SOFIA science instruments:
SUG -6
October 20. 2014
Erin Smith
<table>
<thead>
<tr>
<th>Science Instrument</th>
<th>Type*</th>
<th>Developing Institution</th>
<th>Principal Investigator</th>
<th>Instrument Description</th>
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</thead>
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<tr>
<td>FORCAST</td>
<td>FSI</td>
<td>Cornell University</td>
<td>Herter</td>
<td>Simultaneous Dual Channel Imaging and Grism Spectroscopy (5-25 µm &amp; 25-40 µm)</td>
</tr>
<tr>
<td>GREAT</td>
<td>PSI</td>
<td>Max Planck Institute, Bonn</td>
<td>Güsten</td>
<td>High Resolution (R &gt; 10^6) Heterodyne Spectrometer (1.6-1.9 THz; 2.4-2.7 THz; 4.7 THz)</td>
</tr>
<tr>
<td>HIPO</td>
<td>SSI</td>
<td>Lowell Observatory</td>
<td>Dunham</td>
<td>Visible Light High-Speed Camera (0.3-1.1 µm)</td>
</tr>
<tr>
<td>FLITECAM</td>
<td>FSI</td>
<td>UCLA</td>
<td>McLean</td>
<td>Near Infrared Imaging and Grism Spectroscopy, (1-5.5 µm); Can be used in combination with HIPO</td>
</tr>
<tr>
<td>FIFI-LS</td>
<td>PSI</td>
<td>University of Stuttgart</td>
<td>Krabbe</td>
<td>Dual Channel Integral Field Grating Spectrometer (42-110 µm; 100-210 µm)</td>
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<td></td>
<td>FSI</td>
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<tr>
<td>EXES</td>
<td>PSI</td>
<td>UC Davis</td>
<td>Richter</td>
<td>High Resolution (R &gt; 10^5) Echelle Spectrometer (5-28 µm)</td>
</tr>
<tr>
<td>HAWC</td>
<td>FSI</td>
<td>University of Chicago</td>
<td>Harper Dowell</td>
<td>High-Angular Resolution Wide-Band Camera with 4 Channels (50 µm, 100 µm, 160 µm, 200 µm)</td>
</tr>
<tr>
<td>HAWC+</td>
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</tbody>
</table>
FIFI-LS
Planetary Atmospheres
Chemistry of the cold ISM
Comet Molecules
Dynamics of collapsing protostars
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
Luminosity and Morphology of Star Formation Galactic and Extra-Galactic Regions

SOFIA Science Instruments

Wavelength [μm]

Spectral resolution

HIPO
KBOs, Planet Transits
FLITECAM
FORCAST

GREAT

FIFI-LS

EXES

PAH & organic molecules
Nuclear synthesis in supernovae in nearby galaxies
Composition of interstellar grains
Luminosity and Morphology of Star Formation Galactic and Extra-Galactic Regions

SOFIA Users Group Meeting 10/20/14
<table>
<thead>
<tr>
<th><strong>Science Instrument</strong></th>
<th><strong>Status</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>FORCAST</td>
<td>FORCAST Acceptance Review for imaging modes completed. Software Acceptance Oct 31; New grism 4 installed and tested</td>
</tr>
<tr>
<td>GREAT</td>
<td>UpGREAT (an array heterodyne) to be commissioned in 2015</td>
</tr>
<tr>
<td>HIPO</td>
<td>Commissioning review completed in May 2014</td>
</tr>
<tr>
<td>FLITECAM</td>
<td>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</td>
</tr>
<tr>
<td>FIFI-LS</td>
<td>All Commissioning Flights complete, performed GO science flights</td>
</tr>
<tr>
<td>EXES</td>
<td>Phase 1 Commissioning Complete, will complete commissioning flights in February</td>
</tr>
<tr>
<td>HAWC [x] HAWC+</td>
<td>High-Angular Resolution Wide-Band Camera with 4 Channels (50 µm, 100 µm, 160 µm, 200 µm); under development at JPL and GSFC</td>
</tr>
</tbody>
</table>
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

- 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

8 μm Spitzer/IRAC image of the inner 50 pc of the Galactic Center
**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.
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 \( \sim 0.7 \, \mu \text{m} \)
- 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
SCI-US-PRE-SE04-2032

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
SOFIA/GREAT discovery of interstellar mercapto radicals (SH)

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) SiH (tentative; Schilke et al. 2001)
NH (Meyer & Roth 1991)
OH (Weinreb 1963)

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

QUICK-LOOK data reduction: not fully-calibrated
FLITECAM Status

- Fully commissioned 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
SN2014J
In Flight Sept. 2013: J, H, K

Bands L to R: J, H, K
Files: Sept-27-2013-0088.a.fits
Sept-27-2013-0089.a.fits
Sept-27-2013-0091.a.fits
Scale: 0-1000
Exp.: 1s
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: Field Imaging Far Infrared Line Spectrometer

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: Echelon-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 capability and 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  
Michael Lochenmann, et al.  
22 June 2014 • 6:00 – 8:00 PM

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

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

• 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