Absorption studies of high redshift galaxies

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NCRA/TIFR

Briggs, de Bruyn, Vermuelen A&A 373, 113 (2001)

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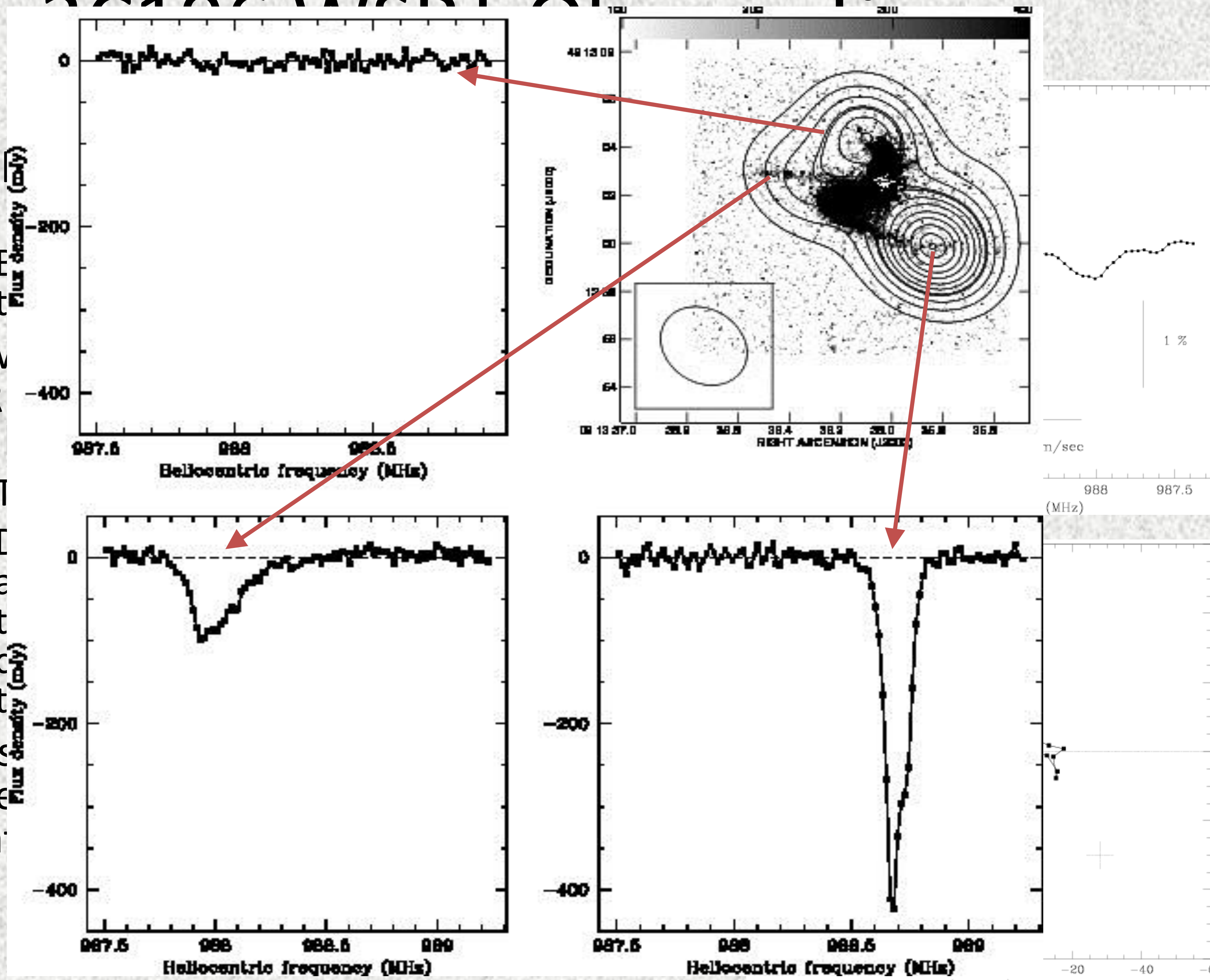
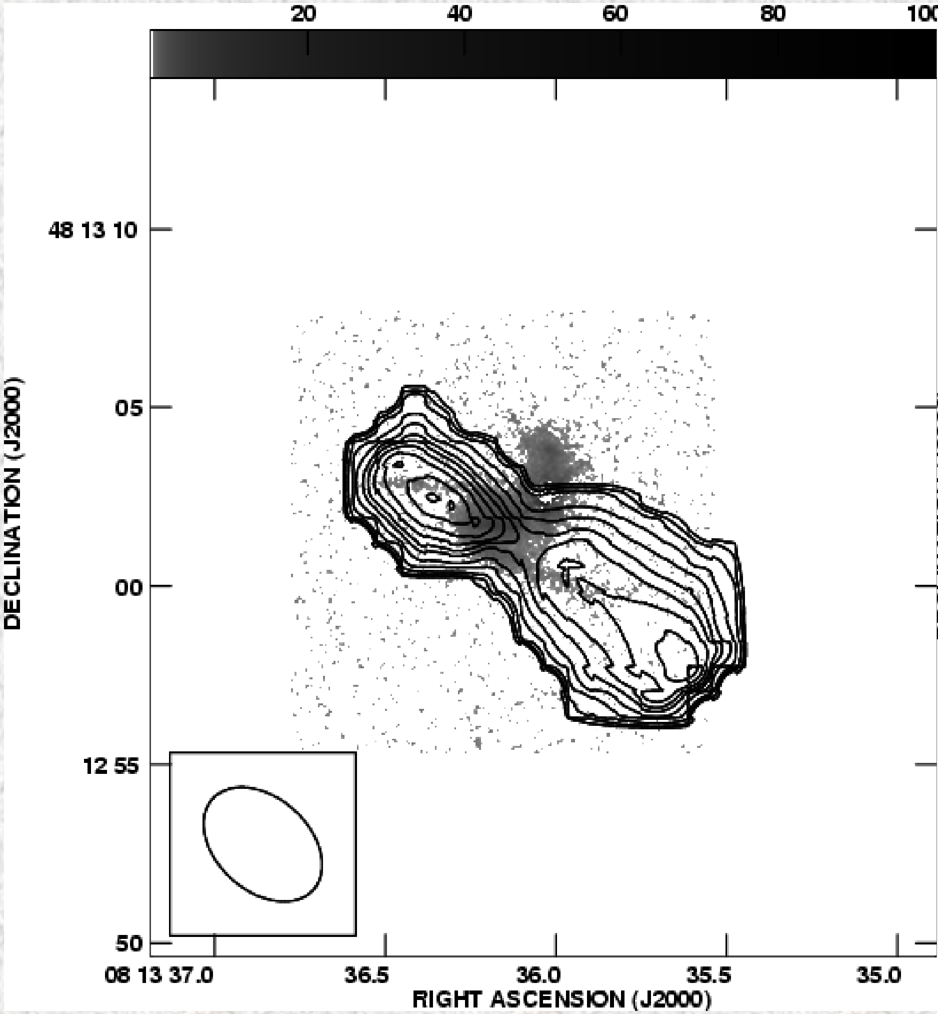
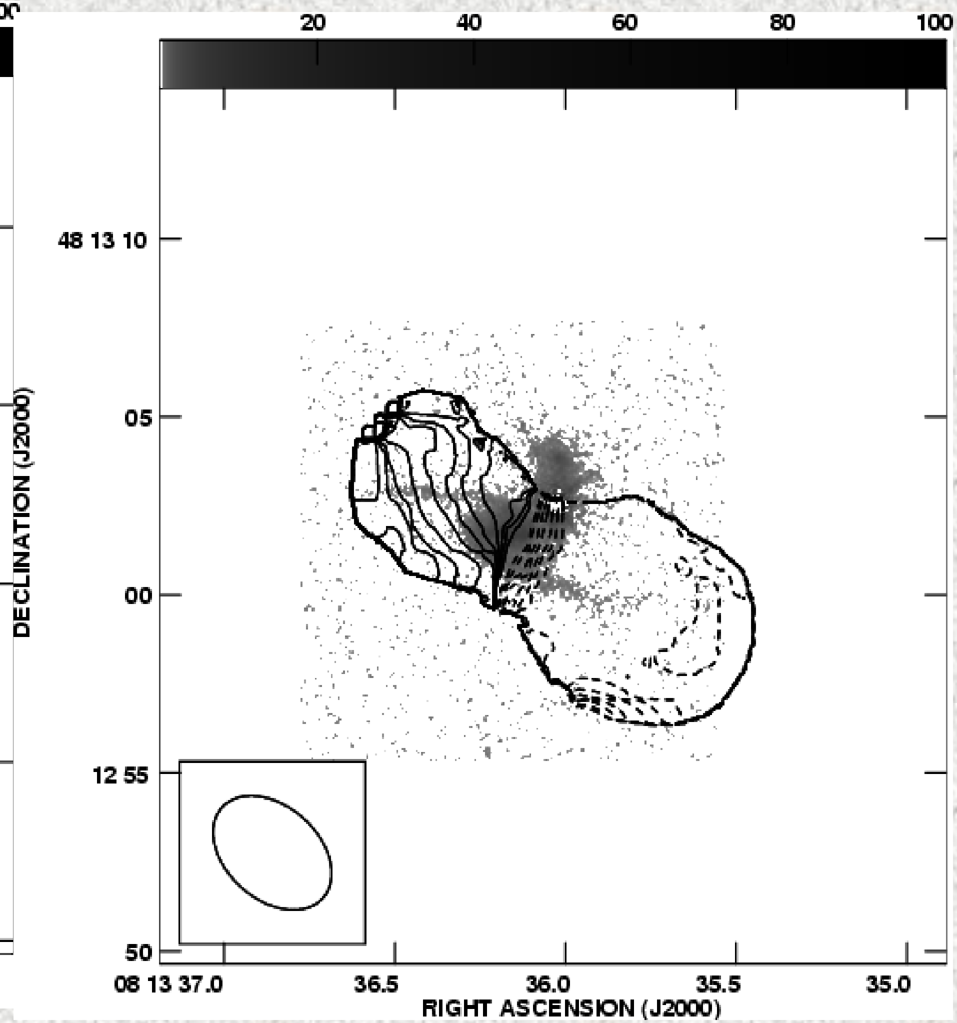


Mapping a $z \sim 0.437$ absorber

Integrated optical depth



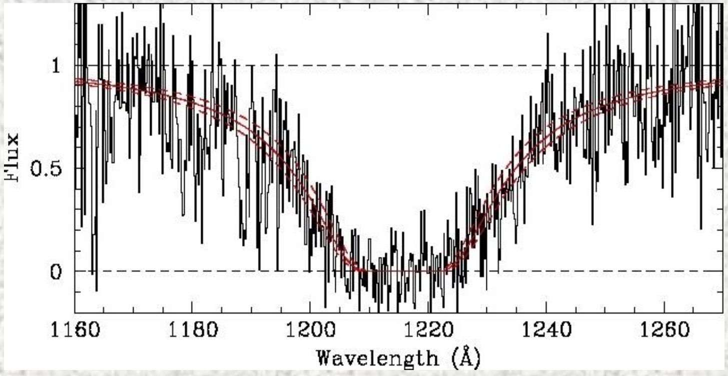
Velocity field



(Kanekar & Chengalur, some day)

HI absorption towards DLAs

- The 21cm absorber towards 3C196 was discovered by Brown & Mitchel (1983) via a blind search using the NRAO 300ft dish.
  - Most subsequent sources of 21cm absorption have been found by searching for absorption towards known Damped Lyman-α Absorbers (DLAs)
- At an HI column density of $\sim 2\ \times 10^{20}$ the bulk of the gas is neutral
  - The optical depth in Ly-α for gas with such high column densities is very high, even in the Lorenzian wings of the lines
- Such gas produces a wide Ly-α absorption, which can be easily detected using ground based optical spectra
  - For z ≥ 1.6 (i.e. at redshifts where the Ly-α line shifts into the optical band)

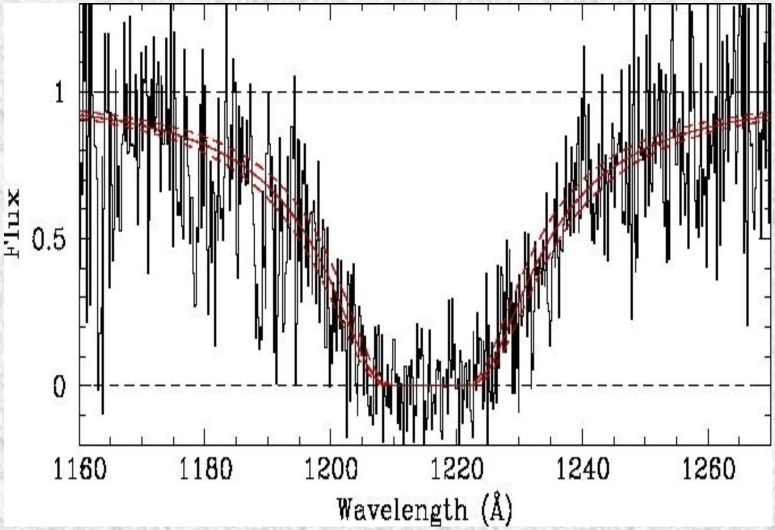


Radio Observations and the Spin Temperature

- The HI column density can be estimated from the width of the Ly-α line

- If the background quasar is radio loud, then τ_{21}, the HI 21cm optical depth can also be determined

- $N_{HI} = 1.823 \times 10^{18} \frac{T_s}{f} \int \tau_{21}(\mathrm{v})\, \mathrm{dv}$
  - Where *f* is the covering factor and T_s is the "spin temperature"



The Spin Temperature

- In the general case of an inhomogeneous multi-phase absorber T_S is the column density weighted harmonic mean of the spin temperatures of each phase
  - True for both optically thick and optically thin absorbers

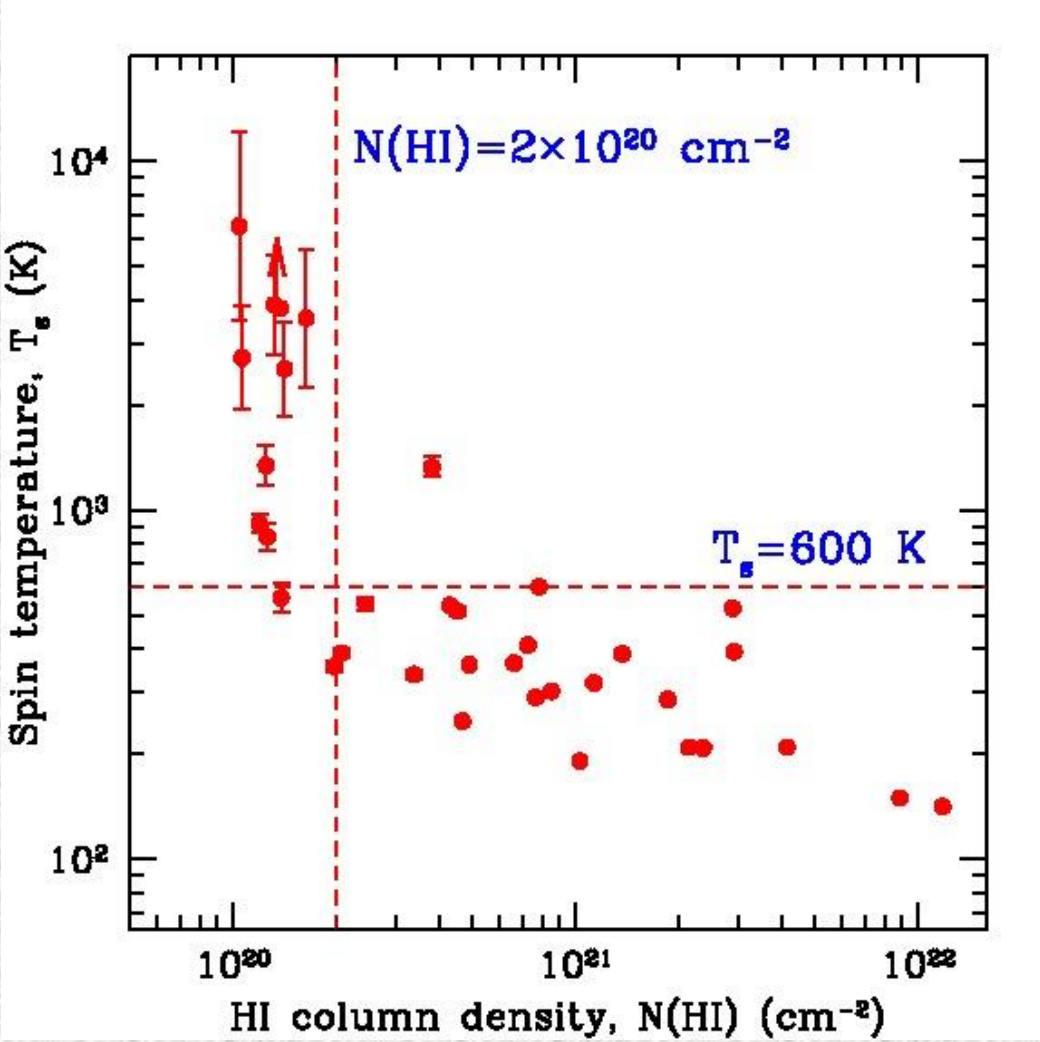
- For e.g
  - 50% CNM (80K) 50 % WNM (6000K) $T_S \approx 158$ K
  - 10% CNM (80K) 90 % WNM (6000K) $T_S \approx 715$ K

- T_S carries information on the distribution of gas in different phases

Kanekar et al. ApJL (2011)

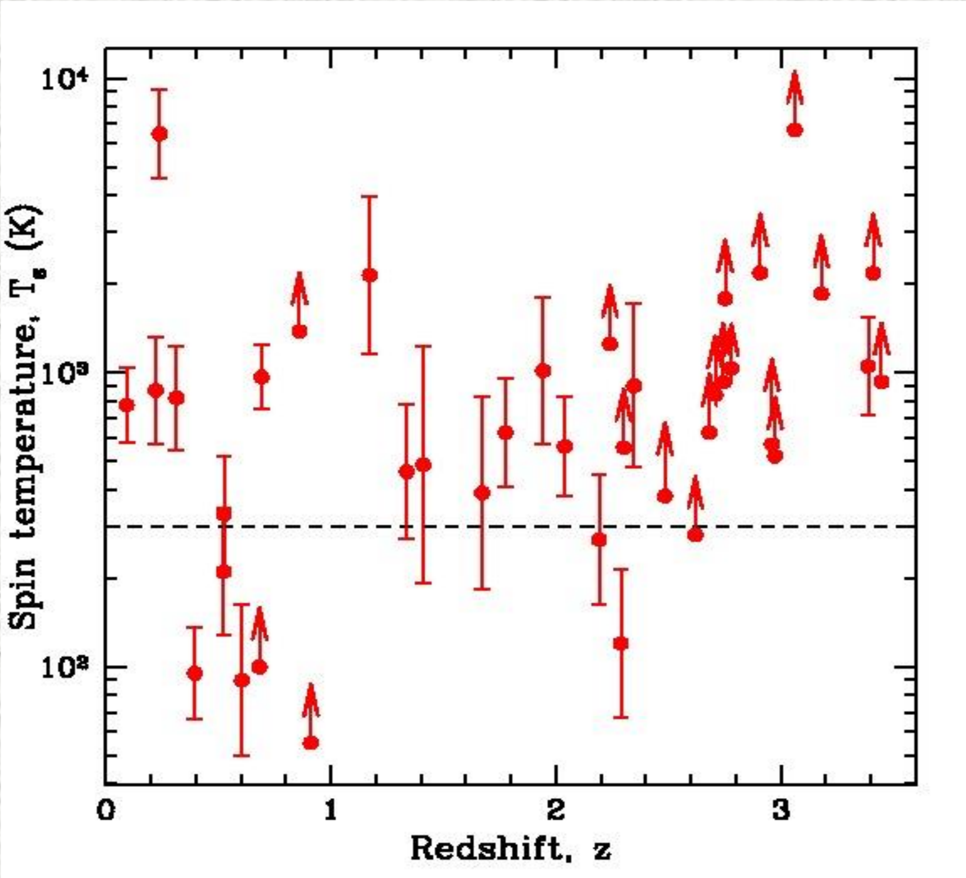
T_s in the Milky Way

- Low values of T_S (≈ 250K) are typical of lines of sight with $N_{HI} \geq 10^{20}$
- Indicative of a threshold for the formation of the CNM
  - Related to providing adequate self shielding to UV radiation?



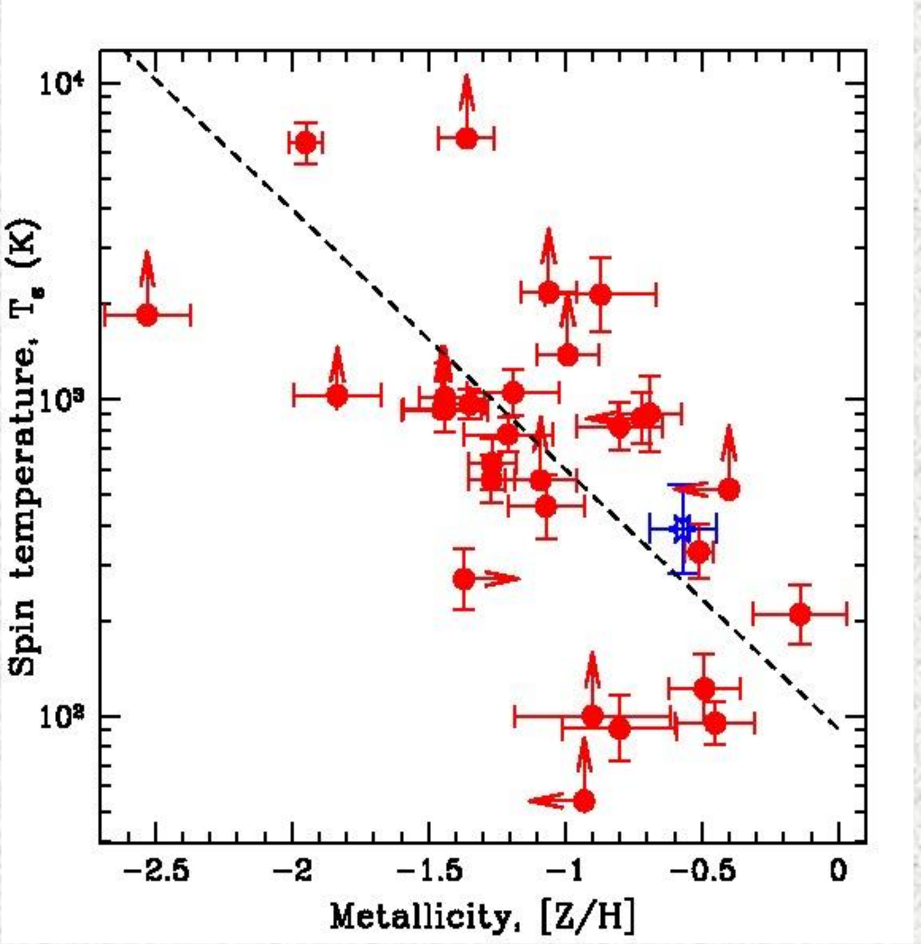
T_s in DLAS

- T_s estimates are now available for 37 DLAs
  - DLAs at z > 2 typically have T_S upper limits ≈ 1000 K
- 4.2σ evidence for a redshift evolution of T_S in DLAs
  - T_S in DLAs and the galaxies differ at a 6σ significance



T_s and Metallicity

Kanekar et al (2013MNRAS (submitted)



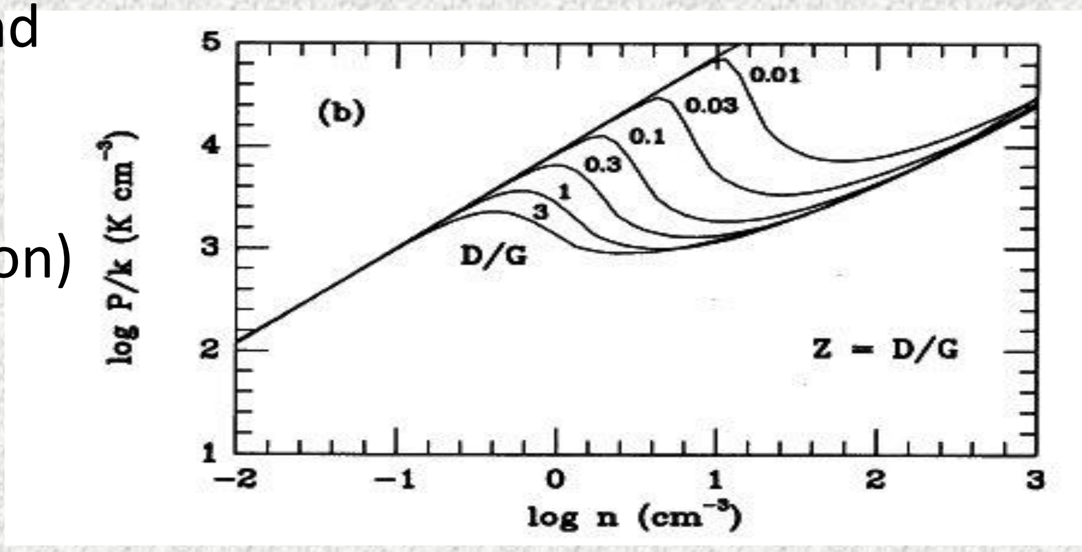
- Metallicity ([Z/H]) estimates are available for 29 DLAs for which T_s has been measured
- Non parametric Kendall-tau test indicates a 3.5σ significance for the anti-correlation between T_S and [Z/H]

Implications of high Ts for the DLA host galaxies

- In two phase models one expects a smaller CNM fraction at low pressures and low metallicities

- High T_S (i.e. low CNM fraction) in high redshift DLAs is consistent with models in which the hosts are small, metal poor galaxies

(Wolfire et al. 1995, ApJ)



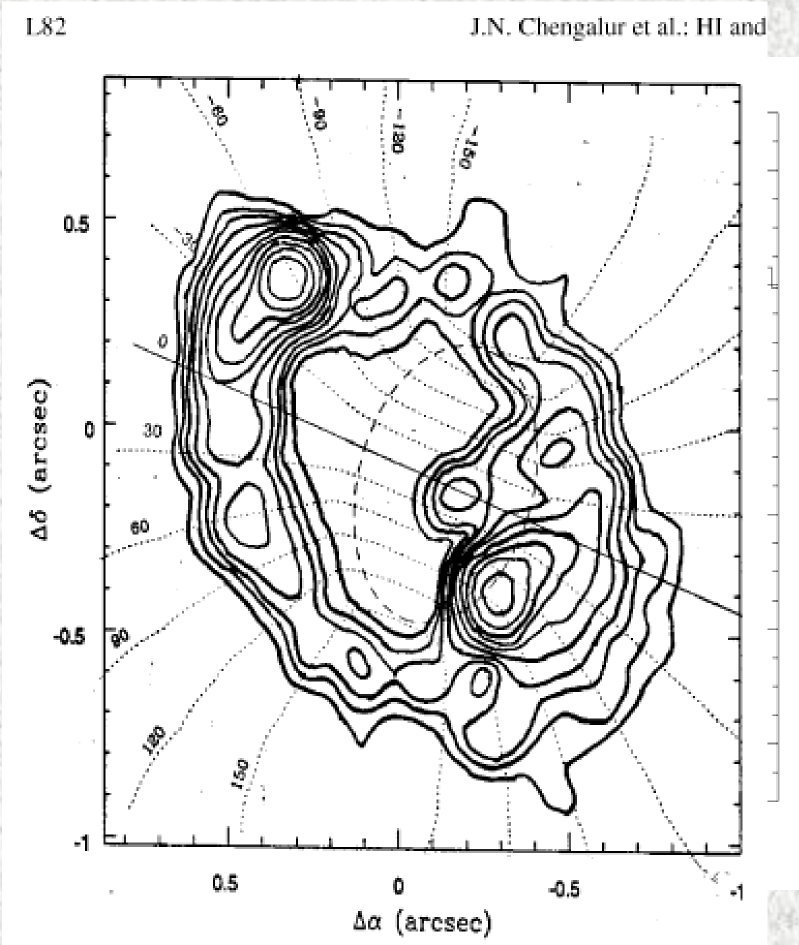
Chengalur & Kanekar 1999, MNRAS

Do the fundamental constants vary?

Chengalur, de Bruyn, Narasimha A&A (1999)

OH Absorption at z ~ 0.89

- HI and OH detected in absorption in the gravitational lens at z ~ 0.89 towards PKS 1830-21
- First detection of OH at cosmological distances
  - Both main lines seen in absorption
- HI and OH absorption was used to construct a kinematical model of the galaxy



Fundamental Constants

- Theories such as GR, the Standard Model etc. have some free parameters, e.g.
  - c,ħ,G, etc.
- The values of these parameters (“fundamental constants”) are determined from observations
- It is assumed that the values of these constants do not vary with time
- A check for the constancy of these models is hence a check of the fundamental correctness of the theory
  - Similar to tests for violation of the equivalence principle etc.

Dimensionless Constants

- Tests generally involve dimensionless constants

- Units themselves are defined in terms of these constants
  - working with dimensionless combinations avoids confusion

- e.g.

  $\alpha = e^2/\hbar c$
  - measure of the "strength" of electromagnetic interaction
  - Frequency atomic spectral lines depends on the value of α

  $\mu = m_e/m_p$
  - Frequency of rotational transitions in molecules depends on μ

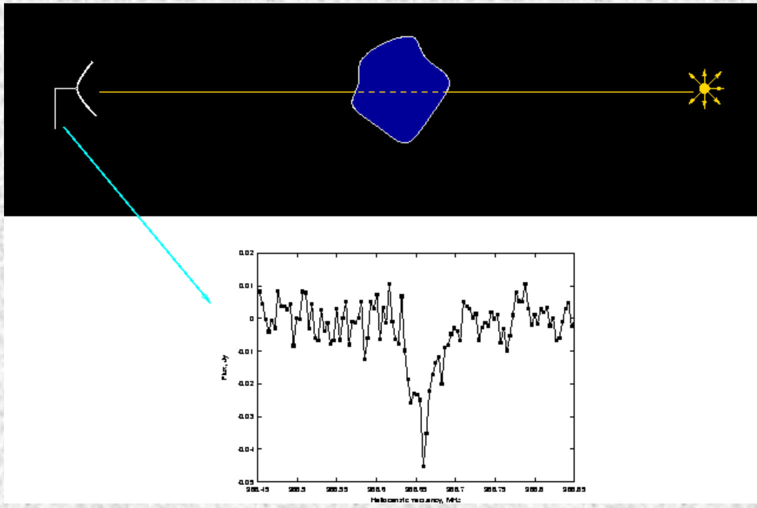
Astrophysical methods

- Compare the observed line frequency to the expected one
  - Difference implies variation in the value of the fundamental constant

- Observed line frequency depends on the (*unknown!*) redshift

- One needs to observe at least two lines
  - One to determine the redshift
  - the other to measure any possible change.
  - Lines have to have different dependence on the fundamental constants

- Narrow absorption lines from cold gas are best suited for precise frequency (redshift) measurements.



Optical Spectral Lines

- The fractional separation between the alkali doublet (e.g. Si IV, MgII) lines $\Delta\lambda/\lambda \sim \alpha^2$

(e.g. Murphy et al. MNRAS, 327, 1237, 2001)

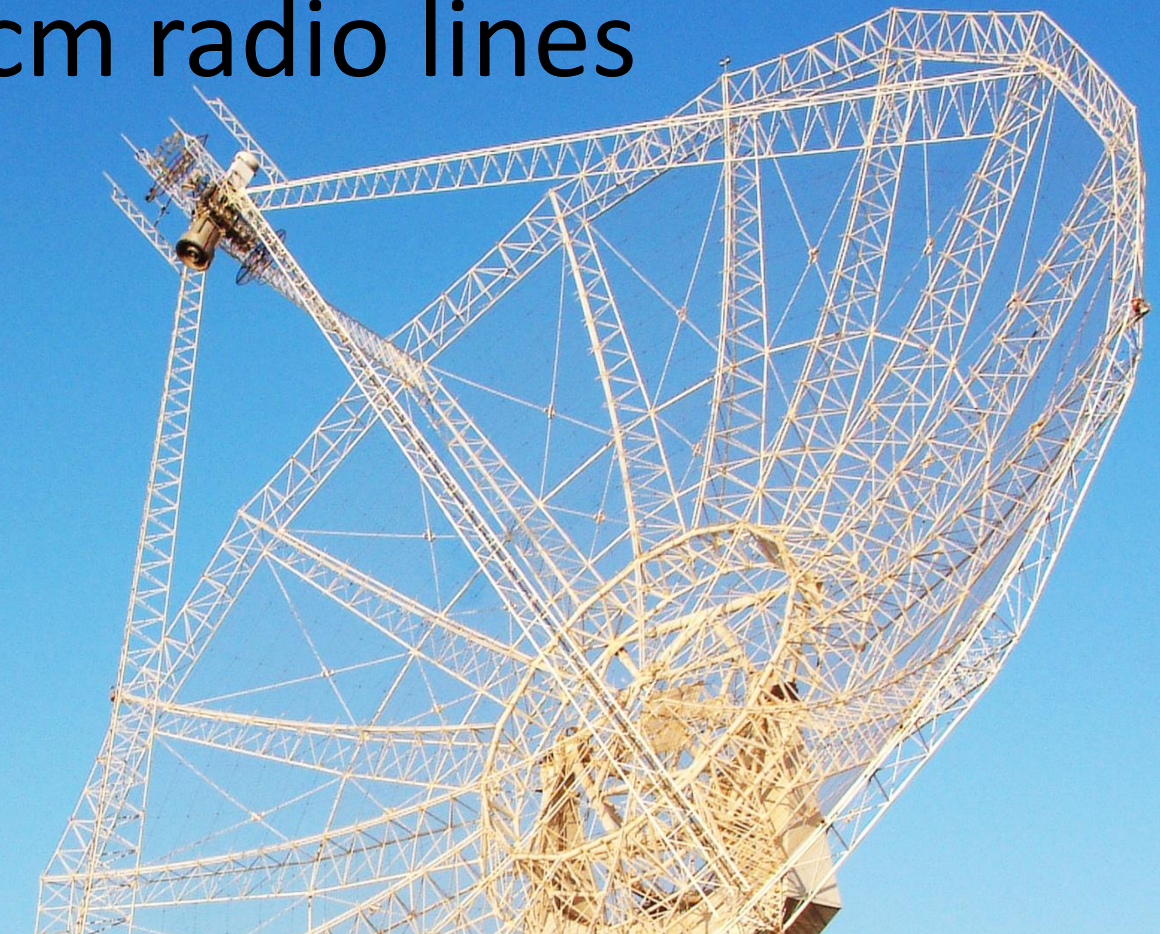
- (Many Multiplet) Relativistic first order corrections lead to different fine structure transitions in different species having different dependencies on α

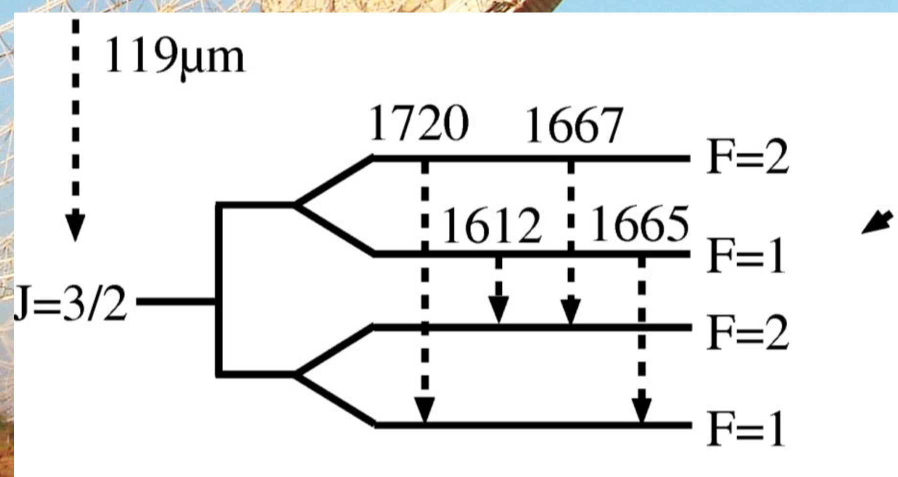
(Dzuba et al. 1999, Phys. Rev. Lett.)

- The MM method gives lower statistical errors, but larger systematic ones, e.g.
  - calibration errors on different echelle orders,
  - kinematical velocity shifts between species
    - Doppler shift corresponding to $\Delta V \sim$ 10km/s $\equiv \Delta z/z \sim 10^{-5}$
  - Isotopic abundance variations

OH 18cm radio lines

- OH emits 4 spectral lines with λ ~ 18cm
  - lines arise from a combination of Λ doubling and hyperfine interaction
  - Line frequencies hence depend on α, μ, g_p



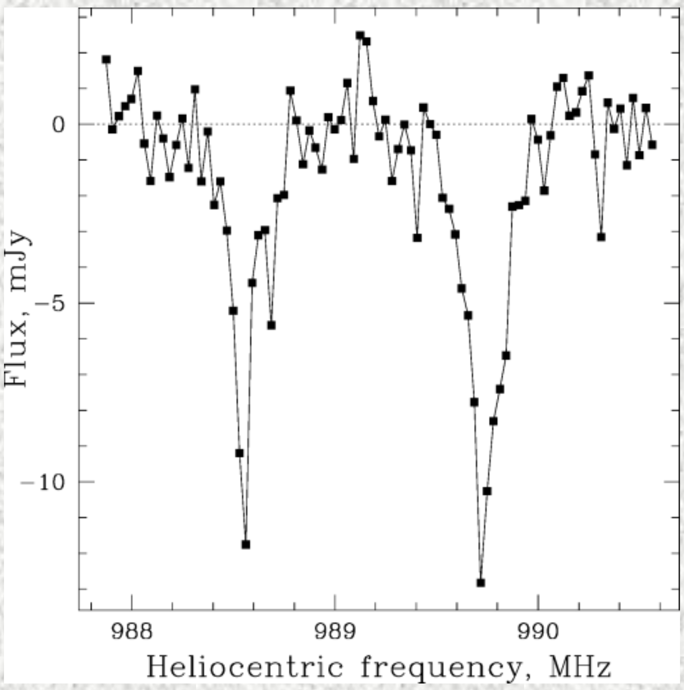


Constraints from OH measurements

- Comparison of the redshifts of the OH main ($\Delta F=0$) lines with redshifts of the HI 21cm (hyperfine) transition and CO mm (rotational) transitions allows one to *simultaneously* constrain $\Delta\alpha/\alpha$ *and* $\Delta\mu/\mu$ and $\Delta g_p/g_p$

- If one assumes that $\Delta g_p/g_p$ is small (e.g. Langacker et al. 2002) then one gets
  - $\Delta\alpha/\alpha = -5.0 \pm 1.5 \times 10^{-6}$
  - $\Delta\mu/\mu = 4.2 \pm 2.2 \times 10^{-6}$

- Results are subject to possibility of kinematical shifts between HI, OH and CO absorbing gas.

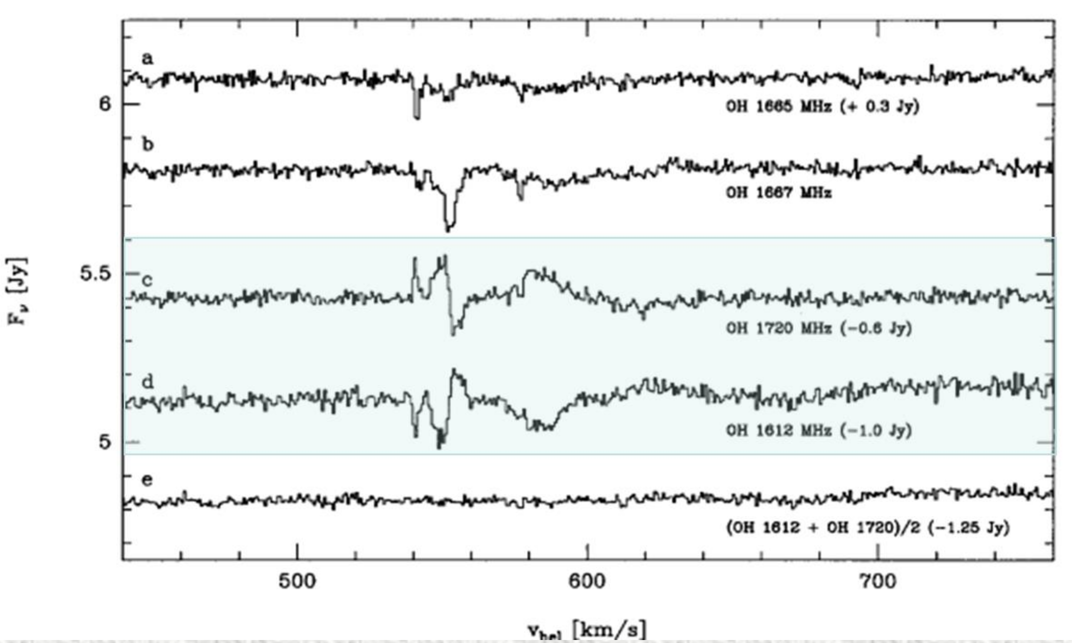


Chengalur & Kanekar PRL 91, 241302 (2003)

Conjugate OH lines

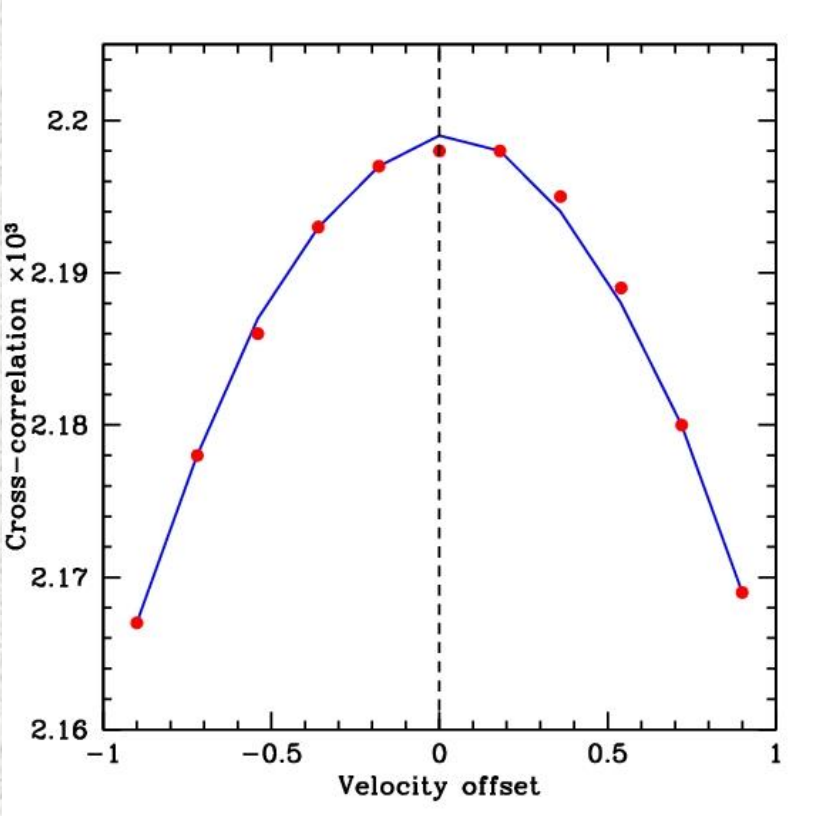
van Langevelde et al. (1995)

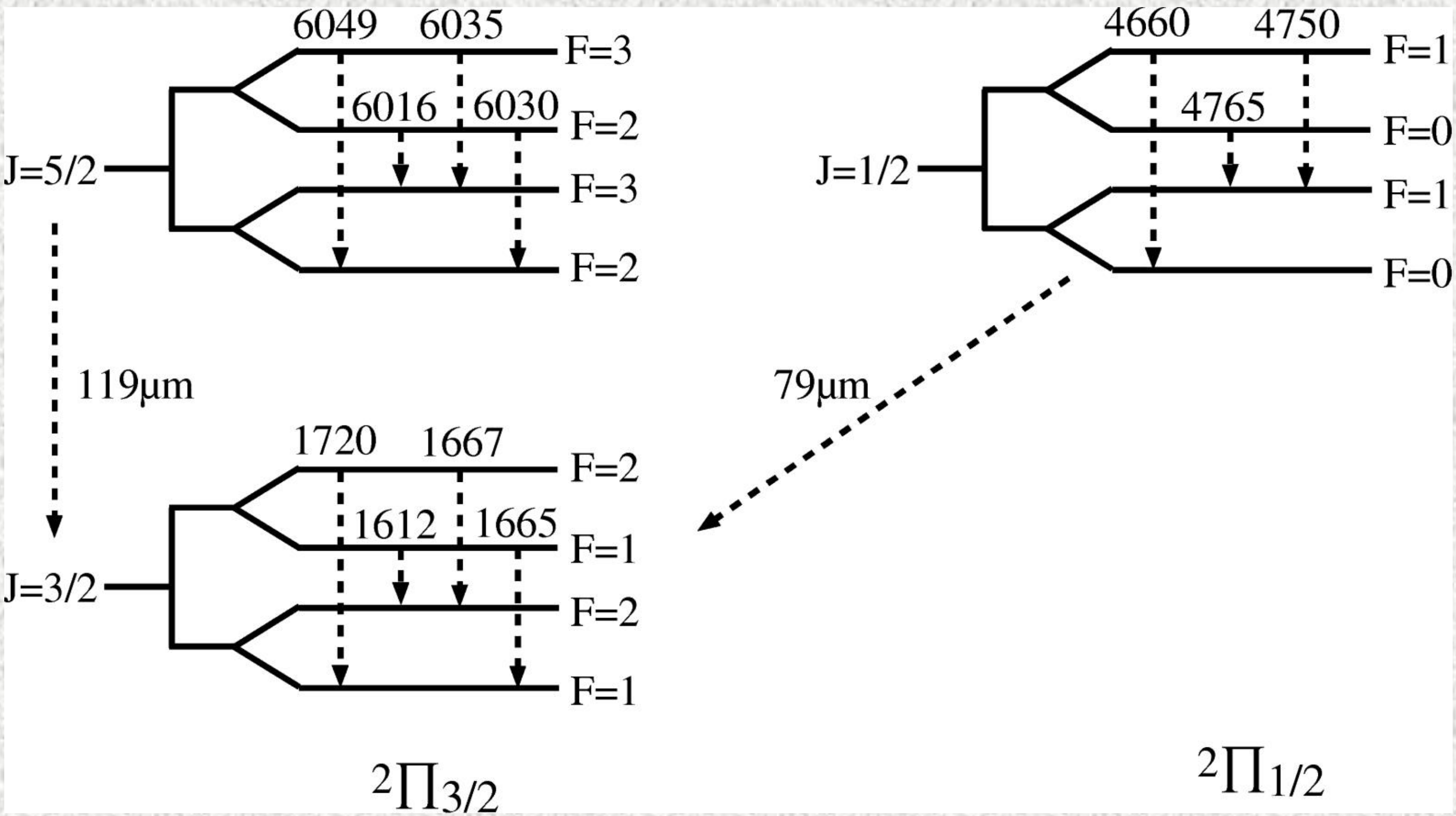
- The OH 'satellite' ($\Delta F=\pm1$) lines are sometimes "conjugate" i.e. have same spectral shape, but opposite signs
  - Consequence of selection rule driven "competitive pumping"



Fundamental Constant Variation from Conjugate OH line

- Since line shape is the same, non parametric, cross correlation techniques can be used to determine spectral shifts
  - High level of independence from systematic effects (kinematic Doppler shifts, isotopic variations, calibration errors…)
  - Can derive significant constraints from a *single* object





- $\Delta F = 0, \pm 1$ allowed.
- 119 μm: 1720 emission,

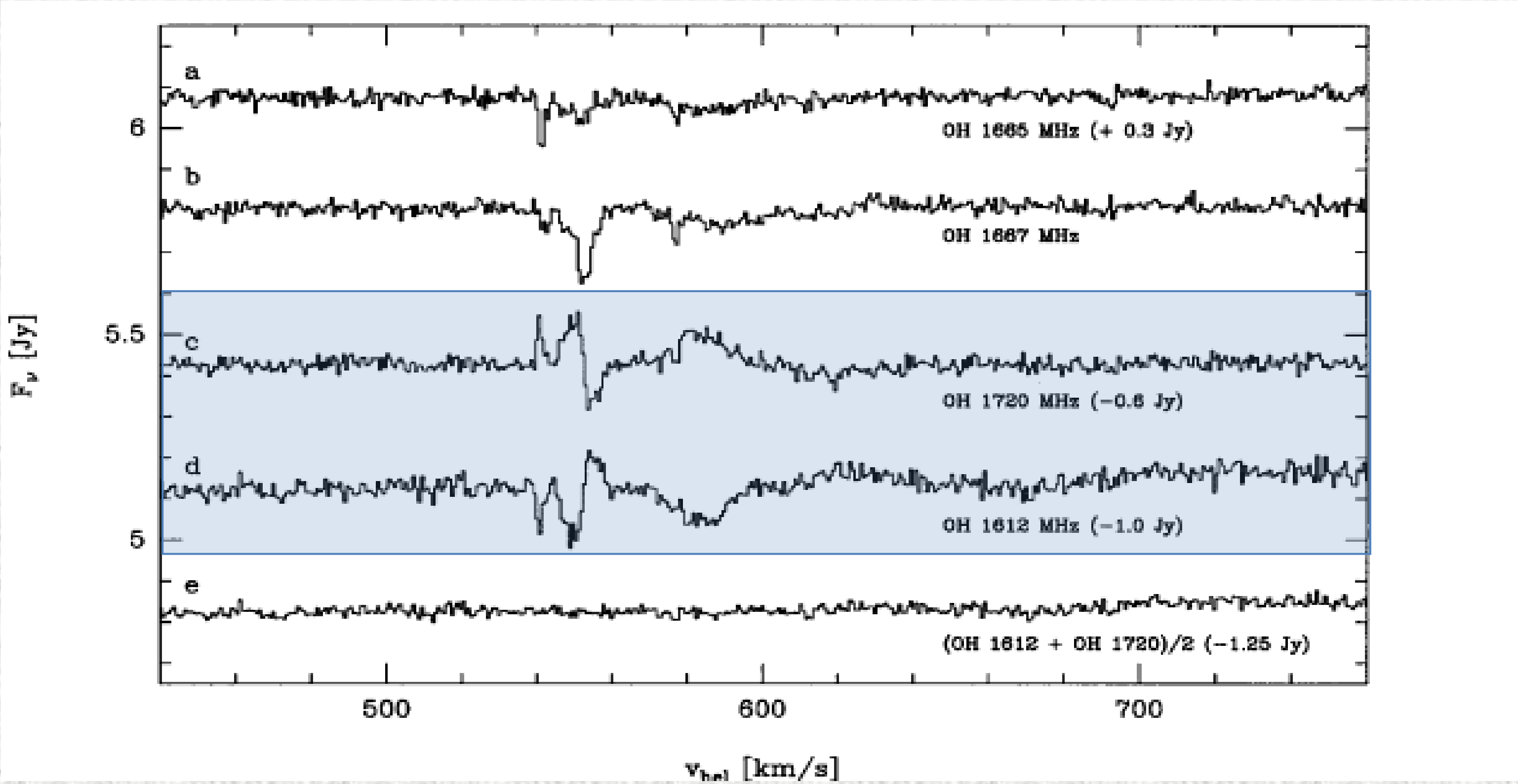
  1612 absorption.
- 79 μm: 1612 emission,

  1720 absorption.

(Elitzur 1976, ApJ;
van Langevelde et al. 1995, ApJL)

Conjugate OH lines from Centaurus A

van Langevelde et al. (1995)



Cross correlation of Centaurus A (z ~0) lines gives expected null result (ΔV = 50 ± 110 m/s)

Kanekar, Chengalur & Ghosh PRL 93, 051302, (2004)

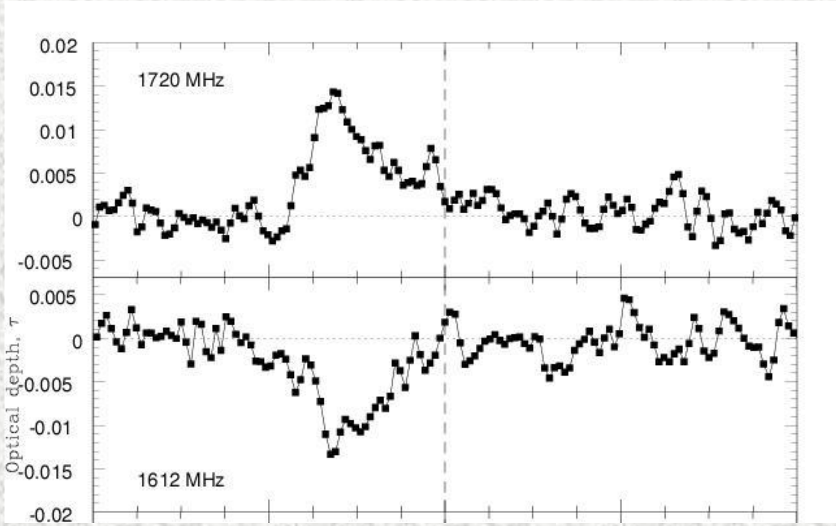
Conjugate OH lines at cosmological distances

- First detection of conjugate lines at cosmological distances was for PKS1413+135, (z= 0.247)

- Data constrain $G \equiv g_p[\alpha^2\mu]^{1.849}$

- Original data leads to

  $\Delta G/G = 2.2 \pm 3.8 \times 10^{-5}$

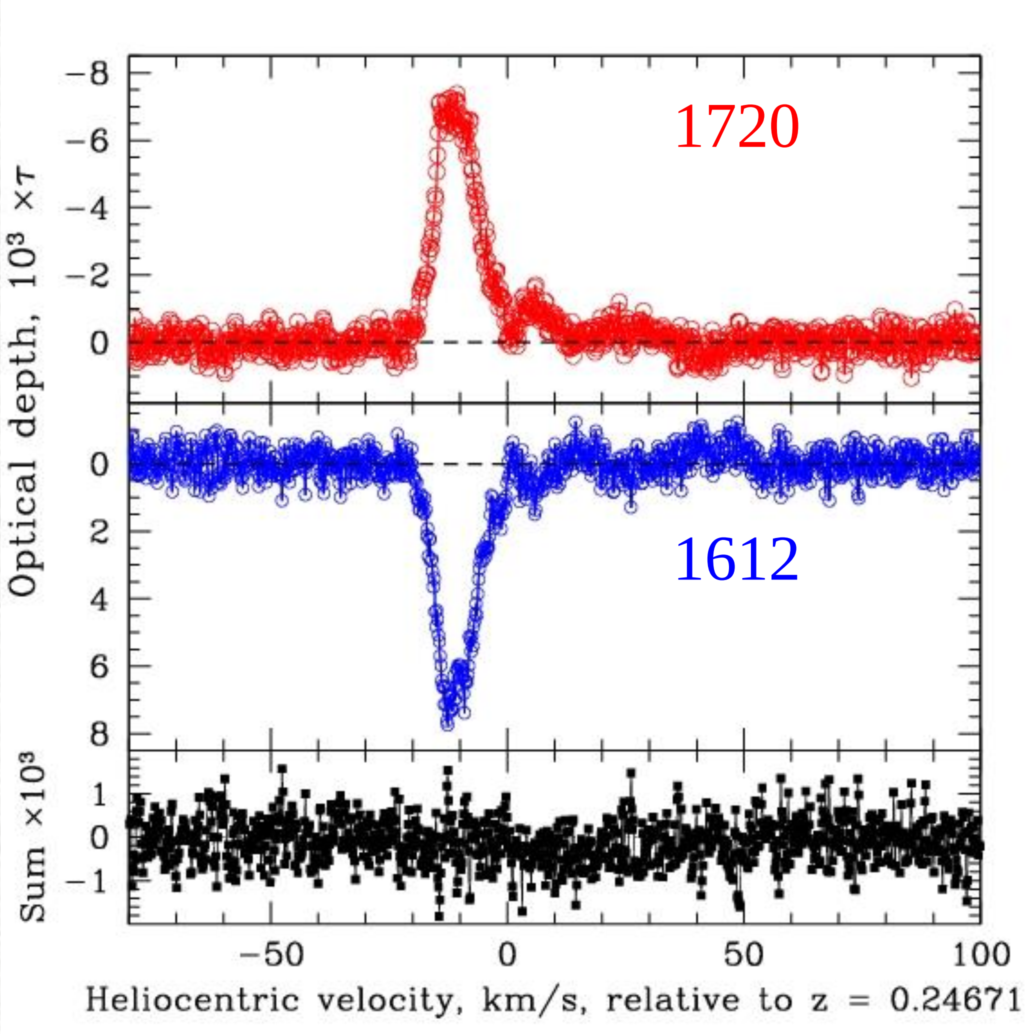


Deep Arecibo observations of the satellite lines

- 125-hour Arecibo integration between 2010 and 2012.
  - Velocity resolution ~ 90 m/s.
- Double position-switching for bandpass calibration
  - rms decreases as $\sqrt{t}$
- Spectral dynamic range ~ 3000 to 1 per 180 m/s channel.
  - Among the most sensitive radio spectra ever obtained!

Kanekar, Chengalur, Ghosh (2013)

A DEEP ARECIBO INTEGRATION ON 1413+135



CURRENT RESULTS

- New Arecibo result: Velocity offset = (-20 $\pm$ 59) m/s
  - [ΔG/G] = (-0.9 $\pm$ 2.9) $\times$ 10^{-6} G ≡ $[\alpha^2\mu]^{1.85}$

- Final weighted average:
  - If $[\Delta\mu/\mu] = 0$ $[\Delta\alpha/\alpha]$ = (-9.9 $\pm$ 6.6) $\times$ 10^{-7}
  - If $[\Delta\alpha/\alpha] = 0$ $[\Delta\mu/\mu]$ = (-1.9 $\pm$ 1.3) $\times$ 10^{-6}

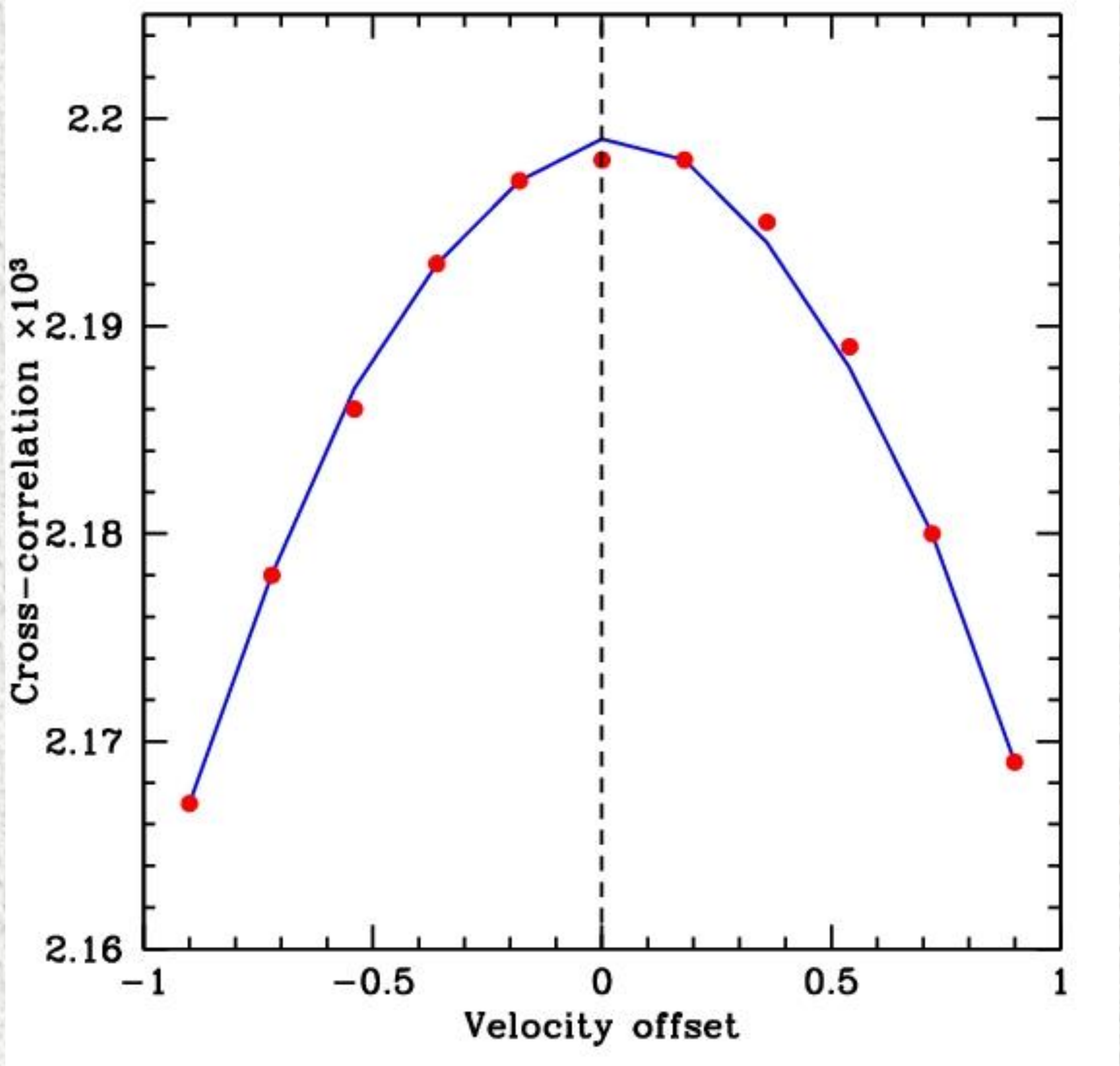

Thank you

Slide courtsey N. Kanekar

Radio Techniques

- HI-21cm and optical resonance lines
  - $X \equiv g_p[\alpha^2/\mu]$ (Wolfe et al. 1976, Phys. Rev. Lett.)
- OH-18cm and HI 21cm lines
  - $X \equiv g_p[\alpha^2/\mu]^{1.57}$ (Chengalur & Kanekar2003, Phys. Rev. Lett.)
- Inversion and rotational lines:
  - $\mu^{3.46}$ (Flambaum & Kozlov 2007, Phys. Rev. Lett.)
- "Conjugate" satellite OH-18cm lines
  - $F \equiv g_p[\alpha^2/\mu]^{1.85}$ (Kanekar et al. 2004, Phys. Rev. Lett.)

A Deep Arecibo Integration on 1413+135



- The cross-correlation peaks at an offset of (-20 ± 59) m/s.
- Error on the offset estimated via a Monte Carlo analysis.

Kanekar et. al. ApJ (2010)

Constraints from deeper WSRT and Arecibo data

- $(\Delta G/G) = (-1.18 \pm 0.46) \times 10^{-5}$
  - $G = g_p (\mu\alpha^2)^{1.85}$
- tentative evidence (2.6 σ) for a smaller value of α, μ, and/or g_p at $z \sim 0.247$,
  - lookback time of ~2.9 Gyr.
- If we assume that the dominant change is in α, this implies $(\Delta\alpha/\alpha) = (-3.1 \pm 1.2) \times 10^{-6}$.