ASTR 1040 Recitation: Cosmology

Ryan Orvedahl

Department of Astrophysical and Planetary Sciences

April 21 & 23, 2014

This Week

- Last Night of Observing: Tuesday April 22 (8:30 pm)
- Heliostat Observing: Friday April 25 (2:30 - 4:30 pm)
- Review Session: Wednesday April 30 (5:00 pm G125)

Today's Schedule

- Past/Current Homework or Lecture Questions?
- General Relativity (only a little bit)
- Cosmology
- Big Bang

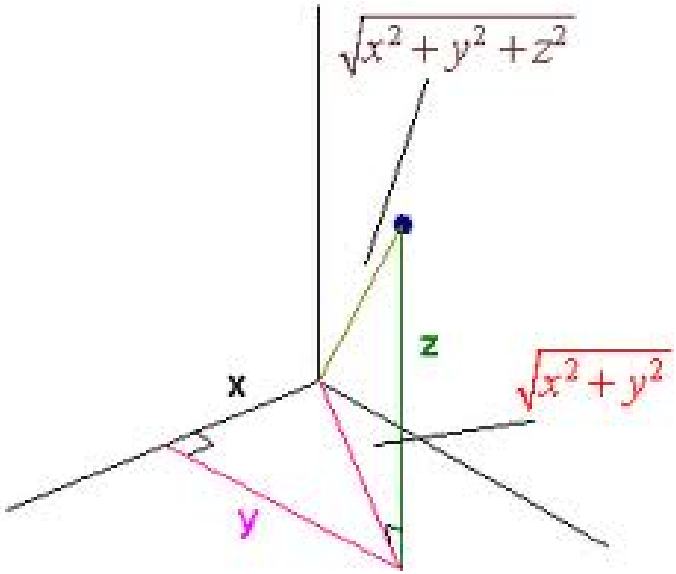
FCQs: ASTR-1040-011/012/013

- Email (Fri) from *FCQ.Office@colorado.edu*
- Check Spam folder, if you have not received it yet
- Can go to: *http://fcq.colorado.edu/ucb_fcq.htm*
- Please complete FCQs by Mon April 28 11:59 pm

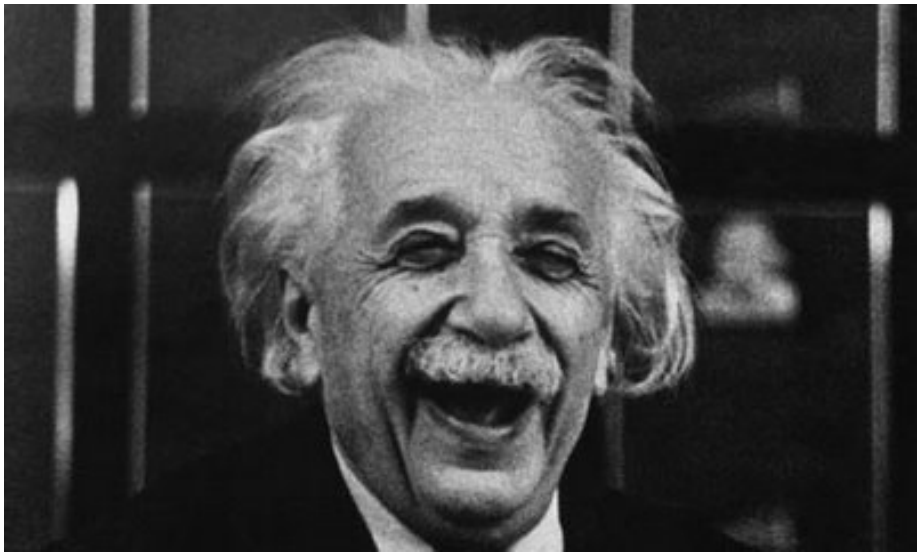
Comments on Exam # 3

General Relativity – Yay!!

Geometry you didn't learn in High School

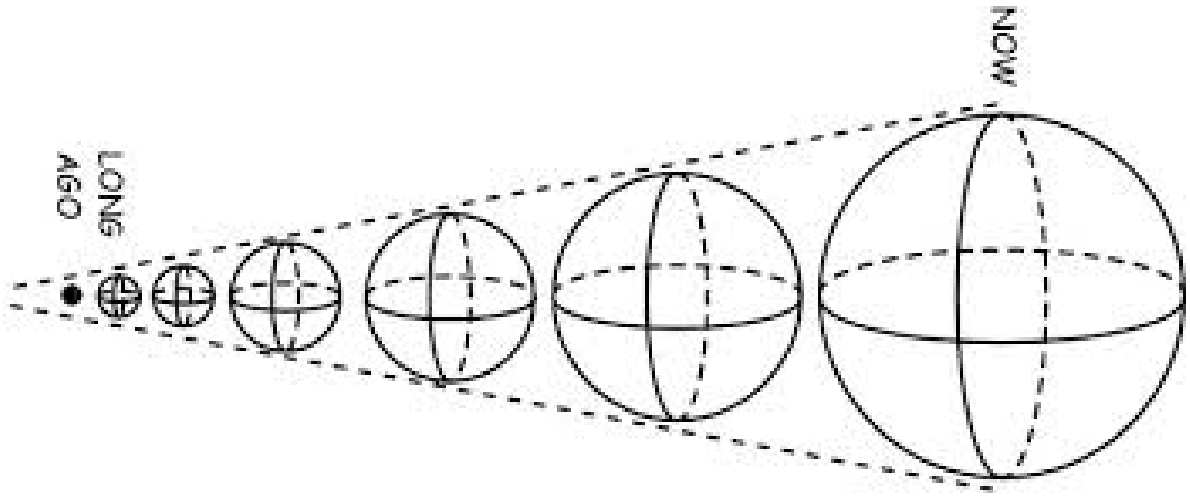


- Constant in any reference frame: $ds^2 = dx^2 + dy^2 + dz^2$



- Constant in any reference frame: $ds^2 = -c^2dt^2 + dx^2 + dy^2 + dz^2$ (FLAT Space ONLY)

What About Geometry of Expanding Universe?



$$ds^2 = -c^2 dt^2 + a(t)\left(dx^2 + dy^2 + dz^2\right)$$

$$ds^2 = -c^2 dt^2 + a(t)\left(\frac{dr^2}{1-kr^2} + r^2 d\theta^2 + r^2 \sin^2\theta d\phi^2\right)$$

$a(t) \equiv$ scale factor, relative expansion of the universe

More General Relativity – Yay!!

- Einstein tensor (Curvature): $G_{\mu\nu} \equiv R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu}$
- Include cosmological constant (Dark Energy): Λ
- Include matter/energy: $T_{\mu\nu}$
- Full Einstein Equations: $G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$

What Is the Scale Factor?

- Solve the Einstein Field Equations
- Assume homogeneous & isotropic universe
- Only leaves 2 independent equations

$$\frac{\left(\frac{da}{dt}\right)^2 + kc^2}{a^2} = \frac{8\pi G\rho + \Lambda c^2}{3}$$

$$\frac{1}{a}\frac{d^2a}{dt^2} = -\frac{4\pi G}{3}\left(\rho + \frac{3p}{c^2}\right) + \frac{\Lambda c^2}{3}$$

What Is the Hubble Constant?

Simply defined to be $H(t) \equiv \frac{1}{a(t)} \frac{da}{dt}$

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- Often see Ω parameters, what are those?
- Further assume that $\Lambda = 0$ and $k = 0$
- Solve for critical density, ρ_c, to get flat universe
- Simply defined as: $\Omega \equiv \frac{\rho}{\rho_c} = \frac{8\pi G \rho}{3H^2}$

Density Parameters

$$H^2(t) = H_0 \left(\Omega_R a^{-4} + \Omega_M a^{-3} + \Omega_k a^{-2} + \Omega_\Lambda \right)$$

- H_0 is Hubble constant of today ($t = t_0$)
- Ω_j are density parameters of today ($t = t_0$)

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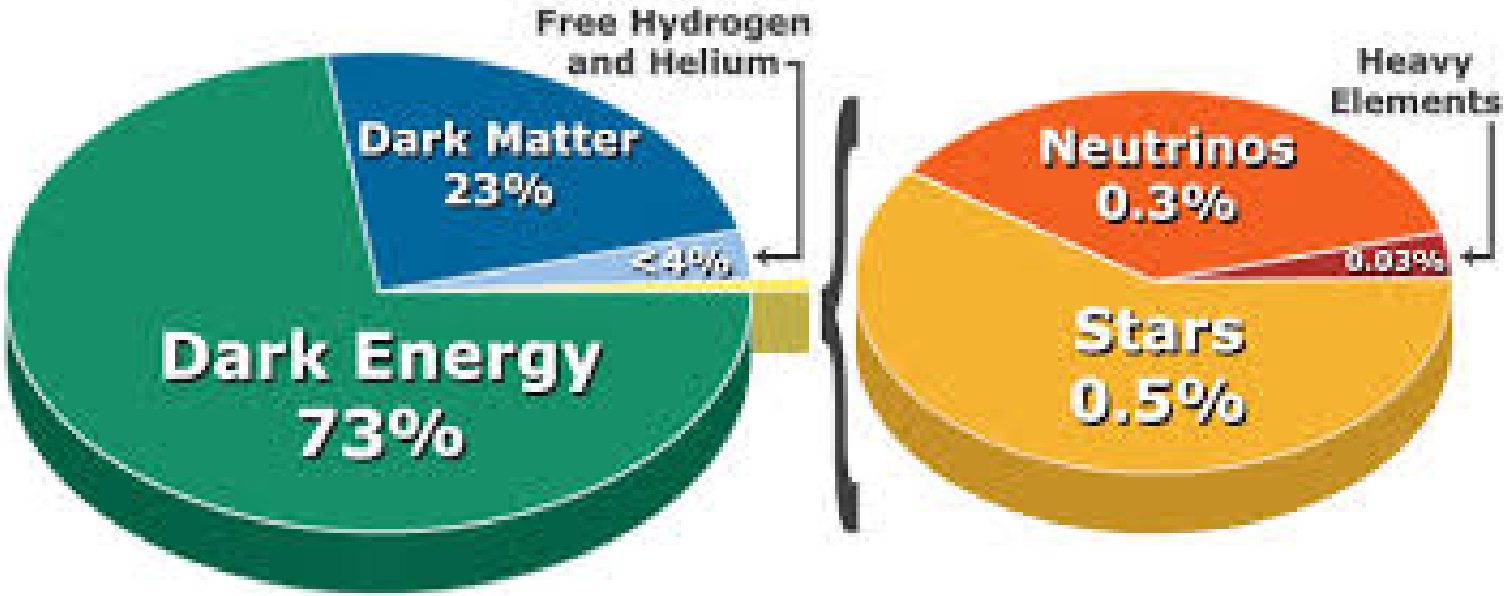
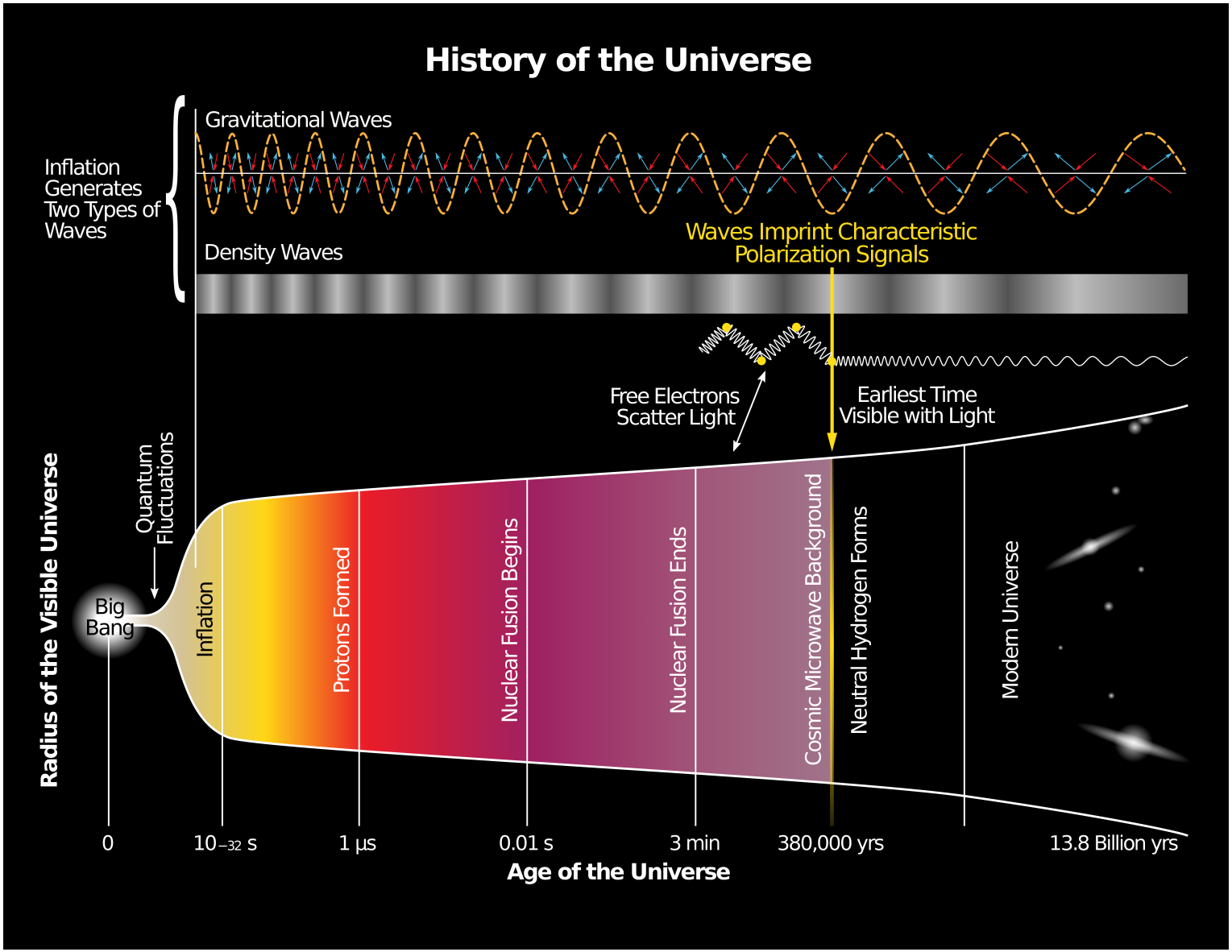
- $\Omega_R = (2.47 \pm 0.27) \times 10^{-4}$
- $\Omega_M = 0.267 \pm 0.0262$
- $\Omega_k = -0.020 \pm 0.021$
- $\Omega_\Lambda = 0.734 \pm 0.029$

Mass-Energy Budget of the Universe



Different Epochs



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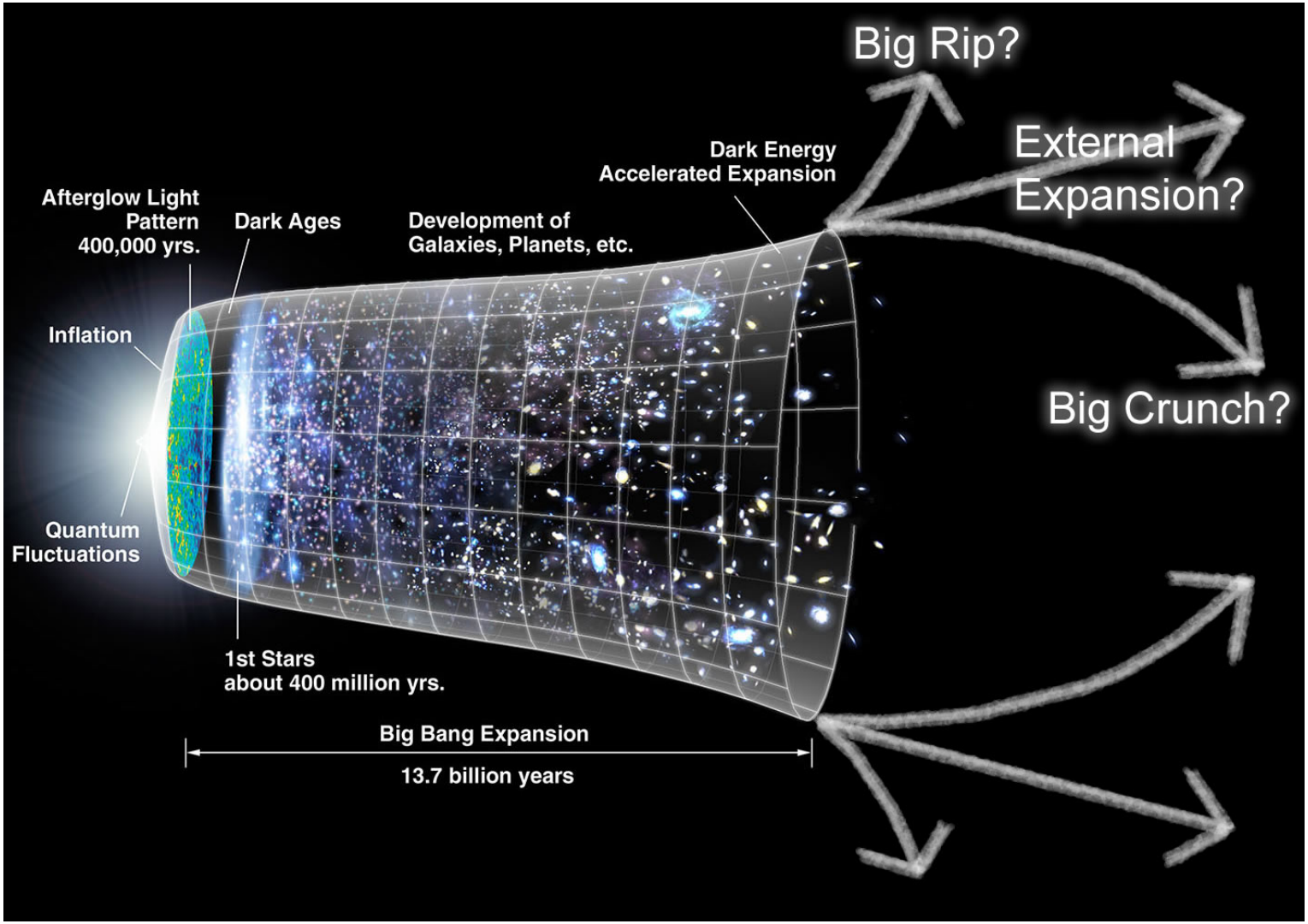
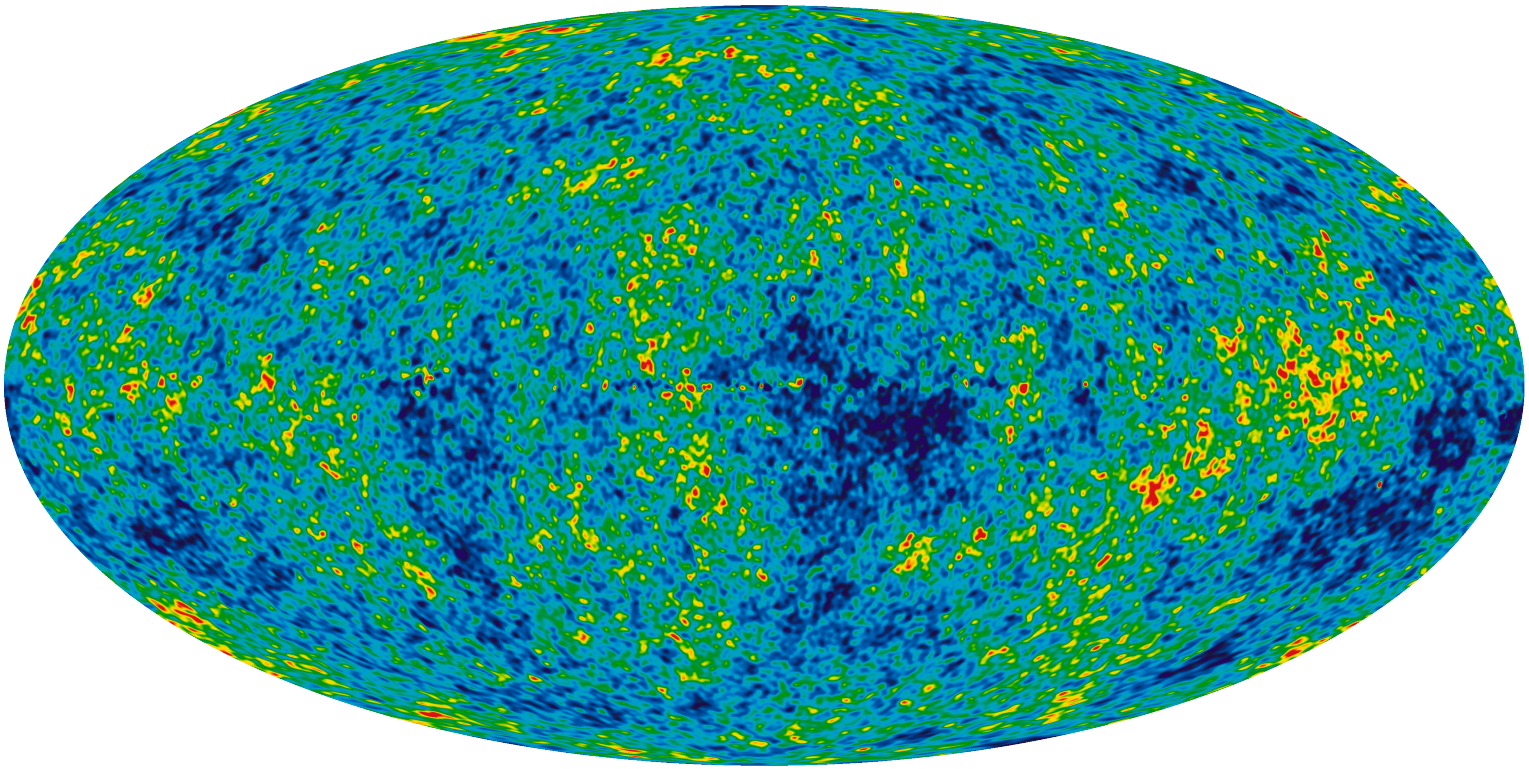
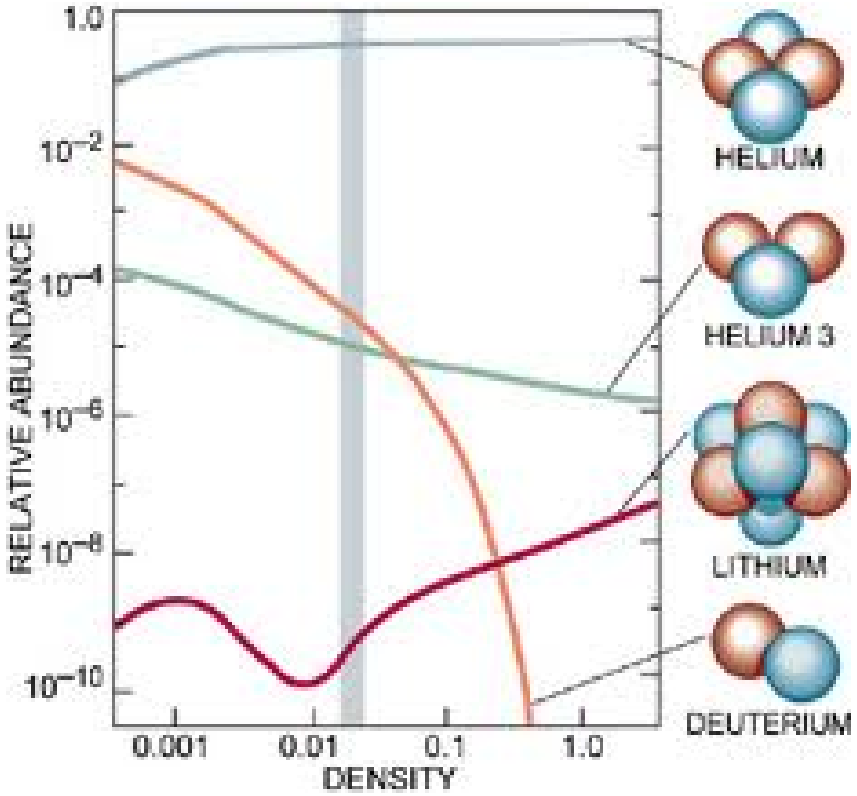


Inflation



Big Bang Nucleosynthesis

- Hot pre-CMB plasma
- Density of universe
- Nuclear Fusion
- $\Rightarrow$ Primordial Composition



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