Absorption Line Signatures of Proto-Dwarf Galaxies

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Abstract

Recent observations suggest that many Lyα clouds may be due to gas in small halos (i.e. "proto-dwarfs"). Gas in such small halos is highly affected by the background UV radiation field. To address this issue we have developed a code that includes most of the chemical and radiative processes found in CLOUDY and incorporates multi-wavelength radiative transfer, non-equilibrium chemistry and gas dynamics. With this code we have conducted detailed simulations of the absorption line signatures of gas in proto-dwarfs. Our results suggest that the column density of CIV (at given HI column) may be suppressed relative to gas in larger objects. Additional proto-dwarf signatures may be detectable in H_2 and CII*, which we will explore in further work.

Introduction

A substantial fraction of the Lyα clouds may be due to gas in small halos corresponding to dwarf galaxies or their progenitors. At low redshifts, for example, van Gorkom et al (1996) have identified a dwarf galaxy fainter than the SMC associated with a Lyα cloud detected in the spectrum of Mrk 335. Many of the recent studies of the relationship between Lyα clouds and galaxies have found Lyα clouds with no corresponding galaxies within several Mpc (e.g., Morris et al 1993; Stocke et al 1995; Tripp et al 1998); these may be clouds affiliated with small halos too faint to be detected in the galaxy redshift surveys employed in the above studies. At high redshifts, it has long been suggested that Lyα clouds may arise in "mini-halos" that are the progenitors of dwarf galaxies (e.g., Rees 1988), and recently the theoretical work of Bond & collaborators (c.f., Bond & Wadsley 1997) has predicted that a large number of small halos with velocity dispersions of roughly 30 km s^{-1} are present at high z. By calculating the absorption line signatures of gas sitting in small halos it may be possible to specifically identify these objects and test if a substantial fraction of the Lyα absorbers are due to proto-dwarf galaxies.

Simulating Proto-dwarfs

Calculating the absorption signatures is significantly complicated by the large effect a background UV radiation field can have on gas in small halos (Kepner et al 1997). To address this issue we have developed a code that includes most of the chemical and radiative processes found in CLOUDY and also incorporates multi-wavelength radiative transfer, non-equilibrium chemistry and gas dynamics. The code computes the quasi-hydrostatic equilibrium states of gas in spherically symmetric dark matter halos (roughly corresponding to dwarf galaxies) as a function of the amplitude of the background UV field. The code integrates the full equations of radiative transfer, heating, cooling and non-equilibrium chemistry for nine species of H and He including H2, as well as C, O, Mg and Si.

For a given input spectrum (see Fig.1), as the amplitude of the UV background is decreased the gas in the core of the dwarf goes through three stages characterized by the predominance of ionized (HII), neutral (HI) and molecular (H_2) hydrogen. The last stage (H_2) marks the onset of runaway cooling and presumably star-formation. Fig.2 shows the column densities of several species for a proto-dwarf in the neutral (HI) phase.

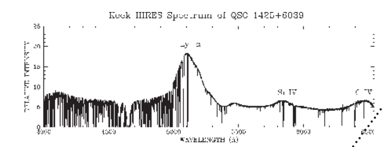


Fig.3: Observed QSO spectrum
Example of a spectrum which can searched for proto-dwarf signatures (courtesy L. Lu & W. Sargent).

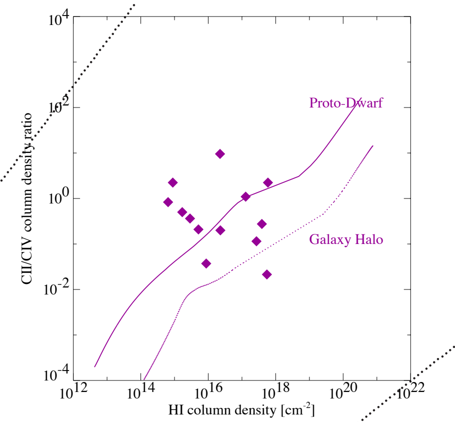


Fig.4: CII/CIV Ratios
Measured upper limits of CII/CIV column density ratios (diamonds), compared with those computed for proto-dwarfs (solid line) and gas in a galaxy halo (dashed line).

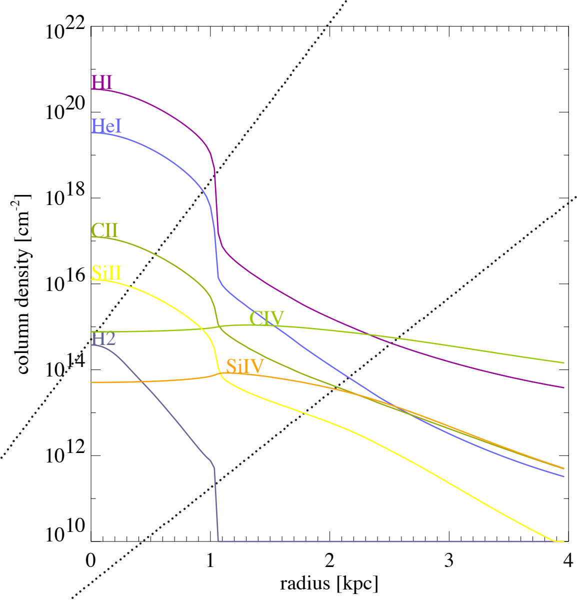


Fig.2: Proto-Dwarf Column Densities
Computed column densities for photo-heated gas in a dark matter halo with a circular velocity of 30 km s^{-1}. The sharp edge at 1 kpc is the H photoionization boundary. During this phase the proto-dwarf resembles an inverted Stromgren sphere.

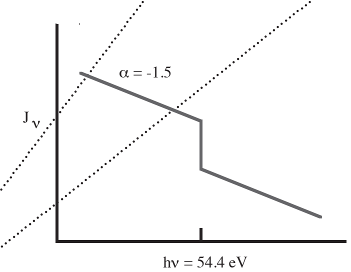
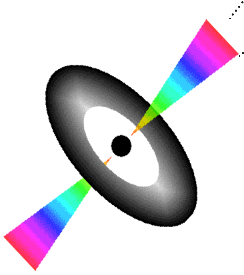


Fig.1: Background Spectrum
Shape of spectrum used to heat proto-dwarfs. Break at 54.4 eV is due to HeII absorption in the IGM.



Results and Conclusions

Because proto-dwarfs are likely to be extremely faint, it will be difficult to build up statistics on the number of Lyα clouds associated with these objects by imaging and redshift surveys, even at low redshifts. Fortunately, it is now routine to detect metals in high redshift Lyα clouds (see Fig.3), and recently Songaila & Cowie (1996) have reported that C IV is detected in 75% of Lyα clouds with N(HI) > 3×10^{14} cm^{-2}. In addition, several groups will observe low redshift quasars with the Space Telescope Imaging Spectrograph (STIS) in Cycle 7, and many of these observations will have adequate sensitivity to detect a variety of metals associated with low z Lyα clouds.

One possible signature of proto-dwarfs is the ratio of CII/CIV as a function of HI column (see Fig.4). Because CIV is suppressed in proto-dwarfs (a geometric effect due to the highly condensed state of the these objects), we see that the CII/CIV ratio will be much larger than what is predicted for the gas in the outer parts of a galaxy. The points in Fig.4 denote upper limits computed from various observations (Savaglio et al 1997; Songaila & Cowie 1996; Tripp et al 1997) and would suggest that the objects with N(HI) < 10^{16} cm^{-2} could possibly correspond to absorption in the outer parts of proto-dwarfs.

If the line of sight of the QSO passes through the ~1 kpc core of a proto-dwarf, extremely high column densities could be observed. Steidel et al (1997) have been unable to identify the damped Lyα system in the spectrum of 3C 336 despite an exhaustive galaxy redshift survey and deep HST and ground-based IR imaging. They conclude that this absorber is probably due to an object with L < 0.05 L* very close to the QSO. Observations of H_2 and CII* could provide additional evidence to test this hypothesis.

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