FLITECAM GTO Plans
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Project 1: Tracing the Evolution of PAHs with FLITECAM on SOFIA

Polycyclic Aromatic Hydrocarbons (PAHs) are small organic molecules believed to be created in the high-temperature outflows of carbon-rich post-AGB stars. These ubiquitous molecules are assemblies of benzene-like structures, which, when excited by a UV photon, produce a series of broad emission bands from 3.3 to 12.7 μm via C-C and C-H vibration and stretching modes (Gillett et al. 1975, Willner et al. 1977, Allamandola 1984, Sellgren 1984, Puget & Léger 1989). PAHs are incredibly common, having been observed in nearly every type of astronomical object including HII regions, the ISM, proto-stellar clouds and planetary nebulae (Peeters, 2002). In fact, recent images from the SPITZER space telescope reveal that PAHs are also present in other galaxies, especially those exhibiting high levels of star formation (Hora, 2004). PAHs may even be effective tracers of star formation (especially B stars), as PAH emission is usually found in the interface between hot regions of ionization and molecular clouds (Peeters, 2004).

Because of the high thermal background emission at wavelengths longer than 2.4 microns, observations of these bands are difficult from ground-based sites. With its combination of high altitude and colder telescope, SOFIA will provide an order of magnitude improvement for PAH observations. By observing the important 3.3 μm PAH feature, which is the only PAH band that falls in FLITECAM's 1-5 μm wavelength range, together with atomic and molecular emission at other near-infrared wavelengths, this project will trace the origin and evolution of PAHs from their birth environment through their processing in the ISM to their incorporation in proto-stellar material. To study this evolutionary sequence we will observe post-AGB stars, young planetary nebulae, HII regions and reflection nebulae. In addition, we will map the distribution of 3.3 μm PAH emission in several large nearby galaxies and correlate the emission with star forming regions. This is a large long-term program that will be extended well beyond the GTO period.

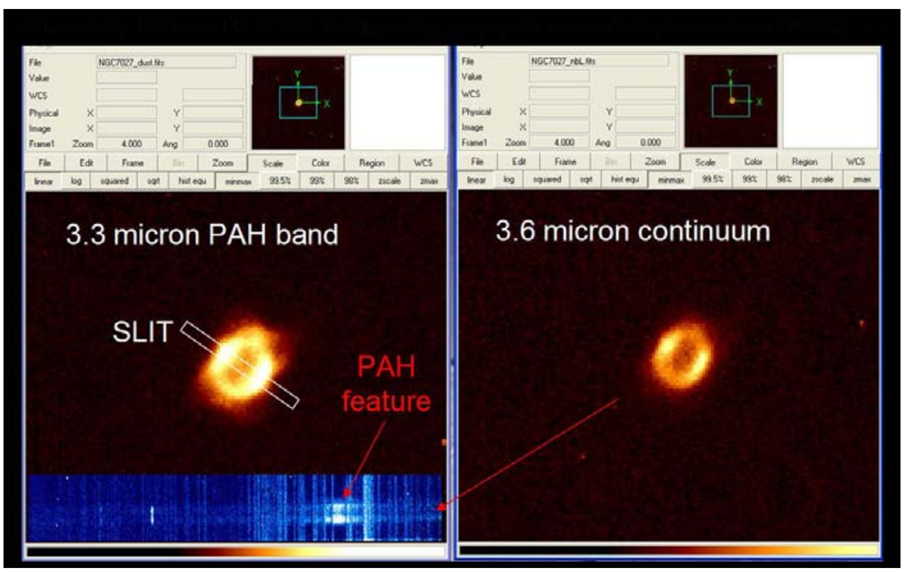

Figure 1: Narrow band images at 3.3 and 3.6 microns of NGC 7027 obtained with FLITECAM on the 3-m Shane telescope at Lick Observatory in June 2004. The inset figure (bottom left) is a raw difference (on-source minus sky) using the grism mode to obtain a spectrum centered around 3.0 microns.

To demonstrate the feasibility of this project prior to the beginning of SOFIA operations we have used FLITECAM on the Lick Observatory 3-m telescope, where we have already detected the 3.3 μm PAH emission feature in numerous objects, despite the higher background of that ground-based site. Figures 1 and 2 illustrate the method for NGC7027.

Depending on the spatial extent and class of object being studied, we will perform both imaging and spectroscopic observations. For extended sources (> 10″ in radius) we will use a set of three narrow band filters centered at 3.08, 3.3 and 3.6 μm to map the distribution of PAH emission and compare this to ionized and molecular gas emission. The latter can be observed by a combination of broad and narrow band images in the K-band (2.0-2.4 μm). These spatial maps of regions 4′ x 4′ in size will produce spectacular first light images because of the contrast between ionized gas, molecular gas and PAH emission. Representative images of this kind obtained at Lick Observatory for NGC7027, S106 and the Orion Bar have been presented at SOFIA meetings.

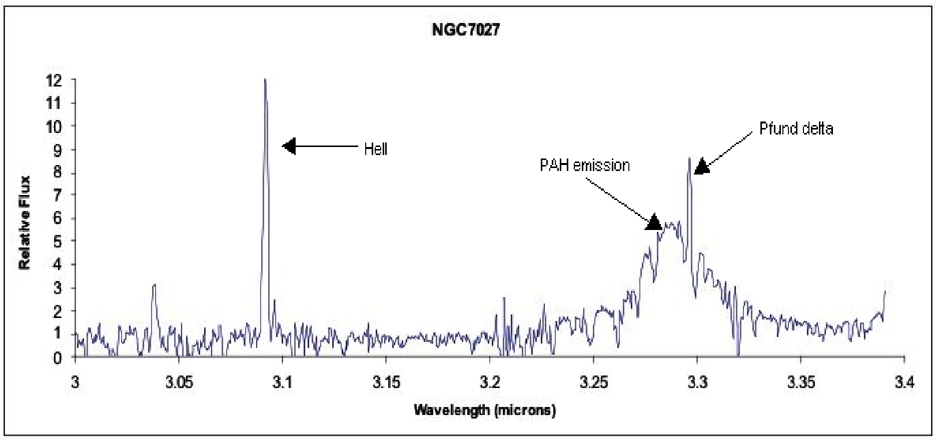

Figure 2: The reduced and extracted spectrum of the broad 3.3 μm PAH feature in NGC7027 at R~1700. Note the many sharp emission lines from ionized gas. Absorption features are caused by water vapor in the Earth's atmosphere and cannot be completely corrected because the lines are saturated in ground-based observations.

Having mapped the distribution of PAH emission we will then use the spectroscopic mode of FLITECAM to obtain spectra with resolving powers ranging from 900-1800 across the PAH emission feature and compare its shape from object to object and trace it spatially within the larger objects. We have already carried out a trial survey of over 20 young and compact planetary nebulae from Lick Observatory and detected PAH emission in over 50% of them. During the GTO program we will repeat these observations and more than double the number of targets.

For the brightest targets we will also search for the expected, but much weaker, spectral features in the 3-5 μm region produced by deuterated molecules (PADs). The initial target list will include many well-known sources. Total on-source observing time plus calibration stars will be about 50 hours, consistent with the GTO allocation cycle over two years.

References

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Table1: Target List for Project 1

Target Name	**RA (2000)**	**Dec (2000)**	**Itime + O/H[1]**	**Type**
NGC 7027	21 07 01.59	+42 14 10.2	1hr 15 min	PN
Bd +303639	19 34 45.23	+30 30 58.9	1hr 15 min	PN
M 2-43	18 26 40.05	-02 42 57.6	1hr 15 min	PN
egg Nebula	21 02 18.75	+36 41 37.8	1hr 15 min	p-agb
Hen 2-459	20 13 57.90	+29 33 55.9	1hr 15 min	PN
IC 5117	21 32 31.03	+44 35 48.5	1hr 15 min	PN
M 3-35	20 21 03.77	+32 29 23.9	1hr 15 min	PN
PN G093.9-00.1	21 29 58.42	+51 03 59.8	1hr 15 min	PN
WHME 1	19 14 59.76	+17 22 46.0	1hr 15 min	PN
HB 5	17 47 56.19	-29 59 41.9	1hr 15 min	PN
NGC 6790	19 22 56.97	+01 30 46.5	1hr 15 min	PN
M 4-18	04 25 50.83	+60 07 12.7	1hr 15 min	PN
IC 418	05 27 28.20	-12 41 50.3	1hr 15 min	PN
NGC 6302	17 13 44.21	-37 06 15.9	1hr 15 min	PN
NGC 6572	18 12 06.37	+06 51 13.0	1hr 15 min	PN
NGC 6886	20 12 42.81	+19 59 22.7	1hr 15 min	PN
CRL 915	06 19 58.22	-10 38 14.7	1hr 15 min	p-AGB
M 1-11	07 11 16.69	-19 51 02.9	1hr 15 min	PN
IC 2501	09 38 47.21	-60 05 30.9	1hr 15 min	PN
HR 4049	10 18 07.59	-28 59 31.2	1hr 15 min	p-agb
He 2-113	14 59 53.52	-54 18 07.2	1hr 15 min	PN
IC 2621	11 00 20.11	-65 14 57.8	1hr 15 min	PN
NGC 5315	13 53 56.97	-66 30 51.0	1hr 15 min	PN
M 2-9	17 05 37.95	-10 08 34.6	1hr 15 min	PN
Pe 1-7	16 30 25.85	-46 02 51.1	1hr 15 min	PN
CP -568032	17 09 00.87	-56 54 48.0	1hr 15 min	PN
NGC 6537	18 05 13.10	-19 50 34.9	1hr 15 min	PN
NGC 6741	19 02 37.09	-00 26 57.0	1hr 15 min	PN
NGC 7026	21 06 18.21	+47 51 05.4	1hr 15 min	PN
HB 12	23 26 14.81	+58 10 54.6	1hr 15 min	PN
AFGL 2132	18 21 15.9	-13 01 27	1hr 15 min	Emission line star
Iras 18184-1623	18 21 18.9	-16 22 29	1hr 15 min	Ir Source/p-agb
NGC 1333	03 29 02	+31 20.9	1hr 15 min	Reflection nebula
M17	18 20 26	-16 10.6	1hr 15 min	HII region
M8	18 03 37	-24 23.2	1hr 15 min	HII region
Sh 2-106	20 27 27.1	+37 22 39	1hr 15 min	HII region
Orion Bar	05 35 22	-05 24.6	1hr 15 min	HII region
Ced 40	05 06 54	-03 20.5	1hr 15 min	Reflection nebula

1. Total on-target integration time plus 25% overhead

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Project 2: Distribution of PAH emission in spiral galaxies with FLITECAM

In addition to the well-known galactic sources of PAH emission described in FLITECAM GTO Project 1, we will also be able to map the distribution of 3.3 μm flux in large nearby galaxies such as M51. We have already made ground-based maps of M51 and other galaxies in shorter wavebands (JHK) but only with SOFIA will we have enough sensitivity to include PAH emission. The Spitzer space telescope has already produced maps of some well-known galaxies (e.g. M31) that show strong emission in the 8 μm IRAC band which contains the PAH feature at 7.6 μm. As illustrated in Figure 3, FLITECAM is well-suited to imaging extended sources.

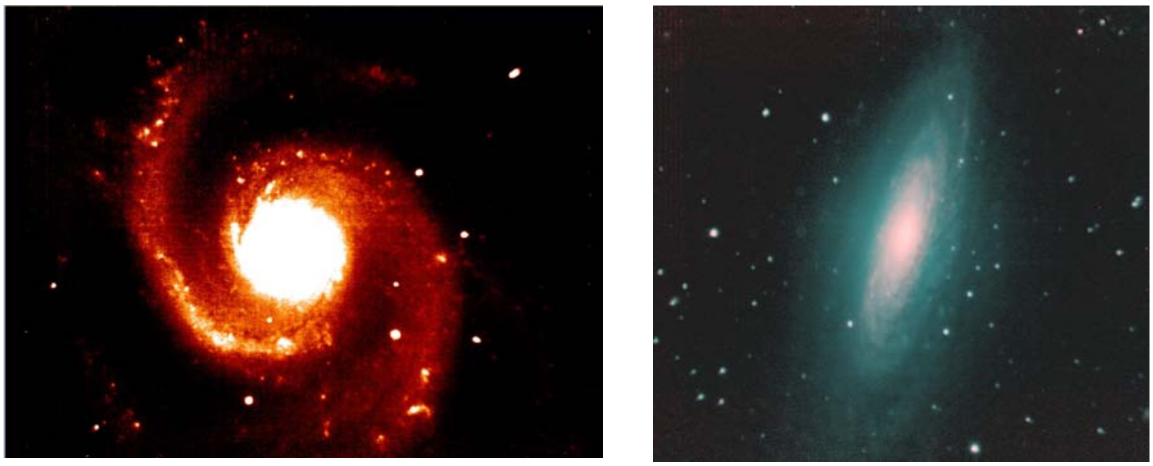

Figure 3: Left is a J-band image of M51. Right is a J/K color composite image of NGC7331. Both images were obtained using FLITECAM on the Lick Observatory 3-m telescope. The exposure time in each filter is about 9 minutes.

On SOFIA, we can also obtain images in selected narrow bands around 3.3 μm with comparable resolution to Spitzer and compare the distribution of PAH emission to that of ionized hydrogen on large scales. The combination of the PAH band and the K band will produce spectacular first light images. Although very challenging, we expect to be able to obtain low resolution (R~900) spectra of PAH emission for selected bright emission knots.

Table2: Target List for Project 2

Target	**RA (2000)**	**Dec (2000)**	**Itime + O/H**[1]	**Type**
Galactic Center	17 45.6	-28 56	3hr	Galactic nucleus
LMC	05 23 34.6	-69 45 22	3hr	Galaxy
SMC	00 52 38.0	-72 48 01	3hr	Galaxy
M 31	00 42 44.31	+41 16 09.4	3hr	Galaxy
NGC 4125	12 08 6.2	+65 10 27	3hr	Galaxy
M 83	13 37 0.7	-29 51 58	3hr	Galaxy
M 77	02 42 40.83	-00 00 48.4	3hr	Galaxy
M253	00 47 33.13	-25 17 17.8	3hr	Spiral
NGC 1068	02 42 40.83	-00 00 48.4	3hr	Seyfert

M66	11 20 15.07	+12 59 21.6	3hr	Spiral
NGC 4038/39	12 01 52.48	-18 52 02.9	3hr	Merger
M64	12 56 43. 88	+21 41 00.1	3hr	Dusty Spiral
NGC 7331	22 37 04.29	+34 24 58.5	3hr	Dusty Spiral
M51	13 29 52.37	+47 11 40.8	3hr	Large Spiral

1. Total on-target integration time plus 30% overhead

With calibration targets this observing list represents about 45 hours of observing. During the initial GTO cycle, only a few representative galaxies will be observed. Our highest priority targets are M31, M51 and NGC4038/39.

We are currently exploring the sensitivity for obtaining spectra of individual knots in extra-galactic sources.

References

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Project 3: Finding Super-Planets with FLITECAM

Because of its large field of view, FLITECAM can survey for very low-mass brown dwarfs in young star forming regions. Some of these young sub-stellar objects are potentially in the planetary mass range below 13 Jupiter masses. By observing young clusters, we take advantage of the several orders of magnitude increase in luminosity of brown dwarfs before they have cooled to the temperatures of their field counterparts. This increase offsets the effect of greater distance to the star forming regions of interest. Some measurements of the initial mass function of brown dwarfs in young clusters have been made (Luhman 1999, Hillenbrand et al 2000, Lada & Lada 1995, Najita et. al. 2000). Most previous studies have been limited to m_K = 17.5 at SNR ~7 and fields of view of order ~25 arcmin^2. With FLITECAM we will extend the completeness limit of surveys in young clusters down to m_K ~20 with SNR ~20 over a 900 arcmin^2 region. A large survey completeness-limited below the hydrogen-burning limit will allow a more comprehensive test of brown dwarf evolutionary models.

Preliminary observations using FLITECAM on the 3-m telescope at Lick Observatory showed that we can achieve a sensitivity of 18th magnitude in H band with SNR=20 in ~20 minutes over our 8′ field of view (Mainzer & McLean 2003, Mainzer et al. 2004). For this work UCLA designed and purchased a set of custom narrow band filters for FLITECAM. The filters were designed to detect various molecular absorption bands (water and methane) useful for identifying late-type stars and brown dwarfs. To accurately distinguish bona fide sub-stellar cluster members from background objects, 5% photometric accuracy (SNR = 20) is required.

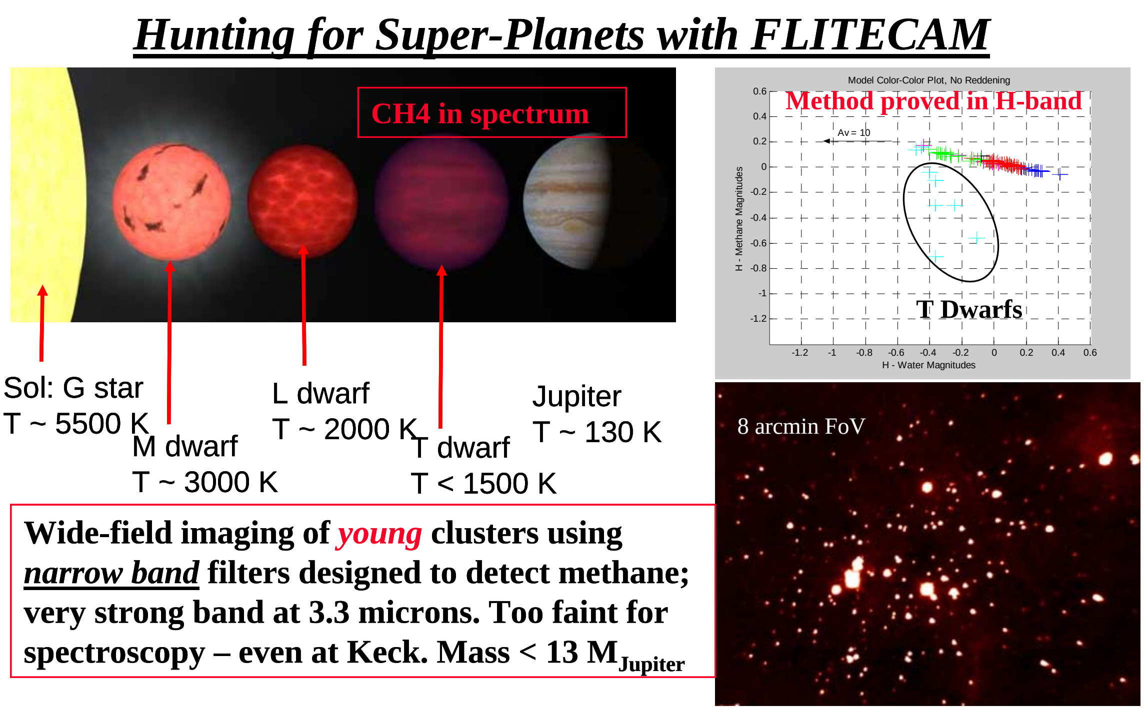

Figure 4: Upper right shows a color-color plot using 3 filters to isolate continuum, methane and water vapor bands in cool low-mass stars and brown dwarfs. T-dwarfs are easily identified. Lower right shows a typical star-forming region observed with FLITECAM. The limiting magnitude in 1 hour is about K~19.

To complement work already being performed using the Spitzer Infrared Space Telescope we will survey two young star forming regions IC348 and NGC1333 (see Tables 2 and 3). These clusters were selected because their young ages (between 0.5 and 10 Myr) imply that any brown dwarfs will be considerably brighter than their field counterparts and at ~300 pc, they are relatively close, yet far enough away that large portions of the cluster can be mapped with relatively few pointings of FLITECAM. The Spitzer MIPS GTO disks team, with whom we are collaborating, has observed these clusters which provided complementary long wavelength data.

Both clusters are ~30′x30′ in extent. We can map each cluster with ~25 pointings of ~1 hour each for a total of 900 $arcmin^2$. During GTO observations we will explore the sensitivity that can be achieved with SOFIA by observing these faint clusters in the K band and in the 3.3 micron CH4 filter resulting from the much lower thermal background. We do not expect to use 25 hours of GTO time on this challenging project. Experience must be gained first.

References

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Table3: Young Star Clusters

Target	**RA (J2000)**	**Dec (J2000)**	**H**	**# Pointings**	**Total T_{int}**
IC348	03h44m30.00s	+32d17m00.0s	18	25	25 h
NGC1333	03h29m02.00s	+31d20m54.0s	18	25	25 h