Bull. Astr. Soc. India (2007) **35**, 223–228

UV observations of globular clusters and nearby galaxies

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Abstract. We propose to identify the hot stellar population of the galactic globular clusters (GCs) using the TAUVEX. These stars can be easily identified in the core of the GCs where the crowding due to the main-sequence stars get dramatically reduced in the UV broad bands. We propose to observe and create a first complete and homogeneous UV data on Magellanic Clouds. Studies of extra-galactic globular clusters in the UV is the only way to estimate their age and metallicity without ambiguity. Such studies have not been done even for M 31. Therefore, we propose that extra-galactic globular clusters should be observed in the UV broad band filters.

Keywords : (galaxy:) globular clusters: general – (stars:) blue stragglers – stars: horizontal branch – (galaxies:) local group – (galaxies:) Magellanic clouds – ultraviolet: galaxies, stars

1. Globular clusters

Globular clusters (GCs) are oldest stellar systems in a galaxy. These clusters have large number of low mass stars with very low metal content. Therefore, globular clusters are ideal objects to understand the stellar evolution of such stars and to test the stellar evolutionary theories.

Types of stars in focus: The GCs are stellar crash test labs. Violent encounters between binaries and single stars in dense cluster cores give rise to exotic stellar population such as Blue Stragglers (BSs), Cataclysmic Variables (CVs), Low mass X-ray binaries

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(LMXBs) and millisecond pulsars. GCs also provide a good testing ground to study the late evolutionary stages of low mass stars, like white dwarfs and horizontal branch stars.

UV advantage: The exotic stars are mostly populated in the cores of the GCs where the stellar crowding makes it impossible to identify them. The HB stars show lesser concentration. These stars are very bright in the UV when compared to the main sequence stars, which make them easy to identify. The main advantage lies in the fact that the stellar crowding gets dramatically reduced in the UV. This has been demonstrated by studies using the previous UV missions and HST.

Why do we study exotic stars?: Widely accepted hypothesis explains the origin of BS stars in the merger of two stars. This has two variants, merger of binary systems where the components gradually spiral together to form a single star. The second scenario is the collisional mergers, which is the remnant of a collision between single stars or a single star and a binary. The BSs made from collisions may have excess He abundance outside the core compared to those made from binary mergers. These two merger mechanisms will create products with different chemistry and hence different position in and through the CMD. This effect may be observable, particularly in the UV colours (Baylin 1992).

LMXBs and CVs : The LMXBs and CVs are observed in the field as well in the GCs. The LMXBs are much more abundant in GCs than in the field. This is explained by the tidal capture of stars by the degenerate stars. The same would result in the production of CVs also. These systems are interacting binaries and can be detected either in x-rays or UV. The CVs are thought to be mostly in the quiet phase and their detection is possible, as they are bright in UV. Time resolved observations could reveal any eruptive events or variability in these CVs. There are models which predict a large number of CVs in GCs, but there are also models which predict the opposite. This is because the lifetime of these binary systems and their evolution are not known (Shara et al. 1996). Hence a comprehensive study of these systems is necessary.

Horizontal branch stars: HB stars are the core-helium burning stars, which span a range in temperature, but with similar luminosity. The GCs are known to exhibit variation in the HB morphology, called the second parameter problem, in which two clusters with same metallicity exhibit difference in the population of the red and blue HB stars. The Blue HB stars (BHBs) can be observed in the UV, where they are easily identified. In clusters with vertical BHB distribution, UV CMD can be used to estimate the temperature range covered by them. When the stars in the BHB evolve, they occupy location close to the BHB such that it is difficult to trace their evolution in the optical CMD. If we use a UV-V colour, then the evolved BHB stars occupy a different location which can be used to trace the evolution and their time scales.

UV colour-magnitude diagram: Similar to the optical CMD, the UV CMD also delineates the location of different types of stars. The BSs, WD sequence and HB stars stand out. Hence it is easy to identify them and study them in the UV as demonstrated by

Ferraro et al. (2001). The optical and UV morphology of the HB stars in the UV CMD is shown in Parise et al. (1998), which is the result of a study of M3 by UIT. The lifetime and the temperature range of HB stars from the model tracks show that the HB phase lasts for 100 Myr. The HB stars extend up to a temperature of 30,000 K. The ratio of the HB lifetime to the post-HB lifetime can be estimated from the ratio of stars in the respective phases. Study of the HB stars in the UV CMD is necessary to understand the evolution of HB stars. The HST study of this object (Ferraro et al. 1998) covers less area which could result in incompleteness. UV studies of more clusters are required to extend this study to other metallicity range and to increase the sample. With a $7''$ resolution, candidate clusters will be chosen to obtain the best results.

The metallicity vs age in Galactic GCs: Model isochrones as a function of HB morphology where the numbers of blue HB stars, RR Lyrae variables and red HB stars are shown as function of metallicity and UV-V colour demonstrates that such a figure can decouple the age and metallicity of the GCs. Lee & Lee (2002) have demonstrated this using the GC data of Lee et al. (1994). This type of figure is required to decouple the age and metallicity degeneracy in the galactic globular clusters. Therefore such studies are mandatory for a large number of galactic globular clusters. This method is not possible for the extra-galactic GCs, simply because the individual stars are not resolved. On the other hand the integrated colours of the extra-galactic globular clusters can be used for the above purpose. Before that, this method needs to be tested with the galactic cluster templates. This also suggests that it is necessary to observe a large number of GCs with a range of metallicity to create a good template.

Previous UV studies of GCs: Ultra Violet Imaging Telescope (UIT) mission is very similar to TAUVEX in resolution and filters, though it had a bigger telescope. Only 4 GCs observed using UIT (M3, M13, M79 and Omega Cen) were studied. So far, not much studies have been done on Globular clusters using GALEX, which has similar resolution as TAUVEX. Thus it is necessary to increase the sample of GCs studied in the UV.

2. Magellanic Clouds

Galaxies in the local group come with a range in metallicity, gas fraction and dust content. Therefore these galaxies are ideal test grounds to understand the nuances of star formation as a function of the above parameters. Near-UV and far-UV fluxes in combination with visible and infrared observations will give valuable information about the environments of star formation in these galaxies. Radio observations of CO and HI can be effectively combined to infer the distribution of molecular and atomic hydrogen. The above information can be put together to study the ISM and the feedback due to star formation.

Magellanic Clouds: This galaxy pair has been forming stars vigorously and the Large Magellanic Cloud (LMC) hosts the nearest star burst environment. Interactions among themselves as well as their interaction with our Galaxy is believed to have triggered the recent star forming events in these galaxies. Thus they are ideal to study the signatures of induced, propagating and large scale star formation in a metal poor environment.

Advantage: These are high galactic latitude objects, hence they can be easily observed by TAUVEX in the survey mode. These galaxies occupy a large area in the sky. Therefore, a homogeneous and complete coverage of the whole entity is not possible in the case of pointed observations. Thus these observations can lead to a first complete and homogeneous observation of the Clouds.

Previous observations: LMC was initially studied using the Vacuum Ultraviolet Imagery (Page & Carruthers 1981 and later by Smith et al. (1987). This had a resolution of 50 arcsec. UIT has observed about 37 locations on the LMC, mainly covering 30 Dor and the northern star forming regions. Deep observations of selected regions have been carried out using the HST. Some field regions have also been studied, to understand the field stars and their star formation history (e.g. Brosch et al. 1999; Almoznino et al. 2005) The above observations do not cover the whole of LMC.

Possible studies: First complete and homogeneous UV data on Magellanic Clouds. Photometric observations in the FUV, NUV in combination with the visual data can be used to study the star forming regions. These data can be used to estimate the star formation rate, efficiency, duration, physical extent and ages. The duration and ages can be used to make snapshots of star formation as a function of time and space. Data on large scale is necessary to create this. Recently Subramaniam & Prabhu (2005) proposed that the recent star formation in the LMC is due to gas accreted from the Magellanic bridge. They explain the differences seen in the distribution of stars and gas by proposing that stars and gas are located in two disks with different line of nodes. Optical and NIR data, which trace the old stellar population, do not show any spiral arms, which is seen in the HI maps. Large scale UV map is necessary to identify whether there is any spiral arm in the LMC delineated by the recent star formation. Identification of any propagating star formation could help in finding the starting point of star formation and its origin.

Star formation history of a few field regions were compared with the cluster formation history in their surrounding fields by Subramaniam (2005). Similar studies can be done by combining the UV and the optical data. Complete study of the SMC is required to do similar studies. It is also required to understand ages during which LMC and SMC has had simultaneous star formation, which is an indication of their encounter. This information is necessary to constraint their models of interaction. In the case of the SMC, star forming environments are located in metal poor regions. Characteristics such as upper end of the mass function, upper mass limit of star formation are needed to be established over a range of metallicities. The above data could address these issues. Due to the low resolution of TAUVEX, stars in the dense regions may not get resolved. The integrated flux from such regions can be used to model the star formation rates.

3. Globular cluster systems in the Local Group

The globular cluster systems (GCSs) in external galaxies are very widely studied in the optical. There has been very little study in the UV, only a few objects are observed in M31. The GCSs can be used as a tool to probe the formation history of the parent galaxy. The age and metallicity distribution of the GCS is a good pointer in this direction. These parameters are estimated using particular features in a CMD, since the individual stars can be resolved in a Galactic GC. For GCs in external galaxies one has to rely on their integrated colour or spectra.

Population synthesis models in the UV regime have been made available recently. Though it was realised that the HB stars and the post-AGB stars have a significant contribution in the UV region, population synthesis models were not available till recently (Lee & Lee 2002). The models from Lee & Lee (2002) provide the integrated colour over a wide range, UV to near IR. Comparison of their models with observations indicate that reliable age estimation is not possible using the currently available optical and IR data. Their models indicate that the relation between the metallicity and (FUV-V) colour can in fact be used as an age discriminant.

The data on M 31 GCs indicate that observations of more clusters in this galaxy is required to estimate the age and the metallicity range. The point to be noted here is that the FUV measurements of M31 GCs are not available and the near UV-V colour does not indicate the age range.

It is needed to understand the bimodal colour distribution seen from many early-type galaxies (Larson et al. 2001) as well as some spirals (Forbes, Brodie & Larson 2001). The origin of the red and blue subpopulations and the implications for the formation of their host galaxies remains unclear. The existence of any relative age difference among the subgroups can be identified using FUVV colour.

4. Previous studies and the drawbacks

Previous studies of the GCs have been carried out mainly by UIT and HST. M 31 was observed by UIT (43 clusters in NUV and 4 in FUV). The studies using the HST concentrated on the core of the GCs. In the case of HST, most of the filters have red leaks, which makes the interpretation of the results difficult (Brosch et al. 1999). GALEX has observed M 31 (200 clusters in NUV and 94 in FUV). These represent 50% and 23% completeness for V 19 mag. Need to detect more GCs, and also in other galaxies including the Local Group.

5. Feasibility estimate

The feasibility of detection and study of the above objects is done with the help of the exposure time calculator. Sample clusters: M3 and M13, M3: Dec. = +28: 22: 31.6 M13: Dec. = +36: 27: 36.9. We find that up to V=18, single scan can reach a S/N ratio of 5.0. In the case of V=20.0, tens of scans may be required. If we adopt deeper observations, then this limit is easy to achieve.

Acknowledgement

This talk was presented on behalf of a team including N.K. Rao and Gajendra Pandey.

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