A Tale of Two Distance Indicators

Nandini Hazra
Gran Sasso Science Institute (GSSI), L'Aquila
Istituto Nazionale di Astrofisica (INAF), Teramo

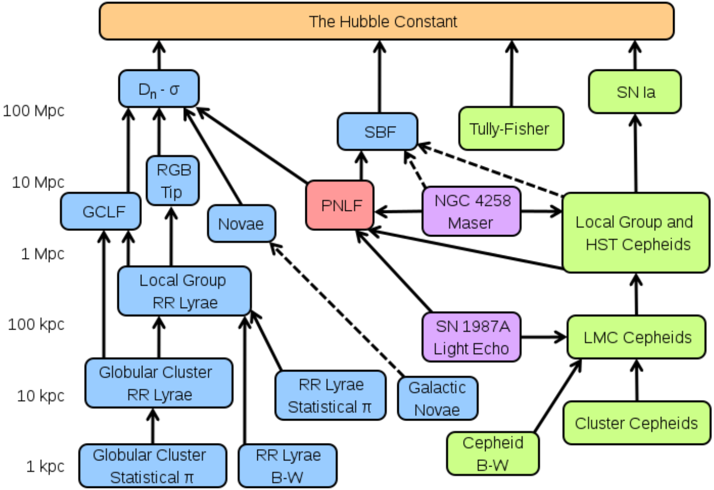
Advisors
Marica Branchesi, Michele Cantiello

Institut Pascal
November 16, 2021

GRAN SASSO SCIENCE INSTITUTE

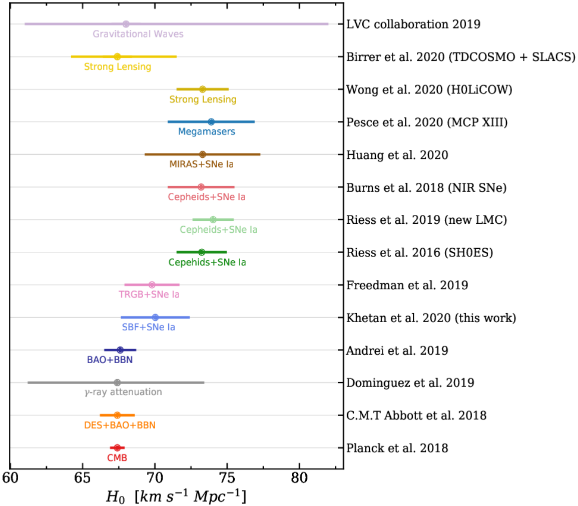
OSSERVATORIO ASTRONOMICO D'ABRUZZO
INAF ISTITUTO NAZIONALE DI ASTROFISICA

Extragalactic Distance Ladder



Why do we need precise distances?

- Astrophysics: precisely measure intrinsic source parameters, such as size and luminosity
- Cosmology: Hubble tension
- Need to reduce errors on individual distances

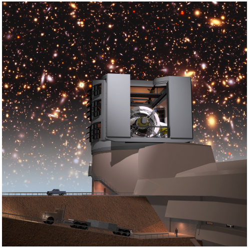


Source: Khetan et al. 2021

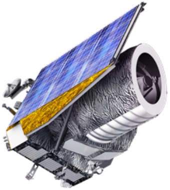
Next generation telescopes : The Vera Rubin Observatory

- Vera Rubin Observatory: Legacy Survey of Space and Time(LSST)
  - 8.4 m telescope, ∼18000 sq deg. survey area, in SDSS ugrizy filters
  - i-band 5σ depth at 10 years 26.8 mag, FWHM 0.7"
- VRO will enormously increase the data of galaxies suitable to measure SBF distances up to 100 Mpc
- Extremely promising to measure the Hubble constant using SBF stand-alone or to calibrate SN type Ia (as shown in Khetan et al. 2021)

VERA C. RUBIN OBSERVATORY

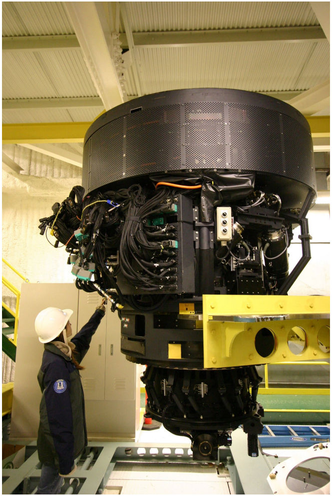


Euclid and JWST



- Euclid wide survey
  - ∼15000 sq deg. survey area, H-band depth 24 mag, FWHM 0.2”
  - SBF $\leq$100 Mpc
- James Webb Space Telescope
  - 6.5 m aperture, 7 times collecting area of HST
  - FWHM 0.06-0.08”

Our objective

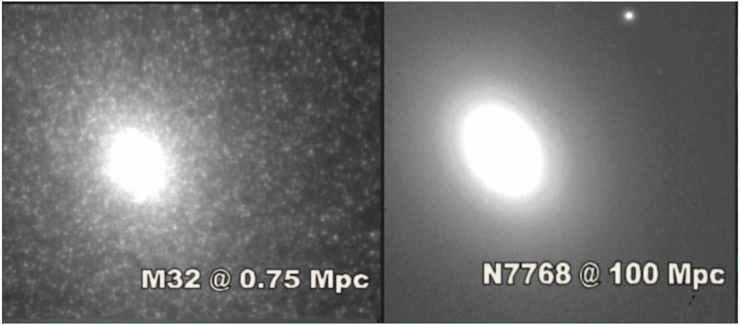


Source: NAOJ

- Build a pipeline with Python for SBF distance measurements that requires minimal human intervention, to exploit all the potentialities of VRO data
- Calibrate and test the pipeline using data from Hyper Suprime Cam(HSC) of Subaru, which is a precursor survey for LSST
- Make it accessible to the scientific community
- In the process : obtain GCLF distance

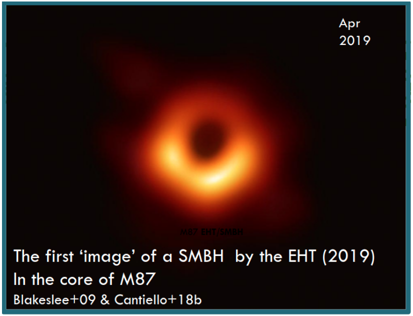
The idea behind the Surface Brightness Fluctuations (SBF) Method

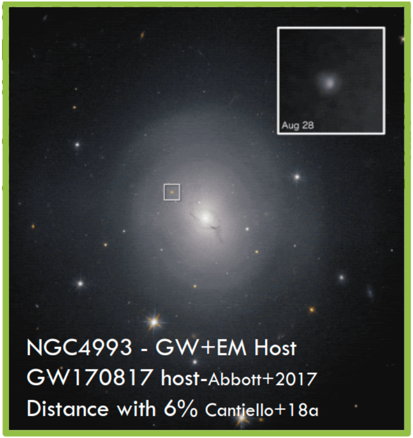
- Closer galaxies display more "mottling" than farther ones, due to unresolved stellar populations: quantified by Tonry et al. in 1988
- SBF can be used to measure precise (6% error) individual distances



Source: M. Cantiello

SBF recent results

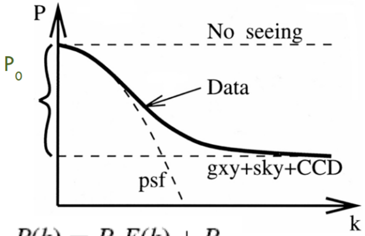




Steps of SBF analysis: Overview

$$\overline{\mathrm{L}} = \frac{\sum_j n_j L_j^2}{\sum_j n_j L_j},$$

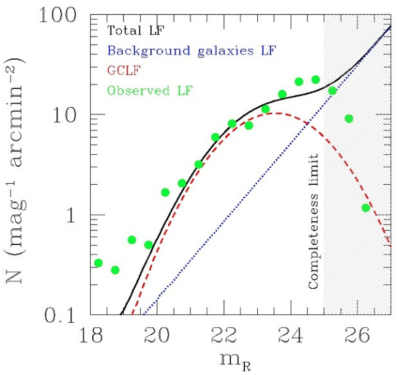
1. Model the galaxy
2. Obtain the residual frame
3. Mask all sources of non stellar fluctuations
4. Estimate the amplitude of the SBF in the Fourier domain
   $I \otimes PSF \rightarrow \tilde{I} x \widetilde{PSF}$
5.



$$P(k) = P_0 E(k) + P_1,$$

Steps of SBF analysis: Overview

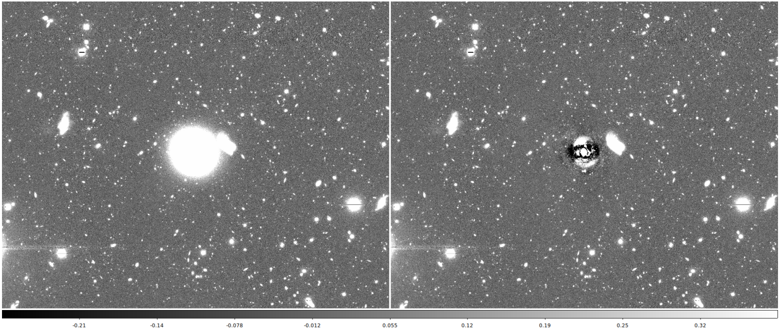
1. Model the galaxy
2. Obtain the residual frame
3. Mask all sources of non stellar fluctuations
4. Estimate the amplitude of the SBF in the Fourier domain
   $I \otimes PSF \rightarrow \tilde{I} x \widetilde{PSF}$
5. Estimate and subtract the flux contribution of un-excised sources: P_r



$$m_X = -2.5log(P_0 - P_r) + m^X_{z.p.}$$

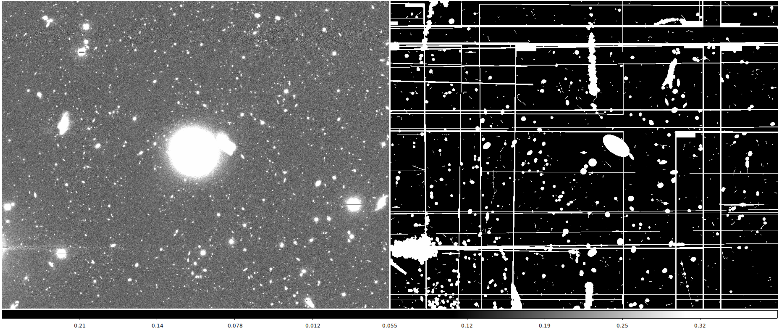
Modelling the galaxy

- Modelling with elliptical isophotes
- Subtract the profile of the galaxy from the image: IC0745



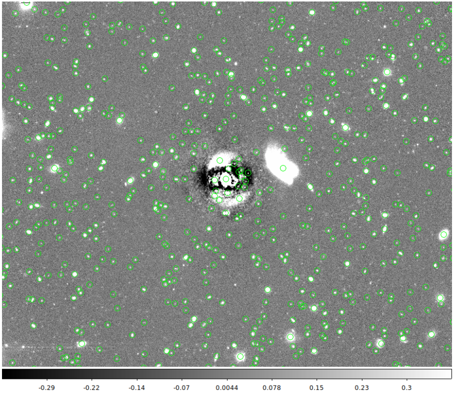
Generating a mask

- Mask dead pixels, contamination, cosmic ray hits: instrument team
- Mask bright objects
- Modelling and masking done iteratively



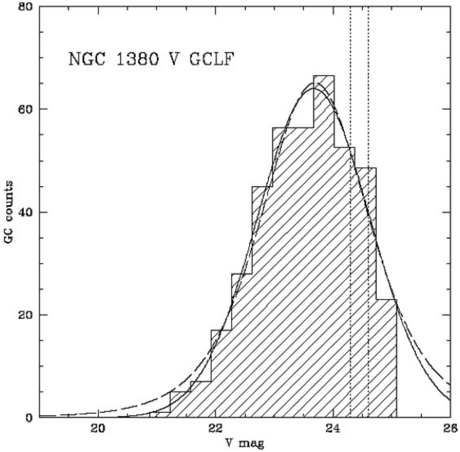
Creating a photometric catalog

- SExTractor: photometry tool
- Detects and generates list of extended and compact objects in frame
- Need to mask everything except underlying stellar population



Globular Cluster Luminosity Function (GCLF)

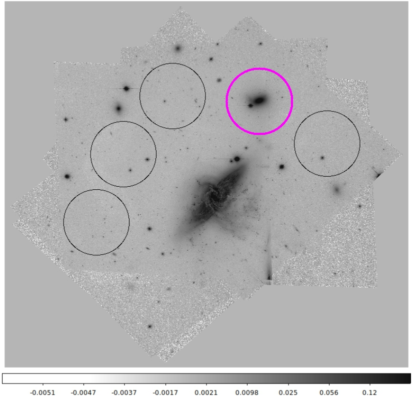
Can be used as a distance indicator



Source: Della Valle et al. 1998

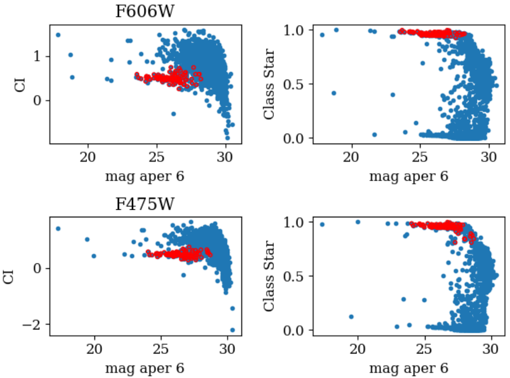
Target and data

- LEDA087327: Lenticular Galaxy in Hydra I cluster, close to NGC3314A/B
- Very deep images from legacy archive of the Hubble Space Telescope: F606W and F475W bands of ACS/WFC



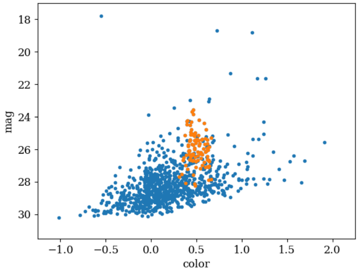
Identifying the Globular Clusters : Part I

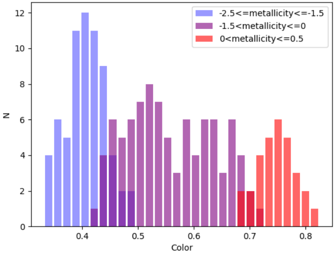
- Perform modelling and photometry exactly as for SBF analysis and evaluate the residuals
- Globular clusters are identified on the basis of different parameters: compactness selection

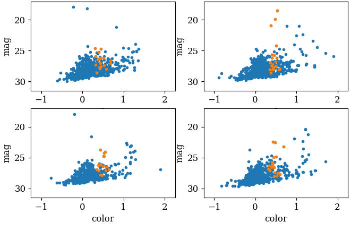


Identifying the Globular Clusters : Part II

- Selection based on color
- Simple Stellar Population models: *COSM²IC* Group at Yonsei University
- Using Ks band magnitude from 2MASS, mass of this galaxy $\sim 10^{10.15} M_\odot$

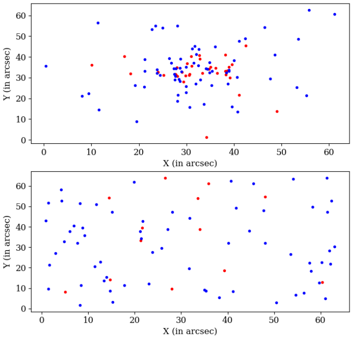


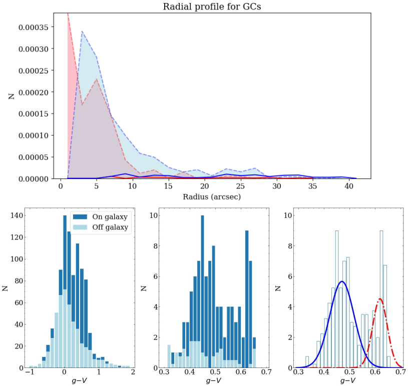




Radial profile and colors

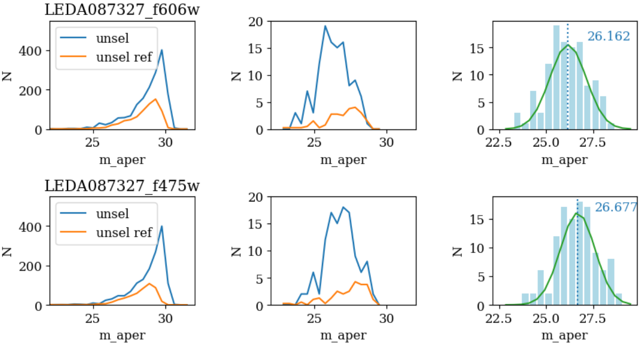
Spatial distribution of red and blue globular clusters in the frame





GCLF in LEDA087327

- Turnover magnitude: m
- Calibrate: M from literature
- $D = m - M \approx 34.0 \pm 0.2$
- Preliminary estimate of Hubble constant
  $H_0 = 70.9 \pm 21.5\ km\ s^{-1} Mpc^{-1}$



Summary

- SBF method can give us fast, accurate distances up to 100 Mpc
- We are developing an automated SBF pipeline on the precursor survey data of the Vera Rubin Observatory
- With minor modifications, we can adapt this pipeline to other instruments (HST, Euclid)
- The pipeline can also produce GCLF distances as a side product

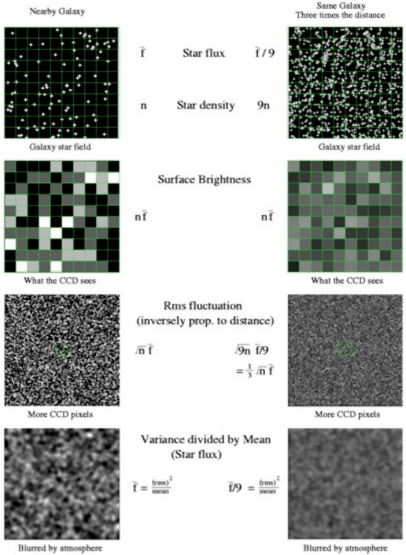
VERA C. RUBIN OBSERVATORY

Euclid consortium

ngrave

Thank You

The idea behind the SBF Method



Source: John Tonry

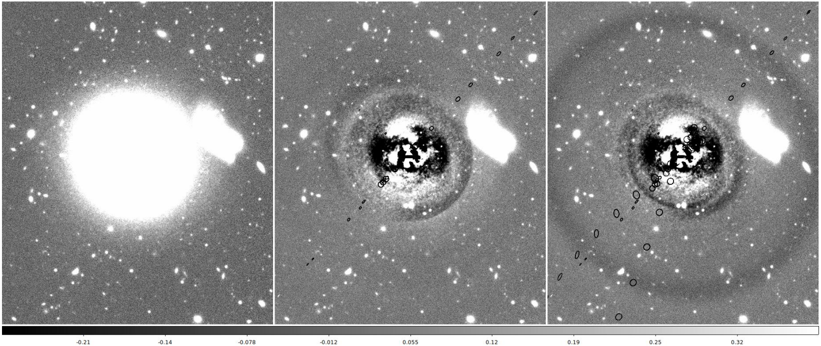
Quantify the pixel-to-pixel variation of surface brightness

$$\bar{\mathrm{L}} = \frac{\sum_j n_j L_j^2}{\sum_j n_j L_j},$$

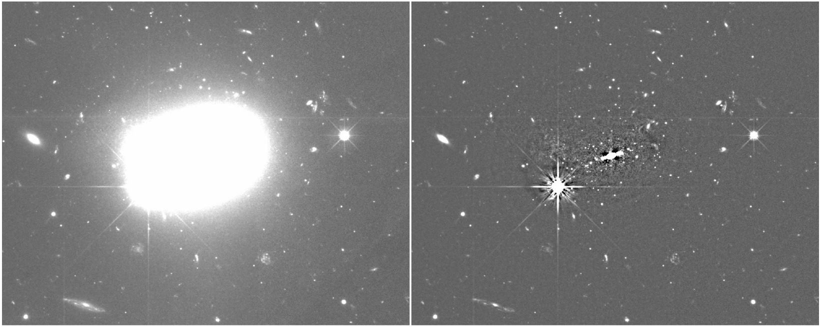
Calibration sample

Galaxy	RA	Dec	B Mag	t type	Dist (Mpc)
I0745	178.551	0.136	14.04	-2.2±1	22.23
N4753	193.095	-1.199	10.57	-1.3±1.1	22.08
N5813	225.297	1.702	11.52	-4.9±0.4	31.77
N5831	226.03	1.221	12.43	-4.8±0.5	27.29
N5839	226.367	1.635	13.69	-2±0.5	20.82

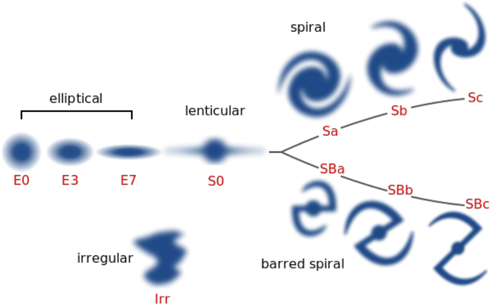
Models : wrong



LEDA087327



Galaxies suitable for SBF analysis

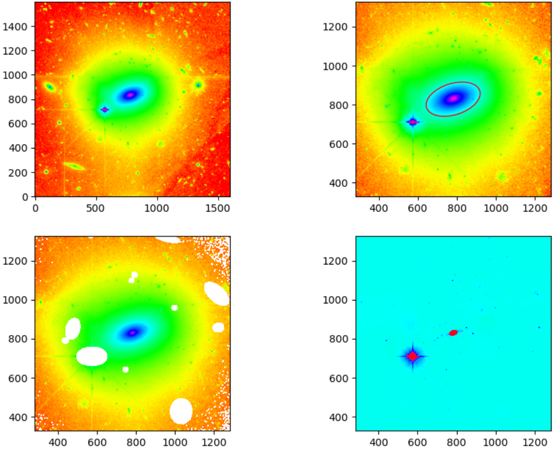


- Spiral galaxies: dust, active star forming regions
- Ellipticals: ideal
- Low surface brightness (LSB), dwarf galaxies
- Distance < 100 Mpc

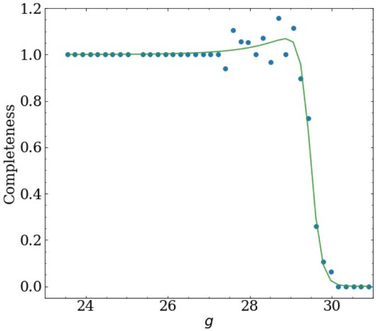
Galaxy sample selection

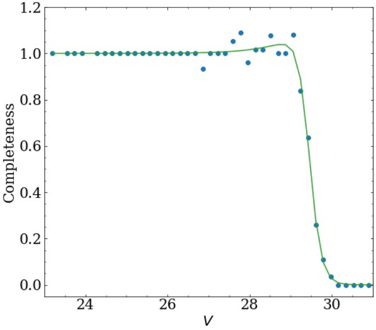
- Calibrating the pipeline on an existing sample from literature
  - 383 galaxies with measured SBF were taken from the major publications in 2001-2007
  - 16 galaxies were found within the observation footprint of HSC
  - 5 had coverage in g and i bands: these were chosen as calibration sample
- Building a new sample for further measurements
  - Bright, elliptical galaxies in HSC footprint
  - Distance smaller than 50 Mpc
  - Multi-band coverage: g and i bands
  - 38 galaxies: brighter than B-band magnitude 17

GCLF in LEDA087327



Completeness Function





GCLF results

Band	m_{TO}	σ	M_{TO}	$m - M$
F475W	26.63±0.09	0.85±0.09	-7.5±0.1	34.1±0.2
F606W	26.16±0.08	0.78±0.08	-7.7±0.1	33.9±0.1