SOFIA Science Synergy
- Herschel as a resource and inspiration

Göran Pilbratt, Herschel Project Scientist

SOFIA workshop, Schloß Ringberg, 15-18 March 2015

Main science areas

Formation of stars and planets

- Formation of massive stars
- Proto-planetary disks
- Astrochemistry in SF regions

ISM of the Milky Way

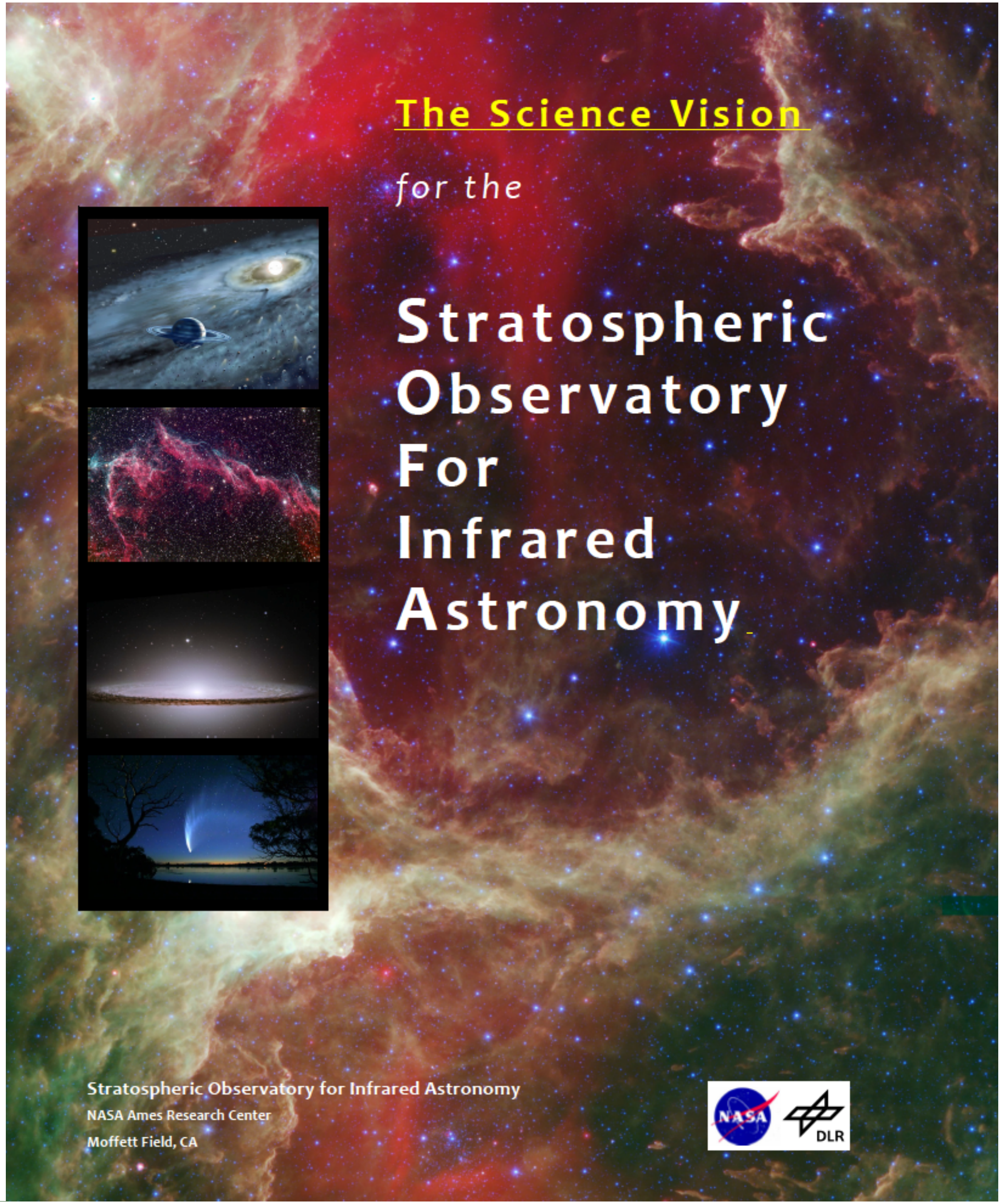
- Massive stars & PDRs
- Diversity & origin of dust – Evolved star contributions
- Role of large complex molecules – Identifications of PAHs
- Deuterium – Constraints from HD

Galaxies & Galactic Centre

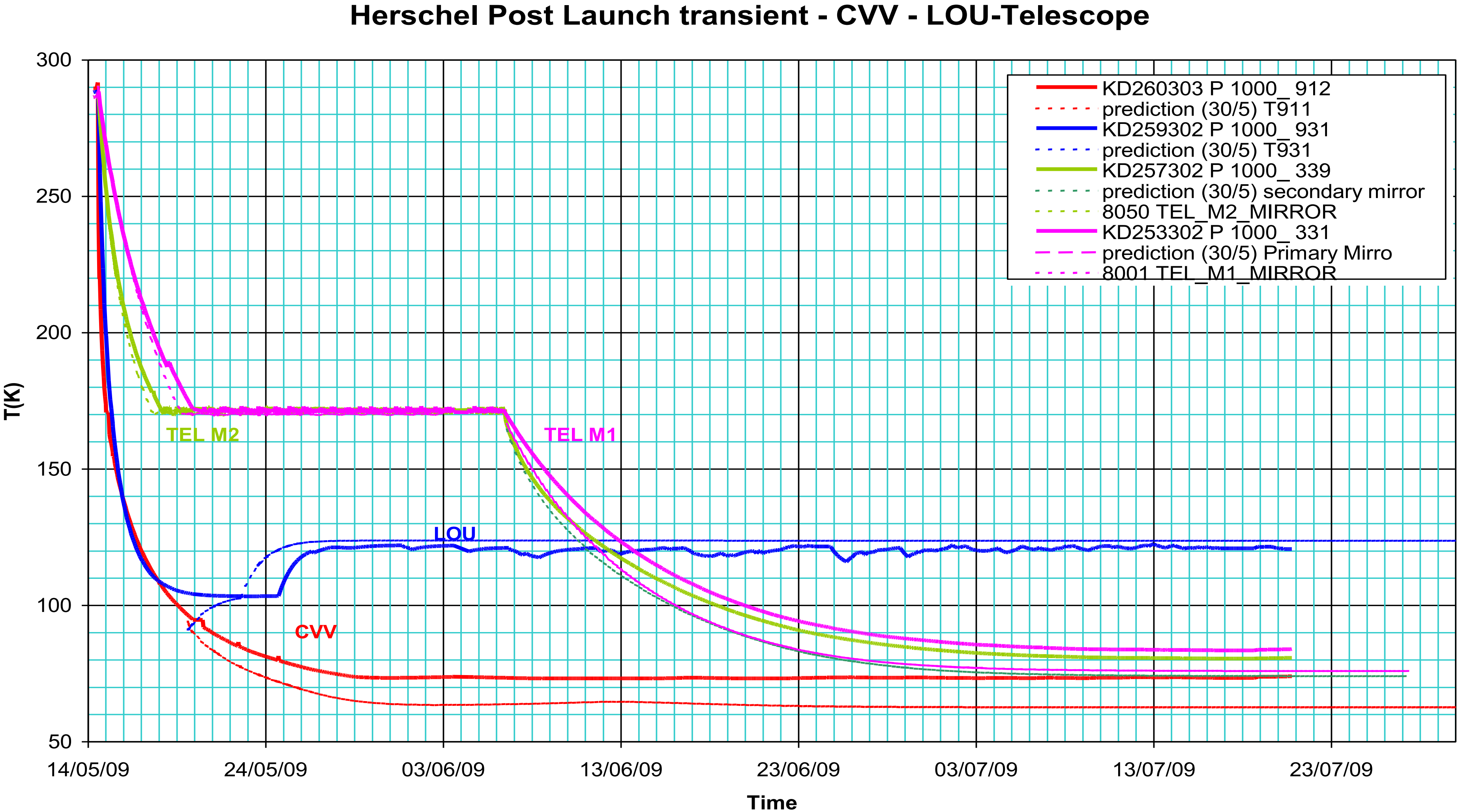
- GC – Warm clouds
- ISM & SF history of galaxies
- Tracing SF history of the universe with FIR fine-structure lines

Planetary science

- Primitive bodies
- Extrasolar planetary material
- Giant planets, Venus, Titan



Cooldown – telescope, LOU, & CVV



Flight Data from MUST server , Prediction from M.Linder (30/5/09)

HERSCHEL SPACE OBSERVATORY

Herschel – the science instruments

<u>3-band camera</u>

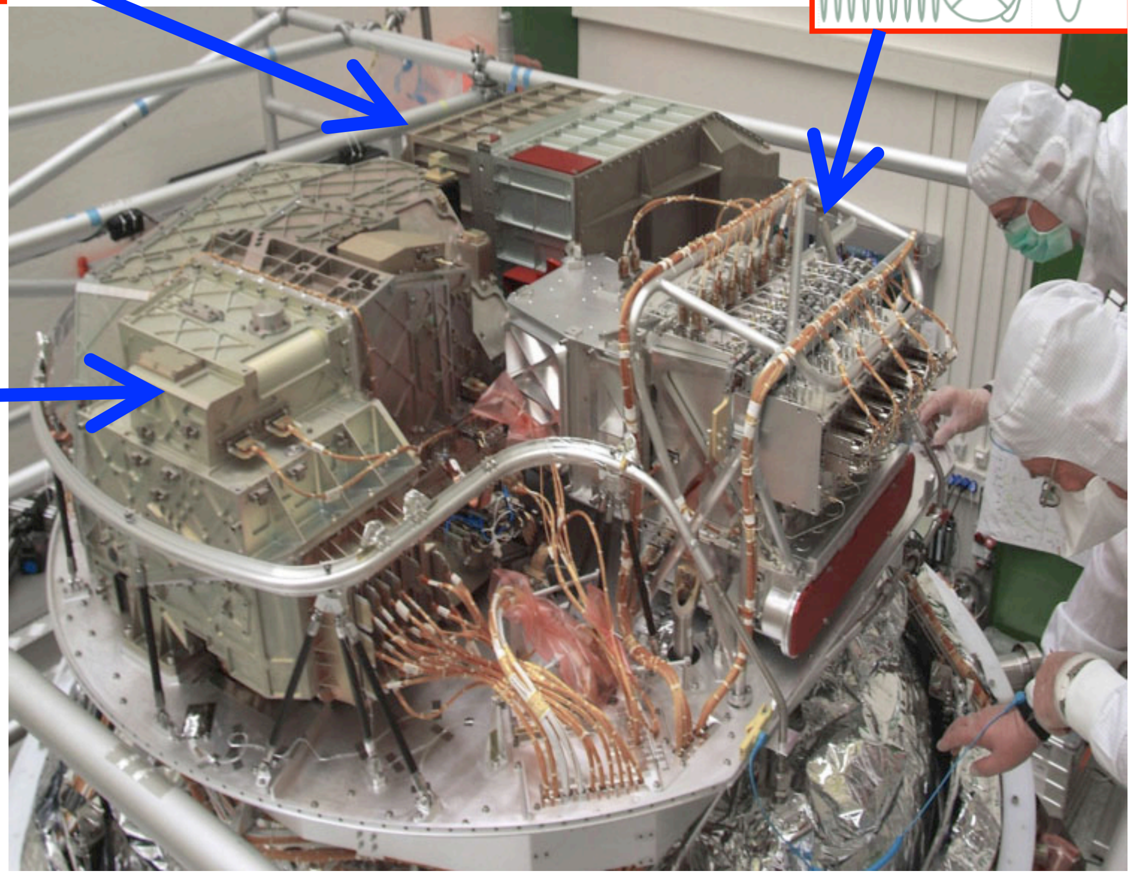
250 + 350 + 500 μm
4 x 8 arcmin FOV

<u>Imaging FT spectrometer</u>

194 - 671 μm (simultaneously)
$\lambda/\Delta\lambda$ = 1300 – 370 (high-res)
= 60 – 20 (low-res)

<u>7-channel heterodyne receiver</u>

480 - 1250 GHz (625 - 240 μm)
1410 - 1910 GHz (212 - 157 μm)
$\lambda/\Delta\lambda = 10^5$-$10^6$ w. BW = 4 GHz



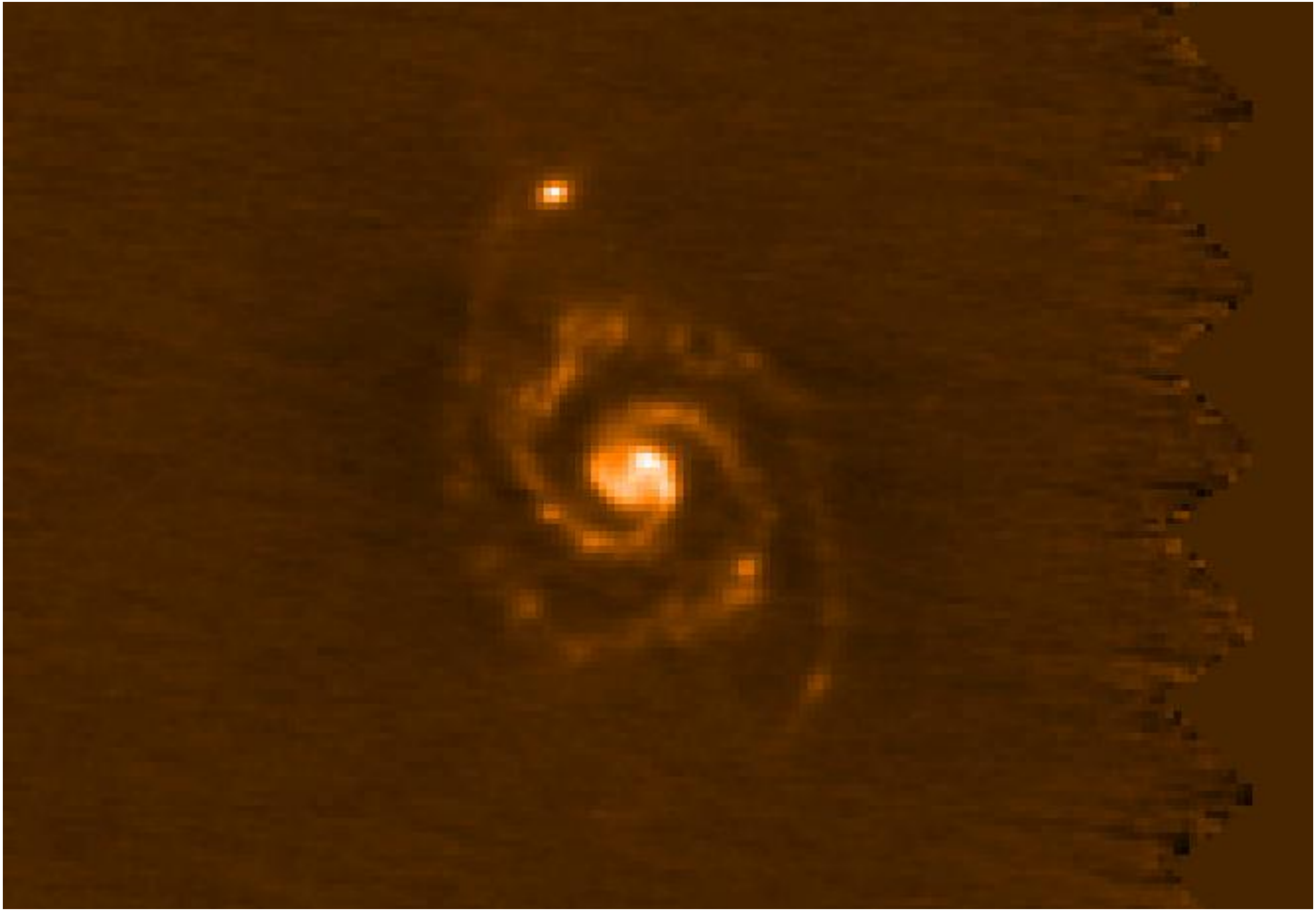
<u>3-band camera</u>

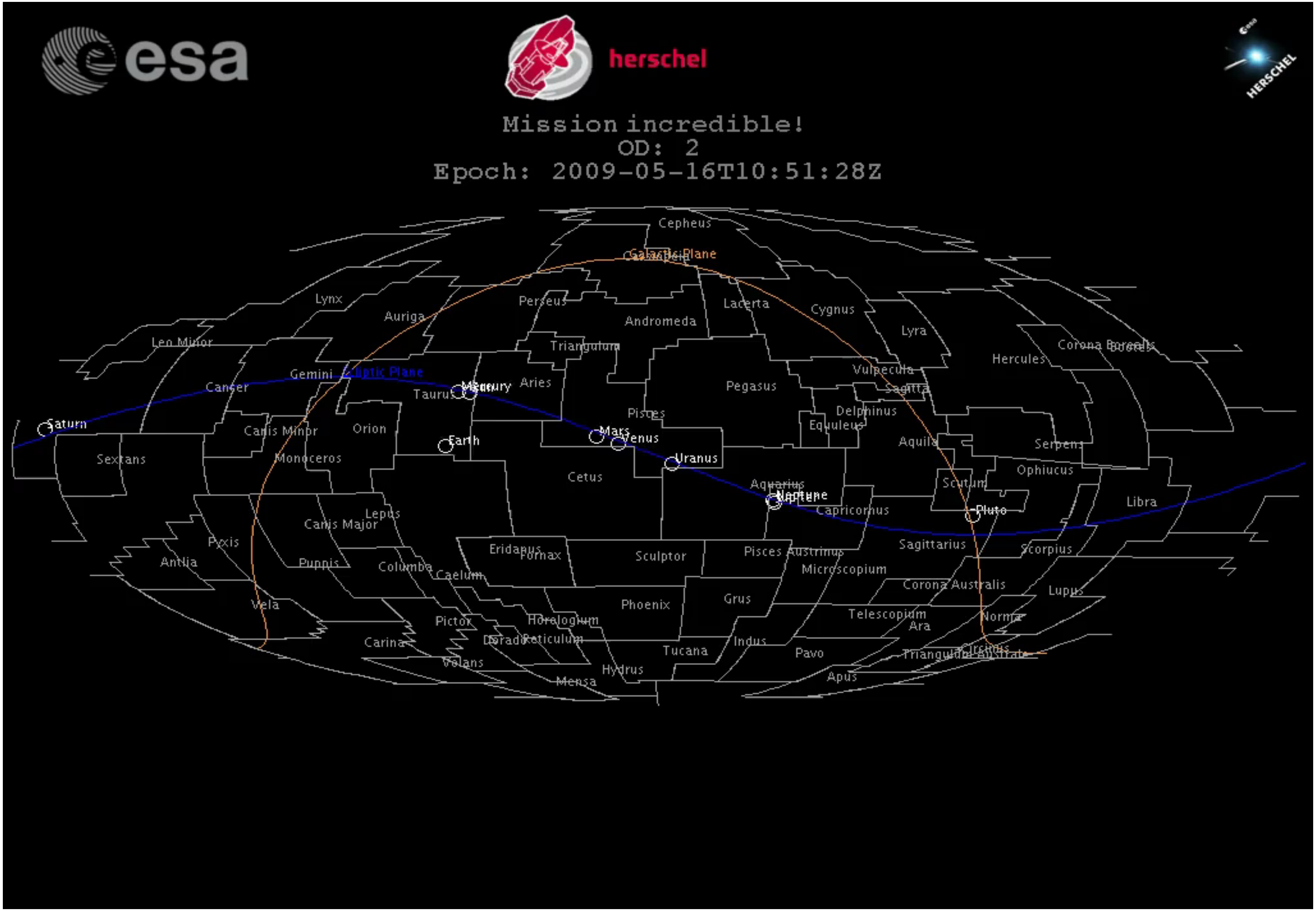
70 or 100 + 160 μm
1.75 x 3.5 arcmin FOV

<u>Imaging grating spectrometer</u>

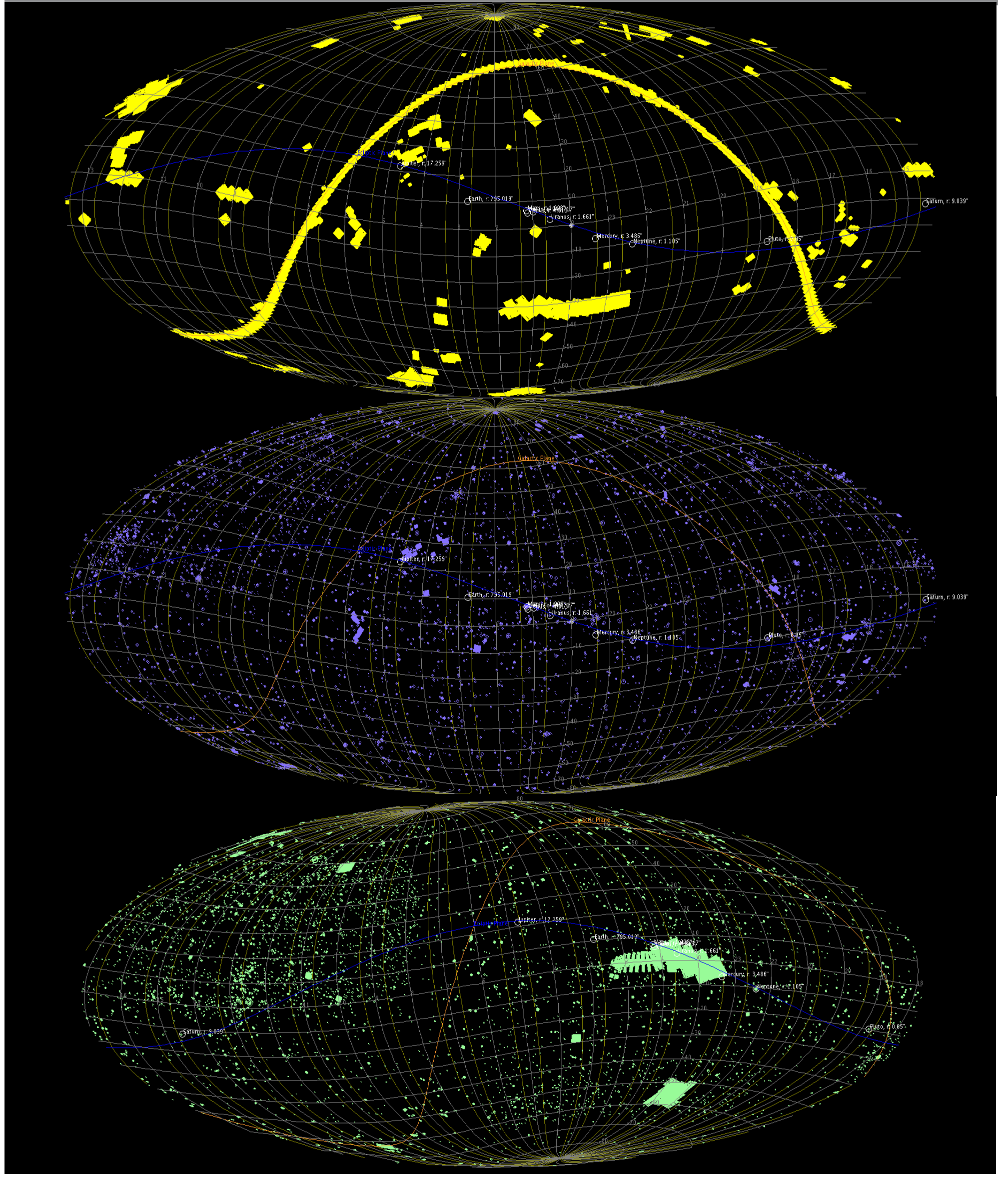
55 - 210 μm (3 orders)
$\lambda/\Delta\lambda$ = 1000 – 4000

Fairing integration on 10 May 2009




esa
herschel
HERSCHEL
Mission incredible!
OD: 2
Epoch: 2009-05-16T10:51:28Z
Cepheus
Galactic Plane
Lynx
Auriga
Perseus
Andromeda
Lacerta
Cygnus
Lyra
Leo Minor
Triangulum
Corona Borealis
Hercules
Gemini
Ecliptic Plane
Cancer
Mercury
Taurus
Aries
Pegasus
Vulpecula
Sagitta
Saturn
Canis Minor
Orion
Pisces
Delphinus
Equuleus
Earth
Mars
Venus
Aquila
Serpens
Sextans
Monoceros
Uranus
Ophiucus
Cetus
Aquarius
Scutum
Neptune
Capricornus
Pluto
Libra
Lepus
Canis Major
Pyxis
Eridanus
Fornax
Sculptor
Pisces Austrinus
Sagittarius
Scorpius
Antlia
Puppis
Columba
Caelum
Microscopium
Corona Australis
Lupus
Vela
Phoenix
Grus
Telescopium
Ara
Norma
Pictor
Horologium
Carina
Dorado
Reticulum
Indus
Pavo
Triangulum Australe
Circinus
Volans
Tucana
Hydrus
Mensa
Apus

Preliminary sky coverage



Totals (uncert +/- 5%)

S/P parallel	6.44
PACS phot	0.67
SPIRE phot	2.28
PACS spec	<0.01
SPIRE spec	<0.01
HIFI	0.06
Total Herschel	9.45

These numbers are %-ages of the entire sky (~41,000 sq deg)

Herschel has observed almost 1/10 of the entire sky!

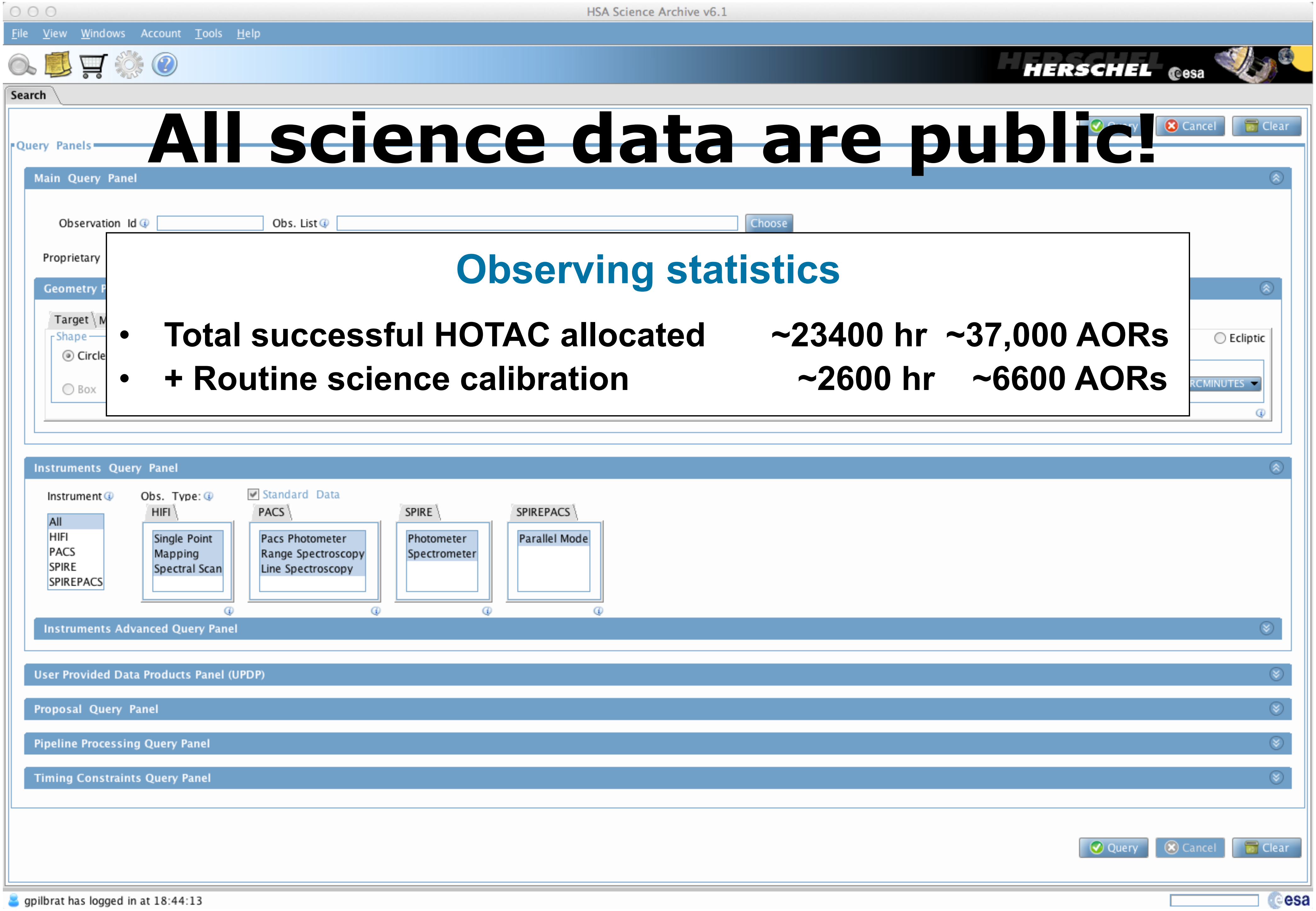
By performing ~23,400 hr of HOTAC approved observing!

HERSCHEL SPACE OBSERVATORY

All science data are public!

Observing statistics

- Total successful HOTAC allocated ~23400 hr ~37,000 AORs
- + Routine science calibration ~2600 hr ~6600 AORs



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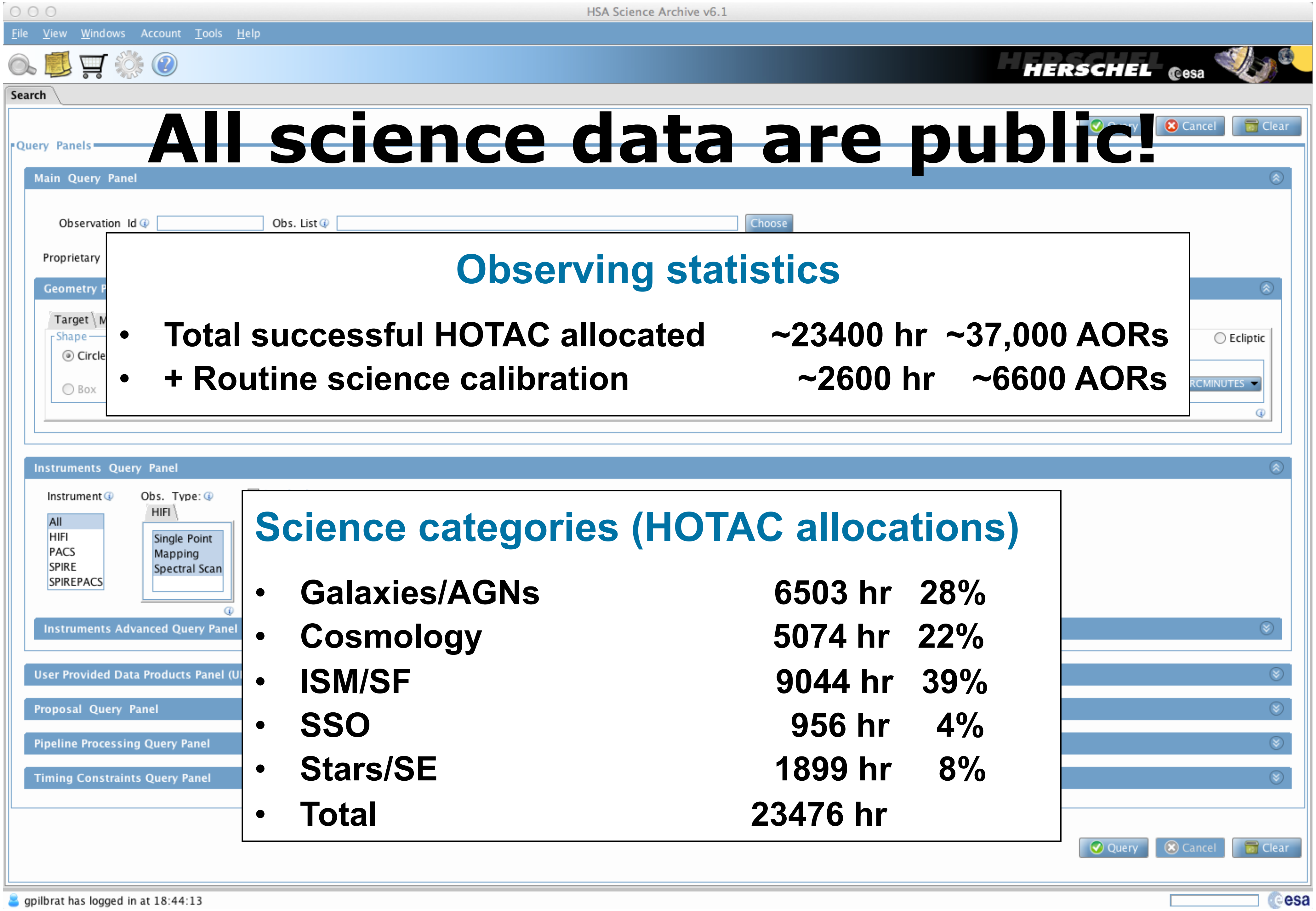
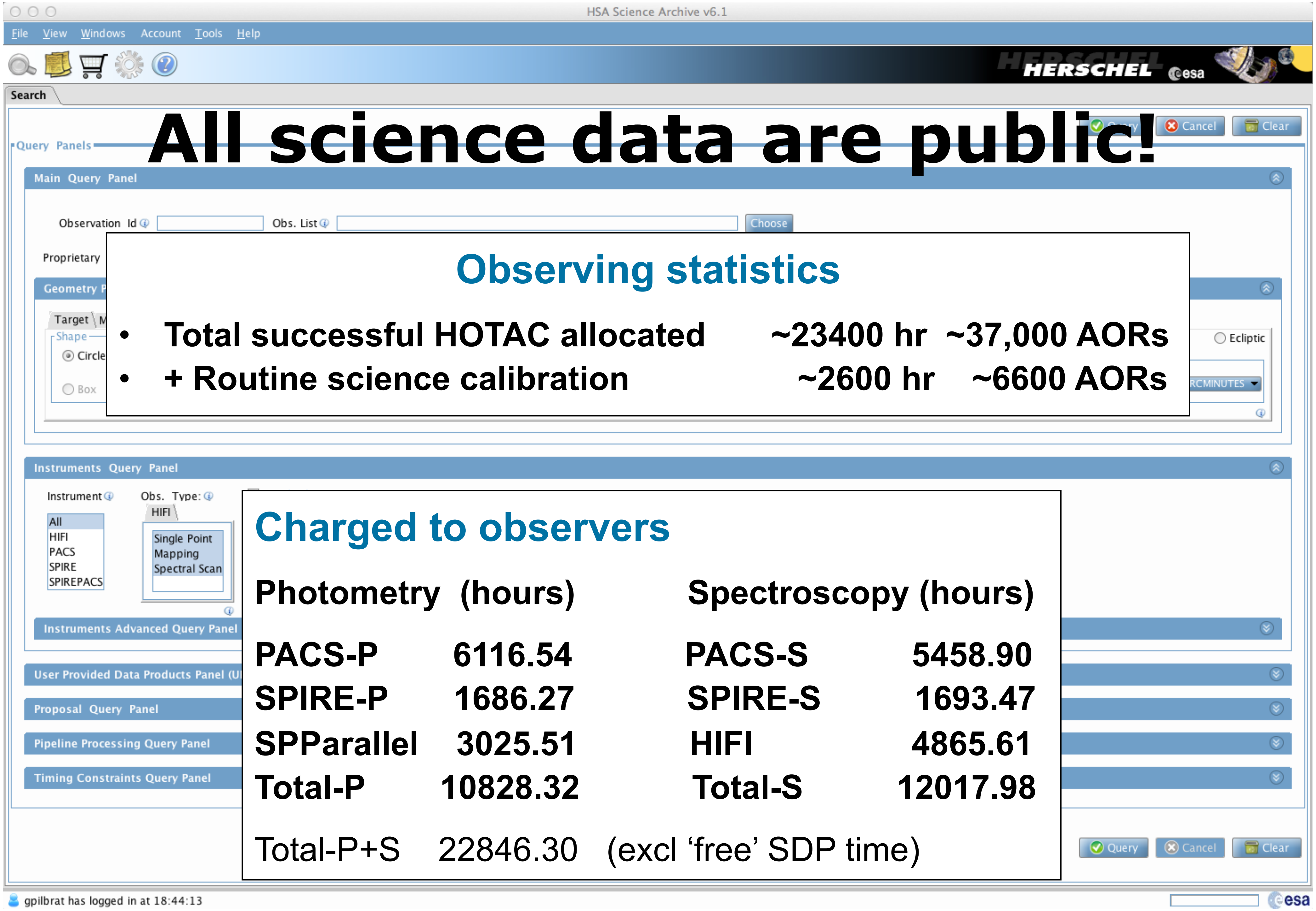
Science categories (HOTAC allocations)

• Galaxies/AGNs	6503 hr	28%
• Cosmology	5074 hr	22%
• ISM/SF	9044 hr	39%
• SSO	956 hr	4%
• Stars/SE	1899 hr	8%
• Total	23476 hr	





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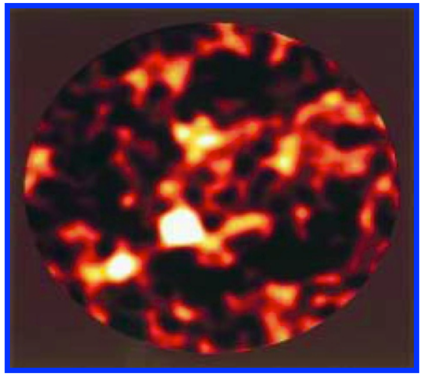
Charged to observers

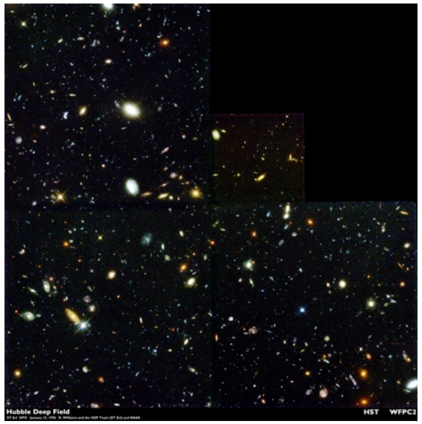
Photometry (hours)		Spectroscopy (hours)	
PACS-P	6116.54	PACS-S	5458.90
SPIRE-P	1686.27	SPIRE-S	1693.47
SPParallel	3025.51	HIFI	4865.61
Total-P	10828.32	Total-S	12017.98

Total-P+S 22846.30 (excl ‘free’ SDP time)

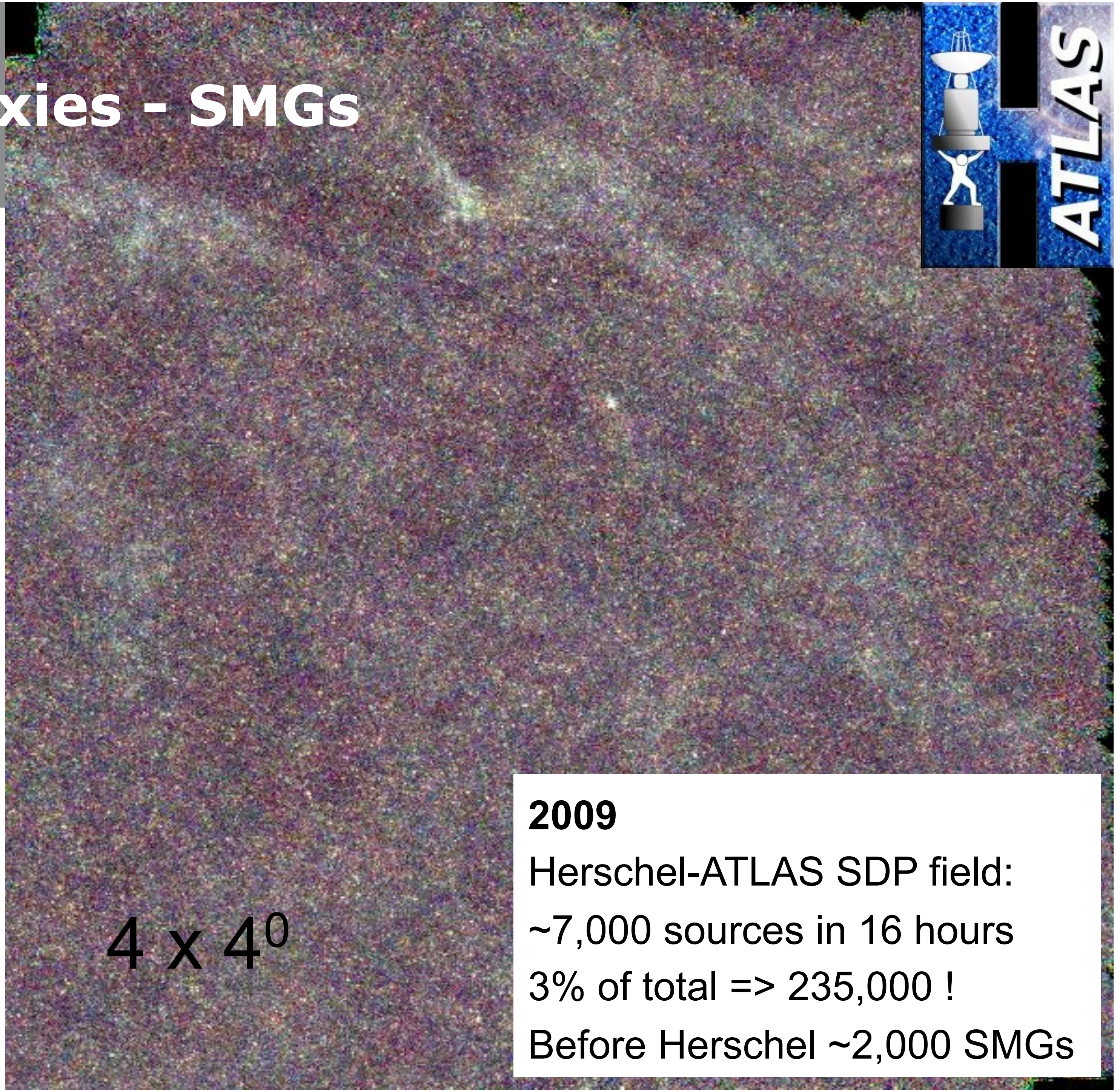
Submm Galaxies - SMGs

1998
SCUBA HDF:
5 sources after 20 exceptional nights





~3 arcmin

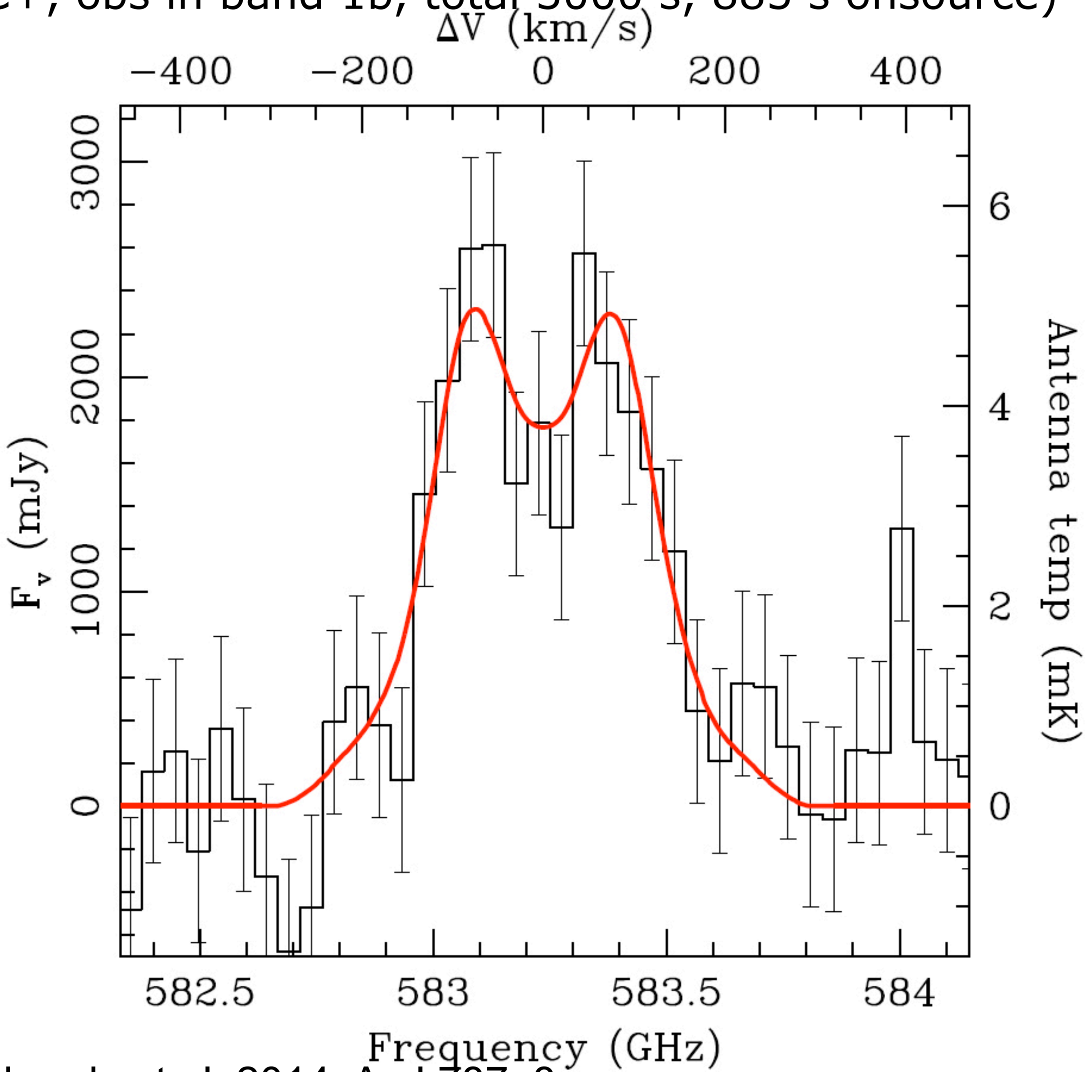


4×4^0

2009
Herschel-ATLAS SDP field:
~7,000 sources in 16 hours
3% of total => 235,000 !
Before Herschel ~2,000 SMGs

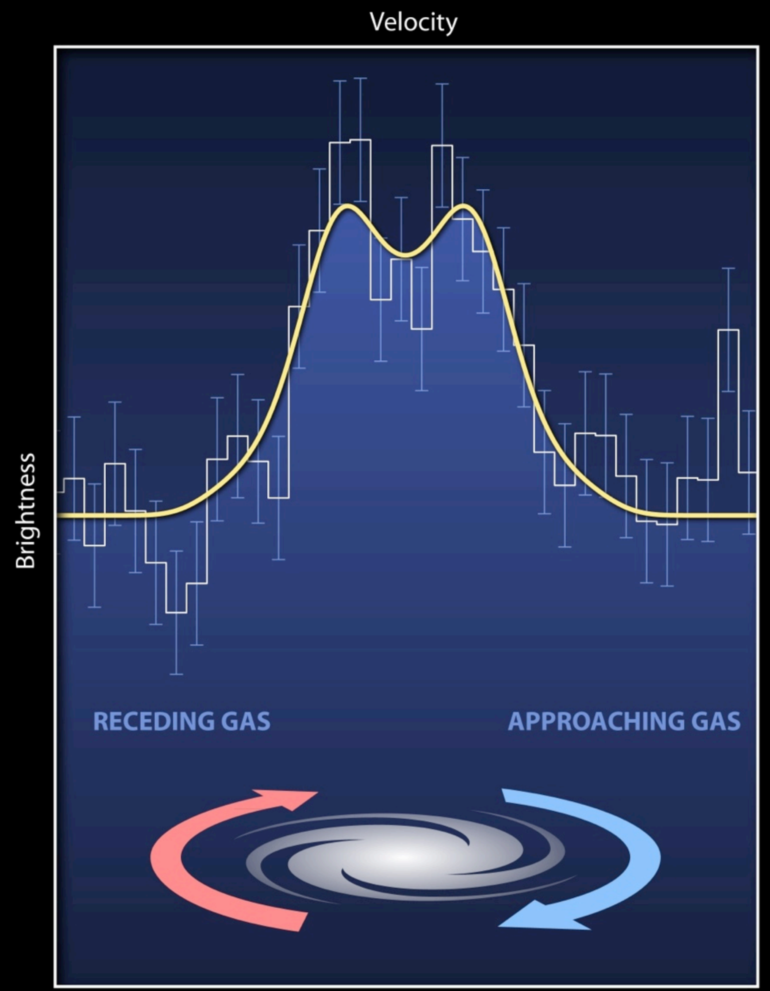
Kinematically mature z=2.26 galaxy

C+, obs in band 1b, total 3000 s, 885 s onsource)



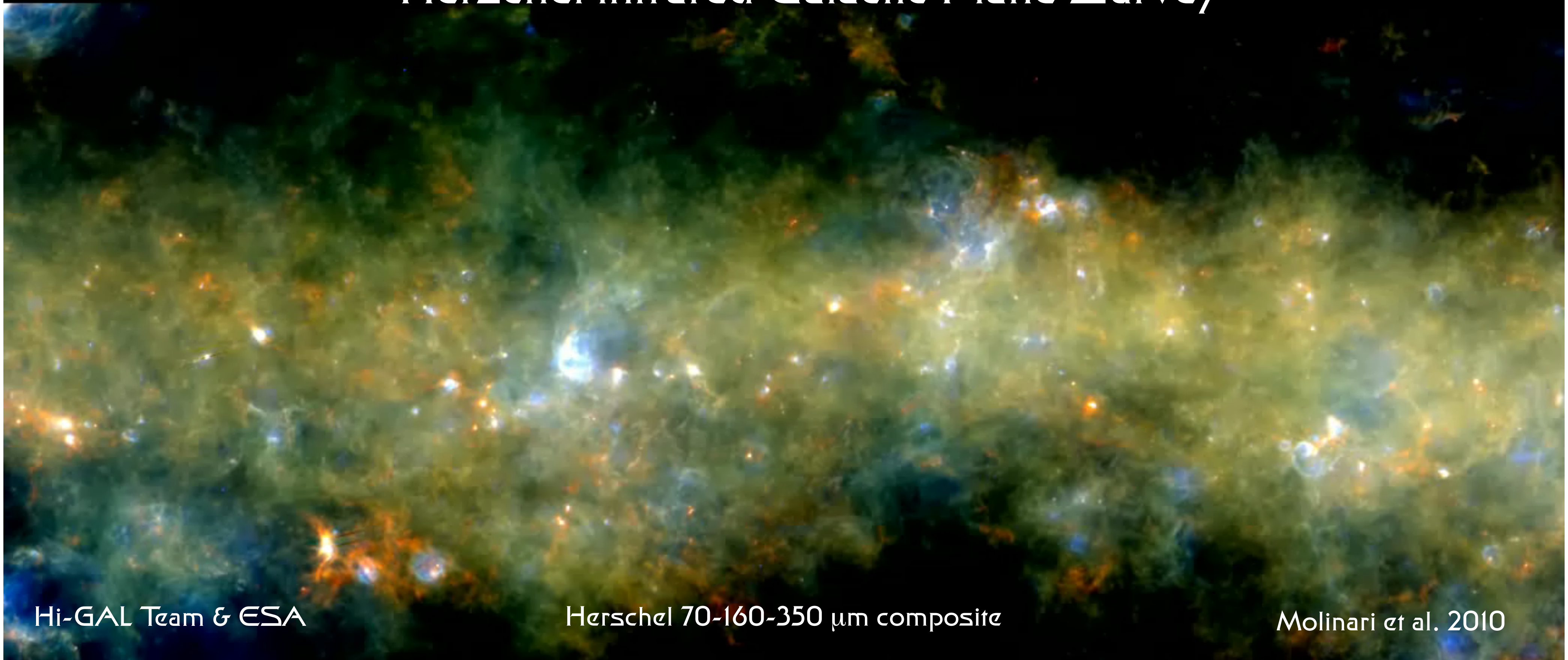
Rhoads et al. 2014, ApJ 787, 8

SDSS090122.37+181432.3 (S0901)



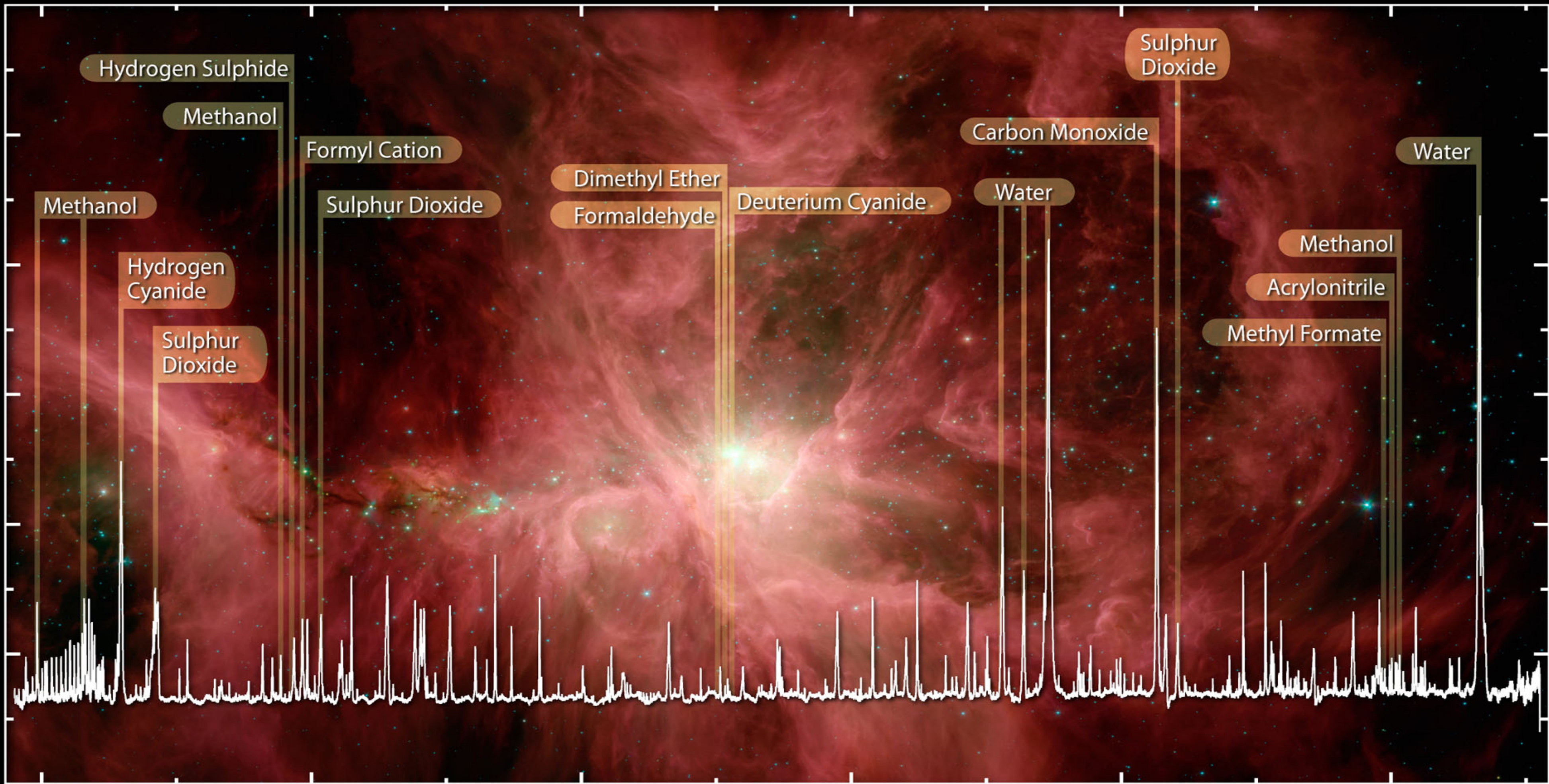
Hi-Gal

Herschel infrared Galactic Plane Survey

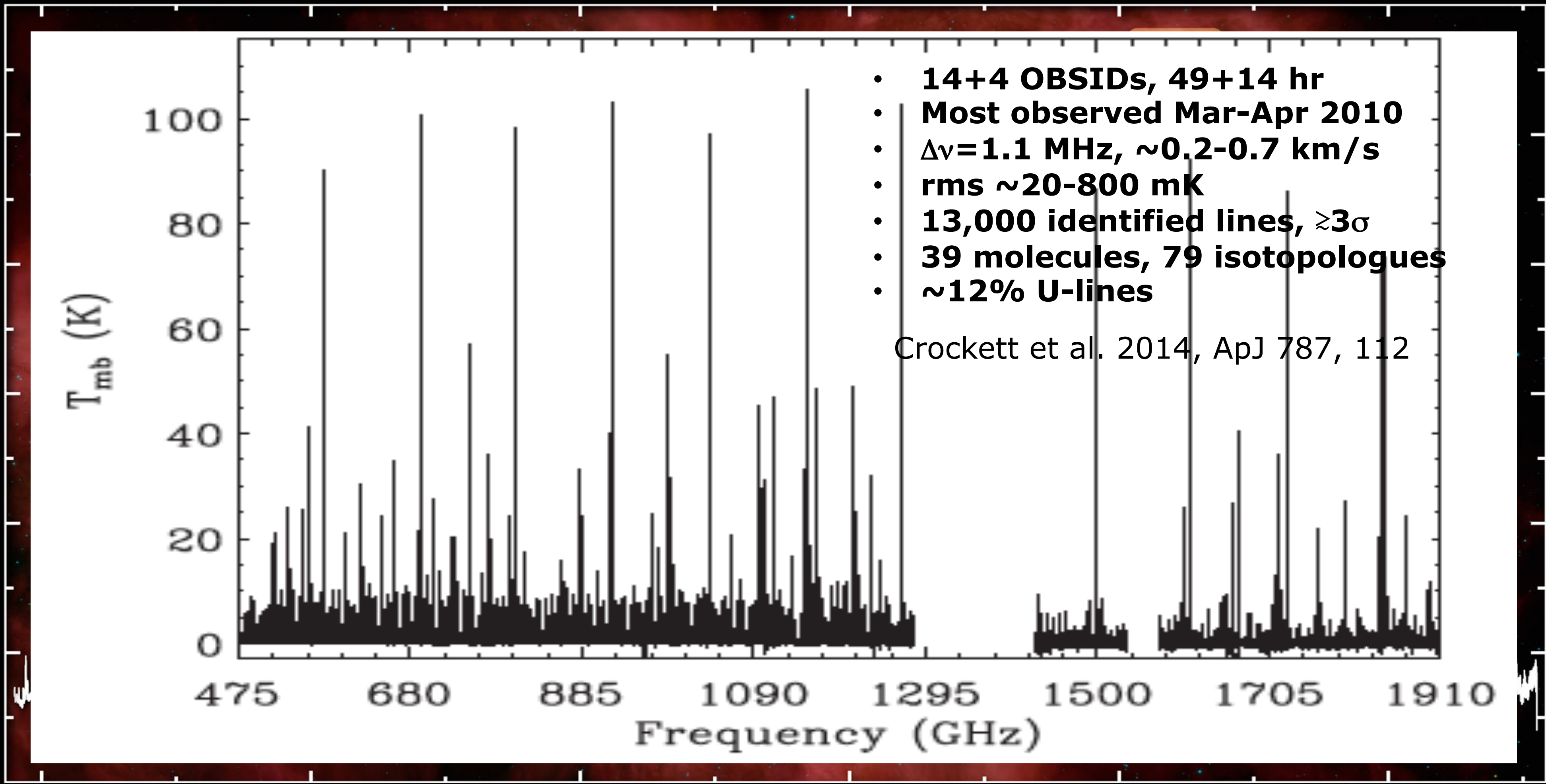


Toward a Predictive Global Model of Galactic Star Formation

Open Time KP for a simultaneous *70-160-250-350-500 μm* continuum mapping of the entire Galactic Plane (|*b*|≤1° following the warp) for <u>a total area of 720 square degrees and 900 hours observing time</u> to deliver a Galaxy-wide Census, Luminosity, Mass and SED of dust structures at all scales from massive YSOs to full Spiral Arms



HIFI Spectrum of Water and Organics in the Orion Nebula



HIFI Spectrum of Water and Organics in the Orion Nebula

E. Bergin

Herschel/HIFI spectral scans

HIFI “full” range spectral scans

Star formation

- Orion KL, SgrB2(M) and (N), Orion South, Orion Bar (HEXOS - TB)
- NGC6334I, OMC-2 FIR4, IRAS16293, L1544, AFGL2591 (CHESS - CC)
- SgrA* (OT) – bands 1-5

Stellar evolution

- IRC+10216, VYCMa (JC)
- IK Tau (calibration)
- II Lup (OT) - bands 1-4
- OH231.8 (OT) – bands 1-5

Solar system

- Mars (HSSO - PH) – bands 1-6

Herschel/HIFI spectral scans

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Solar system

- Mars (HSSO - PH) – bands 1-6

17 targets

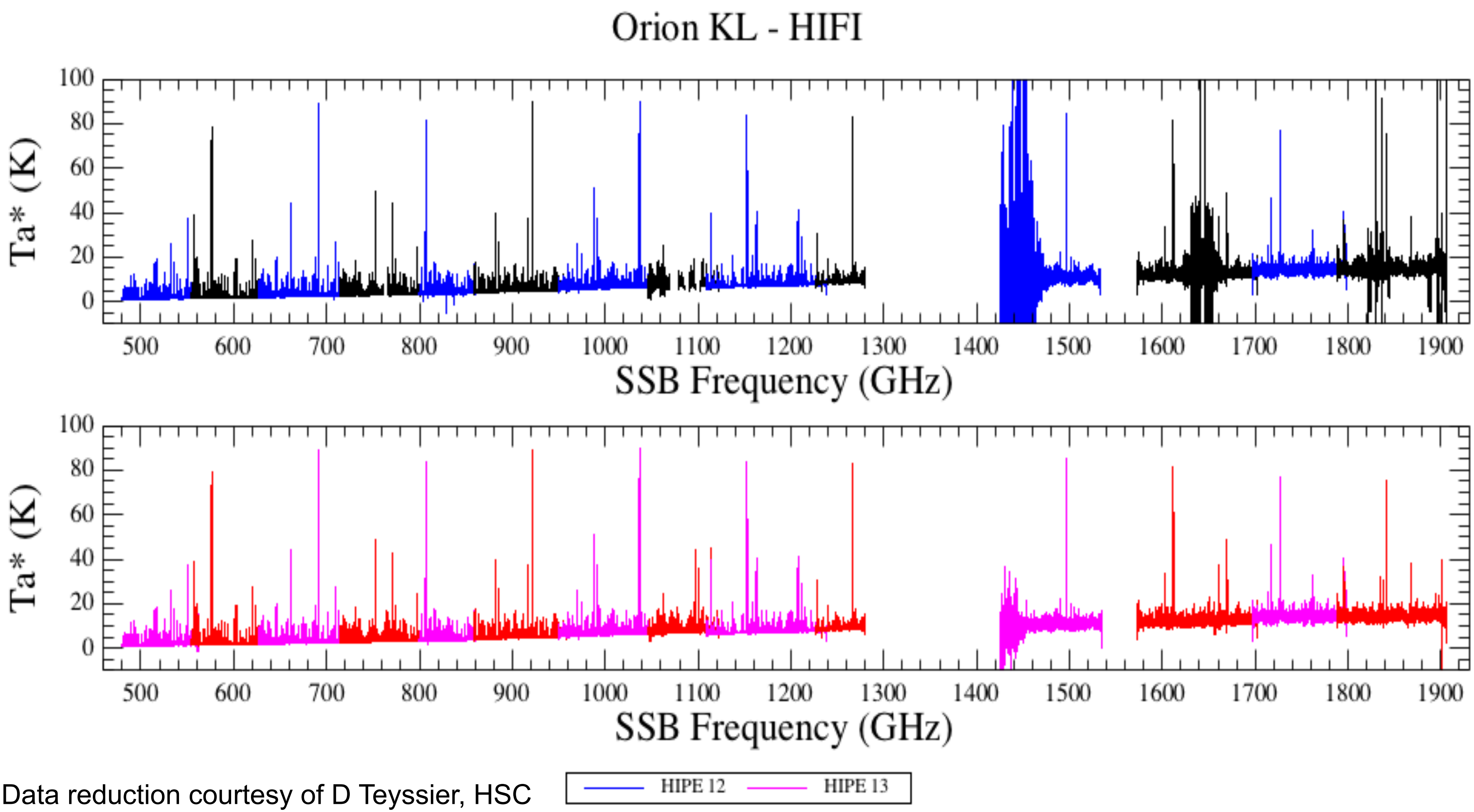
Data reduction intensive

- HIPE 13 out of the box
- Not quite there
- Expert Reduced Data underway

HERSCHEL SPACE OBSERVATORY

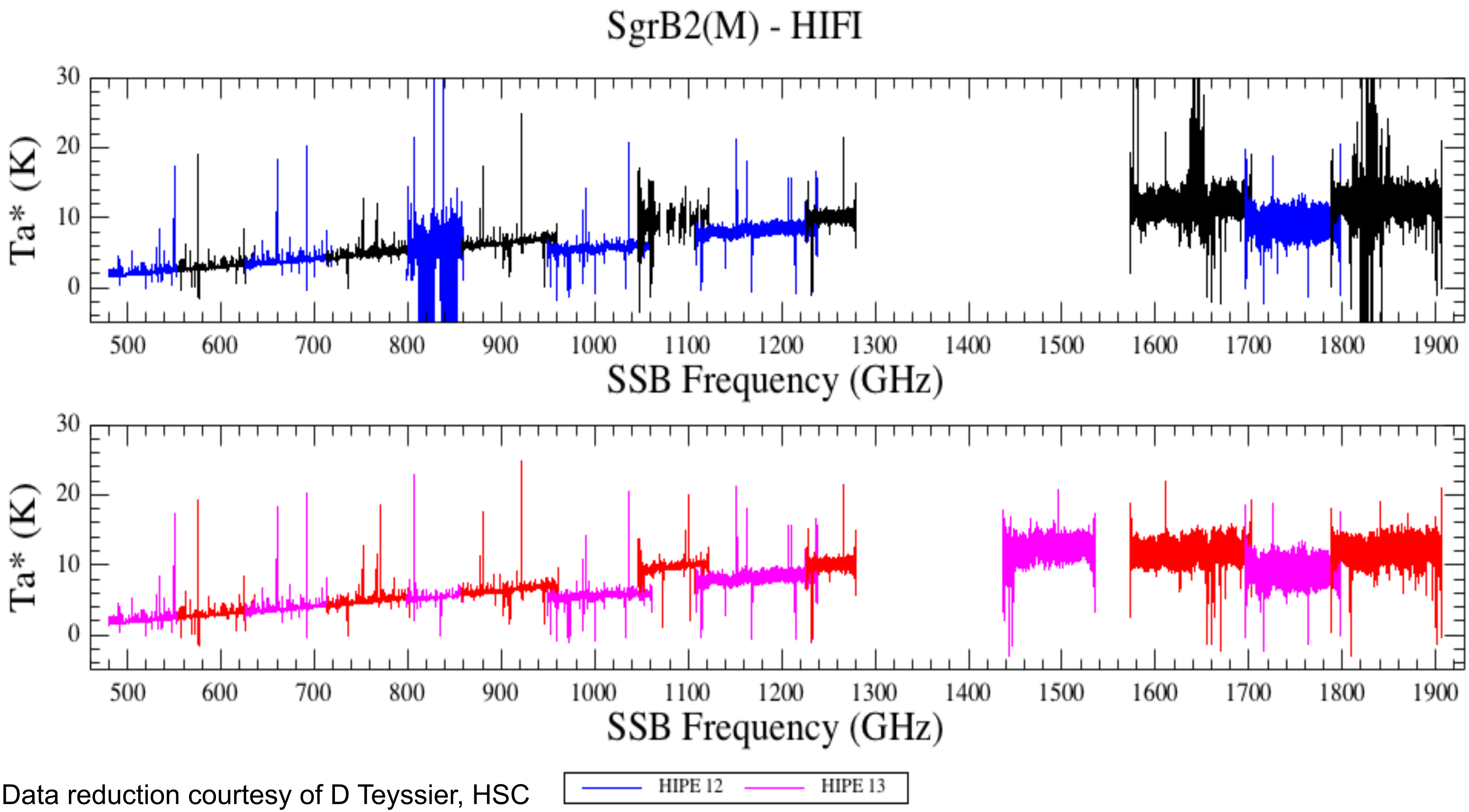
HIFI spectral scans: Orion KL

esa



Data reduction courtesy of D Teyssier, HSC

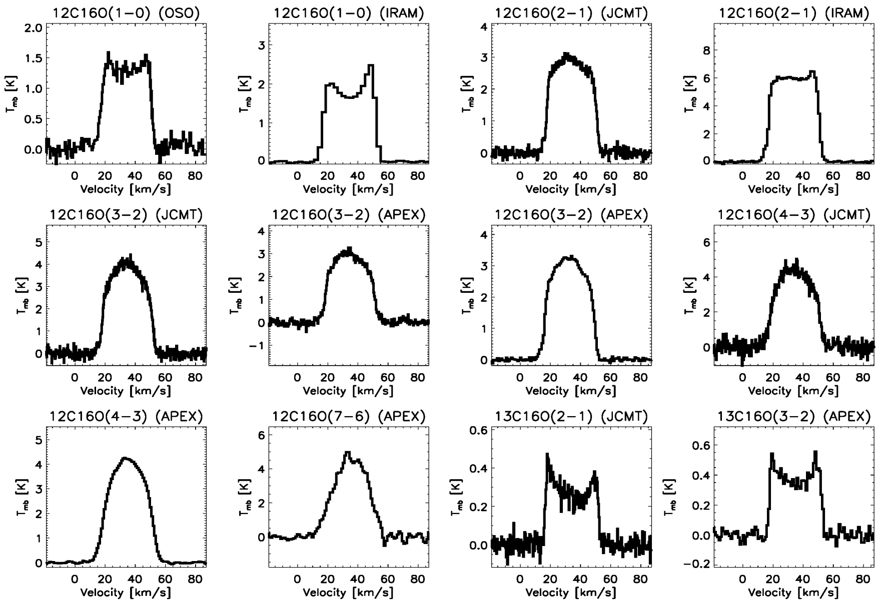
HIFI spectral scans: SgrB2(M)



Data reduction courtesy of D Teyssier, HSC

Evolved stars - spectroscopy

→ **12 molecular line transitions: ~40 hr**



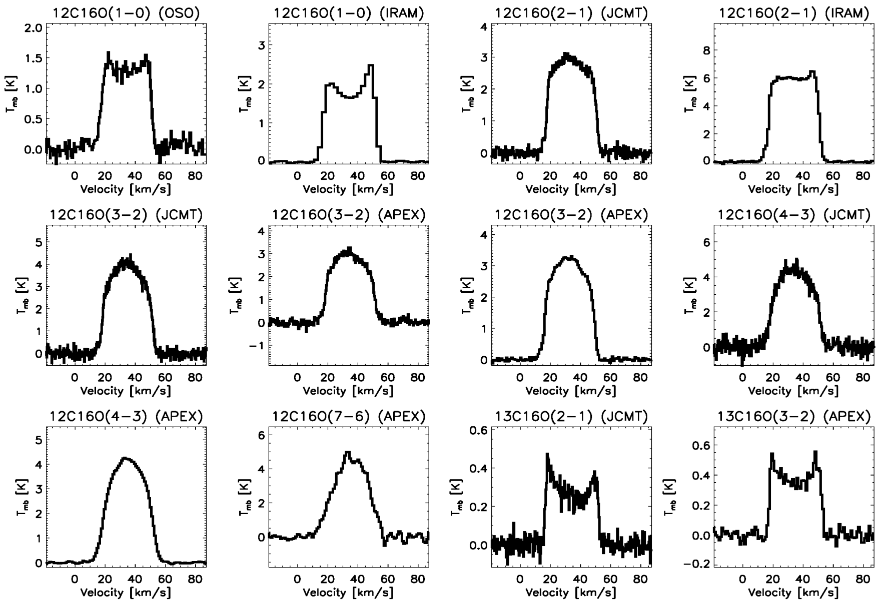
^{12}CO & ^{13}CO line profiles of IK Tau by OSO, IRAM, JCMT, & APEX

Decin et al. 2010, A&A 516, A69

Evolved stars - spectroscopy

From ground-based 10-5000 m altitudes to space, with from 12-30 m telescopes to a 3.5 m telescope

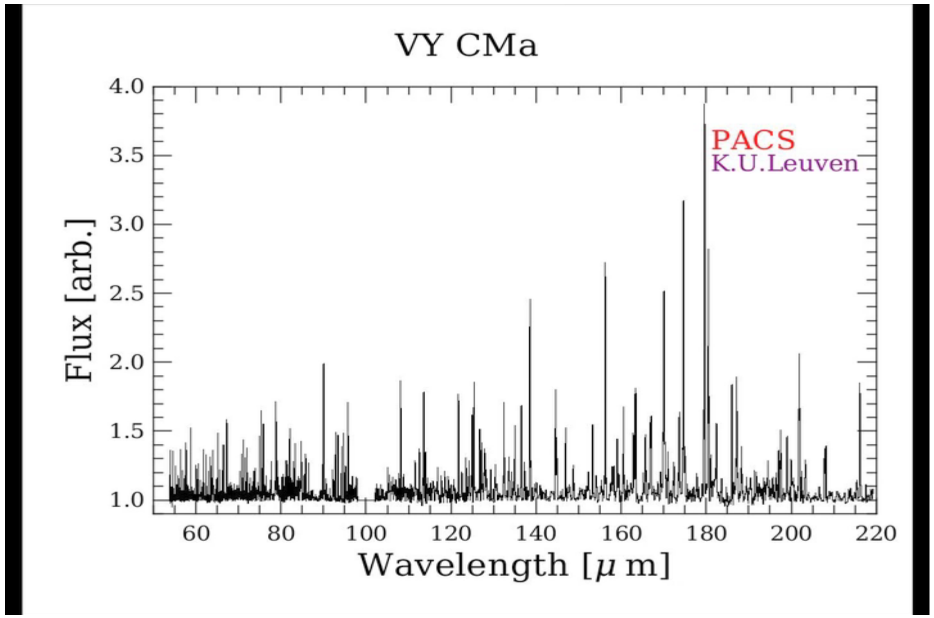
→ 12 molecular line transitions: ~40 hr



^{12}CO & ^{13}CO line profiles of IK Tau by OSO, IRAM, JCMT, & APEX

Decin et al. 2010, A&A 516, A69

→ 930 molecular line transitions: 2 hr

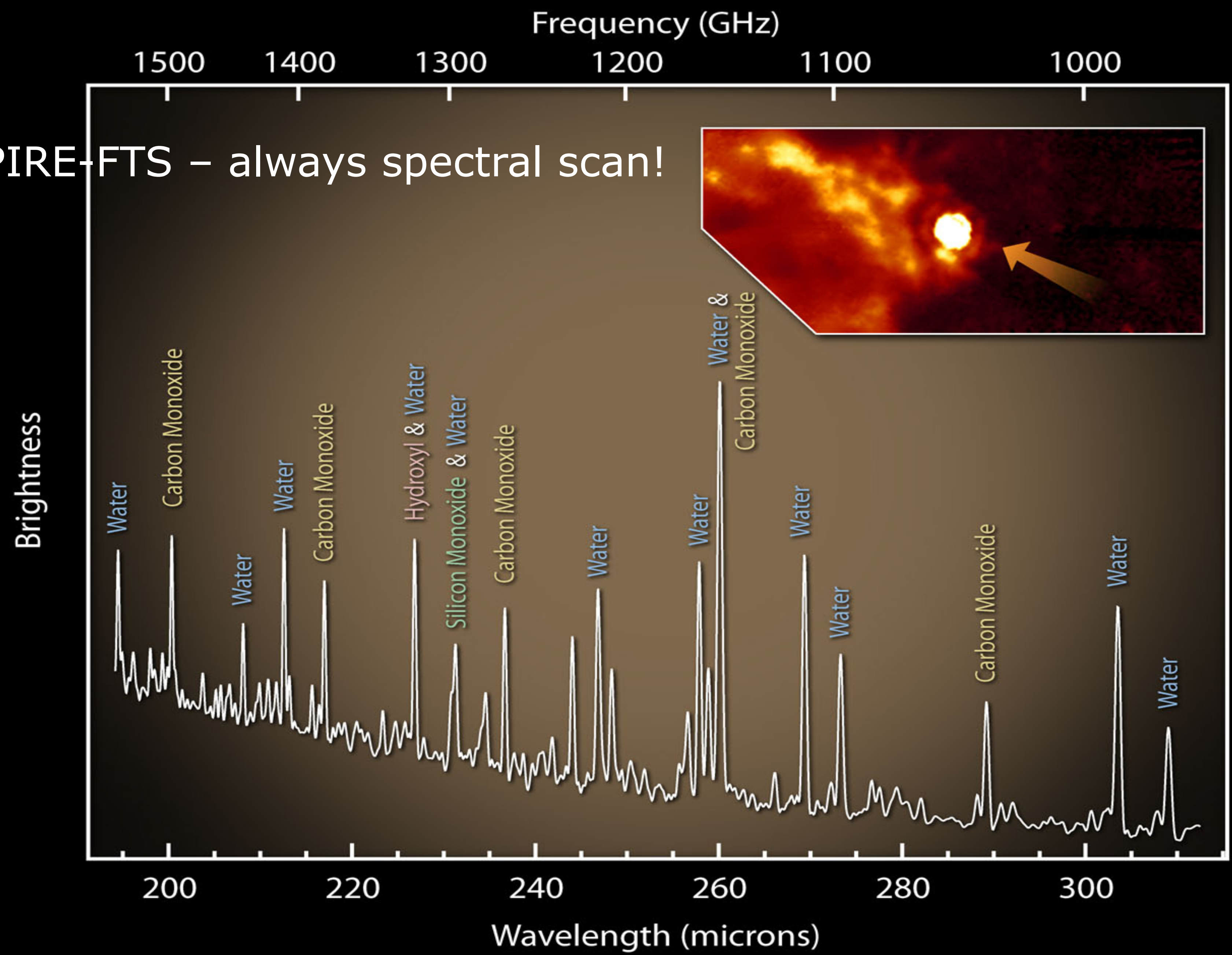


55-210 um PACS spectral scan of VY CMa

Royer et al. 2010, A&A 518, L145

HERSCHEL SPACE OBSERVATORY

SPIRE-FTS – always spectral scan!



VY Canis Majoris

Herschel/PACS spectral scans

Well in excess of 100 targets! (…and incomplete)

Star formation

- HOPS (KPOT - T Megeath) Orion protostars & PBRs: 30+8
- HOBYS (KPGT - F Motte) high-mass SF: ~12
- DIGIT (KPOT - N Evans) envelopes to disks: ~25
- Disk Evol (KPGT - G Olofsson) debris disk beta Pic: 1

Stellar evolution

- MESS (KPOT - M Groenewegen) evolved stars: ~55
- (OT1 - T Ueta) planetary nebulae: ~12
- (OT1 – R Rubin) planetary nebulae: ~5

Galactic

- WADI (KPGT - V Ossenkopf) PDRs ~4

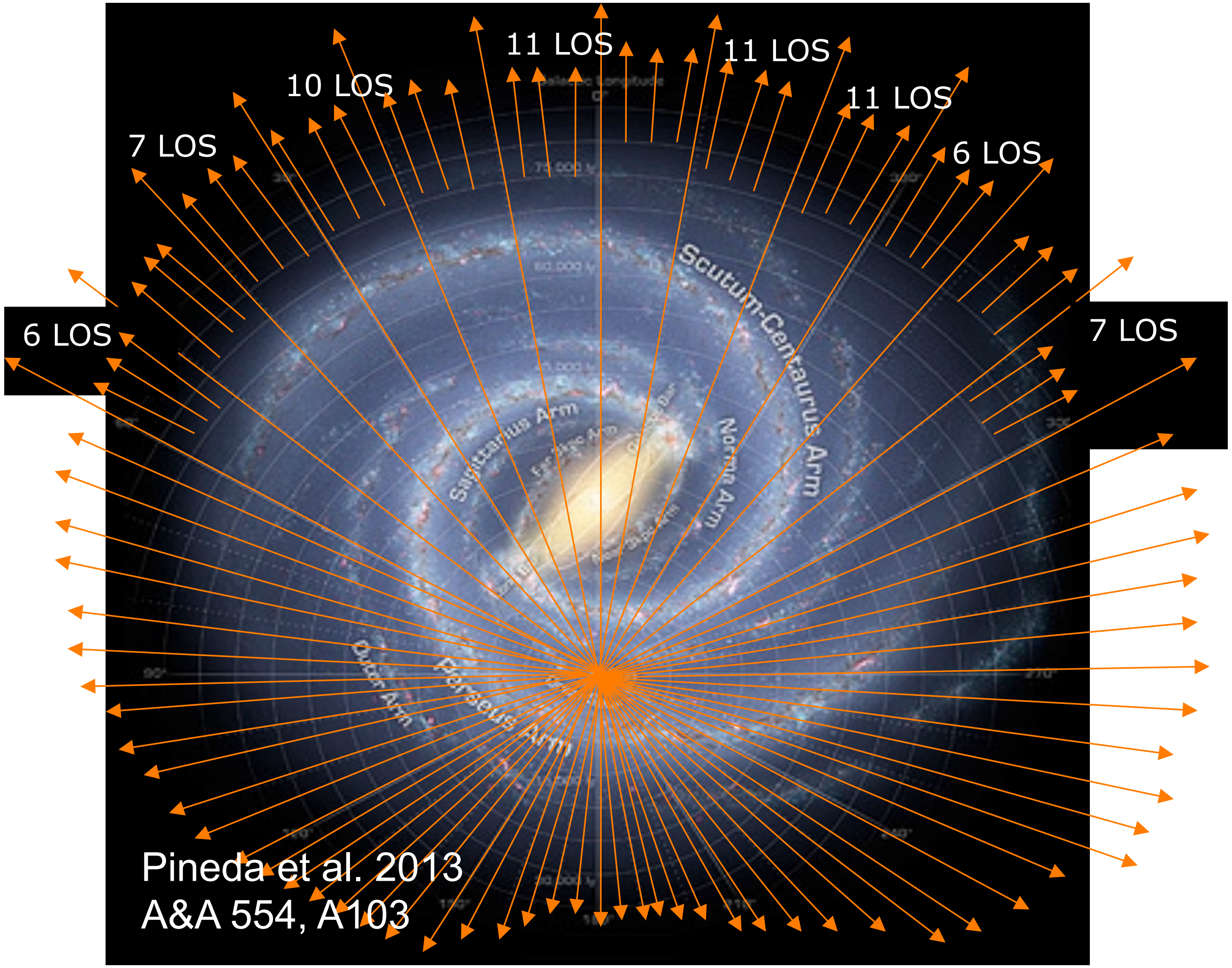
Galaxies

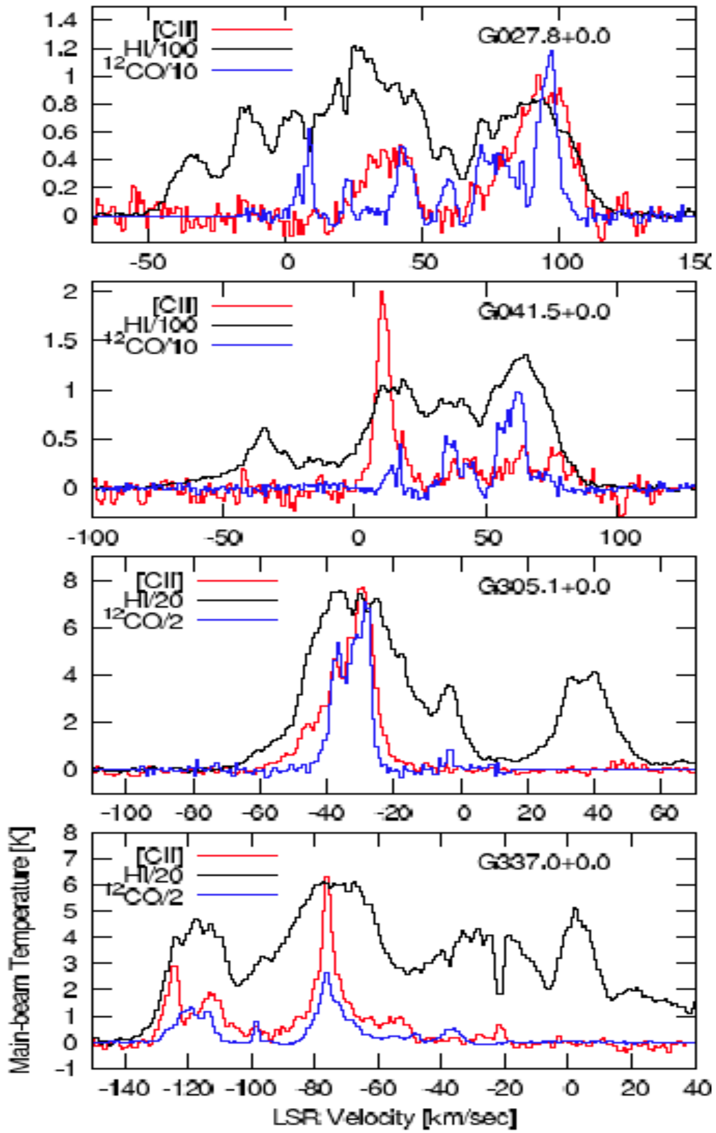
- R Güsten (CenA & NGC253) 2
- E Sturm & J Fischer (M82, NGC1068, NGC4945, Arp220, NGC4418, NGC6240, & Mrk231) 7

HERSCHEL SPACE OBSERVATORY

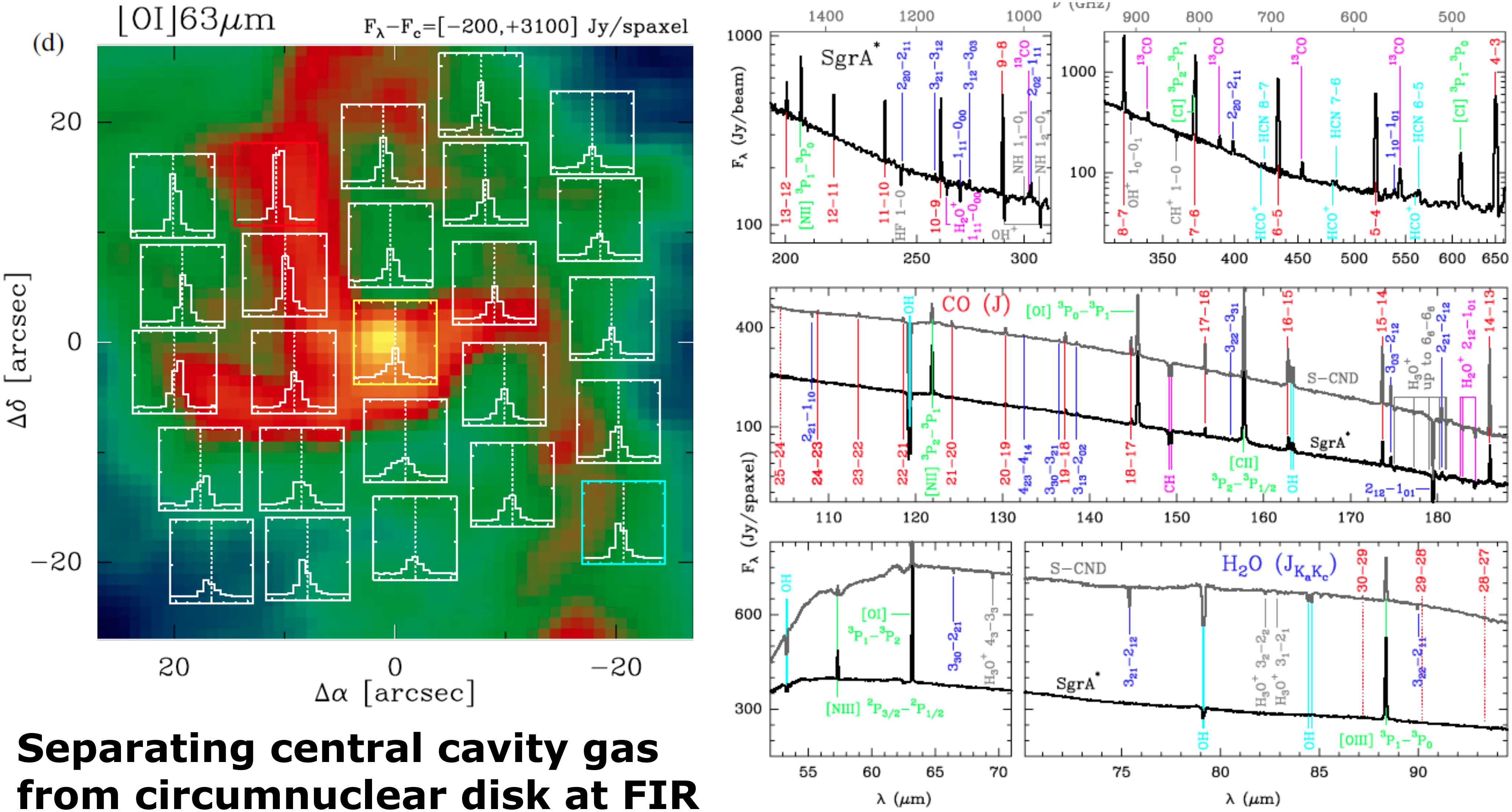
GOT C+ (158 um) HIFI galactic survey

~500 LOS covering the Galaxy





Full PACS/SPIRE spectral survey of Sgr A*



Separating central cavity gas from circumnuclear disk at FIR

Goicoechea et al. 2013; ApJL 769, L13


esa
THE UNIVERSE EXPLORED BY HERSCHEL
15-18 October 2013
ESA/ESTEC, Noordwijk, The Netherlands
An international symposium dedicated to presenting, discussing, and taking stock of the scientific breakthroughs from the Herschel Space Observatory to date, and with a view towards the future
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José Cernicharo
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Jacqueline Fischer
Matt Griffin
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Leo Metcalfe
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Göran Pilbratt
Albrecht Poglitsch
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Congrex - ESA Conference bureau
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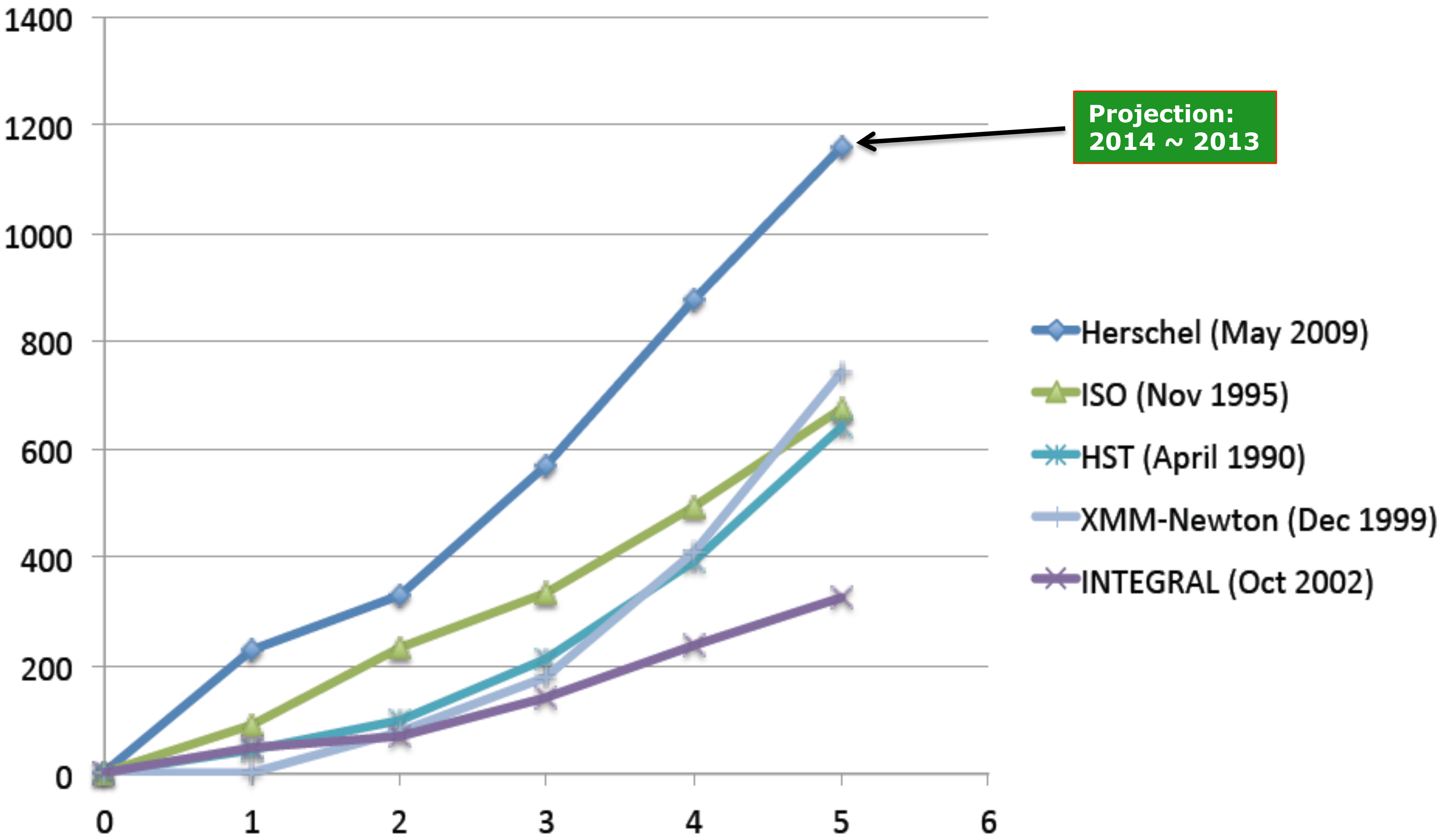
European Space Agency

#Pubs vs calendar yr after launch



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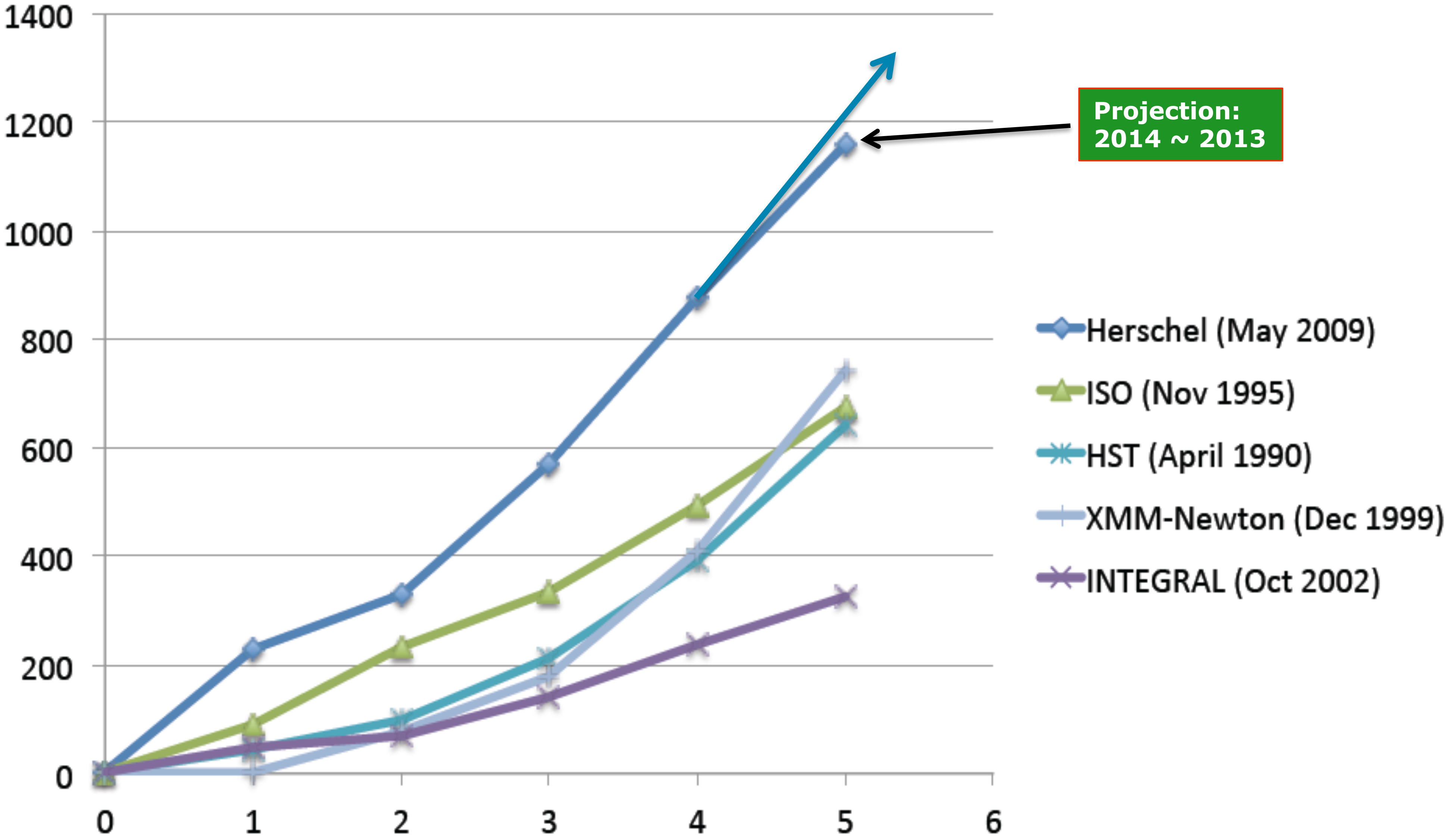
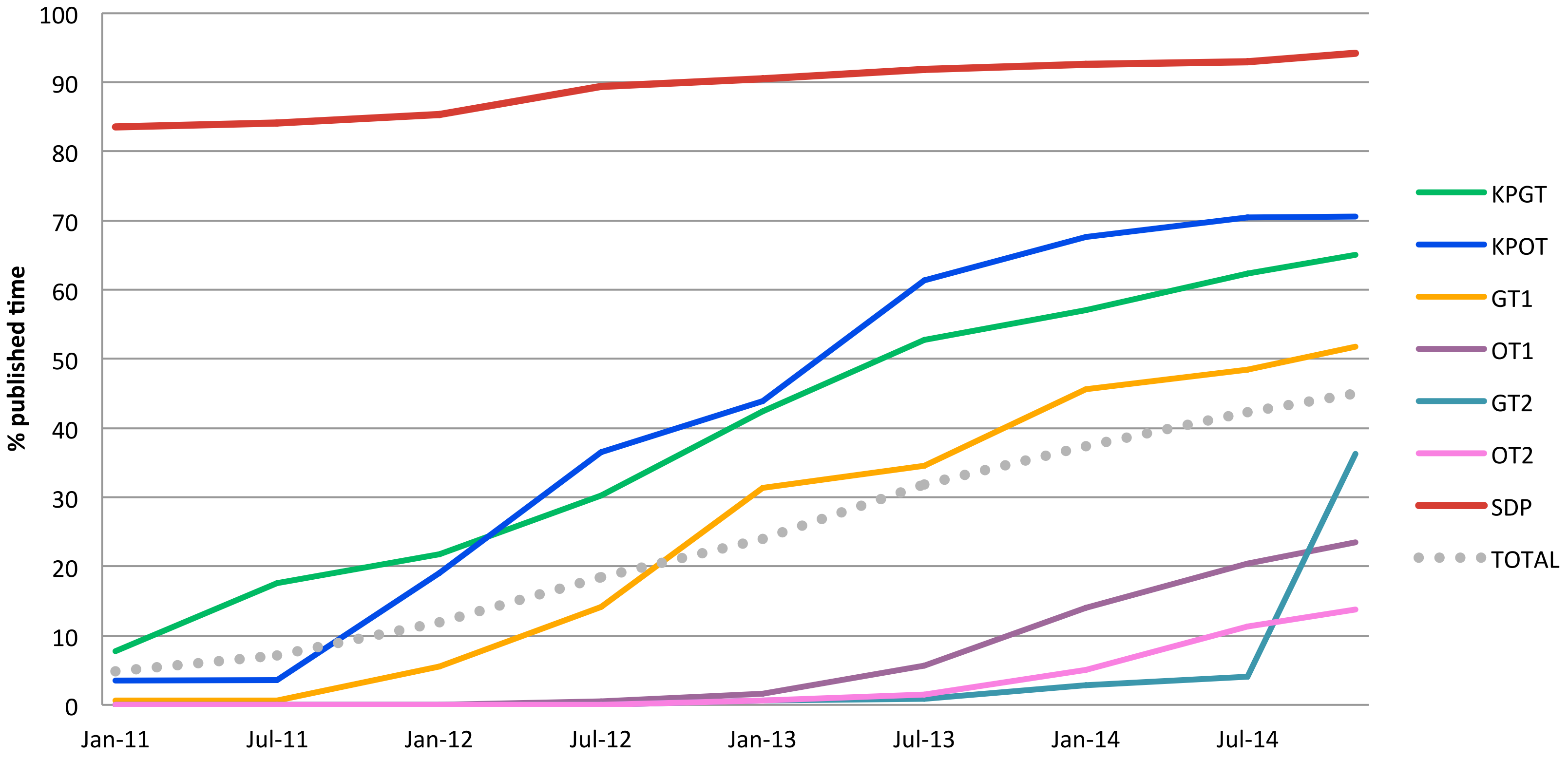


HERSCHEL SPACE OBSERVATORY

Publication evolution - AOs

Awarded time published (Nov 2014 ~1150 papers) ~45% (now 49%)

- Each publication is 'linked' to its observations (OBSIDs)
- Add up the observing times of all 'linked' observations



- SDP Nov-Dec 2009, KP early 2010-, AO1 early 2011-, AO2 early 2012-

HERSCHEL SPACE OBSERVATORY

Publication evolution – (sub)instrumts

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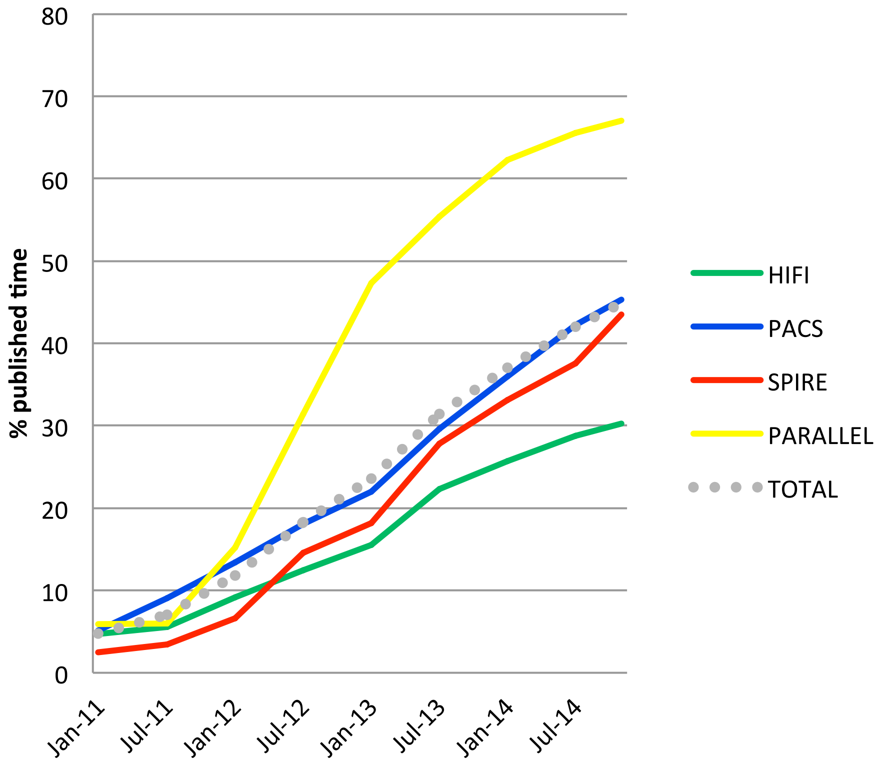

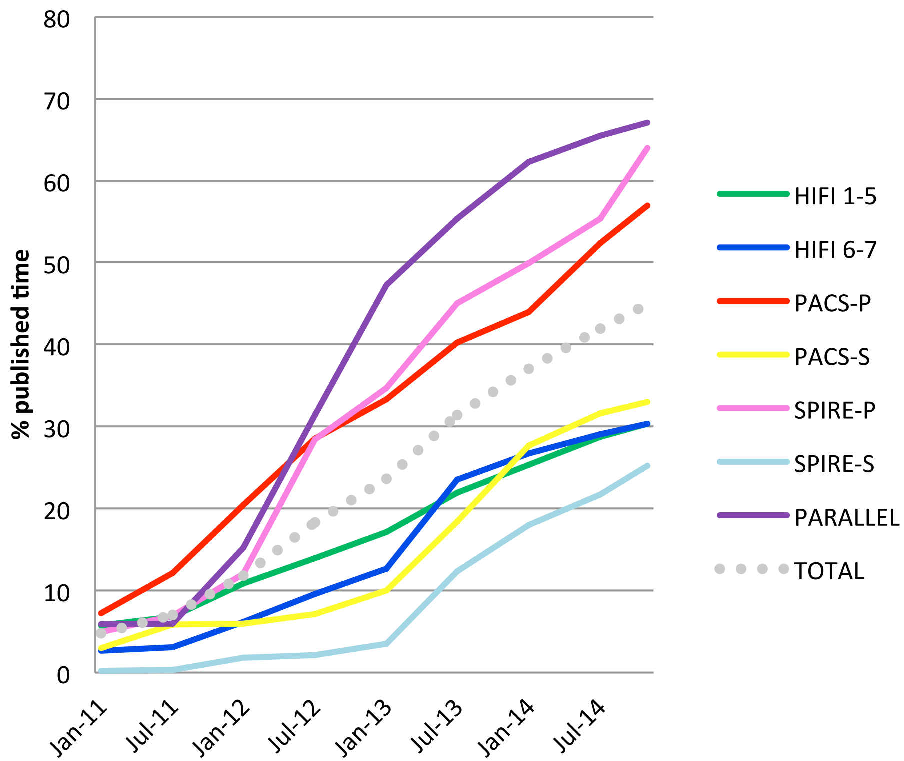

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HERSCHEL SPACE OBSERVATORY

ADS searches (last Friday) – 1338 papers

- Demand both 'Herschel' & 'SOFIA' in abstract
- Publication dates from 07/2010 onwards
- Articles only in refereed journals: 14
- All bibliographic sources: 94

Query Results from the ADS Database

Selected and retrieved **14** abstracts.

#	Bibcode / Authors	Score	Date	Title	List / Acc
1	2015A&A...575A...9P — Pérez-Beaupuits, J. P.; Stutzk Ossenkopf, V.; Spaans, M.; G Wiesemeyer, H.				
2	2014A&A...571A..53B — Beuther, H.; Ragan, S. E.; Os Glover, S.; Henning, Th.; Lin Nielbock, M.; Krause, O.; St Schilke, P.; Güsten, R.				
3	2014ApJ...790...26K — Kreckel, K.; Armus, L.; Groves, B.; Lyubenova, M.; Díaz-Santos, T.; Schinnerer, E.; Appleton, P.; Croxall, K. V.; Dale, D. A.; Hunt, L. K.; and 12 coauthors	1.000	07/2014	A Far-IR View of the Starburst-d	A Z
4	2014ApJ...786..133Y — Yu, Shanshan; Pearson, John C.	1.000	05/2014	Terahertz Measurements of the H	A Z
5	2013AN....334..558Z — Zinnecker, H.	1.000	06/2013	SOFIA: first science highlights ar	A Z
6	2012A&A...542L..21R — Requena-Torres, M. A.; Güsten, R.; Weiß, A.; Harris, A. I.; Martín-Pintado, J.; Stutzki, J.; Klein, B.; Heyminck, S.; Risacher, C.	1.000	06/2012	GREAT confirms transient nature	A Z
7	2012A&A...542L..18S — Schneider, N.; Güsten, R.; Tremblin, P.; Hennemann, M.; Minier, V.; Hill, T.; Comerón, F.; Requena-Torres, M. A.; Kraemer, K. E.; Simon, R.; and 15 coauthors	1.000	06/2012	Globules and pillars seen in the [CII] 158 m	A Z E F
8	2012A&A...542L...9G — Gómez-Ruiz, A. I.; Gusdorf, A.; Leurini, S.; Codella, C.; Güsten, R.; Wyrowski, F.; Requena-Torres, M. A.; Risacher, C.;	1.000	06/2012	High-J CO emission in the Cepheus E proto	A Z E F
			04/2012	ce Observations with SOFIA/FOI	A Z E F
			04/2012	RCAST/SOFIA Observations of	A Z E F
11	2012MNRAS.420.2569B — Brusentsova, T.; Peale, R. E.; Maukonen, D.; Figueiredo, P.; Harlow, G. E.; Ebel, D. S.; Nissinboim, A.; Sherman, K.; Lisse, C. M.	1.000	03/2012	Laboratory far-infrared spectroscopy of terr	A Z E F
12	2011A&A...536A...7P — Planck Collaboration; Ade, P. A. R.; Aghanim, N.; Arnaud, M.; Ashdown, M.; Aumont, J.; Baccigalupi, C.; Balbi, A.; Banday, A. J.; Barreiro, R. B.; and 221 coauthors	1.000	12/2011	Planck early results. VII. The Early Release	A Z E F
13	2011ApJ...733...55Z — Zhang, Yichen; Tan, Jonathan C.	1.000	05/2011	Radiation Transfer of Models of Massive St	A Z E F
14	2010ApJ...720..923Z — Zagorovsky, Kyryl; Brandeker, Alexis; Wu, Yanqin	1.000	09/2010	Gas Emission from Debris Disks Around A	A Z E F

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- Replace SOFIA by ALMA: 54/195
- Replace SOFIA by ISO: 33/74
- Replace SOFIA by Spitzer: 325/760
- Replace SOFIA by XMM: 14/42

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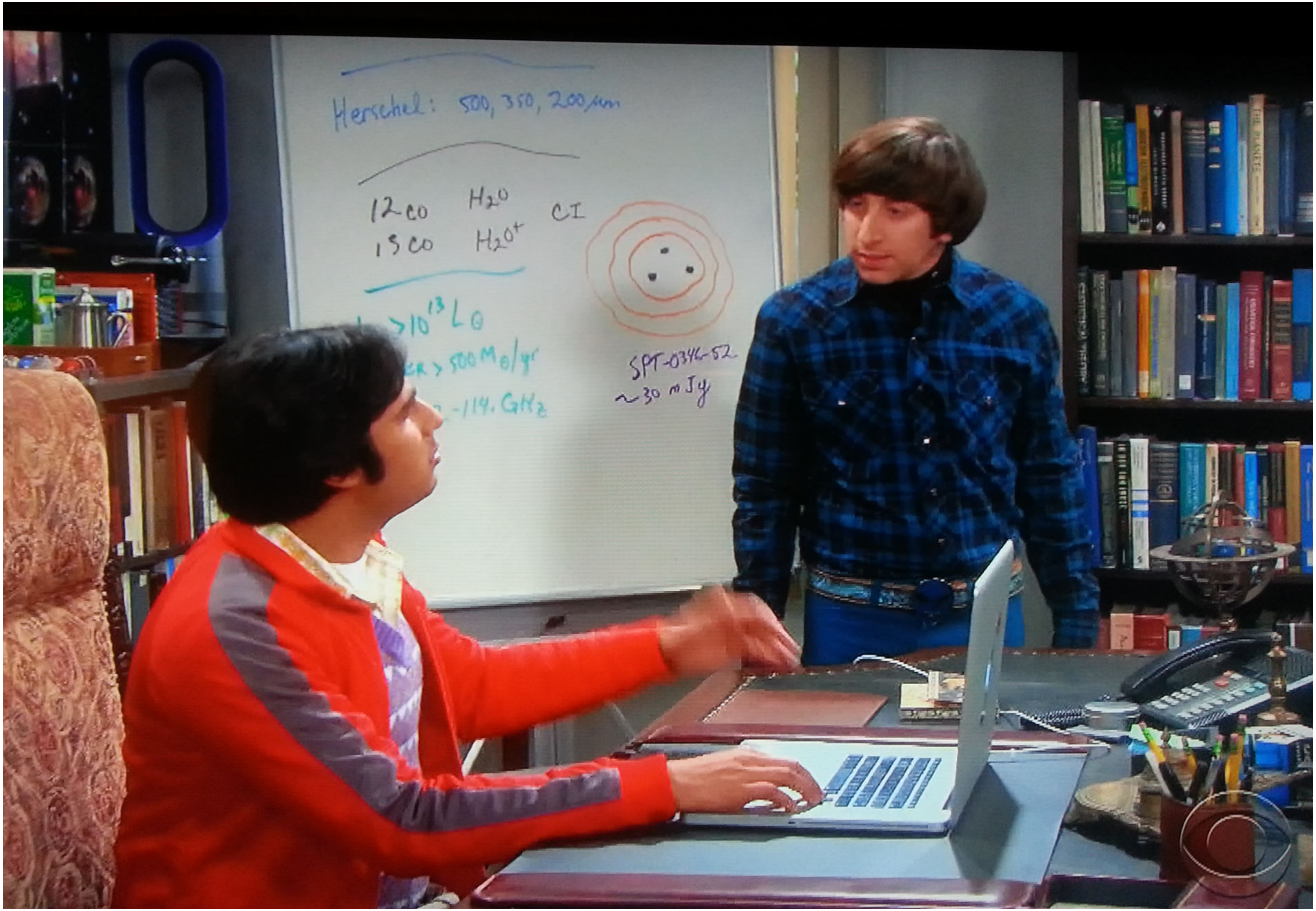
3	2014ApJ...790...26K — Kreckel, K.; Armus, L.; Grov… Lyubenova, M.; Díaz-Santos,… Schinnerer, E.; Appleton, P.;… Dale, D. A.; Hunt, L. K.; and…			
4	2014ApJ...786..133Y — Yu, Shanshan; Pearson, John C.			Terahertz Measurements of the H…
5	2013AN....334..558Z — Zinnecker, H.	1.000	06/2013	SOFIA: first science highlights a…
6	2012A&A...542L..21R — Requena-Torres, M. A.; Güsten, R.; Weiß, A.; Harris, A. I.; Martín-Pintado, J.; Stutzki, J.; Klein, B.; Heyminck, S.; Risacher, C.	1.000	06/2012	GREAT confirms transient nature…
7	2012A&A...542L..18S — Schneider, N.; Güsten, R.; Tremblin, P.; Hennemann, M.; Minier, V.; Hill, T.; Comerón, F.; Requena-Torres, M. A.; Kraemer, K. E.; Simon, R.; and 15 coauthors	1.000	06/2012	Globules and pillars seen in the [CII] 158 m…
8	2012A&A...542L...9G — Gómez-Ruiz, A. I.; Gusdorf, A.; Leurini, S.; Codella, C.; Güsten, R.; Wyrowski, F.; Requena-Torres, M. A.; Risacher, C.;	1.000	06/2012	High-J CO emission in the Cepheus E proto…
			04/2012	…ce Observations with SOFIA/FO…
			04/2012	…RCAST/SOFIA Observations of
			03/2012	… far-infrared spectroscopy of terr…
	Planck Collaboration; Ade, P. A. R.; Aghanim, N.; Arnaud, M.; Ashdown, M.; Aumont, J.; Baccigalupi, C.; Balbi, A.; Banday, A. J.; Barreiro, R. B.; and 221 coauthors		12/2011	Planck early results. VII. The Early Release…
13	2011ApJ...733...55Z — Zhang, Yichen; Tan, Jonathan C.	1.000	05/2011	Radiation Transfer of Models of Massive St…
14	2010ApJ...720..923Z — Zagorovsky, Kyryl; Brandeker, Alexis; Wu, Yanqin	1.000	09/2010	Gas Emission from Debris Disks Around A…


Herschel: 500, 350, 200 μm
12CO H2O CI
13CO H2O+
SPT-0346-52
~30 mJy

Thoughts on SOFIA–Herschel synergy

Observing

- Herschel has performed ~23,500 hr of science observing – but no more!
- SOFIA has performed ~400 hr of science observing (up to Cycle 3)
- SOFIA is observing Cycle 3 now, and will be observing for years to come
- SOFIA has a "wider-scope" observing capability than Herschel had
- SOFIA is constantly improving its instruments – and getting new ones

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Herschel data as a resource

- "Backwards". For "existing" SOFIA observing, check if Herschel adds
- Remember that although Herschel has observed but a fraction of the sky many of the "obvious" targets (per "class") and fields have been observed
- Don't spend precious SOFIA time if ground-based/archive data suffice

HERSCHEL SPACE OBSERVATORY

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Herschel yes – but don't forget Planck and AKARI

- **Planck:**
    - 9 all-sky surveys covering 30-900 GHz, two highest = SPIRE 350 & 500 um
- **AKARI:**
    - 2 all-sky MIR surveys & 4 all-sky FIR surveys

Thoughts on SOFIA–Herschel synergy

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Herschel data as a resource – & Planck & AKARI

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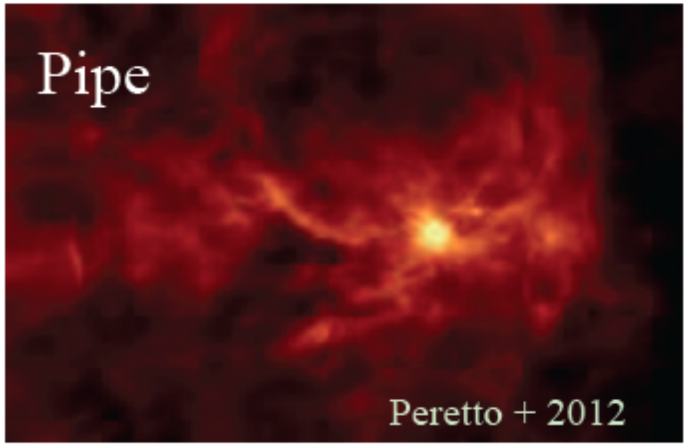
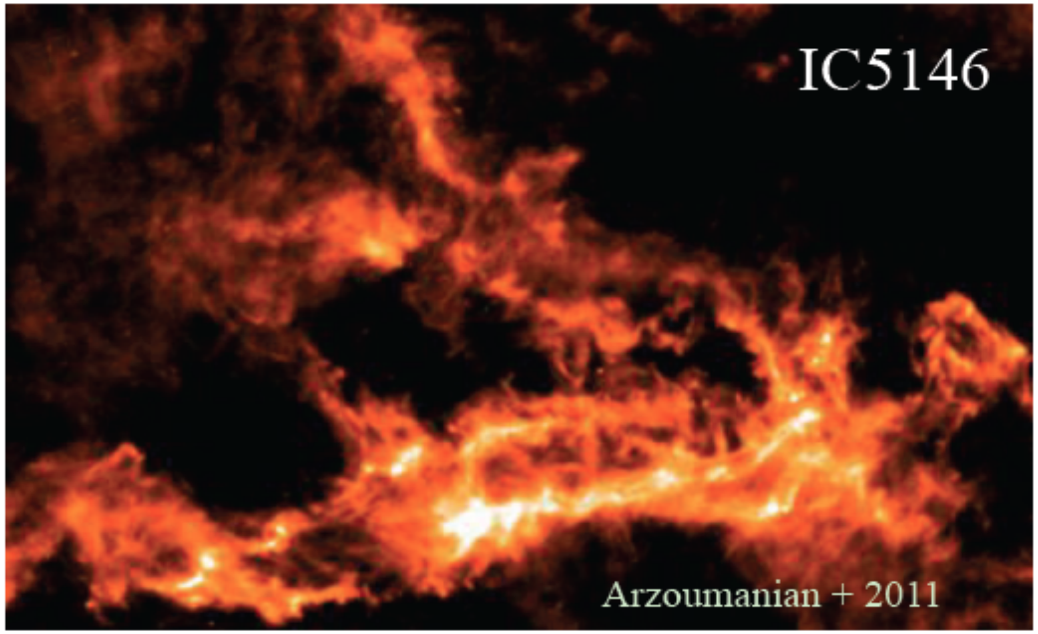
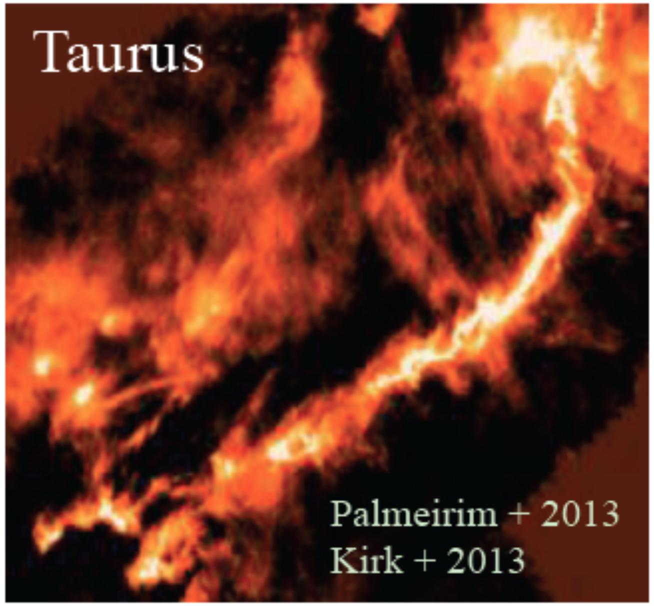
- Remember that although Herschel has observed but a fraction of the sky many of the "obvious" targets (per "class") and fields have been observed
- Don't spend precious SOFIA time if ground-based/archive data suffice
- "Forwards". Get inspired by Herschel, and dream up SOFIA projects
- Use SOFIA to do what Herschel did not – or could not – do: e.g. wavelength coverage, sky coverage, monitoring, targets of opportunity
- Use SOFIA to do better than Herschel could, e.g. C+ (158 um), HD (112 um) [OI] 63 um with upGREAT & FIFI-LS spectral mapping
- Not spectroscopy: I hear rumours about polarimetry! (HAWCpol?)

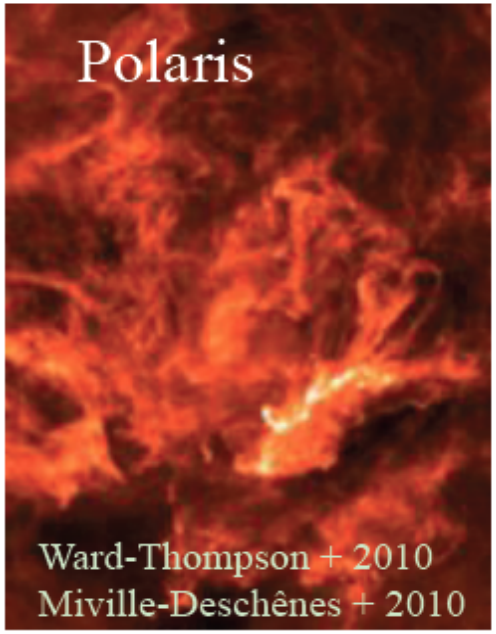
HERSCHEL SPACE OBSERVATORY

Herschel reveals a "universal" filamentary structure in the cold ISM









Science Users Information
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- Observing with ESO Telescopes
- Science Software
- Data Handling and Products
- Science Archive Facility
- Science Activities
- Science Publications
- **Science and Technical Meetings**
  - Seminars and Colloquia at ESO Garching
  - Seminars at ESO Vitacura
  - Conferences and Workshops
- IT Services
- Libraries
- Job Opportunities

ALMA/Herschel Archival Workshop 2015

ESO Garching, April 15-17, 2015

ALMA/*Herschel* Archival Workshop

The *Herschel* Space Observatory has produced high quality photometric and spectroscopic data in the wavelength range approximately 55 to 670 μm during its lifetime from 2009 to 2013. To date, all Herschel science data (~23,400 hours of observations, ~37,000 AORs), in addition to a variety of user-provided data products, are publicly available through the *Herschel* Science Archive. Meanwhile, the ALMA Science Archive is being populated with observations carried out in the first three ALMA observing Cycles, with more data becoming publically available by the day.

The higher frequency ALMA bands overlap with the lower frequency (longer wavelength) *Herschel* bands, and despite the huge difference in spatial resolution, *Herschel* sources provide ideal targets for ALMA follow up. Furthermore, with more and more ALMA data becoming publically available every day, the possibilities to further explore these two complementary datasets that cover the fields of planetary, Galactic and extragalactic astrophysics, increase manifold. However, *Herschel* and ALMA data differ greatly and in order to explore their full potential, the archival users need to be aware not only of the contents of the two archives but of the differences of the datasets, as well.

Many of the Herschel users are increasingly proposing for ALMA time, while a large fraction of ALMA users until now have not spent enough time in checking the Herschel archive to complement their science with Herschel observations.

The target audience are all astronomers that have already used data from either of the two facilities and would now want to expand their knowledge to the neighbouring wavelength regime. The workshop is taking place back to back with the ESO ALMA Cycle 3 Community Days.

Main Goals

The workshop focuses on the ALMA/*Herschel* Synergies and archival research, with the following *scope and goals*:

- Provide examples of science cases based on the combined use of *Herschel* & ALMA data, covering a broad range of astrophysical topics, from star formation to evolved stars to galaxies and cosmology.
- Promote mutual awareness of *Herschel* & ALMA data archive contents
- Show users how to explore, access and visualize *Herschel* & ALMA data products, including existing quick look data analysis tools
- Enable *Herschel* & ALMA archival science
- Assist users in the preparation of Cycle 3 ALMA proposals based on existing *Herschel* data

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15:20	*An introduction to Herschel*	Göran Pilbratt
15:40	*The Herschel archive*	Eva Verdugo
16:00	*The Herschel products*	Anthony Marston
16:20	*The road from Herschel data to publications*	Pedro Garcia-Lario
16:40	*Workflow from searching for Herschel data to extracting science-grade spectro-photometric information*	Ivan Valtchanov David Teyssier

goals:

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Thoughts on SOFIA–Herschel synergy

esa


THANK
YOU !...
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