Probing Ancient Mass Loss with AKARI's Extended Dust Emission Objects

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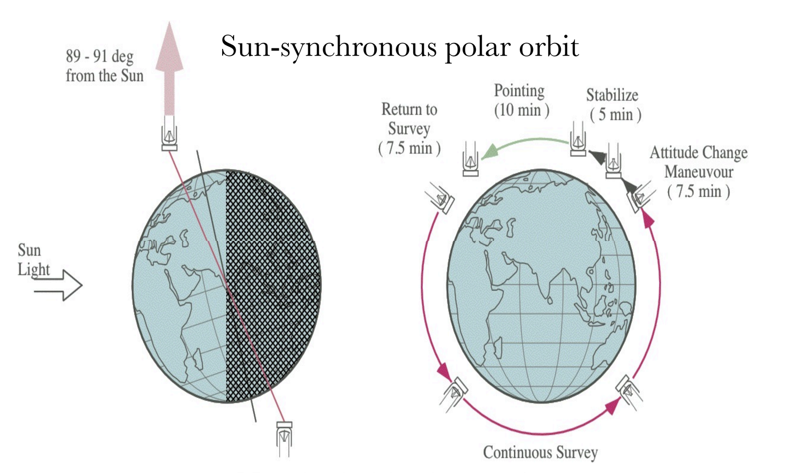
AKARI: Astronomical IR Satellite

AKARI (formerly ASTRO-F), is the second Japanese satellite dedicated to infrared (IR) astronomy, from the Institute of Space and Astronautical Science (ISAS) of the Japanese Aerospace Exploration Agency (JAXA). Its main objective is to perform an all-sky survey with better spatial resolution and wider wavelength coverage than IRAS (first US, UK, Dutch infrared satellite launched in 1983), mapping the entire sky in six infrared bands.

Launched: 21 February 2006
First light: 13 April 2006
End of science op: 17 June 2011
Mirror diameter: 68.5 cm
Temperature: 6 K
Wavelength range: 2-180 μm

Figure 1: Artist rendition of the AKARI satellite.



Nominal altitude: 700 km
Orbital period: 100 min

Figure 2: Flight path of AKARI during the all sky survey (red) and pointing missions (green).

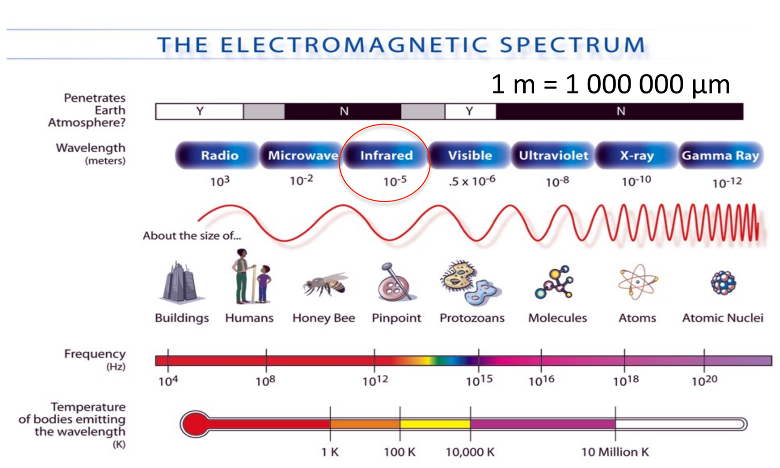


Figure 3: The electromagnetic spectrum and where the infrared light is located.

MLHES Mission Program

The AKARI MLHES (excavating Mass Loss History in Extended dust shells of Evolved Stars) data set is the largest collection of the most sensitive far-infrared (far-IR) images of the cold extended circumstellar dust shells of evolved stars and it is the key to understanding the dusty mass loss phase of stellar evolution (PI: Yamamura). There are 144 objects which have been observed using AKARI's Far-Infrared Surveyor (FIS). FIS has two detector arrays (figure 2) with four bands which capture information from the extended emission targets at different wavelengths.

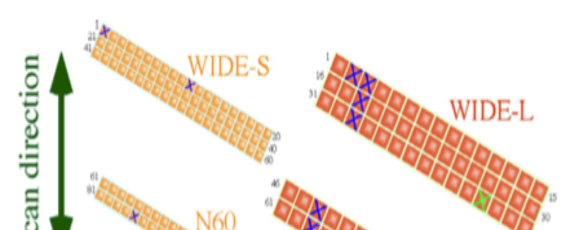


Figure 2: FIS two detector arrays (wide and narrow) are tilted 26.5 degrees respect to the scan direction and have some dead (blue) and badly performing (green) pixels.

Photometric mode				
Band	N60	WIDE-S	WIDE-L	N160
Wavelength Range (μm)[1]	50–80	60–110	110–180	140–180
Central Wavelength (μm)	65	90	140	160
Band Width (μm)[2]	21.7	37.9	52.4	34.1
Detector	Monolithic Ge:Ga[3]		Stressed Ge:Ga	
Array size	20 × 2	20 × 3	15 × 3	15 × 2
Operational Temperature	~ 2.0 K		~ 2.0 K	
Pixel size (arcsec)[4]	26.8		44.2	
Pixel pitch (arcsec)[4]	29.5		49.1	
Readout	Capacitive Trans-Impedance Amplifier (CTIA)			
Spectroscopic mode				
Spectrometer	Martin-Puplett type Fourier transform spectrometer			
Wavelength (μm)	N/A	60–110	110–180	N/A
Resolution (cm^{-1})	N/A	0.36 / 2.4		N/A

Figure 3: Hardware Specifications of the Far-Infrared Surveyor (FIS).

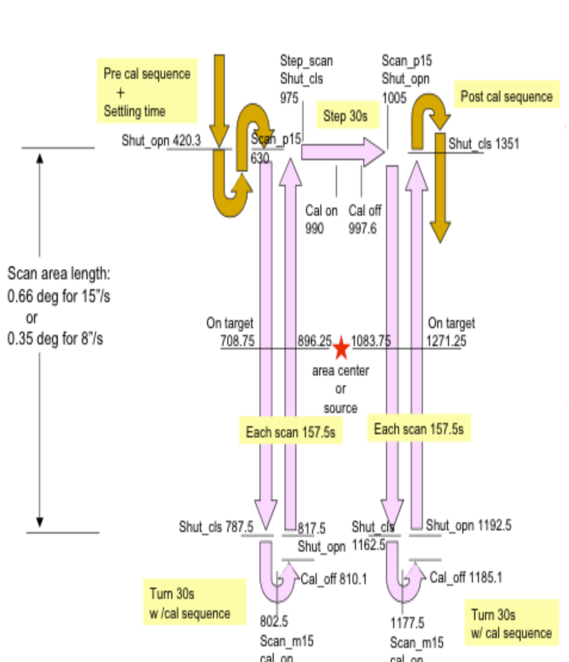


Figure 4 (left): The scan pattern of AKARI around a point source for the MLHES mission program. There are two round trip scans with a cross scan shift. There are five calibration sequences that are taken as AKARI is changing directions where the dark, responsivity, and flat fields are taken. These measurements are used to reduce this time series dependent data using FAST.

While the MLHES data are currently the most sensitive far-infrared images, the data are still sensitivity limited. The next far-infrared satellite will provide the necessary sensitivity and better resolution needed to obtain even colder and fainter components of the circumstellar shells.

FIS-AKARI Slow-scan Tools

FAST is a program that allows for interactive assessment of the data quality and on-the-fly corrections to the time-series data on a pixel-by-pixel basis in order to manually correct glitches that would have been missed in the pipeline process. These corrections include: (1) eliminate bad on-sky calibration sequences, (2) flag out cosmic-rays and their after-effect affected time-series readings from the data stream and (3) remove real sources from local sky-flat frames, among other options.

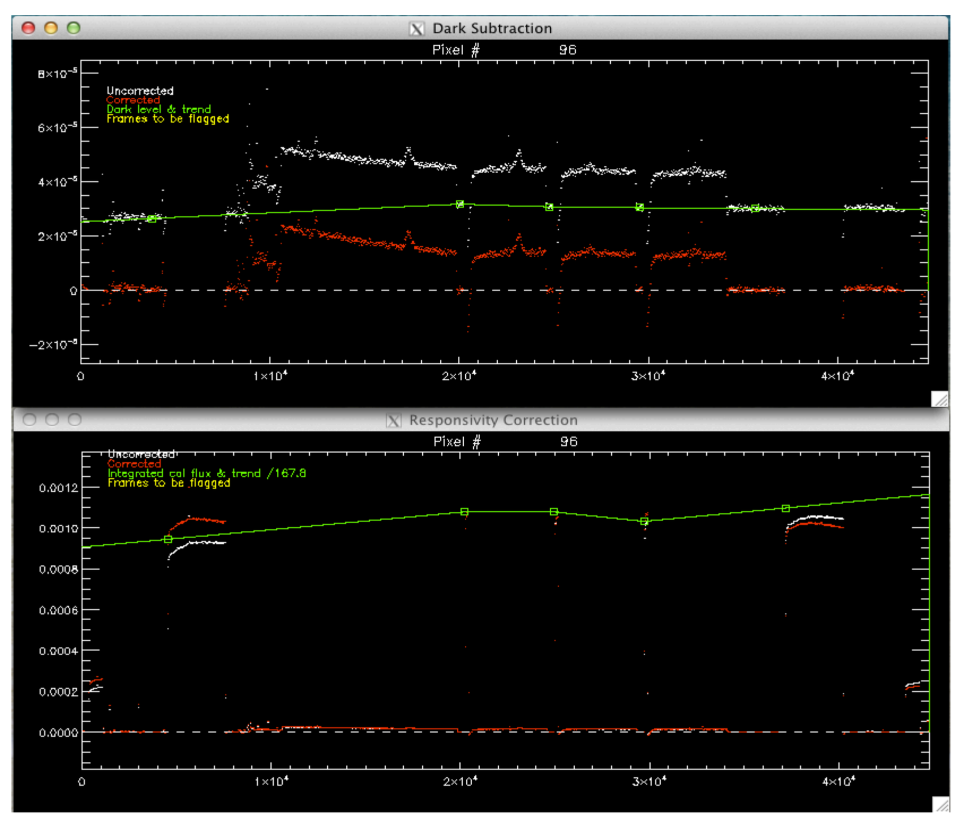


Figure 6: The Dark Subtraction and Responsivity Correction calibration data for an individual pixel (# 96). The white points are the uncorrected data, red are the corrected data, green are the calibration points, the green lines are the fit between the green points which is used as the correction.

Extended Emission Calibration

Original calibration of the FIS detector was done using diffuse galactic cirrus emission with low photon counts. On the other hand, bright point sources can cause the slow transient response effect because of high photon counts. Marginally extended sources consist of regions of high and low photon counts, and therefore, only parts of them suffer from the slow transient response effect. Hence, we needed to devise a specific method to address the detector response as a whole. This method uses a contour aperture to include both the faint and bright emission by setting a threshold of background + 3σ.

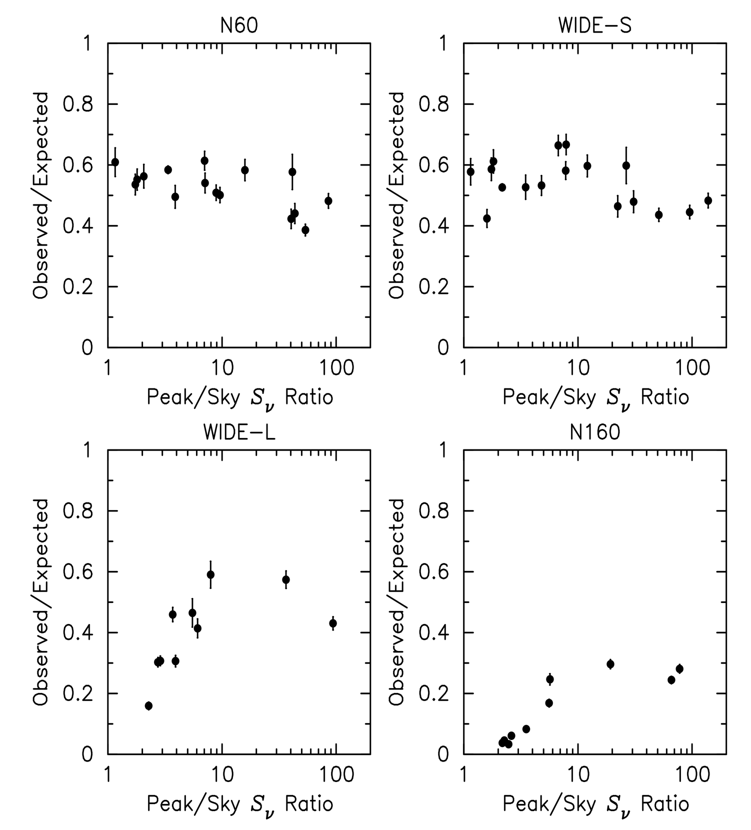


Figure 7: The slow transient response is dependent on the background flux and the peak emission. For the N60/WIDE-S bands, the detector has ~55% response while the WIDE-L/N160 have two different regimes separated at a boundary.

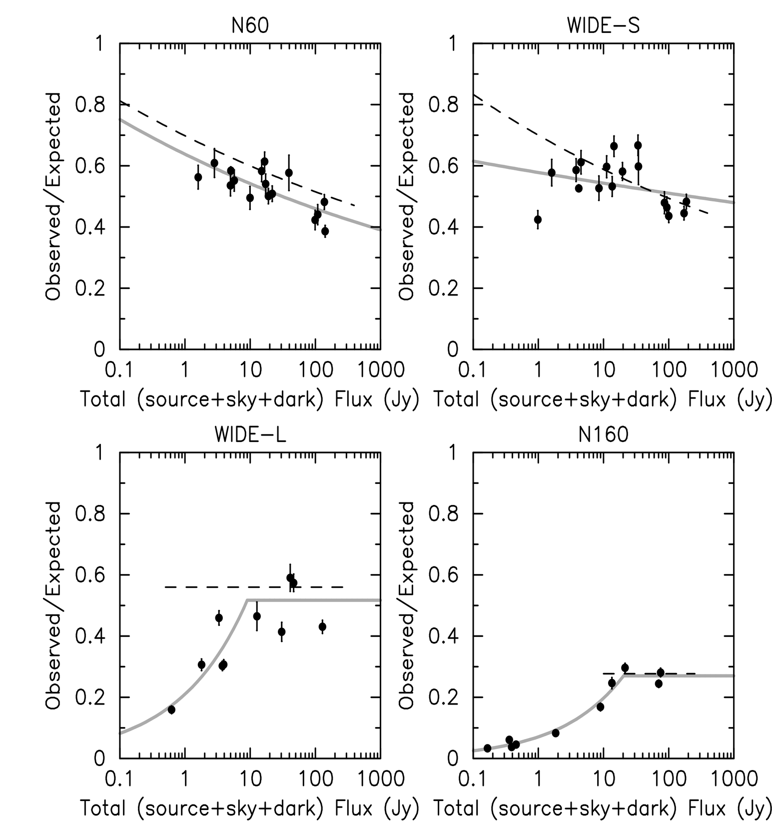


Figure 8: The calibration for point sources has already been completed (dashed lines). The grey lines show the determined correction functions.

SW Band	0 Jy < (TF) ≲ 400 Jy
N60	$R = 0.638\times(TF)^{-0.071}$
WIDE-S	$R = 0.578\times(TF)^{-0.027}$

LW Band	(TF) ≲ boundary	boundary ≲ (TF)
WIDE-L	$R = 0.210\times(TF)^{0.409}$	R = 0.517
N160	$R = 0.071\times(TF)^{0.446}$	R = 0.269

Figure 9: The FIS extended emission slow transient response correction functions. For the WIDE-L and N160 bands, there are two regimes. The boundary for WIDE-L is a total flux (source + sky +dark) of 9 Jy and for N160 is 13 Jy.

Photometry

For point sources, the fluxes are only measured from the PSF core and the flux from the PSF wing is recovered by using an aperture correction scaling factor. This correction method is designed to work only for point sources because it assumes a specific surface brightness profile (i.e., a Gaussian PSF). A specific surface brightness profile cannot be assumed for extended emission. Thus, we used a contour aperture using a background + 3σ cutoff. We also set a radius of interest to ensure that the noise from the edges of the map were not included which was determined from the help of the radial profiles (below).

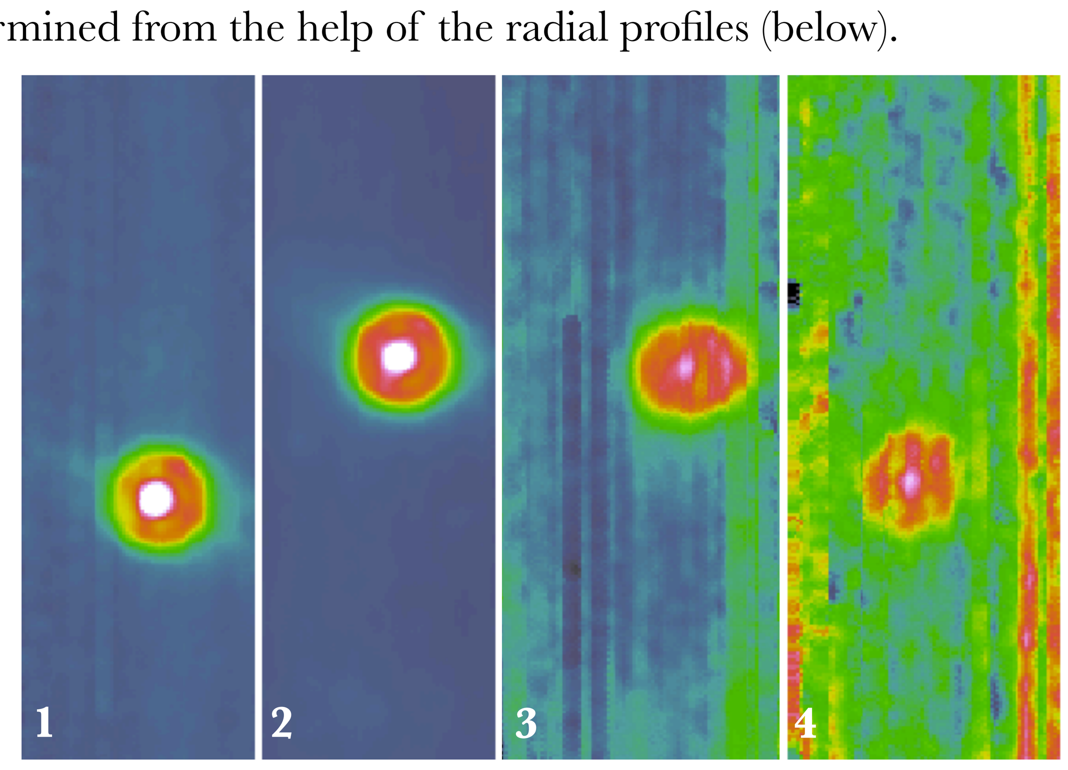


Figure 10: U Hydrae, a famous Carbon star with prominent extended emission, for each band (N60, WIDE-S, WIDE-L, N160), respectively. Panels 3 and 4 show more sky fluctuations near the edges of their frames.

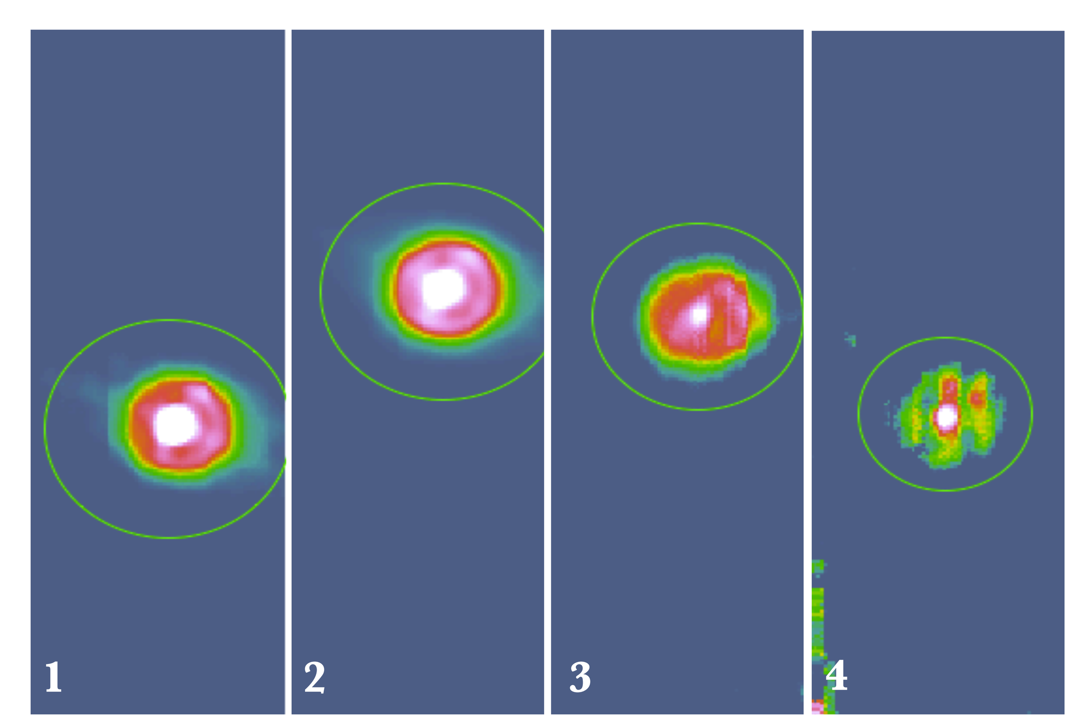


Figure 11: U Hydrae's final contour apertures for each band (N60, WIDE-S, WIDE-L, N160), respectively. The green circles represent the radius on interest for each band.

Color Corrections

The FIS photometric flux is defined for a νF_ν = constant spectrum at the center wavelength of each band. The flux obtained using these derived calibration factors is not the actual flux, but a 'quoted' flux. Therefore, in order to obtain the monochromatic flux at the band center wavelength, we should apply a color correction depending on the Spectral Energy Distribution (SED), which is a modified blackbody, $A \cdot \lambda^{-\beta} \cdot B_\lambda(T)$. A color correction factor, K, is defined as $K = \Delta\nu_{SED} = \Delta\nu_{flat} = F_{obtained} = F_{real}$, where $\Delta\nu$ is the effective band width.

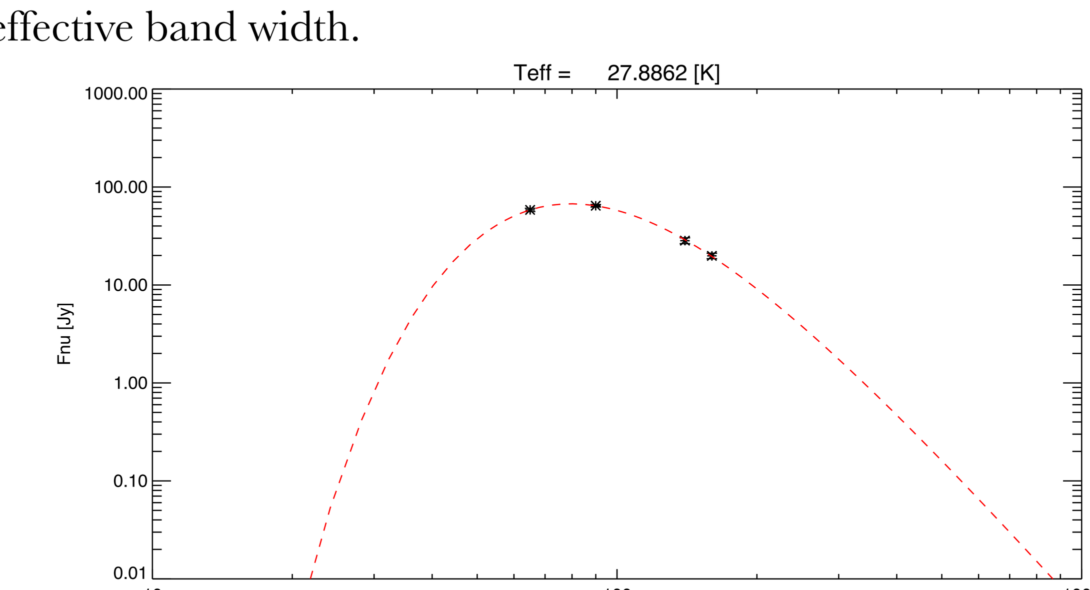


Figure 11: SED fit for U Hydrae using the observed flux measurements from the four bands. To get an accurate fit, you need at least four flux measurements because you are fitting three parameters (A, β, T). Error bars are smaller than the symbols.

Radial Profiles

With deeper images, we can recover even fainter emission so additional structures may appear. In combination with the images (above), radial profiles allow us to 'see' the extended emission and allows us to quantify if what we see in the images is real or just fluctuation in the noise.

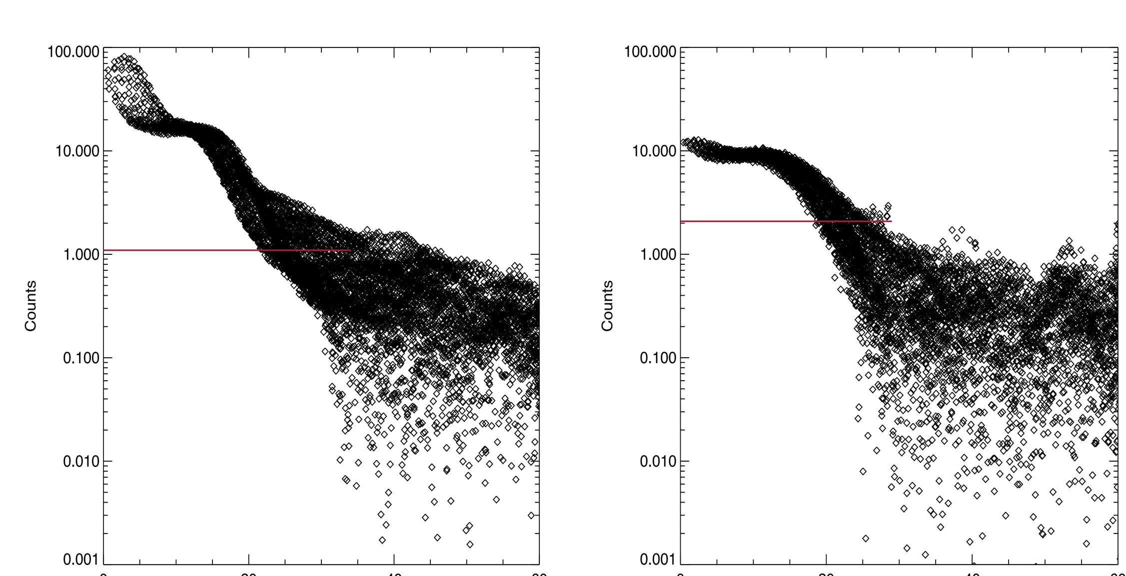


Figure 12 (A-B): Radial Profiles for the N60 and WIDE-L bands for U Hydrae, respectively. The bump closer to 20 pixels shows the extended emission ring which is visible in the photometry contours (above). The red line is the threshold value.

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