THE SYNERGY BETWEEN ALMA & HERSCHEL

(Herschel /ground based facilities)

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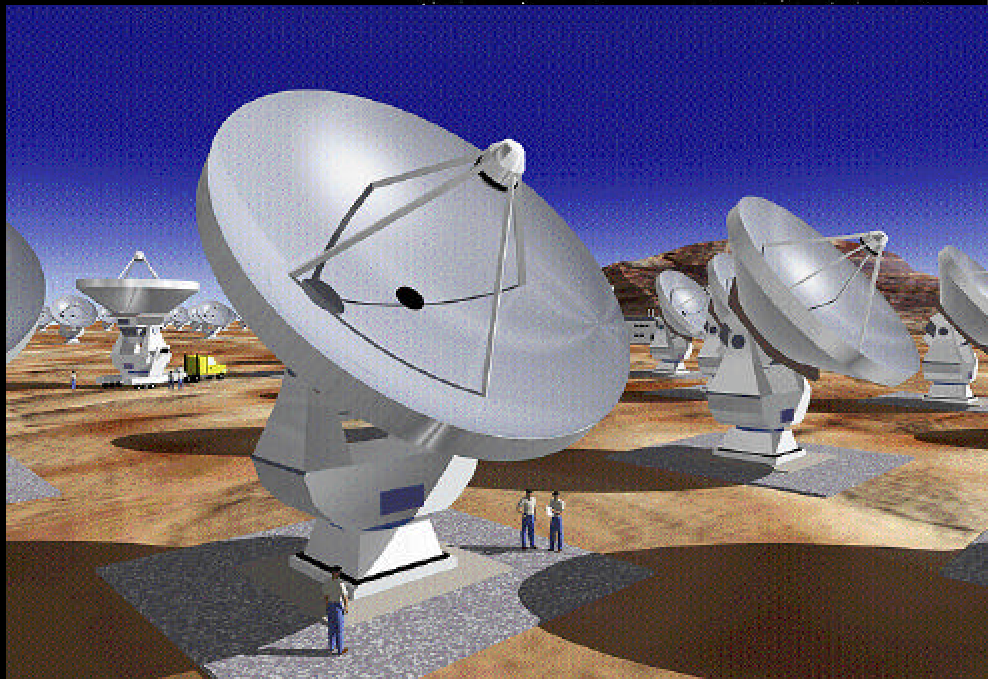

THE ESA-ESO Working Groups

- **THE HERSCHEL-ALMA SYNERGIES**

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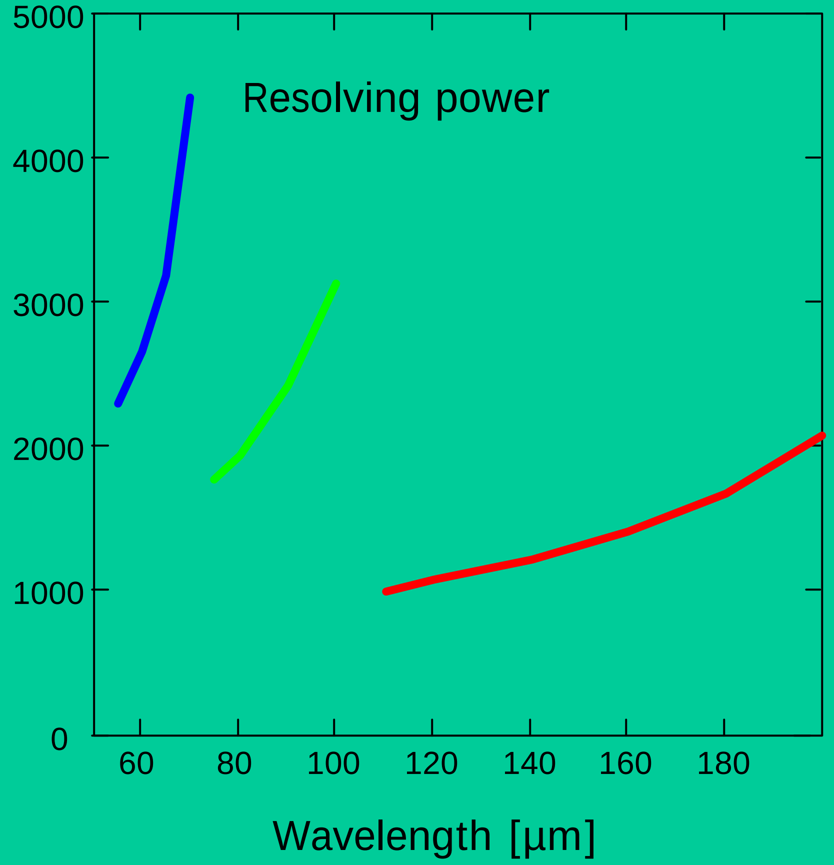
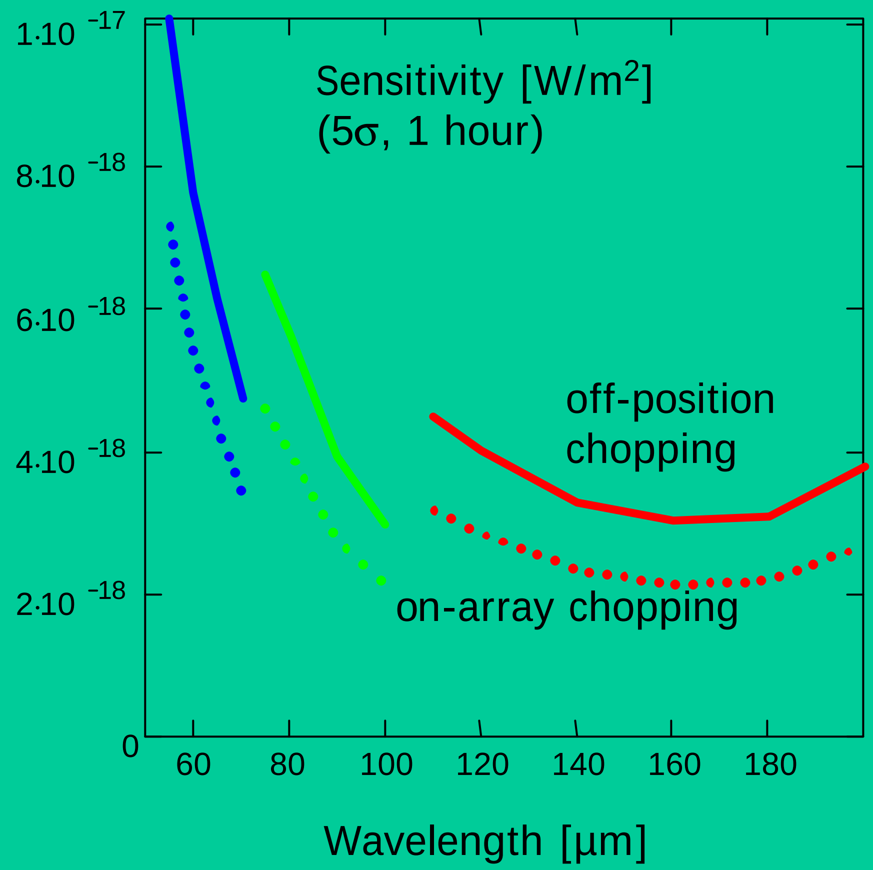
Synergies or complementarity

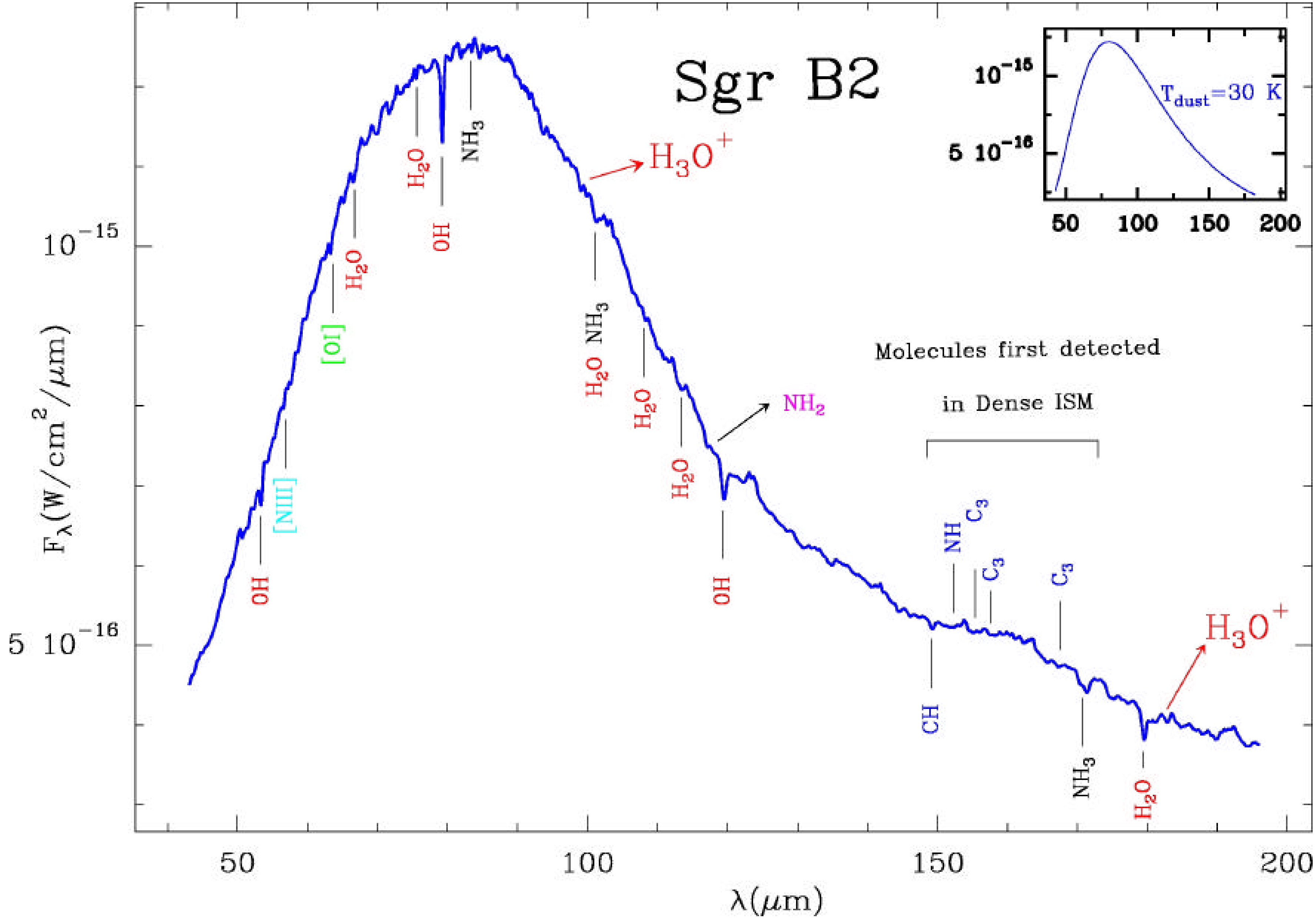
- Different lifetimes (Herschel will operate until 2012, just the date for ALMA first light)
- Different spectral resolution except for HIFI
- Angular resolution 100-1000 better for ALMA
- Surface 600 times larger for ALMA.

Predicted PACS Spectrometer Performance

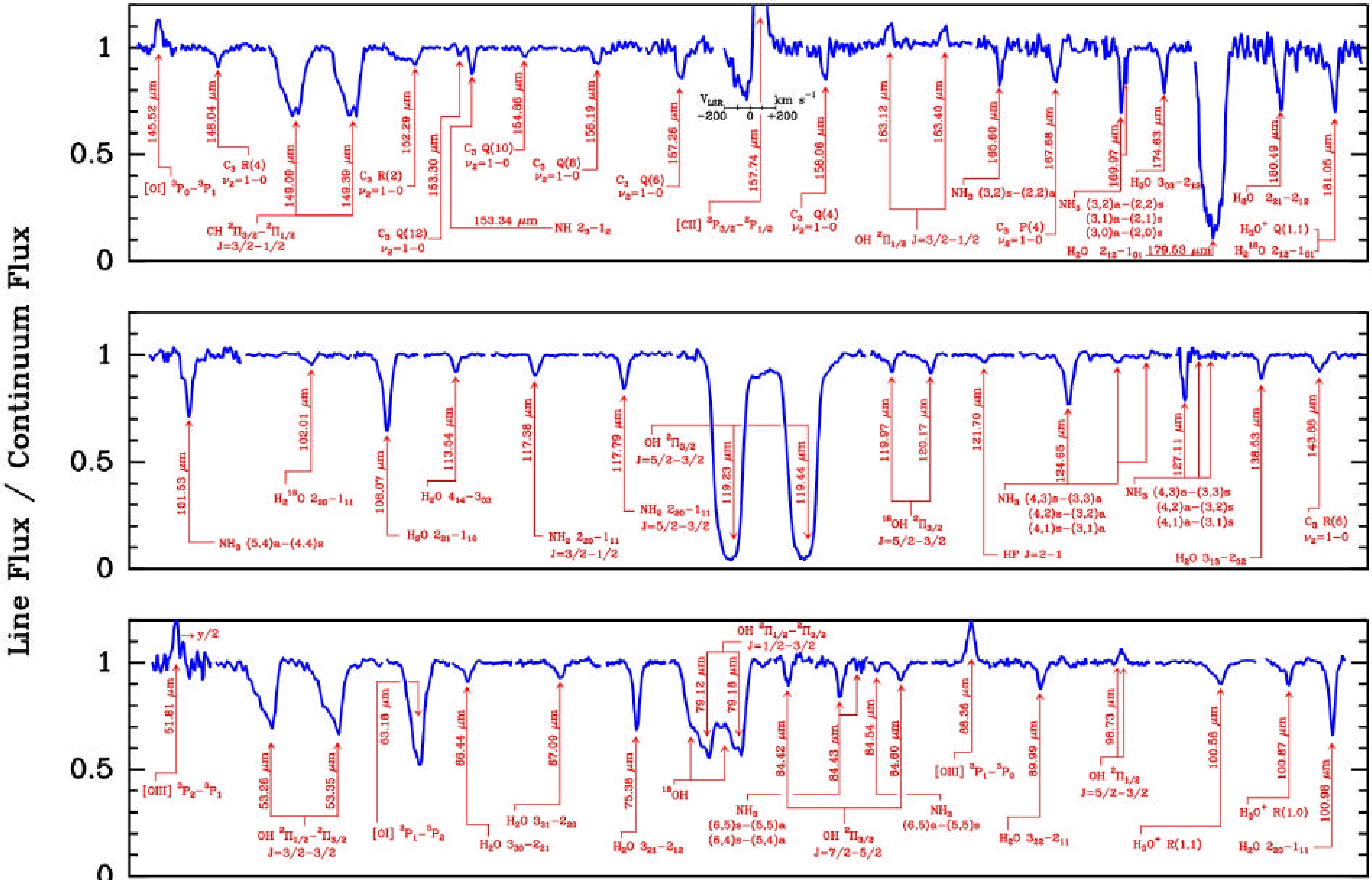




Cernicharo et al., A&A, 1997, 323, L25



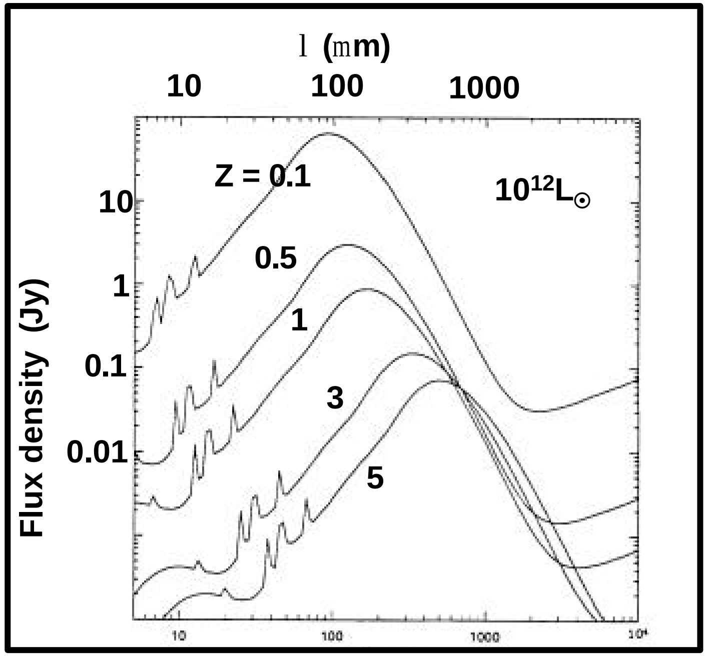
Goicoechea et al. 2004



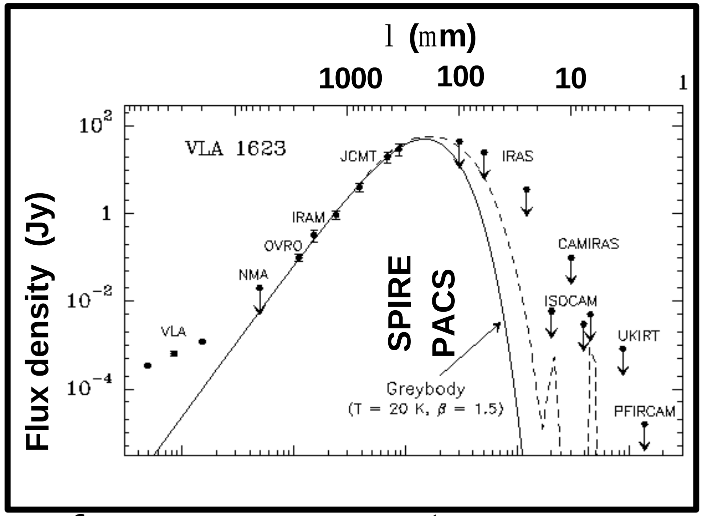
- PACS will provide a unique view of the role of hydrides and Carbon Clusters:
- ALMA will be able to observe the products of reactions of these “hidden molecules”

SPIRE: The Spectral and Photometric Imaging Receiver

- **Main scientific design drivers**
  - **Wide-area extragalactic and galactic surveys with spectroscopic follow-up**
  - **Medium-resolution imaging spectroscopy of the ISM and star-forming regions in our own and nearby galaxies**



- **Sensitivity limited by thermal emission from the Herschel telescope (80 K; e = 4%)**



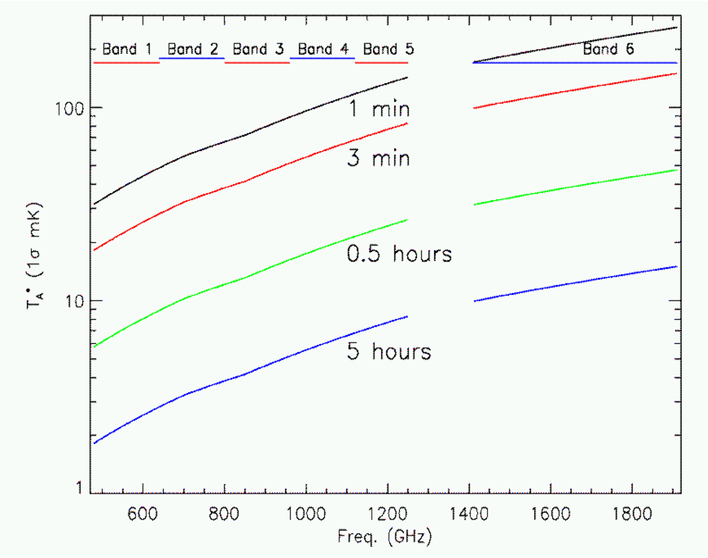
- **^{3}He cooled bolometer detector arrays (0.3 K)**

- **Minimal use of mechanisms**
  - **Photometer beam steering mirror**
  - **FTS mirror drive**

•SPIRE : All CO, HCN, H_2O,, lines in high mass star forming regions (+PACS+HIFI)

•ALMA : detailed view of these regions

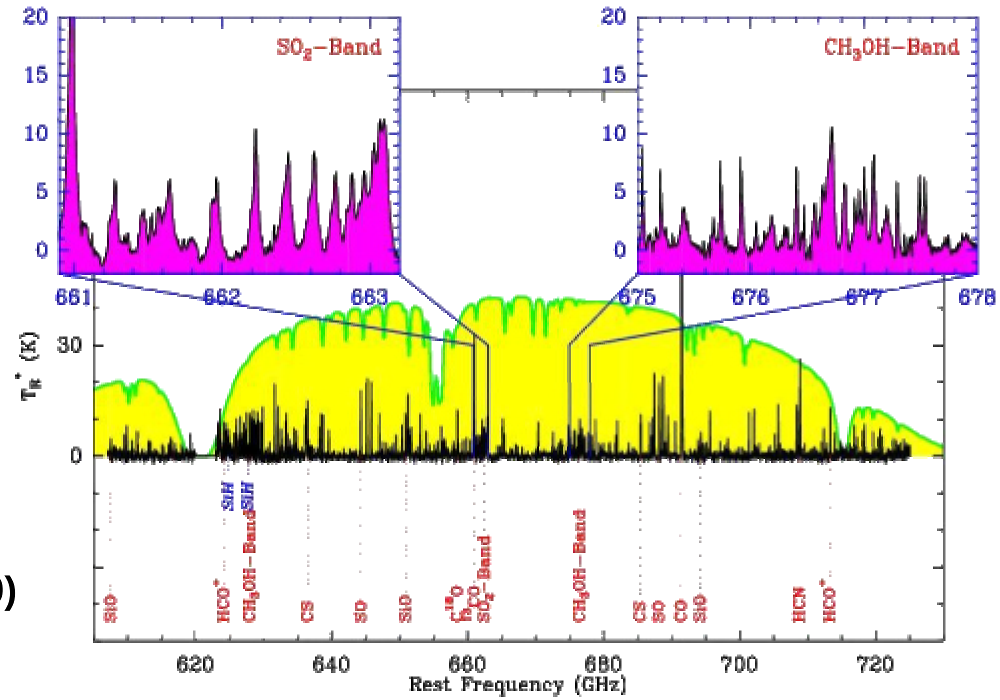
HIFI Expected Performance



- **Noise levels**
- **Setting 4 GHz**
- **Resolution 1 MHz**
- **DSB**

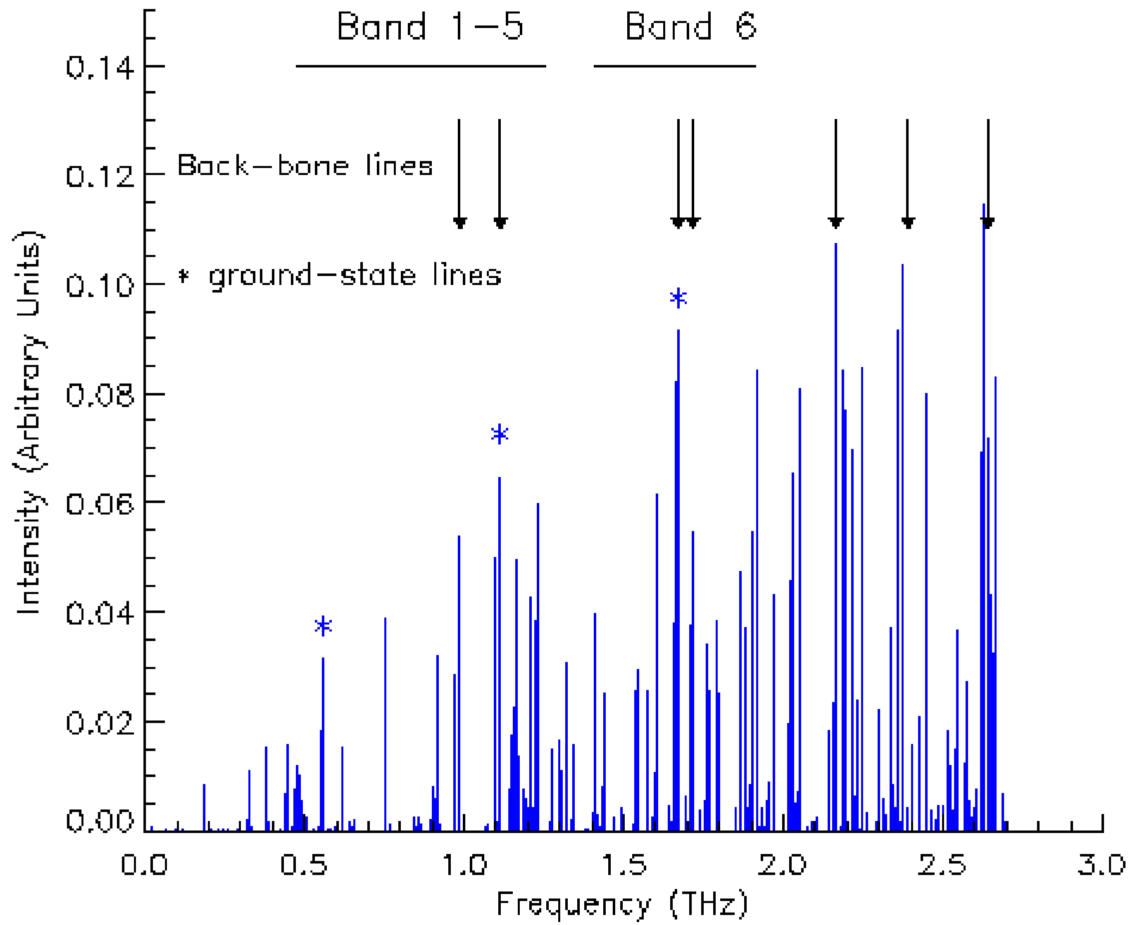
- **CSO Spectrum of Orion: 8 nights**
- **Same spectrum for HIFI: expected less than 1 hour**
- **Total HIFI range in 12 hours**

(Schilke et al. 2000)

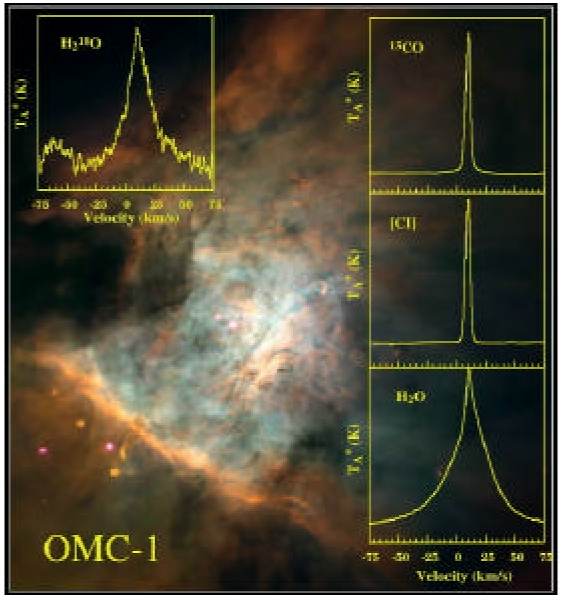


•HIFI : full molecular census ; ALMA : detailed spatial distribution

Science with HIFI – Water



Laboratory Data

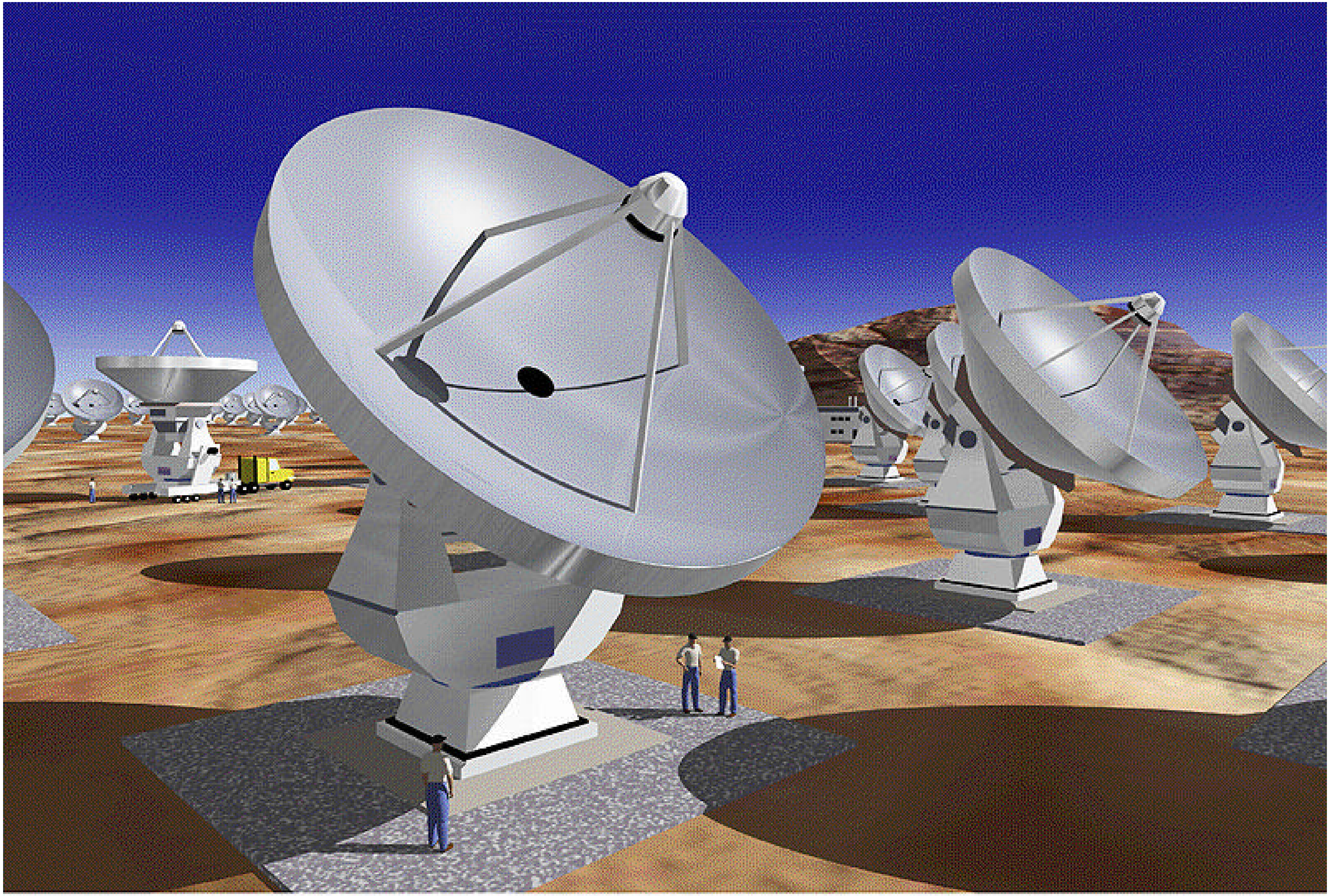


SWAS observations of the Orion Region OMC-1

Courtesy HIFI Project

Table 6: Some Characteristics of the Herschel Spectrometers

System	Wavelength Limits (μm)	Resolution (kms^{-1})	Spectral Coverage (kms^{-1})	Field of View (')
PACS	57-210	80-300	700-3000	0.8
SPIRE	200-300	300-15000	2500-125000	2.6
SPIRE	300-670	480-24000	4000-200000	2.6
HIFI	157-212	0.02-0.2	960-2500	0.2
HIFI	240-625	0.1-0.6	850-625	0.8



Artist's Impression of ALMA
(Atacama Large Millimetre Array)

ESO PR Photo 24a/99 (8 June 1999)

ALMA BASELINE (HAS BEEN REBASELINED to 50 Antennas)

- 64 antennas, transportable
  - 12-m diameter, transportable
  - 25 microns rms surface error
  - 0.6" rms offset pointing error in winds < 9 m/s
  - Fast switching (1.5 degrees in 1.5 sec)
- Configurations from 150-m to 14 km, as continuous as possible.
- 4 frequency bands, dual-polarisation
  - Band 3, 84-119 GHz, SSB
  - Band 6, 211-275 GHz, SSB
  - Band 7, 275-370 GHz, SSB
  - Band 9, 602-720 GHz, DSB
- 183 GHz Water Vapor Radiometers for phase calibration
- 8 GHz bandwidth per polarisation
- High accuracy calibration (3 % absolute, with 1 % goal)
- "Easy to use" instrument

Table 2: ALMA Front Ends [a]

Band 1	(1cm)	31.3-45 GHz	HEMT [b]	
Band 2	(4mm)	67-90 GHz	HEMT	
Band 3	(3mm)	84-116 GHz	SIS [c,d]	**Baseline**
Band 4	(2mm)	125-163 GHz	SIS [e]	**Japan**
Band 5	(1.8mm)	163-211 GHz	SIS [f]	**UE -8 Receivers**
Band 6	(1.3mm)	211-275 GHz	SIS [d]	**Baseline**
Band 7	(0.9mm)	275-373 GHz	SIS [d]	**Baseline**
Band 8	(0.6mm)	385-500 GHz	SIS [e]	**Japan**
Band 9	(0.5mm)	602-720 GHz	SIS [d]	**Baseline**
Band 10	(0.3mm)	787-950 GHz	SIS [g]	**Japan ?**

[a] All with dual polarisation; each polarisation feeds four IF sections, each with a bandwidth of 2 GHz, giving a total bandwidth of 8 GHz in each polarisation. Also uncooled 183 GHz water vapour monitors provide data for phase corrections

[b] High Electron Mobility Transistor receiver

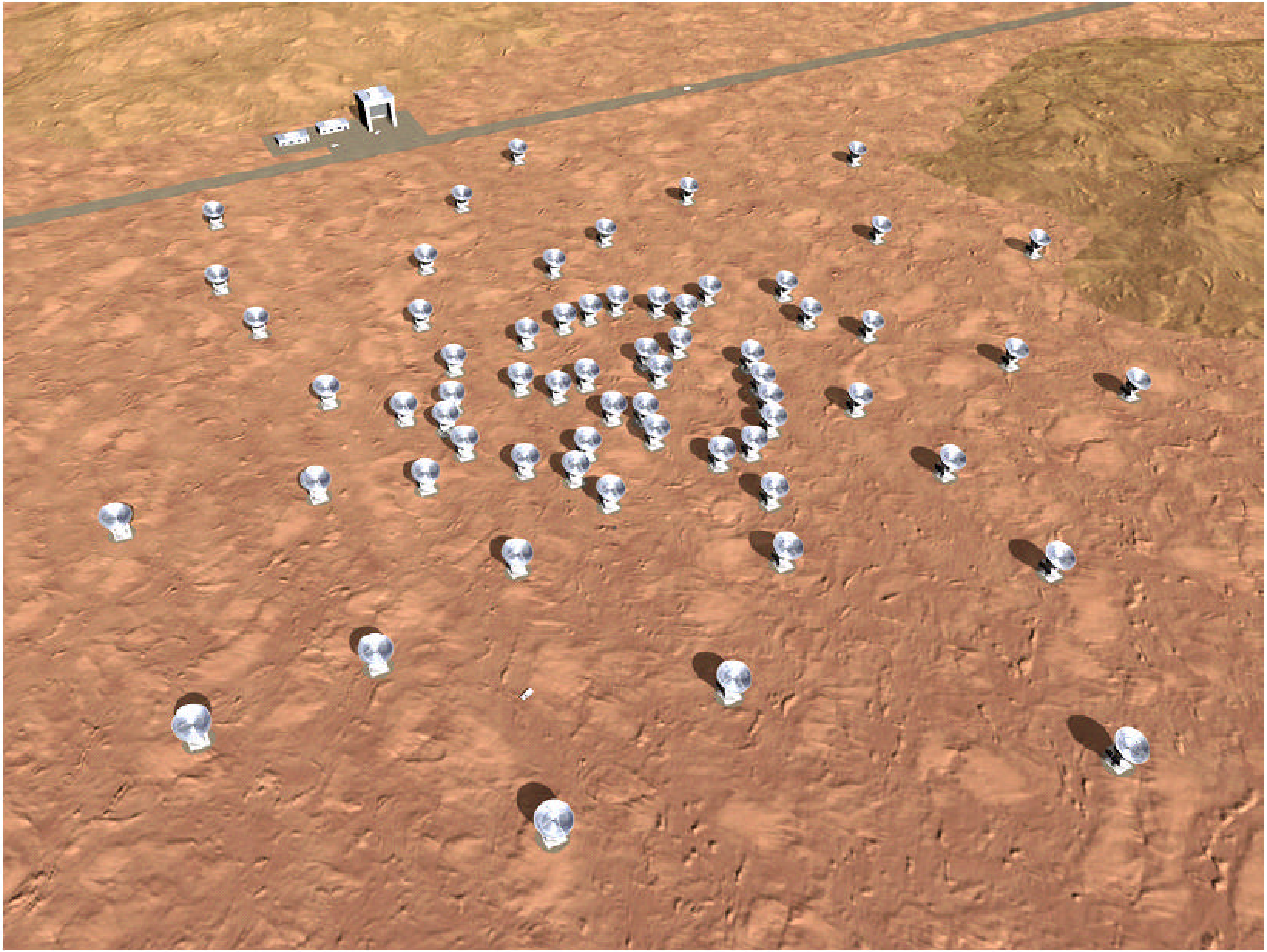
[c] Superconductor-Insulator-Superconductor mixer receivers.

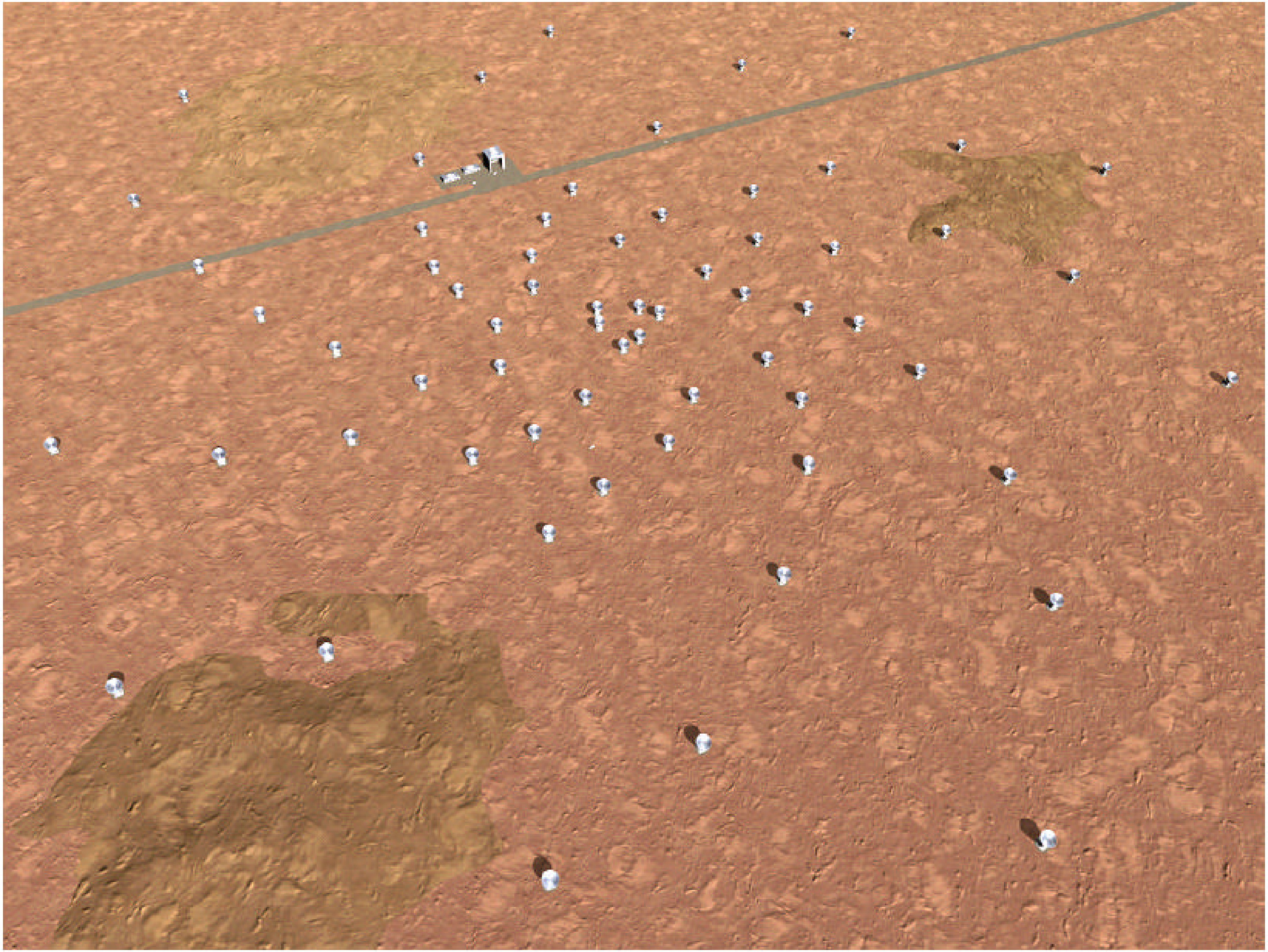
[d] In the bilateral baseline plan

[e] Contribution from Japan

[f] Funded by EC for 6 antennas

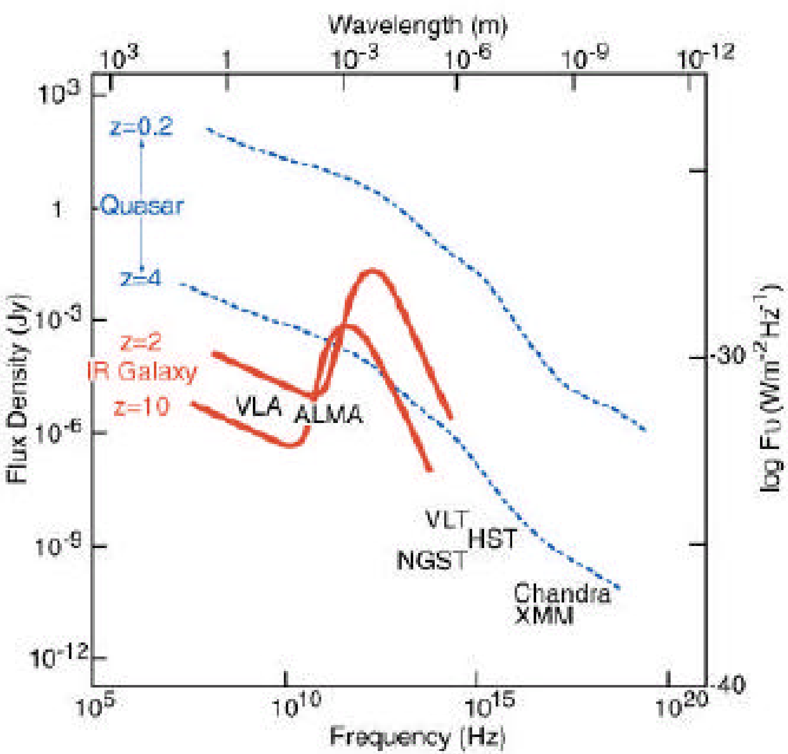
[g] Contribution from Japan; depends on R&D programme



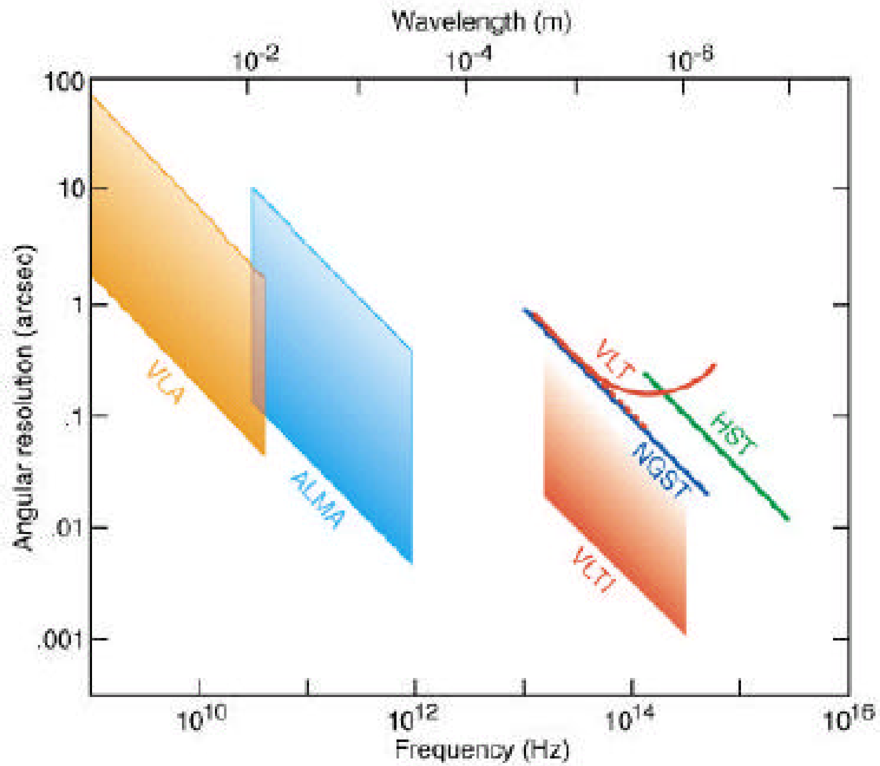


A mm/submm equivalent of VLT, HST, NGST

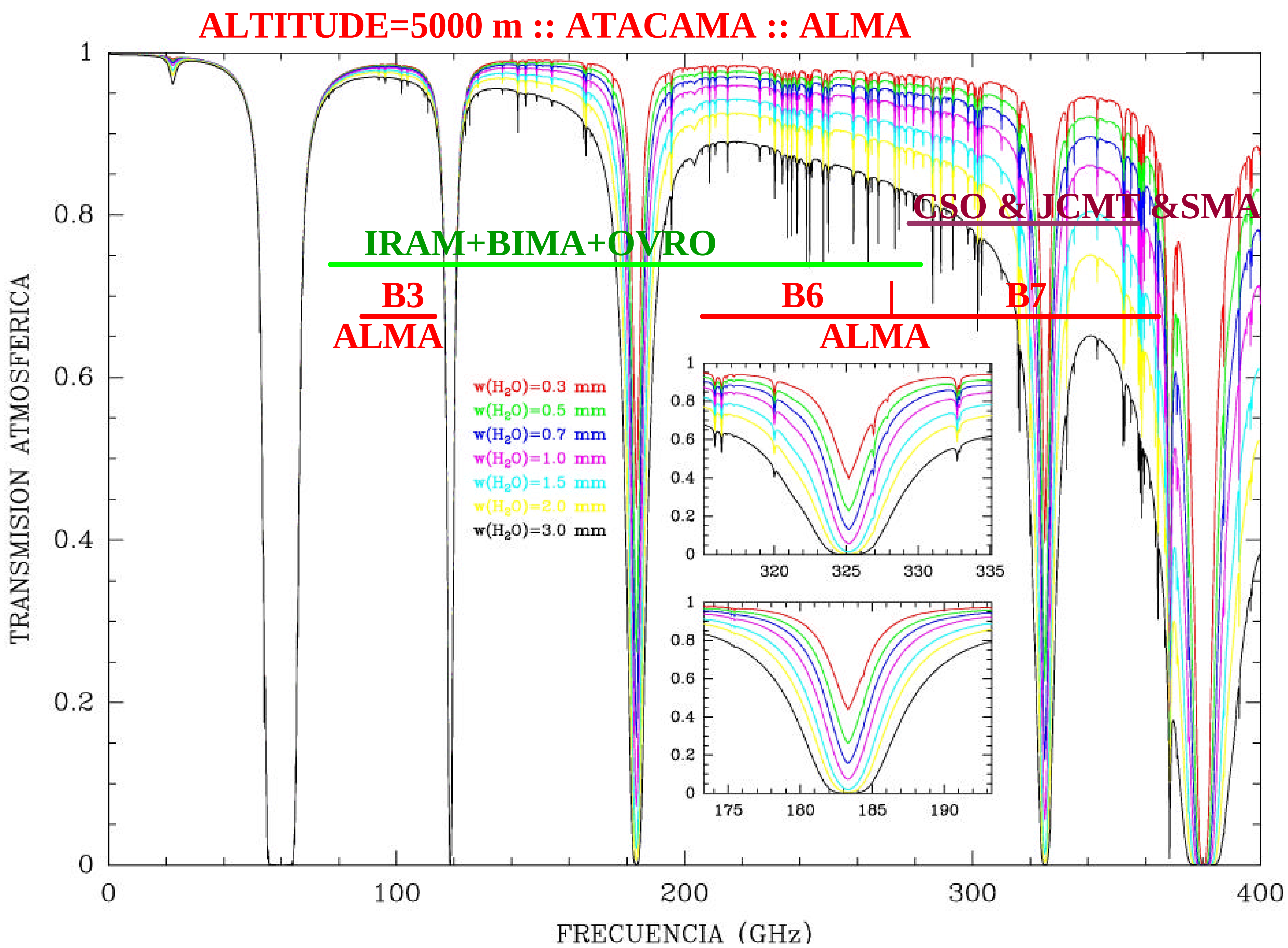
Sensitivity



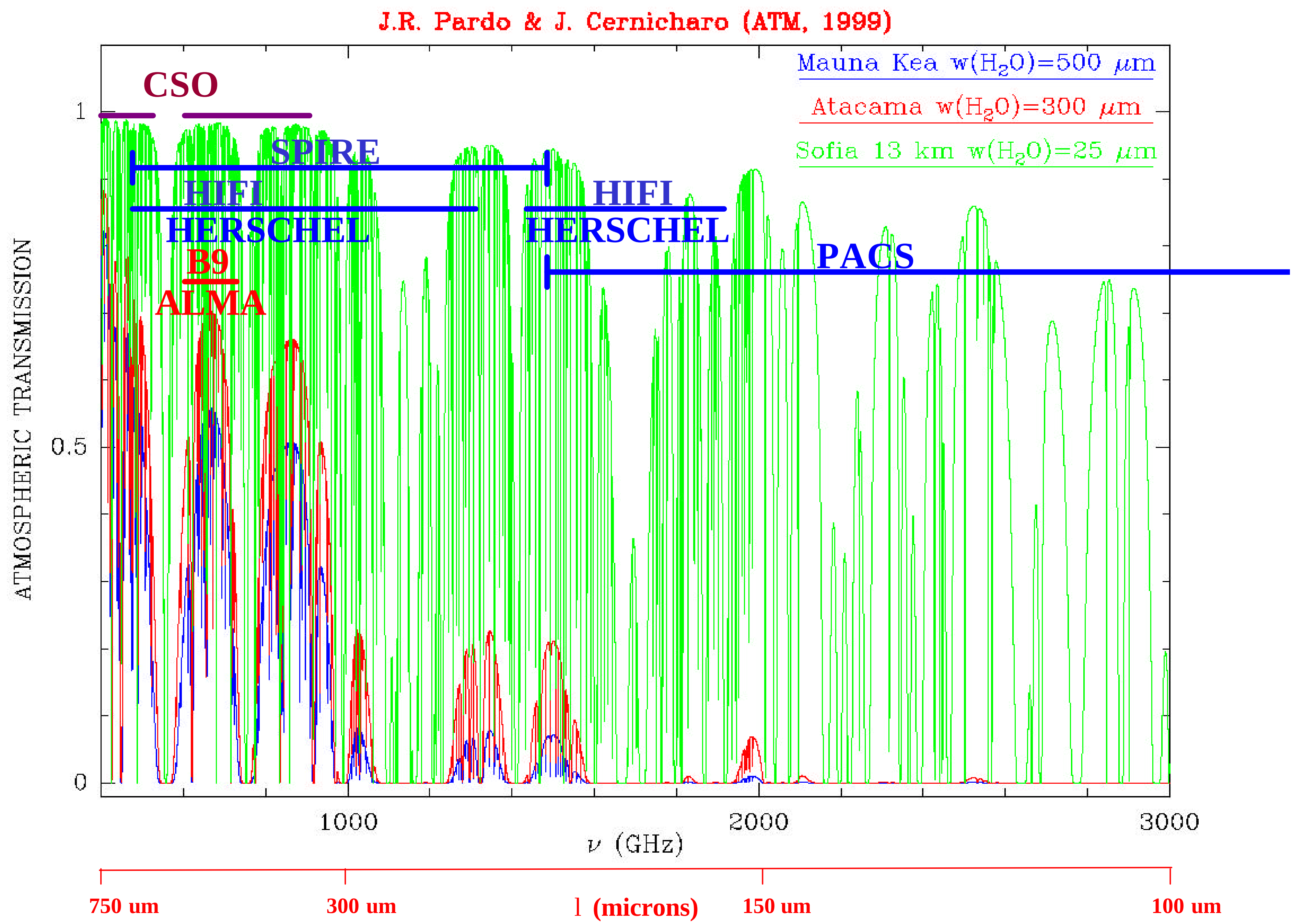
Angular Resolution



From P. Shaver



ALTITUDE=5000 m :: ATACAMA :: ALMA
IRAM+BIMA+OVRO
CSO & JCMT &SMA
B3
ALMA
B6
B7
ALMA
w(H2O)=0.3 mm
w(H2O)=0.5 mm
w(H2O)=0.7 mm
w(H2O)=1.0 mm
w(H2O)=1.5 mm
w(H2O)=2.0 mm
w(H2O)=3.0 mm
TRANSMISION ATMOSFERICA
FRECUENCIA (GHz)


J.R. Pardo & J. Cernicharo (ATM, 1999)
Mauna Kea w(H2O)=500 μm
Atacama w(H2O)=300 μm
Sofia 13 km w(H2O)=25 μm
CSO
SPIRE
HIFI
HERSCHEL
HIFI
HERSCHEL
PACS
B9
ALMA
ATMOSPHERIC TRANSMISSION
1
0.5
0
1000
2000
3000
ν (GHz)
750 um
300 um
l (microns)
150 um
100 um

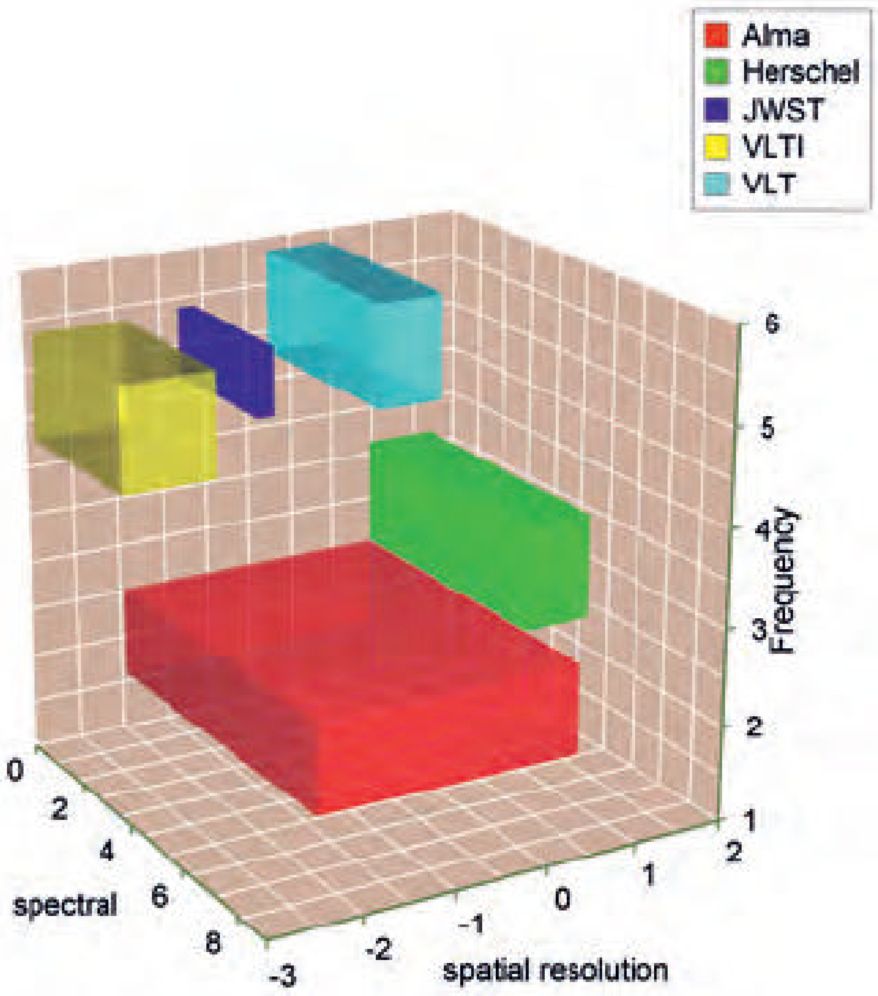
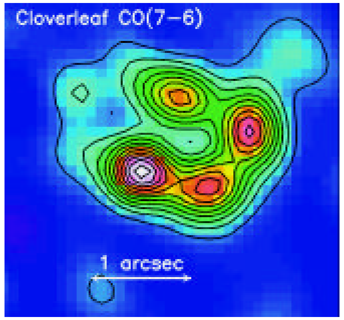


Figure 6: A three-dimensional plot of frequency, angular resolution and resolution for the instruments compared in Fig. 5.



SCIENCE WITH ALMA and THE SYNERGY with HERSCHEL

-Studies of the early Universe

-Gravitational lensing

-QSO molecular absorption lines

-Detailed studies of galaxies

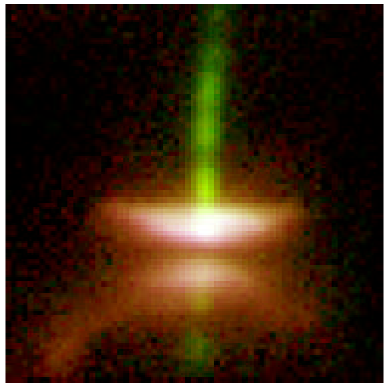
-AGNs

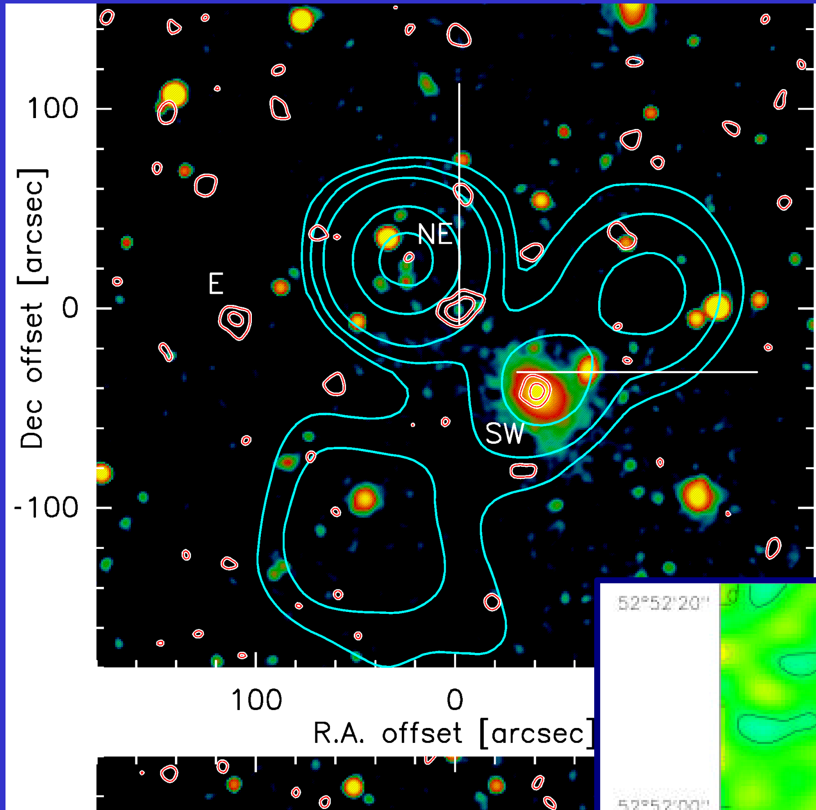
-Interstellar absorption lines

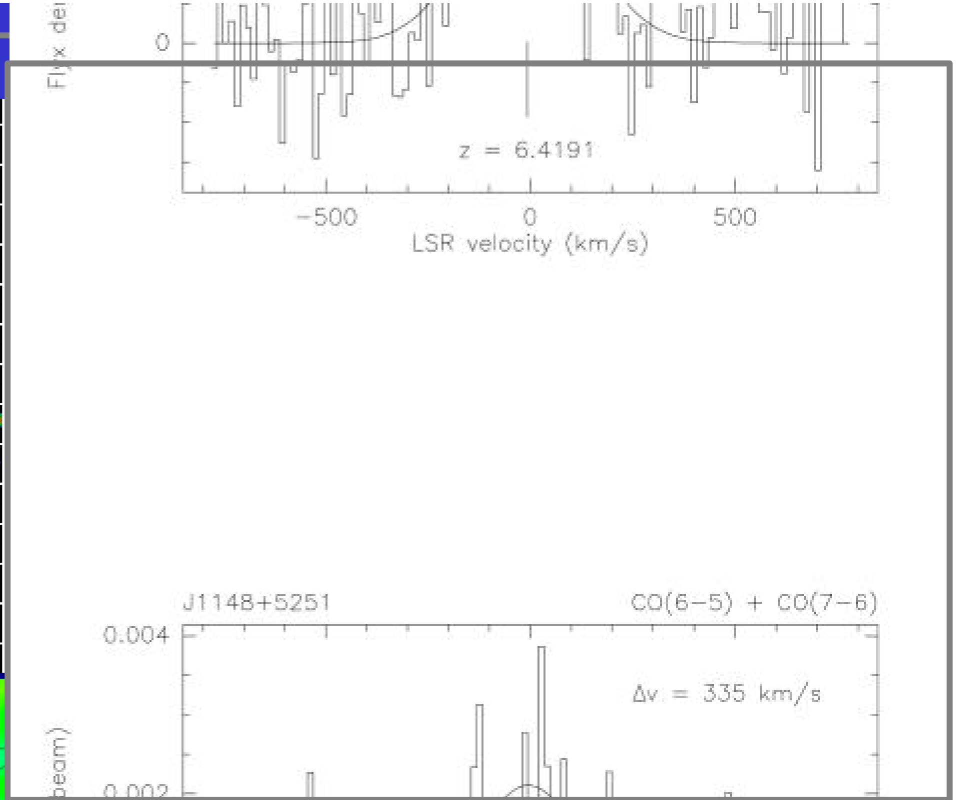
-Astrochemistry

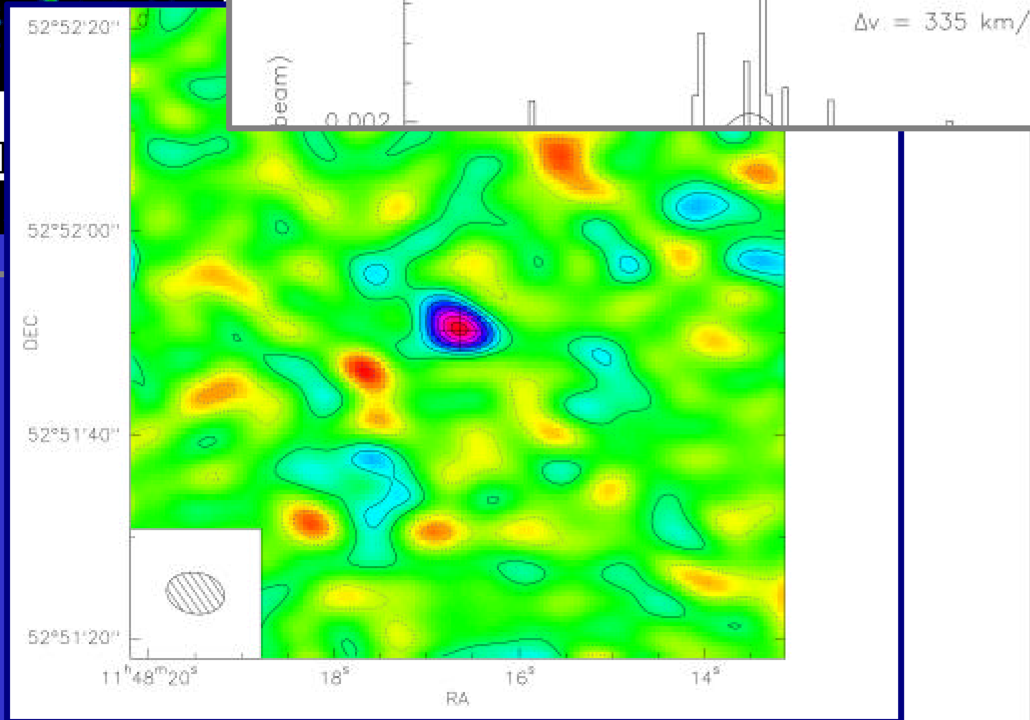
-Protostellar clouds

- Young stellar objets
- Outflows
- AGBs
- Protoplanetary Nebulae
- Masers









Bertoldi et al. 2003

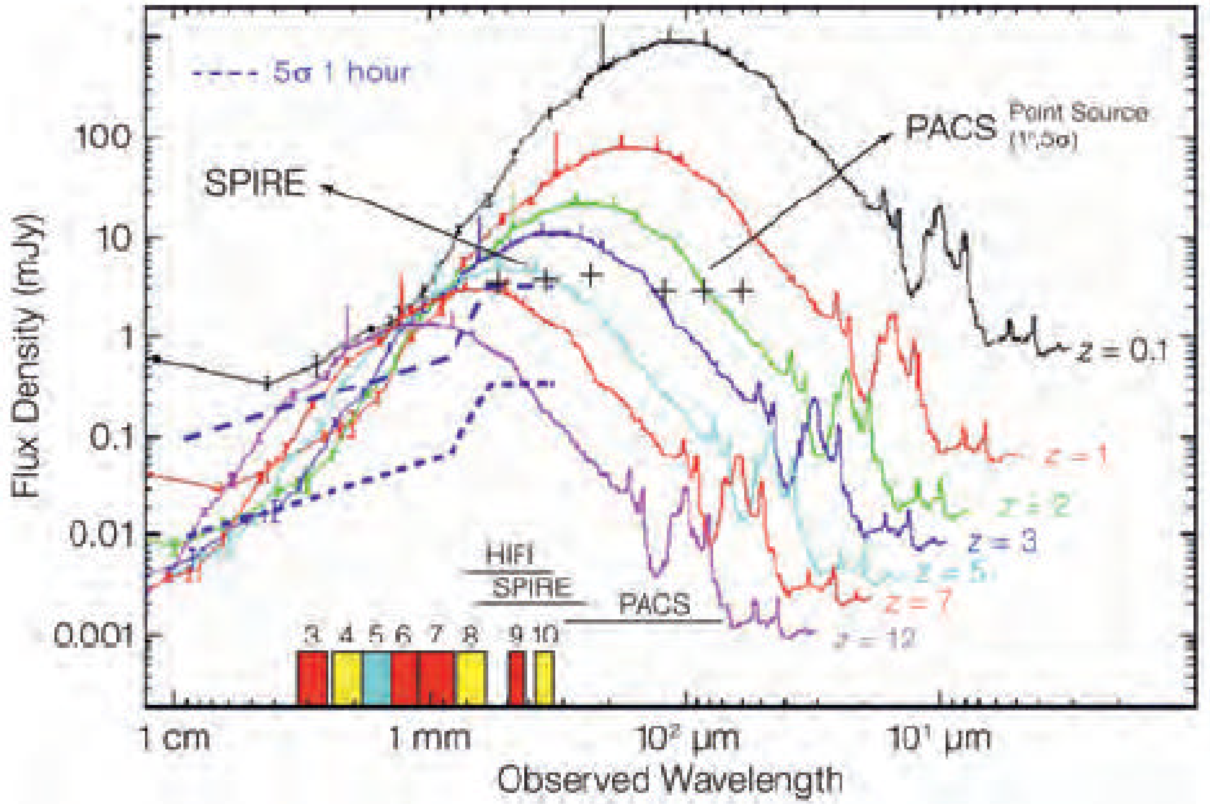
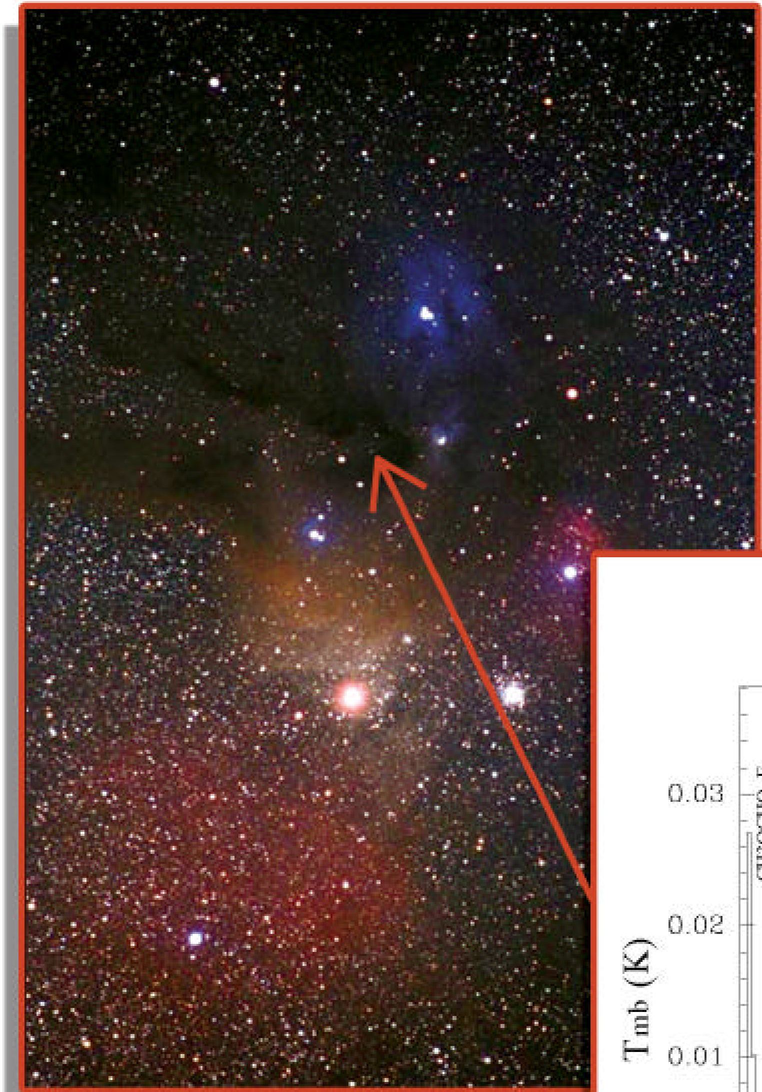
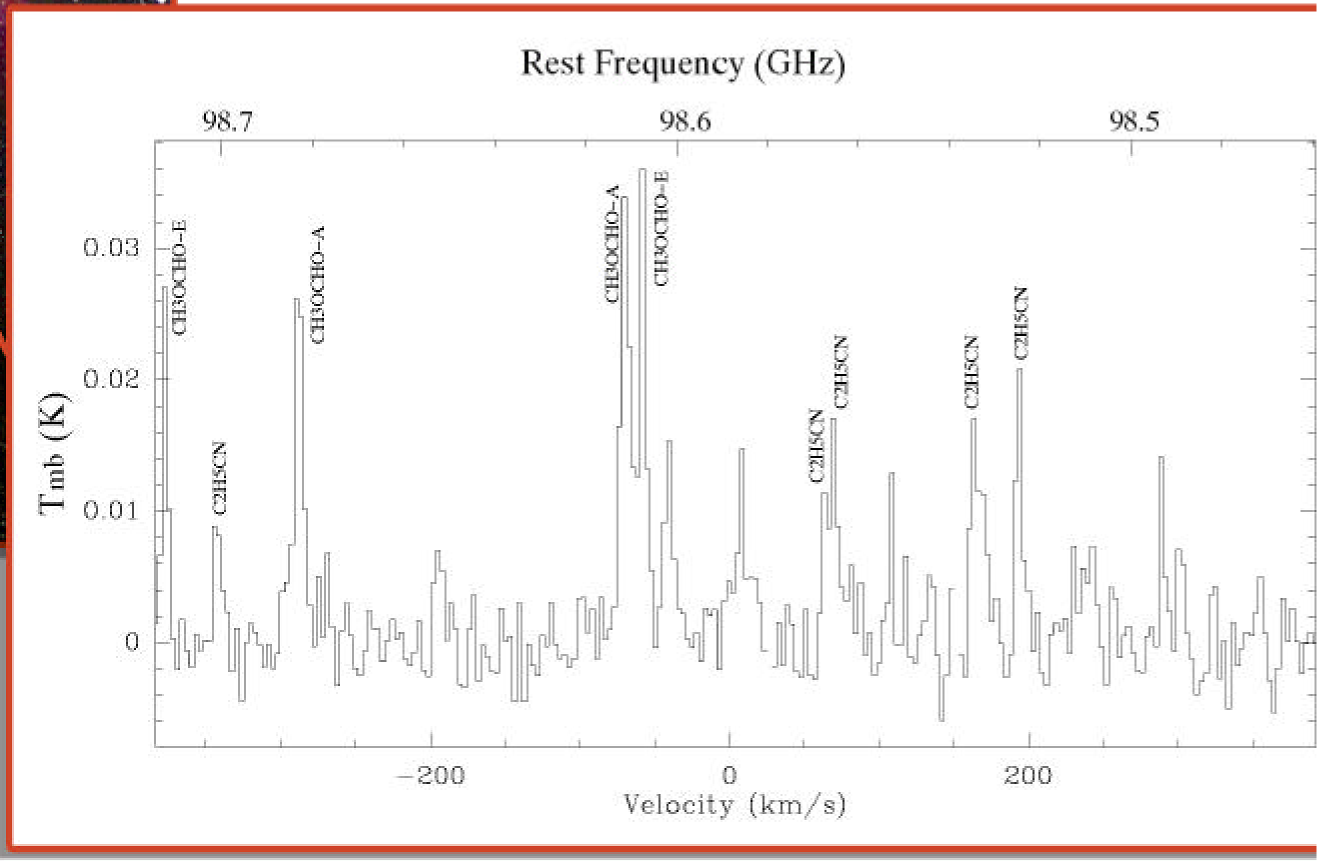


Figure 7: A plot of the emission from the starburst galaxy M82 for different redshifts, z. The horizontal axis is observed wavelength, the vertical axis is predicted flux density in mJy. The crosses show the sensitivity of the Herschel bolometers, taken from Griffin et al., 2005. The dashed lines in the left side of this diagram show the 5-sigma sensitivity of ALMA. The lower dashed curve is for the 64 antenna ALMA and the upper curve for a 6-antenna ALMA. The ALMA receiver bands are shown numbered above the horizontal axis. Cf Fig. 1 for line identifications. The coverages of the Herschel instruments are shown as horizontal lines (HIFI, SPIRES, PACS).

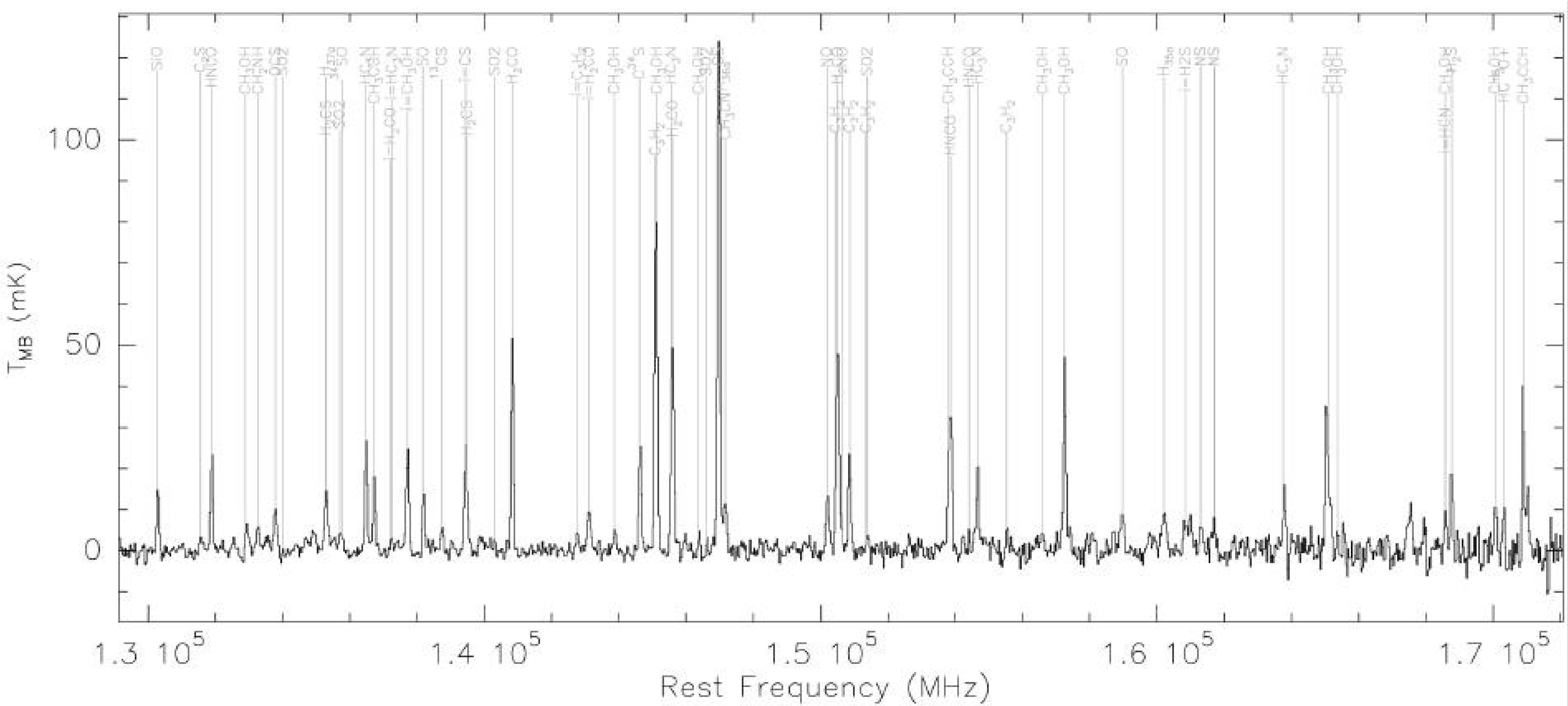
Molecular complexity in solar type protostars





Cazaux et al. 2003

Sergio Martín et al. 2004



Water Vapor

183.3 and 325 GHz

(ALMA FREQUENCIES!!)

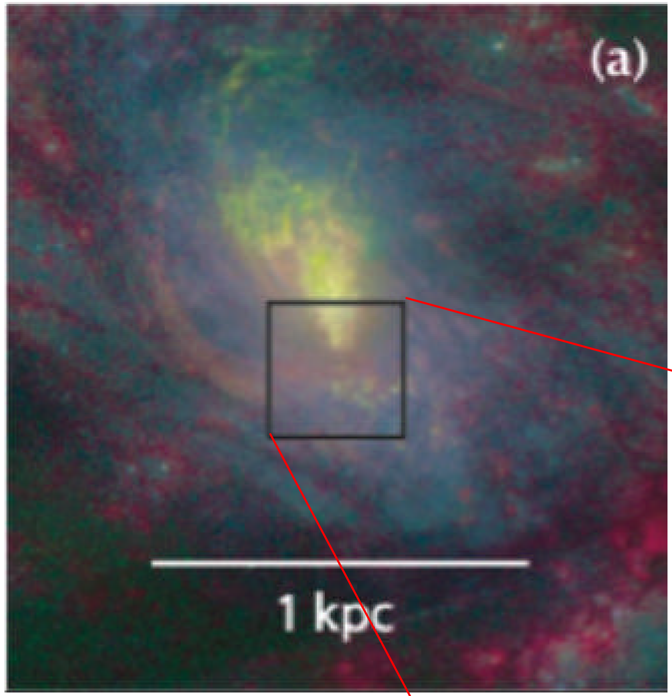
Galaxies

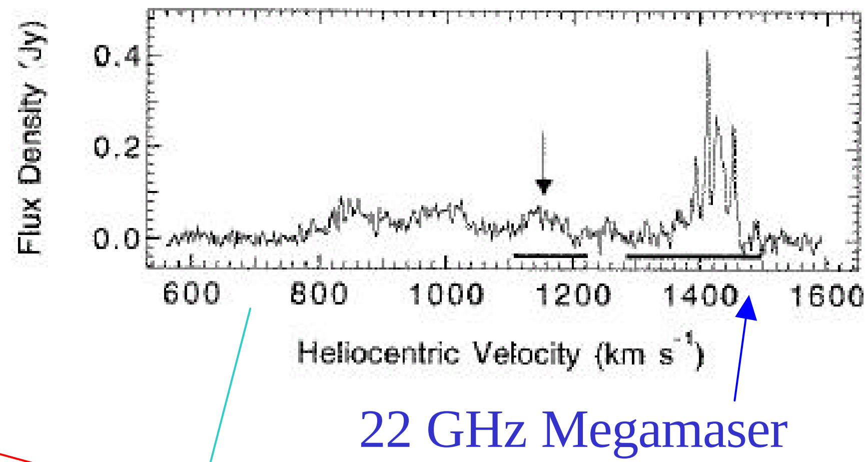
ISM

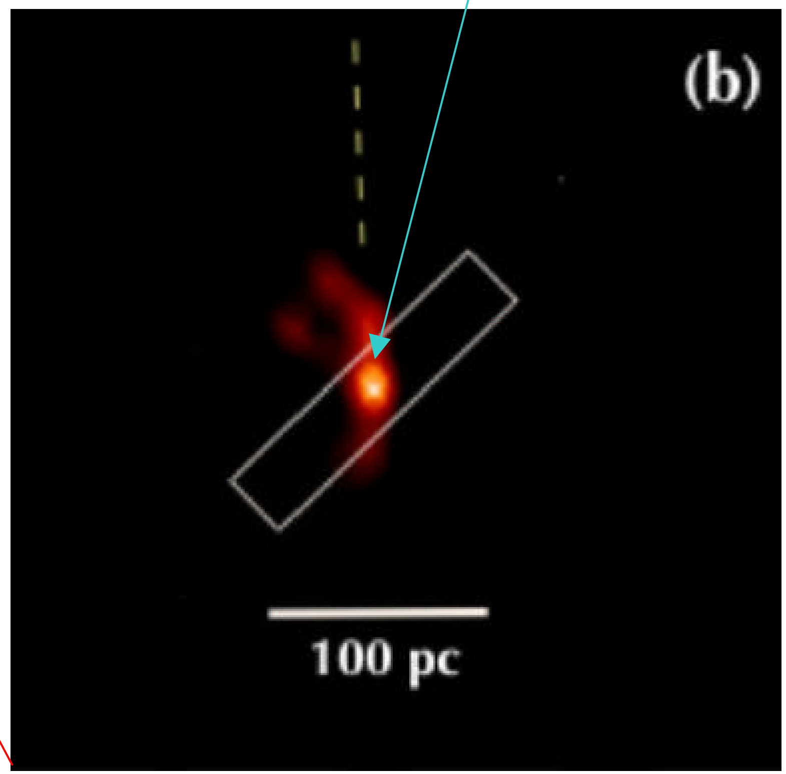
Star Formation

Water Megamasers in AGNs

- Only a few objects show 22 GHz megamaser emission
- Peculiar physical conditions to excite these masers (very restrictive)
- Many sources, showing OH megamasers do not show H_2O emission
- Could ALMA do a similar work in other water lines ?







NGC1068

From Jaffe et al., 2004

Nature

Why not in Arp 220 ?

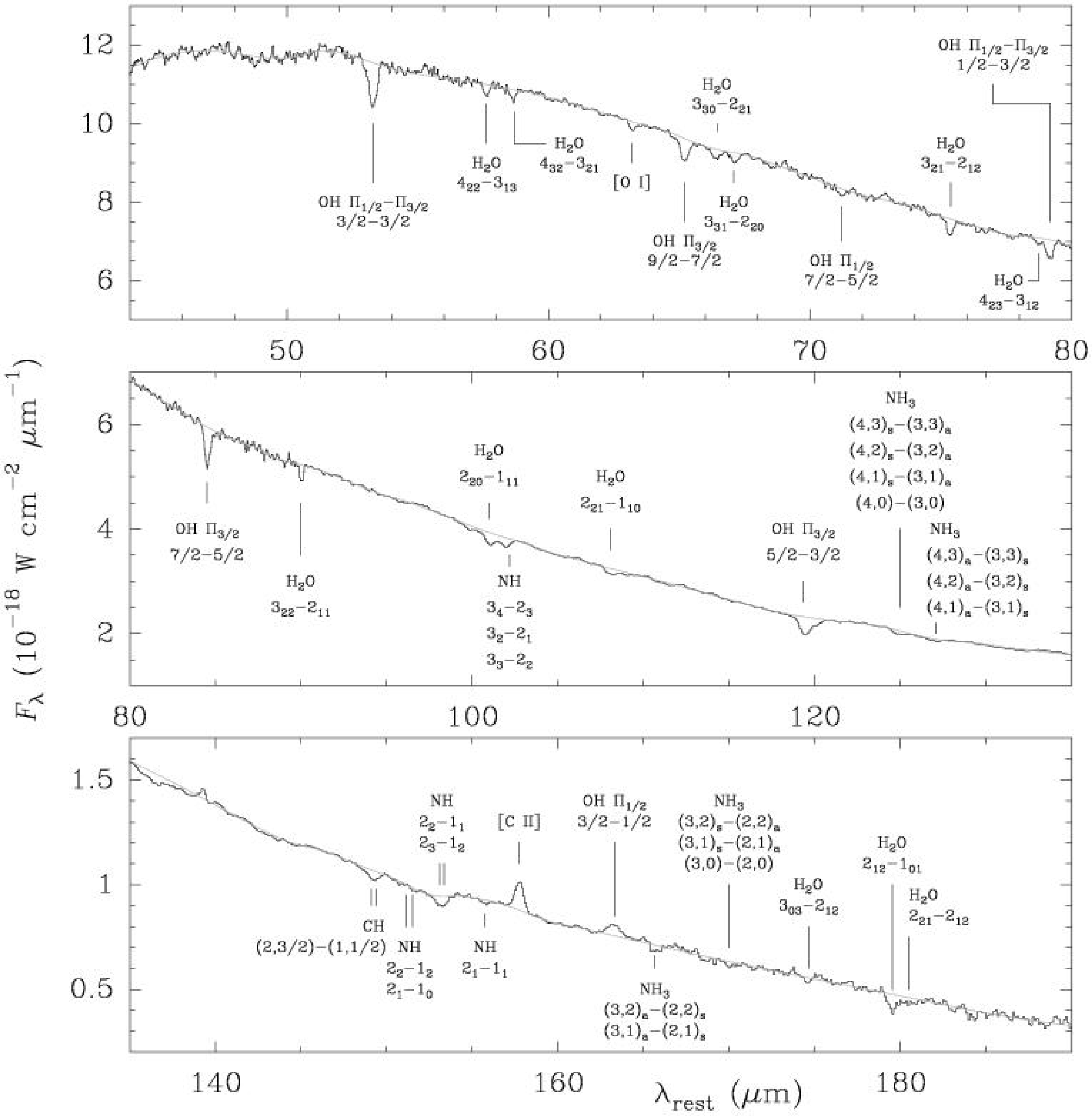


Fig. 1.— ISO/LWS spectrum of Arp 220, where the most prominent line features are identified (see text). The grey line shows the adopted baseline (continuum level).

González-Alfonso et al., 2004

ARP220

30-m IRAM Telescope

Cernicharo et al., 2006, ApJ Lett.

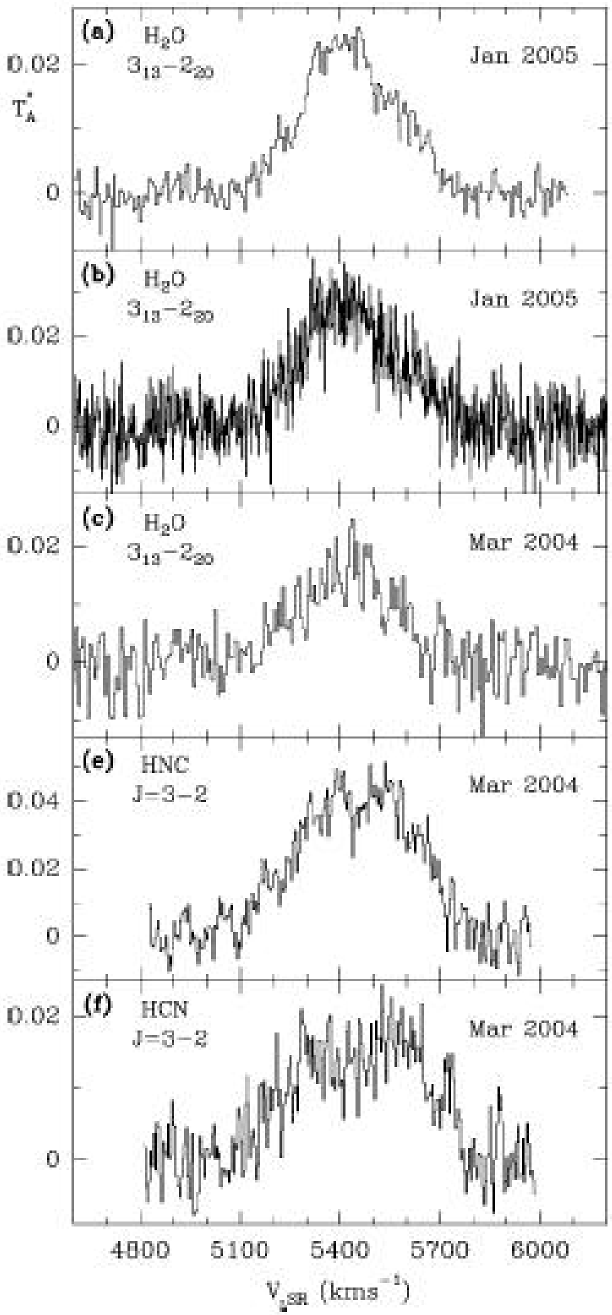
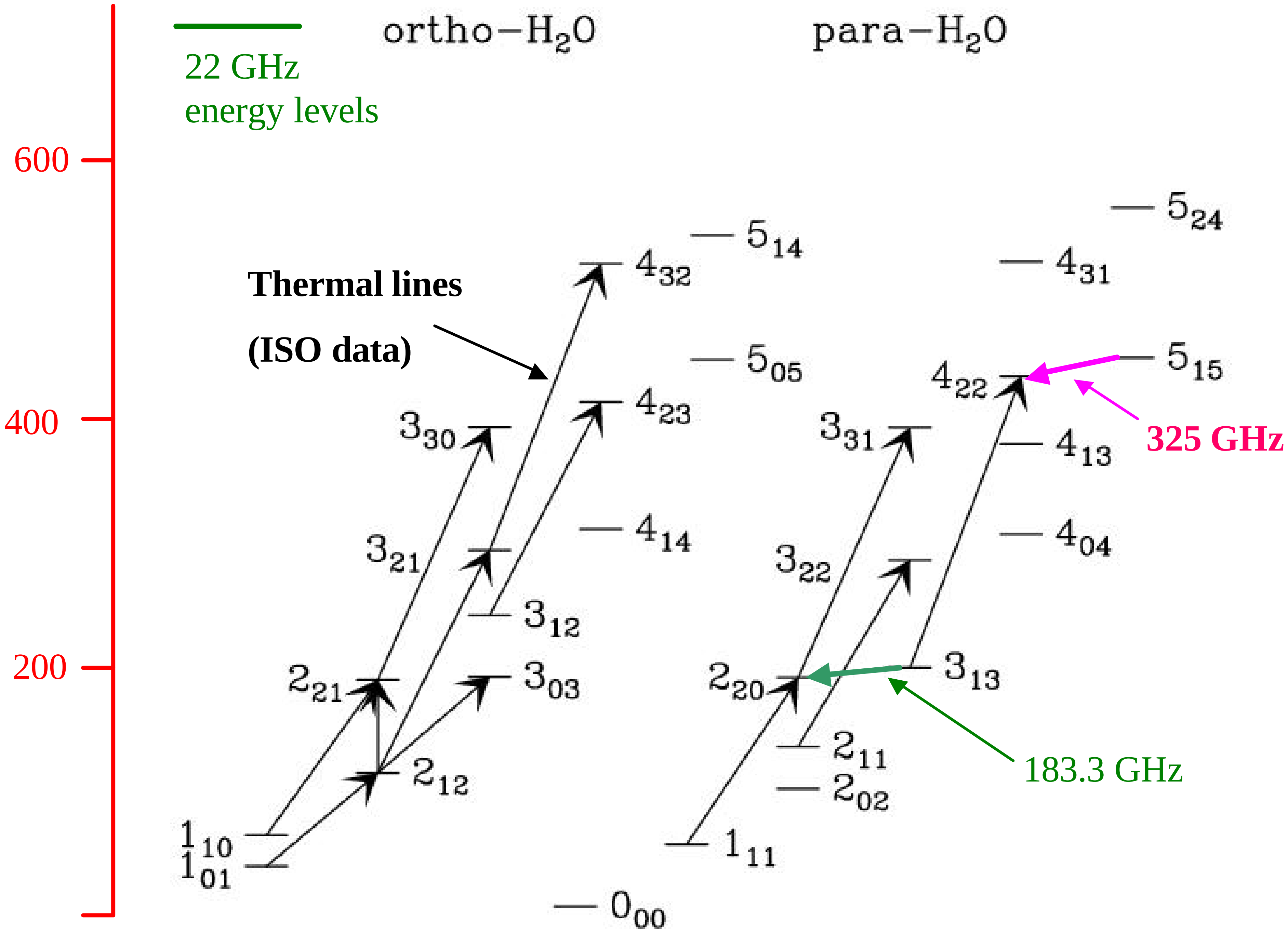
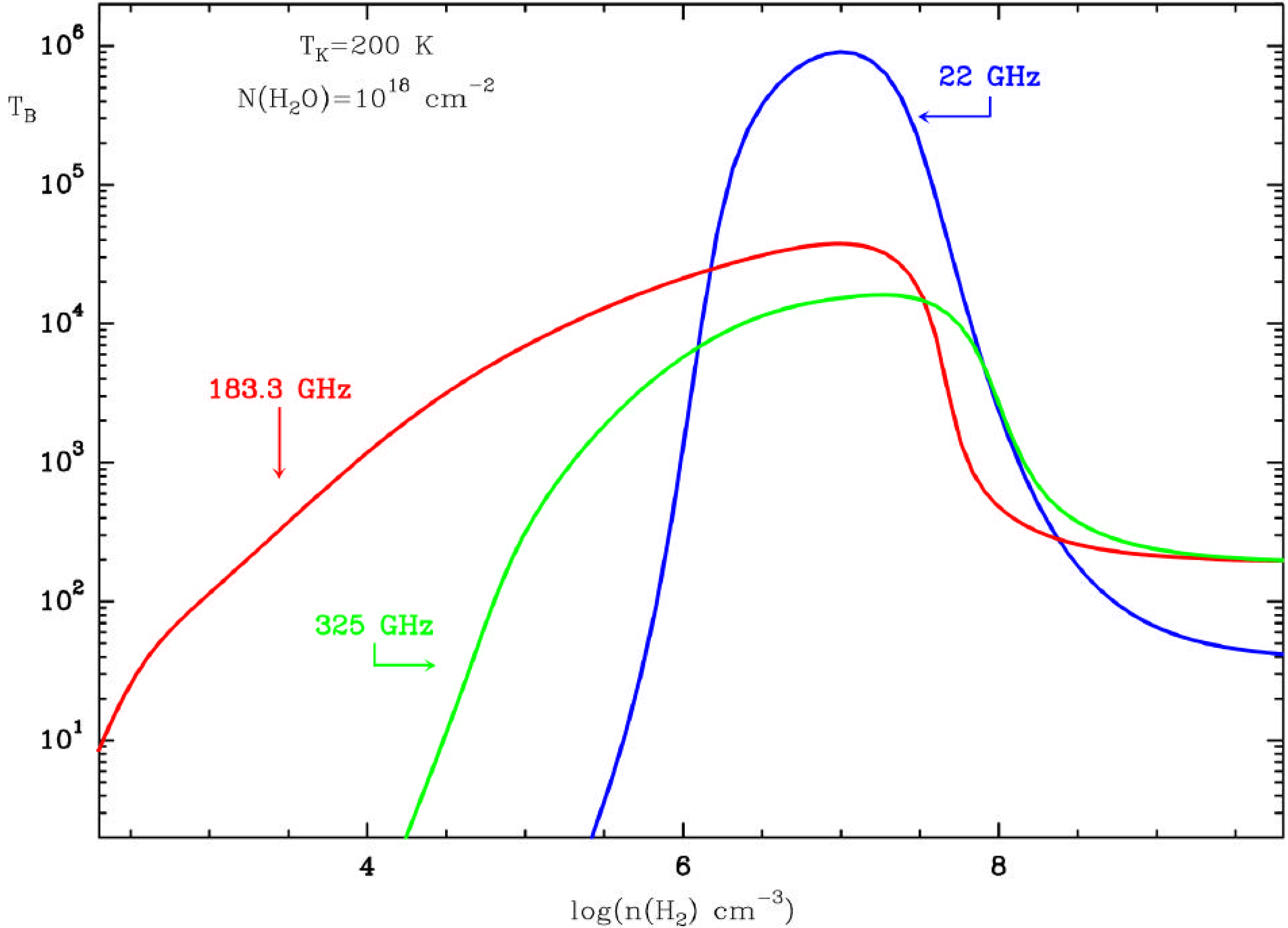


Fig. 1.—HCN (3−2), HNC (3−2), and H_2O $3_{13}-2_{20}$ lines observed with the IRAM 30 m telescope toward Arp 220. H_2O data obtained in two different runs are shown. Differences are probably related to calibration since the atmospheric conditions have a large impact on the atmospheric opacity at 180 GHz.



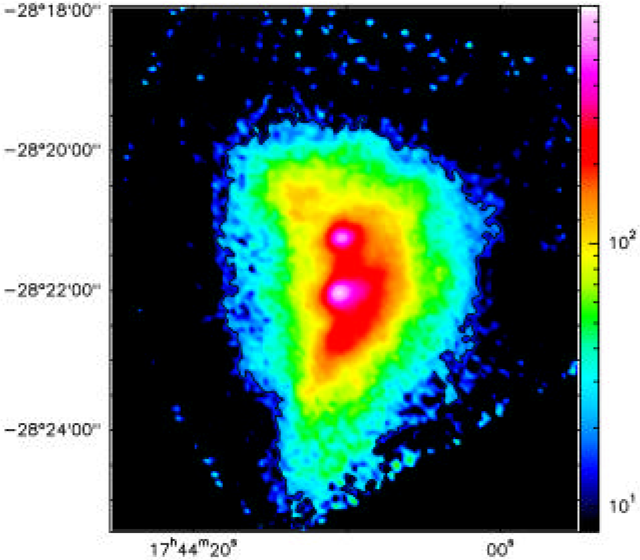
ortho-H2O
para-H2O
22 GHz
energy levels
600
400
200
Thermal lines
(ISO data)
325 GHz
183.3 GHz
5 14
4 32
5 05
4 23
3 30
4 14
3 21
3 12
3 03
2 21
2 12
1 10
1 01
0 00
5 24
4 31
5 15
4 22
3 31
4 13
4 04
3 22
3 13
2 20
2 11
2 02
1 11



T_K=200 K
N(H_2O)=10^18 cm^-2
T_B
22 GHz
183.3 GHz
325 GHz
10^1
10^2
10^3
10^4
10^5
10^6
4
6
8
log(n(H_2) cm^-3)

183 GHz : a tool to study the innermost zones of star forming regions and the nucleii of AGNs, ULIRGs,… !!

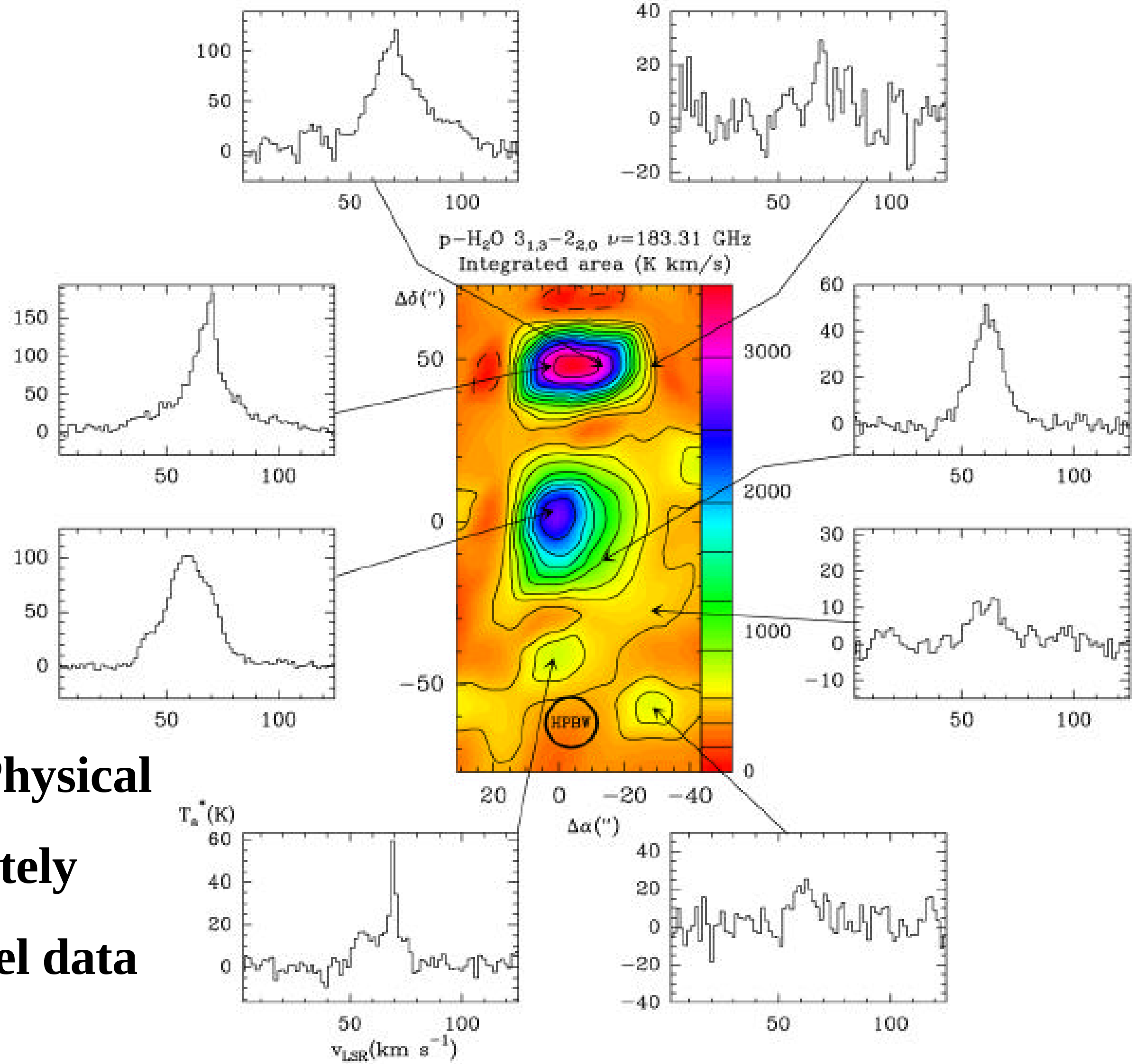
- **IRAM-30m Telescope observations (2900 m altitude)**
- **Detected towards class 0 sources**
- **Detected towards massive star forming regions**
- **Detected in evolved stars**
- **Detected in Galaxies like Arp 220**



350 um continuum emission towards SgrB2 observed with the CSO Telescope (D. Lis)

183.3 GHz observations with the 30-m IRAM radiotelescope towards Sgr B2 (Cernicharo et al., 2004).

w(H_2O)=0.8 mm (telescope elevation = 24º)



183.3 GHz as a tracer of the Physical conditions of the ISM. Absolutely necessary to interpret Herschel data

Contours :

CO

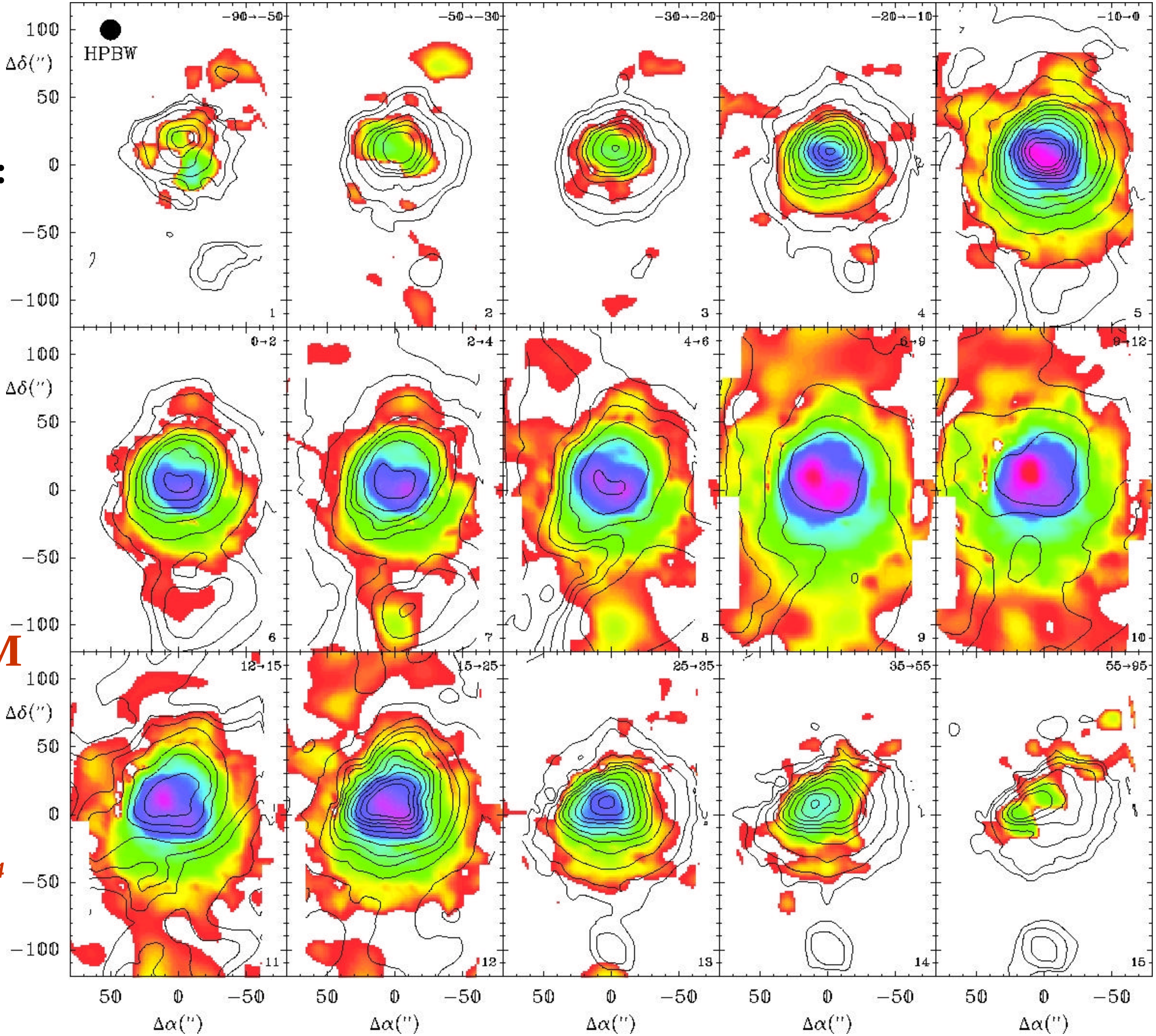
Colors :

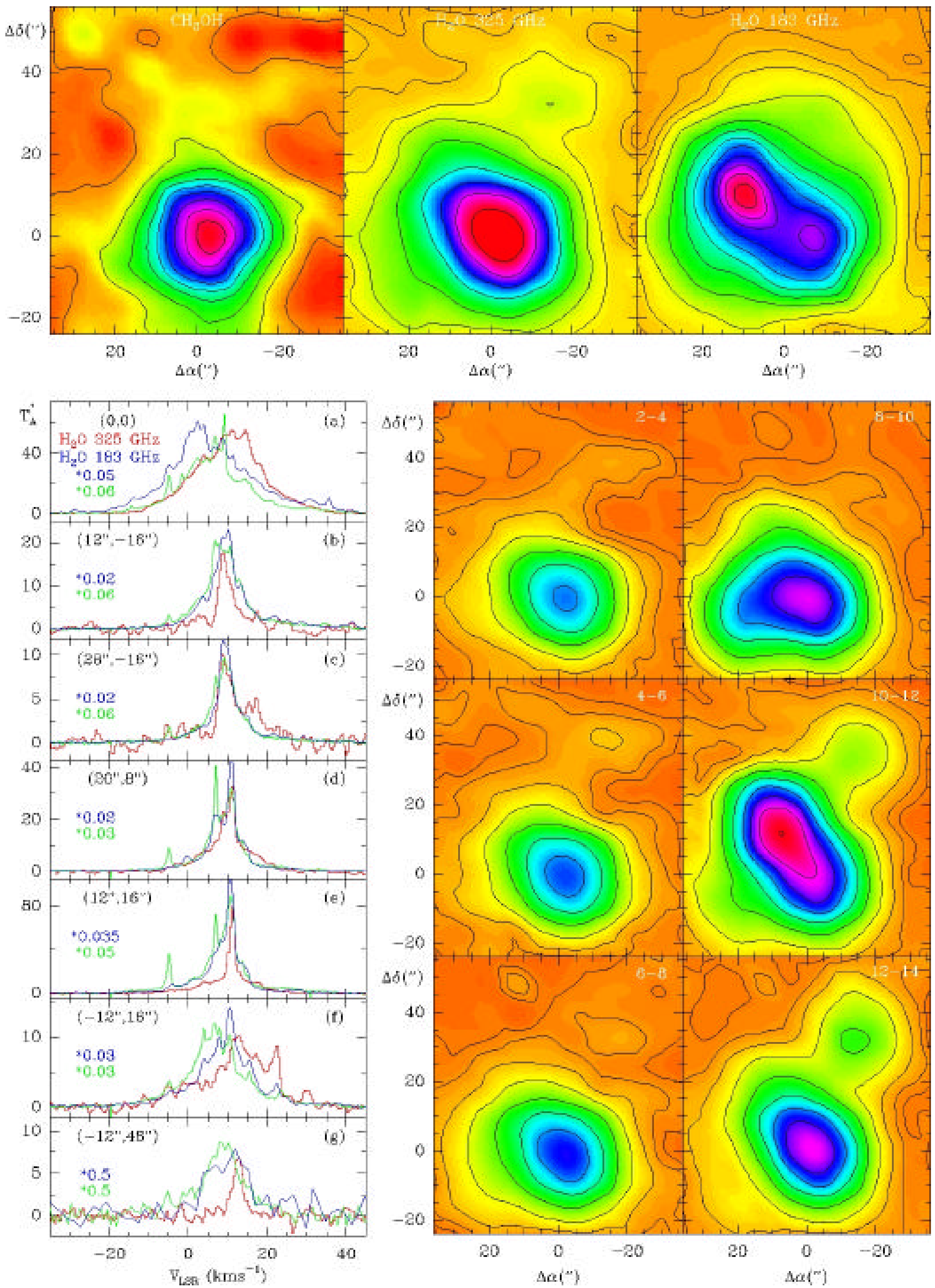
H_2O

30-m IRAM

Telescope

Cernicharo et al., 1994





H_2O at 325 GHz

HPBW = 22”

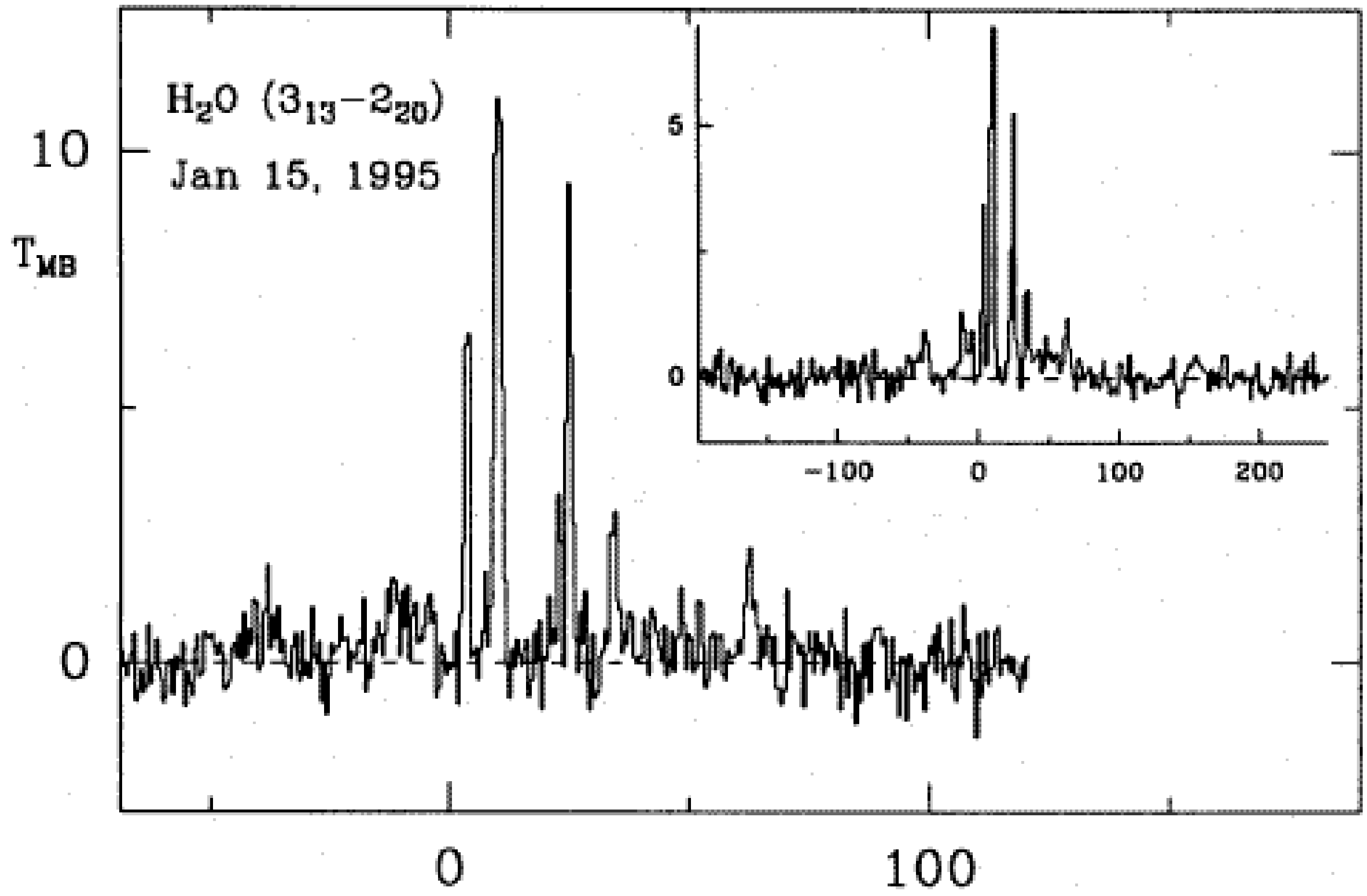
CSO Telescope

Cernicharo et al. 1999, ApJ, 520, 131

The ground based observations of water vapour at 183 and 325 GHz indicated a high abundance for this species, $x(H_2O)=10^{-4}$, in the shocked gas around IRc2, an abundance $\approx 10^{-5}$ in the gas surrounding this source (± 50”) and $>10^{-6}$ over spatial scales ± 2 arcminutes.

There is not way to pump this weak masers if $x(H_2O)$ is below 10^{-6}

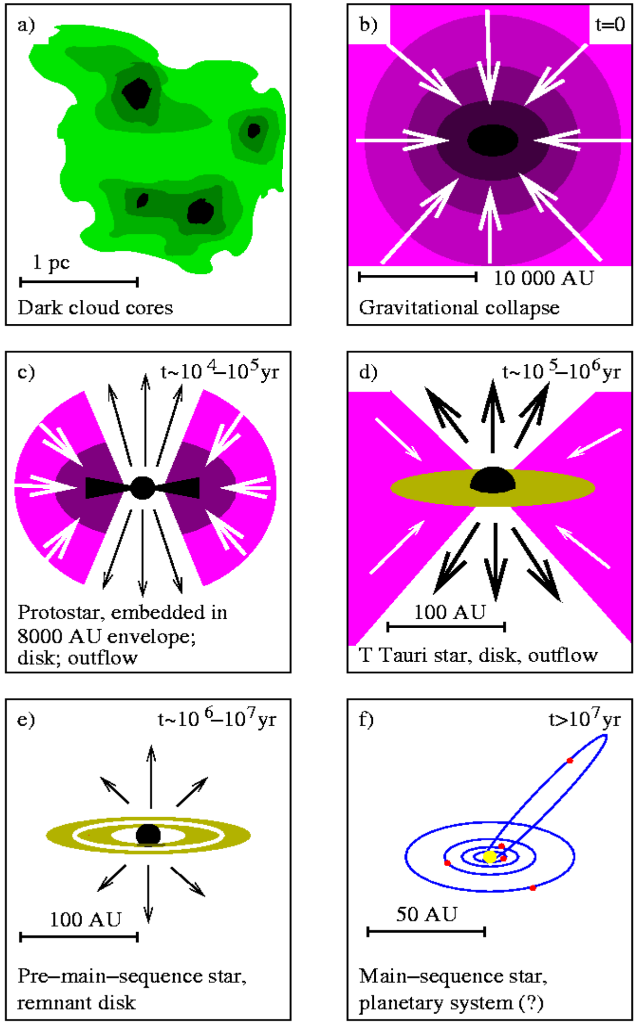
Cernicharo et al., 1996, A.&A., 305, L5



Class 0 source L1448-m at 183.3 GHz

Fig. 3. Water emission in L1448-mm (α(1950)= 3^h 22^m 34.3^s, δ(1950)= 30° 33' 35″), observed in January 1995 with a spectral resolution of 0.5 km s^{-1}. The insert shows the spectrum taken with the 1MHz filters (resolution of 1.6 km s^{-1})

Science with HIFI – The Birth of Stars



Hogerheijde 1998, after Shu et al. 1987

Star formation takes place in a series of steps, with initial collapse followed by copious outflow. Herschel will help us to better understand these sequences and the basic physical processes at play.

Courtesy HIFI Project

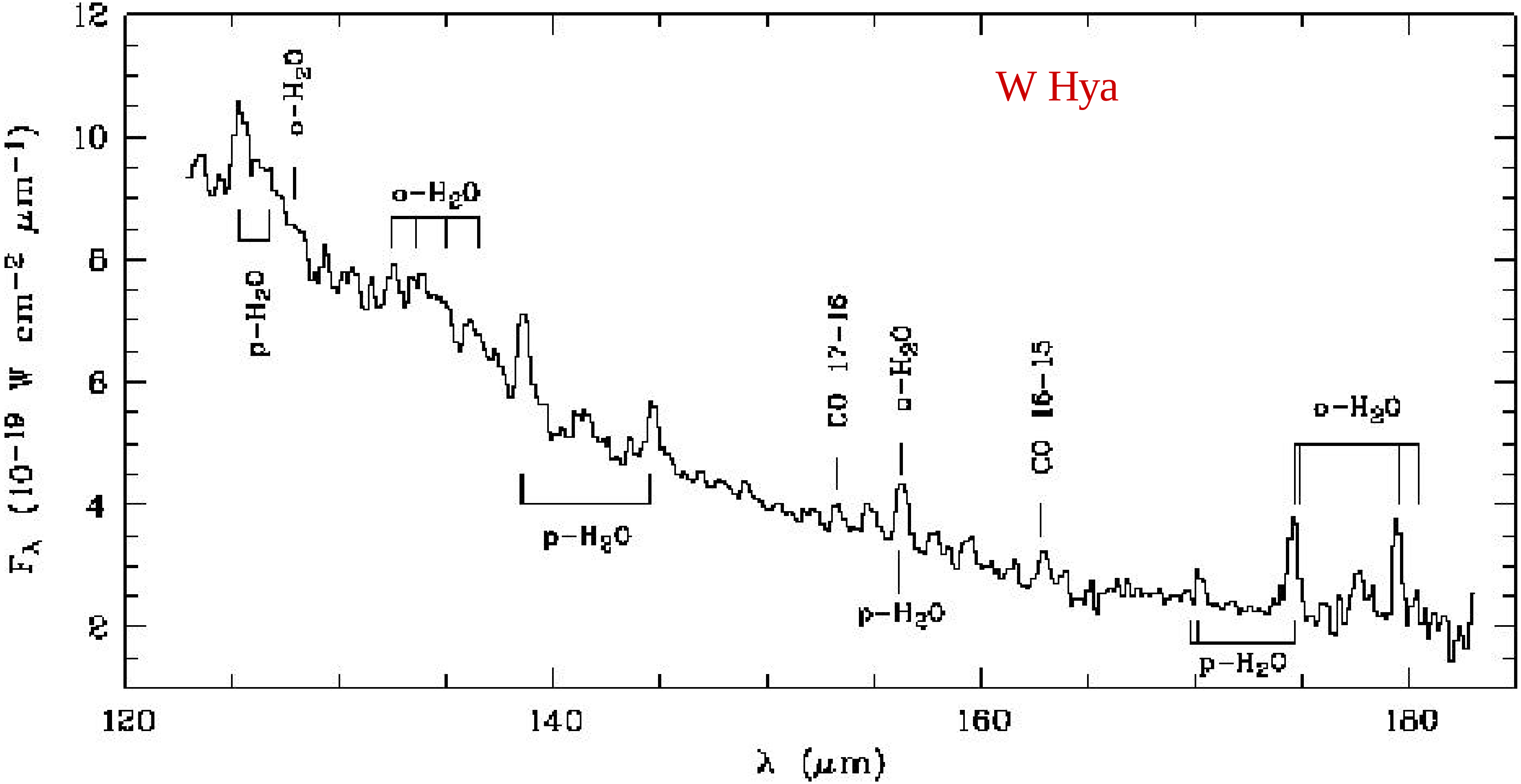
Evolved stars:

O-rich stars : H_2O a key molecule

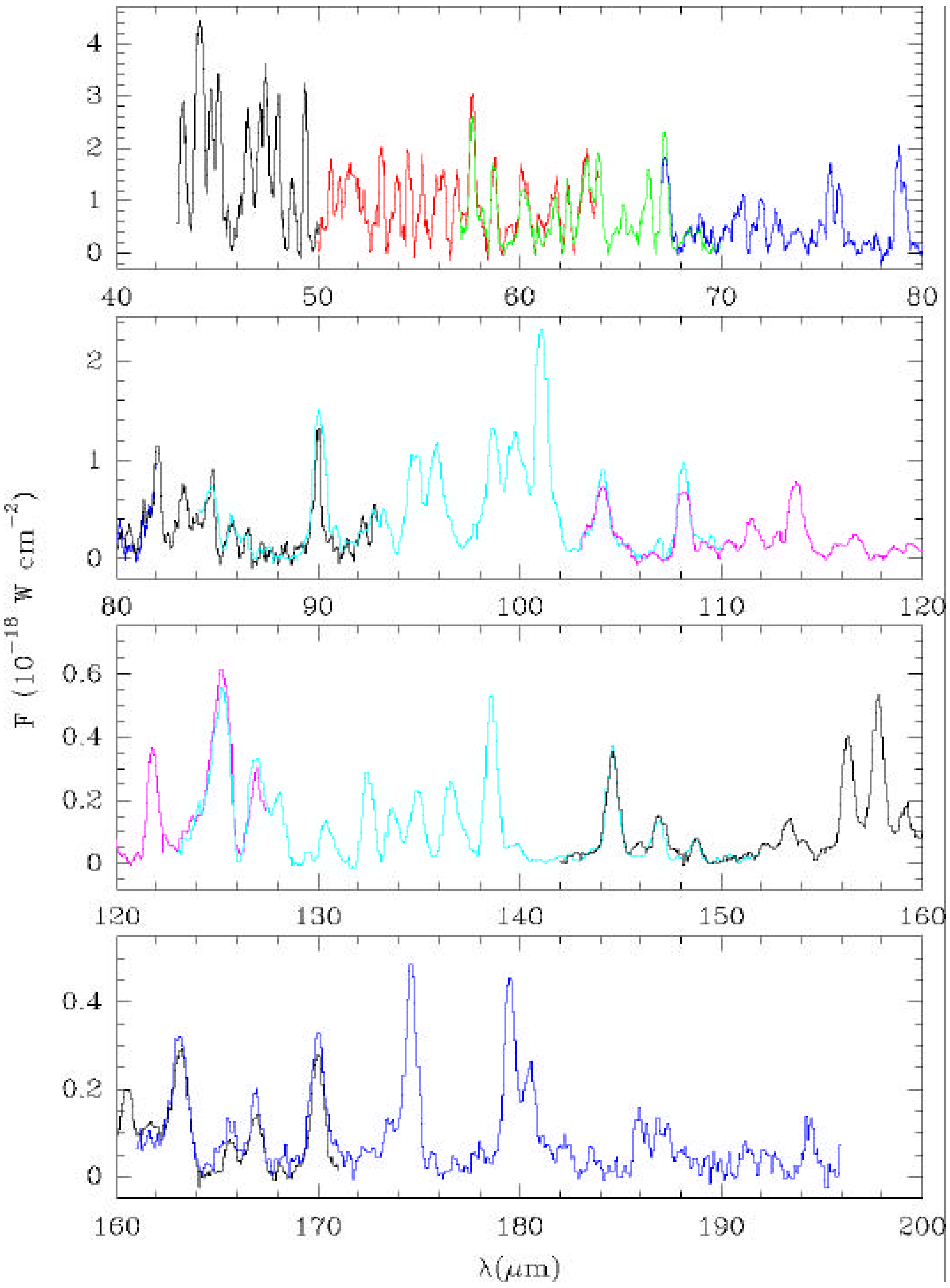
HERSCHEL

C-rich ProtoPlanetary Nebula :

HERSCHEL AND ALMA



Barlow et al., 1996; Neufeld et al., 1996



VY CMa

All features are real

All pure rotational lines of wapour with >43 um detected

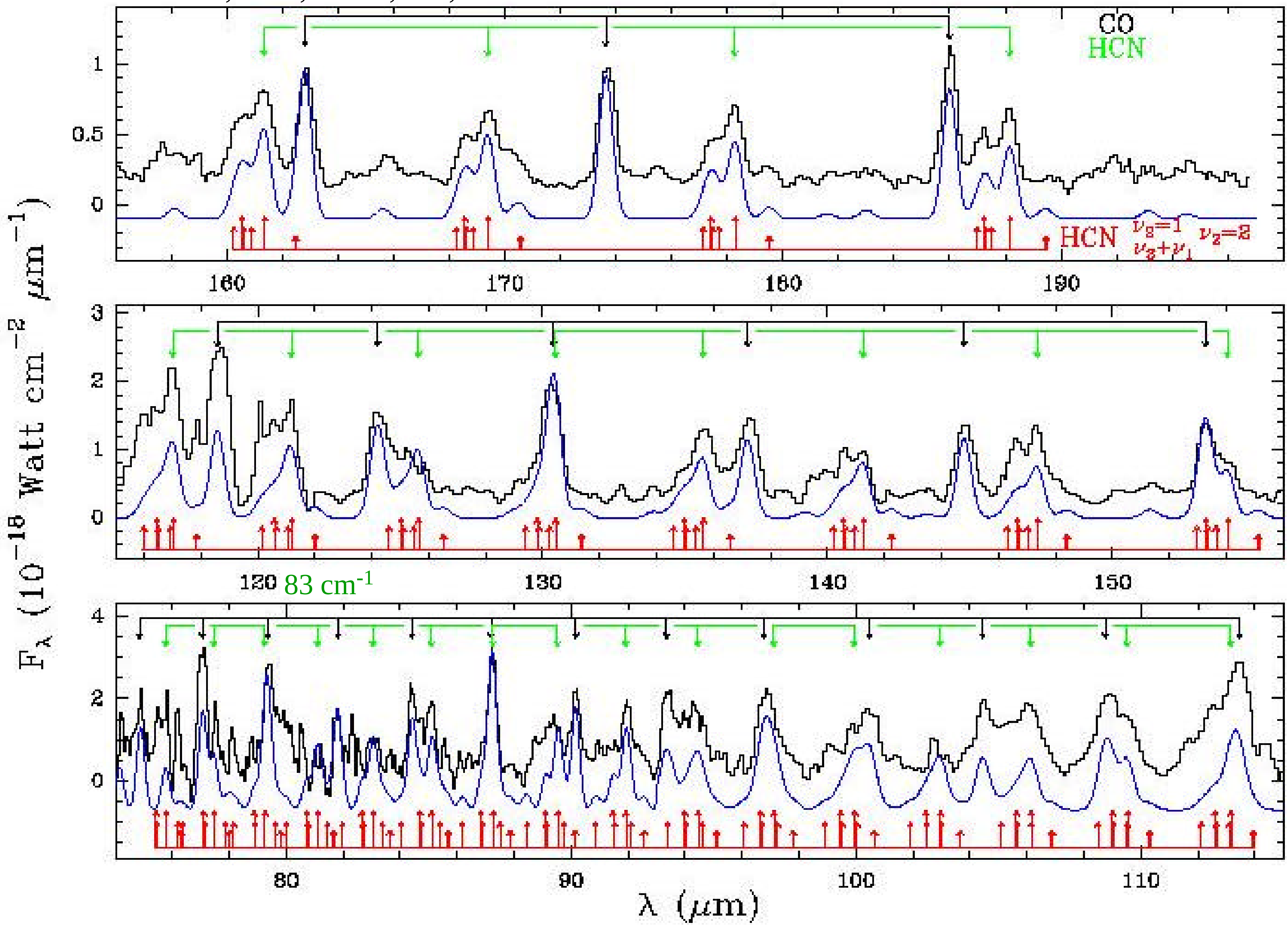
Some lines from the v_2=1 bending level also detected

Modelling requires collisional rates for Tk=20-2000 K including ro-vibrational collisions

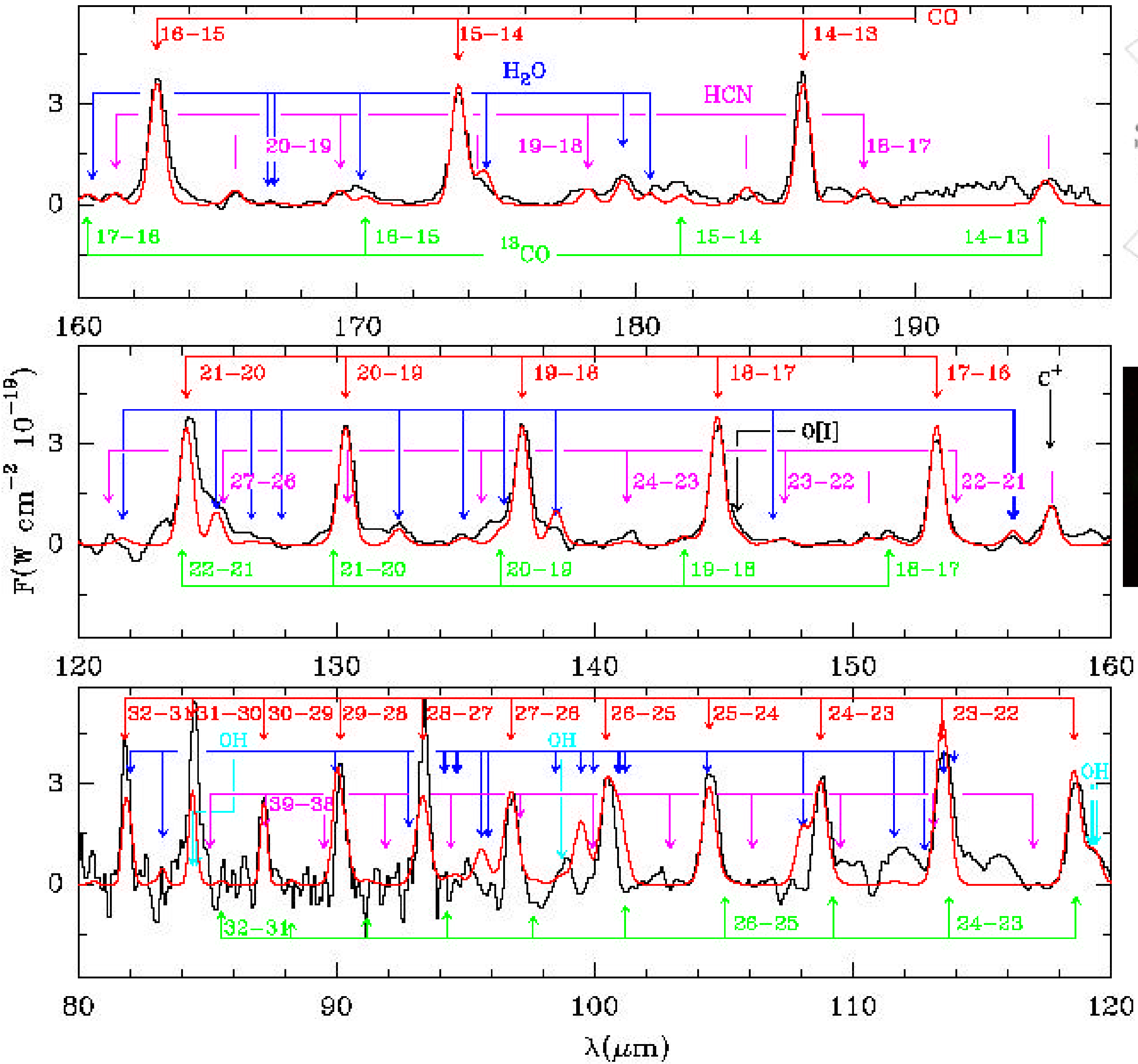
HERSCHEL :HIFI, PACS, SPIRE
ALMA : 183.3 (?) & 325 GHz

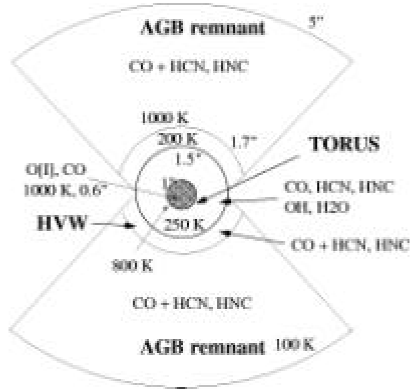
Asensio, Cernicharo, González-Alfonso in preparation

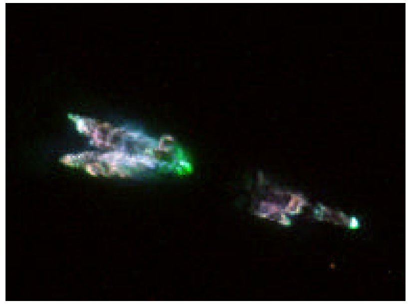
Cernicharo et al., 1996, A.&A., 315, 201



IRC+10216 a C-rich CSE :: HCN (in all v), CO







Herpin & Cernicharo, 2000, ApJ Letters, 530, L129

Synergy between Herschel and ALMA for AGBs and proto-planetary nebulae

*Herschel :

Complete frequency coverage (excitation conditions).

New molecular species and molecular species non observable from ground

Molecules without permanent dipole moment (low bending modes)

*ALMA :

High angular observations of HCN, SiO, and other species in the innermost regions of CSEs (as H_2O)

In some cases (HCN for example) a lot of lines arising from vibratio-nally excited states could be observed ➔ The dust formation zone

HC_3N in vib up to 1400 cm^{-1} (PDRs typical size 1-2", the growth of carbon chains)

CONCLUSIONS

- Prepare proposals for Herschel having ALMA in mind (follow ups with high angular resolution). But ALMA is not limiting at all the science that Herschel will do !!!

- Objetcs found with Herschel / Planck could be excellent targets for ALMA.

- Select frequencies (lines and continuum) in OT KP that will provide unique inputs for future ALMA observations

- REAL SYNERGY BETWEEN Herschel and existing ground based facilities (higher angular resolution, preparatory observations,…)