Herschel & SOFIA Synergies and Complementarities

Dr Göran Sandell

Associate Chief Scientist, SOFIA-USRA

Outline of Material

- Brief Overview of SOFIA
- Why SOFIA and Key Specifications
- Instrumentation
- Comparison of Herschel and SOFIA
- Synergies and complementarities

SOFIA is still alive !

- However, we are going through another program restructure:
  - USRA no longer prime
  - Program office and flight testing now at NASA Dryden
  - Science and Mission still at NASA Ames, but there will be an independent review of science operations in February 07

SOFIA ready to fly

Progress to Date

- We have an airplane
  - Clipper Lindbergh
  - Airplane ready to fly
  - All structural modifications done
  - Door is on (but door controller still to be delivered)
  - First flight in March 07, then ferry flight to Dryden
- We have primary and a telescope delivered to Waco
  - Mirror light-weighted and polished
  - All parts manufactured and working
  - Integrated into aircraft
  - First on Sky results
- We are building a Science Center
- We have selected instruments
  - PI and Facility Instruments

Overview of SOFIA

- Modified Boeing 747-SP aircraft (NASA, USRA, L3)
- 2.5 m telescope (DLR, MAN, KT)
  - Optical-mm performance
  - Obscured IR (15-300 μm) most important
- Operating altitude
  - 41,000 to 45,000 feet (13-14 km)
  - Above > 99% of obscuring H_2O.
- Operations still tbd (USRA, DSI, NASA, DLR), but planned for
  - 20 year lifetime
  - Moffett Field, CA, N211 > 80-people, 20% German
  - Deployments
  - 960 hrs/year (SFH)
  - Build on KAO Heritage

Why SOFIA?

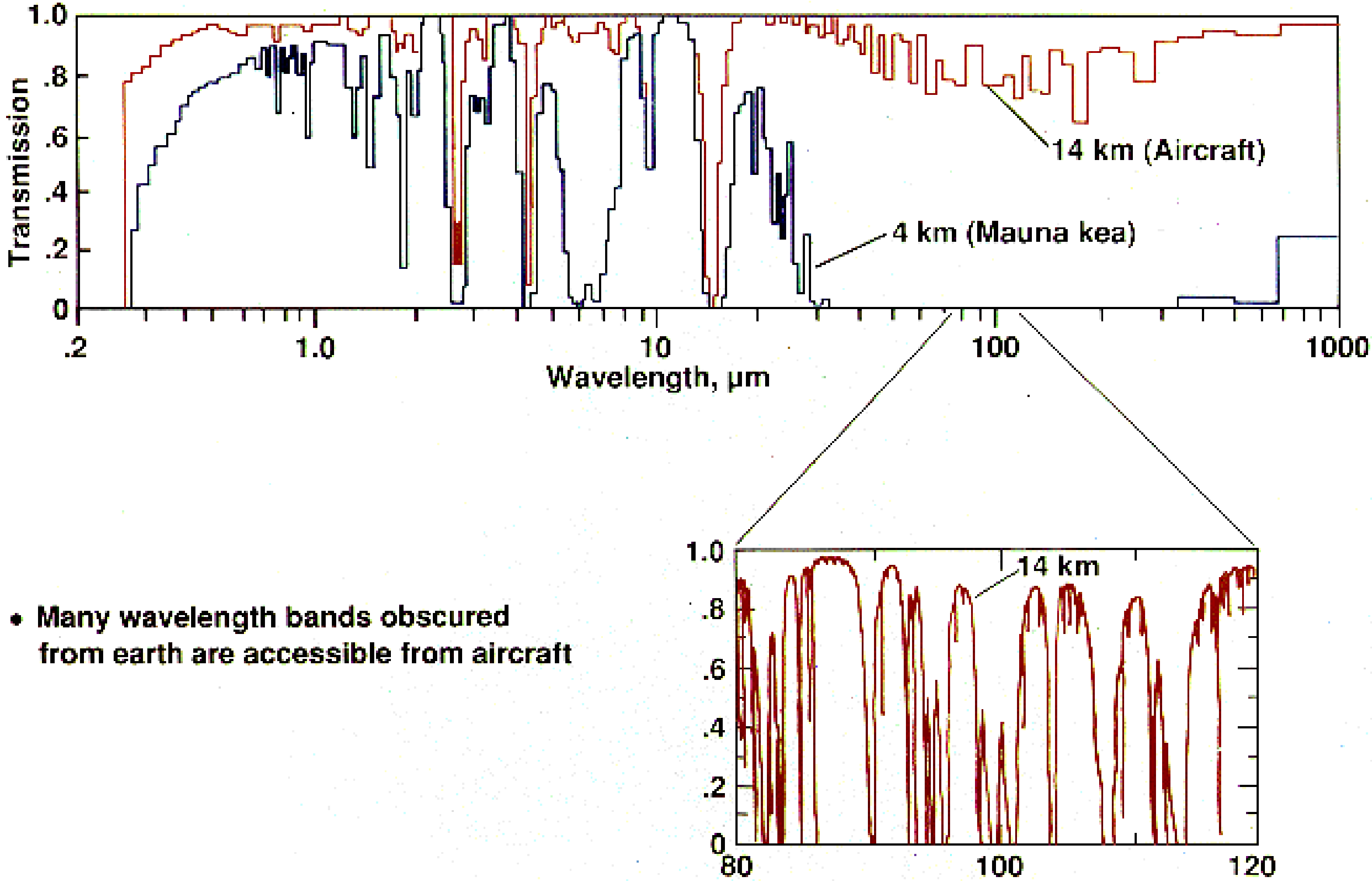
Why have a telescope at 41-45,000 ft (13-14 km)?

– Most IR radiation from space is blocked by atmospheric H_20
– Scale height of H_20 low:
  $h_0 \cong 2$ km
– IR transmission at 14 km is very good:
  >80% from 1 to 800 mm

Why airborne, why not space?

- Long mission lifetime (20 years)
- Take off and land each day (3-4 days a week), full sky coverage with deployments
- Can have large instrument suite (and bulky instruments)
- Can change, repair, & upgrade instruments
- Can add new instruments and easily decommission old ones
- Instruments are accessible
  - Cabin pressure
  - Cabin temperature
- Telescope open
  - Clear viewing
- Training ground for next generation of FIR astronomers

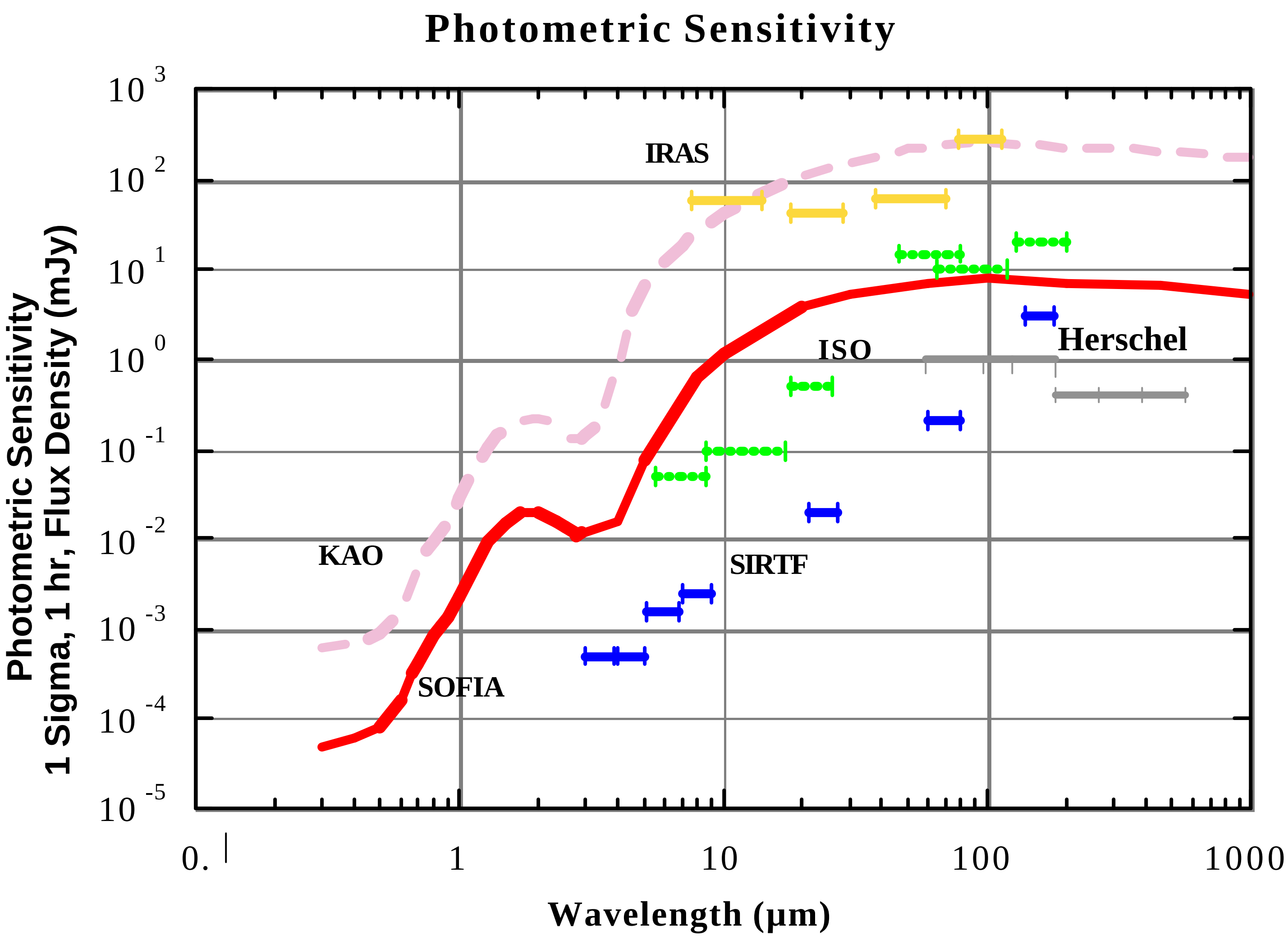
ATMOSPHERIC TRANSMISSION VERSUS WAVELENGTH



- Many wavelength bands obscured from earth are accessible from aircraft

Key Parameters

- Sensitivity
  - emissivity~ 0.1
  - 40-300µm
    ~ ISO point source (both imaging and spectroscopy)
    < Spitzer (3 to 30 times)
  - < 40µm
    - < ISO (x10)
    - << Spitzer (x100)
    - ~ 8 meters at 20µm
- FOV 8’ X 8’ ; 13’ x 13’ max
- Image Size
  ~ – > 15µm: diffraction limited
  - Theta(FWHM)~ wavelength(µm)/10 arcsec
- T ~ 80%; ~ 8/10 lines observable


Photometric Sensitivity
Photometric Sensitivity
1 Sigma, 1 hr, Flux Density (mJy)
Wavelength (μm)
IRAS
ISO
Herschel
KAO
SIRTF
SOFIA
0.
1
10
100
1000
10 3
10 2
10 1
10 0
10 -1
10 -2
10 -3
10 -4
10 -5

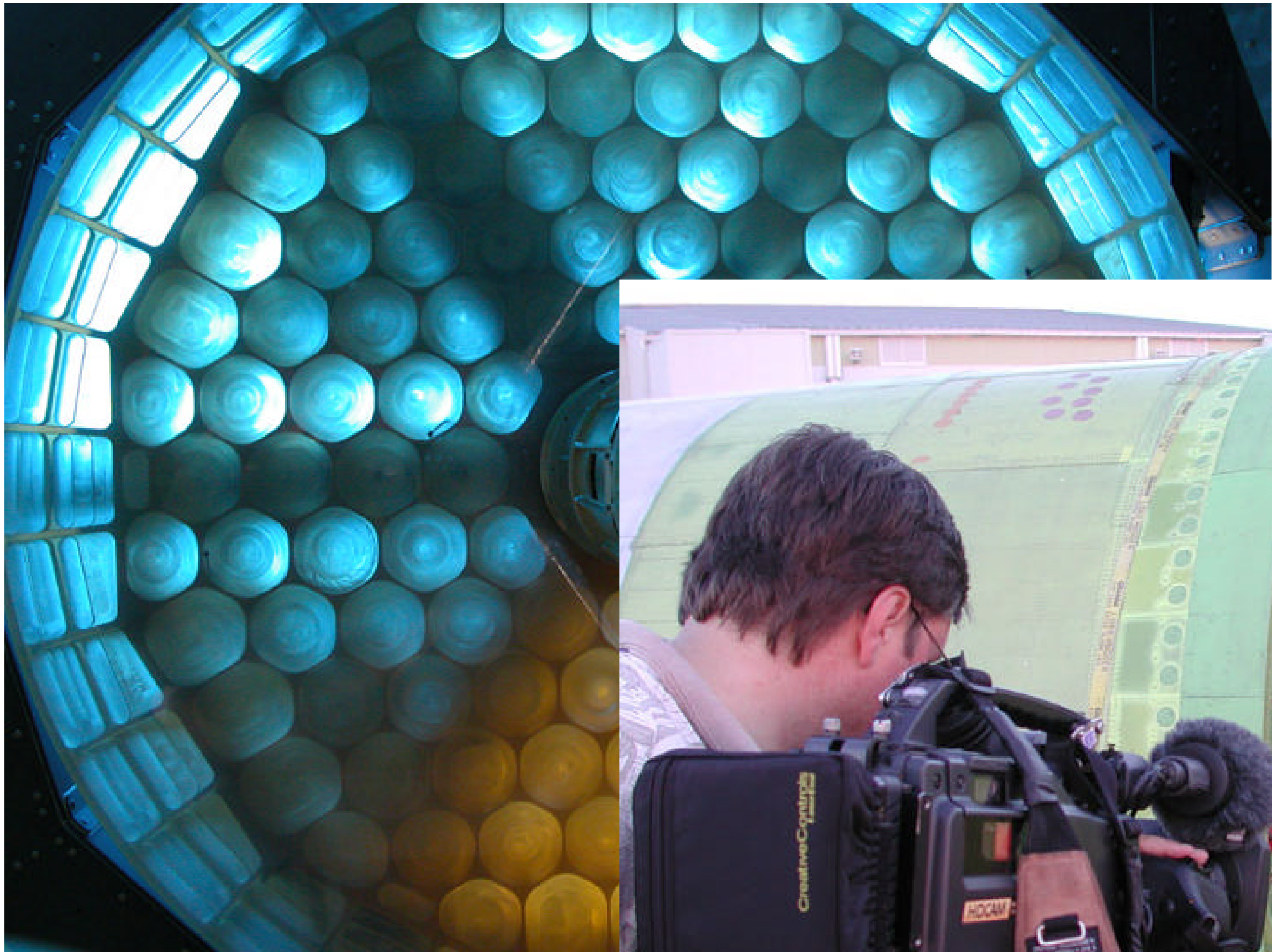
A few photos from the development

- Door
- Telescope assembly

~

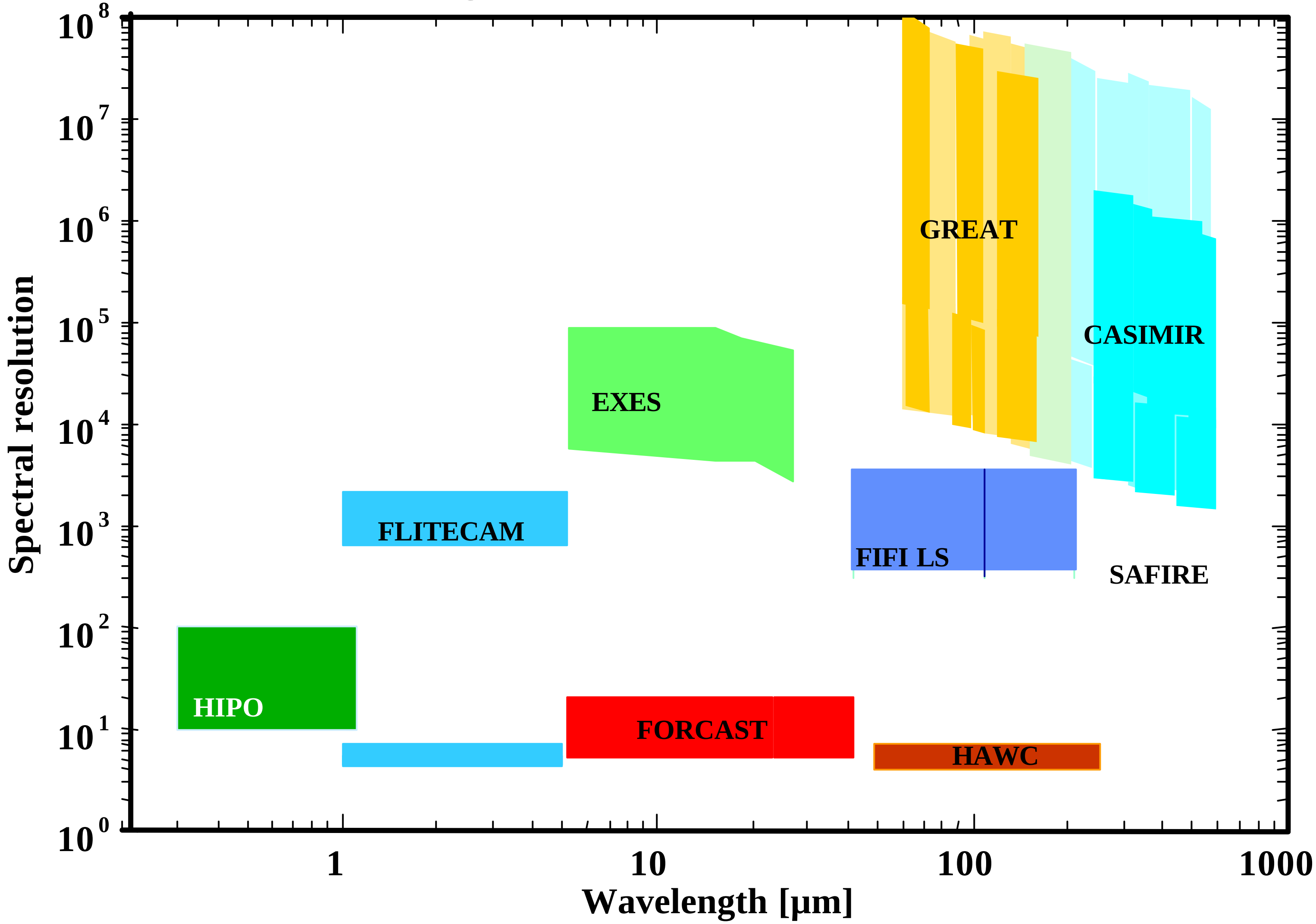
SOFIA Cavity Door Assembly installed on the B747 SP. Above the lower lip of the cavity, slats of the Lower Flexible Door (LFD) are seen where they attach to the Aperture Assembly (AA) which will track the telescope in elevation. At the aft (right side) of the cavity is the contoured ramp (dark brown), on which most of the air stream flowing over the cavity will reattach. The telescope is covered with a blue tarp. Some of the fuselage fairings around the cavity remain to be installed. This picture was taken in early May 2005.

Primary Mirror (without its cover)



SOFIA Performance: Spectral Resolution

(First-Light Science Instruments)



SOFIA Science Instruments

- HIPO (High-speed Imaging Photometer for Occultations) – an optical dual channel, high speed CCD imager
- FLITECAM (First Light Infrared Test Camera) – a near-infrared imager with spectroscopic capabilities
- FORCAST (Faint Object Infrared Camera for the SOFIA telescope) – a mid-infrared dual channel imager with narrow-band filters
- GREAT (German Receiver for Astronomy at Terahertz Frequencies) – a far-infrared heterodyne spectrometer of high spectral resolution
- FIFI-LS (Field Imaging Far-Infrared Line Spectrometer) – a far-infrared integral field spectrometer of moderate spectral resolution
- CASIMIR (CalTech Submillimeter Interstellar Medium Investigations Receiver) – a submillimeter heterodyne spectrometer of high spectral resolution
- HAWC (High-resolution Airborne Wideband Camera) – a far-infrared narrow band imager
- EXES (Echelon-Cross-Echelle Spectrograph) – a mid-infrared grating spectrometer of high spectral resolution
- SAFIRE (Submillimeter and Far-Infrared Experiment) – a fabry-perot spectrometer of moderate spectral resolution.

High Angular resolution Wide-band Camera

HAWC

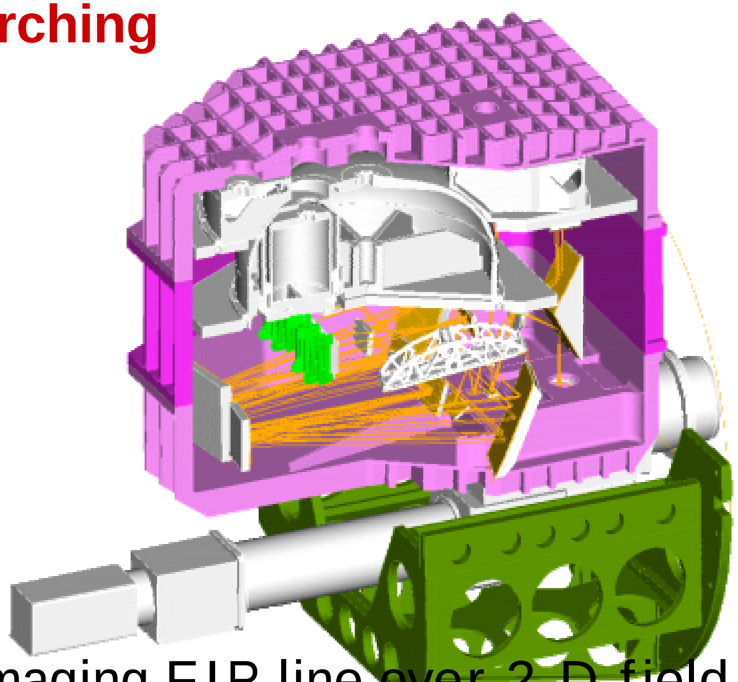
A. Harper PI - U Chicago

Cooled 12x32 pixel pop up bolometer array from GSFC
50-200 μm photometer- filters @ 53, 89, 155, and 215 μm

Far-Infrared Field-Imaging Line Spectrometer

FIFI-LS

A. Poglitch PI - Max Planck Inst. Garching



Far-infrared spectrometer with two simultaneous channels:

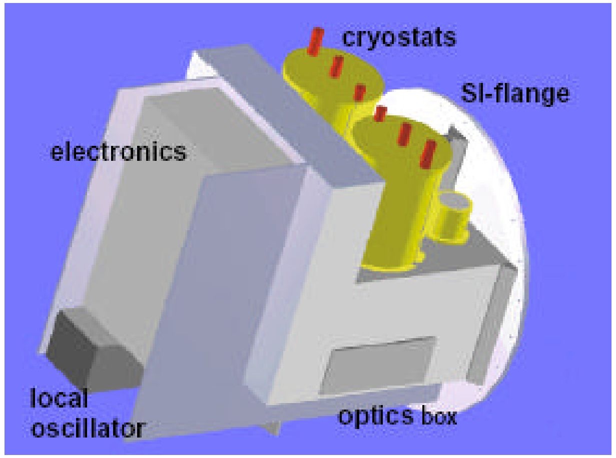
- –Blue 42-110 µm (6” pixels)
- –Red 110-210 µm (12” pixels)

- Integral field concept: instantaneously imaging FIR line over 2-D field
  - –for each channel, 5x5 spatial pixels each having 16 spectral pixels
    - –Moderate Resolving power
    - –1250-5000 depending on wavelength

German REceiver for Astronomy at Terahertz frequencies

GREAT

R. Güsten PI - Max Planck-Bonn/U Köln



➢**Parallel observations in two out of three frequency bands (scientifically selected):**

➢low-frequency band: 1.6 -1.9 THz [KOSMA]
✓ mid-frequency band: 2.4 - 2.7 THz [MPIfR]
✓ high-frequency band: 4.7 THz [DLR-WP]

} **First-Flight Configuration**

➢**Choice of spectrometer backends (simultaneous use possible)**

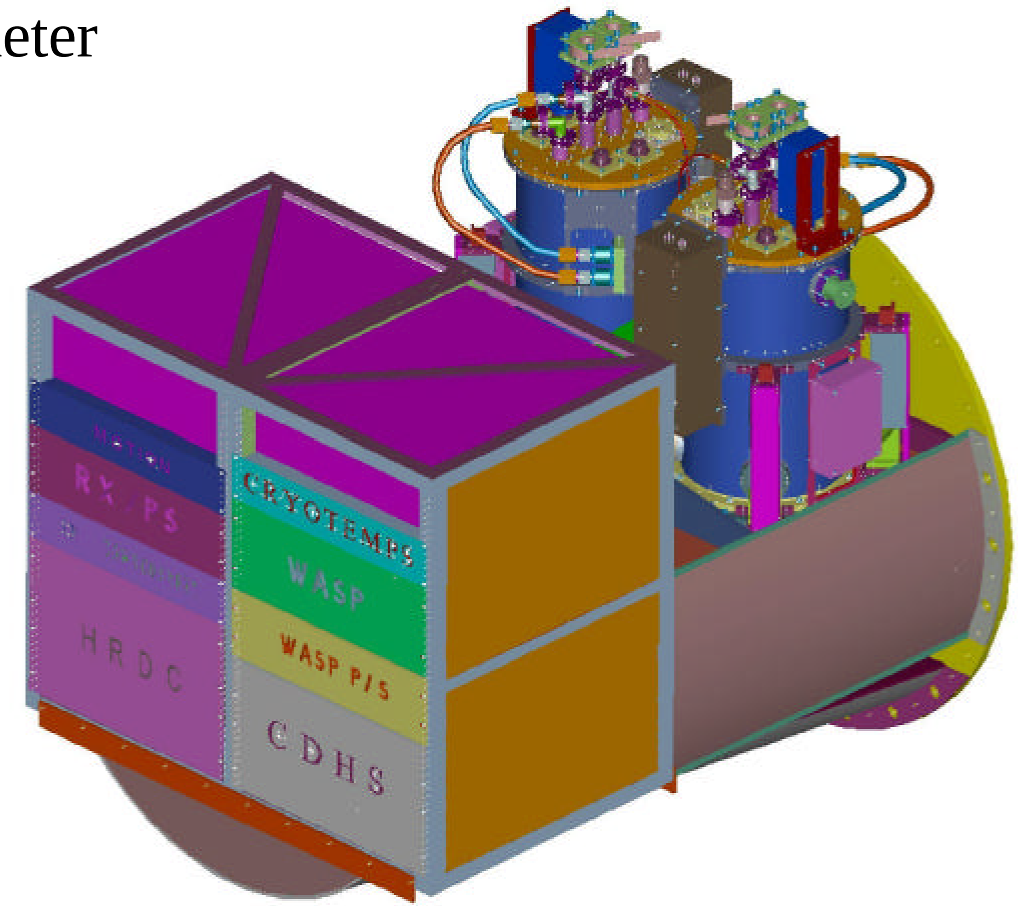
✓ mid-resolution Array Acousto-Optical Spectrometer[KOSMA]
✓ high-resolution Chirp-Transform Spectrometer [MPAe]
✓ (wide band analogue correlator WASP, in collaboration with CASIMIR)

Caltech Airborne Submillimeter Interstellar Medium Investigations Receiver

CASIMIR

J. Zmudzinas PI - Caltech

Heterodyne Spectrometer
250-600 microns
R~10^3-10^8



SOFIA long-wave first-light and Herschel instruments

SOFIA

HAWC	FIFI-LS	CASIMIR	GREAT	(SAFIRE)
53, 88, 155, 215 µ	42-110, 110-220 µ Integ field	250-264, 508-588 µ Heterodyne	~63 µm, 110-125, 158-187 µm Het.	145-655 µm Fab.-Perot
R ~ 7	1500-6000	10^4 – 10^8	10^4 – 10^8	1000-2000
384 x 1	25 x 16	1 x 4000	1 x 4000	1 x 1 x 1

Herschel

PACS-P	PACS-S	HIFI	SPIRE-P	SPIRE-S
60-130, 130-210 µ	57-210 µm Integ field	157-213, 240-600 µ	250, 360, 520 µm	200-670 µ FTS
R ~ 3	1500-6000	10^4 - 10^8	3	20-1000
(512, 2048) x 2	25 x 16	1 x 4000	139, 88, 143 (simul)	37, 19 (simul)

Possible Instrument Upgrades/New Instruments

- Increased wavelength coverage (higher frequencies), more sensitive mixers (CASIMIR/GREAT)
- GREAT upgrade to array (2x4?)
- Far-Infrared Polarimeter
- Far-Infrared Spectrograph
- Larger arrays (FORCAST, HAWC)

SOFIA & HERSCHEL

- The HERSCHEL & SOFIA overviews show that:
  - Both missions have similar instruments and angular resolution, hence largely similar science goals.
  - HERSCHEL is more sensitive, but limited mission time
  - SOFIA more flexible, larger instrument suite (as well as an instrument development program) and long lifetime (~ 20 years).
  - Difference in instrument suites results in great complementarities between the two missions
  - HERSCHEL will launch before SOFIA starts science operations

Collaboration, three phases!

- Before launch
  - Similar calibration needs (& we are collaborating)
- After launch & and through the operations phase
  - Calibration verification and cross calibration between the two observatories
  - Science verification and/or follow-up
- Post Herschel
  - SOFIA will be the only FIR mission
  - Ample opportunities for follow-up work

HIFI vs. CASIMIR & GREAT

- HIFI more sensitive than CASIMIR, full frequency coverage (CASIMIR ~80%)
  - Little difference on strong and/or extended sources
  - Upgrades could narrow the gap
- HIFI can do H_2O - CASIMIR & GREAT can't
- GREAT can do HD and [OI], HIFI can't
- Important to observe a common set of targets for calibration verification
- SOFIA can extend and fill the frequency space
- SOFIA likely to upgrade to heterodyne arrays

HAWC vs. PACS

- HAWC 12 x 32: 53, 89, 115 and 216 µm, all Nyquist sampled, R ~ 5.5
- PACS (blue 32x64, red 16x32): 71, 105, 165 µm, latter two Nyquist sampled (R=3.3)
- PACS ~ 10 times more sensitive
- PACS more of a survey camera, better for faint sources
- HAWC better for SED determination, bright sources, could be upgraded to 128 x 128

SAFIRE vs. SPIRE

- SPIRE, large FOV 4' x 4' in 3 bands: 250, 360, 530 µm, ideal for deep surveys
- SPIRE FTS spectrometer, R ~ 20 -1000
- SAFIRE, Fabry-Perot R ~ 1000-2000
  - More sensitive for spectroscopy ([CII] for z = 0-1,[NII] z ~ 0 -5)
  - Strong diagnostic tool for objects discovered by SPIRE

Mid-IR complementarity

- FORCAST ideal for follow-up in the 5 - 40 µm range
  - Better spatial resolution than Spitzer
  - Can observe bright objects (which saturate in IRAC & MIPS)
- EXES follow-up to HIFI in the mid-IR
  - Provides very high spectral resolution in the 5 - 30 µm region (H_2, H_2O etc)