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DIGIT, GASPS, DEBRIS AND DUNES: FOUR HERSCHEL OPEN TIME KEY PROGRAMS TO SURVEY THE DUST CYCLE IN CIRCUMSTELLAR DISKS

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Abstract. Four accepted HERSCHEL open time key programs, DIGIT, GASPS, DEBRIS and DUNES, will study the evolution of the dust grains in circumstellar disks around young and Main Sequence stars. There is a strong implication of the french community in these four projects which represent a total of 930 hours (>38 days) of HERSCHEL observing time. The DIGIT and GASPS projects will focus on the first stages of planet formation, while the DEBRIS and DUNES projects will search for extra-solar Kuiper Belt analogs around nearby Main Sequence stars. In this paper, we give an overview of the scientific goals of the four projects and of the numerical tools that we will be providing to the teams to model and interpret the HERSCHEL observations from these programs.

1 Introduction

Early 2009, the ESA far-infrared and sub-millimeter space observatory, HERSCHEL, will be launched from the Guiana Space Centre, Kourou (French Guiana), using an Ariane 5 ECA shared with the Planck satellite. With a 3.5 m effective telescope diameter, HERSCHEL will be the largest mirror ever built for a space telescope until the JWST flies. It will be placed on a Lissajous orbit about the second Lagrange point of the Earth-Sun system (L2). Out of the three instruments onboard HERSCHEL, PACS and SPIRE will be of particular interest for the study of the cold circumstellar material about young and Main Sequence stars.

PACS offers imaging photometry at 70, 100 and 160 μm, and 5×5 pixels ($47''\times47''$) integral field spectroscopy with a resolution of a few thousands between 55 and 210 μm. It offers major advances over previous instruments, in particular its higher sensitivity will provide well-characterized SEDs of faint objects, allowing for instance detection of lines a factor of $\sim$100 fainter than possible with ISO/LWS and enabling searches for weak solid-state emission features and a higher spectral resolution (R = 1500 –3000 vs. 200 for ISO/LWS). The much higher spatial resolution ($9.4''$ PACS pixel vs. about $80''$ LWS beam) will furthermore significantly reduce background confusion compared to previous space missions. The SPIRE instrument will offer photometry in 3 channels (240, 350, and 500 μm, simultaneously), and a spectroscopy mode for wavelengths between 194 and 672 μm and with resolutions ranging (at 250 μm) between a few tens to a thousand.

Out of the 62 Open Time Key Program (hereafter OTKP) proposals that were submitted late Octobre 2007, 21 have been (partly) approved, with 10 belonging to the ISM/Star Formation category. These 10 programs include the GASPS, DIGIT, DUNES and DEBRIS projects discussed in this paper. The GASPS and DIGIT OTKPs will essentially focus on the evolution and dissipation processes of gaseous disks during the planet forming period, while DEBRIS and DUNES will perform systematic surveys of nearby Main Sequence stars to search for extra-solar analogs to our Kuiper belt.

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2 Planet-forming disks: GASPS and DIGIT

With a total of 400 h, the GASPS (Gas in Protoplanetary Systems) project is the largest of the OTKP accepted in the ISM/Star formation category. The GASPS team is lead by B. Dent in Edinburgh (UK) and consists of 38 CoIs (`http://www.laeff.inta.es/projects/herschel/index.php`). GASPS will perform an unbiased PACS survey of atomic and molecular gas and dust in more than 250 disks covering a wide range of ages (1–30 Myr), disks masses ($10^{-2}M_\odot$–$10^{-5}M_\odot$), and stellar types (A to M). The majority of the targets lie in 6 of the closest (< 160 pc) young stellar clusters with well defined ages: Taurus, Upper Sco, TW Hya, Tuc Hor, Beta Pic and Eta Cha. The primary goal of GASPS, as the project name states, is a gas census using the far-infrared fine structure lines of carbon and oxygen as probes of atomic gas, together with water lines to probe the molecular gas. But GASPS will also spend a small fraction (5%, 20h) of the observing time on 70 and 170 μm photometry, to define the SED in the same wavelength range as the line data. Together these data will provide a broad picture of disks as they transition from molecular, through atomic, to mainly dusty composition.

The french astronomers involved in GASPS will primarily contribute to analysis and modeling of the observations of the dusty component of the disks, using the radiative transfer code developed at LAOG by Pinte et al. (2006). We will search for the signatures of the dust structure (such as dust settling) which are most obvious (break in the SED slope, change in absolute flux) and can be probed with appropriate color-magnitude and color-color diagrams. Combined with literature data and ancillary observations (accepted IRAM, CARMA, AKARI, SMA, APEX programs for instance), the modeling of the spectral energy distribution will provide a parametrization of the global disk structure and a self-consistently calculated temperature profile through out the disk that will serve as inputs to the chemistry models available to the team. SED fitting of individual objects is gonna be performed by generating large grids of models using the new cluster funded by the ANR project "Dusty Disks" (PI. F. Ménard).

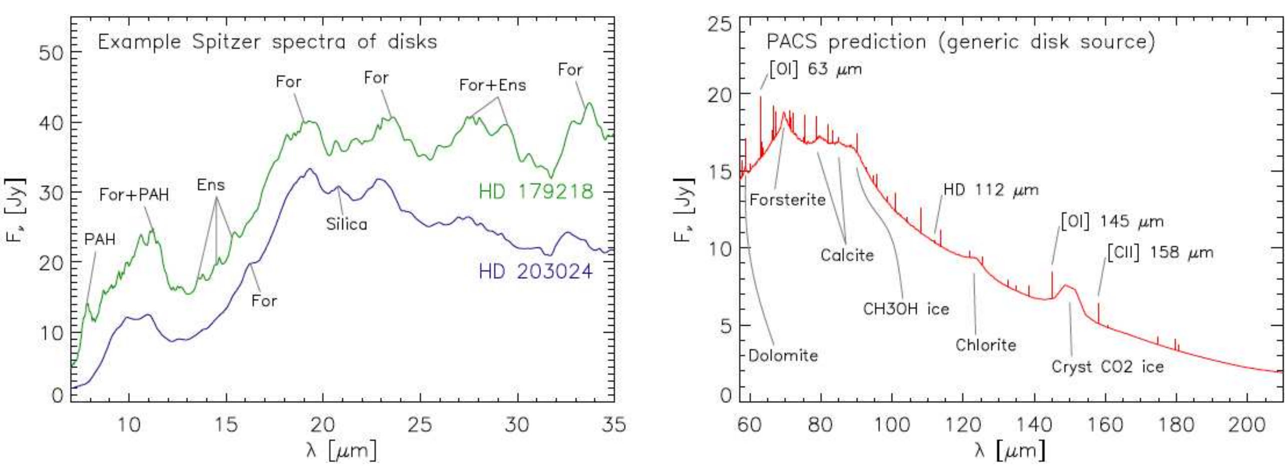

Fig. 1. *Left*: Spitzer spectra (arbitrary units) of two Herbig Ae star sources showing the richness in solid-state features. "For" stands for crystalline forsterite and "Ens" for crystalline enstatite. *Right*: Model spectrum (courtesy of K. Dullemond) of a disk around a Herbig Ae star of $L_* = 30L_\odot$ at a distance of 120 parsec. The dust of the model disk consists of 15% ice (mixture of H_2O , CO_2 and CH_3OH), 10% crystalline forsterite, 0.5% dolomite, 0.5% calcite, 20% chlorite, and the rest amorphous olivine. This composition is illustrative, and does not represent the complete inventory of dust/ice species that Herschel can discover. Most of the gas lines are H_2O, but their overall normalization is arbitrary, so as to show their position and typical relative strengths. The other gas lines (annotated) are mockup lines shown at a strength consistent with the range of predictions.

The DIGIT OTKP (250 h, P.I. Neal Evans, Texas, `http://peggysue.as.utexas.edu/DIGIT/`, 27 CoIs) aims at following the evolution of dust, ice and gas in time from objects embedded in cloud cores through the dissipation of disks. The main tool will be PACS spectral observations of a sample selected to probe the full evolutionary sequence and span a wide range of masses, luminosities, and other variables like environment. PACS offers imaging photometry (dust), broad spectral scans from 57 to 210 μm (dust, ice, strong gas lines), and targeted spectral scans (weak gas lines) well-suited to the goals of DIGIT.

The DIGIT sample is drawn from previous studies, particularly those for which high-quality Spitzer-IRS

Table 1. Targets for the DUNES (140 h) and DEBRIS (140 h) OTKPs

Spectral Class	Observed by DUNES	Observed by DEBRIS	DEBRIS targets shared with DUNES	DUNES targets shared with DEBRIS
M	0	89	8	0
K	54	57	9	35
G	52	48	25	41
F	27	71	50	22
A	0	83	14	0
Total	133	348	106	98

5–40μm spectra exist and show solid-state features than can be ascribed to amorphous and crystalline silicates. A key component of the DIGIT observing program will be full high-S/N spectral scans from 57 to 210 μm of about 23 disk sources with strong continuum. For 12 weaker disk sources, we focus on specific spectroscopic features (e.g. forsterite 69 μm feature), and for 30 of the most evolved disks, we will obtain sensitive searches for residual dust and gas. For the brighest sources, the far-infrared features to be observed will provide critical information on the thermal and mixing history, aqueous content and processing, and elemental composition of the cooler dust at larger disk radii. DIGIT will search for hydrosilicates (e.g. Montmorillonite, Serpentine) and carbonates (e.g. Calcite, Dolomite) that may have formed by aqueous alteration and expected to appear in the most evolved disks. This study represents an extension of the analysis of Spitzer spectra for a hundred of disks around young stars performed by Olofsson et al. (these proceedings) in Grenoble.

3 Exo-Kuiper belts: DUNES and DEBRIS

The DUNES (DUst around NEarby Stars, PI Carlos Eiroa, Spain, 40 CoIs, `www.mpia-hd.mpg.de/DUNES/`) and DEBRIS (Disc Emission via Bias-free Reconnaissance in the Infrared/Sub-millimeter, PI Brenda Matthews, Canada, 27 CoIs) OTKPs are aimed at performing sensitivity-limited (DUNES) or flux-limited (DEBRIS) surveys of faint exo-solar analogues to the Edgeworth-Kuiper Belt (EKB) in statistical samples of nearby stars. These so-called debris disks, which contain much less dust mass than young disks (typically 10^{-3}–$10^{-1} M_\oplus$), survive over billions of years, pointing towards the presence of large reservoirs of colliding asteroid- and evaporating comet-like bodies. Therefore, dust in debris disks is intimately connected to its parent bodies, invisible left-over planetesimals. Observing the dust emission is a powerful way to shed light onto their spatial and size distributions, properties and composition, and ultimately, their accretion history. Furthermore, dust sensitively responds to the gravity of planetary perturbers and thus can be used as a tracer of planets.

DUNES and DEBRIS have very similar objectives and were therefore awarded the same number of hours (140 h for each program) by the time allocation committee. The two teams were requested to coordinate their observing effort since a significant fraction of the targets in the original lists overlapped. The division of common targets has been based on the PACS/100 sensitivity. DEBRIS adopts a flux-limited approach, while DUNES requires the stellar photosphere to be at least detected with a Signal-to-Noise ratio larger than 3 at 100 μm. This fundamental difference in observing strategy directly translates into differences in numbers of targets for each program as the DUNES approach is more observing time-consuming (see Table 1). DUNES will finally observe 133 FGK-type nearby Main Sequence stars and this sample includes known planet-hosting stars (20 as of July 2008) while DEBRIS will observe 348 stars including A and M-type stars, with some shared between the two teams as indicated in the last two columns of Tab. 1. Both the DUNES and DEBRIS surveys are driven by PACS 100/160 observations as the main tool to detect cold dust, with SPIRE photometry used for follow-up (42 targets for DUNES, 100 for DEBRIS). DUNES will in addition observe 49 targets with PACS 70/160 to get some redundancy with existing Spitzer MIPS 70 μm observations and to improve the 160 μm sensitivity.

The PACS and SPIRE observations, combined with ancillary data, will be interpreted using state-of-the-art models developed within the teams to infer the individual properties of the dust disks (mass, temperature, distance, grain size distribution), and to statistically discuss the incidence and evolution of planetesimal belts too faint to be detected from the ground, and too cold to be detected with previous space missions, including with Spitzer. The detected systems will be compared to our own EKB to evaluate whether the solar system is peculiar or rather common. For some of the targets, the observing time has been tailored to able the detection of exo-EKBs as faint as a few times our own EKB which as fractional bolometric luminosity of about 10^{-7} (see Figure 2). Furthermore, since truncated cold disks may be a strong indication of interior planets, resembling the roles played by Neptune and Jupiter in the solar system, they would constitute the best candidates for probing the presence of long-orbital period exo-planets in the solar neighbourhood.

The french CoIs are deeply involved in the modeling aspects of the two programs, providing radiative transfer tools (e.g. Augereau et al. 1999, Pinte et al. 2006) as well as expertise on dynamical modeling of planetary systems (e.g. Morbidelli et al. 2008, Reche et al. 2008). The DUNES modeling effort will in fact be lead by the LAOG CoIs. We will also provide complementary ground-based (sub-)millimeter observations (e.g. survey of disks about M-type stars by Lestrade et al. 2007) as well as near-IR interferometric observations to search for hot exo-zodiacal dust in regions not probed by Herschel (e.g. Absil et al. 2008).

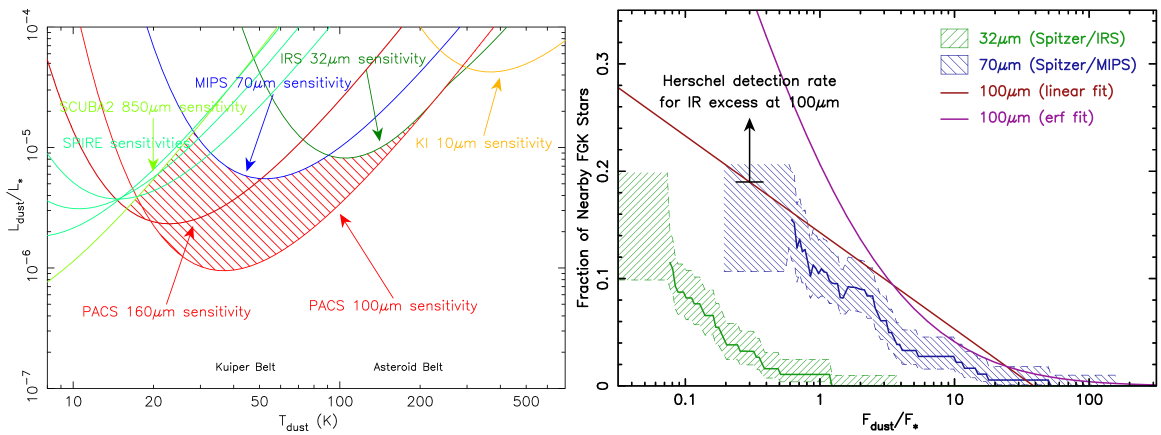

Fig. 2. *Left panel*: Detection limits for a G5V star at 20 pc, following the Bryden et al. (2006) approach. The assumed $1\,\sigma$ fractional flux accuracies are 20% for Spitzer/MIPS at 70 μm, 2.5% for Spitzer/IRS at 32 μm, 10% for PACS 100 μm (i.e. SNR=10), and 100% for PACS 160 μm (SNR=1). *Right panel*: Spitzer detection rates of IR excess as a function of the fractional monochromatic dust flux, $F_{\rm dust}/F_*$. For Spitzer/MIPS at 70 μm, 182 F5-K5 stars were observed by Bryden et al. (2006) and Beichman et al. (2006b). For Spitzer/IRS spectra at 32 μm, 187 F0-M0 stars were observed by Beichman et al. (2006a, 2008). Uncertainties in the underlying distribution due to small number statistics (shaded regions) are large below the detection limits of each instrument/wavelength.

4 Conclusion

The GASPS, DIGIT, DUNES and DEBRIS observations build on the heritage of previous space missions and the four teams will provide to the community a rich database to address the physical and chemical evolution of protostellar and protoplanetary sources, and to study planet formation. The archive will also be invaluable for planning future ground and space missions, aiming in particular at detecting photons from exo-planets. The significant french contribution to the 4 OTKPs is intimately related to the excellent, worldwide visibility of our work in the field of star and planet formation, and in particular through the development of versatile numerical models that will be used to interpret the soon coming Herschel data.

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