THE HISTORY OF INFRARED IN SPACE

HOW TO STUDY DUST GRAINS, ATOMS and MOLECULES IN SPACE

Infrared, submillimeter and millimeter astrophysics

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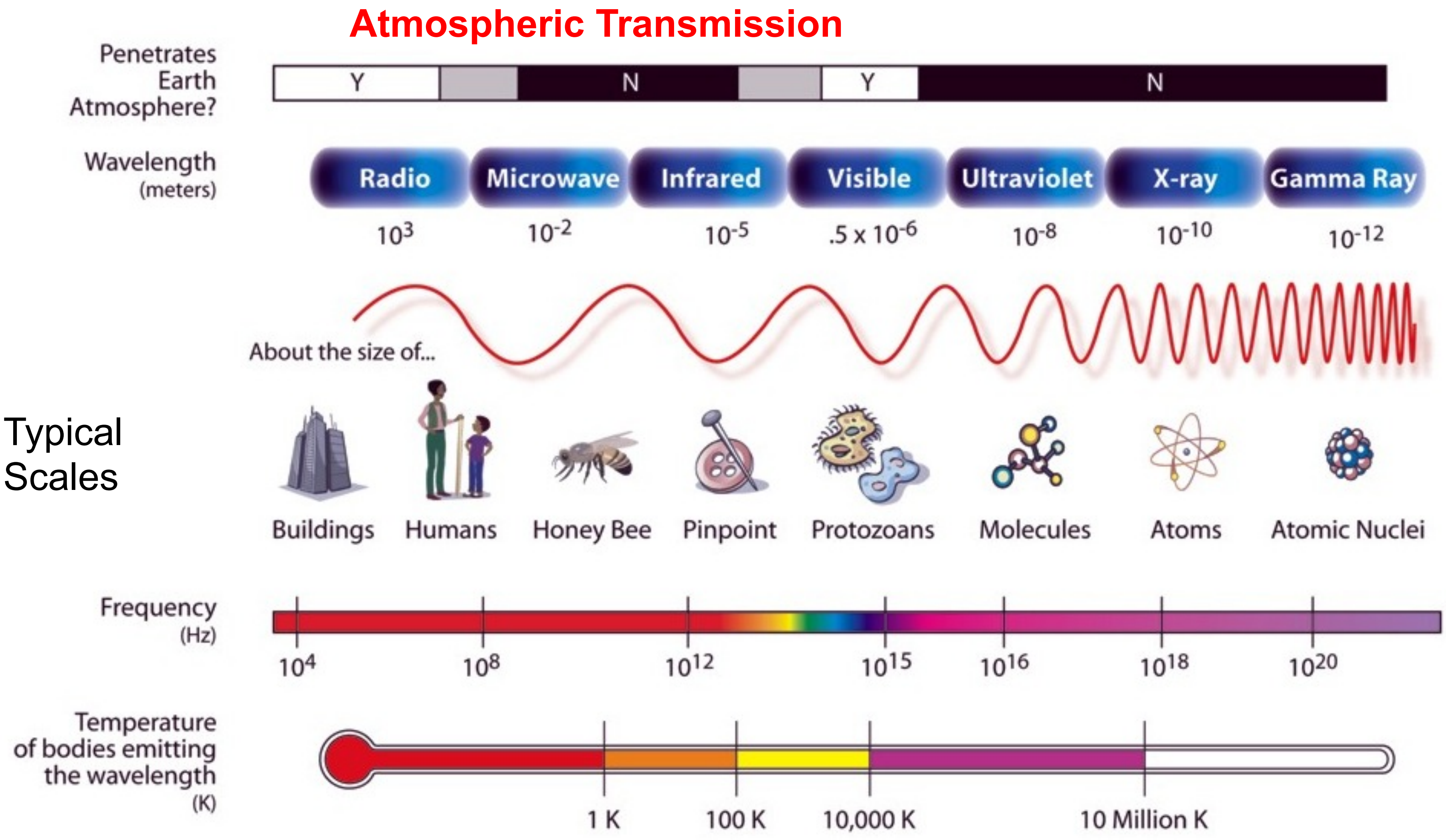
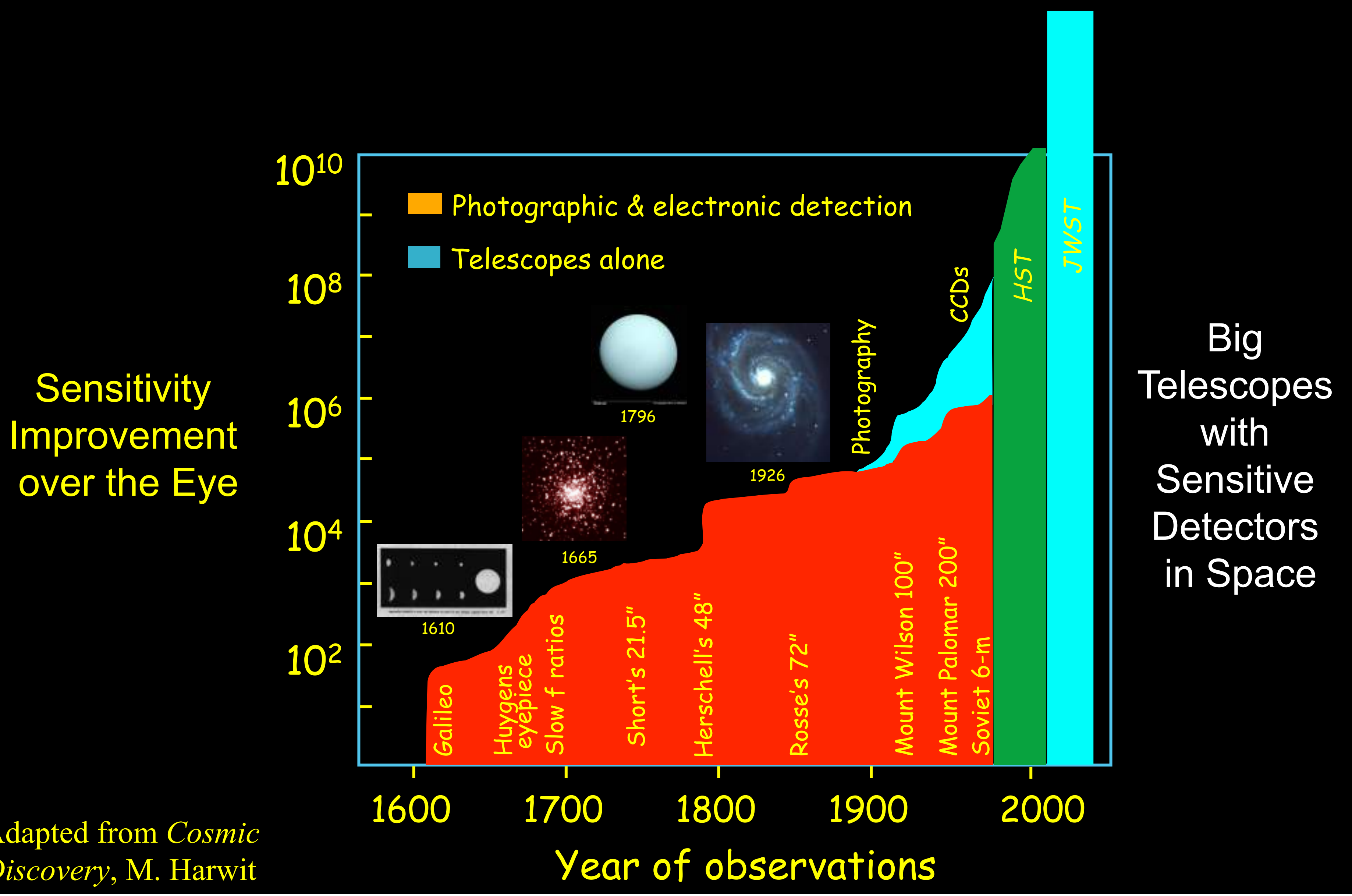
The Electromagnetic Spectrum

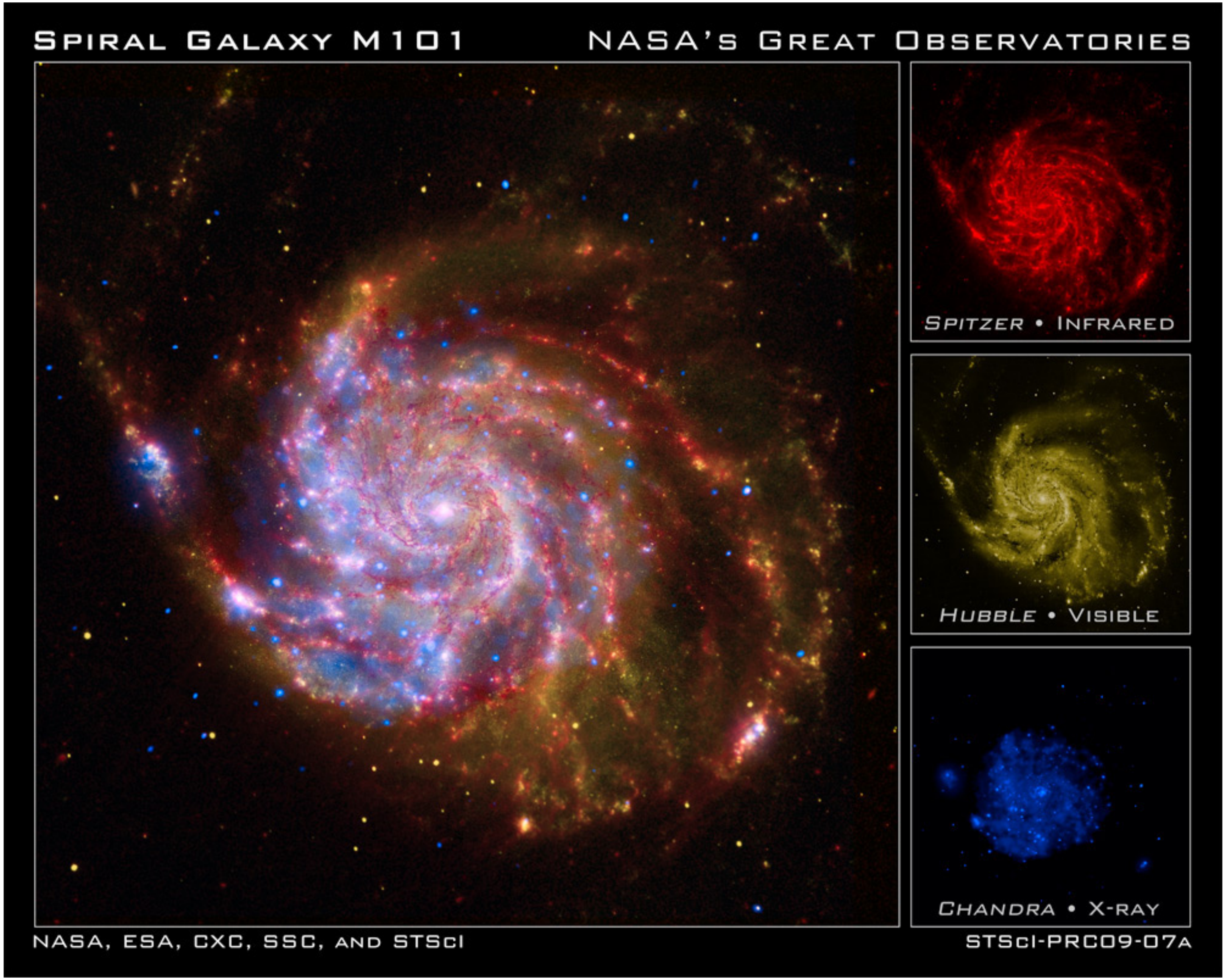


How to win at Astronomy



Adapted from *Cosmic Discovery*, M. Harwit

The need for multiwalength observations: from X-rays, optical, and infrared to millimeter waves



The Discovery of Invisible Light

A Fortunate Accident

In 1800, while placing thermometers in each color of the solar spectrum, Herschel places his “control” thermometer just outside the red end of the spectrum.

Result: the thermometer outside the visible spectrum registered the highest temperature!

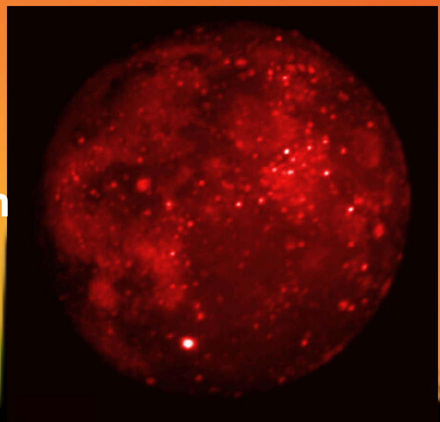
The first detection of invisible light, which Herschel called *infrared* (“*beneath red*”) light.

First steps

1800:
William Herschel
Discovery of IR

1856:
Charles Piazzi
IR from the Moon
Thermocouple & heat

1870:
Lawrence Parsons
Temperature of Moon
From IR



1948:
Moon must be covere
By fine powder

from Michael Burton

IR Facilities: the early days

1961:
Frank Low
Germanium bolometer
Cooled, in dewar
Detect far-IR
Change in conductivity

1960's:
Balloons carry high altitude payloads

1967:
Cooled IR telescopes in rockets
AFGL IR sky survey
4+10+20μm
2363 sources in 30 mins

1967:
Mauna Kea Observatory established
High & dry!

from Michael Burton

IR Facilities Develop

1968:
Leighton & Neugebauer
Mt Wilson
2.2µm IR survey
5,500 sources

Early 1970's:
Most galaxies found
to emit strongly in
IR (M31)

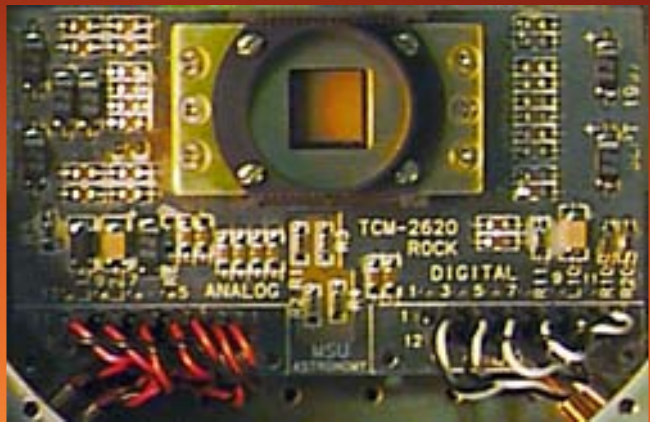
1974:
Kuiper Airborne
Observatory
Rings of Uranus
Water in Jupiter

Mid 1970's:
Far-IR spectrometers
from balloons at
T = 1K
CMBR

from Michael Burton

IR Facilities Mature

1980's:
IR arrays



1983:
IRAS satellite
12+25+60+100μm
500,000 sources
Vega Disk
ULIRGs

1985:
IR telescope
on Shuttle

1989:
COBE
MM + Far-IR sky
CMBR

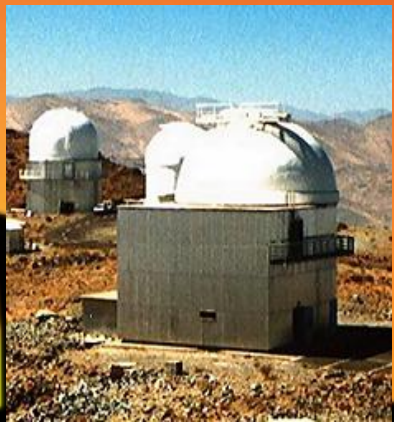
from Michael Burton

IR in the 90s

1994:
SPIREX at the
South Pole

1995:
ESA ISO
2.5-240μm +
spectroscopy

1996:
DENIS
Near-IR sky survey
La Silla, Chile



1996:
MSX
Military satellite
8+11+14+21μm

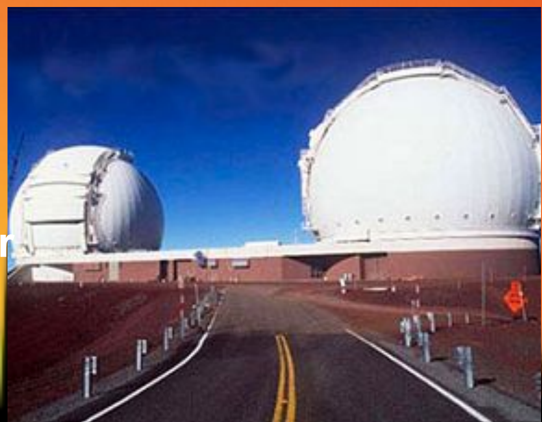
from Michael Burton

IR Astronomy Today

1997:
2MASS
All-sky
1.2 + 1.6 + 2.2μm

1997:
NICMOS on HST
1-2.5μm

2001:
Keck Interferometer



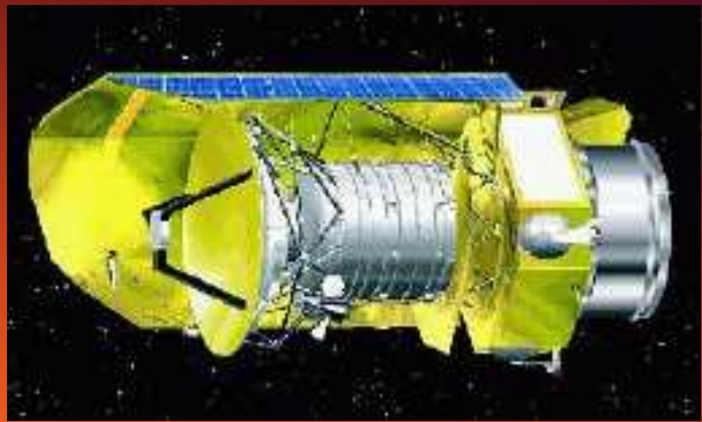
2004:
Spitzer Space Telescope

from Michael Burton

IR Astronomy : the present

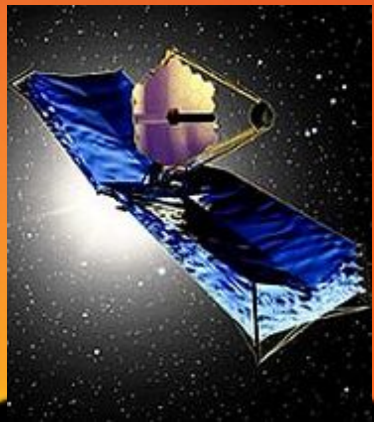
2010: SOFIA - IR spectroscopy

2009: Herschel - far-IR



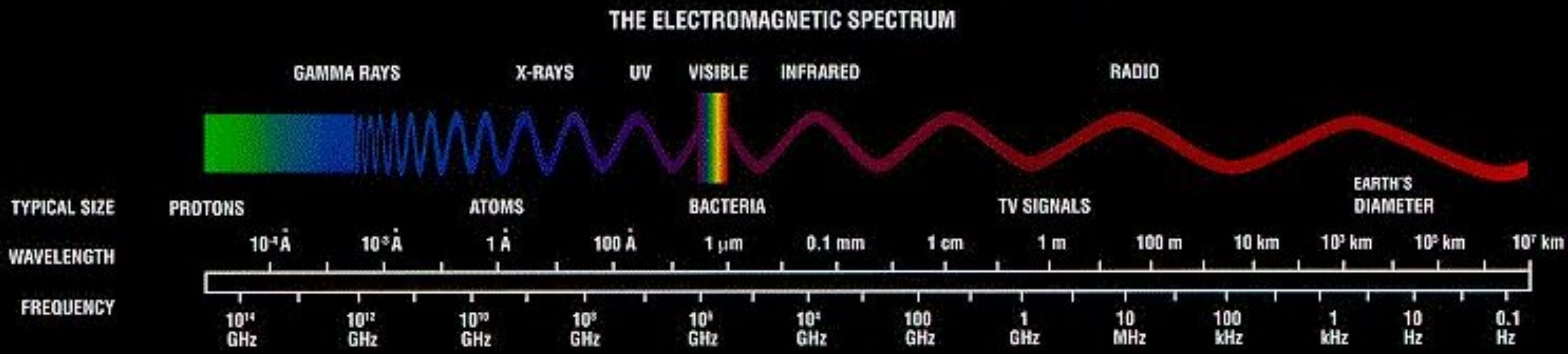
2009:
Planck
CMBR

2019 JWST
telescope



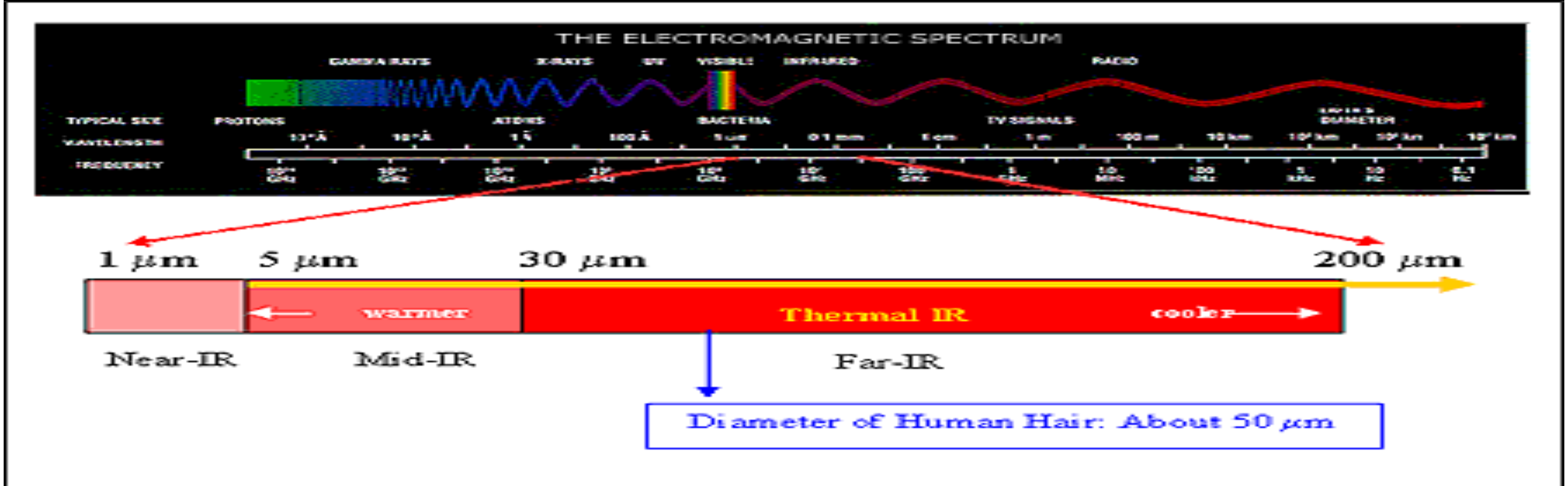
from Michael Burton

Electromagnetic spectrum



Infrared range: longer than optical and shorter than microvawe

Infrared



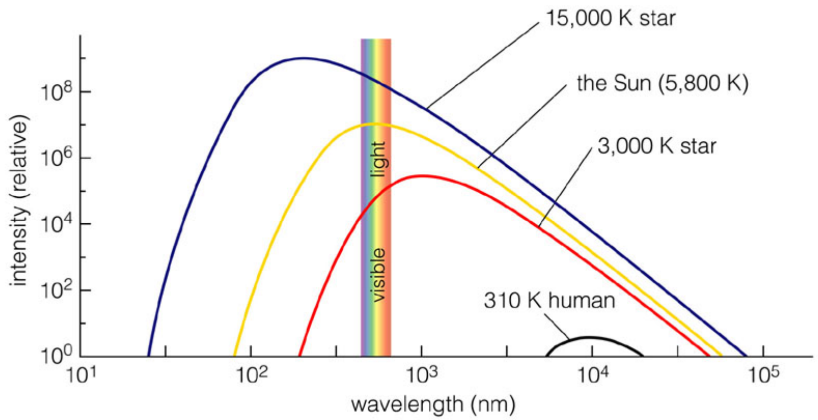
Astronomers roughly divide infrared into three ranges:

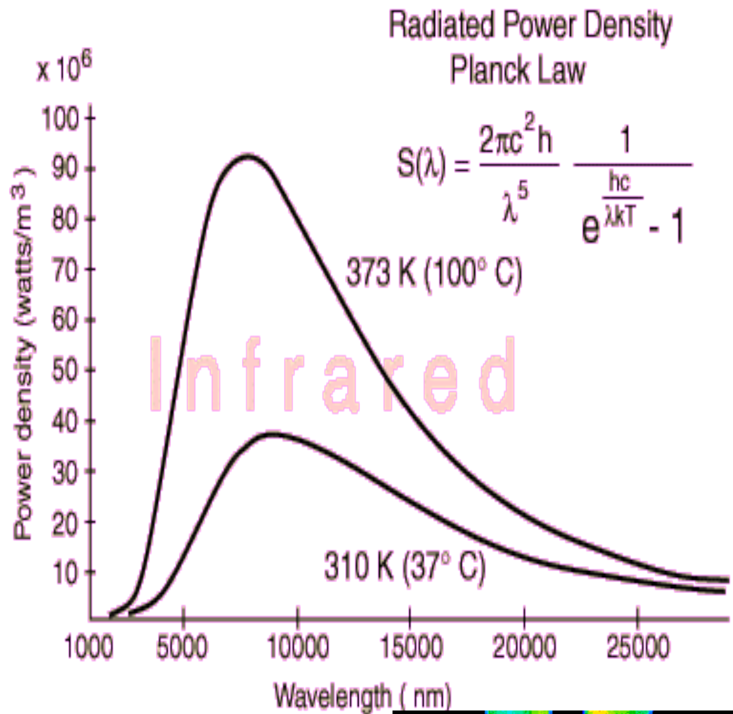
1. near- (NIR: 1 – 5 micrometers),

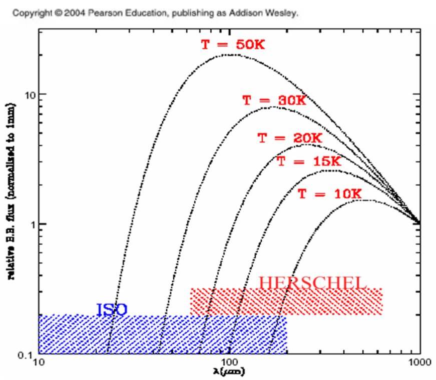
2. mid- (Mid-IR: – 5 -- 30 micrometers)

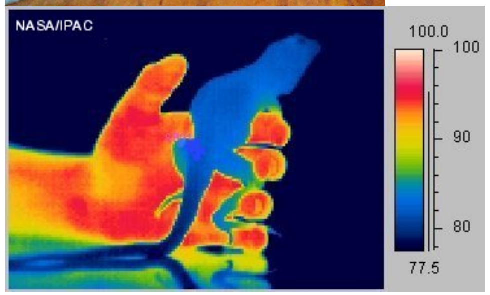
3. far- (FIR: 30 – >200 micrometers).

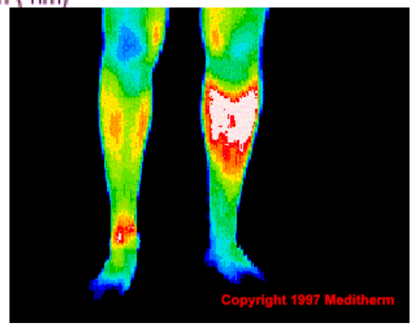
Infrared = heat
All objects in the Universe with ANY temperature radiate in the infrared



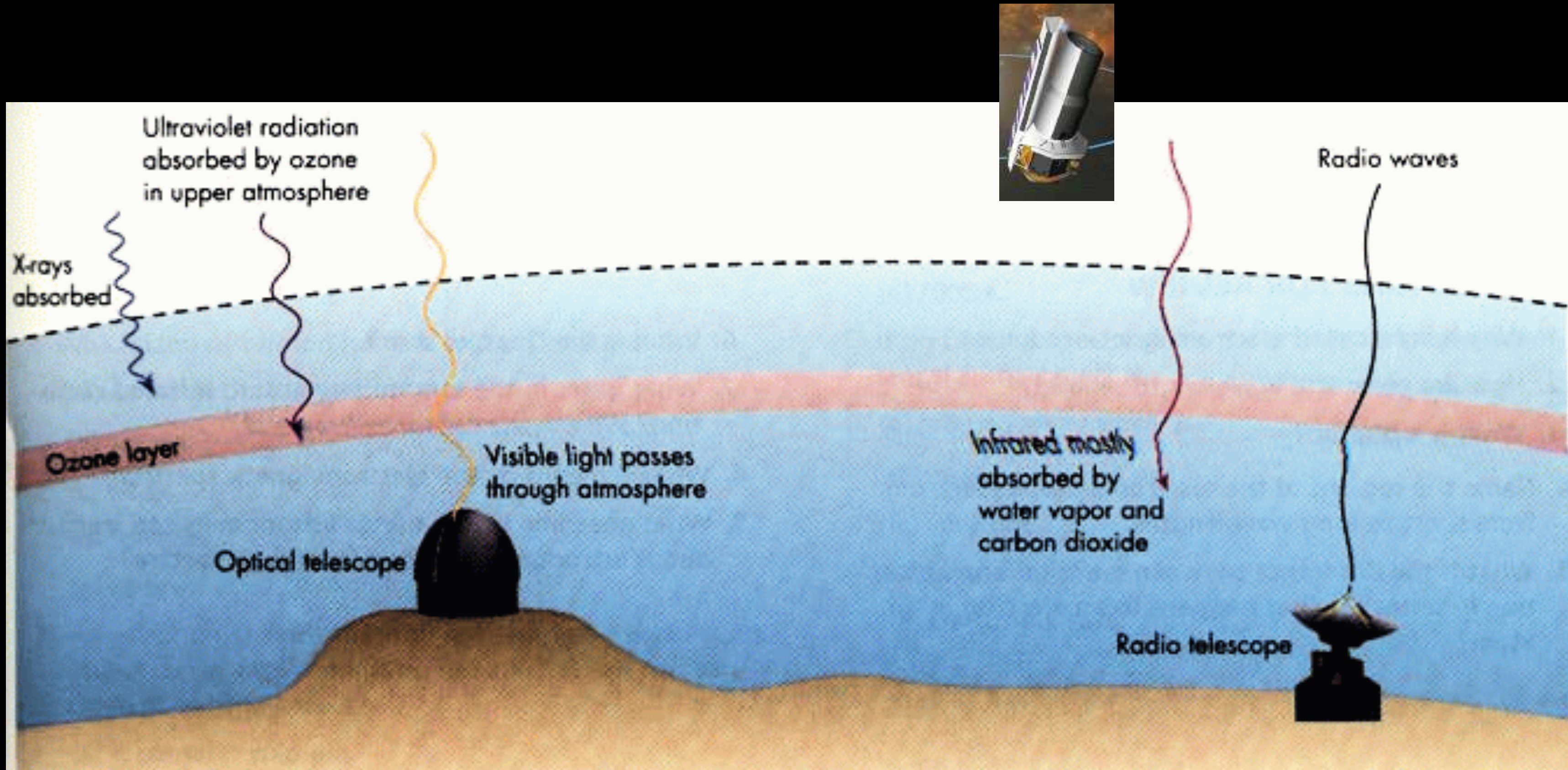






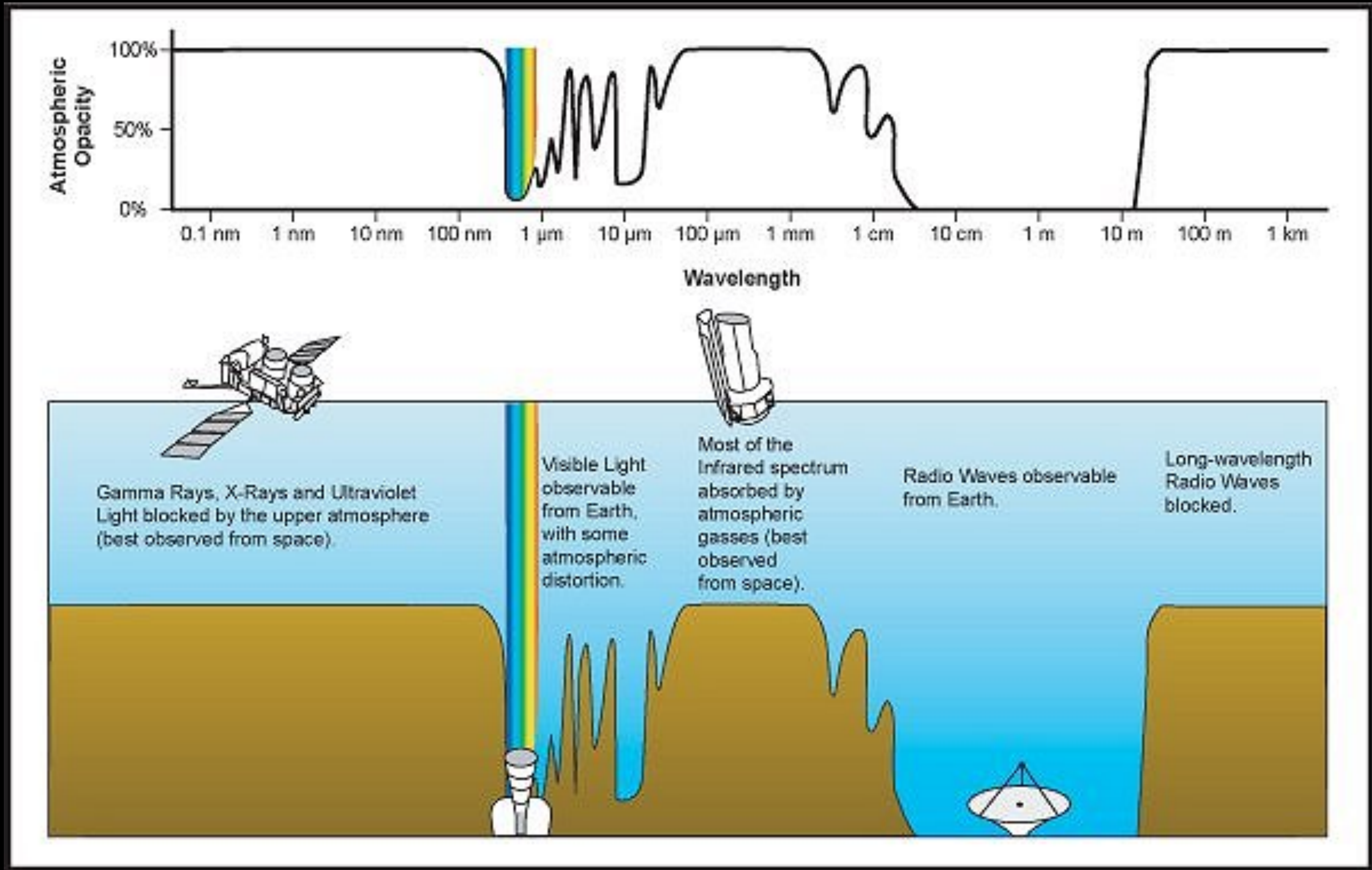


Why a Telescope in Space?

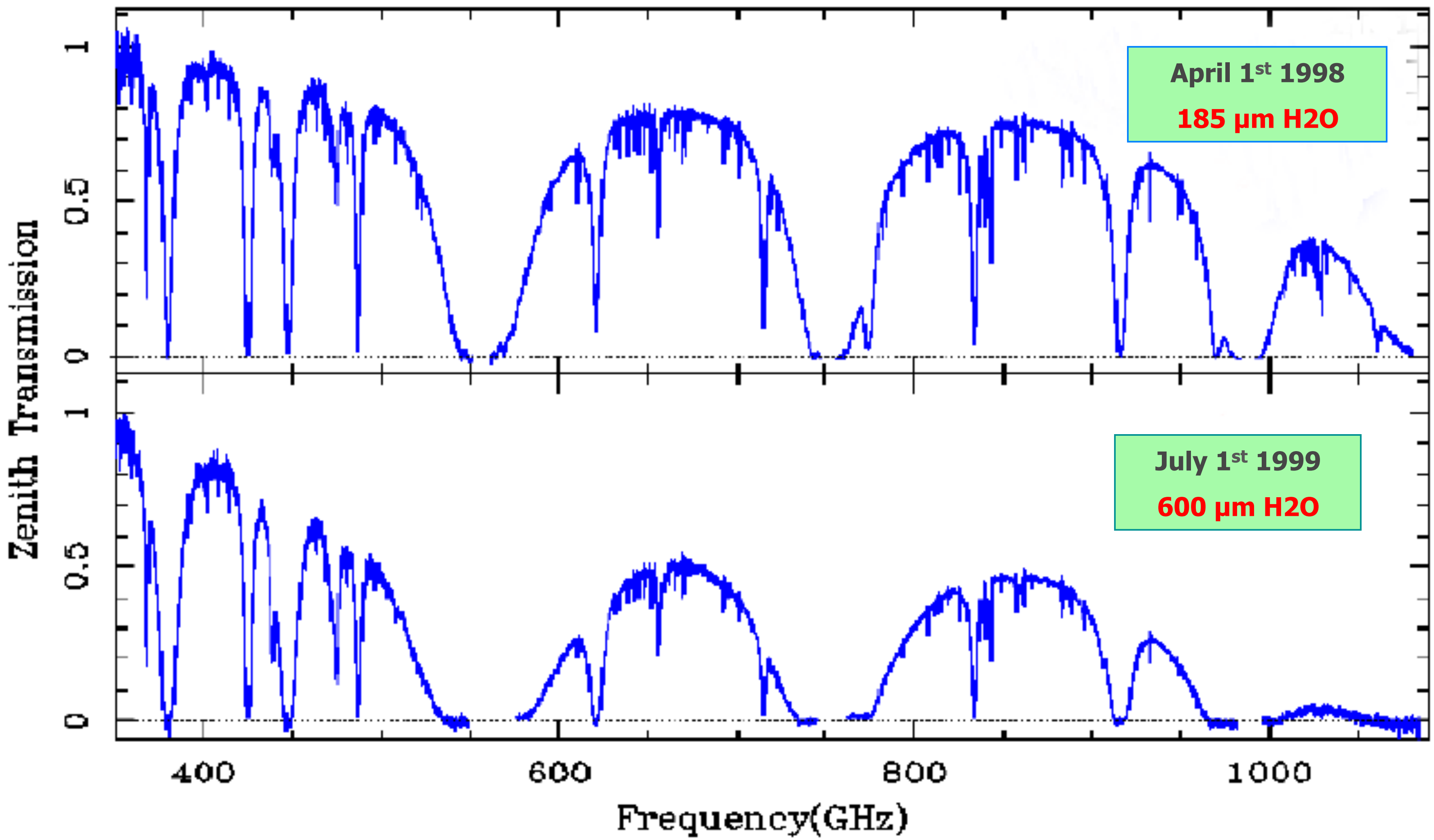


Infrared light is mostly absorbed by our atmosphere.

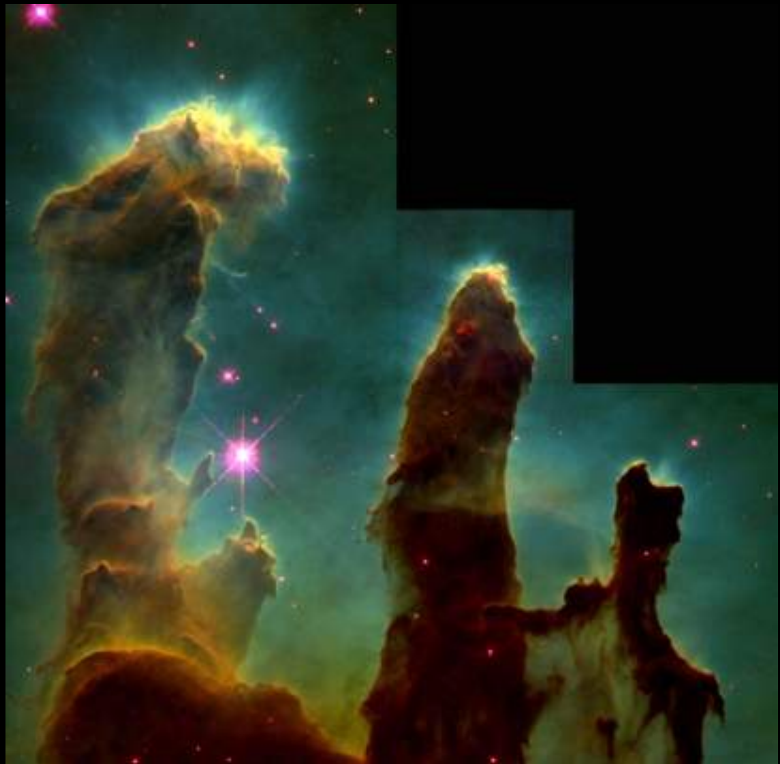
Infrared astronomical observations



Relevant results for continuum-like atmospheric absorption below 1 THz



Why IR? – Because Space is Dusty

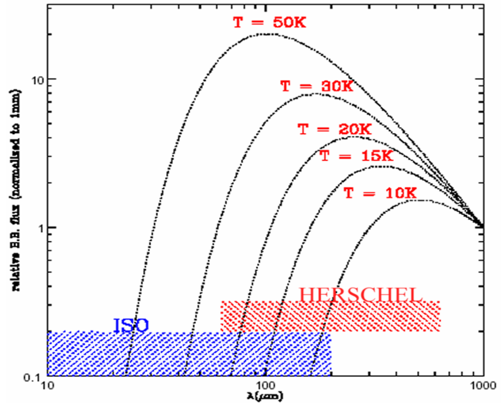


The Eagle Nebula
as seen by HST

The Eagle Nebula
as seen in the infrared

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

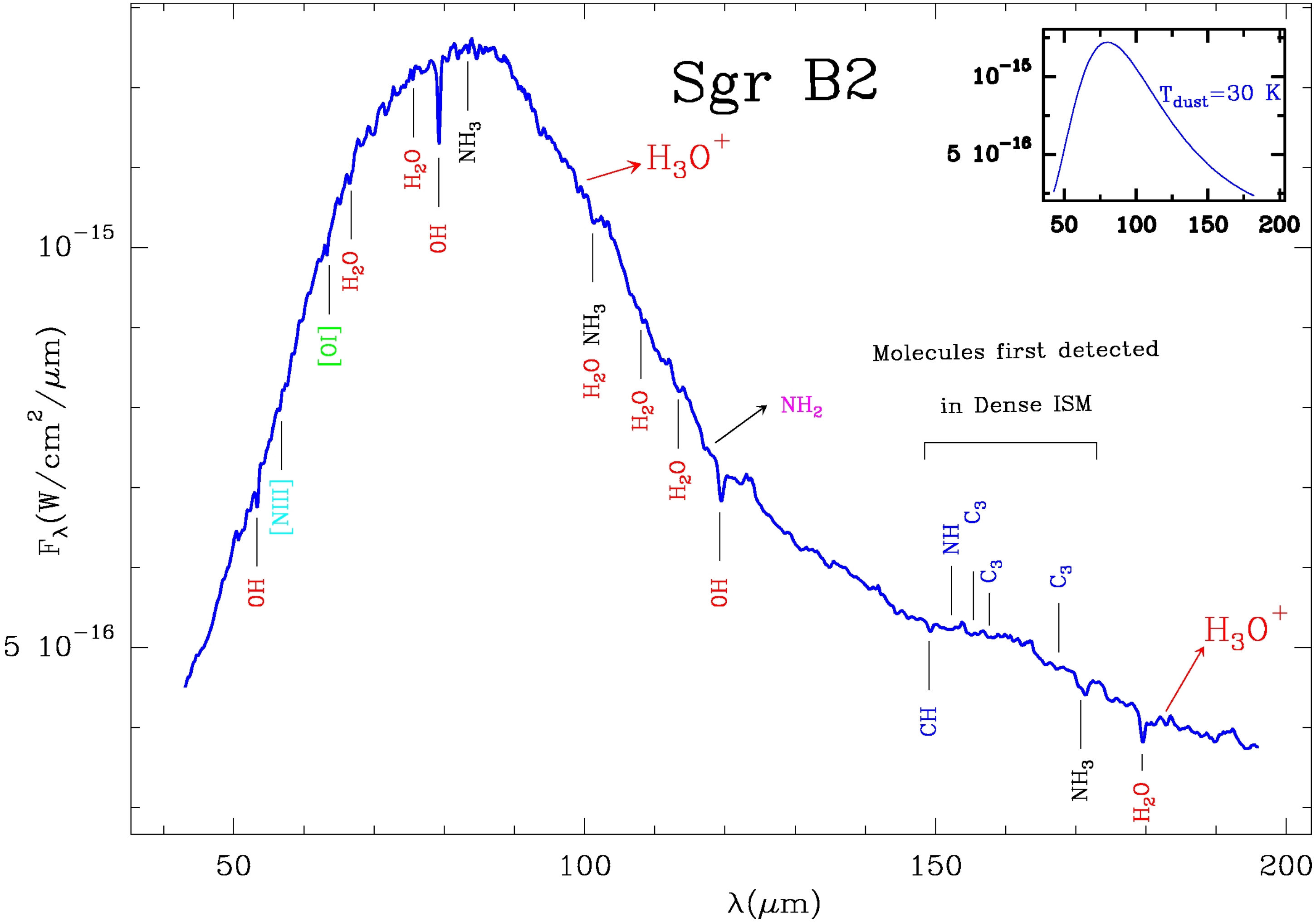
ASTRONOMY
AND
ASTROPHYSICS



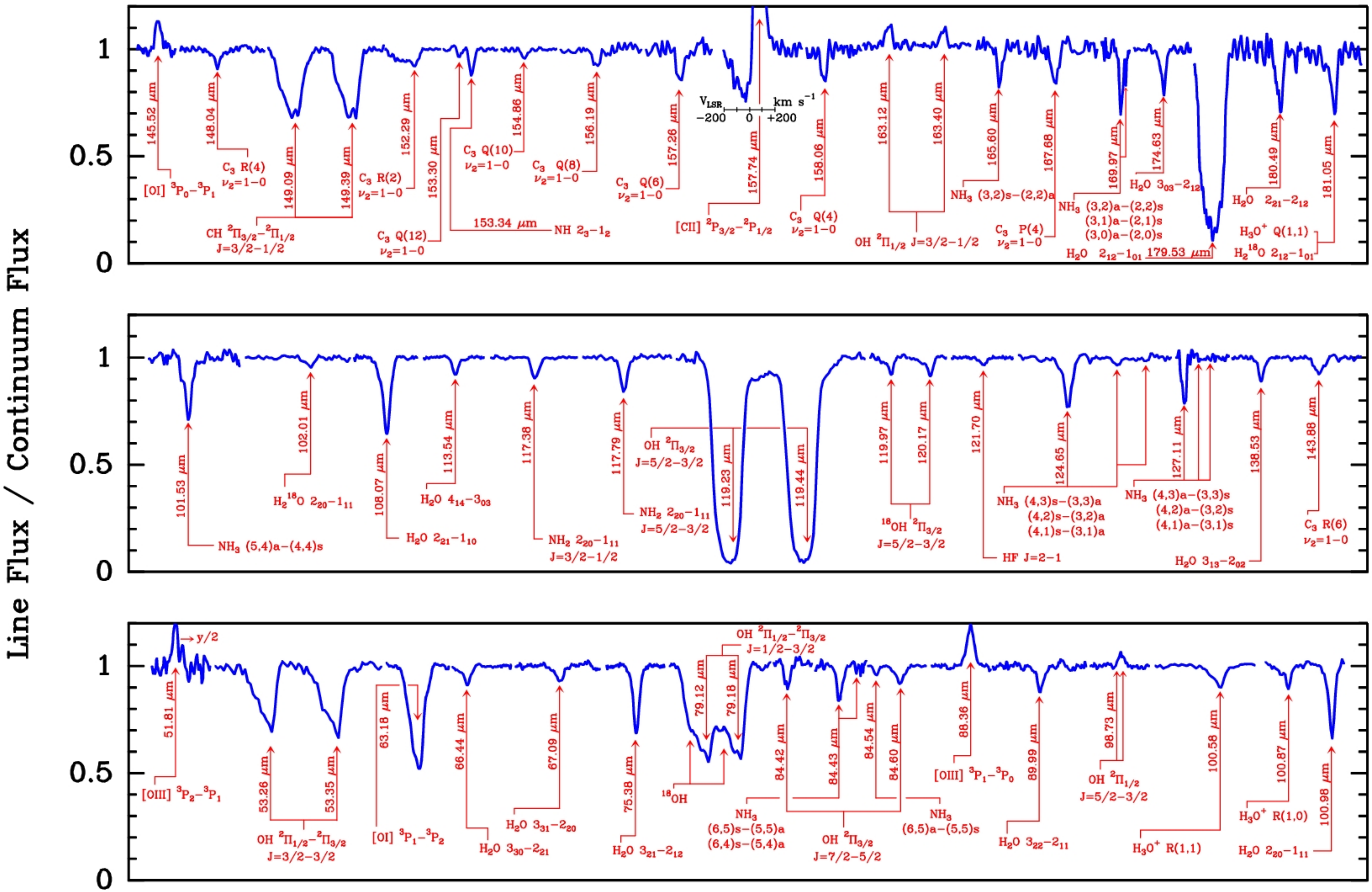
Letter to the Editor

Widespread water vapour absorption in SgrB2[1]

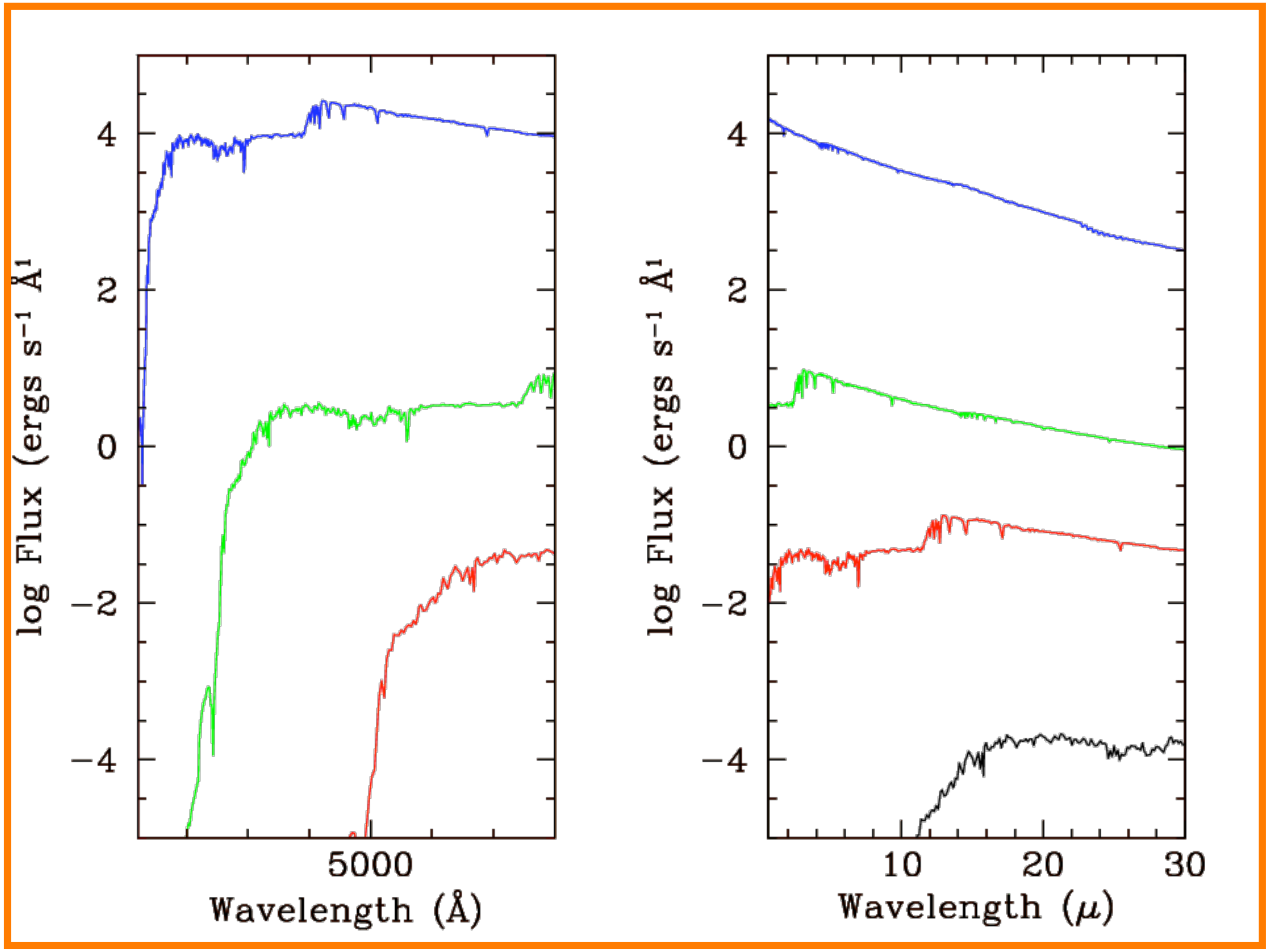
J. Cernicharo[1], T. Lim[2], P. Cox[3], E. González-Alfonso[4,5], E. Caux[6], B.M. Swinyard[7], J. Martín-Pintado[5], J.P. Baluteau[8], and P. Clegg[9]



Goicoechea et al. 2004   Spectral Resolution 4000-7000



Why IR? – Distant galaxies are redshifted

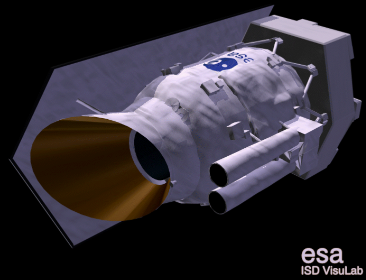


The History of IR Space Astrophysics

- IRAS
- ISO
- Spitzer
- AKARI
- Herschel
- SOFIA

- SPICA
- JWST

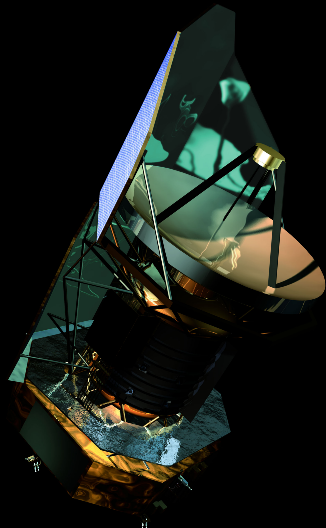
IRAS
1983
USA, UK, NL
Télescope 60 cm
10 - 100 µm



ISO 1995
Europe
Télescope 63 cm
3 - 200 µm

SPITZER
2002
USA
Télescope 80 cm
2 - 200 µm

HERSCHEL
2009
Europe
Télescope 3,5 m
60 - 600 µm



- MILLIMETRE & SUBMILLIMETRE = ODIN, SWAS, COBE, WMAP, Planck, ALMA

Infrared Astronomical Satellite

1974: NASA AO for missions on
Explorer spacecraft.
Competition won by IRAS

Joint project of NASA, NIVR
(Netherlands) and SERC (UK)

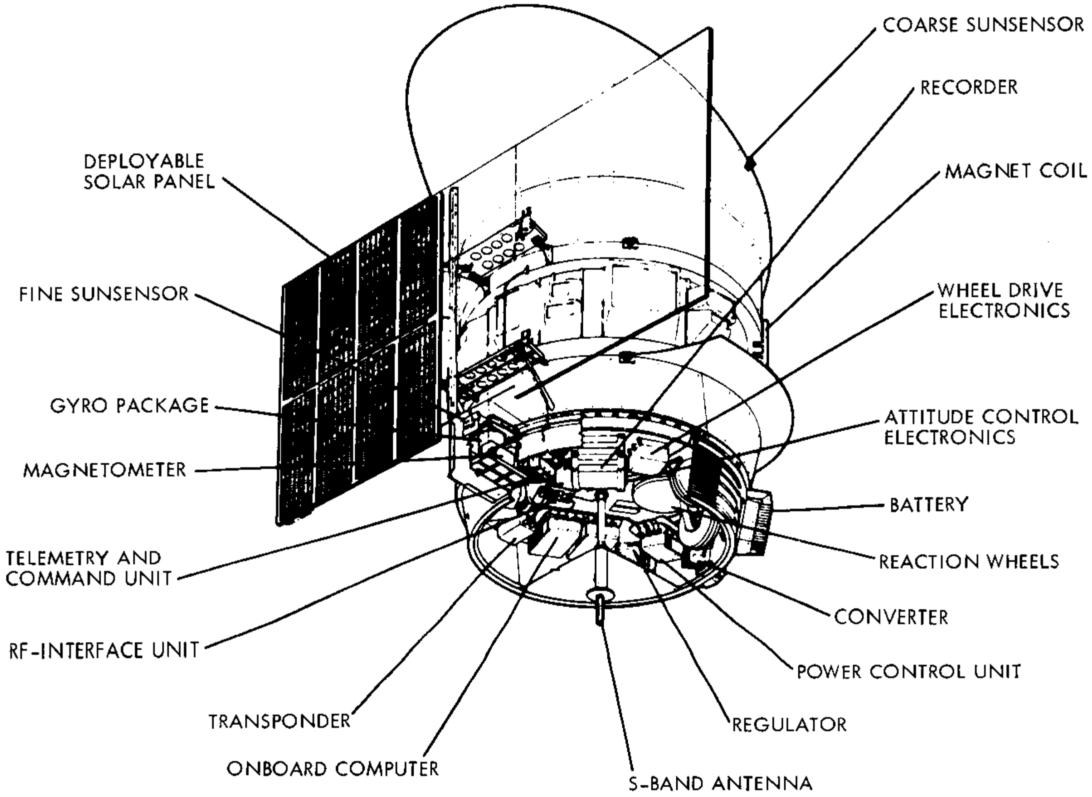
Operational in 1983
Liquid helium depleted after 10 months
(still orbits the Earths but insensitive to
IR emission)

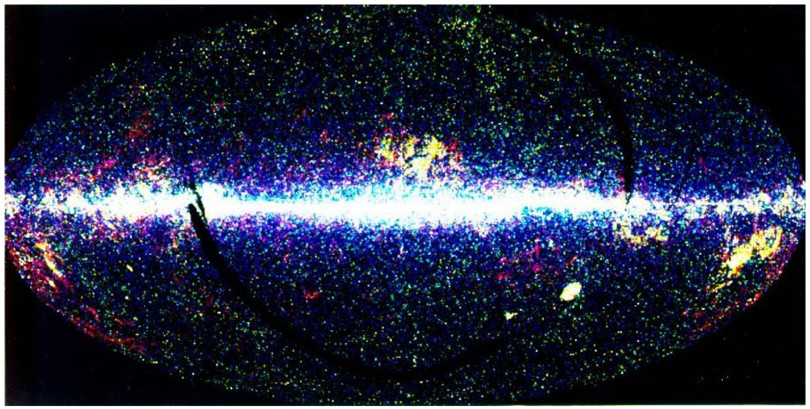
Infrared Astronomical Satellite

Primary mirror of 60 cm diameter
Filters centered at 12, 25, 60 and 100 μm

Main mission goal:
diffraction-limited
all-sky survey in the
four bands.

Extra instruments:
- **LRS spectrograph (8 – 22 μm)**
- **CPC (bad)**



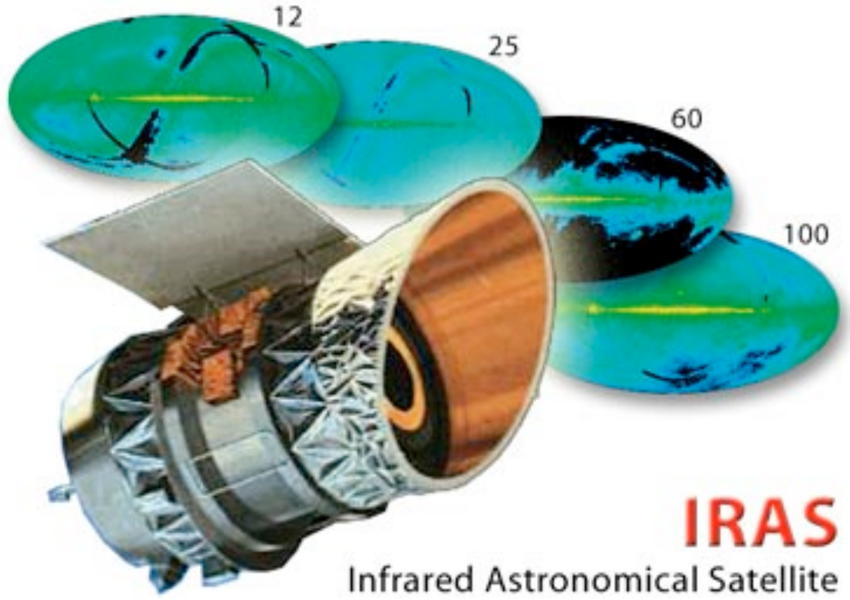


IRAS legacy

Main legacy: All-sky images and the associated catalogues 350 000 objects !

http://irsa.ipac.caltech.edu/

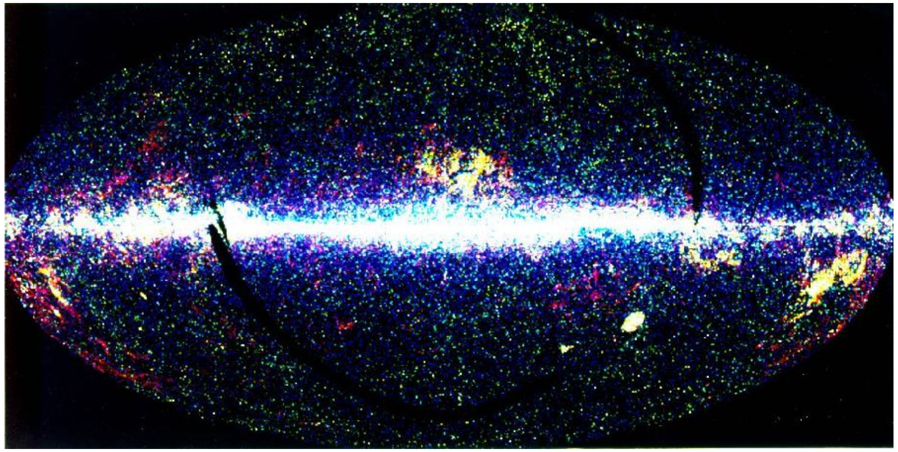
Many interesting discoveries
- **dusty starburst galaxies**
- **circumstellar disks**
- **asteroids**

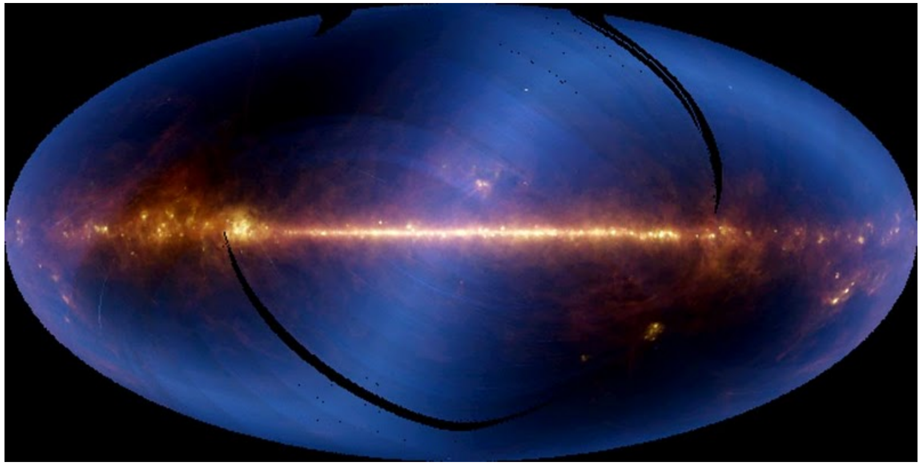


Even today, IRAS is a huge resource for astronomers !
(many objects still unidentified)

IRAS – All Sky in IR

- ~ 350 000 IR point sources in the sky
- which increased the number of cataloged astronomical sources by 70%
- most of them belong to Milky Way: cool stars, nebulae, cirruses...
- plus a few tens of dusty galaxies
- some sources still remain unidentified

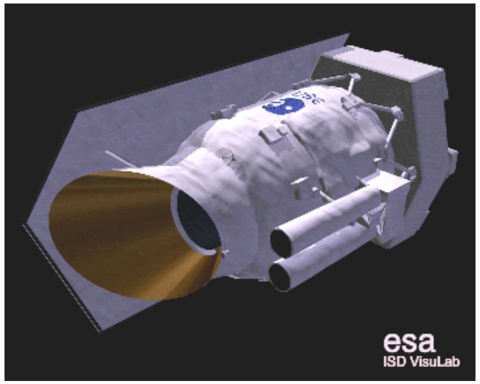


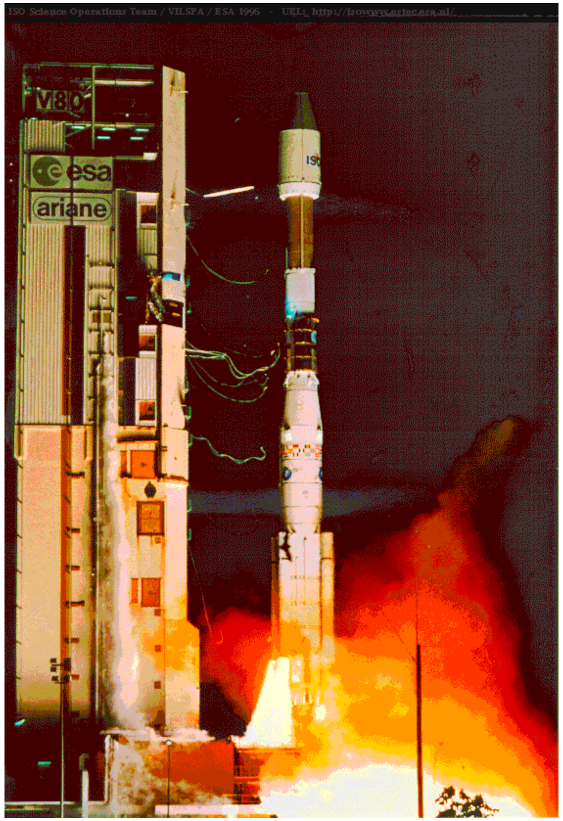


Infrared Space Observatory

European follow-up mission for IRAS
(infrared detector technology developed very fast)

1979: first ideas (before IRAS launch!)
1983: selection of ISO project
Nov 1995: launch
Feb 1996: start of the operations
Apr 1998: depletion of liquid He



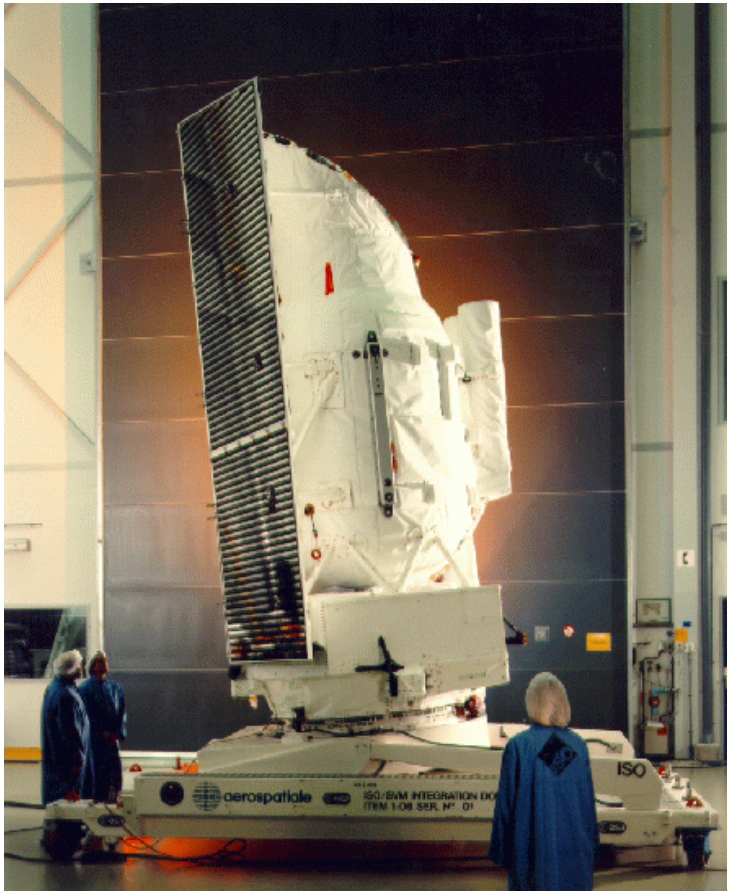


Infrared Space Observatory

ISO design and technology: borrowed heavily from IRAS experience

Telescope diameter 60 cm

Main differences:
- elliptic orbit
- wavelength coverage to 240 µm
- spectroscopy: SWS and LWS
- increased spatial resolution
- sensitivity: 1000 times better !
- no survey instrument

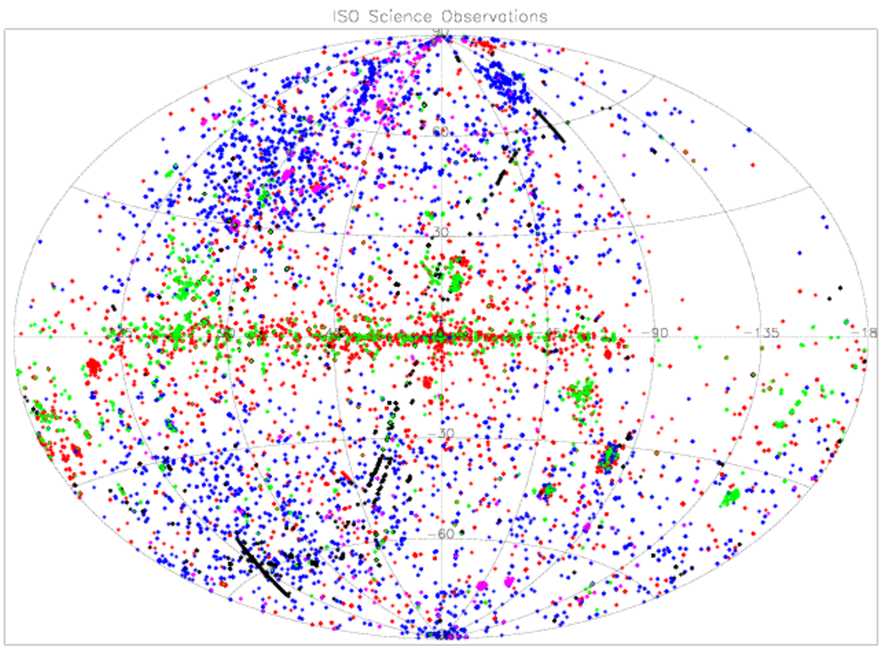


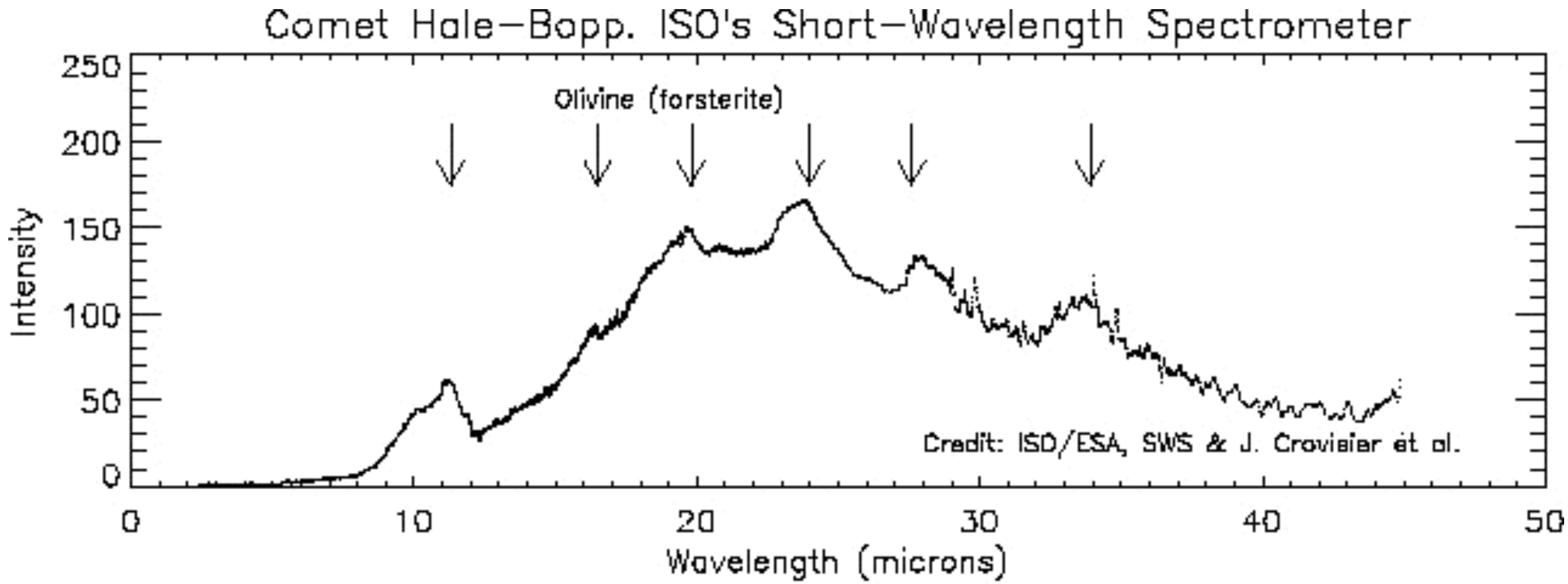
ISO legacy

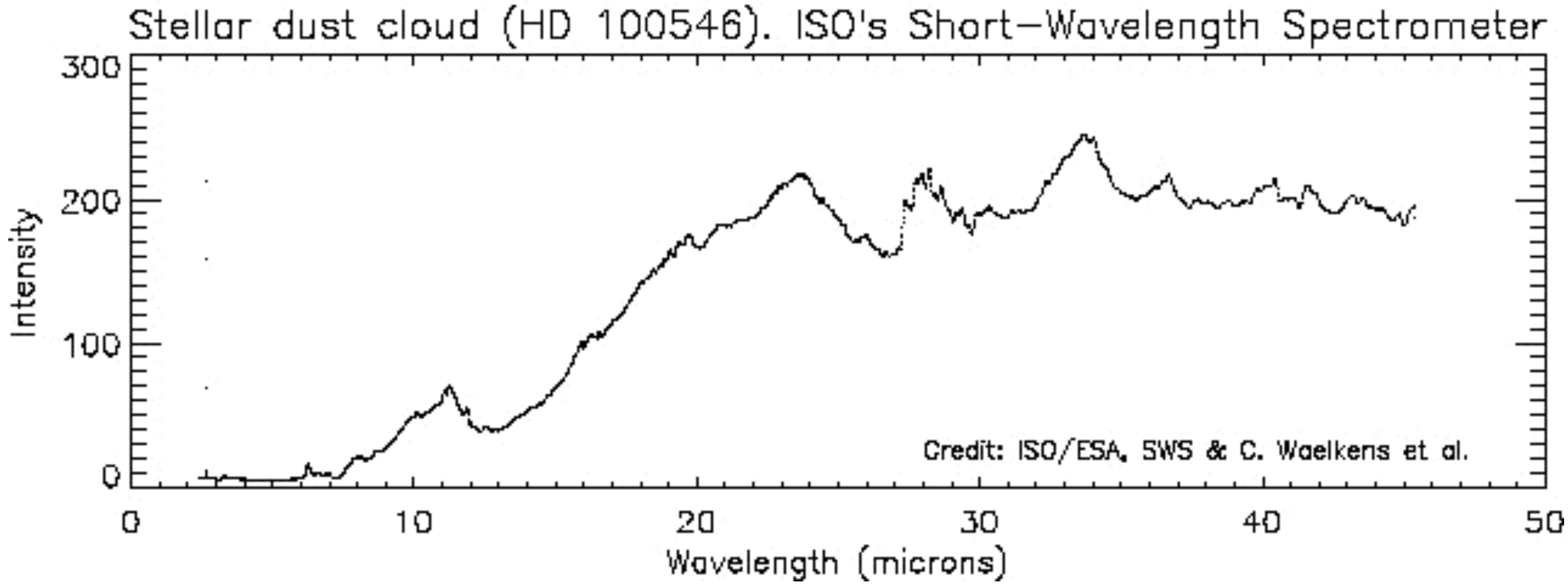
26000+ successful observations
1000+ successful observing proposals
500+ principle investigators

Full data set available to the community in the ISO archive

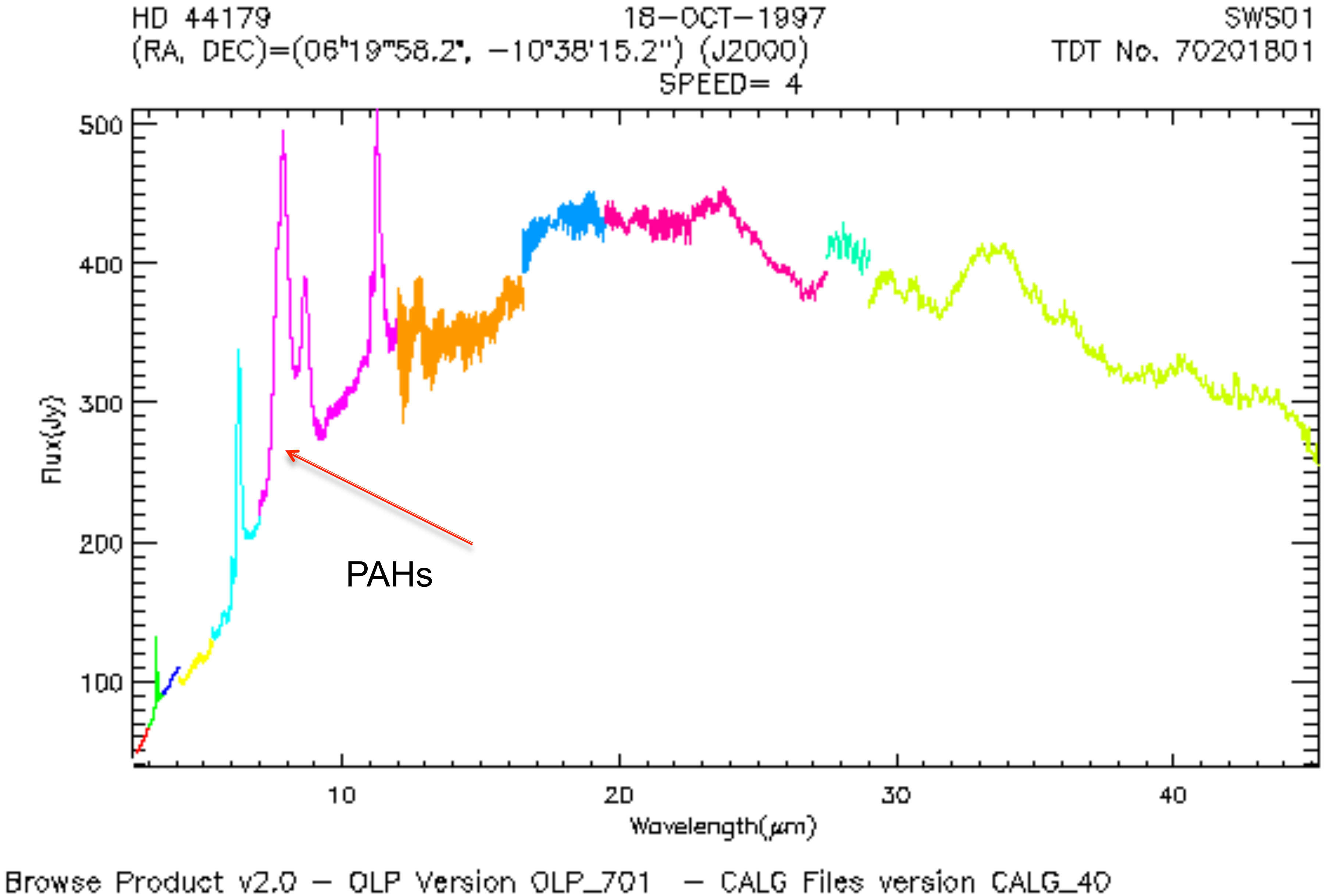
http://iso.esac.esa.int/ida/







Credits: ISO (ESA). SWS & C. Waelkens at al.


HD 44179
18-OCT-1997
SWS01
(RA, DEC)=(06h19m58.2s, -10°38'15.2") (J2000)
TDT No. 70201801
SPEED= 4
Flux(Jy)
500
400
300
200
100
10
20
30
40
Wavelength(μm)
PAHs
Browse Product v2.0 - OLP Version OLP_701 - CALG Files version CALG_40

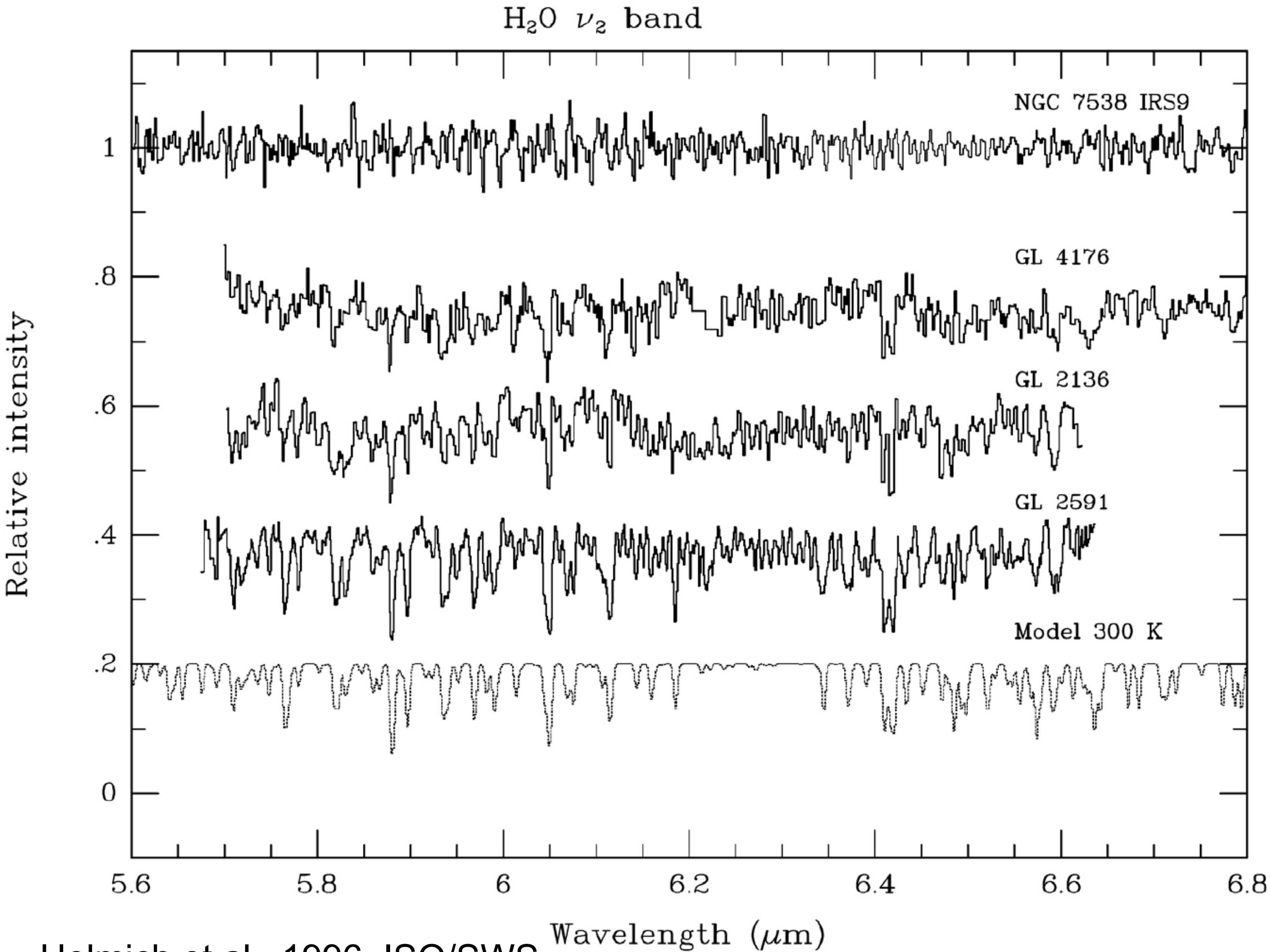
The Quest for H_2O

- Detected in 1969 by Cheung et al through the maser emission at 22 GHz of the 6_{16}–5_{23} transition (Eupp=609 K, Aij=1.9 10–9)
- Observed in small regions with peculiar physical conditions (shocks)
- Earth atmosphere blocks almost all millimeter and submillimeter lines of water
- Most interesting lines in the far infrared and in the mid-infrared (bending mode). High Aij's, high energy levels, high frequencies

ISO capacities for the observation of water

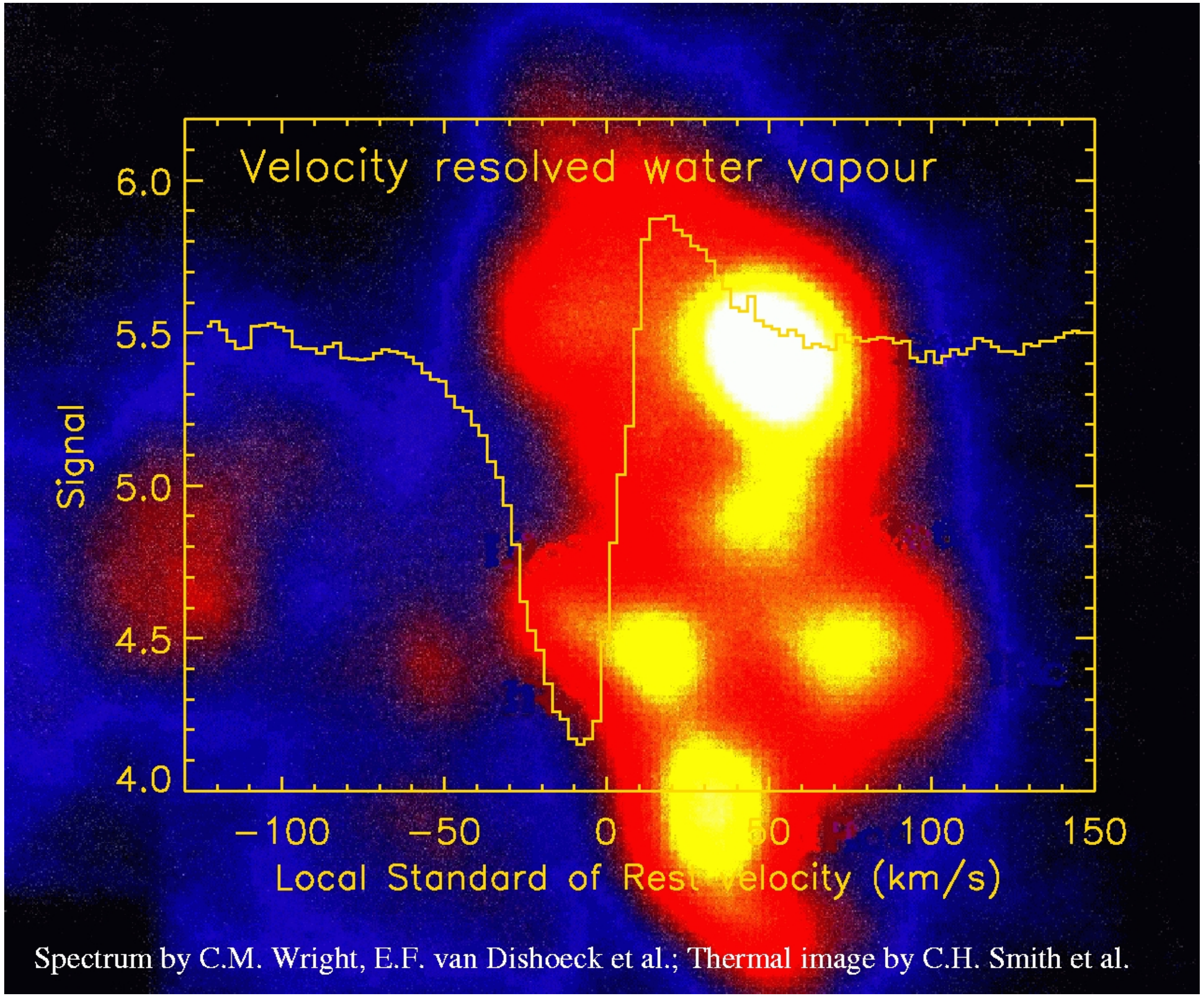
- SWS : high excitation pure rotational lines and the ro-vibrational lines of the stretching and bending modes
- LWS : pure rotational lines
- ISOCAM and LWS : Water Ice
- Main goal in the GT and the open time for many observers

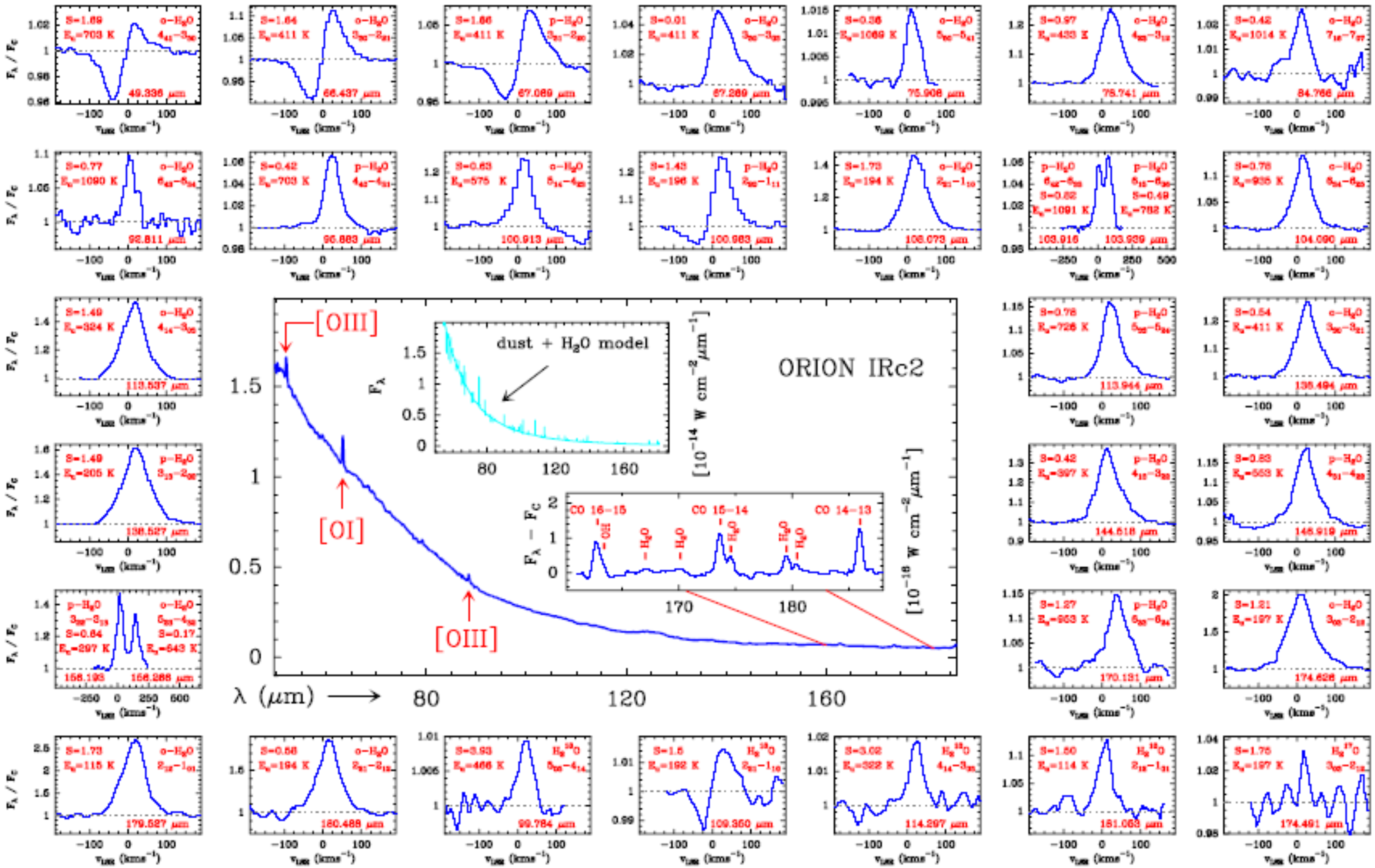
WATER IN WARM REGIONS AROUND HIGH MASS STARS



Helmich et al., 1996. ISO/SWS

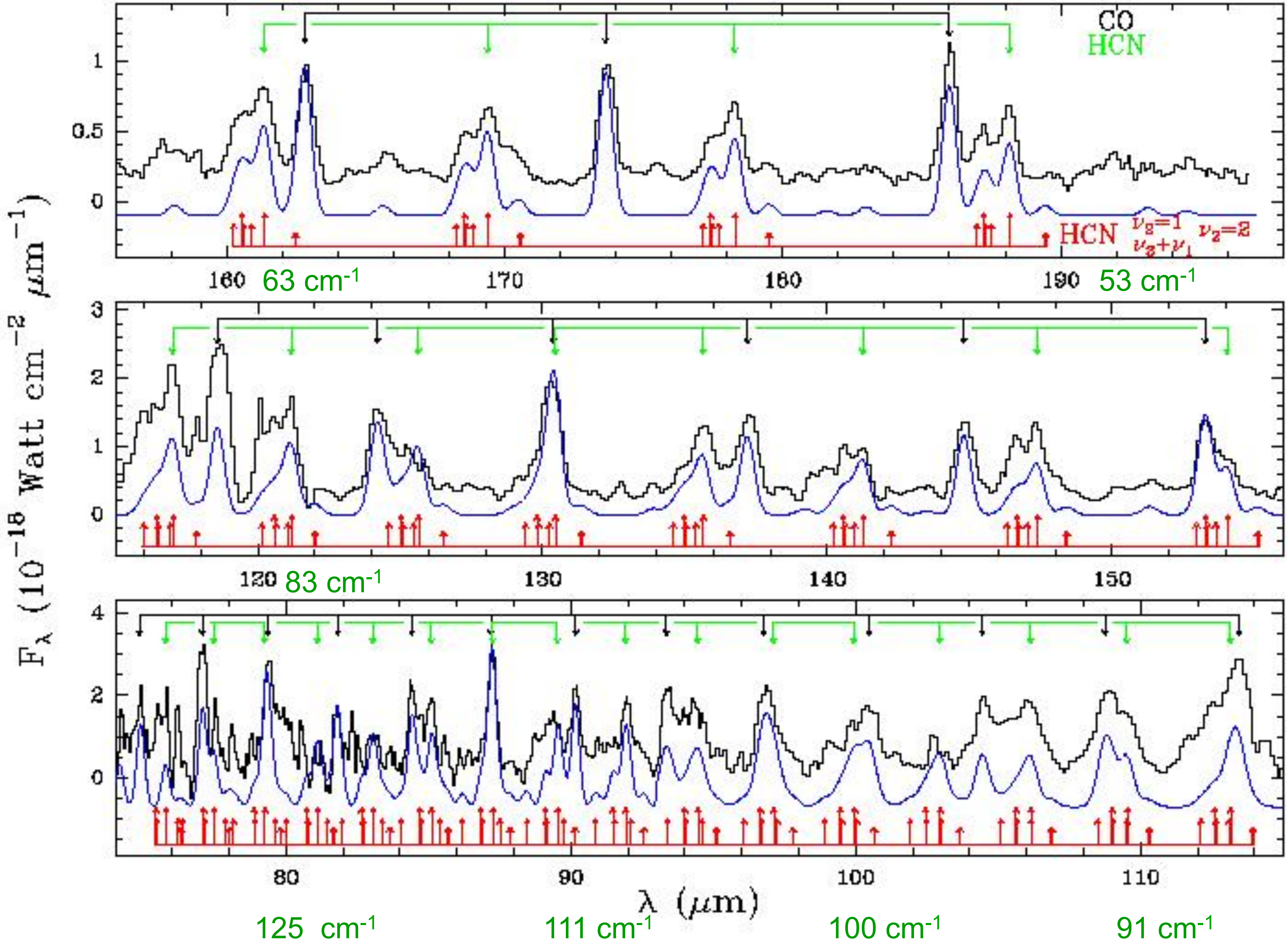
Water in High Mass Star Forming Regions

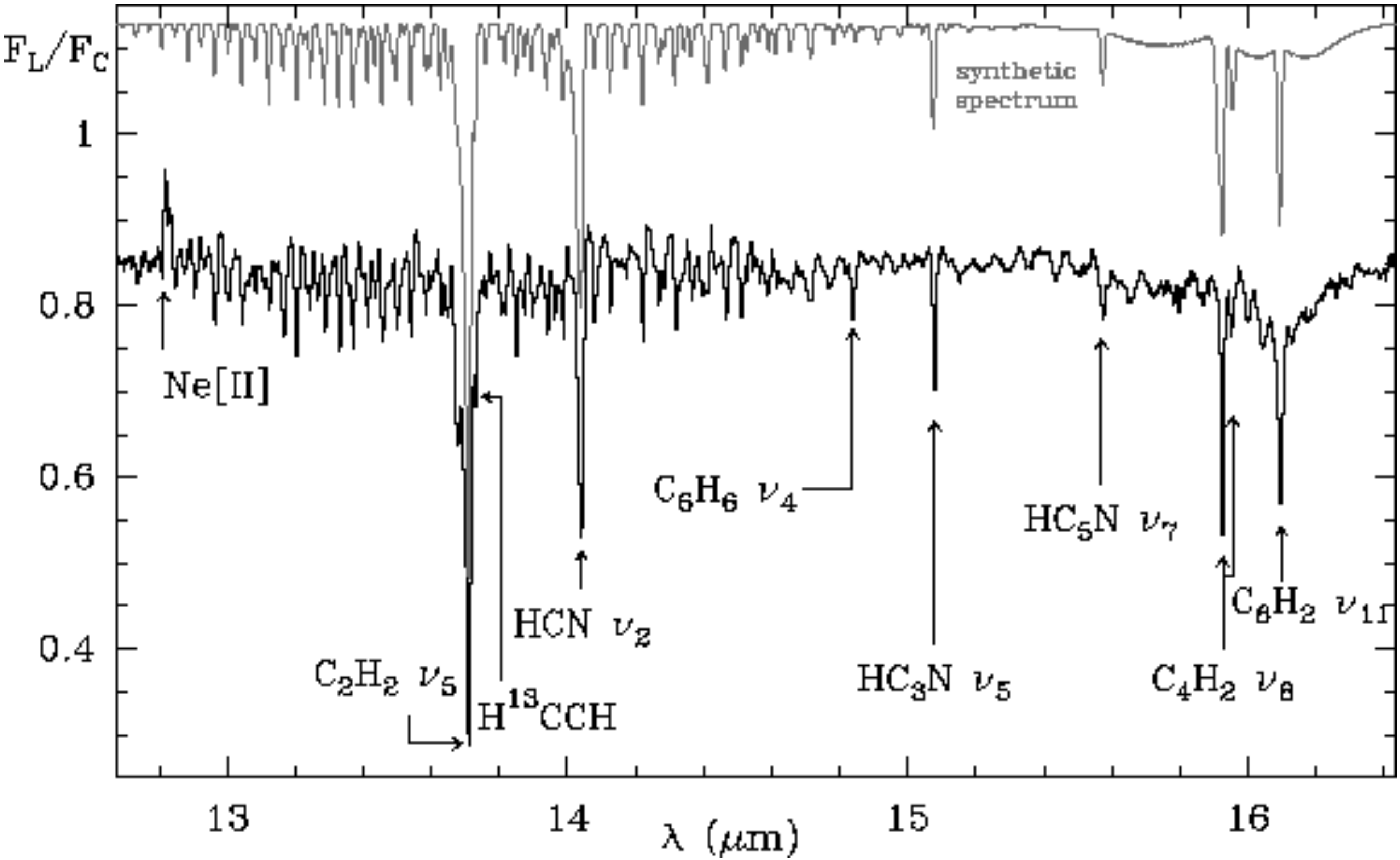




Cernicharo et al., 2006. ISO/LWS FP

Cernicharo et al., 1996, A.&A., 315, 201. IRC+10216 observed with ISO/LWS





F_L/F_C
1
0.8
0.6
0.4
13
14
15
16
λ (μm)
synthetic spectrum
Ne[II]
C_2H_2 ν_5
$H^{13}CCH$
HCN ν_2
C_6H_6 ν_4
HC_3N ν_5
HC_5N ν_7
C_4H_2 ν_8
C_6H_2 ν_{11}

Spitzer Space Telescope

NASA's follow-up mission for IRAS.
Originally seen as a major facility for Spacelab (heavily relying on the Space Shuttle program).

1985 (seeing the success of IRAS): NASA goes for a space observatory

Late 1980s and 1990: hard times for SIRTF

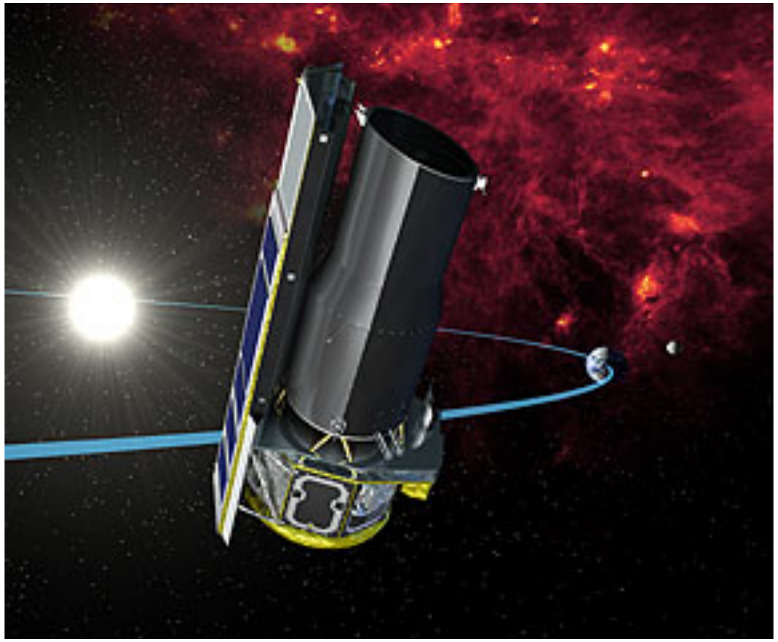
- Challenger explosion
- drastic budget cuts
- serious descoping of the mission

Finally launched in Aug 2003 – end of cold phase in Apr 2009

Spitzer Space Telescope

Main novelties compared to IRAS and ISO

- Earth-trailing heliocentric orbit
- warm-launch cryogenic architecture (only instruments cooled to cryogenic temperatures)
- spectacular increase in detector technology
- increased spatial resolution
  with 85 cm primary mirror



The telescope and the instruments

- Aperture (mirror diameter): 85cm
- 3 instruments: IRAC, IRS y MIPS, with arrays of detectors.

- Infrared camera (4 bands: 3.6, 4.5, 6.0 y 8.0 microns)
- Infrared Spectrograph (low and high resolution 5-38 microns).
- Infrared Photometer (3 bands: 24, 70 y 160 microns).

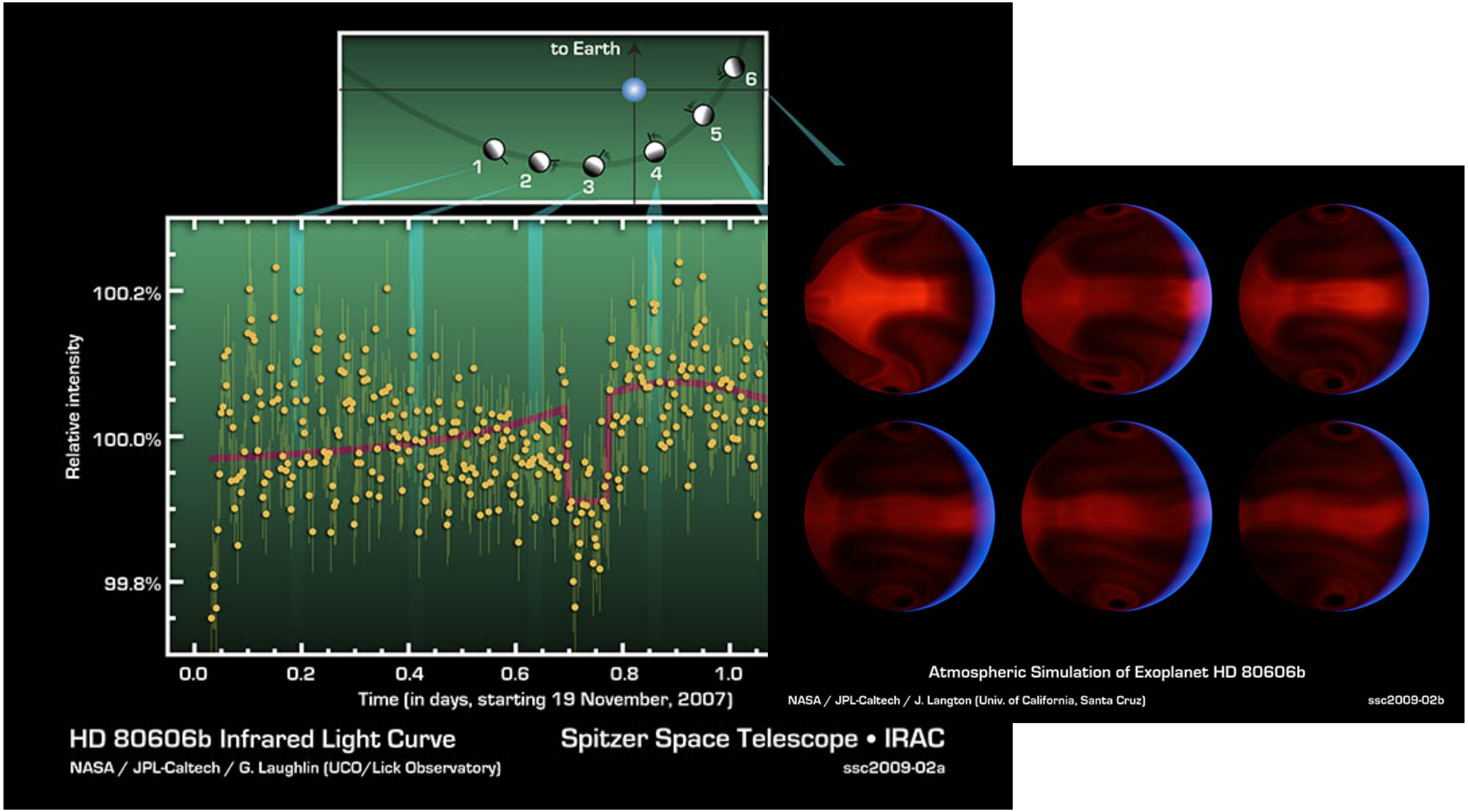
Spitzer legacy

Similar to ISO: general observations (no survey instrument)
Huge archive with loads of data still to be investigated

Similar to HST: legacy programs

Part of the Great Observatories:
Good synergy with HST

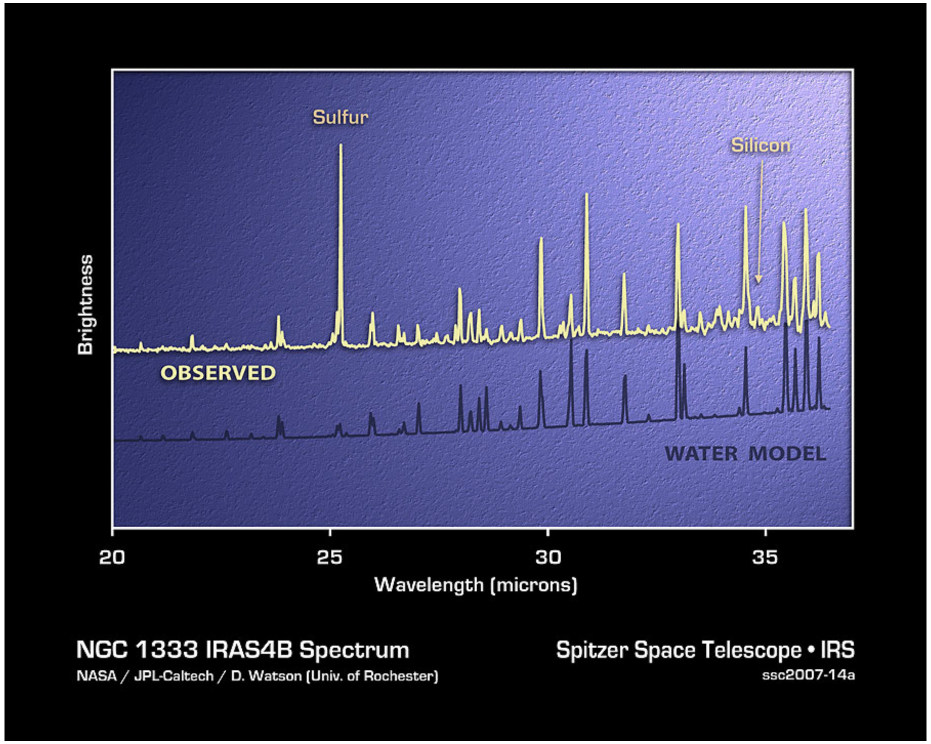
Thermal radiation of Exoplanets

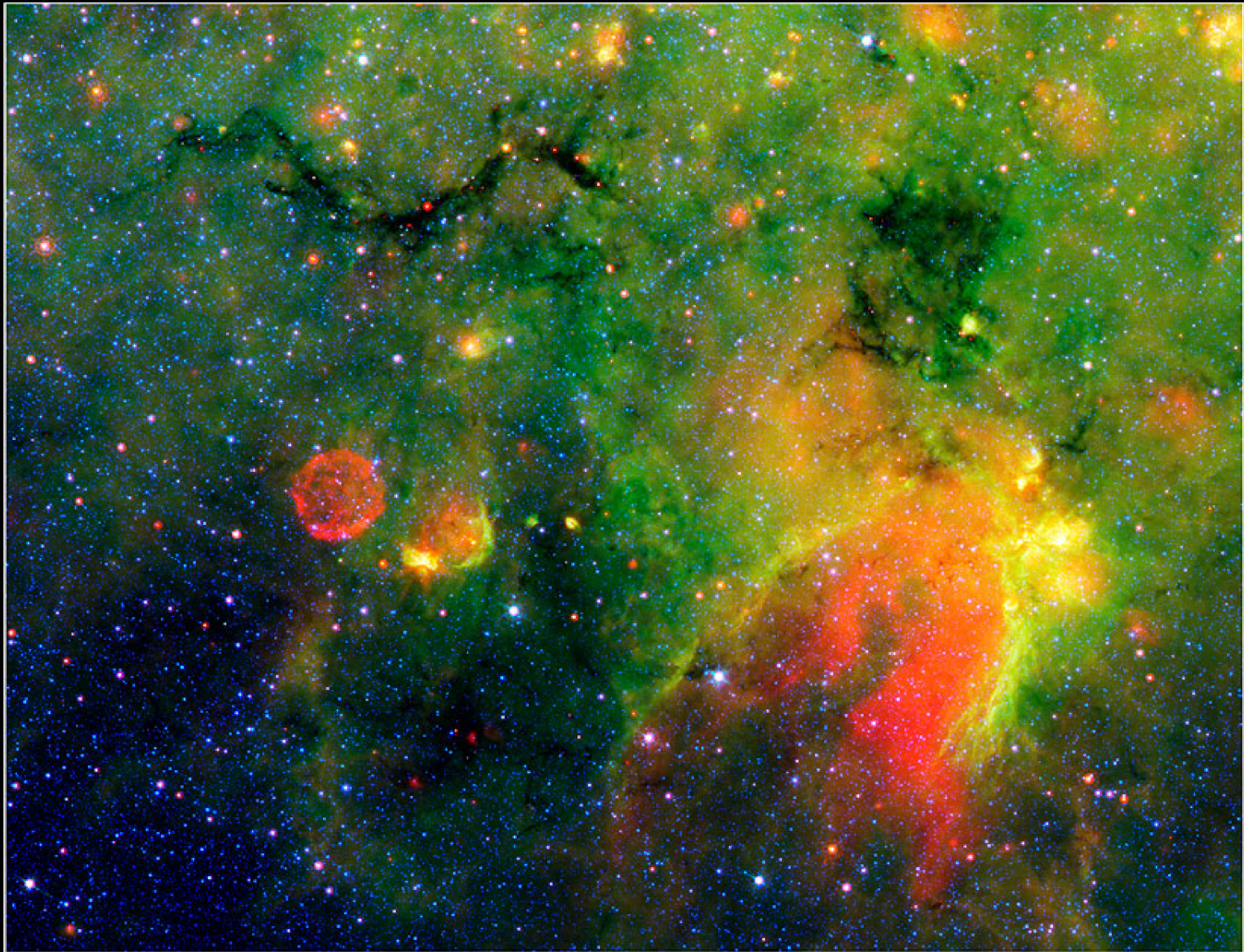


Proto Stars


Embedded Outflow in HH 46/47
Spitzer Space Telescope • IRAC
Inset: visible light (DSS)
NASA / JPL-Caltech / A. Noriega-Crespo (SSC/Caltech)
ssc2003-06f

Star Forming Region NGC1333 & the Source IRAS 4b: Water in action





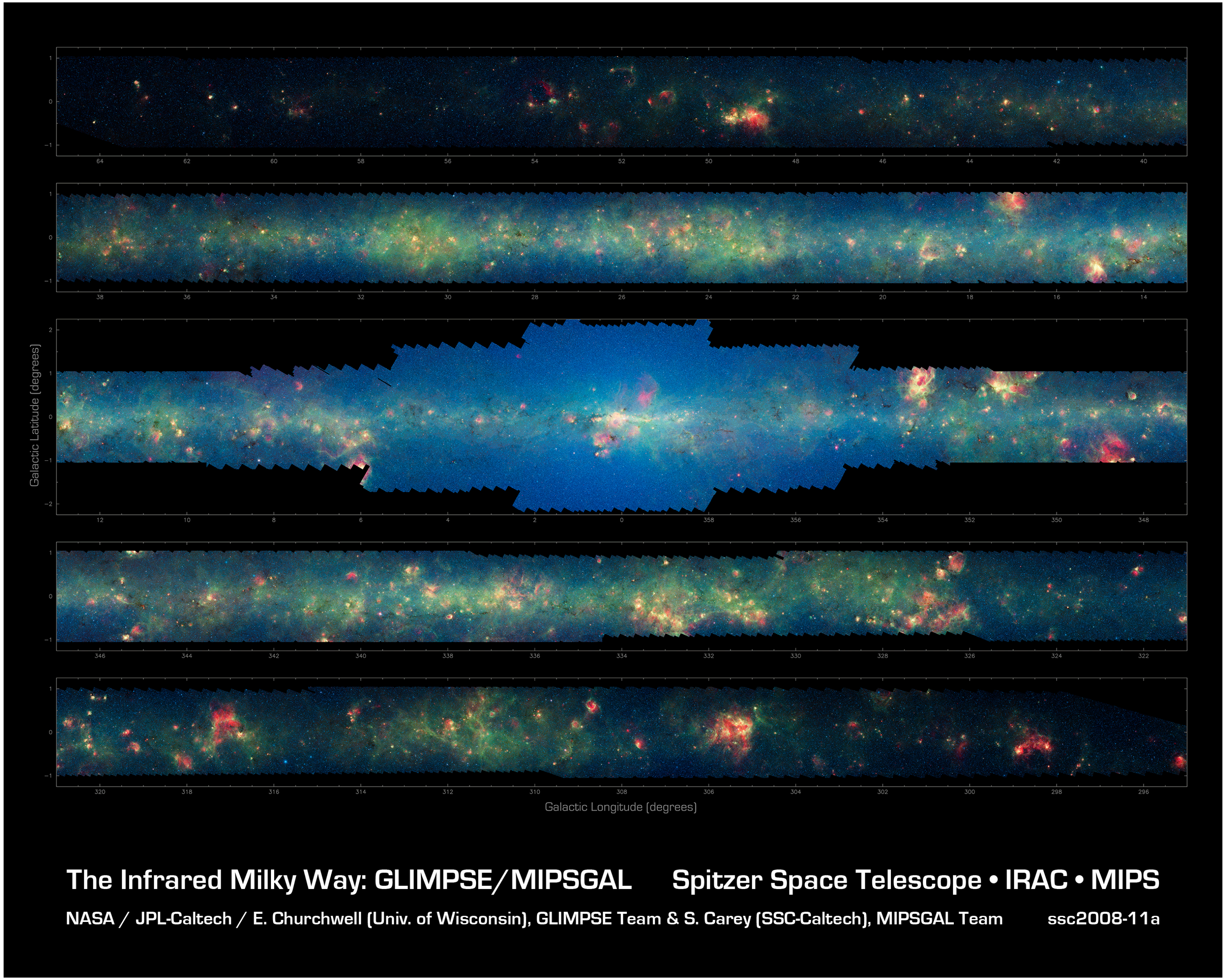
Star Formation and Dust in the Galactic Plane

NASA / JPL-Caltech / S. Carey (SSC)

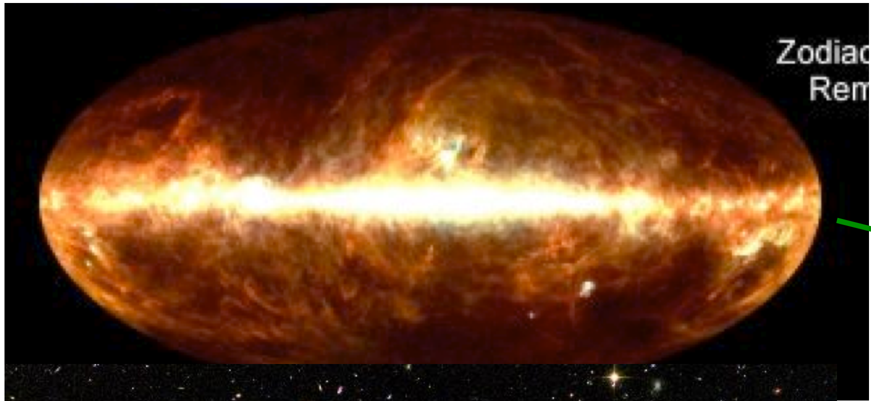
Spitzer Space Telescope • IRAC • MIPS

ssc2006-20a

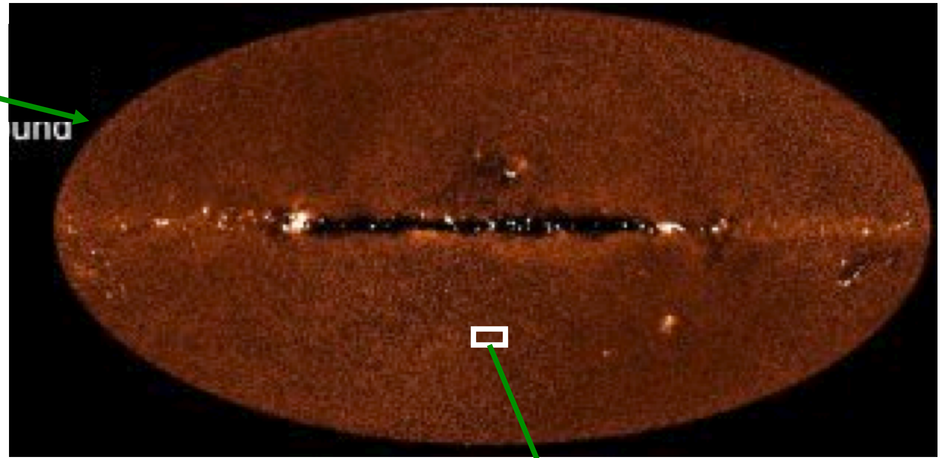
Infrared Surveys



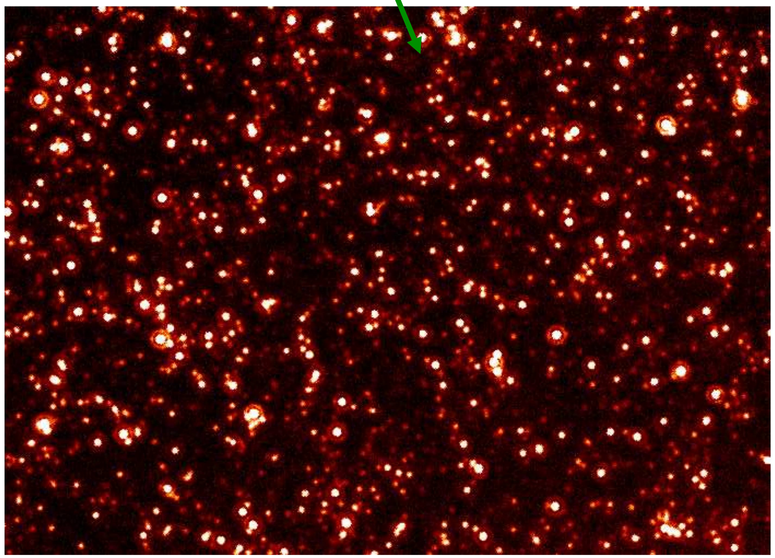
Deep Cosmological Surveys

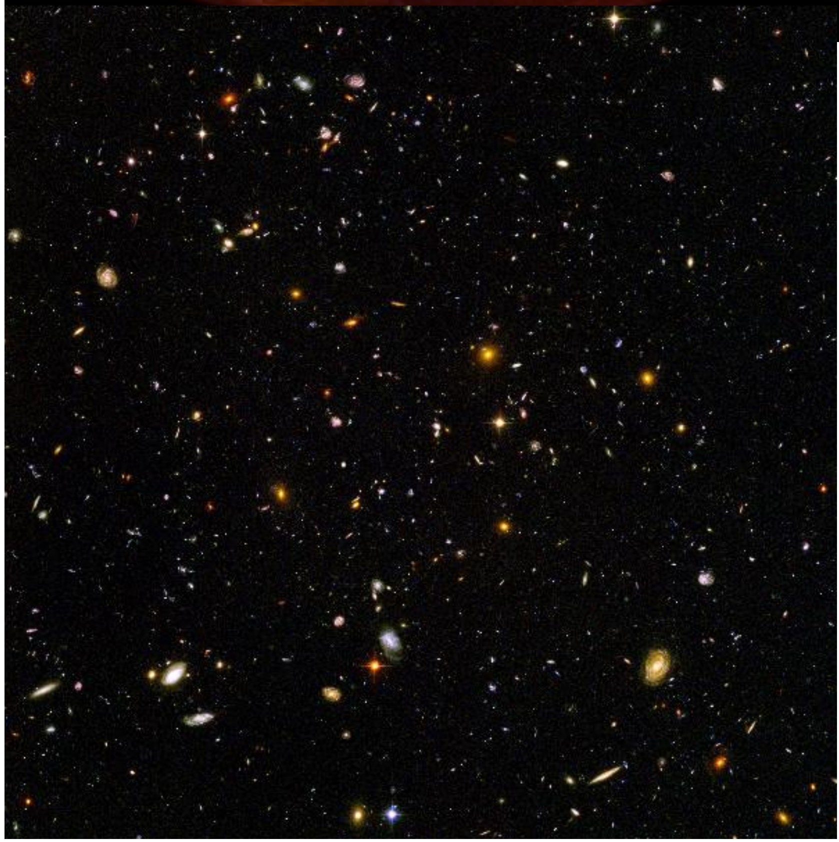


Radiación Infrarroja Cosmológica de Fondo

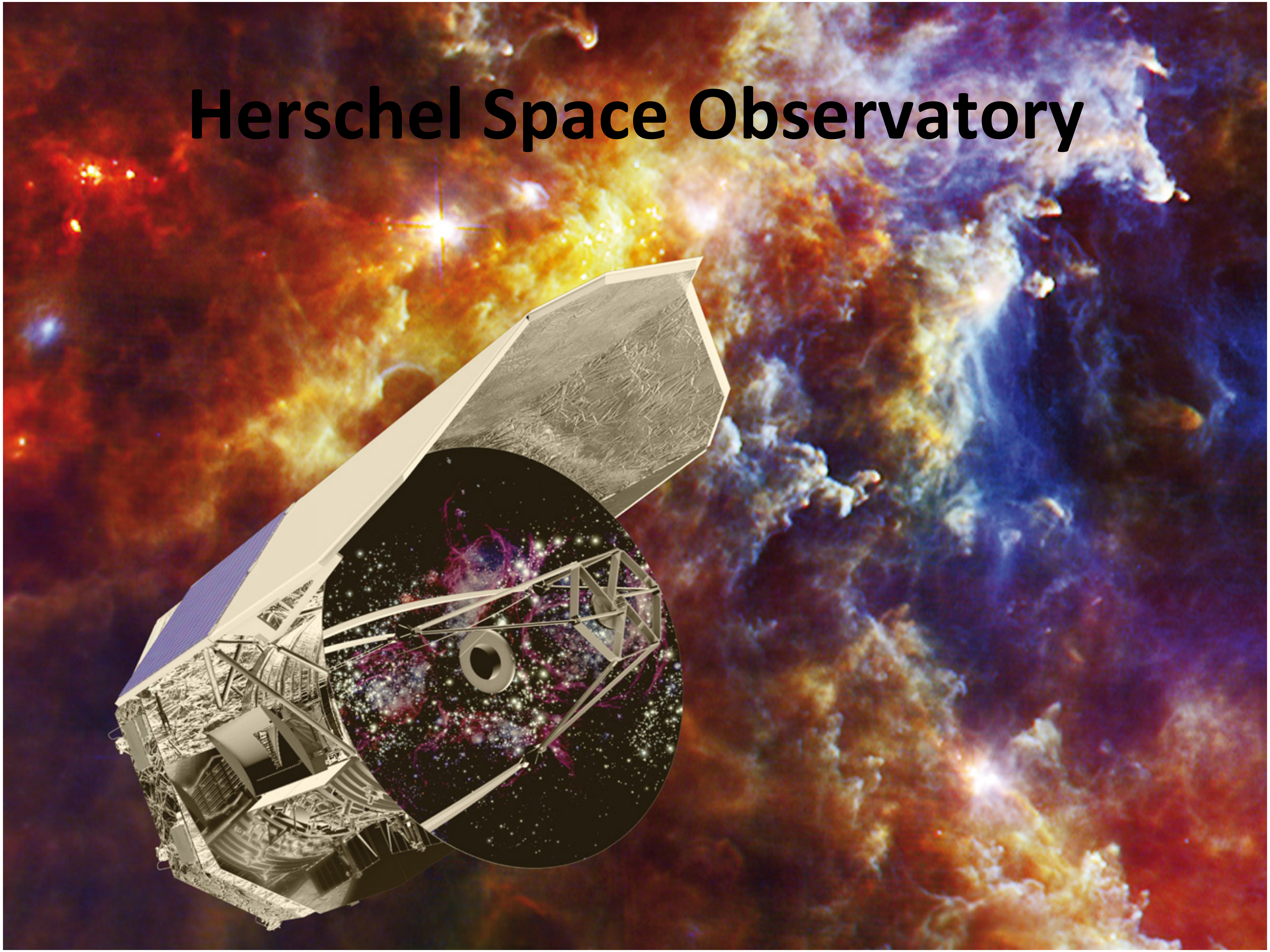


Galaxias Infrarrojas 24um





Campo Ultra-profundo de Hubble


Herschel Space Observatory

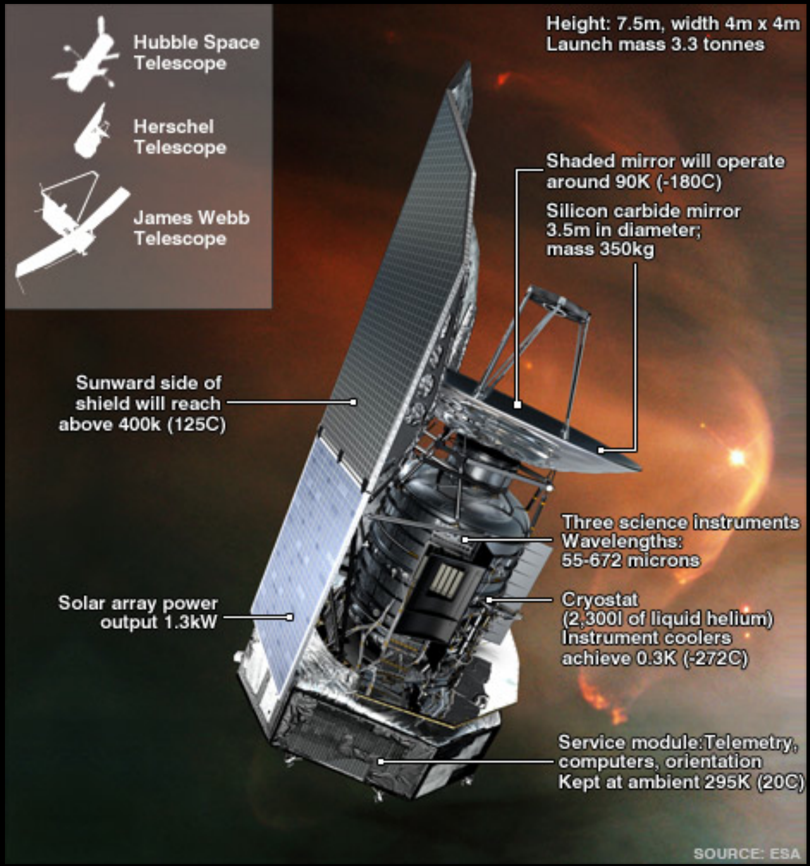
Herschel Space Observatory

State-of-the-art FIR observatory

Fourth cornerstone mission of ESA's Cosmic Vision 2005-2015
Contribution from NASA and CSA

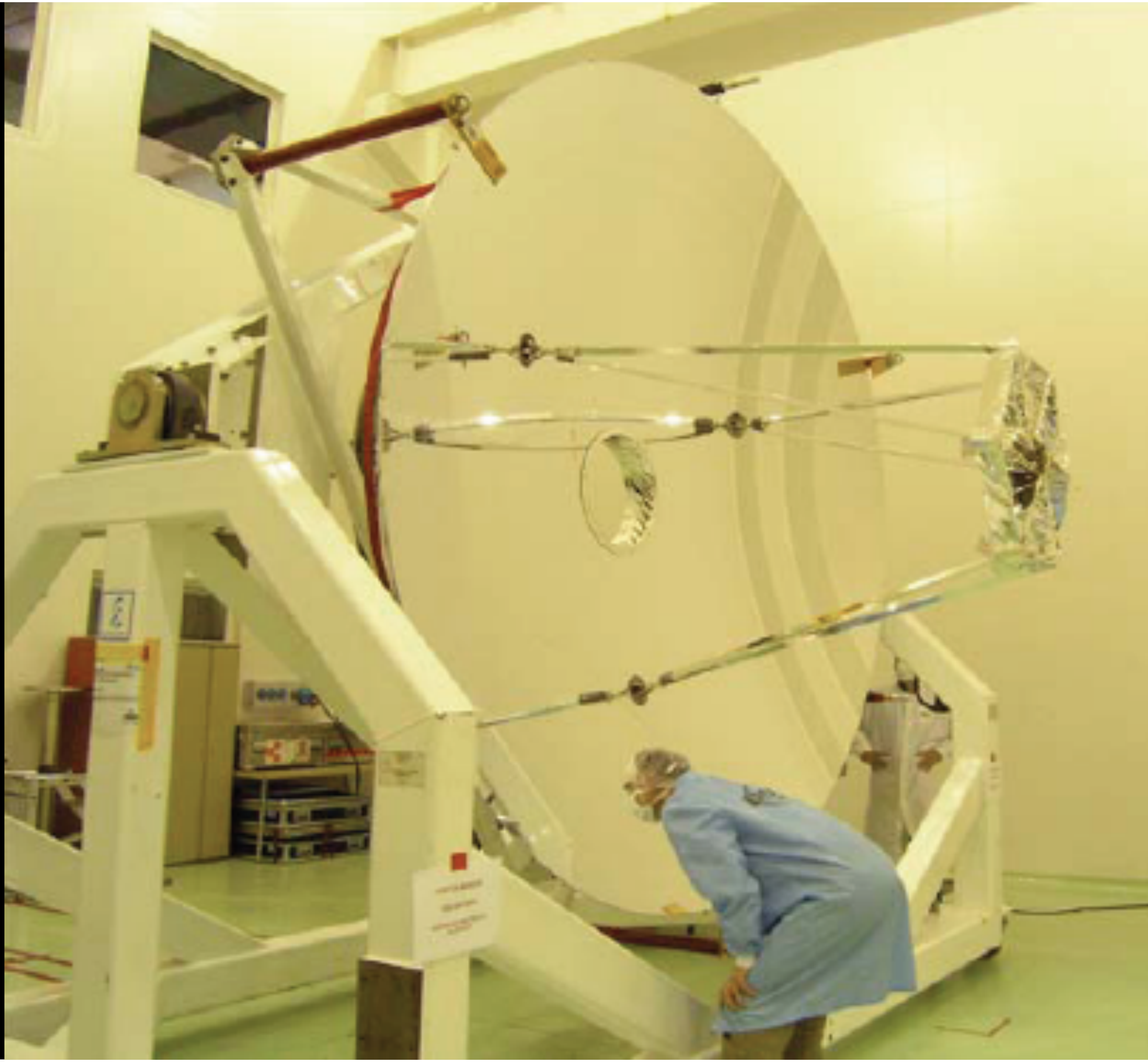
Proposed in 1982 as FIRST
Launched 14 May 2009, together with Planck

Estimated lifetime: 3.5 years (2000 l liquid helium)



Herschel Space Observatory

- telescope diameter 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 4.0±0.4 years
- height / width ~ 7.5 / 4 m
- launch mass ~ 3200 kg
- power ~ 1500 W
- orbit ‘large’ Lissajous around L2
- solar aspect angle 60-120 deg
- launcher (w Planck) Ariane 5 ECA



Herschel 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

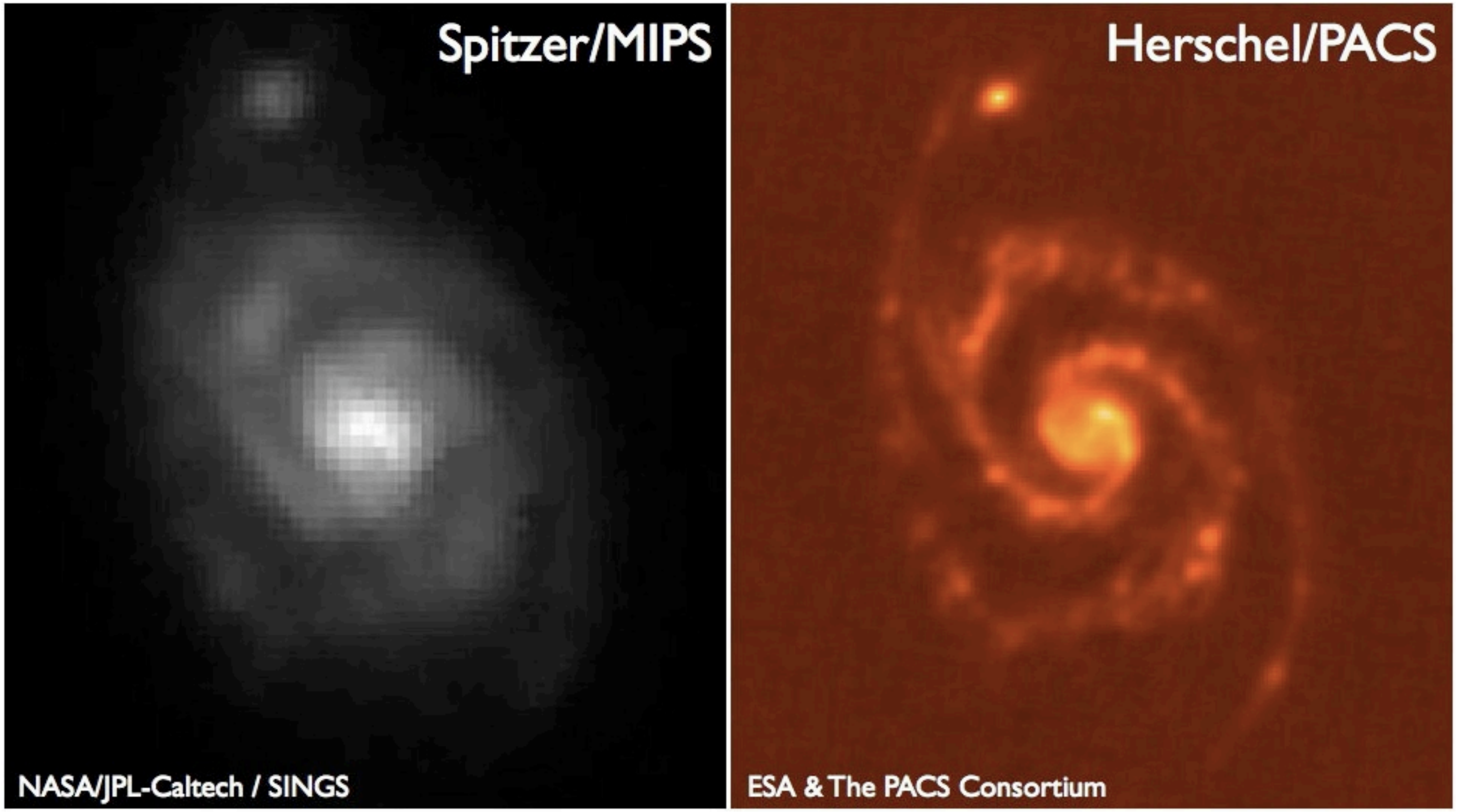
- **SPIRE - Spectral and Photometric Imaging REceiver**
  - PI: Matt Griffin, U Cardiff, Cardiff, United Kingdom
  - imaging photometry and spectro-photometry/-scopy over 200-670 μm
  - 3 bolometer arrays for photometry, 2 bolometer arrays for spectroscopy

- **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

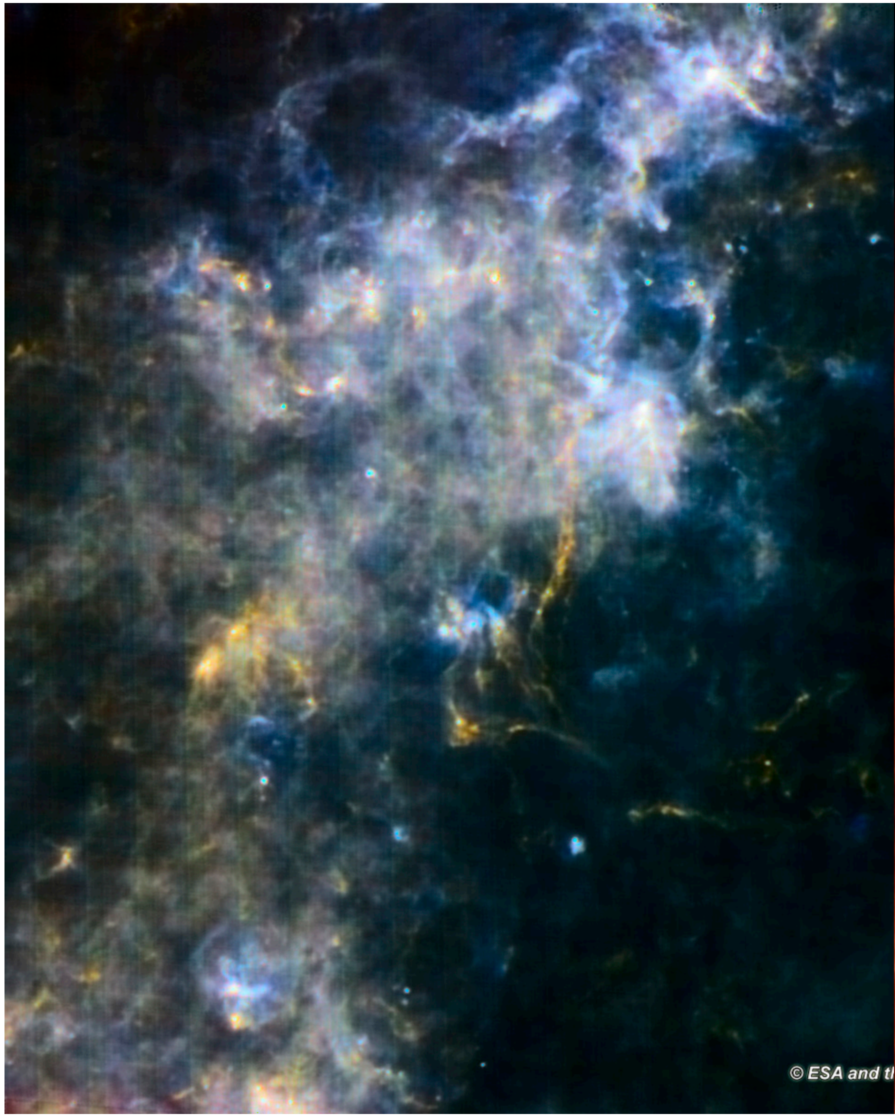
May 2009

Herschel legacy

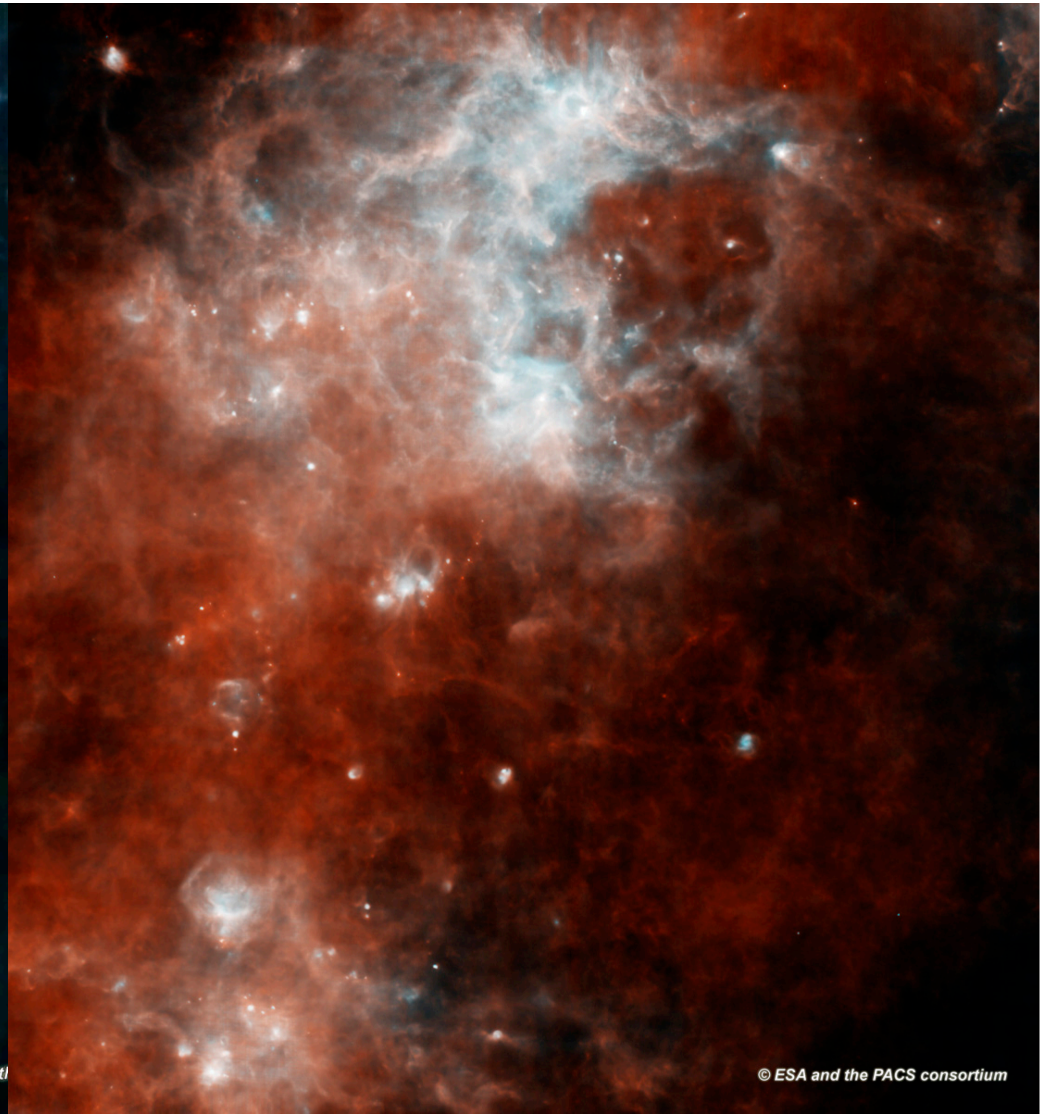
Mode of operations: 1/3 guaranteed time, 2/3 open time
First results were spectacular, the new results as well…



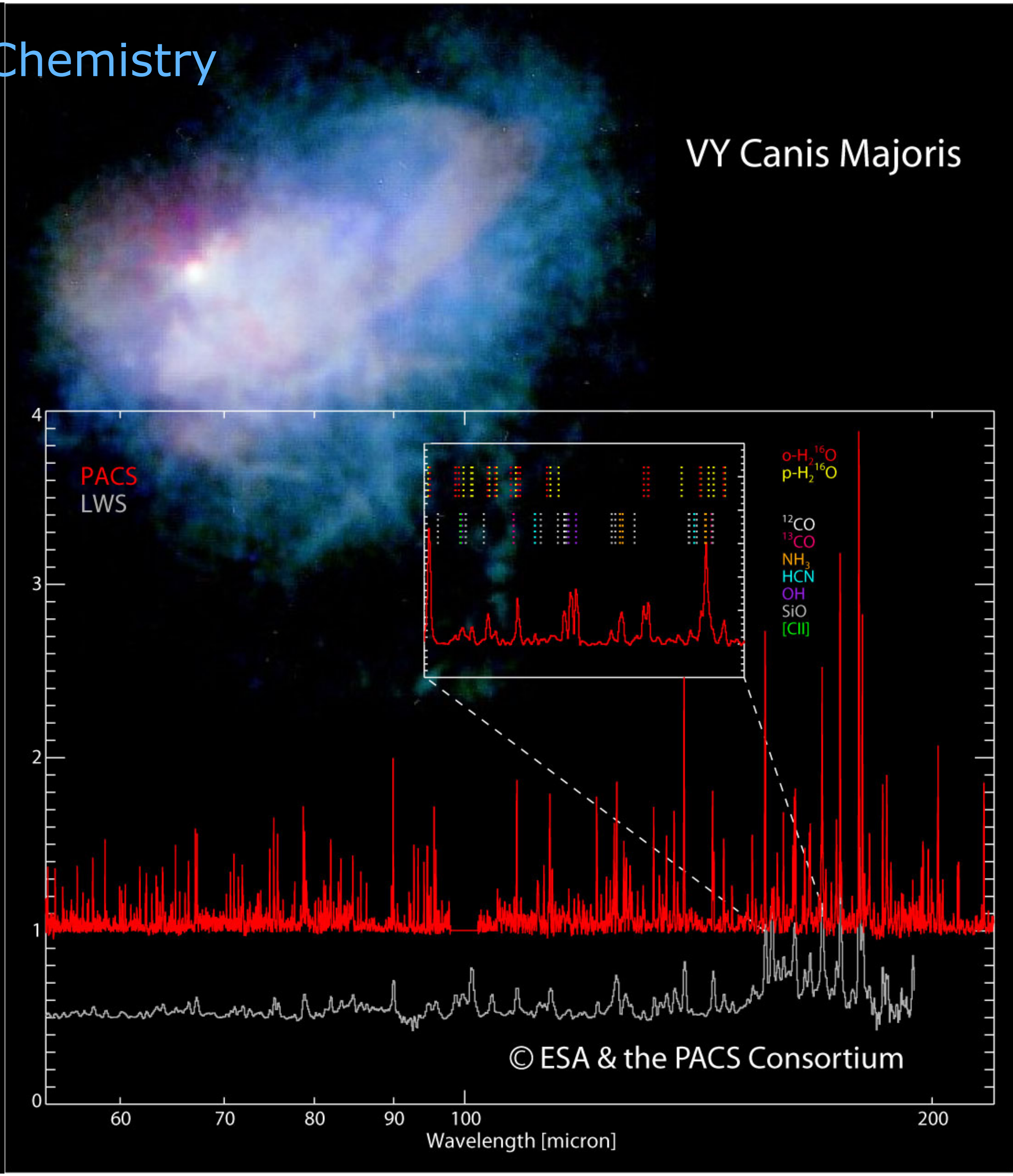
SPIRE

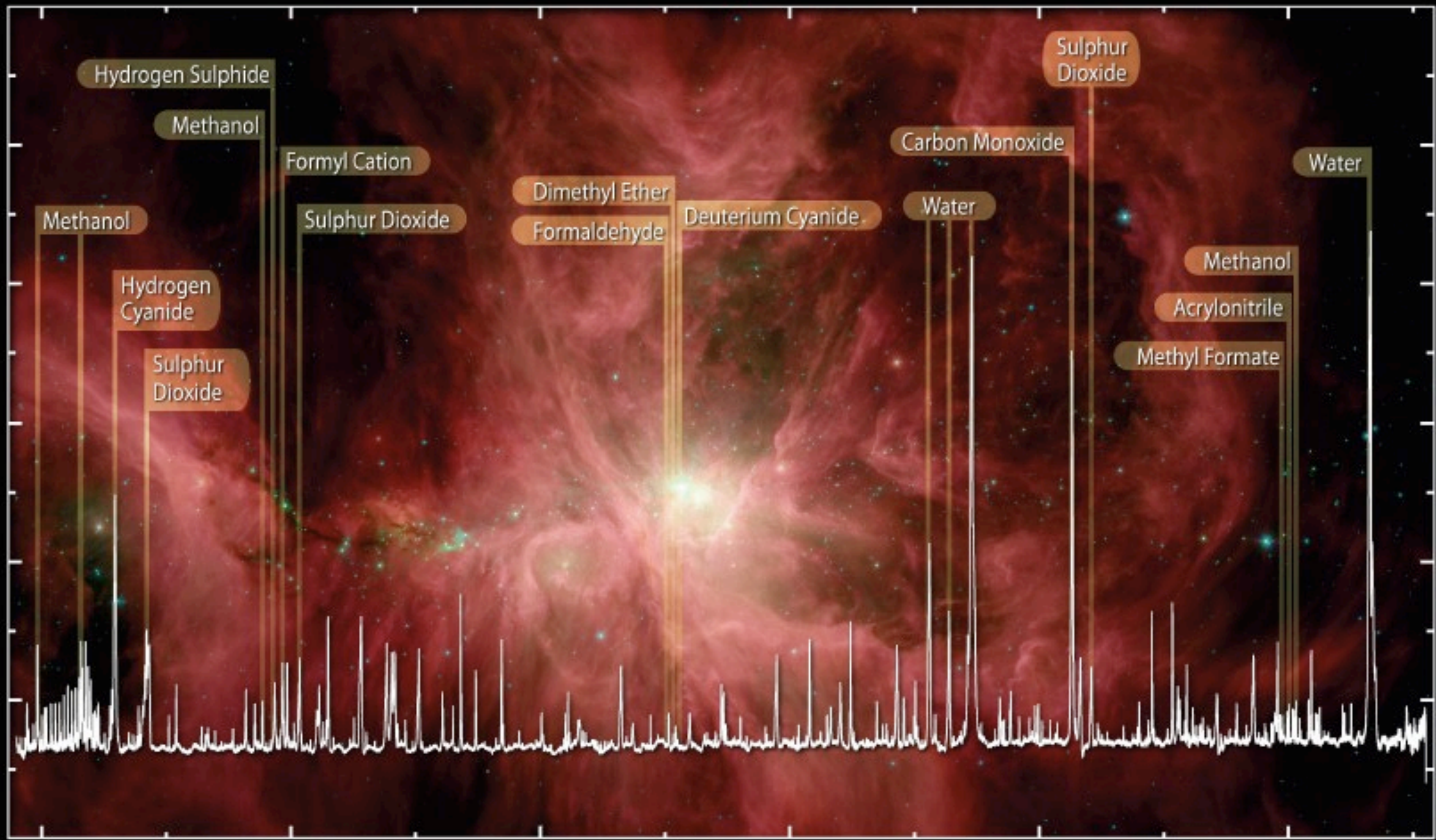


PACS



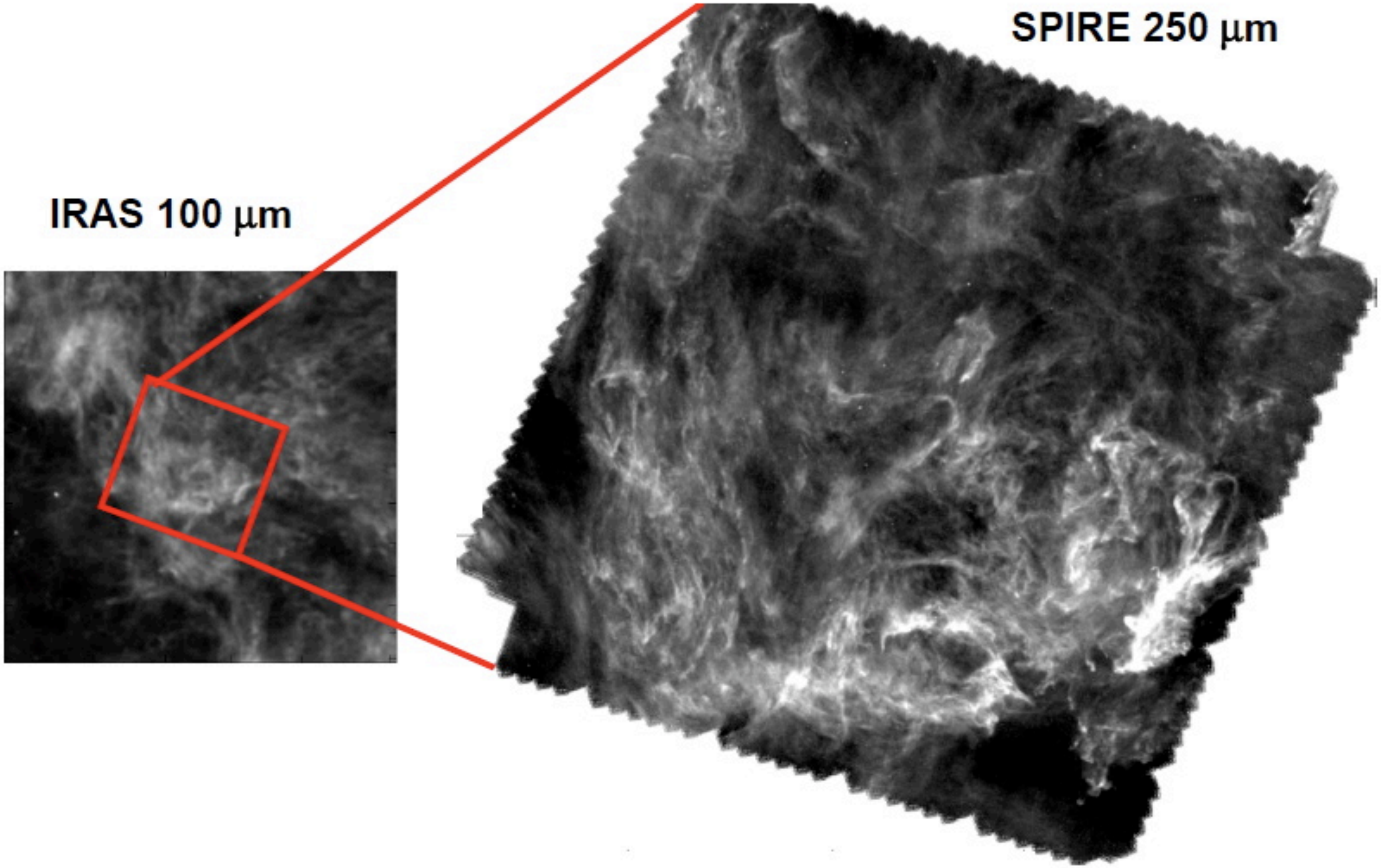
Complex Chemistry



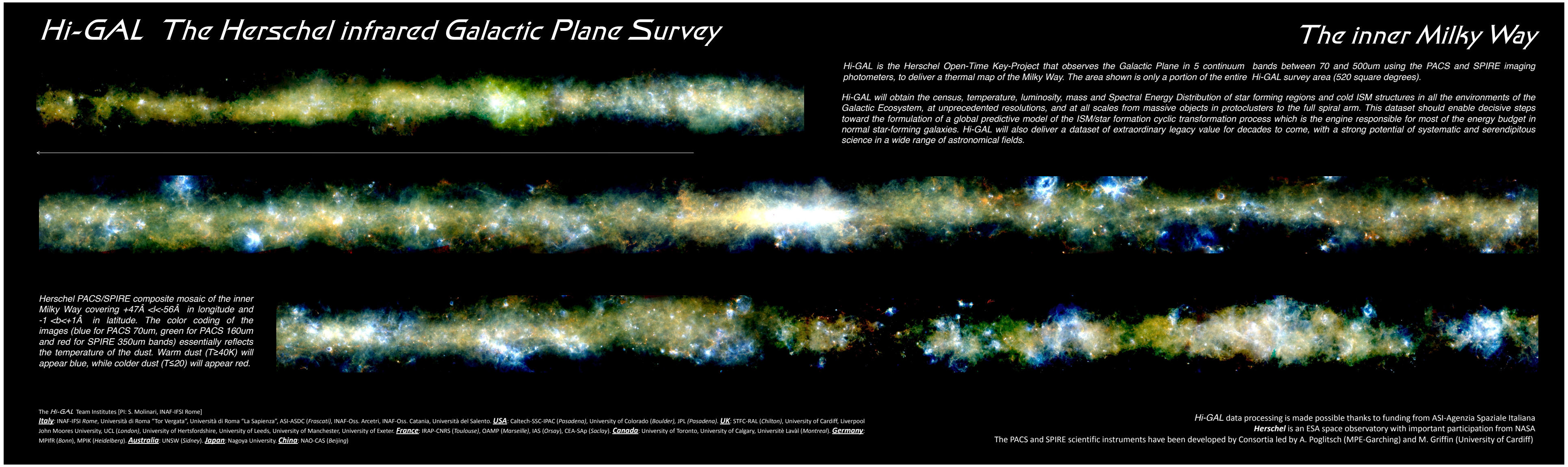


HIFI Spectrum of Water and Organics in the Orion Nebula

Polaris : a cirrus/molecular cloud

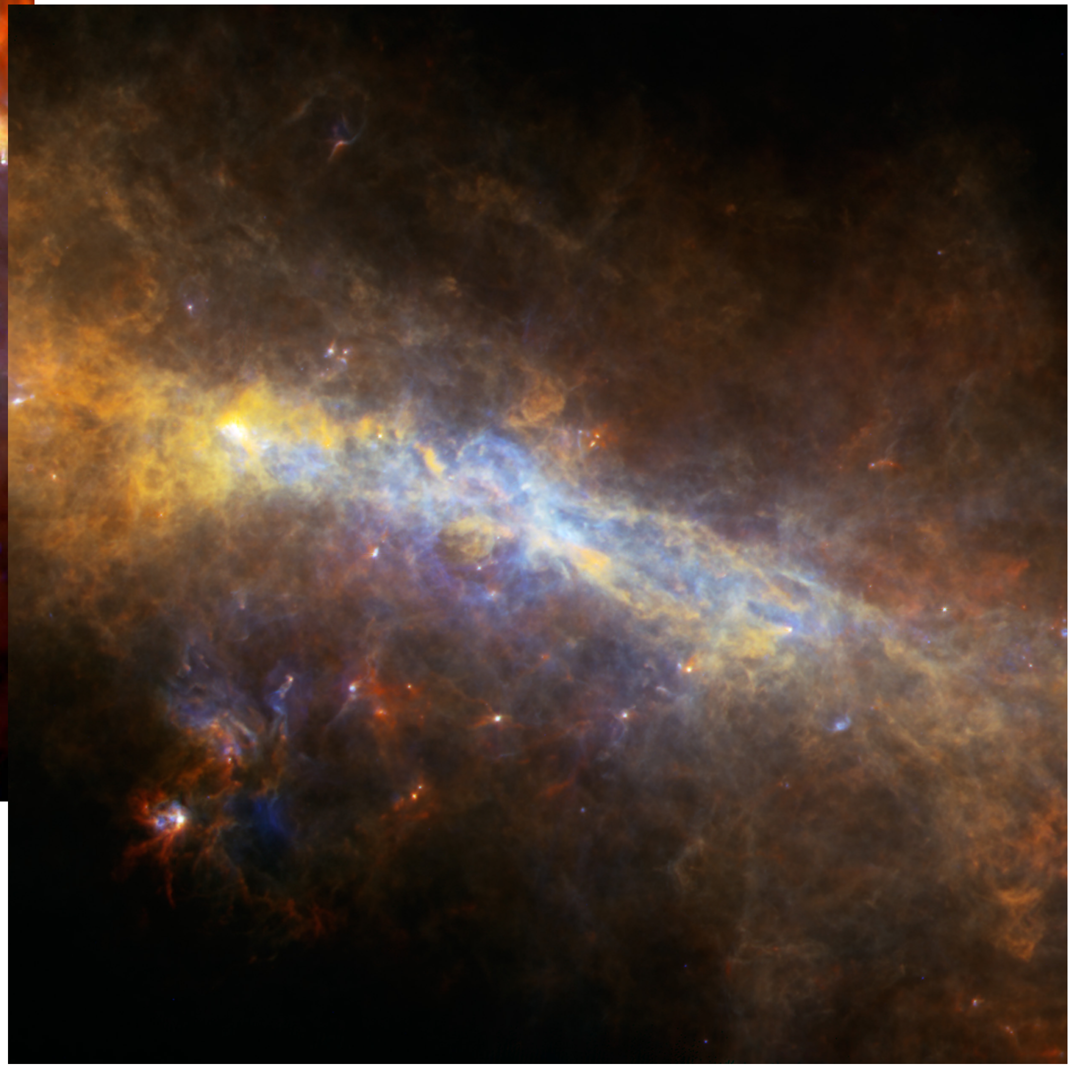


HiGAL: Map of the Galactic Plane

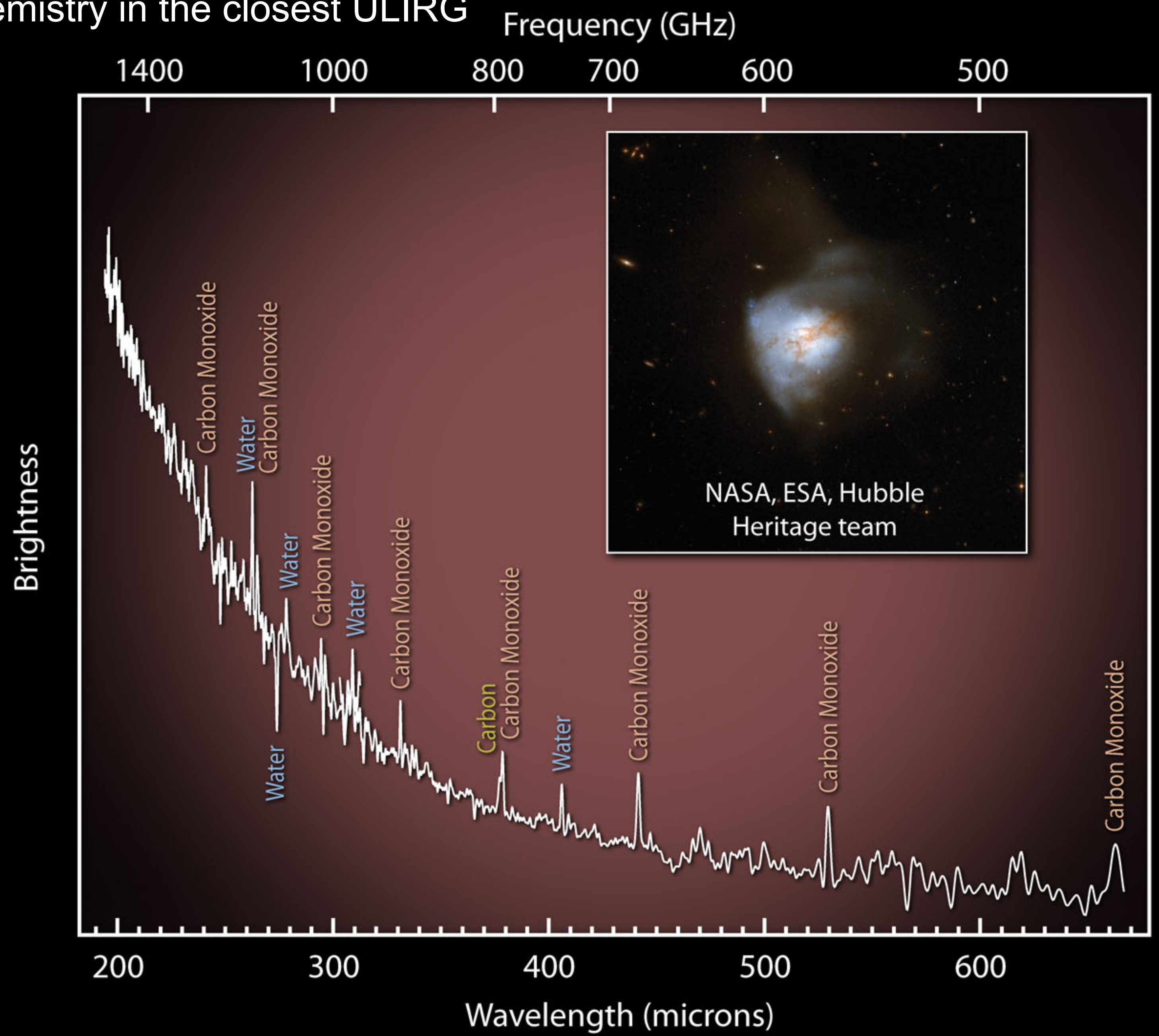


Aigle Nebula

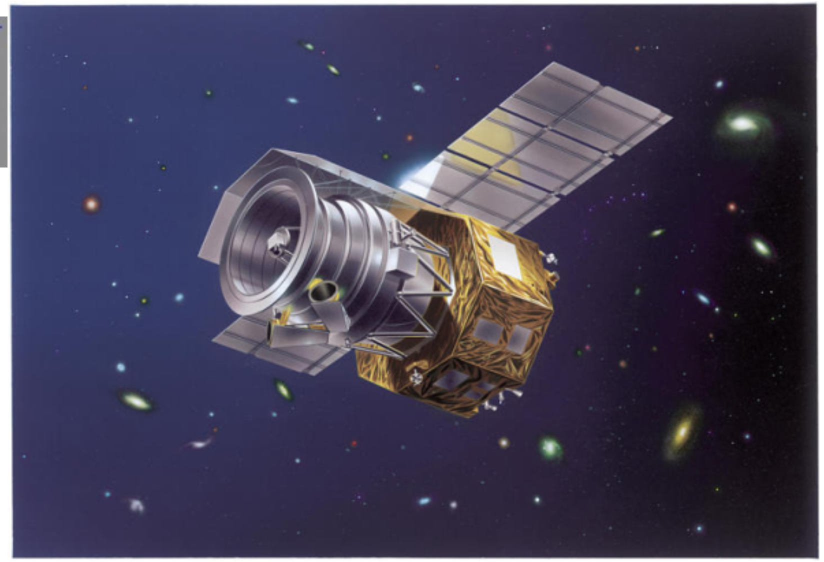
Galactic Center



Rich chemistry in the closest ULIRG

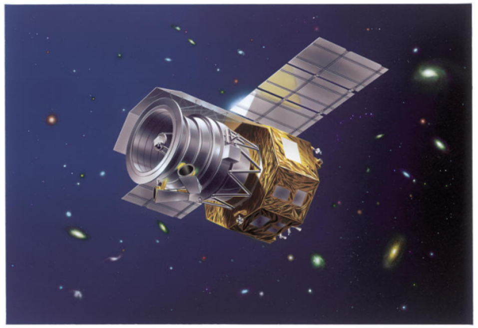


Arp 220



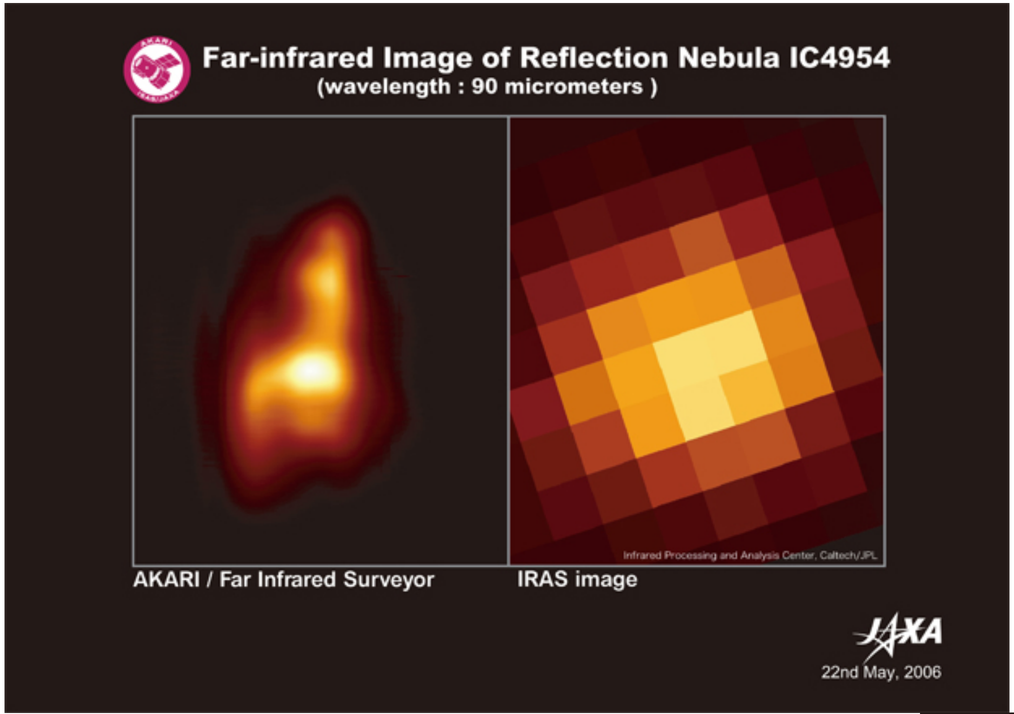
- 68.5 cm diameter telescope
- two main instruments:
  - the Infrared Camera (IRC) – for mid-IR
  - the Far-Infrared Surveyor (FIS) – for FIR
- launched in February 2006
- 16 month cryogenic mission lifetime between May 2006 and August 2007 (needed for FIR observations; liquid helium ran out on 26 August 2007)
- now – the “warm” phase
- deeper; much better resolution than IRAS

AKARI



- 6 IR bands from 9 to 180 μm (broader range than IRAS and reaching longer wavelengths)

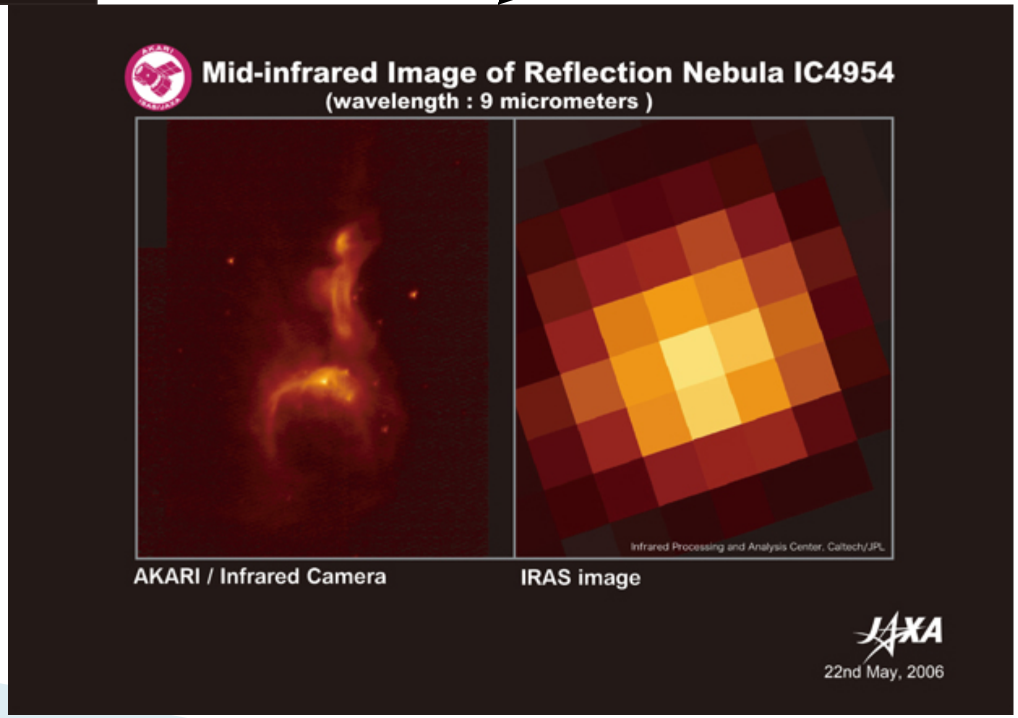
- Planned: All Sky Survey + two deep surveys (NEP and ADF-S) + a series of dedicated pointed observations



Improvement of resolution comparing to IRAS

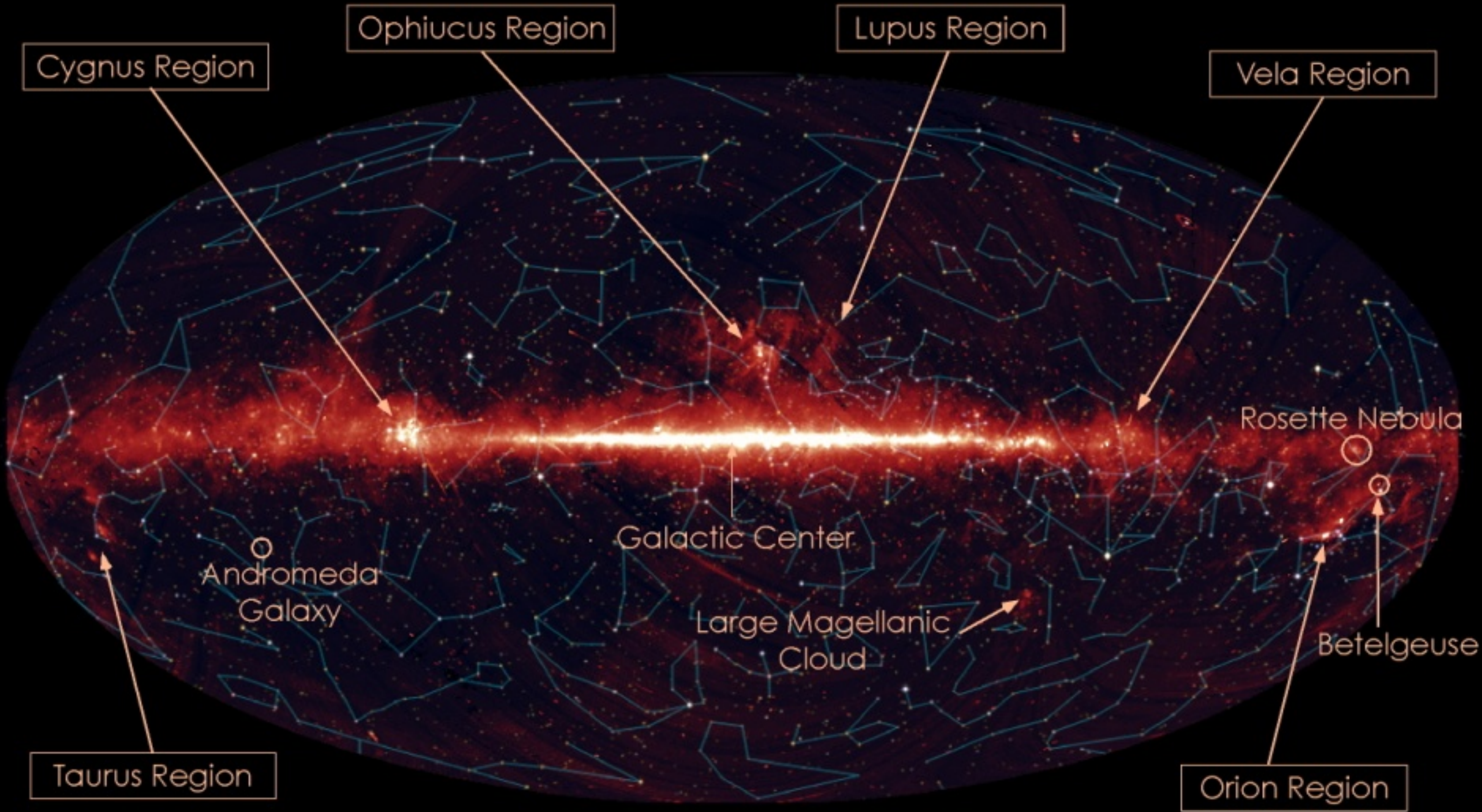
In MIR

In FIR



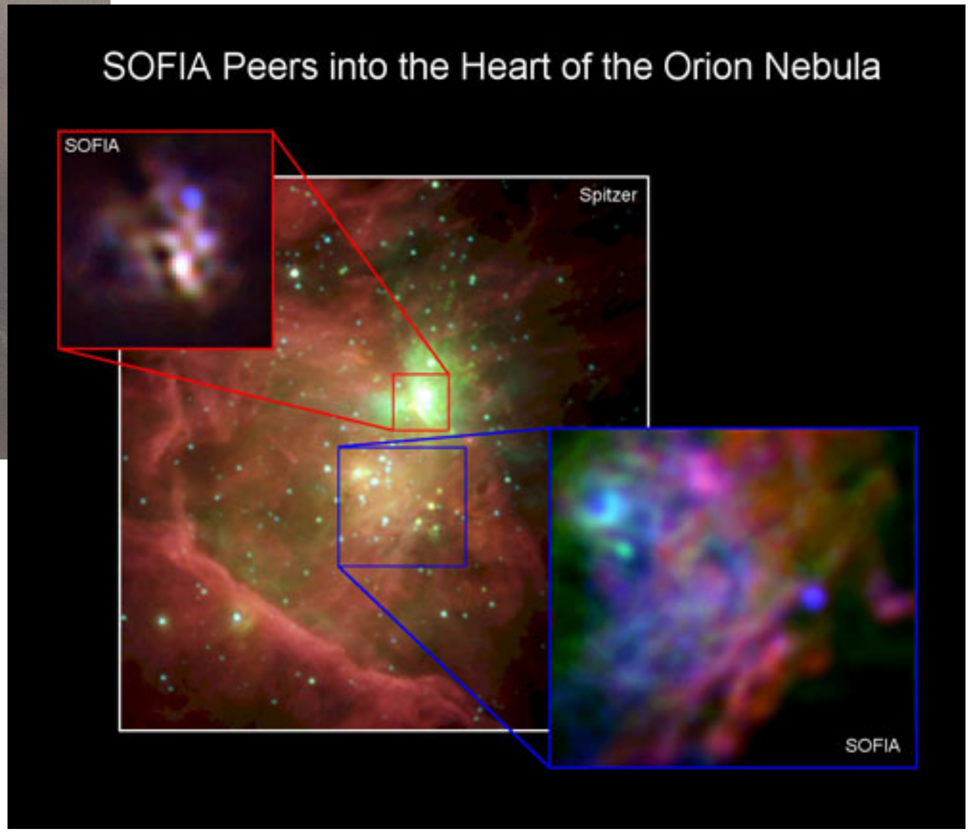
AKARI All-Sky survey at 9 μm

- Emission from the photospheres of stars dominates the 9 μm catalogue: the galactic disc and nuclear bulge are clearly visible at this wavelength



SOFIA (Infrared Stratospheric Observatory)

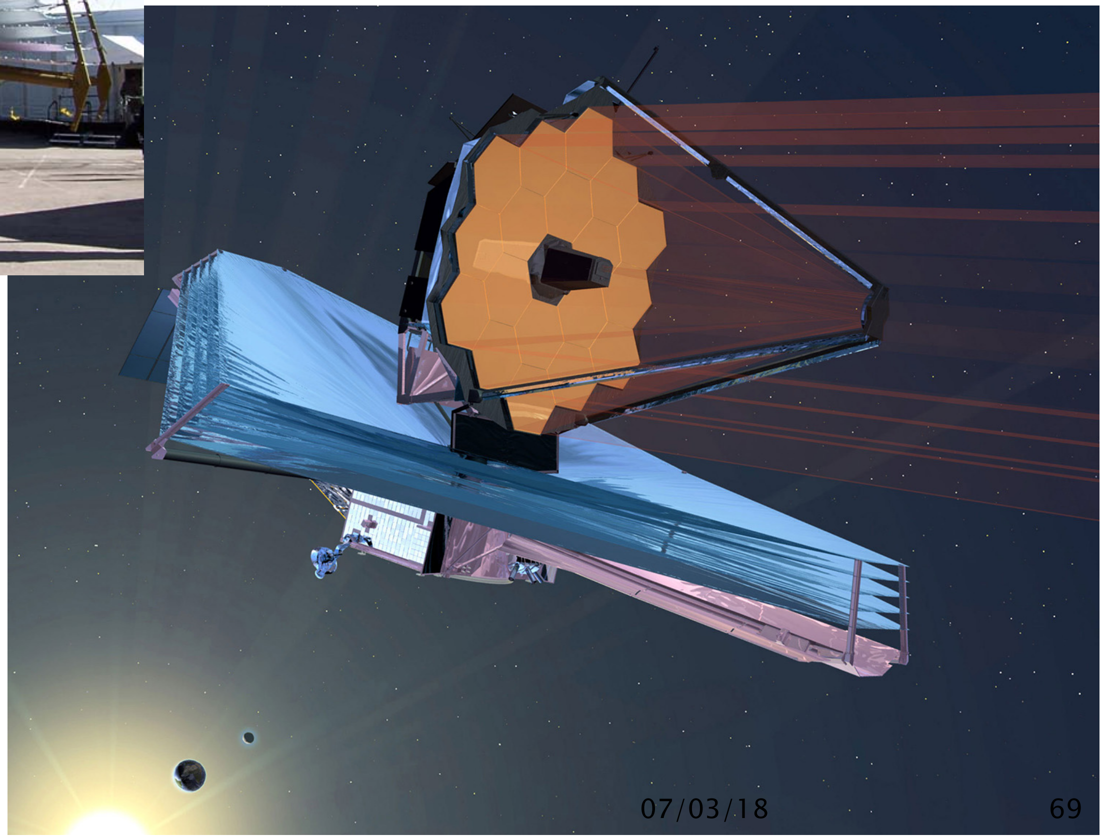
Telescope of 2.5m of diameter



FORECAST
Orion at 8, 20 & 37 micron

The near future:
The James Webb (JWST) Space Telescope

Real scale model



NANOCOSMOS

ALMA: a step beyond in observations

Atacama Large Millimeter Array

An European & Japan & North-American collaboration project

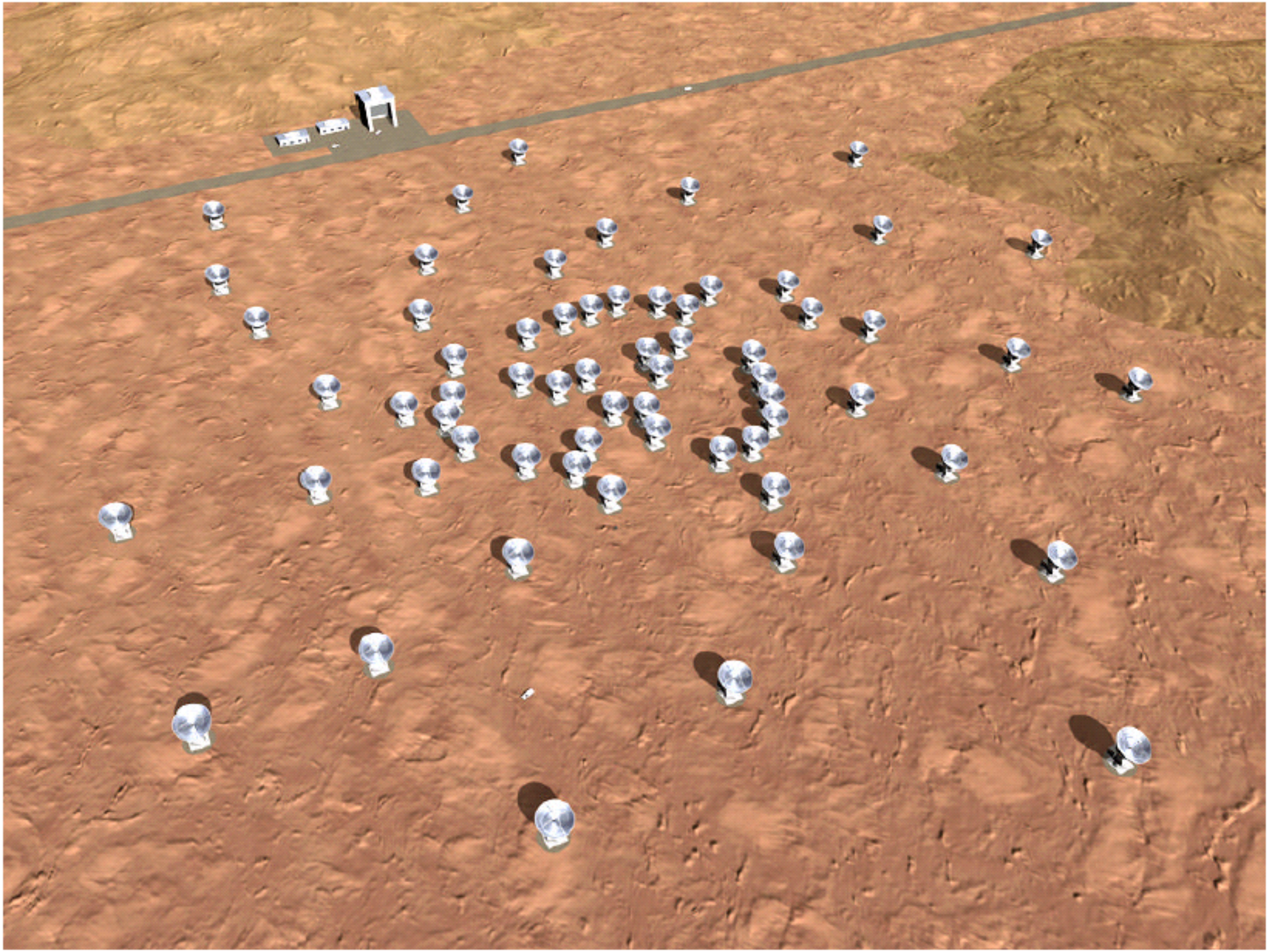
66 antennas with up to 18 km baselines.

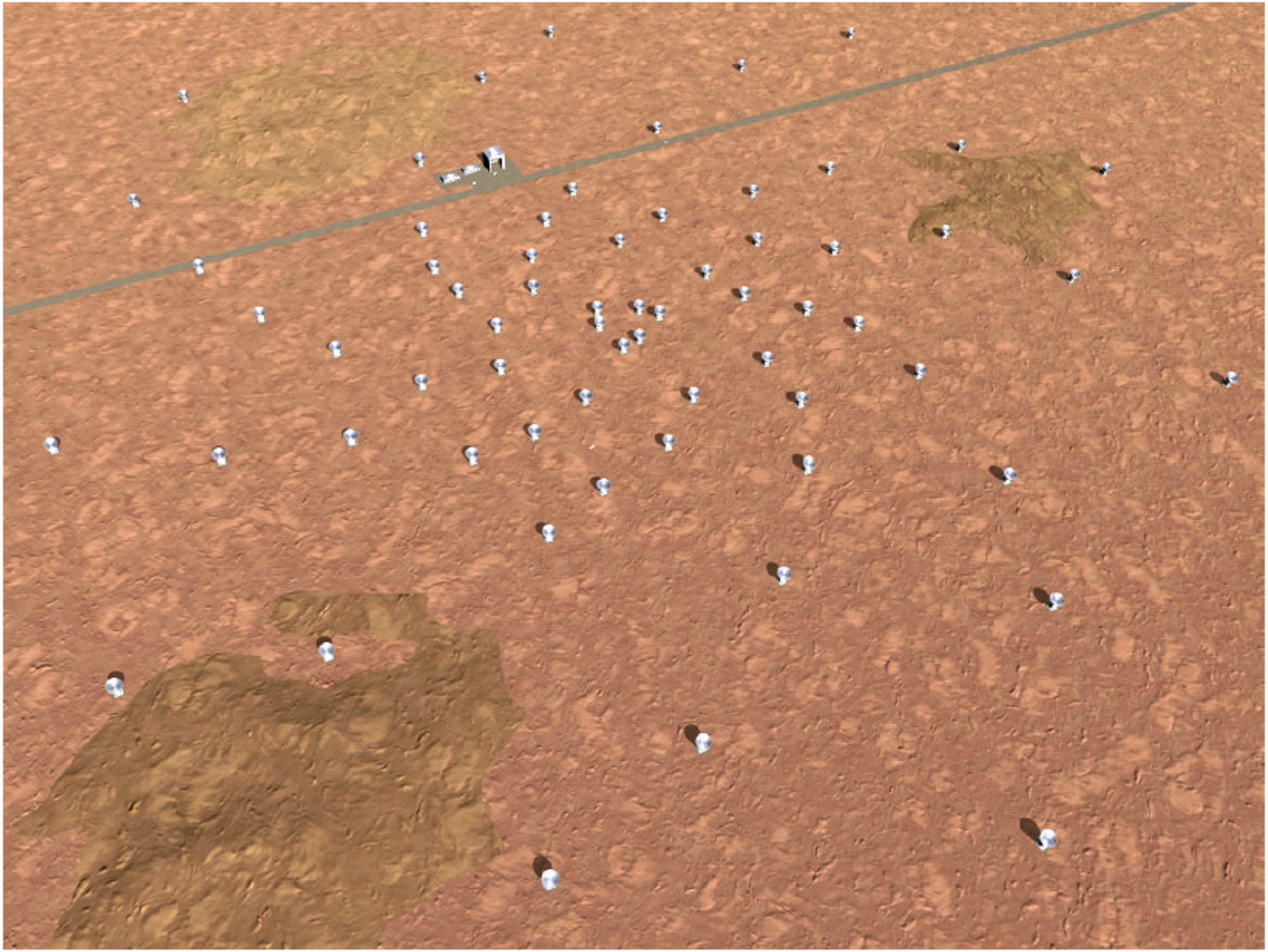
Around 10 times more collecting surface that any other instrument

Full operation end 2014

New and unexpected data are foreseen to come NOW

Unveiling the building blocks of the universe





ACRONYMS THAT WILL BE USED DURING THE SCHOOL

- **ISO/LWS Long wavelength Spectrometer**
- **ISO/SWS Short wavelength Spectrometer**
- **ISO/PHOT Far Infrared Photometer Camera**
- **Spitzer/IRAC**: Infrared Array Camera
- **Spitzer/IRS**: Infrared Spectrograph
- **Spitzer/MIPS**: Multiband Infrared Photometer
- **WISE**: Wide-Field Infrared Survey Explorer –
- **Herschel/PACS**: Photodetector Array Camera & Spectrometer
- **Herschel/SPIRE**: Spectral & Photometric Imaging Receiver
- **Herschel/HIFI**: The Heterodyne Instrument for the Far Infrared
- ALMA : Atacama Large Millimeter Array
- COBE, WMAP, PLANCK (see Tauber's talk)
- JWST (see Carey's talk)