

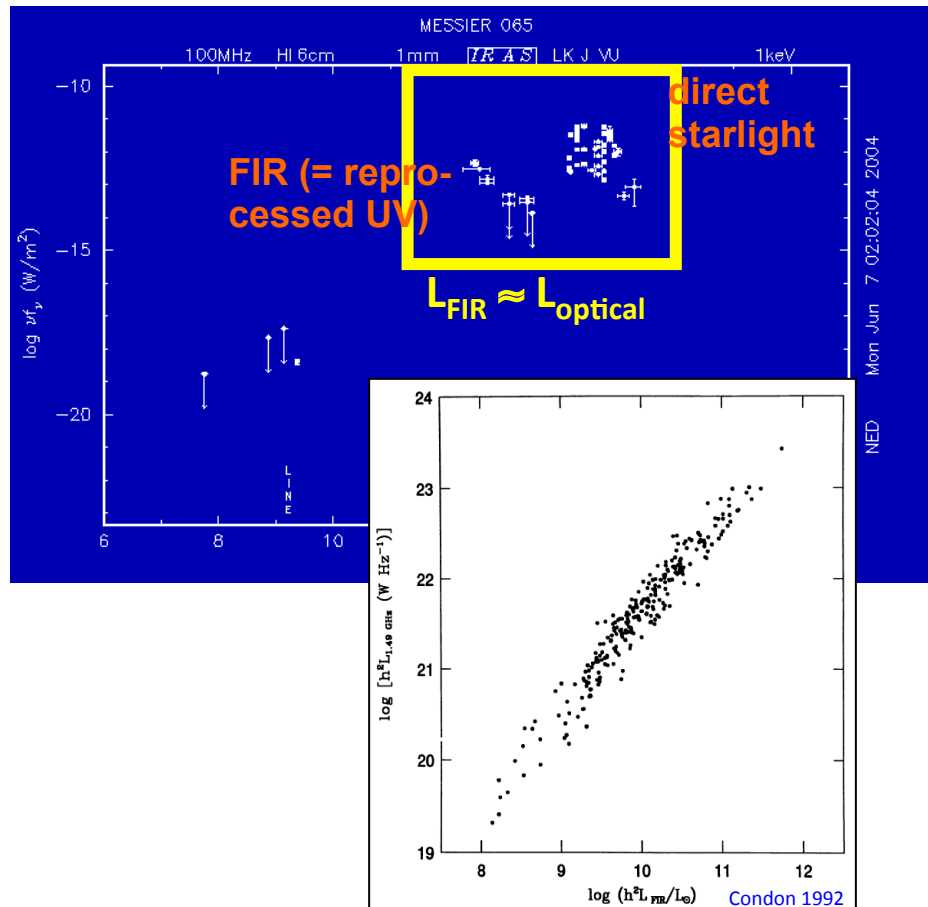
Surveys in the Multi-Wavelength Sky:
Mid-and Far-Infrared and (Sub)millimeter

Karl Menten

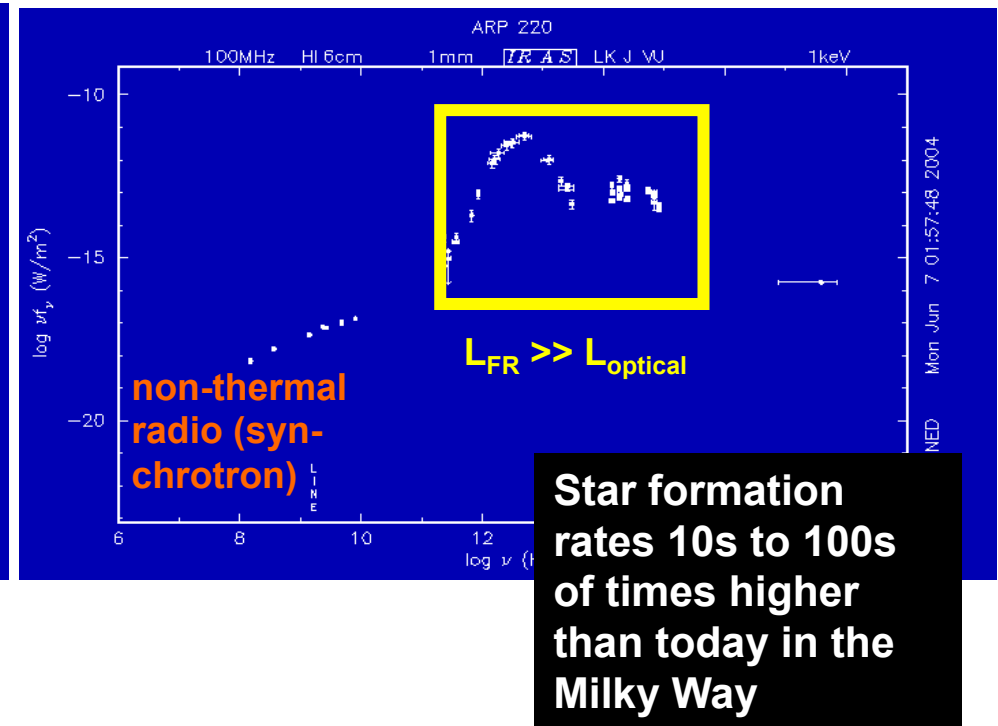
Max-Planck-Institut für Radioastronomie

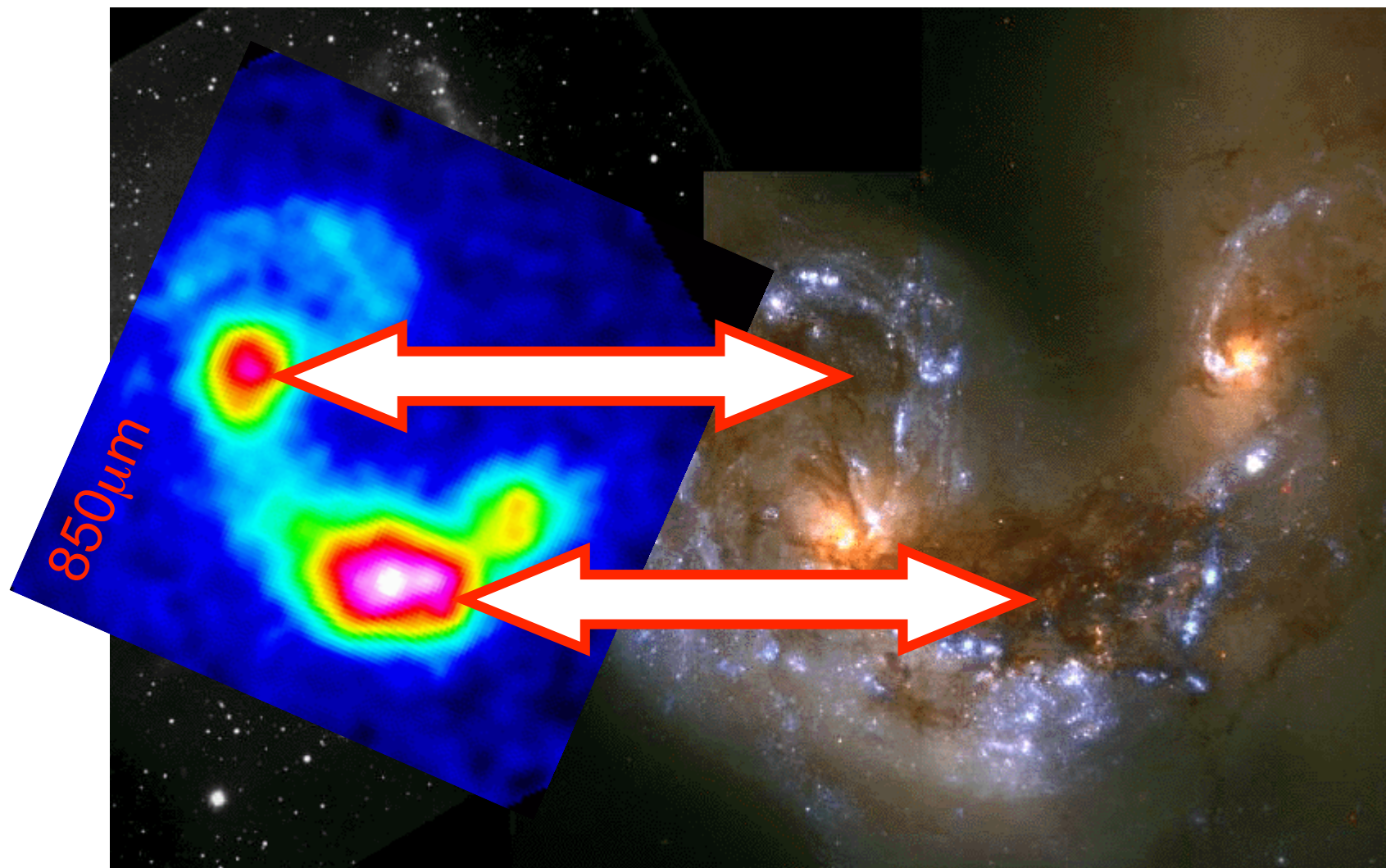
Why FIR?

Spectral energy distribution of the normal spiral galaxy M65



SED of the **Ultra-Luminous InfraRed Galaxy** Arp 220

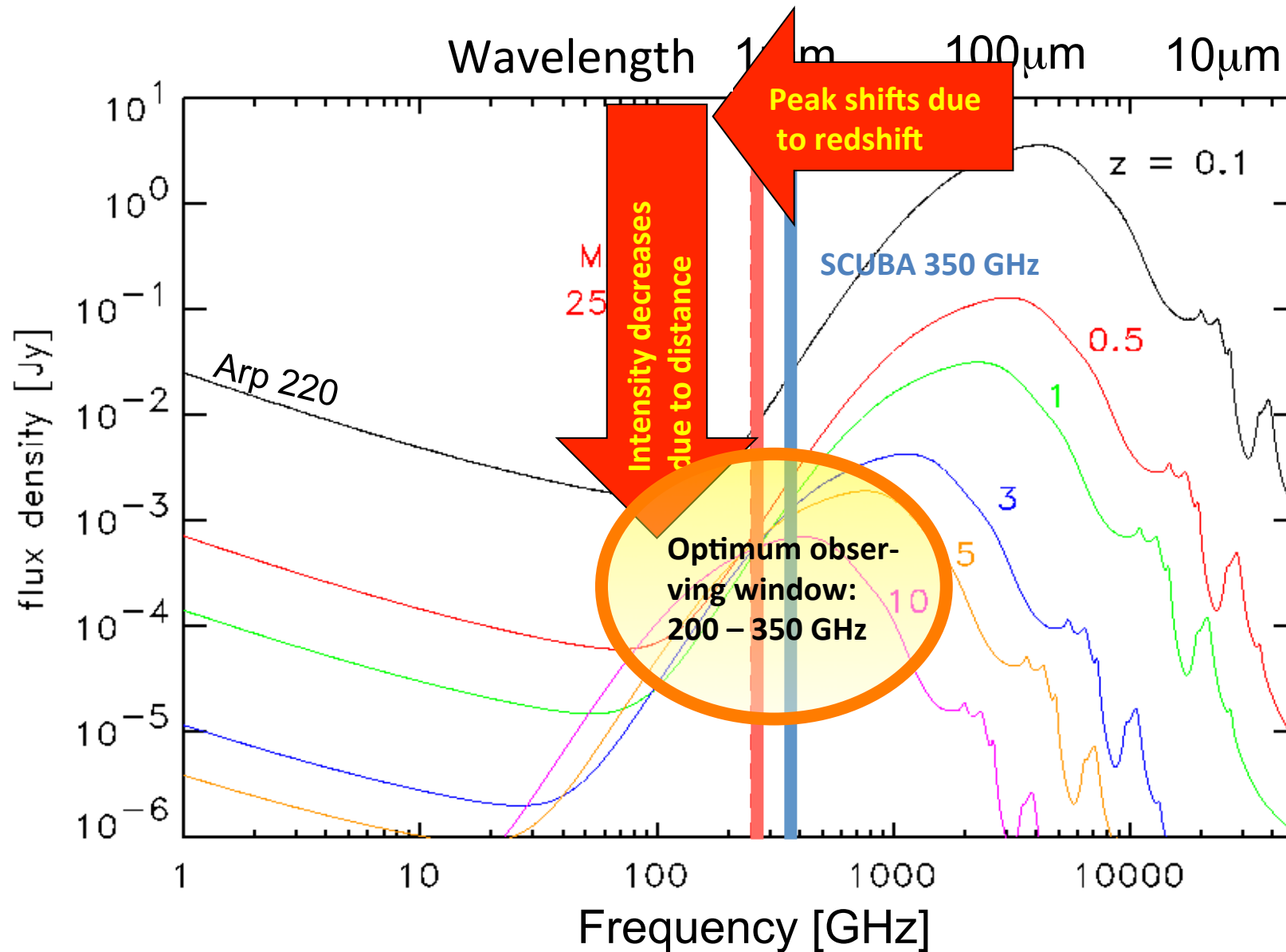




Arp 244 (The Antennae)

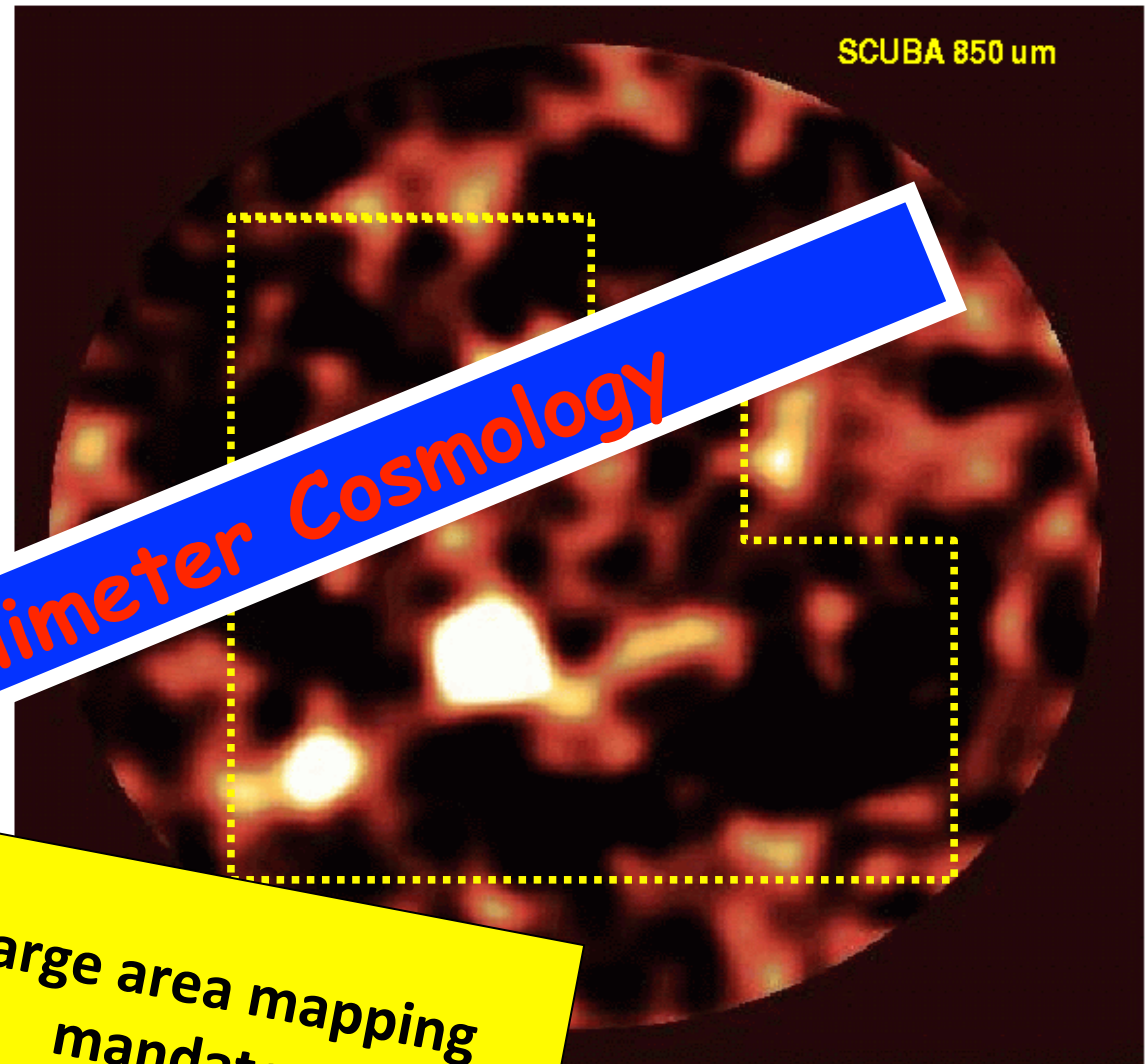
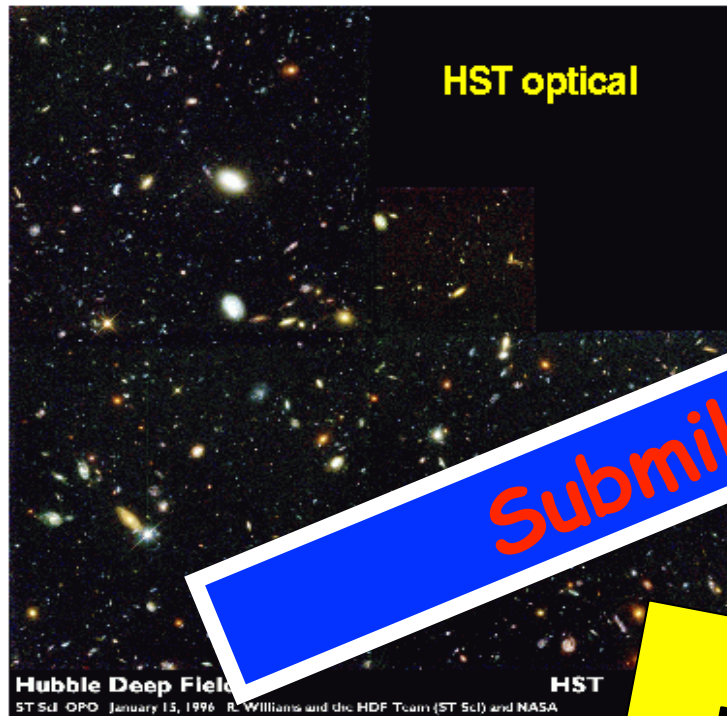
NASA/HST+JCMT

Why (sub)millimeter?



The sub-mm Extragalactic Background resolved:

The Hubble Deep Field



Submillimeter Cosmology

Large area mapping
mandatory!

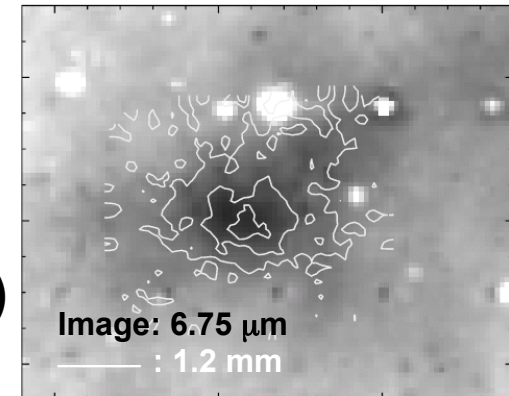
Hughes et al. 1998

Why (sub)millimeter + FIR(II)?

Tracing mass with submillimeter emission from **dust**

Source brightness $S_\nu = B_\nu(T_D)(1 - e^{-\tau_\nu})$

Continuum emission from **interstellar dust** is almost always **optically thin** for wavelengths > 100 μm (frequencies < 3 THz)



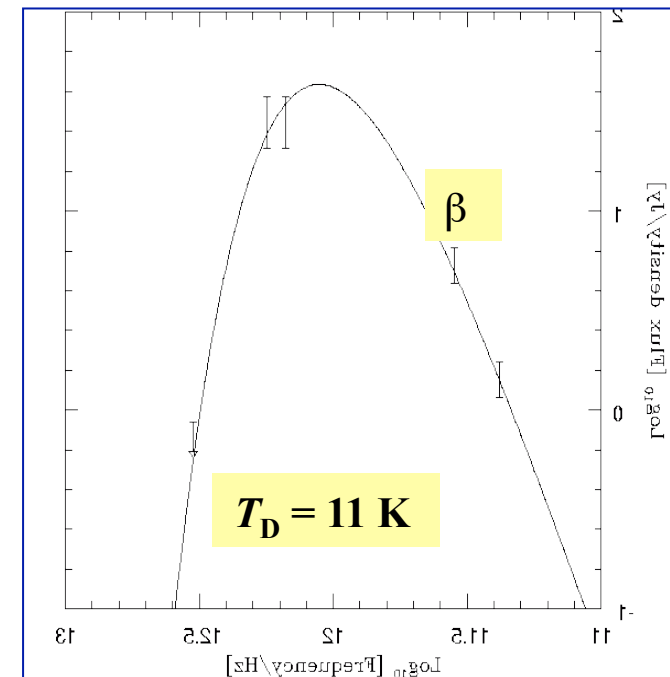
$$S_\nu \approx B_\nu(T_D)\tau_\nu \approx \frac{2k}{c^2} T_D \nu^2 \tau_\nu$$

$$\tau_\nu = \int \kappa dl = N_H \sigma_\nu^H \propto N_H \nu^\beta \quad (1 < \beta < 2)$$

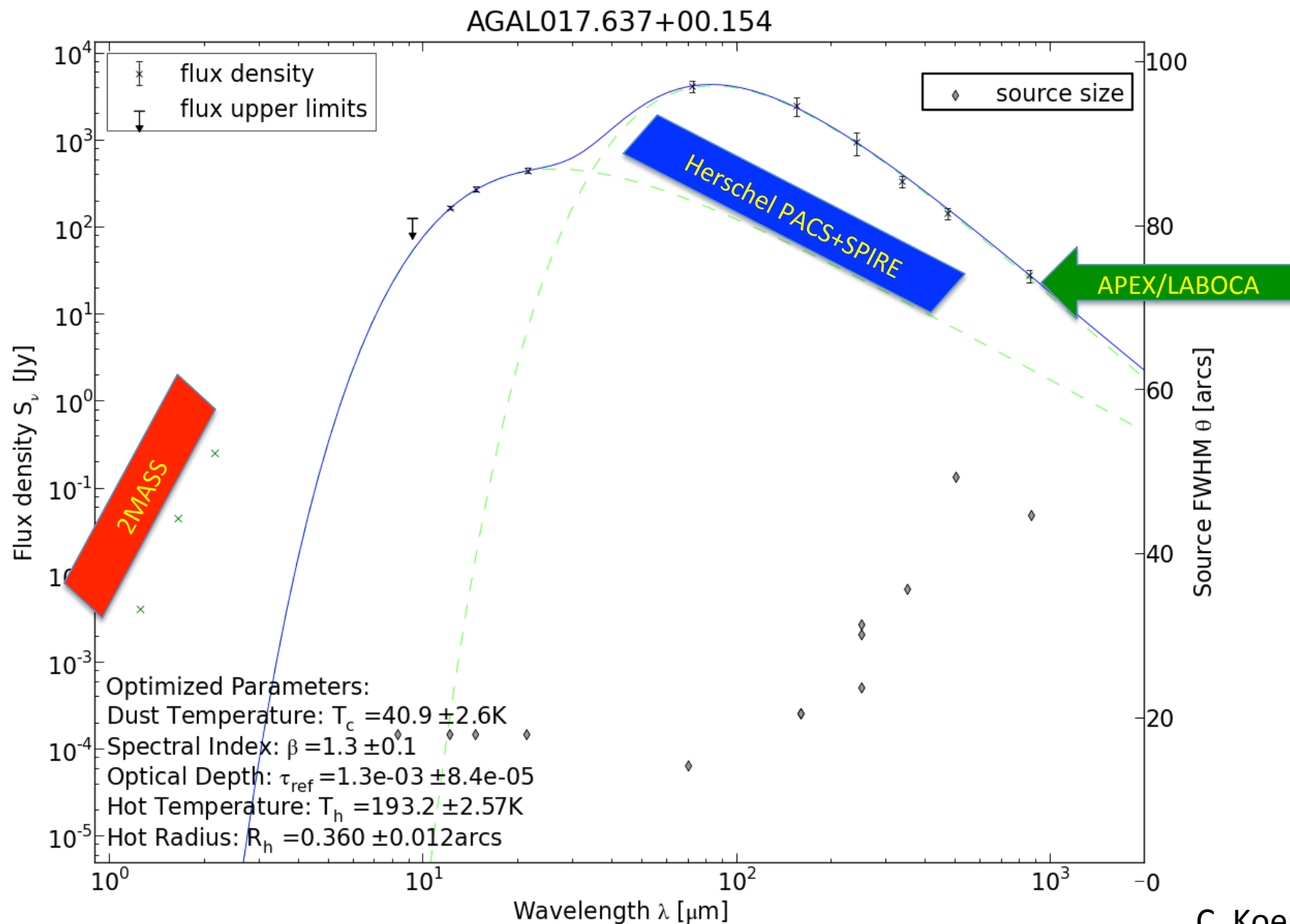
(Sub)mm observations of dust emission yield the total (hydrogen) **column density** and the **gas mass**

$$N_H \propto \frac{\nu^{-2-\beta}}{T_D} S_\nu$$

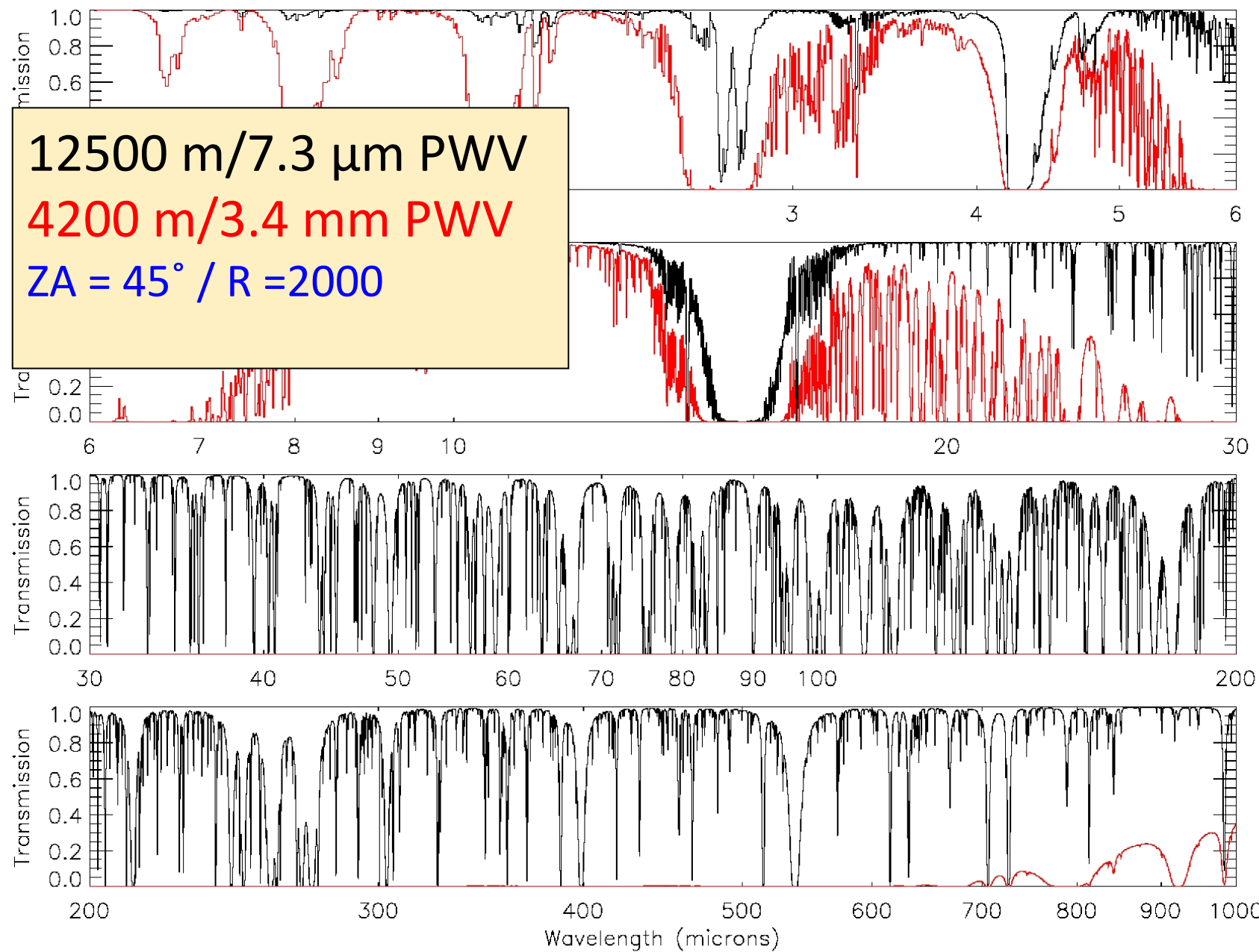
$$M \propto \frac{\nu^{-2-\beta}}{T_D} D^2 \int S_\nu d\Omega$$



CRL 2136 – a High-mass Star-Forming region



C. Koenig



Infrared Astronomical Satellite (IRAS)

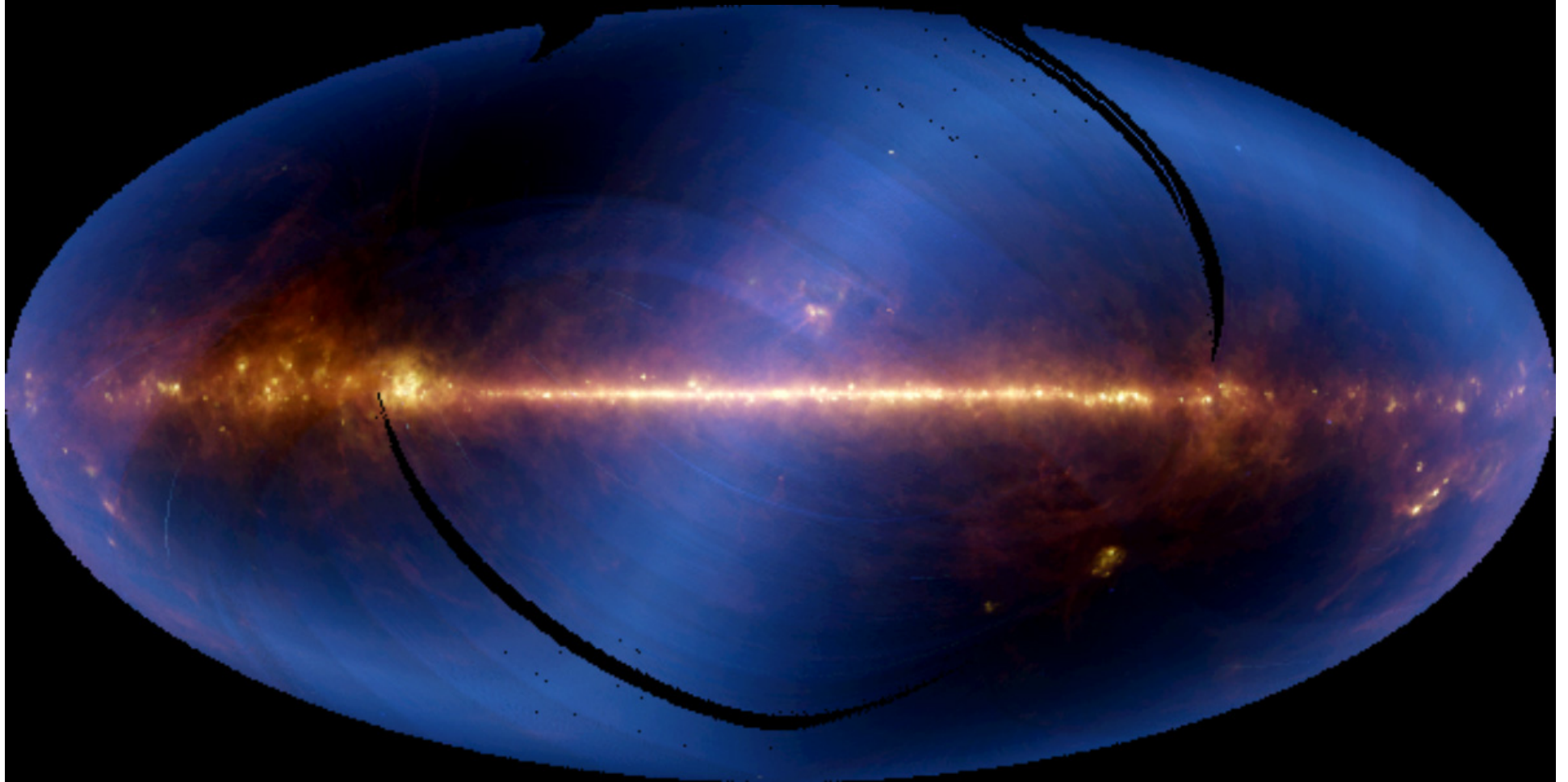
Mission Characteristics

Lifetime:	1983 (11 months)
Wavelength:	• 12 μm • 25 μm • 60 μm • 100 μm
Area Coverage:	96% of the sky
Instruments:	• Survey Array • Low Resolution Spectrometer (LRS) • Chopped Photometric Channel (CPC)
Science Products Generated:	• Sky Survey Atlas • Galaxy Atlas • Extended Galaxy Atlas • Mid-Infrared Galaxy Atlas • Faint Source Catalog • Point Source Catalog • Catalogued Galaxies and Quasars • Serendipitous Survey Catalog • Small Scale Structure Catalog • Asteroid & Comet Survey • Minor Planet Survey
Funding Agency:	The Infrared Astronomical Satellite (IRAS) was a joint project of the US, UK and the Netherlands.
Canonical Paper:	Neugebauer et al. (1984)



... detected about 500000 IR sources

The IRAS Sky



NASA/IPAC Infrared Science Archive

for NASA's Infrared and Submillimeter Data



IRSA Services

Scanpi	A tool for visualizing, plotting, and averaging calibrated IRAS survey scans.
HIRES	HIRES is a powerful tool for studying morphology and for separating confused sources. It uses the Maximum Correlation Method to produce IRAS images with better than nominal resolution.
General Catalog Search	Access available catalogs.
Basic Catalog Search	Quick access to the FSC and PSC catalogs.
IRAS FSC	Download the IRAS Faint Source Catalog v2.0
IRAS PSC	Download the IRAS Point Source Catalog v2.1
ISSA Custom Image Server	Retrieve single images from the IRAS Sky Survey Atlas, overlaid with Point Source and Faint Source Catalog information
The IRAS Sky Survey Atlas	Use Atlas to retrieve multiple FITS images from ISSA, covering a large area.
ISSA Cutouts	Use IRSA's Image Cutouts Service to generate small "cutout" FITS (and JPEG) images from the IRAS Sky Survey Atlas.
Improved Reprocessing of the IRAS Survey (IRIS)	Use Atlas to retrieve the IRIS
IRIS Cutouts	Use IRSA's Image Cutouts Service to generate small "cutout" FITS (and JPEG) images from the IRIS image collection.

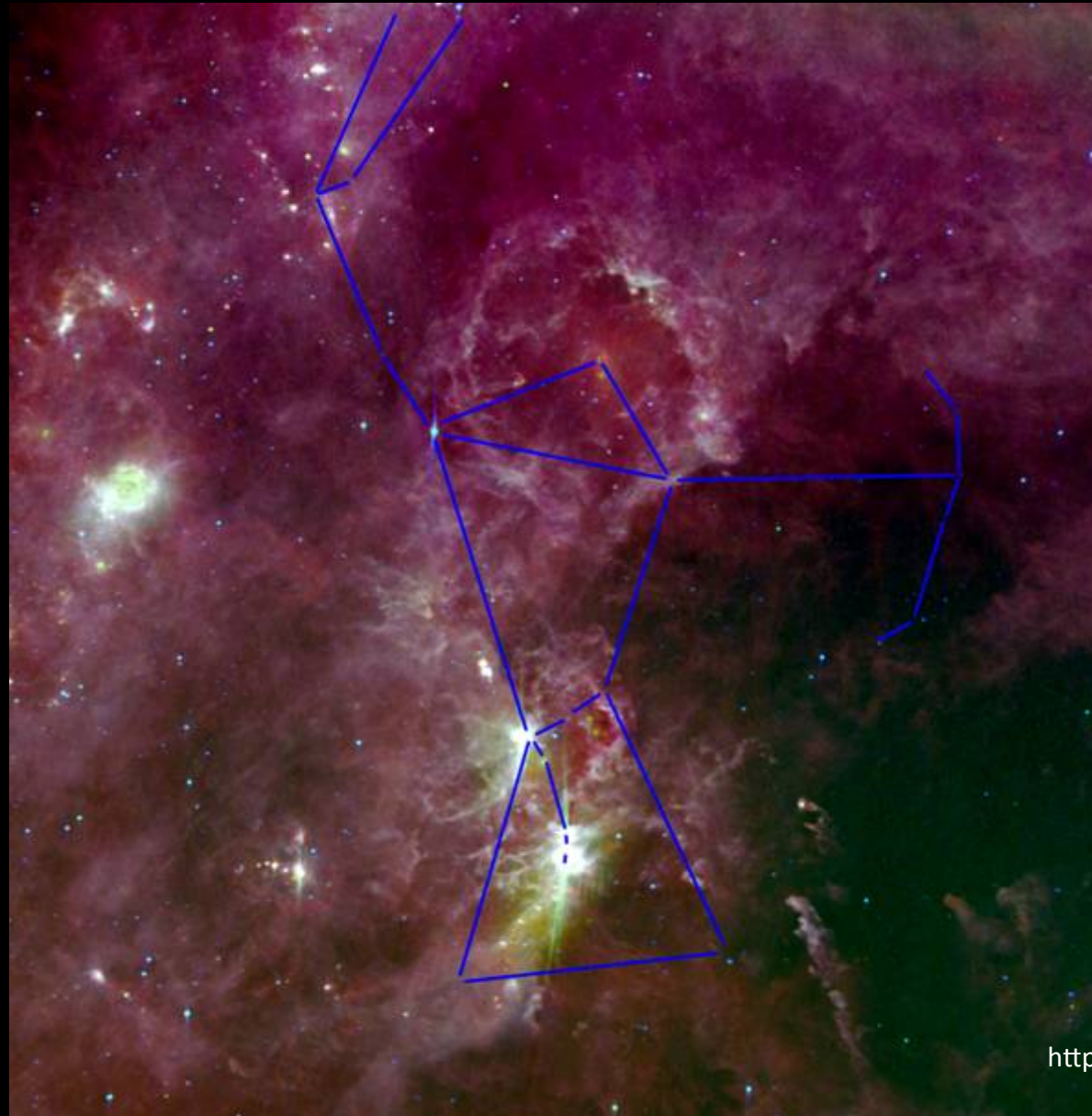
... and many other advanced data products

Constellation Orion



Mid Infrared
Light

IRAS



<http://handsonuniverse.org>

IRAS – Major Discoveries

General

Detected about 500,000 infrared sources, doubling the number of cataloged astronomical sources.

Solar System

- Discovered 6 new comets
 - comets are dustier than previously thought, their dust fills the Solar System
- Detected useful infrared data for 2004 asteroids
- **Detected the zodiacal dust bands** - bands of infrared emission that girdle our solar system which are likely to be debris from asteroid collisions

Stars and Star Formation and the ISM in our Galaxy

- Detected zodiacal dust and dusty **debris disks of material around Vega and several other stars**.
- Detected several **low mass protostars** embedded in clouds of gas and dust
- Cataloged thousands of **hot, dense GMC cores** with embedded high mass proto- and young stellar objects
- Cataloged over 12,000 variable stars
- Found **infrared cirrus** (wisps of warm dust) in almost every direction of space

Galaxies

- Detected ~75,000 starburst galaxies - which are extremely bright in the IR due to intense star formation (**ULIRGS**). Detected strong infrared emission from interacting galaxies
- First identified **IRAS F10214+4724** - at the time, the most luminous object known in the Universe by a factor of 2.

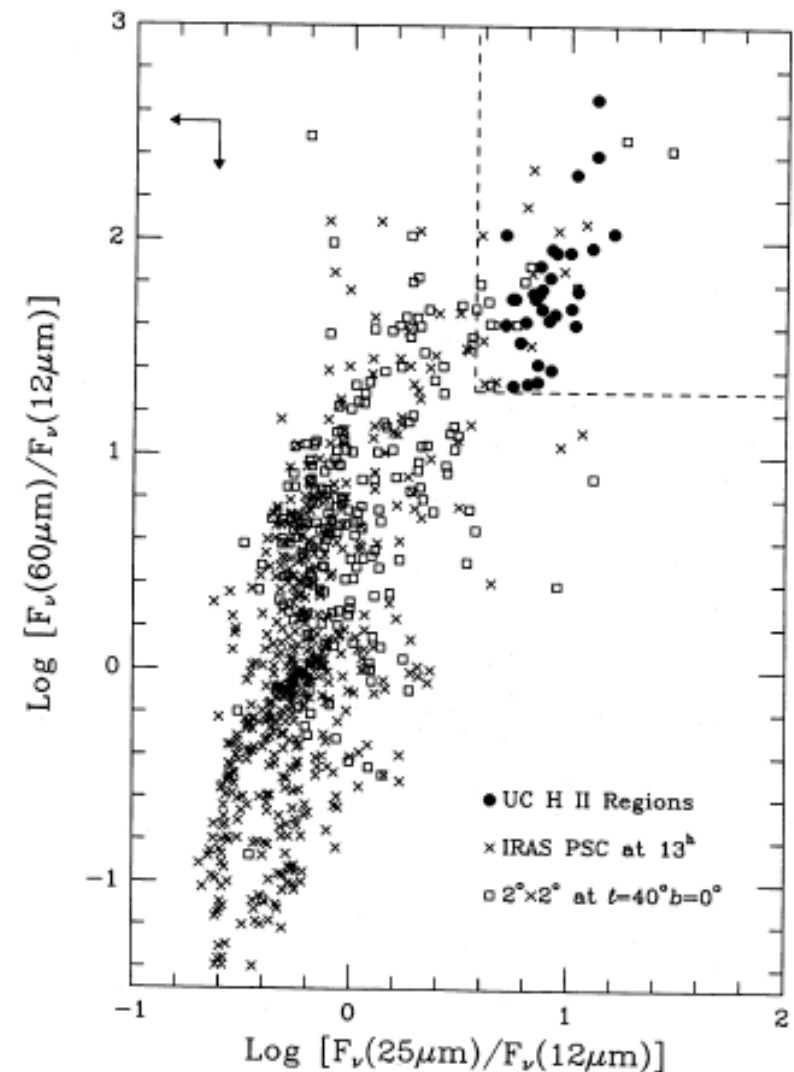
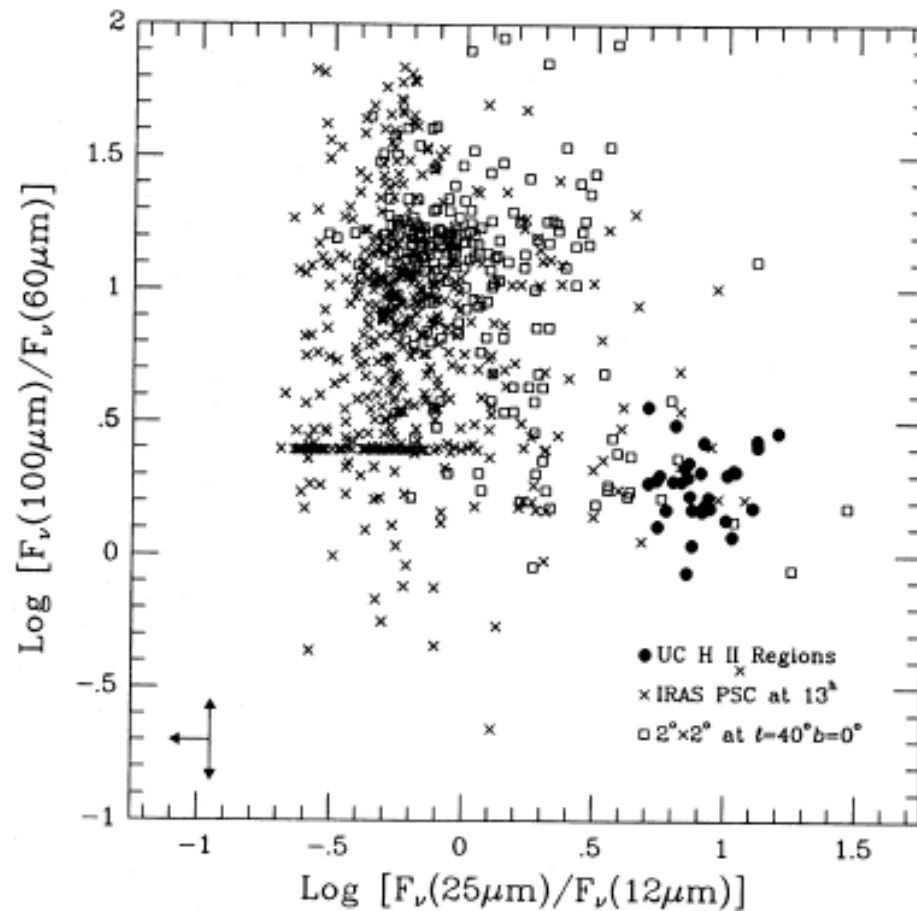
After: http://www.ipac.caltech.edu/outreach/Edu/iras_discoveries.html

The Power of Multi-band Surveys (Color-Color Diagrams) I

MASSIVE STARS EMBEDDED IN MOLECULAR CLOUDS: THEIR POPULATION
AND DISTRIBUTION IN THE GALAXY

DOUGLAS O. S. WOOD AND ED CHURCHWELL
Washburn Observatory, University of Wisconsin-Madison

ApJ 340, 265 (1989)



The Power of Multi-band Surveys (Color-Color Diagrams) II

The IRAS two-colour diagram as a tool for studying late stages of stellar evolution

W.E.C.J. van der Veen and H.J. Habing

Sterrewacht Leiden, P.O. Box 9513, 2300 RA Leiden, The Netherlands

A&A 194, 125 (1988)

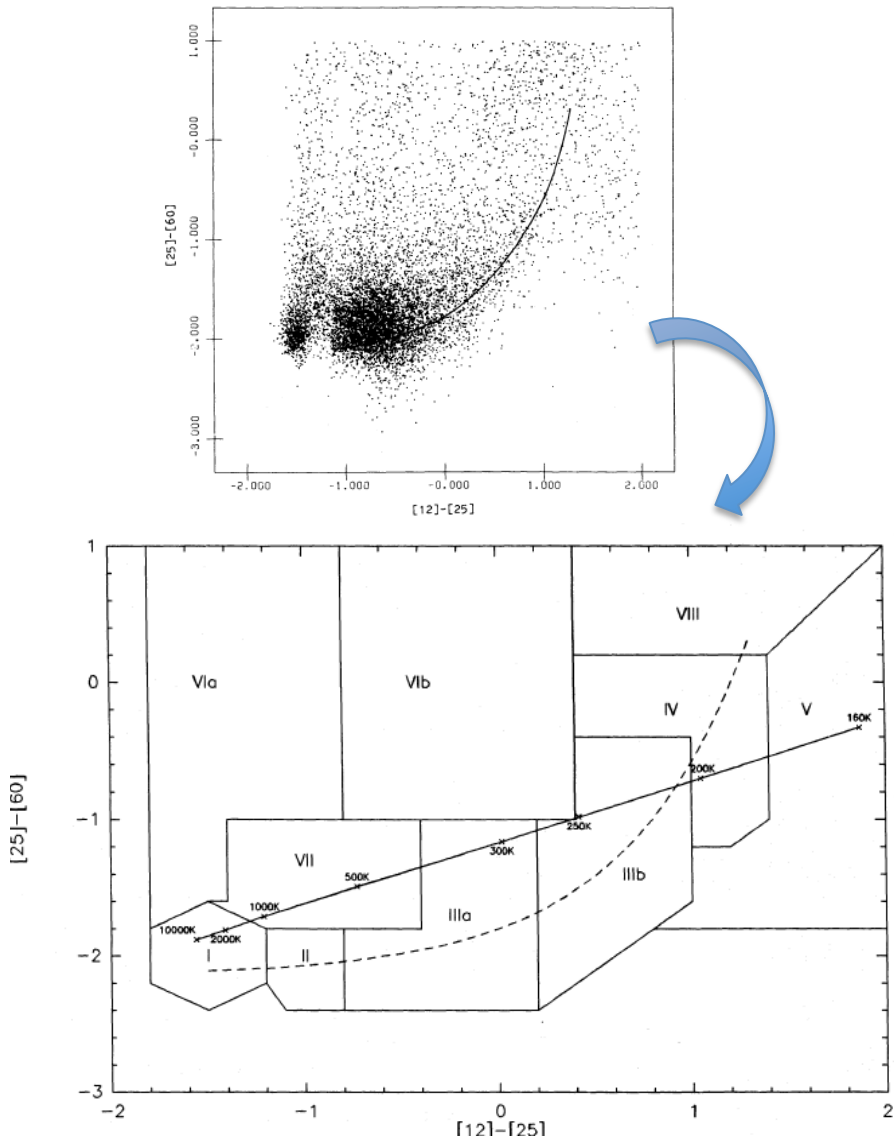


Table 1. Star counts and averaged variability for different regions in the IRAS two-colour diagram as indicated in Fig. 5b

Region	No.	<VAR>	No. (LRS)	LRS class	Characteristic type of object
I	791	12.7	76%	17–19 (89%)	Oxygen-rich non-variable stars without circumstellar shells
II	869	35.0	65%	14–16 (64%) 21–29 (23%)	Variable stars with “young” O-rich circumstellar shells
IIIa	2657	55.1	55%	21–29 (76%) 14–16 (14%)	Variable stars with more evolved O-rich circumstellar shells
IIIb	617	64.7	20%	31–39 (66%) 21–24 (11%) 41–43 (9%)	Variable stars with thick O-rich circumstellar shells
IV	204	29.6	8%	39 (50%) 71–79 (31%)	Variable stars with very thick O-rich circumstellar shells
V	176	16.4	15%	91–96 (69%) 71–79 (27%)	Planetary nebulae and non-variable stars with very cool circumstellar shells
VIa	501	19.9	20%	16–18 (64%) 42–45 (17%) 31–32 (8%)	Non-variable stars with relatively cold dust at large distances; a significant part of the stars is carbon-rich
VIb	605	35.9	5%	22–29 (47%) 14–15 (37%)	Variable stars with relatively hot dust close to the star and relatively cold dust at large distances; some of the objects have proven to be oxygen-rich
VII	2048	40.6	44%	41–47 (30%) 21–29 (22%) 14–16 (35%) 17–18 (11%)	Variable stars with more evolved C-rich circumstellar shells
VIII	315	27.1	10%	71–79 (43%) 91–95 (30%) 33–36 (13%)	Different sort of objects (see text)

Midcourse Space Experiment (MSX)

Mission Characteristics

Lifetime:	1996-1997	
Wavelength:	• A (8.28 μm) • C (12.13 μm) • D (14.65 μm) • E (21.3 μm)	
Area Coverage:	• $0 < l < 360$, $b < 5$ • IRAS gaps • select targets	
Instruments:	• SPIRIT III infrared telescope (33-cm aperture) • solid hydrogen-cooled five line-scanned infrared focal plane arrays	
Science Products Generated:	• Survey images and source catalogs • deeper raster scans of selected star formation regions and galaxies • raster scans of the IRAS gaps	
Canonical Paper:	Egan et al. (2003), Air Force Research Laboratory Technical Report AFRL-VS-TR-2003-1589	

<http://irsa.ipac.caltech.edu/Missions/msx.html>



A three color MSX image of a 6.1° by 4.0° field centered on the Galactic Center.



- In operation 2006 Feb 21–2007 Aug 26 (550 d)
- 68.5 cm effective aperture
- > 94% of the sky covered in survey mode
 - Far Infrared Surveyor (FIS) Bright Source Catalog:
Four FIR bands / 427071 sources
 - Infrared Camera (IRC) Point Source Catalog
Two mid-IR bands / 870973 sources
- Also: 5,000 pointed observations over the wavelength range 2–180 μm in 13 bands, providing comprehensive multi-wavelength photometric and spectroscopic coverage of a wide variety of astronomical sources, e.g.,:
 - nearby solar system objects
 - zodiacal light,
 - brown dwarfs,
 - young stars,
 - debris disks and
 - evolved stars in our Galaxy and in other galaxies of the Local Group.

AKARI 赤外線天文衛星

Band Name	N60	WIDE-S	WIDE-L	N160
Wavelength(micron)	50-80	60-110	110-180	140-180
Detector	Ge:Ga		Stressed Ge:Ga	
Array Format	20x2	20x3	15x3	15x2
Pixel Size(arcsec)	26.79		44.20	
Pixel Pitch(arcsec)	29.47		49.11	
Readout System	Capacitive Trans-Impedance Amplifier (CTIA)			
Sampling Speed(Hz)	25.28		16.86	

FIS : Far-Infrared Surveyor

IRC : Infrared Camera

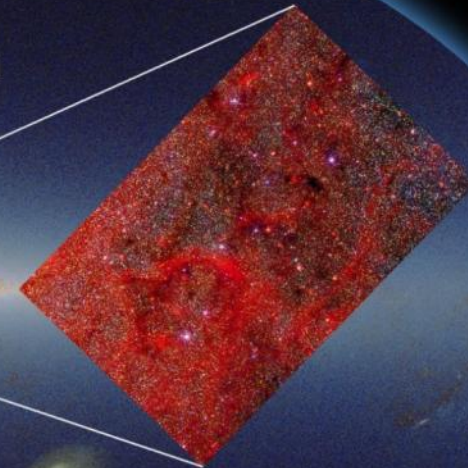
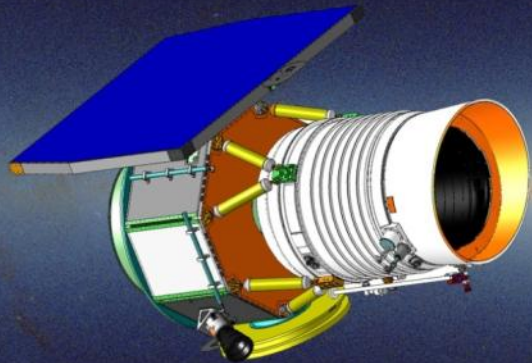
~10 x more sensitive than IRAS

Camera	NIR	MIR-S	MIR-L
Detector Type	InSb	Si:As	Si:As
Array Format	512x412	256x256	256x256
Field of View(arcmin)	9.5x10.0	9.1x10.0	10.3x10.2
Pixel FOV(arcsec)	1.46	2.34	2.51x2.39

National Aeronautics and Space Administration



WISE



Wide-field Infrared Survey Explorer

<http://wise.astro.ucla.edu>

UCLA • JPL • BALL • SDL • IPAC • UCB



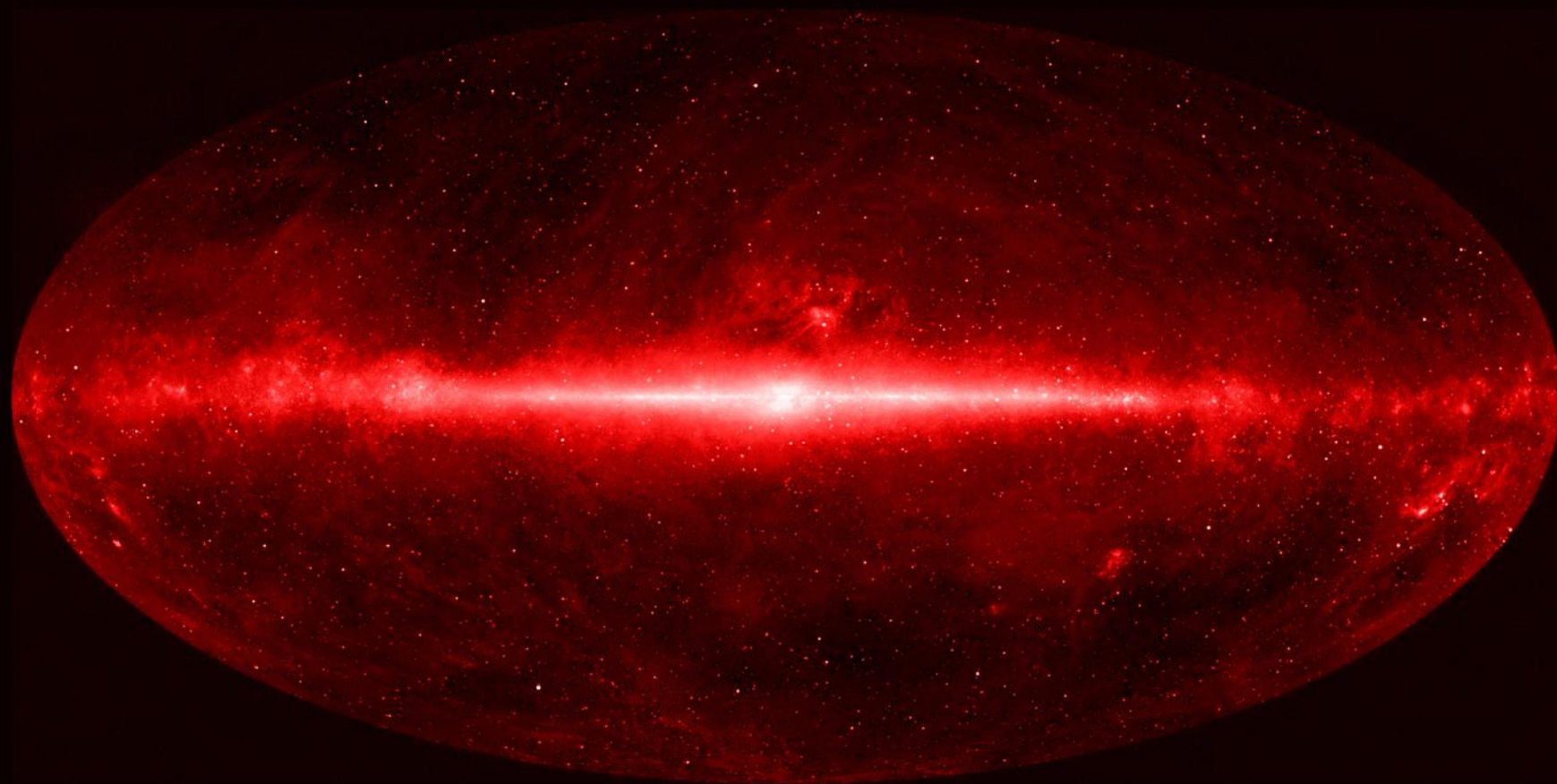
Wide-field Infrared Survey Explorer (WISE)

Mission Characteristics

Lifetime:	9.5 months + 4 months post-cryo (2010)
Wavelength:	3.4, 4.6, 12, and 22 microns
Area Coverage:	AllWISE & All Sky: 100% of the sky 3-Band Cryo: 30% of the sky Preliminary data release: 57% of the sky
Instruments:	Survey Camera
Funding Agency:	NASA
Contributing Institutions:	UCLA, JPL, IPAC/Caltech, UC Berkeley, SDL, BATC
Canonical Papers:	WISE: Wright et al. (2010) NEOWISE: Mainzer et al. (2011)



<http://irsa.ipac.caltech.edu/Missions/wise.html>



WISE

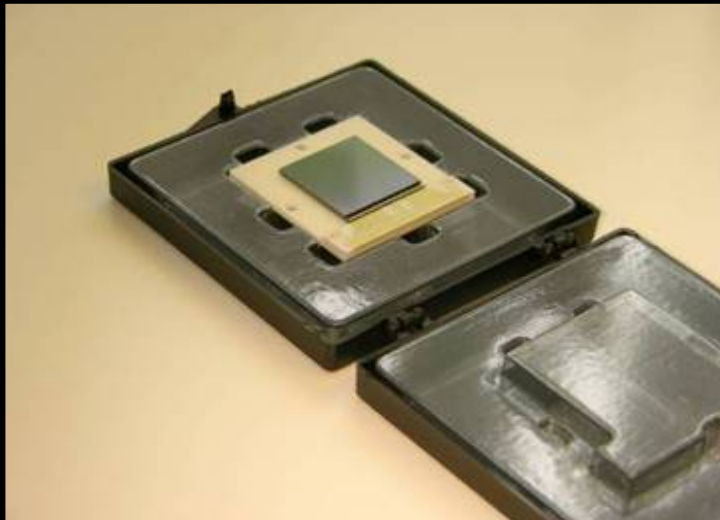
- 1 million images covering the whole sky in four IR bands
- Catalogs of ~500 million objects seen in these 4 wavelengths



WISE Mission: Detectors

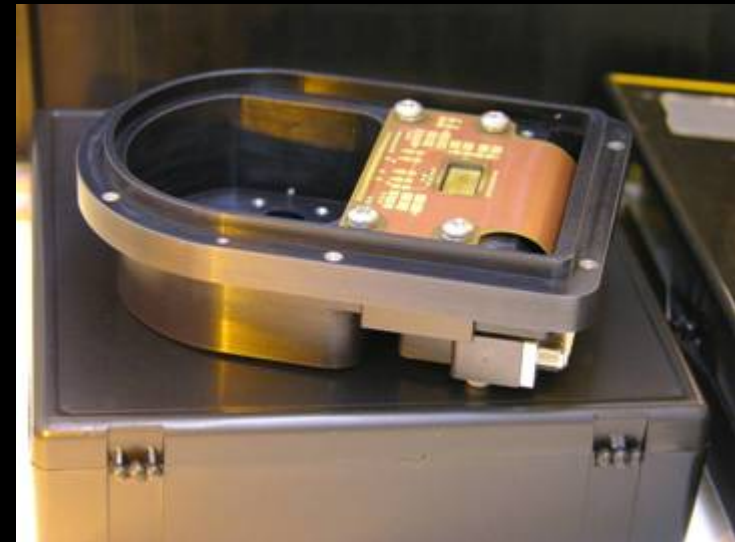


Mid Infrared Detector Array



1024² Si:As Detector

Near Infrared Detector Array



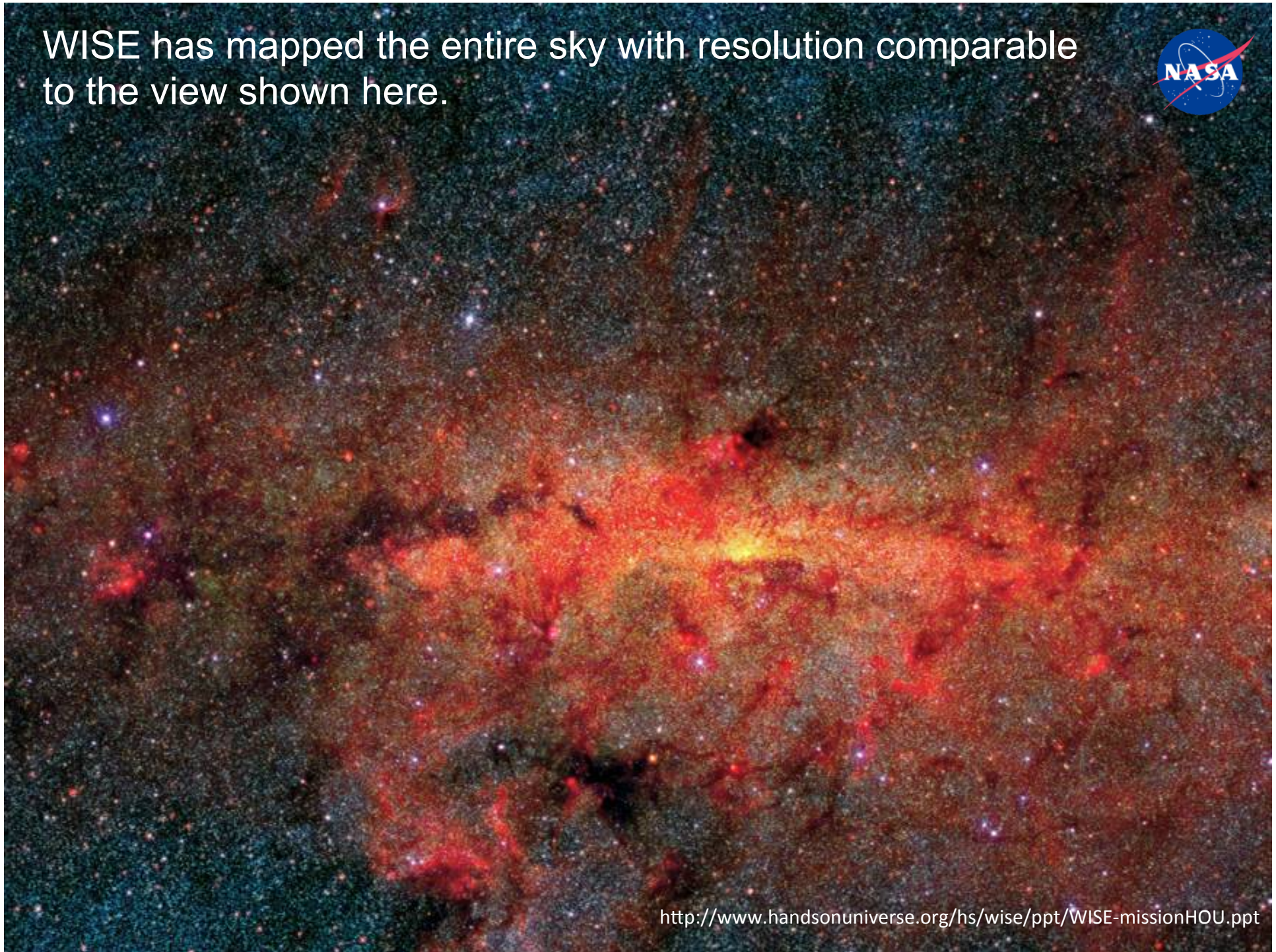
1024² HgCdTe Detector in Focal Plane Mount Assembly

1024² pixels at 3.4+4.6+12+22 μm

IRAS (best view of mid-infrared sky before WISE):



WISE has mapped the entire sky with resolution comparable to the view shown here.



WISE Mission: Wavelengths



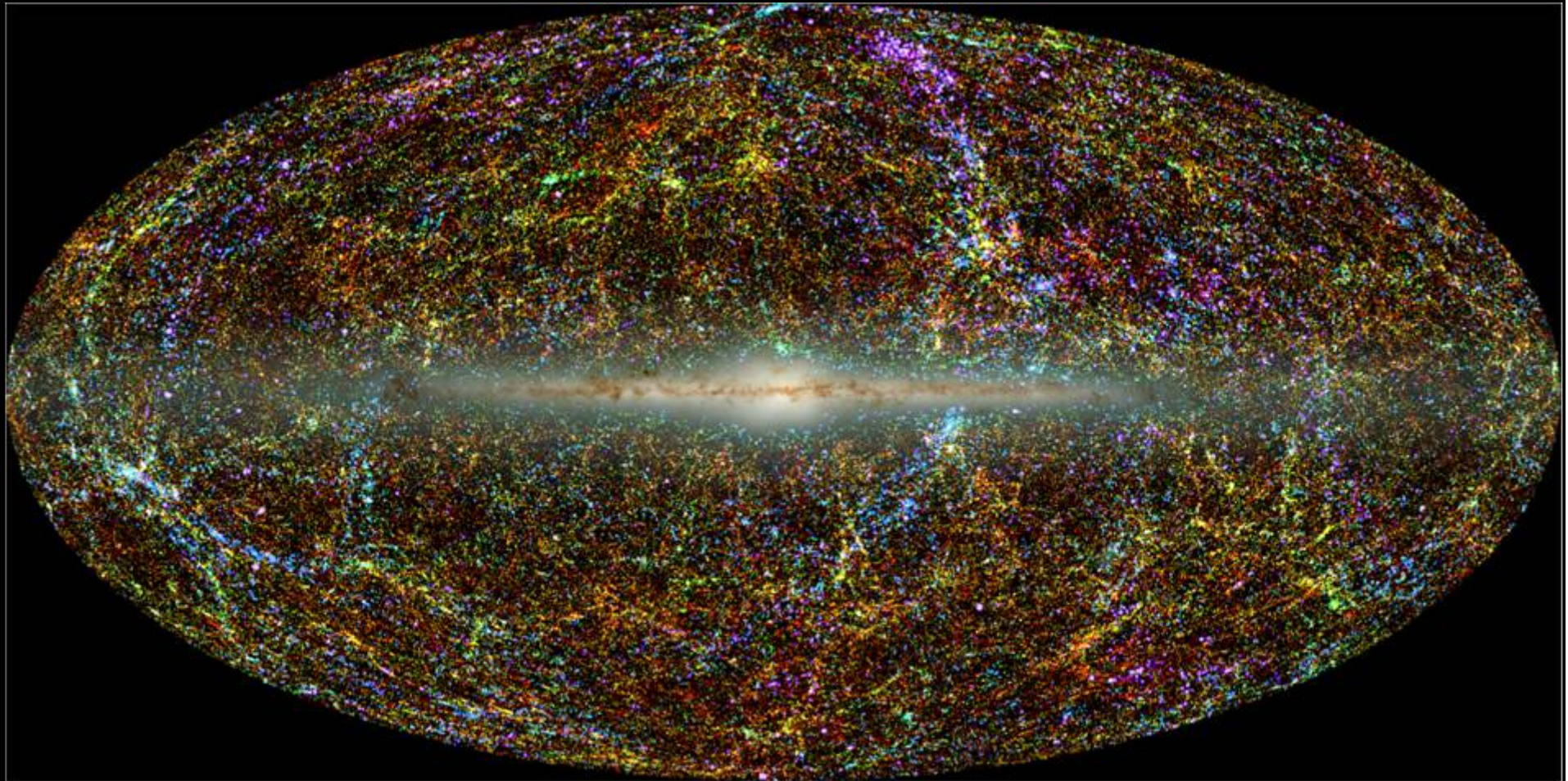
WISE surveyed the sky in two near infrared channels:
3.4 and 4.6 μm



WISE surveyed the sky in two mid-infrared channels:
12 and 22 μm



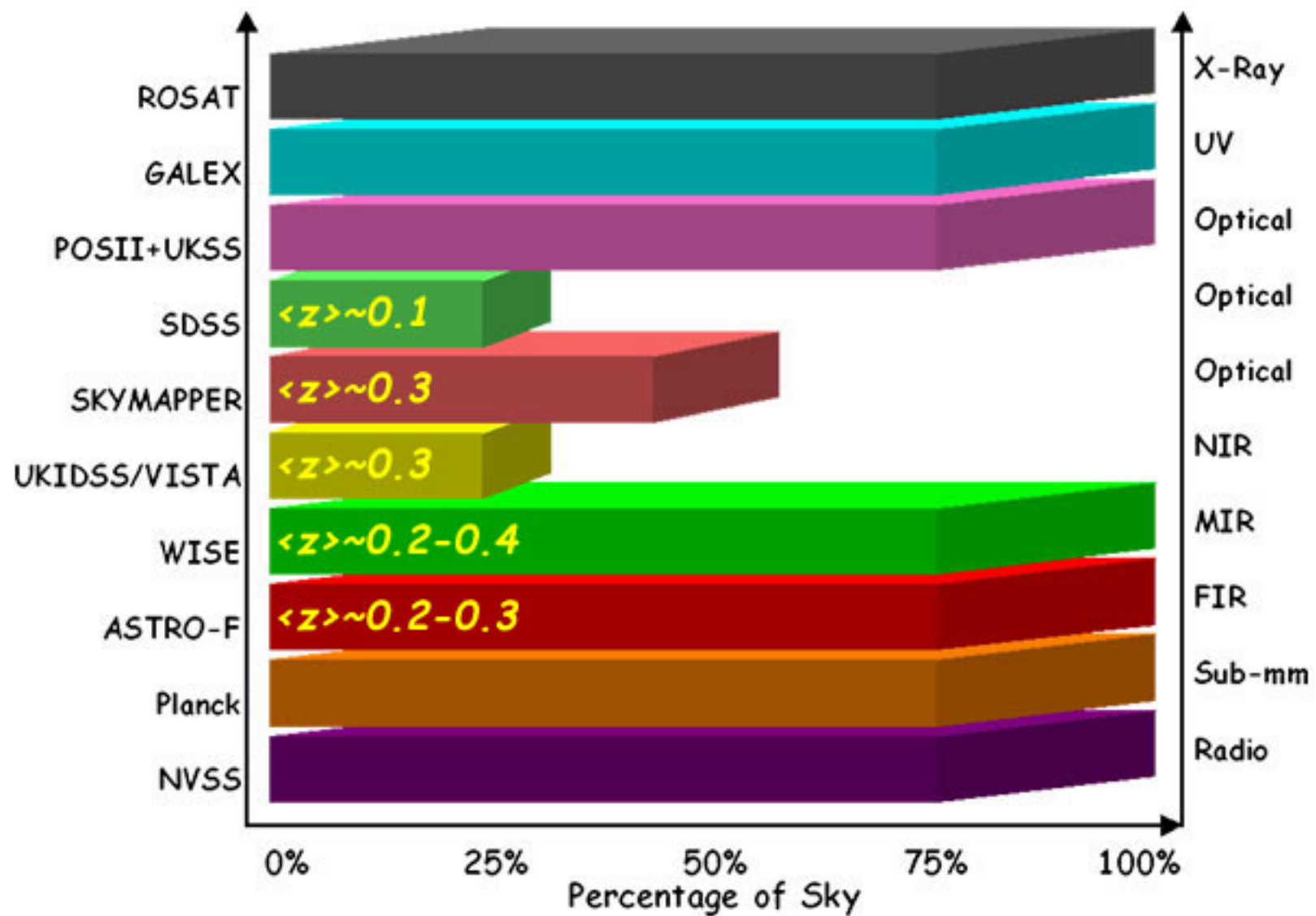
WISE Science: Cosmology



2MASS Surveyed Large Scale Structure out to $z \sim 0.1$

WISE surveys out to $z \sim 0.5$

<http://www.handsonuniverse.org/hs/wise/ppt/WISE-missionHOU.ppt>



Mid/Far-IR space-borne surveys are defined by their detector sizes:

IRAS: 1983

57 cm

12 + 25 + 60 + 100 μm

62 pixels

500000 objects

WISE: 2010

40 cm

3.4 + 4.6 + 12 + 22 μm

4 x 1024^2 pixels

> 560 million objects

The Follow-up Problem: How do I get data for “interesting” objects at wavelengths longer than 25 μm !

NASA's Infrared Missions



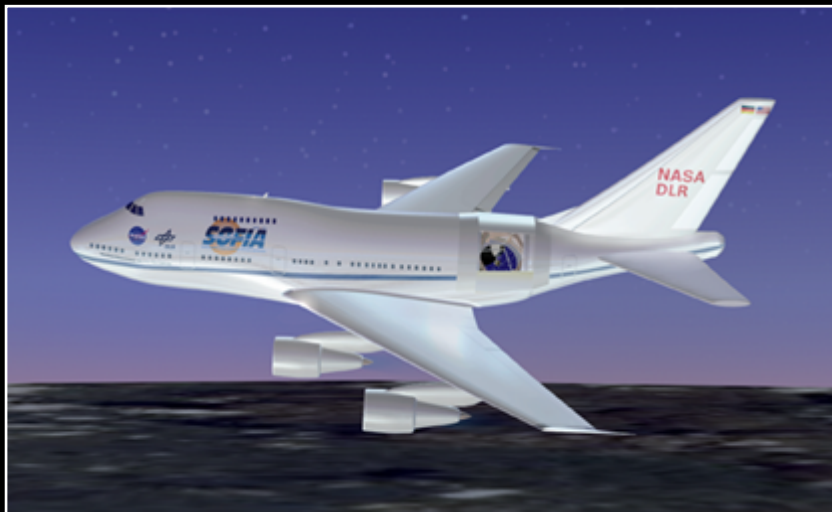
Spitzer Space Telescope



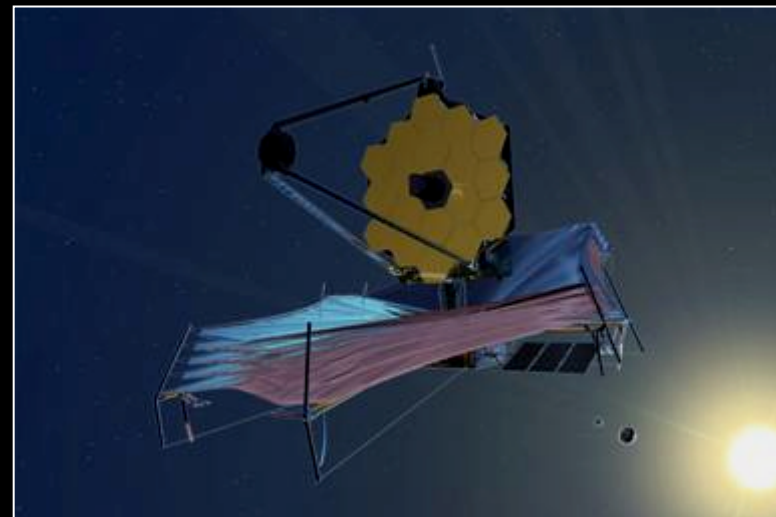
WISE



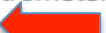
SOFIA



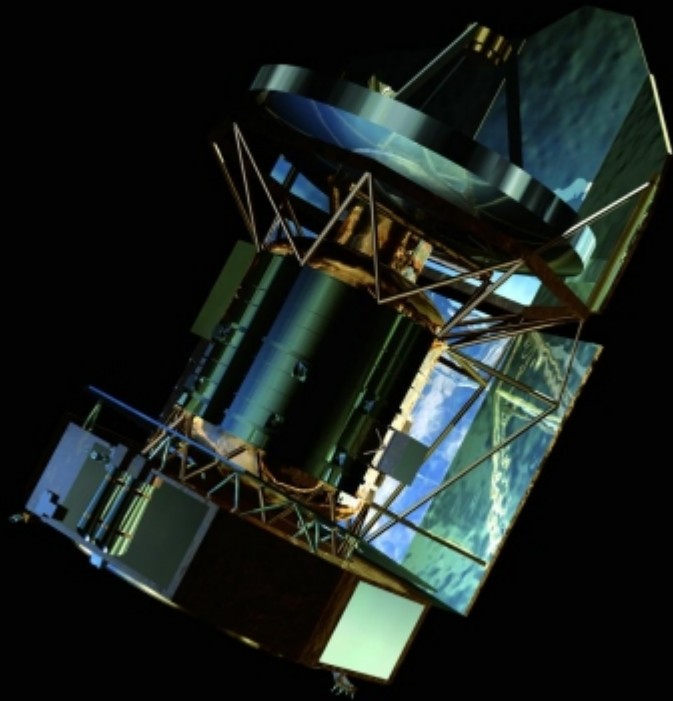
James Webb Space Telescope



The Current Suite of SOFIA Science Instruments

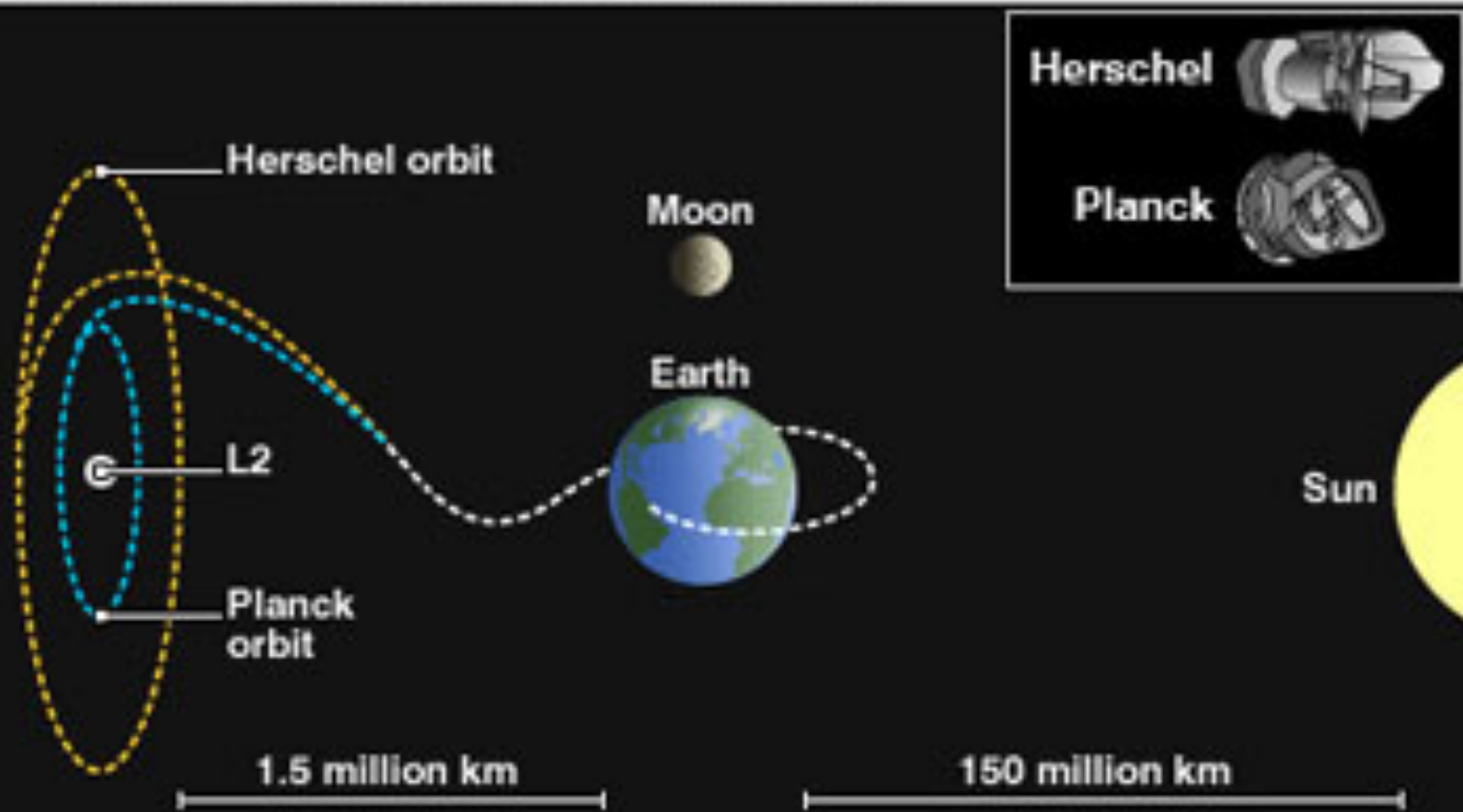
Name	PI	Institute	Description	Class
<u>EXES</u>	M. Richter	Univ. of California, Davis	Echelon Spectrometer 5-28 microns  R=10 ⁵ , 10 ⁴ , or 3000	PSI
<u>FIFI LS</u> *	A. Poglitsch	MPE, Garching	Imaging Grating Spectrometer 42-210 microns 	PSI
<u>FLITECAM</u>	I. McLean	UCLA	Near-IR Camera and Grism Spectrometer 1-5 microns 	FSI
<u>FORCAST</u>	T. Herter	Cornell	Mid-IR Camera and Grism Spectrometer 5-40 microns	FSI
<u>GREAT</u> *	R. Guesten	MPfIR KOSMA DLR-WS	Heterodyne Spectrometer 60 - 240 microns 	PSI
<u>HAWC</u>	D.A. Harper	Univ. of Chicago	HAWC+ High-resolution Airborne Wideband Camera and Polarimeter 50-240 microns 	FSI
<u>HIPO</u>	E. Dunham	Lowell Observatory	High-speed Imaging Photometer for Occultations 0.3 - 1.1 microns 	SSI

HERSCHEL



14 May 2009 – 29 April 2013

DISTANT OUTPOST: HERSCHEL AND PLANCK IN ORBIT



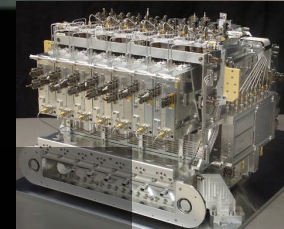
Objects, paths and distances not to scale

HERSCHEL

HIFI (Heterodyne Instrument for the Far Infrared)

480 – 1910 GHz, 7 bands

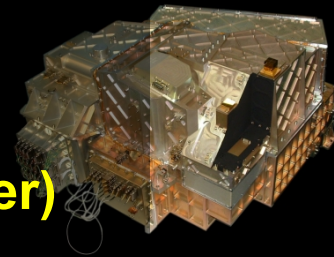
Very high resolution heterodyne spectrometer



PACS (Photodetector Array Camera and Spectrometer)

1.4 – 5 THz: photom. 1.75' x 3.5' / spec 50x50" @ 5"

Imaging photometer / medium resolution grating spectrometer



SPIRE (Spectral and Photometric Imaging Receiver)

0.58, 0.83, 1.2 THz, 4'x4'

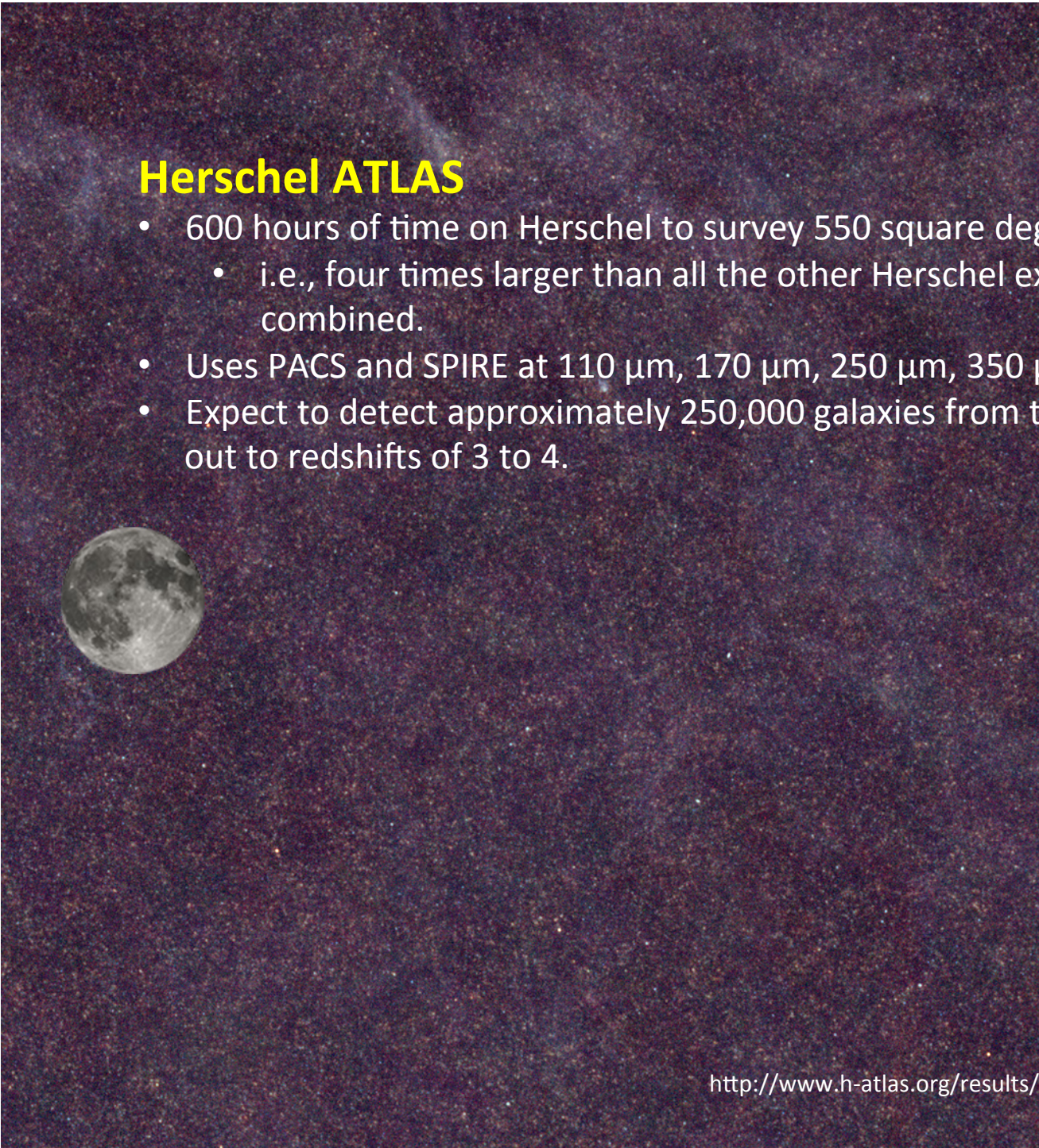
Imaging photometer / imaging Fourier transform spectrometer



Herschel Key Programmes

57% of Herschel observing time in key programmes:

- 21 Guaranteed Time Key Programmes (5879 h)
 - e.g. Hi-GAL: The Herschel infrared Galactic Plane Survey
(PI: Sergio Molinari, 344.3 hours allocated)
- 21 Open Time Key Programmes (5379 h)
 - e.g., Herschel Thousand Degree Survey (H-ATLAS)
(PI: Stephen Eales, 600.0 hours allocated)



Herschel ATLAS

- 600 hours of time on Herschel to survey 550 square degrees
 - i.e., four times larger than all the other Herschel extragalactic surveys combined.
- Uses PACS and SPIRE at 110 μm , 170 μm , 250 μm , 350 μm , & 500 μm .
- Expect to detect approximately 250,000 galaxies from the nearby Universe out to redshifts of 3 to 4.

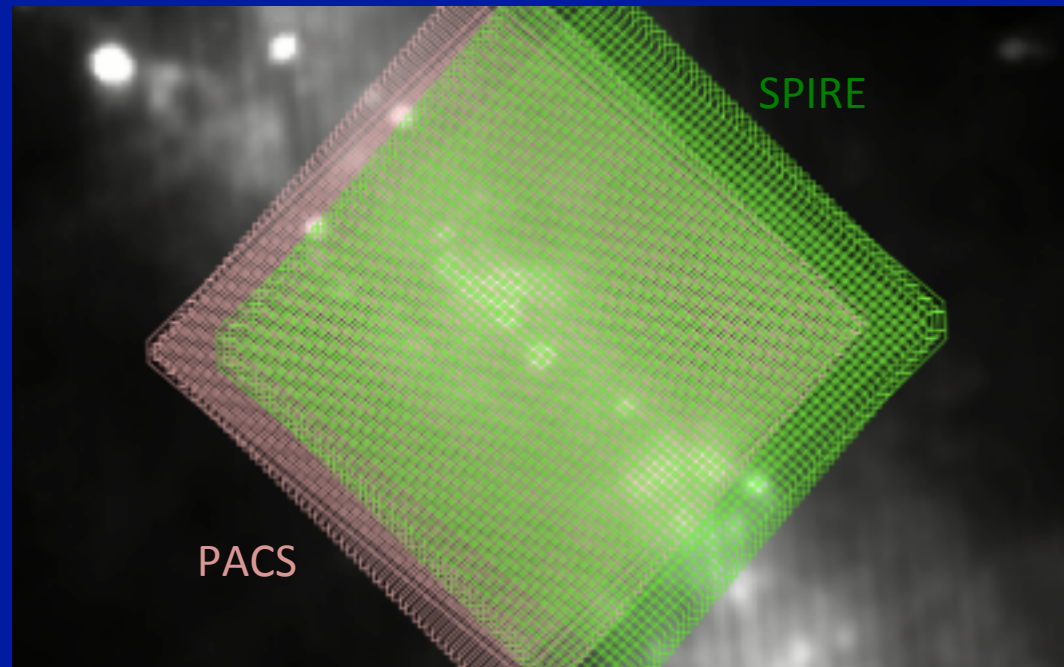
Science Demonstration Phase (SDP) data from Herschel-ATLAS (16 square degrees)

- Numerous strongly lensed sources

<http://www.h-atlas.org/results/highlights/first-data-release-herschel-atlas>

Hi-GAL: The Herschel infrared Galactic Plane Survey

- Image entire Galactic plane ($b = \pm 1^\circ$) with PACS and SPIRE simultaneously at 70, 170, 250, 350 and 450 μm



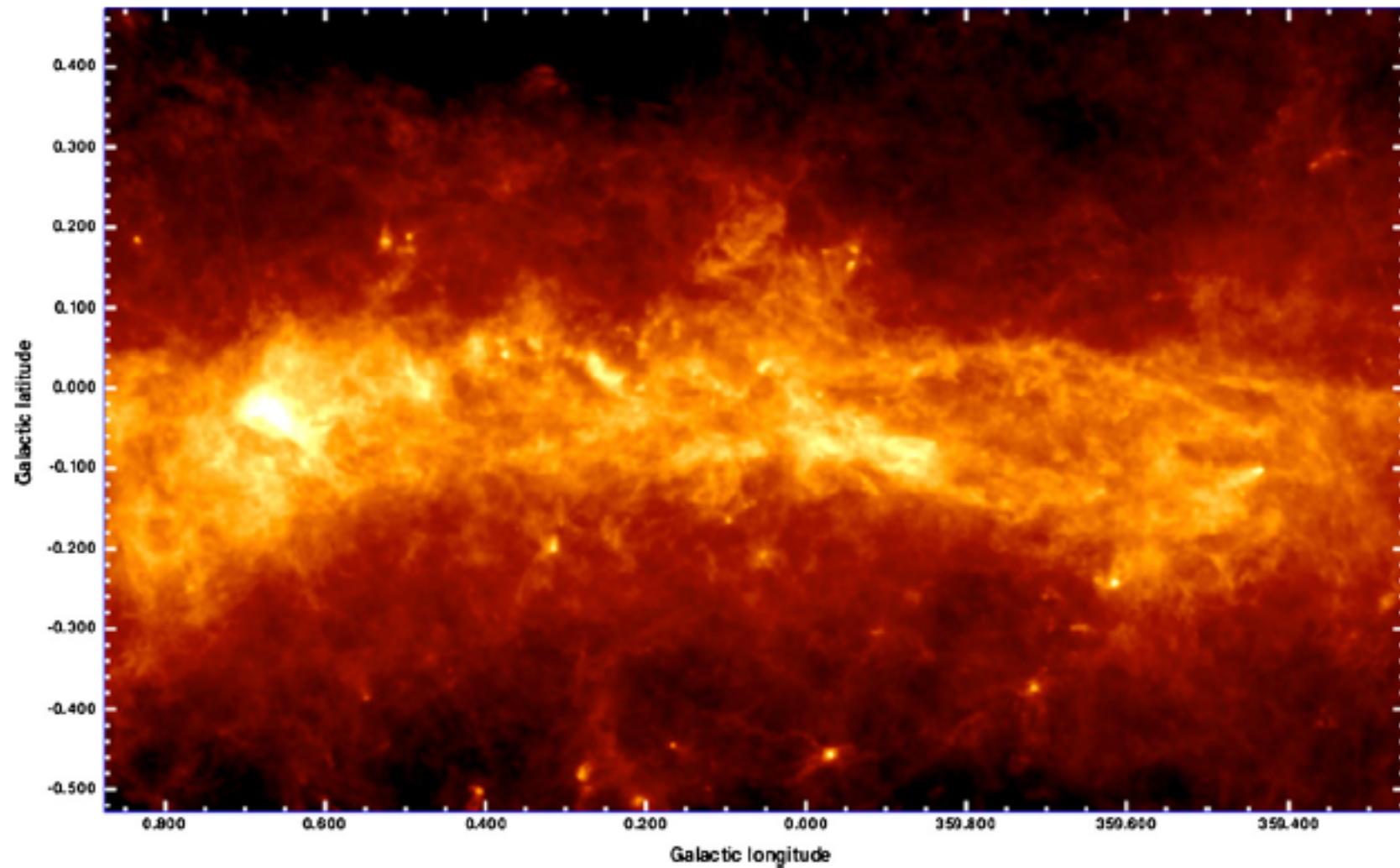


Figure 2. *Herschel* SPIRE 250 μm image of the Galactic center region.

Molinari et al. 2011

***Planck* 2013 results. XXVIII. The *Planck* Catalogue of Compact Sources**

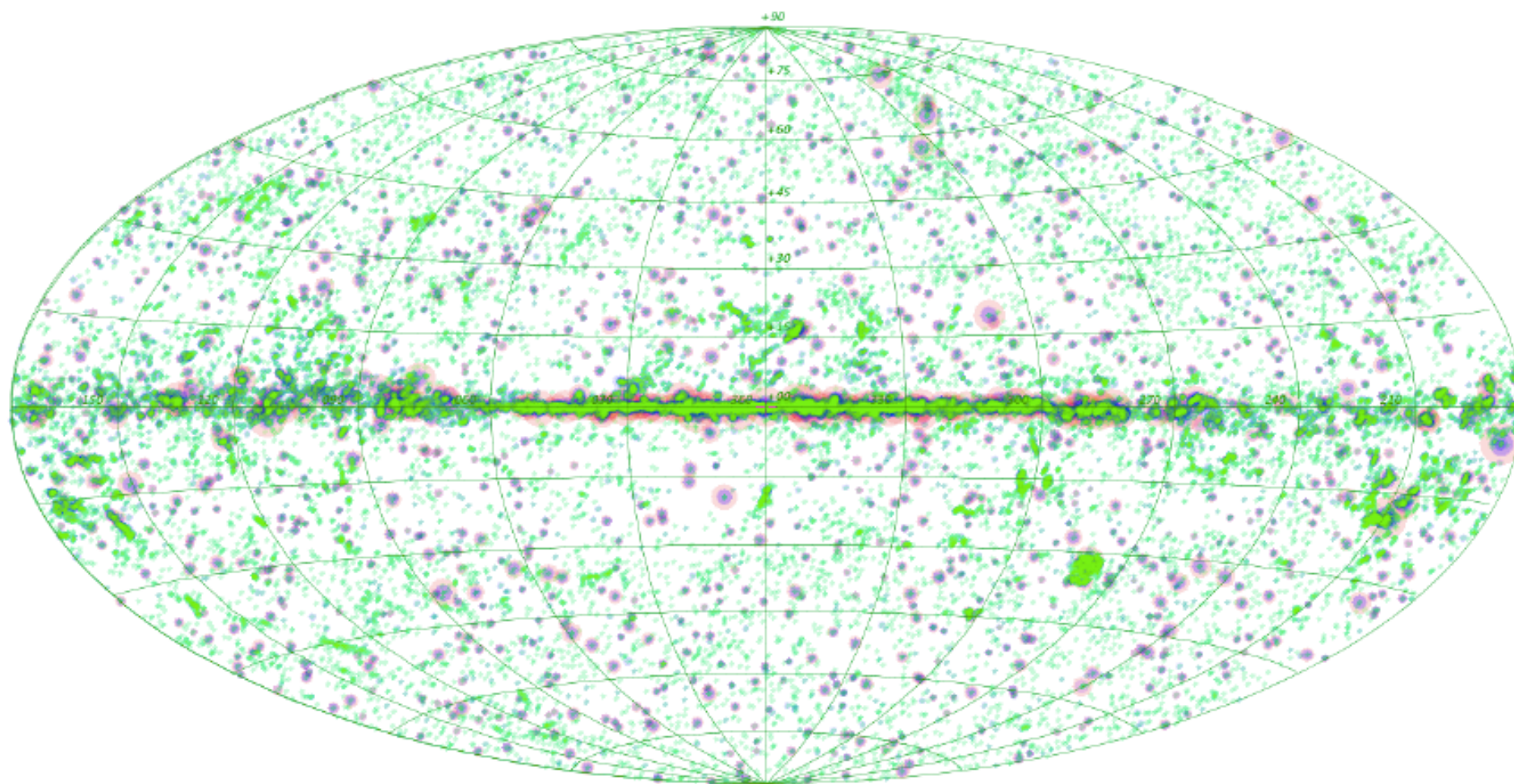
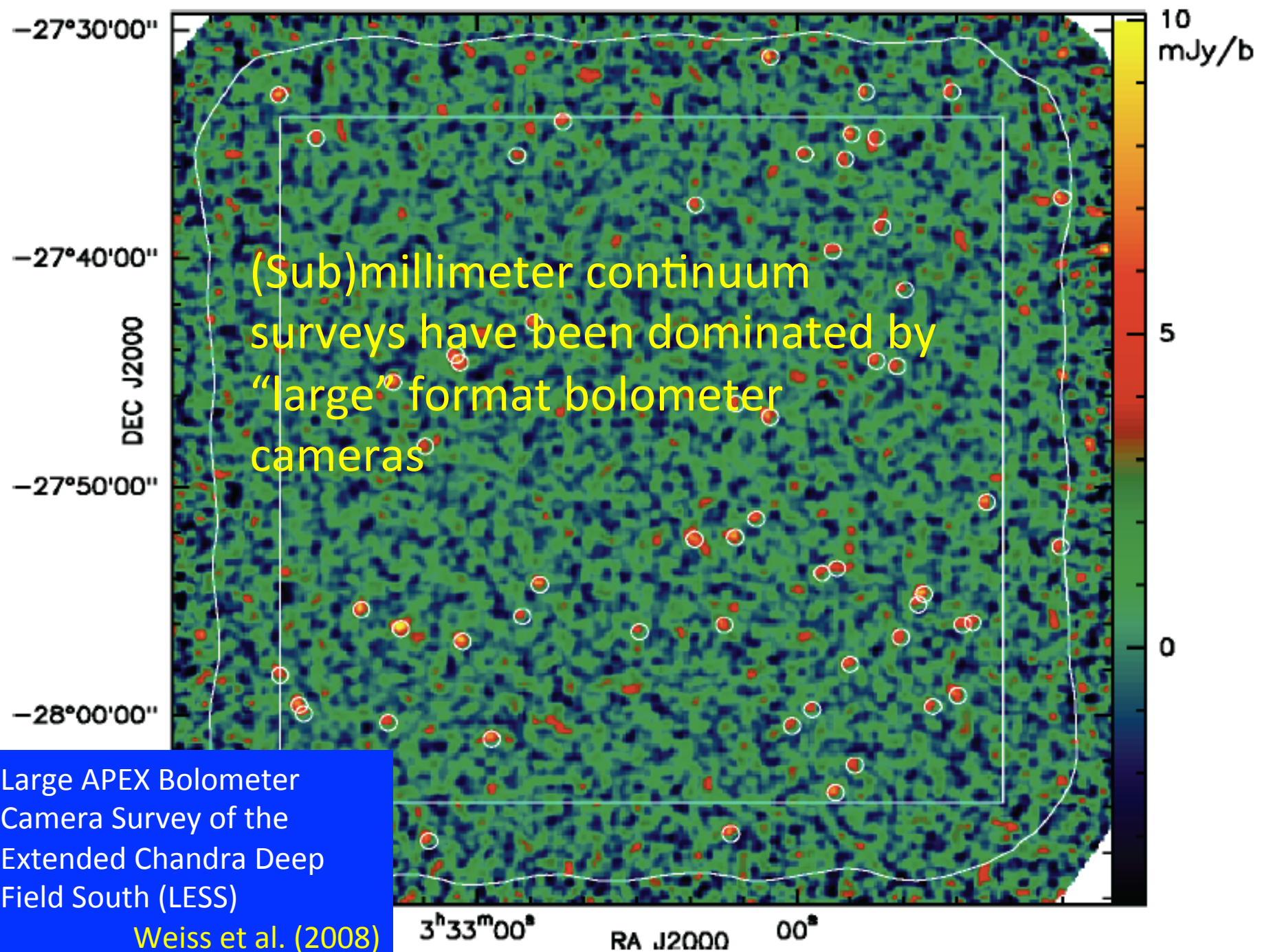


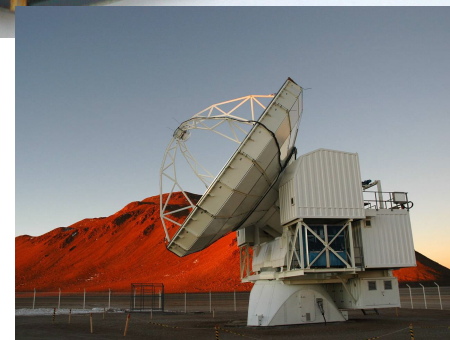
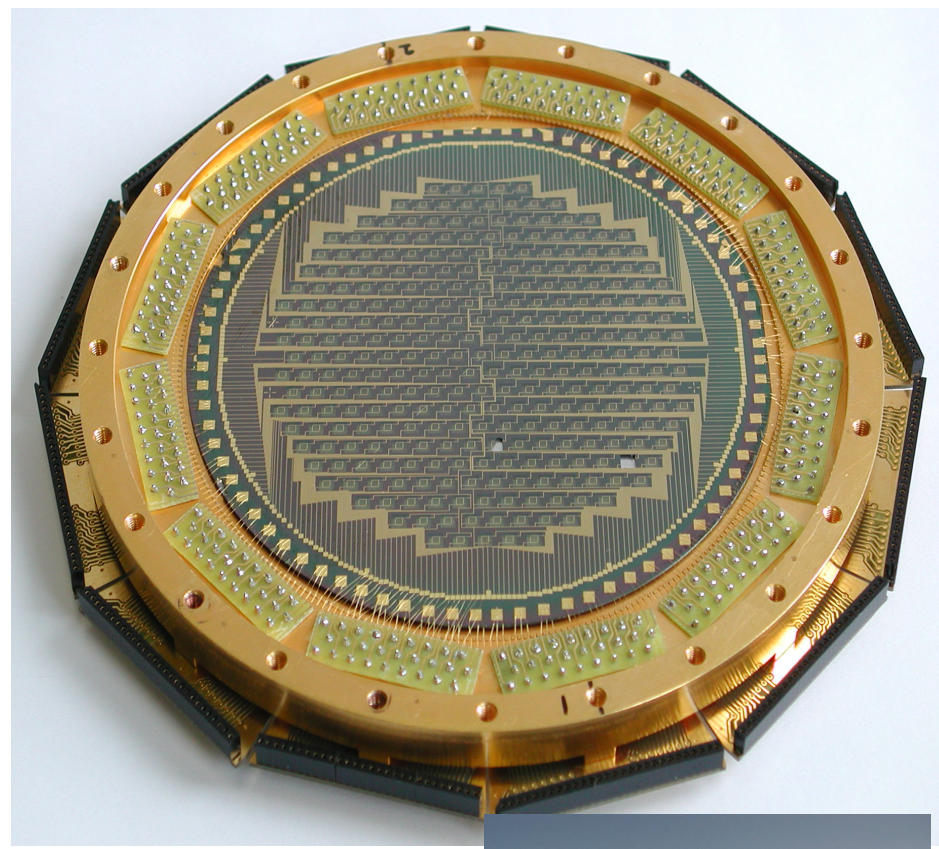
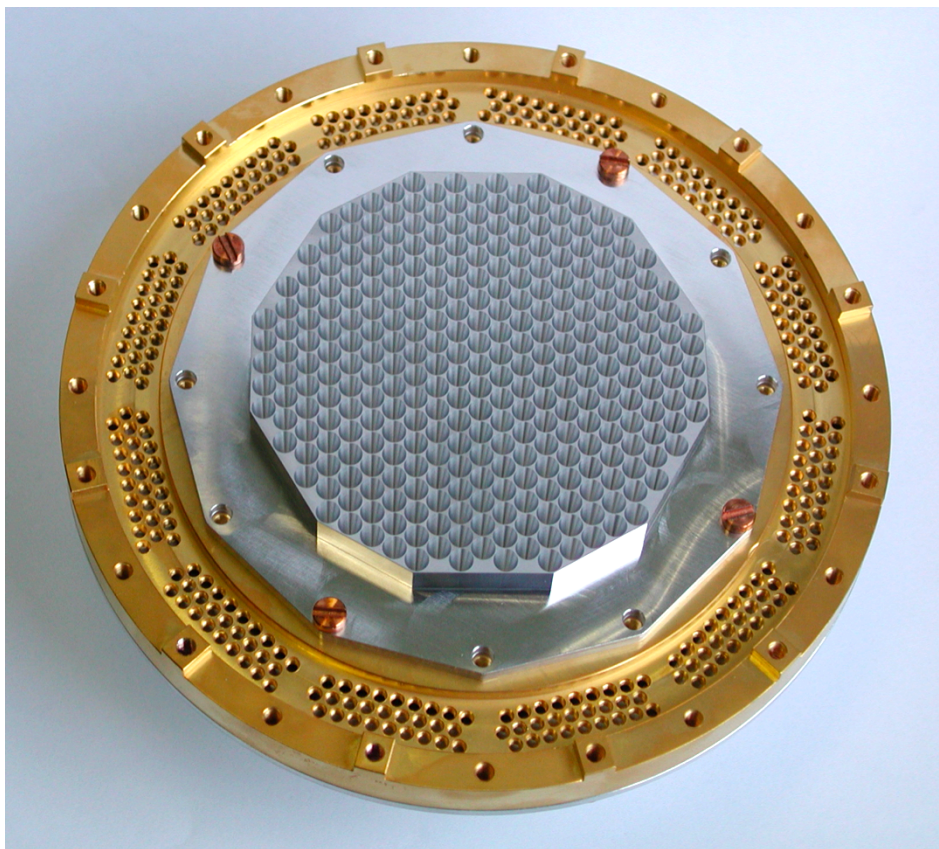
Fig. 1. Sky distribution of the PCCS sources at three different channels: 30 GHz (pink circles); 143 GHz (magenta circles); and 857 GHz (green circles). The dimension of the circles is related to the brightness of the sources and the beam size of each channel.

Table 1. PCCS characteristics.

	Channel								
	30	44	70	100	143	217	353	545	857
Frequency [GHz]	28.4	44.1	70.4	100.0	143.0	217.0	353.0	545.0	857.0
Wavelength, λ [μ m]	10561	6807	4260	3000	2098	1382	850	550	350
Beam FWHM ^a [arcmin]	32.38	27.10	13.30	9.65	7.25	4.99	4.82	4.68	4.33
Pixel size [arcmin]	3.44	3.44	3.44	1.72	1.72	1.72	1.72	1.72	1.72
S/N thresholds:									
Full sky	4.0	4.0	4.0	4.6	4.7	4.8	...	...	...
Extragalactic zone ^b	...	...	...	...	...	...	4.9	4.7	4.9
Galactic zone ^b	...	...	...	...	...	...	6.0	7.0	7.0
Number of sources:									
Full sky	1256	731	939	3850	5675	16070	13613	16933	24381
$ b > 30^\circ$	572	258	332	845	1051	1901	1862	3738	7536
N(>S) ^c :									
Full sky	934	535	689	3425	5229	15107	13184	15781	23561
$ b > 30^\circ$	373	151	191	629	857	1409	1491	2769	6773
$ b \leq 30^\circ$	561	384	498	2796	4422	13698	11693	13012	16788
Flux densities:									
Minimum ^d [mJy]	461	825	566	266	169	149	289	457	658
90 % completeness [mJy]	575	1047	776	300	190	180	330	570	680
Uncertainty [mJy]	109	198	149	61	38	35	69	118	166
Position uncertainty ^e [arcmin]	1.8	2.1	1.4	1.0	0.7	0.7	0.8	0.5	0.4



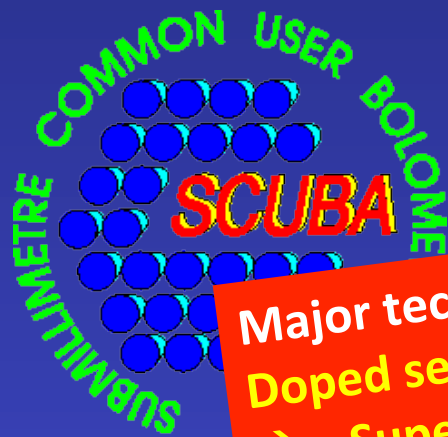
The Large APEX Bolometer Camera – LABOCA



The need for large area mapping:

Bolometer arrays are getting ever larger:

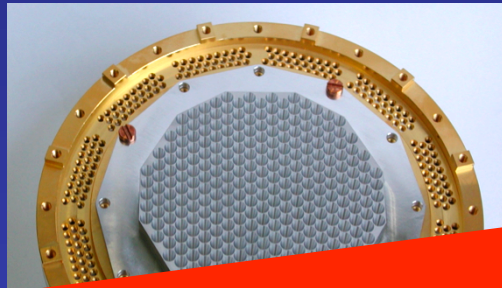
SCUBA



37 bolometers

yesterday

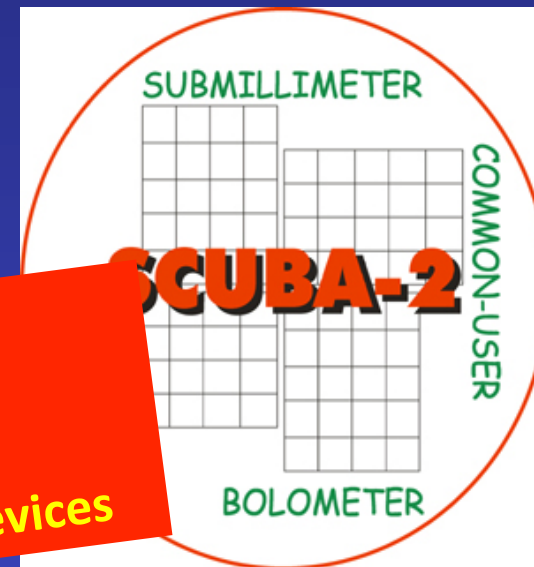
LABOCA



295
bolometers

since 2007

SCUBA-2



2×5128
bolometers

2013

Major technology changes:
Doped semiconductor bolometers
→ Superconducting TES bolometers
→ Microwave kinetic inductance devices

In addition: MAMBO-II, Bolocam, SHARC-II, ...

SPT

The South Pole Telescope



Funded by
NSF



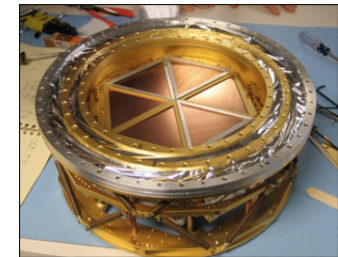
J. Vieira

Telescope

- 10 meter off-axis sub/mm telescope
- located at the geographic south pole
- 1 deg² field of view
- ~1' beams
- optimized for fine scale anisotropy measurements

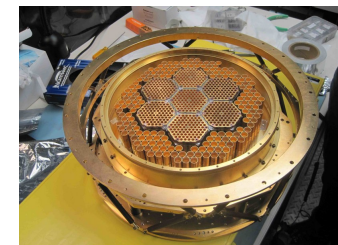
SPT-SZ Camera (1st Generation):

- 2007 – 2011
- 960 pixel mm camera, 1 deg² FOV
- 1.4, 2.0, and 3.0 mm
- completed 2500 deg²
- 18 μK-arcmin depth, ~1 mJy



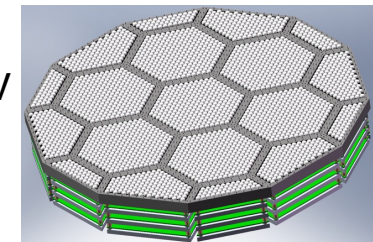
SPT-pol Camera (2nd Generation):

- 2012 – 2015
- 1600 detector mm camera, 1 deg² FOV
- 2 and 3 mm + polarization
- currently surveying 500 deg²
- 4.5 μK-arcmin depth

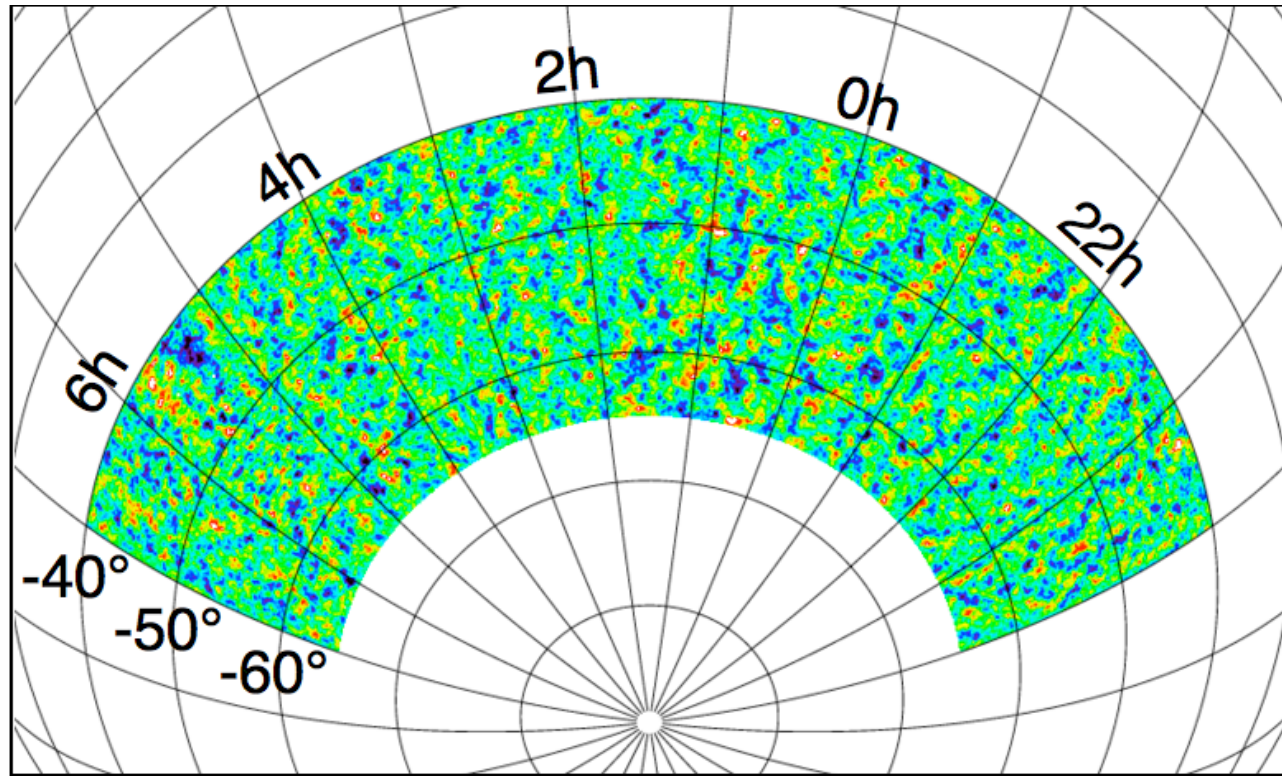


SPT-3G Camera (3rd Generation):

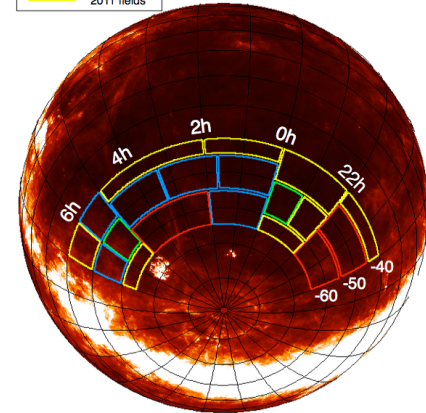
- 2016 – 2020
- 15k detector mm camera, 2.4 deg² FOV
- 1.4, 2, 3 mm + polarization
- planned 2500 deg² x8 deeper
- 2.5 μK-arcmin depth



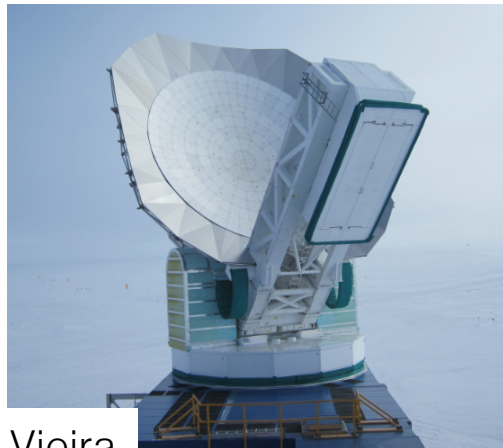
2500 deg² SPT-SZ Survey



2008 fields
 2009 fields
 2010 fields
 2011 fields



IRAS full sky map and SPT survey region



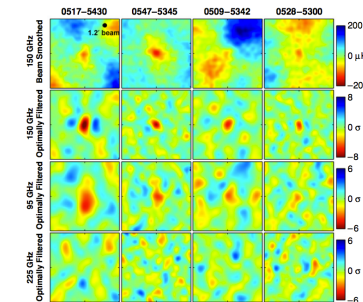
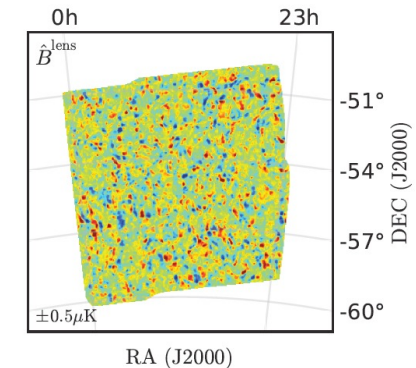
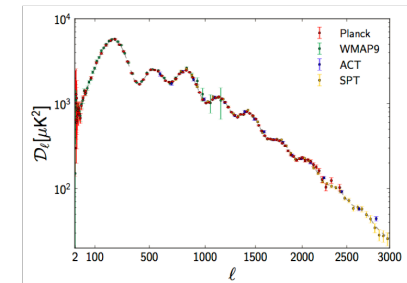
J. Vieira

		SPT-SZ	2008 → 2011	Deep Field	2008 → 2013	SPTpol	2012 → 2014	SPT3G	2015 → 2017
band [mm]	FWHM [']	uK _{CMB} -arcmin	RMS mJy/beam	uK _{CMB} -arcmin	RMS mJy/beam	uK _{CMB} -arcmin	RMS mJy/beam	uK _{CMB} -arcmin	RMS mJy/beam
3	1.7	42	2	6	0.3	6.5	0.3	4.2	0.2
2	1.2	18	1.3	5	0.3	4.5	0.3	2.5	0.2
1.4	1	85	6.8	35	3	--	--	4	0.4
area [deg ²]		2500		200		600		2500	

SPT Science

Cosmic Microwave Background:

- CMB power spectrum: Story *et al.* 2013 ApJ
- CMB Lensing: van Engelen *et al.* 2012 ApJ; Holder *et al.* 2013 ApJ
- Epoch of Reionization: Zahn *et al.* 2012 ApJ
- CMB Polarization: Hanson *et al.* 2013 PRL

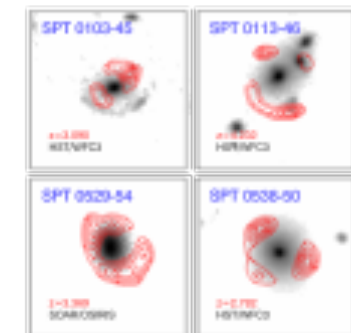


Galaxy Clusters

- SZ cluster catalog: Reichardt *et al.* 2013 ApJ
- Cluster Cosmology: Benson *et al.* 2013 ApJ
- Cluster Astrophysics: McDonald *et al.* 2013 ApJ

Galaxy Evolution:

- Catalog of mm sources: Mocanu *et al.* 2013 ApJ
- High-z strongly-lensed starforming galaxies: Vieira *et al.* 2013 Nature



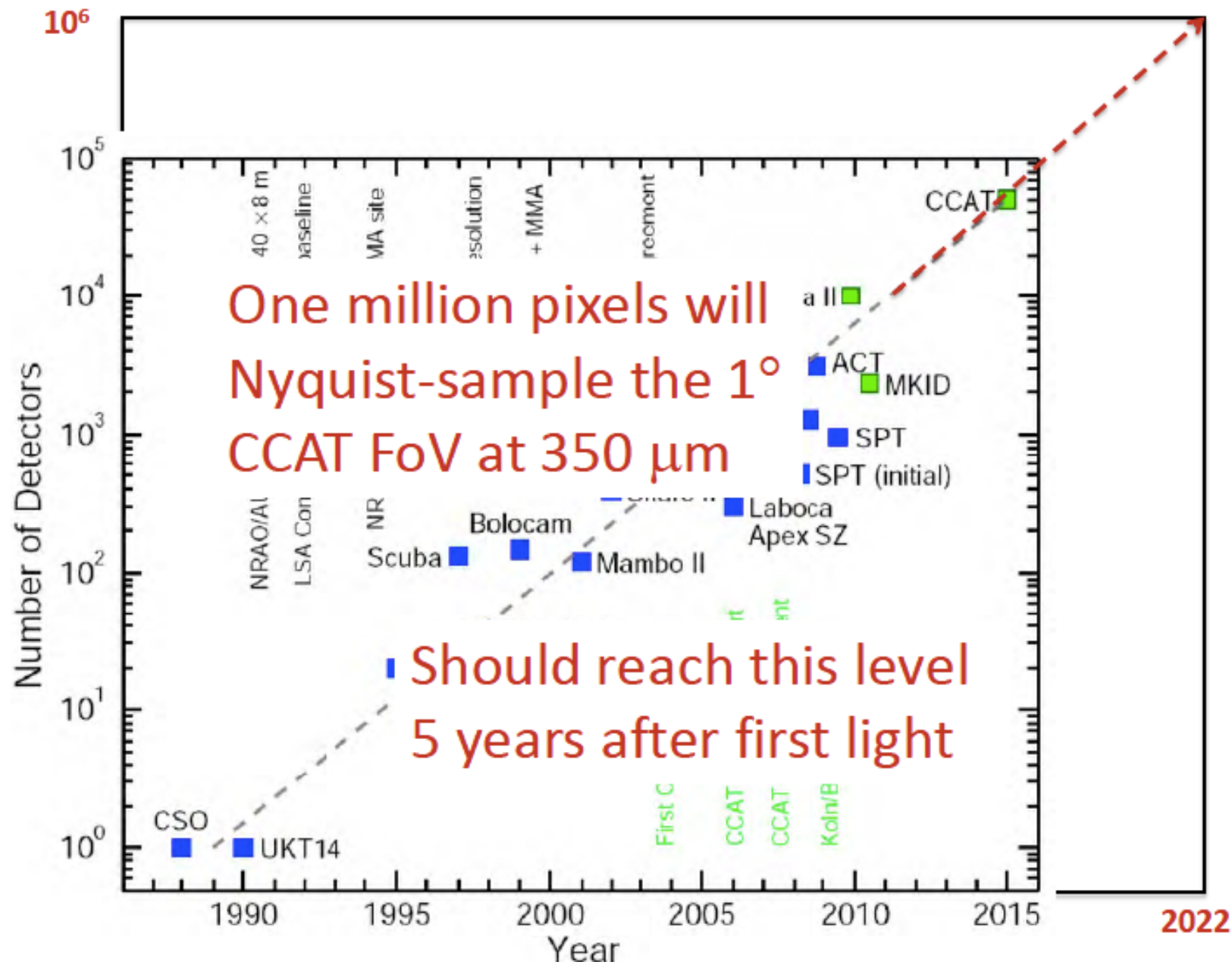
J. Vieira

The Future with CCAT

- 25m telescope at a superb site (ALMA + 600 m) will make submm astronomy object-oriented
- Beam size will allow us to get optical redshifts directly → no need for intermediate followup.
- Extragalactic Instrument Suite:
 - 350 μm camera (Cornell/JPL)
 - 0.85/1.1/1.4/2.0mm camera (Caltech/JPL)
 - X-Spec 1mm spectrometer (JPL)



Instrument	[μm]	aperture [m]	FWHM [arcsec]
Spitzer/IRAC	3.6-8	0.85	2
Spitzer/MIPS	24	0.85	6
Herschel/PACS	70	3.5	5.2
Herschel/SPIRE	250	3.5	18
SPT	1400	10	70
SCUBA	450	15	8
SCUBA	850	15	15
LMT	1100	30 (50)	10 (6)
CCAT	350	25	3.5
CCAT	850	25	8.5





SPICA
Space Infrared Telescope for Cosmology and Astrophysics

Space Infrared Telescope for Cosmology & Astrophysics

SPICA: 現状および観測の特徴について

光赤天連シンポジウム

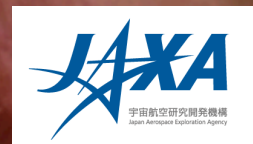
「望遠鏡時間の使い方: 共同利用とプロジェクト」

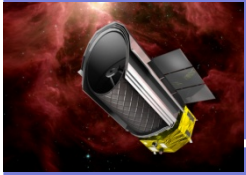
2011年9月6-7日@京都大学理学研究科

松原英雄、中川貴雄、他SPICAプリプロ
ジェクト(ISAS/JAXA)

Institute of Space & Astronautical Science

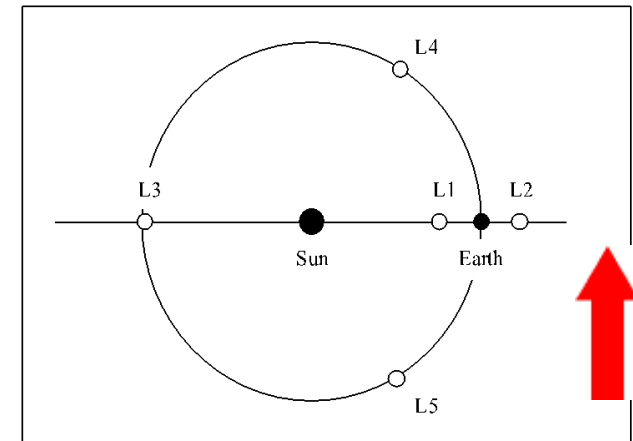
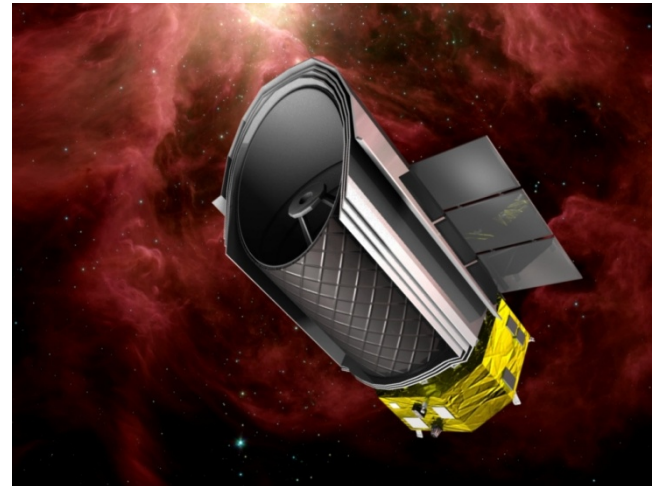
Japan Aerospace Exploration Agency





SPiCA Mission Overview

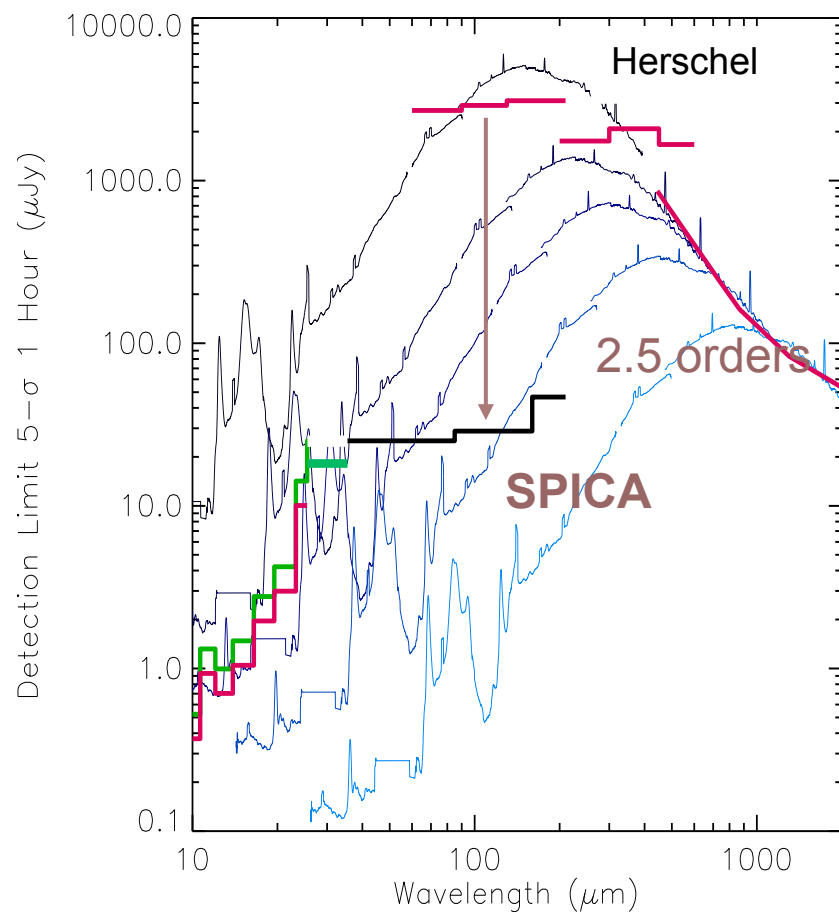
- Telescope: 3.2m (EPD 3.0m), 6 K
 - Superior Sensitivity
 - Good spatial resolution
- Core wavelength: 5-210 μm
 - MIR Instrument
 - Far-Infrared Instrument (SAFARI)
- Orbit: Sun-Earth L2 Halo
- Mission Life
 - 3 years (nominal)
 - 5 years (goal)
- Weight: 3.7 t
- Launch: FY2018 (original plan)
→ 2022???
- International mission
 - Japan, Europe, USA, Korea, (Taiwan)



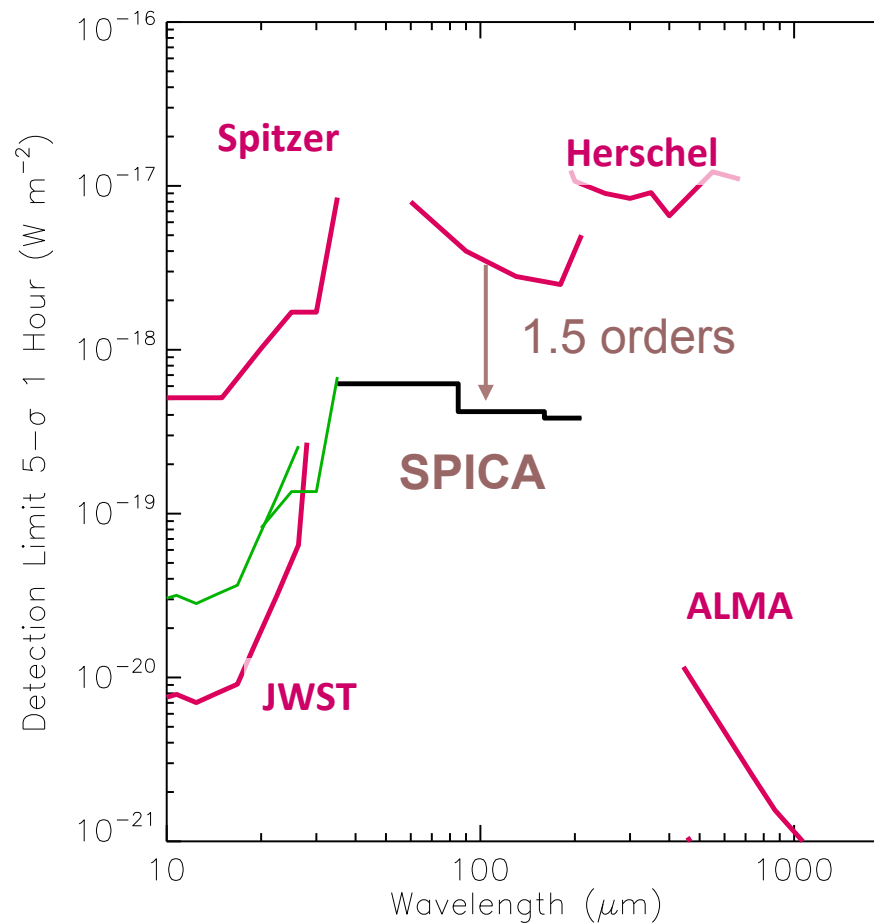


Huge Gain of Sensitivity !

Photometry



Spectroscopy



**FIR and (sub)mm observations address
star formation over Cosmic time**

**There exist no sensitive high resolution
(< 1 arcmin) all sky surveys at wave-
lengths between $22\ \mu\text{m}$ and $21\ \text{cm}$
(frequencies $1.4\ \text{GHz}$ – $14\ \text{THz}$)***

**Are we missing interesting populations of
objects?**

* A blind survey (AT20G) of the whole Southern sky at $20\ \text{GHz}$ was performed with the Australia Telescope Compact Array. 5890 sources were discovered above a flux density limit of $40\ \text{mJy}$ (Murphy et al. 2009)