
The Galaxy Evolution Explorer (GALEX). Its legacy of UV surveys, and science highlights

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Abstract

The Galaxy Evolution Explorer (GALEX) imaged the sky in the Ultraviolet (UV) for almost a decade, delivering the first sky surveys at these wavelengths. Its database contains far-UV (FUV, $\lambda_{eff} \sim 1528\text{\AA}$) and near-UV (NUV, $\lambda_{eff} \sim 2310\text{\AA}$) images of most of the sky, including deep UV-mapping of extended galaxies, over 200 million source measurements, and more than 100,000 low-resolution UV spectra. The GALEX archive will remain a long-lasting resource for statistical studies of hot stellar objects, QSOs, star-forming galaxies, nebulae and the interstellar medium. It provides an unprecedented road-map for planning future UV instrumentation and follow-up observing programs in the UV and at other wavelengths.

We review the characteristics of the GALEX data, and describe final catalogs and available tools, that facilitate future exploitation of this database. We also recall highlights from the science results uniquely enabled by GALEX data so far.

Keywords Ultraviolet: surveys; Astronomical Data Bases: catalogs; Stars: post-AGB; Stars: White Dwarfs; Galaxies: Milky Way; Ultraviolet: galaxies; Ultraviolet: QSOs

1 Introduction. GALEX instrument and data

The Galaxy Evolution Explorer (GALEX), a NASA *Small Explorer* Class mission, was launched on April 28, 2003 to perform the first sky-wide Ultraviolet surveys, with both direct imaging and grism in two broad bands,

FUV ($\lambda_{eff} \sim 1528\text{\AA}$, $1344\text{-}1786\text{\AA}$) and NUV ($\lambda_{eff} \sim 2310\text{\AA}$, $1771\text{-}2831\text{\AA}$). It was operated with NASA support until 2012, then for a short time with support from private funding from institutions; it was decommissioned on June 28, 2013. ¹

GALEX's instrument consisted of a Ritchey-Chrétien-type telescope, with a 50 cm primary mirror and a focal length of 299.8cm. Through a dichroic beam splitter, light was fed to the FUV and NUV detectors simultaneously. The FUV detector stopped working in May 2009; subsequent GALEX observations have only NUV imaging (Figure 1).

The GALEX field of view is $\approx 1.2^\circ$ diameter ($1.28/1.24^\circ$; FUV/NUV), and the spatial resolution is $\approx 4.2/5.3''$ (Morrissey et al. 2007). For each observation, the photon list recorded by the two photon-counting micro-channel plate detectors is used to reconstruct an FUV and an NUV image, sampled with virtual pixels of $1.5''$. From the reconstructed image, the pipeline then derives a sky background image, and performs source photometry. Sources detected in FUV and NUV images of the same observation are matched by the pipeline with a $3''$ radius, to produce a merged list for each observation (Morrissey et al. 2007).

To reduce localized response variations, in order to maximize photometric accuracy, each observation was carried out with a $1'$ spiral dithering pattern. The surveys were accumulated by painting the sky with contiguous *tiles*, with series of such observations. A trailing mode was instead used for the latest, privately-funded observations, to cover some bright areas near the MW plane. These latest data currently are not in the public archive.

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At the end of the GALEX mission, the AIS survey was extended towards the Galactic plane, largely inaccessible during the prime mission phase because of the many bright stars that violated high-count-rate safety limits. A survey of the Magellanic Clouds (MC), also previously unfeasible due to brightness limits, was completed at the end, relaxing the initial count-rate safety threshold. Because of the FUV detector’s failure, these extensions include only NUV measurements (Figure 1).

Much of this short review concerns GALEX’s final data products (from the point of view of science applications; technical documentation is available elsewhere). This choice, at the price of confining science results to a few highlights (Section 7), responds to various inquiries and requests, timely as the almost entire (and final) database is becoming available, and new tools, which will support new investigations.

2 GALEX surveys

GALEX has performed sky surveys with different depth and coverage (Morrissey et al. 2007, Bianchi 2009). The two detectors, FUV and NUV, observed simultaneously as long as the FUV detector was operational; note however that there are occasional observations in which one of the two detectors was off (mostly FUV) due to brief shut-downs, even in the early part of the mission, and in some observations the FUV and NUV exposure times differ (see Bianchi et al. 2014a, in particular their Table 1 and Fig. 2).

The surveys with the largest area coverage are the All-Sky Imaging survey (AIS) and the Medium-depth Imaging Survey (MIS). Exposure times slightly vary within each survey, around the respective nominal exposures of 100 sec for AIS (corresponding to a depth of $FUV \sim 20/NUV \sim 21$ ABmag) and 1500 sec for MIS (corresponding to a depth of ~ 22.7 ABmag in both FUV and NUV). The Deep Imaging Survey (DIS) accumulated exposures of the order of several tens of thousand of seconds in selected fields (for a 30,000 sec exposure, the depth reached is $\sim 24.8/24.4$ ABmag in FUV/NUV). The “Nearby Galaxies Survey” (Bianchi et al. 2003, Gil de Paz et al. 2007) covered initially 436 fields at MIS depth, but hundreds of additional nearby galaxies were mapped by GALEX, as part of MIS or other surveys. Other observations were obtained for guest investigator (GI) programs, and for other targeted regions such as, for example, the Kepler field.

The GALEX database at the end of the mission (2013, data release GR7) contained 214,449,551 source measurements, most of which (210,691,504) from observations with both detectors on. However, a small number of additional datasets obtained throughout the mission, which were not previously included in the archive,

were now reprocessed as part of the MAST effort to finalize the database, therefore the final archive will contain a few more entries. Figure 1 shows the sky coverage of all GALEX observations performed in both FUV and NUV (right), and in NUV regardless of FUV-detector status (left). The map does not include the last NUV trailed observations (CLAUSE dataset).

3 GALEX database and science catalogs

GALEX data can be obtained from the NASA MAST archive at <http://galex.stsci.edu>. They include images (direct imaging or grism) and associated photometry from the pipeline, or extracted spectra. High-level science catalogs (HLSP) are also available, such as those described below, which greatly facilitate some investigations.

Several objects have multiple measurements in the database, due to repeated observations of the same field, or overlap between fields. For studies involving UV-source counts, one needs to eliminate repeats, as well as artefacts. Therefore, we have constructed catalogs of *unique* UV sources, eliminating duplicate measurements of the same object. Separate catalogs were constructed for AIS and MIS, because of the ~ 2 -3 mag difference in depth. The most recent version of such catalogs is published by Bianchi et al. (2014a, hereafter “BCS”, see Appendix A); BCS also presented sky maps showing density of UV sources with various cuts. A previous version, based on data release GR5, was published by Bianchi et al. (2011a, b), who extensively discuss criteria for constructing GALEX source catalogs and matched catalogs between GALEX and SDSS, GSC2, and more. Earlier work on source classification was presented by Bianchi et al. (2007, 2005), Bianchi (2009).

In the GALEX database, the non-detection value for the FUV magnitude, $FUV = -999$, means either that the detector was on but the source was too faint to be measured in FUV, or the FUV detector was off. In order to examine and classify sources by colors, and relative fraction of sources with different colors, Bianchi et al. (2014a, 2011a) restricted the catalogs to those observations in which both detectors were exposed. In addition, these catalogs were conservatively restricted to measurements within the central 1° diameter of the field of view, to exclude the outer rim, where distortions prevent position and photometry of sources to be derived accurately, and counts from rim’s spikes cause numerous artefacts to intrude the source list. For more details we refer to the original BCS publication.

The BCS catalogs include 28,707 AIS fields with both FUV and NUV exposed, covering a unique area

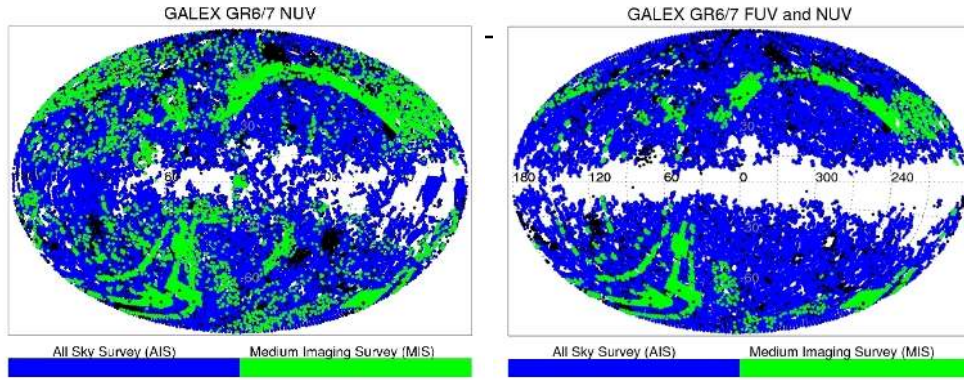


Fig. 1 Sky coverage, in Galactic coordinates, of the GALEX imaging. The surveys with the largest area coverage are AIS (blue) and MIS (green). Observations from other surveys are shown in black (figure adapted from Bianchi et al. 2014a). Data from the privately-funded observations at the end of the mission are not shown. Left: fields observed with at least the NUV detector on; right: fields observed with both FUV and NUV detectors on. The latter constitute the BCScat's.

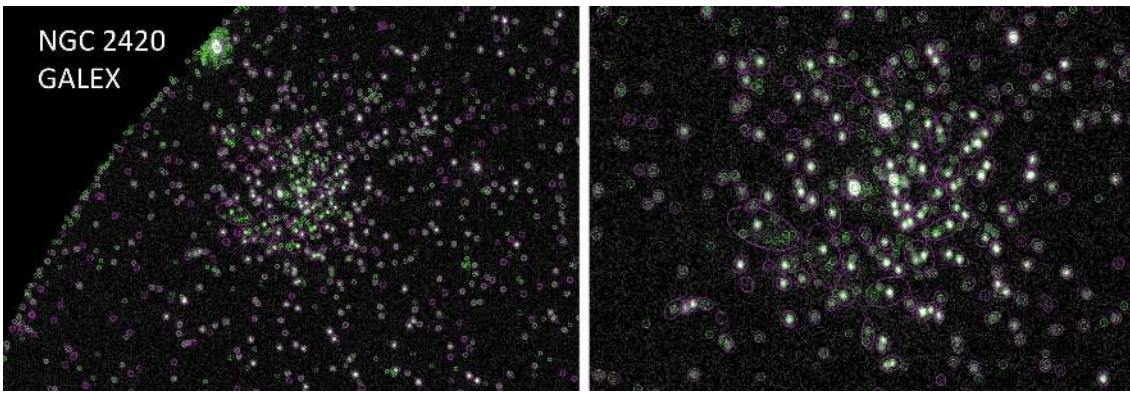


Fig. 2 Portion of a GALEX field with the stellar cluster NGC2420 (de Martino et al. 2008). Green circles mark sources detected with our photometry, the purple contours mark sources as defined by the GALEX pipeline. The right-side image is an enlargement of the crowded region. The left image also includes a section of the field's outer edge, showing how numerous rim artefacts intrude photometric source detections. The rim is excluded from the BCS catalogs.

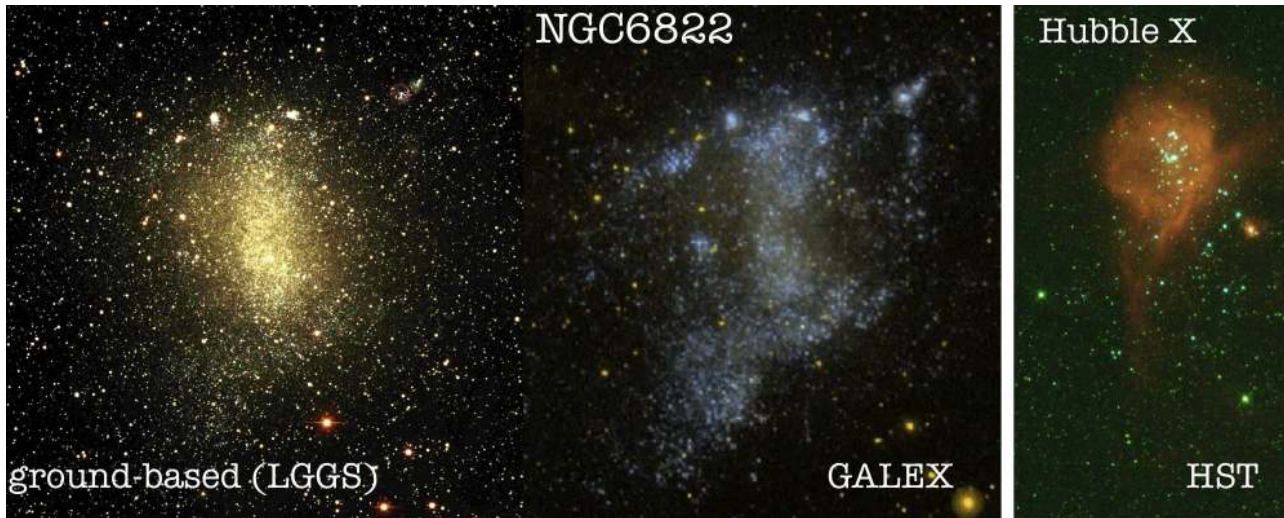


Fig. 3 GALEX images (FUV: blue, NUV: yellow) and optical color-composite images of NGC6822 in the Local Group (Efremova et al. 2011, Bianchi et al. 2011c, 2012) and HST view of one of its most prominent HII regions, Hubble X (Hubble data from Bianchi et al. 2001). Hubble X is one of the two bright knots in the upper part of the galaxy in GALEX and ground-based images; its core is resolved into an association of young stars with HST ($0.1''$ resolution, or ≈ 0.2 pc at a distance of 460 kpc).

of 22,080 square degrees when restricted to the central 1° of each field, and 3,008 MIS fields (2,251 square degrees). An updated version (MIS) will be posted on the same site, including the newly recovered data which will pass final quality test. The area coverage at MIS depth was significantly increased after the FUV detector failed, therefore additional data with NUV-only measurements exist (Figure 1). The BCS catalogs (“BCScat” in MAST casjobs), for AIS and MIS, include **all GALEX observations with both FUV and NUV detectors exposed**, up to the latest, and final, release (GR7). They contain ≈ 71 and ≈ 16.6 Million sources respectively.

4 Using GALEX Data: Notes and Caveats

4.1 Bright sources

High count-rates from UV-bright sources cause non-linearity in the response, or saturation, mostly due to the detector’s dead-time correction. Morrissey et al. (2007) showed that non-linearity, at a 10% rolloff, sets in at $109 \text{ counts s}^{-1}$ for FUV and $311 \text{ counts s}^{-1}$ for NUV. These countrates correspond to FUV=13.73 ABmag ($\sim 1.53 \cdot 10^{-13} \text{ erg s}^{-1} \text{ cm}^{-2} \text{ \AA}^{-1}$) and NUV=13.85 ABmag ($\sim 6.41 \cdot 10^{-14} \text{ erg s}^{-1} \text{ cm}^{-2} \text{ \AA}^{-1}$). A correction for non-linearity is applicable over a limited range, beyond which the measured countrates saturate and the true source flux is no longer recoverable (see their Figure 8). The bright-object limit during most of the mission was $30,000 \text{ counts s}^{-1}$ per source, corresponding to $\sim 9^{\text{th}}$ ABmag for NUV ($\sim 7 \cdot 10^{-12} \text{ erg s}^{-1} \text{ cm}^{-2} \text{ \AA}^{-1}$) and $5,000 \text{ counts s}^{-1}$ per source in FUV ($\sim 9.6 \text{ ABmag}$, $\sim 6 \cdot 10^{-12} \text{ erg s}^{-1} \text{ cm}^{-2} \text{ \AA}^{-1}$). Such limits were relaxed at the end of the mission.

The calibration of GALEX fluxes is tied to the UV standards used for HST (Bohlin 2001). However, all but one of the white dwarf (WD) standard stars have GALEX count-rates in the non-linear regime. Camarota & Holberg (2014) derived an empirical correction to the GALEX magnitudes in the non-linear range, using a well studied sample of WDs with UV spectra and models. Their correction is valid in the bright-flux regime as specified in their work, but would diverge if extrapolated to fainter fluxes. Possible further refinements (Bohlin & Koester 2008) have not yet been explored to our knowledge.

4.2 Crowded fields

Source detection and photometry performed by the GALEX pipeline become unreliable where sources are too crowded relatively to the instrument’s resolution.

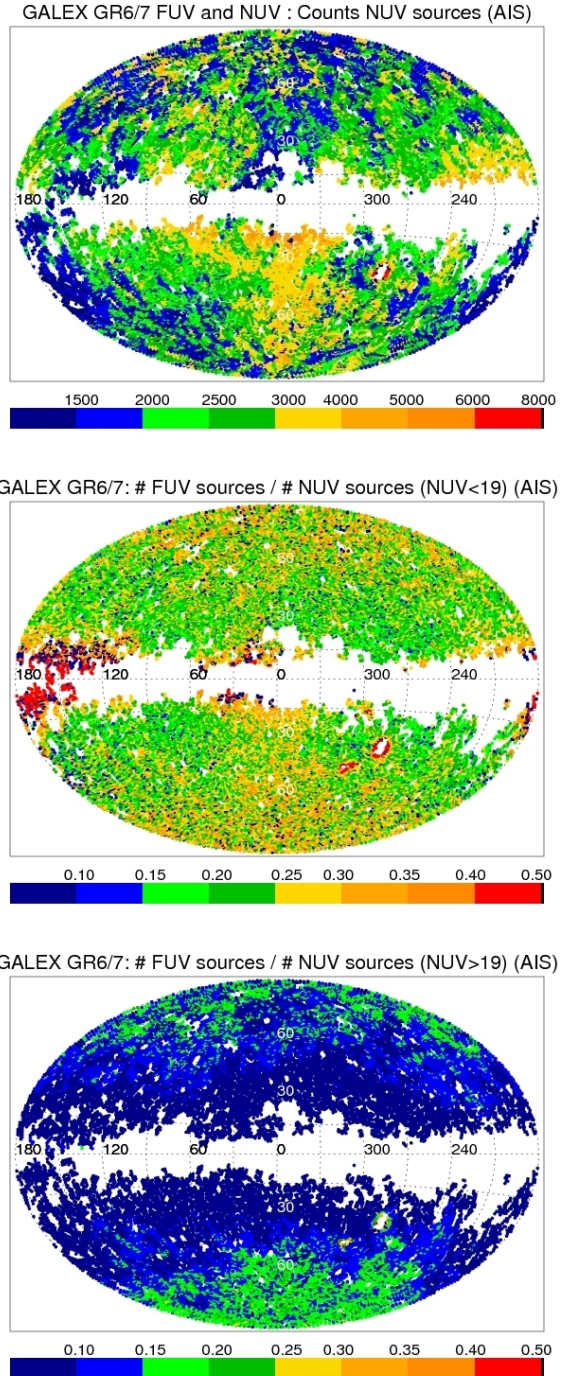


Fig. 4 Counts of NUV sources per square degree (top), from the AIS: part of the structure is due to inhomogeneous exposure times, part is real. Fraction of FUV over NUV detections, in the AIS catalogs, for sources brighter (middle) and fainter (bottom) than NUV=19 ABmag. The latter are dominated by extragalactic sources, the brighter sources contain a high fraction of Milky Way hot stars (see also Bianchi et al. 2011a,b). Maps in Galactic coordinates, adapted from Bianchi et al. 2014a)

Examples include stellar clusters in the Milky Way (Figure 2), fields in or near the Magellanic Clouds (Section 6), and nearby extended galaxies. We note that, in some crowded fields, even sources with separation comparable or larger than the image resolution are sometimes not resolved; see Figure 2 as an example, or Figure 3 of Simons et al. (2014) for a Magellanic Cloud field. In some cases, the local background may compound the crowding around clustered sources. The pipeline, designed for the general purpose of detecting both point-like and extended sources (such as galaxies, with an elliptical shape), may interpret two or more nearby point sources as one extended source; this seems to occur in crowded regions, as Figure 2 shows.

In extended galaxies, because UV fluxes are sensitive to the youngest, hottest stars, which are typically arranged in compact star-forming complexes (see Fig. 3), UV-emission peaks are identified by the pipeline as individual sources. Often, more complex measurements are needed in extended galaxies, with special care to background subtraction (e.g. Kang et al. 2009, Efremova et al. 2011, Bianchi et al. 2011b).

For consistency, all measurements in the master database with FUV and NUV data were used to produce the GALEX BCS catalogs. Large galaxies, stellar clusters, and MC fields were not excluded, to avoid introducing gaps in the catalogs, because what areas must be excluded depends on the specific science application. It is the choice (and responsibility) of the user to exclude known crowded regions when using large datasets, or check the photometry if such regions cannot be excluded, and use specific custom-vetted photometry catalogs for these particular areas when possible.

4.3 Calculation of survey area coverage

Overlaps or gaps may exist between contiguous fields. When unique-source catalogs are used, if field overlaps occur in the subset of choice, the exact area coverage must be calculated. Different tools are or will soon be available, using heal-pixels or tesserae, in the catalogs' web sites (<http://dolomiti.pha.jhu.edu/uvsky> for *BC-Scat*).

5 Variable sources

Serendipitous variability searches in the GALEX database include essentially two possibilities. On one hand, one can compare photometry of objects having repeated observations, either in consecutive orbits or spaced in time during GALEX's several years of operation. The time intervals sampled are the gaps between different

observations, and each measurement is integrated over the entire exposure of its observation. This random cadence is by necessity not optimized for detecting specific periodicities or time-scales, but its serendipitous nature enables a vaster exploration than what a single dedicated program can afford. It was exploited by a number of works, e.g. Welsh et al. (2006, 2007, 2011), Wheatley et al. (2012), Gezari et al. (2013). A catalog of GALEX sources showing conspicuous variations ($\Delta\text{NUV} > 0.6\text{mag}$, $\Delta\text{FUV} > 0.4\text{mag}$) has been compiled by Conti et al. (2014). Over 400,000 sources with $\text{NUV} \leq 21$ ABmag were found to satisfy these criteria, >7,000 of which have over 30 measurements; they include RR Lyrae, eclipsing binaries, flare stars, QSOs, and more.

In the near future, it will also be possible to investigate variability on time scales shorter than the integration time of each observation. By the time this paper will go to press, a new tool will be available, 'gPhoton' (on the MAST web site). It allows users to analyze the entire photon list from an observation, and to extract photometry with user-defined short integration times, within the exposure. Such tool opens new possibilities for studies of short time variations of bright sources, such as the flare from an M-type dwarf discovered by Robinson et al. (2005), that displayed a 1000-fold increase in FUV flux within 200 seconds.

6 GALEX survey of the Magellanic Clouds

GALEX has surveyed the Magellanic Clouds (MC) and their surrounding areas including the Magellanic Bridge (MB). The central regions are only mapped in NUV; because they are very UV-bright, they were avoided during the main mission for risk of detector's damage; later the FUV detector had failed. The coverage is shown in Fig. 5 (insert): it shows a few more fields than Simons et al. (2014) as we are trying to recover data that initially did not pass the quality check and are not yet ingested in the archive. The 5σ depth of the NUV imaging varies between 20.8 and 22.7 ABmag. GALEX imaging provided the first sensitive view of the entire content of hot stars in the Magellanic System, revealing young populations even in sites with extremely low star-formation rate surface density, such as the MB. As discussed in Section 4.2, source crowding limits the quality of source detection and photometry from standard pipeline processing. Therefore, custom PSF-fitting photometry of the GALEX data in the MC survey region was performed.

There are ~ 400 fields within $< 10^\circ$ from the SMC and $\gtrsim 1250$ (depending on quality cut) fields within

$<15^\circ$ from the LMC center, of which $\gtrsim 865$ with AIS-depth exposures, and the rest with longer exposures. The latter set (384 non-AIS fields in the LMC, median exposure of 730 seconds), was presented by Simons et al. (2014). A total of 17 million source detections was reduced to about 11 millions by excluding sources farther than 0.55° from the field center, and sources with roundness/sharpness deviating by $>2\sigma$ from the median PSF. These measurements were merged into a catalog of about 6 million unique sources. This subset from the deeper exposures (albeit mostly in NUV only) encompasses the classical optical extent of the LMC. The fields trace from the lowest hot-star density in the periphery to the most crowded inner sites, from ~ 430 to $\sim 200,000$ stars/kpc 2 brighter than NUV=19 ABmag ($10\times$ more if no magnitude cut is applied).

The final catalog (Thilker et al. 2014a,b) will be posted incrementally on <http://dolomiti.pha.jhu.edu/uvsky>, together with science analysis results. Figure 5 shows also an example of SED model analysis of GALEX sources matched to existing optical data, to characterize hot stars and dust extinction, and to search for evolved stars. Deeper optical observations are planned, to better complement the GALEX catalogs.

7 Highlights of GALEX science results

GALEX was a Small Explorer with a data-rate higher than Hubble. The amount of accumulated data, and the lack of previous wide-field surveys in the UV, yielded varied and numerous results, by now too many to be summarized in one paper. We mention here only a few highlights, some were unexpected discoveries and opened new lines of investigation.

The main science driver for a UV sky survey, at the time when GALEX was designed (selected in 1997), was to measure the history of star-formation in the red-shift range 0-2, about 80% of the life of the universe, when most stars were formed, and when star-formation appeared to have undergone significant evolution (downsizing). See e.g. Salim et al. (2007), Martin et al. (2007), Weyder et al. (2009), Marino et al. (2010, 2013), Lee et al. (2011), Hutchings et al (2010b) to cite only a few works. Among the unexpected findings enabled by GALEX's wide-field, deep UV imaging, was the discovery of tenuous, extended structures of recent star formation, in spiral galaxies, where such extended UV disks (XUVD) stretch up to $5\times$ the optical size of the galaxies (Thilker et al 2005, 2007a; Gil de Paz 2005 and subsequent works). XUVD are found in about 30% of the galaxies. Young stellar populations, mostly in

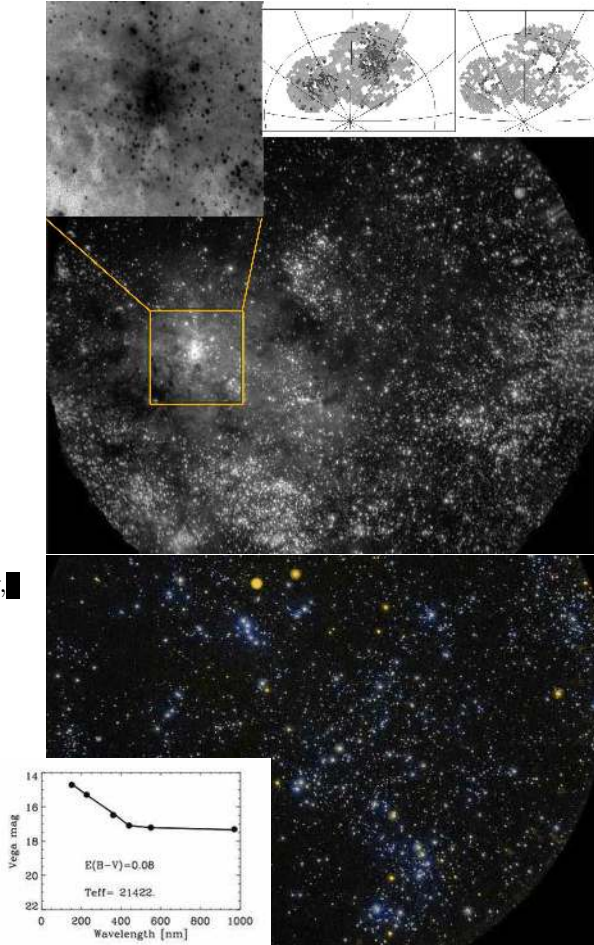


Fig. 5 The top-right insert shows the location of GALEX MC fields with NUV (left) and FUV (right) observations; light-to-dark gray from short (AIS-depth) to deeper exposures. The large NUV image is a region (about 1kpc) including 30 Dor, the latter is shown enlarged in the upper-left panel. In addition to numerous UV-emitting stars, dust lanes and diffuse emission are also conspicuous. The bottom image is a FUV(blue)+NUV(yellow) composite of a region in the Magellanic Bridge, where GALEX reveals presence of hot massive stars in areas with gas density down to $N(H)\sim 10^{20}\text{cm}^{-2}$. The bottom insert is an example of SED-fitting of GALEX+optical photometry.

form of FUV-bright ring structures, were also detected in early-type galaxies, where they account in some cases for $>70\%$ of the FUV flux, though they contain only a few percent of the galaxy mass (e.g. Marino et al. 2011, 2014).

UV fluxes are particularly sensitive to detect presence of hot stars, and finely characterize them; they trace and age-date stellar populations up to a few hundred million years old (Bianchi 2009, 2011), even at extremely low rates of star-formation. At the same time, they offer great sensitivity to interstellar dust, a key component inherently related to star formation.

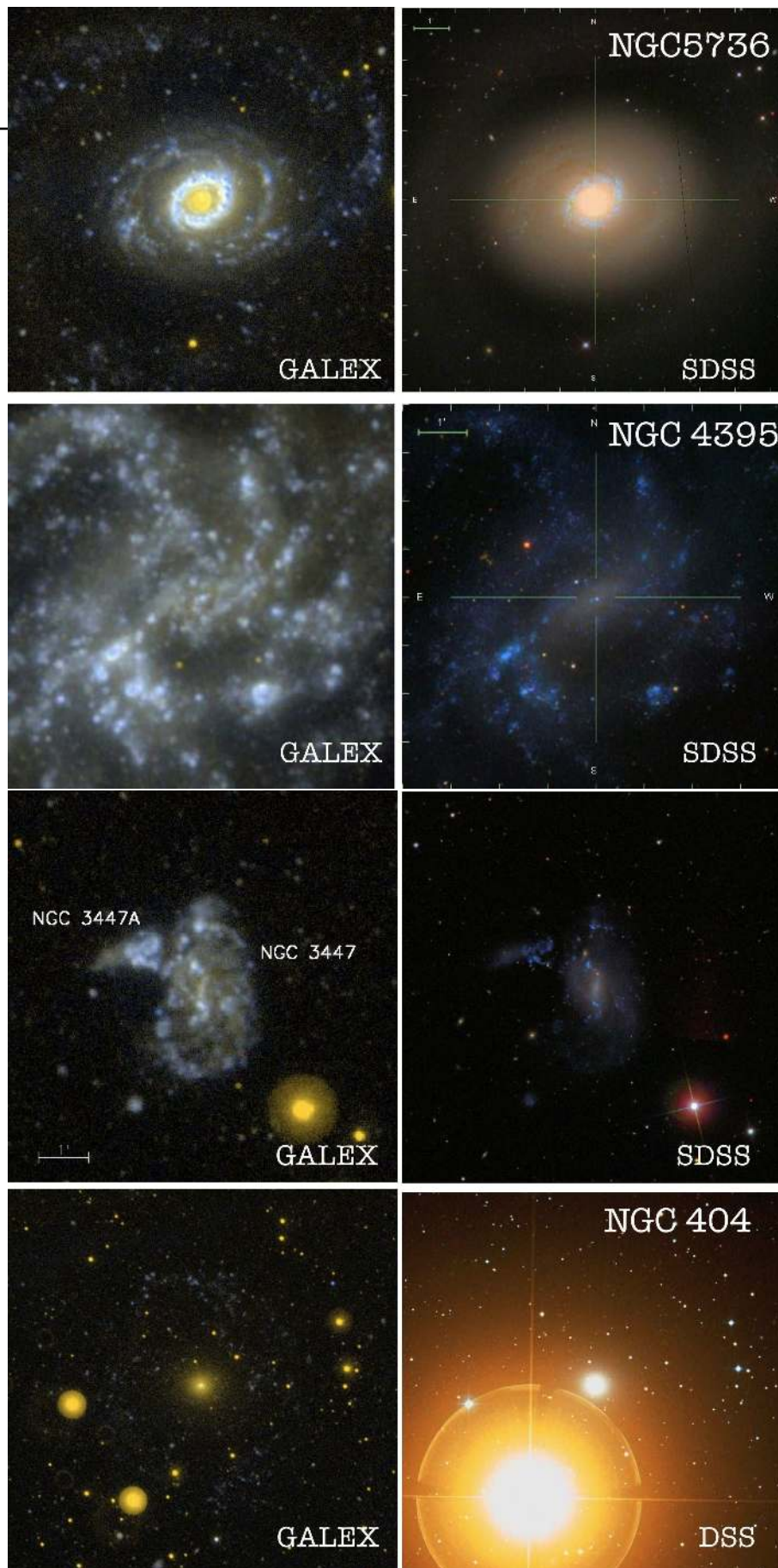


Fig. 6 GALEX images (FUV: blue, NUV: yellow) and optical color-composite images of galaxies of various types. The examples demonstrate the sensitivity of UV imaging to detect recent star formation. One of the most extreme examples is shown in the bottom panel: the nearest S0 galaxy with a ring of FUV-emitting knots between 1 and 4 D_{25} radii, from which Thilker et al. (2010) inferred a star-formation rate of $\sim 2 \cdot 10^{-5} M_{\odot} \text{yr}^{-1} \text{kpc}^{-2}$. A bright foreground star (cold, visible as a yellow dot (NUV source) in the GALEX image) saturates a portion of the optical image; the galaxy nucleus is visible in the center.

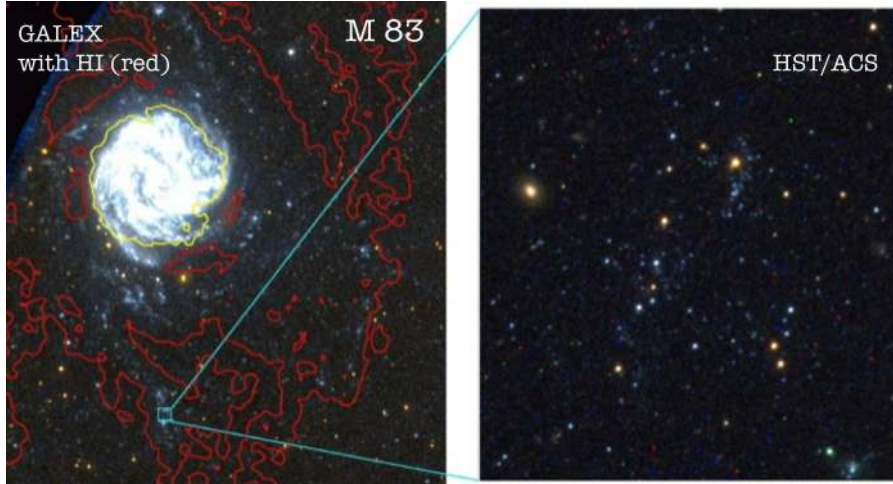


Fig. 7 GALEX image (FUV: blue, NUV: yellow) of M83, the prototype discovery of extended UV disks (Thilker et al. 2005; another prototype was NGC4625, Gil de Paz et al. 2005). The size of the optical image (not shown) is comparable to the yellow contour which is the canonical Toomre gas-density threshold for star-formation. HST imaging (right) resolves the UV-emitting sources in sparse hot-star associations

In Local Group galaxies, GALEX’s resolution probes 10-20 pc scales, smaller than typical OB associations, hence uniquely tracing (and age-dating) the spatial structure of young populations throughout the whole extent of large galaxies. GALEX sensitive maps detect even single hot massive stars (e.g. Figure 5 of Bianchi et al. 2014b for an example in M31, Efremova et al 2011 for NGC6822). A review, although quite succinct, of results on star-formation from GALEX data can be found in Bianchi (2011); examples of the relevance of UV diagnostics for concurrently understanding and modeling dust and the stellar populations were shown by Bianchi et al. (2011c, 2014b), Kang et al. (2009).

The UV sky surveys also include several millions Milky Way stars. In particular, they uniquely enable a census of hot white dwarfs, whose high temperatures and low optical luminosities make them elusive at all wavelengths except the UV. In low-extinction sight-lines (outside the Galactic plane), GALEX MIS-depth fields can measure very hot WDs out to 20kpc (Bianchi et al. 2007). The GALEX unbiased census of hot WD, an increase by over two orders of magnitude over previously known samples, opens new ways to probe post-ABG evolutionary phases (including the poorly known initial-final mass relation, e.g. Bianchi et al. 2011a), to find types of binaries otherwise elusive, such as e.g. Sirius B-like systems, beyond the currently known local sample (98 known <100pc, Holberg et al. 2013), to study binary evolution (mass transfer, possible channels for SnIa progenitors) and Planetary Nebulae (Bianchi 2012).

8 Looking at the future

8.1 Field-of-view versus resolution

In the past decade[s], a score of studies and results on stellar populations in nearby galaxies, possibly more numerous than in any other area, have been yielded by HST and GALEX imaging (considering only the UV domain, within the scope of this discussion). Such data represent two extremes, as illustrated in Figs 3 and 7, between wide-field coverage (GALEX) and very-high resolution, small field of view (HST). The first enables studies of stellar populations across entire extended galaxies in the local universe, needed to fully understand the process and history of star formation as a function of environment (both local conditions and dynamics across the galaxy, and external environmental factors such as interactions and gas accretion), and to eventually build a conclusive picture. The high-resolution data, on the other hand, unravel the resolved stellar constituents of star-forming sites: and the ensemble of physical parameters derived for individual stars, in a variety of local star-forming regions (different metallicity, gas density, etc) provide a space- and age-tomography of such regions (e.g., Bianchi et al. 2014b). If such resolved studies could be extended to a wide variety of conditions, with sufficient filter coverage to break the known $[T_{\text{eff}}, E_{B-V}]$ degeneracy for hot stars, a robust calibration could be derived, for interpreting the comprehensive census of unresolved star-forming sites extensively mapped by the wide-field data. In Local Group galaxies, considering distances between 500 and 1000 kpc, HST imagers gives a resolution (projected)

between ~ 0.1 - 0.5 pc, and GALEX of ~ 10 - 20 pc. Over 500 HST images are needed to cover one GALEX field (~ 700 for WFC3/UVIS, ~ 450 for the largest camera, ACS/WFC, many more for ACS/HRC or STIS fields). The only substantial coverage of a large Local Group galaxy with HST was accomplished with the *PHAT* program, mapping one fourth of M31 (Dalcanton et al. 2012, Bianchi et al. 2014b), at the exorbitant cost of 828 HST orbits.

The only current UV imaging capabilities with intermediate field of view and resolution are SWIFT/UVOT or XMM/OM, with a limited set of filters extending to near-UV. Far-UV measurements are critical to characterize the hottest stars and the youngest stellar populations.

8.2 Filters and sensitivity

The imminent launch of UVIT (Hutchings, this book) will provide a desirable bridge between HST and GALEX imaging capabilities, and offer a much richer choice of UV filters than GALEX. Progress in detector technology and data storage will enable quantum leaps with the next generation of UV instruments. Field size is but one of the trade-offs. The choice of filters is critically determining to what extent the data can answer science questions. We may simplify a complex problem, recalling that to concurrently derive e.g. age and extinction of stellar populations (or T_{eff} and extinction for stars), more than one color is needed (Bianchi et al. 2014b). Metallicity is another “free” parameter (e.g., Bianchi et al. 2012). In addition, the extinction curve in the UV is known to vary with environment, and the correct solution for the physical parameters can only be achieved when such dependence will also be conclusively constrained, and extinction properly accounted for. A broad characterization of extinction properties requires an adequate complement of filters. Spectroscopy provides detailed extinction curves, but with current capabilities (HST spectrographs) it is only possible for a few lines of sight.

GALEX FUV-NUV color has the advantage to be almost reddening-free, as long as the extinction curve is similar to the so-called “Milky Way average” with $R_V = 3.1$ (Bianchi 2011). It follows that, for example, very hot stars can be robustly selected (by T_{eff}) from GALEX data (Bianchi et al. 2011a, 2014a). However, in regions of intense star formation, UV radiation from massive stars affects properties of local dust grains, and the uncertainty in the extinction curve, and ultimately in the interpretation of UV fluxes, can be huge (example in Fig.6 of Bianchi et al. 2011c, or Table 2 of Bianchi 2011). Only a sufficient complement of filters,

extending to the far-UV, would allow modeling to solve concurrently for the object’s physical parameters, and the amount *and type* of interstellar extinction. Not a single instrument, but ideally an array of continued UV capabilities, will bring conclusive answers. Many are presented in these proceedings.

The UV-enabled characterization of young stellar populations in the local universe will inform star-formation and galaxy-evolution models, which in turn will underpin interpretation of large galaxy surveys at cosmological distances, such as those expected from JWST in the next decade, at high redshift, and from ground-based facilities at intermediate redshifts.

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9 APPENDIX. Where to find information, catalogs, and tools

Documentation on GALEX archive data and pipeline products can be found on the MAST site²; some relevant papers, science-ready catalogs and source classification can be found on the author’s “UVsky” project web site³.

The BCS catalogs of GALEX unique sources are publicly available from the author’s website⁴, from MAST⁵ as part of the “High-Level Science Product” collection, and with SQL access from MAST casjobs ([galex/stsci.edu/casjobs](http://galex.stsci.edu/casjobs)), in the context GALEX catalogs: “bcscat_ais” and “bcscat_mis”); they will soon be also available in CDS’s Vizier. Matched catalogs (GALEX BCScat’s matched with SDSS, GSC2, Pan-STARRS, 2MASS, etc.), with useful added flags, are being added on the <http://dolomiti.pha.jhu.edu/uvsky> web site, together with science catalogs of selected samples with derived physical parameters for the sources.

The first version of the BCS catalogs (Bianchi et al. 2011a), and matched GALEX–optical catalogs are also available from <http://dolomiti.pha.jhu.edu/uvsky>, as well as from MAST⁶ and Vizier⁷.

Other GALEX catalogs available from MAST include GCAT (catalog of GALEX unique sources, not updated beyond data release GR6; it differs from BCS unique-source catalog in that it also includes NUV observations (up to GR6) with the FUV detector turned off, and rim/edge sources are not eliminated, but flags are provided), and GALEX catalogs of the Kepler field.

Among the useful tools for exploring GALEX data at MAST, we recall “galexview” (galex.stsci.edu/GalexView);

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²MAST database: galex.stsci.edu

³UVsky site: <http://dolomiti.pha.jhu.edu/uvsky>

⁴<http://dolomiti.pha.jhu.edu/uvsky/BCScat>

⁵BCS on MAST: <http://archive.stsci.edu/prepds/bcscat/>

⁶http://archive.stsci.edu/mast_news.php?out=html&desc=t&id=378

⁷<http://vizier.u-strasbg.fr/viz-bin/VizieR-3?-source=II/312>

since January 2014, GALEX data can also be explored within a broader context from MAST's portal: mast.stsci.edu/explore.

Finally, gPhoton (Million, Fleming, Shiao, 2014, in preparation) is accessible at <https://github.com/cmillion/gPhoton>■

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