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Detection of extended Red Clump in the SMC cluster Kron 3

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Abstract. For the first time, we report the identification of NUV bright red clump (RC) stars and the extension of RC stars over two magnitudes both in color and magnitude axis in NUV vs (NUV − optical) color magnitude diagram. We find that the extension of RC is not due to photometric uncertainties. We suggest that the extension could be an effect of field star contamination. We also suggest that if it is an intrinsic property of the cluster then age and/or metallicity spread within the cluster could be the possible reasons for extended RC.

Keywords. (galaxies:) Magellanic Clouds, galaxies: star clusters, (stars:)- ultraviolet: stars.

1. Introduction

Kron 3 is an intermediate age metal poor massive star cluster, located in the western region of the main body of the SMC. Gascoigne (1966) first presented the color-magnitude diagram (CMD) of this cluster and estimated the age to be ∼2 Gyr. Gascoigne (1980) reported that the cluster is 3 Gyr old. Hodge (1982) suggested metallicity and age of Kron 3 as [Fe/H] = −1.3 (±0.3) dex and 1 Gyr (±0.4), respectively. By fitting isochrones to the cluster CMD, Rich *et al.* (1984) proposed a range in age from 5 to 8 Gyr for Kron 3. Comparing theoretical isochrones (Vandenberg & Bell 1985) to the cluster CMDs, Alcaino *et al.* (1996) proposed an even older age range (8-10 Gyr) than previously claimed for Kron 3. Using archival HST/WFPC2 data, Mighell *et al.* (1998) proposed that the cluster is 4.7(±0.6) Gyr old. The most recent study by Glatt *et al.* (2008) using HST/ACS data suggests the age to be 6.5 Gyr, with a metallicity of Z = 0.001.

Using the optical spectra obtained from Anglo-Australian Telescope (AAT), Gascoigne (1980) estimated the metallicity to be [Fe/H] = −0.6 dex. Studies by Hodge (1982); Rich *et al.* (1984); Alcaino *et al.* (1996); Glatt *et al.* (2008) reported that the cluster metallicity (Z) is 0.001 ([Fe/H] = −1.3 dex), whereas Dias *et al.* (2010) estimated the metallicity as Z = 0.0002.

Therefore, large ranges in age and metallicity have been suggested for this cluster. In this study, we plan to investigate the presence of age and metallicity spread using multi-wavelength data in Kron 3. To achieve the aim, we combine UV observations of this cluster taken with Ultra-Violet Imaging Telescope (UVIT) with HST. Combining UV observation with optical will give us a larger coverage in wavelength. This will help us in estimating age and metallicity of the cluster with better precision.

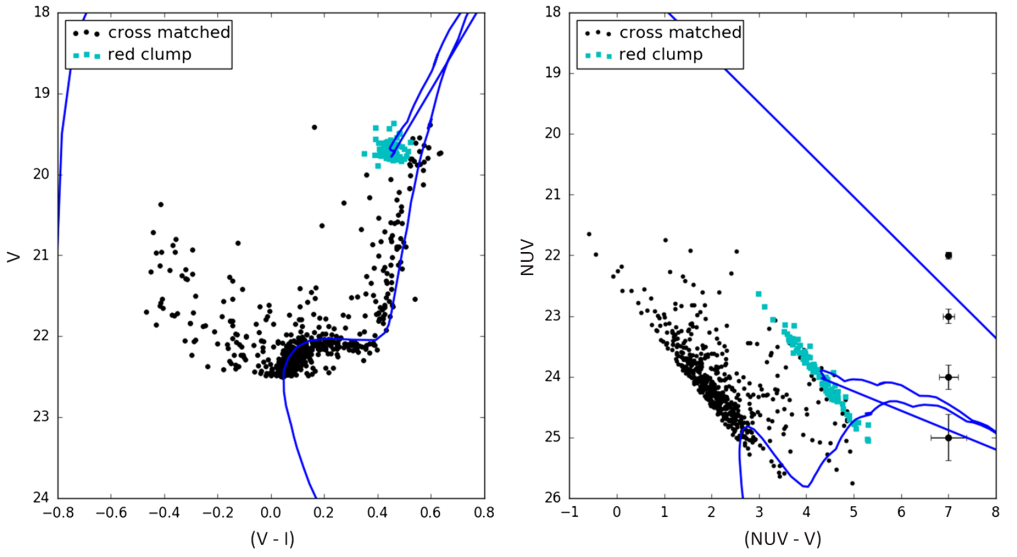

Figure 1. Left panel shows the optical CMD of HLA-UVIT cross-matched stars. The right hand panel shows the UV-optical CMD of the same cross-matched stars. In both plots RC stars are highlighted in cyan and an isochrone (blue) of age 7 Gyr with a metallicity of Z = 0.001 is over plotted onto the CMD.

2. Photometry of UVIT data

The observations of Kron 3 were carried out with the UVIT telescope in one FUV (F148W : 125–175 nm) and one NUV (N242W : 203-281 nm) filters. The total exposure time was 7194 seconds. The science ready images were created for an area of 4K×4K size with a scale of 0.4125″/pixel. Due to the crowding of stars in the central region of the cluster, we performed PSF photometry on the images to estimate the magnitude of stars using the IRAF/DAOPhot package.

3. UV-Optical CMD using UVIT and HST data

We found only a few detections in the FUV band (48) compared to the NUV band (1447) within a cluster radius of 1.′7 (taken from Bica *et al.* 2008). Hence, it is difficult to generate an FUV−NUV CMD in order to study the properties of the cluster. Therefore, we combined NUV observation with optical data in F555W (∼V band) and F814W(∼I band) filters obtained from the Hubble Legacy Archive (HLA†) to fulfil our aim.

From the isochrones of ages older than a few Gyr, we can see that UVIT reaches its detection limit near the main sequence turn-off (MSTO) for the clusters located at the distance of the SMC (see Figure 1). The MSTO of Kron 3 is ∼22.5 mag in V band. Therefore, while cross-matching HLA data with NUV data, we excluded the stars fainter than 22.5 mag in V band. This criterium also helped us to reduce the crowding of stars, mainly in the central region of the cluster and the cross-match between the two data sets became easier. We considered a maximum separation of 1.″0 while cross-matching the two data sets.

† Based on observations made with the NASA/ESA Hubble Space Telescope, and obtained from the Hubble Legacy Archive, which is a collaboration between the Space Telescope Science Institute (STScI/NASA), the Space Telescope European Coordinating Facility (ST-ECF/ESA) and the Canadian Astronomy Data Centre (CADC/NRC/CSA).

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The left panel of Figure 1 shows the V vs (V−I) CMD of HLA-UVIT cross-matched data (black). The RC stars are highlighted in cyan color. An isochrone (blue) of age 7 Gyr and metallicity Z = 0.001 is overplotted onto the CMD after correcting for reddening (E(V−I) = 0.033 mag) and distance modulus (DM = 18.8 mag). The values of age, metallicity, reddening and distance modulus are taken from Glatt *et al.* (2008).

The right panel of Figure 1 shows NUV vs (NUV−V) CMD of the same HLA-UVIT cross-matched data. Different colors in this plot indicate the same as the left panel. We notice that the RC stars are not distributed in a clump anymore in the UV-optical CMD. The plot shows that the RC gets spread out over more than two magnitudes in both magnitude (NUV) and color axis (NUV−V). The plot indicates that a part of the SGB and RGB get fainter that the MSTO in NUV and fall below the detection limit of the UVIT (∼25.5 mag). Therefore, the part of SGB and RGB stars are not fitted to the isochrone due to non-detection of these stars in the NUV band. Photometric errors are also shown in the plot, which indicates a relatively larger error near the detection limit of UVIT. Hence, we focused our study mainly on RC stars, which have less photometric errors in NUV. The plot clearly suggests that the extension of RC stars is not due to the photometric errors.

4. Possible reasons for extended RC

The extension of RC stars in Kron 3 could be an intrinsic or extrinsic property of the cluster. As an extrinsic property the NUV bright populations in the RC could be contaminated by field stars, or the extension is an effect of differential reddening across the cluster. Hence, it is required to examine the field star distribution in the cluster region and decontaminate the cluster region. Due to a smaller field of view of the HST, which covers mainly the inner core region of the cluster, field stars decontamination is not possible in the UV-optical CMD using HLA-UVIT cross-matched data. Therefore, in the follow-up study we plan to use Gaia DR2 data, which has a larger coverage of the cluster, to combine with UVIT data in order to check whether the NUV bright RC stars are the field stars contamination or not.

If RC stars are found to be members of the cluster, i.e. an intrinsic property of the cluster, then the possible reasons for the extended RC could be (i) presence of multiple stellar population, (ii) presence of metallicity gradient among the stars (iii) variable mass loss and (iv) chromospheric activity. Stars with different metallicity values will appear in different location in the CMD. The metal poor stars will appear brighter and bluer in the CMD whereas the metal rich stars will appear relatively fainter and redder. So, the presence of metallicity gradient can cause the extended feature in the RC. This feature becomes more prominent in the UV-optical CMD as the UV region is more sensitive to metallicity. Stars with higher mass loss rate can expose their inner hotter layer by expelling the outer layer and get brighter in NUV. Hence, there are more than one possibilities to get a large spread in the RC. We plan to analyze all the above mentioned possibilities to ensure we understand the reason for getting an extended RC in the cluster Kron 3.

5. Summary

We present the analysis of UVIT-HST data for the intermediate-age cluster Kron 3 in the SMC. For the first time, we report the identification of NUV bright RC stars and the extension of the RC in the CMD. We found that the extension of RC stars is not due to photometric uncertainties. The extension of RC could be an intrinsic or extrinsic property of the clusters. In the follow up study we plan to analyze the effect of field contamination and differential reddening, presence of age and metallicity spread within the cluster.

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