

PROBING FUNDAMENTAL CONSTANT EVOLUTION WITH RADIO MOLECULAR SPECTROSCOPY

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(Image: B. Premkumar)

FUNDAMENTAL CONSTANT EVOLUTION

- Why do we care ?
- Basic technique: Atomic clocks.
- Redshifted spectral lines.
- Conjugate satellite OH lines, at $z \sim 0.25$.
- Inversion and rotational lines, at $z \sim 0.685$.
- The state of the art.
- The future.
- Summary.

WHY DO WE CARE ?

(e.g. Uzan 2011, Liv. Rev. Rel.)

- Fundamental constants: Free parameters of a theory.
e.g. c , e , \hbar , $\alpha = e^2/\hbar c$, $\mu = m_p/m_e$, etc.
- 20 free parameters in the Standard Model & GR!
- Pragmatic view: A test of the basic assumptions of the Standard Model and General Relativity.
- Similar to tests of local position invariance, Lorentz invariance, violation of the equivalence principles, etc.
- Changes in low-energy coupling constants "expected" in higher-dimensional theories. (e.g. Marciano 1984, Phys. Rev. Lett.; Damour & Polyakov 1994, Phys. Rev. Lett.)
 \Rightarrow Low-energy probe of unification theories !

BASIC TECHNIQUE

- Test for changes in *dimensionless* constants (e.g. α)!
This avoids confusion with units (as the definition of a unit often *assumes* that some parameters are constant).
- **Approach:** Measure the same quantity (e.g. time, redshift) with two methods that have *different dependences* on some constant (e.g. α). If the constant changes, the two techniques would yield different values for the measured quantity.

BASIC TECHNIQUE: ATOMIC CLOCKS

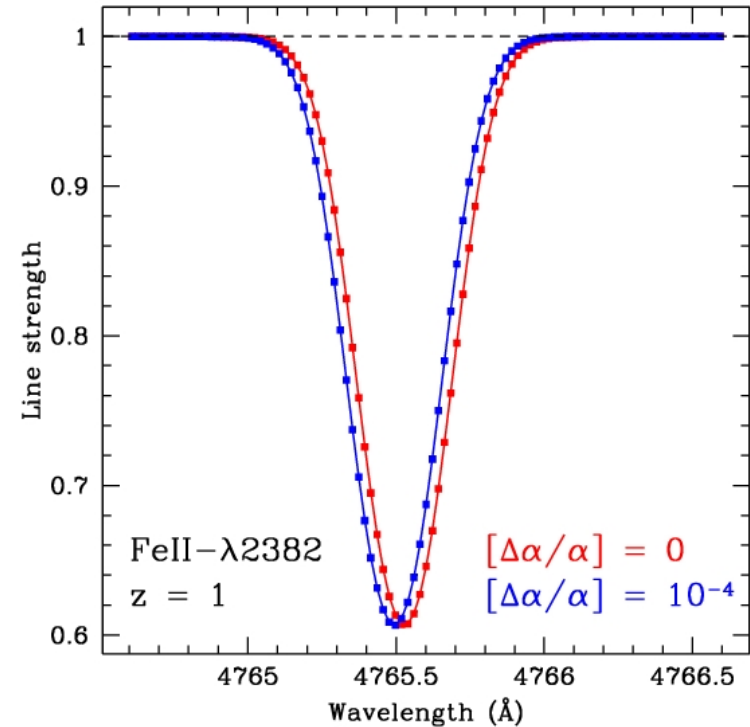
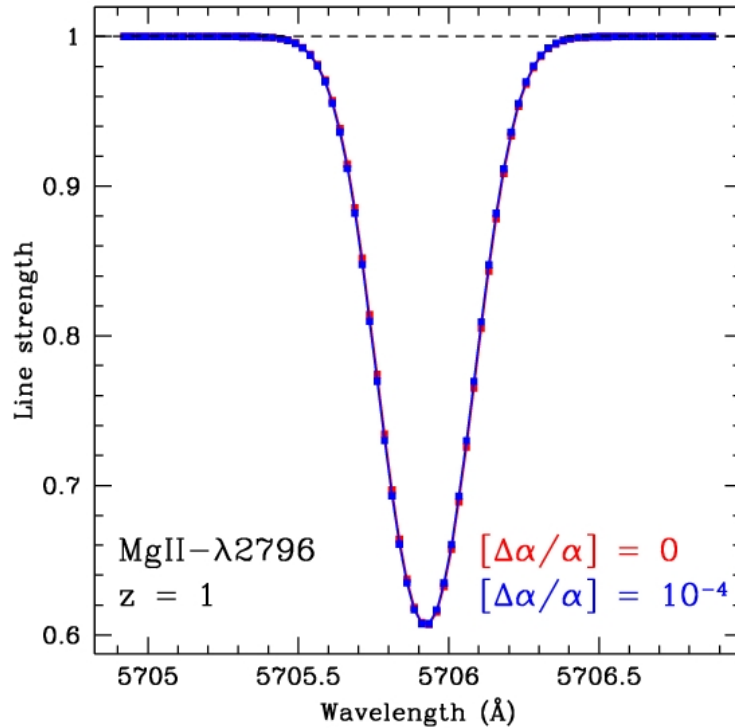
- In atomic clocks, the time is derived from the frequency of a transition between two atomic energy levels, e.g. the Cs-133 transition at 9.192631770 GHz in a cesium clock.
- Transition frequencies have different dependences on α , μ e.g. Cs hyperfine ($\propto g_p[\alpha^2/\mu]$), Al⁺ resonance ($\propto \text{const.}$).
- If α changes, the Cs & Al⁺ frequencies change and the clock times too: *The clocks would show different times!*
- Atomic clock studies $\Rightarrow (1/\Delta t)[\Delta\alpha/\alpha] < 4.6 \times 10^{-17} \text{ yr}^{-1}$.
(Rosenband et al. 2008, Science)
- Atomic clocks: High sensitivity, excellent control over systematic effects! But can probe only tiny fractions of the age of the Universe \Rightarrow *Astrophysical techniques.*

ASTROPHYSICAL TECHNIQUES

- Redshifted spectral lines. (Svedoff 1956, Nature)
- Big Bang nucleosynthesis yields. (Kolb et al. 1986, Phys. Rev. D)
- Cosmic microwave background anisotropies.
(Hannestad 1999, Phys. Rev. D;
Kaplighat et al. 1999, Phys. Rev. D)
- Nucleosynthesis, CMB: degeneracies between values of α , μ , and cosmological parameters. Model-dependent.
Typically, $[\Delta\alpha/\alpha] < 0.05$.
(e.g. Dent et al. 2007, Phys. Rev. D;
Nakashima et al. 2009, Phys. Rev. D)

REDSHIFTED SPECTRAL LINES

- Line rest wavelengths depend on α , μ , etc, *differently!*



MgII: weak dependence on α .

FeII: strong dependence on α .

Change in $\alpha \Rightarrow$ No change in z .

Change in $\alpha \Rightarrow$ Change in z .

- Single measurable: Galaxy redshift.

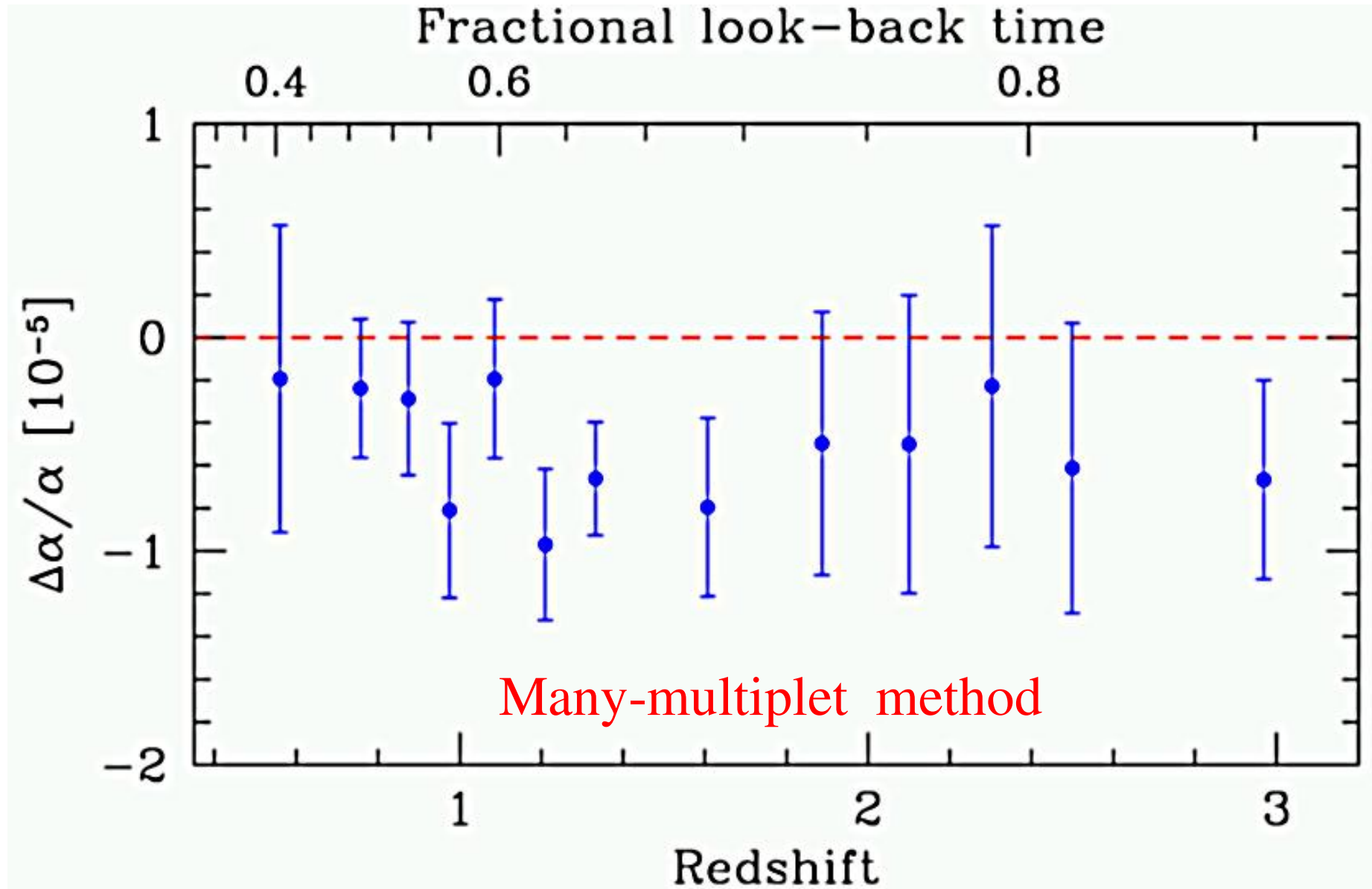
Two techniques : Different spectral lines (FeII, MgII...).

Method: If $z_1 \neq z_2 \Rightarrow$ Change in α from redshift z to today.

REDSHIFTED SPECTRAL LINES

- Infer changes in α from differences in line redshifts!
- **But...** typically, $[\Delta\alpha/\alpha] \sim \Delta z/(1+z) \approx (\Delta V/c)$.
Intra-cloud motions of *few* km/s $\Rightarrow [\Delta\alpha/\alpha] \sim 10^{-5}$.
 \Rightarrow Average over a large sample? Or “special” lines?
- Average large samples: The “many-multiplet method”.
(Dzuba et al. 1999, Phys. Rev. Lett.)
- Wavelengths of fine structure transitions in FeII, MgII, ZnII, NiII, CrII, etc, have different dependences on α due to relativistic corrections \Rightarrow Compare redshifts of different lines and determine $[\Delta\alpha/\alpha]$.
(Webb et al. 1999, 2001, Phys. Rev. Lett.)

“EVIDENCE” FOR A CHANGING α ?



$$[\Delta\alpha/\alpha] = (-5.4 \pm 1.1) \times 10^{-6} \quad (0 < z < 1.8)$$

(Murphy et al. 2004, Lect. Notes Phys.)

REDSHIFTED SPECTRAL LINES

(e.g. NK 2008, Mod. Phys. Lett.)

- **Optical studies:** e.g. Many-multiplet method, H₂ lines.

M-M: $[\Delta\alpha/\alpha] = (-5.4 \pm 1.1) \times 10^{-6} \quad (0 < z < 1.8)$
(Murphy et al. 2004, Lect. Notes. Phys.)

H₂ lines: $[\Delta\mu/\mu] < 4.4 \times 10^{-6} \quad (0 < z < 2.8)$
(King et al. 2011, MNRAS)

- **Serious wavelength calibration issues (errors ~ 1 km/s).**
(Griest et al. 2010, ApJ)

UV lines \Rightarrow difficult to test null result in the Galaxy.

- **Radio molecular lines:** Different methods, systematics.

Different dependences on α , μ , etc.

Frequency calibration better than 10 m/s.

Local lines observable with ground-based telescopes.

RADIO TECHNIQUES: THIS TALK

(e.g. NK 2008, Mod. Phys. Lett.)

- HI-21cm and optical resonance lines:

Sensitive to changes in $X \equiv g_p[\alpha^2/\mu]$.

(Wolfe et al. 1976, Phys. Rev. Lett.)

- HI-21cm and main OH-18cm lines:

Sensitive to changes in $Y \equiv g_p[\alpha^2\mu]^{1.6}$.

(Chengalur & NK 2003, Phys. Rev. Lett.)

- “Conjugate” satellite OH-18cm lines:

Sensitive to changes in $F \equiv g_p[\alpha^2\mu]^{1.8}$.

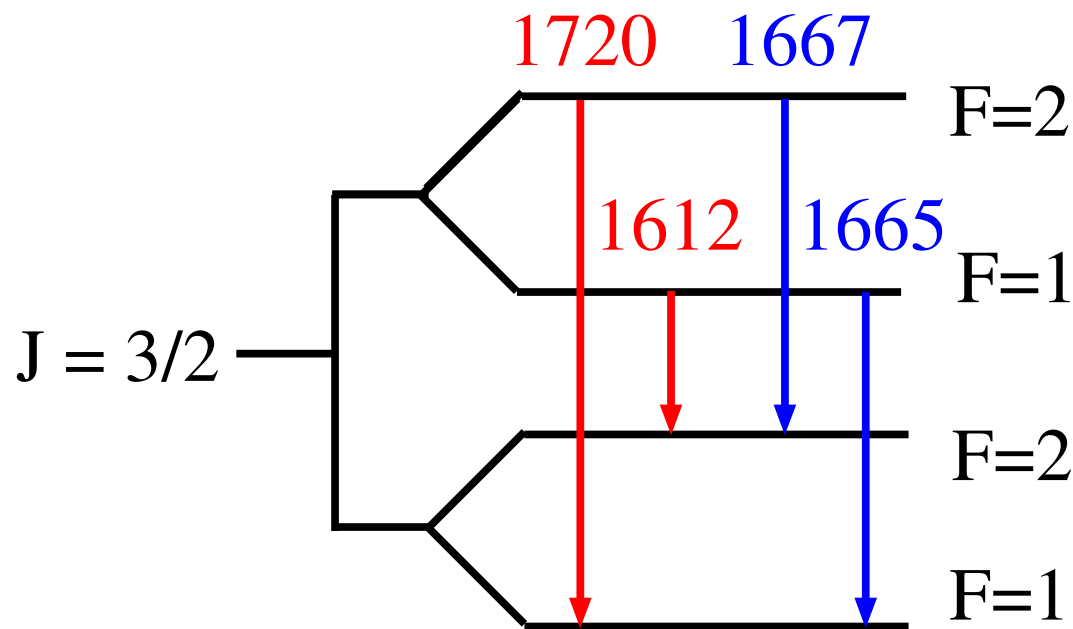
(NK et al. 2004, Phys. Rev. Lett.)

- Inversion and rotational lines:

Sensitive to changes in $\mu^{3.5}$.

(Flambaum & Kozlov 2007, Phys. Rev. Lett.)

HYDROXYL (OH) LINES



“Main” lines:

1667/1665: $\Delta F = 0$

“Satellite” lines:

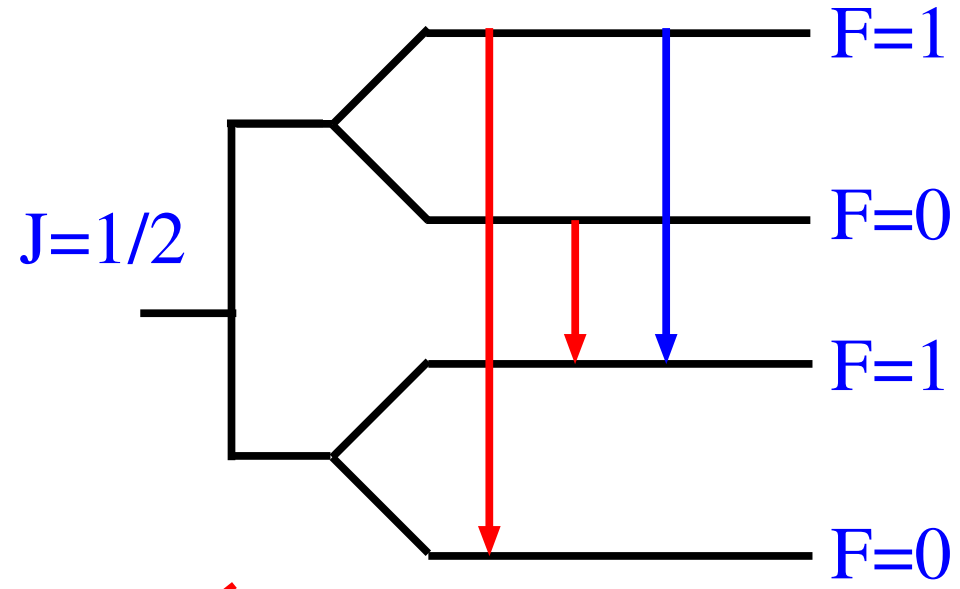
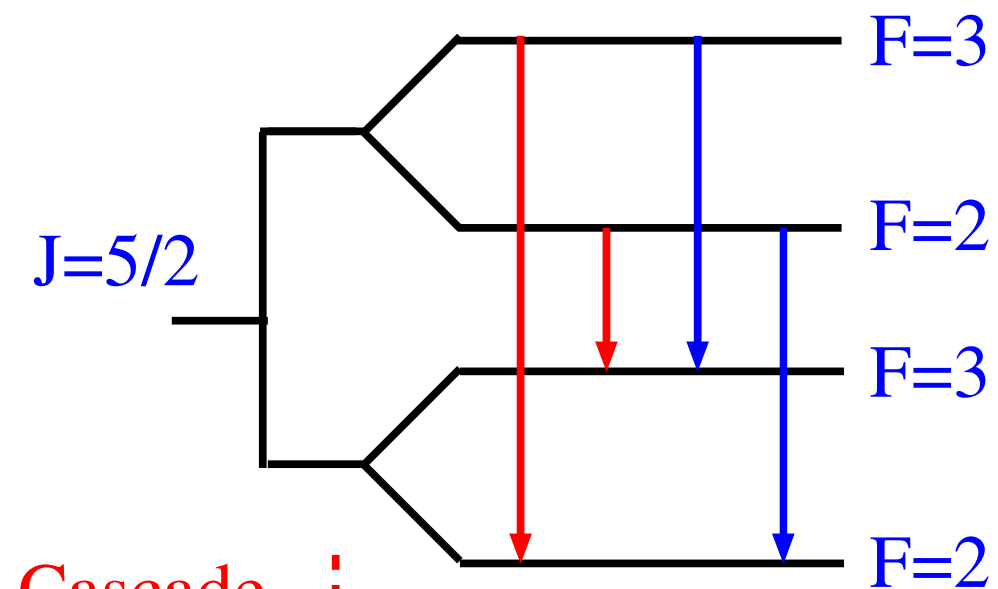
1720/1612: $\Delta F = \pm 1$

- Arise from “ Λ -doubling” & hyperfine splitting \Rightarrow

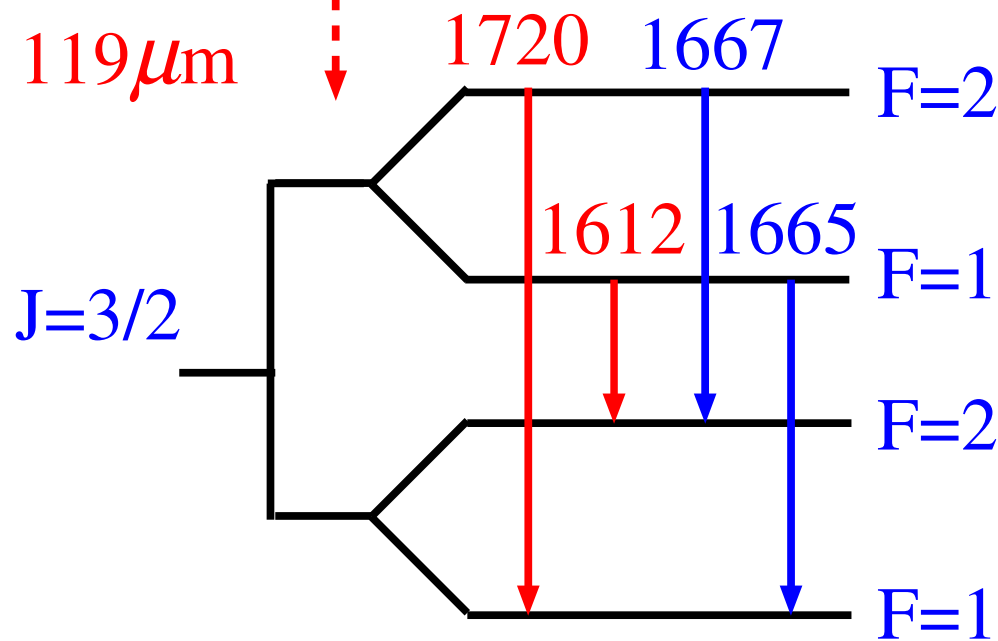
Different dependences on α , μ , g_p . (Darling 2003, Phys. Rev. Lett; Chengalur & NK 2003, Phys. Rev. Lett.)

- Population inversion of $F=2$ & $F=1$ levels \Rightarrow Masing!

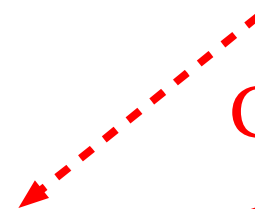
“Conjugate” satellite lines: same shape, opposite sign.

${}^2\Pi_{3/2}$ ${}^2\Pi_{1/2}$ 

Cascade
route-1:
 $119\mu\text{m}$



Cascade
route-2:
 $79\mu\text{m}$

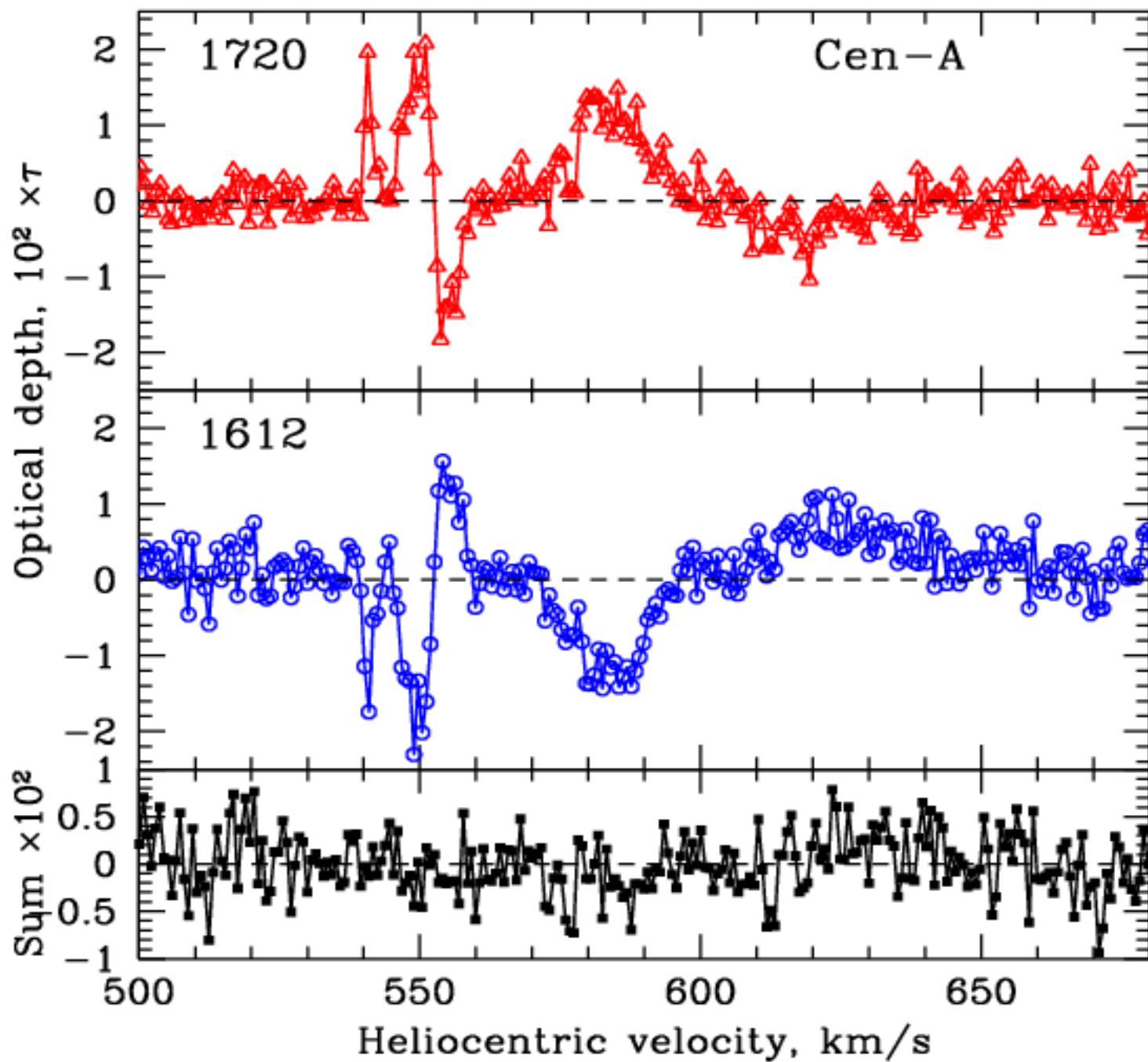


$\Delta F = 0, \pm 1$ allowed

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

Conjugate satellite OH lines in the local Universe

(van Langevelde et al. 1995, ApJL)



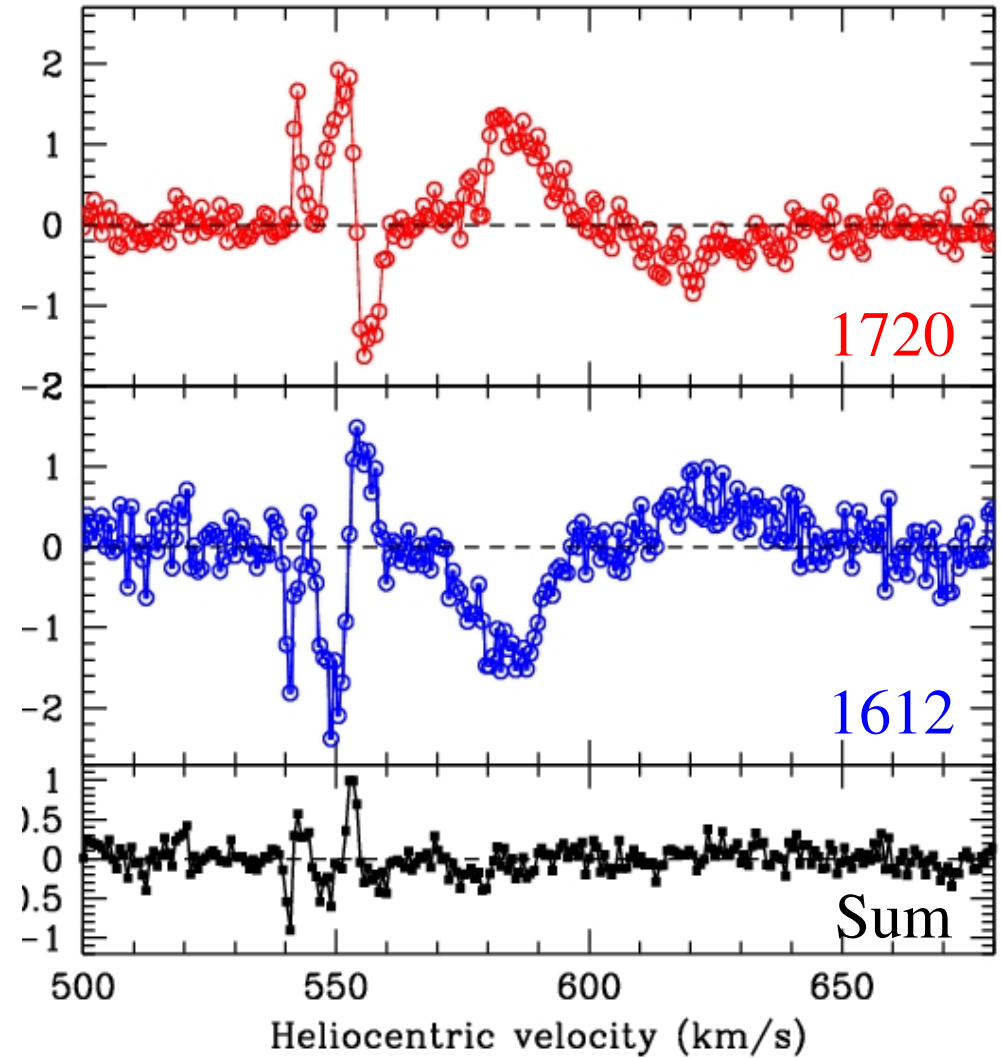
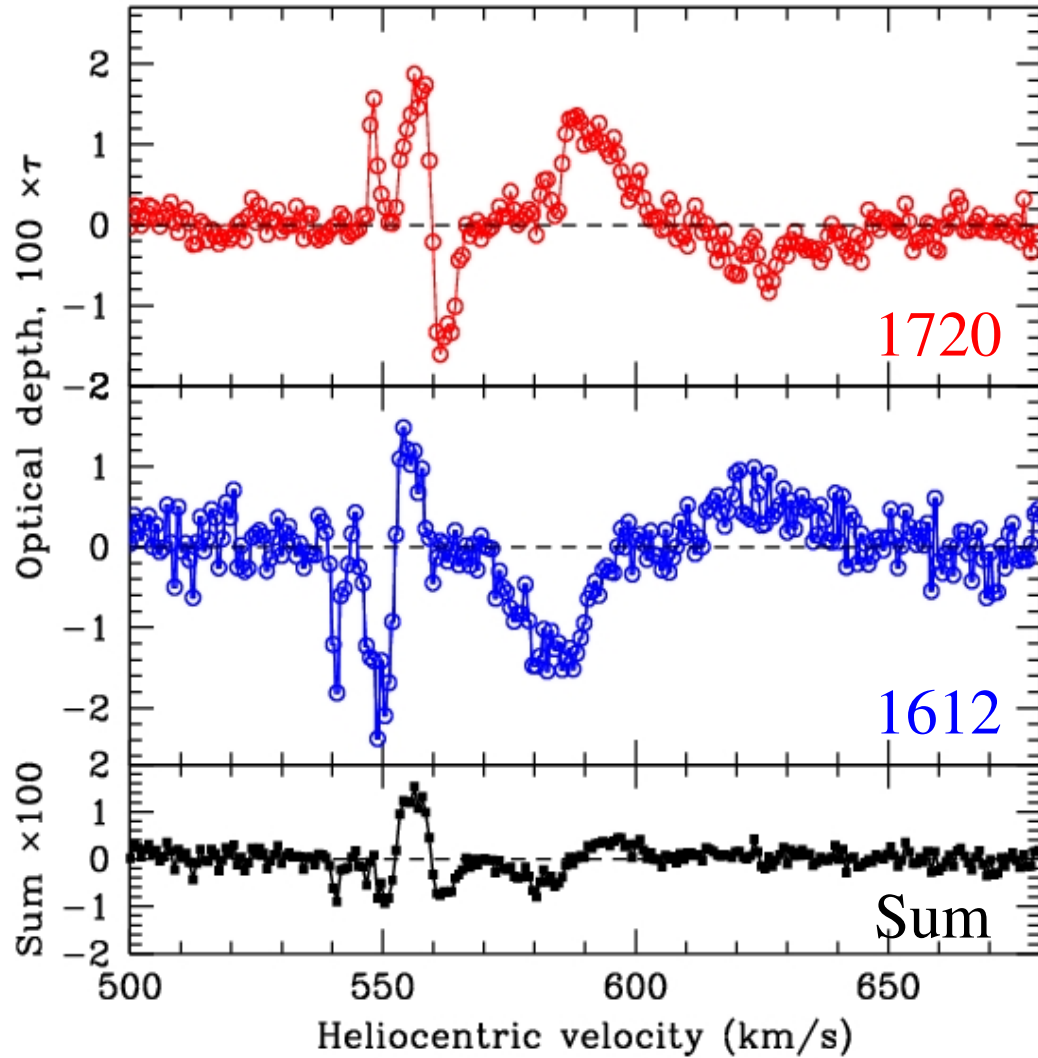
CONJUGATE SATELLITE OH LINES

- Quantum mechanical selection rules \Rightarrow 1720 emission, 1612 absorption, or vice-versa, *with the same shape!*
(Elitzur 1976, ApJ)
- Lines arise in the same gas \Rightarrow No velocity offsets !
- Changes in α , μ , g_p \Rightarrow Same shape, linear translation.
 \Rightarrow Excellent to probe changes in α , μ , g_p .

EXPECTED LINE PROFILES

For $[\Delta\alpha/\alpha] = 1 \times 10^{-4}$

For $[\Delta\alpha/\alpha] = 1 \times 10^{-5}$



CONJUGATE SATELLITE OH LINES

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- Changes in α , μ , g_p \Rightarrow Same shape, linear translation.
 \Rightarrow Excellent to probe changes in α , μ , g_p .
- Inherent test of the applicability of the technique!
- Probes changes from a single space-time location.
- Two redshifted “conjugate” systems, at $z \sim 0.25, 0.77$.
(NK et al. 2004, 2005, Phys. Rev. Lett.)

CONJUGATE SATELLITE OH LINES AT $z \sim 0.247$

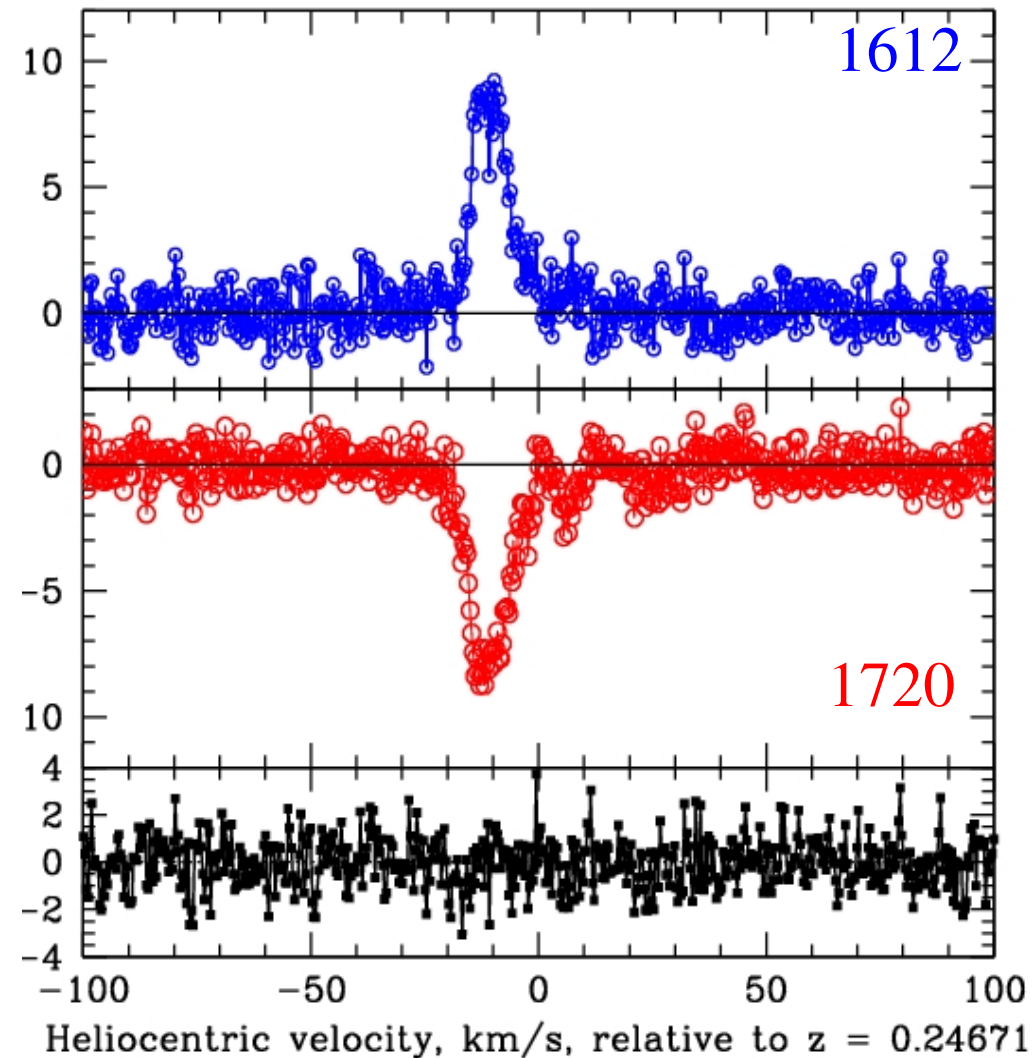
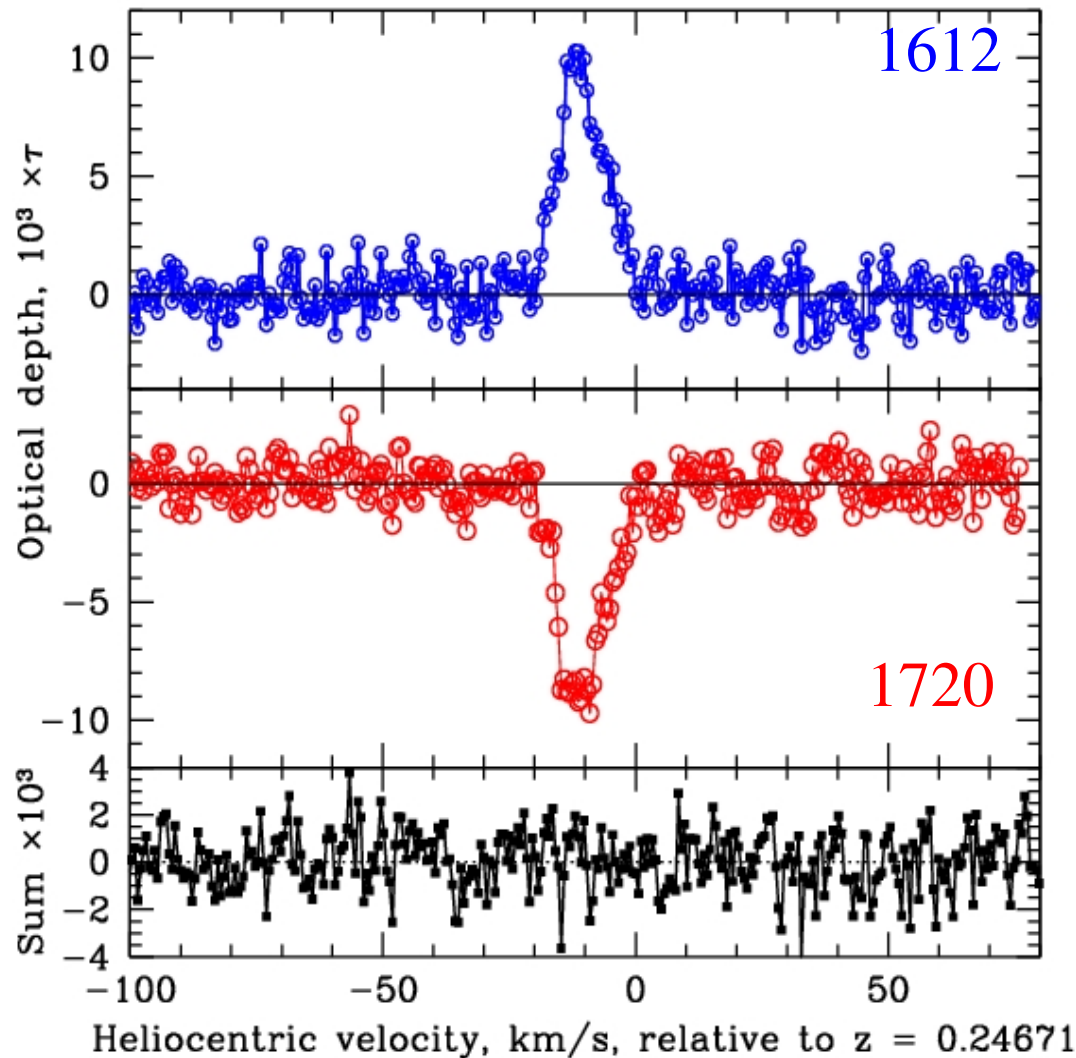
(NK et al. 2010, ApJL)

WSRT, 2005, 60 hours:

$\tau_{\text{RMS}} \sim 0.00085$ per 0.57 km/s

Arecibo, 2008, 40 hours:

$\tau_{\text{RMS}} \sim 0.00045$ per 0.35 km/s

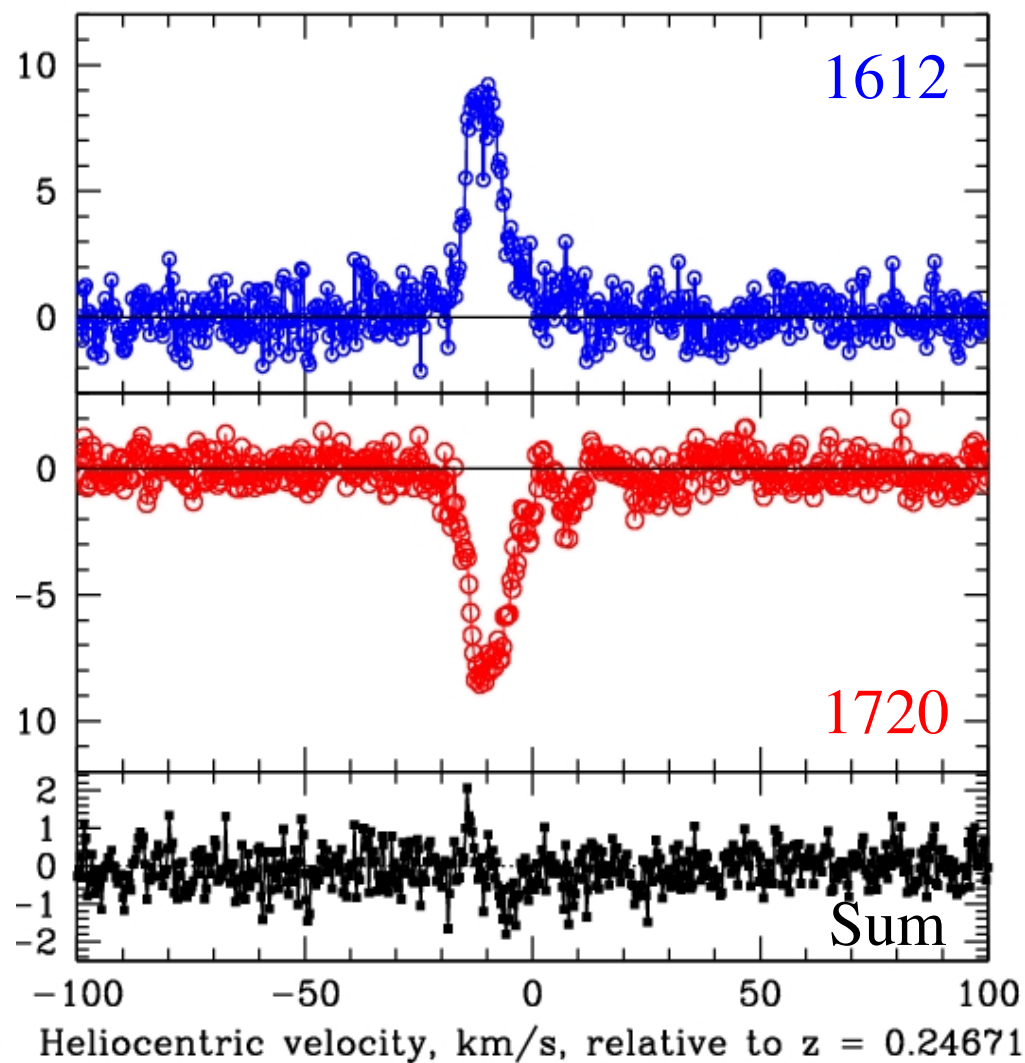
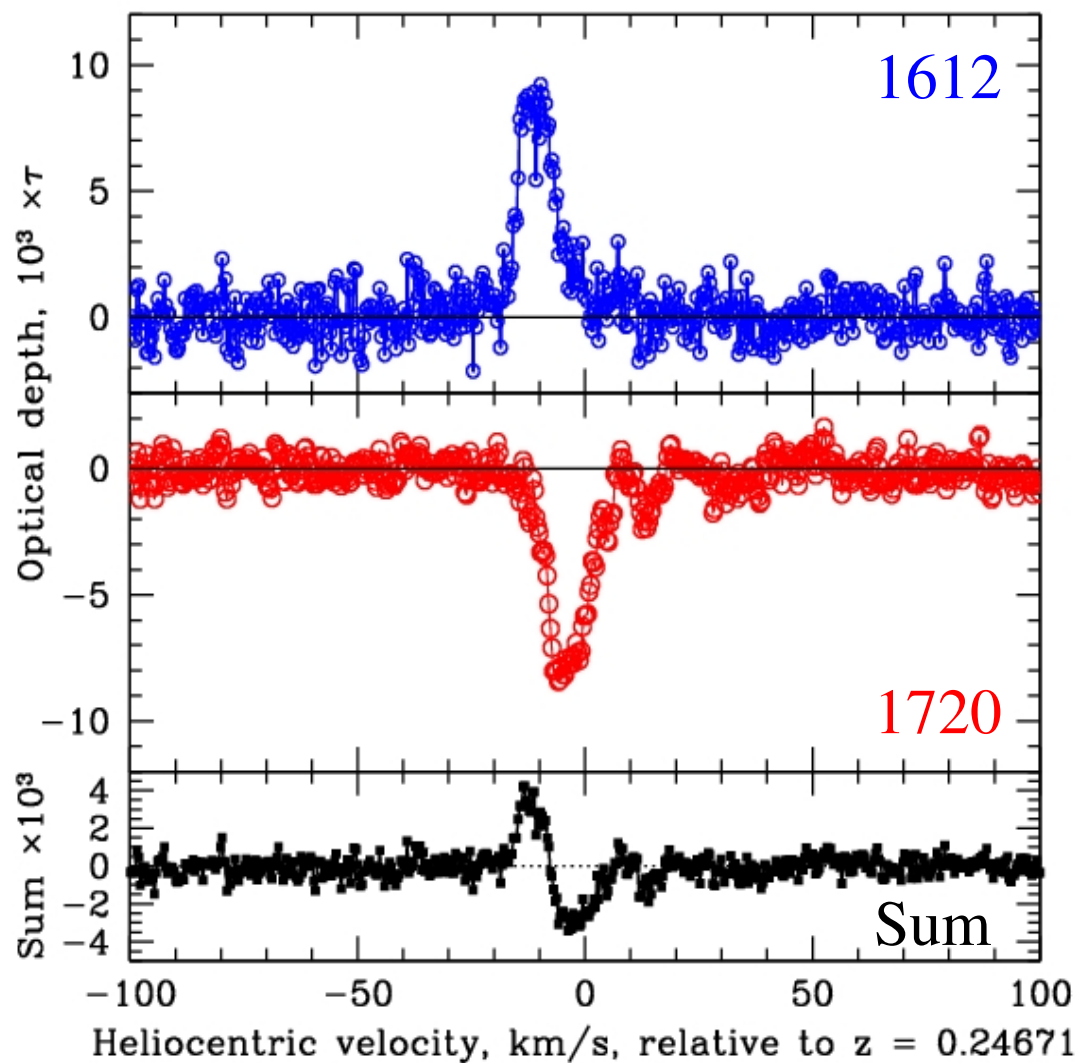


CONJUGATE SATELLITE OH LINES AT $z \sim 0.247$

(NK et al. 2010, ApJL)

For $[\Delta\alpha/\alpha] = 1 \times 10^{-4}$

For $[\Delta\alpha/\alpha] = 1 \times 10^{-5}$



RESULTS

(NK et al. 2010, ApJL)

- Cross-correlation analysis: no need for Gaussian fits!
- Cen. A: Cross-correlation peaks at (0.05 ± 0.11) km/s.

Null result at $z \sim 0$!

- 1413+135: WSRT : Peak at (-0.37 ± 0.22) km/s.
Arecibo : Peak at (-0.20 ± 0.10) km/s.
 $\Rightarrow [\Delta X/X] = (-1.18 \pm 0.45) \times 10^{-5}$; $X \equiv g_p [\alpha^2 \mu]^{1.8}$.

- Redshift offset detected at 99.1% confidence level !

If confirmed, *would imply that α , μ or g_p were smaller in the past* \Rightarrow 160-hr Arecibo run under way.

- Limiting cases,
for $[\Delta g_p/g_p] = 0$ \Rightarrow $[\Delta \alpha/\alpha] = (-3.2 \pm 1.2) \times 10^{-6}$.
 $[\Delta \mu/\mu] = (-6.4 \pm 2.4) \times 10^{-6}$.

INVERSION AND ROTATIONAL LINES

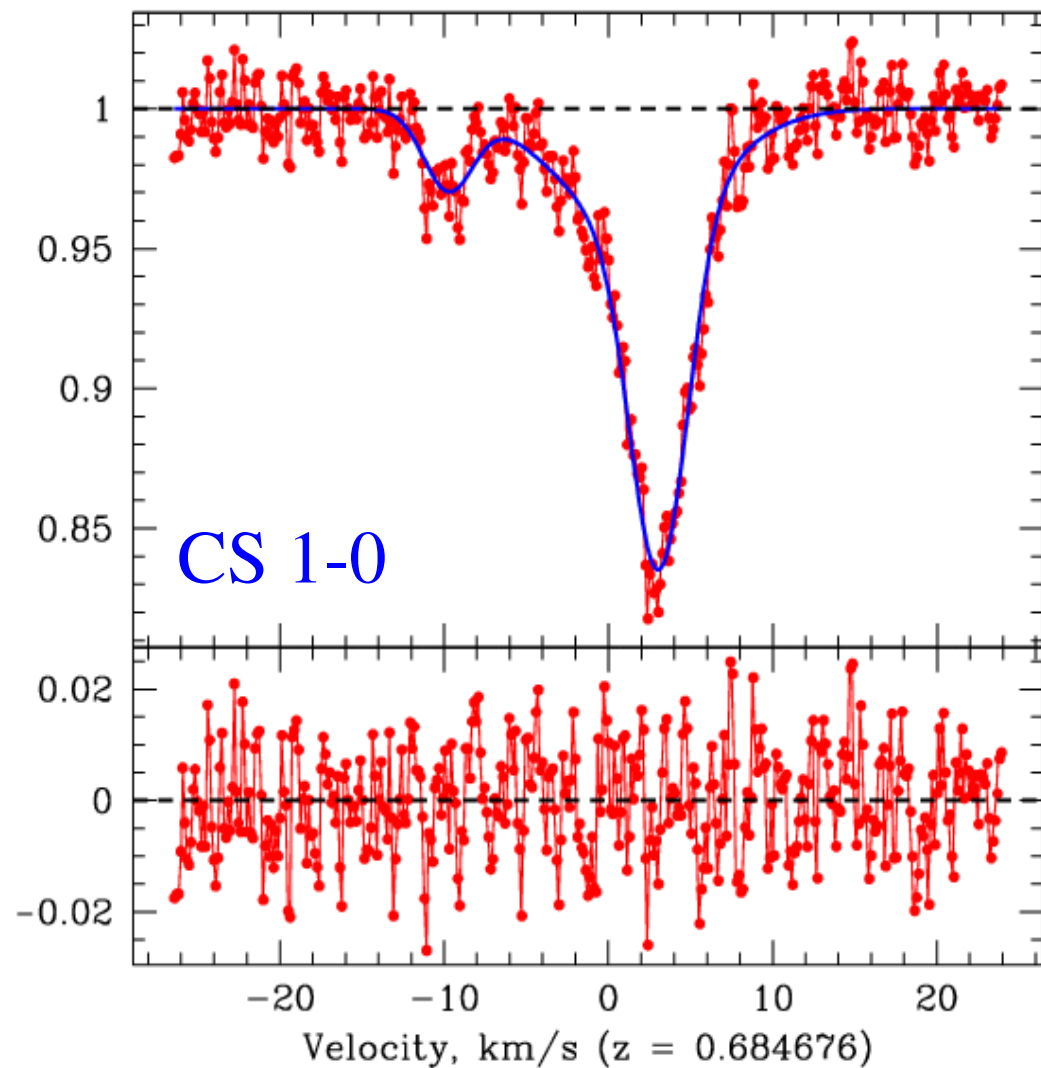
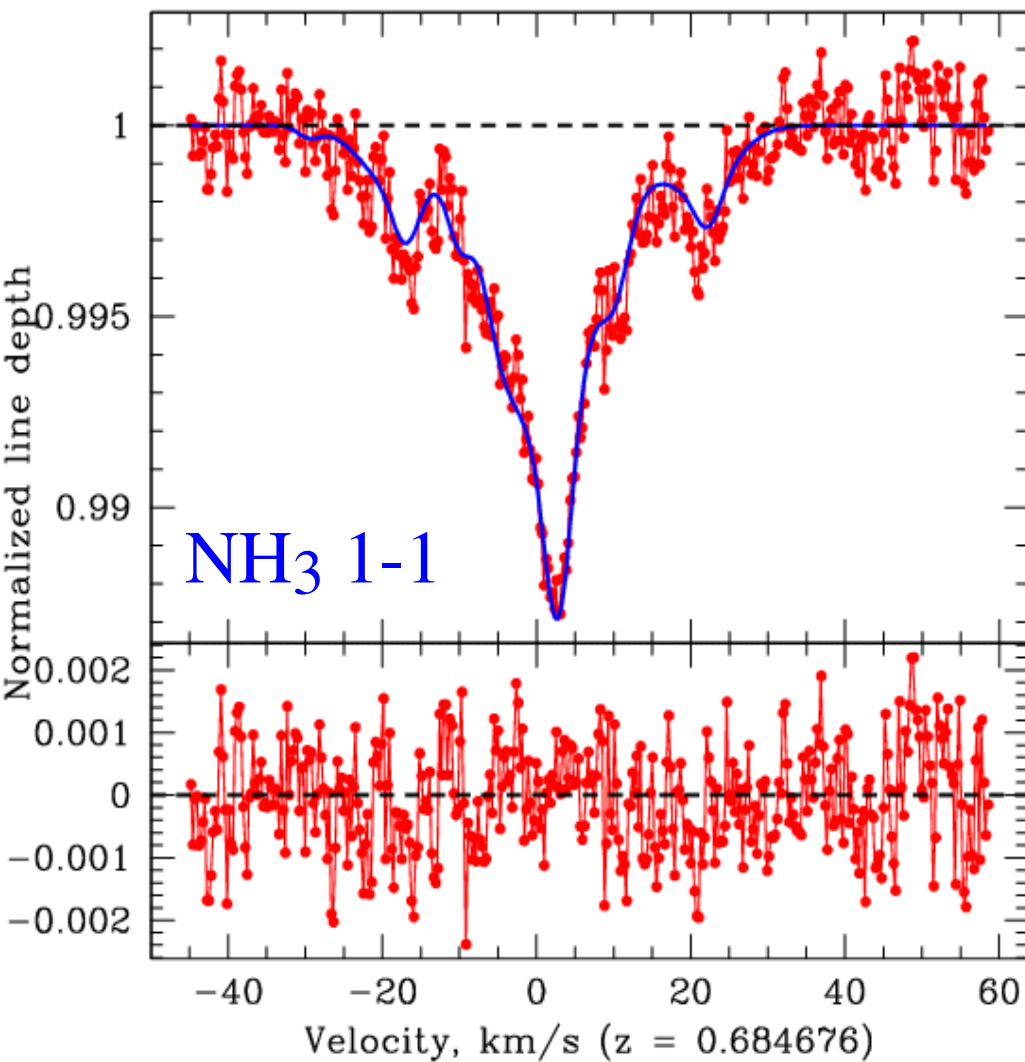
- Comparisons between NH_3 and rotational lines:

Sensitive to changes in $\mu^{3.5}$.

(Flambaum & Kozlov 2007, Phys. Rev. Lett.)

- Best target: $z \sim 0.685$ absorber towards B0218+357.
(Henkel et al. 2005, A&A)
- Optically-thin rotational lines: CS 1-0 & $\text{H}_2\text{CO } 0_{00}-1_{01}$.
Relatively nearby line frequencies: 14, 29, 43 GHz.
CS- H_2CO comparison: test for local velocity offsets.
- GBT spectroscopy in NH_3 , CS & H_2CO lines:
RMS noise ~ 0.0008 per 0.26 km/s (NH_3),
0.01 per 0.12 km/s (CS), 0.003 per 2.8 km/s (H_2CO).

Joint 3-component fit to NH_3 , CS and H_2CO lines with VPFIT, including a single velocity offset between NH_3 and rotational lines. $\chi^2 = 1.05$, noise-like residuals.



RESULTS

(NK 2011, ApJL)

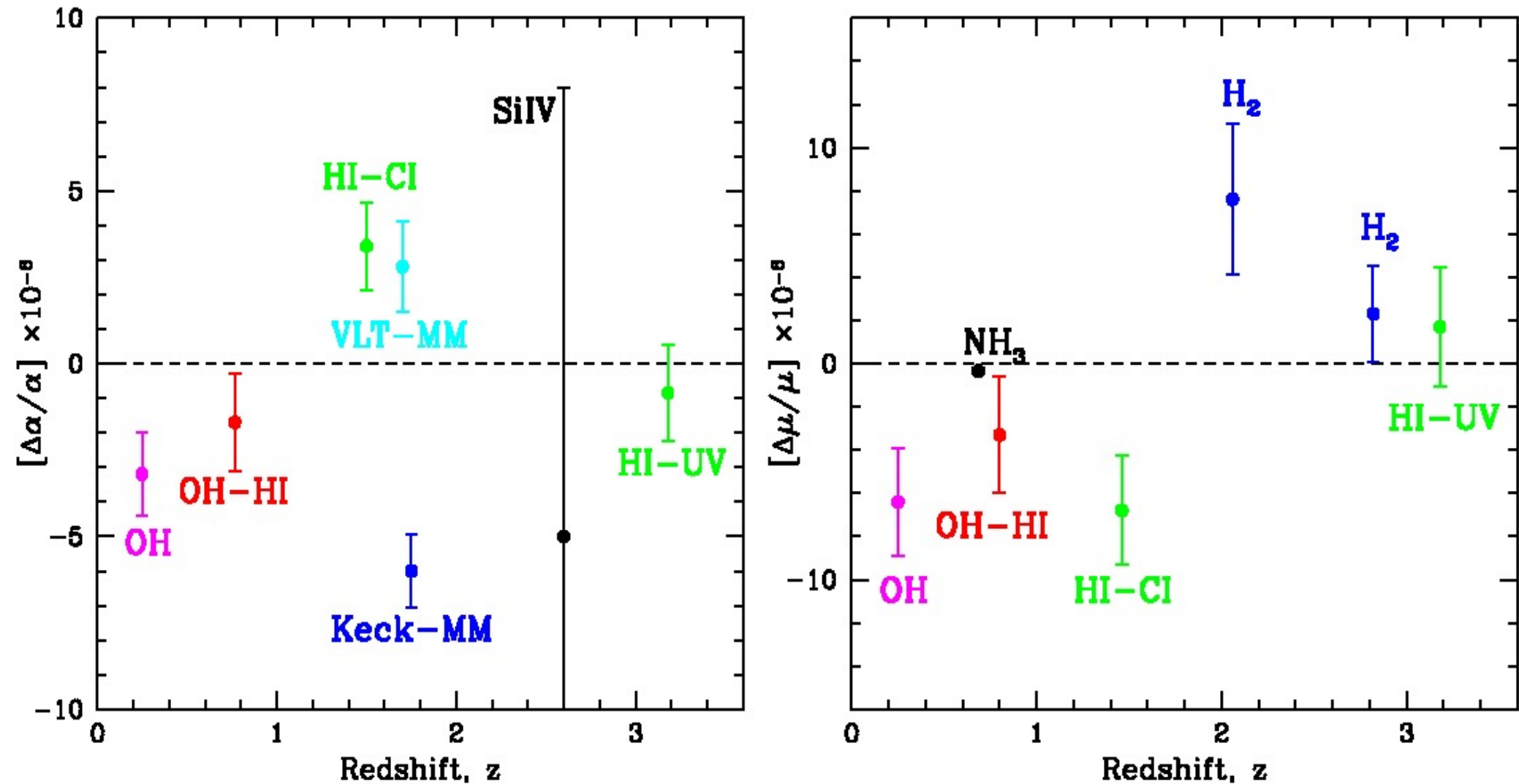
- Joint fit to CS & H₂CO lines $\Rightarrow [\Delta V] = (29 \pm 68) \text{ m/s}$
 \Rightarrow No evidence for local velocity offsets.
- Joint fit to NH₃, CS and H₂CO lines:
 - $\Rightarrow [\Delta V] = (-0.36 \pm 0.10) \text{ km/s}$
 - $\Rightarrow [\Delta\mu/\mu] = (-3.5 \pm 1.0) \times 10^{-7} \quad (z \sim 0.685)$
- $\Rightarrow [\Delta\mu/\mu] = [-3.5 \pm 1.0 \text{ (stat.)} \pm 0.66 \text{ (syst.)}] \times 10^{-7}$
- Possible additional sources of systematic error :
 - Velocity offsets between N-species and C-species ?
 - Time variability in the source morphology ?
- Strongest constraint on changes in *any* constant !

RESULTS

- Conjugate satellite OH lines at $z \sim 0.25$: $X \equiv g_p[\alpha^2\mu]^{1.8}$.
 $\Rightarrow [\Delta X/X] = (-1.18 \pm 0.45) \times 10^{-5}$ (NK et al. 2010, ApJL)
- NH_3 and CS + H_2CO lines at $z \sim 0.68$: μ .
 $\Rightarrow [\Delta\mu/\mu] = [-3.5 \pm 1.0 (stat.) \pm 0.66 (syst.)] \times 10^{-7}$ (NK 2011, ApJL)
- HI-21cm & OH-18cm lines at $z \sim 0.77$: $Y \equiv g_p[\alpha^2\mu]^{1.6}$
 $\Rightarrow [\Delta Y/Y] = [-5.2 \pm 1.5 (stat.) \pm 4.0 (syst.)] \times 10^{-6}$ (NK et al. 2011, in prep.)

THE STATE OF THE ART

(NK 2008, Mod. Phys. Lett.)



(SiIV : Murphy et al. 2001, MNRAS; Keck-MM: Murphy et al. 2004, Lect. Notes Phys; OH: NK et al. 2010, ApJL; HI-Cl: NK et al. 2010b, ApJL; H₂: King et al. 2008, Phys Rev Lett, Malec et al. 2010, MNRAS; NH₃: NK 2011, ApJL; VLT-MM: Webb et al. 2011, Phys. Rev. Lett; HI-UV: Srianand et al. 2010, MNRAS; OH-HI: NK et al. 2011, in prep.).

THE FUTURE

- New telescopes: ALMA & EVLA \Rightarrow Outstanding frequency coverage in millimetre regime.
- New targets: Paucity of high- z molecular absorbers \Rightarrow “Blind” absorption surveys with GBT, EVLA, ALMA.
- New techniques: Require detailed calculations to obtain the dependence of the line frequencies on the different constants, e.g. CH_3OH , H_3O^+ .
(Jansen et al. 2011 Phys. Rev. Lett, Kozlov & Levshakov 2011, ApJ)
- Accurate lab. rest frequency measurements, e.g. OH .
(Hudson et al. 2006, Phys. Rev. Lett, Lev et al. 2006, Phys. Rev. A)
- Spatial changes in the constants ?
(Levshakov et al. 2009, 2010, A&A; Webb et al. 2011, Phys. Rev. Lett)

SUMMARY

- Test of the assumptions of the Standard Model. Low-energy constants expected to change in unified theories.
- Systematic effects are the bane of all techniques!
Conjugate OH method inherently tests for such effects.

- Comparing inversion and rotational lines at $z \sim 0.685$:

$$[\Delta\mu/\mu] = [-3.5 \pm 1.0 (stat.) \pm 0.66 (syst.)] \times 10^{-7}$$

100-hr. GBT run on NH_3 , CS, H_2CO , HC_3N & CH_3CN lines.

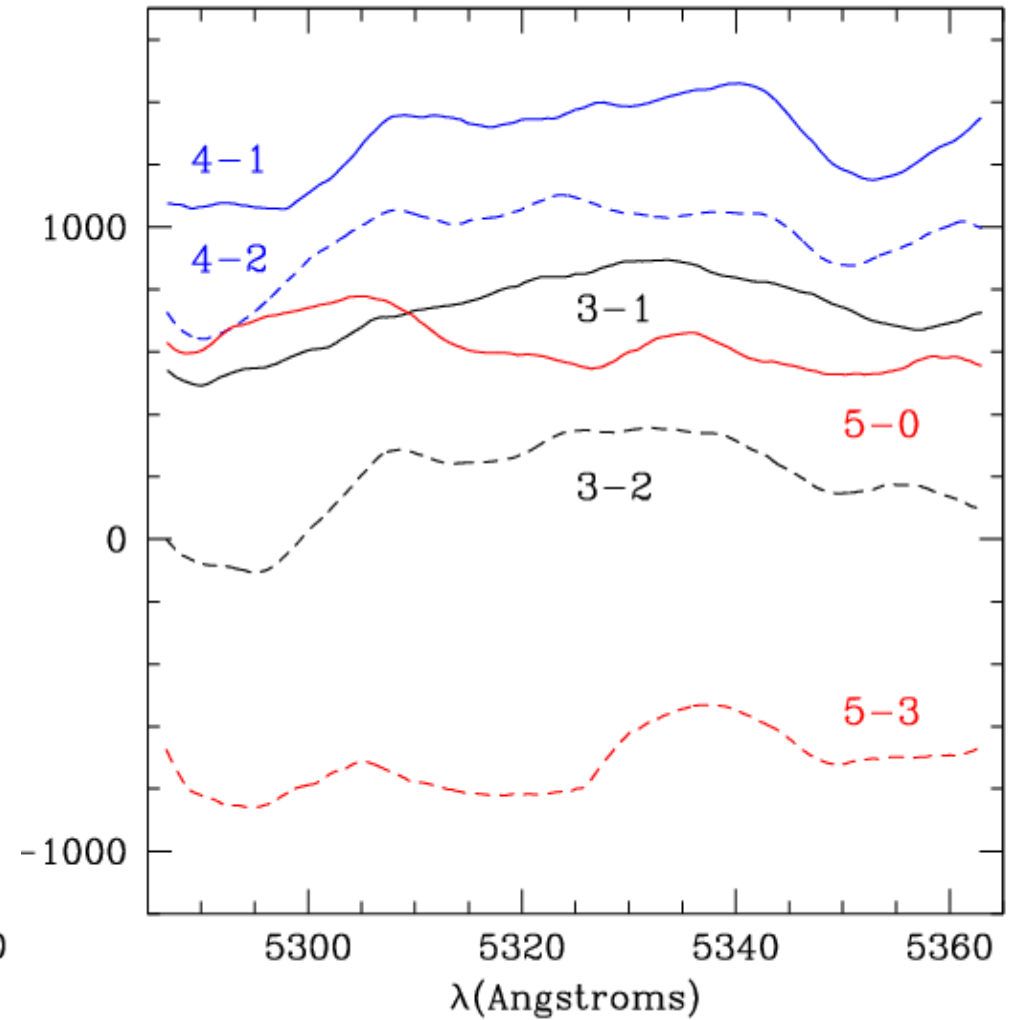
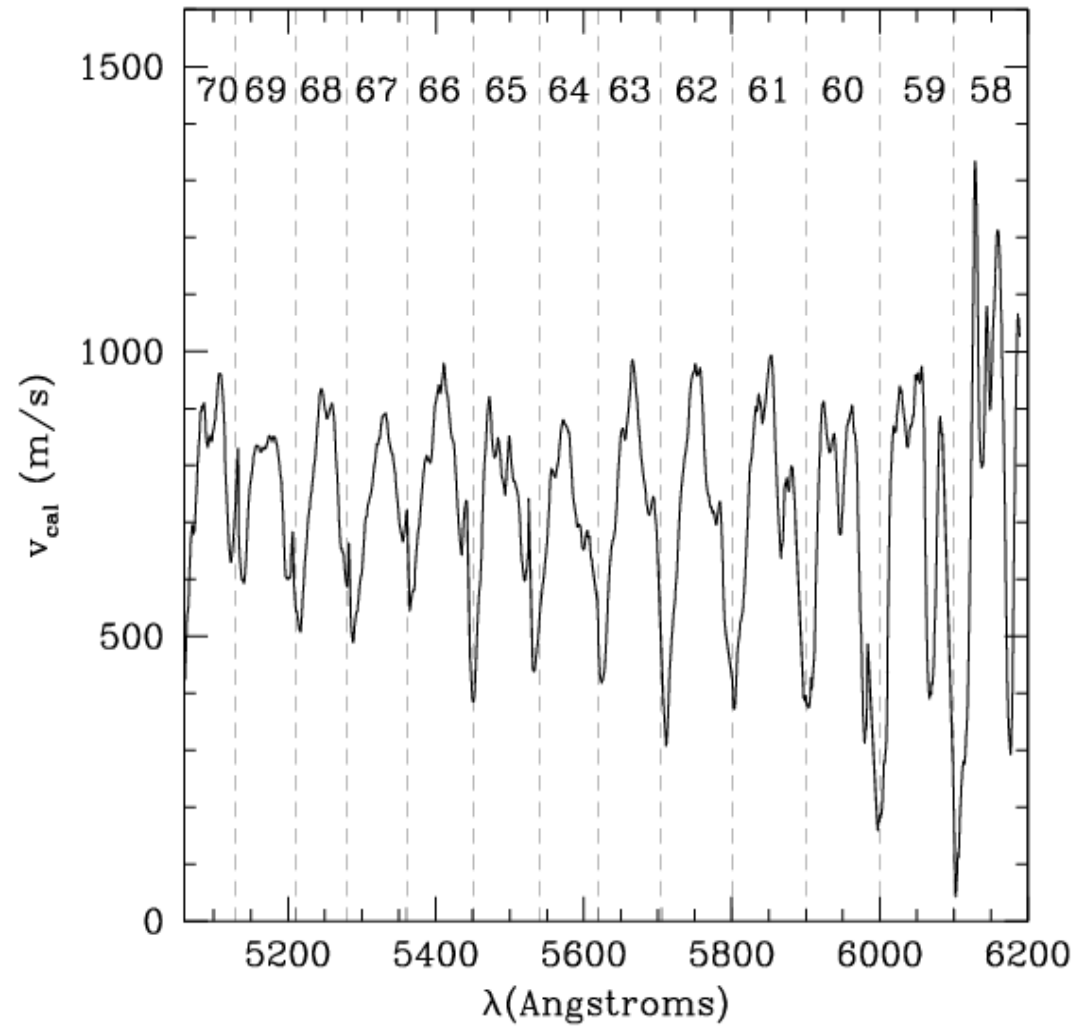
- Conjugate satellite OH lines at $z \sim 0.247$:

$$[\Delta X/X] = (-1.18 \pm 0.45) \times 10^{-5} \quad (X \equiv g_p[\alpha^2\mu]^{1.85})$$

2.6 σ result ! 160-hr. Arecibo run under way.

OPTICAL WAVELENGTH CALIBRATION ?

(Griest et al. 2010, ApJ)



INVERSION AND ROTATIONAL LINES

- Comparisons between NH_3 and rotational lines:

Sensitive to changes in $\mu^{3.5}$.

(Flambaum & Kozlov 2007, Phys. Rev. Lett.)

- Best target: $z \sim 0.685$ absorber towards B0218+357.

(Henkel et al. 2005, A&A)

- Best result so far: NH_3 versus HCN & HCO^+ lines.

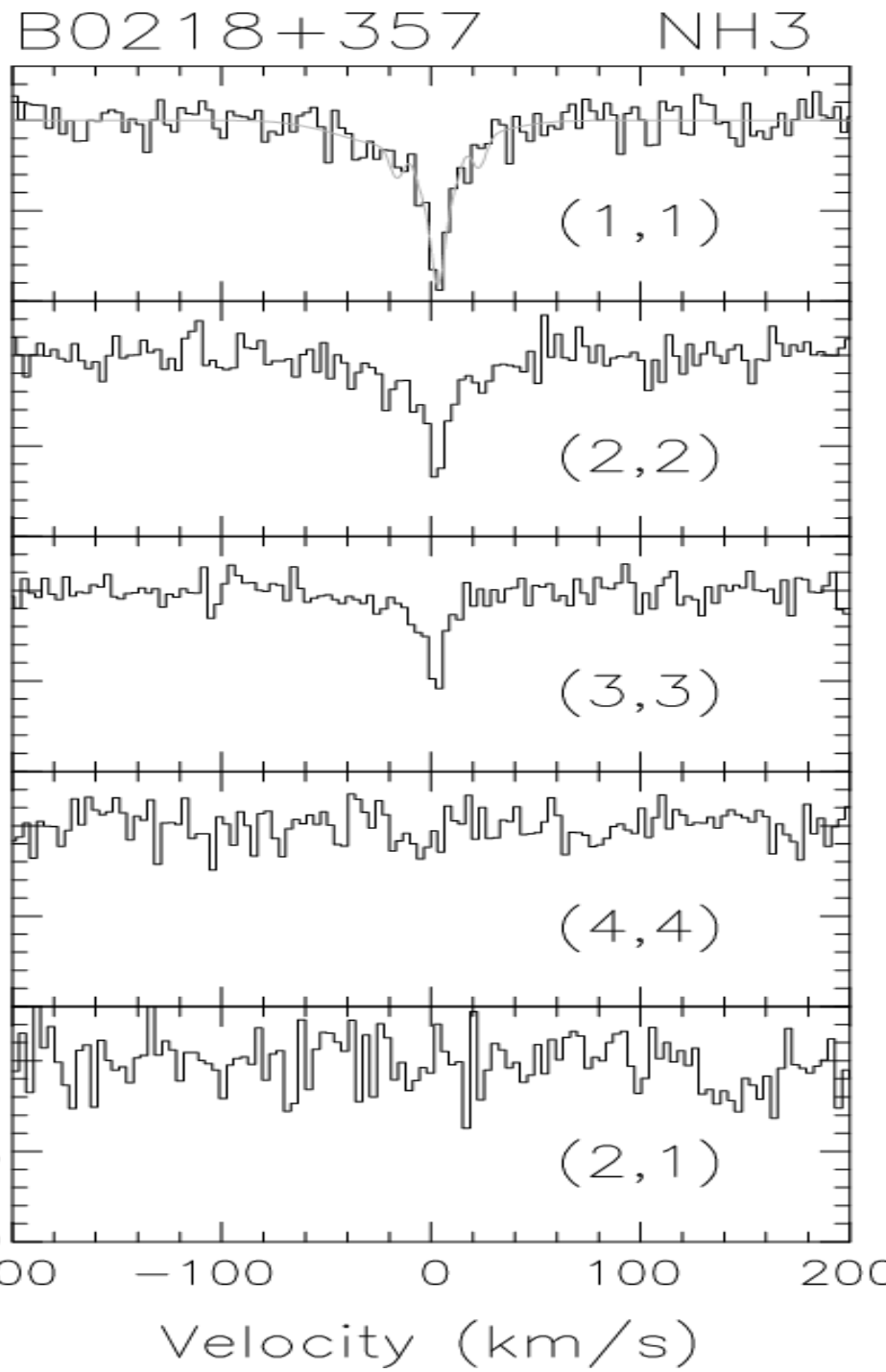
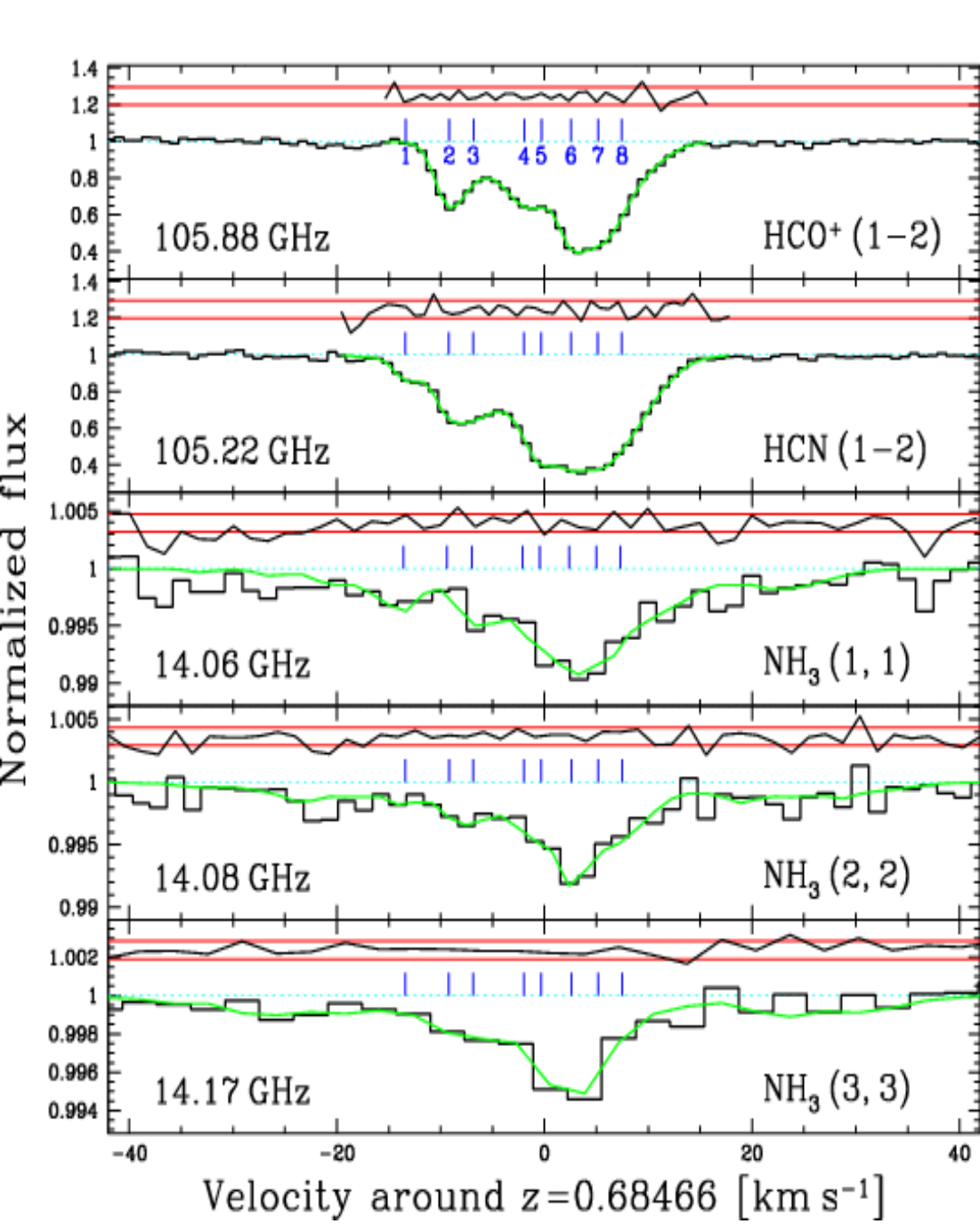
$$[\Delta\mu/\mu] < 1.8 \times 10^{-6} \quad (z \sim 0.685)$$

(Murphy et al. 2008, Science)

- Optically-thick HCN & HCO^+ lines.

Widely-separated frequencies: 14 GHz & 105 GHz.

Low sensitivity in the NH_3 spectra.

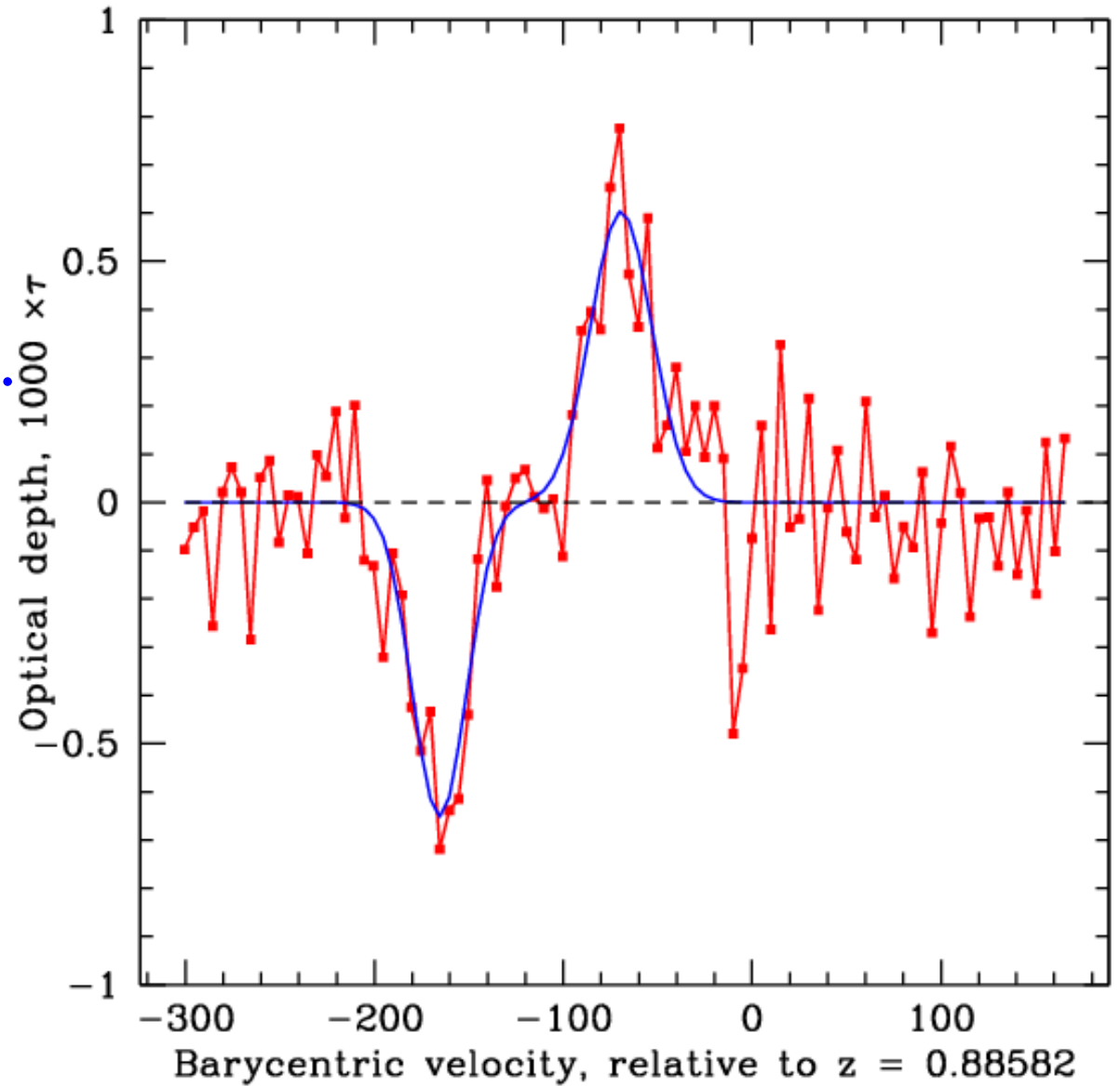


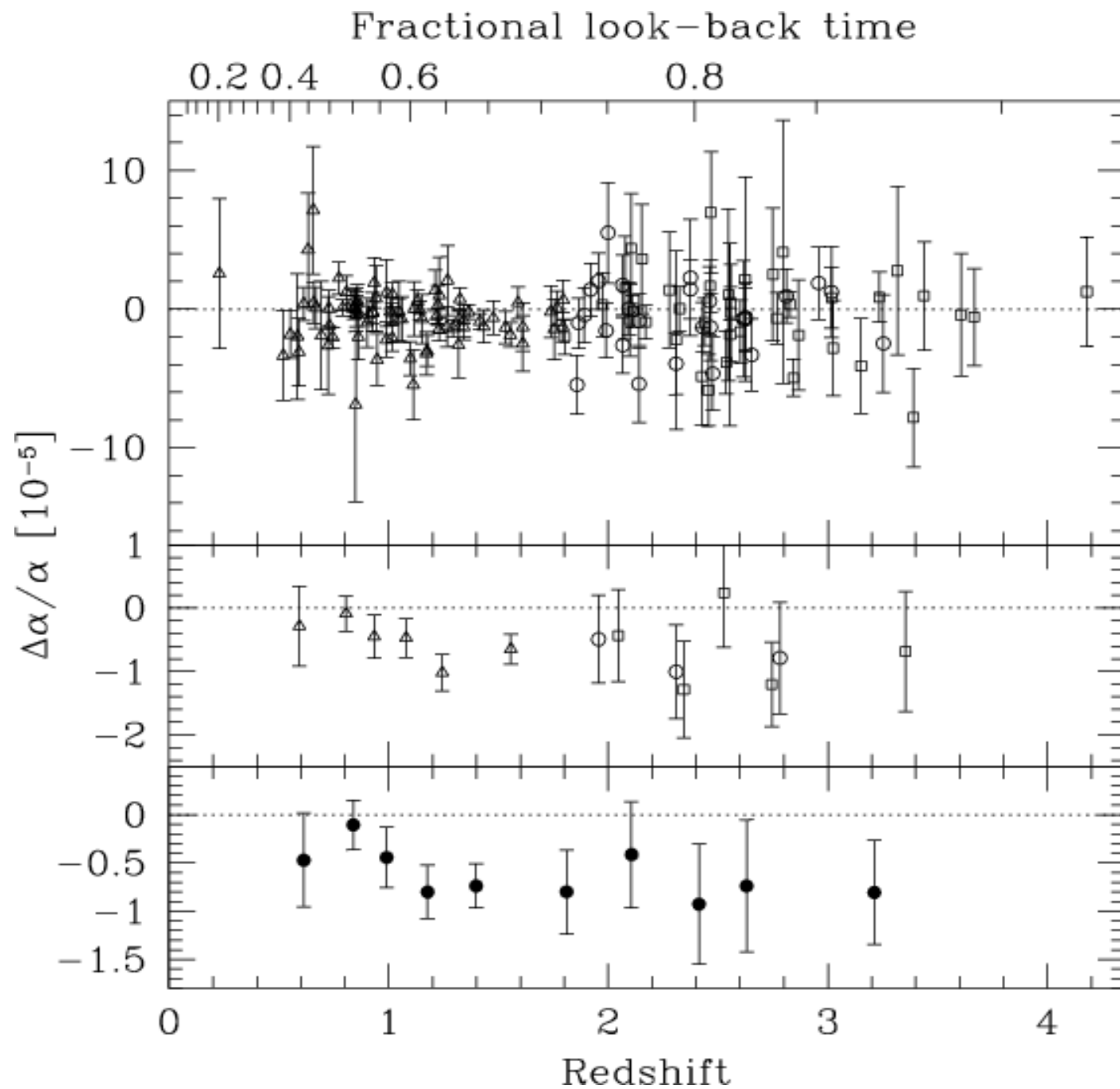
$[\Delta\mu/\mu] < 1.8 \times 10^{-6}$ (Murphy et al. 2008, Science)

1830-21, $z \sim 0.886$

1720 line shows both emission & absorption.

1612 observations in
May 2009.





$$[\Delta\alpha/\alpha] = (-5.4 \pm 1.1) \times 10^{-6} \quad (0 < z < 1.8)$$

(Murphy et al. 2004, Lect. Notes Phys.)

SYSTEMATIC EFFECTS

- Conjugate satellites method: no known systematics.
- Radio frequency calibration not an issue (< 15 m/s).
- Optical wavelength calibration for HI–CI method ?
Currently working on using an iodine cell to get accurate absolute wavelength calibration.
- Local velocity offsets between different species are the main likely source of systematics for the HI–OH and NH₃–CS methods. Note that no offsets are detected between CS and H₂CO lines.

New Targets

We need more radio absorbers !

- Blind* GBT CO/HCO⁺ absorption survey at $0.8 < z < 2$.
- Blind* Arecibo H₂CO absorption survey at $0.1 < z < 1$.
- GBT/GMRT searches for HI-21cm and OH absorption in ``red quasars'', strong MgII absorbers and DLAs.

Things are likely to improve significantly over the next few years with new telescopes like EVLA, ALMA, and ASKAP !

*Blind \equiv No optical selection

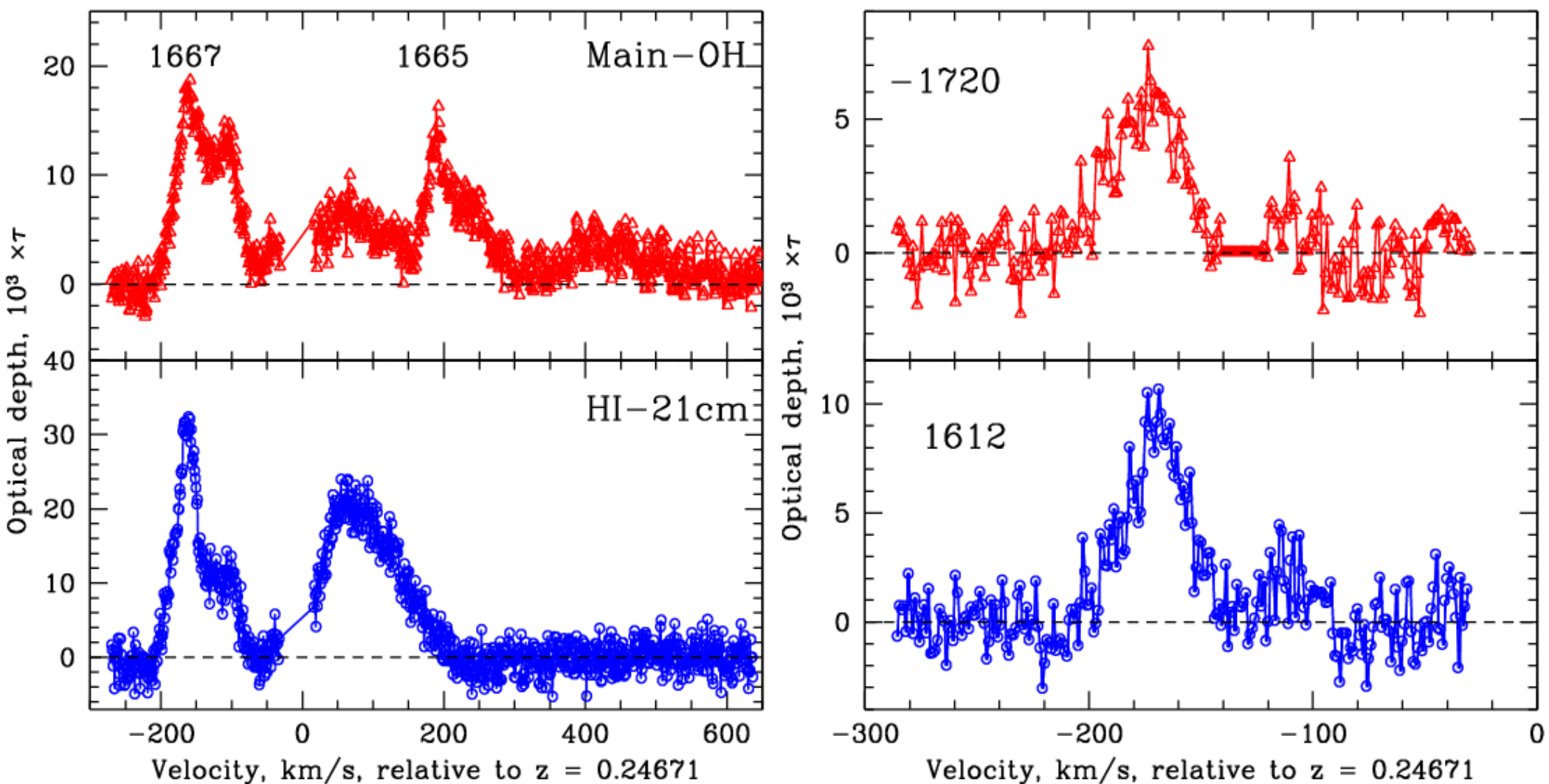
New Telescopes

- EVLA : Large bandwidth + high spectral resolution
 - ⇒ Blind 30 – 48 GHz absorption survey
 - ⇒ CO/HCO⁺ absorbers at $z > 0.8$!
- ALMA : Blind 125 – 163 GHz absorption survey
 - ⇒ CO/HCO⁺ absorbers at $z > 0.1$!
- ASKAP ⇒ HI-21cm absorption surveys at $0.4 < z < 1$.
- SKA ⇒ HI-21cm absorption & conjugate OH at $z < 4$.
 - ⇒ $[\Delta\alpha/\alpha], [\Delta\mu/\mu] < 10^{-7}$ from $z \sim 4$.

(2) OH-18cm & HI-21cm lines at $z \sim 0.765$

75 GBT hours on the OH lines, 35 on the HI-21cm line.

RMS noise ~ 0.0012 (OH), ~ 0.0018 (HI), per 1 km/s.

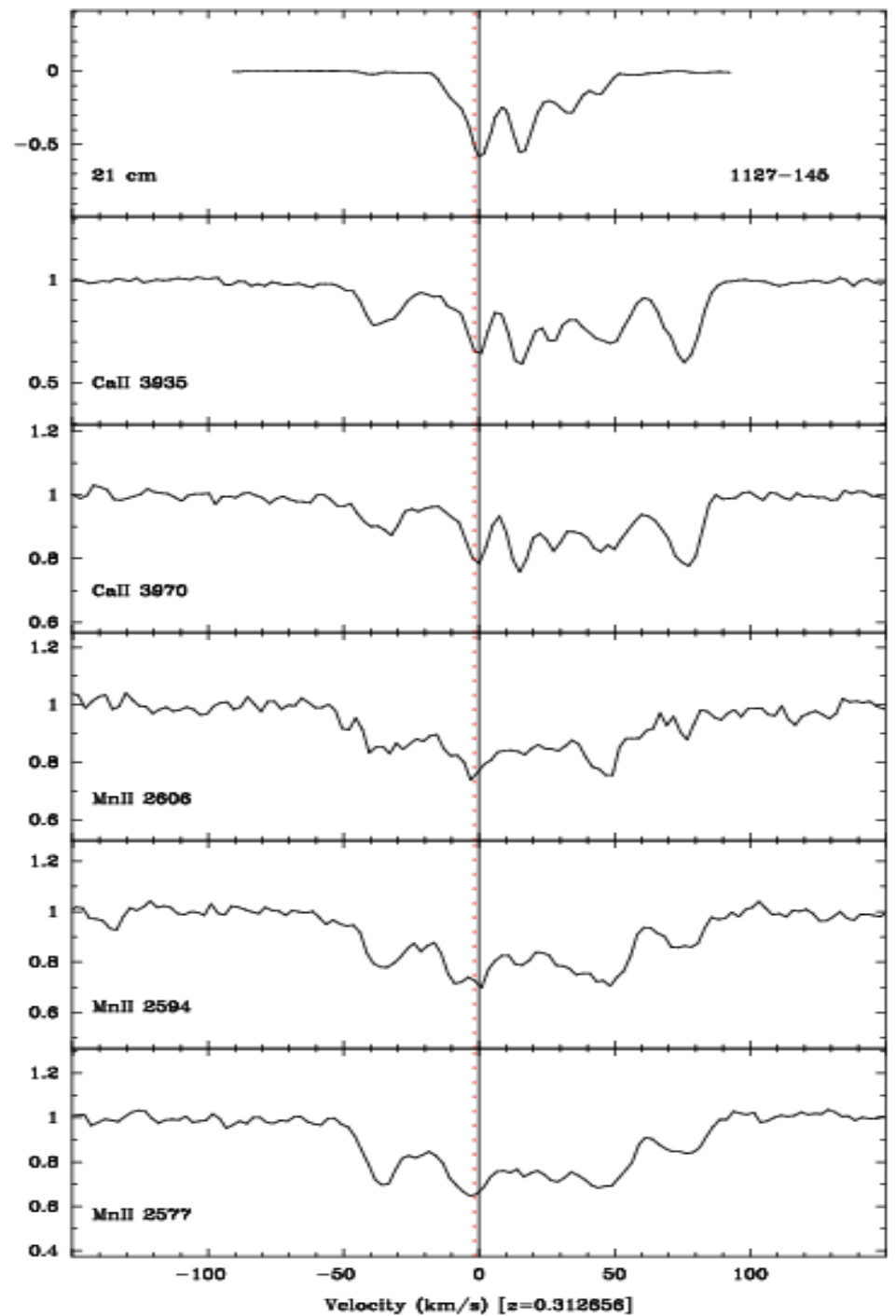
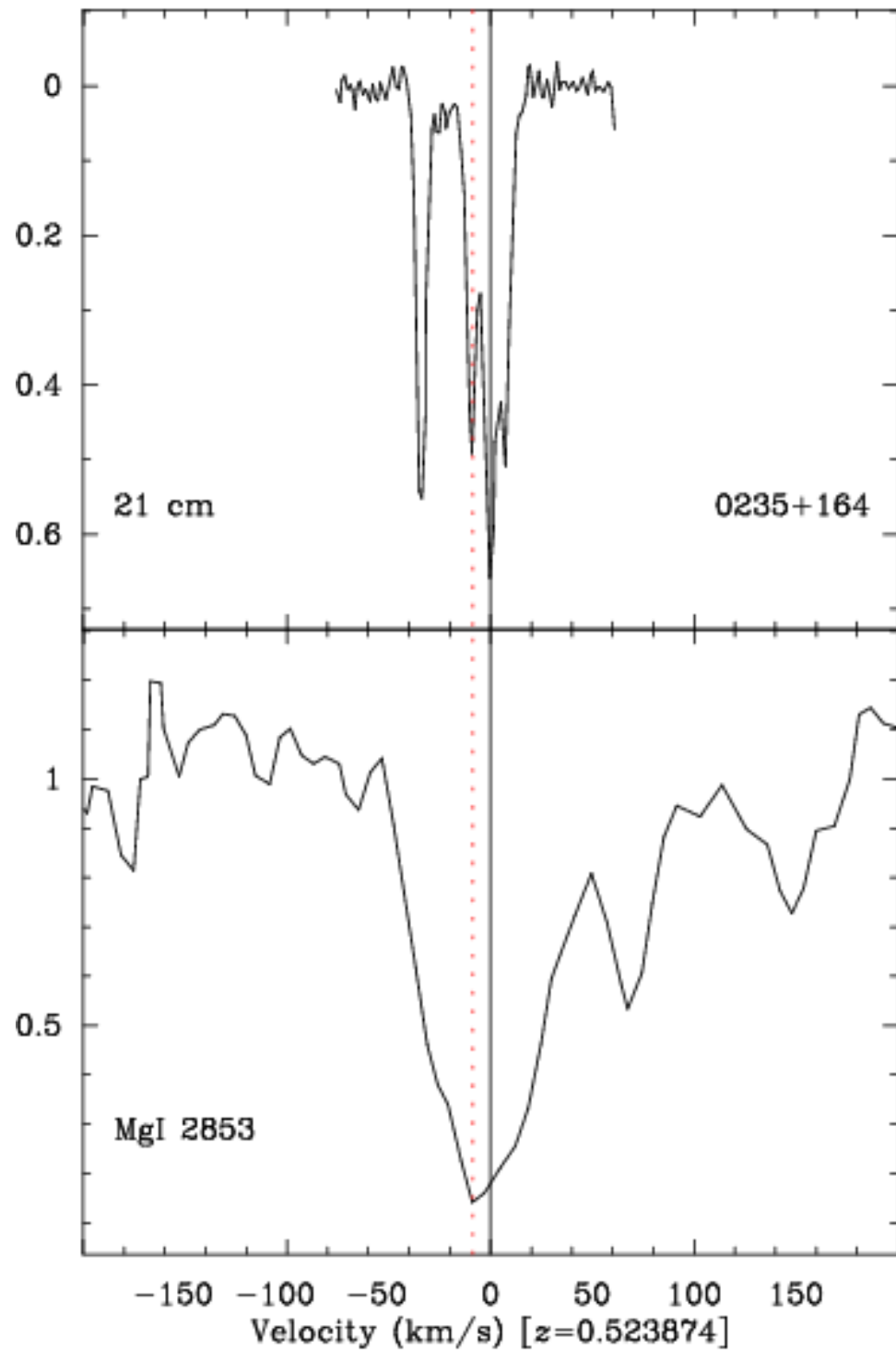


$$\Rightarrow [\Delta Y/Y] = (-5.2 \pm 4.3) \times 10^{-6} \quad (z \sim 0.77) \quad (Y \equiv g_p[\alpha^2 \mu]^{1.57})$$

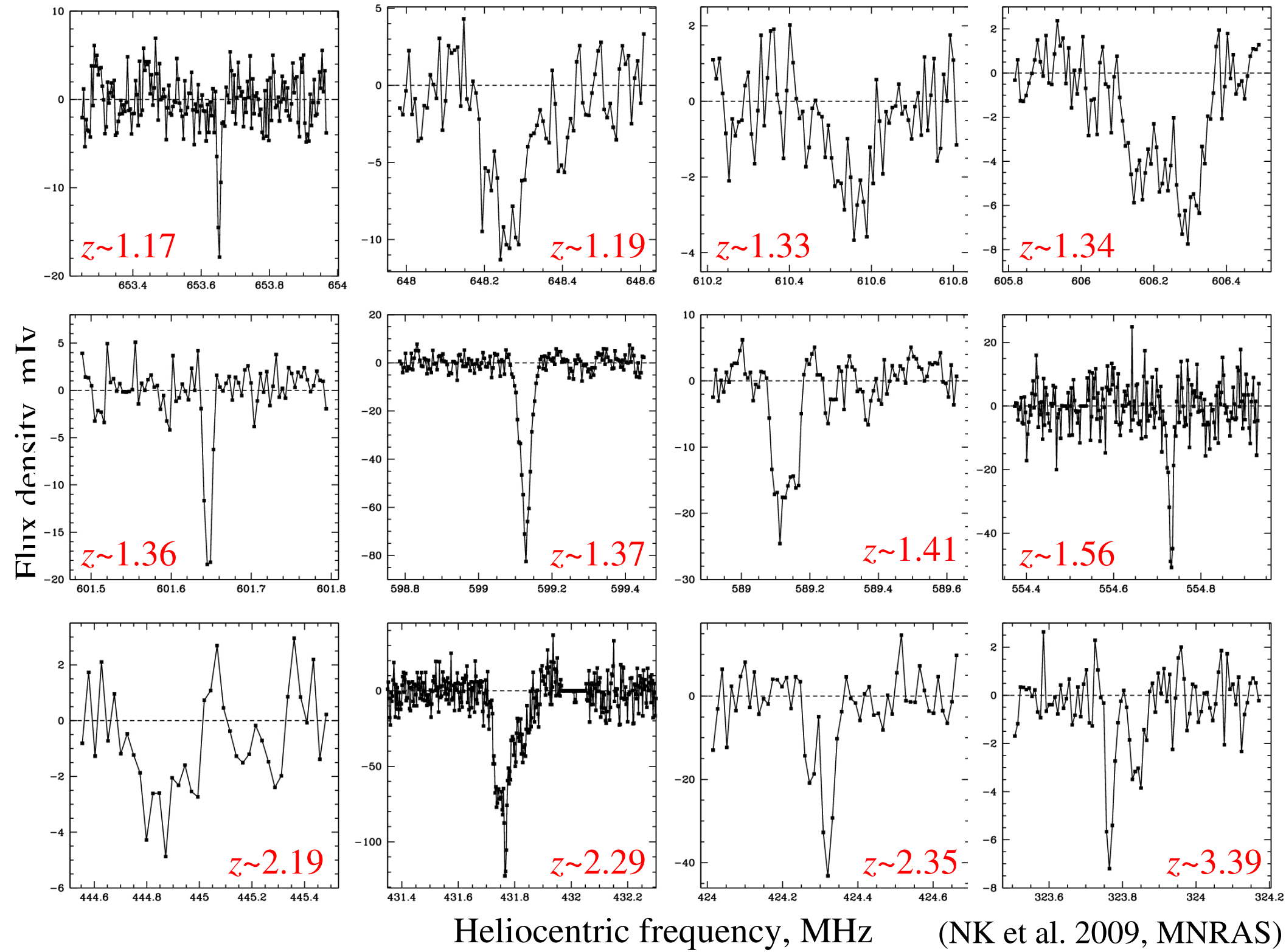
(1) HI-21cm AND UV RESONANCE LINES

- Comparisons between HI-21cm and UV resonance.
Sensitive to changes in $X \equiv g_p[\alpha^2/\mu]$.
(Wolfe et al. 1976, Phys. Rev. Lett.)
- Neutral species (e.g. CI, MgI) best, but ionized species more easily detected in redshifted HI-21cm absorbers.
- Single-component profiles best for such comparisons.
- Until recently, few HI-21cm absorbers known at $z > 1$.
- Best current result: $[\Delta X/X] < 2.0 \times 10^{-5}$ ($0 < z < 1.1$).
Uses ionized species, complex line profiles.

(Tzanavaris et al. 2007, MNRAS)

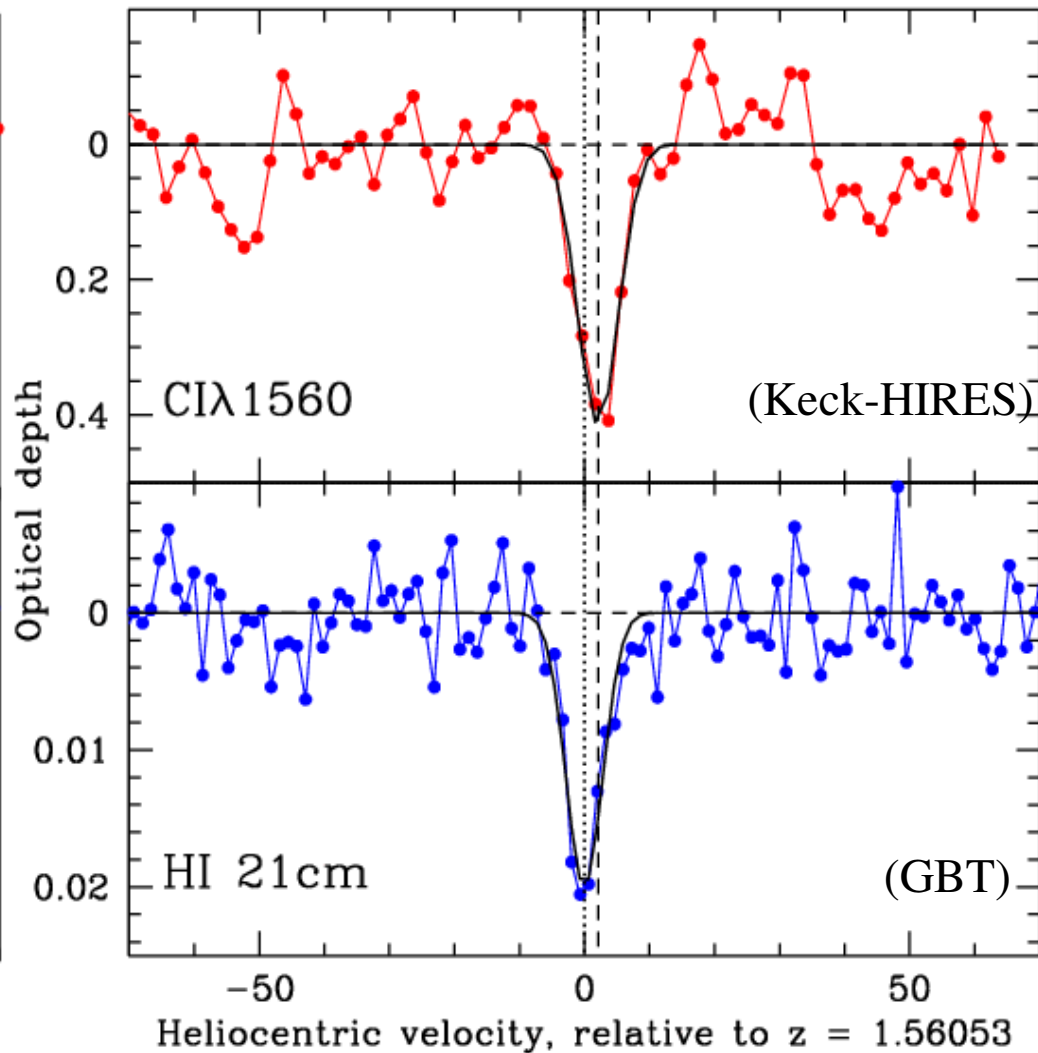
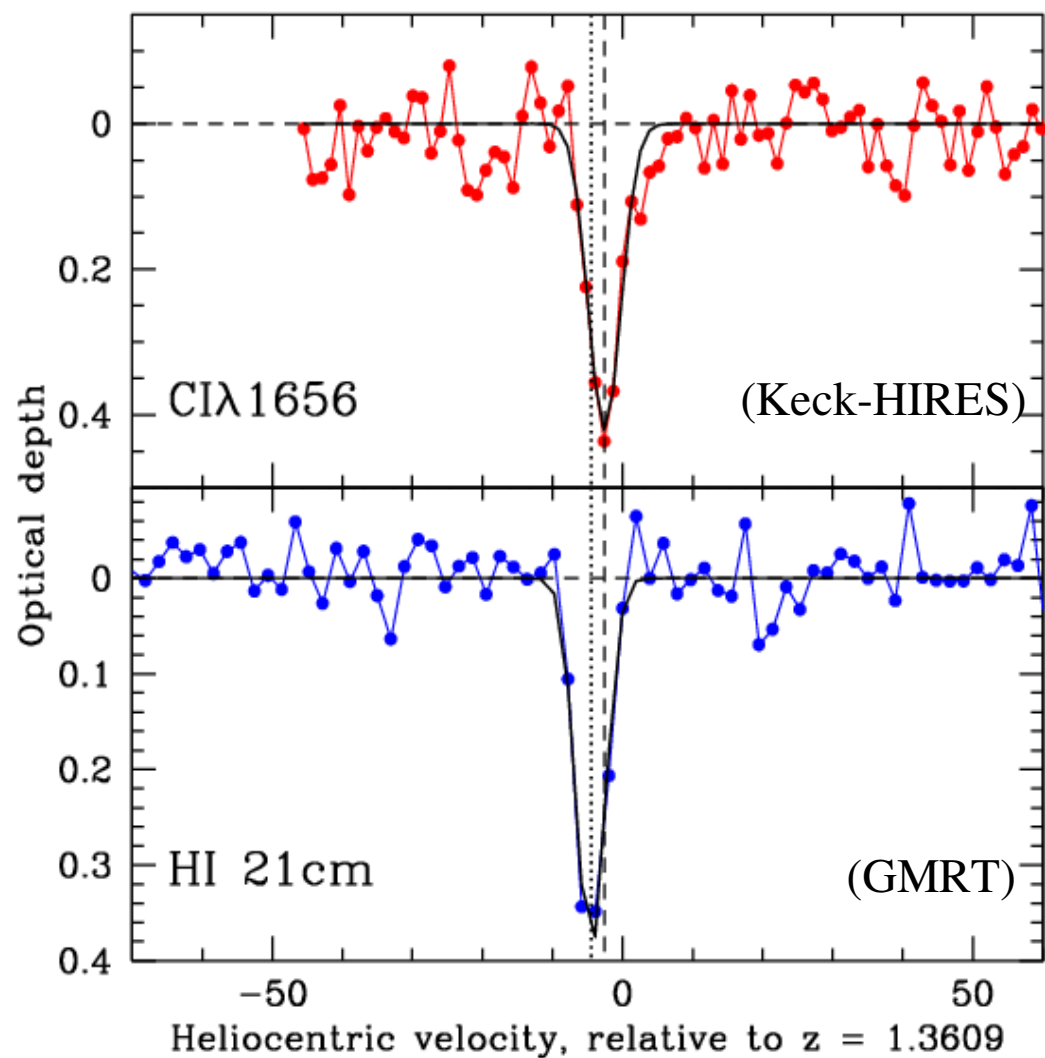


(Tzanavaris et al. 2007, MNRAS)



2337-011, $z \sim 1.3609$

0458-020, $z \sim 1.5605$



- Single-component models in all cases (giving $\chi^2 \sim 1$).

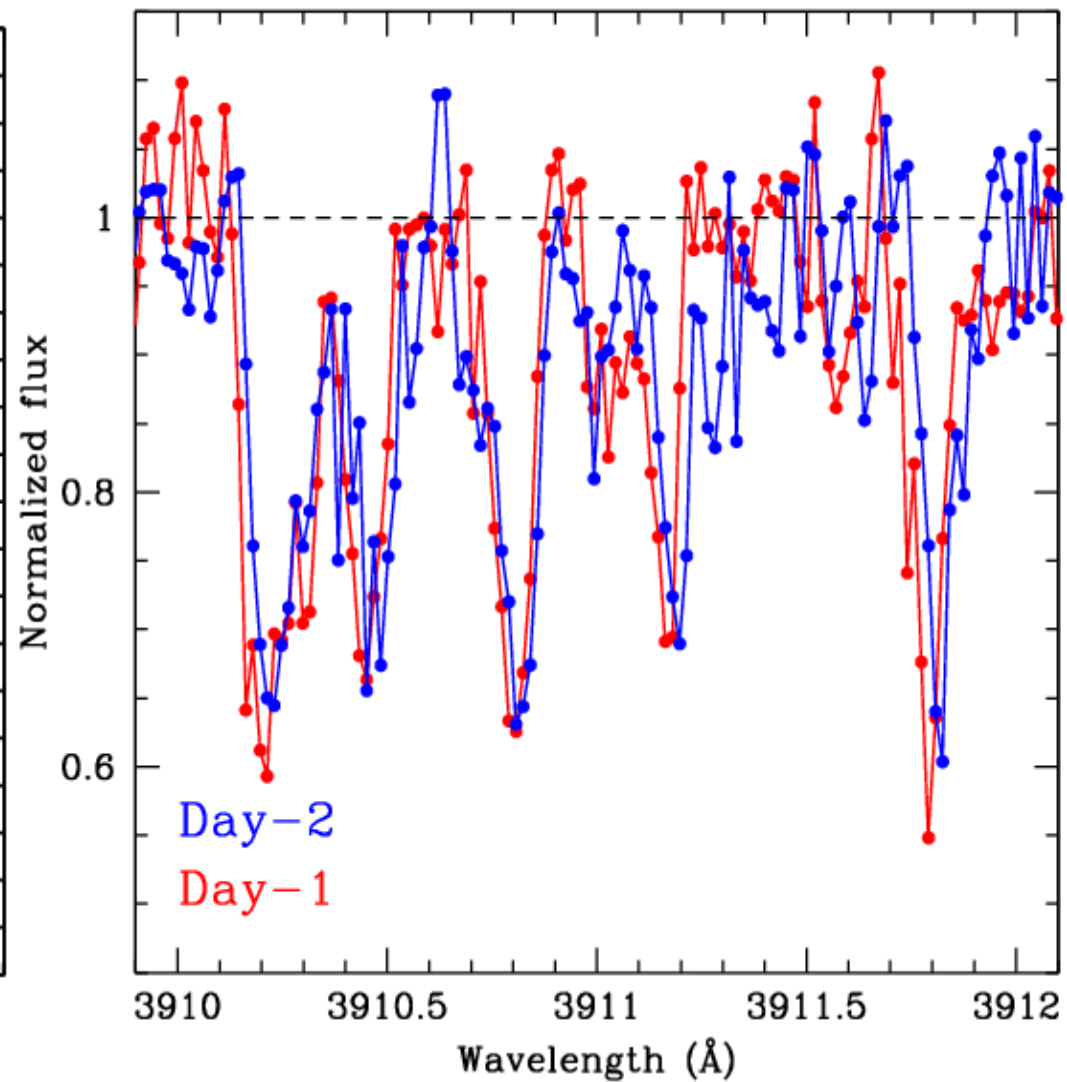
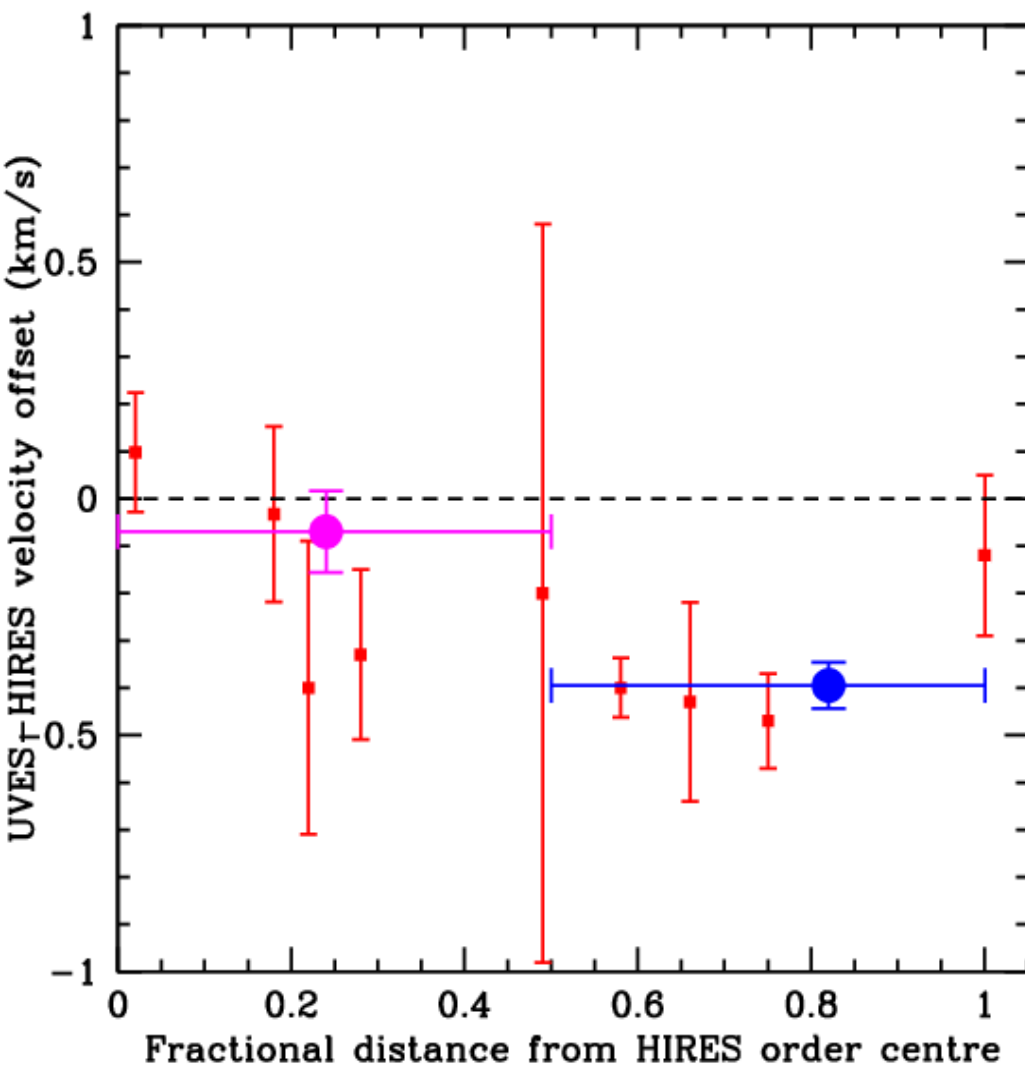
$$2337-011 \Rightarrow [\Delta X/X] = (+6.64 \pm 0.84) \times 10^{-6}$$

$$0458-020 \Rightarrow [\Delta X/X] = (+7.0 \pm 1.8) \times 10^{-6}$$

- $\Rightarrow [\Delta X/X] = (+6.8 \pm 1.0) \times 10^{-6} \quad (0 < z < 1.46)$

- Corresponds to a velocity offset of +2 km/s between HI-21cm and CI lines! **But...**

- Velocity offsets of ~ 0.5 km/s between HIRES and UVES spectra of J2231-0050!
- ~ 2 km/s offsets between HIRES spectra of 2340-0053!
(see also Griest et al. 2010, ApJ)



- Single-component models in all cases (giving $\chi^2 \sim 1$).
 - 2337-011 $\Rightarrow [\Delta X/X] = (+6.64 \pm 0.84) \times 10^{-6}$
 - 0458-020 $\Rightarrow [\Delta X/X] = (+7.0 \pm 1.8) \times 10^{-6}$
 - $\Rightarrow [\Delta X/X] = (+6.8 \pm 1.0) \times 10^{-6} \quad (0 < z < 1.46)$
- Corresponds to a velocity offset of +2 km/s between HI-21cm and CI lines! **But...**
- Systematic errors of 2 km/s in optical velocity scale ?
 - $\Rightarrow [\Delta X/X] = [+6.8 \pm 1.0 (stat.) \pm 6.7 (syst.)] \times 10^{-6}$
- For consistency with the Keck-HIRES many-multiplet result: $[\Delta g_p/g_p] - [\Delta \mu/\mu] \geq (1.14 \pm 0.24) \times 10^{-5}$

WHAT ARE FUNDAMENTAL CONSTANTS ?

(e.g. Uzan 2011, Liv. Rev. Rel.)

- Fundamental constants: Free parameters of a theory; values not predicted but put in from measurements.
- Include coupling constants, particle masses, etc:
e.g. c , e , \hbar , $\alpha = e^2/\hbar c$, $\mu = m_p/m_e$, etc.
- Standard Model & General Relativity: 20 ``constants" !
- Why do the constants take specific values ?
- Are these values fixed in spacetime ? If so, why ?
- α : *It's one of the greatest damn mysteries of physics!*
(Feynman 1985, in QED: The Strange...)

from ours and there are differences in the fitting procedure; (c) despite these differences, 70% of their individual measurements are consistent with that quoted in [3].

Point 1.—In [3], we explain our procedure in detail. In particular, we used $\Delta\alpha/\alpha$ as an external parameter (as in [5]) when Murphy *et al.* used it as an additional fitting parameter. This choice has been tested extensively using simulations. To reiterate this point, we have refitted the systems in our sample using VPFIT keeping $\Delta\alpha/\alpha$ as an external parameter (see Fig. 1). Our new results (closed circles) match our original results (squares) and Murphy *et al.*'s (open squares) within 1σ . We point out that fluctuations in χ^2 curves get indeed smoothed after a large number of iterations but the results from the first and last iterations are found to be very similar. We find significant differences in only two cases.

Point 2.—In the course of the analysis presented in [3] we define two errors for each pixel: one is the error calculated by the ESO-pipeline and one is calculated from the scatter of the different exposures. In principle the two errors should be of the same order but usually they are not because of the nontrivial observational procedure. This can be estimated by comparing the above errors with the scatter in the continuum. Murphy *et al.* used the data made available on the web with standard errors. In Fig. 2 we show the signal-to-noise ratio (SNR) ($1/\sigma$) used by Murphy *et al.* (dots) and by Srianand *et al.* (stars) versus the SNR as measured in the continuum around the absorption lines used in our analysis. Clearly the errors used by Murphy *et al.* are underestimated. Ours are consistent in the low SNR regime and slightly overestimated at high SNR. These measurements are done in the continuum and differences are more crucial in the lines (where we cannot perform this experiment). In addition, our procedure takes into account the differences in spectral resolution in different settings, while this is not the case with VPFIT.

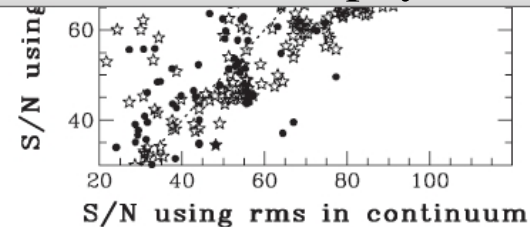


FIG. 2. Comparison of two error spectra.

Point 3.—Despite these differences, it is clear from Fig. 3 (left panel) and Table 1 of Murphy *et al.* [4] that their measurements match ours [3] at $\leq 1\sigma$ level for 16 systems. The corresponding weighted mean is $\Delta\alpha/\alpha = (+0.06 \pm 0.18) \times 10^{-5}$. For the same systems Chand *et al.* find $\Delta\alpha/\alpha = (+0.03 \pm 0.09) \times 10^{-5}$. It is also easy to recognize that only two $>4\sigma$ deviant systems (the $z = 1.5419$ system towards 0002–422 [$\Delta\alpha/\alpha = (-4.655 \pm 0.988) \times 10^{-5}$] and the $z = 0.8593$ system towards 0122–380 [$\Delta\alpha/\alpha = (-4.803 \pm 0.941) \times 10^{-5}$]), dominate the final result by Murphy *et al.*. Excluding these systems we get $\Delta\alpha/\alpha = (-0.19 \pm 0.16) \times 10^{-5}$ for 21 points. Our reanalysis using VPFIT keeping constant resolution across the spectrum and with identical initial guess parameters leads to $\Delta\alpha/\alpha = (0.01 \pm 0.15) \times 10^{-5}$ for 21 systems (excluding two systems that deviate at more than 3σ level) with very little scatter ($\chi_v^2 \sim 1$) contrary to the claims by Murphy *et al.* [4]. Thus we believe, the results presented in [2,3] are robust (although errors are probably larger) and are not due to the failure in our fitting procedure.

Our result disagrees with earlier claims for a variation of α by $>3\sigma$. We are awaiting results from the full independent analysis of ultraviolet and visual Echelle spectrograph data by Murphy *et al.*.