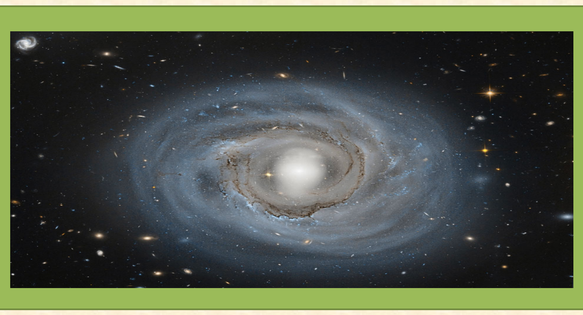

The Surface Brightness Fluctuation Distance to the Coma Cluster

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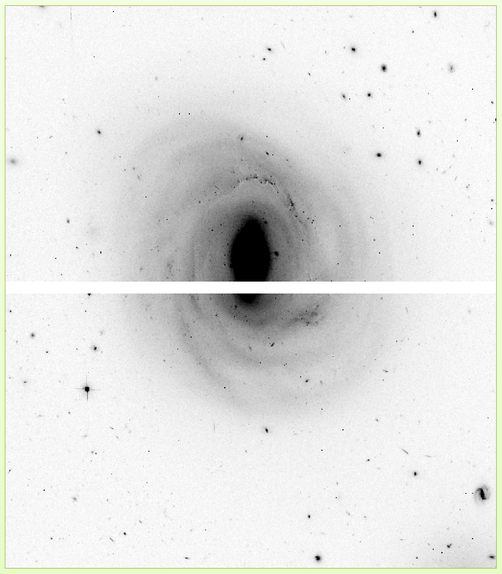
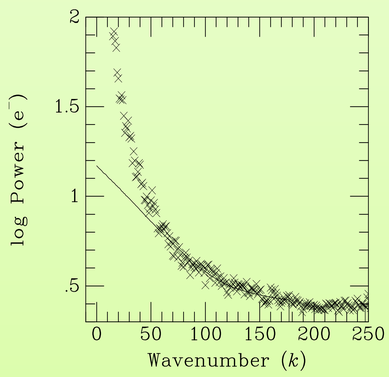
Abstract:

With measuring accurate distances to nearby galaxies using surface brightness fluctuations (SBF), we can further our knowledge of the size, expansion rate, and age of the Universe. The Coma cluster is an important cluster for which there are several existing distance measurements, including a recent one using Cepheid variable stars in the spiral galaxy NGC 4921. Despite the fact that SBF analysis is not typically reliable for spiral galaxies, we were able to do SBF analysis on NGC 4921 using images gathered from the Space Telescope archive. Optical images in the *I* and *r* filters were cleaned and combined to make two separate images of NGC 4921. We also measured the SBF distance to the central giant elliptical galaxy NGC 4874 using Space Telescope infrared images. The result of this work was a SBF distance measurement that will help us calculate the distance to the Coma cluster and understand the properties of the stars in these galaxies. We then compare the Cepheid and SBF distances to the Coma cluster to yield a new measurement of the relative distance between the Virgo and Coma clusters.

SBF Measurement of NGC 4921

Even though measuring SBF in a spiral galaxy is usually not reliable, we tried to measure the SBF distance to NGC 4921, a galaxy that is in the Coma cluster that also has a Cepheid distance measurement. To measure the SBF in NGC 4921 we used F606W and F814W images obtained using ACS. We pieced together the images for each filter and masked dusty regions in the spiral arms and point sources.



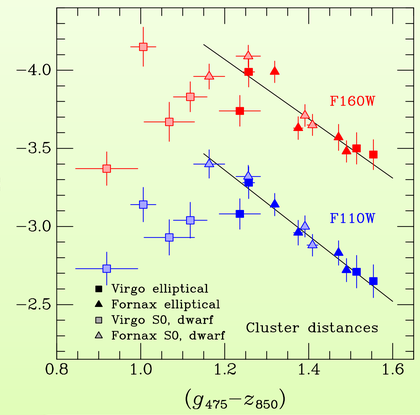


A smooth galaxy fit was made for NGC 4921 and after subtracting we were left with a residual image of the galaxy. After we masked out the regions that interfere with the analysis we divided the galaxy into four quadrants; SBF analysis was then used on each quadrant of the galaxy. The SBF magnitude measured from the power spectrum of the residual image was inconsistent with the Cepheid distance due to the presence of dust and young stars, which bias the SBF distance determination.

The IR SBF Calibration

IR SBF are useful as an extragalactic distance indicator provided that the galaxy color can be used to correct for stellar population variations.

We used SBF measurements of 16 galaxies in Fornax and Virgo to determine the best fit of $\overline{M}$ with galaxy color, using a Cepheid zero point. The rms scatter at the red end is 0.07 mag (*J*) and 0.11 mag (*H*); population variations among bluer galaxies is much larger.

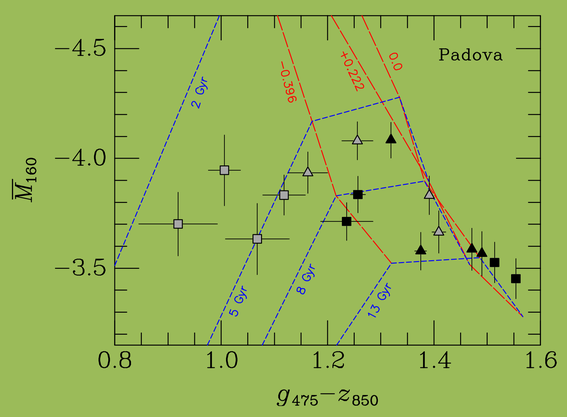


$M_{F110W} = -3.154 + 2.11\,(g_{475} - z_{850} - 1.3)$
$M_{F160W} = -3.879 + 1.90\,(g_{475} - z_{850} - 1.3)$
for $(g_{475} - z_{850}) > 1.2$ (AB mags)

Recommendations for Measuring IR SBF Distances

- Use F110W instead of F160W when possible to minimize exposure time.
- Use flt files without geometric corrections, or use drz files using lanczos3 kernel.
- Measure SBF in giant elliptical and S0 galaxies with old stellar populations for which $(g_{475} - z_{850}) > 1.2$ or $(J_{110} - H_{160}) > 0.22$ AB mag.
- If possible, use ACS $(g_{475} - z_{850})$ colors. The calibration scatter using WFC3/IR $(J_{110} - H_{160})$ colors is larger.
- Typical one-orbit exposure times are sufficient to reach a distance of 80 Mpc. The SBF signal can be detected out to 100 Mpc in a single orbit, but the correction for contaminating point sources will dominate the uncertainty.
- Exposure times for more distant galaxies should be scaled to achieve a point source sensitivity to detect and remove globular clusters 1.5 magnitudes brighter than the peak of the globular cluster luminosity function.

Padova Stellar Population Models



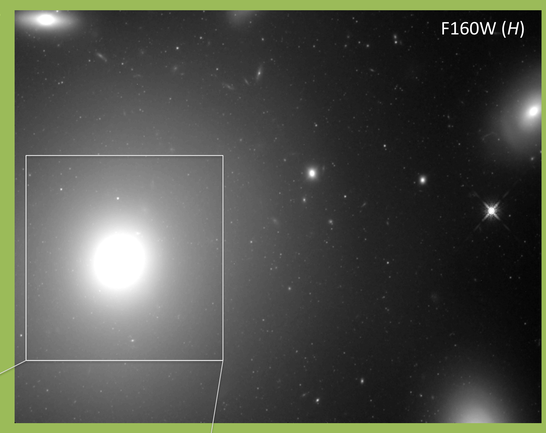
We can probe the stellar populations of these galaxies by comparing SBF magnitudes to population models. This figure shows galaxy color versus absolute fluctuation magnitude with Padova population models for various ages and metallicities (blue lines are isochrones and red lines are lines of constant [Fe/H] metallicity). Using these and other models we find that the larger red elliptical galaxies are older and more metal rich while bluer dwarf ellipticals tend to be younger and more metal poor.

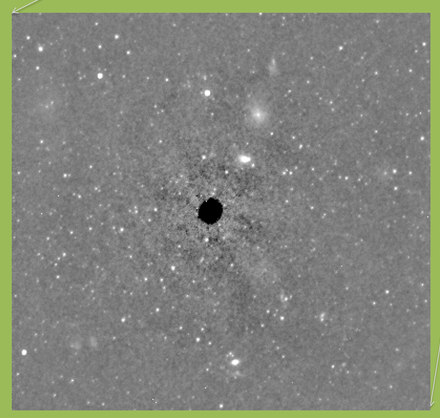
Distance to the Coma Cluster: NGC 4874

SBF measurements of NGC 4874 are summarized as follows:

NGC 4874:
$\overline{m}_{F160W} = 31.47 \pm 0.09$
$(g-z) = 1.537 \pm 0.003$

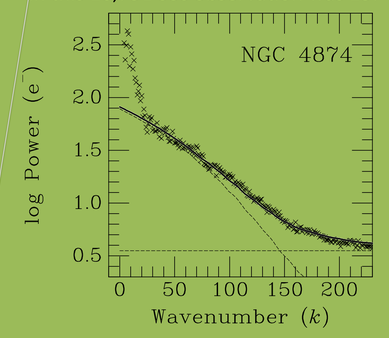
$\overline{M}_{F160W} = -3.43 \pm 0.11$
$(m-M) = 34.90 \pm 0.14$
d = 95 ± 6 Mpc
H_o=75 ± 5 km/s/Mpc





Residual image of the central ≈1 arcmin² of NGC 4874, showing the rich population of globular clusters and numerous galaxies superimposed on the stellar fluctuations.

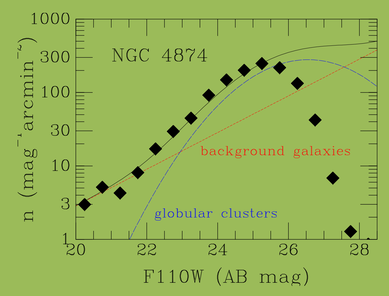
Power spectrum PSF fit. The SBF S/N in this 10,791 sec observation was 29.



Coma–Virgo Relative distance:
$(m-M)_{Virgo} = 31.09$ (Blakeslee et al. 2009)

$\Delta(m-M) = 3.81$ mag (Virgo/Fornax calib.)

Coma is 5.8× farther than Virgo; we have chosen to use the Virgo/Fornax calibration for consistency with Blakeslee et al. 2009.



NGC 4874's rich population of globular clusters was removed from the SBF measurement by first masking those brighter than the completeness limit and then correcting for fainter ones by fitting the luminosity function (above) and integrating fainter than the completeness limit. We cross-checked the globular cluster identifications with F110W (*J*) and F814W (*i*) images of NGC 4874.

References:
[1] Marigo et al. 2008, A&A, 482, 883; Girardi et al. 2010, ApJ, 724, 1030 (Padova models)
[2] Mei, S., Blakeslee, J. P., et al. 2007, ApJ, 655, 144 (ACSVCS-XIII)
[3] Blakeslee, J. P. et al. 2009, ApJ, 694, 556 (ACSFCS-V)
[4] Humphreys et al. 2013, ApJ, 775, 13

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