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O/H Abundances in the Ringed Galaxy NGC 4736: Mixing Processes in the Interstellar Medium

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Abstract. Imaging spectrophotometry in the main nebular lines has been performed on 65 H II regions in the ringed galaxy NGC 4736. O/H abundances were derived using the line ratios [O III]/Hβ and [N II]/[O III] calibrated by Edmunds & Pagel (1984). We show that the O/H scatter in the resonance ring of star forming regions is small, no greater than normally expected in the well-mixed ISM of disks of gas-rich galaxies. The global O/H gradient (-0.046 dex/kpc) in the disk of NGC 4736 is shallower than gradients of normal spirals but comparable to gradients observed in weakly barred spirals. This last result could indicate that radial mixing is or was present in NGC 4736. The oval distortion in the central regions can be responsible for this homogenization but it is also possible that a strong bar was present in the past.

1. Introduction

Recent studies of the O/H abundances in galaxies have shown that large-scale mixing of the ISM is present in disks of gas-rich spirals. For barred galaxies, large-scale *radial flows* induced by bars homogenize the chemical composition on relatively short timescales (< 1 Gyr) in their disks (Friedli et al. 1994; Martin & Roy 1995); O/H gradients in barred spirals are shallower than gradients observed in normal spirals (e.g. Vila-Costas & Edmunds 1992; Martin & Roy 1994). In galactic disks with strong rotational velocity fields, abundance variations in the ISM are also rapidly wiped out *azimuthally* by turbulent diffusion in the shear flow of differential rotation (Roy & Kunth 1995). Because gas clouds are trapped in circular (or elliptical) orbits in resonance rings of H II regions, these rings are laboratories for understanding azimuthal mixing of the ISM in gas-rich galaxies. This paper presents a study of the O/H distribution in such a ringed structure located in the RSab galaxy NGC 4736.

2. O/H Abundances in the Ring of NGC 4736

NGC 4736 (D = 6.3 Mpc) is an early-type galaxy showing a very bright ring of H II regions located at R $\sim$ 48$''$ (Figure 1a). Monochromatic images in the

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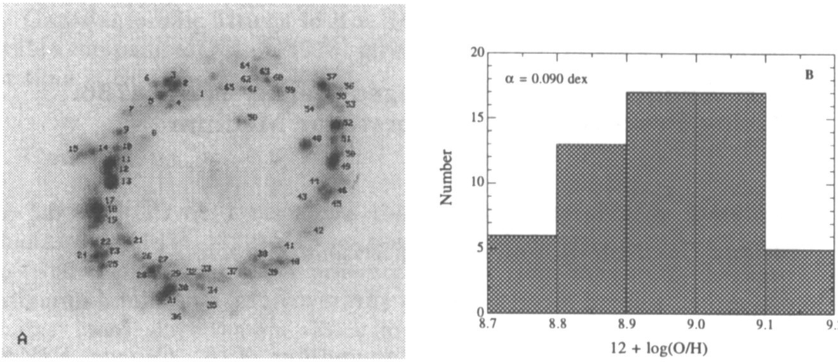

Figure 1. a) Hα image of the ring of NGC 4736. H II regions for which the O/H abundances were derived are identified. b) The O/H distribution in the star forming ring: the O/H spread is small, suggesting that rapid azimuthal mixing is present in the ring.

main nebular lines Hα, Hβ, [O III] 5007 and [N II] 6584 were obtained with the Mont Mégantic 1.6 m telescope. For 65 H II regions, O/H abundances were derived using the line ratios [O III]/Hβ and [N II]/[O III] calibrated by Edmunds & Pagel (1984). Figure 1b shows the O/H distribution in the ring of star forming regions: the O/H spread is *small* (mean deviation $\alpha = 0.09$ dex), no greater than normally expected in the well-mixed ISM of disks of gas-rich galaxies (e.g. NGC 628: $\alpha = 0.091$; NGC 6946: $\alpha = 0.097$ dex).

As discussed by Roy & Kunth (1995), the timescale for azimuthal mixing in the shear flow S is given by

$$\tau_{x_{az}} = \Delta x_{az}^{2/3} S^{-2/3} (vl)^{-1/3}$$

where Δx_{az} is the azimuthal length scale (1/4 of a full orbit), S is the radial gradient in velocity, v is the rms velocity of the clouds and l is the mean free path. For NGC 4736, we can estimate that $\tau_{x_{az}} \sim 200$ Myr (see Martin & Belley 1995). Hence the small O/H variations observed in the resonance ring of star formation in NGC 4736 can be explained by rapid azimuthal mixing of the ISM associated with the ring.

3. The Radial O/H Gradient

We were able to establish the O/H abundances of 6 H II regions in the outer parts of the disk of NGC 4736. The radial O/H gradient is illustrated in Figure 2. The slope (−0.046 dex/kpc), although quite uncertain since the number of points outside the ring is small, is *shallower* than the slope normally observed for a normal spiral (~ -0.08 dex/kpc) but is comparable to gradient slopes derived in weakly barred galaxies (see Roy, this meeting).

3.1. Two Possible Scenarios?

To explain the shallow O/H gradient in NGC 4736, two scenarios are possible:

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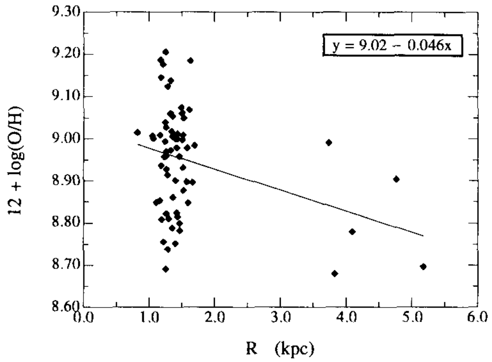

Figure 2. The radial O/H gradient in NGC 4736.

i) The oval distortion observed in the central region of the galaxy induces large-scale radial flows in the disk and these flows are flattening the O/H gradient. However, no large gas streaming motions are observed in the disk of NGC 4736.

ii) NGC 4736 could represent a good example of *secular evolution* along the Hubble sequence whereby late-type spirals are transformed into early-type ones via bars. In such a scenario, the strong bar has funneled large amounts of gas into the central regions while radial flows induced in the disk have flattened the O/H gradient. Nuclear starbursts resulting from the gas sinking into the center contributed to the bulge's growth until enough mass was accreted to dissolve the bar by dynamical instabilities (e.g. Friedli & Benz 1993). The oval distortion observed in the central region could be the remains of the bar (Kormendy 1979).

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