Interactions

Between the German and the Larger European FIR Communities

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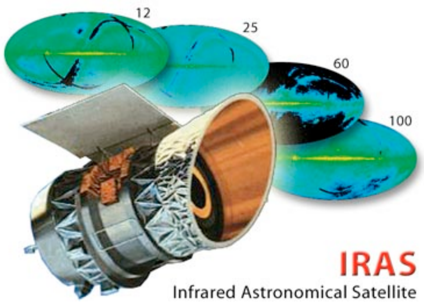
SOFIA International Summit
DLR Oberkassel, 2015 March 2

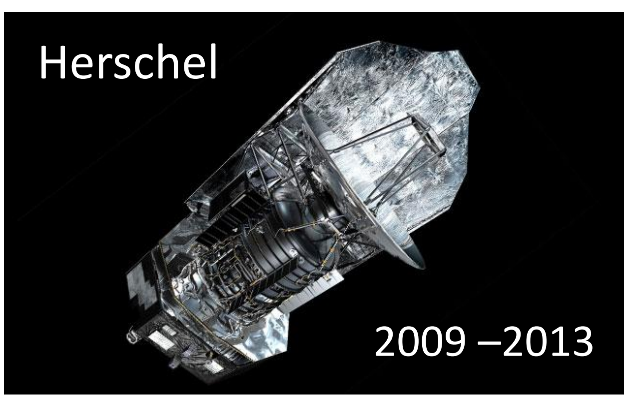

Context: The European astronomical community has free access to world-leading optical facitilities (ESO/VLT) + HST + ALMA + VLA + …

The Historical European FIR Land Scape



1983: NASA (US) +
NIVR (NL) + SERC (UK)

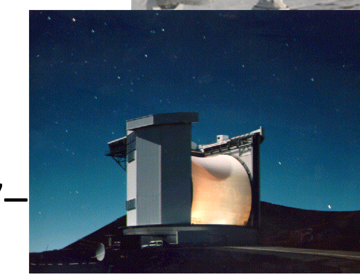
1996-1998: ESA +
NASA + ISAS (JP)
Photometry (+ Polari-
metry) + Spectrosco-
py 2.5 –204 (198) µm
Imaging (2.5 –17 µm)



Complementary:(Sub)millimeter

IRAM 1984–2024

JCMT 1987–



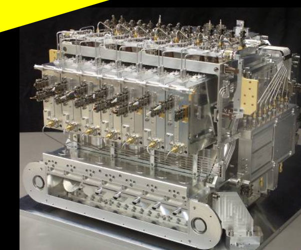
APEX 2006–2022

ALMA 2011–

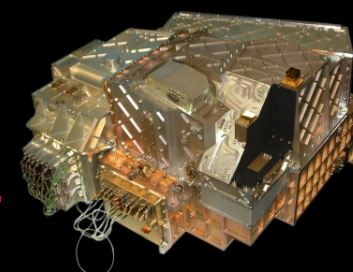
HERSCHEL

MPIfR + U Cologne
→ local oscillator unit
→ crucial for GREAT

HIFI (Heterodyne Instrument for th
480 – 1910 GHz, 7 bands
Very high resolution heterodyne spectrometer



PACS (Photodetector Array Camera and Spectrometer)
1.4 – 5 THz: photom. 1.75 x 3.5' / spec 50 × 50" @ 5"
Imaging photometer / medium resolution grating spectrometer



SPIRE (Spectral and Photometric Imaging Receiver)
0.58, 0.83, 1.2 THz, 4' × 4'
Imaging photometer / imaging Fourier transform spectrometer

Herschel/HIFI: 480–1250 and 1410–1910 GHz

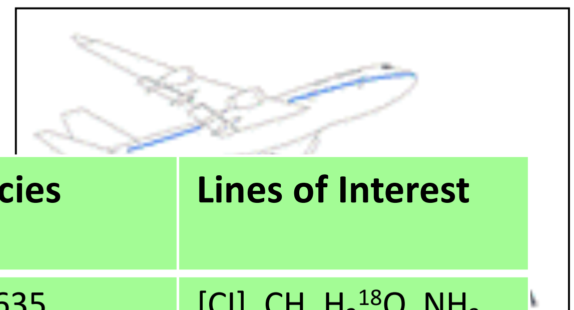
Mixer band	Frequency range	Mixer Element	Matching circuit	Feed/coupling structure	Mixer Development Laboratory
1	480 – 640 GHz	SIS Nb-Al2O3-Nb	Nb on Nb microstrip	corrugated horn and waveguide	LERMA Paris, France
2	640 – 800 GHz	SIS NbTiN-Al2O3-Nb	Al on NbTiN microstrip	corrugated horn and waveguide	KOSMA Koeln, Germany
3	800 – 960 GHz	SIS NbTiN-Al2O3-Nb	Al on NbTiN microstrip	corrugated horn and waveguide	SRON
4	960 – 1120 GHz	SIS NbTiN-Al2O3-Nb	Al on NbTiN		
5	1120 – 1250 GHz	SIS			
6L	1410				
6H	1703				

SOFIA/GREAT and APEX Receivers outperform HIFI in almost every metric (T_{RX}, bandwidth, multiplexing)

→ Instantaneous innovation

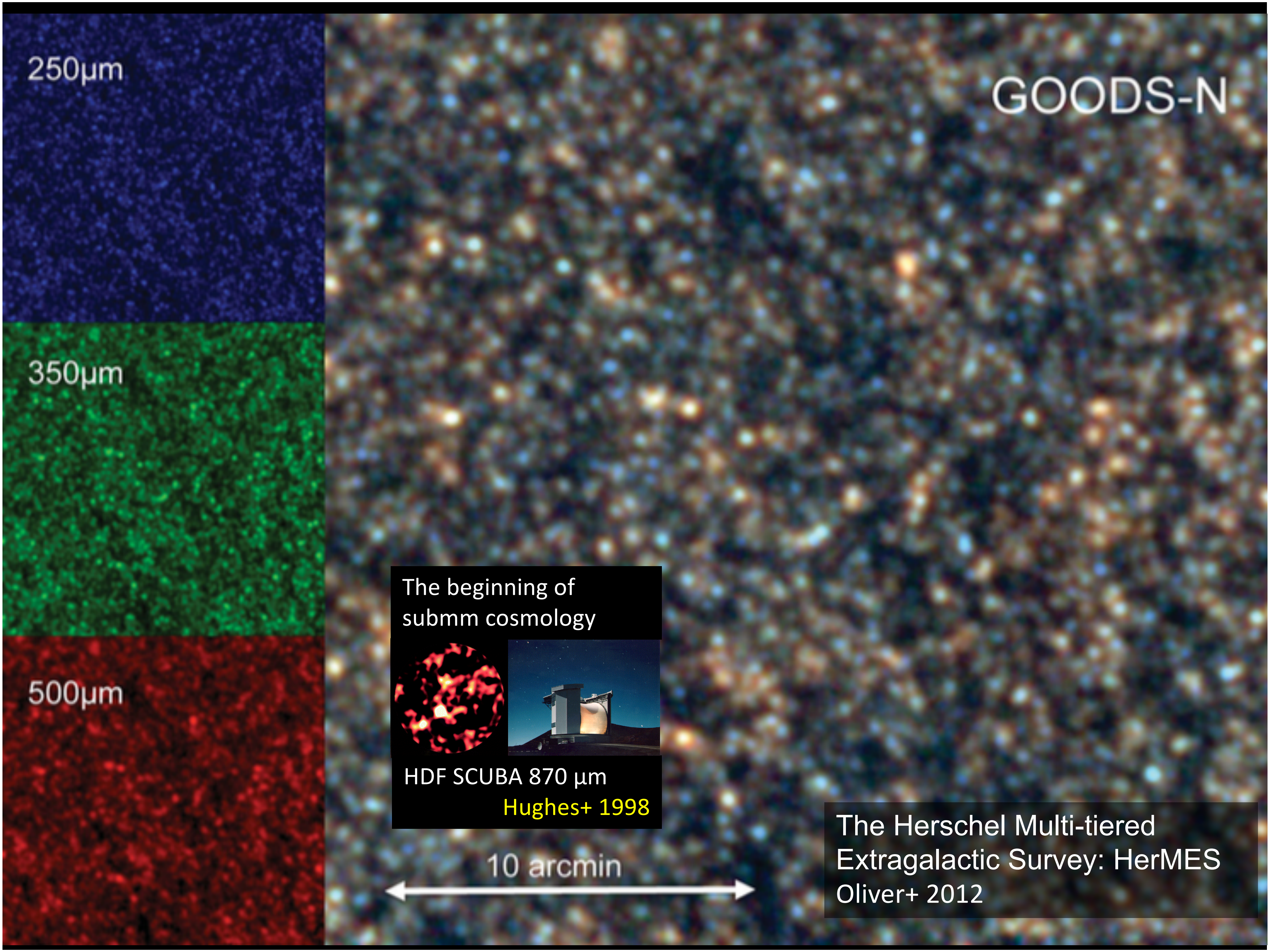
SOFIA/G

Channel	(THz)	Lines of Interest
low-frequency L1 a,b	1.25-1.50 (single pixel)	[NII], CO series, OD,HCN,H_2D^+
low-frequency L2	1.81-1.91 (single	
mid-frequency M a,b	2.5 – 2.7 (single	
high-frequency H	4.7 (single	
upGREAT Low Frequency Array (LFA)	1.9 – 2.5 (14 pi	
upGREAT High Frequency Array (HFA)	4.7 (7 pix	



Channel	Frequencies (THz)	Lines of Interest
4GREAT-1 (HIFI-1)	0.492– 0.635	[CI], CH, $H_2{}^{18}O$, NH_3
4GREAT-2 (HIFI-2)	0.892–1.100	Many
4GREAT-3 (GREAT-L1)	1.2 –1.5	[NII], CO, H_2D^+
4GREAT-4 (GREAT-L2)	1.81–1.91	NH_3, OH, [CII]

http://www3.mpifr-bonn.mpg.de/div/submmtech/heterodyne/upgreat/upgreatmain.html


250μm
350μm
500μm
GOODS-N
The beginning of submm cosmology
HDF SCUBA 870 μm
Hughes+ 1998
10 arcmin
The Herschel Multi-tiered Extragalactic Survey: HerMES
Oliver+ 2012

Many US coauthors

Title: The Herschel Multi-tiered Extragalactic Survey: HerMES

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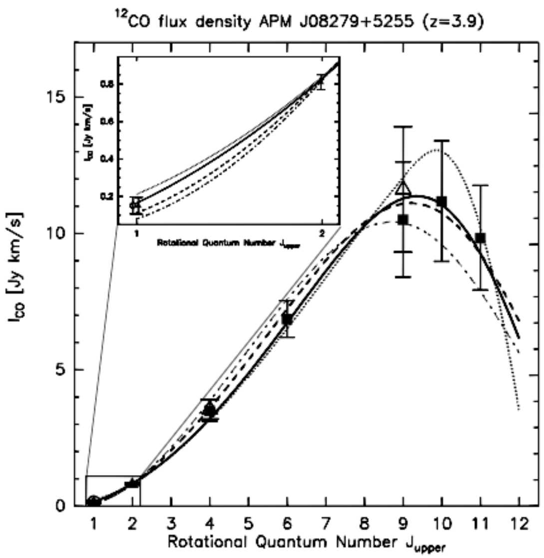
From the Early Universe back to the Milky Way:
CO Spectral Line Energy Distributions

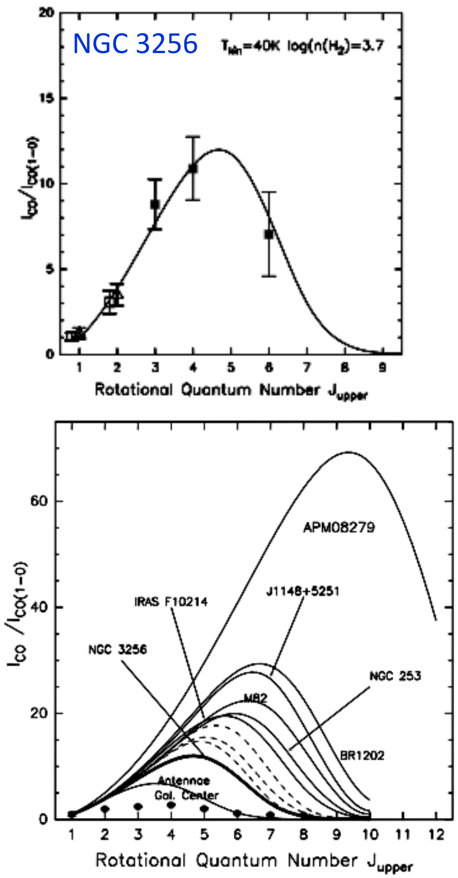
CO Spectral Line Energy Distributions in **Galactic** Sources: Empirical Interpretation of Extragalactic Observations

Local ULIRGs

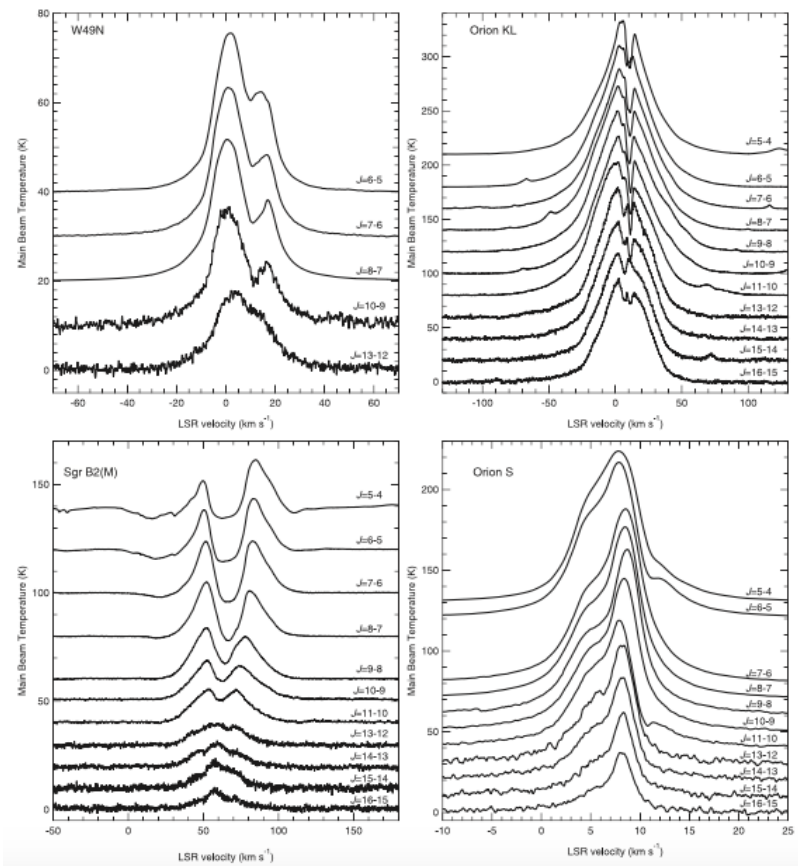
High z



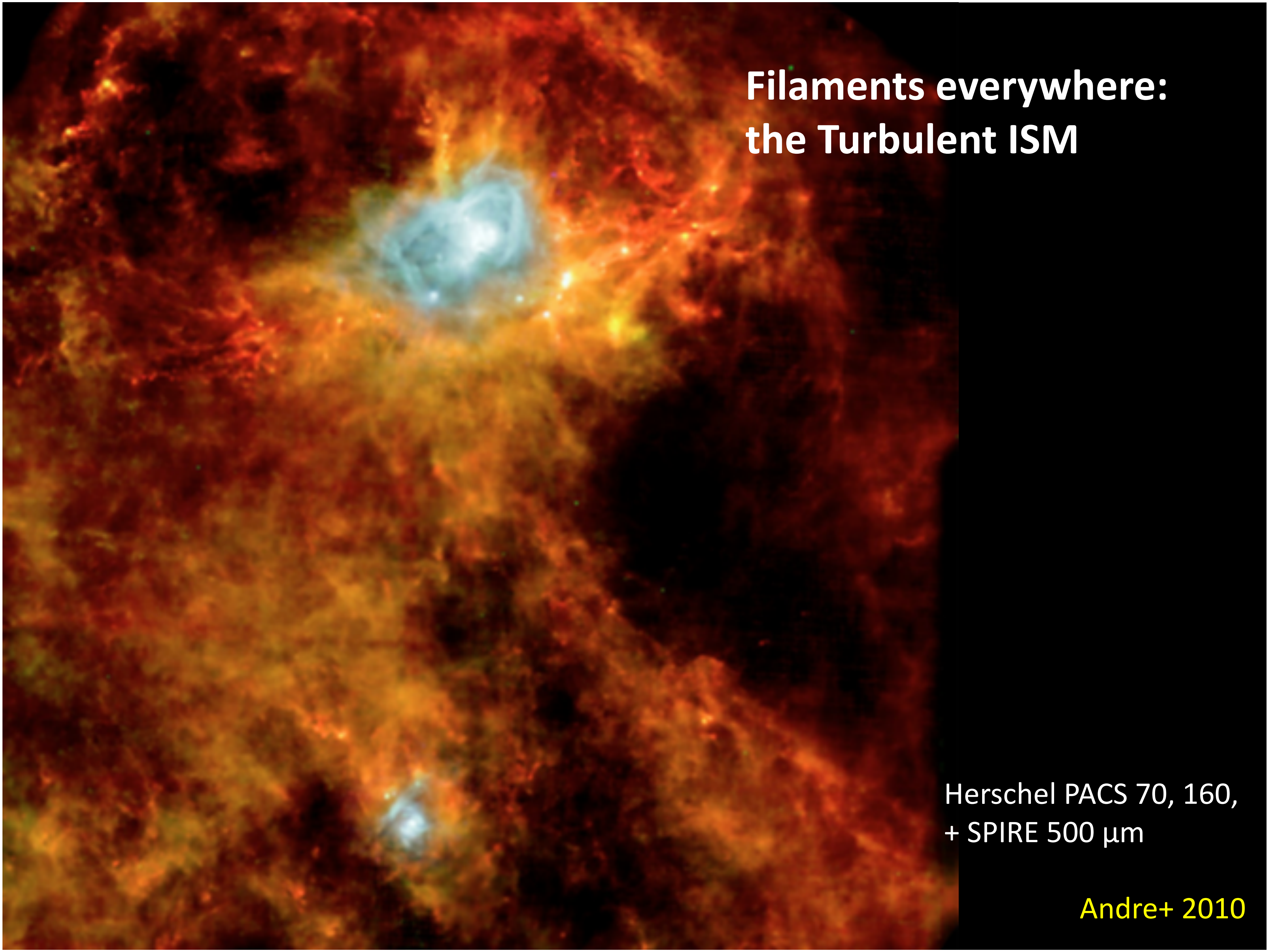
Weiß+ 2007



Ao+ 2009

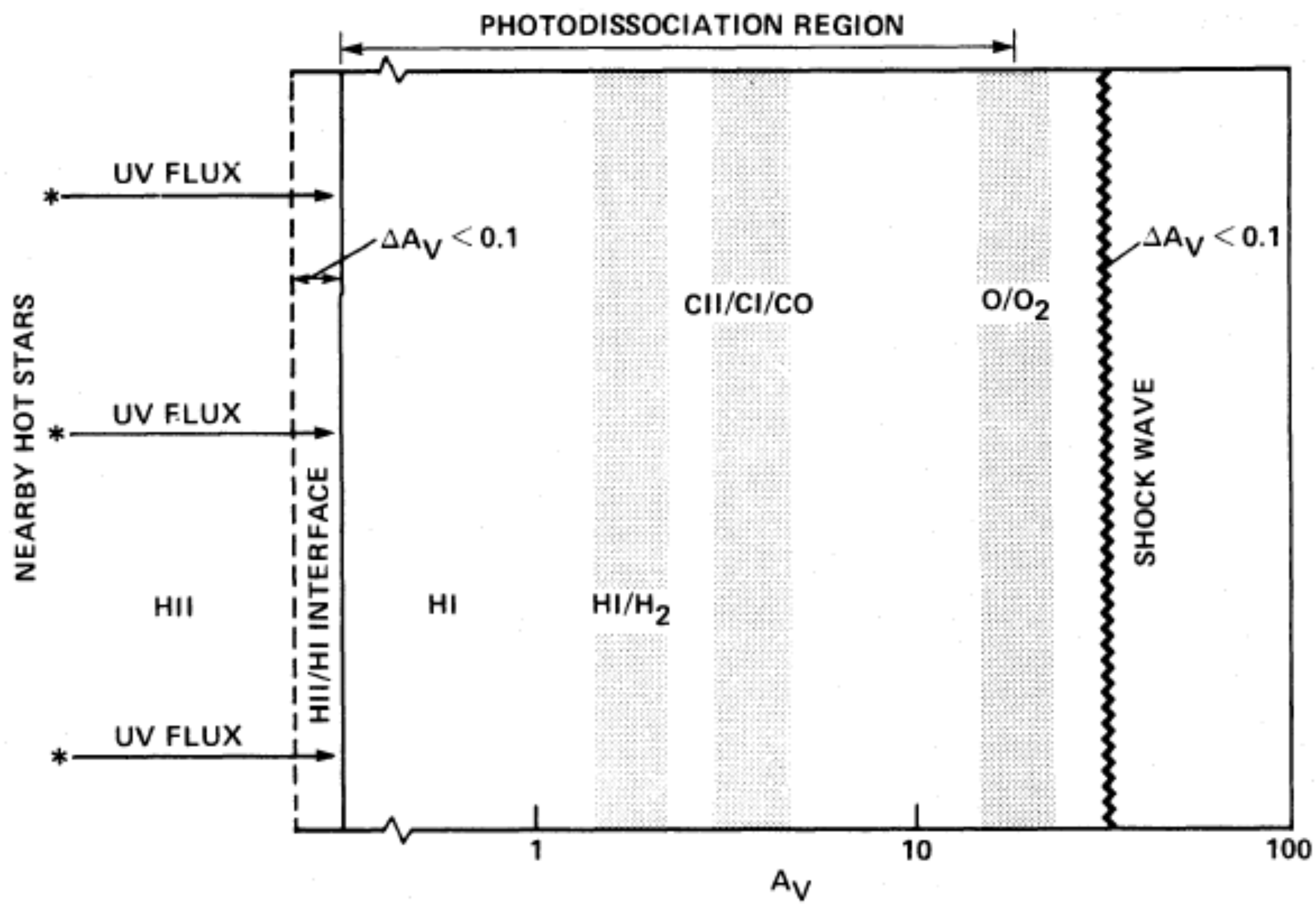


Indriolo+ 2017

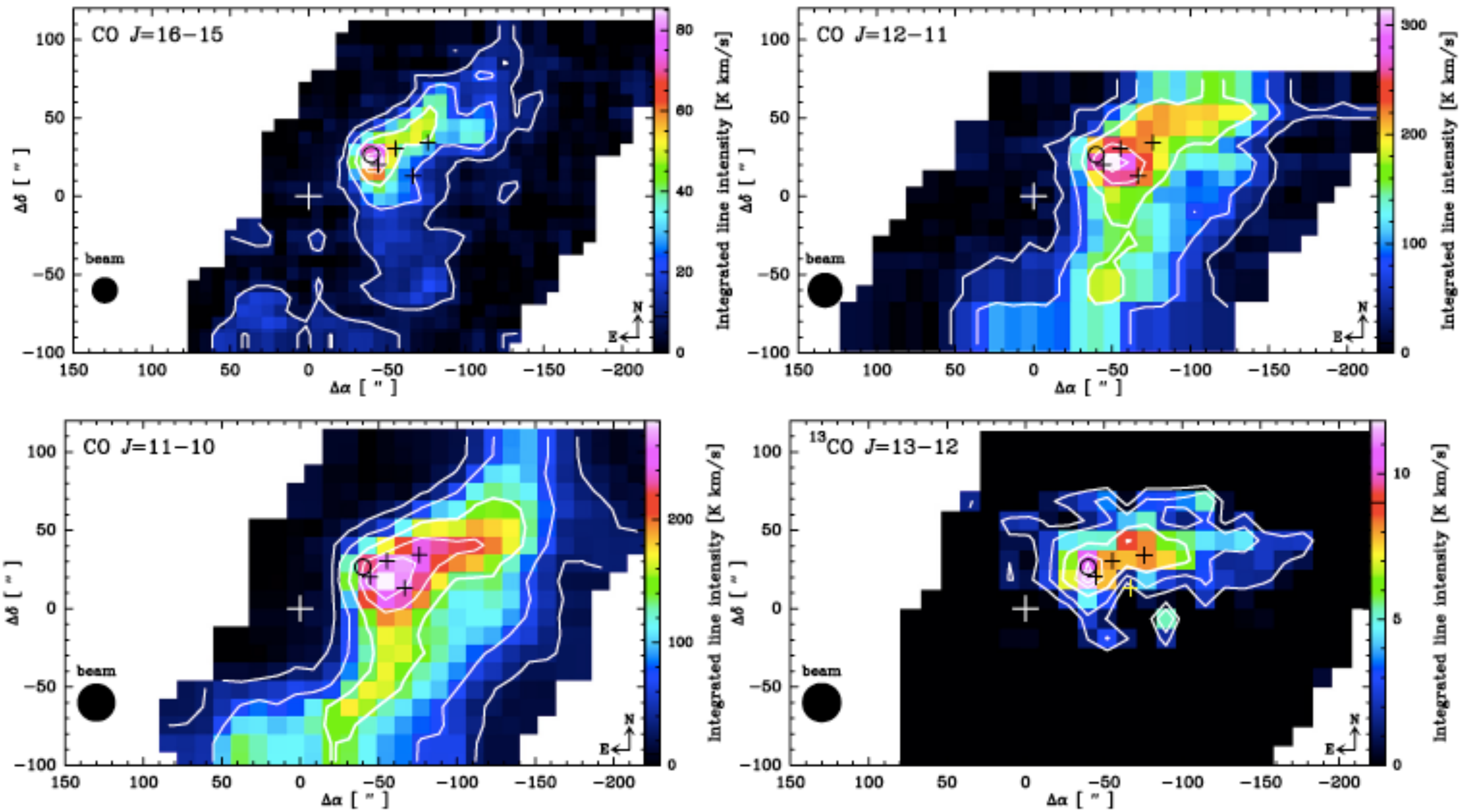

Filaments everywhere:
the Turbulent ISM
Herschel PACS 70, 160,
+ SPIRE 500 μm
Andre+ 2010

PDRs: Photodissociation Regions

Tielens & Hollenbach 1985



PDR Example: The physical conditions in the prominent PDR M 17 SW

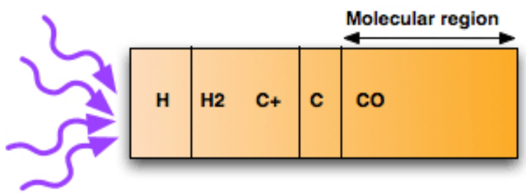


SOFIA/GREAT: Perez-Beaupuits+ 2015

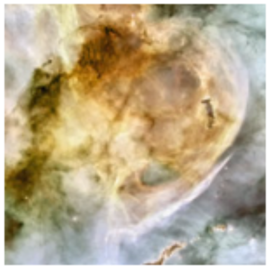
PDR Code | Download | ISMDB | Tools

PDR Code

The code considers a stationary plane-parallel slab of gas and dust illuminated by a radiation field coming from one or both sides of the cloud. The incident radiation field can be the Interstellar Standard Radiation Field (ISRF) and/or a star.



It solves at each point in the cloud, the radiative transfer in the UV taking into account the absorption in the continuum by dust and in discrete transitions of H and H2. The model computes the thermal balance taking into account heating processes such as the photoelectric effect on dust, chemistry, cosmic rays, etc. and cooling resulting from infrared and millimeter emission of the abundant species. Chemistry is solved for any number of species and reactions.



Once abundances of atoms and molecules and level excitation of the most important species have been computed at each position in the cloud, line intensities and column densities can be deduced by a post-processor code.

The Meudon PDR code can be used to study the physics and chemistry of diffuse clouds, photodissociation regions (PDRs), dark clouds, ...

LERMA – Paris Observatory

Scientists and engineers

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Benjamin Godard *(scientist)*
David Languignon *(engineer)*
Jacques Le Bourlot *(scientist)*
Franck Le Petit *(scientist)*
Nicolas Moreau *(engineer)*
Evelyne Roueff *(scientist)*
Carlo-Maria Zwolf *(engineer)*

References

- Le Petit et al., 2006, ApJS, 164, 506
- Goicoechea et al., 2007, A&A, 467, 1
- Gonzalez Garcia et al., 2008, A&A, 485, 127
- Le Bourlot et al., 2012, A&A, 541, 76
- Bron E., 2014, Thesis
- Bron et al., 2014, A&A, 569, 100
- Bron et al., 2016, A&A, 588, 27

Contacts

- support.pdr.ism at obspm.fr

Light Hydrides before Herschel

• Building blocks of larger molecules

Needs bright optically visible stars as background sources → Restricted to a few kpc from Sun

lines from CH, CH^+ and CN have ranslucent interstellar clouds

• H_2 (

• HD

Ther

• OH

Completely new view of diffuse ISM chemistry since 2010!

Needs background sources → Can be done Galaxy-wide

(NIR 1996)

rly 2010s: rschel/HIFI rules!

Now: SOFIA+APEX

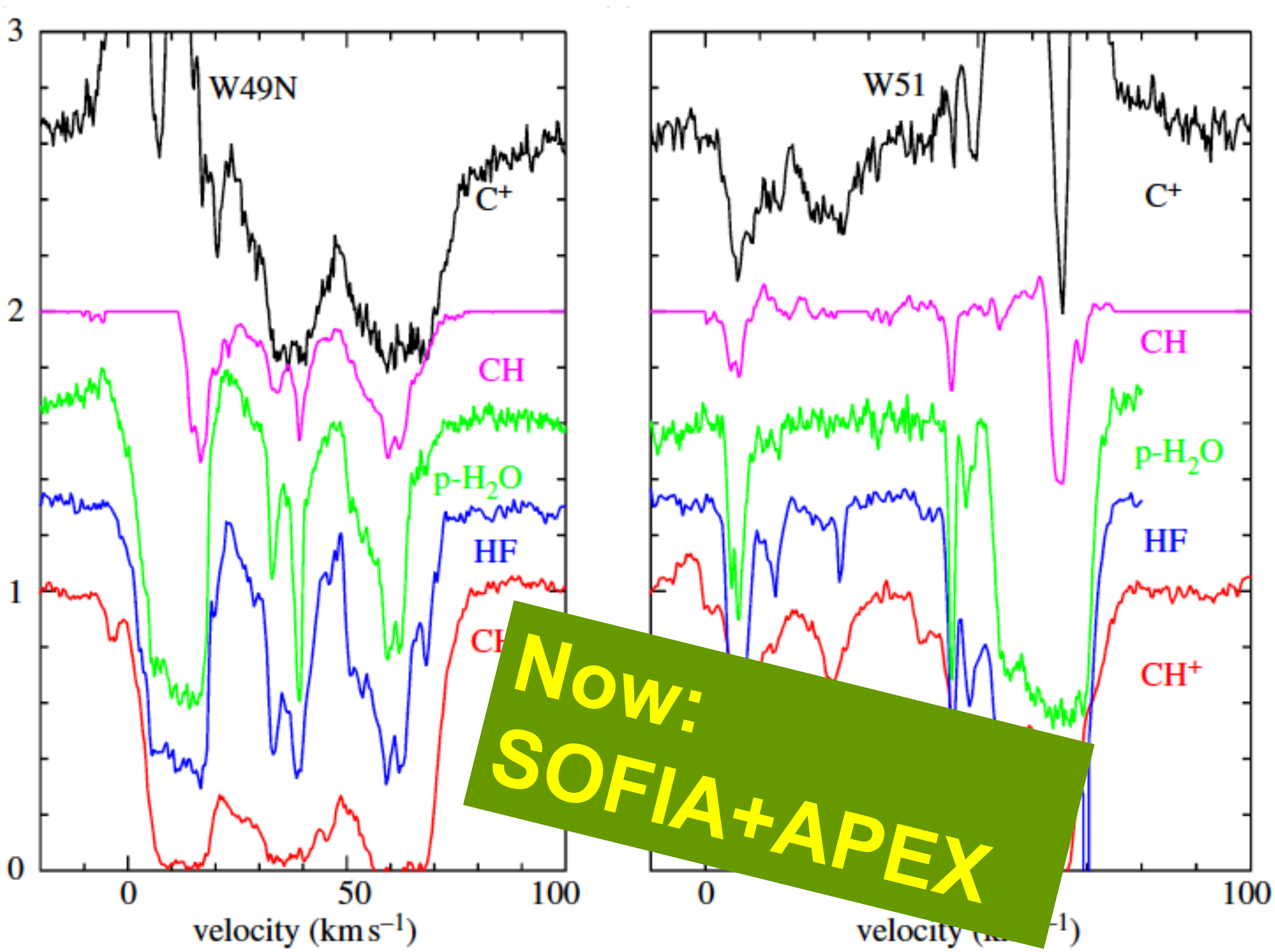
• HDO, D_2O, H_3O^+

After 2000:

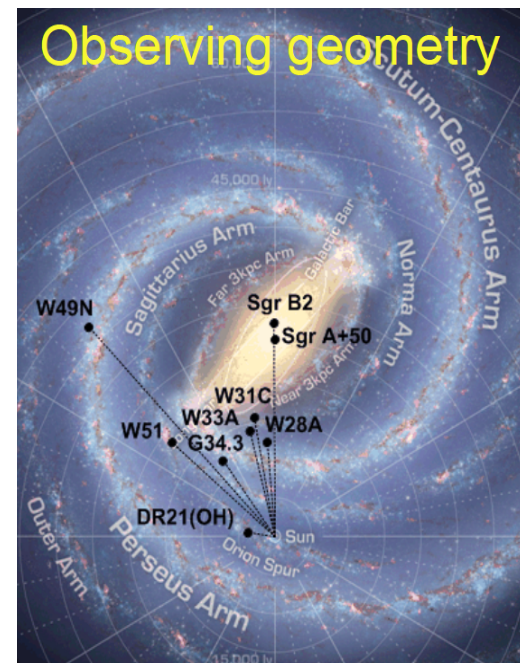
• CH_2 (ISO)

• HF (ISO)

PRISMAS: **PR**obing **I**nterstellar **M**olecules with **A**bsorption Line **S**tudies



Now: SOFIA+APEX



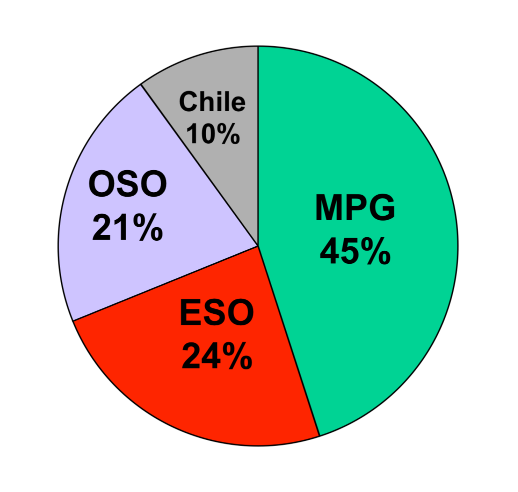
Compilation: Gerin et al. 2012

The Atacama Pathfinder Experiment: a European Submillimeter telescope

… with maximal synergy with SOFIA

The Atacama Pathfinder Experiment (APEX)

Built and operated by
- Max-Planck-Institut fur Radioastronomie
- Onsala Space Observatory
- European Southern Observa



on
Llano de Chajnantor (Chile)
Longitude: 67° 45’ 33.2” W
Latitude: 23° 00’ 20.7” S
Altitude: 5098.0 m

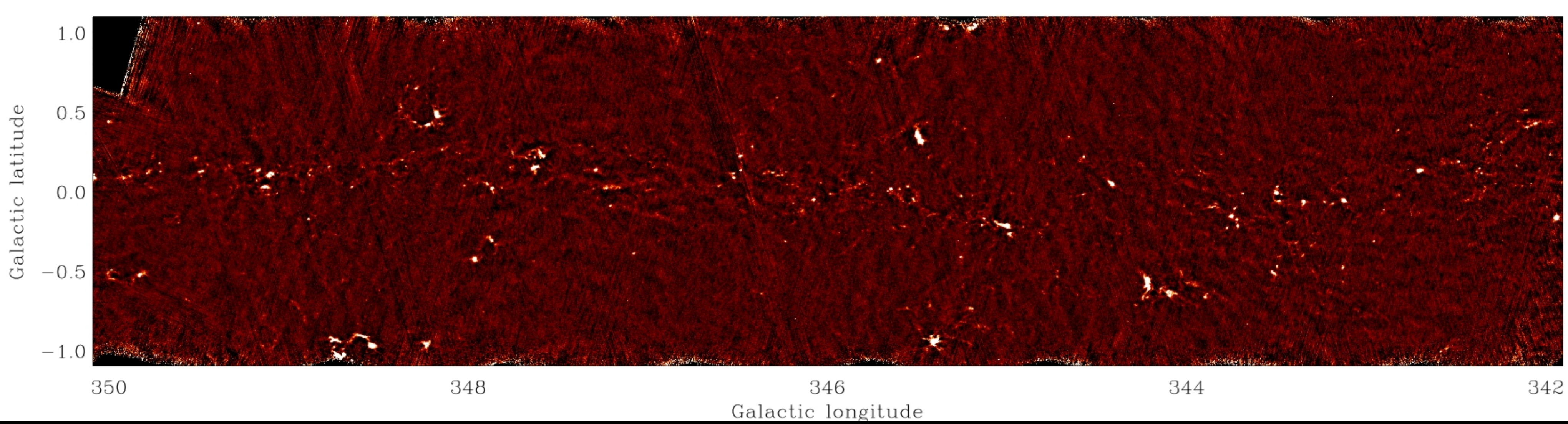
- ∅ 12 m
- λ = 200 μm – 2 mm
- 15 μm rms surface accuracy
- In operation since July 2015
- Initial PI and facility instruments:
    - 345 GHz heterodyne RX
    - 295 element 870 μm Large APEX Bolometer Camera (LABOCA)

http://www.mpifr-bonn.mpg.de/div/mm/apex/

ATLASGAL:
APEX Telescope Large Survey of the Galaxy

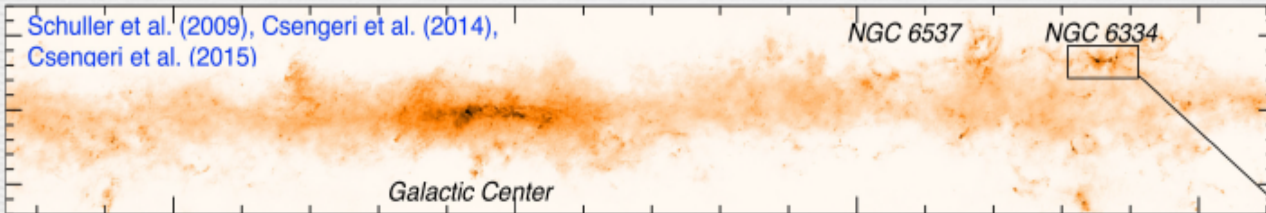
- Main goals:
  - To have a complete 350 GHz census of high mass star formation in the Galaxy (= whole part of Galactic plane visible with APEX)
  - To detect protostellar condensations down tens of solar *masses* throughout the Milky Way

Total observing time: ~1000 hours



ATLASGAL: the most sensitive ground based submm survey

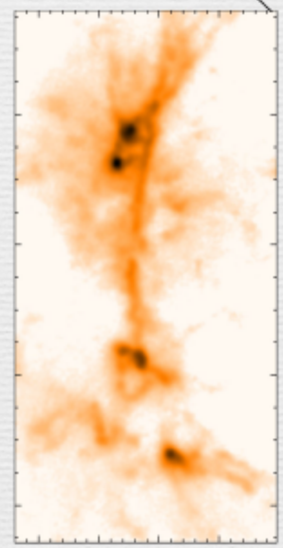
APEX Telescope Large Area Survey of the Galaxy: *~ 420 sq. degree of the inner Galaxy*



APEX

870 μm

ℓ < 60° ← → *ℓ > -80°*



1. Continuum

Catalogs:

- compact sources,
  Contreras+2013,
  Csengeri+ 2014,
  Urquhart+ 2014
- filaments
  Li+ *in prep*

Large scale statistics:

- time-scale estimates
  Csengeri+ 2014,
- dense gas fraction
  Csengeri, Weiss+ 2015
- evolutionary stage indicators
  Urquhart+ 2013a,2013b

> 10 000 sources

2. Distances

kinematic
Wienen+ 2012
Wienen+ 2015
Giannetti+ 2015

maser: BesSel
Brunthaler+ 2009

> 3000 sources

3. Spectroscopy

astro-chemistry
Csengeri+ 2015 (SiO)
Leurini+ 2014 (H_2O)
Giannetti+ 2014 (CO)

> 400 sources

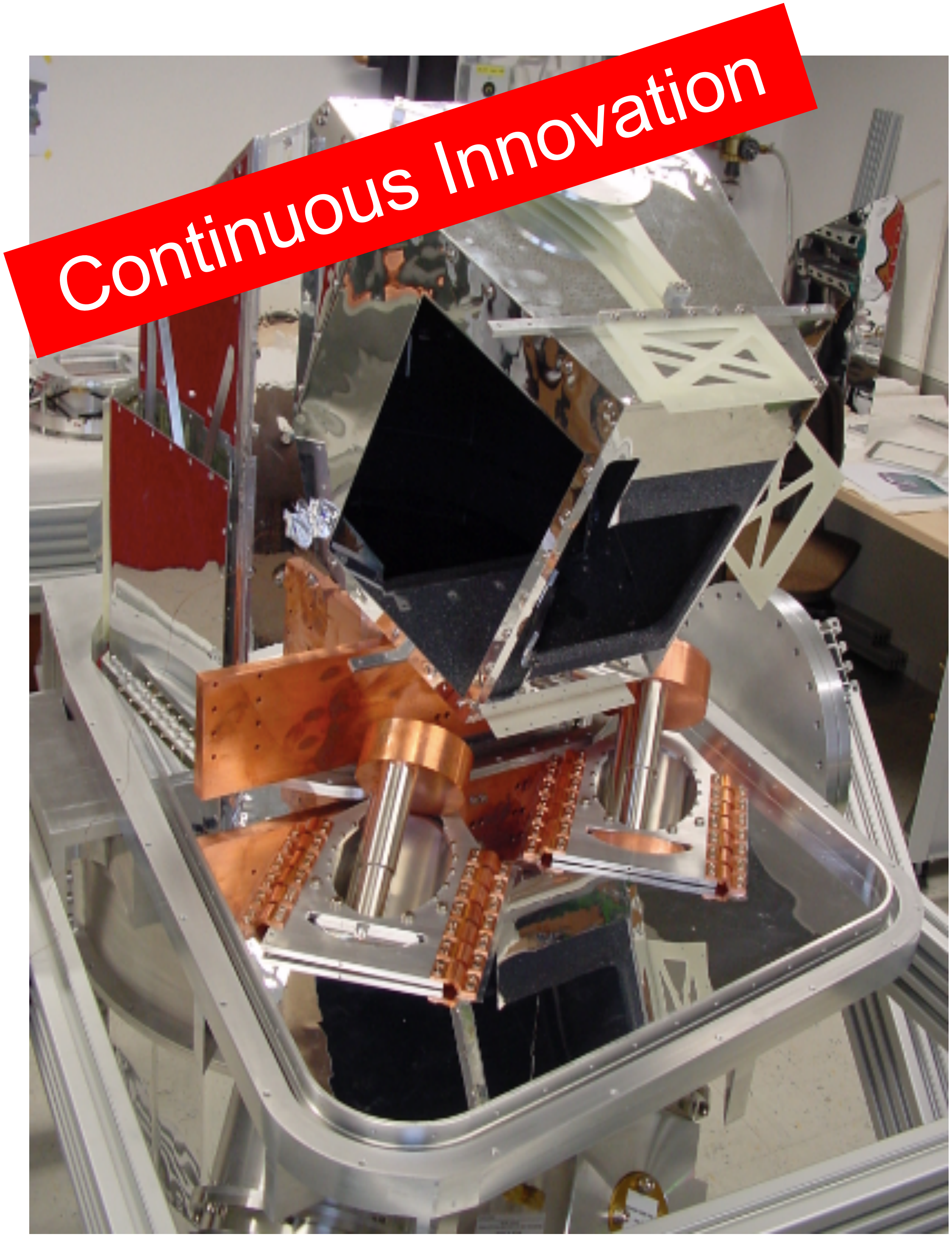
4. Young massive clumps

ALMA follow-up
Csengeri+ *in prep*

~ 40 sources

ATLASGAL database: http://atlasgal.mpifr-bonn.mpg.de/

YouTube DE
atlasgal
Close look at the ATLASGAL image of the plane of the Milky Way
European Southern Observatory (ESO)
Subscribe 11,269
324,211 views
Add to
Share
More
2,241
31



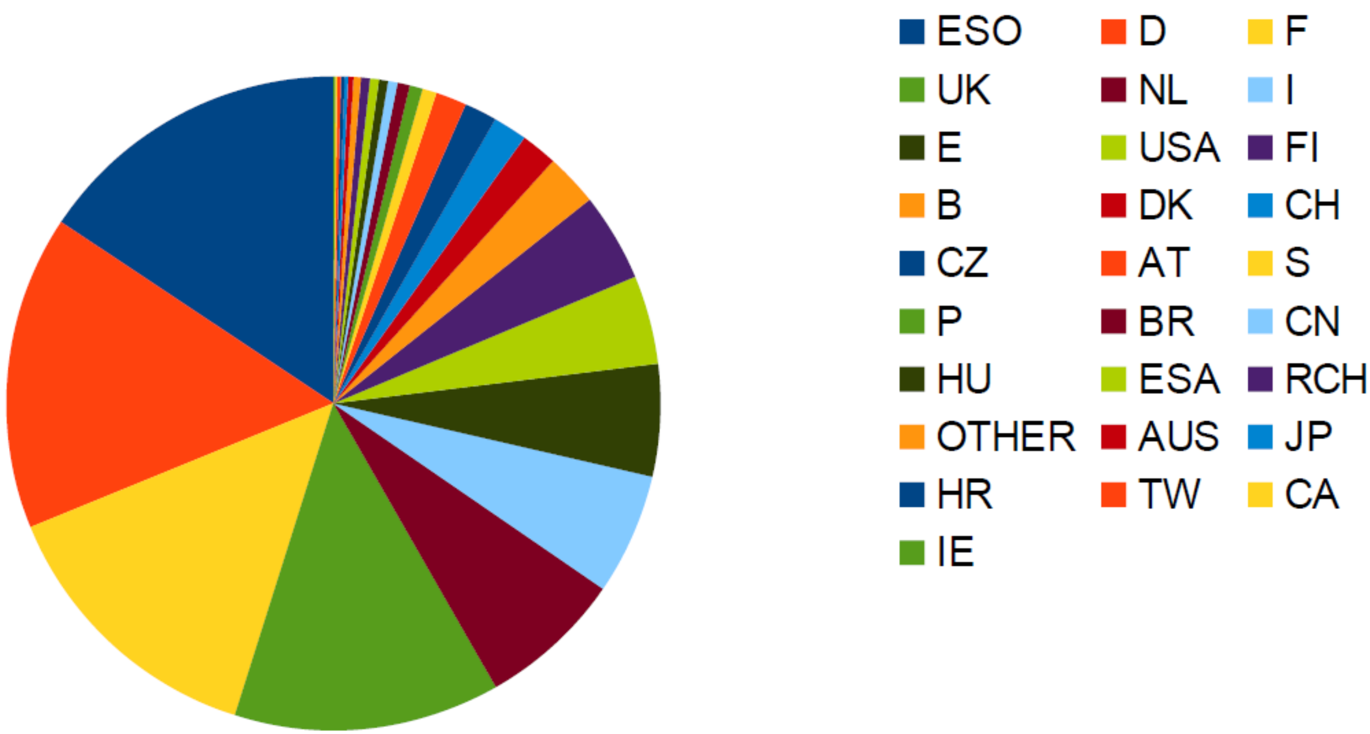
Expected in 2017:

A-MKID (MPIfR + SRON, NL)
3520 pixel at 870 μm
21600 pixel at 350 μm
(filling 15' Field of View)
→ 2016

+ArTeMiS (CEA, Orsay/ESO)
5760 pixel 250+350+450 μm each
→2016

APEX is very international!

Home countries of ESO/APEX proposal principal investigators



Note: 1800 different co-investigators used APEX so far!

GREAT European Collaborations

PI Name	Affiliation	Title	Involved team members	Notes
Denmark				
Kristensen, L.P.	University of Copenhagen	The oxygen budget in low-mass protostars: the NGC1333-IRAS4A R1 shock observed in [OI] at 63mu with SOFIA-GREAT	Güsten, Wiesemeyer	Submitted to A&A.
Netherlands				
Israel, F.P.	Leiden Observatory	Carbon gas in SMC low-metallicity SFRs	Güsten, Okada, Requena-Torres, Risacher, Simon, Stutzki	A&A 589, A28 (2016)
		[C II] 158 μm and [N II] 205 μm emission from IC 342. Disentangling the emission from ionized and photo-dissociated regions	Güsten, Jacobs, Simon, Stutzki	A&A 591A, A33 (2016)
Tielens, A.G.M.	Leiden Observatory	The large scale [CII] emission from the Orion molecular cloud	tba	PhD thesis Cornelia Pabst
Vicente, S.	Groningen	[OI] and OH line profiles from proplyds in Orion and the Carina nebulae	Wiesemeyer	Data processed and anaysed, publication in preparation.
France				
Cormier, D. Madden, S.	Heidelberg/Paris	Disentangling the ISM phases of the dwarf galaxy NGC 4214 using [C ii] SOFIA/GREAT observations	Csengeri, Graf	Submitted to A&A
Gerin, M.	Paris	Chemistry of diffuse clouds	Güsten, Wiesemeyer, tba	Collaboration based on archival, published data
Gusdorf, A.	Paris	Challenging shock models with SOFIA OH observations in the high-mass star-forming region Cepheus A	Csengeri, Güsten, Heyminck, Jacobs, Menten, Requena Torres, Wiesemeyer	A&A 585, A45
Herpin, F.	Bordeaux	Water in Massive protostellar objects: first detection of THz water maser and water inner abundance.	Wiesemeyer, tba	Data processed, delivered and archived.
Schneider, N.[1]	Bordeaux/ Cologne	Globules and pillars seen in the [CII] 158 μm line with SOFIA	Csengeri, Güsten, Requena-Torres, Simon, Stutzki	AA 542, L18 (2012)
		Shocks or PDRs in S106 ? [OI] and high-J CO observations	Simon, tba	Data processed, delivered and archived.
Vastel, C.	Toulouse	Tracing the cold regions of a dense core with para-H2D+ against a bright continuum source	tba	Data processed, delivered and archived.
European Institutions				
Kramer, C.	IRAM Granada	UpGreat CII mapping of six HII regions in M33	Riquelme, tba	Data processed, delivered and archived.
Tibbs, C.T.	ESA (ESTEC)	Role of CII in spinning dust models	Riquelme, tba	Data processed, delivered and archived.

1 See also GENESIS project, cooperation ANR/DFG, https://www.astro.uni-koeln.de/node/965

Compiled by H. Wiesemeyer

Interactions

Between the German and the Larger European FIR Communities

- There are lots of scientist to scientist/group to group collaborations
  - Driven by scientific interest, concentration on
    - ISM physics and chemistry, galactic and (nearby) Galaxies
    - star formation
    - The Galactic center and the central molecular zone
    - Planetary nebulae
    - …
- SOFIA covers broad science, but doesn’t do major FIR areas
    - Large scale continuum imaging, ISM and cosmology deep fields

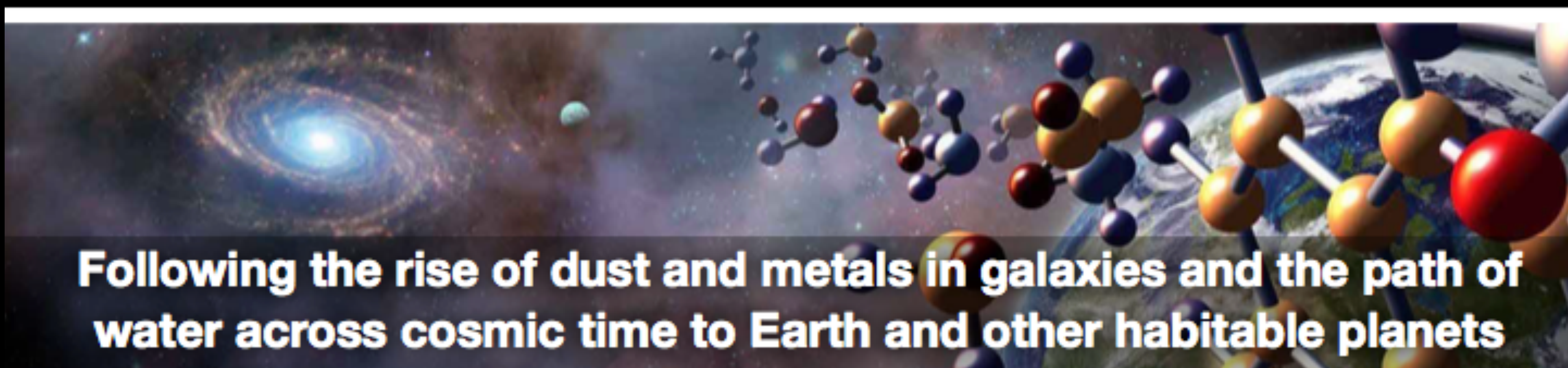
- On a formal level, German institution are involved in the planning of (far) future FIR space missions

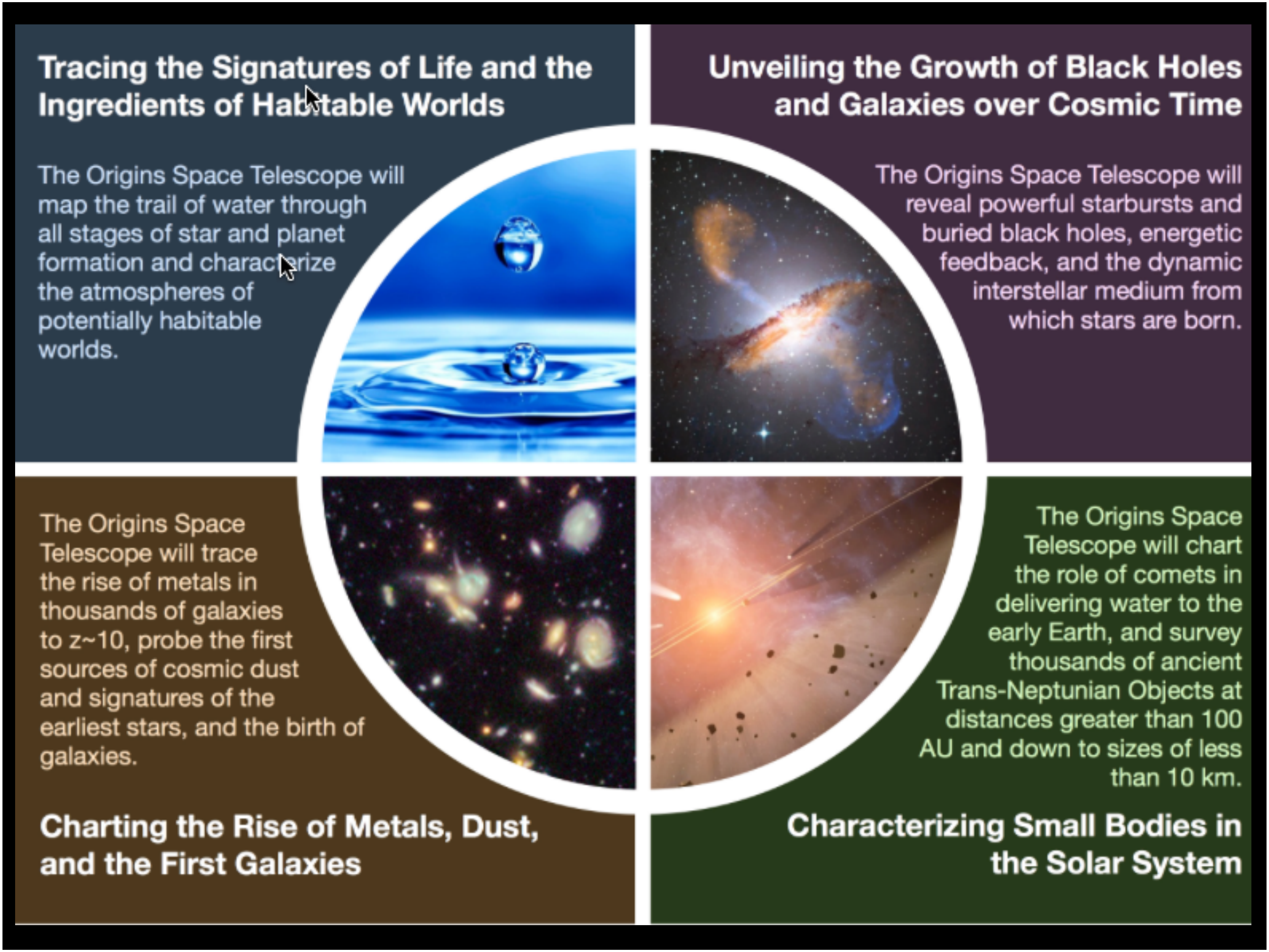
National Aeronautics and Space Administration

NASA

ORIGINS Space Telescope

Seeing Beyond the Light

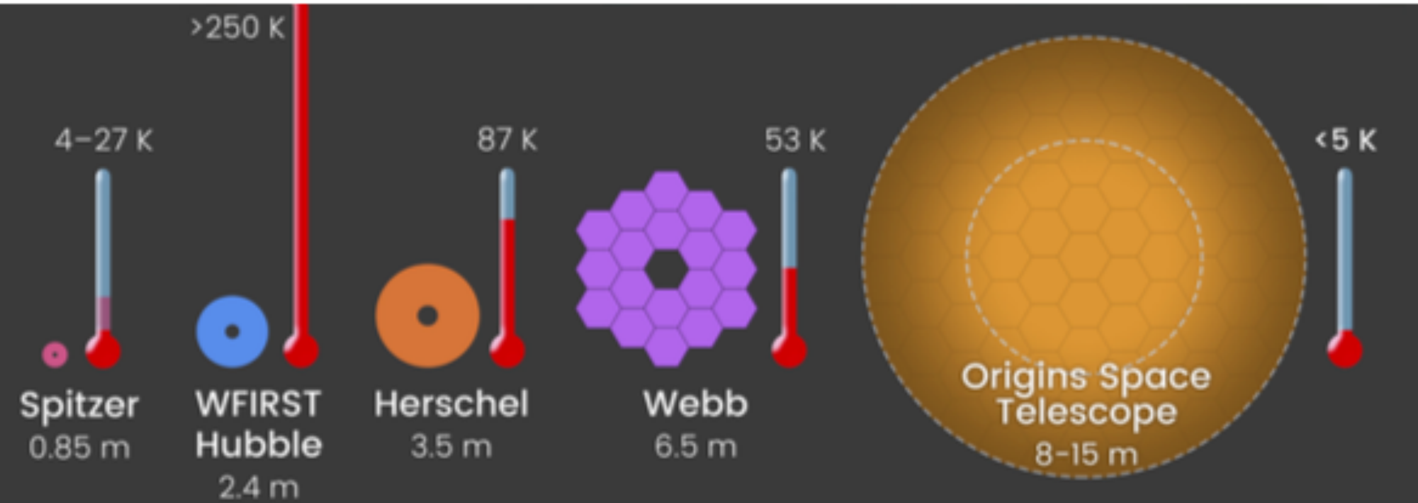



Tracing the Signatures of Life and the Ingredients of Habitable Worlds
The Origins Space Telescope will map the trail of water through all stages of star and planet formation and characterize the atmospheres of potentially habitable worlds.
Unveiling the Growth of Black Holes and Galaxies over Cosmic Time
The Origins Space Telescope will reveal powerful starbursts and buried black holes, energetic feedback, and the dynamic interstellar medium from which stars are born.
The Origins Space Telescope will trace the rise of metals in thousands of galaxies to z~10, probe the first sources of cosmic dust and signatures of the earliest stars, and the birth of galaxies.
Charting the Rise of Metals, Dust, and the First Galaxies
The Origins Space Telescope will chart the role of comets in delivering water to the early Earth, and survey thousands of ancient Trans-Neptunian Objects at distances greater than 100 AU and down to sizes of less than 10 km.
Characterizing Small Bodies in the Solar System

ORIGINS Space Telescope | Capabilities & Characteristics

Origins will be an actively cooled telescope covering the infrared spectrum. Spectrographs and imagers will enable 3D surveys and discover and characterize distant galaxies, exoplanets, and the outer reaches of the Solar System. We would like to hear from you. Contact us at:

email: **OST_info@lists.ipac.caltech.edu** *twitter:* **@NASAOriginsTele**
web: **origins.ipac.caltech.edu** • asd.gsfc.nasa.gov/firs

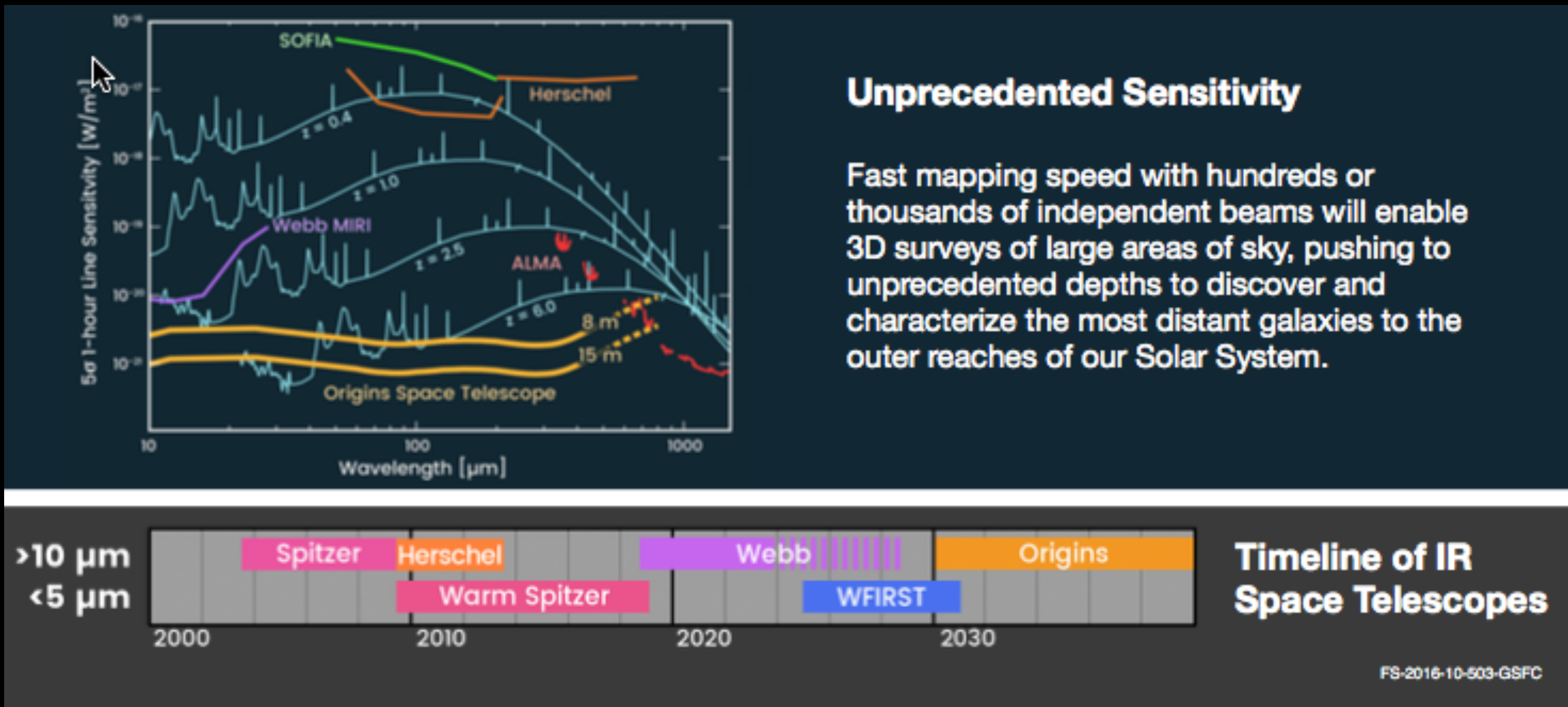


Actively-Cooled Large Aperture

Will attain sensitivities 100–1000x greater than any previous far-infrared telescope

Potential Wavelength Coverage from 5 μm–1 mm

Enables observations of biosignatures in the atmospheres of transiting Earth-like planets, mid- and far-infrared diagnostic lines in galaxies out to redshifts of 10, and characterization of water from the Solar System to the ISM.

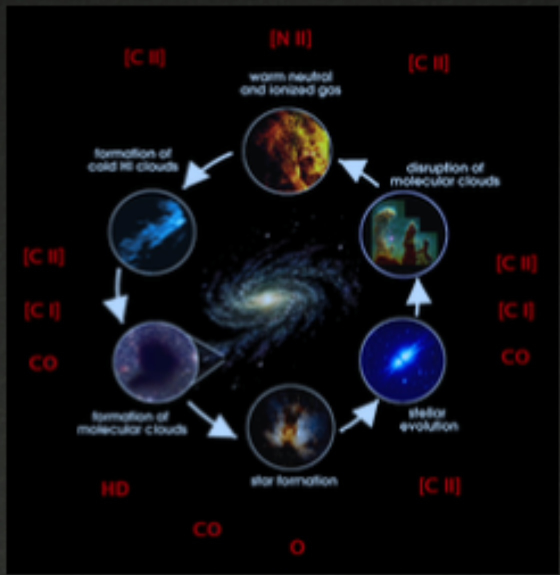


European (ESA) ex officio members of NASA study group:

- Susanne Aalto (Onsala Space Observatory, Sweden)
- Maryvonne Guerin (Observaoire de Paris, France)
- Frank Helmich (SRON, Netherlands Instute for Space Research)
- Karl Menten (MPI for Radio Astronomy, Germany)

FIRSPEX Mission Factsheet (v4.0)
Far InfraRed Spectral Explorer

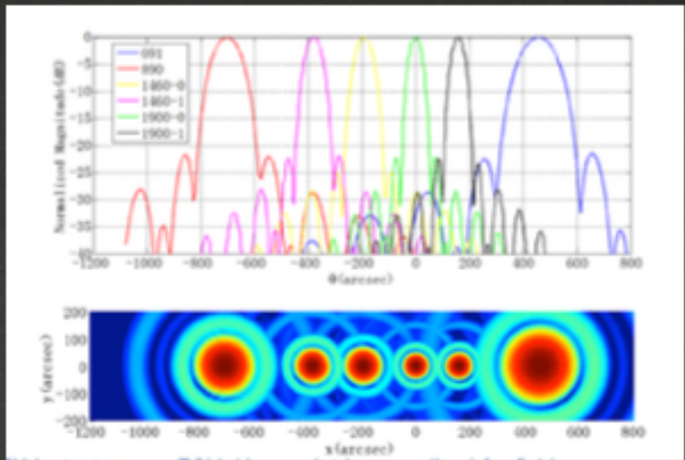
Mission Overview:
- Studying the Life Cycle of the Interstellar Medium in the Universe
- Spectroscopic companion to heritage Galactic Plane Surveys



Core Science:
- The physics/properties of the three phased ISM
- The transition of atomic to molecular clouds
- CO-dark clouds / early SF & feedback / the ISM in galaxies near and far

Telescope and Instrumentation:
- 1.2 m diameter telescope (L2 Halo orbit)
- SIS/HEB mixer technology
- Quantum Cascade Laser (QCL) Technology providing mixer LO power
- Detectors mechanically cooled to 4K

Primary channels:
- [OI] 63 μm (4.7 THz)
- [CII] 158 μm (1.09 THz)
- [NII] 205 μm (1.45 THz)
- [CI] 370 μm (0.81 THz)



FIRSPEX instantaneous-FOV.
Upper: normalised far-field response profile.
Lower: instantaneous FOV as a contour plot in dB.

Core Survey:
- Survey of the Galactic Plane and the Ecliptic Poles
- Pointed follow up observations of galactic targets
- Pointed observations of nearby galaxies
- Pointed observations of selected high-z / lensed galaxies

FIRSPEX Mission Factsheet (v4.0)

Far InfraRed Spectral Explorer

Sensitivity

Species	Freq. (GHz)	Wavelength (microns)	Beam FWHM (arcmin)	TsysDSB (K)	Unresolved Line 1 MHz 5 sec ($W\ m^{-2}$)	T_a K ($1 kms^{-1}$)
CI [370]	809	370.6	1.3	180	4.91×10^{-18}	0.16
NII[205]	1450	206.8	0.7	350	9.55×10^{-18}	0.31
CII[158]	1900	157.8	0.6	500	1.36×10^{-17}	0.45
OI[63]	4700	63.78	0.3	800	2.18×10^{-17}	0.72

Assumed Resolution

Species	Freq. (GHz)	Wavelength (microns)	Galactic Plane (MHz)	Local Galaxies (MHz)	Local Galaxies (MHz)	High-z (MHz)
Velocity			± 150 kms^{-1}	± 500 kms^{-1}	± 300 kms^{-1}	2000 kms^{-1}
CI [370]	809	370.6	0.8	2.7	1.6	5.4
NII[205]	1450	206.8	1.5	4.8	2.9	9.6
CII[158]	1900	157.8	1.9	6.3	3.8	12.7

Assumptions: Based on 120 cm aperture : 5s integration : 1MHz resolution

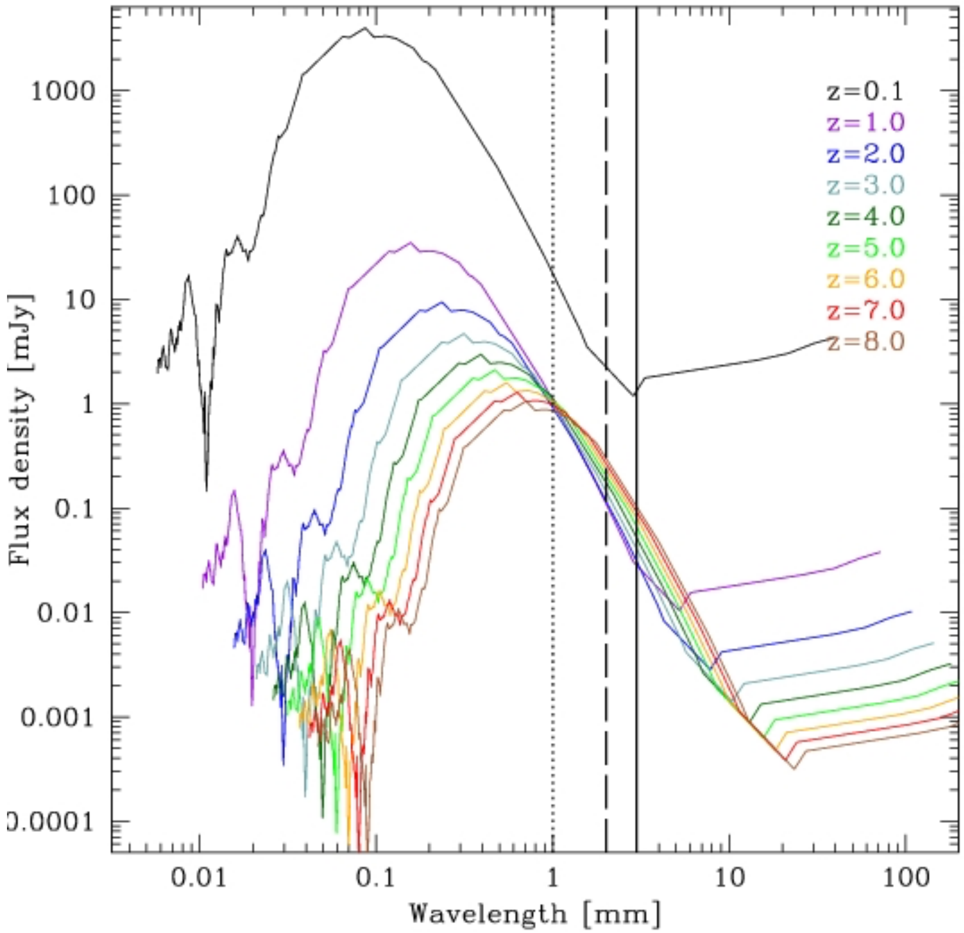

Long duration balloon flights
... an additional option for FIR stronomy

APEX and SOFIA Workshops (in alternating years)

- at Ringberg Castle, Bavaria
- organized by Friedrich Wyrowski
- Next SOFIA workshop March 5-8, 2017


Thanks for your attention

The “negative K-correction”



http://www.mpia.de/homes/decarli/science.html

FIRSPEX payload: High spectral resolution H/D spectrometer