Revealing the Embedded Structures and Sources within Giant HII Regions with SOFIA

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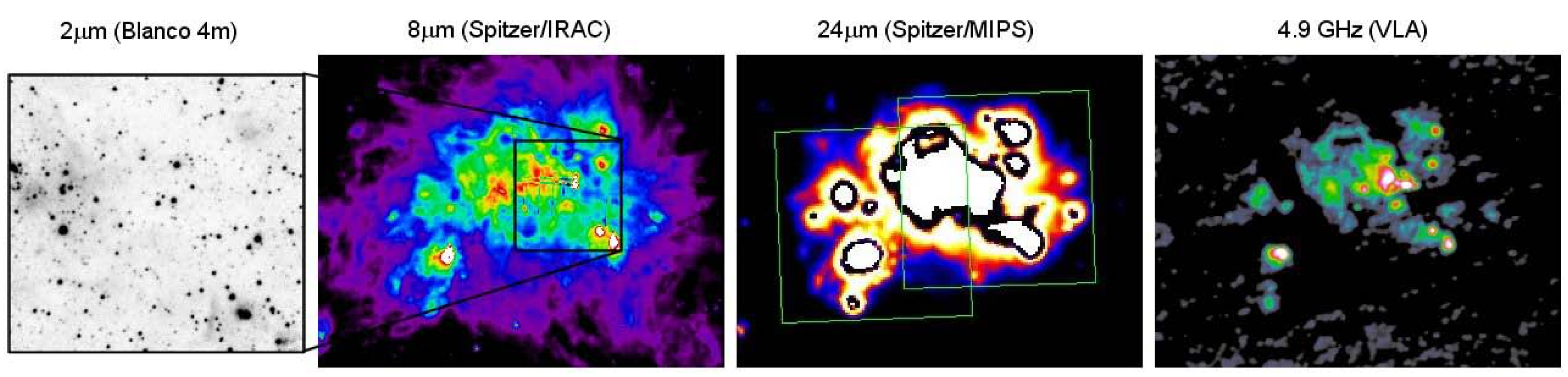
Overview Compared to low mass star formation, relatively little is known about massive star formation. Furthermore, most studies concentrate on the processes of isolated star formation while little is known about clustered star formation, despite the fact that the vast majority of stars are formed within clusters. Giant HII regions harbor young OB clusters, and as such are fantastic laboratories for the study of massive star formation as well as clustered star formation. However, a large percentage of these GHII regions are optically obscured and far away, requiring them to be studied in the MIR/FIR with adequately high spatial resolution. SOFIA 24 and 37um imaging with approximately 3-arcsecond resolution is well-suited for revealing the embedded structures and sources within these regions. These SOFIA observations allow the comparison of the spatial distribution of the hot and warm dust within these GHII regions to the PAHs and hot ionized gas traced by other wavelengths. The observations also expose the population of massive stars in their earliest stages of formation within the GHII regions. These SOFIA observations allow the comparison of the spatial distribution of the hot and warm dust within these GHII regions to the PAHs and hot ionized gas traced by other wavelengths. The observations also expose the population of massive stars in their earliest stages of formation within the GHII regions. A survey is underway to study GHII regions starting with SOFIA's first observing cycle (which began June 2013), which upon completion will catalog all of the known bright GHII regions at the highest spatial resolutions yet achievable at IR wavelengths greater than 25um. In this presentation I highlight the expected results and science to be obtained by this survey, and show SOFIA observations already obtained of the Orion Nebula as a proof-of-concept.

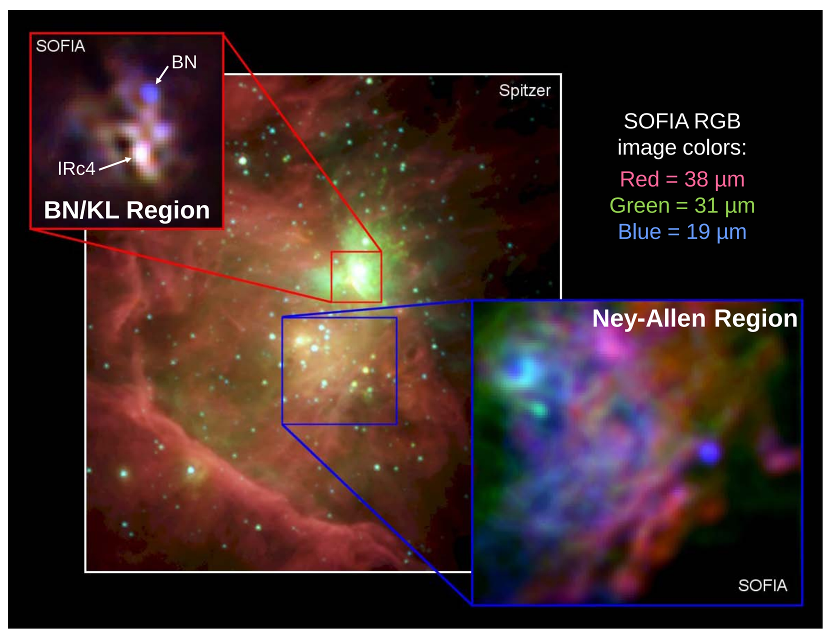
GHII Survey Goals and Experimental Design

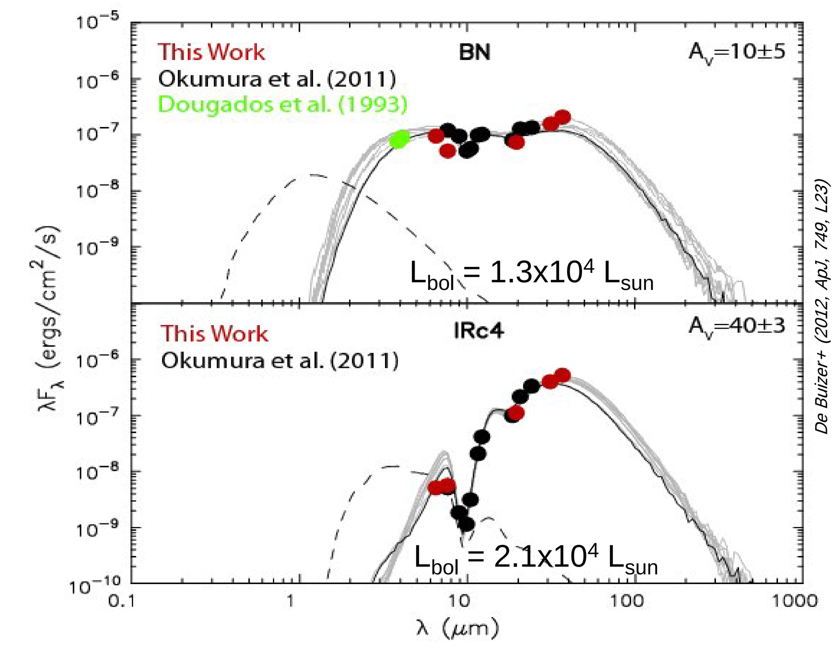
The main goal of this project is to create a comprehensive MIR/FIR survey of all known GHII regions within the Milky Way at never-before-seen resolutions. The work of Conti & Crowther (2004, MNRAS, 355, 899) used a published 6 cm all-sky survey along with data from the MSX and IRAS archives to identify the 56 bona fide GHII regions that will be observed in this survey. For the vast majority of these sources there exists Spitzer 8um (PAH tracer) and Spitzer 24um (warm dust tracer) data for all sources, but the Spitzer 24um images are heavily saturated over large portions of the GHII regions, so will be re-observed with SOFIA (below). Further data already in-hand are 6 cm radio continuum images (ionized gas tracer) of sources at ~4" resolution (below), as well as JHK data (stellar content and hot dust tracer) for most sources. SOFIA 37um data (cold dust tracer) will be taken at never-before achievable MIR resolutions that complement the NIR and radio maps with similar resolution (i.e., all are 2-4"). With such a rich, multi-wavelength and high-resolution dataset, detailed physical conditions (like dust mass, temperature, and optical depth) within GHII regions individually and as a population can be quantified. Moreover, the differences in these properties as a function of the evolutionary phases of massive stars can be determined. Massive stars evolve so quickly that representatives of several "protostellar" evolutionary phases are present within an HII region, grossly distinguished by their SEDs. From this data the evolutionary history of the dust characteristics throughout each region will be investigated as well. Furthermore, dust and gas compete in GHII regions for the FUV photons from the forming massive stars; combining the properties derived from the SOFIA data with the radio data, it will be possible to investigate the detailed energy budget within the GHII regions.



(Above): Example of data in-hand for GHII regions in the survey, in this case W49A. The GHII region begins to reveal itself at $\lambda>5$um. At $\lambda>20$um, images can trace the younger star forming areas of interest, however the Spitzer 24um data are saturated over most of the region (white and black internal areas). Radio observations only trace a limited phase of massive star formation. SOFIA 24 and 37um data will be invaluable in tracing the earliest stages of star formation with in the GHII region. The green squares in the 24um image show the SOFIA/FORCAST field of view (3'x3'), and the 2 pointings to be observed for W49A (2um image from Conti & Blum, 2002, ApJ, 564, 827).

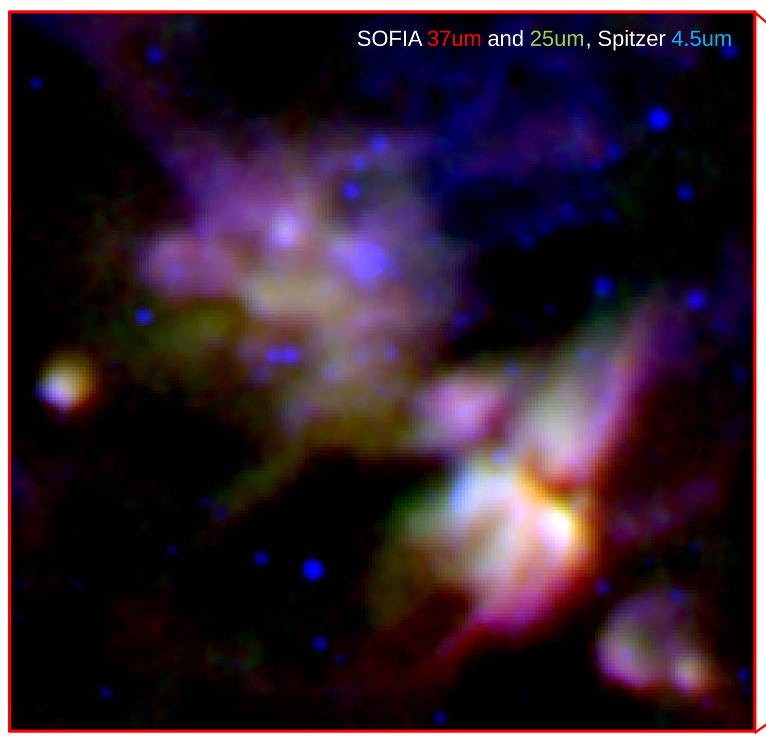
SOFIA Results on the Orion Nebula as a Template

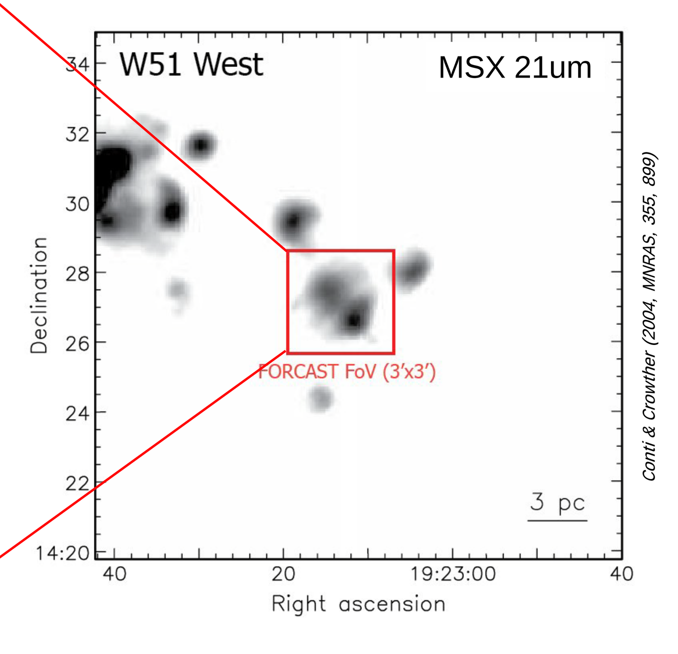




The Orion Nebula is 100s of times smaller in cloud mass than the average GHII regions in this study, however, being the closest sight of clustered massive star formation means that its projected size on the sky is similar to that of distant GHII regions. At the center of the Orion nebula lies the areas known as the BN/KL region and the Ney-Allen region (top right). This HII region was the subject of investigation by SOFIA on one of its very first science flights (De Buizer+ 2012, ApJ, 749, L23). From the SOFIA data we were able to extract dust temperature maps and optical depth maps. These data revealed an emission region never before identified, as well as determined which sources were self-luminous rather than externally heated clumps of gas and dust. Furthermore, by isolating the emission from several sources and plotting these fluxes as a function of wavelength and fitting them with massive star formation models (right bottom), we were able to discern their detailed physical properties. For instance, we concluded for the first time that sources BN and IRc4 are not only embedded massive stars, but are responsible for a large part of the heating in the heart of the Orion. This result was surprising, as previous studies had misidentified IRc4 as just a passive clump of dust and gas. These data are a proof-of-concept that rich, multi-wavelength datasets combined with SOFIA data can lead to interesting new results. Similar analyses will be performed on the GHII regions in this survey.

Initial SOFIA Results: W51 West





W51 West (aka G49.4-0.3) is a sub-component of the much larger W51 complex, but by itself is 20x more massive than the Orion Molecular Cloud. SOFIA observed W51 West on July 1 of this year (2 weeks ago!), and is the first target observed for this survey. There has been very little time to analyze the data, however the figure above-left is a three-color image made from the SOFIA 37um (red), SOFIA 25um (green), and Spitzer 4.5um (blue) data. The whole region just fits within the 3' field of view of the FORCAST camera. From this image alone it can be seen that the data at the three different wavelengths in many areas are tracing distinct regions of emission. The quality of the data can be compared to the MSX 21um image of the region (above-right).

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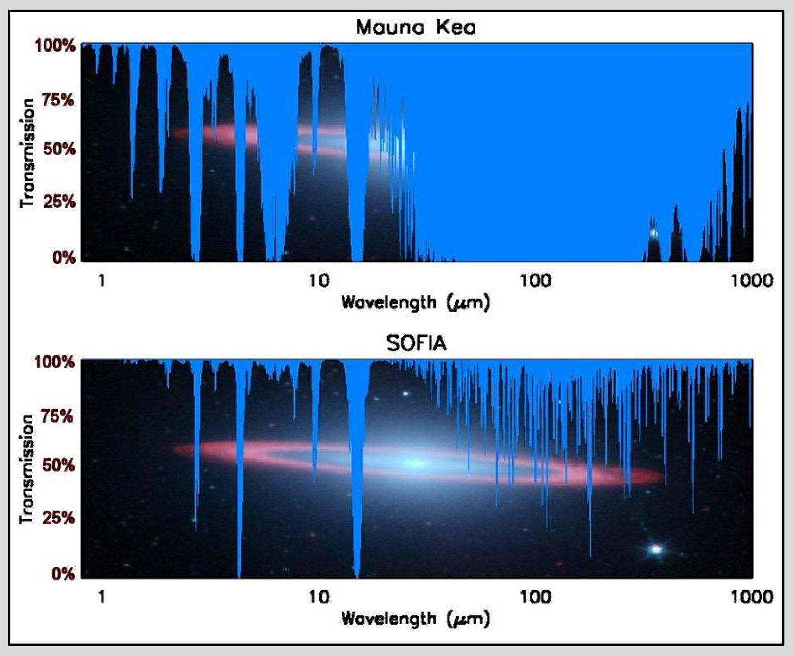
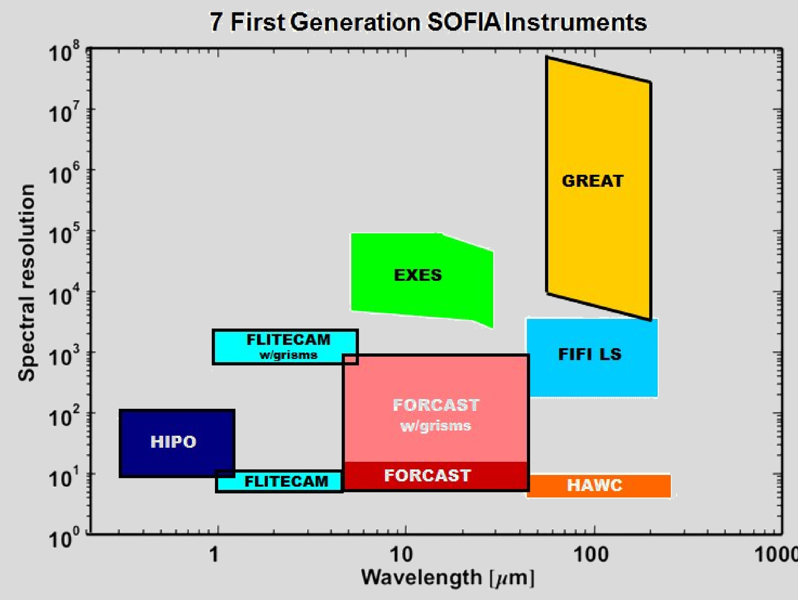
SOFIA Stratospheric Observatory for Infrared Astronomy

The Stratospheric Observatory for Infrared Astronomy



SOFIA (above) is built upon the legacy of NASA's Kuiper Airborne Observatory (KAO), a 0.9 meter infrared telescope that flew from 1974 to 1995 in a Lockheed C141 Starlifter aircraft. Flying at altitudes up to 45000 feet, SOFIA observes with its 2.5 meter telescope from above more than 99% of the Earth's atmospheric water vapor. This opens up observing windows to the universe not available from the ground, including within the expansive 25 to 350 μm wavelength regime (top right). A suite of first generation instruments was chosen to cover most of the operating wavelengths of SOFIA with a variety of spectral ranges (right). SOFIA's "first light" instrument, FORCAST (**F**aint **O**bject infra-**R**ed **CA**mera for the **S**OFIA **T**elescope) will be used for this GHII project. FORCAST is a 5-40 μm imager that is also capable of low-to-medium resolution (R=100-1500) mid-infrared spectroscopy (red boxes in image on right).



See http://www.sofia.usra.edu for more info on SOFIA