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Extended UV (XUV) Emission in Nearby Galaxy Disks

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Abstract. We summarize the main properties of the extended UV (XUV) emission found in roughly 30% of the nearby spiral galaxies observed by the GALEX satellite. Two different classes of XUV disks are identified, the Type 1 XUV disks where significant, structured UV-bright features are found beyond the *classical* azimuthally-averaged star-formation threshold, and the Type 2 XUV disks, which are characterized by very extended (seven times the area where most of the stellar mass is found), blue [(FUV$-K$)$<$5 mag] outer disks. These latter disks are extreme examples of galaxies growing inside-out. The few XUV disks studied in detail to date are rich in HI but relatively poor in molecular gas, have stellar populations with luminosity-weighted ages of $\sim$1 Gyr, and ionized-gas metal abundances of $\sim$Z$_{\odot}$/10. As part of the CAHA-XUV project we are in the process of obtaining deep multi-wavelength imaging and spectroscopy of 65 XUV-disk galaxies so to determine whether or not these properties are common among XUV disks.

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Introduction

Observations by the GALEX satellite (Martin et al. 2005) have recently revealed the presence of UV-bright emission at large galactocentric distances (up to four times the optical radius) in a number of nearby spiral galaxies (see Figure 1). This phenomenon was first seen in the outer regions of the disks of M 83 (Thilker et al. 2005) and NGC 4625 (Gil de Paz et al. 2005). Previous evidence of in-situ star formation in the outer disks of galaxies include Ferguson et al. (1998) and van Zee et al. (1998). The existence of UV emission at large radii is of great relevance since it questions the mere existence of an azimuthally-averaged threshold for the star formation and provides an important test for the applicability of the Kennicutt-Schmidt law at low gas densities. The XUV phenomenon is also useful as a test for the models of the formation and evolution of disks in galaxies, both for SPH/N-body simulations (e.g. Brook et al. 2006) and chemical and spectro-photometric "backward" models (Boissier & Prantzos 2000; Mollá et al. 1996), and, more specifically, for its predicted inside-out formation scenario (Muñoz-Mateos et al. 2007).

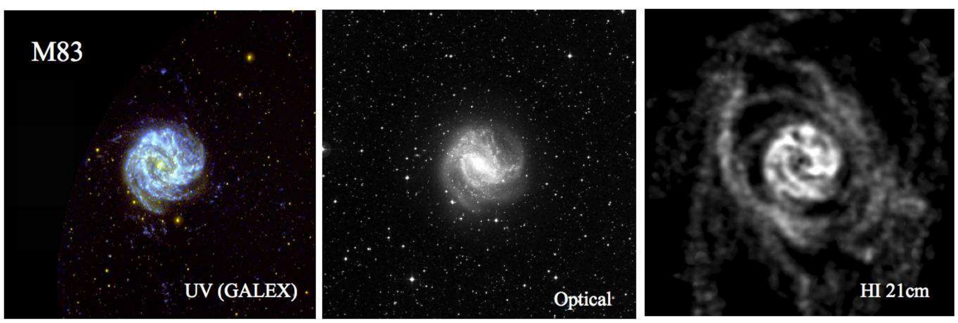

Figure 1. Ultraviolet GALEX (RGB composite of the FUV and NUV images; *left*), optical Digitized Sky Survey (*center*), and HI 21 cm (*right*) images of the XUV-disk galaxy M 83.

XUV-disks Classification

A study of the spiral galaxy population included in the *GALEX Atlas of Nearby Galaxies* (Gil de Paz et al. 2007a) revealed that ~30% of the disk galaxies in the local (D<40 Mpc) Universe show some degree of XUV emission (Thilker et al. 2007). Roughly two thirds of them (20% of the total) show UV-bright complexes structured in the form of spiral segments or irregularly-grouped features beyond the *classical* threshold for star formation deduced from the analysis of Hα imaging data (Martin & Kennicutt 2001), which is located at $\mu_{\rm FUV}\simeq 27.25$ AB mag arcsec^{-2}. These galaxies are classified as Type 1 XUV disks (Thilker et al. 2007). In the remaining third the XUV emission is characterized by ubiquitous UV emission in regions of faint or undetectable optical and near-infrared emission [(FUV$-K$)<5 mag] but inside the surface-brightness threshold for star formation. In these Type 2 XUV disks the blue outer disks cover an area which is at least seven times larger than the area of the isophote encompassing 80% of the light in the K band (i.e. ∼80% of the stellar mass). Type 2 objects are examples of disks growing inside-out at a very high rate (see Muñoz-Mateos et al. 2007).

Photometric and Chemical Properties

The XUV disks are characterized by very blue UV-optical color profiles. The comparison of these colors with the predictions of evolutionary synthesis models indicates luminosity-weighted ages that are either ∼1 Gyr for a continuous star formation or younger if the formation was instantaneous (Gil de Paz et al. 2005, 2007b). We cannot rule out the presence of a more evolved stellar population on top of which significant star-formation activity is now taking place with, perhaps, additional episodes of star formation in between. The analysis of chemical abundances of the outermost regions in the XUV disks of M 83 and NGC 4625 (Gil de Paz et al. 2007b) using ionized gas shows an oxygen abundance of $\sim Z_{\odot}/10$ and (in the case of M 83) a N/O abundance ratio close to Solar. This oxygen abundance is compatible with a continuously-forming 1 Gyr-old populations (Boissier & Prantzos 2000). The high N/O ratio found in M 83 can be explained by either the recent infall of significant amounts of pristine gas in regions having relatively high oxygen abundances and N/O ratios or by the existence of a *top-light* Initial Mass Function (IMF) in these (low-density) regions. A top-light IMF would also explain the relatively paucity of HII regions (as seen in Hα) in these disks. Detailed studies of a larger sample of XUV disks are needed in order to determine whether or not these properties are common to the outer edges of disks.

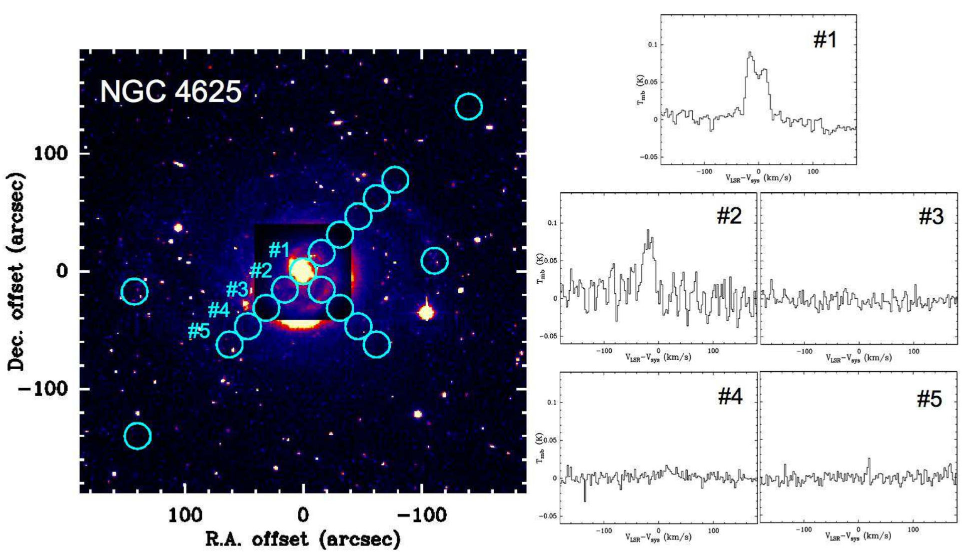

Figure 2. IRAM 30-m ^{12}CO(1-0) observations of the XUV-disk galaxy NGC 4625 (Gil de Paz et al. 2005). *Left:* Deep optical (*R*-band) image of NGC 4625 with the positions observed. The size of the circles represents the size of the IRAM 30-m telescope main beam at 3 mm. For sake of clarity the innermost region of the galaxy is shown with a different scaling. *Right:* Individual ^{12}CO(1-0) spectra obtained along the galaxy semi-major axis.

Atomic and Molecular Gas Content

The outer regions of the XUV-disk galaxies observed to date show very extended HI 21 cm emission with its density peaks being associated with the UV complexes seen by GALEX (see Figure 1). The amount of atomic hydrogen in these reservoirs is large enough to maintain the current level of star formation for several Gyrs. The possible contribution of the molecular gas component is unknown since only the XUV disk of NGC 4625 has been observed to date in CO to the required depth (see Figure 2). Despite the tentative detection of CO at large galactocentric distances in this object, the contribution of the molecular component to the total gas seems to be low compared with that from HI. Currently we cannot rule out the possibility that the HI associated with the XUV disks is primarily due to photo-dissociation of H_2 by FUV photons produced in the same stars that are responsible for the XUV emission.

CAHA-XUV Project: Exploring the Outer Edges of Spiral Galaxies

With the objective of determining whether or not the properties described above, which are based almost exclusively on the detailed analysis of the XUV disks of M 83 and NGC 4625, are common to the entire population of galaxies showing XUV emission ($\sim$30% of the spiral galaxy population) we have recently started a large observing program at the Calar Alto (CAHA) observatory (Almería, Spain). We will be obtaining deep optical ($UBRI$Hα) and near-infrared (JK) imaging of a sample of 65 nearby XUV disks. Follow-up spectroscopy with CAHA 3.5-m and GTC 10.4-m is planned.

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References

Boissier, S., & Prantzos, N. 2000, MNRAS, 312, 398
Brook, C.B., et al. 2006, ApJ, 639, 126
Ferguson, A., et al. 1998, ApJ, 506, L19
Gil de Paz, A., et al. 2005, ApJ, 627, L29
Gil de Paz, A., et al. 2007a, ApJS, 173, 185
Gil de Paz, A., et al. 2007b, ApJ, 661, 115
Martin, D.C., et al. 2005, ApJ, 619, L1
Martin, C., & Kennicutt, R.C. 2001, ApJ, 555, 301
Mollá, M., Ferrini, F., & Díaz, A.I. 1996, ApJ, 466, 668
Muñoz-Mateos, J.C., et al. 2007, ApJ, 658, 1006
Thilker, D.A., et al. 2005, ApJ, 619, L79
Thilker, D.A., et al. 2007, ApJS, 173, 538
van Zee, L., et al. 1998, AJ, 116, 2805