# Part 3. Super Star Clusters and Associations

## Section B. Poster Papers

The excitement of Extragalactic Star Clusters is obvious on the faces of Jesus Maiz-Appelaniz, Eric Peng and their crew as they float down the Trancura River.

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# Star Clusters in Galactic Resonance Rings

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**Abstract.** Resonance rings are intriguing sites of organized star formation in some galaxies. The *Hubble Space Telescope* Wide Field and Planetary Camera 2 has been used to image several resonance rings at high resolution in order to study the star clusters in the rings. Here I summarize results on inner Lindblad resonance rings in ESO 565−11 and NGC 1326, and on an inner 4:1 resonance ring in the Seyfert 2 galaxy NGC 3081. The latter ring provides one of the strongest cases illustrating the connection between star formation and dynamics in disk galaxies.

## 1. Introduction

A resonance ring is a circular or elliptical enhancement in the luminosity distribution of a disk galaxy which, by virtue of its morphology or other characteristics, can be linked to a specific orbital resonance in the disk plane. The main resonances where rings are thought to form include inner Lindblad resonance (ILR), connected to nuclear rings; inner 4:1 ultraharmonic resonance, connected to inner rings; and outer Lindblad resonance (OLR), connected to outer rings. Star formation is important in resonance rings because the rings form by gas accumulation under the continuous action of gravity torques from the bar pattern (Buta & Combes 1996).

## 2. The Nuclear Resonance Rings of ESO 565−11 and NGC 1326

Buta et al. (1999, 2000) describe the properties of young star clusters in the nuclear resonance rings of ESO 565−11 and NGC 1326. Both rings are the most significant star-forming sites in their respective galaxies. Nuclear rings are prone to significant starburst activity owing to their location deep inside the bars of galaxies, where the inner Lindblad resonance normally lies (Elmegreen 1994).

ESO 565−11 is an exceptional case where the ring is lined with very luminous "super star clusters" (Buta, Purcell, & Crocker 1995). The slope of the power law luminosity function is −2.2, typical of other young cluster systems. The nuclear ring in this galaxy is unusual in the sense that it has a linear diameter of 5kpc and an intrinsic axis ratio of 0.55, compared to averages of 1.5kpc and 0.9, respectively, for other nuclear rings (Buta & Crocker 1993, corrected to $H_0 = 75$).

NGC 1326 is different in that its nuclear ring lacks super star clusters and has a much steeper luminosity function, with a slope of −3.7. The high slope



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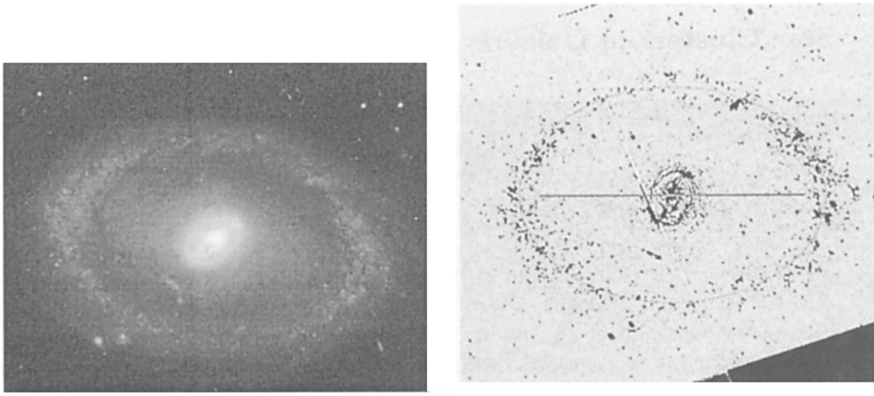

Figure 1. Left: The central region of NGC 3081 as imaged in HST filter F555W ($V$-band). North is offset 9° counterclockwise from the vertical. Right: Deprojected images of NGC 3081 showing only point sources and background galaxies. The horizontal line is the bar axis, and the dotted curve is an ellipse of intrinsic axis ratio 0.71.

could indicate that the ring either has significant numbers of extreme supergiants, or alternatively is exceptionally steeped in lower luminosity clusters. The ring otherwise has a normal shape and size.

## 3. The Inner Resonance Ring of NGC 3081

NGC 3081 has four resonance rings whose contrast is exceptional (Buta & Purcell 1998). More than a thousand point sources line the inner ring in the HST images. Figure 1 (left) shows a logarithmic $V$-band (HST filter F555W) image of the galaxy showing only the nuclear and inner ring regions. This image reveals also how background galaxies are seen through the disk of NGC 3081. Figure 1 (right) shows an image where the background disk light has been removed, revealing only the point sources lining the ring as well as foreground stars and background galaxies. This image has been deprojected and rotated so that the bar axis (line) is horizontal (see Buta & Purcell 1998). The image shows the intrinsic elliptical shape (axis ratio 0.71; dotted curve) of the ring and its alignment with the bar axis.

This ring provides us with an opportunity to explore the connection between star formation and internal dynamics. If you plot the number of star-forming regions, mostly clusters, as a function of deprojected azimuth around the ring, you get the plot in Figure 2 (left). The star clusters and single massive stars clump around the ring major axis zones, also the bar axis (vertical dashed lines). This is easily explained if the ring lies inside corotation, and represents a narrow ensemble of specific periodic orbits where gas spends more time near the major axis. The dotted curve shows the distribution of H$\alpha$ intensity (scaled and in arbitrary units) around the ring, based on groundbased data (Buta & Purcell 1998). The H$\alpha$ emission follows the distribution of ring sources very closely.

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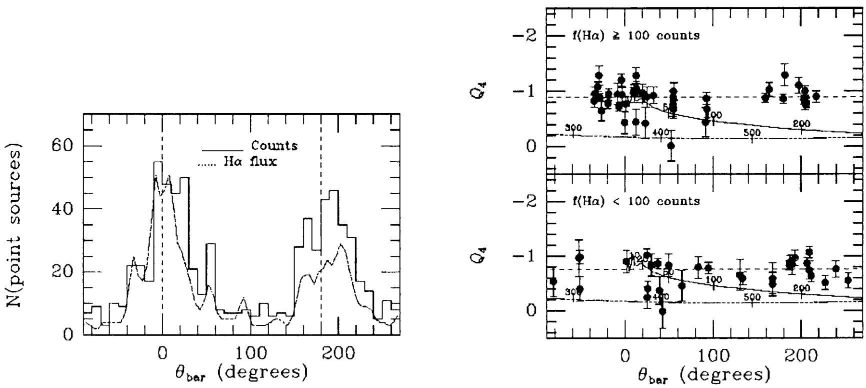


Figure 2. Left: Histogram of counts of point sources around the inner ring versus deprojected position angle relative to the bar axis. Right: Plots of the reddening-free parameter $Q_4$ versus deprojected position angle relative to the bar axis for prominent inner ring clusters. Horizontal dashed lines are at median $Q_4$ values for respective samples.

Can we identify a range of ages around the ring? Figure 2 (right) shows a reddening-free parameter, $Q_4 = (U-B)-0.32(B-I)$, versus deprojected relative bar position angle of the brighter sources in the ring. The curve shows how a cluster might evolve in $Q_4$ with position angle if it is not disrupted and stays in the ring during the estimated orbital period of 370 Myr in the rotating frame (Buta & Purcell 1998). The time dependence of $Q_4$ is based on an instantaneous burst model from Bruzual and Charlot (1996), where the solid curve is for times $<$ 260 Myr, while the dotted curve is for times $>$ 260 Myr. Both curves are labeled by the time in Myr, starting at $\theta_{bar} = 0°$. Clusters are divided according to whether there is significant H$\alpha$ flux (arbitrary units) at their positions or not. The plots suggest that some of the sources might be evolved clusters.

The full results of the study will be contained in Buta, Byrd, and Freeman (2001). This work was supported by NASA/STScI Grant GO 8707.

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