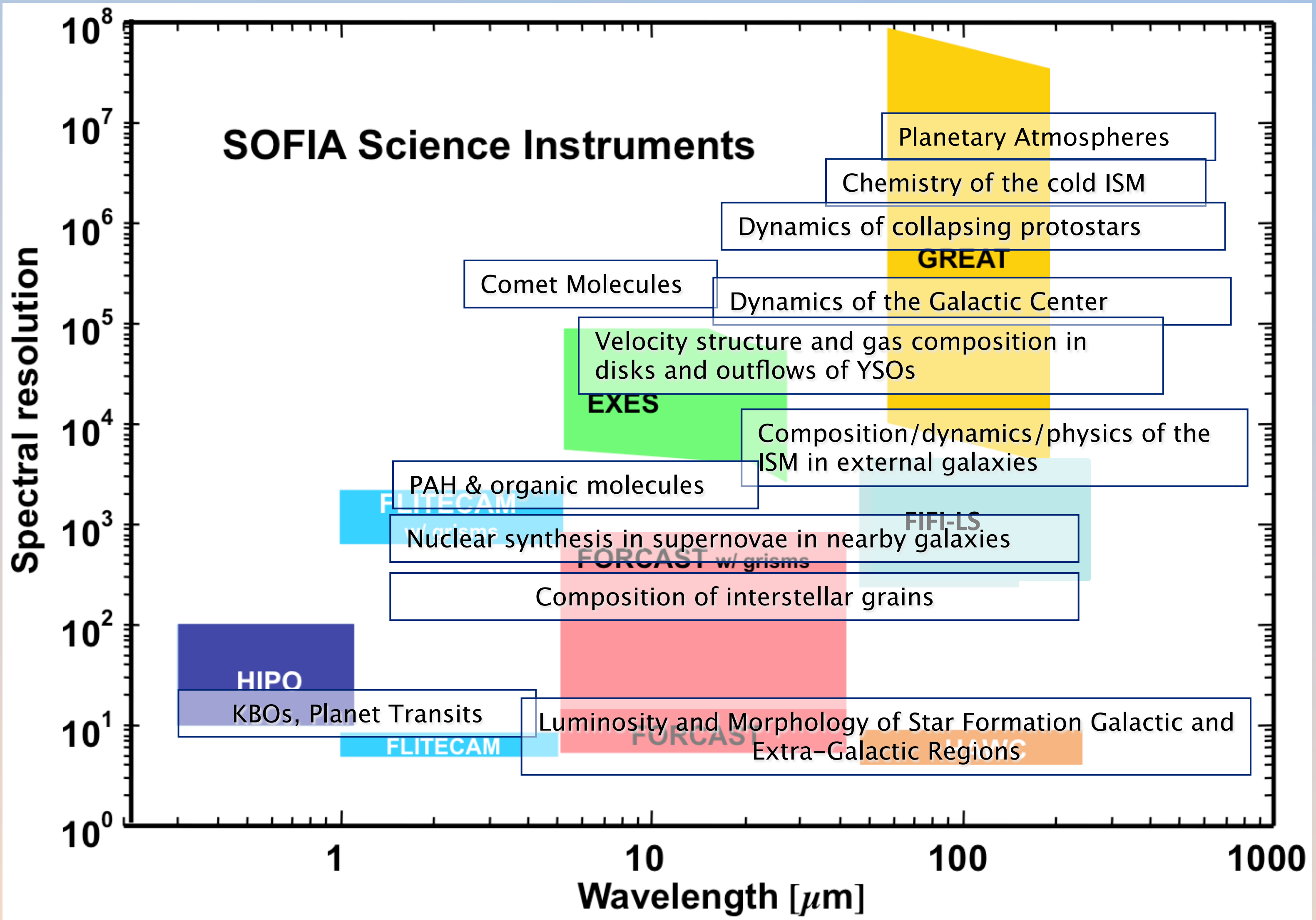
SOFIA science instruments: SUG -6

October 20. 2014

Erin Smith

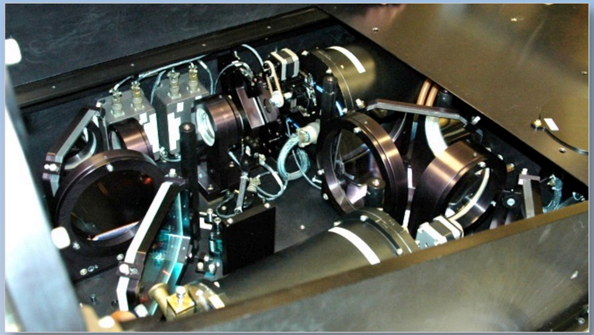
First Generation Science Instruments

Science Instrument	Type*	Developing Institution	Principal Investigator	Instrument Description
FORCAST	FSI	Cornell University	Herter	Simultaneous Dual Channel Imaging and Grism Spectroscopy (5-25 μm & 25-40 μm)
GREAT	PSI	Max Planck Institute, Bonn	Güsten	High Resolution ($R > 10^6$) Heterodyne Spectrometer (1.6-1.9 THz; 2.4-2.7 THz; 4.7 THz)
HIPO	SSI	Lowell Observatory	Dunham	Visible Light High-Speed Camera (0.3-1.1 μm)
FLITECAM	FSI	UCLA	McLean	Near Infrared Imaging and Grism Spectroscopy, (1-5.5 μm); Can be used in combination with HIPO
FIFI-LS	PSI FSI	University of Stuttgart	Krabbe	Dual Channel Integral Field Grating Spectrometer (42-110 μm; 100-210 μm)
EXES	PSI	UC Davis	Richter	High Resolution ($R > 10^5$) Echelle Spectrometer (5-28 μm)
HAWC HAWC+	FSI	University of Chicago JPL	Harper Dowell	High-Angular Resolution Wide-Band Camera with 4 Channels (50 μm, 100 μm, 160 μm, 200 μm)

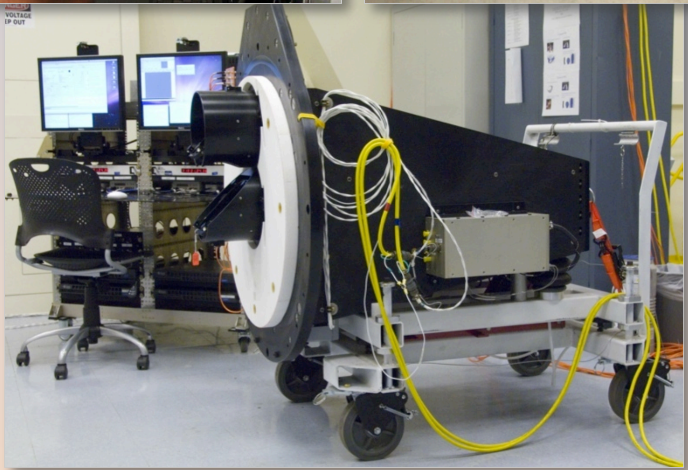

SOFIA Science Instruments
Spectral resolution
Wavelength [μm]
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
1
10
100
1000
GREAT
EXES
FLITECAM w/ grisms
FIFI-LS
FORCAST w/ grisms
HIPO
FLITECAM
FORCAST
HAWC
Planetary Atmospheres
Chemistry of the cold ISM
Dynamics of collapsing protostars
Comet Molecules
Dynamics of the Galactic Center
Velocity structure and gas composition in disks and outflows of YSOs
Composition/dynamics/physics of the ISM in external galaxies
PAH & organic molecules
Nuclear synthesis in supernovae in nearby galaxies
Composition of interstellar grains
KBOs, Planet Transits
Luminosity and Morphology of Star Formation Galactic and Extra-Galactic Regions

Science Instrument	Status
FORCAST	FORCAST Acceptance Review for imaging modes completed. Software Acceptance Oct 31; New grism 4 installed and tested
GREAT	UpGREAT (an array heterodyne) to be commissioned in 2015
HIPO	Commissioning review completed in May 2014
FLITECAM	Near Infrared Imaging and Grism Spectroscopy, (1-5.5 μm); Can be used in combination with HIPO; All Commissioning Flights complete. Long-wavelength glint resolved
FIFI-LS	All Commissioning Flights complete, performed GO science flights
EXES	Phase 1 Commissioning Complete, will complete commissioning flights in February
HAWC HAWC+	High-Angular Resolution Wide-Band Camera with 4 Channels (50 μm, 100 μm, 160 μm, 200 μm); under development at JPL and GSFC

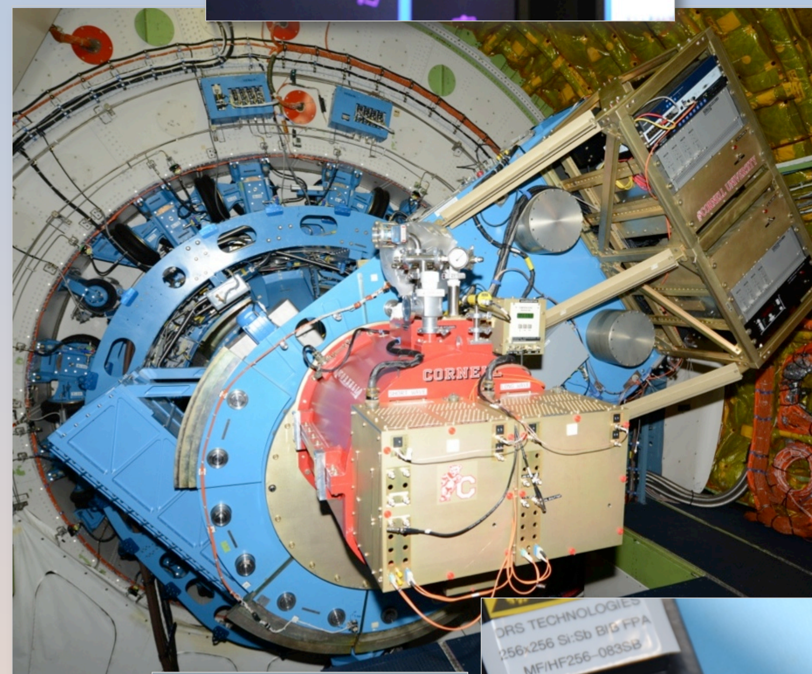
HIPO Status



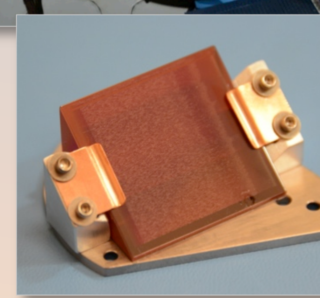
- 1 Pluto occultation flight conducted June 2011
- 4 engineering flights conducted in June and December 2011
- 4 engineering flights conducted in tandem with FLITECAM (aka FLIPO) in October 2011
- 3 engineering/commissioning flights conducted in January and February 2013
- Observed exoplanet transit during the October 2013 FLITECAM commissioning campaign
- Conducted 6 flights of observations in February 2014, including observations of NGC 2024, an exoplanet transit observation and multiple observations of the supernova SN2014J

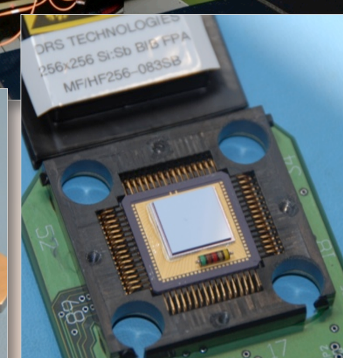


FORCAST Status

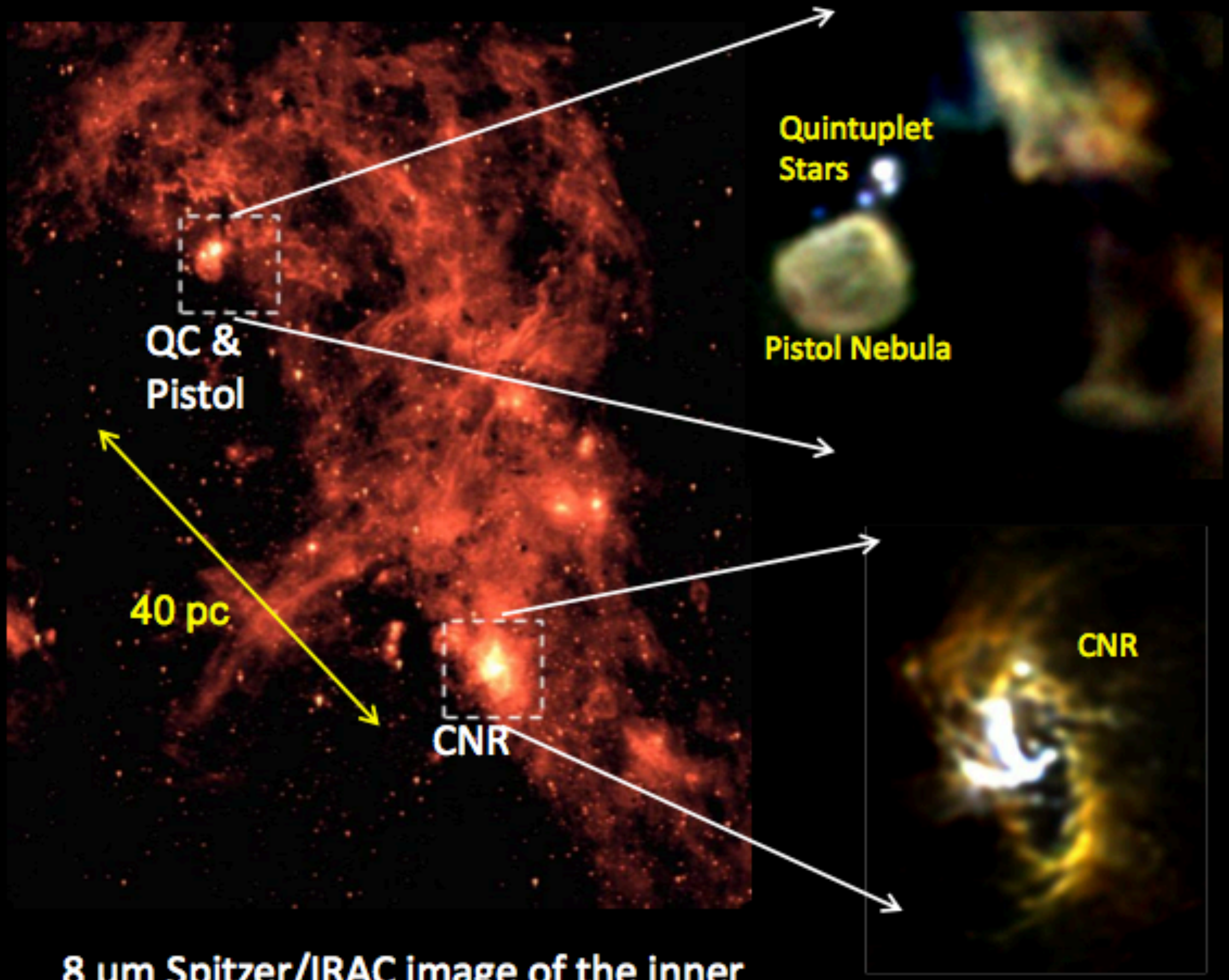


- 3 observatory characterization flights conducted in 2010
- 13 flights conducted during Early Science in 2010 and 2011
- 6 commissioning flights conducted in April, May, and June 2013
- 3 Cycle 1 science flights conducted in June and July 2013
- 5 science flights conducted in September 2013
- Acceptance review for imaging modes conducted March 2014
- Cycle 2 science flights conducted in April 2014
- Next installation expected January 2014
- Grism 4 installed and tested in lab—shows some residual stray light. Will be tested during 2015 line ops and flights in parallel with GO observations





Observations



8 µm Spitzer/IRAC image of the inner 50 pc of the Galactic Center

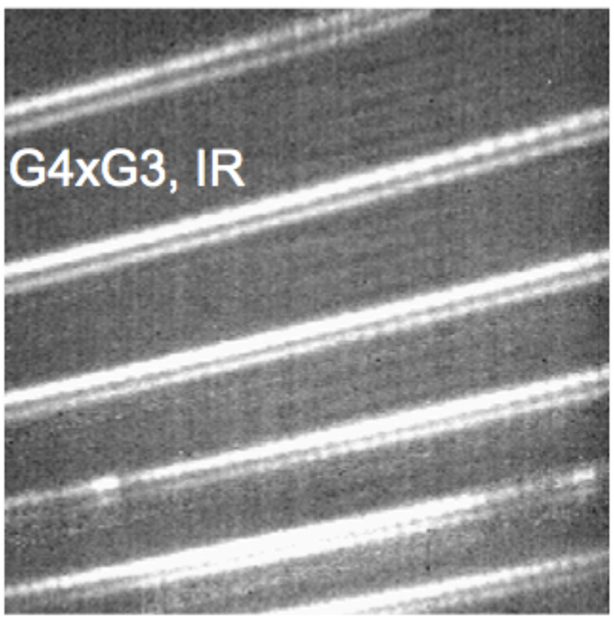
- SOFIA/FORCAST Galactic Center observations conducted during Basic Science flights 63 and 64 on June 4, 2011 and 8, 2011, respectively.

SOFIA/FORCAST images at 19.7 (blue), 31.5 (green), 37.1 (red) µm

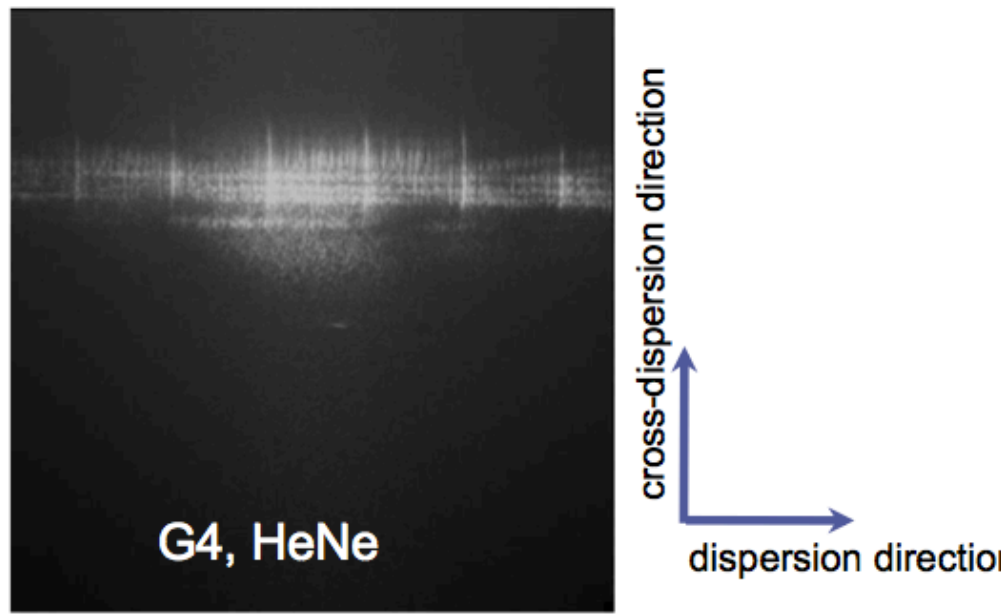
G4 Grism double spectrum

Problem: Multiple infrared diffraction patterns observed for single point source (star) when Grism 4 flight device is used in FORCAST.

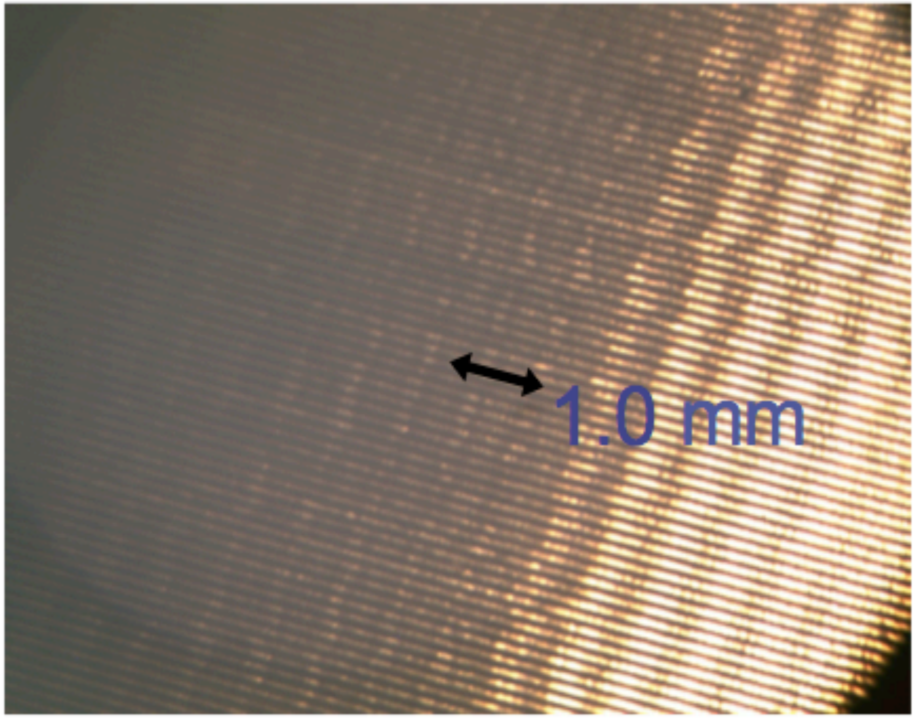
Hypothesis: Multiple orders with more power in the brightest few orders is consistent with a blazed pattern orthogonal to the desired groove pattern



Grism mounted in FORCAST; transmission infrared cross-dispersed spectrum of point source



Grism mounted on optical bench; transmission visible light (HeNe) G4-only spectrum of point source

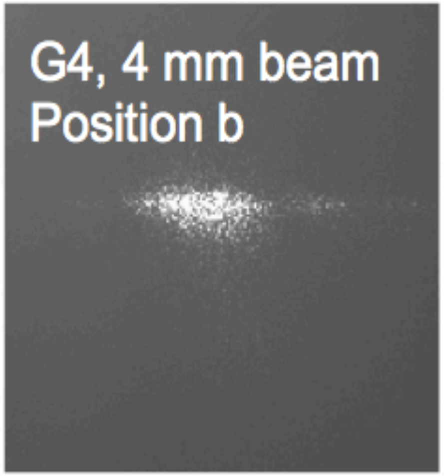


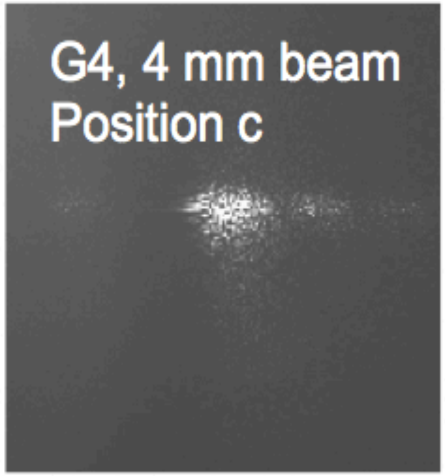
Microscope photograph of Grism 4 groove pattern illuminated with white light

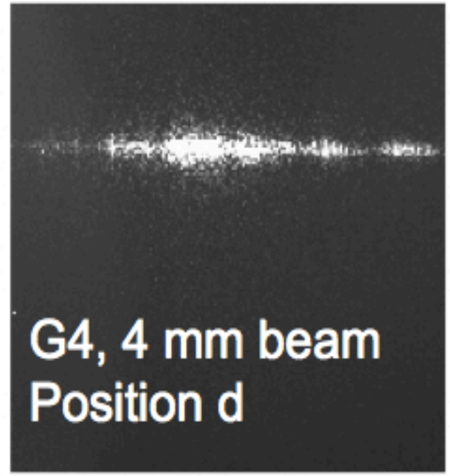
- Grooves appear to have a periodic change in depth or shape with a period of ~0.7 μm
- Difference in intensity of reflected light by the anomalous pattern indicates a blazed pattern (also consistent with the observed multiple orders in the infrared spectrum)

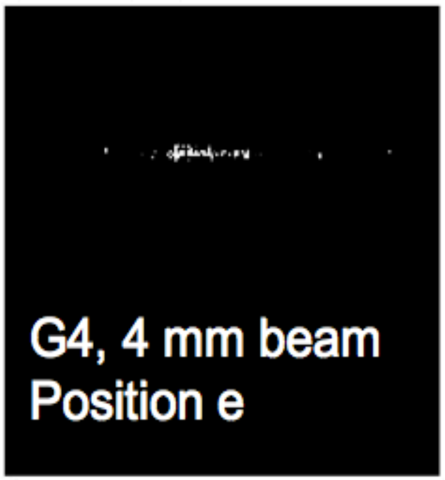
Conclusion: the grism groove profiles have inconsistent depth/shape along the full length of the grooves

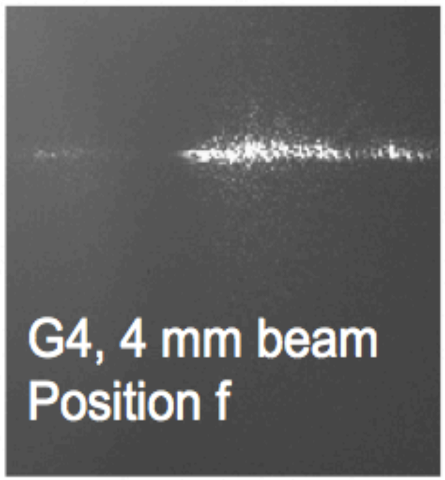
G4-spare HeNe test

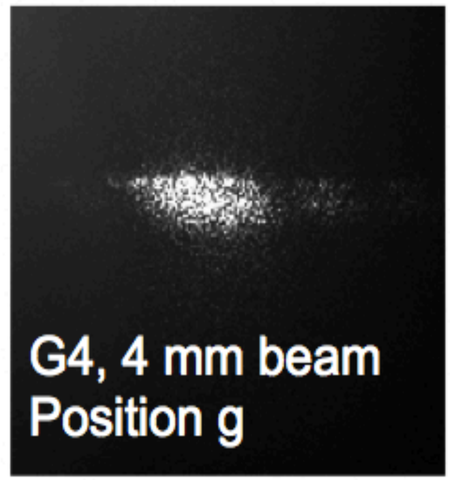


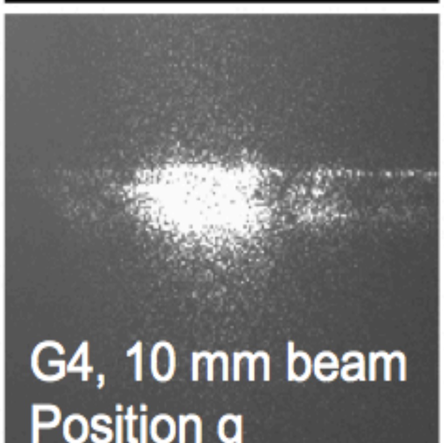


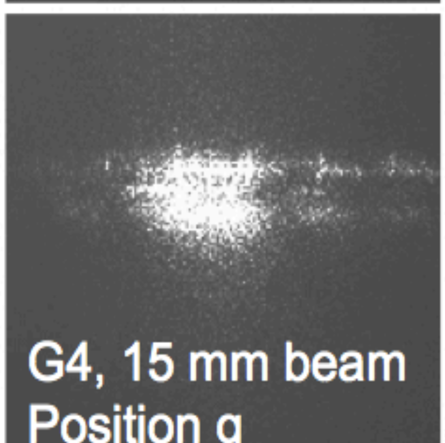


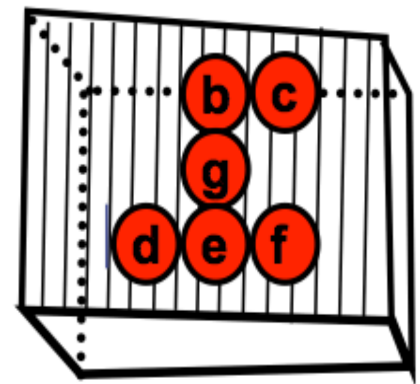


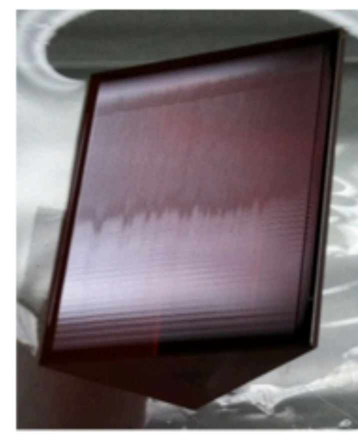








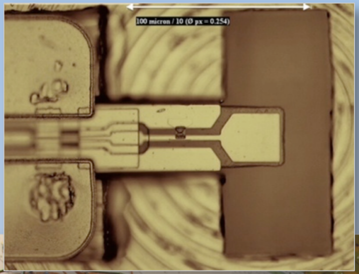


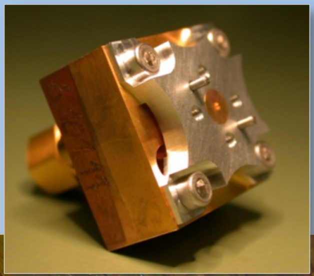


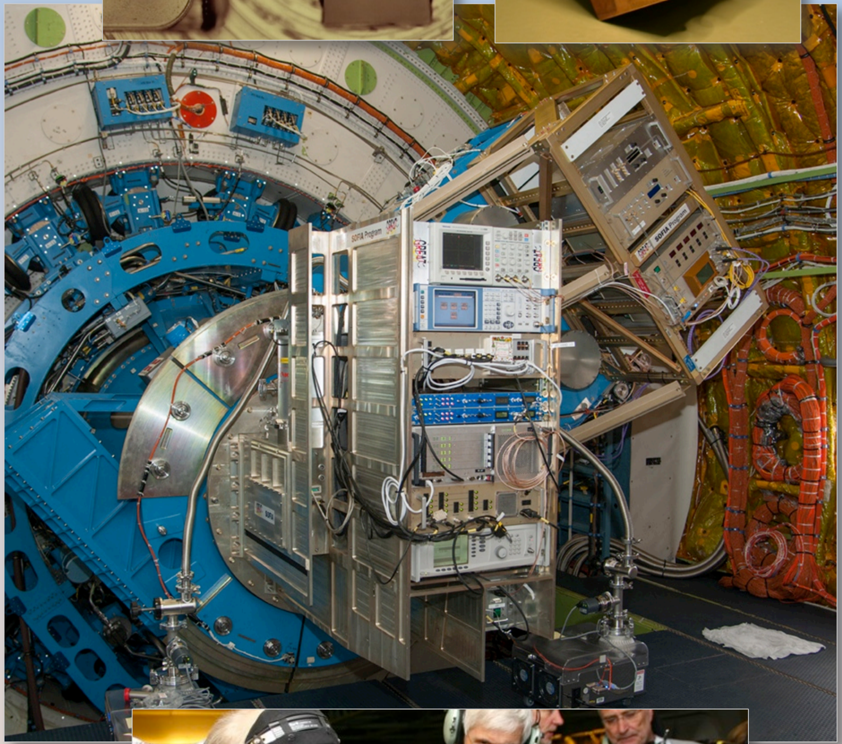
Top half (pos b, c) scatters laser light
Bottom half (pos d, e, f) less scattering
Pos g is in the transition

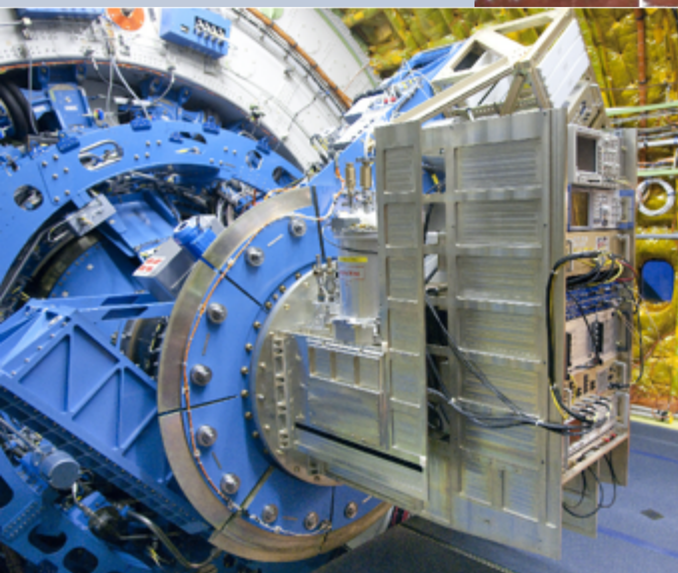
GREAT Status

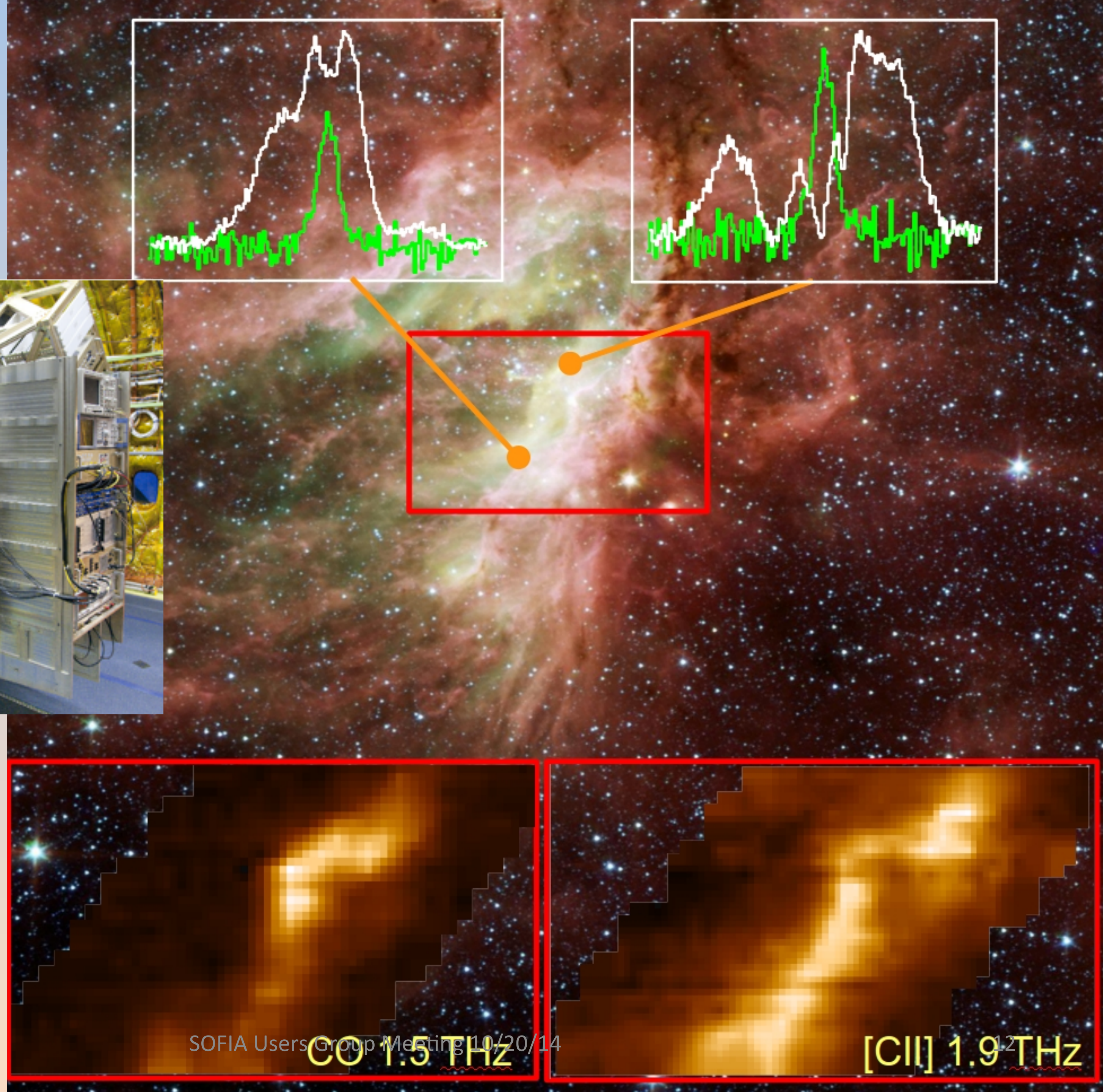
- 18 flights during Early Science in 2011
- Cycle 1 science observations
  - 4 flights in April and July 2013
  - 9 flights from New Zealand in July 2013
- L (~ 1.3, 1.5, 1.9 THz) and M (~ 2.5, 2.7 THz) channel commissioning completed on April and July 2013 flights
- Conducted two flights in February 2014
- Cycle 2 observations conducted in May 2014
- H channel (4.7 THz) flown May 2014
- upGREAT commissioning in 2015, with multipixel heterodyne arrays:
  - 1.9-2.5 THz at two polarizations
  - 4.7 THz



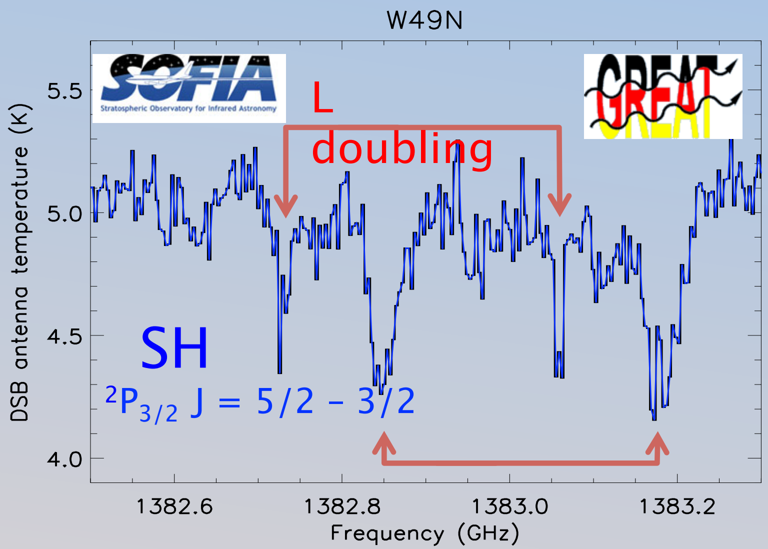


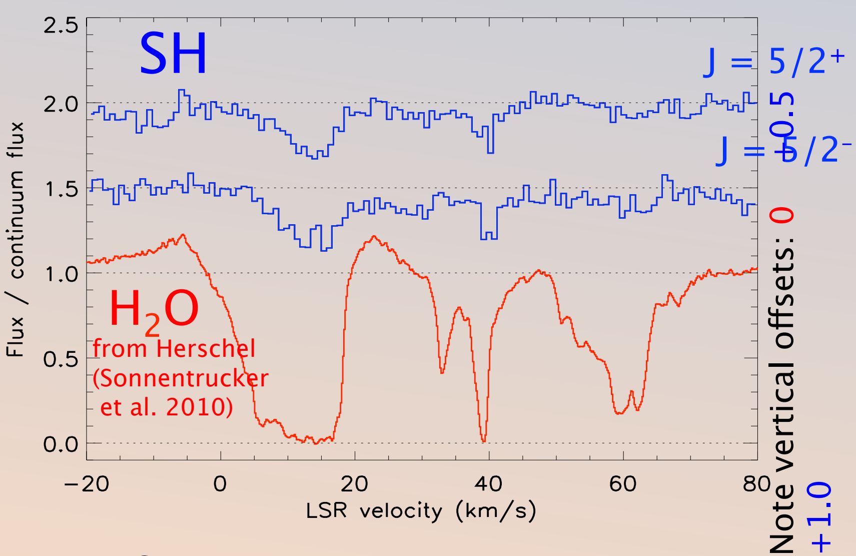





CO 1.5 THz
[CII] 1.9 THz

SOFIA/GREAT discovery of interstellar mercapto radicals (SH)





Neufeld, Falgarone, Gerin, Godard, Herbst, Pineau des Forêts and the GREAT Team (2011)

QUICK-LOOK data reduction: not fully calibrated

SH has been detected in absorption toward W49N and W31C (G10.62 – 0.4)

Its 1.383 THz ground state transition lies in the gap between Herschel/HIFI Bands 5 and 6.

SH is a key hydride, for which astronomical data was conspicuously missing until now.

Its presence suggests a "warm chemistry", driven by shocks or turbulent dissipation, that can enable endothermic formation paths.

Eight neutral diatomic hydrides have now been detected in the ISM:

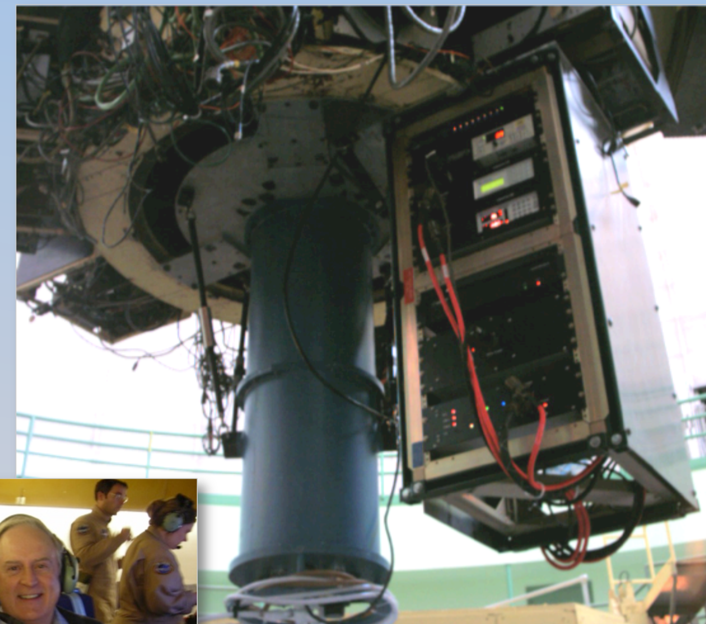
H_2 (Carruthers 1970)
CH (Swings & Rosenfeld 1937)
NH (Meyer & Roth 1991)
OH (Weinreb 1963)

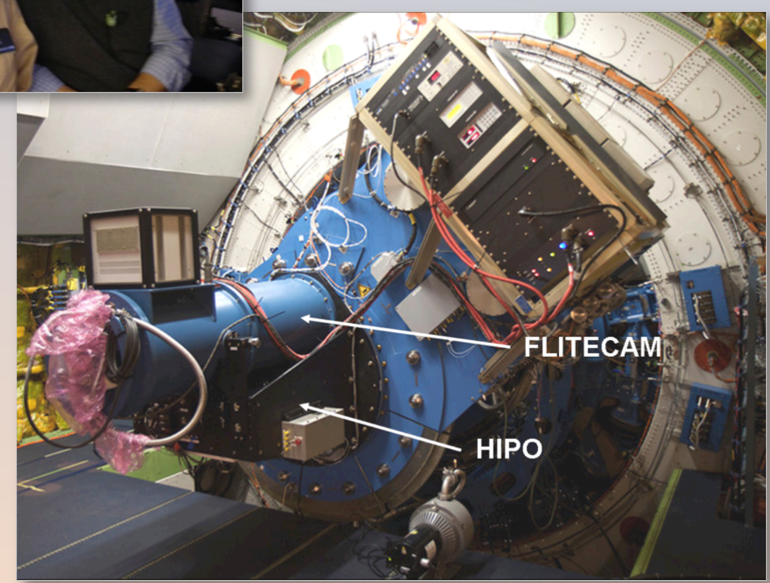
SiH (tentative; Schilke et al. 2001)

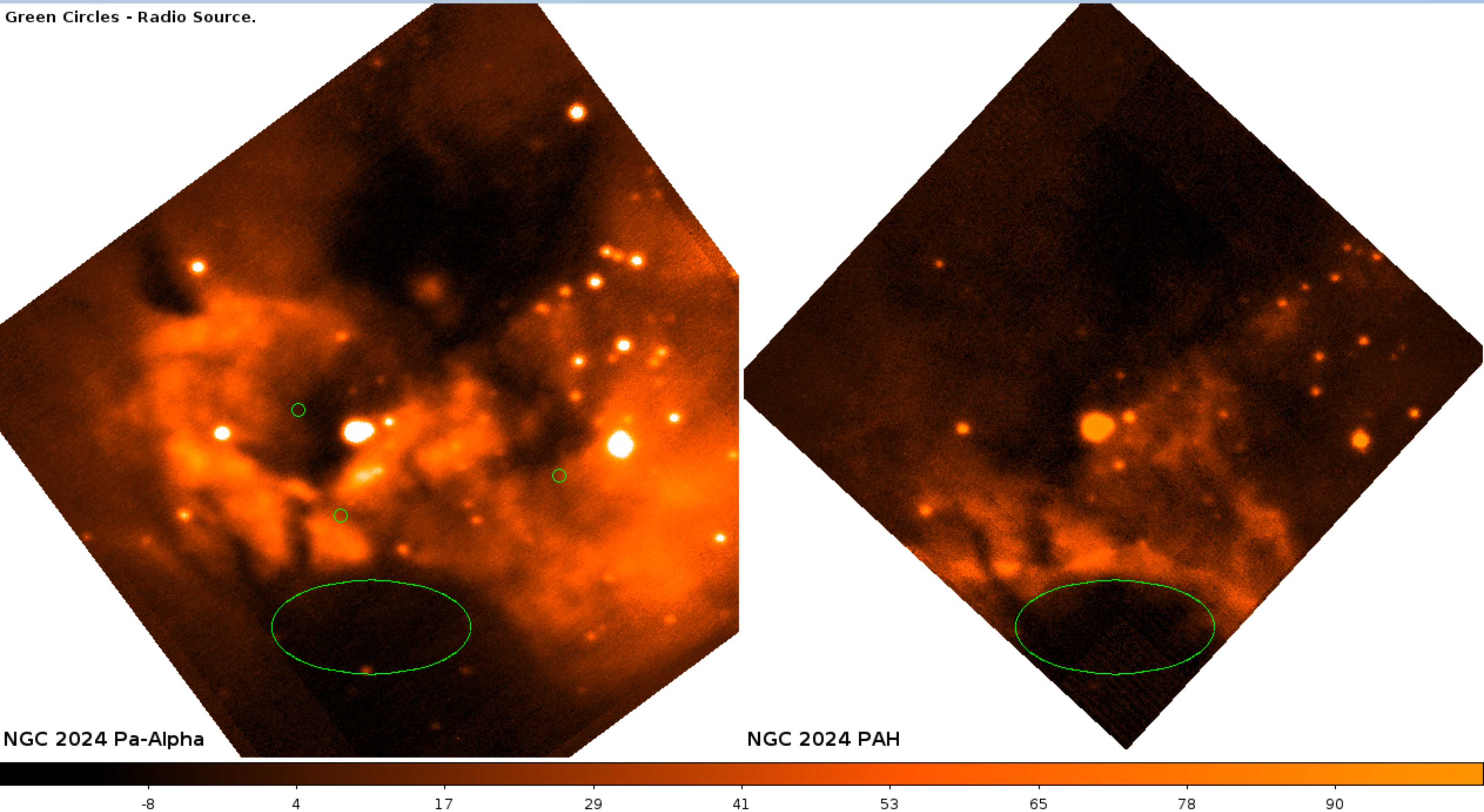
SH (SOFIA/ GREAT 2011)

FLITECAM Status

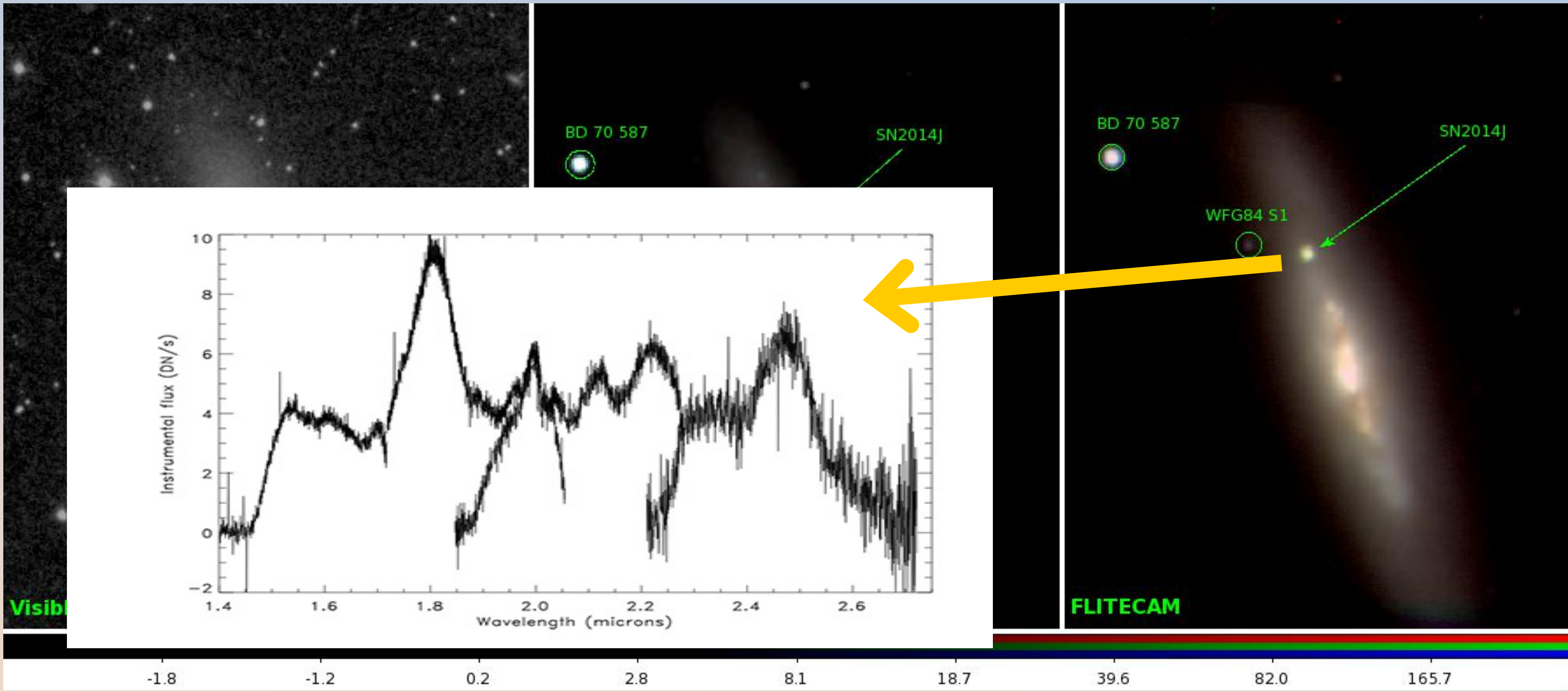
- Fully comissioined in ground-based observations at Lick observatory
- 4 engineering flights conducted in tandem with HIPO (FLIPO) in October 2011
- May 2013 line operations completed successfully
- Instrument currently at UCLA
- 2 commissioning flights with HIPO (FLIPO) in October 2013
- 3 commissioning flights conducted in November 2013
- 6 flights conducted in February 2014, including observations of exoplanet transit and supernova SN2014J



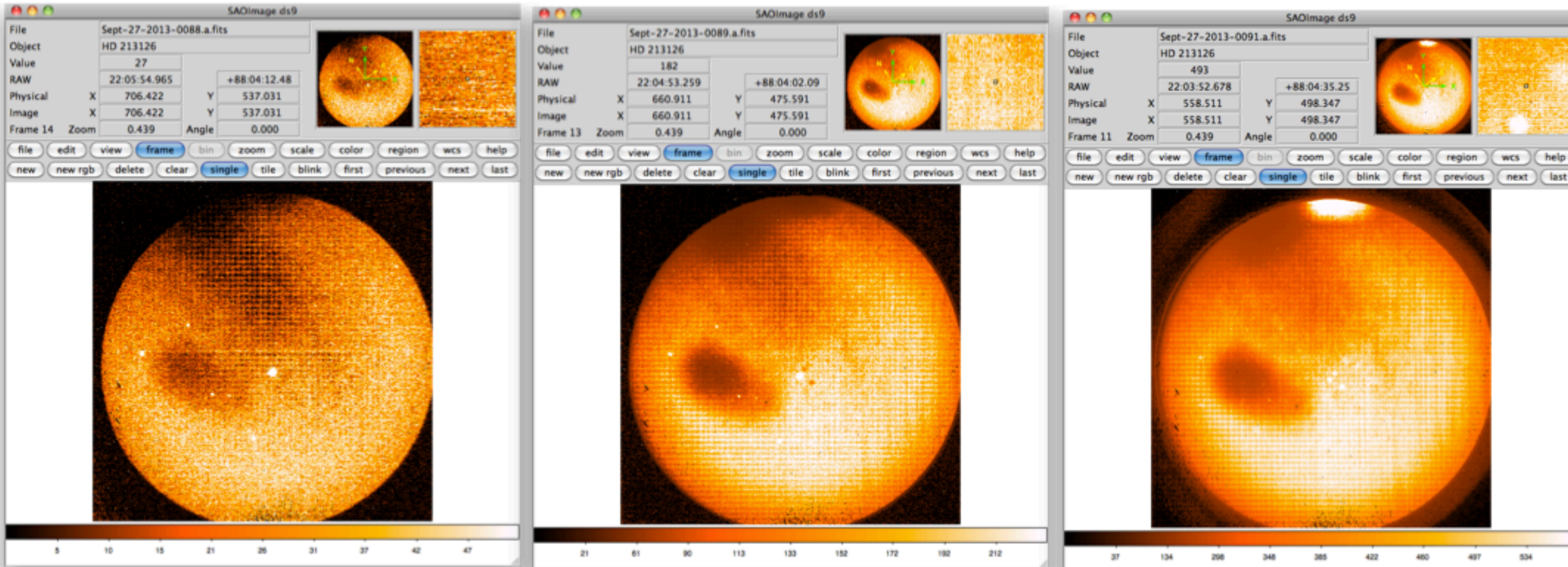



Green Circles - Radio Source.
NGC 2024 Pa-Alpha
NGC 2024 PAH
-8
4
17
29
41
53
65
78
90

SN2014J

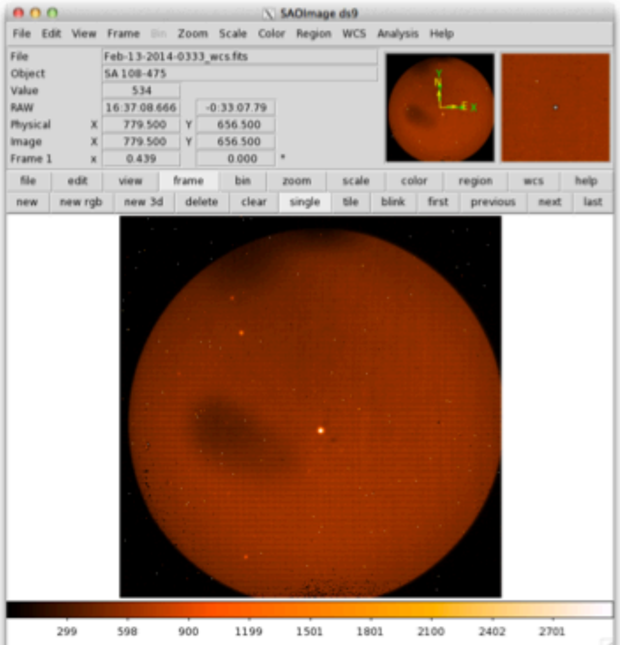

BD 70 587
SN2014J
BD 70 587
SN2014J
WFG84 S1
FLITECAM
Instrumental flux (DN/s)
Wavelength (microns)
10
8
6
4
2
0
−2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
-1.8
-1.2
0.2
2.8
8.1
18.7
39.6
82.0
165.7

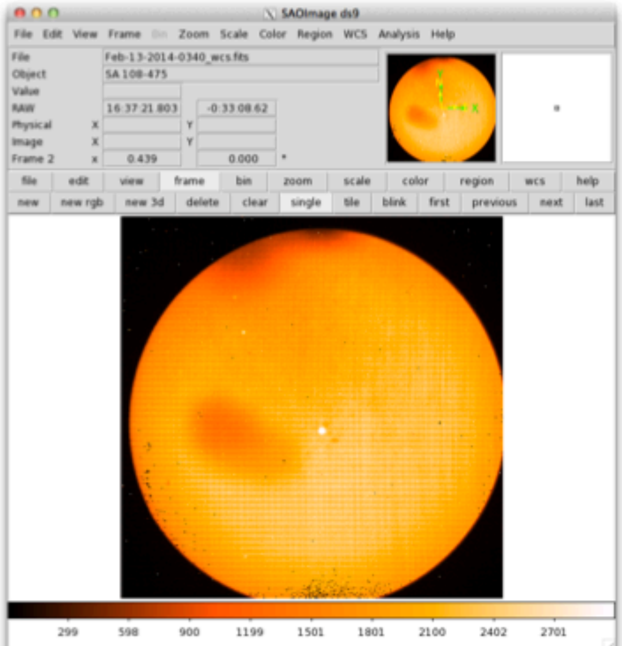
In Flight **Sept. 2013:** J, H, K

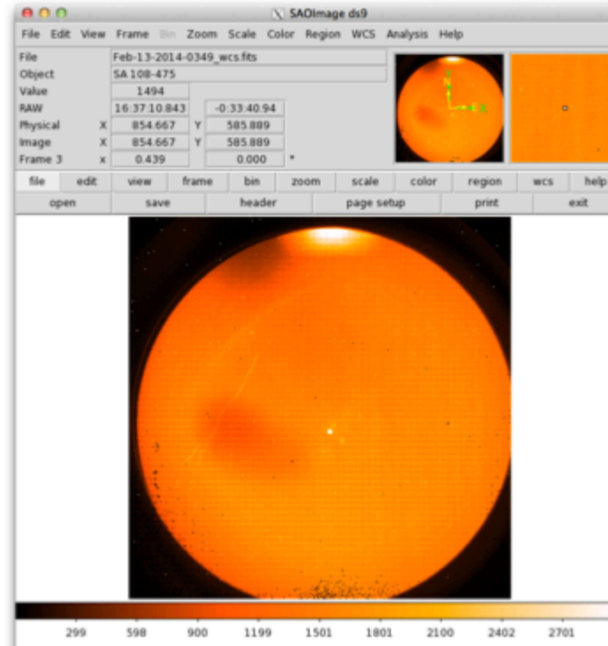


Bands L to R: J. H, K	
Files: Sept-27-2013-0088.a.fits	Scale: 0-1000
Sept-27-2013-0089.a.fits	Exp.: 1s
Sept-27-2013-0091.a.fits	Source: HD 213136

In Flight **Feb. 2014**: J, H, K





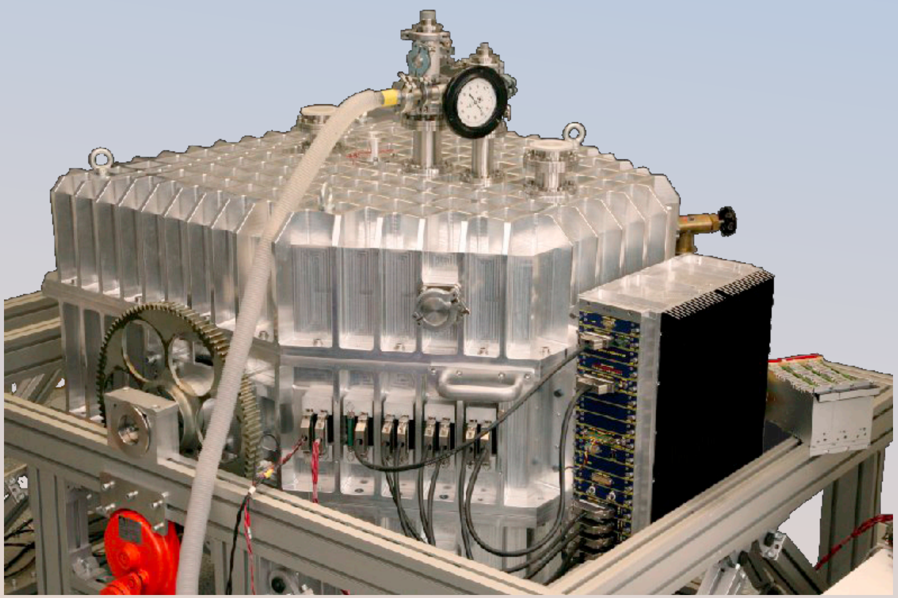


Bands L to R: J. H, K
Files: Feb-13-2014-0333.a.fits
Feb-13-2014-0340.a.fits
Feb-13-2014-0349.a.fits

Scale: 0-3000
Exp.: 1s x 5 coadds
Source: SA 108-475

FIFI-LS

FIFI LS: **F**ield **I**maging **F**ar **I**nfrared **L**ine **S**pectrometer

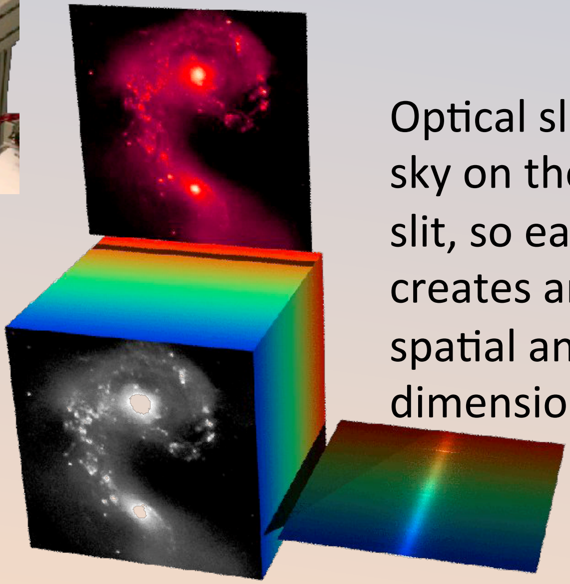


Dual Channel imaging spectrometer (R~1700)

Blue channel: 42-110 microns

Red channel: 110-210 microns

16 x 25 pixel Ge:Ga detector array (each channel)

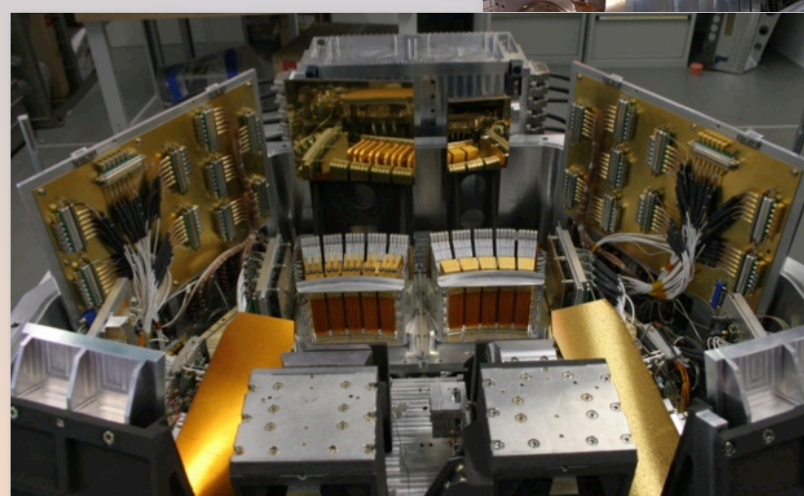


Optical slicer places the 2D sky on the 1D spectroscopy slit, so each observation creates an image cube with spatial and spectral dimensions.

Science: Integral field spectroscopy in the far-infrared; Galaxy evolution; galactic halos; dwarf galaxies

FIFI-LS Status

- Hardware integrated
- FIFI-LS offered as shared-risk in SOFIA Cycle 2 call for proposals
- Pre-ship review completed October 2013
- Commissioning completed in February and April 2014



EXES: **E**chelon-cross
Echelle
Spectrograph

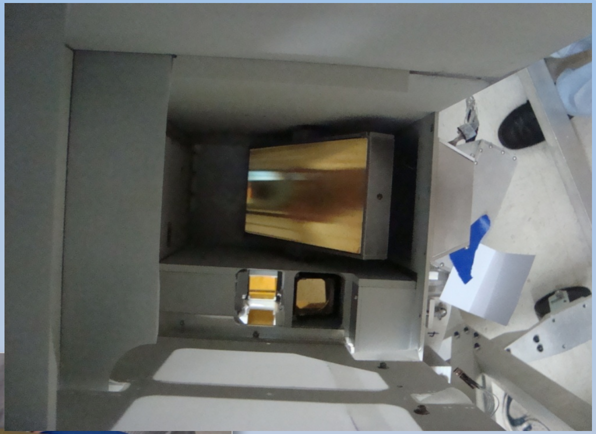
- l: 5 – 28.5 mm
- Detector: 256^2 pixel Si:As BiB
- Platescale: 0.4”/ pixel
- Three resolving modes:
  - Dl: 10^5 for l < 10 mm
  - 10^6 for l > 10 mm
  - 3000 for echellon bypass

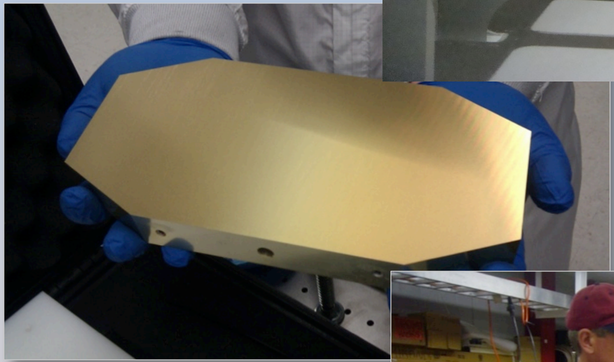
Science:

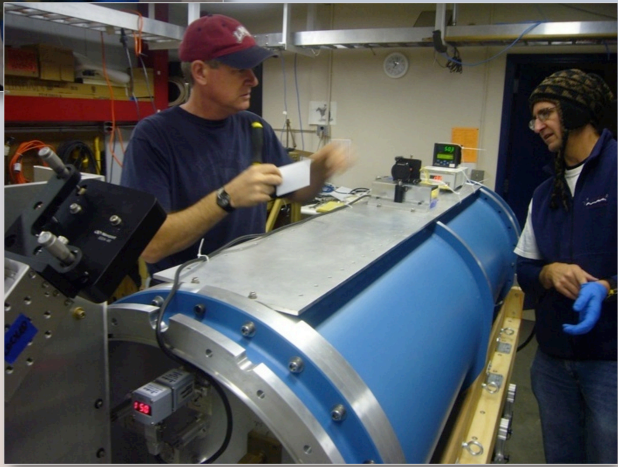
High-resolution spectra of molecules (H_2, NH_4, H_2O) blocked from ground observations.
Molecular clouds, protoplanetary disks, interstellar shocks, planetary atmospheres

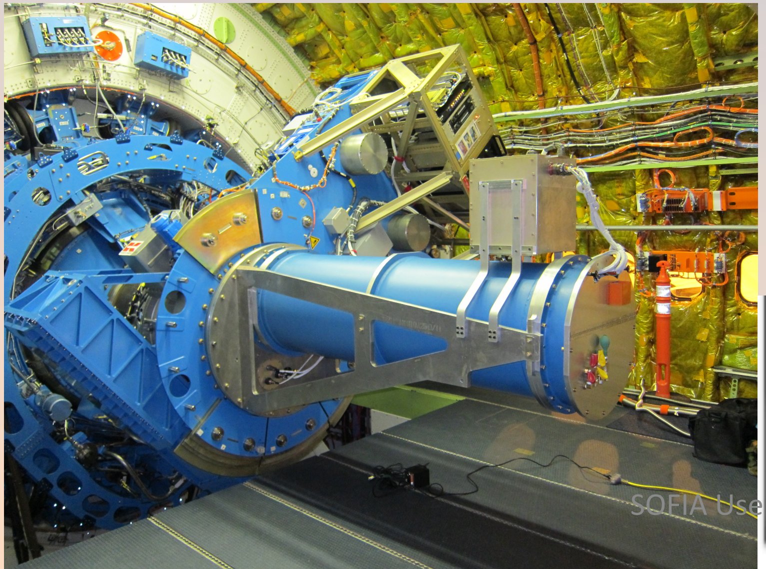
EXES Status

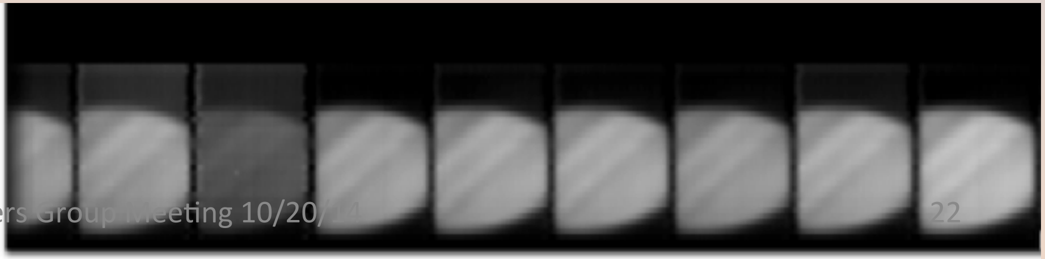
- Hardware integrated
- Demonstrated at Mauna Kea on IRTF
- EXES offered as shared-risk in SOFIA Cycle 2 call for proposals
- Pre-ship review in January 2014
- Commissioning part 1 conducted in April 2014
- Commissioning completing February 2015











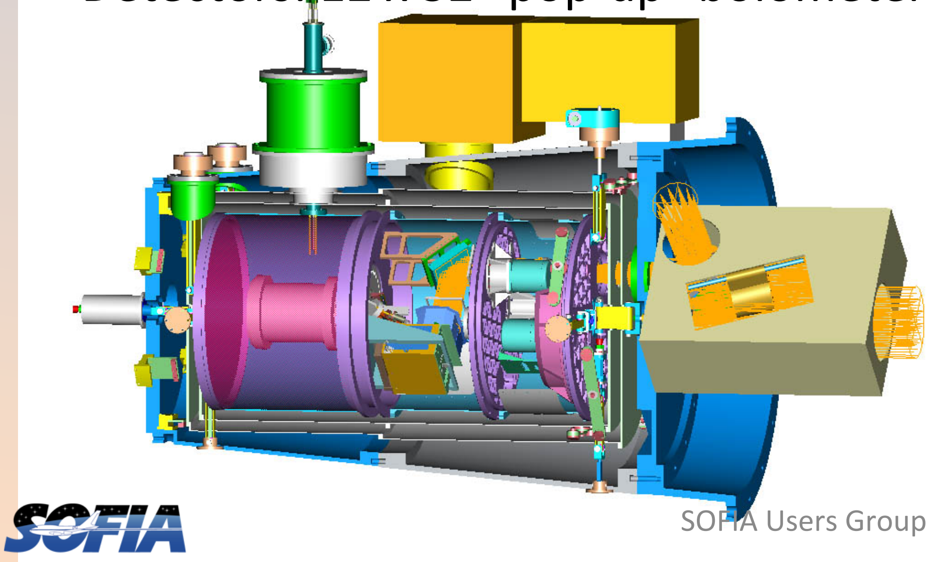
HAWC

HAWC: High-resolution Airborne Wideband Camera

Wavelength range: 40-300 microns in 4 bands

Band	pixel size	FOV
53 microns	2.25 arcsec	27 x 72 arcsec
89 microns	3.5 arcsec	42 x 112 arcsec
155 microns	6.0 arcsec	72 x 192 arcsec
215 microns	8.0 arcsec	96 x 256 arcsec

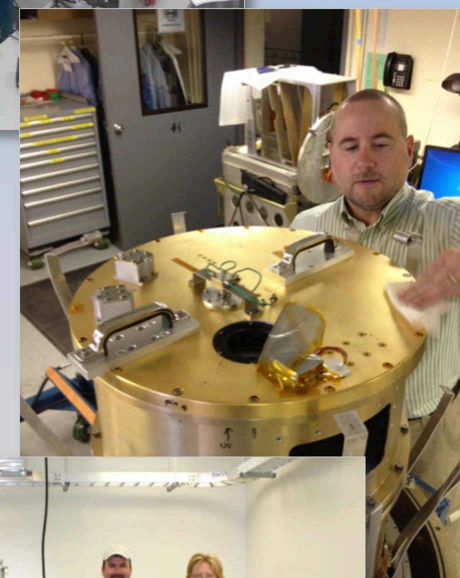
Detectors: 12 x 32 “pop-up” bolometer array

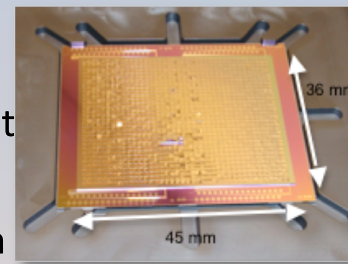


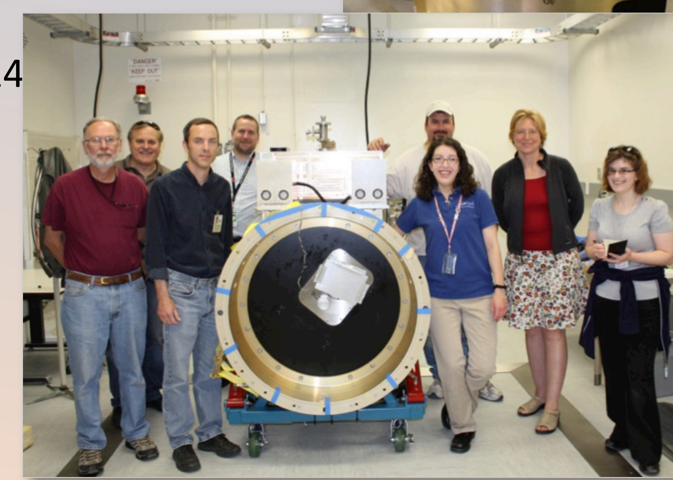
HAWC Science: high angular-resolution imaging in the far-infrared; Star formation; protoplanetary disks interstellar cloud structure; gas and dust production in evolved stars; active galactic nuclei; High-redshift galaxies

HAWC+ Upgrade

- 1st Generation HAWC completed pre-ship review in July 2012
- 2nd Generation HAWC+ upgrade funded in March 2013
- HAWC shipped from Yerkes Observatory to JPL in June 2013
- HAWC+ upgrade will add polarimetry capabilit new detectors to HAWC
- Preliminary design review (PDR) completed in September 2013, CDR completed in January 2014
- Detector Sub-system TIM conducted September 2014
- Delivery and commissioning Summer 2015







First flights of the EXES science instrument on SOFIA
Matthew J. Richter, et al.
24 June 2014 • 4:10 – 4:30 PM

The HAWC+ upgrade program: wide-field far-infrared imaging and polarimetry with SOFIA
Charles D. Dowell, et al
22 June 2014 • 6:00 – 8:00 PM

The integrated motion measurement simulation for SOFIA
Prashant A. Kaswekar, Benjamin Greiner, Jörg Wagner
25 June 2014 • 6:00 – 8:00 PM

FIFI-LS: the facility far-infrared spectrometer for SOFIA
Randolf Klein, et al
22 June 2014 • 6:00 – 8:00 PM

Implementation of an active vibration damping system for the SOFIA telescope assembly
Paul C. Janzen, Paul J. Keas
27 June 2014 • 4:50 – 5:10 PM

Upgrade of the SOFIA target acquisition and tracking cameras
Jürgen Wolf, et al
23 June 2014 • 4:40 – 5:00 PM

General investigator science program on SOFIA
Erick T. Young, et al.
23 June 2014 • 2:00 – 2:30 PM

Environmental testing for new SOFIA flight hardware

SOFIA pointing history
Hans J. Kärcher, et al.
23 June 2014 • 2:50 - 3:10 PM

Evolution of the SOFIA tracking system
Norbert Fiebig, et al.
24 June 2014 • 2:20 - 2:40 PM

Commissioning and first science results of FIFI-LS
Alfred Krabbe, et al.
22 June 2014 • 4:50 - 5:10 PM

FIFI-LS observation planning and data reduction.
Aaron Bryant, et al.
22 June 2014 • 6:00 - 8:00 PM

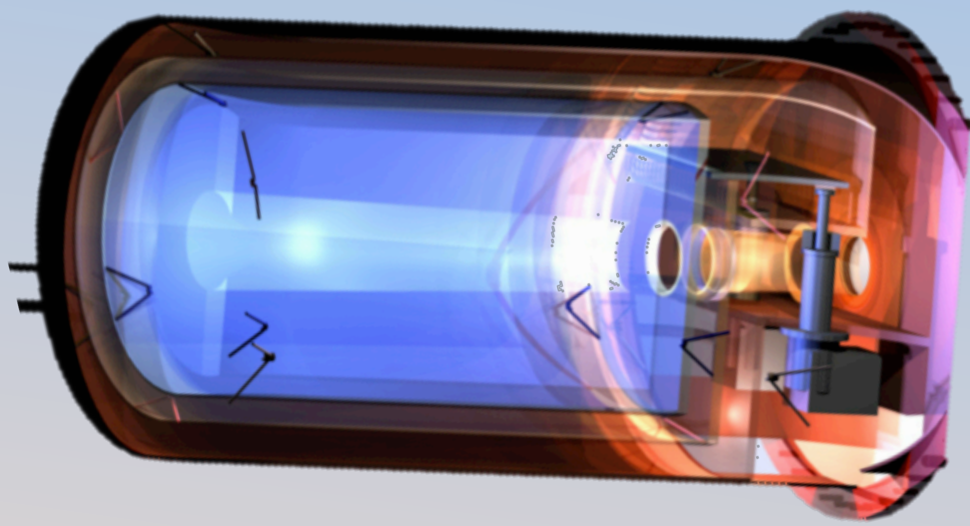
FLITECAM: early commissioning results
Sarah E. Logsdon et al.
22 June 2014 • 6:00 - 8:00 PM

Precise angular positioning at 6K: the FIFI-LS grating assembly
Felix Rebell, et al.
22 June 2014 • 6:00 - 8:00 PM

HIPO in-flight performance improvements
Edward W. Dunham, et al.
22 June 2014 • 4:30 - 4:50 PM

Boresight calibration of FIFI-LS: in theory, in the lab and on sky
Sebastian Colditz et al.
22 June 2014 • 6:00 - 8:00 PM

Generic SOFIA technology demonstration platform



- cryocoolers provide 4K bench
- optical plate populated by Technology Demonstration teams, installed into cryostat.
- Minimal airworthiness changes (outer shell remains unchanged)
- Integrated with SOFIA using standard SI procedures, etc
- Cryostat design can be made available to 3rd generation instrument developers as an example or starting point

Challenges to SOFIA technology demonstration:

- Long timescale
- Difficult airworthiness process
- High cost considering the limited # of flights (compared with FSIs)
- Difficult for smaller labs to take on