UVIT Observations of UV-Bright stars in Galactic Globular Clusters

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Introduction

Galactic globular clusters (GGCs) constitute old stellar populations of different ages and compositions which are crucial to understand stellar evolution. The UV light of these old stellar populations is dominated by hot stars, such as blue horizontal branch stars (BHBs), blue hook stars (BHk), blue stragglers (BSs), post-AGB stars and hot sub-dwarfs (sdB, sdO). UV emission is strongly dependent on the source temperature, therefore hot BHBs are the strongest contributors to the far-UV flux of old stellar populations. The advantage of observing halo GGCs in UV is that they are less crowded in UV band and the interstellar reddening is very low along the line of sight at high galactic latitudes. In order to study the UV photometric properties of the hot UV sources, we have observed four halo GGCs: NGC4147, NGC4590, NGC5053 and NGC7492 using six filters of *Ultra-Violet Imaging Telescope* (UVIT) on-board Indian satellite *AstroSat*. The UVIT observations enable us to understand the horizontal branch morphology of globular clusters in the far-UV and near-UV wavebands.

Observation Table

Name	Date of Observation	Exposure Time (in seconds)					
		FUV (1300-1800 Å)			NUV (2000-2800 Å)		
		BaF_2	Sapphire	Silica	NUVB15	NUVB13	NUVB4
		1541Å	1608Å	1717Å	2196Å	2447Å	1541Å
NGC7492	19th October 2016	-	-	850	-	3276	3014
NGC4590	9th February 2017	860	-	1406	1221	1739	1607
NGC4147	17th April 2017	1536	1648	1209	-	-	-
NGC5053	14th June 2017	-	1423	217	-	1503	817

Table 1: UVIT observation details of four GGCs. The observation were taken using three FUV and three NUV filters. Mean wavelength (in Å) of each filter is shown in the table.

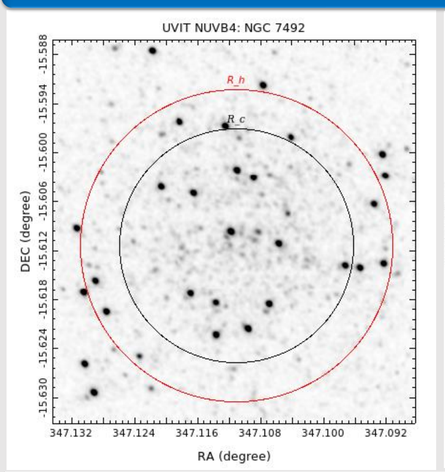
Data Reduction

- We used a customised software package *CCDLAB* (Postma & Leahy 2017) to reduced the UVIT Level1 data into Level2, i.e. to produce good quality of images from raw data-set to do scientific analysis.
- Astrometric correction was done using GAIA DR2 catalogue (Gaia collaboration et al. 2018). We have achieved astrometric accuracy of ~ 0.3" rms on overall images.

Photometry

- We performed crowded field photometry using software package *DAOPHOT* (Stetson 1987) available in image reduction and analysis facility (IRAF).
- We used chi, sharpness and magnitude error criteria to select good photometric sources obtained from *AllSTAR* routine.
- We selected sources with magnitude up to 23.0 AB_{mag} and 22.5 AB_{mag} in NUV and FUV respectively.
- The UVIT observed sources were cross-matched with GAIA DR2 catalogue with a cross-matching radius of 1 arcsec to find optical counterparts of observed sources.

UVIT vs GALEX



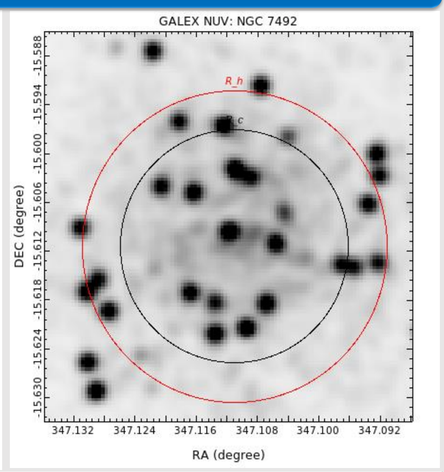
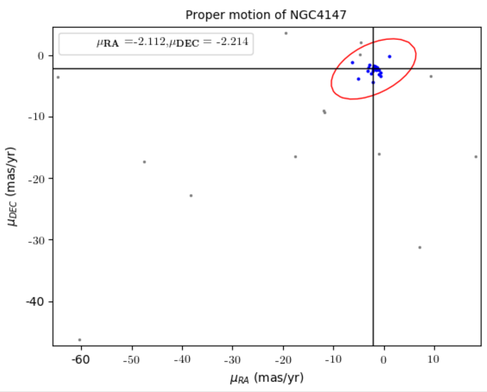


Figure 1: NGC7492 observed with UVIT NUVB4 (PSF ~ 1.5“, *left* image) and GALEX NUV (PSF ~ 4.5“, *right* image) is shown in the figure.

Cluster membership using GAIA Proper Motion



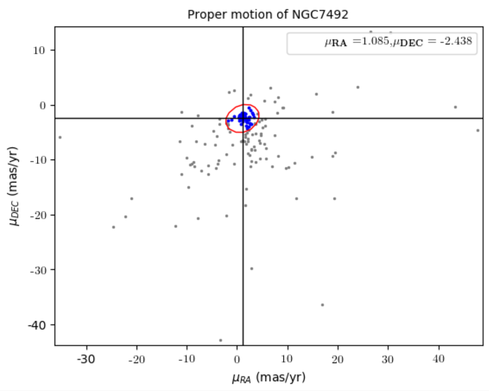
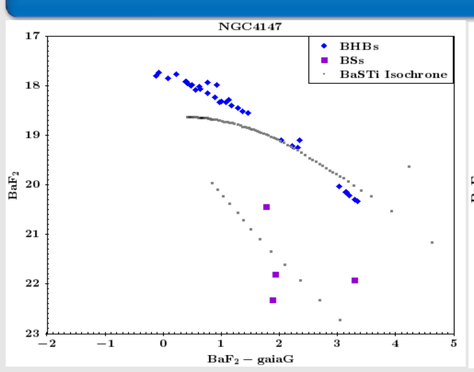


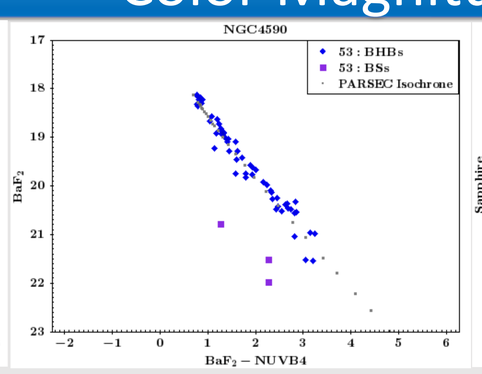
Figure 2: We have shown proper motion in RA (PMRA) and proper motion in DEC (PMDEC) of observed sources with FUV (*left*) and NUV (*right*). We used 1σ gaussian deviation from mean PMRA and mean PMDEC to select sources as cluster members.

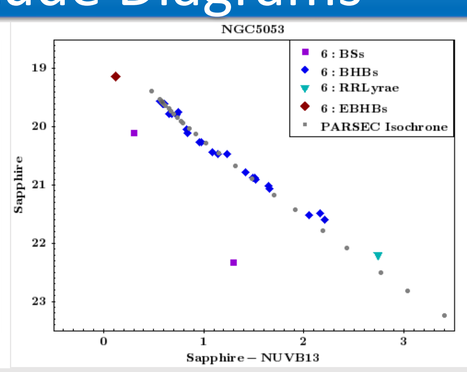
GGCs	PMRA (mas/yr)	PMDEC (mas/yr)	No. of Sources	
			FUV	NUV
NGC4147	-2.112	-2.214	45	-
NGC4590	-2.805	1.819	71	1875
NGC5053	0.604	-1.166	30	539
NGC7492	1.085	-2.438	29	178

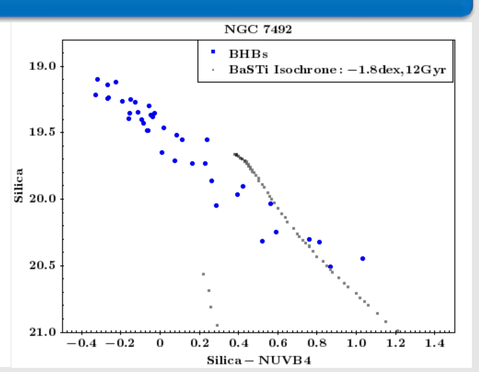
Table 2: Mean proper motion of each cluster and total number of cluster members observed in NUV as well as in FUV are shown in the table.

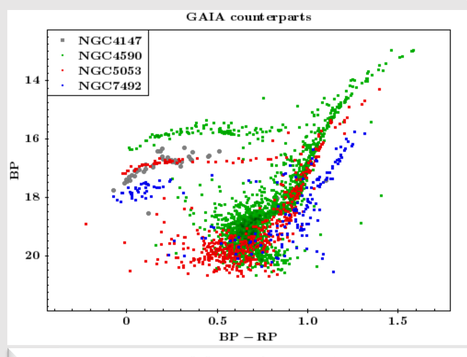
Color Magnitude Diagrams

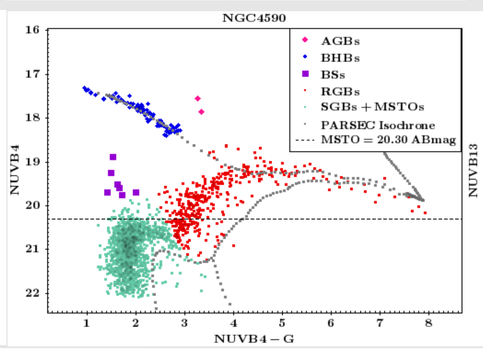


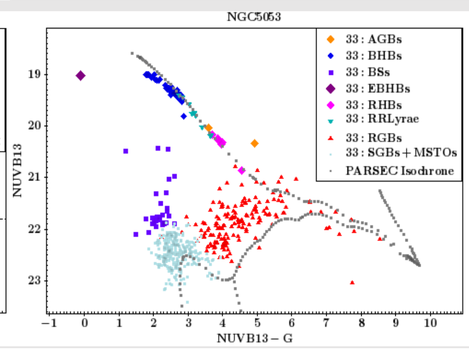












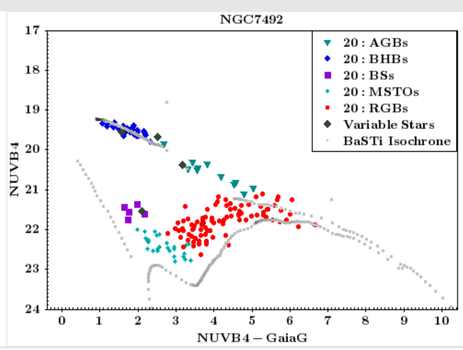


Figure 3: CMDs of four clusters in FUV, NUV and Optical band are plotted to separate out various stellar populations present in clusters (shown in different colors on CMDs, please see *legends*). BaSTI and PARSEC isochrones were fitted on CMDs to verify cluster metallicity, age and distance of each cluster. Cluster parameters are shown in Table 2 and no. of extracted UV bright sources are shown in Table 3.

Cluster Parameters

GGCs	Metallicity [Fe/H]	Distance (kpc)	Age (Gyr)	Isochrone
NGC4147	-1.8	19.3	13.5	BaSTi
NGC4590	-2.23	10.3	12.5	PARSEC
NGC5053	-2.27	17.4	12.3	PARSEC
NGC7492	-1.8	26.3	12.0	BaSTi

Table 3: Cluster parameters of the four GGCs from updated catalogue of GGCs by Harris (2010) were used to fit Isochrones on CMDs .

UV Bright Sources

GGCs	BHBs		BSs		eBHBs
	FUV	NUV	FUV	NUV	
NGC4147	34	-	4	-	-
NGC4590	57	97	3	7	-
NGC5053	25	35	2	29	1
NGC7492	28	28	5	5	-

Table 4: No. of UV sources obtained from CMDs .

Radial Distribution

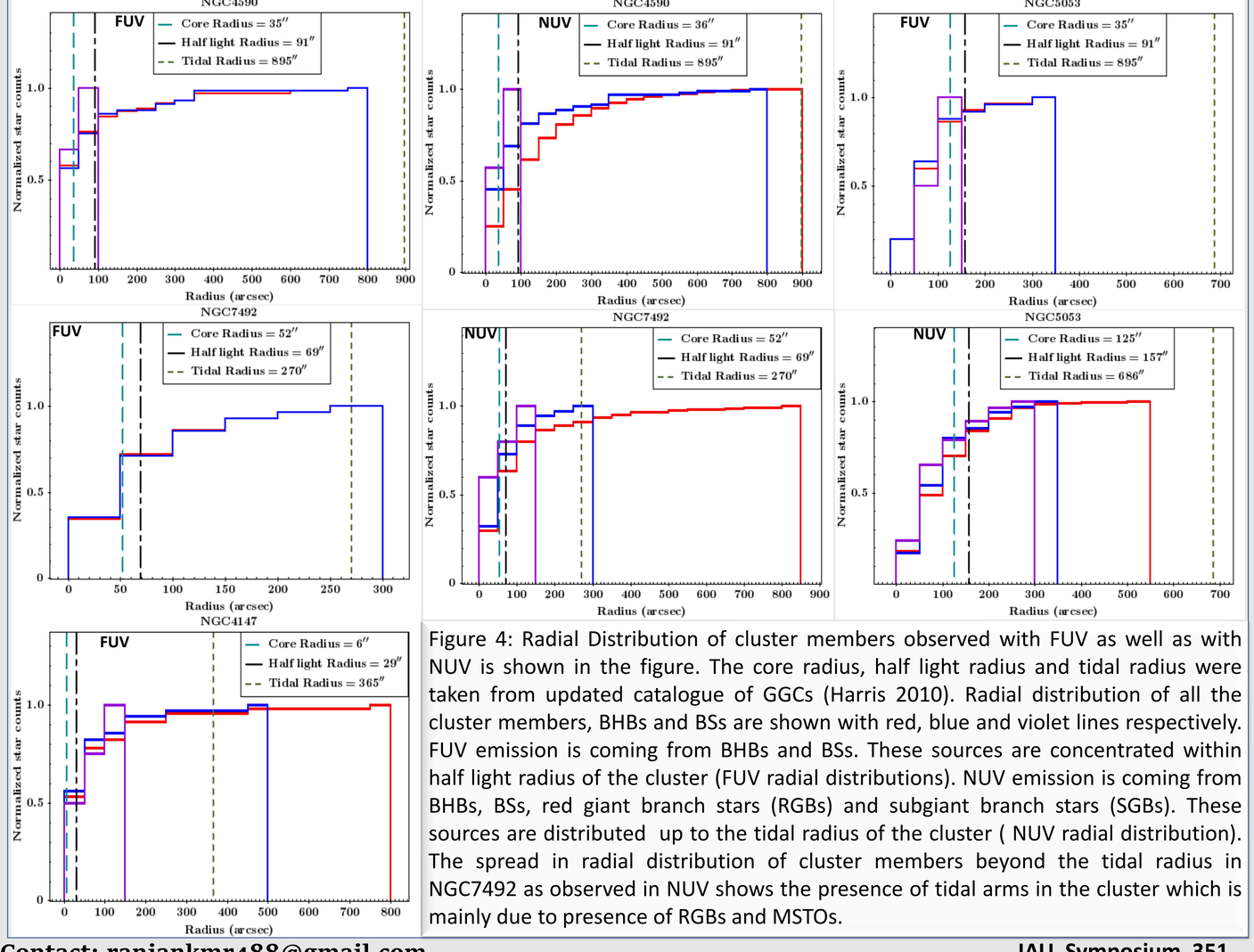


Figure 4: Radial Distribution of cluster members observed with FUV as well as with NUV is shown in the figure. The core radius, half light radius and tidal radius were taken from updated catalogue of GGCs (Harris 2010). Radial distribution of all the cluster members, BHBs and BSs are shown with red, blue and violet lines respectively. FUV emission is coming from BHBs and BSs. These sources are concentrated within half light radius of the cluster (FUV radial distributions). NUV emission is coming from BHBs, BSs, red giant branch stars (RGBs) and subgiant branch stars (SGBs). These sources are distributed up to the tidal radius of the cluster (NUV radial distribution). The spread in radial distribution of cluster members beyond the tidal radius in NGC7492 as observed in NUV shows the presence of tidal arms in the cluster which is mainly due to presence of RGBs and MSTOs.

Temperature Distribution

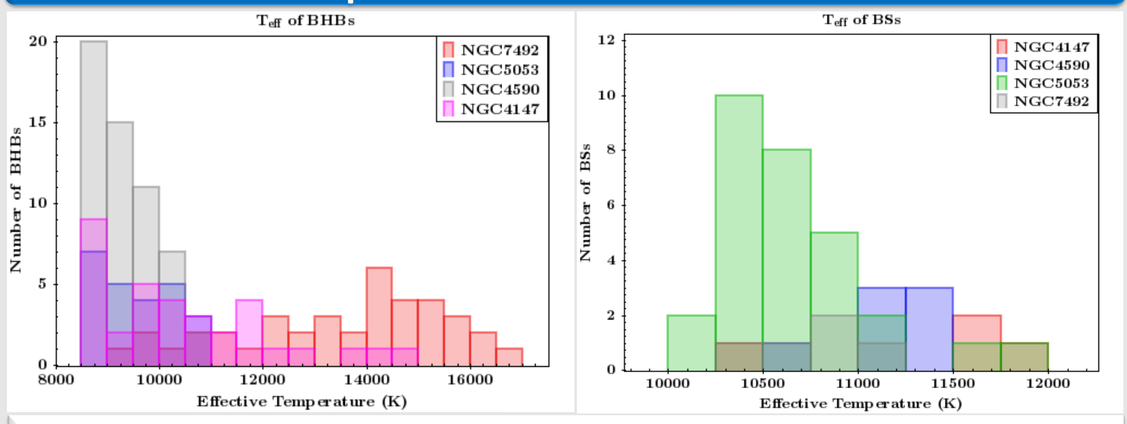


Figure 5: Temperature distribution of BHBs and BSs are shown above. We used Kurucz stellar atmosphere model to obtain color-temperature relation for UVIT and GAIA filters. We used metallicity ([Fe/H]) of -1.5 dex, -2.0 dex and -2.5 dex and log(g) as 4.0 for BHBs and 3.0 for BSs.

Result and Conclusions

- We have studied four halo GGCs NGC4147, NGC4590, NGC5053 and NGC7492 in FUV and NUV bands of UVIT. We found far-UV emission is coming from BHBs and BSs.
- We obtained mean proper motion of each cluster (see table 2) with the help of PMRA and PMDEC of the cluster members using GAIA DR2 proper motion catalogue.
- We separated out various stellar populations present in each cluster using FUV, NUV and Optical CMDs. A list of UV bright sources obtained in each cluster is shown in table 4.
- We obtained the effective temperature of BHBs which varying from 8,000 K to 17,000K and temperature of BSs which varying from 10,000K to 12,000K.
- We found most of BHBs and BSs are concentrated within and nearby core of the cluster. We found presence of tidal arm in NGC7492 in NUV but not in FUV.

References

Castelli F., Kurucz R. L., 2003, in Piskunov N., Weiss W. W., Gray D. F., eds, IAU Symposium Vol. 210, Modelling of Stellar Atmospheres. p. A20 (arXiv:astro-ph/0405087)
Gaia Collaboration et al., 2018, A&A, 616, A12
Harris W. E., 2010, arXiv e-prints
Postma J. E., Leahy D., 2017, PASP, 129, 115002
Stetson P. B., 1987, PASP, 99, 191

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