Galaxy evolution insight from XUV-disks in the Local Universe

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Abstract

The discovery of extended ultraviolet disk (XUV-disk) galaxies early in the GALEX mission invigorated the study of star formation in the low density regime. However, initial results were based on a small set of galaxies with potential bias (T05, GdP05, ZC07, T07, GdP07, L11, M12). At the close of the NASA-supported GALEX mission, the situation has improved greatly with UV observations now available for several thousand nearby galaxies -- forming a comprehensive, statistically significant sample. We review our updated census of XUV-disks (T12) based on the GALEX GR6 data release. We also briefly discuss results from associated programs using HST and Herschel.

The mere existence of XUV-disk galaxies, and their recognition only following GALEX, emphasizes the unique evolutionary perspective provided by wide-field UV imaging.

Galaxy Sample

The parent sample from which we identified XUV-disk galaxies was meant to be as inclusive as possible within a distance of 40 Mpc. Our upper limit on distance was chosen to insure adequate spatial resolution of GALEX data (such that 5" ≈ 1 kpc or better for all galaxies), allowing identification of sparse young stellar complexes.

Our parent sample was obtained from a Hyperleda query returning all galaxies of known Hubble type, with $D_{25} > 1'$, radial velocity corrected for Virgo-infall < 2800 km/s, and MW foreground extinction $A_B < 0.5$ mag.

This selection included 3526 galaxies, but not all of them currently have extant GALEX observations (see below).

The distance limit used for our primary survey is small enough that our basic parent sample does not include many massive ETGs. To investigate massive low surface brightness disk (mLSB) galaxy formation, we also considered a secondary sample of gas-rich, massive ETGs taken from the literature.

GALEX Observations

For each object, we generated custom GALEX coadd stamps for a FOV of 3xD_{25} centered on the galaxy optical position. These stamps were tuned to include all available GALEX data in the FOV, including observations from GR6 and publicly-released GI investigations. We properly account for the substantially different exposure times between various datasets (AIS-depth of ~100s vs. NGS/MIS/DIS depth often >1.5 ks) and remove the sky background during co-addition. Stamps were possible for ~90% of the parent sample though some have coverage gaps for a sizable portion of the target.

XUV-disk Classification

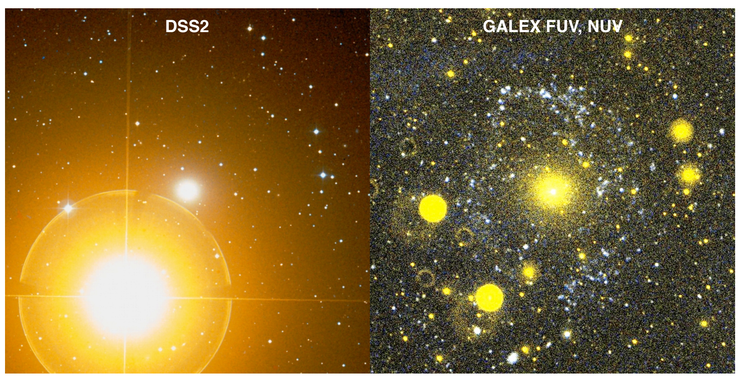
See T07 for a description of the two varieties of XUV-disk morphology. For the new census, we have completed our Type 1 XUV-disk classification via inspection of each FUV [NUV] coadd in comparison to DSS2-red imaging. We are now in the process of incorporating WISE sky survey data (W1-band) to improve the reliability of XUV Type 2 classification, relative to our prior use of 2MASS K_s data.

Results for Type 1 XUV-disks:

Our survey has generated a reference set of a few hundred nearby Type 1 XUV-disks, which will enable us to study the process of ongoing disk growth at z ~ 0 via detailed follow-on analysis (see right column). We are clearly able to detect Type 1 objects more easily the closer they are. Our raw incidence rate is also diminished by those objects for which only AIS-depth imaging is available. Details will be provided in T12, but estimated corrections for these effects suggest that our incidence rate from T07 was correct (20% for Type 1 XUV-disks).

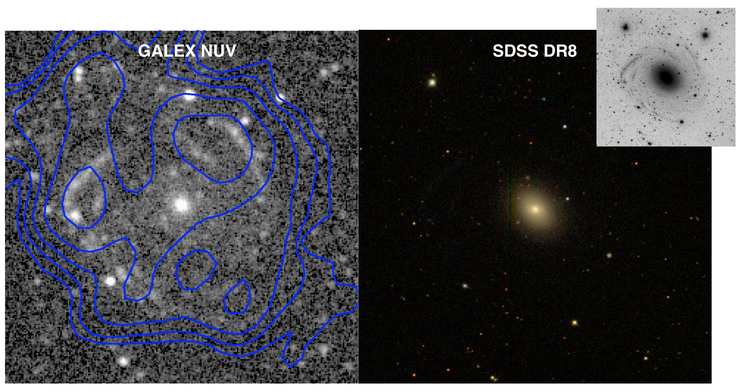
Physically distinct sub-classes have become apparent within our larger sample of confirmed XUV-disks. First, we find that ETGs can also be XUV-disks, often taking ring-like morphology. They were not considered in T07, but several other studies have found them in the intervening time (D09, B10, L11, SR10, M12). Among late-type hosts, we see systems which are tidally disturbed or ram-pressure stripped, in addition to galaxies seemingly having no current environmental influence. For this later class of objects, we find XUV-disks which are essentially a smooth continuation inner disk structure and those which appear disjoint between inner and outer radii, suggesting a previous accretion event. There is obvious variety in the evolutionary history of XUV-disks, which should also be preserved in their LSB optical morphology and deep surface brightness / star count profiles.

The green valley galaxy population of transitional objects is now being studied intensively. ETG XUV-disks such as NGC 404 (below) demonstrate that some of the unresolved GV population may actually be experiencing disk re-growth, with an associated excursion blue-ward off the red sequence.



NGC 404 (optical/left, GALEX/right). From T10, this figure shows the extensive SF ring-like structure completely missed without UV data. This low mass S0 galaxy (stellar mass 7x10^8 $M_\odot$) is currently isolated but has been proposed as a group remnant. The FOV is 15.3 kpc.

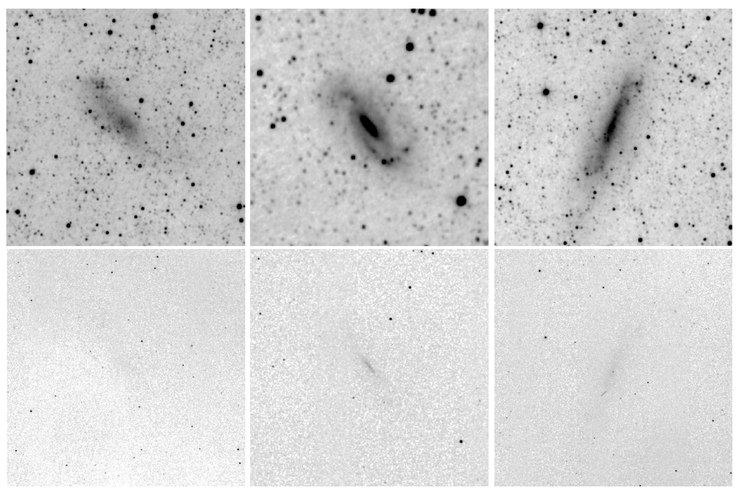
The mLSB prototype object Malin 1 was shown by B07 to be a typical HSB, short scale-length S0 galaxy with an additional outer disk component reminiscent of XUV-disks. We have found additional examples of such hybrid disk structure (see UGC 1382 below), and propose that mLSB disk galaxies are sometimes created in a two-stage process brought on by enhanced gas accretion lagging significantly with respect to the original host formation epoch. Other examples from our mLSB sample show evidence for gas infall, in one case taking the form of a counter-rotating disk.



UGC 1382 (NUV+HI-contours/left, SDSS/right, Stripe82/inset) is a gas-rich E/S0 galaxy presently forming a giant, optically faint disk filling the depicted FOV (128 kpc). HI data kindly provided by L.Young.

Pending Type 2 improvements:

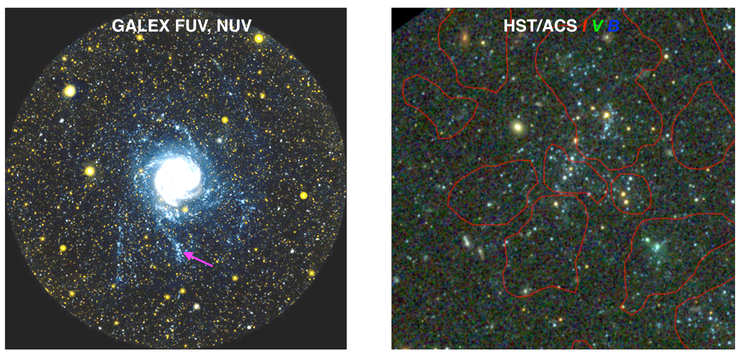
The 2MASS survey is shallow in comparison to WISE W1 imaging. T07 used 2MASS K_s images to define the K_{80} extent of each galaxy, containing 80% of the detected stellar mass, and then examined properites of any LSB star forming zone outside this K_{80} contour to decide if the galaxy was a Type 2 XUV-disk. In some cases, objects were barely detected in K, precluding them from such analysis and causing significant uncertainty even in somewhat brighter galaxies. We now adopt the W1 all-sky imaging from WISE as a superior tracer during our classification work.



Comparison of WISE W1 (top), 2MASS K_s imaging (bottom) for three Type 2 XUV-disk galaxies. W1 better recovers LSB stellar structures.

HST resolves XUV-disks

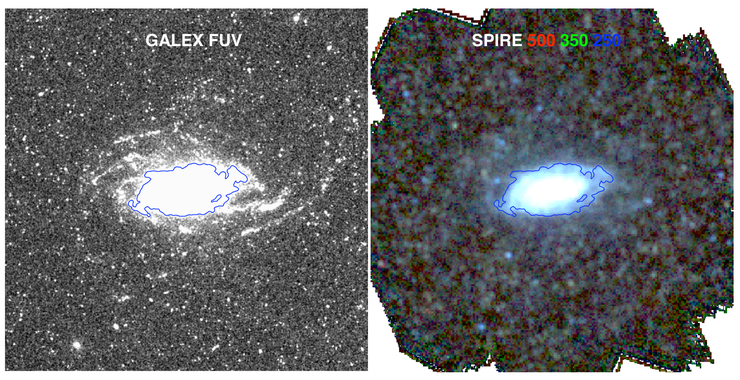
FUV-optical HST imaging shows that the UV clumps seen by GALEX are loose OB associations having spatial and temporal substructure, not bound clusters. HST resolution UV imaging is needed to photometrically classify massive star candidates at the distance of our XUV-disks, but ACS/SBC has revealed O stars with associated Hα emission even in this low-density environment. Stochastic effects will be key when modeling integrated photometry of low mass (<10^3 $M_\odot$) UV-bright associations populating XUV-disks.



M83 (GALEX/left, HST/right). We show the entire XUV-disk detected in the UV (Bigiel+10) and a small subsection for which HST imaging was obtained. Red contours delineate individual UV clumps.

Herschel finds XUV-dust

SPIRE 250-500μm observations from the KINGFISH program have directly revealed dust in the outer portion of a few well-known XUV-disks. SED analysis is now underway. For NGC 5055 (below) it seems ~10% of the total dust mass is in the XUV-disk. Previously H09 has shown outer disk dust in occulting galaxy pairs. These results beg the question of origin: in-situ production? infall w/ gas+dwarfs?



NGC 5055 (FUV/left, SPIRE/right) observations showing the presence of significant dust in the XUV disk / extended HI disk.

New follow-on studies

We have begun observing a subset of the XUV-disks identified in our new census using Subaru for deep optical imaging (e.g. K12) and the JVLA for deep radio continuum (w/PI Murphy) exploratory observations. Multi-object spectroscopy (following GdP07, B09+12) will also be conducted to study radial abundance profiles. We will pursue ALMA observations of a few XUV-disks to test for categorical changes in the GMC population (e.g. Braine +07). Further, we anticipate HI maps from *WNSHS* and *WALLABY* for the complete reference sample of XUV-disks.

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