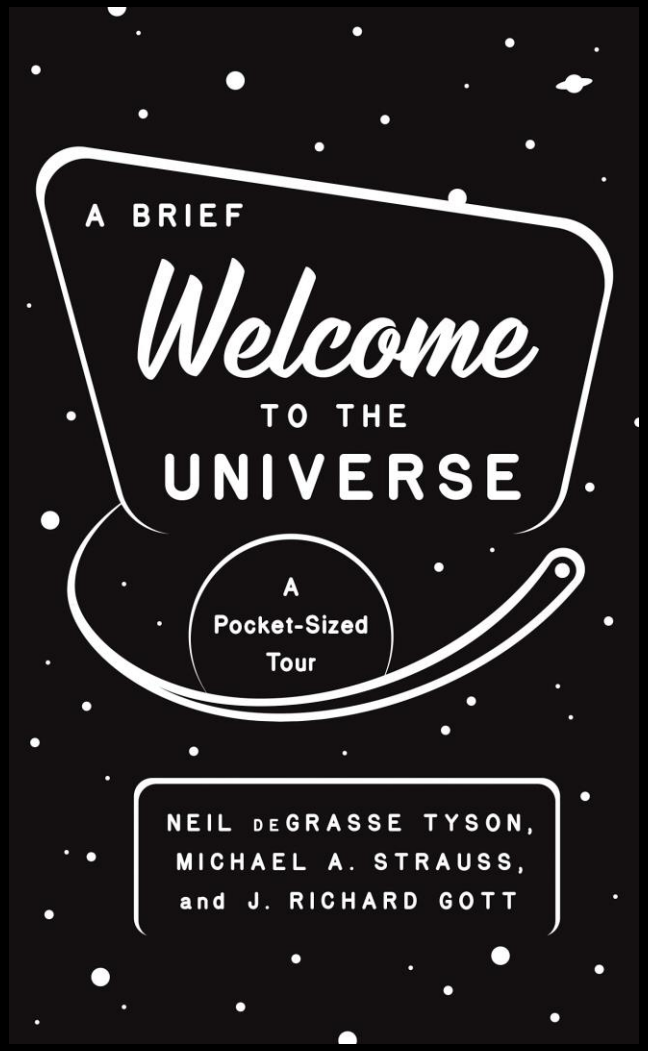
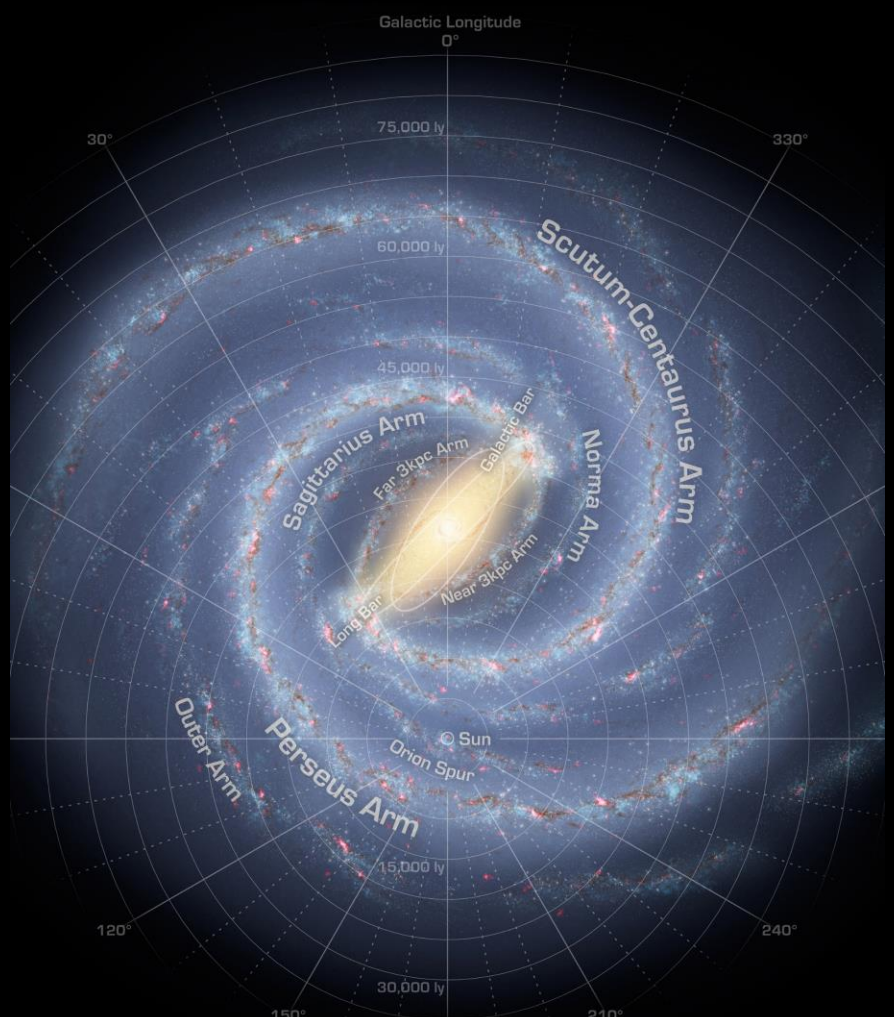

THE BIG BANG THEORY

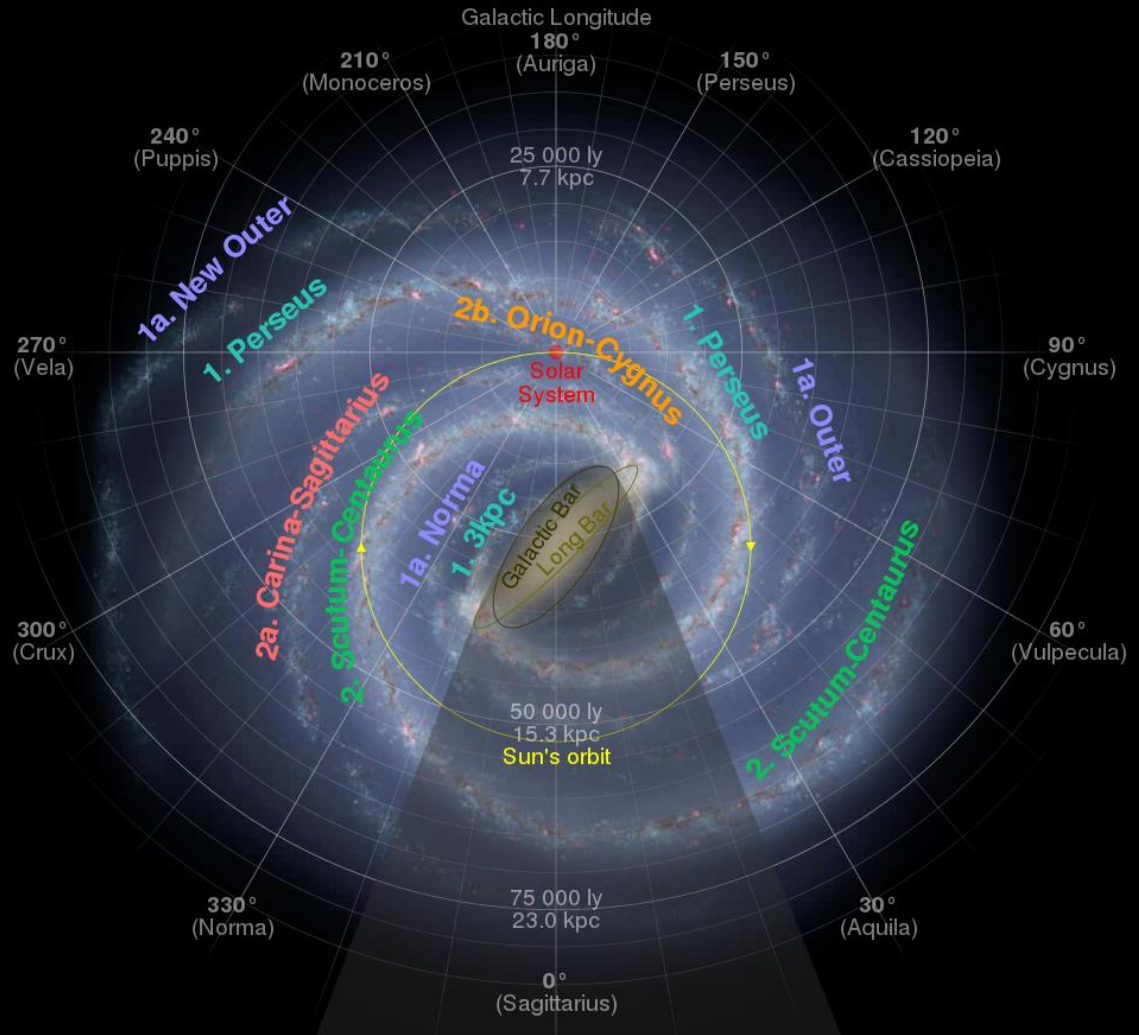
BROUGHT TO YOU BY…

- A really good read! I thoroughly enjoyed chapters 1-6 in particular (not a fan of 7-8…sorry JRG); this powerpoint is based on chapter 6: "Galaxies and the Big Bang" by Michael A. Strauss



THE MILKY WAY: ONE GALAXY AMONG MANY





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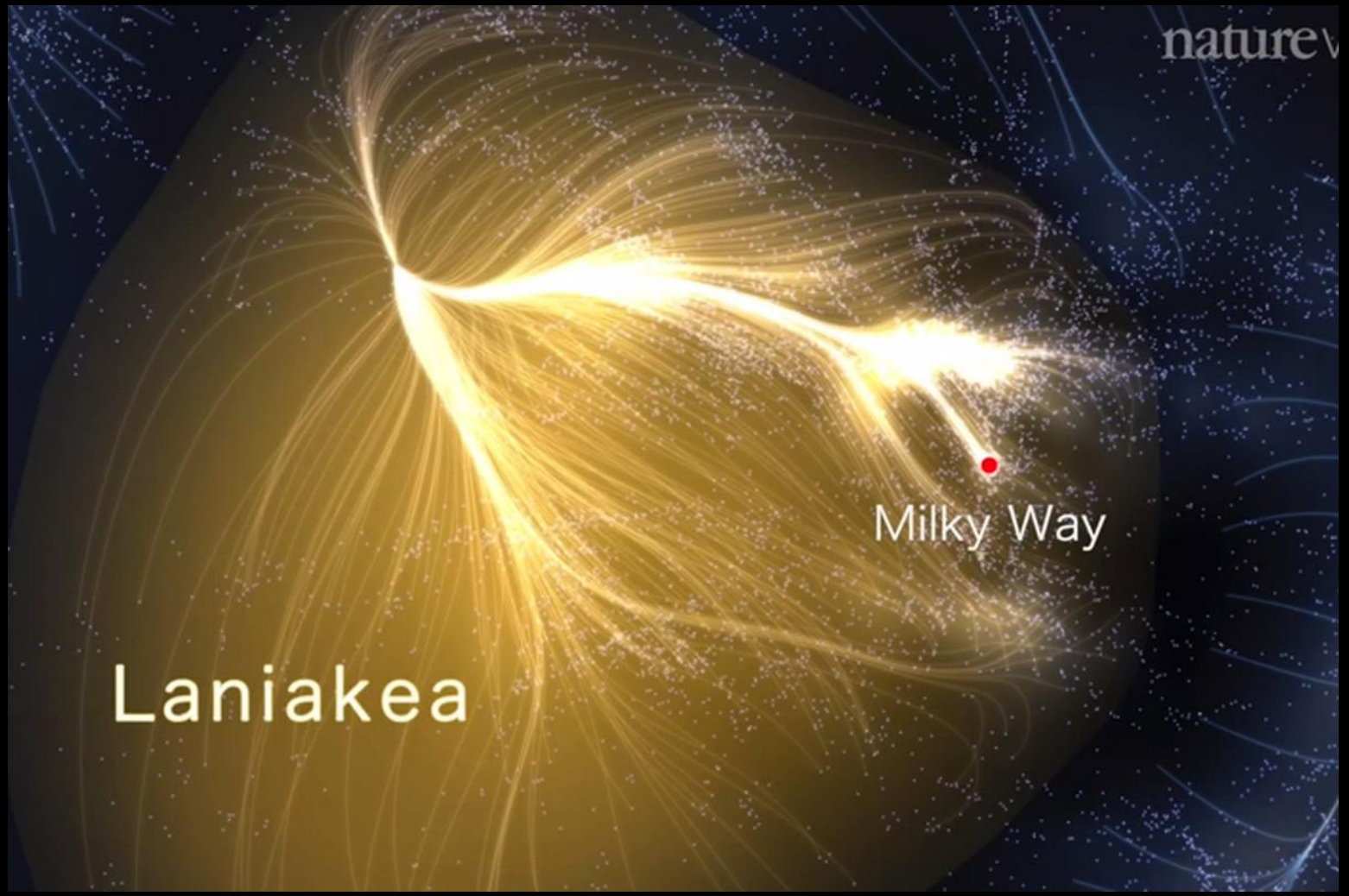
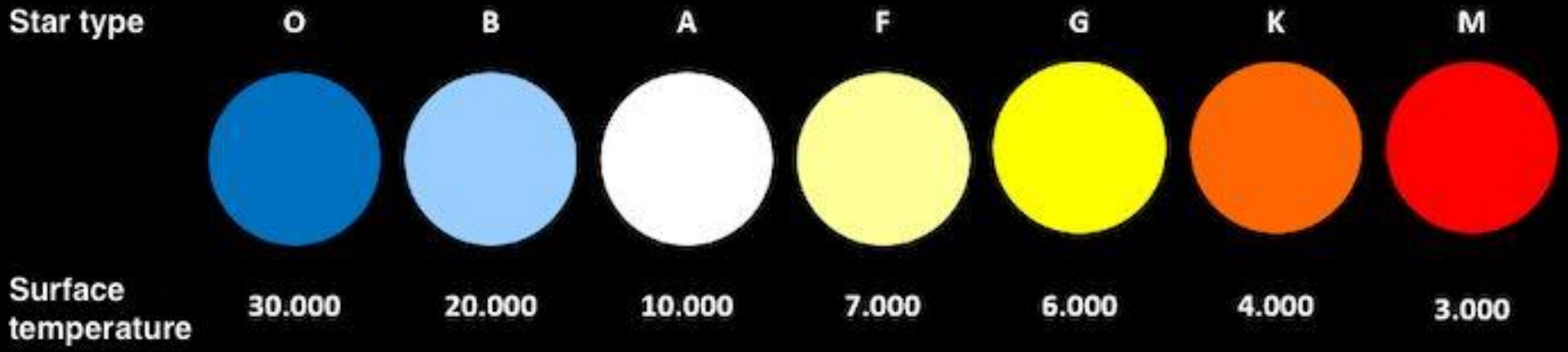


4-minute video:

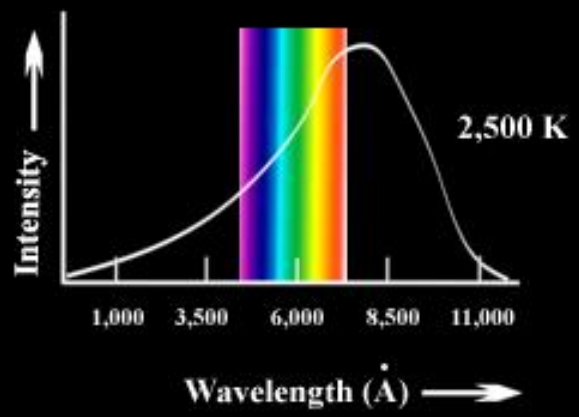
https://www.youtube.com/watch?v=rENyyRwxpHo&ab_channel=naturevideo

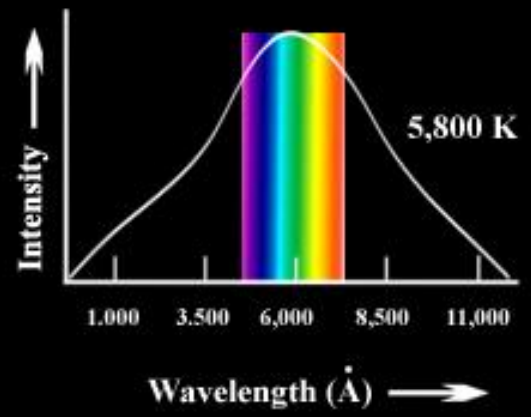
COLOUR AND TEMPERATURE OF STARS

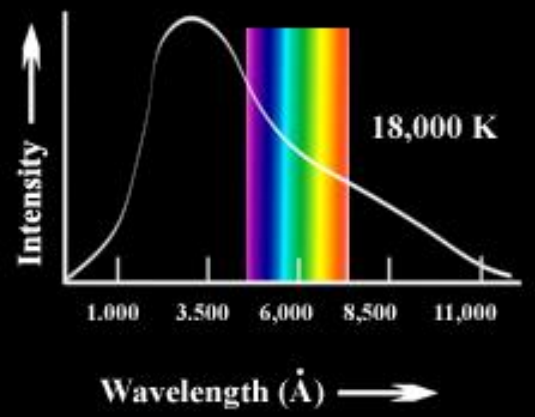
The colour of a star indicates how hot its surface temperature is.

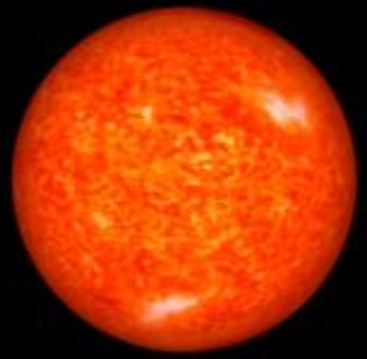


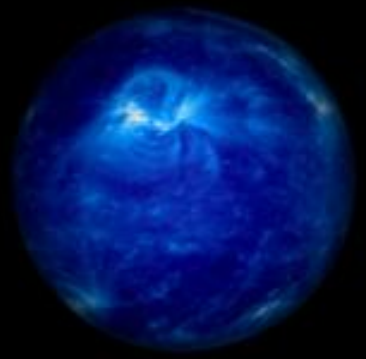
COLOUR AND TEMPERATURE OF STARS











Colors are exagerrated

COMPOSITION OF STARS

- A *spectroscope* is used to analyze the light given off by stars to determine their elemental composition.
- Each element has a unique spectrum.

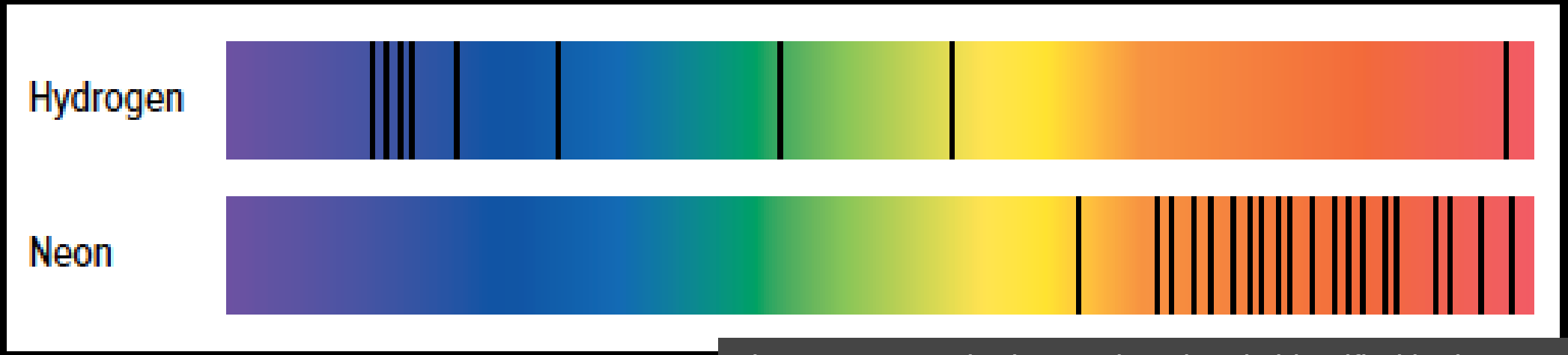
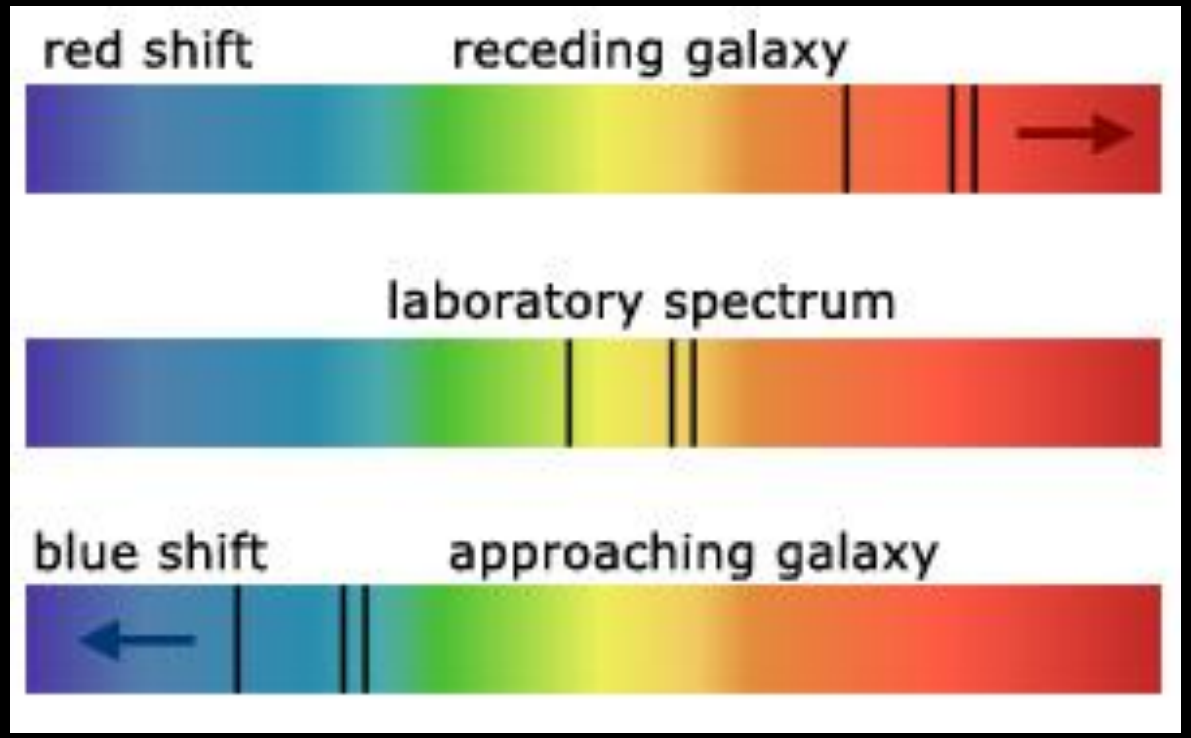


Figure 4.31: Each element is uniquely identified by its spectrum.

LIGHT FROM THE UNIVERSE IS REDSHIFTED (1915)

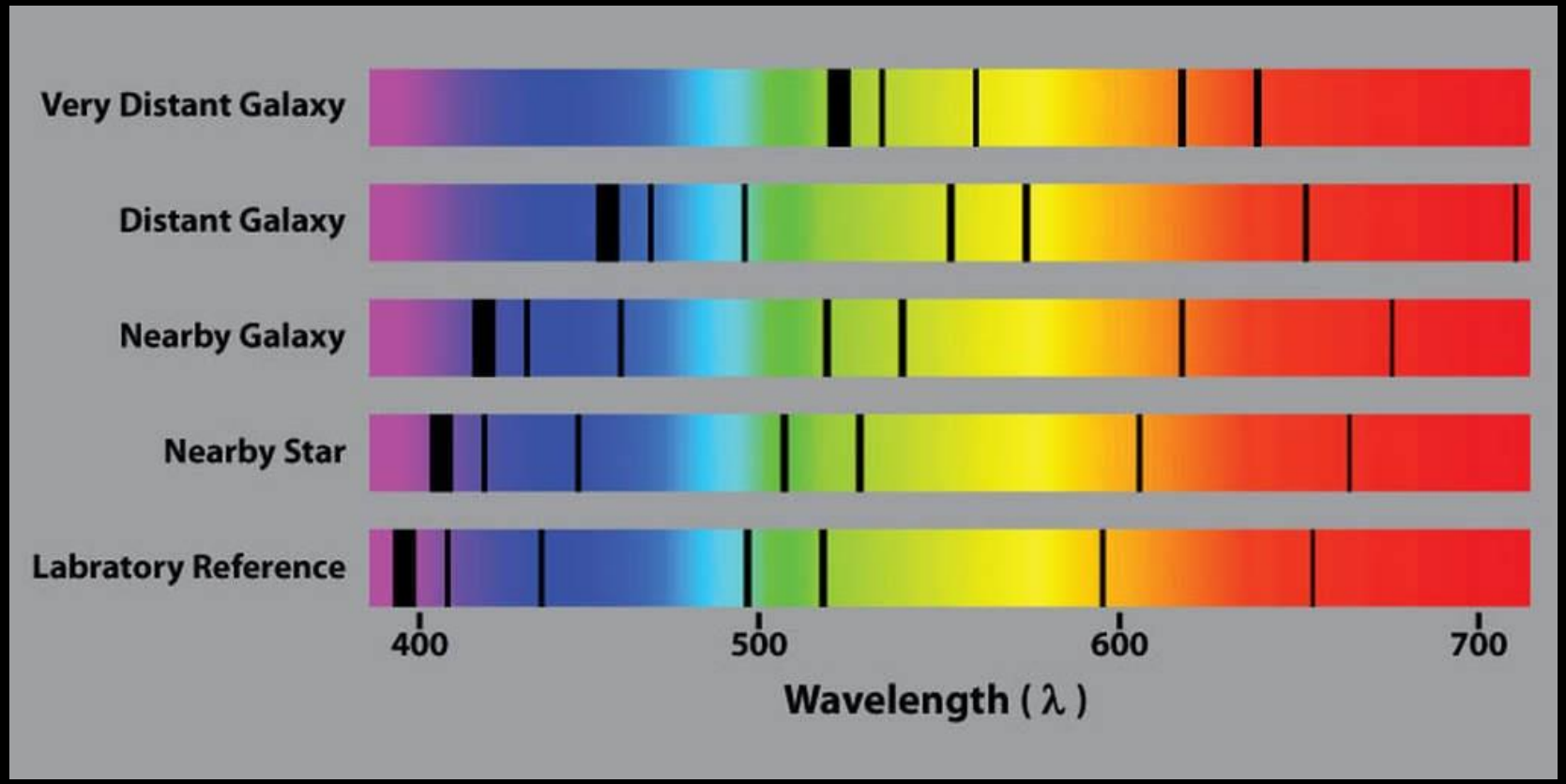
- Scientists studied the light from distant galaxies and stars
- They observed that the light from *almost* all galaxies is redshifted, meaning they are are moving away from us!



Red-shift Explanation Videos:
https://www.youtube.com/watch?v=ikgRZt1BSyk&ab_channel=Astronomic
https://www.youtube.com/watch?v=RO4i_g6gSMU&ab_channel=magipics

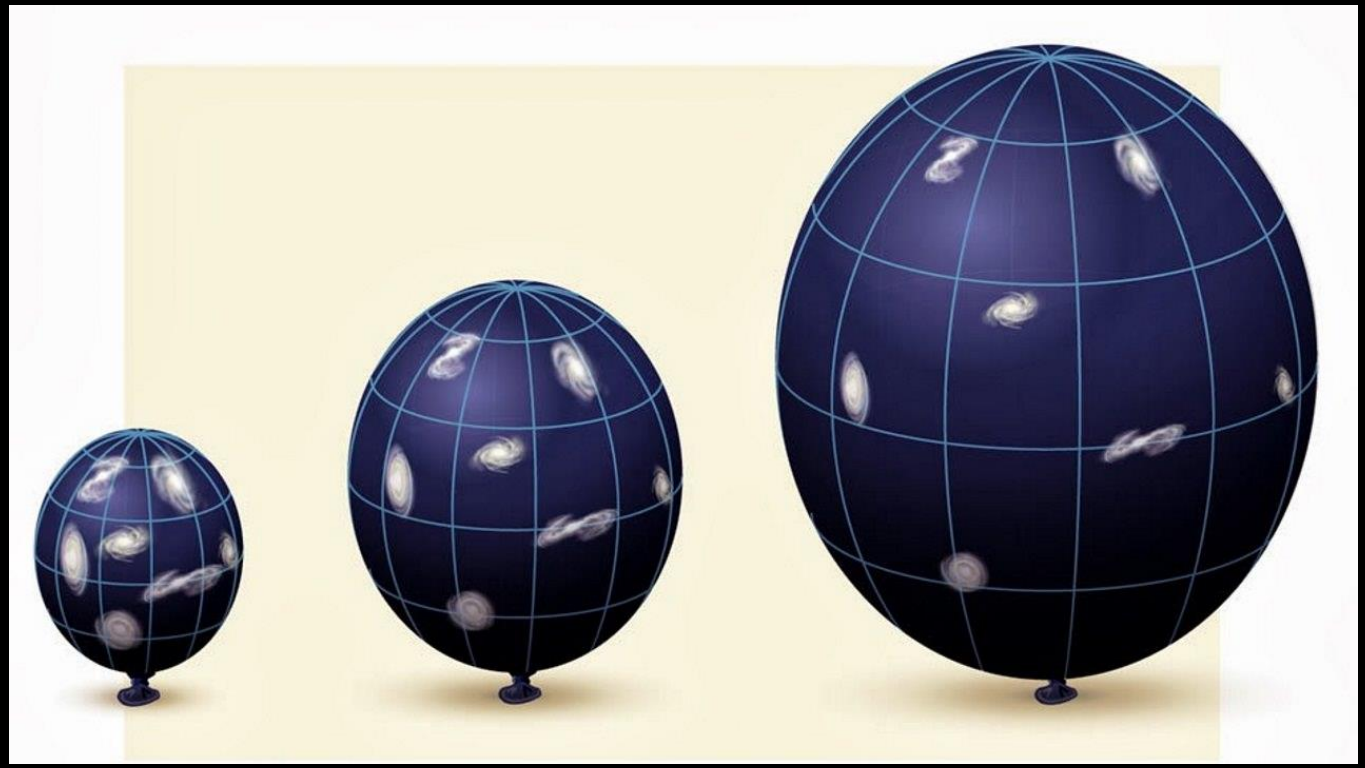
LIGHT FROM THE UNIVERSE IS REDSHIFTED (1915)

- Distant celestial objects are moving away faster than nearby objects.
- Conclusion: The universe is expanding!



THE UNIVERSE IS EXPANDING

The spaces between celestial objects are expanding at a predictable rate, like in this balloon model

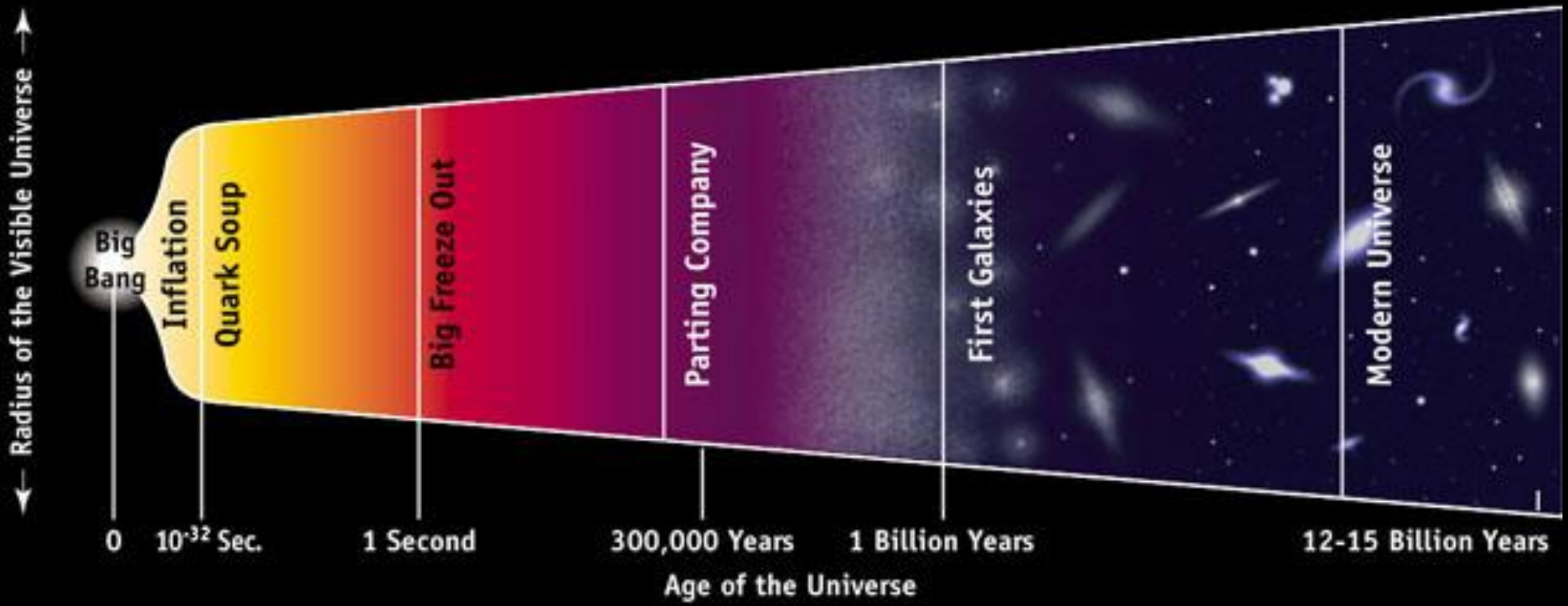


THE BIG BANG THEORY IS BORN

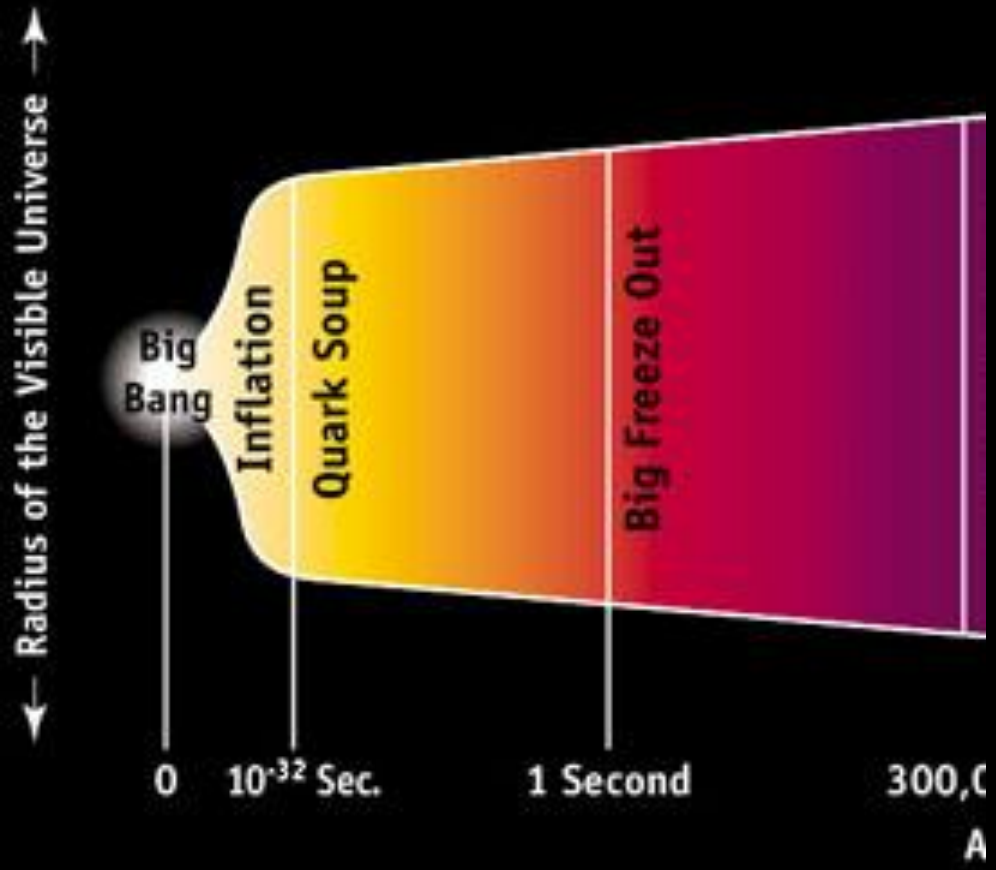
- Extrapolation of universal expansion: At some point in the distant past (approx. 14.6 billion years ago), all the galaxies originated from a single point in space. This is the Big Bang Theory.
- Okay…but I'm not convinced. More evidence needed!

THE BIG BANG THEORY IS BORN

Research from 1948: what would the universe have looked like in its earliest moments?

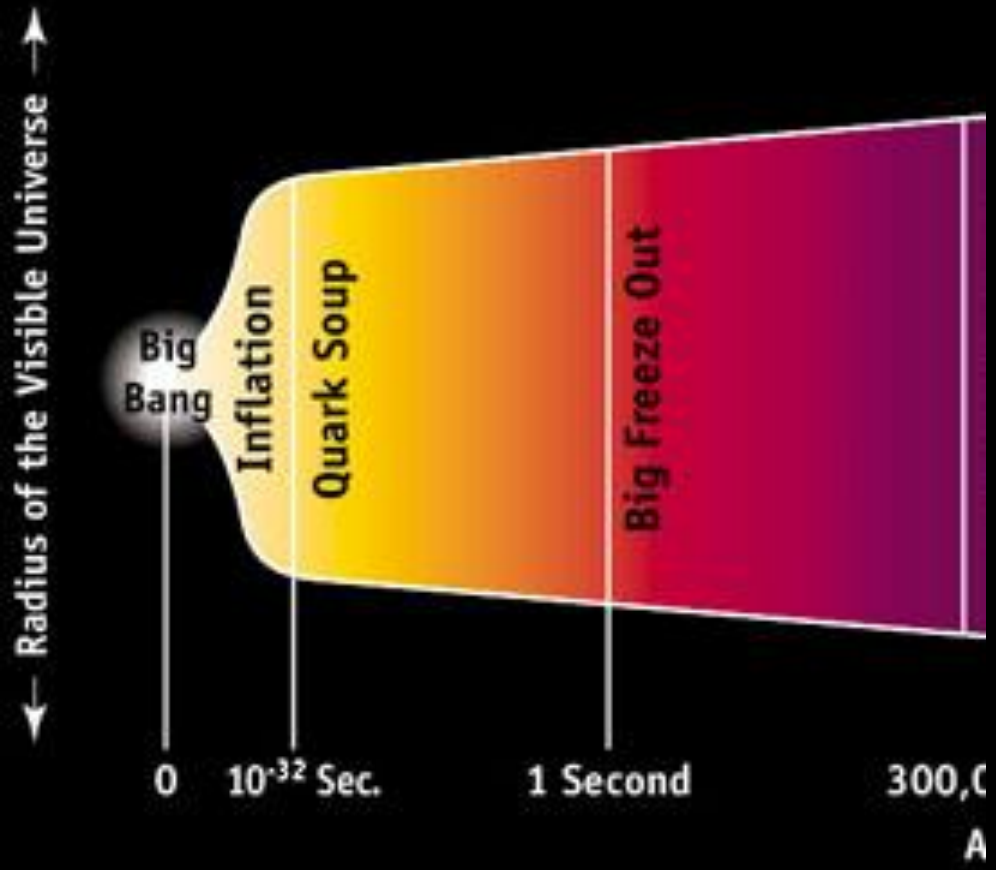


THE BABY UNIVERSE (1 SECOND OLD)



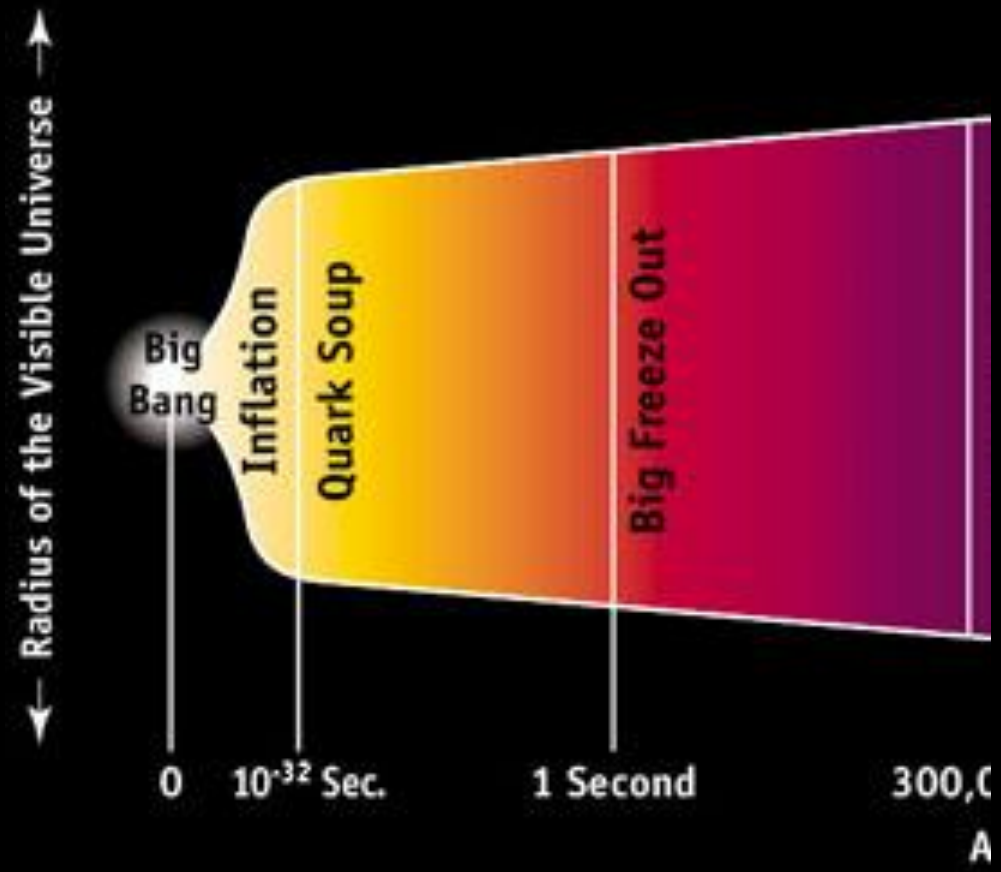
- Very compressed
- Very, ***very*** hot (10^{10} Kelvins hot)
  - 25 million times the boiling temperature of water
  - Too hot for atoms, molecules, or even atomic nuclei to form. Quark Soup.

THE BABY UNIVERSE (2.5 MINUTES)

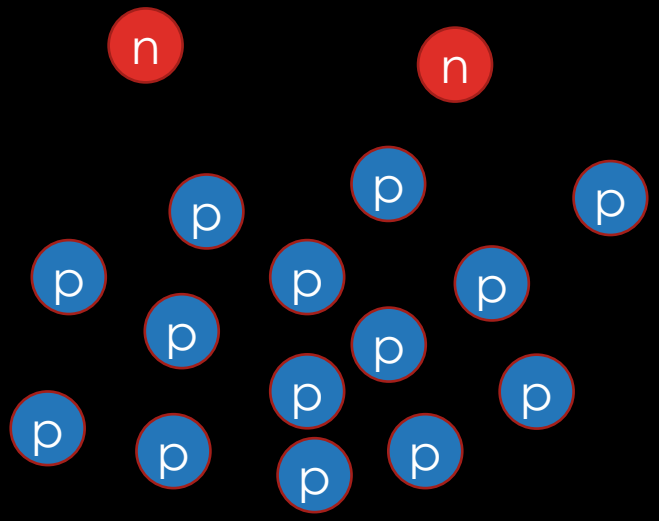


- The universe expands and cools.
- At 150 seconds, the universe has cooled to 10^9 Kelvins.

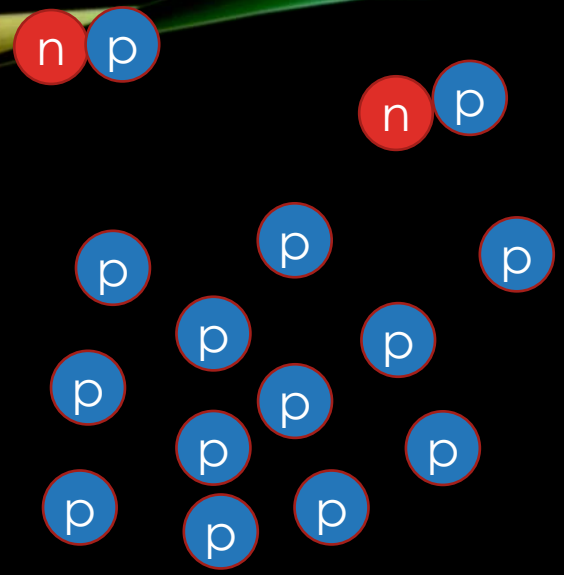
THE BABY UNIVERSE (2.5 MINUTES)



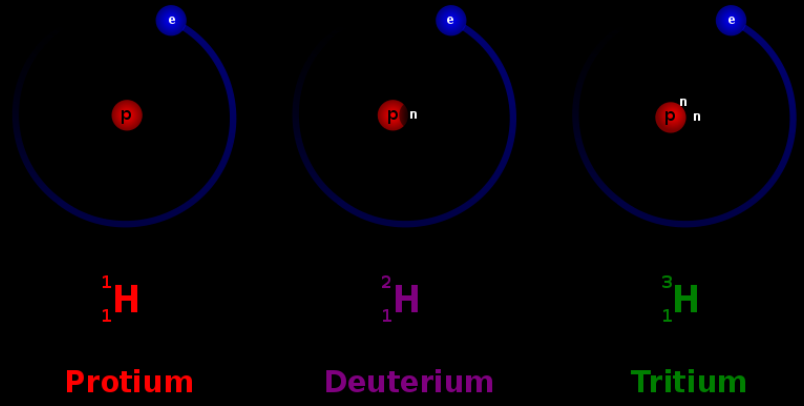
- The hypothesized ratio of subatomic particles under these conditions is 7 protons for every 1 neutron.
- This temperature is cool enough for nuclear fusion: neutrons stick to protons to form deuteron (nucleus of heavy water).

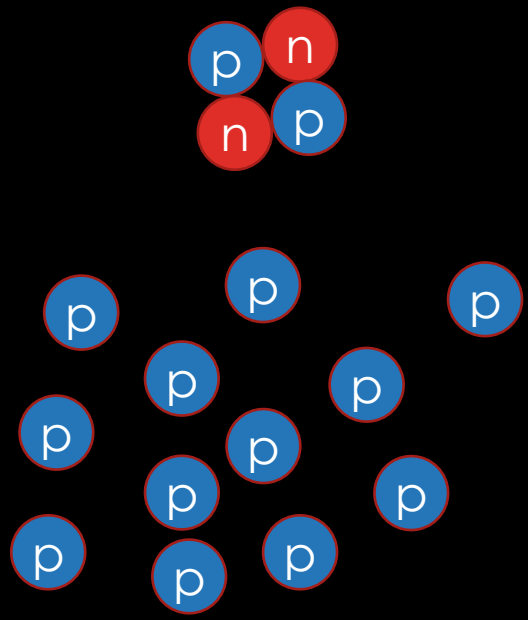


2 neutrons: 14 protons



neutrons stick to protons to form deuterium nucleus
(easier than proton + proton)



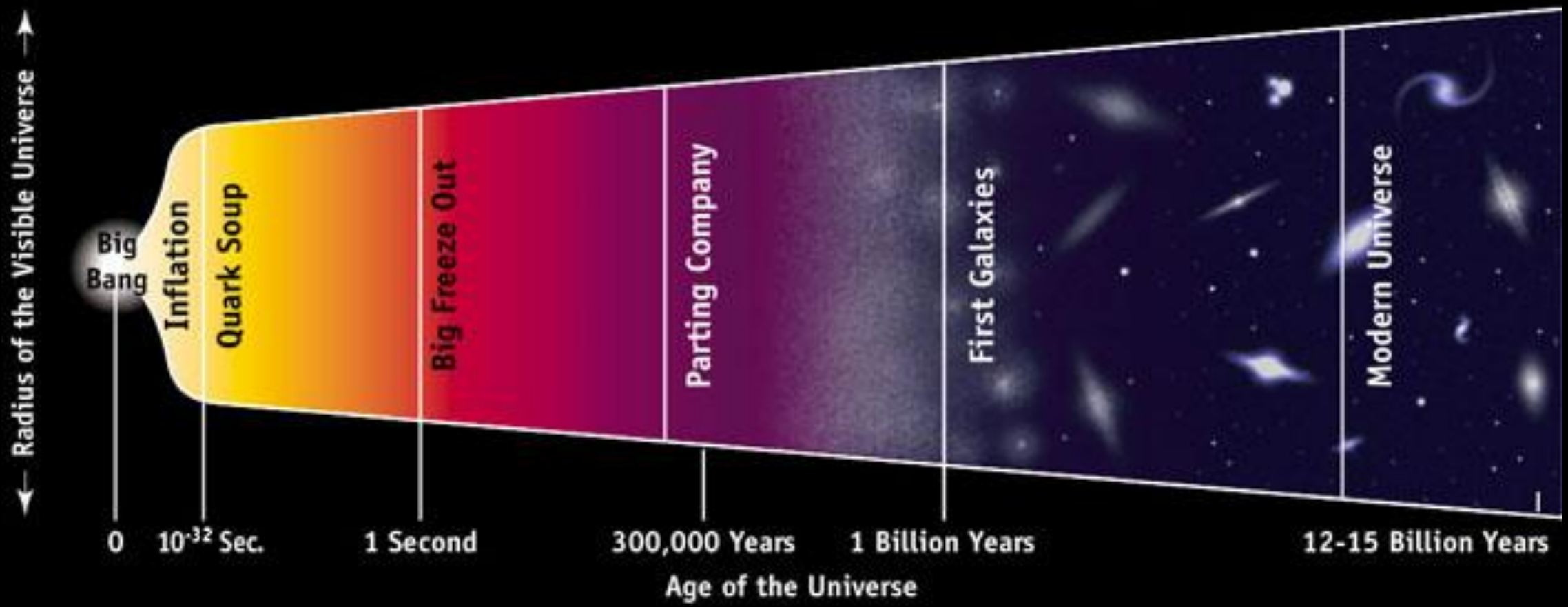


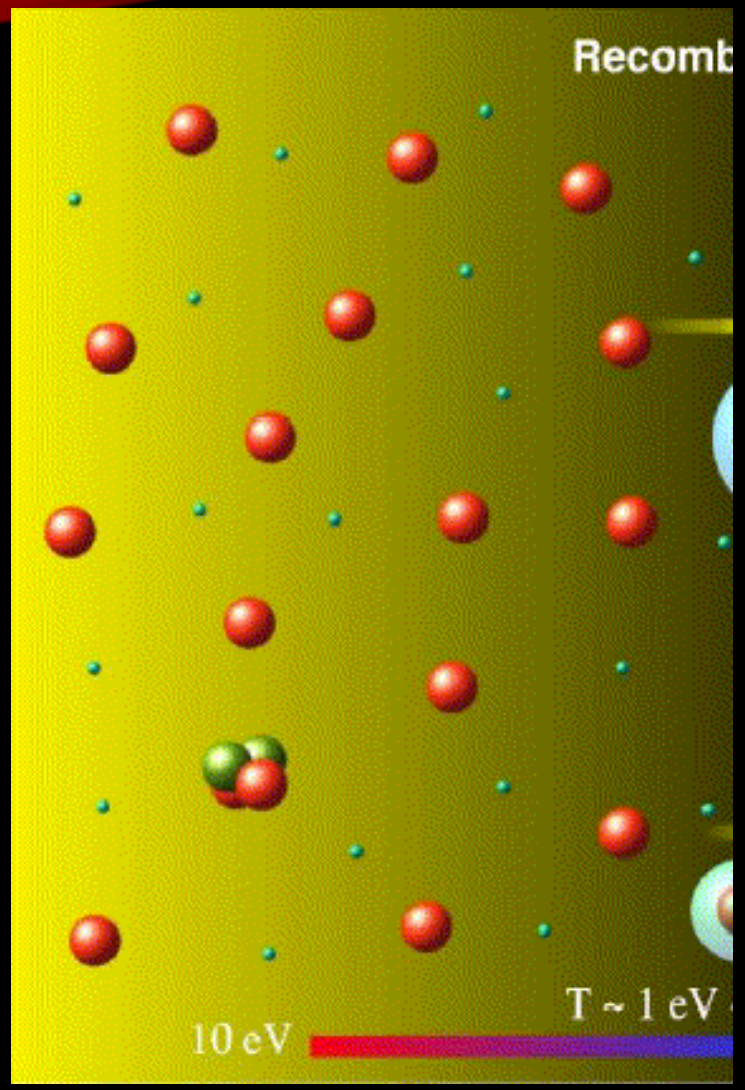
helium nucleus forms

SO WHAT?

1. Data: stars are 90% hydrogen and 8% helium. This exactly matches this model of the Big Bang.
2. Stars make helium too, but very slowly. (It would take billions of years for a typical star to convert even 10% of its hydrogen into helium. Our universe is only 14.6 billion years old!) The “stars-only” explanation does not account for the large amount of helium we see.
3. Stars are incapable of making deuterium. Yet, we see deuterium in trace amounts everywhere in the universe. It must have come from the Big Bang!

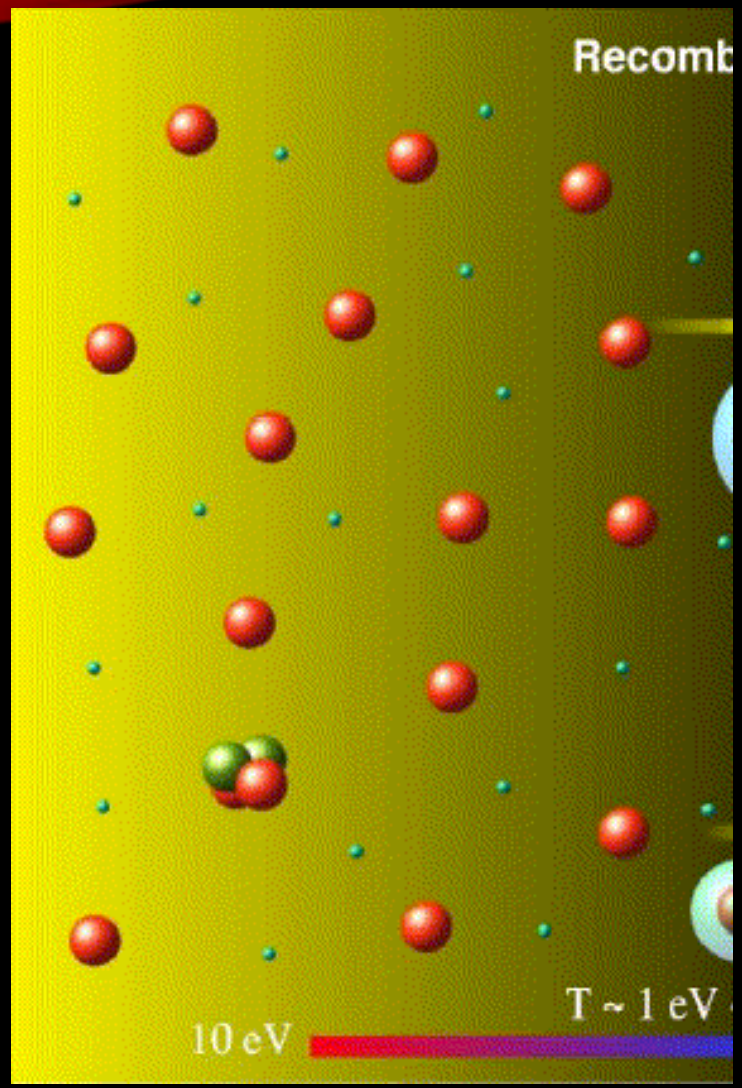
THE BIG BANG THEORY IS BORN





THE NEXT 380,000 YEARS

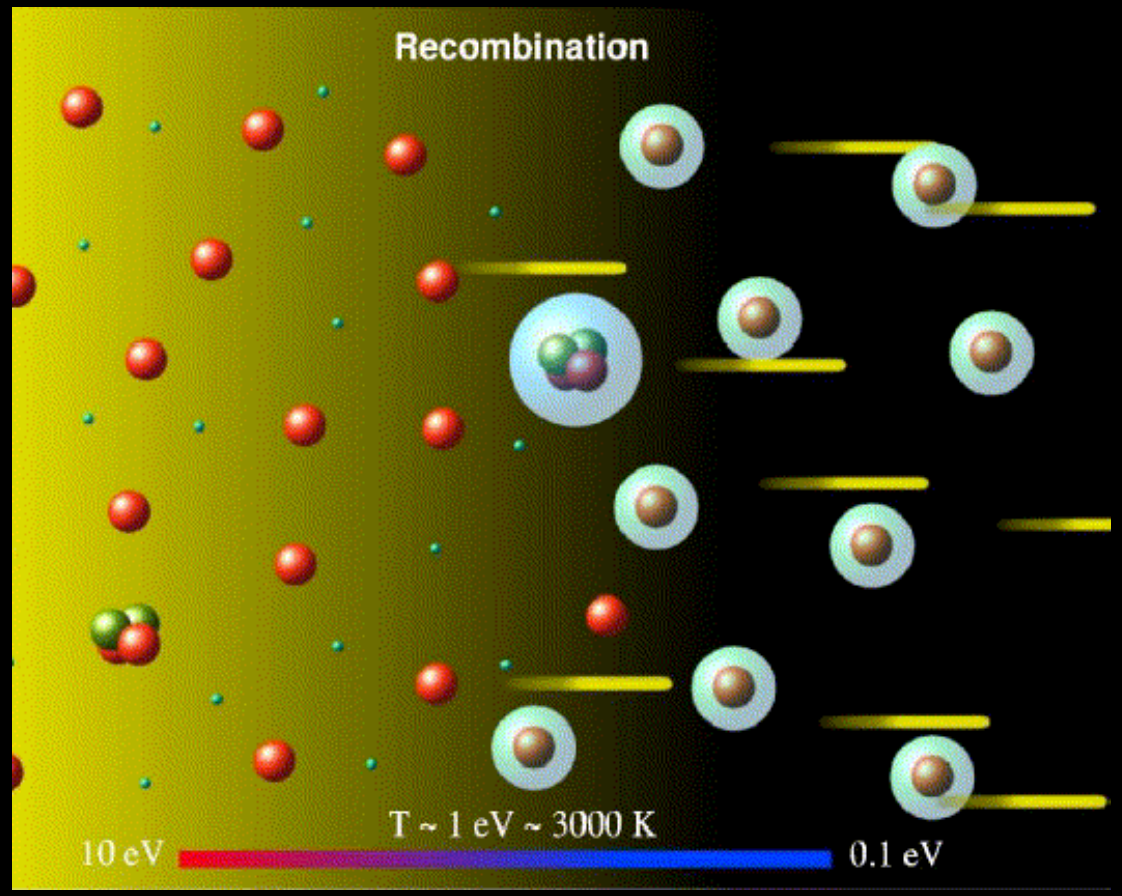
- The universe continues to cool and expand.
- Universe is a plasma consisting of atomic nuclei, electrons, and many high-energy photons of light.



THE NEXT 380,000 YEARS

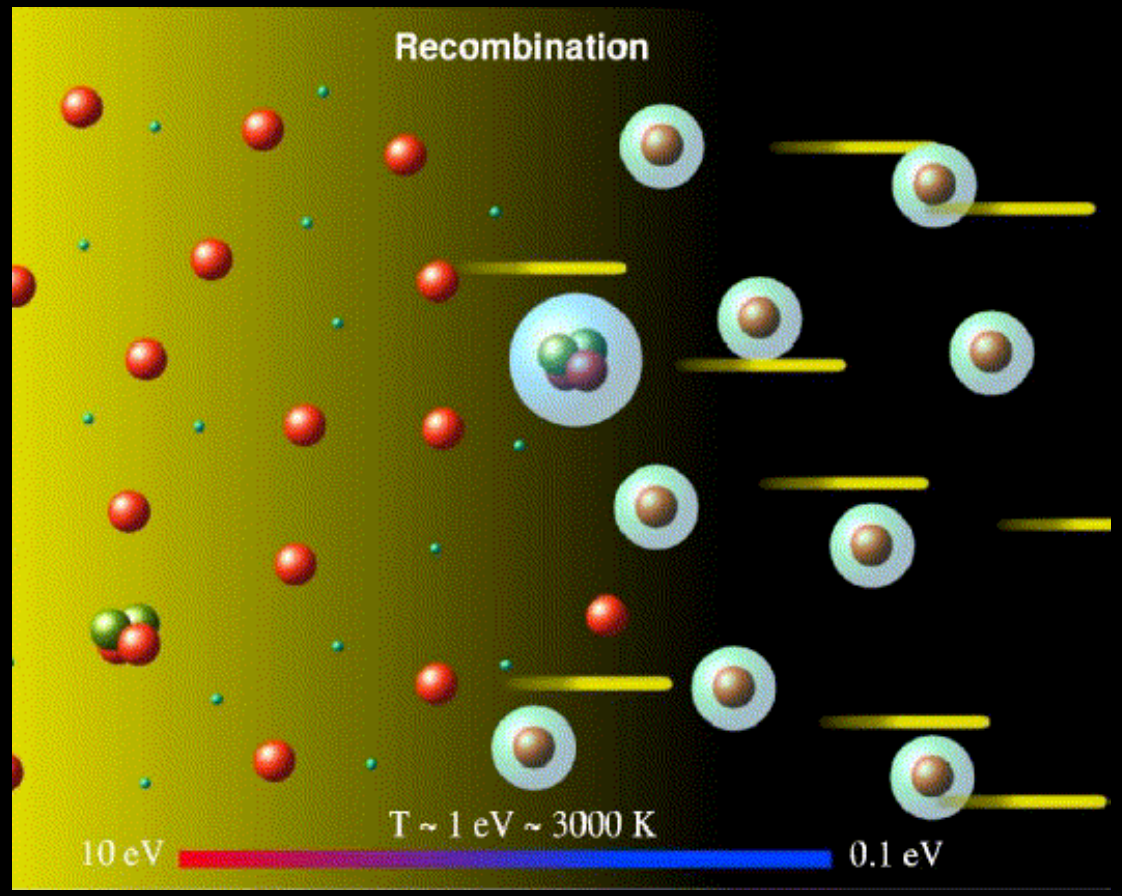
- Photons and electrons do not get along:
  - Atoms do not exist. If an electron happens to collide with a nucleus, it gets knocked off by a photon immediately.
  - Photons bump into free electrons wherever they go. Visibility is very low because photons (light) cannot get out.

A SLIGHTLY OLDER UNIVERSE (380,000+ YEARS)



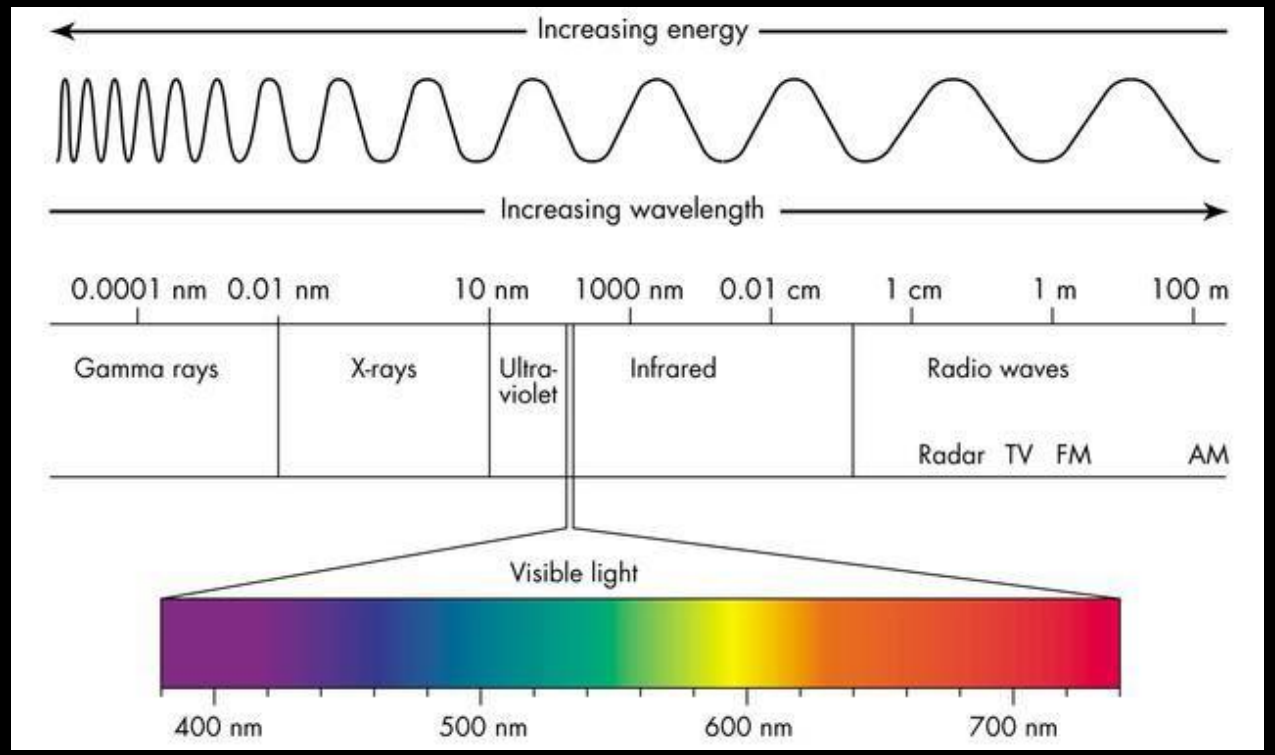
- Universe has now cooled to 3,000K.
- Photons no longer have enough energy to prevent electrons from sticking to nuclei and forming atoms.
- Fewer electrons in the way means photons are free to go! Universe becomes transparent.

A SLIGHTLY OLDER UNIVERSE (380,000+ YEARS)



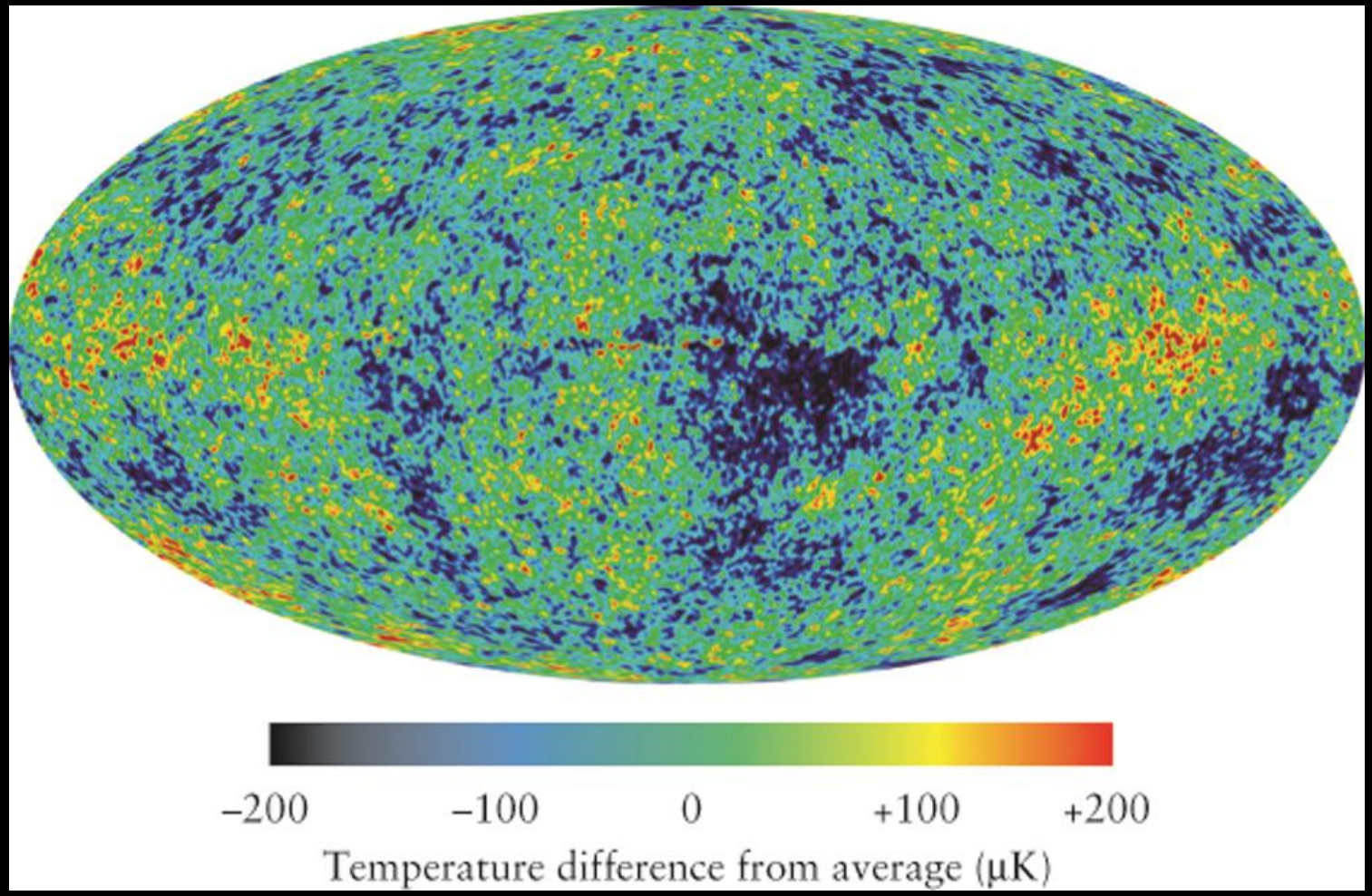
- Prediction: photons should have shot off in all directions with an energy equivalent to the temperature of 3,000K. Where did they go?

THE MODERN UNIVERSE



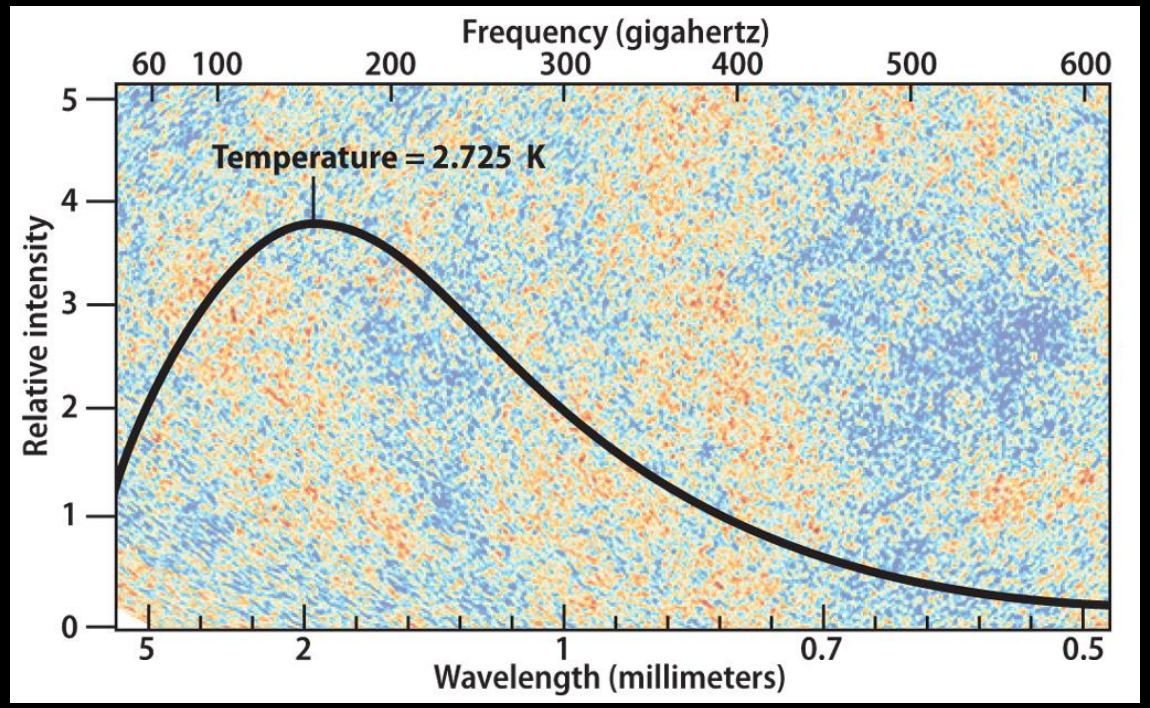
- Remember, light is a wave (3,000K light has a wavelength of 0.001 mm) *and* the universe has continued to expand.
- Prediction (1948): light has red-shifted into microwaves (wavelength of 1 mm) with a temperature of 5K.

THE MODERN UNIVERSE AND COSMIC BACKGROUND RADIATION



THE MODERN UNIVERSE AND COSMIC BACKGROUND RADIATION

- 1965: Arno Penzias and Robert Wilson discovered cosmic microwave background radiation (CMB) – radiation leftover from the Big Bang that had an average temperature of 2.725K…very close to the prediction!
- Penzias and Wilson awarded Nobel Prize in Physics in 1978.



A CONUNDRUM

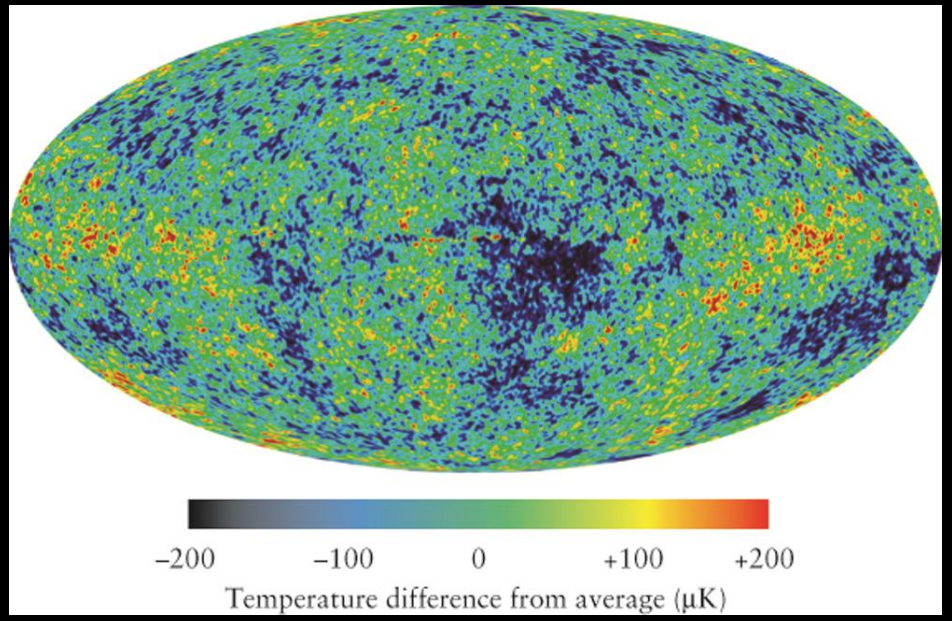
Problem:

- At 380,000 year point, matter in universe was evenly dispersed and the spaces constantly expanding.
- Uniform expansion from 380,000 yr old universe would have resulted in a uniform universe, without galaxies, planets, etc.

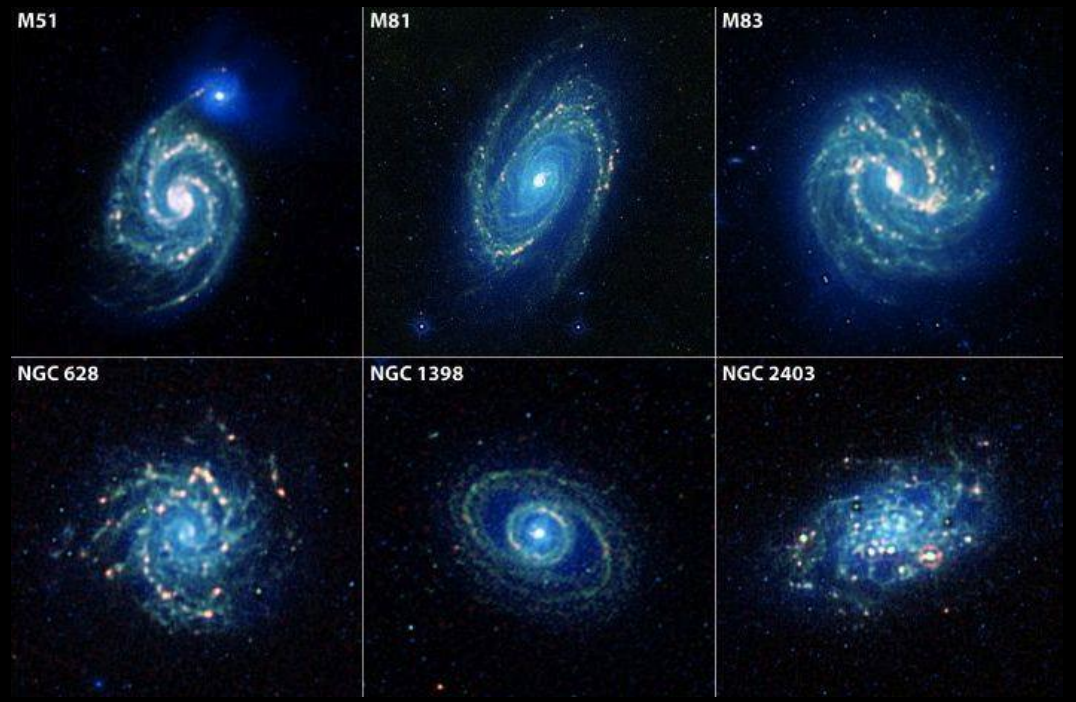
A CONUNDRUM

Reality:

- Fluctuations in CMB (far greater than under uniform universe expansion)



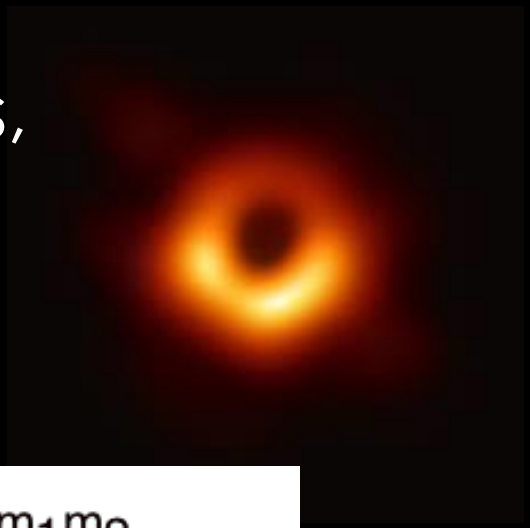
- Galaxies exist!

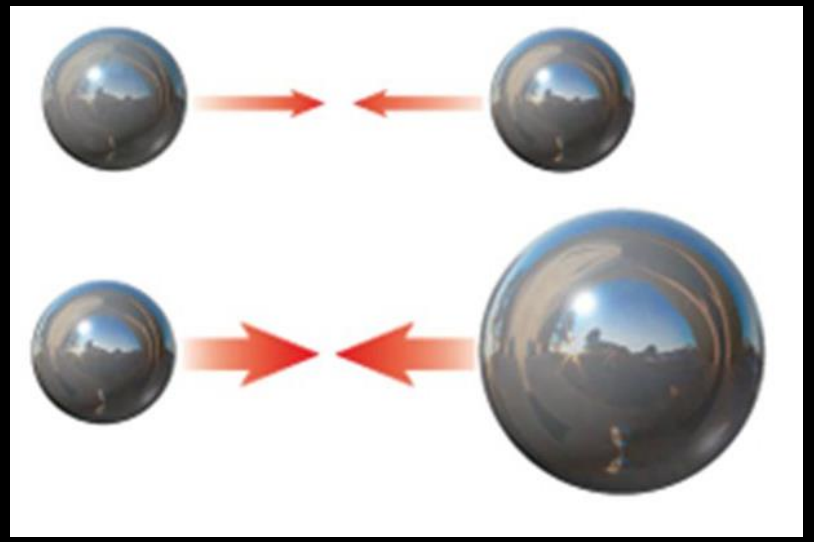


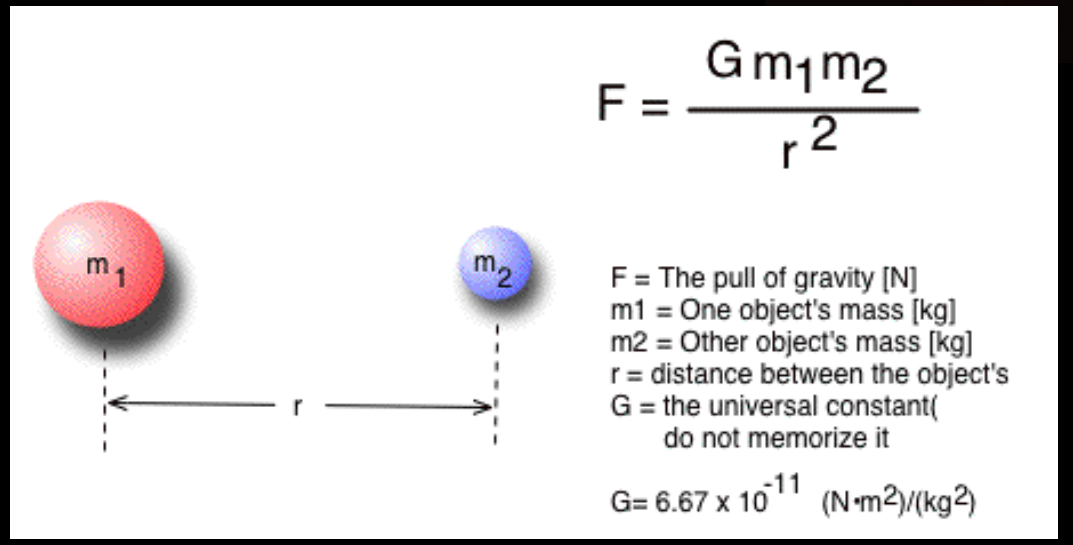
A CONUNDRUM

Scientific Fact:

- To pull matter together (to make planets, galaxies, etc.), you need gravity. And gravity needs mass. (↑ mass → ↑ gravity → ↑ mass etc.)
- Where did this mass come from?

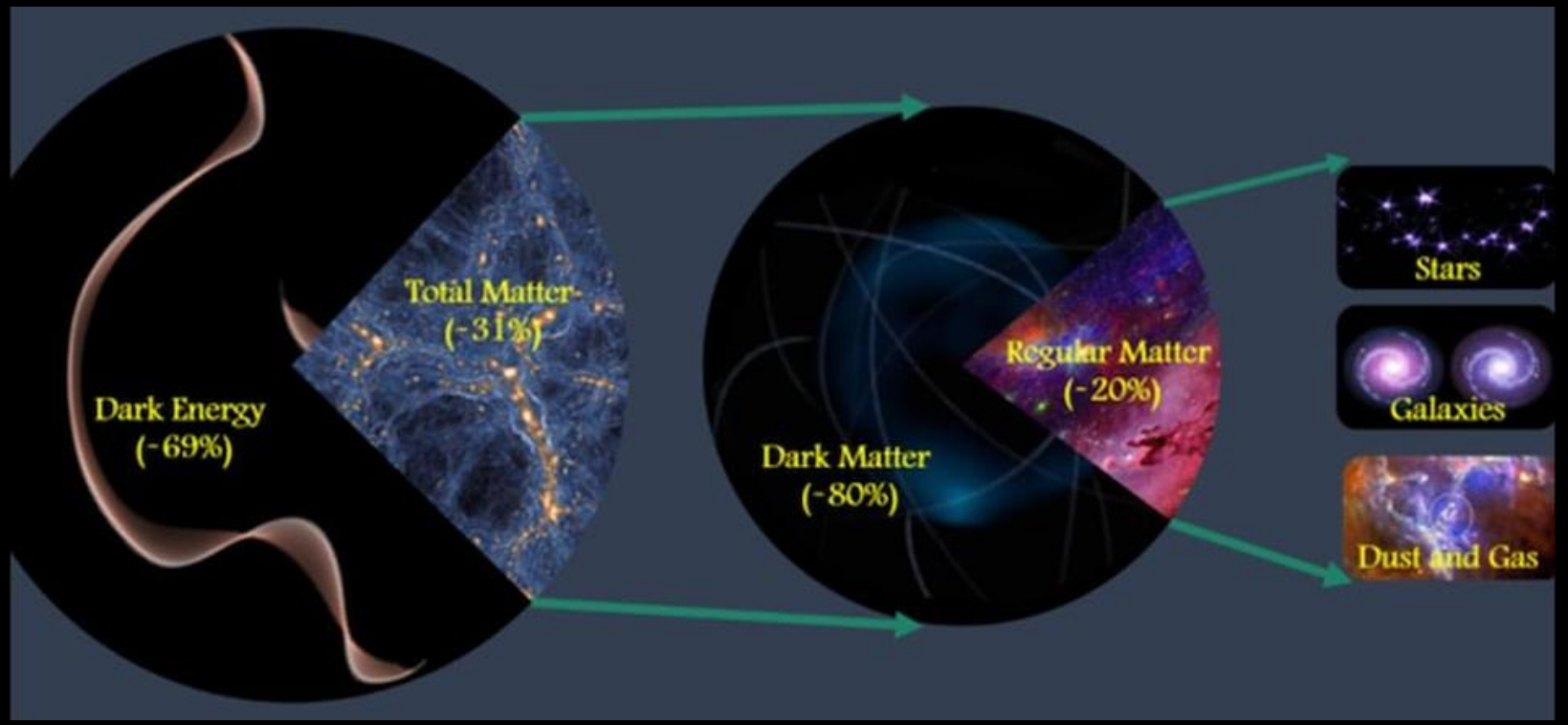




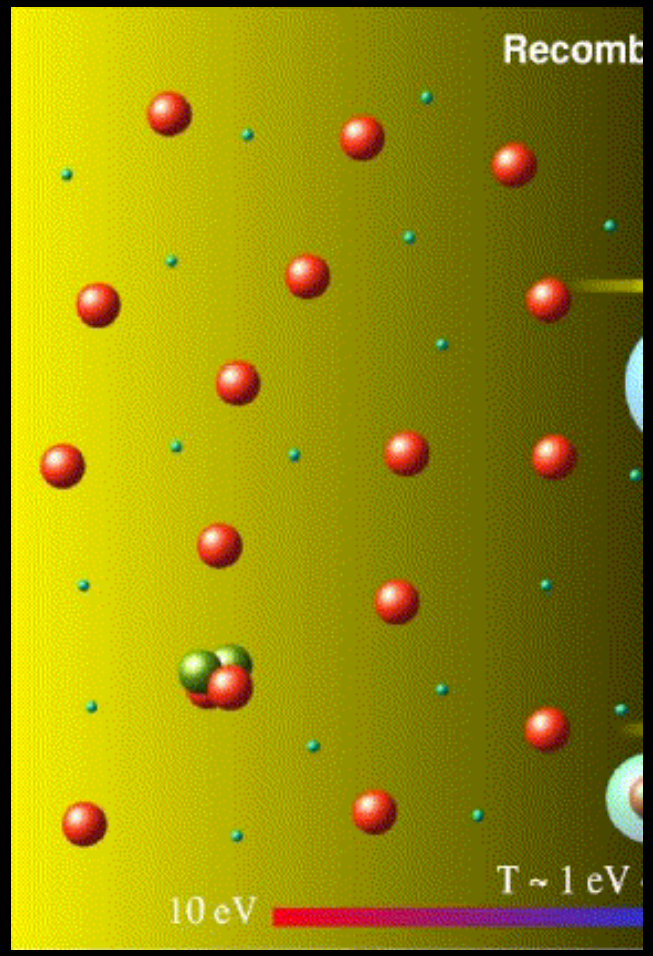


DARK MATTER

- We know it exists, but don't know much about it
- Has mass and volume, but ***does not interact*** with photons, unlike 'normal' matter

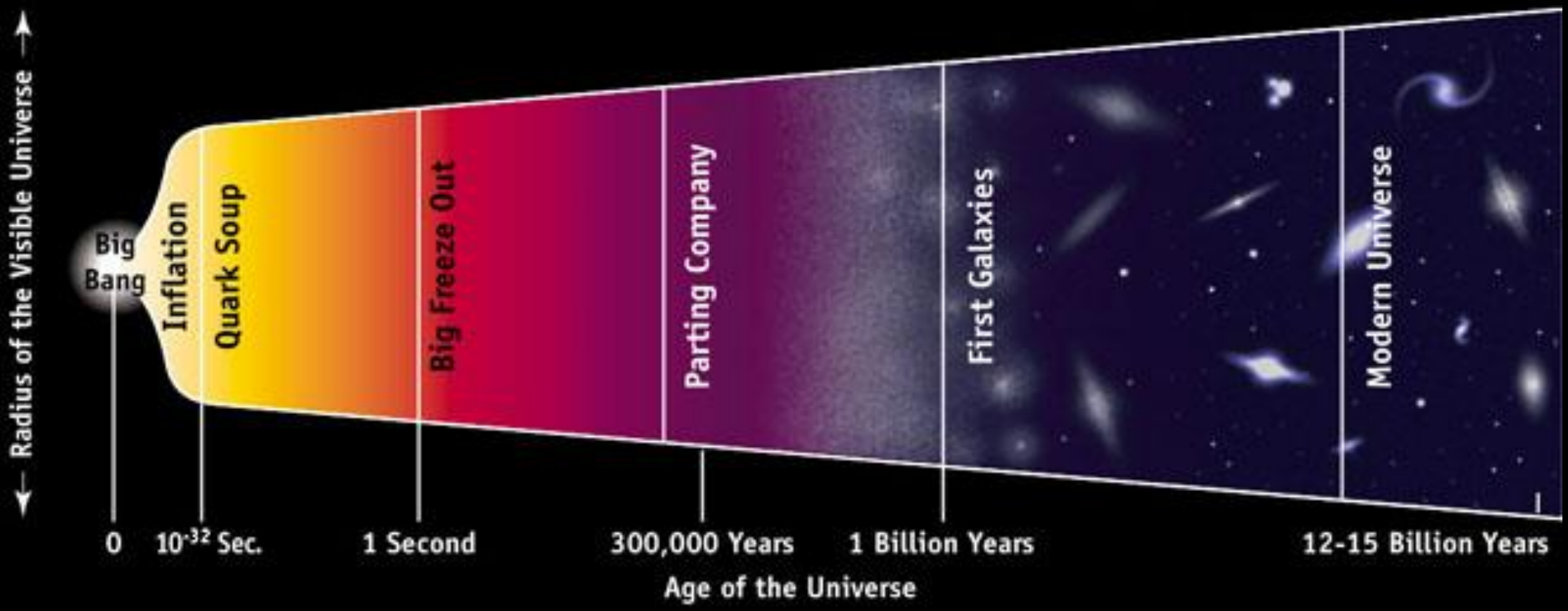


A SOLUTION TO OUR CONUNDRUM



- Review: matter was evenly distributed at the 380,000 year mark because ***photons*** kept interrupting the formation of larger particles
- But what about dark matter?

A SOLUTION TO OUR CONUNDRUM

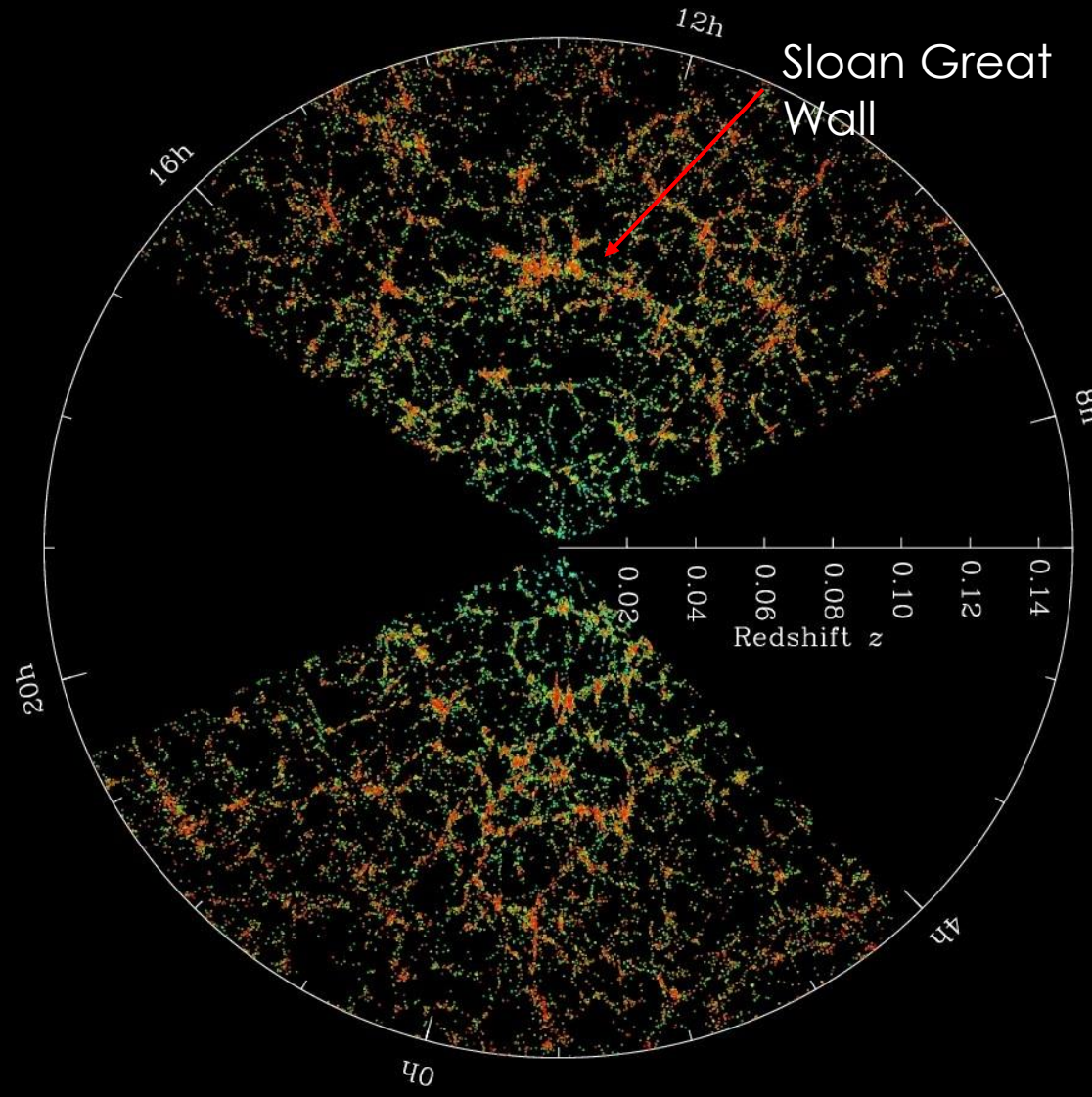


A SOLUTION TO OUR CONUNDRUM

- Dark matter, by definition, is unaffected by light (photons)
- Slight discrepancies in dark matter distribution at the moment of the Big Bang would have had higher gravity, pulling in more dark matter. After the 380,000 year mark, this uneven distribution of dark matter would then have pulled in bits of regular matter, giving galaxies and other celestial bodies a chance to form.
- Scientists are still investigating dark matter ☺

THIS IS REALLY COMPLICATED…

- But it's also beautiful.
- Our observable universe is not random. There are sections that are arranged in non-random structures (e.g. Sloan Great Wall, 1.37 billion light-years long, a giant wall of galaxies) that are predicted under computer simulations that take into account dark matter and all the other elements of modern Big Bang Theory.



ANDROMEDA BLUE-SHIFT