Tidal Dwarf Galaxies, Accretion Tails, and ‘Beads on a String’ in the ‘Spirals, Bridges, and Tails’ Interacting Galaxy Survey

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Abstract.

We have used the GALEX ultraviolet telescope to study stellar populations and star formation morphology in a well-defined sample of more than three dozen nearby optically-selected pre-merger interacting galaxy pairs. We have combined the GALEX NUV and FUV images with broadband optical maps from the Sloan Digitized Sky Survey to investigate the ages and extinctions of the tidal features and the disks. We have identified a few new candidate tidal dwarf galaxies in this sample, as well as other interesting morphologies such as accretion tails, ‘beads on a string’, and ‘hinge clumps’. In only a few cases are strong tidal features seen in HI maps but not in GALEX.

1 Introduction

Tidal disturbances have played an important role in reshaping galaxies and triggering star formation over cosmic time. This is confirmed by Hα, far-infrared, and mid-infrared studies showing that the mass-normalized star formation rates of pre-merger optically-selected interacting galaxies are enhanced by a factor of two on average compared to normal spirals (Bushouse 1987; Kennicutt et al. 1987; Bushouse et al. 1988; Smith et al. 2007).

With the advent of the Galaxy Evolution Explorer (GALEX), a new window on star formation in galaxies is now available. The addition of UV helps to break the age–extinction degeneracy in population synthesis modeling (e.g., Smith et al. 2008). Furthermore, since the UV traces somewhat older and lower mass stars (≤400 Myrs; O to early-B stars) than Hα (≤10 Myrs; early- to mid-O stars), it provides a measure of star formation over a longer timescale than Hα studies. GALEX imaging has shown that some tidal features in interacting galaxies are quite bright in the UV (e.g., Neff et al. 2005). In some cases, tidal features previously thought to be purely gaseous have been detected by GALEX (e.g., Hancock et al. 2007). In other systems, GALEX images have been used to identify new tidal features (e.g., Boselli et al. 2005).

To address these issues, we have used the GALEX telescope to image more than three dozen strongly interacting galaxies in the UV (the ‘Spirals, Bridges, and Tails’ (SB&T) sample). These galaxies were selected from the Arp (1966) Atlas using the following criteria: 1) They are relatively isolated binary systems; we eliminated merger remnants, close triples, and multiple systems in which the
galaxies have similar optical brightnesses. 2) They are tidally disturbed. 3) They have radial velocities less than 10,350 km/s. 4) Their total angular size is $>3'$, to allow for good resolution with GALEX.

Each galaxy was imaged for $\geq 1500$ seconds in the FUV and NUV broadband filters of GALEX, which have effective bandpasses of $1350 - 1705\,\text{Å}$ and $1750 - 2800\,\text{Å}$, respectively. Some of the galaxies that fit our selection criteria were previously observed by guaranteed time projects. For these galaxies, we used the archival GALEX images. The circular GALEX field of view has a diameter of 1.2 degrees. The pixel size is 1''5, and the spatial resolution $\sim 5''$. About 2/3rds of our galaxies have broadband optical images available from the Sloan Digitized Sky Survey (SDSS), while 3/4 have broadband Spitzer infrared images available [Smith et al. 2007]. About half have published 21 cm HI maps.

2 Morphologies

The SB&T galaxies have a large range of collisional morphologies, including M51-like systems, wide pairs with long tails and/or bridges, wide pairs with short tails, close pairs with long tails, and close pairs with short tails. In the current paper, we discuss unusual tidal morphologies in a subset of the galaxies. In [Giroux et al. 2010], we present an Atlas of UV images of additional SB&T galaxies. The full survey is described in detail in [Smith et al. 2010]. For four of the galaxies in the SB&T sample, we have already published the GALEX images as part of detailed studies of the individual galaxies, and compared with numerical simulations of the interaction (Hancock et al. 2007, 2009, 2010; Smith et al. 2008; Peterson et al. 2009, 2010).

There is a large variety of star formation morphologies within the tidal features in this sample. In many cases, the tidal features are quite bright in the UV. This is illustrated by Arp 72 (Figure 1a), whose eastern tail is very prominent in the GALEX images, and has very blue UV/optical colors. Arp 72 is also a good example of the so-called ‘beads on a string’ morphology, in which regularly-spaced clumps of star formation are seen along spiral arms and tidal features. These clumps are generally spaced about 1 kpc apart, the characteristic scale for gravitational collapse of molecular clouds (Elmegreen & Efremov 1996). Such beads are seen in many other systems in our sample, including the northern tail of the western galaxy in Arp 65 (Figure 1b), Arp 82 (Hancock et al. 2007), and Arp 285 (Smith et al. 2008).

In a few systems, we see luminous star forming regions at the base of a tidal feature. We call these features ‘hinge clumps’ (Hancock et al. 2009). These lie near the intersection of the spiral density wave in the inner disk and the material wave in the tail. These may form when dense material in the inner disk gets pulled out into a tail. This lowers the shear, which may allow more massive clouds to gravitationally collapse. Hinge clumps are visible at the eastern end of the Arp 72 bridge (Figure 1a) and the base of the northern tail of Arp 65 (Figure 1b). Hinge clumps are also seen in Arp 82 (Hancock et al. 2007) and Arp 305 (Hancock et al. 2009).

Our sample also includes some candidate ‘tidal dwarf galaxies’ (TDGs), massive concentrations of young stars near the tips of tidal features. The prototypical TDGs in Arp 244 and Arp 245 (Mirabel et al. 1992; Duc et al. 2000)
Figure 1. GALEX images of Arp 72 (left) and the western galaxy of Arp 65 (right). North is up and east to the left in all figures in this paper.

Figure 2. The GALEX (left) and SDSS (right) images of Arp 202. are included in the SB&T sample, along with the bridge TDG in Arp 305 (Hancock et al. 2009, 2010). Another possible TDG is seen in Arp 202 (Figure 2), an interaction between an edge-on disk galaxy and a smaller irregularly-shaped galaxy to the south. A long clumpy tail is visible to the west of the southern galaxy. The tip of this tail is particularly prominent in the GALEX images, and has very blue UV/optical colors. Our optical spectrum shows that this clump is at the same redshift as Arp 202. This source was not detected in our Spitzer 8 µm map (Smith et al. 2007) or in our SARA Hα map, suggesting that it is in a post-starburst stage.

Another SB&T system that may have TDGs is Arp 181 (Figure 3). A clump is visible near the end of the western tail in the GALEX and SDSS images, with very blue optical/UV colors. However, no optical spectrum is available, thus it is unclear whether it is at the same redshift as Arp 181. Further west, another galaxy is visible, without any obvious link to the tail. Our optical spectrum
shows that it is at the same redshift as Arp 181. In the SDSS image it looks like a spiral galaxy or a disturbed disk with short tidal tails. It is extremely blue in NUV − g, and is detected at 8 µm (Smith et al. 2007). This may be either a pre-existing dwarf galaxy or a recently detached TDG.

The SB&T sample also contains numerous examples of accretion from one galaxy to another. One of the best-studied examples is the northern tail of Arp 285, which was likely produced from material accreted from the southern galaxy (Toomre & Toomre 1972; Smith et al. 2008). According to our numerical simulations, the material in this tail fell into the gravitational potential of the northern galaxy, overshot that potential, and is now gravitationally collapsing and forming stars (Smith et al. 2008). We call such features ‘accretion tails’, to distinguish them from classical tidal features. The inner western tail of Arp 284 was likely produced by the same process (Struck & Smith 2003). Another system which may have an accretion tail is Arp 105 (Figure 4). The spiral in this system has a long tail extending to the north, previously classified as a TDG (Duc et al. 1997). The spiral is connected by a bridge to an elliptical galaxy to the south. South of the elliptical is a bright star formation knot (Stockton 1972). Both the northern TDG candidate and the southern knot of star formation are luminous in HI maps (Duc et al. 1997). In the GALEX images, the spiral and the northern TDG are quite bright in the UV, but the highest UV surface brightness is found in the knot of star formation south of the elliptical. We suggest, based on analogy to Arp 285 (Smith et al. 2008) and proximity to the elliptical, that the southern star forming region in Arp 105 is an accretion tail, rather than simply a classical tidal tail coincidently seen in projection behind the elliptical.

Another system with possible mass transfer is Arp 269 (Figure 5a), an unequal-mass pair of galaxies with a bridge. In both the GALEX and SDSS images, an off-center group of blue star forming regions is visible in the smaller galaxy NGC 4485, as well as along the bridge. As noted by Elmegreen et al. (1998), several of these knots of star formation lie in a tail-like structure southwest of NGC 4485. Clemens et al. (2000) suggest that NGC 4485 passed through the disk of the larger galaxy NGC 4490, and ram pressure caused an offset in the location of the interstellar gas in NGC 4485, and thus the observed offset in star formation. We suggest an alternative possibility, that the star formation was triggered by gas flow from NGC 4490 along the bridge. Thus this may be an example of accretion from one galaxy to another.

Our sample contains only a few tidal features with high HI column densities that are not detected in our GALEX maps or published optical maps. One of these systems is Arp 269. In the Clemens et al. (1998) HI maps, two large plume-like features extend 10′ (~20 kpc) to the north and south of the pair. Neither of these plumes is strongly detected in the GALEX or SDSS images, although smoothed SDSS images show a possible hint of the southern plume. This is surprising in light of the relatively high N_{HI} in the inner 5′ (10 kpc) sections of these plumes of 4 × 10^{20} cm^{-2}. It was suggested by Clemens et al. (1998) that these HI features were produced by SN-driven outflow from the main galaxy NGC 4490. Instead, we suggest that the HI plumes are simply gas-rich tidal features. Deeper optical and UV imaging is needed to search for a stellar component to these features.
Figure 3. The GALEX (left) and SDSS (right) images of Arp 181.

Figure 4. The GALEX (left) and SDSS (right) images of Arp 105.

Figure 5. The GALEX images of Arp 269 (left) and Arp 84 (right).
Another system with a gas-rich tidal feature without a GALEX counterpart is Arp 84 (‘The Heron’), a pair of unequal mass spiral galaxies connected by a bridge (Figure 5b). In HI maps, a large gaseous plume extends to the south of the main galaxy [Kaufman et al. 1999]. In spite of its high $N_{HI} \sim 4 \times 10^{20} \text{cm}^{-2}$ and narrow HI line width of $\sim 100 \text{ km s}^{-1}$, no diffuse UV emission is seen in this feature, although a few UV-bright clumps are present. No redshifts are available at present for these clumps. Arp 84 also exhibits ‘beads on a string’ along the inner edge of the northern tail of the smaller galaxy. The most northern knot along this ‘string’ is bright in the GALEX image, as well as at 8 $\mu$m (Smith et al. 2007) and Hα [Kaufman et al. 1999].

3 Summary

In this paper, we present GALEX UV images of a subset of the SB&T interacting galaxy pairs. We identify examples of ‘beads on a string’, accretion from one galaxy to another, and candidate tidal dwarf galaxies. There are only a few tidal features that are bright in HI maps that are not detected in GALEX.

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