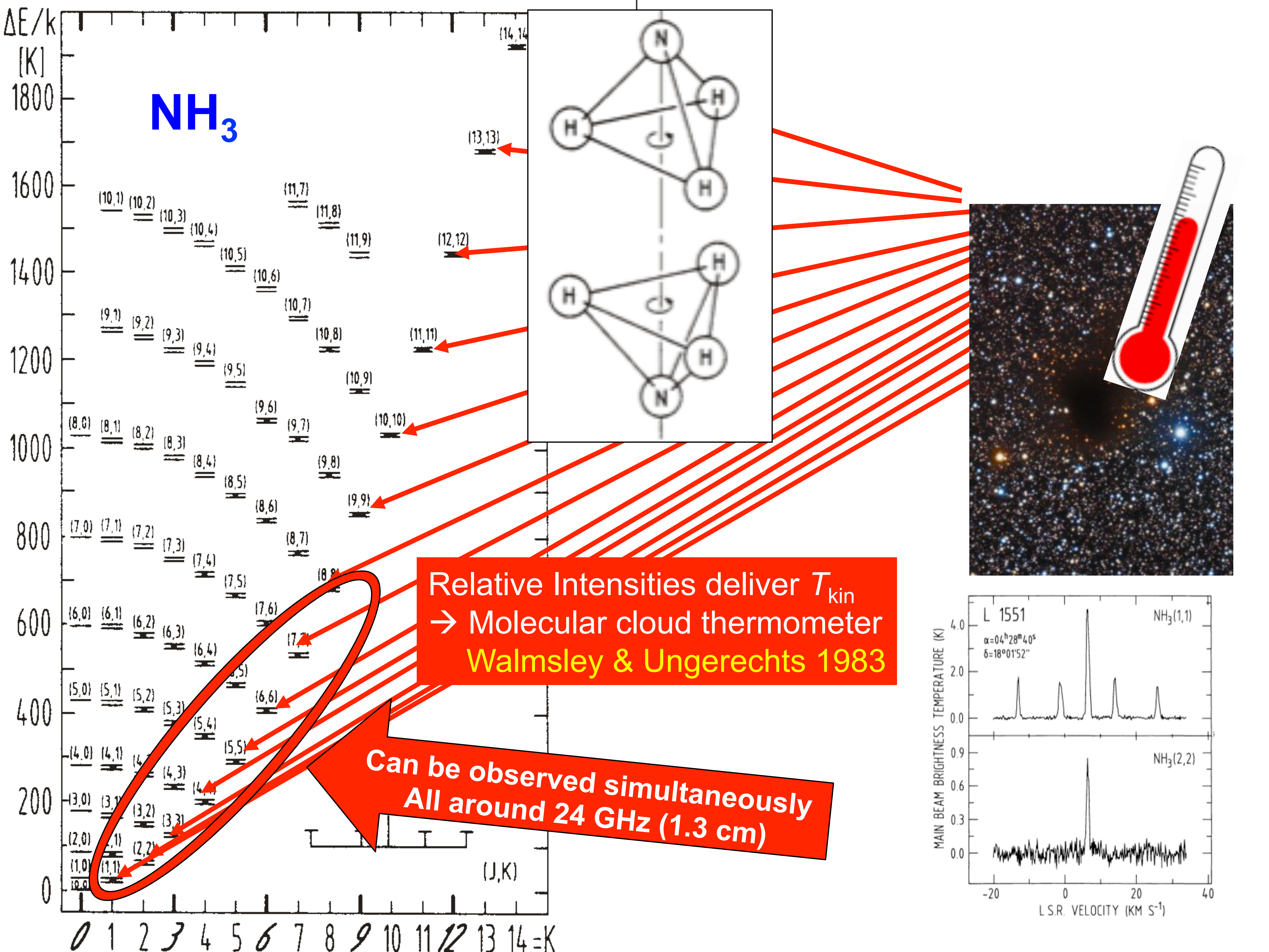
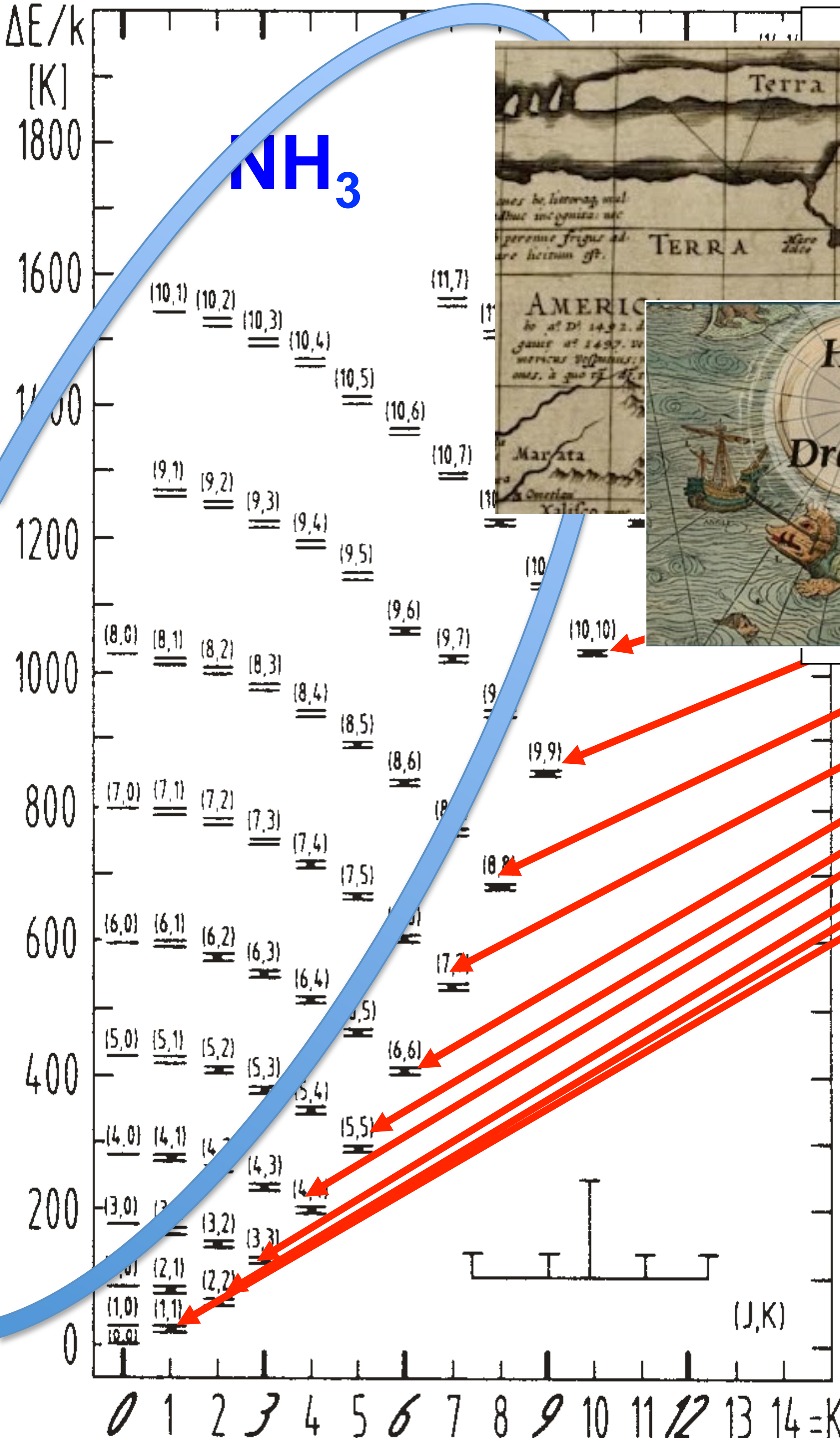
Synergies

Karl M. Menten
Max-Planck-Institut für Radioastronomie

(Some) Synergies

Karl M. Menten
Max-Planck-Institut für Radioastronomie

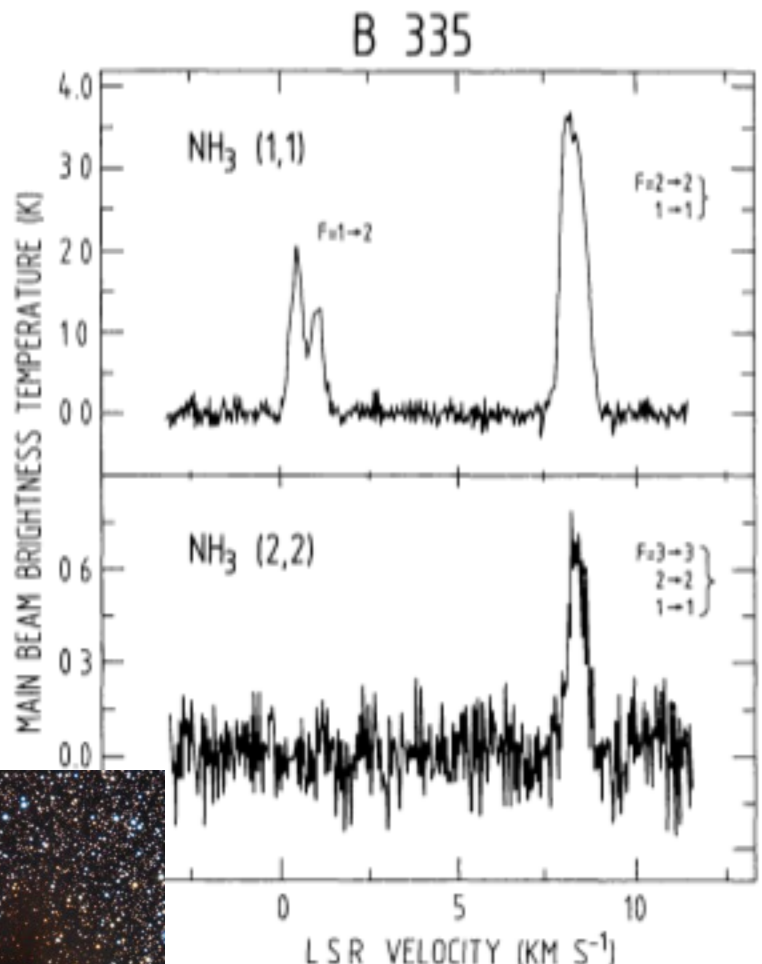

NH3
ΔE/k [K]
1800
1600
1400
1200
1000
800
600
400
200
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 =K
(J,K)
Relative Intensities deliver T_kin
→ Molecular cloud thermometer
Walmsley & Ungerechts 1983
Can be observed simultaneously
All around 24 GHz (1.3 cm)
L 1551
α=04h28m40s
δ=18°01'52"
NH3(1,1)
NH3(2,2)
MAIN BEAM BRIGHTNESS TEMPERATURE (K)
L.S.R. VELOCITY (KM S-1)



Metastable levels (J = K)

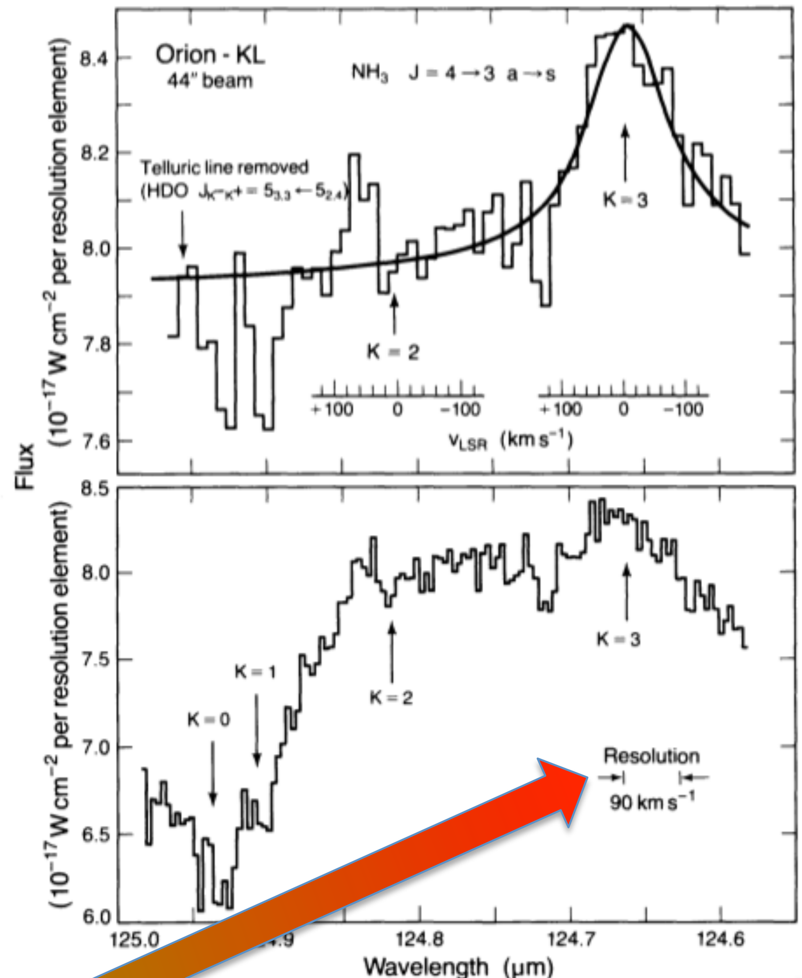
Radio: 1984

K. M. Menten et al.: Ammonia in B 335



FIR: 1983

TOWNES, GENZEL, WATSON, AND STOREY



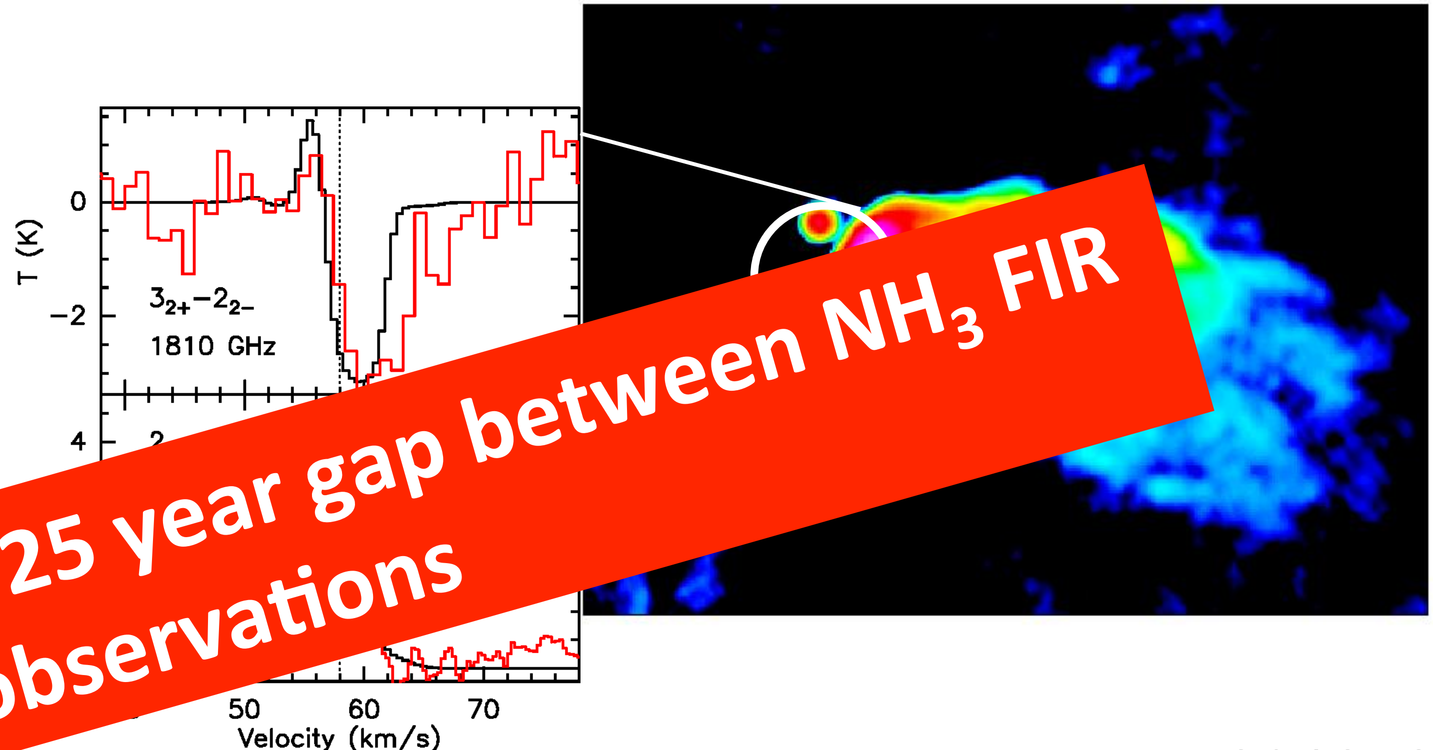
Δv = 0.05 km/s

First (FIR) detection of NH_3 rotational emission (124.6 μm)

Kuiper Airborne Observatory:
1974-1995 / D = 0.915 m

Effelsberg 100 m Telescope:
1974- / D = 100 m

Ammonia/1.8 THz: Probing infall



> 25 year gap between NH_3 FIR observations

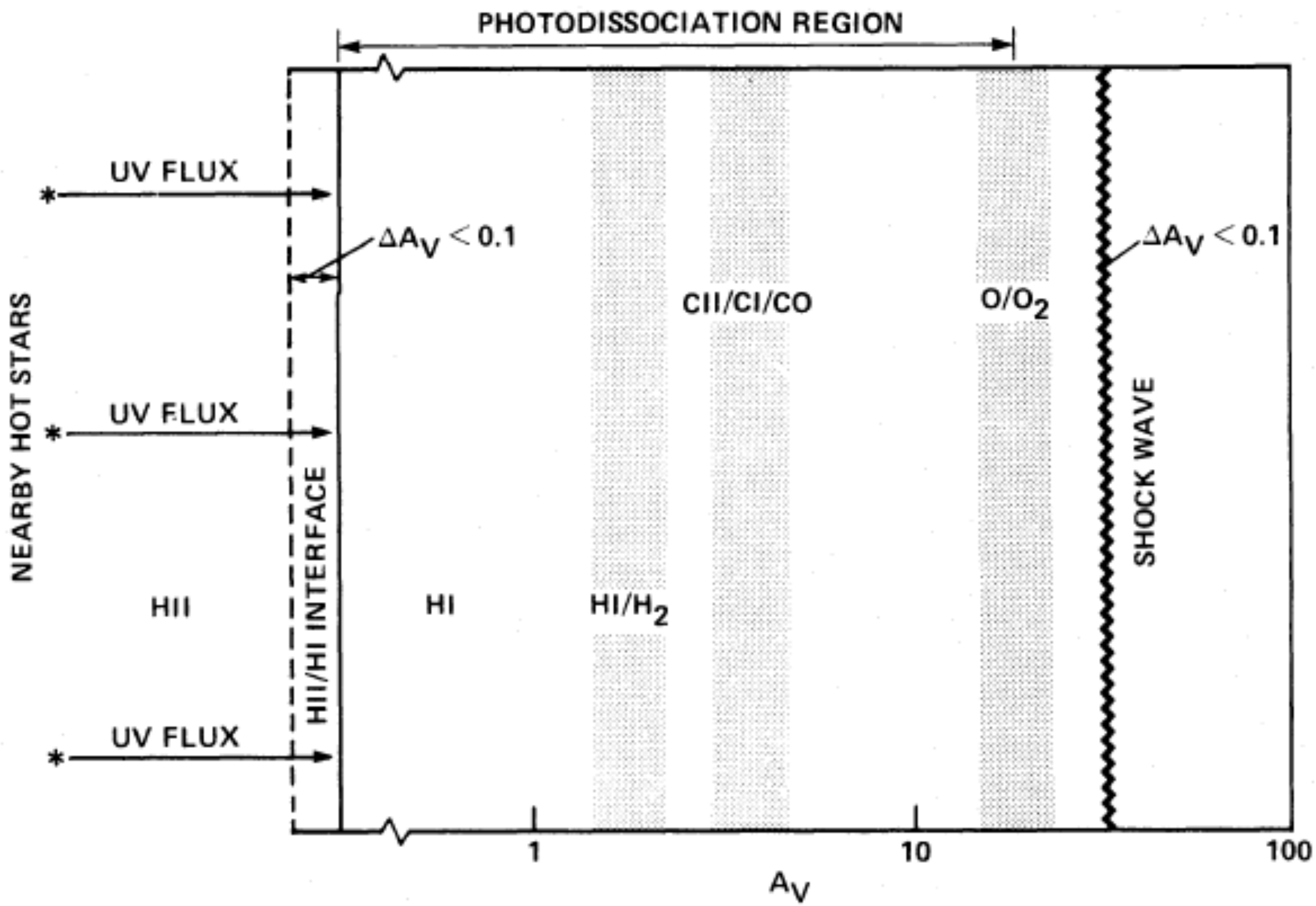
Wyrowski et al. 2012, 2016

→ Mass infall rates:
a few x 10^{-3} $M_{\odot}$/yr

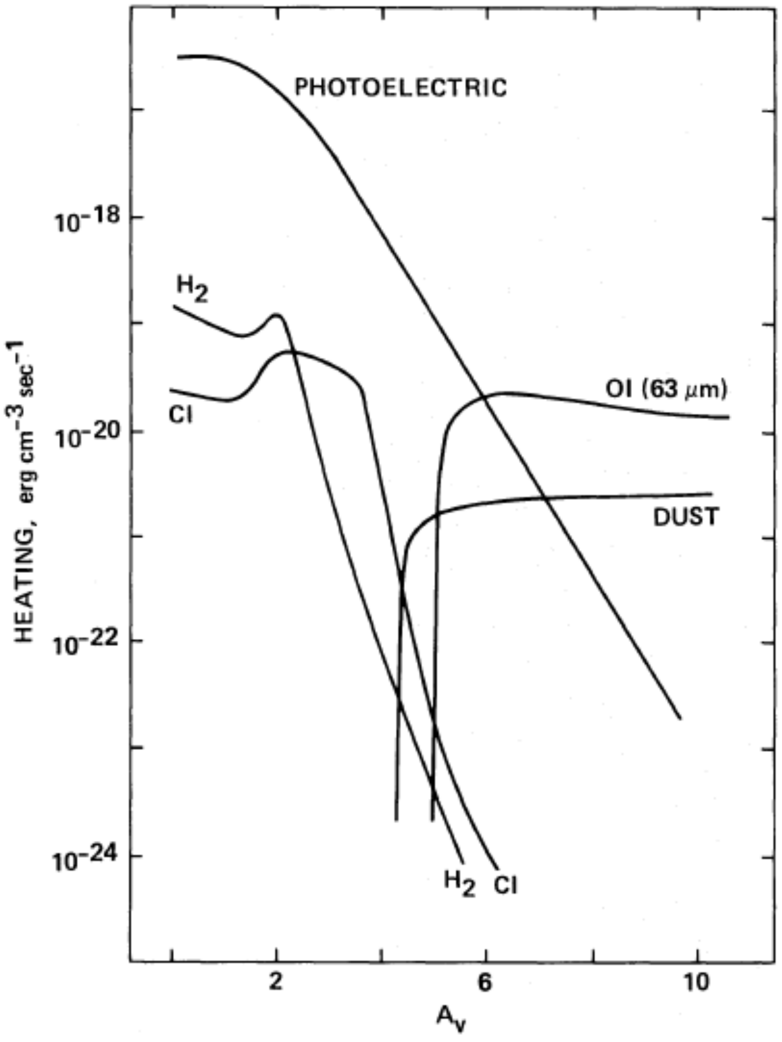
Talk by Friedrich

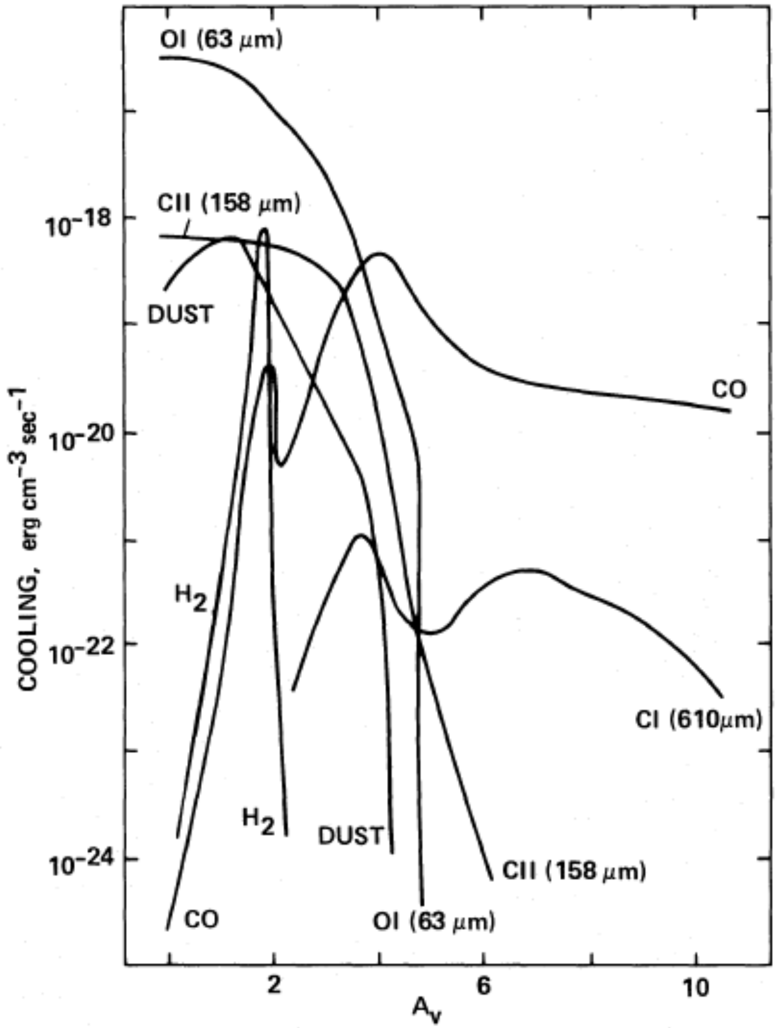
PDRs: Photodissociation Regions

Tielens & Hollenbach 1985



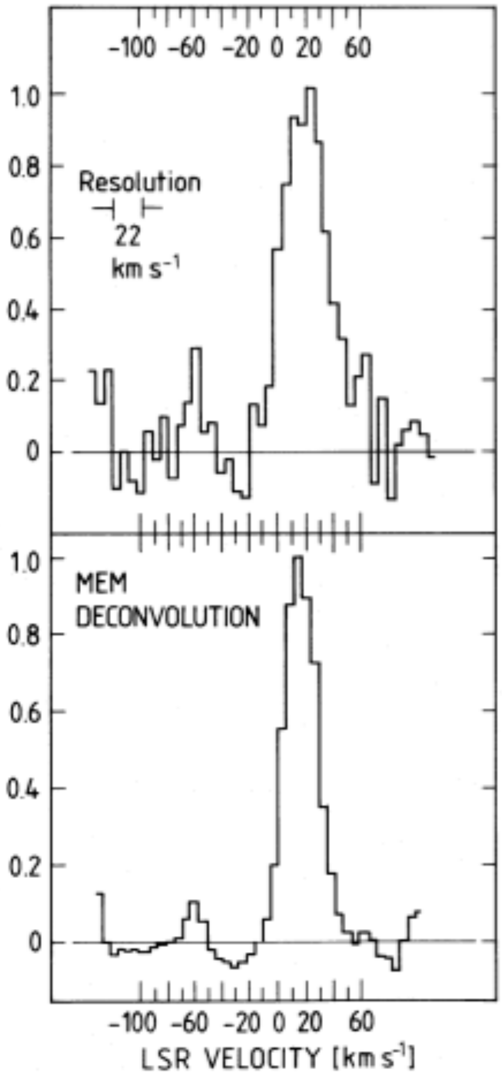
PDRs: Heating Cooling

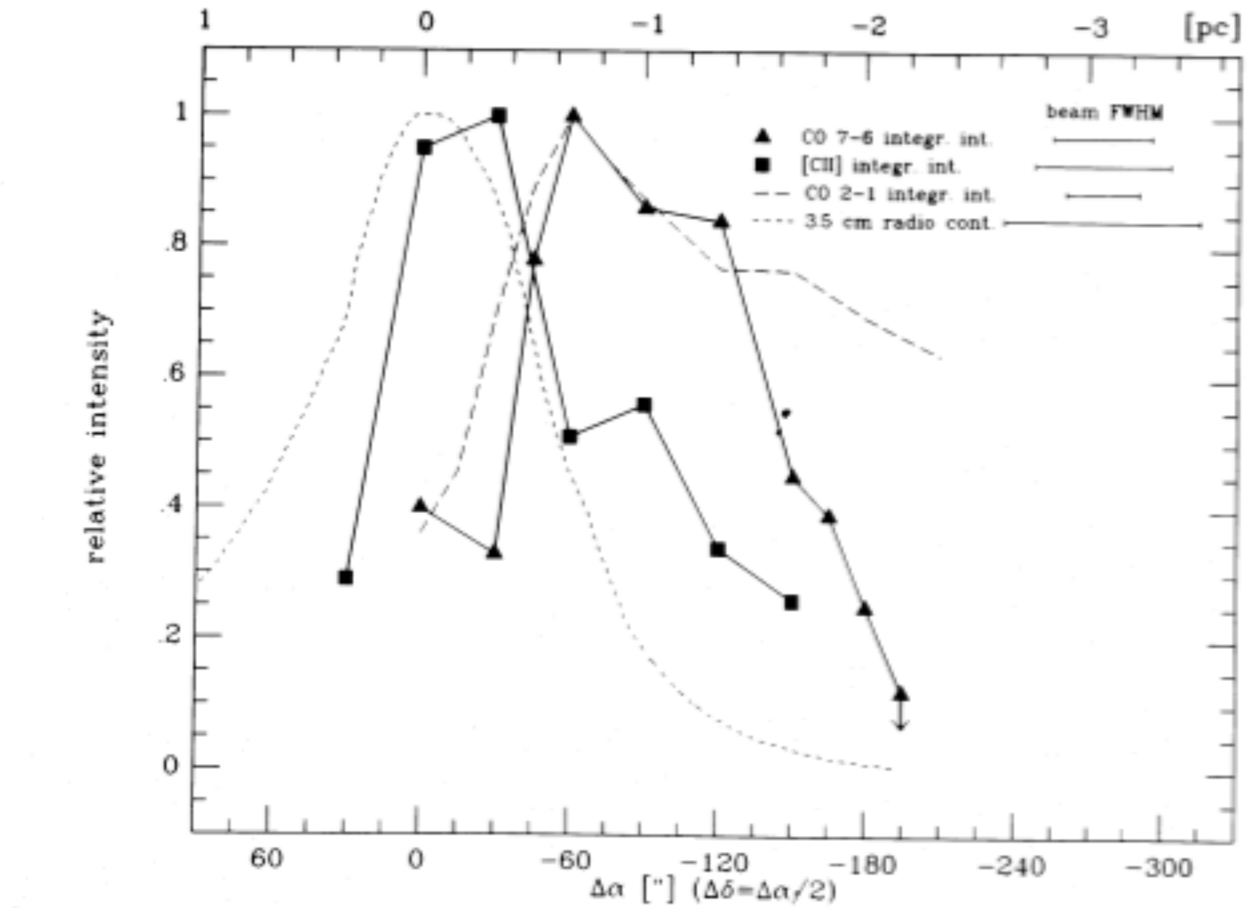




Tielens & Hollenbach 1985

[CII] 158 μm in M17

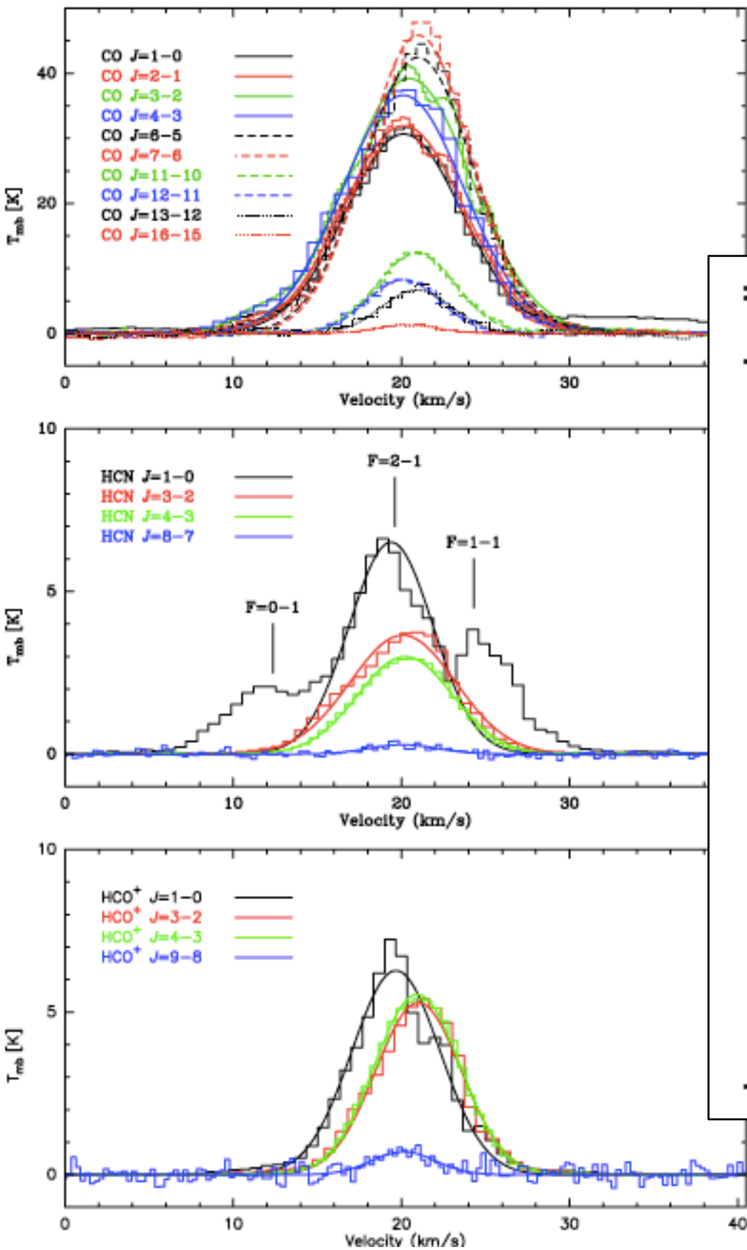




Stutzki, Stacey, Genzel+ 1988

M 17 – the Omega Nebula

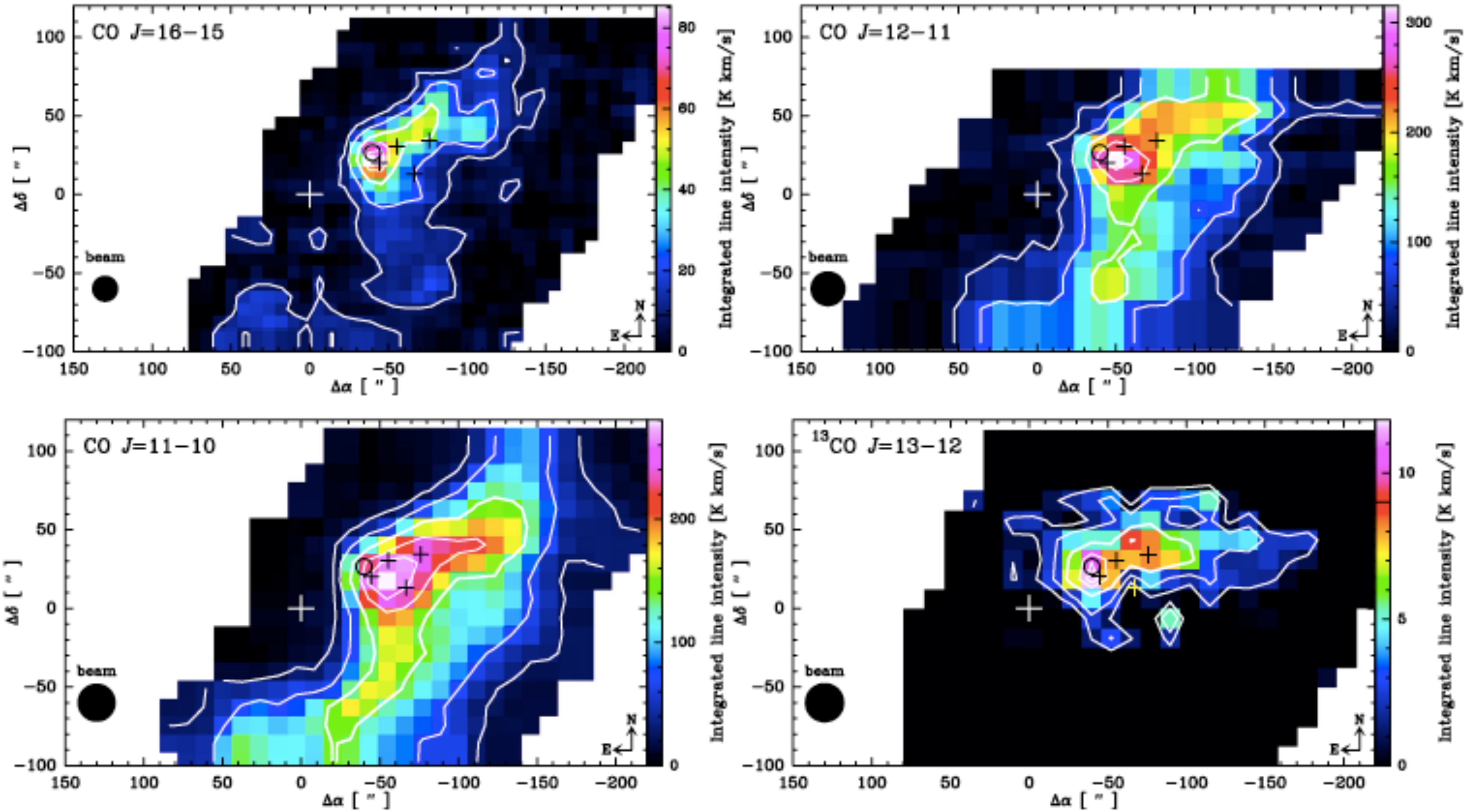
APEX: CO, J =1-0 … 7-6
SOFIA: CO J = 11-10 … 16-15



Parameter	CO	HCN	HCO^+
$\Phi_{cold}(^{12}C)$	1.00 ± 0.00	0.80 ± 0.06	0.80 ± 0.09
$n_{cold}(H_2)$ [cm^{-3}]	4.10 ± 0.00	4.10 ± 0.35	4.10 ± 0.49
T_{cold} [K]	60.00 ± 0.00	60.00 ± 5.17	60.00 ± 7.12
N_{cold} [cm^{-2}]	19.00 ± 0.00	16.20 ± 0.53	15.40 ± 1.01
$\Phi_{warm}(^{12}C)$	0.40 ± 0.00	0.20 ± 0.02	0.20 ± 0.02
$n_{warm}(H_2)$ [cm^{-3}]	5.80 ± 0.00	5.80 ± 0.39	5.80 ± 0.54
T_{warm} [K]	80.00 ± 0.00	80.00 ± 8.61	80.00 ± 8.79
N_{warm} [cm^{-2}]	18.90 ± 0.00	15.10 ± 1.21	15.00 ± 0.56
$\Phi_{cold}(^{13}C)$	1.00 ± 0.00	0.80 ± 0.08	0.80 ± 0.09
$\Phi_{warm}(^{13}C)$	0.40 ± 0.00	0.20 ± 0.02	0.20 ± 0.02
$\Delta V(^{12}C)$ [$km\ s^{-1}$]	6.90	6.10	7.10
$\Delta V(^{13}C)$ [$km\ s^{-1}$]	5.50	6.10	4.40

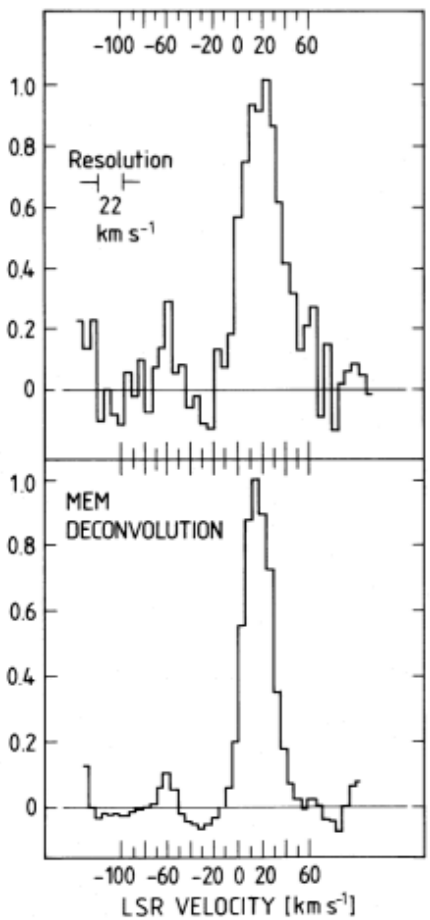
Perez-Beaupuits+ 2015
30 yr after Tielens & Hollenbach!

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

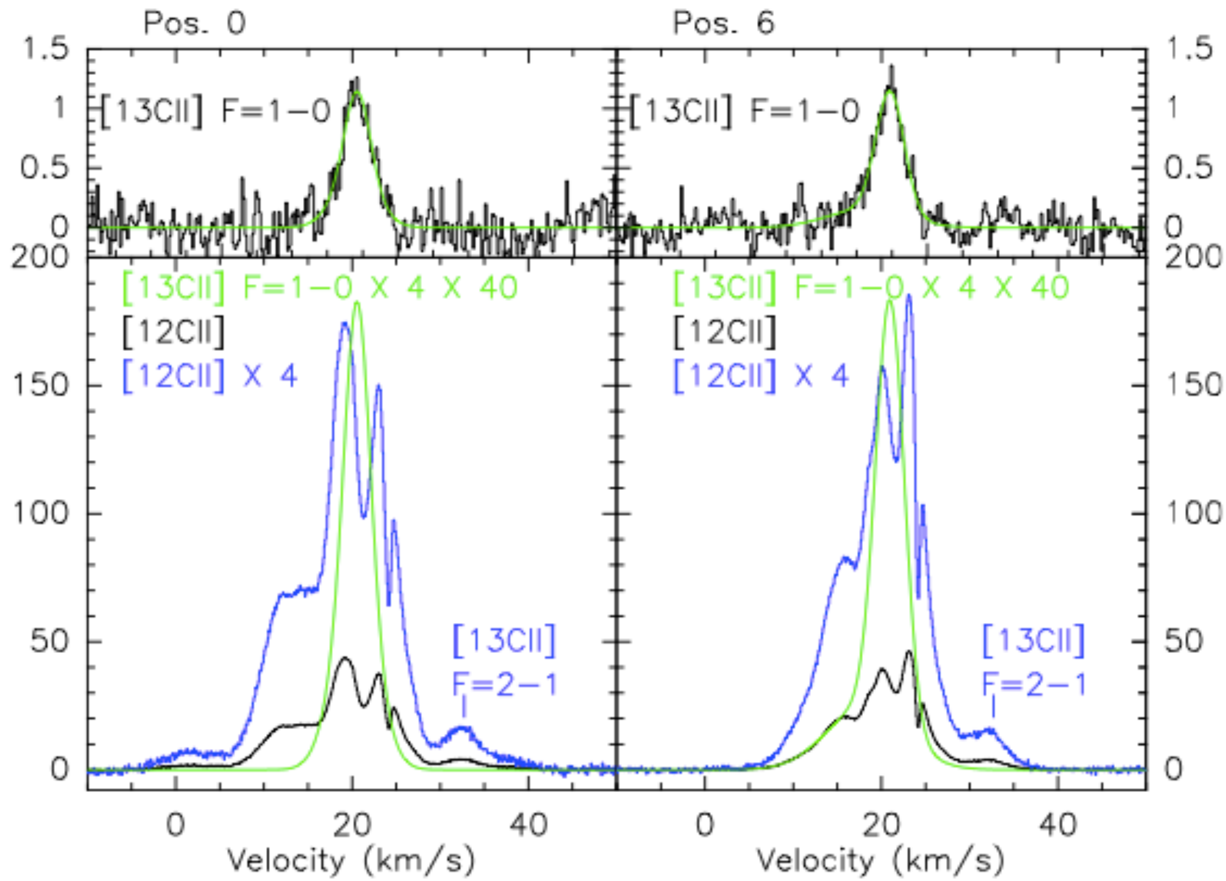


SOFIA/GREAT: Perez-Beaupuits+ 2015

Why high spectral resolution is important!
[$^{12+13}$CII] 158 µm in M 17 with GREAT



Stutzki et al.
1988/KAO



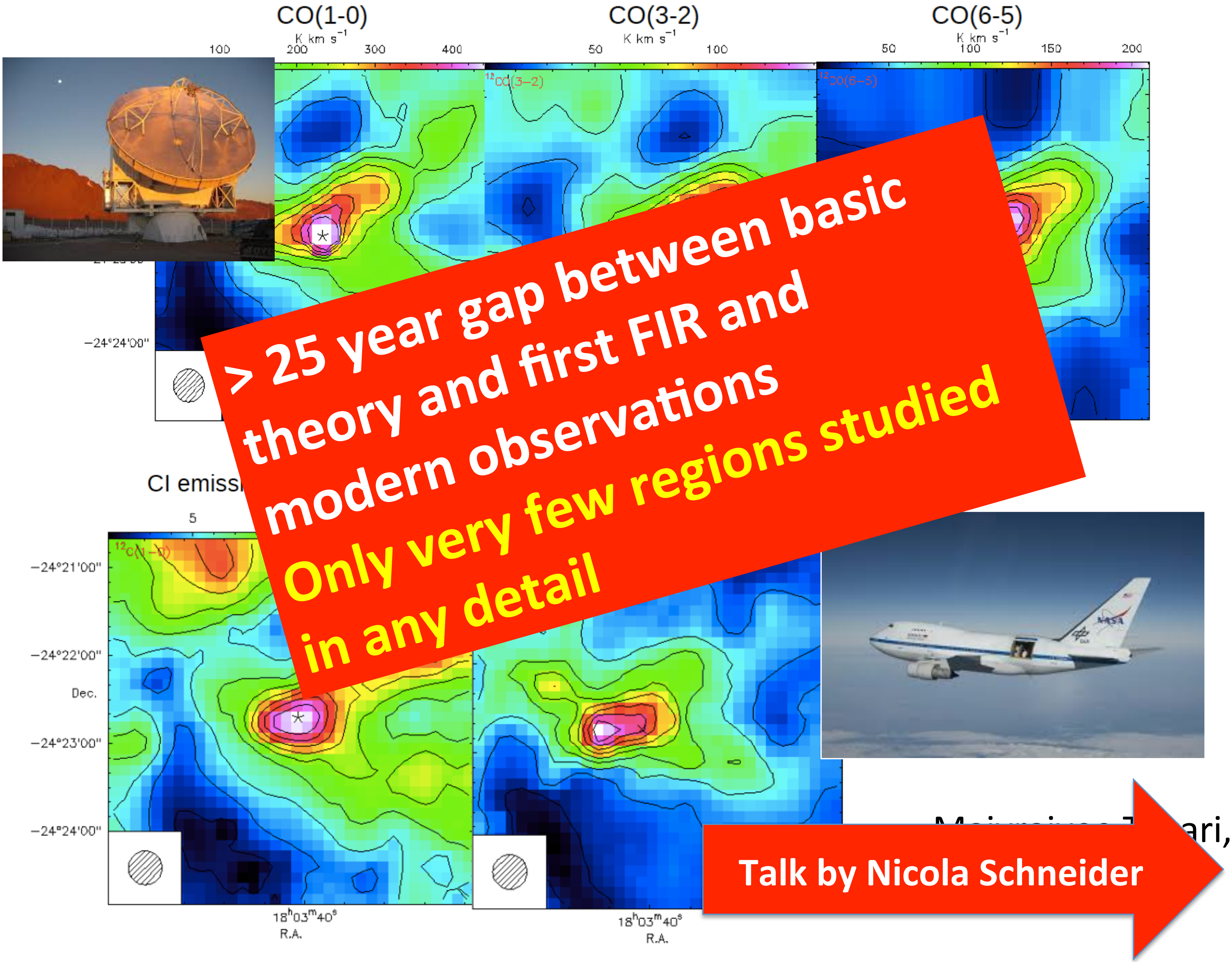
Guevara, Stutzki & Simon SOFIA/GREAT

Talk by Cristian Guevara

The Orion Bar

M 8 – the Lagoon Nebula

Hardly any (sub)mm/FIR studies at all



CO(1-0)
K km s-1
CO(3-2)
K km s-1
CO(6-5)
K km s-1
12CO(3-2)
12CO(6-5)
12C(1-0)
−24°24'00"
−24°21'00"
−24°22'00"
Dec.
−24°23'00"
−24°24'00"
18h03m40s
R.A.
18h03m40s
R.A.
> 25 year gap between basic theory and first FIR and modern observations
Only very few regions studied in any detail
Talk by Nicola Schneider

Far Infrared

Kuiper Airborne Observatory:
1974-1995/*D* = 0.915 m

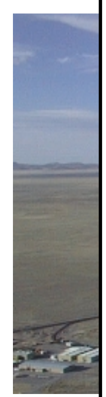
Very long time span witho
significant new observat

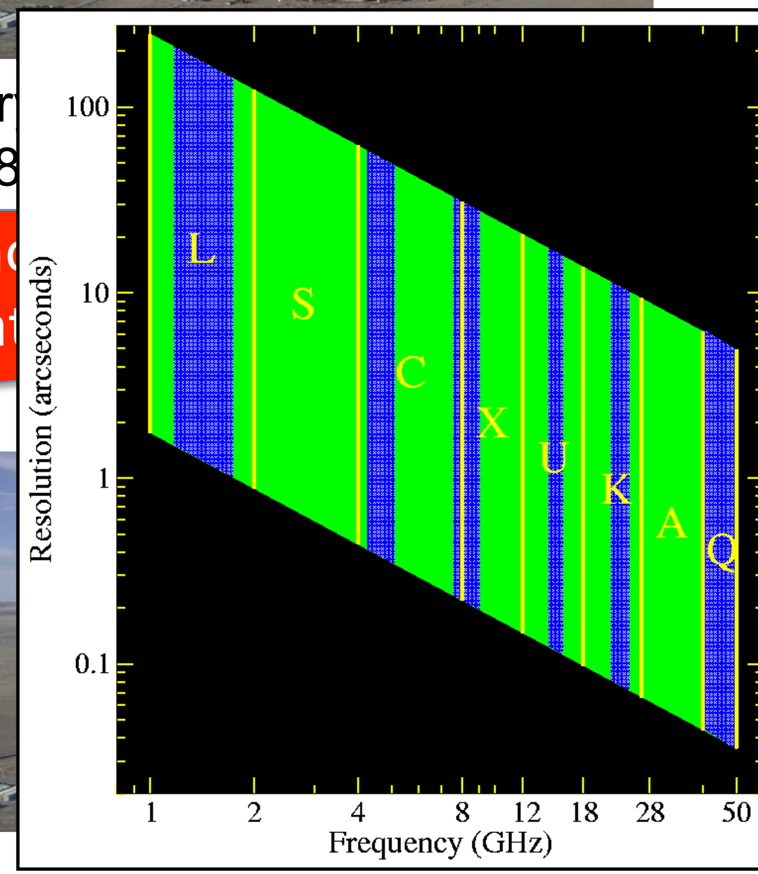
Herschel:
2009-2013/
D = 3.5 m

SOFIA
2011+/*D* = 2.5 m

Radio

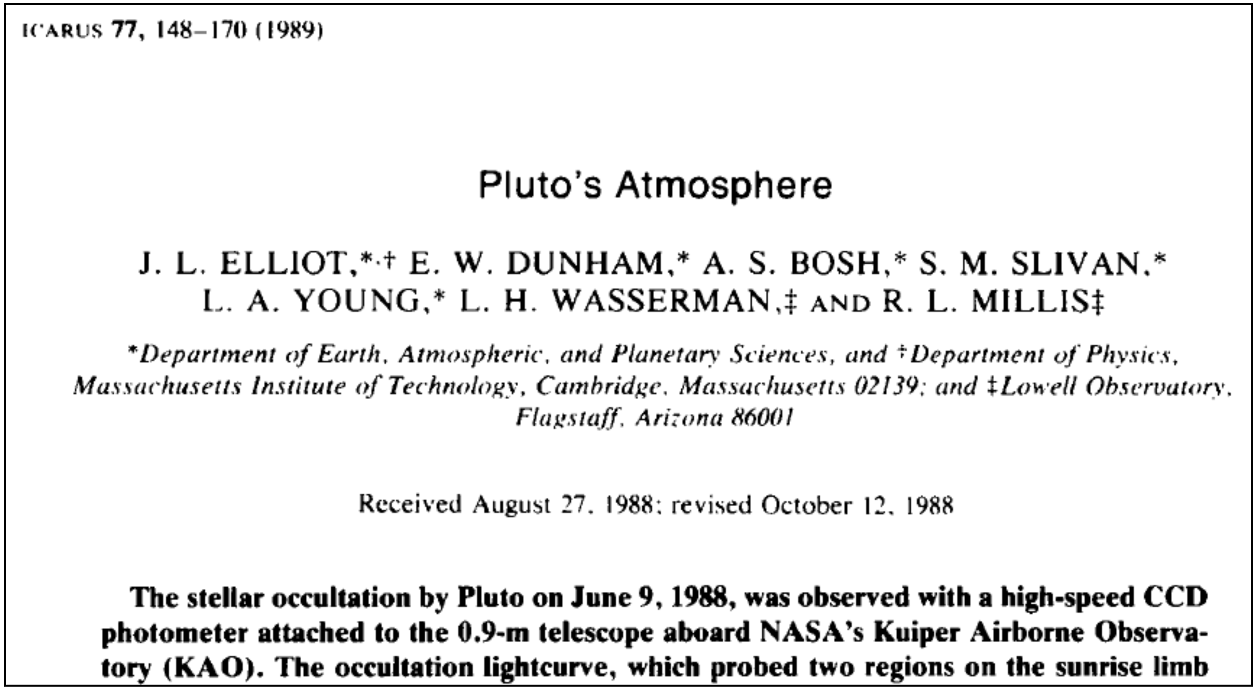
Ver
198





Karl G. Very Large Array:
2011- /27 x 25 m

Long time scales:



ICARUS 77, 148–170 (1989)

Pluto's Atmosphere

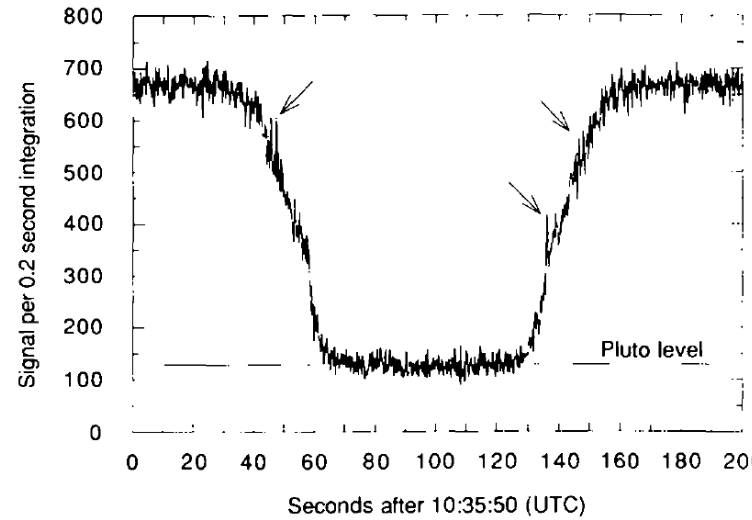
J. L. ELLIOT,*,† E. W. DUNHAM,* A. S. BOSH,* S. M. SLIVAN,*
L. A. YOUNG,* L. H. WASSERMAN,‡ AND R. L. MILLIS‡

*Department of Earth, Atmospheric, and Planetary Sciences, and †Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139; and ‡Lowell Observatory, Flagstaff, Arizona 86001

Received August 27, 1988; revised October 12, 1988

The stellar occultation by Pluto on June 9, 1988, was observed with a high-speed CCD photometer attached to the 0.9-m telescope aboard NASA's Kuiper Airborne Observatory (KAO). The occultation lightcurve, which probed two regions on the sunrise limb

KAO:
June 9, 1988



See FPI+/FliteCam/HIPO poster in the back of this room

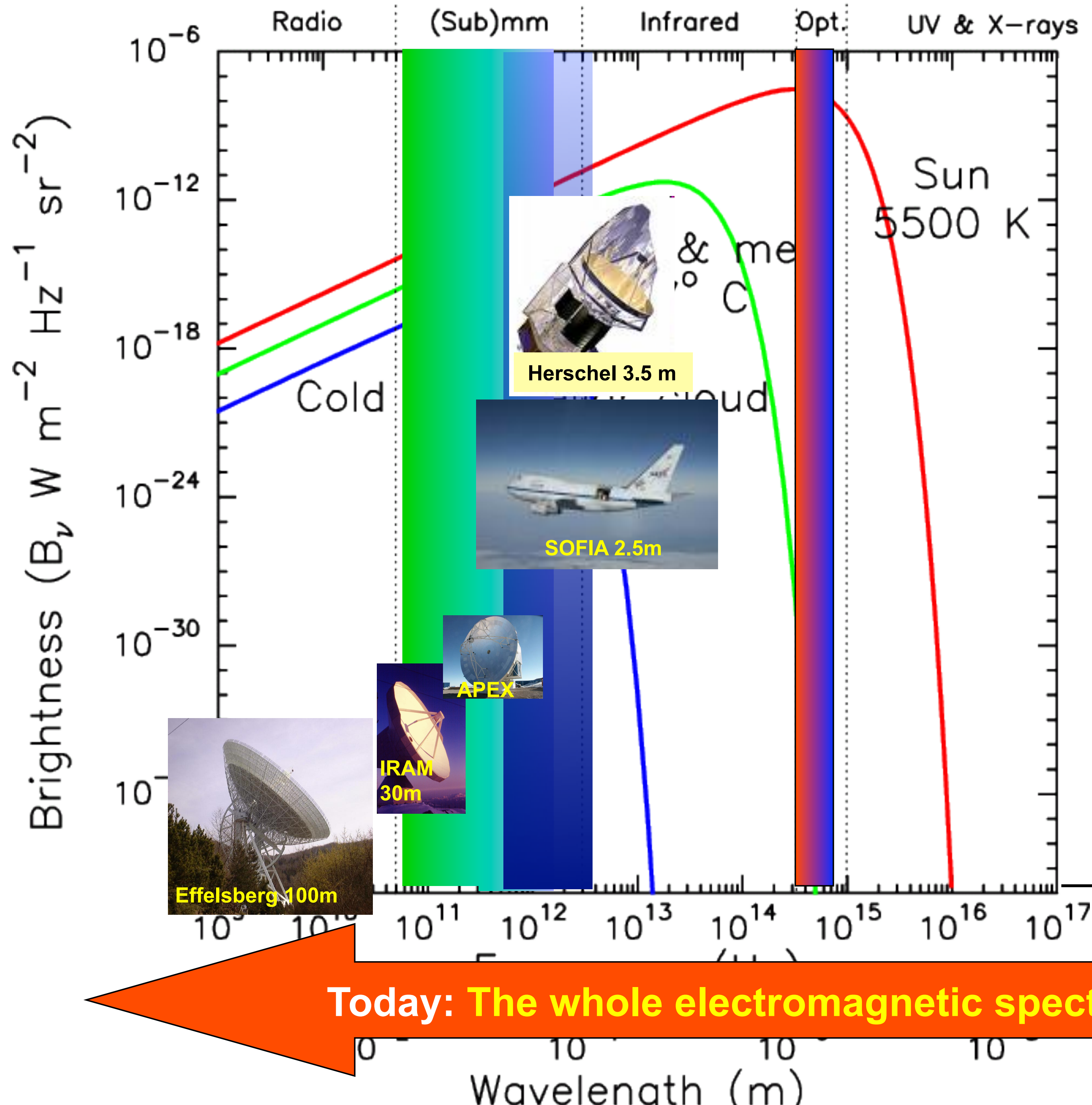
New Horizons:
July 15, 2015

New observatories/telescope facilities are usually

- very expensive
- require long time scales from planning to completion

The Atacama Pathfinder Experiment: a rapid time scale, "inexpensive", project

… with maximal synergy with SOFIA



Max Planck
1858–1947

Today: The whole electromagnetic spectrum!

The Atacama Pathfinder Experiment (APEX)

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

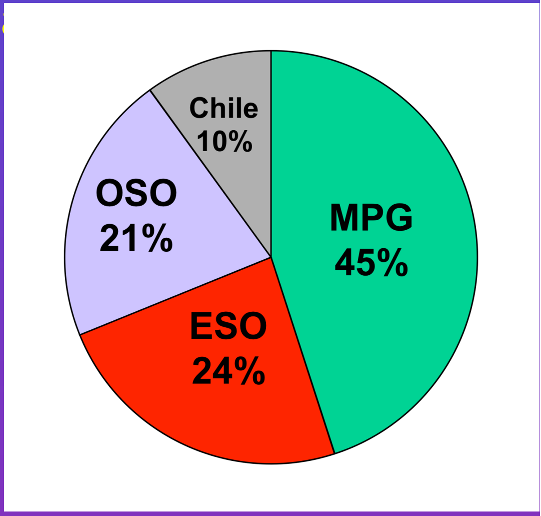
on

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)

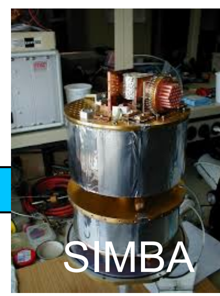
http://www.mpifr-bonn.mpg.de/div/mm/apex/

How APEX Came About:

MPIfR
mm astronomy since 1980s (IRAM 30m)
Sub-mm since 1990

Onsala Space Observatory
mm astronomy since 1980s (20 m dish)

ESO



SEST 15 m (1987–2003)

Atacama Large Millimeter Array Phase I

→ Operate one of the (modifies)prototype antennas as a single dish: APEX

Chajnantor it was to be!

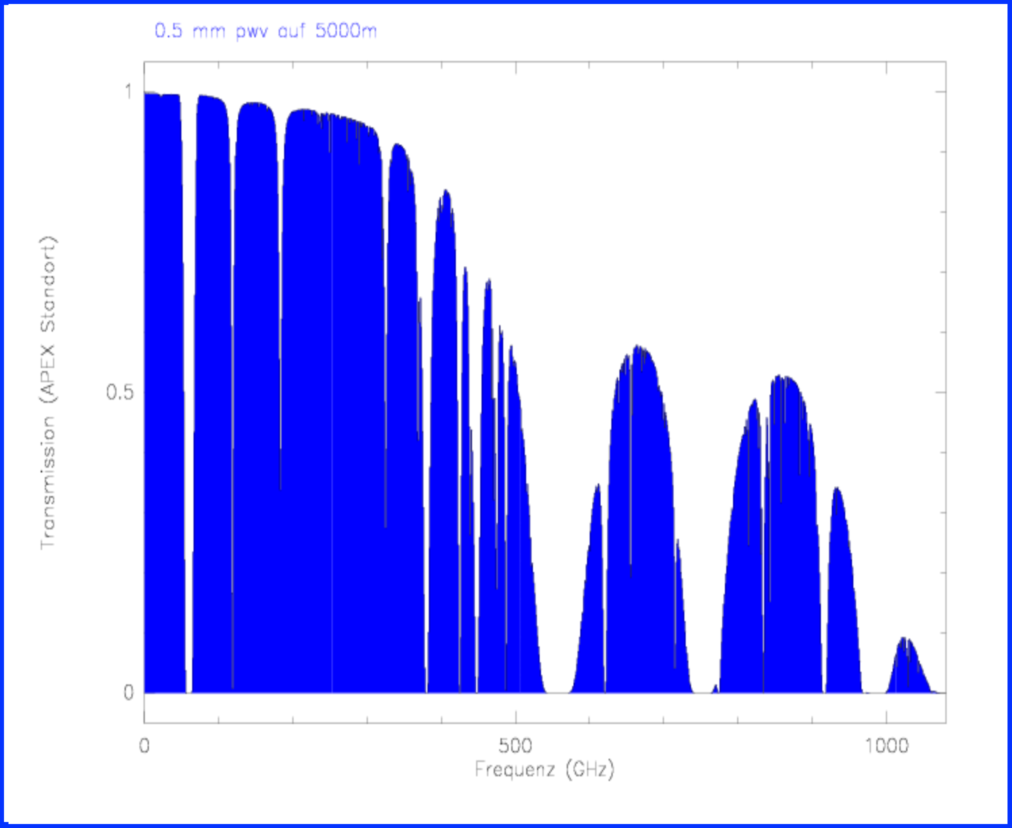
SW from Cerro Chajnantor, 1994 May

AUI/NRAO S. Radford

Expert team selecting the site for the APEX telescope – August 2000

Here!

The biggest problem for submillimeter astronomy: The Earth‘s atmosphere



Transmission Chajnantor (5100 altitude)

Submillimeter Range

Project History: some basic facts

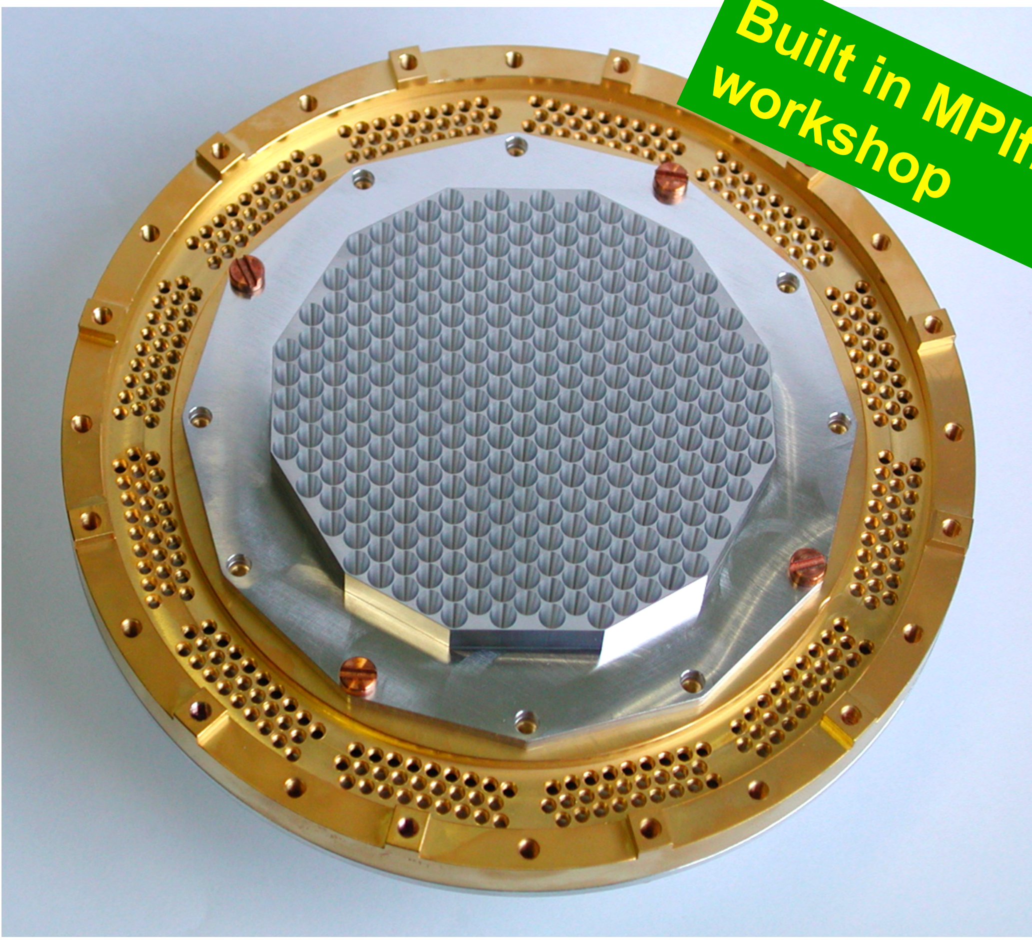
Short Project History:

• Memorandum of Understanding between the Partners	June 01
• contract with Vertex Antennentechnik	02.07.01
• start construction on high site	spring 03
• start commissioning, operation of first submm receiver	spring 04
• successfull commissioning of the antenna	28.06.05
• facility science verificaton	July 05
• begin of regular science operation of facility	August 05
• External review → Decision to extend until 2017	2013
• External review → Decision to extend until 2022	2016

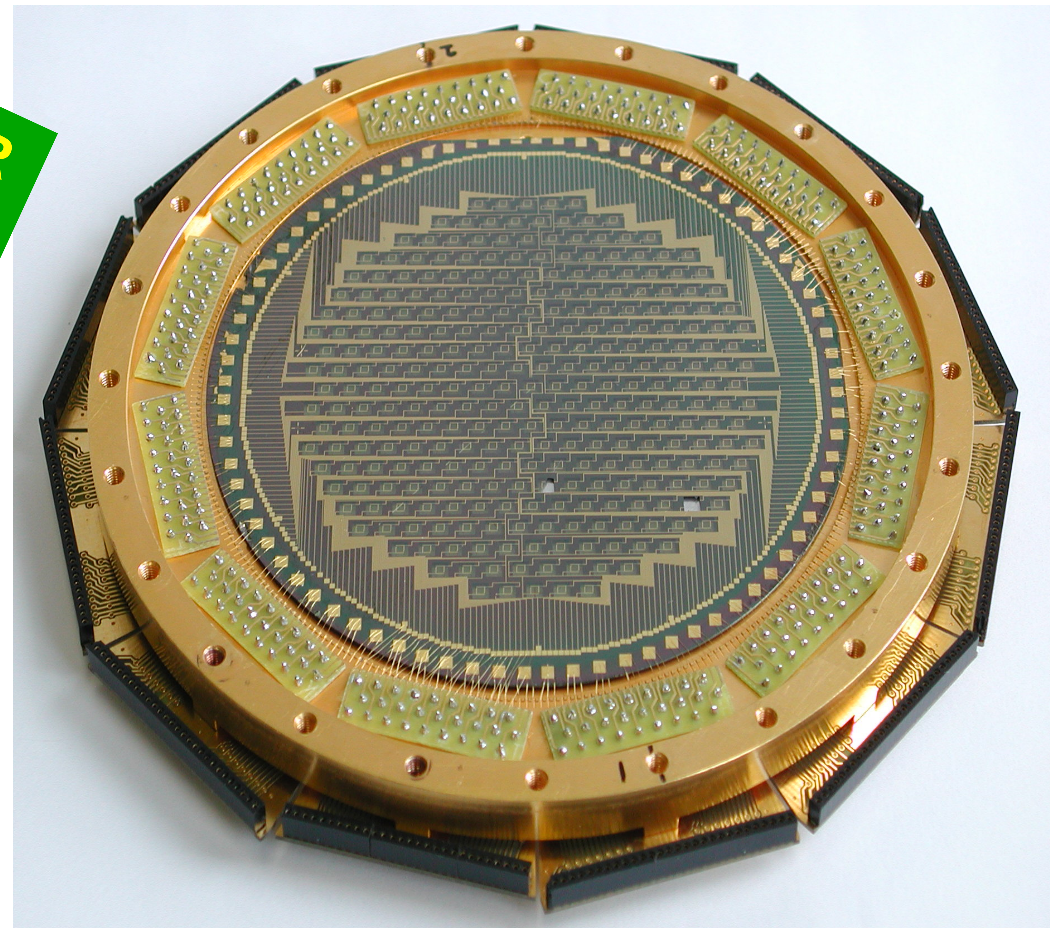
The APEX Work Horse:

The Large APEX Bolometer Camera – LABOCA

Built in MPIfR workshop



Horn array



Bolometer array

Siringo+ 2009

LABOCA

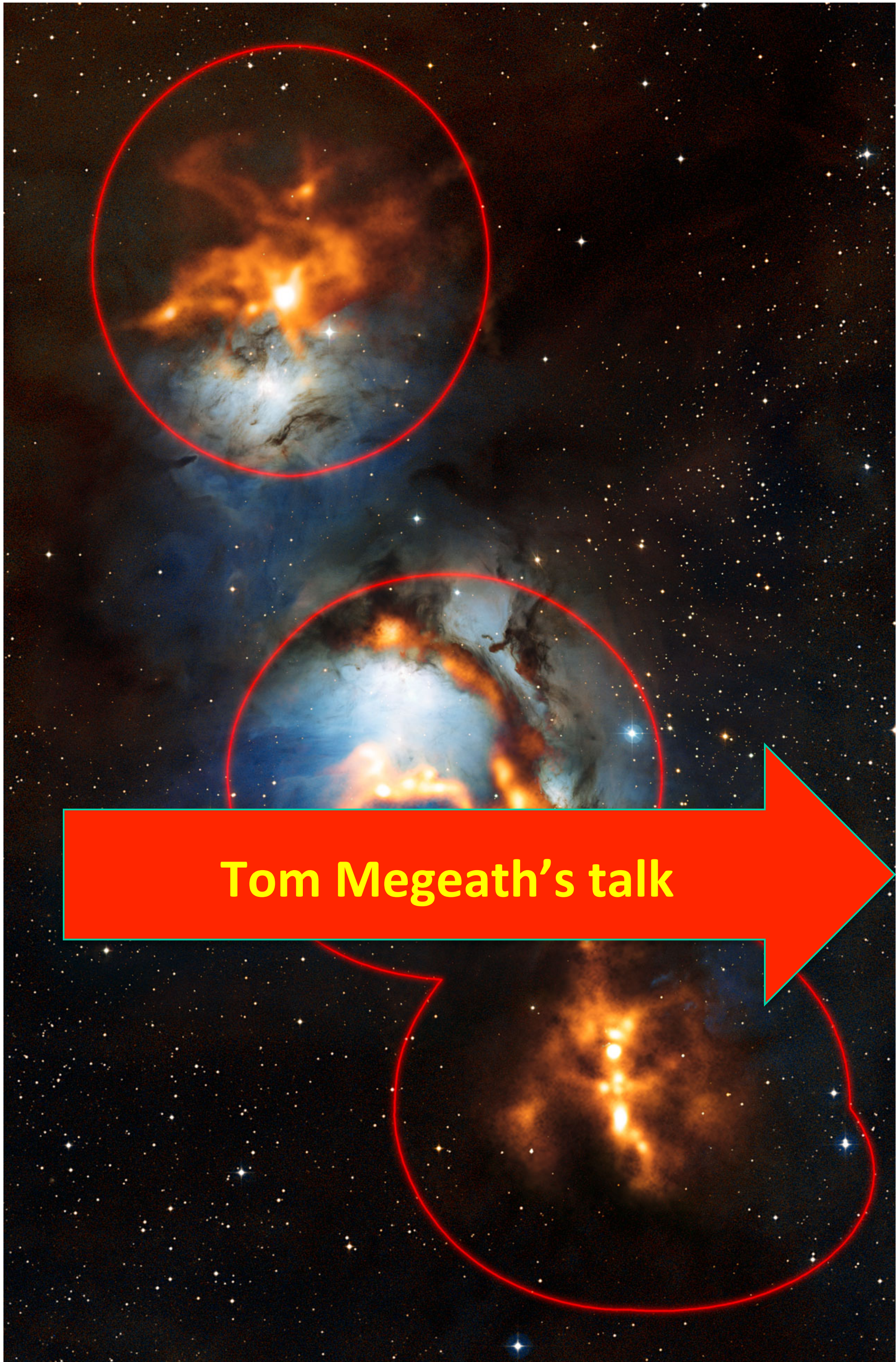
Great-, great-, … grand child of Frank Low's 1961 Germanium bolometer

First installation: September 3, 2006

Sifting through dust near Orion's belt

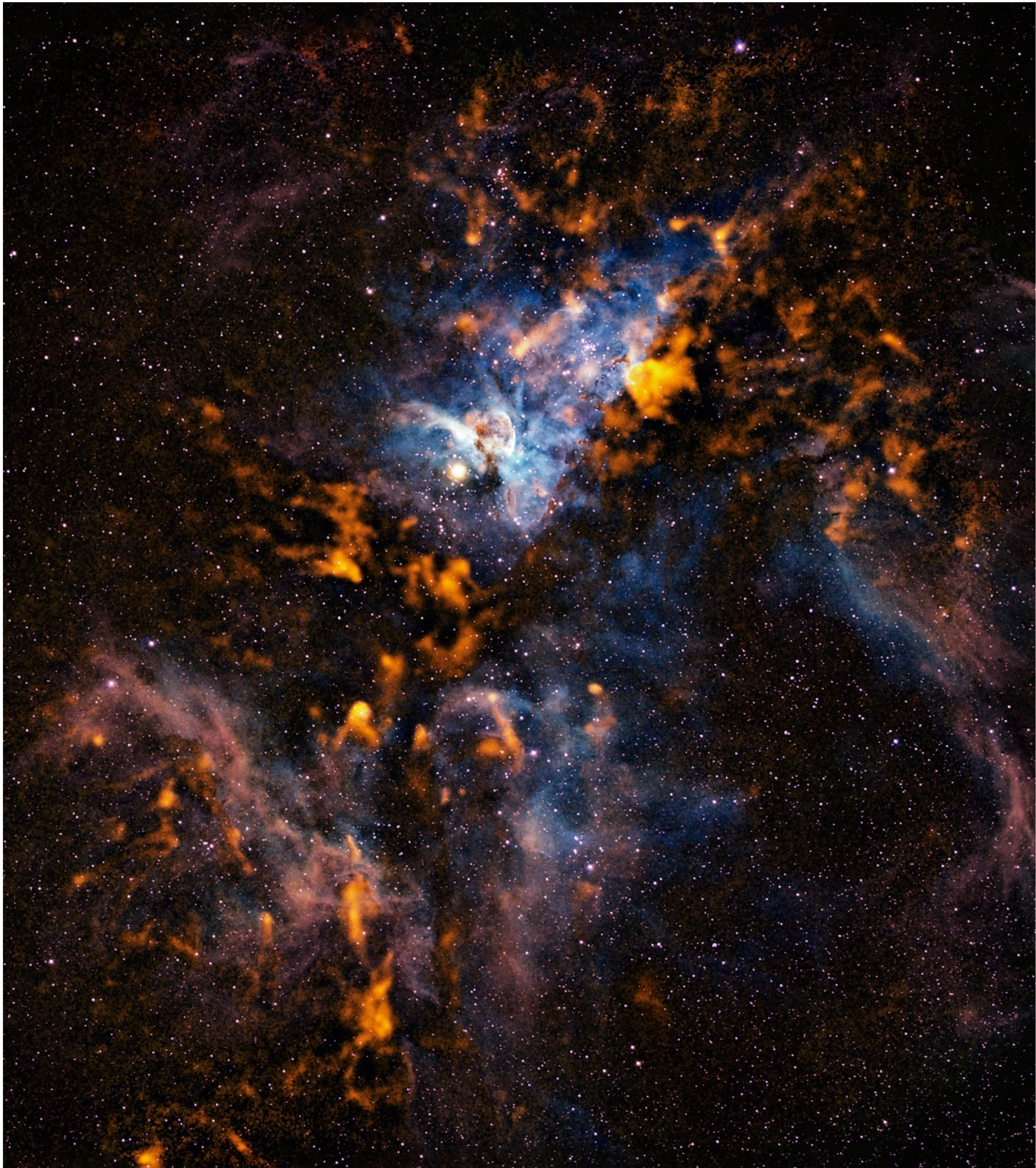
- LABOCA+DSS2
- Complementary to Spitzer & Herschel key programs

Stutz (MPIA),
Stanke (ESO), et al.



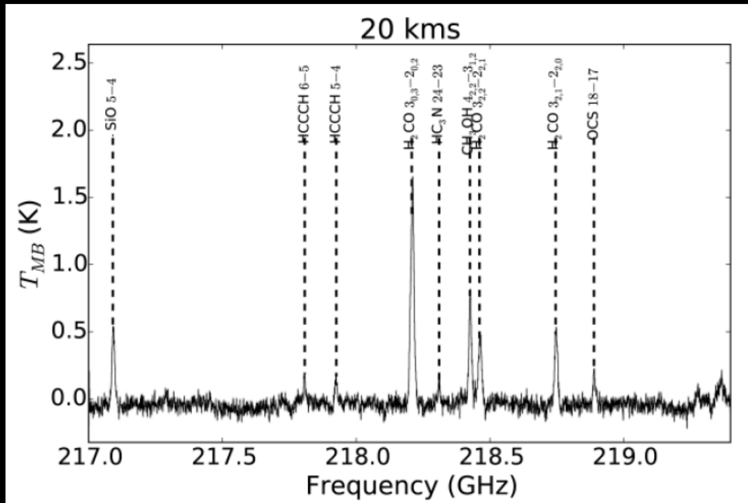
The cool clouds of Carina

- LABOCA
- optical
- One of the most massive SFRs, violent SF
- Preibisch (LMU Munich) et al. 2010



The Galactic Center Region at 870 µm

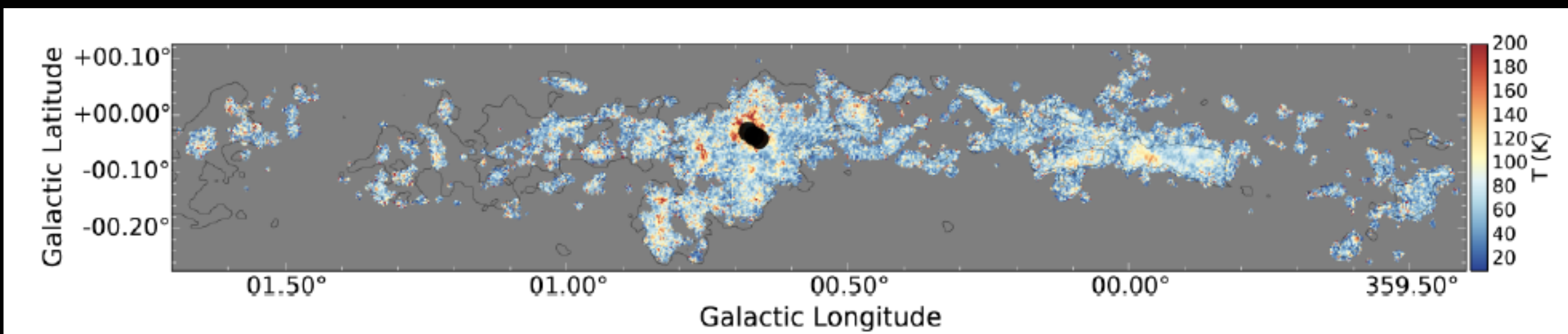
870 µm APEX + Planck



Temperatures in the Central Molecular Zone

Multi-transition APEX imaging of several H_2CO lines reveal kinetic temperatures from 50 to > 100 K in the CMZ

→ Heating (predominantly) by turbulence



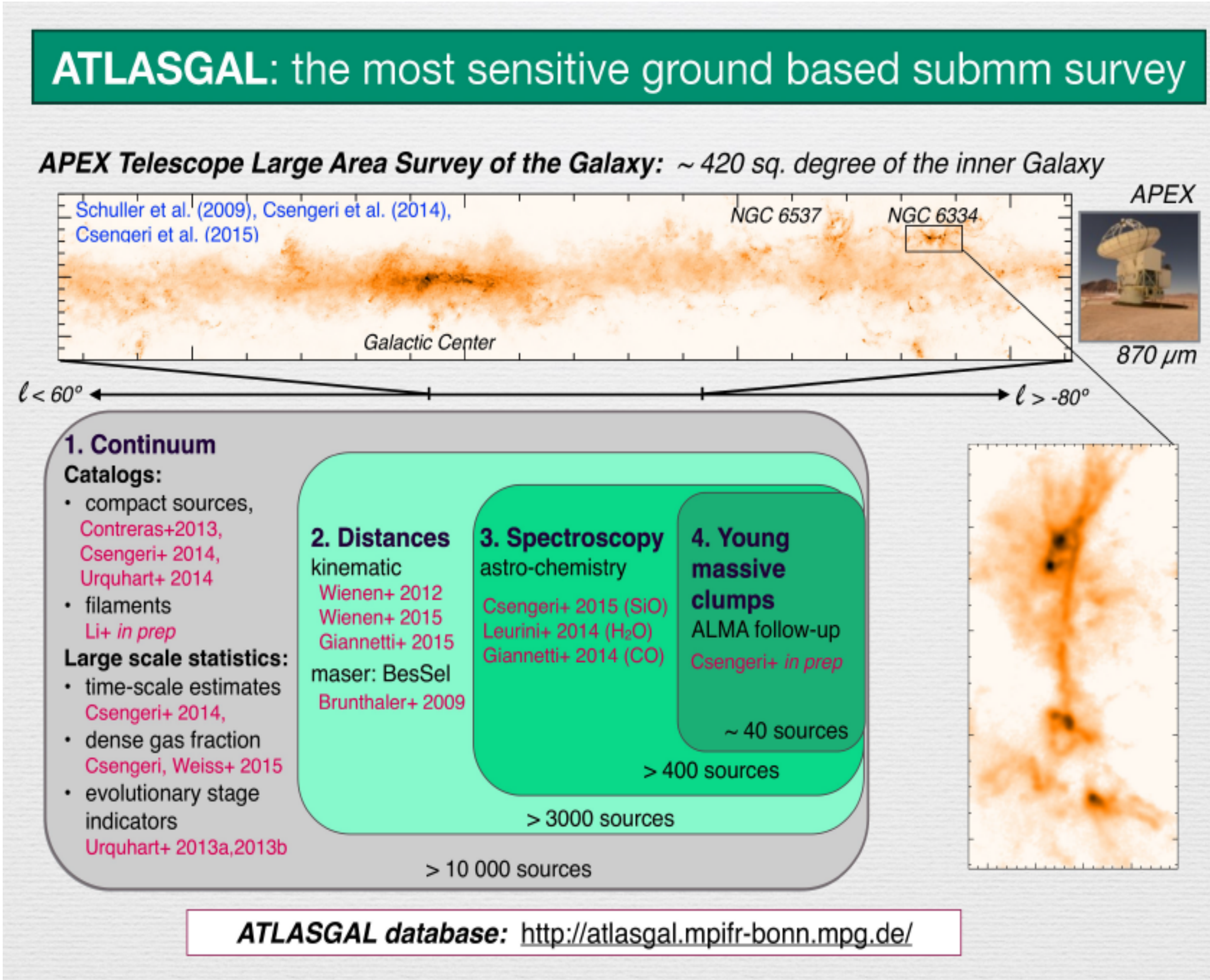
Ginsburg et al. 2016

Ao et al. 2013
Immer et al. 2016

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

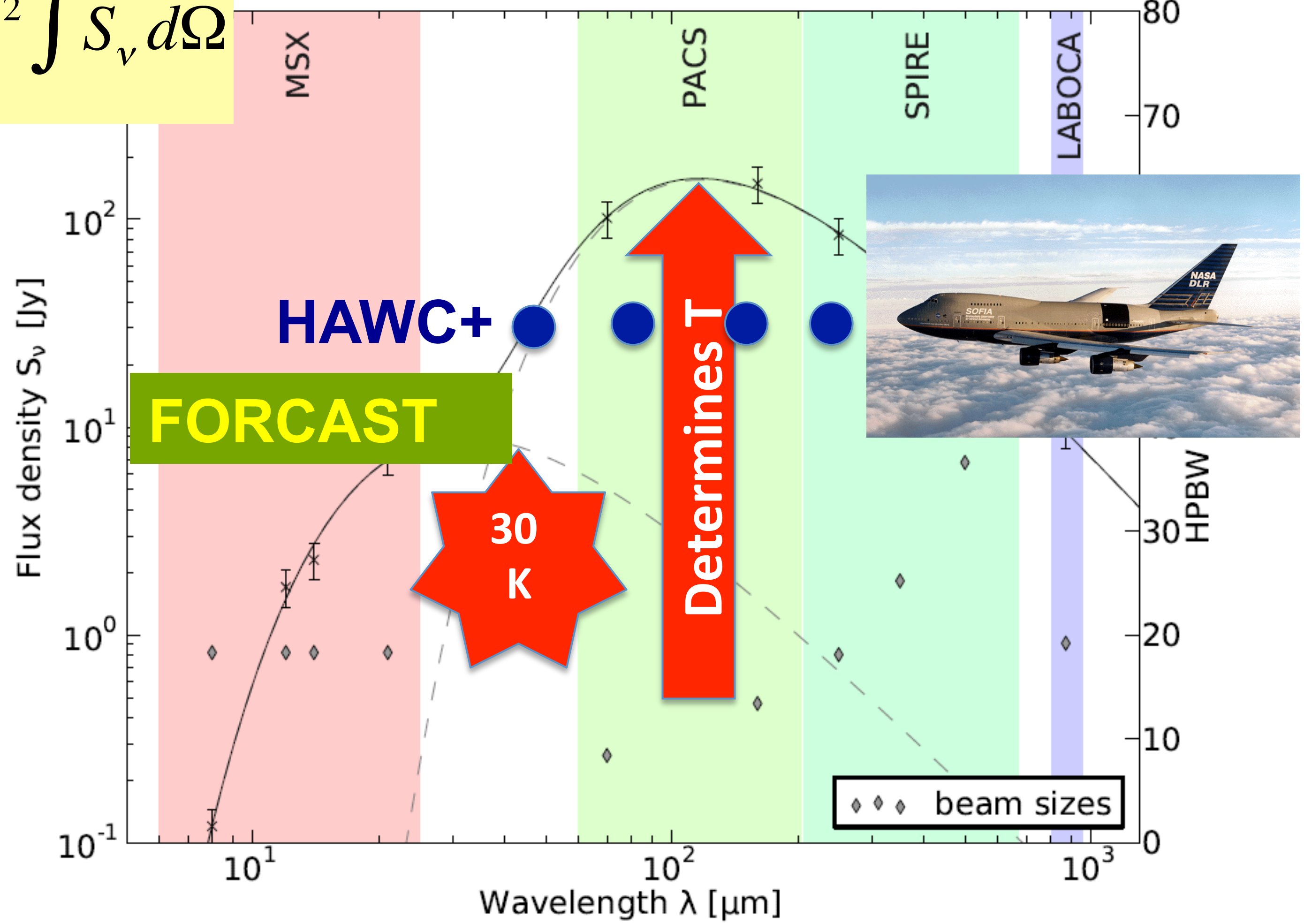

ATLASGAL: the most sensitive ground based submm survey
APEX Telescope Large Area Survey of the Galaxy: ~ 420 sq. degree of the inner Galaxy
Schuller et al. (2009), Csengeri et al. (2014), Csengeri et al. (2015)
NGC 6537
NGC 6334
Galactic Center
APEX
870 μm
ℓ < 60°
ℓ > -80°
1. Continuum
Catalogs:
• compact 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 (H2O)
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

Spectral Energy Distributions:
Probing Luminosities and Masses

$$N_H \propto \frac{\nu^{-2-\beta}}{T_D} S_\nu$$

$$M \propto \frac{\nu^{-2-\beta}}{T_D} D^2 \int S_\nu \, d\Omega$$

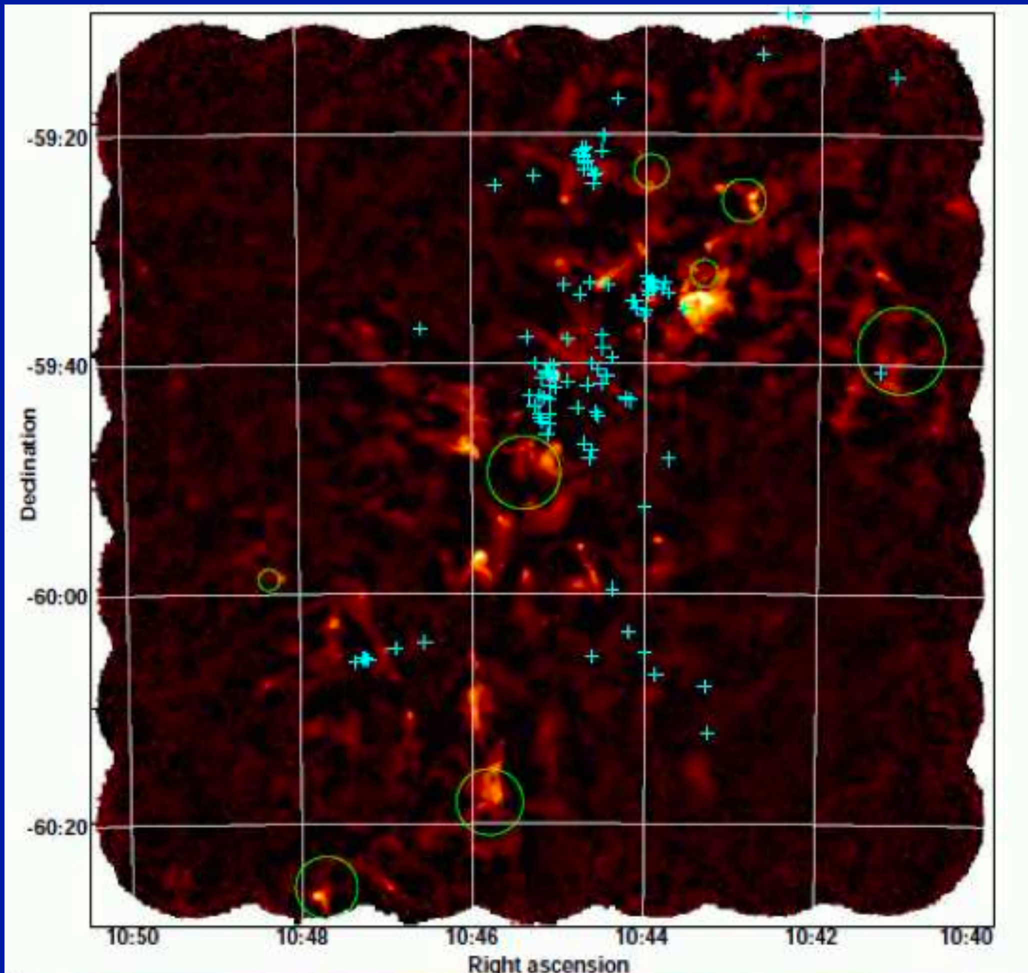


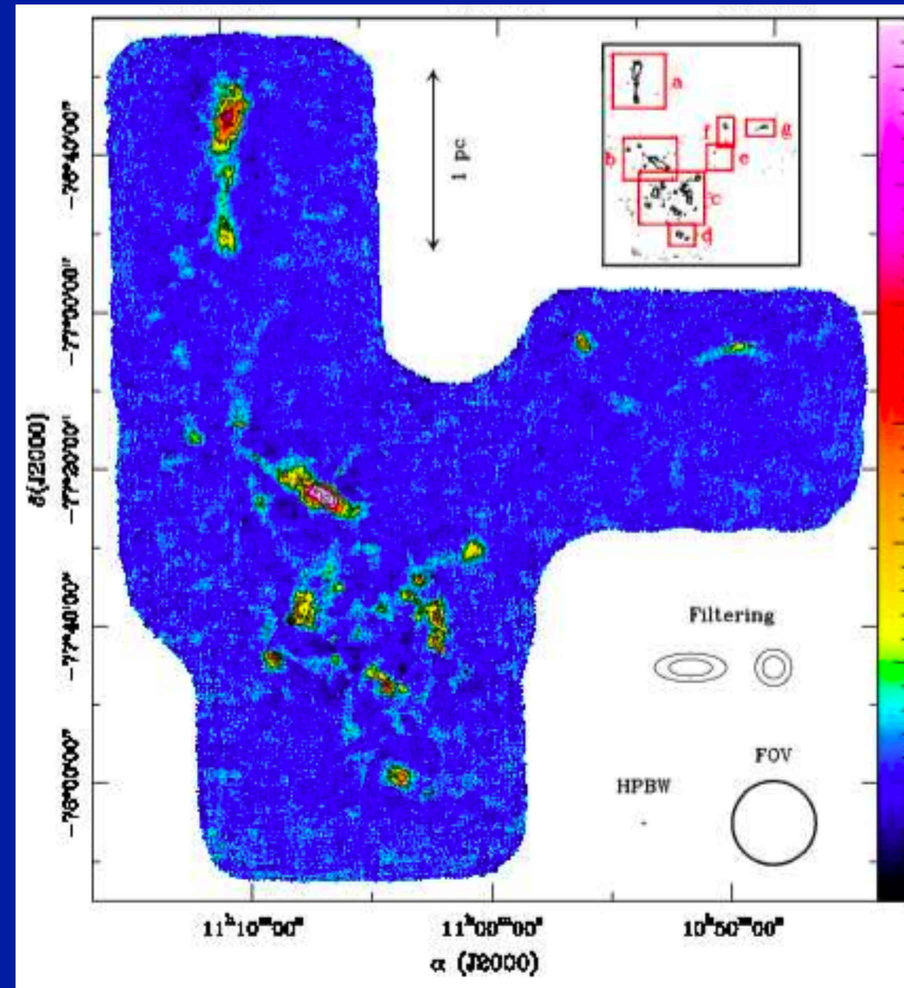
The Future is here!

Atacama Large Millimeter/submillim

- 50 x 12 m ∅ antennas + 1
- Interferomet
- PEX)
- E project

Before we can image interesting regions with ALMA, we have to find them!

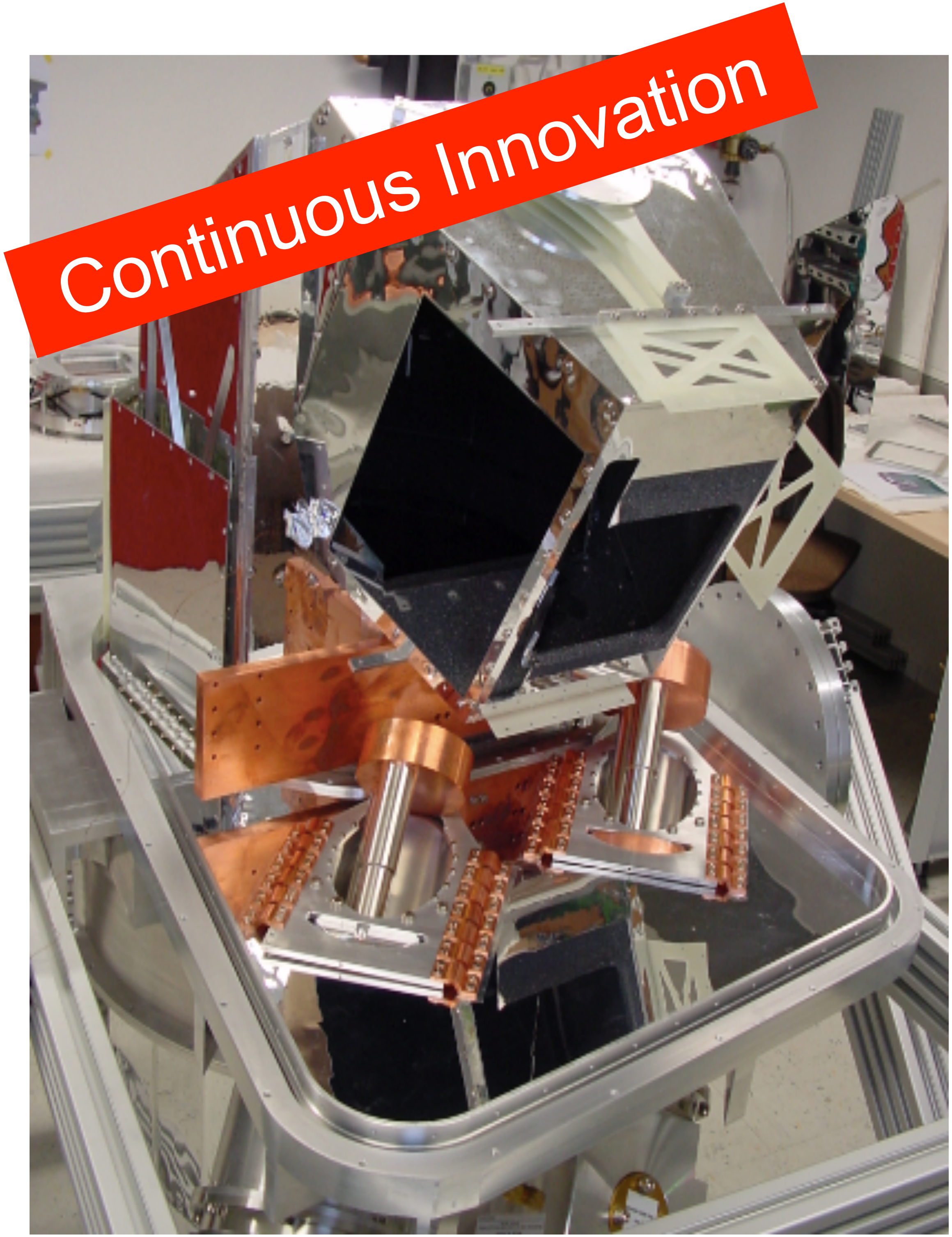




Carina complex/
Preibisch et al. 2011

Chamaeleon I/
Belloche et al. 2011

1 sq. deg would mean ~a 130000
pointing mosaic for ALMA at 345 GHz

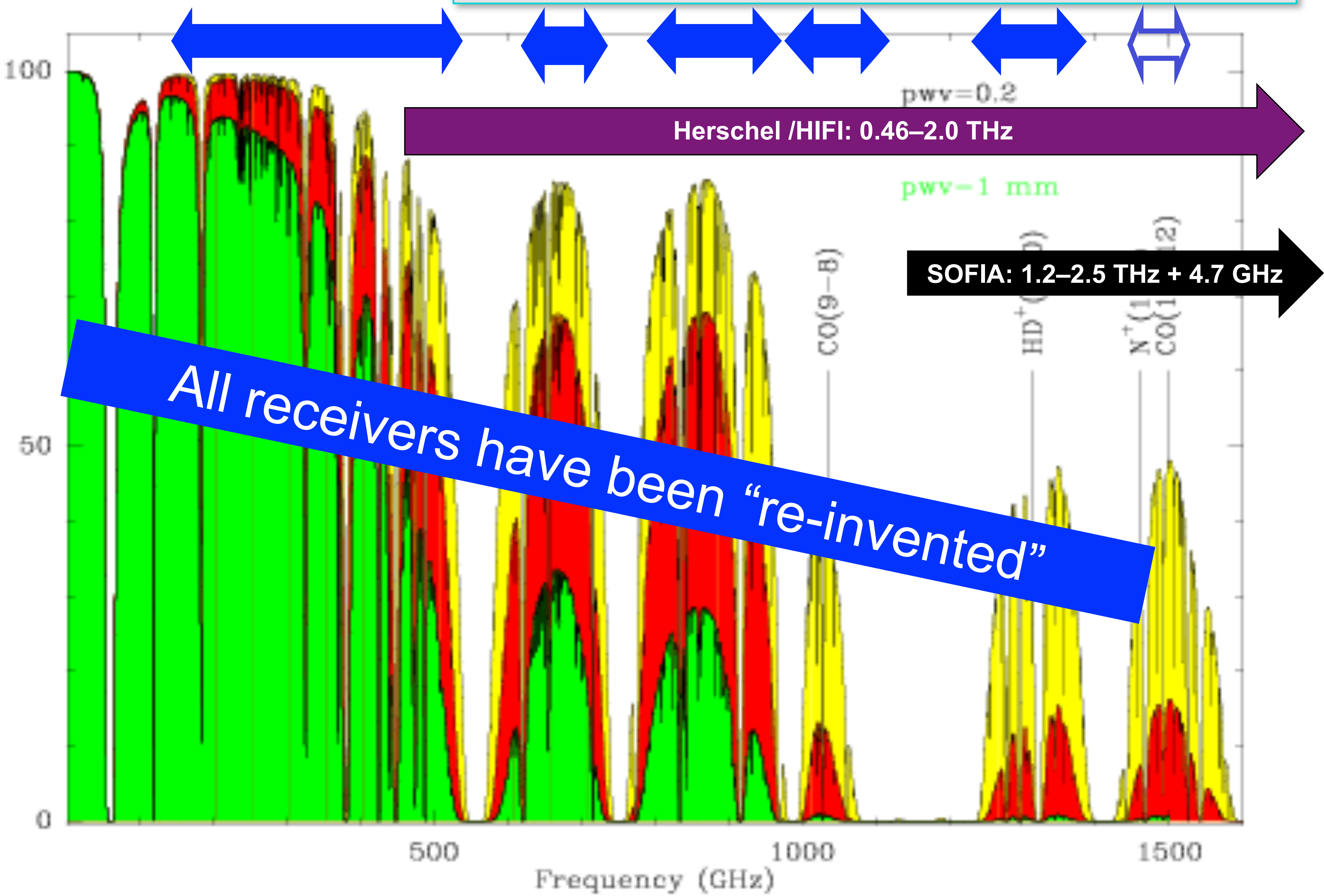


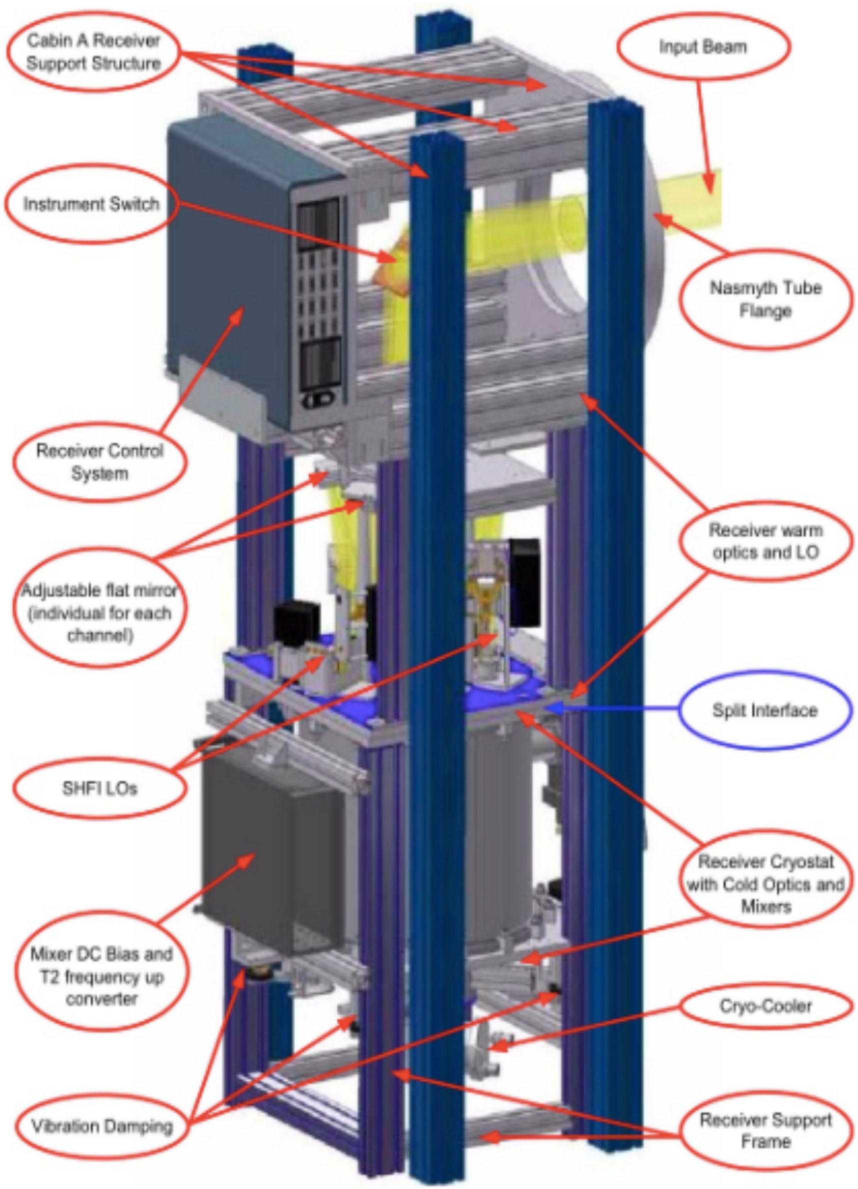
Expected in 2017:

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 Heterodyne Receivers

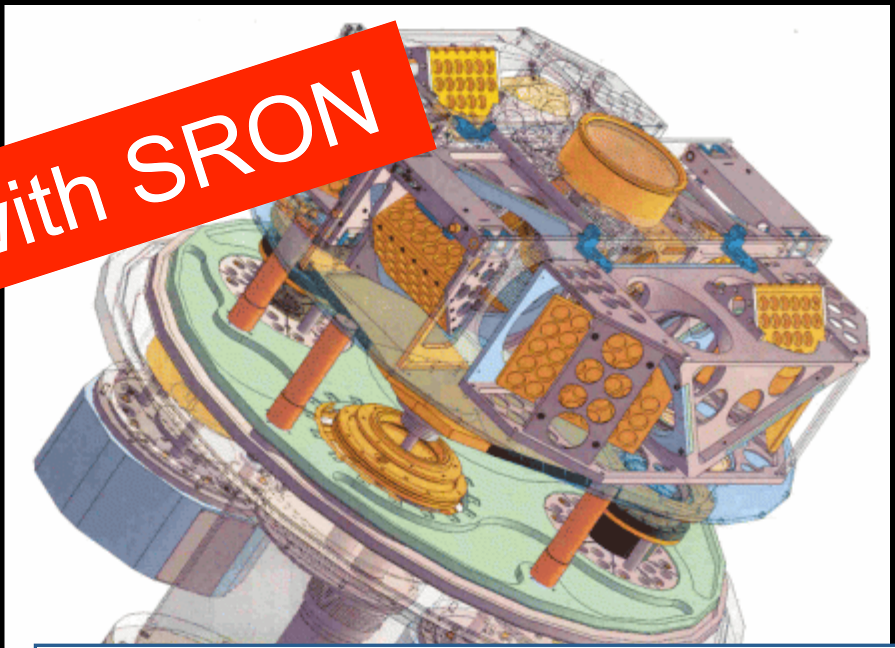



Cabin A Receiver Support Structure
Input Beam
Instrument Switch
Nasmyth Tube Flange
Receiver Control System
Receiver warm optics and LO
Adjustable flat mirror (individual for each channel)
Split Interface
SHFI LOs
Receiver Cryostat with Cold Optics and Mixers
Mixer DC Bias and T2 frequency up converter
Cryo-Cooler
Vibration Damping
Receiver Support Frame

Max-Planck-Institut für Radioastronomie

SRON

Collaboration with SRON

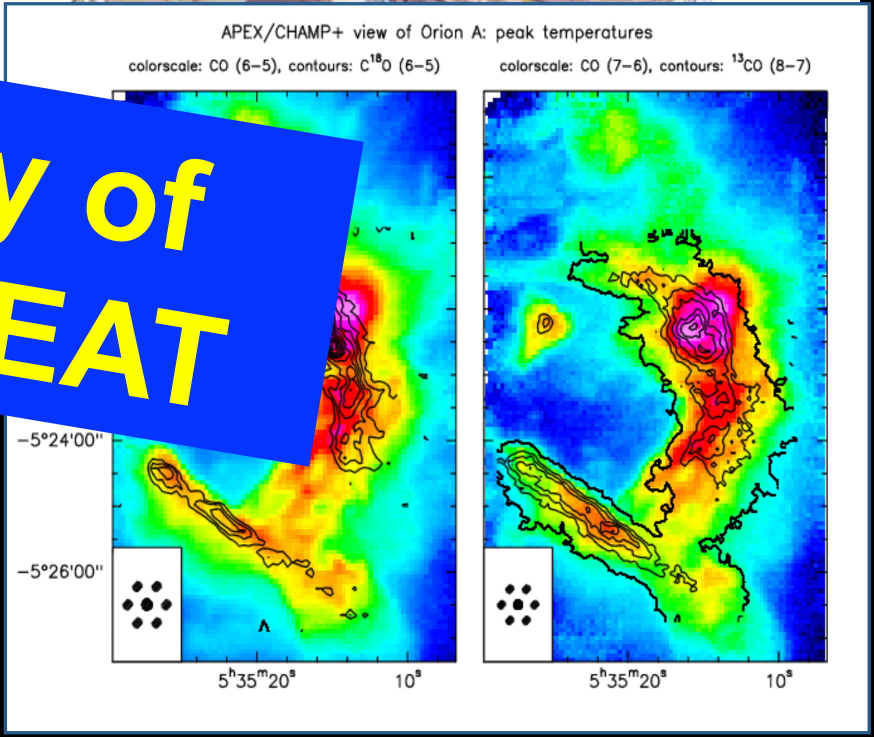


CHAMP+

Carbon Heterodyne Array of the MPIfR

- **2 × 7 pixels**
- **frequency ranges 602**
  790 – 950 GHz simulta
- **beamsize 9" – 7" and 7" – 6"**
- **IF band 4 – 8 GHz**

Daddy of upGREAT

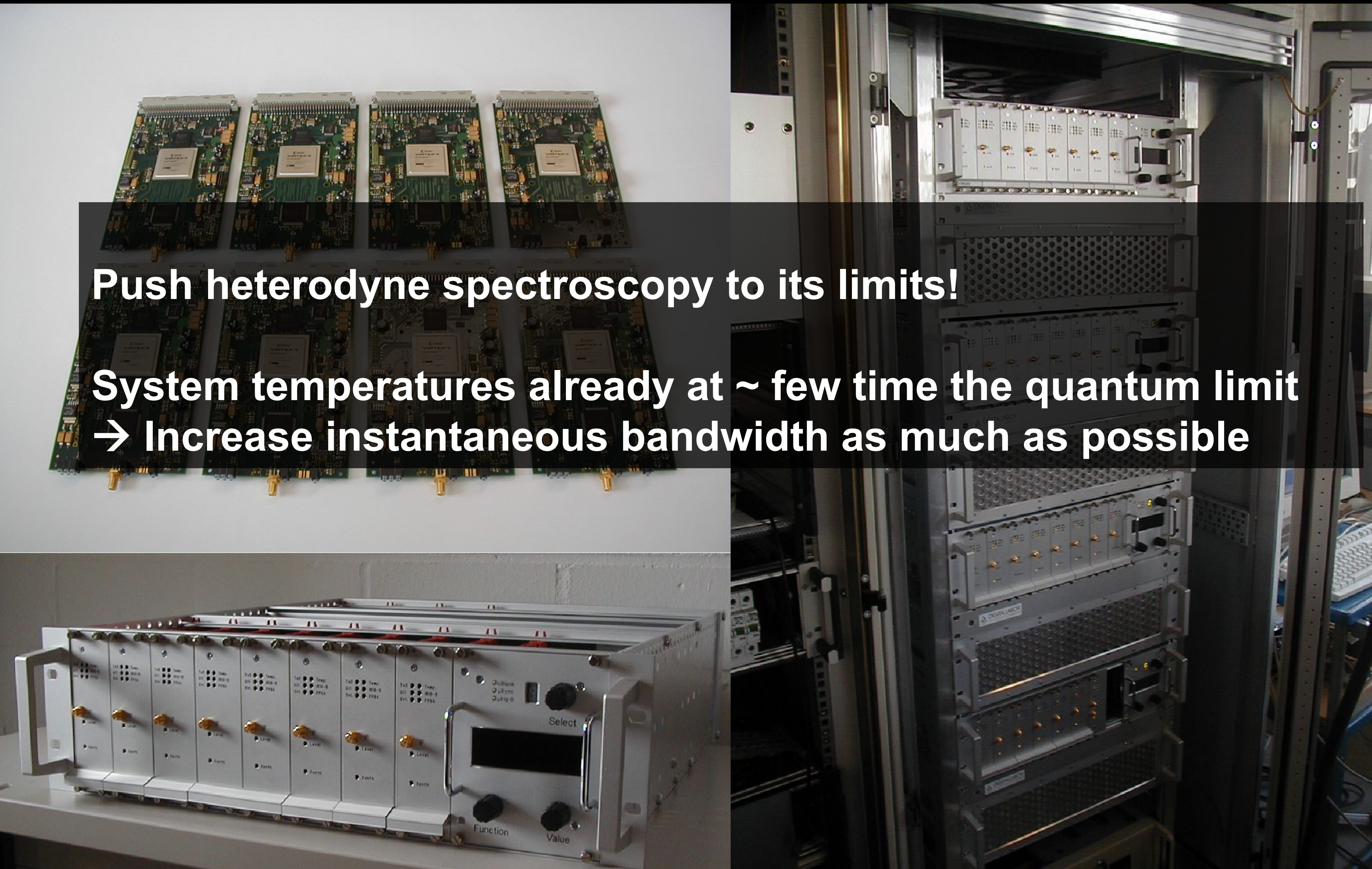


http://www.mpifr-bonn.mpg.de/div/mm/tech/het.html#champ

Peng et al. 2010

Kasemann et al. 2006

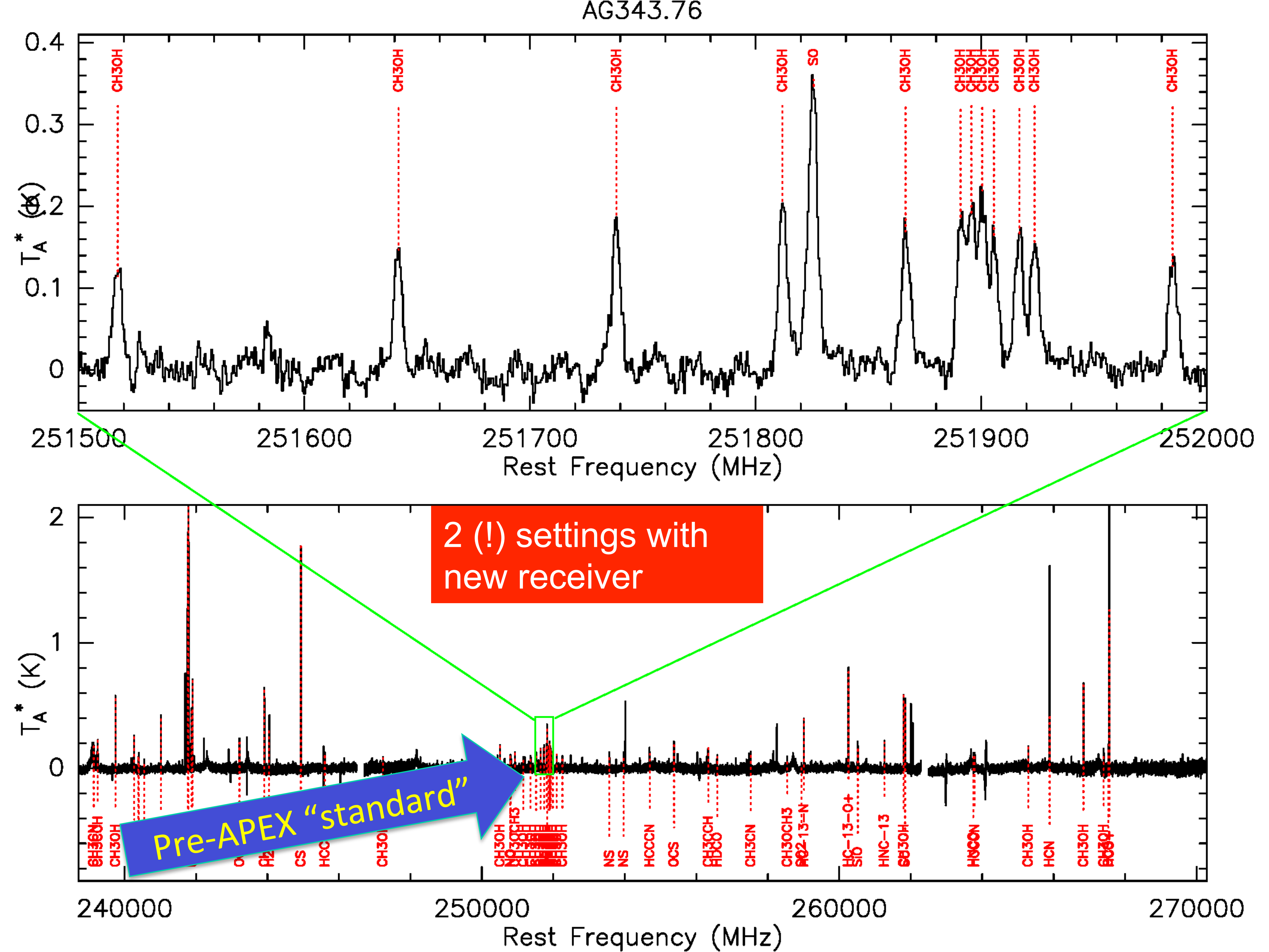
Massive MPIfR digital electronic development



Push heterodyne spectroscopy to its limits!

System temperatures already at ~ few time the quantum limit
→ Increase instantaneous bandwidth as much as possible

APEX Array Fast Fourier Transform Spectrometer: 4 × 8 × 1.5 GHz = 48 GHz/262144 channels

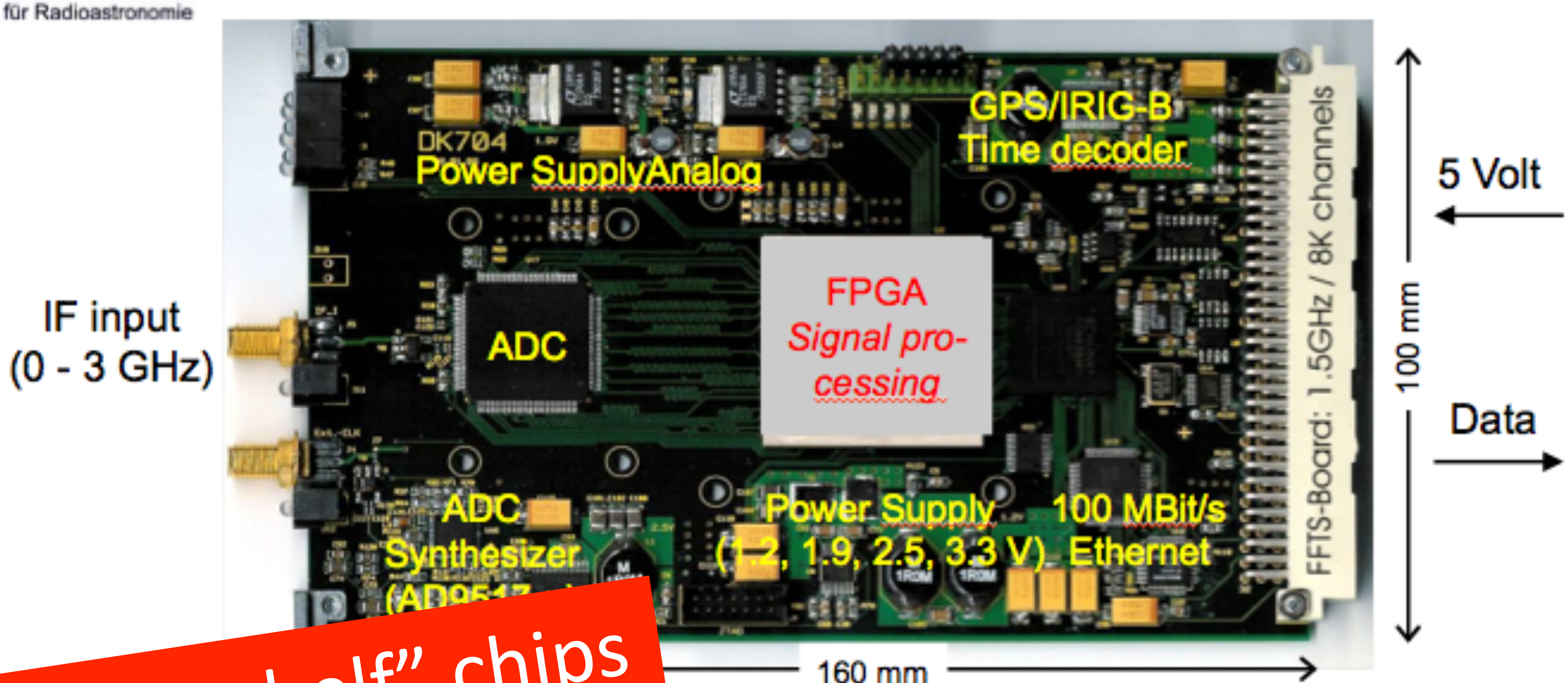


AG343.76
2 (!) settings with new receiver
Pre-APEX "standard"
Rest Frequency (MHz)
T_A* (K)
CH3OH
SO
NS
HCCCN
OCS
CH3CN
HCN
HNC-13

FFTS :: The MPIfR-Board

Max-Planck-Institut für Radioastronomie

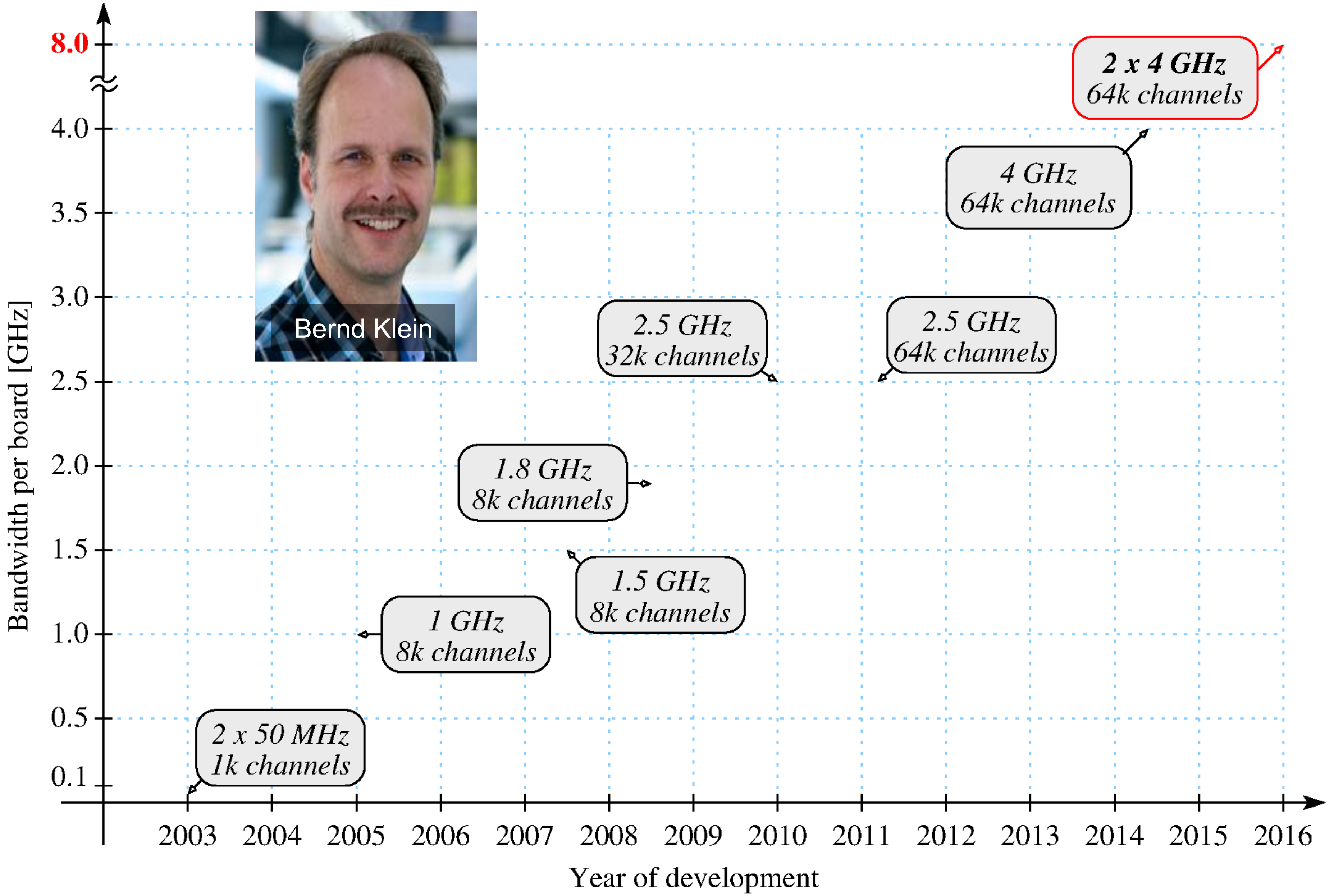
DIGITALLABOR



"Off-the-shelf" chips

- Instantaneous bandwidth: 0.1 – 1.8 GHz
- Spectral resolution @ 1.5 GHz: 212 kHz
- Stability (spec. Allan Variance): > 1000 sec.
- Calibration- and aging free digital processing

MPIfR FFT Spectrometer Development: Time lime



FFTS4G @ upGREAT / SOFIA

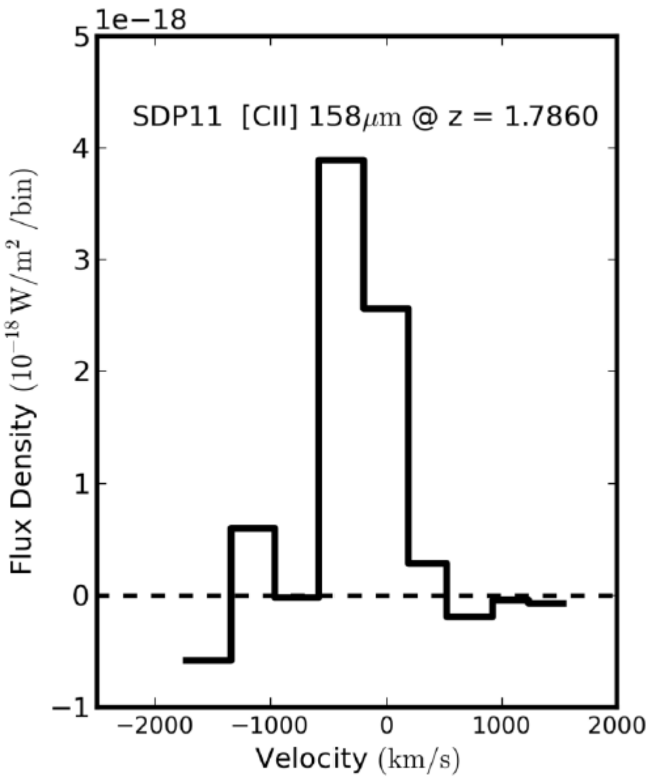
FFTS4G:

- *16 x FFTS4G boards*
- *64 GHz total bandwidth*
- *512k spectral channels*
- *142 kHz spectral resolution*

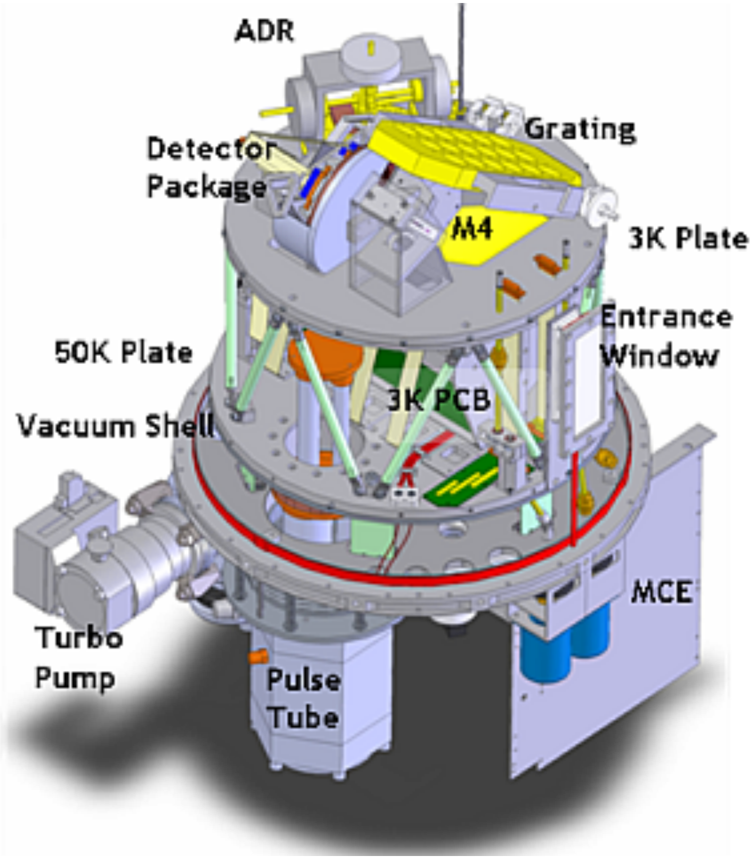
IF-Processor

ZEUS-2: The 2nd Generation z(Redshift) and Early Universe Spectrometer

- An echelle grating spectrometer
- R ~ 1000 in three telluric bands: 215, 400, 645 μm)



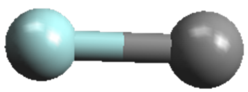
[CII] 158 μm line from H-ATLAS J091043.1-000322



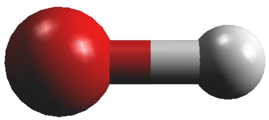
PI: Gordon Stacey, Cornell University

Ferkinhoff+ 2014

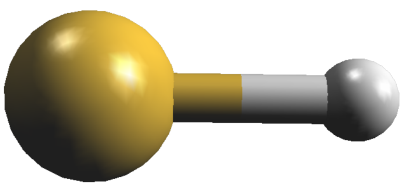
APEX discovered a number of new, interesting, simple molecules in the Interstellar Medium



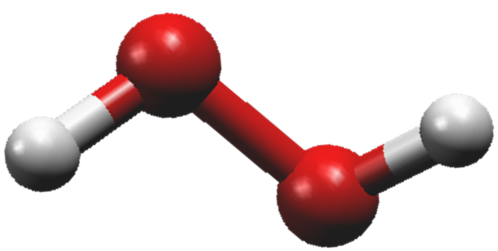
CF^+ — Neufeld et al. 2006



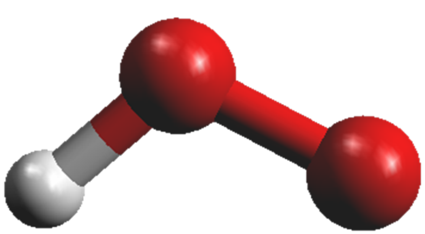
OH^+ — Wyrowski et al. 2010



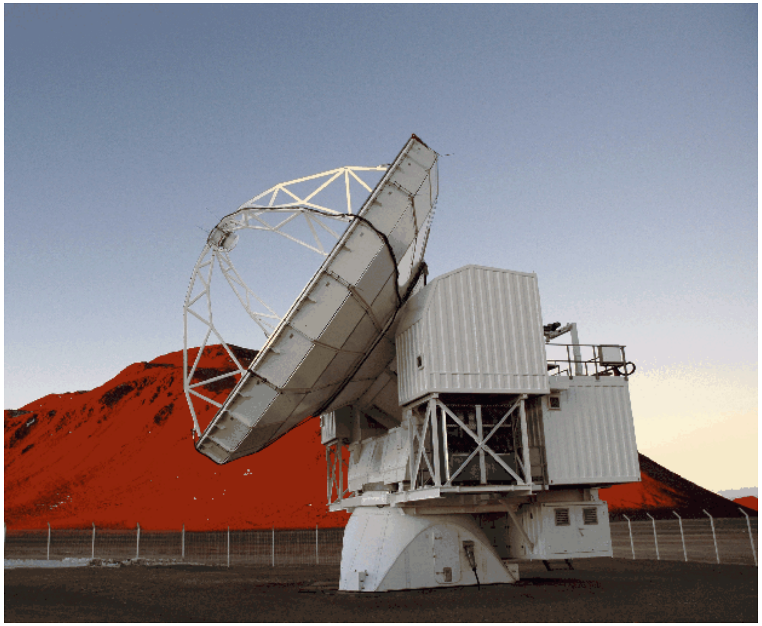
SH^+ — Menten et al. 2011



H_2O_2 — Bergman et al. 2011

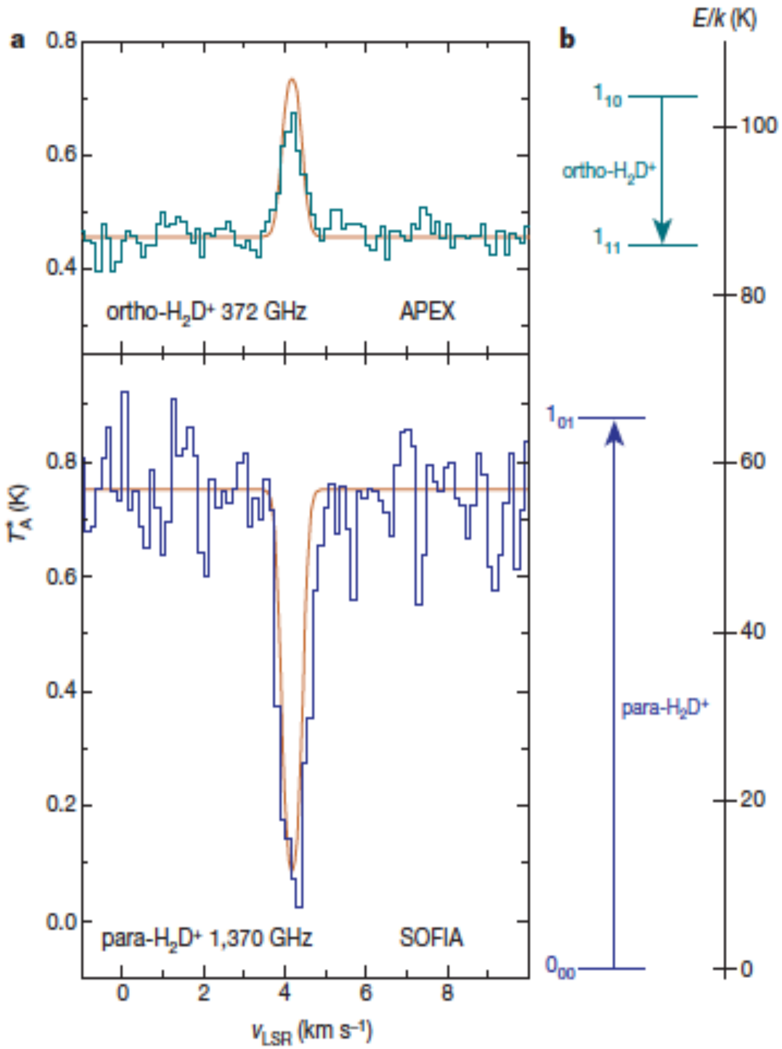


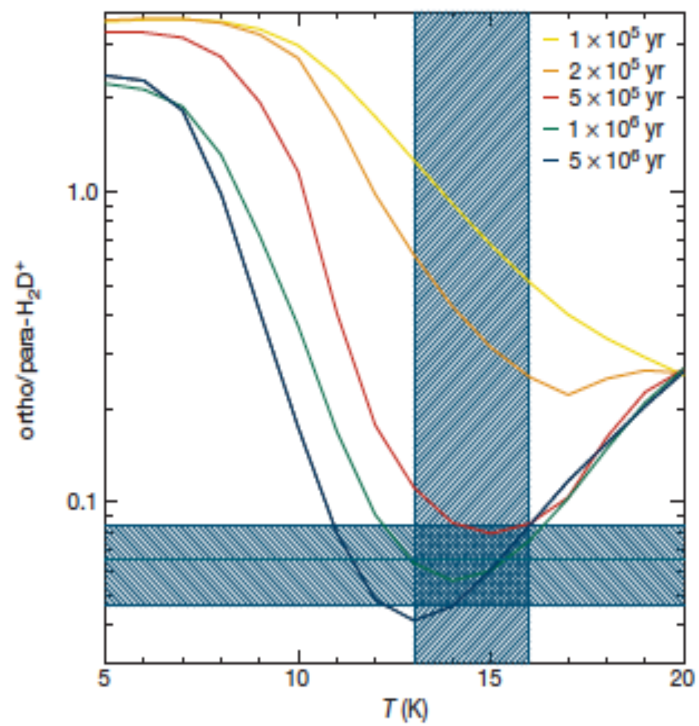
HO_2 — Parise al. 2012



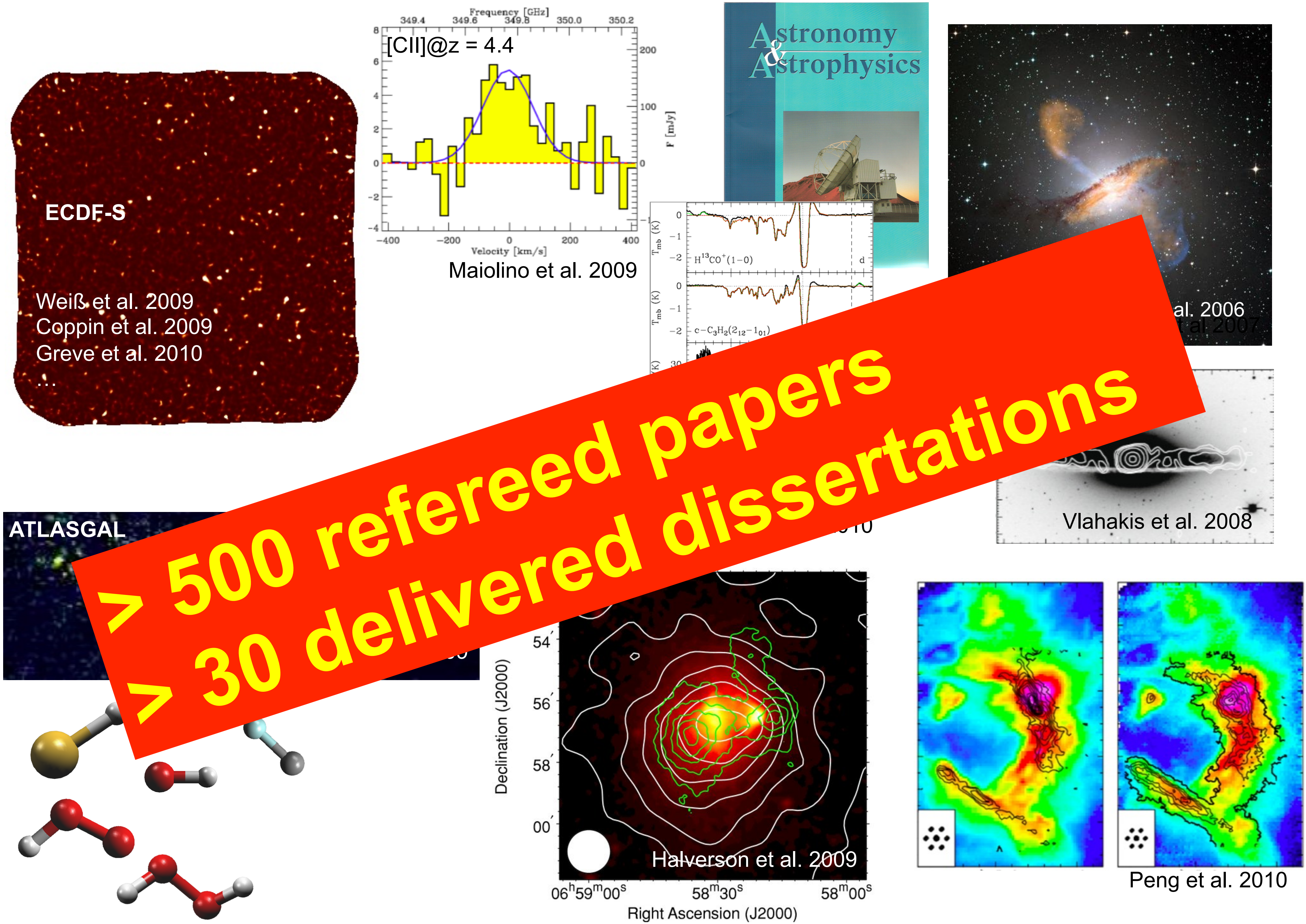
H_2D^+ observations give an age of at least one million years for a cloud core forming Sun-like stars

Sandra Brünken[1], Olli Sipilä[2,3], Edward T. Chambers[1], Jorma Harju[2], Paola Caselli[3,4], Oskar Asvany[1], Cornelia E. Honingh[1], Tomasz Kamiński[5], Karl M. Menten[5], Jürgen Stutzki[1] & Stephan Schlemmer[1]





Nature, 516, 219 (2014)

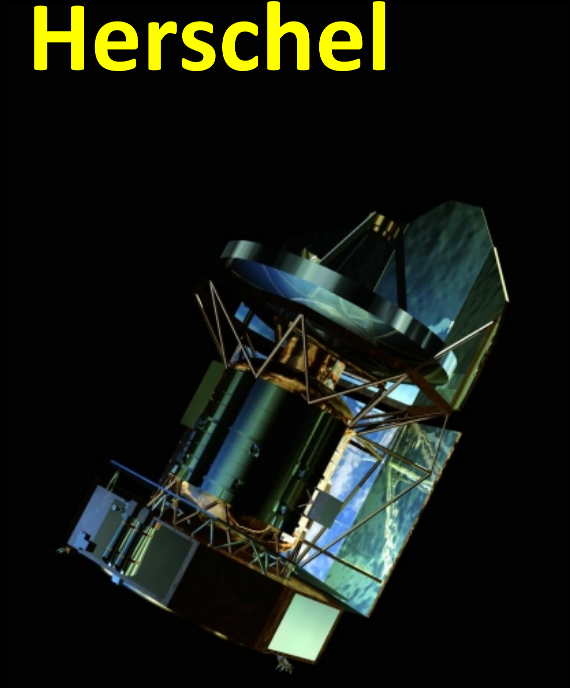


ECDF-S
Weiß et al. 2009
Coppin et al. 2009
Greve et al. 2010
…
Frequency [GHz]
[CII]@z = 4.4
Velocity [km/s]
F [mJy]
Maiolino et al. 2009
Astronomy & Astrophysics
$H^{13}CO^+(1-0)$
$c-C_3H_2(2_{12}-1_{01})$
al. 2006
Vlahakis et al. 2008
ATLASGAL
Declination (J2000)
Right Ascension (J2000)
Halverson et al. 2009
Peng et al. 2010
> 500 refereed papers
> 30 delivered dissertations

APEX has been a pathfinder not only for ALMA…

…but also for **Herschel**

Very high level of synergy: Technological and astronomical



14 May 2009 –29 April 2013

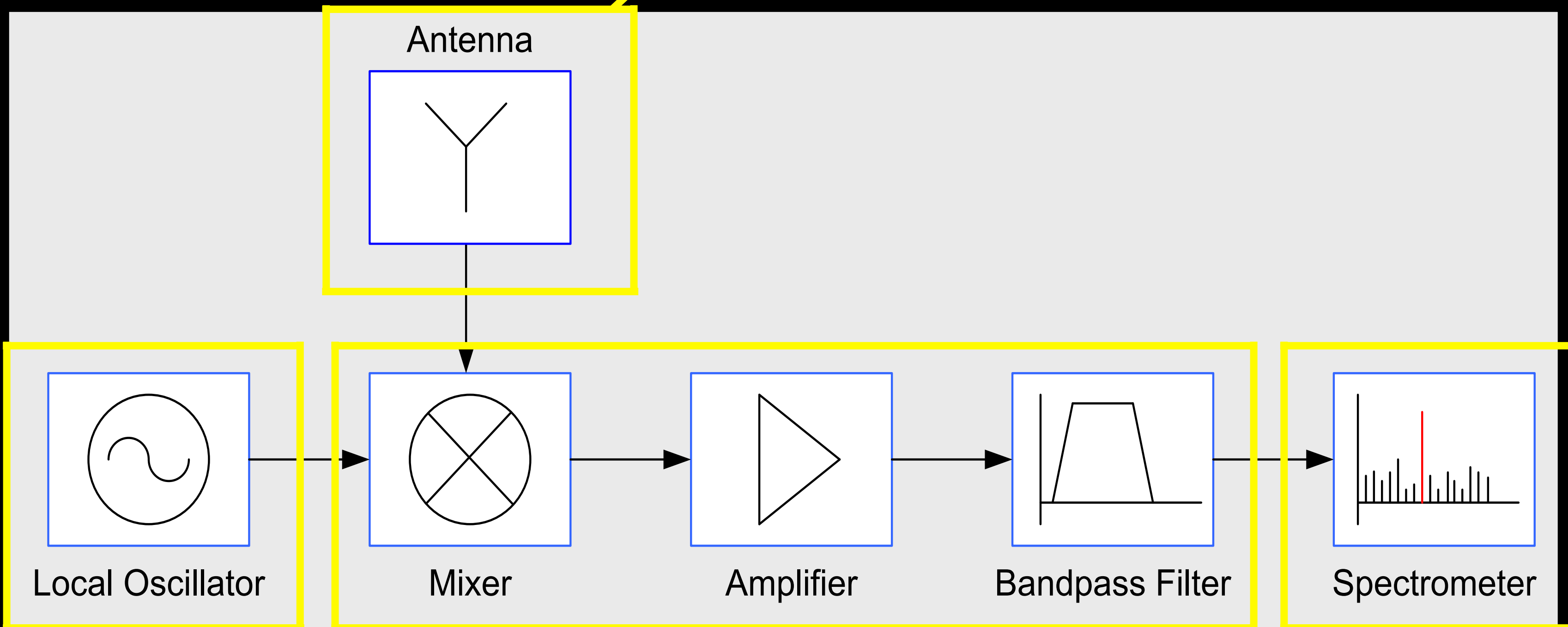
…and **SOFIA**

GREAT

Since 2011

HIFI Heterodyne Instrument for the Far-Infrared

Telescope, primary and secondary mirror



LO Subsystem:
LOU – Local oscillator unit
LCU – LO contol unit
LSU – LO base synthesizer

FPU – Focal plane unit

AOS and autocorrelator

Designed and built by MPIfR-led consortium

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 Groningen, N[illegible]
4	960 – 1120 GHz	SIS NbTiN-Al2O3-Nb	Al on NbTiN microstrip	corrugated horn [illegible]	[illegible]
5	1120 – 1250 GHz	SIS NbTiN-AlN-NbTi[illegible]	Al on N[illegible]	[illegible]	[illegible]
6L	1410 – 1703 GHz	[illegible]	[illegible]	[illegible]	[illegible]

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

[illegible]	[illegible]	[illegible]ines of Interest
lo[illegible]	1.25-1.50 (single pixel)	[NII], CO series, OD,HCN,H_2D^+
low-frequency L2	1.81-1.91 (single pixel)	NH_3,OH,CO(16-15),[CII]
mid-frequency M a,b	2.5 – 2.7 (single pixel)	OH($^2\pi_{3/2}$),HD
high-frequency H	4.7 (single pixel)	[OI]
upGREAT Low Frequency Array (LFA)	1.9 – 2.5 (14 pixels)	OH lines, [CII],CO series, [OI]
upGREAT High Frequency Array (HFA)	4.7 (7 pixels)	[OI]

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

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

$_3$ (NIR 1996)

rly 2010s:
rschel/HIFI rules!

• HDO, D_2O, H_3O^+

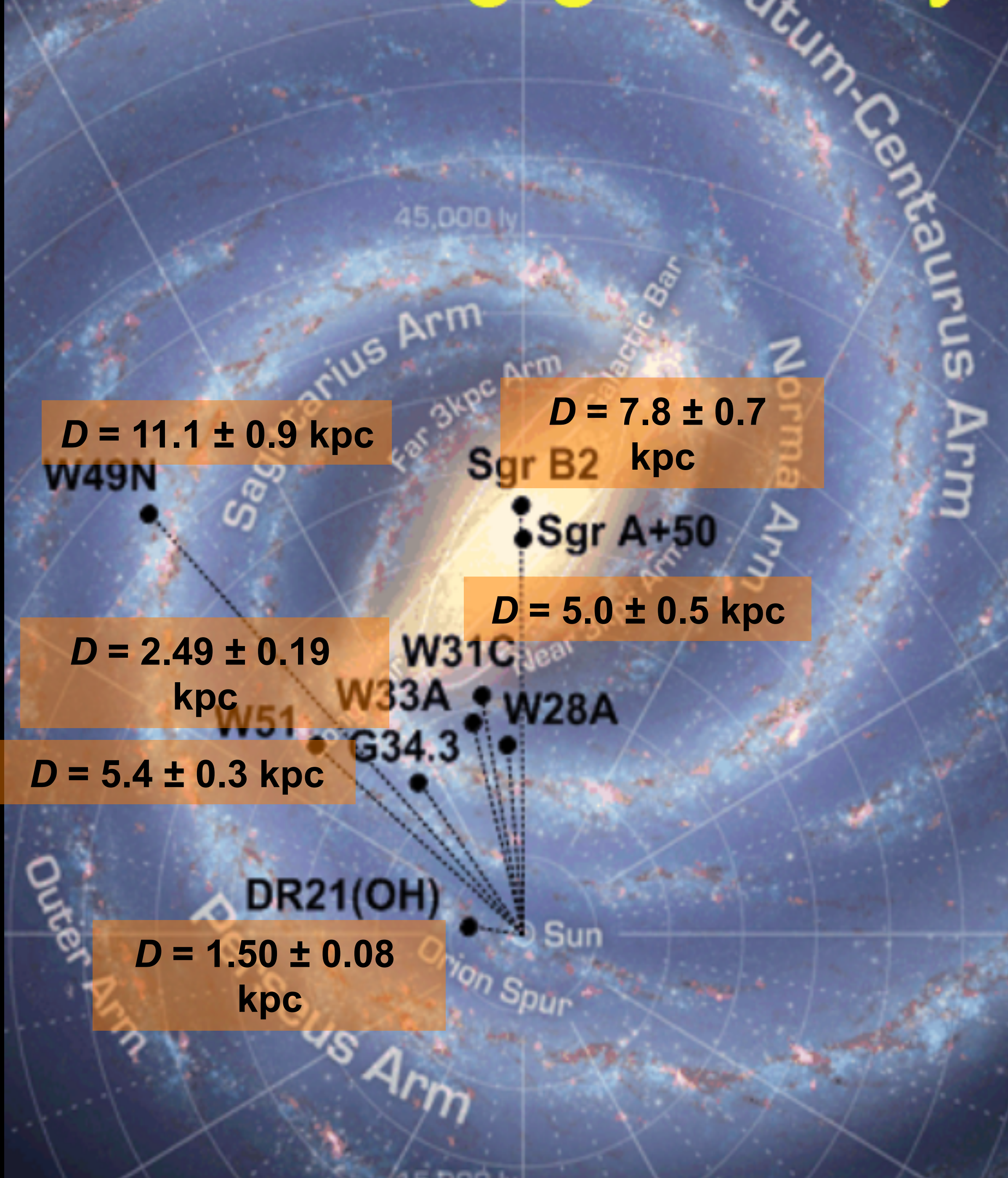
Now:
SOFIA+APEX

After 2000:

• CH_2 (ISO)

• HF (ISO)

Observing geometry

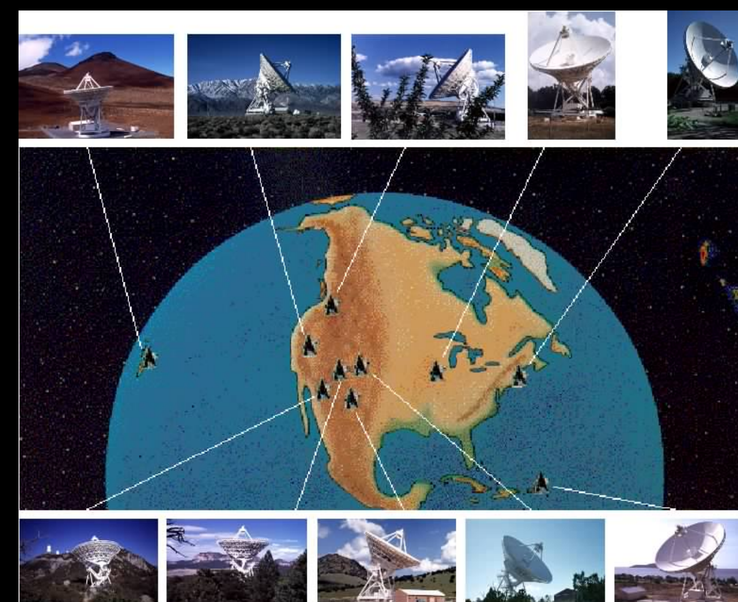


Distances from:

BESSEL

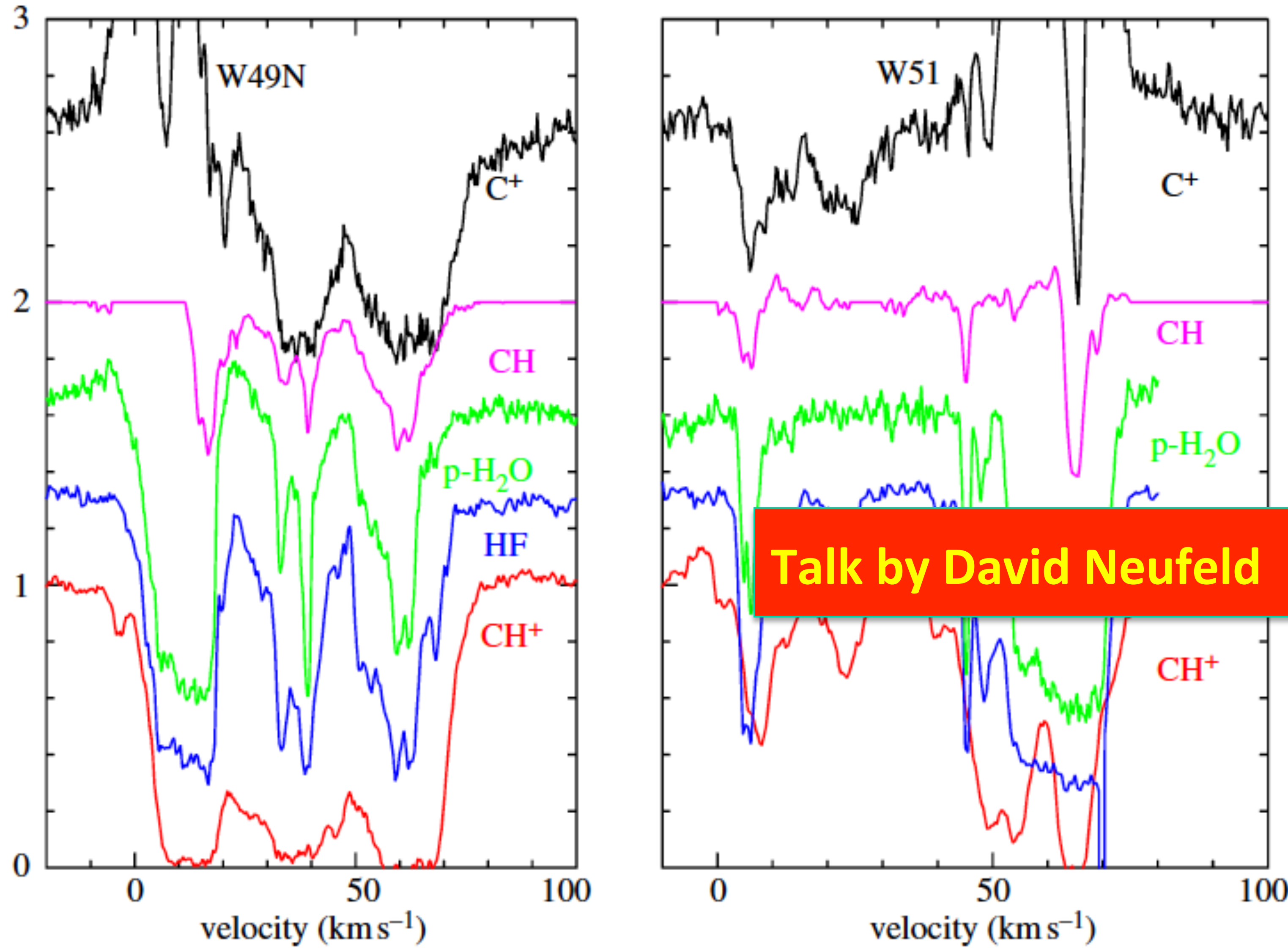
Bar and Spiral Structure Legacy Survey, a VLBA Key Science Project

http://bessel.vlbi-astrometry.org



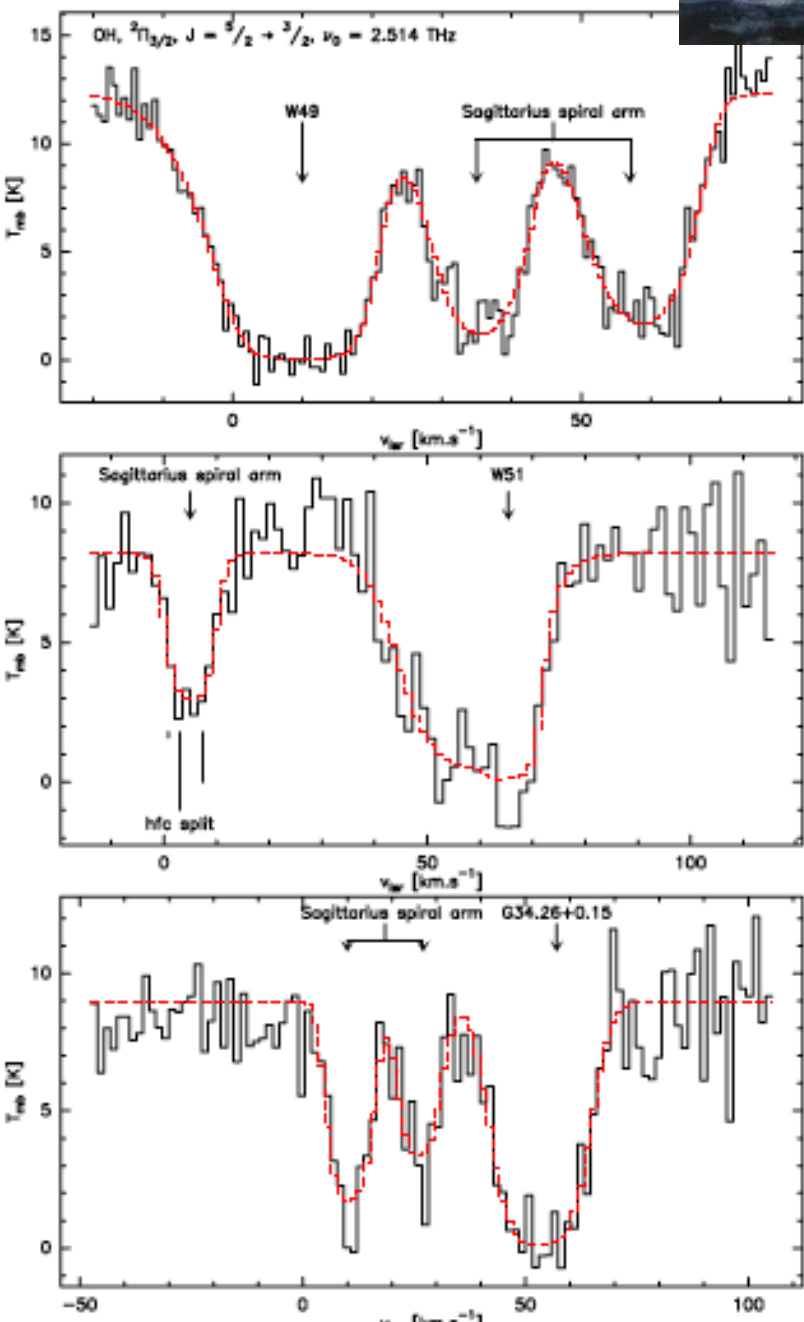
PI: Mark Reid (CfA)

PRISMAS: PRobing Interstellar Molecules with Absorption Line Studies

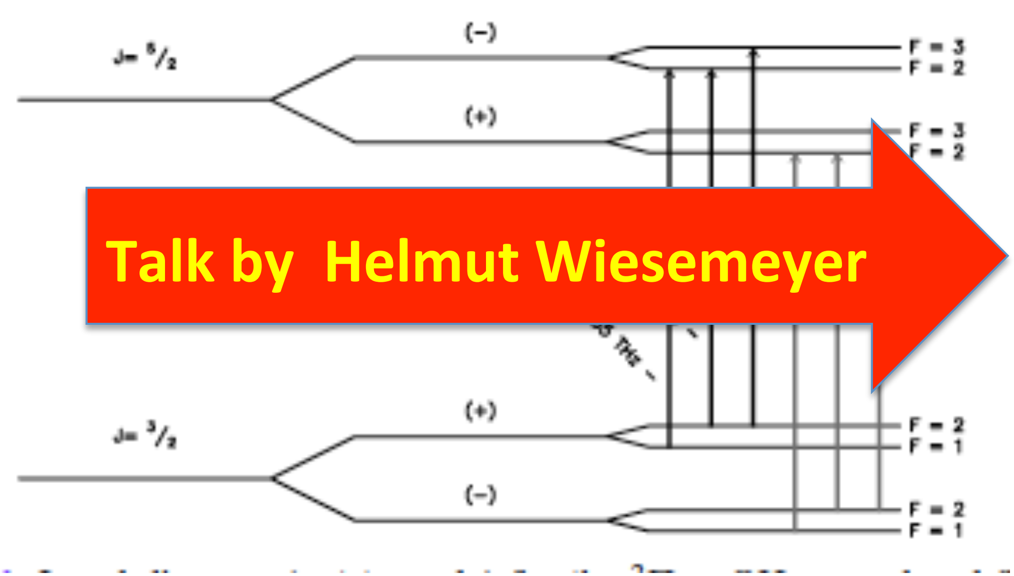


Talk by David Neufeld

Compilation: Gerin et al. 2012



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

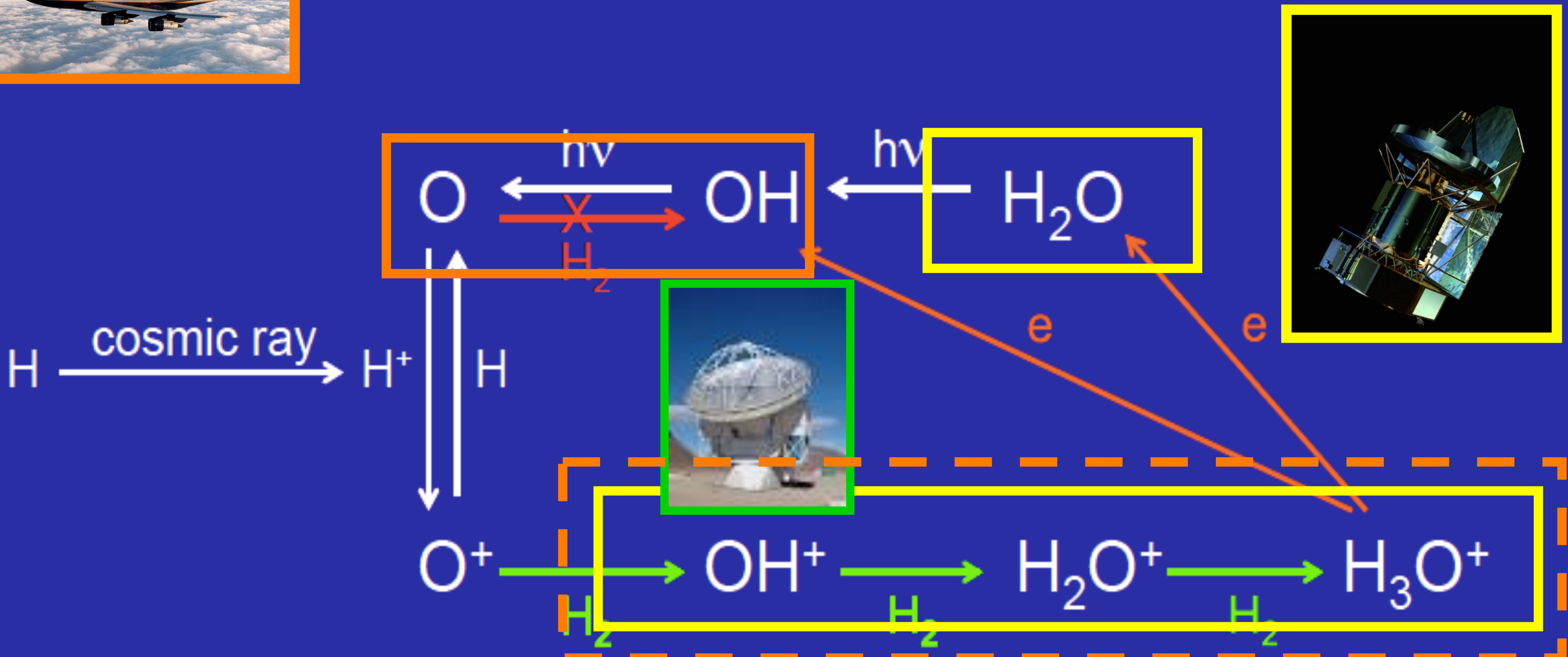


Talk by Helmut Wiesemeyer

Wiesemeyer et al. 2012

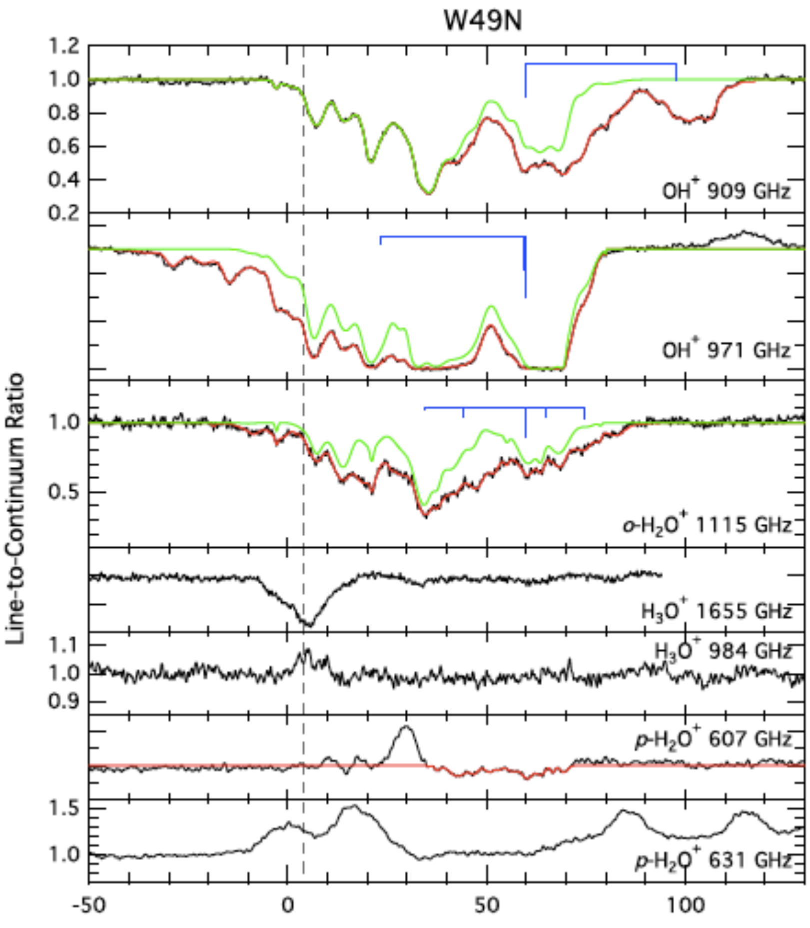
Chemistry of interstellar oxygen

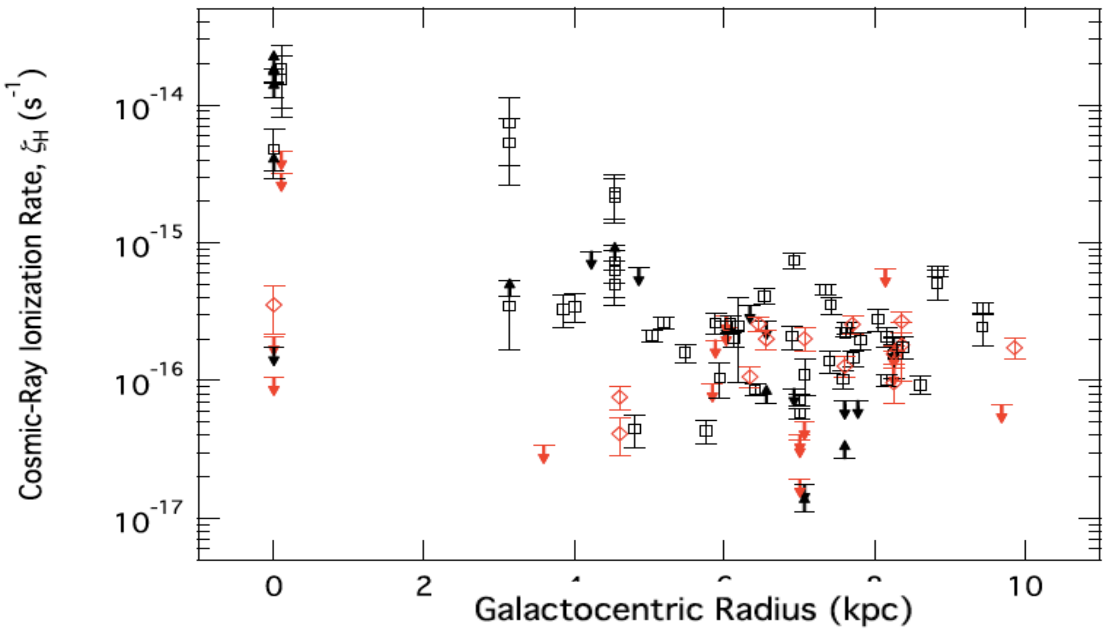
mistry is initiated by cosmic rays

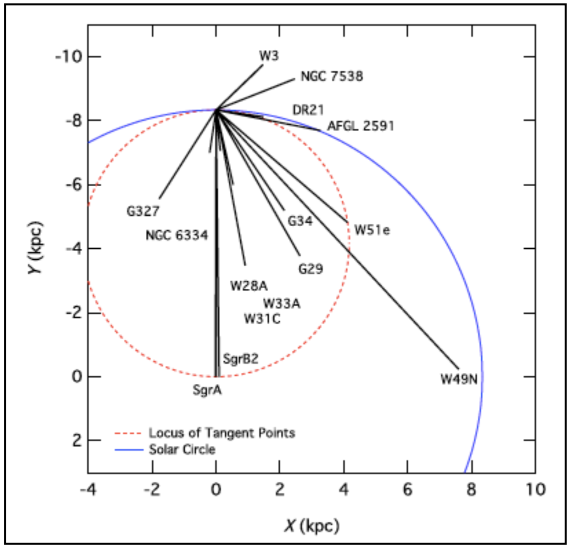


D. Neufeld

The cosmic ray ionization rate over the whole Galaxy



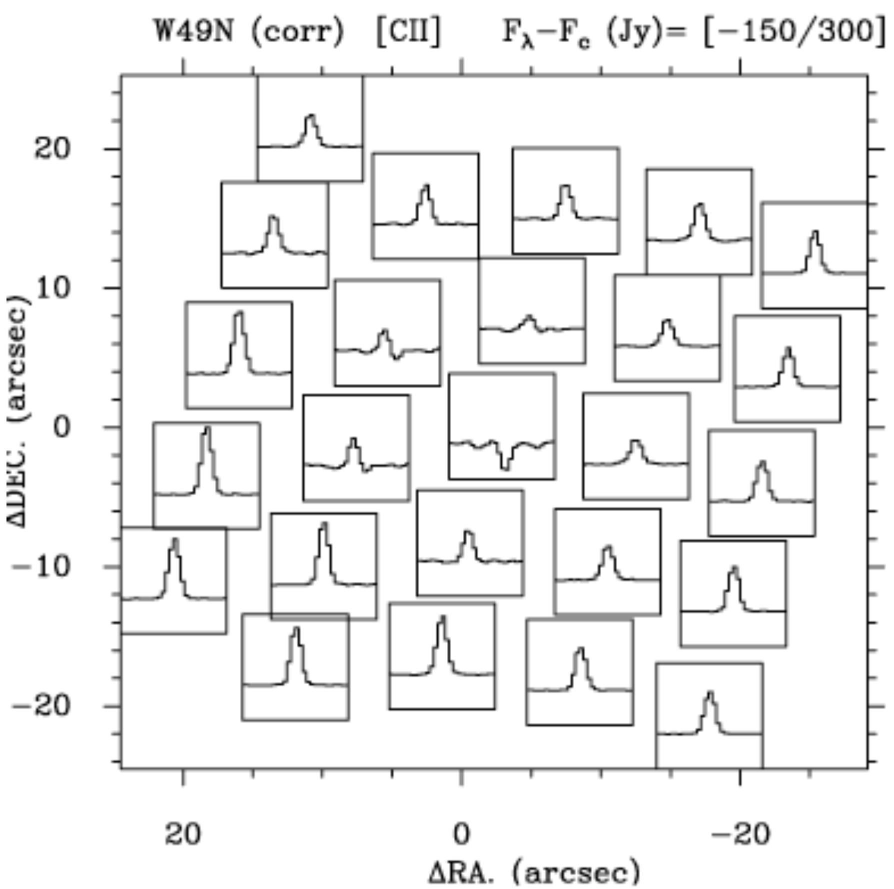




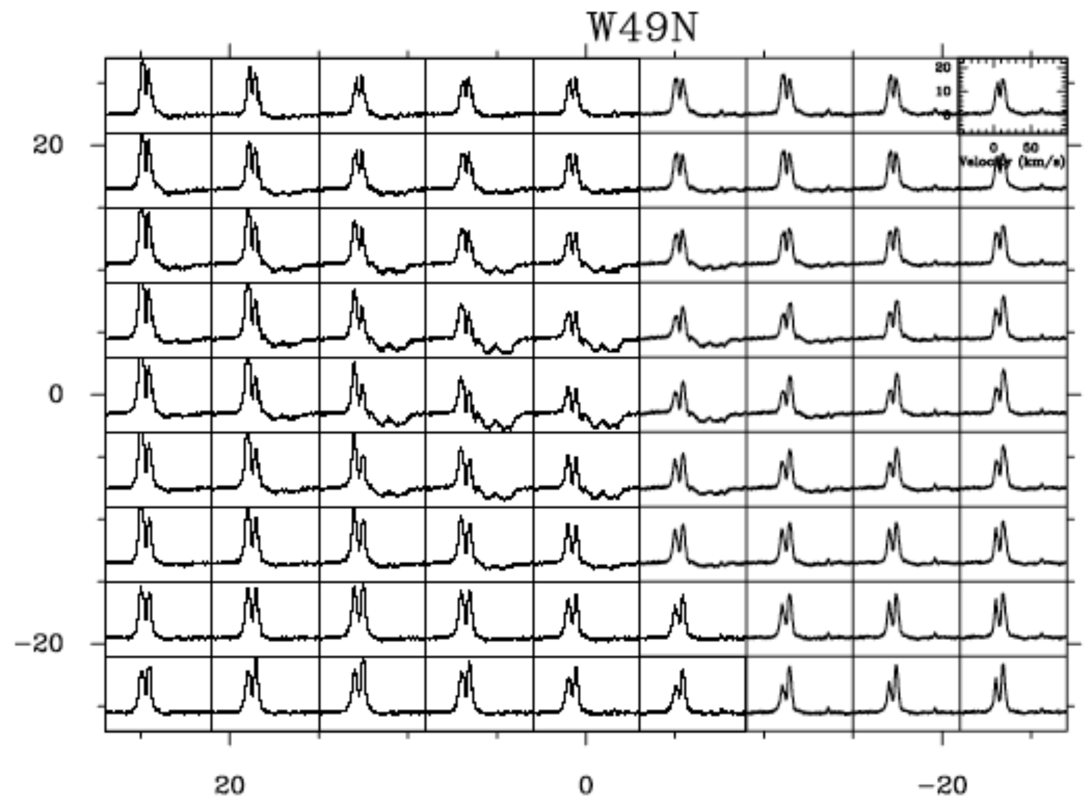
$$\epsilon \zeta_{\mathrm{H}} = \frac{N(\mathrm{OH^+})}{N(\mathrm{H})} n_{\mathrm{H}} x_e \left[\frac{k_7}{N(\mathrm{OH^+})/N(\mathrm{H_2O^+}) - k_6/k_4} + k_5 \right]$$

Indriolo+ 2015

Why high spectral resolution is important: [CII] 158 μm in W49 N with Herschel



PACS

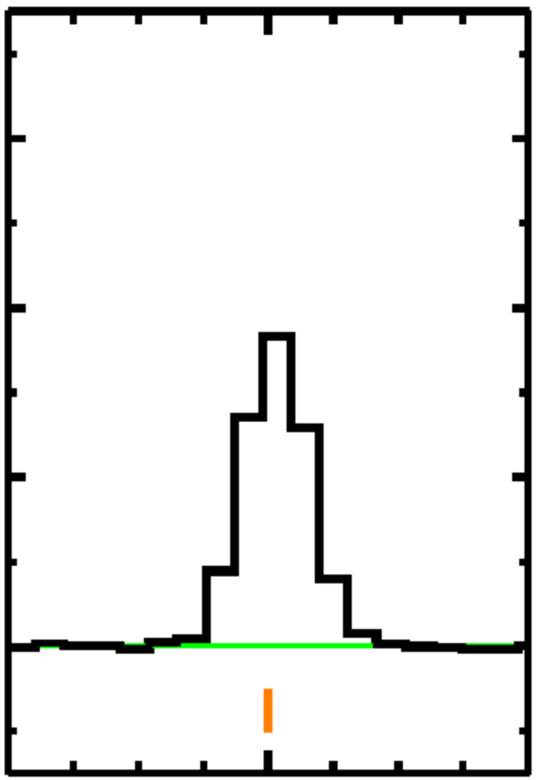


HIFI

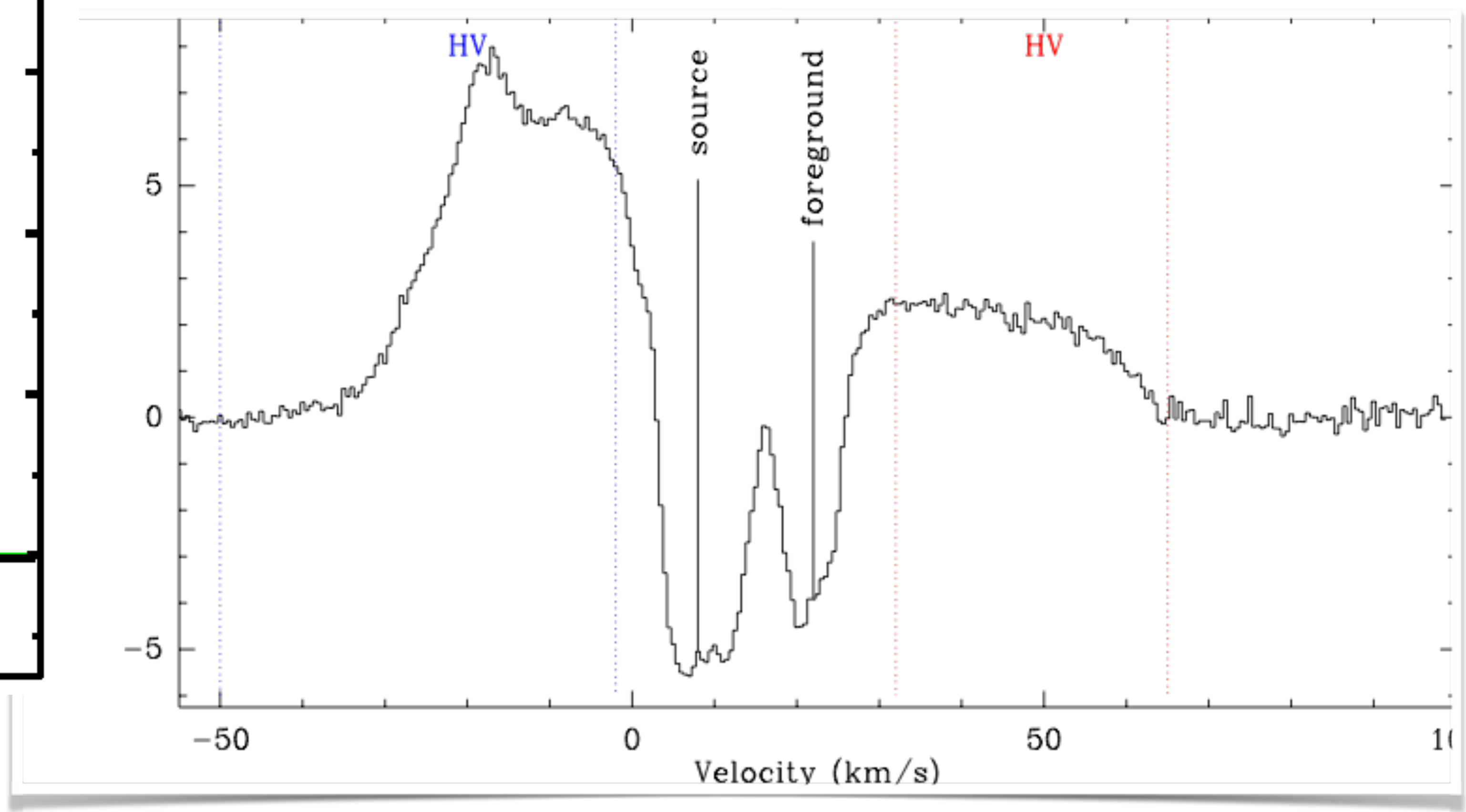
Gerin+ 2014

[OI] 63 µm: from PACS to GREAT

G5.89−0.39

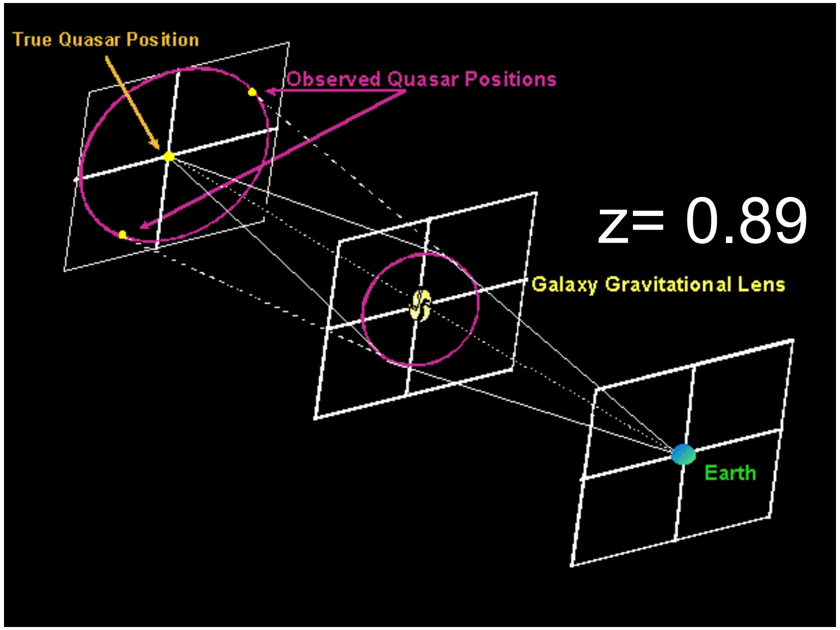


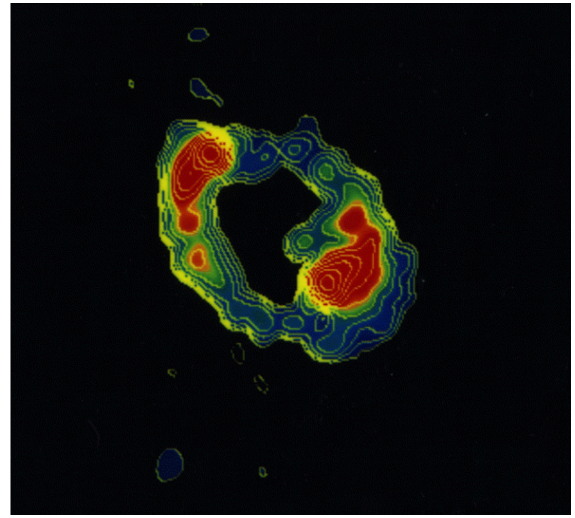
Karska+2013

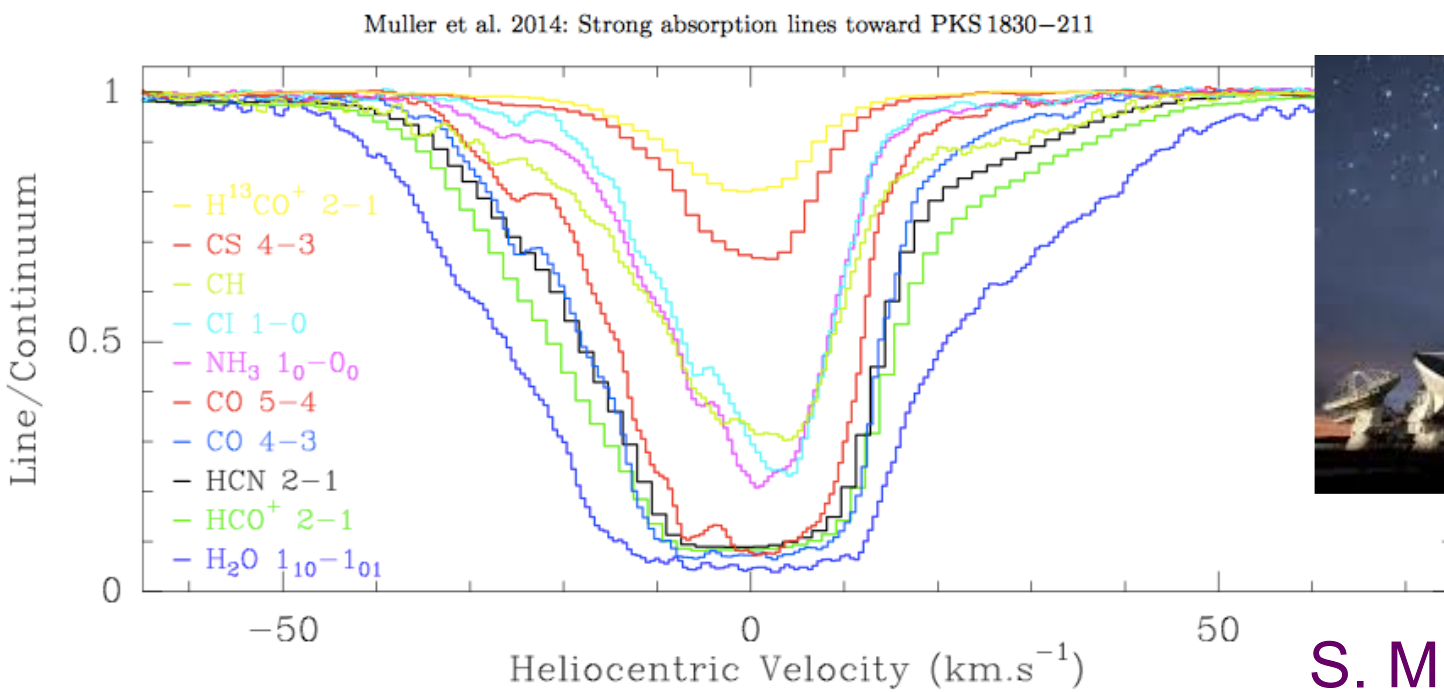


Leurini+2015

From the Local Truth to the distant Universe







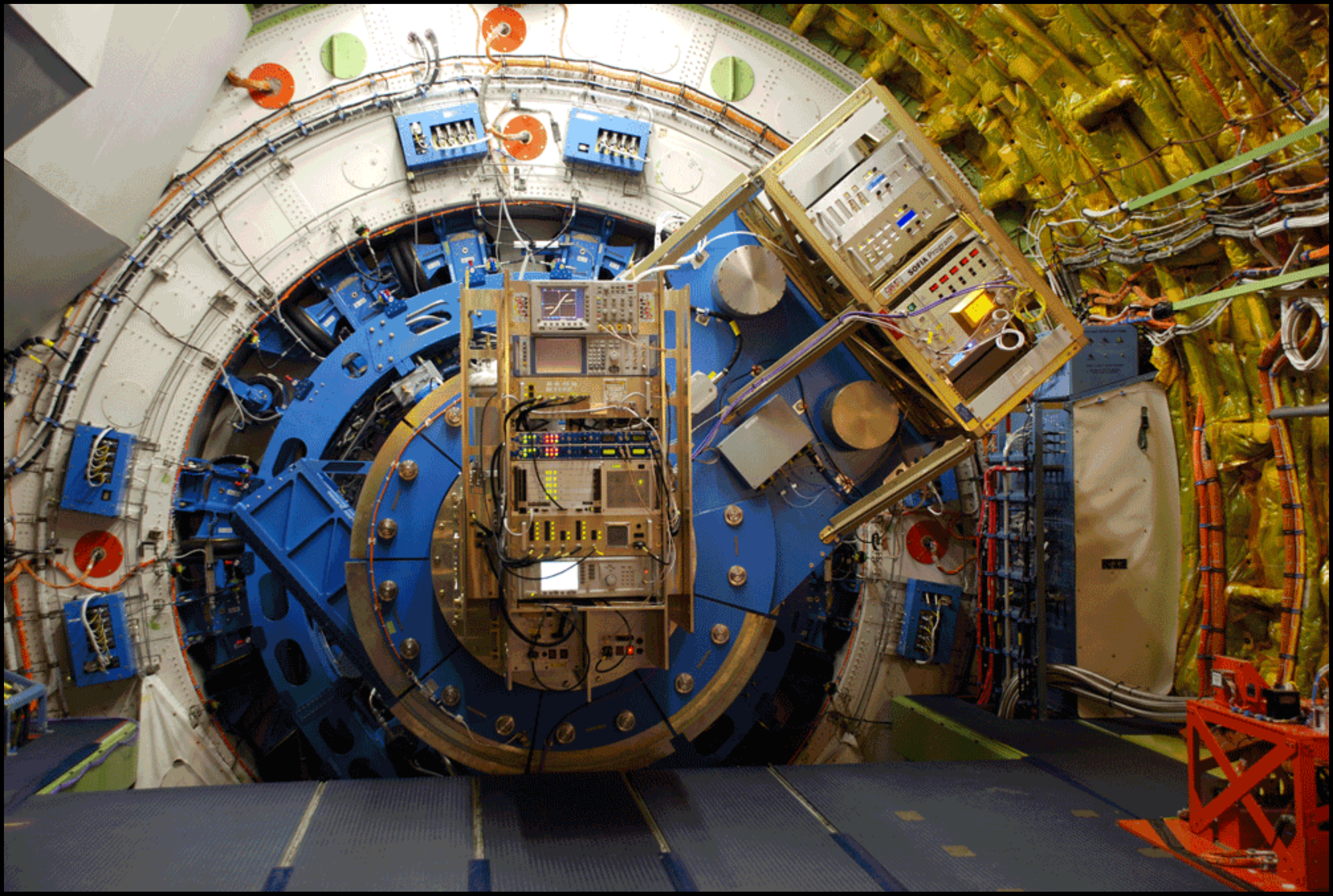
S. Muller+ 2014,15,16

GREAT - the Consortium

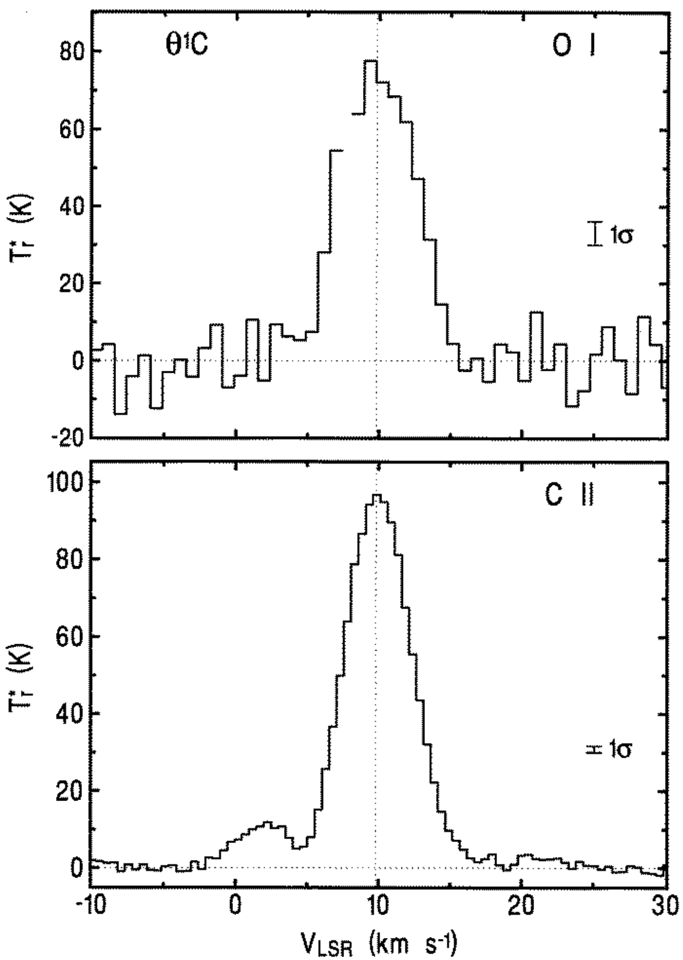
PI-Instrument funded and developed by

- **MPI Radioastronomie** (2.7 THz channel)
  - R. Güsten (PI)
  - S. Heyminck (system engineer)
  - B. Klein (FFT spectrometer)
  - I. Camara, T. Klein (2.7 THz LO)
- **Univ. zu Köln, KOSMA** (1.4/1.9THz channels)
  - J. Stutzki (Co-PI)
  - U. Graf (1.4 &1.9THz LO, Optics)
  - K. Jacobs (HEB mixers up to 2.7 THz)
  - R. Schieder (array-AOS)
- **DLR Planetenforschung** (4.7 THz channel)
  - H-W. Hübers (Co-PI: 4.7 THz HEB, IF, cal unit)
- **MPI Sonnensystemforschung**
  - P. Hartogh et al. (CO-PI: CTS)

GREAT constantly gets re-invented



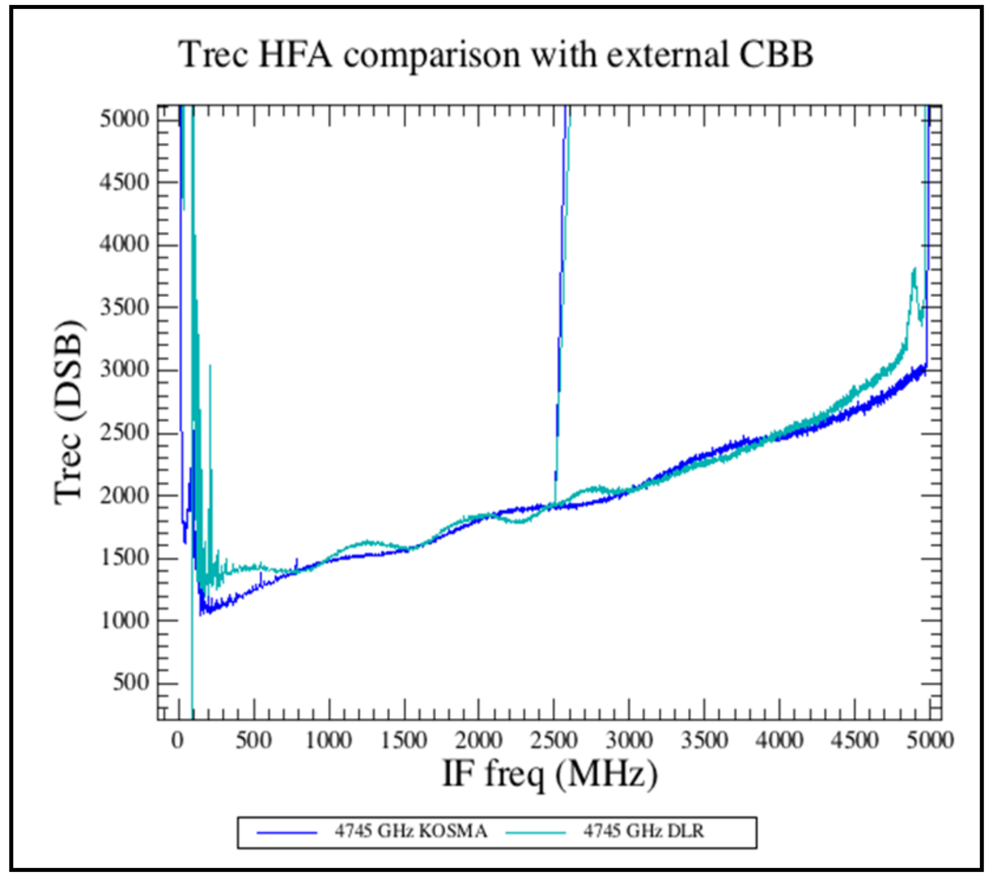
The 4.75 THz (63 µm) OI ground-state fine structure line



First H/D detection in M42

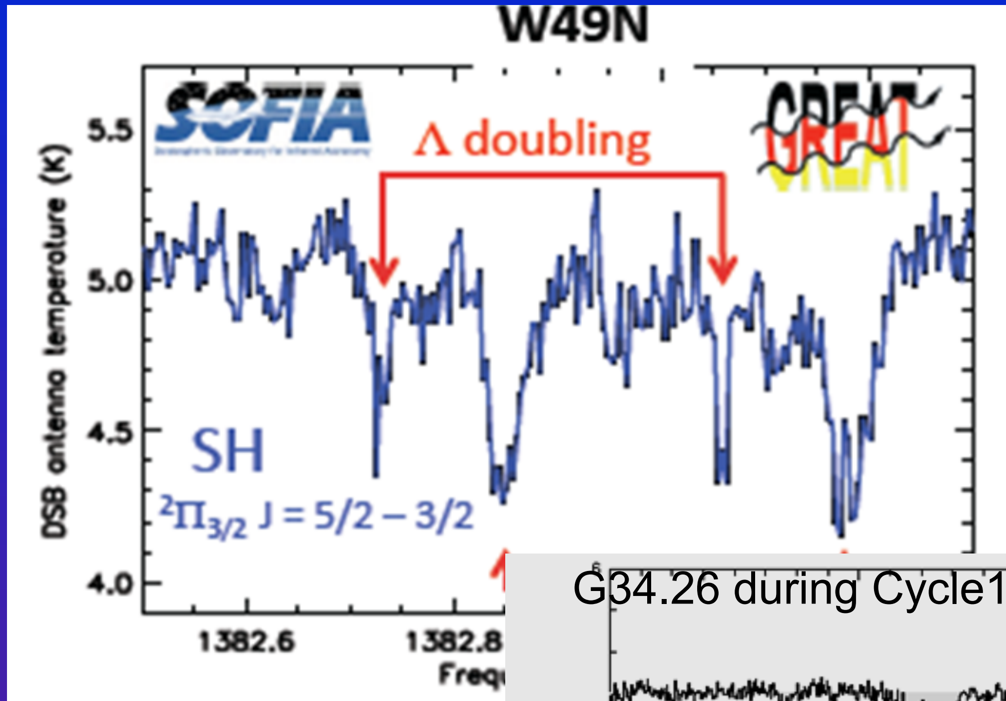
- T_{sys}(DSB) = 70000 K

Boreiko & Betz 1996

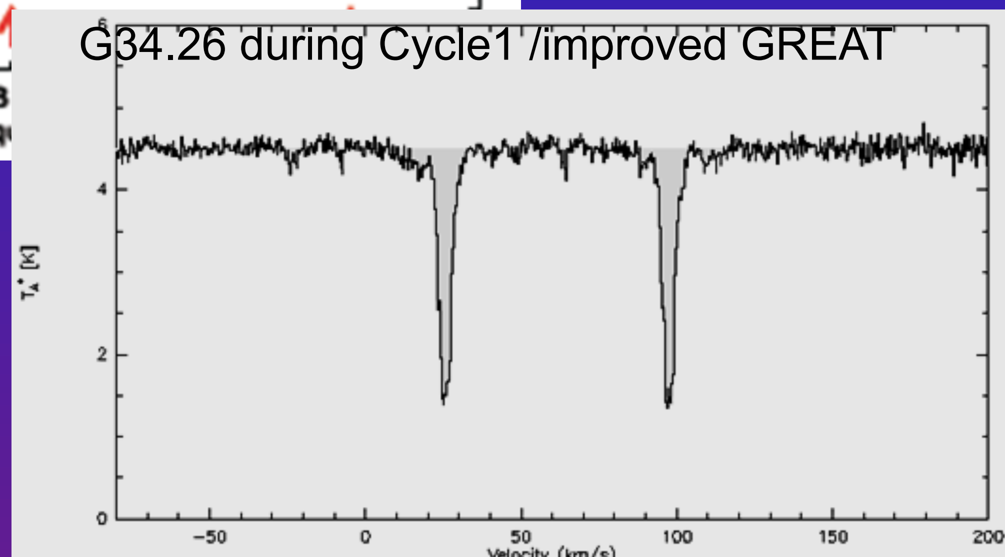


2013:

- **T_{sys}(DSB, KOSMA, Jacobs) ≈ T_{sys}(DSB, DLS-Pf, Hübers) = 1500 K**

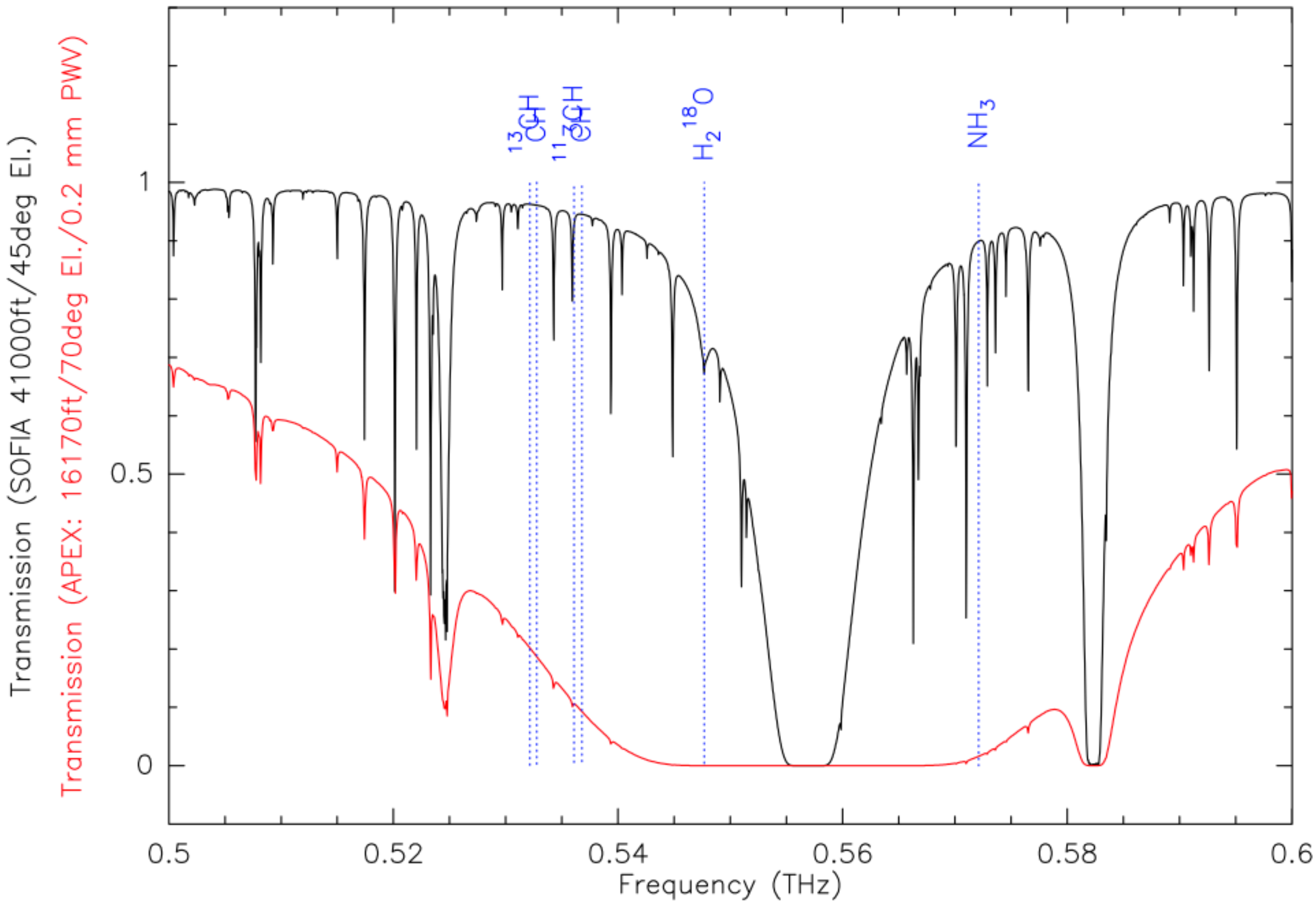


Neufeld et al. 2012



Talk by David Neufeld

4GREAT will increase SOFIA's hydride coverage



Large new observatories/telescope facilities are
- **very expensive**
- **require long time scales from planning to completion**

→ big problem of losing your community
→ important issue when planning for future space missions, e.g., NASA FIR Surveyor

→Keep SOFIA flying!

New instrumentation comes with scientific/technological progress and is (comparitively) cheap

Digital instrumentation gets cheaper and cheaper (Moore's law)
→ Still, high resolution spectroscopy is not even considered for future space missions!
→ Maintain (and finance) an active, dynamic instrumentation program over the whole lifetime of an observatory!
  → Doesn't apply to space missions
→ One important component should be high spectral resolution multi-beam arrays

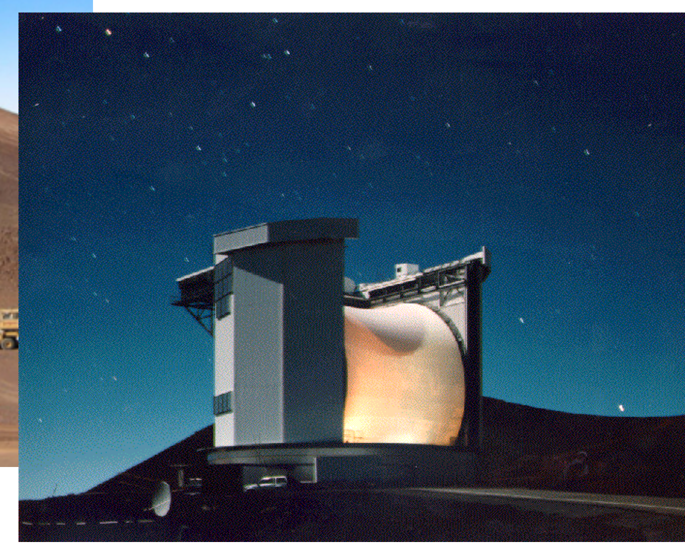
SOFIA's active instrumentation program

EXES	*Echelon-Cross -Echelle Spectrograph*
FIFI-LS	*Field Imaging Far-Infrared Line Spectrometer*
FLITECAM	*First Light Infrared Test Experiment CAMera*
FORCAST	*Faint Object InfraRed CAmera for the SOFIA Telescope*
FPI+	*Focal Plane Imager*
GREAT	*German Receiver for Astronomy at Terahertz Frequencies*
HAWC+	*High-resolution Airborne Wideband Camera*
HIPO	*High-speed Imaging Photometer for Occultations*

For heterodyne spectroscopy, even with multi-beam instruments, SOFIA will never have enough observing time for extended large scale surveys


Long duration balloon flights

(Sub)millimeter Facilities complementary to SOFIA



APEX and SOFIA Workshops (in alternating years)

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

Submillimeter/FIR astronomy is going strong!

Fascinating crossroads of astronomy, basic & applied physics and engineering

Its limits are (still) determined by the limits of terahertz technology

SOFIA and APEX are pushing these limits!


Thanks for your
attention