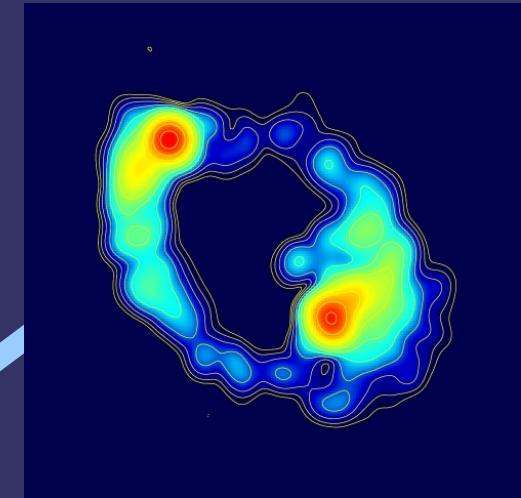
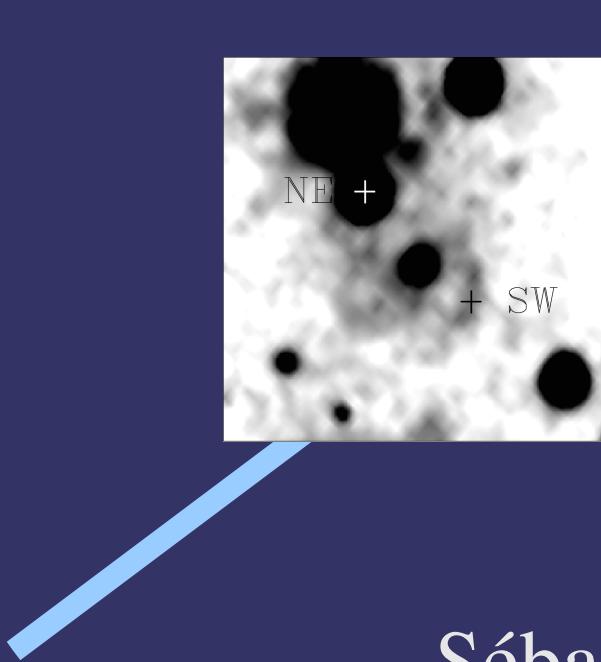


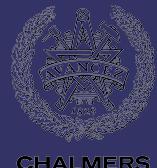
The z=0.89 molecular absorber toward the lensed blazar PKS 1830-211



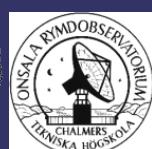
Sébastien Muller

Onsala Space Observatory, Nordic ARC

Chalmers, Sweden



CHALMERS



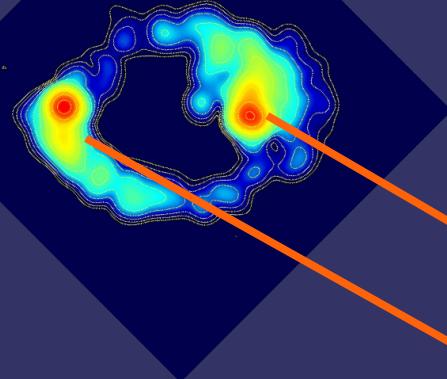
EUROPEAN ARC
ALMA Regional Centre || Nordic

Outline

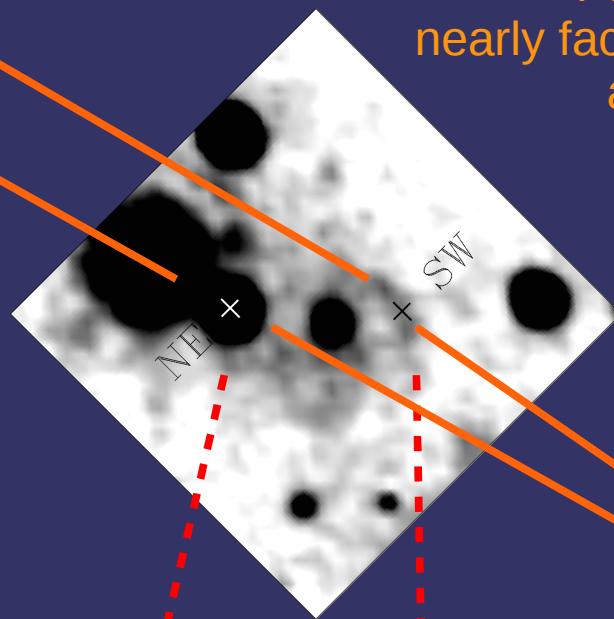
- The PKS 1830-211 absorber
- How does chemistry look like in the disk of a $z=0.89$ galaxy ?
- Molecules as cosmological probes
 - CMB temperature @ $z=0.89$
 - Constancy of fundamental constants
- (Chemical evolution and isotopic ratios at $\frac{1}{2}$ age of the Universe)

The line(s) of sight to PKS1830-211

Lensed blazar at $z=2.5$

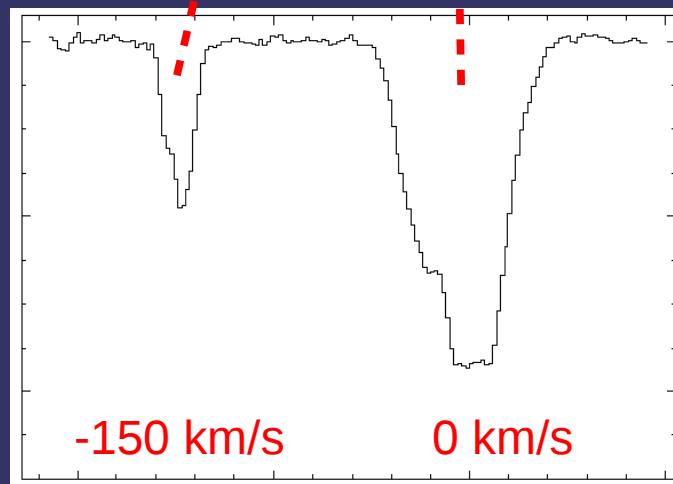


Foreground
nearly face-on spiral galaxy
at $z=0.89$



1''

Molecular absorption
by intervening clouds



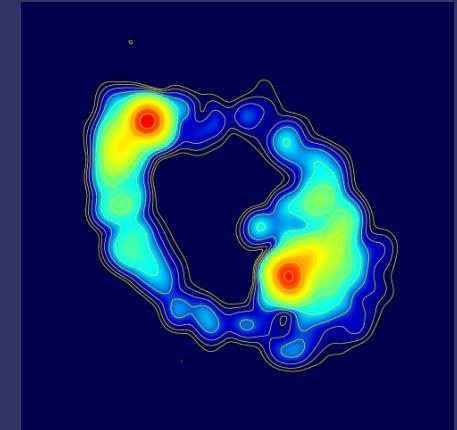
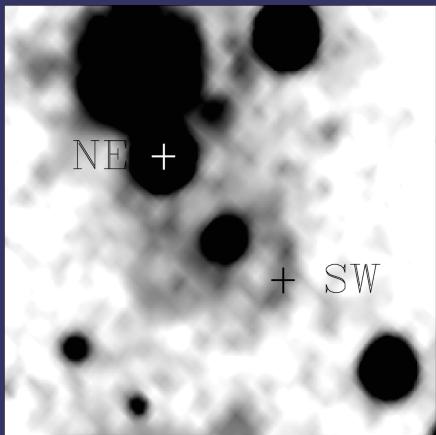
The $z=0.89$ radio molecular absorber toward PKS1830-211 is the most interesting one at $z>0$

Discovered in 1996 by Wiklind & Combes

Of the only 5 distant radio molecular absorbers known to date
 $(0.24 < z < 0.89)$

The PKS1830-211 (main) absorber has:

- highest redshift: $z=0.89$
- brightest mm continuum ($SW>\sim 1$ Jy @3mm)
- illumination beam of a few pc !
- largest amount of absorbing material
 $N(H_2)\sim 10^{22} \text{ cm}^{-2}$
- molecular absorption in two independent LOS
- 42+ species detected toward the SW image
- time variations (continuum & molecular profile)



Chemical inventory toward the SW los

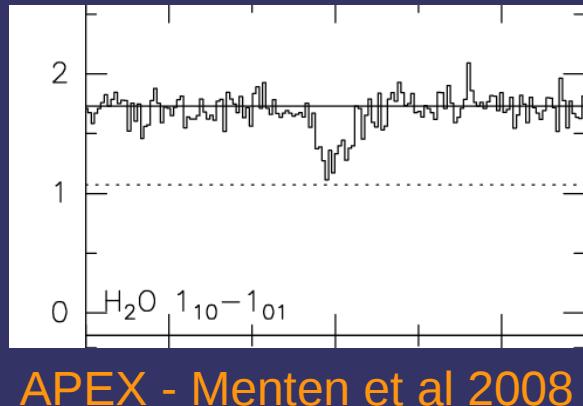
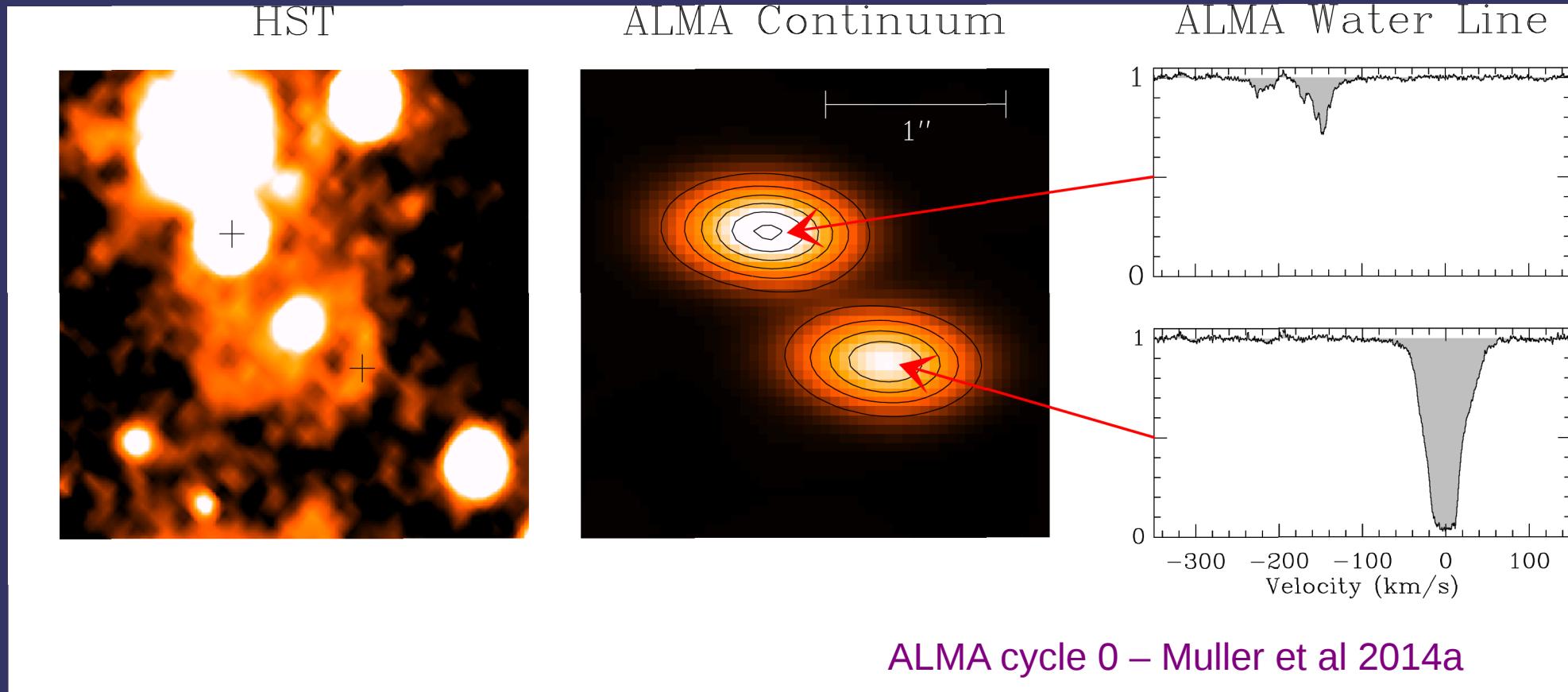
<u>1 atom</u>	<u>2 atoms</u>	<u>3 atoms</u>	<u>4 atoms</u>	<u>5 atoms</u>	<u>6 atoms</u>	<u>7 atoms</u>
H	CH	NH ₂	NH ₃	CH ₂ NH	CH ₃ OH	CH ₃ NH ₂
C	OH	H ₂ O	H ₂ CO	c-C ₃ H ₂	CH ₃ CN	CH ₃ CCH
	CO	C ₂ H	I-C ₃ H	I-C ₃ H ₂	NH ₂ CHO	CH ₃ CHO
	CS	HCN	HNCO	H ₂ CCN		
SiO	HNC	HOCO+		H ₂ CCO		
NS	N ₂ H ⁺	H ₂ CS		C ₄ H		
SO	HCO+			HC ₃ N		
SO+	HCO					
	HOC+					42 species
	H ₂ S					+ 14 isotopic variants
	H ₂ Cl ⁺					
	HCS+					
	C ₂ S					
PdBI, ATCA, ALMA						

(+ SH⁺, H₂O⁺, HCl, CN in ALMA c1
And more to come in c2)

@ z=0.89 !

Muller et al 2006, 2011, 2013, 2014

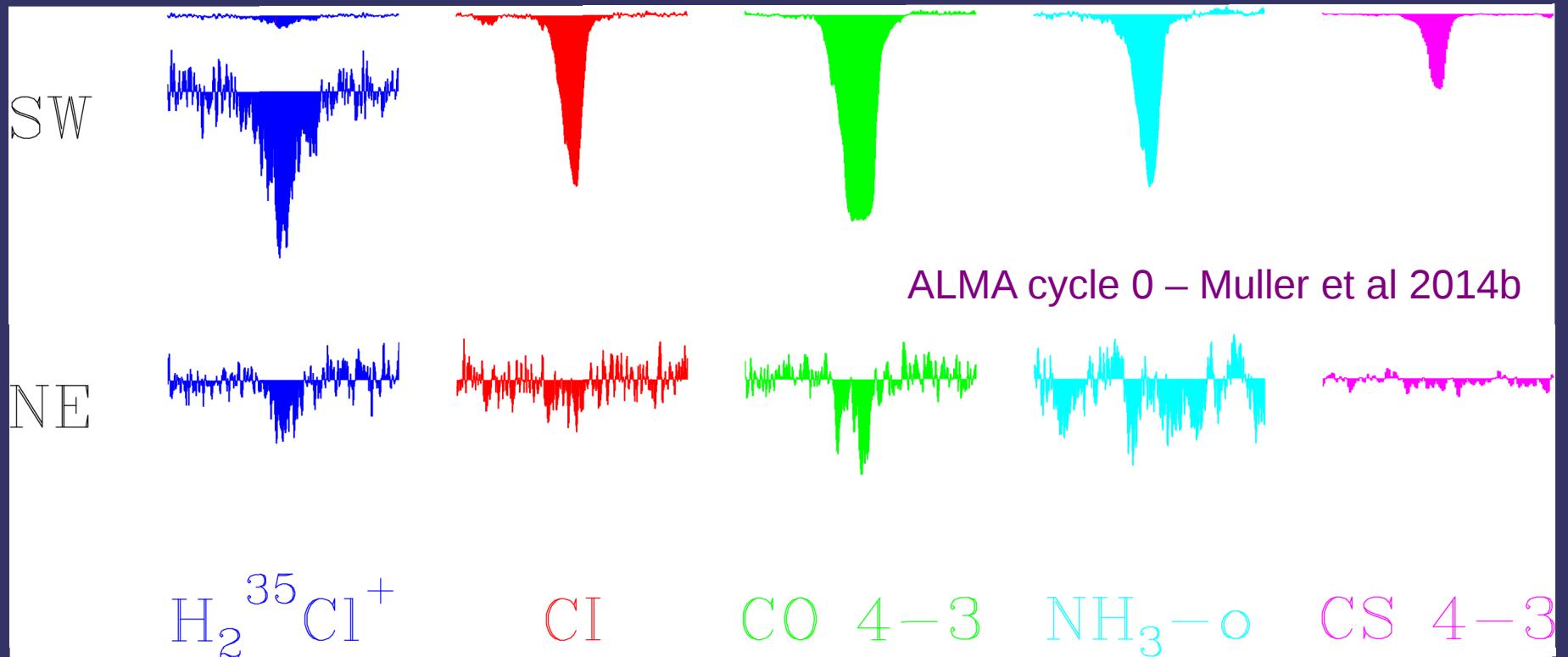
PKS 1830-211 viewed with ALMA



The 557 GHz (ortho) water line:

- Deepest absorption of all lines (so far)
- Heavy saturation toward SW LOS
- Multiple velocity components toward both LOS
- Absorption spanning a large velocity range

Chemical comparison of the two LOS: the case of chloronium



- H_2Cl^+ recently discovered in the ISM with Herschel (Lis et al 2010)
- Surprising detection of H_2Cl^+ toward the NE LOS
 - > Chemical enhancement ($\sim 7x$)
 - > H_2Cl^+ sensitive to UV radiation field = Tracer of diffuse gas
(Lis et al 2010, Neufeld & Wolfire 2009, Neufeld et al 2012)
- H_2O^+ showing the same trend (only those two species so far)

Brief summary “Chemistry in PKS1830”

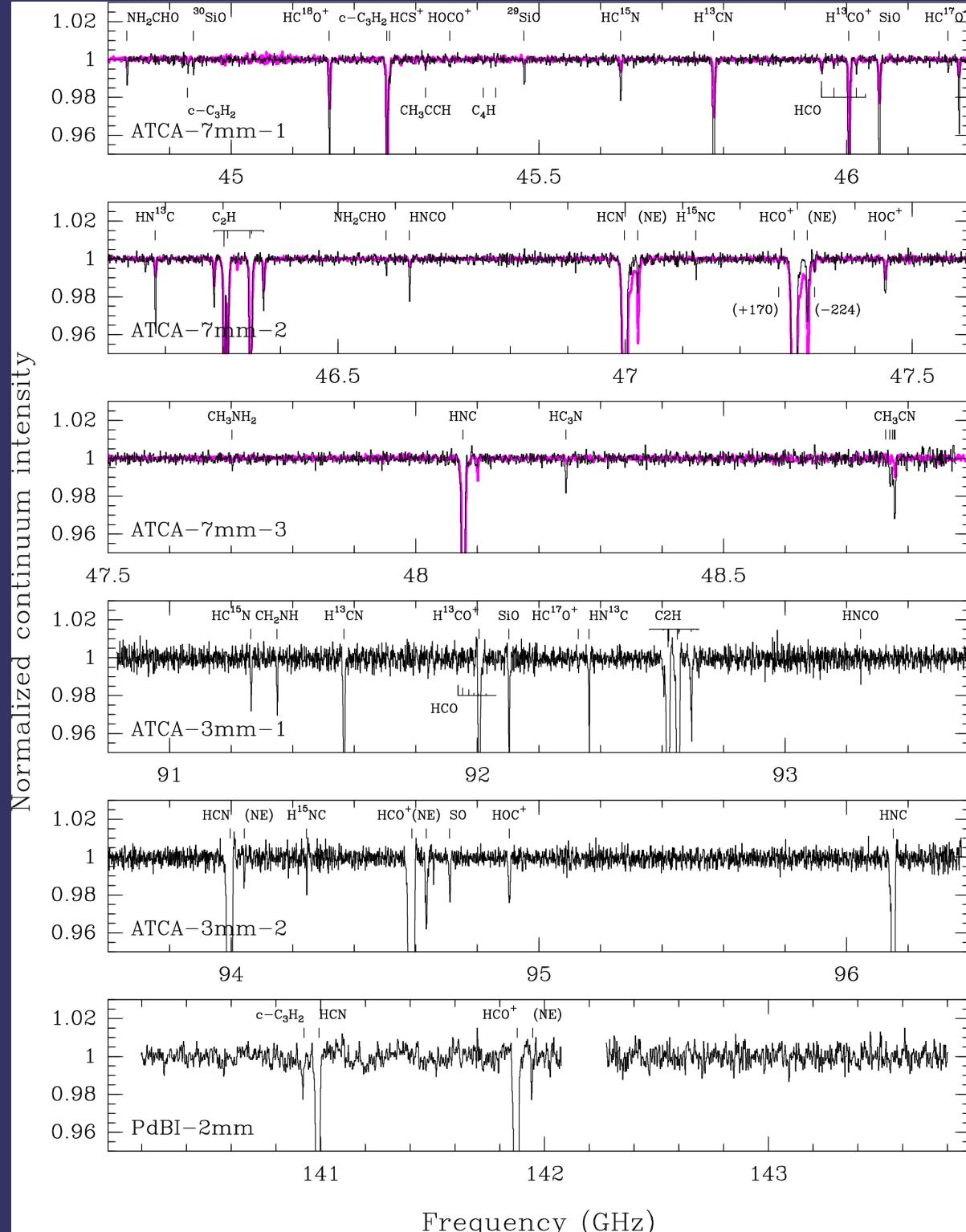
- Derive (robust) molecular abundances

Chemistry typical of diffuse/translucent clouds in the MW

- Observations of species difficult to observe from the ground at $z=0$
e.g. H₂O
- Herschel in the MW (PRISMAS) <=> ALMA at $z=0.89$
e.g., CH+, OH+, H₂O+, HF, ArH+, ...
with high-quality spectral baseline and no contamination by emission
- Time variations provide chance to investigate chemical correlation
- Search for new interstellar molecules ?

Molecules as cosmological probes

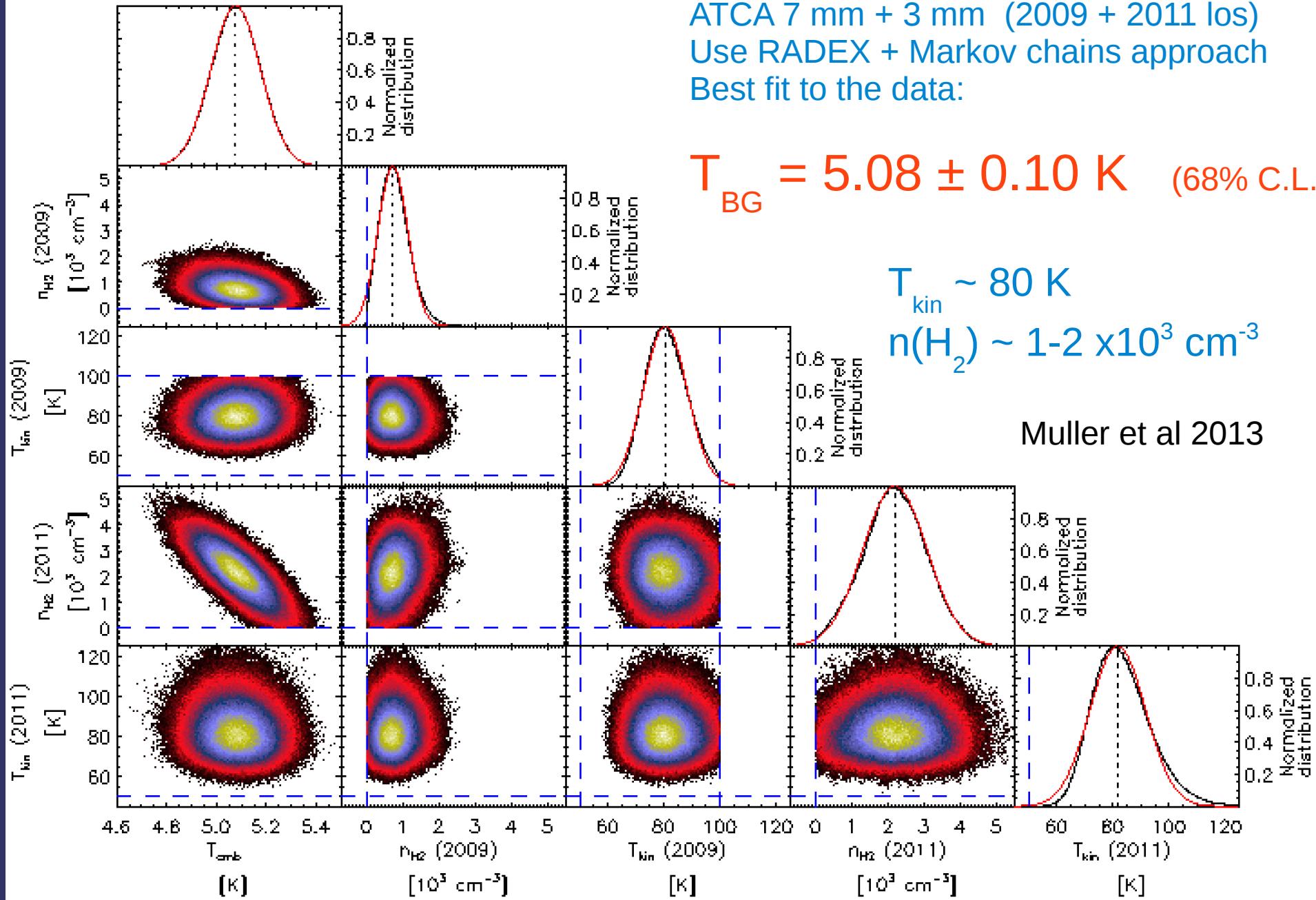
Measurement of the
cosmic microwave background
temperature at $z=0.89$



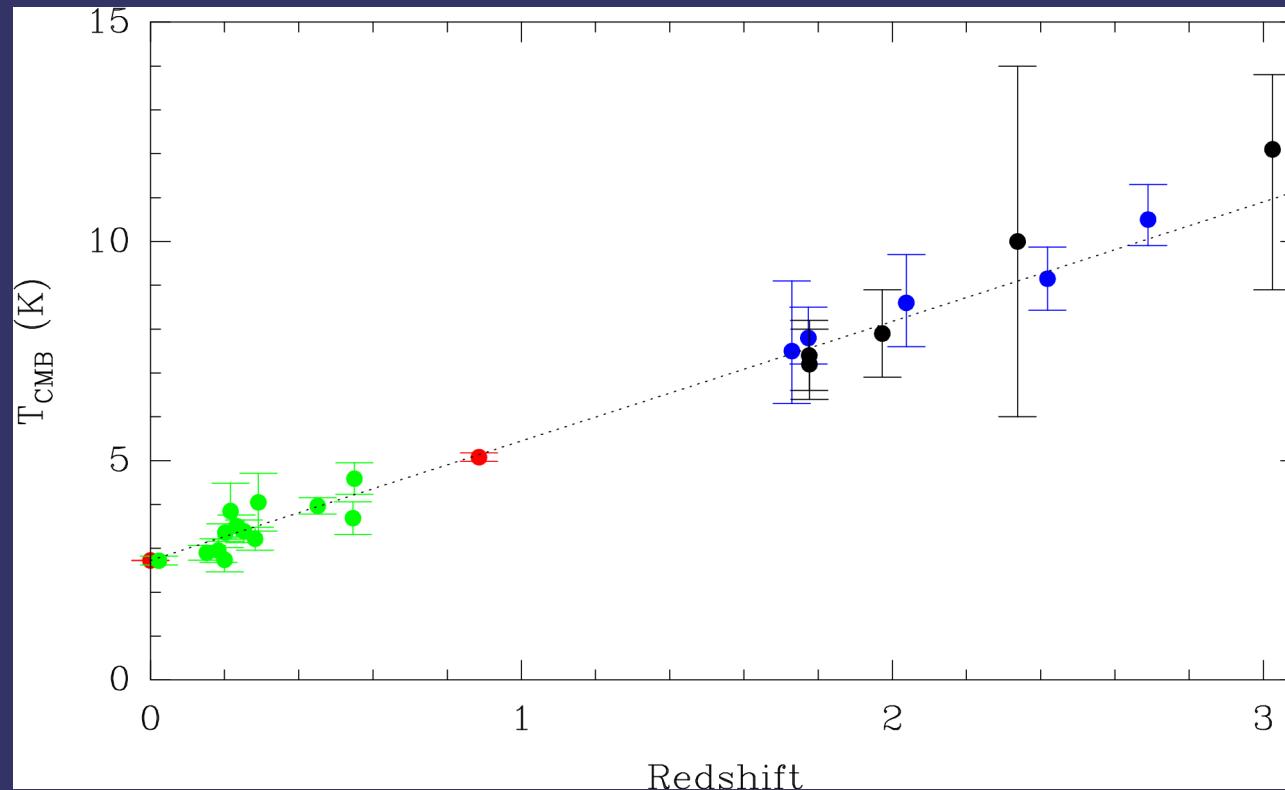
ATCA
@ 7 mm and 3 mm
Observations in July 2011

H13CO+
H13CN
HC15N
c-C3H2
CH3CN
HC3N
SiO
HNCO
SO

Multi-transition multi-species excitation analysis



The T_{CMB} – redshift law



$T_{\text{BG}} = T_{\text{CMB}} (@z=0.89) = 5.08 \pm 0.10 \text{ K}$ See also Noterdaeme et al 2011

-> Consistent with adiabatic expansion of the Universe:

$$T_{\text{CMB}}(z) = T_0 \times (1+z) \dots = 5.14 \text{ K} @z=0.89$$

Molecules as cosmological probes

Constraints on the variation
of fundamental constants

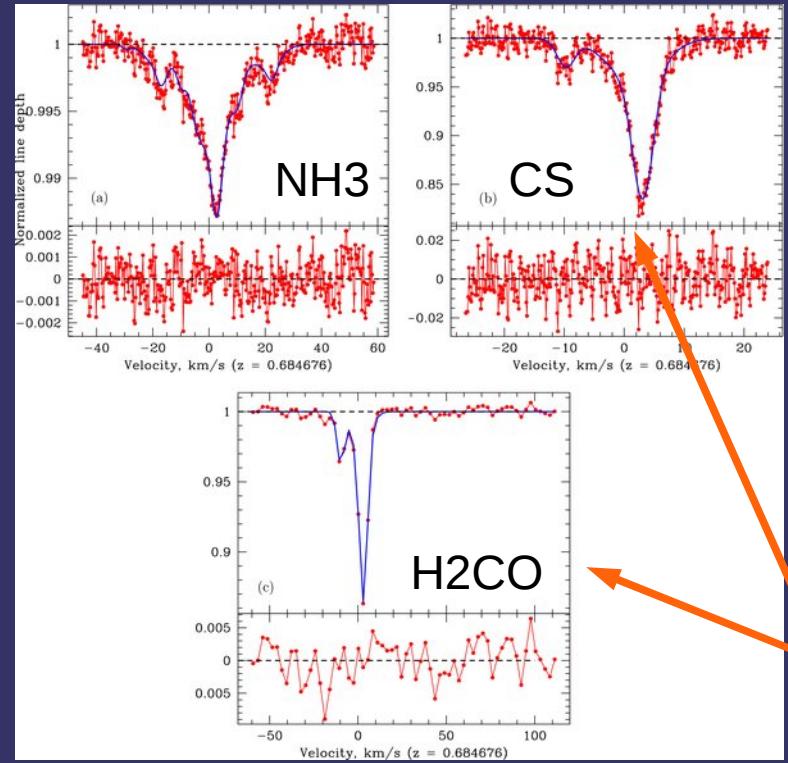
Probing the cosmological variations of fundamental constants, e.g. μ

- Astronomical constraints toward high-z quasars cover longer time (and space) span than laboratory measurements
- A variation of e.g. $\mu = m_p / m_e$ would introduce a shift in transition frequency
Hence a velocity offset between two lines i,j with different freq dependence in μ

$$\Delta V_{ij} / c = \Delta K_\mu \Delta \mu / \mu$$

Sensitivity coefficients

- H₂: $|\Delta K^\mu| \sim 0.01$
- Inversion lines of NH₃ wrt a rotational line: $|\Delta K^\mu| = 3.5$ Flambaum & Kozlov 2007
- Various lines of CH₃OH have different sensitivity: $K^\mu = -40$ to $+50$ Jansen et al 2011
- CI wrt a rotational line $|\Delta K^\mu| = 1$, $|\Delta K^\alpha| = 2$
- CH @532,536 GHz wrt a rotational line: $|\Delta K^\mu| = 0.8$, $|\Delta K^\alpha| = 1.6$ de Nijs et al 2012
- OH conjugate lines have sensitivity to $G = g_p (\mu \alpha^2)^{1.85}$ e.g. Kanekar et al 2010



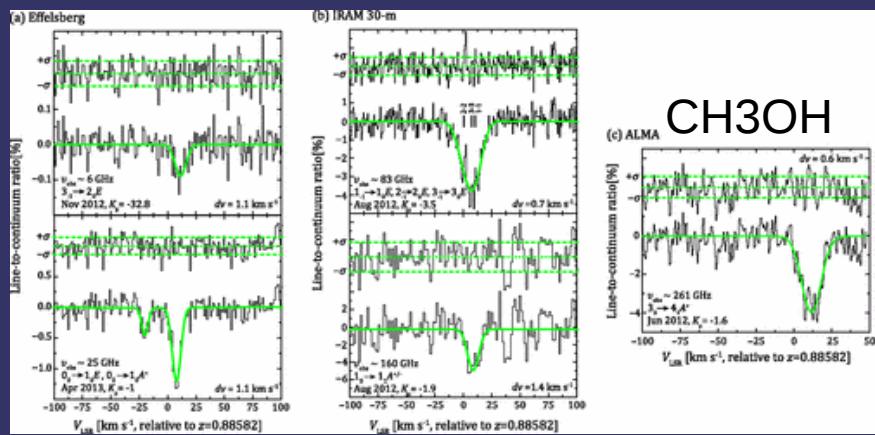
$\Delta V = -0.36 \pm 0.10 \text{ km/s}$
For NH3 inversion lines vs rot line:

$$\Delta V/c = 3.46 \Delta \mu/\mu$$

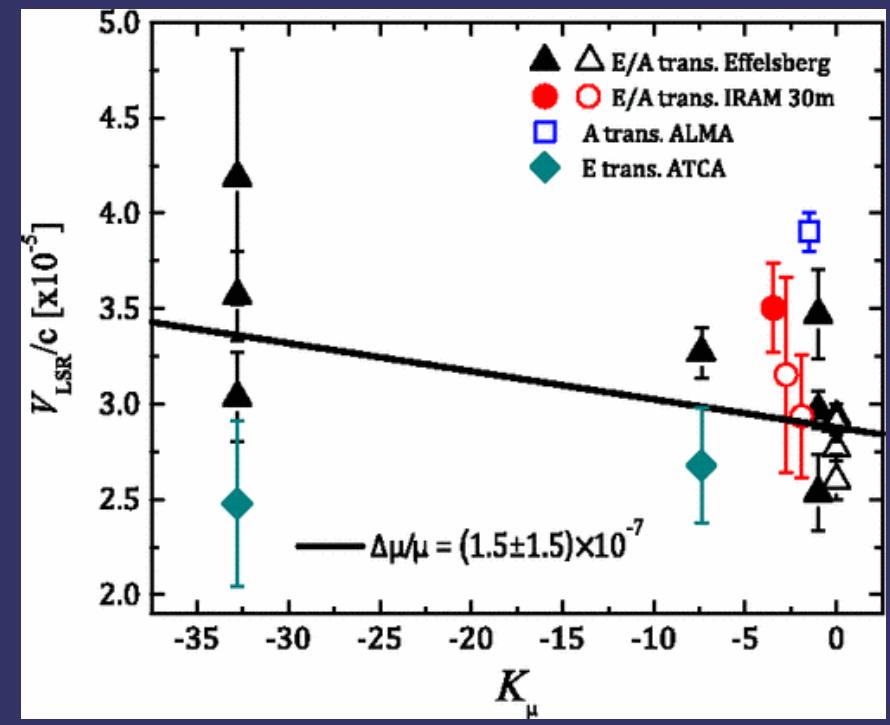
$$\Delta \mu/\mu = (-3.5 \pm 1.2) 10^{-7}$$

@z=0.68 – Kanekar 2011

References



$\Delta \mu/\mu = (1.5 \pm 1.5) 10^{-7}$
@z=0.89 – Bagdonaitė et al 2013



e.g. Constraints on $\Delta\mu/\mu$ using molecules

Method	Target	$\Delta\mu/\mu (<3\sigma)$	Ref.
inv. NH_3 vs (HCO^+ , HCN)	B0218+357 z=0.68	$< 1.8 \times 10^{-6}$	Murphy et al 2008
inv. NH_3 vs HC_3N	PKS1830-211 z=0.89	$< 1.4 \times 10^{-6}$	Henkel et al 2009
inv. NH_3 vs (CS, H_2CO)	B0218+357 z=0.68	$< 3.6 \times 10^{-7}$	Kanekar 2011
inv. NH_3 vs (average of 22 species)	PKS1830-211 z=0.89	$< 2.2 \times 10^{-6}$	Muller et al 2011
CH_3OH vs (average of 22 species)	PKS1830-211 z=0.89	$< 1.4 \times 10^{-6}$	Muller et al 2011
CH_3OH	PKS1830-211 z=0.89	$< 6.3 \times 10^{-7}$	Ellingsen et al 2012
CH_3OH	PKS1830-211 z=0.89	$< 3.0 \times 10^{-7}$	Bagdonaitė et al 2013a
CH_3OH + systematics	PKS1830-211 z=0.89	$< 4 \times 10^{-7}$	Bagdonaitė et al 2013b

Issues:

- Chemical segregation
 - > Observe self-reference (e.g. CH_3OH)
 - > Statistical constraint wrt multi references
- Excitation-opacity effects
- Time variability of the continuum
 - > Simultaneous observation of reference
- Change of the continuum morphology with frequency (spectral index, core shift)

Note: Down to $\Delta\mu/\mu \sim 10^{-7}$ @ $z=0.89$

\Leftrightarrow

$$(\delta\mu/\delta t) / \mu \sim 10^{-17} \text{ yr}^{-1}$$

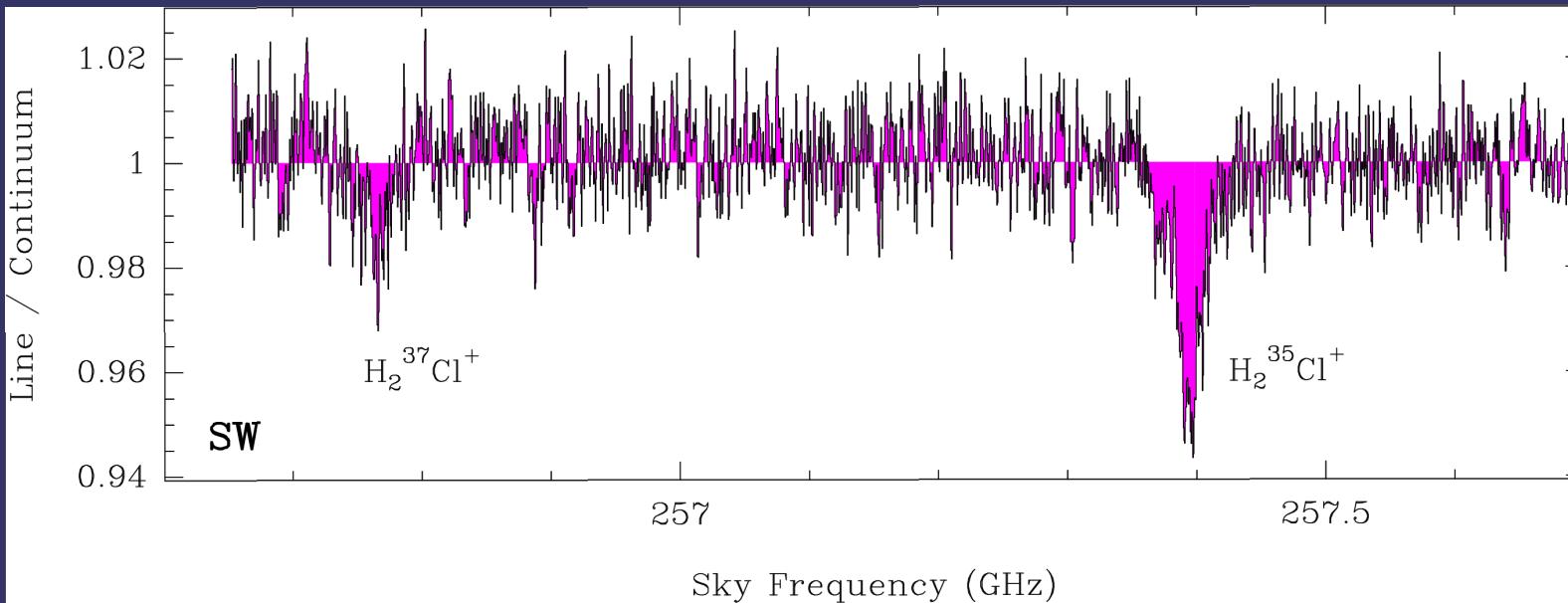
i.e. equivalent to bound on varying constant obtained with the best optical clocks
in laboratory experiments

(assuming a linear evolution)

Chemical evolution of the Universe

Isotopic ratios at
 $z=0.89$

Chlorine



Detection of chloronium $H_2^{35}Cl^+$ and $H_2^{37}Cl^+$ toward PKS1830-211
ALMA Early Science Cycle 0 – Muller et al 2014b

$$\rightarrow {}^{35}\text{Cl}/{}^{37}\text{Cl} = 3.1_{-0.2}^{+0.3} \quad @ z=0.89$$

${}^{35}\text{Cl}/{}^{37}\text{Cl} = 3.1$ Earth
 $= 3.1 \pm 0.6$ IRC+10216 (Cernicharo et al 2000)
 $= 1 - 5$ in various Galactic sources (Cernicharo et al 2010, Peng et al 2010)

Isotopic ratios – brief summary

Isotopologues in absorption -> Isotopic ratios of C, N, O, Si, S, Cl

-> Constraints on nucleosynthesis models

@z=0.89 <-> ~ lookback time of ~half the age of the Universe

Stars with $M <\sim 1.5 M_{\odot}$ have no time to contribute

Some similarities with isotopic ratios measured in starburst galaxies
Where enrichment is dominated by massive stars on short time scales

-> ALMA will give more clues

Summary

-> PKS1830-211 = rich molecular absorber

Chemistry

Robust fractional abundances

Basic interstellar chemistry in the disk of a $z=0.89$ galaxy

Chemistry at $z=0.89$ seems similar to that at $z=0$

Molecules as cosmological probes

-> Evolution of the CMB temperature with redshift

-> Constancy of fundamental constants

-> Isotopic ratios and constraints on nucleosynthesis

-> Looking forward to find more and higher- z molecular absorbers !