

HIFI XGal GT Key Program:

Physical and Chemical Conditions of the ISM in Galactic Nuclei

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ISM in the Galactic Center ($R_{gc} < 25$ pc)

- Physics & Chemistry of the ISM in the Central Gas Layer

Starbursts, Ultraluminous galaxies, and AGNs

- Excitation of starbursts, ULIGs and AGNs
- Interacting galaxies (incl. the Antennae)
- The NUGA sample of galaxies hosting AGN
- Special Case Study: Cen A (NGC 5128)

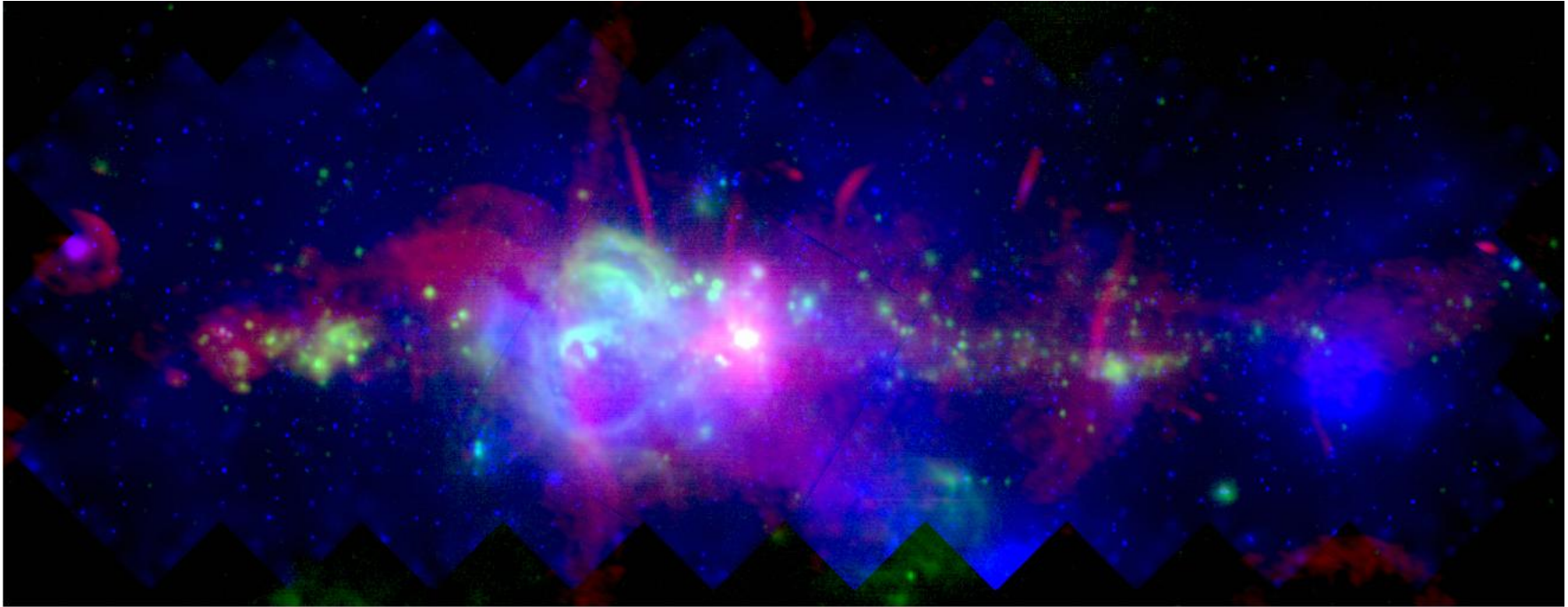
Chemical Complexity in Extragalactic Nuclei

- Line surveys towards extragalactic nuclei
- Absorption towards luminous extragalactic nuclei
- The Physics of the ISM in low-metallicity environments

Spanish Contribution to the HIFI ICC

- OTF image reconstruction (Madrid single spectrum Analysis, **MASSA**)
- Data cube visualization (Madrid Data Cube Analysis, **MADCUBA**)

The Galactic Center



The GC shows:

Star formation (clusters & protoclusters)

Large PDRs illuminated by clusters of massive stars

Strong emission of X-rays (Fe 6.4 keV) and gamma-rays (XDRs)

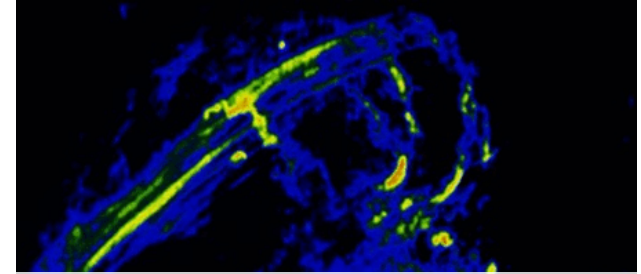
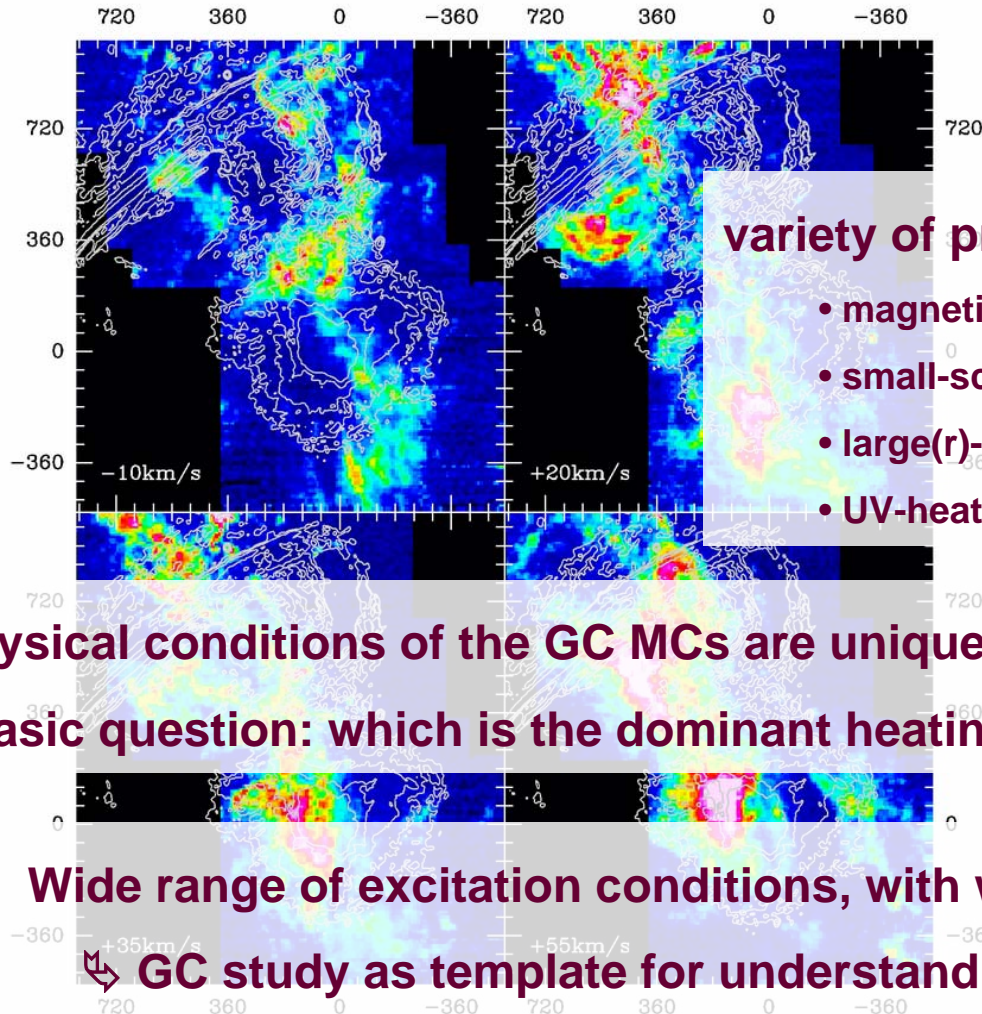
The ultimate super massive black hole candidate

The GC provides a unique laboratory for understanding the activities in the heart of the Milky Way as well as in nuclei of galaxies

The Galactic Center

Physics & chemistry of the ISM in the Central Gas Layer ($R_{gc} < 25pc$)

$^{13}CO(2-1)$ observed with IRAM 30m
overlayed with contours of 20cm emission



variety of processes on stage:

- magnetic viscous heating
- small-scale dissipation of supersonic turbulence
- large(r)-scale J- and C-shocks
- UV-heating in exposed PD layers

! Physical conditions of the GC MCs are uniquely different to pop in gal.plane!

↳ **basic question: which is the dominant heating mechanism at work ?**

Wide range of excitation conditions, with wide range of “micro”-physics

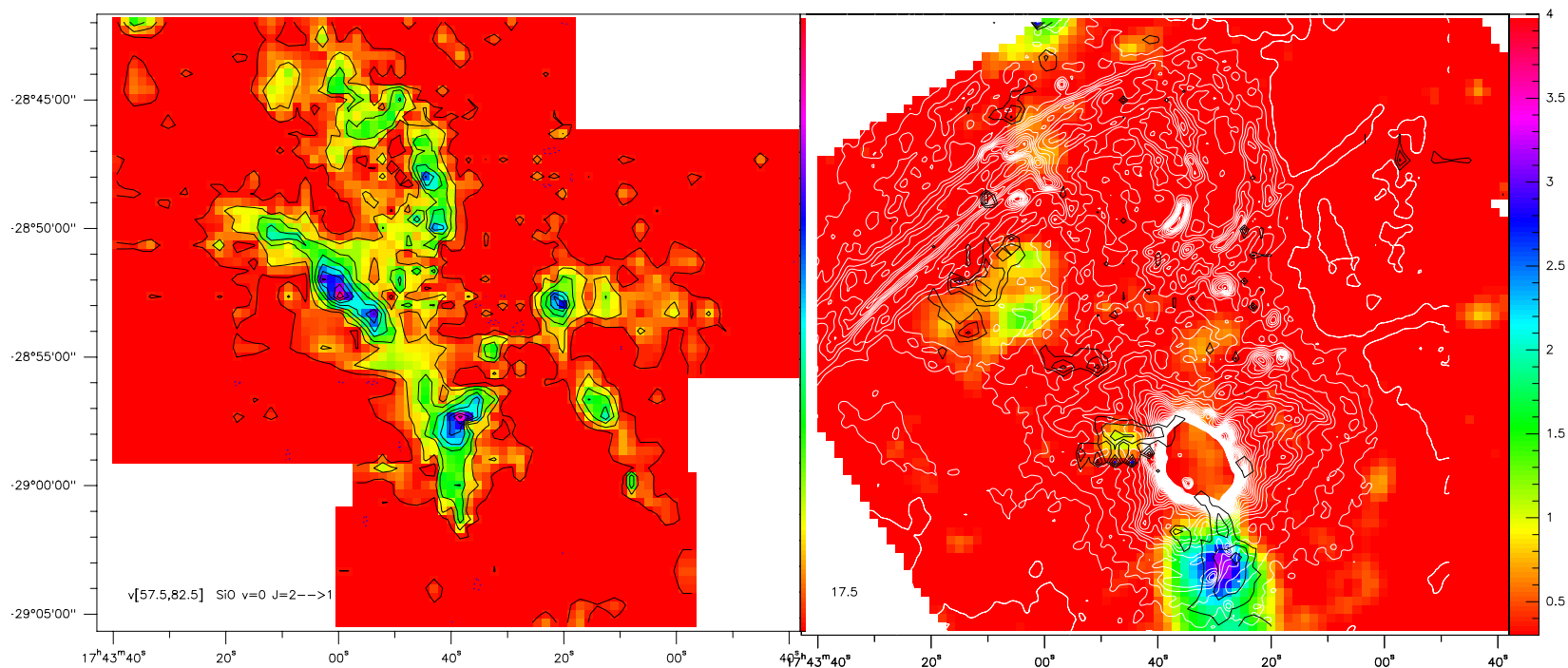
↳ **GC study as template for understanding evolution of extragal nuclei**

Interaction between the NTF and the dense gas

SiO

Amo et al. (2007)

SiO/CS



Is the central vertical field uniform and how and where does it merge with the azimuthal field of the Galactic disk?
What process produces the relativistic particles that illuminate the NTFs via their synchrotron emission?

The Galactic Center

Unbiased large-scale maps of the dominant cooling lines:

Transition	ν [THz]	Obs.Mode	Nyqu. Sampling	Area [arcmin ²]	Backend [GHz / sp.res]
[C I]	492	OTF /Ref	1/2	400	2.0 / 1 MHz
	809		1/2	400	
[C II]	1.90	OTF /Ref	1/2	400	2.4 / 2 MHz
[N II]	1.47	OTF /Ref	1/2	400	2.4 / 2 MHz

Specialty:

- OTF map with fixed Ref. need to have both polarisations at high resolution and a coverage of >600 km/s

The 20'x20' C II map will require 40.000X2 spectra!

Table 2.3 - Complementary observations with PACS

Transition	λ [μ m]	Obs.Mode	Sampling [arcsec]	Area [arcsec ²]	Beam [arcsec]
[O I]	63	Raster	4.7	120x240	4.7
	145		9.4	120x160	10.8
[O III]	88	Raster	4.7	2x120x320	6.7
[N II]	122	Raster	9.4	80x240	9.2

The Galactic Center

Targeted observations towards prominent molecular features

(selected by different micro-physics in H_2O and high CO transitions (10-9 and 13-12))

- **CND** (UV, extreme turbulence)
- **3 quiescent massive cloud cores** (small-scale dissipation of turbulence)
- **G0.18** (UV, magnetic heating)
- **2 thermal bridge filaments** (PDR, most spect. clusters in the Galaxy)

Table 2.5 – Targeted Observations with HIFI: Nitrogen Chemistry

Transition	ν [THz]	Obs.Mode	Nyqu. Sampl.	Area [arcmin ²]	Backend [GHz / sp.res]
NH $1_{23}-0_{12}$	974.5	OTF /Ref	1/2	150	2 / 2 MHz
NH ₂ $1_{11}-0_{00}$	952.6	OTF /Ref	1/2	150	2 / 2 MHz
NH ₃ $1_{00}-0_{01}$	572.5	to be observed simultaneously with the 556.9 GHz water line			

The need of high velocity resolution (Seyfert 2)

Usero et al. (2004)

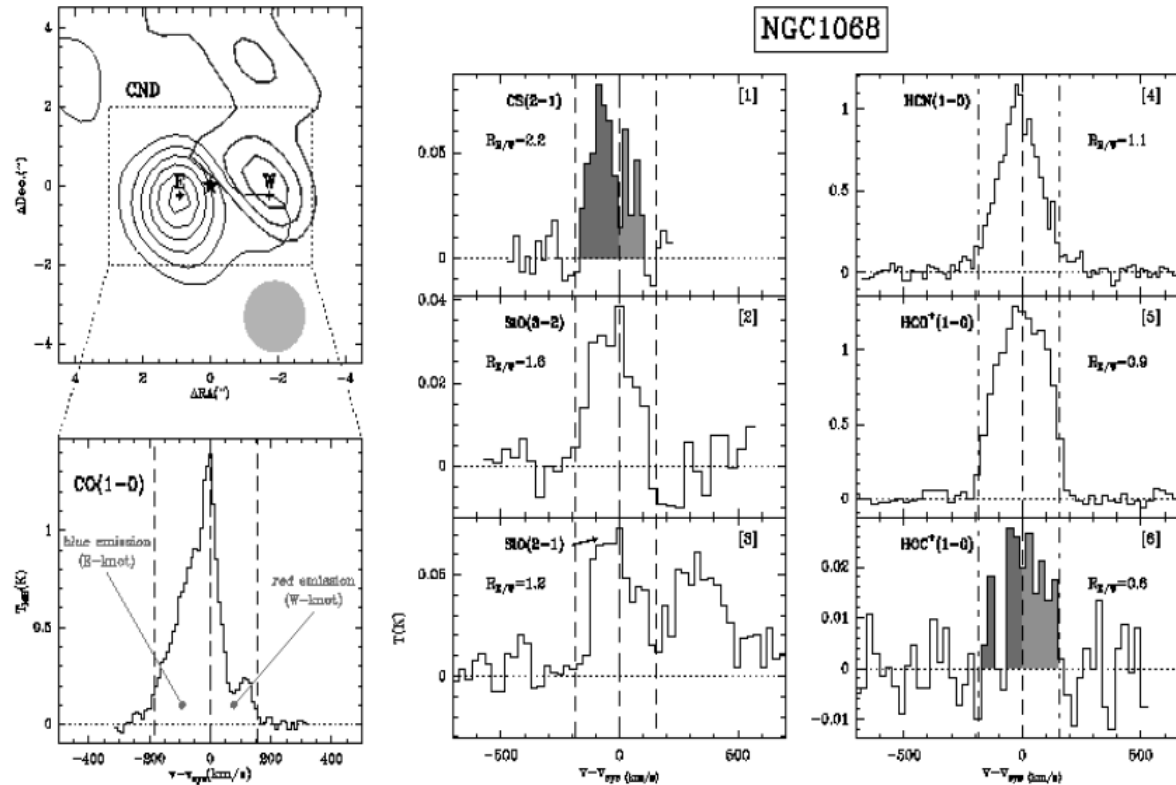
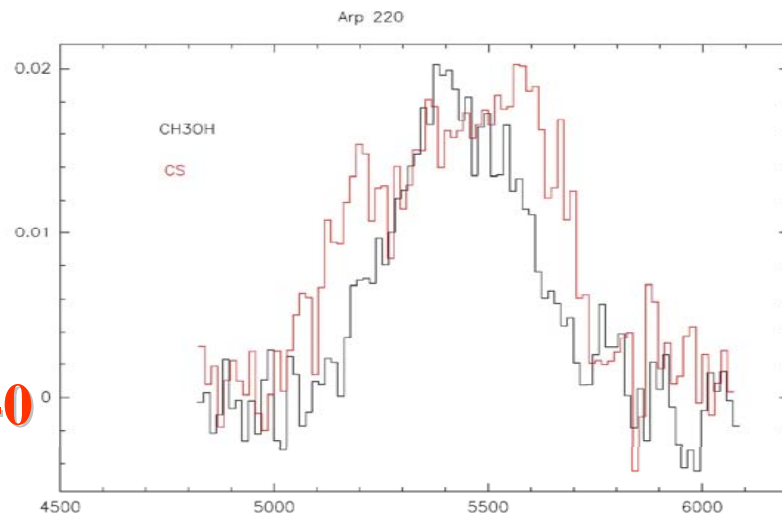
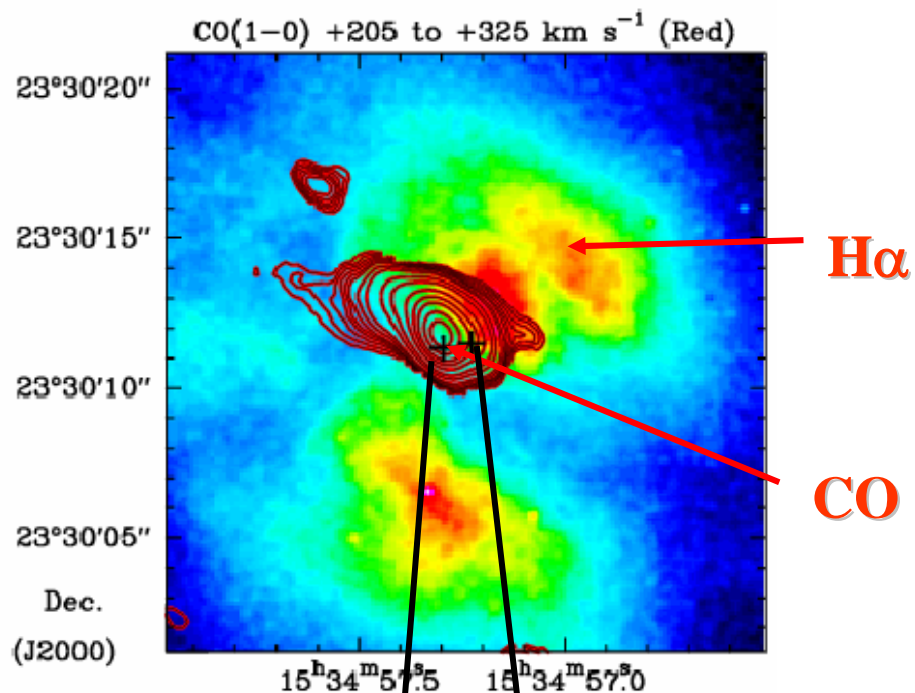


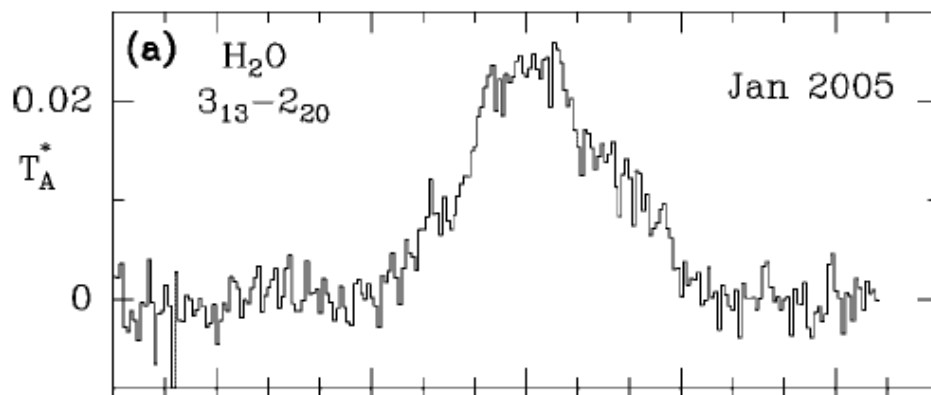
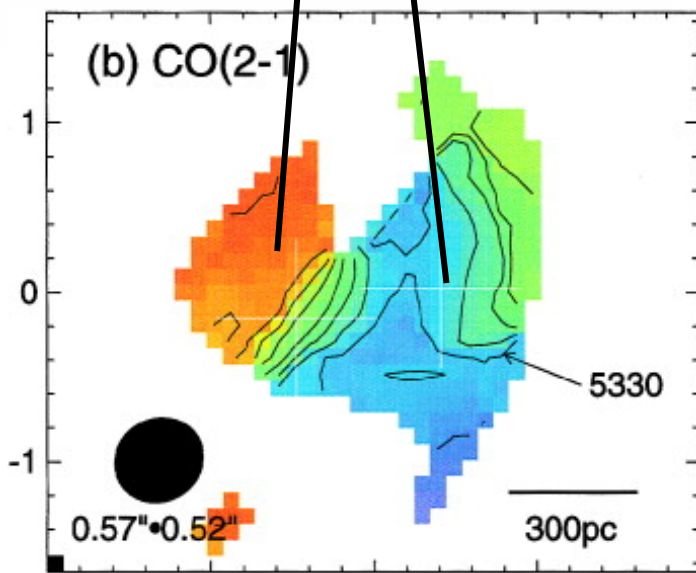
Fig.3.4: Integrated intensity maps of CO(1-0) toward the Circumnuclear Disk of NGC1068 obtained for the 'blue' and 'red' emission components as defined in the text (see also bottom panel). The figure has been adapted from Usero et al. (2004). The maps are derived from the data of Schinnerer et al. (2000). The starred marker highlights the AGN locus. 'bottom panel': Integrated spectrum of CO(1-0) emission in the CND. The W and E knots in the CO map correspond, respectively, to the 'red' and 'blue' components in the spectrum. Molecular lines in the Circumnuclear Disk of NGC1068. Two vertical point-dashed lines at $v-v_{\text{sys}} = -185$ km/s and 155 km/s, delimit the 'blue' and 'red' kinematical components. For each line, the blue-to-red (east-to-west) average brightness temperature ratio: $R(E/W)$ is indicated.

The need of high velocity resolution (ULIGs): Arp220

Martin-Pintado et al. (2007)



Cernicharo et al. (2006)



Sakamoto et al. (1999)

Starbursts, ULIGs and AGNs

- **study representative samples**
 - sample of starburst galaxies, luminous infrared galaxies, ULIGs and AGNs
 - sample of interacting galaxies (incl. case study NGC4038/4039)
 - NUGA sample of galaxies hosting AGNs



- **study representatively in detail: Cen-A**



- study the physical properties of starbursts, ULIGs and interaction zones of galaxies
- determining the distribution, excitation, and dynamics of neutral and partially ionized atomic gas in the inner few kpc of galactic nuclei harbouring an AGN
- determining details on and study the physical properties of the gas phases to understand nuclear activity in galaxies.

Starbursts, ULIGs and AGNs

^{12}CO 6-5	0.689	DBSw	1	2 / 1 MHz	5	20	20	A
^{13}CO 6-5	0.659	DBSw	1	2 / 1 MHz	17	2	20	C
C^{18}O 6-5	0.657	DBSw	1	2 / 1 MHz	19	2	50	C
^{12}CO 10-9	1.148	DBSw	5	2 / 1 MHz	9	10	20	C
^{13}CO 10-9	1.097	DBSw	5	2 / 1 MHz	156	2	50	C
HCN 6-5	0.530	DBSw	5	2 / 1 MHz	136	0.5	50	C
HCO^+ 6-5	0.533	DBSw	1	2 / 1 MHz	34	1	50	C
$\text{o-H}_2^{16}\text{O}$ 1 _{1,0} -1 _{0,1}	0.555	DBSw	1	2 / 1 MHz	22	2	20	C,D
$\text{p-H}_2^{16}\text{O}$ 2 _{0,2} -1 _{1,1}	0.985	DBSw	1	2 / 1 MHz	63	1	50	C,D
$\text{p-H}_2^{16}\text{O}$ 1 _{1,1} -0 _{0,0}	1.109	DBSw	1	2 / 1 MHz	71	1	50	C,D
[C I]	0.490	DBSw	1	2 / 1 MHz	19	2	20	B,D
[C I]	0.806	DBSw	5	2 / 1 MHz	64	2	50	A,D
[C II]	1.895	DBSw	9	2 / 1 MHz	5	15	20	C,D
[N II]	1.456	DBSw	1	2 / 1 MHz	28	5	50	C,D

SBs+ULIGs:

PACS

15 objects

NUGA

28 objects

Transition	λ [μm]	Flux [W/m ²]	# of points	S/N	Obs.time [minutes]
M82 ($v=225$ km/s)					
[O I]	63.2	1.1e-14	9	10	16
[O I]	145.5	5.4e-15	4	10	7
[O III]	88.4	3.6e-15	9	10	16
[N II]	121.9	1.1e-15	4	10	7

Interacting galaxies (incl. the Antennae)

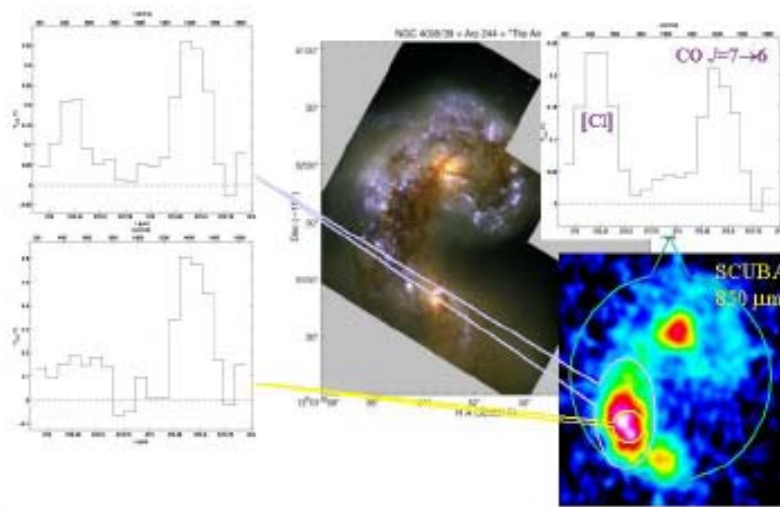


Fig. 3.1. Montage of the Antennae (NGC4038/39) as seen by the HST (center), SCUBA at 850 micron (lower right) and spectra of CO 7-6 and [CII] 809 GHz Integrated over selected areas (SPIFI/UCMT data by Isaak, Papadopoulos & van der Werf, in preparation).

Transition	ν [THz]	Obs.Mode	Nyqu. Sampl.	Area [arcsec ²]
NGC 4038/39 (V=1600 km/s)				
[C I]	0.49	OTF/Ch	1/2	150x150
	0.81	OTF/Ch	1/2	150x150
[C II]	1.90	OTF/Ch	1/2	150x150
[N II]	1.47	10x Ch		

Toomre type	Galaxie	[CII]	[NII]	[CII] brightness	[NII]	[CII] $T \times \Delta V$	[NII]	[CII] T_p	[NII]
		10^{-15} W/m^2		$[10^{-4} \text{ ergs cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}]$		[K km/s]		[K]	
separated	NGC4038/9					see Sect. 3.2.1			
very close	NGC520	2.5	0.36	11	1.6	157	49	0.4	0.10
	Arp 299					see Sect. 3.1			
	NGC3256	13.7	1.3	60 (ext)	5.6 (ext)	100	25	0.2	0.07
merging	NGC6240	2.6	0.27	11	1.2	160	36	0.3	0.07
	Arp220					see Sect. 4.2.1			
merg.remn.	NGC7252								

Cen A: the Giant Elliptical Radiogalaxy

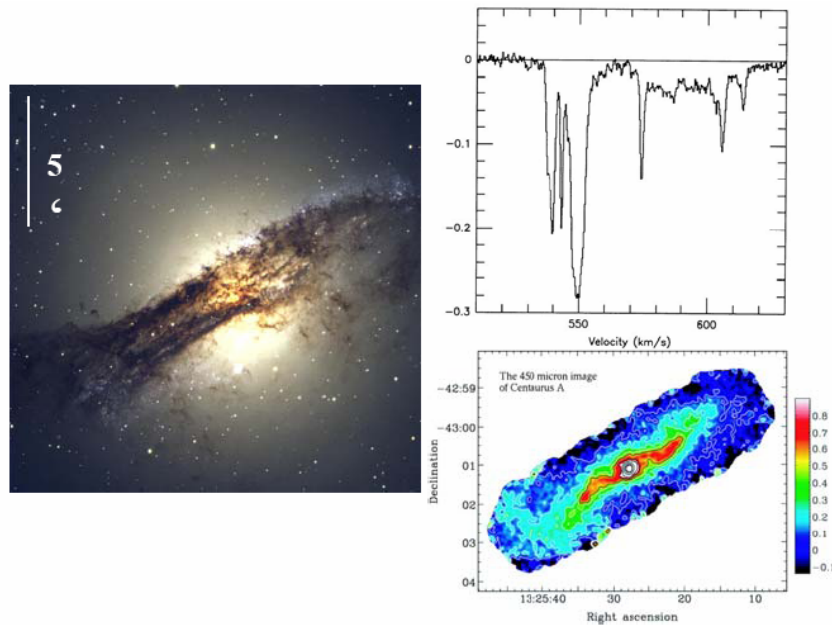


Fig.3.3: Optical image of Centaurus A, compared to the continuum emission at 450 μm as derived from SCUBA observations (Leeuw et al. 2002). The HCO⁺ absorption spectrum reveals a series of narrow-line absorption features, including a forest of red-shifted components (from Israel 1998).

Cen-A (V=575 km/s) - Dusty Disk

[CI]	0.49	OTF	1/2	5	2 / 1 MHz	0.5	4	240"x120"/10 km/s
	0.81		1/2	5		0.5	4	240"x120"/10 /39"
[CII]	1.90	OTF	1/2	5	4 / 1 MHz	3.1	30	240"x120"/10 km/s
[NII]	1.47	OTF	1/2	5	4 / 1 MHz	2.4	20	240"x120"/20 km/s

6.5

Cen-A (V=575 km/s) - Circumnuclear Disk

p-H ₂ ¹⁶ O 2 _{0,2} -1 _{1,1}	987.9	P Rast			4 / 1 MHz	1.5	2	3 positions, 10 km/s
p-H ₂ ¹⁶ O 1 _{1,1} -0 _{0,0}	1113.3	P Rast			4 / 1 MHz	1.8	2	3 positions, 10 km/s
p-H ₂ ¹⁸ O 1 _{1,1} -0 _{0,0}	1101.7	P Rast			4 / 1 MHz	2.5	1	3 positions, 20 km/s
CO (10-9)	1151.9	P Rast			4 / 1 MHz	1.0	2	3 positions, 20 km/s

6.8

Cen-A (V=575 km/s) – Absorption against Nuclear Continuum Disk

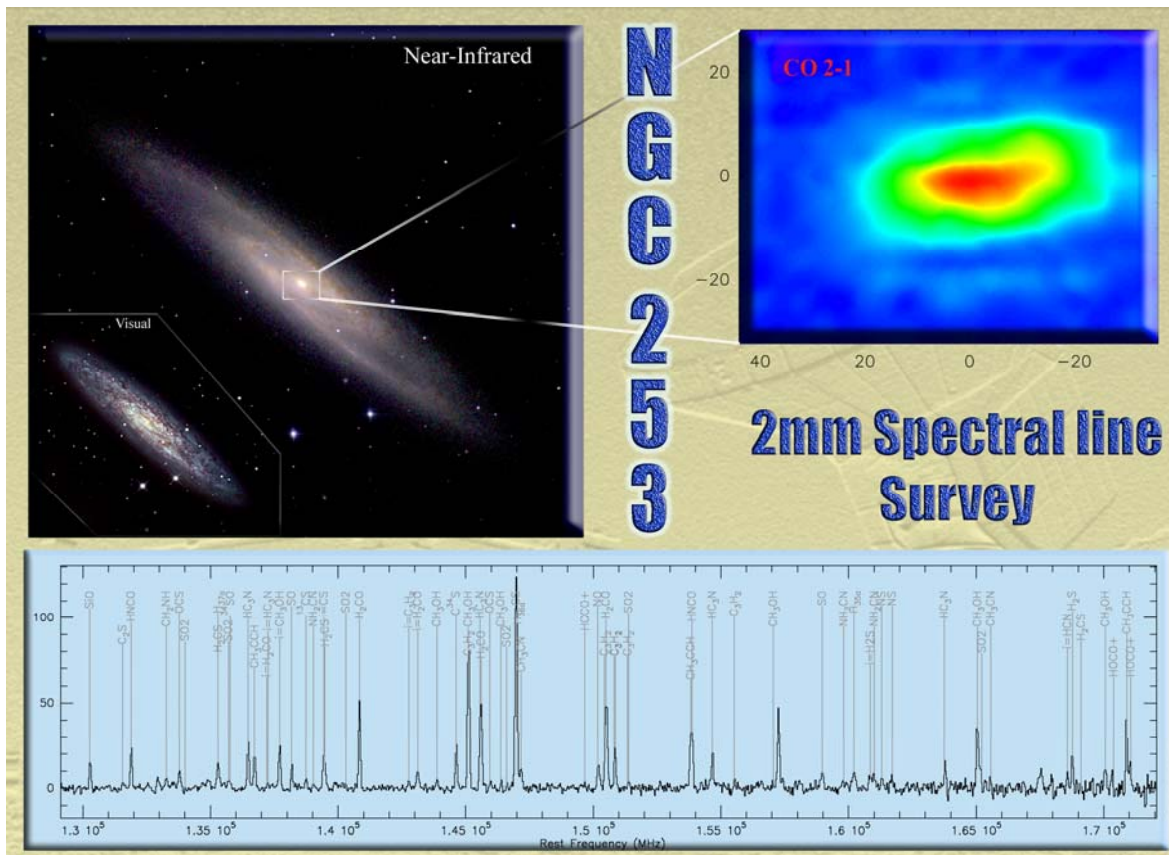
p-H ₂ ¹⁶ O 2 _{0,2} -1 _{1,1}	987.9	P.Sw.			4 / 1 MHz	0.5	2	10 km/s
p-H ₂ ¹⁶ O 1 _{1,1} -0 _{0,0}	1113.3	P.Sw.			4 / 1 MHz	0.6	2	10 km/s
p-H ₂ ¹⁸ O 1 _{1,1} -0 _{0,0}	1113.3	P.Sw.			4 / 1 MHz	0.6	2	10 km/s

Chemical Complexity in Extragalactic Nuclei

I. Line surveys towards extragalactic nuclei

Spectral line surveys with HIFI are fundamental to fully characterize the chemical complexity of galactic nuclei.

Martin et al. (2006)



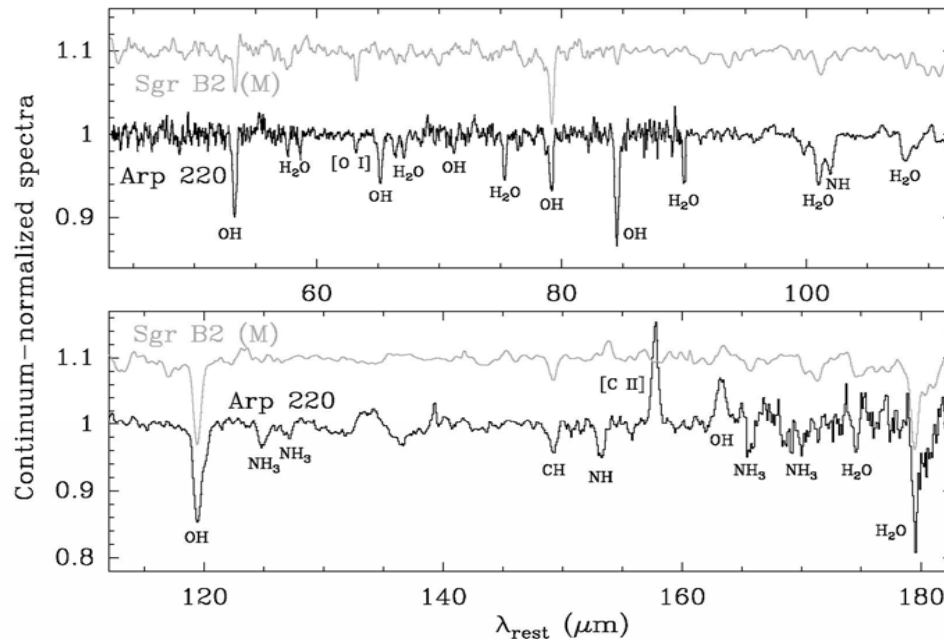
Freq.range	ν [THz]	Obs.Mode
band 1-5	480 -1250	Double beam
band 6 L/H	1410 -1910	wobbler
PACS	Full scan	one source

Chemical Complexity in Extragalactic Nuclei

II. Absorption towards luminous Xgal nuclei (incl. Arp220)

detailed chemical study of those lines that are not accessible from ground,
mainly the water lines and lines in bands 6 & 7.

Gonzalez-Alonso et al. (2004)



Transition	ν [THz]	Obs.Mode
Arp 220 (V=5426 km/s)		
$\text{o-H}_2^{16}\text{O } 1_{1,0}-1_{0,1}$	556.9	Ch
$\text{p-H}_2^{16}\text{O } 2_{0,2}-1_{1,1}$	987.9	Ch
$\text{p-H}_2^{16}\text{O } 1_{1,1}-0_{0,0}$	1113.3	Ch
$\text{o-H}_2^{16}\text{O } 2_{1,2}-1_{0,1}$	1669.9	Ch
$\text{o-H}_2^{18}\text{O } 1_{1,0}-1_{0,1}$	547.7	Ch
$\text{p-H}_2^{18}\text{O } 1_{1,1}-0_{0,0}$	1101.7	Ch
Total		WATER
$[\text{C II}] \ ^2\text{P}_{1/2} - ^2\text{P}_{3/2}$	1900.5	Ch
$\text{OH } ^2\Pi_{1/2} 3/2-1/2$	1834.7	Ch
$\text{NH}_3 \ 3_2-2_2$	1811.6	Ch
$\text{NH}_3 \ 3_2-2_2$	1765.0	Ch
$\text{NH}_3 \ 3_1-2_1$	1763.6	Ch
$\text{H}_2\text{O } 3_{03}-2_{12}$	1716.8	Ch
$\text{CH } J=2-1$	1657.0	Ch
$\text{H}_2^{18}\text{O } 2_{1,2}-1_{0,1}$	1655.9	Ch
$\text{CO } J=14-13$	1611.8	Ch
$[\text{N II}] \ ^3\text{P}_1 - ^3\text{P}_0$	1461.1	Ch
Total		BANDs 6
PACS Full Scan		

Chemical Complexity in Extragalactic Nuclei

III. The Physics of the ISM in low-metallicity environments

Study of physical processes and conditions in a limited sample of regions of low-metallicity ISM

Galaxie	Distance [Mpc]	Z/Z _⊙	L _{IR} (L _⊙)	Peak brightness [CII] [10 ⁻⁴ ergs cm ⁻² s ⁻¹ sr ⁻¹]	Area [arcmin]
LMC	0.05	0.35	5.5(8)	2.5(-4)	
SMC	0.06	0.10		0.6(-4)	
IC10	0.8	0.15	0.1 (9)	0.1(-4)	6x6
NGC1569	2	0.3	0.7 (9)	0.7(-4)	2x1
IC4662	2		0.1 (9)	0.1(-4)	1.3x1
BHB	3	1:			1x1
NGC5253	4	0.4	0.8 (9)		3x2
IZw18	11	0.03			1x1
Haro2	20	0.5	2.7 (9)		1x1



Line	ν [THz]	Area [arcmin]	Grid [arcsec]	Positions No	Δν [kms ⁻¹]	rms [mK]
LMC – N11 (clouds no. 27, 28 & 27)						
[CI]	0.49	1x1	50	2	2	6
	0.81	1x1	30	4	2	6
[CII]	1.90	1x1	10	36	2	90
N + O		1x1	9			

Summary of observing time requests

Project	Total	HIFI	PACS
Physical Conditions of the ISM in the Galactic Center	106	89	17
Excitation Studies of Starbursts, ULIGs & AGN			
Excitation of starbursts, ultraluminous and AGN	100	83	17
Interacting galaxies, incl. case study of Antennae	44	37	7
NUGA sample of AGN	25	25	-
Special Case Study: Cen A	17	15	2
Chemical Complexity in Extragalactic Nuclei			
Line surveys towards extragalactic nuclei	46	36	10
Absorption towards luminous extragalactic nuclei	45	35	10
Physics of the ISM in Low-metallicity Environments	53	37	16
Total time requested [h]	432	353	79



DAMIR-IEM Contribution

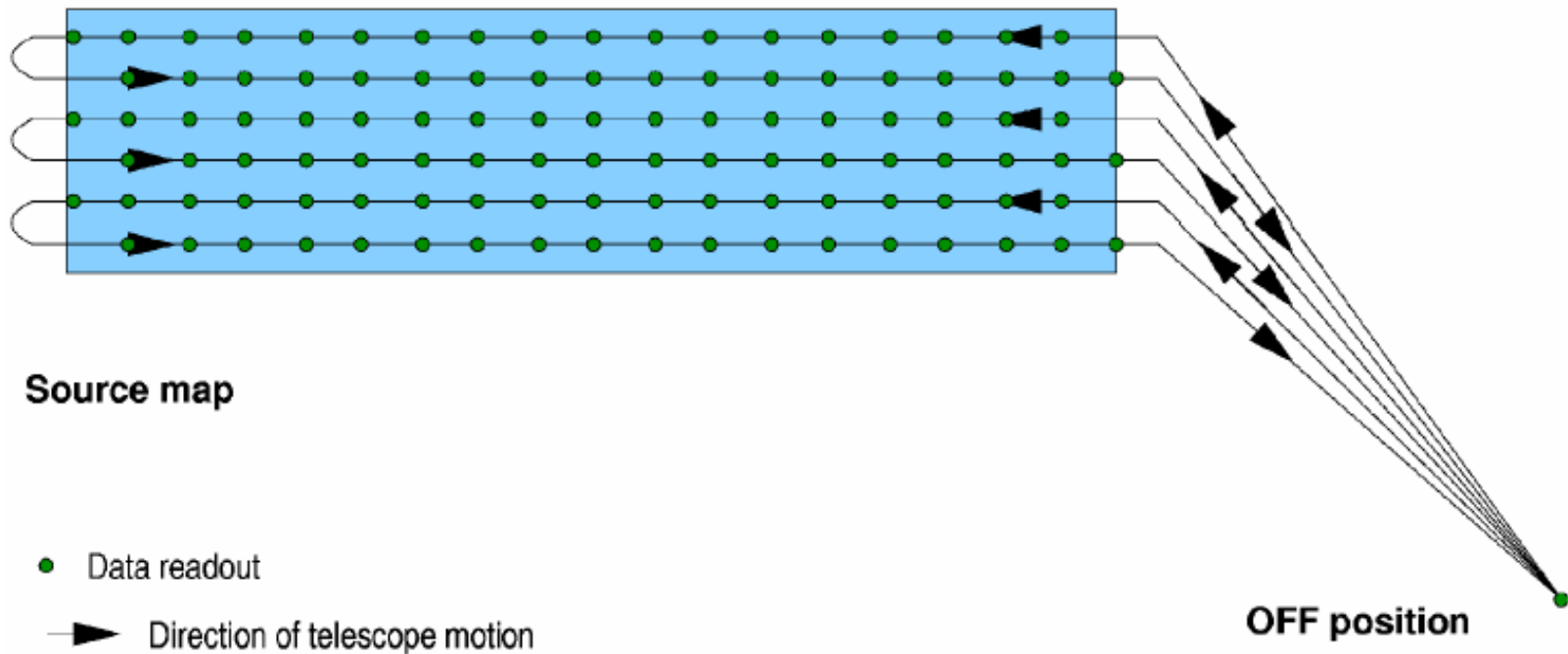
OTF Map Processing

Eduardo Sanchez

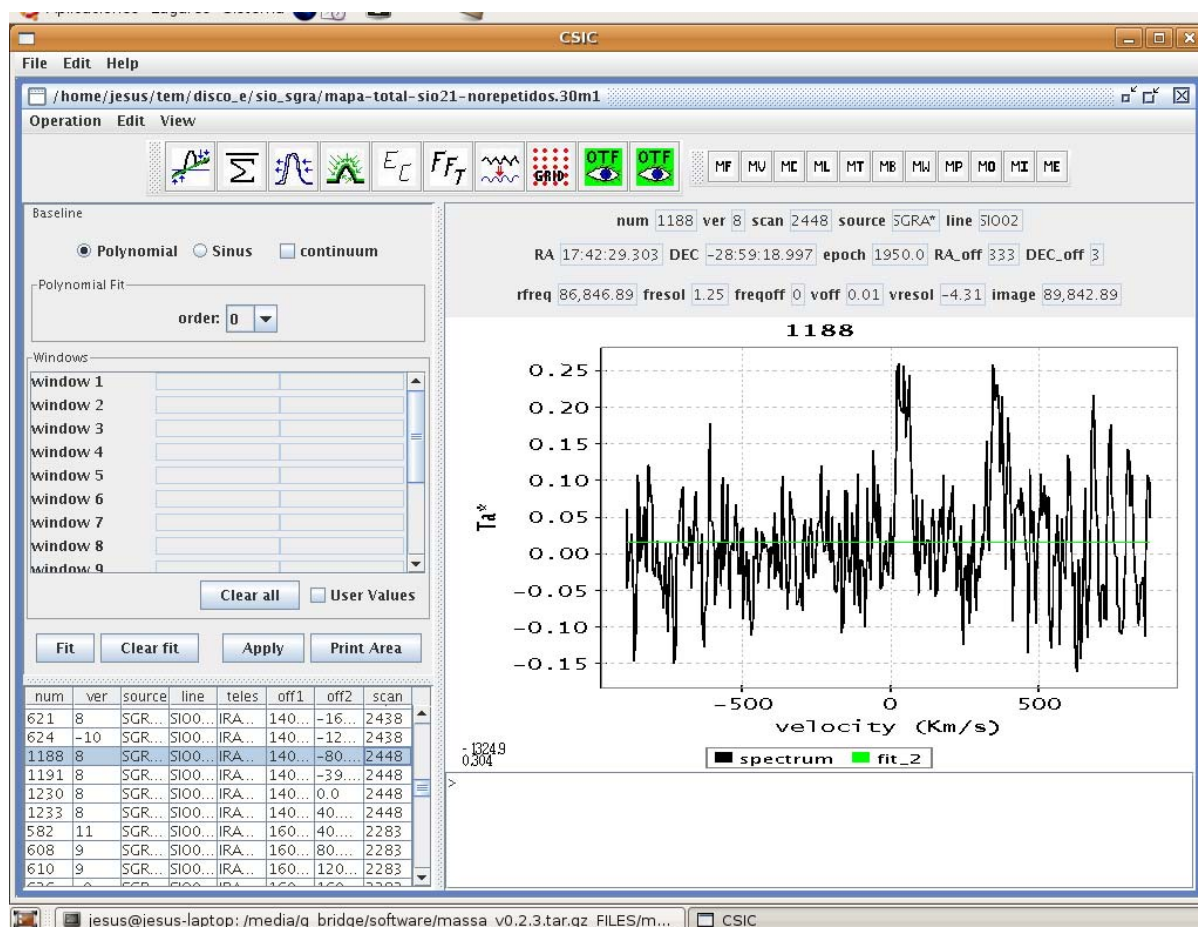
David Hurtado

Laura Diez Merino

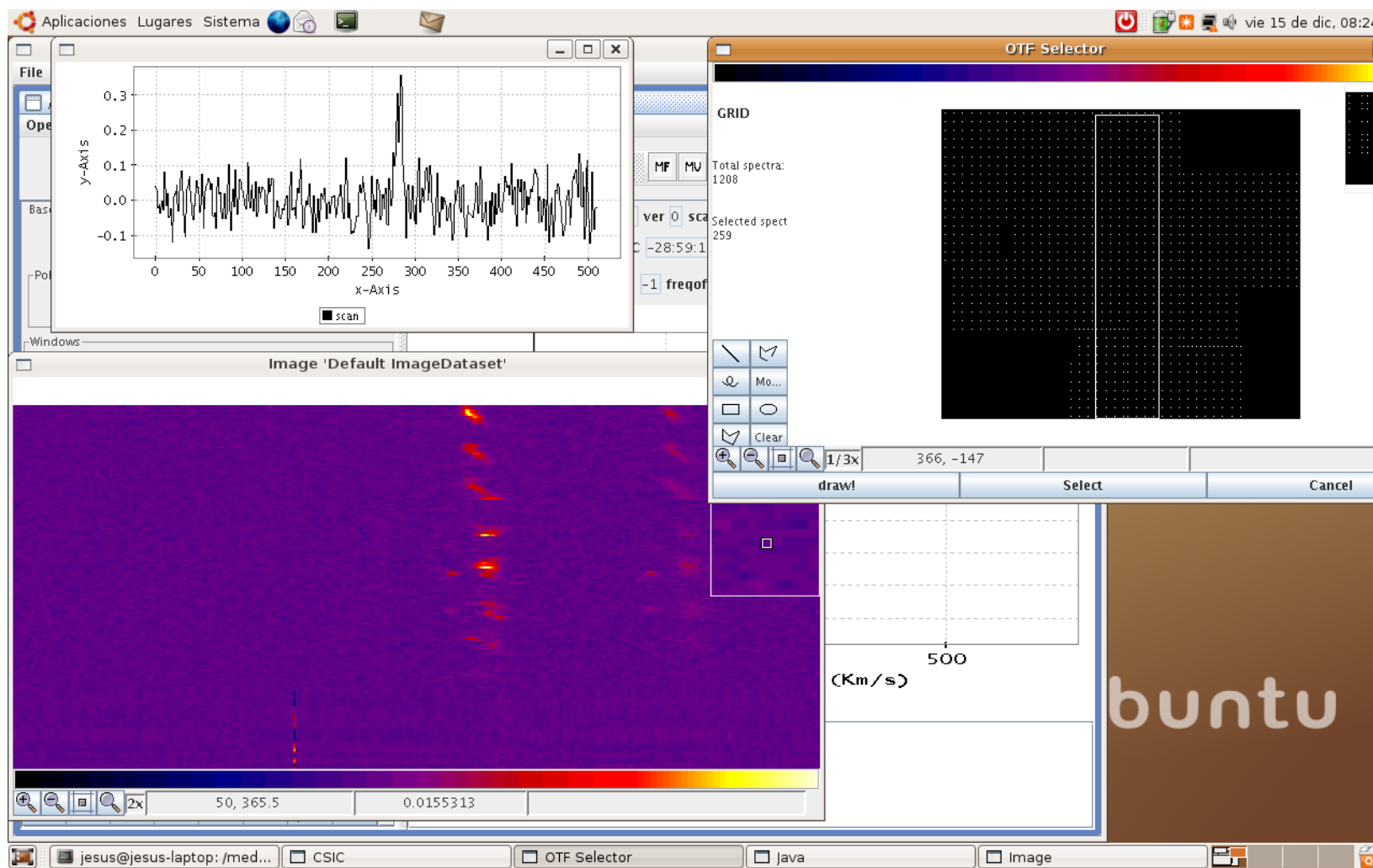
OTF image reconstruction (MASSA)



- Interactive package based on HCSS (Java and Jython)



- Interactive package based on HCSS (Java and Jython)



MADCUBA

