Star Formation in Polar-Ring Galaxies

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Abstract. Polar-ring galaxies are systems with two nearly orthogonal rotational axes, and are therefore clearly the result of galaxy-galaxy interactions. The host galaxies of polar rings are typically gas-poor early-type systems. The rings themselves, however, are typically gas-rich, blue, star-forming systems. They have traditionally been modelled as the remnants of accreted dwarf irregular galaxies. Published results on the molecular gas content, and nebular abundances argue against this model. We present Hα imaging data for three polar-ring galaxies, and derive their HII region luminosity functions. In all three galaxies, the HII region luminosity functions are much steeper than found for any dwarf galaxy. The slopes are generally closer to those of Sa galaxies. Thus the HII region LFs of polar rings join the ISM abundances in resembling the very earliest-type spirals galaxies, rather than their supposed dwarf irregular precursors.

1. Overview of Observed Properties

Polar-ring galaxies (PRGs) are typically early-type (E or S0) galaxies with luminous rings of stars, gas, and dust in nearly polar orbits (see Whitmore et al. 1990 for a review). Polar rings are

- HI rich – $M_{HI}$ up to $10^{10} M_\odot$ (Richter et al. 1994)
- Blue – $(B - V) \approx 0.5$ (Reshetnikov et al. 1994)
- Dusty (Schweizer et al. 1983)
- Actively star-forming (see §2).

In keeping with the above, the traditional model for the formation of PRGs involves the accretion of a gas-rich dwarf galaxy (a dI) by the host. Plausible alternative sources to dI galaxies are primordial HI, and material captured from spiral disks. Polar rings are typically much fainter than spiral disks (e.g. Reshetnikov et al. 1994). As a result, if spirals are the donors, only the outer parts of their disks have been captured.

A problem with the dI accretion picture in particular is that the HI masses of polar rings can be quite large (Arnaboldi et al. 1997; Richter et al. 1994). While this is not a difficulty if the donor is primordial HI, or gas captured from spirals another problem remains: All three of these sources have low heavy
element abundances. However, recent observations reveal that polar rings are often much stronger CO line-emission sources than are low-abundance systems (Galletta et al. 1997), and that the H II region abundances in the two PRGs studied to date are approximately Solar (Eskridge & Pogge 1997, 1998).

2. Hα Imaging

We are studying PRGs in order to understand their origin and evolution, and their place in the context of galaxy evolution in general. In order to evaluate the star-forming properties of polar-rings, we have been obtaining H α imaging of PRGs and PRG candidates. Here, we report our results for three kinematically confirmed PRGs: NGC 2685, UGC 4385, and NGC 4650A. Some properties of these galaxies are shown in Table 1. A point worth emphasizing is that these are not intrinsically luminous galaxies; none are substantially brighter than M33 ($M_B = -18.4$). Our absolute magnitudes are derived using the formalism of Yahil et al. (1977), and adopting $H_0 = 75$ km s$^{-1}$ Mpc$^{-1}$.

| Name       | $B_0$ | Velocity | $M_B$ | HI flux | $M_{HI}/L_B$ |
|------------|------|----------|-------|---------|-------------|
| UGC 4385   | 14.4 | 1969     | -17.6 | 7.93±0.9 | 0.69        |
| NGC 2685   | 11.9 | 876      | -18.5 | 34.2±4.0 | 0.32        |
| NGC 4650A  | 14.3 | 2910     | -18.4 | 23.2±2.4 | 1.09        |

In addition to having rich populations of H II regions, these three systems form an interesting set in that NGC 2685 is the prototype of PRGs with rings that are small compared to the host galaxy, whereas NGC 4650A is the prototype of the large-ringed PRGs. UGC 4385 is an excellent candidate for a forming PRG, as it has a very disturbed morphology, but well-behaved kinematics (Reshetnikov & Combes 1994). In Figure 1, we show an H α + [$N II$] emission-line image of UGC 4385. The contours are the red continuum light. Figure 2 shows emission-line and continuum images of NGC 4650A. Our imaging data for NGC 2685 can be found in Eskridge & Pogge (1997).

3. H II Region Luminosity Functions

From the H α images, we have derived H II region luminosity functions (LFs) for our three targets. These are shown in Figure 3. We note that the data for UGC 4385 and NGC 4650A are not photometrically calibrated. We have fit these LFs with power laws, following the spiral galaxy study of Kennicutt et al. (1989). In all cases, the bright-end slope of the LF is steep. For NGC 2685 and UGC 4385 (top and middle panels of Figure 3), we find $\alpha \approx -2.5$, and for NGC 4650A (bottom panel of Figure 3), $\alpha \approx -3$. These are plotted as solid lines in Figure 3.

As a comparison, typical Sb and Sc spirals have $\alpha \approx -2 \pm 0.3$ (Kennicutt et al. 1989). The dotted lines in Figure 3 show how poorly the canonical $\alpha = -2$
Figure 1. UGC 4385. The greyscale is H$\alpha + [N \, II]$ emission. The contours are red continuum.

Figure 2. NGC 4650A. The red continuum is shown on the left. The H$\alpha + [N \, II]$ emission is shown on the right.
Figure 3. Integrated HII region LFs for the three target galaxies.
power law fits our data. Irregular galaxies, the putative sources of the polar-ring material, have \( \alpha \gtrsim -1.8 \) (Kennicutt et al. 1989; Banfi et al. 1993). Sa spirals tend to have steeper LFs, with \( \alpha \approx -2.6 \) (Caldwell et al. 1991). Our results show that polar rings have H II region LFs that decline much more steeply than any dI studied to date. Indeed, the slopes we find are steep even in comparison to typical Sb and Sc spirals. They are instead more typical of what is seen in Sa spirals.

We note that the shape of the LF for NGC 4650A is similar to the type II LF identified by Kennicutt et al. (1989). This is shown by the dashed line in Figure 3c. Type II LFs have a very steep upper end (\( \alpha \approx -3.3 \)), with a break to a shallower slope (\( \alpha \approx -1.4 \)) at fainter luminosities. As noted above, our data for NGC 4650A are not photometrically calibrated, so we do not know if the break we see is at the correct luminosity. It could, instead be due to sample incompleteness.

4. Summary

PRGs are a class of interacting galaxies wherein the material of the precursors are still distinguishable. Formation models favor low initial heavy element abundances, but both molecular and optical line observations indicate high abundances. Many polar rings are rich in H II regions. This allows for statistical study of the ensemble of H II regions in individual systems. We have studied the H II region luminosity functions for the three PRGs NGC 2685, UGC 4385, and NGC 4650A. We find all three to have very steep slopes for their LFs (\( -3 \leq \alpha \leq -2.5 \)). That is, there is a deficit of bright H II regions in polar rings compared to what is seen in dIs and mid- to late-type spirals. Thus, both the abundances and the H II region LFs of polar rings are very different than those of dIs. Instead, both appear more similar to what is found in \( \sim \)Sa spirals. This argues strongly that polar rings are not the remains of accreted dI galaxies.

Leaving aside the issue of abundances, we conclude with some speculation on the following question: Why do polar rings have such steep H II region LFs?

It could be an IMF effect: Polar rings could make fewer very high mass stars. However, recent work on H II region luminosity functions in spirals indicates that this is not typically a good explanation for their LF slopes (e.g. Bresolin & Kennicutt 1997; Oey & Clarke 1998). More plausibly, it may be a cluster mass function effect: Massive cluster formation is inhibited in the polar ring environment. One plausible mechanism for this is strong shear in the polar ring gas, although this does not appear to be the case for NGC 4650A (Arnaboldi et al. 1997). Another possibility is that it may be an abundance effect. Detailed kinematic and abundance studies are needed to explore this question further.

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