Time Variability of Molecular Emission in the Circumstellar Envelopes of Evolved Stars

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See Poster by D. Teyssier P78,
See Poster by M. Groenewegen P42
The origin of this talk: The line survey of IRC+10216 May 2010

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Herschel/HIFI: first science highlights

LETTER TO THE EDITOR

A high-resolution line survey of IRC +10216 with Herschel/HIFI

First results: Detection of warm silicon dicarbide (SiC₂)


(Affiliations are available on page 5 of the online edition)

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ABSTRACT

We present the first results of a high-spectral-resolution survey of the carbon-rich evolved star IRC+10216 that was carried out with the HIFI spectrometer onboard Herschel. This survey covers all HIFI bands, with a spectral range from 488 to 1901 GHz. In this letter we focus on the band-1b spectrum, in a spectral range 554.5–636.5 GHz, where we identified 130 spectral features with intensities above 0.03 K and a signal-to-noise ratio >5. Detected lines arise from HCN, SiO, SiS, CS, CO, metal-bearing species and, surprisingly, silicon dicarbide (SiC₂). We identified 55 SiC₂ transitions involving energy levels between 300 and 900 K. By analysing these rotational lines, we conclude that SiC₂ is produced in the inner dust formation zone, with an abundance of ~2 × 10⁻⁸ relative to molecular hydrogen. These SiC₂ lines have been observed for the first time in space and have been used to derive an SiC₂ rotational temperature of ~204 K and a source-averaged column density of ~6.4 × 10¹⁵ cm⁻². Furthermore, the high quality of the HIFI data set was used to improve the spectroscopic rotational constants of SiC₂.
**Fig. 1.** Spectra of IRC+10216 observed with HIFI band 1b. *The two upper panels* present the complete spectrum on two different intensity scales. The panels below show different 3 GHz wide ranges of the survey. All data have been smoothed to a spectral resolution of 2.8 km s⁻¹ except for *the right bottom panel*, which shows the spectrum around several vibrational lines of HCN with the nominal WBS resolution (1.1 MHz, ≈0.5 km s⁻¹).
Unexpected observation of anomalous line intensity fluctuations during the search for Hydrides in IRC+10216. No maser lines

Red = Hydrides Search
Dec 2010

Black = Line survey
May 2010
Some lines had identical intensities, other were showing important intensity fluctuations.
2.4. Time variability

IRC+10216 is known to be a Mira-type variable with a periodicity of 1.71 yr. Its 10 μm flux varies by a factor of 2 between minimum and maximum. Because of the calibration method described above, it was important to check for time-related intensity variations. Depending on the relative importance of radiative and collisional excitation, the millimeter line intensities may or may not follow the infrared flux variations. Among the 2-mm lines, the most likely to be affected are: i) those of CS, HC₃N, SiO and SiS, four species whose IR lines are known to be optically thick, as well as ii) the vibrationally excited lines of C₄H and HCN (Lucas & Cernicharo 1989). These lines were observed at several occasions during the 10 yr-long observing period. The ground-state mm lines, observed at a resolution of ≃ 2 km s⁻¹, were found to have stable shapes and intensities (within 20% which is consistent with our calibration uncertainty). The ν = 1, J = 3 − 2 line of CS and several mm lines of vibrationally excited C₄H were observed with a good signal-to-noise ratio at different IR-phase periods in the course of our survey. We saw no intensity variations > 20% which could be correlated with the IR flux phase. However, the strong ν₂ = 1, J = 2 − 1 line of HCN near 177 GHz shows factor of 2 intensity variation with time; this line, however, is known to be masering (Lucas & Cernicharo 1989).

Intensity comparisons are more difficult for weaker lines. We can only quote an upper limit of 20%, which represents the scatter of the intensities recorded at different epochs for the 0.3 − 0.5 K lines. Most of this scatter is probably related to calibration errors, since we found no obvious relation with the IR flux variations.
TIME MONITORING OF THE SiS (J=4-3, 5-4, AND 6-5) EMISSION FROM IRC+10216

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Introduction
We have monitored the SiS (J=4-3, 5-4, and 6-5) emission from IRC+10216. Our aim was to find a correlation between the properties of the lines and the IR flux. The observations were performed with the Onsala 20 m telescope between March 1980 (JD=2 444 300) and September 1987 (JD=2 447 060) with emphasis on the period May 1984 to April 1986 during which data were taken every 3-4 months. This interval corresponds to approximately one period of the IR light curve of IRC+10216. The frequency ranges used in order to cover the investigated lines of the SiS molecule were: 72.6 GHz (J=4-3), 90.8 GHz (J=5-4) and 108.9 (J=6-5). The backends consisted of a 512x1 MHz filterbank and a high resolution 256x0.25 MHz filterbank.

Data analysis
At a first glance at the data one clearly sees the line shape variation of the J=5-4 line, figure 1. It is less obvious in the J=6-5 line and not apparent in the J=4-3 line. The time scale of the changes is in the range of that of the IR light curve of IRC+10216. As a

Many SiS v=0 lines are masering (Fonfría et al., 2006, ApJ, 646, L127)
A MOLECULAR TIME MONITORING OF IRC+10216

• A Total of five observing runs with HIFI/SPIRE/PACS
• Lines selected on the basis of variations observed between the line survey and the hydrides proposal
• Full scans with SPIRE and PACS. All bright lines observed and monitored
• Complemented with 12 observing sessions every 2 months with the 30-m radio telescope. Selected lines of CCH/HNC/SiS/SiO and whole 3mm band. CCH J=4-3 & J=3-2 and HNC J=3-2
CCH variability

See also Poster P78
HNC VARIABILITY
**H$_2$O VARIABILITY**

**HCN VARIABILITY**
SiS VARIABILITY
CO and $^{13}$CO VARIABILITY
SPIRE FTS
All Medium excitation lines of HCN, CO, CS, SiS
Blended with $H^{13}CN$ vib

$\text{mean} = 26. (1.2)$

$\text{mean} = 27. (0.6)$

$\text{mean} = 37. (1.1)$

$P = 680 (22) \text{ d}$

$\psi = 149 (13) \text{ d}$

$\text{mean} = 25. (1.0)$

$\text{mean} = 28. (1.1)$

$\text{mean} = 27. (1.0)$

$\text{mean} = 30. (1.3)$

$\text{mean} = 27. (1.0)$
PACS
High-J lines of HCN, CO, CS, SiS
Very preliminary analysis of time lags

\[ \psi = 296 (7) \text{ d} \]
\[ \psi = 231 (16) \text{ d} \]
\[ \psi = 266 (6) \text{ d} \]

See Poster by Teyssier et al. P78
Can we continue to assume \( \frac{dn(J,v)}{dt} = 0 \) in presence of an IR flux perturbation?

Phase lag between different points of the CSE has to be included in RT equations.

**Time to cross the shell = \( \frac{R_{\text{ext}} - R_{\text{in}}}{c} \approx \) a few days**

Vibrational Einstein coefficients \( (A_{ij}) \sim 0.1-1 \, \text{s}^{-1} \)

Collisions \( \sim 1-3 \times 10^{-4} \times 10^{-10} \sim (1-3) \times 10^{-6} \, \text{s}^{-1} \) (3-10 days)

Rotational \( A_{ij} \sim 10^{-3} - 10^{-7} \, \text{s}^{-1} \) (hours to weeks). Depending on \( J \) and on the molecule.
H to N stretch
\[ \nu_1 \rightarrow 3652 \text{ cm}^{-1} \]
\[
\begin{array}{ccc}
\text{H} & \rightarrow & \text{N} \\
& & \rightarrow \\
& \rightarrow & \text{C}
\end{array}
\]

N to C stretch
\[ \nu_3 \rightarrow 2024 \text{ cm}^{-1} \]
\[
\begin{array}{ccc}
\text{H} & \rightarrow & \text{N} \\
& & \rightarrow \\
& \rightarrow & \text{C}
\end{array}
\]

Bend. \[ \nu_2 \rightarrow 464 \text{ cm}^{-1} \]
\[
\begin{array}{ccc}
\text{H} & \rightarrow & \text{N} \\
& & \rightarrow \\
& \rightarrow & \text{C}
\end{array}
\]

HNC, an example of IR pumping

HNC Daniel et al., 2012, 542, A37
CCH De Beck et al., 2012, 539, A108
Conclusions

• Most molecular Lines in evolved stars can not be used as standard calibrators. Stellar phase is a real concern and a physical basic parameter for any realistic model.

• Determination of isotopic abundance ratios have to be done from simultaneous observations.

• Radiative Transfer in molecular lines affected by infrared pumping has to include a time dependency to account for the infrared flux variations. High-J lines of all molecules affected by IR pumping, even CO.

• If the lines are arising from shells at a given distance from the star the delay between the blue (rear) and red components (front) fluctuations could provide, through a detailed RT analysis, some information on the distance => spatial knowledge of the origin of the emission is needed.

• Molecules abundant in the inner and external regions “could” be less affected by the infrared variations at large distance in the low-J lines. Molecules abundant only in the external regions of the envelope are strongly affected by the infrared flux variations for all Js.

• Some molecules do not show any evident variation of the emerging flux (SiC$_2$ for example). Probably depends on the vibrational dipole moments.