The Herschel Mission

Herschel Calibration Workshop
Leiden, 1 December 2004

Göran L. Pilbratt
Herschel Project Scientist
Astrophysics Missions Division
Research and Scientific Support Department

http://www.rssd.esa.int/herschel
Beginnings to … the present

http://www.rssd.esa.int/herschel
Herschel mission

- **ESA cornerstone observatory**
  - instruments ‘nationally’ funded, int’l - NASA, CSA, Poland – collaboration
  - ~1/3 guaranteed time, ~2/3 open time

- **FIR (57 - 670 µm) space facility**
  - large (3.5 m), low emissivity (< 4%), passively cooled (< 90 K) telescope
  - 3 focal plane science instruments
  - 3 years routine operational lifetime
  - full spectral access
  - low and stable background

- **Unique and complementary**
  - for $\lambda < 200$ µm larger aperture than cryogenically cooled telescopes (IRAS, ISO, SIRTF, Astro-F,…)
  - more observing time than balloon- and/or air-borne instruments (~1000 SOFIA flights per year)
  - larger field of view than interferometers

- **Launch in 2007**

http://www.rssd.esa.int/herschel
Galaxy formation & evolution

The Cosmic

CMB

CIB

COB

Stars/AGN?

Big Bang

CXB

AGN

http://www.rssd.esa.int/herschel
Star formation & evolution

ISM in Galaxies:
- Normal galaxies
- Physical properties of star-forming ISM

ISM in the Milky Way:
- Structure
- Dynamics (pressure)
- Composition (gradients)

Dense cores and star-formation:
- Temperature, density structure
- Dust properties
- Stellar IMF

Late stages of stellar evolution:
- Winds
- Shells
- Asymmetries
- Composition

Solar System:
- Water in Giant Planets
- Atmospheric chemistry
- Water activity and composition of comets

http://www.rssd.esa.int/herschel

HCALWS, Leiden
Göran L. Pilbratt
1 Dec 2004
VG # 5
The Cool Universe

- **Herschel spectral coverage**
  - black-bodies 5-50 K
    - continuum radiation
    - dust grains (re-)radiating
  - gases 10-few100 K
    - brightest atomic/molecular lines

- **Herschel emphasis**
  - formation and evolution of galaxies & stars
  - ISM physics & chemistry
  - solar system bodies

- **Herschel strengths**
  - covers ISM SED peaks
  - wide area mapping
  - spectral scans, water lines
Herschel spacecraft

- telescope diameter: 3.5 m
- telescope WFE: < 6 µm
- telescope temp: < 90 K
- telescope emissivity: < 4%
- abs/rel pointg (68%): < 3.7” / 0.3”
- science instruments: 3
- science data rate: 130 kbps
- cryostat lifetime: 4.0±0.4 years
- height / width: ~ 7.5 / 4 m
- launch mass: ~ 3200 kg
- power: ~ 1500 W
- orbit: ‘large’ Lissajous around L2
- solar aspect angle: 60-120 deg
- launcher (w Planck): Ariane 5 ECA

http://www.rssd.esa.int/herschel
Herschel spacecraft

- telescope diameter: 3.5 m
- telescope WFE: < 6 μm
- telescope temp: < 90 K
- telescope emissivity: < 4%
- abs/rel pointg (68%): < 3.7” / 0.3”
- science instruments: 3
- science data rate: 130 kbps
- cryostat lifetime: 4.0±0.4 years
- height / width: ~ 7.5 / 4 m
- launch mass: ~ 3200 kg
- power: ~ 1500 W
- orbit: ‘large’ Lissajous around L2
- solar aspect angle: 60-120 deg
- launcher (w Planck): Ariane 5 ECA

http://www.rssd.esa.int/herschel
Herschel spacecraft

- Sun Shade
- Solar Array
- Local Oscillator Unit
- Telescope
- Cryo Vacuum Vessel
- Service Module
- Thermal Shields
- Instrument Warm Units

http://www.rssd.esa.int/herschel
Petals ready for brazing
Brazing of primary mirror ‘blank’
Grinding of primary mirror
Warm vibration
Polishing

http://www.rssd.esa.int/herschel
Herschel spacecraft

Sun Shade

Telescope

Solar Array

Cryo Vacuum Vessel

Local Oscillator Unit

Thermal Shields

Service Module

Instrument Warm Units

http://www.rssd.esa.int/herschel
Herschel payload module

http://www.rssd.esa.int/herschel
Herschel payload module

http://www.rssd.esa.int/herschel
Herschel spacecraft
Herschel service module

http://www.rssd.esa.int/herschel
Ground segment
Status & schedule

- Science Payload AO: September 1997
- Invitation to Tender issue: September 2000
- Kick-off of industry: April 2001
- System Requirements Review: June - October 2001
- PDR Satellite: October - December 2002
- Mission level PDR: February 2003
- CDR Herschel Payload Module: May - July 2004
- CDR Satellite: August - October 2004
- Mission level CDR: January - March 2005
- Launch: 3 August 2007

‘Best working schedule’ constructed by industry – based on ESA inputs for telescope and instruments – for Satellite CDR, to be technically and contractually formalized to become ‘nominal schedule’ by Xmas 2004.

http://www.rssd.esa.int/herschel
Launch and orbit

http://www.rssd.esa.int/herschel
Herschel mission phases

• Launch and early operations (LEOP)
• Commissioning and performance verification (SC + payload)
• Science demonstration phase
• Routine science operations phase (36 months)
  – Guaranteed time programmes – GT (32%)
    • open for GT holders only
  – Open time programmes – OT (68%)
    • including discretionary time and targets of opportunity
    • open for all – including GT holders
• Three ‘Call for proposals’ (AO) cycles are foreseen
  – one Call for ‘Key Projects’ programmes only (GT and OT)
  – two Calls for regular programmes (GT and OT)
• Each AO will be divided in two parts
  – GT awarded first
  – OT awarded after GT in same cycle
Herschel observing - generalities

• Top level considerations
  – overall goal is to maximise science return and impact
  – Herschel is a strictly consumables limited mission

• Herschel to a certain degree its own pathfinder
  – follow-up observations must be feasible (data reduction, scheduling)
  – concept of ‘Key Project’ programmes upfront

• Three years of ‘routine science operations’ available
  – LEOP, commissioning, PV, science demonstration, initial 6 months
  – followed by 3 years of ‘routine science operations’
  – approx 1000 days / 20000 hours schedulable time available

• Data rights
  – first year of routine science operations 12 months - then 6 months
  – non-routine phase observations - none (but overlap mechanism)

• All observing proposals – including for GT programmes – will be assessed by the Herschel Observing Time Allocation Committee for scientific merit

http://www.rssd.esa.int/herschel

HCaWS, Leiden
Göran L. Pilbratt
1 Dec 2004
VG # 24
Herschel ‘Key Projects’

- Foreseen to be important upfront (SMP/instrument AO)
  - introduced to ensure that ‘unusually large’ observing programmes can be proposed, selected, and observed
  - need ‘pre-identified’ due to the nature of the foreseen science objectives and the lack of ‘precursor’ (IRAS-type) mission

- Definition of a ‘Key Project’ programme - it must
  - exploit unique Herschel capabilities address (an) important scientific issue(s) in a comprehensive manner
  - require a large amount of observing time to be used in a uniform and coherent fashion
  - produce a resulting well characterised dataset of high archival value

- Data reduction
  - it is recognised that there is a legitimate science return interest that
    - the data generated by the observations are timely reduced, and
    - the data products and tools are made public
  - therefore ‘Key Project’ consortia must demonstrate commitment and ability to perform data reduction, and must make data products and tools publicly available at the end of the proprietary time period

http://www.rssd.esa.int/herschel
‘Rules of the road’

- SMP
  - issued 1997
  - SPC approved
  - basis for AO

- Observation Programmes document
  - elaborating on SMP
  - AWG approved
  - issued 2004

- Available on web
  - ‘community info’

- Basis for updated SMP
  - to come

http://www.rssd.esa.int/herschel
Timeline exercise – (1)

• Logic: Issue ‘Call for Proposals’ (AOs) as late as possible
  – for pure scientific reasons
  – and for performance knowledge reasons
  – but early enough for observers to prepare
  – and to have observations available for scheduling
  – and enable community support staff ‘training on the job’

• AO + 0 mths: Issue AO for ‘Cycle KP’ proposals
• AO + 3 mths: Submission deadline for GT KP proposals
• AO + 6 mths: Selection & announcement of GT KP programmes
• AO + 9 mths: Submission deadline for OT KP proposals
• AO + 12 mths: Selection & announcement of OT KP programmes

• AO + 12 mths: Issue AO for ‘Cycle 1 GT’ proposals
• AO + 15 mths: Submission deadline for GT1 proposals
• AO + 18 mths: Selection & announcement of GT1 programmes

• L: Launch followed by in-orbit operations
Timeline exercise – (2)

- **L:** Launch followed by and in-orbit operations
- **L + 5 mths:** Science demonstration workshop & optimisation of observing programmes
- **L + 6 mths:** Issue AO for ‘OT1’ proposals
- **L + 9 mths:** Submission deadline for OT1 proposals
- **L + 12 mths:** Selection & announcement of OT1 programmes
- **L + 18 mths:** Issue AO for ‘Cycle 2’ proposals
- **L + 21 mths:** Submission deadline for GT2 proposals
- **L + 24 mths:** Selection & announcement of GT2 programmes
- **L + 27 mths:** Submission deadline for OT2 proposals
- **L + 30 mths:** Selection & announcement of OT2 programmes
- **L + 42 mths:** End of nominal mission

- Initial AO foreseen ‘early 2006’
- Subject to optimisation!
Herschel observatory capabilities

- **Photometry - imaging, 6 broad bands in 75-500 µm range**
  - **PACS** - simultaneous 2 colour fully-sampled (0.5Fλ) imaging with FOV 1.75x3.5 arcmin with R~2.5 centred at 75/110 and 170 µm
  - **SPIRE** - simultaneous 3 colour 2Fλ imaging with FOV 4x8 arcmin with R~3 centred at 250, 363, and 517 µm
  - for larger fields ‘on-the-fly’ mapping, mosaicing
  - sensitivity is somewhat wavelength and observing mode dependant, very roughly for point sources 1mJy - 1σ - 1 hour; for mapping confusion limit is important

- **Spectroscopy - in 57-670 µm range, varying R in 20-10^7 range**
  - **PACS** - 5x5 spatial 16 spectral pixels, FOV 0.8 arcmin, R~1500, λ ~57-210 µm
  - **SPIRE** - FTS spectrometer, R ~20-100+, FOV 2.6 arcmin, λ ~200-670 µm
  - **HIFI** - heterodyne spectroscopy with R up to 10^7, λ ~157-212 and 240-625 µm, 2 orthogonal polarisations, 4000 spectral channels per polarisation, single pixel on the sky, mapping by ‘on-the-fly’ or mosaicing observations

- **Very different instrument technologies and performance limitations!**
PACS predicted performance

Photometry

Resolving power

Sensitivity [W/m²] (5σ, 1 hour)

Sensitivity mJy 5σ 1hr

Wavelength [µm]
SPIRE predicted performance

- Photometry
- Spectrophotometry
- Line spectroscopy
- at $5\sigma$, 1 hr

Point source (7-point)

- Jiggle map
- Scan map

Fully-sampled map

Point source/sparse map

http://www.rssd.esa.int/herschel
HIFI mixer performance

http://www.rssd.esa.int/herschel
Early mission phases

• Launch and early operations (LEOP)
  – nominally ~few weeks, but
  – telescope kept warm during s/c cooldown
  – cryo-cover opening (first light!) ~4-6 weeks after launch

• Commissioning and performance verification (SC + payload)
  – nominally ~2 months, but
  – PV plans not yet in place

• Science demonstration phase
  – convince us we know how to operate the observatory
  – demonstrate the capabilities of the observatory
  – convince ourselves we can achieve expected objectives
  – generate ‘pretty pictures’ – and ‘pretty spectra’!?  
  – need to have calibration & data processing in place!

• Begin routine science operations phase (36 months)
  – not later than 6 months after launch
  – initially Key Progs (GT & OT) and ‘regular’ GT progs
Calibration issues

- **Calibration is continuous activity**
  - ILT leading into PV and future improvement
    - by nature ‘only instrument’ measurements at ILT
    - adding ‘observatory’ and ‘environment’ in PV
  - both ground and in-orbit calibration time is limited
    - ground activities resource and schedule limited
    - in-orbit calibration time allocation helium limited
  - in particular the PV phase will be crucial
    - need good preparations – and ability to react
    - need ‘instrument model’ for interpretation – starting now!

- **Calibration ‘physical’ constraints**
  - SAA => [sky visibility limitations](t)
    - but never within 60 deg away from the sun
  - cryo-cover opening (first light!) ~4-6 weeks after launch
  - telescope still slowly cooling down
    - towards unknown operating temperature
Telescope initial cooldown
from HCalSG mtg#3, 7 March 2003

• Telescope launched warm
• Kept at 313 K for 2-3 weeks
• Avoid trapping outgassed contaminants
• Cooling down is slow(ish)
  – long(ish) time constant
  – four e-folding times > 98%
  – not completely consistent picture here => sort out!
• Cryocover opening
  – 4-8 weeks post launch (TBC)
• Start observing!

ASED spacecraft PDR doc
=> time const ~ 5 days

http://www.rssd.esa.int/herschel
Telescope initial cooldown

- Telescope launched warm
- Kept at 313 K for 2-3 weeks
- Avoid trapping outgassed contaminants
  - long(ish) time constant
  - four e-folding times > 98%
  - time const temperature dependent
- Cryocover opening
  - 4-6 weeks post launch (TBC)
- Start observing!
Predicted M1 average temperature
from HCalSG mtg#3, 7 March 2003

The telescope temperature depends critically on the temperatures and emissivities of the thermal interfaces; the sunshade/shield and CVV topside

=> Accurate knowledge before in-orbit operation questionable!
Predicted M1 average temperature
- and gradients

“specified interface”, as specified in AD1

“system” interfaces, as a realistic case, coming from the last S/L predictions.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Average</td>
<td>Max</td>
<td>Average</td>
<td>Average</td>
</tr>
<tr>
<td>SPEC I/F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot case</td>
<td>89.6 K</td>
<td>89.8 K</td>
<td>90.0 K</td>
<td>87.9 K</td>
<td>0.43 K</td>
</tr>
<tr>
<td>Cold case</td>
<td>61.4 K</td>
<td>61.5 K</td>
<td>61.5 K</td>
<td>61.1 K</td>
<td>0.08 K</td>
</tr>
<tr>
<td>Max hot case</td>
<td>91.0 K</td>
<td>91.2 K</td>
<td>91.4 K</td>
<td>89.0 K</td>
<td>0.44 K</td>
</tr>
<tr>
<td>SYSTEM I/F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot case</td>
<td>87.6 K</td>
<td>87.9 K</td>
<td>88.1 K</td>
<td>86.0 K</td>
<td>0.44 K</td>
</tr>
<tr>
<td>Cold case</td>
<td>71.7 K</td>
<td>71.8 K</td>
<td>71.9 K</td>
<td>70.8 K</td>
<td>0.14 K</td>
</tr>
<tr>
<td>Min cold case</td>
<td>67.2 K</td>
<td>67.3 K</td>
<td>67.3 K</td>
<td>66.5 K</td>
<td>0.12 K</td>
</tr>
</tbody>
</table>

The telescope temperature depends critically on the temperatures and emissivities of the thermal interfaces; the sunshade/shield and CVV topside

=> Accurate knowledge before in-orbit operation questionable!
• Herschel is happening now!
• ‘Key Progs’ AO foreseen early 2006!
• We are making it happen!