PANEL A2: GAS AND DUST IN NEARBY AND DISTANT GALAXIES

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Abstract

Potential legacy observing programmes utilising the unique capabilities of the Herschel Space Observatory in the field of gas and dust in nearby and distant galaxies are summarized. These programs were identified during two discussion sessions involving about a hundred scientists in total. The proposed programs are designed to address key issues in the cooling of the gaseous components and the dust properties of nearby and high-z galaxies. Synergy between the nearby and high-z programs exists, since the nearby galaxy results will form a set of benchmark data indispensible for interpreting the necessarily more limited data from the high-z galaxies.

Key Words: Galaxies: gas, dust, evolution, starbursts – Missions: Herschel (FIRST), SIRTF

1. Introduction

The Herschel Space Observatory (HSO) will have the unique capability of measuring the gaseous and dusty components of galaxies in the local universe and to high redshifts with unprecedented sensitivity and spectral resolution. It will therefore provide insight into some of the most outstanding problems on the physics of gas and dust in galaxies in relation to its other properties (type, age, metallicity, morphology, etc.) and, because of the large redshift coverage, address the role of these issues in the buildup and evolution of the galaxy population as a whole. Its full frequency coverage will permit observations of galaxies out to high z without the very severe restrictions imposed by the atmospheric absorption for ground-based or airborne observations. The following sections summarize the conclusions of two sessions where ideas on potential "key" or "legacy" projects that could be carried out with the HSO in the field of gas and dust in nearby and distant galaxies were discussed. We only summarize the key scientific goals (see the individual reviews and contributed papers elsewhere in these proceedings for detailed science motivation) and indicate approximate observing times for these programs, but these should be taken only as a rough guide. More detailed analysis and instrument parameters are needed to refine these estimates.

2. Nearby galaxies

The gaseous and dust components of nearby galaxies emit their principal cooling radiation in the far-infrared and submillimetre regimes. A key goal of the HSO must thus be a complete characterization of the cooling radiation of an unbiased, volume-limited sample of low-redshift galaxies, including all types, ages, and metallicities. The main results derived from this program will be as follows.

1. A complete inventory of the cooling line radiation in nearby galaxies will be obtained. The cooling is dominated by bright fine-structure lines ([CII] 158 μm, [OI] 63 μm) followed by mid- and high-J CO lines, with possible smaller contributions of lines of H_2O, H_2 and atomic carbon. An important result from the ISO mission was the discovery that [CII] emission is suppressed in the ultraluminous infrared galaxies. What are the physical conditions that cause this phenomenon and how does the gaseous component in these galaxies cool? With access to CO $J = 5{\rightarrow}4$ and upwards, all important fine-structure lines, and H_2O lines, the HSO will be in a unique position to answer these questions. This will result in a set of benchmark spectra that are indispensible for our understanding of high-z galaxies, where typically bright lines such as the mid-J CO lines are observed.
2. The dust and gas properties of objects of various types and metallicities will be probed in the HSO observing bands. This will include a range of objects from the normal well-developed spirals M31 and M83, to low-metallicity dwarf irregulars such as the small and large Magellanic Clouds. Detailed properties to be investigated include the deuterium abundance with the HD lines, heavy element abundances (including isotopic abundances through for instance the [^{13}CII] line), water excitation and PAH emission through their bending and flapping modes.

Two observing programmes can be foreseen:

1. a complete, volume-limited sample of about 75 objects including spirals, ellipticals, dwarfs, and starbursts will be observed with a resolution $R = \lambda/\Delta\lambda = 20 - 100$. In addition HIFI will be used for targeting single key transitions. Strips across the objects will be observed with a total integration time of 3 to 5 hours per object, resulting in a total of approximately 300 hours.

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2. complete maps and complete high resolution spectra will be taken on a small (~ 10) sample of selected key objects (or at a precise location within nearby extended objects). This will include objects such as M82, Arp 220, 30 Dor and the Antennae galaxies. Five to ten hours will be needed per object bringing the total observing time to 75 hours for this part of the program.

The time estimate for a nearby galaxies "key" program as outlined above thus becomes roughly 375 hours.

3. Dusty high-z galaxies

Dusty galaxies emit most of their energy in the infrared, and have a very low optical luminosity. They are therefore the ideal targets for surveys with the HSO. Strategies for HSO broadband surveys for dusty galaxies are discussed in detail elsewhere in these proceedings, and will not be repeated here. We merely emphasize that field selection criteria for HSO surveys will likely be similar to other missions at other wavelengths such as SIRTF. Hence there is a need for coordinating such surveys from the outset, in coverage, depth, and observing wavelength. This provides significant added value:

1. for objects detected in several surveys at various wavelengths, the spectral energy distribution (SED) is constrained; this will give a crude estimate of the object redshift, its type (starburst *vs.* active nucleus) and its integrated luminosity;
2. for objects detected in only one survey, and not detected at other wavelengths, the bias of observing only at a particular wavelength can be assessed.

What specific follow-up, that is unique to HSO, should be done by HSO on dusty high-z galaxies during its mission lifetime? For spectroscopic follow-up, a principal problem is the need to have a redshift available. The HSO is not suitable for the determination of redshifts for its survey sources (even using PACS or SPIRE at low spectral resolution), and it must be assumed that the problem of getting redshifts is tackled by a dedicated, vigourous ground-based observing programme, before and during the HSO mission. Realizing full well that this will be far from trivial (cf., the difficulty of identifying counterparts to submillimetre galaxies detected with SCUBA), we will nevertheless, for the sake of this summary, assume that this problem is solved using ground-based observations, and that a suitable sample of dusty high-z galaxies with redshifts will exist. A key follow-up program will then be a characterization of (i) the cooling of their neutral and ionized interstellar media using redshifted [CII], [OI], and [OIII] lines (and possibly other bright lines) with HIFI and (ii) a characterization of the SEDs using multi-band photometry and/or low-resolution spectroscopy. It is impossible to assign a time estimate to these observations at this stage, since it is not known which observing bands will be used, depending on redshift. However, in view of the importance of this programme, and since HSO will provide the only opportunity to obtain these data, a time investment of a few hundred hours is certainly warranted.

4. Studies of other high-z objects

The HSO also provides a unique opportunity to study known high-z objects *not* selected based on their dust emission, such as the optically selected Lyman break galaxies. Again, a precise redshift is assumed to be known from ground-based work. Three programs can be foreseen:

1. PACS and SPIRE can be used on an unbiased sample of optically selected Lyman break galaxies at $z \sim 3$ to estimate their dust content; with a sample of about 20 objects, it will be possible to obtain good limits;
2. HIFI can be used to observe the redshifted [CII] and [OIII] lines from $z \sim 3$ Lyman break galaxies to investigate the cooling of their neural and ionized gas components; flux estimates are very uncertain but this will likely take several hours per line and per source; hence a small sample of selected objects must be targeted; ideally one should make use of gravitationally lensed objects;
3. a more complete investigation is possible for galaxies at lower redshifts; good samples of $z \sim 1$ galaxies should be available by the time of the HSO mission; these will lend themselves to more detailed follow-up in multiband photometry and low-resolution spectroscopy (determining the SEDs) and in the 5 or so brightest diagnostic emission lines with HIFI.

As above, the actual integration time needed is difficult to estimate because of uncertain source fluxes and the fact that, depending on redshift, different observing bands are used. However, a time investment of a few hundred hours will certainly be needed for a meaningful project here. Clearly, much preparatory work remains necessary in this field.

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