Scientific Justification

Recently, there has been a great deal of interest in the possibility that some, or all, of the traditional constants of nature are actually dynamic and change slowly in space and time ([1] - [6]). Only astronomical observations can effectively probe the variability of physical dimensionless constants such as the finestructure constant α or the proton-to-electron mass ratio μ, which are related to fundamental forces of nature. At the moment of writing there are claims for a variability of both α and μ at 5 and 4 σ of confidence limits, respectively although for α they are contrasted by null results. If the variations would be confirmed, the implications are far reaching, revealing new physics beyond the standard model. The level at which possible variations are investigated today sets high demands on all steps involved to gain a better understanding of systematics and the physics behind the observed transitions.

The proton-to-electron mass ratio is measured in different energy transitions of the molecular hydrogen as found in DLA systems and proposed by Thompson [7]. Each vibro-rotational transition of the homonuclear molecule depends differently on its reduced mass. A variation of μ reflects in a correlation of the measured relative shifts of the observed line positions and the according sensitivity towards change in reduced mass. The sensitivity coefficents were refined with high accuracy by Meshkov *et al.* [11] (see Fig. 1). The method to ascertain the proton-to-electron mass ratio via molecular hydrogen has the great advantage that the accuracy of the absolute wavelength calibration has no impact on the result, since only relative observed line positions are taken into account. The specifications of COS match the requirements perfectly. Unfortunately only few systems with observed H_2 are known. The encasing DLA system normally causes a heavyly contaminated continuum. Prior observations of HE0515-4414 [8] indicate a reasonably clean spectrum with unblended H_2 features in the selected range. Some of the lower excitation levels are already identified in that work. However only high excitations of molecular hydrogen imply strong sensitivity towards variation in μ. A paper by Ivanchik *et al.* [4] indicated a possible variation of μ in the quasar spectra of Q0347-383 and Q0405-443. At the time the only data accessible to astronomy. The need to observe those absorption features in the UV restframe with ground based telescopes limited the analysis to quasars with absorption systems at a suitable redshift of about 3.

The $\mathrm{Fe}_{\mathrm{II}}$ lines in the DLA at $z = 1.1508$ have been used by Quast *et al.* [13], Levshakov *et al.* [12] and Chand *et al.* [2] to determine α-variation. An analysis of H_2 for variation of μ would render HE0515-4414 the first system to inspect both fundamental constants. For GUTs there is a direct relation between $\dot{\alpha}$ and $\dot{\mu}$: $\frac{\dot{\mu}}{\mu} \sim \frac{\dot{\Lambda}_{\mathrm{QCD}}}{\Lambda_{\mathrm{QCD}}} - \frac{\dot{v}}{v} \sim R\frac{\dot{\alpha}}{\alpha}$, and a measurement of both in the same system has not been achieved yet. For all GUTs a variation in μ is expected to be larger than α. This allows for an additional constraint. HE0515-4414 poses the sole known opportunity for such attempt.

An analysis in the intermediate redshift range will bridge the gap to laboratory experiments and allow for a spatial distinction. The new feasibility of high quality UV spectra with COS will also permit a more detailed study of the higher excitation states of molecular hydrogen. A subject of great importance. Only very recent measurements and refinements

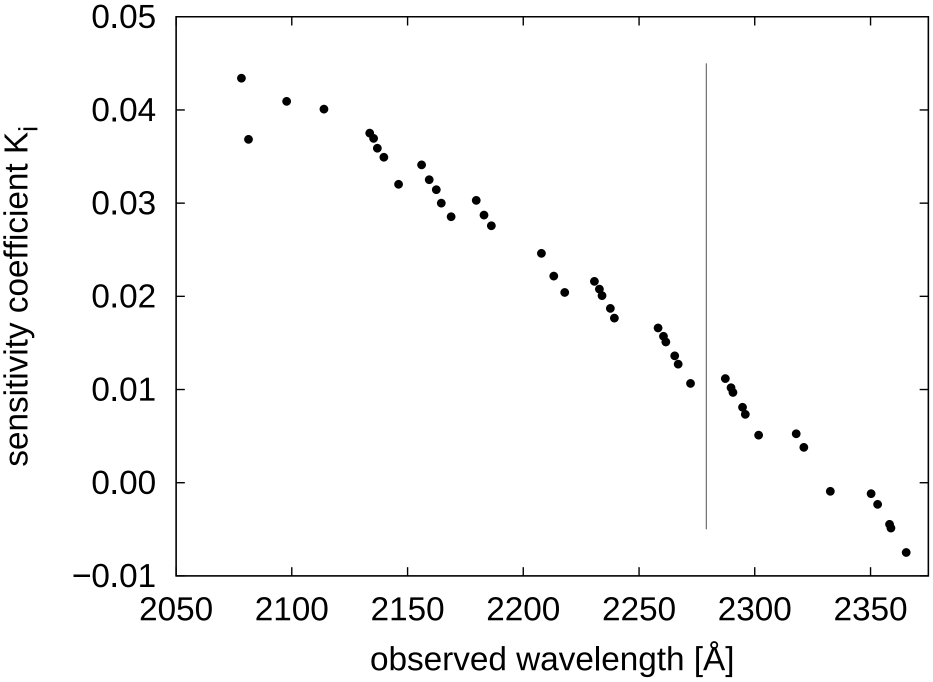

Figure 1: Sensitivity coefficients as calculated by Meshkov *et al.* [11] for the proposed wavelength range. The bar indicates the lower end of the wavelength range of earlier observations [8].

of calculations [1] of the transition wavelengths of vibro-rotational excitations of H_2 enabled the precision reached in todays analysis. The estimated accuracy of the transitions were increased by at least an order of magnitude compared to prior lists by Abgrall *et al.* [9].

Yet there remain uncertainties, since only few systems are observed with high signal to noise ratio at modest resolution. There are no suitable space based observations of H_2 transitions in the UV available (FUSE data were calibrated to H_2 features and hence were not suitable in principle) to evaluate the latest calculations appropriately. Observations with COS will extend the understanding of the higher excited states and at the same time bring forward the investigation of variability of the proton-to-electron mass ratio in adding a new main pillar at a yet unamenable redshift range.

Description of the Observations

We propose to observe HE0515-4414 in the NUV with COS. Due to the enormous brightness (V=14.9) of the quasar we expect to achieve a high signal to noise ratio at moderate exposure times. A high resolution is favored and unbinned data to be taken.

The NUV COS with the G225M grating at two wavelength setups (2217, 2250) will cover a wavelength range of 2101 to 2367 Å. We intend to reach a S/N $\sim$ 22 at a resolution of $\sim 20,000 - 24,000$. To achieve this goal the observation with the grating G225M at

2217 Å requires 14 orbits arranged in 3 visits. For the wavelength setup of 2250 Å with the same grating we require 12 orbits. The observation of HE0515-4414 requires a total of 26 orbits, including overhead for several visits.

That range contains a multitude of H_2 transitions visible in a sub-DLA system at $z_{\mathrm{abs}} = 1.1508$. The peak sensitivity of G225M agrees very well with the wavelength range of interest.

The exposure time has been estimated using the exposure simulator. The proposed obervations call exactly for the prospects of the COS NUV spectrograph. We are primed to expand the current limit on observations in this regard.

Special Requirements

Coordinated Observations

Justify Duplications

Prior observations of HE0515-4414 concentrated on the optical band mostly. The proposed wavelength range has in large parts not been observed with HST before (see Figure 1). The former observations with low signal-to-noise covered a wavelength range down to 2280 Å or transitions in H_2 up to L4R4, respectively (see Fig. 1). We expect to observe many more transitions in the proposed range from 2101 to 2367 Å, potentially up to L12P5. These higher excitated states show a stronger sensitivity towards changes in μ as can be seen in Figure 1. Such observations would allow for a direct verification of recent calculations beyond the Born Oppenheimer Approximation, since the BOA fails at higher vibrational excitation [10]. The minimal overlap of the proposed wavelength range will lead to a deeper insight of calibration errors. Furthermore the data will provide a lever to estimate the influence of different approaches in data reduction, i.e., vacuum correction, an remaining uncertainty that can only be adressed with space based observations.

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