VLA Up-Grade Science Discussion December 4, 1998
High Column Density QSO Absorption Line Systems

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Optical studies of QSO absorption line systems preclude the highest column density systems ($N(\mathrm{HI} + \mathrm{H}_2) \geq 10^{22}$ cm^{-2}) due to dust obscuration ($\mathrm{A}_v \geq 6$, assuming a Galactic dust-to-gas ratio). These high column systems are thought to contain most of the neutral baryonic matter in the universe, and are the best tracers of the dense, (pre-) star-forming ISM in nascent galaxies. Such systems can be studied in absorption in the HI 21cm line, and in many molecular line transitions, thereby providing very detailed physical probes of the absorbing material. The major difficulty in studying these high column density absorption line systems is finding them, since optical selection is no longer applicable. To date, only four redshifted molecular absorption line systems are known, all seen toward 'red quasars', meaning flat spectrum radio sources with faint, or absent, optical counter-parts (for references, see Carilli et al. 1998).

Detecting HI 21cm and molecular absorption in high redshift galaxies opens up many new avenues to study the detailed physics of the dense ISM in high redshift galaxies, including:

- Determining the redshift distribution of high column density absorption line systems (ie. 'damped Lyα systems'), and hence the evolution of the cosmic density of neutral baryonic material, without uncertainties due to dust obscuration.
- High resolution imaging of the cloud structure and dynamics on scales ranging from parsecs to kpc, including (i) imaging the circumnuclear gas in AGN, (ii) imaging the gas in star forming disks in ultraluminous infrared galaxies (see figure 2), and (iii) imaging the ISM and large scale dynamics of gas in 'normal' galaxies at high z.
- Determining the evolution of the cosmic microwave background temperature by determining the excitation temperature of the molecular gas.
- Studying astrochemistry at high redshift, including some unique issues such as the water and molecular oxygen abundances. These molecules cannot be studied in our own galaxy with ground-based observations due to atmospheric absorption lines.
- Determining the evolution of deuterium abundances in the molecular ISM.
- Determining the evolution of basic physical constants, such as the fine structure constant and the nucleon mass.
- In the case of absorption by gravitational lenses, determining the dynamical mass of the lensing galaxy hence providing a fundamental check on gravitational lens theory.

The upgraded VLA could play a dominant role in such studies, due to the high sensitivity, high resolution imaging capability, the wide-field survey capability at low frequency, and the natural interference rejection afforded by an interferometer.

Redshifted Molecular Absorption:

The current VLA is limited to a 50 MHz bandwidth at 43 GHz with 8 spectral channels, implying a total velocity range covered of only 300 km sec^{-1}. Hence, searches for molecular absorption line systems are precluded with the current VLA due to the correlator and limited bandwidth. The upgraded VLA correlator will allow for searches for molecular absorption line systems over a large range in redshift toward faint, flat spectrum radio sources. As an example, the upgraded VLA could survey the frequency range 30 GHz to 50 GHz with a velocity resolution of 50 km sec^{-1} to a sensitivity limit of 0.5 mJy $\mathrm{channel}^{-1}$ in 48 hrs. This corresponds to the first order transition of CO at redshifts between 1.3 and 2.8, and HCN and HCO^{+} at redshifts between 0.7 and 1.9.

Redshifted HI 21cm Absorption:

A complementary experiment is a search for HI 21cm absorption line systems toward high z radio loud quasars and radio galaxies in the redshift range 0 to 0.8. This could be done toward known high z radio sources. However, the upgraded VLA correlator allows for the interesting possibility of blind surveys for redshifted HI 21cm absorption line systems over a large area and redshift range. In 300 hours, the upgraded VLA could survey the redshift range 0 to 0.8 to a 4% optical depth limit (1σ) toward 1.5 mJy background continuum sources at 30 km sec^{-1} velocity resolution, corresponding to an N(HI) limit of 2×10^{20} cm^{-2} assuming a spin temperature of 100 K. Source counts imply about 30 background radio sources with flux densities of 1.5 mJy or more at 1 GHz in a VLA primary beam ($30'$ FWHM), most of which will be at z $\geq$ 0.5. Ultraviolet studies with HST indicate about one high column density absorption system ($N \geq 10^{21}$ cm^{-2}) per unit redshift in this range. Hence we expect at least 24 systems to be detected at $\geq 5\sigma$ in such a survey. Note that this is a lower limit to the number of expected systems, due to the dust bias inherent in optical studies. Moreover, given that all the sources surveyed are within $30'$ of each other, these data could also be used to study large scale structure in the universe by studying the correlation between absorption systems as a function of redshift and source angular separation. Lastly, once an absorption system is detected, the $0.1''$ resolution of the A+ array will allow for detailed imaging of the gas distribution toward the (typically) extended background continuum radio source.

These two surveys would determine the redshift evolution of the cosmic neutral baryon density from z = 0 to 3 without the uncertainties due to dust obscuration inherent in optical studies.

Carilli, Radford, Menten, and Langston (eds) 1998, 'Highly Redshifted Radio Lines', (San Francisco: PASP)

Carilli, Wrobel, and Ulvestad 1998, AJ, 116, 1007

Downes and Solomon 1998, Ap.J., in press

Wiklind and Combes 1996, Nature, 379, 139

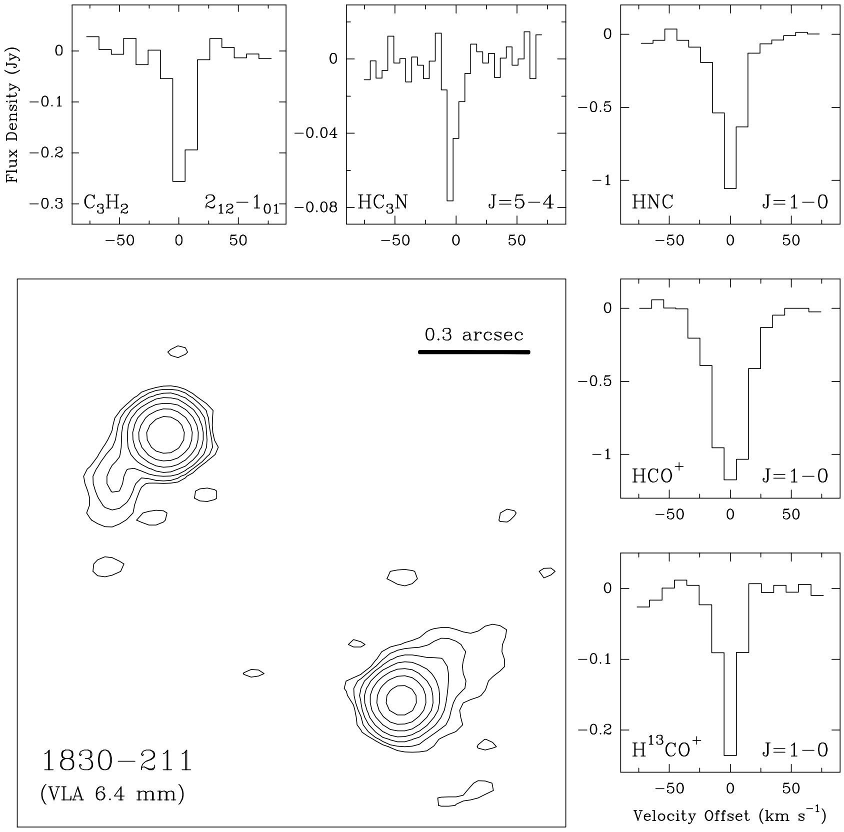


Figure 1. The contour plot shows an image of the 'Einstein ring' radio source PKS 1830-211 at 43 GHz with a resolution of 0.1″ made with the Very Large Array. The source redshift is 2.507. The spectra show molecular absorption by gas in the lensing galaxy, as observed with the Very Large Array toward the southwest radio component. Zero velocity corresponds to a heliocentric redshift of 0.88582.

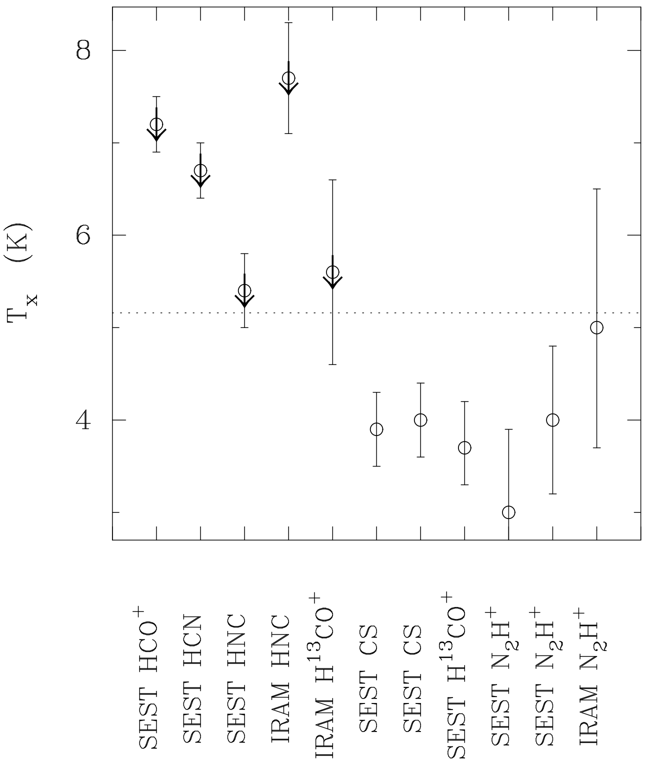
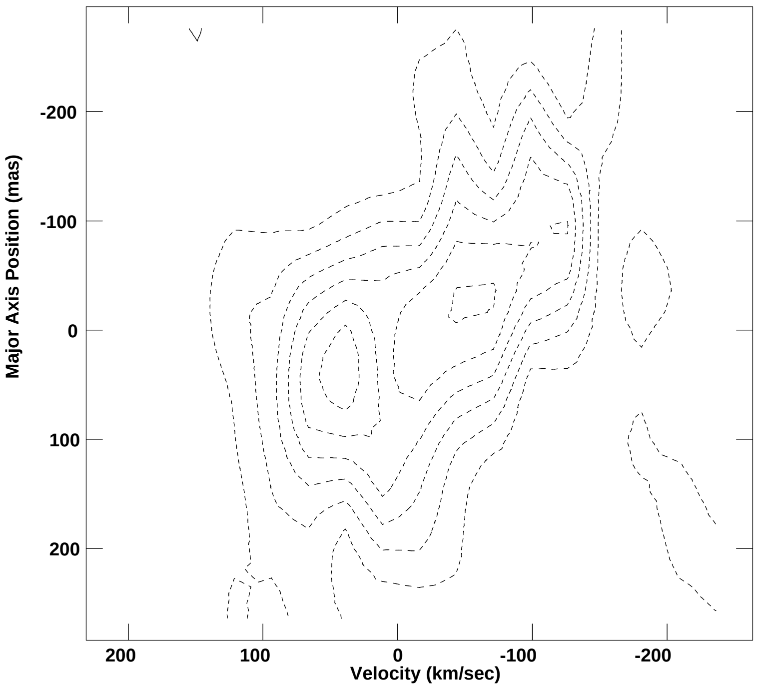


Figure 2. Measure of the excitation temperatures for several molecules shown in abcissa, from two of their rotational transitions. When the lower transition is optically thick, only an upper limit is derived. The horizontal dash line is the cosmic background temperature expected from the big-bang at the redshift of the absorber for PKS1830-211, i.e. $z = 0.88582$ (Wiklind and Combes 1996).

Figure 3. The lower plot shows the position-velocity diagram for CO(2-1) emission along the major axis of the star forming disk in the ultraluminous infrared galaxy Mrk 231 at $z = 0.042$ (Downes and Solomon 1998), with a resolution of $0.5''$. The upper plot shows the same position-velocity diagram, but now for HI 21cm absorption at a spatial resolution of $0.15''$ made with the combined VLA + VLBA (Carilli et al. 1998). The velocity gradient implies an a gravitational mass enclosed within a 50 h^{-1} pc radius of 3×10^8 h^{-1} $M_\odot$.



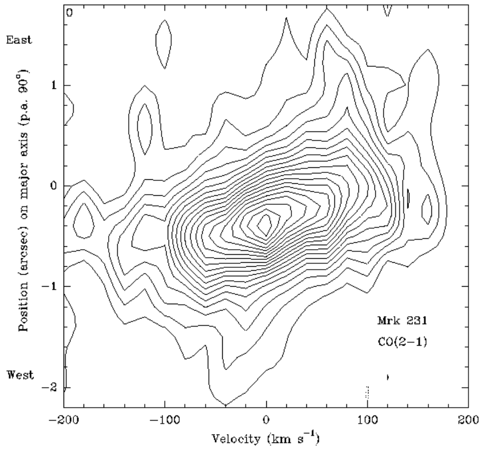


Fig. 7.— **Mrk 231 :** CO(2–1) position-velocity diagram along the line of nodes (p.a. 90°). Contour levels are 1 to 19, in units of 20 mJy beam^{-1}, with $T_b/S = 75$ K/Jy. Beam $= 0''.7 \times 0''.5$. The (0,0) position is $12^{\rm h}56^{\rm m}14.^{\rm s}260$, $56°52'25.''13$ (J2000). Velocity is relative to 221.204 GHz ($cz_{\rm lsr} = 12650\,{\rm km\,s^{-1}}$). The continuum source has been subtracted from the CO data.