UNIVERSITIES SPACE RESEARCH ASSOCIATION

International Electrical and Electronics Engineering (IEEE) – Santa Clara

Stratospheric Observatory for Infrared Astronomy (SOFIA)

Helen J. Hall

November 2, 2010






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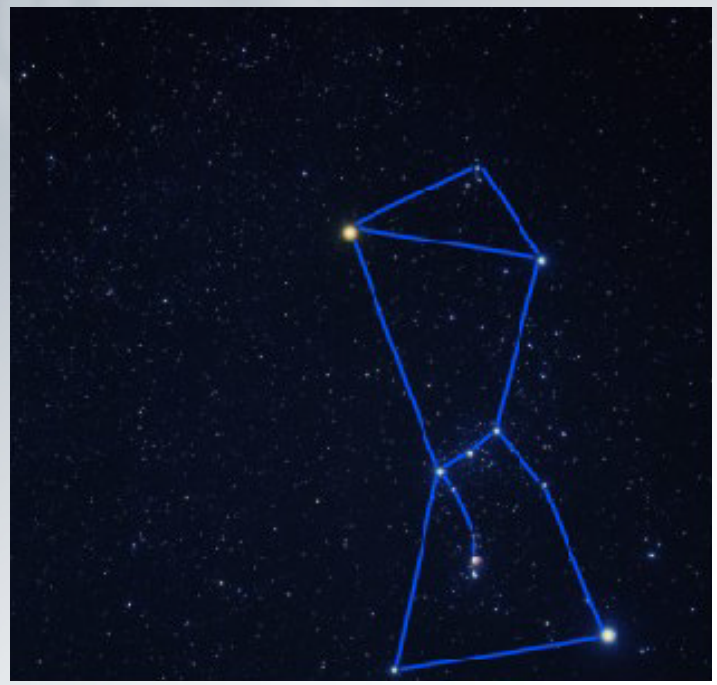
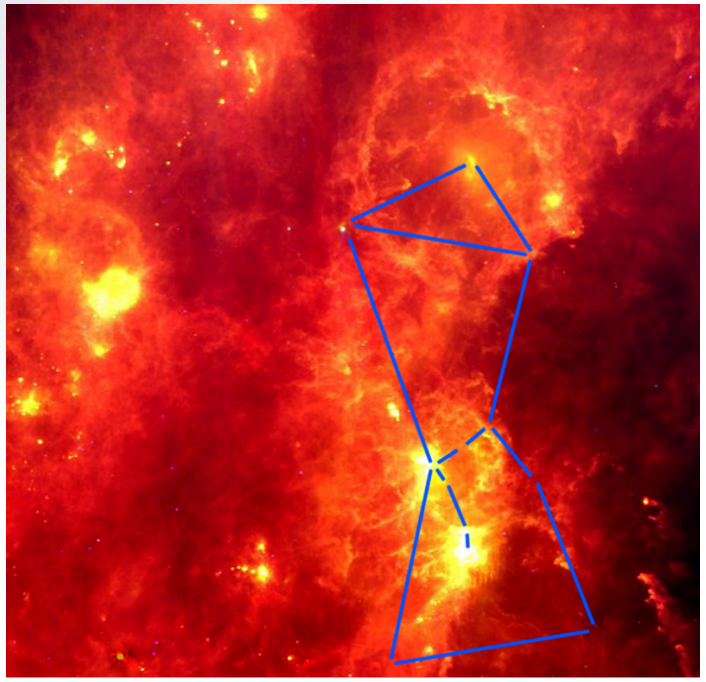
WHY Infra-Red?

An object can appear radically different depending on the type of light collected from it:



view at visual wavelengths



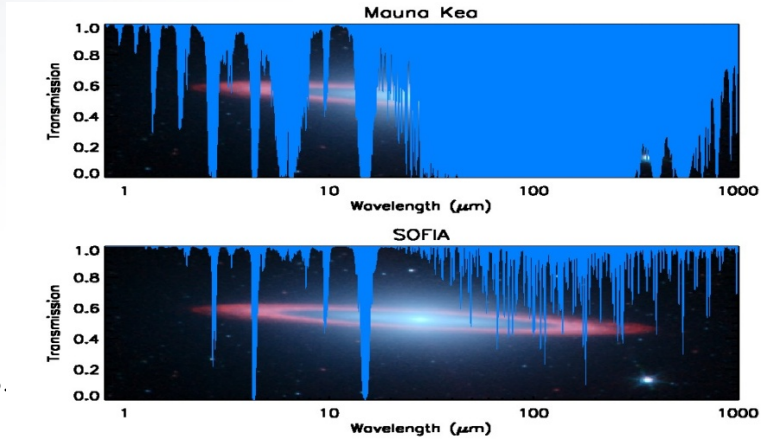
far-infrared view

Constellation Orion

What is SOFIA?

A 2.5 m telescope in a modified B747SP aircraft
- Optical-mm performance
- The obscured Infrared (IR) (30-300 um) is most important

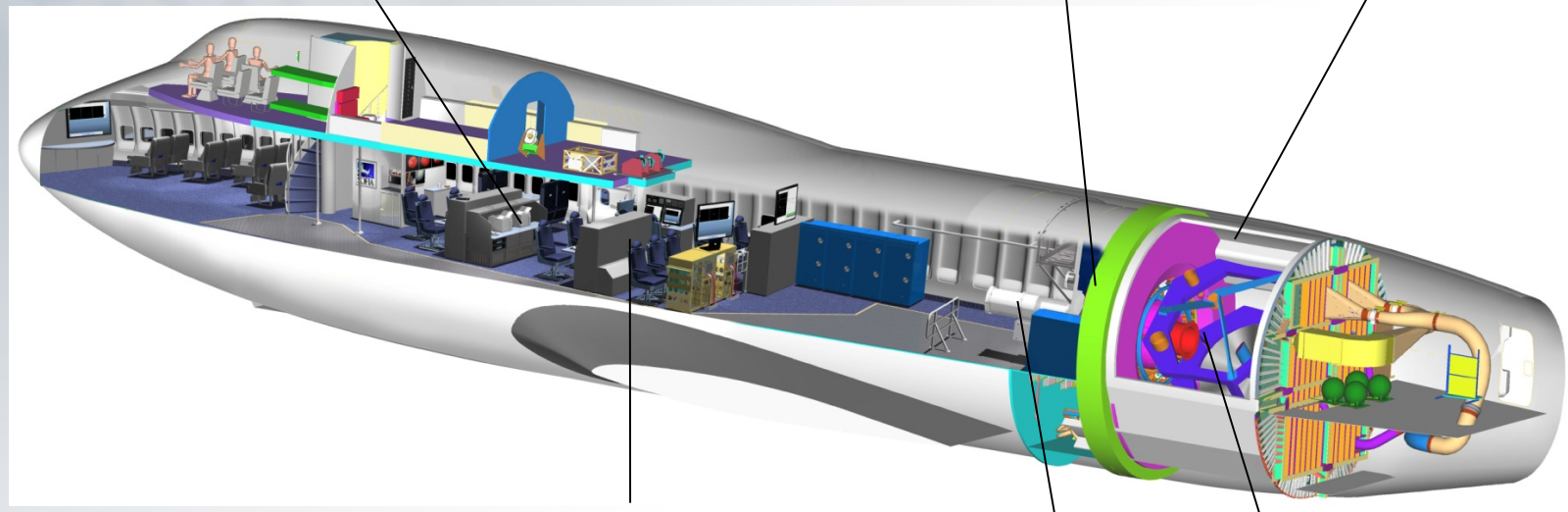
Joint Program between the US (NASA - 80%) and Germany (DLR- 20%)
- USRA and the Deutsches SOFIA Institute (DSI, University of Stuttgart) are the science mission contractors



Built for 20 year lifetime
- Operates at 39,000 to 45,000 feet.
- Above > 99% of obscuring water vapor .
- Wide instrument range. Future Instrumentalists

World Wide Deployments, will ramp up to ~1000 science hours per year
- Science flights to originate from NASA Dryden Flight Research Center (DFRC).
- Science Center is located at NASA Ames Research Center.

SOFIA — The Observatory



Basic Roles & Responsibilities

Dryden Flight Research Center (DFRC)

- Overall Program Management (may be transferred to Ames at full operations).
- Aircraft development, testing, operations and maintenance.
- Palmdale Regional Airport Operating Location

Ames Research Center (ARC)

- "Science Project" management

USRA and DSI

- Science Mission Contractors – Instruments, Observing Time, etc.
- Together form a roughly 76 person Science Center at Full Operational Capability
  - 32 Personnel at Palmdale
  - 44 Personnel at ARC
- DSI is an associate contractor to USRA
  - USRA relations with DSI are very strong.

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The Science Mission Operations has Split Geographic Locations:

SOFIA Science Center at NASA Ames Research Center

- Science Mission Operations Director & Deputy in place
- Science Staff**
- Science Data Network (SOFIA Data Cycle System & Archive)
- Mirror Coating Facility
- Mission Planning
- Systems Integration Laboratory
- Science Instrument Laboratories
- Education & Public Outreach

SOFIA Operations Center at NASA Dryden Aircraft Operations Facility in Palmdale

- Telescope Assembly & Science Instrument Integration Team
- Operations Staff
- Early Science Instrument Laboratories
- Systems Integration Laboratory
- Mission Systems Development (Flight Data & Observatory Data Cache)

***PhD Internships being sponsored between University of Stuttgart and USRA.*

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SOFIA in the Palmdale Hanger

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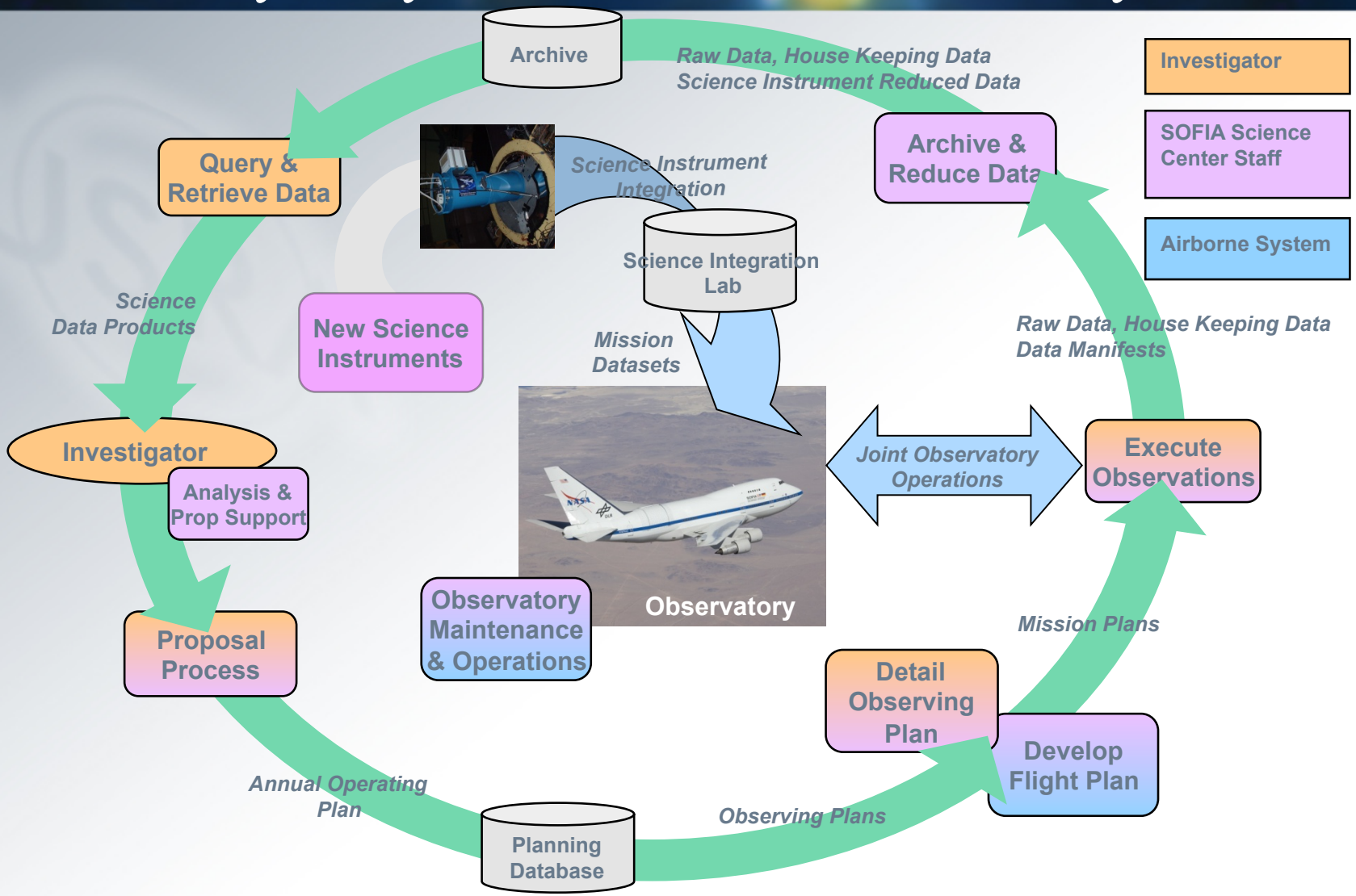
Data Cycle System Tools for Annual Lifecycle



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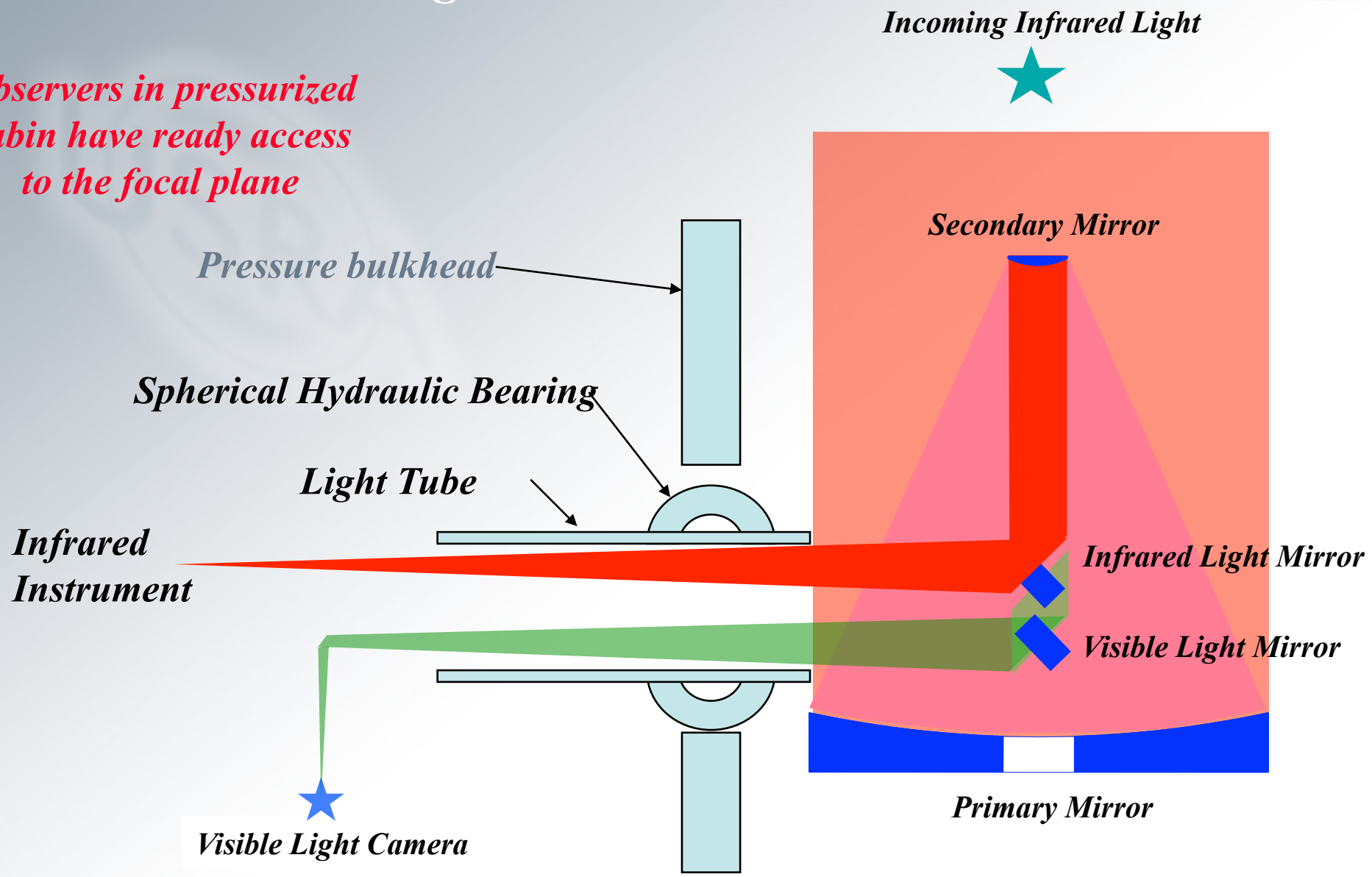
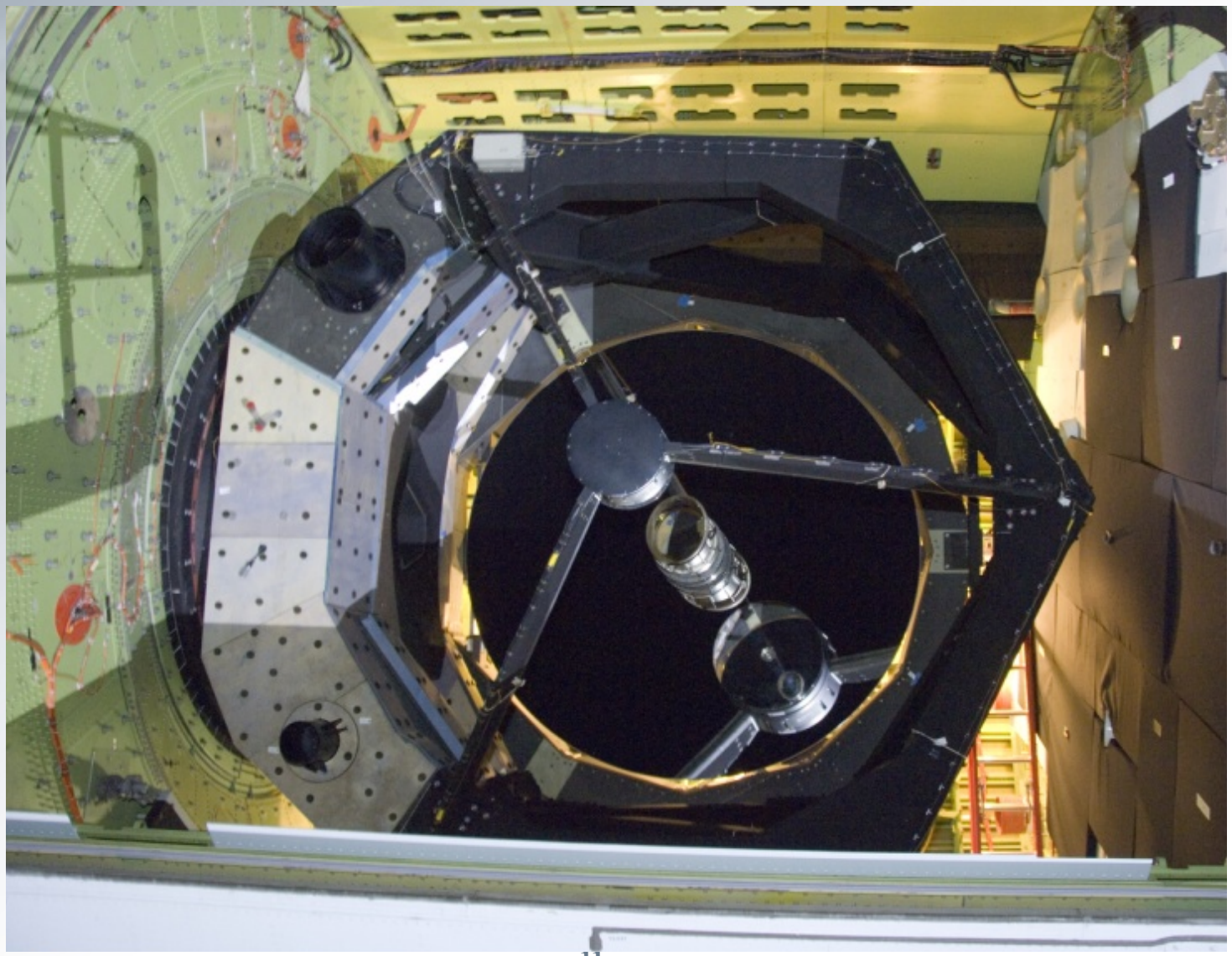
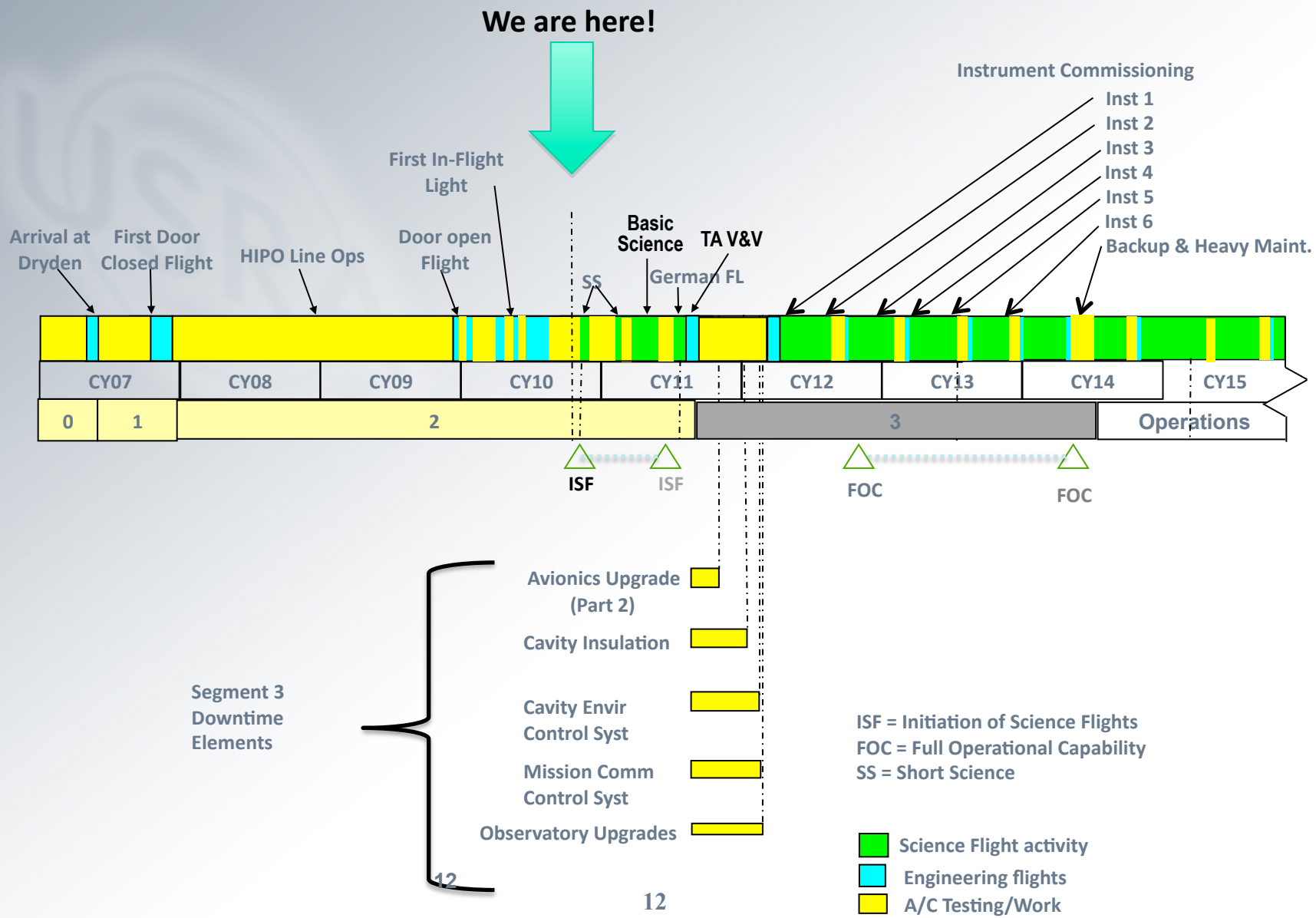
SOFIA Light Path



FORCAST Team on SOFIA MAY 2010

Coated Mirror on SOFIA




We are here!
Instrument Commissioning
Inst 1
Inst 2
Inst 3
Inst 4
Inst 5
Inst 6
Backup & Heavy Maint.
First In-Flight Light
Arrival at Dryden
First Door Closed Flight
HIPO Line Ops
Door open Flight
Basic Science
TA V&V
SS
German FL
CY07
CY08
CY09
CY10
CY11
CY12
CY13
CY14
CY15
0
1
2
3
Operations
ISF
ISF
FOC
FOC
Avionics Upgrade (Part 2)
Cavity Insulation
Segment 3 Downtime Elements
Cavity Envir Control Syst
Mission Comm Control Syst
Observatory Upgrades
ISF = Initiation of Science Flights
FOC = Full Operational Capability
SS = Short Science
Science Flight activity
Engineering flights
A/C Testing/Work

12

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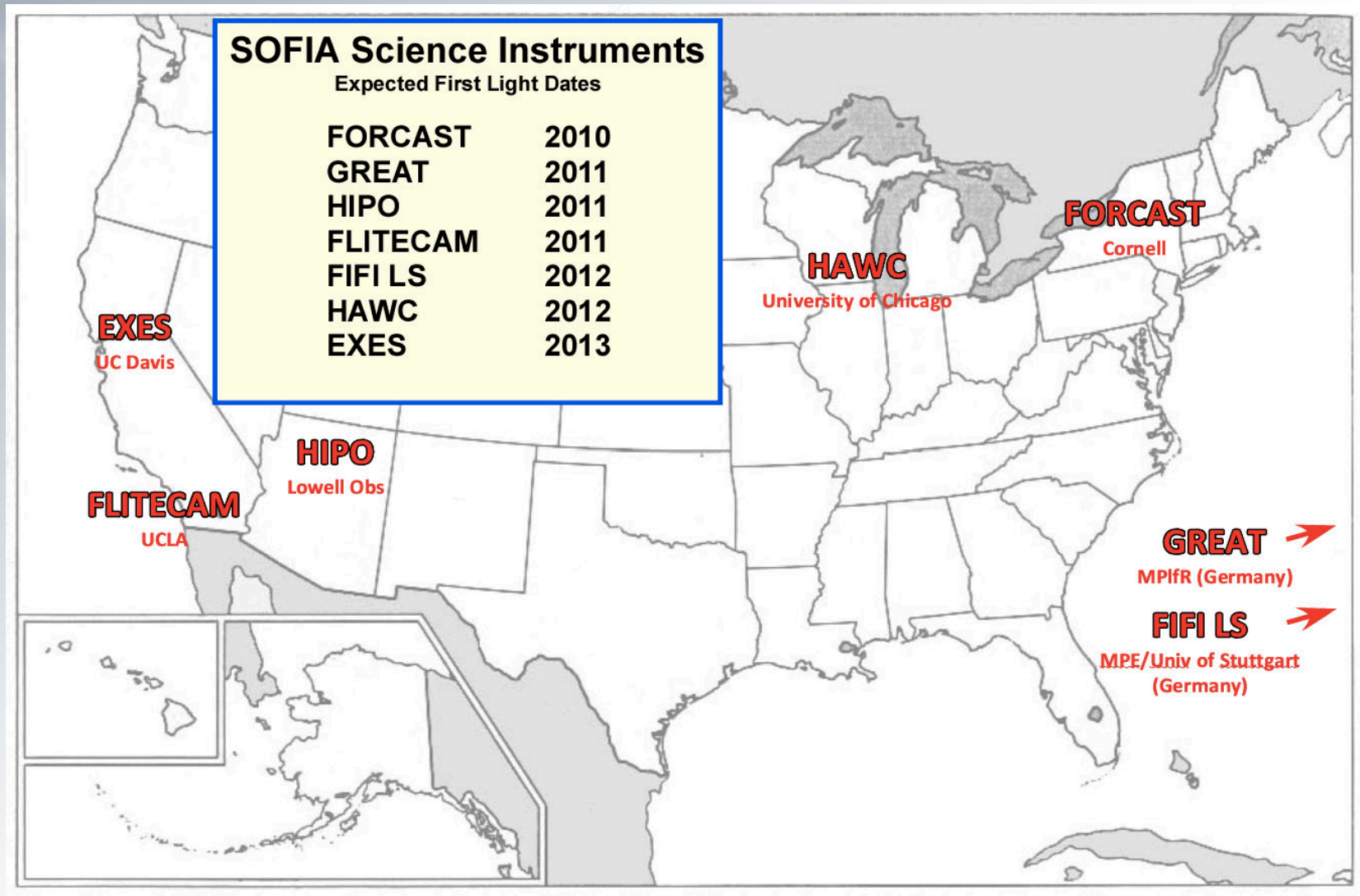
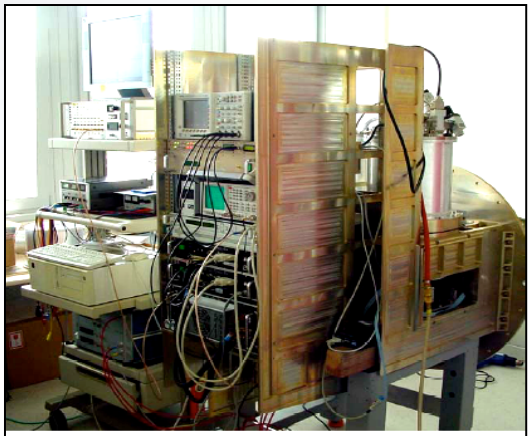
Geographic Distribution of SOFIA Instruments



The Four "First Light" Instruments are in an advanced state of readiness

High Speed Imaging Photometer for Occultation (HIPO) instrument performed characterization operations on Telescope Assembly during Dec 2008

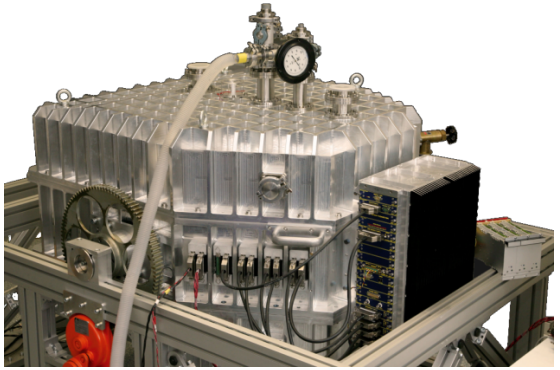
Second SI to fly, German Receiver for Astronomy at Terahertz Frequencies (GREAT) Bonn, Germany February 2011



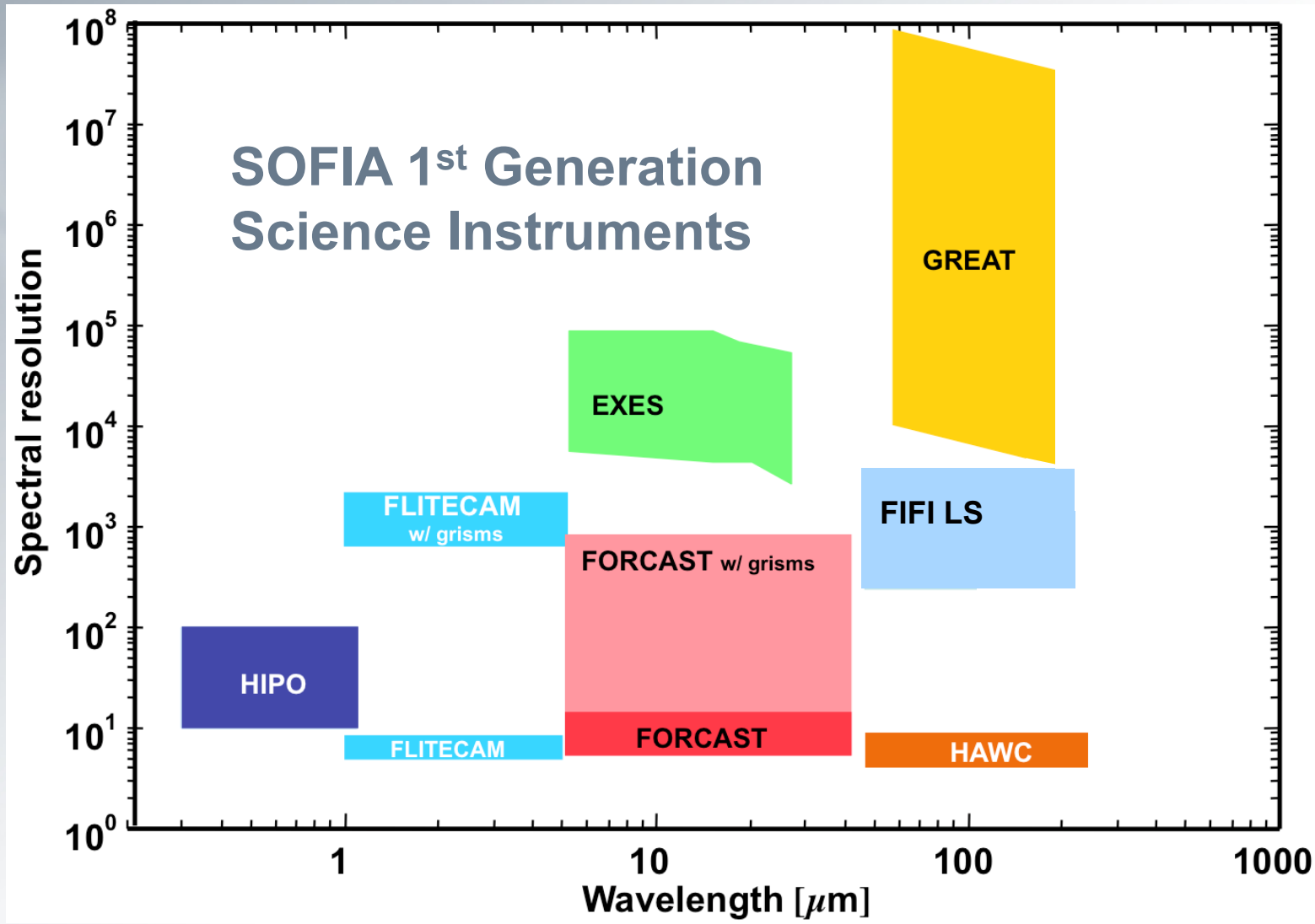
Lab-picture of GREAT equipped with the KOSMA 1.9THz channel

Faint Object InfraRed Camera for the SOFIA Telescope (FORCAST) First Science Instrument (SI) May 2010

Field Imaging Far-Infrared Line Spectrometer (FIFI-LS), Garching Germany, Will be flying 2012

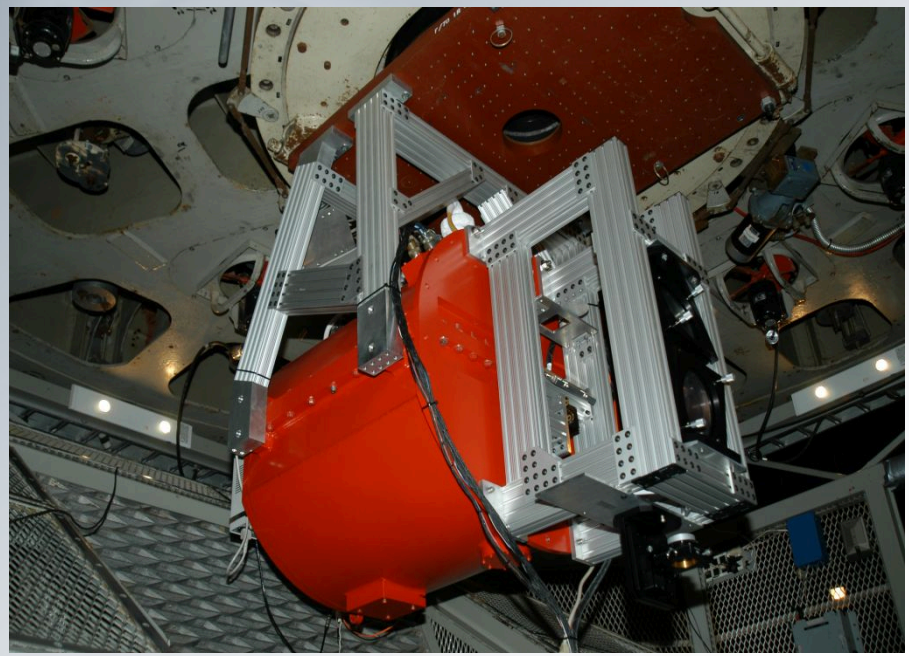


Instrument R/λ graph



FORCAST – Faint Object infraRed CAmera for SOFIA

Facility Instrument

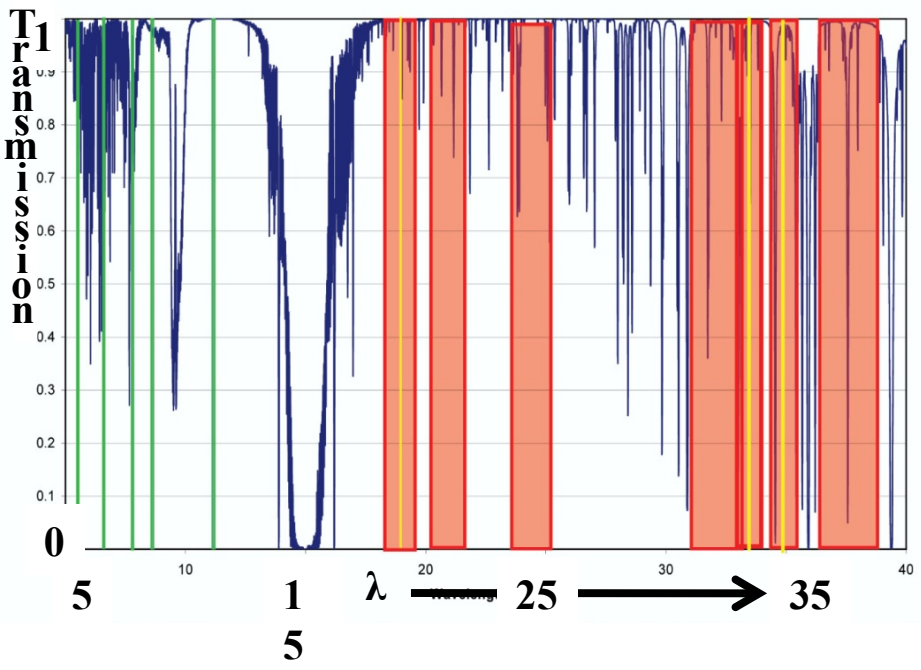


Mounted on the Hale telescope at Palomar

Simultaneous continuum imaging
in two MIR bands &
Low resolution spectroscopy

Principal Investigator:
Dr. Terry Herter,, Cornell University ,
Ithaca, New York

- λ = 5 – 25 µm; 25 – 40 µm [MIR]
- FOV: 3.3“ x 3.2“
- 0.75“ per pixel
- 9 narrow and band filters
- Spectral resolution: 5.7 - 250
- Maximum frame rate: 4 per s for full frame
- Highest time resolution: 1.6 mm
- Detector: 256x256 Si:As ; Si:Sb blocked



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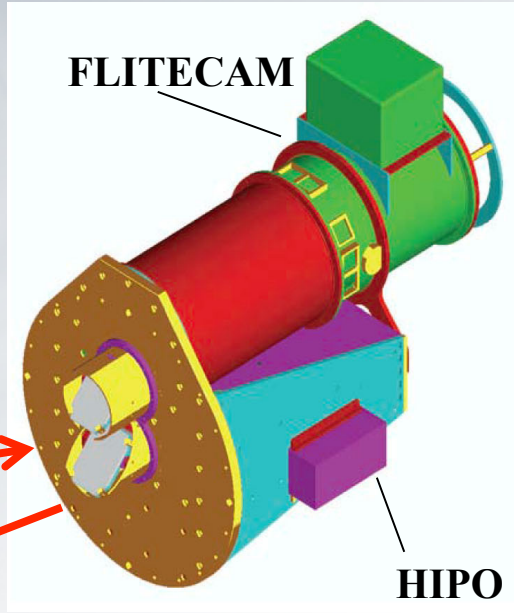
HIPO – High Speed Imaging Photometer for Occultations

Special Purpose Instrument

HIPO co-mounted with FLITECAM



- **λ = 0.3-0.6 µm, 0.4 – 1.1 µm [optical/NIR]**
- **FOV: 5.6“ x 5.6“**
- **1.0“/0.33“/0.055“ per pixel**
- **Maximum frame rate: 10/20 ms for three 80x80 pixel sub-frames**
- **Through put of HIPOs optic: ≥70 % from 0.4 – 0.9 µm**
- **Detector: e2vCCD47-20 frame transfer silicon CCD**
- **Read out noise: ≤ 6/3 electrons**
- **Quantum Efficiency: 40 – 80 %**

Simultaneous high-speed time resolved imaging photometry at two optical/[NIR] wavelength (& FLITECAM >> + NIR)

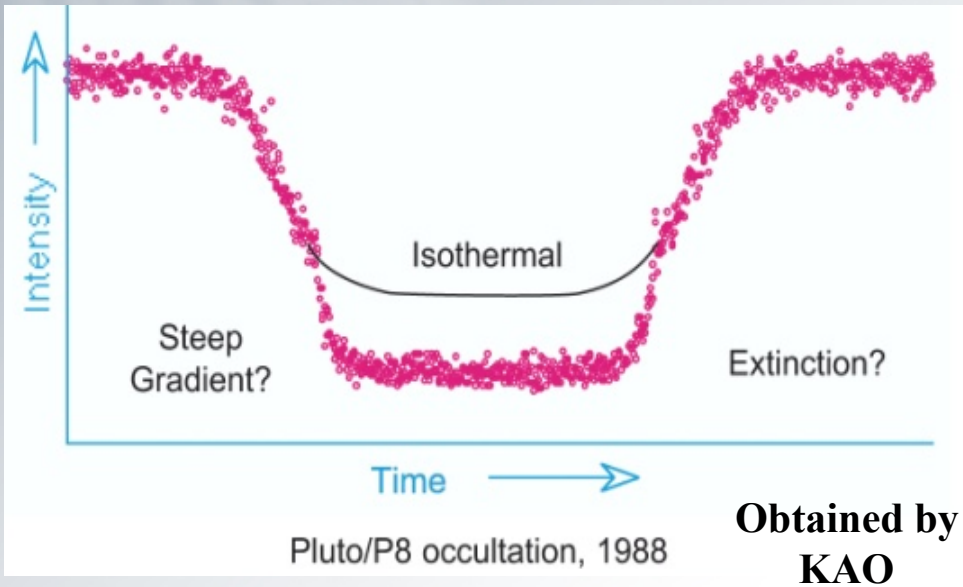
Principal Investigator:
Dr. Edward W. Dunham; Lowell Observatory, Flagstaff , Arizona

Scientific goals with HIPO

A: Stellar occultations to probe

> the atmospheric structure of planets

> surface density structure of planetary rings or comets



Obtained by KAO

Decrease of the stars brightness due to:

> refraction or

> extinction

by the planets atmosphere

Observed Lightcurve can be explained either in terms of

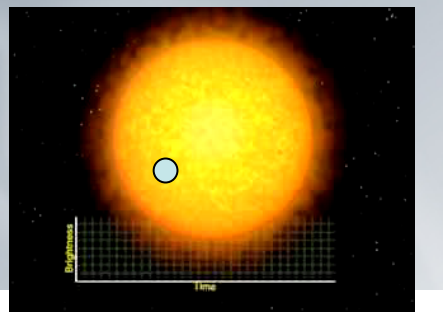
> a strong thermal gradient in Pluto‘s atmosphere or

> by extinction

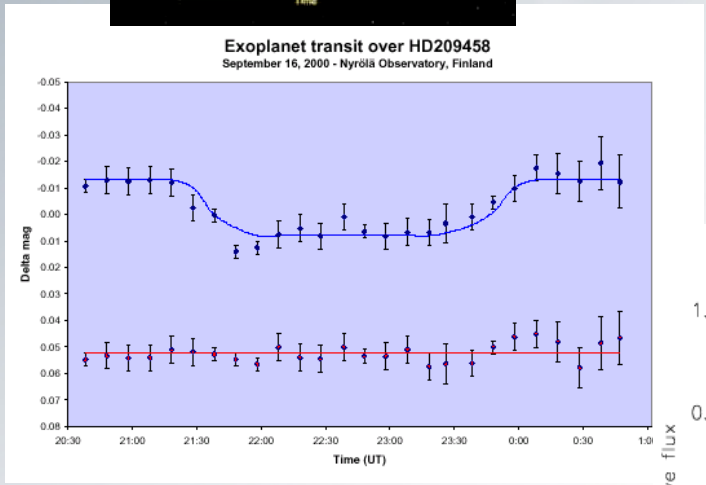
>>Competing can be tested by simultanous observations in the optical and NIR (HIPO & FLITECAM)

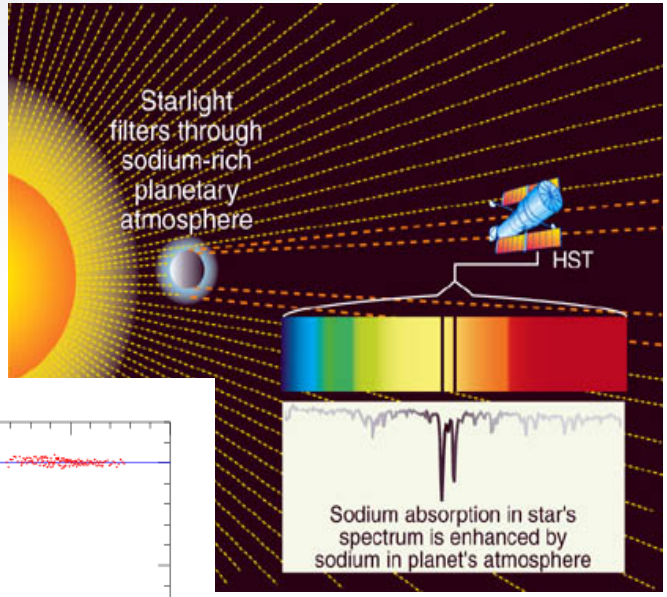
KAO- Kuiper Airborne Observatory

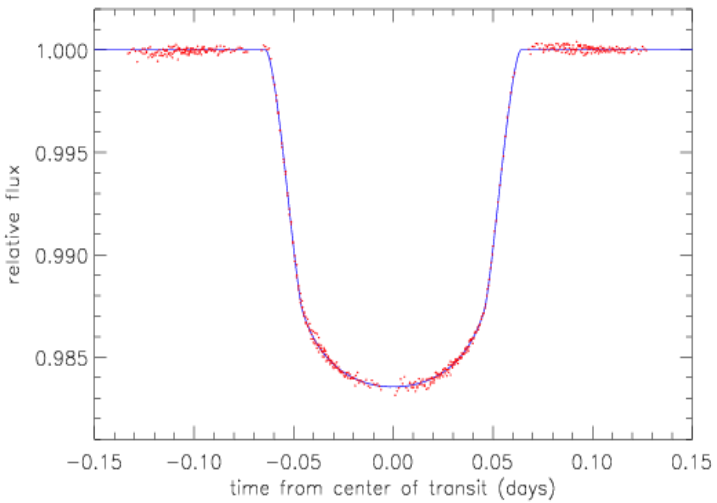
Exoplanets <> planets orbiting distant stars



HD 209458 – 1% Nirölä Obs/Finland Sep. 2000

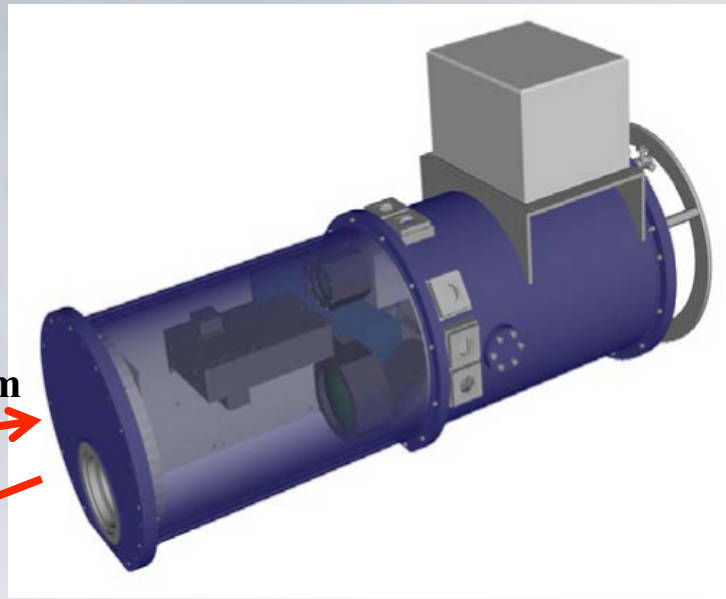






FLITECAM – First Light Infrared Test Experiment CAMera

Facility Instrument



- λ = 1- 5.5 µm [NIR]
- FOV: Ø 8‘
- 0.46“ per pixel
- Filter: J, H, K, L, L`, M & various narrow band filters
- Spectral resolution: 1000- 2000
- Maximum frame rate: 4 per s for full frame
- Detector: Raytheon ALADIN II 1024 x 1024
- Read out noise: ≤ 40 electrons
- Quantum Efficiency: ~ 80 %
- cooled by double liquid helium an nitrogen cyrostat

- Test camera for image quality
- Simultanoulsy mounted with HIPO (see above)

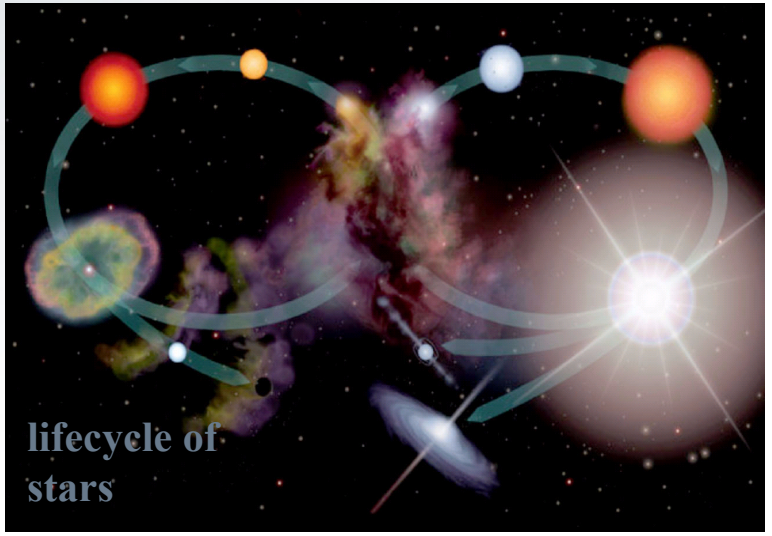
Principal Investigator:
Ian S. McLean, UCLA Div. Astronomy, Los Angeles, California

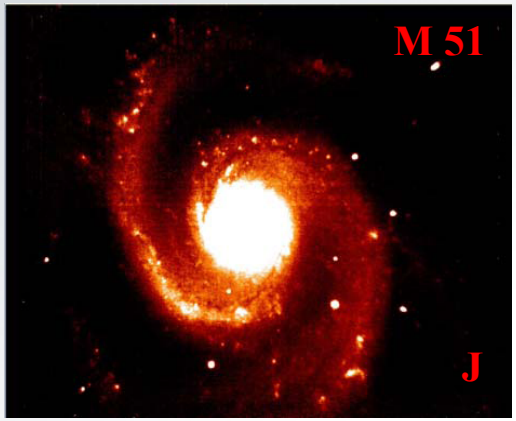
Scientific goals with FLITECAM

A: Tracing the evolution of PAH (@ 3,3 µm – L-Band) as indicator for massive star formation constrains on

- star formation history
- enrichment
- feed back to the ISM

> enrichment of ISM for next generation of stars





Obtained with FLITECAM mounted on the Lick Observatory 3 m telescope (exposure time in each filter: 9 minutes)

PAH - polycyclic Aromatic Hydrocarbons)
ISM – Interstellar medium

Finding super planets (mass > 13 Jupiter masses) and brown dwarf

> Taking advantage of wide – field imaging with narrow band filters to detect methane @ 3.3 µm

Sol: G star	M dwarf	L dwarf	T dwarf	Jupiter
T ~ 5500 K	T ~ 3000 K	T ~ 2000 K	T < 1500 K	T ~ 130 K

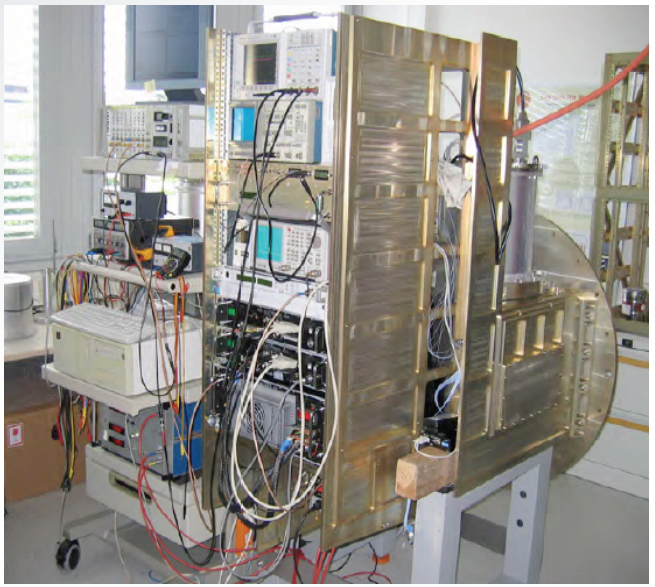
GREAT – German REceiver for Astronomy at THz Frequencies

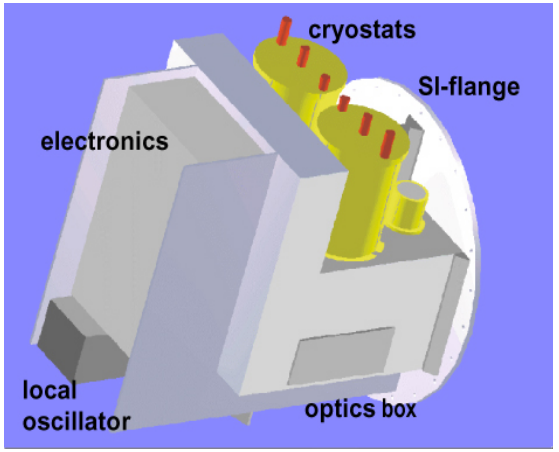
- λ = 1.6 – 1.9 THz, 2.4 – 2.7 THz~ 4.7 THz
  [63 – 187 μm] [FIR]

- velocity resolution: ~100 m/s

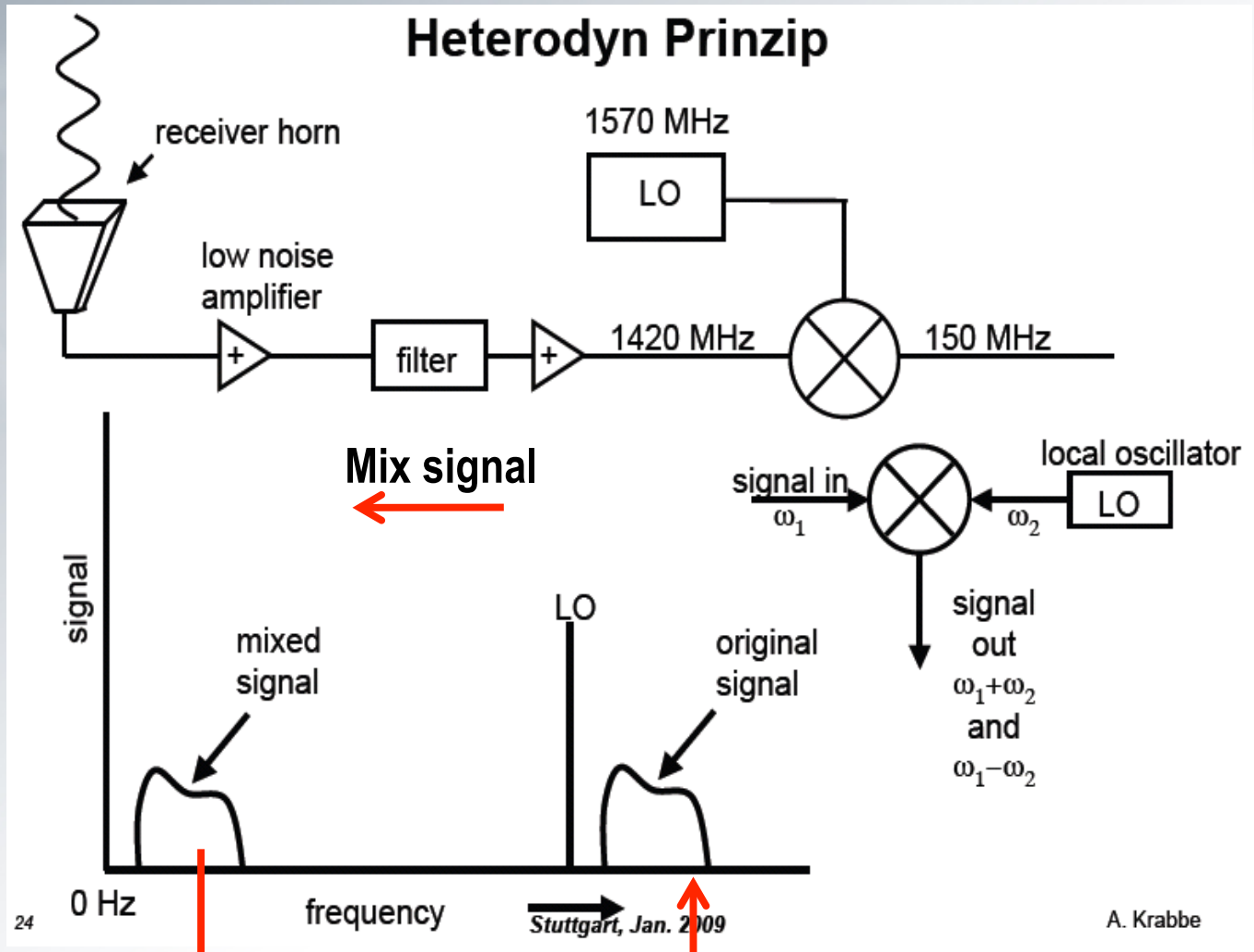
Channels	Astronomical lines
1.25-1.50 THz	[NII], CO, (13)CO, HCN, H2D+
1.82-1.92 THz	[CII], CO
2.4-2.7 THz	HD, OH(2P3/2), CO, (13)CO
4.7 THz	[OI]

- Heterodyne





Principal Investigator:
Dr. Rolf Güsten, MPI für Radioastronomie, Bonn

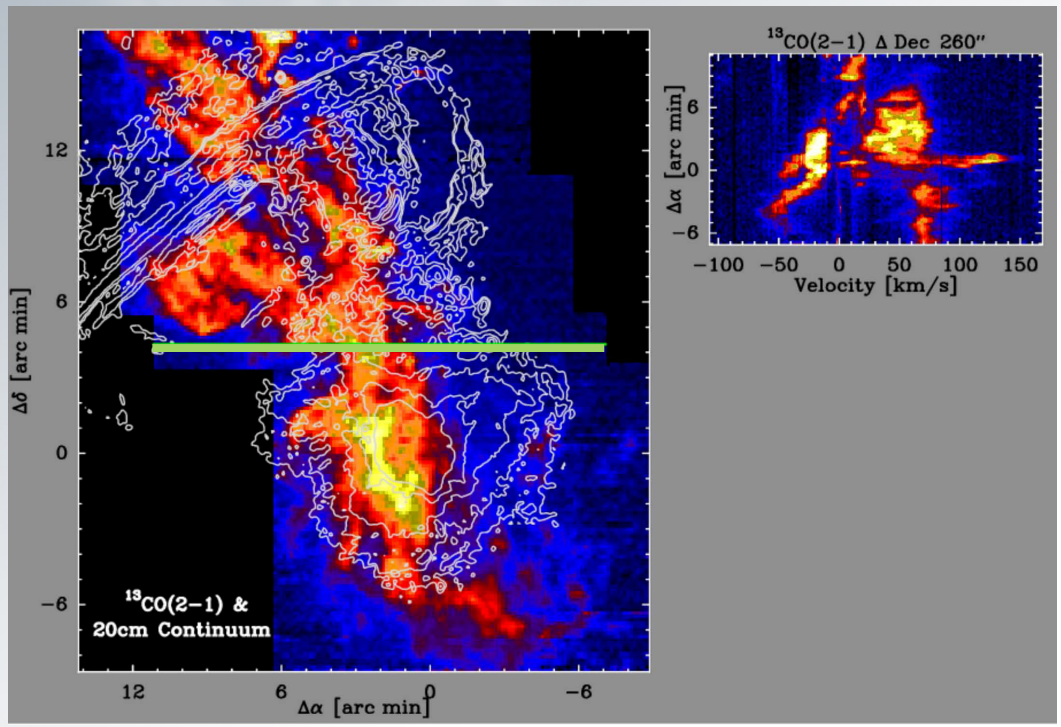


no receiver available

no sufficient receiver available

Scientific goals with GREAT

The [CII]158µm fine –structure transition is the most important cooling line of the cold interstellar medium and therefore critical for its energy balance

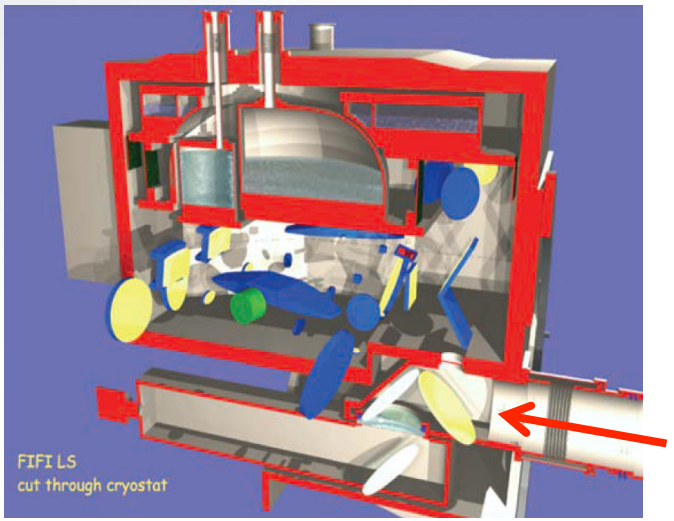


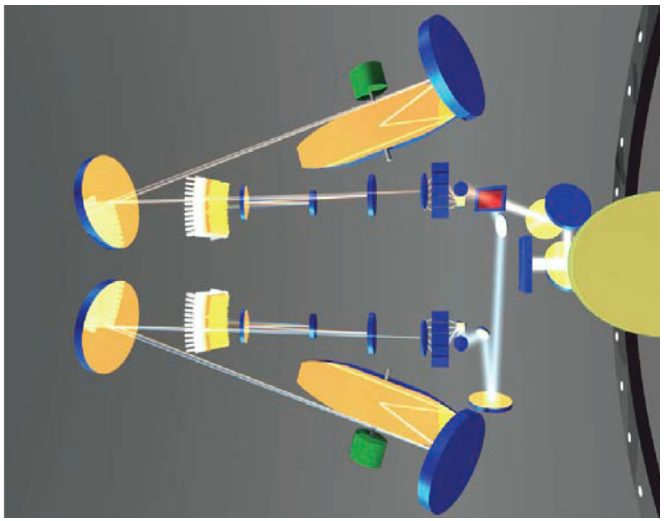
Extended emission in the Galactic Center region, visible in the carbon monoxide rotational line transition CO J=2-1 on the left, has a rich information on the internal dynamics of the source.
This becomes visible in the position velocity cut above.

>Similar velocity structure will be traceable in the [CII] fine structure line and other lines when observed at the spectral resolution provided by GREAT

FIFI-LS – Far Infrared Field Imaging Line Spectrometer

- λ = 42 – 110 µm, 110 – 210 µm [FIR]
- FOV: 30“ x 30“; 60“ x 60“
- 6“/12“ per pixel
- velocity resolution: 150 – 300 km/s
- velocity range 1500 – 3000 km/s
-Detector: Ge:Ga
- Read out noise: ≤ 40 electrons
- Quantum Efficiency: ~ 80 %
- optical system cooled to 4 K; detector cooled to 2 K

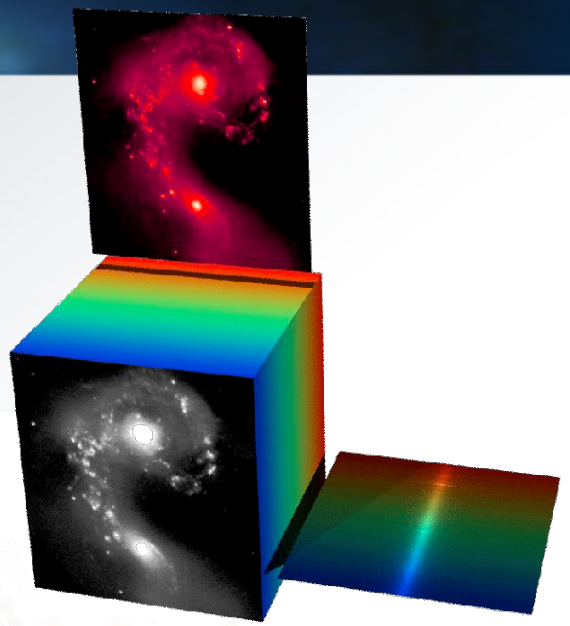


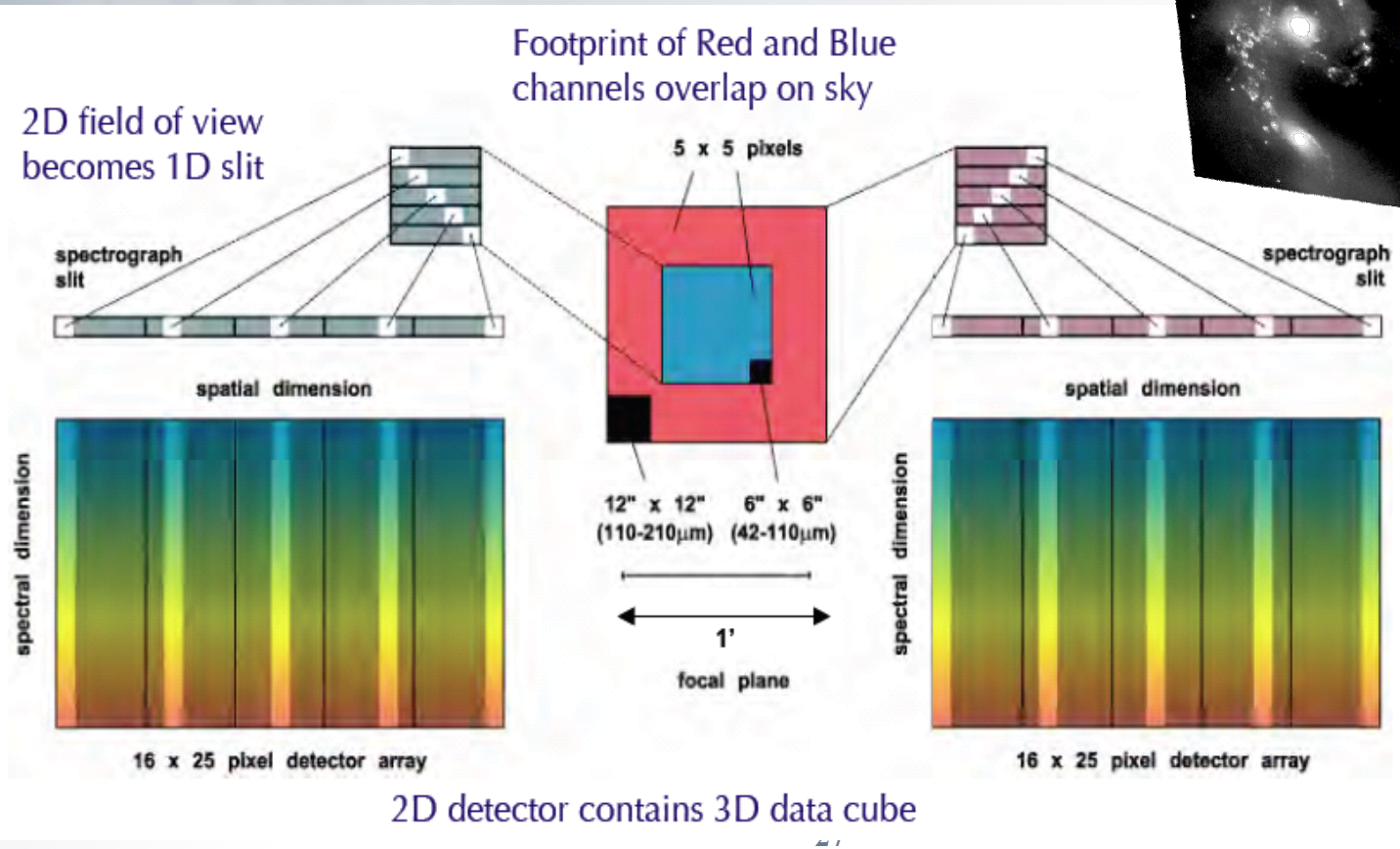


Principal Investigator:
Dr. Albrecht Poglitsch,
MPI für extraterristrische Physik, Garchingen

3D imaging:2D spatially and 1D spectrally

Optical slicer places the 2D sky on the 1D spectroscopy slit, so each observation creates an image cube with spatial and spectral dimensions.



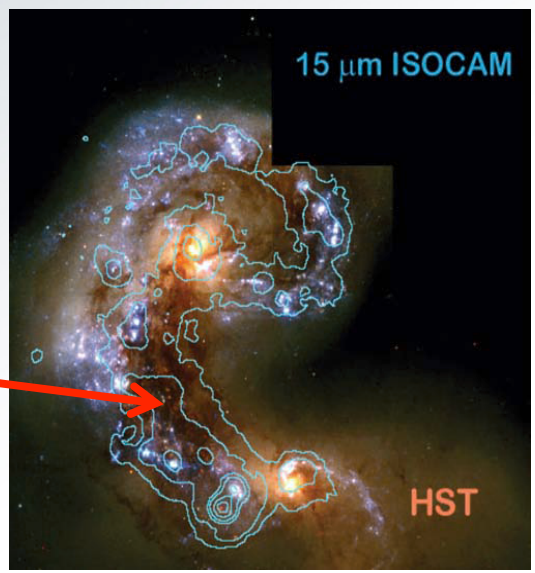


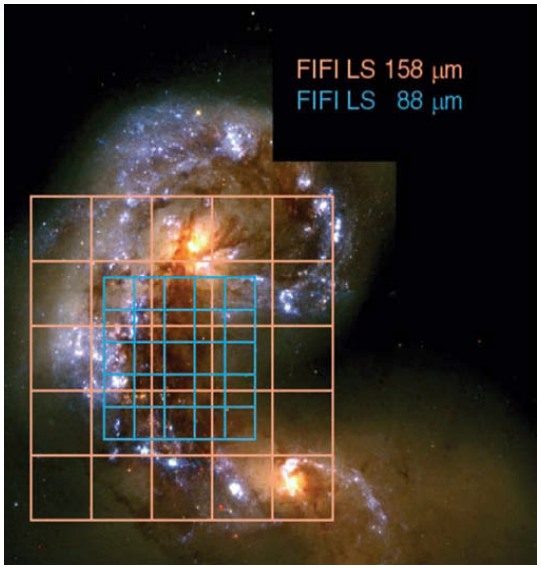
Science Case for FIFI-LS

> Triggered star formation and the interstellar medium in merging/interacting galaxies.

>The relationship between active galactic nuclei and starbursts galaxies.

„The Antennae“ – merging galaxy





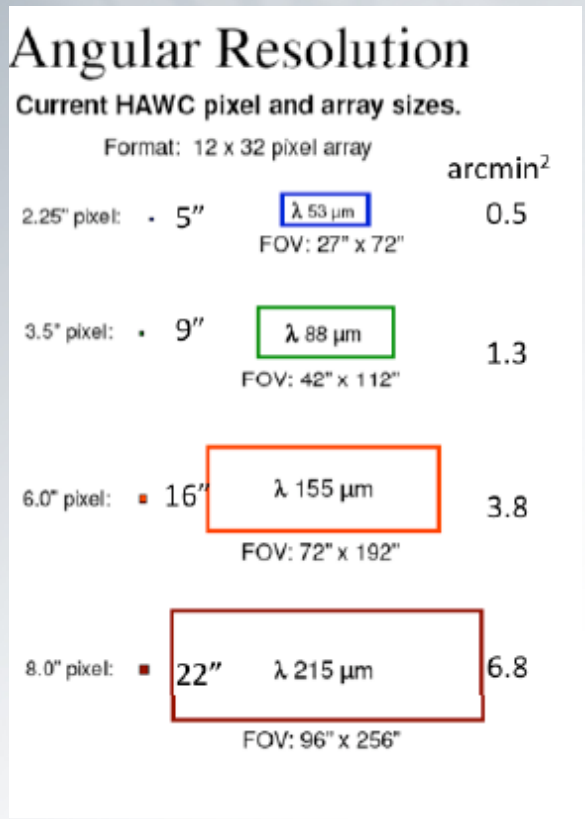
The interaction region is the primary site of activity in the system (the emission is peaked between the galaxy nuclei).

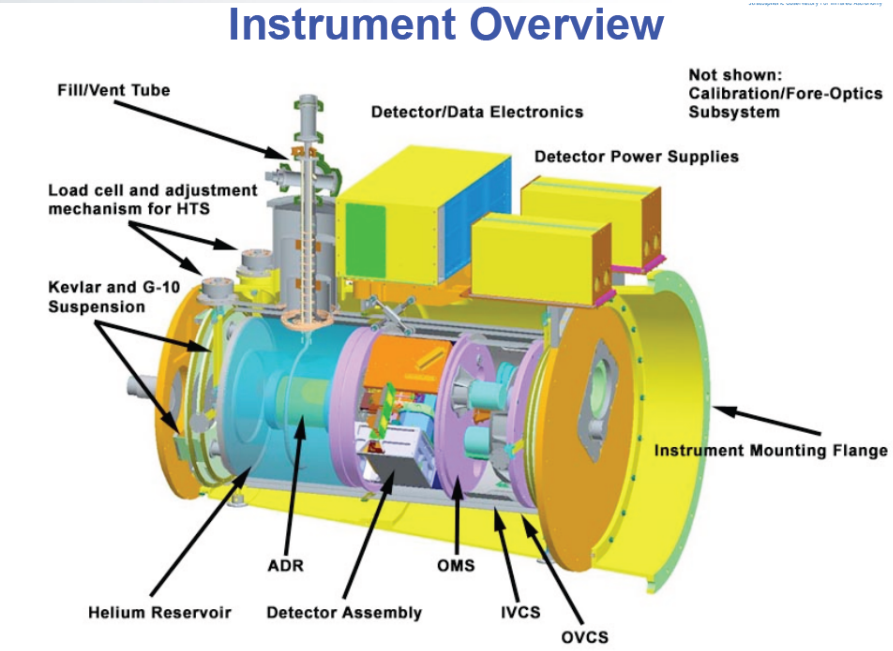
The interaction region is almost completely obscured in the Hubble Space Telescope (HST) image - due to dust.

HAWC: High-resolution Airborne Wideband Camera

-λ = 40- 300 µm [FIR/Submm]
- Four Filters at 53, 88, 155 and 215 µm
- Bolometer Detector: Goddard Silicon Pop-up Detector (SPUD), 12 x 32 array
-May be upgraded to perform Far Infrared Polarimetry

Far Infrared Bolometer Camera





Principal Investigator:
Dr. Al Harper
University of Chicago, Yerkes Observatory,
Williams Bay, Wisconsin

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EXES: Echelon – Cross – Echelle Spectrograph

-λ = 5-28.5 µm [Mid-IR]
-Three Modes at 105, 104, and 3000
-Detector: Si:As Blocked Impurity Band (BIB) 256 x 256
-Al 6061 (Hyperfine diamond machined)
4“ x 4“ square, 40“ long grating
Three Spectral Modes:
-R = 50-100,000 cross-dispersed
-R = 15,000 long-slit
-R = 4,000 long-slit
plus source acquisition and pupil imaging camera

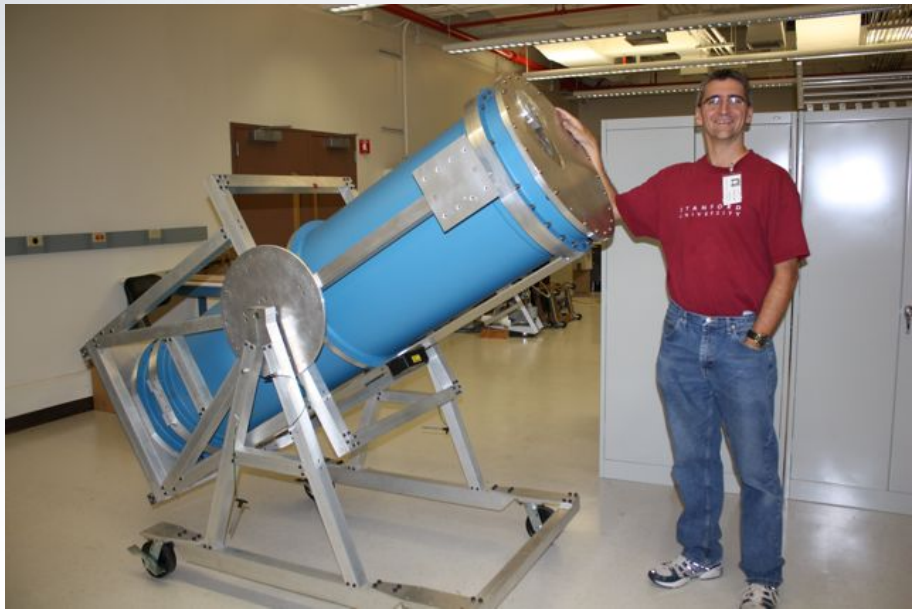
Science Drivers:

Proto-planetary disks
H2, H2O, CH4 in emission and absorption
line shapes give spatial distribution in Keplerian disks

Gas in star-formation regions
H2O, CH4, C2H2, HCN, CH3, NH3, HNCO, Fe, Fe+, O+3, Ne+, Ne+4, S, S+2, S+3, Ar+, Ar+2, Ar+4

Atmospheres of Planets and Satellites

High Resolution Echelon Spectrometer



Principal Investigator:
Dr. Matt Richter, University of California Davis, being built at NASA Ames Research Center

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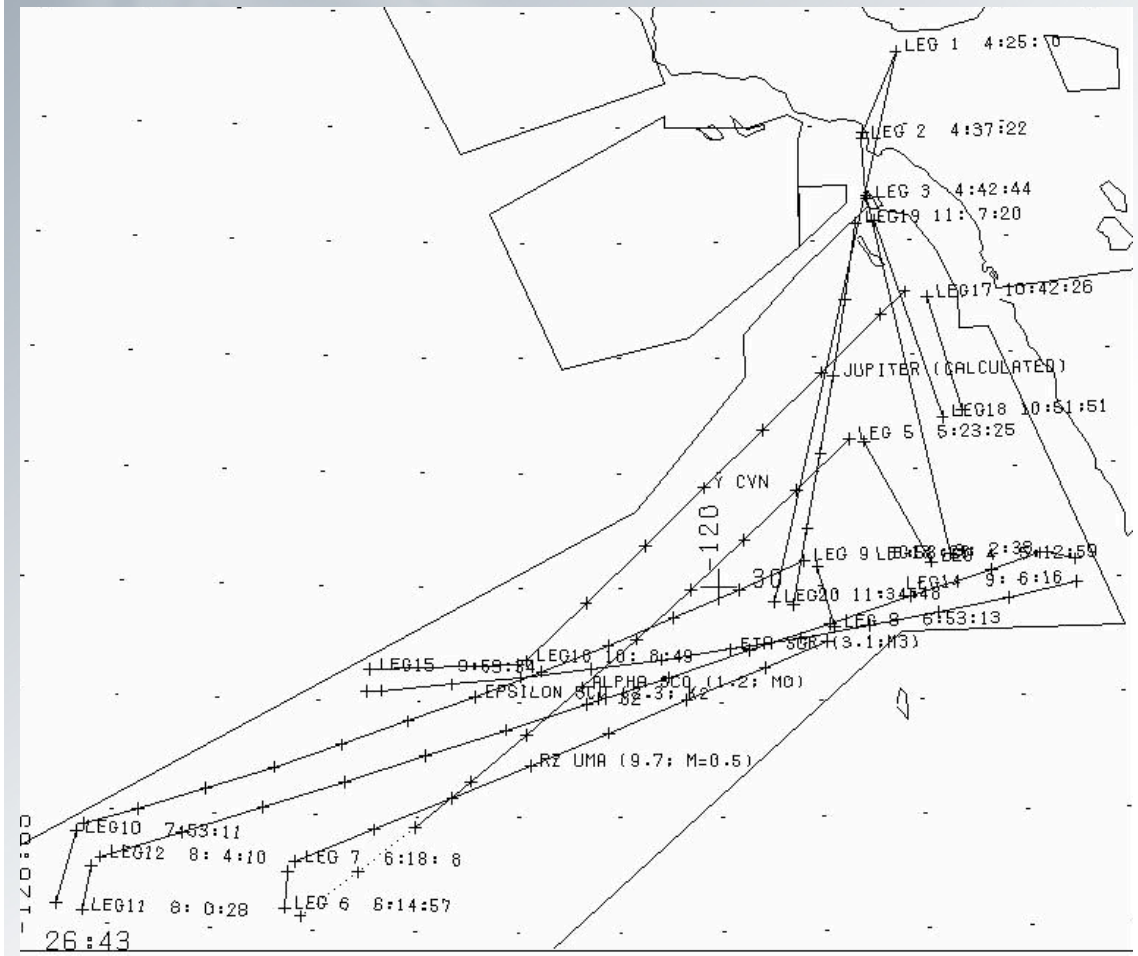
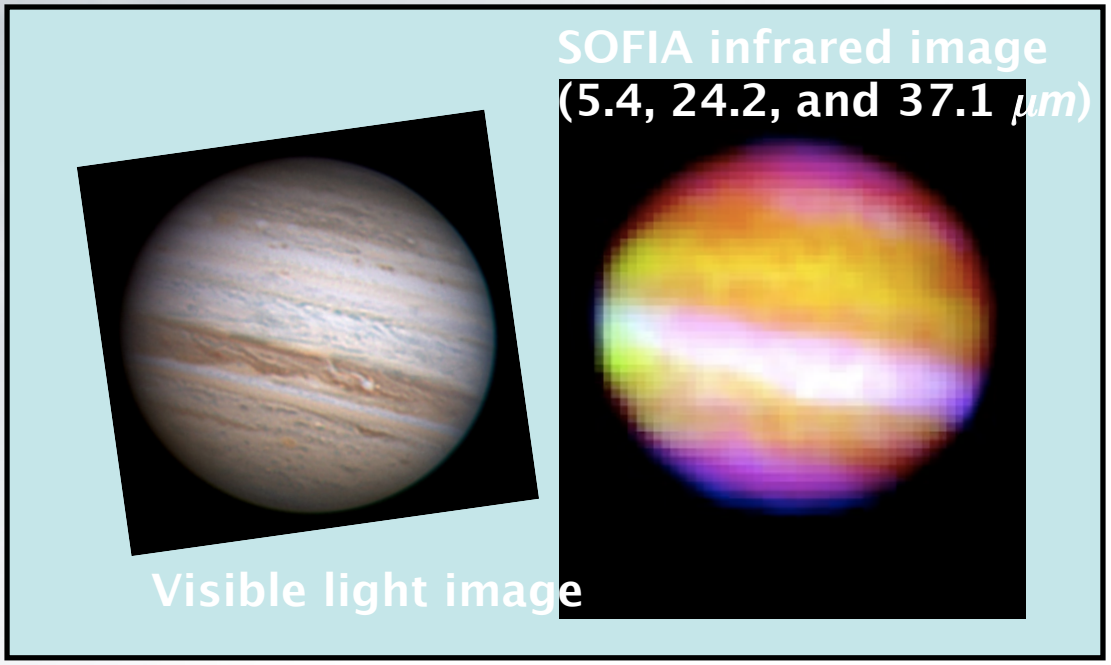
First Light Flight Plan

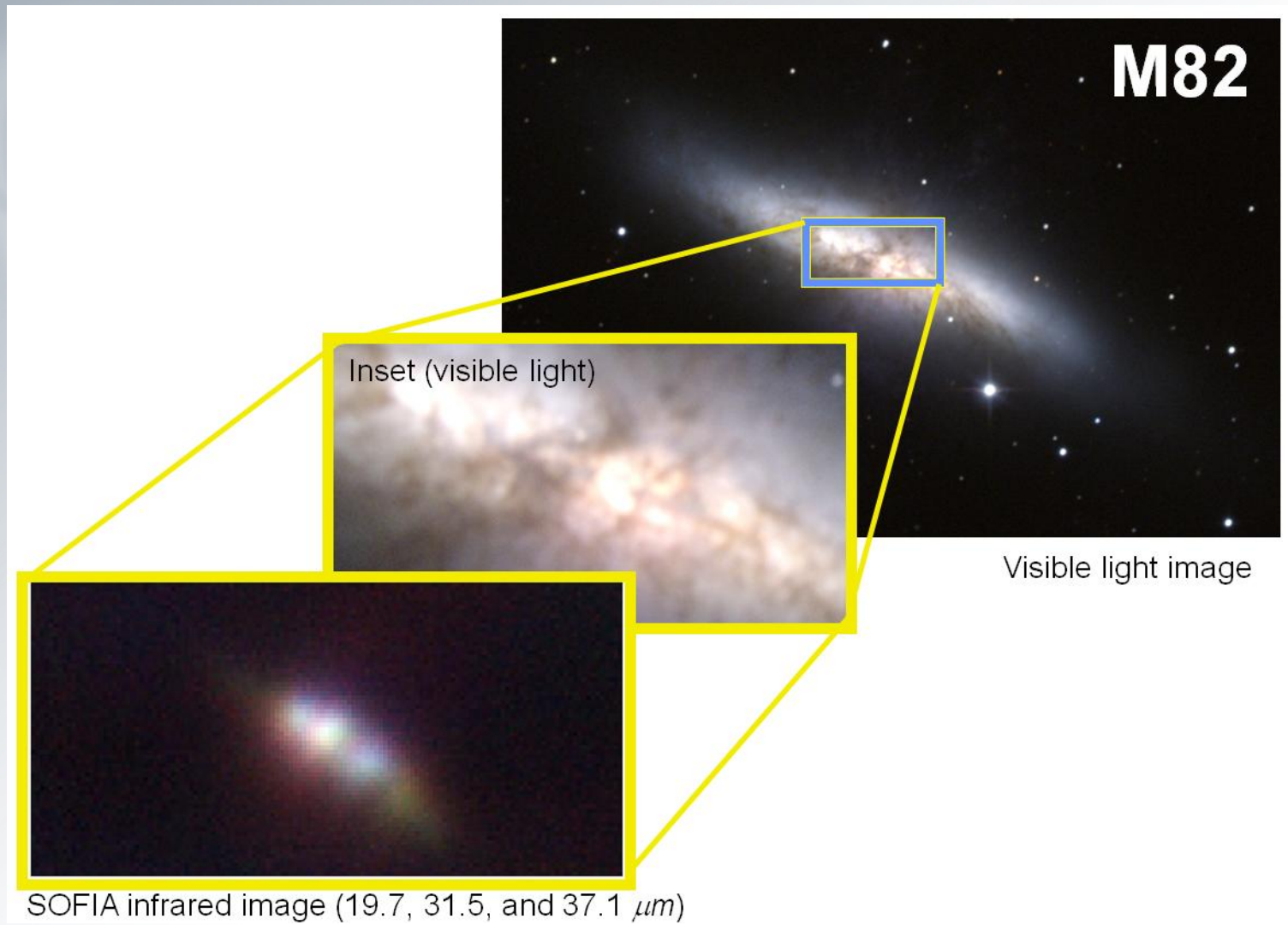


Leg	OBJECT	PDT start	DUR Min
1	DEAD LEG	09:50	14
2	DEAD LEG	10:05	9
3	DEAD LEG	10:15	7
4	DEAD LEG	10:24	10
5	**ALPHA SCO**	**10:34**	**27**
6	**TW OPH**	**11:01**	**22**
7	DEAD LEG	11:25	3
8	**RZ UMA**	**11:29**	**25**
9	DEAD LEG	11:56	3
10	**EPSILON SCO**	**11:58**	**30**
11	**RHO UMA**	**12:31**	**25**
12	DEAD LEG	12:58	11
13	**M 82**	**01:11**	**36**
14	DEAD LEG	01:48	5
15	**ETA SGR**	**01:54**	**53**
16	DEAD LEG	02:48	5
17	**LAMBDA DRA**	**02:54**	**25**
18	**V CVN**	**03:20**	**25**
19	DEAD LEG	03:46	12
20	DEAD LEG	04:00	4
21	**JUPITER**	**04:06**	**27**
22	DEAD LEG	04:35	40

First Light Planetary Science



First Light - Galaxy



UNIVERSITIES SPACE RESEARCH ASSOCIATION

SOFIA has an active Education and Public Outreach Joint US & German

Education

Research flight experience for educators
Summer workshops for college faculty and students to encourage research, Production and dissemination of curricula & class activities; school visits

Public Outreach

Displays at public events
April: "Spaceward Bound," Yuri's night
May: SOFIA podcast for "365 days of astronomy" for "First Light" flight

Public Affairs (Public Information & Press Relations)

Press releases and media productions:
First open-door flight
First Light flight
Short Science results
SOFIA *Branding*

Science Community Outreach

SOFIA exhibits, talks, posters at science conferences
Support for colloquia by SOFIA scientists and engineers
Convince the Community that we are real

UNIVERSITIES SPACE RESEARCH ASSOCIATION

SOFIA modeled after the Kuiper Airborne Observatory FOSTER educator flight program

- Program making progress!
  - First Light (Heat) with FORCAST was a great success.
  - Aircraft handles well even with door open.
  - Envelope now cleared to 45,000ft
  - First science in 2010

- SOFIA will be one of the primary facilities for far-IR and sub-millimeter astronomy for many years

SOFIA First Light Image, May 25, 2010