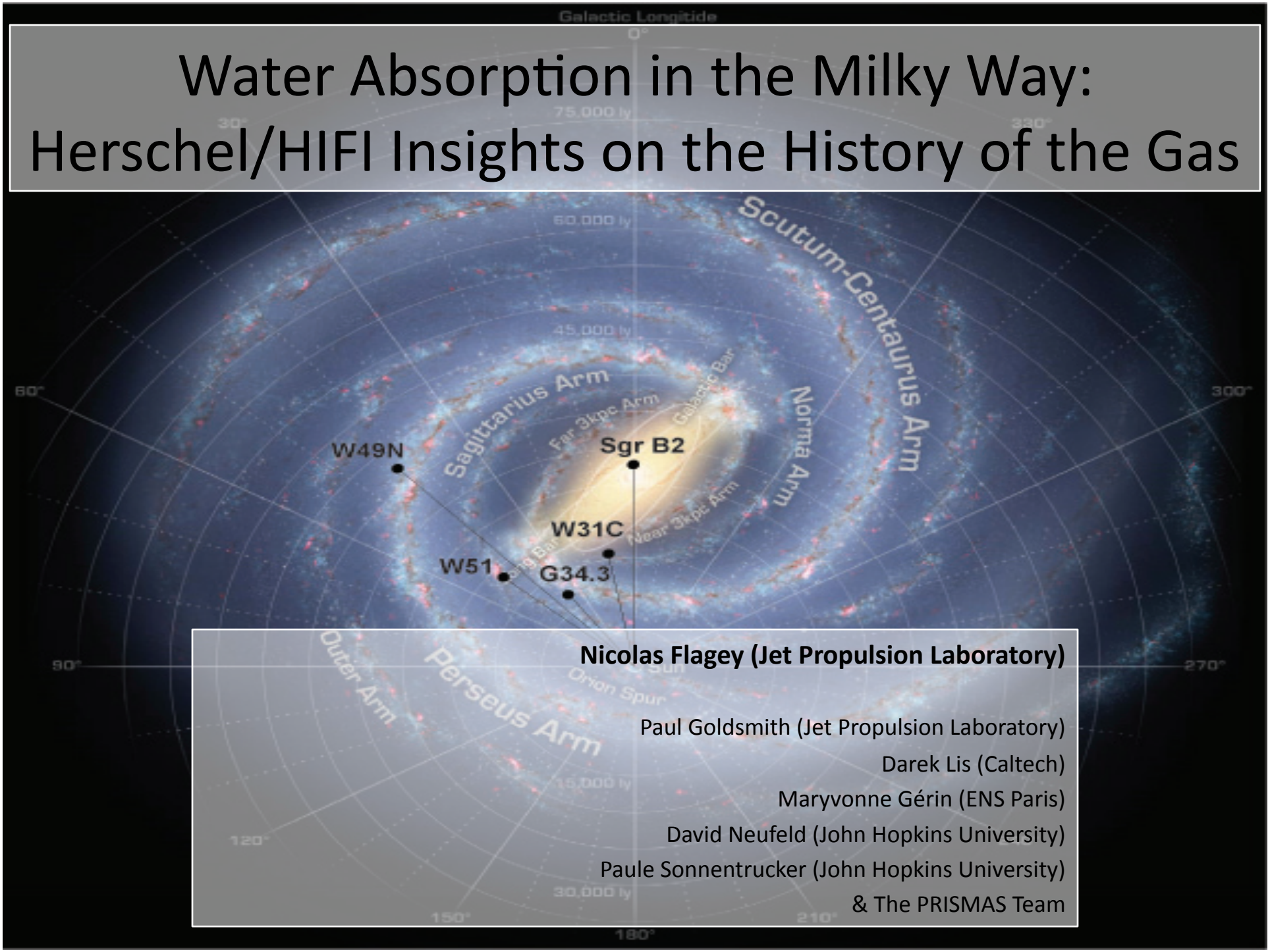
Water Absorption in the Milky Way: Herschel/HIFI Insights on the History of the Gas



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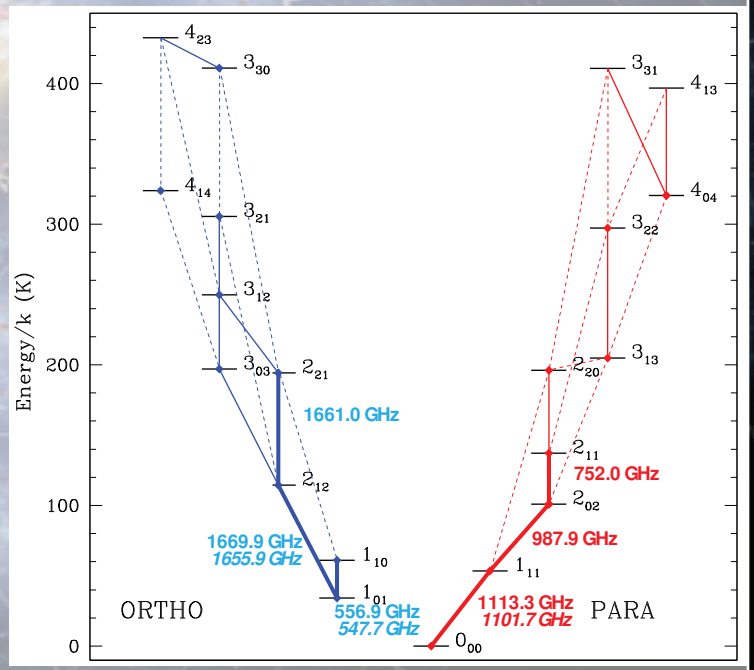
Water absorption in the Milky Way

- The importance of water
  - Reservoir of oxygen
  - Important coolant of dense gas, strongly affects star formation
- The detection of water
  - Water masers *(Knowles et al. 1969)*
  - Water emission & absorption in the Galaxy with SWAS *(Harwit et al. 1998, Neufeld et al. 2002,Plume et al. 2004)*
  - Water in emission at z=3.9 *(van der Werf et al 2011)*
- Formation of water molecules (O chemical reactions network)
  - Low temperature: O ➔ OH^+ ➔ H_2O^+ ➔ H_3O^+ ➔ H_2O
  - High temperature: O ➔ OH ➔ H_2O
  - Dust grain: O_{gr} ➔ H_2O_{gr} ➔ H_2O

Water absorption in the Milky Way

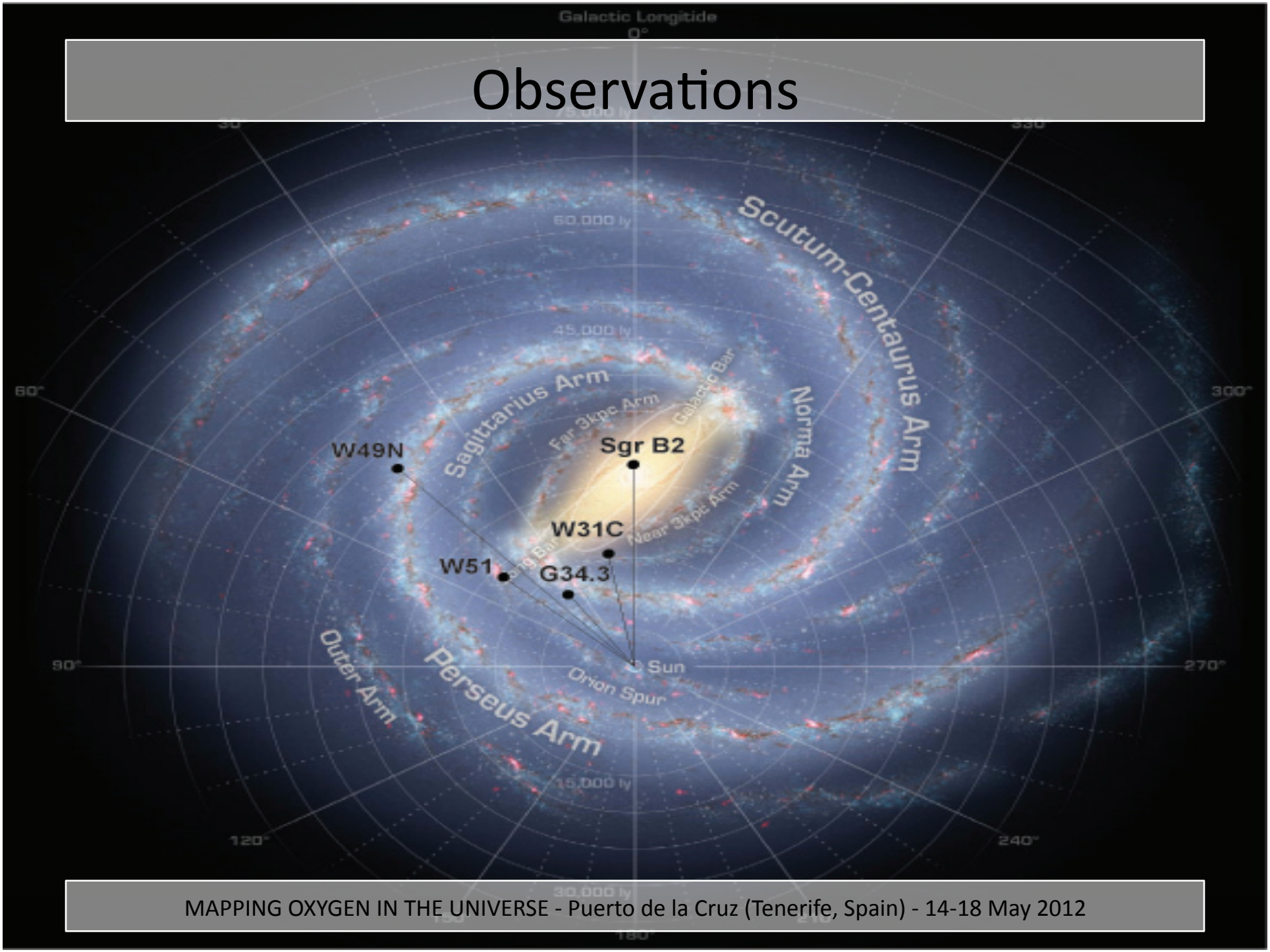
- Ortho- and para-water
  - No radiative transition allowed
  - Conversion through collisions, dependant on temperature & density
  - Ortho-to-para ratio of 3 for temperature above ~ 50K and below 3 at lower temperature
  - Tracing water formation temperature
    or
    Later thermalization with the gas



Observations

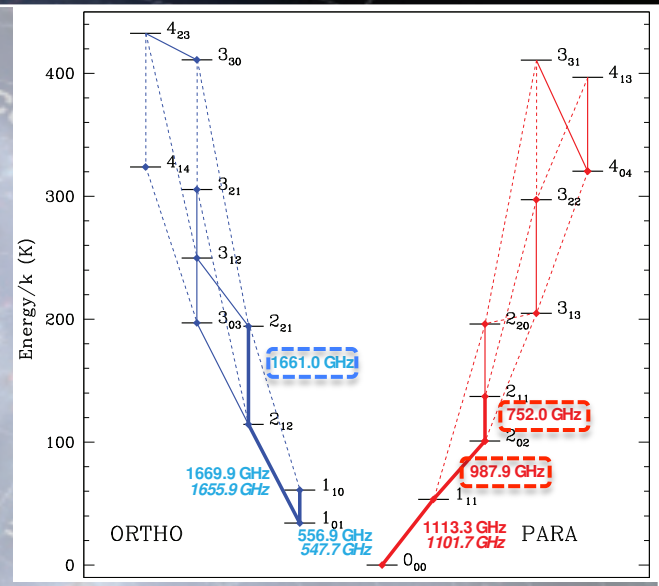
- PRISMAS
  - Herschel Guaranteed Time Key Program
  - PRobing InterStellar Molecules with Absorption line Studies
  - P.I. Maryvonne Gérin (ENS Paris)
  - 128 hours, mostly HIFI
  - 25 molecules
  - 8 Galactic lines of sight toward strong dust continuum sources (W51, W49N, W33A, W31C, W28A, G34.2+0.1, DR21(OH), Sgr B2(M))
- Goals (for water)
  - Constrain column density, abundance and ortho-to-para ratio of water in interstellar clouds

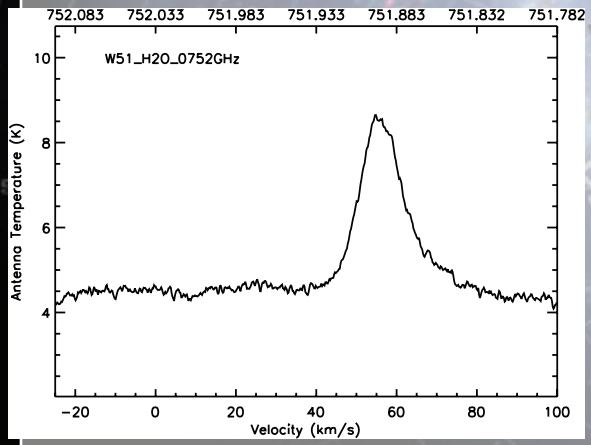
Observations

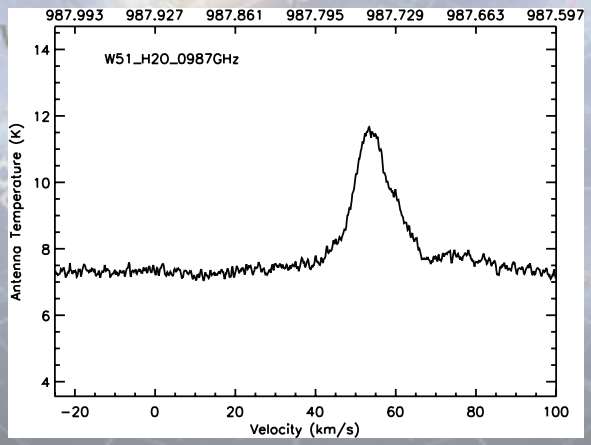


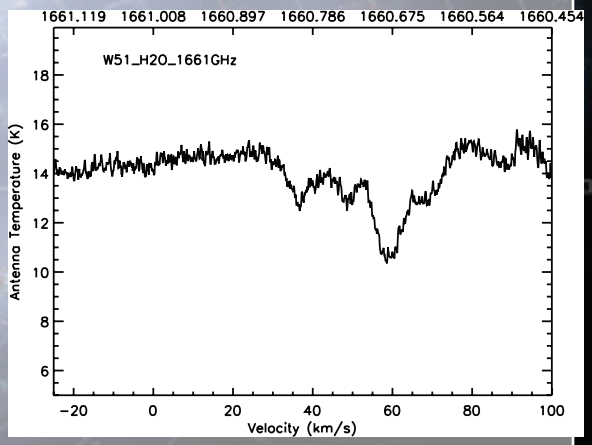
Observations

- $H_2{}^{16}O$ excited transitions
  - Pure emission at 752 GHz
  - Possible absorption at 987 GHz
  - Contamination from other sideband at 1661 GHz



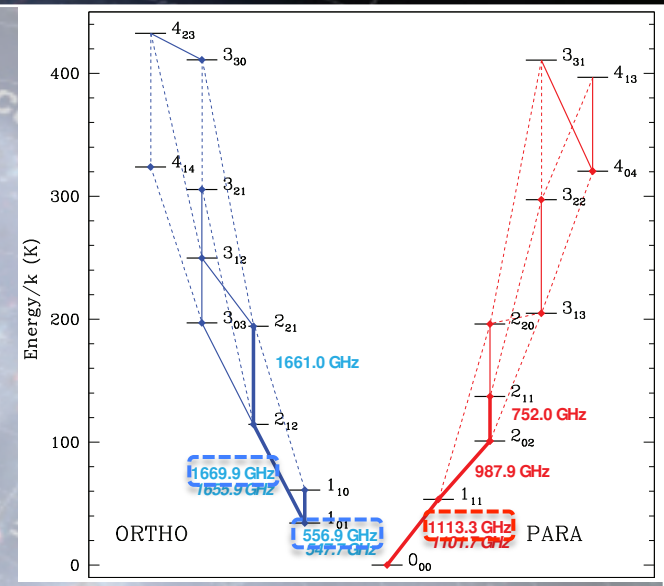


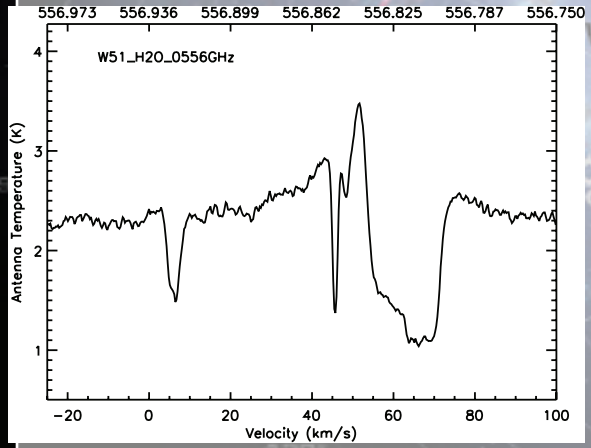


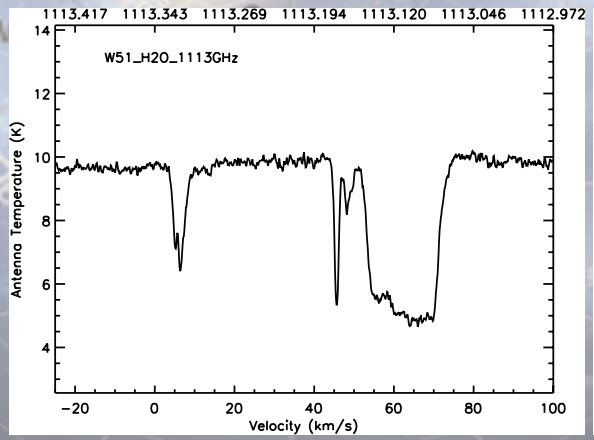


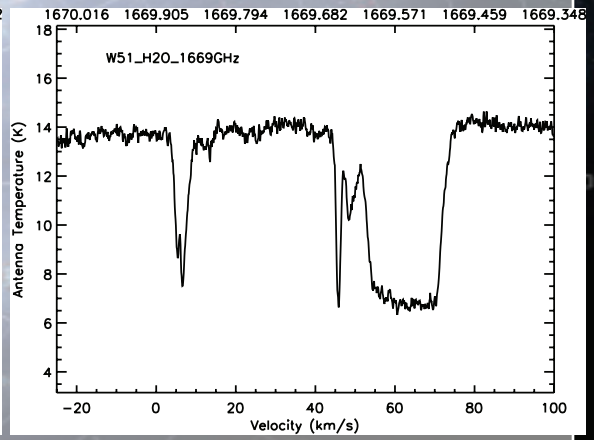
Observations

- $H_2{}^{16}O$ ground state transitions
  - Same lower level for 556 & 1669 GHz
  - Strong absorption at the velocity of the source
  - Emission still present at 556 GHz
  - Other absorption features from interstellar clouds



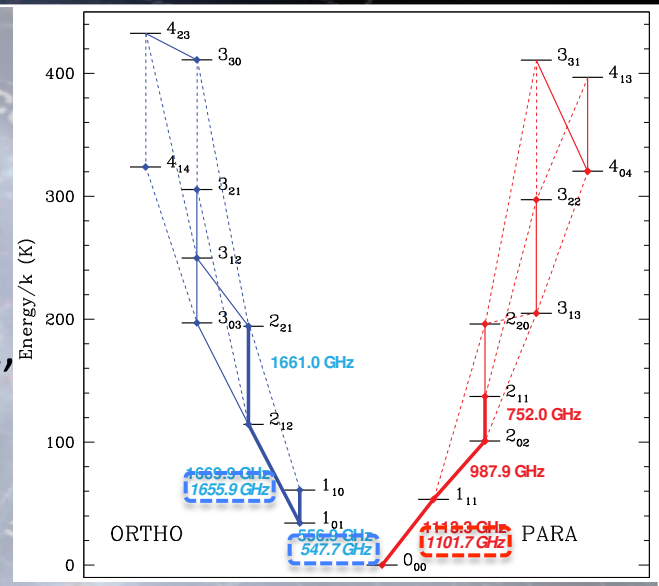


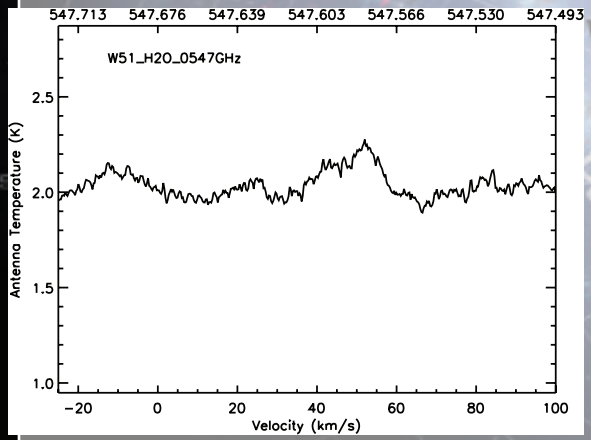


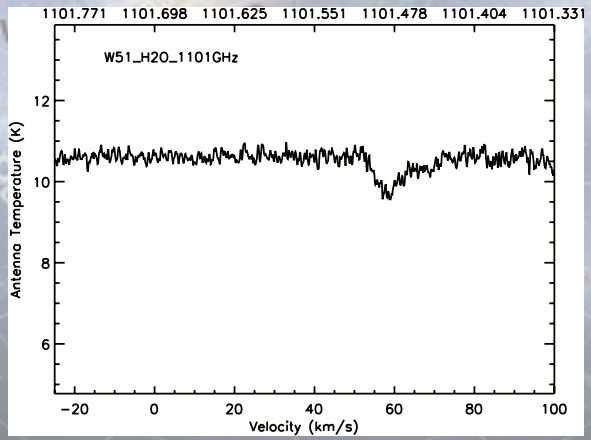


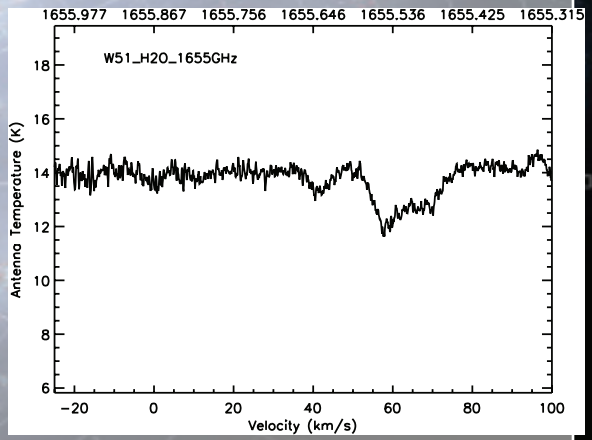
Observations

- $H_2{}^{18}O$ ground state transitions
  - Detection of the only absorptions due to the source, because of the very low abundance ($H_2{}^{16}O/H_2{}^{18}O$ ~ 500)
  - Contaminations (absorption) at 1655 GHz, (emission) at 547 GHz



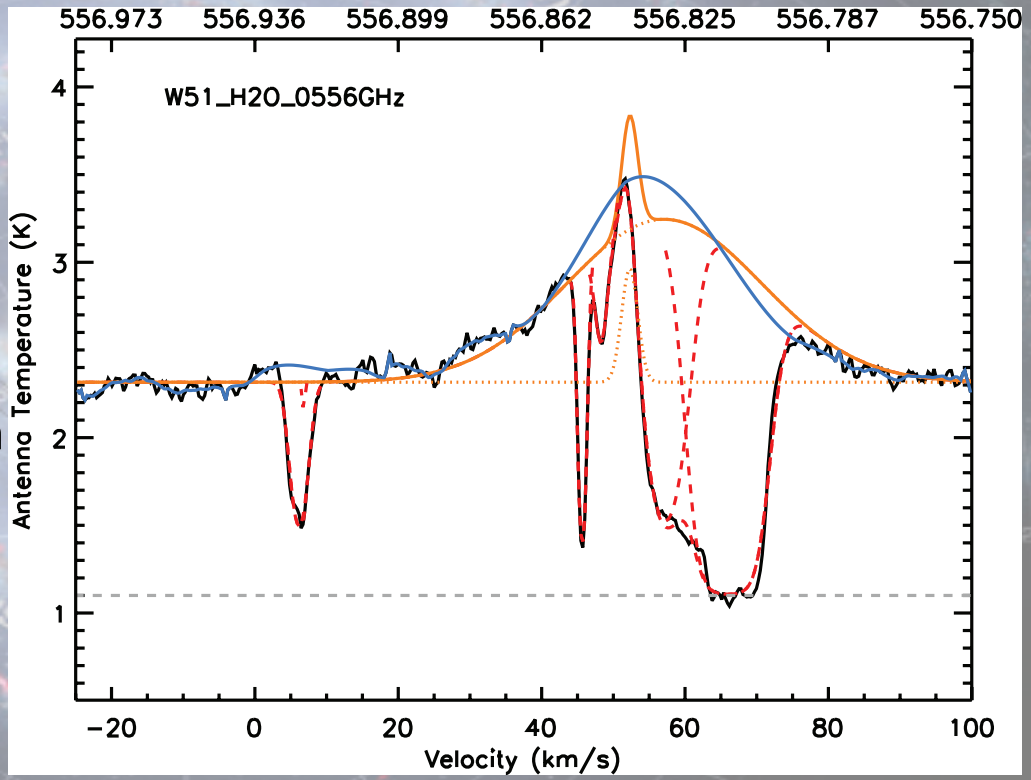






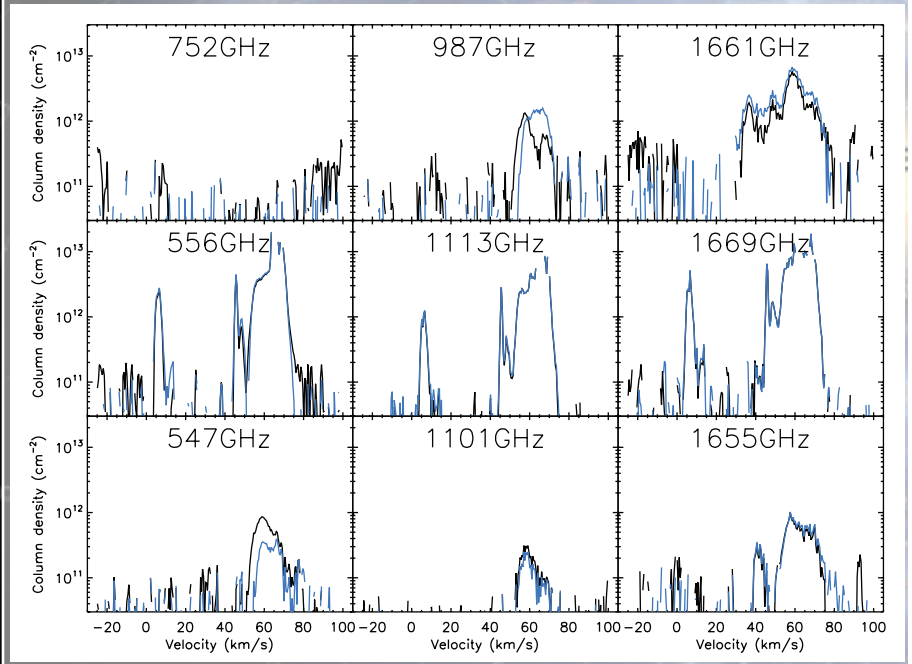
Method

- Ortho-to-para ratio ← column density ← optical depth
  - Importance of constraining the continuum (true dust continuum + water lines)
  - Method #1: interpolation (blue)
  - Method #2: multi gaussian fit (orange) using para-meters from excited transitions for emission lines



Results

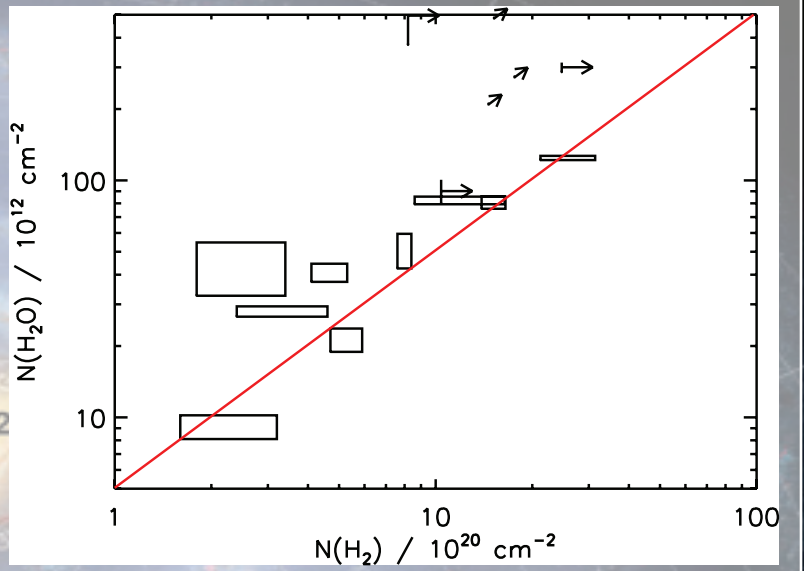
- Column density profiles for the lower level of each transition



Transition (GHz)	v_0 (km/s)	FWHM (km/s)	τ_0	$N_l(H_2O)$ ($\times 10^{12}$ cm^{-2})	Notes
0987 GHz	57.8	7.68	0.32	23.0 ± 4.2	(src)
	67.9	6.72	0.14	8.66 ± 5.0	(src)
1661 GHz	37.1	6.31	0.27	23.5 ± 3.1	CH
	48.6	7.16	0.24	24.3 ± 9.7	CH
	58.7	6.71	0.75	69.4 ± 19.	(src)
	68.0	11.5	0.24	37.9 ± 84.	(src)
1113 GHz	6.18	2.78	0.83	5.40 ± 0.23	
	6.50	0.491	0.31	0.359 ± 0.12	
	45.6	0.964	2.03	4.55 ± 0.20	
	48.5	2.65	0.36	2.21 ± 0.35	
	56.3	4.53	2.50	26.5 ± 1.6	(src, sat)
	65.1	6.20	14.93	216. ± 9.7	(src, sat)
0556 GHz	6.18	2.59	1.13	13.6 ± 0.93	
	6.78	0.587	0.07	0.139 ± 0.48	
	45.7	1.19	1.78	9.89 ± 0.52	
	48.4	2.04	0.37	3.54 ± 0.61	
	57.3	6.00	1.67	46.8 ± 2.1	(src, sat)
	65.9	7.16	5.38	179. ± 7.0	(src, sat)
1669 GHz	6.40	2.73	1.45	18.4 ± 0.51	
	6.45	0.225	0.57	0.955 ± 0.43	
	11.7	4.15	0.09	1.75 ± 0.32	(osb)
	45.8	1.08	2.43	12.3 ± 0.51	
	48.8	3.23	0.67	10.0 ± 0.63	
	56.2	4.79	2.95	65.8 ± 4.1	(src, sat)
	64.8	6.71	18.87	590. ± 48.	(src, sat)
1101 GHz	58.2	6.82	0.23	3.70 ± 6.7	(src)
	66.9	6.52	0.09	1.33 ± 2.1	(src)
0547 GHz	57.7	7.26	0.32	10.7 ± 16.	(src)
	66.3	12.0	0.14	8.00 ± 10.	(src)
1655 GHz	40.6	6.48	0.10	3.12 ± 0.44	(osb)
	58.5	8.81	0.34	14.1 ± 2.1	(src)
	68.5	7.50	0.21	7.24 ± 0.92	(src)

Water column density

- For interstellar clouds $N(H_2O)$ between a few 10^{12} and a few 10^{13} cm^{-2}
- $N(H_2)$ from CH and HF observations *(Godard et al. 2012)*
- Water abundance not varying significantly from cloud to cloud at $\approx 5 \times 10^{-8}$

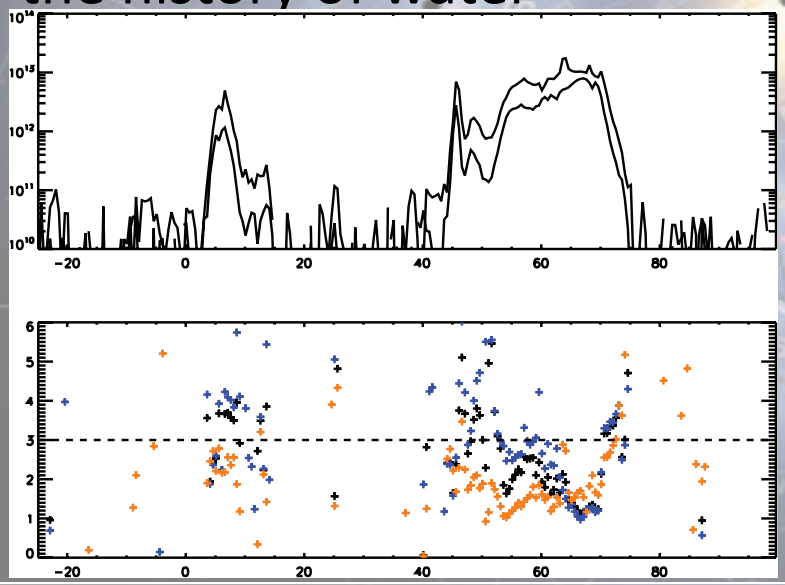


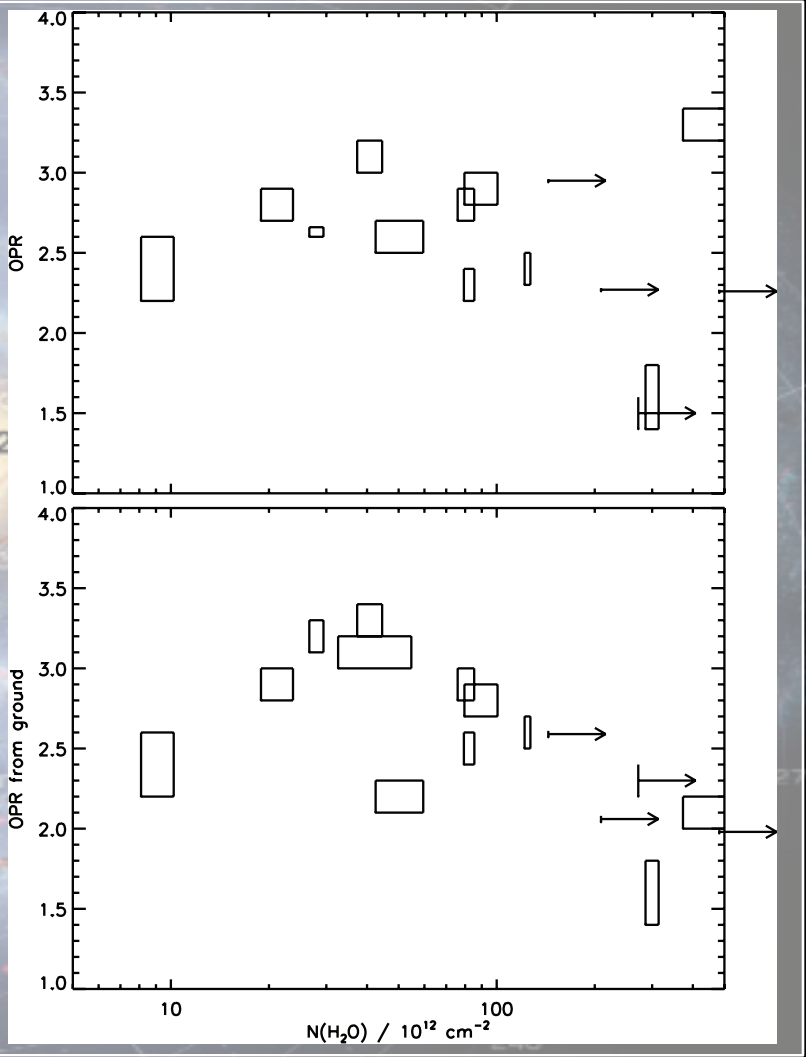
Water column density

- Discrepancy between the two ortho ground state transitions
  - "High" excitation temperature affects differently estimates of N_{101}
  - More water emission at 556 than 1669 GHz
  - Different filling factor (beam size of 14" at 1669 GHz vs 41" at 556 GHz) because of clumps in interstellar clouds
- Comparison with SWAS observations (beam of 3'x4') reveals that absorption features from within the source are diluted (≈small) while interstellar features are the same
- Fractional abundance of water in ground states > 90%
  - Excitation temperature of ~10K (upper limit)
  - H_2 density of 10^6 cm^{-3} (upper limit)

Ortho-to-para ratio

- Most filaments in agreement (within a few sigma) with OPR value of 3
- Several filaments significantly below 3 tracing cold event in the history of water





Conclusions

- First time observations of all the ground states levels + first few excited transitions of water with Herschel
- Evident contamination of the interstellar absorption features by the emission from the "continuum" source
- Nonetheless:
  - Column density of water ≈10^{13} cm^{-2} in interstellar clouds
  - Abundance of ≈$5x10^{-8}$ that of H_2
  - OPR mostly in agreement with the high temperature limit value
- Needed:
  - Better modeling of the water emission
  - Analysis of subtle effects (e.g. variations in the wings of the absorption features)