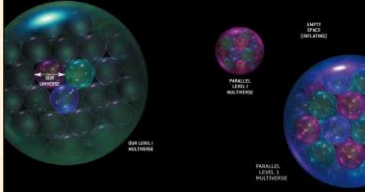


## ASTR 1020: Stars & Galaxies

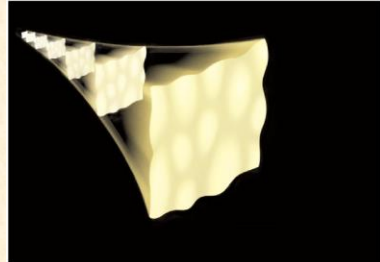
December 9, 2013

- *Mastering Astronomy* Homework on **The Big Bang** is due December 13<sup>th</sup>. Must submit all *Mastering Astronomy* homeworks by Dec. 14 at 7:30 pm.
- Any requested grade corrections & extra credit papers must be submitted to Lucas by 3 pm on Dec. 13.
- **Meet at Fiske Planetarium on Wednesday** for show "Exploring the Cosmos from the Moon".
- **Final Exam:** December 14, 7:30 – 10:00 pm; Chapters: 1, 4, 5, 6, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23. Review session on Friday night at 7:00 pm in EDUC 155.



## Today

- Evidence for the Big Bang Theory
- The results of Inflation



Reading Clicker Question: Which of the following types of mass or energy appears to be most abundant in our Universe?

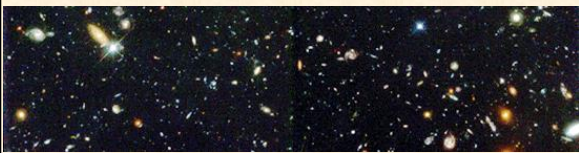
- A. ordinary (baryonic) matter
- B. extraordinary (non-baryonic) matter
- C. dark energy
- D. radiant energy (light)

Reading Clicker Question: Which of the following types of mass or energy appears to be most abundant in our Universe?

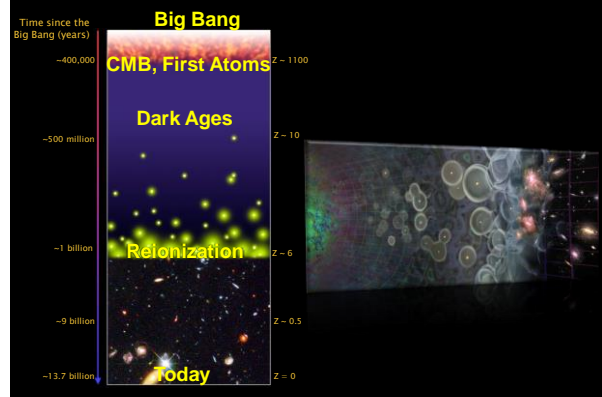
- A. ordinary (baryonic) matter
- B. extraordinary (non-baryonic) matter
- C. dark energy
- D. radiant energy (light)

## Era of Stars & Galaxies (also called Epoch of Reionization)

- About 0.5 billion years after Big Bang, first stars and galaxies start to form ( $z \approx 20$ ).
- First stars in galaxies ionize gas surrounding the galaxies.



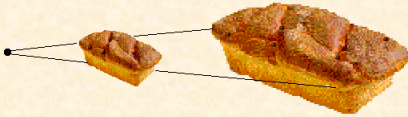
## Reionization and the Dark Ages



## Evidence for the Big Bang

### 1) Expanding Universe

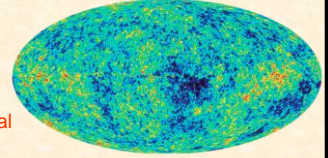
=>... run time backwards....



## 2) The Cosmic Microwave Background (CMB)

Observed all around us  
(*homogeneous & isotropic* on largest scales).

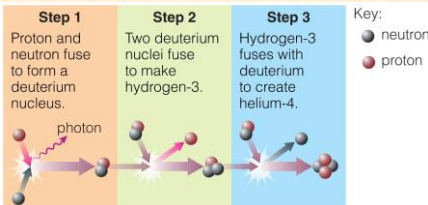
Remarkably uniform in all directions (isotropic) → something truly **universal**



Fits theory perfectly- the universe was once opaque and hot.

## 3) Helium is a minimum of 25%

- Big Bang theory prediction: 75% H, 25% He (by mass). This prediction matches observations of primordial gases → **universal** amount.
- Argues whole universe was millions of degrees for a **short** time.



**Clicker Question:** If the current density of normal matter in the Universe were 10 times as great as it is now, we would expect to observe

- More deuterium
- Less deuterium
- About the same amount of deuterium

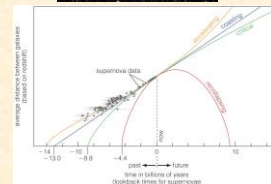
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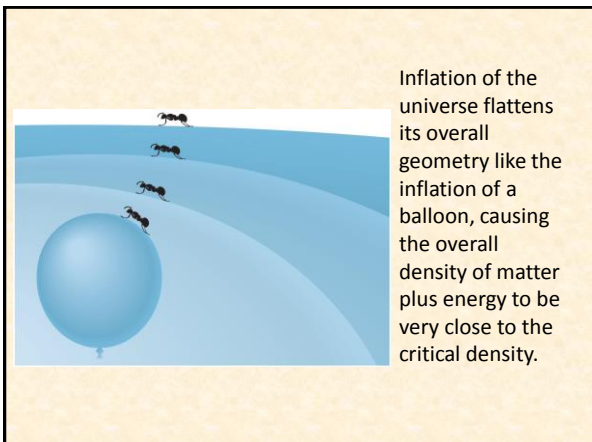
Protons & neutrons fuse to first produce deuterium and the deuterium fuse to produce helium. More baryons in early universe would have increased the rate of fusion and used up more deuterium so there would be less today.

## 4) Ages of stars

- Oldest stars ~ 13 billion years old
- Consistent with models of expansion containing dark matter and dark energy







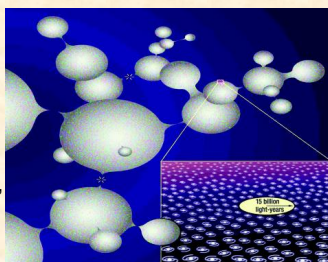
## Our current understanding of the Universe

- Overall geometry is flat.
  - Total mass + energy is just enough to create a flat geometry.
- Total matter is ~ 27% of total.
  - Ordinary matter is ~ 4% of total.
  - Dark matter is ~ 22% of total.
- Dark energy is ~ 74% of total.
- Age is 13.7 billion years.

*In excellent agreement with observations of present-day universe and models involving inflation and WIMPs!*

## A New Idea: Cosmological Branes

- Extra dimensions folded into a membrane of spacetime.
- Gravity “leaks through” added dimensions & is weakened.
- Collision of “branes” triggers creation of new Universe (bubbles)?



In inflation, our universe may be a minuscule part of one of many bubbles.