EVOLUTION OF THE EUV BACKGROUND FROM QUASAR ABSORPTION LINE STUDIES

JILL BECHTOLD
Steward Observatory
University of Arizona
Tucson, AZ 85721

Abstract. The integrated extreme ultraviolet (EUV) radiation from quasars and other high redshift sources provides an ambient ionizing radiation field which may photoionize the gas seen as quasar absorption lines. In particular, the observed evolution of the Lyα forest clouds probably results in part from the evolution of the EUV metagalactic field. Estimates of the EUV field as a function of redshift can be made from measuring the "proximity effect" in quasar spectra; uncertainties in these estimates may be large. Given the uncertainties, the estimated EUV field at z$\approx$3 derived from the proximity effect is in reasonable agreement with the expected contribution from luminous quasars.

1. Introduction

Rees & Setti (1970) first pointed out that quasars are likely to be a significant source of hard UV photons at high redshift, and worked out estimates of how the field should evolve with redshift. Photoionization by this intergalactic field may be important in understanding the intergalactic medium (e.g. Jakobsen, these proceedings), the Lyα forest (e.g. Ikeuchi and Turner 1991; Charlton, Salpeter and Hogan 1993) and optically thin metal-line systems (e.g. Reimers 1995), and the gas in the outermost regions of the Milky Way (e.g. Savage 1995). In addition, evidence for other sources of radiation at high redshift may be implied if independent measures of the EUV field imply values larger than known sources (e.g. Bajtlik, Duncan & Ostriker 1988). The reader is referred to recent reviews of the EUV background by Bechtold (1993,1995) and Madau (1995).

M. Kafatos and Y. Kondo (eds.), Examining the Big Bang and Diffuse Background Radiations, 237–244.

2. Predicted Sources of EUV Background

The expected contribution of a population of objects to the mean ambient radiation field can be described by the specific intensity J_ν seen by an observer at redshift z, and frequency ν, and can be computed by integrating over the luminosity function of all sources at higher redshifts. Other inputs include the EUV spectrum of individual objects (since photons at higher energies are redshifted and contribute to the background at lower energies at any redshift), the cosmological parameters (q_o and H_o), and the amount and distribution of dust and gas which attenuates the EUV radiation.

Luminous quasars are likely an important source of photons (Rees & Setti 1970; Sargent *et al.* 1980; Bechtold *et al.* 1987; Miralde-Escude & Ostriker 1990; Madau 1992). Less luminous AGNs and obscured quasars may be important, particularly at low redshift (Ostriker & Heisler 1984; Wright 1986; Terasawa 1992; Fall & Pei 1993). Hot stars in high-redshift galaxies which are expected to have higher star-formation rates than present-day galaxies may contribute a substantial background, if the UV photons can leak out of the star-forming regions (Rees & Setti 1970; Tinsley 1972; Code & Welch 1982; Bechtold *et al.* 1987; Miralde-Escude & Ostriker 1990). In all cases, the effect of attenuation by intervening absorption is likely important, so that the radiation field an observer "sees" at any redshift is generated relatively locally (e.g. Madau 1995 and references therein).

Other sources have been suggested, including the decay of massive particles left over from a hot Big Bang (Cowsik 1977; DeRujula & Glaskow 1980; Kimble, Bowyer & Jakobsen 1981; Melott & Sciama 1981). Decays result in line emission, which is subsequently smeared out with redshift into a background continuum radiation field (e.g. Sciama, these proceedings). This explanation for the EUV background continues to survive observational tests (e.g. Miralde-Escude & Ostriker 1992; Sciama 1995).

3. Empirical Measures of the EUV Background

3.1. Z≈0

Even if the source of EUV photons turns off at redshift z , J_ν will decay as $(1+z)^4$ in the absence of absorption. Thus local limits on J_ν place constraints on the field at higher z.

Hα emission from 21-cm clouds gives a limit on the ionizing flux, assuming Case B recombination theory. Reynolds (1987) and Songaila, Bryant, & Cowie (1989) report detections of Hα from high velocity 21-cm clouds in the Milky Way. Such measurements are difficult since this emission is weak compared to the much brighter background of Hα emission from the warm, ionized ISM (Reynolds 1987). In addition, estimates depend on how far the high velocity clouds are above the plane of the Milky Way, and hence how important other sources of ionizing radiation such as O and B stars are. Similarly, limits can be placed on Hα emission from isolated extragalactic 21-cm clouds, which appear to be far from stars, so one expects the metagalactic field to dominate (Reynolds *et al.* 1986; Stocke *et al.* 1991; Donahue *et al.* 1994). The strongest limits so far are reported by Vogel *et al.* (1994) who observed part of the Haynes-Giovanelli cloud HI 1225+01 (Giovanelli and Haynes 1989), and derive $J_\nu < 1\text{x}10^{-22}$ erg cm^{-2} s^{-1} Hz^{-1} sr^{-1}.

The sharp cut-off in the HI disks in spiral galaxies may result from photo-ionization by the EUV background (Silk & Sunyaev 1976; Bochkarev & Sunyaev 1977). Sharp edges have been inferred from 21-cm studies of a number of galaxies (e.g. Corbelli & Schneider 1990, van Gorkom 1993, van Gorkom *et al.* 1994), and have been modeled by Maloney (1993), Charlton, Salpeter & Hogan (1993), and Dove and Shull (1994). Assuming that tidal truncation is not important, the values for J_ν are quite low, $J_\nu \approx 4\text{x}10^{-23}$ erg cm^{-2} s^{-1} Hz^{-1} sr^{-1}.

Direct measurement of the extragalactic background can be attempted just longward of the Lyman limit (e.g. Paresce 1990, Bowyer 1991, Henry 1991; Martin *et al.* 1991). These observations are difficult, and the limit on the extragalactic component depends on the large and unfortunately highly uncertain subtraction of Galactic starlight which is scattered by dust. Several speakers at this symposium discuss the complexities in the related issue of understanding the far-IR background. Hopefully progress in modeling the dust emission will help in deriving more secure limits on the EUV background as well.

3.2. RESULTS FROM THE LYMAN ALPHA FOREST

The number of Lyα forest lines near the quasar being used to measure the absorption is smaller than expected from statistics of lines with z(abs) $<<$ z(em) (Weymann, Carswell & Smith 1981; Murdoch *et al.* 1986). This so-called "proximity effect" may result from photo-ionization of the Lyα clouds by the EUV photons from the quasar itself. Given the strength of the proximity effect as a function of redshift from the quasar, one can estimate the ambient field far from the quasar (e.g. Bajtlik, Duncan & Ostriker 1988). Carswell *et al.* (1987) first pointed out that the lack of a strong effect in the z=3.78 quasar PKS 2000-33 implied that the EUV background is too large to be from quasars. Since then, estimates of the contribution from quasars have increased substantially since many high redshift quasars have been discovered (see Schmidt, these proceedings) so that the descrepency is not very large, perhaps only a factor of three. Bajtlik, Duncan & Ostriker

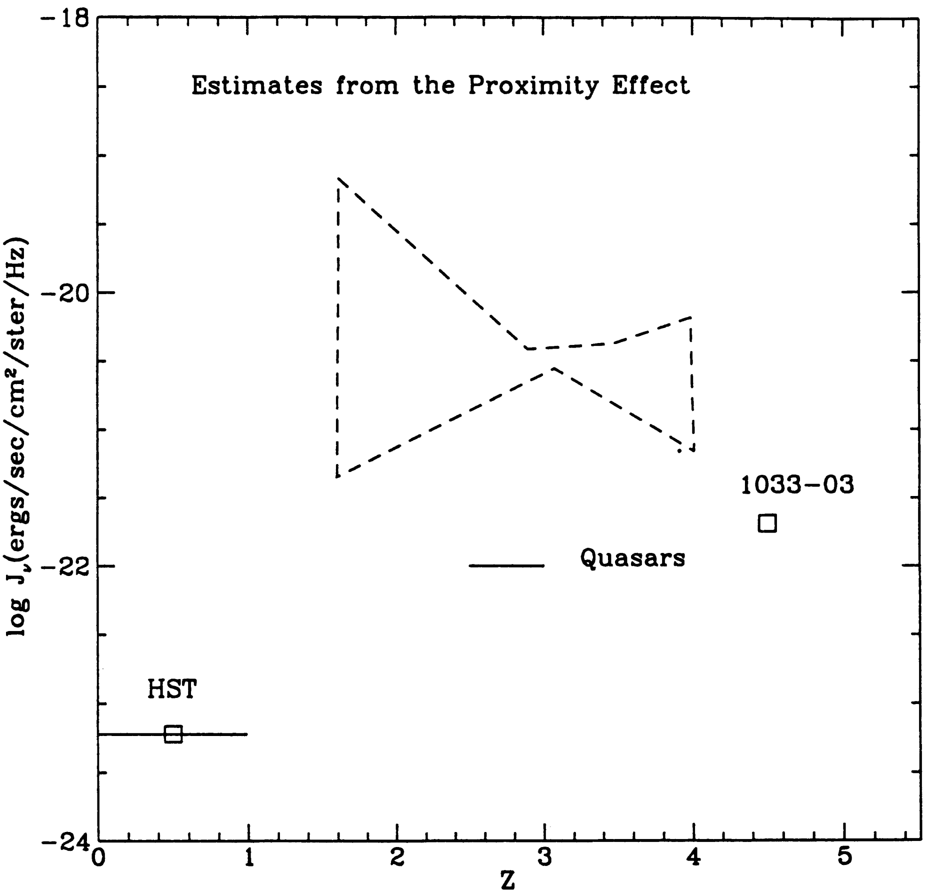

Figure 1. Estimates of the intergalactic radiation background at the Lyman limit from the proximity effect. Dashed lines shows allowed region from Bechtold (1994). HST estimate is from Kulkarni and Fall (1993), and point labeled 1033-03 is from Williger *et al.* (1994). The estimated contribution from known quasars is indicated.

(1988) have emphasized that if the proximity effect estimates are larger than the integrated background expected from quasars then another source of ionizing radiation is implied – quasars obscured by dust, or hot stars in young galaxies for example (see also Fall & Pei 1993).

The most recent estimates of the proximity effect based on optical observations of the Lyα forest (so z$\approx$1.6-4) are given by Bechtold (1994). Williger *et al.* (1994) derive a value for J_ν at higher redshift from the spectrum of one very high redshift quasar at z=4.5. At low redshift, Kulkarni & Fall (1993) used the FOS data from the quasar absorption line key project of Bahcall *et al.* (1993) to derive J_ν at z$\approx$0-1. All authors use the simply photoionization model described by Bajtlik, Duncan & Ostriker (1988).

The results are shown in Figure 1. The relatively large uncertainty at $z \sim 2$ results from the fact that there are very few quasars with published spectra in existing samples (see Bechtold 1995, Bechtold *et al.* 1995). However the general trend that the EUV field is smaller at $z \approx 0$ and $z \approx 4.5$ than at $z \approx 3$ is probably secure.

A number of sources of *systematic* uncertainties in the results of Figure 1 need also be considered. Most effects tend to imply that the background has been *overestimated* by the simple models by plausibly as much as a factor of 10 (see Bechtold 1994, 1995 for complete reviews). One interesting and ultimately tractable effect is that the redshifts of the quasars themselves are probably systematically underestimated for the high redshift objects, since they rely on redshift of Lyα and C IV emission. These lines are probably systematically shifted with respect to the narrow lines and Balmer lines, which for z=2-3 quasars are in the near-IR (Espey 1993; Bechtold 1994). The relative shift in low redshift objects can be as high as 1500 km/sec. If the quasars are really at higher redshift, then the observed Lyα forest clouds are farther away from the quasar than assumed, and the importance of the quasar radiation has been overestimated; hence the "true" J_ν is lower than derived above. Substantial advances in IR array technology recently (see Figure 2) allow the rest-frame optical emission lines of large numbers of high redshift quasars to be studied in detail for the first time. The preliminary evidence is that the shifts between Lyα and narrow [O III] may be quite substantial and vary from object to object. Overestimates of factors of 3-9 for J_ν are then implied. Within a year, a large enough sample should be in hand to sort out this effect.

4. Acknowledgements

This research was supported by NSF grant AST-9058510. Travel to the IAU was supported by an IAU travel grant, and a travel grant from the American Astronomical Society.

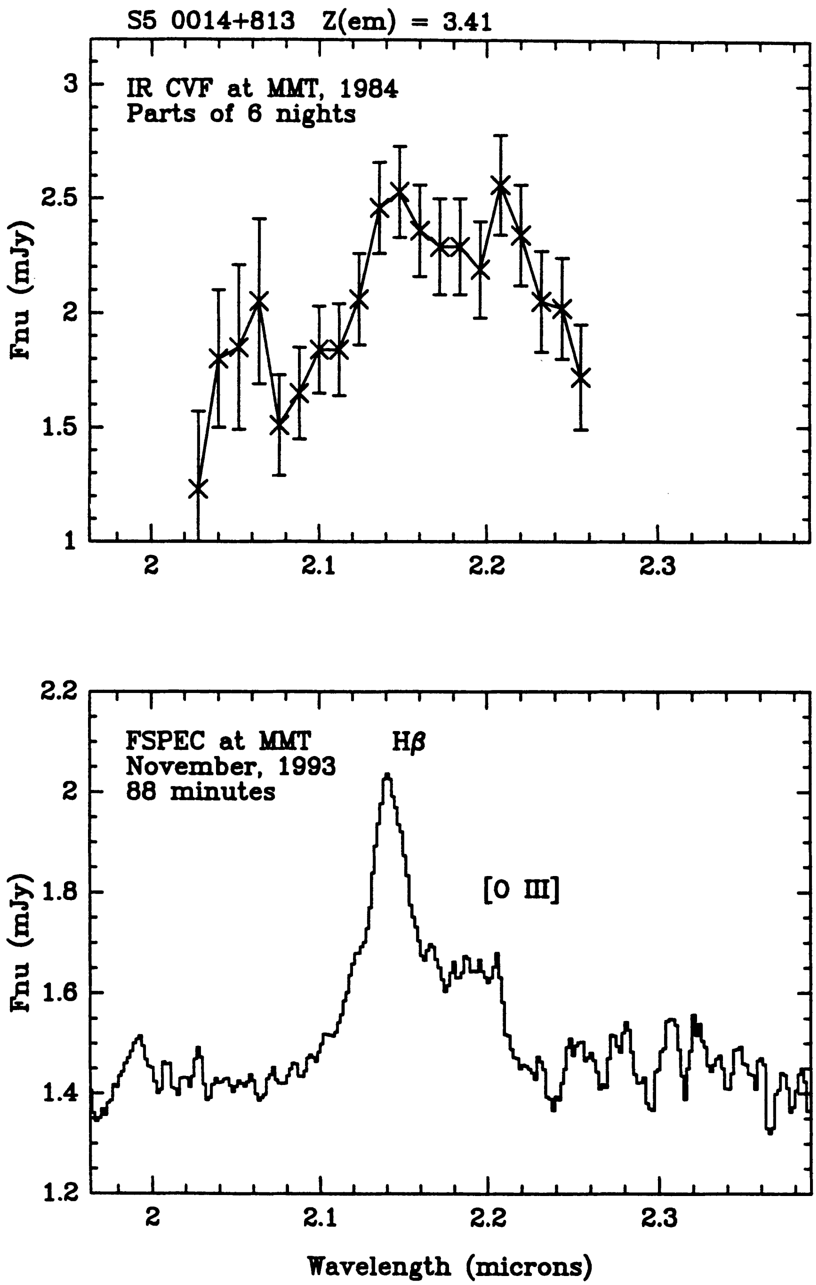

Figure 2. Spectra of the region near rest-frame H-beta and [O III] for the high-redshift quasar S5 0014+813. Top is from Kuhr *et al.* (1984); bottom is from Bechtold, Kuhn and Rieke (1995).

References

Bahcall, J.N. *et al.* (1993), *ApJS*, 87, 1.

Bajtlik, S., Duncan, R. C. and Ostriker, J. P. (1988), *ApJ*, 327, 570.

Bechtold, J. (1993), in the *Third Teton School on the Evolution of Galaxies and Their Environment*, ed. J. M. Shull and H. A. Thronson, (Dordrecht:Kluwer), p. 559.

Bechtold, J. (1994), *ApJS*, 91, 1.

Bechtold, J. (1995), in proceedings of ESO Workshop on QSO Absorption Lines, Garching, ed. G. Meylan, in preparation.

Bechtold, J., Weymann, R. J., Lin, A. and Malkan, M. (1987), *ApJ*, 315, 180.

Bechtold, J., Kuhn, O. and Rieke, M. (1995), in preparation.

Bechtold, J., Dobrzycki, A., Scott, J., Foltz, C. and Lesser, M. (1995), in preparation.

Bochkarev, N. G. and Sunyaev, R. A. (1977), *Astron.Zh.*, 54, 957; translated in *Soviet Astronomy*, 21, 542.

Bowyer, S. (1991), *ARAA*, 29, 59.

Carswell, R. F., Webb, J. K., Baldwin, J. A. and Atwood, B. (1987), *ApJ*, 319, 709.

Charlton, J. C., Salpeter, E. E., and Hogan, C. J. (1993), *ApJ*, 402, 493.

Code, A. D. and Welch, G. A. (1982), 256, 1.

Corbelli, E. and Schneider, S. E. (1990), *ApJ*, 356, 14.

Cowsik, R. (1977), *Phys. Rev. Lett.*, 39, 784.

De Rejula, A. and Glashow, S. (1980), *Phys. Rev. Lett.*, 45, 942.

Donahue, M., Aldering, G., and Stocke, J. (1994), paper 60.05 presented at May 1994 AAS meeting, Minneapolis.

Dove, J. B. and Shull, J. M. (1994), *ApJ*, 423, 196.

Espey, B. R. (1993), *ApJ*, 411, L59.

Fall, S. M. and Pei, Y. C. (1993), *ApJ*, 402, 479.

Giovanelli, R. and Haynes, M. P. (1989), *ApJ*, 346, L5.

Henry, R. C. (1991), *ARAA*, 29, 89.

Ikeuchi, S. and Turner, E. L. (1991), *ApJ*, 381, L1.

Kimble, R., Bowyer, S. and Jakobsen, P. (1981), *Phys. Rev. Lett.*, 46, 80.

Kuhr, H., McAlary, C. W., Rudy, R. J., Strittmatter, P. A. and Rieke, G. H. (1984), *ApJ*, 275 L33.

Kulkarni, V. P. and Fall, S. M. (1993), *ApJ*, 413, L63.

Madau, P. (1992), *ApJ*, 389, L1.

Madau, P. (1995), in proceedings of the ESO Workshop on QSO Absorption Lines, Garching, ed. G. Meylan, in preparation.

Maloney, P. (1992), *ApJ*, 398, L89.

Martin, C., Hurwitz, M. and Bowyer, S. (1991), *ApJ*, 379, 549.

Melott, A. L., and Sciama, D. W. (1981), *Phys. Rev. Lett.*, 46, 1369.

Miralde-Escude, J. and Ostriker, J. P. (1990), *ApJ*, 350, 1.

Miralde-Escude, J. and Ostriker, J. P. (1992), *ApJ*, 392, 15.

Murdoch, H. S., Hunstead, R. W., Pettini, M. and Blades, J. C. (1986), *ApJ*, 309, 19.

Ostriker, J. P. and Heisler, J. (1984), *ApJ*, 278, 1.

Paresce, F. (1990), in *The Galactic and Extragalactic Background Radiation*, ed. S. Bowyer, and C. Leinert, p. 307.

Rees, M. J. and Setti, G. (1979), *A&A*, 8, 410.

Reimers, D. (1995), in proceedings of the ESO Workshop on QSO Absorption Lines, Garching, ed. G. Meylan, in preparation.

Reynolds, R. J. (1987), *ApJ*, 323, 553.

Reynolds, R. J., Magee, K., Roesler, F. L., Scherb, F. and Harlander, J. (1986), *ApJ*, 309, L9.

Sargent, W. L. W., Young, P. J., Boksenberge, A. and Tytler, D. (1980), *ApJS*, 42, 41.

Savage, B. (1995), in proceedings of the ESO Workshop on QSO Absorption Lines, Garching, ed. G. Meylan, in preparation.

Sciama, D. (1995), in proceedings of the ESO Workshop on QSO Absorption Lines,

Garching, ed., G. Meylan, in preparation.
Silk, J. and Sunyaev, R. A. (1976), *Nature*, 260, 508.
Songaila, A., Bryant, W. and Cowie, L. L. (1989), *ApJ*, 345, L71.
Stocke, J. T., Case, J., Donahue, M., Shull, J. M. and Snow, T. P. (1991), *ApJ*, 374, 72.
Terasawa, N. (1992), *ApJ*, 392, L15.
Tinsley, B. M. (1972), *ApJ*, 178, 319.
van Gorkom, J. H. (1993), in *The Third Teton Conference on The Environment and Evolution of Galaxies*, ed. J. M. Shull and H. A. Thronson (Dordrecht:Kluwer), p. 343.
van Gorkom, J. H., Cornwell, T., van Albada, T. S. and Sancisi, R. (1994), in preparation.
Vogel, S. N., Weymann, R., Rauch, M. and Hamilton, T. (1994), preprint.
Weymann, R. J., Carswell, R. F. and Smith, M. G. (1981), *ARAA*, 19, 41.
Williger, G. M., Baldwin, J. A., Carswell, R. F., Cooke, A. J., Hazard, C., Irwin, M. J., McMahon, R. G., Storrie-Lombardi, L. J. (1994), *ApJ*, 428, 574.
Wright, E. L. (1986), *ApJ*, 311, 156.