The Herschel Space Telescope

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Thank Prof. Cheng Li

Outline

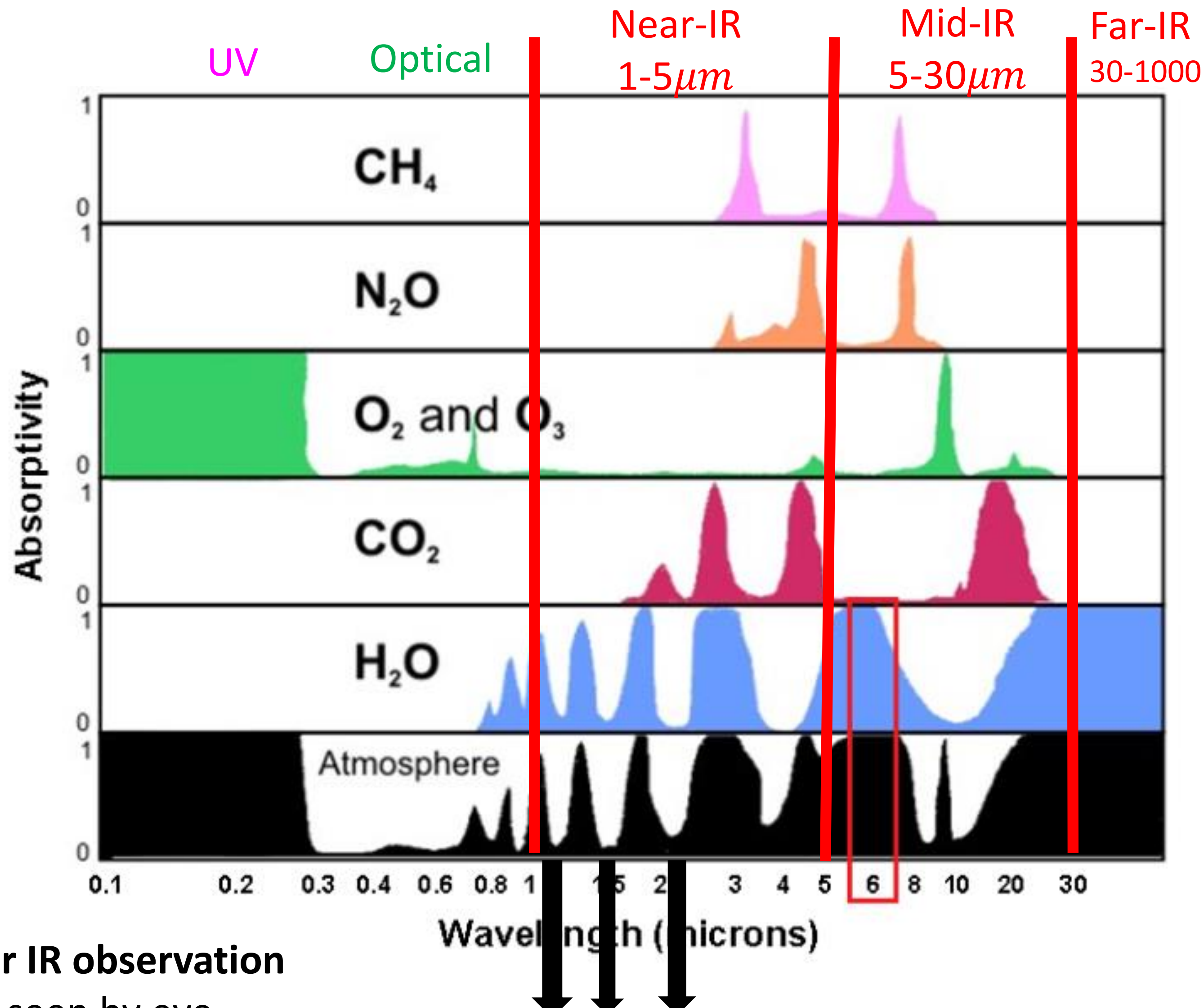
The Herschel Space Telescope

- Introduction to IR observation
    - History, and difficulties of IR observation
    - Special features of IR telescope
    - IR source in the Universe
- Herschel Instrument
    - Payload, telescope, and detectors
- Herschel science
    - High-z galaxy formation
    - Interstellar molecules
    - ISM and star formation

1.1 Introduction: IR – history and atmosphere windows

William Herschel(1738 – 1822)

Discover IR radiation in 1800



Ground:

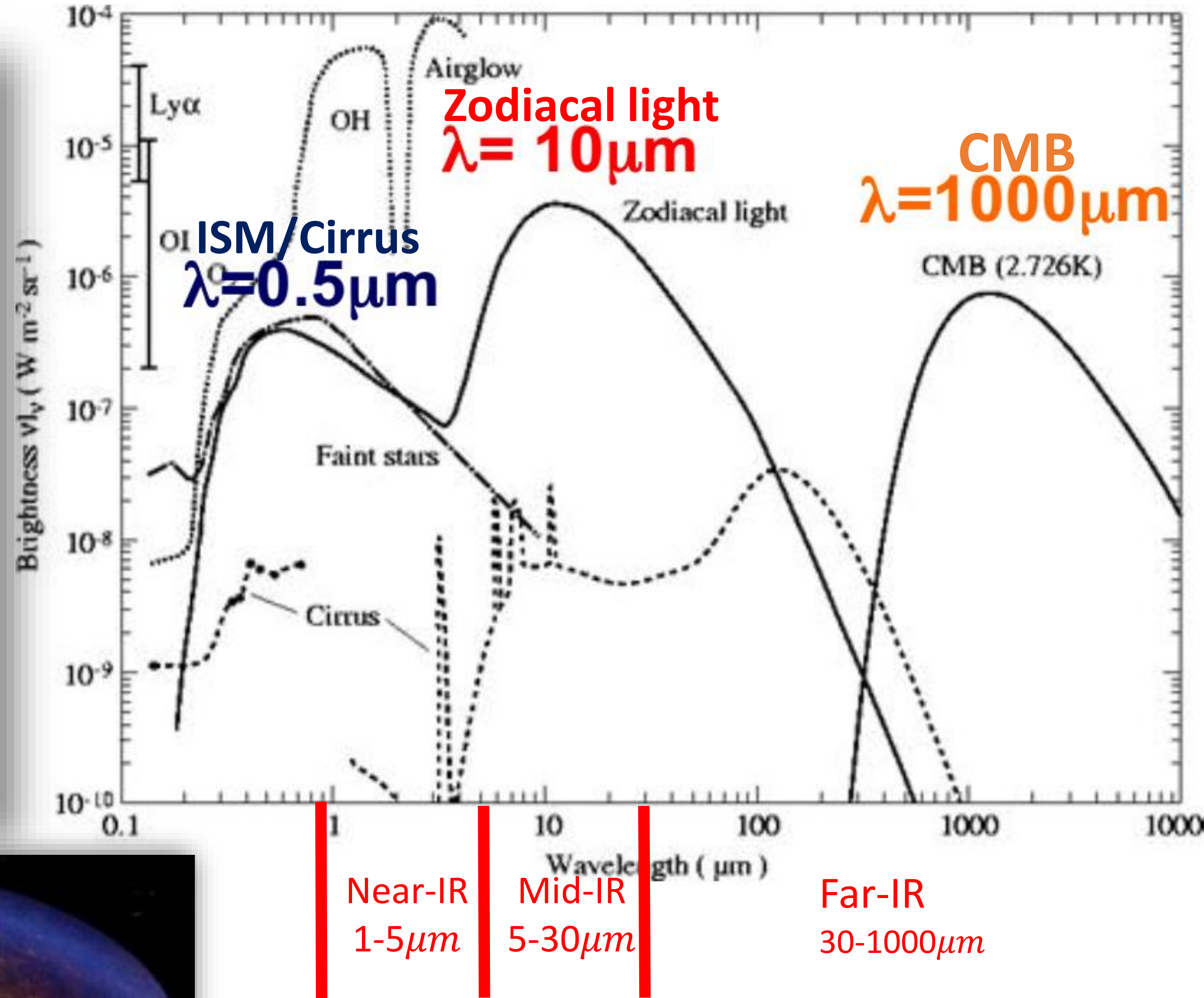
2MASS NIR Bands

Difficulties for IR observation

1. Can not be seen by eye
2. Complicated detectors
3. Absorption by atmosphere
4. Background

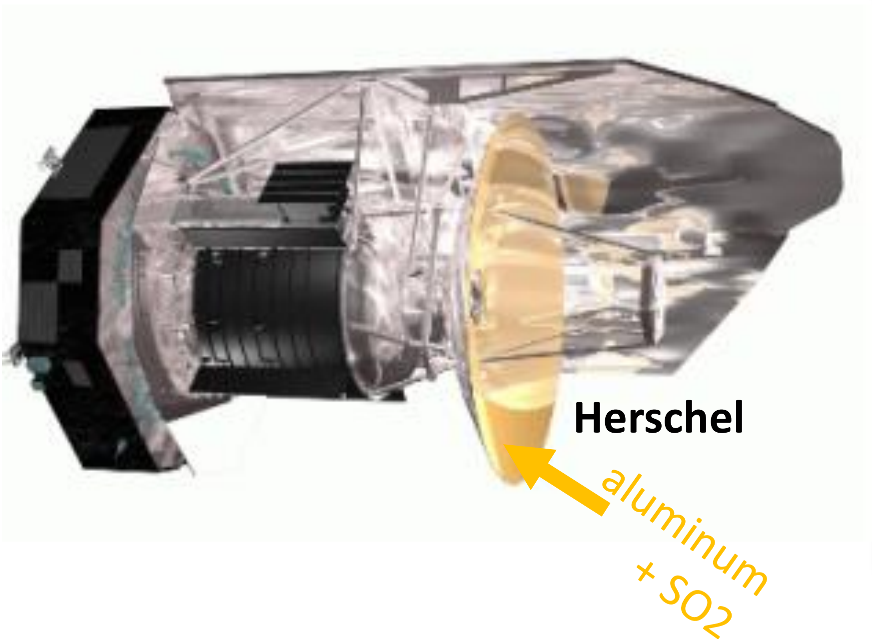
Kong X., 2017, slides

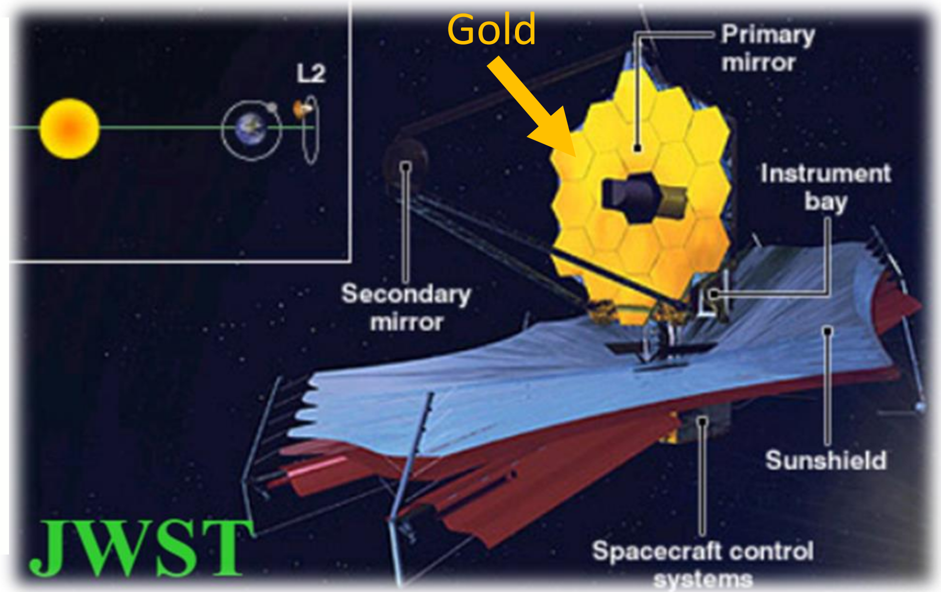
1.2 Introduction: background IR emission



IR background is anywhere

1.3 Introduction: IR observation and Instrument





Much different from optical instrument

Special site: cold/dry at ground, L2 at space
Special coating, aluminum/silver/gold
Open structure, only necessary frame
Large f-number
Chopping and Nodding observation mode

1.4 Introduction: IR source

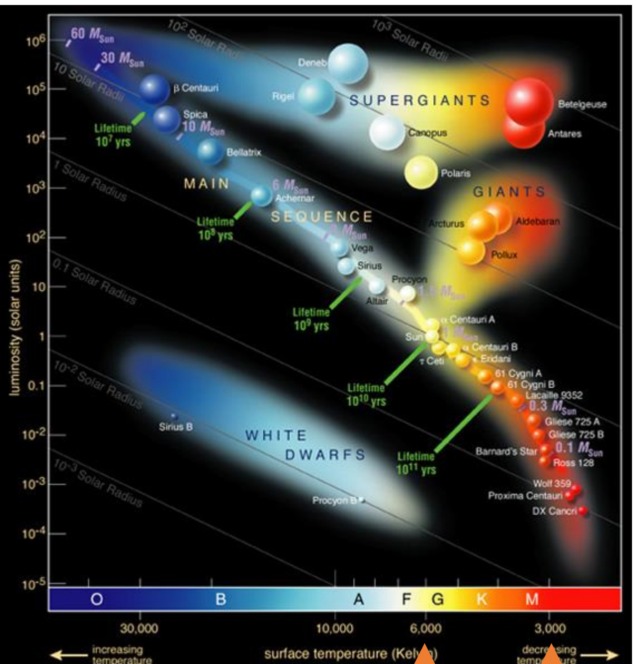
波 段	波长范围	温 度	What can be studied
Gamma rays	100keV-100MeV	>10^8K	accretion disks, gamma-ray bursts
X-rays	<1-100keV	10^6-10^8K	Hot gas in clusters of galaxies, stellar coronae, accretion disks
Ultra-violet	900-3000Å	10^4-10^6K	Hot stars, white dwarfs, SF
Optical	3000Å-1μm	10^3-10^4K	Sun-like stars
Infra-red	1-1000 μm	10-10^3K	Dust, planets, brown dwarfs
Microwave	1cm	<10K	Background radiation of the Universe (remnant of Big Bang)
Radio	>1m	<10K	Radiation from electrons moving in a magnetic field: pulsars

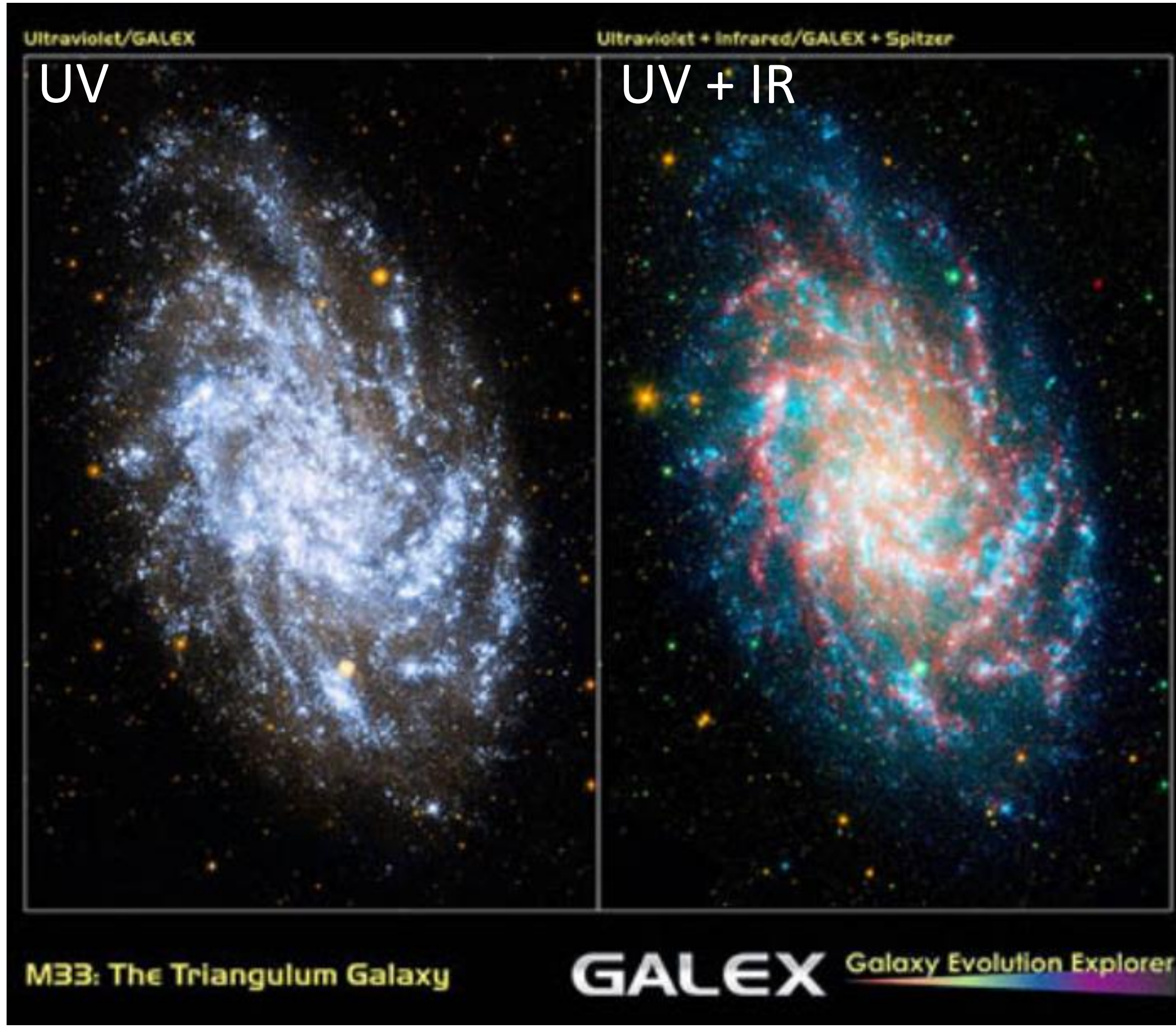
SPECTRAL REGION	WAVELENGTH RANGE (microns)	TEMPERATURE RANGE (degrees Kelvin)	WHAT WE SEE
Near-Infrared	(0.7-1) to 5	740 to (3,000-5,200)	Cooler red stars Red giants Dust is transparent
Mid-Infrared	5 to (25-40)	(92.5-140) to 740	Planets, comets and asteroids Dust warmed by starlight Protoplanetary disks
Far-Infrared	(25-40) to (200-350)	(10.6-18.5) to (92.5-140)	Emission from cold dust Central regions of galaxies Very cold molecular clouds

1.4 Introduction: IR source

Wien's Law

$$\lambda_{\text{peak}} \sim \frac{3000.\mu m}{T/K}$$

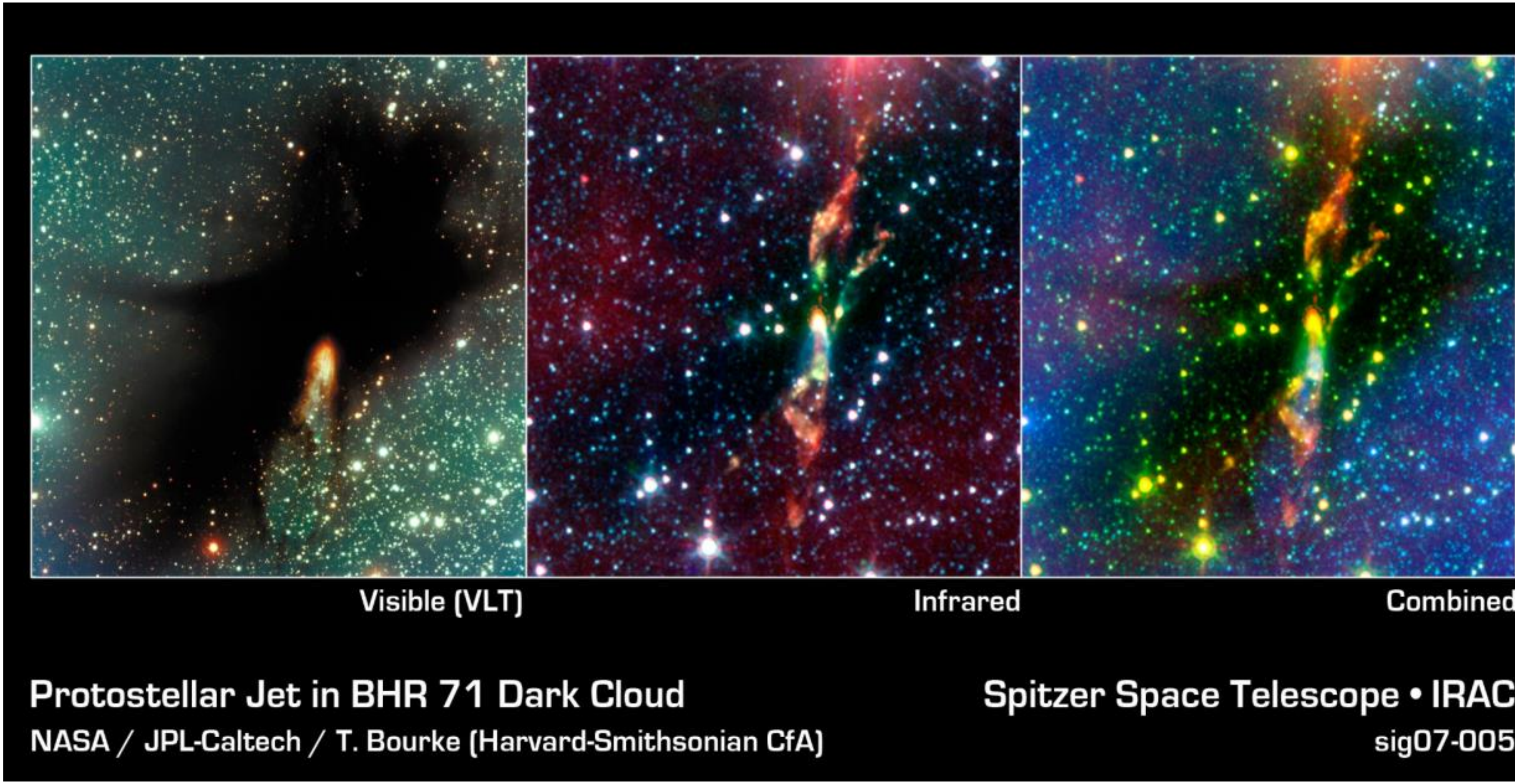




6000K $\sim 0.5\mu m$

3000K $\sim 1\mu m$

1.4 Introduction: IR source



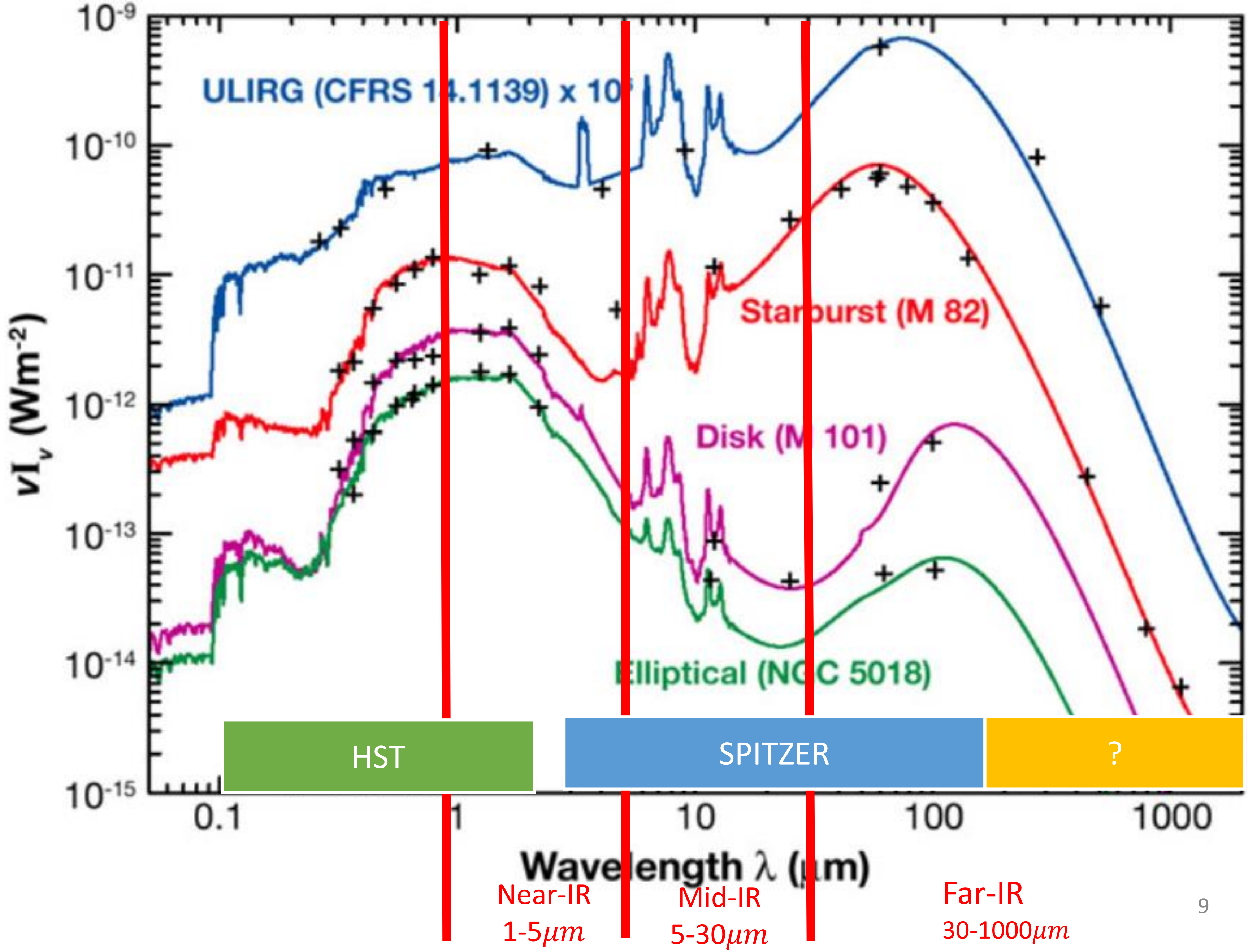
Dust

- Re-emit
  100K => $\lambda_{peak} = 30\mu m$ 10K => $\lambda_{peak} = 300\mu m$
- Shift to higher wavelength at higher redshift
- In the whole Universe, dust absorbs half of star radiation

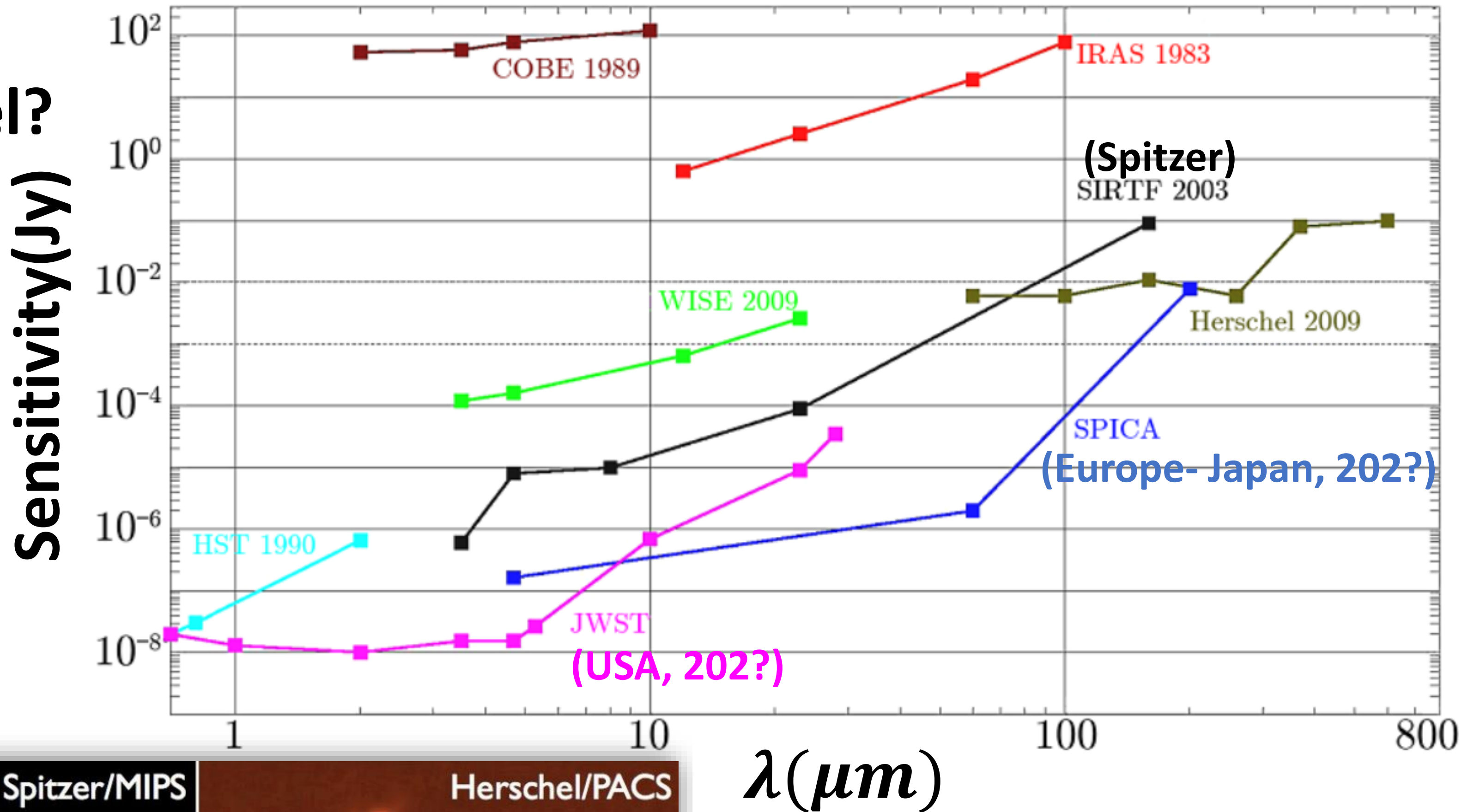
Wien's Law

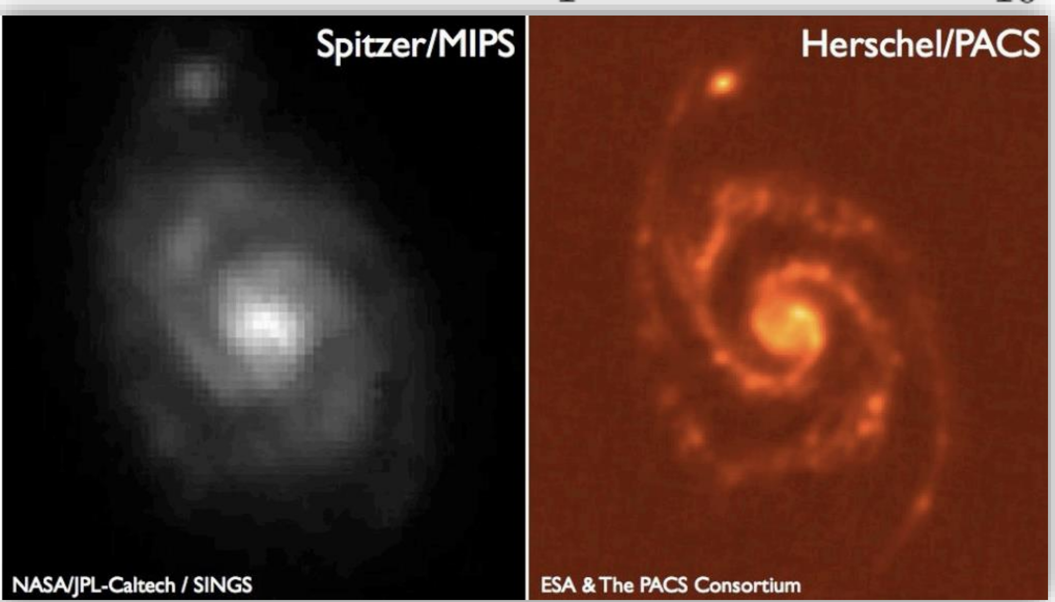
$$\lambda_{\text{peak}} \sim \frac{3000.\mu m}{T/K}$$

1.4 Introduction: IR source



1.5 Why Herschel?





Longer Wavelength
(colder, higher-z object)

Sensitivity and Resolution
- Best sensitivity at FIR and sub-mm
- Nice spatial resolution

Large Mirror
- 3.5m main mirror

2.1 The Life of Herschel Space Telescope

FIRST(1982)

- proposed 30 years ago

Rename as Herschel(2000)

- as fourth cornerstone mission of ESA Horizon 2000 program
- cooperate with NASA

Launch (2009)

- Ariane 5 rocket
- together with Planck
- L2, 0.01 AU from earth

Stop (2013)

- run out of He
- goes into heliocentric orbit

2.2 Input and Output

Herschel €1.1 billion – 4 year
HST - $10billion – 20 year

~37000 scientific observations
~26000 hours for sci. data
>6600 scientific calibrated data,
> 25 per month

up to 2017, > 2000 papers
up to 2018, >= 136 PhD thesis

SAO/NASA Astrophysics Data System (ADS)

Private Library HerschelPapers (Herschel Refereed Publications Library, last modified 26-Nov-2018) for gpilbratt@rssd.esa.int — Go to bottom o

(Note: the link on the library name is a public link to this library)

Selected and retrieved **2379** abstracts. — Sort options

#	Bibcode / Authors	Score / Title	Date	List of Links / Access Control Help
1	2019MNRAS.482.1715M Matsuura, Mikako; De Buizer, James M.; Arendt, Richard G.; Dwek, Eli; Barlow, M. J.; Bevan, Antonia; Cigan, Phil; Gomez, Haley L.; Rho, Jeonghee; Wesson, Roger; and 3 coauthors	1.000 SOFIA mid-infrared observations of Supernova 1987A in 2016 - forward shocks and possible dust re-formation in the post-shocked region	11/2019	A E F X R C U
2	2019ITIP...28..713P Piazzo, Lorenzo	1.000 Image Estimation in the Presence of Irregular Sampling, Noise, and Pointing Jitter	02/2019	E R
3	2019Icar..319...86T Teanby, N. A.; Irwin, P. G. J.; Moses, J. I.	1.000 Neptune's carbon monoxide profile and phosphine upper limits from Herschel/SPIRE: Implications for interior structure and formation	02/2019	A E R U

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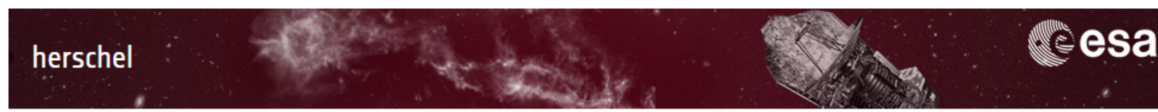

Herschel » Publications » PhD Theses

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PHD THESES RELATED TO HERSCHEL

In addition to scientific papers PhD theses are important results from Herschel and from the effort invested to make the mission possible.

We are trying to list all PhD theses related to Herschel - based both on "technical" work and on scientific results - but can only do so if they are brought to our attention.

Please report any missing PhD theses either by raising a Helpdesk ticket or by sending an email.

The most recent update to this list was done on 11 December 2018, it now contains 138 theses.

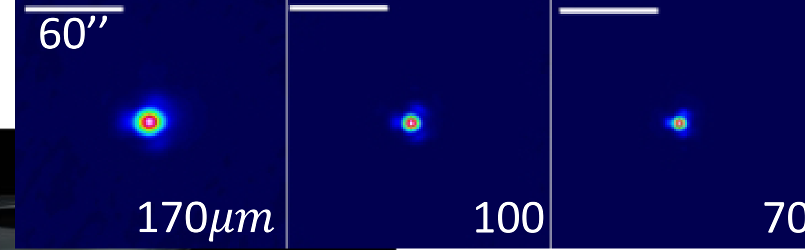
[The list below can be sorted by clicking on the ***AUTHOR, TITLE*** *or* ***YEAR*** *columns]*

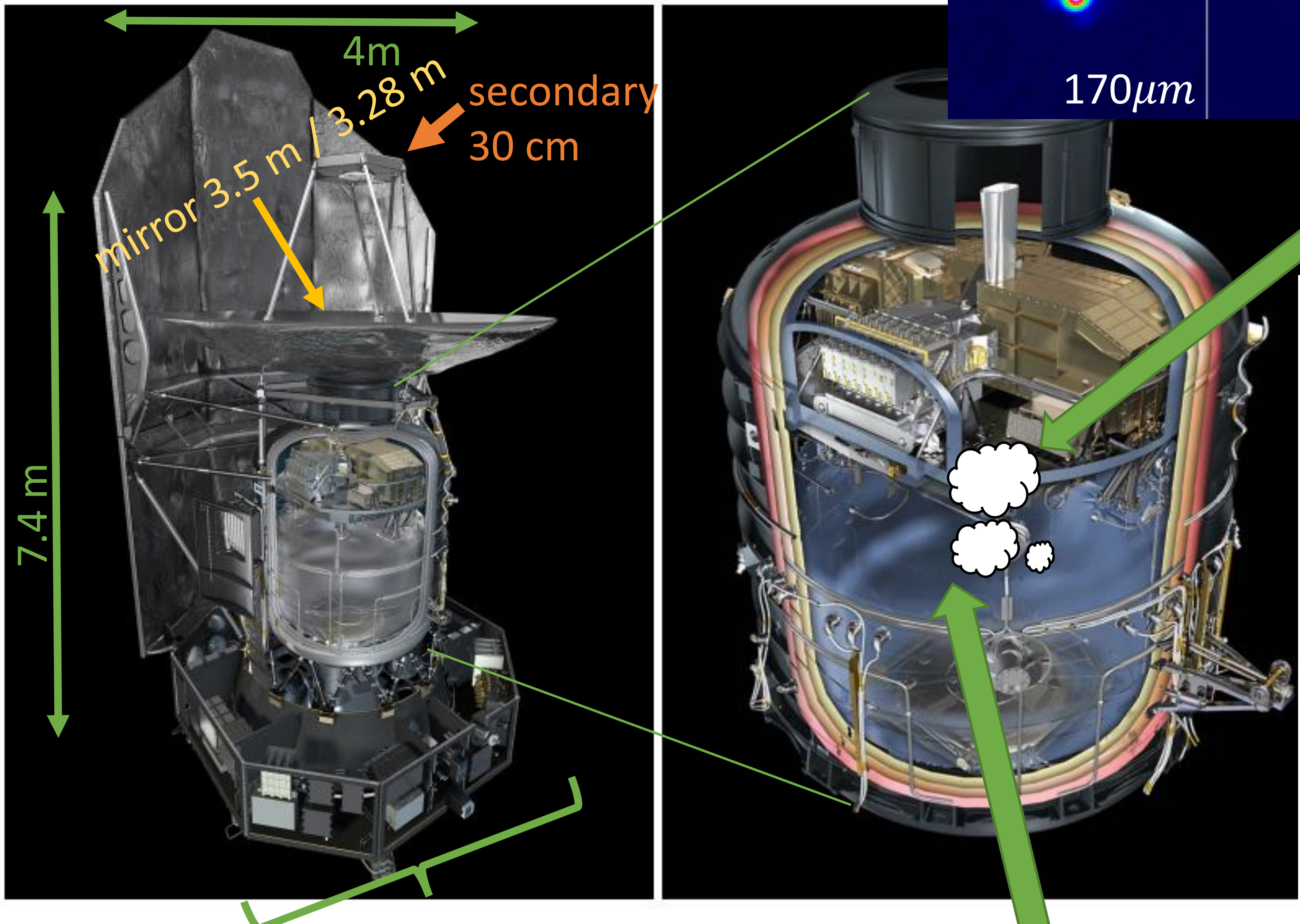
AUTHOR	TITLE	YEAR
Agius, Nicola Kristina	Dust in Early-type galaxies using Herschel-ATLAS and GAMA data	2014
Alberts, Stacey	Dusty star formation in extreme environments: Galaxies and galaxy clusters in the distant universe	2014
Andree-Labsch, Silke	Three-dimensional modelling of the emission of clumpy PDRs	2015
Aniano Porcile, Gonzalo Jorge	Modeling dust in the interstellar medium	2012
Arab, Heddy	Evolution of interstellar dust with Herschel	2012
Aresu, Giambattista	High energy irradiated protoplanetary disks: the X-rays and FUV role in thermo-chemical modeling	2012

https://www.cosmos.esa.int/web/herschel/theses

2.3 Herschel Instrument

PSF





Sci. instrum.
HIFI + PACS + SPIRE

HIFI

PACS

SPIRE

(Photodetector Array Camera and Spectrometer)

image photometer +
spatial resolved spectrometer
broad band photo.
  250, 350, 500 μm
  FOV: 4' x 8'
medium resol. spec.
  194-671 μm
  spec resol. 1000-4000
  FOV: ~2.6'

150 ~ 670 μm spec.
+
70, 100, 170, 250, 350, 600 μm photo.

Designing Target:
- Large
- High reflectivity
- Cold
- Low mass (SiC)

Cassegrain focus
Aluminum +SO2 coated
Telescope - Natually cooled
Operational T $\sim 85K$ at L2
f-number ~ 8.7
Angular resol. ~ 7'' at 100μm

Superfluid Helium
$\sim$ 2800 kg (total: 3400 kg)
Cooled to $< 2.0\ K$
Lifetime $>$ 3.5 years

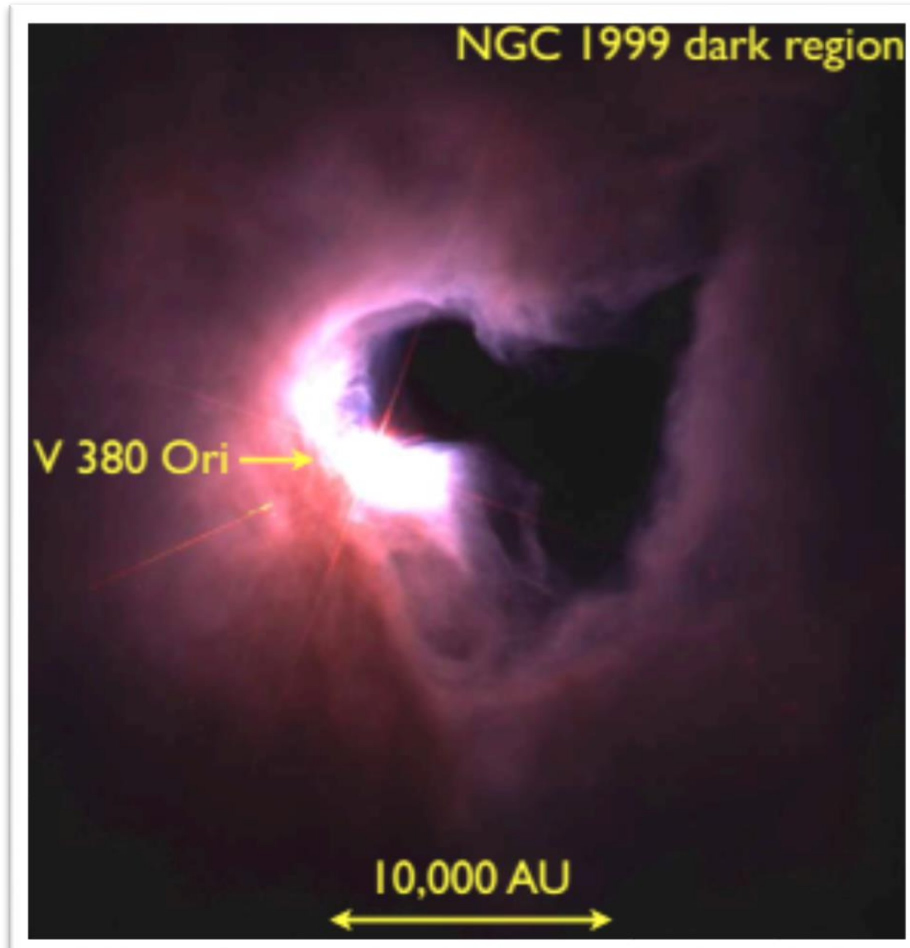
Pilbratt G. L., 2010
Griffin M. J., 2010

3. Herschel science

High-z galaxy formation

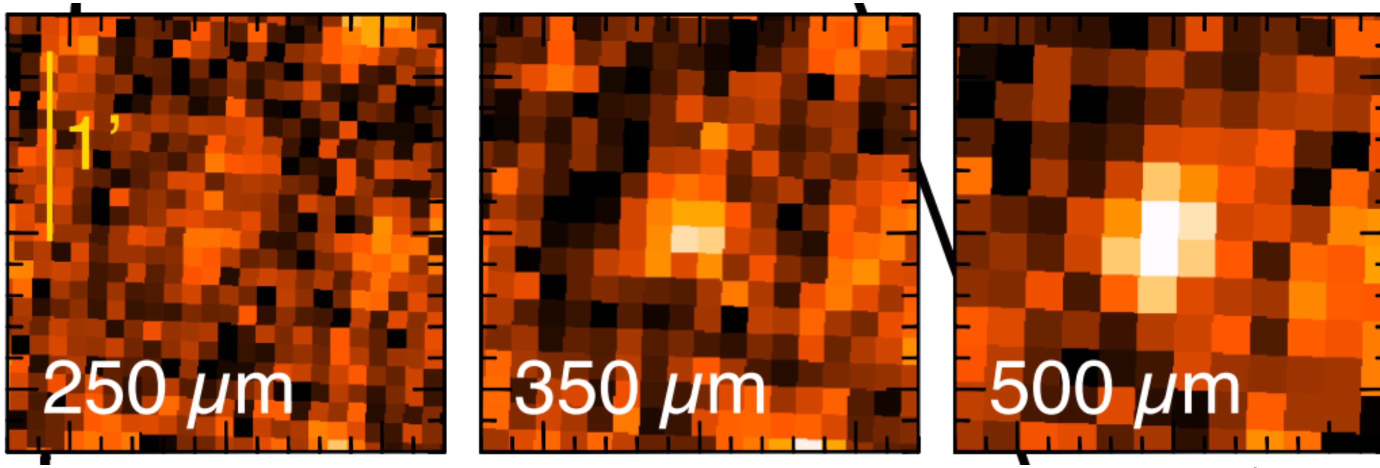
Interstellar molecules

ISM and star formation



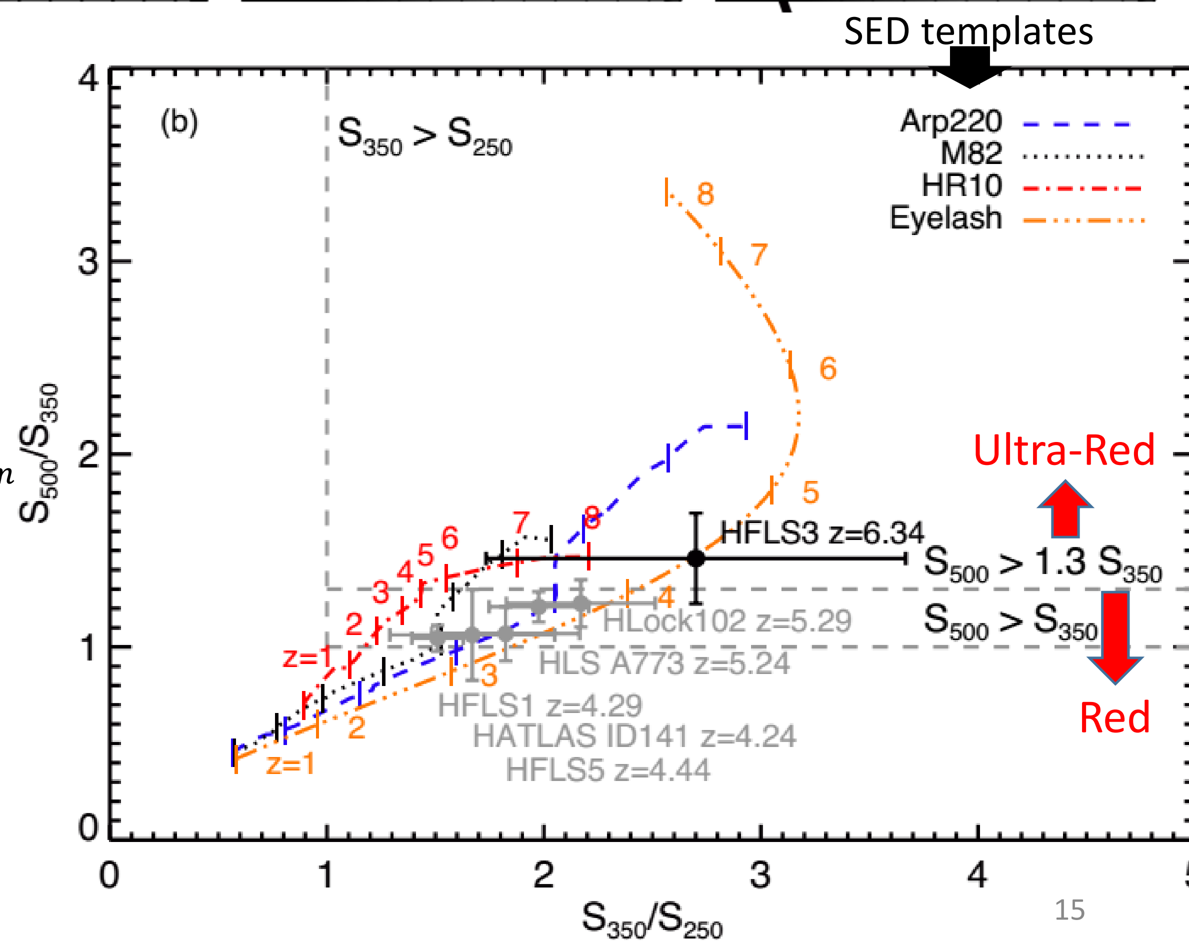
Herschel Science

3.1 High-z Starburst galaxy



Herschel FIR bands image

- Marginally resolve the source:
  HFLS3 $d \sim 3pkpc \sim 1''$
  Resolution of Herschel ~ $10''$
- Target Selection : Ultra-red
  $S_{250\mu m} < S_{350\mu m}$
  $\&\& \ 1.45 S_{350\mu m} < S_{500\mu m}$
- Multiple follow-up observations to identify spectral:
  z = 6.34:
  ARMA,PdBI,SMA…, CO, [CI], [CII]



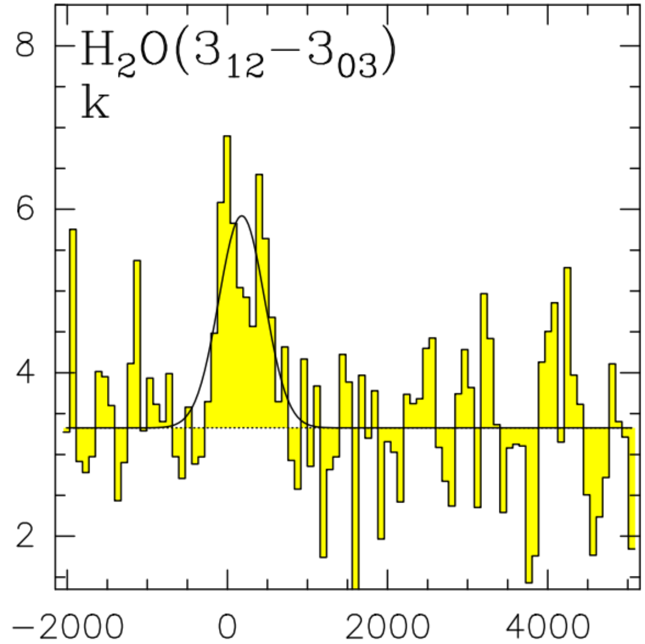
Dominik, 2016, Nat.
A Dust-Obscured Massive Maximum-Starburst Galaxy at a Redshift of 6.34

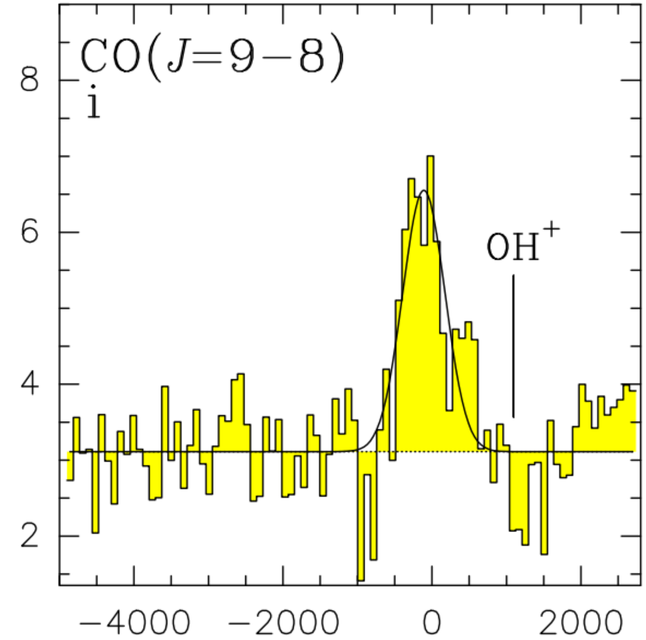
Herschel Science

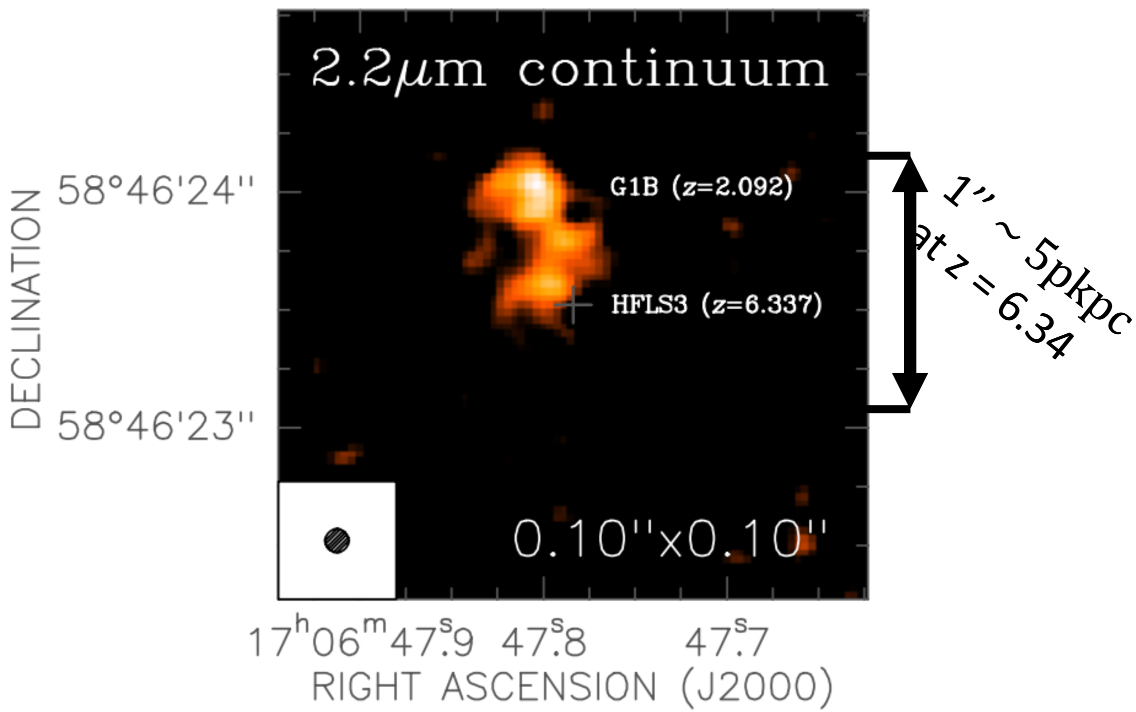
3.1 High-z Starburst galaxy

Ground-base radio follow-up

- many molecular lines
- asymmetric line profile => molecular outflow







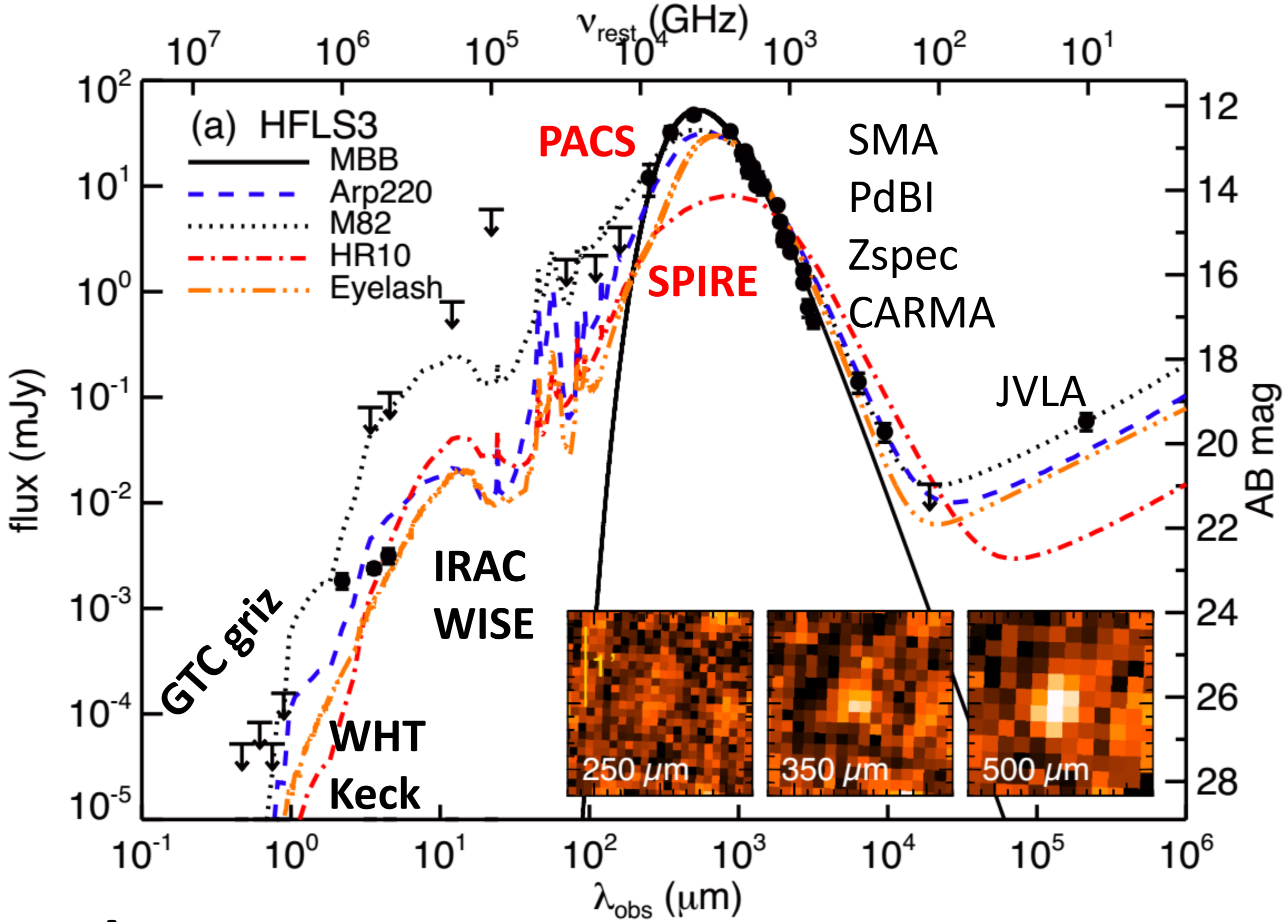
Keck NIR follow-up

- Adaptive optical correction
- Pixel size : 0.04''
- Seeing: 0.4'' ~ 0.8'' => PSF: 0.1''

Herschel Science

3.1 High-z Starburst galaxy

- SED fitting by multiple bands observation
- data from >= 12 instruments

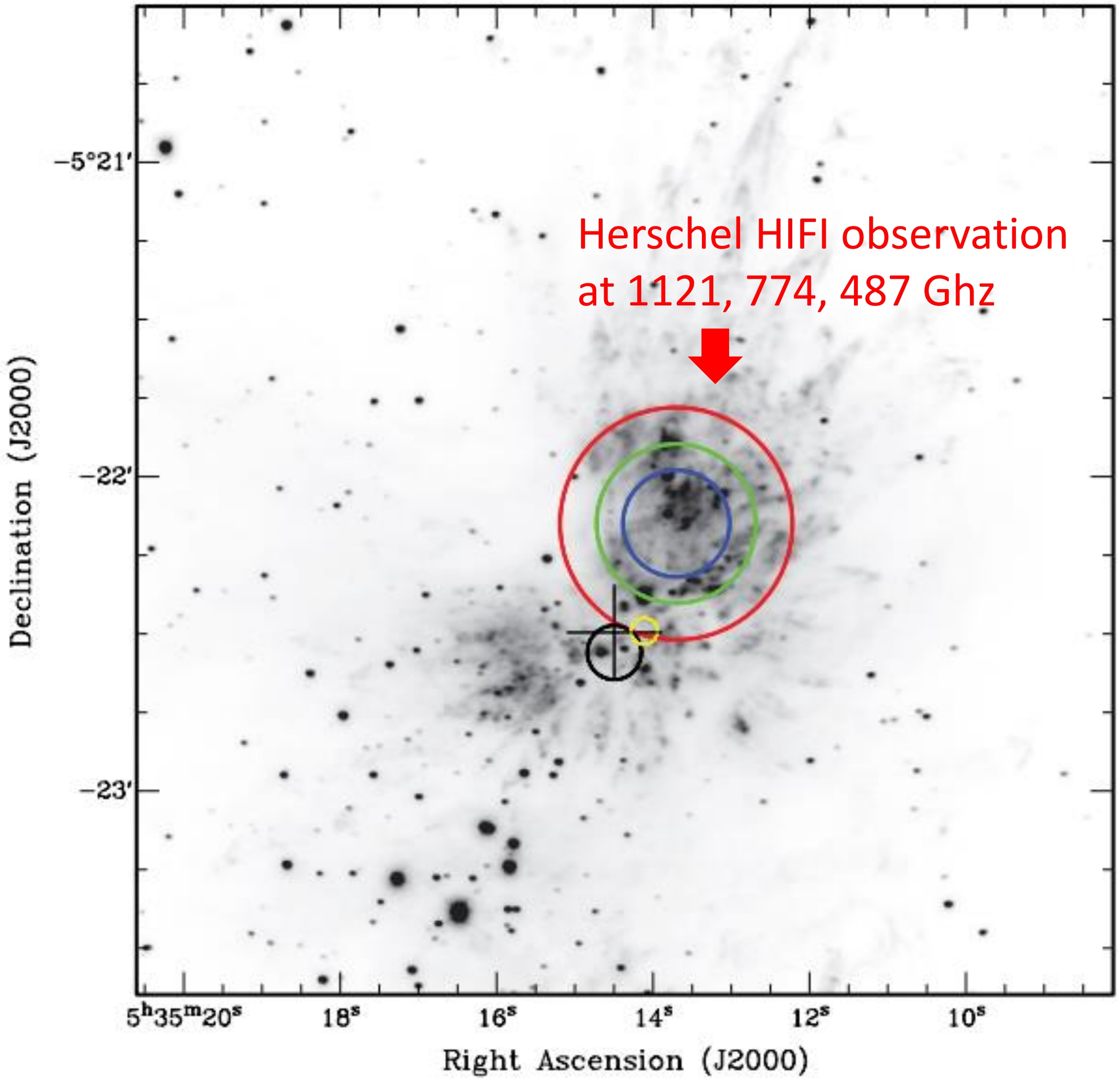


Physical parameters

- SED => L_{FIR} => SFR: 2900 Msun/yr and M_{dust}~$1.3 \times 10^9 M_\odot$
- L_{CO}=>Molecular gas mass M_{gas}~$1.04 \times 10^{11} M_\odot$
- Stellar population synthesis $M_* = 4.5 \times 10^{10} M_\odot$
- CO line FWHM => dynamical mass $M_{dyn} = 2.7 \times 10^{11} M_\odot$ (40 % dark matter)

Herschel Science

3.2 Inter-stellar Molecules

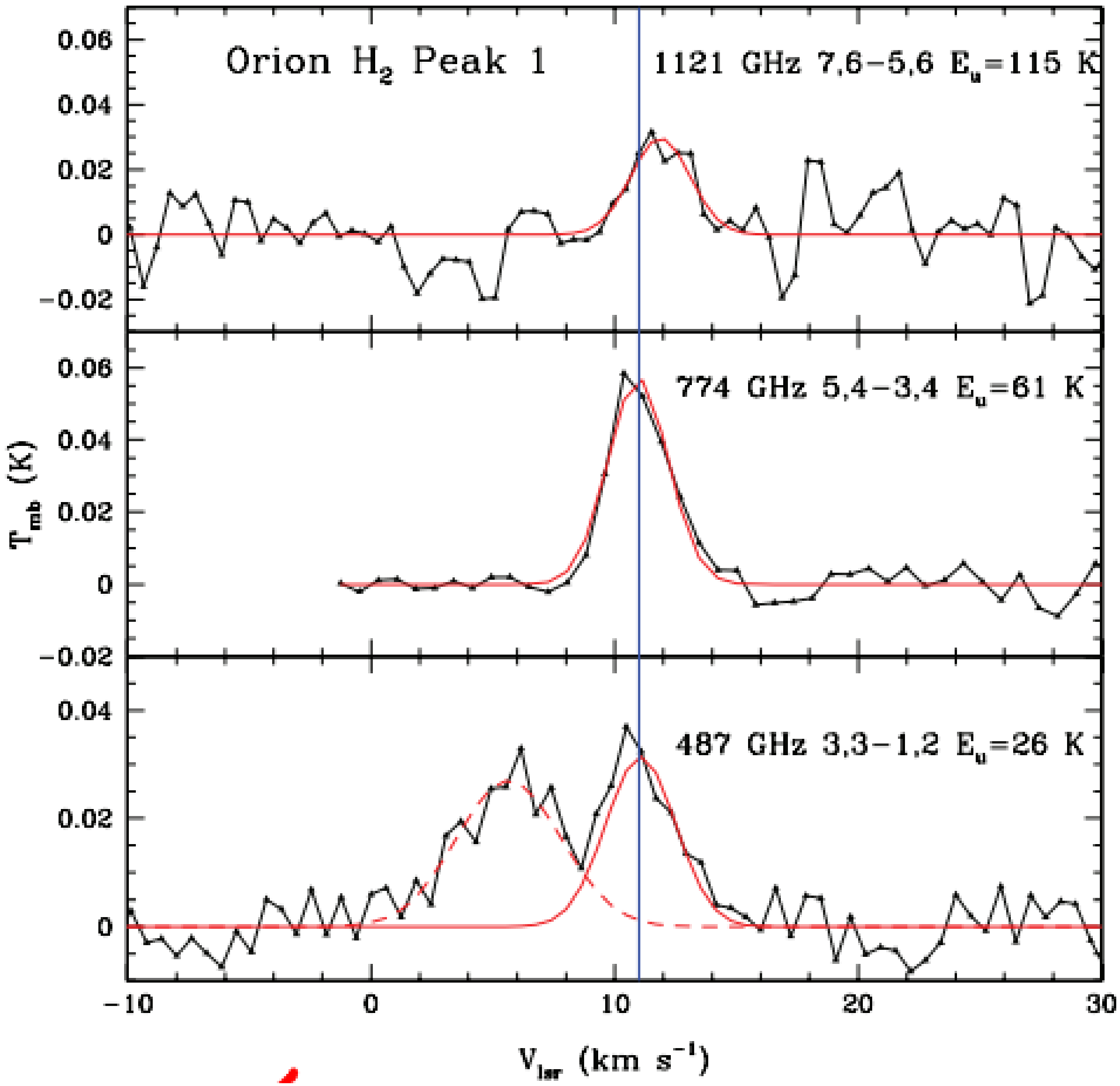


- 2μm H_2 image in Orion
- O2 production: complicated O => OH^+ => $H2O^+$ => H_3O^+ => OH^+ => OH => O_2
- last step => peaked at 80K
- At low temperature => model sensitive (x100 uncertainty), predicted O2 to H2 abundance ratio from 10^{-5} to 10^{-7}
- Abundant, gas phase CO > O2 > H2O, but hard to observe O2 due to atmosphere absorption
- Herschel HIFI observation beam width 19'', 28'', 44''

Goldsmith P. F., 2011

Herschel Science

3.2 Inter-stellar Molecules



Emission line intensity

$\Rightarrow$ O_2 column density $6.5 \pm 1.0 \times 10^{16} cm^{-2}$

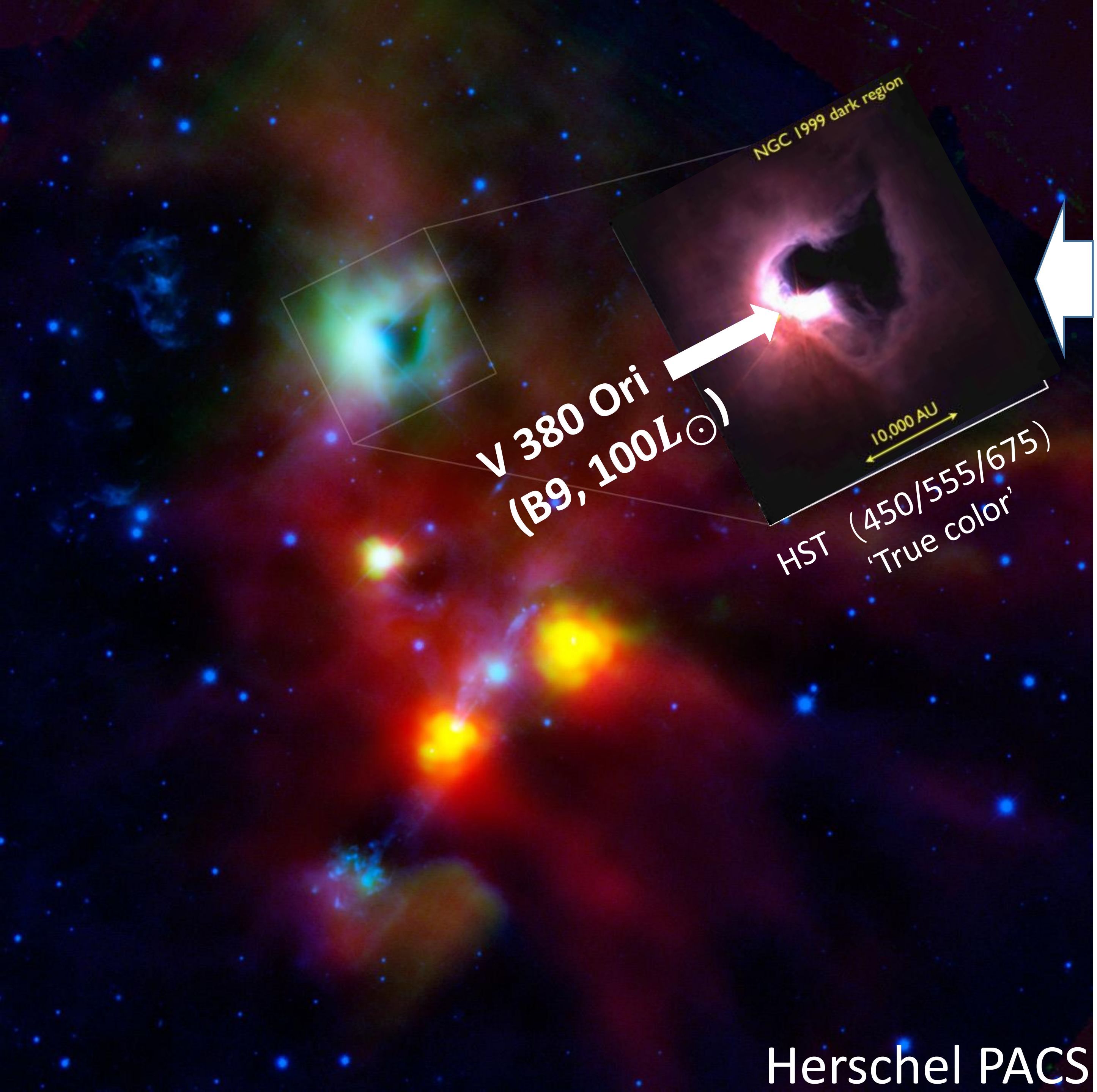
$\Rightarrow$ mass fraction O_2/H_2 = $3{\sim}7 \times 10^{-7}$

- Second time to observe O_2 molecule, with small uncertainty
- Provide better constraint to chemistry synthesis model

Goldsmith P. F., 2011

Herschel Science

3.3 Star formation

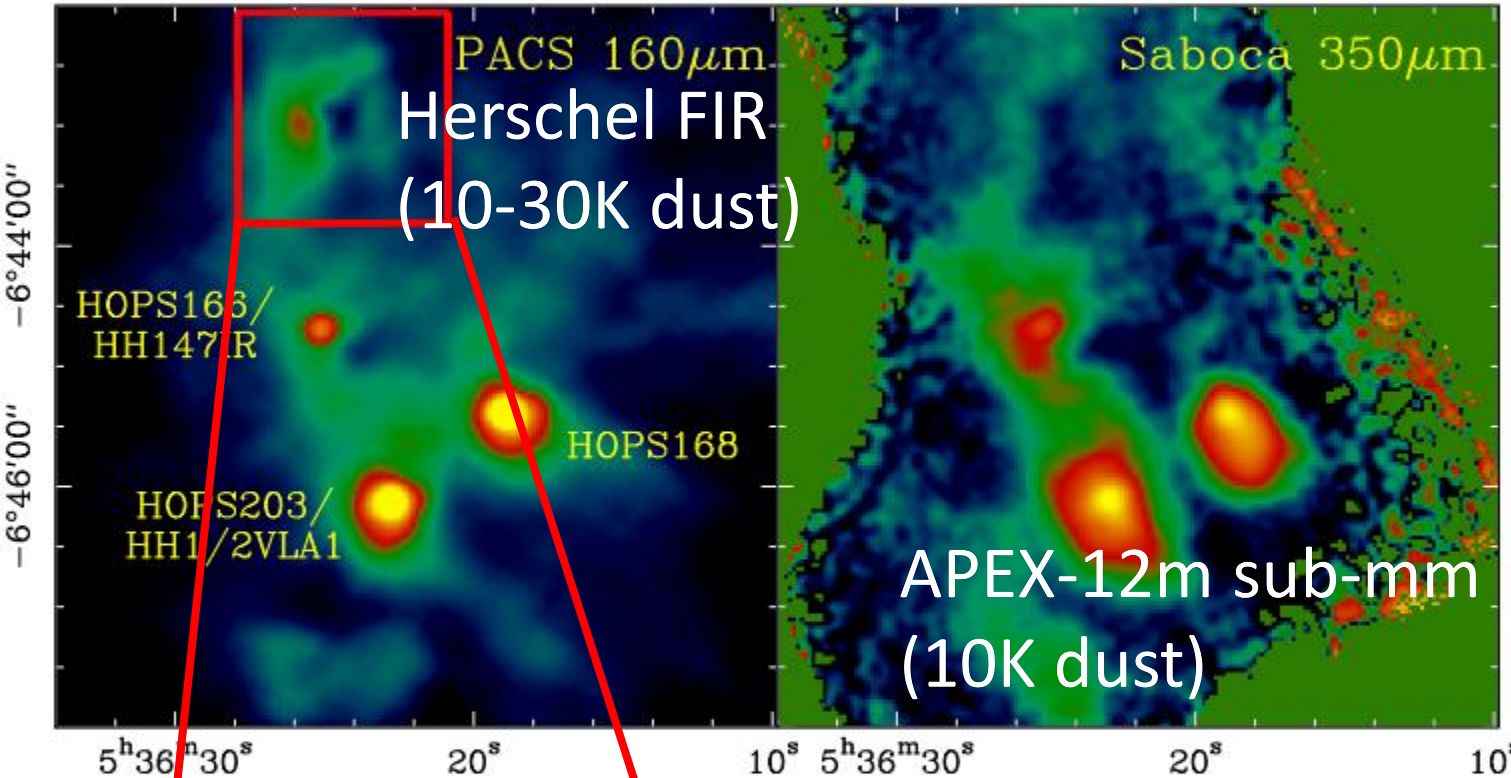


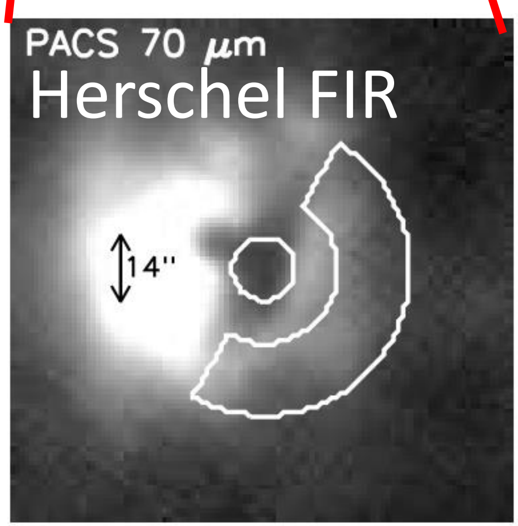
NGC 1999
– dark nebula

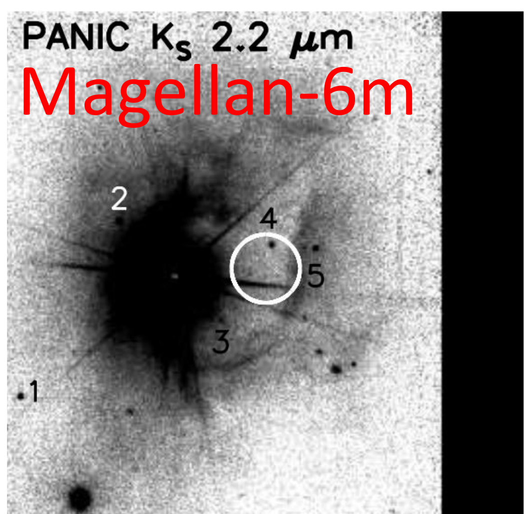
1997 HST, 'a hole'

2009 Herschel, still a hole

Stanke T., 2018







Herschel Science

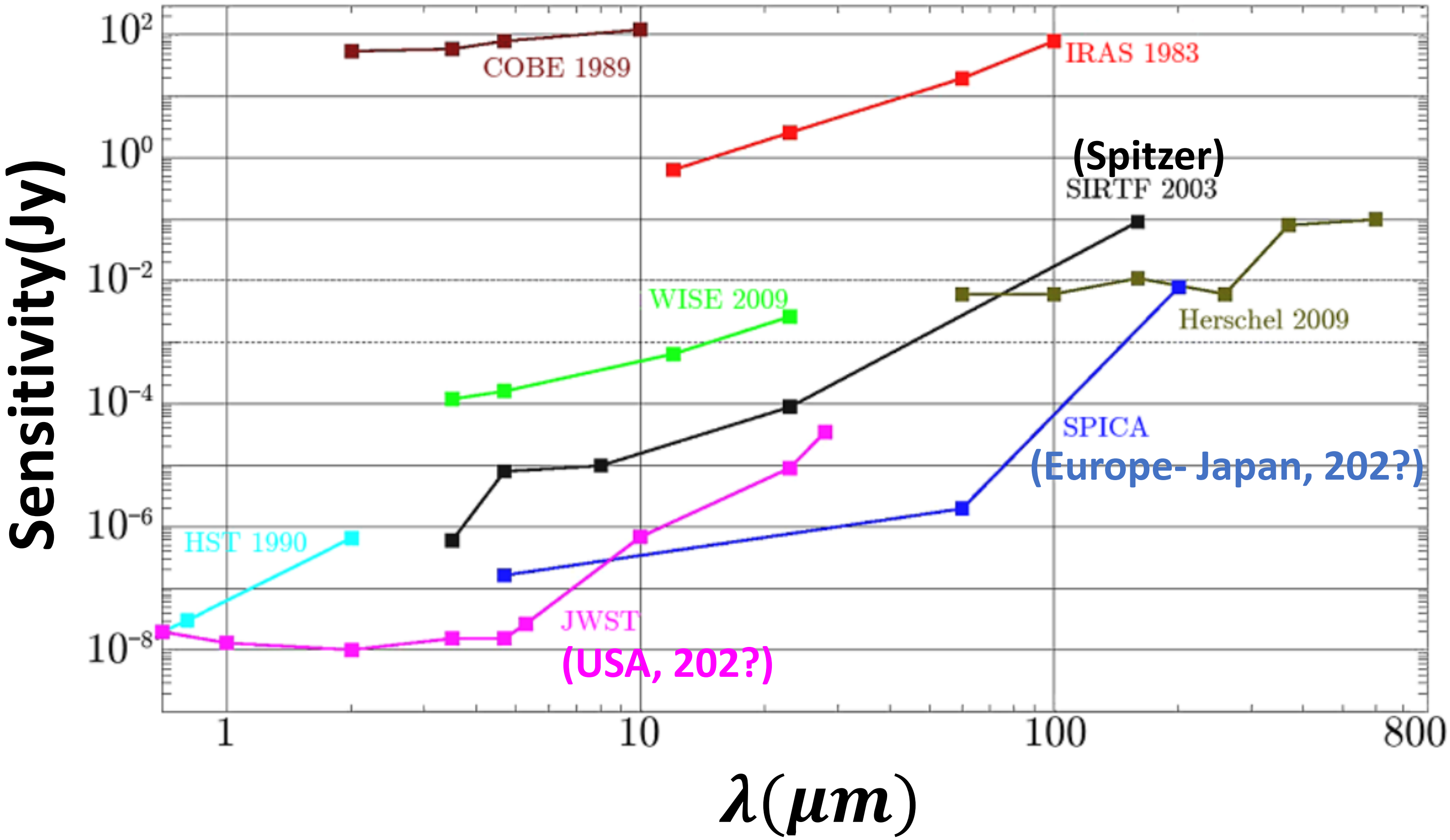
3.3 Star formation

Possible solution

- V 380 Ori (B9, 100$L_\odot$)
- A hole clean-up by the massive star

Stanke T., 2018

Next Generation IR telescopes



Kong X., 2017, slides

Summary
The Herschel Space Telescope

- IR observation is difficult, but promising
- Special design is need for an IR telescope
- Herschel is as expensive as HST, but necessary and successful
  - High-z galaxy formation
  - Interstellar molecules
  - ISM and star formation