# Classification and Properties of Milky Way Sources from the GALEX UV Surveys

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## ABSTRACT

We used Galaxy Evolution Explorer (GALEX) imaging survey data matched to the Sloan Digital Sky Survey (SDSS) in overlapping areas to explore the nature of the UV sources. We classify the sources by comparing their seven band photometry (GALEX far-UV, near-UV, SDSS $u$, $g$, $r$, $i$, $z$ ) to model colors computed for different astrophysical objects, taking into account the effects of extinction. The initial sample covers mostly high galactic latitudes, and includes about 2 million sources. Based on our stellar models, we estimate that the GALEX surveys can detect hot White Dwarfs throughout the Milky Way halo (down to an estimated radius of $0.04R_\odot$ at the depth of the Medium Imaging Survey), providing an unprecedented improvement on the census of such objects in the Galaxy. Their observed surface density is consistently represented by the Milky Way models. Optical spectra available for a large subsample confirm the classification for the candidates selected from the GALEX photometry with about 97% purity for single hot stars and between 45-31% for binaries containing a hot WD and a cooler companion.

*Key words:* UV imaging, UV surveys, hot stars, Milky Way structure, optical surveys

## 1. Survey Data. Sky Coverage.

We used a database obtained by matching the GALEX first data release GR1 (*Medium Imaging Survey*, MIS and *All-sky Imaging Survey*, AIS) and SDSS DR3 catalogs. Details can be found in Bianchi et al. (2006). One important issue in the analysis of matched catalogs is to first appreciate the relative contributions of various sources at ultraviolet wavelengths and their respective surface density. With an instrumental field of view of 1.2 degrees and frequent overlapping observations, we needed first to calculate the unique area of overlap bewtween the GALEX and SDSS surveys. The Hierarchical Triangular Mesh (HTM) partition of the SDSS/GALEX archive could not be used to compute the area coverage taking into account overlap between GALEX fields, and common areas of GALEX-SDSS fields, due to the HTM's intrinsic inability to return accurate areas, and an error in the areas and vertices of the triangular tassels, that prevented calculation of exact areas of the HTM tassels. We have therefore built a different partition of the sky using a convenient geometry, and determined the areas of unique sky coverage of our matched catalogs. The overlapping areas are 363 deg$^2$ for the GALEX AIS (622 fields) and 86 deg$^2$ for the GALEX MIS (122 fields).

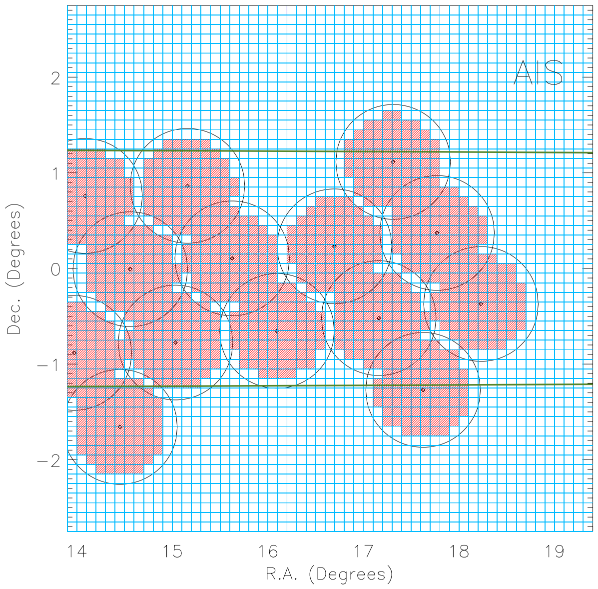


Figure 1: Illustration of our calculation of the unique area of overlap between GALEX fields (round) and SDSS (a SDSS strip is outlined in green/grey). The blue/gray grid represents our partition of the sky. The red/filled tassels are counted to determine the area of overlap between the surveys. To exclude artifacts, we only used the central (1° diameter) portion of the GALEX fields; this is reflected in our calculation of the area coverage.

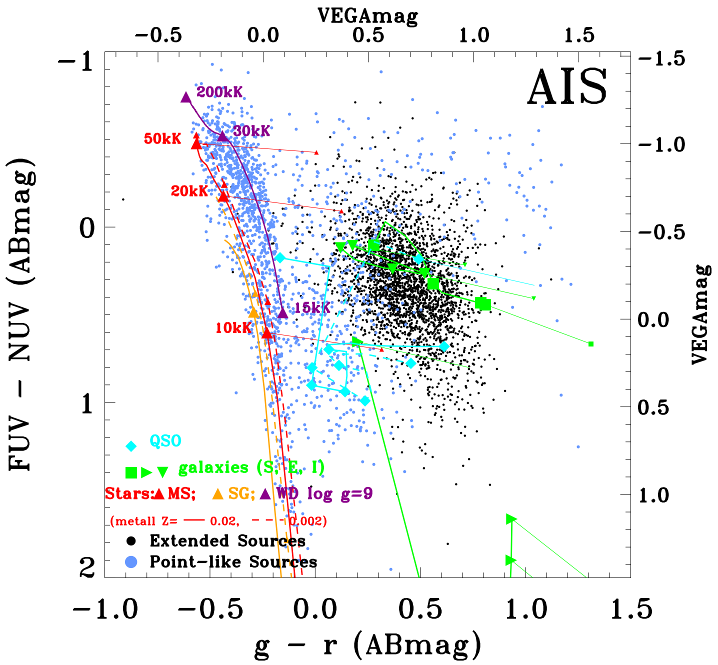


Figure 2: Sample color-color diagram (adapted from Bianchi et al. 2006) including GALEX (FUV, NUV) and optical photometry. Blue/grey dots: observed *point-like* sources i.e. stars or QSOs; black dots: *extended sources* (galaxies). Model colors: stellar models as a function of $T_{\rm eff}$ for three gravities (supergiants, main sequence, and log g=9; note the clustering of most hot sources around the high gravity stellar locus, purple models), QSOs as a function of redshift and galaxy colors as a function of age (ellipticals, irregulars, spirals). Reddening of E(B-V)=0.5 is indicated with lines connecting large symbols (intrinsic colors) to smaller symbols (reddened colors). Binaries (WD+cool star) are blue/grey points seen above the galaxies, with blue FUV-NUV color but redder optical color than a WD.

## 2. The catalogs. The models. Classification of the UV Sources

The final catalog of UV sources was created by eliminating multiple matches between the GALEX and SDSS sources, and eliminating duplication of GALEX sources (all GALEX observations of the sources observed in more than one field are included in the on-line catalog in the MAST archive). In figures 2 and 3 we compare observed colors from our matched catalog with synthetic colors from theoretical models calculated for different astrophysical objects. Theoretical stellar colors for main sequence and supergiant stars are derived from a number of stellar libraries for a total of six metallicity values (two cases shown in the color-color diagrams: solar, and one tenth solar). White dwarf (WD) models were calculated by us with the TLUSTY code of Hubeny & Lanz (2005), for different gravities and solar, pure-H and pure-He abundances. To define the locus of galaxies, we computed broad-band colors from templates for Ellipticals, Spirals and Irregulars, calculated using the GRAZIL code (Bressan et al. 1998, Silva et al. 1998). We show in the figures these model colors as a function of age. For QSO colors we used both a composite model of Francis et al. (1991) revised as described in Bianchi et al. (2005), as well as the SDSS average template, extrapolated at long and short wavelengths. See Bianchi et al. (2006) for more details. We show sample color-color diagrams including data from the All-Sky Imaging Survey (AIS) that has typically ∼100 second exposures with a 5 $\sigma$ NUV limiting magnitude of $m_{\rm NUV}$∼20.8, and from the Medium Imaging Survey (MIS), with typical ∼1500 second exposures and limiting magnitude of $m_{\rm NUV}$∼22.7 in the AB system.

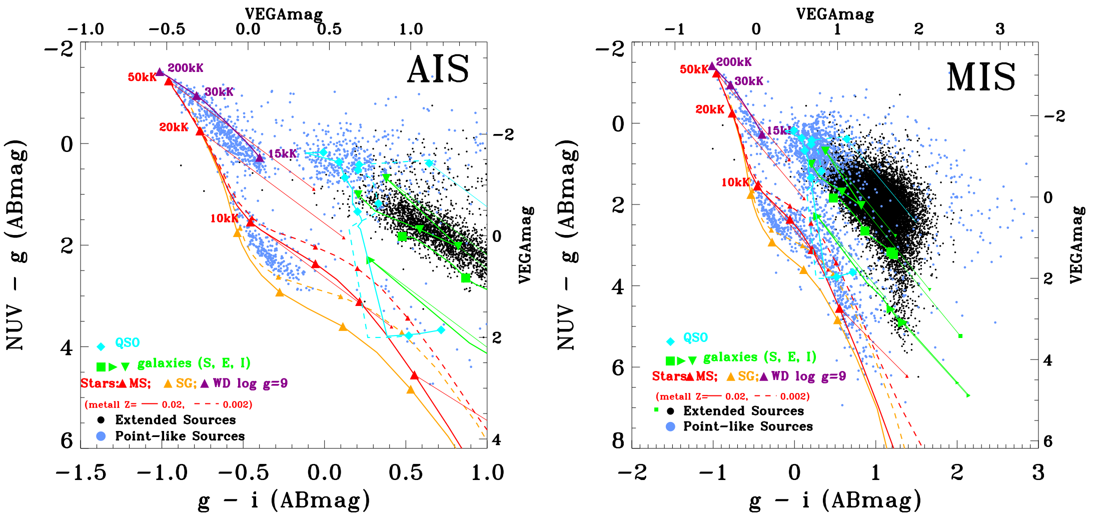


Figure 3: In this color-color diagram (symbols as in previous Figure) stars and galaxies are well separated, and the low-$z$ QSOs are in between. At the AIS depth (left), the number of Galactic and extra-galactic sources is about equal. The number of extragalactic objects increases at fainter magnitudes (right). Note that we used a different scale for the axes, to show a larger range of parameters in the MIS panel. The MIS data used in this paper cover a smaller area than the AIS, hence fewer hot sources are seen.

## 3. Conclusions and Summary

Results include the identification of several thousand low-redshift QSOs, and catalogs of Milky Way hot objects, such as subdwarfs and hot White Dwarfs, significantly larger than previous catalogs. The surface densities, uncorrected for completeness, are shown for the latter in Figure 4, where we also plot predictions for the observed density of such objects calculated with the Besançon Milky Way model (Robin et al. 2003, 2004). We assumed a standard diffuse absorption of $A_{\rm V}$=0.7/kpc, and calculated the predictions down to $g<$ 24, with no population age selection. The sample shown covers mostly high and intermediate galactic latitudes. Sources from all the GALEX GR1 fields overlapping with SDSS DR3 are shown in the figures. The location of the fields is shown in Figure 1 of Bianchi et al. (2006).

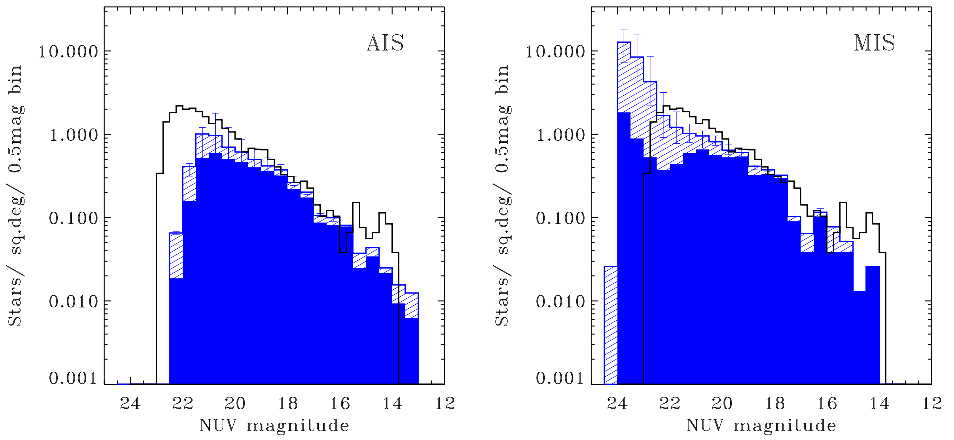


Figure 4: The NUV-band density of hot stars selected from the FUV-NUV (GALEX) color. Solid-color histograms show "single" hot WD candidates, dashed histograms include both single-WD and objects with optical colors redder than what correponds to a hot WD with the observed UV color. These include binaries with a hot WD and possibly also extragalactic objects contaminating the sample, as suggested by their number increasing at fainter magnitudes (MIS). The black line shows the predictions by the Milky Way model. The AIS is better sampled because it covers a larger area, but the MIS extends to fainter magnitudes (see Bianchi et al. 2006).

Follow-up work include: (1) SED fitting for all objects, and spectral fitting for a subsample, to determine physical parameters and extinction; (2) kinematical information; (3) extension to lower galactic latitudes to study the structure of these stellar populations in the Milky Way. See http://dolomiti.pha.jhu.edu for updates.

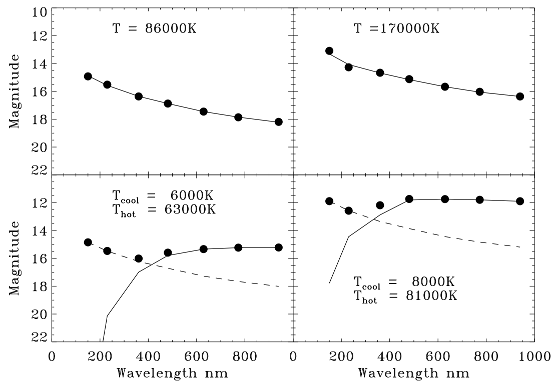


Figure 5: Examples of SED fitting (GALEX FUV, NUV, and five SDSS optical bands) with model magnitudes for stars (main sequence and WD model grids). The observed magnitudes (large dots) in the AB system are plotted at the effective wavelength of the broad-band filters. Errors are smaller than the dots. The best fit model is shown with a line connecting the model magnitudes. The two top panels show hot single WDs, the lower panels show examples of binaries containing a main sequence cooler star (solid line model) and a WD (dashed line model). $T_{\rm eff}$ values from the fits are indicated. Extinction is determined concurrently during the fitting process.

*Acknowledgements:* We gratefully acknowledge NASA's support for construction, operation and data analysis of the GALEX mission, developed in cooperation with the French CNES and Korean Ministry of Science and Technology.

## References


[1] Bianchi, L. et al. , *Astrophysical Journal*, 619, L27, 2005

[2] Bianchi, L. et al. , *Astrophysical Journal Supplements*, in press, 2006

[3] Bressan, A., Granato, G.L., and Silva, L. , *A.& A.*, 332, 135 1998

[4] Francis, P. J., et al. , *Astrophysical Journal*, 373, 465, 2001

[5] Hubeny, I., and Lanz, T. , *Astrophysical Journal*, 439, 875, 1995

[6] Robin, A.C. et al. , *A.& A.*, 409, 523, 2003

[7] Robin, A.C. et al. (erratum), *A.& A.*, 416, 157, 2004

[8] Silva, L. et al. , *Astrophysical Journal*, 509, 103, 1998