Characterising alpha: Fundamental constants in the recombination epoch

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Fundamental constants are defined in our lab frame, not at high redshifts

\[ \alpha_{\text{EM}} = \frac{1}{137.036\ldots} \quad \bar{\mu} = \frac{m_e}{m_p} \]

Allow us another test of EW theory and epochs

\[ \alpha_{\text{EM}} = \frac{g_{\text{EM}}^2}{\hbar c} = \frac{g_2^2}{\hbar c \sin \theta_W} \]

Allows for really cool extensions to the standard model (Bekenstein 1982 onwards)

\[ L = -mc\sqrt{u^\mu u_\mu} + \frac{e_0\varepsilon}{c} u^\mu A_\mu \]
Spatial variations of \( \alpha \) in quasars

Natural nuclear chain reactions at Oklo (carbon dating for \( \alpha \))
Fuji et al (2002)

Helium produced during BBN dependent on \( \alpha \)
Ichikawa and Kawasaki (2002), Li and Chu (2005)

Changes to the CMB due to temporal variations in \( \alpha \)

Constraints from Planck and COre
Recombination
CMB
MCMC
Semi-blind PCA
Spectral distortions
All recombination calculations with CosmoRec (Chluba and Thomas 2010), verified with HyRec (Ali-Haimoud and Hirata 2010).

**Period of hydrogen recombination**

Recombination
Adding $\alpha$ to recombination

\[ \frac{\Delta \alpha}{\alpha} = 0.1 \]

same acceleration for He II recombination at earlier times

accelerated recombination

$\Rightarrow$ earlier decoupling

$X_e$


物理过程受到影响的 α

- 有效过渡率（i.e. $R_{ij}$）
- 光照传热校正

图中显示了电离率和光子的净变化是正的，最大的变化是由于能量重新分配。

两个光子衰变

（Lyman α 转换）
（能量重新分配）

（Rescaling of $m_e$ gives similar results but, rec+phot is positive at low redshift and $\sigma_T$ goes the other way — more to come）

LH and Chluba (2017)
Ionization history

\[
\frac{\Delta \alpha}{\alpha} = +0.1
\]

Visibility function

CMB Power spectra

Conservation of \( g(z) \) leads to dip

Acceleration moves the peak

Pushed to smaller scales, lower diffusion damping

Propagating \( \alpha \)
Constant changes in $\alpha \rightarrow$ discontinuous changes in $\alpha$

Maybe a toy model: minimise changes around maximum visibility??

$$\alpha(z) = \alpha_0 \left( \frac{1 + z}{1100} \right)^p$$

LH and Chluba (2017)

Time dependent $\alpha$
2013: Planck TT + lowP + lensing  
2015: Planck TTTEEE + lowTEB + lensing

\[ \Delta m_e/m_e = 2 \times 10^{-3} \]
\[ \Delta H_0/H_0 = -0.02 \]
\[ \Delta H_0/H_0 = -0.01 \]
\[ \Delta H_0/H_0 = -10^{-3} \]

\[ \Delta \alpha/\alpha = 10^{-3} \]
\[ \Delta \alpha/\alpha = 10^{-2} \]
\[ \Delta T_0/T_0 = -10^{-2} \]

\[ p = 5 \times 10^{-3} \]

Watch out for \( \sigma_T \)!!

Strong degeneracy between \( \Theta_{MC}/H_0 \) and \( \alpha \)

LH and Chluba (2017)
Variational model → Bias

δP_i → ∂_iC_l → F_{ij}

\[ P = X_e \]


\[ P = f_{\text{ann}} \]

Finkbeiner et al (2011)

\[ P = \tau_{\text{reion}} \]

Ferraro and Smith (2018.. 2 days ago)

Effective principal component analysis
Responses from $X_e$

Perturbation response for $X_e$ with perturbation redshift $z = 1108$

$\Delta X_e/X_e$ in %

$\delta \ln C_l/\delta p$

$z$

$l$

HI

HeI

TT

EE

$\Delta X_e/X_e$ in %

$\delta \ln C_l/\delta p$

$z$

$l$
Responses from $\alpha$

Perturbation response for $\alpha_{\text{pc}}$ with perturbation redshift $z = 1108$

Responses from $\alpha$ LH and Chluba (2018, in prep)
- Centred around the maximum of the visibility function
- Restricted range of redshifts for the principal components
- Full set of principal component functions orthogonal to 0.01%

*confirmation of Farhang (2012) CVL modes

LH and Chluba (2018, in prep)
Modes are similar due to degenerate effects of $X_e$ basis.
- \( \alpha \) and \( m_e \) will affect the peaks and their locations in the CRR.
- carefully consider the Helium recombination.
- really nice probe into universe around (and before) recombination.
- big challenge! We’re on it! (LH and JC)

Recombination radiation
Pedagogical insight into BSM physics and alternative ideas surrounding fundamental constants

The CMB provides allows us to challenge the constancy of these fundamental values at recombination

Semi-blind analysis will allow us to constrain the most likely differences in these parameters given the data

Spectral distortions — a new way to probe parameters such as $\alpha$, $m_e$ and much more