The Color-Dependent Frequency of XUV Disks In Low-Mass E/S0s

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Abstract. We identify a high frequency of Type 1 XUV disks, reflecting recent outer disk star formation, in a sample of 31 E/S0s with stellar masses primarily below $M_* \sim 4 \times 10^{10} M_\odot$. Our ~40% identification rate is roughly twice the 20% fraction reported for late-type galaxies. Intriguingly, in the dwarf mass regime (below $M_* \sim 5 \times 10^9 M_\odot$) where gas fractions clearly rise, Type 1 XUV disks occur in ~70% of red-sequence E/S0s but only ~20% of blue-sequence E/S0s, a population recently linked to active disk rebuilding, especially in the dwarf regime. Our statistics are preliminary, but could indicate that for dwarf E/S0s Type 1 XUV disks are primarily related to weak or inefficient outer-disk star formation rather than to star formation capable of driving substantial disk growth. Substantial growth may instead be associated with populations that have low XUV-disk frequency, possibly explaining the similar ~20% frequencies for normal late types and low-mass blue-sequence E/S0s.

The recent discovery of extended ultraviolet (XUV) disks (e.g., [1], [2]), reflecting ongoing star formation beyond the optical radii and traditional star formation thresholds of late-type galaxies, has provided an intriguing look beyond the optical radii and traditional star formation thresholds (e.g., [3], [4]), reflecting ongoing star formation beyond the optical radii and traditional star formation thresholds (e.g., [4], [5]). Blue-sequence E/S0s, may provide a direct look at disk growth in progress at z=0. A separate line of research on “blue-sequence E/S0s,” morphologically defined E/S0 galaxies on the blue sequence in color vs. stellar mass space, may provide a direct look at disk growth in progress at z=0 (Fig. 1), a process predicted by hierarchical models (e.g., [6], [7]). Blue-sequence E/S0s increase dramatically in abundance below the gas-richness threshold mass at $M_* \sim 5 \times 10^9 M_\odot$, the regime in which neutral-atomic/gas/stellar mass ratios ≥ 1 become common (Fig. 1, see [8] regarding corrected mass scale). As shown in [8], many blue-sequence E/S0s display the global gas reservoirs and specific star formation rates necessary for significant stellar disk growth on relatively short timescales. As a result, if the XUV-disk phenomenon is associated with disk building in general, we might expect to observe XUV disks preferentially among blue-sequence E/S0s.

Although the first XUV-disk studies, such as [9], emphasized the optical radii, XUV disks around E/S0s are increasingly being found as well (e.g., [10], [11], [12], [13]). However, the question remains: are XUV disks in E/S0s related to the probable active disk-builders, the blue-sequence E/S0 population? We address this question by examining the frequency of XUV disks in E/S0s as a function of both sequence and mass, finding a surprising but illuminating lack of association between Type 1 XUV disks and E/S0s at the low-mass, gas-rich end of the blue sequence.

Our sample of 31 E/S0s encompasses all of the Nearby Field Galaxy Survey (NFGS, [14]) blue-sequence E/S0s and the majority of NFGS red-sequence E/S0s with $M_* \leq 4 \times 10^{10} M_\odot$ (Fig. 1), where many E/S0s have substantial gas, and relatively undisturbed blue-sequence E/S0s with the potential for disk regrowth are observed (Fig. 1). In addition to these 25 NFGS E/S0s, we include 6 blue-sequence E/S0s from the “HyperLeda+” sample of [14].

In [9], Type 1 XUV disks are defined as displaying more than one structured UV-bright emission complex beyond a centralized surface-brightness contour corresponding to the expected star formation threshold (equated to an NUV surface brightness of 27.35 AB mag arcsec$^{-2}$ in [9], roughly matching typical Hα and HII thresholds; we label the corresponding radius $R_{UVF}$). In addition, this definition requires that the XUV emission take on a different morphology from any underlying optical emission.

We classify our sample galaxies based on the Type 1 XUV-disk definition using GALEX NUV images with a minimum exposure time of 1500 s. For comparison of UV and optical morphologies, we employ DSS-II red images (http://archive.stsci.edu/dss). These classifications supersede the preliminary, purely visual (made without reference to $R_{UVF}$) classifications of [15]. The Type 1 XUV disks in our E/S0s can extend to several times $R_{25}$ as has been found in late types (e.g., [1], [2], [9], see also [16]). We find radial extents (to the last measured NUV point) between ~0.8 and 3 times $R_{25}$, with an average of ~1.6.

Compared to XUV disks in late-type galaxies, our E/S0 XUV disks tend to be redder. However, using outer-disk FUV−NUV colors and assuming the observed UV emission comes from young stars, we still estimate <1 Gyr ages for our E/S0 XUV disks from simple stellar population (SSP) models (although a mixed old plus young population is presumably present, we defer multiple-component stellar population modeling to a future paper). Comparing
with UV model colors of [17] for an instantaneous starburst with $Z = 0.02$ (as in [9] Figure 1), our average Type 1 XUV-disk FUV−NUV color of $\sim 1.6$ corresponds to a stellar population with an approximate age of 500 Myr.

Although the UV upturn, i.e., UV emission associated with old stellar populations ([18]), is a plausible source for excess UV flux in E/S0s, the FUV−$K$ colors we measure, as well as independent evidence for actual or potential star formation (e.g., H$_\alpha$ or HI detections in all but two of our XUV-disk galaxies), largely support an association of our XUV disks with recent star formation.

Type 1 XUV disks occur in 13/31 or 42$^{\pm 11}\%$ of our E/S0 sample. This frequency is approximately double the 20$\%$ Type 1 XUV-disk frequency found in [9] for a mostly late-type galaxy sample. We find XUV disks in both red- and blue-sequence E/S0s over a large range in stellar mass (Fig. 1). The widespread nature of the XUV-disk phenomenon seems to suggest an association with evolutionary processes affecting the galaxy population broadly, such as gas accretion and/or minor satellite interactions.

We also observe a complex mass and sequence dependence of XUV-disk incidence: the relative abundance of red- vs. blue-sequence XUV-disk galaxies seems to reverse across the gas-richness threshold mass. On the red sequence, the XUV-disk frequencies are low and high (33$^{+11}_{-25}\%$ and 71$^{+18}_{-28}\%$) above and below the threshold mass, respectively. On the blue sequence, the corresponding frequencies are high and low (50$\pm 20\%$ and 18$^{+19}_{-12}\%$). For low-mass E/S0s, the association we observe between red color and a high frequency of Type 1 XUV disks suggests that these disks typically experience inefficient or weak star formation instead of the pronounced star formation expected on the blue sequence in this gas-rich regime. This link between Type 1 XUV disks and weak/inefficient star formation is supported by previous studies (e.g., [9, 19]).

Based on these results, observing Type 1 XUV disks in E/S0s may not provide the best indication of significant disk regrowth. Instead, relatively low XUV-disk incidence, as is found for both low-mass blue-sequence E/S0s and normal late-types ([9]), may be characteristic of populations with active disk building in progress. Our findings highlight the need for a more general UV-bright disk definition, which will be addressed in future work.

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Fig. 1. E/S0 sample in color-stellar mass space. Small grey symbols indicate galaxies in the NFGS, the parent sample for all but six of our E/S0s. The dashed line divides the red and blue sequences, and the vertical line marks the gas-richness threshold mass ([3]). The 30 E/S0s from GALEX program GI3-0046 are denoted by open circles, and CGCG 065-002 from program GI5-042 is denoted by an open triangle. Type 1 XUV-disk galaxies in this sample are marked with asterisks.