PANEL B4: ASTROCHEMISTRY

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Abstract

A summary of the discussion on key programs within the area of astrochemistry to be performed with the *Herschel Space Observatory* is presented. The two main proposed key programs are: (i) complete line scans of ∼50 sources in all phases of the interstellar → stellar life cycle with HIFI, PACS and SPIRE (∼1200 hr); and (ii) selected H_2O line observations of ∼200 sources ranging from cold clouds to hot cores with HIFI and PACS (∼700 hrs). Two smaller potential key programs include: (iii) deep line integrations on O_2 for ∼5 sources with HIFI (∼100 hrs); and (iv) maps of [C II], [N II] and [C I] in the diffuse interstellar medium with HIFI (∼150 hr).

Key words: Molecules – Water – Interstellar Medium – Star Formation

1. Introduction

During the meeting 'The Promise of FIRST', held in Toledo December 11–15 2000, two discussion sessions were organized to solicit ideas on potential 'key' or 'legacy' projects to be carried out with the *Herschel Space Observatory* (formerly known as FIRST). The discussions in the area of 'Astrochemistry' took place jointly with those on 'Star Formation' (summarized by P. Harvey, this volume) and were attended by ∼100 participants. Two major key programs and two minor programs were identified. The following sections summarize the conclusions and provide a brief motivation for each of the programs. Detailed science cases can be found elsewhere in these proceedings. Approximate telescope times for each of the programs are indicated, but these should be considered only as a rough guide. More detailed simulations and better characterization of the instrument parameters are needed to refine these estimates,

2. Line survey key program

The far-infrared and submillimeter wavelength range covered by the instruments on *Herschel* is a wide, poorly explored region. Deep line surveys of a significant number of sources with different physical characteristics will therefore be a unique legacy of *Herschel*. The importance of spectral surveys using ground-based submillimeter telescopes and the *Infrared Space Observatory* has been amply demonstrated in the last two decades (see review by van Dishoeck, this volume). In summary, the main results that can derived are: (i) an *unbiased* census of the molecular content of the region; (ii) identification of chemical diagnostics at different evolutionary phases; (iii) accurate determination of physical parameters from line ratios owing to good relative calibration; (iv) probe of the different dynamical processes such as shocks, turbulence and infall, by comparing high-spectral resolution line shapes of molecules with different excitation and chemistry; (v) measurement of the total cooling rate of the gas, in particular the contributions from CO and H_2O; (vi) direct measurement of the contribution of the lines to the broadband continuum, which can affect the determination of the dust parameters; and (vii) opportunities for unexpected discoveries of new, sometimes exotic, species.

Table 1 outlines a key program of ∼1200 hrs to survey ∼50 sources in all phases of the interstellar–stellar lifecycle, from diffuse clouds to star-forming regions and outflow shocks to the envelopes around late-type AGB stars and planetary nebulae and eventually supernova remnants. The latter sources are also contained in a key program in the area of 'Stars'. The majority of the time is used for HIFI observations, but complementary PACS data are advocated as well to cover important features (in particular H_2O) at shorter wavelengths and to obtain information about their spatial distribution. Complementary SPIRE spectral scans are also potentially interesting.

The total time has been estimated assuming ∼24 hours per line of sight for HIFI to obtain 20–60 mK rms, 3 hours per line of sight for PACS to reach 1×10^{-17} W m^{-2} 1σ and 1.5 hours per line of sight for SPIRE to reach a similar limit. For some sources, shorter integration times may be appropriate once the confusion limit is reached. About 20 of the 50 sources need to be observed early in the mission to plan subsequent key, guaranteed and open-time observations. These data need to be made public immediately.

3. H_2O key program

High spectral and spatial resolution observations of thermal H_2O lines are a unique project for *Herschel*, since these lines are inaccessible from the ground or airplane and are not covered by any other planned space mission

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Table 1. Summary line survey key program

Type of region	No. of Obj.	No. of LOS/Obj.	Total
Diffuse clouds (abs)	3	1	3
Quiescent cloud cores			
Warm	3	1	3
Cold	2	1	2
High-mass YSOs			
Warm envelopes	3	1	3
Hot cores	3	1	3
Low-Intermediate mass YSOs			
Class 0	3	1	3
Class I	3	1	3
Class II	3	1	3
Shocked gas			
Outflows	3	3	9
Supernovae	3	1	3
Evolved stars			
O-rich	2	1	2
C-rich	2	1	2
Protoplanetary nebulae	2	1	2
Planetary nebulae	2	1	2
PDRs	3	1	3
Galactic Center (SgrA*, SgrB2)	2	1	2
Galaxies	2	1	2
Total			50

in the next two decades. H_2O is a key molecule in the oxygen chemistry and plays an important role in the cooling of clouds. It has many lines in the far-infrared and submillimeter range, covering a wide range of excitation conditions. Because its abundance is increased by orders of magnitude in warm gas compared with cold regions and because the level populations are determined by a combination of collisions and pumping by infrared radiation due to warm dust, H_2O is also an excellent diagnostic of the physical structure, dynamics and geometry of the sources.

To fully exploit the diagnostic potential of H_2O, a variety of lines with a range in excitation energy, A-values (back-bone and non back-bone) and optical depth ($H_2{}^{18}O$, HDO) of both ortho- and para-H_2O needs to be observed. The proposed observations can be divided into pointed observations with HIFI and PACS (∼350 hours) and maps in selected lines with HIFI and PACS (∼350 hours) (SPIRE to be determined) for a total of ∼700 hours. The pointed observations are summarized in Table 2. This table does not include H_2O observations of comets and extragalactic sources proposed in other programs. Compared with the line survey program, significantly more time per H_2O line is spent for the cold and 'luke-warm' regions. For the warmer regions, the integration times are comparable. For all types of regions, a much larger sample of objects is observed than that in the line survey program, but over a limited wavelength range. The mapping part assumes 5–20 sq arcmin maps of ∼100 regions in 3–5 H_2O lines with ∼1 hr per line per map.

The selection of lines, settings and sources should be refined through further simulations and needs to be coordinated with other programs to assure that complementary data on, e.g., dust and CO are obtained to constrain the source structure.

4. O_2 KEY PROGRAM

The HIFI instrument covers a number of unique molecular lines which are not accessible to any other planned mission in the next two decades. Deep integrations on these features will be a valuable legacy of the *Herschel* mission.

One key molecule is O_2, which is predicted by models to be the dominant reservoir of oxygen deep inside molecular clouds. However, O_2 has not yet been detected by SWAS (see Melnick, this volume) at abundance levels more than an order of magnitude below those of dark cloud models. Because of the large size of the SWAS beam

Table 2. Summary H_2O key program (excluding solar system/galaxies)

Type of region	No. of H_2O Lines	No. of Obj.	Av. Time/Line (min.)	Total Time (hr)
Cold regions ∼10-20 K dark clouds, absorption LOS, disks	5	10	60	50
Luke-warm regions ∼50-100 K GMCs, protostellar envelopes	15	50	10	130
Warm regions ∼100-500 K hot cores, inner warm envelopes O-rich evolved stars	25 (20 settings)	80	4	100
Hot regions ∼500-2000 K shocks, outflows	> 100 (40 settings)	50	2	70
Total		190		350

($\sim 3'$), these results apply primarily to the lower density GMC material rather than the densest molecular cores. The ODIN satellite will be able to make an order of magnitude deeper searches for O_2 at 118 GHz, but in an even larger beam ($\sim 10'$).

Two options for follow-up O_2 observations with HIFI on *Herschel* are presented. First, if O_2 is not detected by SWAS or ODIN, deep integrations of 20 hrs per source for 5 sources are proposed for a total of 100 hrs. Alternatively, if O_2 is detected by SWAS or ODIN, O_2 can be mapped within the SWAS/ODIN beam by *Herschel*. The estimated time is again ∼100 hrs, depending on line flux.

5. Diffuse ISM key program

Because of their low surface brightness, maps of the [C II], [N II] and [C I] fine-structure lines in the diffuse interstellar medium ($A_V \leq 1$ mag) are a unique project for *Herschel*-HIFI. Such data can constrain the structure and thermal balance of the cold neutral medium and disentangle the contributions from the warm ionized medium.

The proposed program is to map a $4' \times 4'$ field in the [C II] 1.9 THz, [N II] 1.46 THz and [C I] 809/492 GHz lines for a total of 150 hours.

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