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FUSE OBSERVATIONS OF THE He II LYα FOREST AND IMPLICATIONS FOR THE IONIZING RADIATION FIELD

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RESUMEN

Presentamos observaciones del FUSE en la banda en la banda de 100-1187Å con un poder de resolución de 15,000. Resolvemos la absorción de Lyα del H II como un bosque discreto de líneas de absorción en el intervalo de z entre 2.3 a 2.7. Aproximadamente el 50 por ciento de estas líneas tiene contrapartes en H I en los espectros del Keck. Los cocientes de densidades columnares del H II al H I están entre 1 y > 1000 con un valor promedio de 80. Su distribución es comparable a la de los índices espectrales de los cuasares sin emisión en radio. Los cocientes menores que 100 son los esperados cuando la ionizacion del gas absorbente se debe a un espectro duro proveniente de la luz integrada de los cuasares. Sin embargo, muchas líneas de absorción tienen cocientes > 100, que indican contribuciones adicionales al campo de radiación por galaxias con brotes estelares, o por radiación de cuasares altamente filtrada. Las fluctuaciones de los cocientes a escala de líneas individuales implican que el campo de radiación ionizante no es uniforme.

ABSTRACT

We present Far-Ultraviolet Spectroscopic Explorer observations of the line of sight to the quasar HE2347–4342 in the 1000–1187 Å band at a resolving power of 15,000. We resolve the He II Lyα absorption as a discrete forest of absorption lines in the redshift range 2.3 to 2.7. About 50 percent of these features have H I counterparts in Keck spectra. The He II to H I column density ratio ranges from 1 to > 1000 with an average of 80. Its distribution is comparable to the distribution of spectral indices of radio-quiet quasars. Ratios of < 100 are consistent with photoionization of the absorbing gas by a hard ionizing spectrum resulting from the integrated light of quasars. However, many absorption features show ratios of > 100 that indicate additional contributions to the ionizing radiation field from starburst galaxies or heavily filtered quasar radiation. Fluctuations in the ratio on the scale of individual features implie that the ionizing radiation field is not uniform.

Key Words: **COSMOLOGY: DIFFUSE RADIATION — COSMOLOGY: OBSERVATIONS — GALAXIES: INTERGALACTIC MEDIUM — GALAXIES: QUASARS: INDIVIDUAL (HE2347-4342) — ULTRAVIOLET: GENERAL**

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The intergalactic medium (IGM) is the gaseous reservoir that provides the raw material for the galaxies that dominate our view of the visible universe. By observing distant quasars, we can explore the IGM by examining the absorption features it imprints on the transmitted light. From the relative column densities of the various gaseous species, we can infer the processes responsible for ionizing the gas, e.g., radiation from quasars in the early universe, or from early bursts of star formation.

We observed the $z = 2.885$ quasar HE2347–4342 with *FUSE* (Kriss et al. 2001). As shown in Figure 1, our spectrum shows the transition from an optically thick Gunn-Peterson trough (Gunn & Peterson 1966) to a translucent medium at a redshift of ~ 2.7. Discrete, resolved absorption features account for most, if not all, of the opacity—we have resolved the He II absorption into a He II Lyα forest, analogous to the H I Lyα forest. By making a detailed comparison of individual He II absorption features to their counterparts in the H I Lyα forest, we can infer the shape of the ionizing spectrum illuminating the absorbing gas. The measured ratios of He II to H I column densities, $\eta = \mathrm{N(HeII)/N(HI)}$, are shown in Figure 2. An IGM photoionized by the integrated light from quasars has values of $\eta = 30 - 100$. Thus, most of the observed absorption features are consistent with photoionization by quasar radiation. Using the relationship between η and spectral index calculated by Fardal, Giroux, & Shull (1998), we calculate spectral indices for the incident radiation for each absorption feature. Figure 3 compares the distribution of inferred spectral indices to those measured for radio-quiet quasars (Telfer et al. 2002). For features with measured columns for both H I and He II, the distributions are indistinguishable. The intrinsic breadth of the spectral index distribution for individ-

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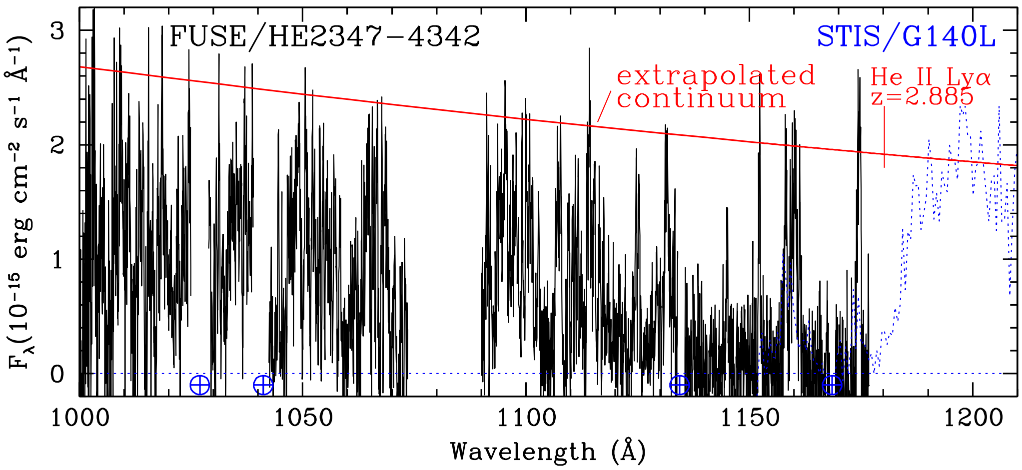

Fig. 1. *FUSE* and *HST* spectra of the $z = 2.885$ quasar HE2347–4342. Note the opaque absorption by He II Lyα at wavelengths longward of 1130 Å ($z > 2.72$), punctuated by occasional transparent windows, and the translucent He II Lyα forest at shorter wavelengths.

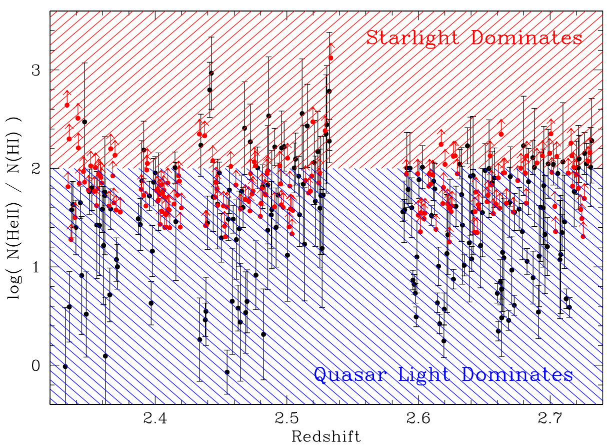

Fig. 2. Points with error bars (black) have measured He II columns from *FUSE* observations and measured H I columns from Keck spectra. Points with upward arrows (red) are lower limits computed using the He II column measured from the *FUSE* spectrum and an upper limit of $10^{12.3}$ cm^{-2} for H I absorption lines. The lower (blue) shaded area shows values of He II to H I column density ratios dominated by spectra typical of quasars. In the upper (red) shaded area, starlight makes a contribution comparable to, or greater than, that of quasars.

ual quasars naturally accounts for the large scatter in η. For features detected only in He II with no H I counterparts, the inferred spectral indices are significantly softer than the general quasar population, indicating a greater contribution from starlight or heavily filtered quasar radiation.

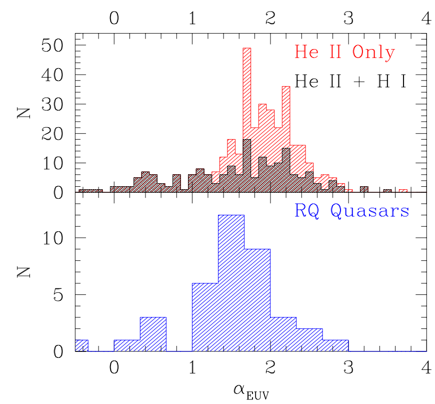

Fig. 3. Bottom panel: The distribution of extreme ultraviolet spectral indices for radio-quiet quasars (Telfer et al. 2002). Top panel: The black histogram is the distribution of spectral indices inferred for the observed ratios of He II to H I column density. This is statistically indistinguishable from the quasar distribution. The light histogram is a distribution of lower-limits to spectral indices derived from spectral features with only H I upper limits. This distribution has significantly higher spectral indices than does the quasar distribution.

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