Barred Galaxies
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Properties of H II Regions Along Galactic Bars

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Abstract.
A study of general properties of H II regions along the bars of 11 spiral galaxies is presented. From Hα imaging, distributions, morphology and star formation rates are established. Physical conditions derived from spectrophotometry reveal that strong shocks are absent in H II regions along bars and electron densities appear to be normal. Abundance distributions indicate that mixing of the ISM is taking place along bars.

1. Introduction

In recent years, thanks to new Hα surveys, UV and near-IR observations, considerable progress has been made in understanding large-scale star formation in disk galaxies. For barred spirals, Kennicutt (1994) has provided an excellent review of their star formation properties. From Hα data, at least two facts seem now well-established for SB galaxies: *i)* The global star formation rates (SFRs) in barred galaxies are similar to SFRs of normal spirals; *ii)* Star formation distributions in barred spirals are very diversified. As discussed by Phillips (1993; these proceedings), among the intriguing star formation properties of barred galaxies is the variety of star formation activity *along* their bars. For early-type barred spirals, a few (if any) H II regions are observed in their bars but for late-type ones, star formation activity can be quite intense along the bar.

Since gas flows are present along bars, H II regions located in this environment are laboratories for understanding the role played by gas dynamics on processes leading to star formation. This leads to the main question addressed by this paper: *Are H II regions formed along bars different than normal disk regions?* To answer this question and to investigate star formation taking place in bars in more detail, a general study (observations and simulations) of H II regions along galactic bars was performed.

2. Observations

A sample of 11 barred galaxies (3 SBb/bc and 8 SBc) was studied. Hα imaging was performed with the Steward Observatory 2.3m and the Mont Mégantic 1.6m telescopes. Galactic continuum images were also obtained and subtracted from the Hα images. Flux were calibrated by observing standard stars. Long-slit spectroscopy (3500 – 7000 Å) was achieved with the MMT for almost all of the H II regions in the bars of these objects. A comparison sample, formed by

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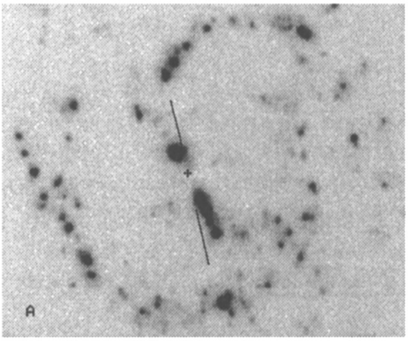

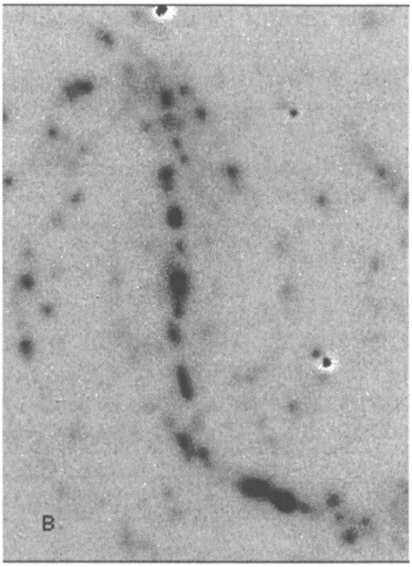

Figure 1. Hα images of two barred galaxies showing star formation activity along their bars. *a)* NGC 3359 (SBc) (full lines represent the major axis of the stellar bar and the cross, the optical center of the galaxy); *b)* NGC 7479 (SBbc)

observing a few (5-10) *disk* H II regions in each galaxy, was also obtained in order to clearly establish whether the physical conditions derived in regions along bars are really associated with the bar environment.

3. Hα Morphology and Star Formation Rates

Examples of Hα images obtained for this project are shown in Figure 1. From the complete sample of galaxies, three general distributions of star formation (SF) are observed along galactic bars:

A) Intense SF along the bar but no SF in the galactic center (e.g. NGC 3359)

B) SF activity along the bar and moderate SF in the center (e.g. NGC 7479)

C) A few (if any) H II regions along the bar but intense SF in the center (e.g. NGC 3504)

Some other interesting morphological properties can also be established:

i) For some late-type barred spirals, there is an important offset or "twist" (up to 15°) between major axes of the Hα bar and the stellar bar, the former *leading*

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the latter (except for one case in the sample, NGC 7741).

ii) The Hα bar is usually considerably shorter than the stellar bar and much narrower (typical width $\sim$ 500 pc).

iii) For SBb galaxies, H II regions along the bars are found to be strongly associated with the dust lanes.

• Star Formation Rates

Star formation rates can be estimated from Hα fluxes using the method described by Kennicutt (1989). All fluxes were corrected for dust extinction using the ratio Hα/Hβ derived from the spectra. As discussed by Phillips (1993), the correction for extinction is probably severely *under*estimated in inner parts of galactic disks. Minimal SFRs in bars cover a large range of values:

$$\boxed{\mathrm{SFR\ (bars)} = 0.01 - 2\ \mathrm{M_\odot\ yr^{-1}}}$$

For one galaxy, NGC 7479, we can estimate the transformation rate (ϵ) of gas into stars in its bar. The SFR (bar) is $\sim$ 0.5 $\mathrm{M_\odot\ yr^{-1}}$ and the gas inflow is $4 \pm 2 \times 10^6$ $\mathrm{M_\odot\ Myr^{-1}}$ (Quillen et al. 1995). If we assume that both values are constant over 1 Myr, we find $\epsilon \sim 10\%$, which is a typical value assumed, for instance, in numerical models of galaxies with ongoing star formation (e.g. Friedli & Benz 1995). This result suggests that a significant amount of gas is not consumed along the bar and is sinking into the galaxy center; star formation is observed in the nuclear region of NGC 7479 (classified as a LINER) (Figure 1b).

4. Physical Properties

From the spectrophotometric data, several physical conditions of H II regions along bars can be studied:

• Excitation

Diagnostic diagrams of nebular line ratios are tools to establish the physical conditions of excitation in H II regions. In particular, these diagrams can be used to verify if *strong* shocks are present in star forming regions along galactic bars. Such diagrams were studied by Kennicutt et al. (1989) to show that a secondary ionization mechanism (shocks or hard UV radiation) is present in nuclear "hotspots".

Figure 2 shows two familiar diagnostic diagrams for H II regions along bars and the disk regions of the comparison sample. *There are no obvious signs of strong shocks (200 – 300 km s^{-1}) affecting the line ratios of H* II *regions located in the bars.* However, we cannot reject the hypothesis that *low-velocity* shocks, which do not affect the line ratios significantly in these diagrams, are present. Nevertheless, the absence of strong shocks is very instructive. The "chain" morphology revealed by Hα images suggests that gas clouds are driven to specific

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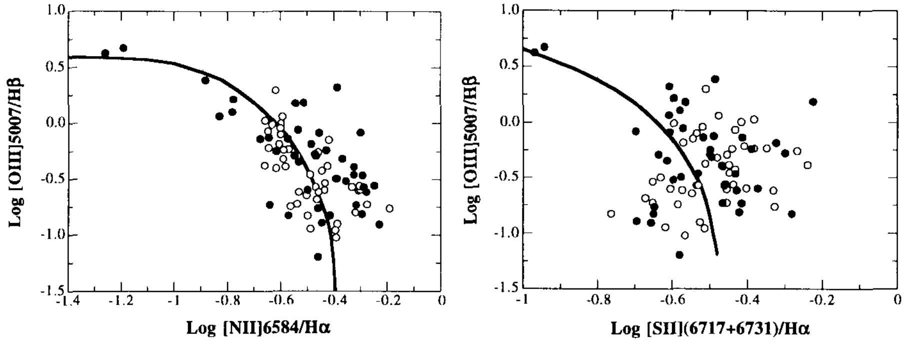

Figure 2. Diagnostic diagrams for H II regions along bars (open circles) and disk H II regions (black symbols). The full lines represent the sequence of normal disk regions from Veilleux & Osterbrock (1987).

locations along bars. The above result indicates that star formation is not triggered by strong shocks at these locations but rather by the combination of the high density of gas accumulated there and low-velocity shocks. It is interesting to note that using the Toomre parameter, for which the gas density plays a major role in triggering star formation, Friedli & Benz (1995) were able to reproduce the main characteristics of SF activity (morphology, kinematics and SFR) along the bar of NGC 7479.

• Electron Densities

Electron densities can be estimated using the line ratio [S II] 6717/ [S II] 6731. Figure 3 shows the comparison between the density distributions of H II regions along bars and regions in galactic disks. Contrary to what is observed in nuclear "hotspots" (Kennicutt et al. 1989), electron densities of H II regions in bars appear to be normal ($10 - 100$ cm^{-3}).

• Abundances

As discussed by Roy (these proceedings), O/H abundances in H II regions can be estimated by using a semi-empirical method relating O/H to specific nebular line ratios like ([O II] + [O III])/Hβ or [N II]/[O III]. Since gas flows are present along galactic bars (Athanassoula 1992), H II regions located in this environment can be used to test if *radial mixing* of the ISM occurs in bars. Figure 4 shows the O/H distribution along the bar major axis of NGC 3359. The O/H scatter is significantly smaller than the spread observed for a similar range of radii in the disks of gas-rich galaxies (see Martin & Belley, these proceedings). Similar behavior is seen in the bars of the other galaxies studied. This is a clear indication that radial mixing of the ISM is effectively taking place along galactic bars.

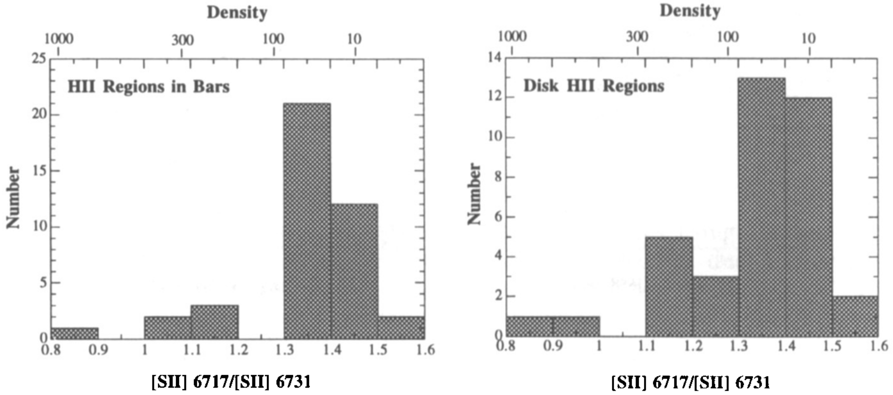

Figure 3. Distributions of electron densities N_e for H II regions along bars and normal disk regions.

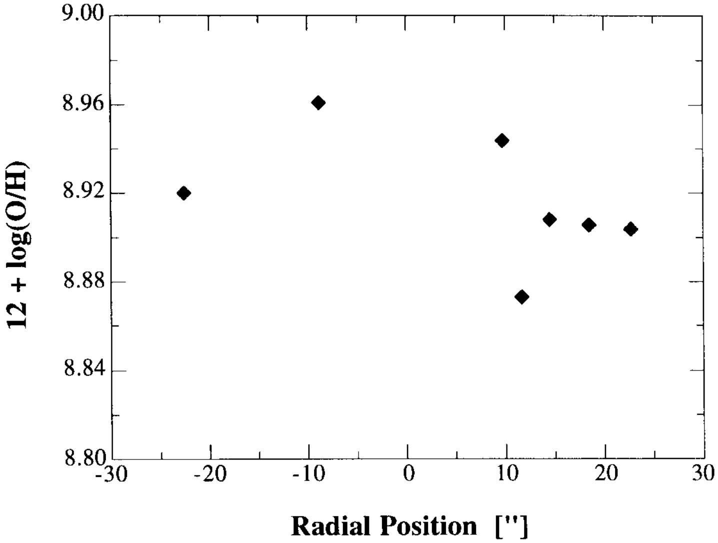

Figure 4. O/H distribution along the Hα bar of NGC 3359.

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5. Conclusion

One of the most intriguing properties of barred galaxies is the wide variety of star formation activity along their bars. In this paper, some morphological properties of the "Hα bars" have been established and the physical conditions of H II regions observed along these bars were found to be normal. However, many questions remain to be answered especially about the prevalence of SF in bars and its link with gas fueling nuclear starbursts. Large Hα surveys, HST observations and more simulations should help in understanding the phenomenon.

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References

Athanassoula, E. 1992, MNRAS, 259, 345

Friedli, D. & Benz, W. 1995, A&A, 301, 649

Kennicutt, R. C. 1989, ApJ, 344, 685

Kennicutt, R. C., Keel, W. C., & Blaha, C. A. 1989, AJ, 97, 1022

Kennicutt, R. C. 1994, in Mass-transfer Induced Activity in Galaxies, I. Shlosman, New York: Cambridge University Press), 131

Phillips, A. C. 1993, Ph.D Thesis, University of Washington

Quillen, A. et al. 1995, ApJ, 441, 549

Veilleux, S. & Osterbrock, D. E. 1987, ApJS, 63, 295

Discussion

T. Hawarden: Do you have examples where both Hα and dust lanes are seen?

P. Martin: Dust lanes in bars are seen in a few *early-type* SB galaxies in my sample. In these, some H II regions are observed to be very close to the dust lanes, in small "groups" quite different than the "chains" observed in strong barred late-type galaxies which usually do not have dust lanes in their bars.

S. Laine: Can you estimate the age of the bar in NGC 7479?

P. Martin: The simulations of Friedli & Benz (1995) suggest that the bar is young ($\sim$ 500 Myr). A good test would be to verify if a break is observed in the radial O/H gradient, as is seen in NGC 3359 (see Roy, these proceedings).

B. Elmegreen: In NGC 7479, is it possible that the low transformation rate of gas into stars obtained is the result of imprecise measurements?

P. Martin: Star formation rates from Hα fluxes are affected by extinction and in N7479, H II regions in the bar are found near the dust lanes so it is possible that the SFR is severely underestimated. In this case, all the gas accreted in the bar could be transformed into stars but since a large amount of gas is *already* in the center, an important fraction is probably not consumed along the bar.