LINE SURVEYS WITH HERSCHEL

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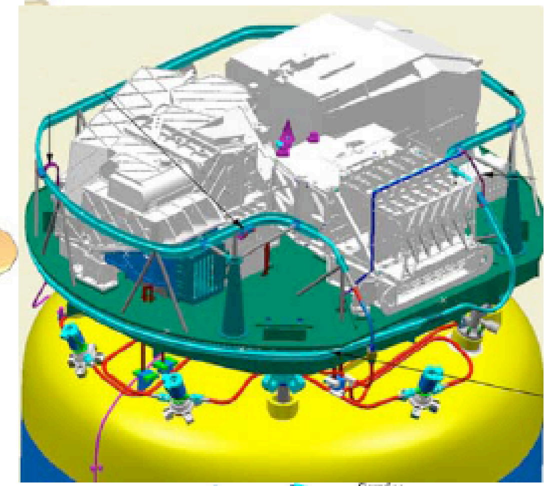
Herschel in a nutshell

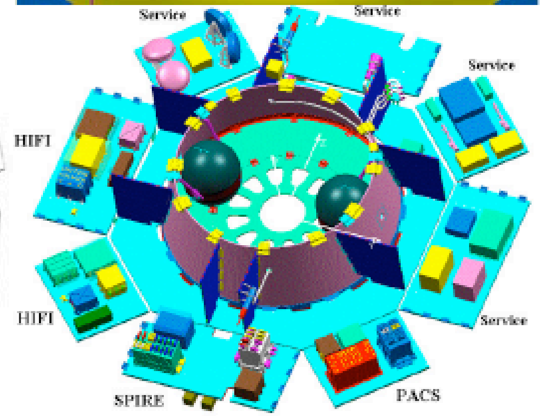
- **ESA cornerstone observatory**
  - instruments 'nationally' funded, int'l - NASA, CSA, Poland – collaboration
  - ~1/3 guaranteed time, ~2/3 open time
- **FIR (57 - 670 μm) space facility**
  - large (3.5 m) monolithic low emissivity passively cooled telescope
  - 3 focal plane science instruments
  - 3 years routine operational lifetime
  - full spectral access
  - low and stable background
- **Unique and complementary**
  - for λ < 200 μm larger aperture than cryogenically cooled telescopes (IRAS, ISO, Spitzer, Akari,…)
  - more observing time than balloon- and/or air-borne instruments
  - larger field of view than interferometers
- **Launch in 2008**
  - **the initial observing AO was issued on 1 Feb 2007**

HERSCHEL SPACE OBSERVATORY

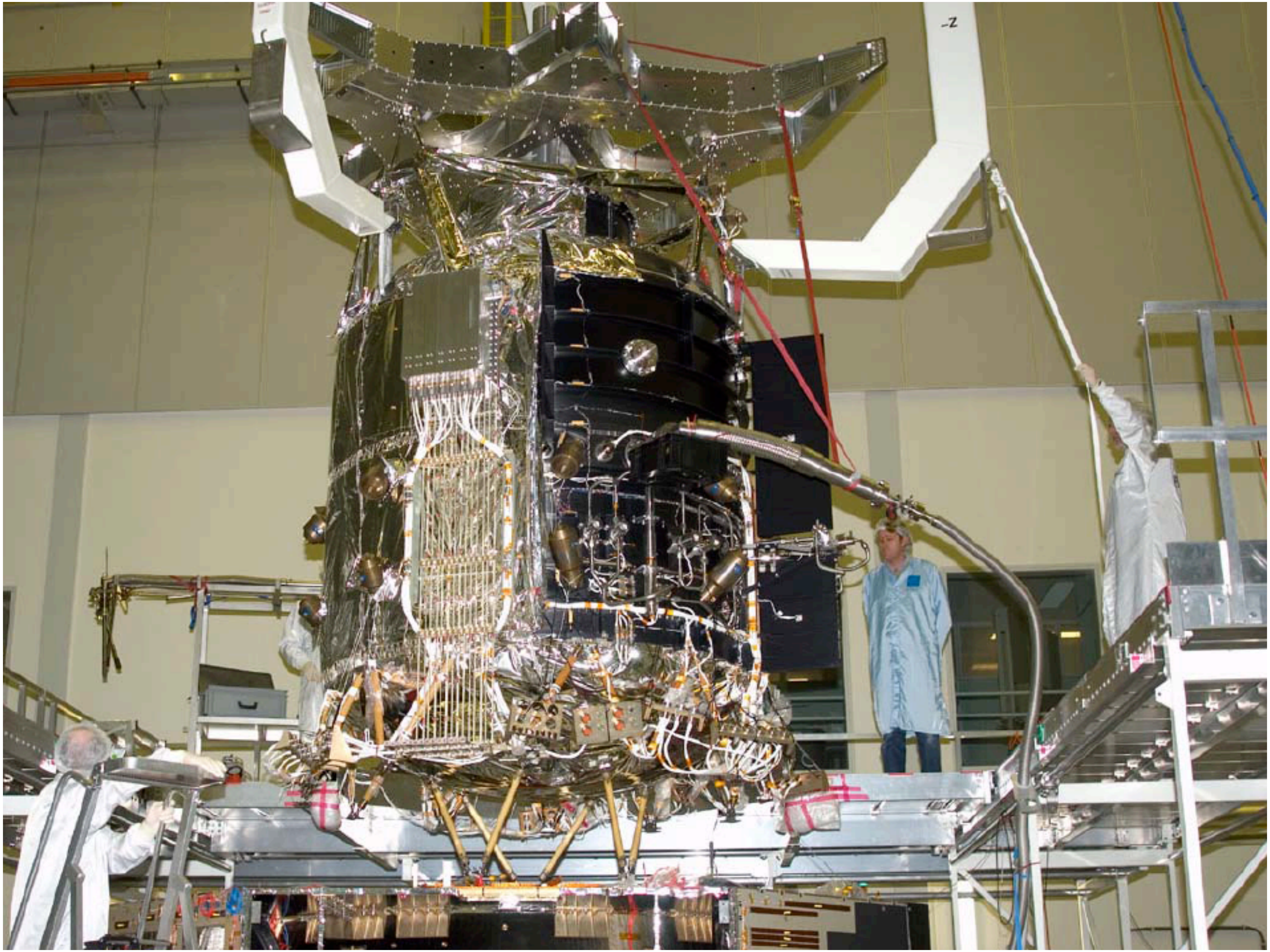
Herschel spacecraft *specs*

- 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 SVM/STM

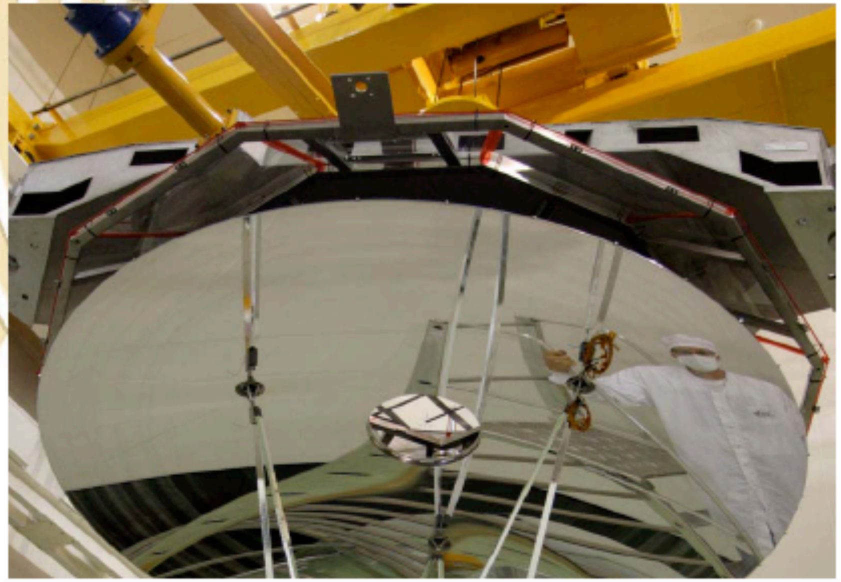

-Z

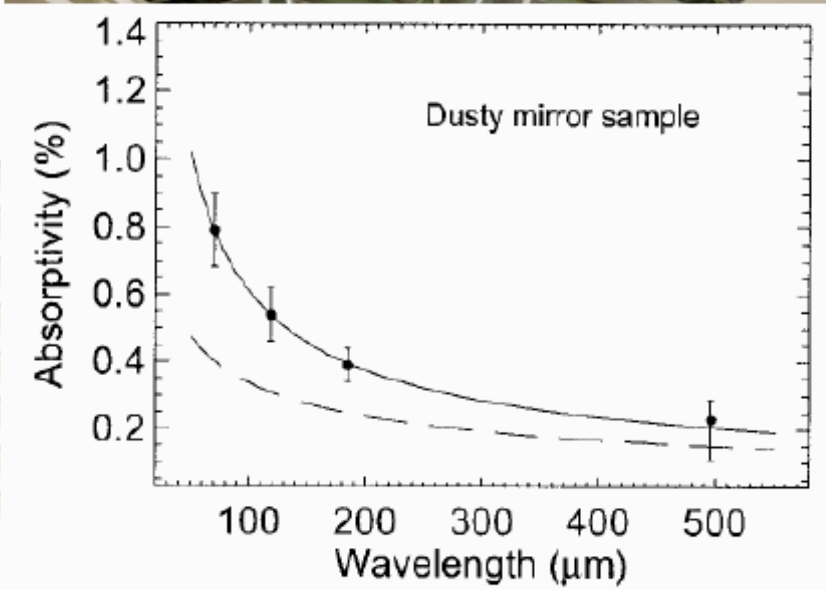
Herschel telescope

- **Cassegrain optics**
- **M1 diameter 3.5 m**
- **M2 is undersized (stop)**

➔ **effective aperture 3.3 m**

- **WFE at the best focus 5.5 μm at 70 K OK**
- **Encircled energy OK**
- **Mass 315 kg (~90% SiC)**
- **Predicted**
  - operating temp somewhere in the range 60-90 K
  - Gradients across M1 small
    - Sun direction ~0.2 K
    - Orthogonal ~0 K
  - Gradient M1-M2 ~2 K





HERSCHEL SPACE OBSERVATORY

Launcher

- Launcher version:
  - Ariane 5 - ECA (cryogenic upper stage)
  - qualification flight V164
- Payload configuration:
  - Planck in lower position
  - Herschel in upper position
  - Sylda5/ACU2624
  - Long fairing
- Launch Autonomy:
  - 25 hours
- L2 Injection strategy:
  - direct injection
  - 25 minutes powered phase
- L2 Injected mass capability:
  - ≥6273 kg including adaptors

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HERSCHEL SPACE OBSERVATORY


August 2008 !!

Science Instruments

- **PACS - Photodetector Array Camera and Spectrometer**
  - **PI: Albrecht Poglitsch, MPE, Garching, Germany**
  - **Imaging photometry and spectroscopy over 57- 210 μm**
  - **2 bolometer arrays for photometry, 2 (stressed) Ge:Ga arrays for spectroscopy**
- **SPIRE - Spectral and Photometric Imaging REceiver**
  - **PI: Matt Griffin, Cardiff University, United Kingdom**
  - **Imaging photometry and spectro-photometry/-scopy over 200 - 670 μm**
  - **3 bolometer arrays for photometry, 2 bolometer arrays for spectroscopy**
- **HIFI - Heterodyne Instrument for the Far Infrared**
  - **PI: Thijs de Graauw, SRON, Groningen, The Netherlands**
  - **Very high resolution spectroscopy over 480 - 1250 and 1410 - 1910 GHz**
  - **SIS and HEB mixers, auto-correlator and AOS spectrometers**

http://herschel.esac.esa.int/OT_KP_wkshop.shtml

HIFI Instrument

Requirements / Resulting Concept

Design Requirements

HIFI designed for:

- Spectral Scans and Spectral line surveys
- Very high spectral resolution
- Widest possible coverage in the unexplored FIR/Submm range

1. **Frequency coverage:**
   480 – 1250 GHz (625-240 μm)
   1410 – 1910 GHz (212-157 μm)

2. Sensitivity

Near-quantum noise limit sensitivity

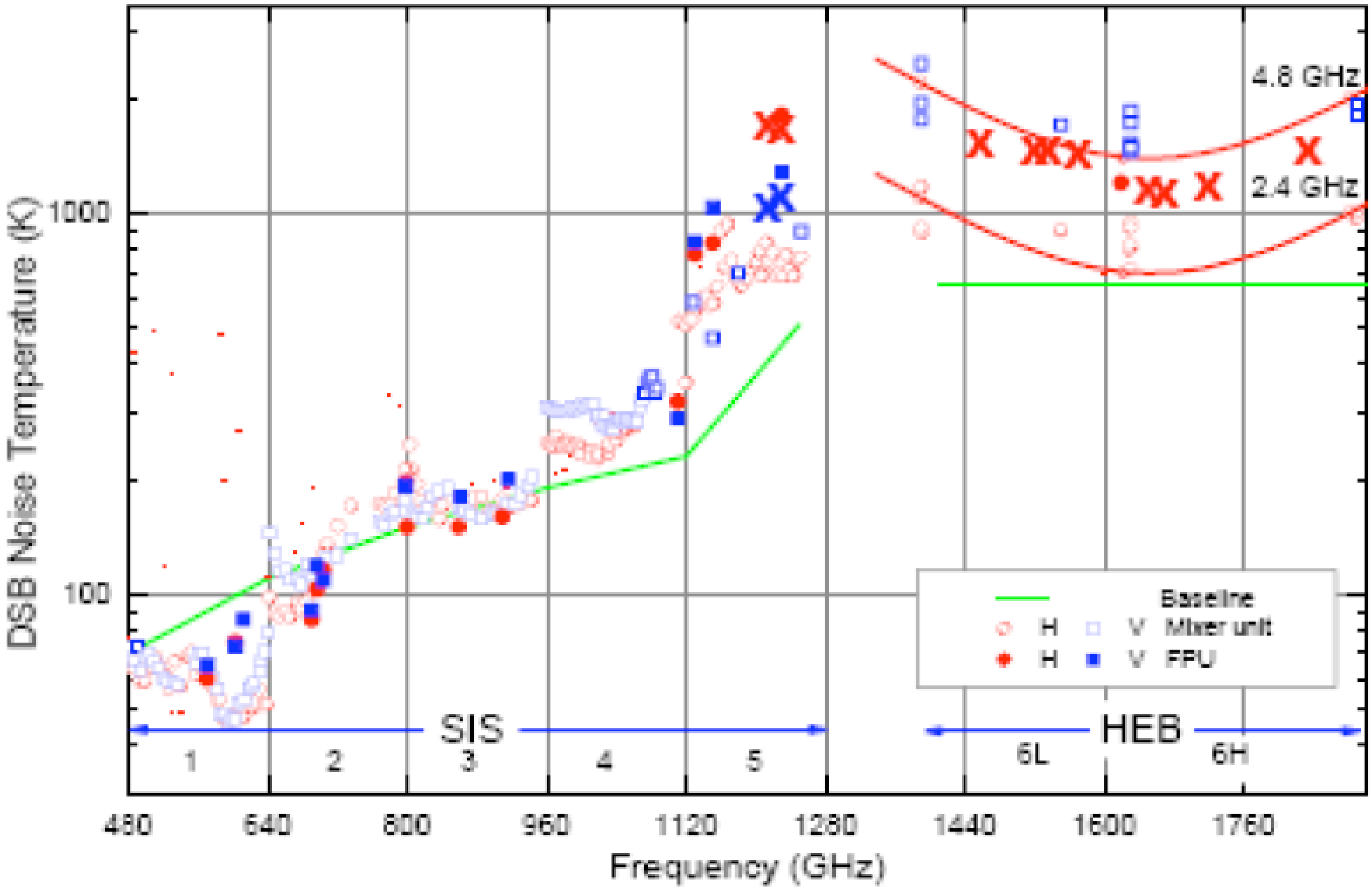
- IF bandwidth/Resolution:
  - 4 GHz (in 2 polarisations)
  - 140 – 280 kHz –0.5 and 1 MHz

3. Calibration Accuracy: 10% baseline; 3% goal

Implementation

- **Heterodyne spectroscopy**
  - single pixel on the sky
  - very high spectral resolution
- **7 dual-pol mixer bands**
  - 480-1250 GHz (625-240 mm) 5x2 SIS mixers, IF 4-8 GHz
  - 1410-1910 GHz(212-157 mm; 2x2 HEB mixers, IF 2.4-4.8 GHz
- **14 LO sub-bands**
  - LO source unit in common
  - LO multiplier chains
- **2 spectrometer systems;**
  - for each polarisation
    - auto-correlator spectrometer
    - acousto-optical spectrometer

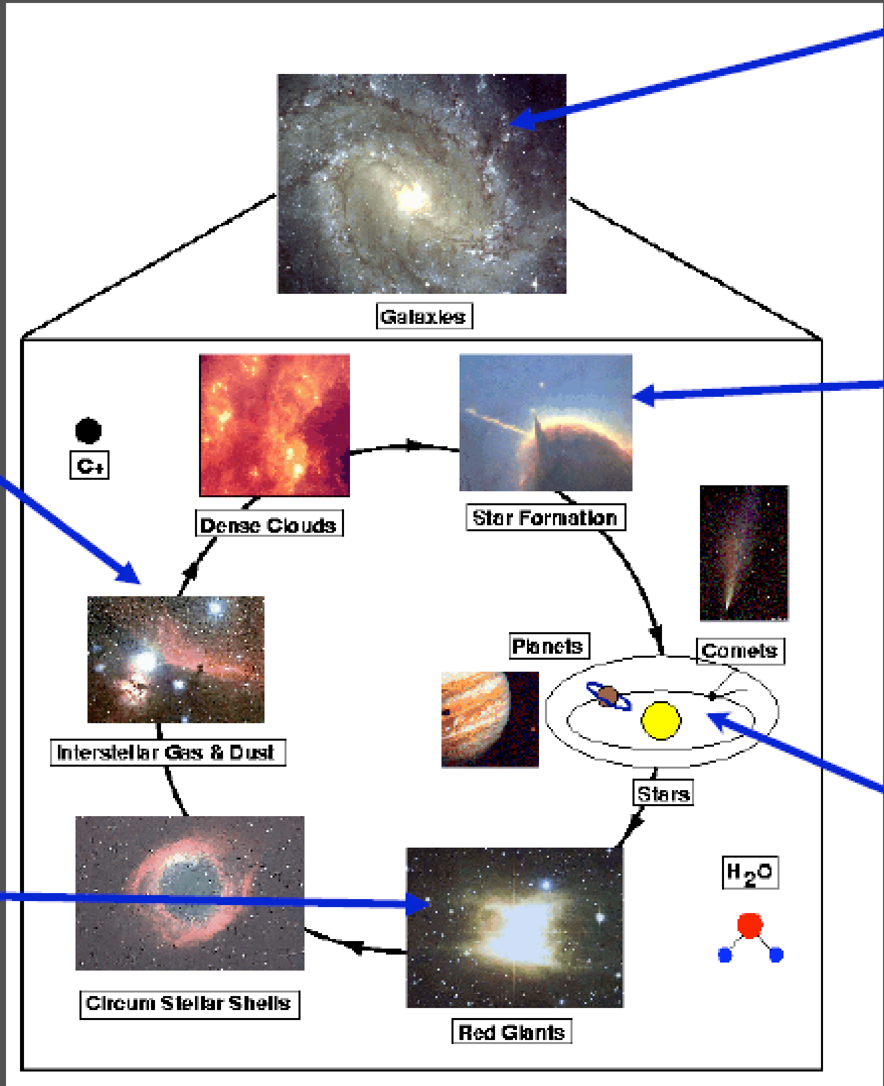
Single pixel on the sky
Angular Resolution (with Herschel): 12"- 40"


DSB Noise Temperature (K)
1000
100
Frequency (GHz)
480
640
800
960
1120
1280
1440
1600
1760
4.8 GHz
2.4 GHz
Baseline
H
V
Mixer unit
H
V
FPU
SIS
HEB
1
2
3
4
5
6L
6H

HIFI EXPECTED SENSITVITY ESTMATED JANUARY 2007 (+ large effects from overheads)

	Mixer Band						
	1	2	3	4	5	6	7
Frequency range	480-640	640-800	800-960	960-1120	1120-1250	1410-1660	1660-1920
Receiver Noise (SSB) (K)	180	400	480	900	2000	3000	3200
Flux limit (1σ, 1hr, 1km/s) (mK)	5.8	11	13	22	46	60	60
Flux limit (1σ, 1hr, 1km/s) (Jy)	2.6	5.2	5.7	9.9	21	36	36
Flux limit (1σ, 1hr, 1km/s) (10^{-18} Wm^{-2})	0.06	0.14	0.18	0.36	0.87	2.0	2.2
Line scan (50 GHz in 10 hr, 1σ) (mK)	8	14	25	35	100	150	150

HIFI Science Targets in a nutshell: Life Cycle of Galaxies



<u>ISM in Galaxies</u>
- Physical conditions
- Star formation

<u>ISM in the Milky Way</u>
- Physical conditions
- Chemistry
- Energetics
- Dynamics
- Isotopic gradients

<u>Star formation</u>
- Physical conditions
- Chemistry
- Energetics
- Dynamics
- Role of Water

<u>Stellar evolution</u>
- Mass loss
- Composition

<u>Solar System</u>
- Water in Giant Planet
- Chemistry Martian atmosphere

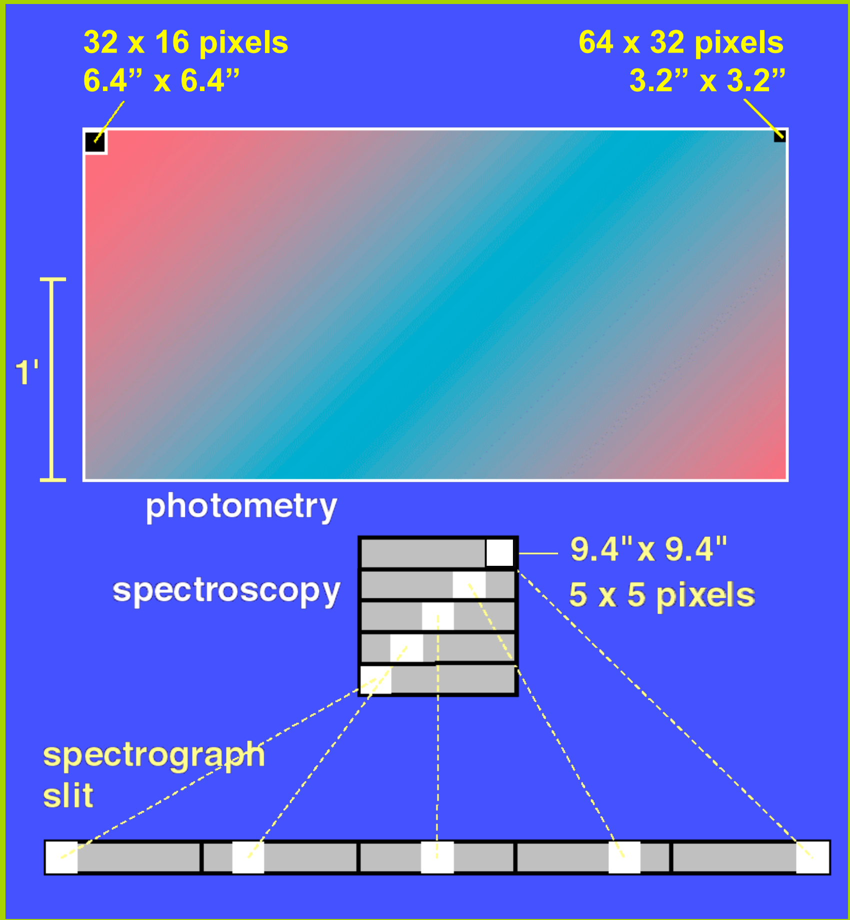
HIFI KEY PROGRAMS (8)

- Water in star forming regions: WISH — Ewine van Dishoeck
- Spectral surveys of star forming regions HS3F — Cecilia Ceccarelli
- Herschel Observations of Extra0ordinary Sources (Orion/Sgr B2) HEXOS — Ted Bergin
- Molecular Carriers in the ISM: MOLIS — Maryvonne Gerin
- H2O and Co2 obs. Of AGB, PPNe and PNe:HIFISTARSA — Valentin Bujarabal
- Warm and dense ISM: WADI — Volker Ossenkopf
- Physical and Chemical Conditions of ISM in Gal. Nuclei HEXGAL — Rolf Guesten
- Water and Chemistry in the Solar System — Paul Hartogh

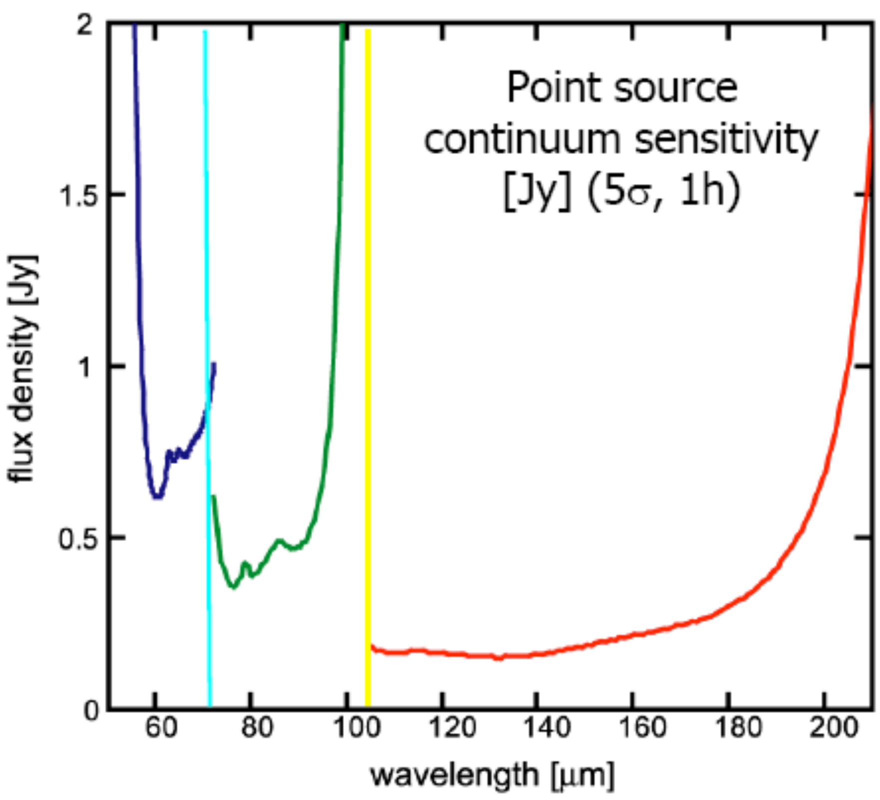
PACS :Instrument Concept

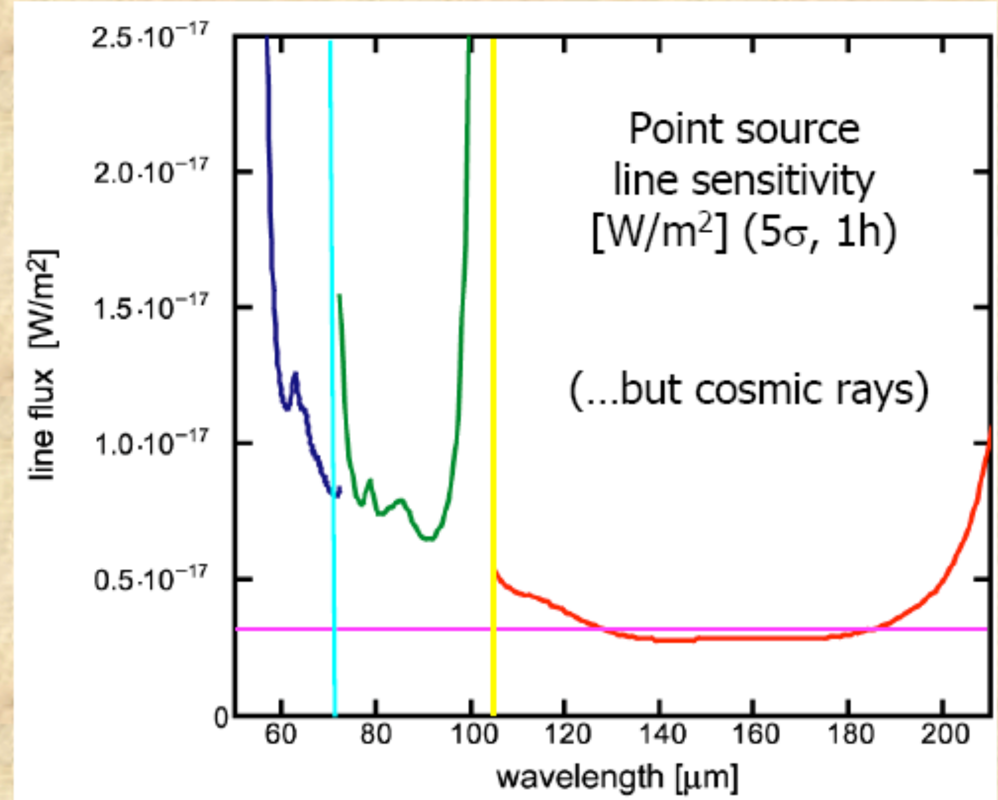
- **Imaging photometry**
  - two bands simultaneously (60-85 or 85-130 μm and 130-210 μm) with dichroic beam splitter
  - two filled bolometer arrays (32x16 and 64x32 pixels, ~ full beam sampling)
  - point source detection limit ~4 mJy (5σ, 1h)
- **Integral field line spectroscopy**
  - range 57 - 210 μm with 5x5 pixels, image slicer, and long-slit grating spectrograph (R ~ 1500)
  - two 16x25 Ge:Ga photoconductor arrays (stressed/unstressed)
  - point source detection limit 3…20 x10^{-18} W/m^2 (5σ, 1h)

Focal Plane Footprint



Expected Performance Spectroscopy





- Sensitivity gap from ~ 95 to 105 μm
- Calculated for (off-array) chopping
- Sensitivity requirement partly met

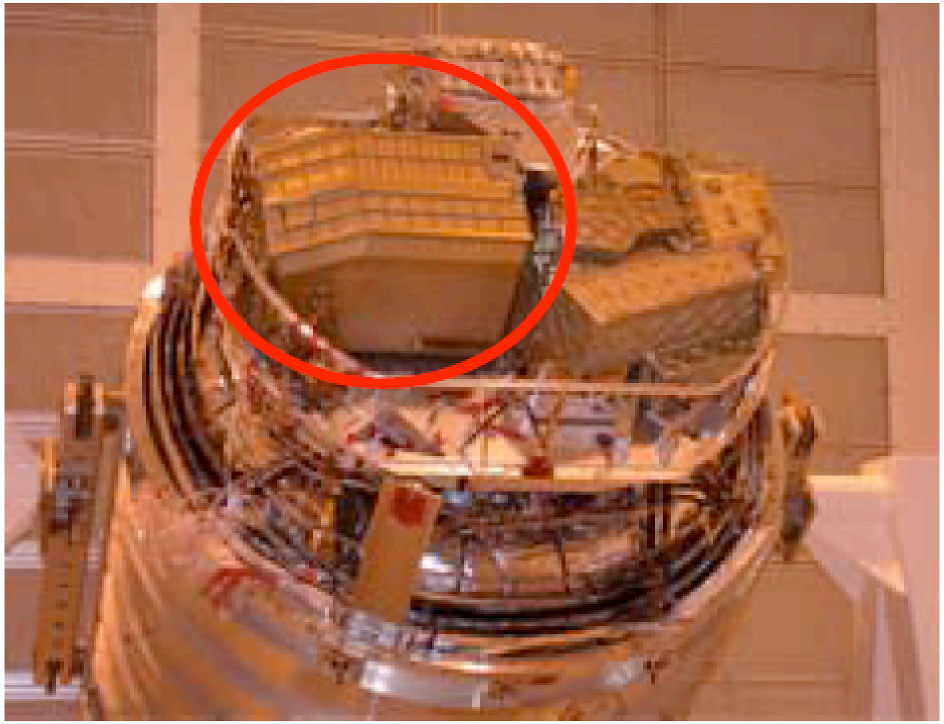
PACS GT Key Programmes (Summary):

Extragalactic surveys (PEP):	Lutz, Elbaz, Andreani, Cepa et al.
Dusty young universe:	Meisenheimer et al.
IR bright galaxies at 0<z<1:	Sturm, Klaas, Madden et al.
Low Metallicity Dwarf Galaxies:	Madden et al.
Gould belt SF survey:	Andre, Saraceno et al.
Earliest phases of star formation:	Henning et al.
Debris Disks:	Waelkens et al.
Birth of high-mass stars:	Zavagno et al. (SPIRE-led)
Post-main-sequence stars:	Groenewegen, Kerschbaum et al.
Solar system:	Waelkens et al. (HIFI-led)

SPIRE

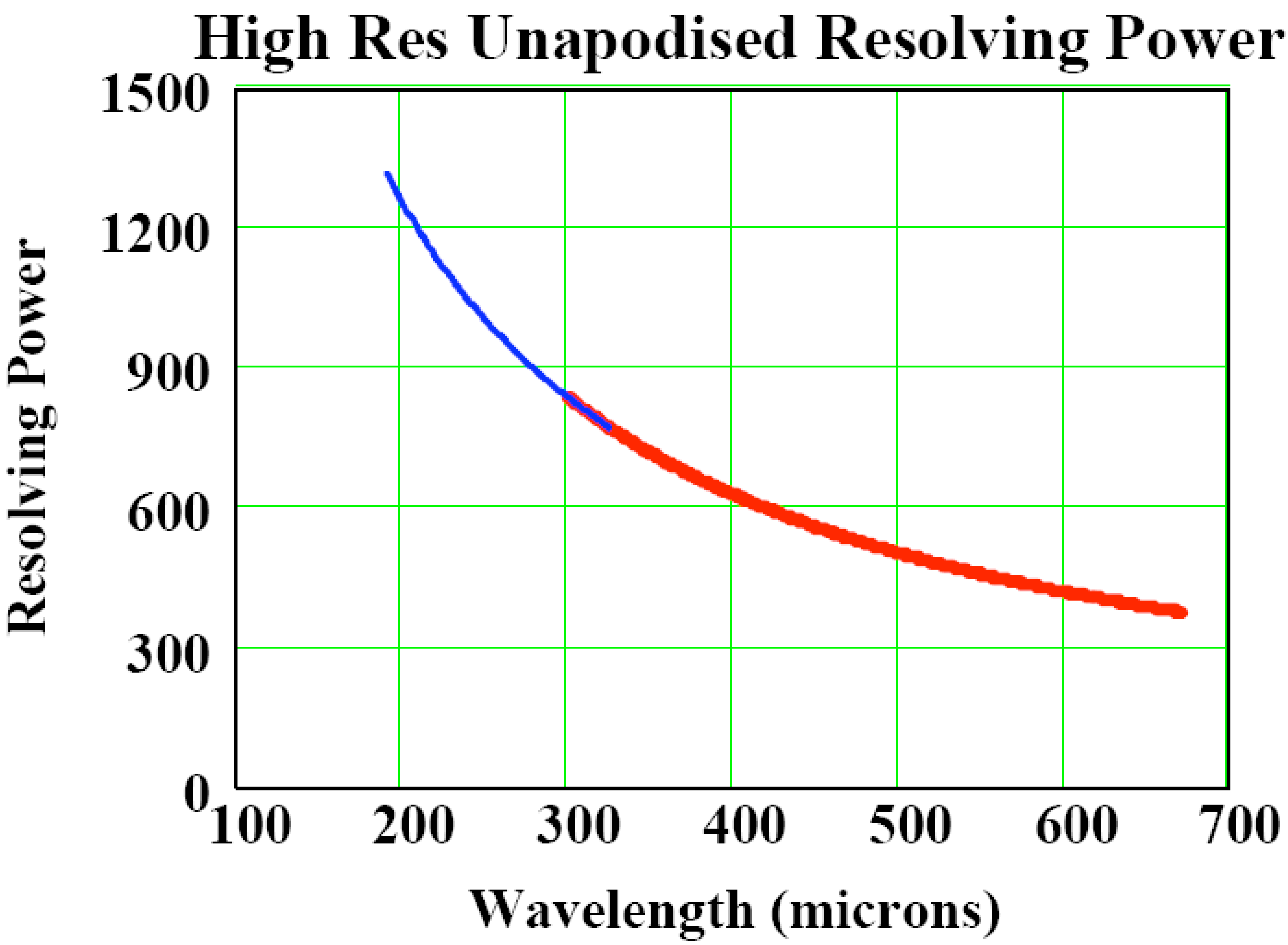
Spectral and Photometric Imaging Receiver

- **3-band imaging photometer**
  - 250, 350, 500 μm (simultaneous)
  - $\lambda/\Delta\lambda \sim 3$
  - 4 x 8 arcminute field of view
  - Diffraction limited beams (18, 25, 36")

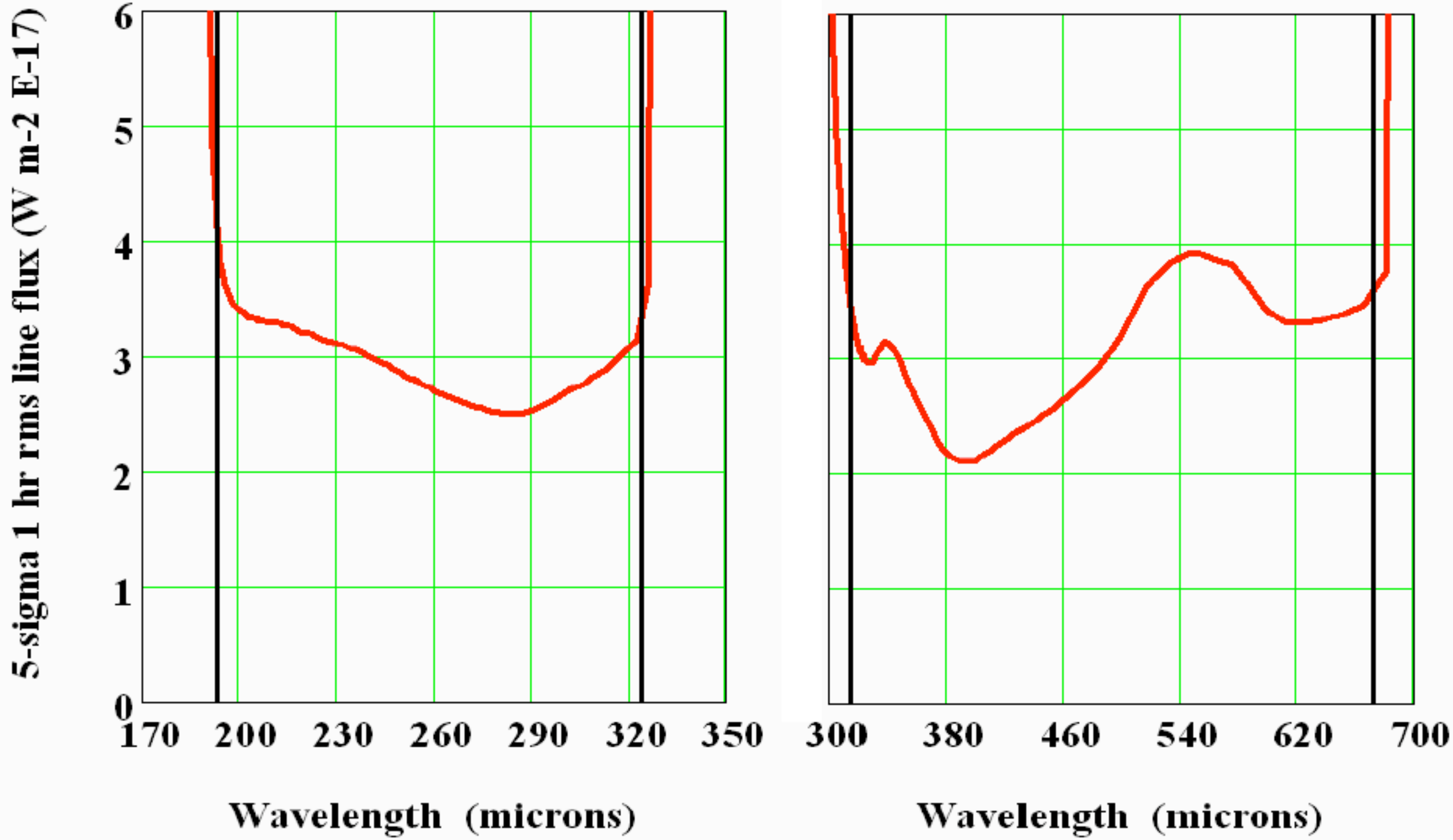


- **Imaging Fourier Transform Spectrometer**
  - 194 - 672 μm (complete range covered simultaneously)
  - 2.6 arcminute field of view
  - Two overlapping bands: 194 – 324 μm and 316 – 672 μm
  - Beam FWHM: ≈ 16" ≈ 35"
  - $\Delta\sigma$ = 0.04 cm^{-1} ($\lambda/\Delta\lambda \sim$ 20 - 1000 at 250 μm)

FTS Spectral Line Resolving Power
($\Delta\sigma = 0.04\ cm^{-1}$)



FTS Line Spectroscopy ($W\ m^{-2} \times 10^{-17}$ 5-σ 1 hr)

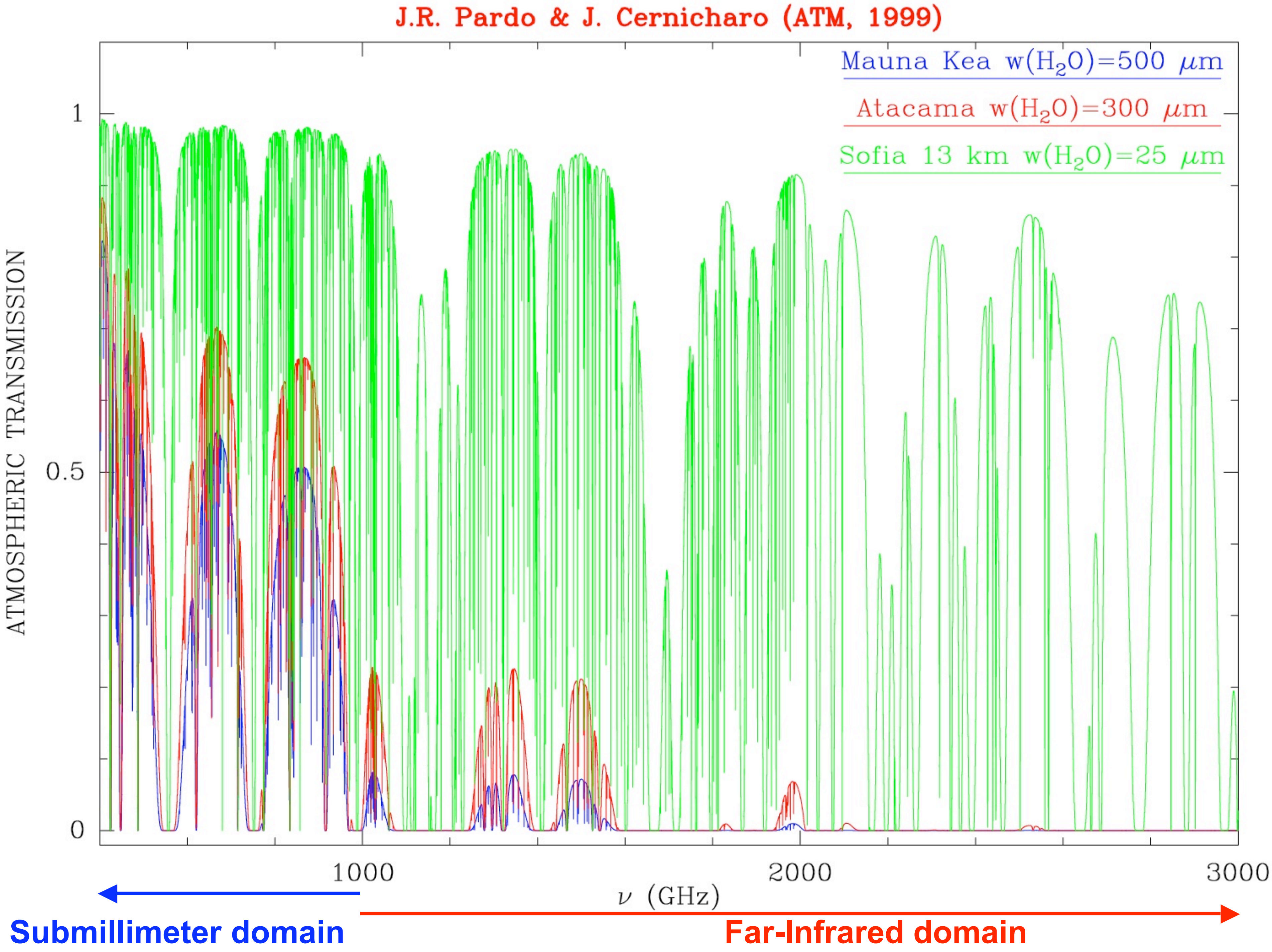


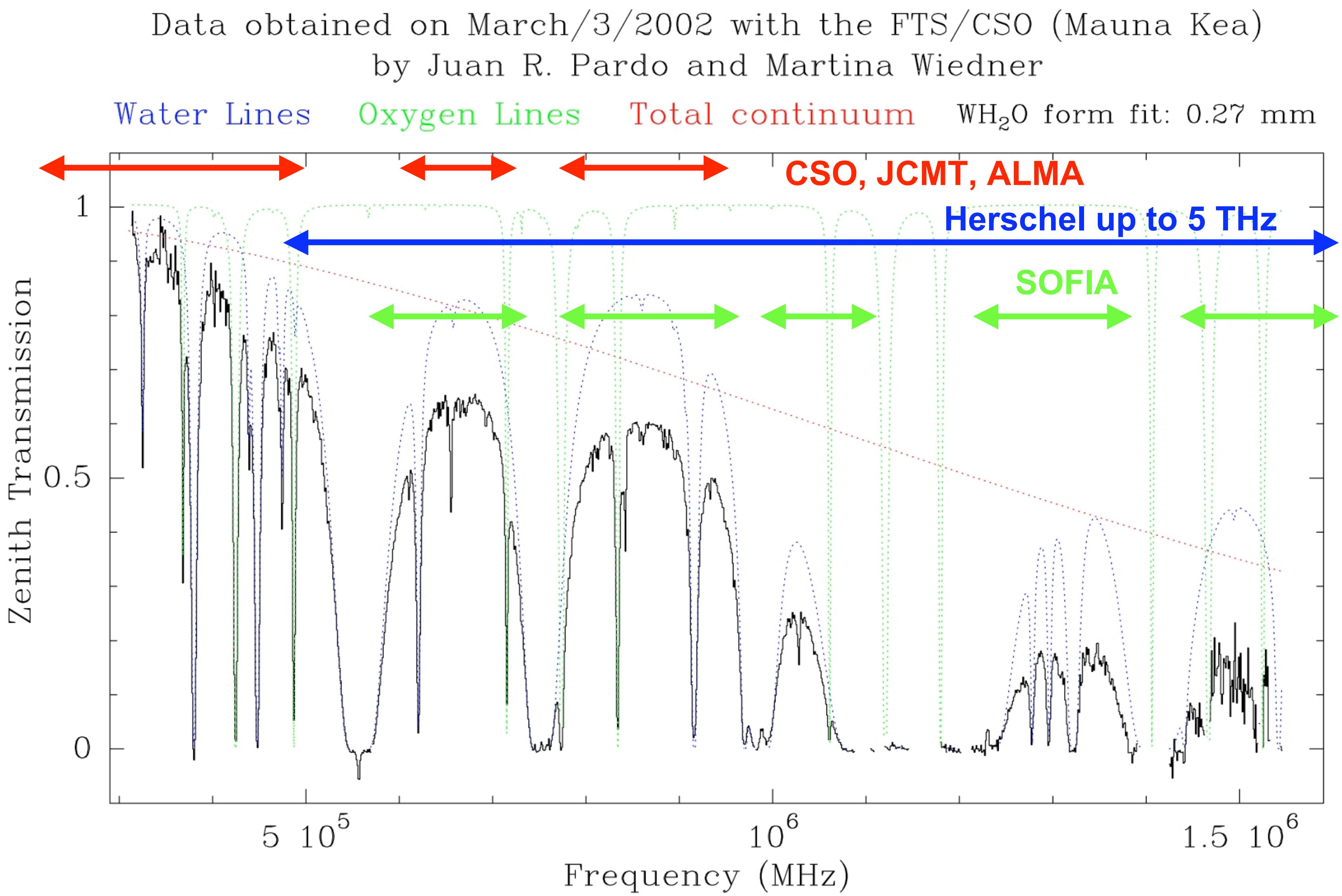
Division of SPIRE GT (1898 hrs)

SAG 1	High-redshift galaxies	43%
Coordinators: Jamie Bock and Seb Oliver		
SAG 2	Local galaxies	15%
Coordinators: Walter Gear and Suzanne Madden		
SAG 3	Star formation	16%
Coordinators: Philippe André and Paolo Saraceno		
SAG 4	Interstellar medium	9%
Coordinators: Alain Abergel and Jean-Paul Baluteau		
SAG 5	Solar system	2.5%
Coordinators: Regis Courtin and Bruce Swinyard		
SAG 6	Stellar & circumstellar	7.5%
Coordinators: Mike Barlow and Göran Olofsson		

LINE SURVEYS

- Why unbiased spectral coverage with HIFI ?
- To do what ?
- Limits (Molecular parameters)
- What sources ?
- What outcome from low spectral resolution surveys (PACS, SPIRE) ?
- The quest for chemical complexity → from Herschel to ALMA


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
ATMOSPHERIC TRANSMISSION
1
0.5
0
1000
2000
3000
ν (GHz)
Submillimeter domain
Far-Infrared domain



Data obtained on March/3/2002 with the FTS/CSO (Mauna Kea)
by Juan R. Pardo and Martina Wiedner
Water Lines
Oxygen Lines
Total continuum
WH2O form fit: 0.27 mm
CSO, JCMT, ALMA
Herschel up to 5 THz
SOFIA
Zenith Transmission
1
0.5
0
5 10^5
10^6
1.5 10^6
Frequency (MHz)

What we know about the far-IR molecular emission/absorption in interstellar and circumstellar clouds ?

- KAO (atomic fine structure lines, some high-J CO observations, OH, CH, …)

- JCMT, CSO (submillimeter), SWAS (H_2O at 557 GHz), ODIN (H_2O at 557, O_2, NH_3)

- ISO (H_2O, OH, CH, CH^+, high-J CO & HCN, dust, C_3, C_4, …)

So far, the ISO database is the main input for the study of the molecular content of molecular clouds in the far-IR

(but poor angular resolution and limited spectral resolution)

The scientific cases for heterodyne instruments in the submillimeter and far-Infrared :

- Observation of light molecular species (H_2O, OH, CH, CH^+)
- Observation of high-J transitions of abundant molecular species (CO, HCN, …)
- Observation of molecules without permanent dipole moment (C_3, C_4, …, complex organic molecules)
- Observation of atomic fine structure lines ([OI],[CII],[NII],…)
- Observation at frequencies blocked by the Earth atmosphere (H_2O)

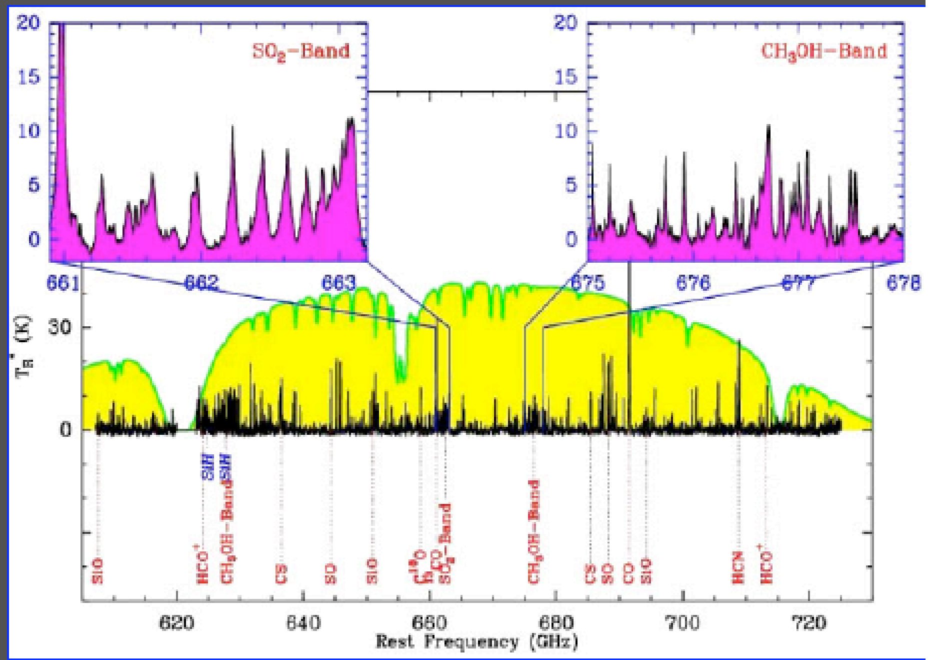
What kind of instruments ?

- Sensitive interferometers (ALMA)
- Airborne telescopes (SOFIA)
- Space Platforms (SWAS, Odin, Herschel, future space large telescopes or interferometers)

HIFI UNIQUE SCIENCE II: SPECTRAL SURVEYS

HIFI will make unbiased spectral scans of many different regions discovering a host of new species and determine reliable abundances !

- **What is the molecular inventory of space ?**
- What processes dominate interstellar chemistry ?
- How complex can the molecular universe be ?
- What is the role of interstellar molecules in the inventory of newly formed planetary systems ?
- What is the role of interstellar molecules in the origin of life ?
- What role do these molecules play in the physical evolution of these regions ?



Spectral Survey of Orion
in the ground-based windows

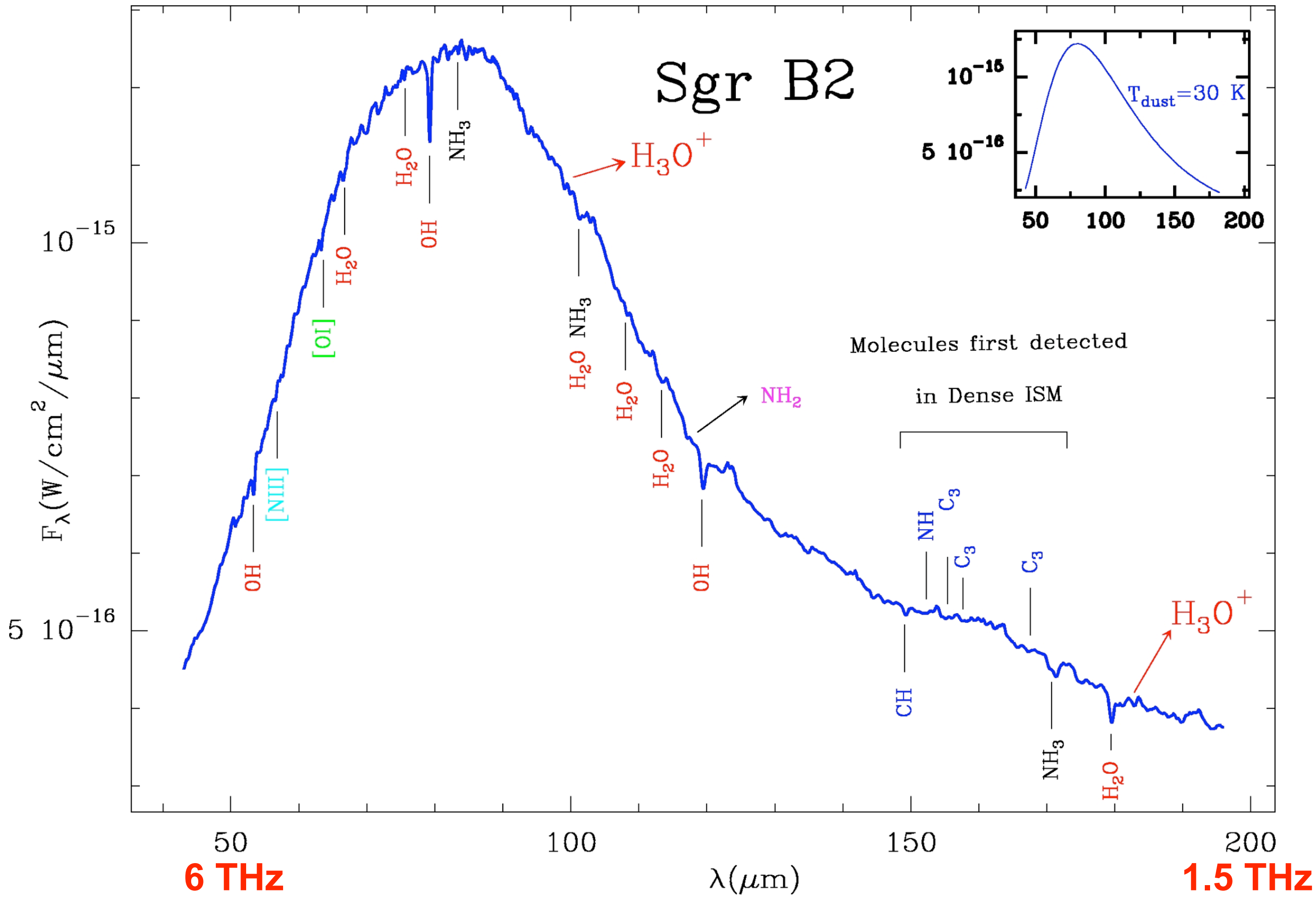
Astron. Astrophys. 323, L25–L28 (1997)

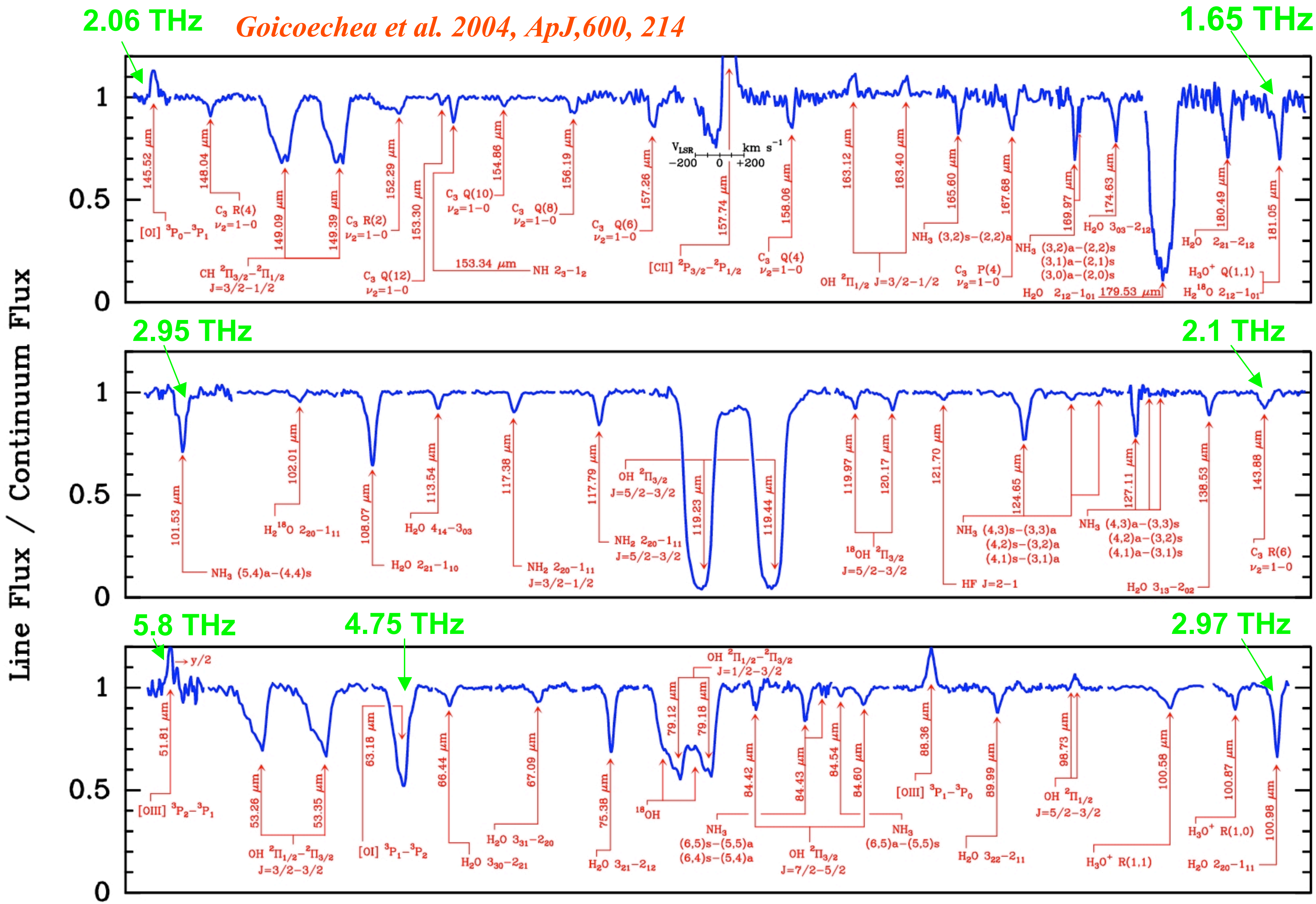
ASTRONOMY AND ASTROPHYSICS

Letter to the Editor

Widespread water vapour absorption in SgrB2[1]

J. Cernicharo[1], T. Lim[2], P. Cox[3], E. González-Alfonso[4,5], E. Caux[6], B.M. Swinyard[7], J. Martín-Pintado[5], J.P. Baluteau[8], and P. Clegg[9]



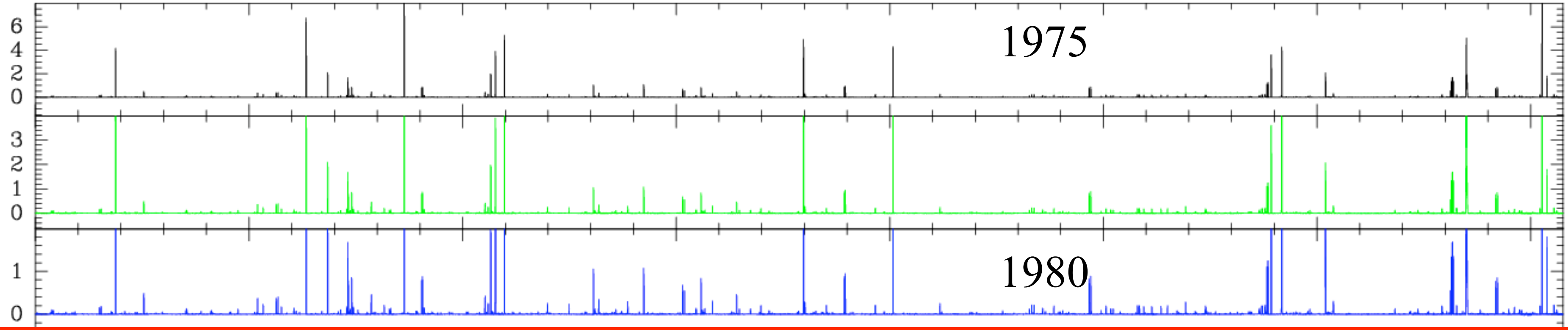


Low resolution Spectroscopy with ISO (Infrared Space Observatory)

Unbiased frequency coverage

- All rotational lines arising from energy levels pumped through collisions and or photons are observed
- Large range of physical conditions
- Good determination of physical parameters and molecular abundances
- All molecules observed, including isotopes and vibrationally excited states ➔ Molecular abundances ➔ chemical constraints

3mm line survey of IRC+10216 -30m IRAM telescope-

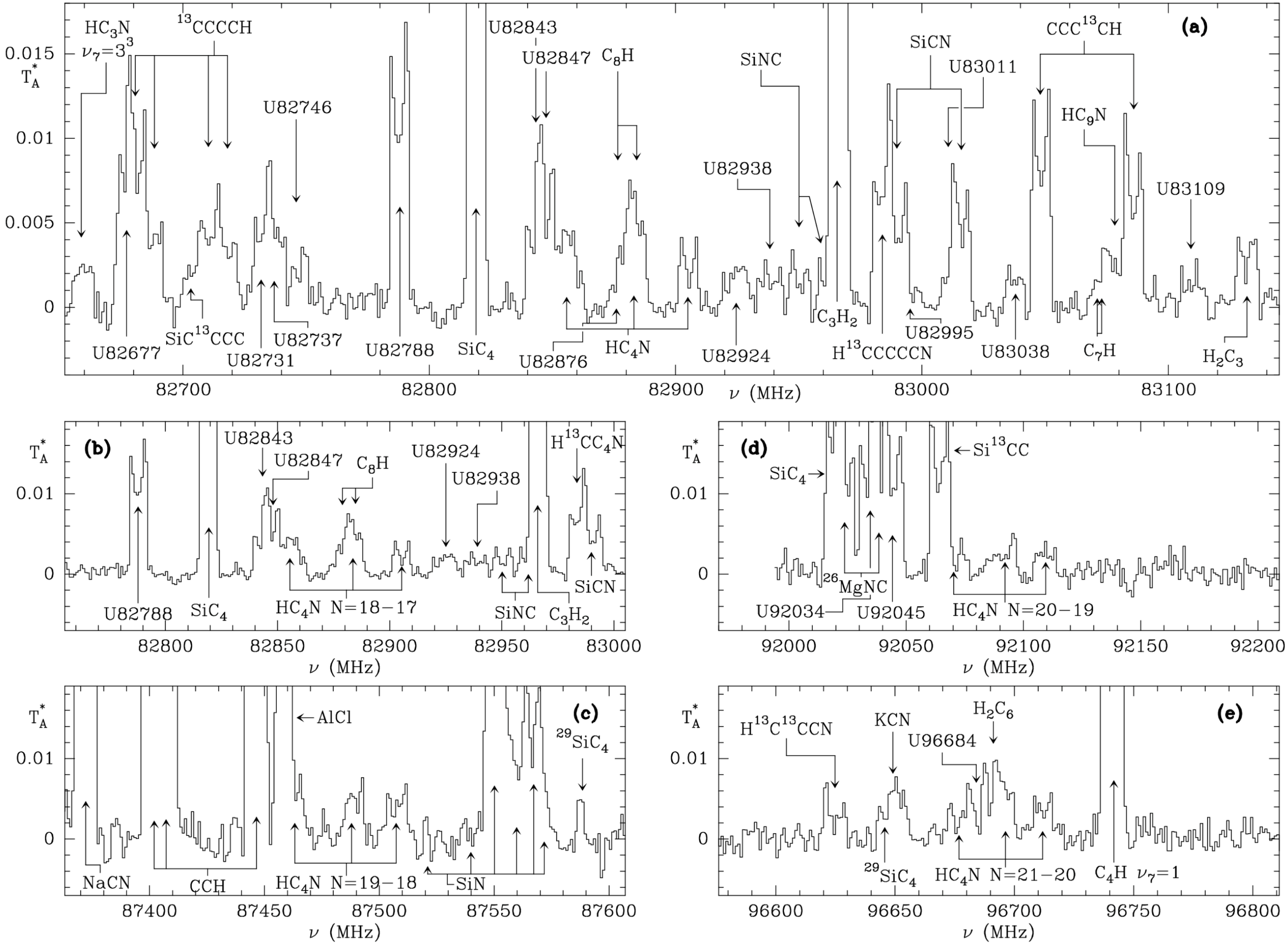


• What we could expect from line surveys ?

• Why we want to carry out line surveys ?

•What we need to interpret ALMA & Herschel line surveys ?

2007



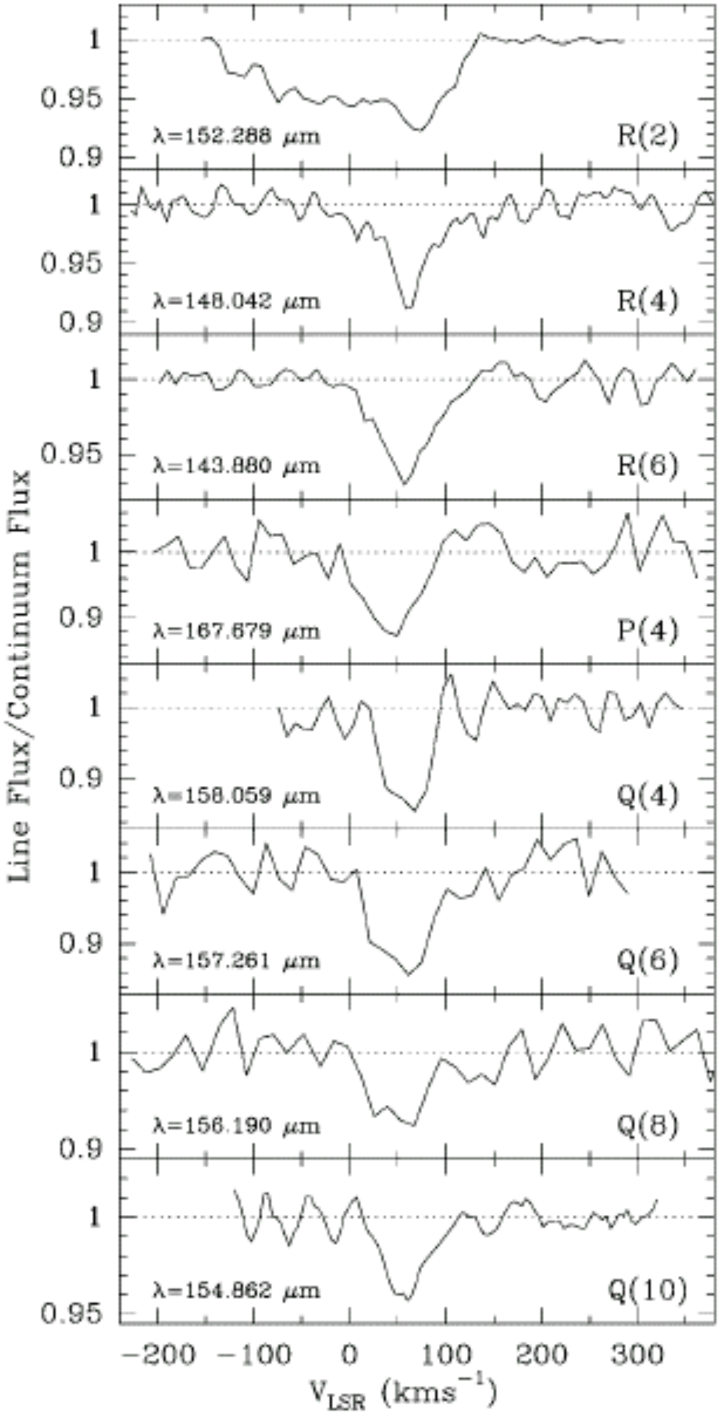
HC_4N :: Cernicharo et al., 2004, ApJLetters   SiNC: Guélin et al., 2004, A&A

So far all chemical models are fine tuned to fit the observed molecular abundances

What happens with molecules without dipole moment ?

How to identify large carbon molecules like PAHs ?

What kind of molecules could be observed ?



THE ASTROPHYSICAL JOURNAL, 534:L199–L202, 2000 May 10

FAR-INFRARED DETECTION OF C_3 IN SAGITTARIUS B2 AND IRC +10216[1]

JOSÉ CERNICHARO AND JAVIER R. GOICOECHEA
CSIC, Instituto de Estructura de la Materia, Departamento Física Molecular, Serrano 121, E-28006 Madrid, Spain
AND
EMMANUEL CAUX
Centre d'Etude Spatiale des Rayonnements, CESR/CNRS–Université Paul Sabatier, BP 4346 F-31029 Toulouse Cedex, France
Received 2000 February 11; accepted 2000 March 23; published 2000 May 5

ABSTRACT

We report on the detection of nine lines of the ν_2 bending mode of triatomic carbon, C_3, in the direction of Sagittarius B2. The *R*(4) and *R*(2) lines of C_3 have been also detected in the carbon-rich star IRC +10216. The abundances of C_3 in the direction of Sgr B2 and IRC +10216 are $\simeq 3 \times 10^{-8}$ and $\simeq 10^{-6}$, respectively. In Sgr B2 we have also detected the 2_3–1_2 line of NH with an abundance of a few times 10^{-9}. Polyatomic molecules will have a weak contribution from their pure rotational spectrum to the emission/absorption in the far-infrared. We suggest, however, that they could be, through their low-lying vibrational bending modes, the dominant carriers of emission/absorption in the spectrum of bright far-infrared sources.

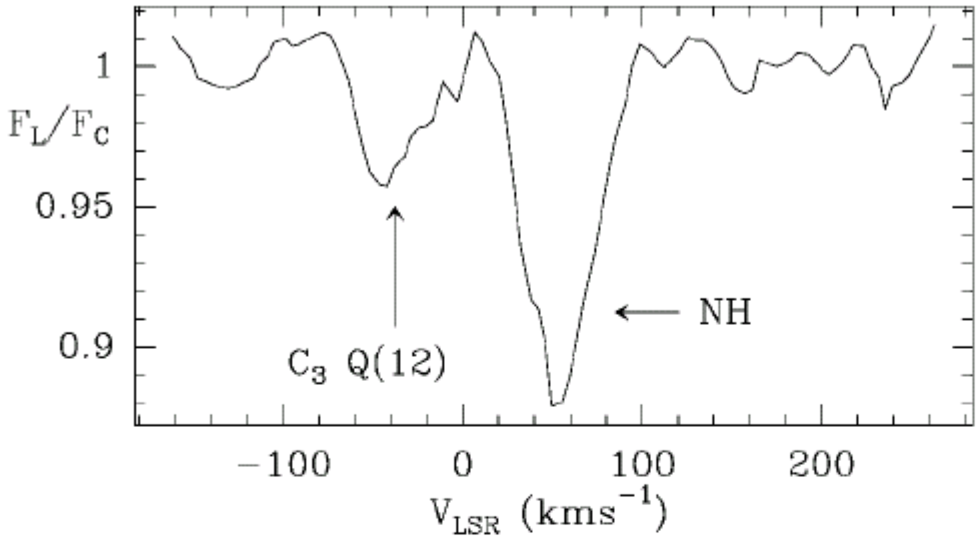
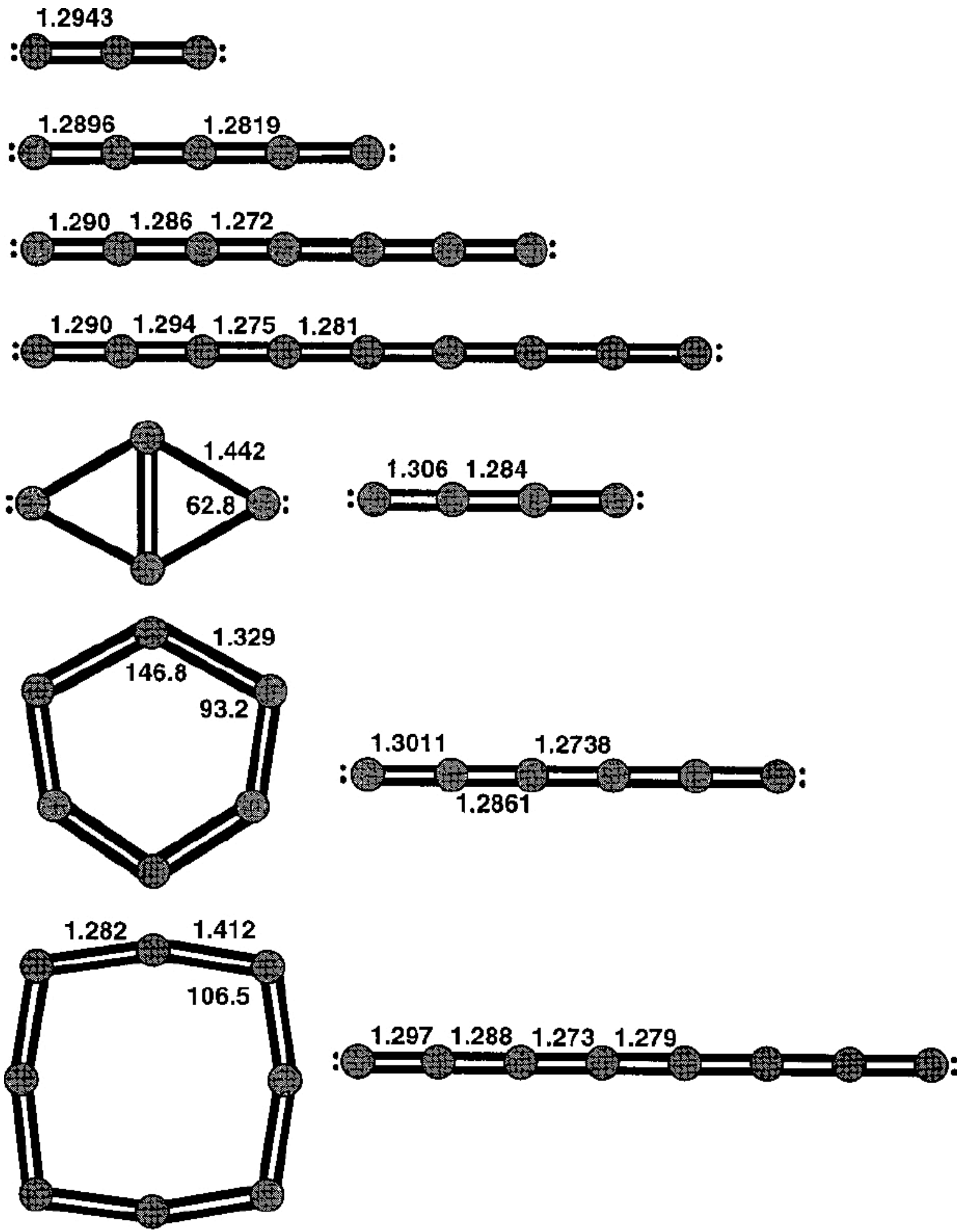


FIG. 3.—The 2_3–1_2 line of NH in Sgr B2. In the same spectrum, the C_3 *Q*(12) is also detected with an absorption of 3.5%.



Cumulenic Carbon Clusters

C_3 ν_2=63.4 cm^{-1} (158 μm)

C_4 ν_5= 160±4 cm^{-1} (61-64 μm)

C_5 ν_7= 107±5 cm^{-1} (89-98 μm)

C_6 ν_9= 90±50 cm^{-1} (71-250 μm)

C_7 ν_{11}= 80 cm^{-1} (125 μm)

C_8 ??

C_9 ν_{15}= 51 cm^{-1} (196 μm)

C_{10} ? (linear isomer observed)

Orden & Saykally 1998
Chem. Rev. 98, 2313

Looking for exotic molecules

- Very exciting work
- But many simple and potential species still missing
- Some interesting species can not be observed due to lack of permanent dipole moment (CH_4, C_2H_4, C_2H_6,…)
- What to look for ?

DRAFT VERSION JUNE 8, 2007
Preprint typeset using LaTeX style emulateapj v. 12/14/05

DISCOVERY OF INTERSTELLAR PROPYLENE (CH_2CHCH_3): MISSING LINKS IN INTERSTELLAR GAS–PHASE CHEMISTRY .

N. MARCELINO[1], J. CERNICHARO[1], M. AGÚNDEZ[1], J. MARTÍN-PINTADO[1], R. MAUERSBERGER[2], E. ROUEFF[3], M. GERIN[4], AND C. THUM[5]

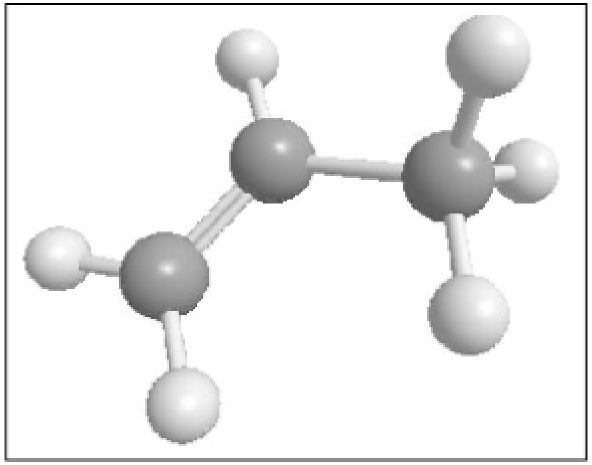
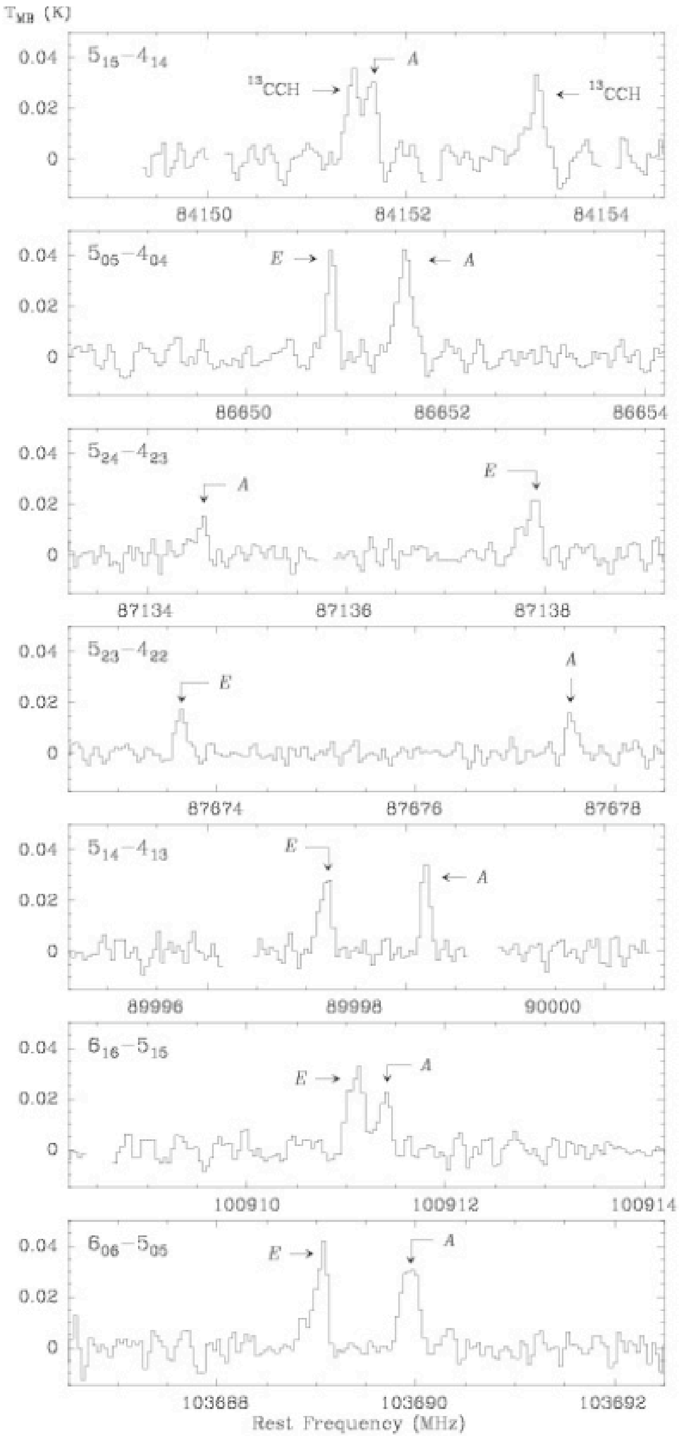


FIG. 2.— Molecular structure of Propylene. Spheres represent carbon (dark grey) and hydrogen (light grey) atoms.

CH_2CHCH_3
Propylene,
Propene,
Methylethene

We report on the discovery with the IRAM 30 m radio telescope of propylene, also called propene (CH_2CHCH_3), in the direction of the dark cloud TMC-1. Propylene is the most saturated hydrocarbon ever detected in space through radio astronomical techniques. In spite of its weak dipole moment, 6 doublets (A and E species) plus another line from the A species have been observed with main beam temperatures above 20 mK. The derived total column density of propylene is 4×10^{13} cm^{-2}, which corresponds to an abundance relative to H_2 of 4×10^{-9}, i.e., comparable to that of other well known and abundant hydrocarbons in this cloud. Although this isomer of C_3H_6 could play an important role in interstellar chemistry, it has been ignored by previous chemical models of dark clouds as there seems to be no obvious formation pathway. The discovery of this saturated species in a dark cloud indicates that a thorough analysis of the completeness of gas phase chemistry has to be done.

Subject headings: astrochemistry — line: identification — ISM: abundances — ISM: clouds — ISM: molecules



A Hot-core like molecule in a cold molecular core (TMC1)

An unexpected molecule → No formation paths available in chemical models. No frequencies in the public catalogs

A very abundant species
$X(CH_2CHCH_3)=X(c\text{-}C_3H_2)$!!!!!

MISSING LINKS IN GAS PHASE CHEMISTRY ? OR RICH DUST SURFACE CHEMISTRY EVEN IN DARK CLOUDS

CHEMICAL AND PHYSICAL EVOLUTION OF THE GAS & DUST: FROM COLD DARK CLOUDS TO PROTO-STELLAR CORES, HOT CORINOS & HOT CORES, PROTO-PLANETARY DISKS

Far-IR observation of the bending modes of large organic molecules not observable through pure rotational lines due to the lack or weakness of their dipole moment

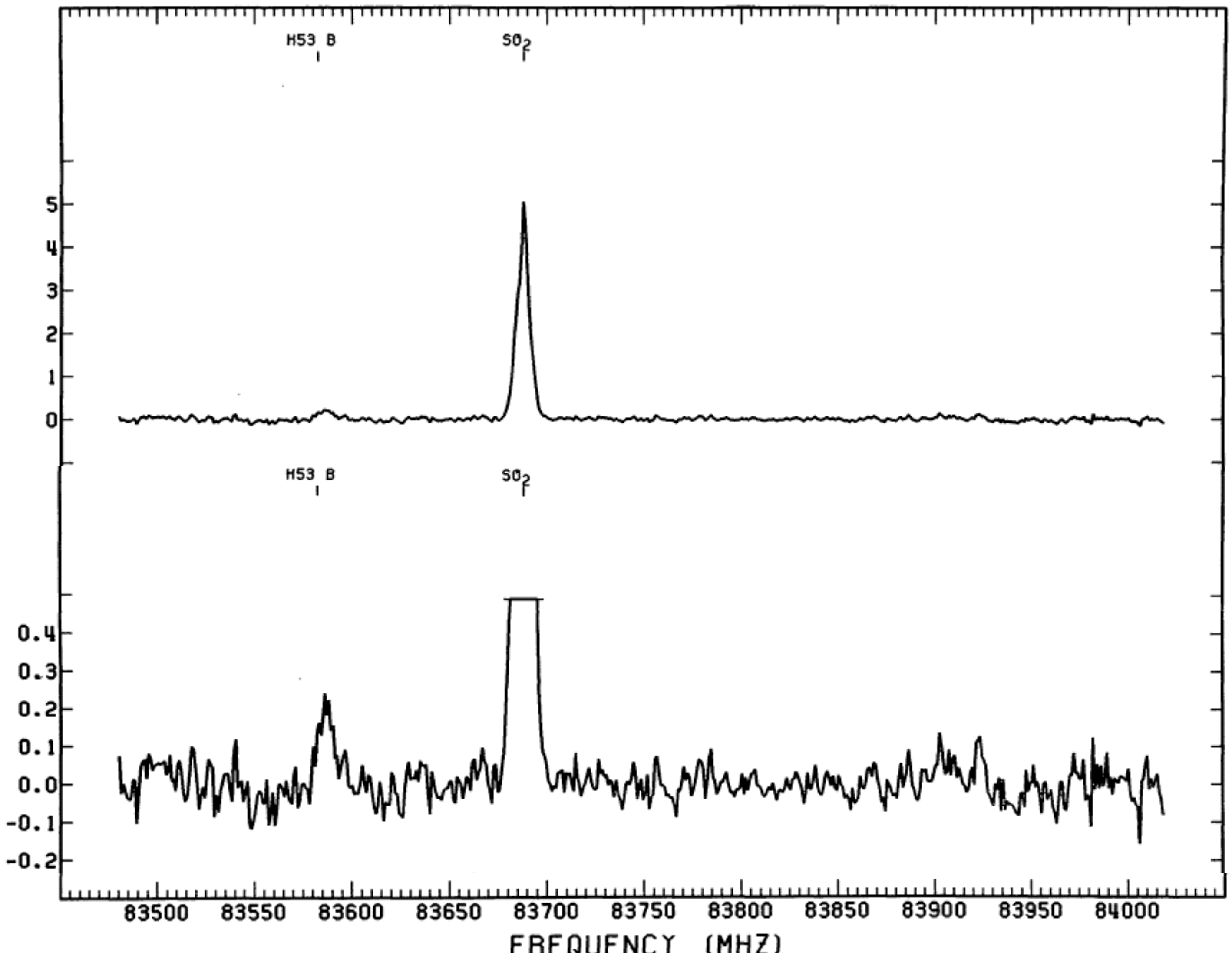
Large Organic Molecules ?

- So far all detected complex organic molecules are derivatives of CH_4, CH_2CH_2 and CH_3CH_3, ($CH_3CH_2CH_3$) (NONE OF THESE SPECIES HAVE BEEN OBSERVED IN COLD DARK CLOUDS !!!!)
- Larger Species searched in the Orion survey but not found yet : $CH_3CH_2CH_2OH$, $CH_3CH_2CH_2CN$,….
- Abundance factor between 2 and 3-C species > 10 !
- Line Confusion requires a large number of transitions to be confident about possible new detections.

Orion

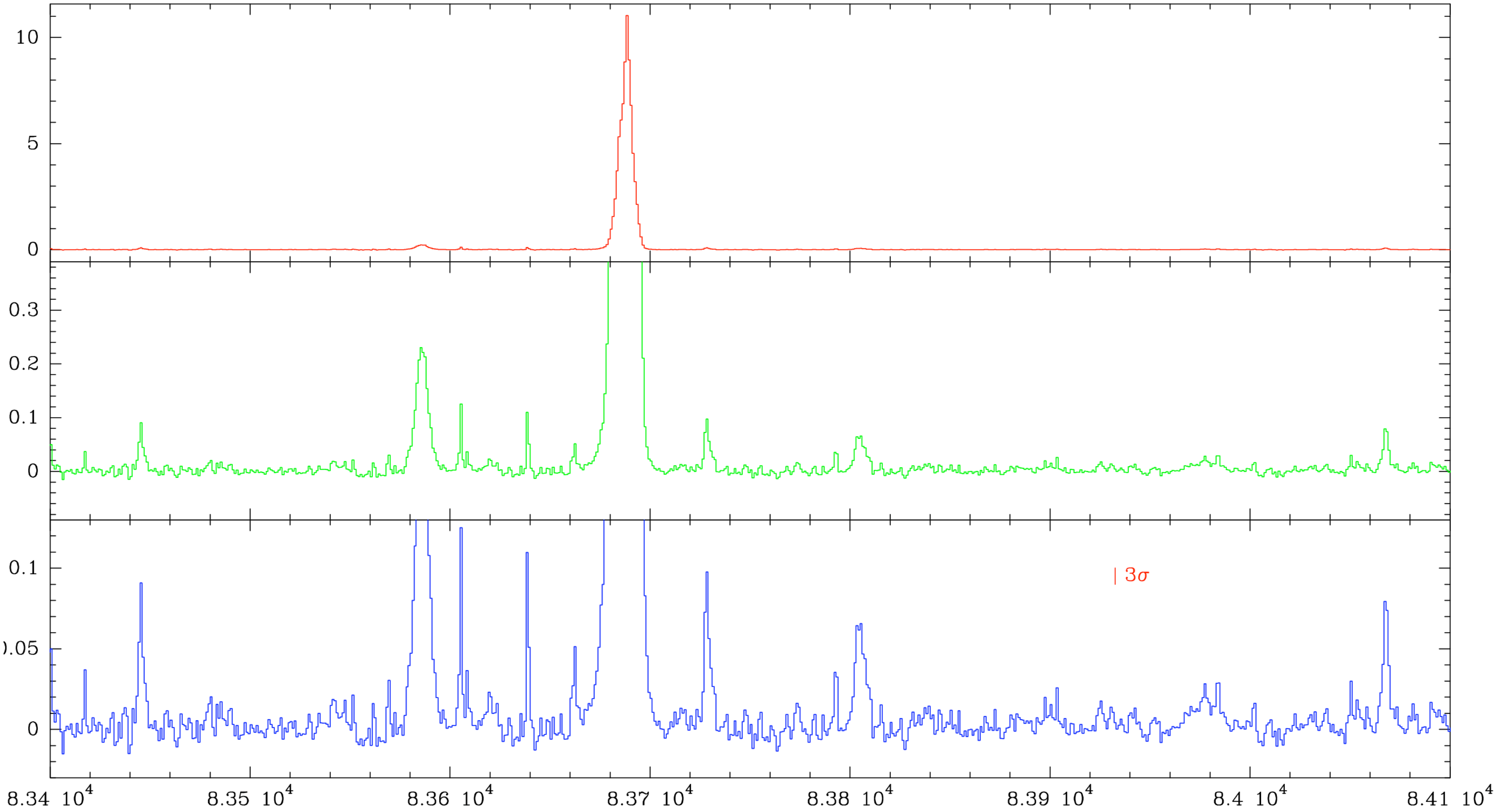
- The prototype of hot molecular cloud
- The main target for many astronomers
- A real nightmare to interpret even with present facilities !
- But a mandatory step in understanding star formation and a template for other distant objects

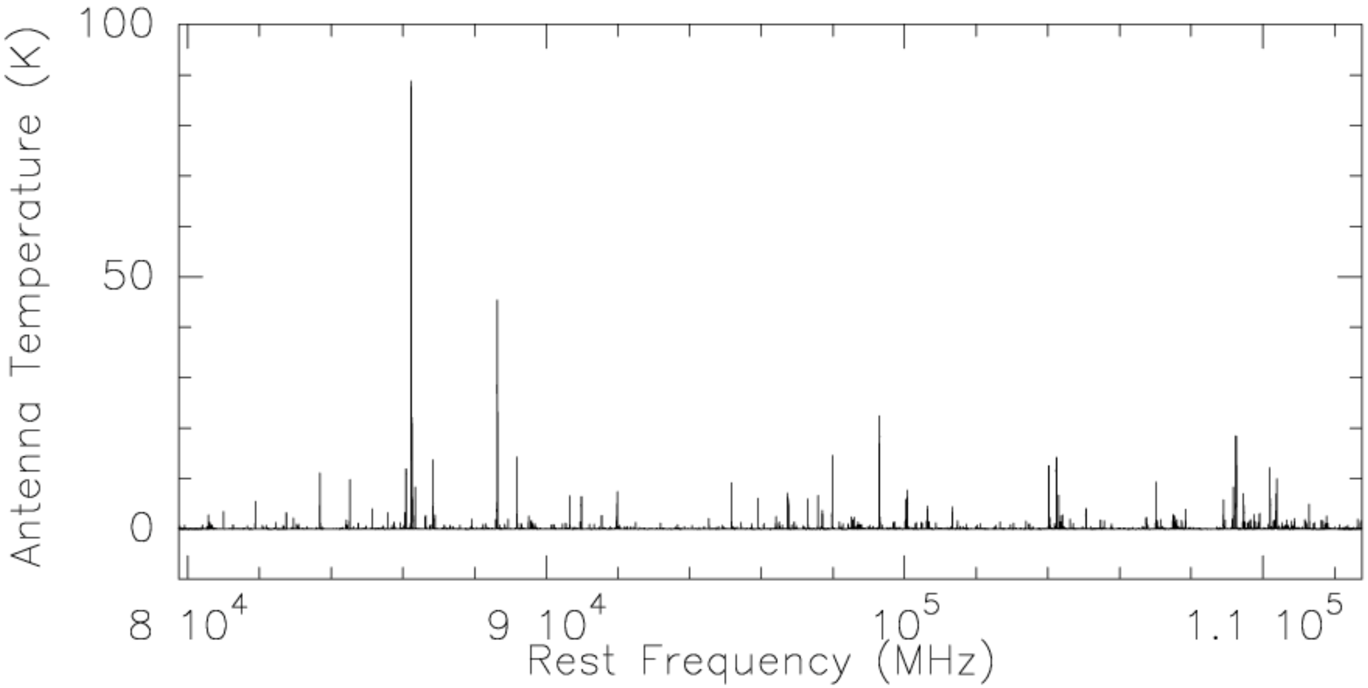
(Ted Bergin proposal is devoted to line surveys of Orion and SgrB2)



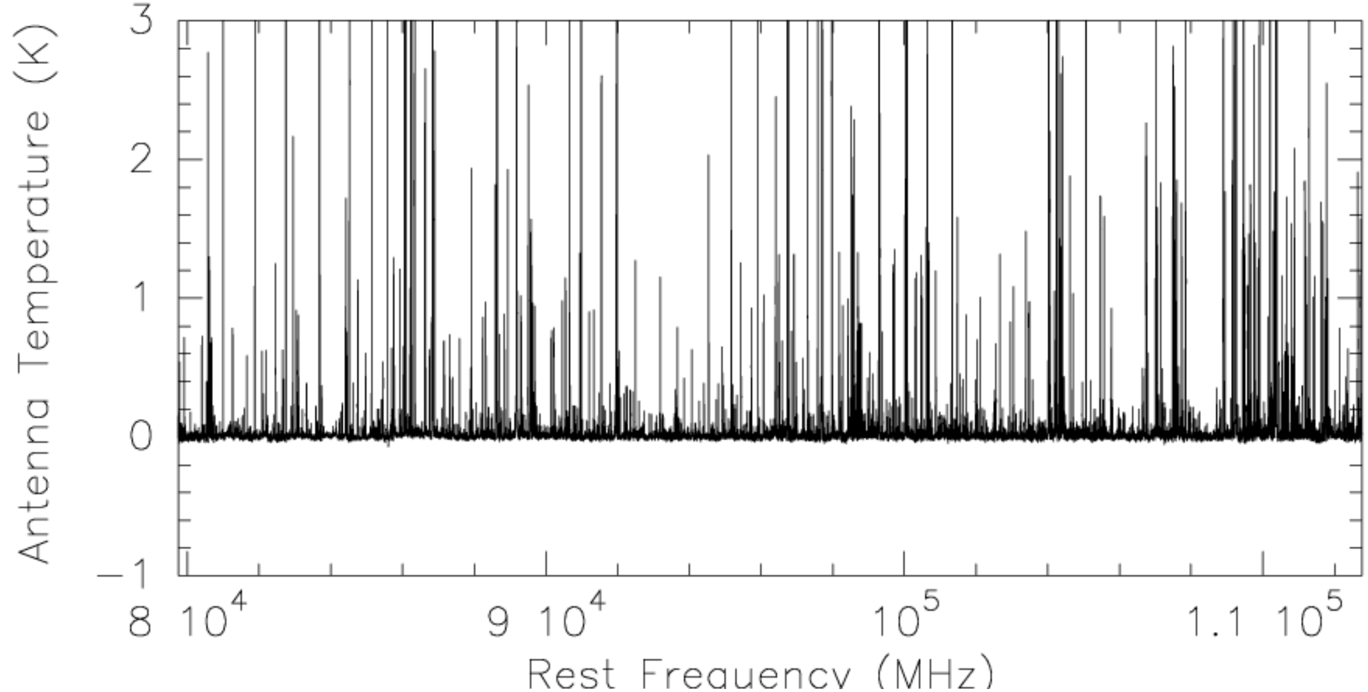
•Onsala line survey of Orion. State of the art in the 80's

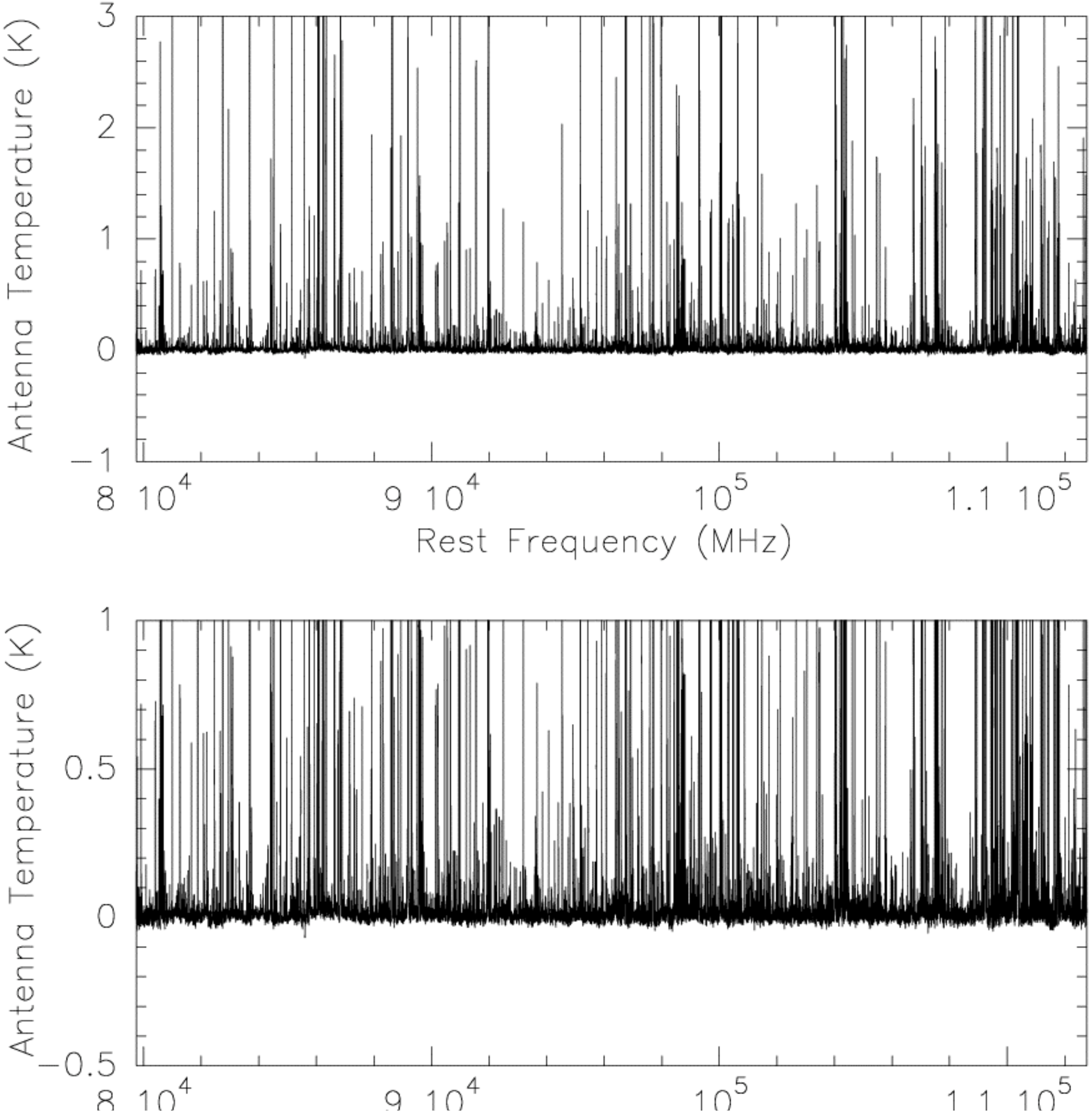
IRAM 30m spectrum; 40 min integration; Tsys=100 K





•Belen Tercero, PhD, DAMIR

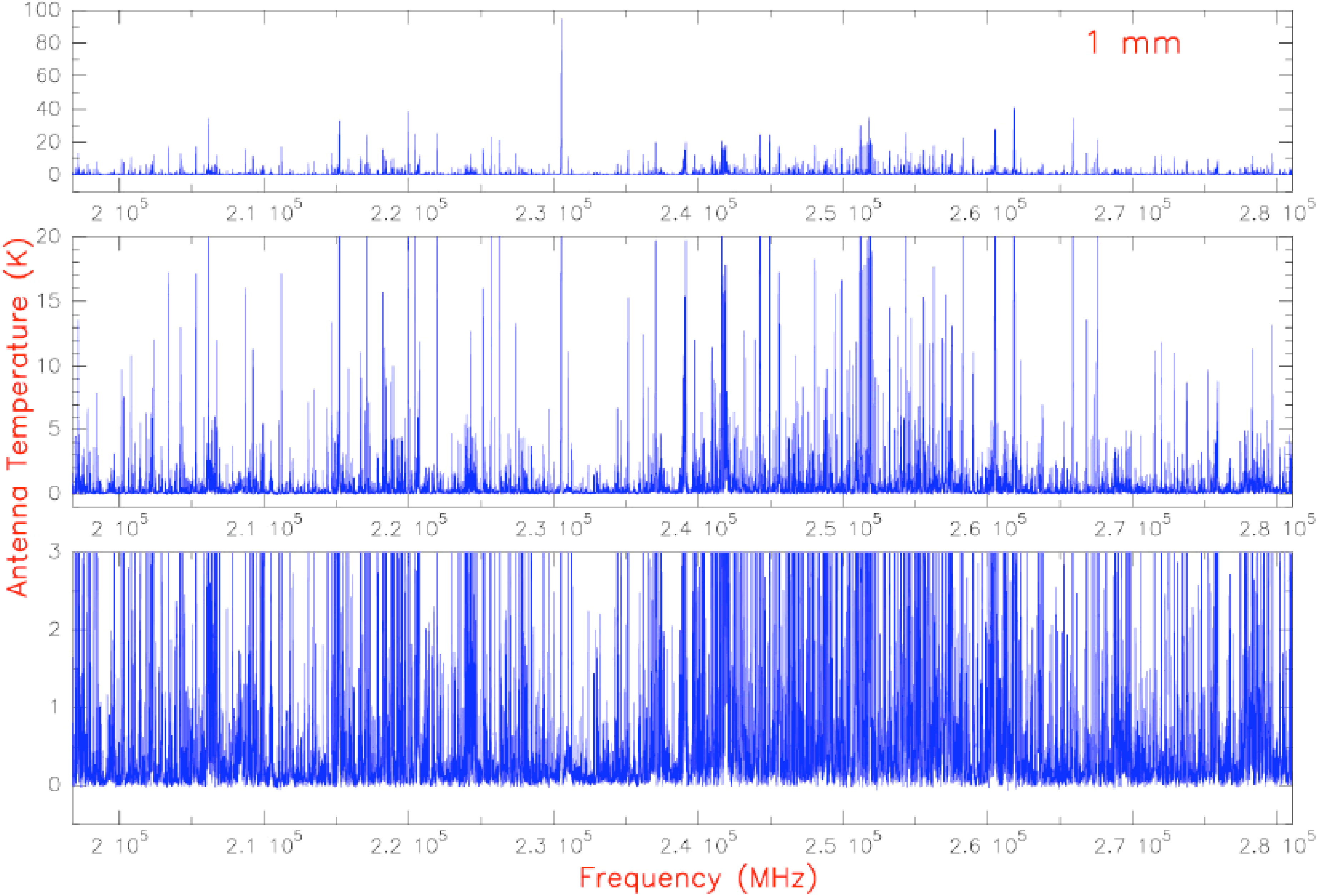


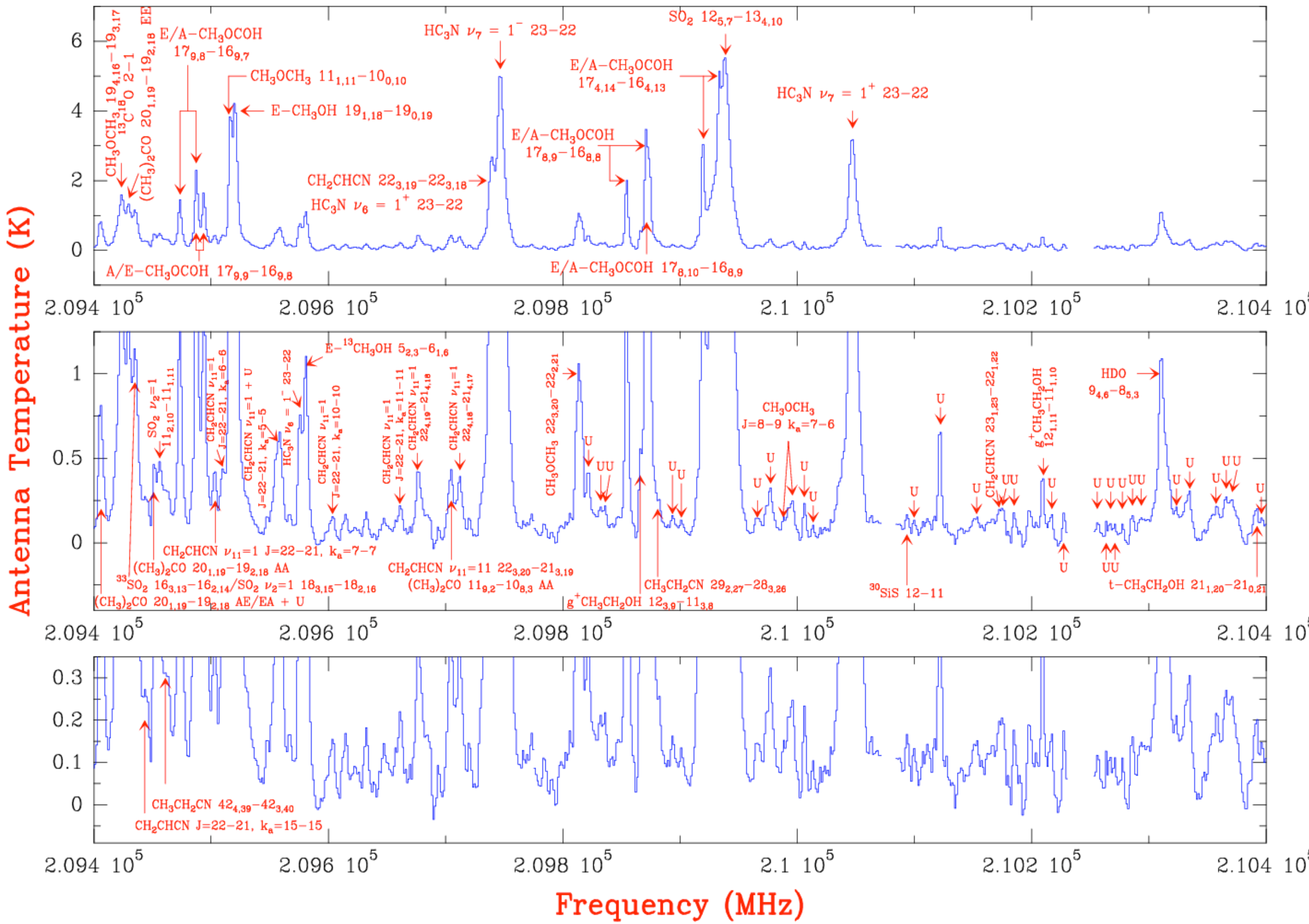


Antenna Temperature (K)
3
2
1
0
−1
8 10^4
9 10^4
10^5
1.1 10^5
Rest Frequency (MHz)
Antenna Temperature (K)
1
0.5
0
−0.5
8 10^4
9 10^4
10^5
1.1 10^5

•Orion as seen with the 30-m IRAM Telescope. 10 min observing time/GHz

35 hours observing time *B. Tercero & Cernicharo*





Antenna Temperature (K)
Frequency (MHz)
2.094 10^5
2.096 10^5
2.098 10^5
2.1 10^5
2.102 10^5
2.104 10^5
CH3OCH3 19_{4,16}−19_{3,17}
13C18O 2−1
(CH3)2CO 20_{1,19}−19_{2,18} EE
E/A−CH3OCOH 17_{9,8}−16_{9,7}
CH3OCH3 11_{1,11}−10_{0,10}
E−CH3OH 19_{1,18}−19_{0,19}
A/E−CH3OCOH 17_{9,9}−16_{9,8}
CH2CHCN 22_{3,19}−22_{3,18}
HC3N ν6 = 1+ 23−22
HC3N ν7 = 1− 23−22
E/A−CH3OCOH 17_{4,14}−16_{4,13}
E/A−CH3OCOH 17_{8,9}−16_{8,8}
E/A−CH3OCOH 17_{8,10}−16_{8,9}
SO2 12_{5,7}−13_{4,10}
HC3N ν7 = 1+ 23−22
SO2 ν2=1 11_{2,10}−11_{1,11}
CH2CHCN ν11=1 J=22−21, ka=6−6
CH2CHCN ν11=1 + U
CH2CHCN J=22−21, ka=5−5
HC3N ν6 = 1− 23−22
E−13CH3OH 5_{2,3}−6_{1,6}
CH2CHCN ν11=1 J=22−21, ka=10−10
CH2CHCN ν11=1 J=22−21, ka=11−11
CH2CHCN ν11=1 22_{4,19}−21_{4,18}
CH2CHCN ν11=1 22_{4,18}−21_{4,17}
CH3OCH3 22_{3,20}−22_{2,21}
CH3OCH3 J=8−9 ka=7−6
CH2CHCN 23_{1,23}−22_{1,22}
g+CH3CH2OH 12_{1,11}−11_{1,10}
HDO 9_{4,6}−8_{5,3}
U
CH2CHCN ν11=1 J=22−21, ka=7−7
(CH3)2CO 20_{1,19}−19_{2,18} AA
33SO2 16_{3,13}−16_{2,14}/SO2 ν2=1 18_{3,15}−18_{2,16}
(CH3)2CO 20_{1,19}−19_{2,18} AE/EA + U
CH2CHCN ν11=11 22_{3,20}−21_{3,19}
(CH3)2CO 11_{9,2}−10_{8,3} AA
CH3CH2CN 29_{2,27}−28_{3,26}
g+CH3CH2OH 12_{3,9}−11_{3,8}
30SiS 12−11
t−CH3CH2OH 21_{1,20}−21_{0,21}
CH3CH2CN 42_{4,39}−42_{3,40}
CH2CHCN J=22−21, ka=15−15

Herschel will unveil the far-IR spectrum of this source ALMA will provide hundreds of Orions –even in Orion itself - !!

- 30m IRAM telescope 80-280 GHz = 16000 lines in Orion

8000 unassigned in 2005 !!

6000 unassigned in 2007 !!

How to proceed ? What to do ?

Around 1000 Ulines less per year (optimistic view).

Problems for Herschel ::

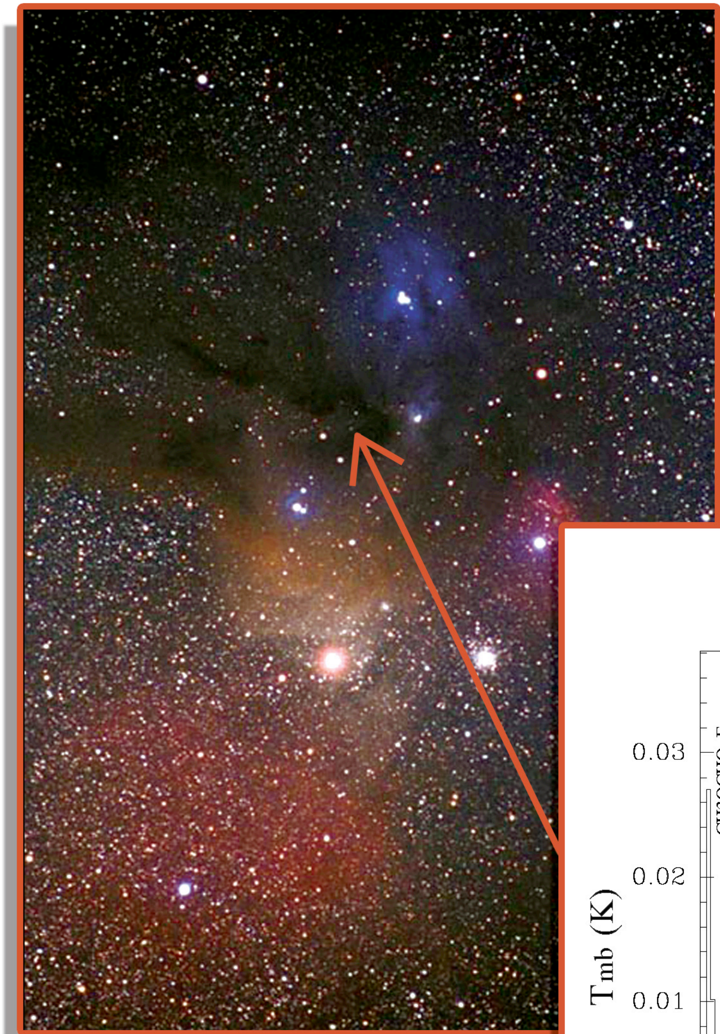
Accurate line frequencies up to 2 THz of most abundant molecules

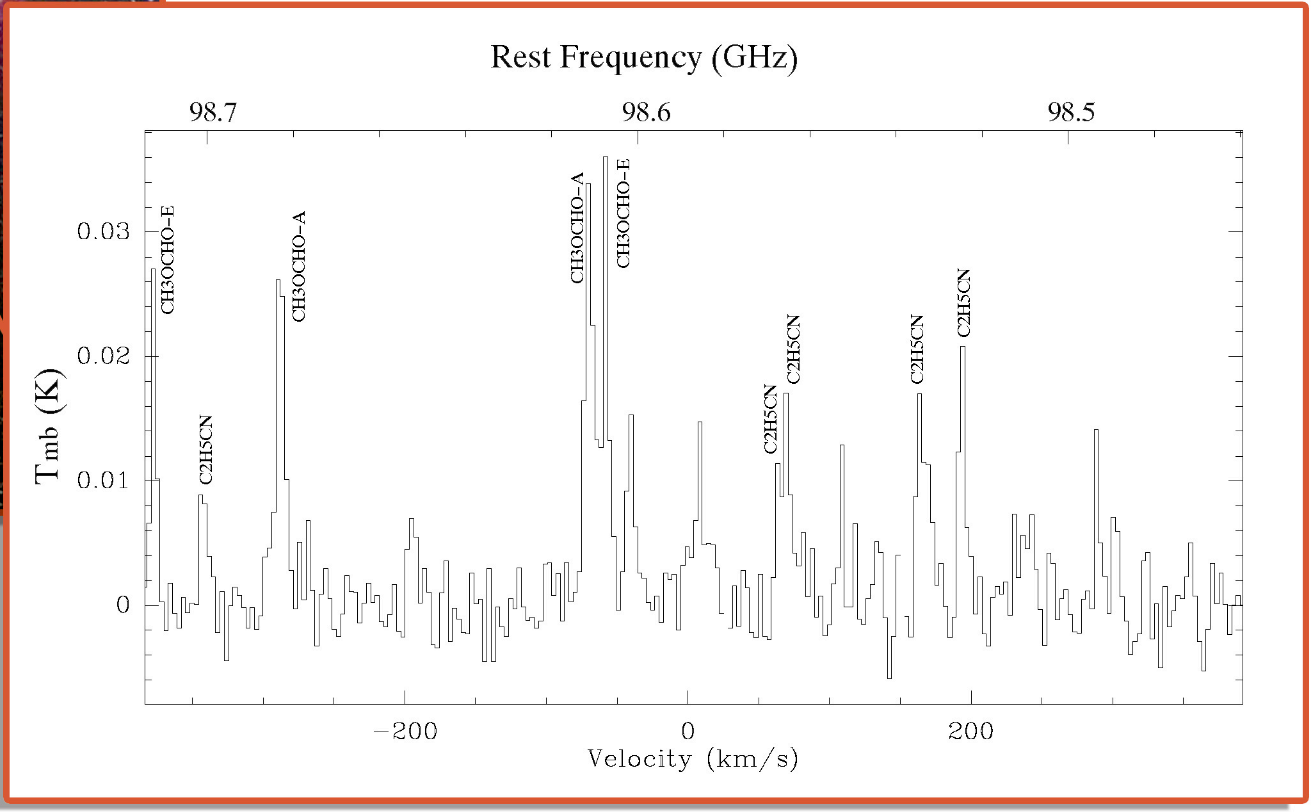
Problems for ALMA:

Accurate line frequencies up to 1 THz for all molecules
& their isotopes
& their vibrationally excited states

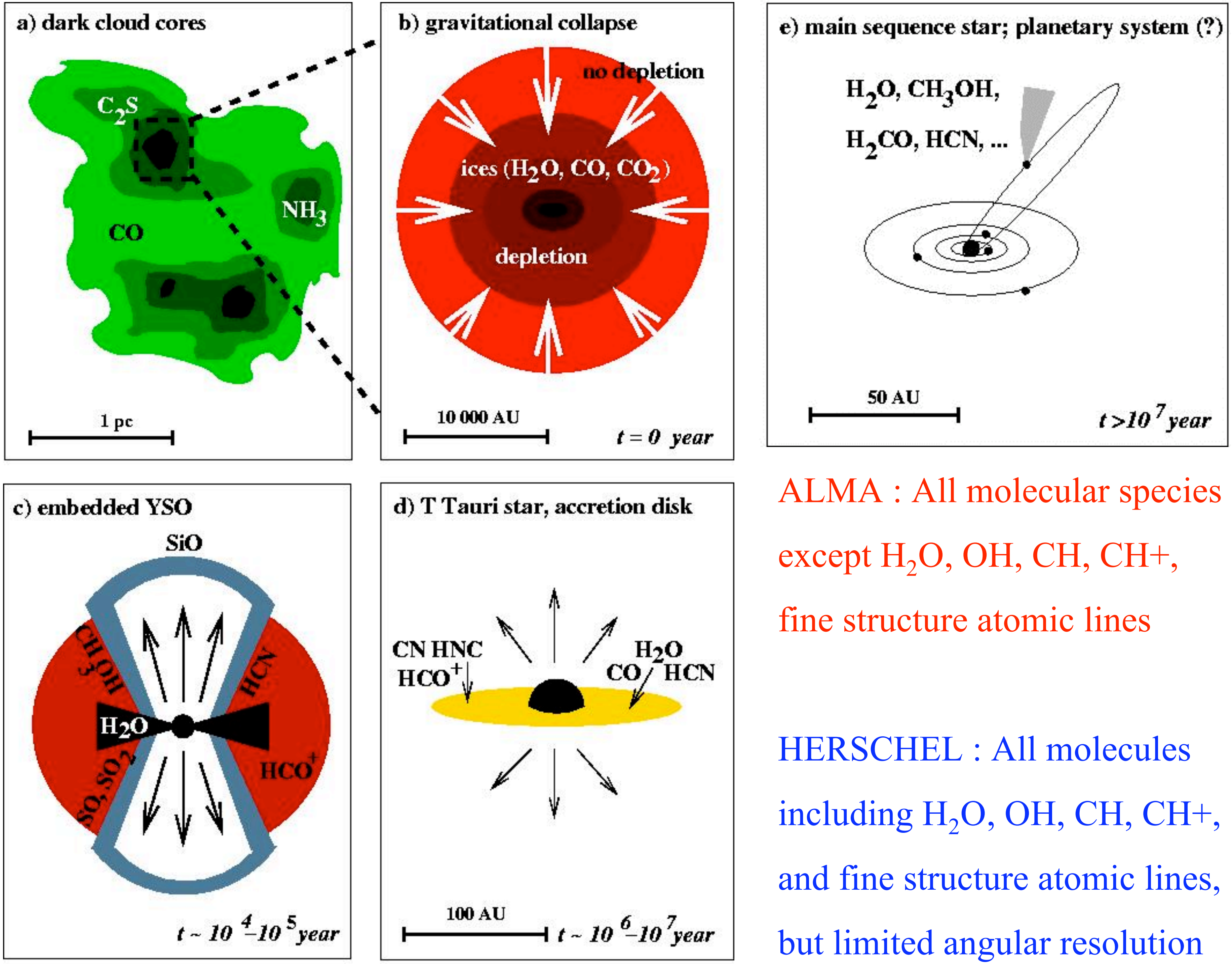
C. Ceccarelli HIFI program : Unbiased line surveys of star forming regions

Molecular complexity in solar type protostars





Cazaux et al. 2003



ALMA : All molecular species except H_2O, OH, CH, CH+, fine structure atomic lines

HERSCHEL : All molecules including H_2O, OH, CH, CH+, and fine structure atomic lines, but limited angular resolution

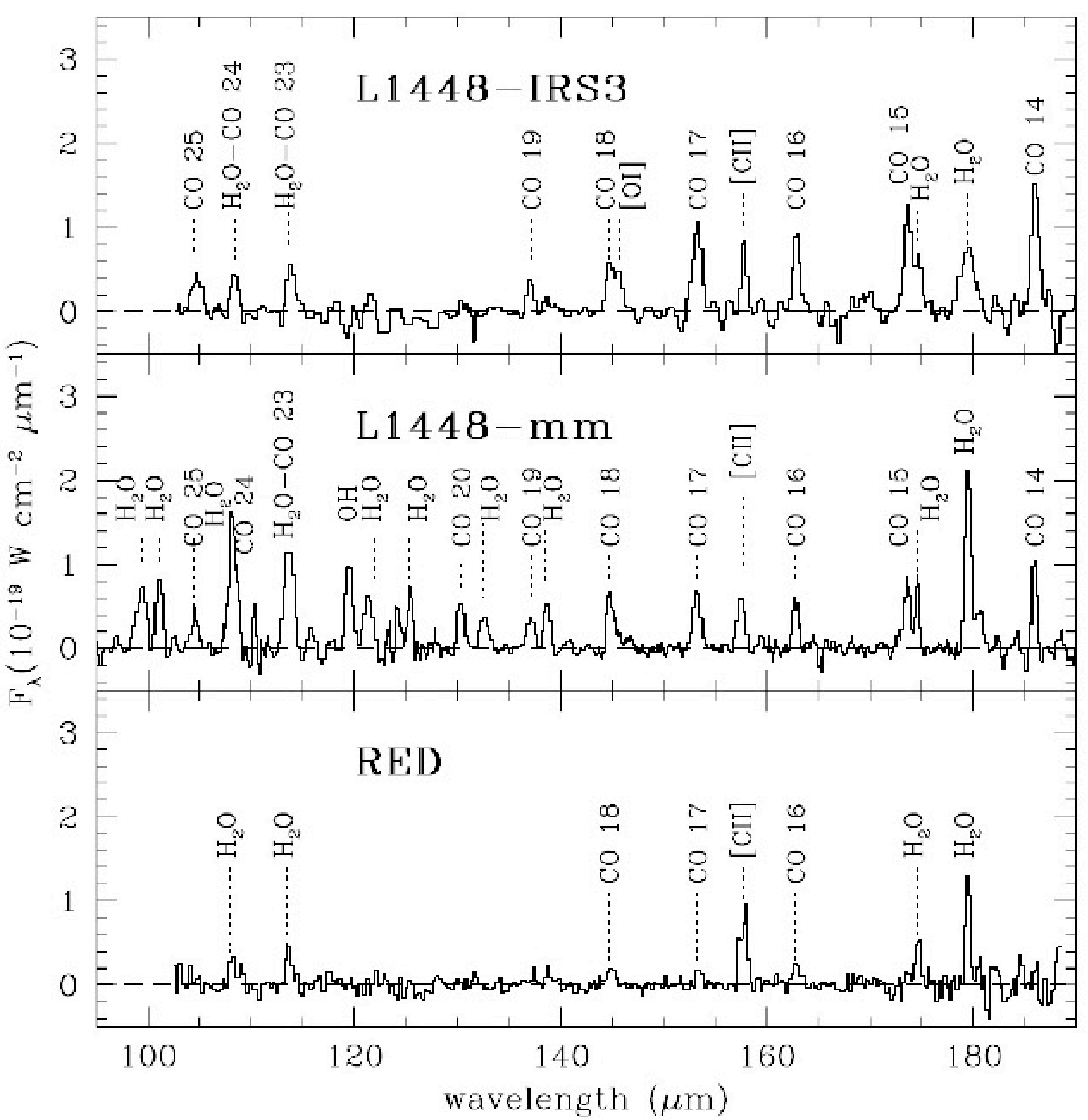


Figure 1. ISO/LWS continuum-substracted spectra in the direction of L1448-IRS3 and L1448-mm and the red lobe of the outflow associated to L1448-mm. The lines from OH, H_2O and CO, together with atomic fine structure lines, are indicated in the different panels. (From Nisini et al. 2000).

The real world : Orion & CRL618 lines every where

BUT WE INTERPRETED CRL618 AT 98% !!

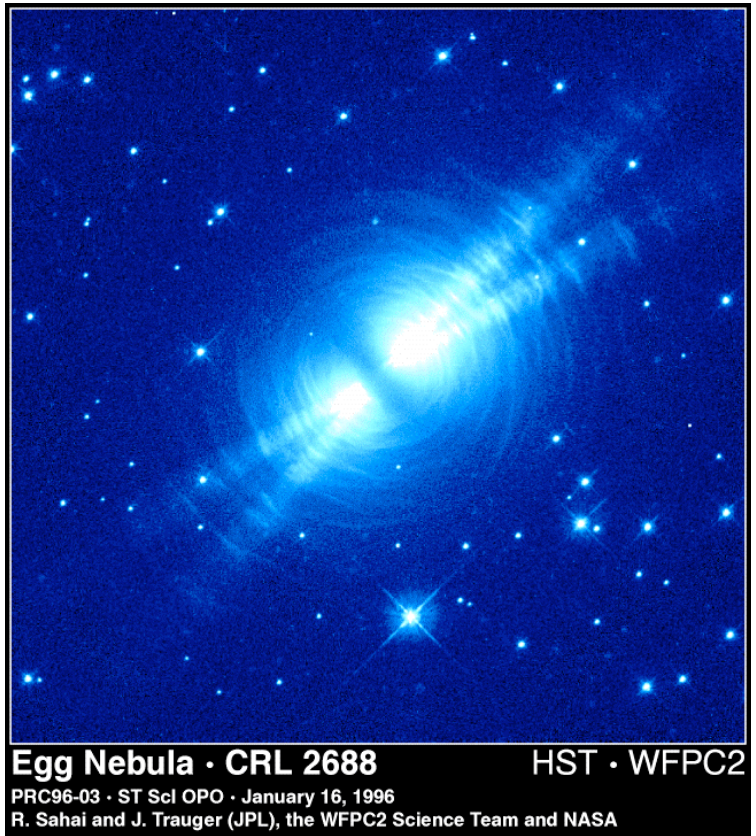
Main conclusion :Each source needs a specific model and an specific subset of molecules from line catalogs !! It is possible to make a deep study on molecular complexity if we have the correct molecular inputs

WORK DONE AT DAMIR (CSIC; MADRID)

by Juan Ramón PARDO and collaborators

The inner part of the neutral envelope is quickly ionized by the UV photons from the hot central star. An HII region is created and in the frontier with the neutral envelope a photodissociation region is produced.

The increase of temperature and the presence of UV photons, together with the anisotropic winds arising from the star excavate the neutral envelope and an important fraction of ionizing photons escape the envelope.



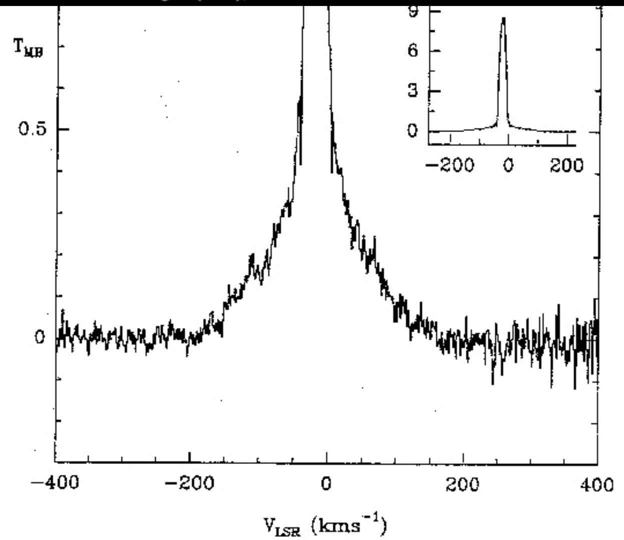


Fig. 1: CO J=2–1 line profile toward CRL 618. Ordinate is the main beam-averaged brightness temperature in kelvin.

Cernicharo et al., 1989
Gammie et al., 1989

ernicharo. “Dusty

Spectroscopy and Molecular Astrophysics with Herschel & ALMA:

How can we interpret the spectrum of a molecular cloud with a high line density ? (for example CRL618 or Orion)

→**Modelling the physical and chemical structure**

What we need ?

Molecular parameters :

Frequencies (with error estimates)

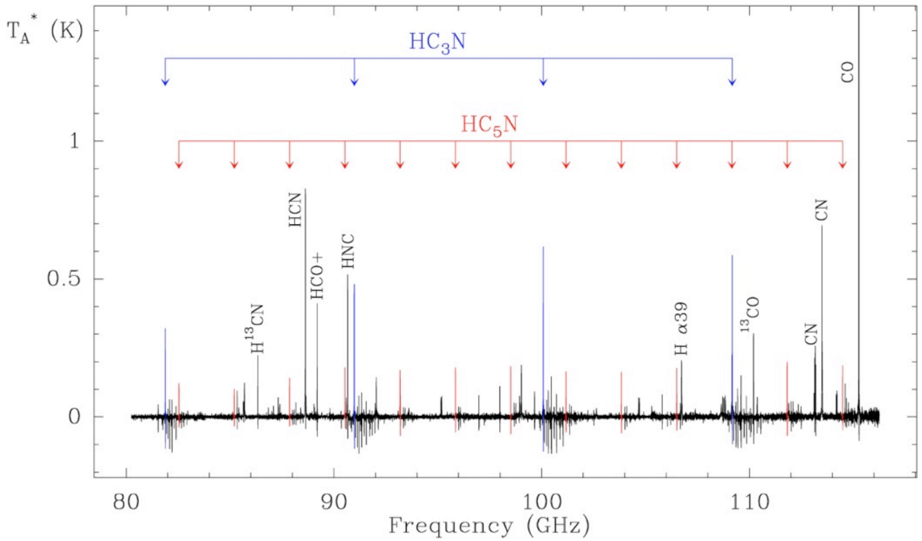
Line strengths

Dipole moments

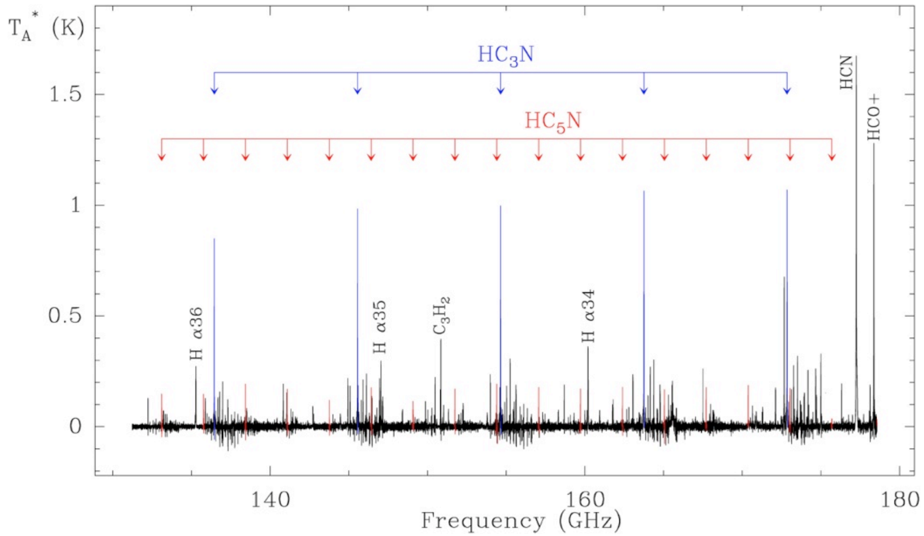
Collisional rates (PES)

•CRL618 Spectral Line Survey

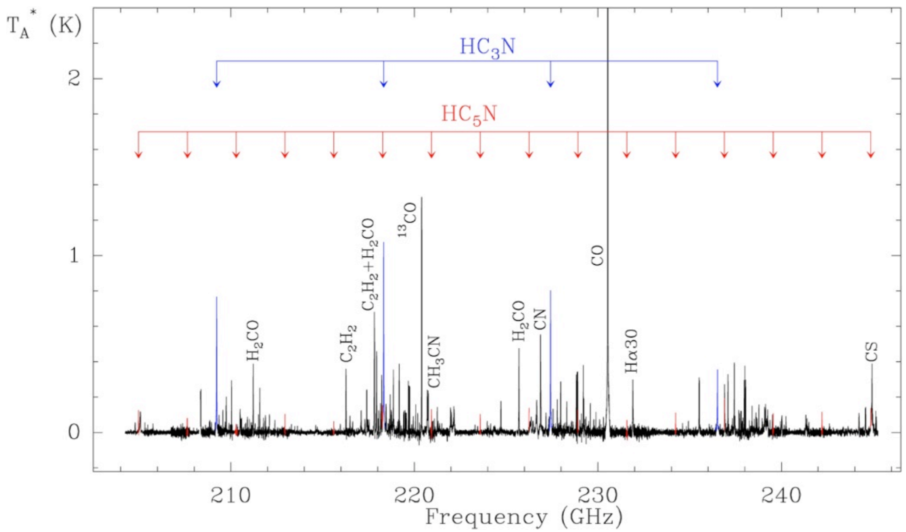
• λ ~ 3 mm



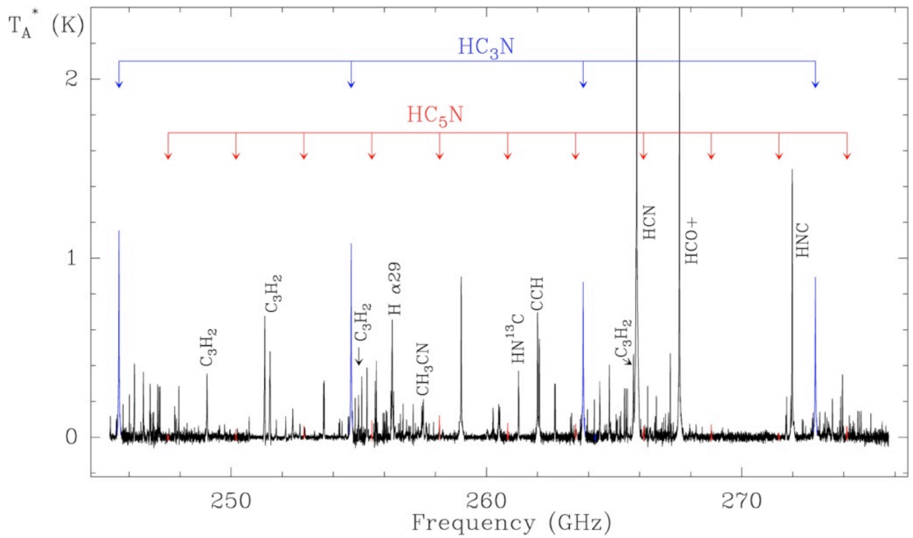
• λ ~ 2 mm



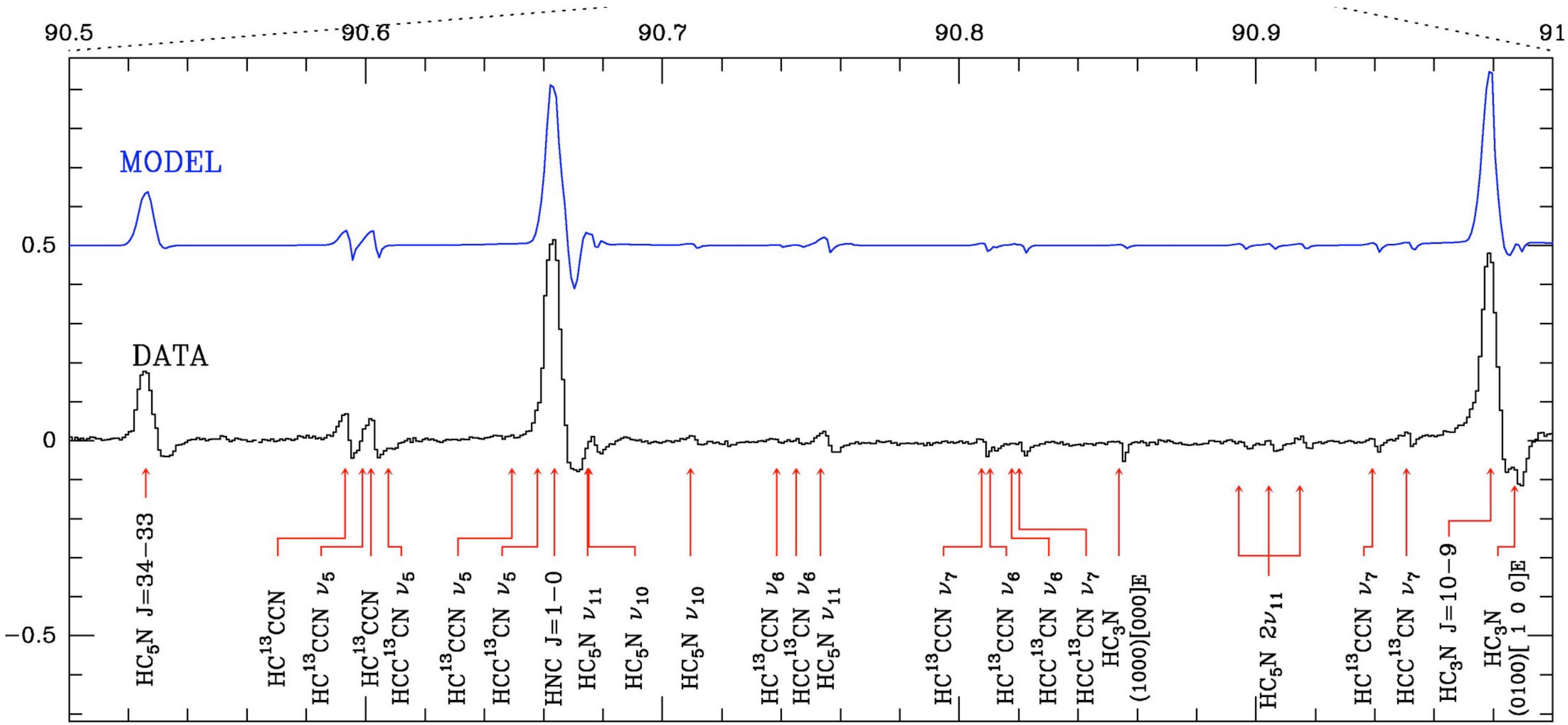
• λ ~ 1.3 mm



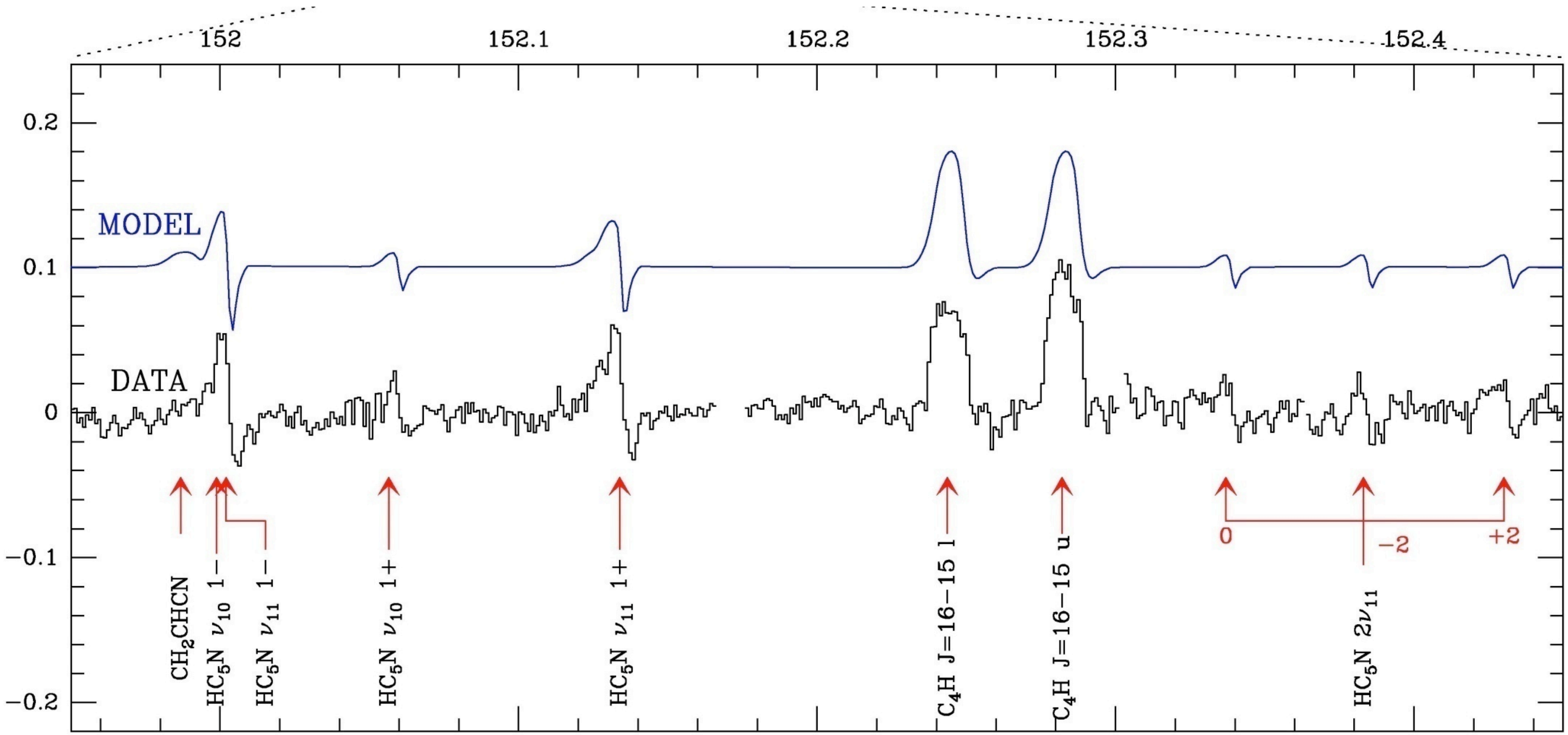
• λ ~ 1.0 mm



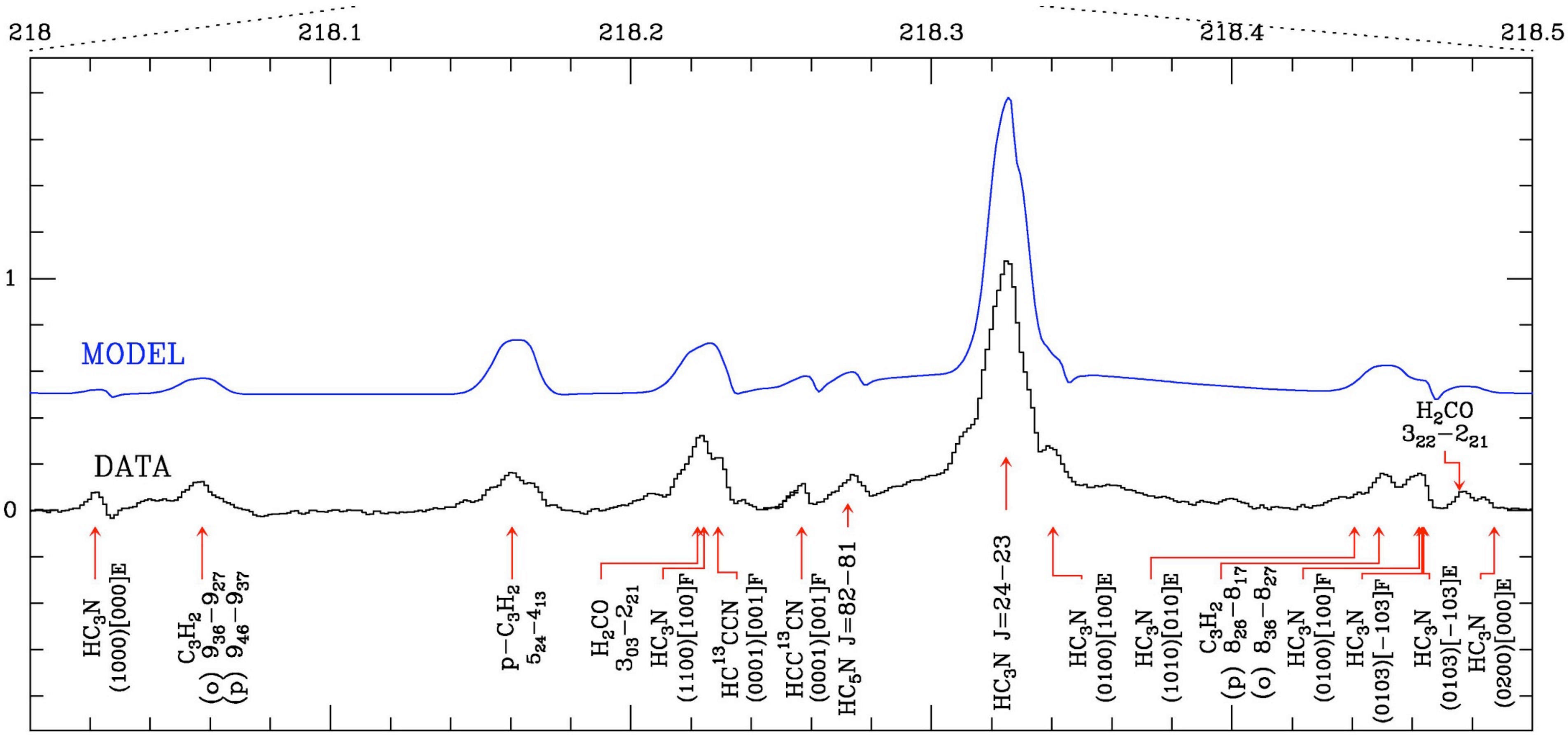
•3 mm window : Data and final model



•2 mm window : Data and final model



•1.3 mm window : Data & final model



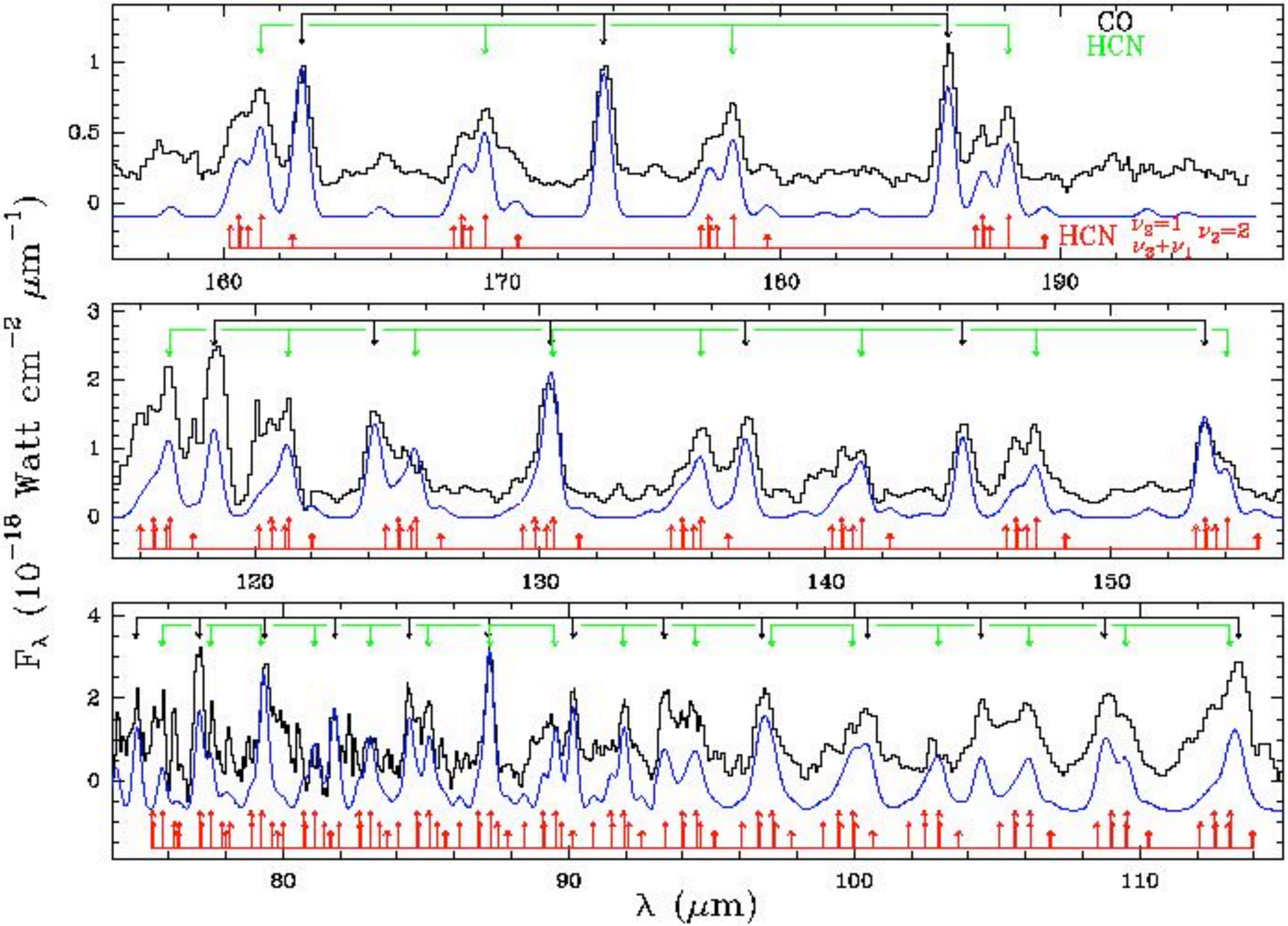
HERSCHEL OPEN TIME PROPOSAL for AGBs (Pardo et al.)

- HIFI, but also very sensitive PACS and SPIRE line surveys of evolved stars :
- IRC+10216
- CRL618
- NGC7027
- VyCMa
- NML Tau
- OH 231.8

HERSCHEL → CHEMICAL COMPOSITION, PHYSICAL CONDITIONS ACROSS THE CSEs.

ALMA →spatial resolution below 0.1” (very strong brigthness temperatures !!) →Chemistry & Physics of CSEs

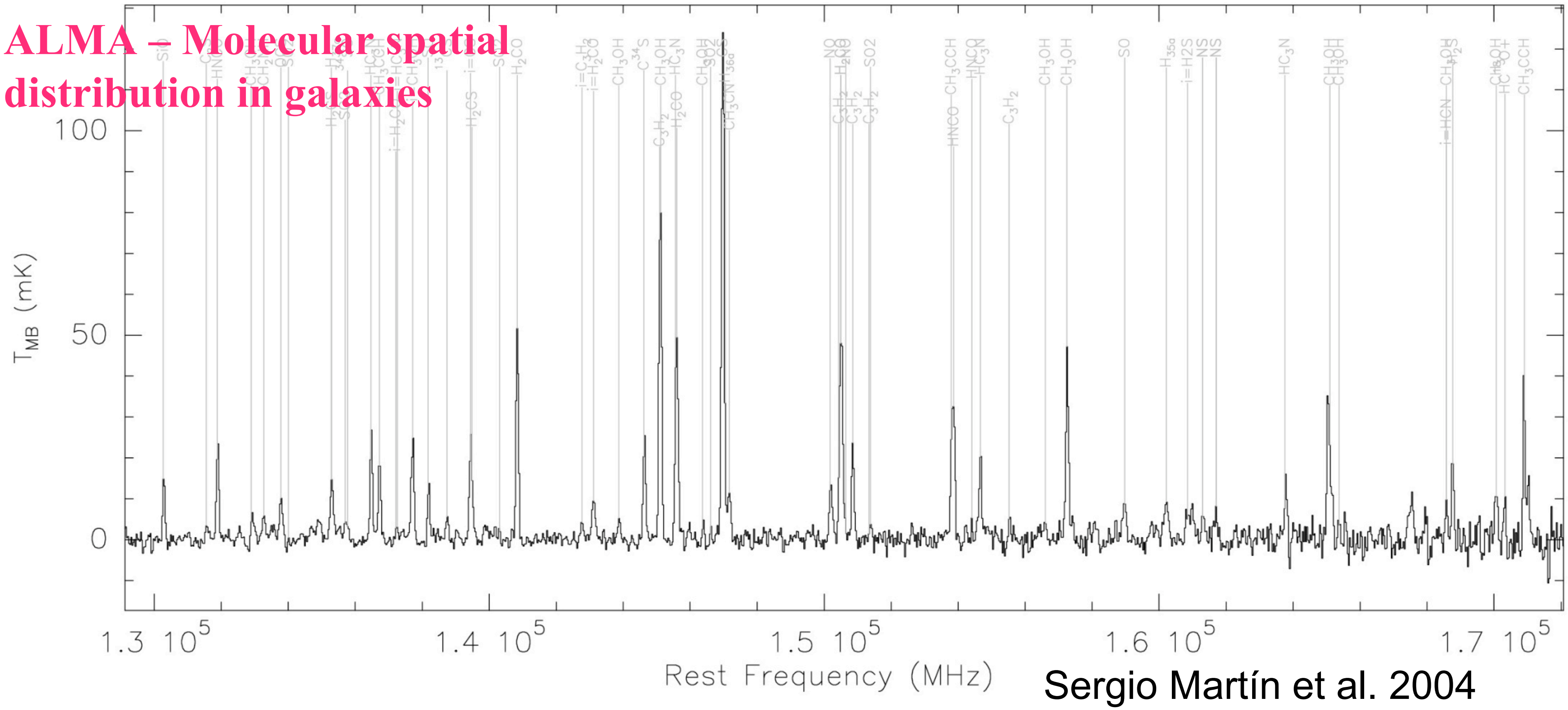
Low spectral resolution ISO spectrum of IRC+10216 :: PACS and SPIRE are much more sensitive and have larger spectral resolution !!



LINE SURVEYS IN GALAXIES : CHEMICAL COMPOSITION, PHYSICAL CONDITIONS

HERSCHEL : WARM GAS

ALMA – Molecular spatial distribution in galaxies



Sergio Martín et al. 2004

***HERSCHEL (2008):**

Complete frequency coverage (excitation conditions of the gas).

New molecular species (gas composition)

Molecules without permanent dipole moment (low bending modes); carbon clusters

***ALMA (2012):**

High sensitivity : all molecular species; complex organic molecules

Protoplanetary disks; molecular content of galaxies;

Cosmology (molecules in high-z objects)

High angular observations of HCN, SiO, and other species in the innermost regions of CSEs (dust formation zone).

Frequencies and molecular parameters for :

(1) Isotopes of all abundant species

(2) Vibrationally excited states of all large molecules (HC_3N, HC_5N, HC_7N, …, C_6H, C_7H,…., SO_2, CH_3OH, CH_3OCH_3,…)

(3) Ro-vibrational transitions of species like C_3H, C_4H, C_5H, C_6H, C_7H (all them have low frequency bending modes). Torsional states of CH_3-X molecules

- ➔ **Most of data related to (3) could be obtained from astronomical observations if (1) and (2) are available in good spectral catalogs**

- ➔ **When (1) (2) and (3) satisfied ➔ new molecules ➔ Chemical complexity.**
- ➔ **(1) & (2) mean an excelent input to the study of the physical conditions of molecular clouds.**