Variability of the proton-to-electron mass ratio on cosmological scales

Quasar absorption line spectroscopy

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Overview

• Short introduction of theory behind variation
• How is variation reflected in observations?
• Molecular Hydrogen H₂
• Methods involved
• Analysis
• Summary and Outlook
Theory of shilly-shally constants
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Kaluza-Klein theories

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Variability of the proton-to-electron mass ratio on cosmological scales – p.
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• another byproduct: scalar field as possible source for acceleration
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• variation of the gravitational constant $G_N$. Recent paper last week:
  $\dot{G}_N/G_N \lesssim 10^{-17}\text{yr}^{-1}$. 
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- measure possible variation on cosmological scales
How to measure variation?

molecular hydrogen $\text{H}_2$ - energy levels

\[ E_{\text{total}} = E_{\text{electronic}} + E_{\text{vibration}} + E_{\text{rotation}} \quad \text{(BOA)} \]
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- the classical oscillation frequency dependent on the *reduced mass* as $\mu^{-\frac{1}{2}}$. 
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- rotational transitions are proportional to $\mu^{-1}$
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- homonuclear molecule - no detectable mere vibrational or rotational spectrum
- only observable in combinations with electronic transitions (UV-Band)
- UV radiation is a very efficient dissociator of H₂, so any H₂ that survived would presumably be located inside very dense interstellar clouds.
- So far observations have borne out this supposition.
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(Varshalovich & Levshakov 1993)
How to measure variation?

sensitivity coefficient \( K_i = \frac{d \ln \lambda_i^0}{d \ln \mu} \)
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(Reinhold et al. 2006)
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- local observations with UV-satellite COPERNICUS
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- transitions in UV (restframe) – redshifted into visual band
extragalactic H$_2$

- highly inhomogeneous, clumpy distribution

extragalactic $\mathrm{H}_2$

- highly inhomogeneous, clumpy distribution \cite{1}
- observable only in dense systems

Quasar absorption line spectroscopy
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- rotating massive black hole
- hot, dense accretion disk
- torus of cooler gas and dust
- small dense emission line clouds
- accelerated jets of relativistic particles
- to large-scale radio lobes

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Quasar absorption line spectroscopy
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- Quasars as bright distant background sources against which intervening gas can be observed.
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  e.g., the Ly$\alpha$ transition at $\lambda_{\text{rest}} = 1215.67$ Å
Quasar absorption line spectroscopy

(Springel et. al 2006)
Quasar absorption line spectra - probing the universe

Q 0347−383

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Q 0347–383
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Variability of the proton-to-electron mass ratio on cosmological scales – p. 20
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(Ivanchik et al. 2005)
Quasar absorption line spectra - probing the universe

simulated fits to estimate accuracy
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Variability of the proton-to-electron mass ratio on cosmological scales – p. 21
Quasar absorption line spectra - probing the universe

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Variability of the proton-to-electron mass ratio on cosmological scales – p. 22
\[ b = (1 + z_{\text{abs}}) \times \frac{\Delta \mu}{\mu} \]
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corresponding to \( \frac{\Delta \mu}{\mu} = 2.1 \pm 1.4 \times 10^{-5} \)

(Reinhold et al. 2006: \( \frac{\Delta \mu}{\mu} = 2.0 \pm 0.6 \times 10^{-5} \))
\[ b = (1 + z_{\text{abs}}) \times \frac{\Delta \mu}{\mu} \]
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Merely transitions with high vibrational quantum numbers in the first rotational level contribute to a positive result.
News or noise?
no detectable correlation in a 85% subset
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No detectable correlation in a 85% subset

\[ |\Delta \mu / \mu| \leq 4.9 \times 10^{-5} \text{ over the period of } \approx 11.5 \text{ Gyr} \]
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• line lists of required accuracy just available ⇒ increased need for high resolution
• in general attach more importance to data reduction
• search for more quasar spectra with DLA and H$_2$ signatures
• further simulations of detectability of variation
• better understanding of the nature of DLAs
The Ratio of Proton and Electron Masses

FRIEDRICH LENZ
Düsseldorf, Germany
(Received April 5, 1951)

The most exact value at present\(^1\) for the ratio of proton to electron mass is 1836.12±0.05. It may be of interest to note that this number coincides with \(6\pi^5=1836.12\).

\(^1\)Sommer, Thomas, and Hipple, Phys. Rev. 80, 487 (1950).
Nine separately observed spectra with errorbars and exemplary fit of L1R1.
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