Large scale (pc) mechanical heating in the nearby AGN–SB composite galaxy NGC 4945[1]

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Understanding the dominant heating mechanism in the nuclei of galaxies is crucial to understand star formation in starburst (SB), the active galactic nuclei (AGN) phenomena and the relationship between the star formation and AGN activity in galaxies.

We study the nearby composite SB–AGN galaxy, NGC 4945, by a multi–transition analysis of the spatial distribution of the ^{12}CO emission to establish which is the dominant heating mechanism.

We present far–infrared (FIR) and sub–millimeter (sub–mm) ^{12}CO line (from $J_{up} = 4$ to 19) maps and single spectra using the Heterodyne Instrument for the Far Infrared (HIFI), the Photoconductor Array Camera and Spectrometer (PACS), and the Spectral and Photometric Imaging REceiver (SPIRE) onboard *Herschel*, along with APEX data.

We combined the Spectral Line Energy Distribution (SLED) and the LTE analysis of the ^{12}CO images to derive the thermal structure of the Interstellar Medium (ISM) for spatial scales raging from 150 pc to 2 kpc. Our main results obtained from the ^{12}CO analysis show that a clear trend is found in the distribution of the derived temperatures and the SLED/IR ratios. It is remarkable that at scales of 150–300 pc, the highest temperature, derived from the high–J lines, is not found toward the nucleus, but toward the galaxy plane. At intermediate scales (350 pc–1 kpc) we also see large temperatures in the direction of the X–ray outflow. The thermal structure derived from the ^{12}CO multi–transition analysis suggests that shocks dominate the heating of the ISM in the nucleus of NGC4945 located beyond 100 pc from the center of the galaxy. Shocks are likely produced by the barred potential and the outflow observed in X–rays.

[1]Observations based on *Herschel* which is an ESA space observatory with science instruments provided by European–led Principal Investigator consortia and with important participation from NASA.

EUV and X-ray Irradiation in Star Forming Regions

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Ionized hydrides are fundamental precursor molecules in cosmic chemistry, and many hydride ions have become observable in high quality for the first time thanks to the *Herschel Space Observatory*. CH^+ and OH^+, and also HCO^+, affect the chemistry of water. For this reason they have become of interest in the WISH (Water in Star-forming Regions with Herschel) key program.

Ionized hydrides also provide complementary information on irradiation by far UV (FUV), X-rays and cosmic rays. This was the goal of the Radiation Diagnostic subprogram. Ionization is an essential ingredient for the acceleration of jets and outflows. The targeted lines of CH^+, OH^+, H_2O^+, and C^+ were detected mostly in blue-shifted absorption. H_3O^+ and SH^+ were detected in emission and only toward some high-mass objects (Benz et al. 2016).

In low-mass YSOs the column density ratios of CH^+/OH^+ can be reproduced by simple chemical models implying an FUV flux of 2 – 400 times the ISRF at the outflow cavity walls. If the FUV flux required for low-mass objects originates at the central protostar, a substantial FUV luminosity, up to 1.5 $L_\odot$, is required. Upper limits for the X-ray luminosity can be derived from H_3O^+ observations. To detect evidence for X-ray emission, a different selection of molecules would be required including nitrogen-containing ionized hydrides.

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Herschel observations of evolved stars

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The spectroscopic capabilities of the three instrument on board Herschel have permitted to study the submillimetre and far-infrared spectrum of the circumstellar envelopes of evolved stars. In particular, the high spectral resolution and broad band coverage offered by the HIFI heterodyne instrument, has permitted the detailed study, for the first time, of the emission of water vapour in these objects. SPIRE and PACS have permitted to study the same molecule in very high excitation lines. I will summarize the results obtained by Herschel in this field devoting particular attention to the molecular content unveiled by these far-infrared observations.

The sensitivity of the instruments have also permitted, in short observing times, to carry out a time monitoring of some of these objects showing the important role that infrared pumping plays in the excitation of the molecular energy levels and in the emerging emission in the rotational lines of abundant molecular species (see Figure 1).

Finally, I will place these results in the context of recent observations with ALMA and other radio telescopes and interferometers.

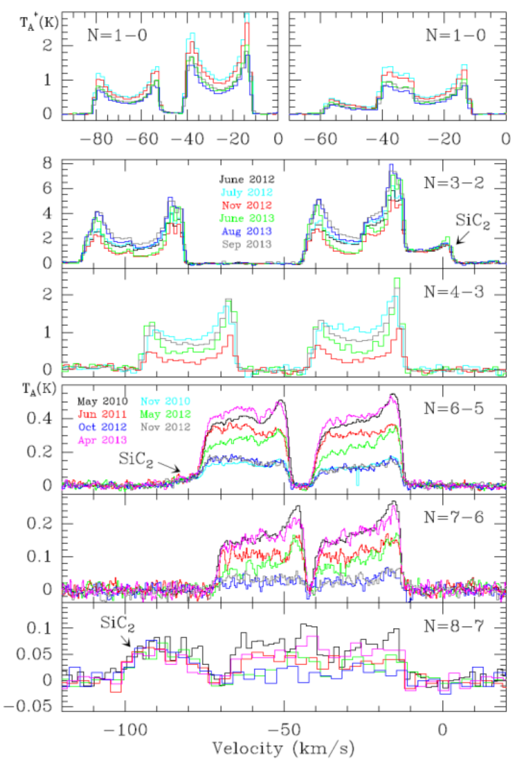

Figure 1: CCH lines observed with the IRAM 30 m telescope (N = 1–0, 3–2, 4–3) and with HIFI (N = 6–5, 7–6, 8–7). The different colors correspond to the observing dates with both instruments. The abscissa is velocity in km s^{-1} with respect the frequency of the strongest hyperfine component. Intensity scale is antenna temperature in K.

The Interstellar Medium Properties of Nearby Luminous Infrared Galaxies

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The Herschel Space Observatory has boosted our knowledge of the physical processes that drive galaxy evolution. Far-infrared (IR) spectral features, like fine-structure emission lines from ionized and neutral atomic species, have allowed us to characterize the properties of the star formation and interstellar medium (ISM) of galaxies near and far. In particular, luminous infrared galaxies (LIRGs; IR luminosities > 10^11 Lsun) represent a key stage in galaxy formation and evolution. They are the most important population of galaxies at redshifts z > 1, accounting for more than 50% of all obscured star formation produced in the Universe at those epochs. Studying this galaxy population and their local counterparts is therefore fundamental to understand the physics of the multi-phase medium of the most active, star-forming efficient galaxies in the Universe across cosmic time. In this talk I will report results obtained using more than 300 hours of observations with Herschel PACS and SPIRE regarding the gas and dust properties of the largest, most complete sample of LIRGs in the local Universe: The Great Observatories All-sky LIRG Survey (GOALS). I will focus on the characterization of the ISM via the brightest far-IR emission lines, like [CII], [OI], [OIII] and [NII]. I will show how galaxies that experience more compact nuclear star formation also host individual star-forming regions with physical properties significantly different from those found in normal star-forming galaxies, like the Milky Way.

A census of dense cores in the Serpens region from the Herschel Gould Belt survey

The Herschel Gould Belt survey mapped the far-infrared dust continuum emission from nearby star-forming regions, to better understand how the prestellar core phase influences the star formation process. I'll present the complete census of dense cores in the Serpens. This star-forming region, located at 436 pc, nearby the Aquila Rift complex, is characterized to be a young (less than 1Myr), and active low-mass star-forming region. I'll present the statistics of prestellar core in this region, discussing their gravitational stability, and particularly focusing on its core mass function, and its connection with the stellar initial mass function. The correlation between the spatial distribution of cores and the filamentary structure of the cloud is also explored. Finally, I'll present a comparison between our results and both previous literature on Serpens complex and Herschel studies on other Gould Belt star-forming regions.

The Herschel Orion Protostar Survey (HOPS) @ 10 Years

Mayra Osorio (Instituto de Astrofisica de Andalucia, CSIC; Spain)

Protostars trace the conversion of interstellar gas into stellar mass, and a detailed understanding of the evolution of protostars is an essential step towards understanding the IMF, the rate of star formation, and the origin of proto-planetary of disks. With its ability to efficiently observe large samples of protostars in the far-IR, Herschel characterized the properties of the low mass protostars populating the molecular clouds within 500 pc of the Sun.

The richest such sample is found in Orion and was studied by HOPS, which assembled 1-870 micron SEDs from 2MASS, Spitzer, Herschel and APEX for 330 protostars. We overview the results of HOPS: that the mechanical luminosity of protostellar outflows, as traced by the far-IR CO lines observed by PACS, is strongly correlated with the radiant luminosity of protostars, as measured with the HOPS SEDs, ii.) that the envelope densities decrease exponentially with time, and iii.) the discovery of protostars too deeply embedded to detect with Spitzer. We also explore how HOPS is the foundation of new studies, such as observations with ALMA, VLA and SOFIA of a luminous outflow from an intermediate mass star, and the discovery by ALMA and VLA of collapsing gas fragments heated by compression, and where the collapse is limited by cooling time, and not gravitational free fall times.

Beating Herschel's Confusion limit to explore the Galaxy Main Sequence

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Deep, far-infrared (FIR) cosmological surveys with Herschel are known to suffer from source confusion and blending. Infrared (IR) emission provides information on star formation rates (SFRs) via thermal dust emission, which peaks in the FIR. Thus, to gain the best constraints on the IR emission, and hence the SFR, it is necessary to de-blend the deep Herschel images.

To perform this de-blending, we expand the Bayesian de-blending tool XID+ to include a flux density prior. This prior is derived from fitting spectral energy distributions to data at shorter wavelengths that suffer less from confusion and blending. The result is a statistically more reliable extracted flux density for each object and hence a more reliable IR luminosity and SFR.

We use these results to examine the main sequence of star forming galaxies (MS), a tight correlation between the SFR and stellar mass, over $0.2 < z < 6.0$ in the COSMOS field. This allows us to trace how the MS has evolved over the majority of the history of the universe and link the high redshift, star-forming universe with the local universe.

In this presentation, I will briefly introduce XID+ and our expansion to include the flux density prior before moving on to discuss the results of examining the MS over such a large redshift range.

The Perseus star-forming region before and after Herschel

In this talk I will present the results of Herschel photometric observations of the Perseus star-forming region observed with PACS and SPIRE as part of the Herschel Gould Belt Survey. Emphasis will be given not to the results themselves, but to how our vision of this region has changed thanks to Herschel observations: I will present what was known before Herschel with ground (sub)mm observations (BOLOCAM) and space observations (Spitzer); and what has emerged, and changed, when Herschel data came into the game. I will also show why PACS *and* SPIRE were both important.

Tracing the Gas Composition of Titan´s atmosphere with Herschel and ground-based telescopes

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The nitrogen (N_2)-dominated atmosphere of Titan, Saturn's largest moon, exhibits a great diversity and complexity of molecules and high organic material abundances, its origin is poorly understood. Spectroscopic observations at different spectral ranges, high spectral resolution and sensitivity, and at different temporal coverage during a Titan's year (29.5 Earth years) offer the opportunity of exploring and helping to advance the study of the abundance distribution of constituents on Titan (e.g. CH_4, CO, HCN, H_2O).

In the framework of the Herschel guaranteed time key programme "*Water and Related Chemistry in the Solar System*", also known as *Herschel Solar System Observations* (HssO), the Herschel Space Observatory and its three instruments onboard explored the atmosphere of Titan. Here I report key observations carried out with Herschel and complementary ones with ground-based facilities, investigations of the composition, and abundances inferred.

With Herschel, these advances and discoveries allow a further characterization of the complex atmosphere of Titan and help to advance the study of the abundance distribution and the investigation of a variety of processes in Titan atmosphere.

Title*: Intermediate Redshift Ultraluminous Infrared Galaxies: a new population unveiled by Herschel or more of the same?*

Author: *Dimitra Rigopoulou*

Abstract: *With far-infrared luminosities in excess of 10E12 Lsun, Ultraluminous Infrared Galaxies (ULIRGs) are amongst the most intensely star-forming objects in the Universe. They have routinely been used as templates for high-z submm luminous galaxies. Yet, observational evidence supports the existence of strong evolution in the properties of the ISM of nearby and distant ULIRGs. Using Herschel, ALMA and optical integral field units we have established a program to study the ISM properties of intermediate redshift ULIRGs originally selected based on Herschel 250 microns fluxes. Through observations of far-infrared fine structure lines, spatially resolved low-J carbon monoxide (CO 3-2) tracing the molecular gas and Ha tracing the ionised gas we have concluded that the ISM properties of these intermediate redshift ULIRGs are different to those of local ULIRGs and more akin to those of high-z star-forming galaxies. Our study confirms the existence of strong evolution in the ISM properties of ULIRGs between z=0 and z~1 and that this evolution is already taking place at z~0.3*

``Star formation in 3D: synergy between Herschel and Gaia.''

Veronica Roccatagliata – University of Pisa

The study of star formation and young clusters have been completely revolutionized in the last 10 years thanks to Herschel, in the first case, and just in the last few years thanks to the second release of Gaia.
In this talk I will discuss a step further in the study of both aspects of star formation combining these two ESA space missions: Herschel and Gaia.
The multiple populations in young clusters detected in a few cases by Gaia can be intrinsically related to the structure of the molecular cloud still present in those regions traced by Herschel.
I will present as examples the results on the multiple populations in two close low-mass star-forming regions, with a pronounced filamentary molecular cloud.
In one case using the Gaia data we found the region to be at slightly higher distance than previously thought.
Presenting the method applied to find kinematically the multiple populations, I will discuss the effect on the results of taking into account the correlations between parallaxes and proper motions.
The combination of the Gaia data with the Herschel far-infrared continuum maps allow us to understand if the peculiar spatial distribution of the two populations is caused by the filamentary structures.
Moreover, a 3D view of those regions can be obtained combining the column densities and the distances from Gaia of sources with an accurate measured extinction.
I will finally present the possibility of detecting a filaments perpendicular to the line of sight, thanks to combination of the two ESA space missions.

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The Herschel Extragalactic Legacy Project (HELP); the final word on Herschel extragalactic fluxes?

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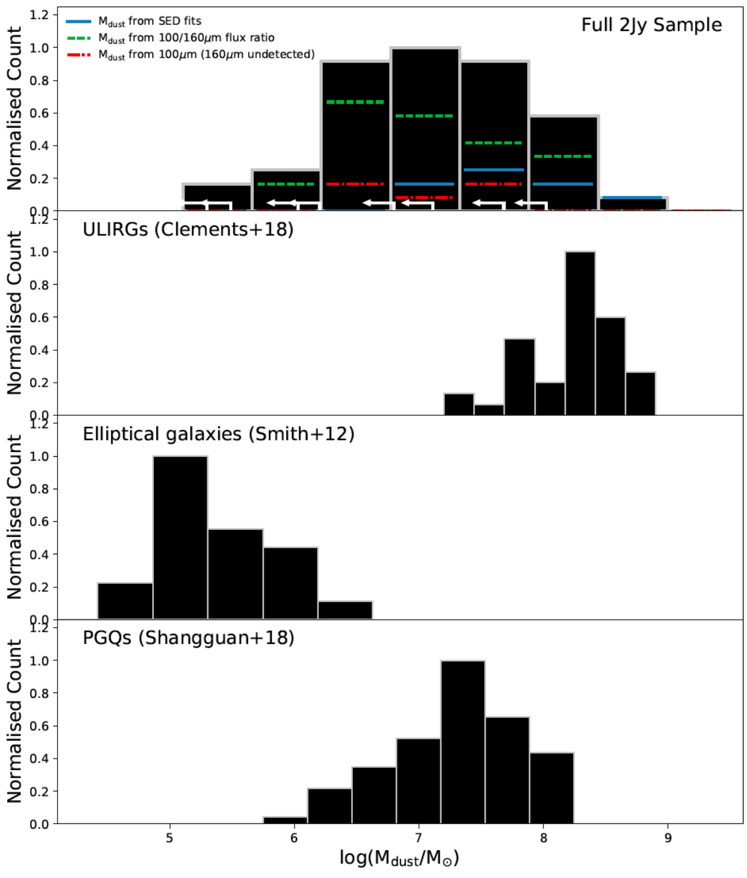
In this talk I will present the HELP data processing pipeline which is gearing up for its first data release. This has involved processing 1300 square degrees of extragalactic sky to produce a catalogue of 170 million objects. As part of the data release we have produced photometric redshifts, Herschel fluxes using the Bayesian forced photometry XID+ code, and spectral energy density fits with the CIGALE code.

I will also present early results on far infrared luminosity functions and discuss complexities related to modelling selection effects. I will finish by giving examples of how to access the database using the Virtual Observatory at susseX (VOX) including some queries to generate rare or interesting objects such as ultra-luminous infrared galaxies and hot dust obscured galaxies.

The Herschel view of the cool ISM contents of quasar host galaxies: a new probe of triggering mechanisms

Clive Tadhunter, Department of Physics & Astronomy, University of Sheffield

Luminous, quasar-like AGN play a key role in galaxy evolution, driving powerful outflows that regulate the star formation in galaxy bulges. However, we still do not fully understand how such AGN are triggered. Although optical imaging studies have provided evidence for triggering in galaxy mergers, the nature of these mergers (e.g. whether major or minor) has remained obscure. Herschel observations of the cool ISM contents of the host galaxies provide key additional information. Here I present the results of deep PACS & SPIRE observations of the 2Jy sample of 46 powerful radio galaxies (0.05 < z < 0.7) that were taken as a "Must Do" program in the last days of Herschel. With detection rates of 100% and 90% respectively at 100μm and 160μm, these observations allow the dust masses to be accurately quantified for the first time in a substantial, complete sample of luminous AGN. Combined with Herschel observations of other samples of luminous AGN, the results demonstrate that, in contrast to the popular idea that quasars are triggered in major, gas-rich mergers, the triggering mergers are relatively minor. I consider these results in the context of existing and upcoming ALMA observations of the cool ISM in AGN host galaxies.



Herschel dust masses as a probe of quasar triggering mechanisms. Histograms showing Herschel-derived dust masses for the 2Jy sample of luminous, radio-loud AGN (top panel), nearby ULIRGs (2nd panel from top), early-type galaxies (3rd panel from top), and PG quasars (bottom panel). The fact that the dust masses of most of the 2Jy and PG objects are intermediate between those of ULIIRGs and early-type galaxies, provides key evidence that quasars are triggered in relatively minor mergers (see Tadhunter et al. 2014, Dicken et al. 2019).

Herschel-SCUBA2 Synergies – A 10-year Perspective

Professor Derek Ward-Thompson – UCLAN

Herschel revolutionised our views on star formation. In particular, the Herschel Gould Belt Survey produced images at 5 wavelengths of all of the nearby star-forming regions. This allowed maps of temperature and column density to be produced. This showed that the filamentary model represents the dominant mode of star formation for solar-mass stars. Follow-up work with SCUBA2 on JCMT has allowed the central parts of all of the nearby star-forming regions to be mapped at higher angular resolution, and parameters such as the long-wavelength dust emissivity index, beta, to be constrained much more tightly. I will present a summary of the last 10 years of progress, including measurements of the detailed virial balance in pre-stellar cores, and an evolutionary virial diagram for cores. I will finish with the latest results from the SCUBA2 polarimeter, POL2, and discuss how this has allowed us to incorporate magnetic fields into the energetics of core evolution and proto-star formation.

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Herschel-SOFIA complementarity (and beyond)

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SOFIA, the Stratospheric Observatory for Infrared Astronomy went into full operational gear in 2014, shortly after the Herschel Space Observatory ran out of fuel and went out of operations. Thus, SOFIA quickly followed upon and benefitted from Herschel, but also was able to go beyond Herschel, thanks to its more up-to-date and versatile continuing instrumental developments.

I will briefly review where SOFIA succeeded in exploring the observational gaps left open by Herschel and pushed further the frontiers of far-infrared astronomy, using SOFIA/GREAT (the HIFI equivalent) and SOFIA/FIFI-LS (the PACS equivalent), and finally SOFIA/HAWC+ (the sort-of-equivalent of SPIRE).

In particular, this includes the possibility of carrying out far-infrared polarimetric observations (50-200 microns) with HAWC+, a capability that was not available on Herschel. I will show some results on the magnetic field structure based on recent HAWC+ dust continuum data in Orion, the Galactic Center, and 30 Dor.

I also hope to show highlights from SOFIA/GREAT in the frequency domains inaccessible to HIFI (GREAT single pixel 2.5/4.7 THz for ground-state OH/[OI] absorption/emission studies and its multi-pixel upGREAT arrays LFA and HFA at 1.9 and 4.7 THz, for [CII] and [OI] mapping).

If time, I will describe HIRMES, the next generation spectrometer on SOFIA (25-122 micron range, with special focus on the 112 μm and 56 μm key lines of the HD 1-0 and HD 2-1 rotational transitions).