Report on the ESO Workshop

The Impact of Herschel Surveys on ALMA Early Science

held at ESO Headquarters, Garching, Germany, 16–19 November 2010

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The ESA Herschel Space Observatory is currently producing new and exciting results, thanks to its unprecedented sensitivity, spectral resolution and wide-area surveying capabilities at far-infrared and submillimetre wavelengths. Many of the new discoveries by Herschel will require high angular resolution follow-up observations with ALMA. The goal of the workshop was to discuss the priorities for ALMA Early Science follow-up of the Herschel photometric and spectroscopic surveys. The possibility, or need for, simultaneous observing programmes with ALMA and Herschel was also discussed.

The ESA Herschel Space Observatory is currently in operation, covering the spectral range from the far infrared to the submillimetre, and will complete most of the key programme observations by early 2011. The exciting first results from Herschel on galaxy formation and evolution, on galactic star formation, stars and circumstellar discs, the interstellar medium, and on our own Solar System, are highly complementary to the science that the Atacama Large Millimeter/submillimeter Array (ALMA) will soon deliver. ALMA will allow a great leap forward at high angular and spectral resolution in the exploration of the cool Universe — the earliest evolutionary stages of galaxies, stars and planets. ALMA is currently in its scientific commissioning and science verification phase. The current expectation is that Early Science observations will start in the second half 2011.

Herschel and ALMA make an excellent complementary pair, not only in wavelength regime, providing rich molecular spectra and well-sampled spectral energy distributions, but also in angular resolution. The high angular resolution that ALMA will provide makes it the perfect resource to follow up the science targets observed and identified in the wide-area multi-band photometric and spectroscopic surveys performed by Herschel.

Figure 1. The workshop participants collected in the entrance hall at ESO Headquarters.

The workshop had the goal of discussing the science rationale for possible early ALMA follow-up observations based on the first exciting Herschel results. Another topic raised in the meeting was whether there are observations where simultaneous Herschel–ALMA observations would be desirable: given Herschel's limited lifetime they would have to be identified on a short timescale. The sessions were broadcast with a live video connection to a Joint ALMA Observatory meeting room in Santiago. Figure 1 shows a photograph of the workshop attendees.

Cosmological surveys, active and nearby galaxies

The first results of the Herschel deep field and wide-area surveys were reviewed by G. de Zotti, S. Eales and E. Le Floch. These surveys allow the evolution of far-infrared luminosity functions to be measured as a function of redshift on statistically significant samples of objects, thus mapping the evolution of star formation in the Universe. In addition, the wide-area surveys have allowed significant numbers of rare objects to be revealed. The sources found by these surveys are ideal targets for ALMA to measure the molecular gas content, dynamical masses and morphology at high angular resolution. Initial follow-ups of the gravitationally lensed candidates have shown the potential of high angular resolution millimetre observations (see Figure 2). Detailed studies of relatively small samples of luminous submillimetre galaxies with current millimetre-wave interferometers are already showing the role played by merging, gas accretion and secular evolution. As presented by L. Tacconi, ALMA will allow these studies to be significantly extended and a coherent picture of galaxy formation and evolution to be built.

In this context, observations of atomic gas in high redshift galaxies in the submillimetre are flourishing with the current generation of single dish telescopes and interferometers. The enormous step forward expected in this area with ALMA was discussed by F. Walter, R. Maiolino and K. Knudsen. Indeed preliminary test data from ALMA appear to confirm the prospects in this field (see Figure 3). The

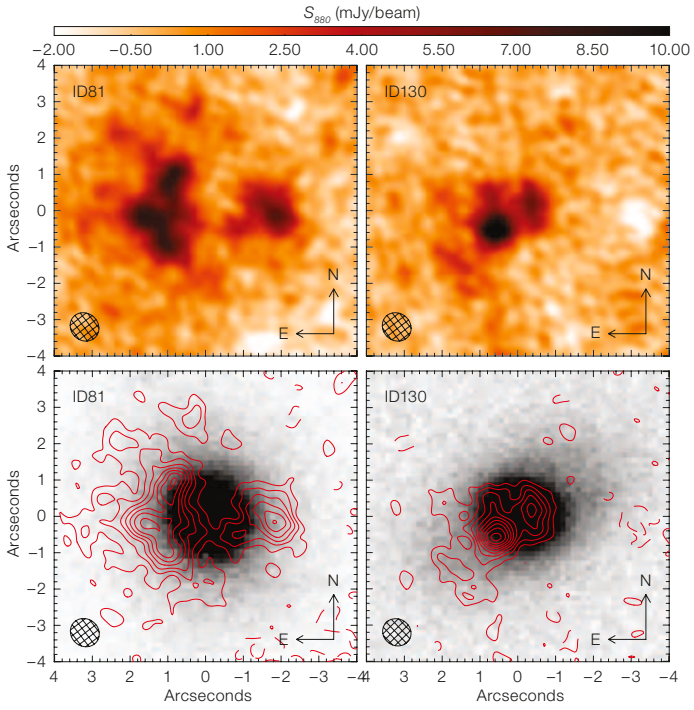

Figure 2. Submillimetre continuum images (upper) of the lens systems ID81 and ID130 from the SMA. The same continuum maps are shown (lower) as contour maps superimposed on Keck *i*-band images. (H-ATLAS team; Negrello et al., 2010).

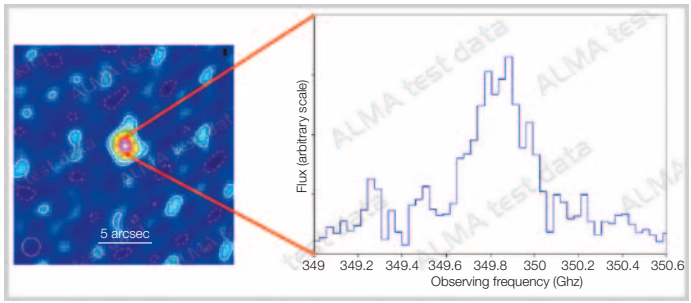

Figure 3. ALMA test data on the [C II] line from BRI 0952 at z = 4.4 (ALMA CSV team; the original APEX detection is from Maiolino et al., 2009).

need for a full complement of ALMA Band 5 receivers to explore the key redshift range between eight and ten was especially emphasised.

The wealth of new insights on nearby galaxies that is being gained with Herschel was reviewed at the conference by F. Combes and C. Wilson. Herschel photometry and spectroscopy are starting to allow us to probe the star formation and interstellar medium of nearby galaxies with unprecedented detail. These observations are a necessary milestone on the road to understanding the cosmological evolution of the interstellar medium in its proper context. The synergy with ALMA in this respect would be enhanced by comprehensive measurements of the fine structure far-infrared atomic lines in the nearby Universe to be compared with future submillimetre studies at high redshift. ALMA high angular resolution observations of these galaxies will allow us to place what we understand of the interstellar medium (ISM) and star formation in our own Galaxy in context. The ALMA test data on NGC 253 have already started to show the great potential in this field (see Figure 1 of Testi et al., 2010).

Star and planet formation in our own Galaxy

Herschel is investing a large amount of time as part of the guaranteed and open time key programmes to investigate the process of star formation by surveying nearby molecular clouds and the Galactic Plane. Ph. Andre, J. di Francesco and S. Molinari reviewed the progress of the wide-area photometric surveys and illustrated the initial results on the core mass function, the filamentary structure of molecular clouds and the ISM (see Figure 4). The thresholds for the formation of clouds and cores in filaments in the Galactic Plane and in the nearby star-forming regions were discussed, as well as the possible role of magnetic fields and instabilities in the evolution of the filaments. This topic was clearly identified as an area requiring high angular resolution molecular line and polarisation follow-up with ALMA. P. Caselli and C. Ceccarelli reviewed the Herschel results and the ALMA prospects for the study of the chemistry of the molecular gas in the earliest phases of star formation. The choice of the correct tracer to study the earliest phases of star formation was discussed; thanks to the expected sensitivity of ALMA, rare isotopes will be the prime targets when studying the cold and dense inner regions of molecular clouds and prestellar cores.

The formation of massive stars, clusters and their effect on the global evolution of galaxies were discussed in several sessions. The models and observational constraints were reviewed by J. Bally, J. Tan and A. Zavagno. S. Bontemps, M. Pestalozzi and S. Ragan discussed the main results in this field from the Herschel imaging survey of young stellar objects (HOBYS), the Galactic Plane survey (HIGAL) and the earliest phases of star formation (EPOS) projects, highlighting the prospects for early ALMA follow-up at high angular resolution.

The formation of low-mass stars and the role and properties of discs at the earliest stages of collapse were discussed in the context of the initial conditions for the formation of planetary systems (M. Walmsley, A. Maury, A. Stutz). The field of protoplanetary discs, which is being explored with Herschel, will fully benefit from ALMA's sensitivity and high angular resolution. K. Dullemond and S. Guilloteau illustrated our current understanding of the theoretical framework and observational constraints of grain growth in discs and discussed how ALMA will allow the study of the evolution of solids and the formation of planetesimals in discs. ALMA will also study in detail the chemistry of the molecular gas in discs and the

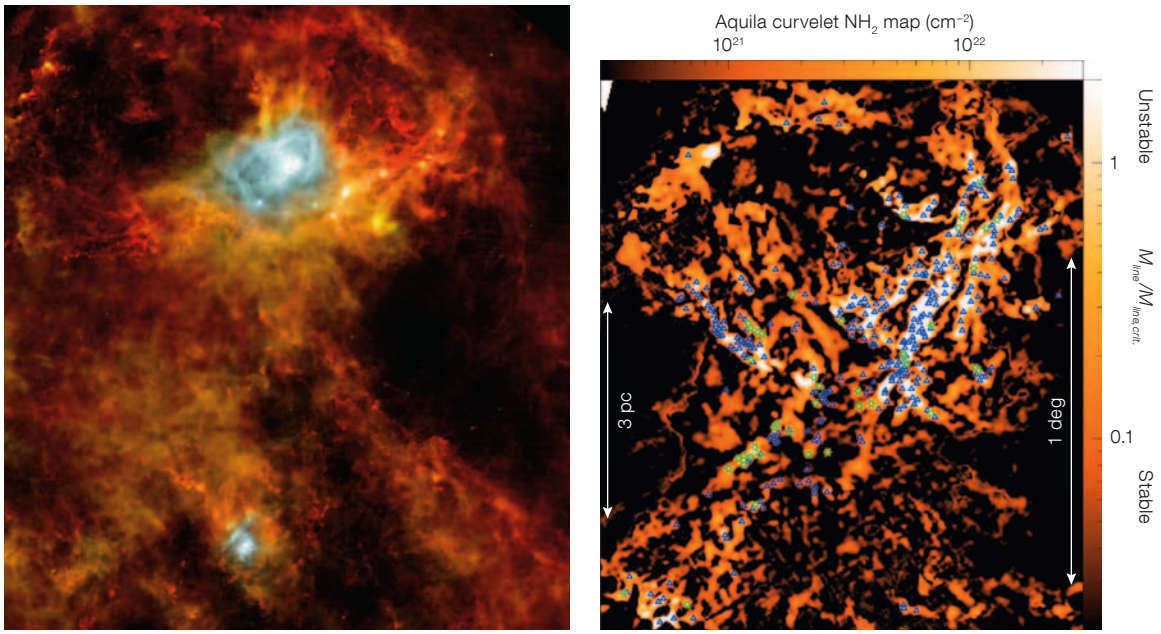

Figure 4. The Aquila molecular cloud complex as observed with Herschel: PACS-SPIRE colour composite on the left, filamentary structure and cores on the right (adapted from André et al., 2010).

formation of complex, possibly pre-biotic molecules, a field that is just starting to be explored with Herschel. Of particular relevance is the study of the gas-to-dust mass ratio and its possible variation across the disc, as well as the chemistry of water (O. Panić, I. Kamp and M. Hogerheide). The scientific opportunities offered by ALMA when fully equipped with Band 5 receivers for the study of water and its isotopes in discs and star-forming regions were emphasised.

Evolved stars

The main Herschel results obtained so far on evolved stars were reviewed by Ch. Waelkens and J. Cernicharo. Spectra of these objects from the Herschel heterodyne instrument HIFI, Photodetector Array Camera and Spectrometer (PACS) and the Spectral and Photometric Imaging REceiver (SPIRE) are revealing a new wealth of information on the chemistry in the envelopes and the yields to the interstellar medium (see Figure 5). The full ALMA array will allow the molecular atmospheres of these stars to be studied at the angular resolution required to spatially resolve the formation of complex molecules as a function of the height above the radio photosphere.

Solar System objects

Most (sub-)millimetre astronomers are very familiar with Solar System bodies, which are normally observed as primary calibrators at these wavelengths. While much is known about these objects, and, in spite of the fact that many have been studied in detail *in situ* by astronomical spacecraft, much is still to be learned. Two main areas were discussed at the meeting: the study of planetary atmospheres and comets in molecular lines; and the study of the continuum emission from minor rocky bodies. R. Moreno, P. Hartog and M. Rengel highlighted the importance of spatially resolved studies of the chemistry in the atmospheres. Water was a recurrent theme in this scientific area and the synergy between Herschel and ALMA was highlighted by all the speakers.

T. Müller and P. Hartogh showed the latest results of the observations of minor bodies of the Solar System with Herschel. Several Trans-Neptunian Objects (TNOs) have been detected at far-infrared and submillimetre wavelengths allowing the development of detailed models of their structure and composition, which require ALMA follow-up. A small set of Main Belt asteroids are being monitored by Herschel and APEX to evaluate them as secondary flux calibrators at far-infrared and submillimetre wavelengths. The initial results of this programme were also reported at the meeting in a poster by C. Goddi and collaborators (see Figure 6). A common, well-understood and accurately modelled set of calibrators for Herschel and ALMA are needed to meet the stringent ALMA calibration goals and will provide a consistent calibration between the two observatories, a prerequisite for combining data. The primary HIFI and SPIRE calibrators, Neptune and Uranus, will be too large for ALMA at high frequencies and for extended array configurations, thus establishing a good network of common secondary calibrators is very important.

The bright future of far-infrared and submillimetre astrophysics

The highlights of the meeting were the numerous and exciting scientific results that Herschel is providing. There is a strong and very active community working on trying to extract the best possible science from the unique opportunity that Herschel represents. Nevertheless, it was also obvious that this community has ALMA on their radar and several groups had already been preparing preliminary ideas and follow-up observations for ALMA Early Science and beyond. While the time overlap when

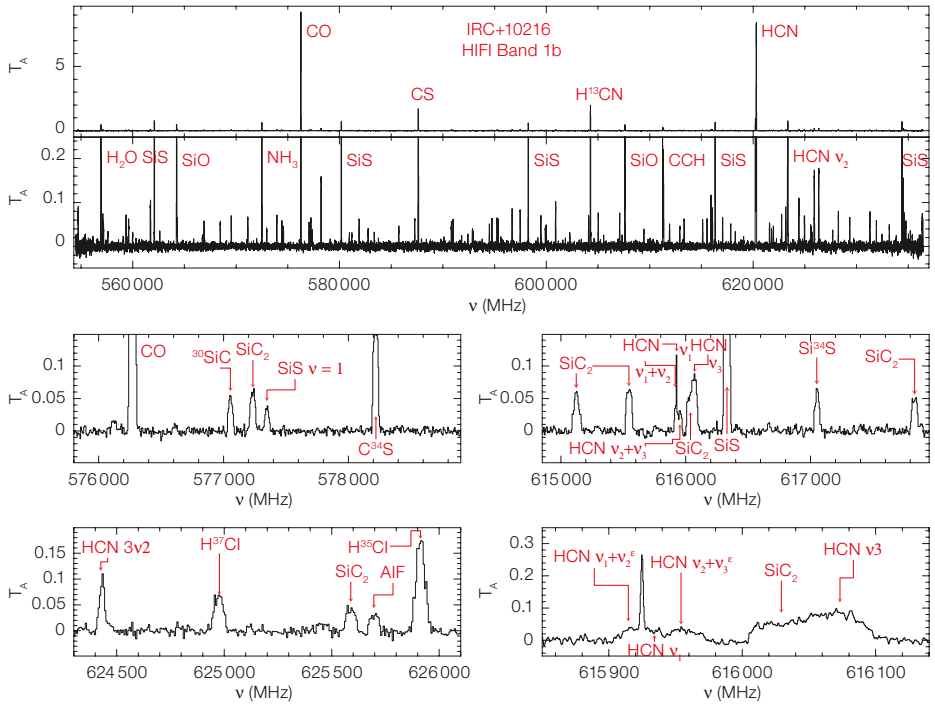

Figure 5. Herschel/HIFI spectrum of IRC+10216 showing the rich chemistry of the wind from this prototypical carbon-rich AGB star (Cernicharo et al., 2010).

both Herschel and ALMA are operational will be much shorter than originally hoped, it is expected that there will be a period of at least one year in which the two observatories will potentially be available for simultaneous observations. It was emphasised that science cases for potential simultaneous observations should be identified soon, and proposals should be ready for submission by the coming deadlines in summer 2011. The possibility of disseminating advanced data products in the community was seen as an opportunity for a long-lasting legacy for the Herschel, especially in view of long-term follow-up observations with the full ALMA array and its future upgrades.

The lively discussion at the meeting convinced us that the future of far-infrared and submillimetre astrophysics looks bright and we look forward to the flood of scientific results that will come from the combination of the unique capabilities of both ALMA and Herschel.

The organisation of this workshop would have not been possible without the help of the ESO Fellows L. Cortese, A. Maury and O. Panić; in addition E. Bressert, S. Longmore, L. Ricci, F. Trotta and the Garching IT helpdesk supported the multi-room, multi-site broadcasting of the sessions and the necessary microphone operations. Special thanks go as usual to C. Stoffer who always steered the practical organisation back to the right path. The workshop was sponsored by ESO and Radionet, which provided travel support to a number of participants.

The presentations and most of the posters are available in electronic form on the conference website[1].

References

André, P. et al. 2010, A&A, 518, L102
Cernicharo, J. et al. 2010, A&A, 518, L136
Maiolino, R. et al. 2009, A&A, 500, L1
Negrello, M. et al. 2010, Science, 330, 800
Testi, L. et al. 2010, The Messenger, 142, 17

Links

[1] Conference web page: http://www.eso.org/sci/meetings/2010/almaherschel2010/program.html

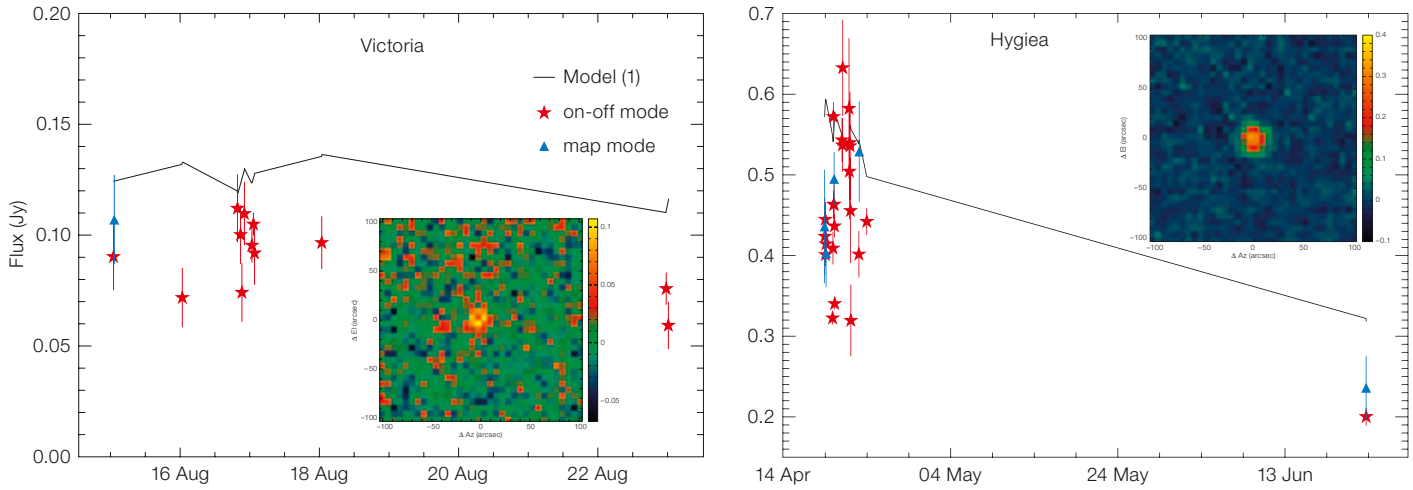

Figure 6. APEX/LABOCA 870 μm measurements of the Hygea and Victoria asteroids with time (Goddi et al., 2011).