Abstract: Herschel 10 years after launch: science and celebration, ESAC, 13-14 May 2019

Herschel observations of the filament paradigm for star formation: Where do we stand?

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Herschel imaging surveys of Galactic molecular clouds have revolutionized our observational understanding of the link between the structure of the cold interstellar medium (ISM) and the star formation process. I will give an overview of the results obtained in this area as part of the Herschel Gould Belt survey and will summarize the main aspects of the new paradigm for solar-type star formation favored by Herschel observations. While interstellar filaments have been known for quite some time, Herschel results demonstrate that they are truly ubiquitous, probably make up a dominant fraction of the dense molecular gas in GMCs, present a high degree of universality in their properties, and are intimately related to the formation of prestellar cores.

Overall, the available observations support a picture in which molecular filaments and prestellar cores represent two fundamental steps in the star formation process: First, multiple large-scale compressions of interstellar material in supersonic turbulent MHD flows generates a cobweb of filaments in the ISM; second, the densest filaments fragment into prestellar cores (and subsequently protostars) by gravitational instability, while simultaneously growing in mass and complexity through accretion of background cloud material. This paradigm differs from the classical gravo-turbulent picture in that it emphasizes the role of geometry and anisotropic growth of structure in the star formation process. It provides new insight into the inefficiency of star formation in GMCs and the origin of the stellar initial mass function.

The formation and evolution of molecular filaments remain poorly understood, however. I will discuss additional observational constraints coming from complementary ground-based millimeter line studies and Planck polarization data, which shed some light on this issue. I will also emphasize the need for high-resolution far-IR polarimetric imaging from Space to clarify the role of magnetic fields.

Herschel and Active Galaxies

Peter Barthel, Kapteyn Institute, University of Groningen

Herschel has yielded invaluable new understanding of the properties and the nature of the circumnuclear dust and gas in nearby and distant active galaxies, and has shown how these important constituents relate to the growth of the accreting black hole and to the growth of the galaxy.

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The Herschel view on water in star and planet formation

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In this talk I will provide framing that the Herschel Space Observatory has provided towards our understanding of the disposition of water in star and planet formation. In all I will discuss the presence of water on large scales which is believed to arise within the surface photodissociation region.

Towards successively smaller scales water vapor is seen with very lower abundance within pre-stellar cores which hints at a massive reservoir of water frozen as ice. Water vapor emission is widely associated with stellar birth via energetic emissions within shocked outflowing gas and this emission may provide a signpost for active star formation near and far. Weak and rotationally cold (< 30 K) water vapor emission was detected within planet-forming disks. When combined with higher excitation lines detected with Spitzer this cold emission enables unique constraints to be placed on the water ice-vapor transition which represents an important chemical transition in planet formation.

In all, Herschel has provided unique context and I will use this framing to explore the next steps in our study of water in the universe which will be directed towards planet formation and the link to (exo)planetary systems.

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Interstellar Hydrides with Herschel : from the 20th to the 21th century

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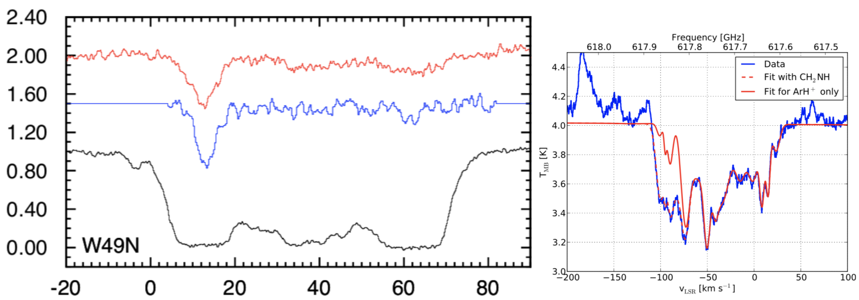
While interstellar hydrides have been among the first interstellar molecules to be spectroscopically identified in the 1930's to 1960's years, detailed information on how their abundance, excitation, and spatial distribution varied among the different conditions and environment encountered in the interstellar medium came much later. Indeed many of the best spectroscopic diagnostics of interstellar hydride are not easily accessible from ground-based observatories but need airborne or space-born telescopes. This lack of data was accompanied by a relative scarcity of theoretical discussion of hydride chemistry except for active discussions on the origin of CH+ because there was no so many data to question the accepted wisdom. The landscape changed with the nearly simultaneous advent of targeted water missions (SWAS, ODIN) and sensitive far infrared telescopes (ISO, Spitzer) which both demonstrated the diagnostic potential of hydrides but also put forward the difficulties in understanding these simple molecules. The development of submillimeter astronomy from the ground, and above all the launch of Herschel offered much diverse spectroscopic capabilities including the new spectral domain between 200 and 350 µm that was not accessible before. This allowed full spectral scans and targeted surveys for hydride transitions that had never been observed. In this talk I will describe how the PRISMAS program was prepared, which information was at hand and what was learned from the Herschel observations. I will also discuss the next steps with more hydride measurements with SOFIA, but also from the ground in redshifted galaxies, and possibly with the next generation of far infrared satellite.



The Figure presents on the left Herschel/HIFI spectra of CH^+ (black), $^{13}CH^+$ (red) and SH^+ (blue) toward the star forming region W49N (Godard et al. 2012). The right plot presents the spectrum of ArH^+ toward SgrB2, with the data in blue and the fit in red for ArH^+ (Schilke et al. 2014).

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Herschel Observation of water in the solar system

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Herschel, with its unprecedented sensitivity in the far infrared wavelengths range, has provided exciting new insights into solar system science addressing topics such as the origin and formation of the solar system, the water cycle of Mars, the source of water in the stratospheres of the outer planets, the isotopic ratios in cometary and planetary atmospheres and a number of new detections (possibly related to cryo-volcanic activity) including the Enceladus water torus, water atmospheres and emissions of the Galilean satellites and Ceres and the ocean like water in a Jupiter family comet.

This talk will provide the highlights of the Herschel findings and address topics still under investigation and finally present open questions and future prospectives.

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Herschel extragalactic deep surveys: Results and legacy

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Roughly half of the radiation from evolving galaxies in the early Universe reaches us in the far-infrared and submillimeter wavelength ranges. The Herschel Space Observatory has dramatically enhanced our ability to use this information in the context of multi-wavelength studies of galaxy evolution. Near its peak, three-quarters of the cosmic infrared background is now resolved into individually detected sources. The use of far-infrared diagnostics of dust-obscured star formation and of interstellar medium conditions has expanded from extreme and rare extreme high-redshift galaxies to more typical main-sequence galaxies and hosts of active galactic nuclei out to z~2 and beyond. These studies shed light on the evolving role of steady equilibrium processes and of brief starbursts at and since the peak of cosmic star formation and black hole accretion.

The interstellar medium conditions of high-z massive star-forming galaxies, as expressed in the far-infrared spectral energy distribution and in the ratio of mid- and far-infrared emission, are better described in relation to the evolving main sequence of star-forming galaxies than by absolute infrared luminosity. Most star formation happens near the main sequence. Complementary to and together with ground-based CO and dust mm interferometry, Herschel-based dust masses have been established as a tracer of the total interstellar medium mass of high-z galaxies, providing the first comprehensive picture of the evolving gas content of high-z galaxies.

Until the next sensitive far-infrared mission, Herschel will remain the prime reference for star formation rates of dusty high-z galaxies, and a key source of objects for characterization of kinematics and ISM conditions.

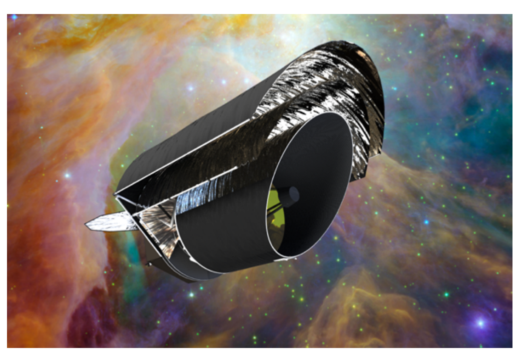
Speaker: Dr. Margaret Meixner Affiliations: STScI, JHU, and NASA/GSFC(visitor)

Title: The Origins Space Telescope: a NASA Decadal 2020 Mission Concept

Abstract: Origins Space Telescope (*Origins*) mission concept study explores the question "Where did we come from?" by investigating the origins of life's essential elements: carbon (C), oxygen (O), and nitrogen (N), as well as the dust from the first stars, through their buildup in galaxies, to the creation of habitable planetary systems to the transport of water to habitable worlds. *Origins* and its suite of instruments will utilize next-generation detectors and operate with spectral resolving power from ~3 to $3x10^5$ over wavelengths from 2.8 to 590 μm. The telescope and instruments will be cryocooled to 4.5 K, and the light collecting area, 25 m^2, will match that of the James Webb Space Telescope (JWST), resulting in an astrophysical limited background sensitivity that is >1000 times more sensitive than prior far-IR missions. *Origins* will be agile enough to observe thousands of square degrees and can be used to conduct wide-shallow surveys to spot rare interesting objects and narrow-deep surveys to probe the early Universe. The *Origins'* design builds upon the technical heritage of *Spitzer* and *JWST* with advanced cryocoolers and a simple deployment (sunshield) that makes it elegant, stable and agile, yet extremely powerful (Fig ES-1). *Origins* robust technology development plan ensures mature detectors (Technology Readiness Level 6) by the mid-2020s, in time for *Origins* to be launched by the mid-2030s.

Origins will measure the missing half of light emitted by galaxies over cosmic time, transforming our understanding of how galaxies and supermassive black holes evolve. *Origins* will follow the trail of water from the birth of the planet-forming disk to the assembly of pre-planetary materials, and in comets to understand the origin of Earth's oceans. Building upon and greatly extending the discoveries by JWST, *Origins* will characterize the atmospheres of exoplanets around nearby M dwarf stars and identify potentially habitable worlds. In these exoplanets, *Origins* will be able to detect the spectroscopic fingerprints of molecules such as ozone, methane, nitrous oxide, carbon dioxide, and water, revealing atmospheric biosignatures and providing direct evidence for life. *Origins* is not only capable of addressing known questions, but its vast discovery space will allow astronomers in the 2030s to understand new phenomena and ask new and important questions about our origins in the Universe.

The Origins Space Telescope mission concept.



The Milky Way as a Star Formation Engine

Sergio Molinari
INAF-IAPS, Rome

The Milky Way Galaxy, our home, is a complex ecosystem where a cyclical transformation process brings diffuse barionic matter into dense unstable condensations to form stars, that produce radiant energy for billions of years before releasing chemically enriched material back into the ISM in their final stages of evolution. Star formation is the trigger of this process, eventually driving the evolution of ordinary matter in the Universe from its primordial composition to the present-day chemical diversity necessary for the birth of life.

I will present an overview of the results of the Hi-GAL (Herschel infrared Galactic Plane Survey) key-project, a 720 square-degree survey of the entire Galactic Plane in five bands between 70 and 500 micron carried out with the HERSCHEL satellite. From diffuse ISM clouds, through a pervasive network of filamentary structures, down to the formation of dense clumps, the Hi-GAL survey traces the morphology and physics of dust structures at all spatial scales from the individual star formation site to the panoramic view of entire spiral arms.

Hi-GAL is the keystone of a suite of latest-generation Galactic Plane continuum and spectroscopic surveys from the infrared to the radio, that enabled us to a homogeneous analysis and classification scheme for nearly 30,000 candidate filamentary structures and more than 100,000 dense clumps with heliocentric distance determinations. We are now able to complete the first resolved map of the Star Formation Rate in the Milky Way and analyse in detail its variation with Galactocentric distance and with respect to spiral arms, as well as in comparison to star formation triggering agents.

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Evolution of Herschel science objectives from initial ideas to launch

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The first ideas of what in the end became the Herschel Space Observatory emerged in the late 1970s. At the time observations mainly in the near infrared had established the existence of sources, e.g. embedded objects, not prominent or even visible at all in the optical, and furthermore emission from molecules in the cold interstellar medium had been discovered.

It had become obvious that exciting discoveries were waiting to be made in the part of the spectrum between the optical and the radio: infrared astronomers wanted to push towards longer wavelengths, while radio astronomers wanted to push towards higher frequencies, i.e. shorter wavelengths. Since much of this spectral regime is either poorly or not at all accessible through observations from groundbased, or even airborne, facilities, a push towards space was a natural development.

The first written reference of the science objectives of Herschel dates from 1982 in the form of the proposal for a Far InfraRed and Submillimetre space Telescope (FIRST), submitted to ESA in November 1982. They were based on the outcome of a dedicated workshop held in May 1982. Inevitably there was an evolution over time of the science objectives from the FIRST proposal in 1982 to the launch of Herschel in 2009. Although many fundamental ideas persisted, the path was certainly not always straight, sometimes a better description would be tortuous. Over this long timeframe the mission was repeatedly challenged; including scientifically, technically, and based on estimated costs.

Insiders will recognize terms like Assessment Report, Horizon 2000, Segovia, Liège, System Definition Study, Tiger Team, Red Book, backup studies, telescope studies, Grenoble, merged mission, Toledo, Key Programmes, to name some of the most prominent ones. In this talk I will focus on the science objectives and discuss how they changed, or did not change, over time, and what the drivers behind the evolution were.

Abstract: The SPICA Mission, science and its instruments

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Herschel has shown us the way in unraveling the various physical and chemical processes in the evolution of galaxies over cosmic time and of planetary forming disks in our own Milky Way. The main disadvantage of Herschel was its limited sensitivity. With a cooled telescope (below 8K) and ultrasensitive detector arrays a whole new Universe will be accessible. SPICA is the concept that is currently studied by a worldwide consortium of scientists and instrument builders as one of the three candidates for the 5th medium size mission slot in the Cosmic Vision program of the European Space Agency, with the Japanese Space Agency JAXA as junior partner.

The SPICA concept has an actively cooled 2.5m dish and three focal plane instruments offering spectral resolving power ranging from ~50 through 11000 in the 17-230 μm domain as well as ~28,000 spectroscopy between 12 and 18 μm. Additionally, SPICA will be capable of efficient 30-37 μm broad band mapping, and small field spectroscopic and polarimetric imaging in the 100-350 μm range. With SPICA far infrared spectroscopy with an unprecedented sensitivity of ~5x10-20 W/m2 (5σ/1hr) comes within reach, such that galaxy evolution, metal and dust production over cosmic time as well as the formation of planetary systems can all be studied in detail and in a statistical sense.
In this presentation we will update you on the science, the mission and the SPICA instruments.

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Extragalactic Molecular Outflows

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Gas outflows driven by intense star formation and/or active galactic nuclei are important agents in the evolution of galaxies. Among other things they may produce the observed black-hole–galaxy mass relation by regulating and quenching both star formation in the host galaxy and black hole accretion. Finding observational evidence of such feedback processes in action, and quantifying the processes at work is one of the main challenges of current extragalactic astronomy.

Before Herschel, outflows had been observed frequently in many starbursts and QSOs, but they had been detected mostly in the ionized and neutral atomic gas component. However, to inhibit star formation in the host galaxy, outflows have to affect the *molecular* gas out of which stars form. Herschel detections of P-Cygni profiles of far-infrared OH lines have been a major step forward in characterizing the molecular phase of outflows from local galaxies. And although these detections were restricted to ~50 sources, they have triggered and formed the basis of what has now become a major branch of science with (sub-)mm arrays like ALMA and NOEMA.

In this review I will summarize the Herschel results regarding extragalactic molecular outflows, assess how they have stimulated and influenced contemporary sub-mm studies, and review how our current knowledge has advanced since the first Herschel observations.

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Planck – the "other side" of the Herschel/Planck Project – and its scientific connections to Herschel

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Planck was launched towards an orbit around L2 on 14 May 2009 together with Herschel, sharing the same launcher. They separated from each other less than half an hour after liftoff, marking an end to the close association of the development of the two satellites, which had formally started in 1998 when ESA adopted both missions as a single ESA Project. It is therefore appropriate that this 10th-launch-anniversary celebration of "Herschel and its science" should also involve Planck.

In this talk, I will briefly remind the main objectives and achievements of Planck, which are based on the observations of the Cosmic Microwave Background. In addition to its main objectives, Planck was designed and expected to be an important source of astrophysical information, both Galactic and extra-galactic. Indeed, the frequency range covered by the Planck maps is ideal to observe the emission of some of the major components of the interstellar medium. The all-sky Planck surveys trace directly the thermal emission from cold dust, and can also be decomposed into tracers of the ionized, neutral, and molecular gas phases of the ISM. Planck yields therefore a quite complete view at large angular scales of all the diffuse components of the ISM, which is particularly important to study the large-scale properties of the Milky Way. But the Planck data also allows to study astrophysical processes in individual external galaxies and clusters of galaxies, and to map the unresolved backgrounds which they contribute to. One particular area of high astrophysical interest which Planck has had a high impact in is related to its ability to measure polarized emission, which has led to an unprecedented view and understanding of the role of magnetic fields in the ISM.

Many of the astrophysical areas in which the Planck surveys have had an impact overlap with and complement investigations by Herschel, and most of this talk will be dedicated to discuss a selection of them.