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Bar-Driven Disk Evolution: Grand-Design Nuclear Spirals

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Abstract. Our study of the grand-design spiral galaxy NGC 5248 reveals that the feature previously thought to be an inclined disk is in fact an extended bar of semi-major axis 7.1 kpc, embedded within a fainter outer disk which is visible out to a radius of 17.2 kpc. NGC 5248 provides a classic demonstration of how an extended large-scale stellar bar embedded within a faint outer disk can be missed if imaging studies lack the sensitivity detect the outer disk. This effect may well lead high redshift studies to underestimate the fraction of barred galaxies. Through multi-wavelength observations and hydrodynamical modeling, we also demonstrate that the grand-design nuclear spiral on scales of 75–225 pc in NGC 5248 forms part of an extended grand-design spiral which can be traced from 8 kpc down to 80 pc and appears to be driven by the large-scale stellar bar. This study suggests that grand-design spirals on scales of several 10–100 pc, which are increasingly common in *HST* images of galaxies, can be generated by bar-driven gaseous spiral density waves which propagate inside the OILR. This propagation is particularly effective when the central mass concentration is low. Conversely, an existing large central mass

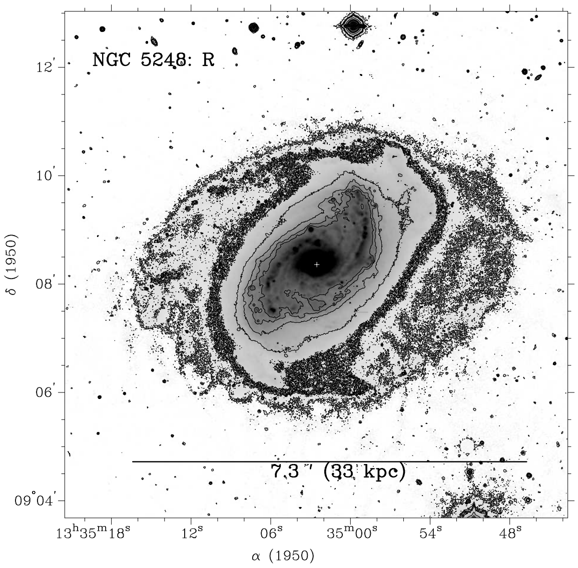

Figure 1. The *R*-band image reveals a hitherto unknown prominent stellar bar of size $95''$, embedded within a fainter outer disk which is visible out to a radius of $230''$ (17.2 kpc) (From Jogee et al. 2002a).

concentration favors other bar-driven gas transport mechanisms such as dynamically decoupled secondary nuclear bars.

1. The extended large-scale bar in NGC 5248

For decades, the grand-design spiral galaxy NGC 5248 has been postulated to be either unbarred or to host a short bar of semi-major axis $22''$ (1.6 kpc). Jogee et al. (2002a) present dynamical and morphological arguments which suggest that NGC 5248 must in fact host an extended large-scale stellar bar. One dynamical argument comes from the presence of prominent dust lanes on the *inner (concave) sides* of young stellar spiral arms out to a radius $r \geq 70''$ (5 kpc). Such a dust lane morphology is expected to exist only inside the corotation resonance (CR) of the arms, where young stars which form when gas is compressed by shocks, seen as dust lanes, can overtake the pattern. From this argument alone, we expect that the CR of the spiral pattern in NGC 5248 is beyond $70''$. If the spirals are driven by a bar, as is suggested by the absence of any significant signs of recent interaction, then the semi-major axis of the bar must be comparable in size to that of their common CR. Isophotal analysis of a deep *R*-band image (Fig. 1) with a large ($11'\!.3 \times 22'\!.5$) field of view confirms this expectation. It reveals that the feature previously thought to be an inclined disk is in fact an extended bar of semi-major axis $95''$ (7.1 kpc). The actual outer disk is more extended and visible out to a radius of $230''$ (17.2 kpc) (Fig. 1). The bar has a deprojected peak ellipticity of 0.44, a fairly constant position angle of 135°, and a CR of $\sim 115''$.

Conclusion: This study of NGC 5248 emphasizes that weak bars can show extended star-forming spirals *inside* the bar in contrast to the classic strong bars which show such features *beyond* the bar end. The physical basis is that weak bars have characteristic weak shocks and shear which can induce SF along their leading edges, while in strong bars, SF is suppressed due to the strong shocks and strong shear in the postshock flow. NGC 5248 also provides a classic demonstration of how an extended large-scale stellar bar embedded within a faint outer disk can be missed if imaging studies lack the sensitivity detect the outer disk. This effect can easily lead high redshift studies to underestimate the fraction of barred galaxies (Jogee et al. 2002a).

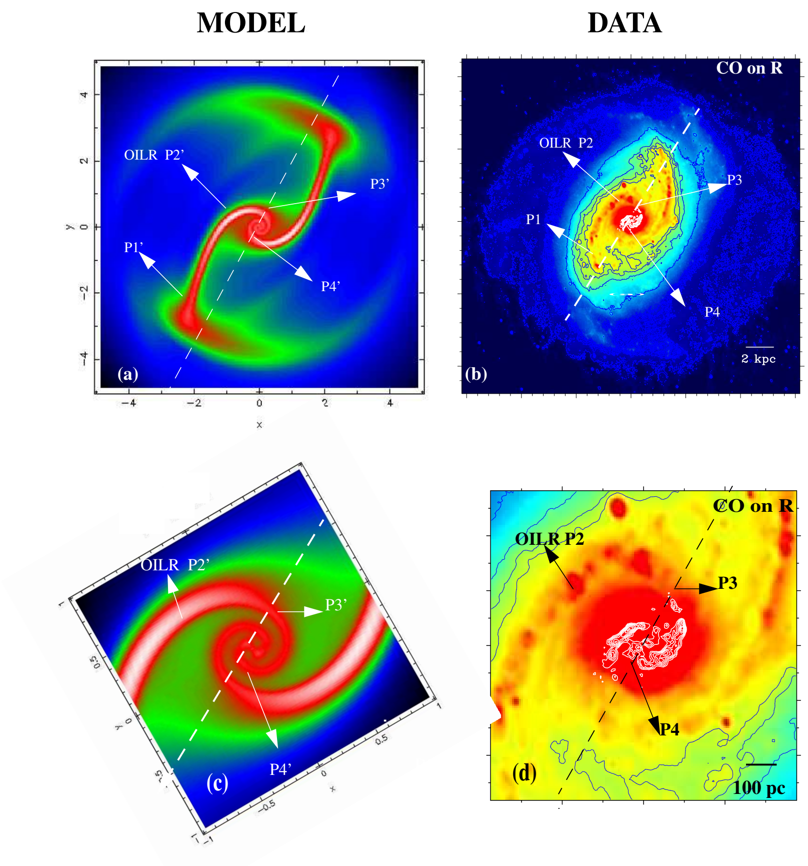

Figure 2. Comparison of CO and R-band spirals in the central [a=9kpc, c=3 kpc] of NGC 5248 with hydrodynamical models [b, d] of bar-driven gaseous spiral density waves (SDW). A dotted line shows the large-scale stellar bar. See text for details (from Jogee et al. 2002b).

2. Grand-design spirals from 8000 to 80 pc

High resolution observations increasingly show that grand-design dust spirals on scales of few (10–100) pc are common in galaxies. NGC 5248 offers an excellent opportunity to shed light on the the origin and role of such features since it harbors a grand-design nuclear dust spiral from a radius $r \sim 225$ pc to ~ 75 pc (Laine et al. 1999). From OVRO CO (1–0) data, *HST* and ground-based optical/NIR data, and Fabry–Perot Hα observations, Jogee et al. (2002b) show that the grand-design nuclear spiral, in fact, forms part of an extended grand-design spiral which can be traced from $r \sim 8$ kpc to ~ 80 pc, over more than 360° in azimuth. In particular, the spiral crosses the OILR of the bar at 2.0 kpc and connects to two massive (1.2×10^9 M$_\odot$) trailing molecular spiral arms which show non-circular streaming motions of 20 to 40 km s^{-1}. The molecular arms continue from $r \sim 1.5$ kpc to 375 pc where they feed a circumnuclear starburst ring. At $r \sim 600$ pc, they connect to two narrow young (10 Myr) K-band arms which cross the starburst ring and delineate UV-bright super star clusters in the ring. The K-band arms continue down to 225 pc where they connect to the grand-design nuclear dust spiral which continues down to ~ 75 pc, crossing a second Hα ring of radius 95 pc, and a double-peaked molecular feature.

According to the density wave theory, *stellar* density waves cannot propagate inwards across the OILR but *gaseous* density waves can. We compare (Fig. 2) the data to models of bar-driven gaseous SDW by Englmaier & Shlosman (2000). Strong bar shocks near the OILR excite a trailing non-linear high amplitude gaseous SDW which weakens rapidly as it travels inside the OILR. Inside a transition radius, a linear low amplitude gaseous SDW can be excited. In NGC 5248, the latter appears to be associated with the nuclear dust spiral. We find good agreement between the modeled and observed gas morphology (Fig. 2), gas kinematics, and pitch angle of the spirals (see Jogee et al. 2002b).

Conclusion : This combination of observations and modeling suggest that grand-design spirals on scales of 1 kpc to tens of pc can be driven by a bar. Bar-driven gaseous SDW can propagate inside the OILR and this propagation is particularly effective when the central mass concentration is low, as characterized by a shallow rotation curve. Conversely, in the regime of very large central mass concentrations, other bar-driven gas transport mechanisms are favored such as dynamically decoupled secondary nuclear bars.

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