The European IR/Submm community coming of age

Catherine Cesarsky

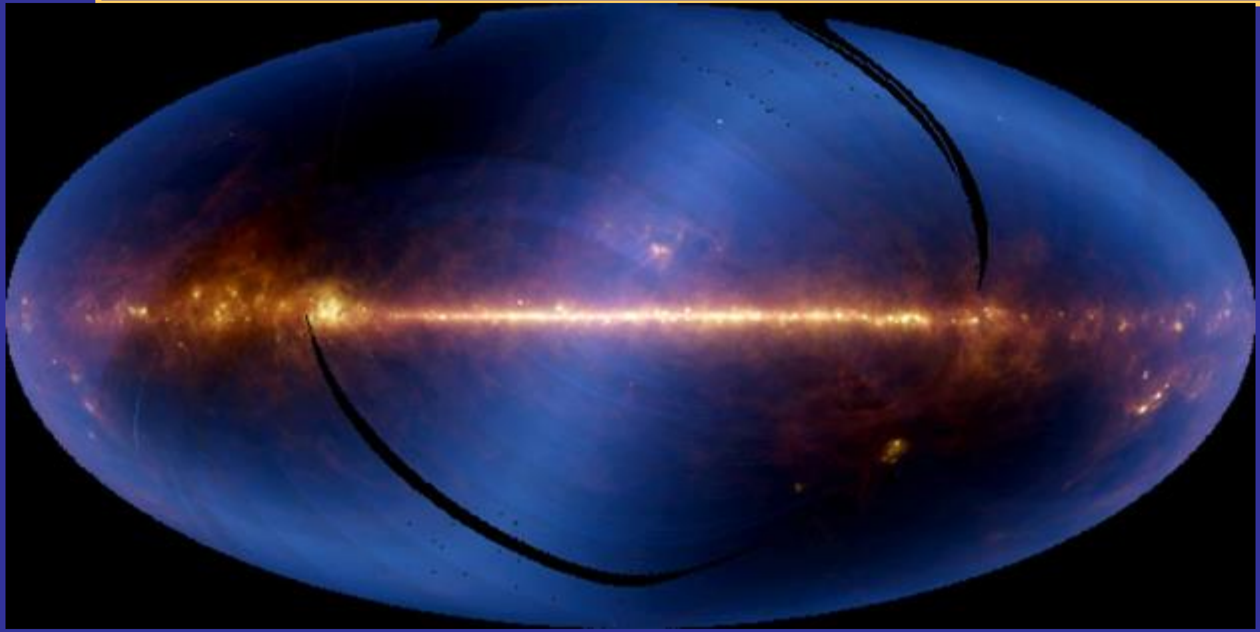
Dap, Université Paris Saclay

In honour of Thijs de Graauw

Thank you to the generous colleagues who lent me viewgraphs in view of my computer crisis

- Thijs De Graauw
- Martin Kessler
- Albrecht Poglitsch

All sky survey in 4 IR bands: IRAS satellite, 1983



IRAS detection of local LIRGs et ULIRGs

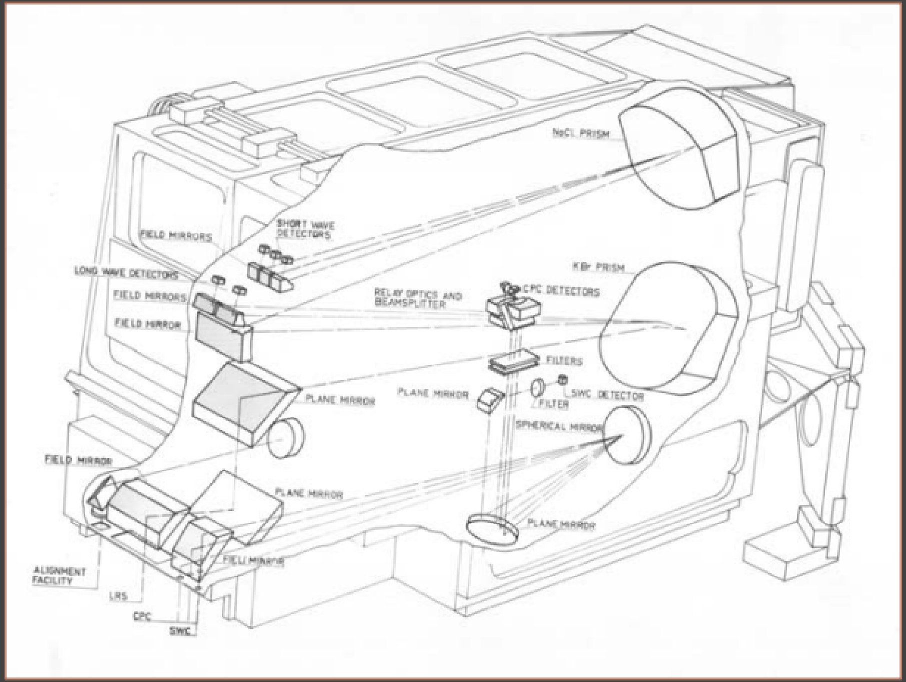
LIRGs (11< log (L_{IR}/Lo)<12) ULIRGs (12 <log L_{IR}/Lo)

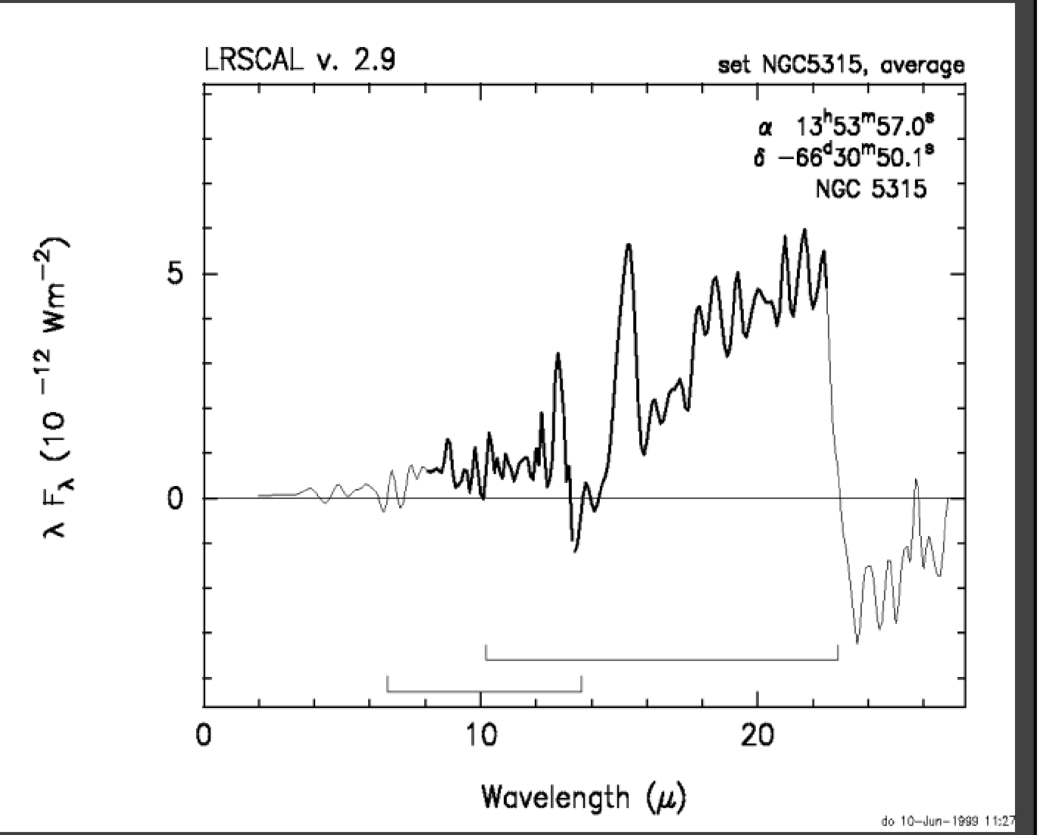
-objets rare, the brightest ones in the local universe

-Responsible for 6% of IR emission in local universe, and 2% of bolometric luminosity (Soifer et al 1991)

- Often associated to galaxy mergers (Sanders & Mirabel, 1996)

IRAS – LRS results: the ISO spectroscopy stimulus

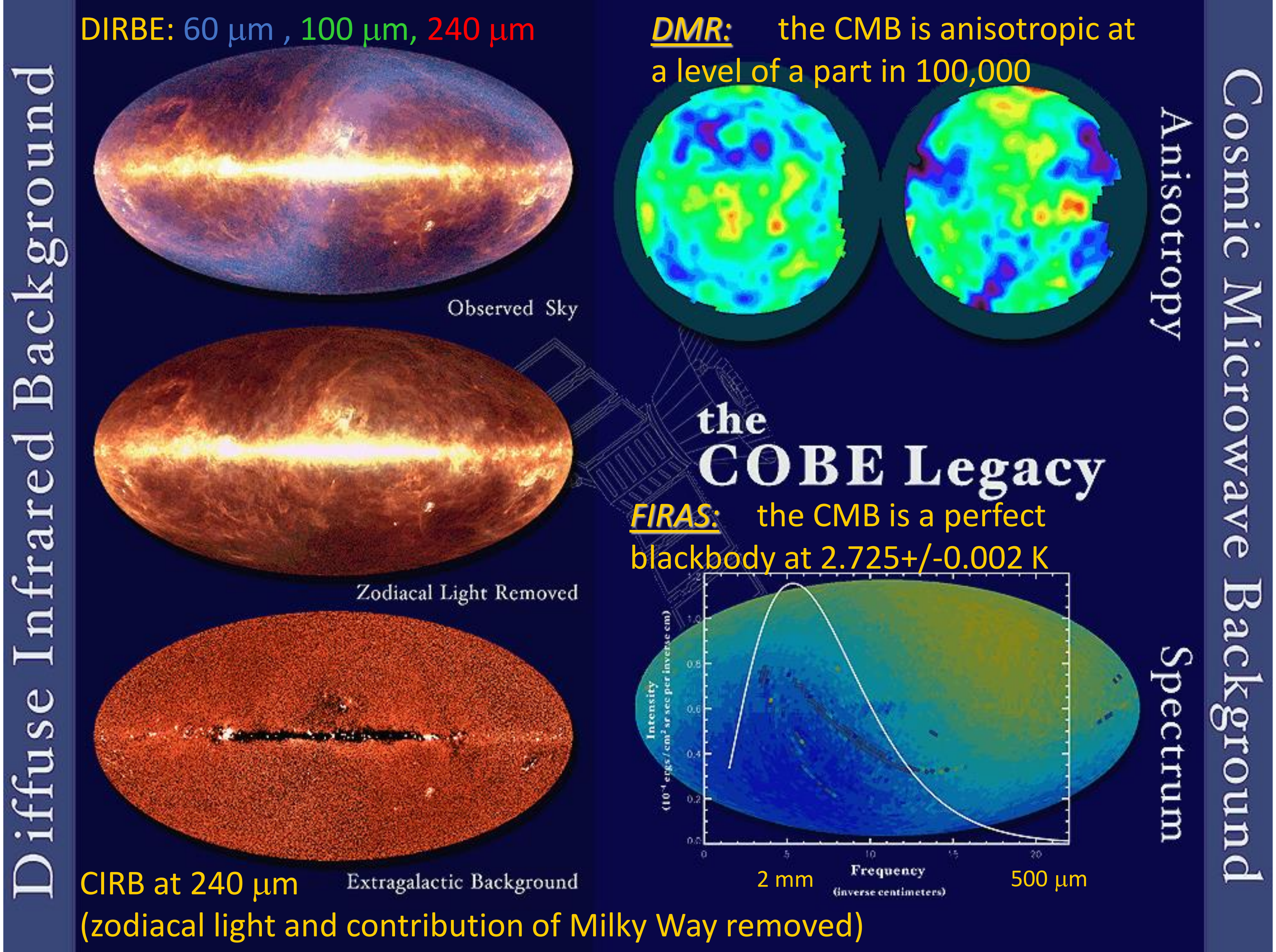




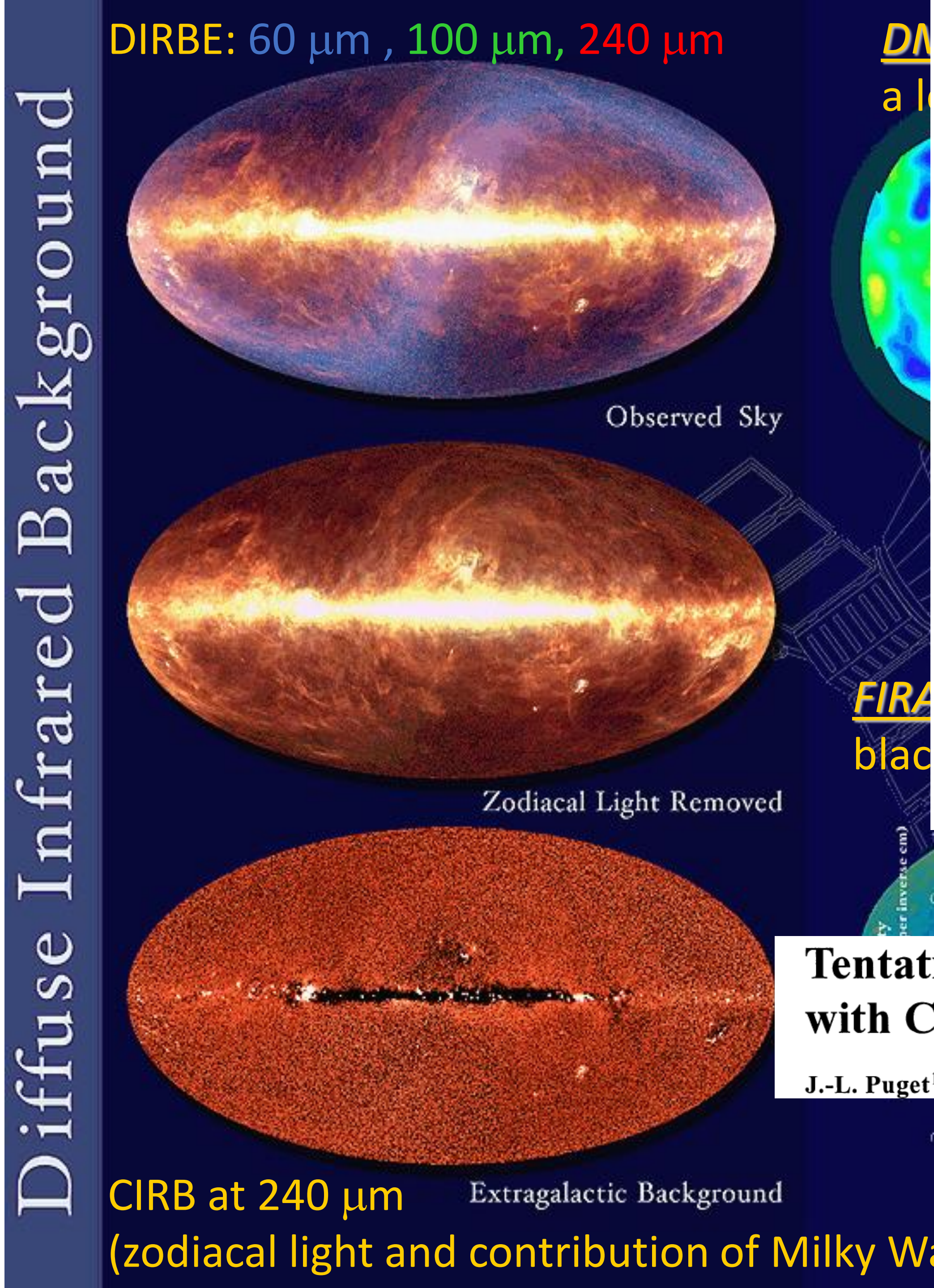
LRS: Slit-less prism spectrometer,
Spectrum build-up by satellite sky scanning
Wavelength range: 8-24 micron;
Resolution: ~20-40

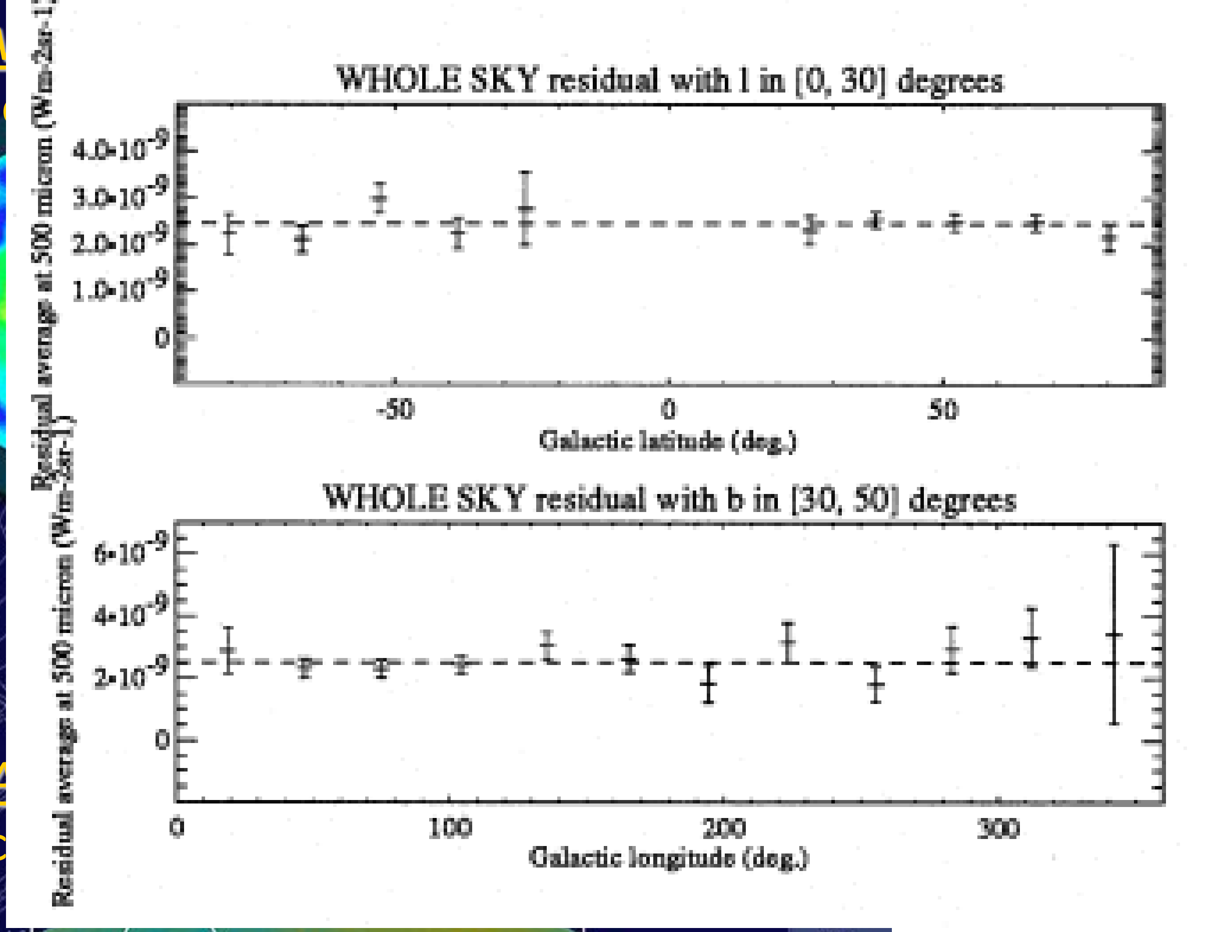
SRON

Launch
November
1989



1996

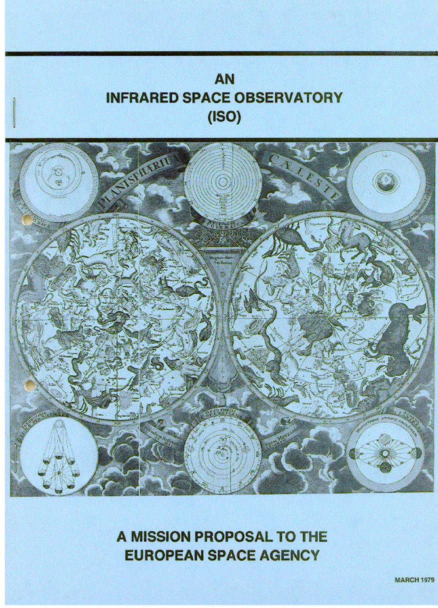




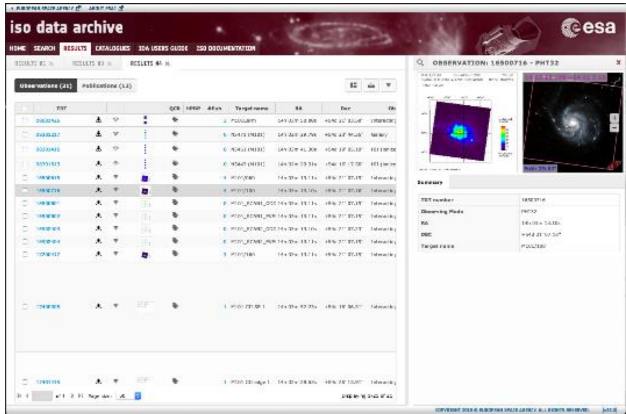
Tentative detection of a cosmic far-infrared background with COBE

J.-L. Puget[1], A. Abergel[1], J.-P. Bernard[1], F. Boulanger[1], W.B. Burton[2], F.-X. Désert[1], and D. Hartmann[2,3]

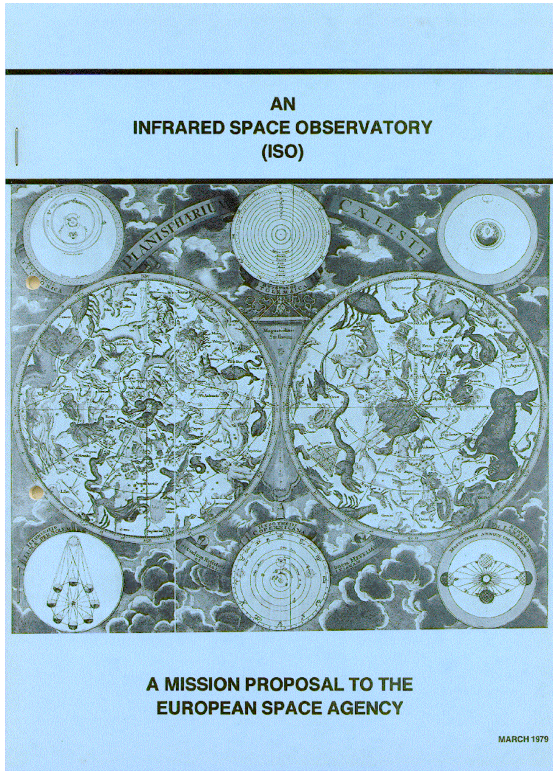
ISO Timeline

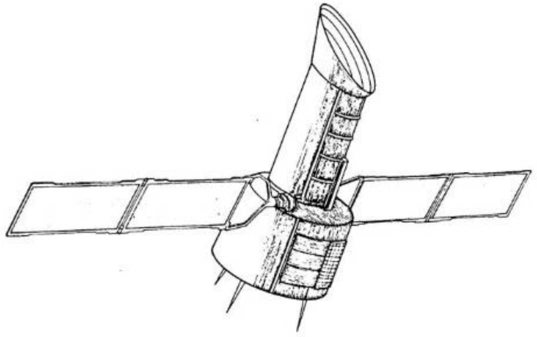


- Proposal 1979
- ISO selected 1983
- Science Management Plan – *new for ESA!* 1984
- Instruments & Mission Scientists selected 1985
- Development 1986 - 1995
- Launch 17 Nov. 1995
- Routine operations 4 Feb. 1996 – 8 Apr 1998
- Switch-off of satellite 16 May 1998
- Archive (IDA) opens 1998
- ISO Handbook (5 vols) 2003
- End of “Active Archive” phase 2006
- New ISO Archive 2020

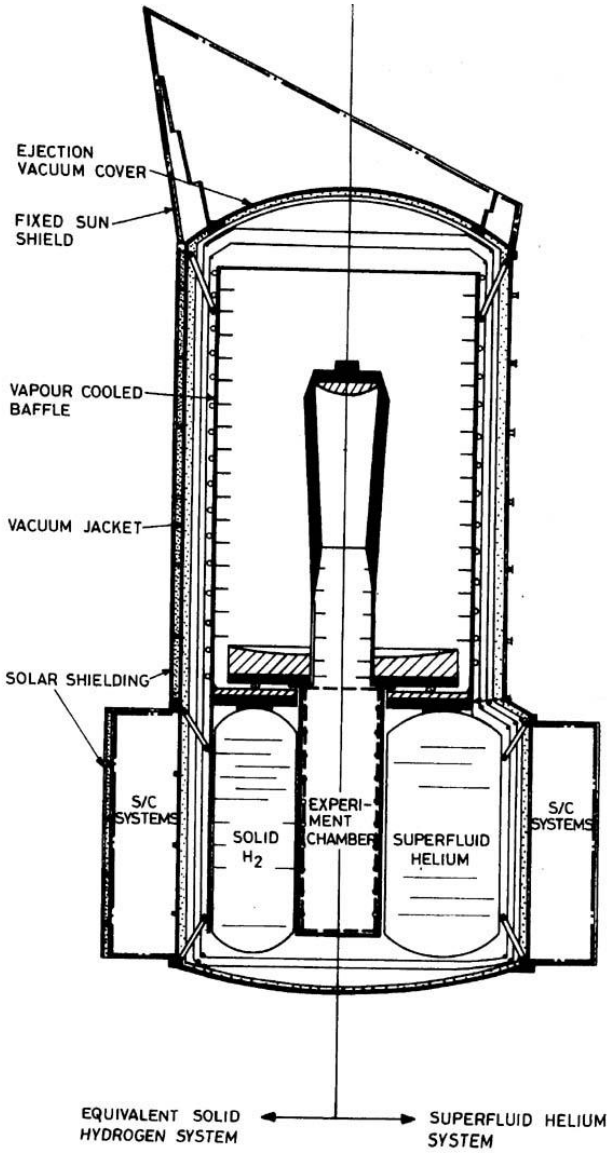


1979: Proposal to ESA

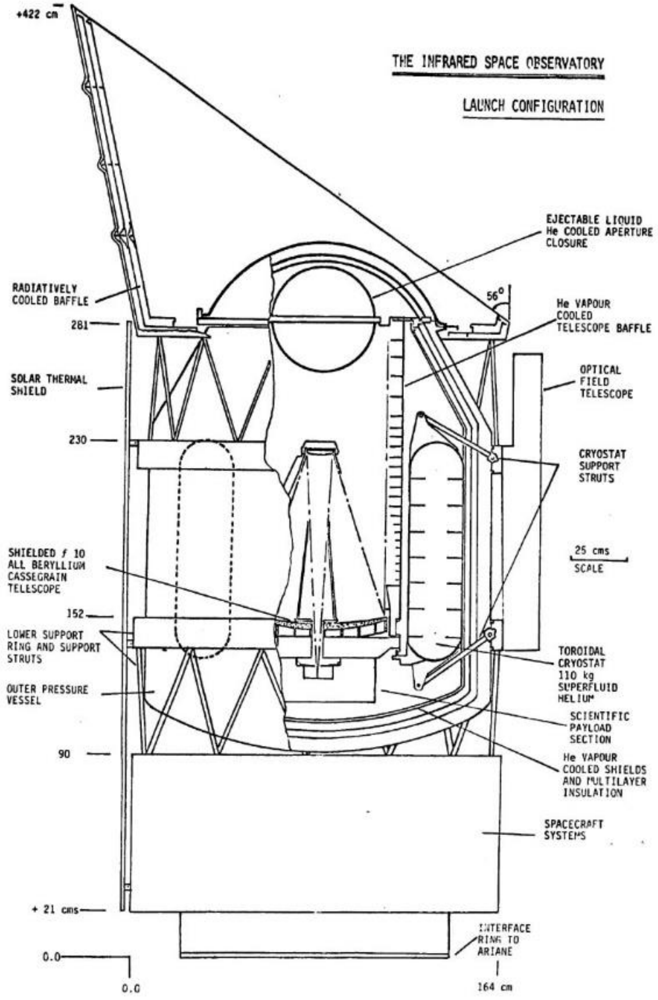




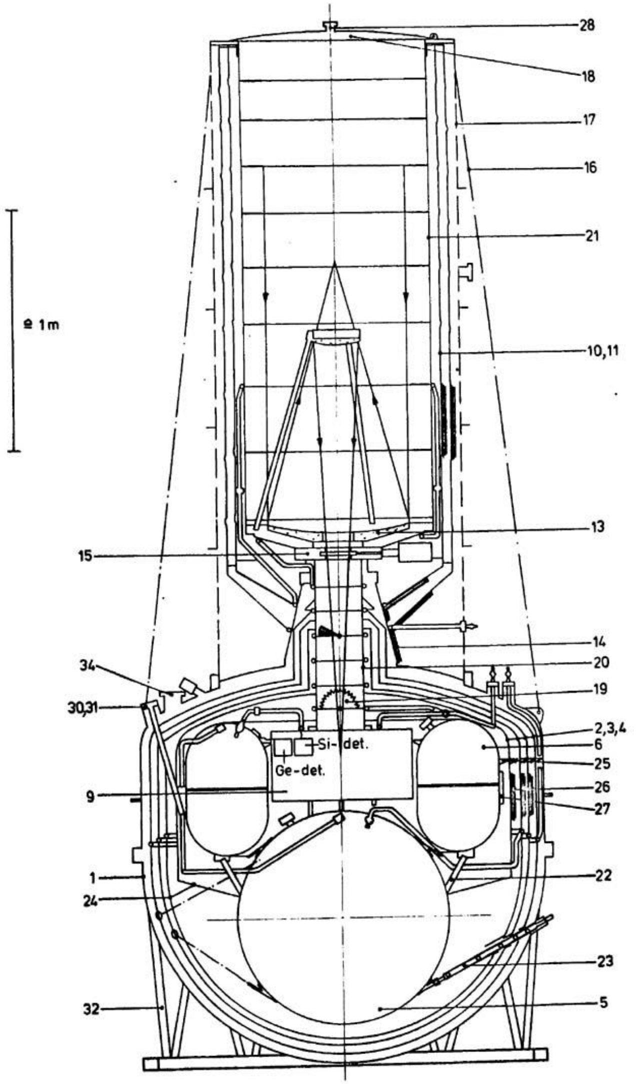
- Proposal:
  - Astronomy and atmospheric research
  - 1m diameter mirror
  - Also heterodyne instruments
  - LHe **or** solid H_2 cryogenics
- Context:
  - IRAS (1983), COBE (1989) and GIRL (X) under study/construction
  - No proven European expertise in space IR instrumentation / cryogenics
  - European IR community just starting up
    - No UKIRT yet



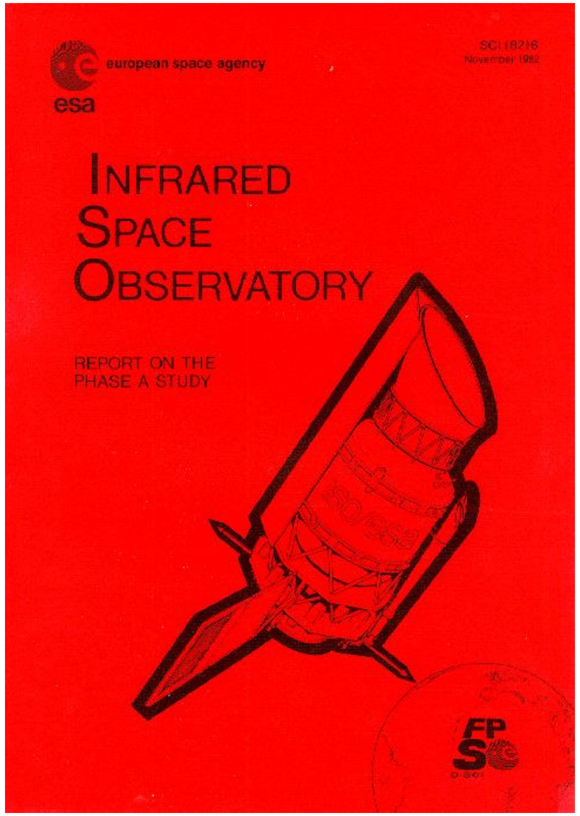
1979-80: Assessment & Pre-Phase A Studies

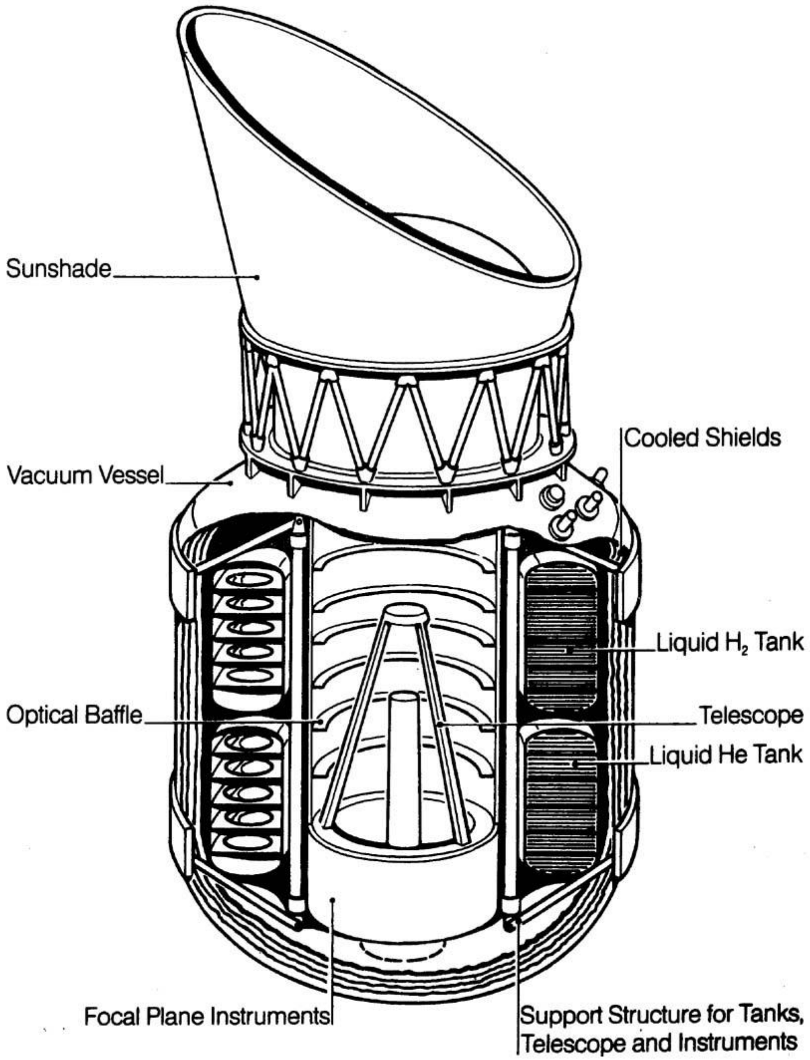


- Assessment Study:
  - Dropped atmospheric research
  - Reduced mirror to 60 cms
  - Dropped heterodyne instruments
  - 20 man-years for science operations!!
  - LHe cryogenics
- Pre-Phase-A Study:
  - Hybrid cryo-system: LHe and LH_2



1981-1982: Phase A Study





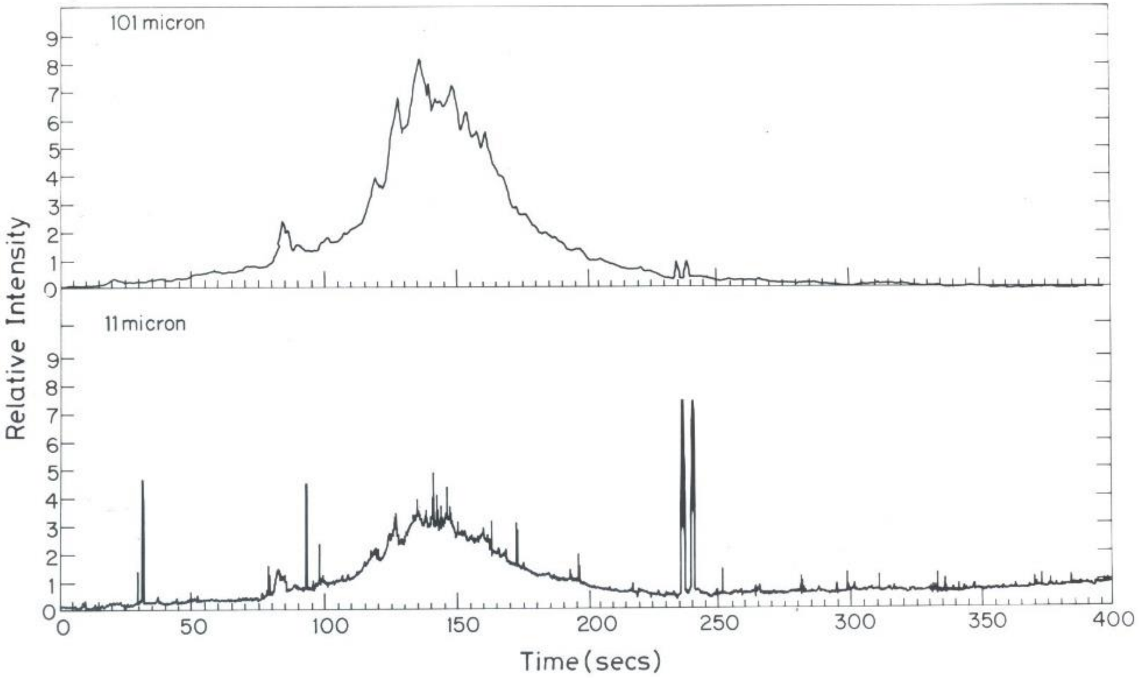
- Back to toroidal cryogenic tanks
- Maintained LHe/LH_2 hybrid!

1983: ISO Selected

- First scans of IRAS displayed at/after mission selection meeting in Scheveningen

- ISO selected unanimously (out of 5 candidates)

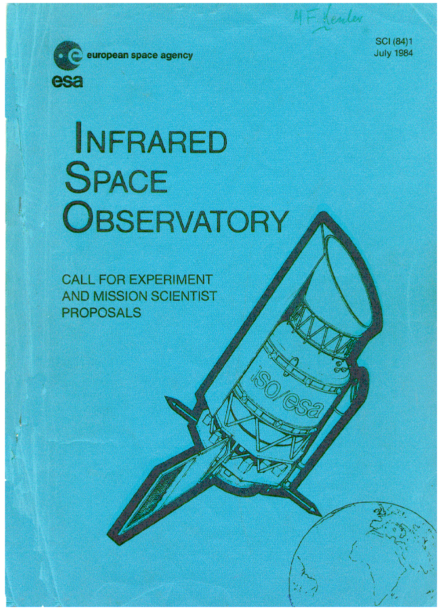
- (BTW: Almost led to studies of FIRST (later Herschel) being stopped)

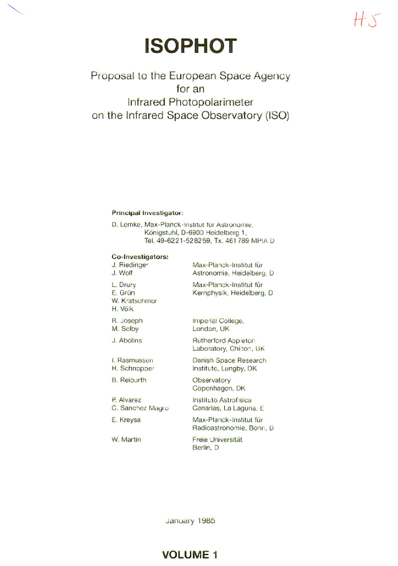


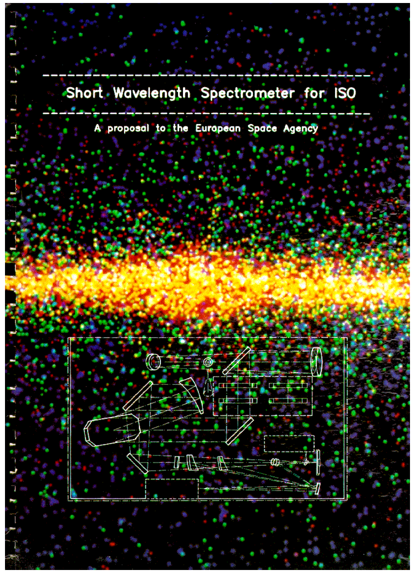
1985: Instruments Selected

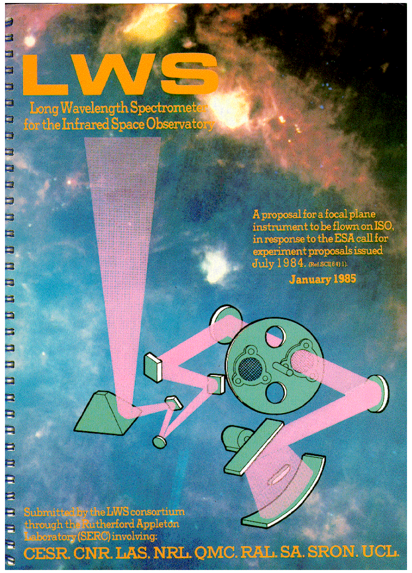
- IR community self-organised and made 4 complementary proposals:
  - ISOCAM (2.5 - 17μm)
  - ISOPHOT (2.5 - 240μm)
  - Short Wavelength Spectrometer (SWS, 2.5 - 45μm)
  - Long Wavelength Spectrometer (LWS, 43 - 197μm)

- 5 Mission Scientists selected.









ISO Spectroscopy Consortium Formation
Objective: to optimise ISO spectroscopy: Science and Instruments

Initiated in April 1983 and invitation mailed to participate:

- Kick-of Meeting in Groningen May 1983 (Ge, It, UK,, Fr, NL …)
- Meetings in Paris, Frascati, Ringberg, Marseille, London, etc
- Study on concepts: Michelson versus Grating instrument
- Sept ’83 Proposal for a specific LW Spectrometer ~~design~~ by Chanin and de Graauw
- Grating instrument “selected” followed by design lay-out by J-I LeGall (Marseille), Wijnbergen, Furniss, et al.…

SRON

ISO Spectroscopy Consortium Formation II

- **Spring/early summer 1984 consortium formation LWS and SWS:**
- LWS a UK/French team with lead by UK, with P. Clegg as PI
- SWS a NL/German team with lead by NL, with ThdG as PI

Separate Working groups on Fabry-Perot and Cryo Mechanisms

ESA DSc was kept informed about these developments

ISO SCIENCE WORKSHOP

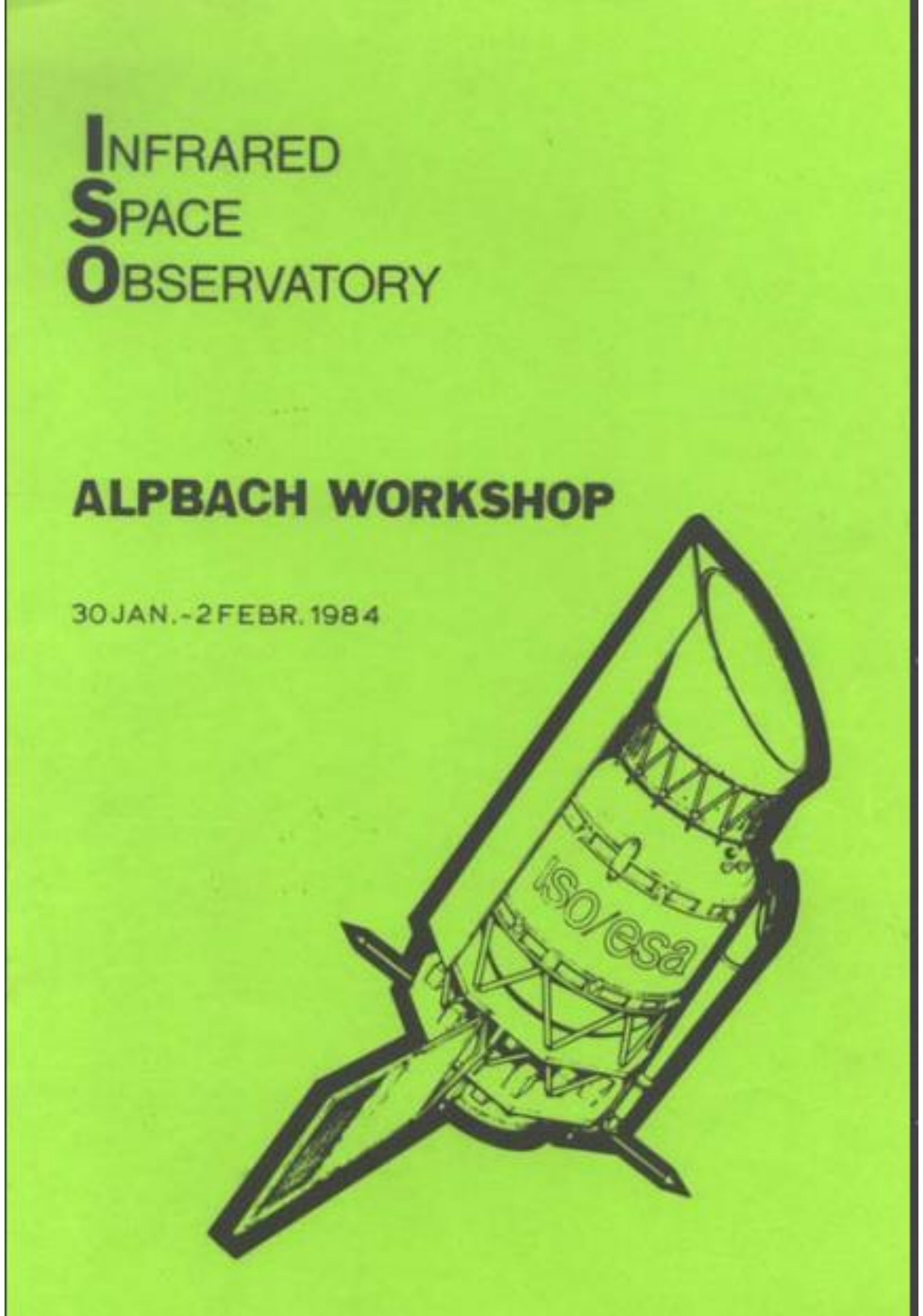
30 Jan. - 2 Febr. 1984

Alpbach - Tirol - Austria

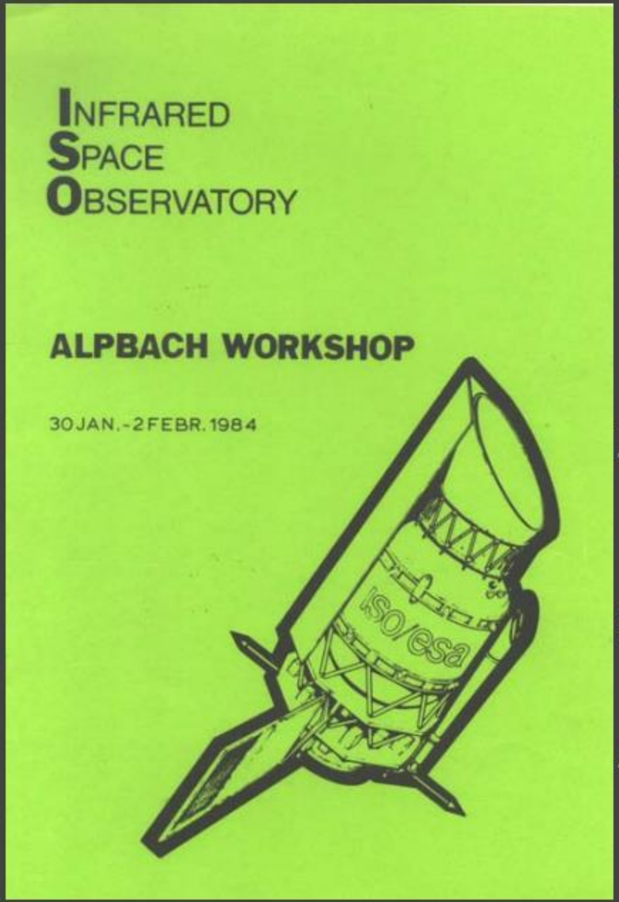
The scientific organizing committee:
C. Cesarsky (chair-person), P. Clegg, R. Emery, H. Habing, R. Joseph, D. Lemke, A. Moorwood, L. Nordh, P. Salinari, Th. de Graauw (local organizer).

List of participants:

Dr. M. Anderegg	ESTEC
Dr. I. Appenzeller	Landessternwarte
Dr. M. Barlow	University College Dept. of Physics and Astronomy
Dr. J. Beckman	Dept. of Physics Queen Mary College
Mevr. L. de Boer	Astronomy Division, SSD ESTEC
Prof. Dr. A Bonnetti	Physics Dept. Florence Univ.
Dr. C. Cesarsky	Service d'Astrophysique
Dr. P. Clegg	Queen Mary College
Dr. M. Combes	Observatoire de Meudon
Dr. J. Crovisier	Observatoire de Meudon



Preparing ISO instrument proposals



Alpbach science meeting in february 1984:

Following first IRAS results with SED peaks >100 µm

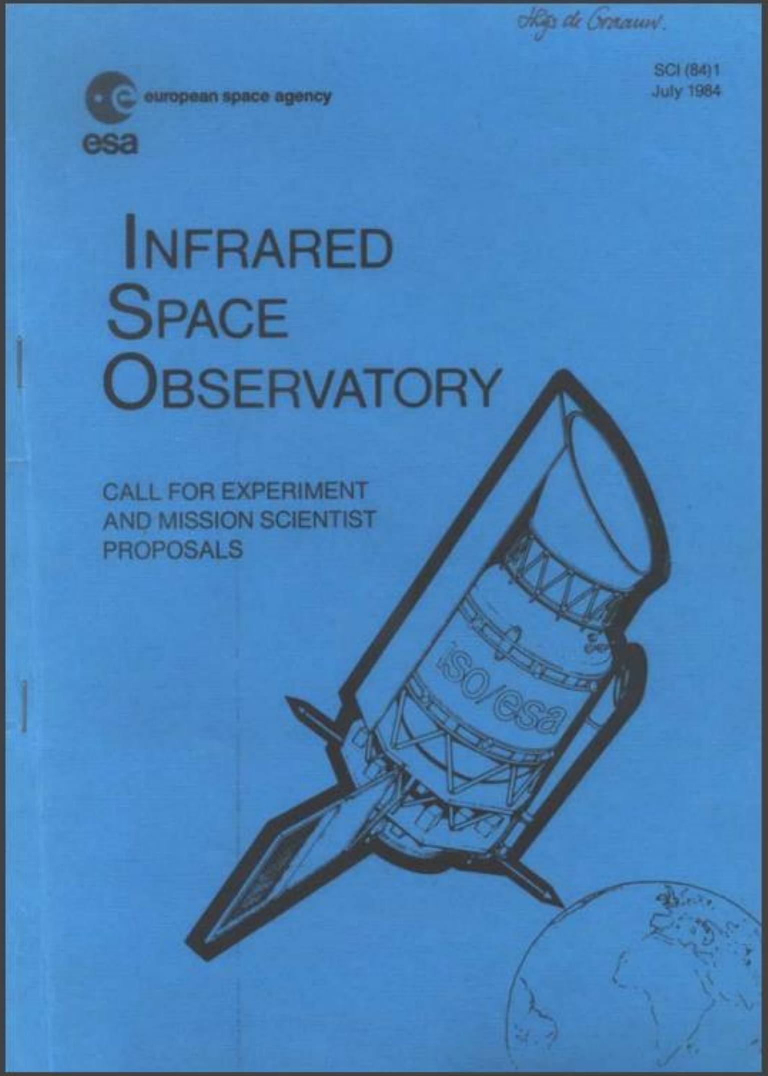
- Extension wavelength range to 200 µm
- Request higher spatial resolution:
  requiring better pointing
  (Michelson F.O.V. ~ 30 arcsec)

June-August '84: SWS consortium, with external experts (Genzel; Lacy), decides to depart from Michelson and go Grating, as in LWS.

SWS proposal prepared with Echelle and F-P at the entrance of the instrument.

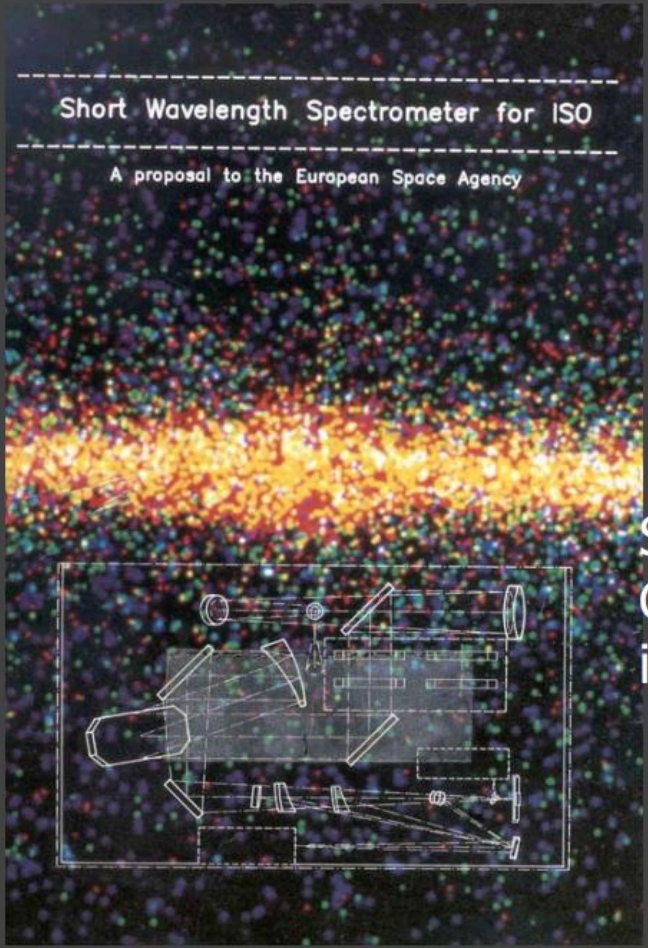
After acceptance, redesign to low order, dual grating/dual Fabry-Perot (after grating spectrometer), forced by non-availability of array detectors and inferior pointing.

July 1984: ISO-AO for instruments



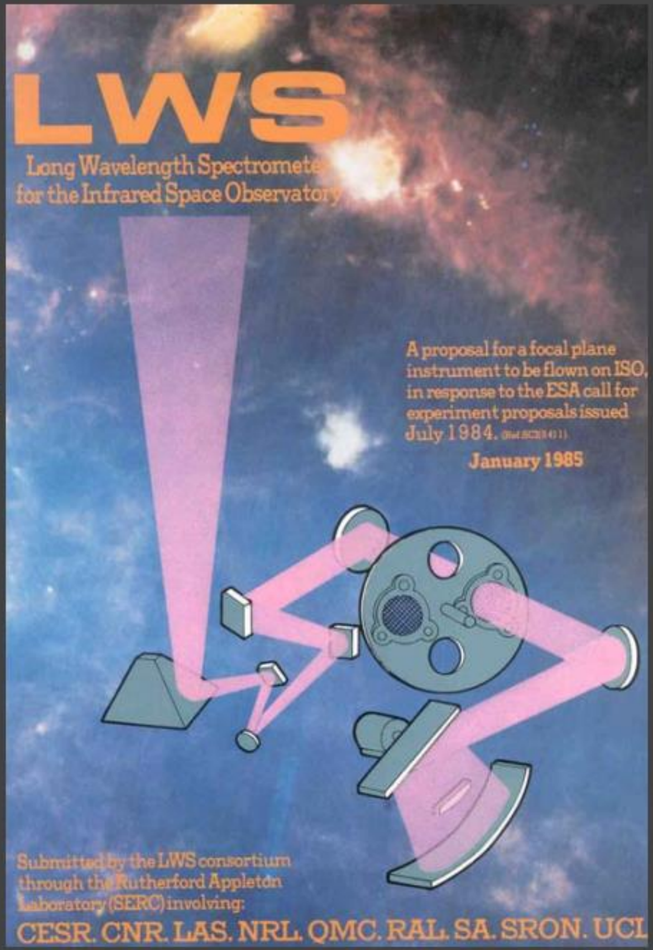
- ESA wanted competitive proposals, however….
- 4 instrument teams were formed and 4 proposals made
- Basic arrangements made in and just after Alpbach meeting

ISO Proposals: LWS and SWS



LWS:
Grating/F-P
instrument
43-200 μm

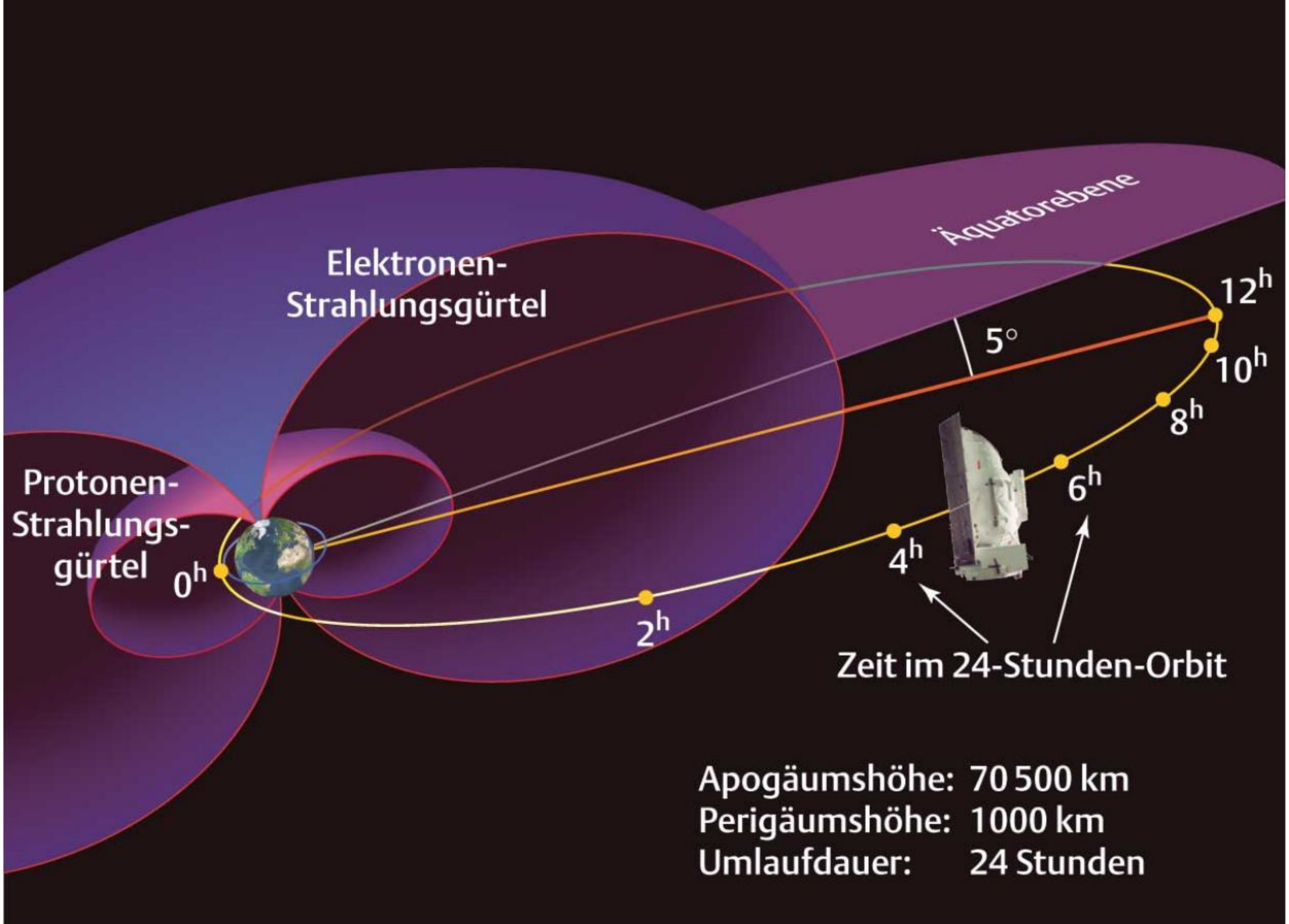
SWS:
Grating/F-P
instrument
2.4-45 μm



SRON

Major ISO Transformations

- Cryogenics from:
  solid H2 and liq. He
  via liq. H2 and liq. He
  to all liq. He
- From extendable solar panels to solar panels on radiation shield
- Pointing performance was greatly enhanced during operations, from
  10 arcsec -->> 1 arcsec


Elektronen-
Strahlungsgürtel
Äquatorebene
Protonen-
Strahlungs-
gürtel
0h
2h
4h
6h
8h
10h
12h
5°
Zeit im 24-Stunden-Orbit
Apogäumshöhe: 70 500 km
Perigäumshöhe: 1000 km
Umlaufdauer: 24 Stunden

ISO and SIRTF in the eighties

The two project scientists:
Martin Kessler and Mike Werner

SIRTF, Shuttle Infrared Telescope Facility, 1 m mirror, first priority of US decadal survey.
ISO (mirror 60 cm) was selected in June 1983. The SIRTF instruments were selected in 1984, the ISO ones in 1985.
At first ESA-NASA meeting after ISO selection, NASA proposed a collaboration: give us the money, we will make a super SIRTF.
At every international meeting, Martin presented ISO, giving expected launch date.
Mike presented SIRTF, always announcing a launch date a few months earlier.
By 1990, Shuttle possibility abandoned. Death march of american Pis.
1991: SIRTF first priority in Bahcall decadal survey.   1993; SIRTF selection as a freeflier.
ISO pioneer mission. The problem of access to infrared array detectors.
ISO launched in 1995, SIRTF (Spitzer) in 2004. Very fruitful cooperation in exploitation between Europe, USA, and Japan.

April 1994: Call for Proposals Issued

August 1994: Proposals Received

- 1000 proposals, each in multiple copies!!
- Observing Time Allocation Committee of 35 external scientists

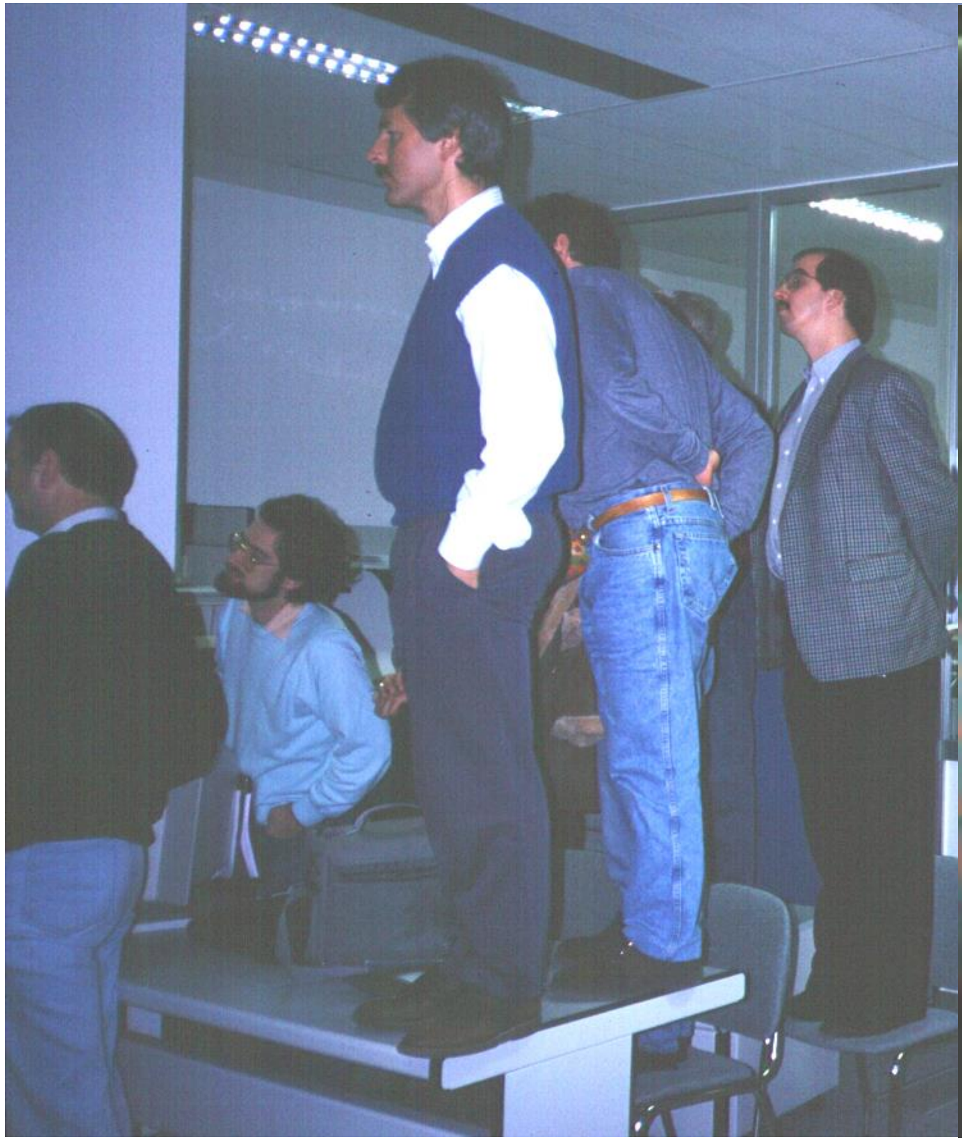
Visitors

ISO satellite in Kourou, november 1995

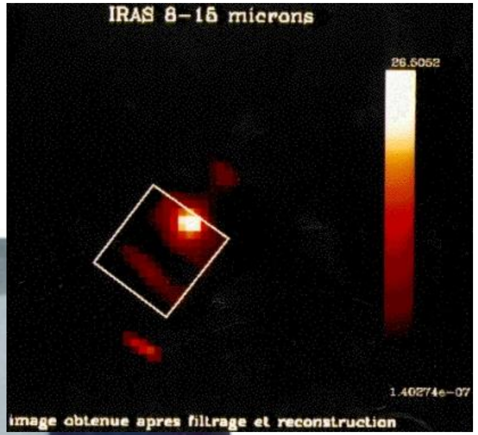
Launch

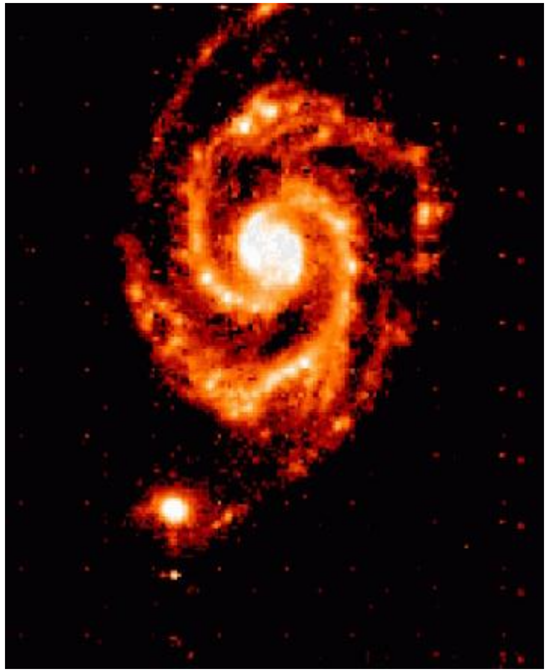
Nov 1995

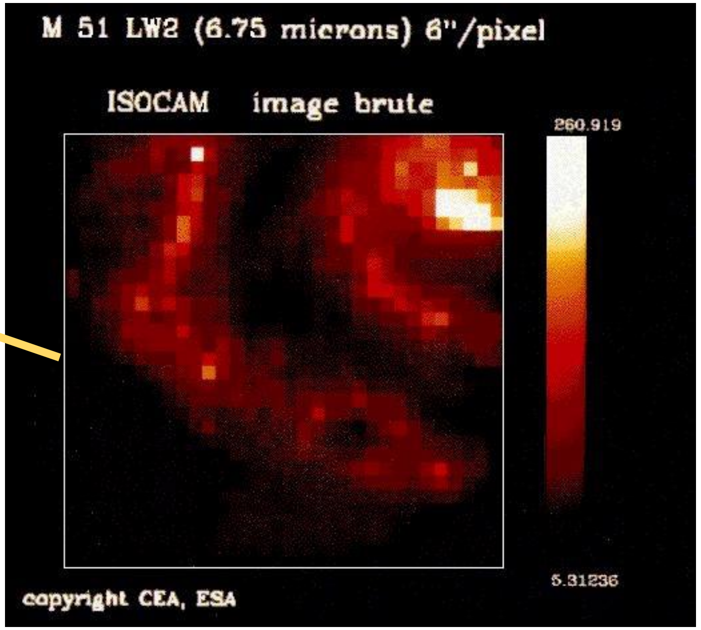
November 1995: Cover Off & CAM First Light



December 1995 : a happy ISOCAM team in Villafranca after the first light of ISOCAM







1985-2001: ISO Science Team

- 50 meetings from 1985 – 2001
- Highly exciting!
- Not a laptop in sight!!

1985-2001

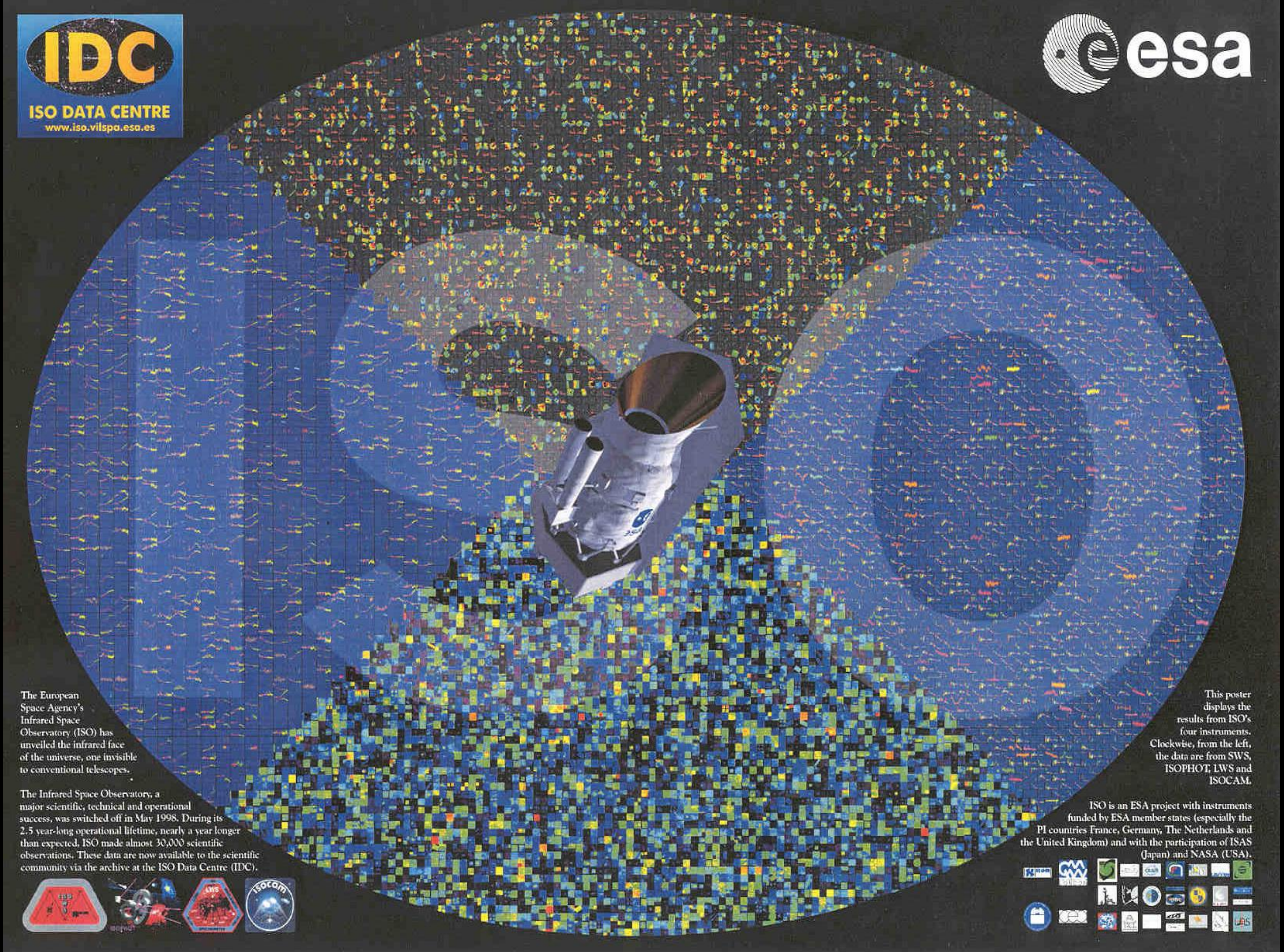
Last meeting:
September
2001

Martin Kessler, ? , Thijs and Alberto Salama in Thijs boat, 2001

Project Manager’s Assessment after mission

Project scientist:

- Technical and operational:
  - excellent data from all instruments
  - superb satellite
    - pointing up to x10 better than specs
    - excellent optical performance and straylight rejection
    - cryogenic life >10 months longer than required 18 months
  - efficient ground operations:
    - practically no anomalies and scheduling efficiency > 92%
    - SOC approach influencing future missions
- Performance:
  - x1000 more sensitive and x100 better angular resolution than IRAS at 12μm
  - over 30000 observations
  - results impacting astronomy from ‘comets to cosmology’.


IDC
ISO DATA CENTRE
www.iso.vilspa.esa.es
esa
ISO
The European Space Agency's Infrared Space Observatory (ISO) has unveiled the infrared face of the universe, one invisible to conventional telescopes.
The Infrared Space Observatory, a major scientific, technical and operational success, was switched off in May 1998. During its 2.5 year-long operational lifetime, nearly a year longer than expected, ISO made almost 30,000 scientific observations. These data are now available to the scientific community via the archive at the ISO Data Centre (IDC).
This poster displays the results from ISO's four instruments. Clockwise, from the left, the data are from SWS, ISOPHOT, LWS and ISOCAM.
ISO is an ESA project with instruments funded by ESA member states (especially the PI countries France, Germany, The Netherlands and the United Kingdom) and with the participation of ISAS (Japan) and NASA (USA).
LWS
isocam

ISOCAM was
a complex instrument

2 channels

4 different magnifications

12 – 14 filters by Channel

Spectro-imaging with CVF

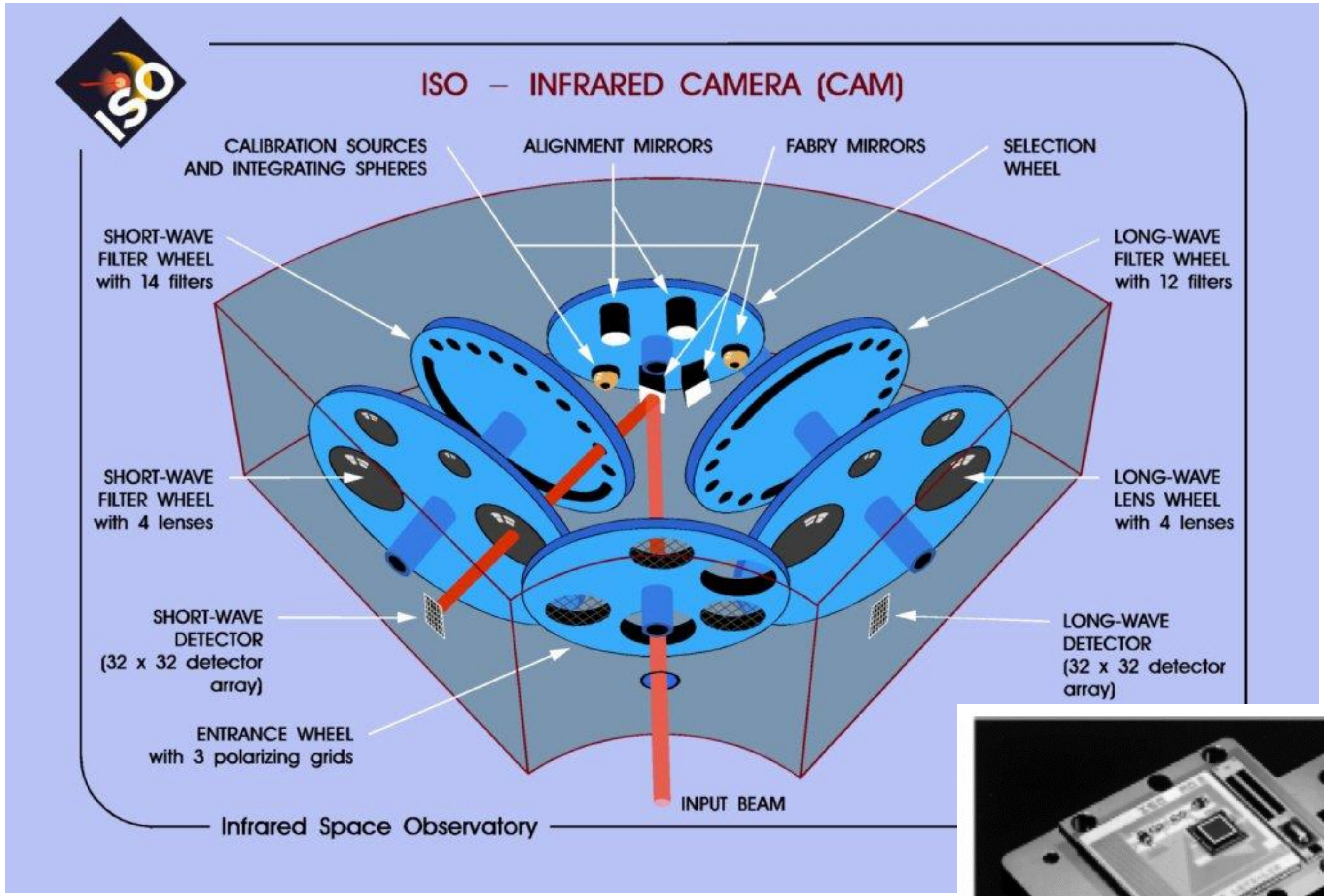
Polarization capability

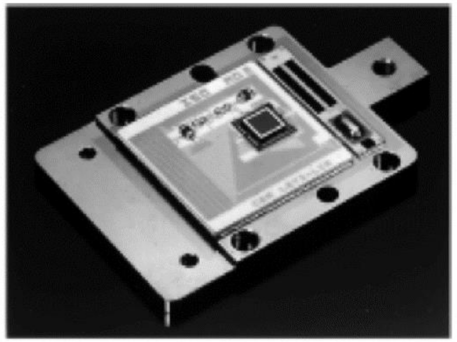
Internal calibration source

2 panoramic detectors 32*32 pixels

Optical bench and detectors at 2 K

Multitasks on board software





LW 4-17μ
32x32 100μx100μ
Si:Ga DRO
LETI-LIR/SAp
R.N. 180 e⁻
T=3.8K

ISOCAM :

A women led project

Catherine Cesarsky	PI
Danièle Imbaut	Project Manager
Danièle Auternaud	Project Manager at Aérospatiale in charge of the optical bench
Geneviève Debouzy	Head of Science Programs at CNES

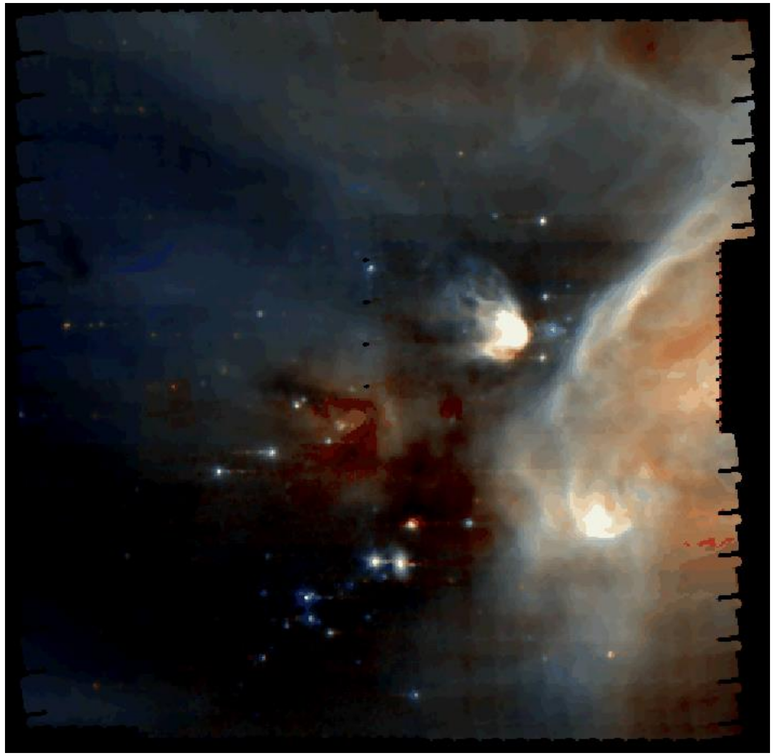
Courtesy Laurent Vigroux

Star formation in a dark cloud

Abergel, A.; Bernard, J. P.; Boulanger, F.; Cesarsky, C.; Desert, F. X.; Falgarone, E.; Lagache, G.; Perault, M.; Puget, J. -L.; Reach, W. T.; Nordh, L.; Olofsson, G.; Huldtgren, M.; Kaas, A. A.; Andre, P.; Bontemps, S.; Burgdorf, M.; Copet,E.; Davies, J.; Montmerle, T.; Persi, P.; Sibille, F.

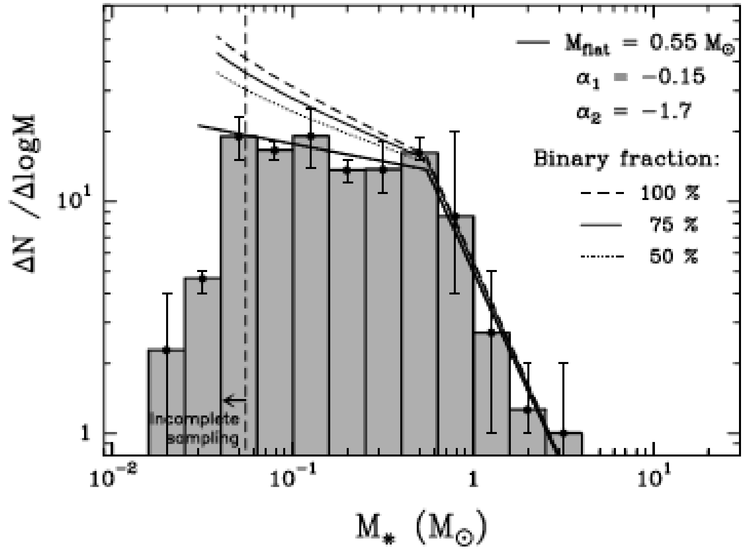
ρ Oph dans le visible

ρ Oph in mid infrared (ISOCAM) (Abergel et al. 1996, 1998☺



First census of Young Stellar Objects in nearby star formation regions

First mass function of Young Stellar Objects



ISOCAM observations of the ρ Ophiuchi cloud: Luminosity and mass functions of the pre-main sequence embedded cluster*,**

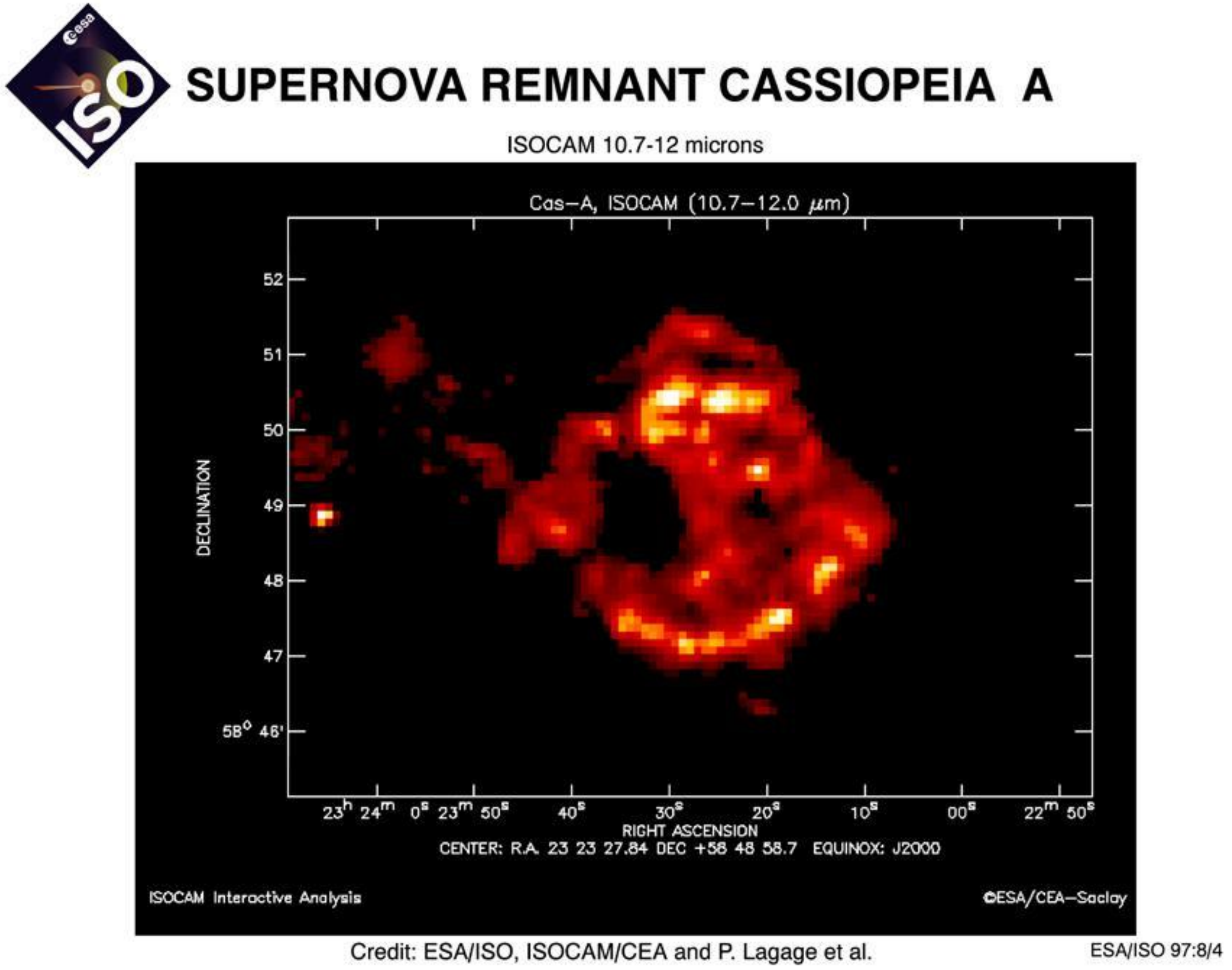
S. Bontemps[1,2], P. André[3], A. A. Kaas[4,2], L. Nordh[2], G. Olofsson[2], M. Huldtgren[2], A. Abergel[5], J. Blommaert[6], F. Boulanger[5], M. Burgdorf[6], C. J. Cesarsky[3], D. Cesarsky[5], E. Copet[7], J. Davies[8], E. Falgarone[9], G. Lagache[5], T. Montmerle[3], M. Pérault[9], P. Persi[10], T. Prusti[6], J. L. Puget[5], and F. Sibille[11]

Fig. 8. Mass function of the 123 Class II YSOs. The range of possible age distributions (see Sect. 5.1) induces a range of masses for each star and thus an uncertainty on the derived histogram displayed as vertical error bars. The best two-segment power-law mass function of Sect. 5.1 (heavy solid curve), and the effect of binarity as a function of the binary fraction from 50% to 100% (light curves – see Sect. 6.2) are shown. The vertical dashed line marks the completeness level of 0.055 $M_\odot$.

Dust formation in the Cassiopeia A supernova

P.O.Lagage, AClaret, J.Ballet, F.Boulanger, C.J.Cesarsky, D.Cesarsky, C. Fransson, and A. Pollock   1996

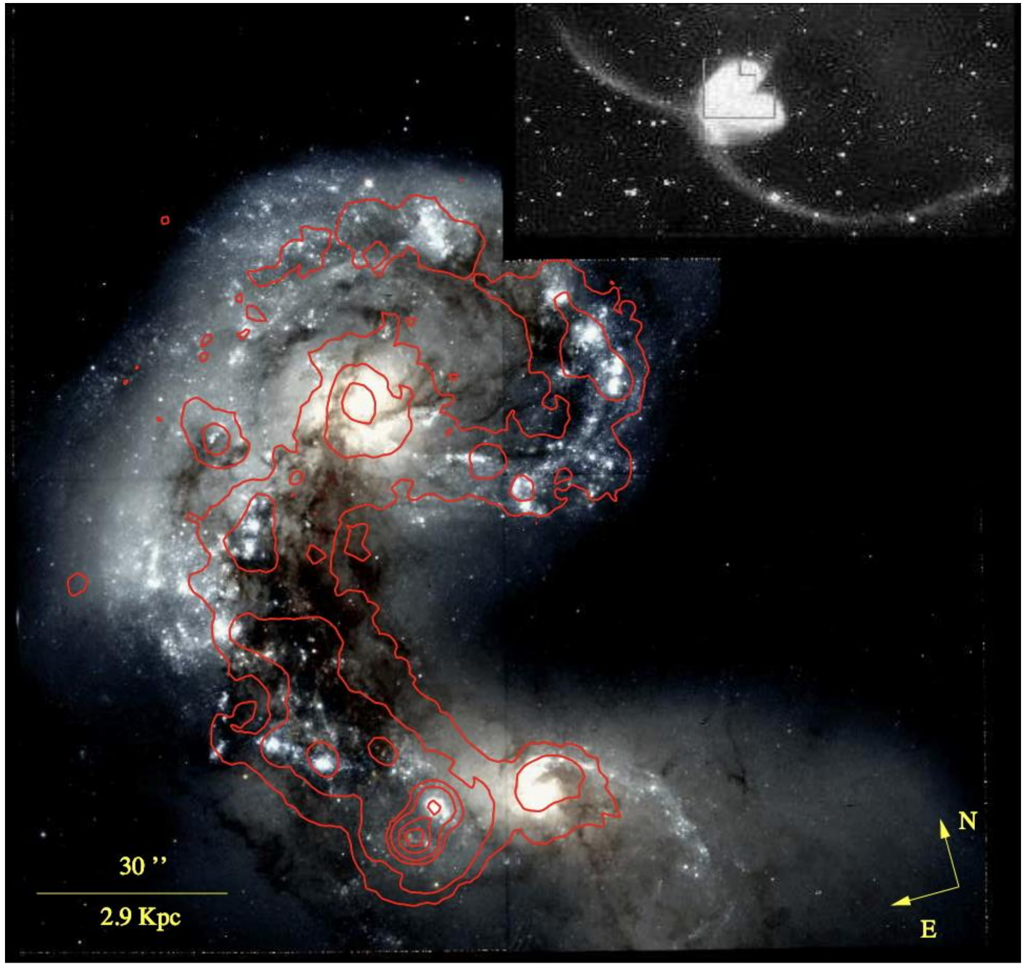
First evidence for dust formation from the new material expelled by the supernova, in fast moving knots. The emission is due to the grains in the evaporation interfaces between cool optical knots and the hot supernova cavity gas.



Mapping and physical properties of star formation regions in normal and starburst galaxies

The dark side of star formation in the Antennae galaxies

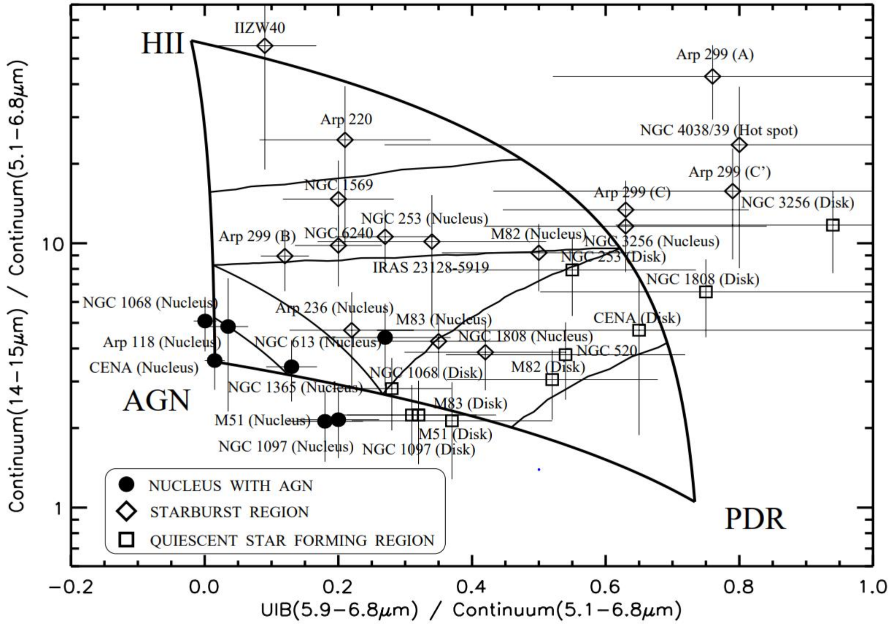
I.F. Mirabel[1], L. Vigroux[1], V. Charmandaris[1], M. Sauvage[1], P. Gallais[1], D. Tran[1], C. Cesarsky[1], S.C. Madden[1], and P.-A. Duc[2]

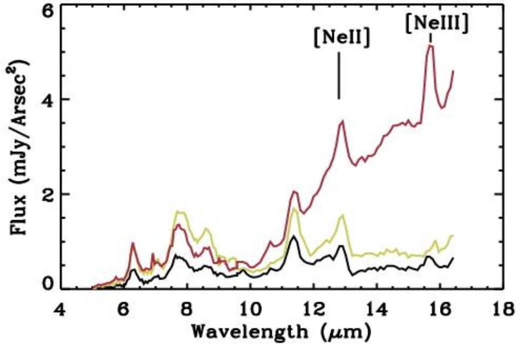


Mid-infrared diagnostics to distinguish AGNs from starbursts*

O. Laurent[1,2], I.F. Mirabel[1,3], V. Charmandaris[4,5], P. Gallais[1], S.C. Madden[1], M. Sauvage[1], L. Vigroux[1], and C. Cesarsky[1,6]

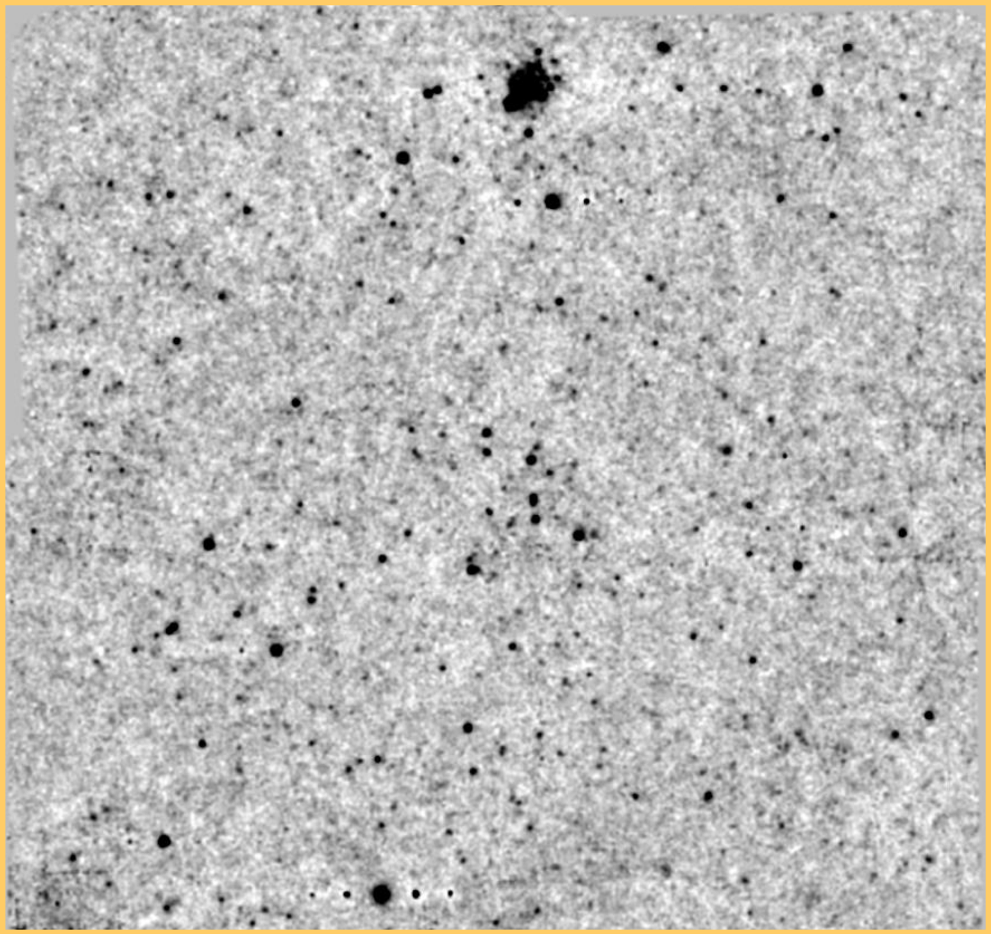
2000

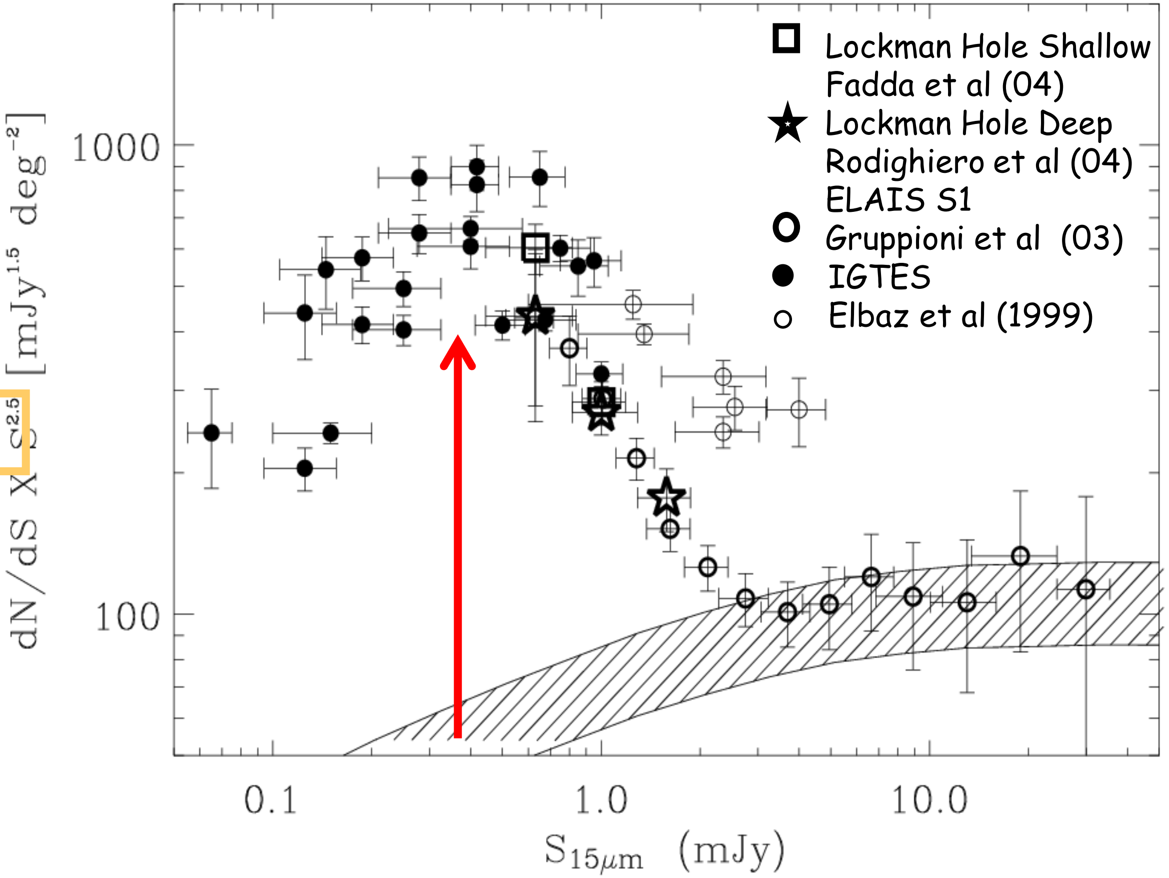




ISOCAM galaxy counts at 15 μm (1000 galaxies<2mJy)

Marano field



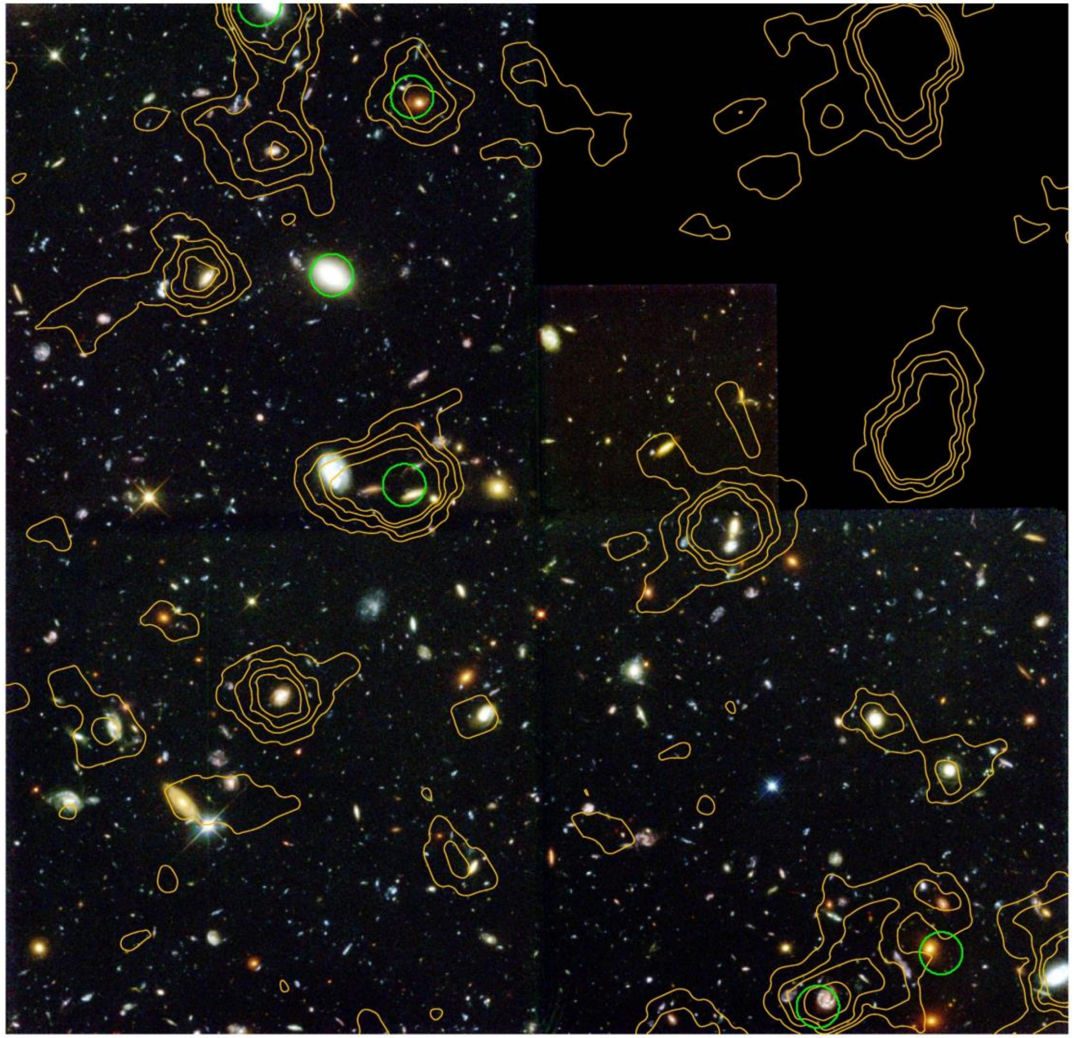


D. Elbaz1 , C.J. Cesarsky1,2 , D. Fadda1 , H. Aussel1,3 , F.X. Desert ´ 4 , A. Franceschini5 , H. Flores1 , M. Harwit6 , J.L. Puget7 , J.L. Starck1 , D.L. Clements7 , L. Danese8 , D.C. Koo9 , and R. Mandolesi10 1999

Hubble Deep Field

Aussel, H.; Cesarsky, C. J.; Elbaz, D.; Starck, J. L.1999

ISOCAM 7 μm (○) and 15 μm
superimposed with Hubble Space Telescope image

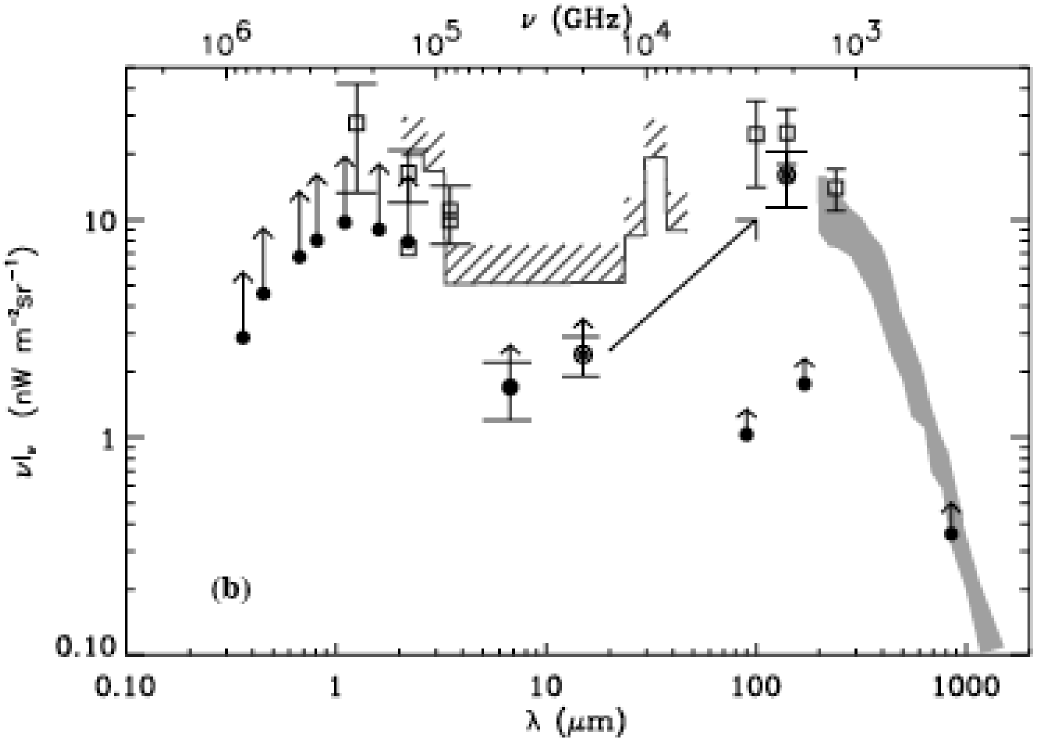


Visible light : NASA/ESA/HST and R. Williams and the HDF Team (STSCI)
Infrared : ESA/ISO/ISOCAM, CEA-Saclay and H. Aussel et al.

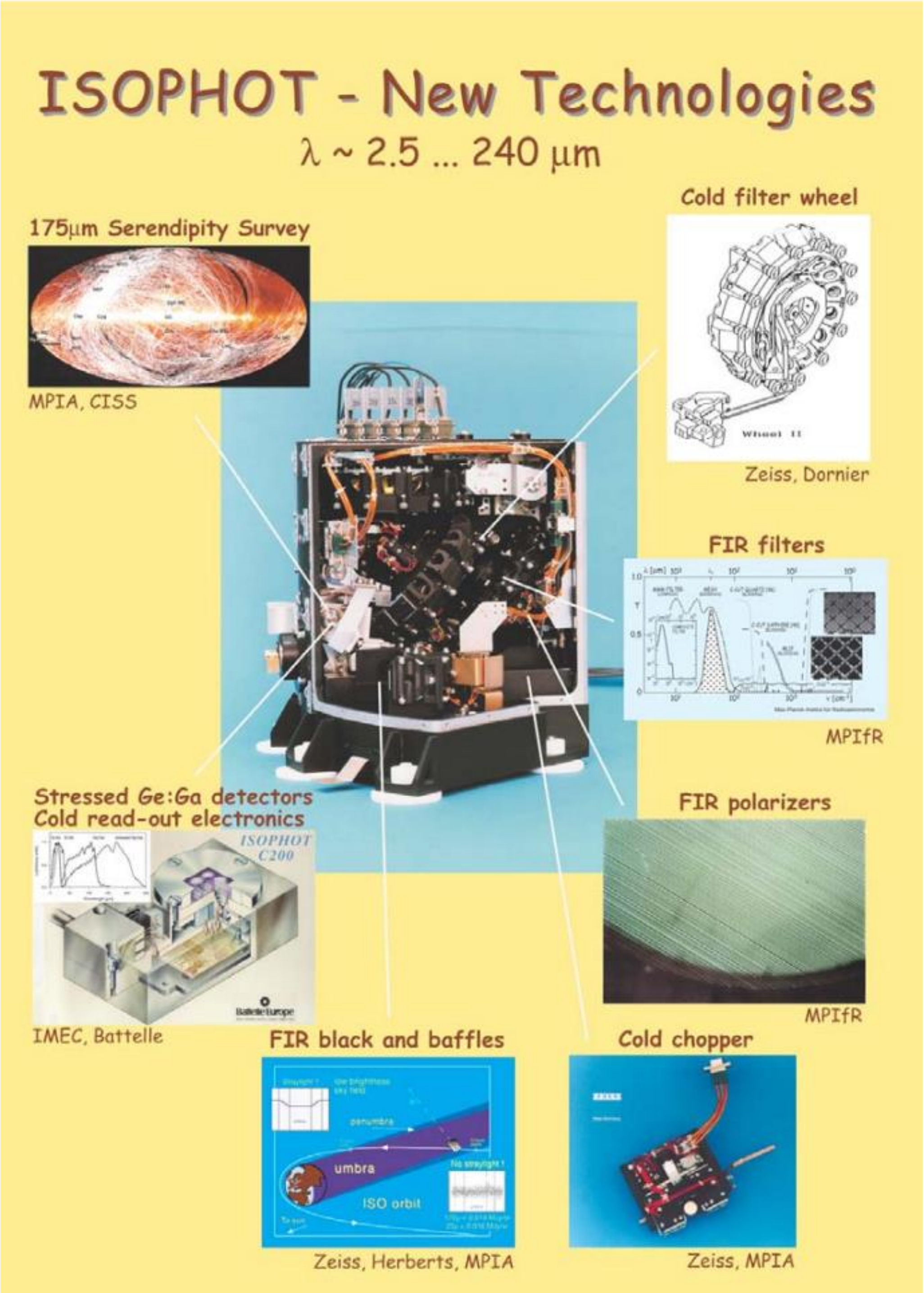
ISOCAM detected a distant high 15μ luminosity population of galaxies.
75% of ISOCAM galaxies (z<1.2) are LIRGs and ULIRGS. They make the bulk of the cosmic IR background, (80%) Comoving IR light density at z~1 70 times higher than today. (2002)

The bulk of the cosmic infrared background resolved by ISOCAM

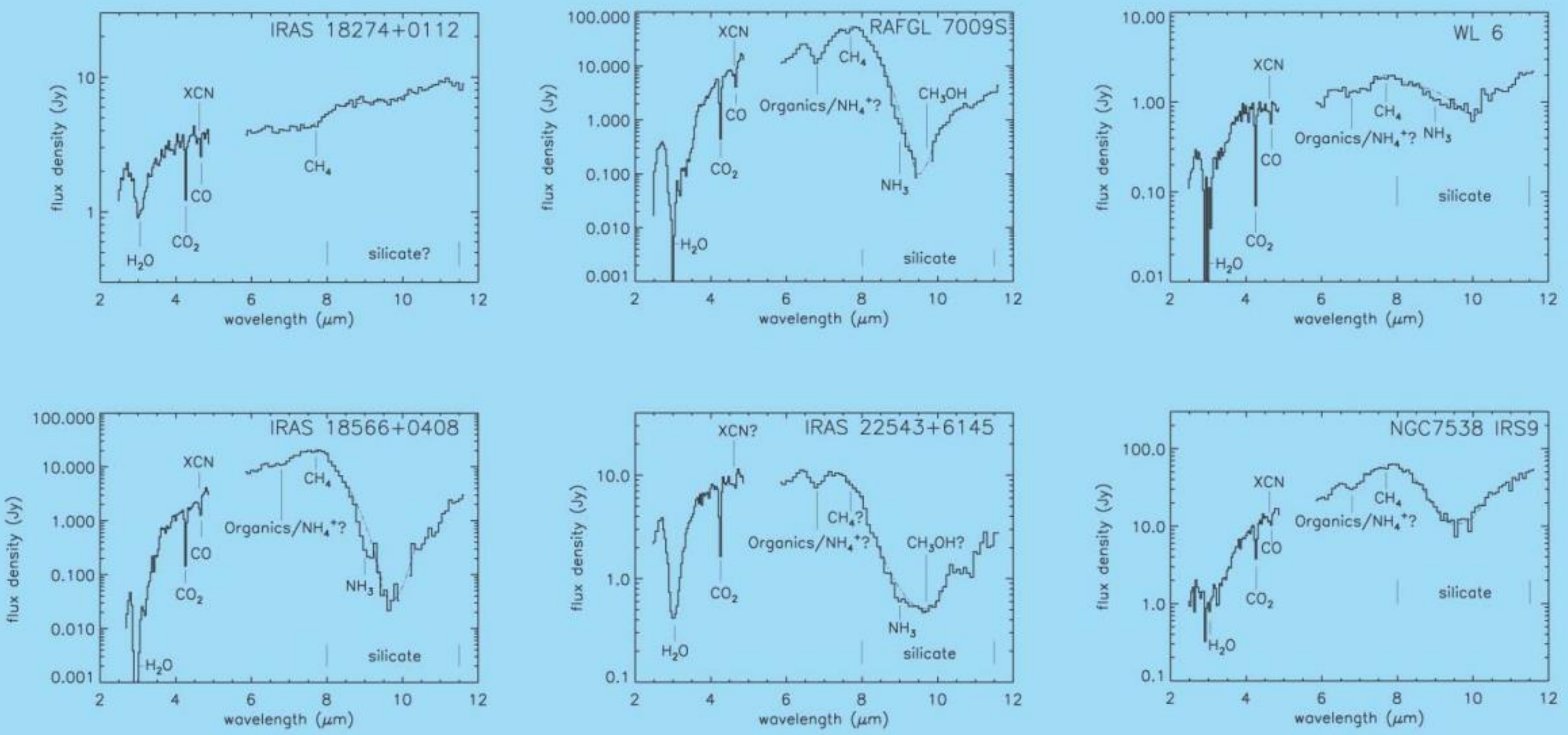
D. Elbaz[1,2,3], C. J. Cesarsky[1,4], P. Chanial[1], H. Aussel[1,5], A. Franceschini[6], D. Fadda[1,7], and R. R. Chary[3]

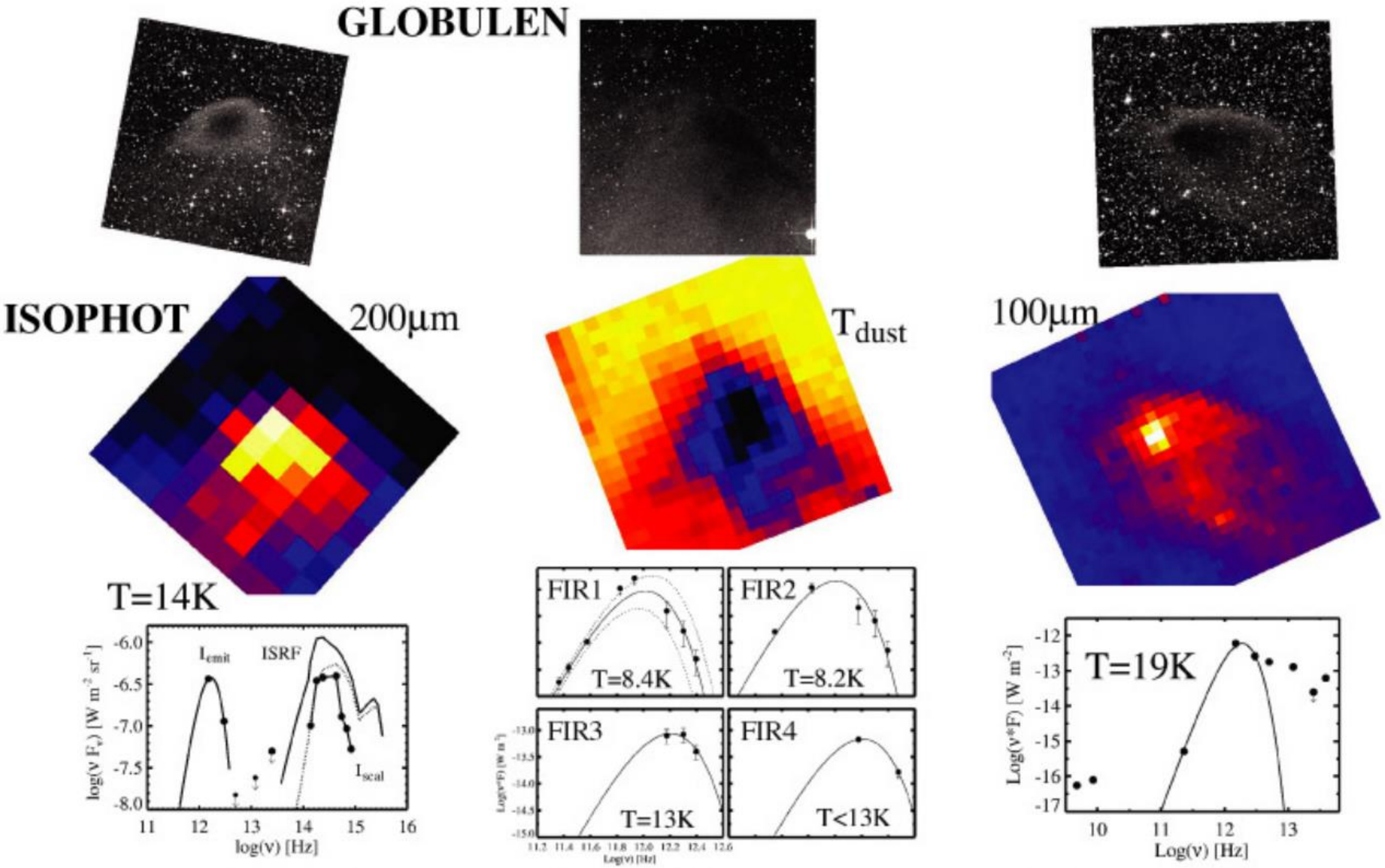


Cold chopper used by Pacs in Herschel
Cold wheel mechanism by MIRI in JWST



The ISOPHOT–S legacy of interstellar ices
(101 sources: 68 young objects, 33 evolved stars)





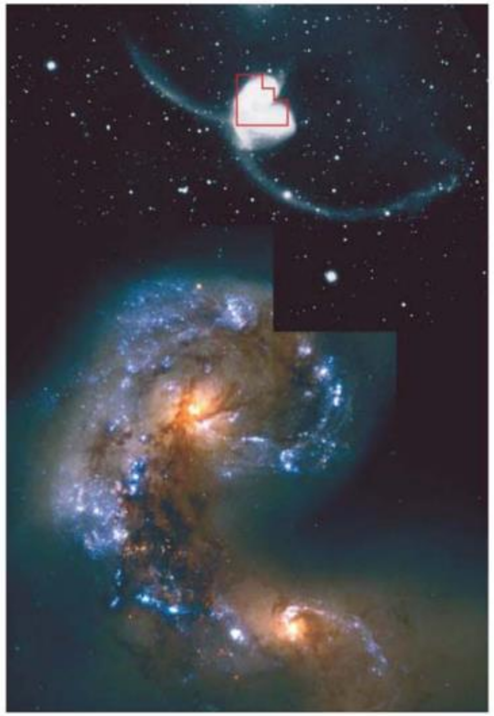
Thumbprint Nebula:
no star formation

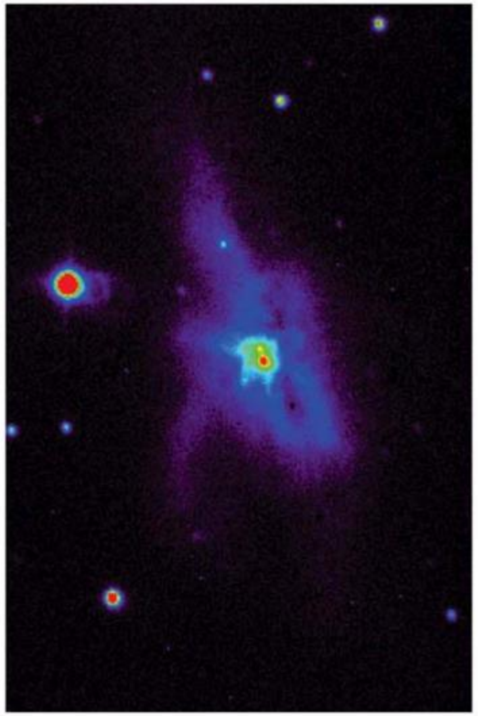
Lynds 183:
pre-protostellar sources

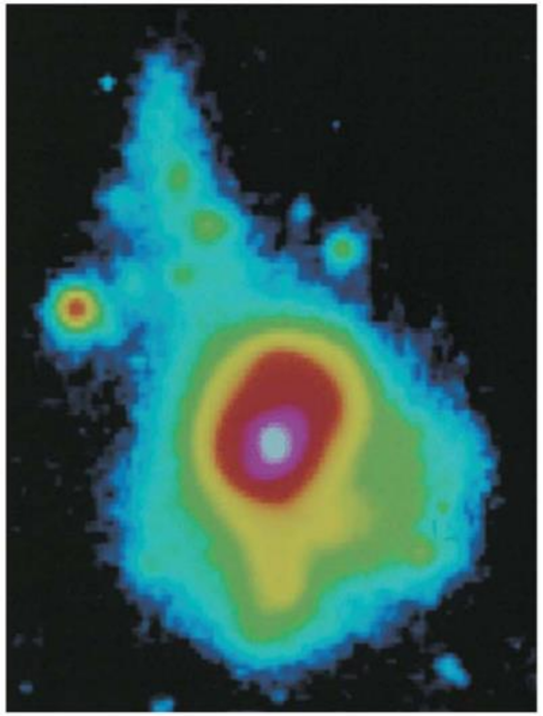
DC303.8-14.2:
embedded protostar

Lehtinen, Mattila, Lemke et al

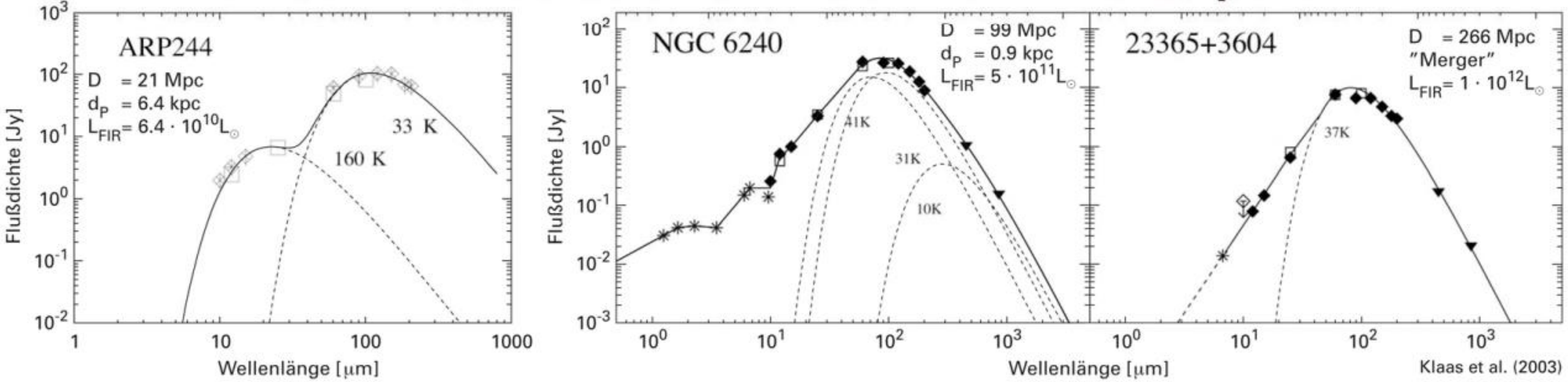
Dietrich Lemke,MPIA
ESAC, Dec 2006



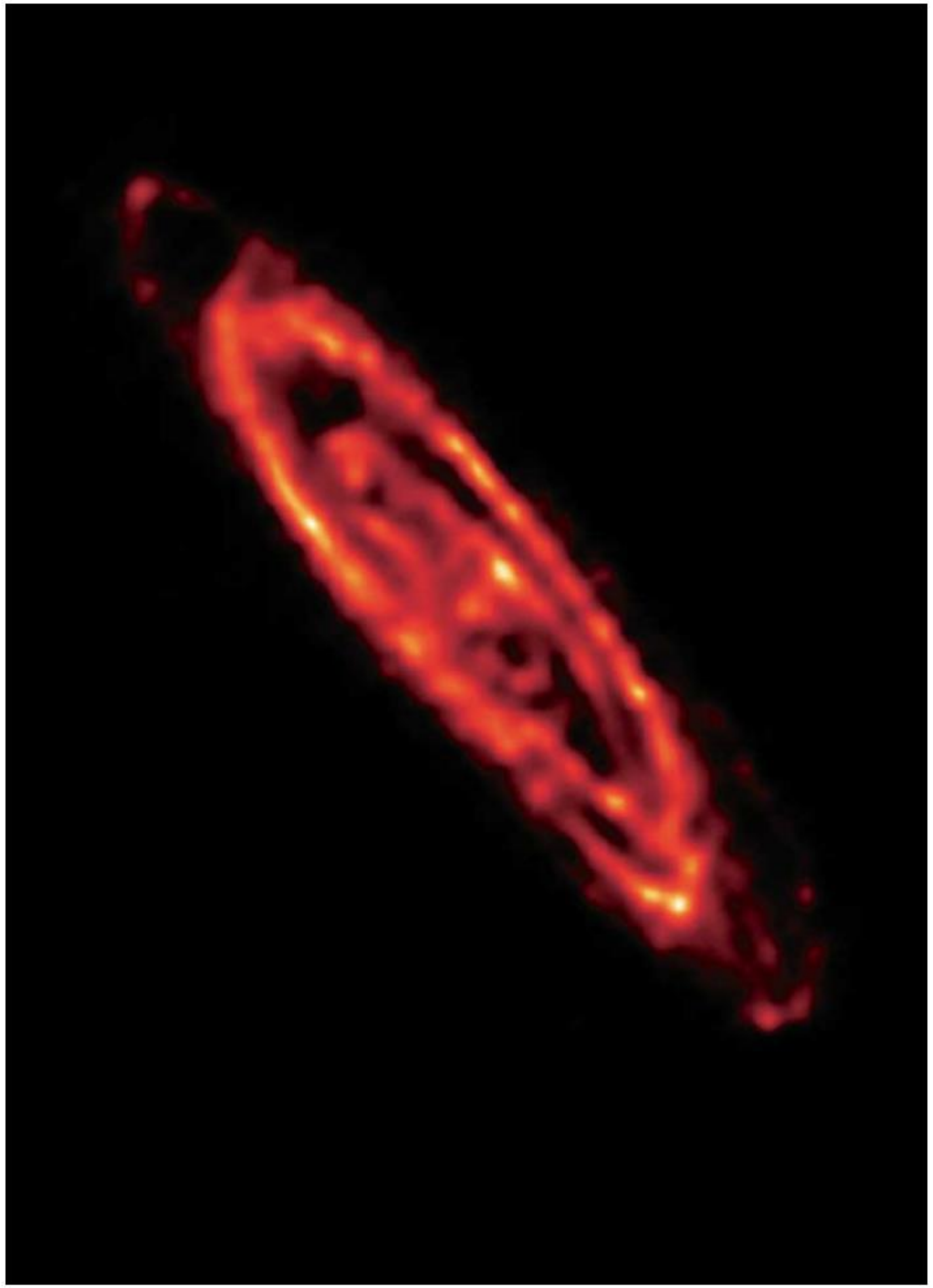




Wechselwirkende Galaxien – ISOPHOT Infrarotspektren



Dietrich Lemke,MPIA
ESAC, Dec 2006



M 31

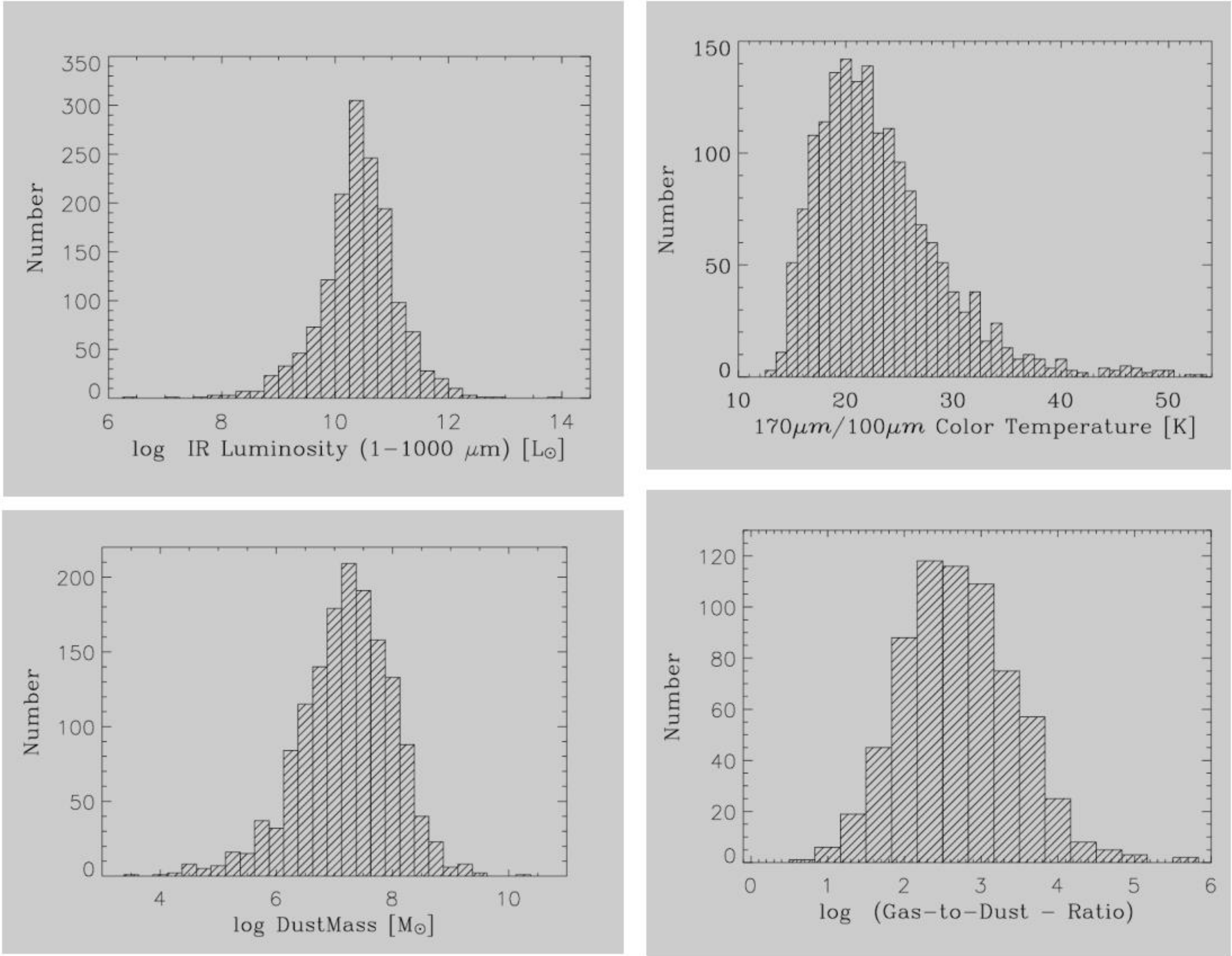
170 µm

Haas, Lemke, Stickel
et al 1998

Dietrich Lemke,MPIA
ESAC, Dec 2006

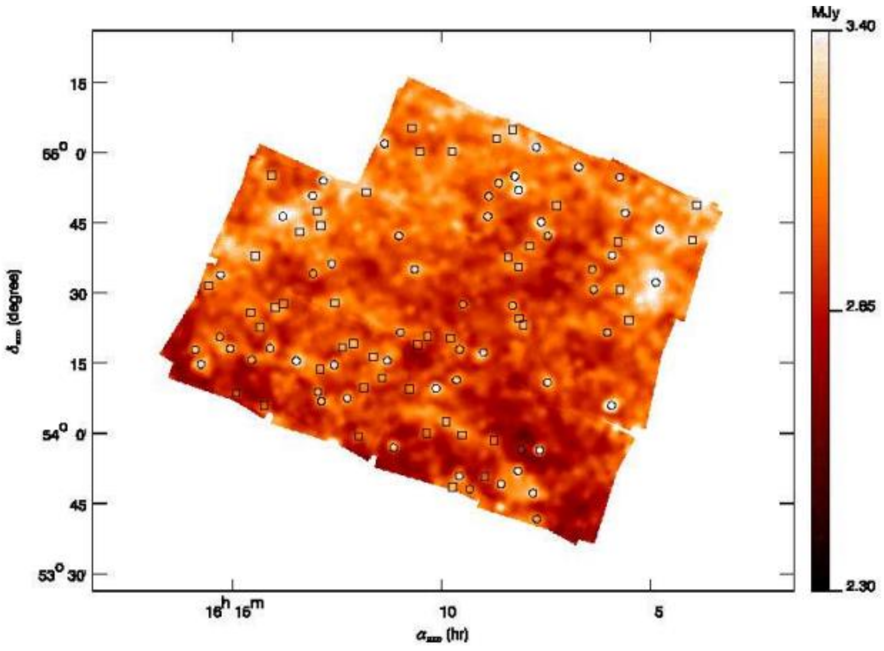
Statistical Results from ISOSS: Galaxies

Ser



FIRBACK. A deep survey at 175 microns with ISOPHOT

J.L. Puget , G. Lagache , D.L. Clements , W.T. Reach , H. Aussel , F.R. Bouchet , C. Cesarsky , F.X. Désert , H. Dole , D. Elbaz , A. Franceschini , B. Guiderdoni , and A.F.M. Moorwood **, 1999, followed by Dole et al., 2001**

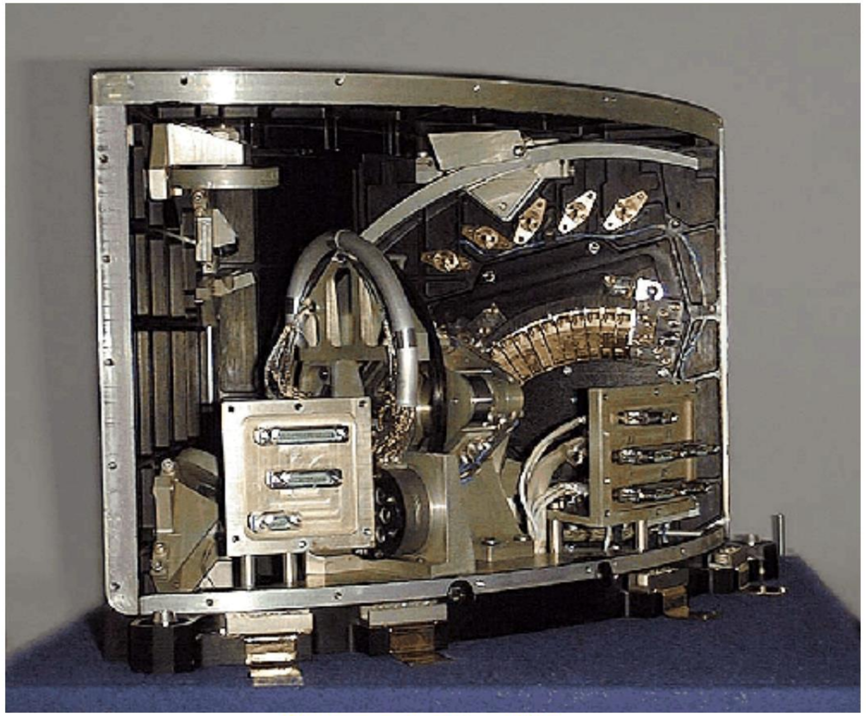


An area of 0.25 square degree was covered and a detection level of ~100 mJy (5σ) was reached Source density for objects with a flux above 200 mJy exceeds the counts expected for sources found in the IRAS deep surveys with a similar flux by about an order of magnitude. The detected sources account for only 10 % of the cosmic IR background.

An extrapolation of the counts down to about 10 mJy would be needed to account for the whole background at this wavelength.

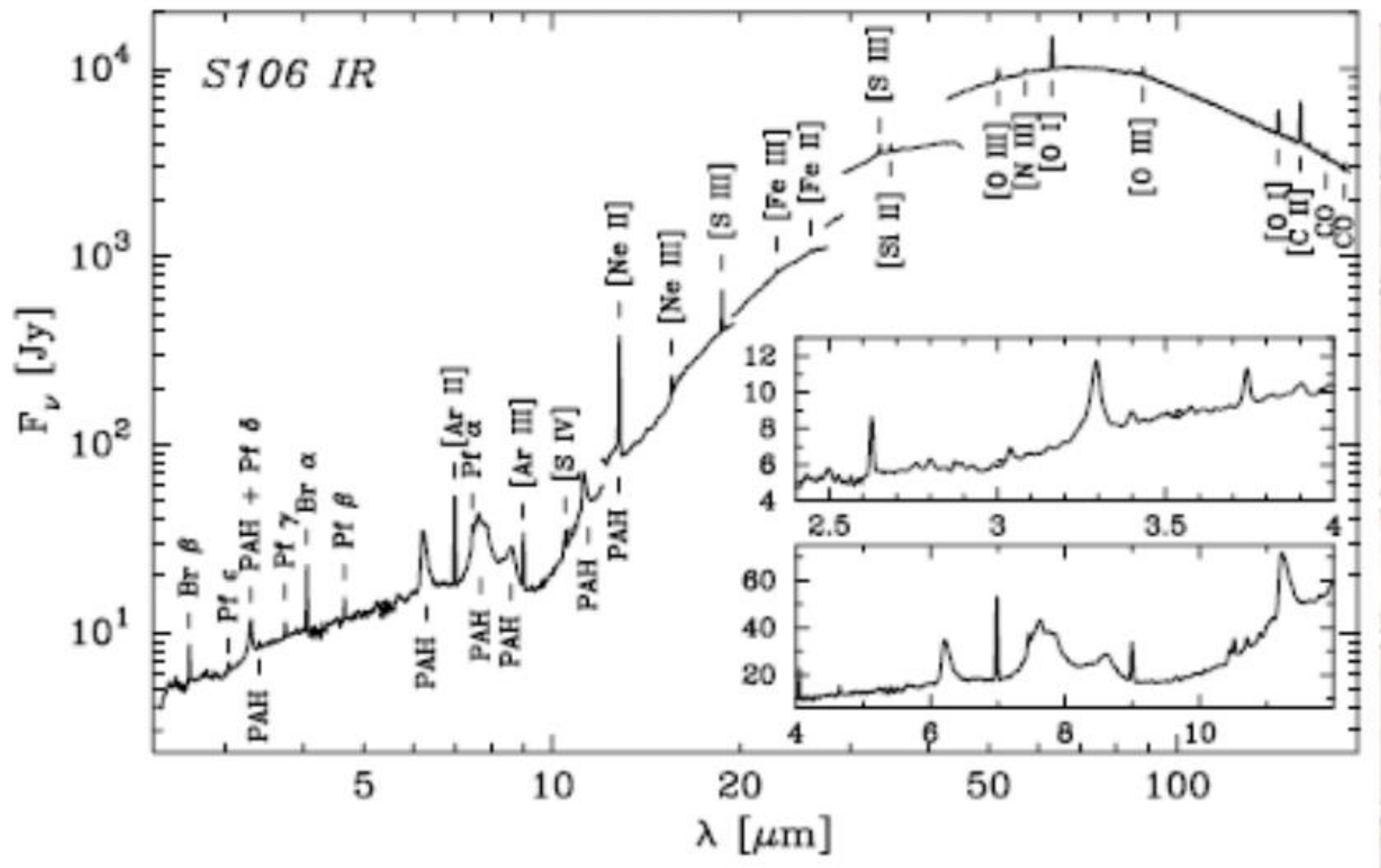
LWS

LWS

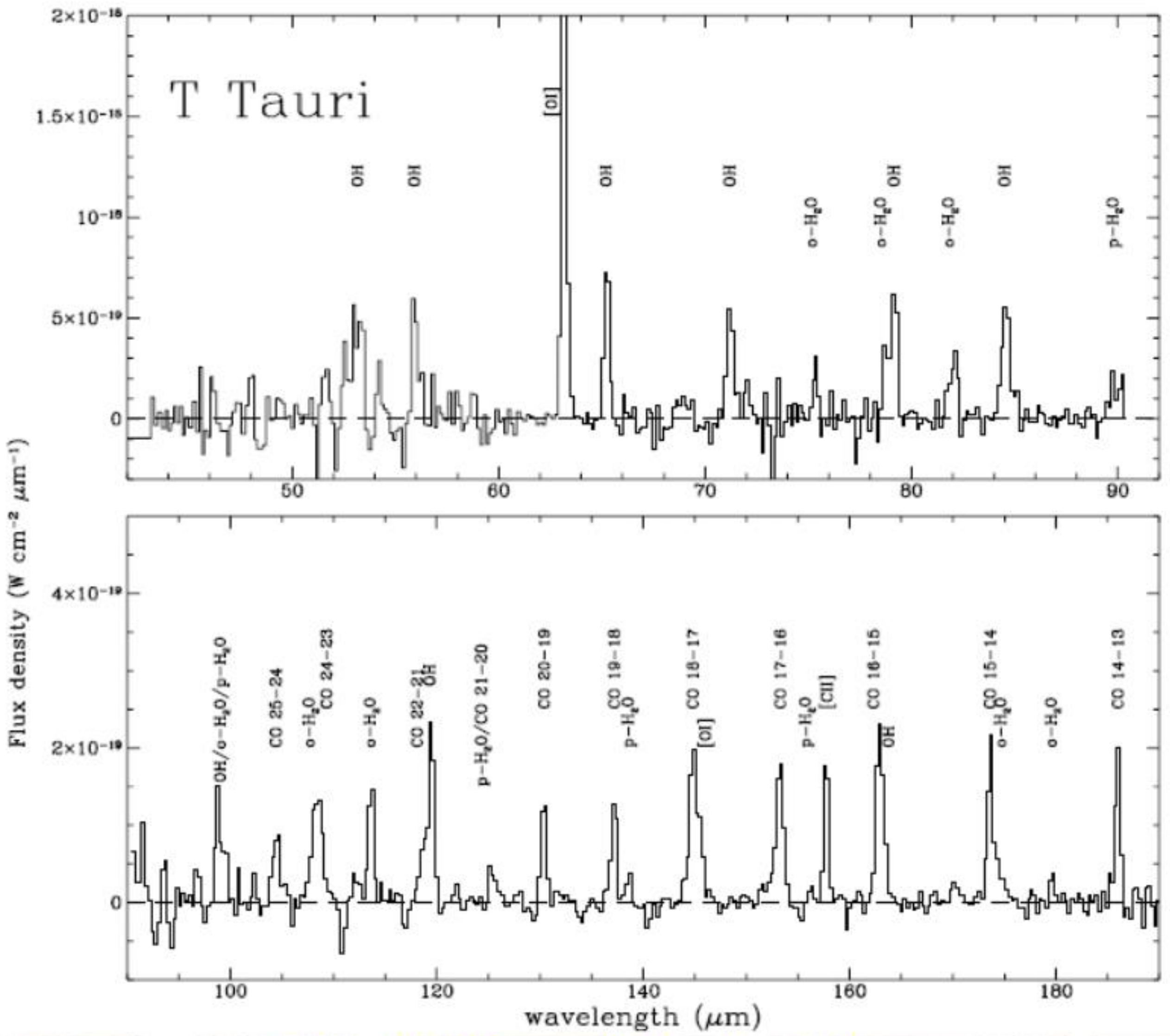


Photograph of the LWS

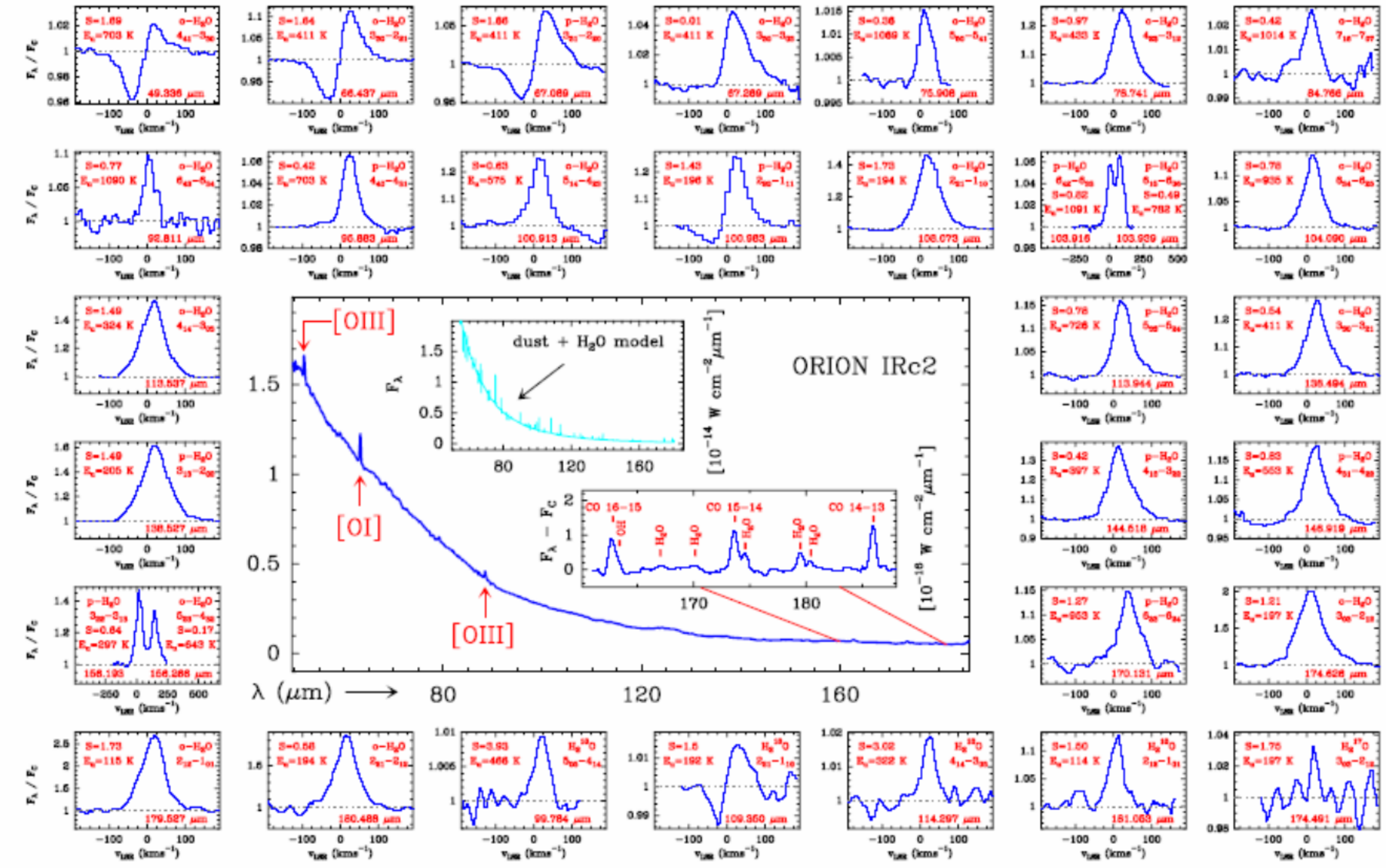
Stars young….



S106: combined SWS-LWS scan (van den Ancker)

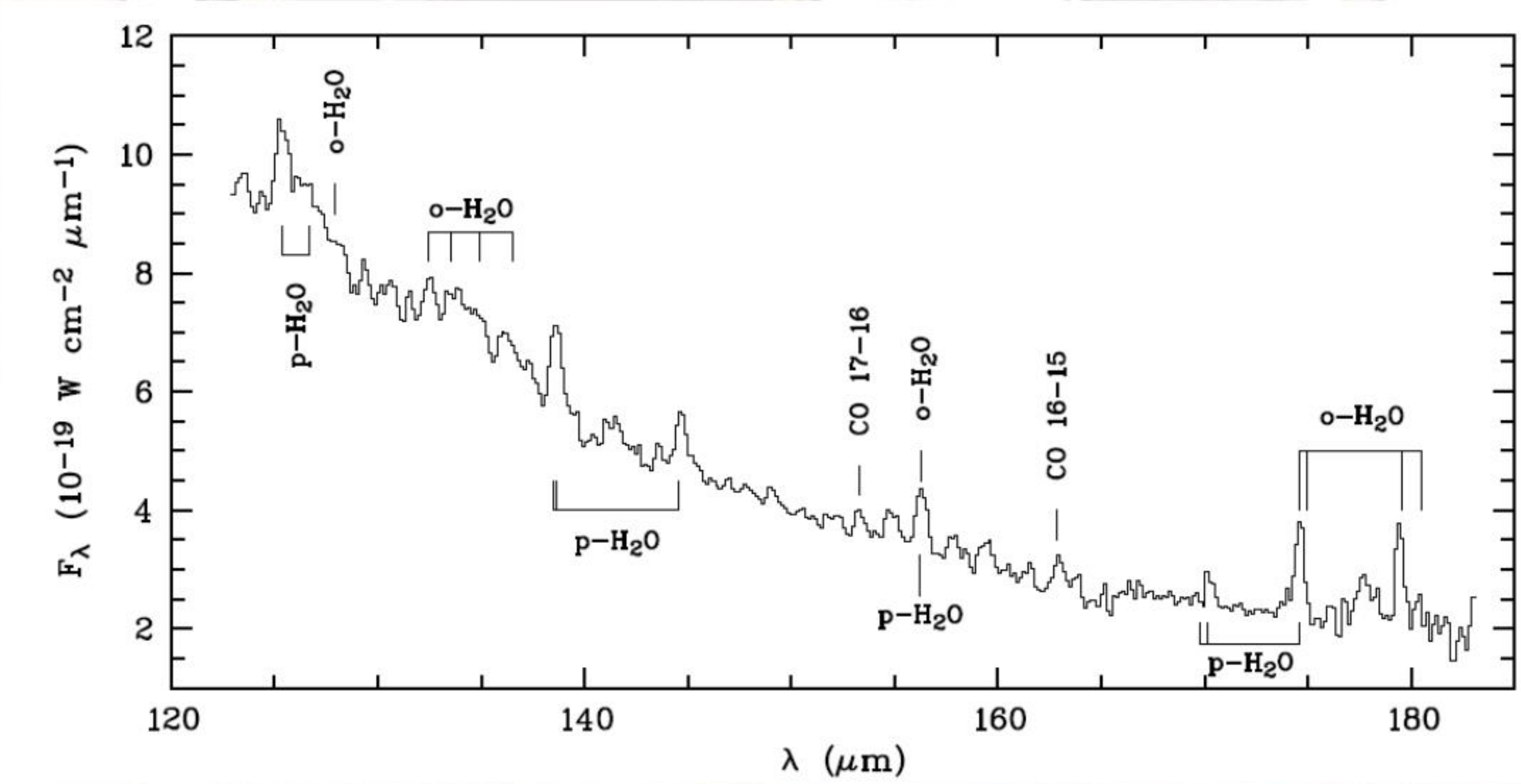


T-Tauri: LWS scan (Spinoglio et al.)

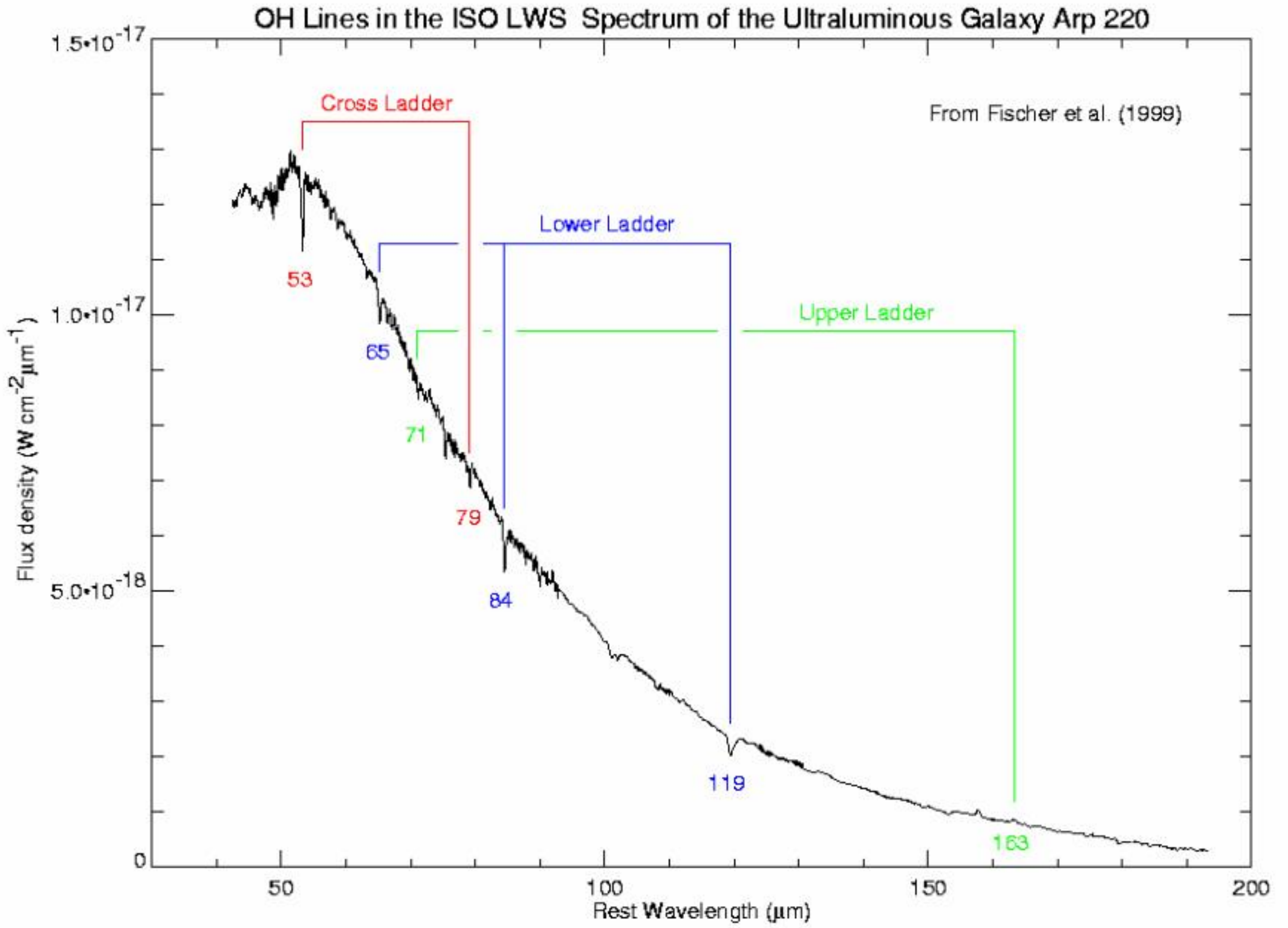


Cernicharo et al., 2006

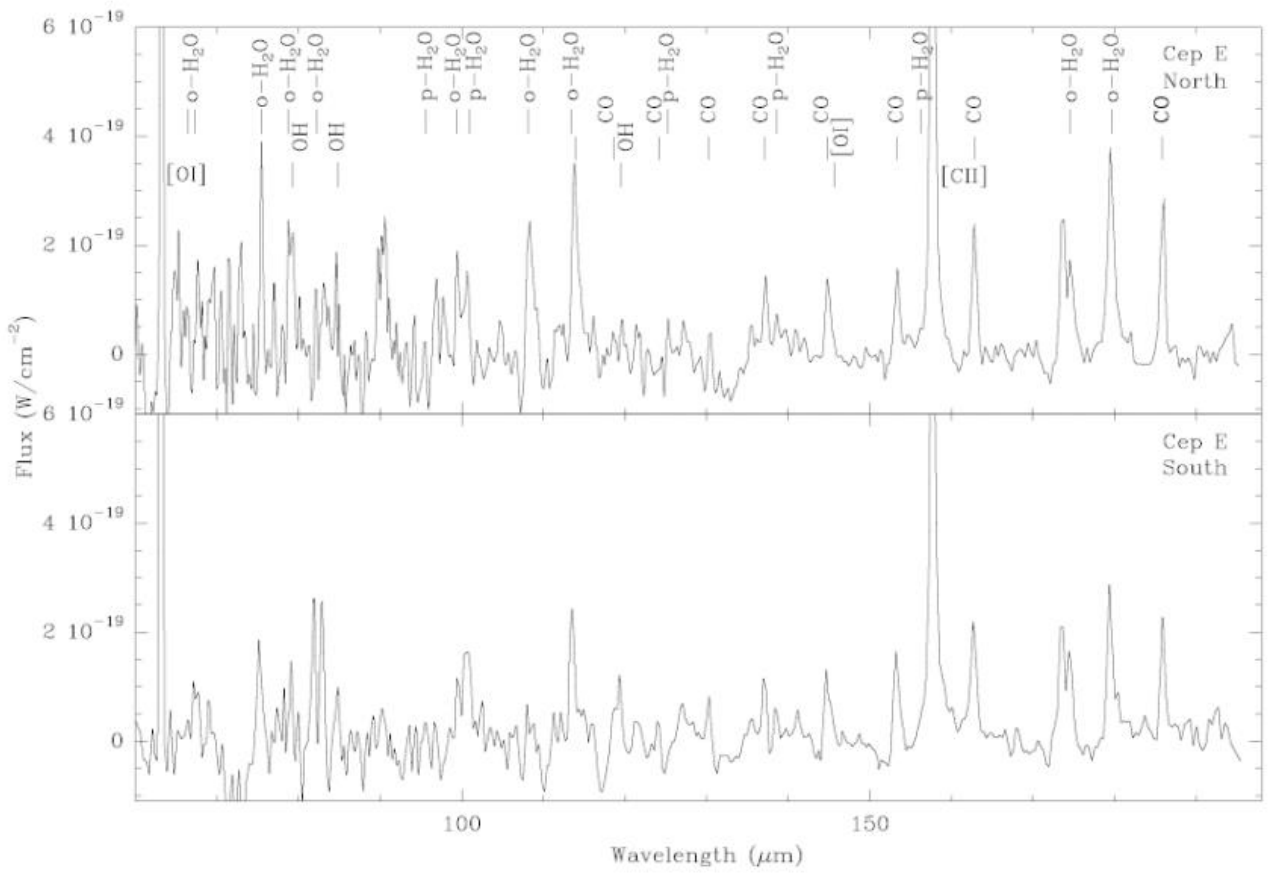
.. and the old



W Hya (Barlow et al)

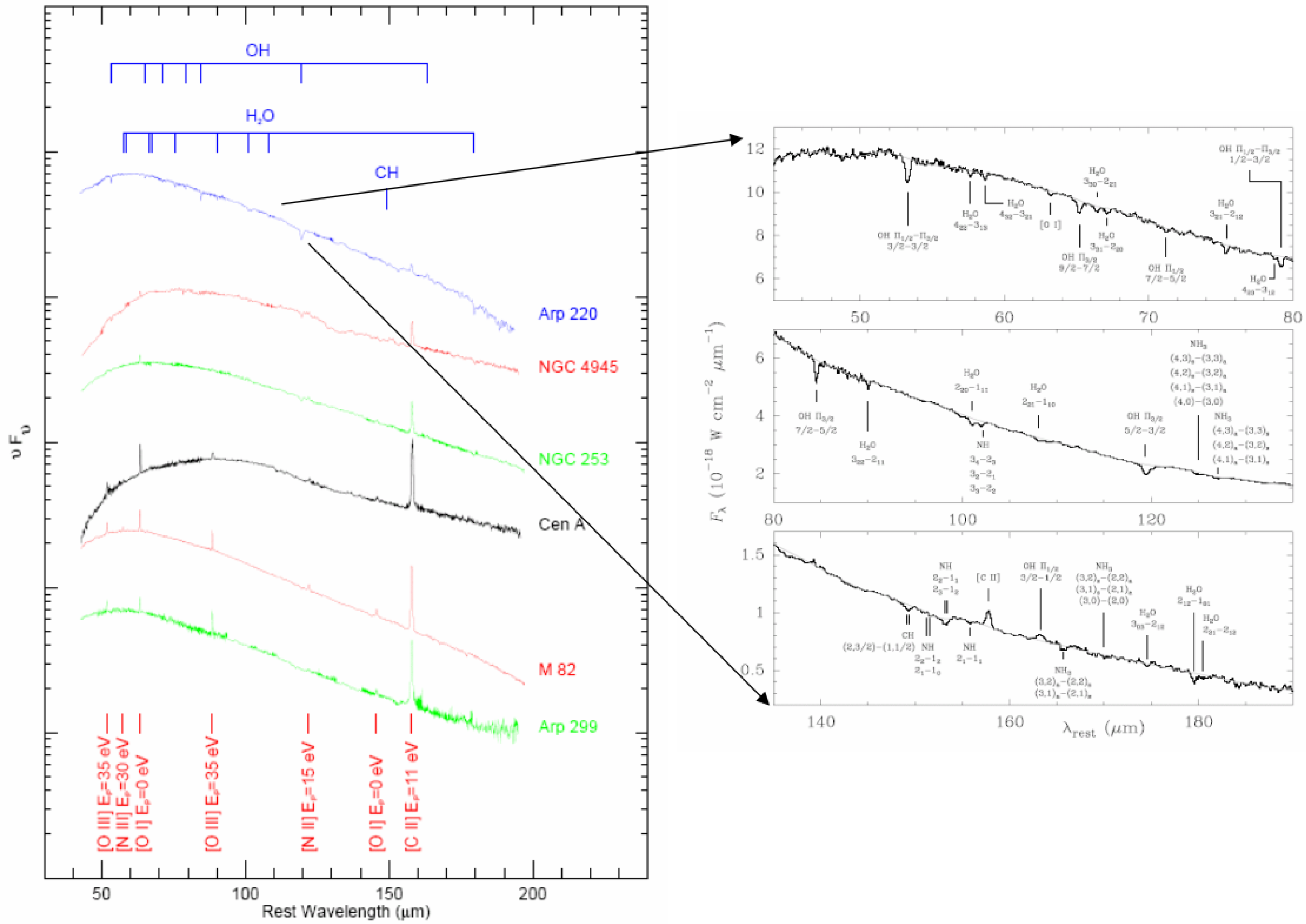

OH Lines in the ISO LWS Spectrum of the Ultraluminous Galaxy Arp 220
From Fischer et al. (1999)
Cross Ladder
Lower Ladder
Upper Ladder
53
65
71
79
84
119
163
Flux density (W cm-2 µm-1)
1.5•10-17
1.0•10-17
5.0•10-18
0
50
100
150
200
Rest Wavelength (µm)

The ISM:



Emission lines galore in full grating LWS spectra of Cep E North and Cep E South (Noriega-Crespo).

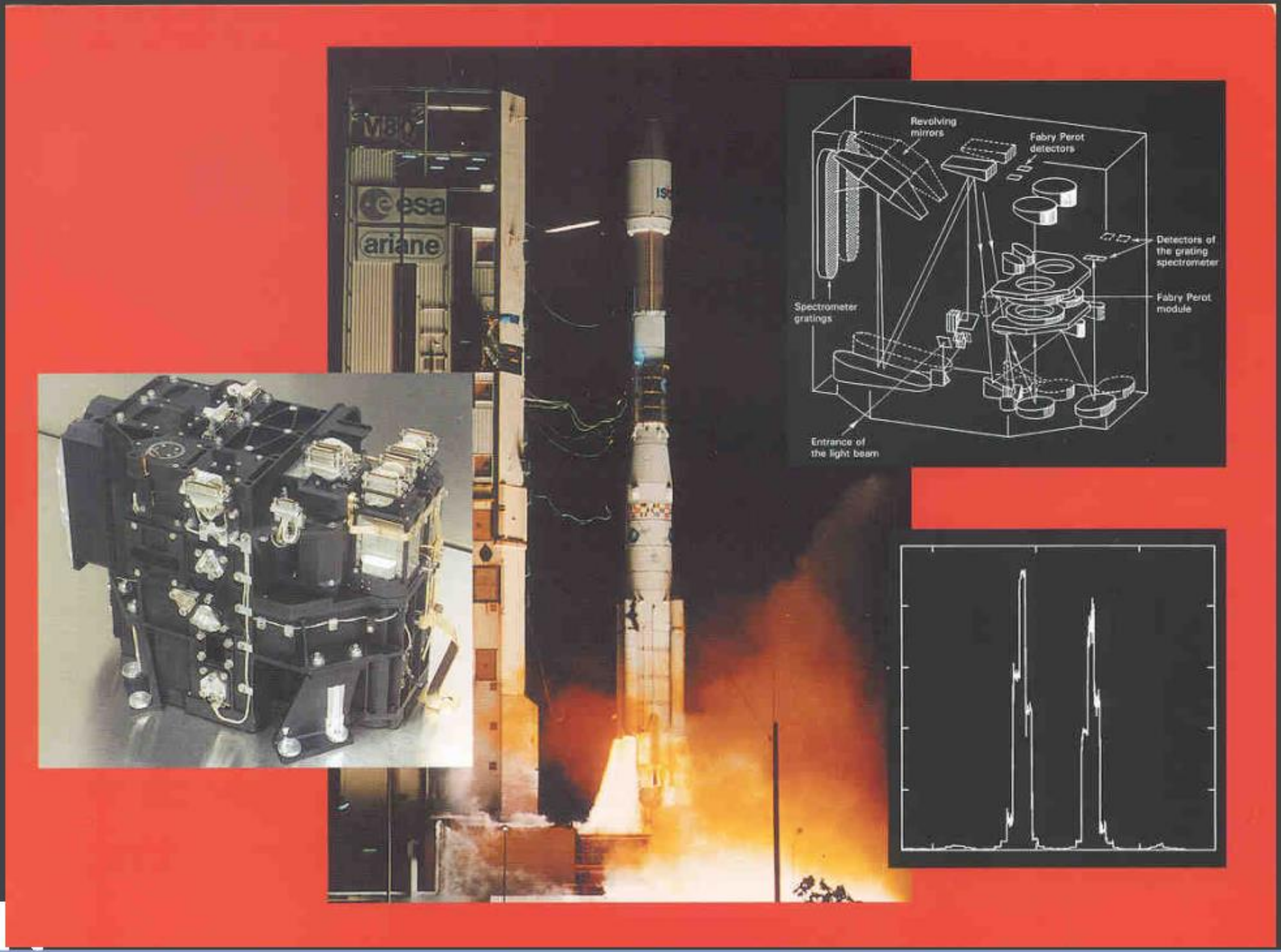
and spectra of other galaxies



Fischer et al.; Gonzalez-Alfonso, et al.

SWS Consortium:

SRON Groningen and Utrecht with MPE Garching
later also: KULeuvenin operation phase
Special detector support from AFGLand Steward Observatory
FPU Design with TNO-TPD



SRON

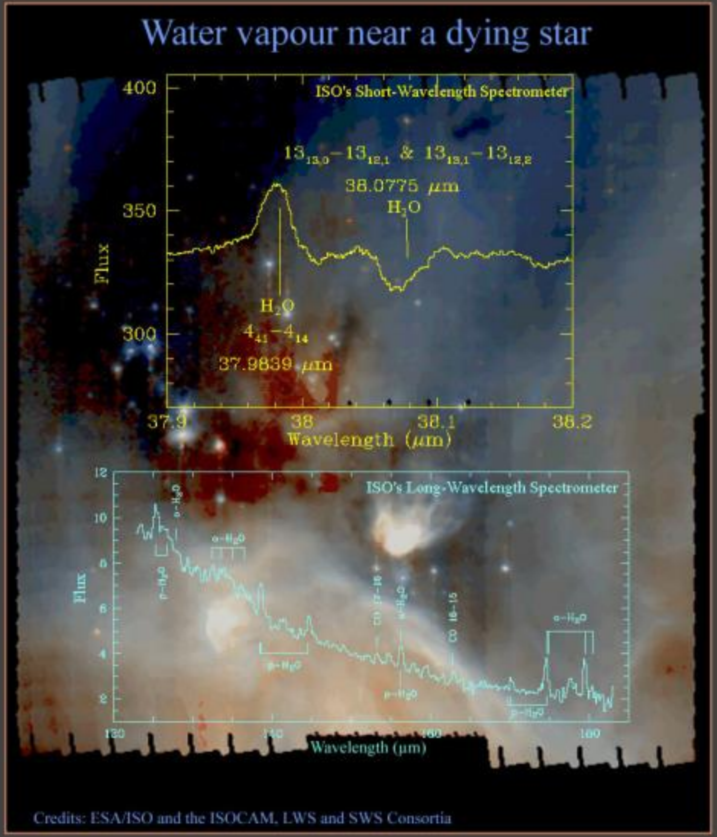
Some Scientific Highlights of ISO spectroscopy

A) Unveiling IR Molecular Universe:

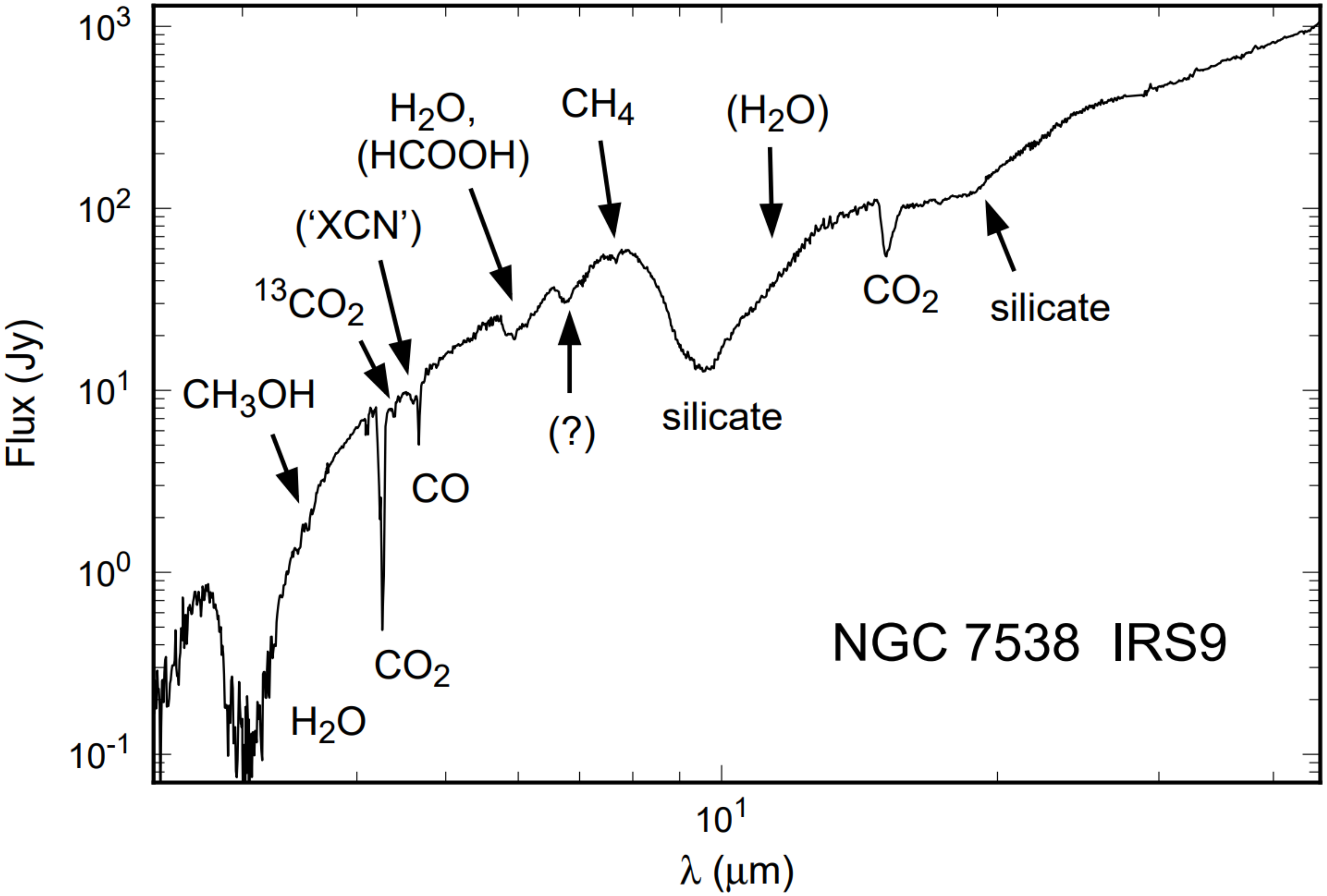
- H_2
- H_2O
- Ices
- PAHs
- Many more Molecules

B) (F)IR Spectral characterisation of a wide variety of cosmic sources
More than 1500 full spectra:
from 2.45-45 μm
and 43-200 μm

C) Set the stage for Spitzer and Herschel and the direction for JWST-MIRI

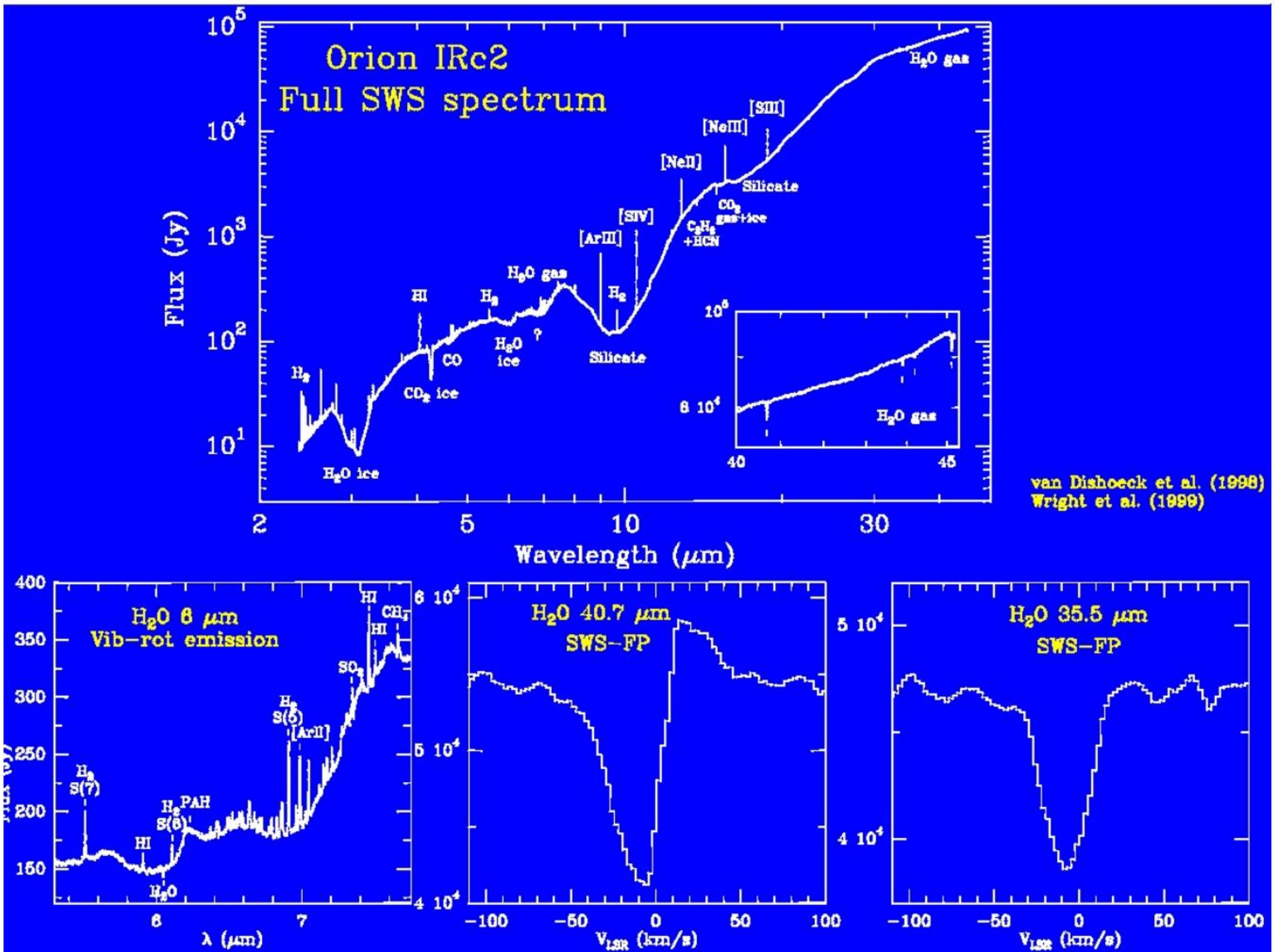


Interstellar ices



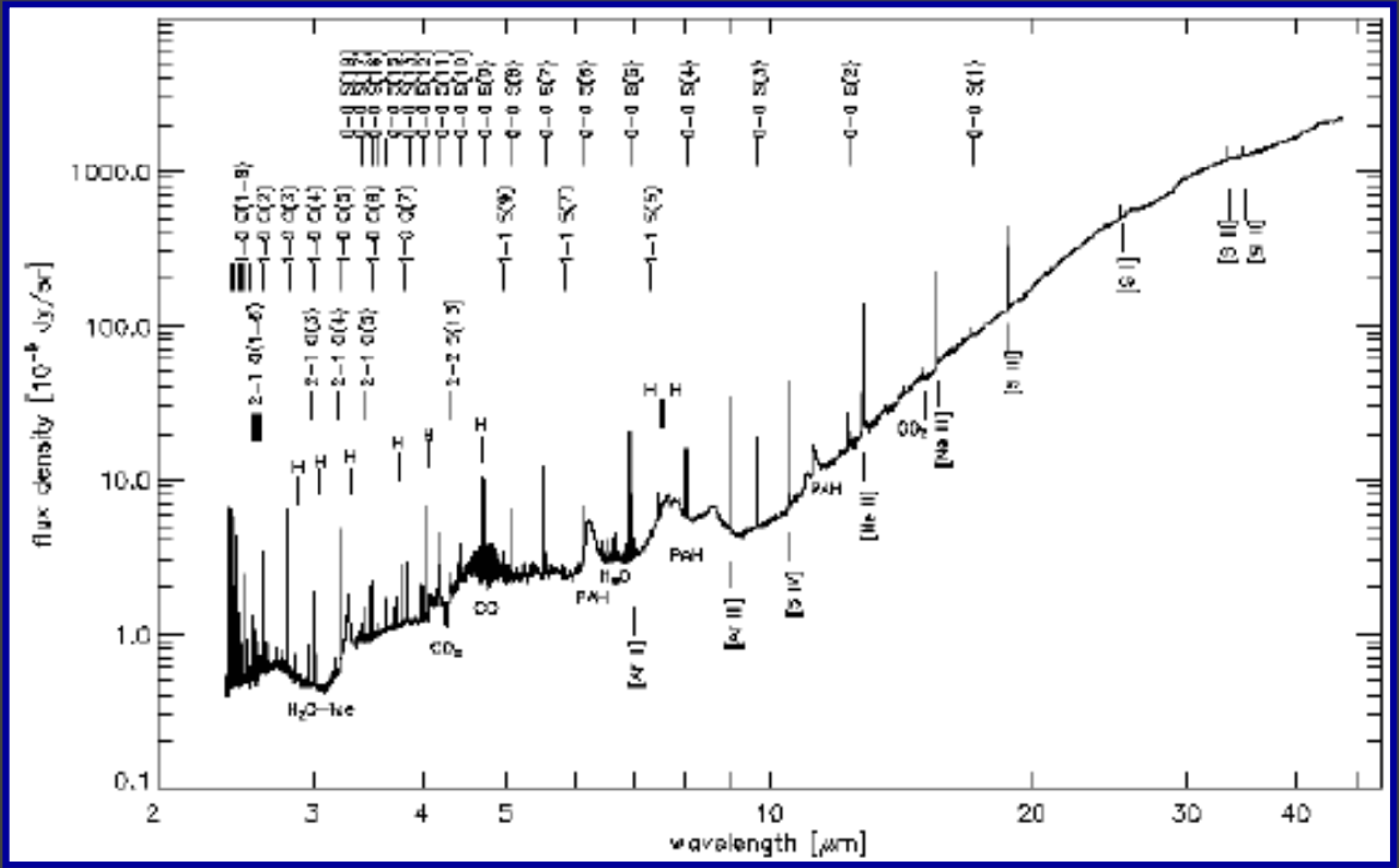
Whittet et al. 1996

Water

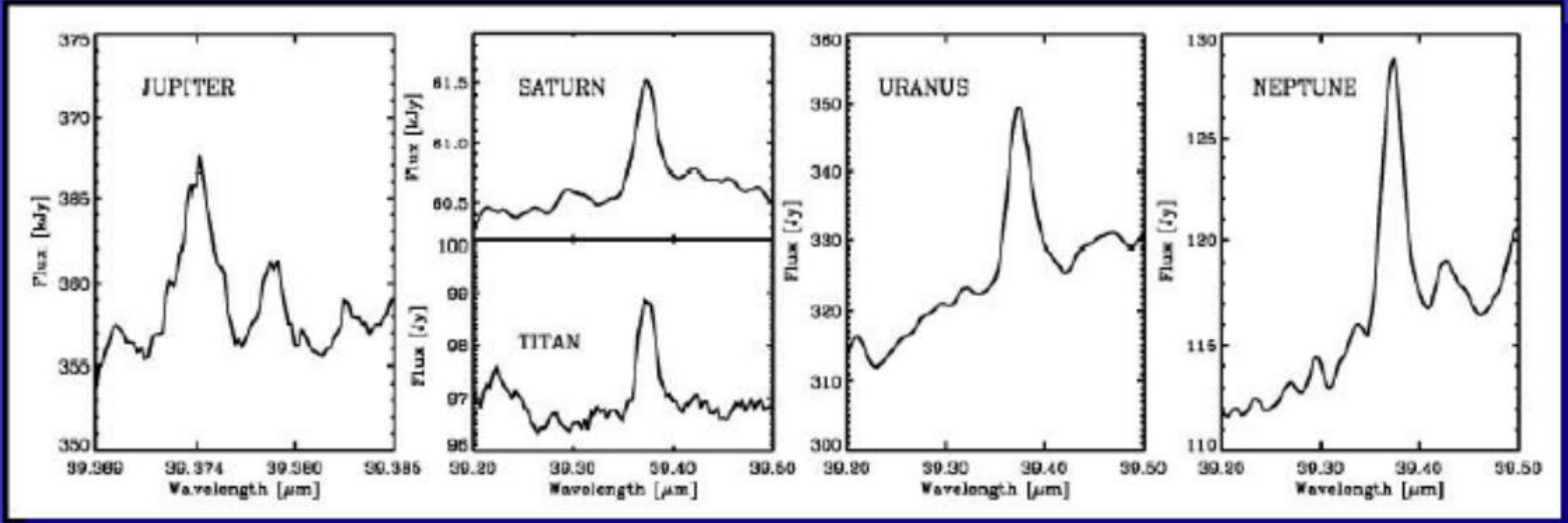


Orion IRc2
Full SWS spectrum
Flux (Jy)
Wavelength (μm)
H2O gas
[SIII]
[NeIII]
[NeII]
Silicate
CO2 gas+ice
C2H2 +HCN
[SIV]
[ArIII]
H2
H2O gas
HI
H2
H2O ice
CO
CO2 ice
H2O ice
Silicate
H2O gas
van Dishoeck et al. (1998)
Wright et al. (1999)
H2O 6 μm
Vib-rot emission
λ (μm)
H2O 40.7 μm
SWS–FP
VLSR (km/s)
H2O 35.5 μm
SWS–FP
VLSR (km/s)

SWS spectrum towards the brightest H2 emission peak of the Orion OMC-1 outflow of Orion Peak 1 (Rosenthal et al 2000)

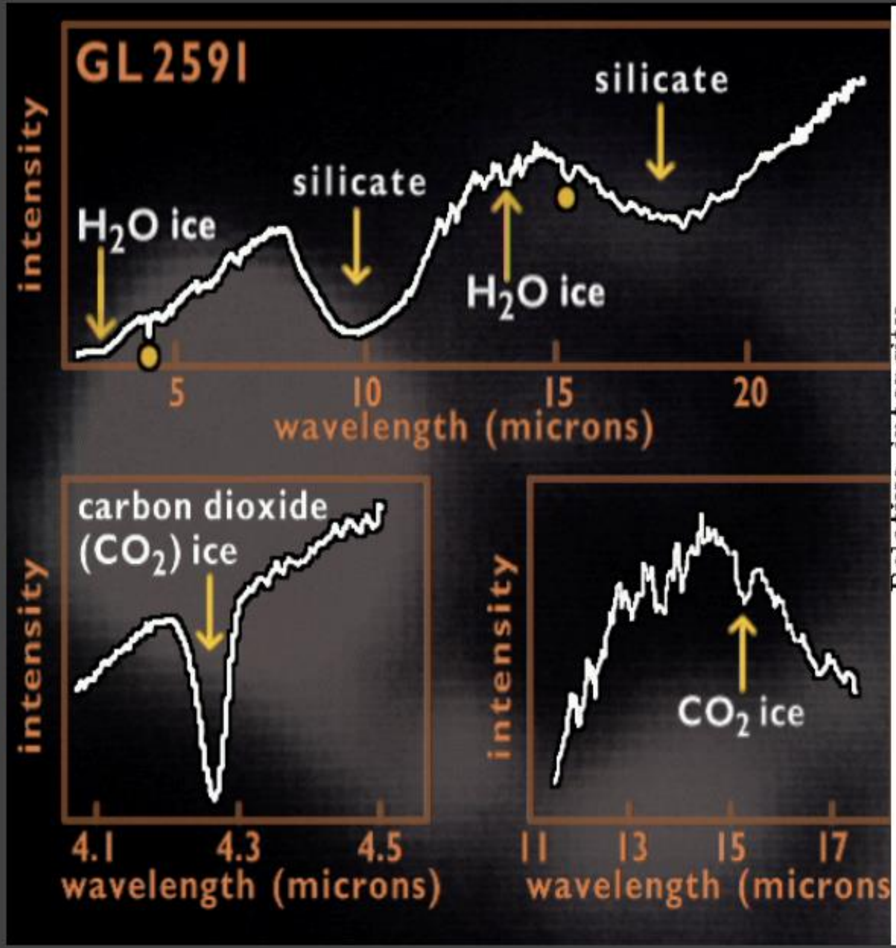


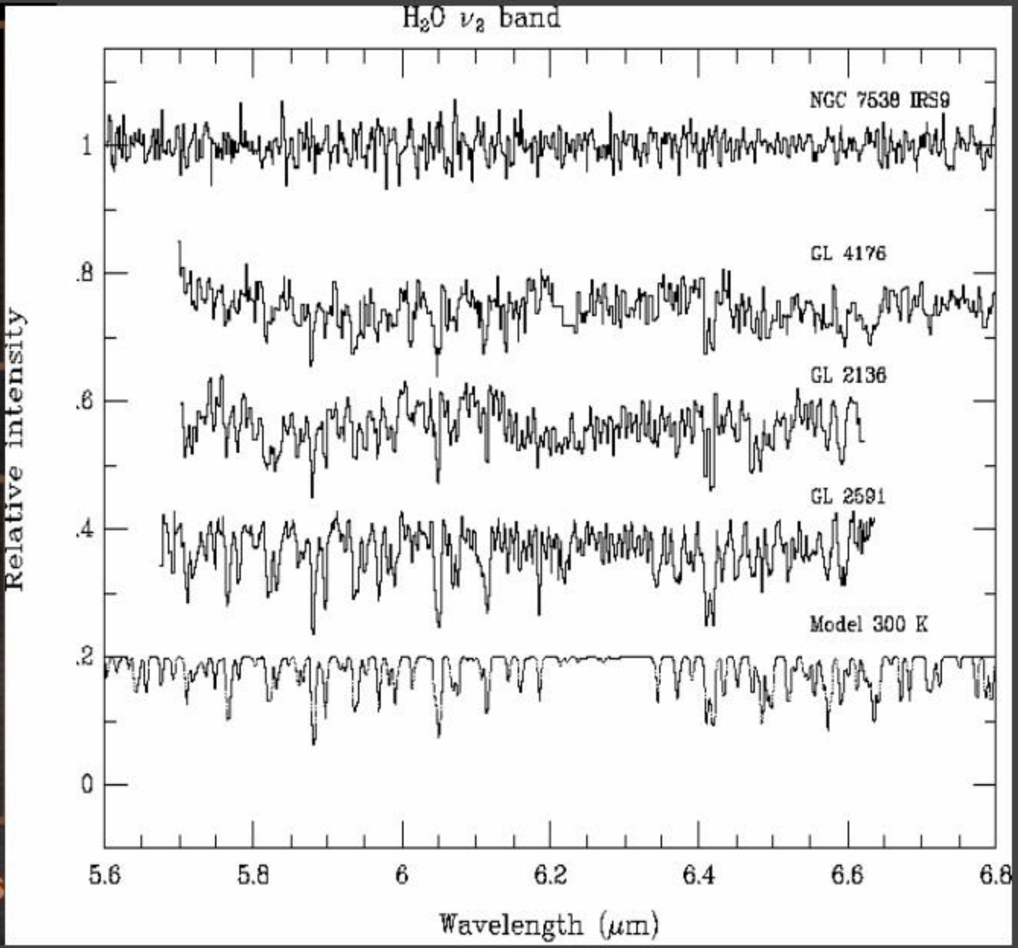
Water in the Solar System
Feuchtgruber/Lellouch/Coustenis



Feuchtgruber et al., 1997, Lellouch et al., 1997, Coustenis et al., 1998

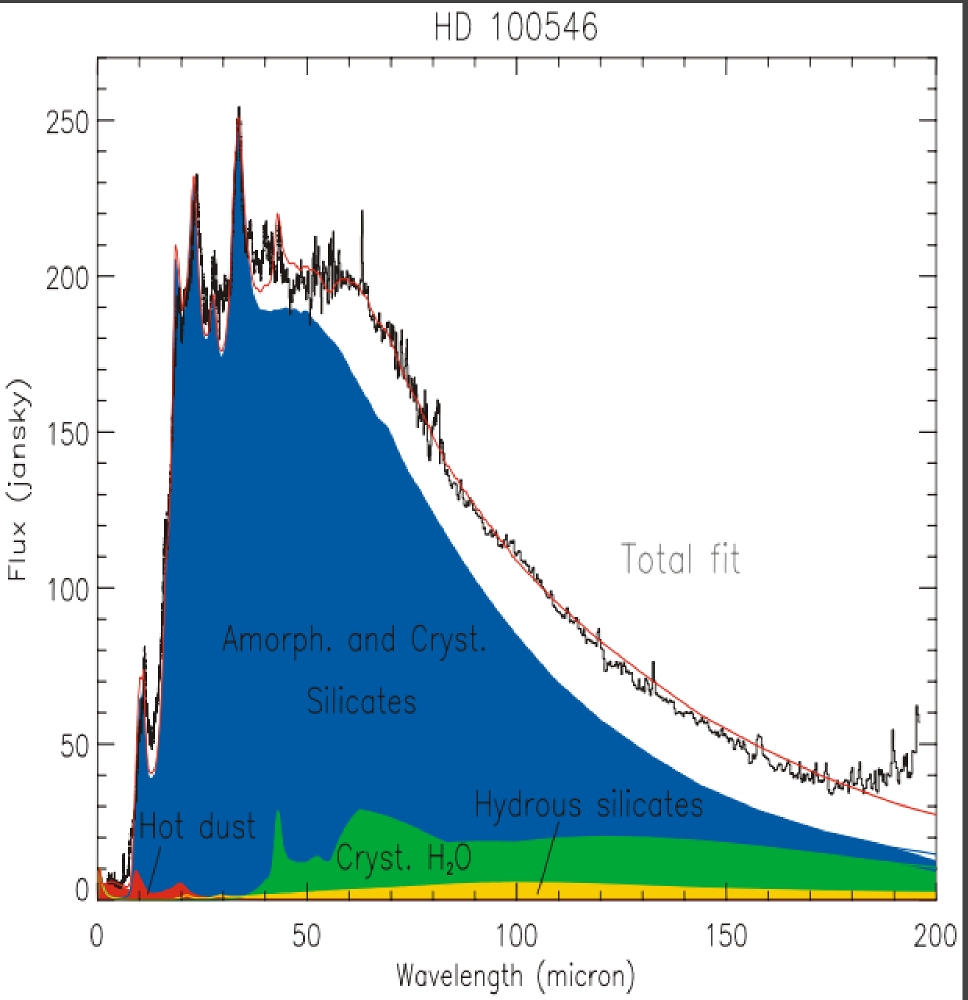
SWS spectra of a young star surrounded by a dense cloud, GL 2591 Normalised SWS spectra of NGC 7538 IRS9, GL4176, GL2136 and GL2591, shifted by 0.0, -0.2, -0.4 and -0.6 respectively. A model H2O spectrum is shown for comparison(Van Dishoeck, Helmich)

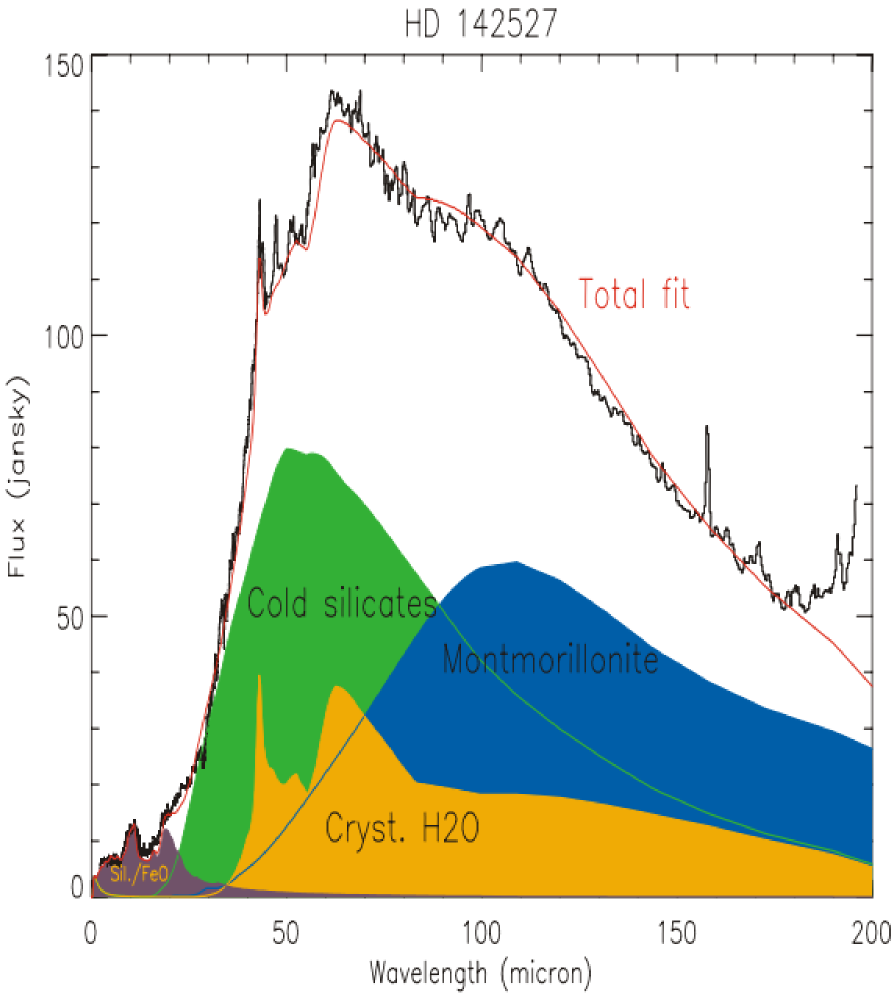




SRON

Properties of dusty disks surrounding Herbig Ae/Be stars : detailed modeling of dust shell of selected sources to fit the spec (K. Malfait)



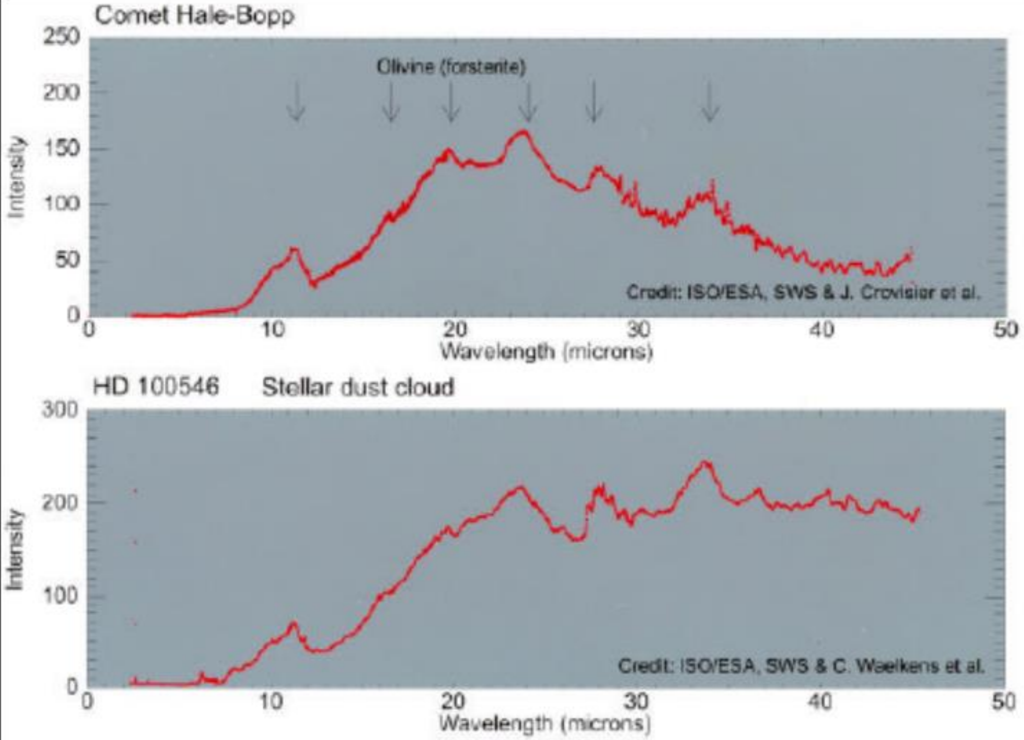


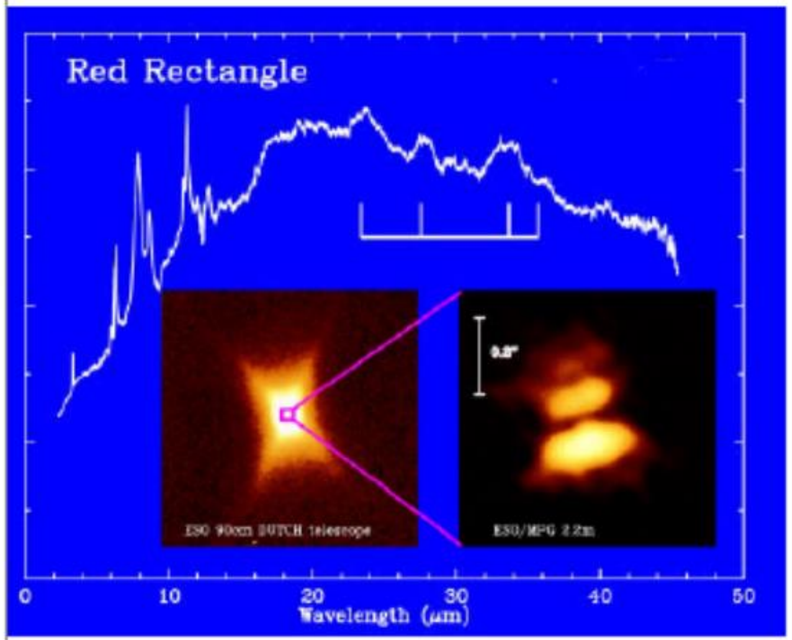
C. Kemper

Crystalline silicates

- Important ISO discovery and legacy
  - From nothing to main thing
- Traces thermal processing, cosmic ray irradiation and shocks
- Opened up field of astromineralogy
- Future promise:
  - Disk evolution, grain growth, planet formation
  - Processing in active galaxies

Crystalline Structures

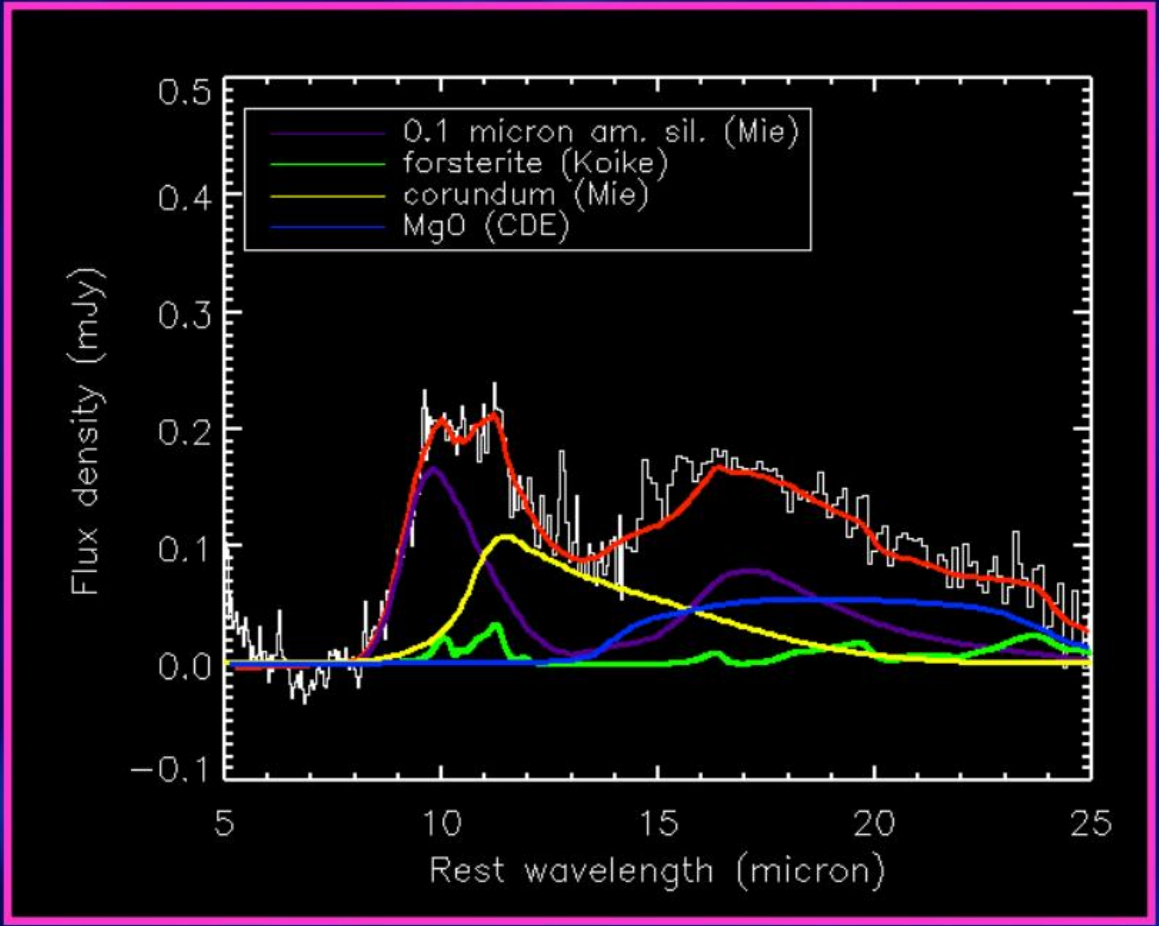




Waters et al., 1998

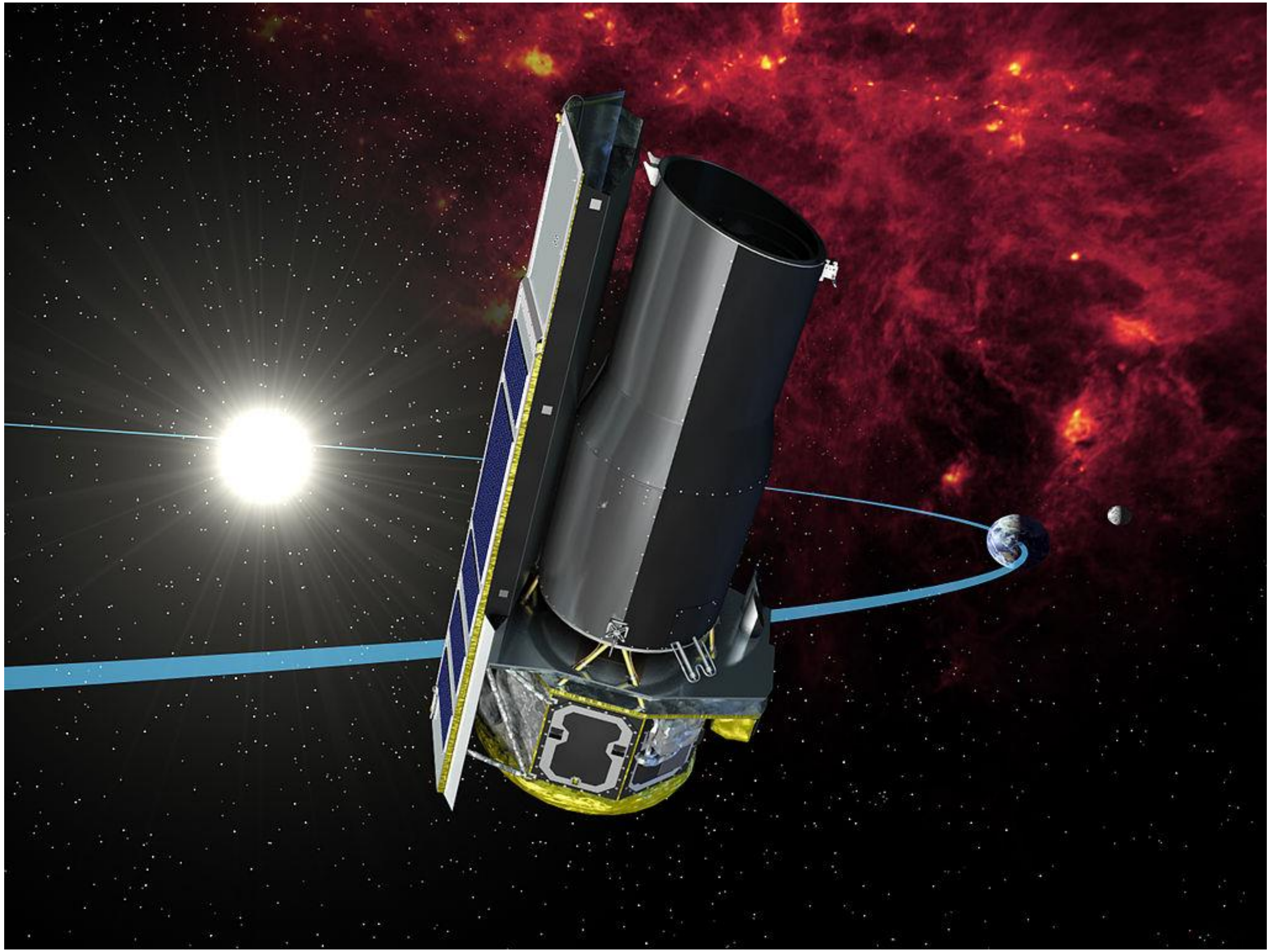
- Crystalline structure enables identification of components.
- ISO's observations link Earth, Comet Hale-Boop, young star, old star.
- Why are crystalline silicates not seen in the ISM?

Active galaxies



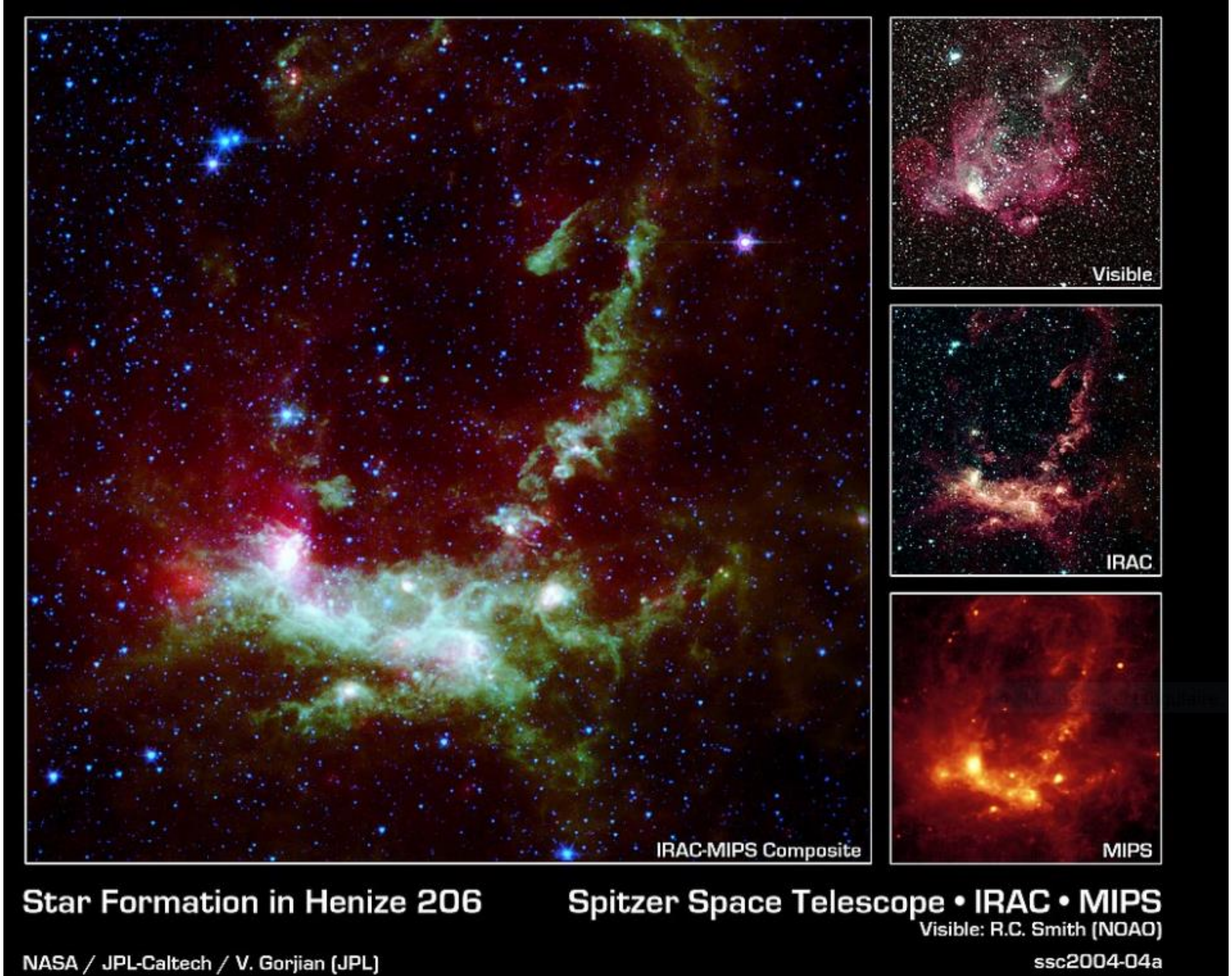
Markwick-Kemper et al.

SPITZER
2003



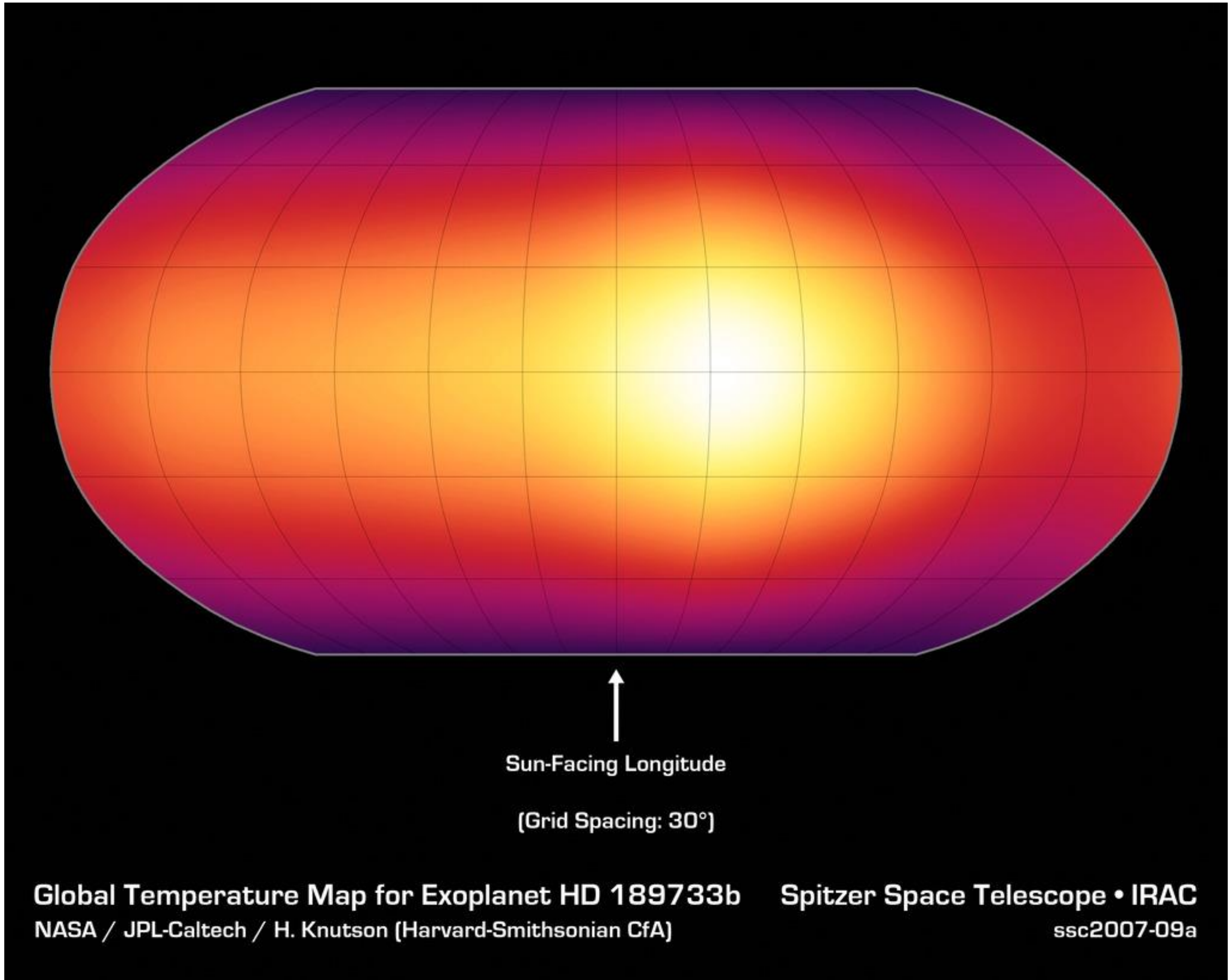
"SIRTF" Visit

1998

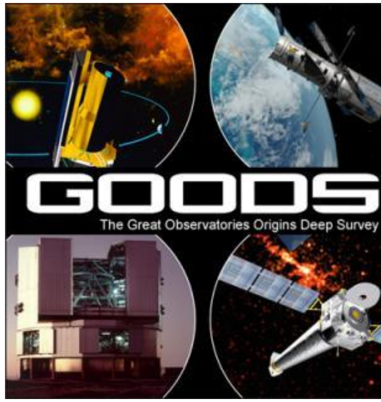

IRAC-MIPS Composite
Visible
IRAC
MIPS
Star Formation in Henize 206
Spitzer Space Telescope • IRAC • MIPS
Visible: R.C. Smith (NOAO)
NASA / JPL-Caltech / V. Gorjian (JPL)
ssc2004-04a

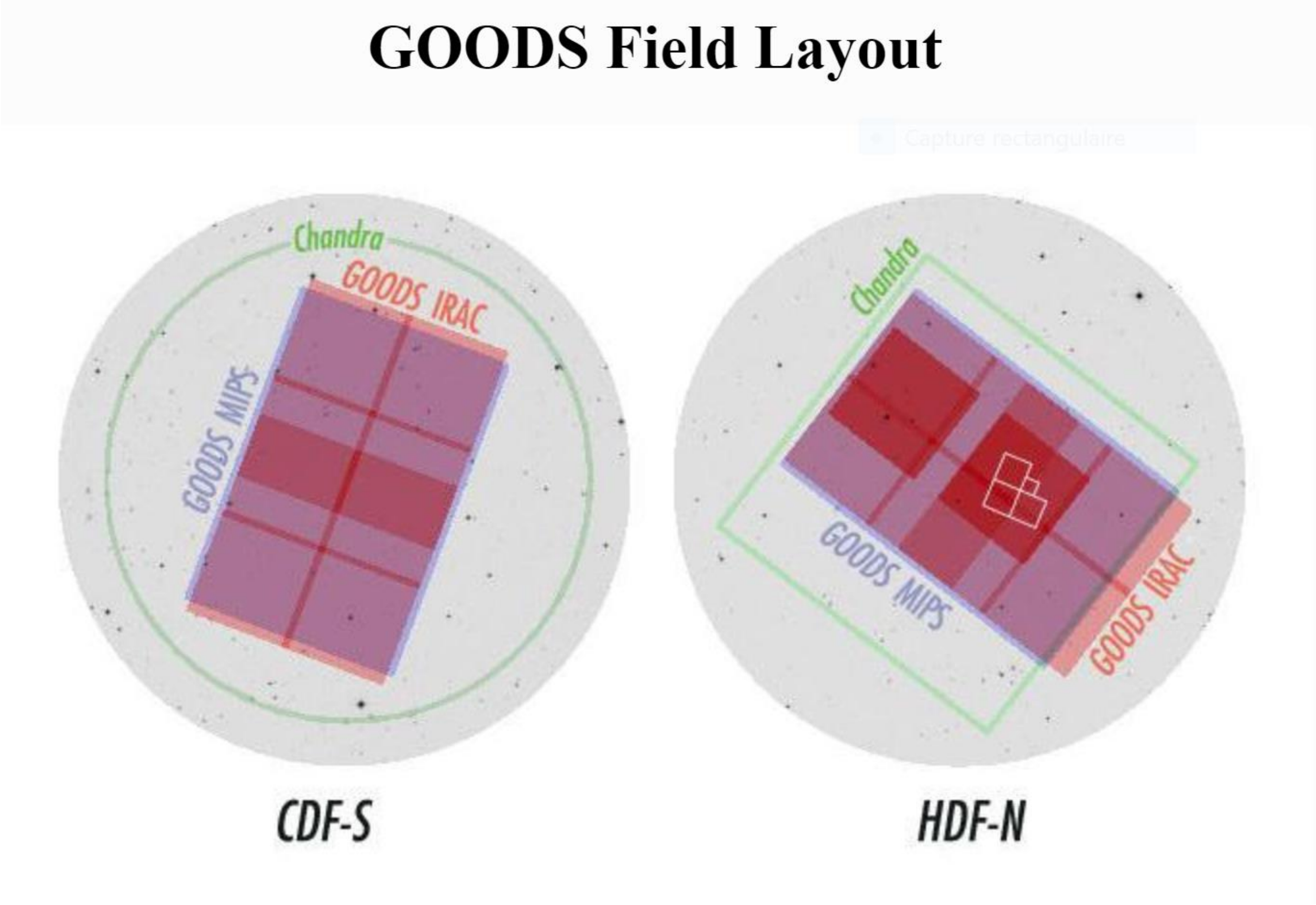

TRAPPIST-1 System
b
c
d
e
f
g
h
Illustration

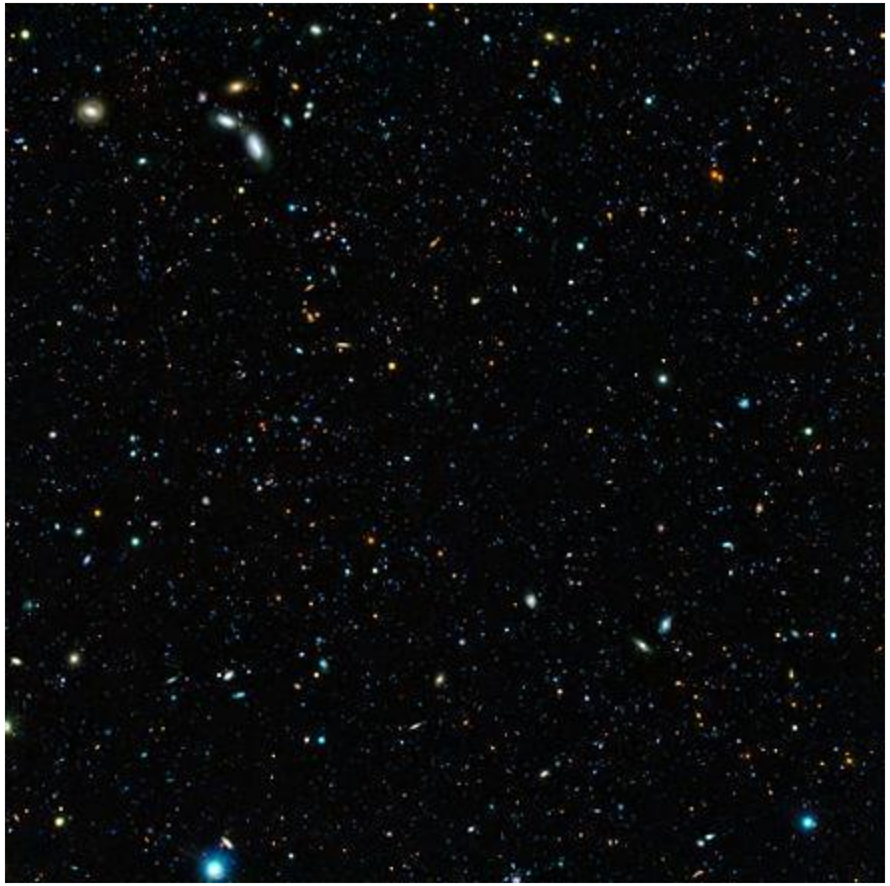
Atmospheres of exoplanets



The Great Observatories Origins Deep Survey
two fields of 10' by 16'



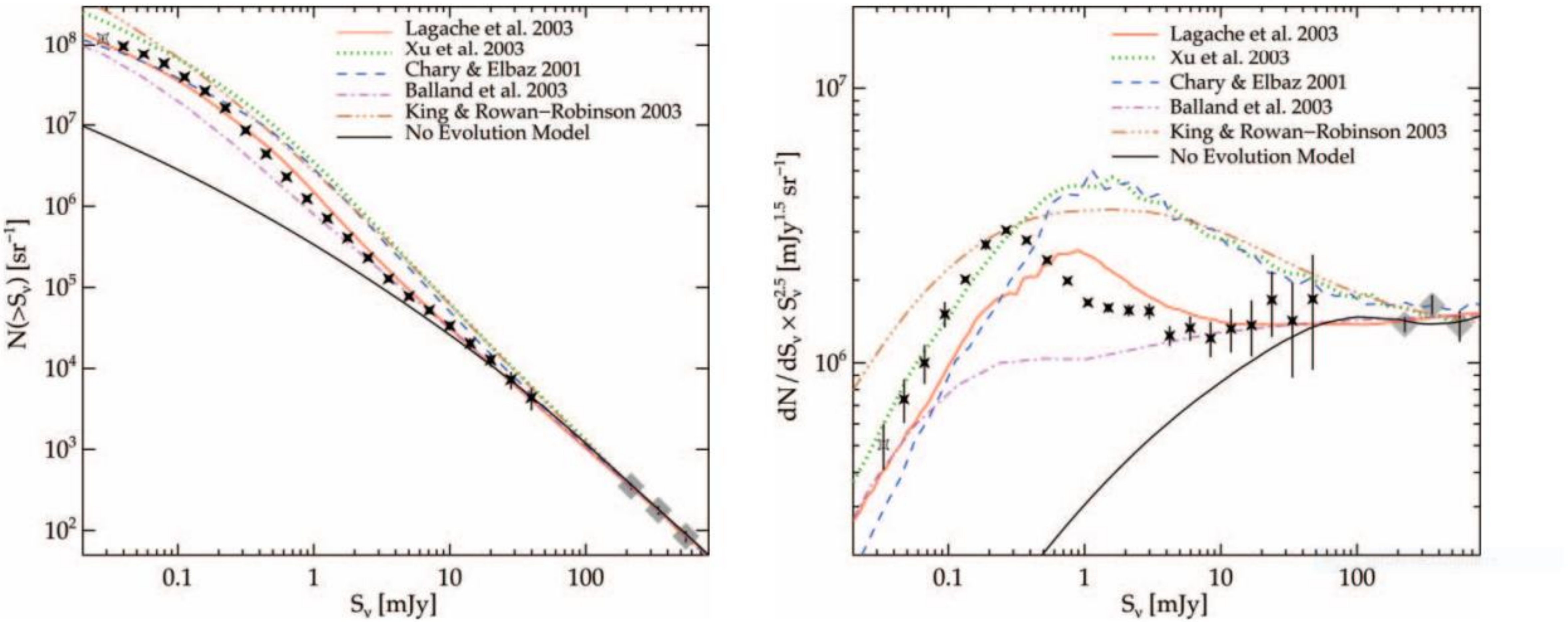




VLT Image over GOODS South

THE 24 MICRON SOURCE COUNTS IN DEEP SPITZER SPACE TELESCOPE SURVEYS , 2004

C. Papovich,2 H. Dole,3 E. Egami,2 E. Le Floc'h,2 P. G. Pe´rez-Gonza´lez,2 A. Alonso-Herrero,2, 4 L. Bai,2 C. A. Beichman,5 M. Blaylock,2 C. W. Engelbracht,2 K. D. Gordon,2 D. C. Hines,2, 6 K. A. Misselt,2 J. E. Morrison,2 J. Mould,7 J. Muzerolle,2 G. Neugebauer,2 P. L. Richards,8 G. H. Rieke,2 M. J. Rieke,2 J. R. Rigby,2 K. Y. L. Su,2 and E. T. Young2: **70% of 24μ background**



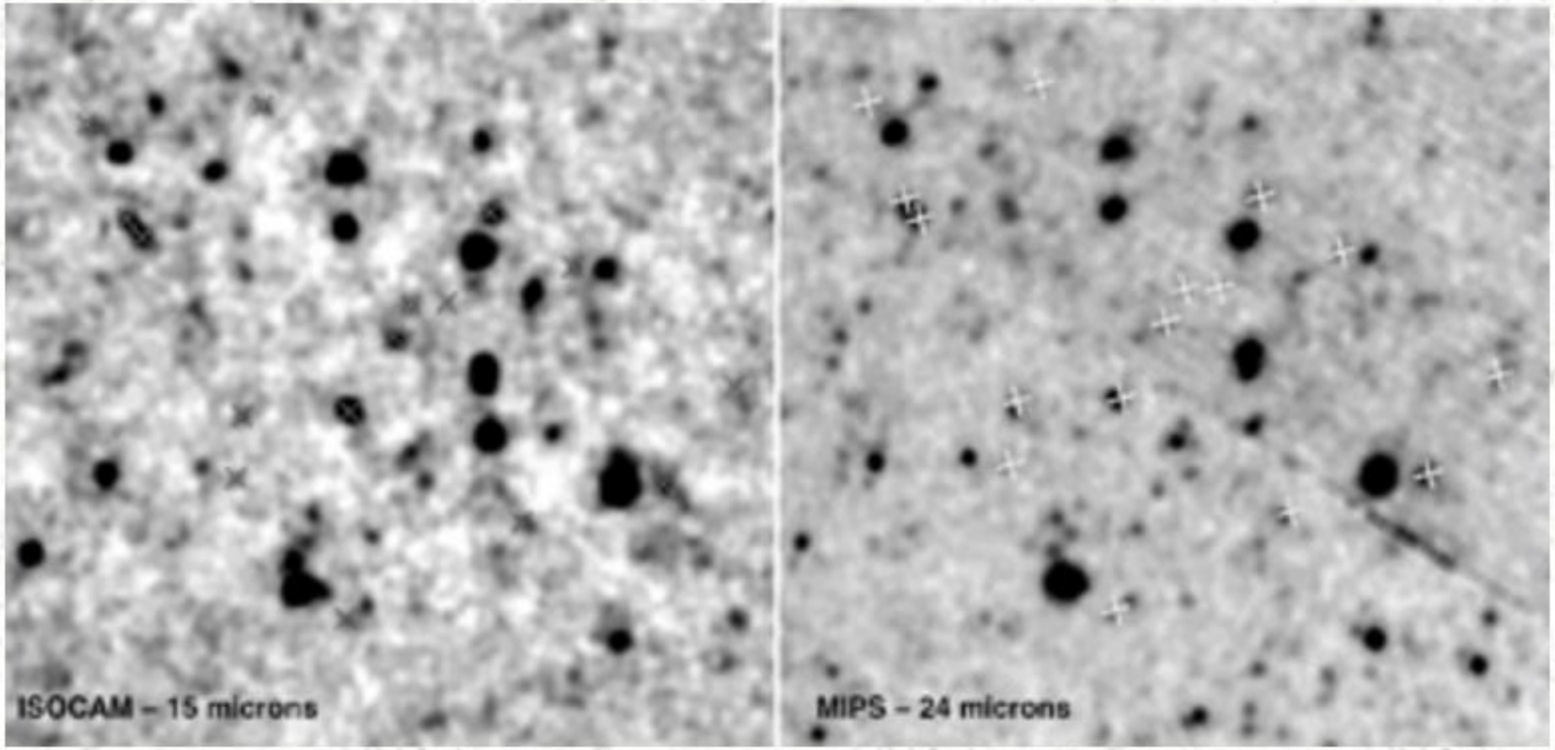


Figure 18. ISOCAM 15 μm image (left) of the Ultra-Deep Survey in the Marano FIRBACK field (depth 140μJy, 80% completeness) versus Spitzer MIPS-24 μm image (right; depth 110μJy, 80% completeness). The crosses identify 16 galaxies detected at 15 and 24 μm for which VLT-FORS2 spectra were obtained and which SEDs were fitted in Elbaz *et al.* (2004).

Main sequence, and
THE LESSER ROLE OF STARBURSTS FOR STAR FORMATION AT z = 2

G. Rodighiero et al. 2011

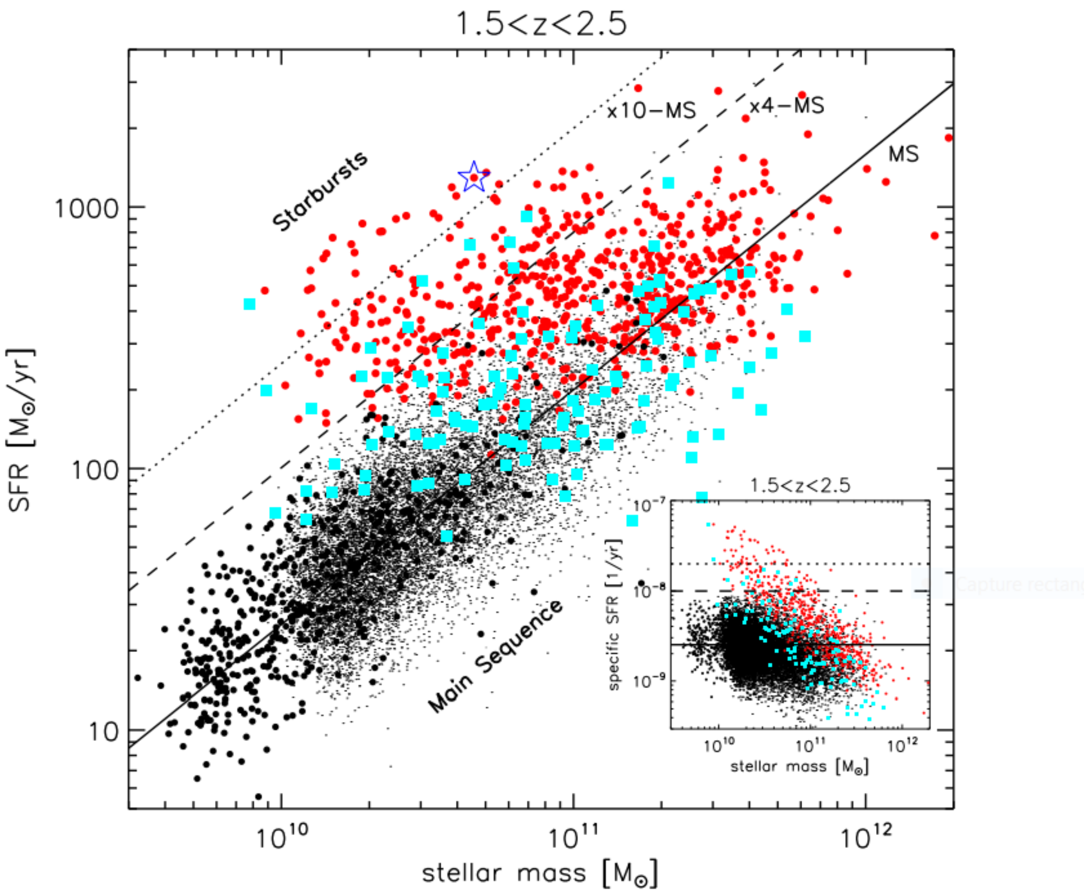
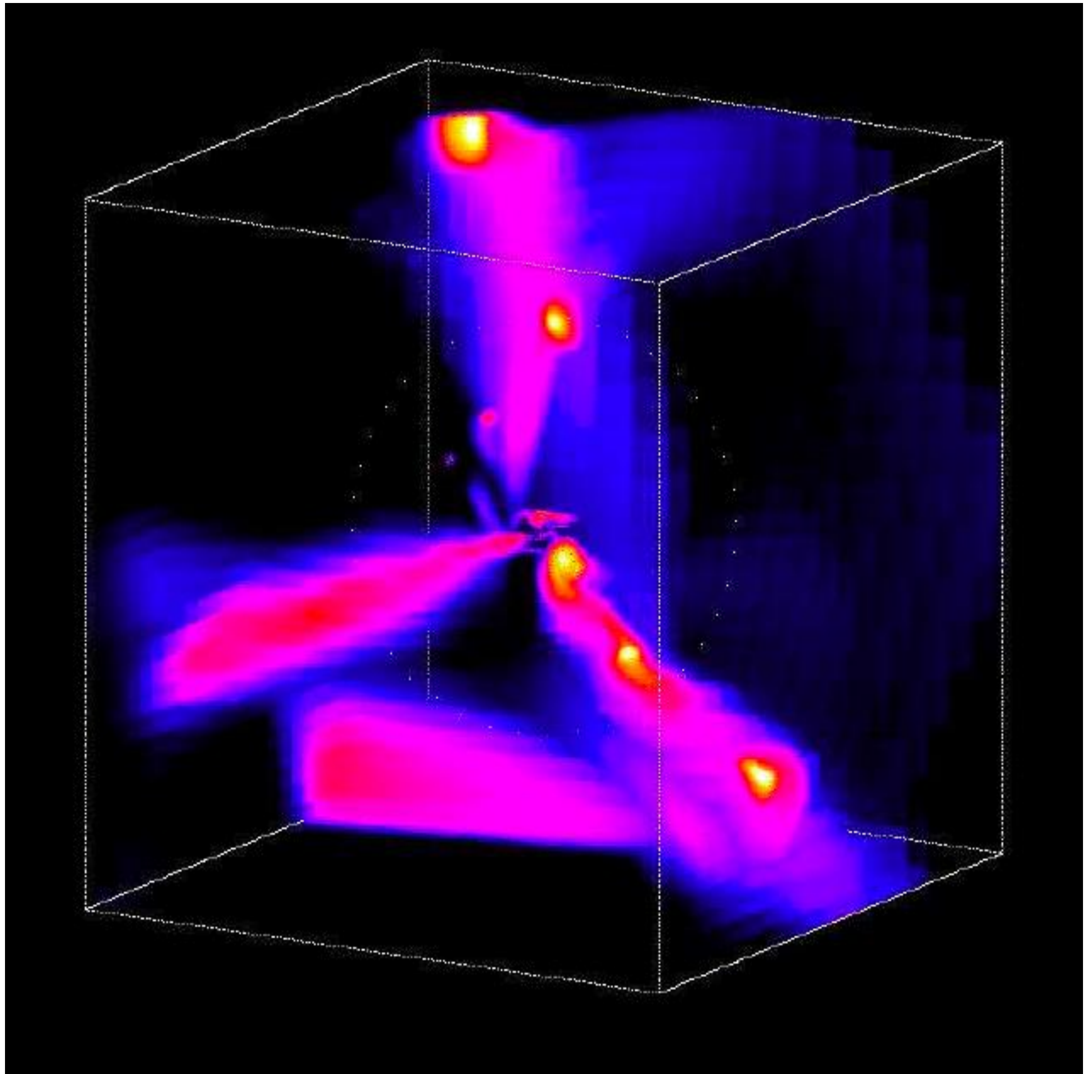


Figure 1. Stellar mass – Star Formation Rate relation at $1.5 < z < 2.5$. We use four main samples: the "shallow" PACS-COSMOS sources (red filled circles), the deeper PACS-GOODS South (cyan squares), the BzK-GOODS sample (black filled circles) and the BzK-COSMOS sources (black dots). The solid black line indicates the main sequence (MS) for star-forming galaxies at $z \sim 2$ defined by Daddi et al. (2007), while the dotted and dashed lines mark the loci 10 and 4 times above the MS (along the SFR axis), respectively. The star indicates the PACS source detected by Aztec at 1.1mm in the COSMOS field. In the smaller inset, we show the same information as in the main panel, however here the stellar mass is presented as a function of the SSFR.

Toward a paradigm shift in galaxy formation/evolution: Cold streams in early massive hot haloes as the main mode of galaxy formation

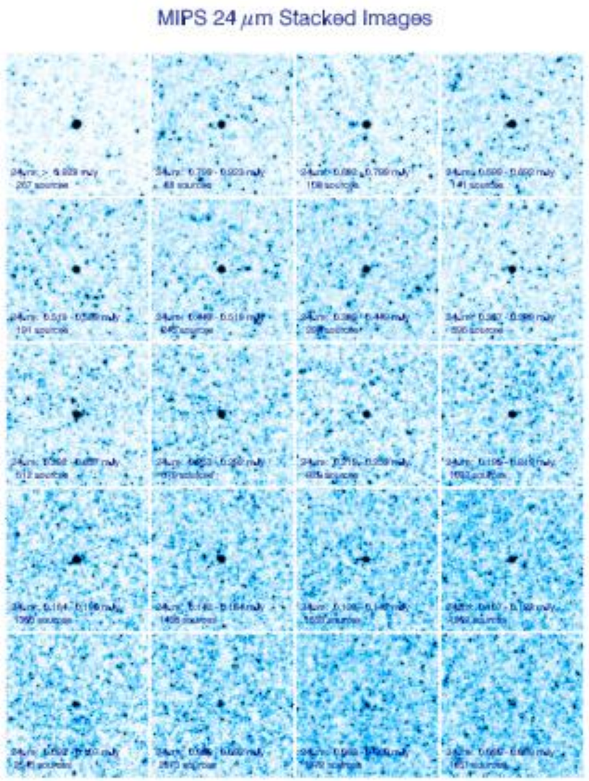


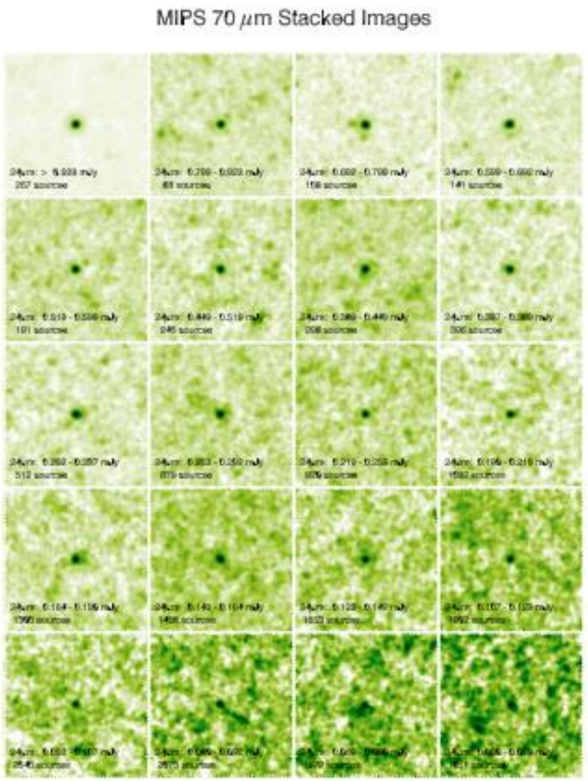
Cold gas stream feeds
high-z massive galaxies:
Shown in 3 dimensions
(box of side length 320 kpc

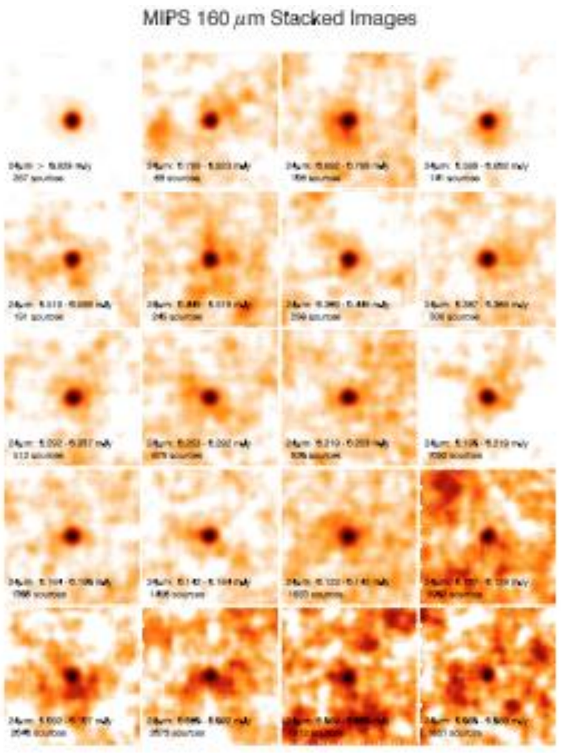
Dekel et al 2009 Nature

The cosmic infrared background resolved by Spitzer, 2006
(stacking of FIR sources on 24 µ sources)

H. Dole, G. Lagache, J.-L. Puget, K. I. Caputi, N. Fernández-Conde , E. Le Floc'h, C. Papovich, P. G. Pérez-González, G. H. Rieke, and M. Blaylock







Mid-Infrared (MIR) 24 µm selected sources contribute to more than 70% of the Cosmic Infrared Background (CIB) at 70 and 160 µm

Herschel - Key dates and figures

- **FIRST Proposal submitted to ESA in November 1982**: ***Far Infrared and Submillimeter Space Telescope***’, *a* **‘High Throughput Heterodyne Spectroscopy**
- **1986: Segovia meeting conclusions and recommendation a telescope with an 8 m aperture** coherent (heterodyne) spectroscopy up to [CII] line (157 um), non-coherent (direct detection) spectroscopy and imaging

1990-91: FIRST System Definition Study (SDS)

  - baseline 4.5 m telescope, 8 m telescope dead.

- .Finally FIRST became Herschel, cornerstone of the ESA programme Horizon 2000, with a 3.5m mirror in SiC.
- Wavelength domain 60-600 μm
- Three instruments:
  - HIFI: High resolution heterodyne spectroscopy.
  - SPIRE: bolometer imaging and spectro-imaging.
  - PACS: bolometer imaging and photoconductor spectro-imaging.
- **It was launched with Planck in 2009, lasted until 2013**

What Does Herschel Add?

- Large telescope
  - 3.5 m diameter
  - collecting area and resolution
- New spectral window
  - 55-672 µm: bridging the far infrared & submillimetre – the ‘cool’ universe
- Novel instruments
  - wide area mapping in 6 ‘colours’
  - imaging spectroscopy
  - very high resolution heterodyne spectroscopy
- Power to study
  - galaxy evolution over cosmic time
  - star formation near and far
  - interstellar medium physics/chemistry
  - our own solar system

SPIRE

SPIRE – Spectral and Photometric Imaging Receiver

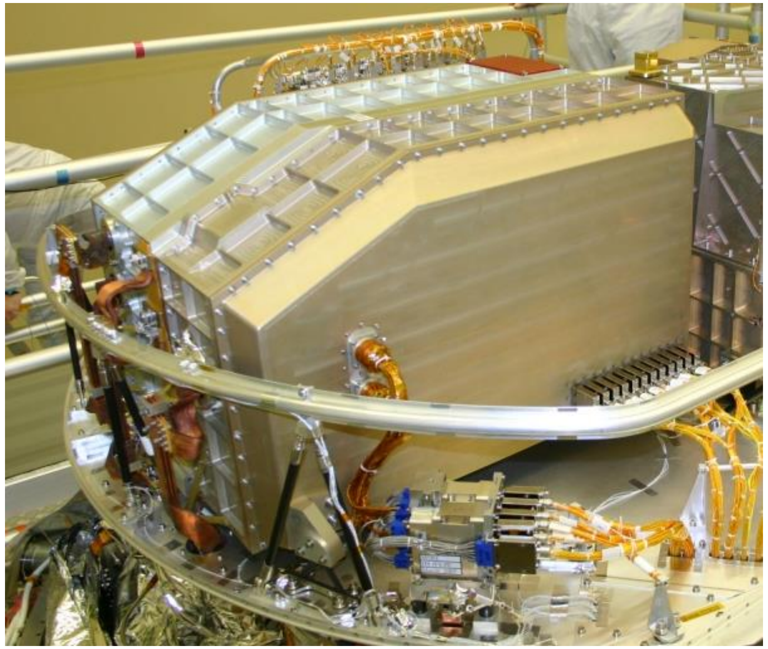
- **PI: Matt Griffin, U Cardiff, Cardiff, United Kingdom**
- **Co-PI: Laurent Vigroux, CEA, Saclay, France**
- **Imaging photometry and spectro-photometry/-scopy over 194-672 µm**
- **3 bolometer arrays for photometry, 2 bolometer arrays for spectroscopy**

3-band imaging photometer

- **250, 350, 500 µm (simultaneous)**
- $\lambda/\Delta\lambda \sim 3$
- **4 x 8 arcminute field of view**
- **Diffraction limited beams (17, 24, 35")**

Imaging Fourier Transf. Spectrometer

- **194 - 324, 316 - 672 µm**
- **2.6 arcminute field of view**
- $\Delta\sigma = 0.04 - 2\ cm^{-1}$ ($\lambda/\Delta\lambda \sim 20 - 1000$ at 250 µm)



PACS

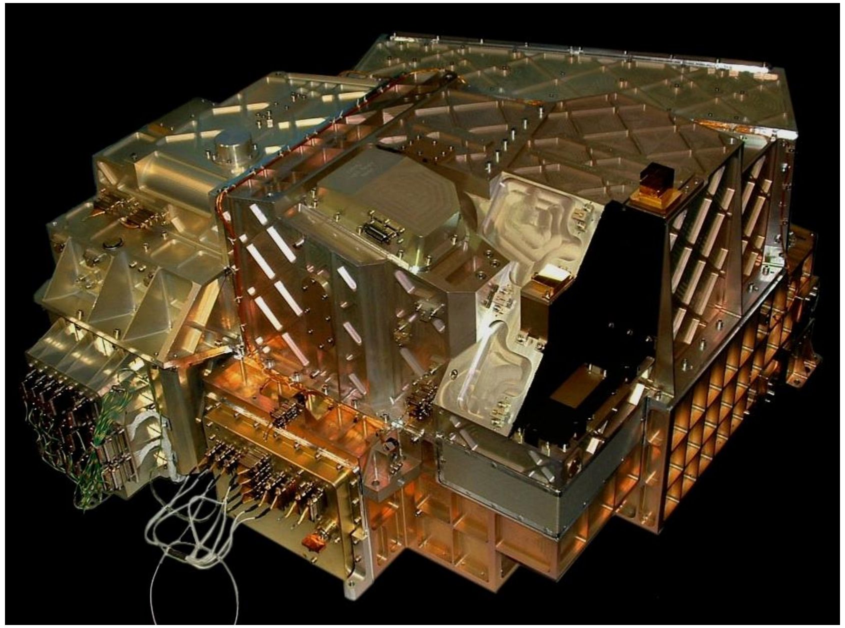
PACS – Photodetector Array Camera and Spectrometer

- PI: Albrecht Poglitsch, MPE, Garching, Germany
- Co-PI: Christoffel Waelkens, KU Leuven, Belgium
- Imaging photometry and spectroscopy over 55-210 µm
- 2 bolometer arrays for photometry, 2 Ge:Ga arrays for spectroscopy

3-band imaging photometer

λ (µm)	70	100	160
FWHM (arcsec)	6	8	12
λ/Δλ	2.5	2.8	2.1

- Simultaneous obs at 70/100 & 160 µm
- 3.5 x 1.75 arcmin fully sampled FOV

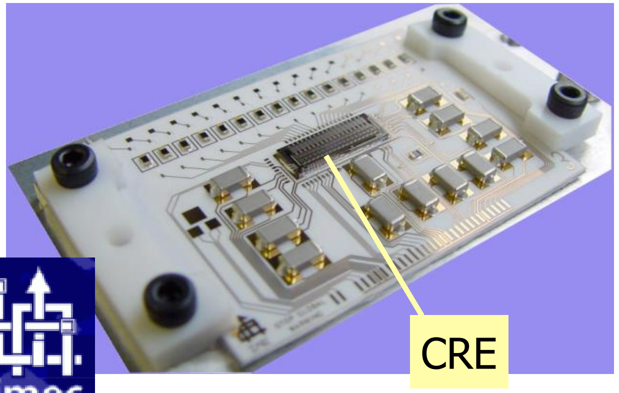


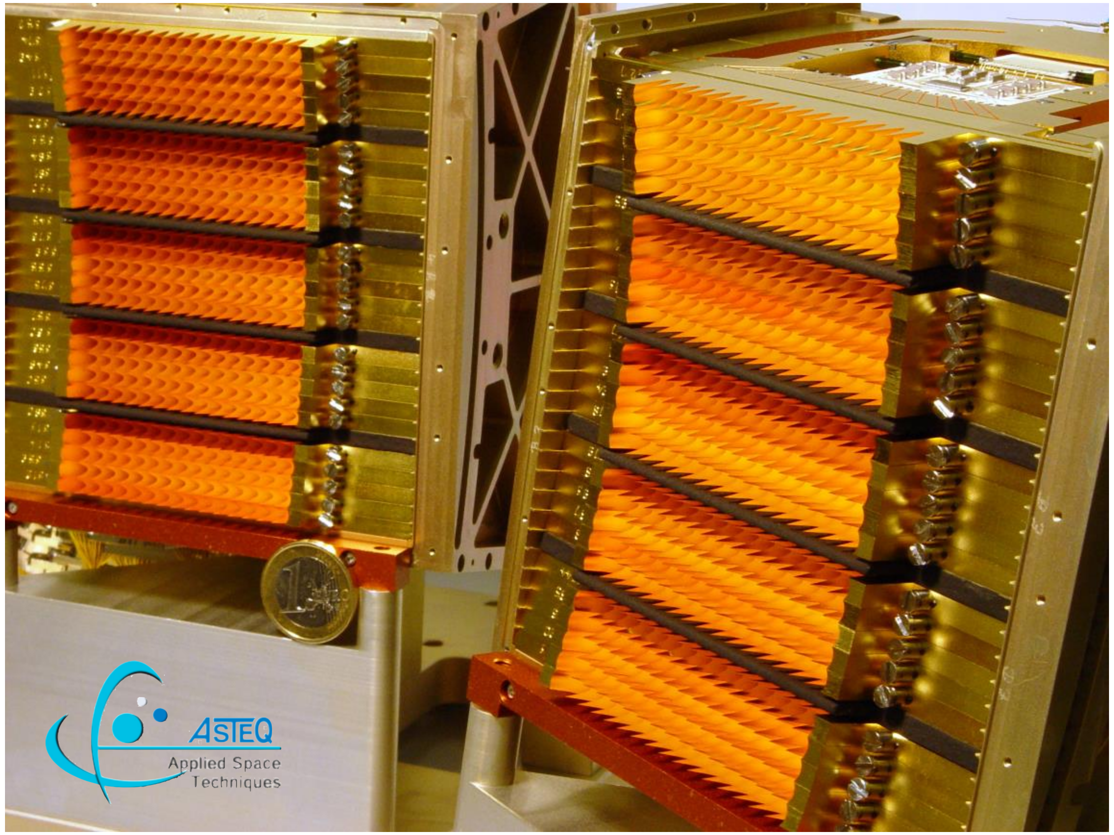
Imaging grating spectrometer

- FOV (arcmin) fully sampled 0.8’ x 0.8’
- λ order 1,2,3 102-210, 71-98, 55-73 µm
- λ/Δλ 1500-4000

PACS Photoconductor Arrays (Spectrometer)

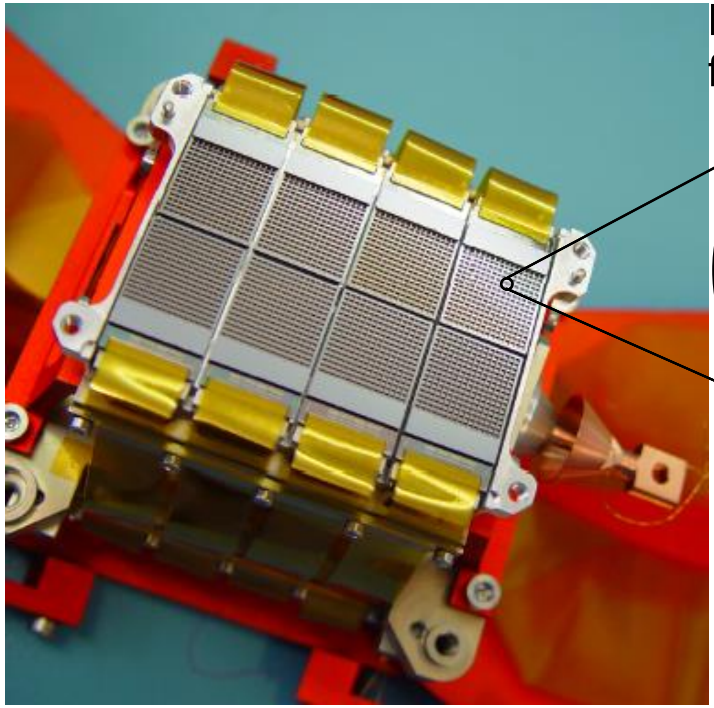
- Two 25x16 pixel filled arrays
- Extrinsic photoconductors (Ge:Ga, stressed/unstressed)
- Integrated cryogenic readout electronics (CRE)
- Near-background-noise limited performance



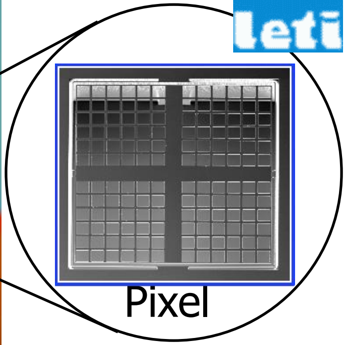


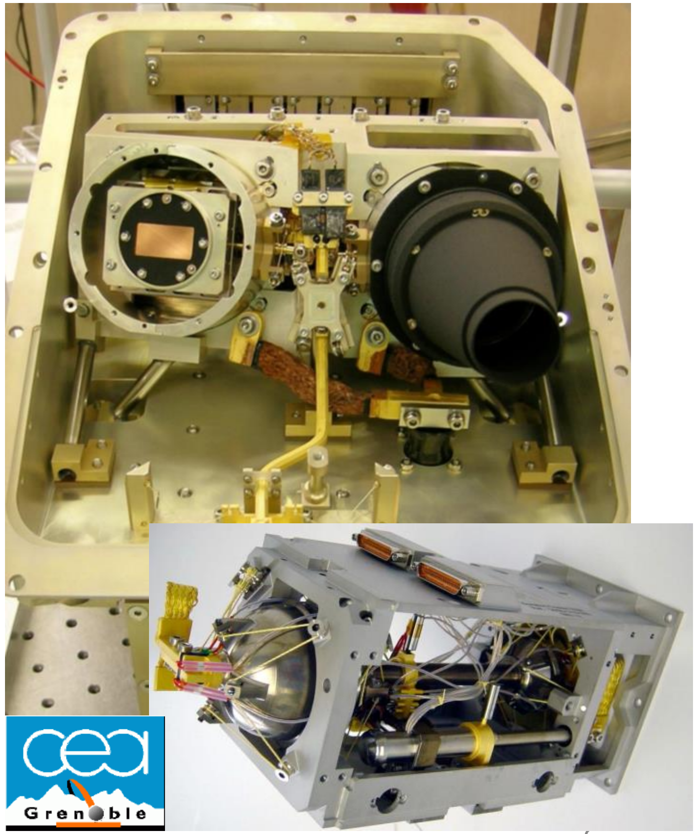
PACS Bolometer Arrays (Photometer)

- Two filled arrays: 64x32 pixels (blue) and 32x16 pixels (red)
- Bolometers and multiplexing readout electronics operating at 0.3K
- Detector/readout noise comparable to background-noise (FM)
- Cooler hold time >60h



Blue focal plane





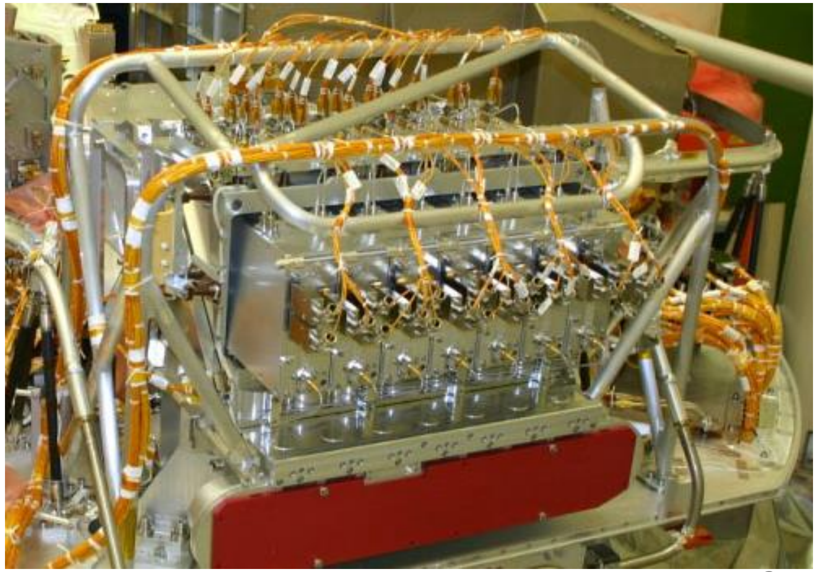
Photometer unit with blue + red focal planes and ^{3}He cooler

HIFI

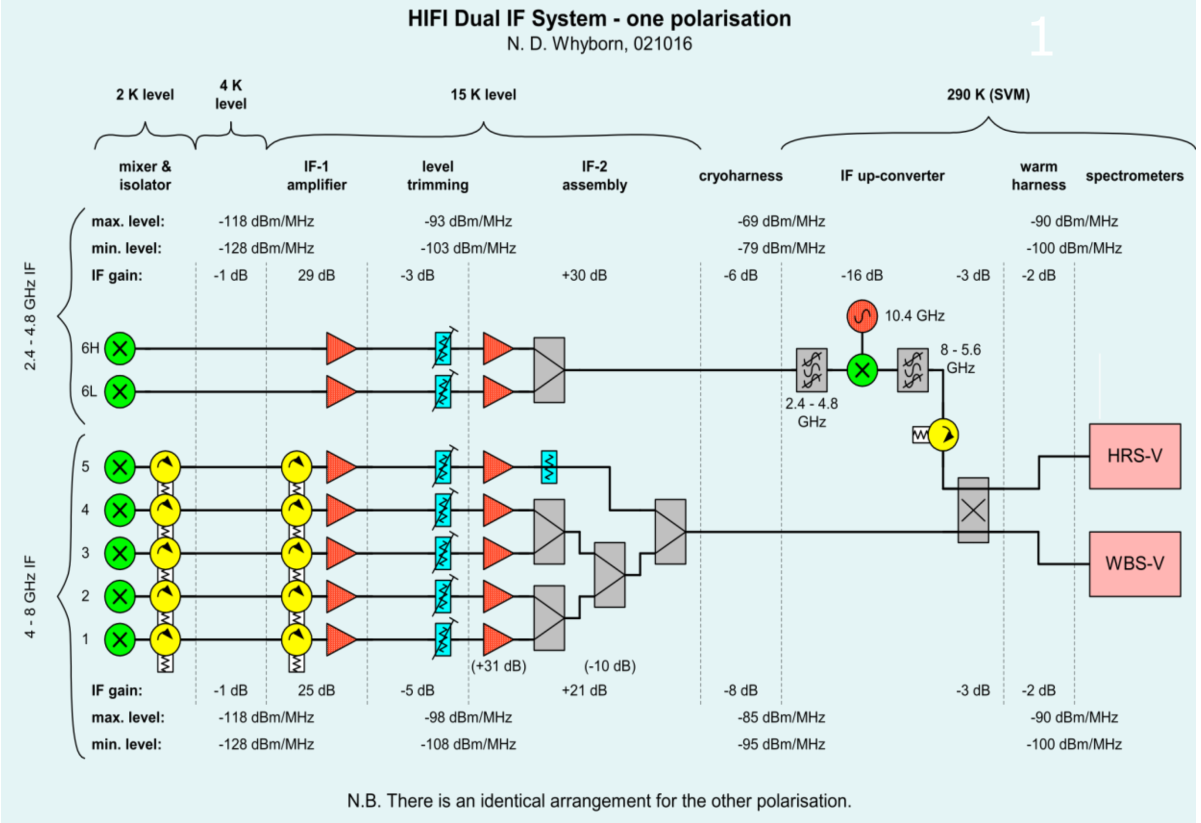
HIFI – Heterodyne Instrument for the Far Infrared

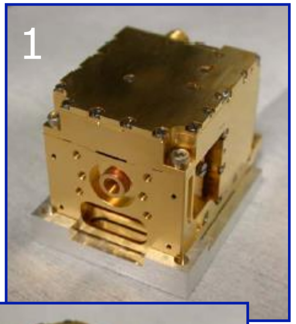
- **PI: Frank Helmich, SRON, Groningen, The Netherlands**
- **Co-PIs: Tom Phillips, Caltech, USA; Jürgen Stutzki, U Köln, Germany; Emmanuel Caux, CESR, France; and Thijs de Graauw, SRON**
- **Very high resolution spectroscopy over 480-1250 and 1410-1910 GHz**
- **SIS and HEB mixers, auto-correlator and AOS spectrometers**

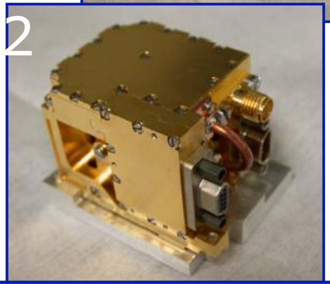
- **Seven-channel heterodyne**
- **Single pixel on sky (non-imaging)**
- **Frequency coverage:**
  - **480 - 1250 GHz (625 - 240 μm)**
  - **1410 - 1910 GHz (212 - 157 μm)**
- **Frequency res. 140 kHz - 1 MHz**
  - **AOS & autocorrelator spectrom.**
- **Instantaneous IF BW: 4/2.4 GHz**
- **Beam FWHM 12”- 45”**

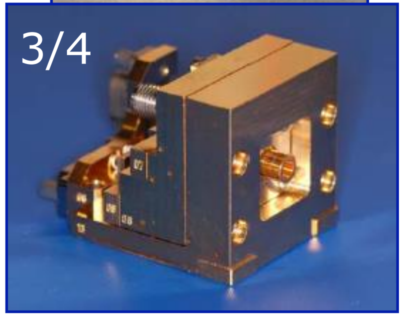


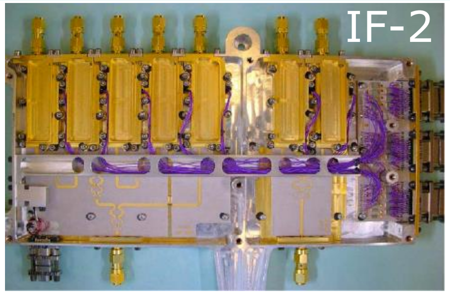
HIFI Signal Chain: Mixers and Amplifiers

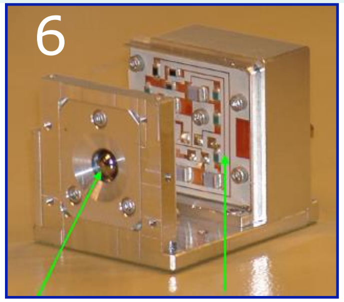




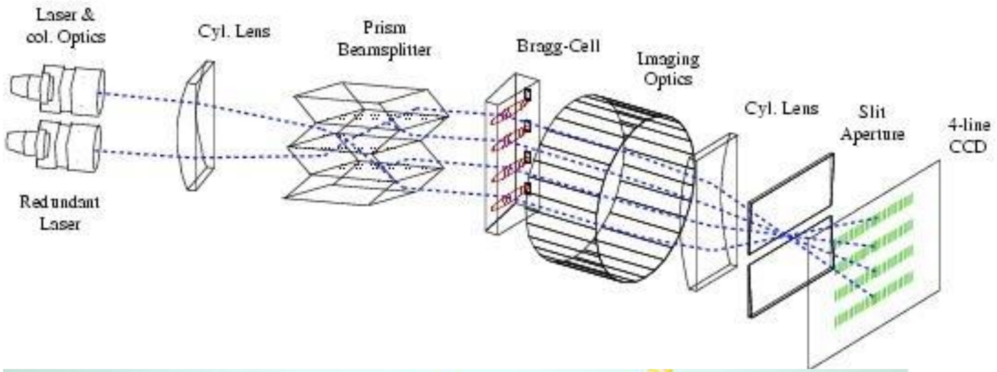


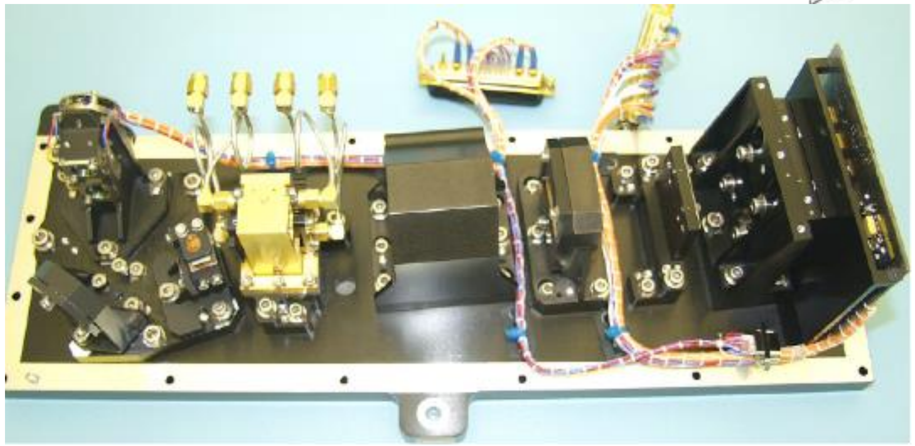






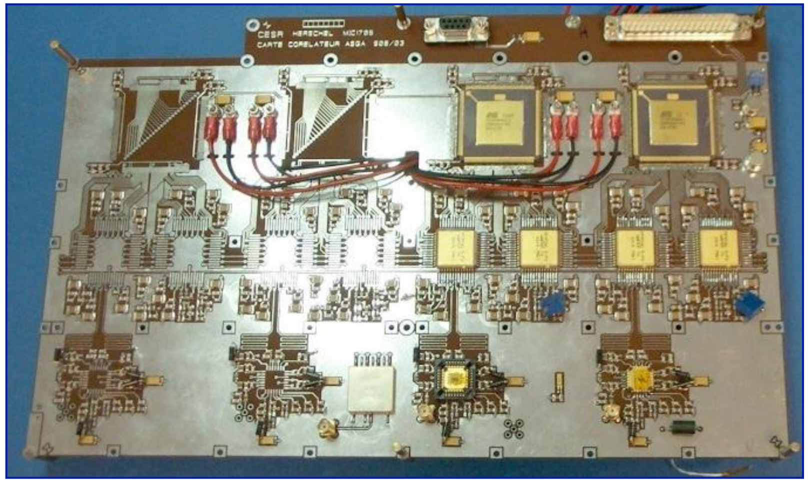
HIFI Signal Chain: Back-End Spectrometers





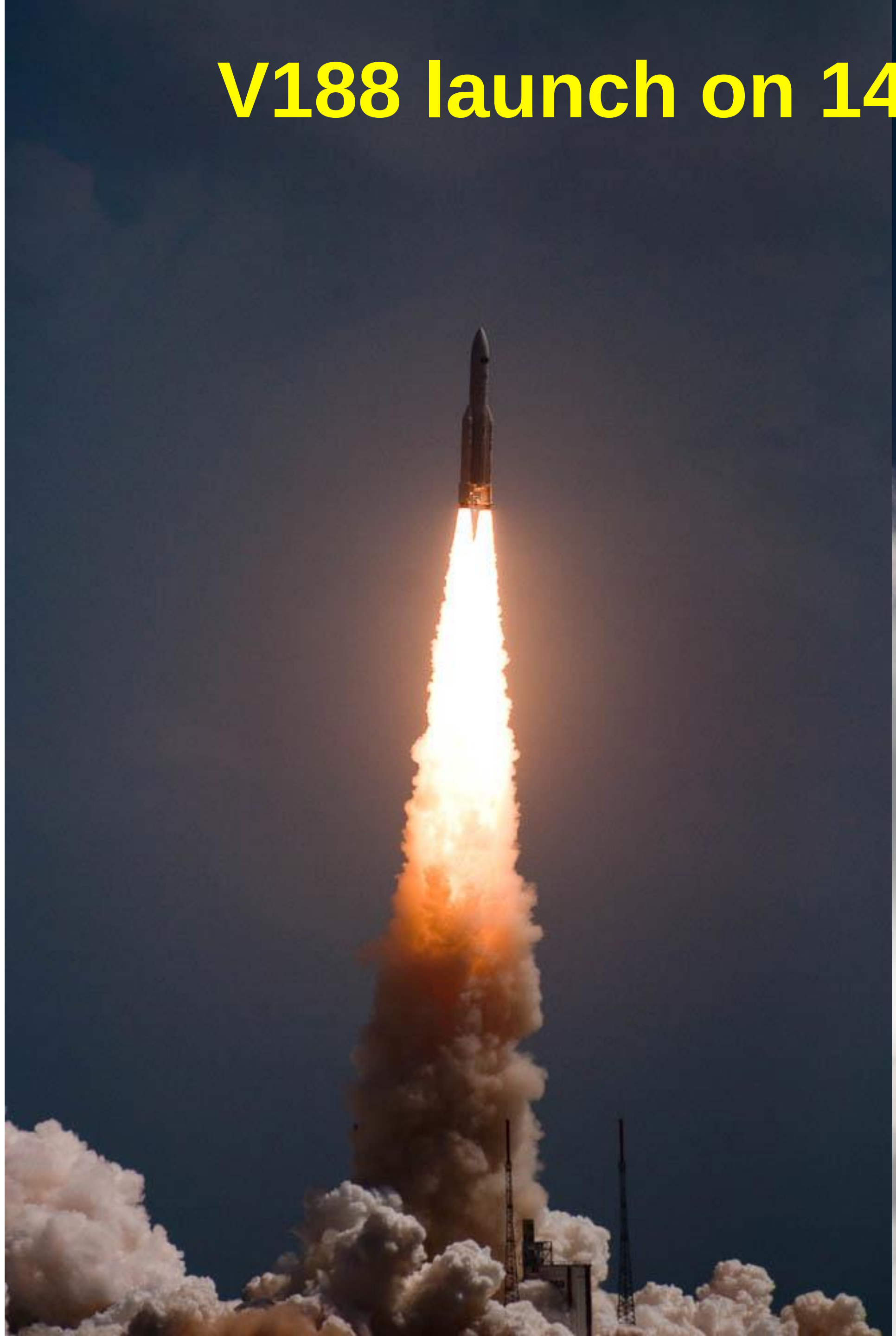
Source module | Bragg-cell | Imaging optics | Cyl. lens | CCD

WBS (acousto-optical) with 1.1 MHz resolution and 4GHz bandwidth



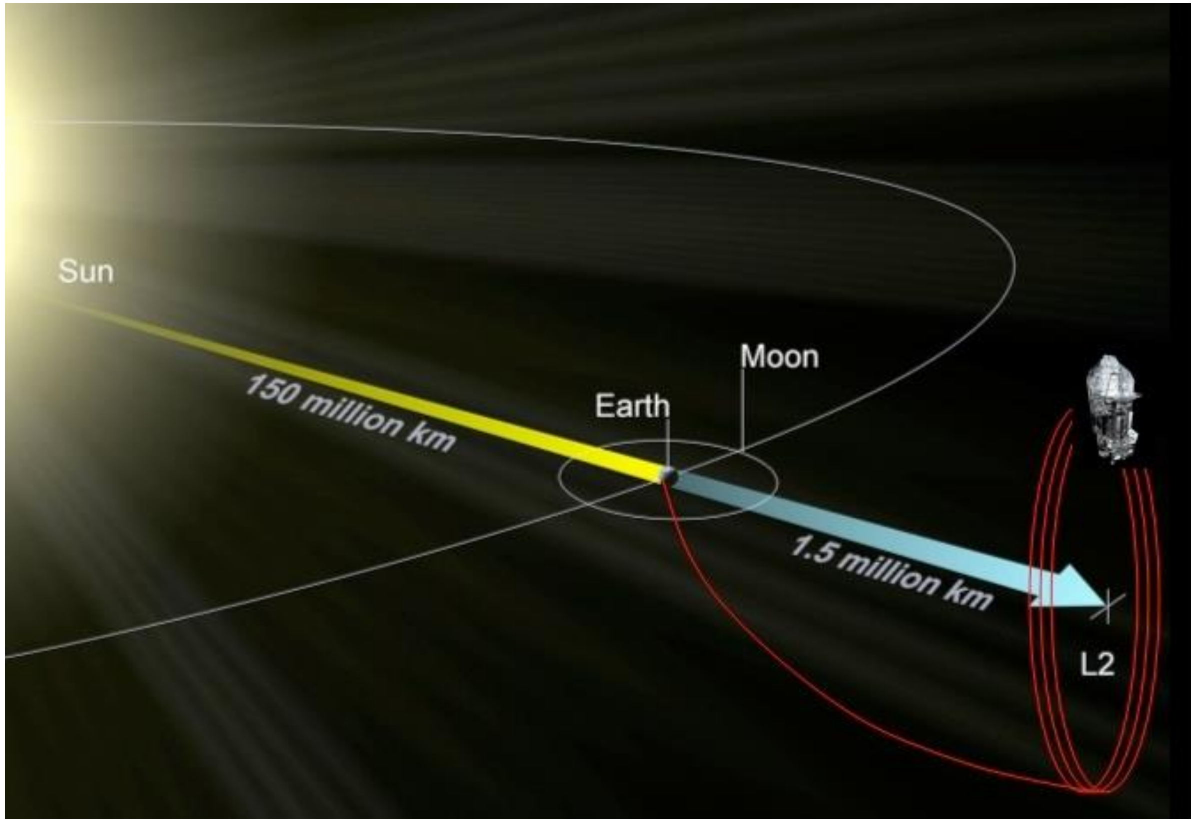
HRS (auto-correlator) with 0.125 MHz resolution and 0.25 GHz bandwidth

V188 launch on 14 May 2009

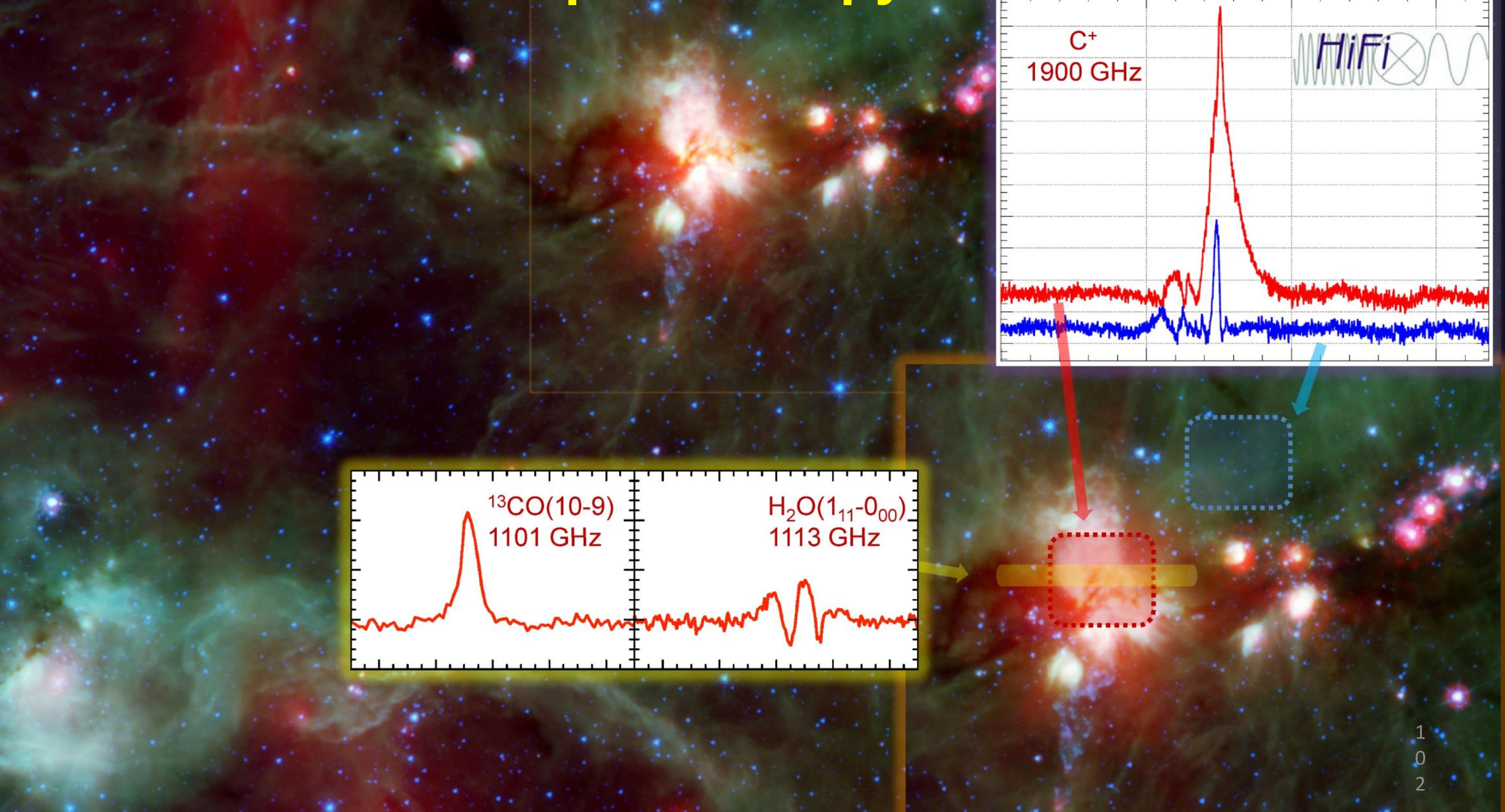


Operational Orbit around L2

- **Sun, Earth, and Moon in the 'same direction' in the sky**
  - **Thermally favourable and stable environment**
  - **Good access to the sky for observations**
  - **Avoid Earth's radiation belts**

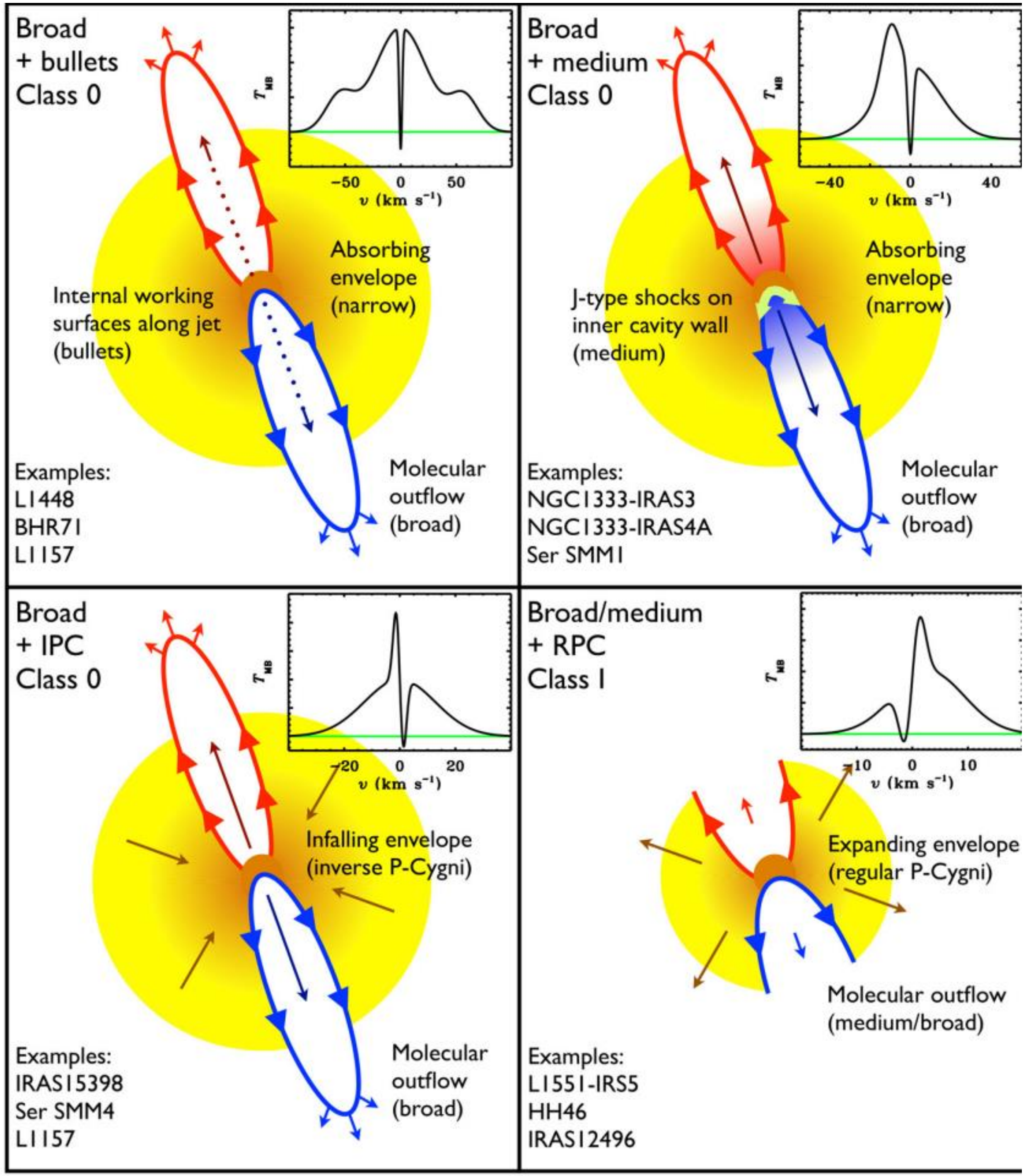


Herschel First Light:
HIFI THz Spectroscopy

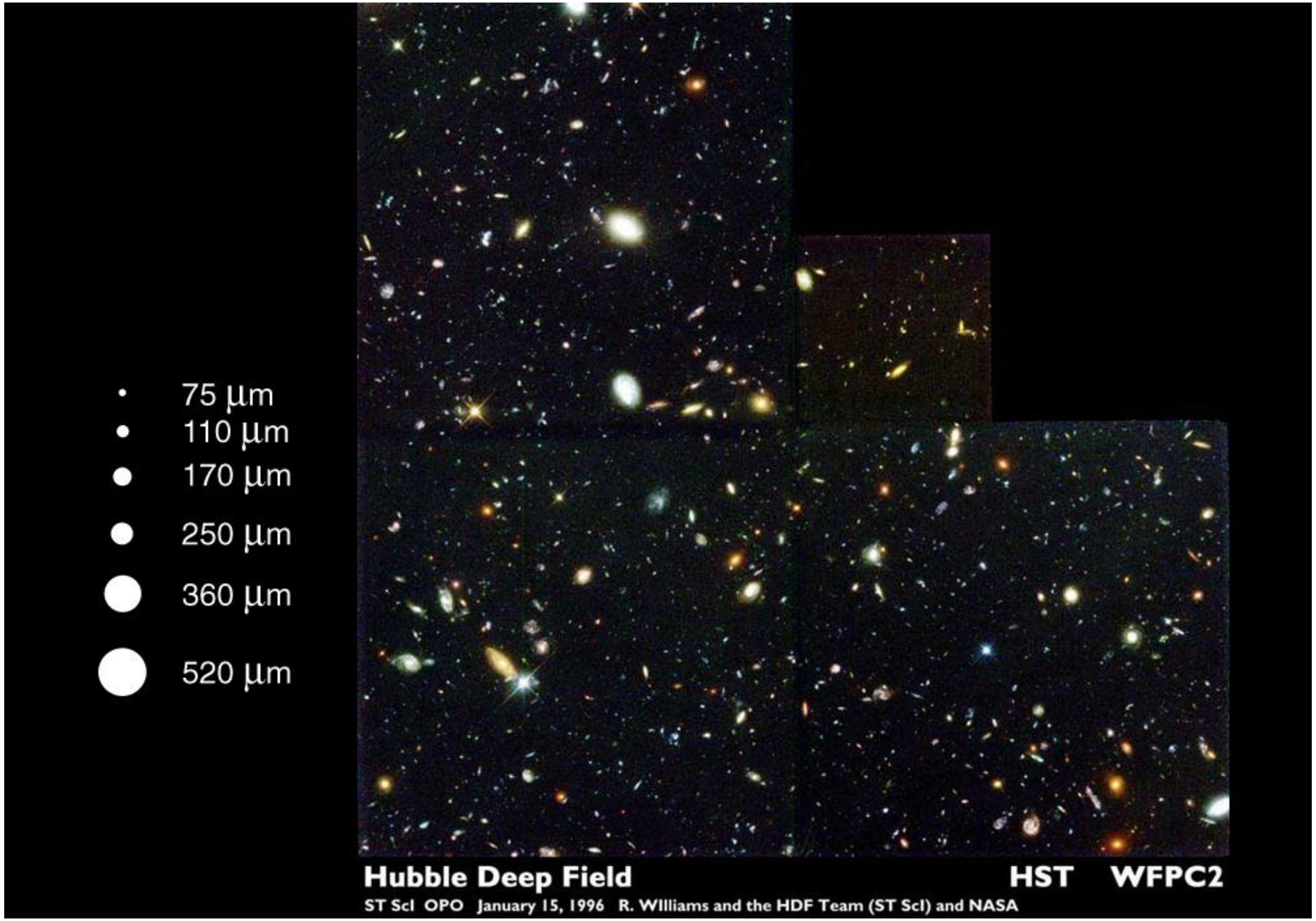


The different dynamical and energetic components in protostars directly traced by water emission

Kristensen et al. 2012

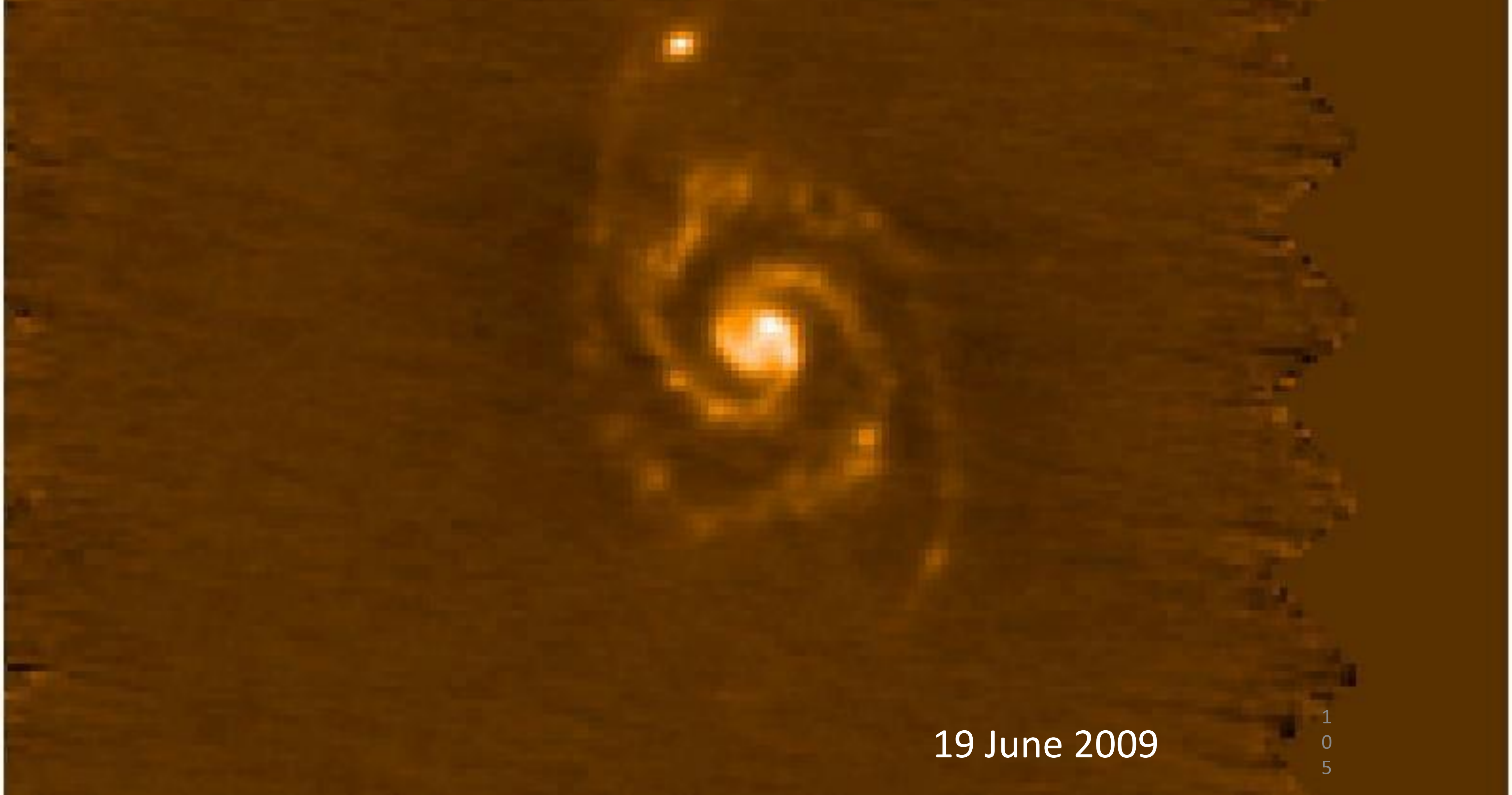


Angular Resolution

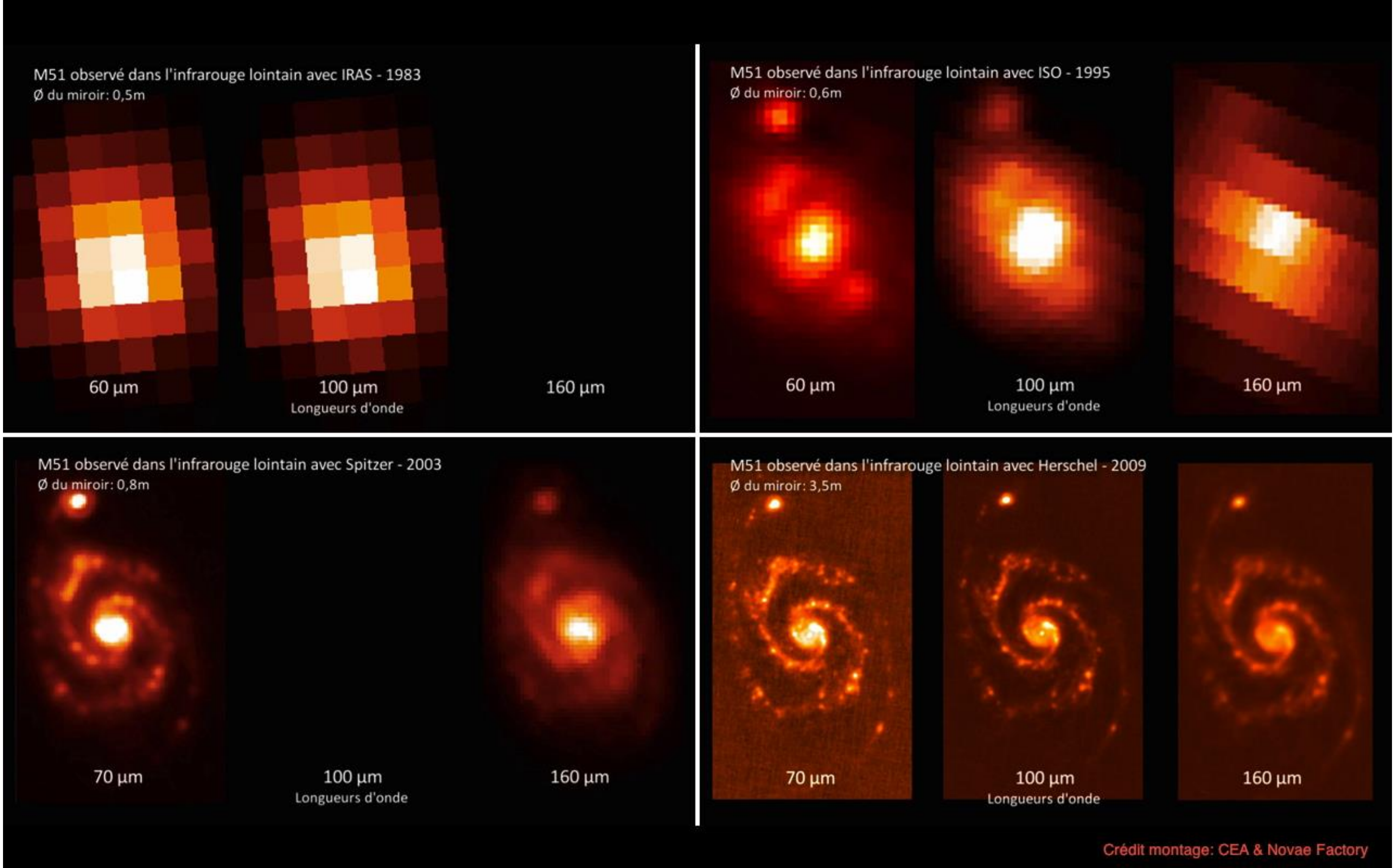


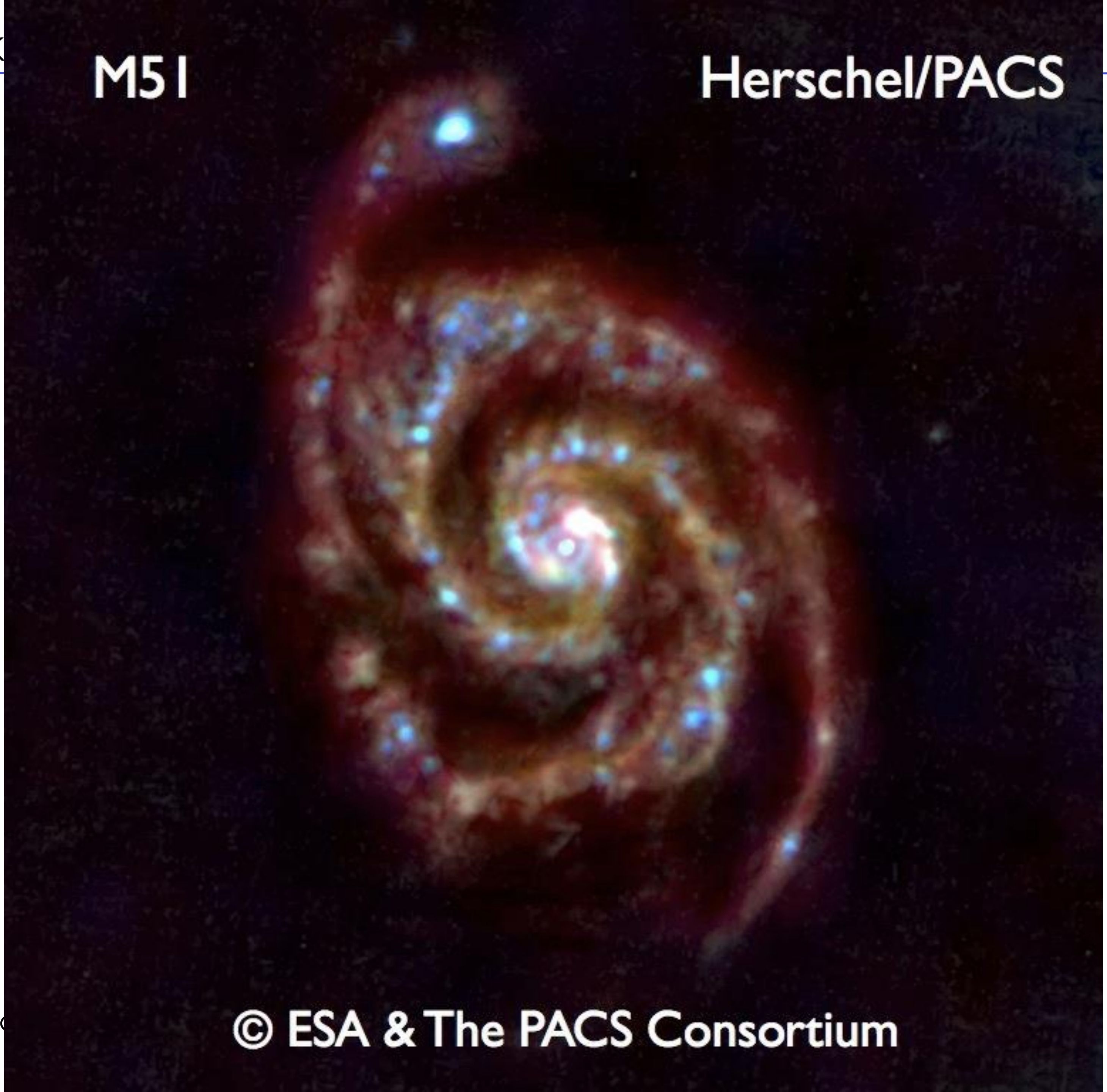
Sizes of the SPIRE and PACS beam sizes on the HDF north Field

First Results – M51 “Sneak Preview”

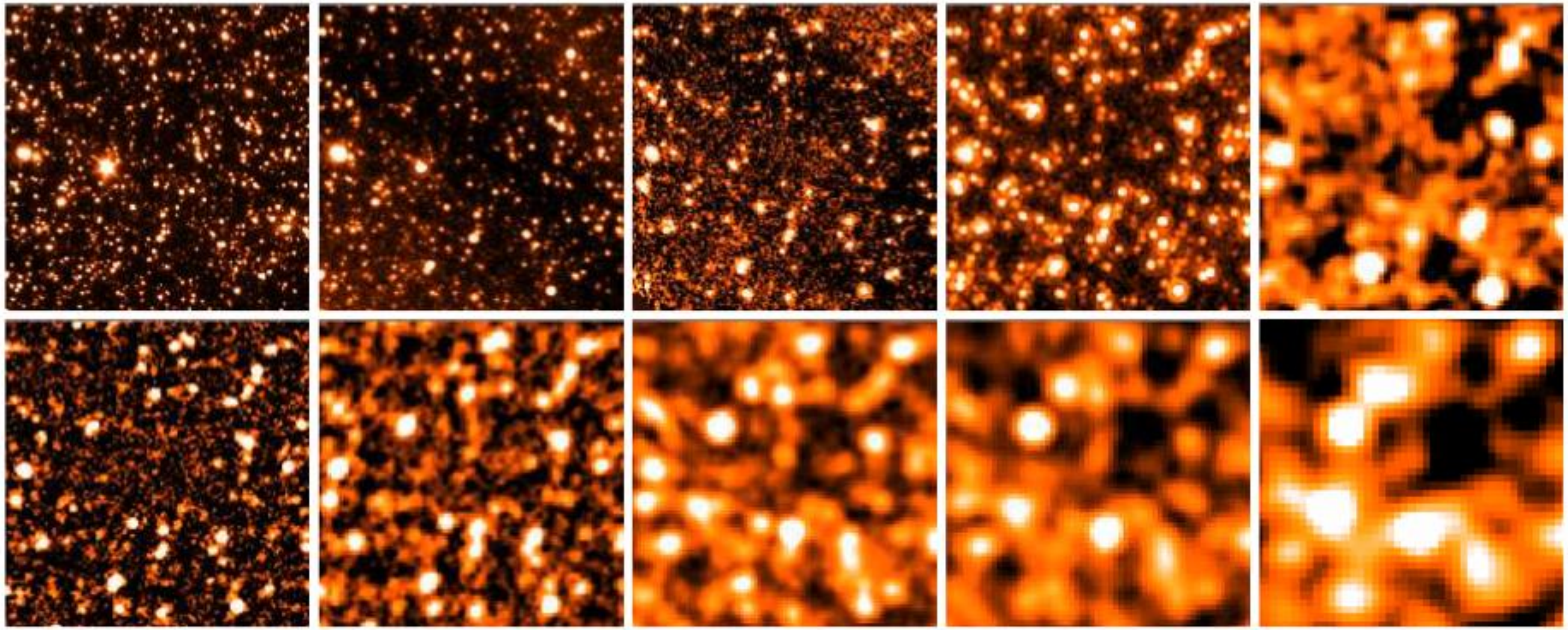


19 June 2009


M51 observé dans l'infrarouge lointain avec IRAS - 1983
Ø du miroir: 0,5m
60 µm
100 µm
Longueurs d'onde
160 µm
M51 observé dans l'infrarouge lointain avec ISO - 1995
Ø du miroir: 0,6m
60 µm
100 µm
Longueurs d'onde
160 µm
M51 observé dans l'infrarouge lointain avec Spitzer - 2003
Ø du miroir: 0,8m
70 µm
100 µm
Longueurs d'onde
160 µm
M51 observé dans l'infrarouge lointain avec Herschel - 2009
Ø du miroir: 3,5m
70 µm
100 µm
Longueurs d'onde
160 µm
Crédit montage: CEA & Novae Factory



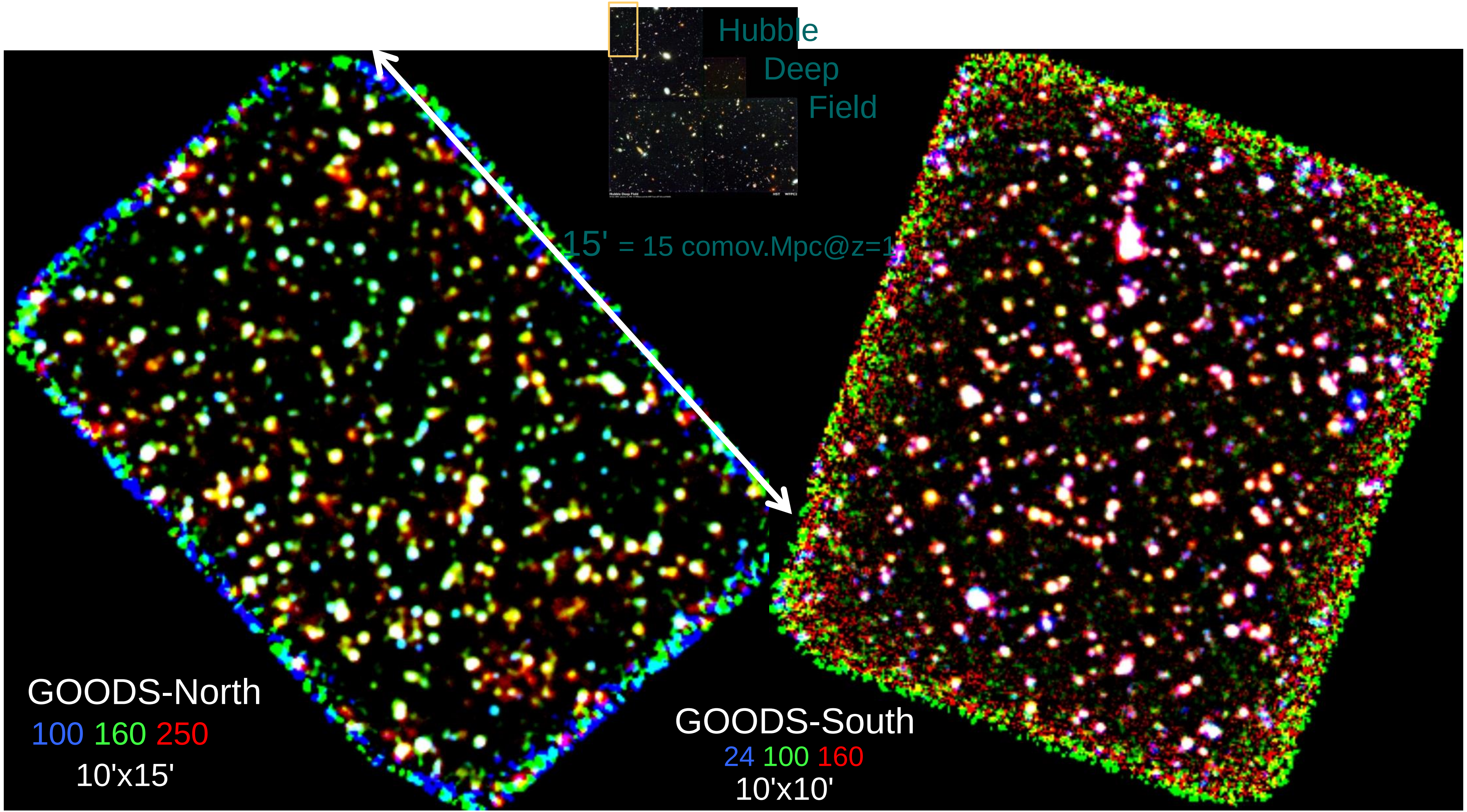
Hers...

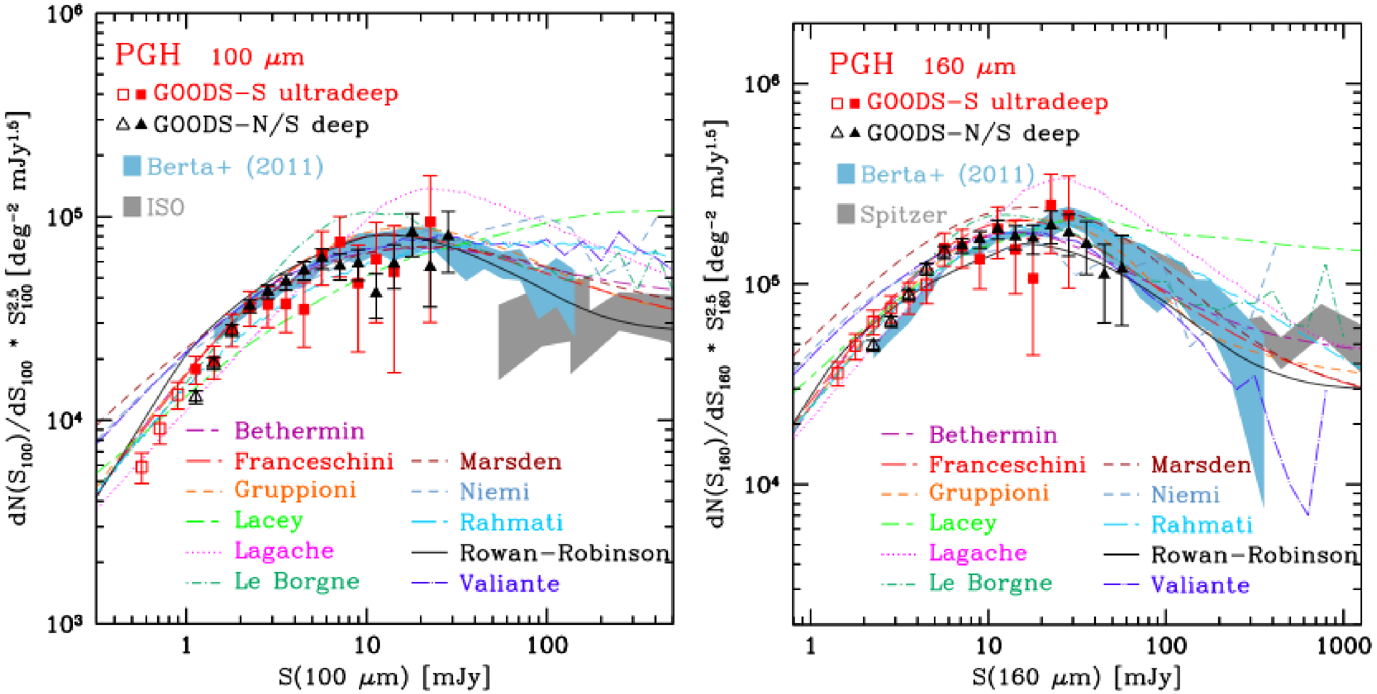


Postage stamp images of the same 5′×5′ region of the GOODS–North field ranging from 3.6µm (upper-left) to 500µm (bottom-right). Upper panel: five Spitzer images (85cm telescope diameter) obtained with IRAC at 3.6 and 8 µm, the IRS peak-up array at 16 µm and MIPS at 24 and 70 µm (from upper-left to upper right).
Bottom panel: five Herschel images (3.5m telescope diameter) obtained with PACS at 100 and 160 µm and SPIRE at 250, 350 and 500 µm (from bottom-left to bottom-right).
This illustrates the impact of the increasing beam size as a function of wavelength: the number of sources that are clearly visible at each wavelength increases when going from the longest to the shortest wavelengths (with the exception of the 70 µm image, which comes from Spitzer and not Herschel).

The Great Observatories Origins Deep Survey : far IR imaging with Herschel

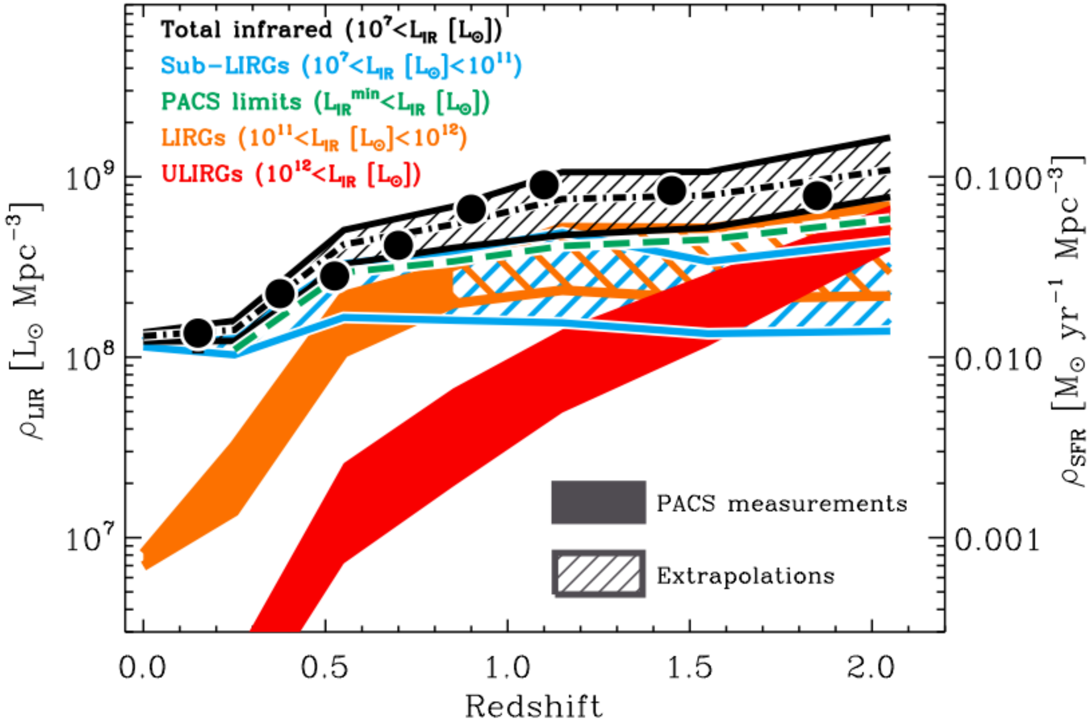
Deepest images of the sky in the far IR : ~2000 sources





The deepest Herschel-PACS far-infrared survey: number counts and infrared luminosity functions from combined PEP/GOODS-H observations,
B. Magnelli1,2, P. Popesso1, S. Berta1, F. Pozzi3, et al. 2013.

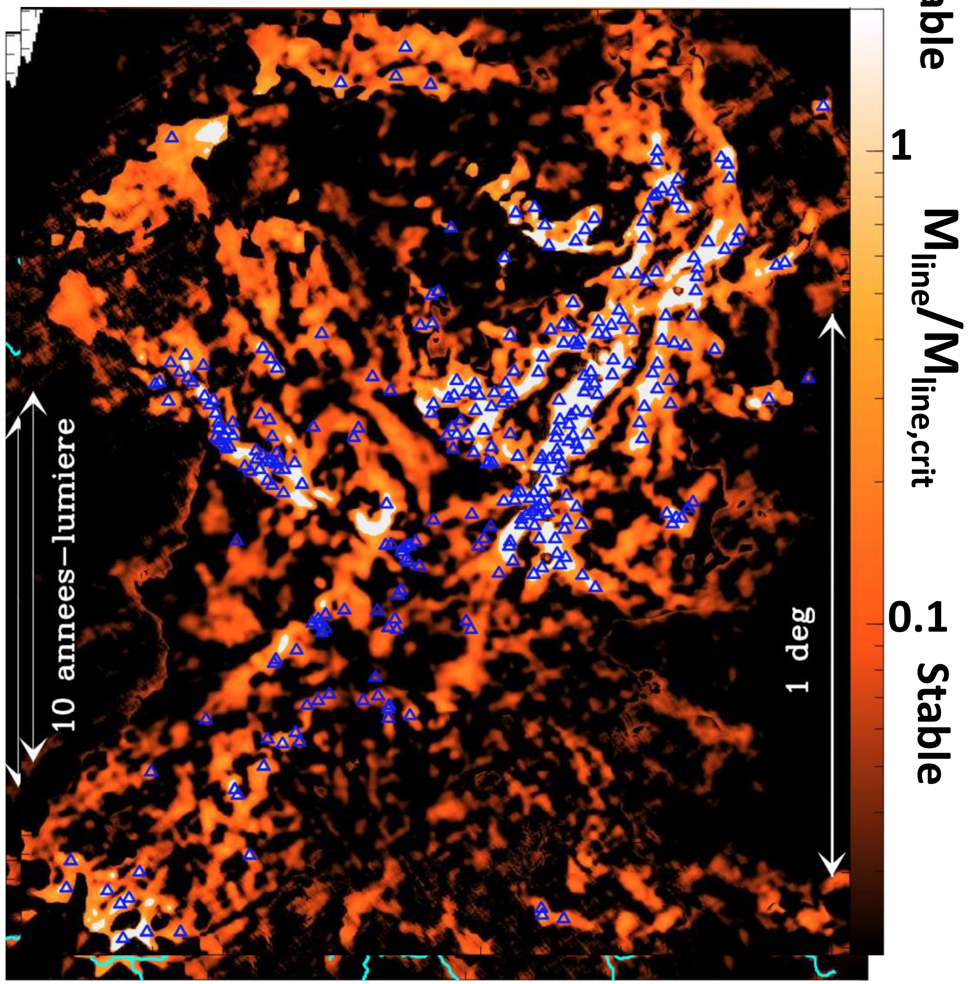
Differential number counts, normalized to the Euclidean slope.



Evolution of the total comoving IR density, from PACS survey down to 0.6 and 1.3 mJy.
Blue: faint galaxies, orange and red: LIRGs and ULIRGs.
Resolves 75% of cosmic IR background.

Most pre stellar cores are found along dense molecular filaments

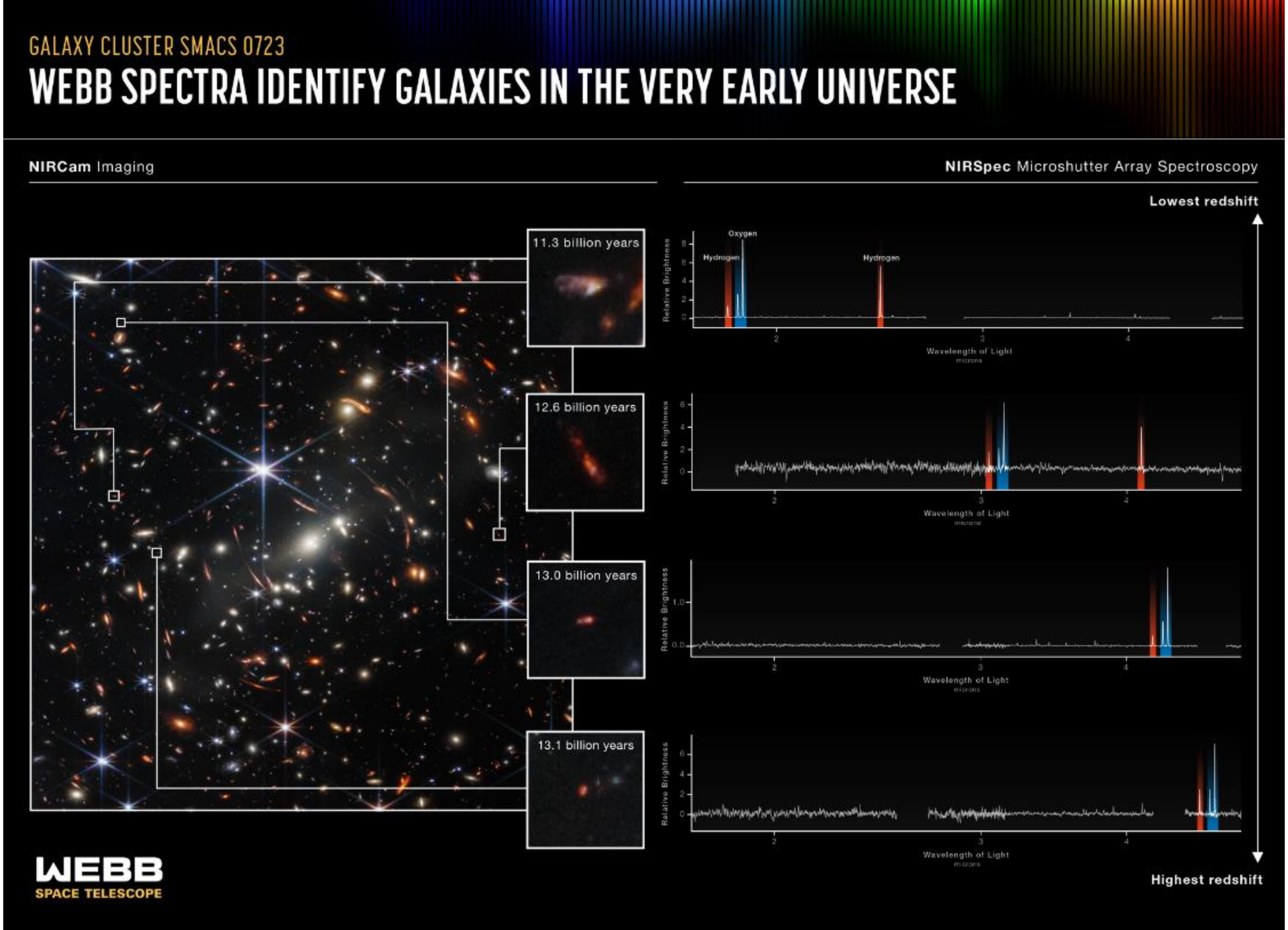
Pre stellar cores in the Aquila cloud complx △



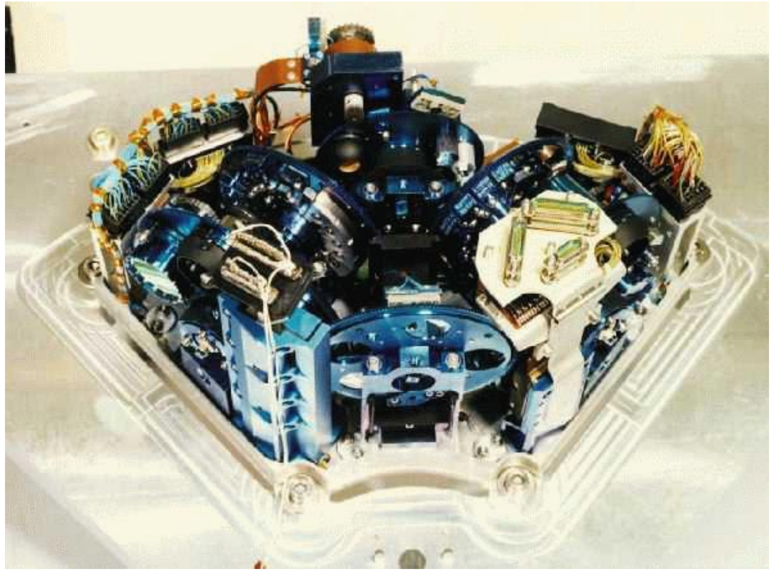
Ph. André et al.,"From filamentary clouds to prestellar cores to the stellar IMF: Initial highlights from the Herschel Gould Belt Survey", A&A 518L (2010)

- Atacama Large Millimeter/submillimeter Array
  - 54 x 12m + 12 x 7m antenna's on Chajnantor at 5050m
  - 7 – 0.35 mm (30-900 GHz) in 10^{+} atmospheric windows
  - World's most powerful radio interferometer
  - Cold Universe: formation of planets, stars and galaxies
- Global partnership
  - North America (37.5%), East Asia (25%) & ESO (37.5%)
  - In cooperation with Chile

ALMA inauguration in 2013.
Thijs de Graauw and President Pineiro.
Thijs famously said: ALMA is “the largest science project ever, where nobody was in charge, but we have made it work.”


GALAXY CLUSTER SMACS 0723
WEBB SPECTRA IDENTIFY GALAXIES IN THE VERY EARLY UNIVERSE
NIRCam Imaging
NIRSpec Microshutter Array Spectroscopy
Lowest redshift
11.3 billion years
12.6 billion years
13.0 billion years
13.1 billion years
Oxygen
Hydrogen
Hydrogen
Relative Brightness
Wavelength of Light
Highest redshift
WEBB
SPACE TELESCOPE

ISOCAM : the IR camera of ISO
(November 1995 to May 1998)

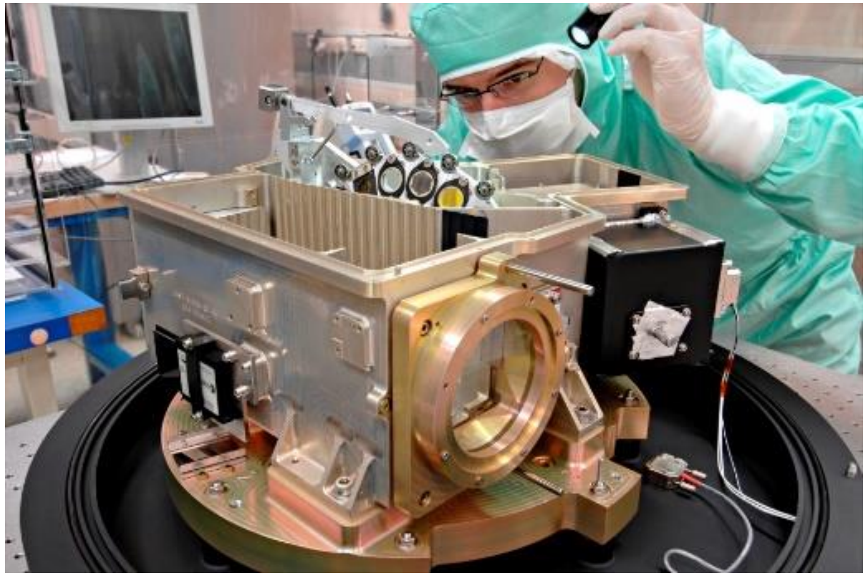


Two channels :

2.5 – 5.5 μm;
- InSb 32x323 detector array
- PfoV : 1.5, 3, 6, 12 arcsec
- 11 filters + a CVF (R about 35)

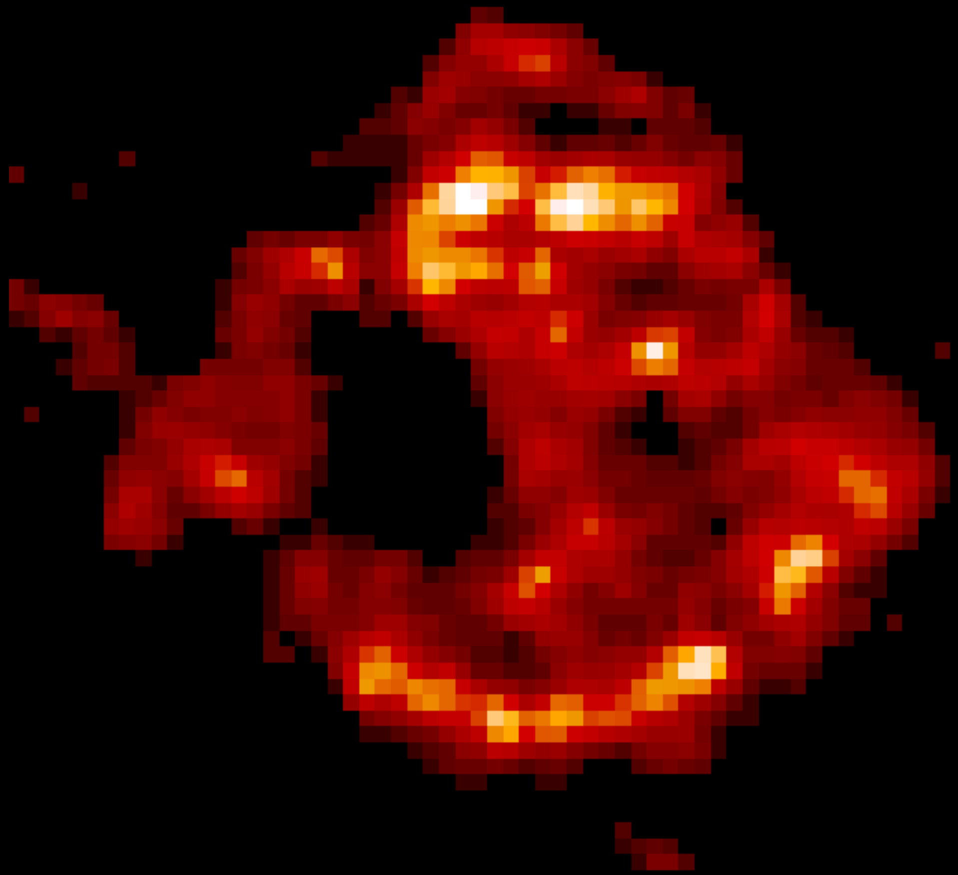
4 – 18 μm;
- SiGa 32x32 detector array
- PfoV : 1.5, 3, 6, 12 arcsec
- 10 filters + a CVF (R about 35)

MIRIm, the imager of MIRI, the Mid IR Instrument of the JWST
(Decembre 2021 - …)



4.9 – 25.5 μm
- 1024x1024 Si:AS detector
- PFoV : 0.11 arcsec;
- Field : 74 x 113 arcsec^2
- a set of 9 filters
- 4 coronagraphs
- a Low Resolution Spectrometer 5 – 12 μm (R about 100)

Supernova Cas A



ISOCAM : 10.7 – 12 microns
(P.-O. Lagage et al. 1996)

MIRI composite i
(Dan Milisavljevic

Interested early in his career, early 70s, in infrared heterodyne mixing and detection, Thijs has often been the impulse and/or at the helm of the European mid, FIR and sub mm facilities. There are no limits to the gratitude we collectively owe him.