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Does the counter-streaming instability produce lopsided dE,Ns?

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Abstract. We present evidence that FCC 046, a dE,N galaxy with an offset nucleus, suffered a counter-streaming instability. This instability may explain the presence of lopsided nuclei in other dE,Ns if these galaxies are weakly rotating. The counter-streaming needed for the instability may result from the destruction of box orbits during the assembly of the nucleus.

Keywords. instabilities, stellar dynamics, galaxies: dwarf, galaxies: evolution, galaxies: kinematics and dynamics, galaxies: structure

1. Introduction

About half of all dwarf elliptical (dE) galaxies harbor a bright central nucleus. Tidal stripping of dE,N galaxies in a dense environment may liberate these nuclei to form both the ultracompact dwarfs (Phillipps *et al.* 2001; Drinkwater these proceedings) and massive globular clusters, such as ω Cen in the Milky Way (Gnedin *et al.* 2002) and G1 in Andromeda (Meylan *et al.* 2001). In a fraction of dE,Ns, the nucleus is displaced with respect to the centers of the outer isophotes of their host galaxies. Based on photographic plate material, Binggeli *et al.* (2000) estimate a typical offset of $\sim 1''$ ($\sim$100 pc) in the Virgo cluster for $\sim$20% of dE,Ns. Various models have been proposed for explaining the offset/lopsided nuclei. One possibility is that the lopsided systems are produced by the counterstreaming instability (Zang & Hohl 1978; Sawamura 1988; Palmer & Papaloizou 1990; Merritt & Stiavelli 1990; Levison *et al.* 1990; Sellwood & Merritt 1994; Sellwood & Valluri 1997). This instability can occur whenever two coincident stellar populations counter-rotate relative to each other. The result is a lopsided distribution, i.e. a significant $m = 1$ Fourier component in the density distribution (for comparison, the more familiar bar instability corresponds to an $m = 2$ Fourier component). N-body simulations have found that the lopsidedness produced by the counter-streaming instability are robust and long-lived. When the system has zero net angular momentum then the lopsidedness is stationary while it rotates slowly if the system has some angular momentum.

2. FCC 046

Observations of FCC 046 have produced suggestive evidence for counter-streaming in FCC 046 (De Rijcke & Debattista 2004). FCC 046 is a dE,N on the outskirts of the Fornax cluster; its nearest neighbor is a dwarf over 100 kpc away from it (in projection). Photometry of FCC 046 (De Rijcke *et al.* 2003) and VLT FORS2 long-slit spectra with an instrumental resolution $\sigma_{instr} = 30$ km s^{-1} were available to us, as well as *Hubble Space Telescope* (*HST*) archival images in the F814W and F555W filters.

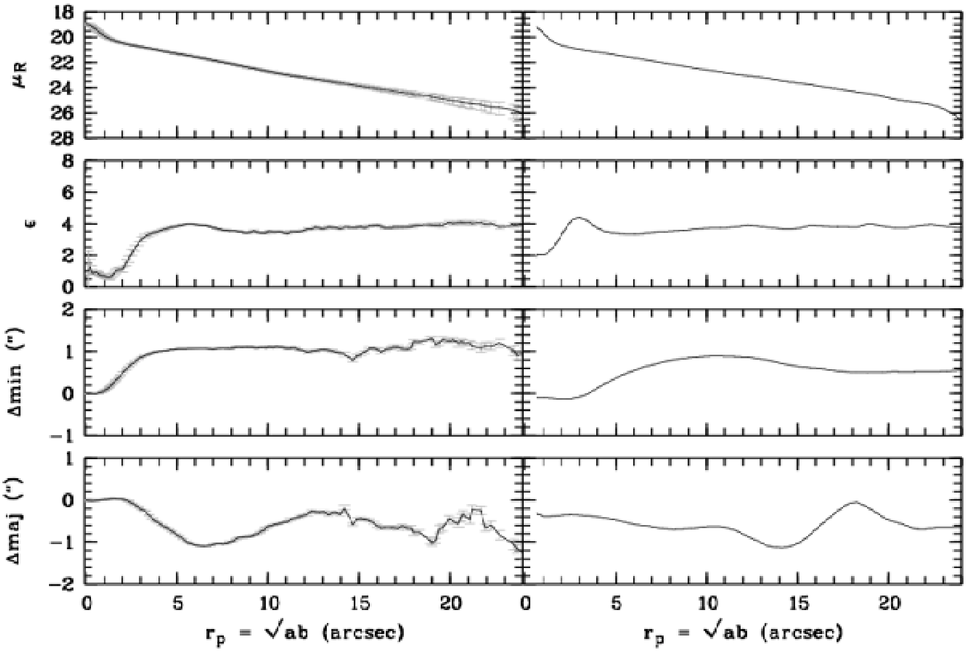

Figure 1. The parameters of ellipse fits for FCC 046 (left panels) and of the N-body simulation (right panels). The centers of the ellipses were allowed to vary. The central surface brightness of the N-body simulation was set to match that of FCC 046. The simulation can reproduce the gross structural properties of FCC 046.

The nucleus of FCC 046, which comprises some 10% of the B-band light, is offset from the center of the outer isophotes by some $1.2''$. In the *HST* images, the nucleus is clearly resolved, with FWHM $= 0.27''$, ruling out that it is a foreground star. Moreover, the spectra show that its velocity is identical to the main galaxy, which excludes a background galaxy.

Photometry (Figure 1) reveals an important property of the lopsidedness in FCC 046, namely that it extends beyond the nucleus out to $\sim 4''$ or a full exponential scale-length of the outer light profile. *Thus the lopsidedness is not due merely to a massive globular cluster displaced from the galaxy center.* It is a coherent, large-scale feature of the galaxy. The relative isolation of FCC 046 makes it unlikely that the lopsidedness was tidally induced, unless a long-lived mode was excited (Weinberg 1994). On the other hand, the absence of rotation in FCC 046 (De Rijcke & Debattista 2004) makes it possible that the counter-streaming instability generated the lopsidedness.

To explore this possibility, we compared N-body simulations with slit observations of FCC 046. Here we discuss one such simulation which produced a reasonable facsimile of the global structure of FCC 046. Briefly, the simulation consisted of nucleus inside a flattened (E8) unrotating disk with mass ratio $0.08 : 0.92$. The model went through the counter-streaming instability. The resulting system reproduces the gross features of FCC 046 (Figure 1). We then used this N-body simulation to produce a model spectrum consisting of a flat continuum and a δ-function absorption line broadened by the instrumental profile. On the major-axis, the model predicts no evidence of counter-rotation within $8''$ of the nucleus, and increasing line splitting at larger radii. On the minor-axis, the model predicts no line splitting. All these predictions are borne out by the spectra, albeit at low signal-to-noise (see Figure 2).

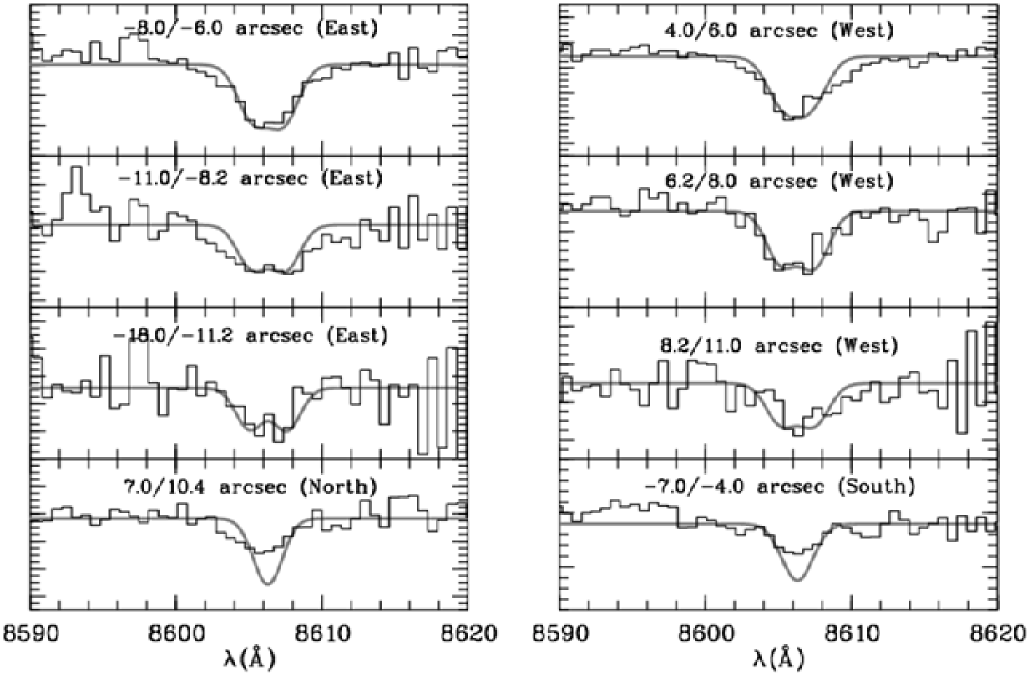

Figure 2. The strongest Ca II absorption line in FORS2 spectra of FCC 046 (histograms) compared with the prediction from the N-body simulation (gray line). The top three panels are along the major-axis centered on the nucleus, while the bottom panel is on the minor axis. Some evidence of counter-streaming is seen on the major-axis where it is predicted by the simulation, and absent where it should be.

3. What causes counter-streaming?

If the counter-streaming instability is producing these lopsided dE,Ns, what causes the counter-streaming in the first place? One possible mechanism is the destruction of box orbits in a slowly, or non-, rotating triaxial galaxy. Box orbits can be destroyed by a growing central mass, which can be the nucleus itself in the case of dE,Ns. If the nucleus grows to more than ∼2% in mass, then destruction of box orbits takes a few crossing times ($\sim 10^7$–10^8 yr for a dE,N). Because the colors of nuclei are very similar to those of their host galaxies (Lisker, these proceedings), gas infall is likely not the way that nuclei grow. A more promising possibility is that sinking globular clusters merge at the center to form the nucleus.

4. Conclusions

Although FCC 046 appears to have counter-streaming, the evidence at this point is merely suggestive, not definitive. Testing the counter-streaming hypothesis only requires high spectral resolution and high S/N observations.

If the nuclei grow via the merger of globular clusters, then the nuclei of dE,Ns may provide a channel by which super-massive black holes (SMBHs) grow. We note that a SMBH has been detected in G1, a giant globular cluster believed to be the tidally stripped nuclear remnant of a dE,N.

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Discussion

Moore: How does destruction of the box orbits leave you with a counter-streaming population? Would a cuspy halo stabilise the system?

Debattista: If the system starts out with no angular momentum, by conservation of angular momentum, the scattering of the box orbits must leave a system with no angular momentum. Therefore box orbits will scatter to loop orbits in equal numbers for the two rotation senses. The effect of central mass growth and box orbit scattering is to generate a tangentially biased distribution (Goodman & Binney 1984; Merritt & Quinlan 1998).

In our simulations we find the scale of the lopsidedness decreases as the inner halo becomes increasingly massive. The instability can still occur in fairly massive halos but presumably massive enough cusps would inhibit the instability. However, as with bars, tidal interactions may provoke it in otherwise stable systems. Once a lopsidedness forms, because its motion is generally slow at best, the instability is not efficiently damped.

Read: To what extent does your model rely on the assumption of box orbits initially — would these orbits be expected in the initial conditions?

Debattista: Not very much. Counter-streaming can be generated in at least one other way: secondary infall. We did not consider this possibility very likely, simply because dwarf ellipticals may not be as efficient at accreting equal-sized objects. But this is admittedly a bias, and may be wrong. Any source of counter-streaming in dE,Ns is a candidate for generating the initial conditions which lead to the lopsidedness. The possibility that counter-streaming is generating these lopsided dE,Ns can be observationally tested independent of the hypothesis that box orbit scattering is giving rise to counter-streaming.

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