# Star formation Studies with SOFIA

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SOFIA, the Stratospheric Observatory for Infrared Astronomy, has now reached full operational capability and is equipped with powerful instruments suitable for star formation studies. Two more 2nd generation instruments are about to be commissioned. The call for 3rd generation instruments is pending.

## Our 1st Generation 'workhorse' Instruments for Star Formation Studies:

**FORCAST,** a dual channel mid-infrared camera with grism spectroscopy. The short wavelength camera covers 5 - 25 $\mu$m, the long wavelength camera 25 - 38 $\mu$m. Both cameras have a set of both narrow and wideband filters and have the same FOV, 3.2' x 3.2'. The grisms provide spectral resolutions, R, of 70 - 300 in long slit mode and from 800 to 1200 in cross-dispersed mode. FORCAST is ideal for imaging IR bright star forming regions, which were saturated in *Spitzer* and WISE observations.

**GREAT** is a state-of-the-art dual channel German heterodyne receiver. The "low" frequency mixers cover 1.25 - 1.50 THz and 1.81 - 1.91 THz. The mid-frequency channel covers the OH ground state line at 2.5 THz, and the high frequency channel targets the [OI] 63 $\mu$m line at 4.745 THz. The latter two were not covered by HIFI. All mixer bands have been commissionioned and are available to the astronomy community. GREAT offers ample opportiunities to study the physics and chemistry in star formation regions, including infall, outflows, supernova shocks, as well as PDR regions.

**EXES** is an Echelon-Cross-Echelle Spectrograph operating from 4.5 $\mu$m - 28.3 $\mu$m with very high spectral resolution, R ~ 100,000. It is ideal for studying the physical conditions and chemistry of hot gas in accretion disks by observing the pure rotational of lines of $H_2$, organic molecules, and hot $H_2O$. Within this wavelength range there are many atomic and ionized lines. EXES will complete its commissioning by the end of February 2015.

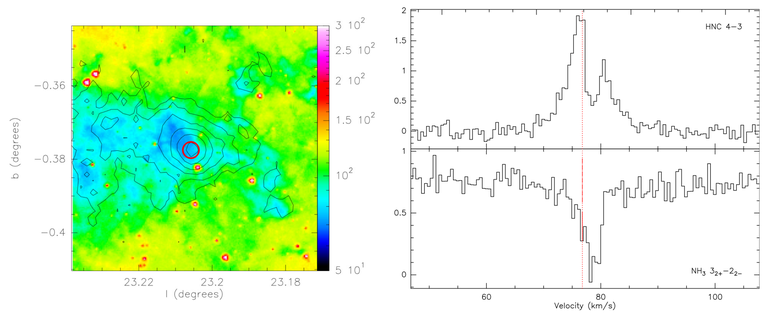
**FIFI-LS** is a 5 x 5 integral field spectrometer similar to PACS, but has higher angular resolution in the blue channel (FOV = 30"x30"). With FIFI-LS we can map [CII] and [OI] in disks and outflows and also probe their physical conditions using high J CO transitions. FIFI-LS is expected to complete its commissioning in March 2015.

For further details, see the SOFIA web page: **www.sofia.usra.edu**

## A few recent sicence highlights

### Infall in an Infrared Dark Cloud

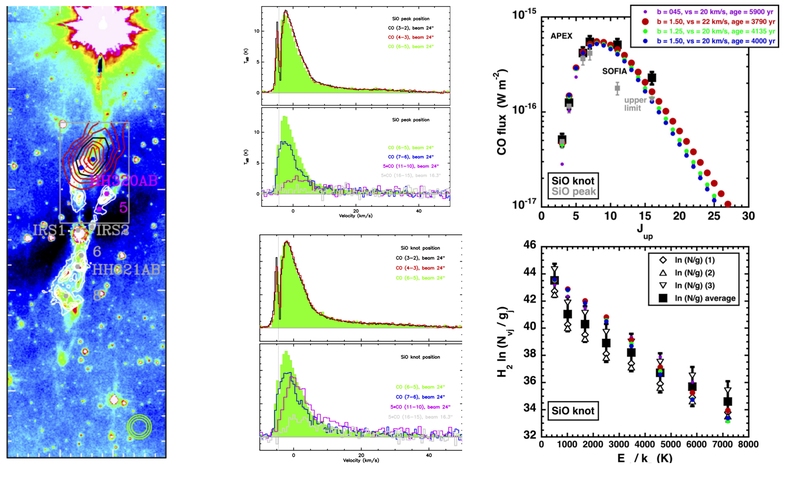
Friedrich Wyrowski et al. (A&A, to be submitted)




The first conclusive evidence of infall toward a massive YSO embedded in an IR dark cloud. The image to the left is a GLIMPSE 8 $\mu$m image with the IRDC seen in blue overlaid with contours of 870 $\mu$m dust emission from ATLASGAL. The spectra to the right show red-shifted $NH_3$ (GREAT: bottom panel) seen in absorption against the dust continuum. The HCN 4-3 emission line (top panel; APEX data) shows a blue-skewed profile, indicative of infall. The systemic velocity determined from $C^{17}O$ 3-2 (APEX) is marked as a dotted vertical red line.

### Impact of pure shocks in the BHR71 bipolar outflow

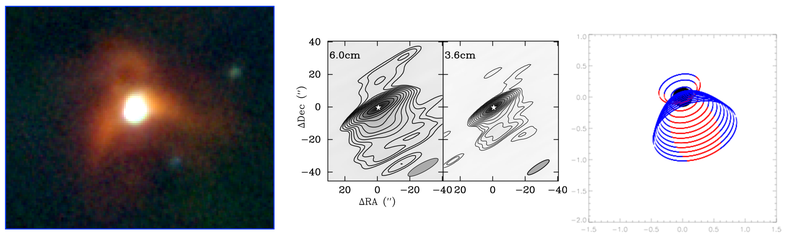
A. Gusdorf, R. Güsten, D. Riquelme, J. Eislöffel, S. Leurini et al.
(2104, A&A, submitted)




New high J CO observations with GREAT ($J_{up}$ = 16 & 11) and APEX ($J_{up}$ = 7, 6, 4 &3) combined with pure rotational $H_2$ lines (*Spitzer*) constrain the shock models in a shock position of the bipolar outflow from BHR 71. This is a southern (DEC = -65°) low-mass YSO, which is very similar to the well-studied L1157 outflow in the north. The GREAT observations were taken in July 2013 during the southern deployment to New Zealand.

### MWC297, a young high-mass star with a disk and an ionized outflow

W. Vacca, G. Sandell & R. Plambeck (ApJL, in prep.)




FORCAST 3-color (11, 19.7 & 31.4 $\mu$m) image of the entrained warm dust surrounding the bipolar ionized jet from MWC 297.The ionized jet, imaged with the VLA (middle panel) shows that the jet has a wide opening angle to the south, where it exands into a low density covity and that it is compressed in the north by the dense molecular cloud, as seen even more clearly in the FORCAST image. MWC 297, spectral type B1.5 Ve, is one of the nearest, d = 250 pc, high-mass stars. The clear bipolarity of the outflow constrains the inclination of the disk to 50° or higher, see model to the right.

## 2nd Generation Instruments

**HAWC+** , the High-Angular-Resolution Wideband Camera provides imaging and polarimetry in the far-infrared (50 -240 $\mu$m) in five optimized spectral bands. It has two backshort under grid (BUG) arrays and provides a field of view ranging from 1.7'x2.7' for Band A (53 $\mu$m) up to 6.1'x9.7' in Band E (216 $\mu$m). Polarimetry is achieved with a wave grid polarizing beam splitter and a set of cryogenic rotating half wave plates. HAWC+ will be ready for commissioning in early 2016.

**upGREAT** is a mid-sized array of HEB mixers. The low frequency array (LFA) is designed to cover the frequency range 1.9 - 2.5 THz with 2 x 7 pixels for orthogonal polarization with a central pixel. The LFA will cover most of the L2 and M bands (current GREAT single pixel receivers) including the [CII] 158 $\mu$m line at 1.9 THz. Commissioning of the LFA is scheduled for May 2015.
The high frequency array (HFA) is a 7 pixel array targeting the important [OI] 63 $\mu$m line at 4.745 THz which will operated in parallel with the LFA. The timeline for completion is spring 2016.

## 3st Generation Instruments

The promise of SOFIA would be realized by a third generation of instruments. A possible call is under study by NASA.