Probing the Water Chemistry in Young Stellar Objects with Hydroxyl

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Summary

The reaction network of water plays a crucial role in the chemical evolution of young stellar objects. Many of the molecules and ions involved are not accessible from the ground but can be easily observed with the Herschel Space Observatory. The hydroxyl radical OH is not only a major reactant in the water network but also a key species in the oxygen branch of the dense cloud chemistry as well as an important coolant in star forming regions.

Herschel observations of OH far infrared transitions in low- and high-mass protostellar envelopes of various evolutionary stages cover a wide wavelength range at unprecedented resolution and sensitivity. First PACS results for the low-mass class I source HH46 show that OH peaks strongly on source and is much less spatially extended than e.g. water and oxygen. The OH emission was modeled using a slab model in escape probability formalism.
In addition, the PACS data show an asymmetry among the OH doublets which may provide insight into the excitation mechanism of the OH far infrared lines.

Additional HIFI observations were carried out for two sources but yielded no detections of OH hyperfine structure lines.

I. Astrochemistry of H_2O and OH

- The chemical network of water plays a crucial role in the evolution of protostars. Water provides many rotational transitions and is equipped with a high dipole moment, which makes it an excellent coolant. Sufficient cooling is necessary for the continuation of the gravitational collapse.
- H_2, being the most abundant molecule in space, is generally ionized by cosmic ray particles penetrating all of interstellar space. This H_2^+ reacts rapidly with another H_2 molecule to form H_3^+. H_3^+ can react with O to form OH^+ and successively H_2O^+ and H_3O^+ ions. Ion-electron recombination then leads to the dissociation of the H_3O^+ into different products, among them H_2O and OH.

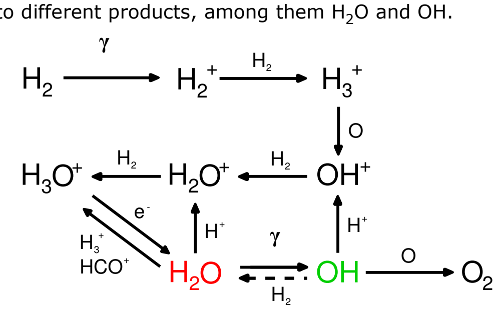
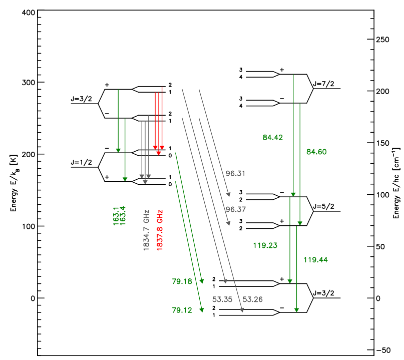


Fig. 1: Chemical reaction network of water and related species

- Photo-dissociation of water to OH is one of the main water destruction paths at temperatures below 250 K which are typical for low-mass young stellar objects in early stages. The inverse reaction, OH + H_2 → H_2O + H takes place only at higher temperatures due to an activation energy barrier. The OH abundance is therefore sensitive to the presence of high energy photons. Chemical models therefore predict OH to be a potential tracer for ionizing protostellar radiation (X-rays, FUV).

II. PACS and HIFI Observations

- OH doublets were detected with PACS at 79, 84, 119 and 163 μm towards the class I low-mass young stellar object HH 46. The lines peak strongly on source while water and oxygen are much more extended.



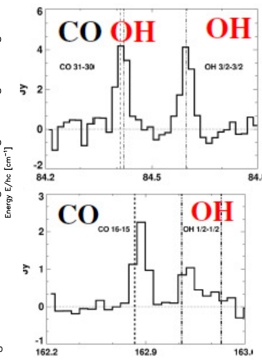


Fig. 2: Left: Term diagram of OH. Transitions in green were observed with PACS, those in red with HIFI. Wavelengths are given in micron.

Fig. 2: Right: PACS spectra for the 84 and 163 μm OH transitions.

- Additional observations were carried out with HIFI for the 163.1 μm (1837 GHz) triplet towards HH46 and NGC 1333 IRAS 2. In contradiction to the converted PACS flux, nothing was detected. One possible explanation is that the lines are much broader than expected.

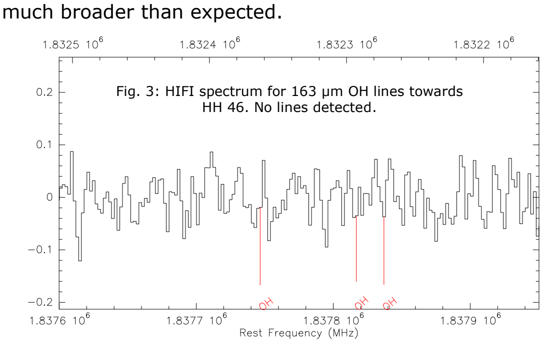


Fig. 3: HIFI spectrum for 163 μm OH lines towards HH 46. No lines detected.

III. OH Modeling for HH 46

- Spherically symmetric model (van Kempen et al., 2009) run through a slightly modified version of the radiative transfer code RATRAN (Hogerheijde & van der Tak, 2000) yields 79, 84 and 119 μm lines in absorption. The lines observed with PACS are in emission. We therefore concluded that the spherical models overestimate the optical depth.
- To investigate a larger parameter space, we used simple slab models in escape probability formalism. Good fits are obtained for T ≥ 500 K, n ≥ $3*10^7$ cm^{-3} and low dust column densities.

References:
Bruderer et al., submitted
M.R. Hogerheijde, F.F.S. van der Tak 2000, A&A 362, 697
P. Stäuber, S.D. Doty, E.F. van Dishoeck, J.K. Jorgensen, A.O. Benz 2004, A&A 425, 577
P. Stäuber, S.D. Doty, E.F. van Dishoeck, A.O. Benz 2005 A&A 440, 949
T. A. van Kempen et al., 2009, A&A 501, 633
T. A. van Kempen, L. E. Kristensen et al., submitted

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