ASTROSAT/UVIT Photometry of PHAT Stars in M31

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Introduction

M31 is the nearest neighbouring massive galaxy. Like our Galaxy, it is a spiral; however, since we have an outsider's view unobscured by the dust lanes in our Galaxy, we can use it to understand the structure of our Galaxy.

A number of surveys have been performed on M31 in different wavebands. The highest resolution survey is the optical HST Panchromatic Hubble Andromeda Treasury (PHAT), which covered the northern ~1/3 of M31, and can resolve objects ~10 milliarcseconds apart (Williams et al., 2014). PHAT used 6 filters from NUV to IR; the IR data is crowding-limited. The previous NUV/FUV survey of M31 was performed by Galex at a spatial resolution of 4 to 5 arcseconds (Kang et al., 2009).

The Ultraviolet Imaging Telescope (UVIT) has a spatial resolution of 1 arcsecond and field of view of 28 arcminutes. From 2017 to 2019, it surveyed M31 in 19 fields. All UVIT fields have data in the FUV CaF2 filter and more than half have data in NUV filters. The FUV filters cover the wavelength range 1200 to 1900 Angstroms and the NUV filters cover the range 2000 to 3000 Angstroms.

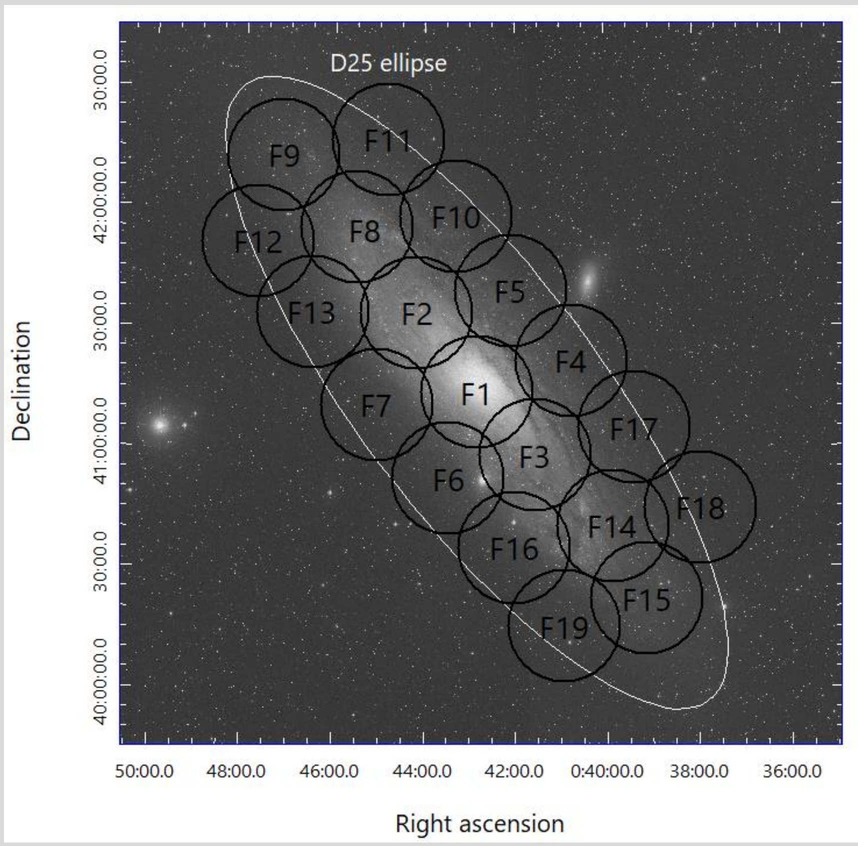

Fig. 1. M31 UVIT survey fields on DSS2 image.

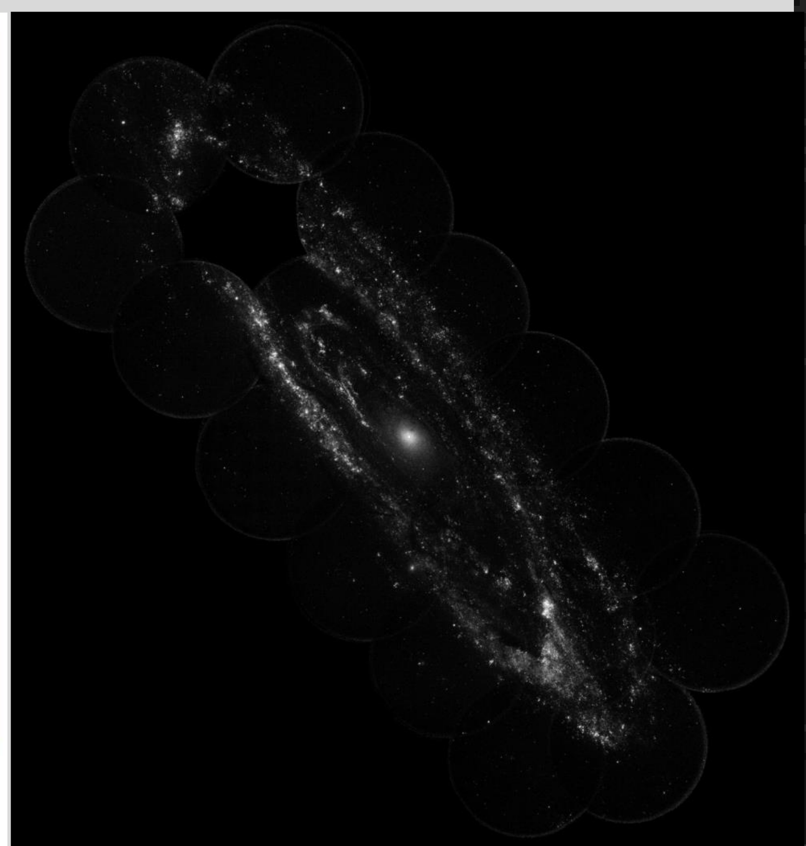

Fig. 2. UVIT CaF2 mosaic of M31 (less F8).

Previous work with UVIT on M31 carried out SED fits for 30 hot stars with PHAT data in the bulge (Leahy et al. 2018), created a UVIT point source catalog (Leahy et al. 2020a), matched UVIT with Chandra sources for SED fitting (Leahy et al. 2020b), and presented new data processing with improved astrometry and photometry (Leahy et al 2020c). Work currently underway is described below.

References

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Acknowledgement

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Data Analysis- Stars

UVIT data are processed using the software package CCDLAB (Postma & Leahy, 2017). CCDLAB calibrates the image to the sky using an auto-solving WCS algorithm (Postma & Leahy, 2020). New flat field maps were used for each filter (Tandon et al., 2020).

UVIT has 1" resolution, enough to resolve individual hot stars in M31 in uncrowded regions. Even in crowded regions a significant number of stars can be resolved. In Fig.3 we show the UVIT fields that overlap the PHAT survey and in Fig. 4 show the a CaF2 FUV image of a small area (30"x30") in F2. Also shown are F275W-filter sources with Vega magnitudes brighter than 20.5, which can be matched in position and magnitude with UVIT NUVN2 filter source (both at 275nm band) to verify the match between UVIT and PHAT.

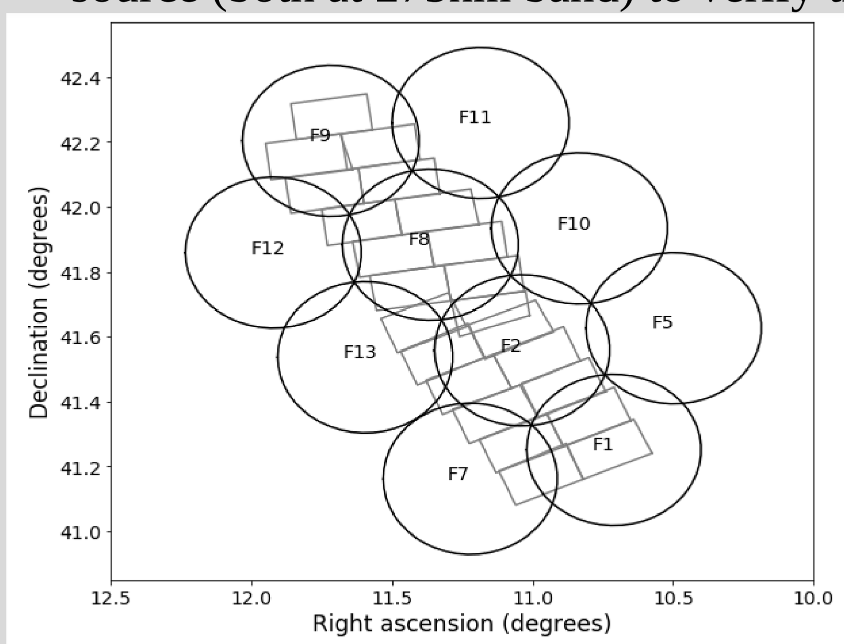

Fig. 3. M31 northern UVIT fielda on PHAT survey.

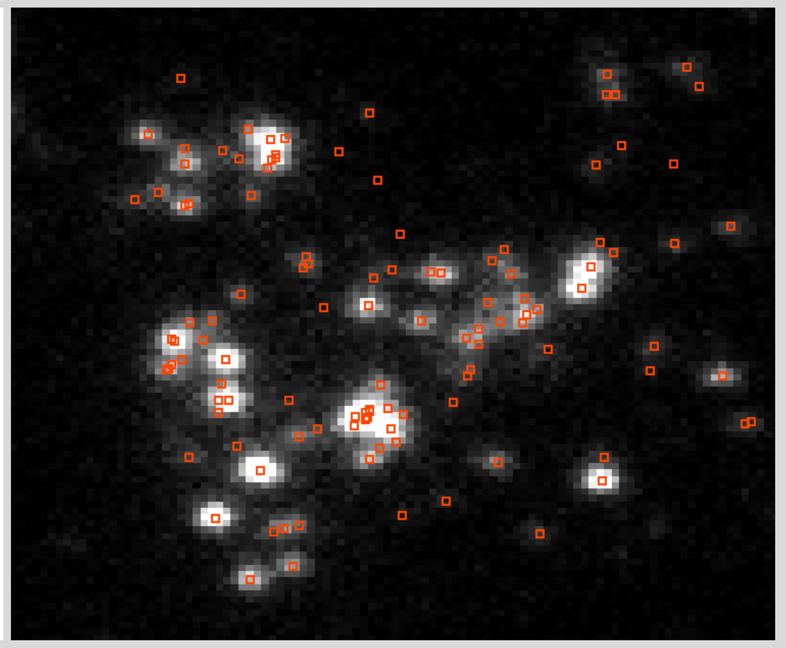

Fig. 4. UVIT CaF2 30x30" area with PHAT F275W sources (m_{VEGA}<20.5) marked in red

Using fields 1, 2, 7 and 13, which have UVIT NUV N2 data, we have matched 943 UVIT sources with PHAT sources. These are currently being analyzed using CMDs and SED fitting. Fig. 5 shows the FUV-NUV observed and theoretical CMDs, showing consistency of the detected sources with hot stars.

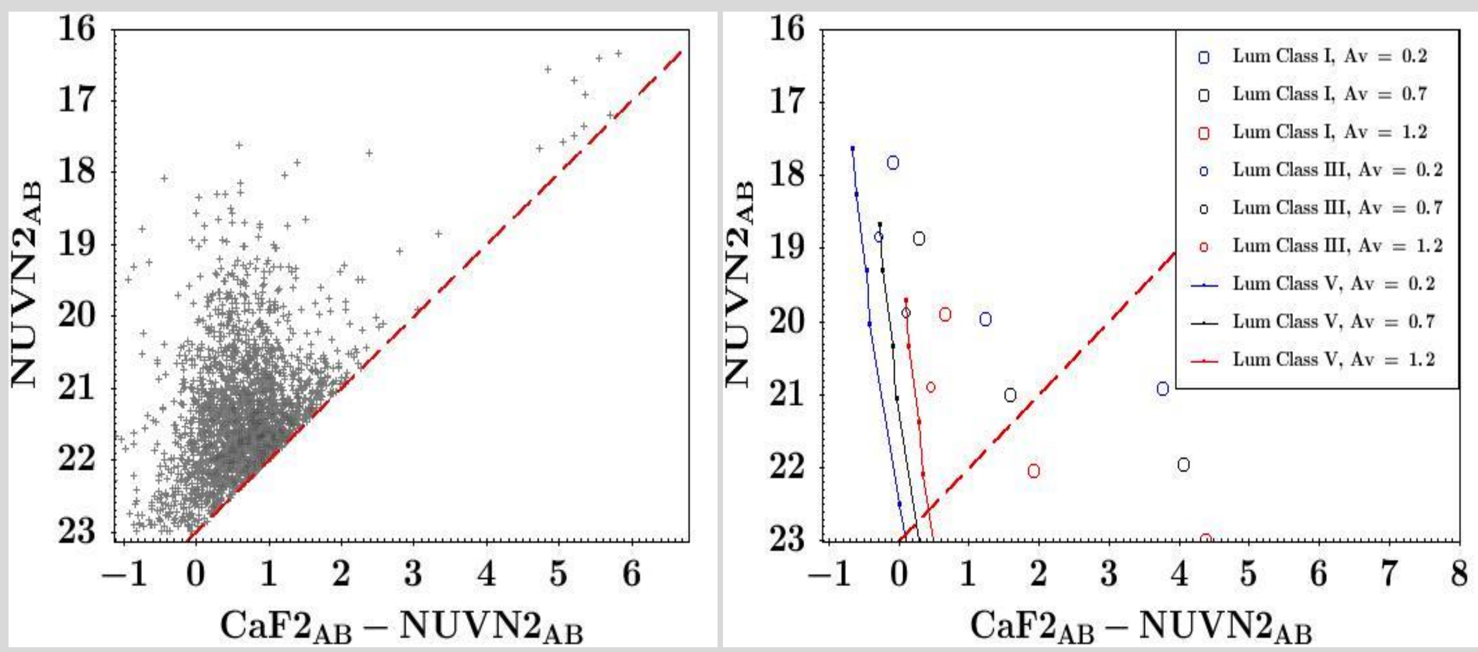

Figure 5. Colour magnitude diagram for the UVIT sources with measured magnitudes (left) and theoretical magnitudes (right). Luminosity class V includes O3V, O5V, O8V, B0V, B3V (others are too faint and off the diagram); I includes B0I, A0I, F0I (others too faint); III includes B0III (others too faint). The red dashed line shows the approximate detection limit for the UVIT telescope.

Combining, UVIT and PHAT photometry for resolved source, we can carry out SED fitting to determine more accurately the properties of the hot stars. In Fig. 6 we show one example, where the fit requires both a hot star and a cool star. For most other cases, 2 stars are required. This is not surprising because cool stars are much more numerous and are usually crowded for M31.

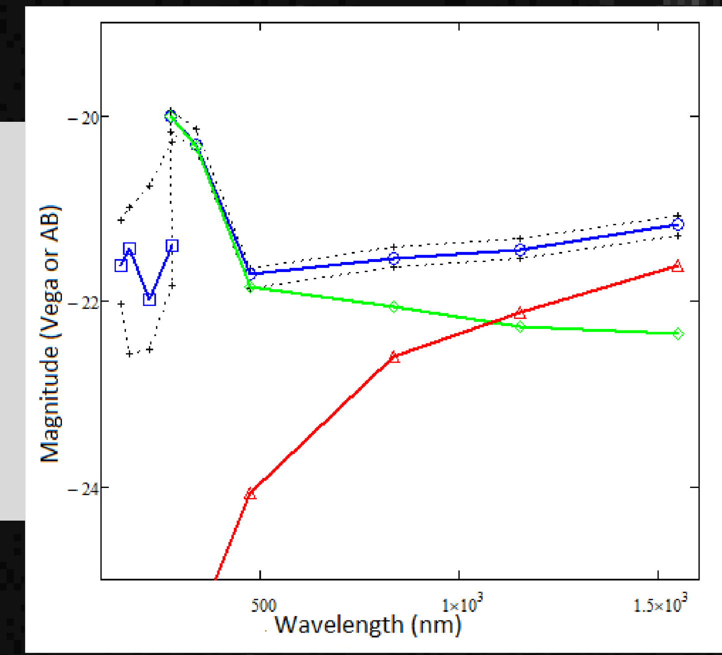

Figure 6: Fit of 2 component stellar spectrum (CK models) to the combined UVIT (4 data, AB magnitudes) plus PHAT (6 data, Vega magnitudes): best-fit is a hot star with T= 49 000K, radius 6.6 R_{sun} plus cool star with T=5700 K, radius 42 R_s

Analysis- Bulge Structure

The bulge of M31 has been observed in 5 different UVIT filters: in FUV CaF2, Sapphire, Silica and in NUVB15 and NUVN2. The bulge appears as a diffuse glow in FUV and NUV (see Fig.1 for the FUV CaF2 image- the bulge is the central ~5' of the whole 150'x150' image. We are analyzing the different images to determine the FUV/NUV structure of the bulge. Fig. 7 shows the central 5.5'x5.5' image of the bulge, with contours of constant surface brightness and elliptical fits to the surface brightness. We extracted radial/elliptical surface brightness profiles for each filter, then fit these with bulge models. A single Sersic fit is ruled out, but double Sersic or Gaussian core plus Sersic fit the data well. We find smaller Sersic indices for NUV than for FUV. To understand the nature of stellar populations in the bulge, we made a color-color diagram (Fig. 8), which shows the mean stellar temperatures decrease with distance from the center. More complex spectral models with stellar populations are undergoing testing.

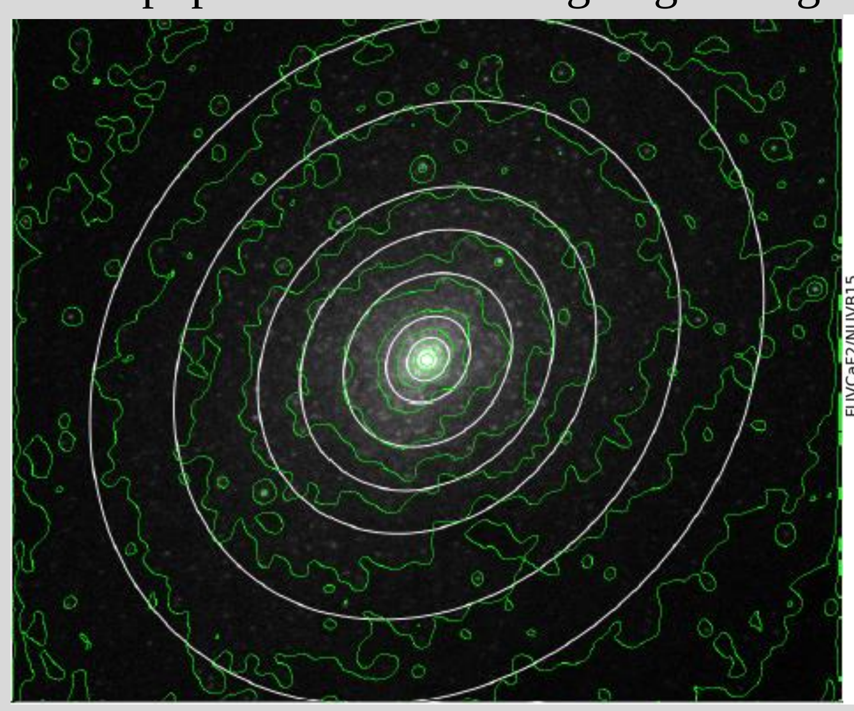

Fig. 7. M31 FUV CaF2 image with contours (green). The white ellipses are determined by fits to the image.

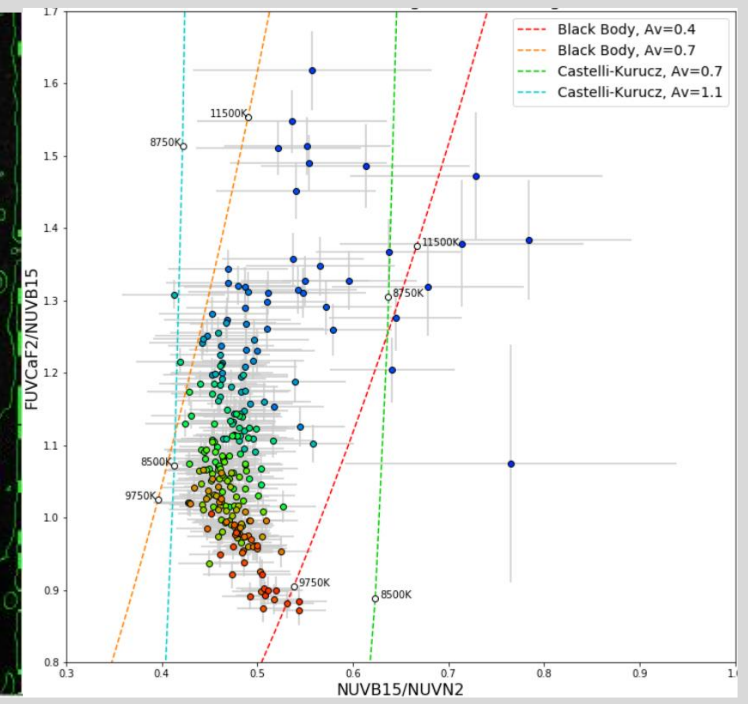

Fig. 8. UVIT color-color diagram of the bulge with lines of constant extinction for varying temperature.

Conclusion: The UVIT data have been reprocessed with improved position and photometry, allowing new investigations of the stellar populations of M31 in different areas, such as in spiral arms, inter-arm, and in the bulge. For single sources, the combined FUV-NUV-optical photometry produces good stellar constraints. For the bulge, individual stars are not resolved, necessitating a stellar population approach (in progress). The new results promise to much improve our knowledge of different UV-emitting hot star populations in M31.