Hunt for Molecules
F. Combes, F. Casoli, E. Falgarone, L. Pagani (eds)

ODIN'S HUNT FOR MOLECULES

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Abstract. Selected results from Odin's third and fourth year of astronomy observations are discussed in the context of molecular hunting in a variety of targets - benefiting from the tunability of the sub-millimetre wave mixers, the sensitivity of the 119 GHz O_2 search HEMT receiver, and the capability of simultaneous observations by two or three receivers. Odin's spectral scan observations of Orion KL will be used to illustrate the care needed in line identification work. At low intensities the line blending is severe. E.g., it turns out that the high velocity parts of the outflow wings of the $1_{10} - 1_{01}$ lines of $H_2{}^{18}O$ and $H_2{}^{17}O$ mainly are caused by SO_2, $^{34}SO_2$ and CH_3OH emissions. Odin's spectral scan search for primordial molecules also will be briefly discussed.

1 Introduction

The Odin sub-millimetre wave spectroscopy satellite (Figure 1) – funded jointly by the space agencies in Canada, Finland, France and Sweden and intended for astronomy as well as aeronomy research – was launched on 20 February 2001. Odin houses an offset Gregorian telescope of diameter 110 cm, equipped with an actively cooled (to about 140 K) receiver package consisting of four tuneable sub-mm Schottky mixers (covering 486–504 and 541–581 GHz) and a fixed-tuned HEMT receiver at 118.750 GHz dedicated to sensitive O_2 searches. Any combination of three receivers can be simultaneously used together with a broadband 1720 channel acousto-optical

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Fig. 1. Odin in orbit

spectrometer (BW = 1050 MHz; channel spacing 0.6 MHz) and two flexible hybrid autocorrelation spectrometers (BW= 100−−800 MHz; channel spacing 0.125–1 MHz). The antenna main beam efficiency is close to 90% and the beamwidths are about $2.1'$ and $9.5'$ at sub-mm and mm wavelengths. More detailed presentations of the Odin project, the satellite and its equipment, and new astronomy results from the first year of observations can be found in a Special Odin Letters Edition of A&A (Nordh et al. 2003 and subsequent papers). Highlights from the second and third year of Odin observations have been collected in our rather extensive progress report at COSPAR 2004 in Paris (Hjalmarson et al. 2005), treating many of the topics of the present paper in more detail than is possible here.

Before I proceed to discuss some of our recent Odin results I want to thank the organising committee for inviting me to participate in this meeting in celebration of my very good and reliable friend Pierre Encrenaz. Pierre, together with Gerard Mégie, have been our very important and enthusiastic French Odin supporters during more than a decade.

2 Selected Odin highlights

2.1 The hunt for interstellar O_2

Since this topic is treated in considerable detail at this meeting by our dedicated O_2 hunter Laurent Pagani, I will be very brief and refer to his paper (cf. also Hjalmarson et al. 2005). It may be important to note that we get Odin's deep O_2 searches "almost for free", since we can use the 118.750 GHz O_2 receiver simultaneously with sub-mm observations of other molecular lines, e.g., the ground state rotational transitions of H_2O, $H_2{}^{18}O$ and NH_3. This also includes detailed mapping (at $1'$ spacing) of the sub-mm emissions since the sub-mm beam width is $2.1'$, while the O_2 beam width is $9.5'$. According to our firm upper limits (including possible low-level detections in ρ Oph A and Orion KL, to be verified or disproved by planned long integrations) O_2 is much less abundant (by a factor 1000) than expected from chemical models. Our O_2 search limit in the metal poor Small Magellanic Cloud also is interestingly low (Wilson et al. 2005).

2.2 The hunt of cometary molecules - H_2O, $H_2{}^{18}O$ and NH_3

As surely will be evident from the contribution at this meeting by Nicolas Biver, this has been a very successful area of Odin research. Up to now 12 comets, including Tempel 1 (the target of Deep Impact on 4 July 2005), have been observed, monitored and also mapped (cf. Biver et al. 2006, Hjalmarson et al. 2005). Here the high velocity resolution available (100 m/s) and the possibility to use two receivers tuned to H_2O or $H_2{}^{18}O$ have been very beneficial.

2.3 A glance at Martian aeronomy - H_2O, $H_2{}^{18}O$ and CO $(5-4)$

This topic likely will be included in the contribution at this meeting by Emmanuel Lellouch and a paper analysing the Odin observations has been published (Biver et al. 2005). Here I just note that our observations of Mars have demonstrated the presence of water vapour up to high altitudes, but that the abundance is 1000 times lower than in the terrestrial atmosphere.

2.4 Spectral scan searches for primordial molecules

This topic will be covered at the current meeting by Monique Signore and Roberto Maoli. Since this is a very important research area strongly argued for by Pierre Encrenaz, I will here give some additional comments. Odin has performed the first, pioneering, spectral scan searches for primordial molecules (covering the frequency range 547–578 GHz) towards two selected WMAP hot spots in the cosmic microwave background radiation. We are here searching for spectral lines, or ideally identifying patterns of lines, from primordial molecules (e.g., H_2, $H_2{}^+$, HD, HD^+, HeH^+, LiH, LiH^+) in cloud structures formed at unknown redshifts during the “dark ages” of the evolving Universe (z =1000–10, corresponding to about 300 000 to 300 000 000 years after the Big Bang). Our current progress was presented on a poster at the recent IAU astrochemistry symposium in Asilomar, CA (Encrenaz et al. 2005). As yet no signals have been identified, but the scientific impact of a line detection is easy to imagine. However, in view of Odin’s limited sensitivity this may be considered a “pilot study”, aiming at testing and developing observation, data reduction and pattern recognition methods in preparation for deeper searches planned to be performed by Herschel Space Observatory (upon Pierre’s initiative).

2.5 Circumstellar envelopes - too much H_2O and NH_3, but no PH

The weak H_2O signal detected by Odin in the oxygen rich circumstellar envelope of the ageing star W Hya has led to quite an astonishing interpretation. Excitation and radiative transfer analysis of the H_2O lines observed by Odin and ISO, combined with the mass-loss rate determined from CO observations, leads to a water abundance of $(2\text{–}3)\times10^{-3}$ – higher than the elemental O abundance (Justtanont et al. 2005). Additional water from evaporation of comets, i.e., signs of the existence of an extrasolar cometary system, could be the explanation.

A very similar suggestion may appear from Odin’s detection of weak H_2O and NH_3 signals from the surroundings of the nearby carbon rich ageing star IRC +10216, where very low abundances of these species were expected. However, the observed abundances were estimated to be as high as 2×10^{-6} and 1×10^{-6}, primarily leading to the conclusion that the major chemical processes are not known well enough (Hasegawa et al. 2006). While the enhanced H_2O abundance could be caused by evaporation of comets, in accordance with the interpretation of the earlier H_2O detection by SWAS, the high abundance of NH_3 is not so "easily" explained, unless these comets are much more ammonia rich than the comets we know in our solar system.

A deep Odin search for the PH ($N = 1 - 0$) line group at 553.36 GHz in IRC +10216 has led to an upper limit well below the solar phosphorous abundance (Bernath et al. 2006).

2.6 On absorptions, outflows and infall seen in H_2O and NH_3 lines

Since the H_2O $1_{10} - 1_{01}$ transition at 557 GHz has a critical density as high as $3 \times 10^8\,\mathrm{cm}^{-3}$, in lower excitation regions most of the molecular population is expected to remain in the lowest energy state, "ready to absorb radiation from behind". Hence it is only natural that our water spectra, for good and for bad, suffer from pronounced absorption features, where the absorbed background may not only be dust continuum but also can be the line emission itself, e.g. in terms of outflow emission.

Odin has observed a number of suspected strong H_2O and NH_3 absorption line sources, selected because of their strong sub-mm background continuum emission: Sgr B2 (cf. Hjalmarson et al. 2005), Sgr A (several positions; cf. Sandqvist et al. 2003), W 49 N, W 51 and also the hot core source G 34.3−0.2. The rather challenging spectra currently are undergoing analysis, in several cases combined with ground-based support observations using the Onsala 20 m telescope.

Odin, as well as SWAS, has observed a number of molecular clouds and candidate infall sources, where prominent H_2O outflow emission spectra are intersected by equally prominent deep narrow absorptions. The results of Odin's simultaneous H_2O and NH_3 mapping towards the very nearby (at a distance of only 160 pc) low-mass star-formation regions IRAS 16292−2422 and ρ Oph A appear to be best, if not uniquely, explained as infall/outflow interaction. Papers by Ristorcelli , Schöier, Larsson and their collaborators soon should be ready for submission. Our IRAS 16292−2422 results were presented on a poster at the recent IAU astrochemistry symposium in Asilomar, CA (Ristorcelli et al. 2005).

Odin's H_2O and NH_3 observations against the dust continuum of the hot core source G 34.3−0.2 (see Figure 2), may be an even more convincing case of infall/outflow interaction, and where the H_2O spectrum also exhibits multiple, deep foreground absorptions. The deep absorption feature seen in H_2O as well as in NH_3 at +60 km/s, i.e., red-ward of the hot core velocity

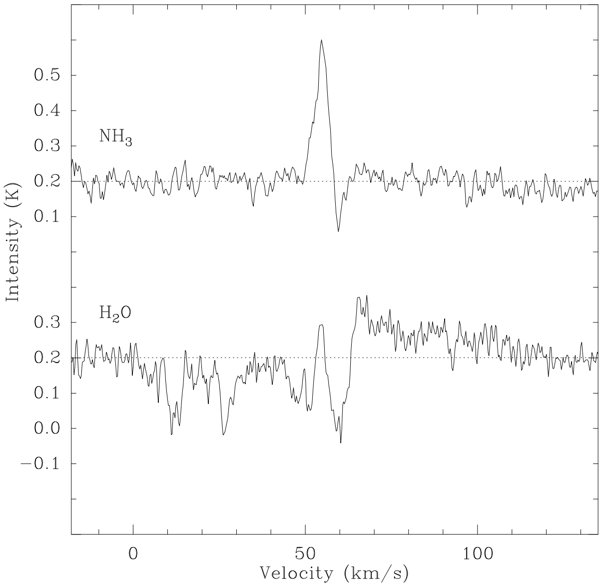

Fig. 2. Infall/outflow interaction and multiple absorptions in the NH_3 $(1_0 - 0_1)$ and $H_2O(1_{10} - 1_{01})$ spectra observed against the dust continuum emission of the hot core source G 34.3−0.2.

(+57 km/s), obviously must take place in front of the hot core continuum source. Therefore the absorbing gas must move towards the star-formation core, the signature of inward motion. We also should note that the rather prominent hot core emission visible in NH_3 is almost completely hidden by absorptions in case of H_2O. A red-ward H_2O high-velocity outflow wing is visible, while its low-velocity part and also the expected blue-ward outflow wing are invisible because of deep H_2O absorption features (cf. also Hjalmarson et al 2005).

2.7 Some results from Odin's spectral scan of Orion KL

Benefiting from Odin's capability of simultaneous broad-band observations using any two sub-mm receivers connected to three spectrometers we have performed a spectral line survey of the bands 486–492 and 541–576 GHz - bands which are impossible or very difficult to observe from ground based observatories - towards the Orion KL molecular cloud. The frequency steps were 0.5 GHz, allowing all bands to be covered by two separate 25 hour observations, resulting in a total observing time of about 1000 hours. As is evident from Figure 3, presenting the 547–563 GHz spectrum of Orion KL together with line identification markers, the data quality is very good. The line density in fact is as high as that obtained from ground-based observatories at neighbouring sub-mm frequencies (JCMT: White et al. 2003; CSO: Schilke et al. 2001).

The line blending apparent in Figure 3 sometimes may cause severe interpretation problems, especially when knowledge of spectral line shapes for specific species are needed, as is rather clearly demonstrated by the various water vapour spectra shown in Figure 4. While the HDO ($2_{02} - 1_{11}$), p-H_2O ($6_{24} - 7_{17}$) and o-H_2O ($1_{10} - 1_{01}$) spectra do not appear to suffer appreciably from overlaps with other molecular lines, this is indeed not the case for the o-$H_2{}^{18}O$ and o-$H_2{}^{17}O$ emissions. It turns out that the high velocity parts of the outflow wings of the $1_{10} - 1_{01}$ lines of $H_2{}^{18}O$ and $H_2{}^{17}O$ mainly are caused by SO_2, $^{34}SO_2$ and CH_3OH emissions. However, using the now available spectral scan multi-transition observations of the "poisoning" species we can recreate the "true" o-$H_2{}^{18}O$ and o-$H_2{}^{17}O$ emissions, which mainly seem to emanate from the low-velocity outflow. The corresponding o-H_2O emission, in addition to a partly self-absorbed emission from the low-velocity outflow, exhibits prominent high-velocity wings (cf. Hjalmarson et al. 2005, Olofsson et al. 2003). The newly identified emissions from HDO and p-H_2O, detected via Odin's spectral scan, appear to originate in other (also well-known) source components. The p-H_2O emission line (the upper state energy of which is 867 K) shows the velocity and width characteristics of the very compact "hot core" source, where hence the water vapour abundance must be very high - as may be expected from hot core (evaporation) chemistry models. The HDO ($2_{02} - 1_{11}$) line, the upper state energy of which is 66 K, appears to show the low-velocity outflow emission, perhaps a hot core hump, and in addition a clear narrow-line emission feature peaking at 8 km/s (emission from the warm compact ridge

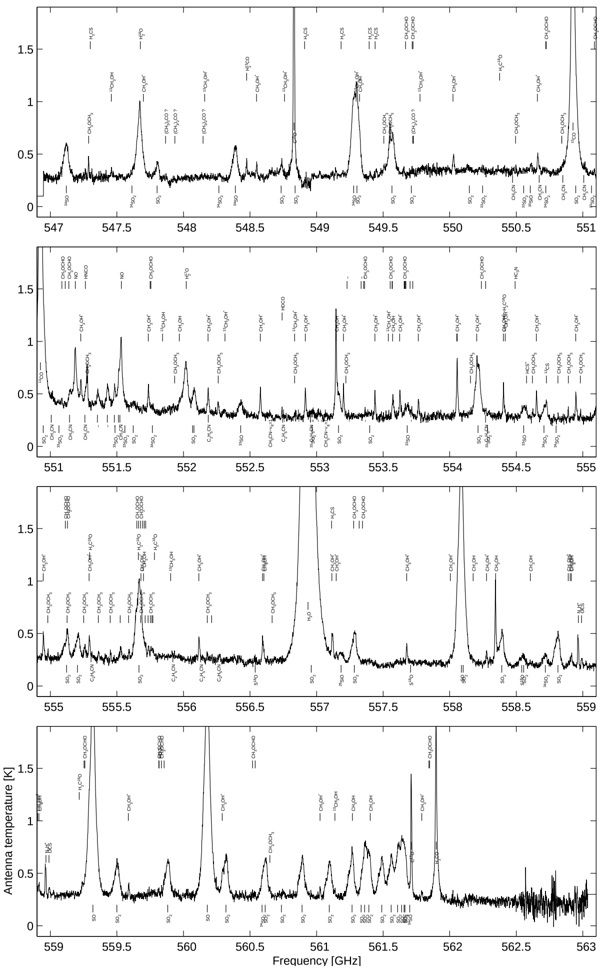

Fig. 3. Part of the Orion KL spectral scan, including molecular line markers. Note the severe line blending.

core?; or perhaps, if I may speculate somewhat, from the heated interface layer between the M 42 HII region and the molecular cloud, where the extended prominent narrow-line o-H_2O $(1_{10}-1_{01})$ emission observed by SWAS

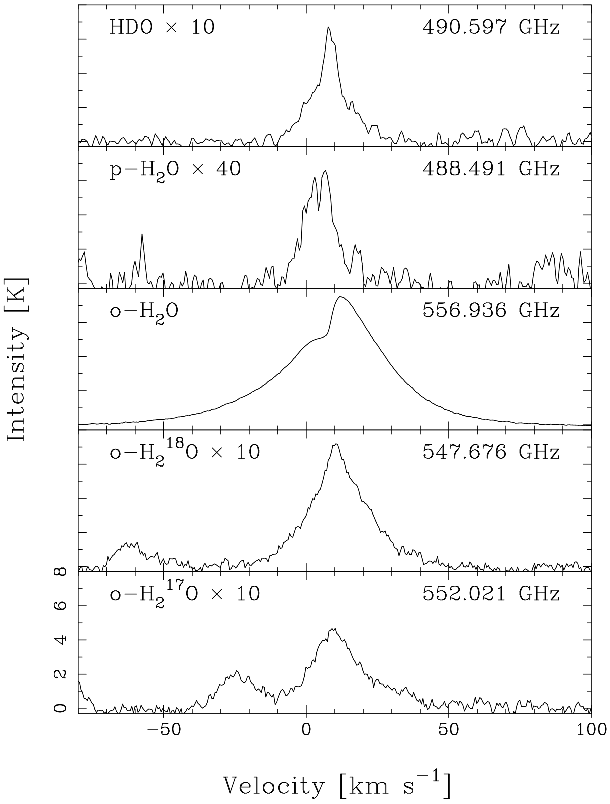

Fig. 4. Water spectra extracted from the Orion KL spectral scan. From top to bottom: HDO ($2_{02}-1_{11}$) - E_u = 66 K; para-H_2O ($6_{24}-7_{17}$)) - E_u = 867 K; ortho-H_2O ($1_{10}-1_{01}$) - E_u = 27 K; ortho-$H_2{}^{18}O$ ($1_{10}-1_{01}$) - E_u = 27 K; ortho-$H_2{}^{17}O$ ($1_{10}-1_{01}$) - E_u = 27 K. Note that the visible high-velocity outflow wings of the $H_2{}^{18}O$ and $H_2{}^{17}O$ emissions mainly are caused by blends with other lines: SO_2 at −65 km/s and $^{34}SO_2$ at +35 km/s in case of of $H_2{}^{18}O$, which also suffers from CH_3OH blending at −5 km/s; 2× SO_2 at −25 km/s and CH_3OH at +35 km/s in case of $H_2{}^{17}O$. The appearances of all the lines are discussed in the text (2.7).

and Odin appears to originate ??). Limited Odin mapping of this relatively strong HDO line hence is very desirable. If the this HDO emission were extended, this would strengthen the scenario leading to the extended bright o-H_2O ($1_{10} - 1_{01}$) emission - evaporation of icy grain mantles (accreted in an earlier, colder cloud phase) in the warm interface layer (cf. Melnick and Bergin 2005, Hjalmarson et al. 2005, Wirström et al. 2005, 2006).

The Odin spectral scan data reduction and identification work has been performed in parallel at Onsala Space Observatory and at University of Calgary. A progress poster was presented at the recent IAU astrochemistry symposium in Asilomar, CA (Persson et al. 2005) and papers on the spectral scan results and the subsequent analysis are currently being prepared by Olofsson, Persson and collaborators.

3 An outlook towards Herschel Space Observatory

In view of the Herschel to Odin beam area ratio of about 10 and Herschel's at least 10 times lower system temperature in the 550 GHz band we may foresee a dramatic increase in sensitivity - a factor $>$ 10 000 in case of compact sources. We may now look forward to a sub-millimetre wave facility of great promise - the Herschel Space Observatory - to be in operation in the very near future, and with Pierre Encrenaz as one of the Mission Scientists. I am convinced that our "surveying" observations by Odin and SWAS will serve as useful guides to these forthcoming observations.

Acknowledgements

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