Dynamical Masses of ACS Virgo Cluster Survey Galaxies

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Lisa Glass and Moo Cat (not a collaborator :)

Abstract

Recent results from the Virgo Cluster Survey (VCS) of early-type galaxies (performed using ACS on HST) show that a much higher fraction of galaxies have bright star clusters at their centres than previously thought. Between 66 and 82 percent of the galaxies surveyed contain nuclear star clusters (NSCs). These are found in intermediate and low luminosity galaxies. Conversely, many of the higher luminosity galaxies have confirmed supermassive black holes (SBHs). It is possible that most if not all galaxies contain some form of central massive object (CMO), either a NSC or a SBH. In fact preliminary results suggest that NSC mass and SBH mass have the same scaling relation with total host galaxy mass! However, this relation is based on simple virial estimates of the galaxy mass. This poster presents our efforts to find the dynamical masses of the galaxies, using Jeans equation modeling. Preliminary results find the mass of M87 to be 1.3 x 10^{12} solar masses. The next step is to apply the model to the rest of the VCS galaxies in order to verify that NSC and SBH mass truly do scale with total galaxy mass in the same way.

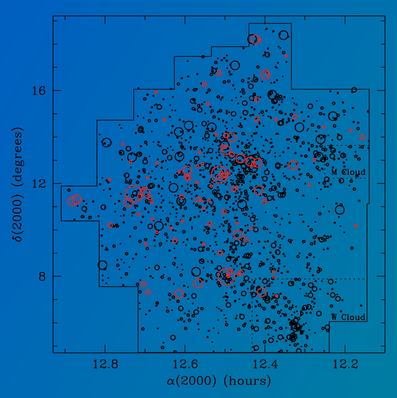
1. Data

100 early-type galaxies: E, S0, dE, dE,N, dS0, dS0, N, selected from the Virgo Cluster Catalog (VCC) (Binggeli et al. 1985) and confirmed members of Virgo (from radial velocities)

Magnitude limits:
$9.3 \leq B_T \leq 16.0$
$-21.8 \leq M_B \leq -15.$
(factor 460 in B-band luminosity)

Completeness:
100% for $B_T \leq 12.15$
54% for $12.15 \leq B_T \leq 16.0$

Spectra:
Long slit spectra from KPNO for the 69 ACSVCS galaxies brighter than M_B = -16.5 and from Keck for the faintest.



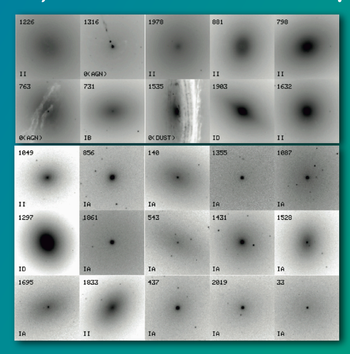
Distribution of VCC galaxies on the plane of the sky, adapted from Binggeli et al. (1987). The red symbols denote the full sample of 100 early-type galaxies from the ACS Virgo Cluster Survey. For full details about the survey see Cote et al. 2004 ApJS 153, 223.

2. Surface Brightness Profiles

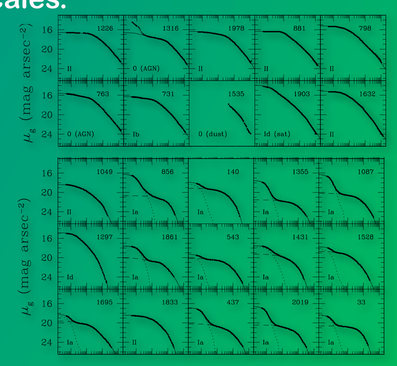
The surface brightness profiles are fit with Sersic models. The fits are accurate global representations of the global profiles, except inside a characteristic break radius. The break radius is typically between 0.1 and 1 arcseconds and corresponds to ~ 2% of the effective radius.

Bright galaxies typically show central light deficits with respect to the inward extrapolation of the Sersic model, while the great majority of low- and intermediate-luminosity galaxies show central light excesses.

A Sersic model modified to follow a power law inside the break radius (i.e. core-Sersic model) can fit the observed profiles over all scales.


M_B < -20.3

-16.9 < M_B < -16.4



M_B < -20.3

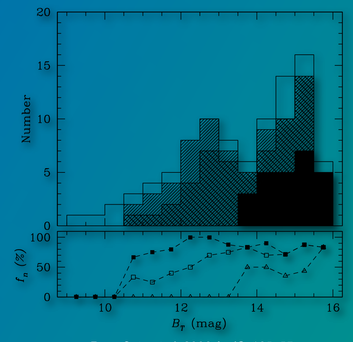
-16.9 < M_B < -16.4

3. Frequency of Nucleation

The light excesses are interpreted to be nuclear star clusters (NSCs).

One interesting result from VCS is how often galaxies are nucleated:

Virgo Cluster Catalogue frequency of nucleation:
~ 25% (for VCS galaxies)
VCS frequency of nucleation:
~ 66% - 82%

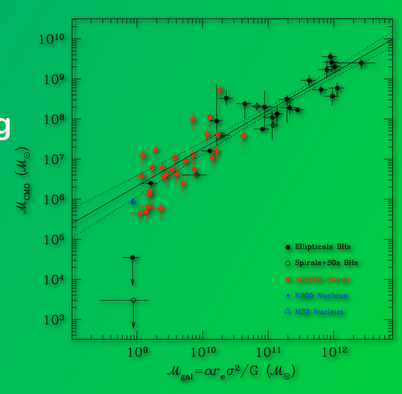


From Cote et al. 2006 ApJS, 165, 57
See also: Carollo, Stiavelli & Mack 1998; Matthews et al 1999; Boker et al. 2002, 2004; Balcells et al. 2003, Lotz et al. 2004; Graham & Guzman 2003; Grant et al. 2005

4. A Relationship Between Nuclear Star Clusters and Supermassive Black Holes

When the masses of the VCS SBHs and NSCs are plotted against the virial mass of the host galaxies, we find that they essentially follow the same scaling relation:

$$\frac{\mathcal{M}_{\text{Central Massive Object}}}{\mathcal{M}_{\text{Galaxy}}} = 0.17\% \ (0.06\% - 0.50\%)$$



Ferrarese et al. 2006 ApJ 644, L21

The Question:

Would this relationship hold true if total galaxy mass were known dynamically?

5. Approach

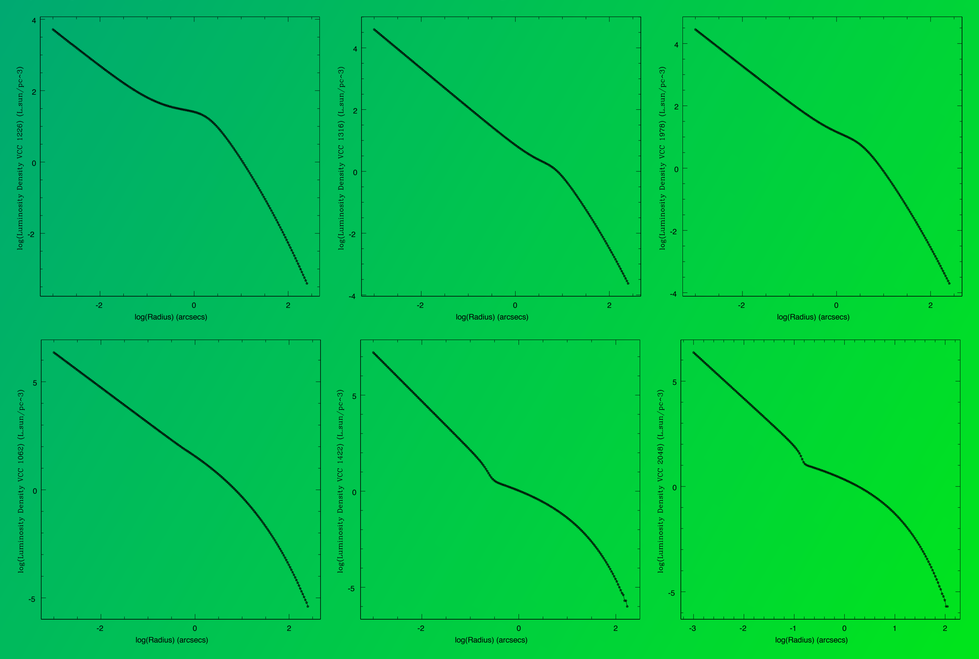
- Deproject surface brightness profiles to obtain the luminosity density profiles $j(r)$.
- Assume a radially invariant mass-to-light ratio Υ. The mass density profile $\rho(r) = \Upsilon j(r)$ is then known, assuming a spherical galaxy.
- Use the isotropic Jeans equation to solve for velocity dispersion $\sigma(r)$.

$$\frac{d(\rho\sigma^2)}{dr} = -\rho\frac{d\Phi}{dr}$$

- Compare the velocity dispersion profile to the observations.
- Using a least squares method, fit for the mass-to-light ratio that best reproduces the velocity dispersion profile.
- Use the mass-to-light ratio and the total integrated light to find total dynamical mass.

6. Deprojected Surface Brightness Profiles

As part of this project we will also investigate if the claimed dichotomy in the inner slopes of the surface brightness profiles of early type galaxies translates into a similar distribution when the luminosity density profiles are analyzed.
The deprojected profiles for a few selected galaxies are shown below.



7. Recent Results: Using $\sigma(r)$ of M87 to Find Υ and Total Mass

Since the VCS galaxies were observed in both the g and z bands, we find mass-to-light ratios of M87 for each band. (Note that only observations for radius > 6" were used to fit the model.)

We find:

$$\Upsilon_z = 5.8$$
$$\Upsilon_g = 15.0$$

This corresponds to

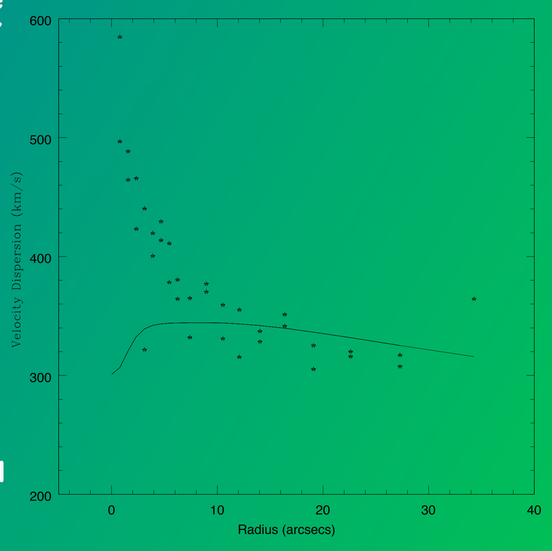
$$g - z = 1.6$$

which is very consistent with the colour for M87 from Ferrarese et al. 2006, ApJS, 164, 334.

Our results are also consistent with van der Marel 1994, 270, 271.

Integrating the mass density profile, we find:

$$M_{\text{tot}} = 1.3 \times 10^{12} M_\odot$$



The stars are the velocity dispersions obtained using KPNO long slit data.
The line represents our model for velocity dispersion profile.

8. What's Next?

- Complete the same analysis as we did for M87 for the other 99 Virgo Cluster Survey galaxies. This study will also be repeated for 43 galaxies in the Fornax cluster using a similar data set.

- Compute the slopes of the inner regions of the luminosity density profiles as a further test of whether a core power-law dichotomy exists or not.