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Rings and Pseudorings as Tracers of Galactic Resonances

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ABSTRACT. The inner, outer, and nuclear rings and pseudorings of early to intermediate Hubble-type spiral galaxies offer the best evidence for the detectability of specific orbit resonances in normal galaxies. Here I briefly summarize my work on the statistical and morphological properties of outer rings and pseudorings, and how these properties relate the rings to the outer Lindblad resonance.

1. INTRODUCTION

Galaxy rings are a very natural phenomenon to associate with dynamical orbit resonances. This is because most galaxies have nonaxisymmetric components in their potential, and because a resonance is a special place where material experiences significant secular disturbance, leading to a rearrangement of the density distribution over a long period of time. However, unlike the rings of Saturn, where particle collisions help to clear a gap near a major resonance with a moon, the formation of a galaxy ring would involve cloud collisions, which, if stars form, would make the resonance or near-resonance region bright. With a little knowledge of the physics involved, galaxy rings have the potential to be powerful probes of internal galaxy dynamics, more powerful even than the features seen in "grand design" spirals that have been the subject of most of this conference.

It is obvious that if specific types of galaxy rings can be linked to specific dynamical resonances, then we would have an important indirect handle on the pattern speeds that characterize bars, ovals, and some density waves. Hardly anything is known about what determines this important parameter, how it varies from galaxy to galaxy, whether it changes with time, and whether the different features we see all have the same pattern speed. It is also clear from recent theoretical studies that rings may be a product of long-term secular evolution and that their presence in various states may indicate different timescales are at work in different galaxies.

In this paper I discuss my effort to identify the outer Lindblad resonance, or OLR, in normal galaxies statistically using the models of Schwarz (1981) as a guide. Schwarz linked both outer rings and the related outer pseudorings (called R and R′, respectively, by de Vaucouleurs 1959) to the OLR in barred galaxies and moreover showed that two ring types were allowed at that resonance which differ in morphology and alignment with respect to the bar. It is obvious that if these two types of rings, *with the appropriate morphologies and bar alignments,* do in fact exist, then we would have an important handle on identifying the location of the OLR in some galaxies. Searching for these has been a major goal of my research.

2. SURVEY OF OUTER RINGS AND PSEUDORINGS

The SRC-J, ESO-B, and ESO-R southern sky surveys are a goldmine for the study of ring phenomena in galaxies. The SRC-J survey is the backbone of what I call the "Catalog of Southern Ringed Galaxies," or CSRG, project, whose status was summarized by Buta (1991). The fine grain of the IIIa-J emulsion and the limiting surface brightness of $\mu_B \approx 27.0$ mag arcsec^{-2} make it possible to detect very small as well as very low surface brightness rings. However, the images on the charts are frequently overexposed in the crucial inner regions. The ESO-B "Quick blue" survey charts are more useful for core regions, but they are generally underexposed, the grain size is larger, and they are less sensitive to bars because bars are generally dominated by an old stellar population. The ESO-R survey charts are less useful than ESO-B for core regions and rings, because of both overexposure and the general blue color of rings, but are more sensitive to weak bars than the SRC-J or ESO-B survey. It is clear that a combination of these surveys would make a better catalog of ringed galaxies than each survey alone.

At the present time, the CSRG includes more than 1000 galaxies displaying outer rings and pseudorings. For these features the catalog compiles measurements of apparent diameters, axis ratios, and relative major axis position angles with respect to bars. These measurements contain information on *intrinsic* shapes and orientations of rings with respect to bars, and are essential if we want to address the important theoretical findings made by Schwarz. The CSRG has been carried out in two phases: CSRG I, which is based on cursory searches for ringed galaxies on 575 SRC-J fields, with the ESO-B survey films being used initially as the auxiliary for overexposed cores. CSRG I was begun in 1984 June, and discontinued in 1990 March. In 1990 July, I began CSRG II, which is an independent research of the same fields as in CSRG I in addition to fields for which J charts were not available at the time of CSRG I. CSRG II uses the ESO-R survey films exclusively as the auxiliary for overexposed cores and weak bars and is a more complete, more polished survey than CSRG I. About 320 fields have been re-searched. My goal is to publish the averaged catalog in the near future. Here I will show that the data in CSRG II support the conclusions concerning outer rings and pseudorings that Buta (1985, 1986) deduced from CSRG I data.

The overlap between CSRG's I and II has provided well-determined estimates of the external errors in the diameters (d), axis ratios (q), and bar/ring position angles (θ). I find that σ_1 [d(mm)]$=0.05d$ based on 542 measurements; $\sigma_1(q)=0.067q$ based on 271 estimates; and $\sigma_1(\theta) = 6^\circ.4$ based on 169 measurements. I expect that $\sigma_1(\theta)$ depends on axis ratio, since the angle is undefined for round rings. However, evaluation of this dependence is deferred to a later paper. These errors are small enough that distributions of axis ratios and angles should contain meaningful information if a large enough sample is used and if the assumption of random spin orientations to the line of sight is valid.

The two morphological subtypes of OLR rings and pseudorings identified by Schwarz were found in abundance during the course of CSRG I and were first described by Buta (1986). The variety with an $\approx 180^\circ$ winding of the arms was classified using the terminology R_1', while the 270° variety was classified as R_2'. The terminology is consistent with de Vaucouleurs (1959), with only the subscripts added to make the distinction. Buta and Crocker (1991) published an atlas of CCD images and color index maps of eleven examples of each subtype, and also provide a useful schematic.

From CSRG II, I have extracted the information on 832 outer rings and pseudorings over the range of types S0° to Sd, and the range of families SA to SB. Among these objects, 26% are classified as being of the R_1 or R_1' types, 16% of the R_2' type, and 3% of the R_1R_2' type. Thus, 45% of the outer features could be placed into these suspected OLR subcategories. If we reject any object which does not have a bar, since the OLR subclasses are not readily distinguished among them, then these percentages would all go up, but the point is that a substantial fraction of the outer rings and pseudorings could be placed into the OLR morphological subcategories.

Next I derived the distributions of axis ratios and angles for all barred galaxies (types SAB, SA$\underline{\text{B}}$, and SB) having a diameter $d \geqslant 0.63$ mm$=(0'.70)$, the median diameter over the whole available sample. For double-outer-ringed systems (types R_1R_2'; see Buta and Crocker 1991), the two features were each treated with half weight so as not to bias the distributions. Because of the difficulty of detecting rings in highly inclined galaxies, the number of galaxies in the catalog having $q<0.5$ is deficient, and therefore I must restrict the analysis to $q \geqslant 0.5$.

Figure 1(a) shows the distribution of the axis ratios for 263 galaxies. The noteworthy feature of the plot is the significant deficiency of galaxies in the roundest bin, $q=0.9$–1.0. If outer rings and pseudorings are intrinsically circular and if the spin axes of the galaxies are randomly oriented to the line of sight, then we would expect to observe a uniform distribution of axis ratios. The deficiency of objects in the roundest bin is almost certainly due to the shapes being significantly noncircular on average.

Figure 1(b) shows the distributions of relative bar/ring position angles for the same set of galaxies as in Fig. 1 (a), except that an angle was not measureable for about 30 of the 263 objects. The plot shows two similar-sized peaks, one in the 0°–10° bin and one in the 80°–90° bin, and a minimum in the 40°–50° bin. If bars are randomly oriented with respect to the major axes of outer rings and pseudorings, then we should see a more uniform distribution of angles in this kind of plot. However, the strange two-peaked distribution can be explained if outer rings and pseudorings have two preferred alignments with respect to bars: parallel or perpendicular. It turns out that if one restricts the analysis to those galaxies subclassified as either R_1 or R_1', they are found to provide a substantial fraction of the galaxies in the 80°–90° peak, while those classified as R_2' provide many of those in the 0°–10° peak.

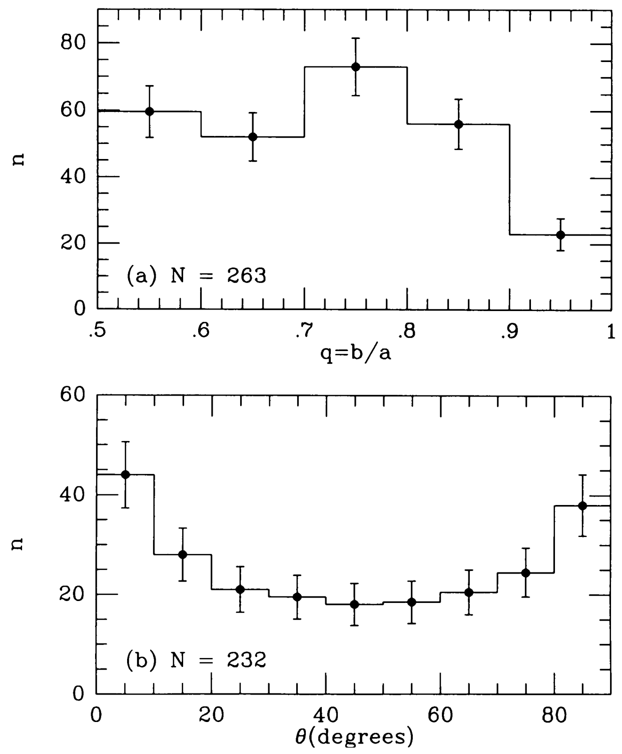

FIG. 1—Distributions of (a) apparent axis ratios and (b) apparent relative bar/ring position angles for CSRG II outer rings and pseudorings having an apparent diameter $d \geqslant 0'.70$.

The distributions in Figs. 1(a) and 1(b) are very similar to those given in Buta (1985, 1986) based on CSRG I data. In those papers, expected distributions were simulated under the assumption of random orientations of spin axes, and compared to the observed distributions. The elongated intrinsic shapes and alignments deduced were suggested to support the identification of outer rings and pseudorings with the OLR. The previous results are now confirmed.

3. CONCLUSIONS

The CSRG has provided definitive information on the detectability of the outer Lindblad resonance in normal galaxies. The morphology, shapes, and alignments of outer rings and pseudorings all support the findings of Schwarz. CSRG II has confirmed the initial findings of CSRG I, but there is more to be done. CSRG II has 287 fields remaining to be re-searched, and the availability of the SRC Equatorial and Palomar II sky surveys means that many more examples of rings can be found. More theoretical work is needed, and to this end my co-workers and I have made some progress which will be discussed in future papers.

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