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From Discovery to Innovation...

Synergy of ALMA with Herschel

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1738-1822

- 2006 ESA-ESO Report on ALMA-Herschel synergy available at:

  http:www.stecf.org/coordination/esa_eso/alma-herschel.php

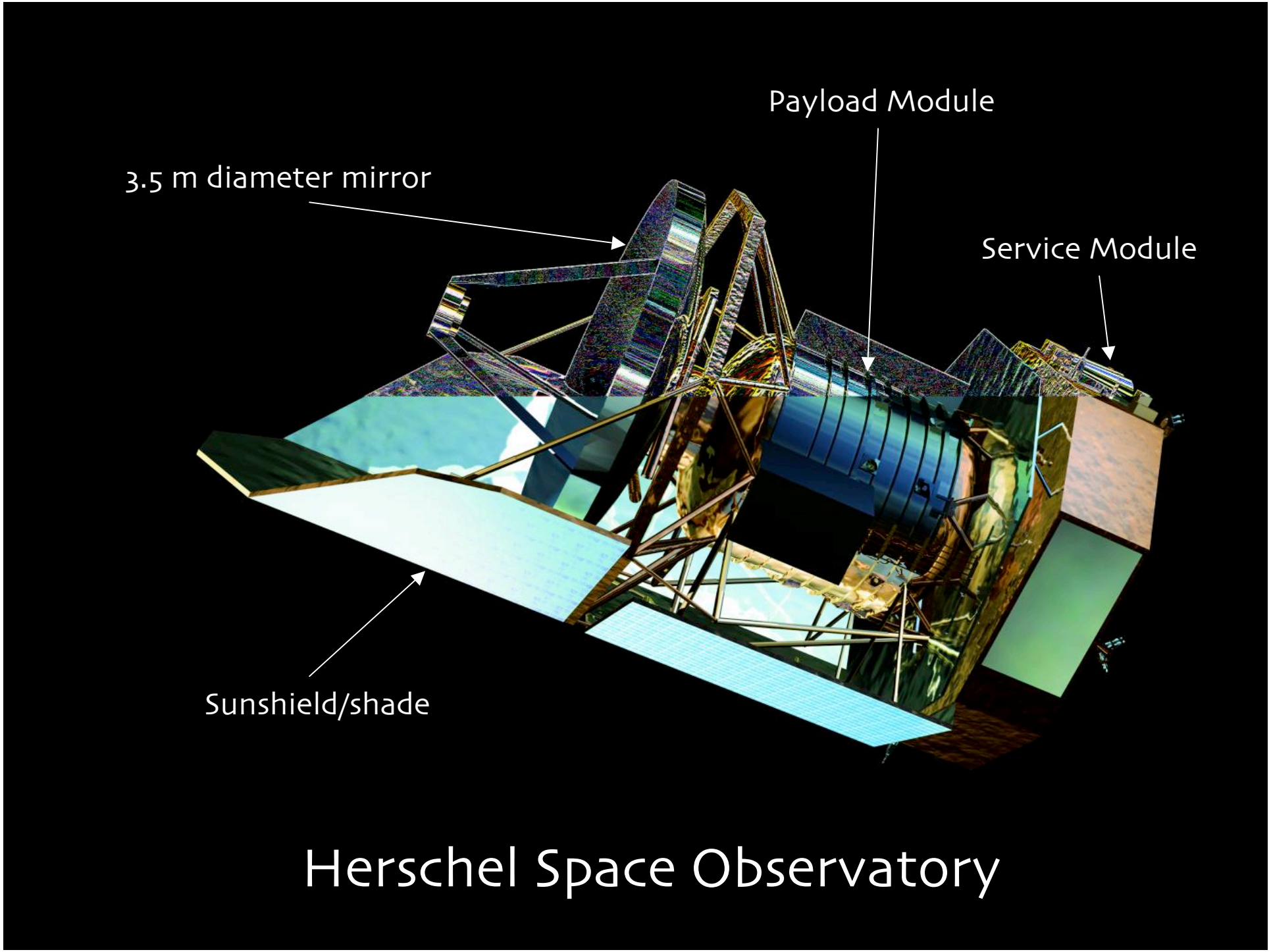
- This talk is **not** a rehash of that report

Synergy Punch Line

- Herschel Launch: **2008** (August)
- Herschel start of Operations: **2009** (January)
- Herschel cessation of Operations: **2011**?

- ALMA Early Science (16): **2010** (Q3)
- ALMA Full Operations (50): **2012** (Q4)

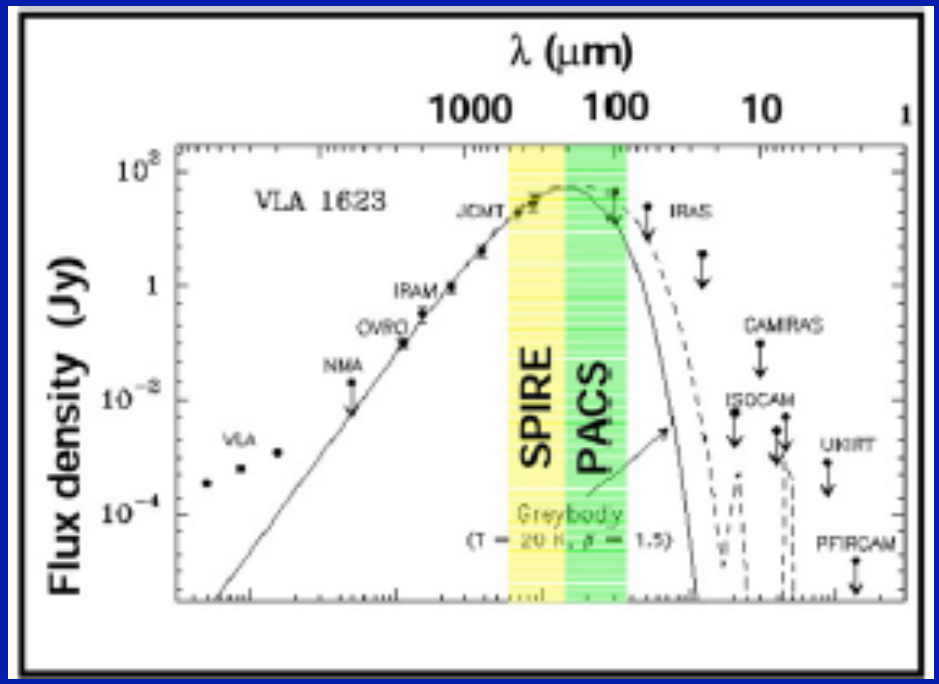
- Imaging with Herschel will provide the higher frequency "pathfinder" observations for ALMA

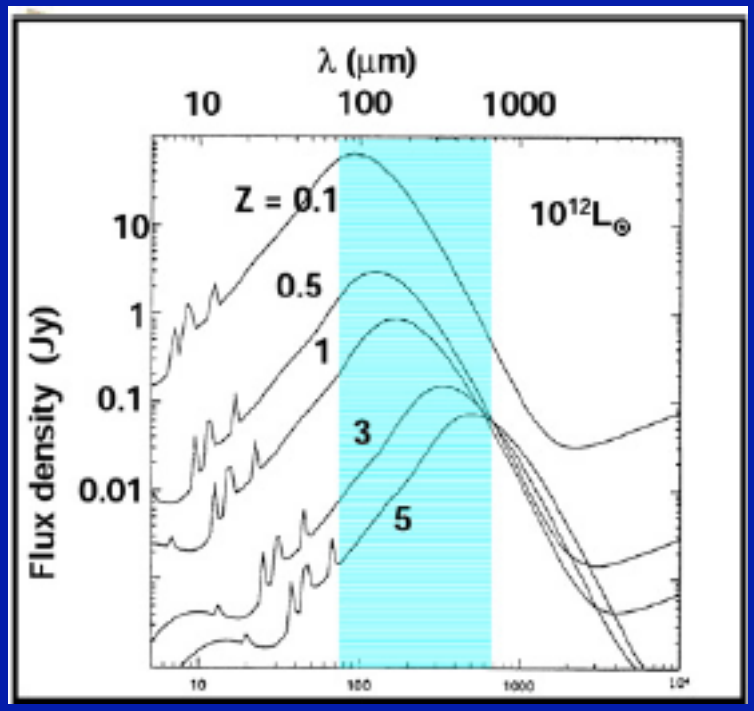


Herschel Space Observatory

Herschel Primary Science Goals

- The cool universe: formation of galaxies and stars, ISM physics/chemistry, solar system objects





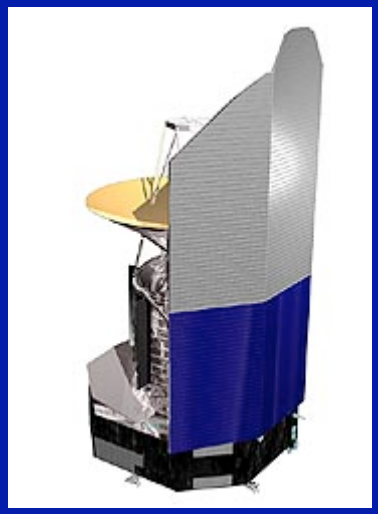
- Herschel's large aperture, low background and no atmospheric attenuation = high sensitivity

Herschel Factoids

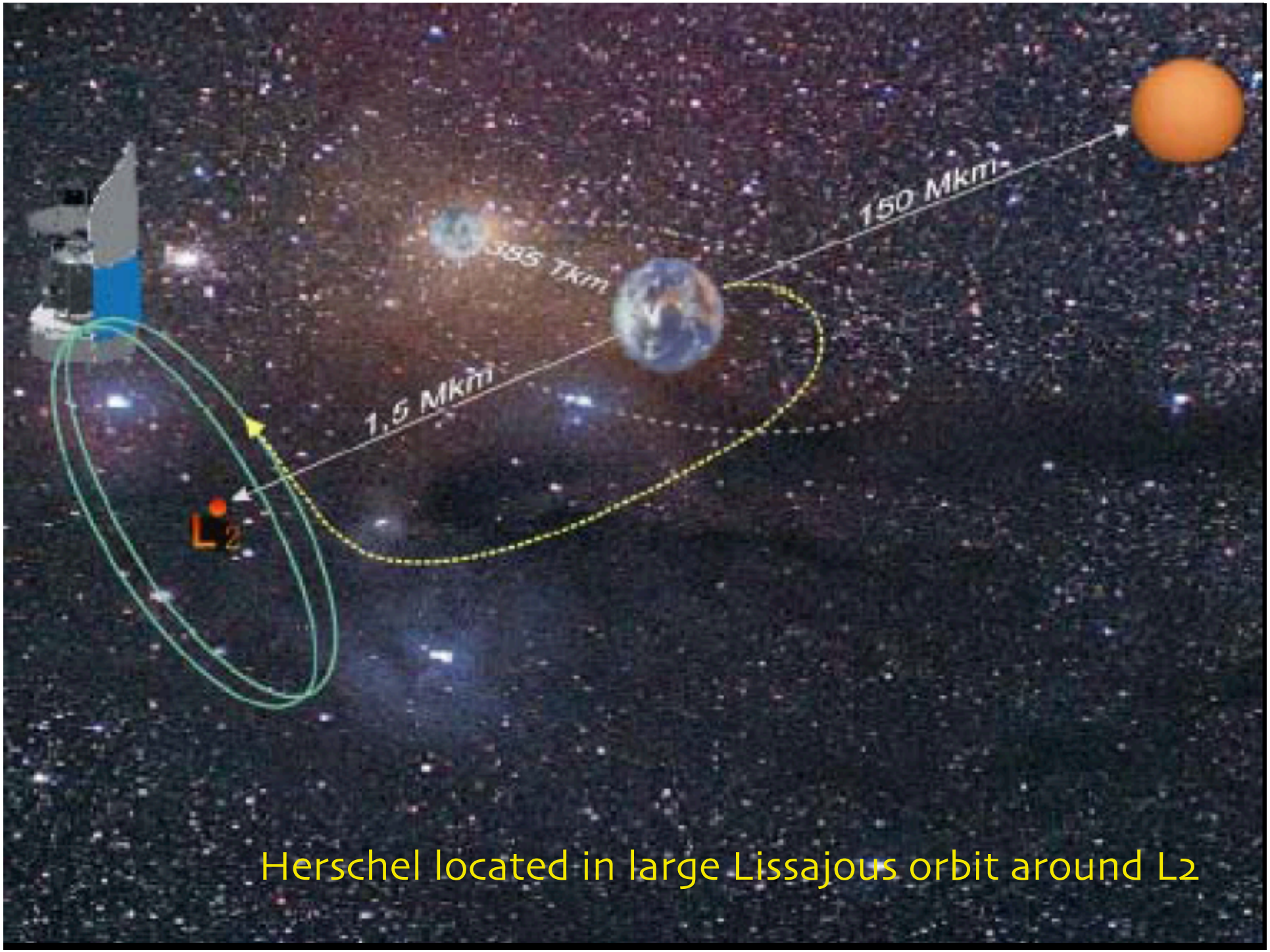
- primary diameter = 3.5 m (large!)
- primary material = SiC with a thin reflective Al layer + plasil layer
- primary WFE* < 6%
- telescope temperature < 90 K
- telescope emissivity < 4%
- abs/rel pointing (68%) < 3.7" / 0.3"
- science instruments = 3
- cryostat lifetime > 3.5 years
- height / width ~ 7.5 m / 4 m
- launch mass = 3200 kg
- power ~ 1500 W

* wave front error

cold side



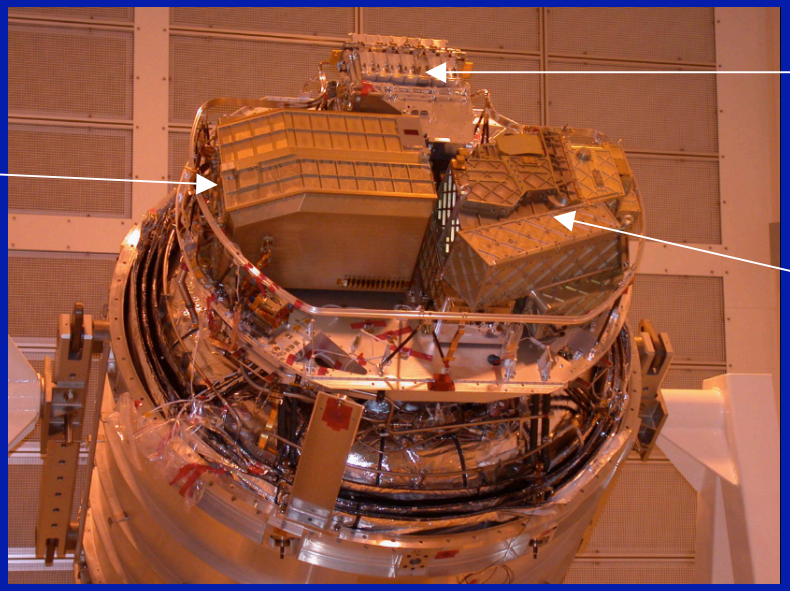
hot side



Herschel located in large Lissajous orbit around L2

The 3 Herschel Instruments

- **PACS** (*Photodetector Array Camera and Spectrometer*)
- **SPIRE** (*Spectral and Photometric Imaging REceiver*)
- **HIFI** (*Heterodyne Instrument for the Far-Infrared*)



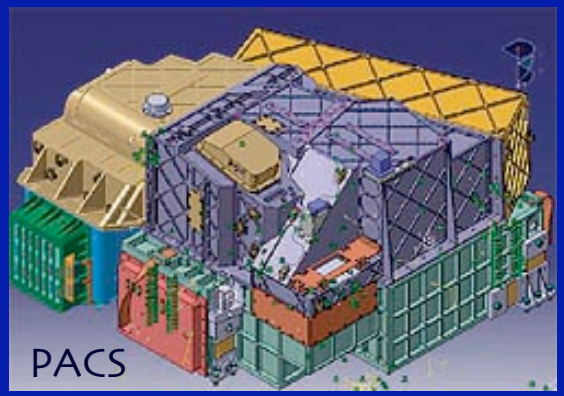
(EQMs)

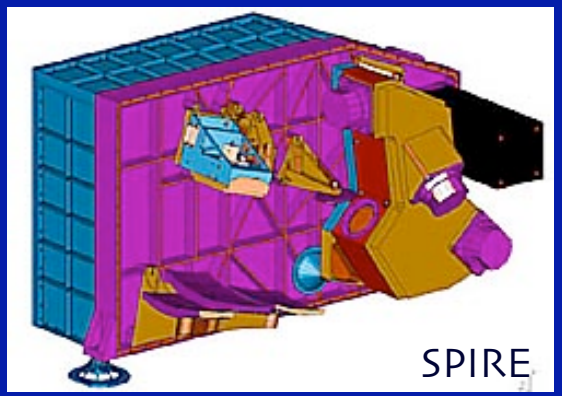
Herschel Instruments

- Photometry/Imaging: 6 bands at 75-520 μm

  - **PACS**: 1.7′ x 3.5′ FOV at 75/110 μm and 170 μm
  - **SPIRE**: 4′ x 8′ FOV at 250, 363 and 517 μm

  - sensitivity: ~ 1 mJy - 1 σ - 1 hour (confusion!)
  - no chopping! (no spatial filtering of emission)
  - angular resolution: **~15″ x (λ/250 μm)**

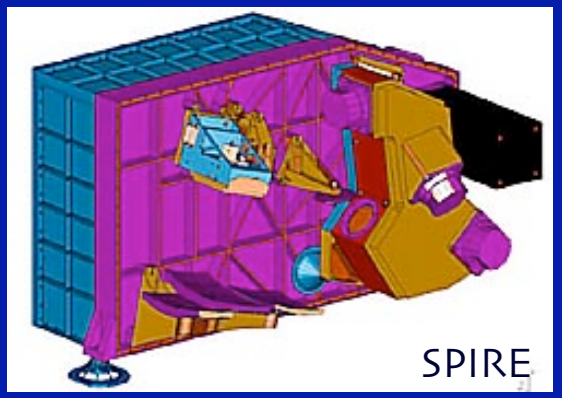


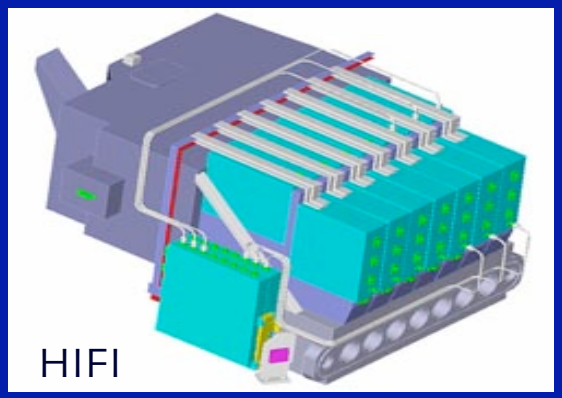


Herschel Instruments

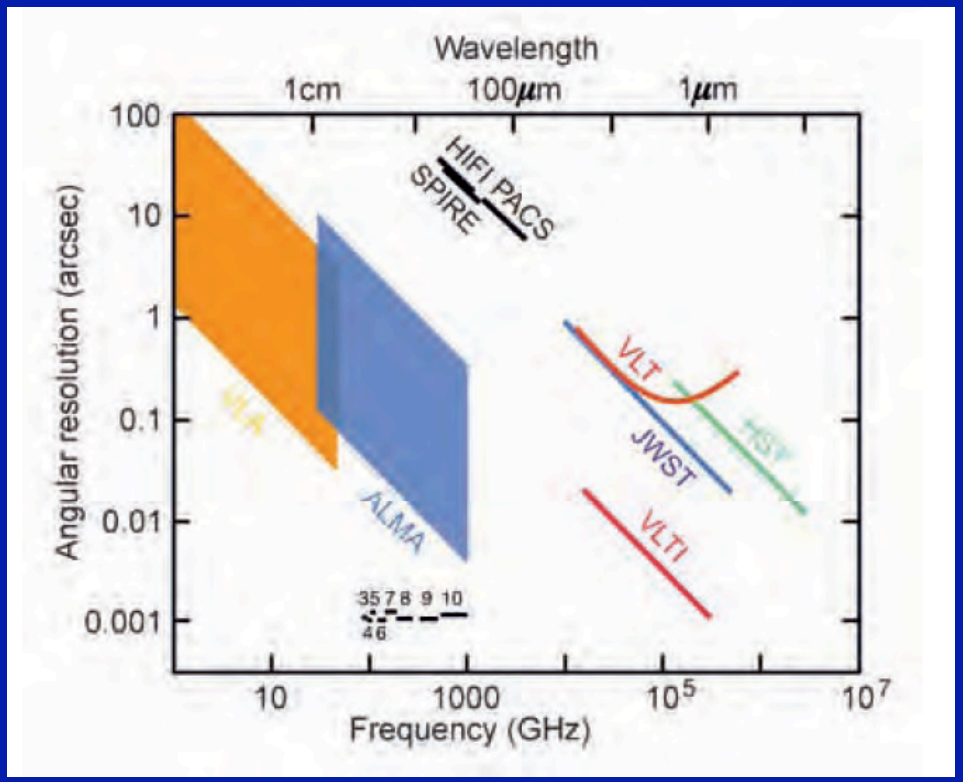
- Spectroscopy: 57 - 670 μm range, R = 20 - 10^7

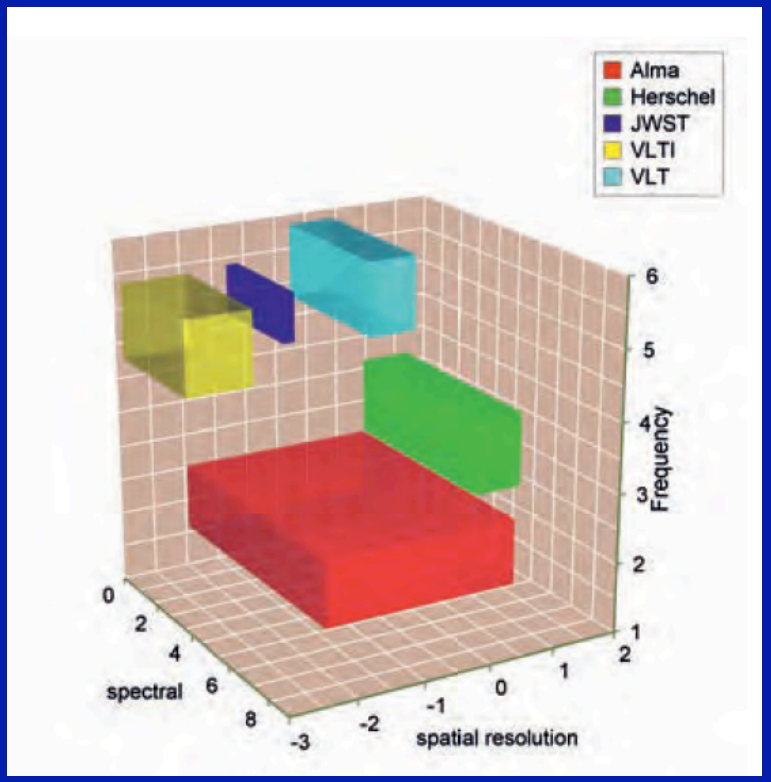
  - **PACS**: (*grating*) 0.8′ FOV at 57 - 210 μm,
    R = 1500 - 4000, 5 x 5 spatial x 16 spectral pixels
  - **SPIRE**: (*FTS*) 2.6′ FOV at 200 - 670 μm,
    R = 20 - 100
  - **HIFI**: (*heterodyne*) 1-pixel FOV at 157 - 212 μm and
    240 - 625 μm (no gaps), 4000 channels, R = 10^7





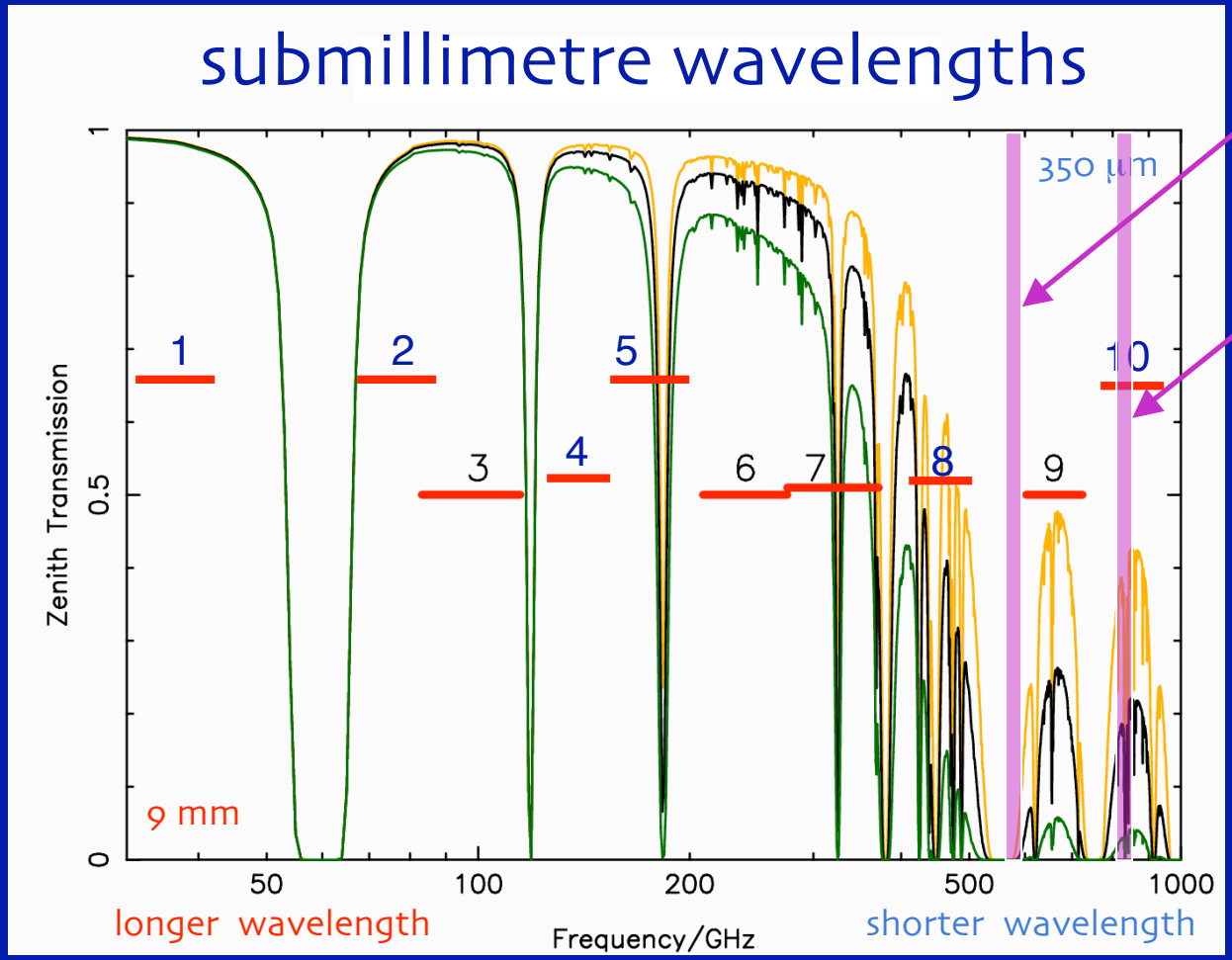
ALMA/Herschel "Discovery Space" Plots





Herschel has wide FOV (mapping),
ALMA has high spatial resolution (details)

Comparison of ALMA/Herschel Bands



SPIRE 520 μm

SPIRE 360 μm

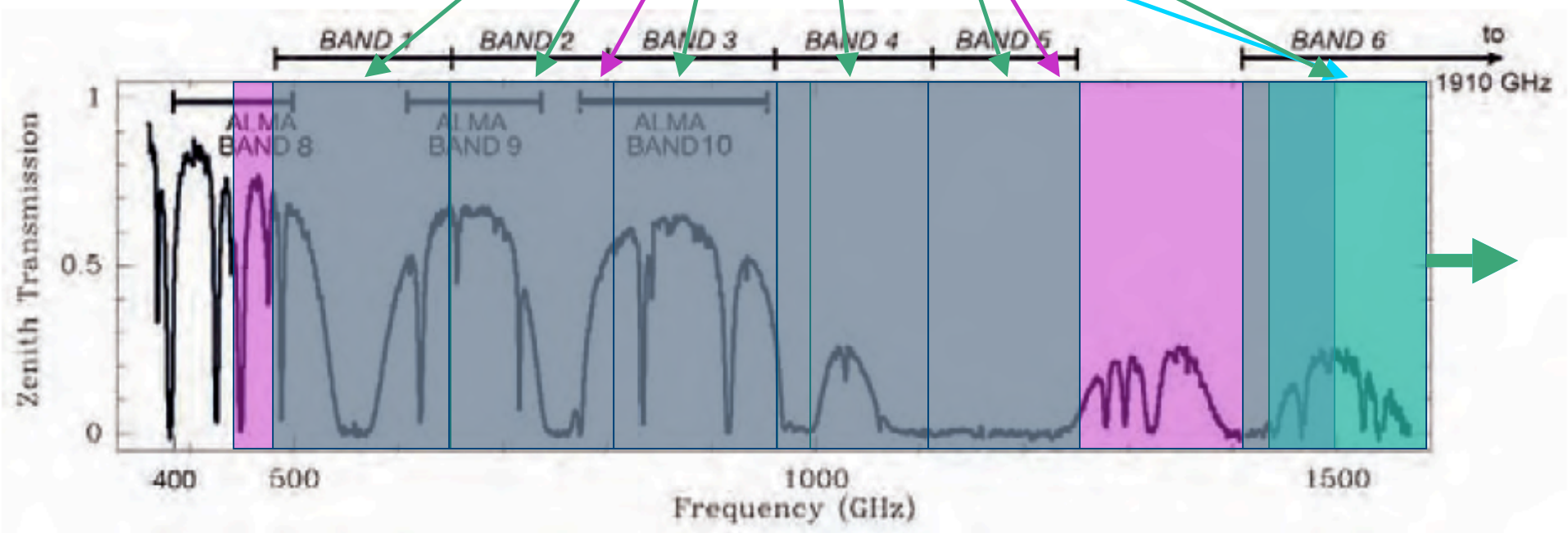
(other 1 SPIRE and 3 PACS bands unseen from ground)

Only direct photometric overlap in Band 10!

Comparison of ALMA/Herschel Bands

PACS spectroscopic bands: 57 – 210 μm

HIFI spectroscopic bands: 157 – 625 μm



Partial overlap with ALMA bands 8, 9 & 10

No coverage of ALMA bands 1 – 7

Lines of Interest in Overlap Bands

neat-o lines!

Table 7: Frequencies, Assignments & Estimated Atmospheric Transmission where ALMA and Herschel HIFI Receiver Bands Overlap

Molecule or Atom	Transition	Energy of Lower Level (K)	Frequency (GHz)	Transmission (percent)
ALMA Band 8:				
CS	J = 10-9	106	489.8	37.1
CI	$^3P_1$-$^3P_0$	0	492.2	51.8
NH_2D	$J_{KaKc} = 4_{13}$-4_{14}	152	494.4	54.3
HDO	$J_{KaKc} = 1_{10}$-1_{01}	22	509.3	38.9
ALMA Band 9:				
HDO	$J_{KaKc} = 2_{11}$-2_{02}	66	599.9	21.7
D_2O	$J_{KaKc} = 3_{03}$-1_{11}	26	607.4	30.2
HCO^+	J = 7-6	90	624.4	21.3
SiH	$J_F = (3/2)_1$-$(1/2)_1$	0	624.9,627.7	24.9,36.5
$H^{37}Cl$	J = 1-0	0	625.0,625.9	25.5,30.6
DF	J = 1-0	0	651.1	51.1
^{13}CO	J = 6-5	79	661.0	53.9
D_2H^+			690	49.9
CO	J = 6-5	83	691.5	48.1
ALMA Band 10:				
CO	J = 7-6	116	806.6	39.2
CI	$^3P_2$-$^3P_1$	24	809.3	40.6
H_2CO	$J_{KaKc} = 12_{0,11}$-$11_{0,11}$	228	855.2	48.9
^{13}CO	J = 8-7	148	898.0	40.6
HDO	$J_{KaKc} = 1_{11}$-0_{00}	0	893.6	40.1
LiH	J = 2-1	21	887.3	34.0
H_2CO	$J_{KaKc} = 12_{1,11}$-$11_{1,10}$	249	896.7	40.5
D_2O	$J_{KaKc} = 2_{12}$-1_{01}	17	897.9	40.6

Herschel is a Pathfinder for ALMA

- SPIRE and PACS offer **wide-field photometric mapping**:
  - will provide large, confusion-limited maps in which many objects will be detected at "low" spatial resolution
- SPIRE and PACS offer **moderate-FOV spectral mapping**:
  - will provide images of lines at low- to moderate spectral resolution
- HIFI offers **single-pixel observations**:
  - will provide ground-breaking work of new spectral territory at high spectral resolution

- Herschel data will provide source lists for high spatial resolution follow-up with ALMA

Herschel Timeline: Telescope

- **2008 August** - LAUNCH
- travel to L2, cooldown
- commissioning & performance verification
- science demonstration + workshop

} 6 mos.

- routine science operations (36 months+):
  - ~1000 days of available time (**2009-2011**)
  - ~1/3 share is Guaranteed Time (GT) to instrument teams
  - ~2/3 share is Open Time (OT) to world community
- three "Calls for Proposals" (Cycles) foreseen:
  - one for Key Projects (>100 hrs), GT & OT
  - two for regular programs, GT & OT
  - in every cycle, GT obs'ns made before OT obs'ns

Herschel Timeline: Data

- AO issued *as late as possible*, to maximize timeliness of scientific programmes and knowledge of instruments

- **2007 Feb 1**: AO for KP proposals issued
- **2007 Apr 5**: deadline for GT KP proposals

present

- **2007 Jul 5**: selection/announcement of GT KP projects
- **2007 Oct 25**: deadline for OT KP proposals
- **2008 Feb 28**: selection/announcement of OT KP projects
- **2008 Feb 28**: AO for regular GT proposals
- **2008 Apr 3**: deadline for GT1 proposals
- **2008 Jun 5**: selection/announcement for GT1 projects
- **2008 August**: LAUNCH

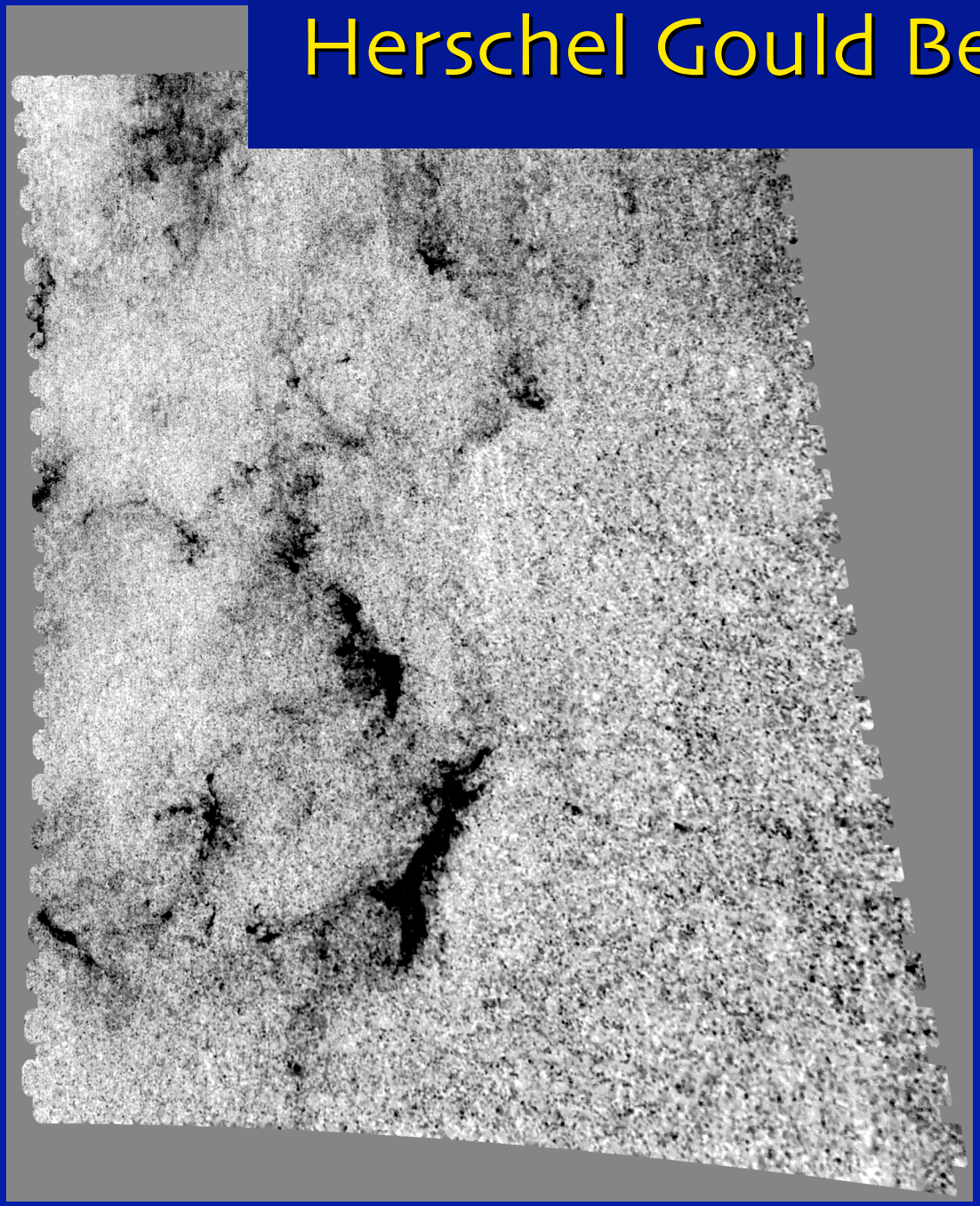
Relevant Herschel GT Key Projects

- SPIRE/PACS *"Herschel Gould Belt Survey" :*
  (PI's: P. Andre & P. Saraceno)

- SPIRE/PACS/HIFI *"Stellar Disk Evolution"*
  (PI: G. Olafsson)

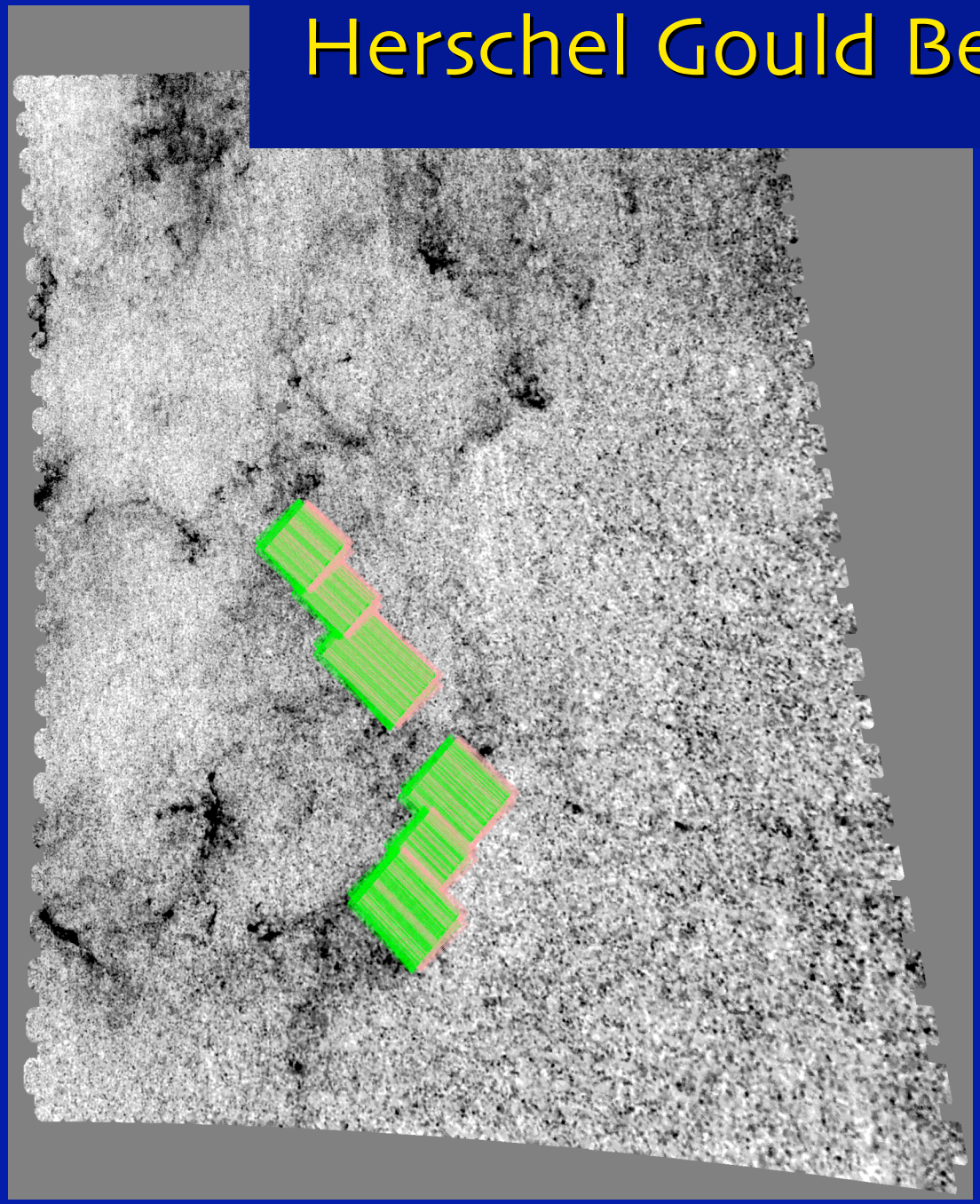
- HIFI *"Water In Star-forming environments with Herschel (WISH)"*
  (PI: E. van Dishoeck)

Herschel Gould Belt Survey



extinction map
of Orion A & B

Herschel Gould Belt Survey



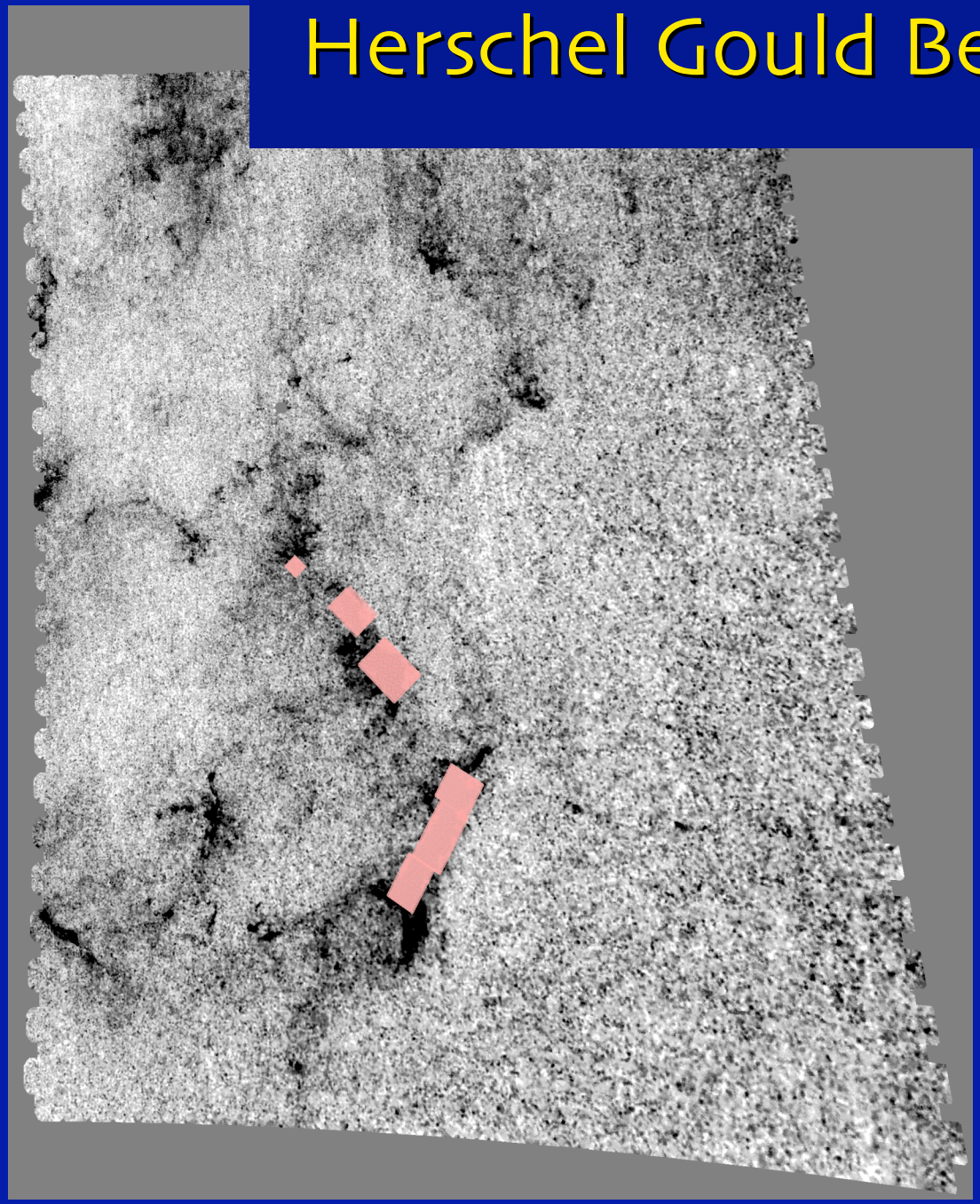
extinction map
of Orion A & B

PACS (70/170 μm)
and SPIRE
parallel mode
AORs

37 hours total

good match to
Spitzer coverage

Herschel Gould Belt Survey



extinction map
of Orion A & B

PACS only
AORs
(110/170 μm)

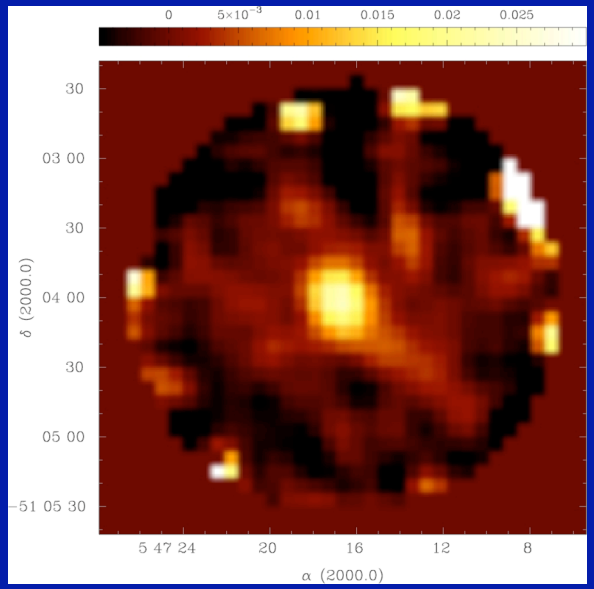
29 hours total

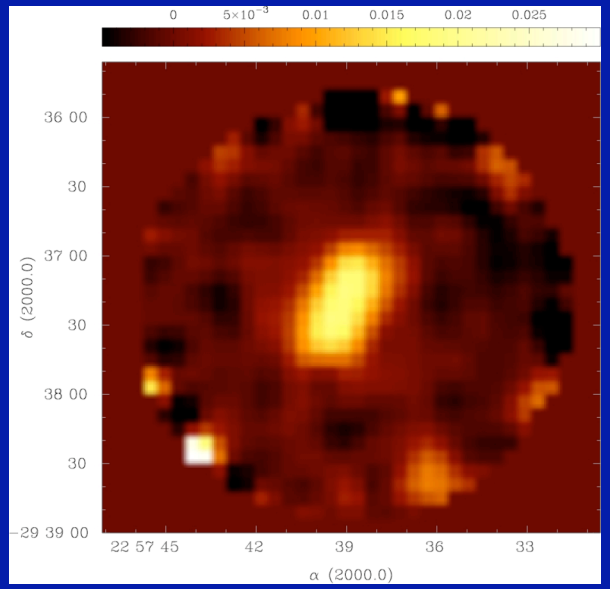
Relevant Herschel GT Key Projects

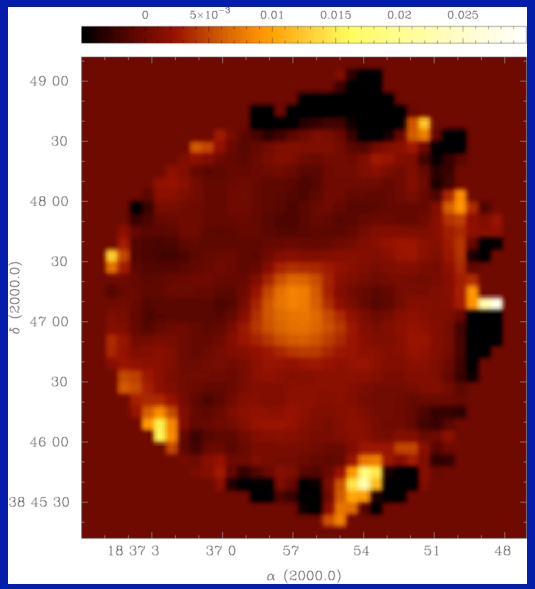
- SPIRE/PACS *"Herschel Gould Belt Survey" :*
  - map 16 molecular clouds < 500 pc with SPIRE + PACS in parallel mode, for 145 deg^2 in 272 hrs
  - follow-up high A_v regions (55 deg^2) with PACS, in 195 hrs
  - total = 467 hrs (depends on overheads)
  - will be sensitive at 10 σ to cores > 0.2-0.3 M_{sun} at Orion, lower mass limit for closer clouds
  - identify all embedded SF locations, test mass f'n slope for differences with cloud environment

Stellar Disk Evolution

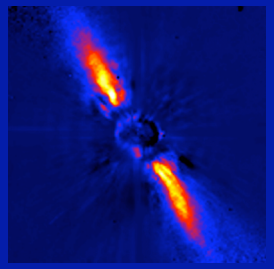
850 μm SCUBA obs of debris disks



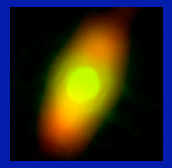




Beta Pictoris



Fomalhaut

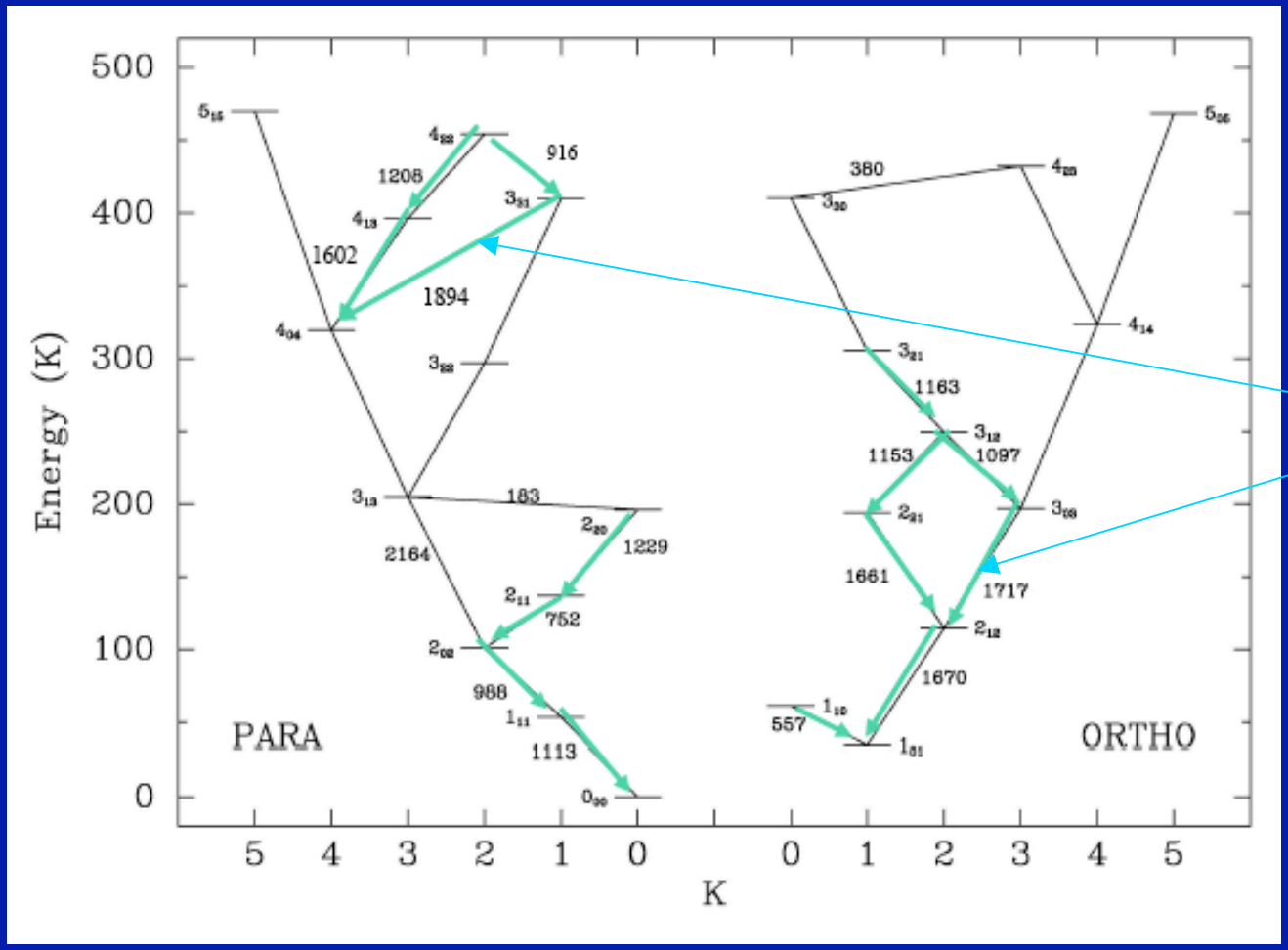


Vega

Relevant Herschel GT Key Projects

- SPIRE/PACS *"Stellar Disk Evolution" :*
  - map 6 extended debris disks with SPIRE + PACS (Vega, Fomalhaut, ε Eri, β Pic, AU Mic, τ Cet)
  - 19 hrs of 70/170 μm PACS obs'ns and 6 hrs of SPIRE obs'ns (i.e., to the confusion limit)
  - probe line emission towards these with PACS, SPIRE and HIFI, for solid state features
  - PACS: 55 - 210 μm (14 hrs); (O I and forsterite)
  - SPIRE: 200 - 670 μm (12 hrs)
  - HIFI: H_2O at 557 GHz, NH_3 at 572 GHz, C I at 492 GHz (20 hrs)

Water in Disks



H_2O lines observable with HIFI

H_2O is a major unknown factor in interstellar chemistry, Herschel will observe it well

Relevant Herschel GT Key Projects

- HIFI *"Water In Starforming environments with Herschel (WISH)"*
  - a 499 hr program of cores, protostars and disks
  - use HIFI to observe H_2O, $H_2{}^{18}O$, $H_2{}^{17}O$, O, OH lines, in disks test for vertical mixing between cold midplane, warm interiors and outer PDRs
  - H_2O is the main ice reservoir, drives chemistry

  - 92 hr disk program: 3 mK rms for 557 GHz line, and 10 mK rms for 1113 GHz line of H_2O for TW Hya, DM Tau, LkCa 15, and MWC 480

Major Opportunities for Disks!

- These are the only disk-related Guaranteed Time Key Projects that have been awarded time by the HOTAC
- There is a lot of ground left to cover in OT: low-mass disks, nearby stars, moving groups, disk evolution, etc.
- OT Key Project Deadline coming up fast!

Summary

- Herschel will probe disks over a relatively unexplored regime of the EM spectrum at high sensitivities
- data will provide important pathfinder info for ALMA
- 2/3 observing time is available to the world community, 2009-2011, so use Herschel while it is available!
- For more info see *http://www.rssd.esa.int/herschel*