PHYSICAL CONDITIONS IN THE NUCLEUS OF OUR GALAXY

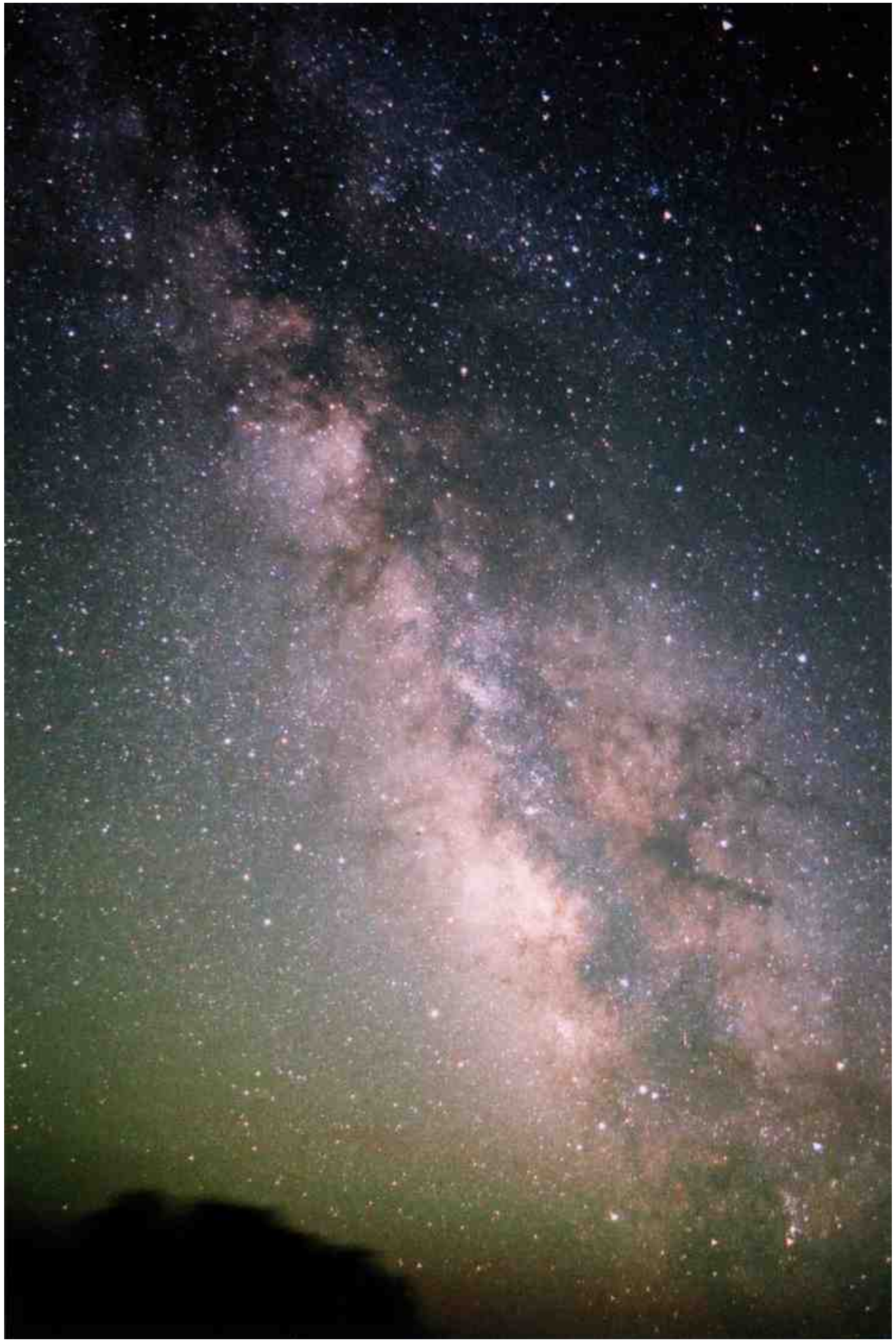
Miguel Angel Requena Torres

Max-Planck-Institut für Radioastronomie

Collaborators:

R. Güsten, A. Weiss, B. Klein, S. Heyminck, C. Risacher, T. Klein, C. Leinz, S. Philipp, + HEXGAL and GREAT teams

SOFIA Community Task Force Tele-Talks, July 2012



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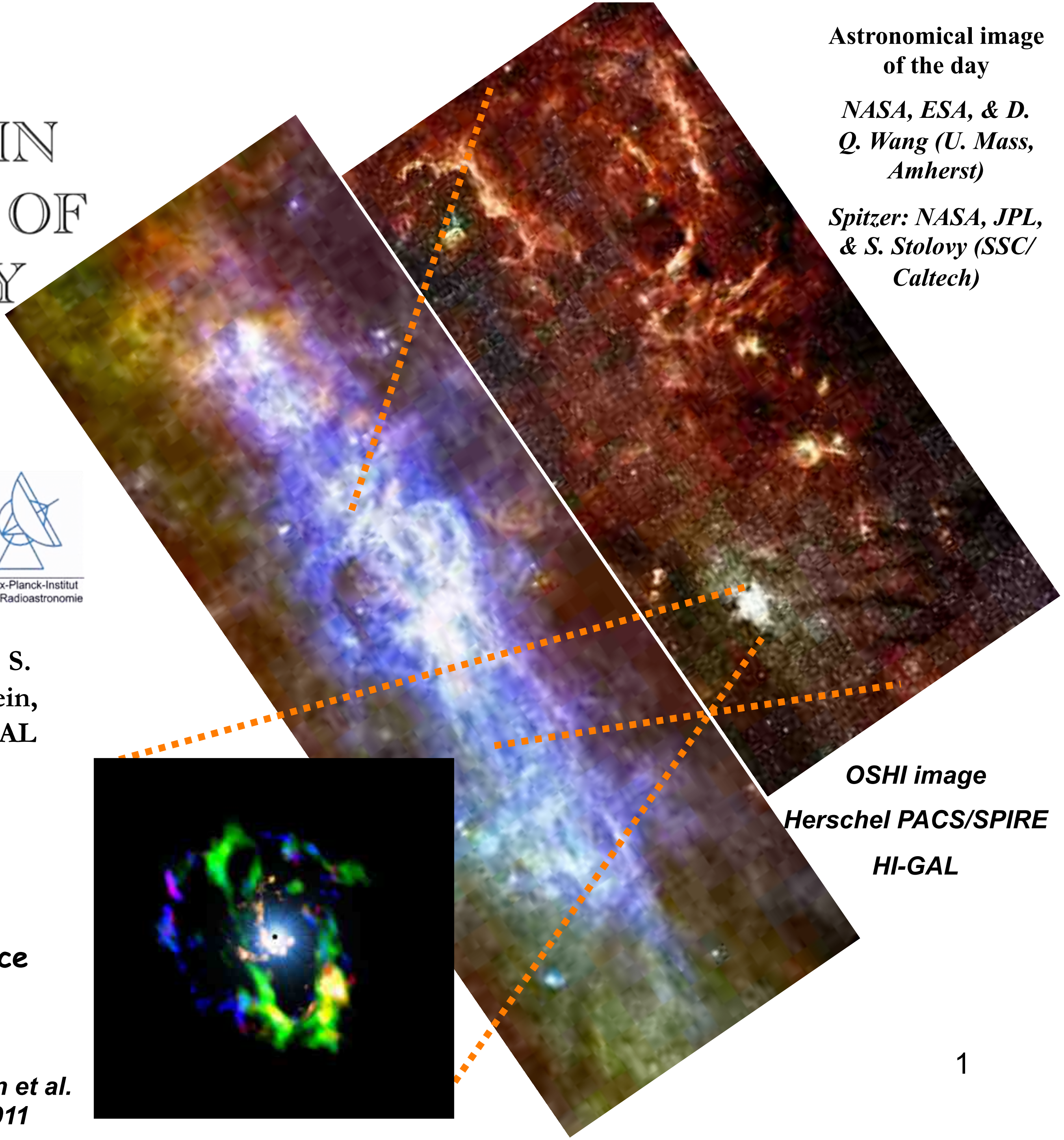


Astronomical image of the day

NASA, ESA, & D. Q. Wang (U. Mass, Amherst)

Spitzer: NASA, JPL, & S. Stolovy (SSC/ Caltech)

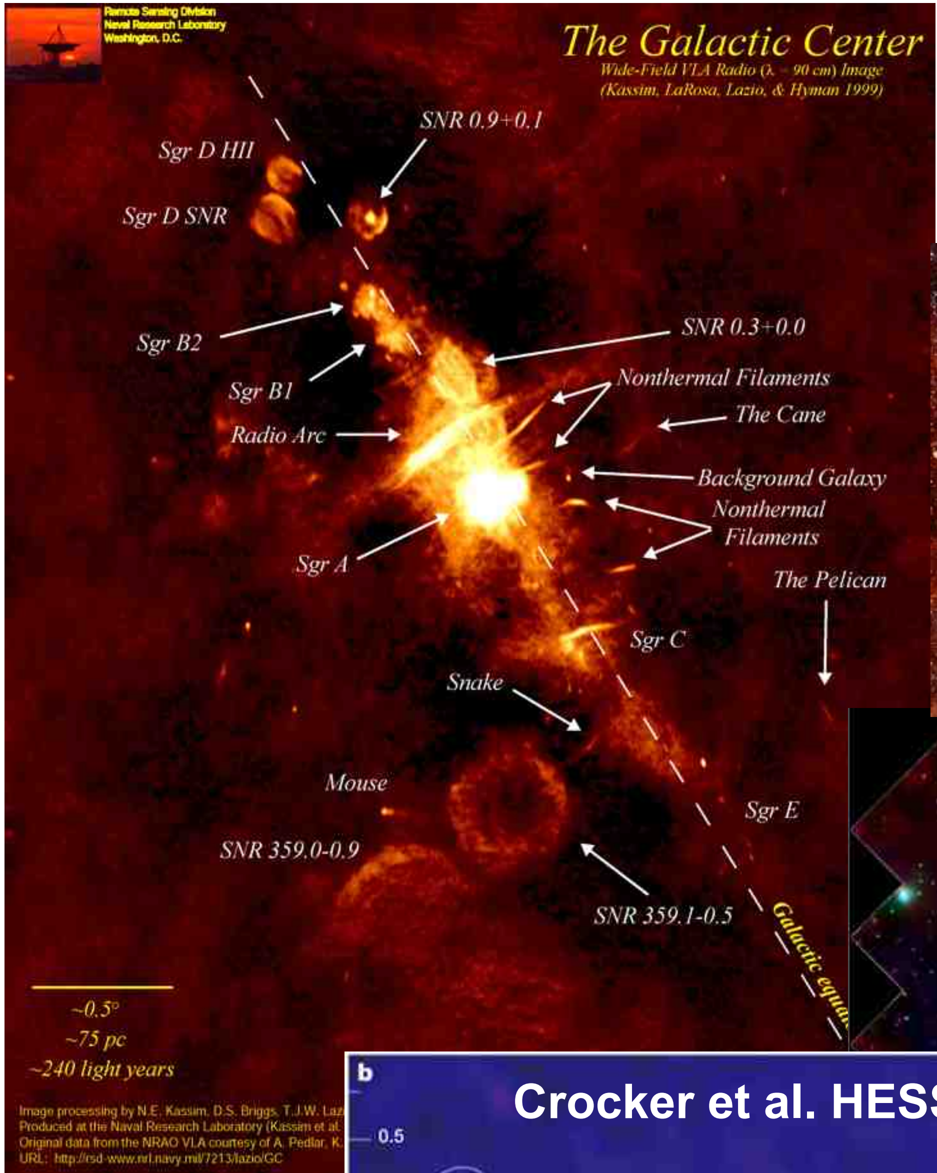
OSHI image

Herschel PACS/SPIRE

HI-GAL

Martin et al. 2011

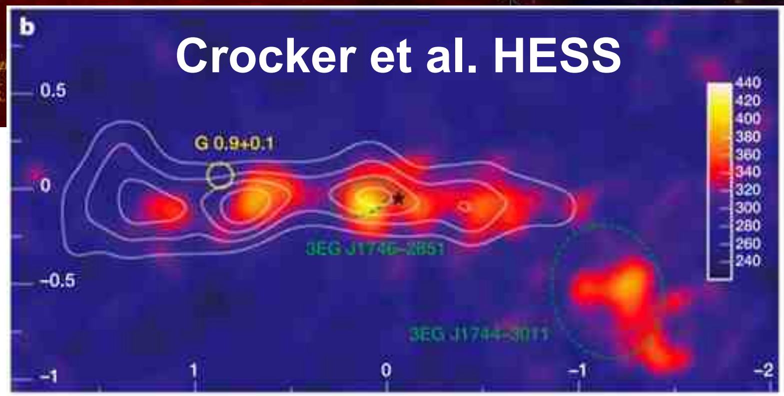
SOFIA Community Task Force Tele-Talks, July 2012



90cm radio continuum, image processed by Kassim, LaRosa, Lazio & Hyman 1999

Wang et al. 2010 HSA/Spitzer

Wang et al. 2002 Chandra



Crocker et al. HESS

	GC	Disk
Cloud sizes [pc]	20-30	few-30
Vel. dispersion [kms^{-1}]	15 – 30	≤ 5
Mean Gas Density [cm^{-3}]	10^{4-5}	10^{2-3}
Magnetic Field [mG]	~ mG	≤ 0.1
$^{12}C/^{13}C$ ratio	20-25	75

Dust: cold component ~15-30 K

Gas temperatures: 15-500 K (NH_3 & H_2)

(Güsten et al.1981, Morris et al.1983 and Huttermesiter et.al. 1993)

$T_{gas} > T_{dust}$ in galaxies Mauersberger et al. (2003)

What is the dominant heating Mechanism?

UV radiation, X-rays, shocks, Cosmic rays?

Reviews:

Morris (1996),

Mezger (1996),

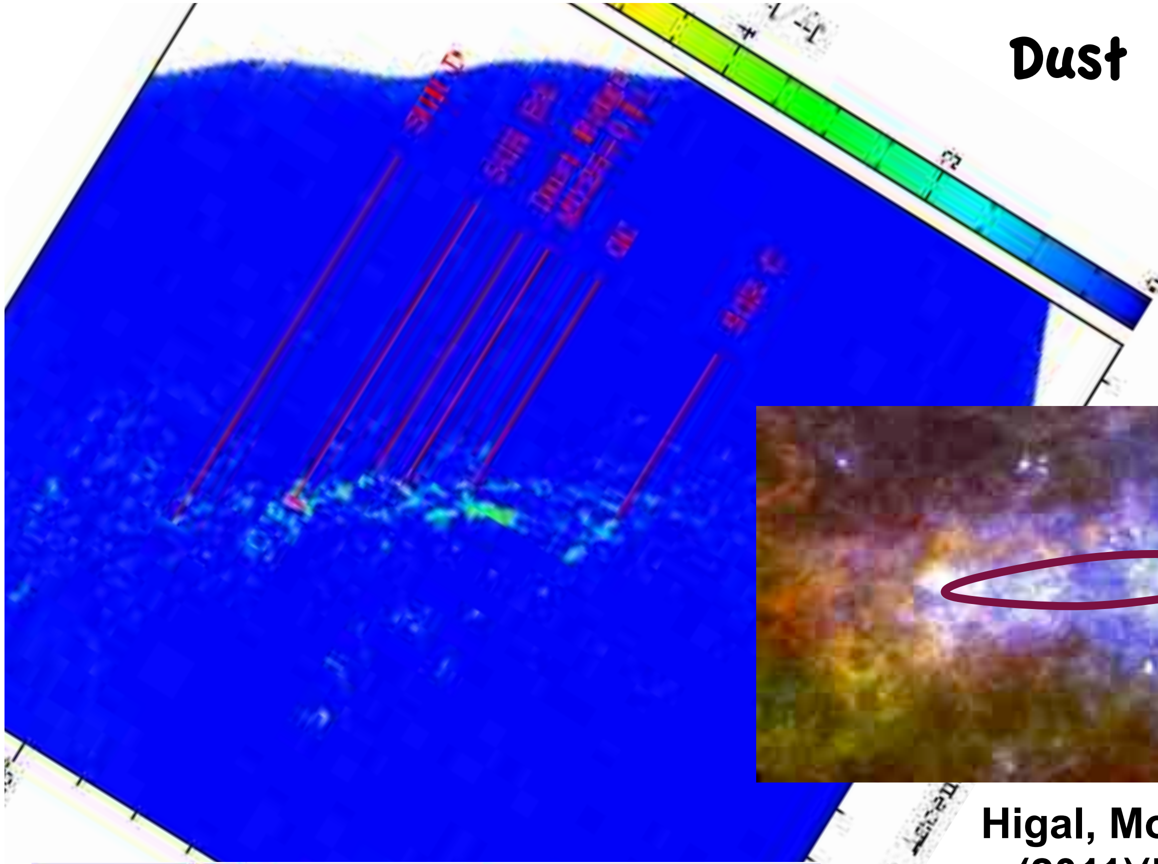
Güsten (2004),

Morris et al. (2006)

Morris et al. (2009)

Genzel et al. (2010)

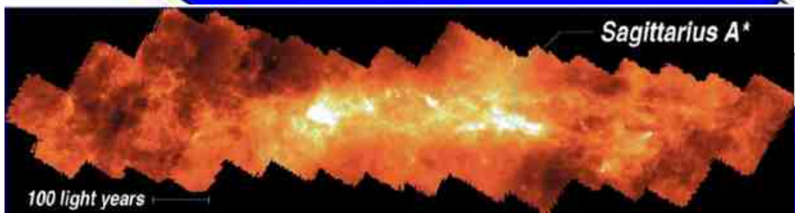
Dust emission



ATLASGAL (The APEX Telescope Large Area Survey of the Galaxy) **850 microns (Schuller et al. 2009, Immer et al. 2010).**

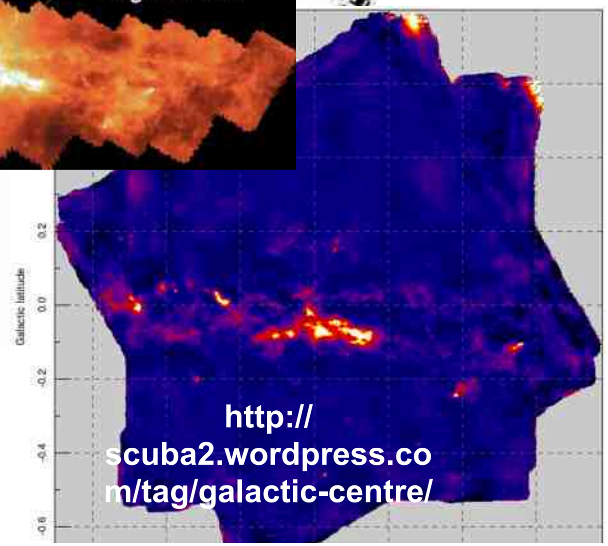
Higal, Molinari et al. (2011) and Etxaluze et al. (2011)(PACS 70, 160 +SPIRE 250, 350 500)

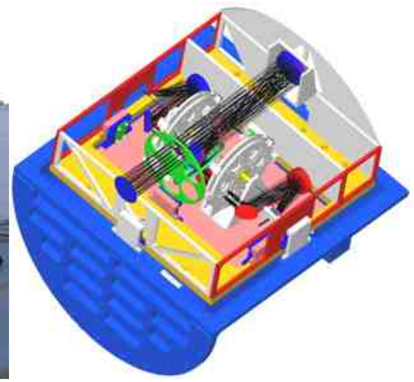
And I want to see the results from the new CND maps of Forcast!



Oldest SCUBA maps 450 and 850 microns (*Pierce-Price et al. 2004* and the latest Garcia-Marin et al. 2011)

And new map from SCUBA-2 (850)



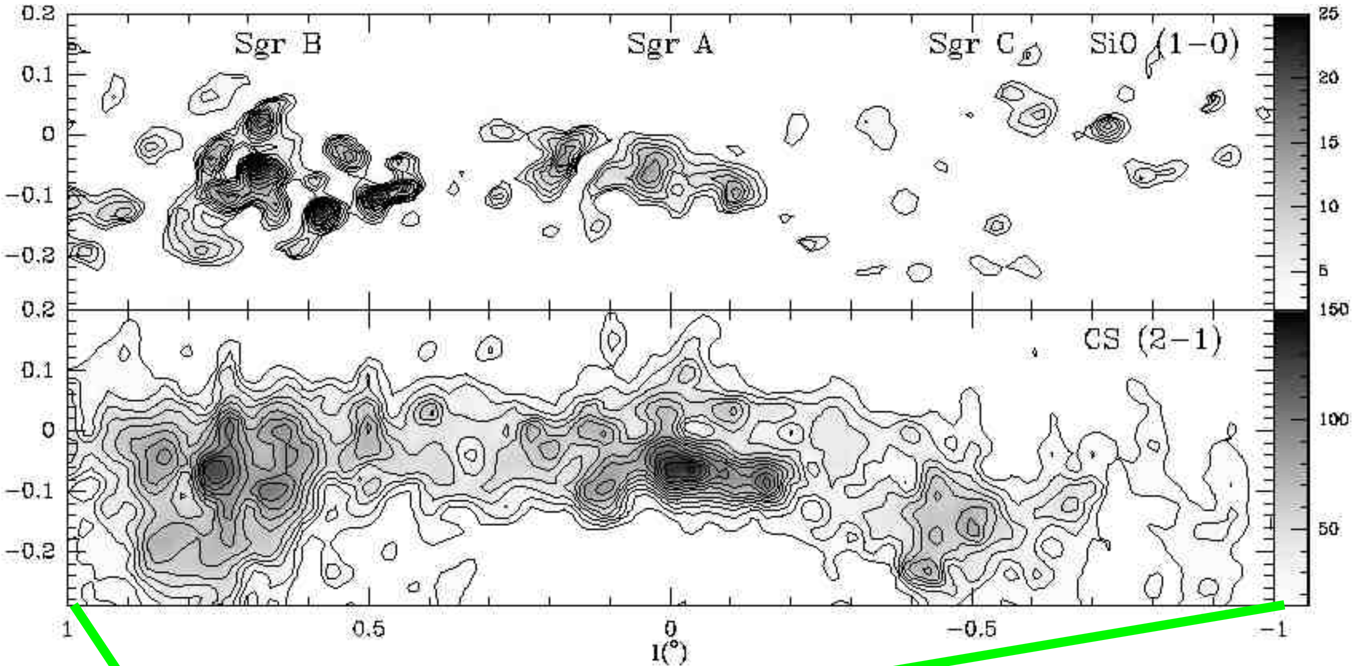


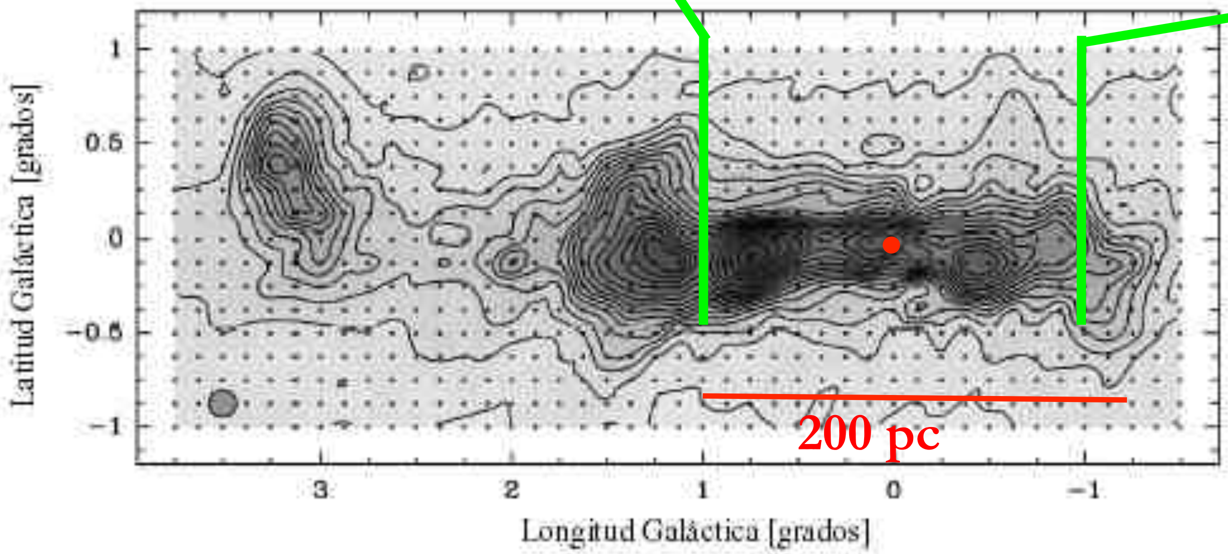
Molecular gas in the GC

SiO → Shock Tracer

Martín-Pintado et al. (2000)

CS → Dense gas tracer





CO ← Molecular gas tracer

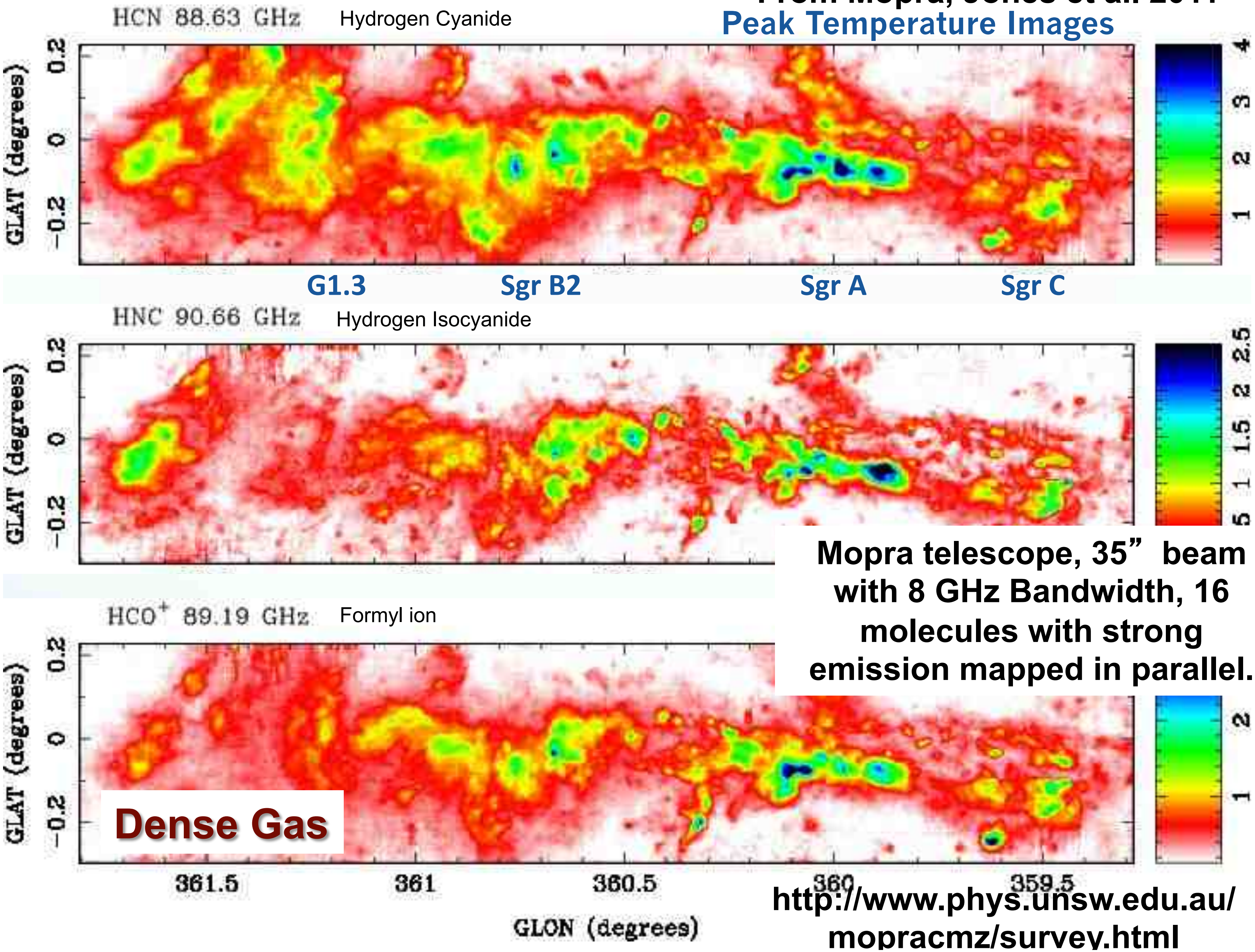
$10^8 M_\odot$

Bania et al. (1980)
Bally et al. (1987)
Dahmen et al. (1998)

Widespread emission of complex organic molecules, Martín-Pintado et al. (2001), Requena-Torres et al. (2006, 2008) and Jones et al. 2011

From Mopra, Jones et al. 2011

Peak Temperature Images

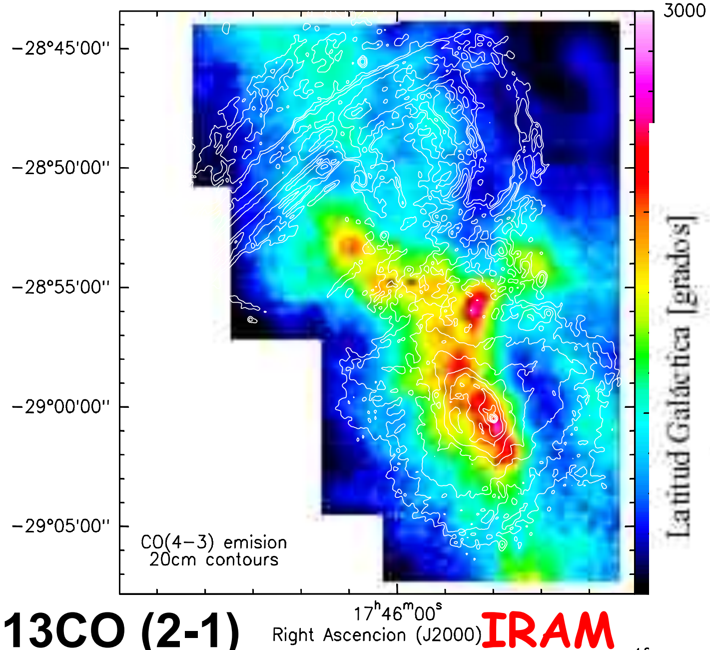


Mopra telescope, 35” beam with 8 GHz Bandwidth, 16 molecules with strong emission mapped in parallel.

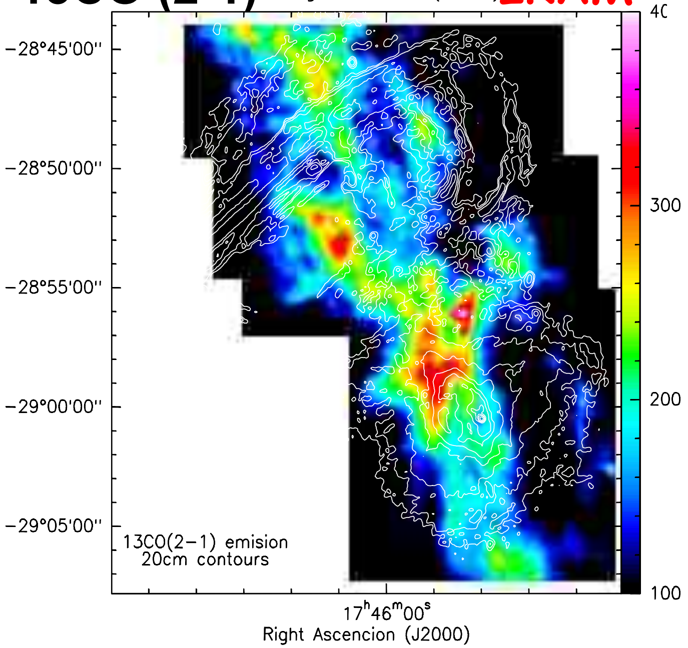
http://www.phys.unsw.edu.au/mopracmz/survey.html

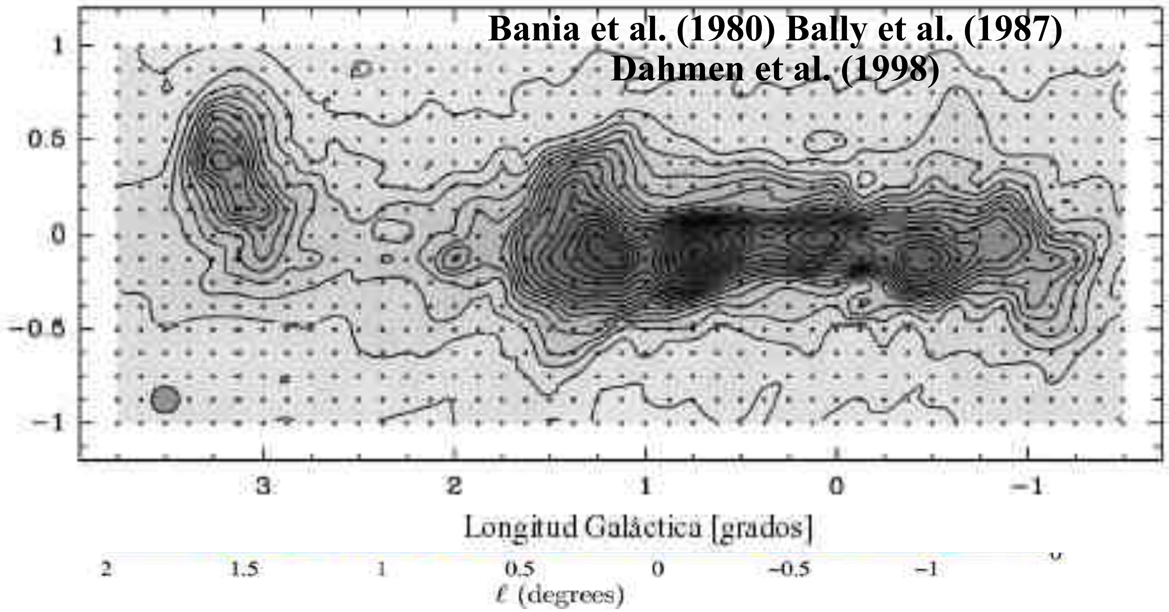
Other CO maps in the GC area

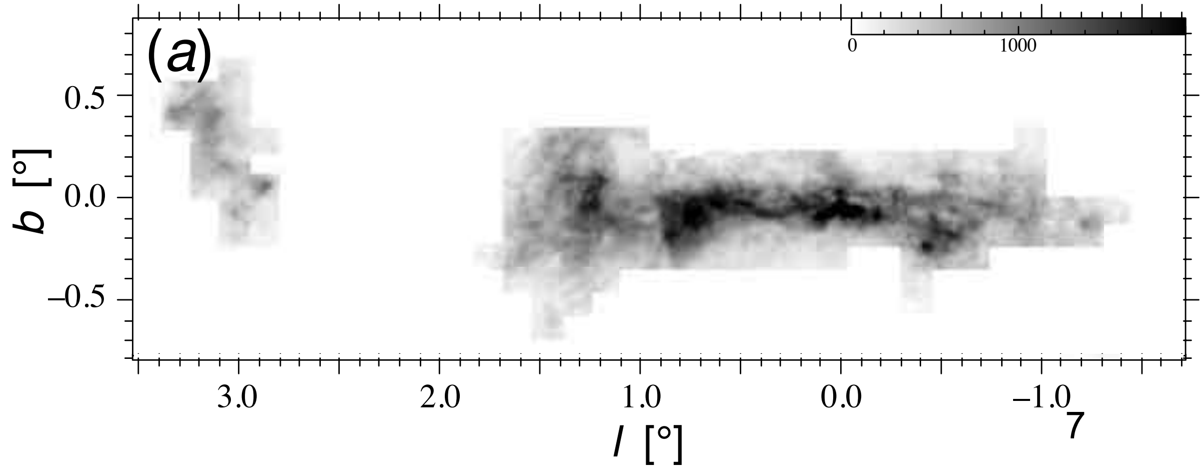
CO (4-3) CSO



13CO (2-1) IRAM







Oka et al. 2011, CO 3-2 maps with ASTE 22"

APEX

Atacama Pathfinder EXperiment

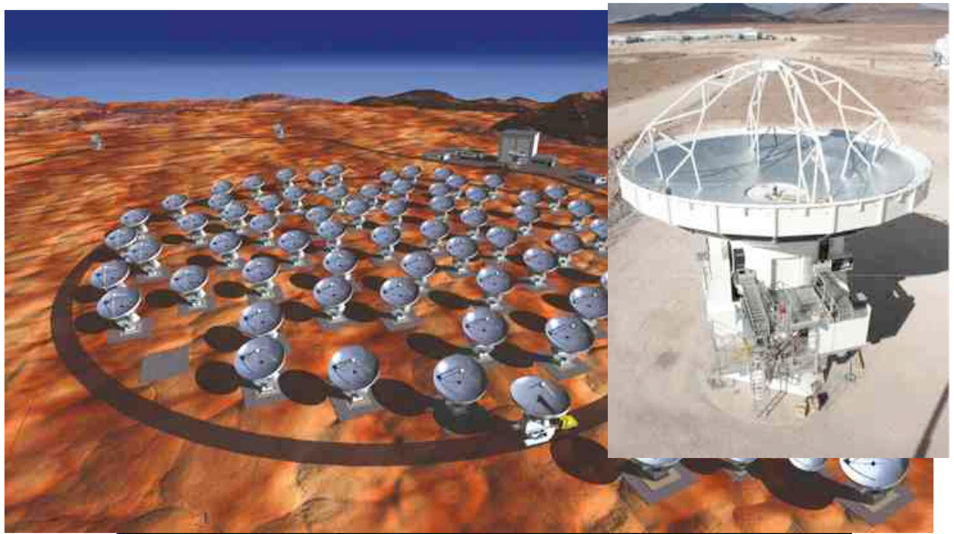
Max-Planck-Institut
für Radioastronomie

Llano de Chajnantor

Latitude : 23º00'20.8" South

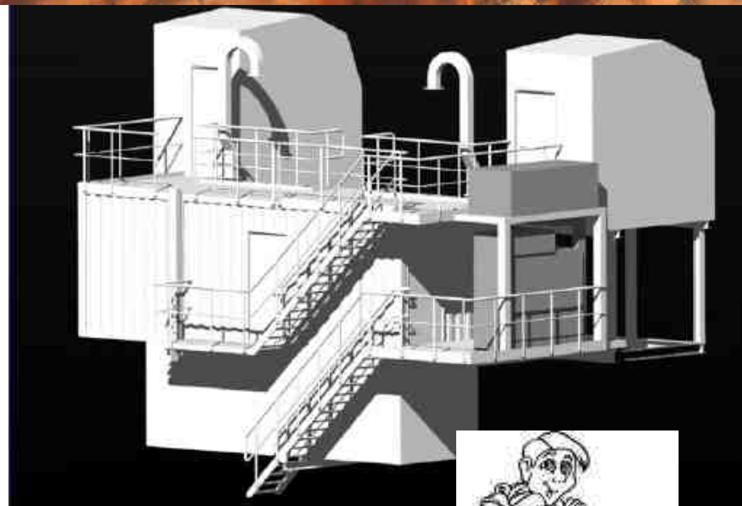
Longitude :67º45'33.0" West

Altitude : 5105 m



- Vertex Antenna, as the american contribution to ALMA
- 12m diameter, 14µm rms surface accuracy
- Alt-Az mounting
- 2 Nasmyth + 1 Cassegrain receiver cabins
- Wobbler (2Hz, <150” amplitude azimuthal chops)
- Beam width:

  7.8" * (800 / f [GHz])



Heterodyne (from 210 to 1200 GHz), Bolometers (345 and 860 GHz), and POLKA in commissioning phase.

APEX And the good work of CHAMP+

(MPI + The Netherlands)

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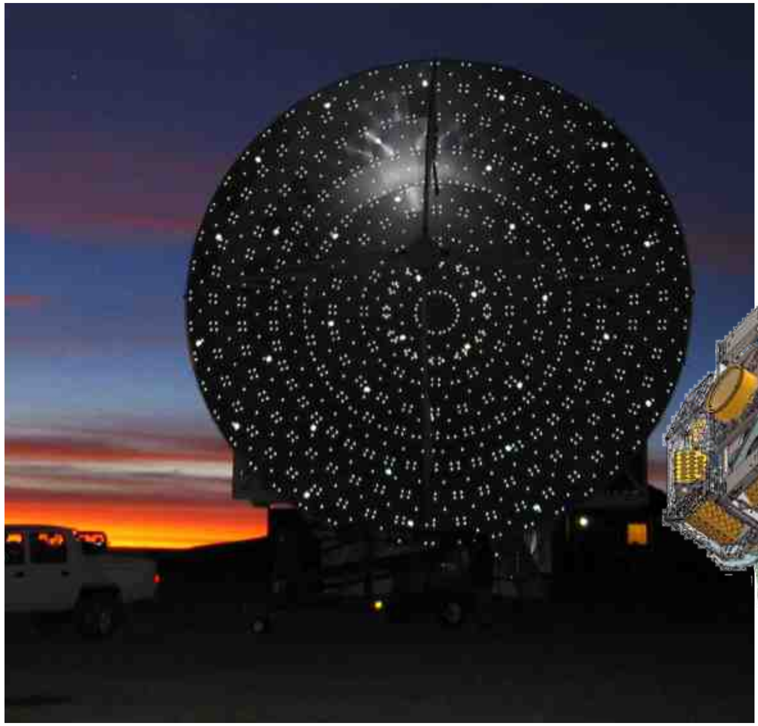
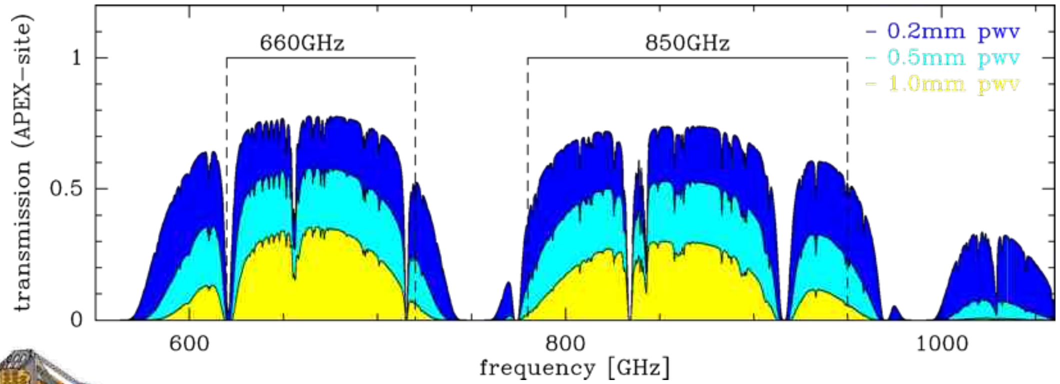
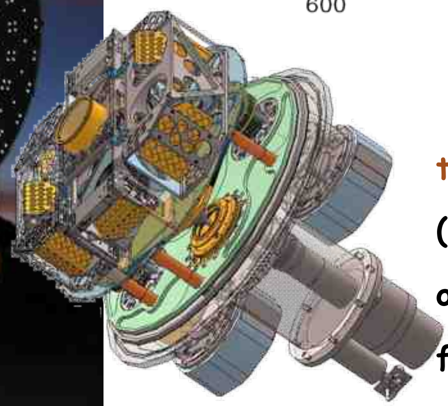
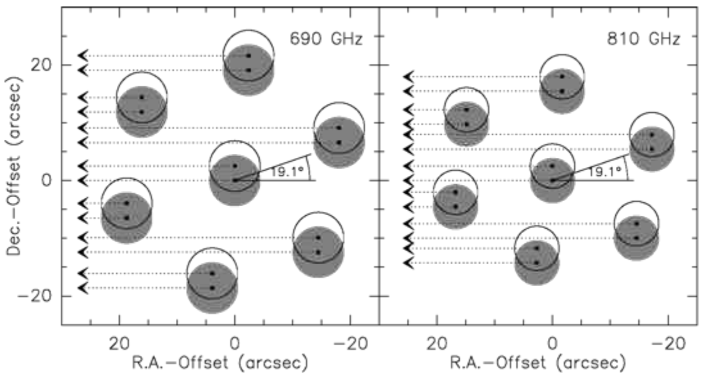
für Radioastronomie









two 7-pixel sub-arrays

(620 – 720 GHz and 780 – 950 GHz)

orthogonal polarizations – parallel observations

fixed tuned DSB SIS-mixers (SRON)

mixer instant. bandwidth: 4 – 8 GHz

main optics cooled to 15 K

SSB-filter for both sub-arrays

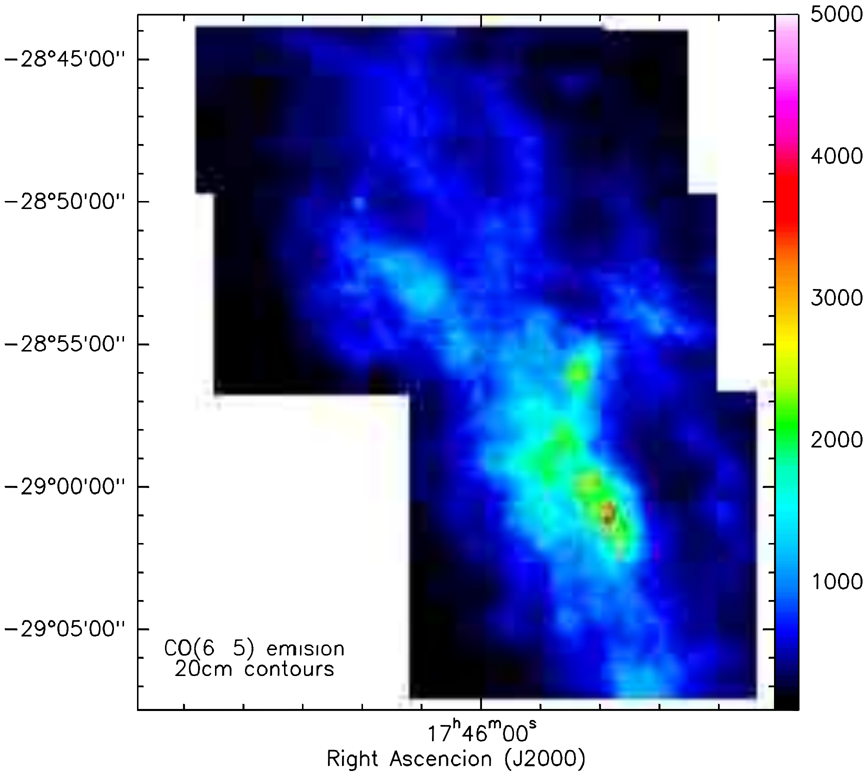
image side-band terminated at 15 K

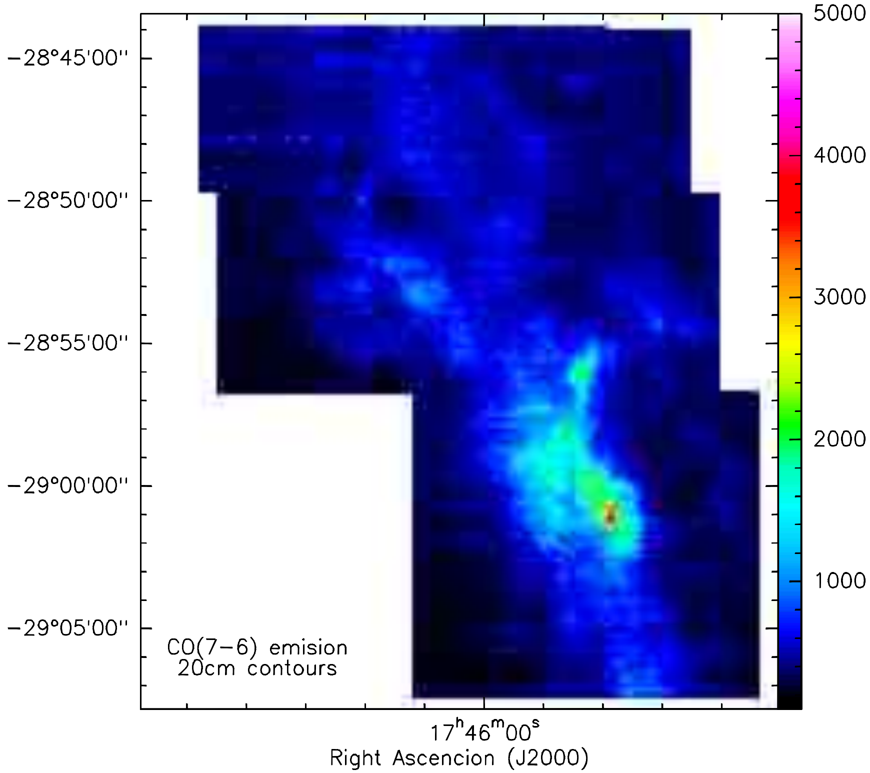
image de-rotation

backend/IF - 2.8 GHz instantaneous bandwidth

APEX maps

CO (6-5) and (7-6) emission in the inner 50 pc of the Galaxy





Integrated emission dv=[-150,150]

The 50 inner parsecs of the Galaxy (25'x15')have been map the CO (6-5) and (7-6) transitions with CHAMP+. Beam sizes of ~9" and ~8", more than 100,000 spectra per map, ~20 hours observing with APEX. RMS of 0.3 and 0.5 K.

APEX maps

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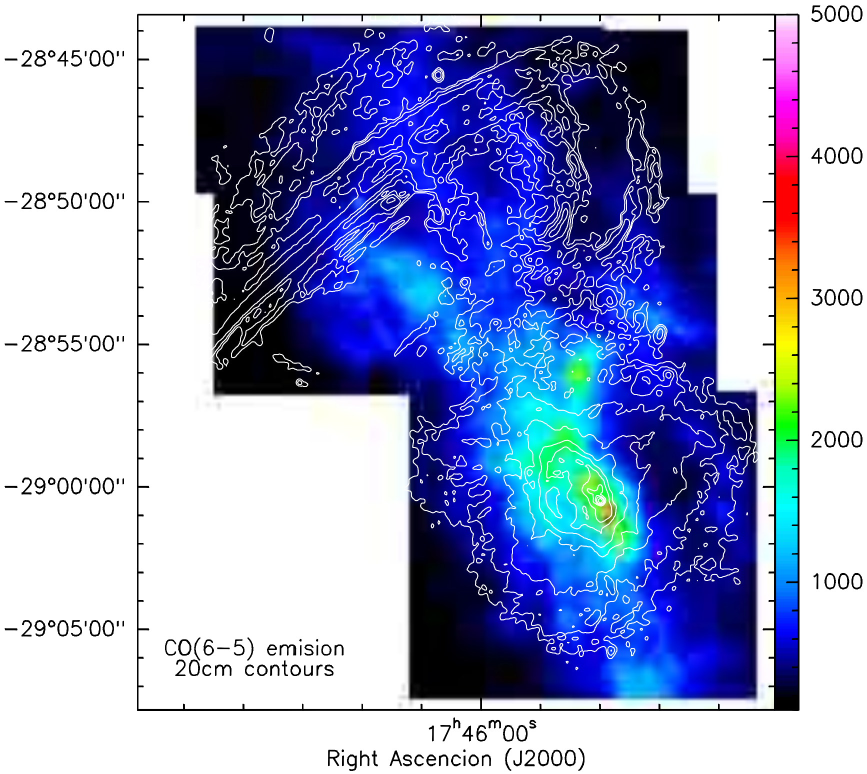

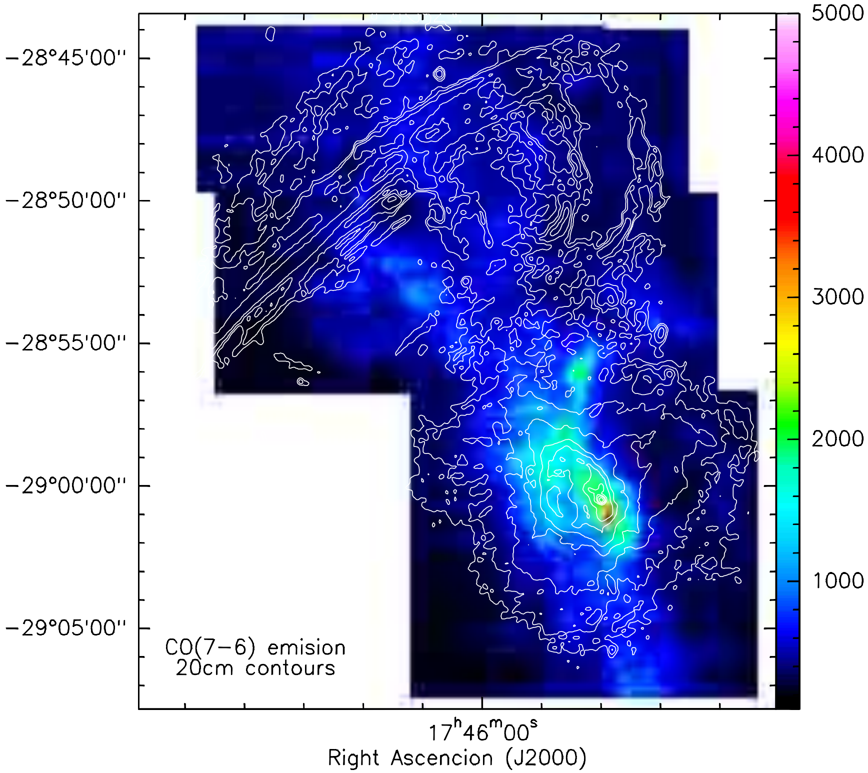

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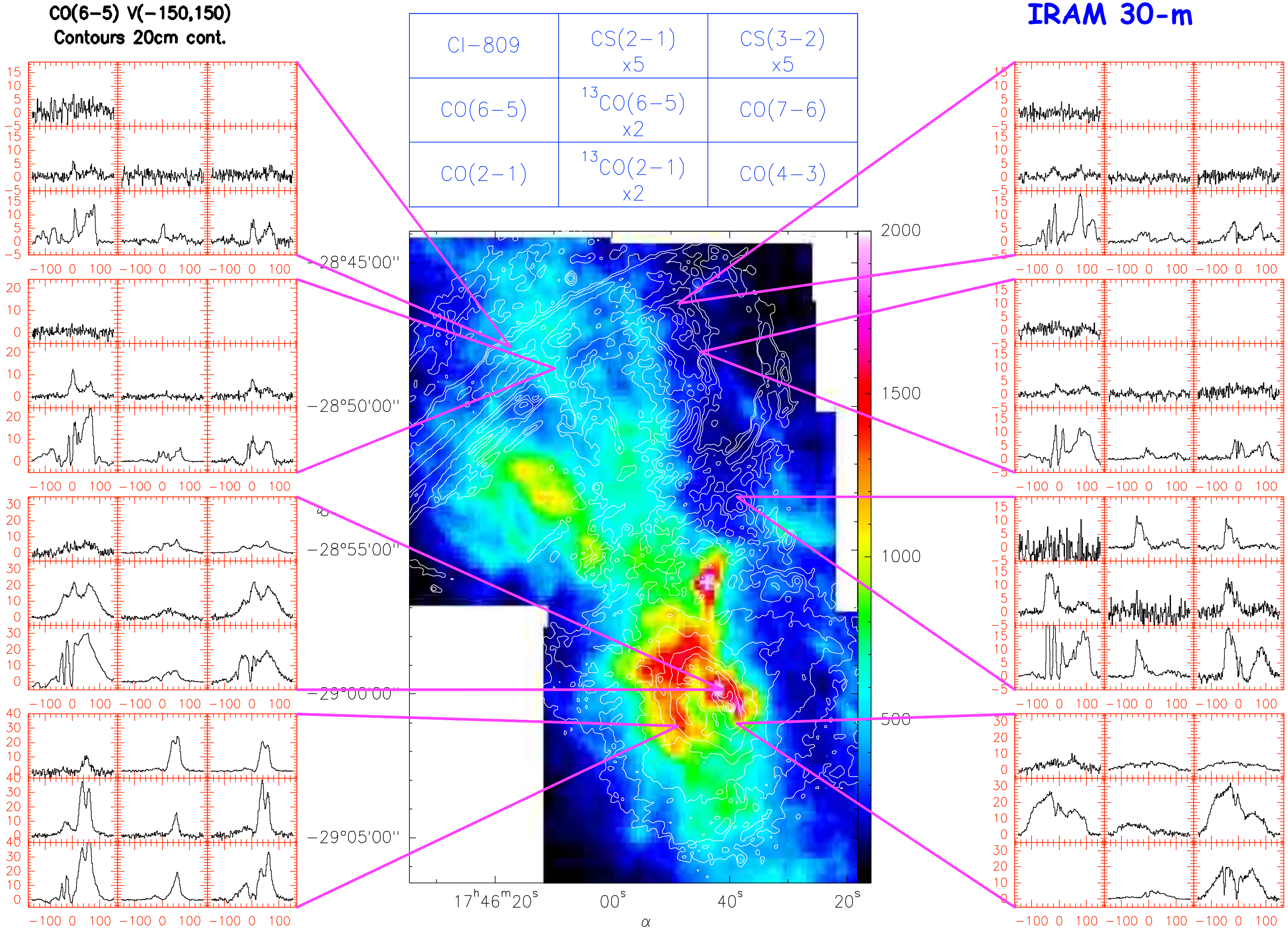
+data from CSO and IRAM 30-m

CI-809	CS(2−1) x5	CS(3−2) x5
CO(6−5)	^{13}CO(6−5) x2	CO(7−6)
CO(2−1)	^{13}CO(2−1) x2	CO(4−3)

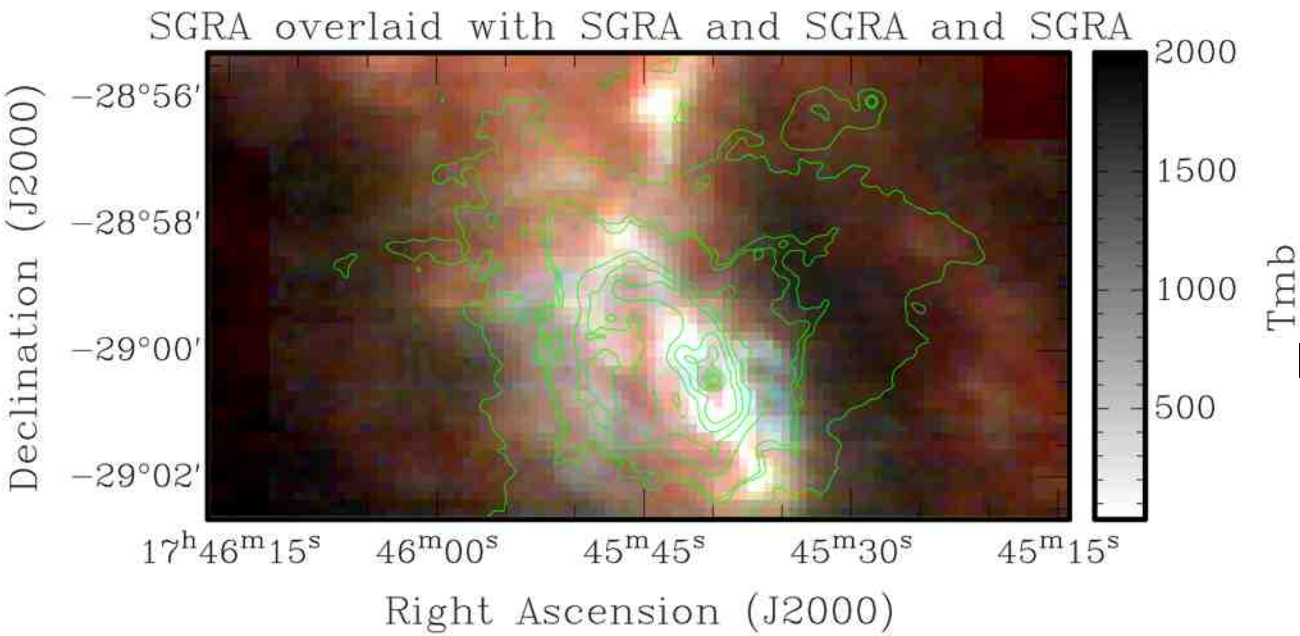


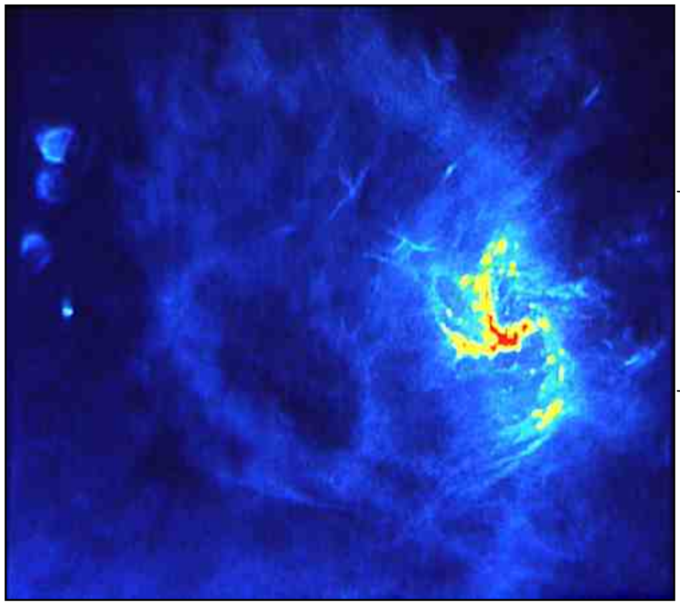
Regions of interest:

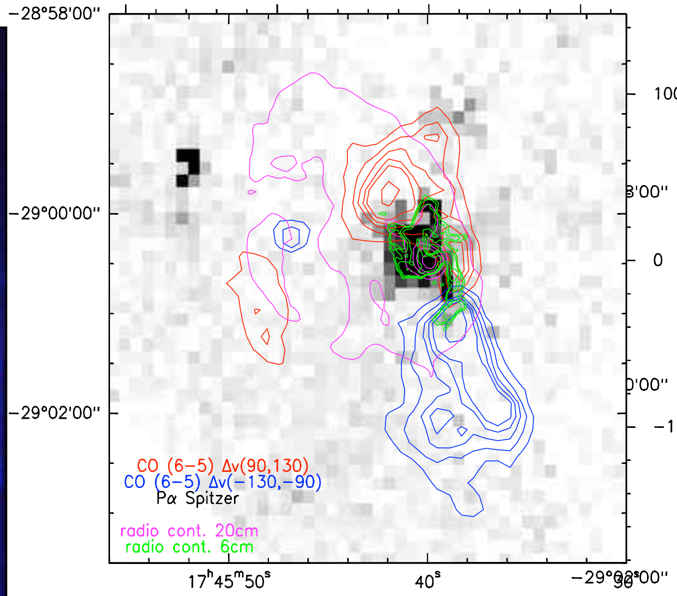
The CND

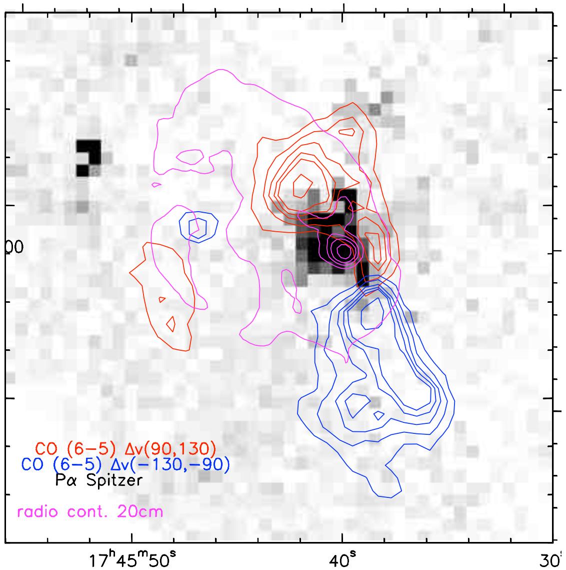
Integrated intensity (-150,150)

CO(4-3)
CO(6-5)
CO(7-6)





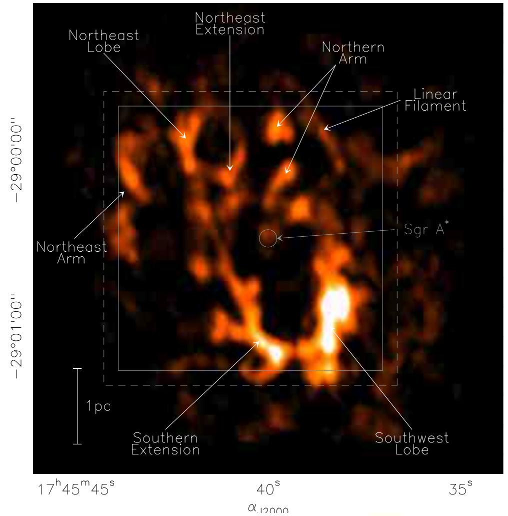


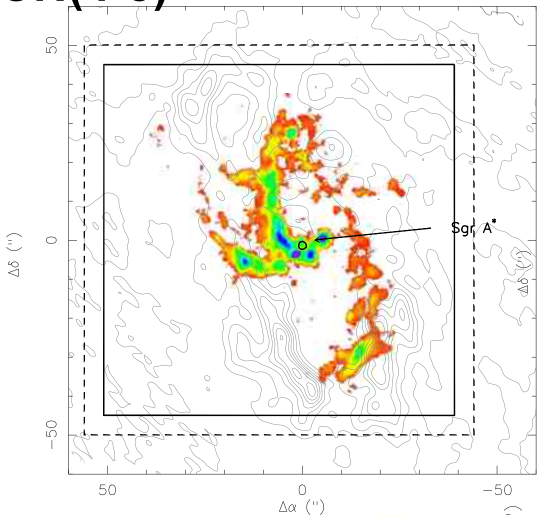


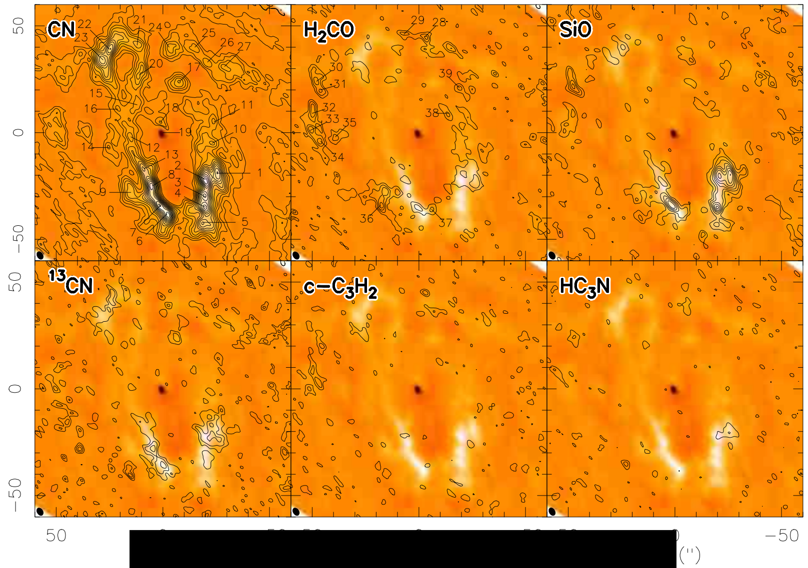
Interferometric observations

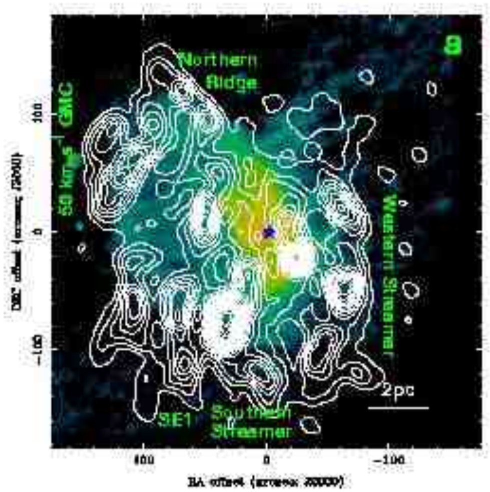
HCN(4-3)

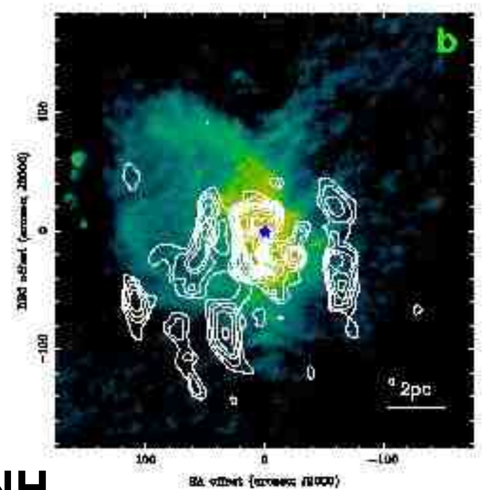
Herrnstein, R. M. & Ho, P. T. P. 2005, ApJ, 620, 287
Christopher et al. 2005, ApJ, 622, 346
Montero-Castaño et al. 2009, ApJ, 695, 1477
Martín et a. 2012, A&A, 539, A29



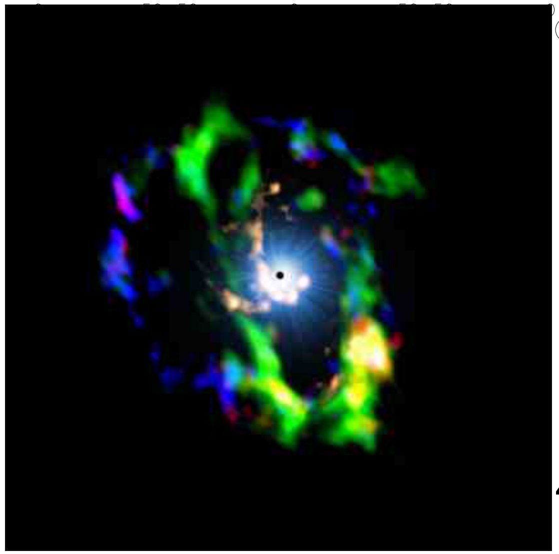








NH_3

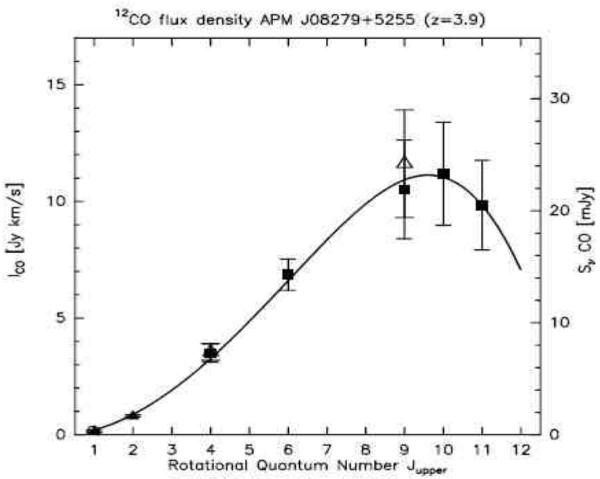


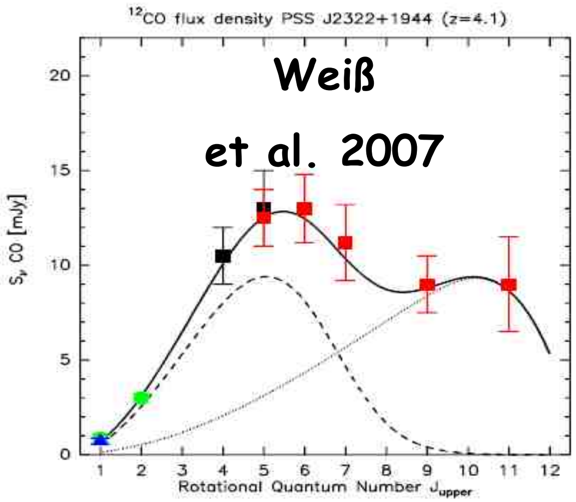
RGB composite SMA image of CN (green), H_2CO (blue), SiO (red) (Martín et al. 2012) combined with the VLA H90α recombination (orange, Roberts & Goss 1993) at ~ 4″ ×3″, and 2″ resolutions

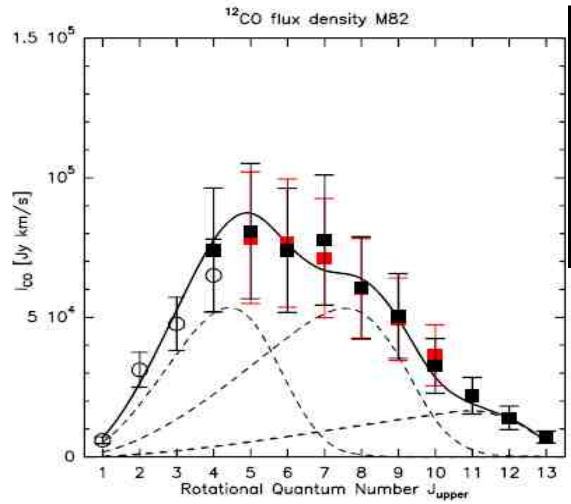
CO SED in galactic nuclei

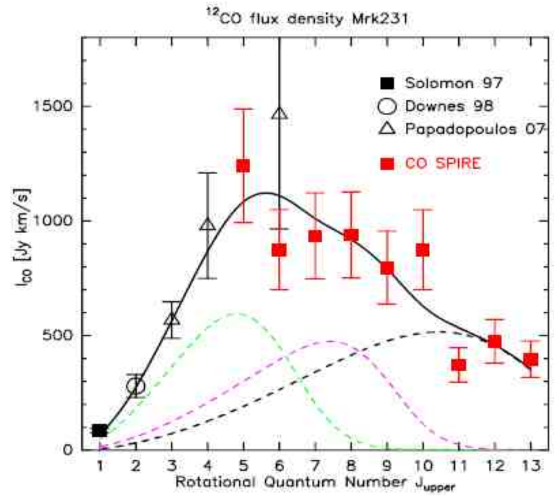
CO SED in galaxies have been largely study for the high-z galaxies (IRAM and other ground based telescopes).

With HERSCHEL and now with SOFIA, we can access the nearby galaxies and the GC.









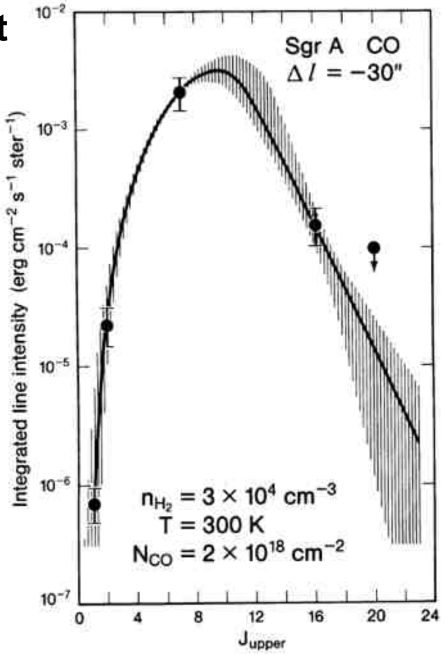
LVG modeling

Panuzzo et al. 2010

van der Werf et al. 2010

CO SED in the Galactic Center

Harris et al. 1985



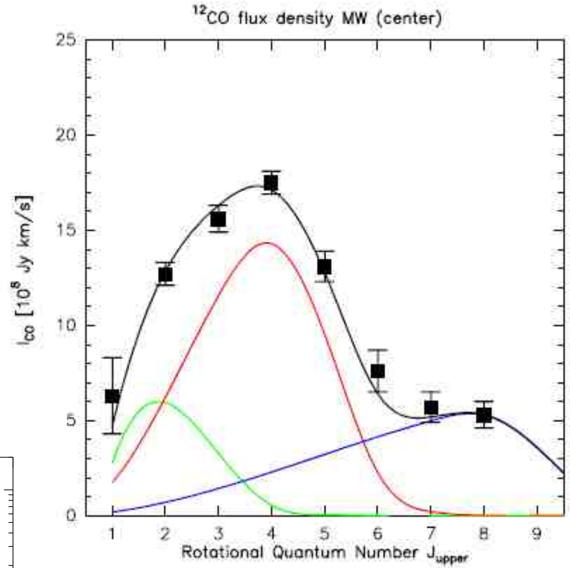
Lugten (1984), Genzel et al. (1985) here the first to detect the CO(15-14) and CO(21-20)

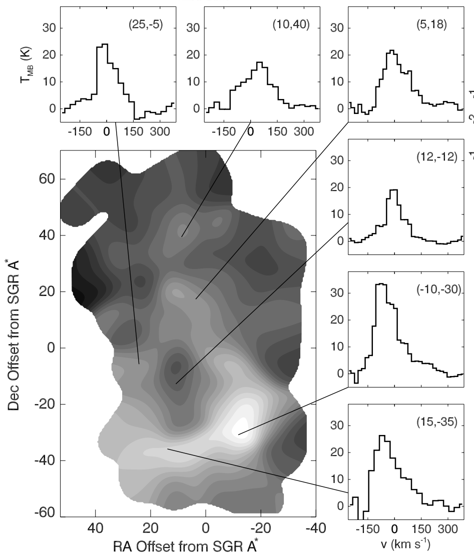
line in the vicinity of Sgr A* using the Kuiper Airborne Observatory (KAO).

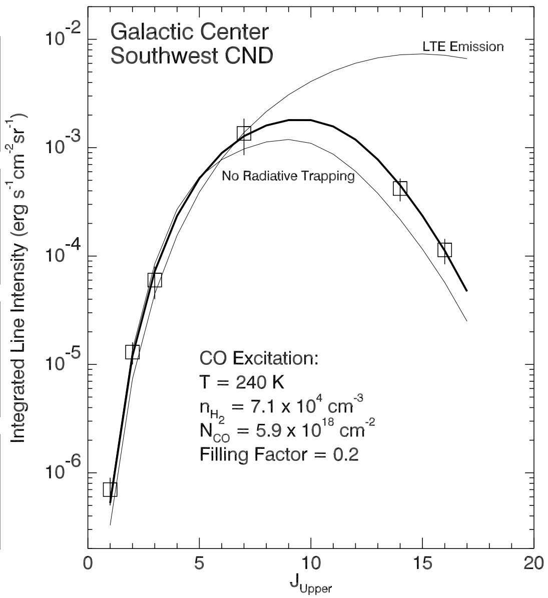
(and example, 60" and 100Km/s spectral resolution)

CMZ of the MW

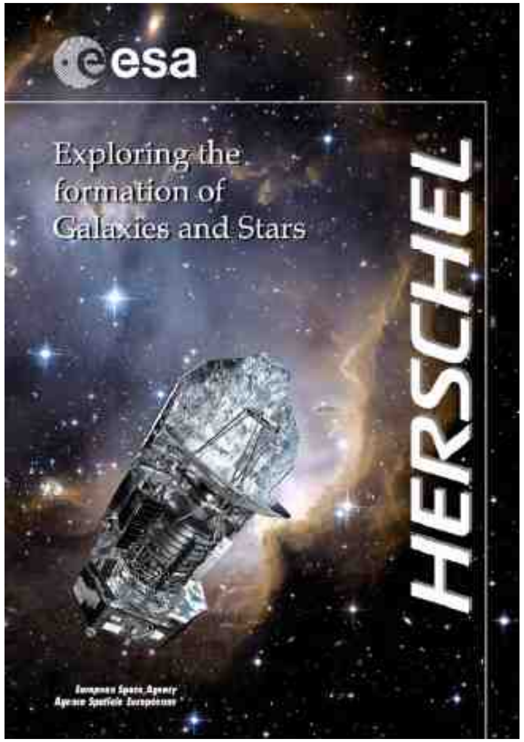
COBE, Fixsen et al. 1999





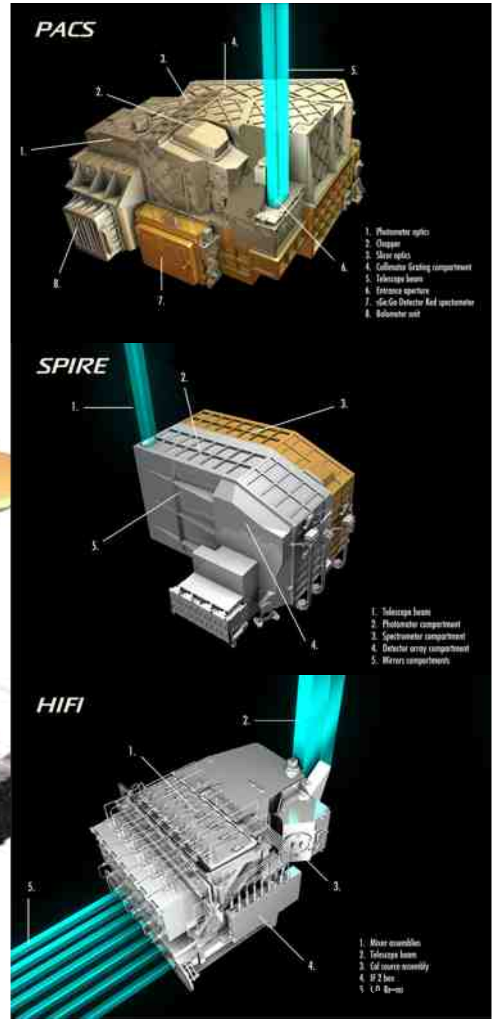


Bradford et al. (2005) did the latest update in the CO excitation in the CND, still low resolutions and beam sizes for the analysis 44" and 70 km/s resolution.



HERSCHEL

- telescope (eff) diam (3.3) 3.5 m
- telescope WFE < 6 μm
- *telescope temp* *< 90 K*
- *telescope emissivity* *< 4%*
- *abs/rel pointg (68%)* *< 3.7" / 0.3"*
- science instruments 3
- science data rate 130 kbps
- *cryostat lifetime* *> 3.5 years*
- height / width ~ 7.5 / 4 m
- launch mass ~ 3300 kg
- power ~ 1500 W
- orbit 'large' Lissajous around L2
- solar aspect angle 60-120 deg
- launcher (w Planck) Ariane 5 ECA



Herschel was launched the 14th of May, 2009, and is expected to live till February 2013.

Guaranty Time

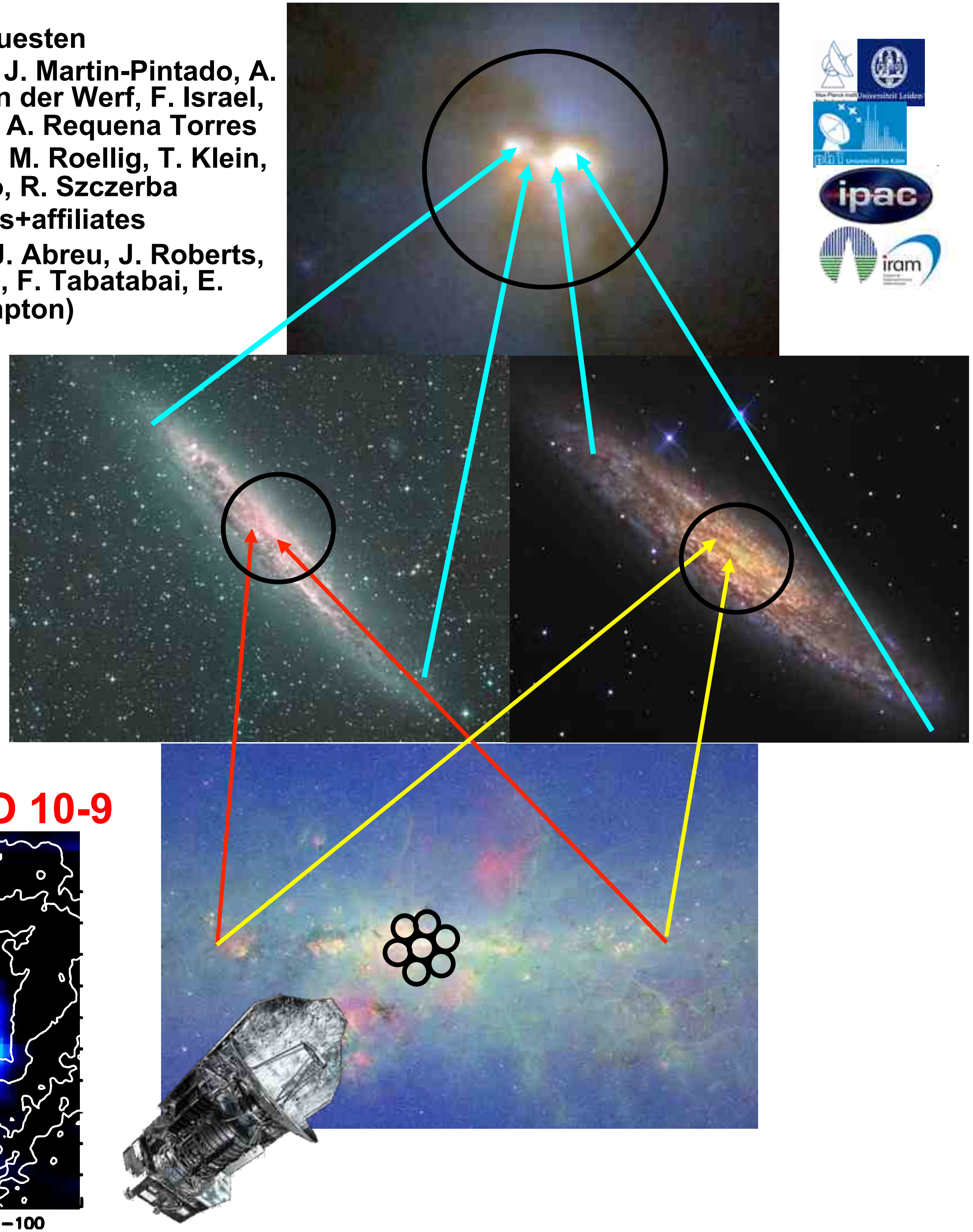
Herschel EXtra GALactic KP:

Physical and chemical conditions of the ISM in Galactic Nuclei

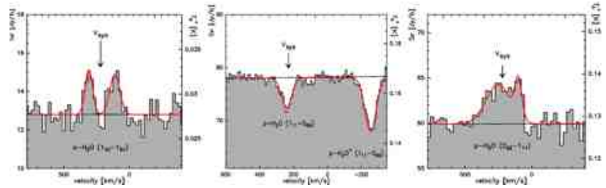
PI: R. Güsten

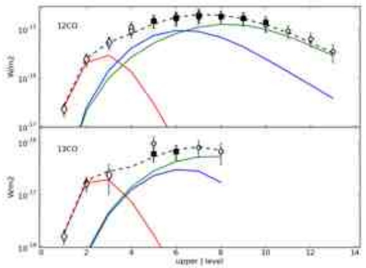
HEXGAL

PI:Rolf Guesten
Coordinators: A. Weiss, J. Martin-Pintado, A. Harris, J. Stutzki, P. Van der Werf, F. Israel, C. Kramer, S. Lord, M. A. Requena Torres
Other Co-investigators: M. Roellig, T. Klein, S. Garcia-Burillo, R. Szczerba
+Collaborators+affiliates
(E. Loenen, A. Weiss, J. Abreu, J. Roberts, P. Fiadino, Y. Okada, F. Tabatabai, E. Polehampton)

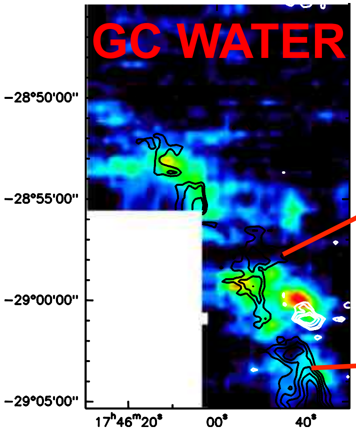


HIFI observations of water lines in M82 **(Weiss et al. 2010)**

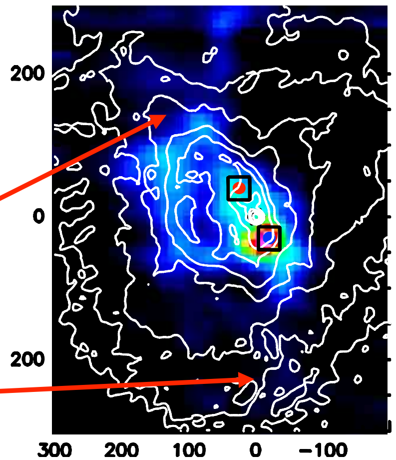




Dense gas: M82: (Loenen et al. 2010)

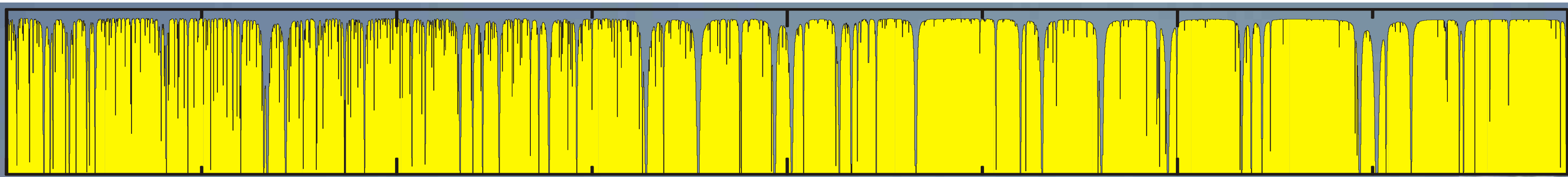


CO 10-9

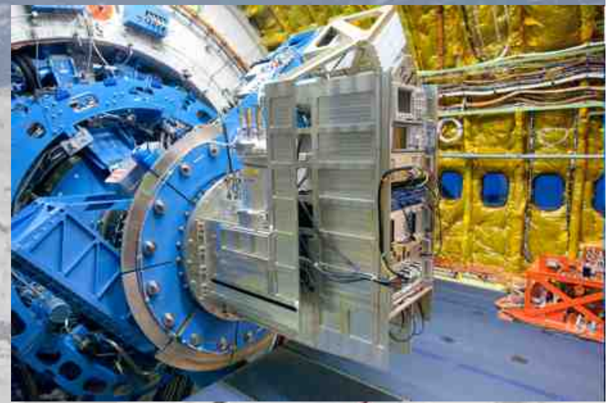


SOFIA

Stratospheric Observatory for Infrared Astronomy



German Receiver for Astronomy at THz Frequencies



GREAT

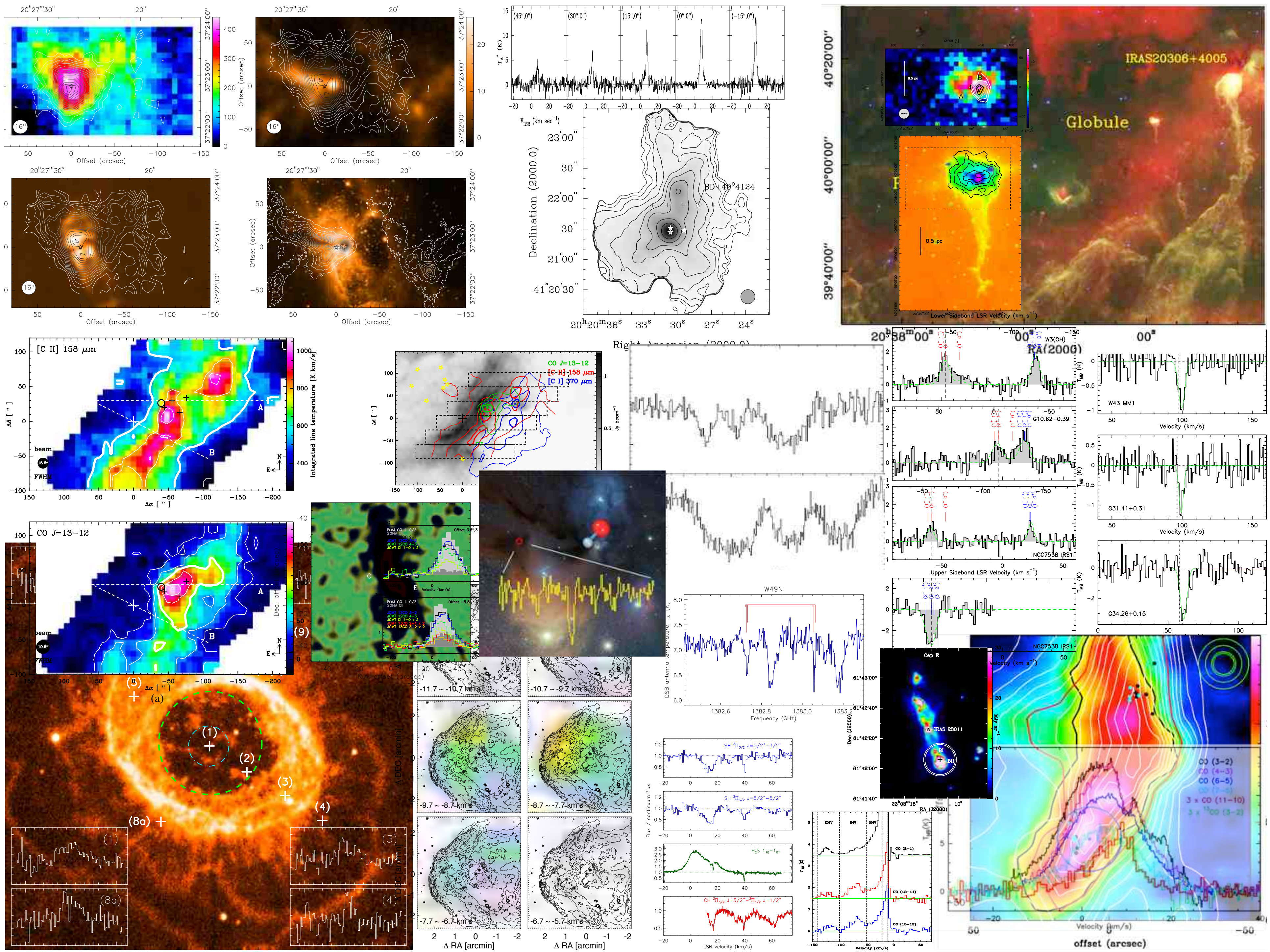
Channel	Frequencies [THz]	Astronomical lines of interest
low-frequency #1	25 – 1.50	[NII], CO(12-11), $^{(13)}$CO(13-12), HCN(17-16), H_2D^+
low-frequency #2	1.82 – 1.92	[CII], CO(16-15)
mid-frequency	2.4 – 2.7	HD, OH($^2\Pi_{3/2}$), CO(22-21), $^{(13)}$CO(23-22)
high-frequency	~ 4.7	[OI]


First upgrade to the rear of the plane…
SOFIA
First flight to Germany!
SOFIA's First
Trans-Atlantic Crossing
September 2011
Flight Plan Name: File: KPMD-EDDK_postMOPs.fp
Flight ID: 2011/09/16
Est. Takeoff Time: 2011-Sep-16 17:00 UTC
Est. Landing Time: 2011-Sep-17 04:47 UTC
Flight Duration: 11:47
Weather Forecast : 1200 Tue Sep 13 2011 - 0000 Fri Sep 16 2011 UTC
Saved: 2011-Sep-14 20:04 UTC User: kbower

Science from observations with GREAT during the Early Science phase

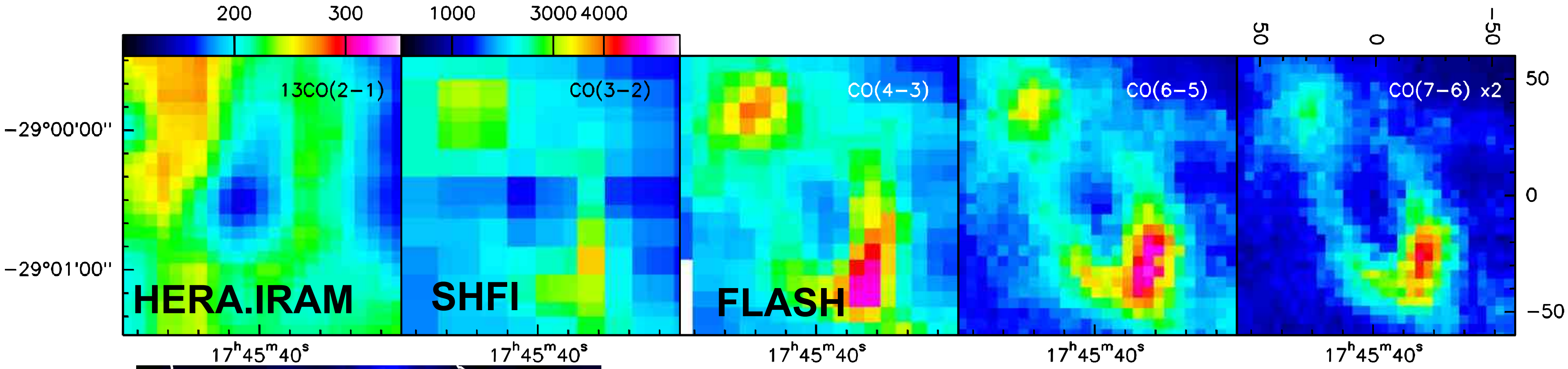
GREAT was operated during SOFIA s Short (4 flights) and Basic Science (12 flights) phase to address a wide variety of timely astrophysical topics. A total of 18 scientific publications was submitted for a Special Feature of Astronomy & Astrophysics (Vol& , May 2012), complemented by 4 technical papers describing the GREAT instrument.

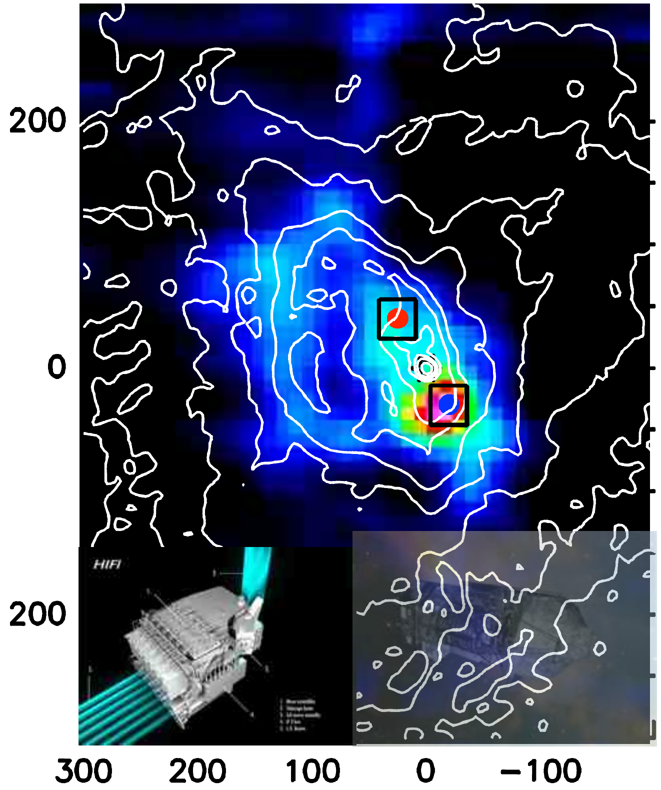
T. Csengeri	SOFIA observations of far infrared hydroxyl emission toward ultra-compact HII/OH maser regions
J. Eislöffel	SOFIA observations of CO(12 11) emission along the L1157 bipolar outflow
A. Gomez	High-J CO emission in the Cepheus E protostellar outflow observed with SOFIA/GREAT
U. Graf	[^{12}CII] and [^{13}CII] 158 m emission from NGC 2024: Large column densities of ionized carbon
A. Gusdorf	Probing MHD Shocks with High-J CO Observations: W28F
B. B. Mookerjea	The structure of hot gas in Cepheus B
D. Neufeld	Discovery of interstellar mercapto radicals (SH) with the GREAT instrument on SOFIA
Y. Okada	Dynamics and PDR properties in IC1396A
B. Parise	Detection of OD towards the low-mass protostar IRAS 16293-2422
J.-P. Perez-Beaupuits	The ionized and hot gas in M17 SW: SOFIA/GREAT THz observations of [C II] and ^{12}CO J=13-12
M. Requena	GREAT confirms transient nature of the Circumnuclear Disk
M. Röllig	[CII] gas in IC 342
R. Sahai	Probing the Mass and Structure of the Ring Nebula in Lyra with SOFIA/GREAT Observations &
G. Sandell	GREAT [CII] and CO observations of the BD+40ï¿½4124 region
N. Schneider	Globules and pillars seen in the [CII] 158 m line with SOFIA
R. Simon	SOFIA observations of S106: dynamics of the warm gas
H. Wiesemeyer	High-resolution absorption spectroscopy of the OH 2PI3/2 ground state line
F. Wyrowski	Terahertz ammonia absorption as a probe of infall in high-mass star forming clumps
S. Heyminck et al.	GREAT: the SOFIA high-frequency heterodyne instrument
P. Pütz et al.	Terahertz hot electron bolometer waveguide mixers for GREAT
B. Klein et al.	High-resolution wide-band Fast Fourier Transform Spectrometers
Xin Guan et al.	GREAT/SOFIA atmospheric calibration



Offset (arcsec)
Declination (2000.0)
Right Ascension (2000.0)
BD+40°4124
IRAS20306+4005
Globule
0.5 pc
Lower Sideband LSR Velocity (km s⁻¹)
[C II] 158 μm
CO J=13-12
Integrated line temperature [K km/s]
beam
FWHM
CO J=13-12
[C II] 158 μm
[C I] 370 μm
W49N
Frequency (GHz)
DSB antenna temperature, T*A (K)
W3(OH)
G10.62−0.39
NGC7538 IRS1
Upper Sideband LSR Velocity (km s⁻¹)
W43 MM1
G31.41+0.31
G34.26+0.15
Velocity (km/s)
Cep E
IRAS 23011
RA (J2000)
CO (3−2)
CO (4−3)
CO (6−5)
offset (arcsec)
Δ RA [arcmin]
-11.7 ~ -10.7 km s⁻¹
-10.7 ~ -9.7 km s⁻¹
-9.7 ~ -8.7 km s⁻¹
-8.7 ~ -7.7 km s⁻¹
-7.7 ~ -6.7 km s⁻¹
-6.7 ~ -5.7 km s⁻¹
LSR velocity (km/s)
Flux / continuum flux

CO SED in the Galactic Center

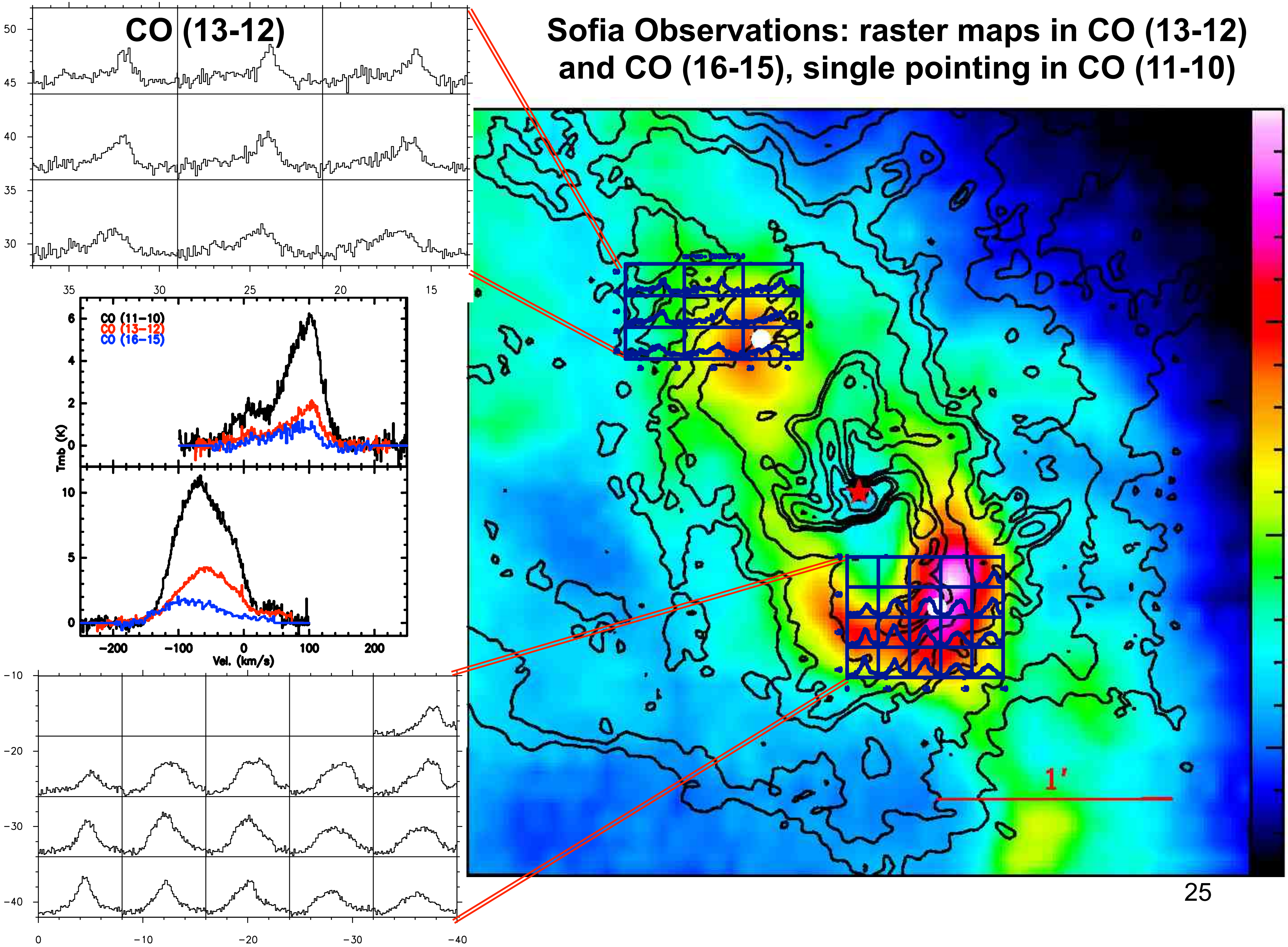


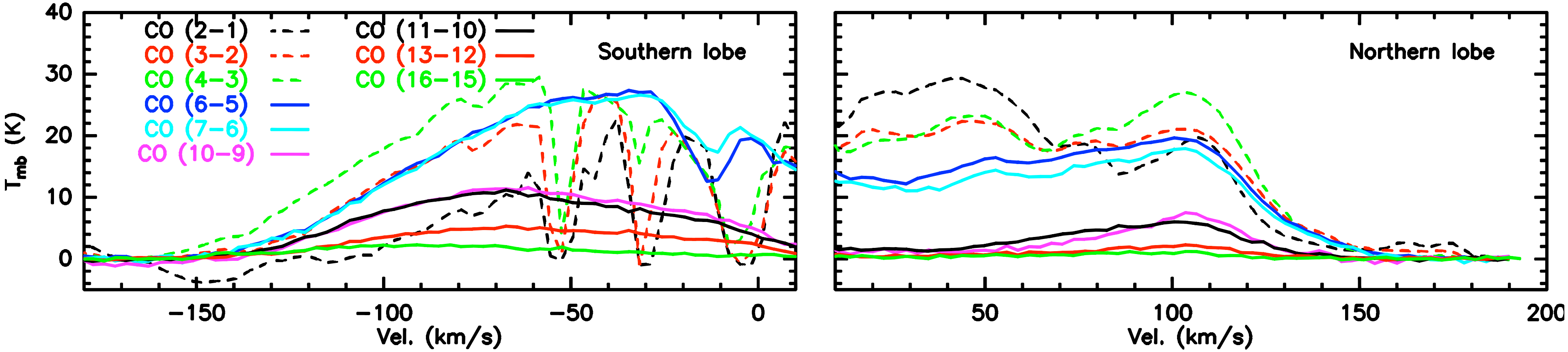


Herschel *CO* (10-9) Map

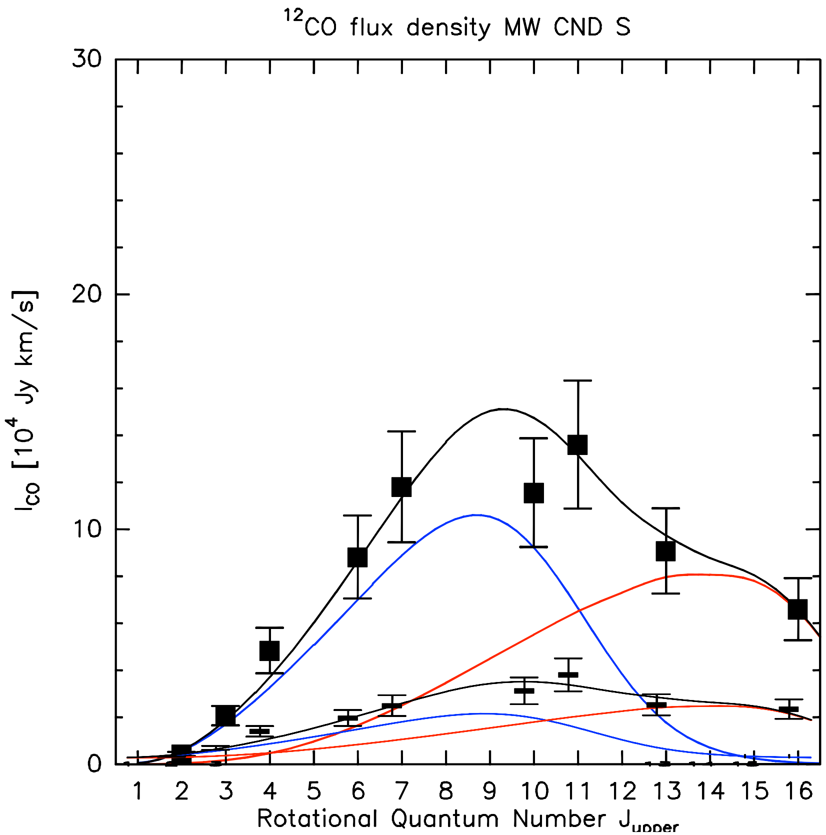
	J_u-J_l	Freq. (MHz)	E_u (K)	Tel./Inst.	Beam (")	η_{mb}
CO	2-1	230538	5.53	IRAM30M/HERA	10.7	0.54
	3-2	345796	16.60	APEX/SHFi	17.9	0.73
	4-3	461040	33.19	APEX/FLASH	13.4	0.60
	6-5	691473	82. 98	APEX/CHAMP+	8.9	0.45
	7-6	806651	116.16	APEX/CHAMP+	7.7	0.43
	10-9	1151986	248.88	HERSHEL/HIFI	18.6	0.64
CO	11-10	1267014	304.16	SOFIA/GREAT	22.5	0.54
	13-12	1496923	431.30	SOFIA/GREAT	19.0	0.54
	16-15	1841346	663.36	SOFIA/GREAT	15.5	0.51
^{13}CO	2-1	220398	5.3	IRAM30/HERA	11.2	0.54
	6-5	661067	79.33	APEX/CHAM+	9.4	0.48
	13-12	1431153	412.34	SOFIA/GREAT	19.9	0.54

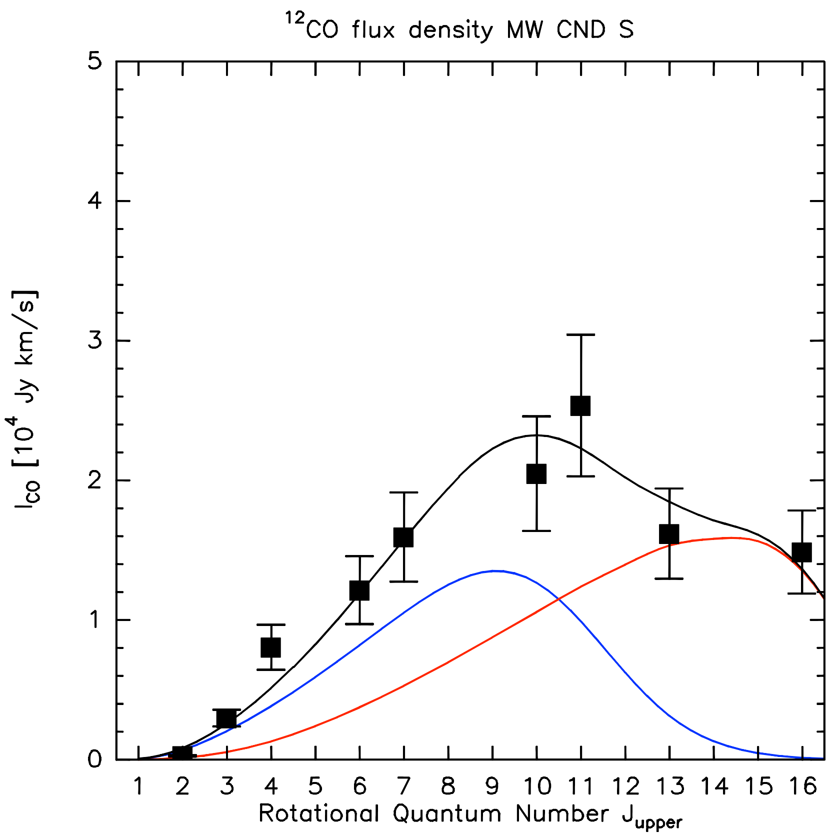
Sofia Observations: raster maps in CO (13-12) and CO (16-15), single pointing in CO (11-10)

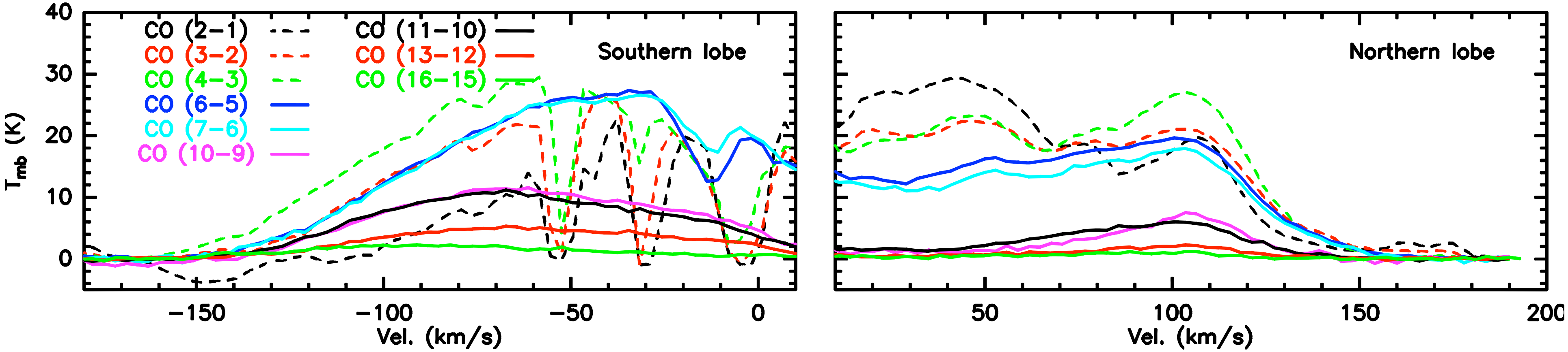




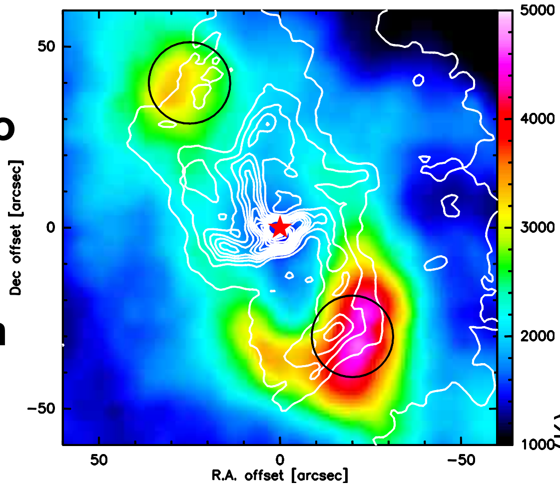
With high spectral resolution, we have the possibility to separate excitation components in velocities too.

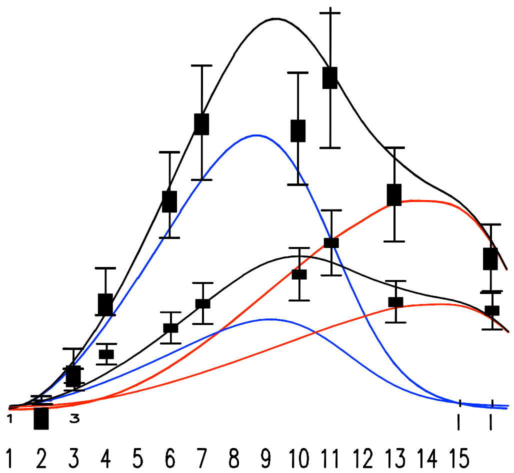


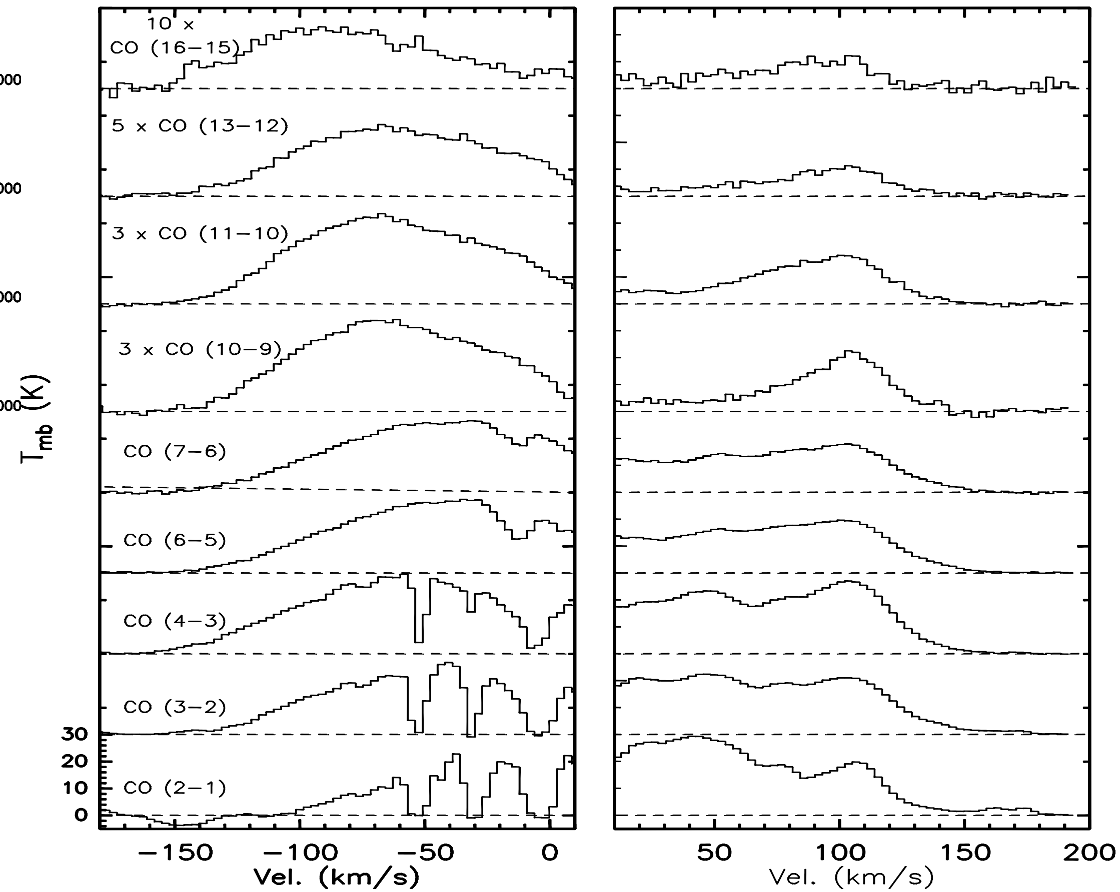




All data smoothed to the same beam size 22.5" and extracted in two Sofia positions







Constrains in the GC:

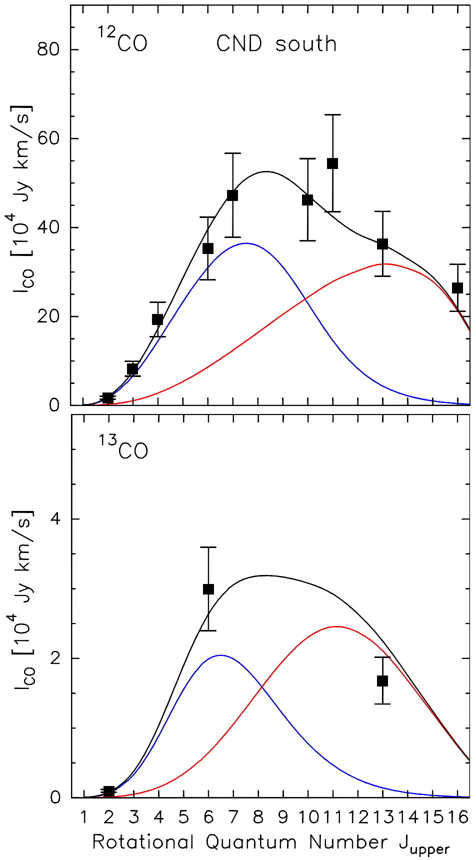
^{13}CO in three transitions.

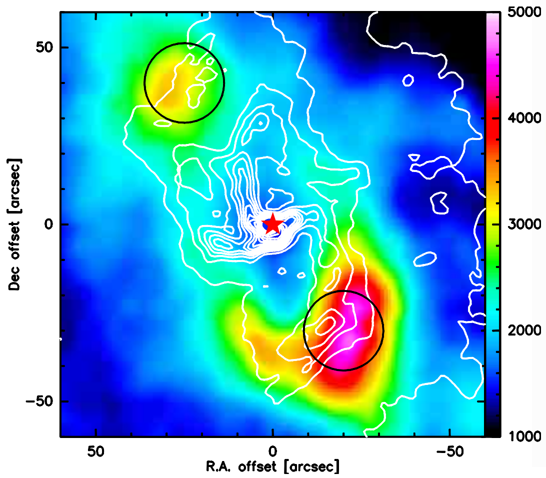
$^{12}C/^{13}C$ ~20-25

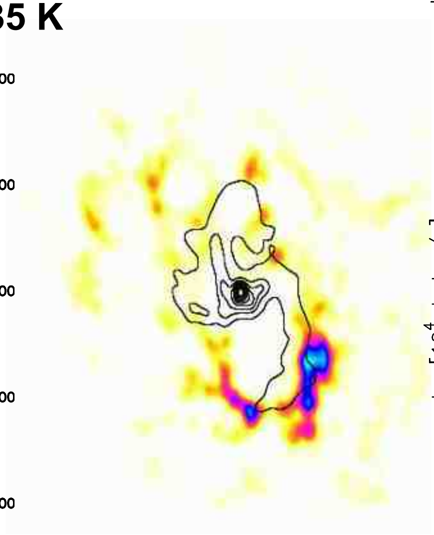
100-200 km/s/pc

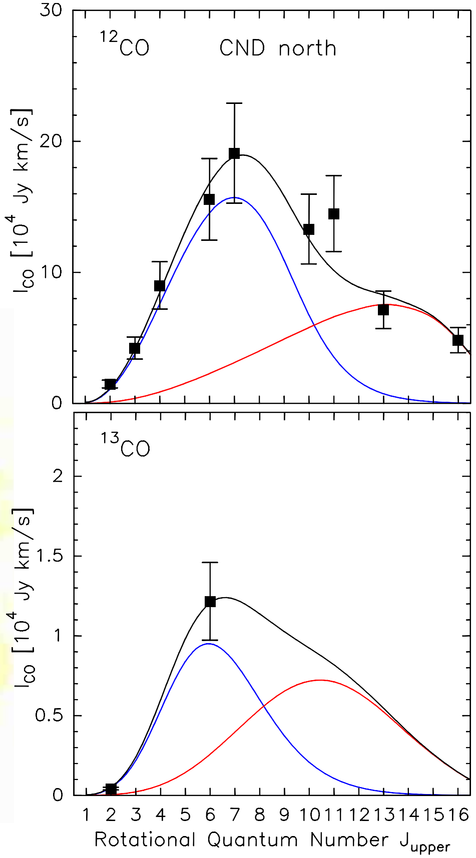
$[CO]/[H_2]$ ~ 8 x 10^{-5}

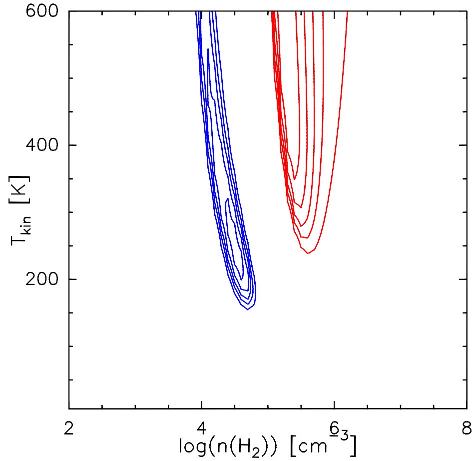
T_{kin} > 135 K











n_{H2} $10^{5.2}$ cm^{-3}

T_{kin} 500 K

N_{H2} $10^{23.34}$

0.008 pc

n_{H2} $10^{4.5}cm^{-3}$

T_{kin} 200 K

N_{H2} $10^{22.64}$

0.031 pc

High temperatures in contrast with dust emission (24/75K) probably due by shocks

CND of ~1.2 10^4 Msun
Lower than interferometric studies, but they assume virialize material, that we do not see. Our densities are below the Roche limit (10^7 cm^{-3})

n_{H2} $10^{5.3}$ cm^{-3}

T_{kin} 325 K

N_{H2} $10^{23.15}$

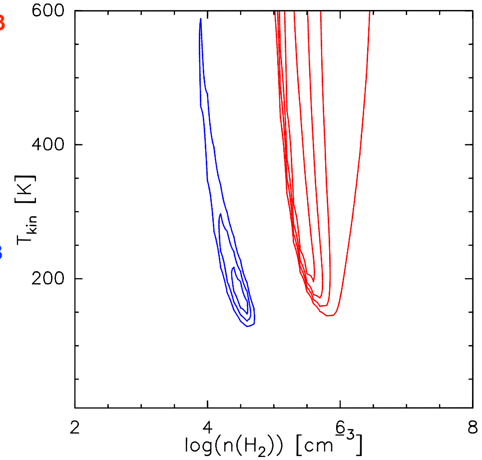
0.006 pc

n_{H2} $10^{4.5}cm^{-3}$

T_{kin} 175 K

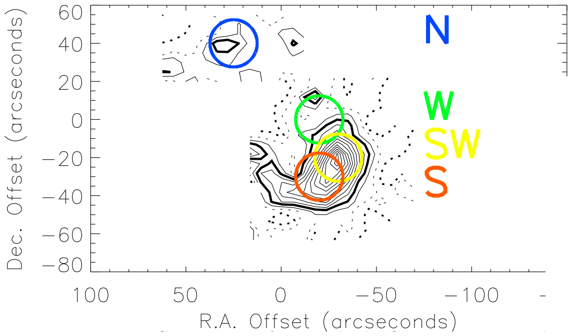
N_{H2} $10^{22.35}$

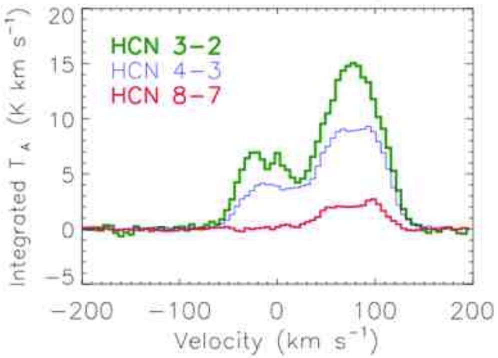
0.032 pc

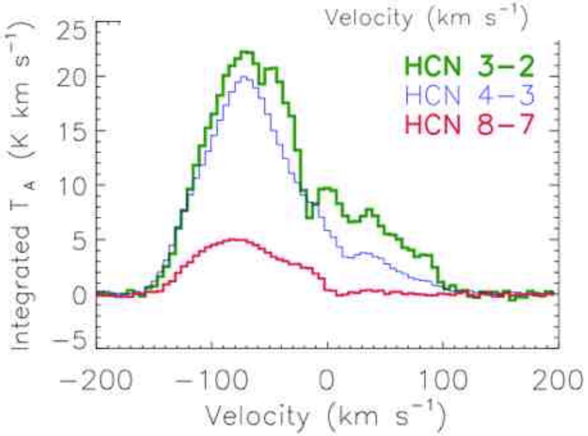


Parallel project in the CND

Multi HCN analysis







Affected by infrared pumping??

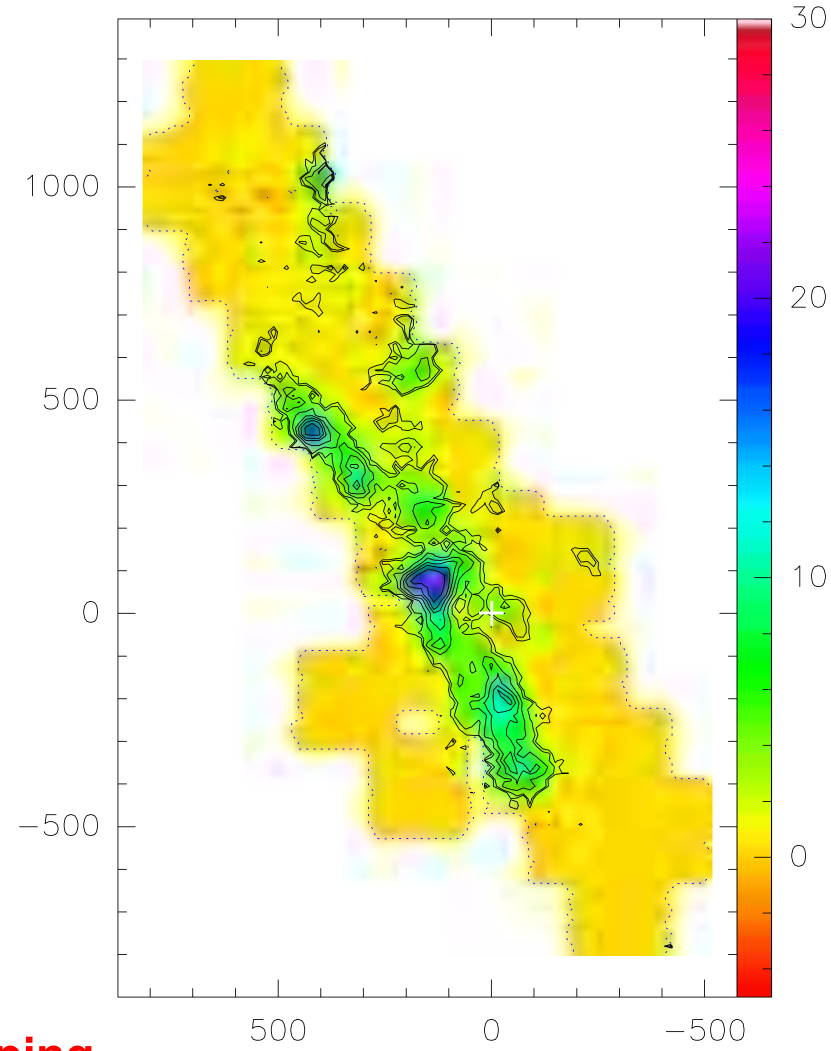
Shocks??

Mills et al. (2012)

+PACS OI, OIII, NII mapping in SGRA (in progress)

+ PACS/SPIRE legacy mapping of the SGRA complex

(Being observed right now)

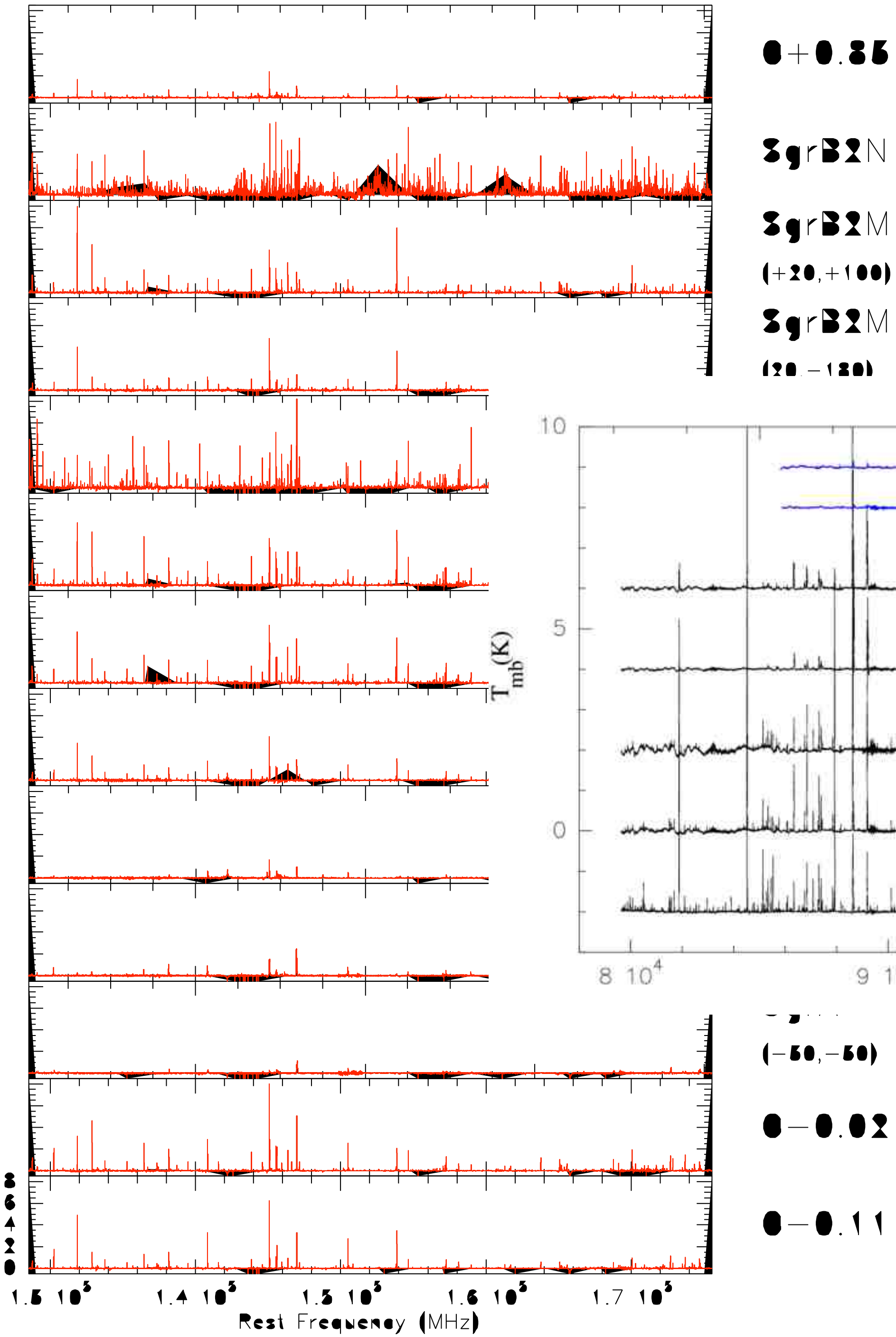


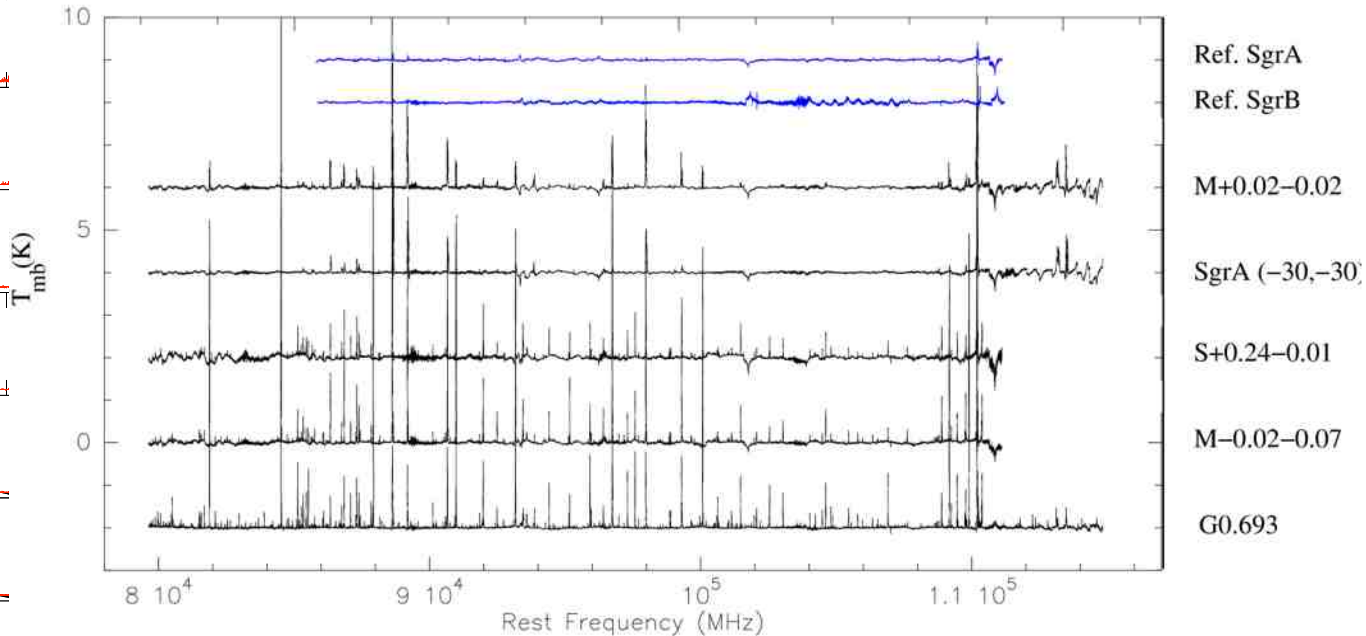
Ao et al 2012. LVG analysis of H_2CO in the GC

IRAM 30m 2mm surveys by Martin et al.

3mm surveys by Aladro et al.

And we good the 1 mm surveys from APEX

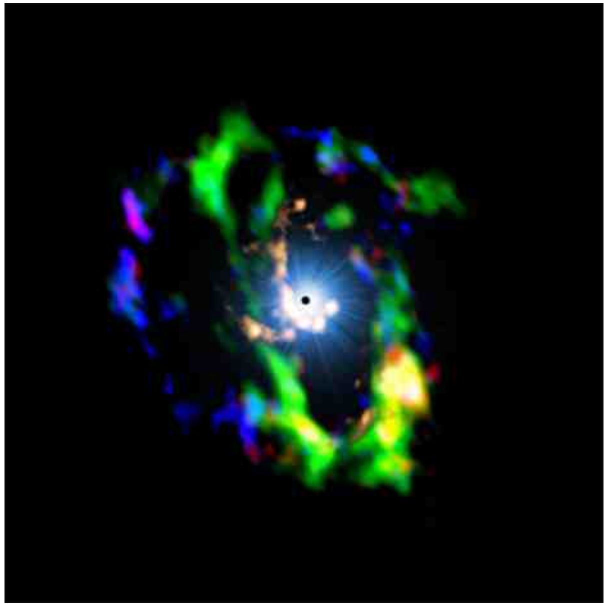




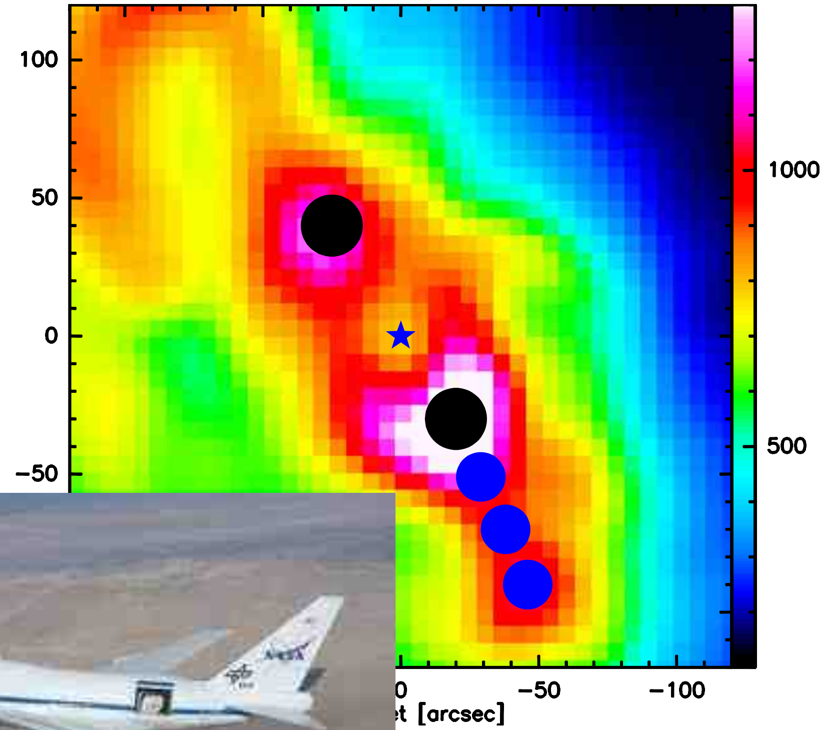
CND with Alma and Sofia

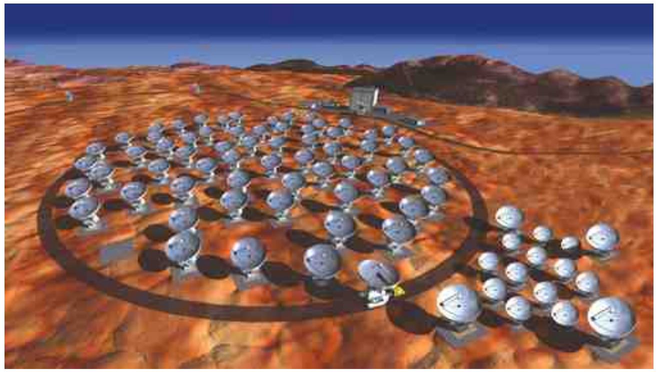
Martin et al.

High resolution images of the molecular and ionize gas in the CND



Requena-Torres et al.





Physical conditions along the CND

Summary

- **High spectral and spatial resolution maps of the CO (6-5) and CO (7-6) lines have been observed with the CHAMP+ instrument in APEX**
- **APEX have been used, together with IRAM-30M, HERSCHEL and SOFIA, to study the CO excitation in the CND with better spectral and spatial resolutions than before. Updating the physical conditions there**
- **Using this data we conclude that the (inner) CND is best described by a collection of transient filamentary streamers and clumps (Güsten et al. 1987). Its mass is comparatively low, few 10^4 Msun, which has implications on the mass accretion rate toward the central object (Genzel et al. 2010)**
- **The APEX maps still contain information of several regions of interest, that need extra work and data. And other data from this telescope and HERSCHEL are still being analyze**

- *APEX will be used to obtained detailed CO (3-2) and ^{13}CO (3-2) emission in the regions of interest*
- *With Sofia/GREAT we will study the variations in the excitation along the CND*
- *ALMA will be used to study the ionized material in the CND*

GREAT

THANKS

Transition	E_{up}[K]	ν[THz]	$\int T_{mb} \cdot dv$ [K km/s] CND-S	CND-N	
$^{12}CO(2\text{-}1)$	5.5	0.230	797.4	670.4	I
$^{13}CO(2\text{-}1)$	5.3	0.220	49.0	21.2	I
$^{12}CO(3\text{-}2)$	16.6	0.346	1668.3	852.9	A
$^{12}CO(4\text{-}3)$	33.2	0.461	2199.6	1023.5	A
$^{12}CO(6\text{-}5)$	83.0	0.691	1782.3	786.7	A
$^{13}CO(6\text{-}5)$	79.3	0.661	165.5	67.2	A
$^{12}CO(7\text{-}6)$	116.2	0.807	1753.0	708.6	A
$^{12}CO(10\text{-}9)$	248.9	1.152	841.5	242.1	H
$^{12}CO(11\text{-}10)$	304.2	1.267	818.8	218.0	G
$^{12}CO(13\text{-}12)$	431.3	1.497	391.6	77.0	G
$^{13}CO(13\text{-}12)$	412.3	1.431	26.5		G
$^{12}CO(16\text{-}15)$	663.4	1.841	188.2	34.4	G

Modeling results

	gas phase	r_0 (pc)	T_{kin}	log $n(H_2)$	log $N(H_2)$
CND-S	low exc.	0.31	200^{+300}_{-70}	$4.5^{+0.2}_{-0.5}$	22.64
	high exc.	0.08	500^{+100}_{-210}	$5.2^{+0.4}_{-0.2}$	23.34
CND-N	low exc.	0.32	175^{+425}_{-45}	$4.5^{+0.3}_{-0.7}$	22.35
	high exc.	0.06	325^{+275}_{-165}	$5.3^{+0.6}_{-0.3}$	23.15

HCN (4-3)
positions