Molecular Absorption measurements in high-z objects

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Molecular Absorptions

Up to now, only 5 systems: PKS1413, B3 1504 (self-abs) B0218, PKS1830, PMN J0134 (OH): gravit lenses + local: CenA, 3C293 (0.045), 4C 31.04 (0.06)

Depend mainly on the background source ~ 30-100 times more sources with ALMA?

Combes & Wiklind 1998
Scientific goals

1. Detection of molecules at high $z$
   much more sensitivity (1 $M_\odot$) and complementary to emission

2. Evolution of chemical abundances
   not only CO, but a molecular survey possible

3. Measure of Hubble constant (gravitational lenses), $T_{CMB}$

4. Variation of constants ($\alpha$, $g_p$, $\mu = m_e/m_p$)
   Superstrings, Kaluza-Klein, compactified extra-dimensions
   Predict spatio-temporal variations

Local absorptions: 3C293

Morganti et al 2003:
1400km/s-wide HI absorption blue-shifted

Evans et al 1999 (OVRO)

3C293, PdB, 1mm continuum
Garcia-Burillo et al 2006

Warped disk in CO
Redirect the jet?
Interaction between the jet and ISM produces the HI outflow
Molecular gas seen in front of jet
Garcia-Burillo et al 2006

CO(2-1) : colours
HCO+ : contours
3C293

CO(2-1) Emission and abs
PV diagram showing HCO+ abs in front of the jet
HCO+(1-0) in emission: contours and in absorption (colours)
Higher redshift absorptions

First system towards the BLLac object **PKS1413+135** (Wilkind & Combes 94) after many unfruitful searches towards DLAs

Since then, 5 systems are known, but remain rare
Three of them are **gravitationally lensed objects**
PKS1830-211 and B0218+357, PMN J0134

Redshifts range up to z~1 (the QSO at z~2), **difficult to find higher redshifts QSO, that are strong enough in the mm (steep spectrum)**

**K-correction is against us!** The QSO radio emission decreases with $\nu$ (up to now, flat-spectrum sources..)

→ **We should follow the redshift of the radio continuum to cm $\lambda$**
Selection of candidates, for the IRAM study:

-- Strong mm source (0.15 Jy at 3mm) only 100-200

-- already an absorption detected in HI-21cm, or DLAs, or MgII or CaII

-- absence of previous absorption, but known gravitational lens (VLBI) (Webster et al 95, Stickel & Kuhr 93)

-- same as above, without any known redshift: the case of PKS1830-211

  The redshift was discovered in the mm sweeping of the band (14 GHz = 14 tuning, and already 2 lines)

--sources where the redshift searched is that of the QSO

Mostly negative results!
PKS1413+135 $z=0.247$

Very narrow absorption $< 1$ km/s (2 comp) 
BlLac, very variable, also in radio

optically thick, $N(\text{H}_2) > 10^{22}$ cm$^{-2}$, $A_v > 30$ mag

McHardy et al 94
B3 1504+377 \( z = 0.672 \)

7 different molecular lines
Large separation 330 km/s
nuclear ring + spiral arm

\[ \text{HNC/HCN} \Rightarrow T_{\text{kin}} = T_{\text{ex}} \]

HCO+ enhanced by 10-100
diffuse medium + clumps
B0218+357 \( z = 0.685 \)

Gravitational lens (A and B + ring)
The largest column density \( 10^{24}\text{cm}^{-2} \)

Two images separation 335mas (1.8kpc)

All three CO isotopes are optically thick

Search for \( \text{O}_2 \) without atmospheric absorption

Lines at 368 and 424 GHz

\( \text{O}_2/\text{CO} < 2 \times 10^{-3} \) (Combes et al 97)

most of O in OI??
Two images A and B, separated by HST (335mas)
Browne et al 1997

CLASS and JVAS survey (VLA, MERLIN..)
VLBI structure of B0218+357

A-component

Extended radio jet component
+ 2 bright cores
A tangentially stretched

B-component

Biggs et al 2003
8.4 GHz, 1mas beam
H$_2$O detection at 557 GHz, very large $\tau = 40,000$

H$_2$O ubiquitous and cold
$T=10-15$ K
$H_2O/H_2 = 10^{-5}$

NH$_3$ detection at 2cm
Henkel et al 2005
B0218+357

Images A and B, separated by HST. The distance between the 2 images is 317mas in optical, while 335mas in radio (due to extinction).

The lens is almost face-on. Spiral arms complicates the lens analysis.

H₀ = 70 km/s/Mpc if spiral arms are taken into account (61 km/s/Mpc if masked out)

York et al (2005)
2 V-comp, covering each A or B
PdB  (Wiklind & Combes 1998)

Slight temporal variability

PKS1830-211 $z=0.88582$

Frye et al 97
Monitoring, measure of $H_0$

The single dish (without resolving the 2 images) can follow the intensity of the two, since they are absorbing at two V

Monitoring during 3 years (1h per week)

$\Rightarrow$ delay of $24 \pm 5$ days, $H_0 = 69 \pm 12$ km/s/Mpc
Evolution of chemical conditions?

There does not seem to be variations versus $z=0$ (open circles) but large scatter, even at $z=0$ (Lucas & Liszt 94, 06)

Upper limits **deuterated mol** Shah et al 1999
CO(4-3) detection, upper limit CI, Gerin et al 1997
Measure of Tcmb (z)

Low excitation (diffuse gas)
Tex \sim Tcmb

The case for PKS1830-211

Several transitions give the same result (slightly lower, due to a microlens)

From UV H_2 lines
Srianand et al 2000
Reimers et al 2003
Cui et al 2005
PKS1830-211, PDB survey

Low $^{14}$N/$^{15}$N, young stars

Muller et al 2006, low $^{17}$O/$^{18}$O,
PMN J0134-0931

$z=0.7645$ lens in front of the QSO $z=2.22$ (6 images)

HI and OH detected at GBT: Kanekar et al 2005

$\Rightarrow$ Variations of constants
Absorption in radio

Variations of $\gamma = \alpha^2 \, g_p \, \mu$ with $\mu = m_e/m_p$

HI 21cm hyperfine ratio $\sim \mu_p \, \mu_B / h \, a^3$  $a =$ Bohr radius $= h^2/m_e \, e^2$

$\mu_p = g_p \, e \, h / 4m_p \, c$  $\mu_B = eh/2mc$

CO rotation lines $\sim h / (M \, a^2)$  $M$ reduced mass

In fact variations of $\alpha^2 \, g_p$

as variations of $M/m_p$ are suppressed by a factor $m_p/U \sim 100$

Advantages: heterodyne techniques  spectral resolution of $10^6$

Cold gas $\rightarrow$ narrow lines

From Alkali Doublet (AD) CIV, SiII, SiIV, MgII, AlIII...

$\Delta \alpha/\alpha = (-0.6\pm0.15) \times 10^{-5}$

Webb et al 2001
Murphy et al 2003
8 QSO lines of sight
22 systems
Voigt profiles fits
Variation of $\alpha$

For PKS1413, a resolution of 40m/s is required to resolve the lines!

Results:

$\Delta y/y = (-0.16 \pm 0.36) \times 10^{-5}$ for B0218

$\Delta y/y = (-0.20 \pm 0.20) \times 10^{-5}$ for PKS1413

→ precision comparable to the MM method, without detection

Problems of kinematical bias?

Tests at low redshift:
Absorptions of HI and HCO+ in our own Galaxy in front of remote quasars (Lucas & Liszt 1998)
Dispersion of only 1.2km/s
Corresponding to $\Delta y/y = 0.4 \times 10^{-5}$
PMN J0134-0931 + B0218+357

\[ F = g_p \left[ \frac{\alpha^2}{\mu} \right]^{1.57} \]

\[ \Delta F/F = (0.44 \pm 0.36_{\text{stat}} \pm 1.0_{\text{syst}}) \times 10^{-5} \text{ for } 0 < z < 0.7 \]

\[ \Rightarrow \text{No evolution} \]

Sensitivity at 2\(\sigma\) of \(\Delta \alpha/\alpha \sim 6.7 \times 10^{-6}\)

\(\Delta \mu/\mu \sim 1.4 \times 10^{-5}\) over half of the age of the universe

Conjugate emission/absorption of the 4 OH lines

The pumping mechanism guarantees that the gas is the same (no problem of kinematical dispersion)

OH-18cm detected with GBT

No HCO+(2-1) with IRAM (3mm)

No 6cm H2CO with ATCA, No 2cm with VLA

Kanekar et al (2005)
Local tests: open symbols
QSO absorptions: filled symbols
Olive et al (2002) meteorites in solar system
Conclusions on variations of constants

--Method AD (22 systems) and MM (many multiplet) 143 systems
\[ \Delta \alpha/\alpha = (-0.5 \pm 1.2) \times 10^{-5} \] (Murphy et al 2003)

\[ \Delta \alpha/\alpha = (-0.06 \pm 0.06) \times 10^{-5} \]

--Method Radio \[ \Delta y/y = (-0.20 \pm 0.4) \times 10^{-5} \] for PKS1413 & B0218

\[ \Delta \alpha/\alpha = (0.05 \pm 0.24) \times 10^{-5} \]


Find many other sources with ALMA
Why so few radio absorbers?

5 in molecules (one only OH), and 50 in HI-21cm ($z>0.1$)

**Circles:** $\text{H}_2$ absorption in DLA

**Stars:** molecular absorptions (mm +OH)

**Curran et al (2006)**
13 sources searched
Only 1 HI-21cm detection (+ tentative OH)

**Future:** search for other DLA (~100) and sub-DLA systems

$\text{H}_2$ detected in 10% of DLA, have a very low $f_{\text{H}_2} \times 10^{-6}$

$f_{\text{H}_2}$ could be higher in sub-DLA, as well as metals (Khare et al 2006, Kulkarni et al 2006)
Typical projects with ALMA (DRSP)

1 ➞ **Molecular survey** PKS1413, PKS1830, CenA, 7 priority bands, (wide), resolution 1-4km/s

2 ➞ **Search new systems:**
- towards 60 selected radio loud AGNs with mm cont flux > 50mJy
- **Criteria:** obscuration, gravitational lensing, suppressed soft X-ray flux
- Search over the entire redshift range using the technique of frequency scanning.
Density of radio quasars (Parkes flat-spectrum, 878 sources)
Optical quasars follow the same curve very similar to star formation history

Flat-spectrum= beamed BLLac, QSO..

z-cutoff, Shaver et al (1996)

Wall et al (2005)
Prospectives

**Number of sources:** at low and high z, depends on the N(S) curve, in particular flat spectrum (compact, young AGN)

⇒ 1 or 2 orders of magnitude

Weakened by the non-favorable K-correction

⇒ Could be interesting to search 3mm systems at cm wavelengths, with Band 1 and 2 in the future.