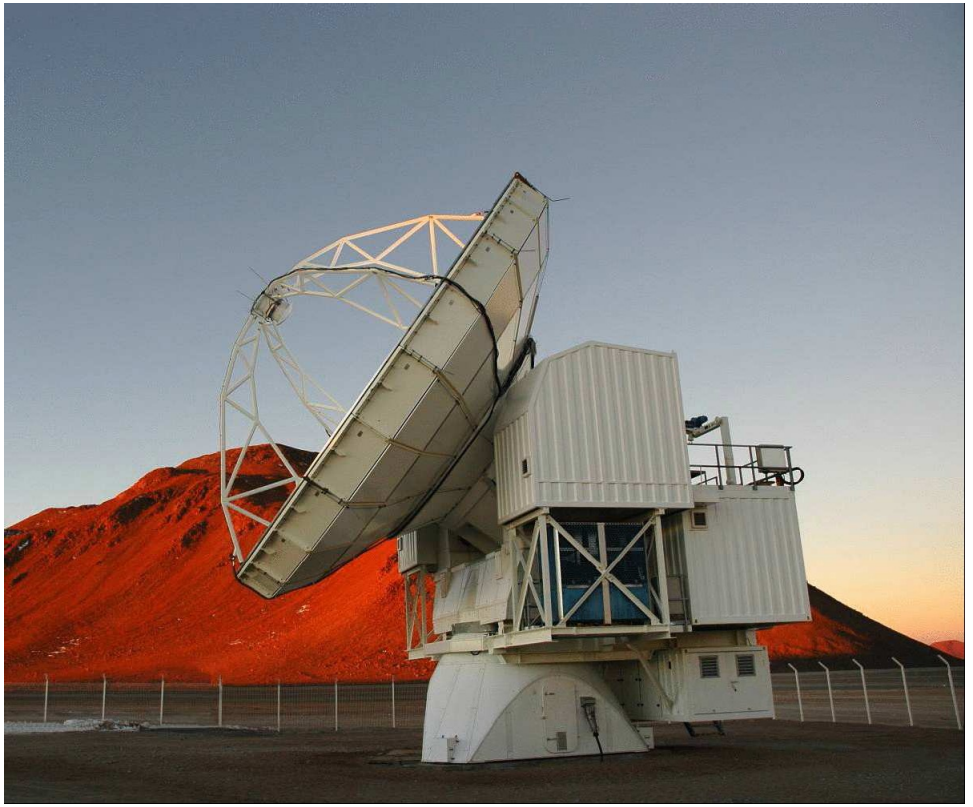
The Atacama Pathfinder Experiment (APEX)

Friedrich Wyrowski
Max Planck Institute for Radio Astronomy
Bonn, Germany



10 years of APEX!

Hot Science of the Cold Universe

The "Atacama Pathfinder Experiment" in Chile starts its second decade

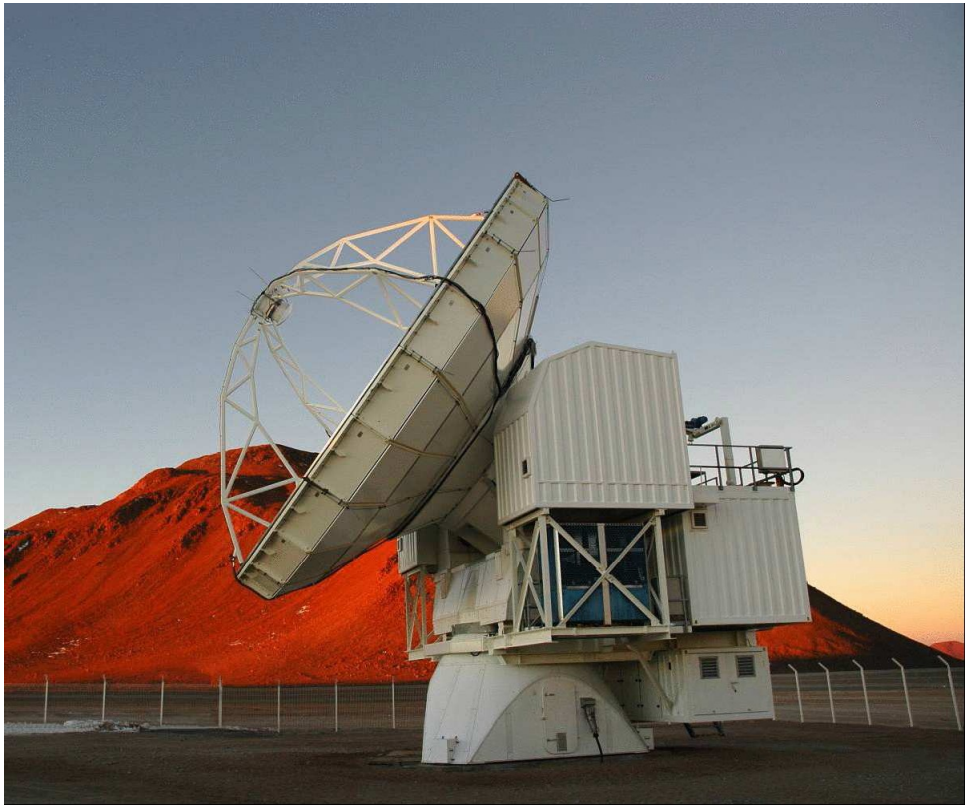
February 09, 2016

During 10 years of operation, the Atacama Pathfinder Experiment (APEX) 12 m submillimeter telescope has significantly contributed to a wide variety of astronomy science areas, ranging from the discoveries of new interstellar molecules to large and deep imaging of the submillimeter sky, leading to insights into star formation from our Milky Way to distant starburst galaxies in the early Universe.

On the occasion of this anniversary, a celebration was held at the APEX base station in Sequitor, San Pedro de Atacama, including a visit to the APEX telescope at the Chajnantor plateau, 5100 m above sea level.

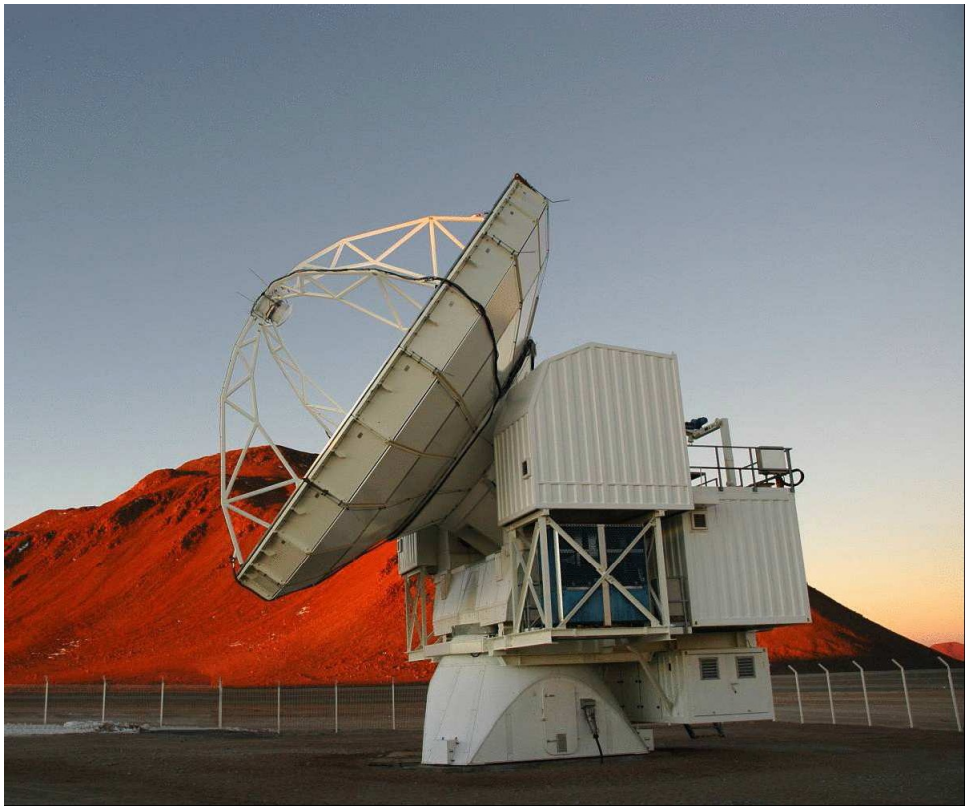
Outline

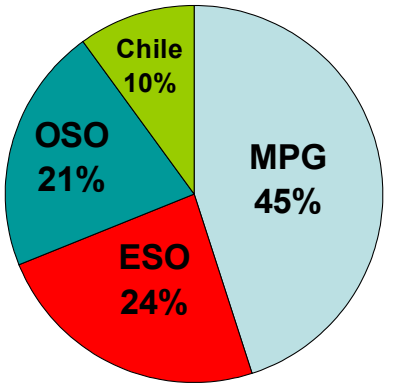
- APEX overview/current instrumentation
- Science teaser
- APEX2022
- APEX upcoming instruments



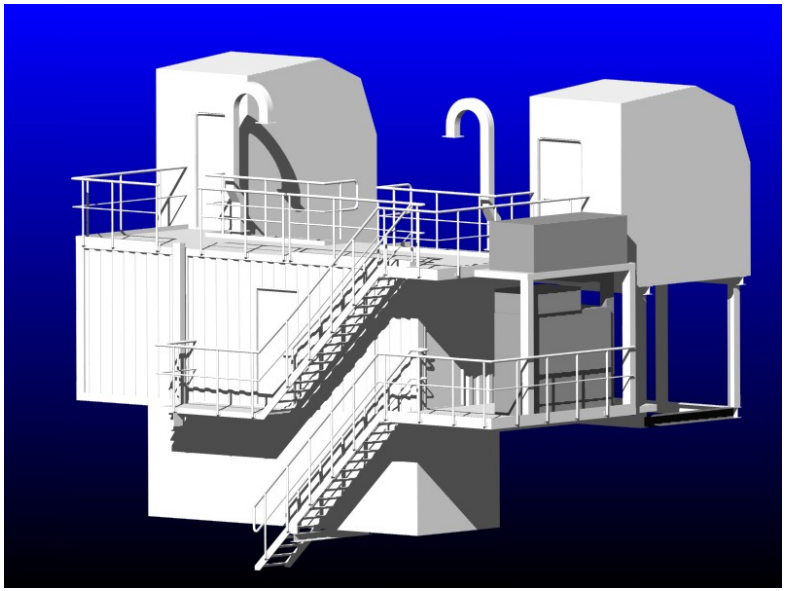
APEX in a nutshell

- 12m, modified copy of ALMA prototype ant.
- At 5100m on Chajnantor Plateau (ALMA site)
- MPG/ESO/OSO & Chile
- Base in Sequitor @ 2500m with control room etc.
- Surface ~ 14 micron
- Wobbling secondary
- BEs: many FFTSs
- FEs: Heterodyne Rxs: 160-1100GHz, Continuum arrays
- In operation since 2005





APEX vs. ALMA antennas



The **APEX design** is based on the **ALMA**/N.A. **Prototype**

but modified for single-dish operation of a wide suite of instruments

by adding two Nasmyth cabins, two large equipment containers and a wobbling secondary

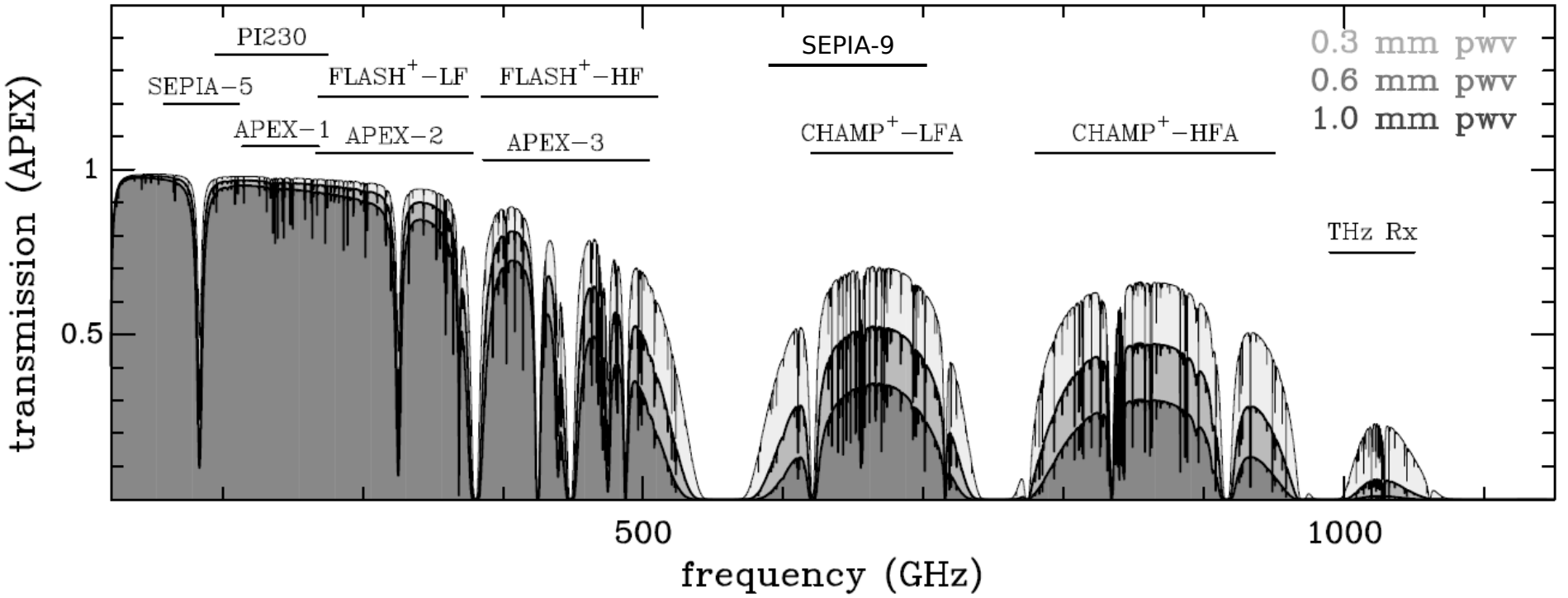
APEX Instrumentation

• Heterodyne facility and PI instruments cover all atmospheric windows accessible from the Chajnantor Plateau

• CHAMP+: 2x7pix. heterodyne camera (450 & 350µm atm. windows)

• Several newcomers that pave the way for the future instrumentation suite → PI230, SEPIA-5/9

• Continuum: workhorse LABOCA (870µm, ~300 pix), SABOCA (350µm, 30 pix), but newcomers on the way → AMKIDs, ArTeMiS



Backends:
Fast Fourier Transform Spectrometer
(B. Klein, MPIfR)

- 1. Generation (2008-): AFFTS
  - 1.5 GHz bandwidth, 8k spectral channels
- 2. Generation (2010/11-): XFFTS
  - 2.5 GHz bandwidth, 32k / 64k
- 3. Generation (2015-): FFTS4G
  - 4 GHz bandwidth, 64k
  - direct IF sampling (4 – 8 GHz)

mm VLBI
(see also E. Ros talk)

- From 2009 on: Combined OSO/MPI effort to prepare APEX for VLBI
- From 2012 on: 1.3 mm (230 GHz) VLBI runs involving APEX achieved sub-mas resolution key science targets (Sgr A*, M 87, BL Lac, OJ 287, and others).
- In 2015, APEX + SPT + other stations achieved 38 μas resolution

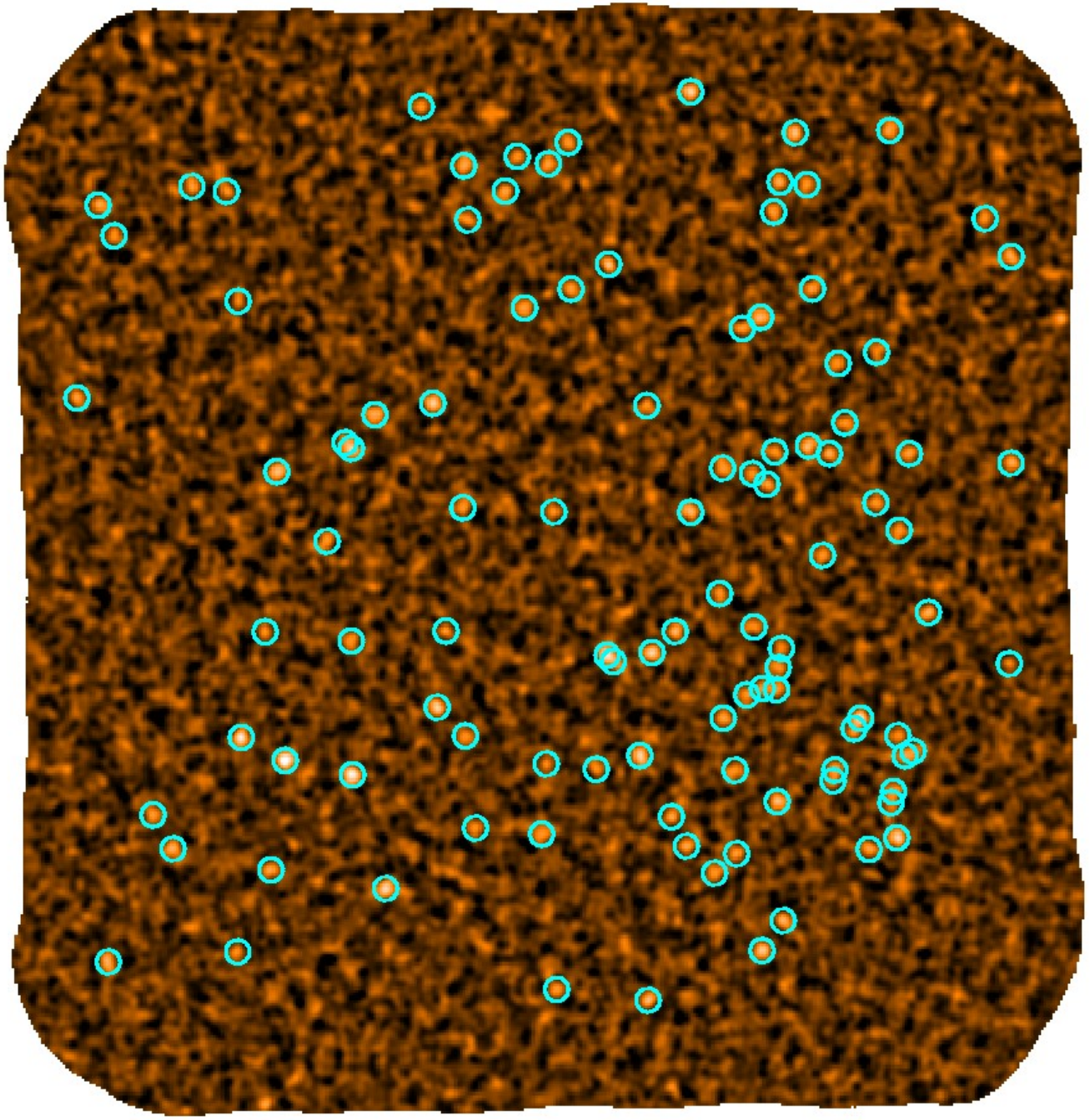
Proposal submission:
Frequent opportunities!

- 4 queues, all 2 deadlines/year, large projects mostly done in partnerships
  - ESO, deadlines Fall/Spring
  - OSO, deadlines Fall/Spring
  - Chile, open for scientists at Chilean institutions
  - MPG, open for scientists at German institutions, quick turnaround (as fast as two months)

Science Teaser

- Very limited, subjective selection
- Large, multi-partner projects
- But many smaller-sized projects, APEX is very versatile and has a large userbase
- Many multi-wavelengths projects

The Large APEX Bolometer Camera Survey of the Extended Chandra Deep Field South (LESS) –> Early evolution of Galaxy

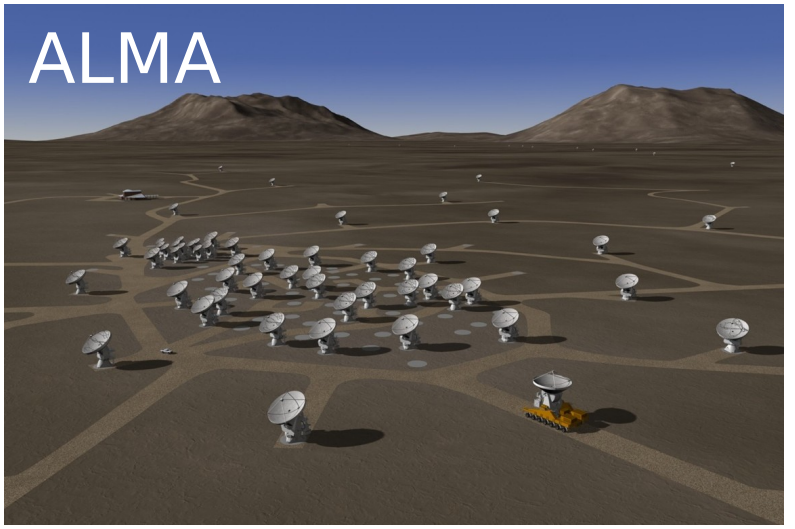


- Extended Chandra Deep Field South
- 1.2 mJy/bm
- Detected 126 submillimeter sources
- Largest, most homogenous, most sensitive 870μm survey
- Limitation: only 19” resolution!

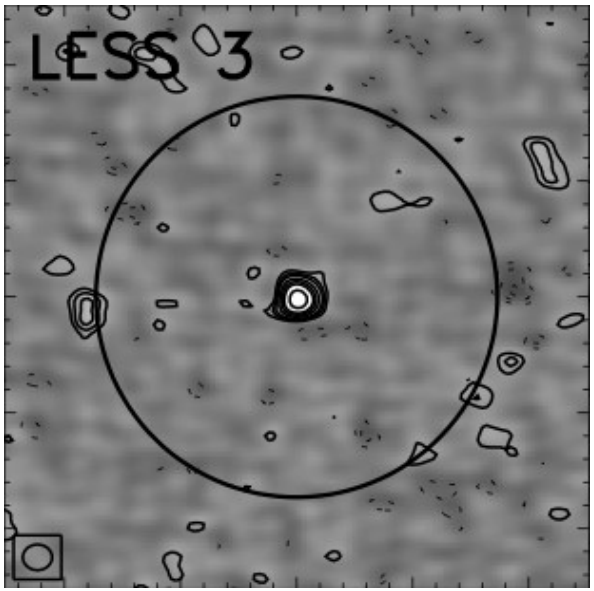
Triggered many follow up studies!

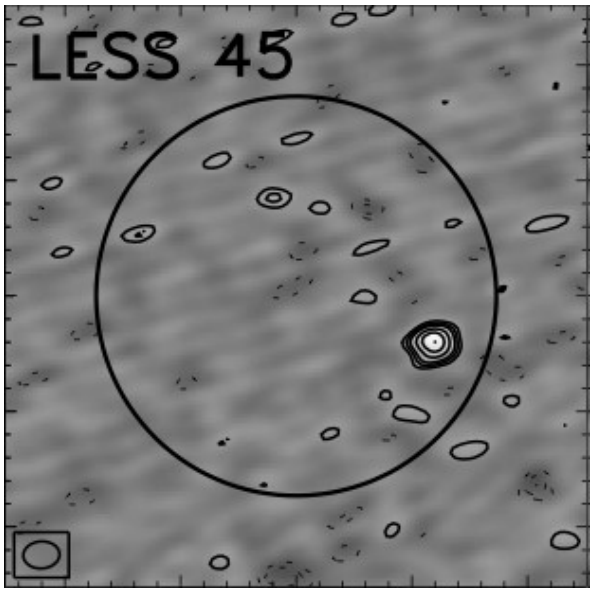
Weiss et al. (2009)

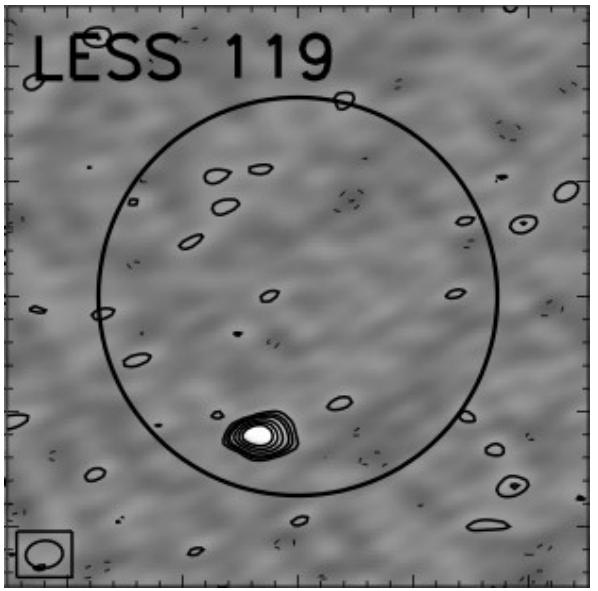
Immense amount of follow up studies, e.g.:
ALMA LESS = ‘ALESS’



- Cycle 0 to map 126 LESS SMGs (PI: I. Smail)
- 870μm (345 GHz) – Band 7
- Compact configuration →1.5” resolution
- 3× deeper than LESS in only 2 min!







Hodge+ 2013; Karim+2013, Decarli+ 2014

Dusty Starburst Galaxies in the Early Universe as Revealed by Gravitational Lensing

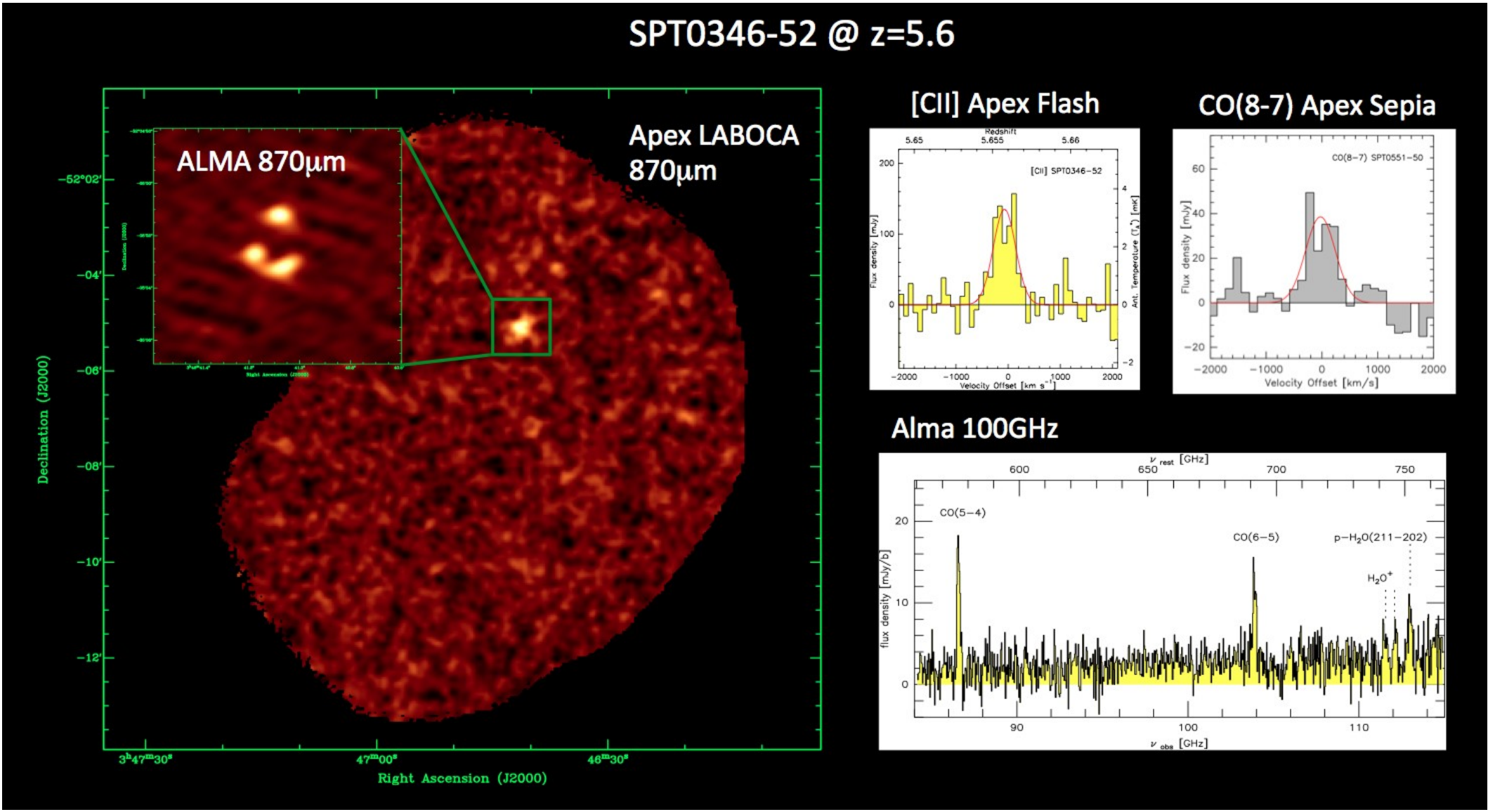
- Greve et al. (ApJ 756, 101, 2013)
- Vieira et al. (Nature 495, 344, 2013)
- Hezaveh et al. (ApJ 767, 132, 2013)
- Weiß et al. (ApJ 767, 88, 2013)

SPT finds 26 very strong sources in mm surveys → Magnified by gravitational lensing

APEX LABOCA and SABOCA observations (870 and 350 µm) → Steep spectral indices

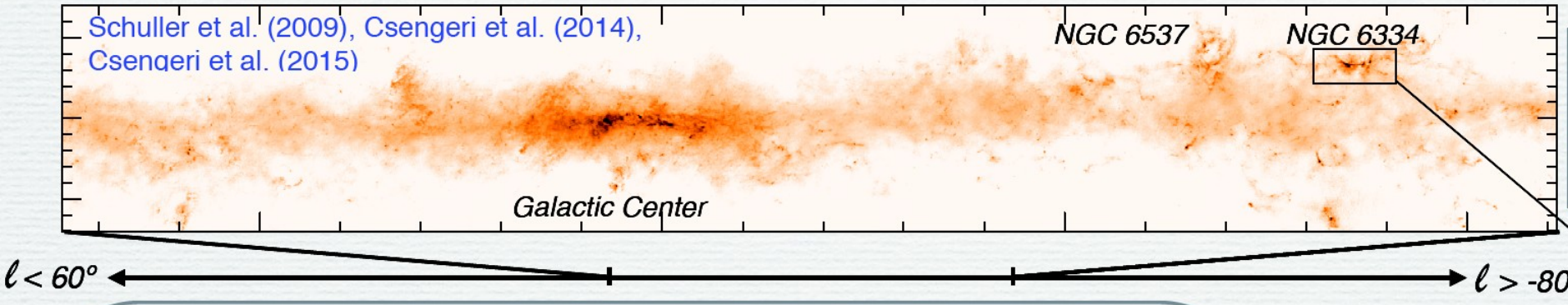
ALMA 3 mm and 870 µm spectroscopic (+ continuum) imaging reveals clear evidence for gravitational lensing and accurate redshifts for the majority of sources

Weiß+2013, Gullberg+2014, Strandet+2016



ATLASGAL: the most sensitive ground based submm survey

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



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

2. Distances

kinematic

Wienen+ 2012
Wienen+ 2015
Giannetti+ 2015

maser: BesSel

Brunthaler+ 2009

3. Spectroscopy

astro-chemistry

Csengeri+ 2015 (SiO)
Leurini+ 2014 (H_2O)
Giannetti+ 2014 (CO)

4. Young massive clumps

ALMA follow-up

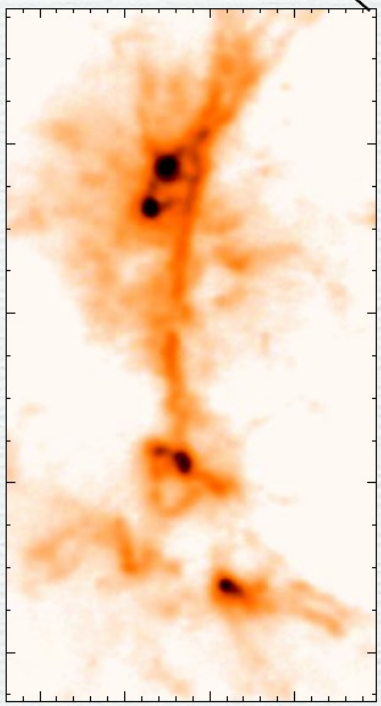
Csengeri+ *in prep*

~ 40 sources

> 400 sources

> 3000 sources

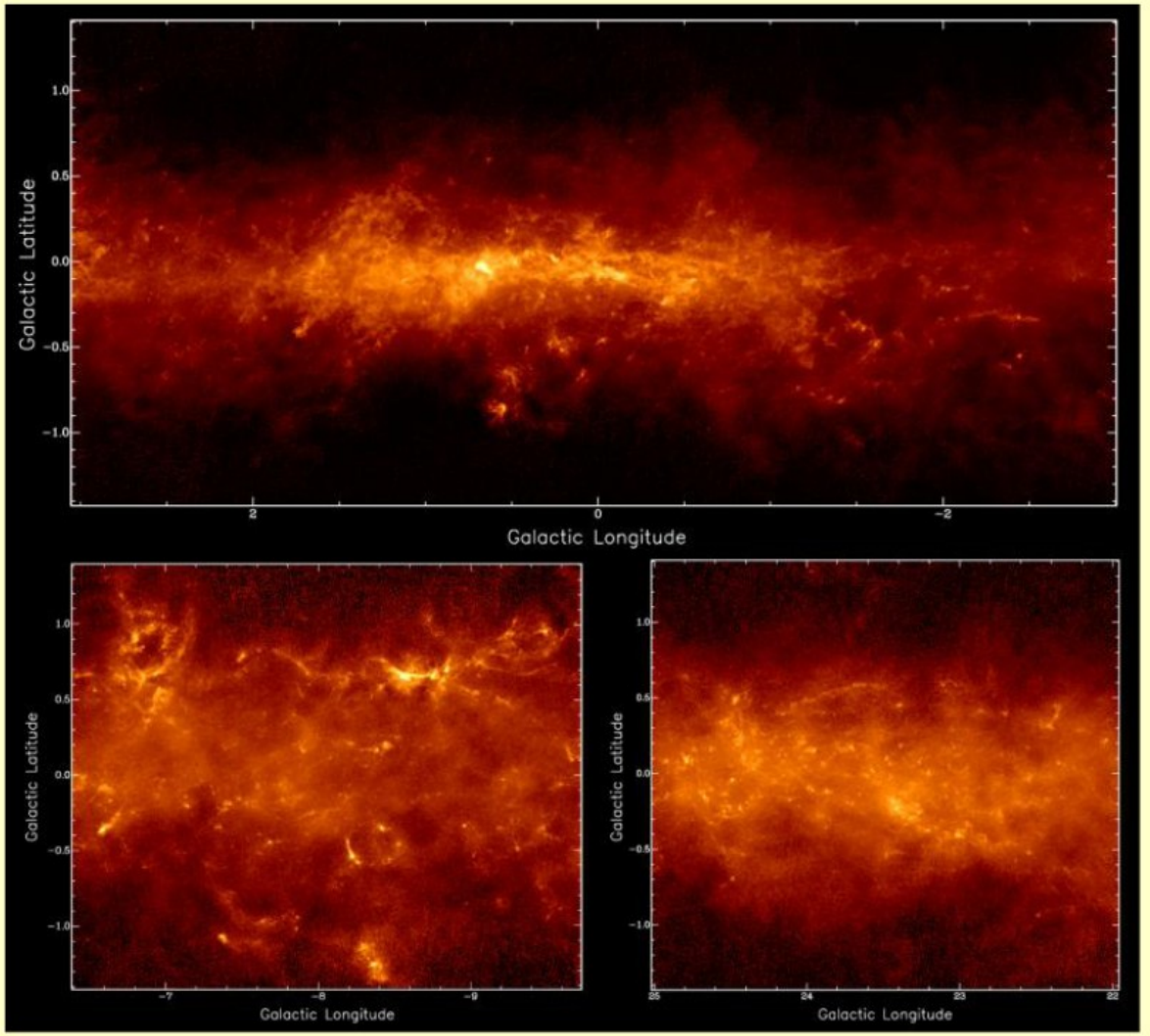
> 10 000 sources



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

ATLASGAL – Planck combination

Csengeri+2016, A&A 585, 204

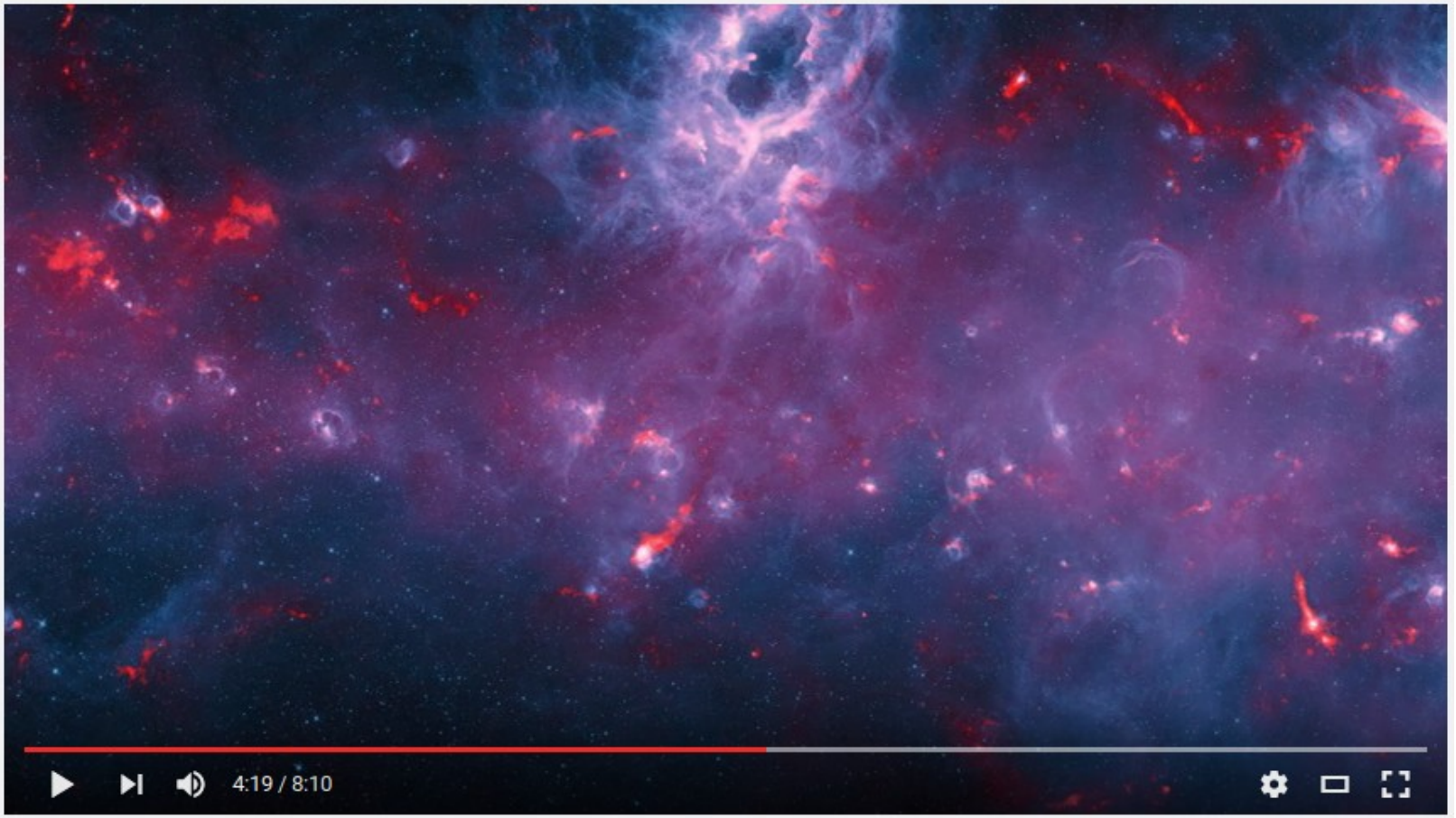


- Covers all spatial scales
- Dense gas fraction 2-5% in the galactic plane
- Total SFR 1.3 Msol/yr
- Coming next: AMKIDS350 with Herschel/SPIRE!

Publicly available at: http://atlasgal.mpifr-bonn.mpg.de

YouTube SE

atlasgal



Close look at the ATLASGAL image of the plane of the Milky Way

European Southern Observatory (ESO)

Subscribe 11,222

323,641 views

Add to Share More 2,237 31

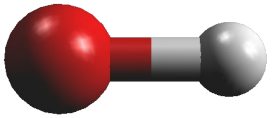
Published on Feb 24, 2016

This video takes a close look at a new image of the Milky Way released to mark the completion of the APEX Telescope Large Area Survey of the Galaxy (ATLASGAL). The APEX telescope in Chile has mapped the full area of the Galactic Plane visible from the southern hemisphere for the first time at submillimetre wavelengths — between infrared light and radio waves — and in finer detail than recent space-based surveys.

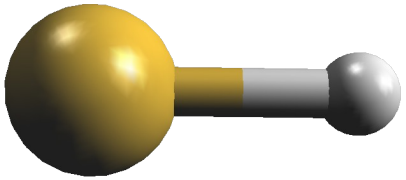
SHOW MORE

APEX discovered a number of new, simple molecules in the ISM

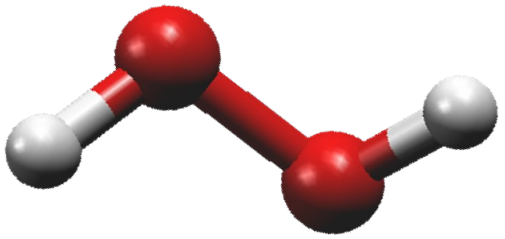
CF^+ Neufeld et al. 2006



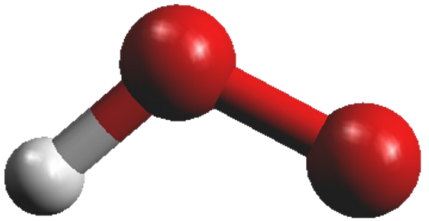
OH^+ Wyrowski et al. 2010



SH^+ Menten et al. 2011



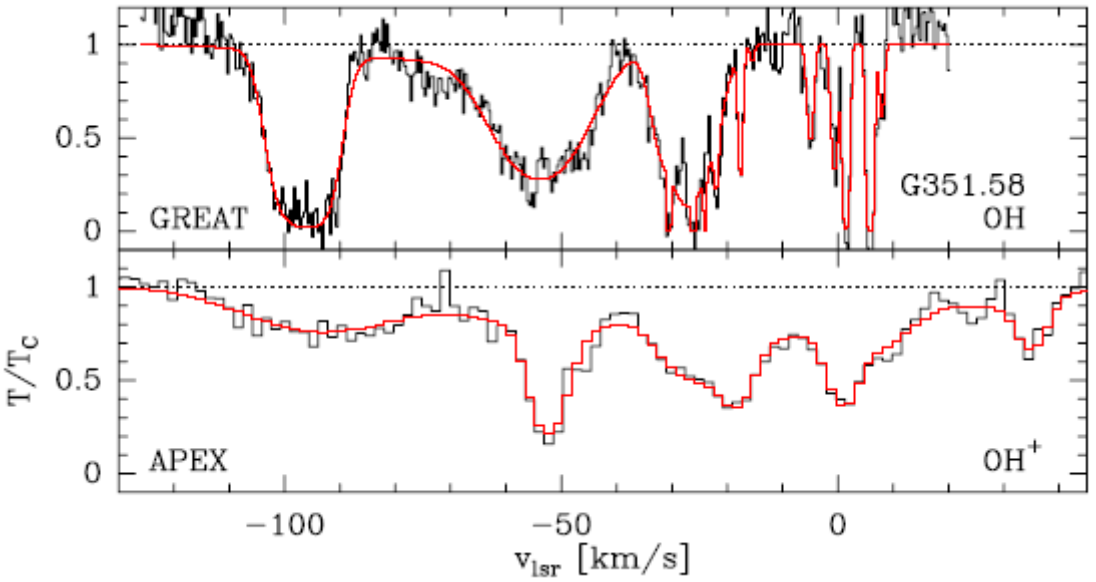
H_2O_2 Bergman et al. 2011



HO_2 Parise al. 2012

Oxygen Chemistry in Diffuse clouds

Wiesemeyer+2016



SOFIA/GREAT:

Transition	Frequency [GHz][a]	A_E [s^{-1}][b]
OH, $^2\Pi_{3/2}$, $J = 5/2 \leftarrow 3/2$		
$F = 2^- \leftarrow 2^+$	2514.298092	0.0137
$F = 3^- \leftarrow 2^+$	2514.316386	0.1368
$F = 2^- \leftarrow 1^+$	2514.353165	0.1231
^{18}OH, $^2\Pi_{3/2}$, $J = 5/2 \leftarrow 3/2$		
$F = 2^+ \leftarrow 2^-$	2494.68092	0.0136
$F = 3^+ \leftarrow 2^-$	2494.69507	0.1356
$F = 2^+ \leftarrow 1^-$	2494.73421	0.1221

APEX: 2nd strongest OH^+ fine structure line @ 1033GHz with MPIfR THz RX (Leinz+2010)

APEX2022

- Current agreement running out end of 2017
- Partners prepare extension of project to end of 2022
  - Project review in Januar 2016 → positive recommendation of extension
  - Now partners waiting for responses of individual requests to the corresponding funding agencies. Already positive feedback from MPS.

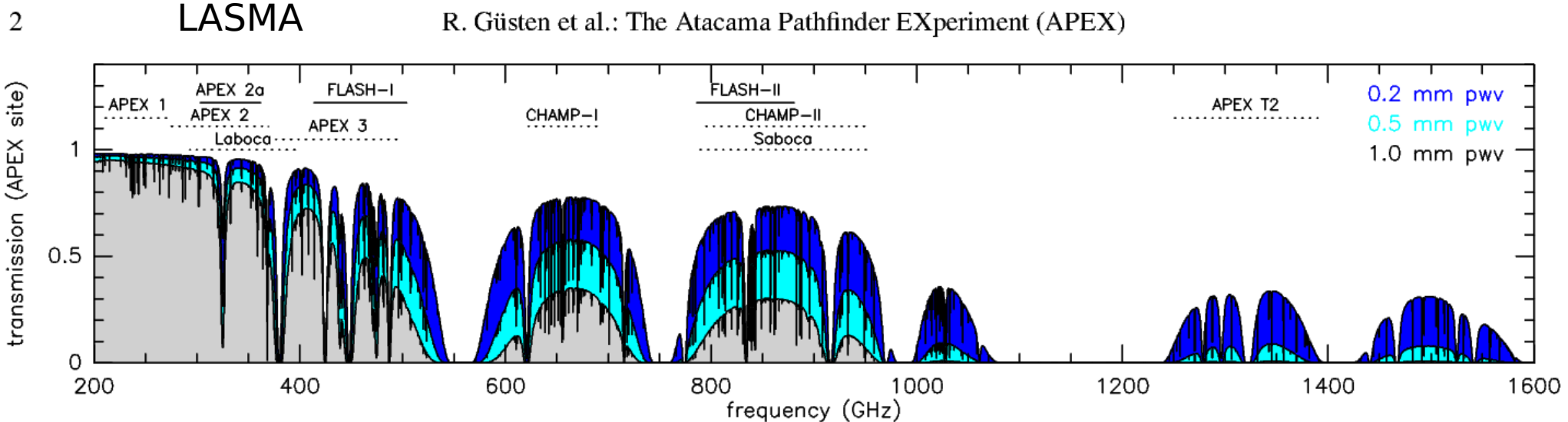
Upcoming new APEX instruments

- Given the ALMA high resolution/sensitivity "competition", expand large scale capabilities → powerful new continuum & line cameras
  - Heterodyne: LASMA camera
  - Continuum: A-MKIDs and ArTeMiS cameras
- In addition: more sensitive, larger BW & frequency coverage heterodyne receiver suite

| 2 ArTeMiS colors |

A-MKIDs870 A-MKIDs350

LASMA

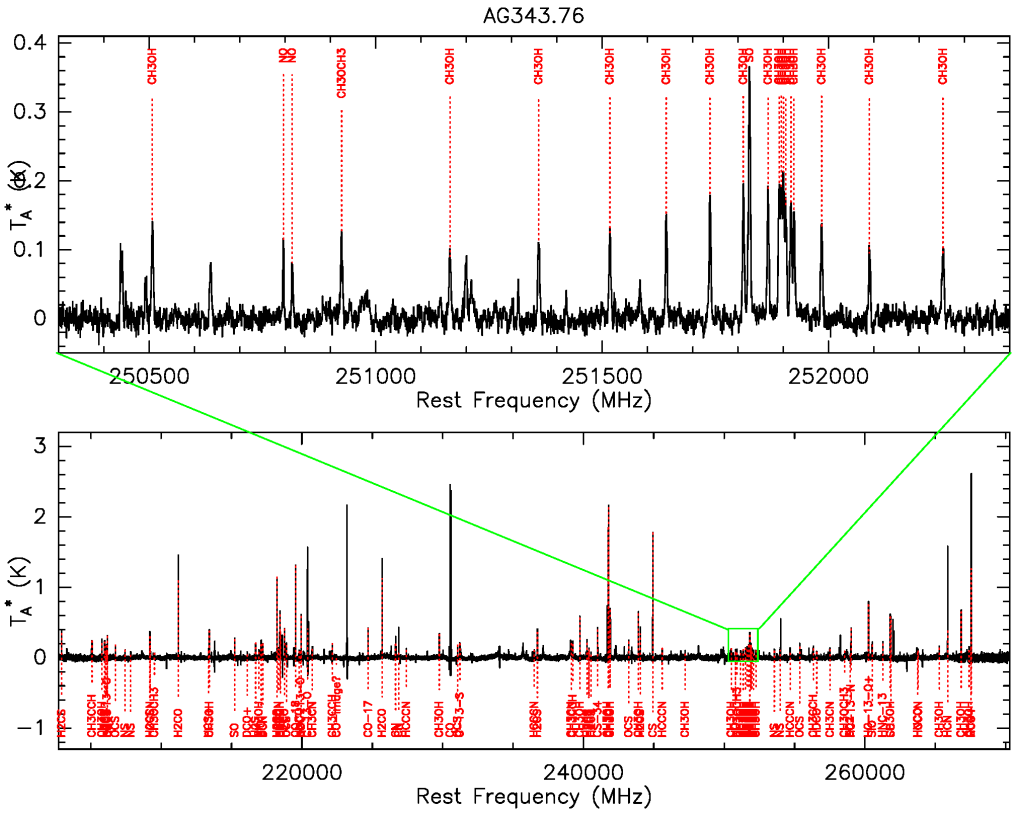


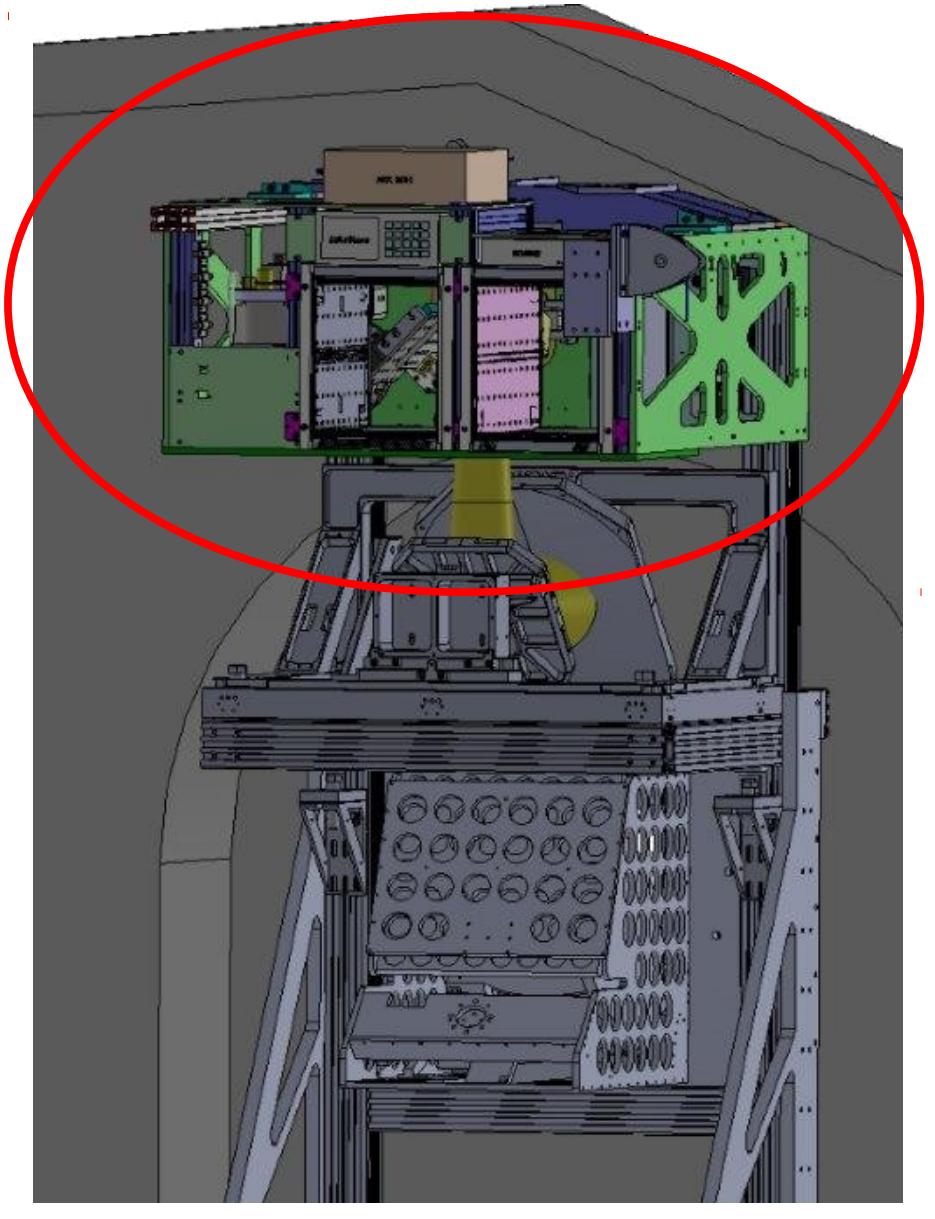
SEPIA (OSO/ESO, see also talk by Belitzky)

- Band 5
  - 2SB mixers (ALMA Band 5 cartridge)
  - Dual polarization (158-211 GHz)
  - IF 4-8 GHz (but plans for 4-12 GHz)
  - Operational since 2015
- Band 9 (ALMA Band 9)
  - DSB at start (later 2SB)
  - Dual Polarization (600–722 GHz)
  - IF 4-8 GHz (later 4-12 GHz)
  - Ongoing commissioning
- Band 7 in preparation

PI230 (MPIfR, Dec2015)

- 230 GHz heterodyne instrument
  - for 230GHz VLBI, line surveys, …
- 2SB dual polarization operation
- IF-bandwidth: 8 GHz per side-band
  => in total 32 GHz

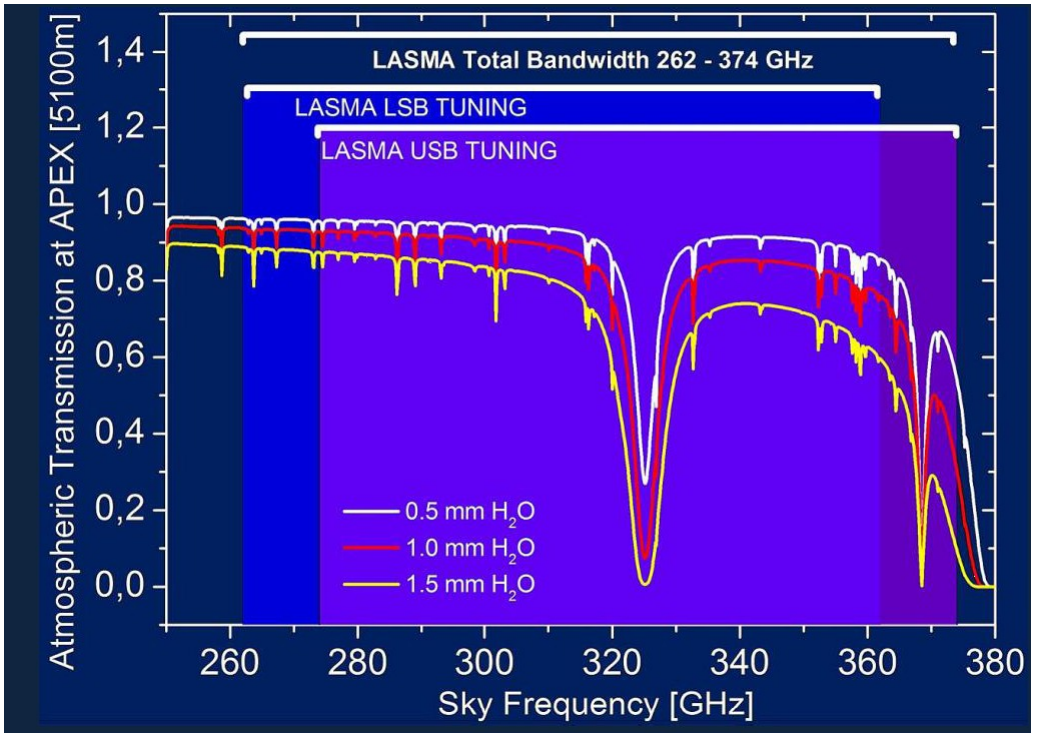


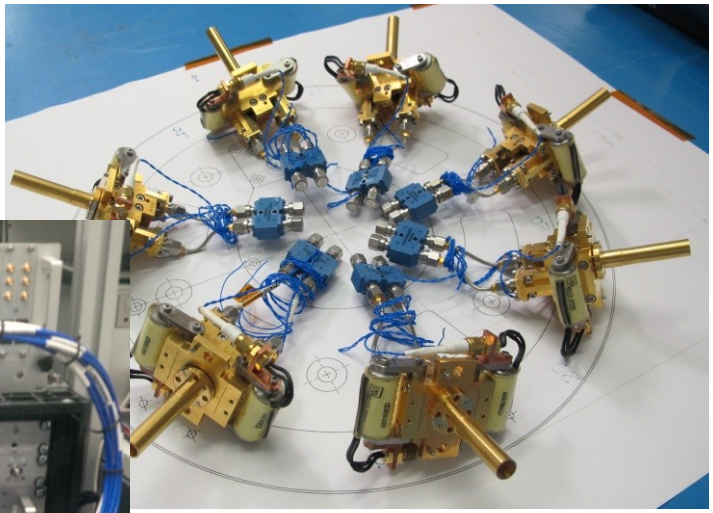


LAsMA (MPIfR)

7 pixel single polarization heterodyne system

- hexagonal pixel arrangement (2 Fλ)
- uses IRAM 345GHz 2SB SIS mixer
- tuning range 270 – 370 GHz
- fully remote operation possible
- Nasmyth cabin B
- K-mirror as image de-rotator
- second polarization accessible for future upgrades
- up to 8 GHz IF band-width per channel
- new 14 channel common B-cabin IF and BE system already installed
- new FFTS4G backend
- Build-up started





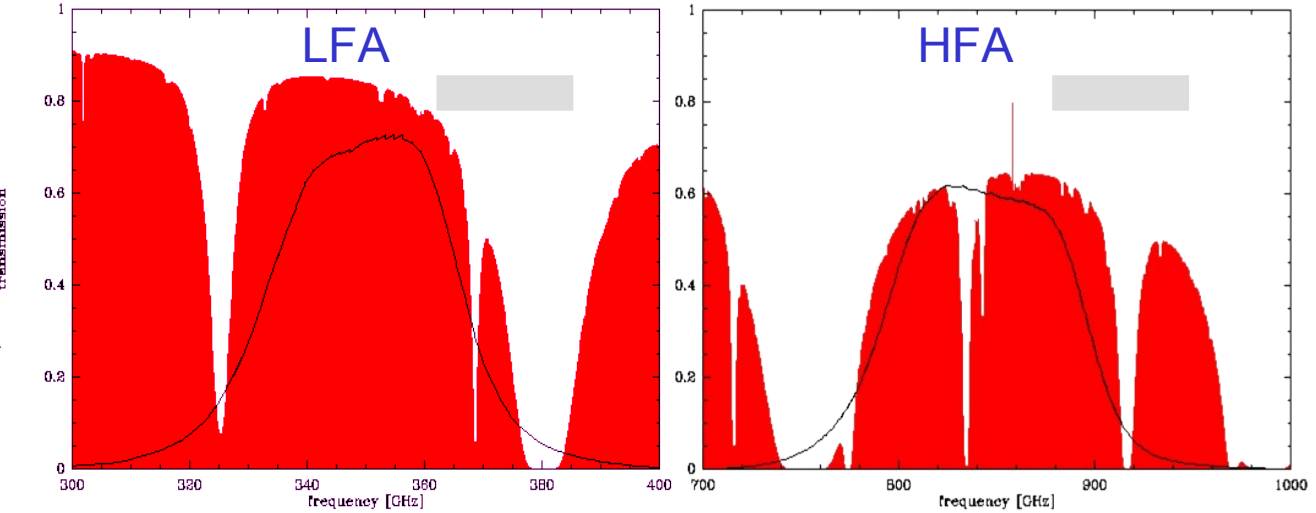
A-MKID specs (MPIfR with SRON, see also talk by Baryshev)

- dual color APEX direct detection camera
  - LFA: 347 GHz (34 GHz width, from 330 to 364 GHz / HP width)

HFA: 850 GHz (100 GHz width, from 800 to 900 GHz / HP width)

squared field of view: > 15 x 15 arcmin^2

- Superconductive pair-breaking detector → shift of resonance frequency
- number of pixels
  - pixel spacing 1 Fλ
  - hexagonal arrangement
  - ➔ **3520 pixel in LFA**
  - ➔ **21600 pixel in HFA**



- detectors operating with sensitivities dominated by the sky background
- good system stability that allows mapping of extended structures
- cooling:
  - two 4K pulse-tube closed cycle systems
  - He 10 sorption cooler (<300 mK)

A-MKIDs in the C-cabin

→ Finish commissioning of 870mu array this year

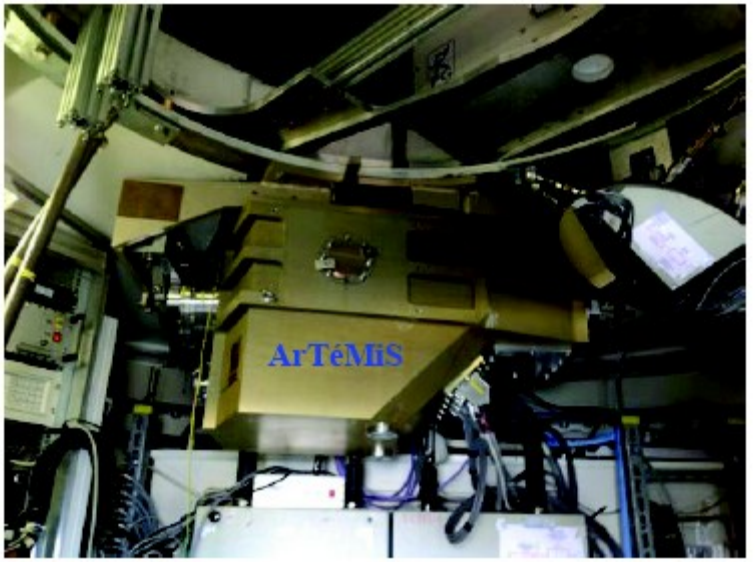
ArteMiS:

A large-format, multi-wavelenths bolometer camera for APEX (ESO PI instrument)

- CEA collaboration
- 2304 @ 350 µm
- 2304 @ 450 µm
- FOV = 4.7’ × 2.5’

  @ 350/450 µm
- Fully sampled
- Commissioning of full array mid 2016

Cryostat in APEX Cassegrain cabin



NGC6334 (credit ESO)

New instruments allowing new science

New bolometer cameras

- PACS/APEX@350µm matching beams
  - resolve/characterize filaments/MSF clumps
- Submm spectral indices
- 350µm Galactic Plane survey including also (parts) of the outer Galaxy
- Polarization currently with POLKA but also planned for new arrays
- extragalactic deep fields, nearby galaxies, magellanic clouds

New heterodyne RXs

- Short turnaround for new frequency windows (e.g. ALMA band 5)
- Array RXs: Complementing GP surveys with kinematics/chemistry
- Large BW: broad lines + line combinations, simultaneous spatial/spectral surveys!
- Large scale excitation studies in combination with CHAMP+/upGREAT
- → moving from studies of individual lines to full characterization of physical and chemical conditions

Summary

- Even in ALMA era, do not underestimate importance of science on large scales:
  - Large scale surveys @ APEX as pathfinder/complement for ALMA science but also probe larger scale physics/chemistry in their on right
- APEX provides quick turnaround to probe new ideas, with respect to both science and technology
  - Constant & rapid innovation and operation of the best possible instrumentation
- APEX THz (incl. SOFIA), high-J CO, hydrides, fine structure lines complement ALMA for full picture of cooling budget and chemistry and allow to study local high-z templates