SOFIA Observations of the Planetary Nebula NGC7027

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ABSTRACT: NGC7027 is one of the brightest and best-studied planetary nebulae. The nebula is 2900 light years from earth, and approximately 0.08 parsec in physical size making it one of the youngest known planetary nebula with an estimated age of just 600 years. NGC7027's central 16th magnitude star is pumping out the energy of 6000 suns, and at 185,000 Kelvin the star is one of the hottest known. NGC7027 was imaged using the FORCAST instrument on SOFIA at 6.4, 6.6, 11.1, 19.7, 24.2, 33.6, and 37.1 microns. The HBPW of the measurements is 4-to-6 pixels [~3 to 4.5 arc sec] across the bands. Analysis indicates a bright well-resolved nebula with an overall angular size of ~14 X 17 arc sec. The morphology is similar to what is seen in ground-based infrared and radio continuum images. The size varies little with wavelength. The SED derived from the SOFIA observations varies moderately but systematically across the nebula, with the longer wavelengths becoming relatively brighter at the edges. Analysis of the images has been carried out under the NASA-IPAC Teacher Archive Research Program with portions of the work being carried out at the Jet Propulsion Laboratory, operated by the California Institute of Technology under a contract with NASA.

The SOFIA Data

File	LAMREF	CALFCTR	# COADDS
b199	6.4	0.25574	8
b215	6.4	0.2565	8
b217	6.4	0.25657	8
b193	6.6	0.29226	8
b196	6.6	0.29245	8
b209	6.6	0.29385	8
b212	6.6	0.29402	8
b192	11.1	0.60528	52
b208	11.1	0.60528	52
b186	19.7	1.18718	13
b189	19.7	1.18744	13
b205	19.7	1.18813	13
b185	24.2	0.67579	6
b202	24.2	0.67667	6
r186	33.6	0.04458	6
r189	33.6	0.04464	6
r205	33.6	0.04478	6
r185	37.0	0.0644	8
r202	37.0	0.06473	8

SOFIA Images

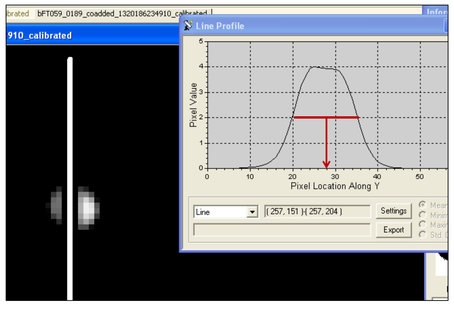
- All images were taken on 05/21/2011 (exposure time for all images ~30 sec.) using the SOFIA FORCAST Instrument (3 @ 6.4 microns, 4 @ 6.6 microns, 2 @ 11.1 microns, 3 @ 19.7 microns, 2 @ 24.2 microns, 3 @ 33.6 microns, 2 @ 37.0 microns), and provided as Level 3 data.
- During pipelining of the data, the SOFIA images were resampled to a pixel scale of 0.77" x 0.77"
- All images at a given wavelength were coadded.
- Based on information from the SOFIA Help Desk, all data that are merged or coadded in the SOFIA archive are rotated so that North is up and East is left. Although at the time our data were processed no solid numbers yet existed on what the errors were associated with the sky rotation angle, a realistic estimate was better than +/- 2 degrees accuracy.

NOTE: Since NITARP attempts to engage high school students in authentic research, further data processing and analysis was completed using relatively inexpensive or free data analysis software packages that are more accessible to schools.

- SalsaJ - http://salsaj.softpedia.com/
- MaxIm DL Version 4 - http://www.cyanogen.com/maxim_main.php
- Microsoft Excel - http://office.microsoft.com

Additional Image Processing Completed

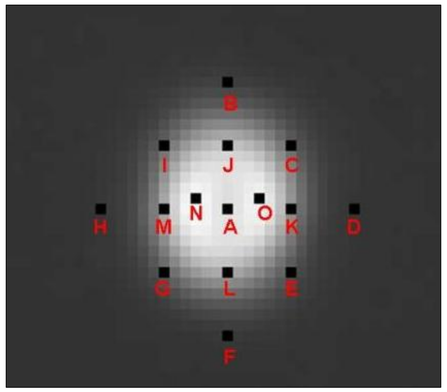
- The calibration factor (CALFCTR) provided in each image header file was applied to images individually using SalsaJ.
- Using MaxIm DL, all images were then rotated 41 degrees counterclockwise so that the visible lane in NGC7027 paralleled the vertical pixel columns.



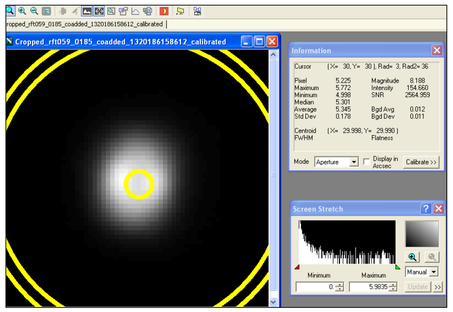
- SOFIA images did not contain world coordinate data in the image headers, making it a challenge to align images for further analysis. Vertical slices were taken across NGC7027 to establish the central lane, and the center pixel at Full-Width-Half-Max (FWHM) of the profile was established as NGC7027's center. (**See image left**)

- A box 60 x 60 pixels, with the central point of NGC2027 at x=30, y=30 was cropped out. This new cropped image was used in the data analysis process.

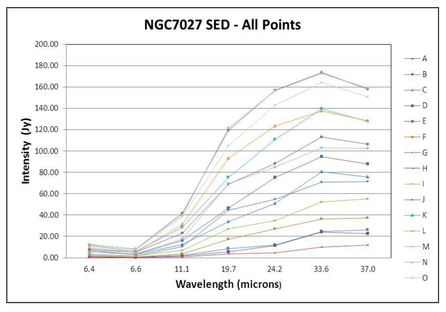
Analyzing NGC7027

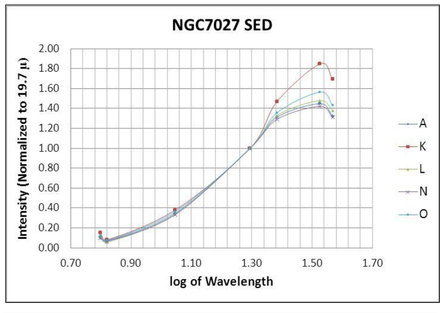


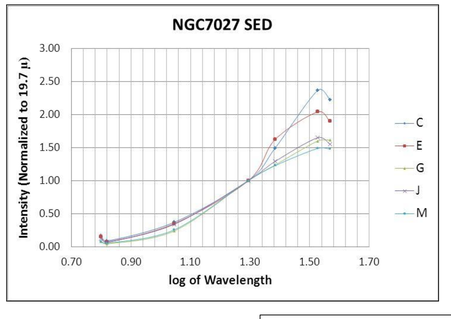
(**Above**) A grid was established across the nebula, and intensity was measured at points A though O. Points N and O were added since they appeared to be the brightest points.

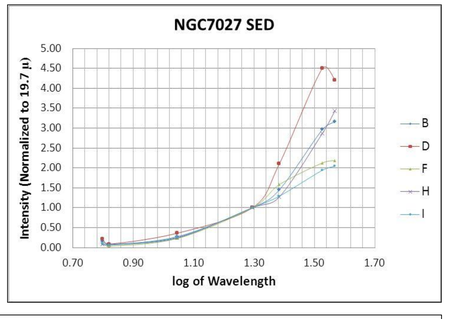


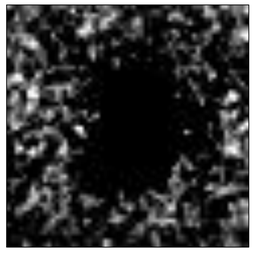
(**Above**) Intensity measures were made using MaxIm DL. An Aperture radius of 3 pixels (~2.4") was selected since, 1) the images themselves could not be precisely aligned, and 2) the measured FWHM resolution of the FORCAST camera across the channels is ~3.6-to-4.8 arc seconds.





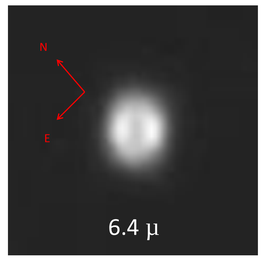


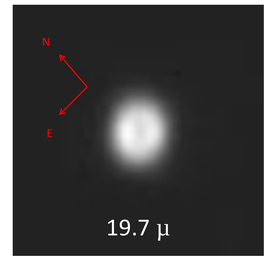


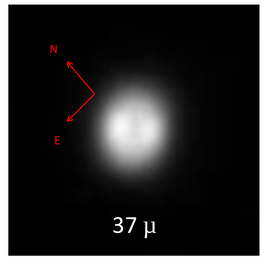


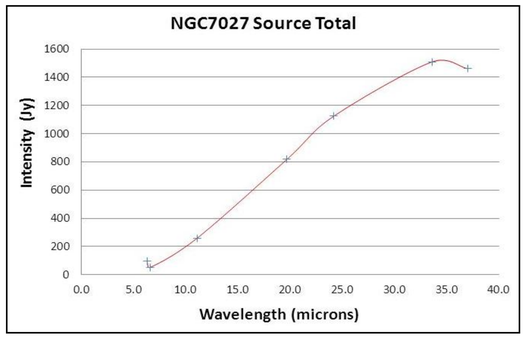
(**Above**) The Spectral Energy Distributions were plotted using Microsoft Excel. The first is a plot of intensity at the measured wavelength for all points A-O, and the others have been broken out based on intensity and normalized to the 19.7 μ data. **NOTE: We assume emission is thermal radiation from dust.** (**Left**) Three 6.3 micron images were added and four 6.6 micron images were added as well. The combined 6.3 micron image was normalized against the combined 6.6 micron image. 6.3 was subtracted from 6.6 in an attempt to identify any residual; potentially due to PAH in the nebula. **PAHs appear to be reasonably well mixed with the dust that is producing most of the radiation.**

Conclusions and Discussion



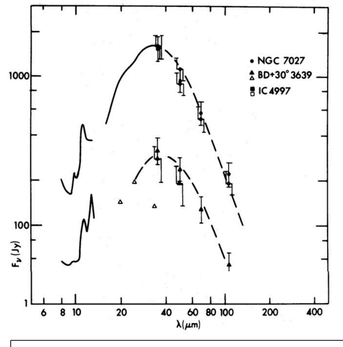


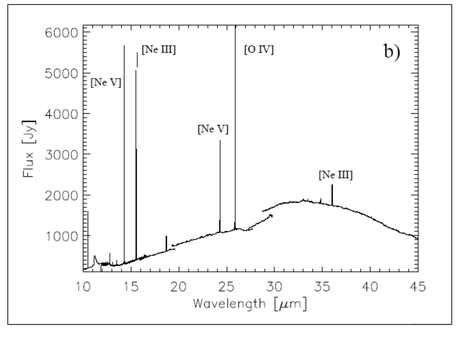




(**Above**) Three of the nineteen images taken with the SOFIA FORCAST camera. No significant difference in structure between λ.

(**Left**) Plot of the total source SED generated using the average intensity of target, NGC7027, in available images at each available wavelength.





(**Above Left**) Upper line graph NGC 7027, 8 – 13 micron spectrometry from Gillett et al – 1973, 15 – 30 micron spectrometry from McCarthey et al – 1979, and 37 – 108 micron data from Moseley, H.. (**Above Right**) From Salas et al – 2001.

- **These observations provide the first true image of NGC7027 at the λ's where it radiates most of its power.**
- **There is good agreement between previously published total source SED and our current findings.**
- **The gross structure of NGC7027 is independent of wavelength, and there is no evidence for an exterior shell of cold material.**
- **The central dip is visible in the infrared images.**

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