The mm & submm sky in the Planck era

Göran Pilbratt, Herschel Project Scientist
The Cool Universe – Planck 2011

Herschel Space Observatory as seen by Planck

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- Herschel covers the IR peak and pushes into the submillimetre
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Importance of the FIR & submm

- Half of the energy created in the Universe since the CMB has been reprocessed into the IR
- Herschel covers the IR peak and pushes into the submillimetre: cold black-bodies & spectral lines
Herschel – the machine

3 novel science instruments:
PACS, SPIRE, HIFI

Detectors working at ~2 K and 300 mK

Warm electronics in SVM

Launch Mass: ~3400 kg

Power: ~1200 W

3-axis stabilisation

Sunshield and solar array

Telescope (3.5m)

Helium-II cryostat (~ 2400 litres, 3.5 years lifetime)

Service Module
Herschel – the science instruments

3-band camera
250, 350, 500 μm (all simultaneously)

Imaging FT spectrometer
194 - 671 μm (simultaneously)
λ/Δλ = 1300 – 370 (high-res)
= 60 – 20 (low res)

3-band camera
70 or 100, 160 μm (2 simultaneous)

Imaging grating spectrometer
55 - 210 μm (3 orders)
λ/Δλ = 1000 – 4000

7-channel heterodyne receiver
480 - 1250 GHz (625 - 240 μm)
1410 - 1910 GHz (212 - 157 μm)
λ/Δλ = 10^5 - 10^6
Instantaneous BW: 4 GHz
What does Herschel offer?

**Large telescope**
- 3.5 m diameter
- collecting area and resolution

**‘New’ spectral window**
- 55-671 μm – bridging the far infrared & submillimetre – the ‘cool’ universe

**Novel instruments**
- wide area mapping in 6 ‘colours’
- imaging spectroscopy
- very high resolution heterodyne spectroscopy

**Herschel objectives**
- star formation near and far
- galaxy evolution over cosmic time
- ISM physics/chemistry
- our own solar system
- provide 3 years of routine observing
- observatory offered to community
Launch on 14 May 2009!
Taking stock – the first year in-flight

Launched on 14 May 2009
- 14 June 2009 - cryo-cover opening, followed by first observation
- 15 July 2009 - Performance Verification Phase commenced
- 2 August 2009 - HIFI anomaly
- 12 September 2009 – first Science Demonstration Phase observation
- 18 October 2009 – first Routine Science Phase observation

SDP Initial Results workshop 17-18 December 2009
- 10-14 January 2010 – HIFI turned on
- February-April 2010 – HIFI catching up, allocated ~50% of the time
- 9 March 2010 – HSA and HIPE publicly available
- 31 March 2010 – submission deadline A&A Special Issue papers

HIFI Initial Results workshop 12-13 April 2010

Herschel First Results symposium 4-7 May 2010
- 20 May 2010 – first in-flight open time (OT1) AO issued
- 31 May 2010 – submission deadline A&A HIFI Special Feature papers
- 22 July 2010 – OT1 proposal submission deadline
Hi-GAL – mapping the Galactic plane

Merry Christmas and a Happy New Year from the Hi-GAL Team

Image of the dust emission in a portion of the Galactic Plane obtained by combining Herschel data at 70, 160 and 350 microns. The region spans some 10 degrees in galactic longitude and 2 in galactic latitude in the first quadrant (between l=35 and l=47).
Filaments permeate the ISM on all scales

**Herschel**
SPIRE 500 μm + PACS 160/70 μm

**Planck**
HFI 540/350 μm + IRAS 100 μm

ESA and the Gould Belt KP

ESA and the HFI Consortium

Ophiuchus

Aquila

15 deg
SPIRE/PACS 70-500 μm imaging of the bulk of nearby (d < 0.5 kpc) molecular clouds (~ 160 deg²), mostly located in Gould’s Belt.

**Motivation: Key issues on the early stages of star formation**

- What determines the distribution of stellar masses = the IMF?
- What generates prestellar cores and what governs their evolution to protostars and proto-brown dwarfs?
“First images” from the Gould Belt Survey

Aquila Rift
star-forming
molecular cloud
(d ~ 260 pc)

Red : SPIRE 500 μm
Green : SPIRE 160 μm
Blue : PACS 70 μm

~ 3.3 deg x 3.3 deg field

Könyves et al. 2010
Bontemps et al. 2010
André et al. 2010
A&A special issue
Confirming link prestellar CMF & IMF

Könyves et al. 2010
André et al. 2010
A&A special issue

341-541 prestellar cores in Aquila - factor ~ 2-9 better statistics than earlier studies:

e.g. Motte, André, Neri 1998; Johnstone et al. 2000; Beuther & Schilke 2004; Stanke et al. 2006; Enoch et al. 2006; Alves et al. 2007; Nutter & Ward-Thompson 07

- Good (~ one-to-one) correspondence between core mass and system mass: \( M_\star = \epsilon M_{\text{core}} \) with \( \epsilon \approx 0.2-0.4 \) in Aquila

- The IMF is at least partly determined by pre-collapse cloud fragmentation (cf. models by Padoan & Nordlund 2002, Hennebelle & Chabrier 2008)
Only the densest filaments are gravitationally unstable and contain prestellar cores (▲).

The gravitational instability of filaments is controlled by the value of their mass per unit length $M_{\text{line}}$ (cf. Ostriker 1964, Inutsuka & Miyama 1997):

- unstable if $M_{\text{line}} > M_{\text{line, crit}}$
- stable if $M_{\text{line}} < M_{\text{line, crit}}$
- $M_{\text{line, crit}} = c_s^2/G \sim 15 M_\odot/\text{pc}$ for $T = 10K$

Simple estimate:

$M_{\text{line}} \propto N_{\text{H}_2} \times \text{Width}$

Unstable filaments highlighted in white in the $N_{\text{H}_2}$ map.
HIFI – Orion KL spectral survey
Orion KL

Orion KL Spectrum: Most complete spectrum of molecular gas at high spectral resolution ever obtained.

~100,000 lines
Orion KL - Band I

The Orion KL Spectrum: Most complete spectrum of molecular gas at high spectral resolution ever obtained.

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HIFI and Spectral Surveys

- Orion KL Spectrum: Most complete spectrum of molecular gas at high spectral resolution ever obtained.
- ~100,000 lines
HEXOS (E. Bergin) Orion KL Spectrum:

- “Data quality is excellent: *Most complete spectrum of molecular gas at high spectral resolution ever obtained.*”
- CSO: 40 GHz with 30 mK rms in ~36 hours
- Herschel: “*In 50 hours of HIFI time we have covered 1150 GHz!*”
- *The whole spectrum contains ~100,000 lines*
“First images” from the Gould Belt Survey

Polaris translucent cloud
(d ~ 150 pc)

Red : SPIRE 500 $\mu$m
Green : SPIRE 250 $\mu$m
Blue : PACS 160 $\mu$m

~ 7 deg$^2$ field

Ward-Thompson et al. 2010
Miville-Deschênes et al. 2010
A&A special issue
Polaris (Abergel)
The Herschel ATLAS
Astrophysical Terahertz Large Area Survey

- Largest area survey with Herschel (~550 sq deg)
- PACS and SPIRE fast parallel mode:
  - 100 μm
  - 160 μm
  - 250 μm
  - 350 μm
  - 500 μm
- 5 sigma sensitivities of 132, 126, 33, 36 and 45 mJy /beam at 100-500 μm
- Detect ~10^5 sources to z~3
- Eales & Dunn
NGP and Equatorial fields chosen to allow maximum overlap with existing and planned surveys GALEX, 2dF, SDSS, GAMA, UKIDSS, KIDS, VIKING, PanSTARRS, DES, SPT, SASSy and to be accessible to new facilities which will be valuable for follow-up ALMA, SKA and prototypes, SCUBA2, LOFAR, e-MERLIN.
Progress in submm observations

1998
SCUBA HDF:
5 sources after 20 exceptional nights

To scale!

~3 arcmin

2009
Herschel-ATLAS SDP field:
15,000 sources in 16 hours
3% of total => 500,000 !!
Green box: 6000 sources
Evolution of the 250 um Luminosity Function

Dye et al, A&A special issue

3 billion years ago
2 billion years ago
1 billion years ago
Now
GOODS-N (Oliver & Lutz)

PACS
100/160 µm

SPIRE
250/350/500 µm

10 arcmin

250 µm
350 µm
500 µm
Deep Herschel/PACS blank fields

PEP GOODS-N 30h
100+160μm during Science demonstration phase
~300 sources

PEP GOODS-S
113+113h
70+100+160μm
~800 sources
From Spitzer/MIPS ...
From Spitzer/MIPS to Herschel/PACS

Preliminary!
Resolving the CIRB

PEP:
• 100 & 160 μm: 45% & 52%
• Stacking of 24 μm sources 50% & 75%

HerMES:
• Confusion limited counts 250, 350, & 500 μm: 15%, 10%, 6%
• P(D) 250, 350, & 500 μm: 65%, 60%, & 45%
From MIPS to PACS

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Highest redshift quasar known: $z=6.42$ (Meisenheimer)
Mission (cryostat) lifetime

(i) Thermal modelling, and (ii) He mass measurements
Mission (cryostat) lifetime

Large uncertainties

[Graph showing helium contents over time with various lines and markers indicating different measurements and calculations.]
Observing opportunities

Pre-flight AO – Key Programmes

• In 2007
• 21 Guaranteed Time (GT) Key Programmes
• 21 Open Time (OT) Key Programmes

First in-flight AO – AO1: GT1 & OT1

• OT1: May-July 2010
• 35 GT1 programmes
• 241 OT1 programmes – priorities 1 & 2

Second in-flight AO – AO2: GT2 & OT2

• OT2: May-July 2010 – exact dates TO BE DECIDED
• n GT1 programmes
• m OT1 programmes

More information on the HSC website

• Execution status by end of 2010: 63% GT KP & 56% OT KP
• AO dates and documentation (when released, now OT1 for reference)
• Abstracts of all accepted observing programmes
• AORs can be downloaded using HSpot, and public data through HSA
Herschel Latest News

Status summary: Herschel was successfully launched together with Planck on 14 May 2009. Currently Herschel is conducting routine science phase operations. On 30 December 2010 the approximate completion percentages were: KPGT 63%, KPOT 56%, and GT1 34% (remember GT1 is a factor of ten smaller than KPGT and KPOT). More detailed information will be provided commencing in the near future.

Elapsed time since launch on 14 May 2009 at 13:12 (UTC).

Herschel and XMM-Newton join forces observing M31! A few hours after completing 600 days in-flight Herschel together with XMM-Newton have been featured in the BBC Stargazing Live show joining forces observing M31, the Andromeda Galaxy. The observations very convincingly display the importance of having access to multiple regions in the spectrum, each providing unique and complementary information. For more information see the reports on the ESA and ESA Space Science portals, and the ESA Science & Technology, the UK Herschel outreach, and the BBC News websites. Furthermore in French on the French Herschel outreach and in Spanish on the El Puls websites.

Happy New 2011 from the Herschel Science Centre! For Herschel clearly 2010 has been the year of coming out! Stunning results are presented by Herschel observers in a multitude of meetings around the globe. It really has been an exceptional time to work on Herschel, and we believe all of our observers share this sentiment. So, from all of us, to all of you, a very happy, prosperous, and exciting 2011. Added in press: We have just learned that the A&A special issues reprint