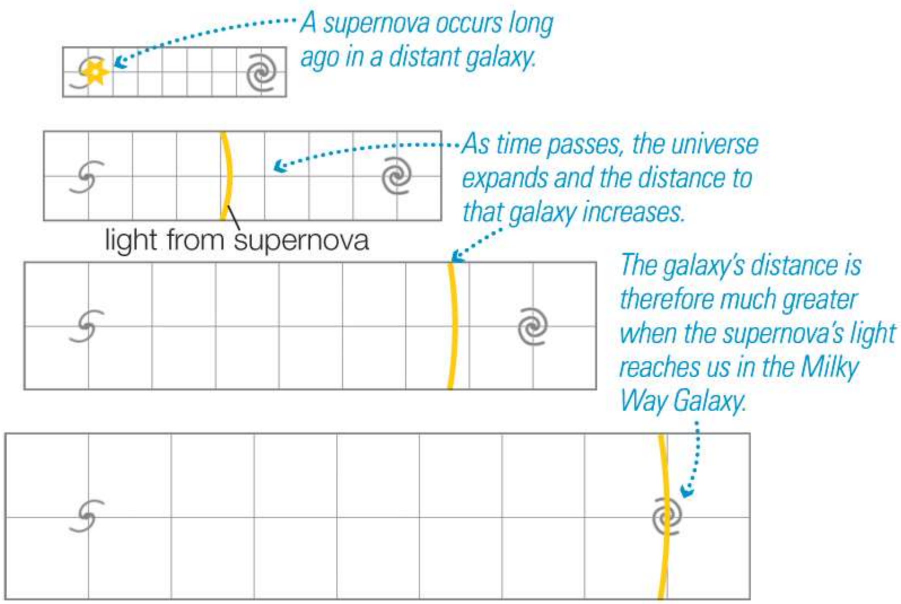
$$\sim \frac{1}{H_0}$$

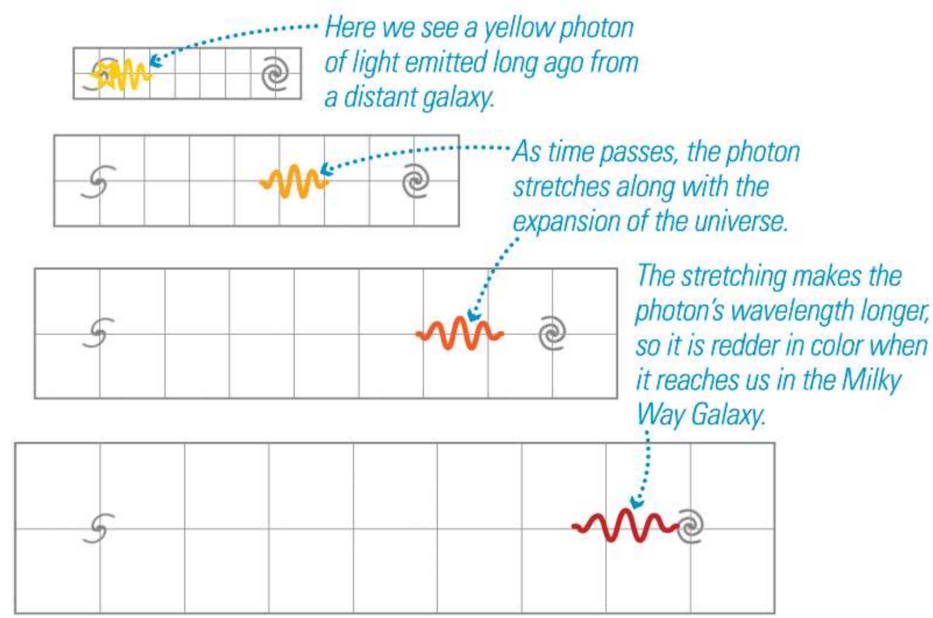
The age of the Universe is determined to be approximately 14 billion years old (assuming the rate of increase is constant, and ignoring local group galaxies)



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

What’s Next?

Chapter 17: The Birth of the Universe (Abridged)

17.1. The Big Bang Theory

- What were the conditions like in the Early Universe?
- How did the early universe change with time?

17.2. Evidence for the Big Bang

- How do observations of the cosmic microwave background support the big bang theory?
- How do the abundances of the elements support the Big Bang theory?

17.3. The Big Bang and Inflation

- What key features of the universe are explained with inflation?
- Did inflation really occur?

17.4. Observing the Big Bang for yourself

- Why is the darkness of the night sky evidence for the big bang?

Olber's Paradox

If the universe were:

- Infinite
- Unchanging
- The same everywhere

Then wouldn't we expect to receive sunlight from every single spot in the sky?

→ We don't see light coming from every direction. Most of the sky is dark. This supports the idea that the universe is finite, and may have originated from a single point…

Thought Question

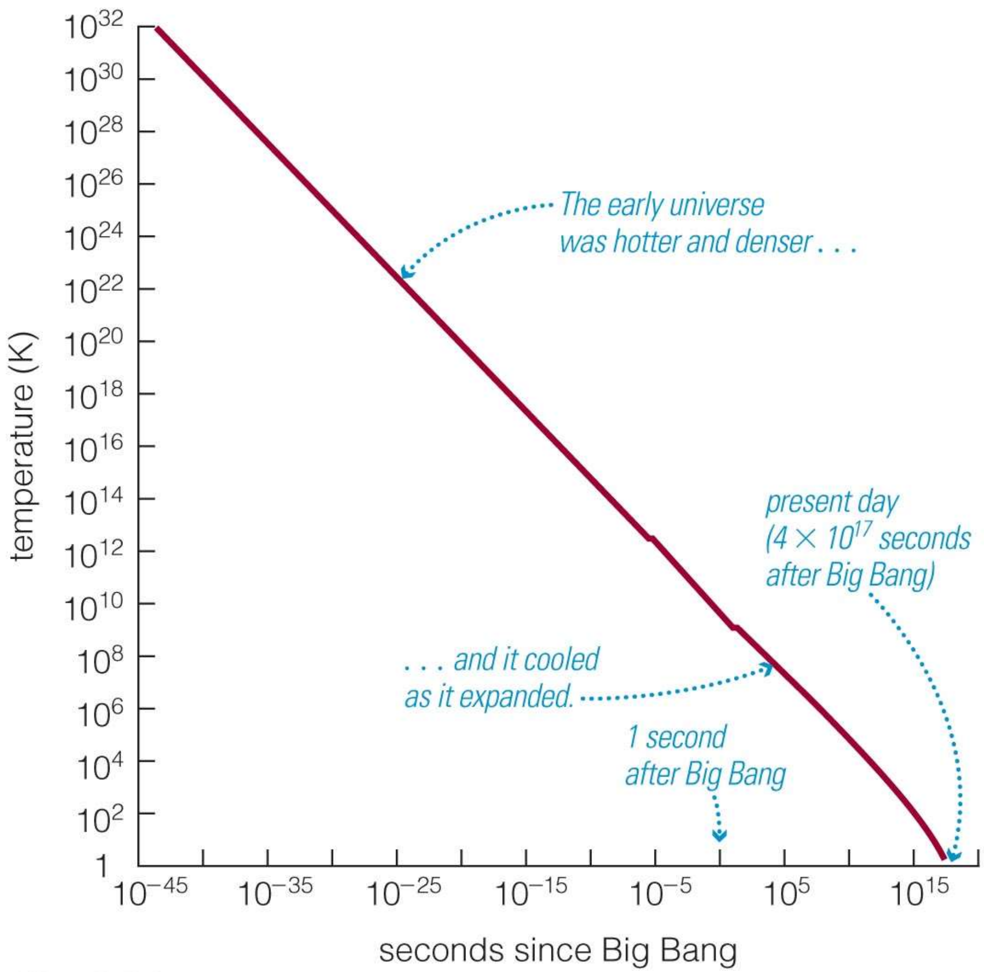
Last lecture, we talked about how the Hubble constant, which allowed us to determine how fast galaxies are moving away from us.

We also determined that by extrapolating ‘back in time’ we could estimate a rough time estimate for when all of the galaxies would have originated from the same ‘point’ … which we estimated at ~ 14 billion years.

Based on what we remember about the ideal gas law (PV=nRT), what would happen if we tried to fit all of matter in the known universe into a very close space?

→ **The pressure and temperature would become enormous!**

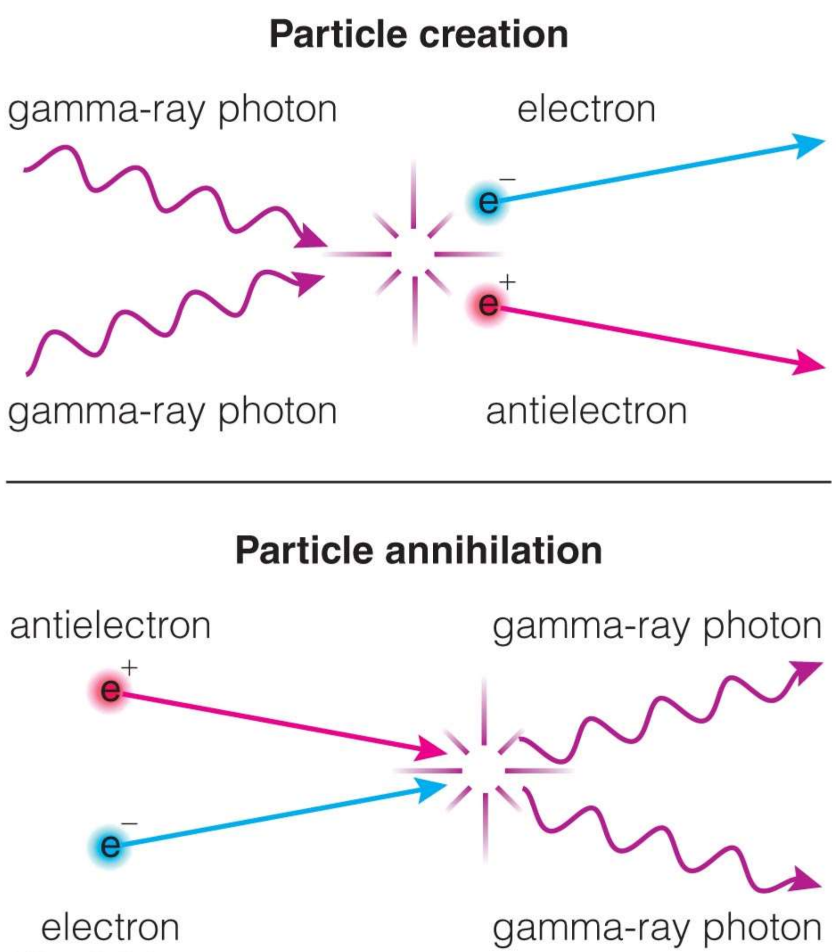
The First Moments of the Big Bang



Extrapolating backwards, we can estimate that the average temperatures would have been exceedingly hot in the beginning…

… So hot in fact, that in the very early stages, the distinction between light and matter would not have been possible.

Light, Matter & Antimatter



- We saw previously that a positron (an antielectron) and an electron can recombine to form two 0.511 MeV gamma rays…

$E=mc^2$

- The opposite is also true, it is possible to generate matter (both electrons and anti-electrons) from two 0.511 MeV gamma rays…
- The same thing can happen to generate protons and antiprotons, you just need A LOT more energy to do so.
- In our universe, the amount of ordinary matter is in excess of the amount of anti-matter we observe…
- How can this be possible?

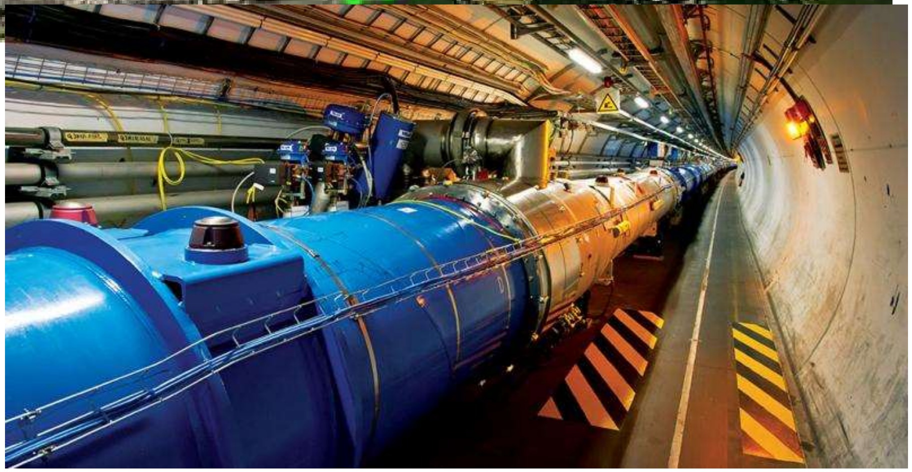
→ **We don't know! but we know that an imbalance of 1 in 10^9 normal matter particles not being annihilated would be required.**

The Large Hadron Collider

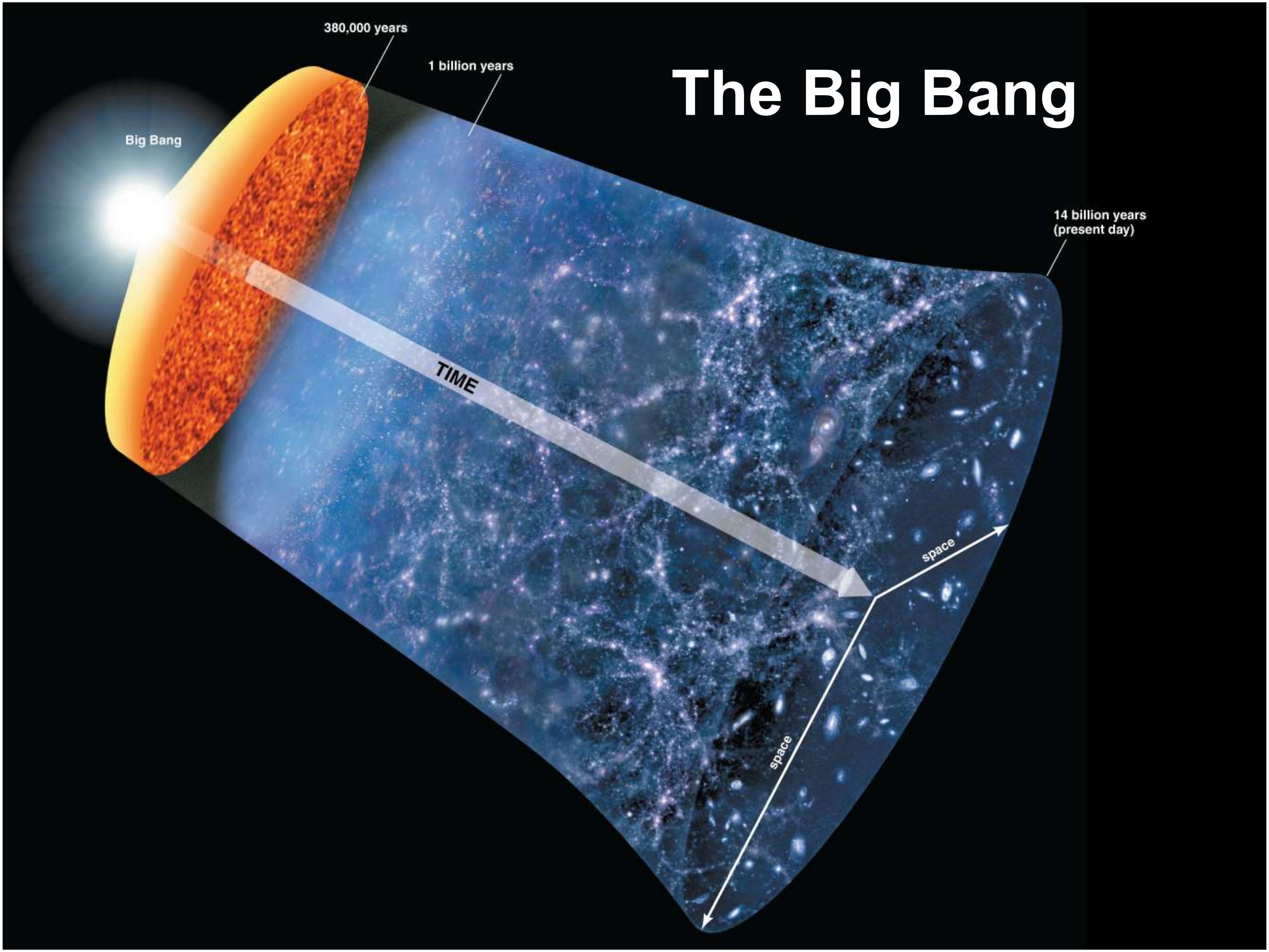
~ 17 mile long loop in Geneva

Can accelerate particles to ~8 TeV

(or 99.999999% the speed of light)



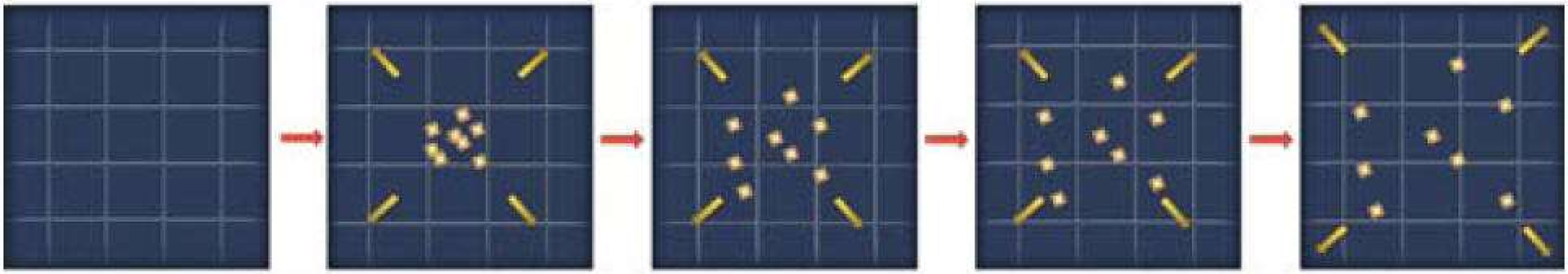
The Big Bang


380,000 years
1 billion years
Big Bang
14 billion years
(present day)
TIME
space
space

WHAT KIND OF EXPLOSION WAS THE BIG BANG?

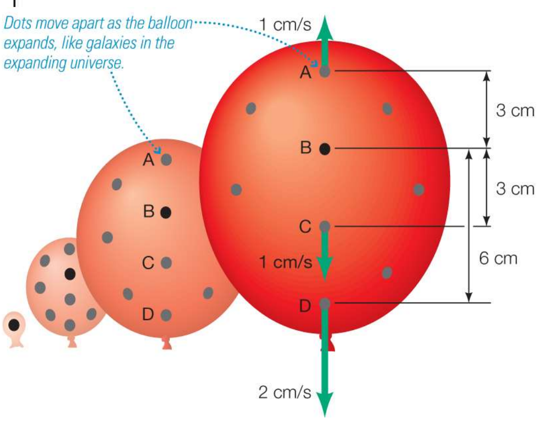
WRONG: **The big bang was like a bomb going off at a certain location in previously empty space.**

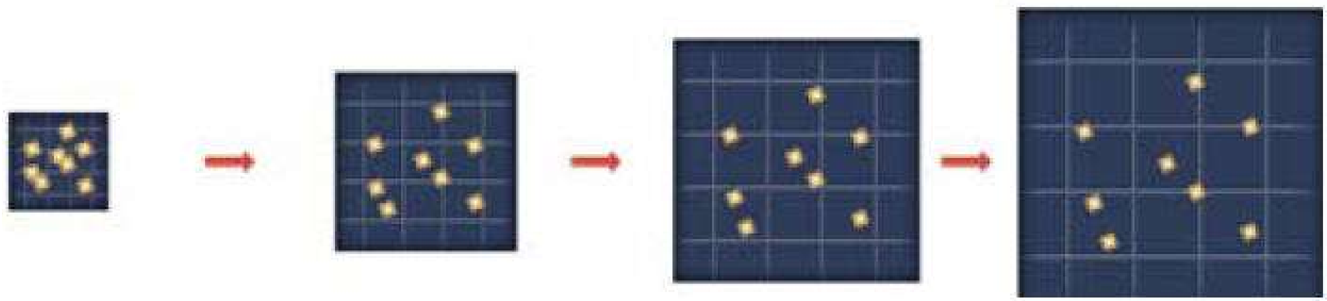
In this view, the universe came into existence when matter exploded out from some particular location. The pressure was highest at the center and lowest in the surrounding void; this pressure difference pushed material outward.



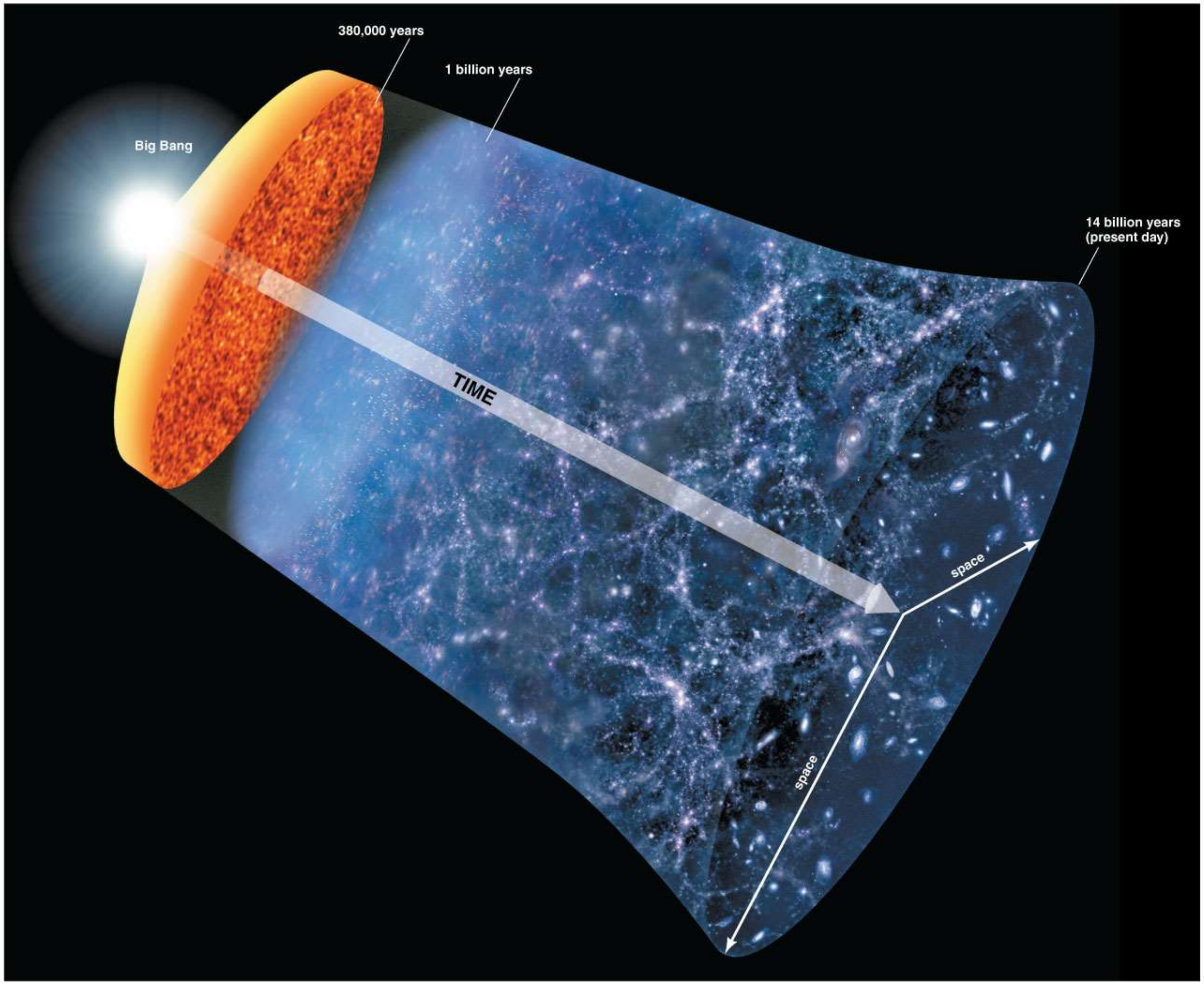
RIGHT: **It was an explosion of space itself.**

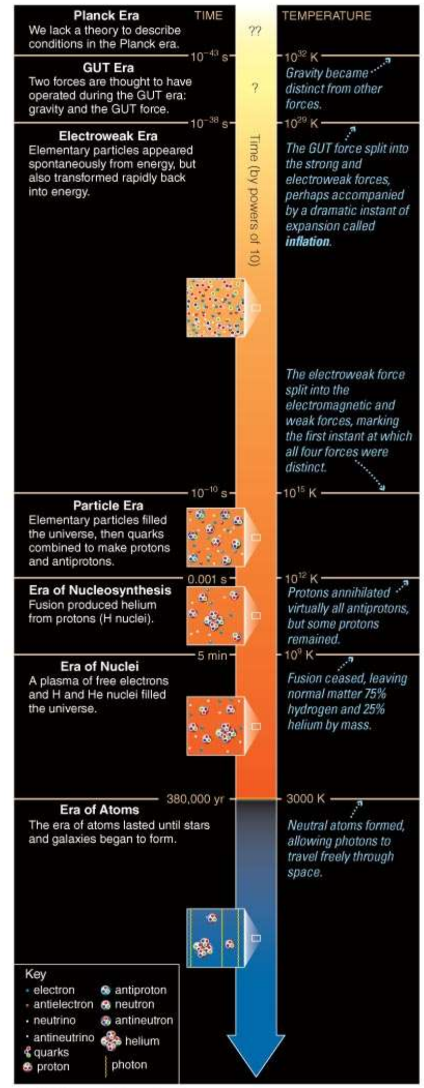
The space we inhabit is itself expanding. There was no center to this explosion; it happened everywhere. The density and pressure were the same everywhere, so there was no pressure difference to drive a conventional explosion.



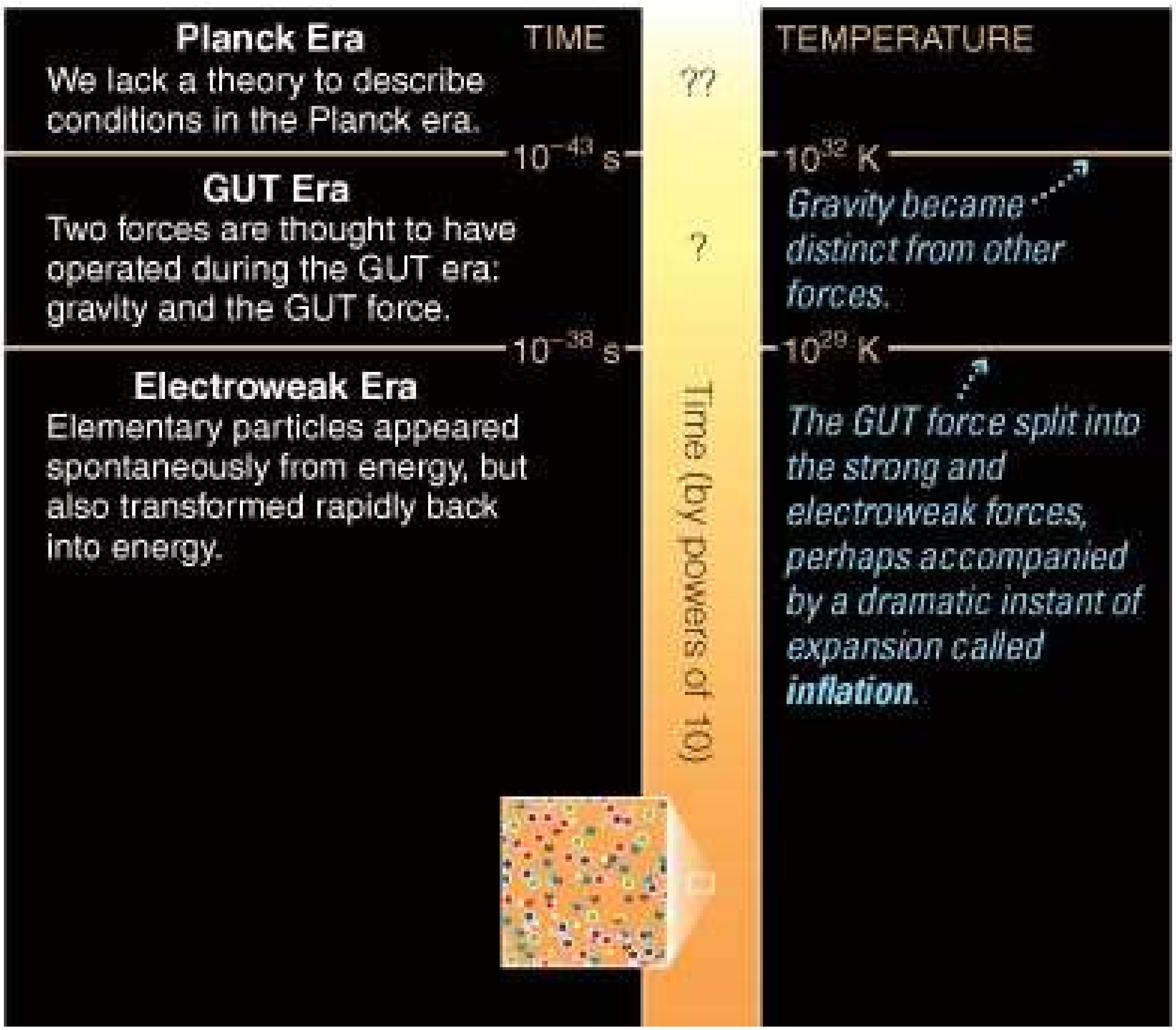


Break down of the Big Bang





Break down of the Big Bang
The early era's (<10^{-10} s)



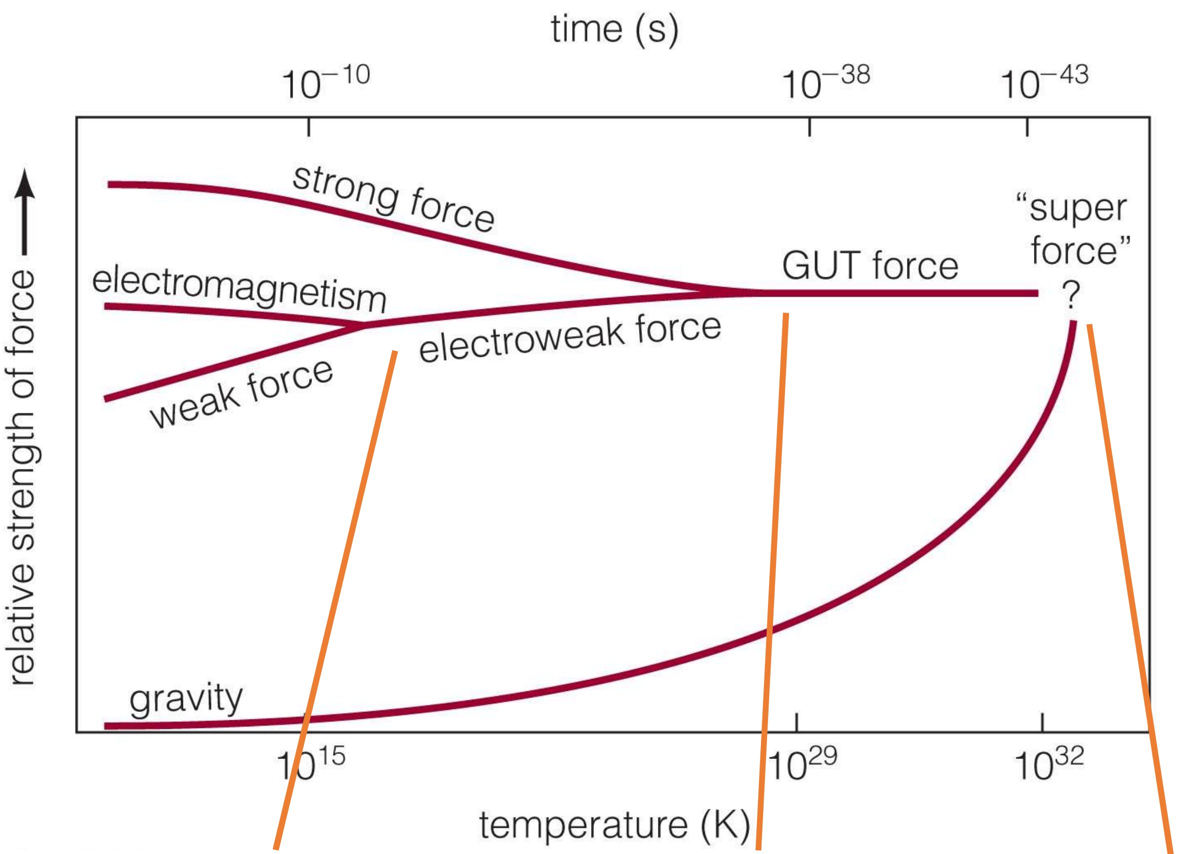
Planck Era:

Time: < 10^{-43} s
Temp: > 10^{32} K

No theory of quantum gravity yet

All forces may have been unified

What Happens to Forces at High Temperatures?



Four known forces in universe (present day):

Strong Force

Weak Force

Electromagnetism

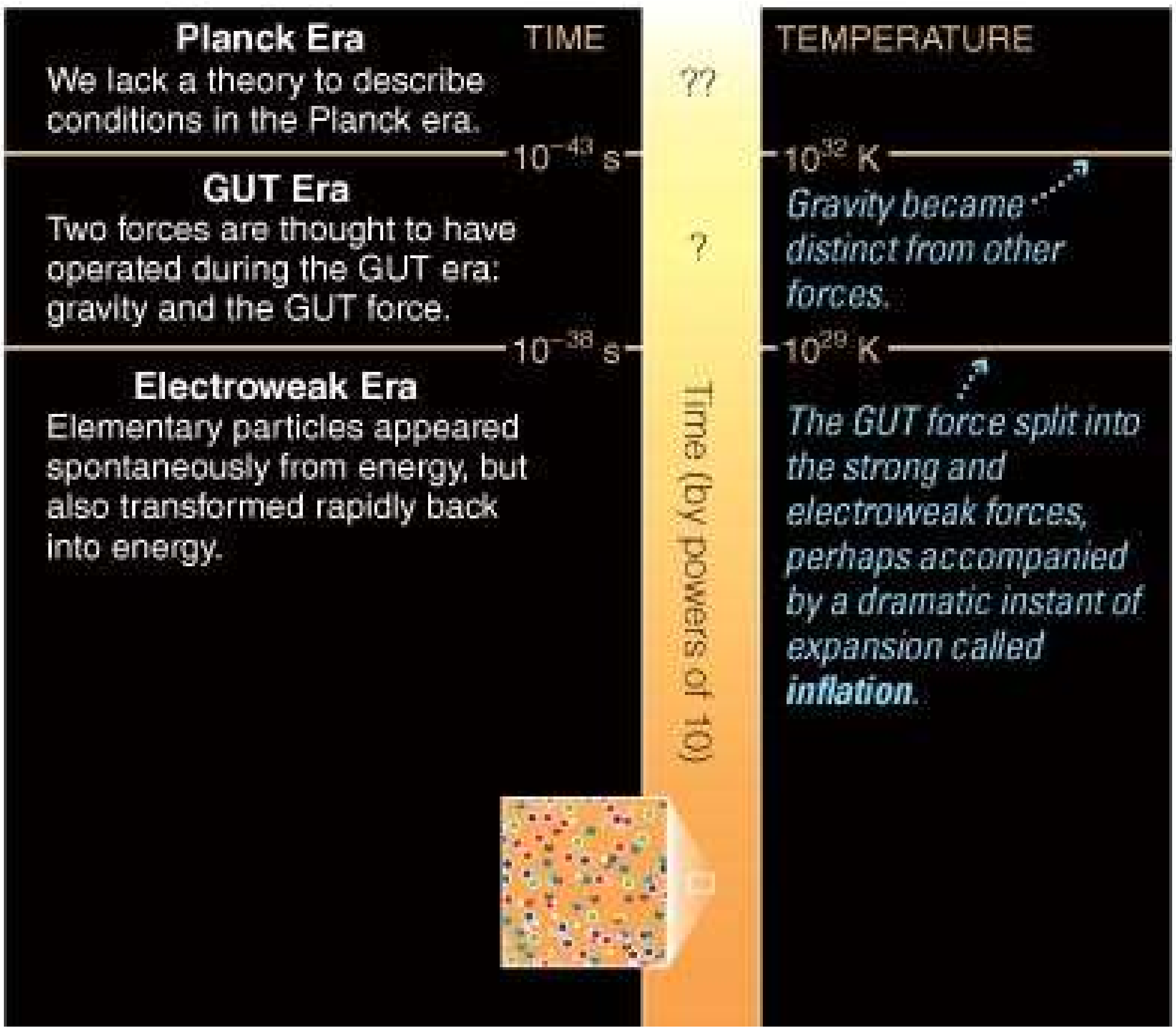
Gravity

Yes!
(Electroweak)

Maybe
(GUT)

Who knows?
(Theory of Everything)

Break down of the Big Bang The early era's (<10^{-10} s)



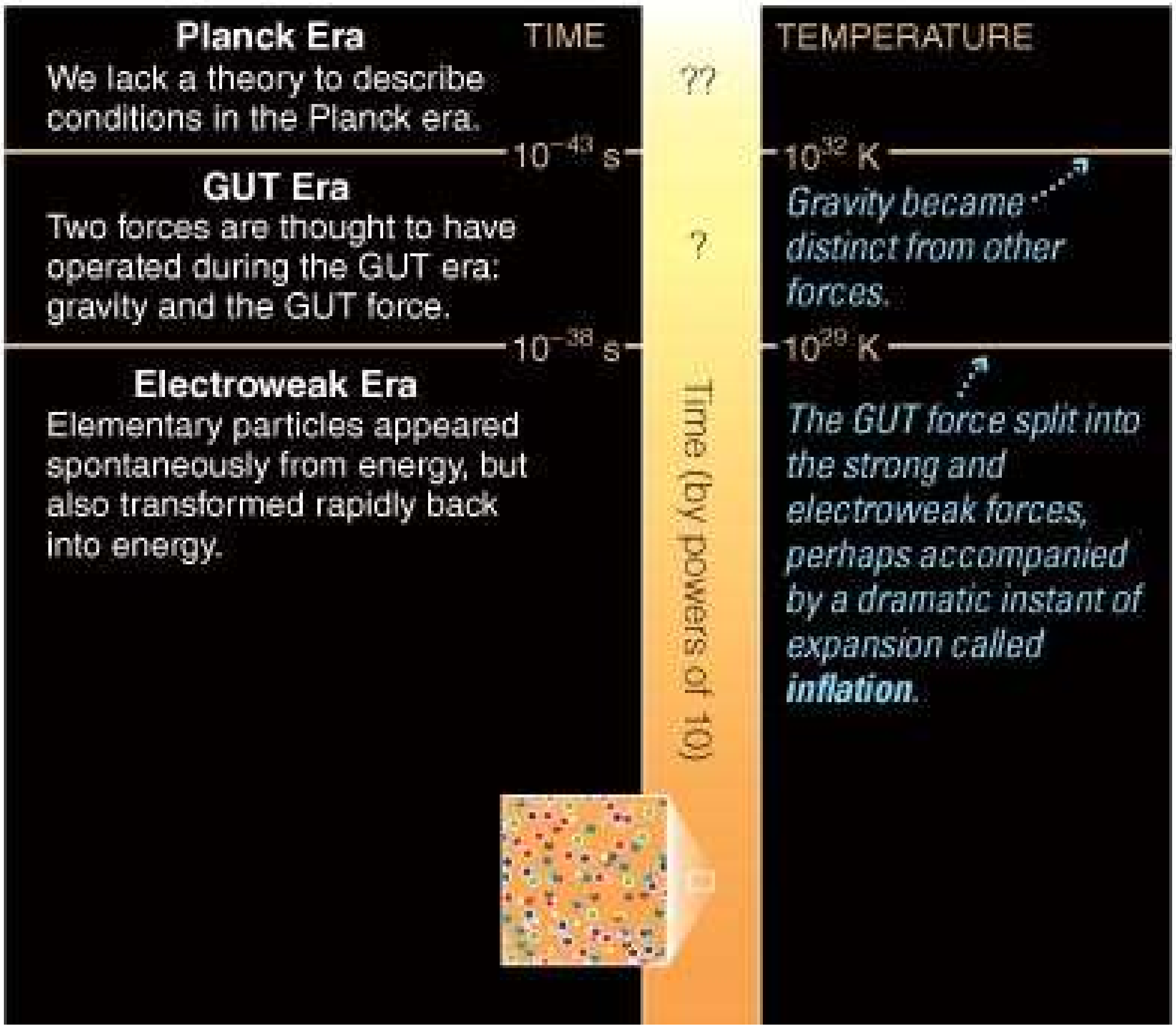
GUT Era: Grand Unified Theories…

Time: 10^{-43}–10^{-38} s
Temp: $10^{3}2$–10^{29} K

GUT era began when gravity became distinct from other forces.

GUT era ended when strong force became distinct from electroweak force.

Break down of the Big Bang The early era's (<10^{-10} s)

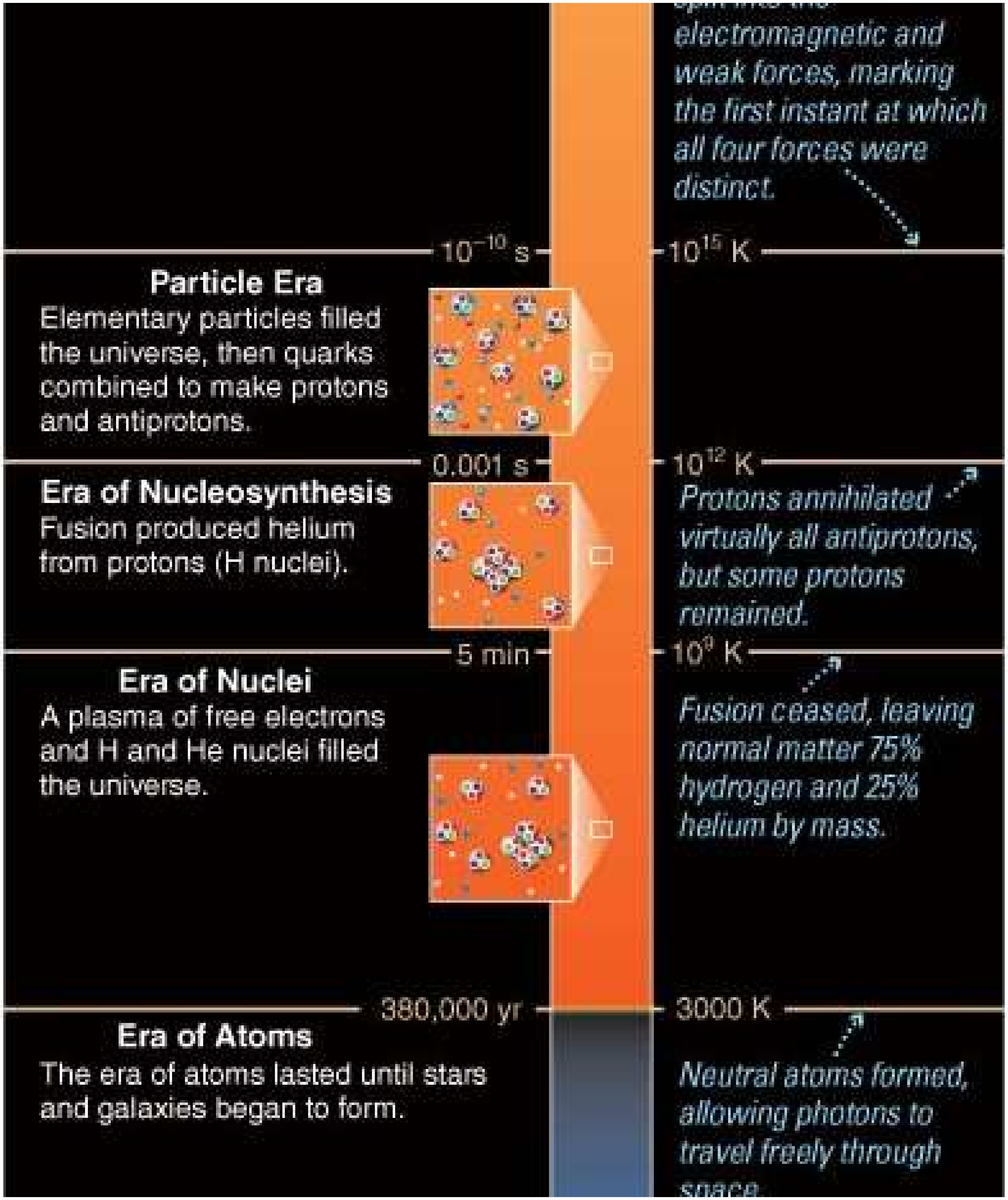


Electroweak Era:

Time: 10^{-10}–10^{-10} s
Temp: 10^{29}–10^{15} K

Gravity became distinct from other forces.

Strong, weak, and electromagnetic forces may have been unified into GUT force.



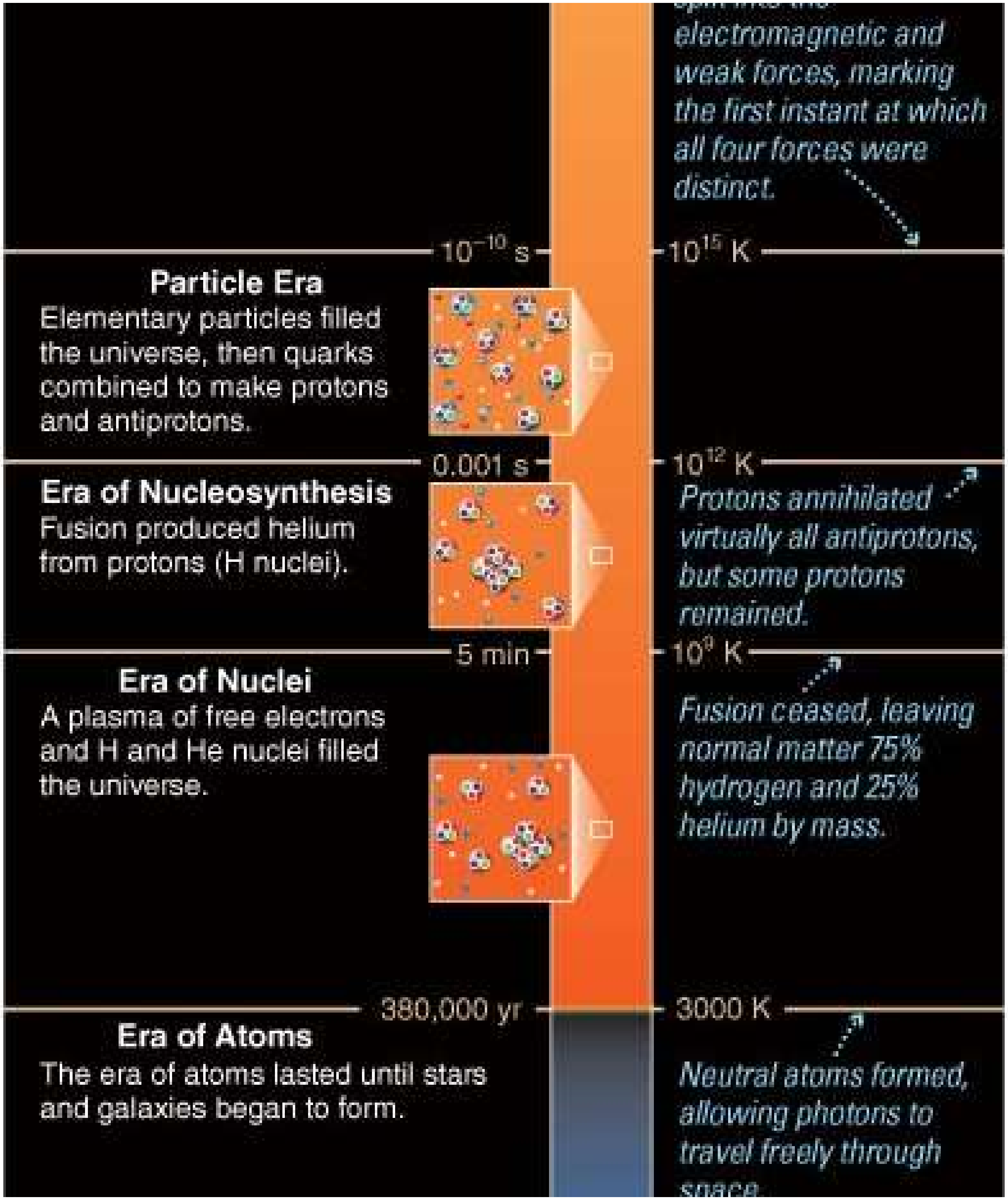
The Big Bang: Later Era's

Particle Era:

Time: 10^{-10}–0.001 s
Temp: 10^{15}–10^{12} K

Amounts of matter and antimatter are nearly equal.

(Roughly one extra proton for every 10^{9} proton–antiproton pairs!)



The Big Bang: Later Era's

Era of Nucleosynthesis:

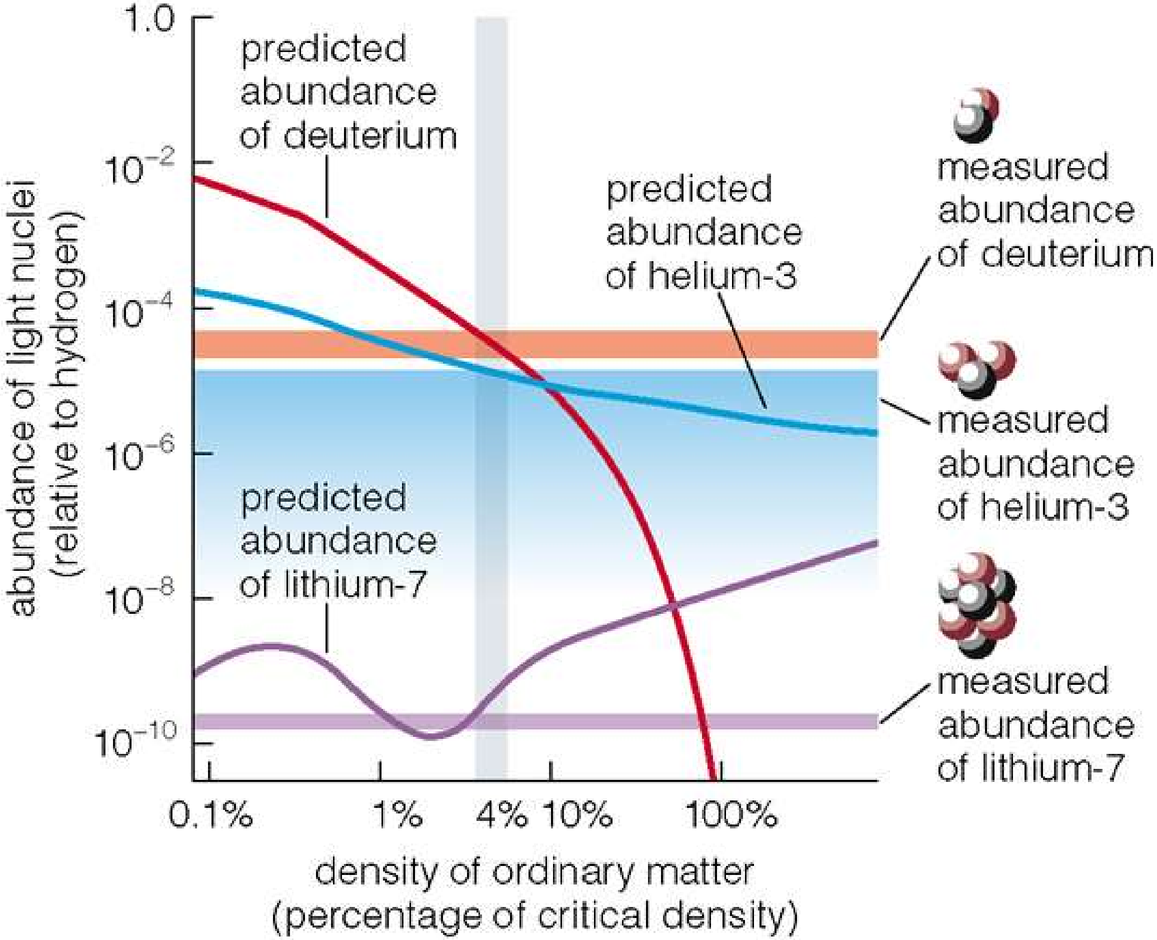
Time: 0.001s – 5 min
Temp: 10^{12}–10^{9} K

Began when matter annihilates remaining antimatter at ~0.001 s.

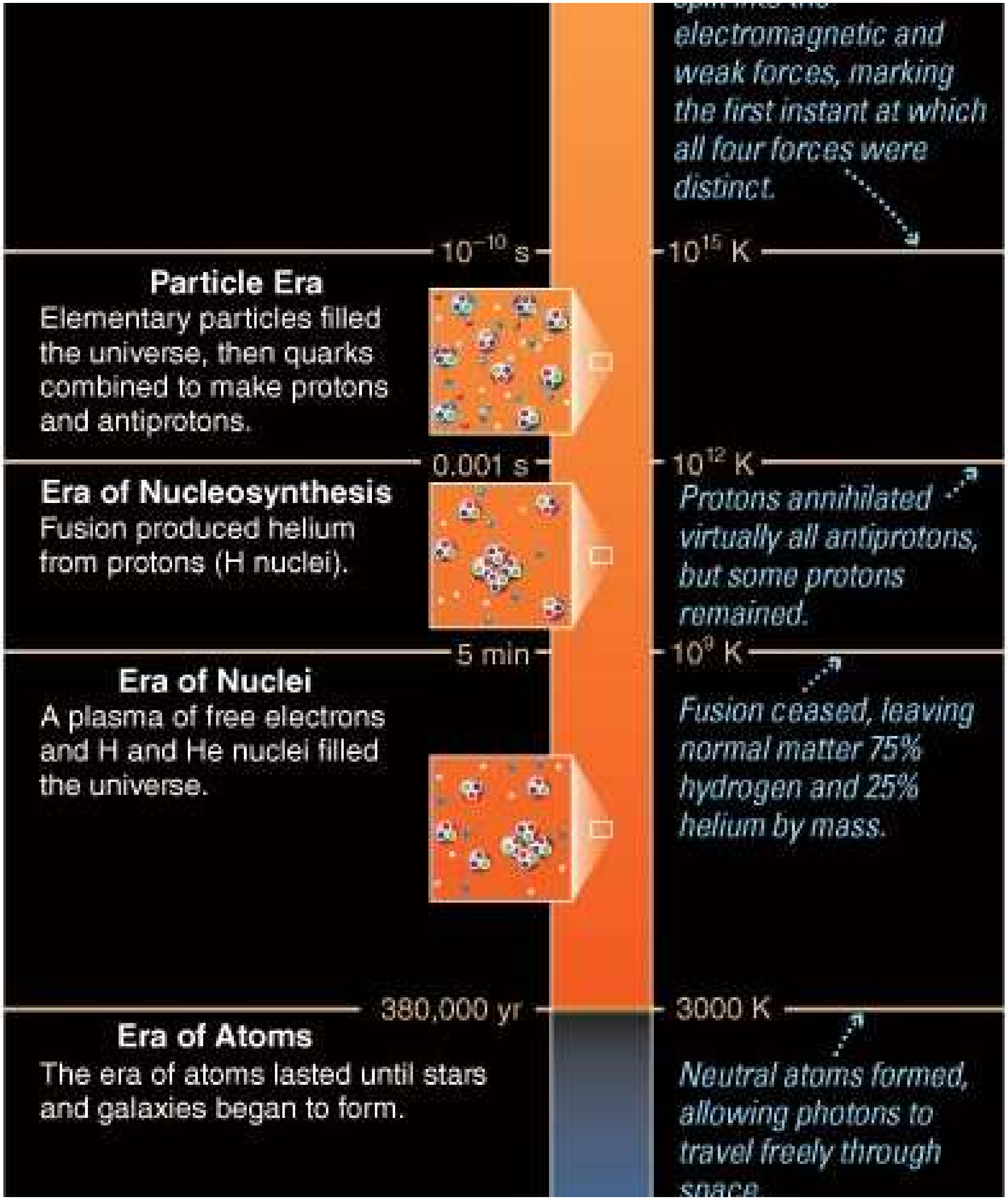
Nuclei began to fuse.
→Deuterium
→Helium
→Lithium

More Evidence of the Big Bang

- Due to the rapid expansion, fusion only lasted a few minutes…
- Only sufficient time to make a few elements/isotopes



- Based on our knowledge of the efficiency of fusion reactions, we can determine that the approximate temperatures and densities agree with models of the conditions in the Big Bang
- Furthermore, we will use this to constrain how much ordinary matter there is in the universe (chapter 18).
- Abundances of other light elements agree with Big Bang model having 5% normal matter –*evidence for WIMPS?*



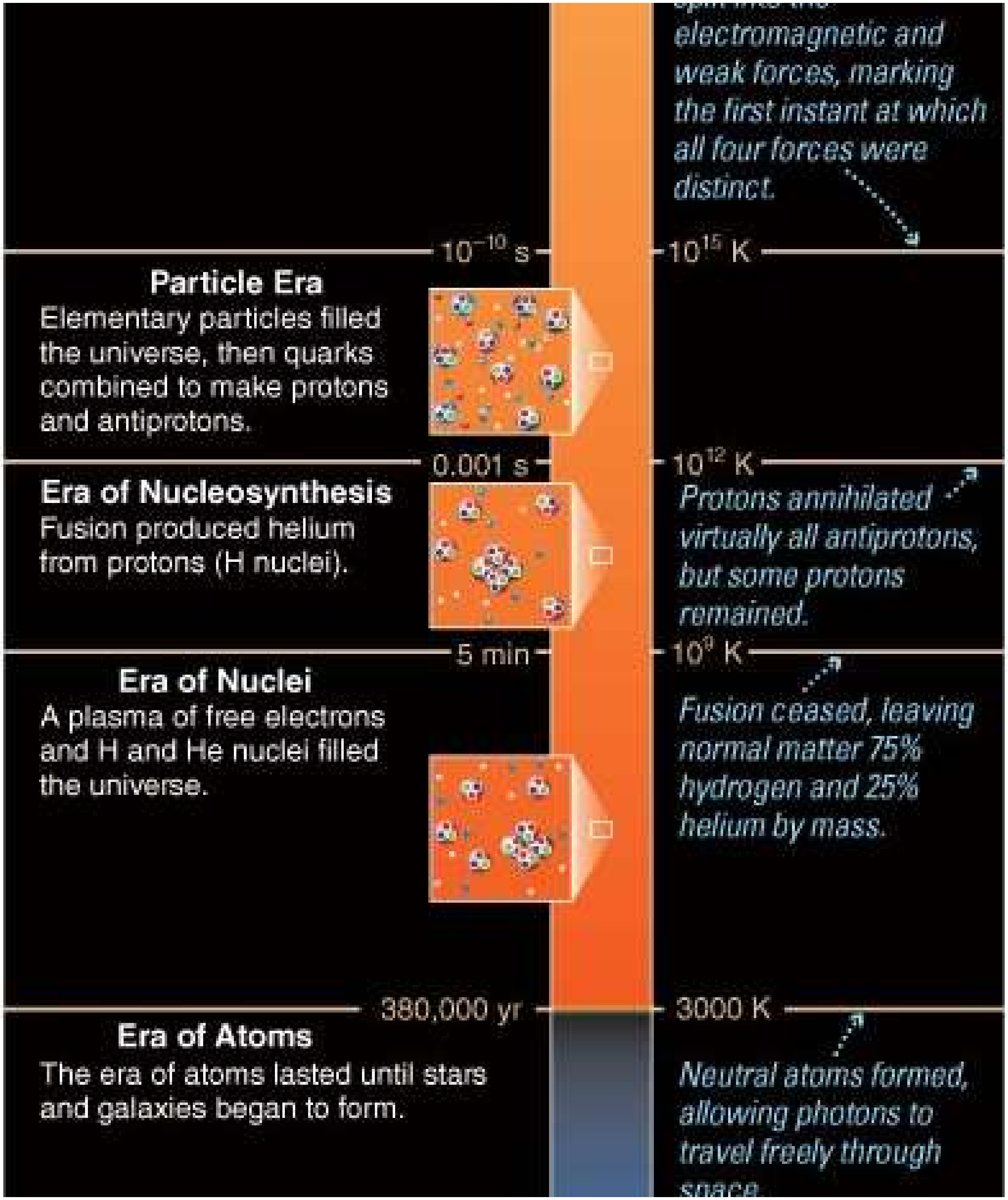
The Big Bang: Later Era's

Era of Nuclei:

Time: 5 min–380,000 yrs
Temp: 10^9–3000 K

Helium nuclei formed at age ~3 minutes.

This is how most Helium is produced (not in the cores of stars; this accounts for ~ 10% in modern day)



The Big Bang: Later Era's

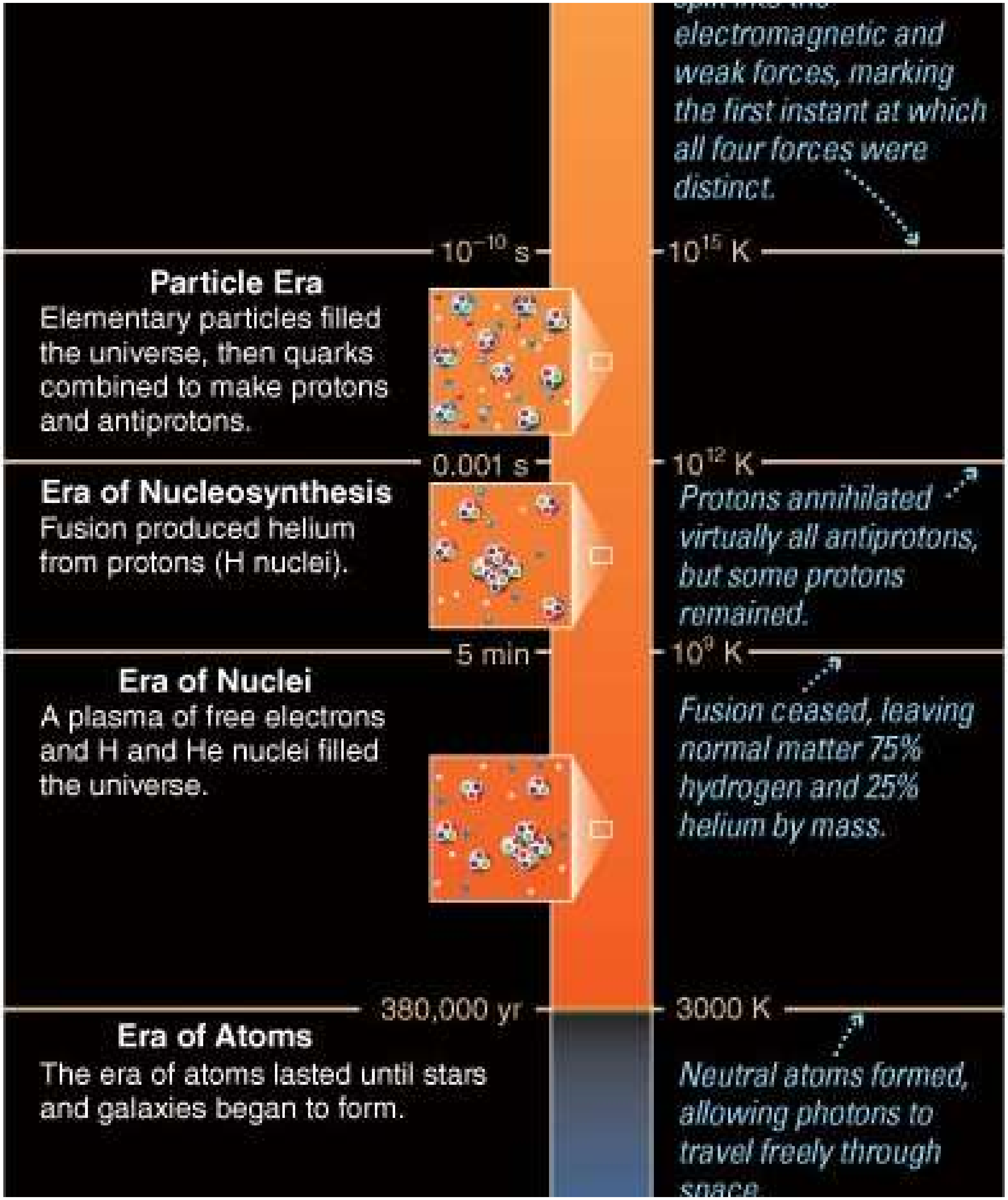
Era of Atoms:

Time: 380,000 years–1 billion years
Temp: 3000–20 K

Atoms formed at age ~380,000 years.

Background radiation is released (CMB)

Now Begins the Era of Darkness…



The Big Bang: Later Era's

Era of Galaxies: (now)

Time: ~1 billion years – present
Temp: 3-30 K

The first stars and galaxies had formed by ~1 billion years after the Big Bang.

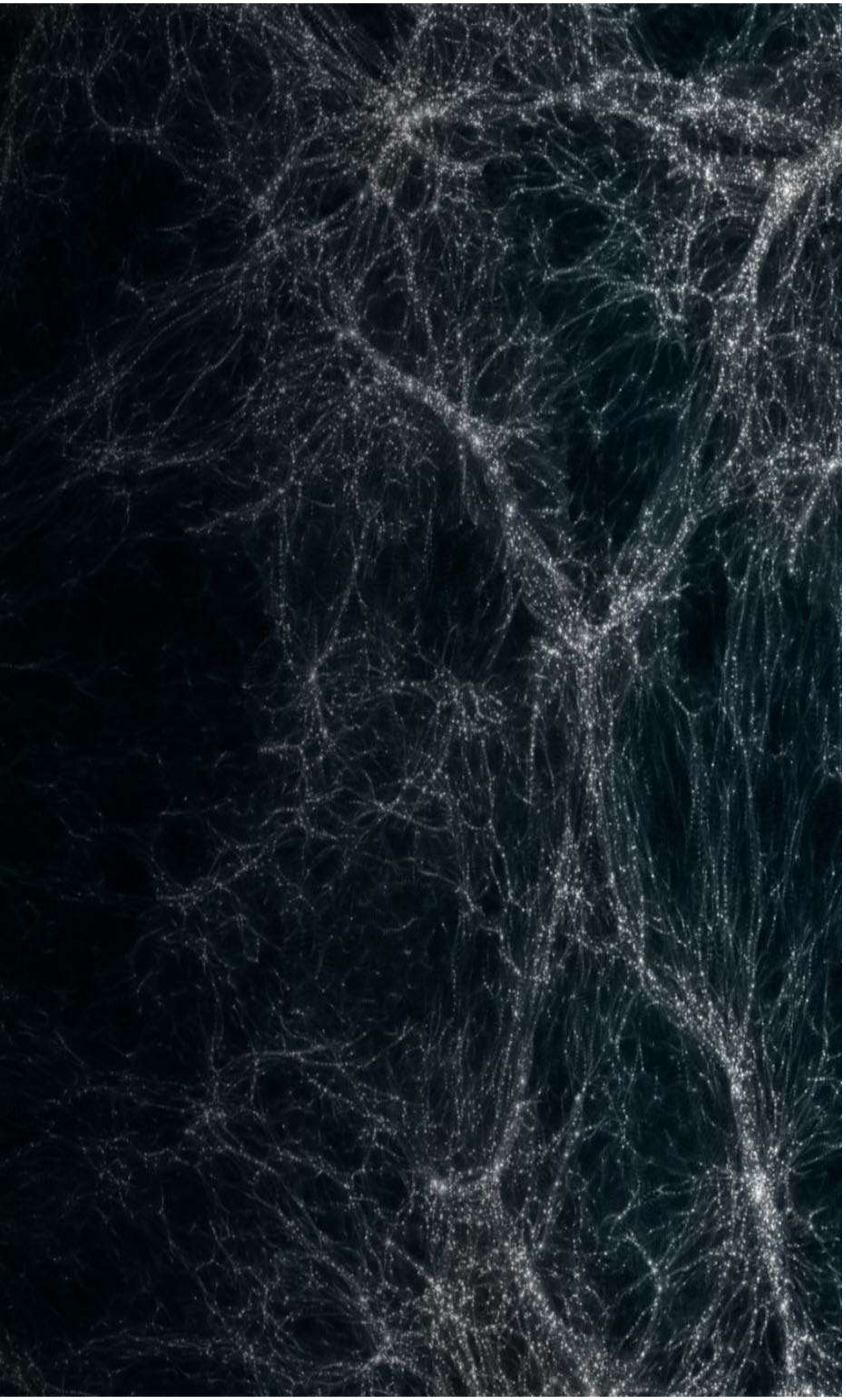
Once stars form, the Era of Darkness ends…

Is there any evidence for an era of darkness? Well yes, it would have taken time for gravity to start playing a role and forming stars/galaxies… we will see more with James Webb

Is there any evidence that light suddenly was set free when the first atoms formed? Yes, the CMB…

→ Recall that free-electrons (not bound to atoms) are really good at stopping light from getting out of the Sun

→ But what happens when the temperature drops and atoms start forming? ***The light will no longer be trapped!***



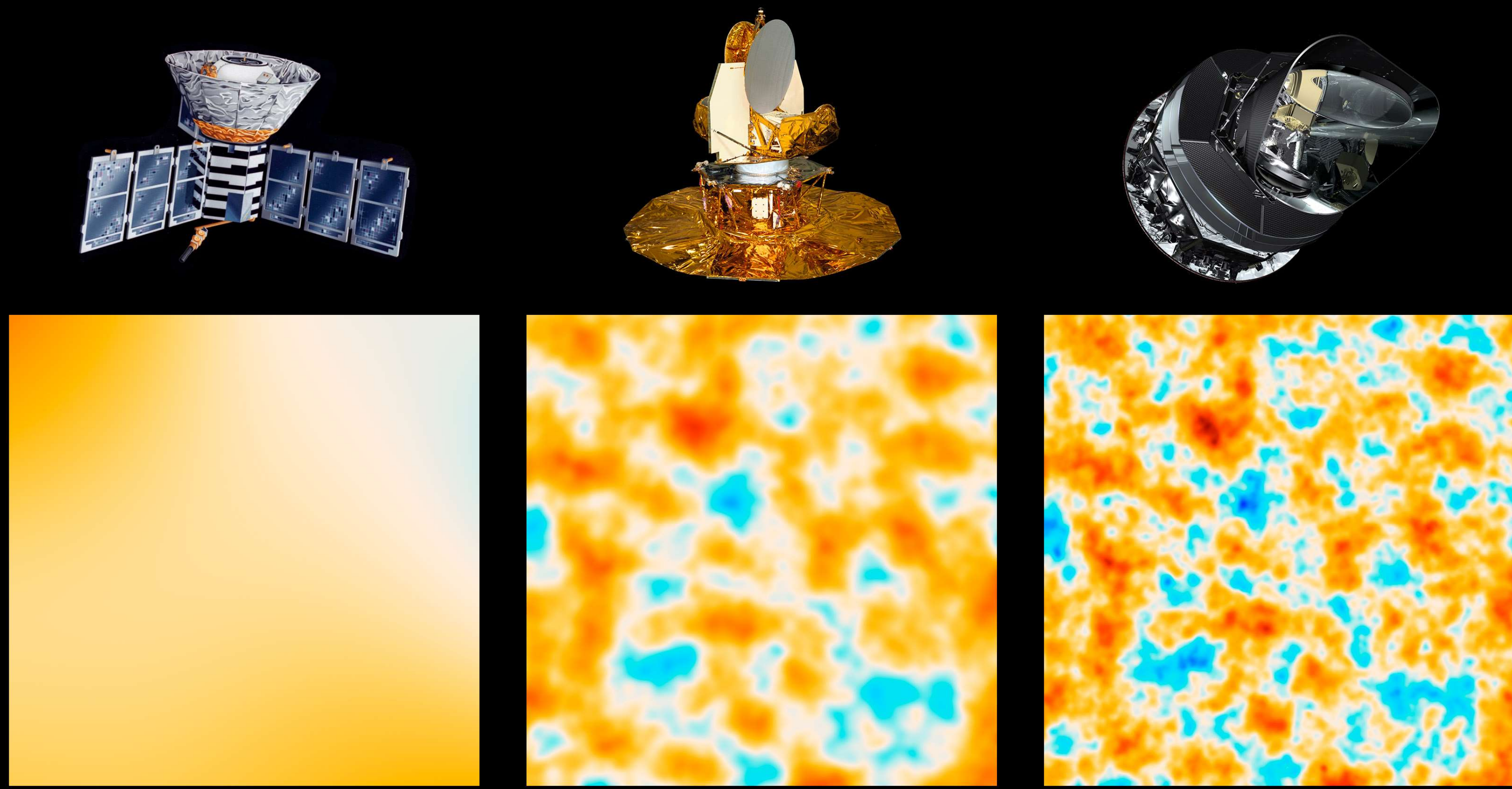
The Cosmic Microwave Background (CMB)

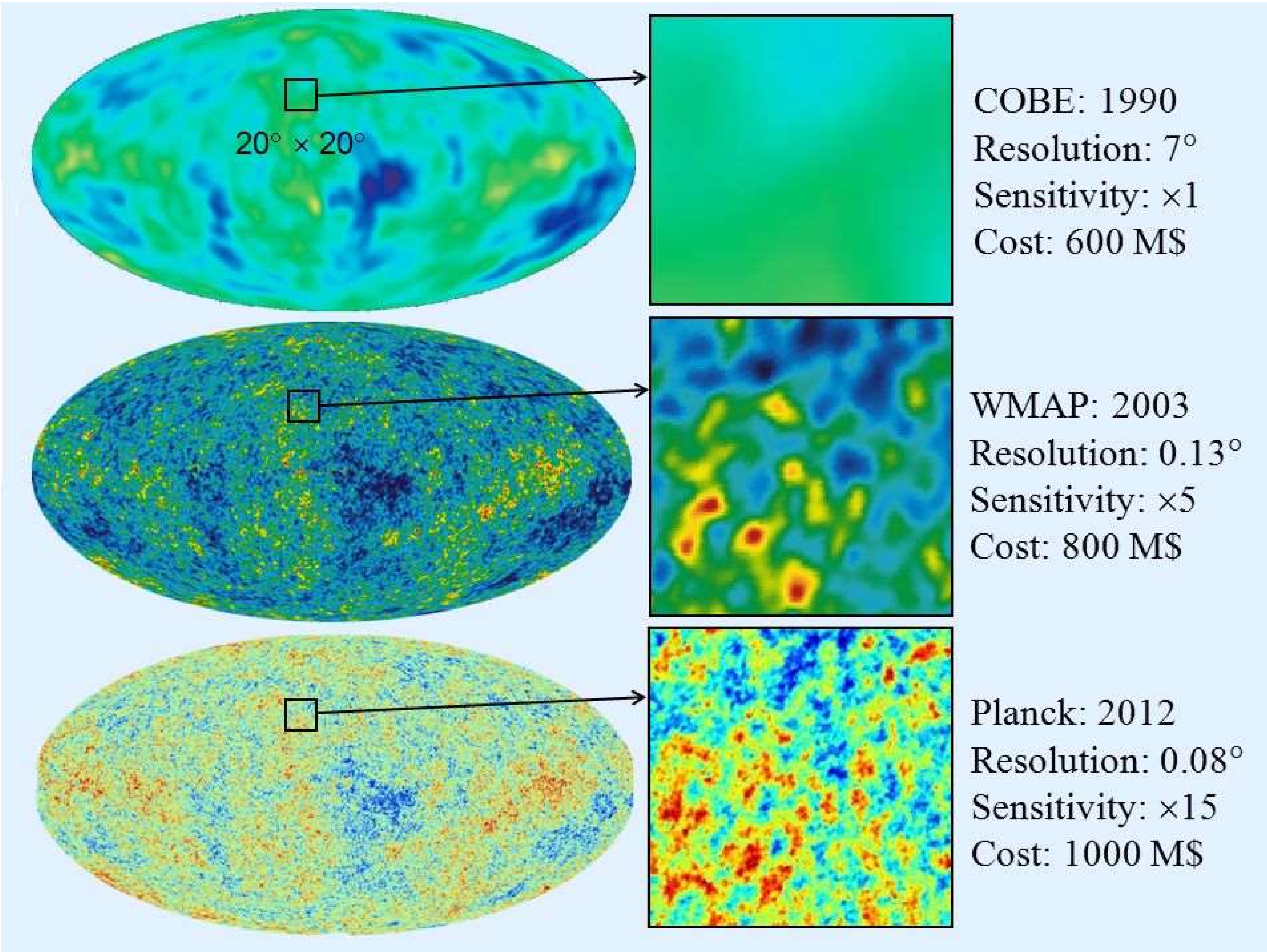
What is this strange noise?

It’s everywhere!

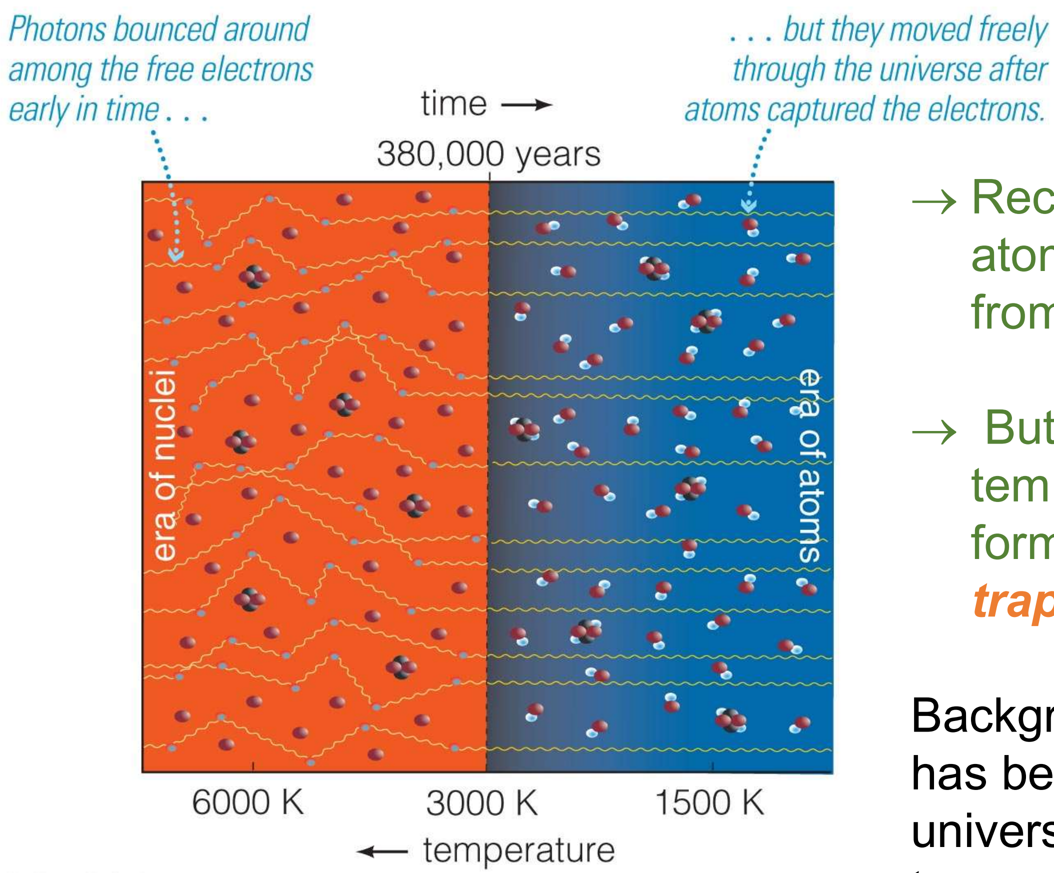
The *cosmic microwave background* – the radiation left over from the Big Bang – was detected by Penzias & Wilson in 1965

The Cosmic Microwave Background (CMB)




20° × 20°
COBE: 1990
Resolution: 7°
Sensitivity: ×1
Cost: 600 M$
WMAP: 2003
Resolution: 0.13°
Sensitivity: ×5
Cost: 800 M$
Planck: 2012
Resolution: 0.08°
Sensitivity: ×15
Cost: 1000 M$

What is The Cosmic Microwave Background (CMB)?



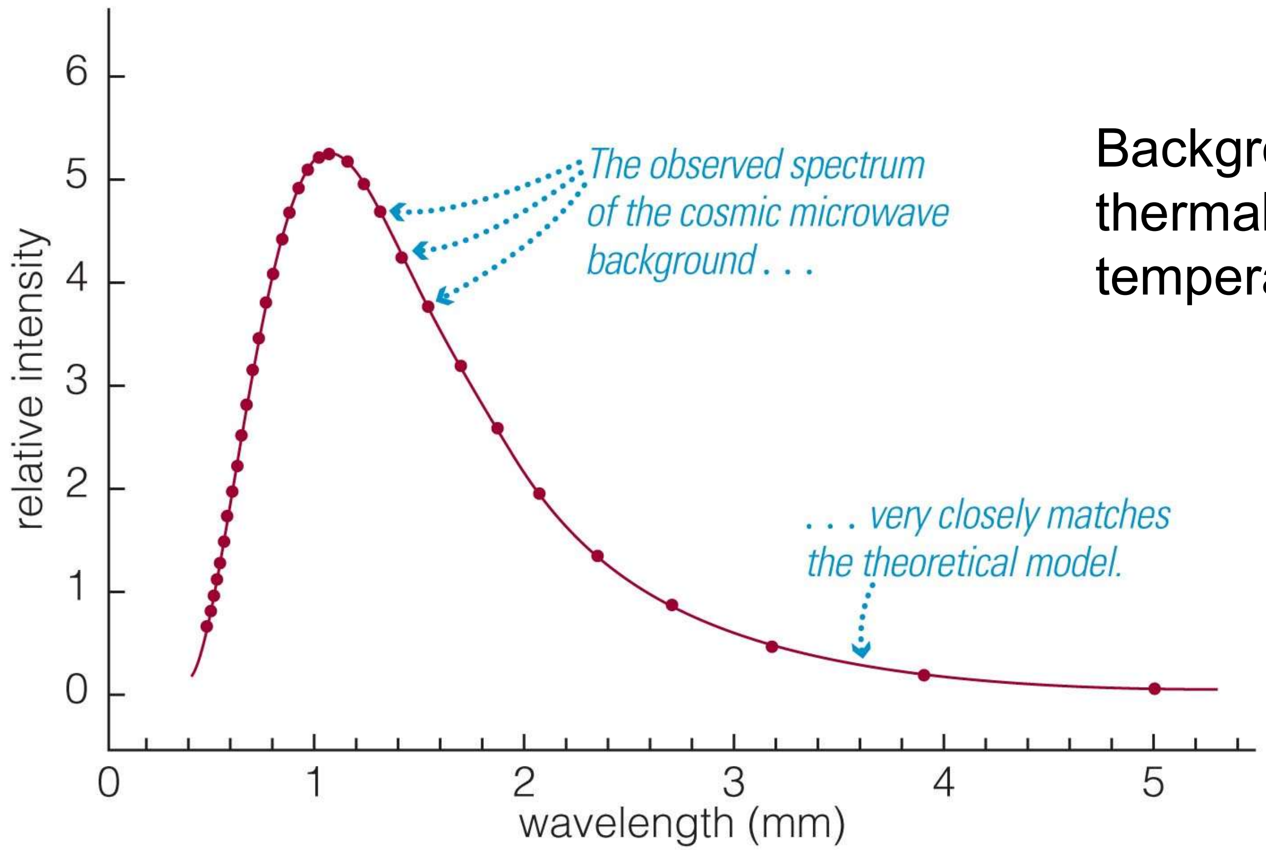
→ Recall that free-electrons (not bound to atoms) are really good at stopping light from getting out of the Sun

→ But what happens when the temperature drops and atoms start forming? ***The light will no longer be trapped!***

Background radiation from the Big Bang has been freely streaming across the universe since atoms formed at temperature **~3,000 K: *visible/IR.***

→ ***Why do we observe in microwave??***

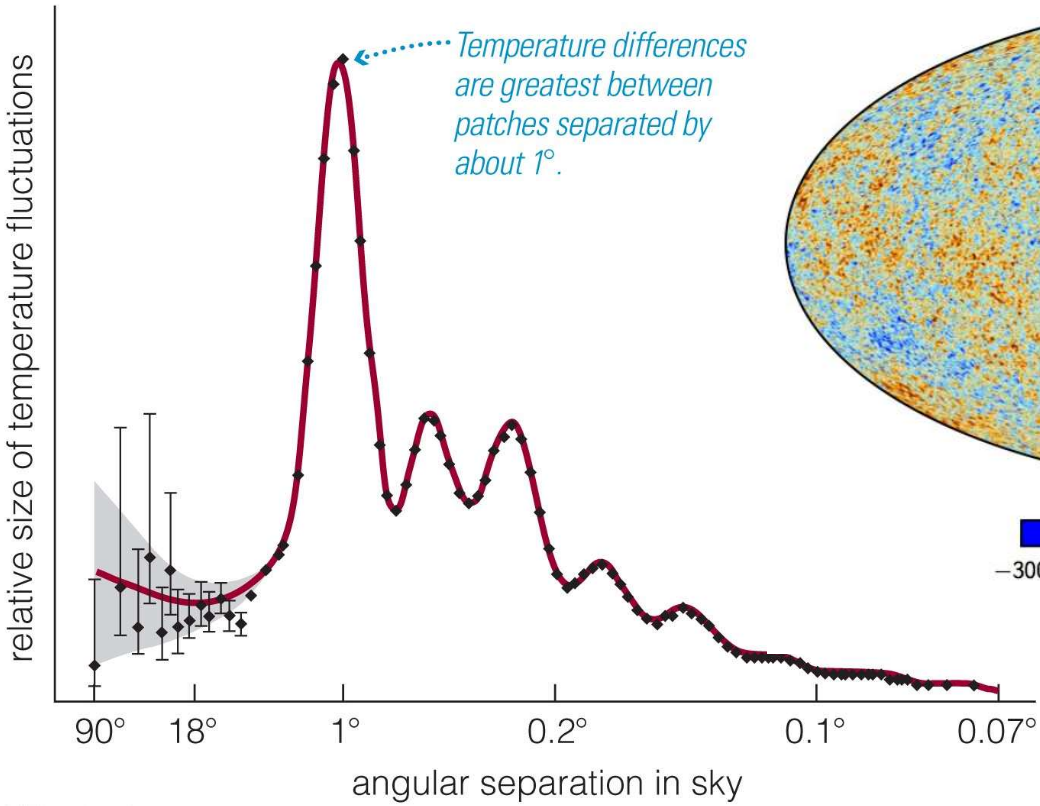
What is The Cosmic Microwave Background (CMB)?

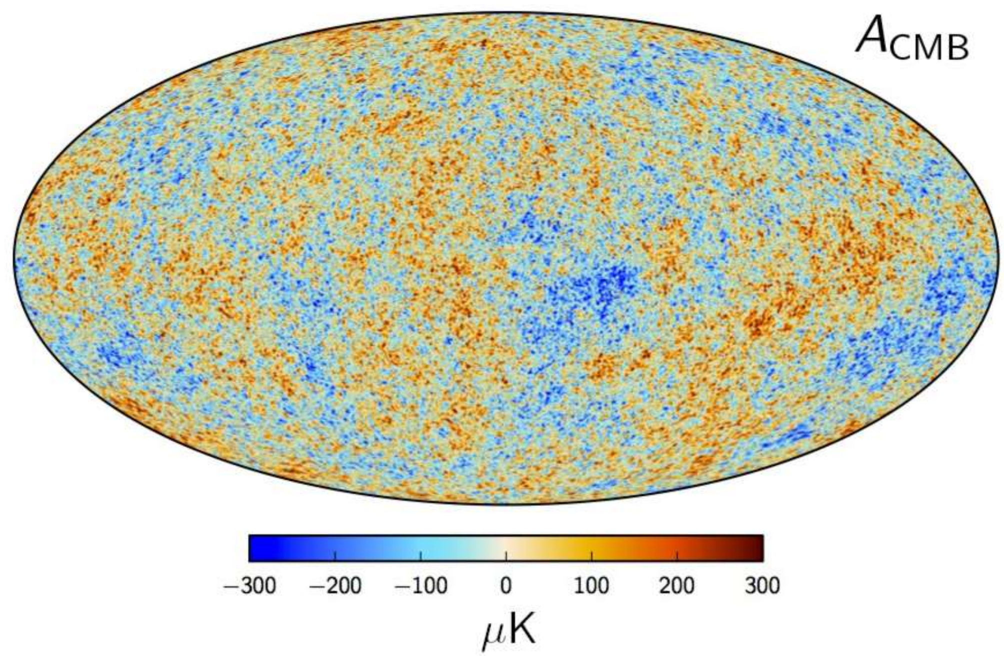


Background has near perfect thermal radiation spectrum at temperature 2.73 K.

→ Expansion of the universe has red-shifted thermal radiation from that time to ~1000 times longer wavelength: *microwaves*.

What is The Cosmic Microwave Background (CMB)?

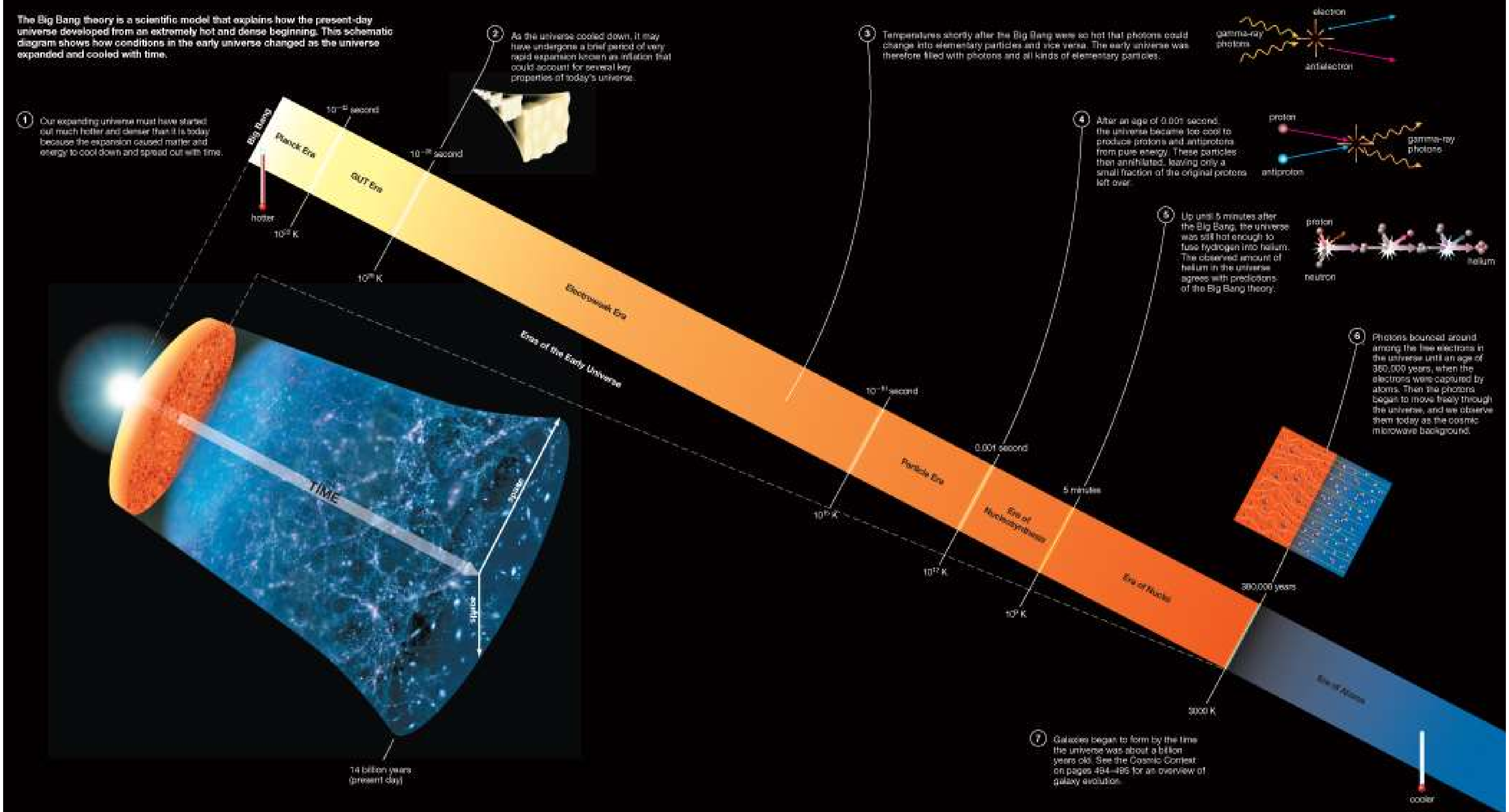




- Very uniform (~1 in 100,000 deviation) but with some structure to it…
- The variation shown here should lead to deviations in the patterns that formed the galaxies…

→ *Will need to explain what these deviations lead to…*

Summary of the Big Bang



End of Todays Lecture