Analysis of Deuterium Abundance

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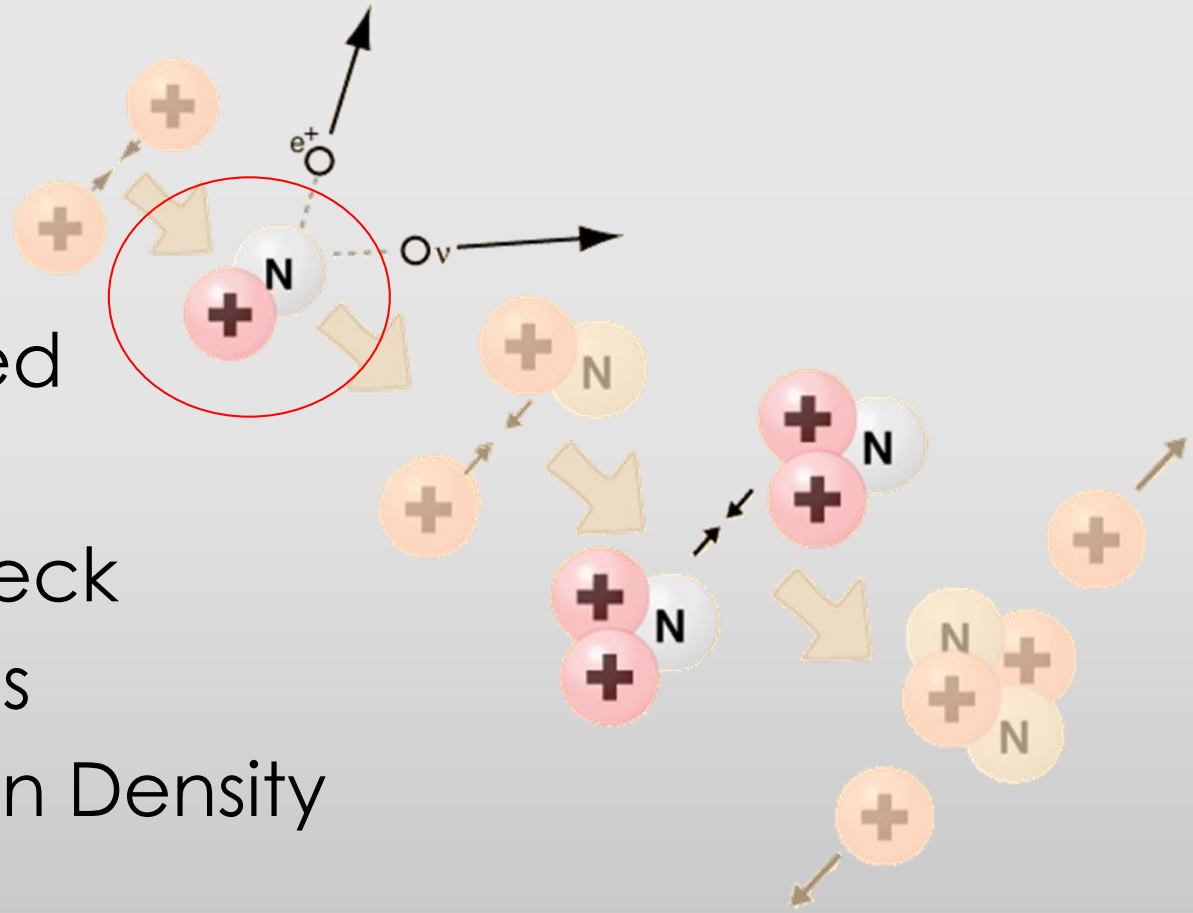
Big Bang Nucleosynthesis

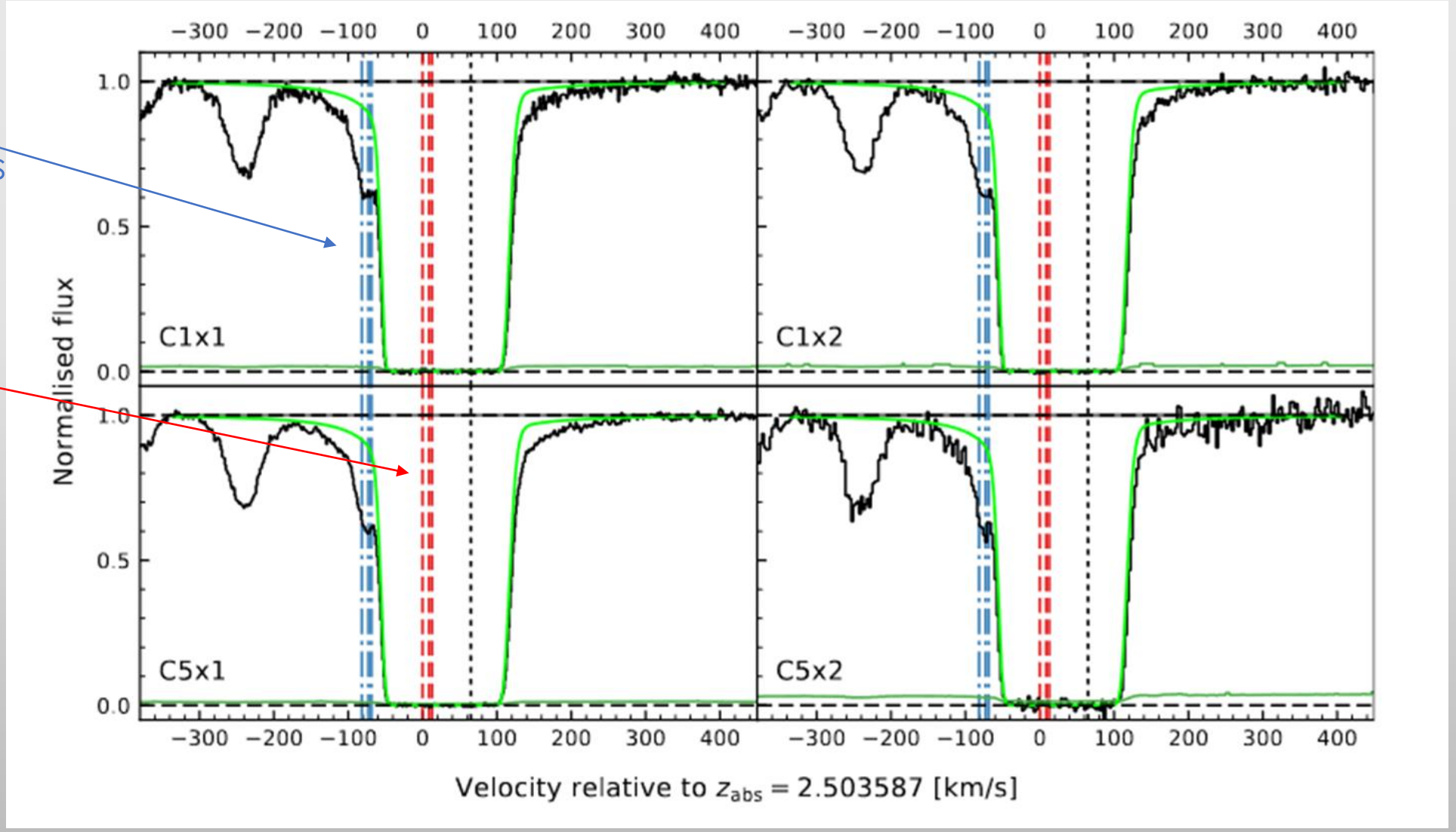
- Hydrogen to Lithium Produced
- Fusion Lasted For 20 Minutes
- Deuterium is a Fusion Bottleneck
- Lightest Isotope with Neutrons
- Production Sensitive to Baryon Density



Spectroscopy

Deuterium Lyman Lines

Hydrogen Lyman Lines



Zavarygin et al's Results

$$(\mathrm{D/H})_p = (2.545 \pm 0.025) \times 10^{-5}$$

$$\Omega_b \mathrm{h}^2 = 0.02174 \pm 0.00025$$

Quasar	D/H($\times 10^5$)	Reference
HS 0105+1619	$2.58^{+0.16}_{-0.15}$	Cooke et al. (2014)
J0407-4410	$2.8^{+0.8}_{-0.6}$	Noterdaeme et al. (2012)
Q0913+72	$2.53^{+0.11}_{-0.10}$	Cooke et al. (2014)
Q1009+2956	$2.48^{+0.41}_{-0.13}$	Zavarygin et al. (2018)
J1134+5742	$2.0^{+0.7}_{-0.5}$	Fumagalli et al. (2011)
Q1243+3047	2.39 ± 0.08	Cooke et al. (2018)
J1337+3152	$1.2^{+0.5}_{-0.2}$	Srianand et al. (2010)
SDSS	2.62 ± 0.07	Cooke et al. (2016)
J1358+6522	2.58 ± 0.07	Cooke et al. (2014)
J1419+0829	2.51 ± 0.05	Cooke et al. (2014)
J1444+2919	$1.97^{+0.33}_{-0.28}$	Balashev et al. (2016)
J1558-0031	$2.40^{+0.15}_{-0.14}$	Cooke et al. (2014)
PKS1937-1009	$2.45^{+0.30}_{-0.27}$	Reimer-Sørenson et al. (2015)
PKS1937-101	2.62 ± 0.05	Reimer-Sørenson et al. (2017)
Q2206-199	1.65 ± 0.35	Pettini & Bowen (2001)

Median Statistics

Truncated 13 Weighted Mean

$$(\mathrm{D/H})_p = (2.545 \pm 0.025) \times 10^{-5}$$

$$\Omega_b \mathrm{h}^2 = 0.02174 \pm 0.00025$$

All 15 Median

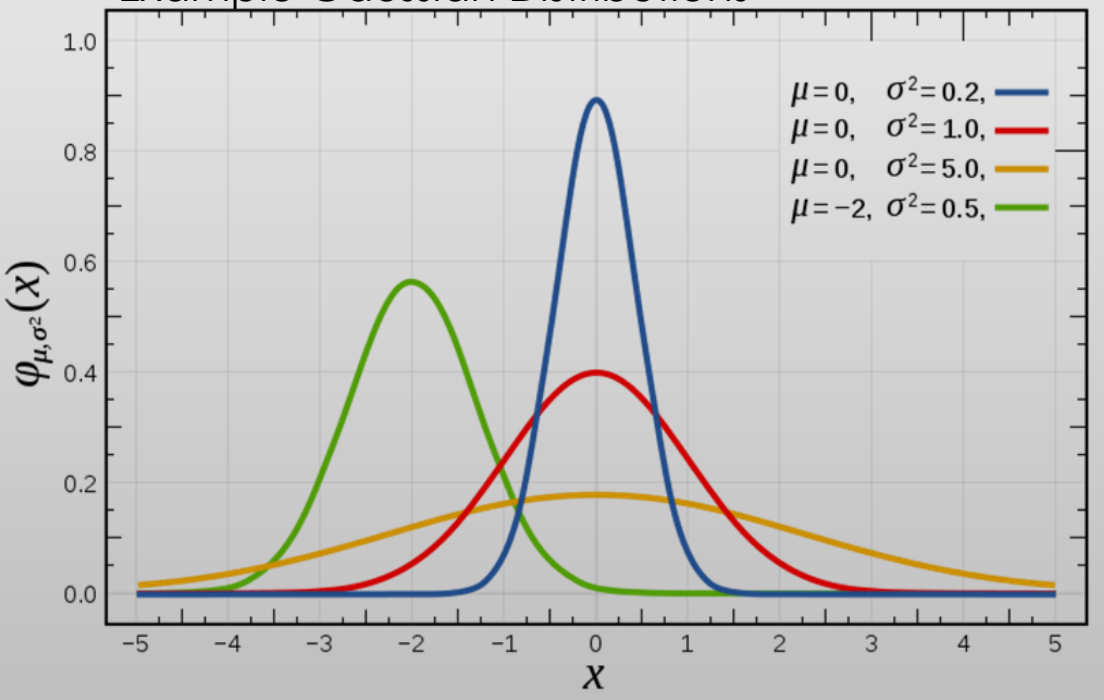
$$(\mathrm{D/H})_p = (2.48 \pm 0.065) \times 10^{-5}$$

$$\Omega_b \mathrm{h}^2 = 0.02209 \pm 0.00041$$

$$P = \frac{2^{-N} N!}{i!\,(N-i)!}$$

1σ (2σ) at 68.27% (95.45%)

Example Gaussian Distributions



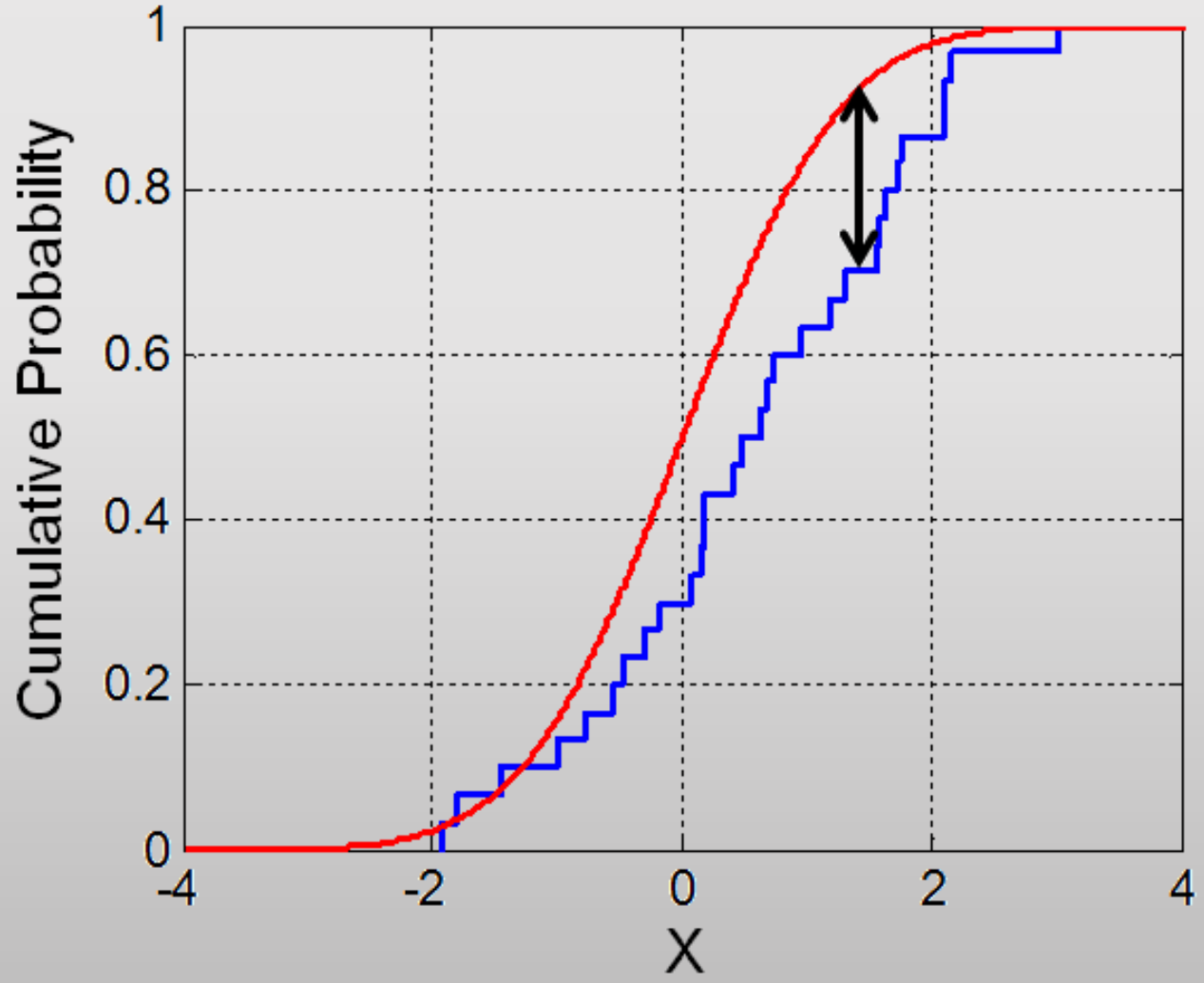
Kolmogorov-Smirnov Test

$$Q_{KS}(z) = 2\sum_{j=1}^{\infty}(-1)^{j-1}\exp(-2j^2z^2)$$

$$z = \left(\sqrt{N} + 0.12 + 0.11/\sqrt{N}\right) * D$$

$$\text{Prob}(D > \text{Observed}) = Q_{KS}(z)$$

	All 15 p	Truncated 13 p
Gaussian	0.809	0.997
Cauchy	0.921	0.604



Baryonic Density

Truncated 13 Weighted Mean

$$(\mathrm{D/H})_p = (2.545 \pm 0.025) \times 10^{-5}$$

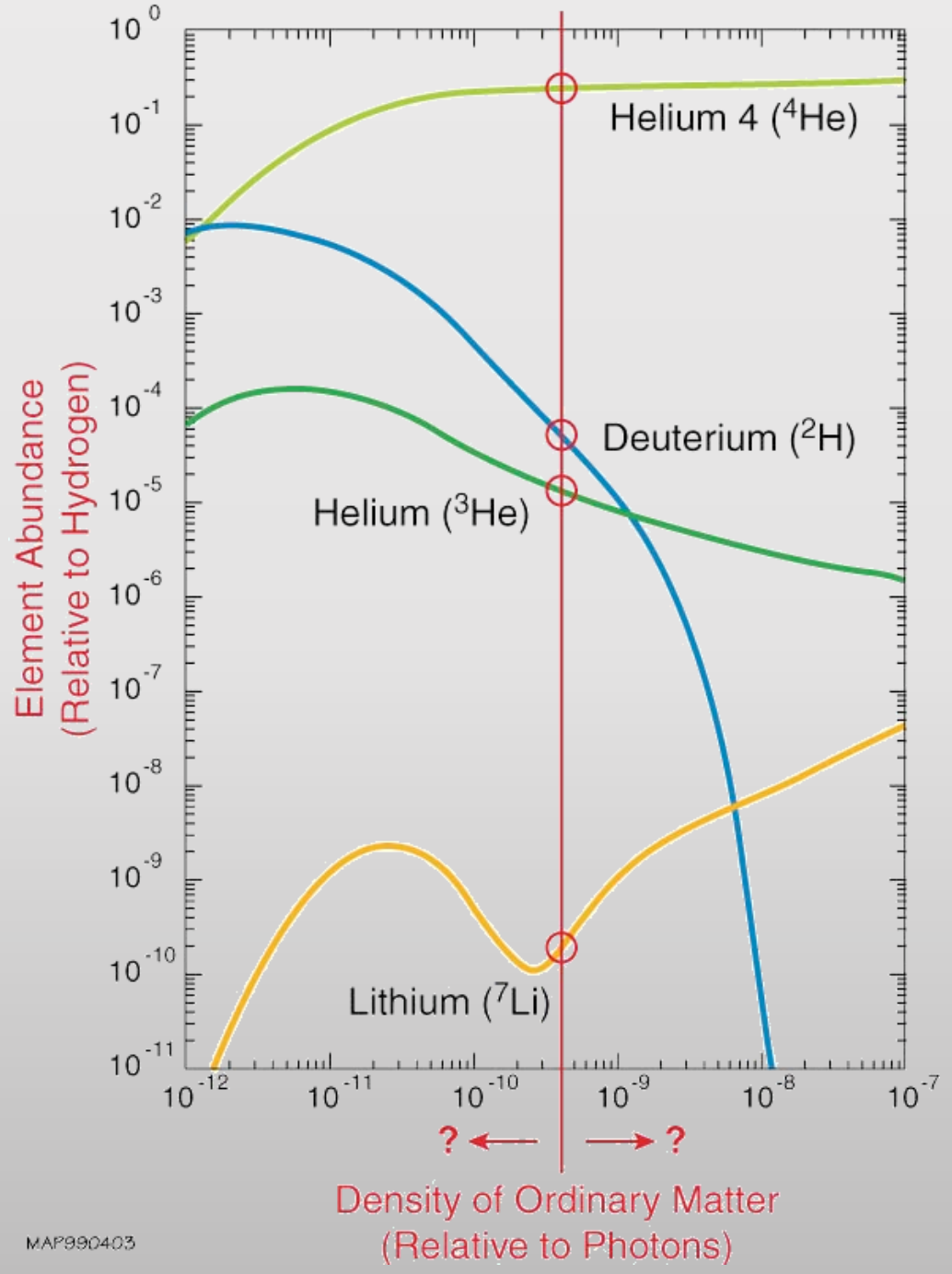
$$\Omega_b \mathrm{h}^2 = 0.02174 \pm 0.00025$$

All 15 Median

$$(\mathrm{D/H})_p = (2.48 \pm 0.065) \times 10^{-5}$$

$$\Omega_b \mathrm{h}^2 = 0.02209 \pm 0.00041$$

$$(\mathrm{D/H})_p = (2.45 \pm 0.04) \times 10^{-5} \left(\frac{\Omega_b h^2}{0.02225}\right)^{-1.657}$$

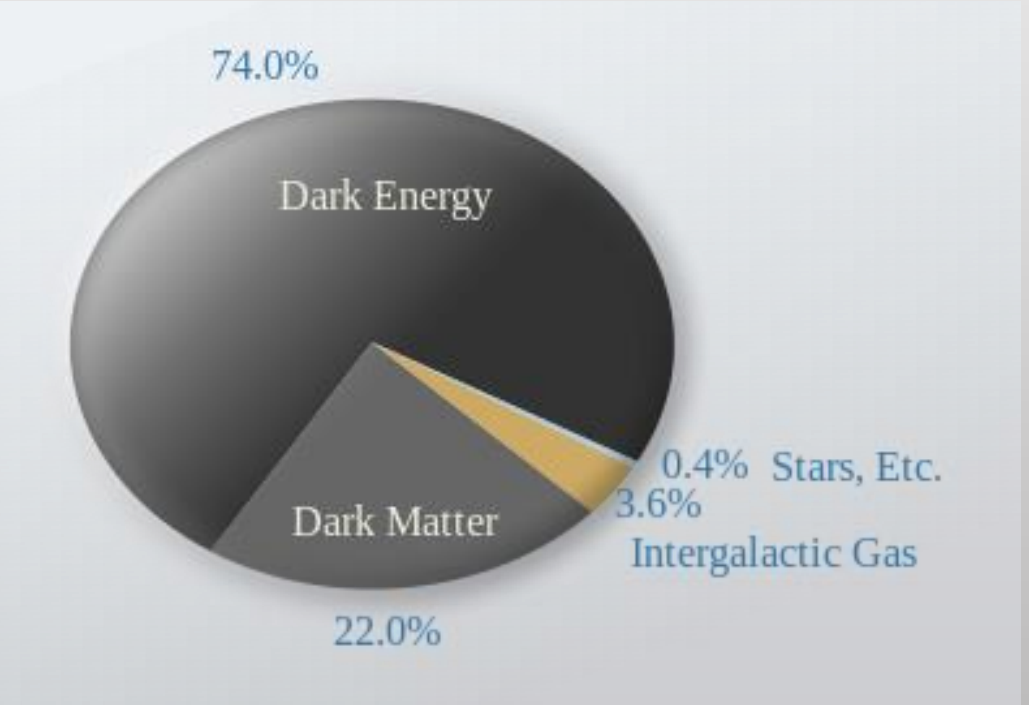


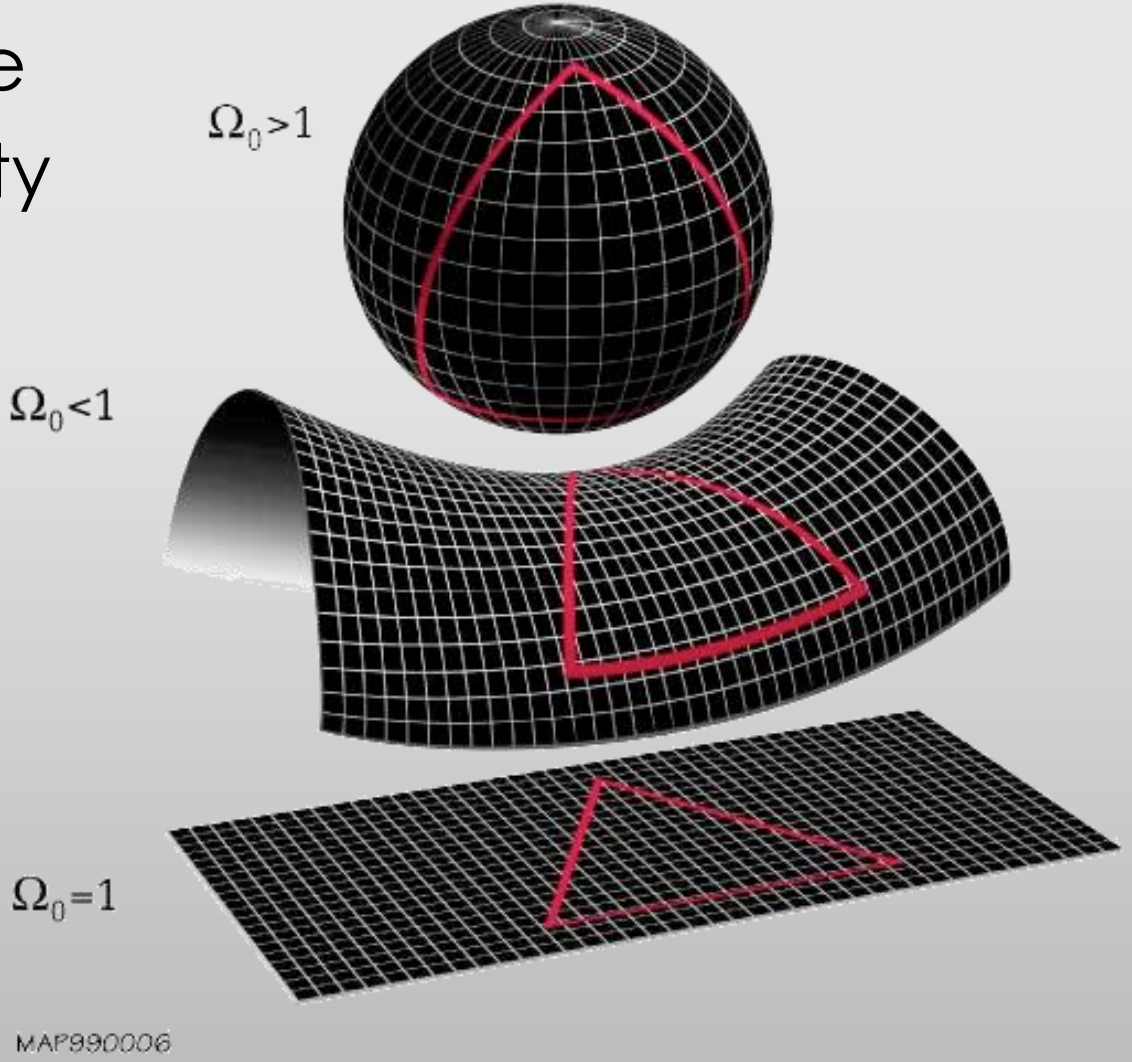
Planck Collaboration

	CMB Data Alone			CMB and Other Data		
Cosmogony	$\Omega_b h^2$	WMσ	Median σ	$\Omega_b h^2$	WMσ	Median σ
Flat ΛCDM	0.0225 ± 0.00023	1.5	0.34	0.02232 ± 0.00019	1.8	0.51
Nonflat ΛCDM	0.02305 ± 0.0002	4.1	2.1	0.02305 ± 0.00019	4.1	2.1
Flat XCDM	0.02229 ± 0.00023	1.6	0.43	0.02233 ± 0.00021	1.8	0.52
Nonflat XCDM	0.02305 ± 0.0002	4.1	2.1	0.02305 ± 0.0002	4.1	2.1
Flat φCDM	0.02221 ± 0.00023	1.4	0.26	0.02238 ± 0.0002	2.0	0.64
Nonflat φCDM	0.02303 ± 0.0002	4.0	2.1	0.02304 ± 0.0002	4.0	2.1

The End of the Universe

- End Determined by Curvature
- Curvature Depends on Density
- $\Omega_0 = Density/Critical\ Density$





Further Research

- More Data Points
- Other Cosmological Data Sources
- Comparing More Distributions

Acknowledgements

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