The Binary Nucleus In VCC 128:

A Candidate Supermassive Black Hole in a Dwarf Elliptical Galaxy

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Abstract

Searching through archival Hubble Space Telescope (HST) images of dwarf elliptical galaxies, we identified galaxies with compound nuclei. HST Wide Field Planetary Camera 2 (WFPC2) images of the Virgo Cluster dwarf elliptical galaxy VCC 128 reveal an apparently double nucleus. The two components, which are separated by 32 pc in projection, have the same magnitude and color. Spectra of this double nucleus are inconsistent with one or both components being emission-line background objects or foreground stars. The most likely interpretation is that, as suggested by Lauer et al. (1996) for the double nucleus of NGC 4486B, we are seeing a nuclear disk surrounding a supermassive black hole (SMBH). This is only the second time an early-type dwarf (dE/dSph) galaxy has been suggested to host a SMBH.

HST Imaging

We explored the nuclear morphology of 50 dwarf elliptical (dE) galaxies using the *HST* archive. We found a double nucleus in VCC 128 (Figure 1), a dE (B = -15.5) in the outskirts of the Virgo Cluster (VC). The 2 nuclei are separated by 32 pc (assuming a VC distance of 16.5 Mpc). The two components are equally bright (V ~ -8.5) and have the same color (V-I ~ 1.0). A color map shows no evidence of obscuration in the nuclear region. The two nuclei are marginally resolved, with a FWHM of ~3.5 pixels (PSF is 1.3 pixels).

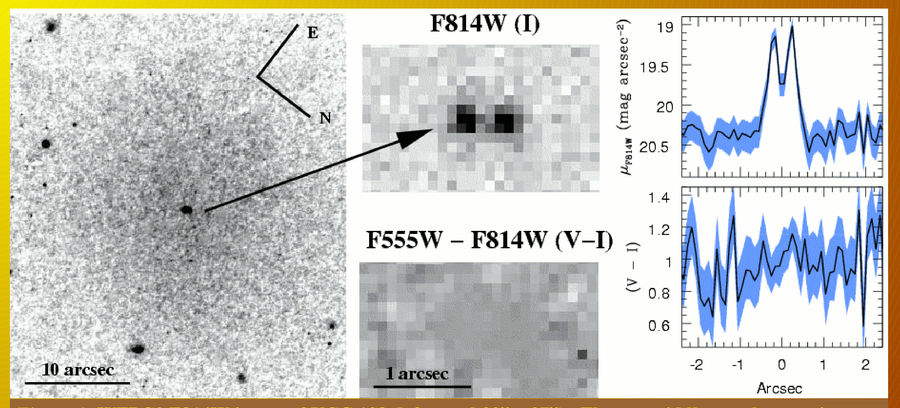

Figure 1: **WFPC2 F814W image of VCC 128 (left panel 32" x 37"). The top middle panel zooms into the central 2.5" x 1.5", showing that the nucleus is resolved into two components. The bottom middle panel shows the same zoom into the *V-I* color map, with *V-I* ranging from 1 – 2 mag. The top right panel shows the light profile of a 5 pixel wide slit across the major axis of the nucleus. The bottom right panel shows the color profile for the same slit.**

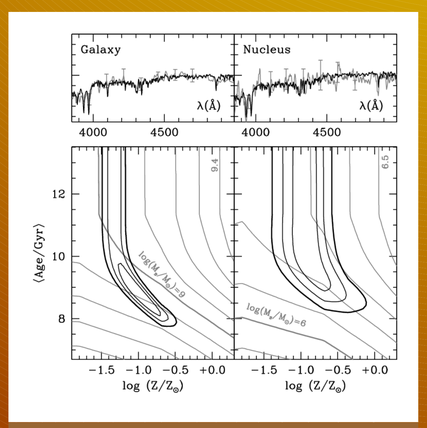

Figure 2: **Top Observed SEDs (gray) of galaxy (left) and nucleus (right) and the best fitting models (black). Bottom Corresponding mean properties of the best-fitting stellar populations. Confidence levels (black lines) are 1, 2 and 3 (thick lines) sigma. Stellar mass contours are shown in gray.**

Spectroscopy

We obtained low resolution (2.4 A/pixel) long-slit spectra through the nucleus of VCC 128 at the Apache Point Observatory 3.5-m telescope. A total of 4 hours over two runs, were obtained..

After standard reductions, the background galaxy was subtracted from the nuclear spectrum (Figure 2). The nuclear spectrum does not contain any emission lines, ruling out a background object. It is poorly fit by a stellar spectrum but is in excellent agreement with a source in the Virgo Cluster, confirming that this is the nucleus of VCC 128.

We modeled the nuclear and galaxy spectra with the population synthesis models of Bruzual & Charlot (2003). We compared SEDs of composite stellar populations with exponentially decaying star formation rate assuming a formation epoch z = 3 and a Chabrier (2003) initial mass function. The nucleus was found to be consistent with a relatively metal-rich stellar population older than 1 Gyr. The best fit nuclear mass is one million solar masses (Figure 2).

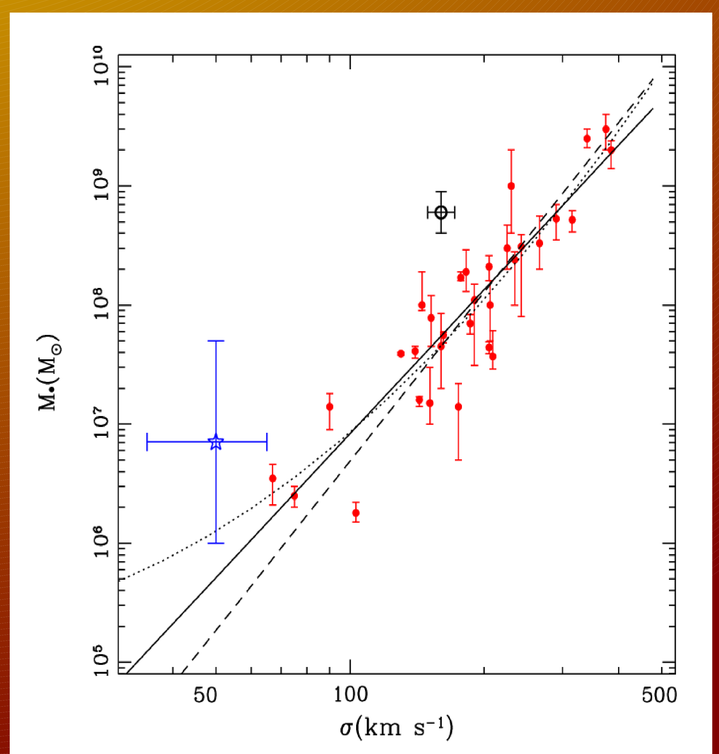

Figure 4: **Estimated location of VCC 128 (blue star) in the M-sigma plane. The solid red circles are from Tremaine et al. (2002). The fits are, for solid, dashed and dotted lines, those of Tremaine et al. 2002, Merritt & Ferrarese (2001) and Wyithe (2006) respectively.**

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Interpretation

Double nuclei had previously been discovered in 2 galaxies, M31 (the Andromeda galaxy) and NGC 4486B (Lauer et al. 1993, 1996, 2005). Tremaine (1995) suggested that the double nucleus in M31 is a Keplerian disk in rotation about the SMBH which M31 is known to host. The SMBH in that case sits on the fainter of the two nuclei, which is also the center of the galaxy. Meanwhile, the brighter nucleus is the result of stars slowing down at apoapsis as they rotate about the SMBH in an eccentric disk. Such eccentric disks have been shown to be stable in N-body simulations (e.g. Jacobs & Sellwood 2001). In NGC 4486B instead, the SMBH is situated between the two nuclei.

Because of the similar colors and magnitudes of the two nuclei, we (Debattista et al. 2006) propose a similar model for VCC 128 (Figure 3). This implies the presence of a SMBH in this dwarf galaxy.

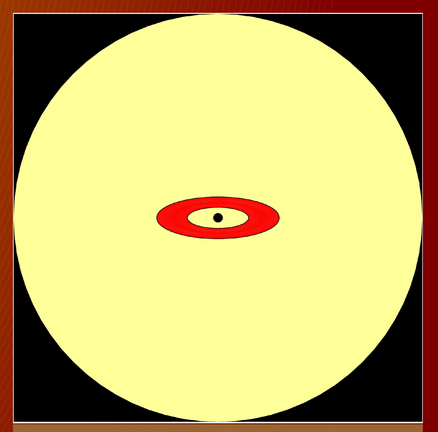

Figure 3: **Model of VCC 128. The outer envelope of stars (yellow) surrounds a stellar ring (red) orbiting around a SMBH (black dot). Seen in projection, the ring of stars appears as a double nucleus.**

Significance

We obtain a lower limit on the SMBH mass by assuming it must be at least as massive as the surrounding nucleus. We obtain an upper limit if we assume the same nuclear disk to SMBH mass ratio as in NGC 4486B (1.9%). These give a mass range 1 – 50 million solar masses. This makes VCC 128 the second early type dwarf galaxy with evidence of a SMBH (Maccarone et al. 2005).

Assuming a velocity dispersion of 35-65 *km/s*, typical of a dwarf galaxy of this luminosity (De Rijcke et al. 2005) puts this galaxy in tentative agreement with the M-sigma relation (Gebhardt et al. 2000; Ferrarese & Merritt 2000; Tremaine et al. 2002; Wyithe 2006) (Figure 4).

It is likely that the dark halo of VCC 128 has a virial velocity less than 200 *km/s*, the limit proposed by Ferrarese (2002) below which SMBH formation is inefficient.

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