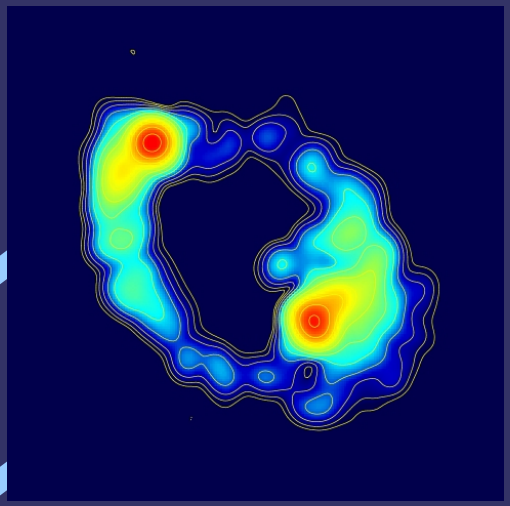
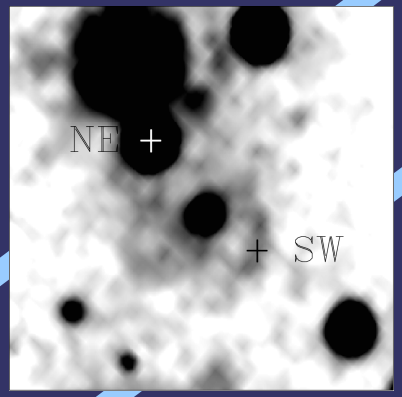
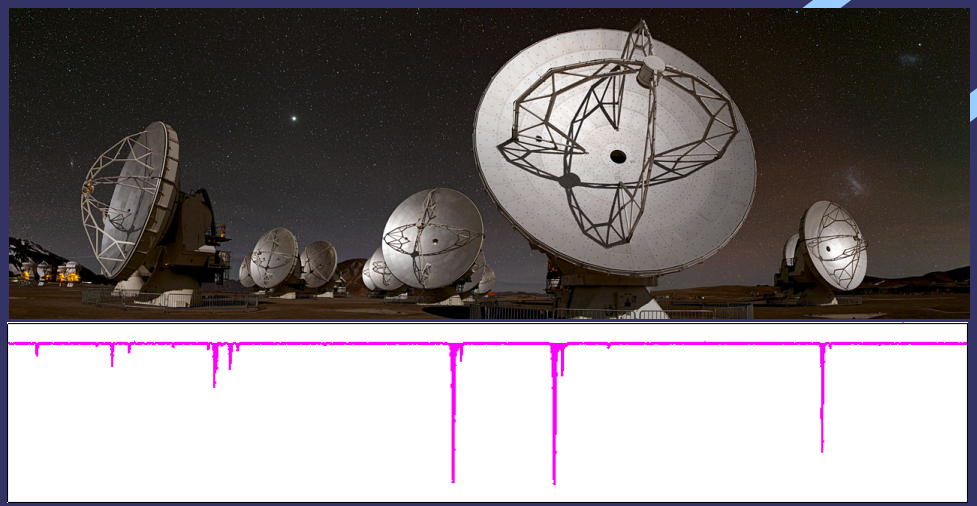
Hydrides toward PKS 1830-211







Sébastien Muller

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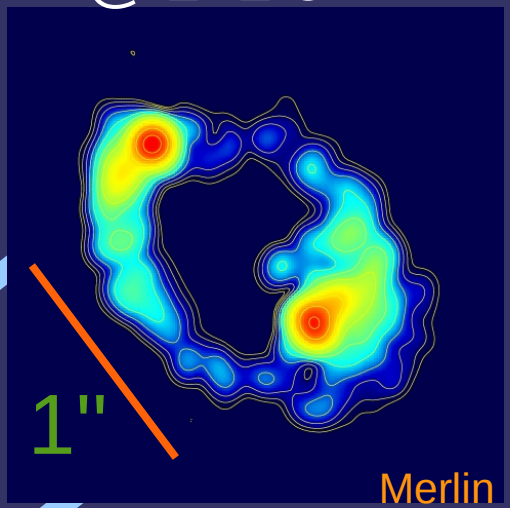
Department of Earth and Space Sciences
Chalmers University of Technology, Sweden

CHALMERS

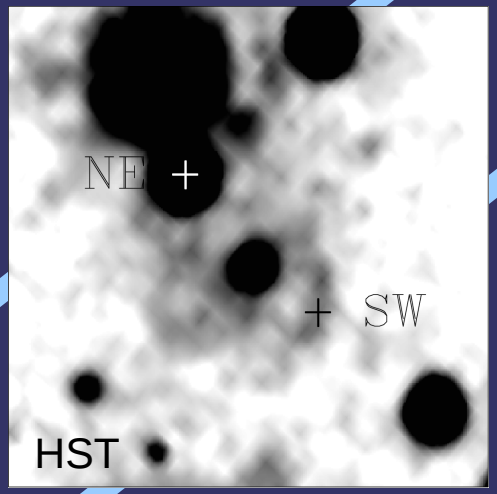
EUROPEAN ARC
ALMA Regional Centre || Nordic

The line(s) of sight to PKS1830-211

Lensed blazar
@ z=2.5

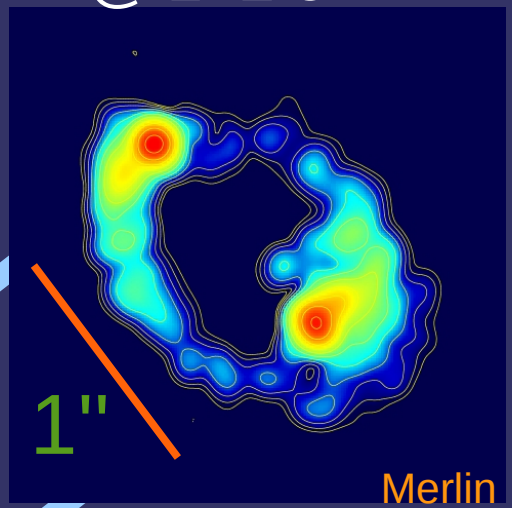


Foreground
nearly face-on spiral galaxy
@ z=0.89

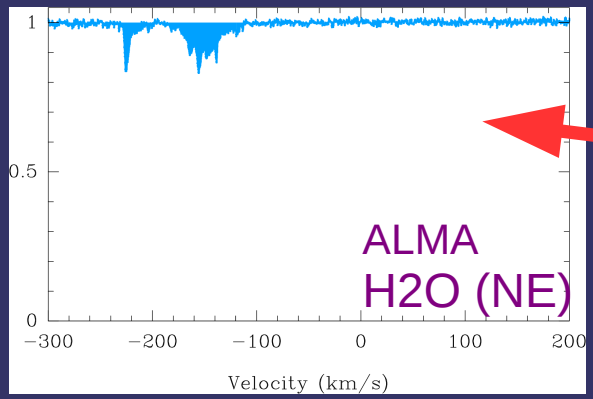


The line(s) of sight to PKS1830-211

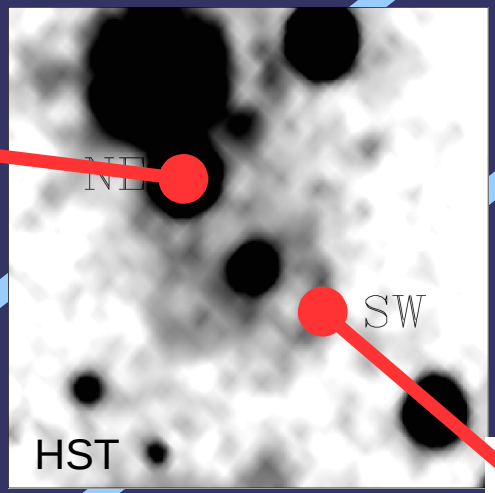
Lensed blazar
@ z=2.5



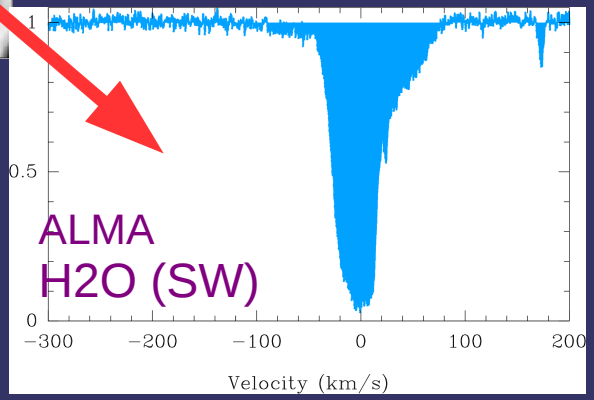
Absorber =
nearly face-on spiral galaxy
@ z=0.89



$N(H_2) \sim 1 \times 10^{21}$ cm^{-2}



~ mas / pc scale



$N(H_2) \sim 2 \times 10^{22}$ cm^{-2}

PKS 1830-211, ALMA, and hydrides

Absorption at high-z:

- No signal dilution by distance (as sensitive at high-z than local)

- Outstanding angular resolution = size of the continuum illumination
  PKS1830-211 images have size of a fraction of mas at mm
  1 mas = 8 pc @z=0.89
  Volume of absorbing gas ~ 1 pc^2 x several 100 pc

- Pure absorption spectra (no contamination by emission bcs dilution by distance)

PKS 1830-211 with ALMA:

- For z=0.89, ground state transitions of many hydrides redshifted into ALMA bands

- High sensitivity

- High-quality spectral baseline

- Two independent lines of sight through the absorber's disk = comparison

Chemical inventory toward the SW los

1 atom	2 atoms	3 atoms	4 atoms	5 atoms	6 atoms	7 atoms
H	CH (*)	NH_2	NH_3	CH_2NH	CH_3OH	CH_3NH_2
C	CH+ (*)	H_2O (**)	H_2CO (**)	c-C_3H_2	CH_3CN	CH_3CCH
	OH	H_2O+	l-C_3H	l-C_3H_2	NH_2CHO	CH_3CHO
	OH+	C_2H	HNCO	H_2CCN		
	HF	HCN (**)	HOCO+	H_2CCO		
	CN	HNC (**)	H_2CS	C_4H		
	CO (**)	N_2H+		HC_3N		
	CF+	HCO+ (***)				
	SH+ (*)	HCO				
	HCl (*)	HOC+				
	ArH+ (*)	H_2S (**)				
	SiO (**)	H_2Cl+ (*)				
	CS (*)	HCS+				
	NS	C_2S				
	SO					
	SO+					

51 species detected

+ 24 isotopic variants (*)

Including 13 hydrides

All (exc. H and OH) observed at mm/submm
e.g., Muller et al. 06, 11, 13, 14, 16, in prep.
PdBI, ATCA, ALMA cycle 0,1,2

Upper limits on D-species, H_2F+, O_2, ...

@ z=0.89 !

Chemical inventory toward the NE los

1 atom	2 atoms	3 atoms	4 atoms	5 atoms	6 atoms	7 atoms
H	CH		NH_3			
C	CH+ (*)	H_2O	H_2CO	c-C_3H_2		
	OH	H_2O+				
	OH+	C_2H				
	HF	HCN				
		HNC				
	CO					
		HCO+				
	ArH+ (*)					
		H_2Cl+ (*)				

19 species detected

+ 3 isotopic variants (*)

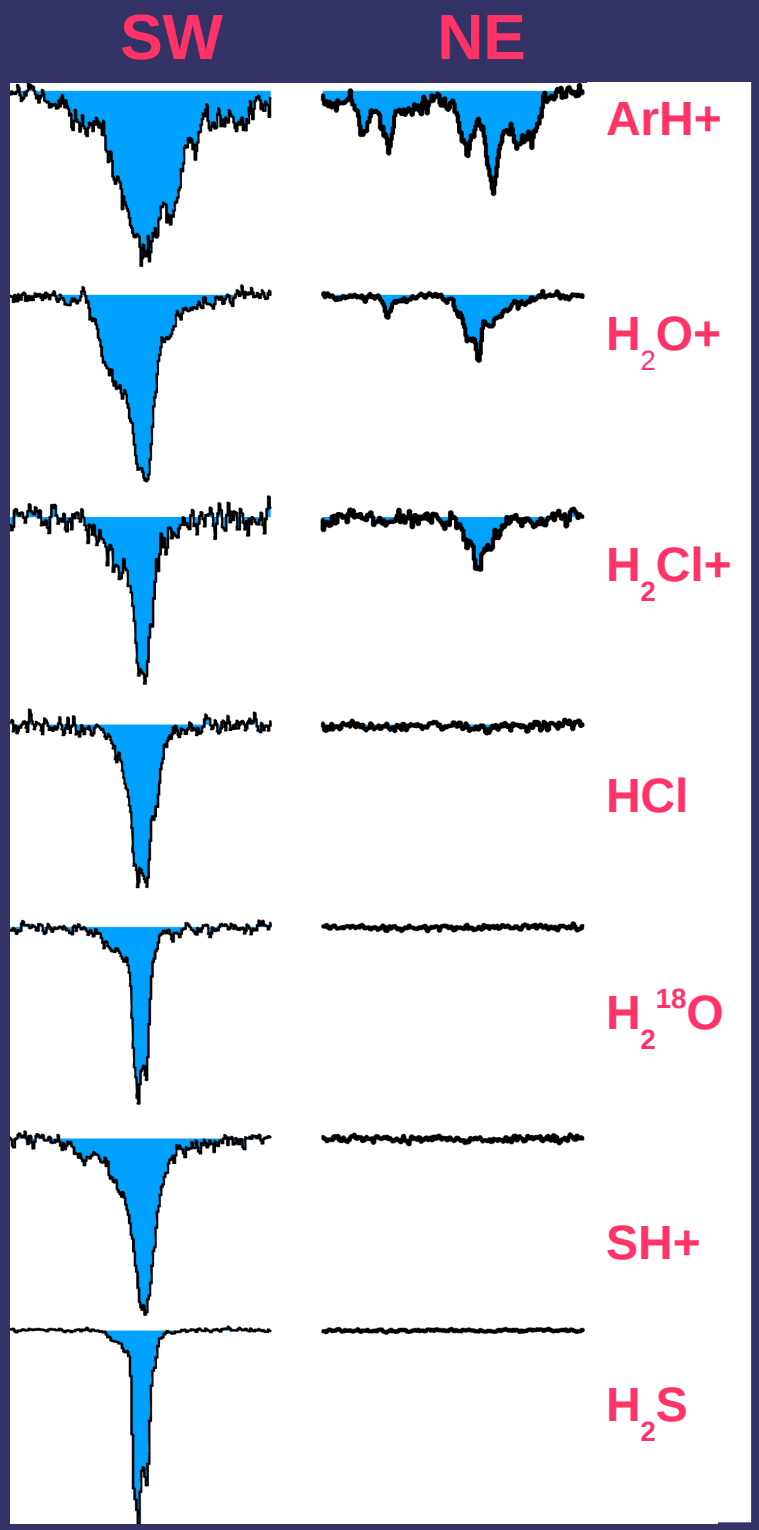
Including 9 hydrides

All (exc. H and OH) observed at mm/submm
e.g., Muller et al. 06, 11, 13, 14, 16, in prep.

PdBI, ATCA, ALMA cycle 0,1,2,3

@ z=0.89 !

Comparison of the two los



Enhanced NE / SW ratio

Diffuse gas tracers
Low molecular fraction

No detection toward NE

Higher molecular fraction tracers

Species	Column densities (cm^{-2}) SW	NE	Ratio SW/NE
HI	1.3×10^{21}	2.5×10^{21}	0.5
ArH+	2.7×10^{13}	1.3×10^{13}	2.1
OH+	1.6×10^{15}	7.6×10^{14}	2.2
CH+	$>6.2 \times 10^{14}$	1.9×10^{14}	> 3.3
H_2Cl+	1.4×10^{13}	3.7×10^{12}	3.8
H_2O+	2.7×10^{14}	7.0×10^{13}	3.9
CH	7.7×10^{14}	3.5×10^{13}	22
HF	$>3.4 \times 10^{14}$	0.18×10^{14}	>19

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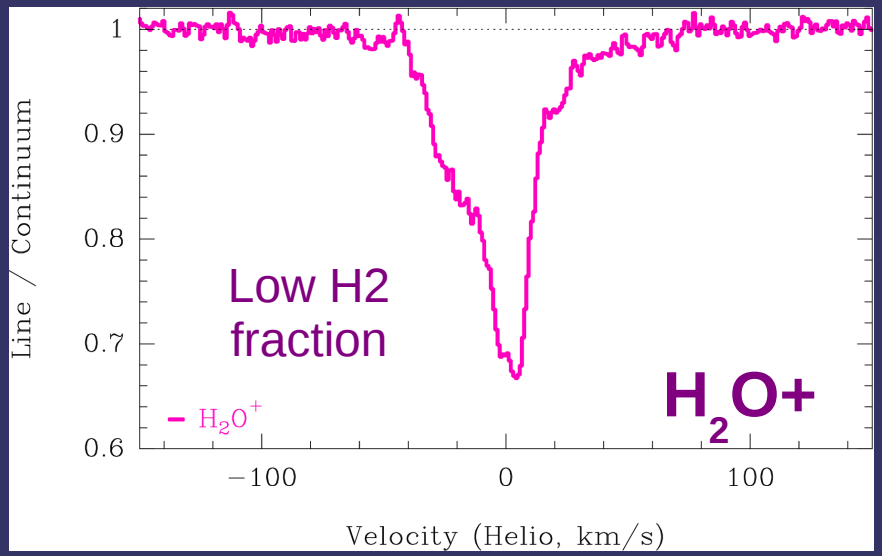
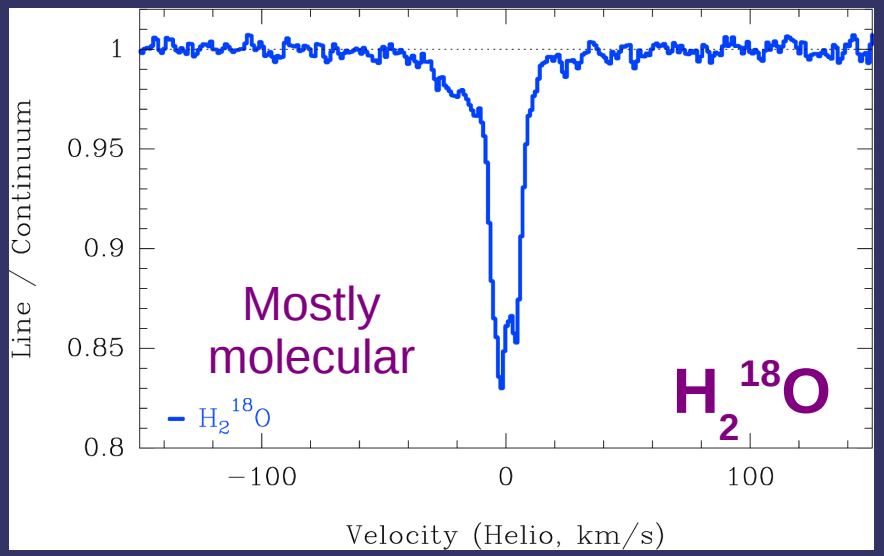
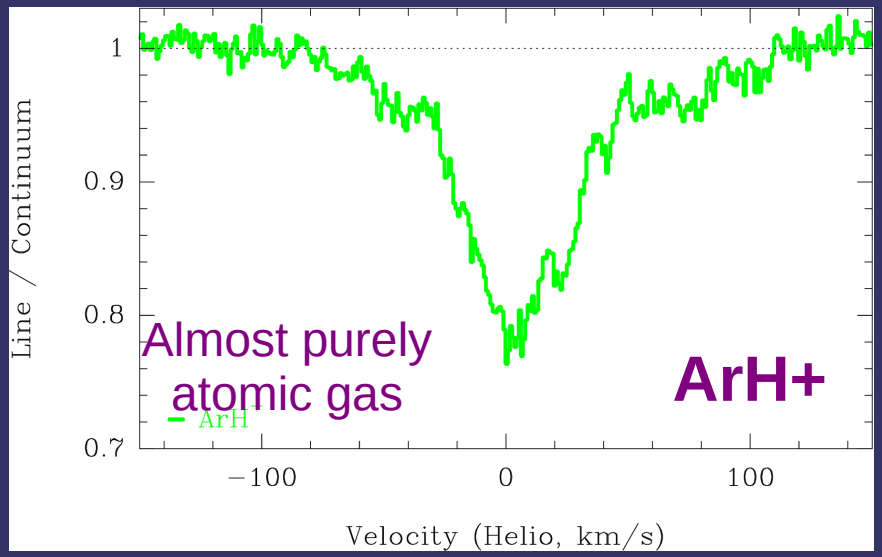
Tracers of increasing molecular fraction

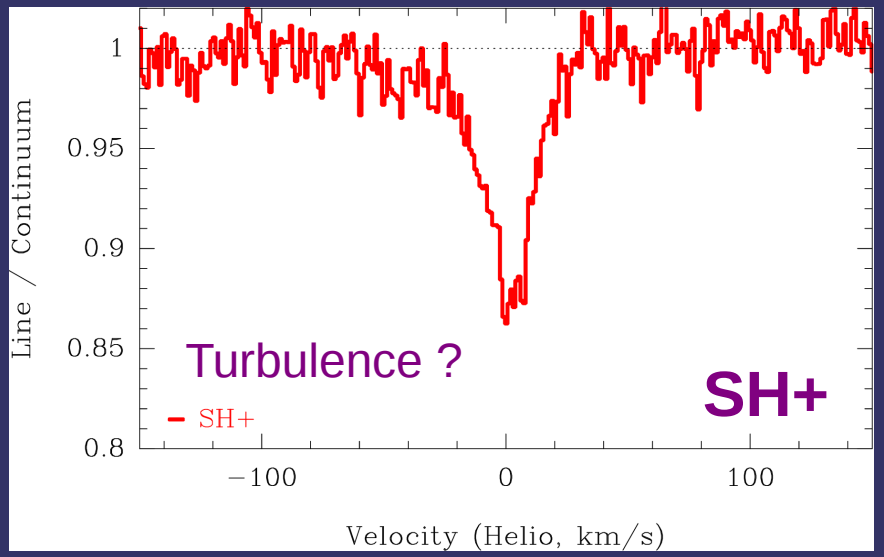
→ multi-phase composition of the absorbing gas

Comparison of SW line profiles





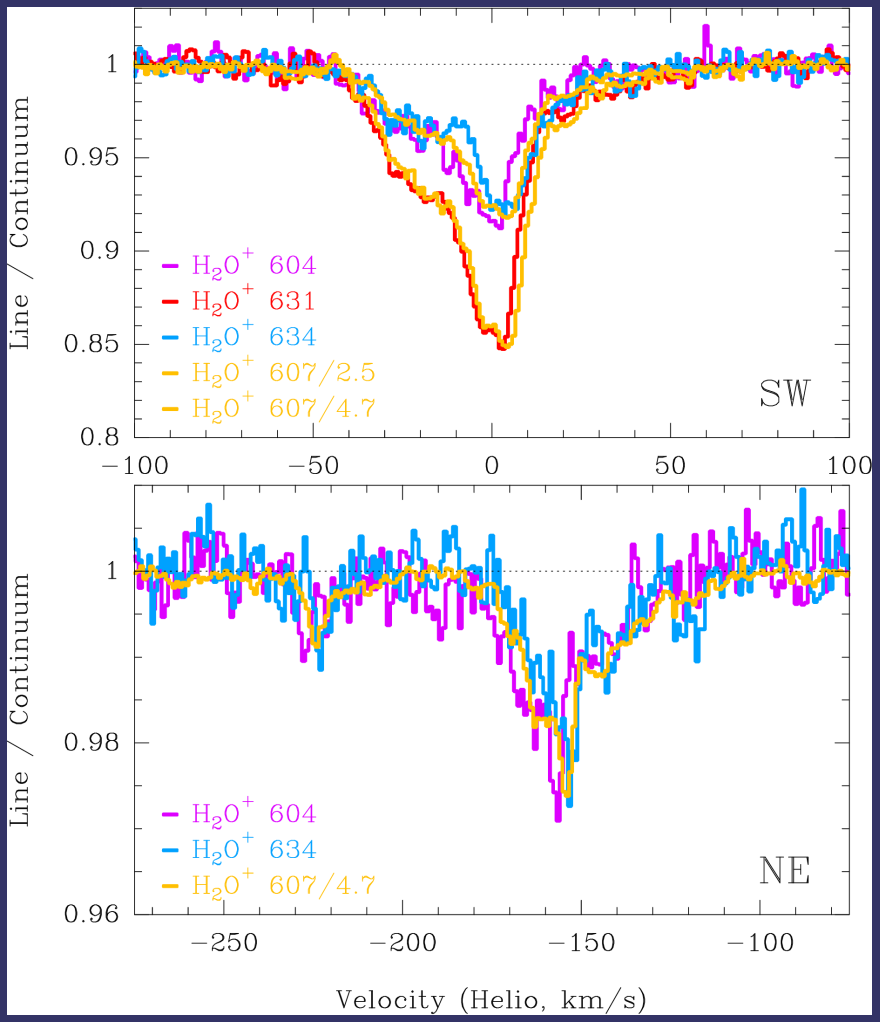




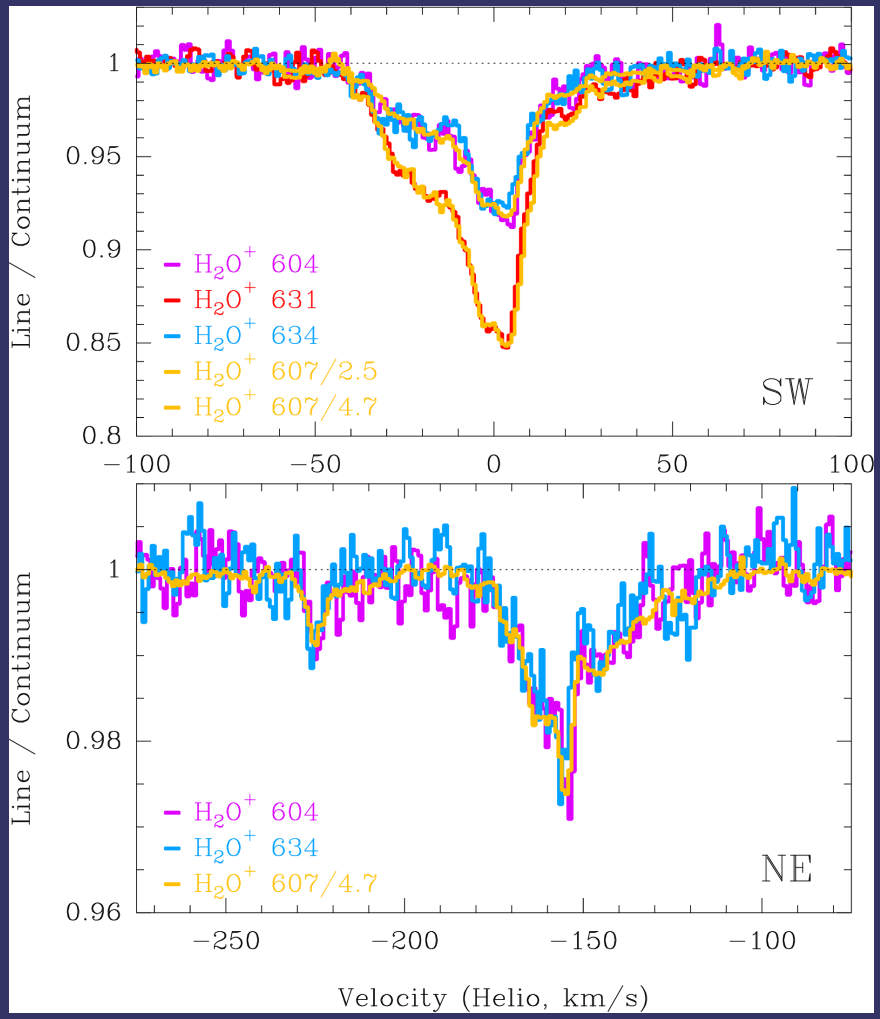
>> different gas components along the line of sight

ALMA cycle 2

Spectroscopy: Refining rest frequencies for p-H_2O^+



Old CDMS freq (unc of a few MHz)



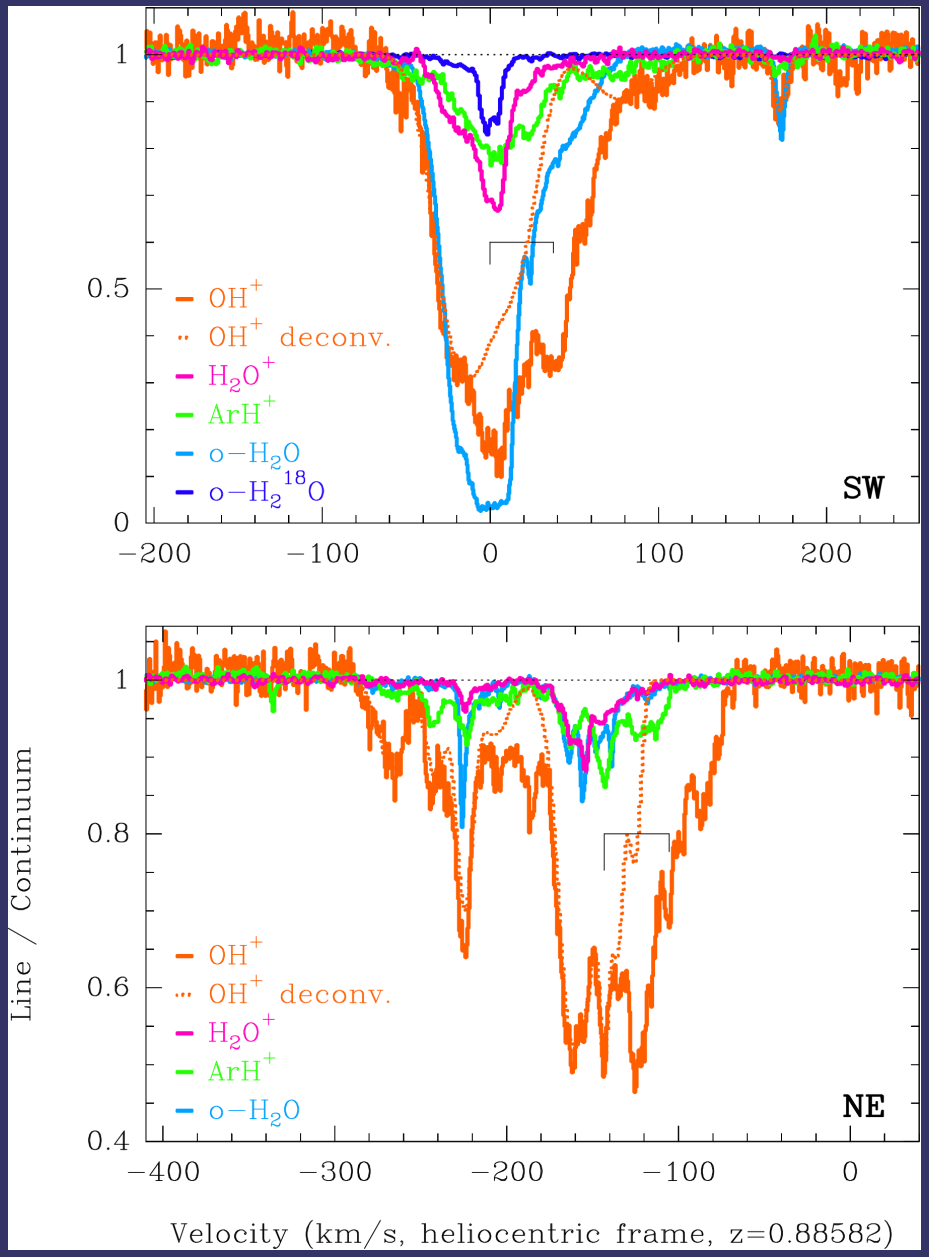
New ALMA freq

Some frequency shifts of up to 5-6 MHz for p-H_2O^+ (604, 607, 631, 634 GHz)

CDMS entries updated

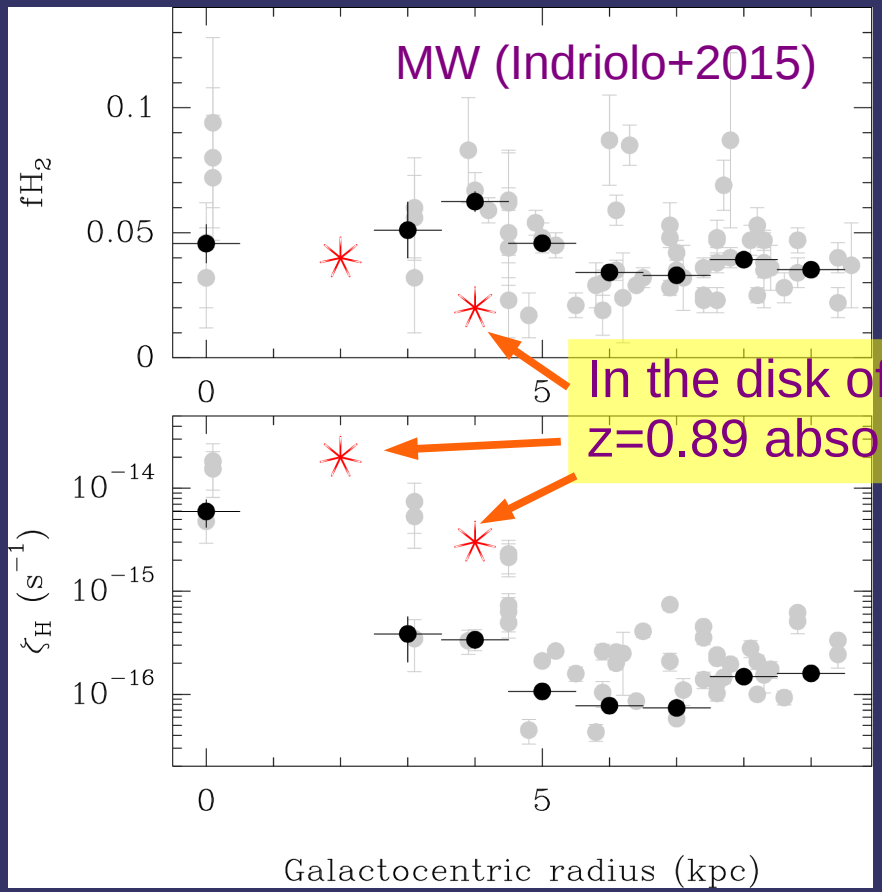
Muller et al 2016

Fraction of molecular hydrogen
Cosmic-ray ionization rate of atomic hydrogen



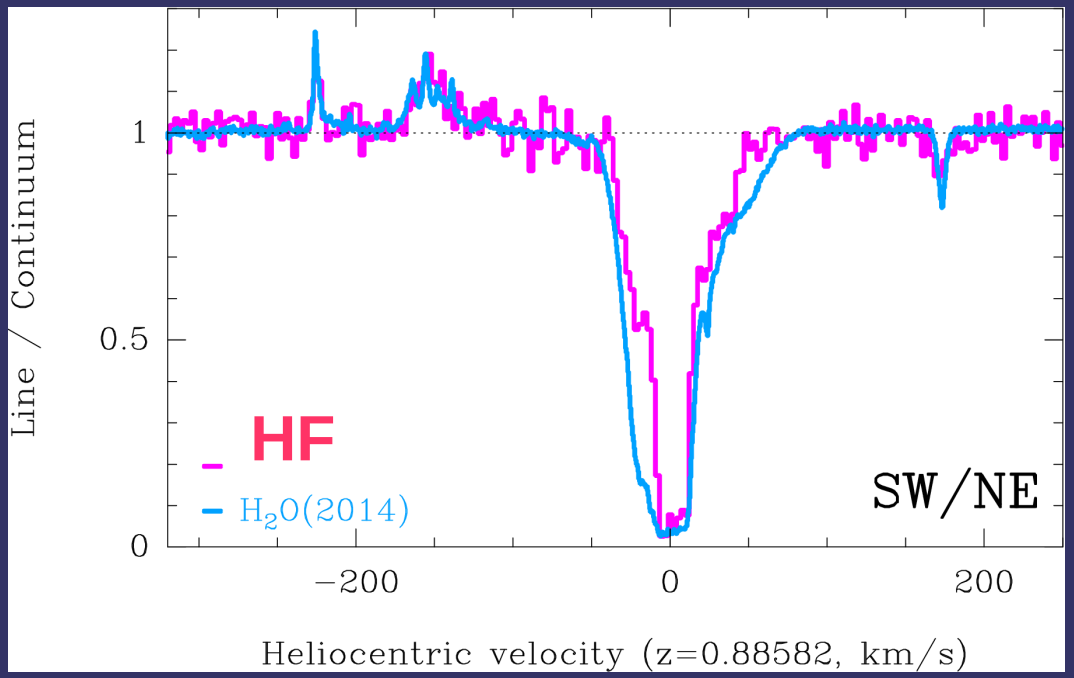
Use OH+ and H2O+ relative abundances
See e.g. Hollenbach+2012, Indriolo+2015

(Caveat: fractional abundance of electrons)



Muller et al 2016

Fluorine-bearing hydrides

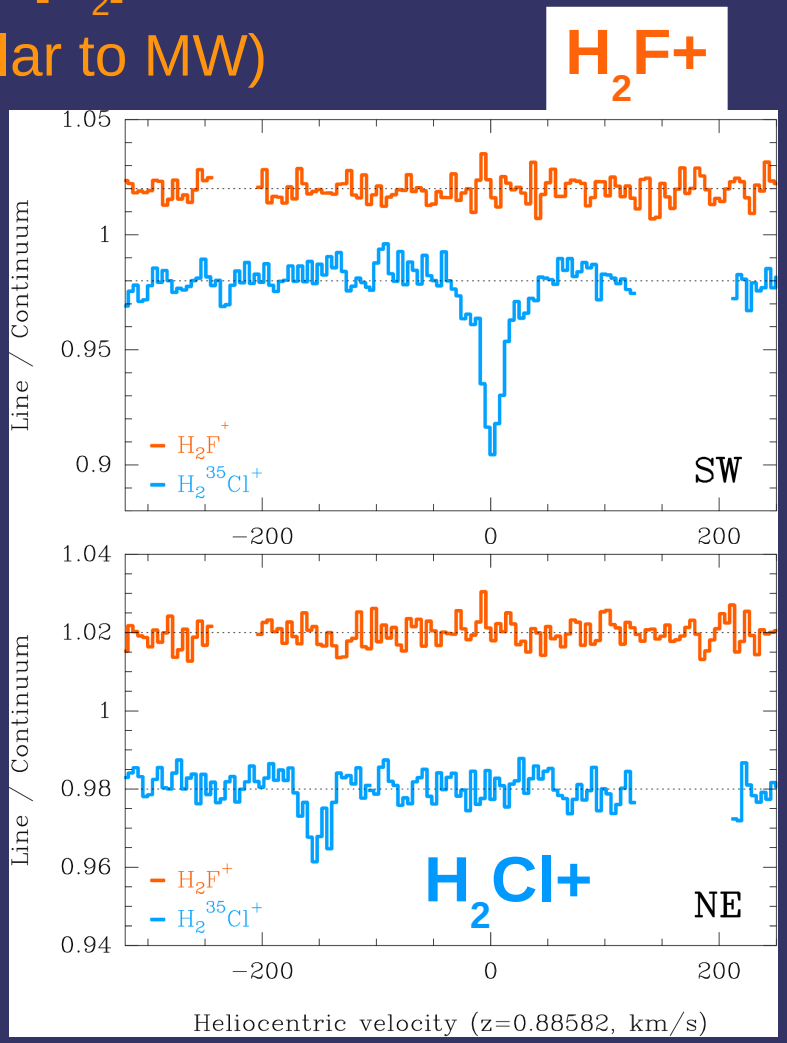


The HF J=1-0 (1.2 GHz) line is redshifted to 653 GHz (ALMA B9)

[HF] / [H_2] ~ 2 x 10^{-8}
(similar to MW)

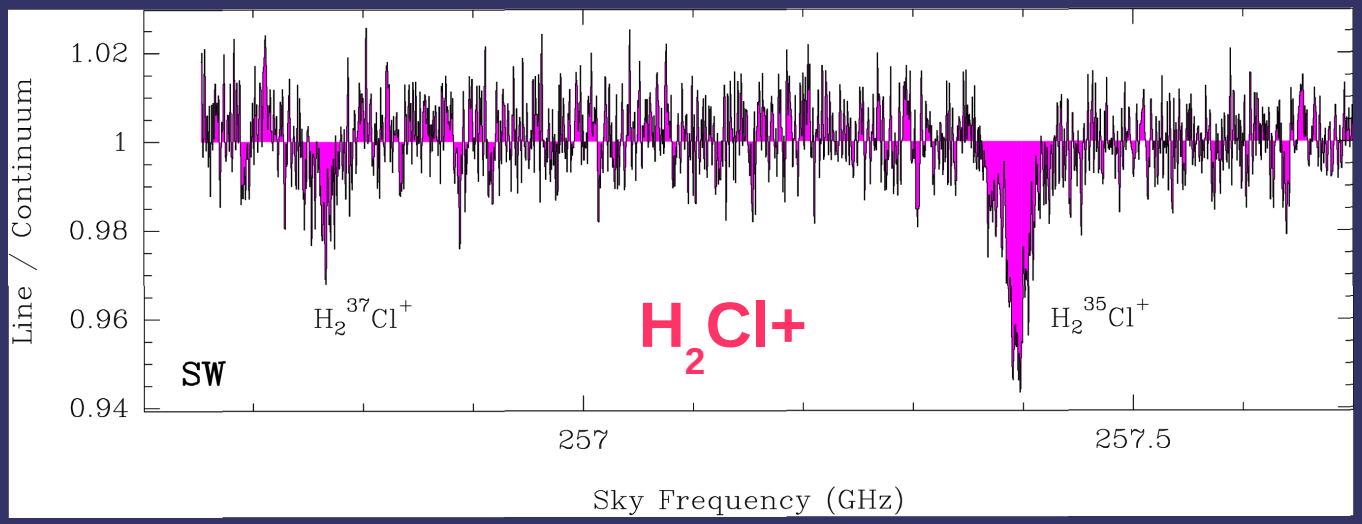
H_2F^+ non detected

[H_2F^+] / [HF] < 1 / 386



Kawaguchi, Muller, et al. 2016

Chlorine-bearing hydrides



ALMA Cycle 0 – Muller et al 2014b

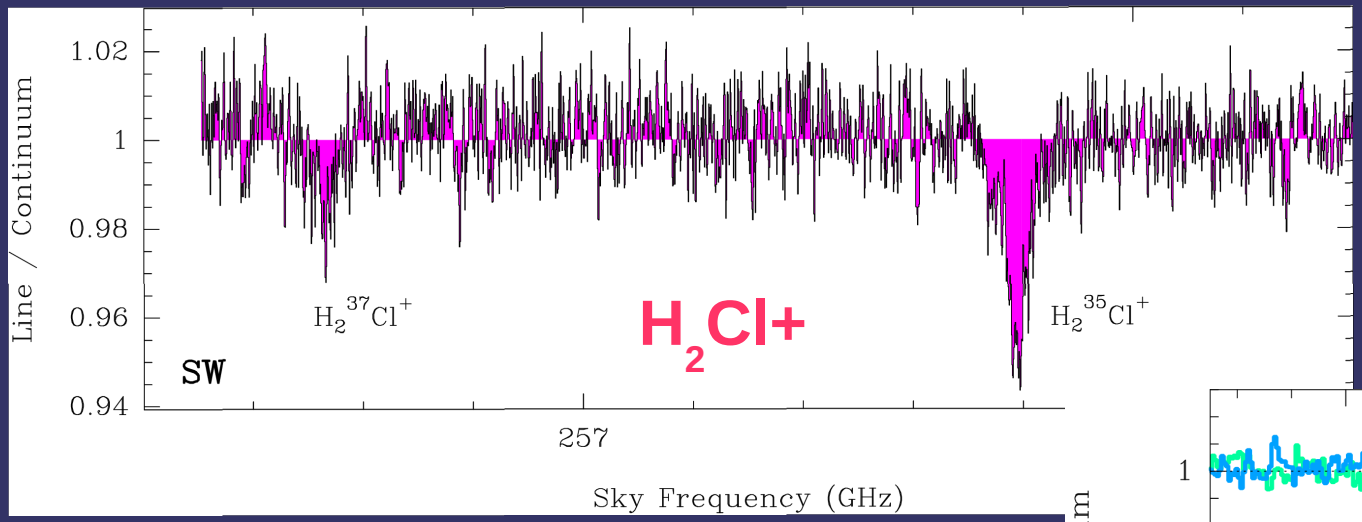
$^{35}Cl/^{37}Cl = 3.1\ ^{+0.3}_{-0.2}$ @z=0.89

$^{35}Cl/^{37}Cl$ = 3.1 Earth

= 3.1 +- 0.6 AGB IRC+10216 (Cernicharo et al 2000)

= 1 – 5 in various Galactic sources (Cernicharo et al 2010, Peng et al 2010)

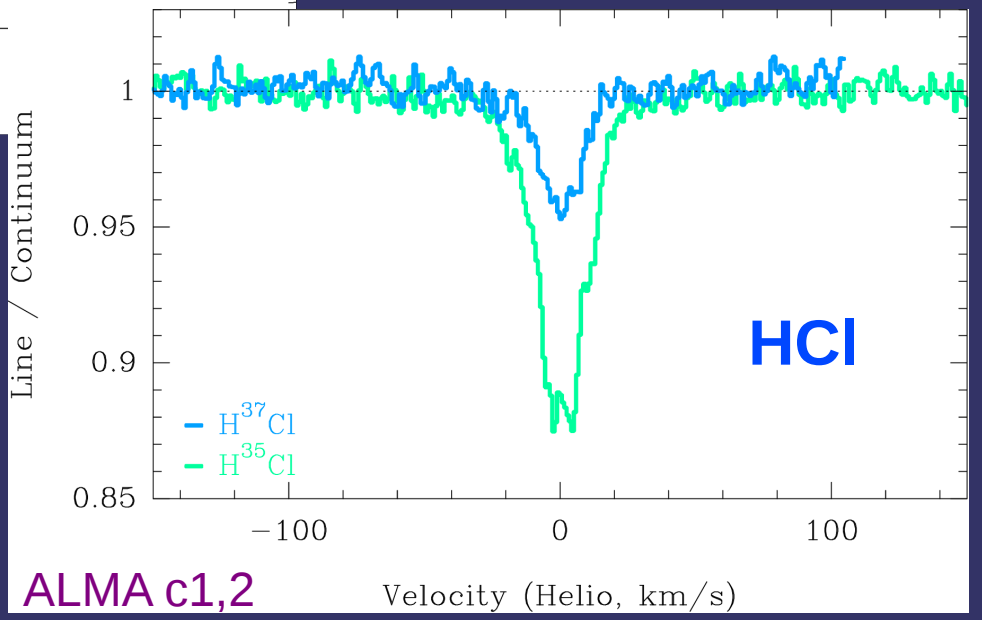
Chlorine-bearing hydrides



H_2Cl^+

ALMA Cycle 0 – Muller et al 2014b

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



HCl

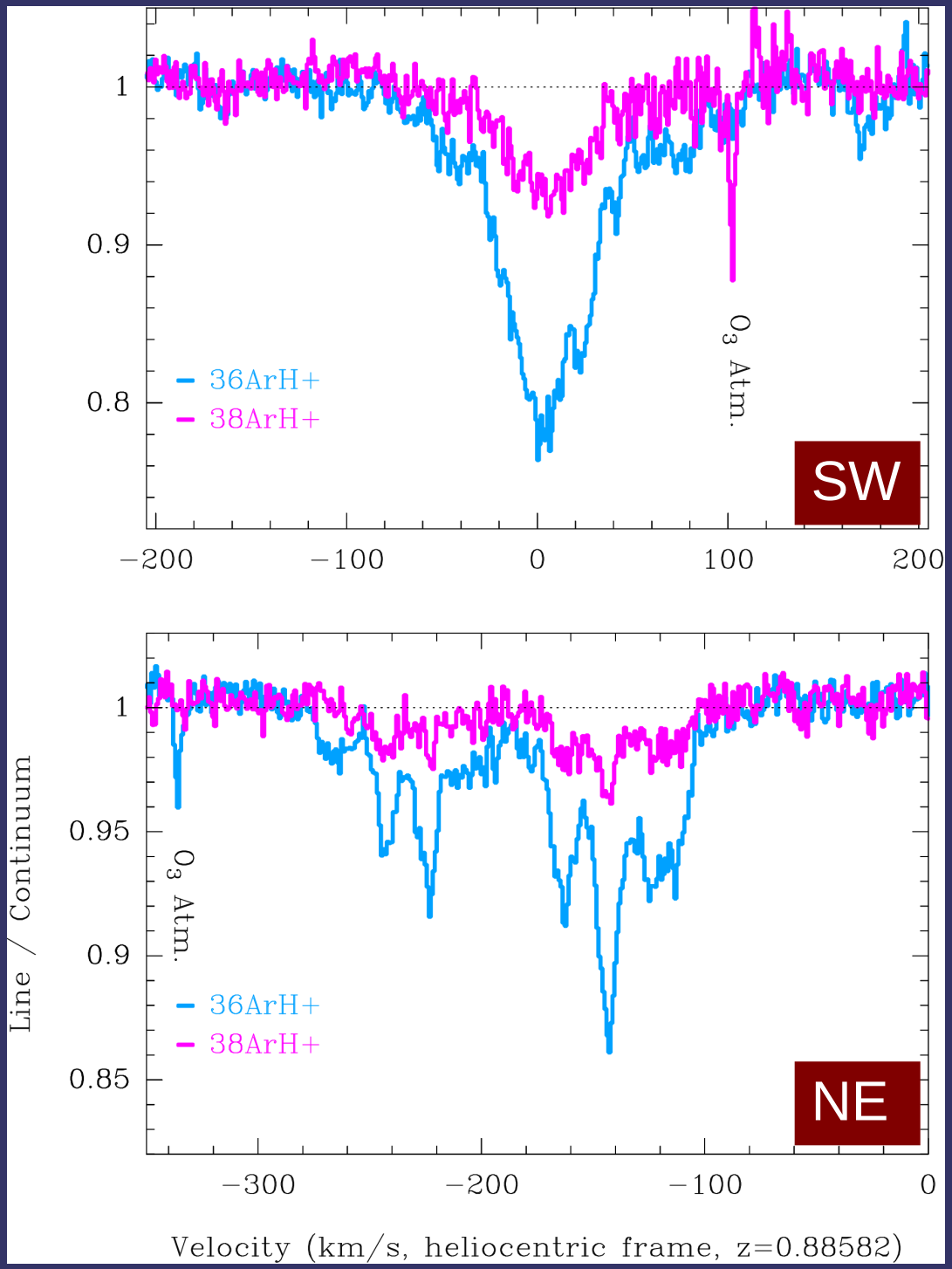
ALMA c1,2

$^{35}Cl/^{37}Cl$ = 3.1 Earth

= 3.1 +- 0.6 AGB IRC+10216 (Cernicharo et al 2000)

= 1 – 5 in various Galactic sources (Cernicharo et al 2010, Peng et al 2010)

Argonium ArH+



Detection of argonium in SW & SW los

$^{36}Ar/^{38}Ar$ = 3.46 +/- 0.16 (SW)
= 4.5 +/- 0.3 (NE)
@z=0.89

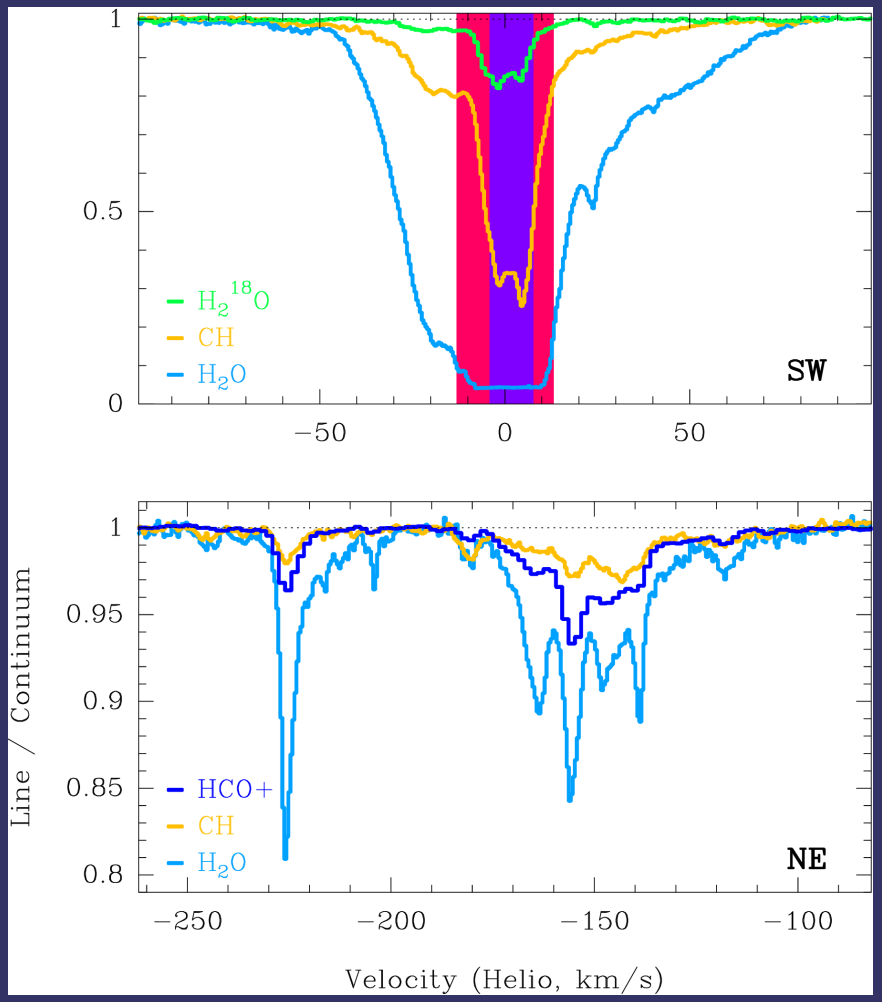
Müller H., Muller S., et al 2015

Solar value: 5.5

Alpha-elements Si, S, Ar all have different ratios @z=0.89 than solar ...

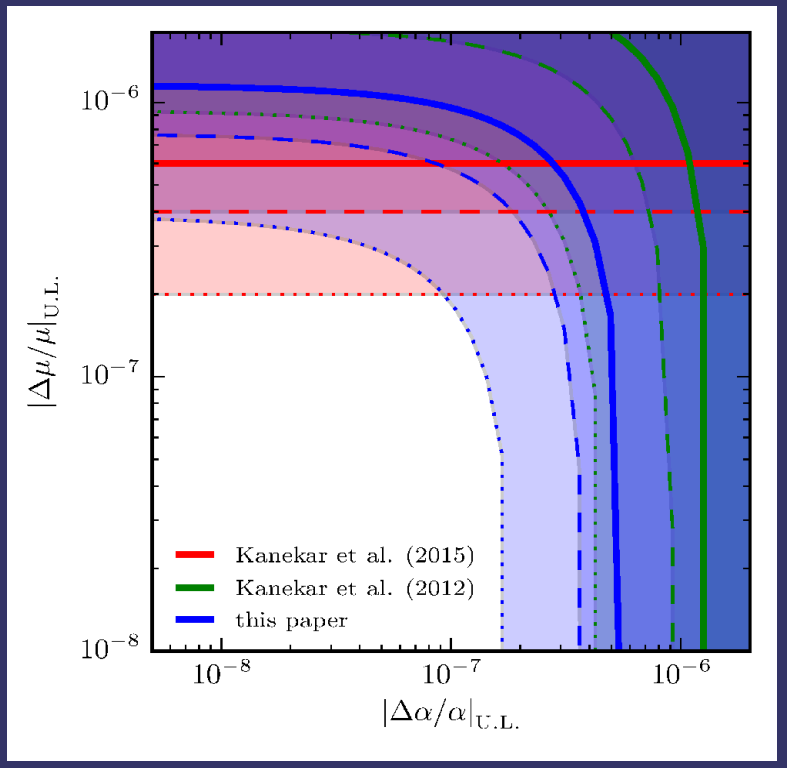
= signature of massive stars nucleosynthesis (?)

Variations of fundamental constants



	Kμ	Kα
CH (532, 536 GHz)	-0.2	+1.6
H_2O (557 GHz)	-1	0

Beelen, Muller, et al. in prep

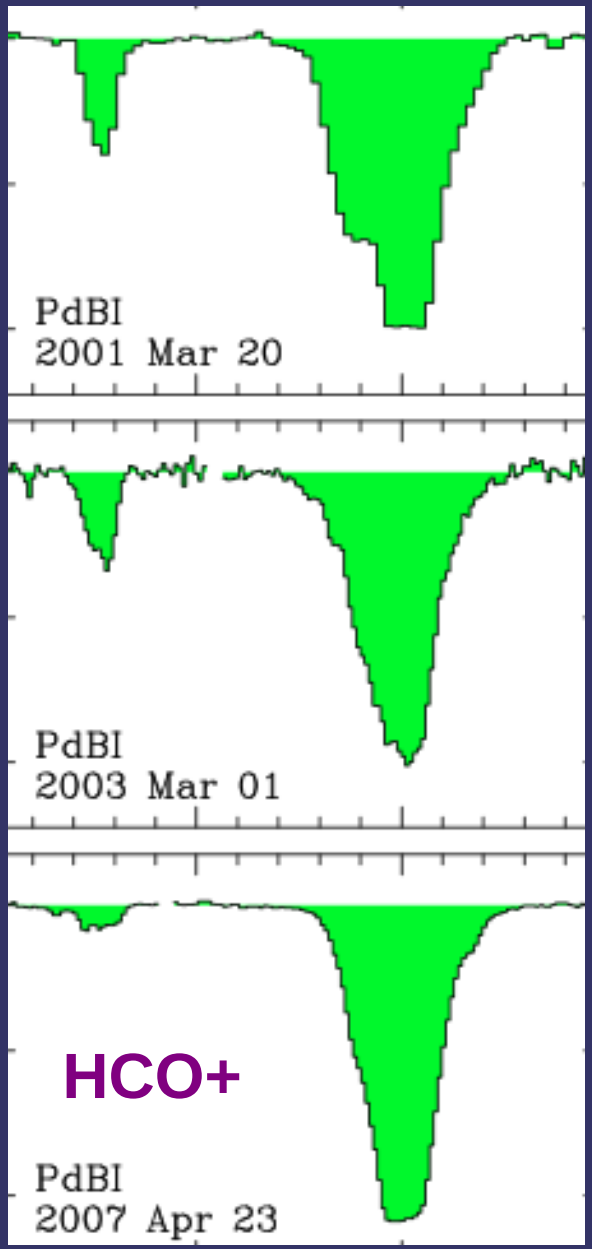


$\Delta V(CH,H_2O) = 0.059 +/- 0.093$ km/s

$\Delta\alpha/\alpha < 5.8\ 10^{-7}$ (3σ)

$\Delta\mu/\mu < 1.2\ 10^{-6}$ (3σ)

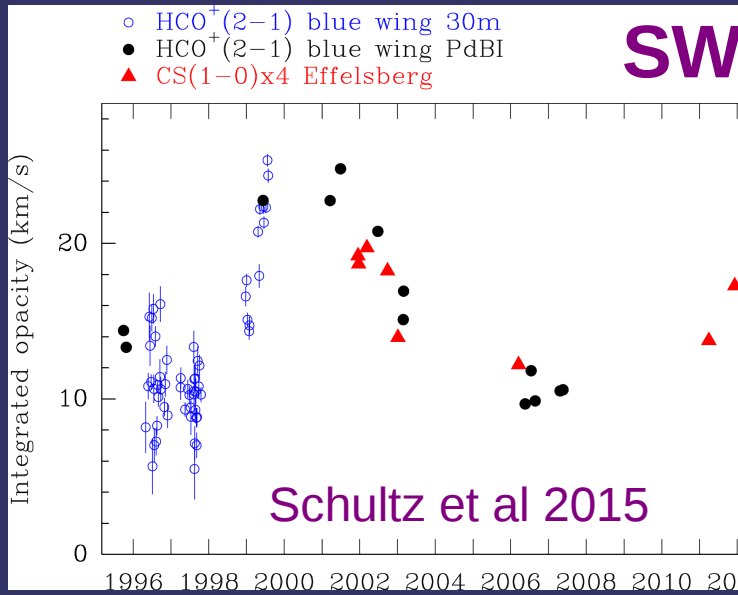
Time variations of the absorption profiles

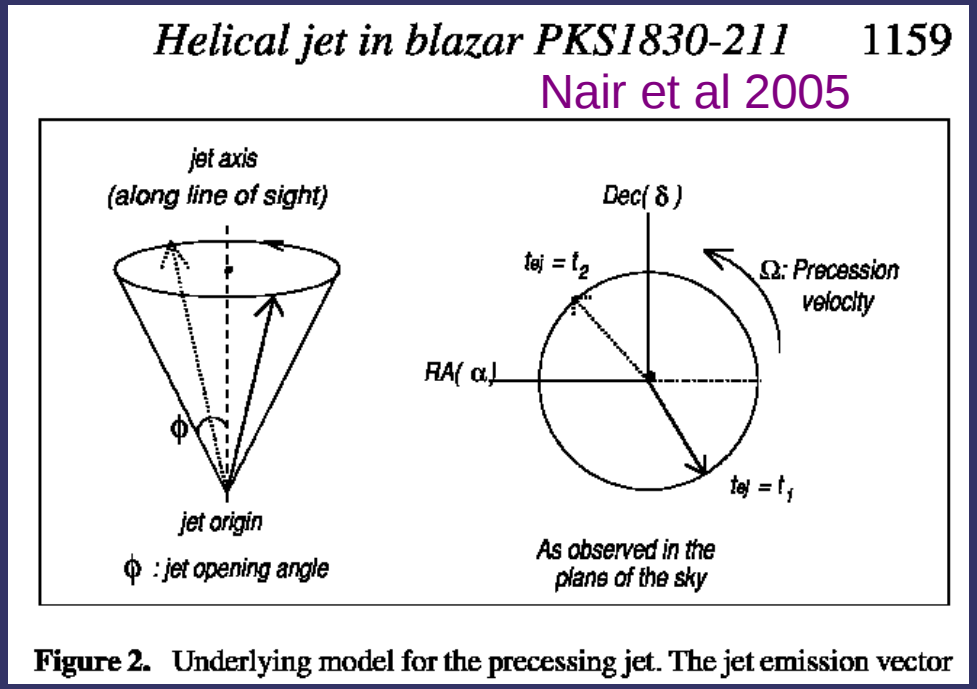


Long term monitoring revealed drastic changes in the absorption
Year timescale
Mostly NE but also SW

-> Intrinsic changes in the blazar

Muller & Guelin 2008





Time variations of the absorption profiles

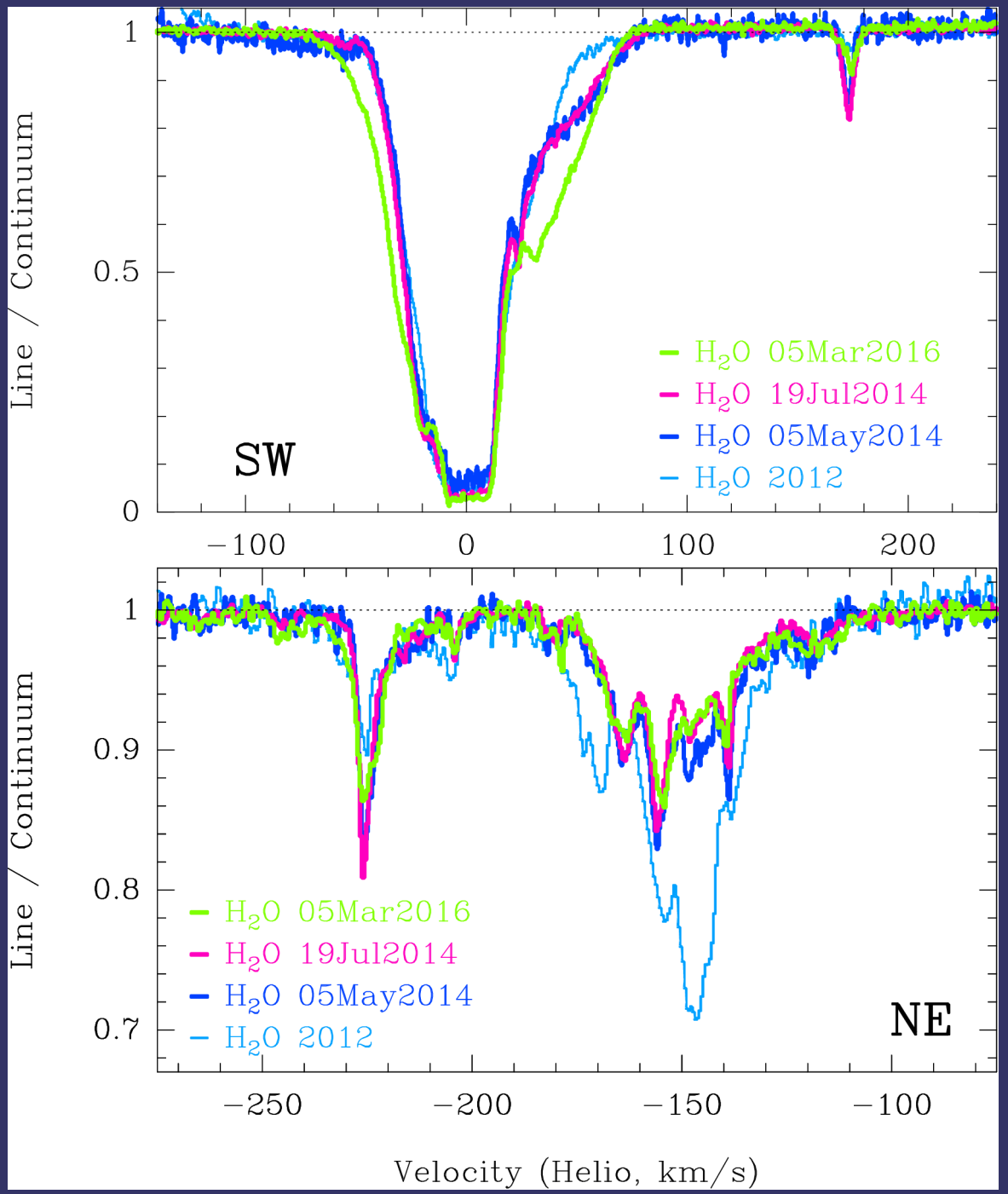
ALMA H_2O 2012 – 2016

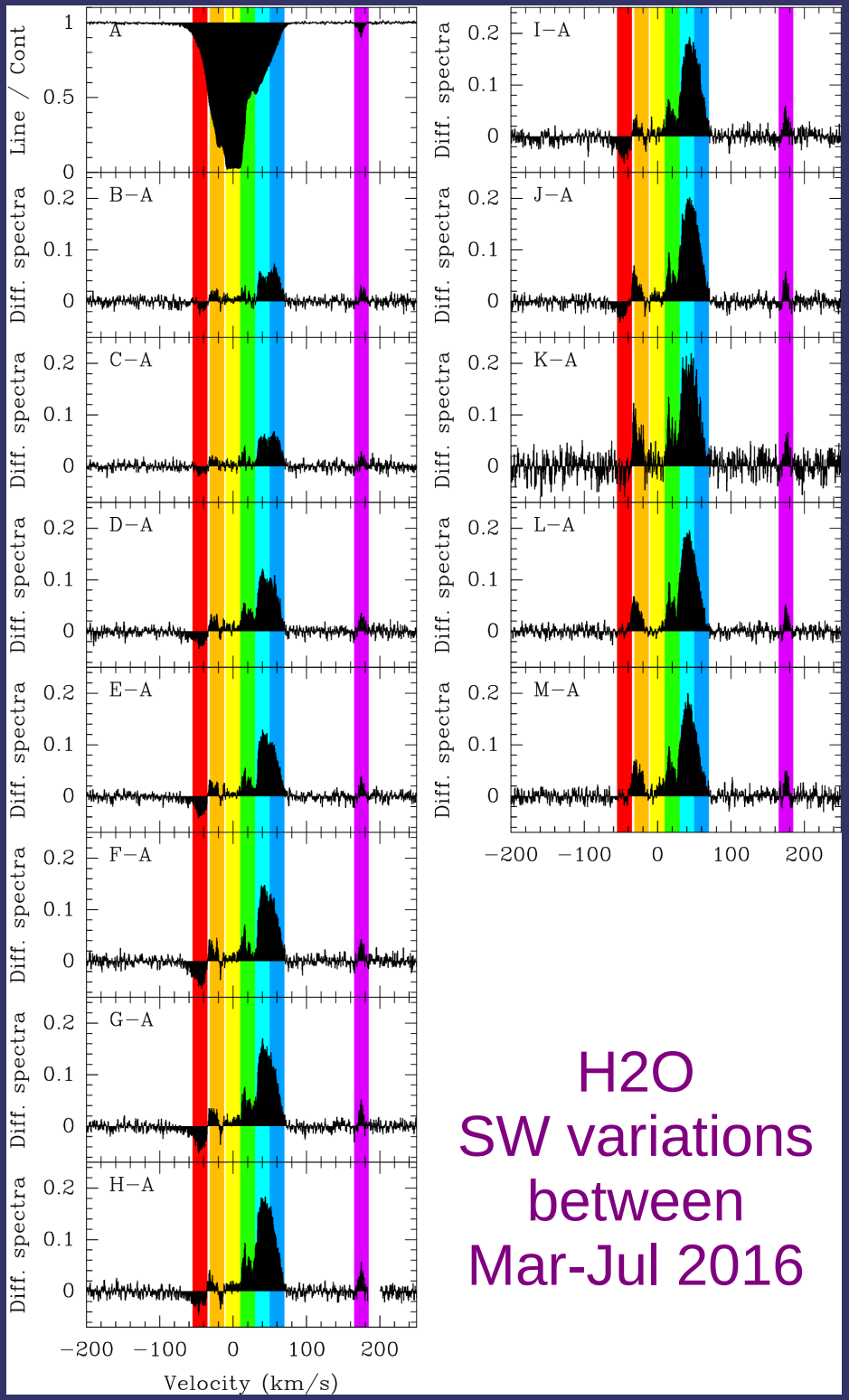
Tomography
of absorbing clouds

Chemical correlation of species !

Nature of of the gas (per velocity components)

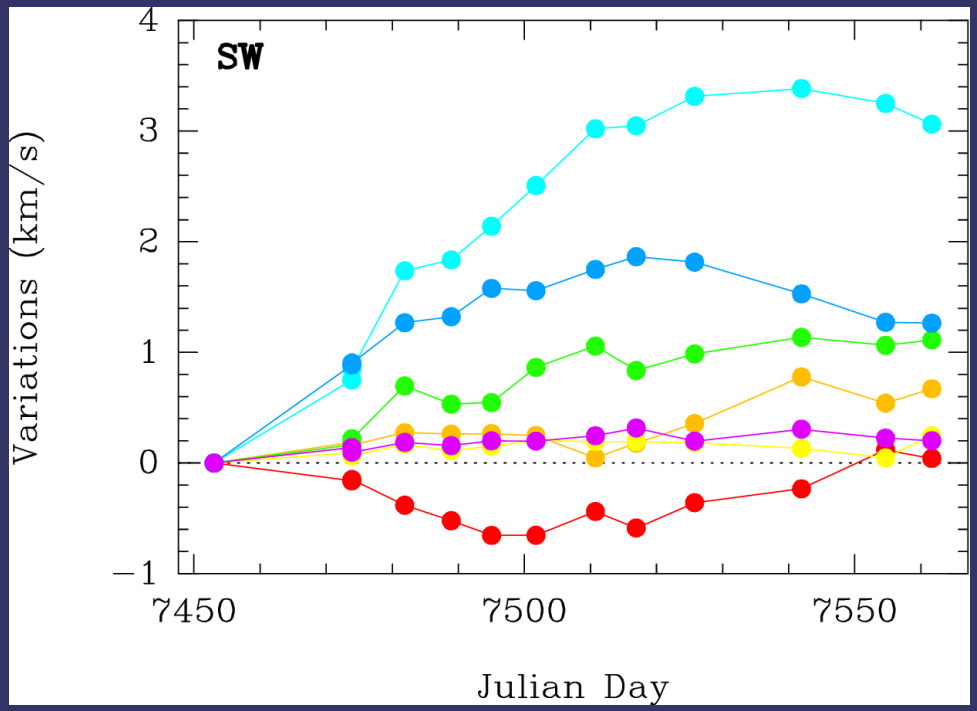
ALMAc3: monitoring project

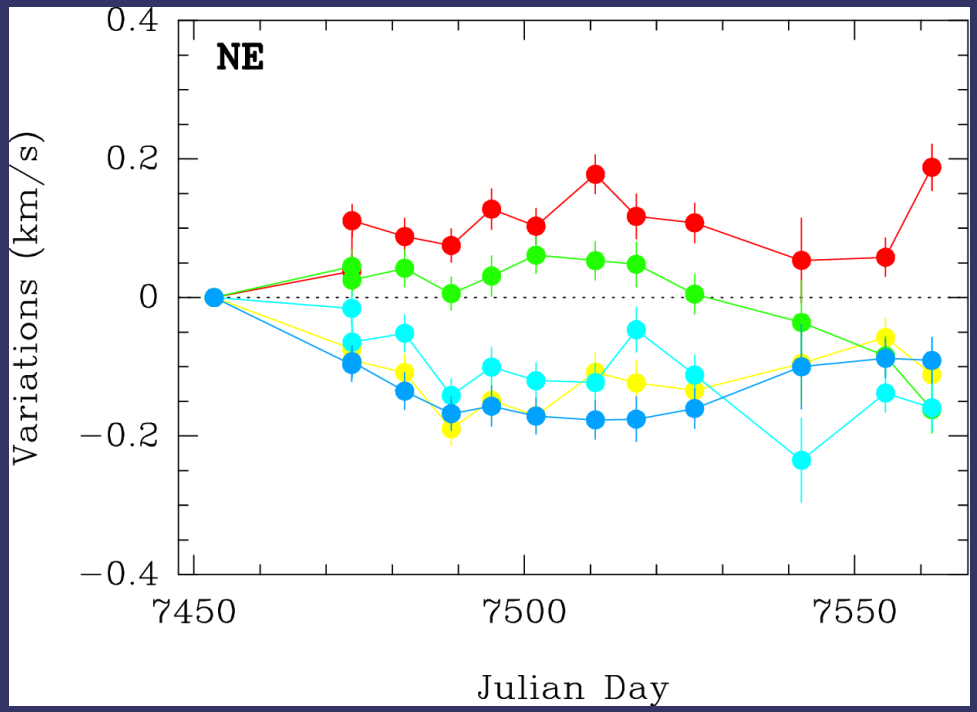




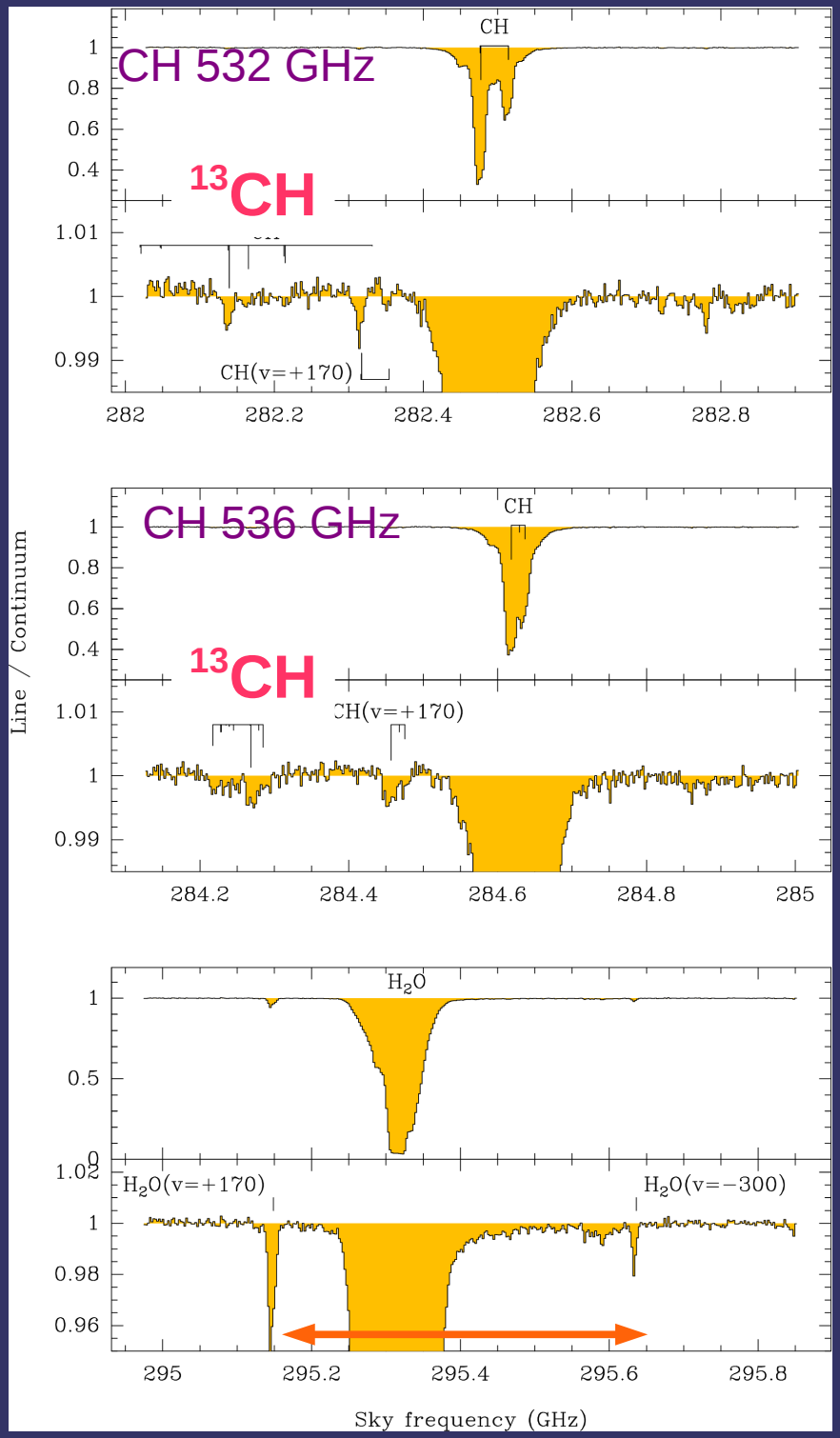
H2O
SW variations
between
Mar-Jul 2016

H_2O time variations





- Smooth and continuous time variations on week timescale
- The source covering factor of SW is not ~100%
  for the wings
- The submm continuum is indirectly resolved



Stacked spectra

Detection of ^{13}CH

(Preliminary ^{12}CH / ^{13}CH ~ 100)

Continuous water absorption between -300 to +170 km/s

(Inclination ~17-35 deg)

Conclusions

- Chemistry seems to be universal

- Hydrides are powerful diagnostic tools
  even at high-z !

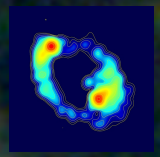
- PKS 1830-211 is (unique) by far the most interesting
  known absorber to date

- We are slowly (re)starting a second absorber

  B 0218+357 z_{abs}=0.68, more on redshifted hydrides to come

- High-z (z>1) molecular absorbers WANTED !

PKS1830-211



Lensed images of the background quasar

z=0.89 absorber

Foreground z=0.19 galaxy

HST, Courbin et al

TABLE 2
HST/WFPC2 PHOTOMETRY

Component	F814W ≈ *I*	F555W ≈ *V*
S1	19.33 ± 0.04	21.90 ± 0.18
NE	21.97 ± 0.05	25.8 ± 0.2
SW	>24.9	>26.3
G	22.04 ± 0.25	≥ 24.7
G2	20.69 ± 0.13	22.24 ± 0.25

Winn et al 2002