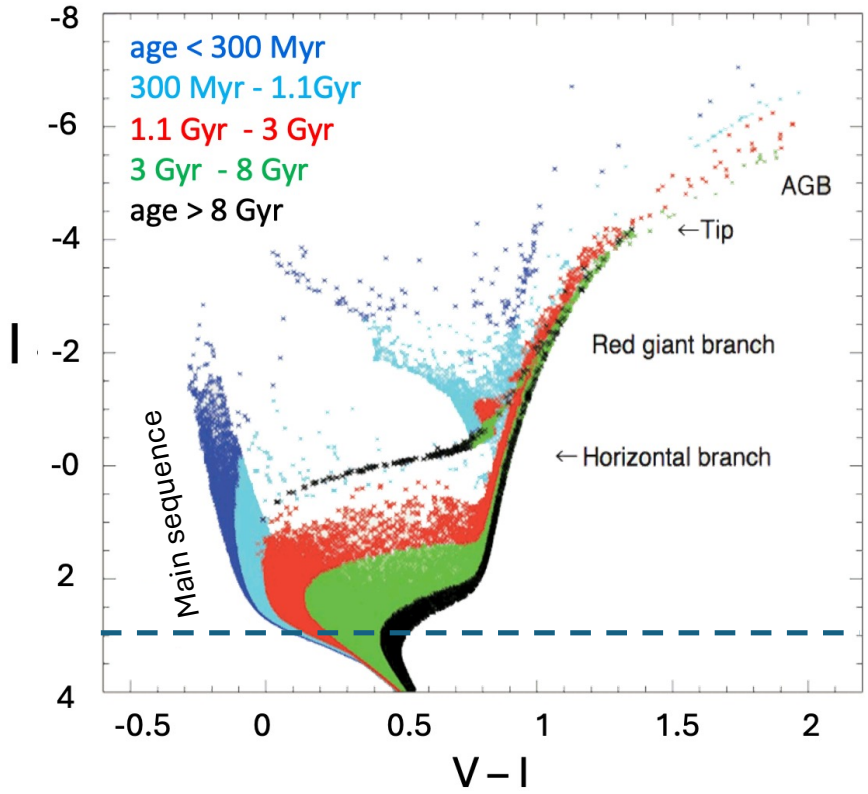
Euclid Legacy Science: Milky Way and Local Universe

Francesca Annibali[1] (MWRSP deputy lead)
and
Leslie Hunt[2] (LU co-lead),
on behalf of the MWRSP and LU working groups

[1] INAF-OAS
[2] INAF-OAA

Tracing galaxy evolution with resolved stars

Color-magnitude diagrams are powerful tools to age-date stars



I=28,
1 Mpc

Tracing galaxy evolution with resolved stars

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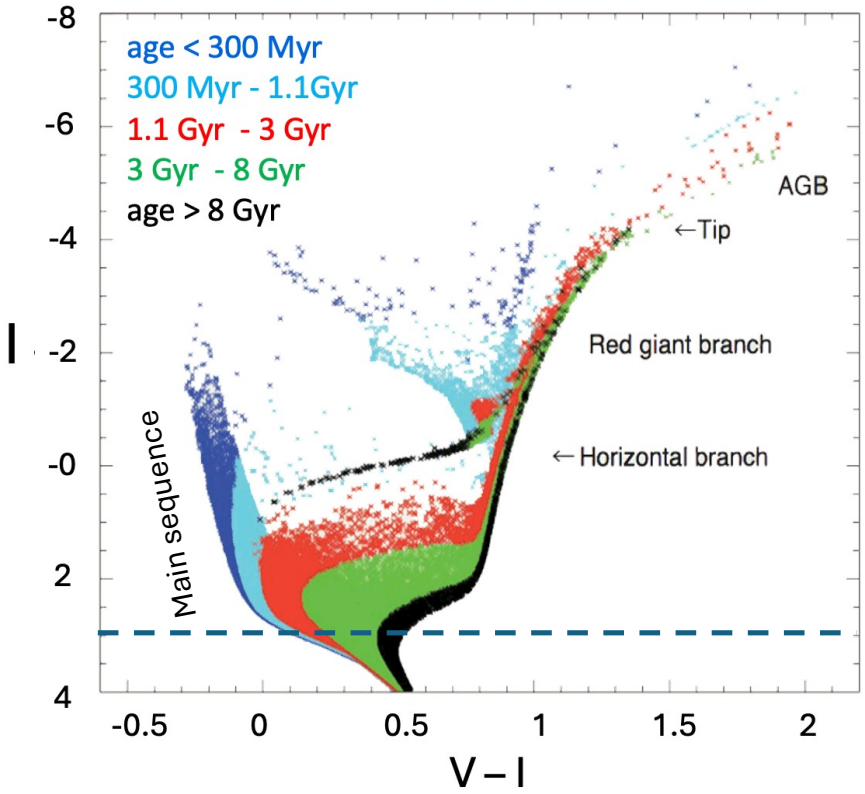

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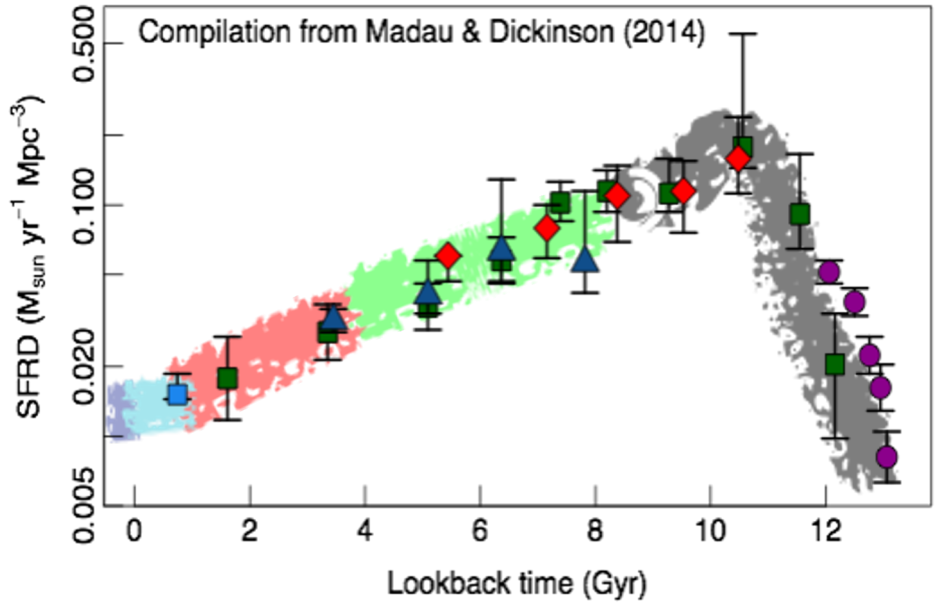
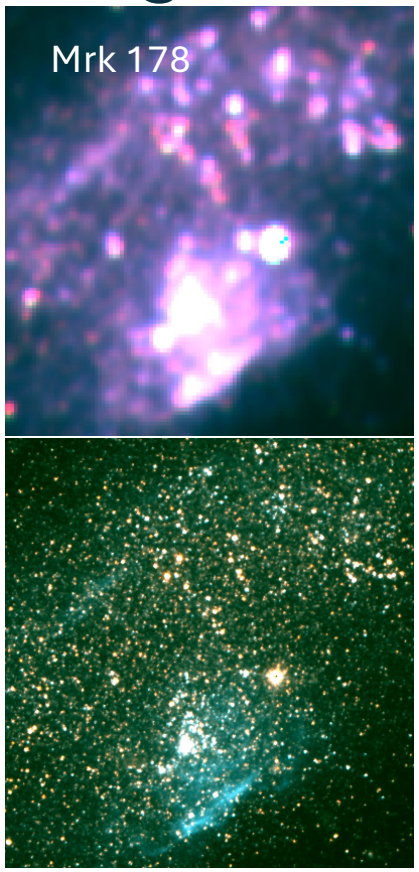


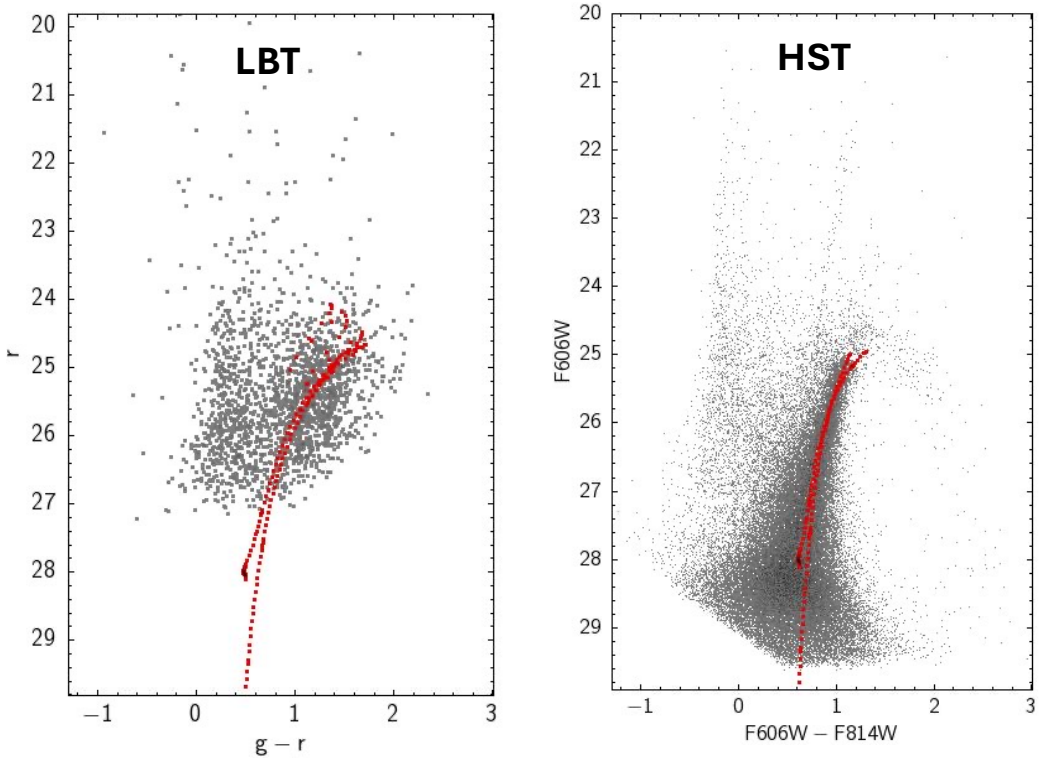
The deeper the CMD,
the higher the *z* we can probe

The Euclid revolution: high angular resolution & large FoV

LBT (8.4 m)
seeing limited

HST (2.4 m)
diffr. limited





Resolving individual stars to deep magnitudes requires **high angular resolution** in crowded fields!

The Euclid revolu
high angular reso

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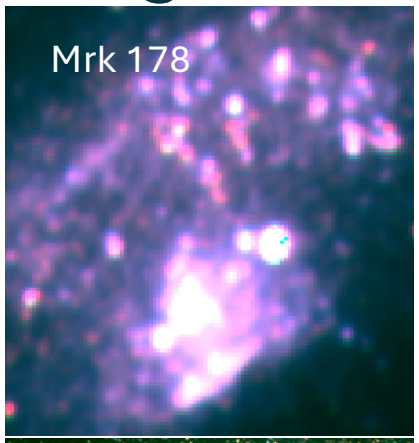
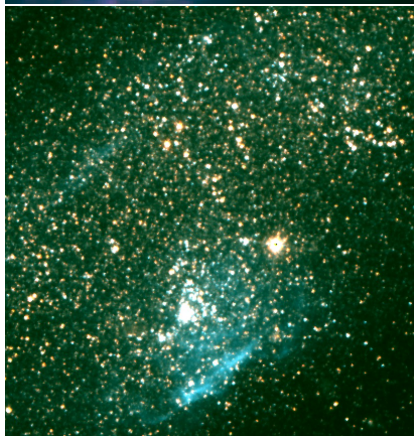
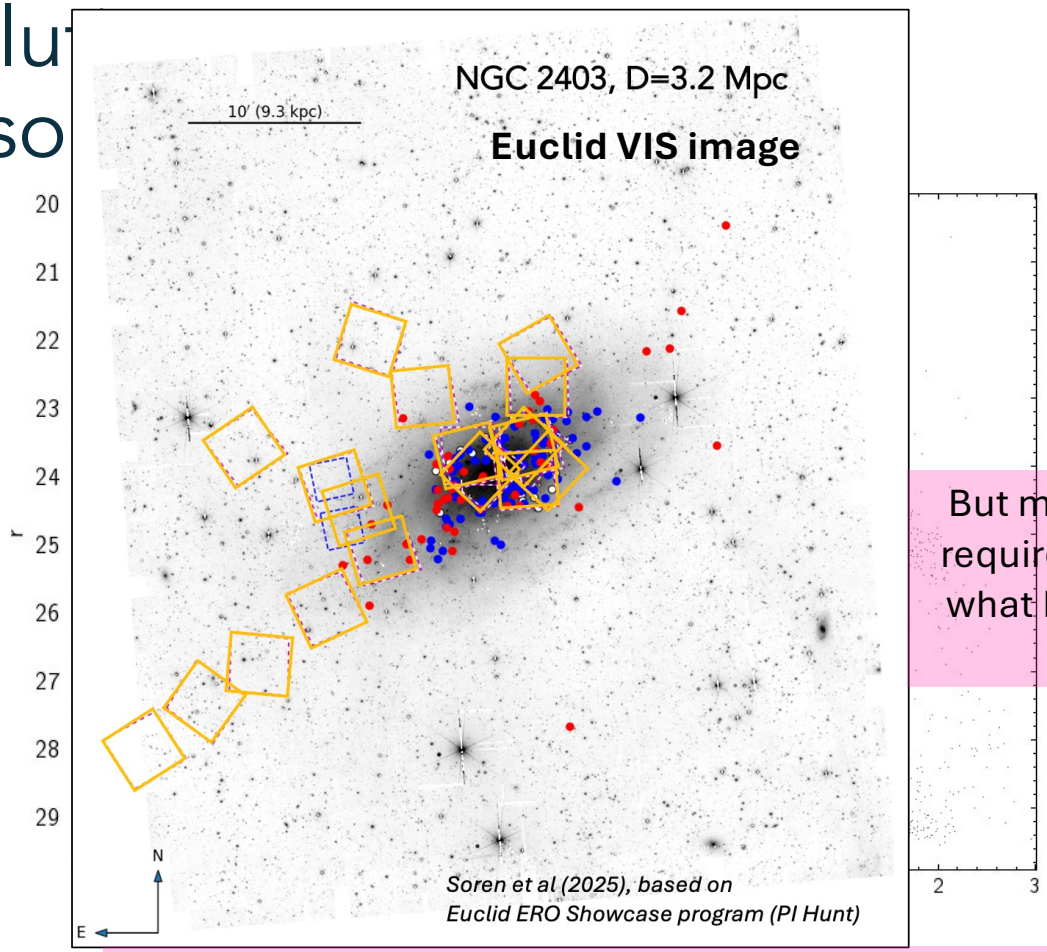
seeing limited



HST (2.4 m)
diffr. limited

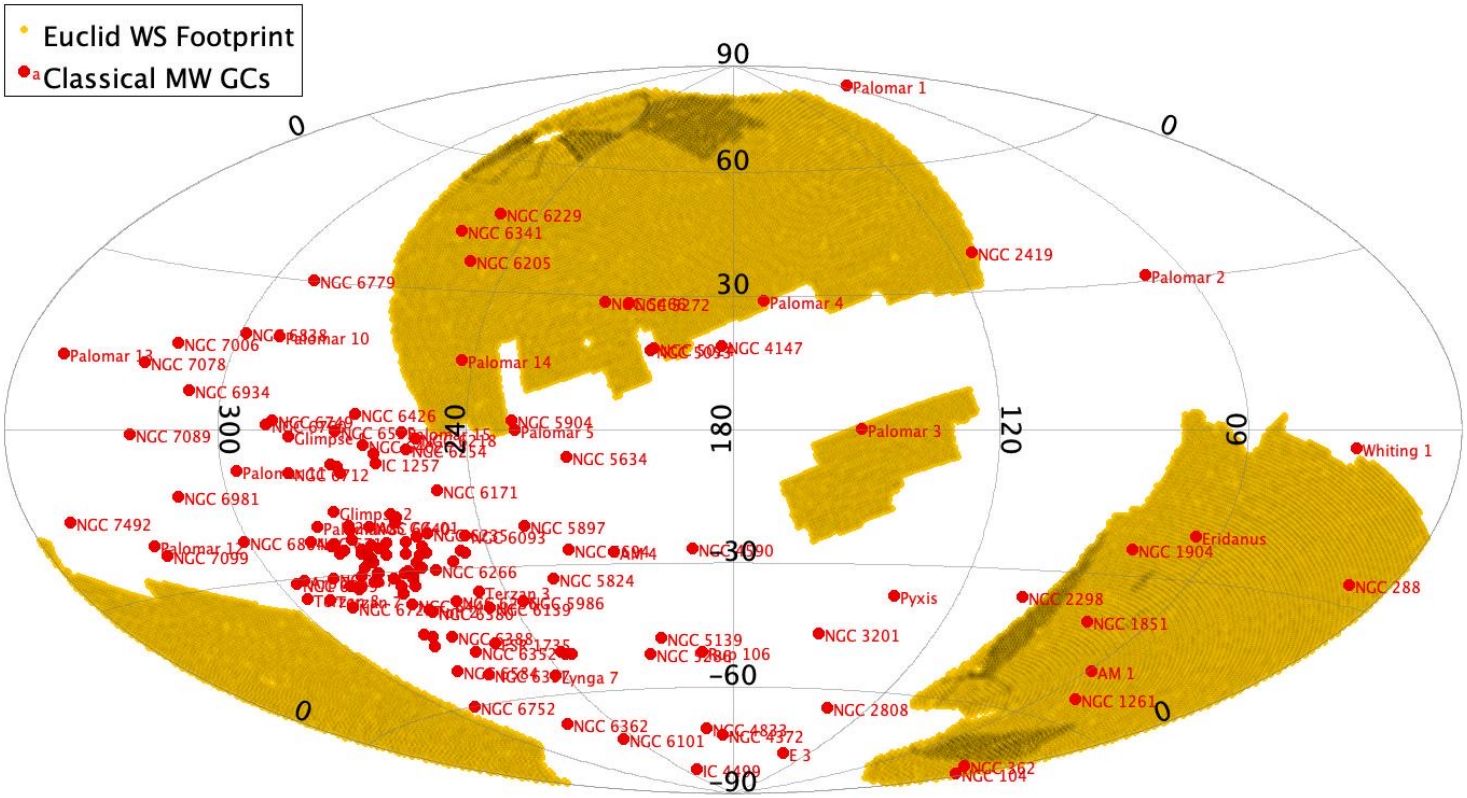




But many many pointings required with HST to cover what Euclid can do in just one shot!

Resolving individual stars to deep magnitudes requires **high angular resolution** in crowded fields!

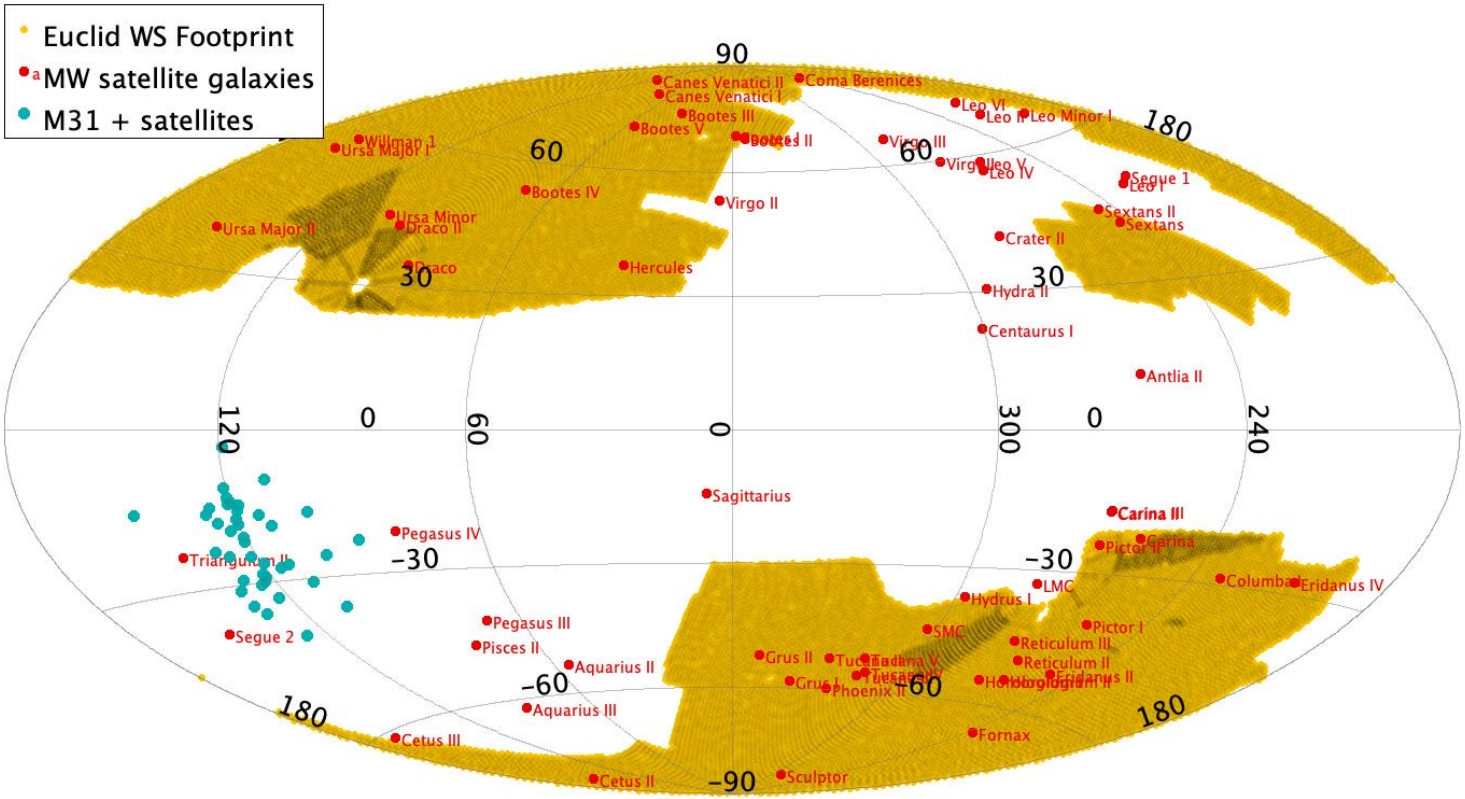
Euclid Wide Survey will image many nearby systems



Several Galactic GCs

Not the bulk of the GC system toward the Galactic Center

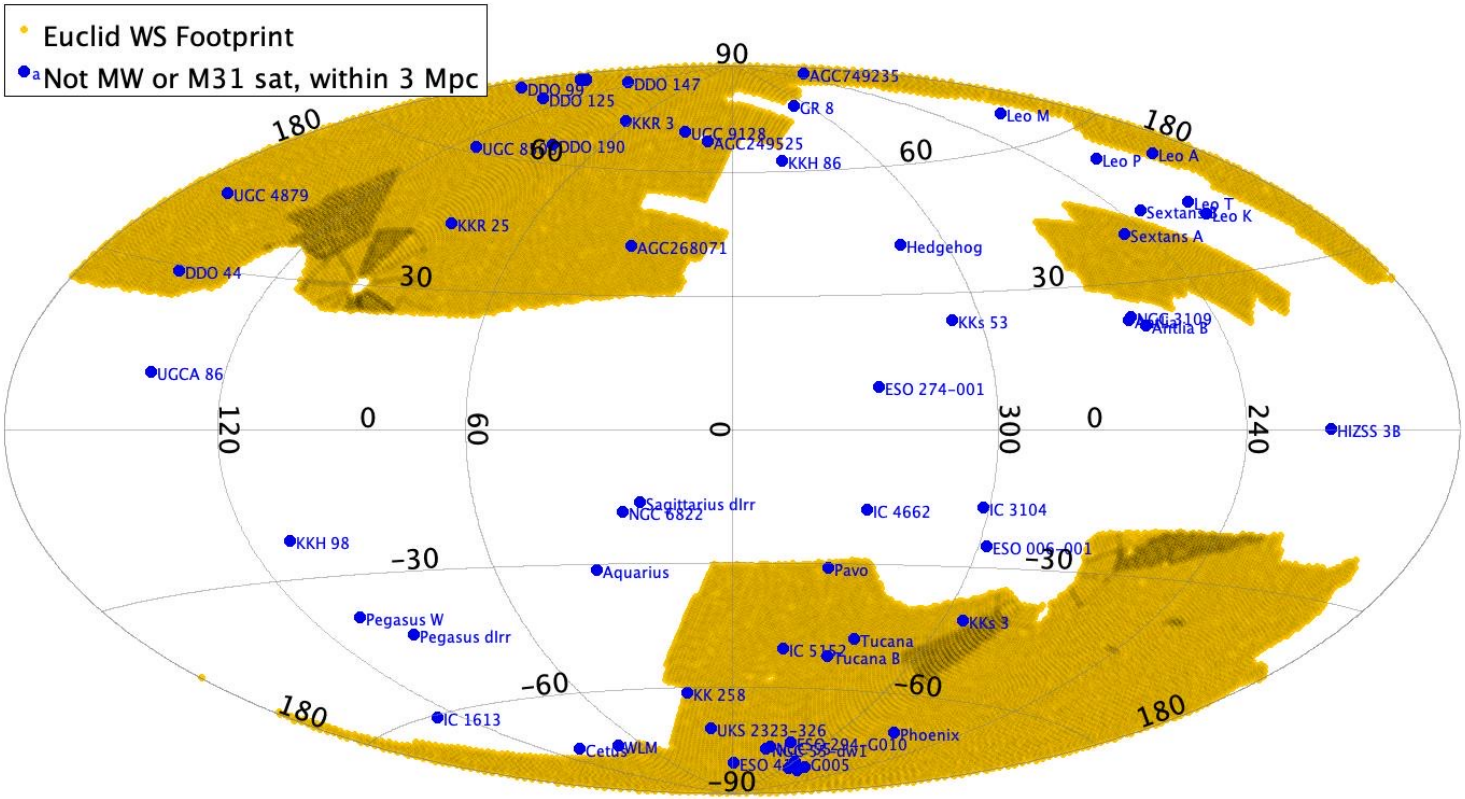
Euclid Wide Survey will image many nearby systems



Huge number of MW dwarf satellites: dSphs and UFDs

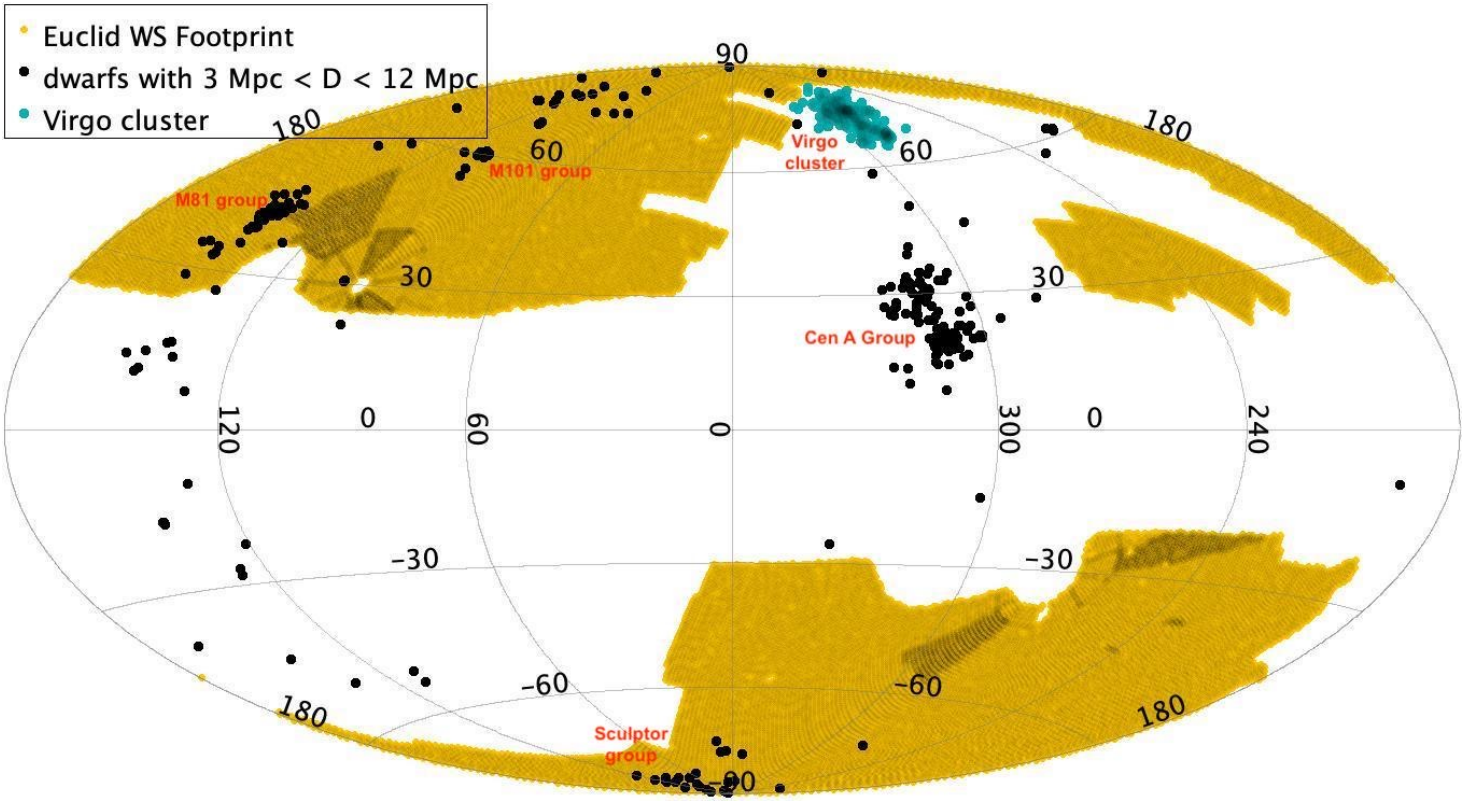
Not M31+M33 & Satellites

Euclid Wide Survey will image many nearby systems



Many late type dwarfs in the outskirts of the LG and just beyond

Euclid Wide Survey will image many nearby systems



M81 group,
M101 Group,
Sculptor group

Not Cen A, Not Virgo

The Milky Way and Resolved Stellar Populations (MWRSP) SWG

Leads: *B*. Goldman, E. Balbinot, F. Annibali (Deputy-lead)

Work Packages:

Italian contribution

WP-Photometry: Stellar populations age, Z, distances (F. Annibali/ M. Rejkuba)

WP-Spectroscopy: star classification and radial velocities (M. Manteiga/ G. Torralba Elipe)

WP-Galactic Globular clusters: extended halos of GCs (D. Massari)

WP-Extra -Galactic Globular clusters: Joint WP with the Local Universe SWG (Ariane Lançon)

WP-Ultra-Cool dwarfs: (R. L. Smart / C. Reyle)

The Milky Way and Resolved Stellar Populations (MWRSP) SWG

Leads: *B*. Goldman, E. Balbinot, F. Annibali (Deputy-lead)

Approved DR1 Key Projects :

Italian contribution

DR1-KP-MWRSP1: Globular Clusters

Coordinators : E. Dalessandro, S. Larsen

DR1-KP-MWRSP2: Resolved stellar peripheries

Coordinators: A. Ferguson, E. Balbinot

DR1-KP-MWRSP3: The Magellanic Clouds

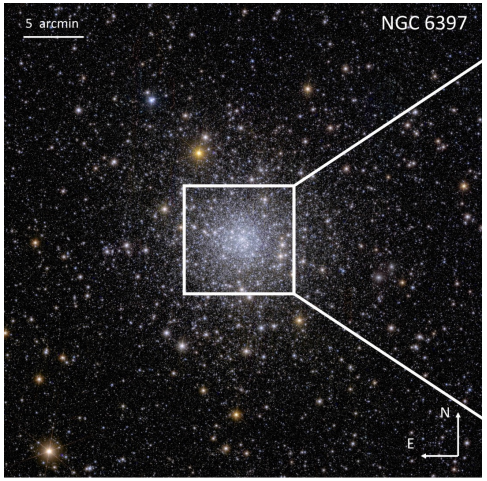
Coordinators: M. Romero

Euclid: ERO – AGGIORNARE)

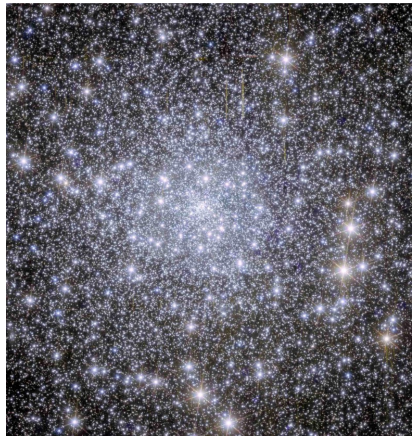
The Periphery of Milky Way Globular Clusters

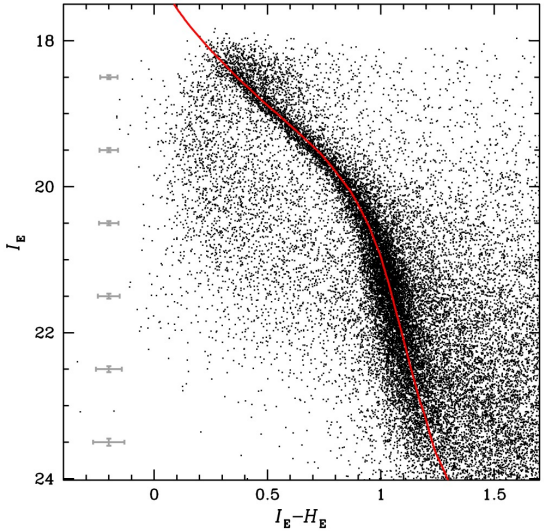
D. Massari, E. Dalessandro, et al.(2024)

- ERO program targeting two MW GCs, **NGC 6397** and **NGC 6254** (PI Massari)
- Imaging in I_E,Y_E,J_E,H_E, depth similar to Wide Survey
- Resolving stellar peripheries of GCs, looking for tidal tails induced by interaction with the MW

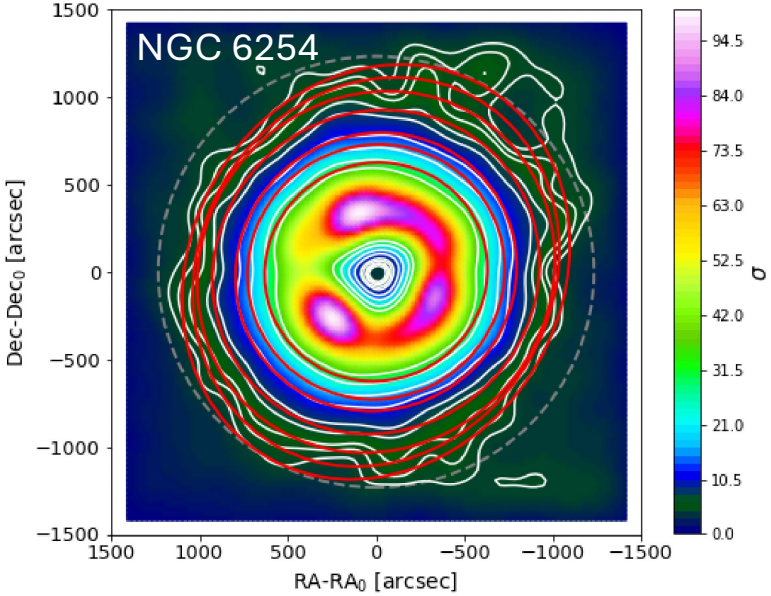


Euclid: ERO – Globular Clusters-image processing by J.-C. Cuillandre





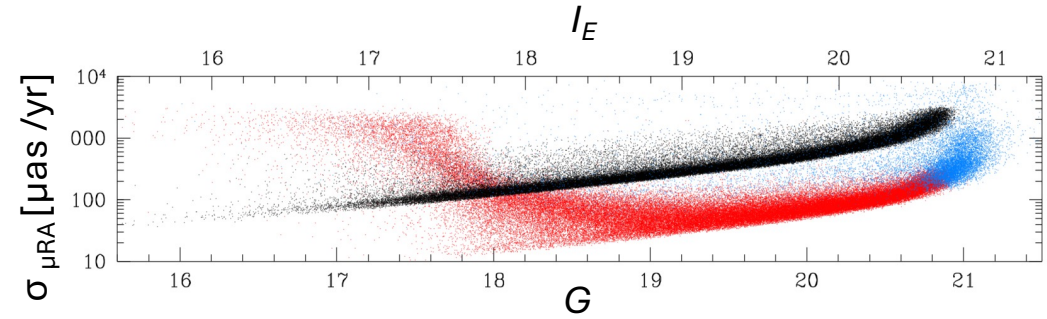
Density map from resolved star counts provides evidence for tidally induced morphological distortions in NGC 6255

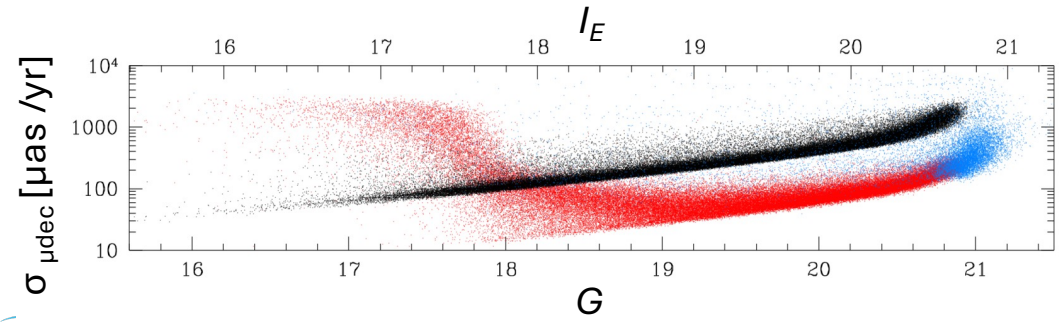


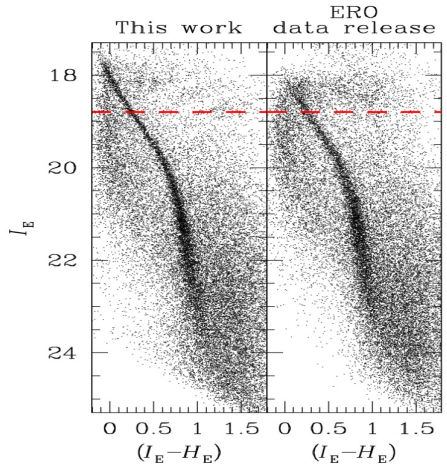
High precision Astrometry and Photometry with Euclid

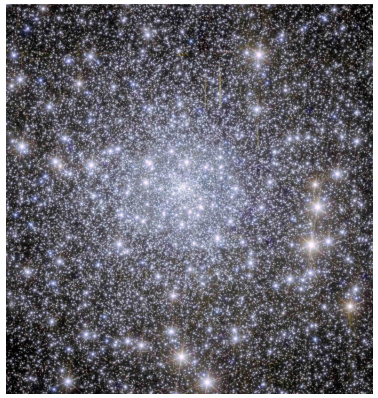
M. Libralato, L. Bedin, M. Griggio, D. Massari , et al.(2024)

- Test on ERO data of **NGC 6397** (PI Massari) with specific pipeline for high precision astrometry and photometry









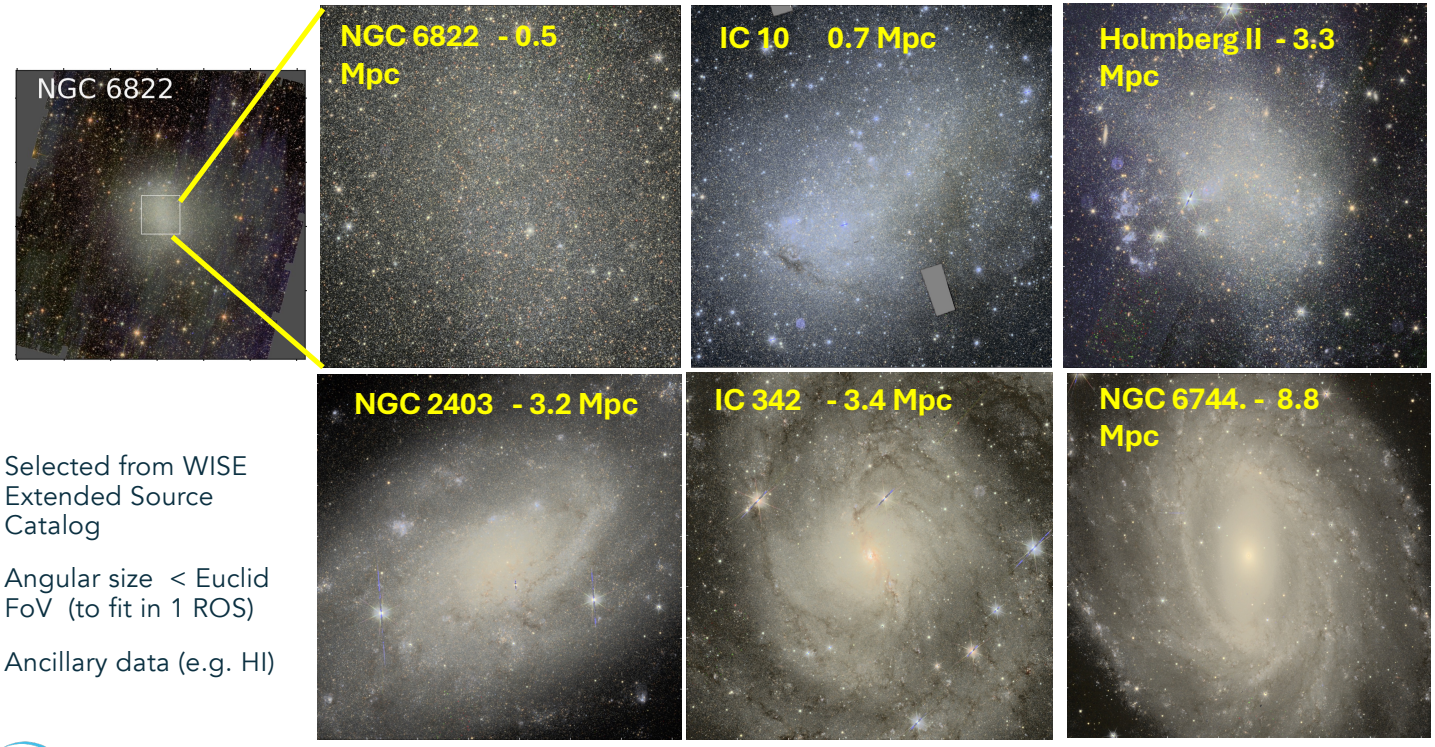
- Astrometric precision of **0.7 mas** in Euclid VIS and **3 mas** in NISP
- Comparison of Euclid astrometry with Gaia DR3 (epoch 2016) provides higher precision PMs than Gaia!

Potentially, multi-epoch Euclid astrometry would allow for high precision PMs down to I_E~26!!

Resolved Stellar Populations in Nearby Galaxies

L. Hunt, F. Annibali, et al.(2024)

Euclid ERO Nearby Galaxy Showcase Program (PI Hunt)



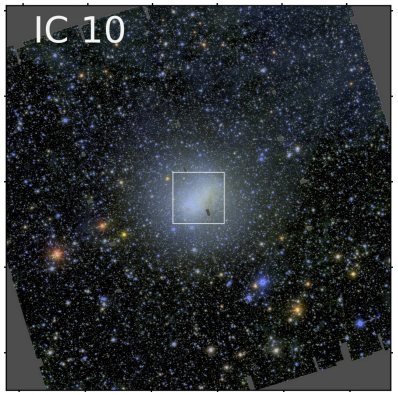
3 dwarfs

3 spirals

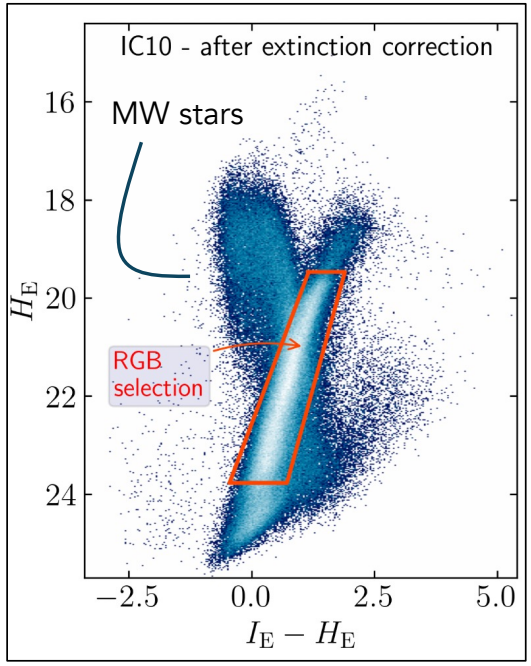
- Selected from WISE Extended Source Catalog
- Angular size < Euclid FoV (to fit in 1 ROS)
- Ancillary data (e.g. HI)

The extended stellar component in the dwarf IC10

F. Annibali, A. Ferguson, P. Sanchez-Alarcon, P. Dimauro, et al, in prep.



Spatial distribution of RGB stars



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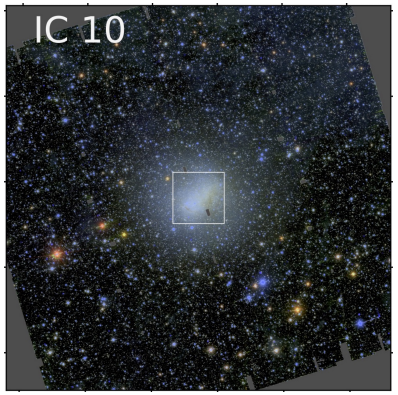

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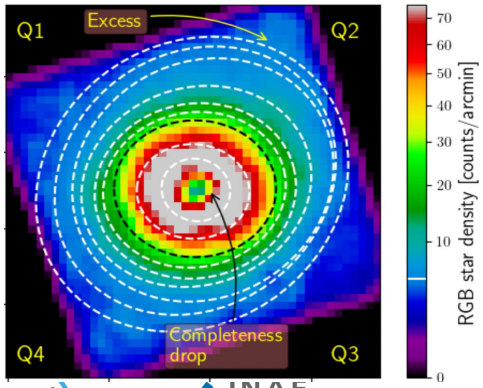
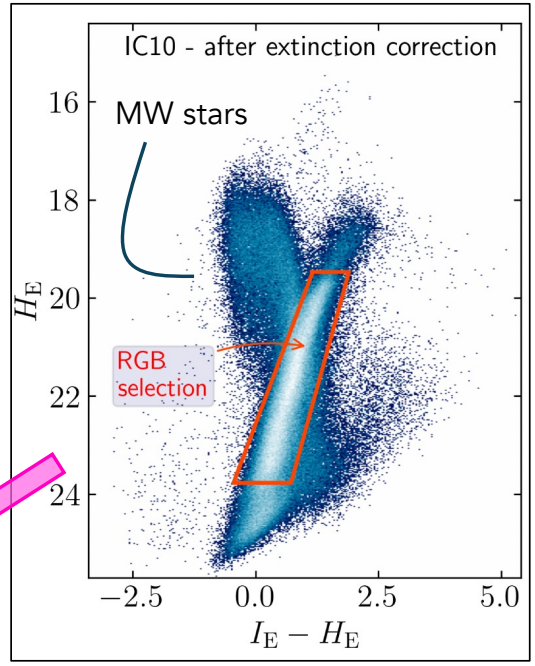
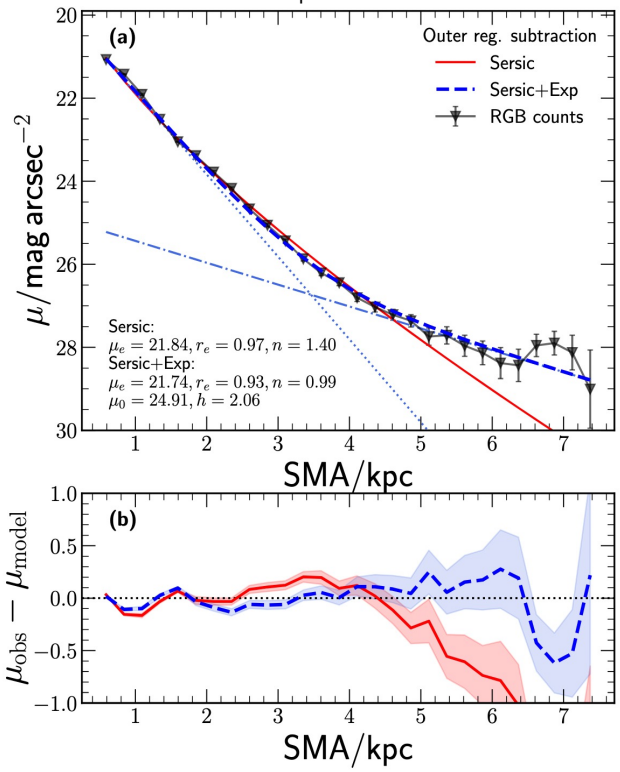




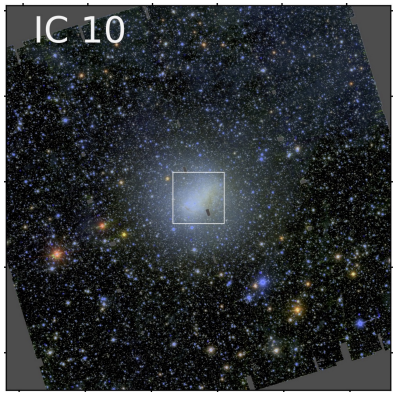
Stellar component much more extended than previously thought!

Stellar profile requires two distinct components



The extended stellar component in IC10

F. Annibali, A. Ferguson, P. Sanche



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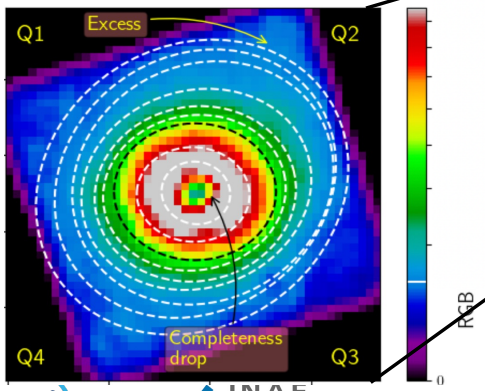
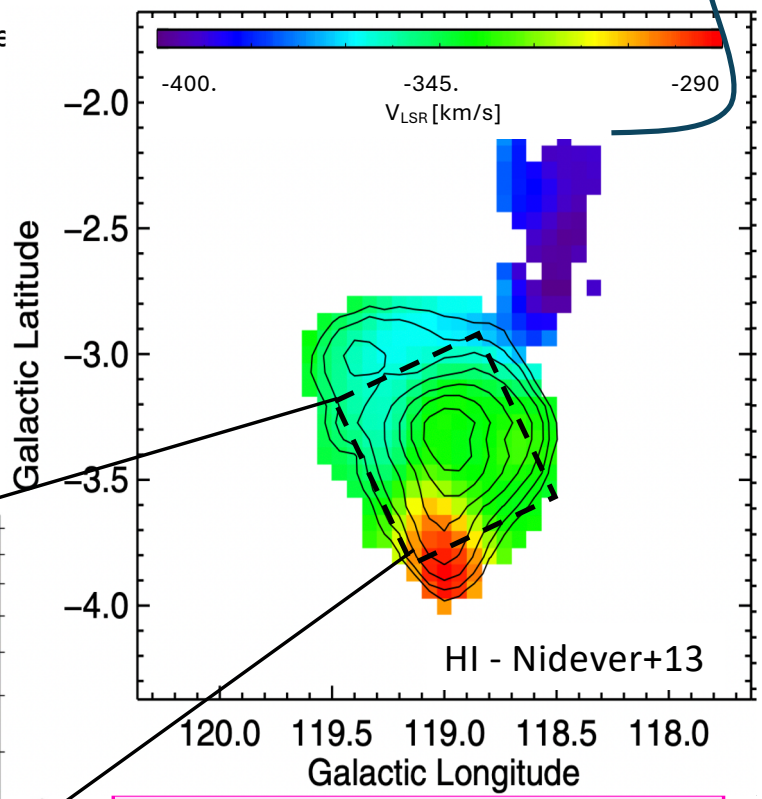


Interaction with dwarf satellite



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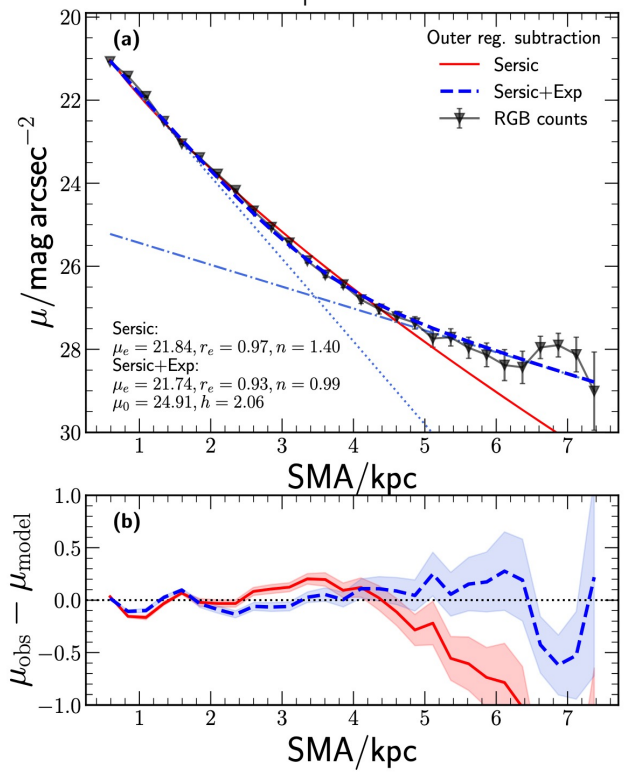


The Local Universe(LU) SWG

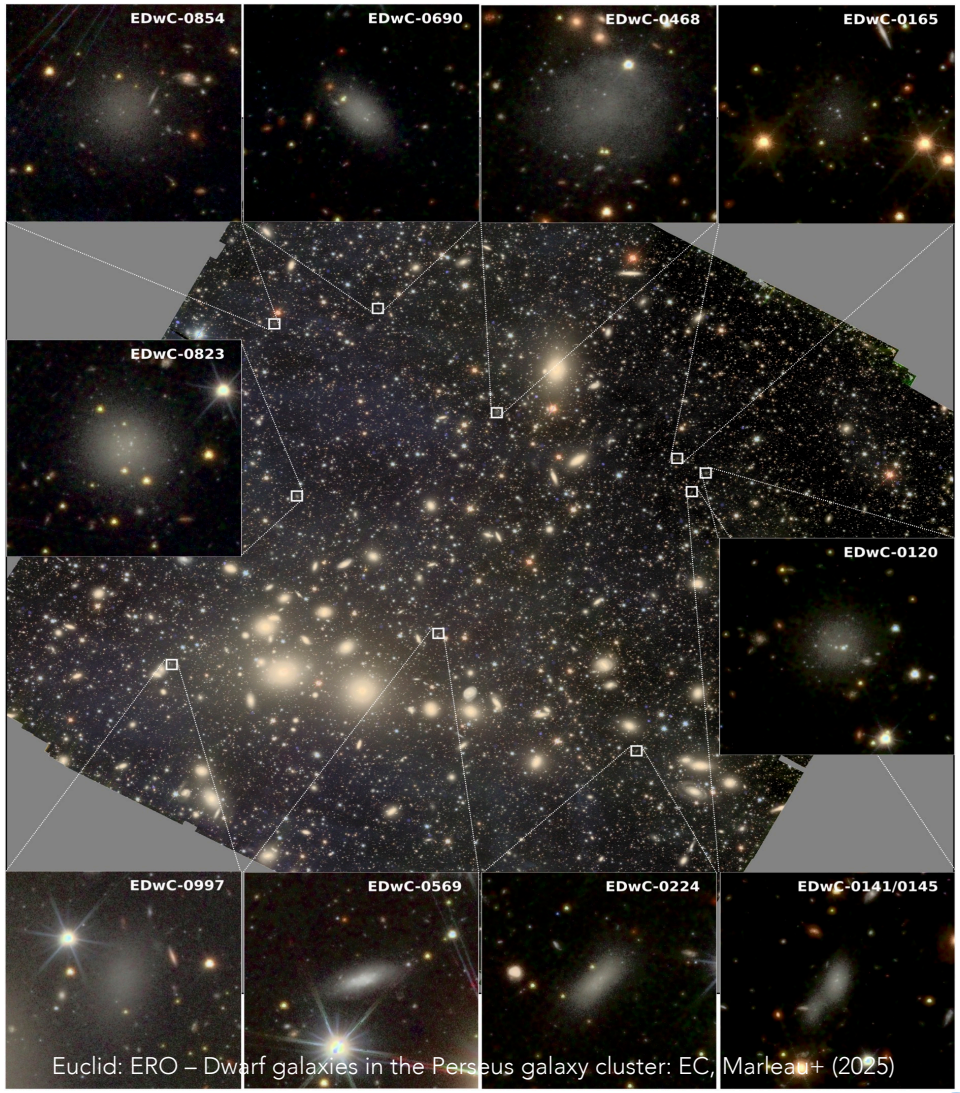
Leads: M. Fabricius, L. Hunt, F. Marleau, T. Saifollahi (Junior Deputy)

Two main science themes for the LU motivated by Euclid's capabilities:

(1) **low surface brightness features** because of their importance for probing remnants of hierarchical structural assembly in galaxies (stellar streams, tidal debris, intracluster light, dwarf galaxies, …)

(2) superb spatial resolution enables measuring **physical properties** on parsec /10s of pc scales, and characterization of **extragalactic globular clusters (EGCs)**

Euclid will image to unprecedented depths faint, low surface brightness galaxies, stellar streams/tidal debris, and globular clusters in galaxies up to z~0.2, enabling new galaxy demographics and new distance calibrations through surface-brightness fluctuations



Euclid: ERO – Dwarf galaxies in the Perseus galaxy cluster: EC, Marleau+ (2025)

Approved pre-launch Key Projects and Q1/DR1 Key Projects

LU Key Project I: Opening Euclid's window on low surface brightness
Coordinators: Enrica Iodice, Reynier Peletier, Leslie Hunt

LU Key Project II: Simulating the Euclid View of the Local Universe
Coordinators: Johan Knapen, Crescenzo Tortora

Italian contribution

KP-LU-DR1-1: Euclid's low surface brightness view of the nearby universe from DR1
Coordinators: Leslie Hunt, Francine Marleau

KP-LU-DR1-2: Stellar populations in nearby galaxies from DR1
Coordinators: Daniela Carollo, Crescenzo Tortora, Karina Voggel

KP-LU-DR1-3: The Fornax Cluster and Supercluster: New insights from Euclid
Coordinators: Pierre-Alain Duc, Enrica Iodice

KP-LU-DR1-4: Surface Brightness Fluctuation distances with Euclid
Coordinators: Rebecca Habas, Simona Mei

Work Packages:

WP-PPZ: Physical parameters and photometric redshifts (Marco Scodeggio / Crescenzo Tortora)

WP-FAR: Distance estimates (Simona Mei)

WP-DET: Detection Algoritms (Paola Dimauro)

WP-MOR: Morphology measurements (Louis Quilley)

WP-LBG: Dwarf and low surface brightness galaxies (Pierre-Alain Duc / Reynier Peletier)

WP-DIF: Diffuse emission (Fernando Buitrago)

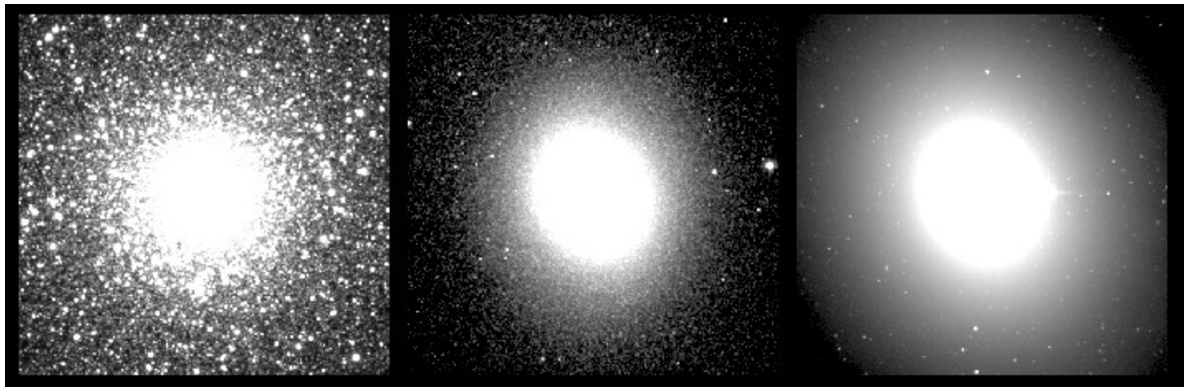
WP-EGC: Extragalactic globular clusters (Ariane Lançon)

Italian contribution

Distance measurements with Surface Brightness Fluctuations

Lead: Michele Cantiello (INAF-OA Teramo)
Rebecca Habas (post-doc supported by INAF Large grant EDGE, PI Hunt)

See R. Habas POSTER!



MW Globular Cluster
~10 kpc

Messier 32
~770 kpc

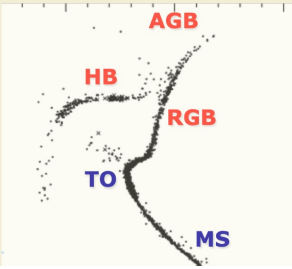
Messier 49
~16500 Mpc

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

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

f^2 ➔ bright stars weight more

$$\overline{m} \sim \langle m_{RGB} \rangle$$



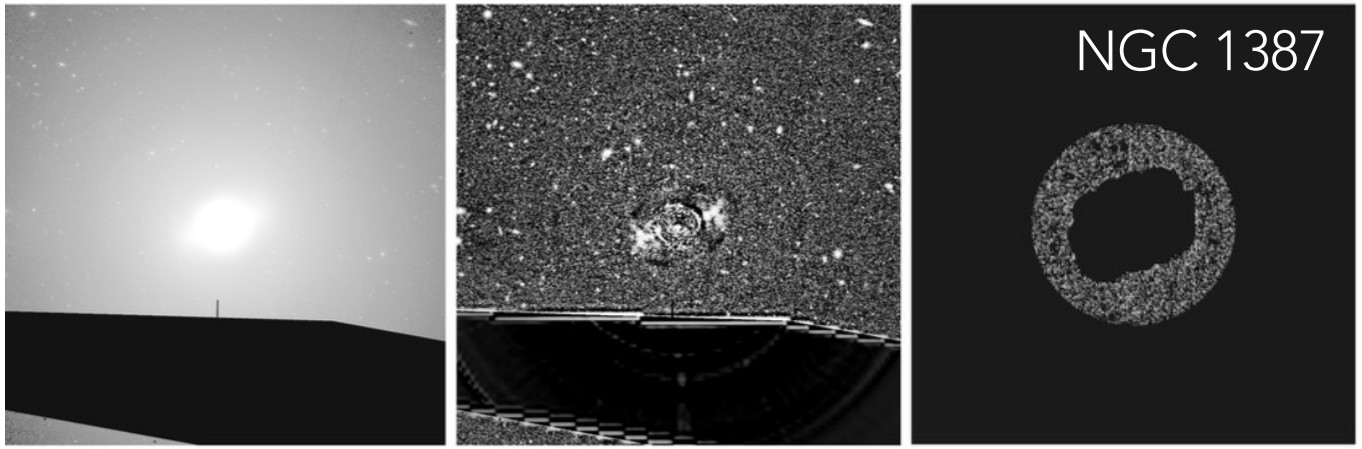
Tonry & Schenider 1988
Tonry, Ajhar & Luppino 1990
Blakeslee, Ajhar & Tonry 1999..

- Preferred targets: elliptical galaxies with smooth SB profile
- Number of 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

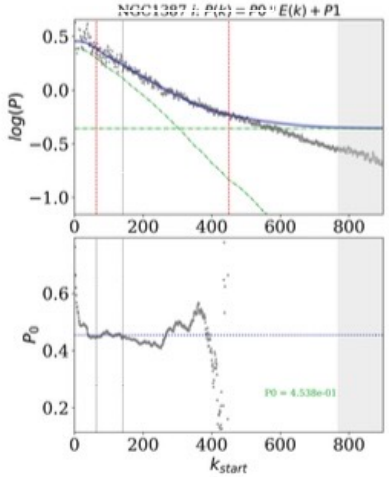
Goal: to develop a self-contained, automated code for the community, adapted to *Euclid*. Conservatively, >50 Mpc with Euclid.

Distance measurements with Surface Brightness Fluctuations

original image | residual image | fluctuations (2D covariance)



power spectrum of azimuthally averaged fluctuations



R. Habas, M. Cantiello, et al. in prep.

Fornax cluster for the first tests:

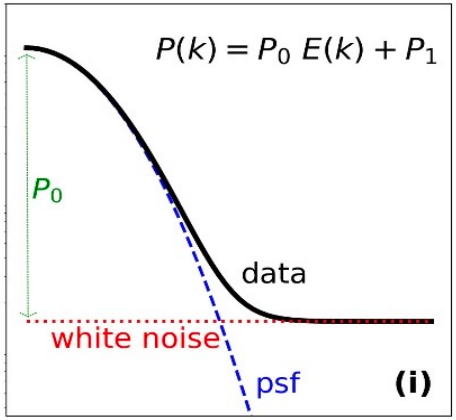
- close enough to measure SBF
- several galaxies already have SBF measurements (e.g., Blakeslee et al. 2009)
- dwarf candidates already identified

Measure SBF in I_E band:

- better resolution
- Lanczos3 interpolation for stacking (interpolation method important)
- *SPOIL ALERT: bi-linear interpolation kills SBF signal*

See R. Habas POSTER!

schematic power spectrum



Physical Parameters and Redshift (PPZ) WP

Abdurro'uf, Tortora et al. 2025

Leads: Crescenzo Tortora, Marco Scodeggio

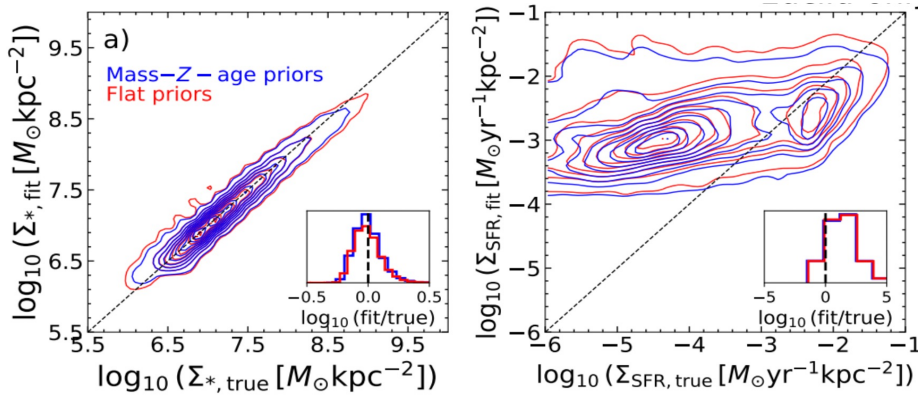
Objectives:

- photometric redshifts and integrated stellar populations for galaxies at z < 0.2
- spatially-resolved stellar population maps for nearby galaxies
- Test performance of spatially resolved-SED fitting on mock datasamples (e.g. EURISKO, used in Humphrey, Cunha, Bisigello, Tortora, et al 2015)

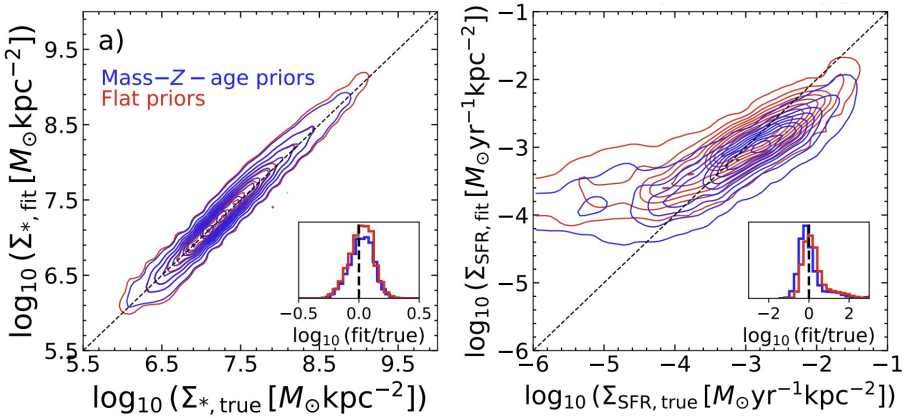
Results:

1. stellar mass density well recovered with Euclid-only bands
2. improved performance when adding ancillary data from other surveys

Euclid only



GALEX + LSST +Euclid

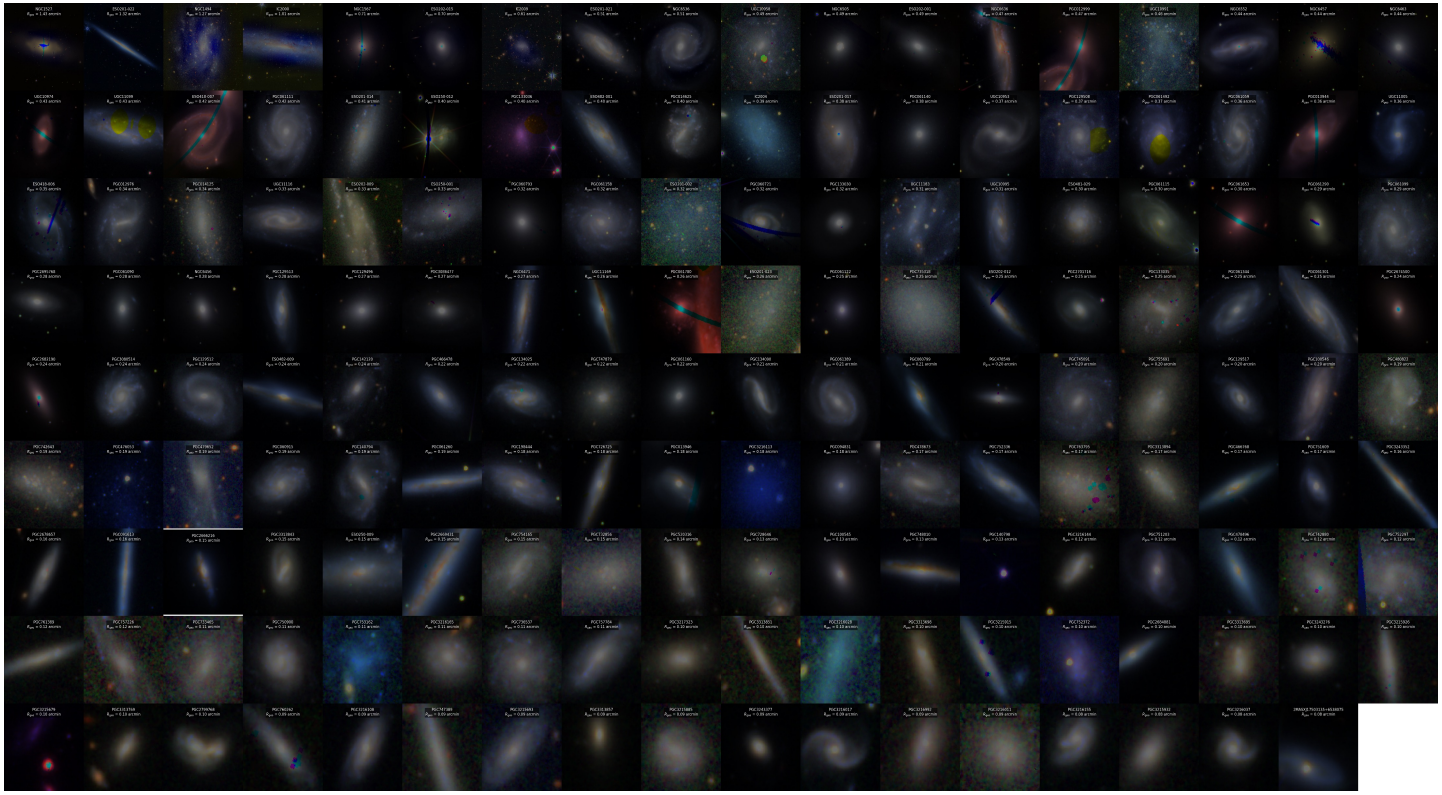


PPZ WP: Plans for DR1

DR1 contains ~5000 local galaxies with distances.

Objectives:

- Colour maps
- Application of the spatially-resolved SED fitting and machine learning tools
- Morphological characterization

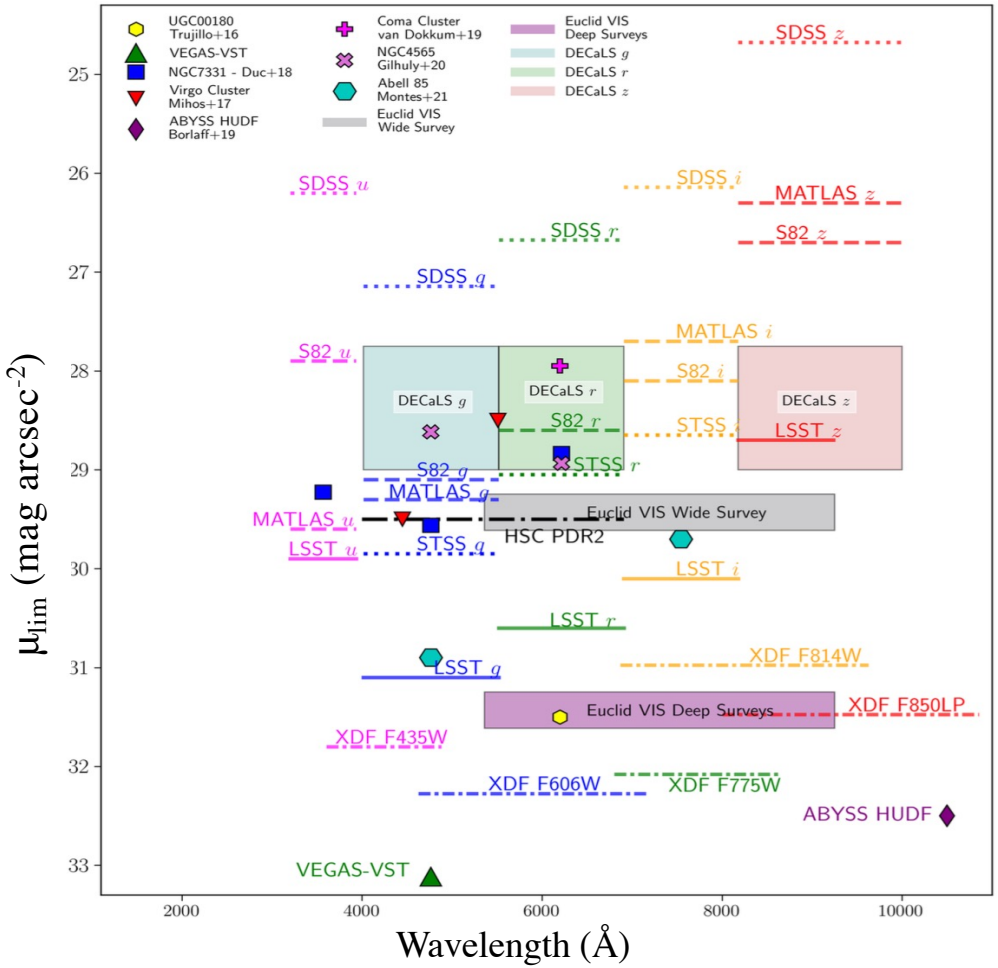


IYH colour images of Q1 galaxies with distances from HECATE catalog (Kovlakas et al. 2021) – Image credits: Tortora/Euclid

Euclid as a Low Surface Brightness Machine

Comparison of the **surface brightness limit** (3**σ**, 10x10 arcsec^2) for the Euclid/VIS Wide Survey and Deep Survey, compared with a selection of deep optical and near-infrared surveys.

Although a few surveys may go deeper, they do so over very small areas. Euclid will probe the LSB universe on a huge area of the sky, opening up a new parameter space for LSB science

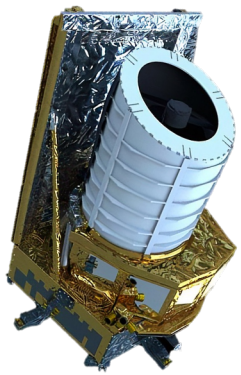


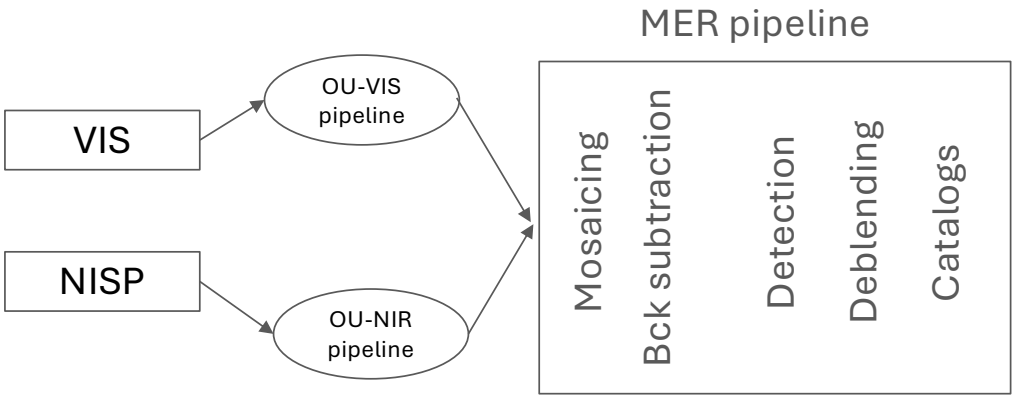
Taken from EC, Borlaff+ (2022), see also Scaramella+ (2022)

Low Surface Brightness Data Labs pilot study

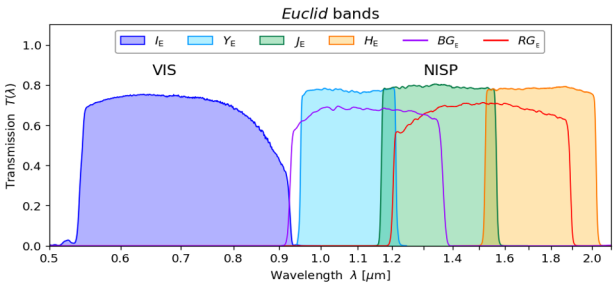
P. Dimauro et al., *in prep.*

EC pipeline optimized for the main Science goal of Euclid: Cosmology





See Paola Dimauro hands-on session on Wed July 2nd!



Need an LSB friendly pipeline

Low Surface Brightness Data Labs pilot study

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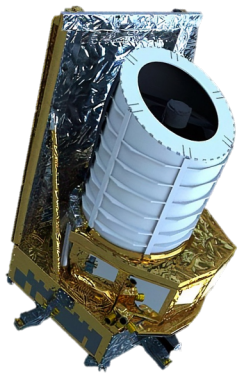

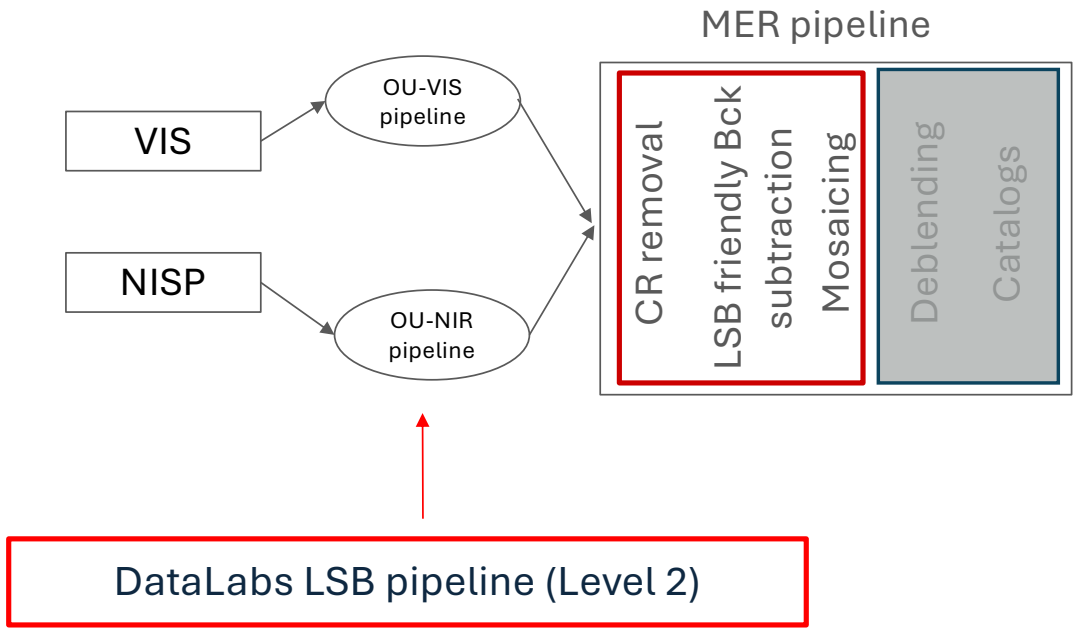

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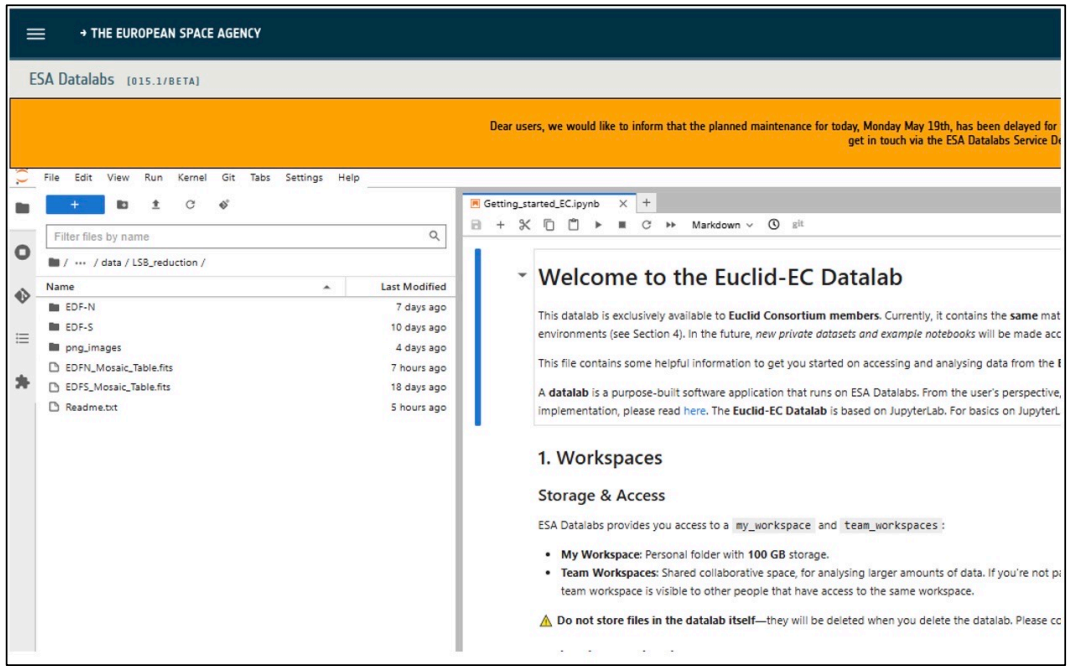
Now available LSB pipeline-reduced **VIS** and **NISP** images in Datalabs: datalabs.esa.int

Euclid team_workspace
Euclid-Consortium data
LSB_reduction
VIS
EDF-N
EDF-S

- EDFN_Mosaic.table.fits
- EDFS_Mosaic.table.fits



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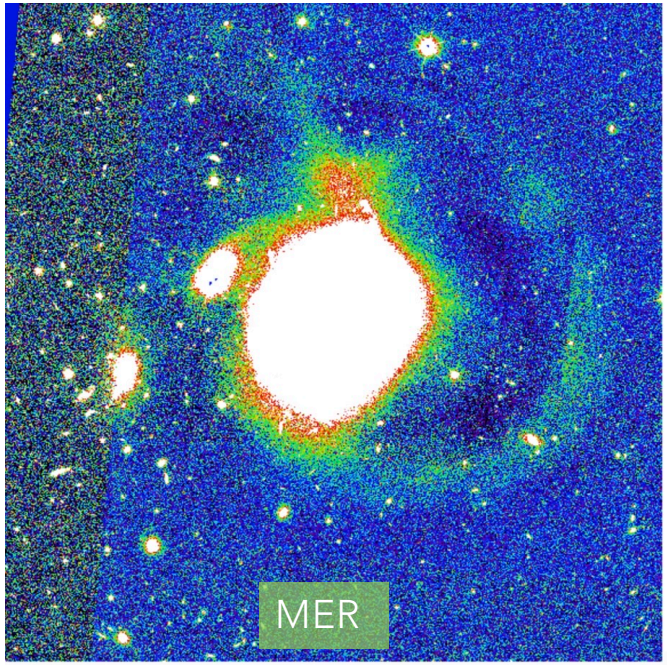
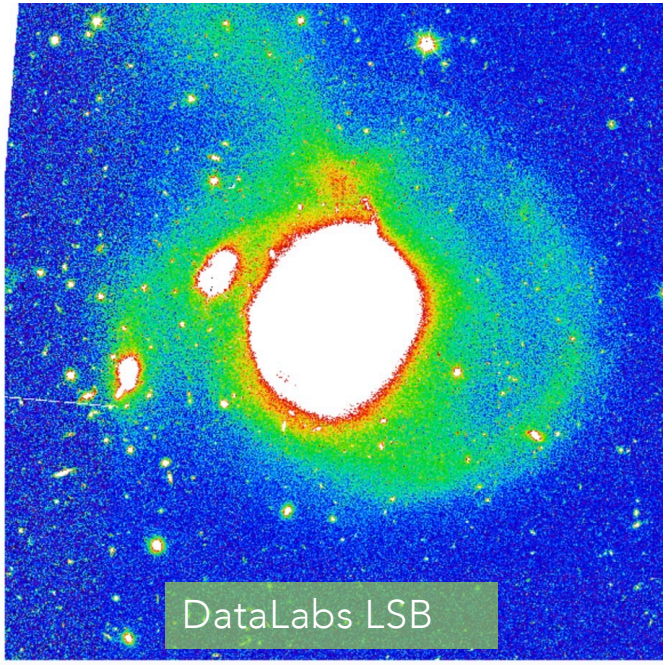
Low Surface Brightness Data Labs pilot study

Comparison MER and DataLabs LSB pipelines: ***ESO202-023 post merger*** *(courtesy J. Miro)*





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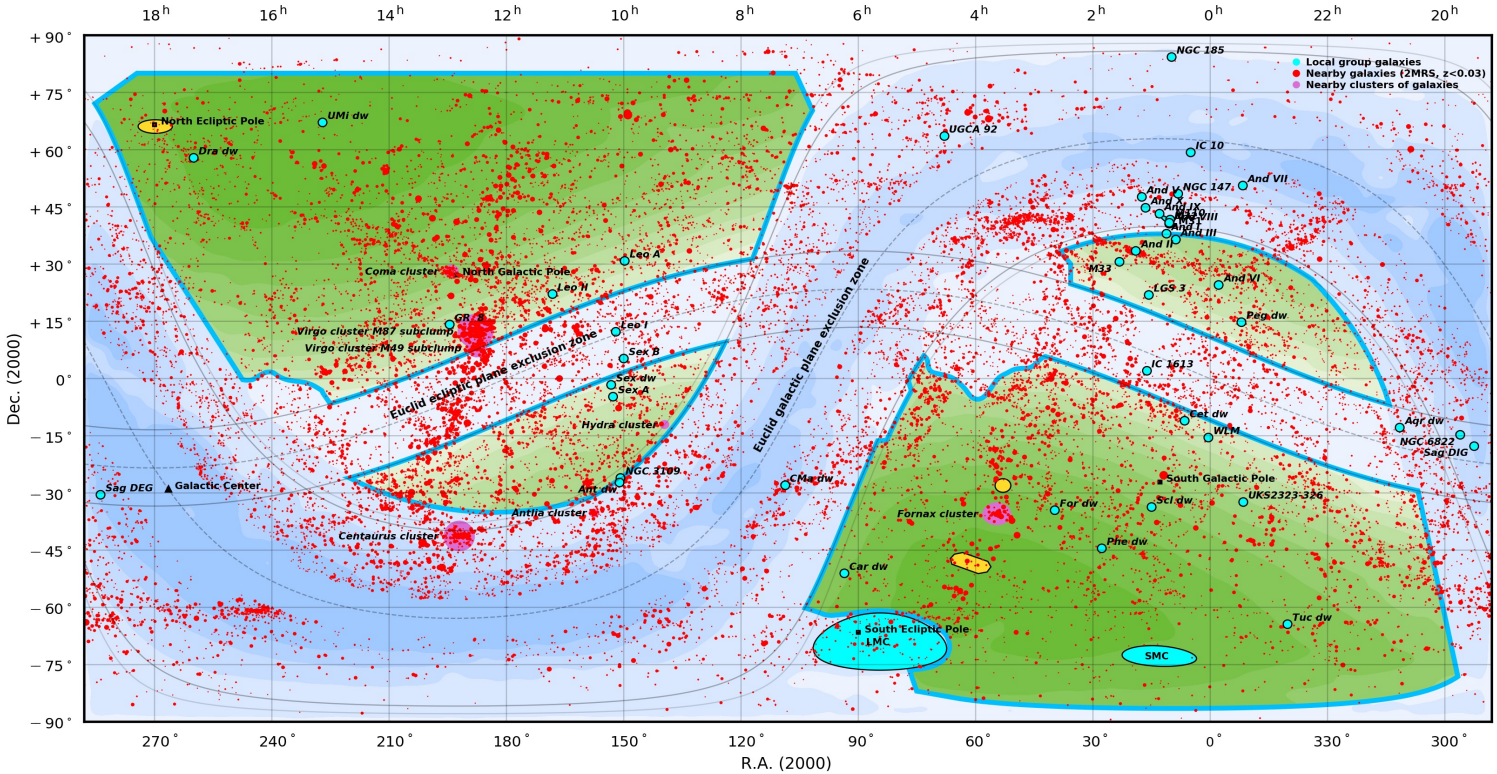
MER pipeline tends to oversubtract background



Euclid VIS 1-sigma asinh limiting surface brightness (LSB science performance) and the nearby universe up to z=0.03

Wide Survey region of interest : 17 Kdeg.^{2} compliant with a 15 Kdeg.^{2} survey

Deep Fields : North=10 deg.^{2}, Fornax=10 deg.^{2}, South=23 deg.^{2} (+2 mag.)

⇒ metric reflecting the ultimate science LSB performance based on profile extraction

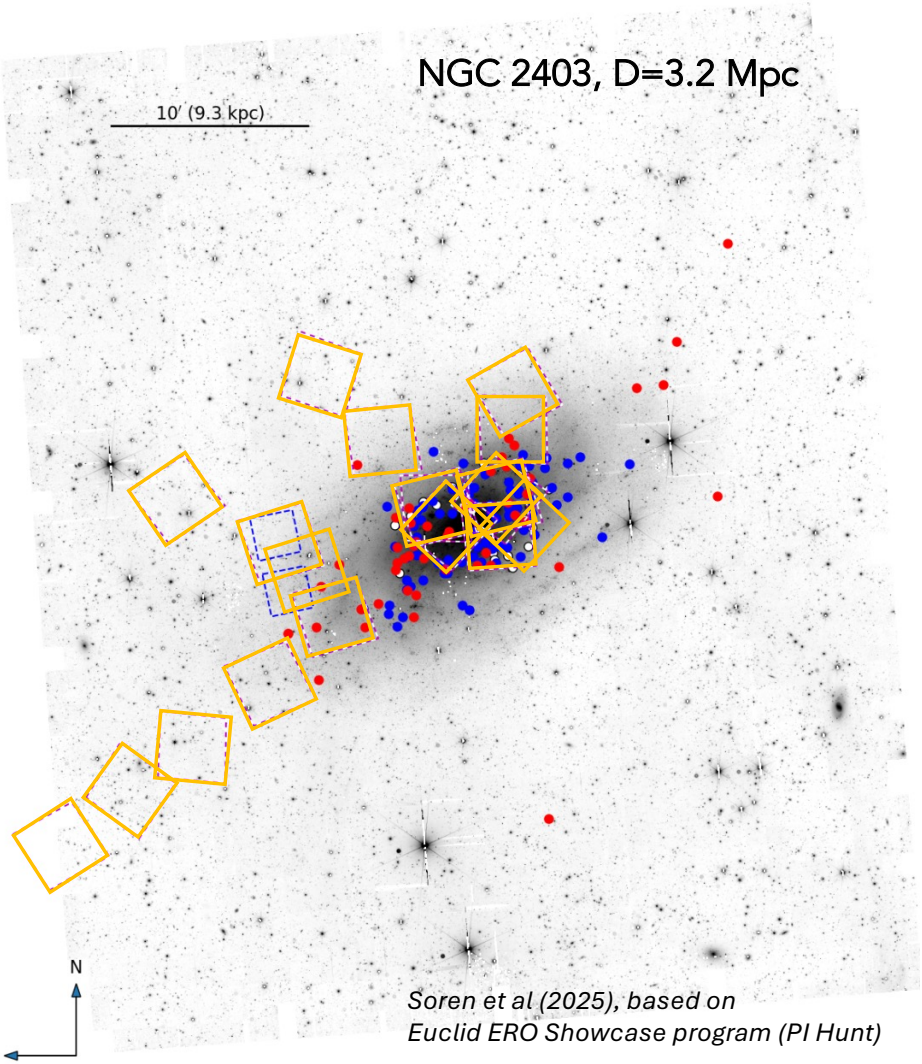
Limiting surface brightness: mag/arcsec^2, 10^{2}arcsec^2 scale

29.61 29.65 29.69 29.73 29.77 29.81 29.85 29.89 29.93 29.97

⇒ *System zero point and sky+telescope+instrument backgrounds on 3 stacked exposures of t_int=575 seconds each (ROS 2019)*

⇒ *Valid for areas away (>0.5 deg.) from bright stars (<4th mag.)* **LSB asinh metric: Mihos et al. 2013, Lupton et al. 1999**

AGGIORNARE: Euclid will image to unprecedented depths faint, low surface brightness galaxies, stellar streams/tidal debris, and globular clusters in galaxies up to z~0.2, enabling new galaxy demographics and new distance calibrations through surface-brightness fluctuations



Soren et al (2025), based on Euclid ERO Showcase program (PI Hunt)