Odin spectral line observations of Sgr A and Sgr B2 at submm wavelengths and in the 118-GHz band

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Abstract. Since its launch in 2001, the Odin satellite has been observing the Galactic Centre Sgr A Complex (CND, +20 and +50 km s\textsuperscript{-1} Clouds) as well as the nearby star formation region, Sgr B2, a number of times. Observations have been made in the 118-119 GHz and 486-581 GHz bands. A limited mapping of the Sgr A Complex in the H\textsubscript{16}O line has been performed and new observations of the H\textsubscript{18}O line took place in 2006. In the 118-119 GHz band, a strong line of HC\textsubscript{3}N (J = 13 – 12) has been detected at a number of positions - sensitive upper limits have been obtained for the O\textsubscript{2} (1\textsubscript{1} – 1\textsubscript{0}) and the SiC (\textsuperscript{3}H\textsubscript{2}, J = 3 – 2) lines. Towards Sgr B2, submm observations have yielded absorption profiles of H\textsubscript{2}\textsuperscript{16}O, H\textsubscript{2}\textsuperscript{18}O, H\textsubscript{2}\textsuperscript{17}O, NH\textsubscript{3}, and \textsuperscript{15}NH\textsubscript{3}.

1. Introduction

The Odin satellite [1] was launched on 20 February 2001 and is now entering its sixth year of operation (Fig. 1). It is equipped with a 1.1 m offset Gregorian telescope and a cryogenic receiver package of four tunable, SSB, submm Schottky mixers covering the 486-504 and 541-581 GHz frequency range and a fixed-tuned HEMT receiver at a frequency of 118-119 GHz. This is a mission shared between aeronomy and astronomy on a 50/50 basis. The Swedish-led project is funded jointly by the Swedish National Space Board (SNSB), the Canadian Space Agency (CSA), the National Technology Agency of Finland (Tekes) and the Centre National d’Etudes Spatial (CNES, France). The Swedish Space Corporation (SSC) is the prime industrial contractor and is also responsible for the satellite operation.

The Galactic Centre, with its important sources, the Sgr A Complex and Sgr B2, has been of prime importance in Odin’s observing program. The first detection of water in the Sgr A Complex with Odin was reported in 2003 [2]. In this paper we concentrate on further observations of the Sgr A Complex and refer to [3] for a preliminary presentation of the Sgr B2 results.

Observations in the Sgr A Complex have been mostly towards three positions, namely Sgr A* with the CircumNuclear Disk (CND), the +50 and the +20 km s\textsuperscript{-1} molecular clouds. Spectral
lines probed have been 119- and 487-GHz O$_2$, 492-GHz C$\text{I}$, 548-GHz H$_{18}$O, 557-GHz H$_{16}$O, 572-GHz NH$_3$, and 576-GHz CO ($J = 5 - 4$). We present here only 118-119 GHz, H$_{16}$O, and CO ($J = 5 - 4$) results.

Figure 1. The Odin satellite.

Figure 2. Observed positions in the Sgr A Complex are marked by circles whose 2-arcmin diameter indicates the Odin submm beam. The whole region depicted is slightly larger than the 10-arcmin 119-GHz Odin beam. The Complex consists of the 20-cm continuum radiograph, the CND (thin lines) in HCN, the Molecular Belt and its +20 (SW white circle) and +50 (NE white circle) km s$^{-1}$ Cloud components in 2-mm H$_{2}$CO (solid lines) with isovelocity contours (broken lines). The coordinates are epoch 1950.0. (adapted from [4])

2. The submillimetre observations
A limited mapping has now been performed in the Sgr A Complex (Figs. 2 and 3) using the H$_{16}$O line. Water is seen in emission from the CND and the +20 and +50 km s$^{-1}$ Clouds, and in absorption from the Expanding Molecular Ring (EMR) near $-130$ km s$^{-1}$, the 3-kpc spiral Arm near $-50$ km s$^{-1}$, the $-30$ km s$^{-1}$ Arm, and the Local Sgr Arm near 0 km s$^{-1}$. There is also evidence of absorption from a High Positive Velocity Gas (HPVG) component between 100 and 200 km s$^{-1}$ in some positions. No baselines have been subtracted and the effect of the submm dust continuum emission from the Molecular Belt is clearly noticed in the levels of the profiles.

In 2003 [2] we presented the Odin observation of H$_{18}$O towards the Sgr A$^{*}$ CND position. No emission (or absorption) was visible in that profile whose channel resolution was 0.6 km s$^{-1}$ and whose rms noise was 0.02 K. In the late spring of 2006 we scheduled 150 orbits for Odin to observe the +50 km s$^{-1}$ Cloud position. If these observations lead to a positive detection of the H$_{18}$O line, a similar observing period will probably be scheduled for the +20 km s$^{-1}$ Cloud in early 2007.
The Odin observations of the 557-GHz $\text{H}_2^{16}$O line in the seven positions mapped in the Sgr A Complex and shown in Fig. 2. The coordinate offsets are relative to the position of Sgr A*. The range of velocity of the profiles is $-250$ to $+250$ km $s^{-1}$ and the range of antenna temperature is $-0.1$ to $+1.5$ K. These range values are also indicated on the x- and y-axes, respectively, of the profile inset at the Sgr A* position at (0,0).

The Odin observations of the 576-GHz CO ($J = 5 - 4$) line towards the $+50$ km $s^{-1}$ Cloud, the CND and the $+20$ km $s^{-1}$ Cloud are shown in Figs. 4-6 where they are compared with ground-based observations of C$\text{t}$, CO ($J = 7 - 6$) and CO ($J = 4 - 3$) lines [5], smoothed to the Odin 2-arcmin angular resolution. Note that the pronounced absorption features seen in the $\text{H}_2^{16}$O line at $0$, $-30$ and $-50$ km $s^{-1}$ are not seen in the Odin CO ($J = 5 - 4$) line but only in the lower excitation CO ($J = 4 - 3$) line. It is interesting that similar infrared absorption features arising from cold $\text{H}_3^+$ have also been detected [6].

3. The 118-GHz millimetre observations
One of the main motivations for the Odin project is to search for interstellar $\text{O}_2$ and a specially designed radiometer is dedicated to this mission at a frequency around 119 GHz. It has turned out that this is a very elusive molecule and many long-integration-time searches towards a variety of objects have only yielded upper limits, implying very much lower abundances than expected from theoretical calculations [7]. The one important exception to this is the detection of a weak $\text{O}_2$ emission feature in the $\rho$ Oph molecular cloud [8].
The 118–119 GHz observations were part of the larger Galactic Centre project, where Sgr A* CND, the +20 and +50 km s$^{-1}$ Clouds were observed at submillimetre wavelengths. These three components of the Sgr A Complex are only separated by a couple of arcmin and all lie within the 10 arcmin Odin 119-GHz beam, irrespective of the position observed. Thus all the mapping positions can be integrated together to obtain sensitive 119-GHz limits. Furthermore, the 119-GHz receiver on board Odin is unfortunately not properly phase-locked but slowly drifts in frequency. However, regularly during each orbit, Odin observes the Earth’s atmosphere which allows for monitoring the stability of the receiver and correcting for any frequency drift using the telluric oxygen line [9]. Due to this slow frequency drift, the O$_2$ frequency has moved to the edge of the band but instead admitted other line frequencies to be observed.

The 118–119 GHz observations of the three positions during 2004 have been coadded after careful frequency calibrations and the resulting profile is shown in Fig. 7. The strong line present in the middle of the band we propose is due to the $J = 13 – 12$ transition of the HC$_3$N (cyanoacetylene) molecule which has a rest frequency of 118.2707322 GHz. The clarity and sharpness of the strong HC$_3$N feature renders confidence in the reliability of the frequency calibration. Due to an uncertainty of low-level features in earlier 119-GHz observations from 2003, we have indicated in Fig. 7 the expected positions of both the O$_2$ ($1_1 – 1_0$) line at a rest frequency of 118.7503430 GHz and the SiC ($^3$Π$_2$, $J = 3 – 2$) line at a rest frequency of 118.112437/93 GHz [10]. The rms noise is not uniform across the band, which has a channel velocity resolution of 1.6 km s$^{-1}$, and we therefore have two limits: for the O$_2$ line the rms value is 4.4 mK, and for the SiC line the rms value is 7.9 mK.

In Fig. 8, we show the different mapping observations which were coadded in Fig. 7. It is
Figure 7. Odin 118-GHz observations of the Sgr A Complex region in the Galactic Centre - total integrated profile, channel resolution: 1.6 km s\(^{-1}\). Small velocity scales are shown above each expected position of line features.

Figure 8. HC\(_3\)N “map” showing the three profiles obtained towards the +50 km s\(^{-1}\) Cloud (upper left), Sgr A* CND (upper right) and the +20 km s\(^{-1}\) Cloud (lower right) - channel resolution is 4.7 km s\(^{-1}\). The total integrated profile with a channel resolution of 1.6 km s\(^{-1}\) is shown in the lower left.

clear from both the velocity half-widths (which are of the order of 50 km s\(^{-1}\)) and the velocities of the peak temperatures that the HC\(_3\)N profiles show behaviour consistent with their dominant sources being the +20 and +50 km s\(^{-1}\) Clouds in the Molecular Belt. These are relatively warm (\(\approx 100\) K), high density (\(\approx 10^{4.5}\)) Giant Molecular Clouds, with moderate velocity dispersion which, however, have only few signs of star formation.

References
[1] Frisk U., Hagström M., Ala-Laurinaho J., et al. 2003 A&A 402 L27
[2] Sandqvist Aa., Bergman P., Black J.H., et al. 2003 A&A 402 L63
[3] Hjalmarson Å., Bergman P., Biver N., et al. 2005 Advances in Space Research 36 1031
[4] Sandqvist Aa. 1989 A&A 223 293
[5] Martin C.L., Walsh W.M., Xiao K., et al. 2004 ApJS 150 239
[6] Oka T., Geballe T.R., Goto M., et al. 2005 ApJ 632 882
[7] Pagani L., Olofsson A.O.H., Bergman P., et al. 2003 A&A 402 L77
[8] Larsson B., Liseau R., Pagani L., et al. 2006 A&A (submitted)
[9] Larsson B., Liseau R., Bergman P., et al. 2003 A&A 402 L49
[10] Pickett H.M., Poynter R.L., Cohen E.A., et al. 1998 J. Quant. Spectrosc. & Rad. Transfer 60 883 - http://spec.jpl.nasa.gov/