A UKIRT [FeII] Study of M33 and its Supernova Remnants

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Abstract

Supernova remnants (SNRs) are generally identified and studied at optical, X-ray or radio wavelengths. However, studies of supernova remnants in the infrared have shown that SNRs are linked to strong [FeII] emission which originates from gaseous iron produced when a supernova shock wave destroys dust in the interstellar medium. This study furthers an attempt to develop [FeII] observations as a detection and diagnostic tool for extragalactic SNRs. Using the United Kingdom Infrared Telescope (UKIRT) Wide Field Camera (WFCAM), deep imaging of M33 has been obtained in broad bands H and K and narrow bands λ=1.644 µm [FeII] and λ=2.141 µm H_2. M33 is a spiral galaxy less than 1 Mpc away and has a long history of SNR studies, however a detailed map of narrow-band infrared emission has never been made until now. Analysis of [FeII] emission throughout the galaxy is examined as well as infrared emission from previously identified supernova remnants and supernova remnant candidates.

Introduction, Motivation & Overview

Supernovae and supernova remnants (SNRs) play an important role in the evolution of the interstellar medium of their host galaxies. To better understand this role, it will be necessary to obtain large samples of these objects and examine how their properties relate to their physical environments. This study furthers a previous investigation to determine the efficiency of IR imaging in the identification of supernova remnant candidates (SNRcs). But identifying SNRs is only the beginning, spectra and/or imaging at multiple wavelength regimes will be necessary to fully understand how supernovae and their remnants affect the evolution of their host galaxies.

In the preceding study, NGC 6946 was imaged using the WIYN High Resolution Camera (WHIRC) in broad bands J and H and narrow bands designed to measure λ=1.644 µm [Fe II] emission and Paβ emission. The power of this previous method resided in the use of additional narrowband "off" filters, slightly offset from the emission line filters, to more accurately measure continuum emission at the source than a broad band filter would be able to do. That particular analysis resulted in the identification of 72 SNRcs which had a high confidence of being SNRs, but still require spectroscopic follow-up.

Observations & Methods

In this study, very deep and high resolution imaging of M33 was obtained using the 3.8m United Kingdom Infrared Telescope (UKIRT) Wide Field Camera (WFCAM). Imaging was obtained in broad bands H and K and narrow bands λ=1.644 µm [FeII] and λ=2.141 µm H_2 (1-0 S1). Since WFCAM lacks an offset narrow band filter to estimate continuum contamination (as is the case with most telescopes), the broad band must be used to estimate continuum emission. Luckily, the relatively flat H band transmission curve and the placement of the [FeII] filter very near the center of the H band help reduce the errors common to such an estimation.

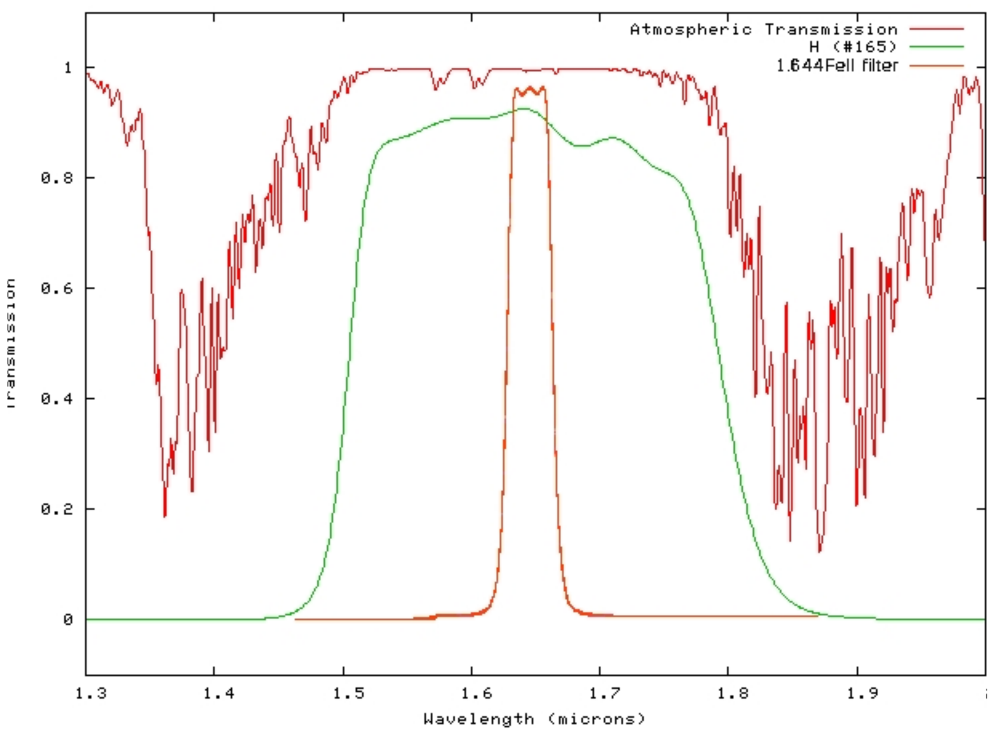

Figure 1. This image shows the filter profiles for the WFCAM broad band H filter and narrow band 1.644 µm [FeII] filter along with an atmospheric transmission profile for reference.

WFCAM was designed with surveys in mind and has four arrays spaced such that four pointings combine to fill a solid tile ~.79 deg^2 in area.

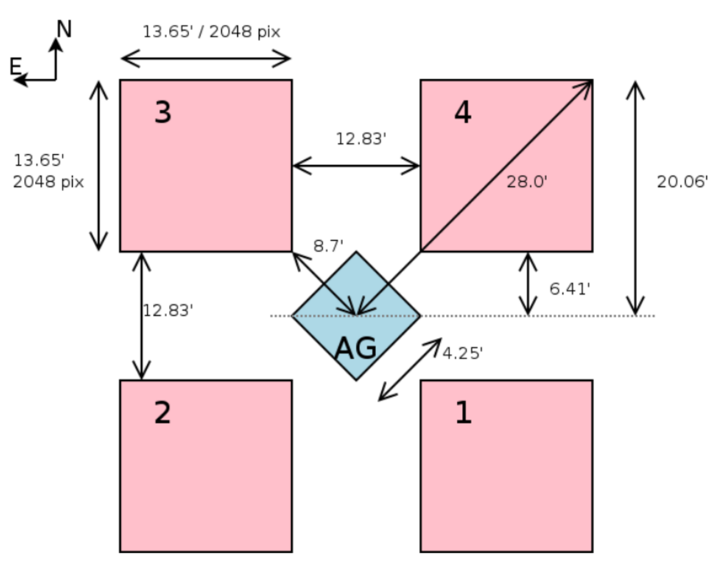

Figure 2. The WFCAM focal plane, showing the four Rockwell Hawaii-II 2048 x 2048 pixel detectors, spaced by 94%, with an optical guide camera centered between the arrays.

All images were obtained between September and November of 2018. Four separate tile locations were chosen to help encompass more of the galaxy and also to help offset a region of reduced sensitivity on one of the detectors. The resulting observational design produced very deep imaging over much of the galaxy's area with reduced depth in the outer regions.

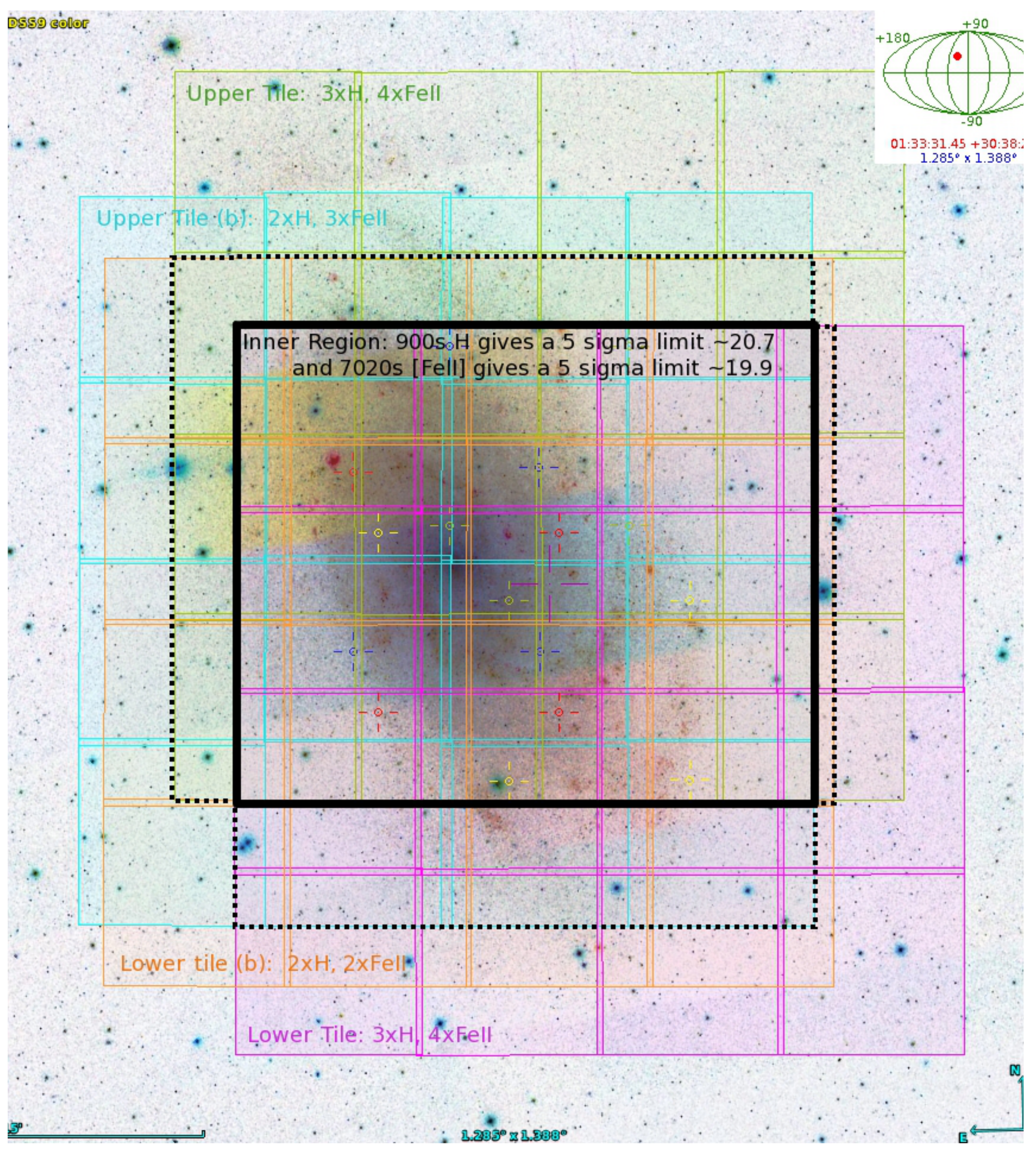

Figure 3. This image shows footprints of the WFCAM observations displayed on an optical image of M33. The solid black line shows the region where all four tiles overlap, achieving the greatest depth of this study. But even in the dashed regions, where only 3 tiles overlap, the H depth is ~20.5mag and the [FeII] depth is ~19.8mag (where depth is stated as 5σ point source sensitivity).

A WFCAM data reduction pipeline run by the Cambridge Astronomical Survey Unit (CASU) ingests the raw frames from UKIRT. The raw frames are flattened, sky-subtracted (etc.) and stacked. Starlink software was used to mosaic these reduced images together, although some sky modeling still needs to be done to combine images from different parts of the night, or different nights. At the present time, a zeroth order sky matching has been made. A slightly more thorough fit is planned in order to produce [FeII] flux measurements.

Analysis & Results

With ground-based imaging, the analysis of this type of data can be difficult. What one would like to find is a source of particularly strong [FeII] emission (in this case at λ=1.644 µm), which requires a continuum subtracted [FeII] image. It is the continuum subtraction that can be difficult, often complicated by issues of sky subtraction, let alone different color terms from differing stars.

However, one can start by just blinking an H image with an [FeII] image. If an object is strongly visible in the [FeII] while negligible in H, you can be sure it is a strong [FeII] source with a strong detection threshold.

And in fact, a quick look at the M33 data showed a number of objects prominently visible in [FeII] while relatively absent in H. There is no doubt that these are large regions of [FeII] emission, where iron has been dissociated into a gaseous state in the ISM (one would think by a shock wave) and is excited into an ionized state.

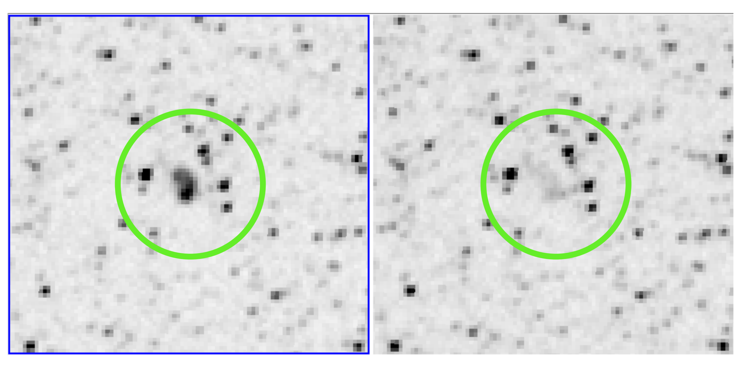

Figure 4. Preliminary search, object "C", is an incredibly strong [FeII] source, as well as a previously identified SNR.

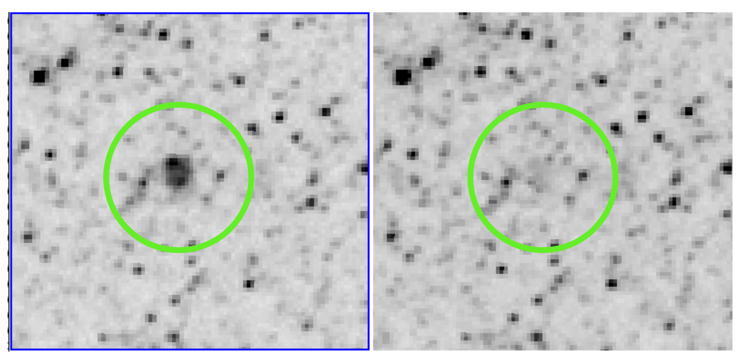

Figure 5. Similarly, preliminary search object "E" is a previously identified SNR.

A color image, with [FeII] loaded as red and H loaded as green shows most everything in the galaxy is a similar shade of yellow, save for 9 very obvious red objects. These are the the strongest [FeII] emitters in the galaxy and 7 of them coincide with previously known SNRs. For the most part, they also coincide with the SNRs with the brightest optical counterparts. Quite interestingly, though, two of these red regions do not lseem to be listed as any of the previously known ~200 SNRs/SNRcs in M33. Nonetheless, these have a high probability of being SNRs, and may be embedded or hidden by dust that makes them unlikely to spot in the optical.

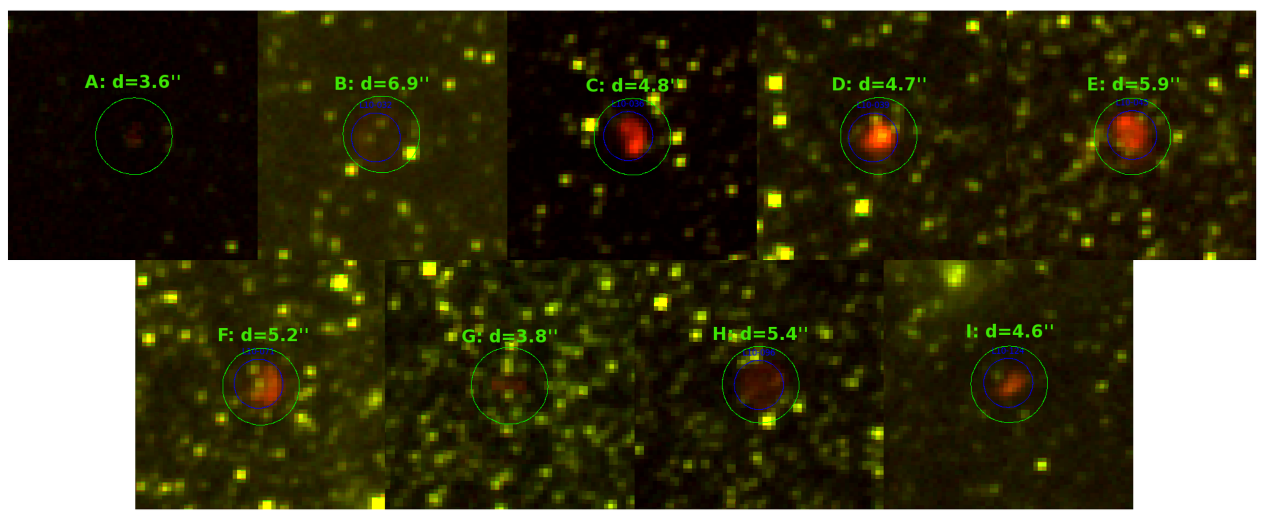

Figure 6. Preliminary search objects A through I are displayed. All objects except "A" and "G" are previously know (optically bright) SNRs. Diameters are roughly measured by eye. Results are summarized below.

ID	D (arcsec)	RA	DEC	Alt ID
A	3.6	1:32:58.95	+30:45:42.50	NA
B	6.9	1:33:23.81	+30:26:13.78	L10-032
C	4.8	1:33:28.99	+30:42:17.10	L10-036
D	4.7	1:33:31.18	+30:33:33.19	L10-039
E	5.9	1:33:35.90	+30:36:27.29	L10-045
F	5.2	1:33:54.85	+30:33:10.64	L10-071
G	3.8	1:34:06.10	+30:40:56.32	NA
H	5.4	1:34:10.69	+30:42:24.03	L10-096
I	4.6	1:34:33.01	+30:46:39.00	L10-124

Work in the Making

The M33 [FeII] images collected with UKIRT are unparalleled in depth and resolution. The reduced images will be carefully mosaicked together with polynomial sky matching and a difference image will be made using the H band to estimate the continuum contamination. The difference image will be subject to a blind search for SNRcs. Afterward, fluxes of identified objects and previously known objects will be examined.

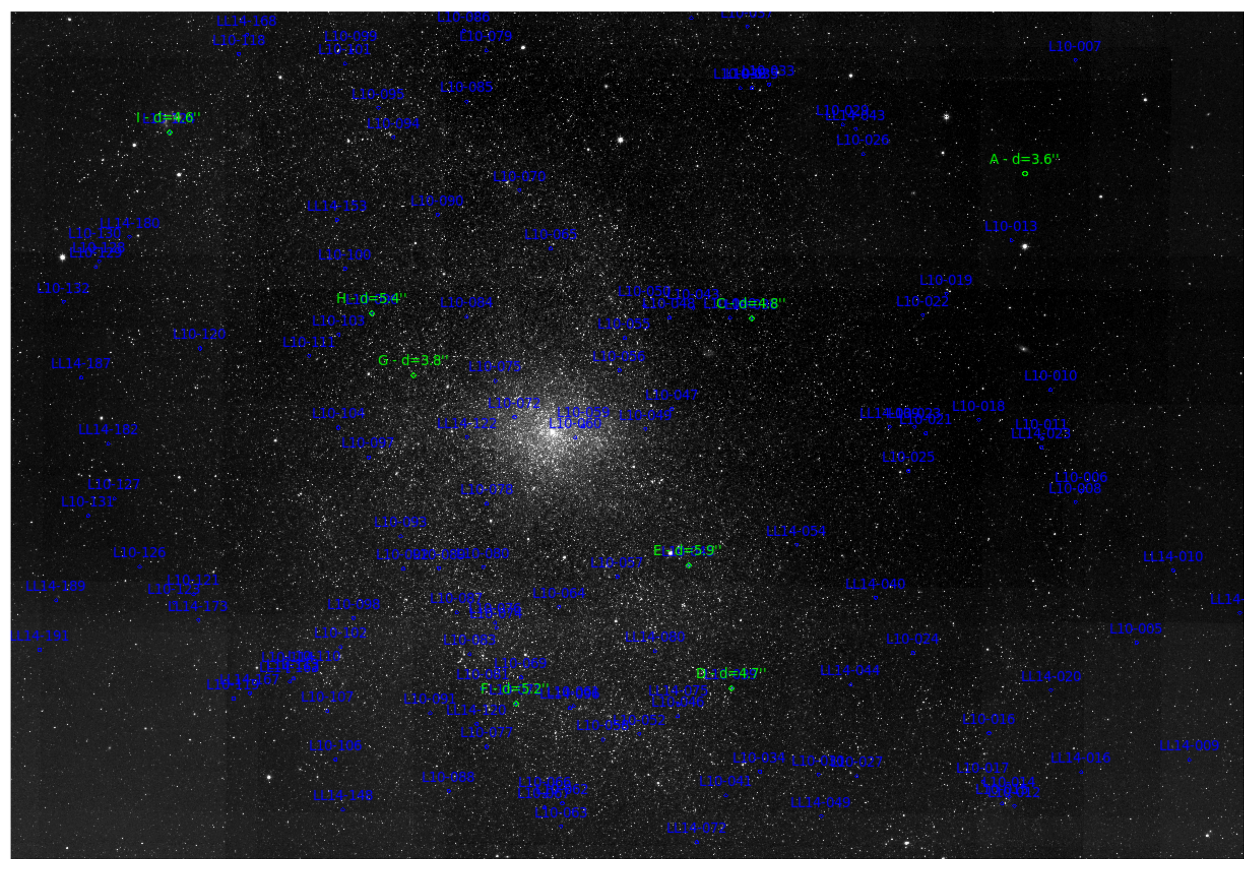

Figure 7. Part of the [FeII] mosaic is shown here, although the mosaic is so large and detailed, a small print will undoubtedly fail to display it clearly. Blue regions show SNRs compiled in a recent paper by Long et al. (2018), green regions are the 9 preliminary objects in this study.

USNO

Imaging was obtained through PI use of UKIRT through the United States Naval Observatory Flagstaff Station.
General UKIRT image processing is expertly handled by the Institute of Astronomy, Cambridge University.
Work from (Long, K., Blaire, W., Milisavljevic, D., Raymond, J.C. & Winkler, F. 2018, ApJ, 855, 140) is cited here.
For further information on the background of this study, please see (Bruursema, J., Meixner, M., Long, K., Otsuka, M. 2014, AJ, 148, 41) and references therein, and the PhD thesis for Justice Bruursema, available through the Johns Hopkins University library.

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