From Lithium to Uranium: Elemental Tracers of Early Cosmic Evolution
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The Fe/Mg Abundance Ratio: A Diagnostic of Nucleosynthesis in the Early Universe?

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Abstract. The Fe/Mg abundance ratio may be one of the fundamental indicators for nucleosynthesis in the Early Universe. Even at the highest redshift, QSO broad-lined regions (BLRs) exhibit prominent 2000-3000Å Fe II(UV) band and Mg II 2800Å resonance doublet emission in the restframe UV. The Mg is formed in Type-II SNe, while Fe has been traditionally thought to be produced in Type Ia SNe. These different origins imply a sharp falloff in Fe abundance at very high-z. However, these predictions are clouded by uncertainties about the nature of the first stars and in the nuclear yields from supernovae models. Our theoretical studies of Fe II in QSO BLRs show that Fe and Mg abundance cannot be directly deduced from the observed Fe II(UV)/Mg II, because it is sensitive to luminosity and microturbulence, as well as abundance. Observationally, support for a luminosity dependence comes from SDSS data for QSOs that show a Fe II(UV)/Mg II correlation with luminosity at z $\sim$ 1.8–2.0.

Keywords. Quasars: emission lines, nuclear reactions, nucleosynthesis, abundances

1. Summary

QSO spectra show prominent 2000–3000Å Fe II UV band and 2800ÅMg II doublet emission up to the highest known redshift (z = 6.4). The interpretation of the Fe II(UV)/ Mg II emission ratios in QSO broad Lined Regions (BLRs) has major cosmological implications. However, just how this observed ratio varies with redshift is not clear. Also, it has been assumed that the Fe II (UV)/Mg II scales with the Fe/Mg abundance ratio. Observed Fe II(UV)/Mg II ratios show large scatter, 1 to 20, with no falloff up to z $\sim$ 6.4(Barth *et al.* 2003; Venkatesan *et al.* 2003, and references therein). If there is a Fe II(UV)/Mg II redshift dependence, it may be masked by other systematic effects.

The traditional view has been that the Mg is produced in Type II SNe from massive stars, while the Fe arises in white dwarf Type Ia SNe. Because of the timescales of these two sources, the Fe/Mg abundance ratio should decrease with increasing redshift (Hamann & Ferland 1993).

However, work by Matteucci & Recchi (2001) and Venkatesan *et al.* (2003) suggest nuclear yields from type II SNe (cf. Nomoto *et al.* 1997)and a normal IMF can explain the observed Fe II (UV)/Mg II emission ratio, without resorting to unusual IMFs (Bromm 1995) and pair-instability SNe of short-lived, massive Pop. III stars, $M_* = 140$–$260 M_\odot$ (Heger & Woosley 2002). But, recent theoretical work presented at this meeting (Arnett 2005; Maeder 2005; Nomoto 2005) suggest that rotation, mixing, and asymmetric ejection could dramatically alter predictions for nuclear yields from SNe.

We have a detailed model for Fe^+ and used it to test the input atomic data and to calculate Fe II emission in a variety of astrophysical objects (Verner *et al.* 2002),

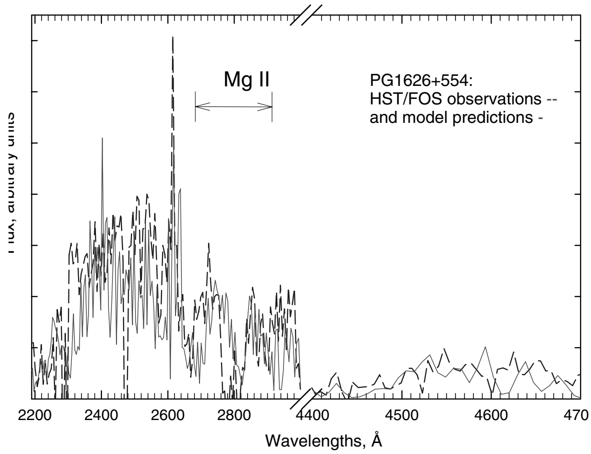

Figure 1. Fe II emission in the low-z QSO, PG1626+554 (z = 0.133). The observed and predicted Fe II flux (arbitrary units) versus wavelength, plus the approximate region affected by Mg II, are indicated.

before attempting QSO BLRs. Our current Fe^{+} model includes 830 energy levels (up to 14.06 eV) and yields emission for 344,035 lines. Our modeling of BLRs reveals that Fe II(UV)/Mg II is not only sensitive to Fe and Mg abundance, but to microturbulence and luminosity (Verner *et al.* 2003, Verner & Peterson 2004). Detailed models match the Fe II emission in the QSO PG1626+554 for adopted solar Mg and Fe abundances (Fig. 1). Improved Fe II atomic data and other enhancements promise even better fits from 1000Å to 1 μm where Fe II is seen. The reader is referred to Verner *et al.* (2002, 2003, and 2004) for more detailed descriptions of this ongoing work.

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