

Measuring surface brightness fluctuations in galaxies

A secondary distance indicator to determine extragalactic distance

Ching-Yin Ng, Yee-Ching Lam, Ren-bin Yan

Department of Physics, CUHK



Motivation

In 1988, Tonry and Schneider [1] proposed the surface brightness fluctuations (SBF) method. It is based on the fact that

- The fractional poisson fluctuation in the number of stars per resolution element is proportional to $1/d$
- The surface brightness of a galaxy is independent of distance

By measuring the ratio between the Poisson fluctuation and the surface brightness, we can derive the distance of a galaxy.

Unlike other methods, SBF requires only one deep observation along with data in multiple colors to calibrate for the stellar population [2].

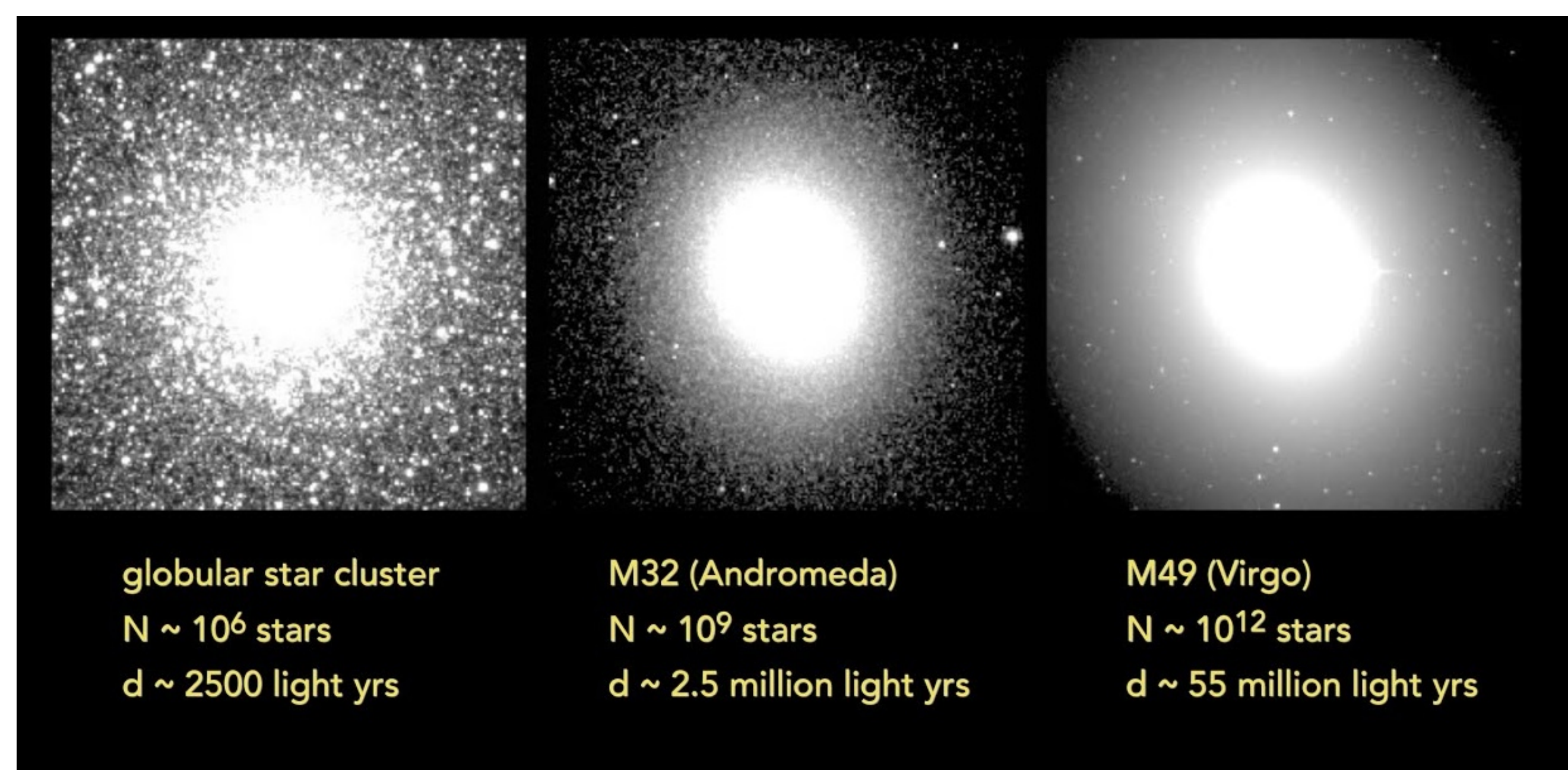


Figure 1: Images of galaxies at different distances. Galaxies look more smooth as the distance increase. Image credit: Blakeslee, J. P.

Method

To obtain the underlying fluctuations, a smooth galaxy model is fitted and subtracted from the galaxy image. We also masked bright sources that does not belong to the galaxy.

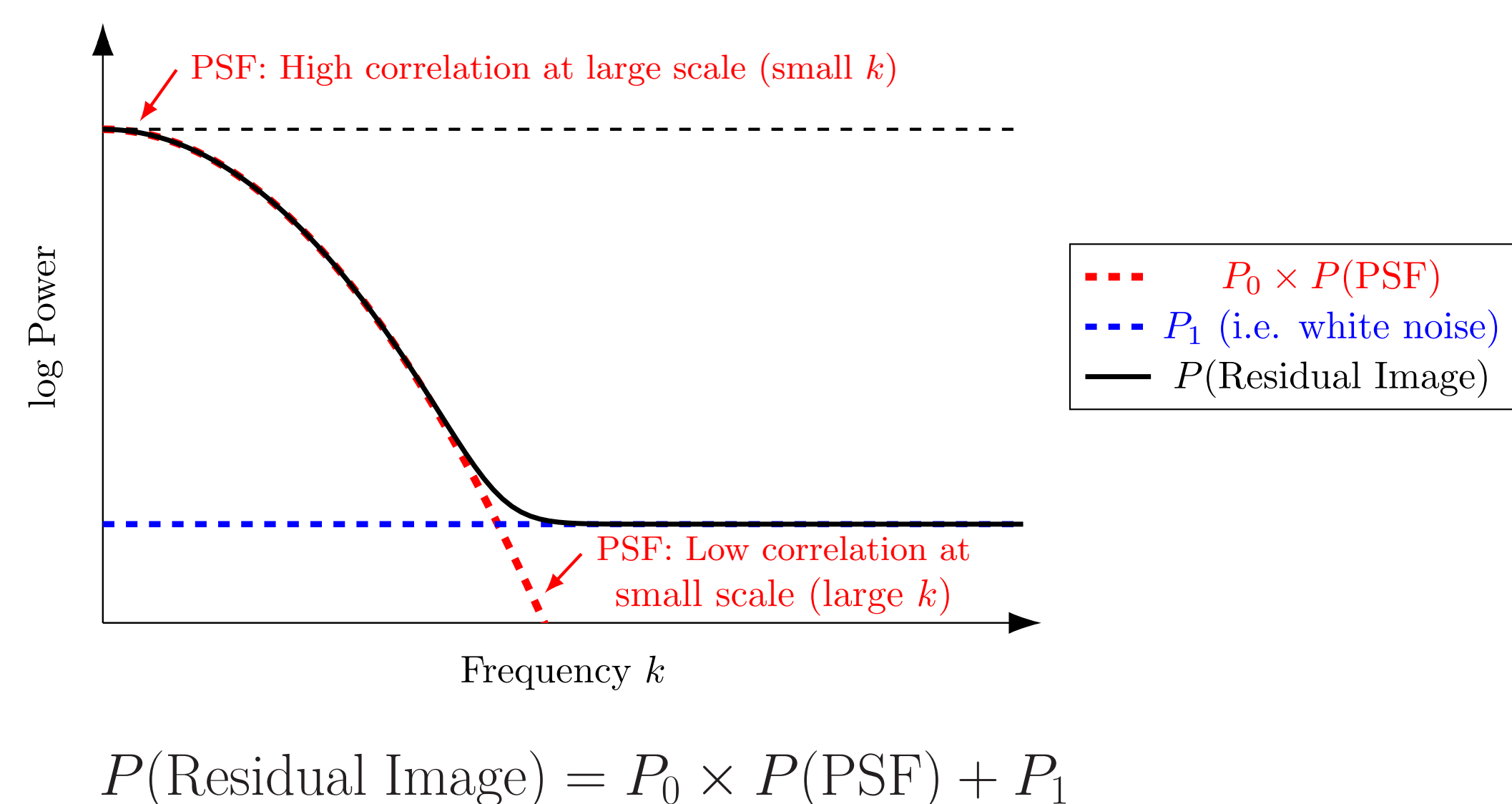


Figure 2: Illustration of azimuthally averaged power spectrum

Optical diffraction and aberration turns a point source into a point spread function (PSF), which smooths out the small scale fluctuations in Fourier space. This allows us to effectively differentiate the intrinsic fluctuation from instrumental noise, which has a white power spectrum. Therefore, we follow the procedures:

- Fourier transform the residual image
- Fit point spread function (PSF) model to the data to obtain P_0
- Estimate P_{bkg} by random sampling in nearby blank fields
- Subtract P_{bkg} from P_0 to obtain the true fluctuation,

$$P_{\text{SBF}} = P_0 - P_{\text{bkg}}. \quad (1)$$

- For convenience, convert P_{SBF} into AB magnitude $\overline{m}$.

After that, calibration is needed to determine the distance.

In this project, we used the near-infrared F110W (J_{110}) and F160W (H_{160}) filters on HST WFC3/IR. We chose near-infrared because our targeting early-type galaxies are dominated by red giant stars, which has a stronger SBF signal in near-infrared [2].

The differences of galaxy brightness in the two filters ($J_{110} - H_{160}$) were calculated with the Photutils package in Python. Then, we can determine $\overline{M}$ using the calibration formula by Jensen, et al. [3]. This enables us to calculate distance d via the distance modulus

$$\overline{m} - \overline{M} = 5 \log_{10}(d/10). \quad (2)$$

Results

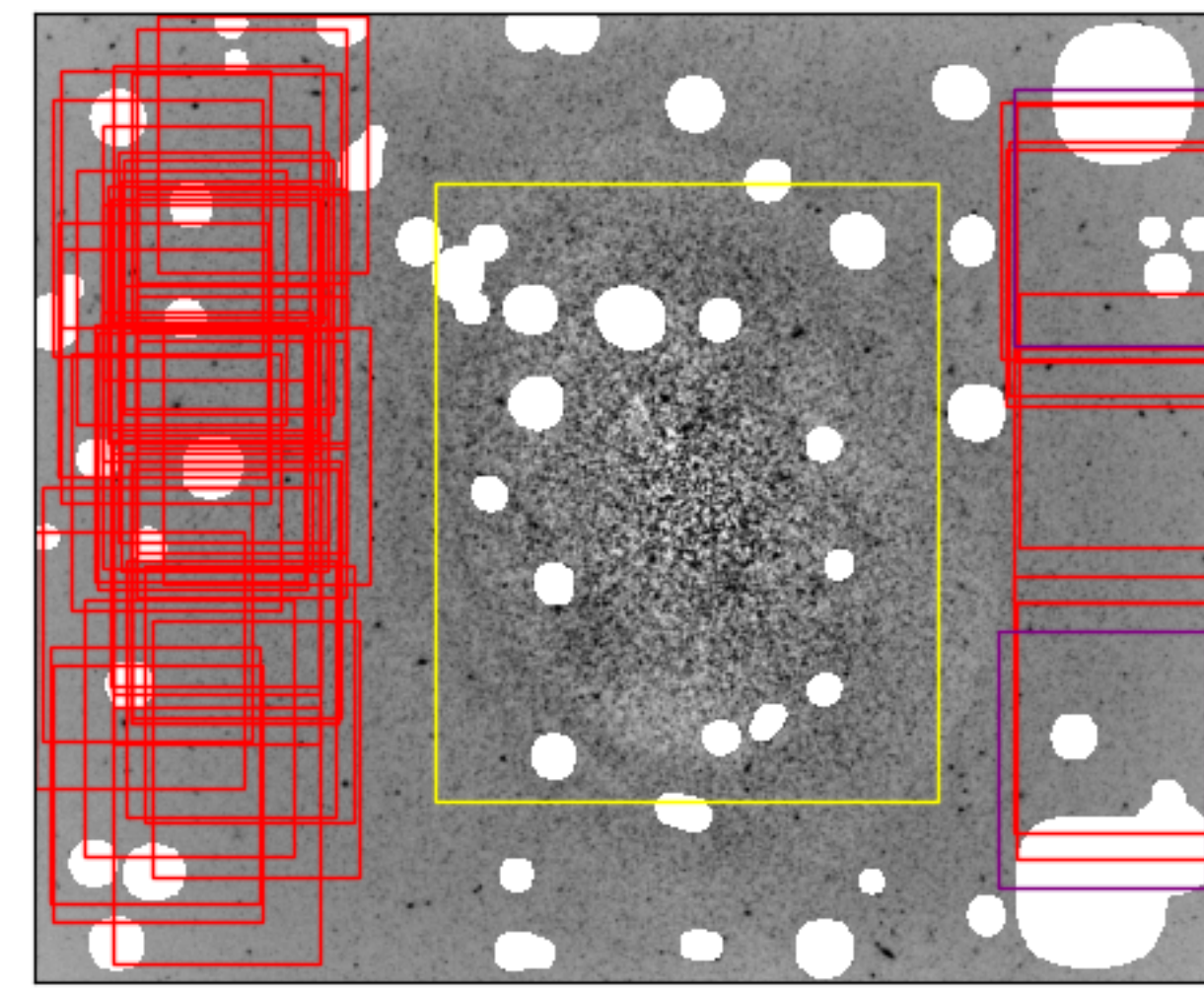


Figure 3: Estimating P_{bkg} by random sampling in residual image of IC1919.

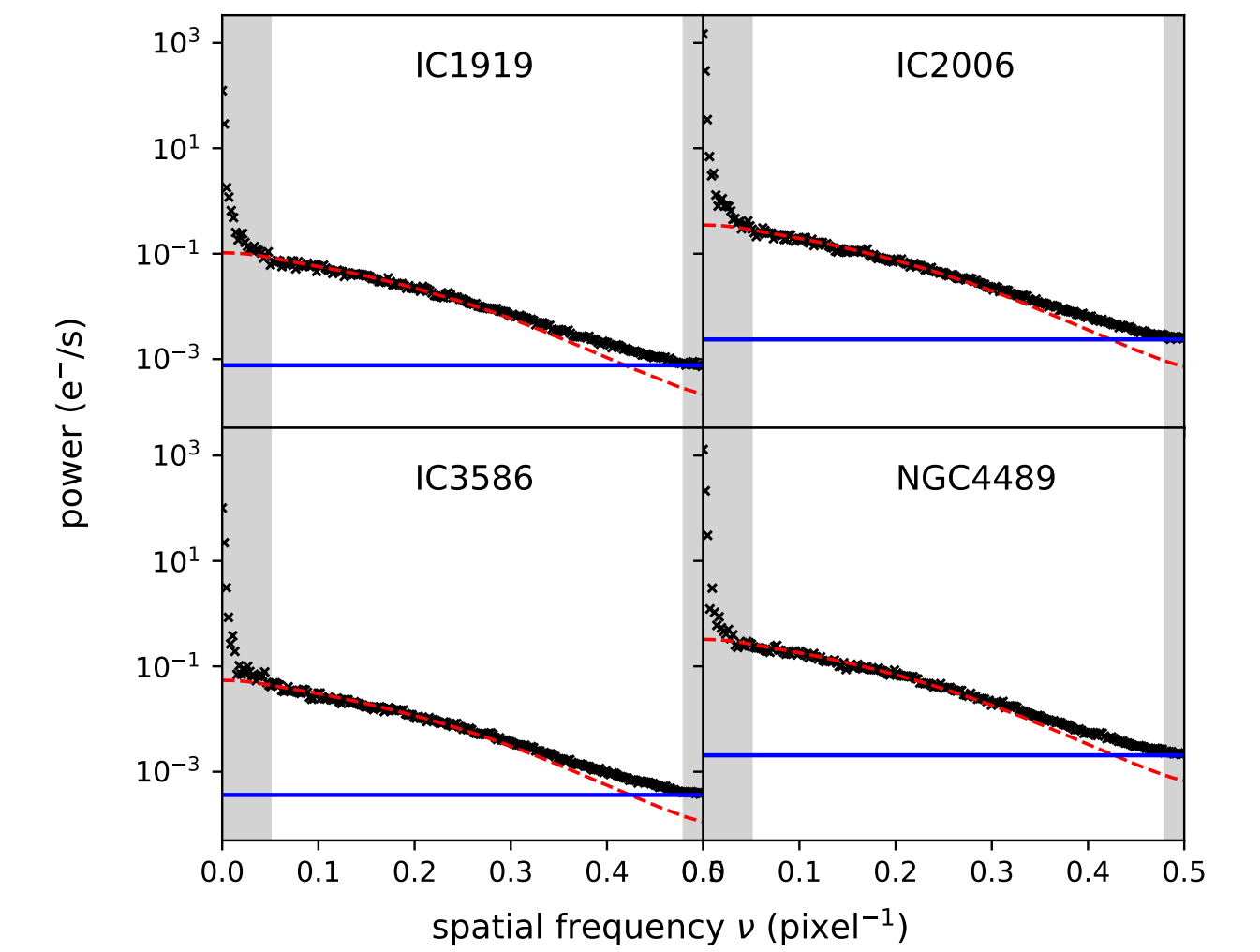


Figure 4: Fitted data of four galaxies in Fornax and Virgo in J_{110} filter.

As an example, we show the residual image of IC1919 in figure 3, where the yellow frame encloses the target galaxy and the red frames enclose the sampled background blank fields. In figure 4, we fitted the spatial power spectrum of four galaxies to obtain their P_0 . Similarly, P_{bkg} is estimated by fitting the PSF of the blank fields from random sampling.

In table 1, we present our results of distance modulus. Results from Jensen, et al. [3] are also provided for comparison. The difference between the two results is within 0.2 mag., which is about 8.5% difference in distance.

Table 1: Distance modulus of four galaxies in Fornax and Virgo.

Galaxy	$\overline{m} - \overline{M}$	$(\overline{m} - \overline{M})_{\text{Jensen}}$
Fornax		
IC1919	31.44 ± 0.02	31.485 ± 0.073
IC2006	31.58 ± 0.09	31.525 ± 0.086
Virgo		
IC3586	31.08 ± 0.03	31.093 ± 0.080
NGC4489	30.79 ± 0.05	30.935 ± 0.069

Discussion

The result is satisfactory given the time constraint of the project. Yet, some problems remain to be solved.

One of the major issues is the masking process. Although we have used the scarlet package to detect bright sources, manual inspection and editing are often needed, which is vulnerable to human-error. We also have issues in building a ePSF model for fitting.

Nevertheless, the SBF method is a powerful tool to produce reliable distance measurements. Despite its complexity, it has little dependence on the cosmic distance ladder. With the ongoing Hubble tension, the SBF method is a promising alternative in constraining H_0 .

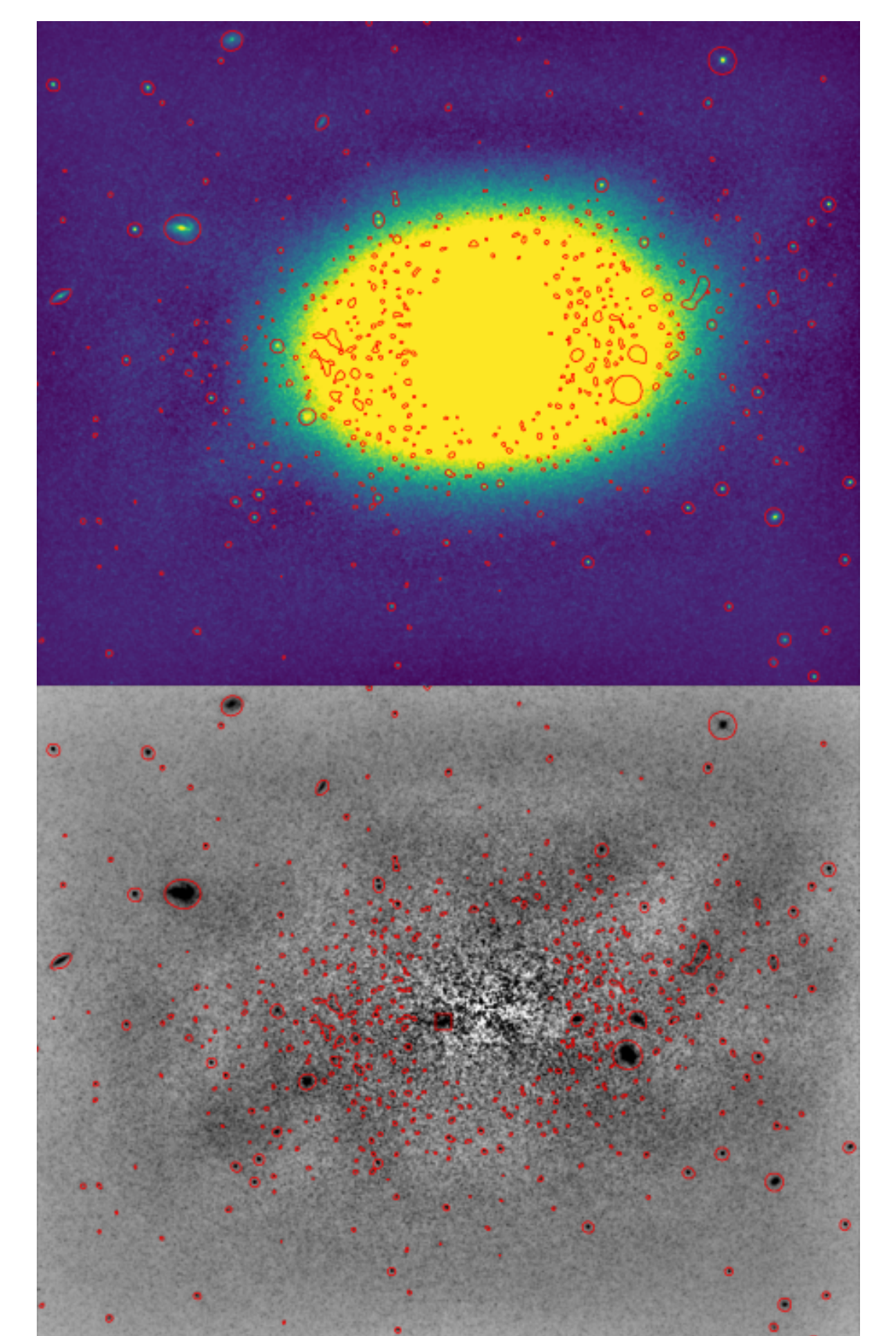


Figure 5: Detecting bright sources with scarlet

References

- [1] Tonry, J. L., and Schneider, D. P. (1988). Astron. J. 96, 807.
- [2] Blakeslee, J. P., Jensen, J. B., Ma, C.-P., et al. (2021). ApJ. 911, 65.
- [3] Jensen, J. B., Blakeslee, J. P., Gibson, Z., et al. (2015). Astron. J. 808, 91.

Acknowledgements

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