Introduction to Herschel

- Science synergy with ALMA

Göran Pilbratt, Herschel Project Scientist

ALMA-Herschel workshop, ESO, Garching, 15-17 April 2015

Herschel in a nutshell

Large 'warm' telescope

- 3.5 m diameter aperture
- collecting area and resolution

'New' spectral window

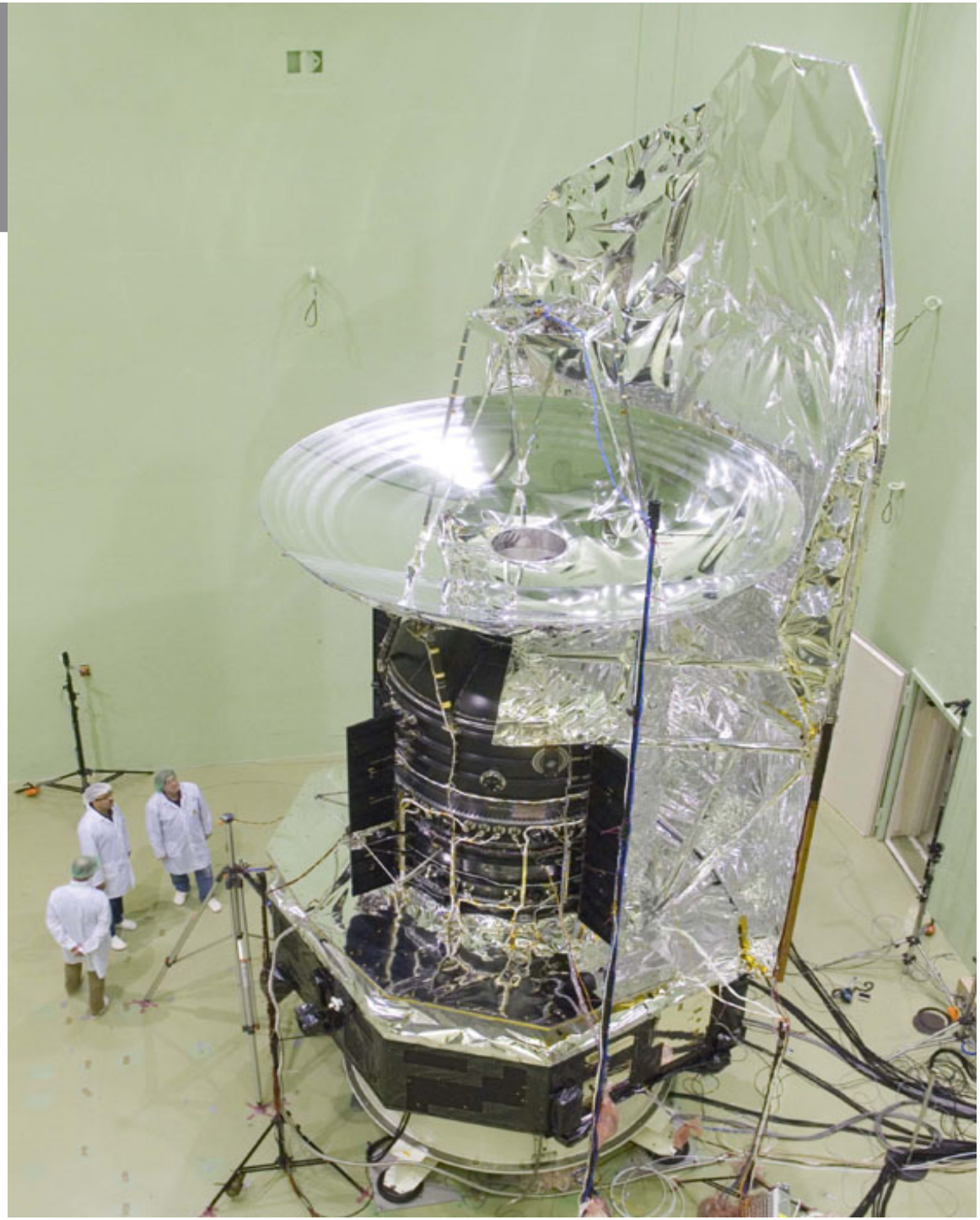
- ~55-670 μm – bridging the far infrared & submillimetre – the 'cool' universe

Novel instruments

- wide area mapping in 6 'colours'
- imaging spectroscopy
- very high resolution heterodyne spectroscopy

Science: the 'cool' universe

- star formation & evolution near & far
- galaxy evolution over cosmic time
- ISM physics/chemistry
- our own solar system & IR excess
- provide 3 years of routine observing



Fairing integration on 10 May 2009

Herschel – the science instruments

3-band camera

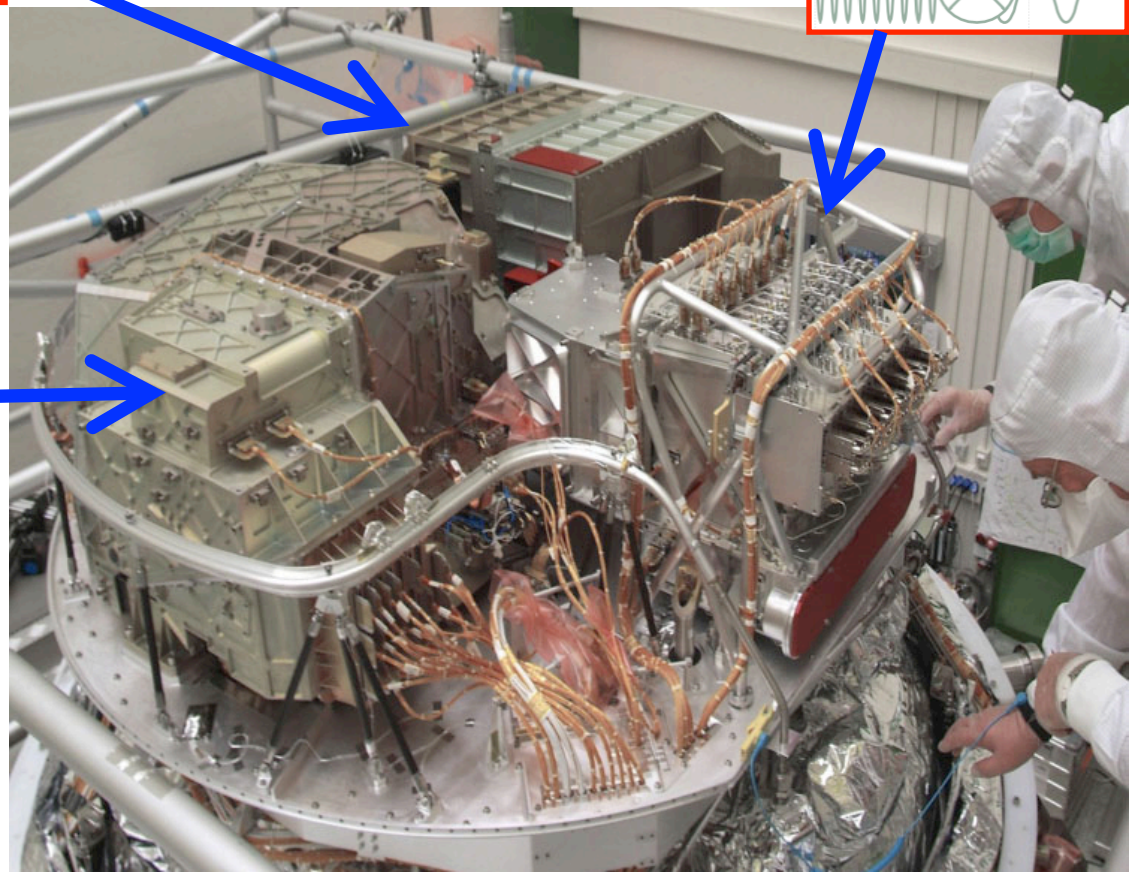
250 + 350 + 500 μm
4 x 8 arcmin FOV

Imaging FT spectrometer

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

7-channel heterodyne receiver

480 - 1250 GHz (625 - 240 μm)
1410 - 1910 GHz (212 - 157 μm)
λ/Δλ = 10^5-10^6 w. BW = 4 GHz



3-band camera

70 or 100 + 160 μm
1.75 x 3.5 arcmin FOV

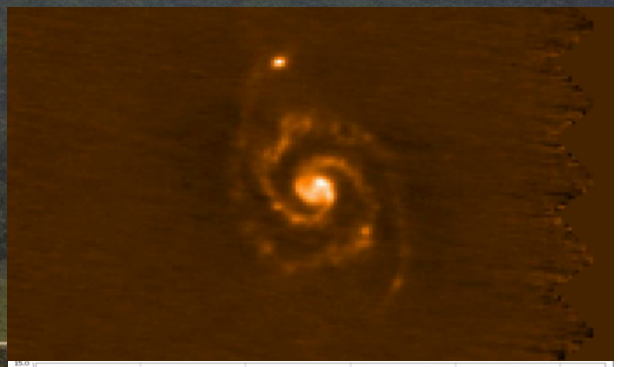
Imaging grating spectrometer

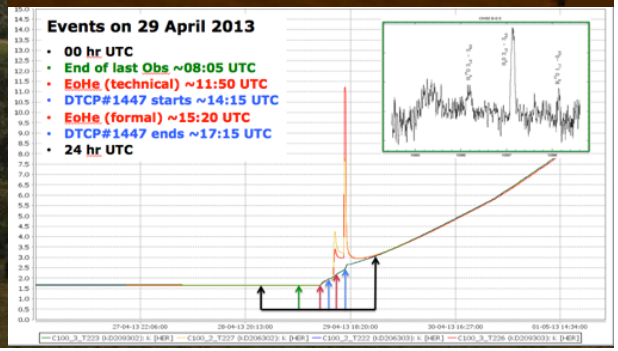
55 - 210 μm (3 orders)
λ/Δλ = 1000 – 4000

Launch on 14 May 2009 …

… sneak preview on 14-15 June 2009

… end of helium on 29 April 2013





Launch on 14 May 2009 …

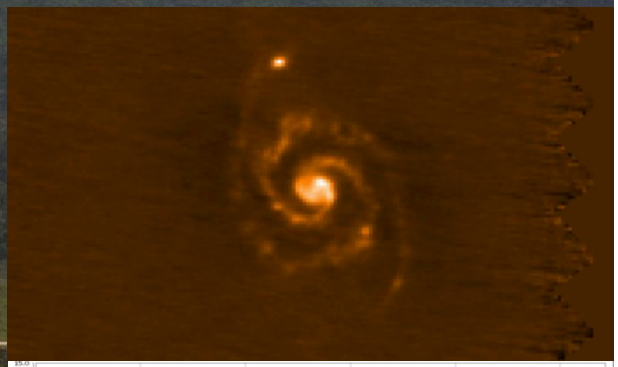
… sneak preview on 14-15 June 2009

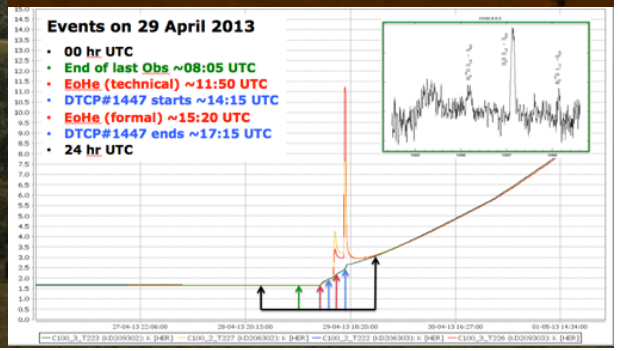
… end of helium on 29 April 2013

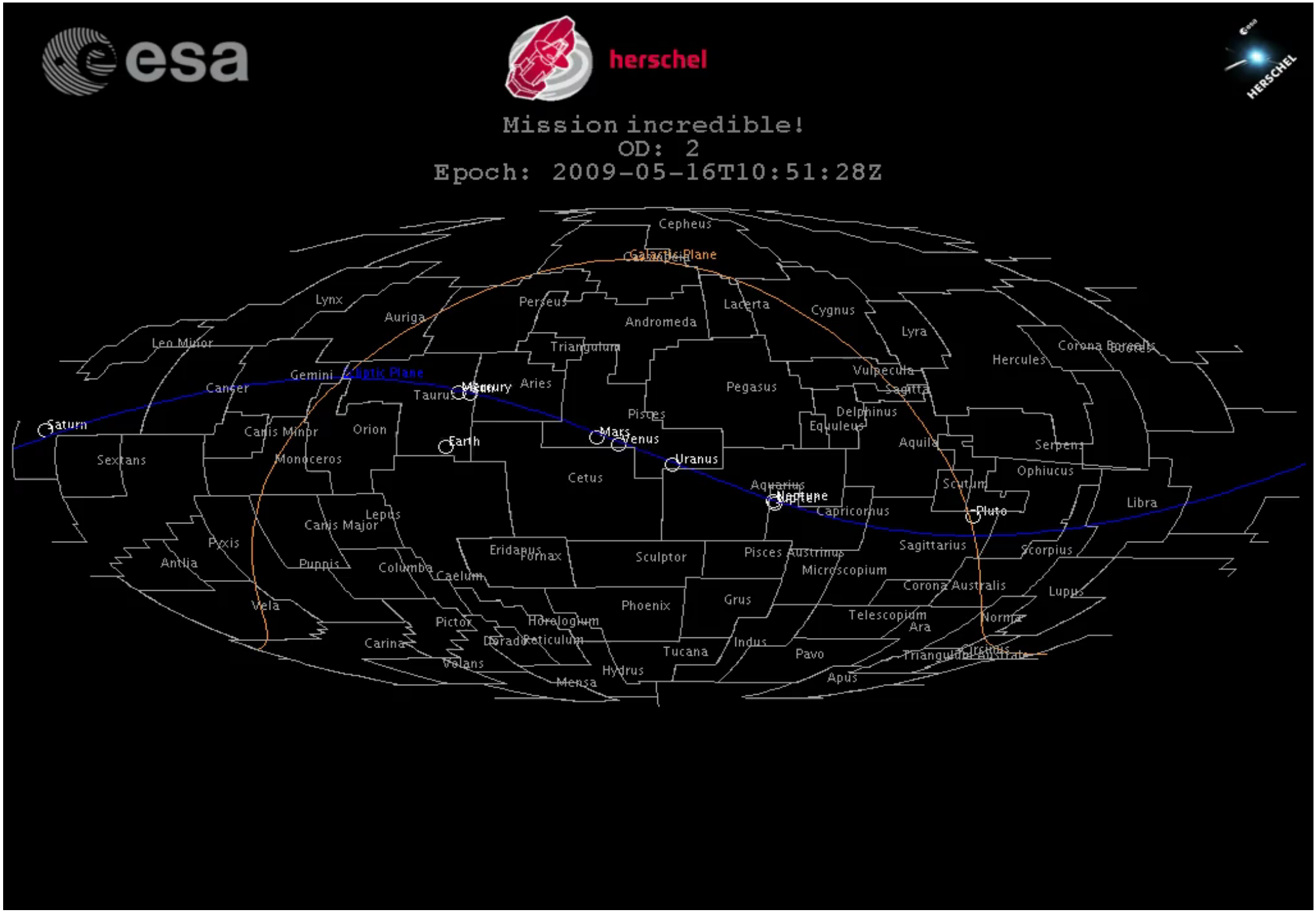
… last telecommand on 17 June 2013

… satellite now in “parking” orbit

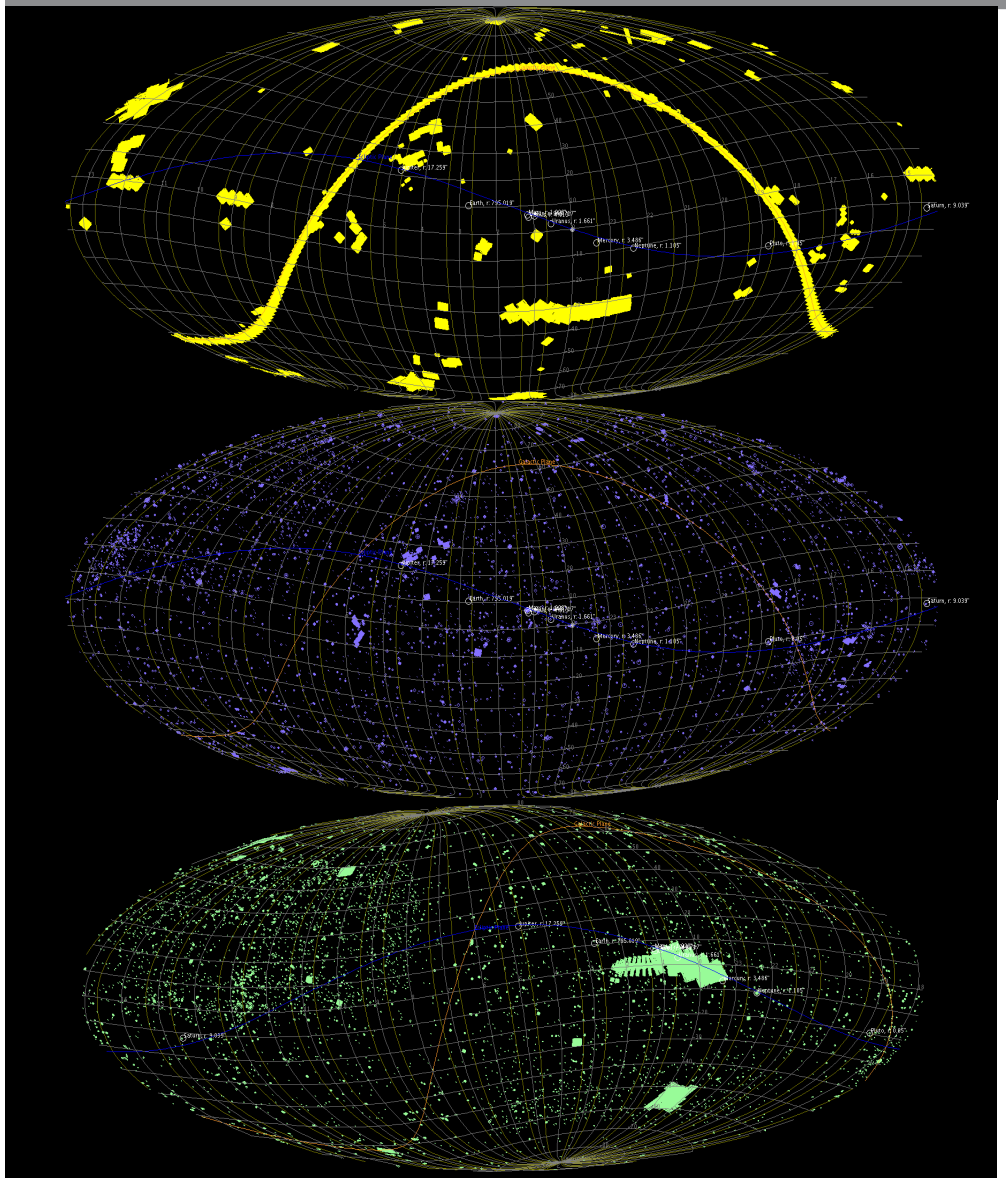
… mission in post-operations phase until end 2017






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

Preliminary sky coverage



Totals (uncert +/- 5%)

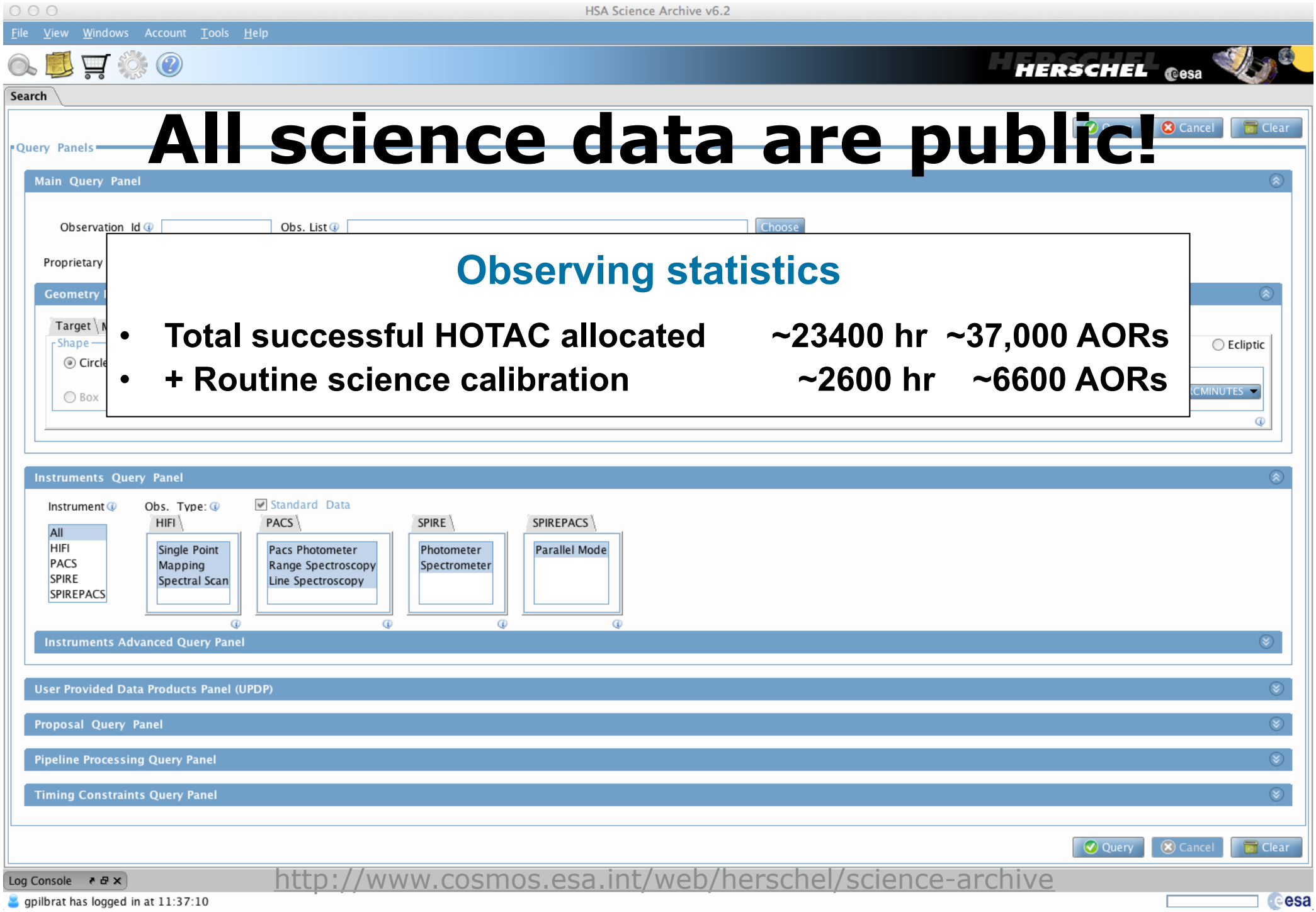
- S/P parallel 6.44
- PACS phot 0.67
- SPIRE phot 2.28
- PACS spec <0.01
- SPIRE spec <0.01
- HIFI 0.06
- Total Herschel 9.45

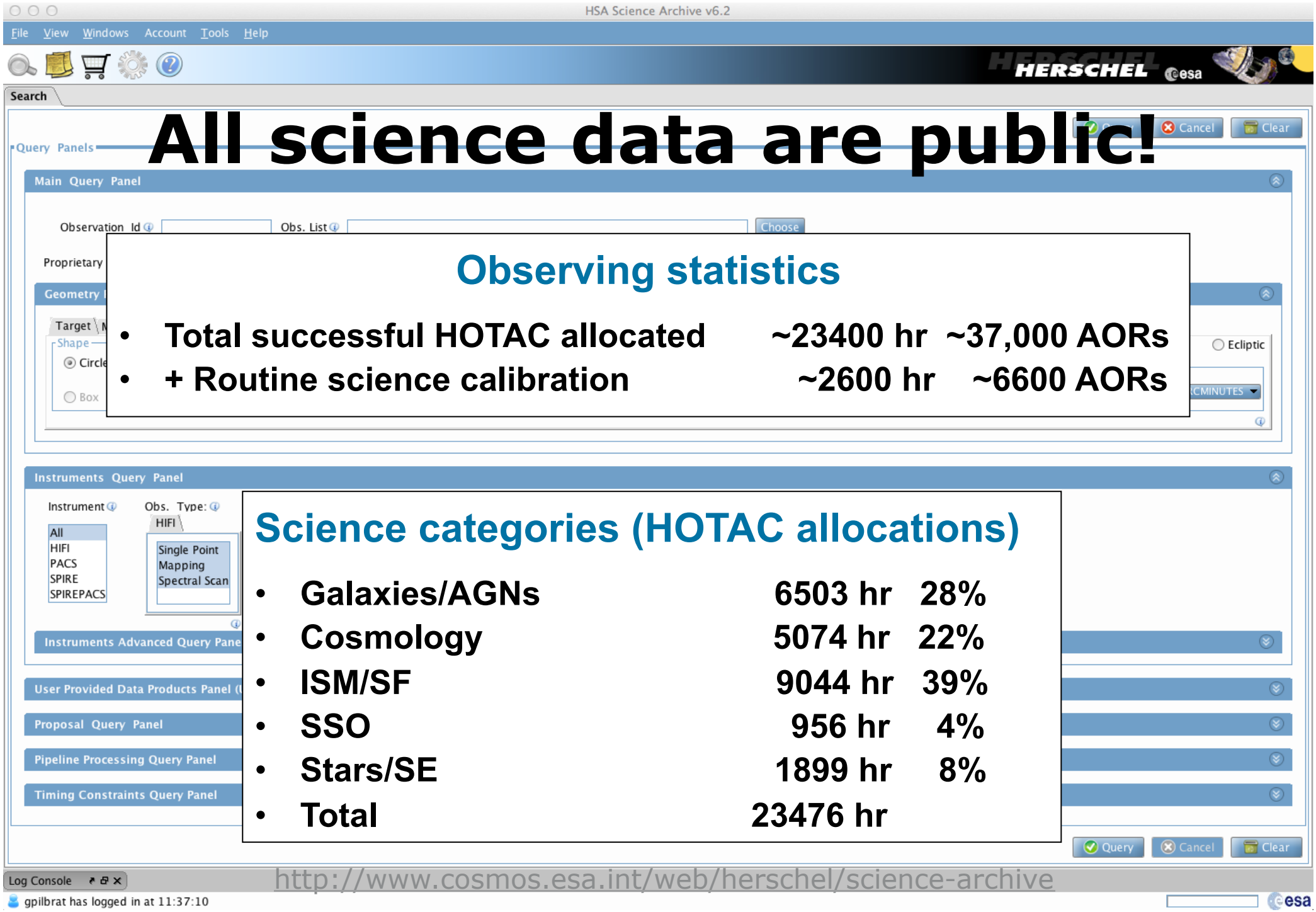
These numbers are %-ages of the entire sky (~41,000 sq deg)

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

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

HERSCHEL SPACE OBSERVATORY


HSA Science Archive v6.2
File View Windows Account Tools Help
HERSCHEL esa
Search
All science data are public!
Query Panels
Cancel
Clear
Main Query Panel
Observation Id
Obs. List
Choose
Proprietary
Observing statistics
• Total successful HOTAC allocated ~23400 hr ~37,000 AORs
• + Routine science calibration ~2600 hr ~6600 AORs
Geometry
Target
Shape
Circle
Box
Ecliptic
Instruments Query Panel
Instrument
Obs. Type:
Standard Data
All
HIFI
PACS
SPIRE
SPIREPACS
HIFI
Single Point
Mapping
Spectral Scan
PACS
Pacs Photometer
Range Spectroscopy
Line Spectroscopy
SPIRE
Photometer
Spectrometer
SPIREPACS
Parallel Mode
Instruments Advanced Query Panel
User Provided Data Products Panel (UPDP)
Proposal Query Panel
Pipeline Processing Query Panel
Timing Constraints Query Panel
Query
Cancel
Clear
Log Console
gpilbrat has logged in at 11:37:10
http://www.cosmos.esa.int/web/herschel/science-archive
esa



All science data are public!

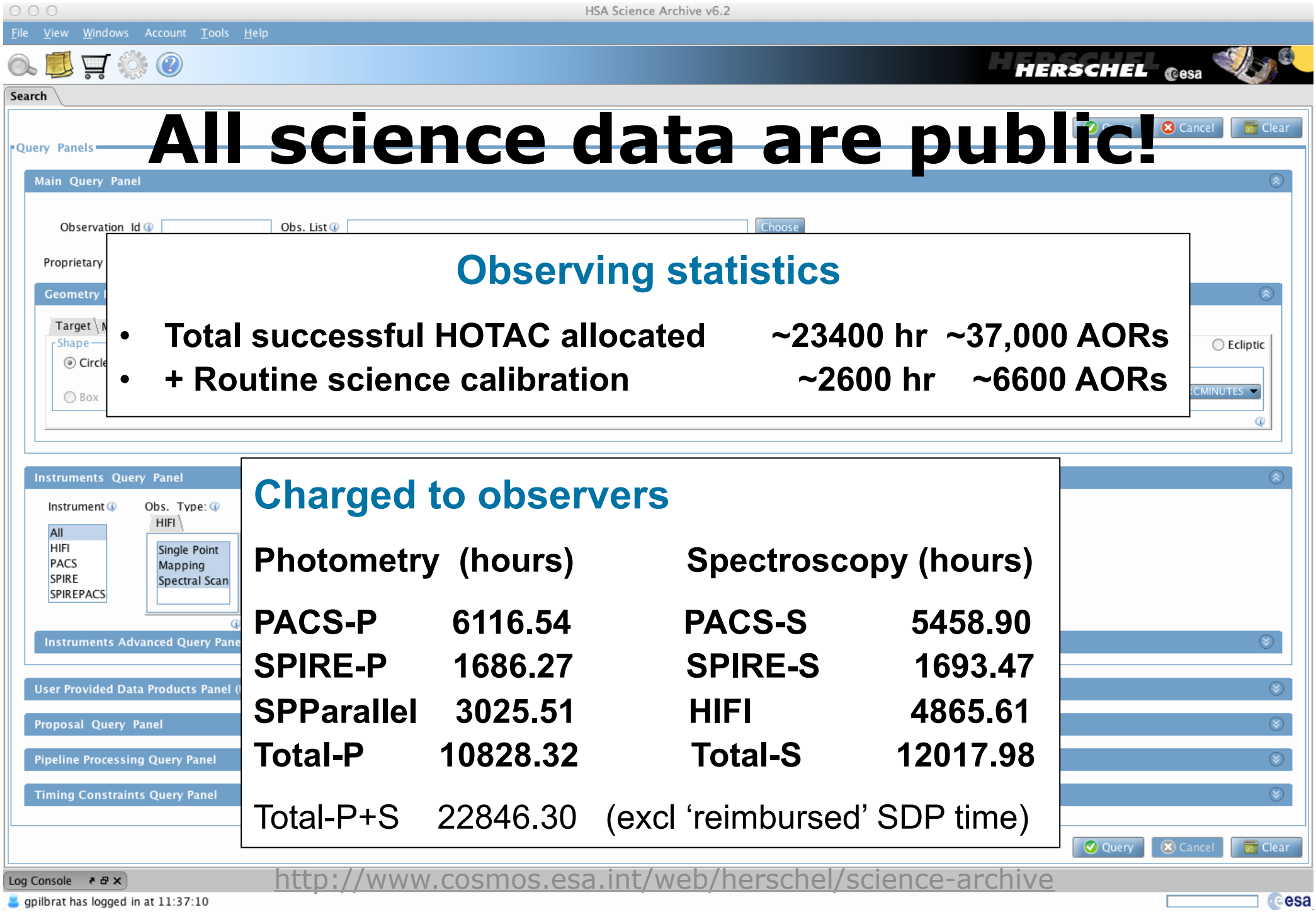
Observing statistics

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

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	

http://www.cosmos.esa.int/web/herschel/science-archive



All science data are public!

Observing statistics

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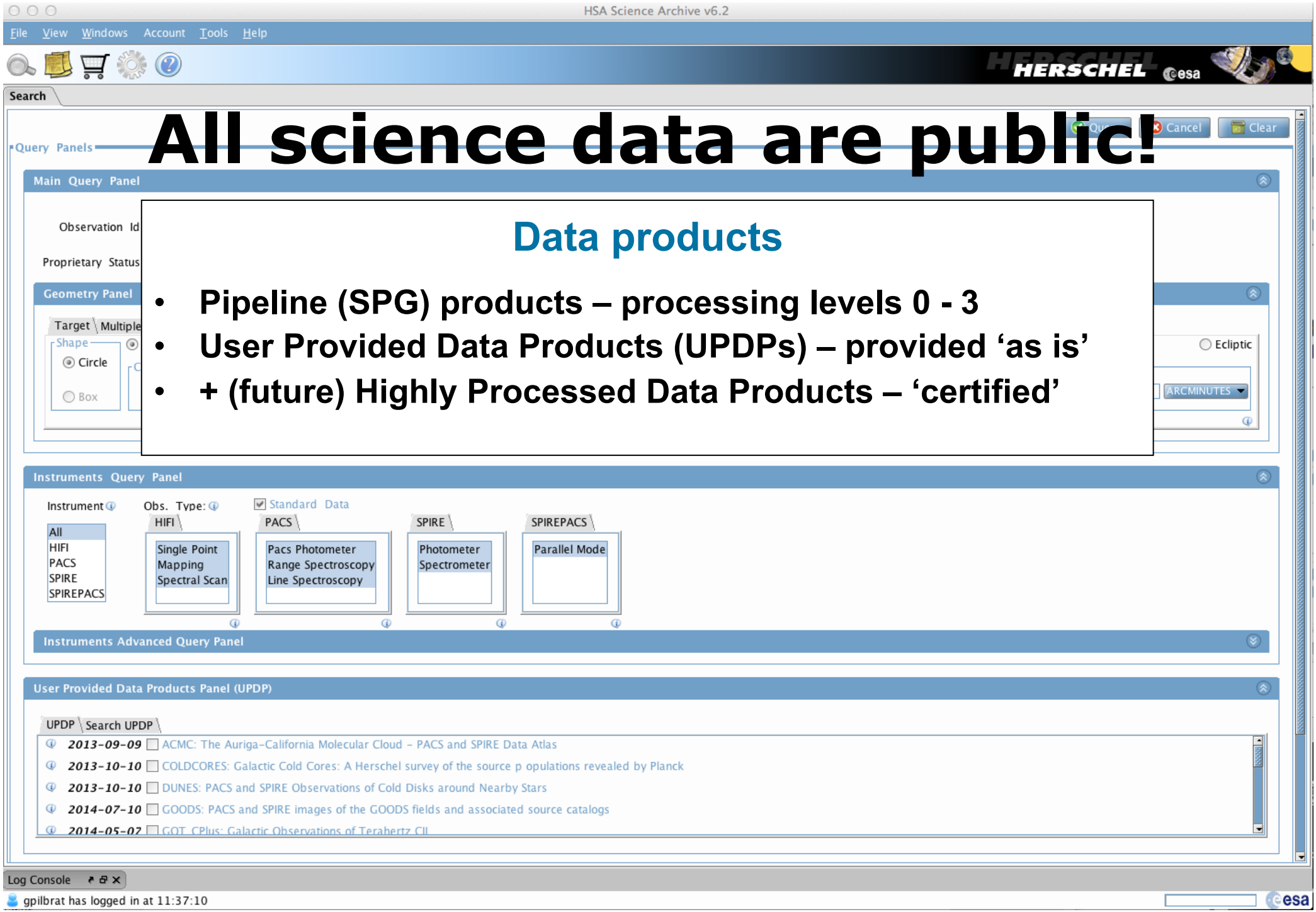
- + Routine science calibration ~2600 hr ~6600 AORs

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 'reimbursed' SDP time)	

http://www.cosmos.esa.int/web/herschel/science-archive



All science data are public!

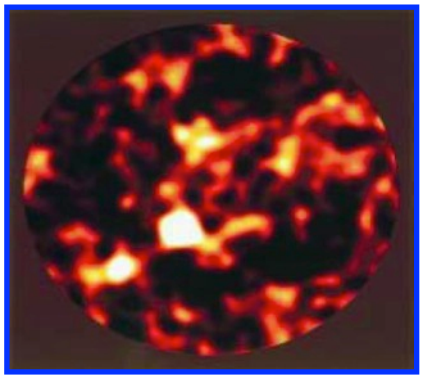
Data products

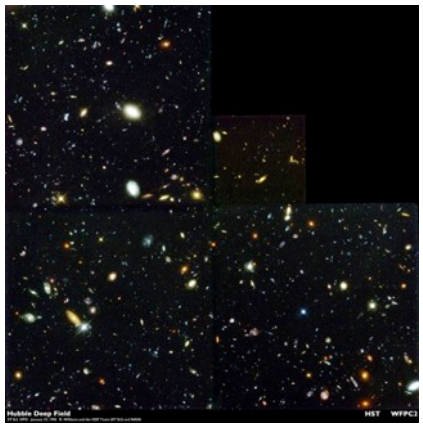
- Pipeline (SPG) products – processing levels 0 - 3
- User Provided Data Products (UPDPs) – provided ‘as is’
- + (future) Highly Processed Data Products – ‘certified’

Proposal ID	Proposal Name	Release Note	User Provided Data Products Repository	Related Publications	Latest update	Ingested in HSA ?
KPGT_ebergin_1	HEXOS: Herschel Observations of EXtra-Ordinary Sources: The Orion and Sgr B2 Star-Forming Regions	HEXOS Release Note	HEXOS Data	Crockett et al. 2014a Crockett et al. 2014b Neill et al. 2014	[19-Feb-2015]	NO
KPOT_mmeixner_1	HERschel Inventory of The Agents of Galaxy Evolution (HERITAGE) in the Magellanic Clouds	HERITAGE README file	HERITAGE Data HERITAGE Band Merged Catalogs	Meixner et al. 2013 Seale et al. 2014	[21-Nov-2014]	**YES** (except the band merged catalogs)
GT1_golofs01_4 GT2_jbouwman_3	SPIRE spectroscopy of protoplanetary disks	Data Release Note	Data Repository	van der Wiel et al. 2014	[29-Oct-2014]	**YES**
KPGT_soliver_1	HerMES	HerMES Release note	HerMES Data Release	HerMES related publications	[11-Jul-2014]	**YES**
KPGT_cwilso01_1	Physical Processes in the Interstellar Medium of Very Nearby Galaxies	VNGS Release note (SPIRE data) VNGS Release note (PACS Phot data) VNGS Release note (PACS Spec data)	VNGS Data release (SPIRE data) and postcards VNGS Data release (PACS Phot data) and postcards VNGS Data release (PACS Spec data)	Bendo et al. 2012	[10-Jul-2014]	YES (PACS Spec data on going)
KPOT_wlangerl_1	State of the Diffuse ISM: Galactic observations of the Terahertz CII Line (GOT CPlus)	GOT CPlus Release Note	GOT CPlus Data GOT CPlus Postcards	Pineda et al. 2013 Langer et al. 2014	[07-Feb-2014]	**YES**
KPGT_aabergel_1	Evolution of interstellar dust	Release Note	Herschel IDOC Database (HESIOD)	Related Publications	[18-Nov-2013]	NO
KPOT_rkennicu_1	Key Insights on Nearby Galaxies: a Far Infrared Survey with Herschel (KINGFISH)	KINGFISH Data Products Delivery - DR3 User's Guide	KINGFISH Data Products (DR3) repository	Kennicutt et al. 2011	[21-Oct-2013]	**YES**
KPOT_mjuvela_1	Galactic Cold Cores: A Herschel survey of the source populations revealed by Planck	ColdCores Release Note	ColdCores Data Repository	Juvela et al. 2010, 2011, 2012	[1-Oct-2013]	**YES**
KPOT_celroa_1	Cold Disks around Nearby Stars. A Search for Edgeworth-Kuiper Belt analogues (DUNES: DUst disks around NEarby Stars)	The DUNES archive (Release Note)	DUNES Final Archive	Eiroa et al. 2013	[09-Jul-2013]	**YES**
KPOT_pgolds01_1	Herschel Oxygen Project (HOP)	Data Release Document	HOP Data	Goldsmith et al. 2011	[6-May-2013]	**YES**
OT1_pharve01_3	The Auriga-California Molecular Cloud: A Massive Nearby Cloud With Powerful Diagnostics For Early Stages of Star Formation.	Harvey et al. 2013	Data Repository	Harvey et al. 2013	[11-Mar-2013]	**YES**
KPGT_dlutz_1	PACS Evolutionary Probe (PEP)	PEP Release Note (PACS data) PEP Release Note (SPIRE data)	PEP public data releases	Lutz et al. PEP related publications	[01-Mar-2013]	**YES**
KPGT_vbujarra_1	HIFISTARS: The physical and chemical circumstellar environments around evolved stars	HIFISTARS Release Note	HIFISTARS Data Repository	Bujarrabal et al. 2012	[16-Nov-2012]	**YES**
KPOT_delbaz_1	The Great Observatories Origins Deep Survey : far-infrared imaging with Herschel (GOODS)	GOODS-Herschel release documentation	GOODS-North Data GOODS-South Data	GOODS-Herschel related publications	[12-Sep-2012]	**YES**
KPOT_ckrame01_1	Herschel M33 extended survey (HerM33es)	HerM33es : Herschel M33 extended survey - SPIRE Data Products Delivery User's Guide HerM33es: Herschel M33 extended survey - PACS Data Products Delivery User's Guide	HermesPublicData	Xilouris et al. 2012 Boquien et al. 2011 Kramer et al. 2010	[2-Mar-2012]	**YES**
KPOT_jdavie01_1	The Herschel Virgo Cluster Survey (HeViCS)	Data Reduction for HEVICS Public Data Release of 2 Scan DatA	The first HeViCS public data release	The HeViCS papers	[2-Sep-2011]	NO
KPOT_seales01_2	H-ATLAS	First data release of the Herschel ATLAS	H-ATLAS SDP images and files H-ATLAS SDP catalogue	PACS maps (Ibar et al. 2010) SPIRE maps (Pascale et al. 2010) S-band source catalogue (Rigby et al. 2010)	[24-Oct-2010]	NO

Submm Galaxies - SMGs

1998
SCUBA HDF:
5 sources after 20 exceptional nights



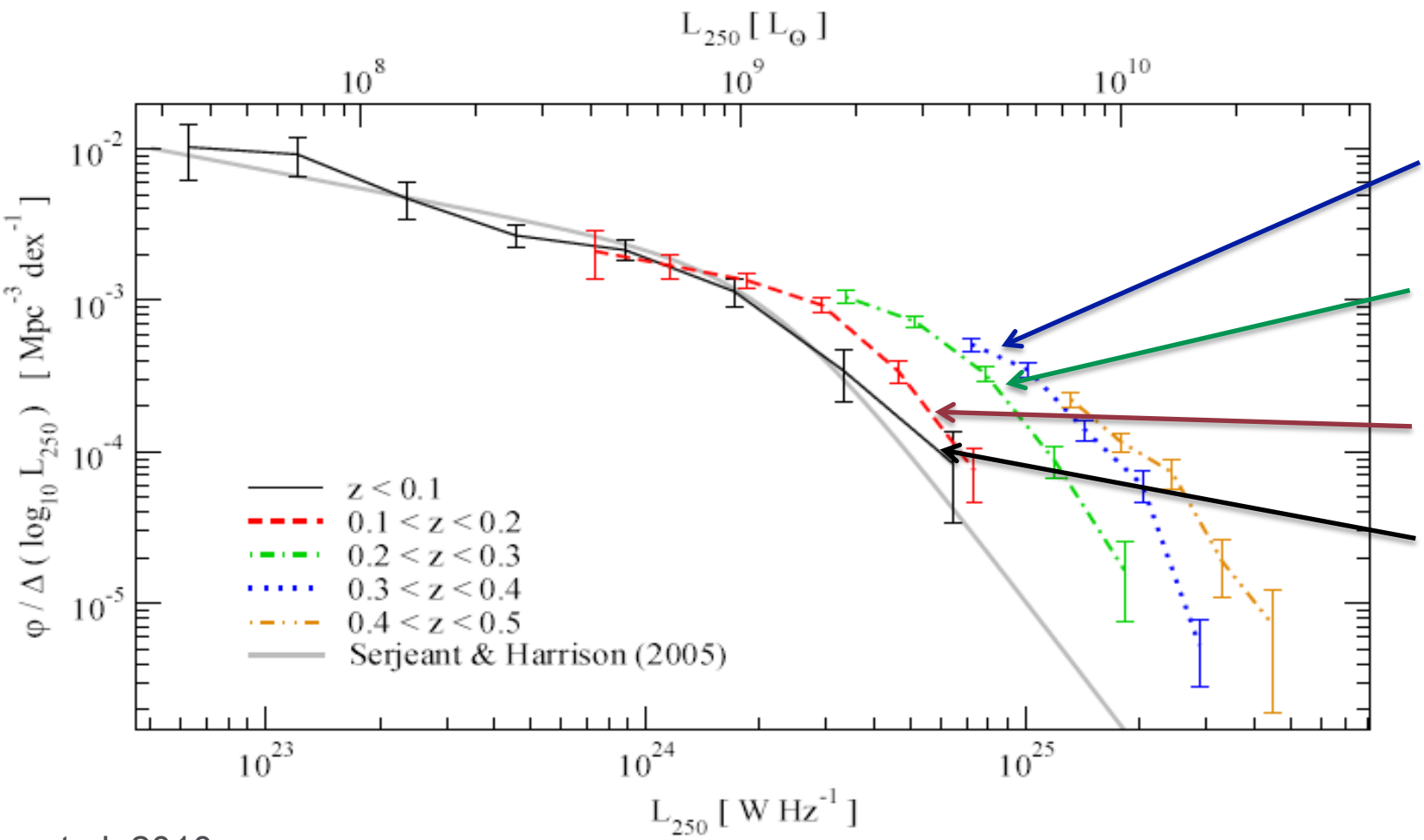


~3 arcmin

4 x 4^0

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

Evolution of the 250 um Luminosity Function



3 billion years ago

2 billion years ago

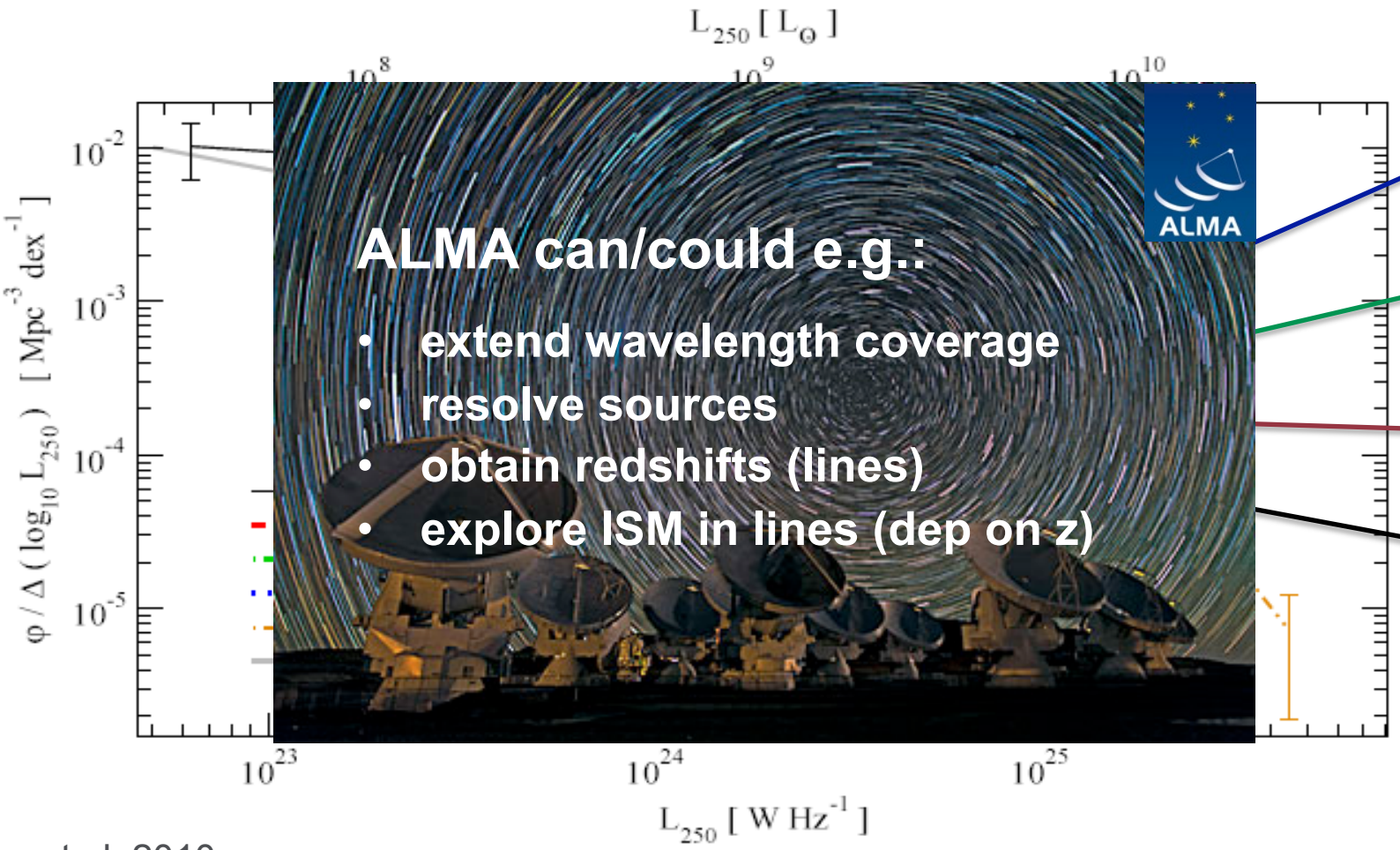
1 billion years ago

Now

Dye et al. 2010
A&A 518, L10 (Special Issue)

HERSCHEL SPACE OBSERVATORY

Evolution of the 250 um Luminosity Function



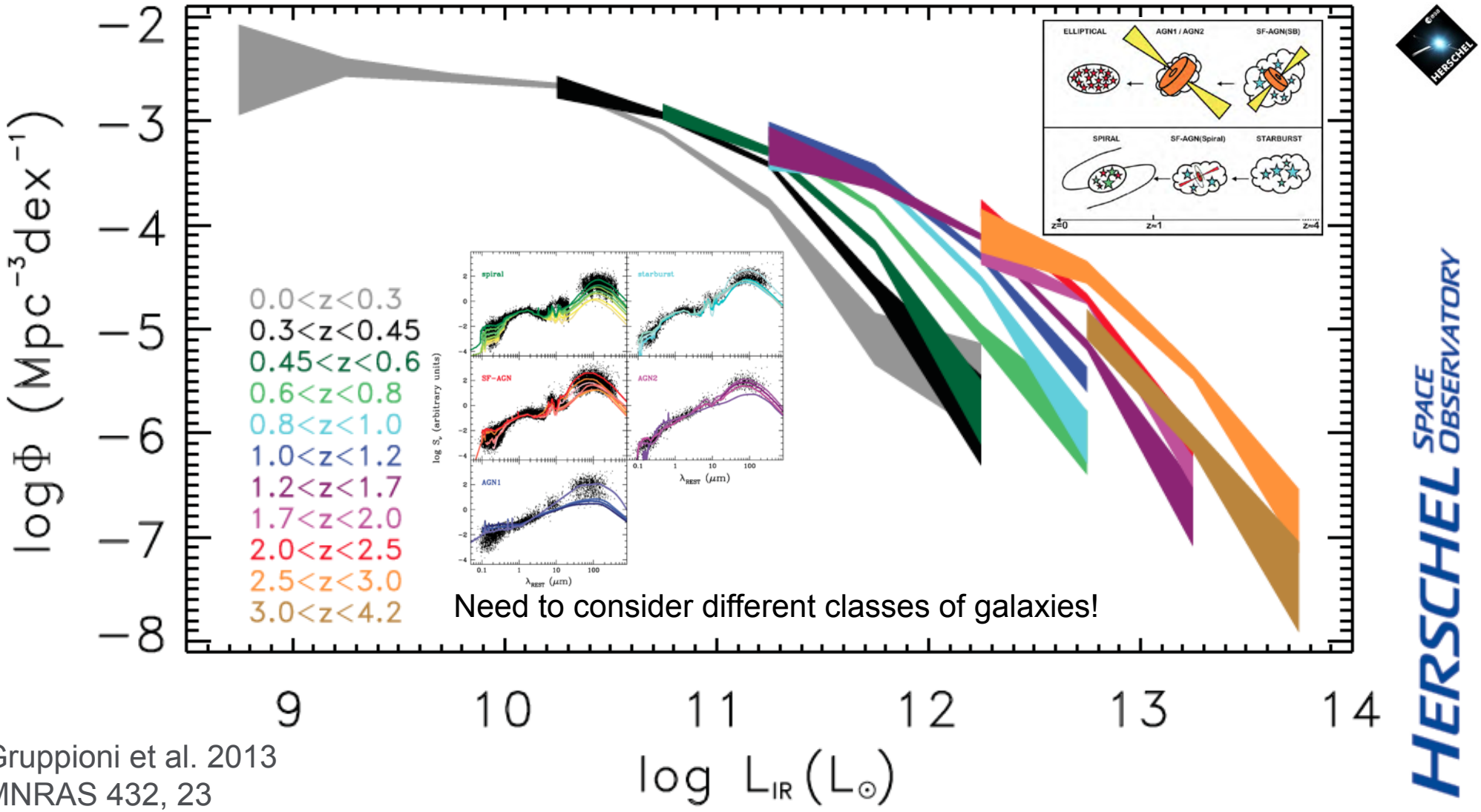
ALMA can/could e.g.:

- extend wavelength coverage
- resolve sources
- obtain redshifts (lines)
- explore ISM in lines (dep on z)

Dye et al. 2010
A&A 518, L10 (Special Issue)

HERSCHEL SPACE OBSERVATORY

Total IR LF from four PEP fields



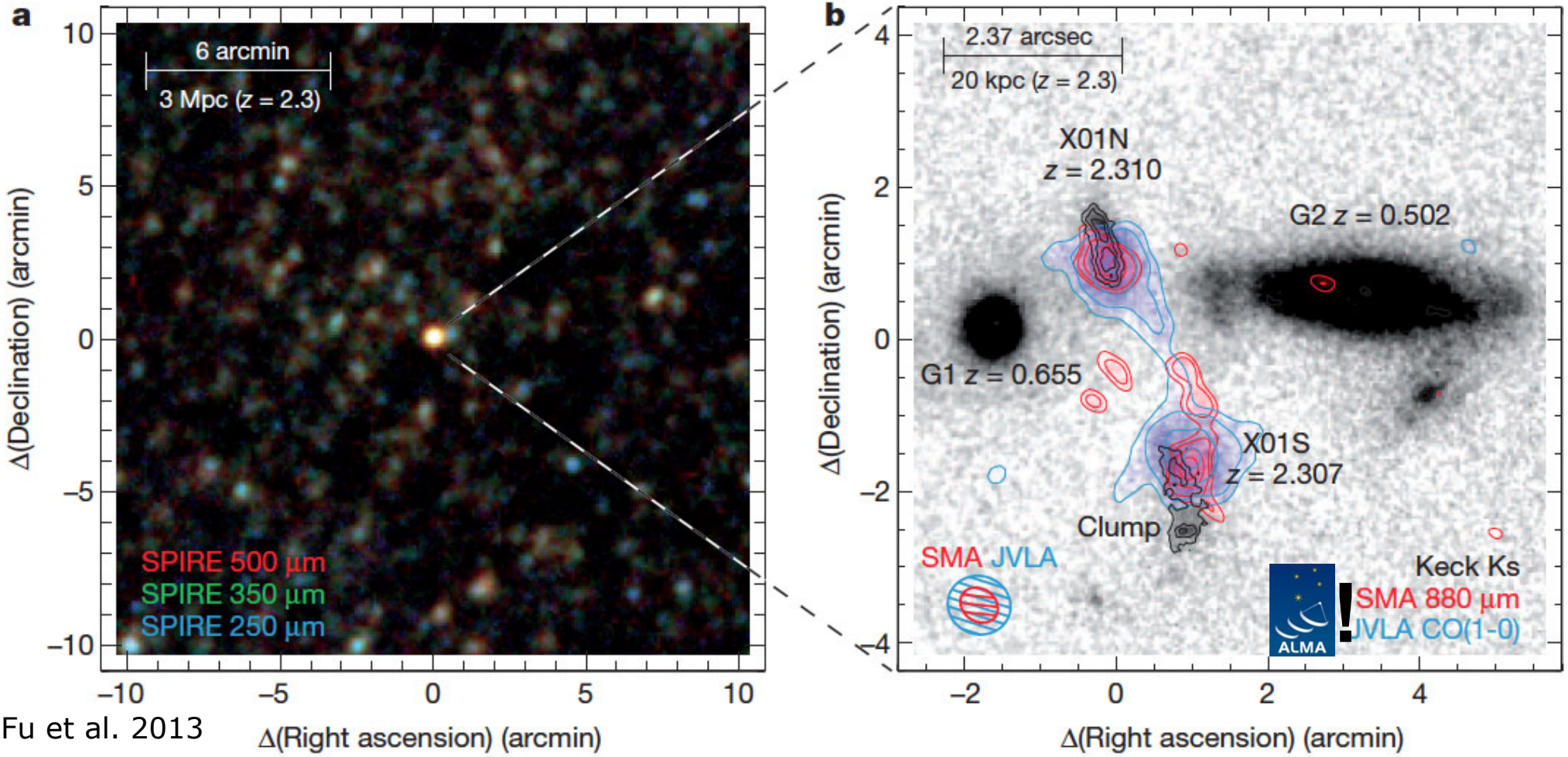
Gruppioni et al. 2013
MNRAS 432, 23

HERSCHEL SPACE OBSERVATORY

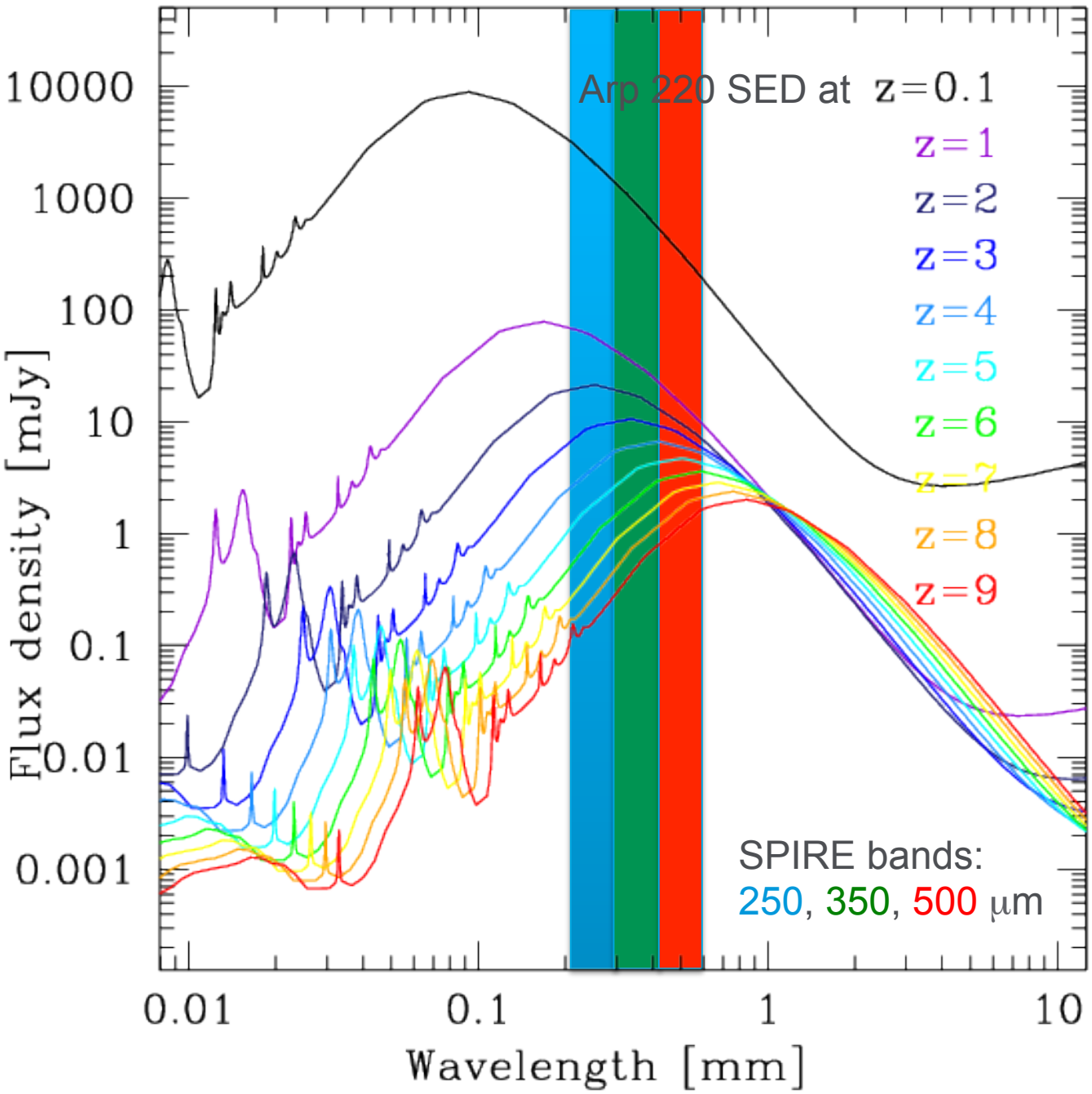
HXMM01 – massive merger at z=2.3

Merger of two SMGs, S_{850} ~20 mJy, separation 19 +/- 4 kpc

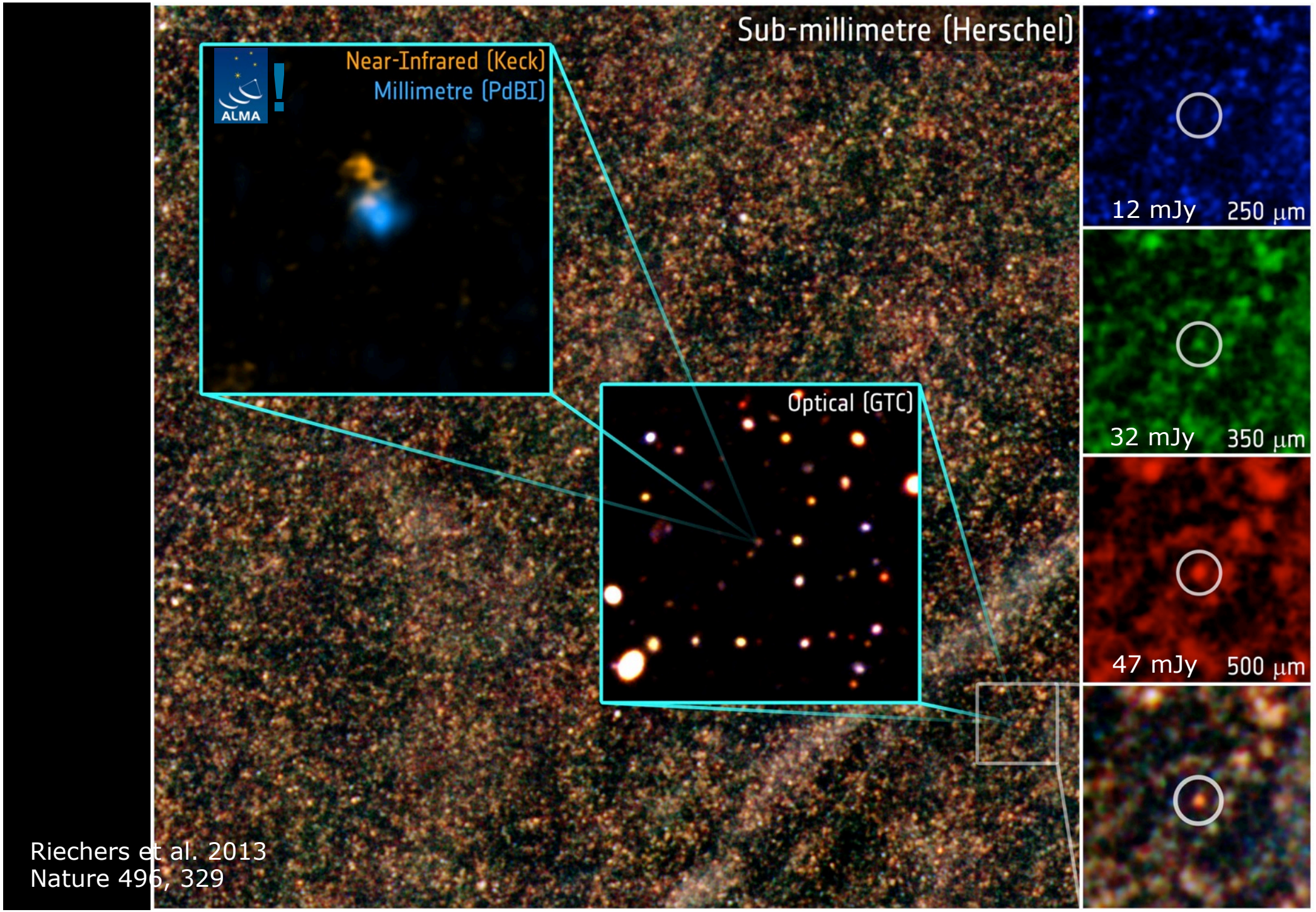
Mol gas mass (23 +/- 6)x $10^{10} M_{sun}$
SFR 2000 +/- 400 M_{sun}/yr



Fu et al. 2013



Roberto Decarli



Riechers et al. 2013
Nature 496, 329

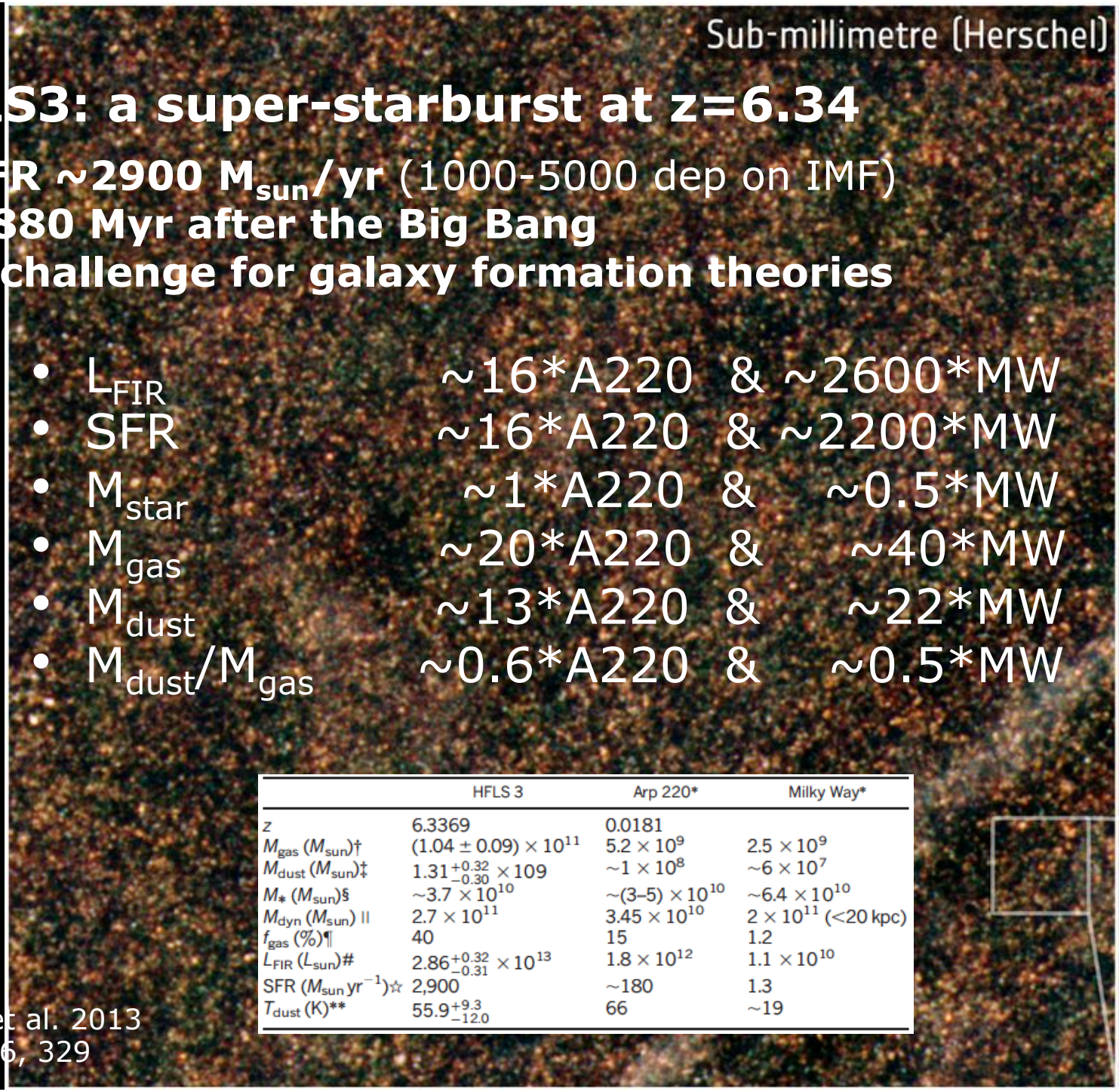
HFLS3: a super-starburst at z=6.34

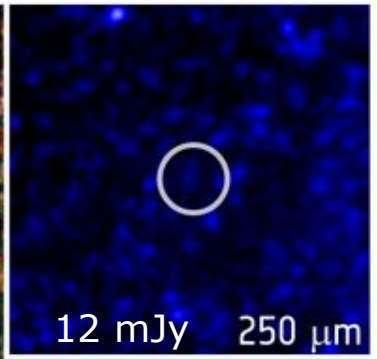
- **SFR ~2900 M_{sun}/yr** (1000-5000 dep on IMF)
- **~880 Myr after the Big Bang**
- **A challenge for galaxy formation theories**

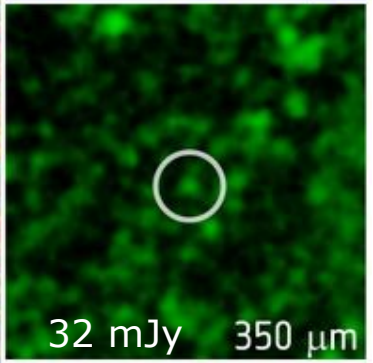
- L_{FIR} ~16*A220 & ~2600*MW
- SFR ~16*A220 & ~2200*MW
- M_{star} ~1*A220 & ~0.5*MW
- M_{gas} ~20*A220 & ~40*MW
- M_{dust} ~13*A220 & ~22*MW
- M_{dust}/M_{gas} ~0.6*A220 & ~0.5*MW

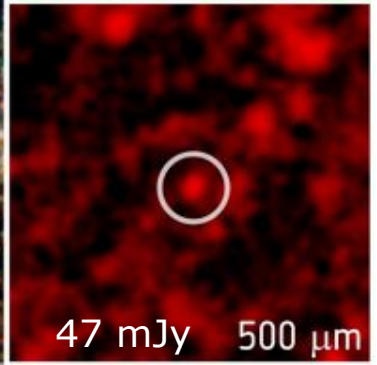
	HFLS 3	Arp 220*	Milky Way*
z	6.3369	0.0181	
M_{gas} (M_{sun})†	$(1.04 \pm 0.09) \times 10^{11}$	5.2×10^{9}	2.5×10^{9}
M_{dust} (M_{sun})‡	$1.31^{+0.32}_{-0.30} \times 109$	$\sim 1 \times 10^{8}$	$\sim 6 \times 10^{7}$
M_* (M_{sun})§	$\sim 3.7 \times 10^{10}$	$\sim(3\text{–}5) \times 10^{10}$	$\sim 6.4 \times 10^{10}$
M_{dyn} (M_{sun}) ‖	2.7×10^{11}	3.45×10^{10}	2×10^{11} (<20 kpc)
f_{gas} (%)¶	40	15	1.2
L_{FIR} (L_{sun})#	$2.86^{+0.32}_{-0.31} \times 10^{13}$	1.8×10^{12}	1.1×10^{10}
SFR ($M_{sun}\,yr^{-1}$)☆	2,900	~180	1.3
T_{dust} (K)**	$55.9^{+9.3}_{-12.0}$	66	~19

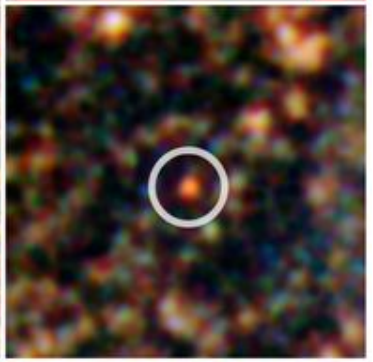
Riechers et al. 2013
Nature 496, 329

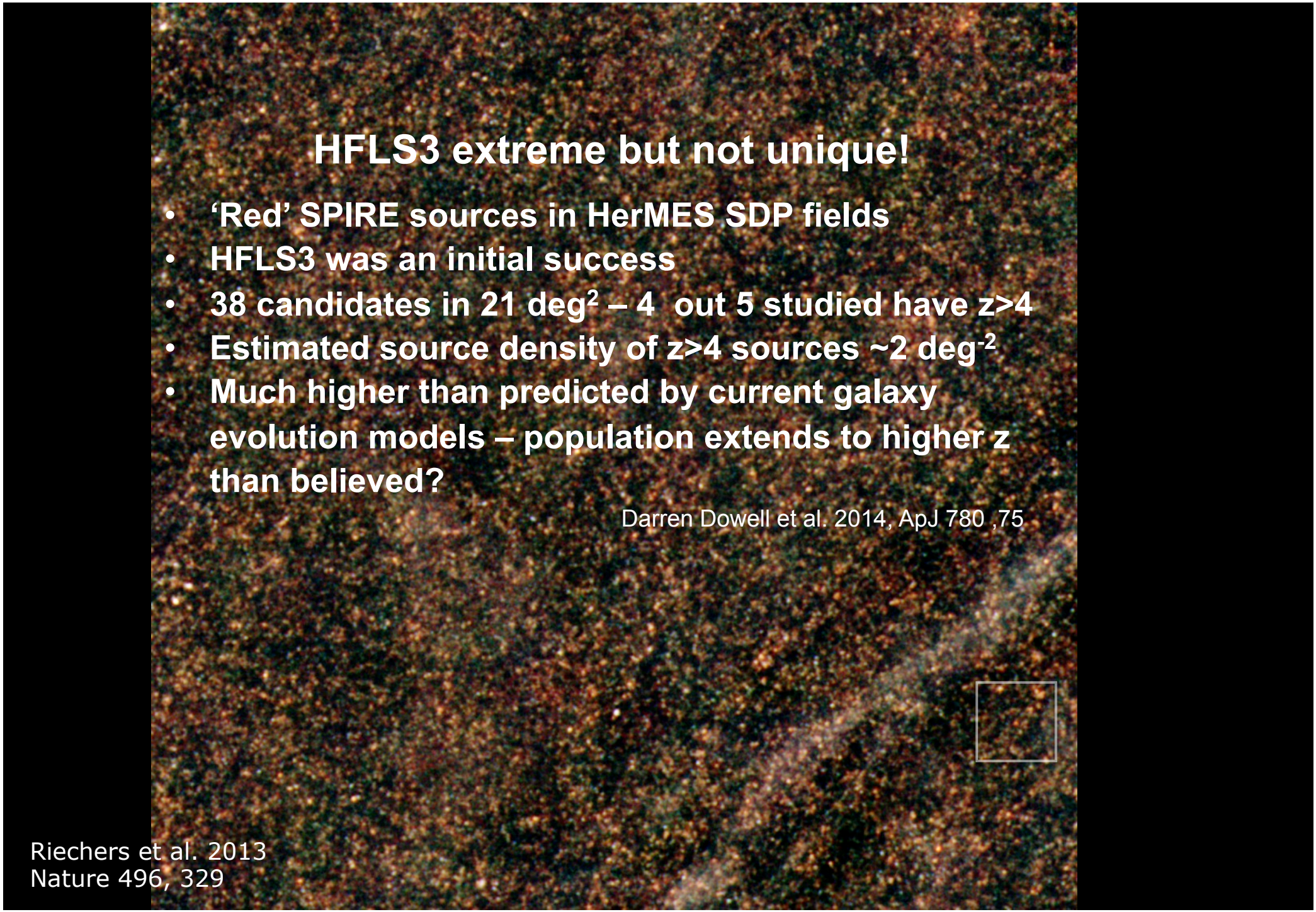






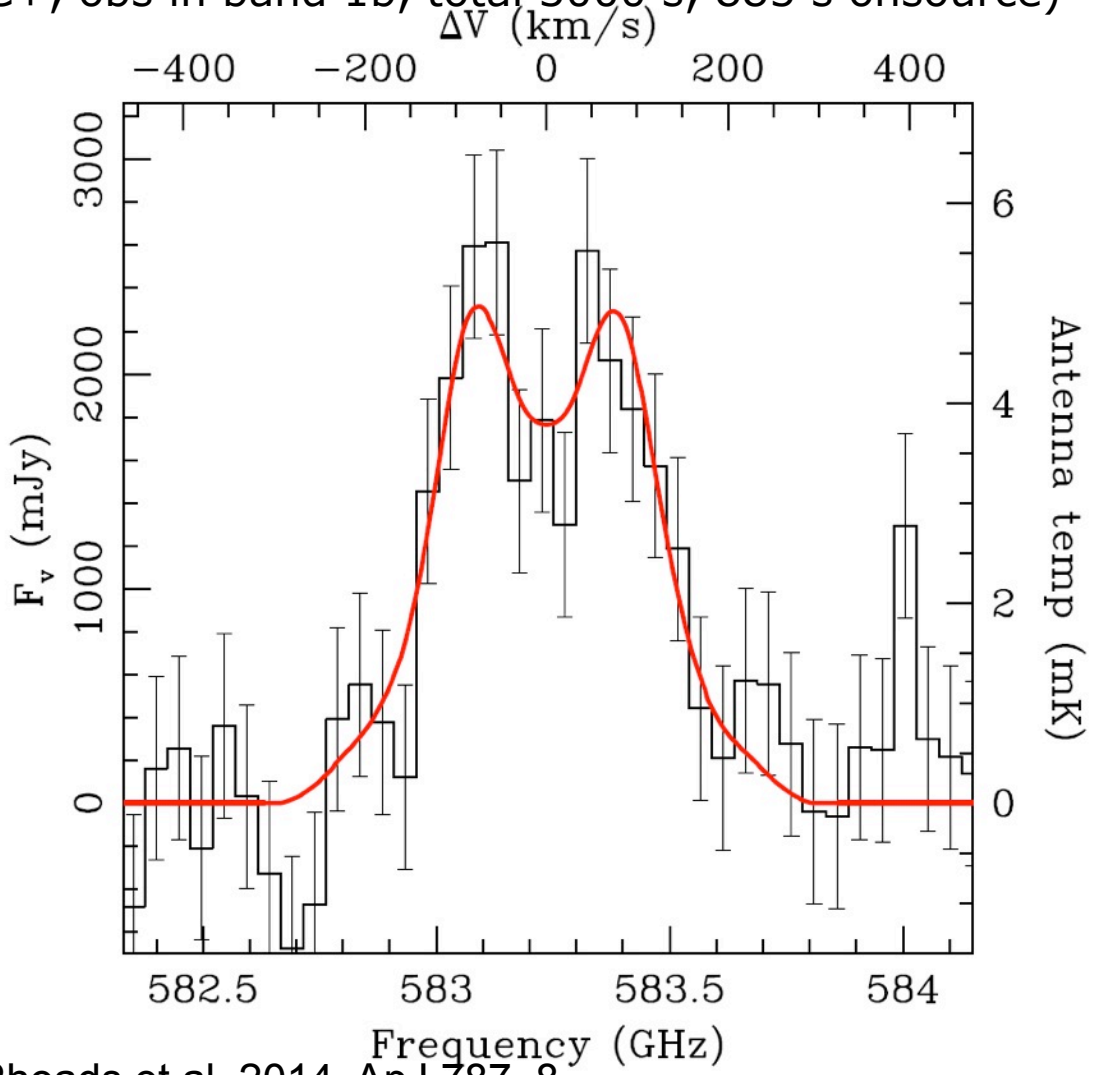





HFLS3 extreme but not unique!
• 'Red' SPIRE sources in HerMES SDP fields
• HFLS3 was an initial success
• 38 candidates in 21 deg^2 – 4 out 5 studied have z>4
• Estimated source density of z>4 sources ~2 deg^{-2}
• Much higher than predicted by current galaxy evolution models – population extends to higher z than believed?
Darren Dowell et al. 2014, ApJ 780 ,75
Riechers et al. 2013
Nature 496, 329

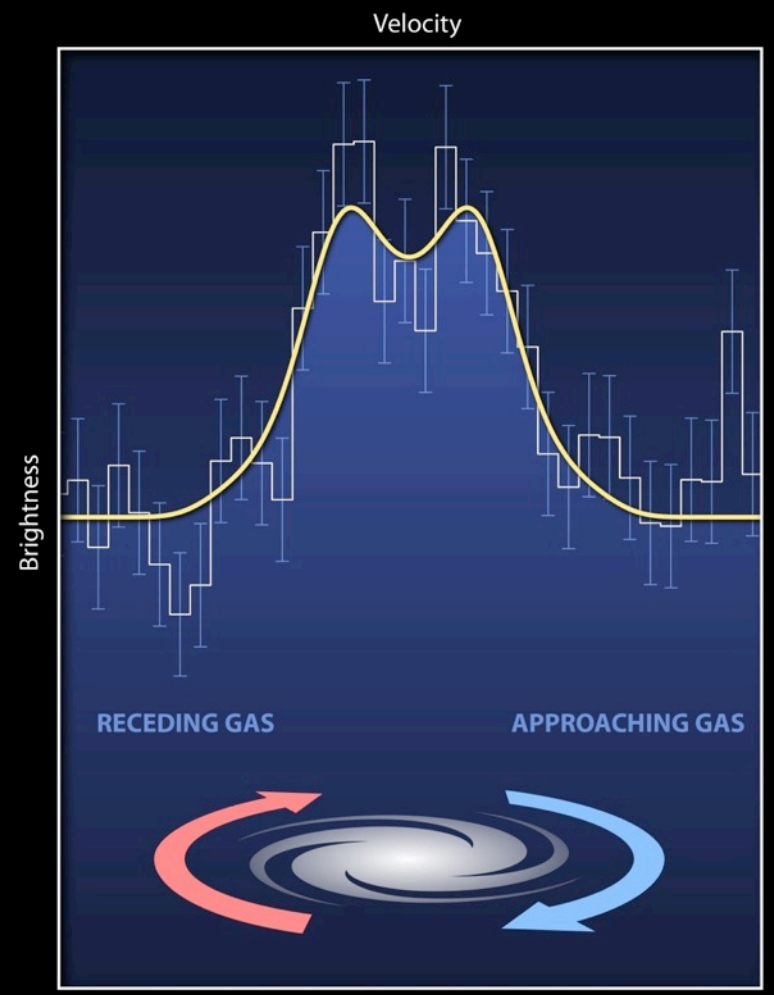
Kinematically mature z=2.26 galaxy

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



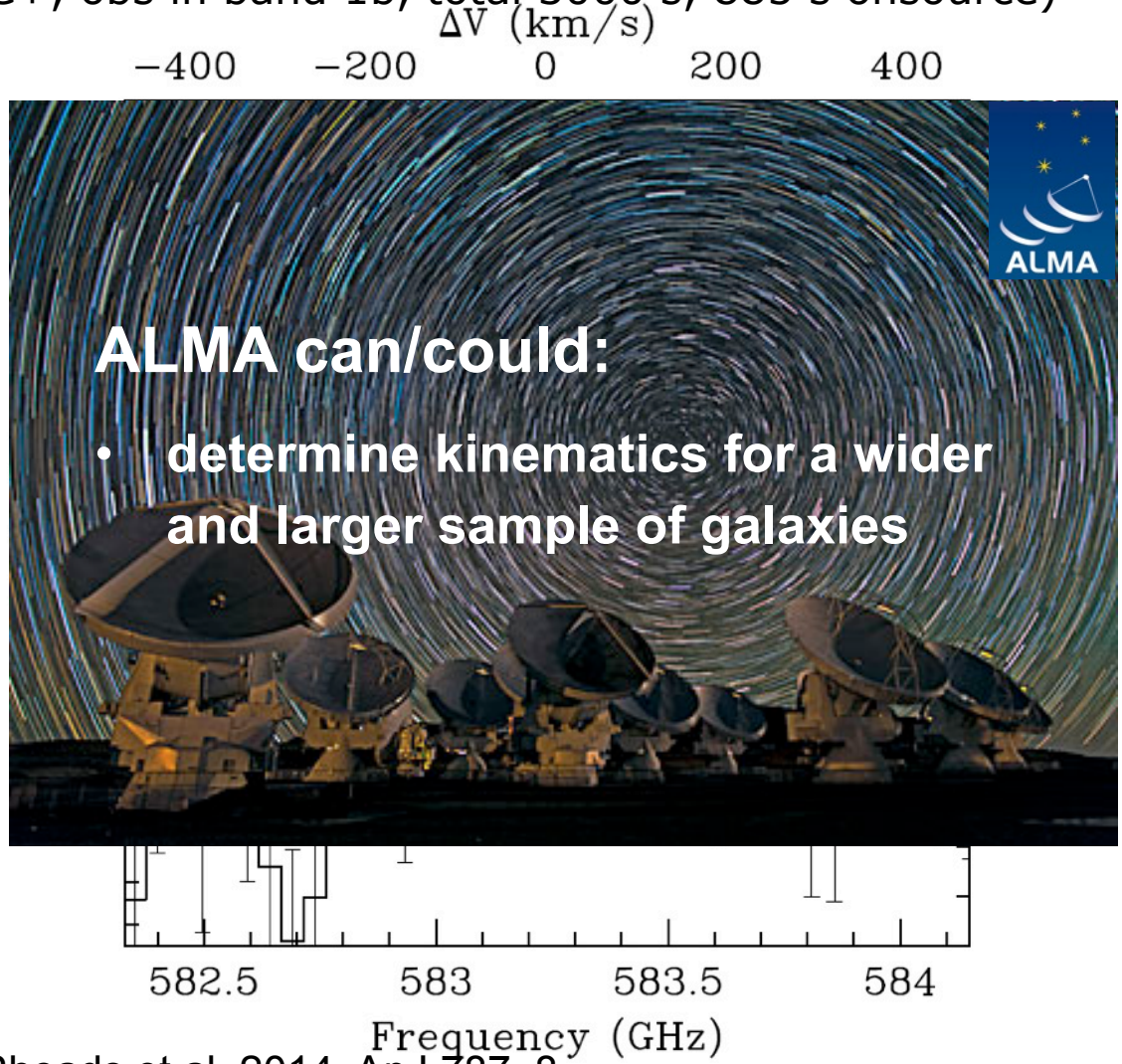
Rhoads et al. 2014, ApJ 787, 8

SDSS090122.37+181432.3 (S0901)



Kinematically mature z=2.26 galaxy

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

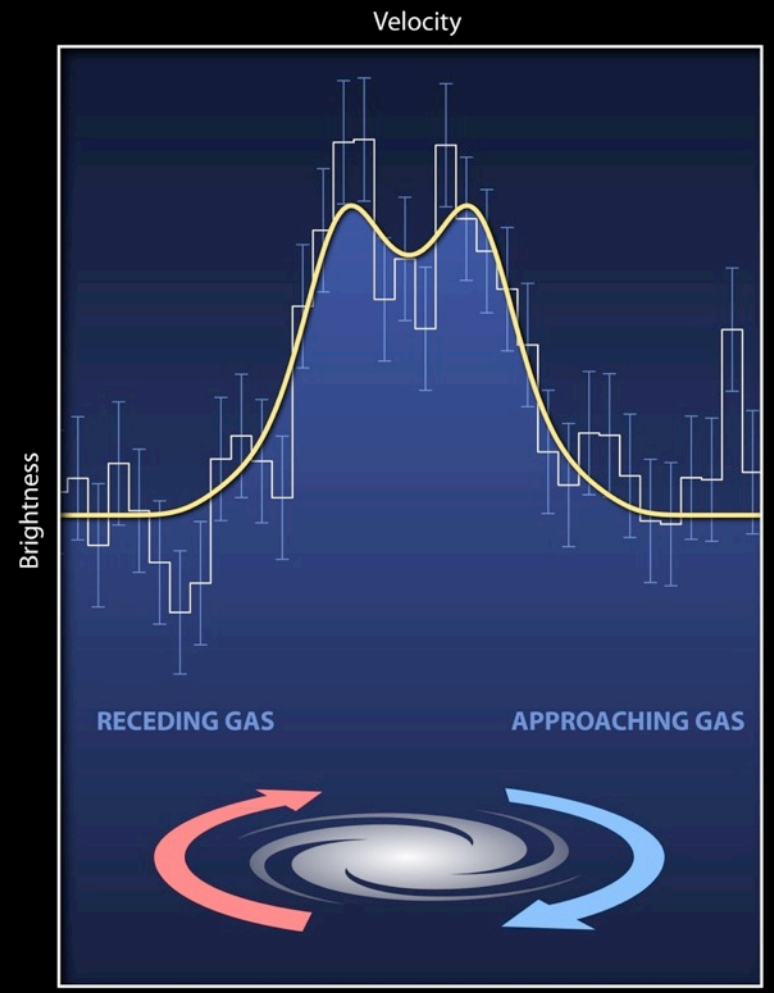


ALMA can/could:

- determine kinematics for a wider and larger sample of galaxies

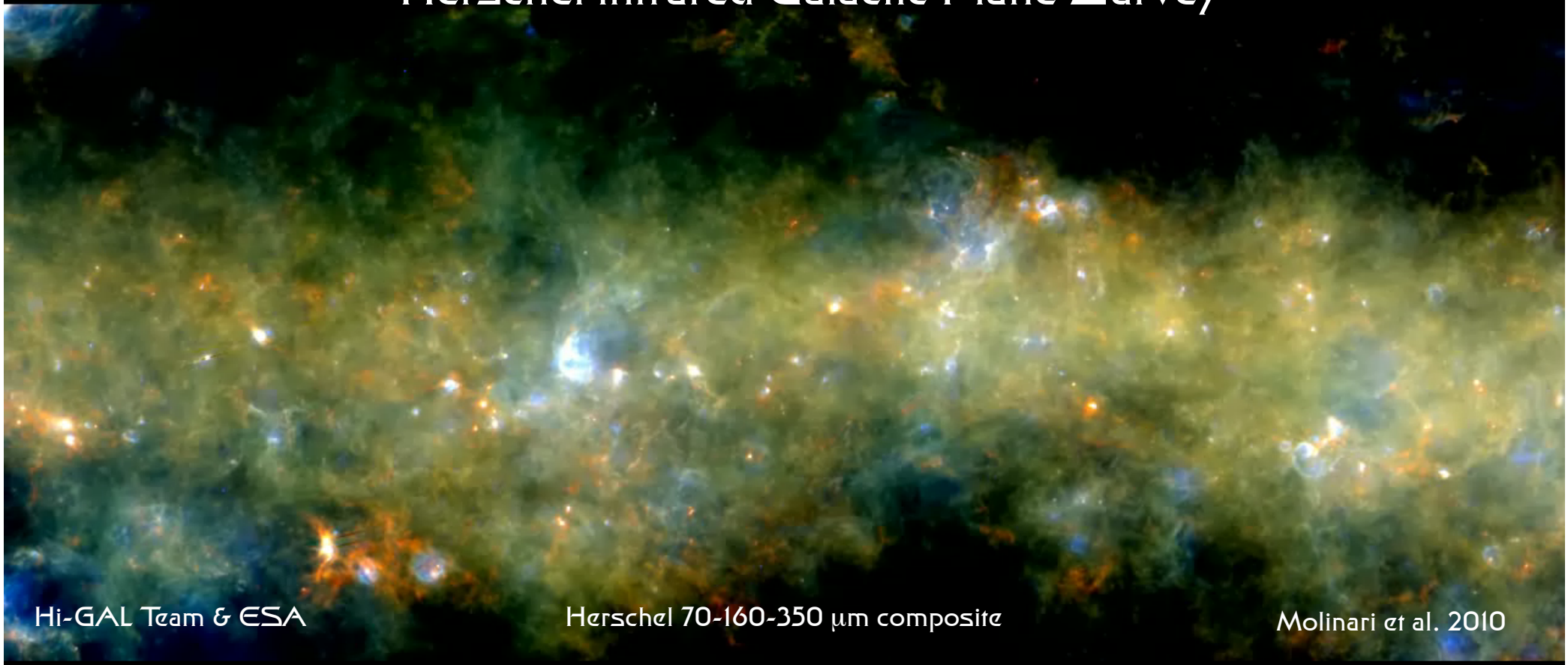
Rhoads et al. 2014, ApJ 787, 8

SDSS090122.37+181432.3 (S0901)



Hi-Gal

Herschel infrared Galactic Plane Survey

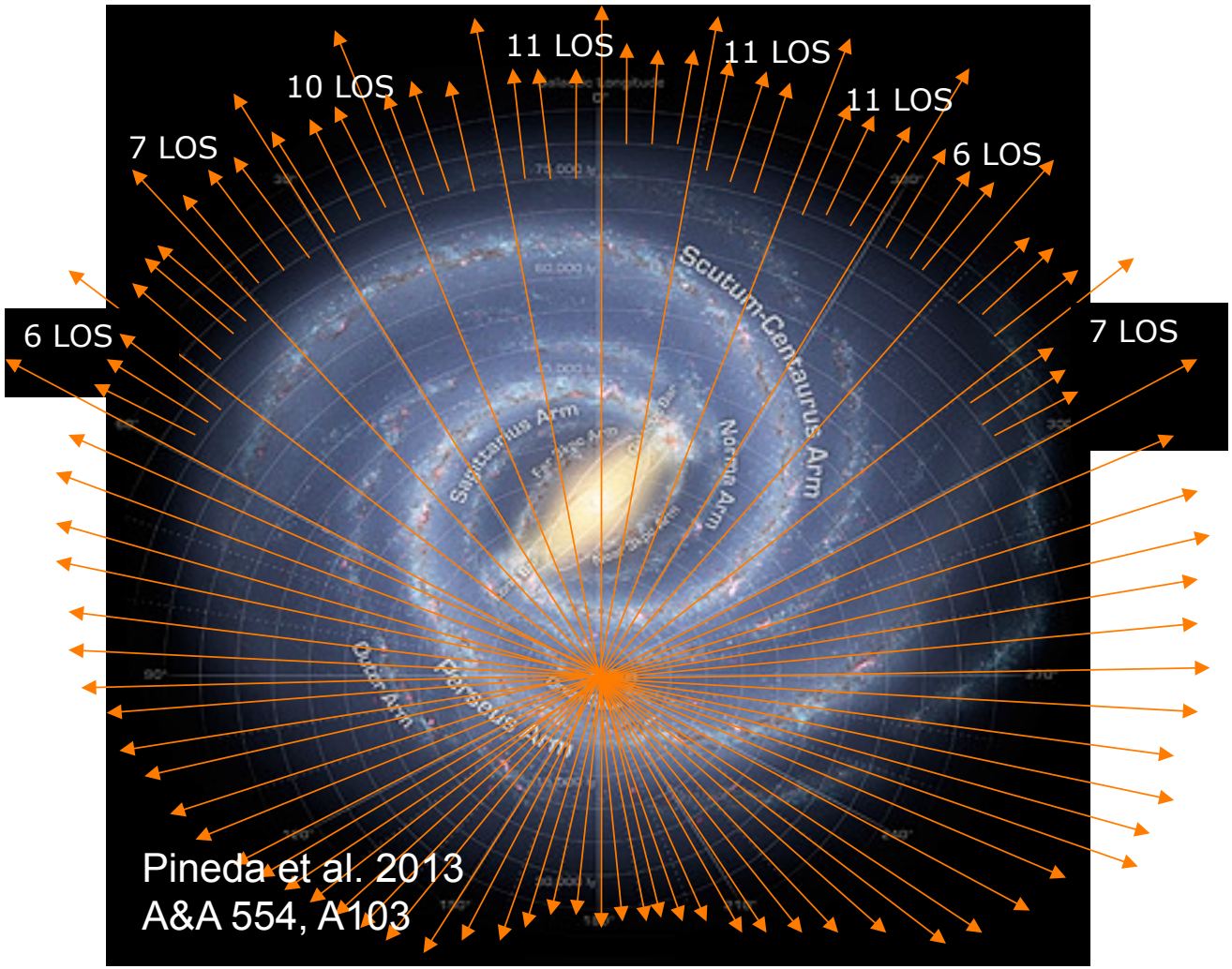


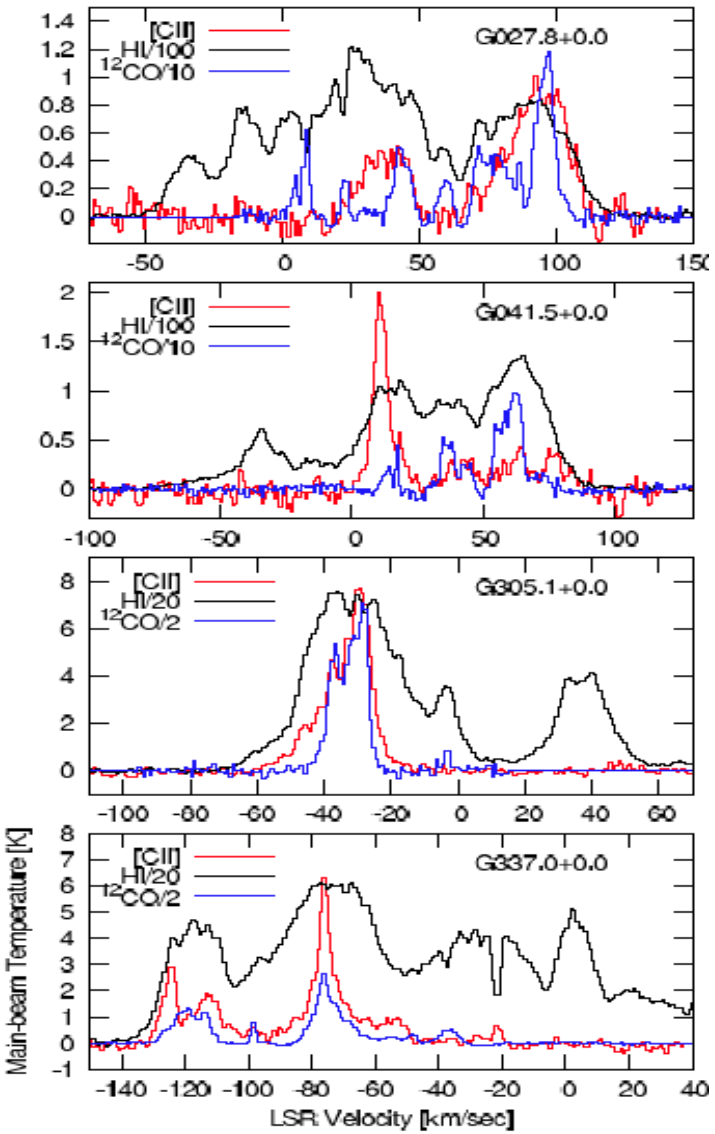
Toward a Predictive Global Model of Galactic Star Formation

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

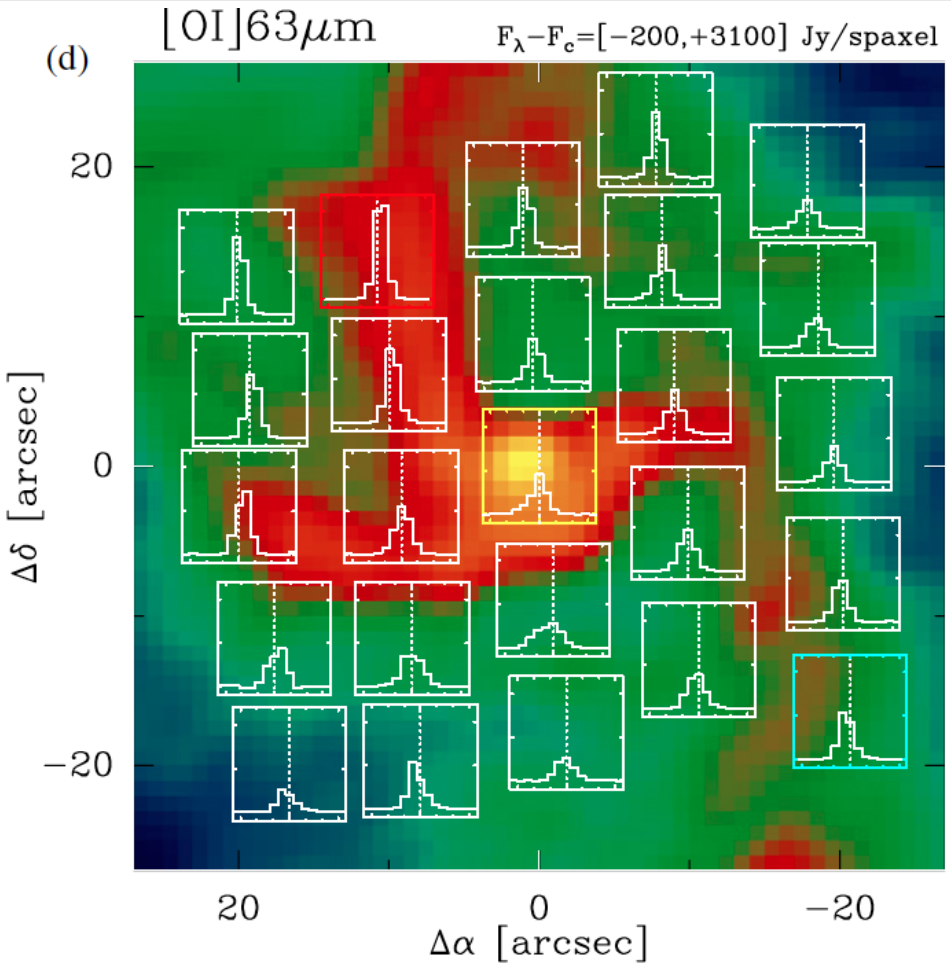
GOT C+ (158 um) HIFI galactic survey

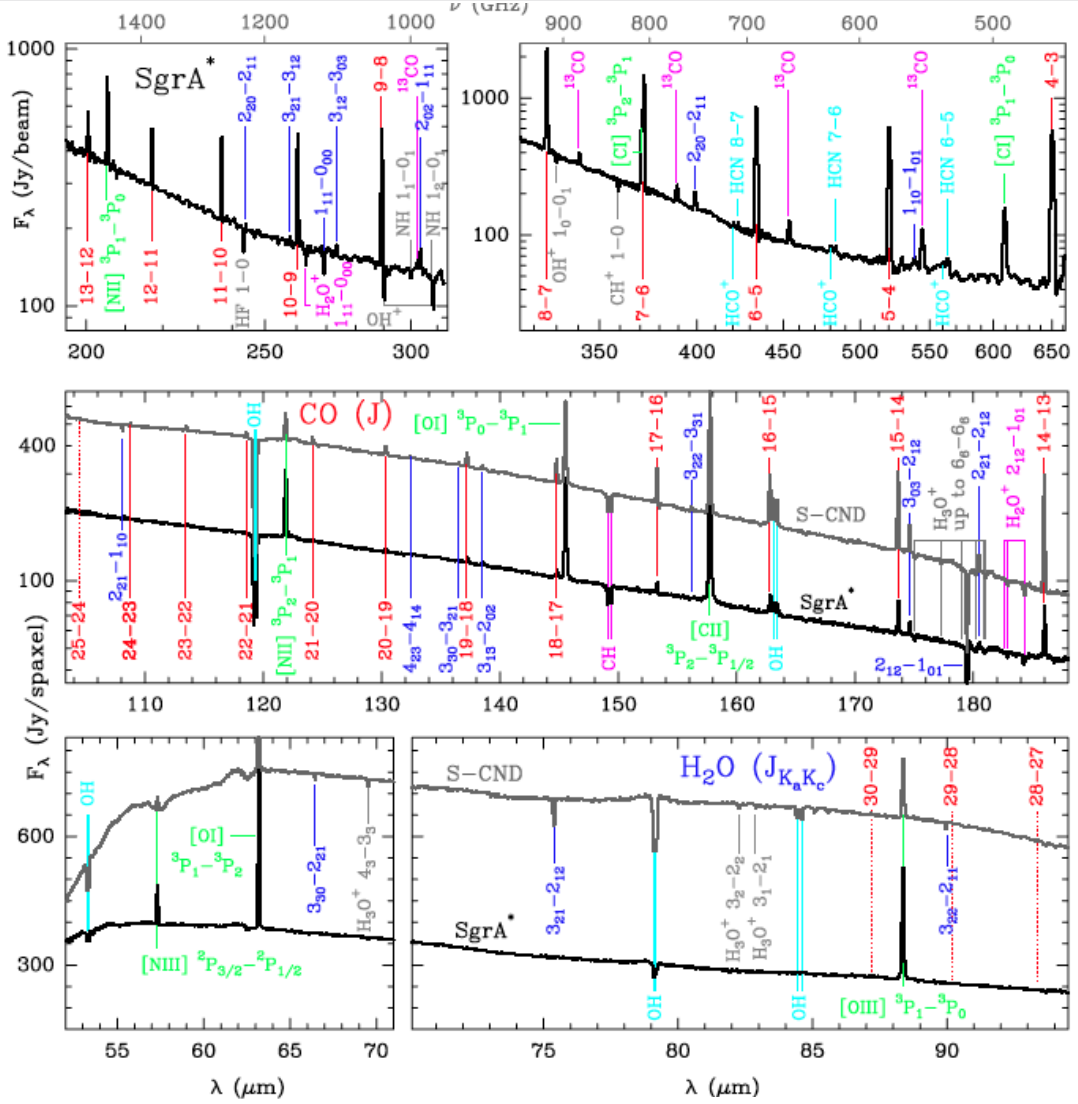
~500 LOS covering the Galaxy





Full PACS/SPIRE spectral survey of Sgr A*





Separating central cavity gas from circumnuclear disk at FIR

Goicoechea et al. 2013; ApJL 769, L13

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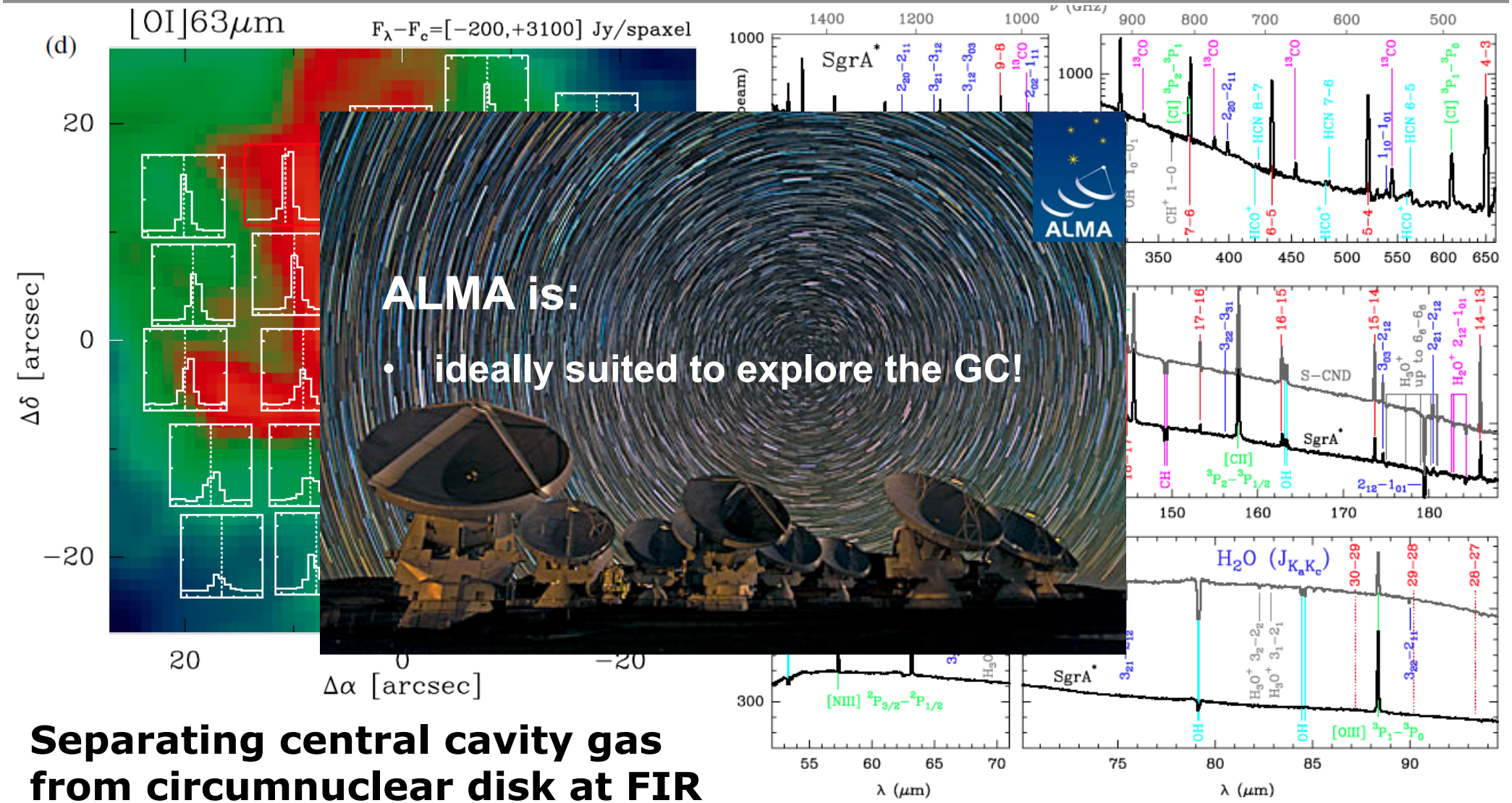

Separating central cavity gas from circumnuclear disk at FIR

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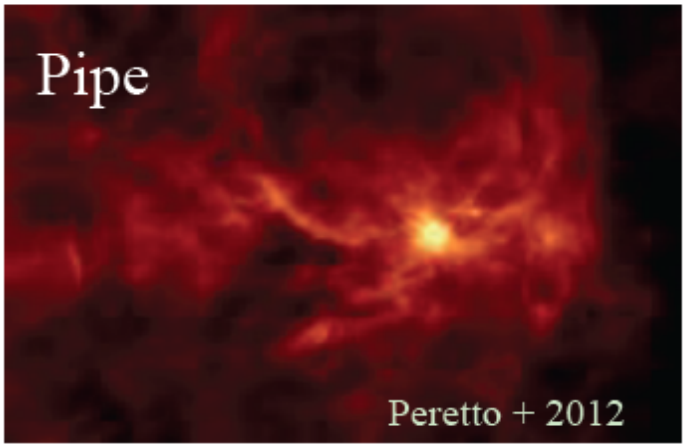
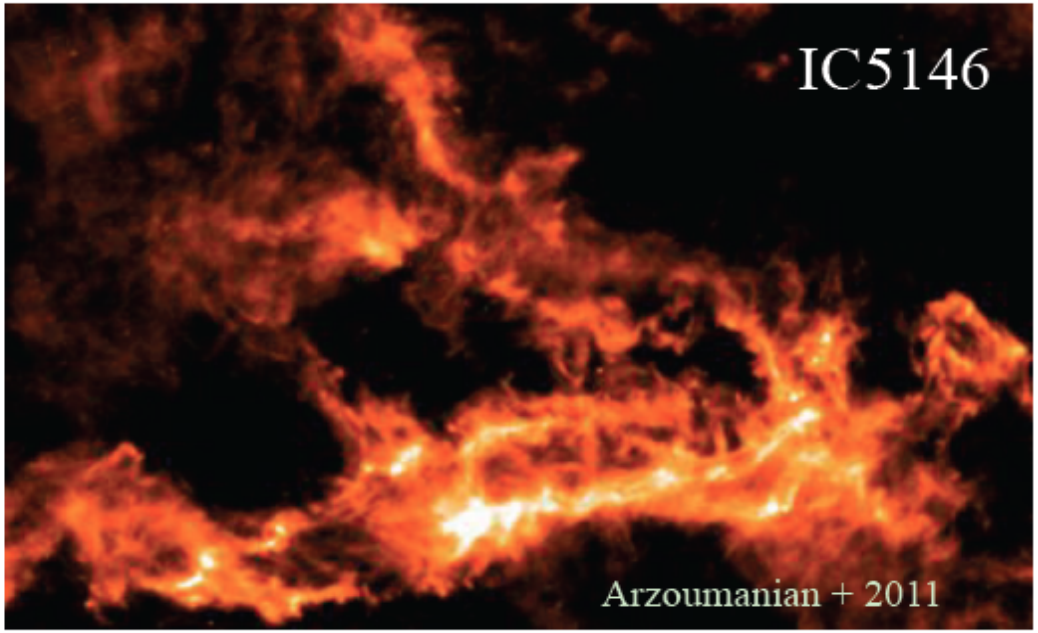
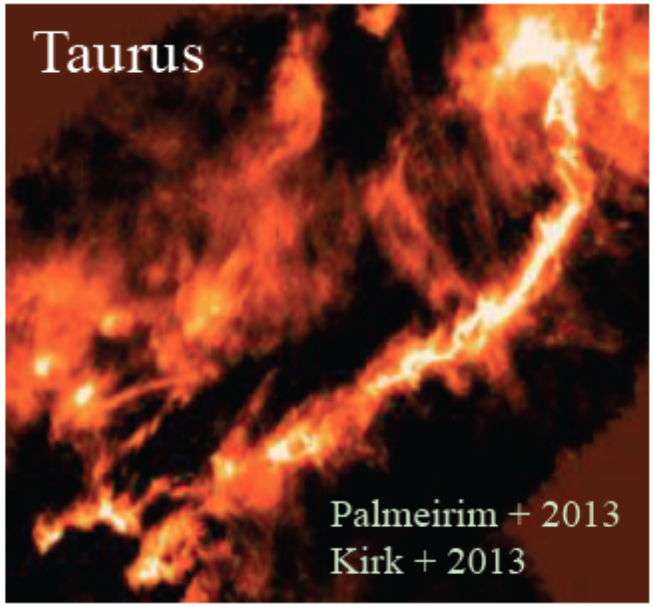
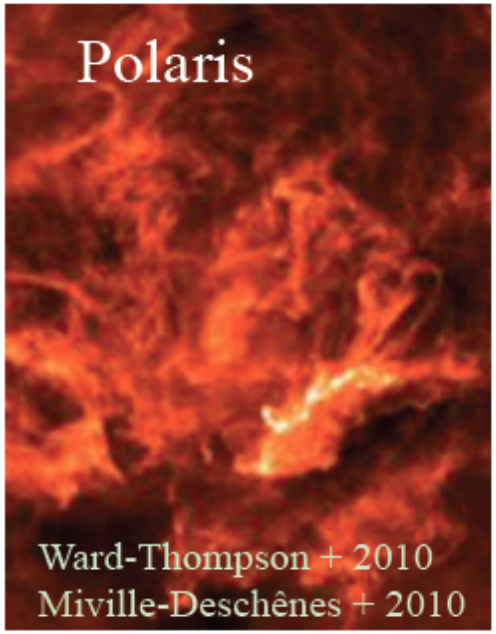
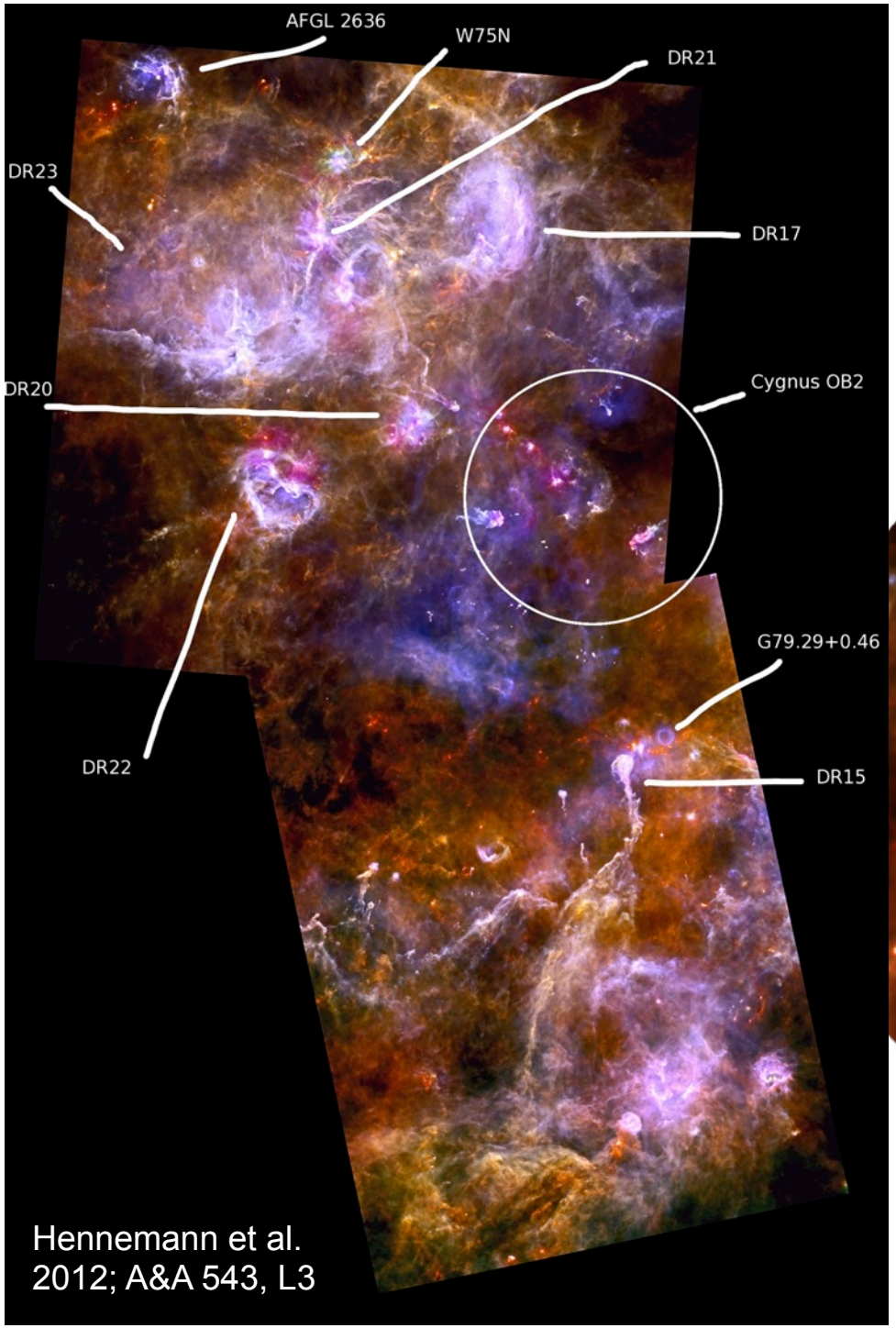
Herschel reveals a "universal" filamentary structure in the cold ISM



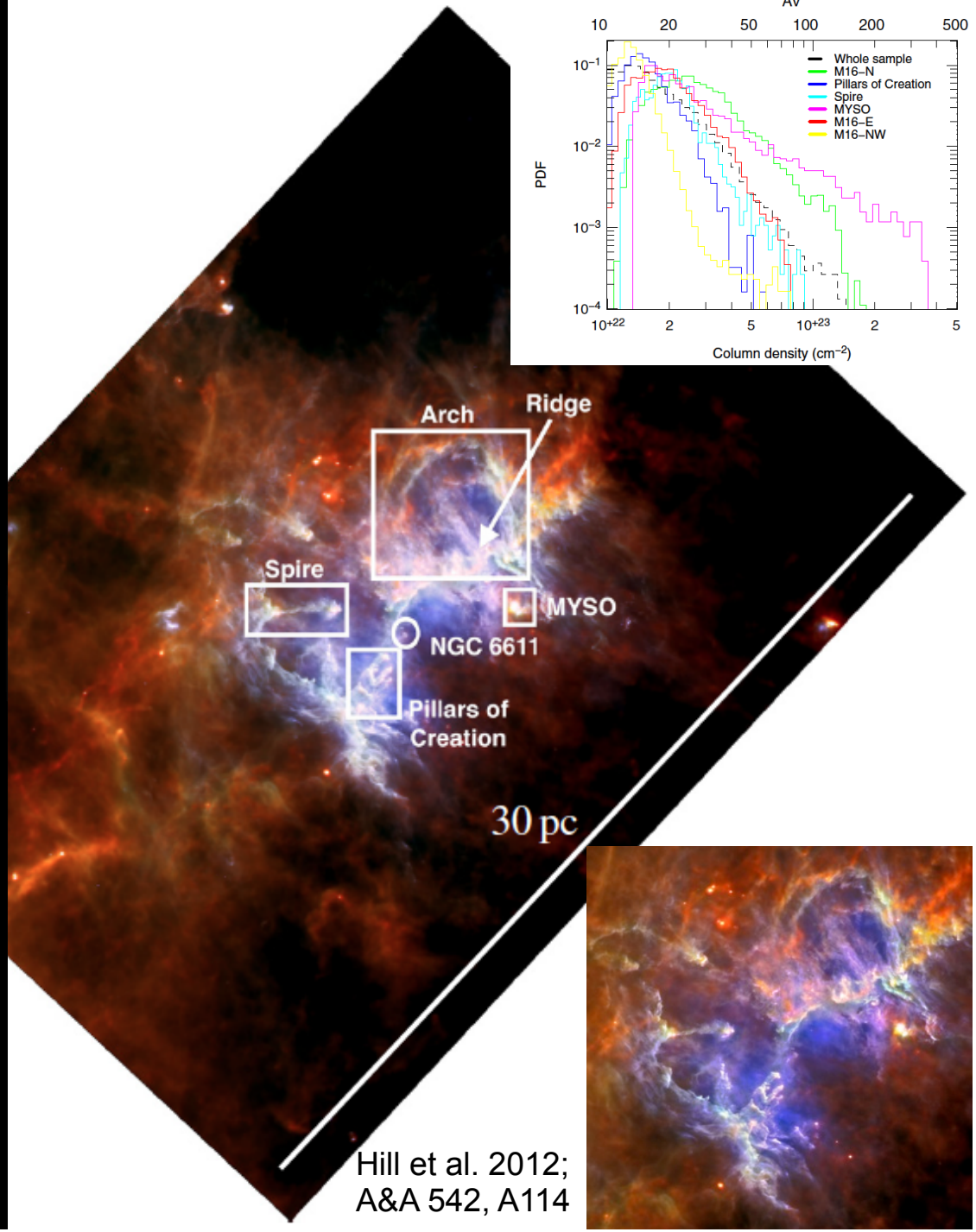




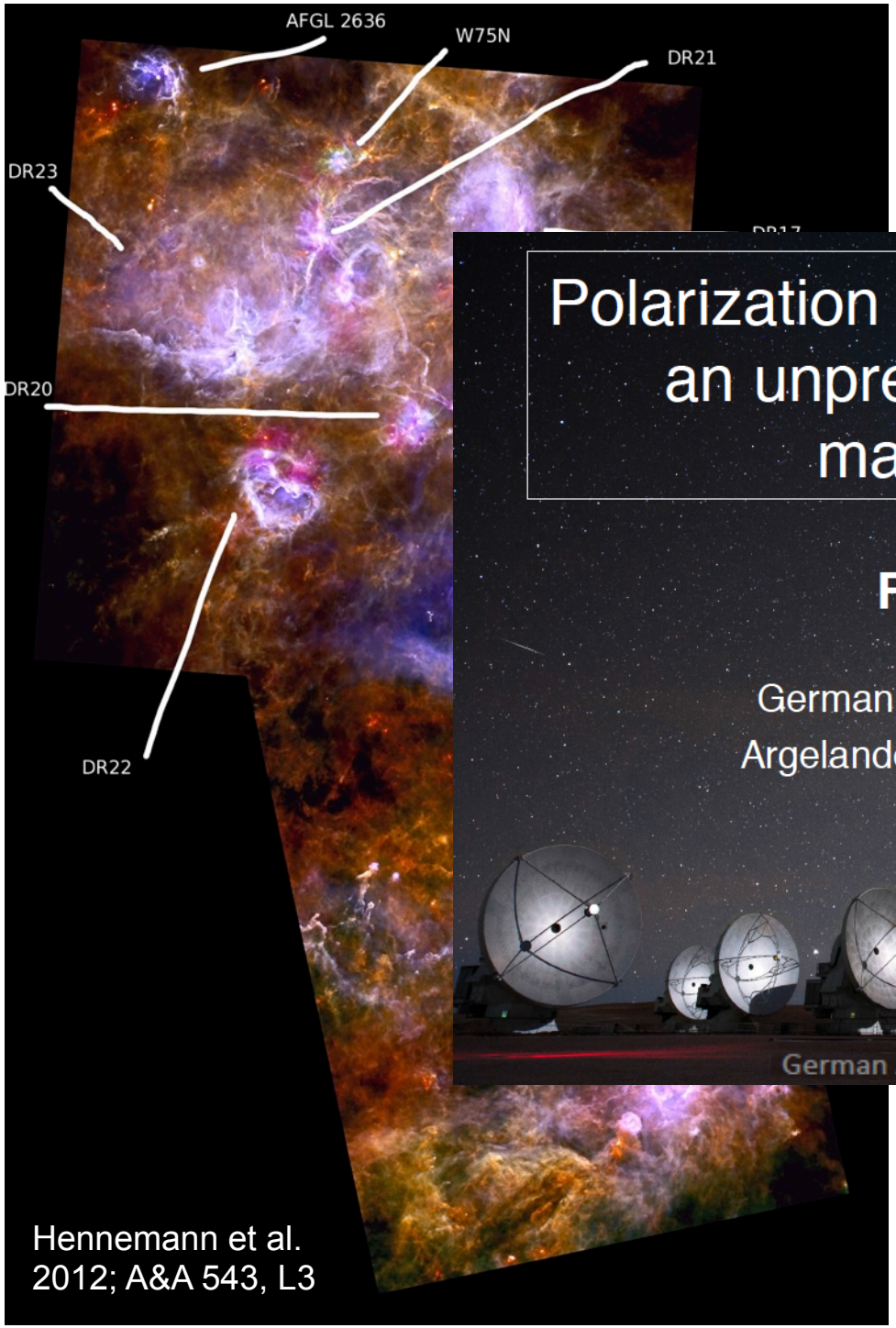




Hennemann et al. 2012; A&A 543, L3



Hill et al. 2012; A&A 542, A114



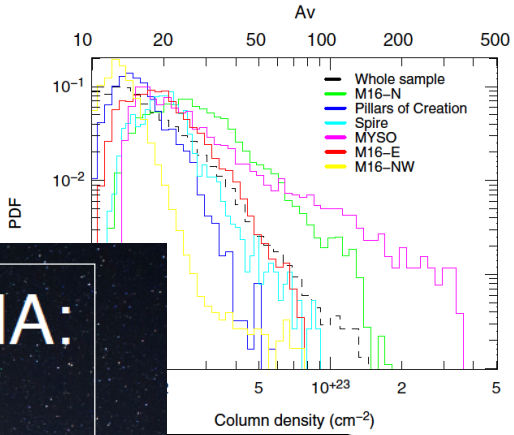
Polarization prospects with ALMA: an unprecedented view of magnetic fields

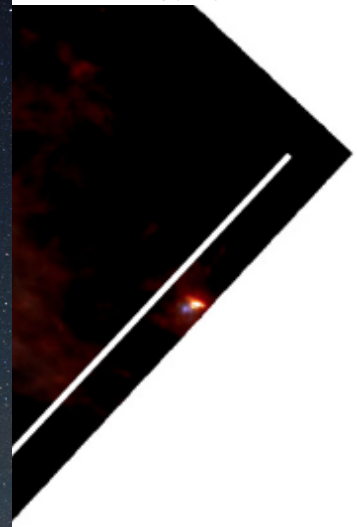
Felipe Alves

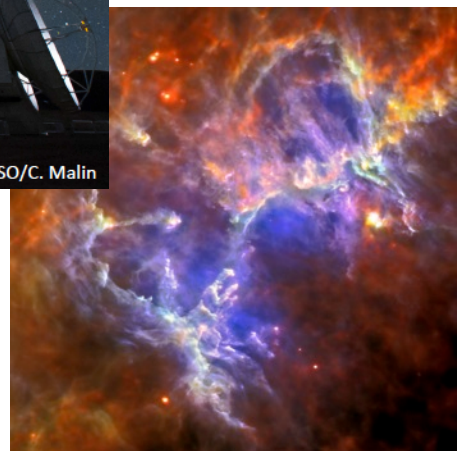
German ALMA Regional Center
Argelander-Institut für Astronomie

German ALMA Community Days 2013

Credit: ESO/C. Malin

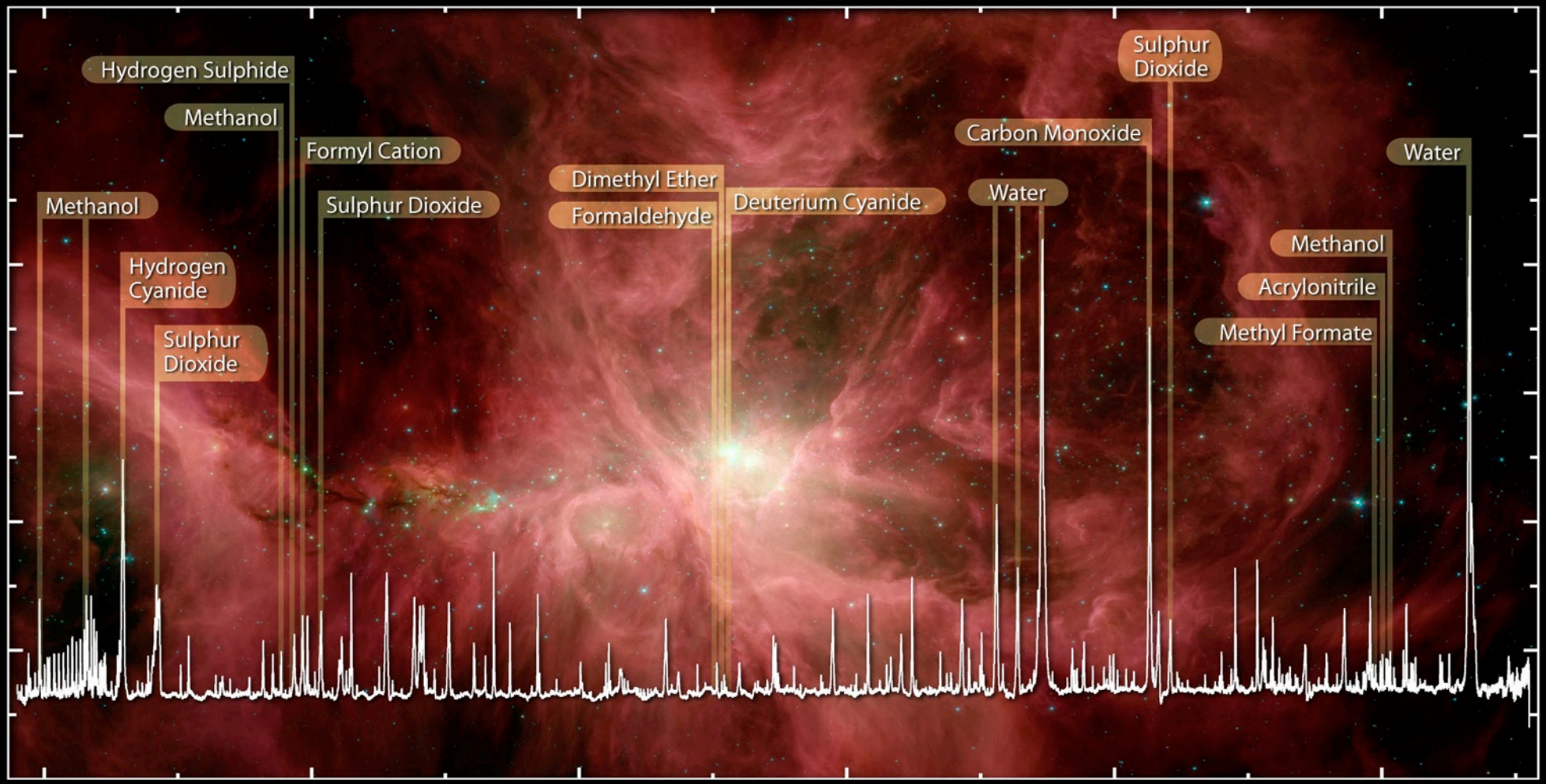






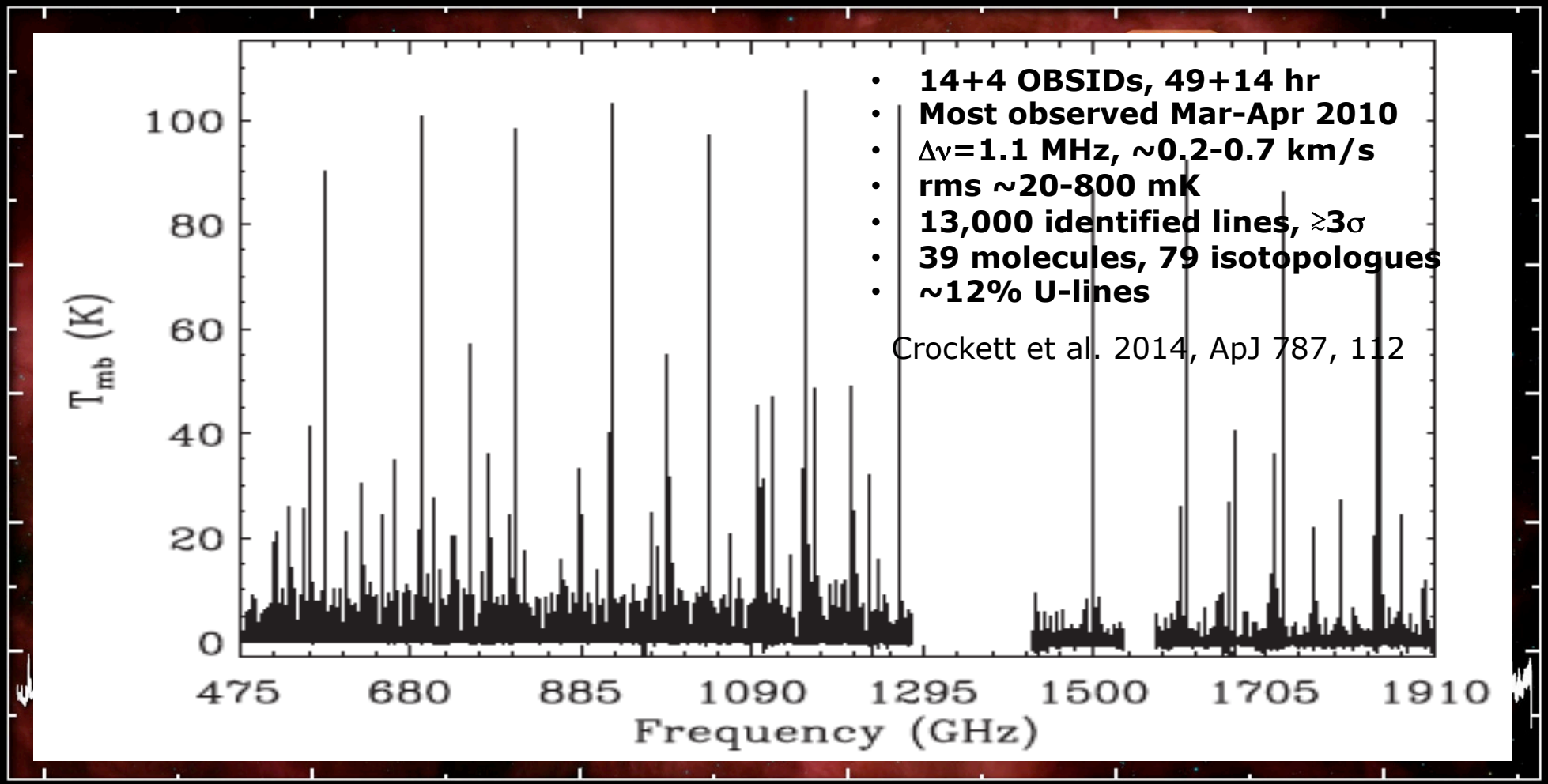
Hennemann et al. 2012; A&A 543, L3

Hill et al. 2012; A&A 542, A114



HIFI Spectrum of Water and Organics in the Orion Nebula

E. Bergin



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 (soon)
- Almost there
- Expert Reduced Data underway

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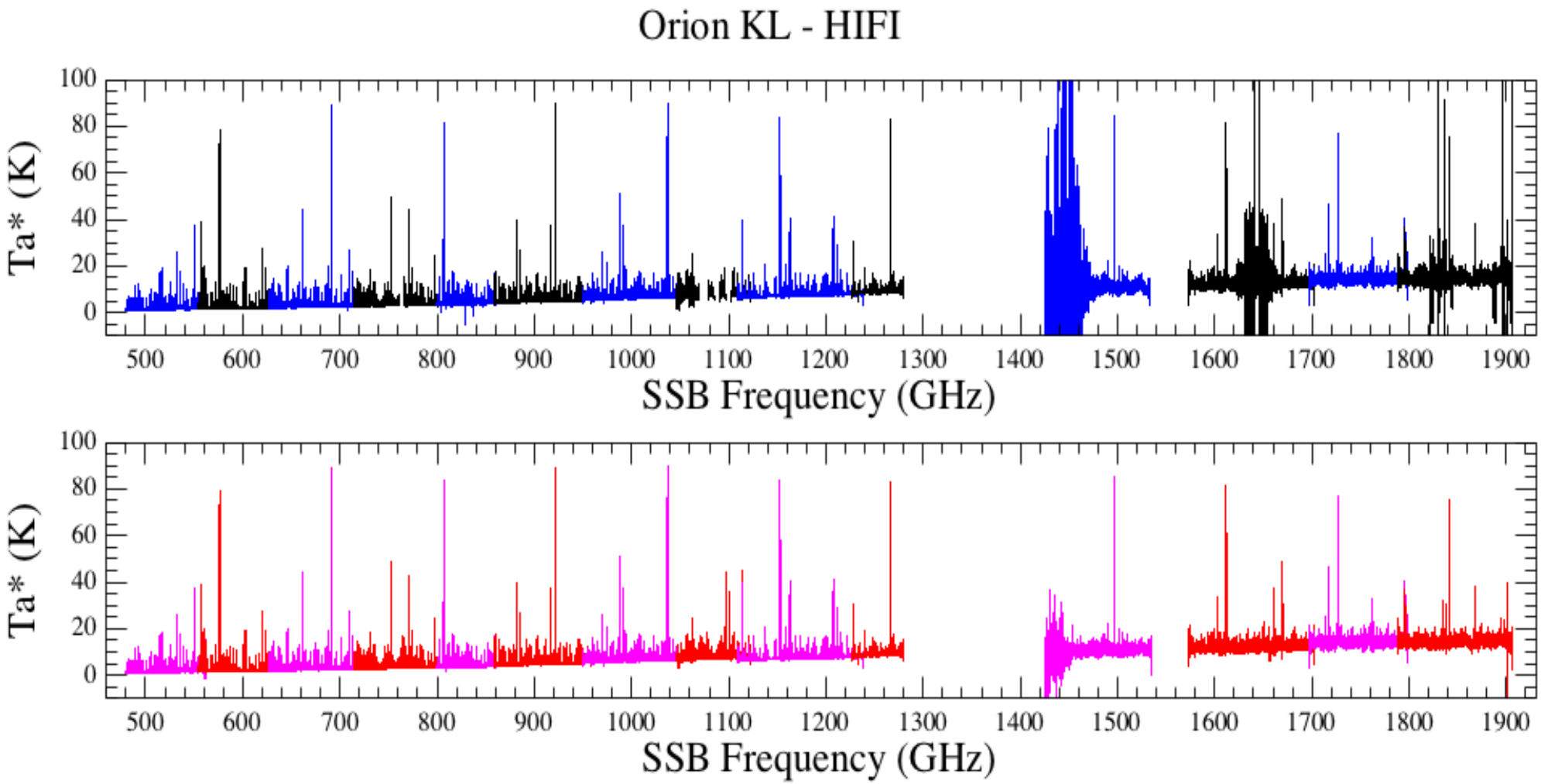
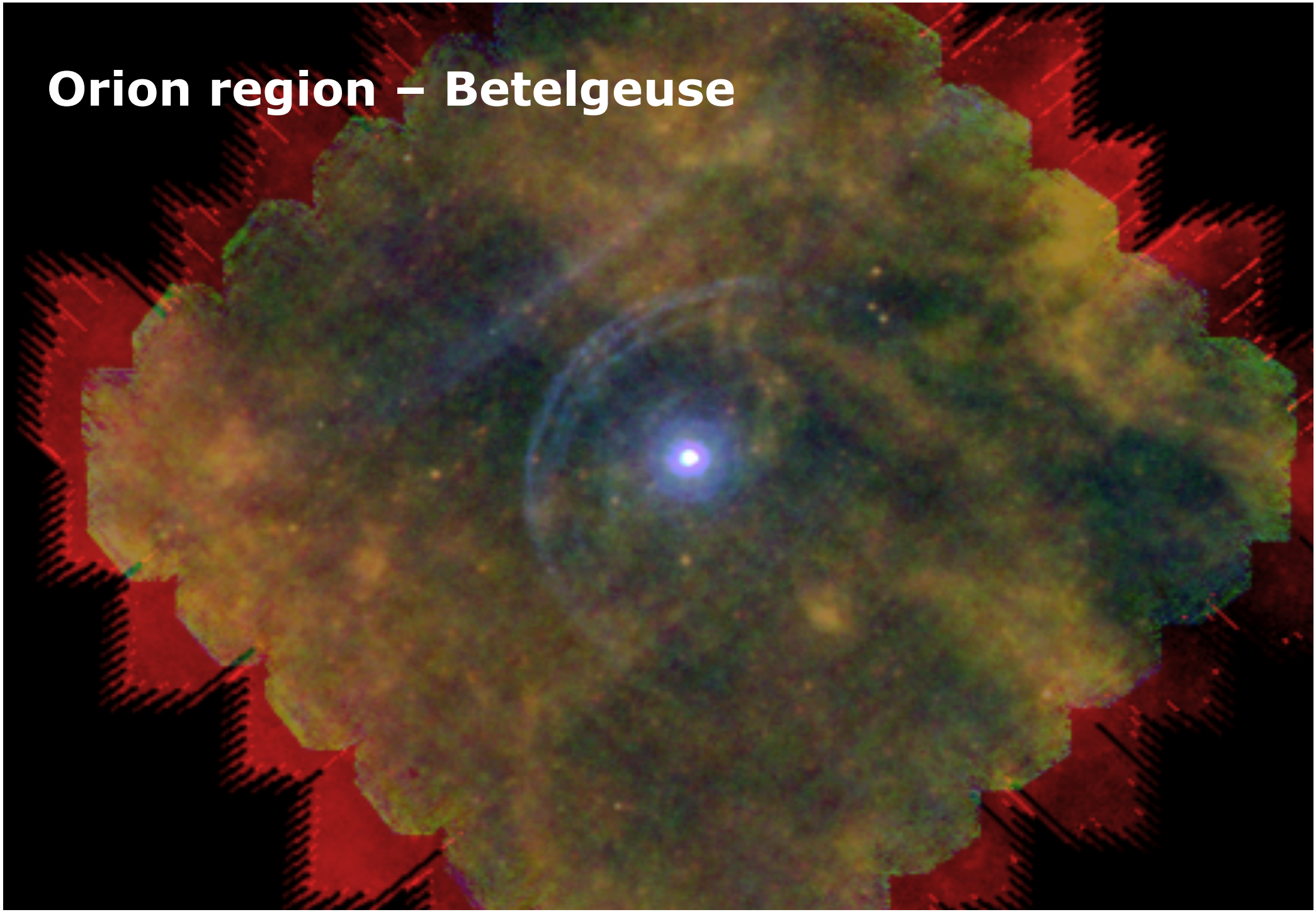
HIFI spectral scans: Orion KL



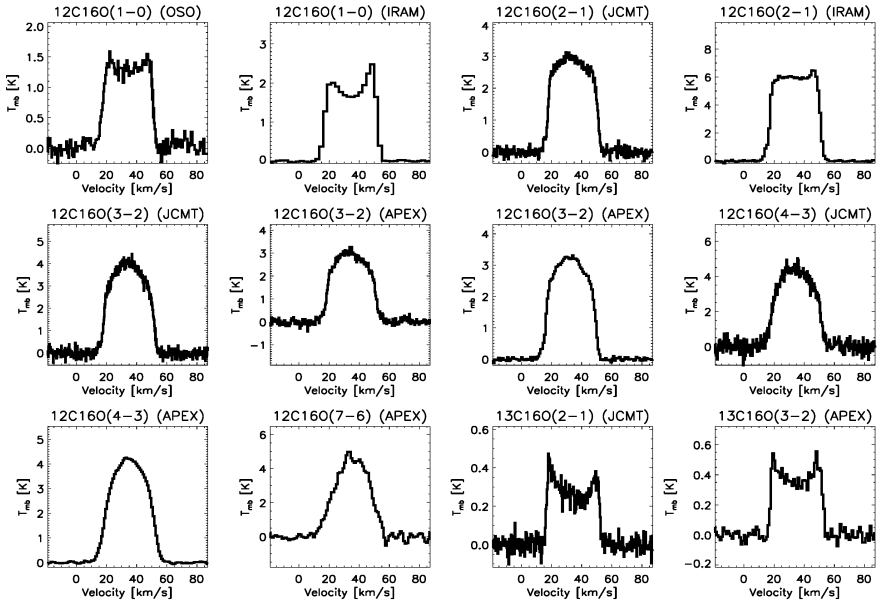
Data reduction courtesy of D Teyssier, HSC

Orion region – Betelgeuse



Evolved stars - spectroscopy

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



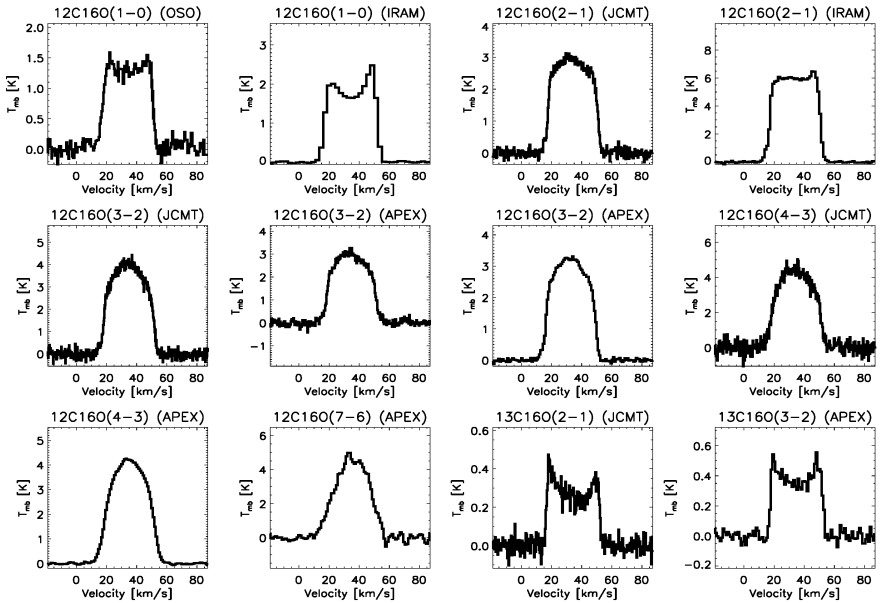
^{12}CO & ^{13}CO line profiles of IK Tau by OSO, IRAM, JCMT, & APEX

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

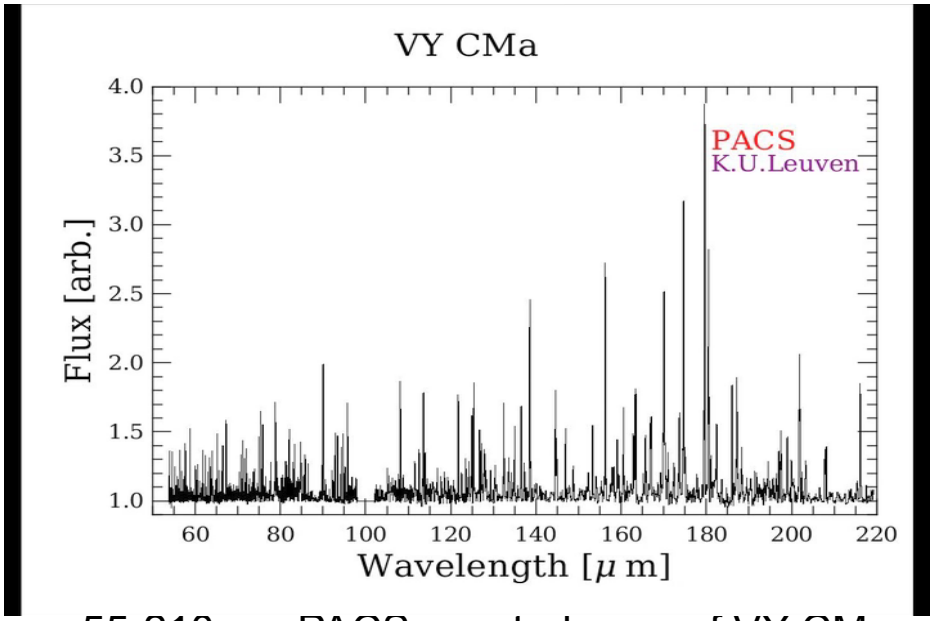
→ **12 molecular line transitions: ~40 hr**



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

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

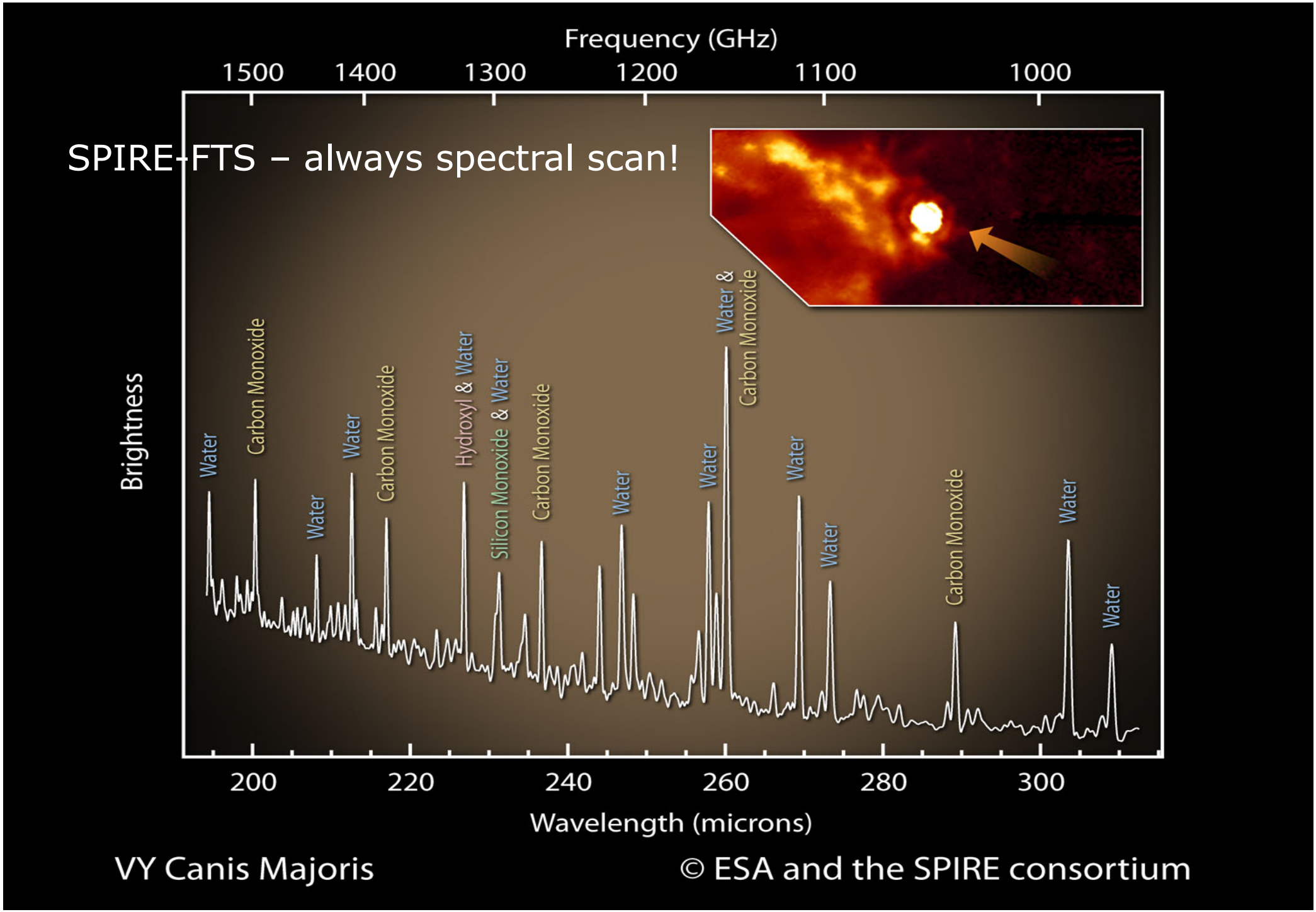
→ **930 molecular line transitions: 2 hr**



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!
Frequency (GHz)
1500
1400
1300
1200
1100
1000
Brightness
Water
Carbon Monoxide
Water
Water
Carbon Monoxide
Hydroxyl & Water
Silicon Monoxide & Water
Carbon Monoxide
Water
Water
Water & Carbon Monoxide
Water
Water
Carbon Monoxide
Water
Water
200
220
240
260
280
300
Wavelength (microns)
VY Canis Majoris
© ESA and the SPIRE consortium

Herschel/PACS spectral scans

In excess of 150 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

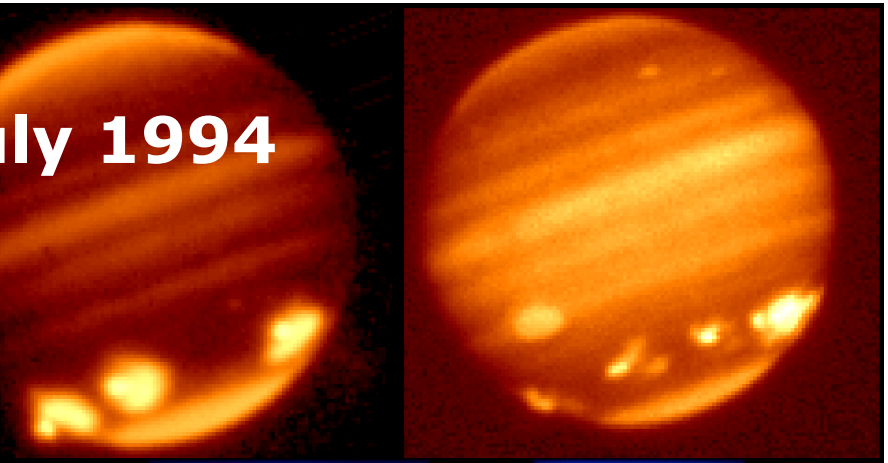
- WADI (KPGT - V Ossenkopf) PDRs ~4

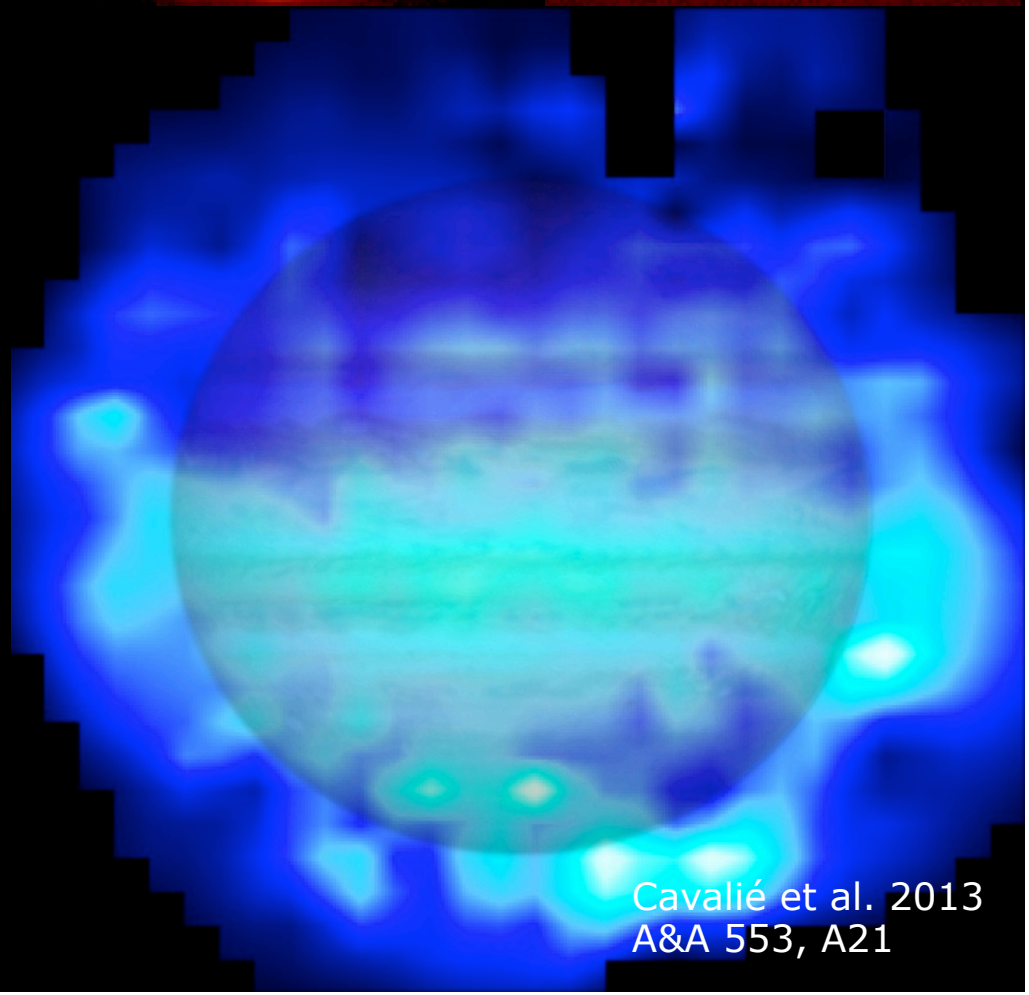
Galaxies

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

HERSCHEL SPACE OBSERVATORY

Comet SL9 Jupiter impact in July 1994





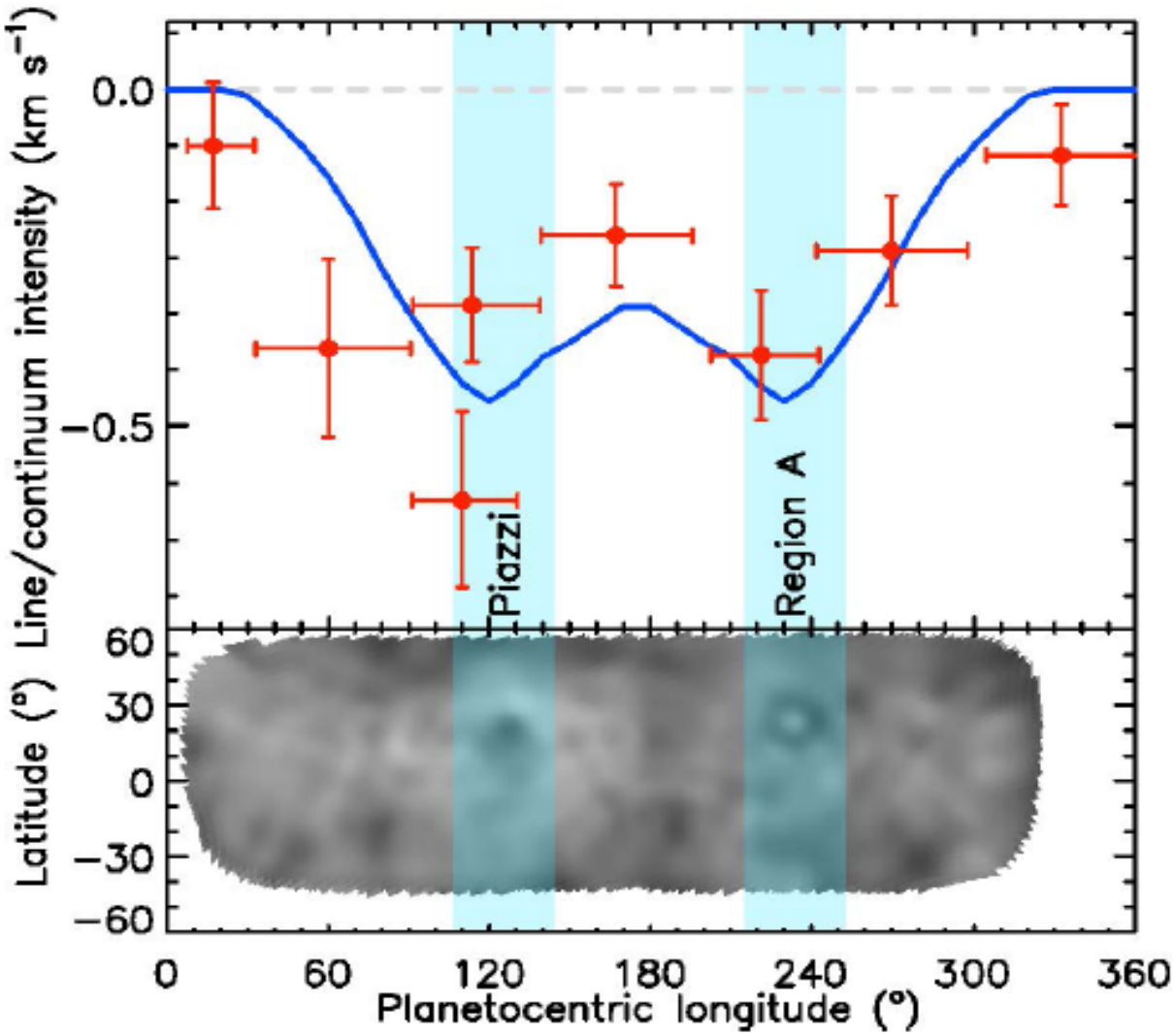
Herschel water observations =>

- PACS provides extent across disc
- HIFI provides vertical (pressure) profile
- ‘All’ water high in the stratosphere – well above tropospheric cold trap => external
- Asymmetry between hemispheres suggest single event – rules out moons / icy rings
- **The observed water originates from the July 1994 SL9 impacts!**

Cavalié et al. 2013
A&A 553, A21

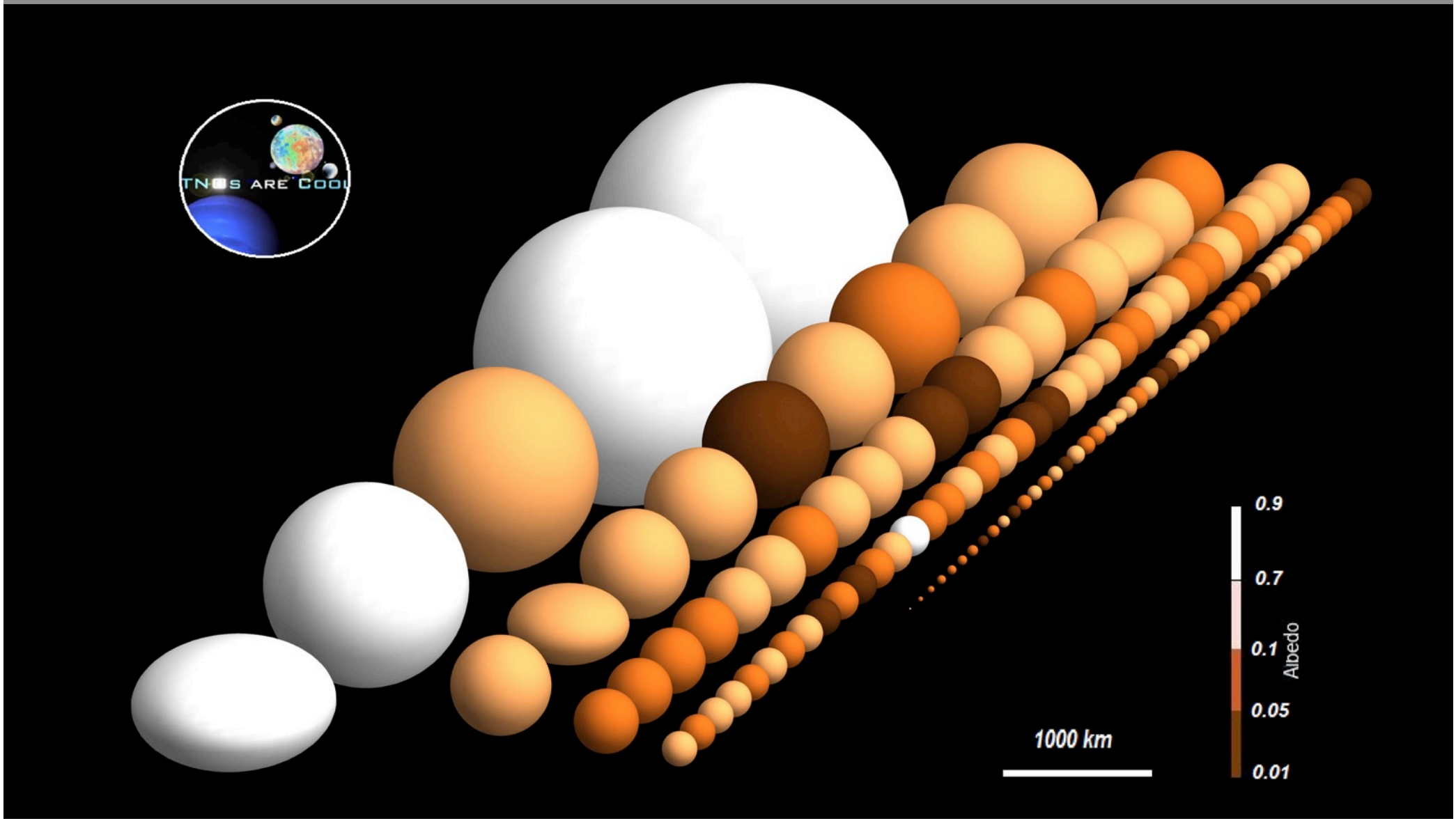
Water on dwarf planet (1) Ceres

- Water in the asteroid belt!
- Four epochs of observations
- On last occasion monitoring for entire Ceres revolution => ‘resolve’ surface features
- Source of water expected connected to two surface features
- For each source: $Q(H_2O)$ = 10^{26} mol/s (3 kg/s continuously)
- Corresponds to ~0.6 km^2 of ice at the surface => 10^{-7} of Ceres surface and 10^{-5} of source regions



Küppers et al. 2014; Nature 505, 525

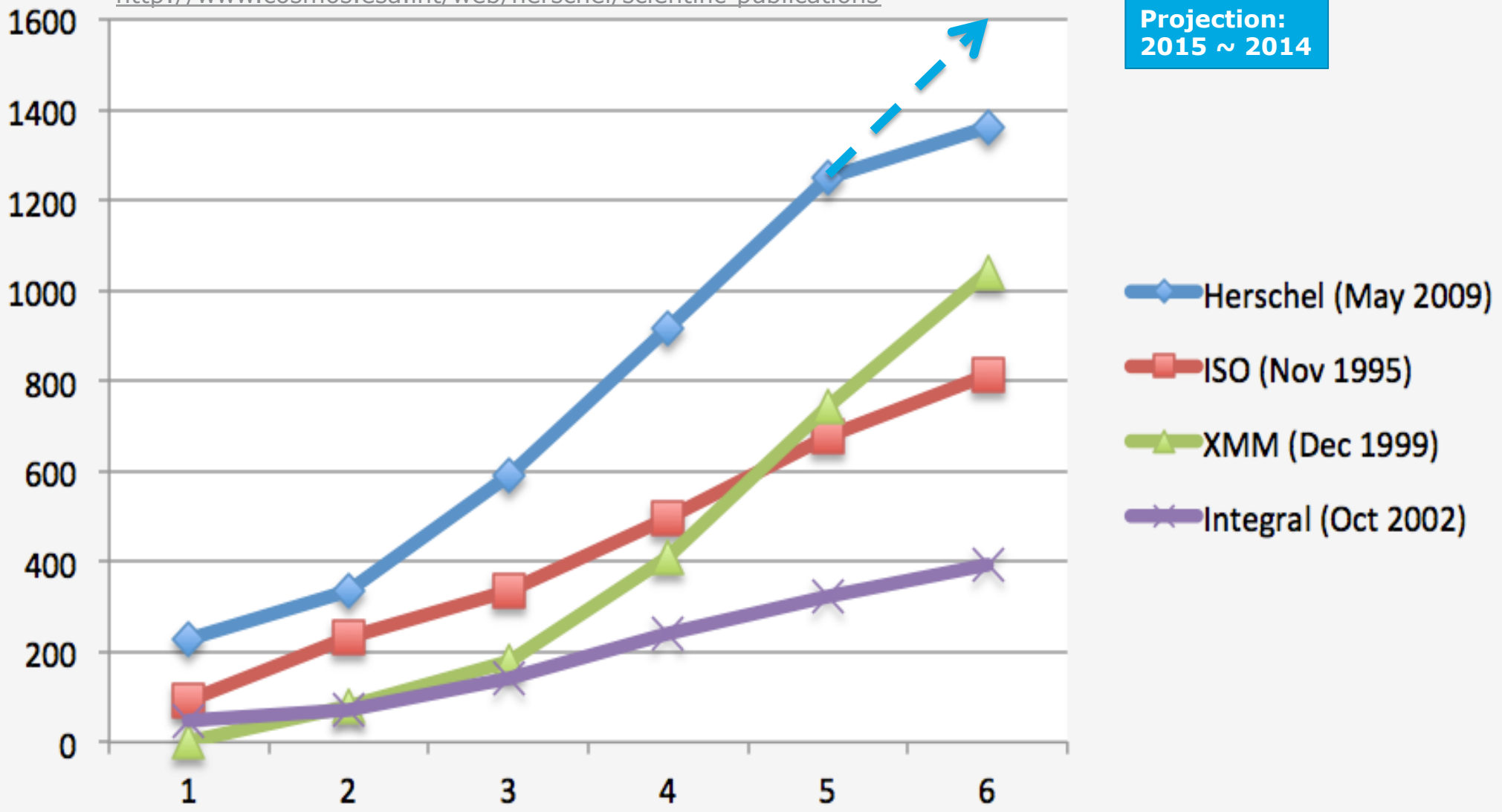
TNOs – becoming living worlds?

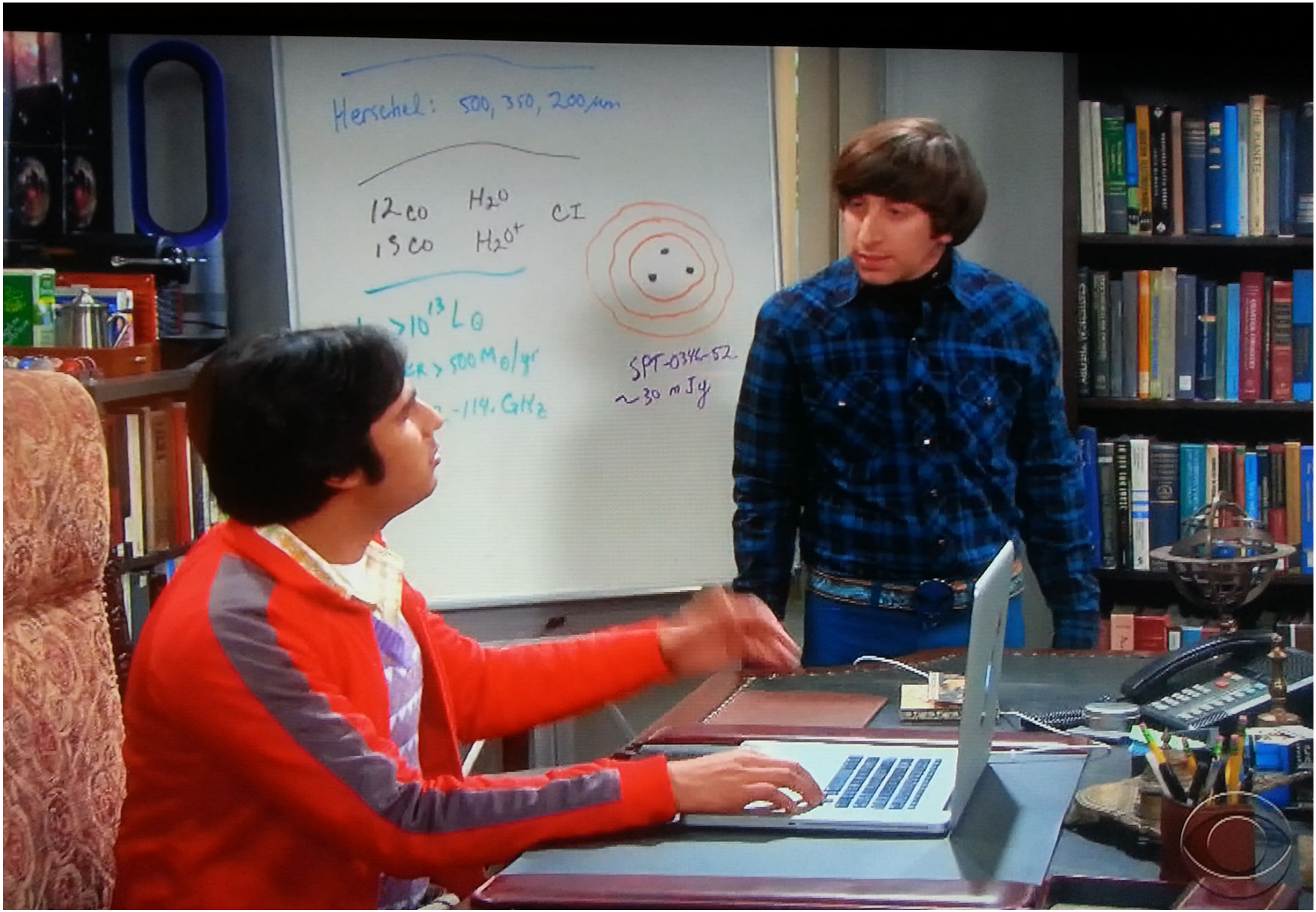


http://www.cosmos.esa.int/web/herschel/the-universe-explored-by-herschel

#Pubs vs #calendar years after launch

http://www.cosmos.esa.int/web/herschel/scientific-publications

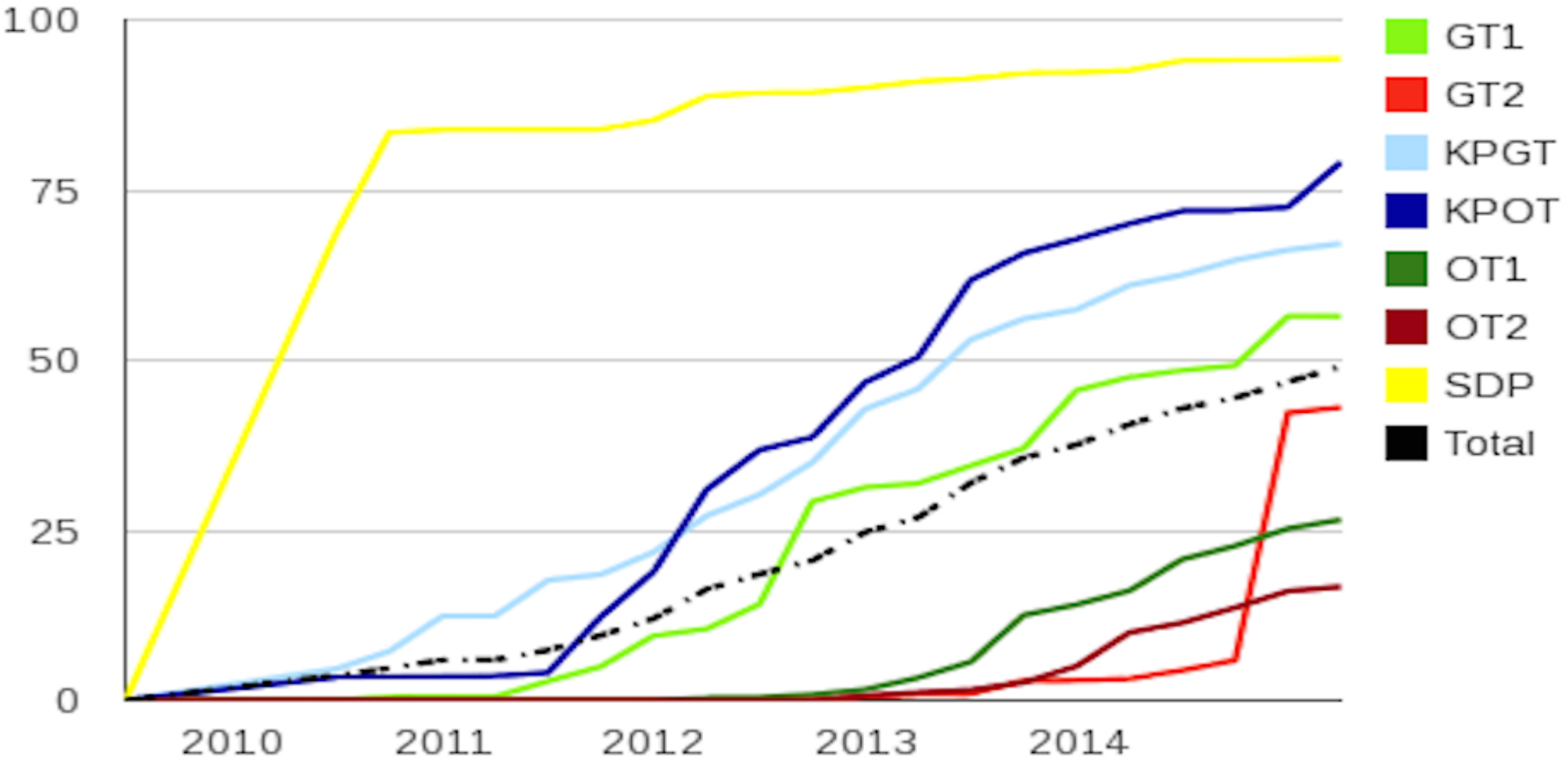



Herschel: 500, 350, 200 μm
12CO
13CO
H2O
H2O+
CI
SPT-0346-52
~30 mJy

Pubs evolution vs instr – 1363 pubs

HOTAC awarded time published – total ~49%

- Pubs 'linked' to OBSIDs – add up the observing times of all 'linked' observations



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

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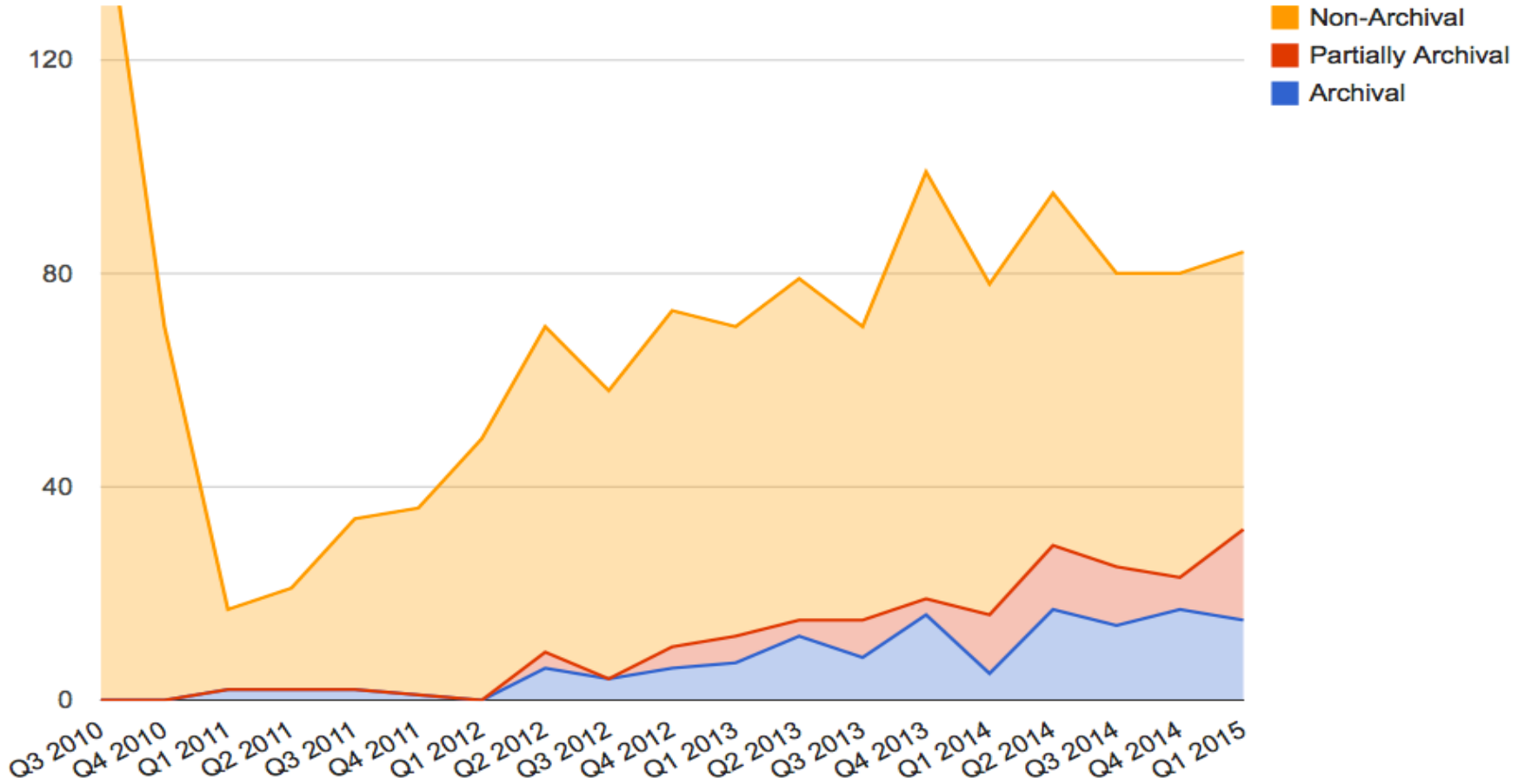

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HERSCHEL SPACE OBSERVATORY

Private Library HerschelPapers **(Refereed papers based on Herschel inflight measurements, last modified 12-Apr-2015) for gpilbratt@rssd.esa**

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Selected and retrieved **1363** abstracts.

#	Bibcode Authors	Score Title	Date	List of Links Access Control Help
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2	2015MNRAS.449.2274I Hopwood, R.; Polehampton, Swinyard, B. M.; Fulton, T.; van der Wiel, M. H. D.; Ben 10 coauthors			
3	2015MNRAS.449.1309C García-Bernete, I.; Ramos A Pulido, J. A.; Alonso-Herrer Portal, M.; Castillo, M.; Per Esquej, P.; González-Martín and 7 coauthors			eracting system Arp 245
4	2015MNRAS.449..715W Walker, D. L.; Longmore, S. Kruijssen, J. M. D.; Rathbor Jackson, J. M.; Foster, J. B.;			
5	2015MNRAS.449..373D Delvecchio, I.; Lutz, D.; Berta, S.; Rosario, D. J.; Zamorani, G.; Pozzi, F.; Gruppioni, C.; Vignali, C.; Brusa, M.; Cimatti, A.; and 8 coauthors	1.000 Mapping the average AGN accretion rate in the SFR-M* plane for Herschel-selected galaxies at 0 < z <= 2.5	05/2015	A Z E F X R C U
6	2015MNRAS.449L..82G Greaves, J. S.; Whitelaw, A. C. M.; Bendo, G. J.	1.000 The subsurface of Pluto from submillimetre observations	04/2015	A Z E F R U

ADS searches

- Demand both ‘Herschel’ & ‘X’ in abstract
- Publication dates from 07/2010 onwards
- Articles only in refereed journals/ All
- Herschel & ALMA: 55/233
- Herschel & SOFIA: 15/98
- Herschel & ISO: 33/88
- Herschel & Spitzer: 331/881
- Herschel & AKARI: 15/40
- Herschel & XMM: 16/48


THANK
YOU!..
http://www.cosmos.esa.int/web/herschel/