Extra-galactic distances for the next generation surveys: the surface brightness fluctuation method

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ITA-INA-S6) Directable SW contribution for the Galaxies SC: Tools for the measurement of surface brightness fluctuations on LSST data

Coordinator

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Post-doc on LSST

3 years (ending March 2027)

Gabriele Riccio

Post-doc on Euclid

3 years (ending May 2027)

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Software Engineer

Matteo Canzari

Stellar population models

Gabriella Raimondo

Extra-Galactic distances: what's the tension?

- **Reliable distances** are required to understand most observed objects & phenomena
- **Errors in distances** imply significant fractional uncertainties in derived quantities

  Masses (e.g., central black holes, dark matter halos); Physical sizes;

  Dynamical time scales; Star Formation Rates; Ages…
- **Precise extragalactic distances** play a key role in the H_0 controversy, a major issue in modern cosmology

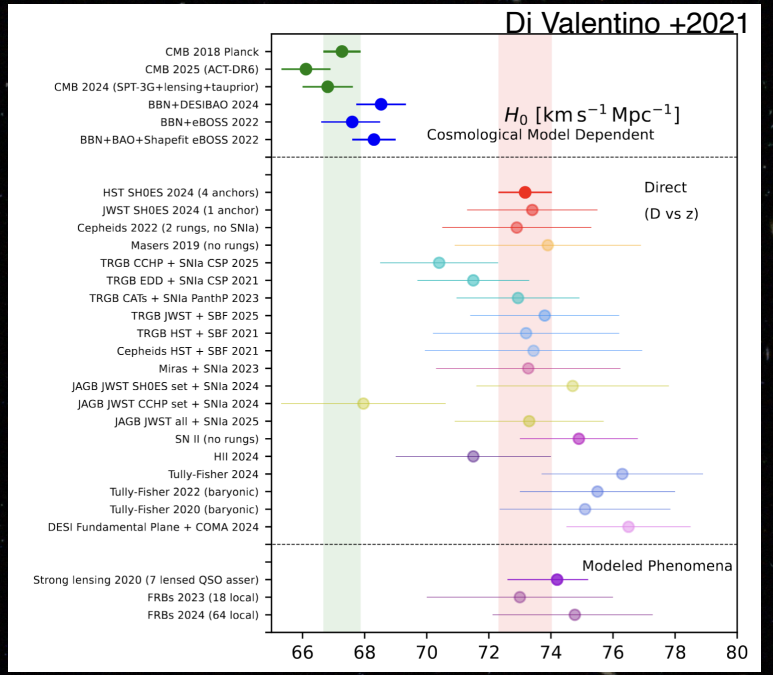
APRIL 1, 2025 | 7 MIN READ

The Hubble Tension Is Becoming a Hubble Crisis

A long-simmering disagreement over the universe's present-day expansion rate shows no signs of resolution, leaving experts increasingly vexed

BY ANIL ANANTHASWAMY EDITED BY LEE BILLINGS

An artist's concept of cosmic history, starting with a representation of the big bang (*top*) that progressively blossoms into our modern-day expanding universe (*bottom*). Mark Garlick/Science Photo Library/Alamy Stock Photo

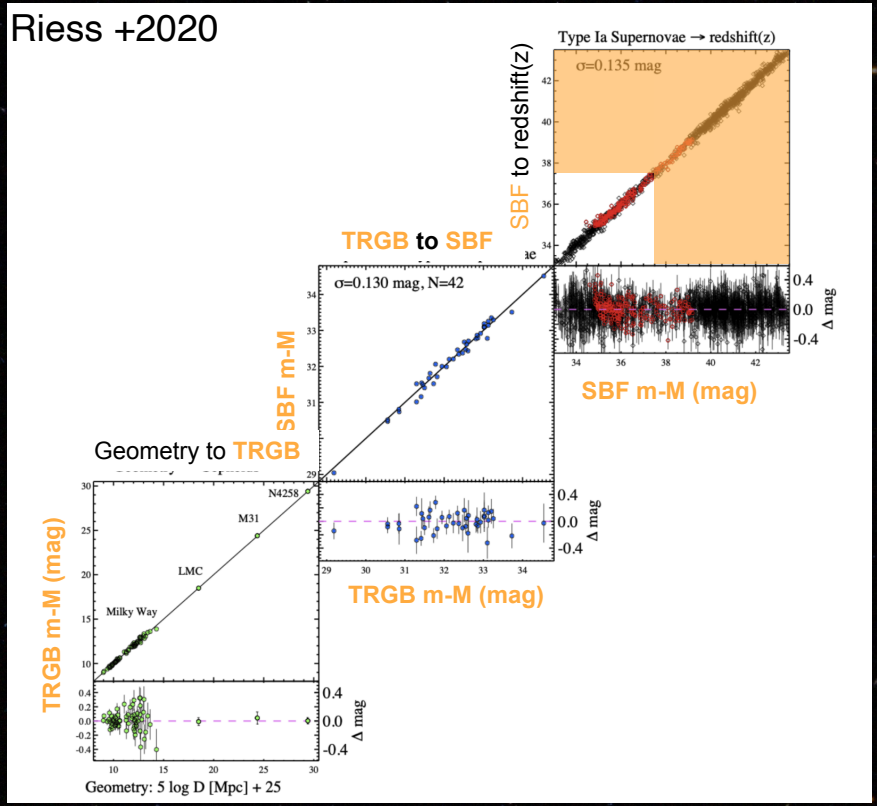


Pop II ladder

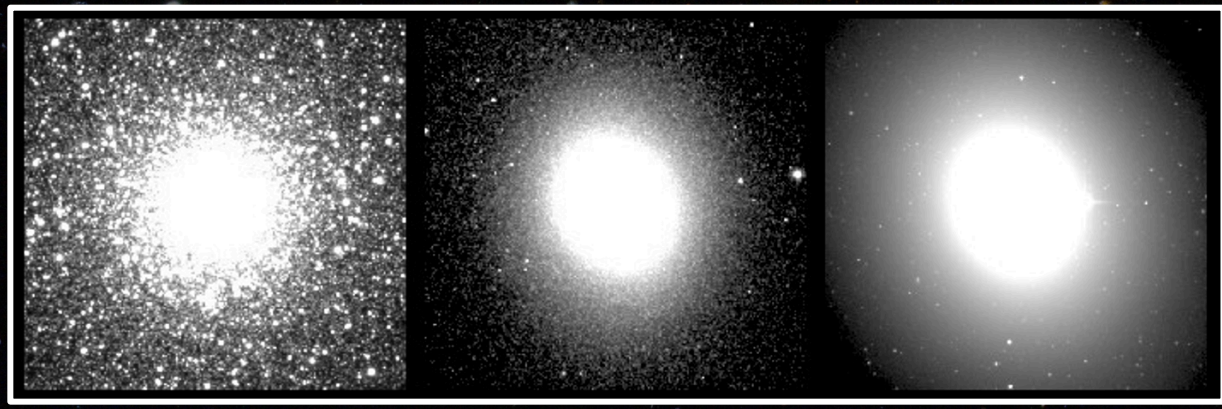
Geometry → TRGB

TRGB → SBF

SBF → galaxy distances, dwarf membership, Hubble flow



Surface Brightness Fluctuation (SBF)



MW Globular Cluster ~10 kpc

Messier 32 ~770 kpc

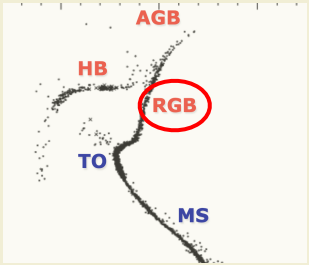
Messier 49 ~17 Mpc

Slide Basics: R. Kudritzki/M.Cantiello
Images: J. Blakeslee

SBF def.: Ratio 2nd to 1st moments of stellar luminosity function

$$f_{SBF} \equiv \overline{f} \equiv \sum_i n_i f_i^2 / \sum_i n_i f_i$$

f^2 ➔ bright stars weight more



Tonry & Schenider 1988
Tonry, Ajhar & Luppino 1990
Blakeslee, Ajhar & Tonry 1999...

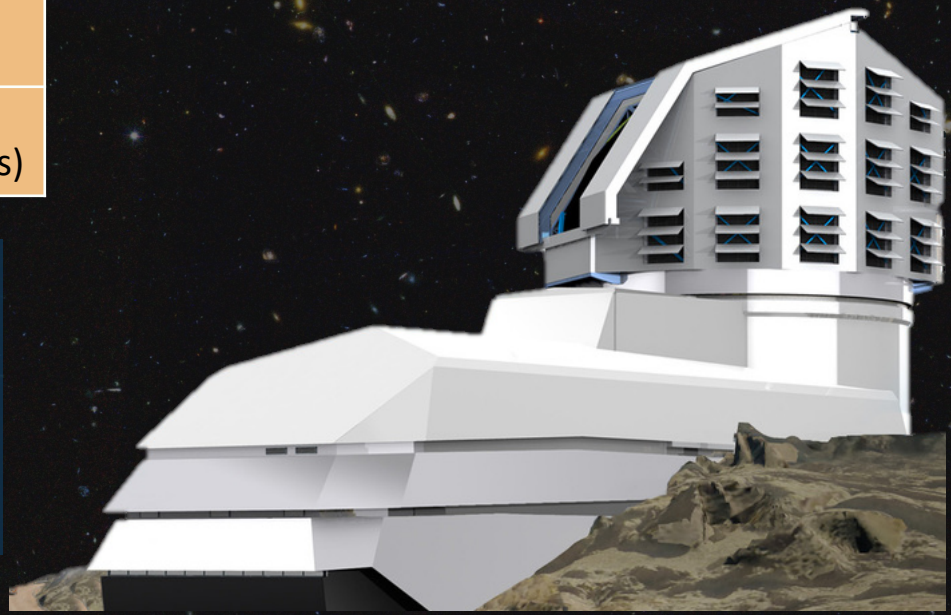
- Preferred targets: Elliptical galaxies with smooth surface brightness profiles.
- Number of unresolved stars/pixel has Poisson fluctuations, more distant galaxies appear smoother.
- Observed “mottling” is directly related to the target distance. Measurement error on this mottling 0.05 mag or less
- No dust or non-stellar-count fluctuations!

SBF with LSST (promising)	
5σ-depth (mag)	26.3-26.8 (i-band)
FWHM (arcsec)	0.6-0.7
Filters	ugirzy
Sky coverage (sq. deg)	~18.000
D_{Max}	~70 Mpc (for the best candidates)

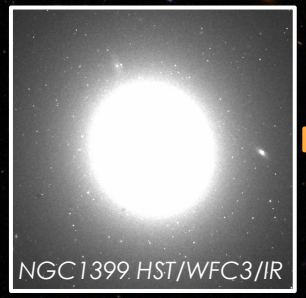
Build the most accurate 3D map of the local universe.

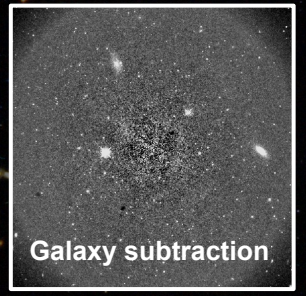
Measure H0 independently from Cepheid and SNe Ia.

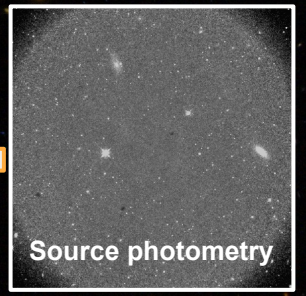
- Thousands of optimal/good candidates
- >>10^3 non-optimal candidates for which distances to 10-20% can be derived (in some cases no other distance indicator might be available)



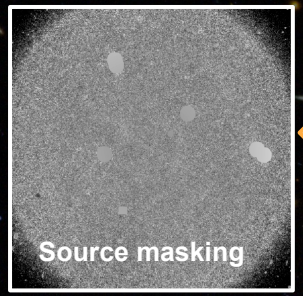
Measuring SBF is a long process…



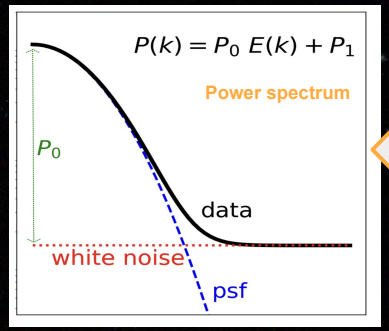




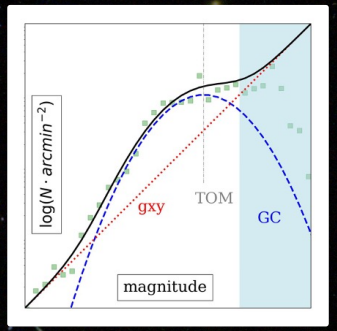
(Usually done manually)



P_0: Total fluctuation term



P_r: Spurious fluctuation term



$\bar{m}$ ⟵

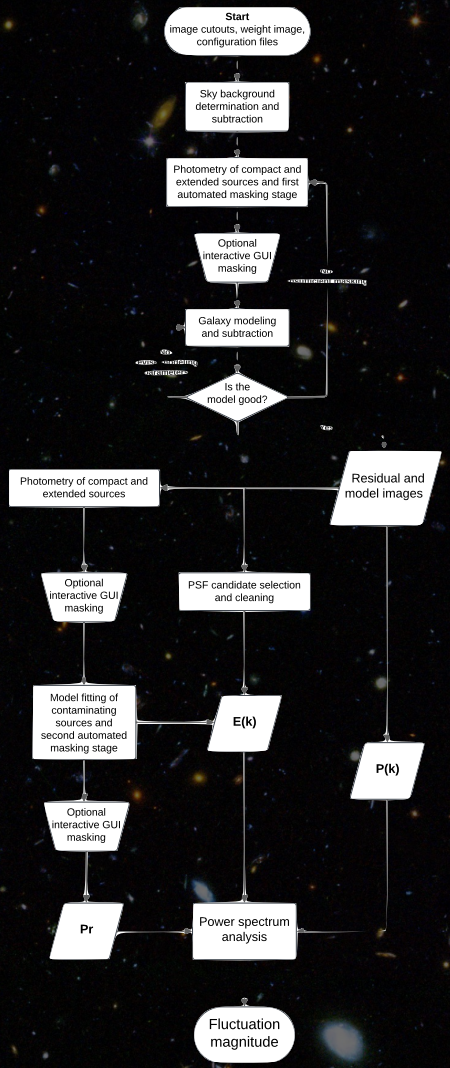
Many steps involved + Heavy user interaction

=

t ~ hours

Stellar counts fluctuations $P_f = P_0 - P_r$

$$\overline{m}_{band} = -2.5\log\left(P_f\right) + m_{zp,\,band}$$



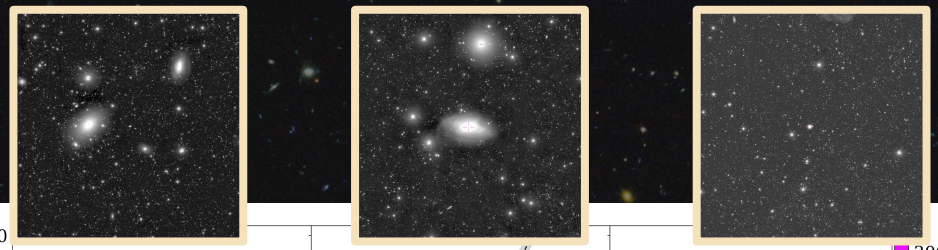
FAST-SBF

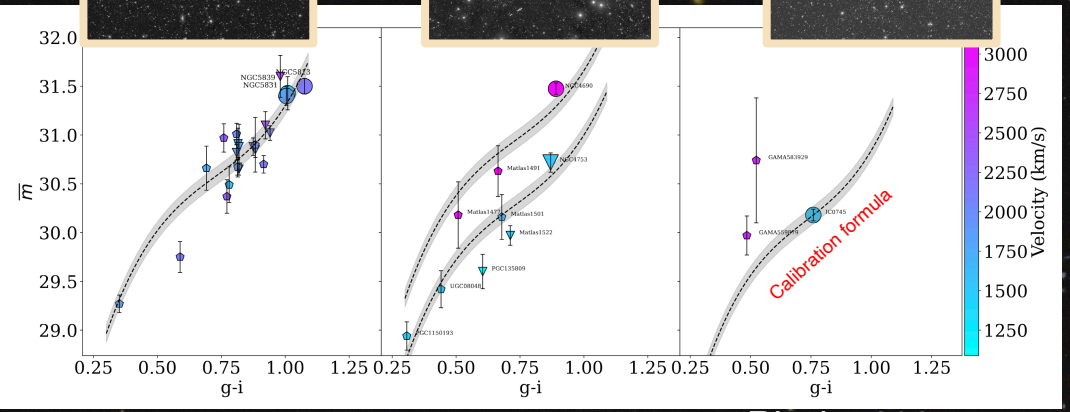
(Flexible Automated Self-contained Tool for SBF)

- Flexible: the pipeline is optimise to work on the major large-field surveys
- Automated: the user interaction is reduced at the minimum (with the aim to remove it completely), maintaining reliable results.
- Self-contained: all the steps of the entire analysis are carried out by one tool.
- Fast: takes from few seconds to tens of minutes (depending on the source) to completely analyse a galaxy.

FAST-SBF: first results

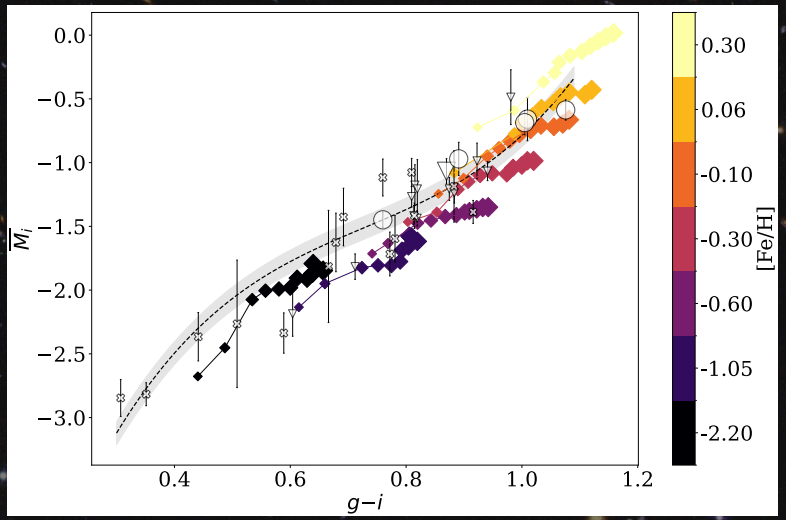
Subaru HSC-SSP (LSST precursor)





Riccio+2025

Riccio+2025

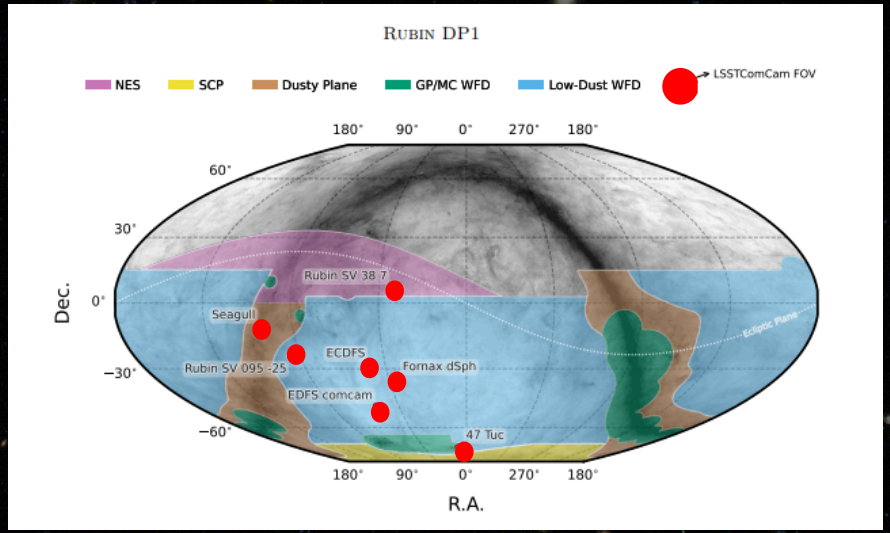


Distance and comparison with SSP models

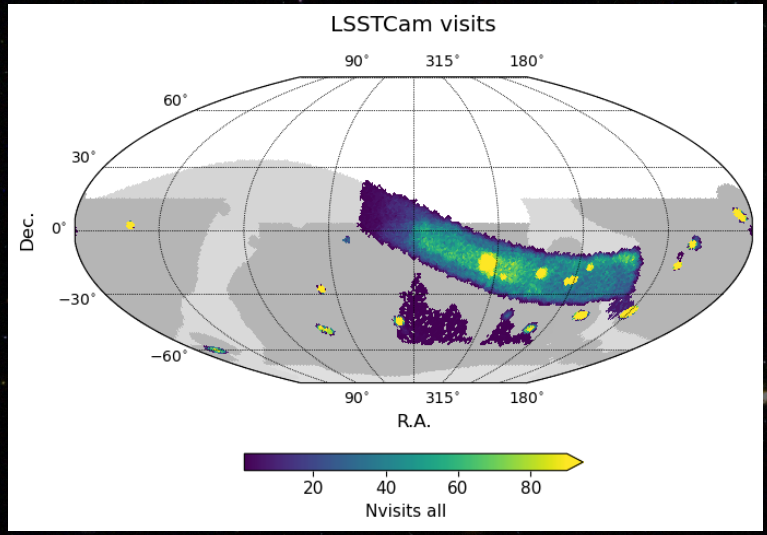
$$\bar{M} = \alpha \times color + \beta$$

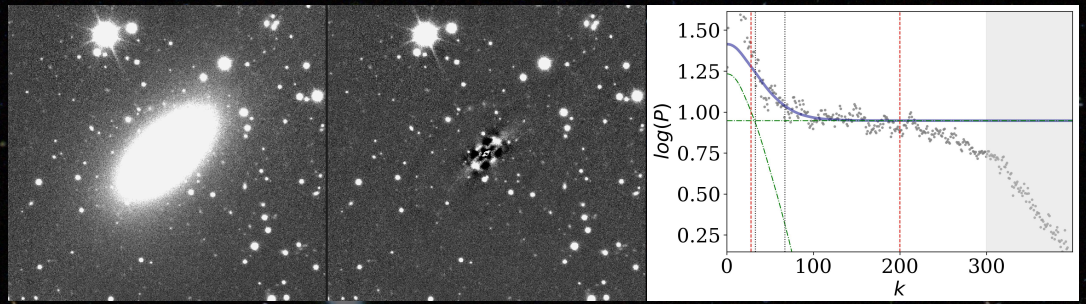
β tied to Cepheid or TRGB.
Also validated through simple stellar population models.

First result on DP1 (ComCam)



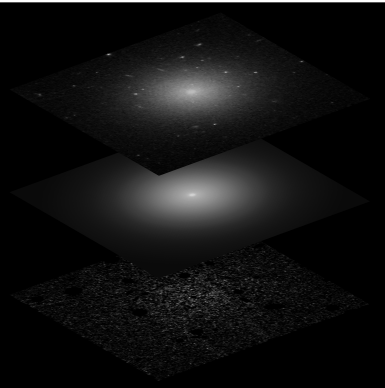
DP2 (LSSTcam) expected by mid July 2026





LSST Discovery Alliance

Catalyst post-doc alliance



FAST-SBF in Teramo:
a workshop to measure distances with Surface Brightness Fluctuations

Teramo, Italy
20 - 23 July 2026

SOC: John Blakeslee, Enzo Brocato, Michele Cantiello, Matteo Canzari, Rebecca Habas, Joe Jensen, Gabriella Raimondo, Gabriele Riccio

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Summary

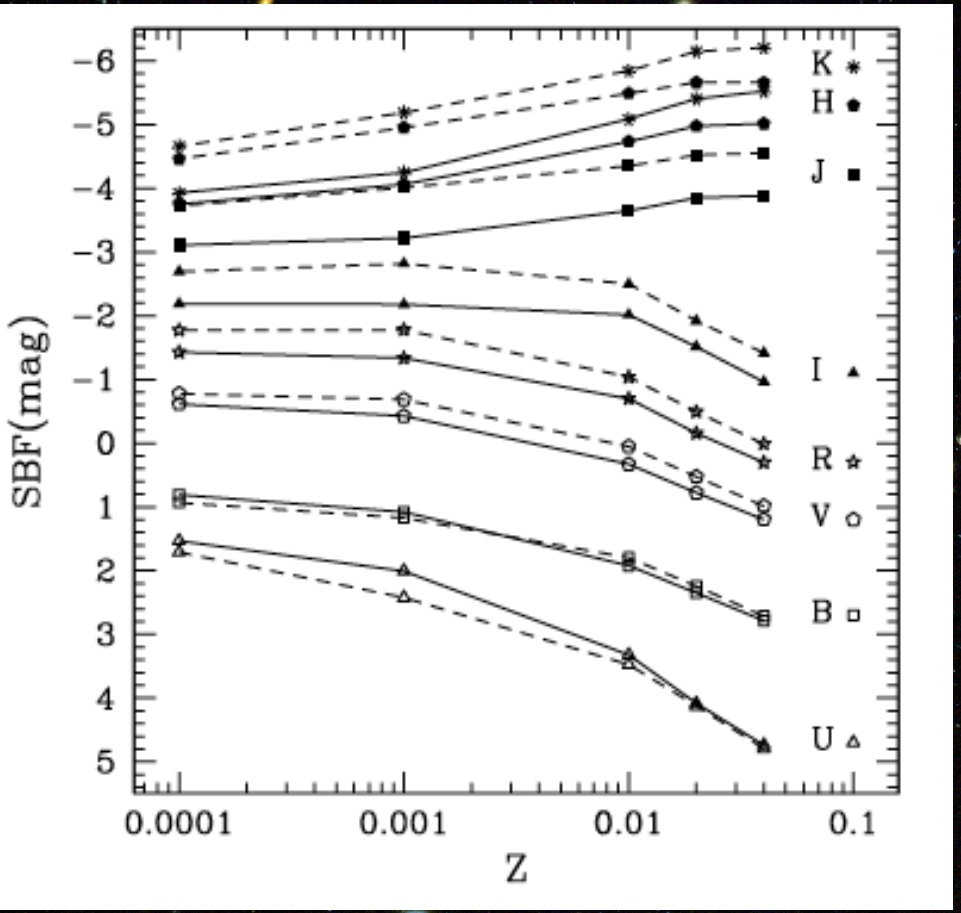
Science:

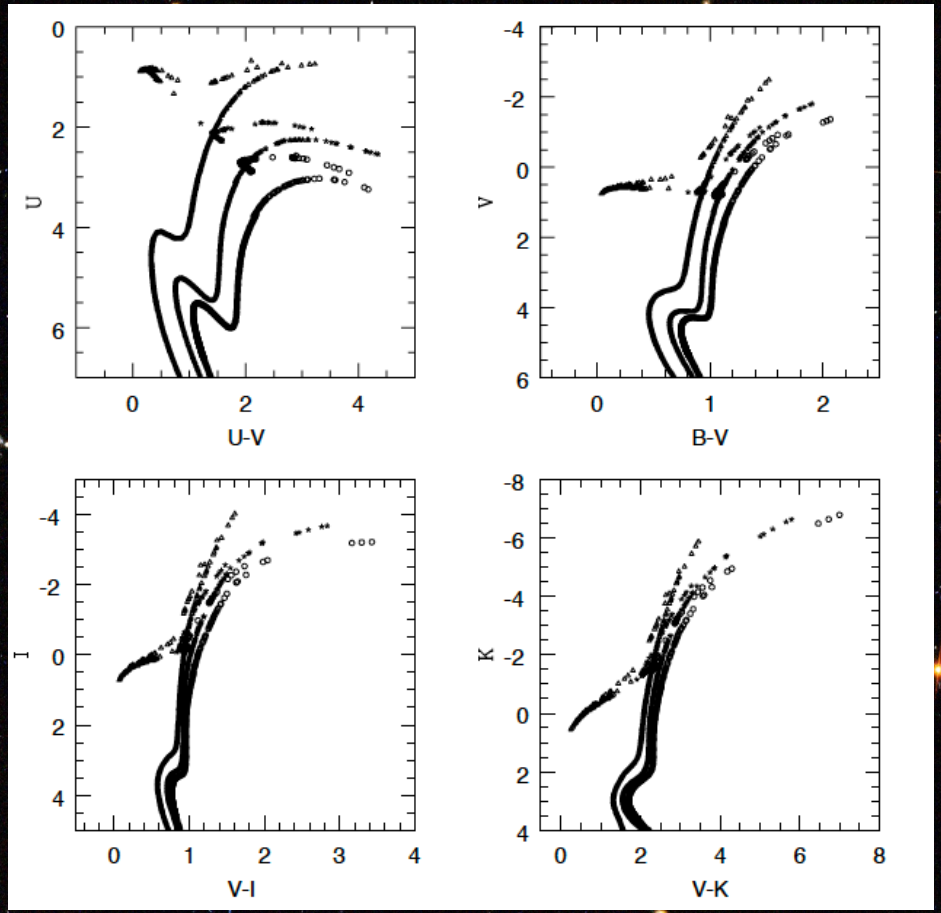
- Precise on single red/bright targets: ~5%
- Δd/d~15/20% on the other extreme, dwarf galaxies
- Easy observations
- Well understood and modelled origin of the signal
- The method needs to be adapted to run in “production mode” to deliver robust results quickly and with minimal human intervention
- The method is promising for both distance indicator and stellar population diagnostic, especially for dwarfs

FAST-SBF

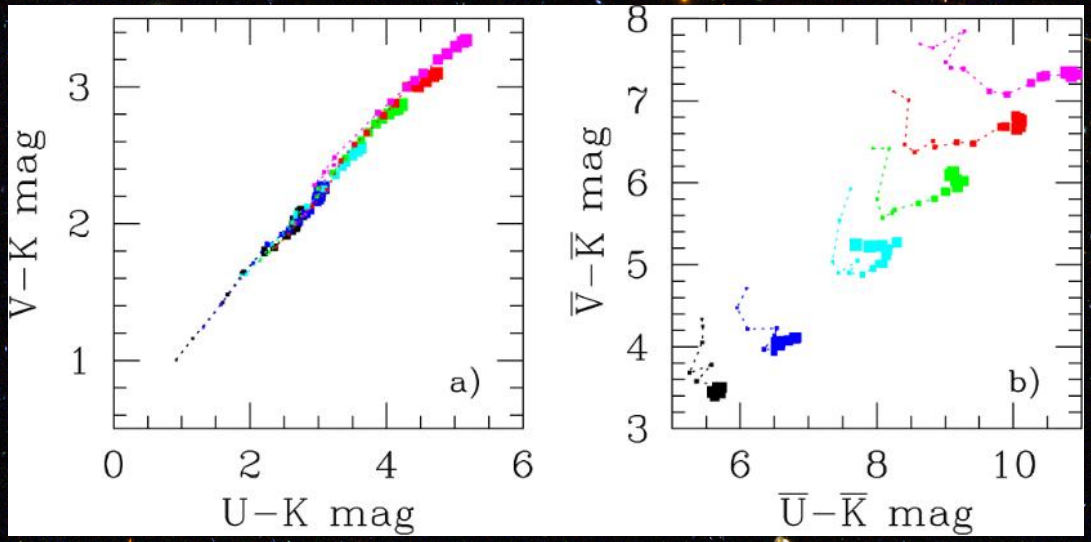
In-kind(*2024-2026*):

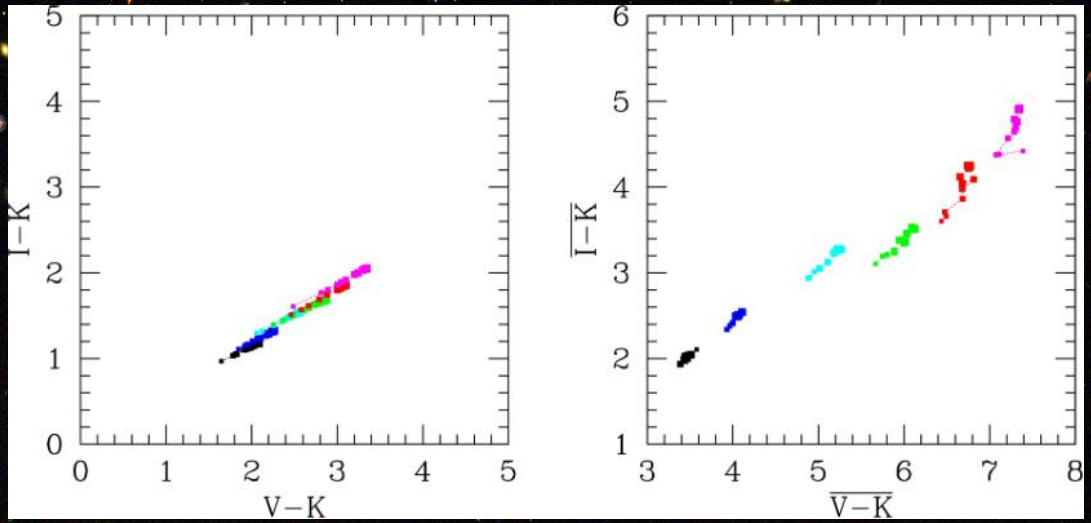
- Develop a tool for the SBF analysis capable of handling big data.
- Testing the pipeline on LSST precursors.
- Data preview 1
- Data preview 2 (July - September 2026)
- Data Release (*>2027*)

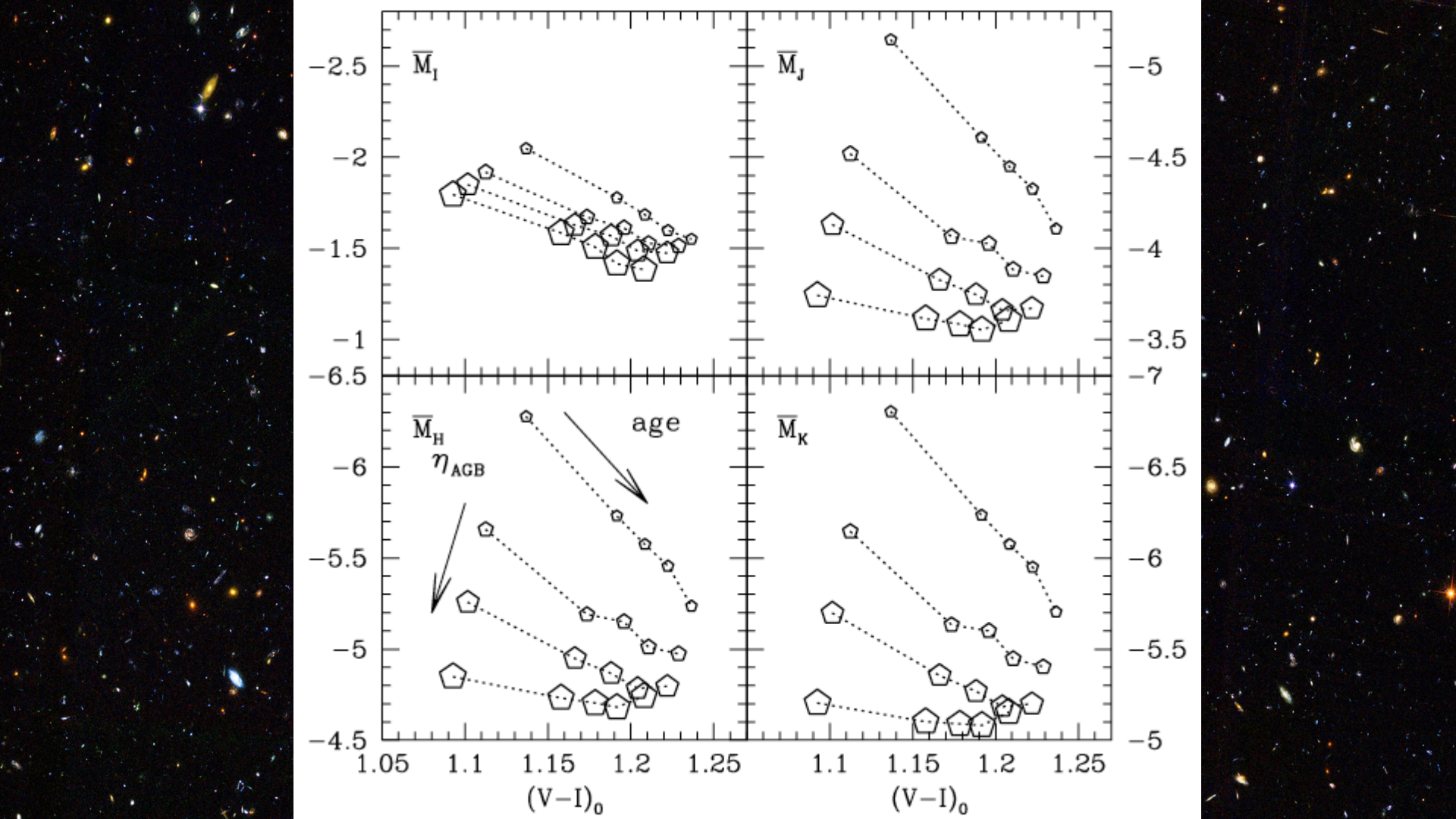

SBF(mag)
Z
0.0001
0.001
0.01
0.1
K
H
J
I
R
V
B
U


U
U-V
V
B-V
I
V-I
K
V-K

Regarding SBF in the context of stellar populations…





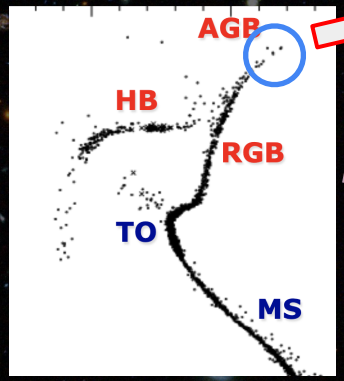

$\overline{M}_I$
$\overline{M}_J$
$\overline{M}_H$
η_{AGB}
age
$\overline{M}_K$
−2.5
−2
−1.5
−1
−6.5
−5
−4.5
−4
−3.5
−7
−6
−5.5
−5
−4.5
−6.5
−6
−5.5
−5
1.05
1.1
1.15
1.2
1.25
$(V-I)_0$

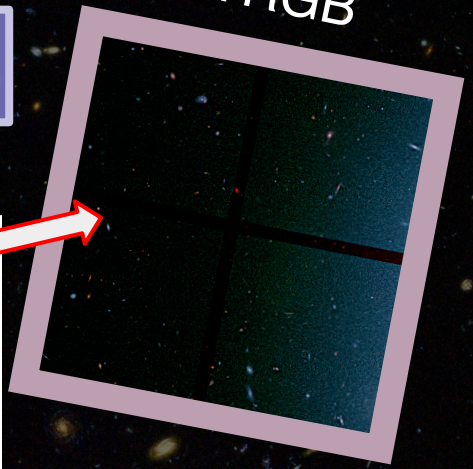
The TRGB-SBF project with the JWST

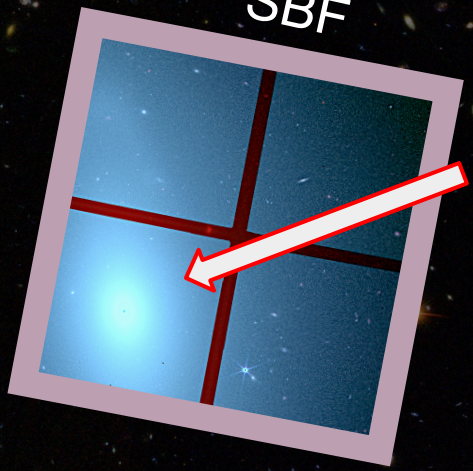
NIRCAM: ideal layout

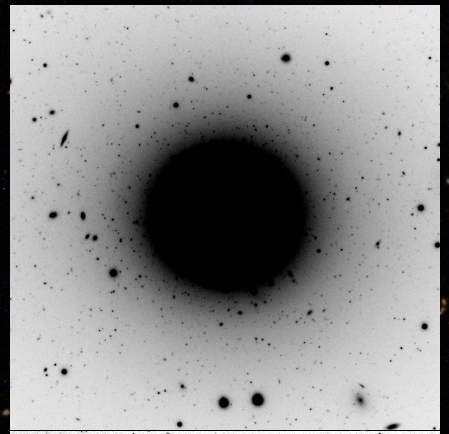
Jensen+25

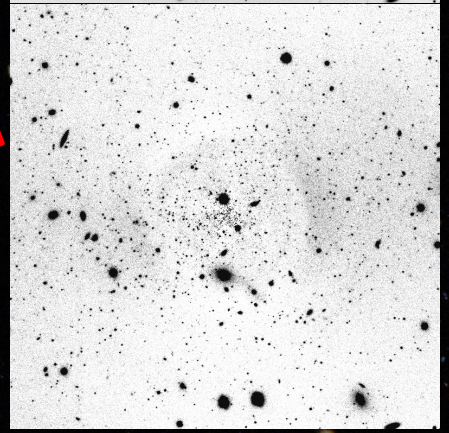
$H_0 = 73.8 \pm 0.7 \pm 2.3$ km/s/Mpc





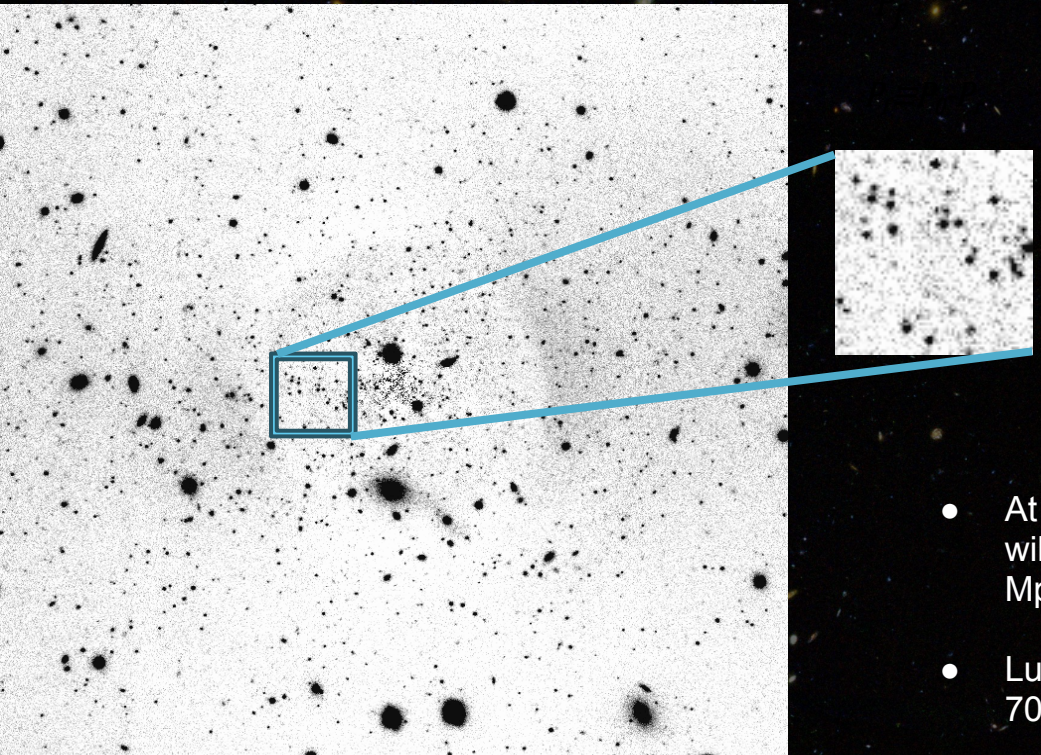


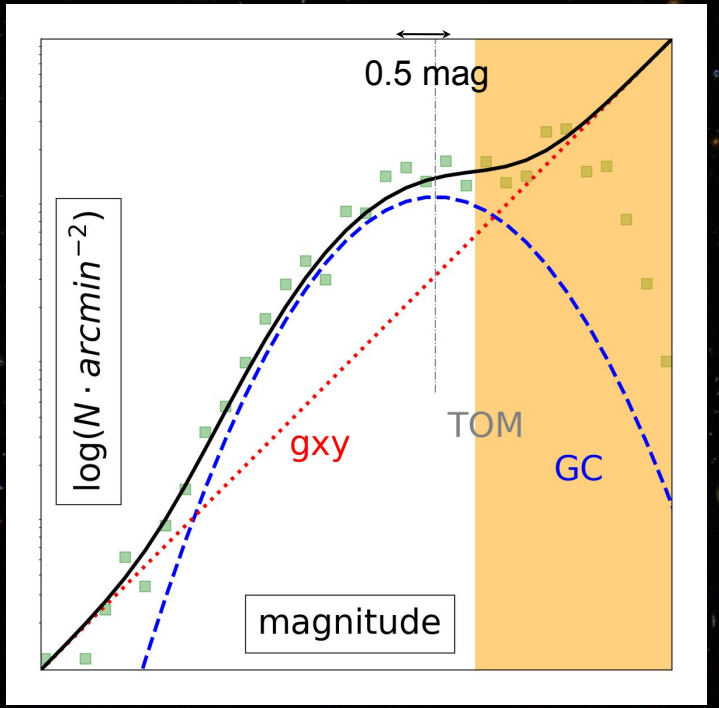




SBF with LSST: maximum distance

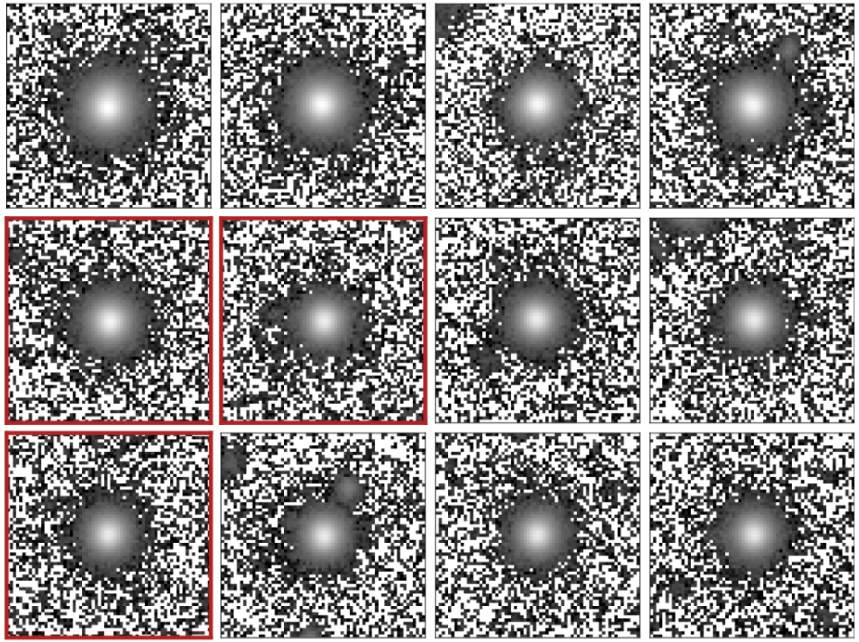
- Main limiting factor in measuring SBF at large distances: ‘spurious fluctuations’, mostly from globular clusters host in the galaxy.

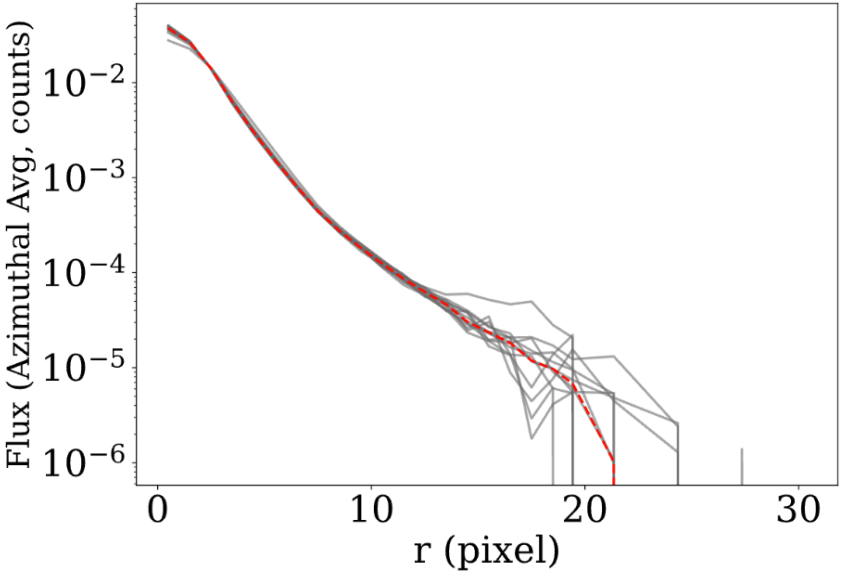


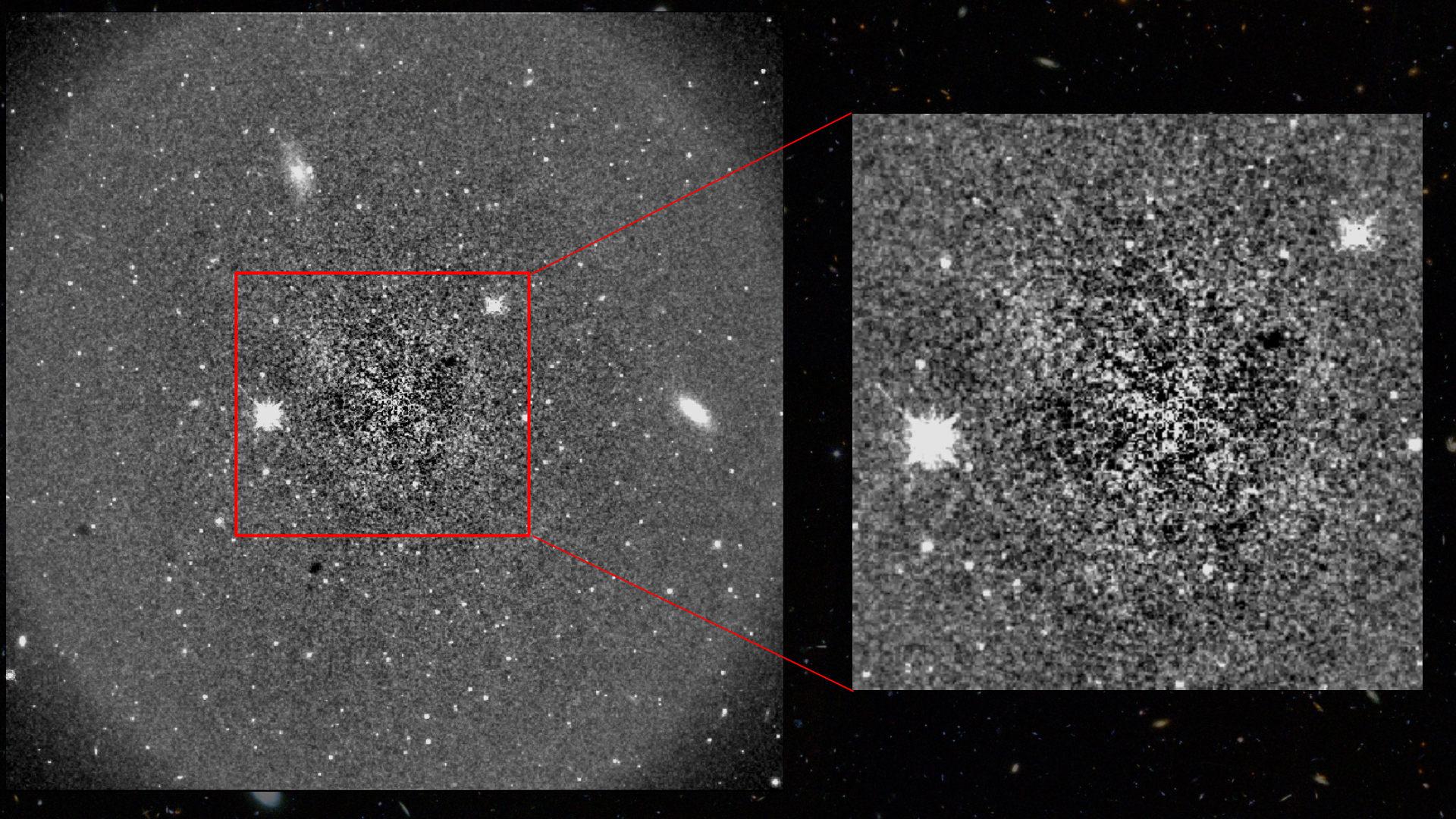


- At the present LSST survey specs: in final coadds SBF will be measured in all bands. Largest distances (~50 Mpc) reached in i, z and y bands.
- Lucky cases (good FWHM, bright red target, …) possibly 70 Mpc.

Name (1)	(g-i) (mag) (2)	$\overline{m_i}$ (mag) (3)	$\overline{m} - \overline{M}$ (mag) (4)	d (Mpc) (5)
NGC 5813	1.206 (0.004)	31.58 (0.08)	31.92 (0.12)	24.2 (1.3)
PGC 053521	0.991 (0.007)	30.92 (0.08)	32.02 (0.12)	25.4 (1.4)
PGC 053587	0.998 (0.013)	30.98 (0.28)	32.07 (0.29)	26.0 (3.5)
PGC 053636	0.921 (0.017)	30.74 (0.10)	32.01 (0.13)	25.2 (1.6)
PGC 1165764	0.455 (0.022)	29.35 (0.09)	32.04 (0.13)	25.6 (1.5)
PGC 1192611	0.798 (0.026)	30.73 (0.22)	32.23 (0.24)	28.0 (3.2)
PGC 1193898	0.988 (0.019)	30.95 (0.09)	32.08 (0.13)	26.0 (1.5)
PGC 1205406	0.897 (0.039)	30.57 (0.18)	31.90 (0.20)	23.9 (2.3)
PGC 1208589	0.887 (0.028)	30.45 (0.17)	31.79 (0.20)	22.8 (2.1)
PGC 1230503	0.920 (0.016)	31.08 (0.11)	32.36 (0.14)	29.6 (1.9)
PGC 184851	1.050 (0.007)	31.09 (0.07)	32.02 (0.12)	25.4 (1.4)
PGC 3350761	1.105 (0.033)	31.68 (0.21)	32.46 (0.23)	31.1 (3.4)
PGC 3350757	1.047 (0.023)	31.18 (0.14)	32.16 (0.17)	27.0 (2.1)
PGC 3350778	0.932 (0.018)	30.72 (0.06)	31.98 (0.11)	24.9 (1.2)
PGC 4018458	0.872 (0.037)	31.05 (0.14)	32.42 (0.17)	30.5 (2.4)
PGC 4018466	0.936 (0.043)	30.96 (0.23)	32.20 (0.25)	27.6 (3.18)
PGC 4074773	0.858 (0.017)	31.04 (0.16)	32.25 (0.18)	28.1 (2.4)
NGC 5839	1.131 (0.004)	31.50 (0.17)	32.17 (0.19)	27.2 (2.4)
PGC 1199471	0.927 (0.023)	30.75 (0.08)	32.01 (0.12)	25.2 (1.4)
PGC 4009173	0.688 (0.028)	29.82 (0.16)	31.55 (0.18)	20.4 (1.7)
NGC 5831	1.133 (0.008)	31.48 (0.09)	32.17 (0.13)	27.1 (1.6)
PGC 1190315	1.043 (0.07)	30.79 (0.09)	31.78 (0.14)	22.7 (1.5)
PGC 1216386	0.918 (0.017)	30.89 (0.08)	32.17 (0.12)	27.1 (1.5)
NGC 4753	0.958 (0.002)	30.70 (0.07)	31.86 (0.11)	23.5 (1.2)
PGC 1150193	0.363 (0.049)	28.97 (0.14)	32.01 (0.17)	25.2 (2.1)
PGC 135809	0.667 (0.053)	29.63 (0.18)	31.37 (0.20)	18.8 (1.8)
PGC 183384	0.780 (0.013)	30.0 (0.10)	31.51 (0.13)	20.1 (1.2)
PGC 3295853	0.750 (0.041)	30.20 (0.23)	31.77 (0.25)	22.5 (2.6)
PGC 44066	0.5012 (0.013)	29.46 (0.19)	31.72 (0.21)	22.1 (2.1)
NGC4690	0.975 (0.003)	31.515 (0.06)	32.63 (0.11)	33.5 (1.7)
PGC 1115603	0.736 (0.026)	30.67 (0.26)	32.26 (0.27)	28.4 (3.6)
PGC 1124896	0.570 (0.025)	30.22 (0.34)	32.22 (0.35)	27.8 (4.5)
IC 0745	0.828 (0.008)	30.21 (0.06)	31.63 (0.11)	21.17 (1.1)
GAMA559879	0.546 (0.037)	30.01 (0.056)	32.09 (0.11)	26.2 (1.3)
GAMA583929	0.586 (0.047)	30.78 (0.64)	32.73 (0.64)	35.1 (10.4)



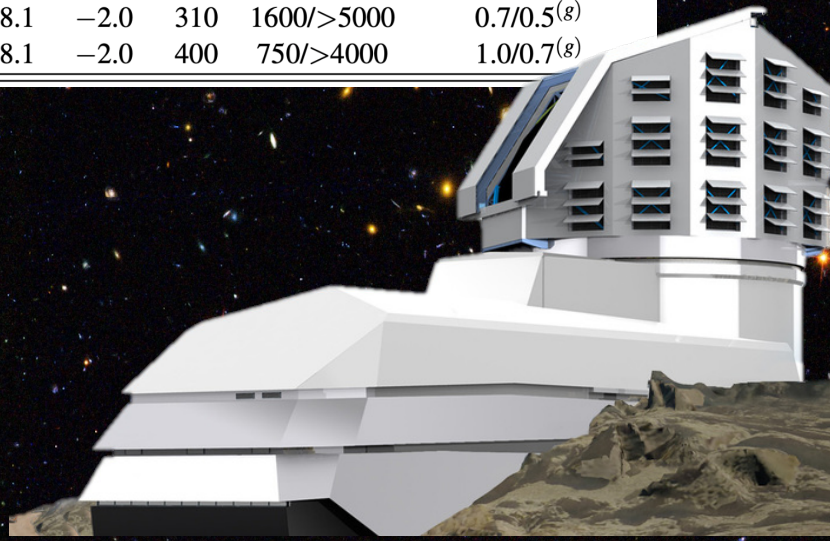

Flux (Azimuthal Avg, counts)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
10
20
30
r (pixel)



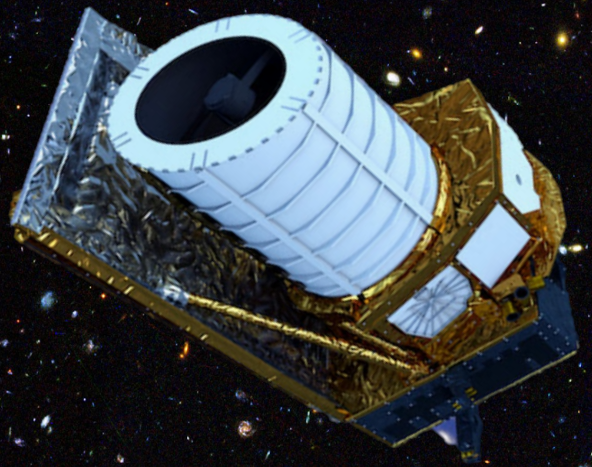
Rubin Legacy Survey of Space and Time (LSST)

Telescope (constraint) (1)	Band (2)	Depth[a] (mag) (3)	GCLF peak[b] (4)	GCLF offset[c] (5)	d_{Max} (Mpc) (6)	Optimal/good candidates (7)	$\delta H_0/H_0$ (%) optimal/good (8)
Rubin (Dec$\leq$ 15°)	i	26.8	−8.5	+0.5	70	50/1500	1.2/<0.5
Euclid ($\|b\| \geq 23°$)	H_{Euclid}	24.0	−8.6	−1.5	55	20/600	1.0/<0.5
Roman[e]	J_{F129}	28.0	−8.3	−1.0	230	1500/>5000	0.7/0.5[g]
Roman[e]	H_{F158}	28.0	−8.6	−1.5	300	1600/>5000	0.7/0.5[g]
JWST[e]	J_{F115W}	27.5	−8.3	−1.0	180	900/>5000	0.9/0.5[g]
JWST[e]	H_{F150W}	27.7	−8.6	−1.5	290	1600/>5000	0.7/0.5[g]
JWST[e]	K_{F200W}	27.8	−8.1	−2.0	310	1600/>5000	0.7/0.5[g]
ELT[f] (Dec$\leq$ 0°)	K	28.5	−8.1	−2.0	400	750/>4000	1.0/0.7[g]

	LSST
5σ-depth (mag)	26.3-26.8 (i-band)
FWHM (arcsec)	0.6-0.7
Filters	*ugrizy*
Sky coverage (sq. deg)	~20.000



Euclid



Telescope (constraint) (1)	Band (2)	Depth[a] (mag) (3)	GCLF peak[b] (4)	GCLF offset[c] (5)	d_{Max} (Mpc) (6)	Optimal/good candidates (7)	$\delta H_0/H_0$ (%) optimal/good (8)
Rubin (Dec$\leq 15°$)	i	26.8	−8.5	+0.5	70	50/1500	1.2/<0.5
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JWST[e]	K_{F200W}	27.8	−8.1	−2.0	310	1600/>5000	0.7/0.5[g]
ELT[f] (Dec$\leq 0°$)	K	28.5	−8.1	−2.0	400	750/>4000	1.0/0.7[g]

Coverage	Passband	5σ Depth (mag)	Peak GCLF (AB mag)	Peak offset & galaxy bk (mag)	d_{Max} (Mpc)	Bright candidates
~15 k sq.deg. (|b|≥23°)	VIS/H_E	~26.0	-8.3	-0.5 (-0.5)	50	400