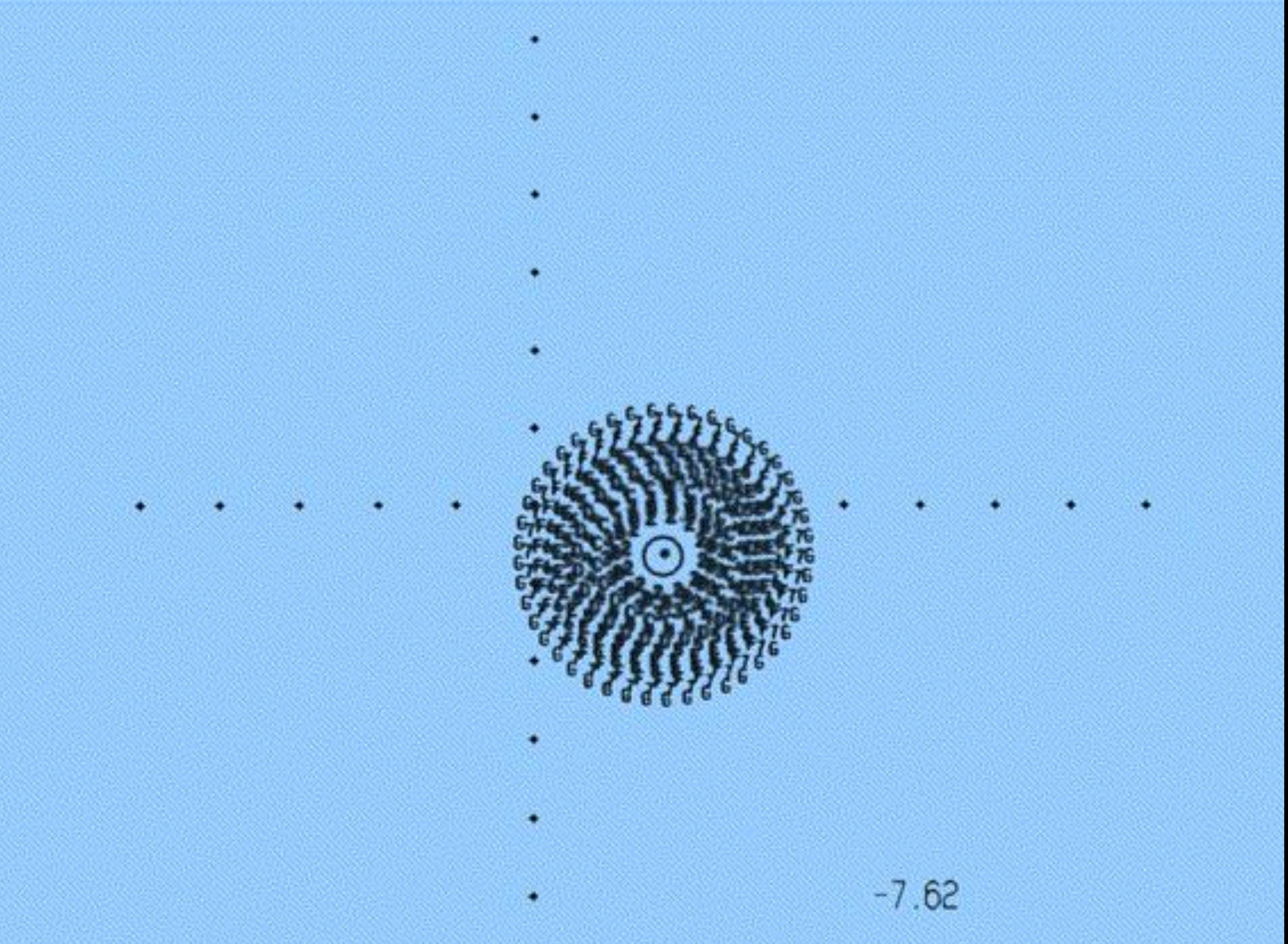
Below the iceberg: Low surface brightness astronomy with HST, Euclid, and Roman

Alejandro S. Borlaff NASA/Ames Research Center
Pamela Marcum, Scott Rohrbach, Sarah Caddy, Anton Koekemoer, Seppo Laine, Mireia Montes

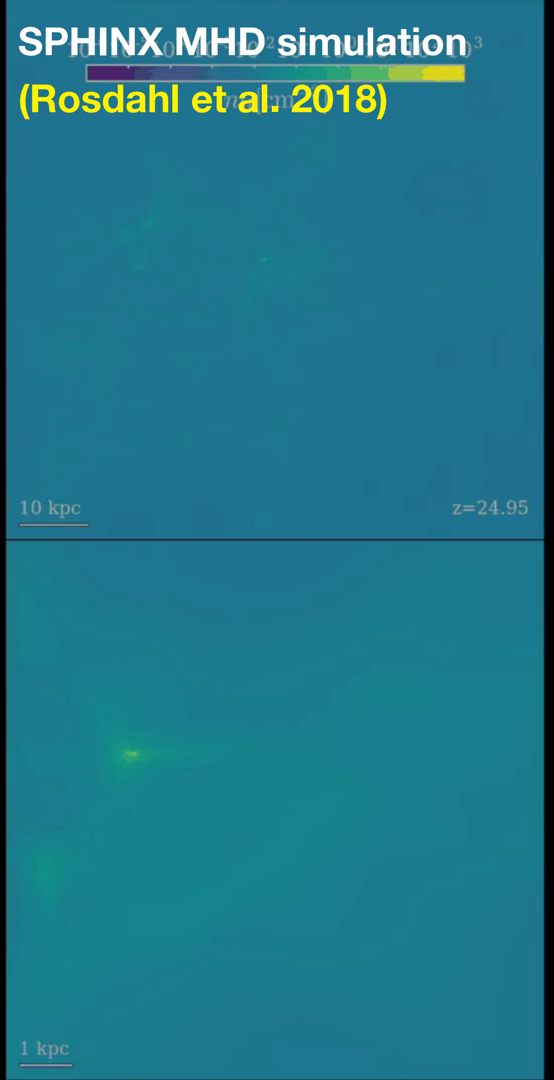
Roman Science Inspired by Emerging JWST Results - Thursday 22, 2023 - STScI

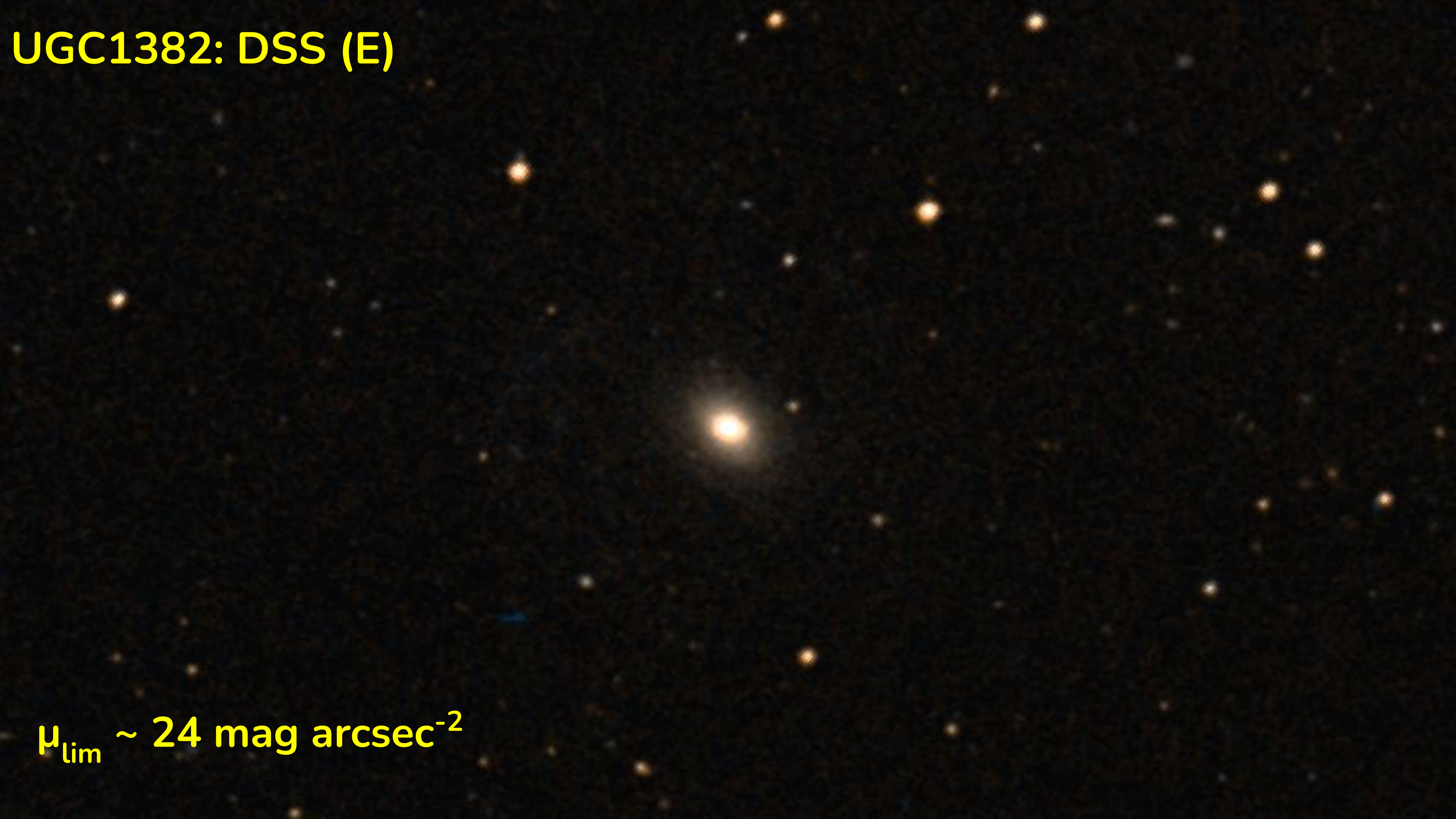


Toomre & Toomre: Galactic Bridges and Tails (1971-1973)

SPHINX MHD simulation

(Rosdahl et al. 2018)

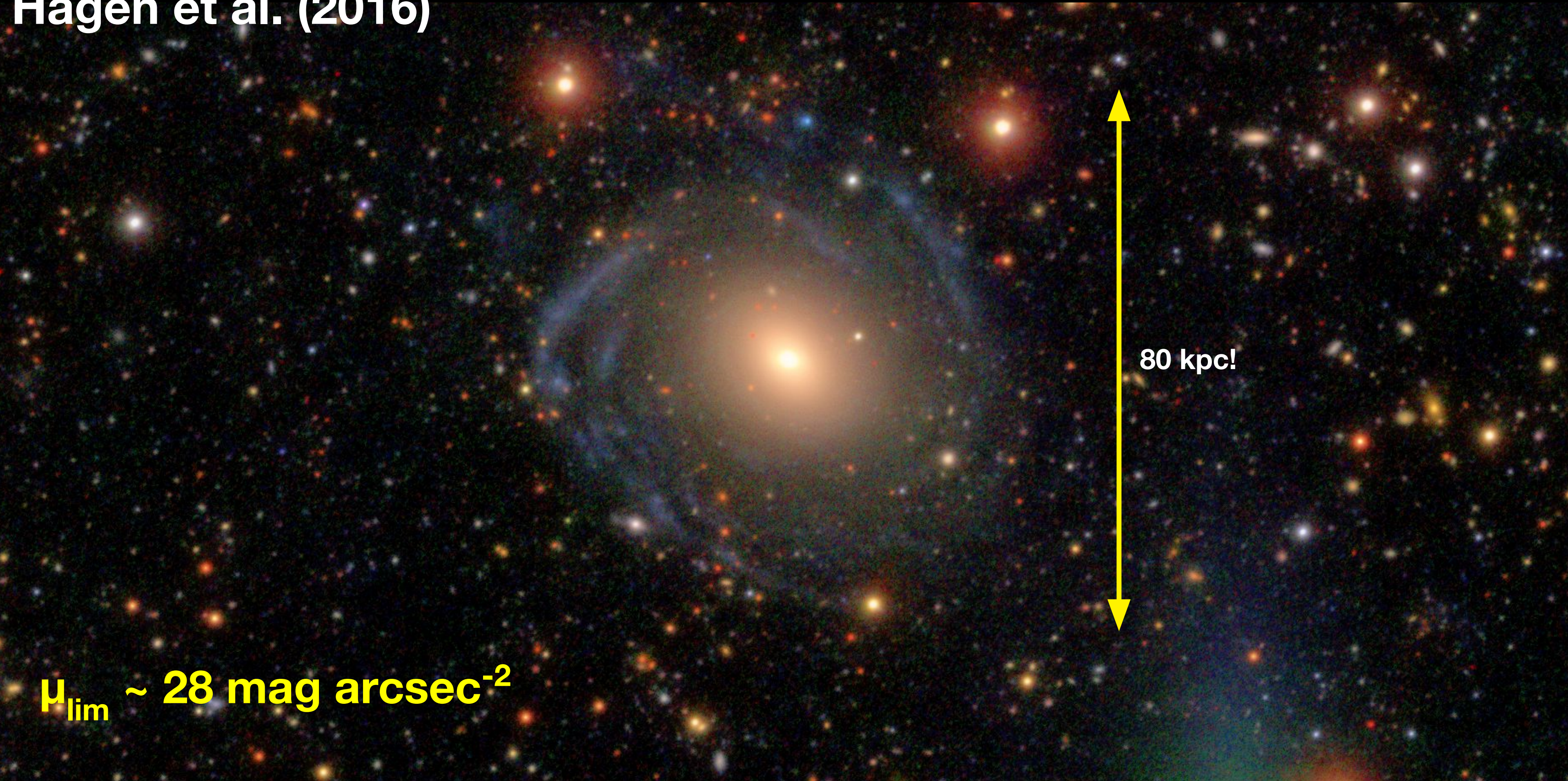



UGC1382: DSS (E)
μ_{lim} ~ 24 mag arcsec^{-2}

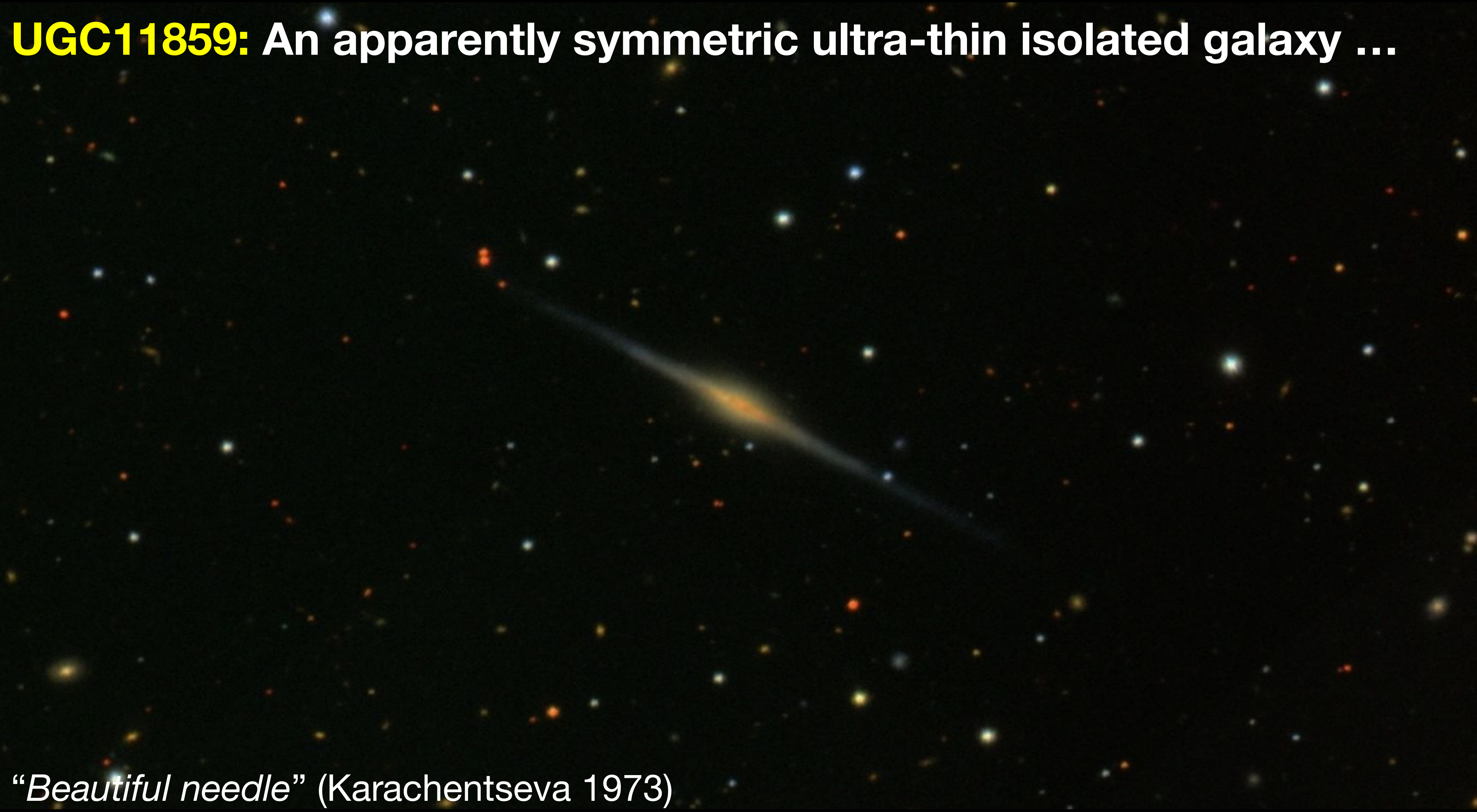

UGC1382: SDSS (E? S0?)
μlim ~ 26.5 mag arcsec-2

UGC1382: A Giant Low Surface Brightness Spiral Galaxy

Hagen et al. (2016)

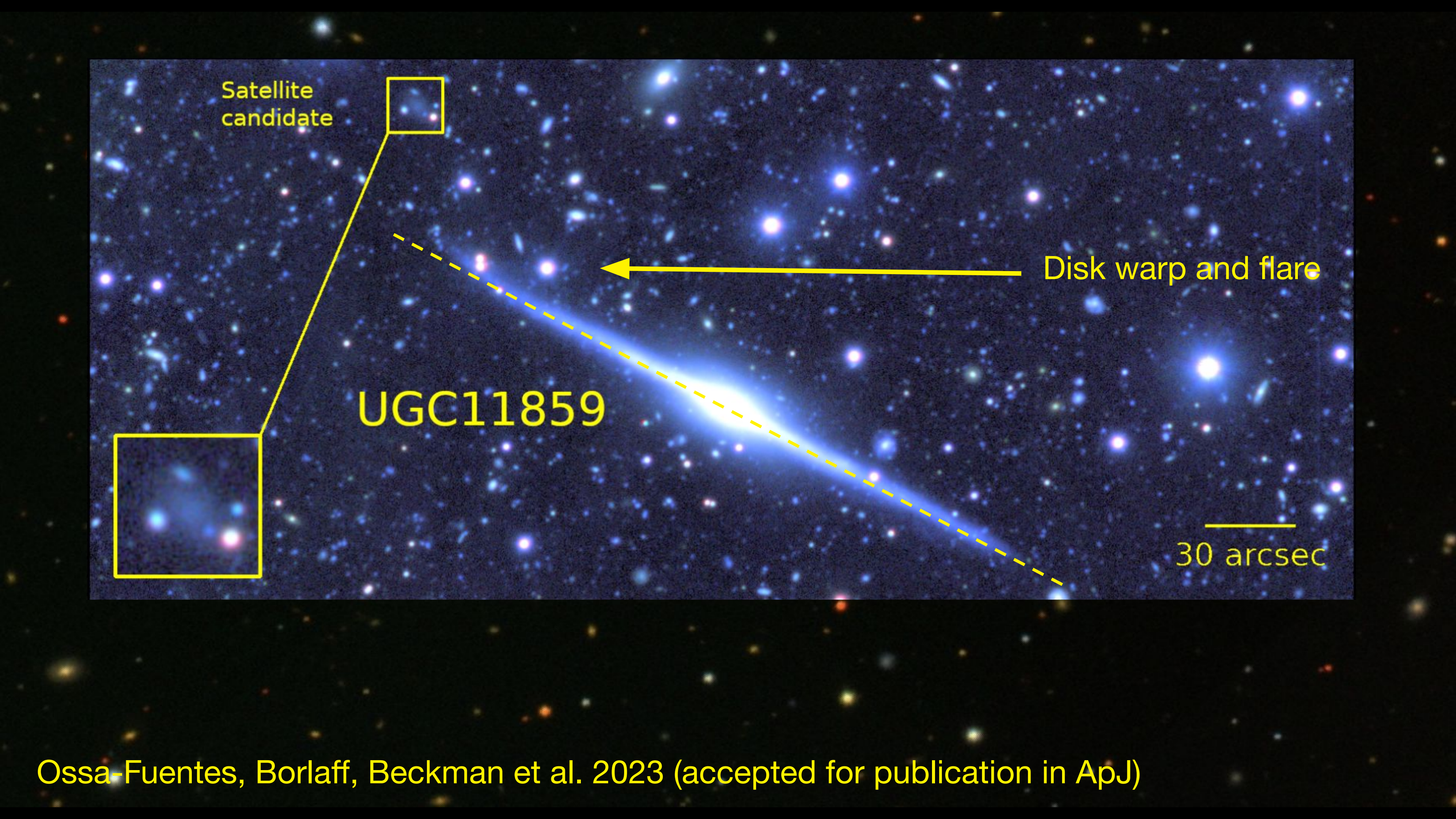


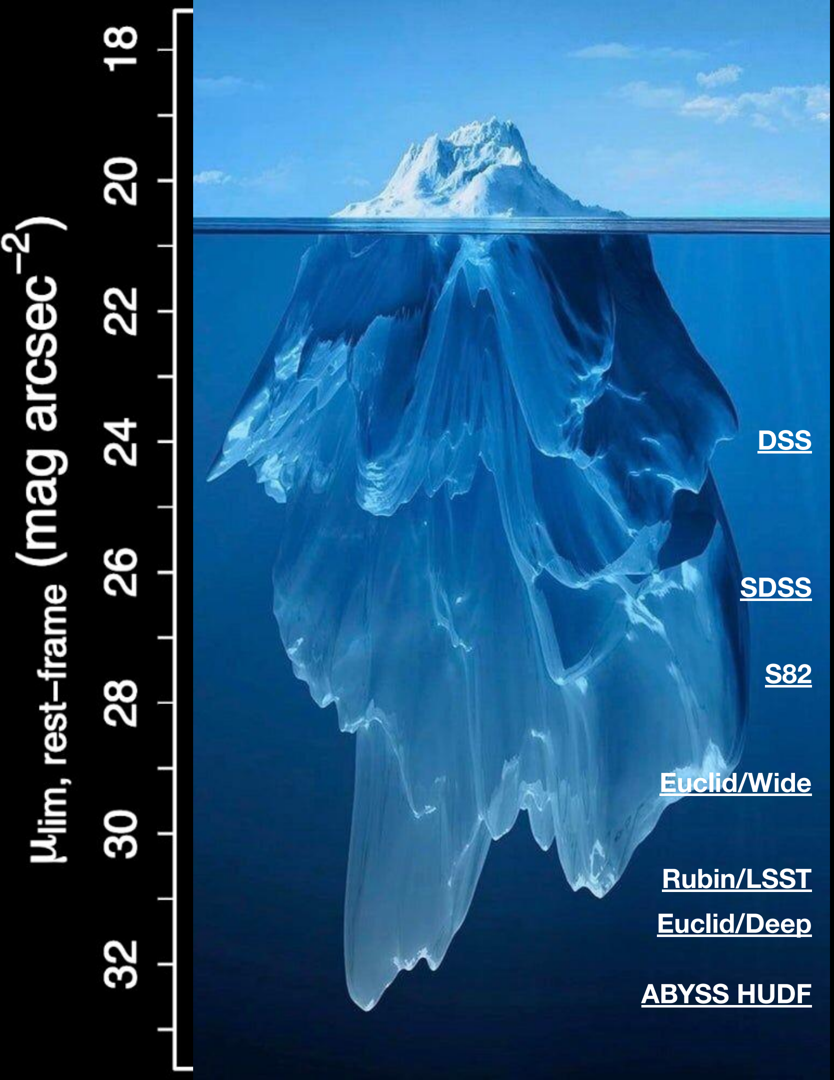
UGC11859: An apparently symmetric ultra-thin isolated galaxy …



“*Beautiful needle*” (Karachentseva 1973)

Ossa-Fuentes, Borlaff, Beckman et al. 2023 (accepted for publication in ApJ)


Satellite
candidate
Disk warp and flare
UGC11859
30 arcsec
Ossa-Fuentes, Borlaff, Beckman et al. 2023 (accepted for publication in ApJ)



Bright galactic cores

Central regions of Milky Way like galaxies

Spiral disks

Galactic disk truncations

Giant low surface brightness galaxies

Ultra-diffuse galaxies

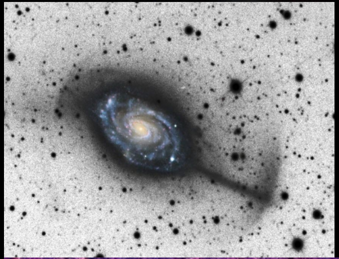
Stellar streams, tidal tails

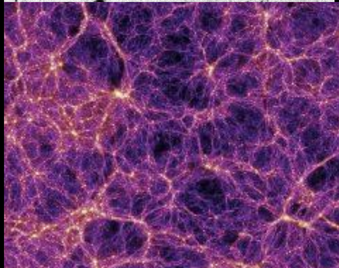
Intra-cluster light

Inner stellar halos

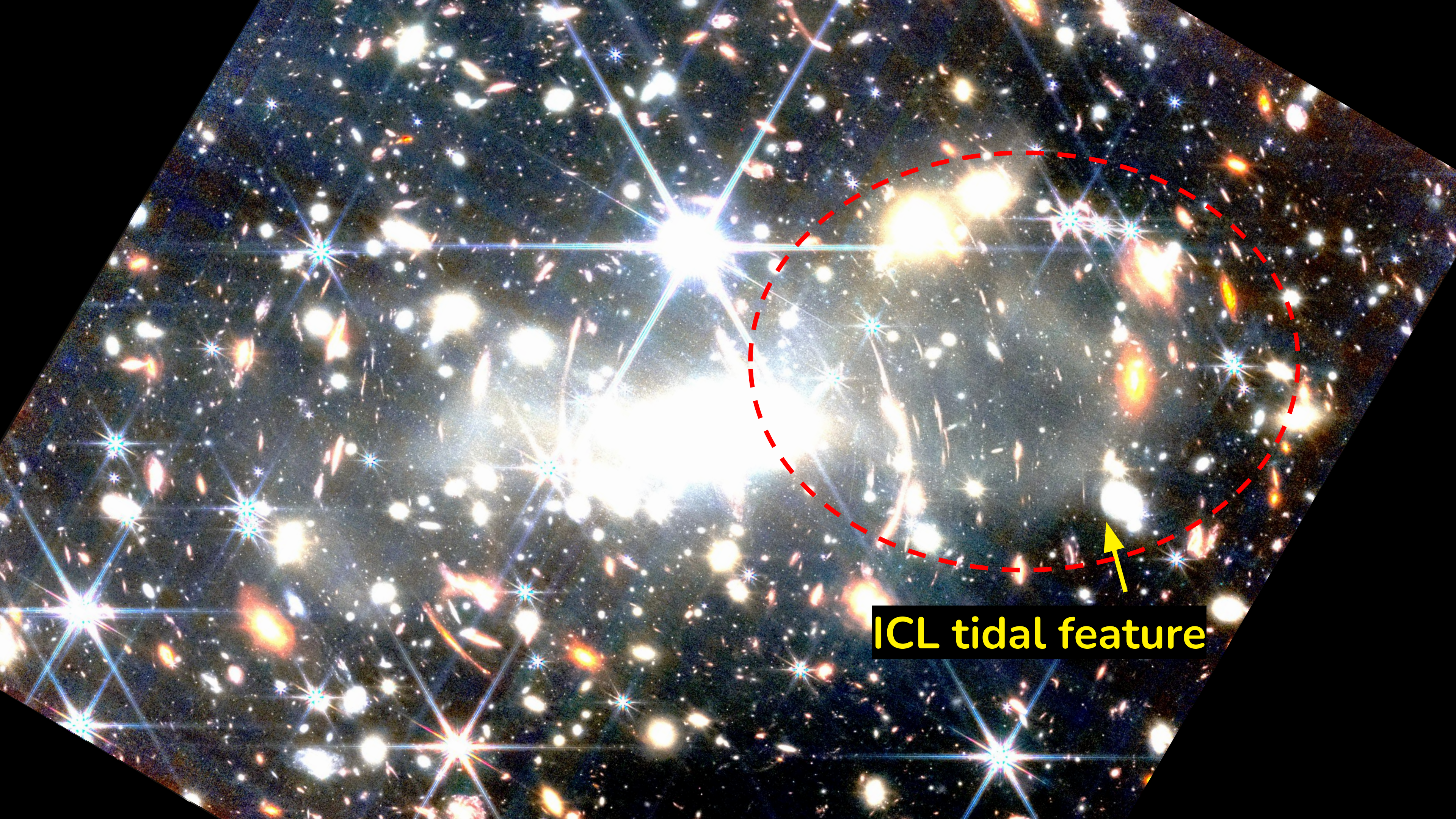
Outer stellar halos

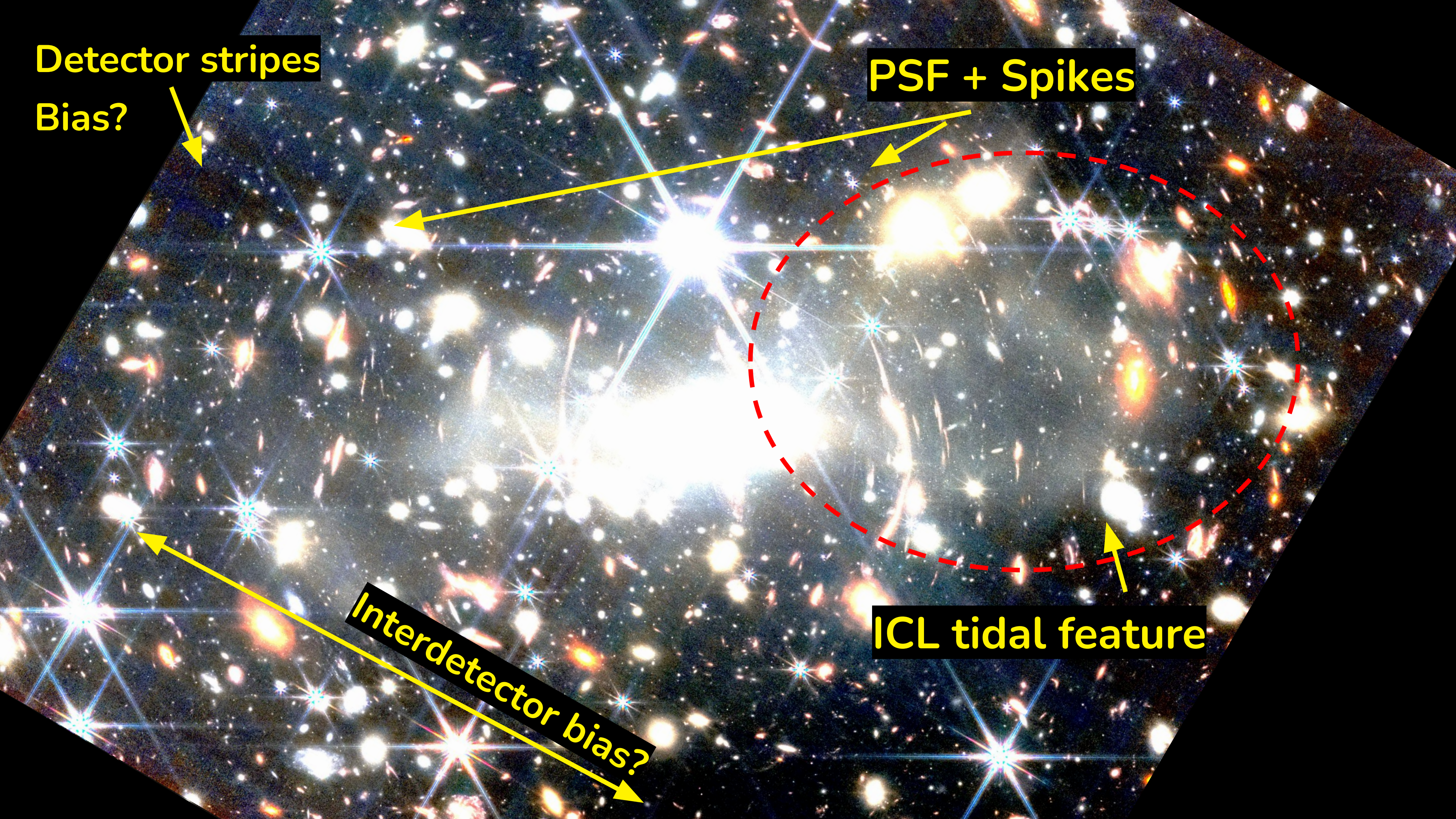
Cosmic web / New structures (?)






SMACS J0723.3-7327
JWST/NIRCam


ICL tidal feature


Detector stripes
Bias?
PSF + Spikes
ICL tidal feature
Interdetector bias?

Correction of low surface brightness gradients in JWST

Montes & Trujillo (2022)

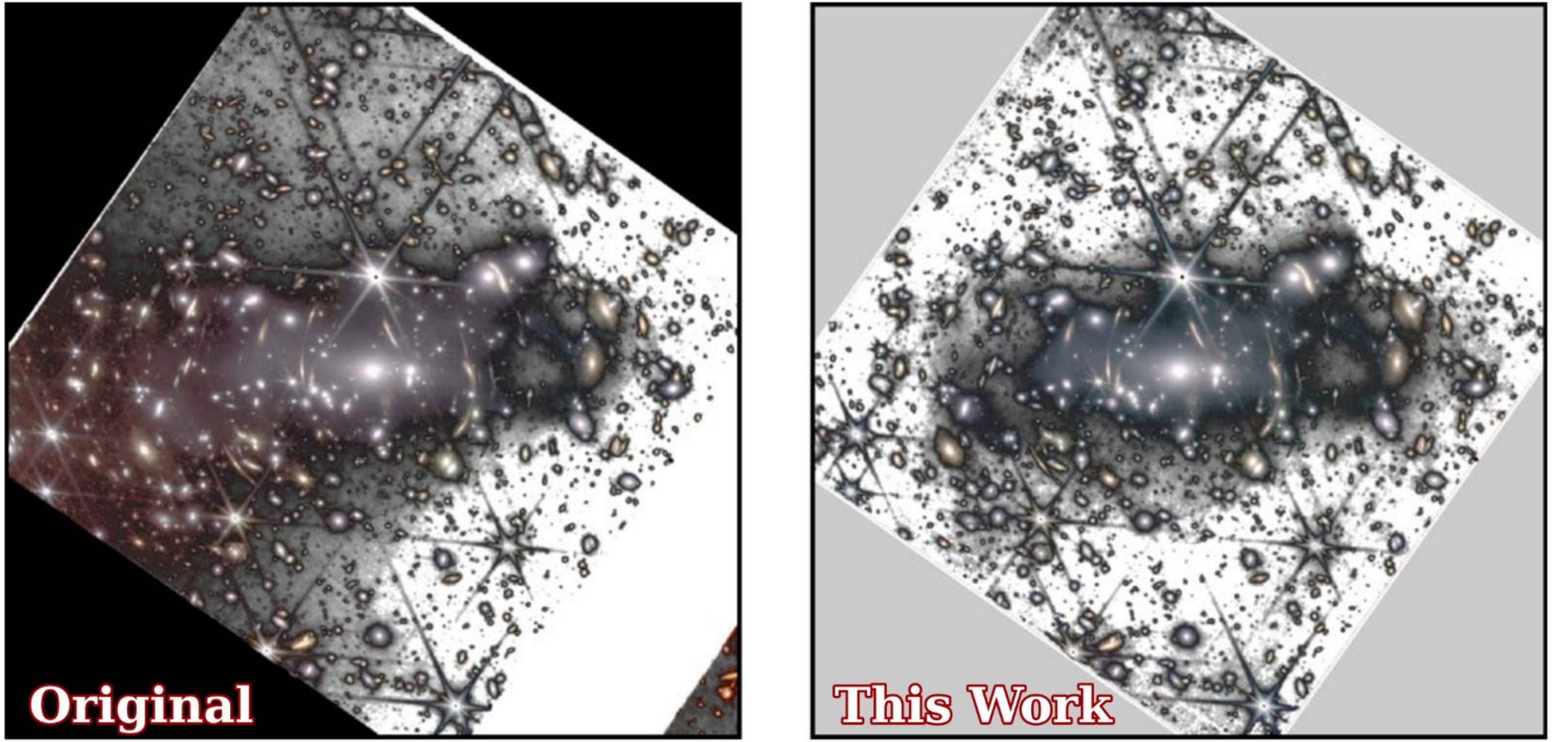


Figure 6. Left panel: RGB color-composite image using the original calibrated coadds of the long-wavelength channels. Right panel: RGB color-composite image using the rereduced coadd images created in this work. Note the huge improvement of correcting the strong light gradient toward the east side on the NIRCam.

Correction of low surface brightnes

Montes & Trujillo (2022)

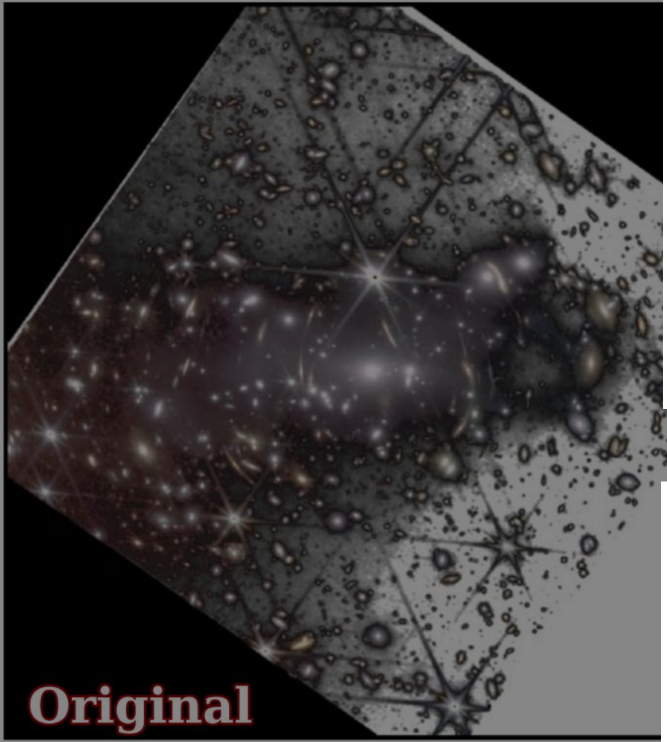


Figure 6. Left panel: RGB color-composite image using the original ca
using the rereduced coadd images created in this work. Note the huge i

In theory:

μ_{lim} ~ 31.2 mag arcsec^{-2}

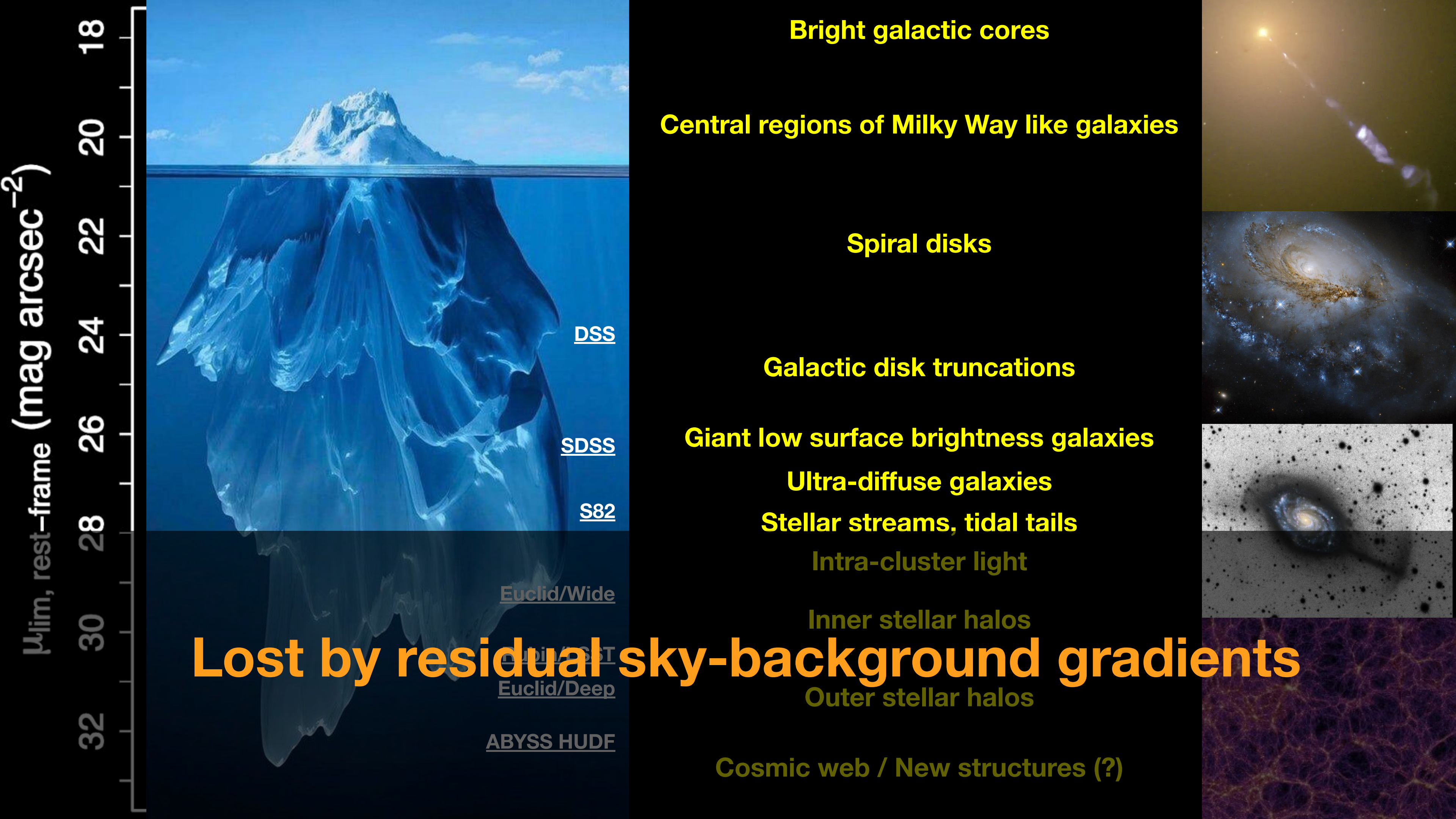
Table 1
Summary of the NIRCam Observations Used in This Work

Filter	Channel	Exp. Time (s)	Surface Brightness Limits[a] (mag arcsec^2)
F277W	Long	7537.2	31.28
F356W	Long	7537.2	31.32
F444W	Long	7537.2	31.10

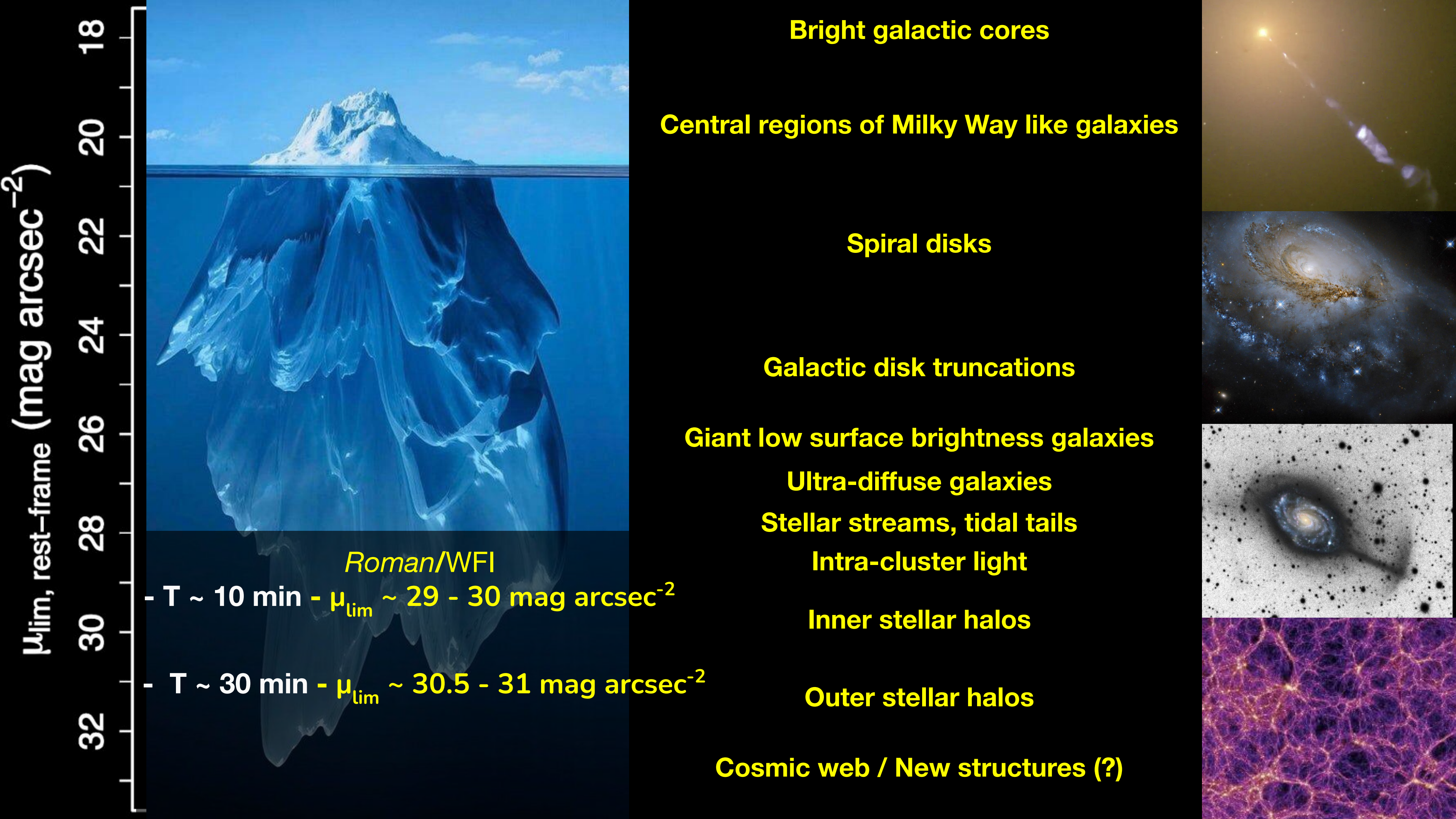
Note.
[a] The surface brightness limits correspond to a sky fluctuation of 3σ in an area of 10×10 arcsec^2.

But in practice, residual gradients dominate

While the above limiting surface brightnesses are representative of the local depth, the current global background of the data is still affected by mild gradients left during the rereduction process. Therefore, we conservatively decided not to explore the surface brightness profiles of the ICL beyond $\mu_{F444W} \sim 28$ mag arcsec^{-2}. In Figure 2, the surface brightness profiles are shown down to $\mu_{F444W} \sim 28$ mag arcsec^{-2} (~350 kpc).

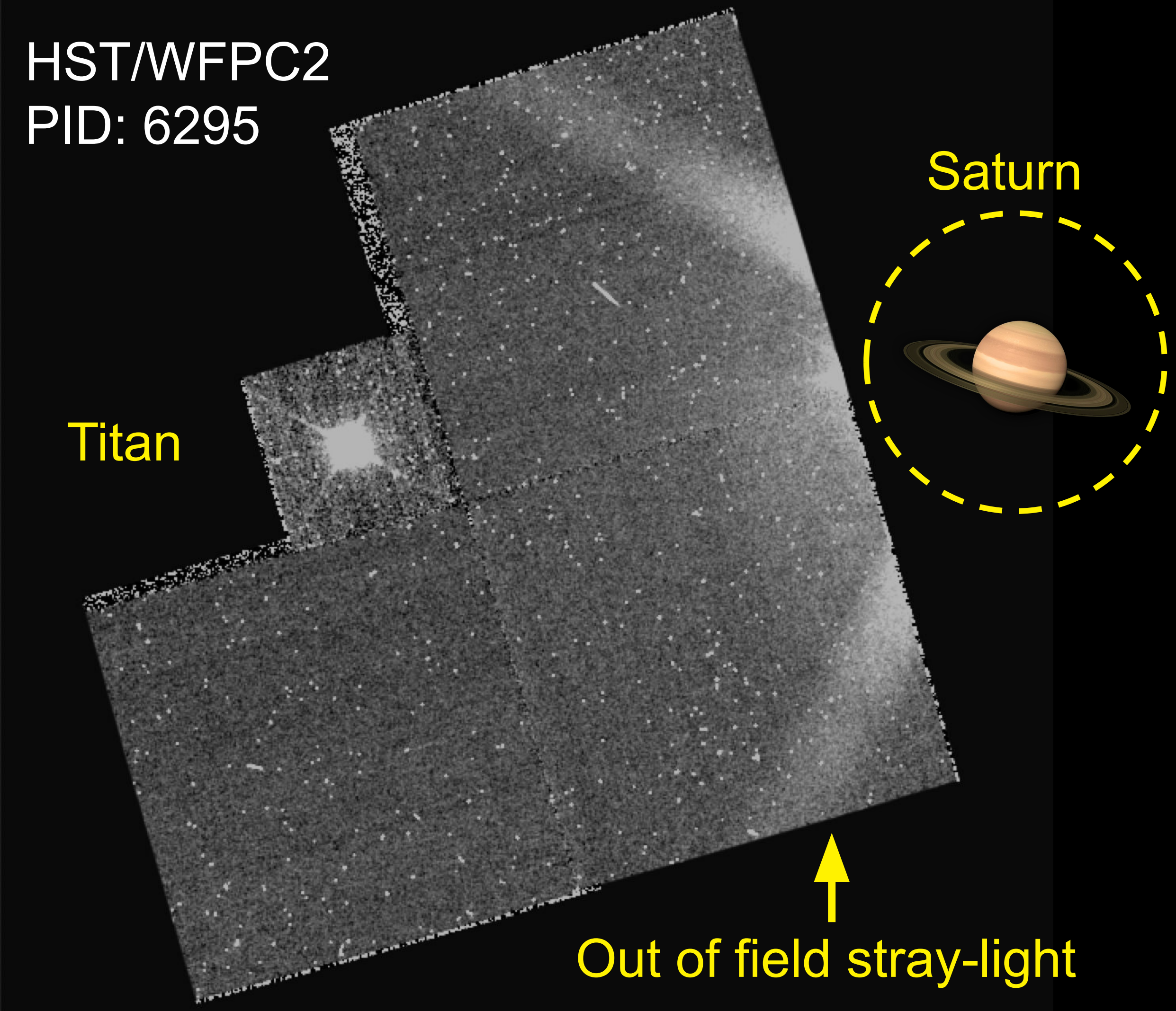


$\mu_{lim,\ rest-frame}$ (mag arcsec^{-2})
18
20
22
24
26
28
30
32
DSS
SDSS
S82
Euclid/Wide
Euclid/Deep
ABYSS HUDF
Bright galactic cores
Central regions of Milky Way like galaxies
Spiral disks
Galactic disk truncations
Giant low surface brightness galaxies
Ultra-diffuse galaxies
Stellar streams, tidal tails
Intra-cluster light
Inner stellar halos
Outer stellar halos
Cosmic web / New structures (?)
Lost by residual sky-background gradients



μlim, rest-frame (mag arcsec⁻²)
18
20
22
24
26
28
30
32
Roman/WFI
- T ~ 10 min - μlim ~ 29 - 30 mag arcsec-2
- T ~ 30 min - μlim ~ 30.5 - 31 mag arcsec-2
Bright galactic cores
Central regions of Milky Way like galaxies
Spiral disks
Galactic disk truncations
Giant low surface brightness galaxies
Ultra-diffuse galaxies
Stellar streams, tidal tails
Intra-cluster light
Inner stellar halos
Outer stellar halos
Cosmic web / New structures (?)


Unwanted
systematic
light!



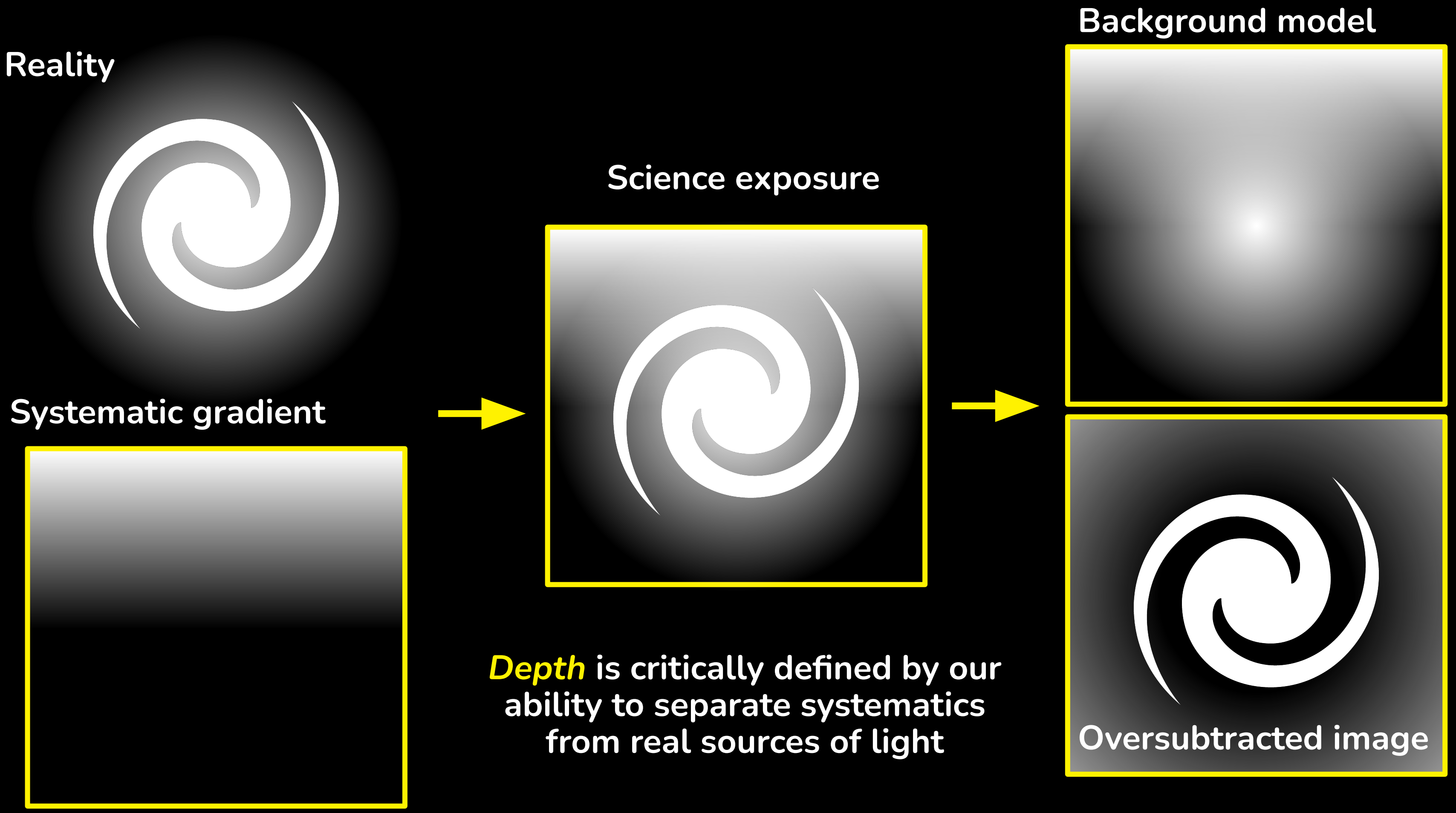
The PSF allows to measure the light received by a pixel from a source inside the FOV

The NDI (normalized detector irradiance) tell us how much light a pixel receives from a source outside the FOV

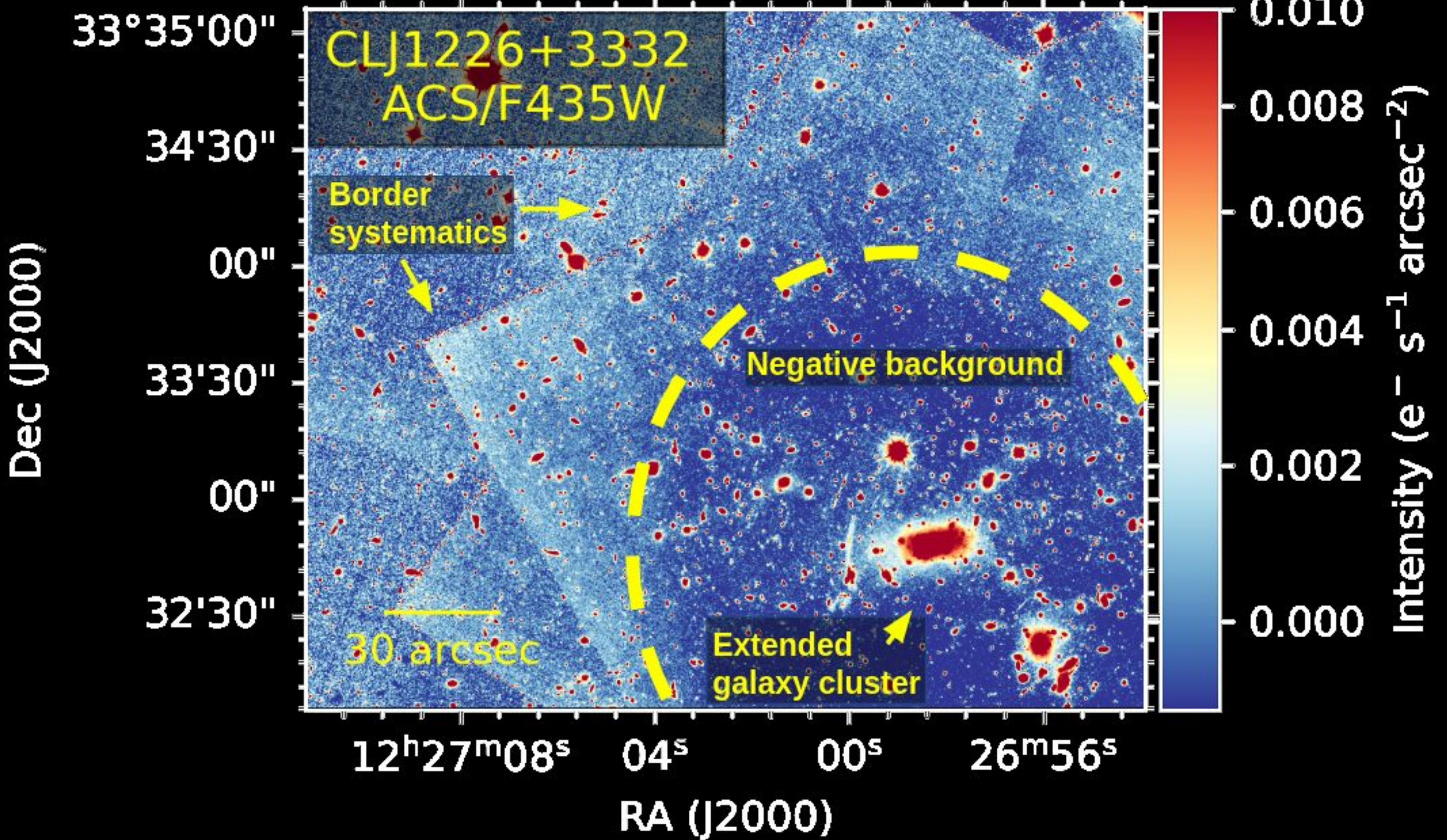
We can model and correct stray-light gradients.

Principle #1: You can’t subtract the background if the source gets comparable to the FOV *

*Not really - but it is very hard



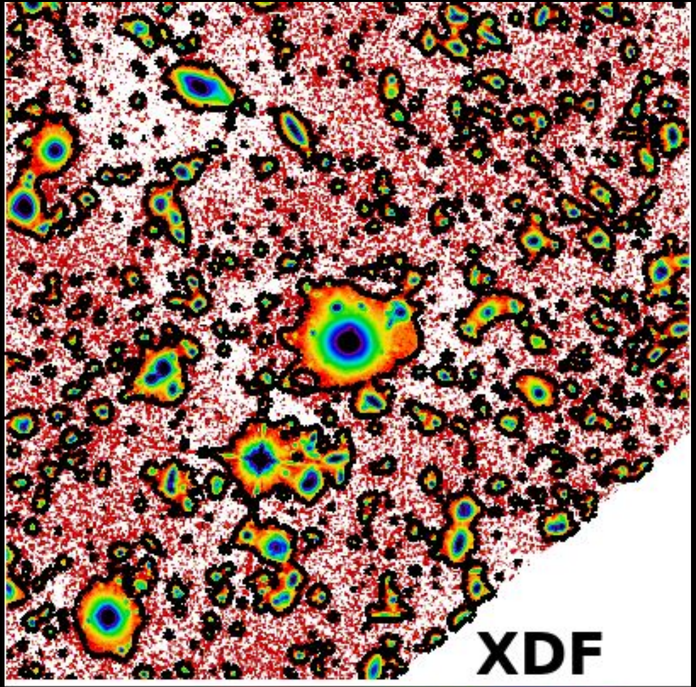
Depth is critically defined by our ability to separate systematics from real sources of light

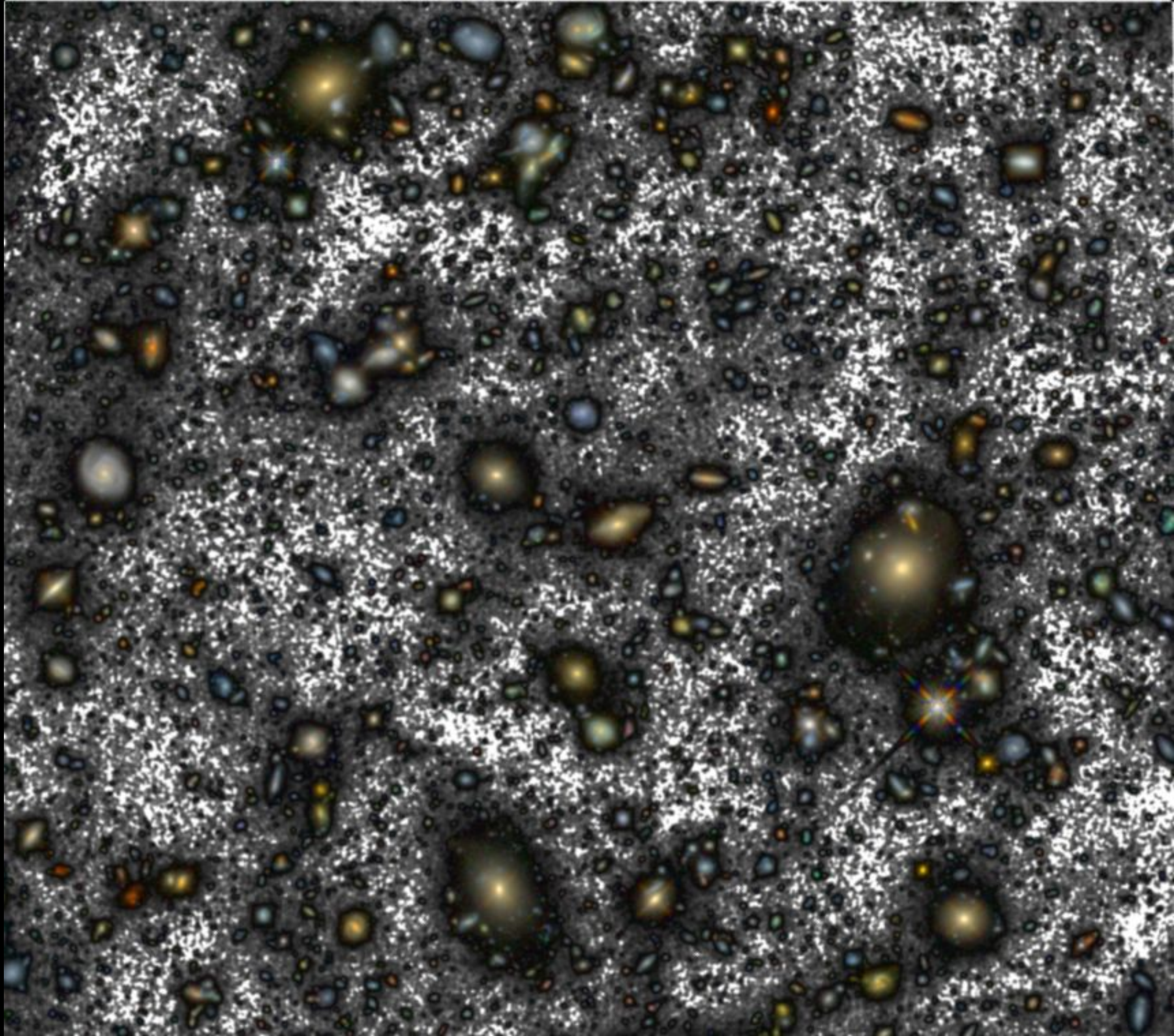

CLJ1226+3332
ACS/F435W
Border systematics
Negative background
Extended galaxy cluster
30 arcsec
33°35'00"
34'30"
00"
33'30"
00"
32'30"
Dec (J2000)
12h27m08s
04s
00s
26m56s
RA (J2000)
0.010
0.008
0.006
0.004
0.002
0.000
Intensity (e− s−1 arcsec−2)

The missing light of the Hubble Ultra Deep Field

ABYSS HUDF (Borlaff et al. 2019)

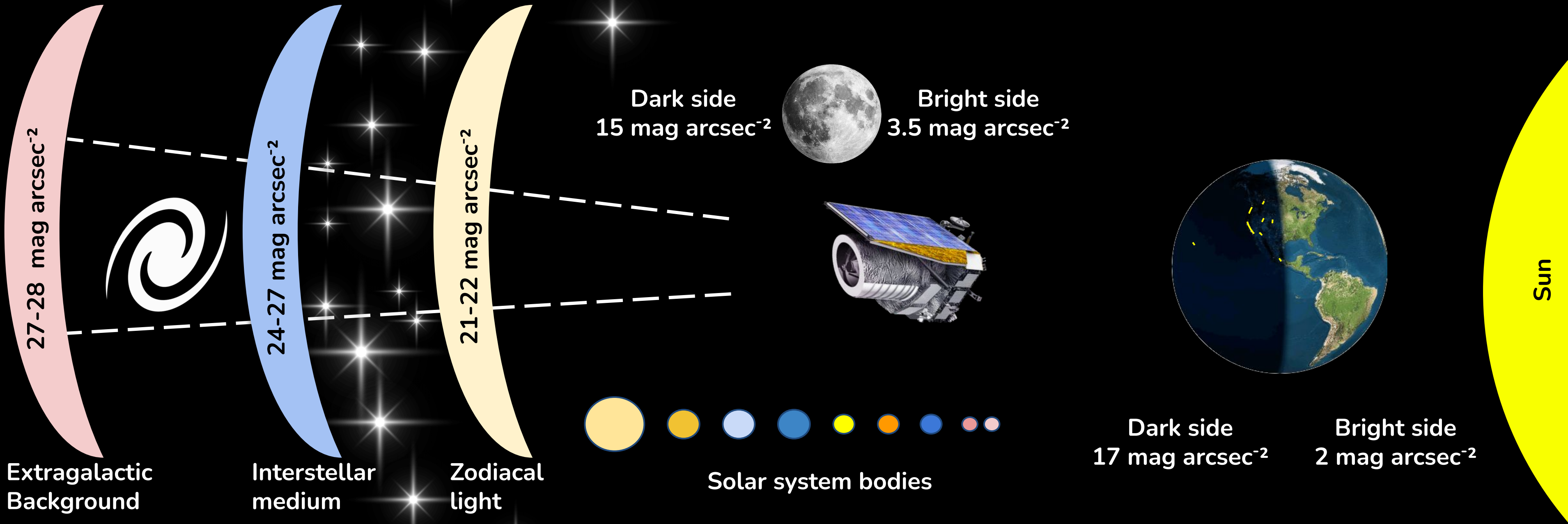
Improving old Hubble mosaics by using better sky-calibration





Deep imaging is a problem of dissecting layers of light

Galaxies, cirrus, zodiacal light, stray-light...

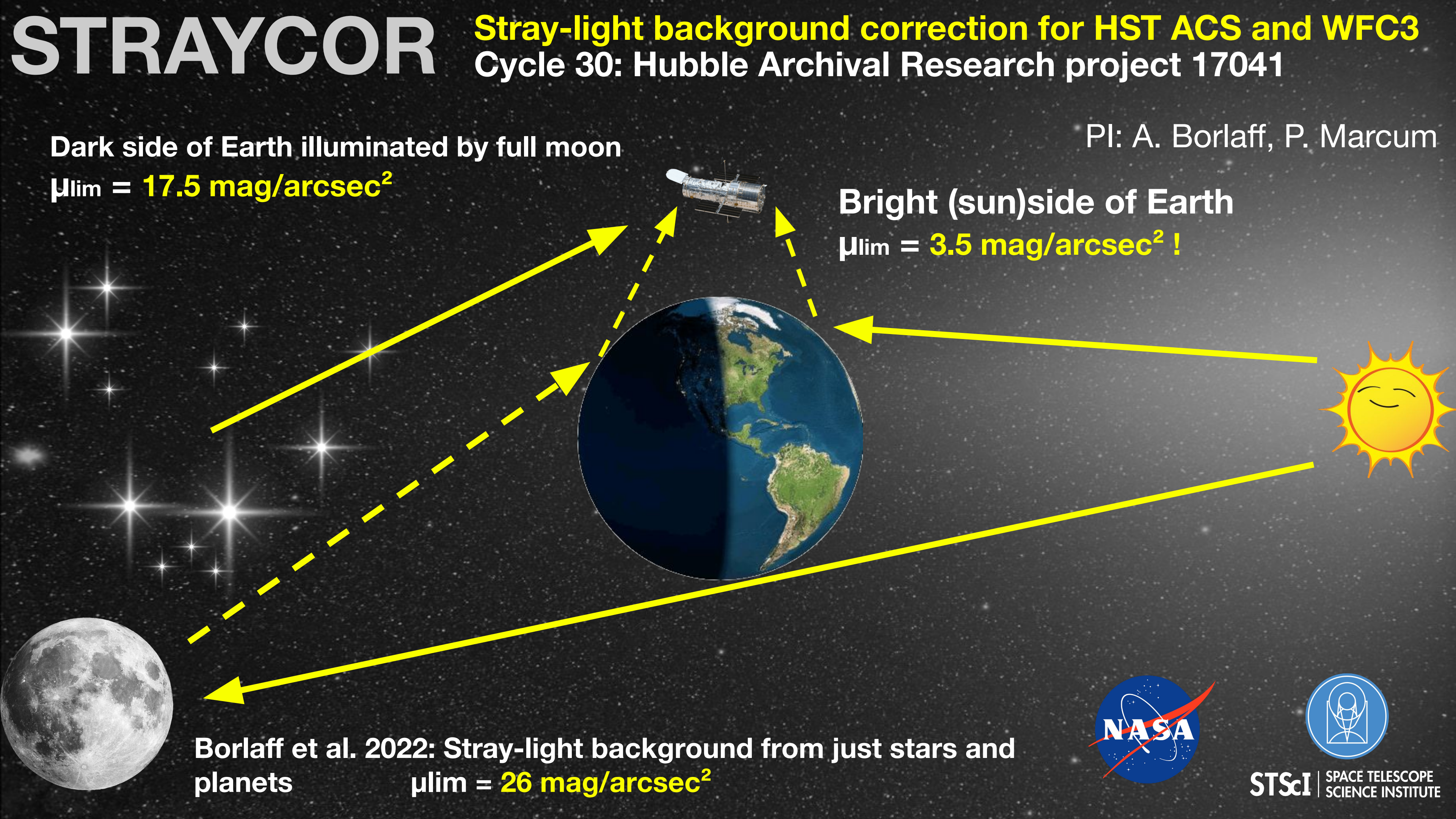


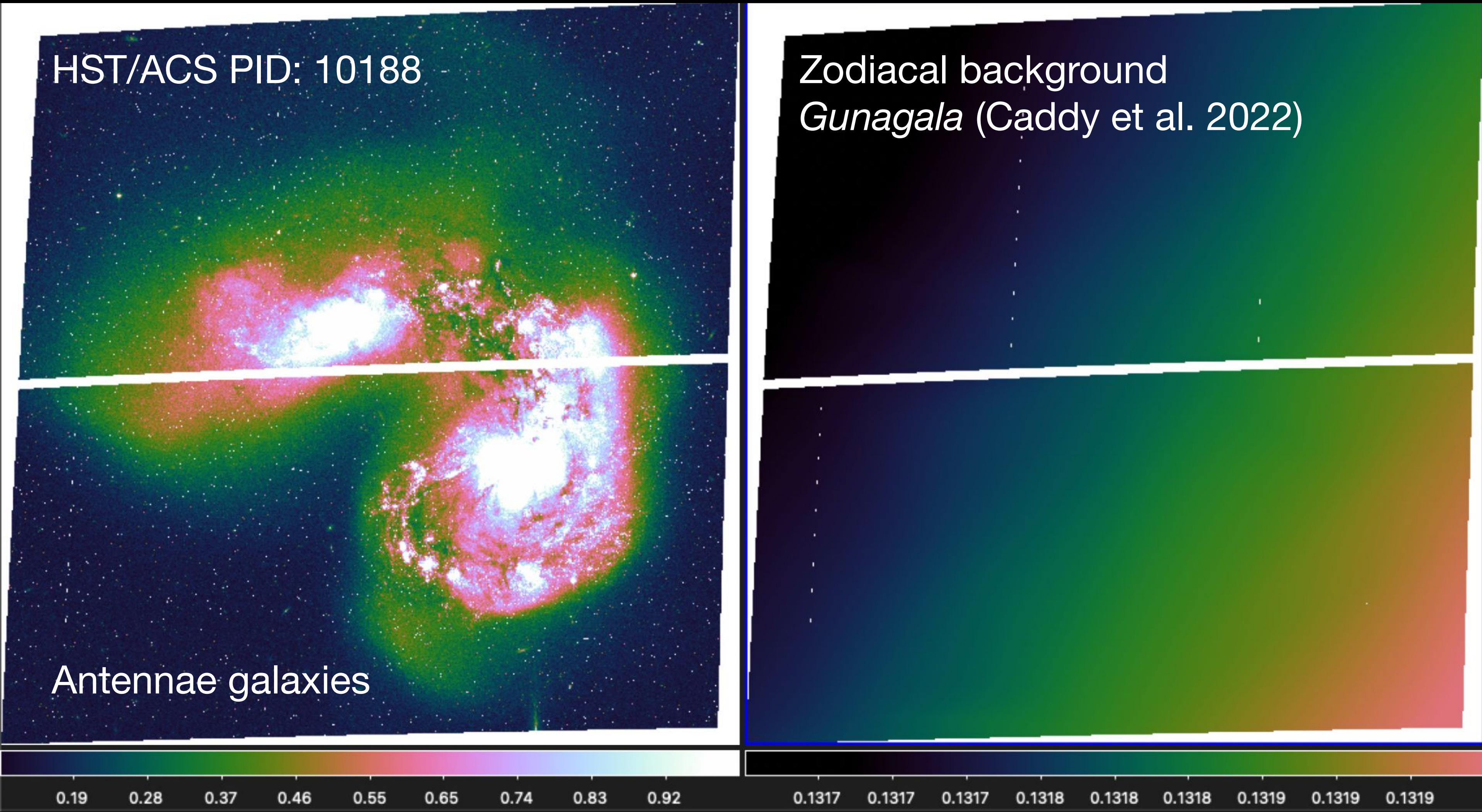
In-field sources

Masking, sky-background correction, PSF correction, dust cirrus vs. extra-galactic features identification

Out-of-field (stray-light)

Mission planning + Normalized Detector Irradiance (NDI) stray-light correction


STRAYCOR
Stray-light background correction for HST ACS and WFC3
Cycle 30: Hubble Archival Research project 17041
PI: A. Borlaff, P. Marcum
Dark side of Earth illuminated by full moon
μ_{lim} = 17.5 mag/arcsec^2
Bright (sun)side of Earth
μ_{lim} = 3.5 mag/arcsec^2 !
Borlaff et al. 2022: Stray-light background from just stars and planets μ_{lim} = 26 mag/arcsec^2
NASA
STScI SPACE TELESCOPE SCIENCE INSTITUTE

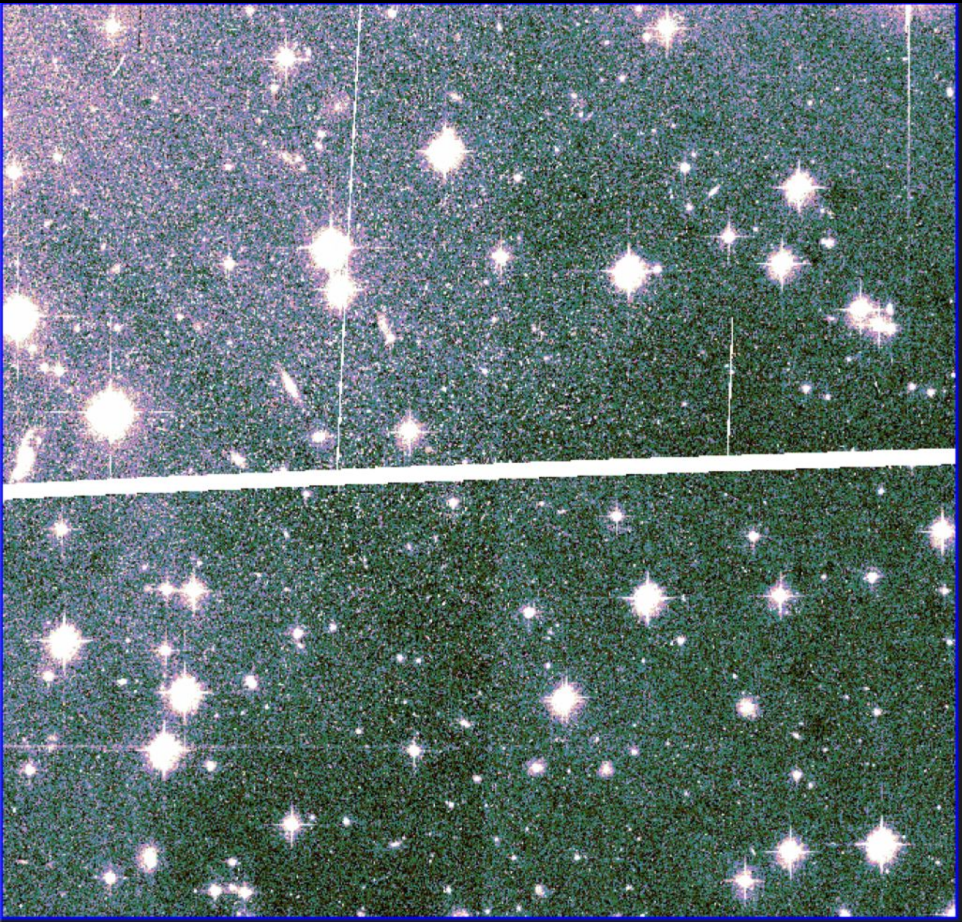


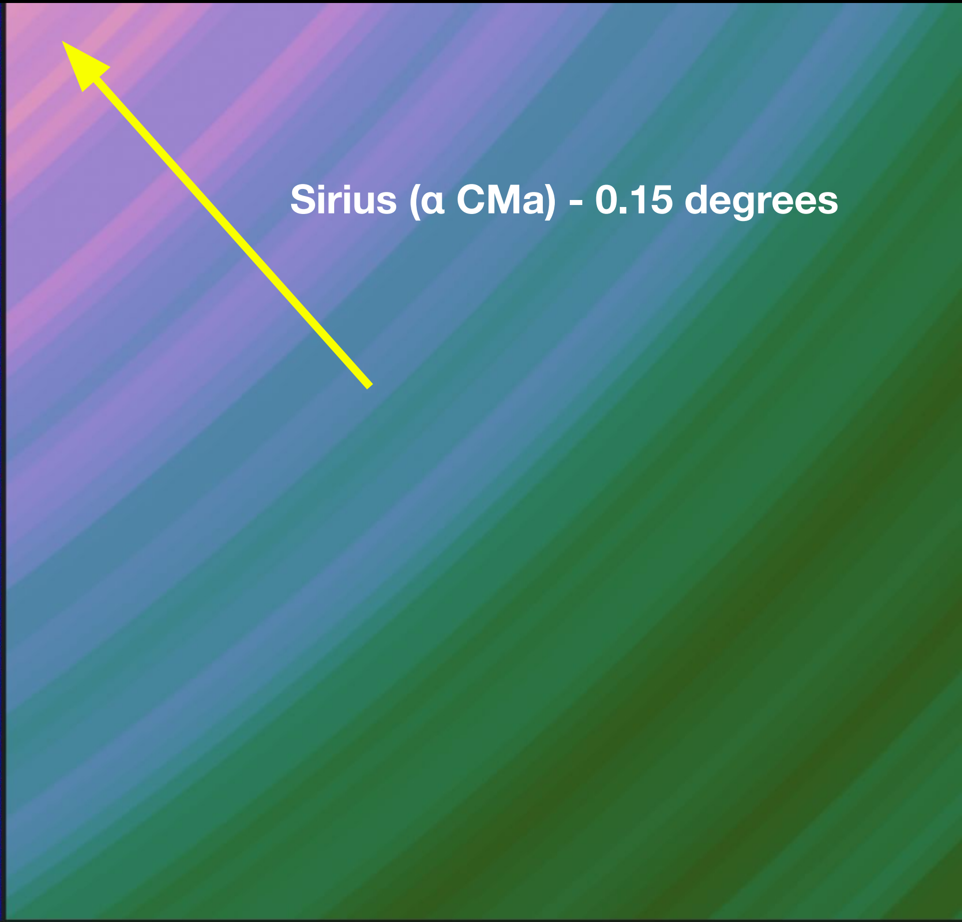
HST/ACS PID: 10188
Antennae galaxies
0.19
0.28
0.37
0.46
0.55
0.65
0.74
0.83
0.92
Zodiacal background
Gunagala (Caddy et al. 2022)
0.1317
0.1317
0.1317
0.1318
0.1318
0.1318
0.1319
0.1319
0.1319

In-orbit calibration of HST/ACS stray-light blocking

HST/ACS PID: 9984

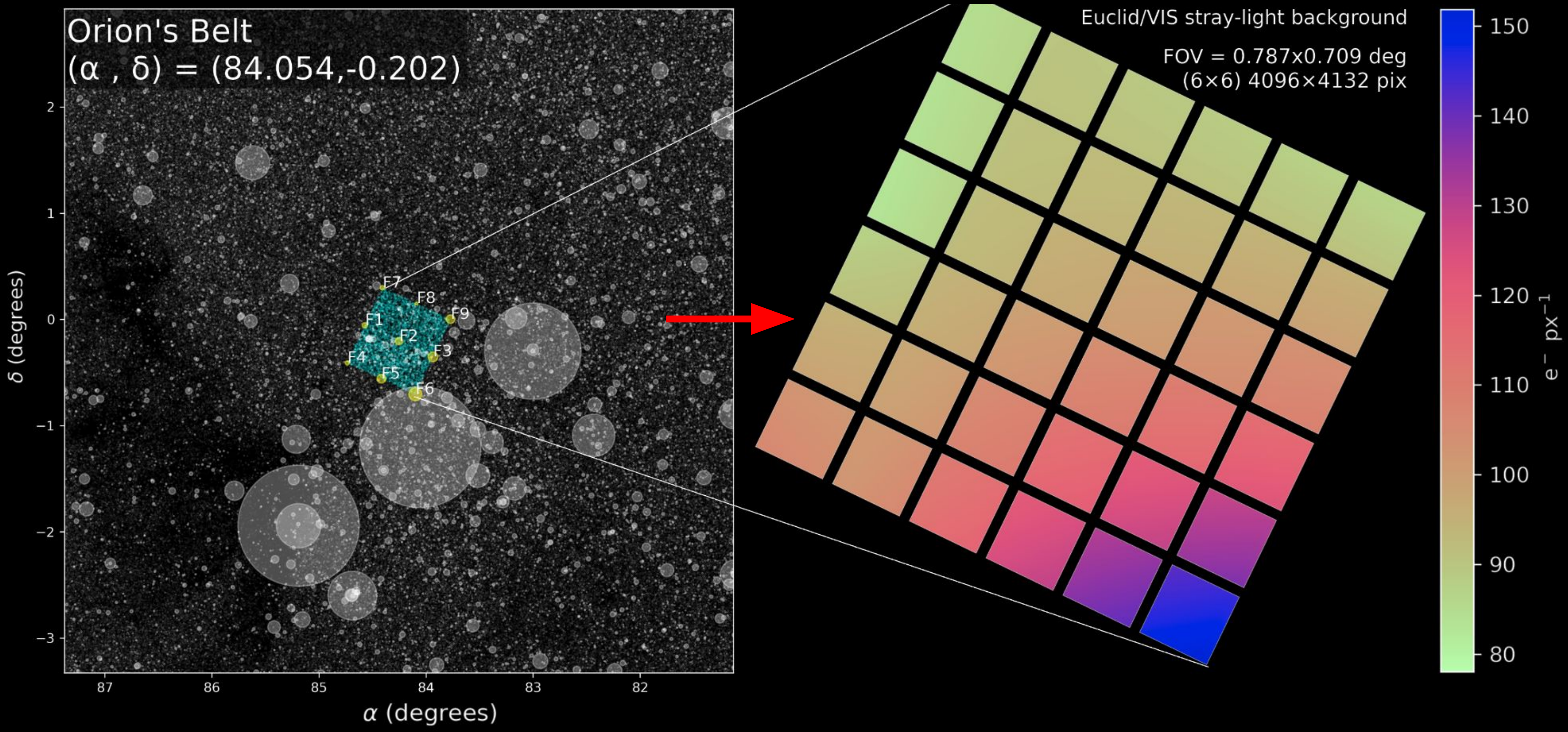
Borlaff et al. *in prep.*

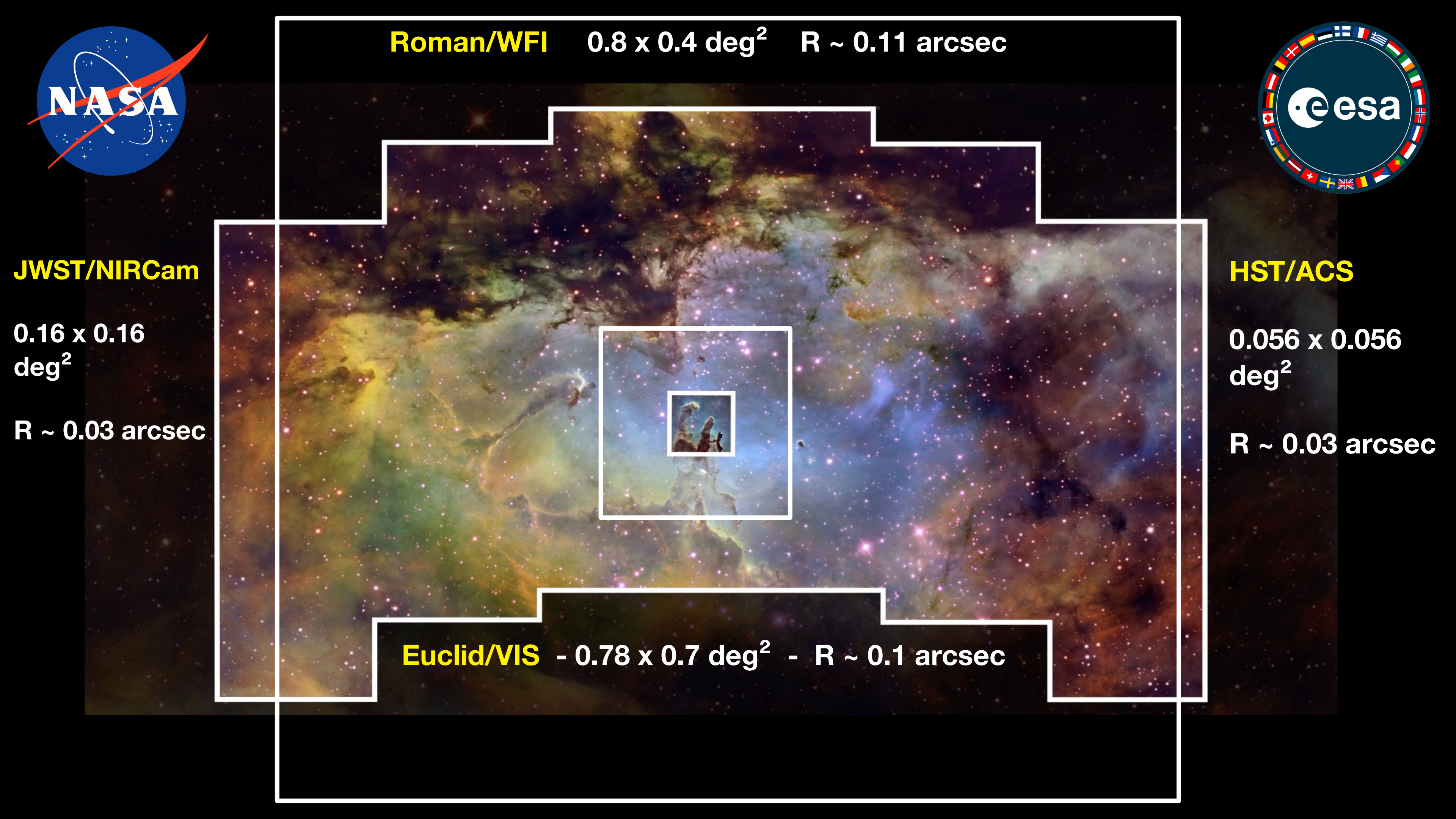


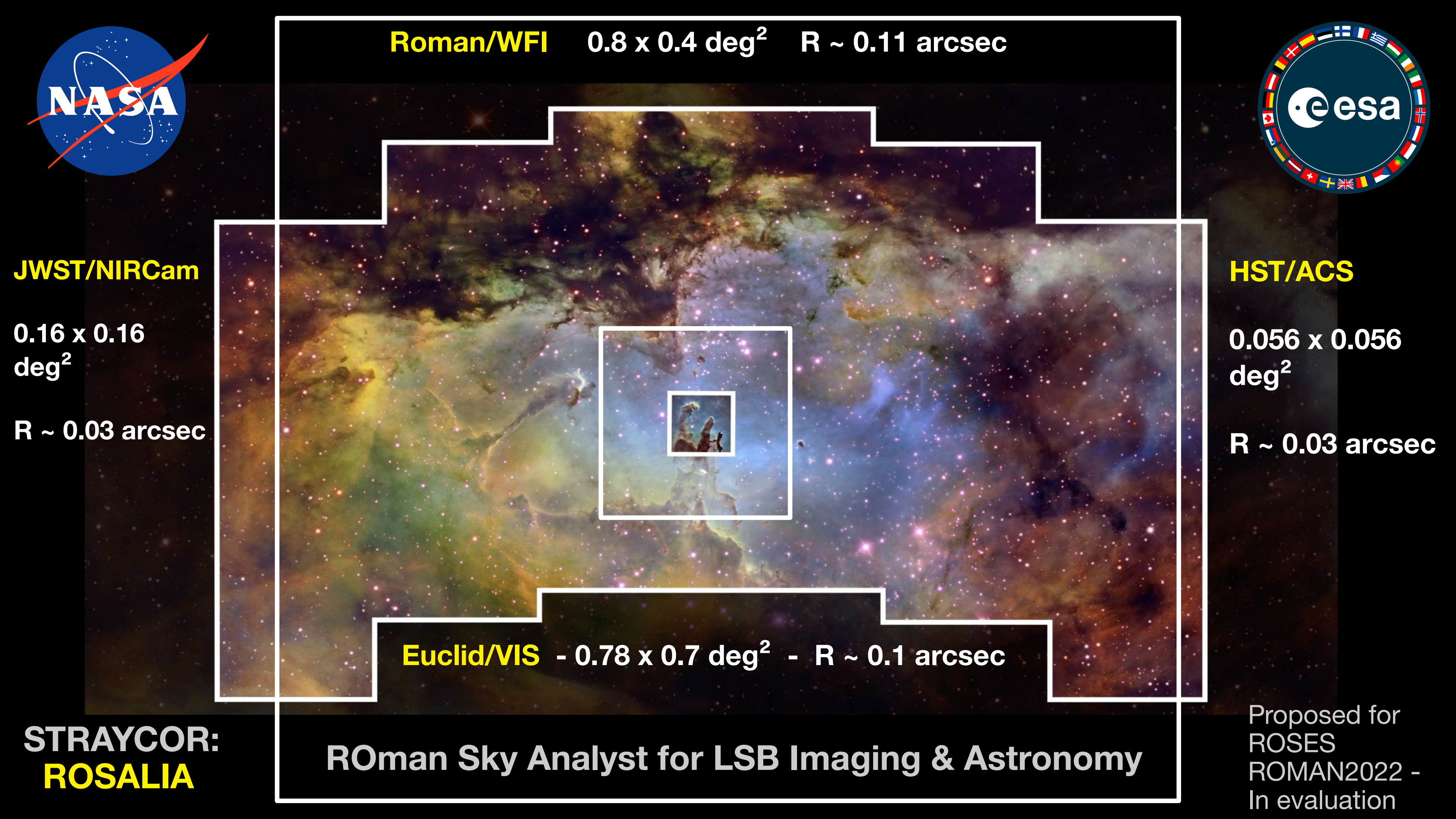


Predicting stray-light using ESA/Gaia & NDI/PSF

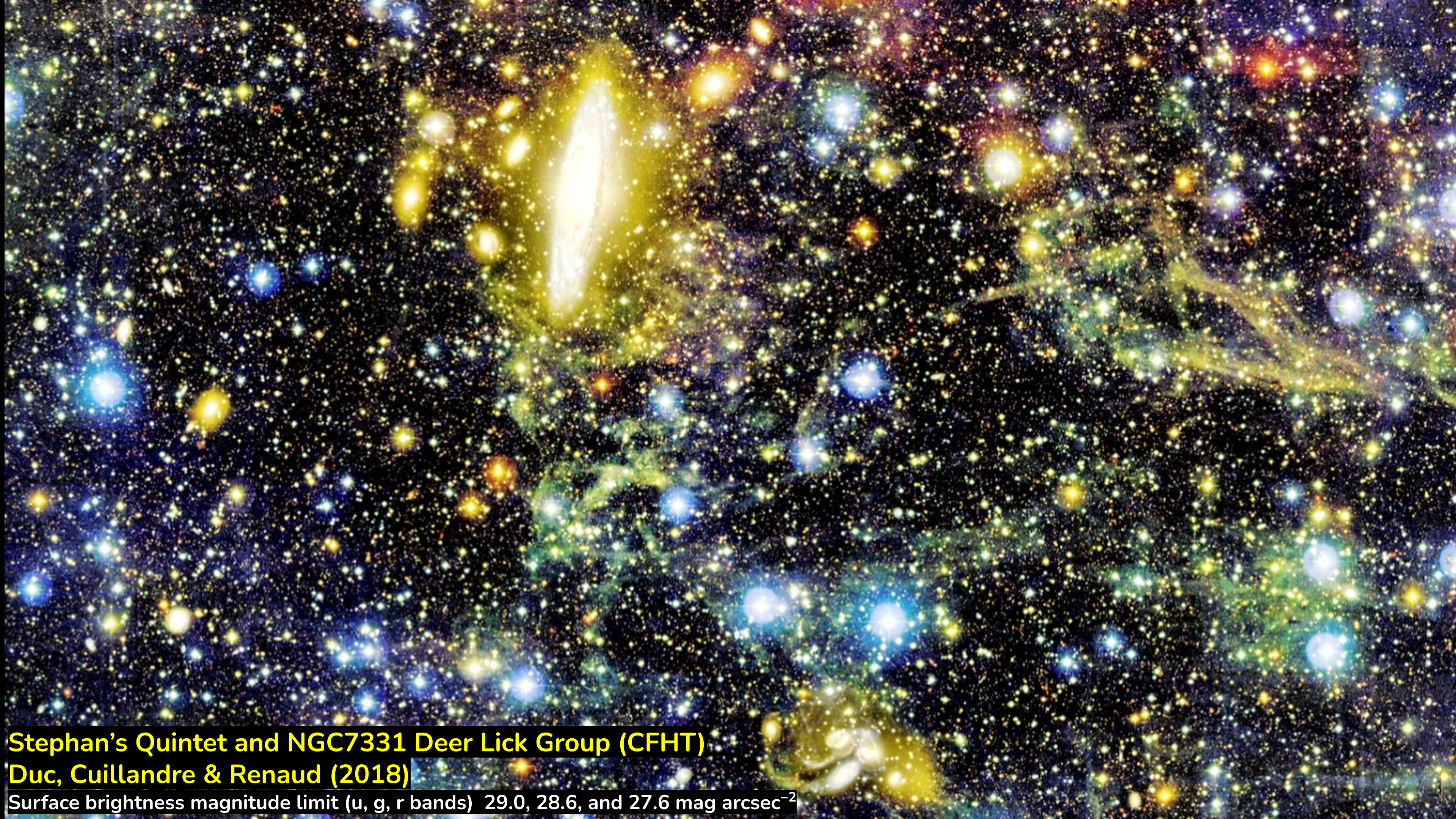
Borlaff et al. 2022 - A&A




NASA
esa
Roman/WFI 0.8 x 0.4 deg^2 R ~ 0.11 arcsec
JWST/NIRCam
0.16 x 0.16 deg^2
R ~ 0.03 arcsec
HST/ACS
0.056 x 0.056 deg^2
R ~ 0.03 arcsec
Euclid/VIS - 0.78 x 0.7 deg^2 - R ~ 0.1 arcsec


Roman/WFI 0.8 x 0.4 deg^2 R ~ 0.11 arcsec
JWST/NIRCam
0.16 x 0.16 deg^2
R ~ 0.03 arcsec
HST/ACS
0.056 x 0.056 deg^2
R ~ 0.03 arcsec
Euclid/VIS - 0.78 x 0.7 deg^2 - R ~ 0.1 arcsec
STRAYCOR:
ROSALIA
ROman Sky Analyst for LSB Imaging & Astronomy
Proposed for ROSES ROMAN2022 - In evaluation
NASA
esa


Stephan's Quintet and NGC7331
Deer Lick Group (SDSS)
Surface brightness magnitude limit
(g-band)
26.5 mag arcsec^{-2}



Stephan's Quintet and NGC7331 Deer Lick Group (CFHT)
Duc, Cuillandre & Renaud (2018)
Surface brightness magnitude limit (u, g, r bands) 29.0, 28.6, and 27.6 mag arcsec^{-2}

Conclusions

1 - New image reductions keep improving Hubble Archive

Unexplored extended z~1 stellar halos in the ABYSS Ultra Deep field

STRAYCOR HST AR project starting now!

STRAYCOR ROSALIA/Roman: Waiting for evaluation!

2 - Deep, Wide, and sharp (*Euclid, Roman*) surveys are coming

We must get ready before being buried in data

3 - An absolute calibration of the sky-background is the next challenge of LSB studies

Understanding foregrounds is the key to bring low surface brightness Universe to light

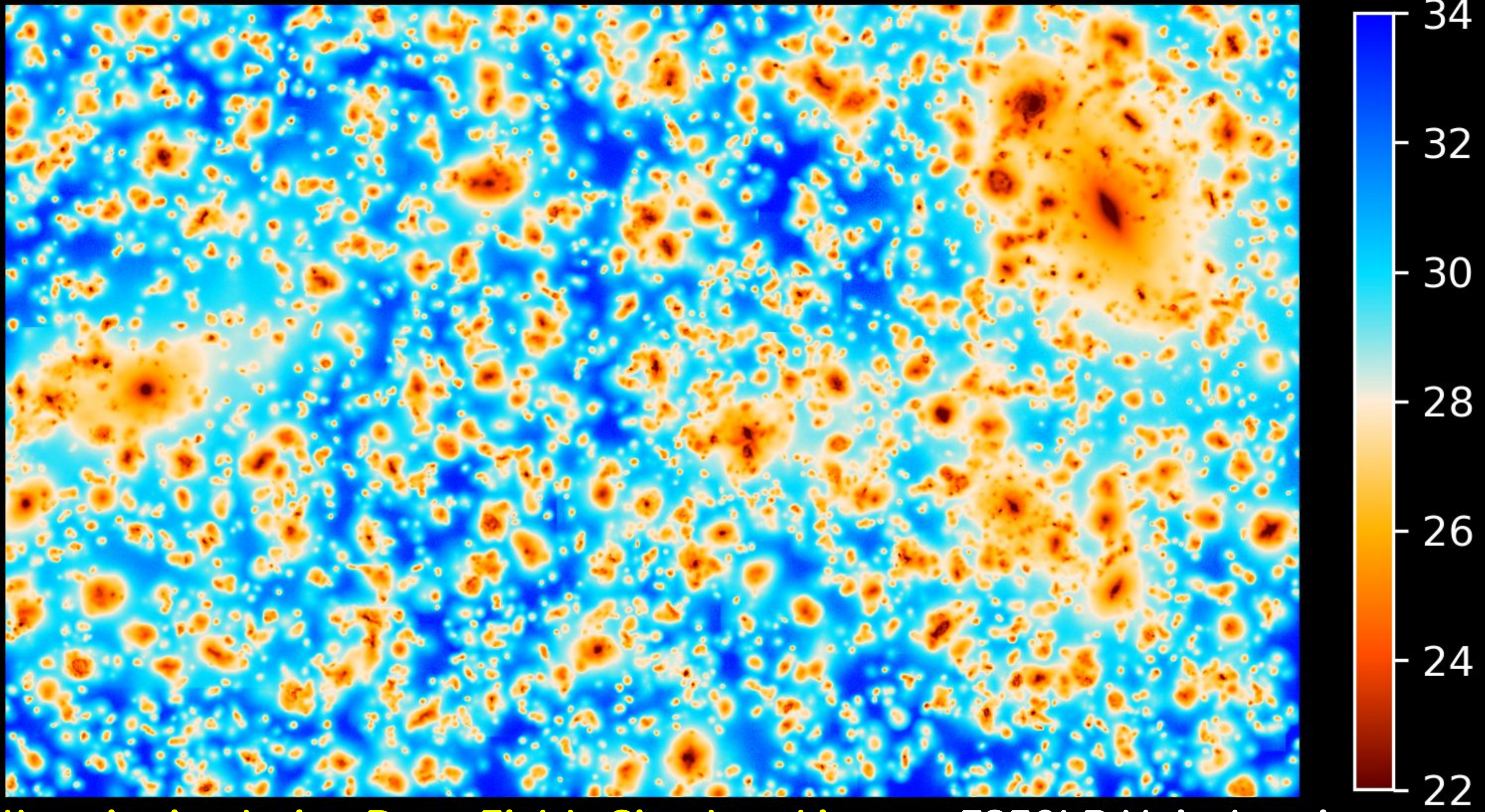
a.s.borlaff@nasa.gov

Why should we go to space for LSB?

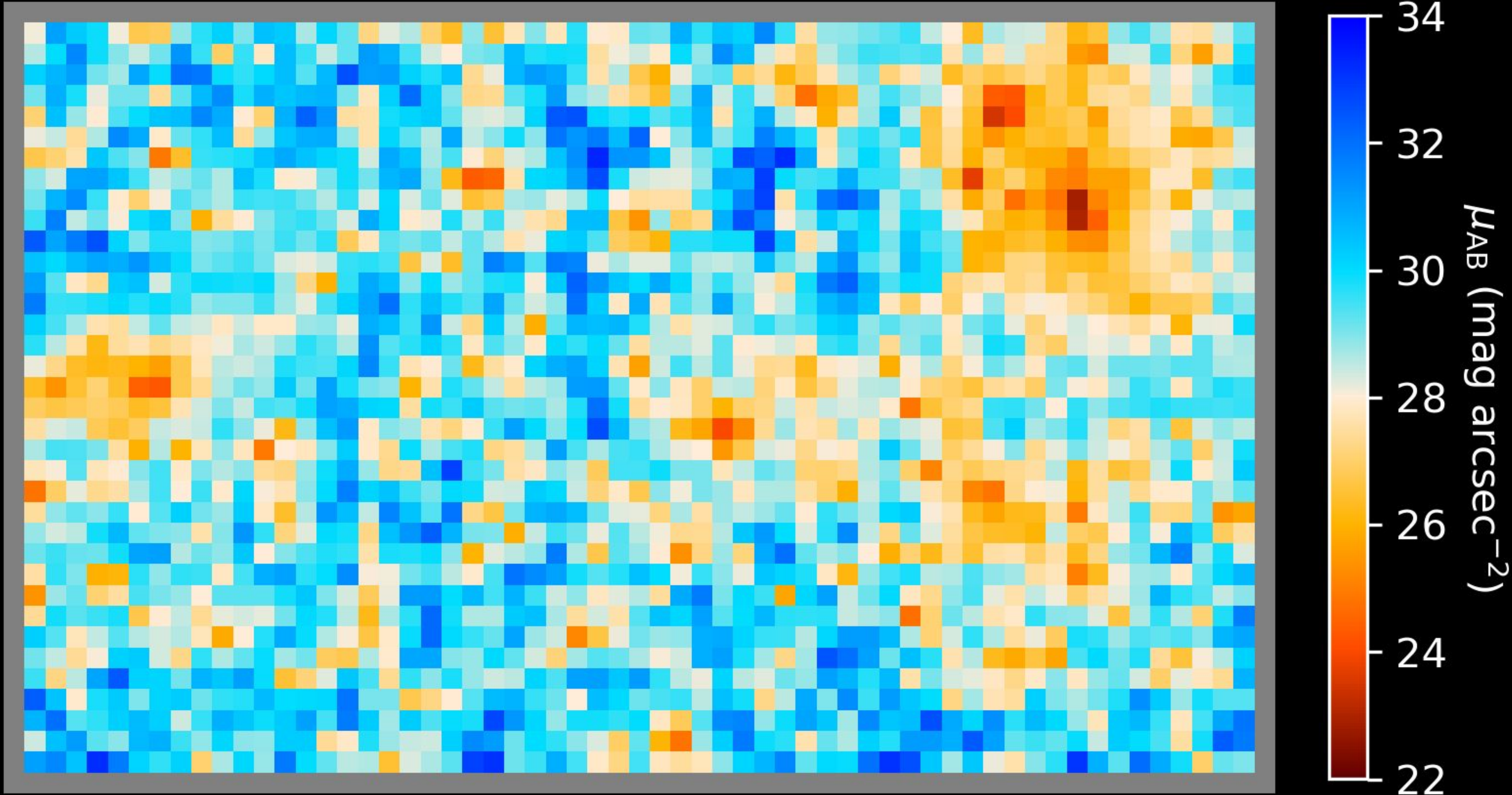
1) Better sensitivity

2) Access to other wavelengths

3) Better resolution



Illustris simulation Deep Fields Simulated image F850LP Noiseless image



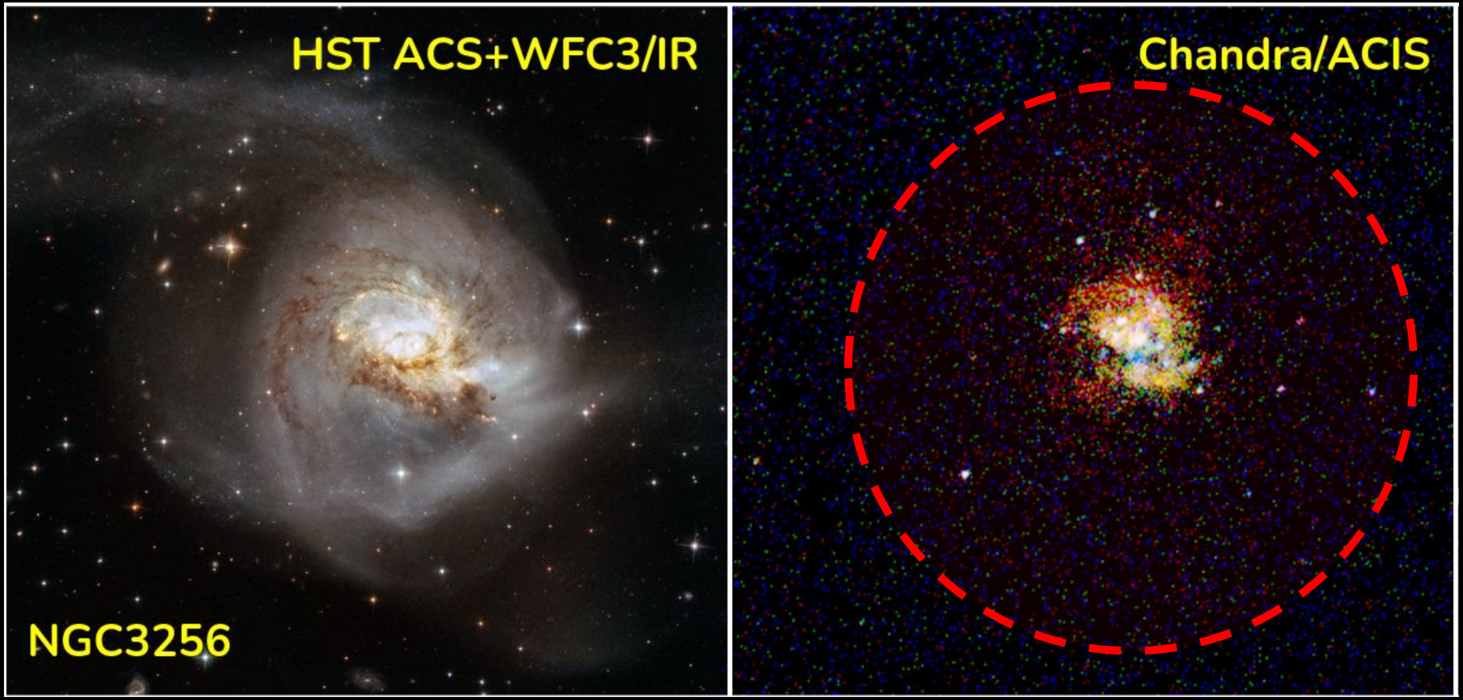
Dragonfly resolution (2.85" / pixel)

Every pixel contains an object!

Beyond optical: Hot gas X-ray galactic halos with Chandra

Cycle 24: Chandra Archival Research project 24610329

PI: A. Borlaff, P. Marcum



Optical imaging | **X-ray imaging**

Black Marble project - Earth Observation

ESA/F-Mission

"Discovery & Exploration" Mission

ARRAKIHS

Analysis of Resolved Remnants of Accreted galaxies as a Key Instrument for Halo Surveys (ARRAKIHS)

Industrial Heritage (to guarantee **feasibility** and **affordability**)

SATLANTIS · APCO TECHNOLOGIES · OHB SWEDEN

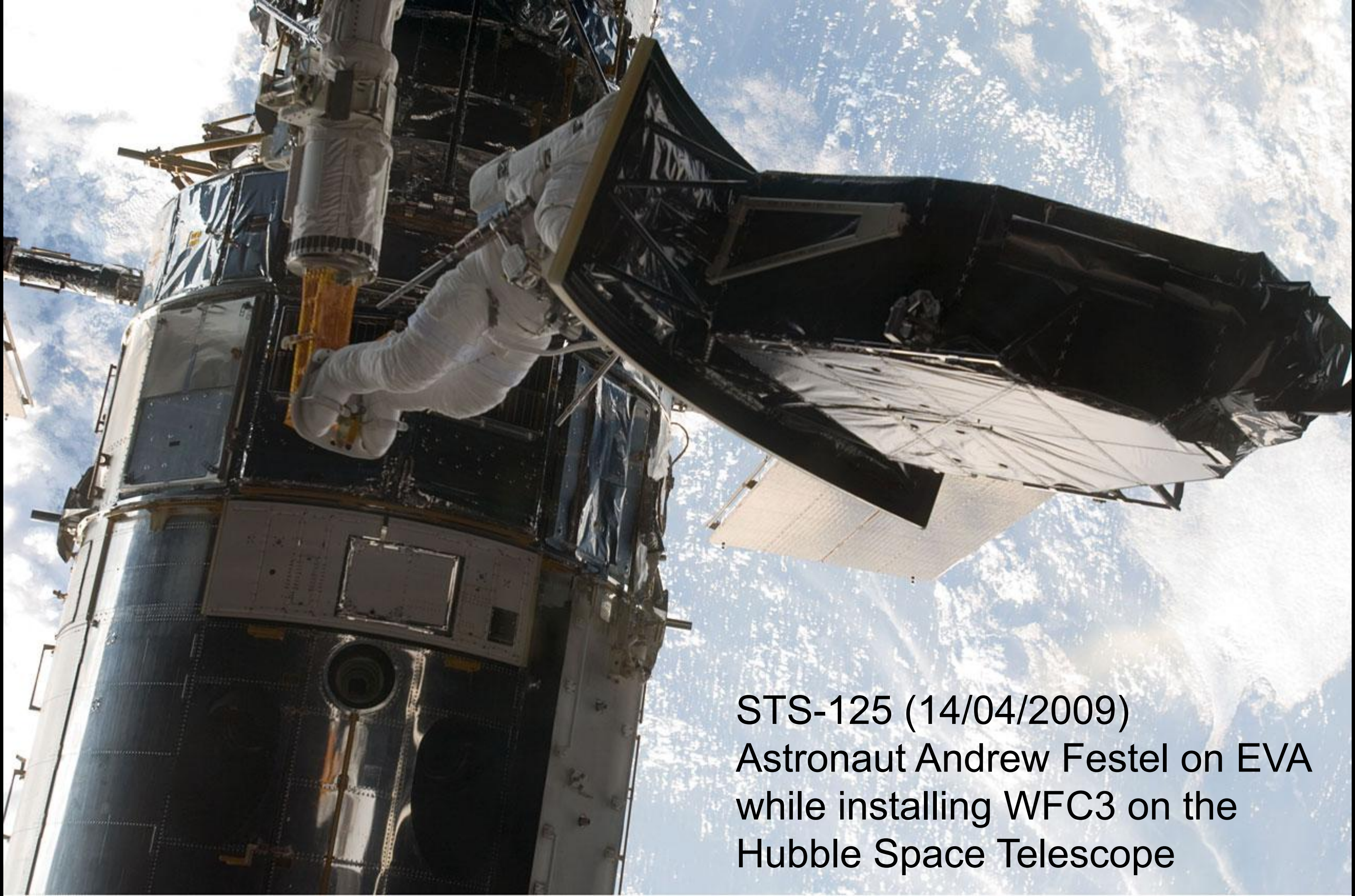
Public Agencies (to guarantee financial **support**):

CDTI Centro para el Desarrollo Tecnológico Industrial

Rymdstyrelsen Swedish National Space Agency

AGENCIA ESTATAL DE INVESTIGACIÓN

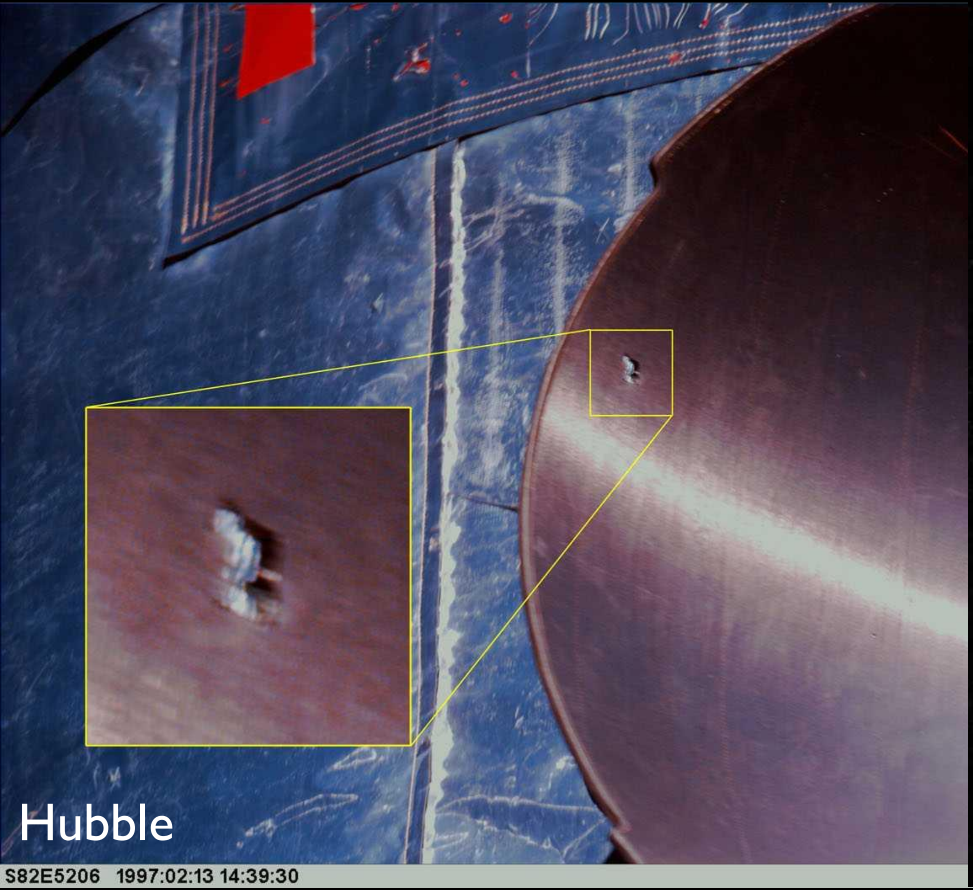
Announced in Nov, 2nd, 2022!

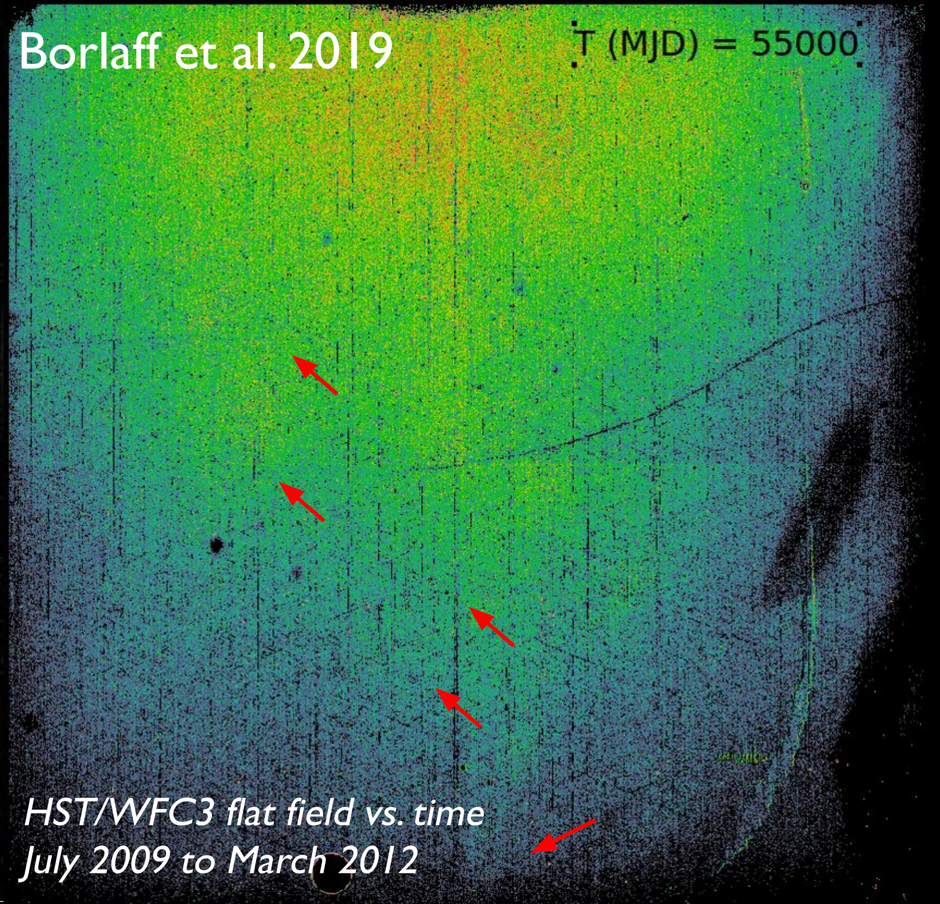


STS-125 (14/04/2009)
Astronaut Andrew Festel on EVA while installing WFC3 on the Hubble Space Telescope

Flat fielding – Why time dependent?

Space is a hard place to live: Micrometeoroids & space debris





Flat fielding – Why time dependent?

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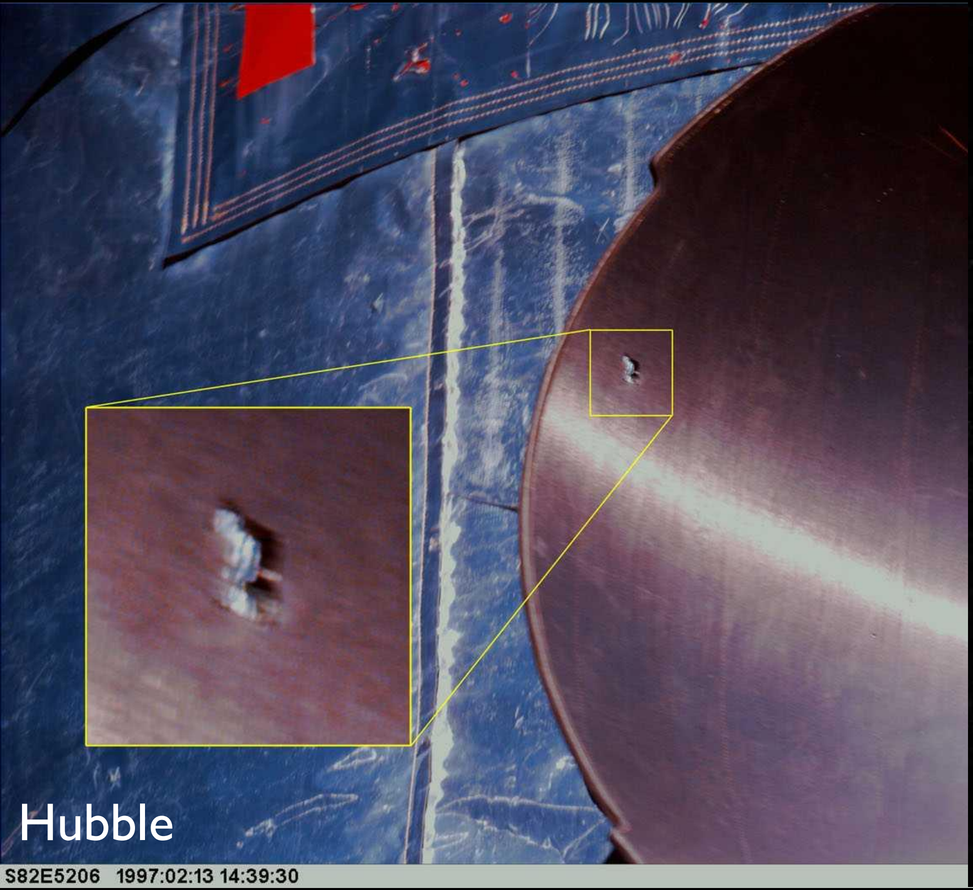
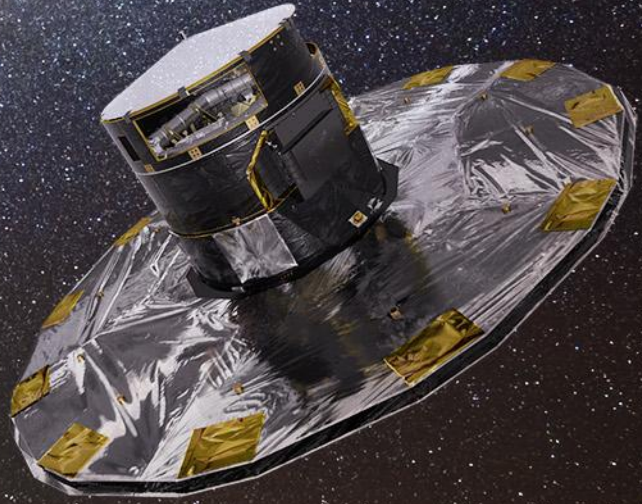


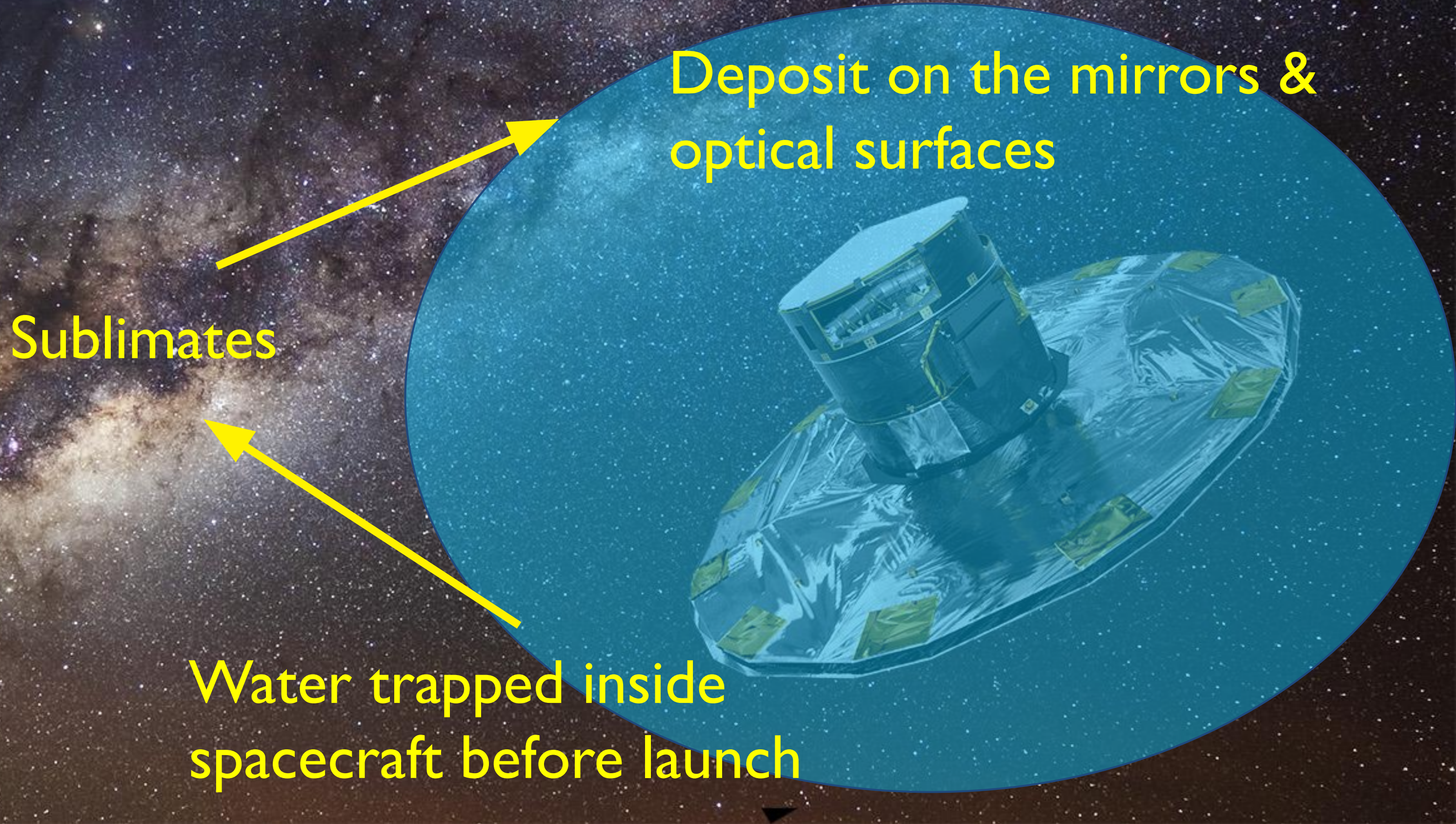
Flat fielding – Why time dependent?

Water ice contamination and molecular outgassing



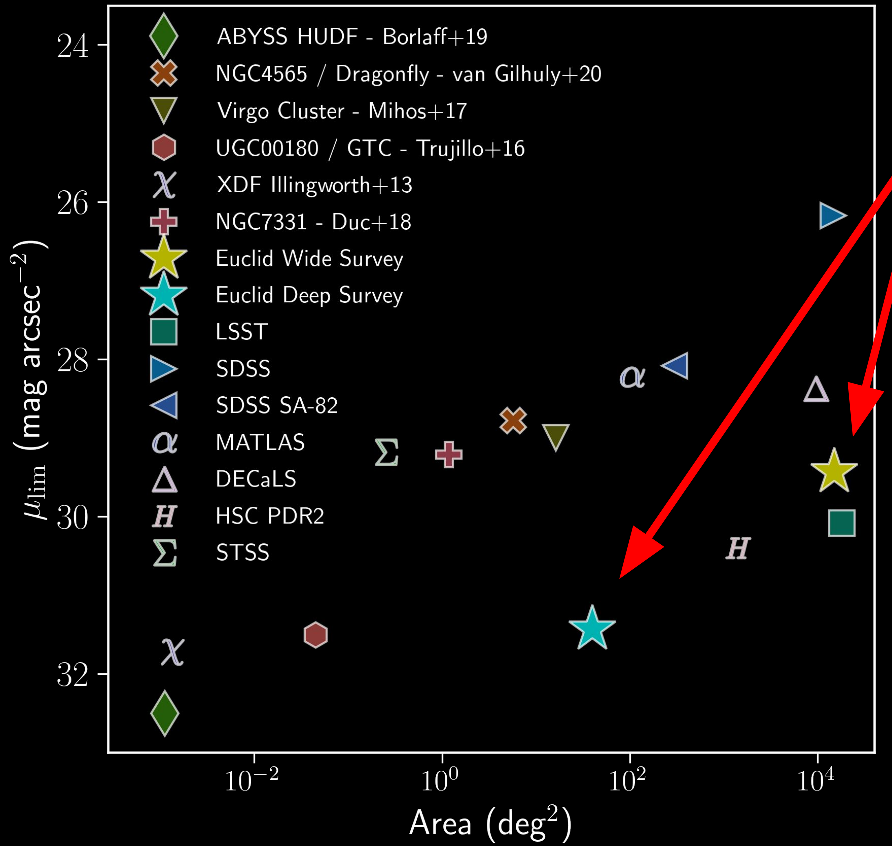
Flat fielding – Why time dependent?

Water ice contamination and molecular outgassing



Exploring the low surface brightness Universe with Euclid

Alejandro S. Borlaff [1,2], Pedro Goméz-Álvarez [2], Bruno Altieri [2], Roland Vavrek [2], Pamela M. Marcum [1], René Laureijs [3], Ralf Kohley [2] et al. 2021
1) NASA ARC, 2) ESA / ESAC, 3) ESA /ESTEC



Expected Euclid depths
(3σ, 10x10 arcsec^2)

Wide survey:
(15,000 deg²)
μ_{lim} ~ 29.5 mag arcsec^{-2}

Deep surveys:
(40 deg²)
μ_{lim} ~ 31.5 mag arcsec^{-2}!

Borlaff et al. 2022

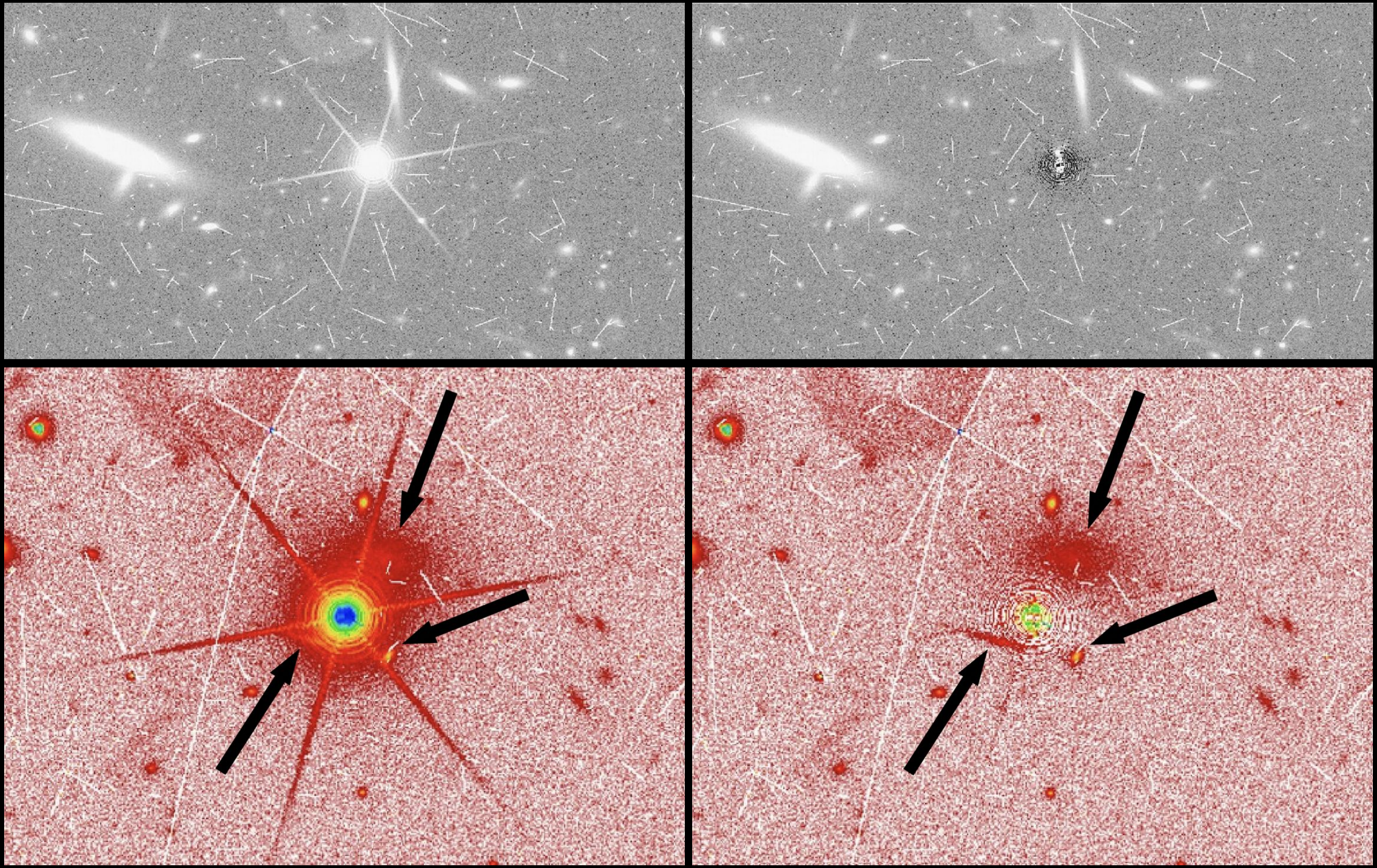
Automated PSF subtraction of in-FOV stars for Euclid

Gnuastro
Akhlaghi & Ichiwaka (2015)

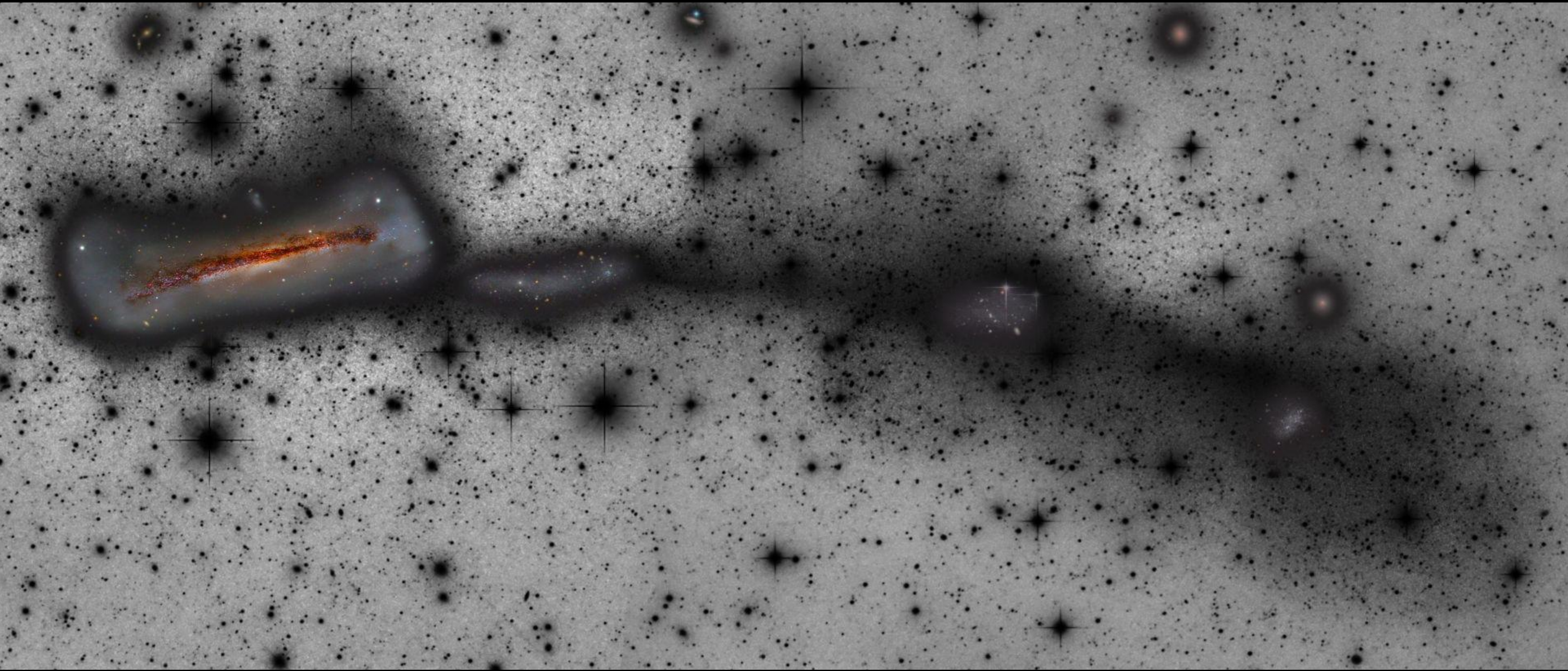
Infante-Sainz et al. (2020)

+

Euclid WP-DIF PSF paper (in prep.)

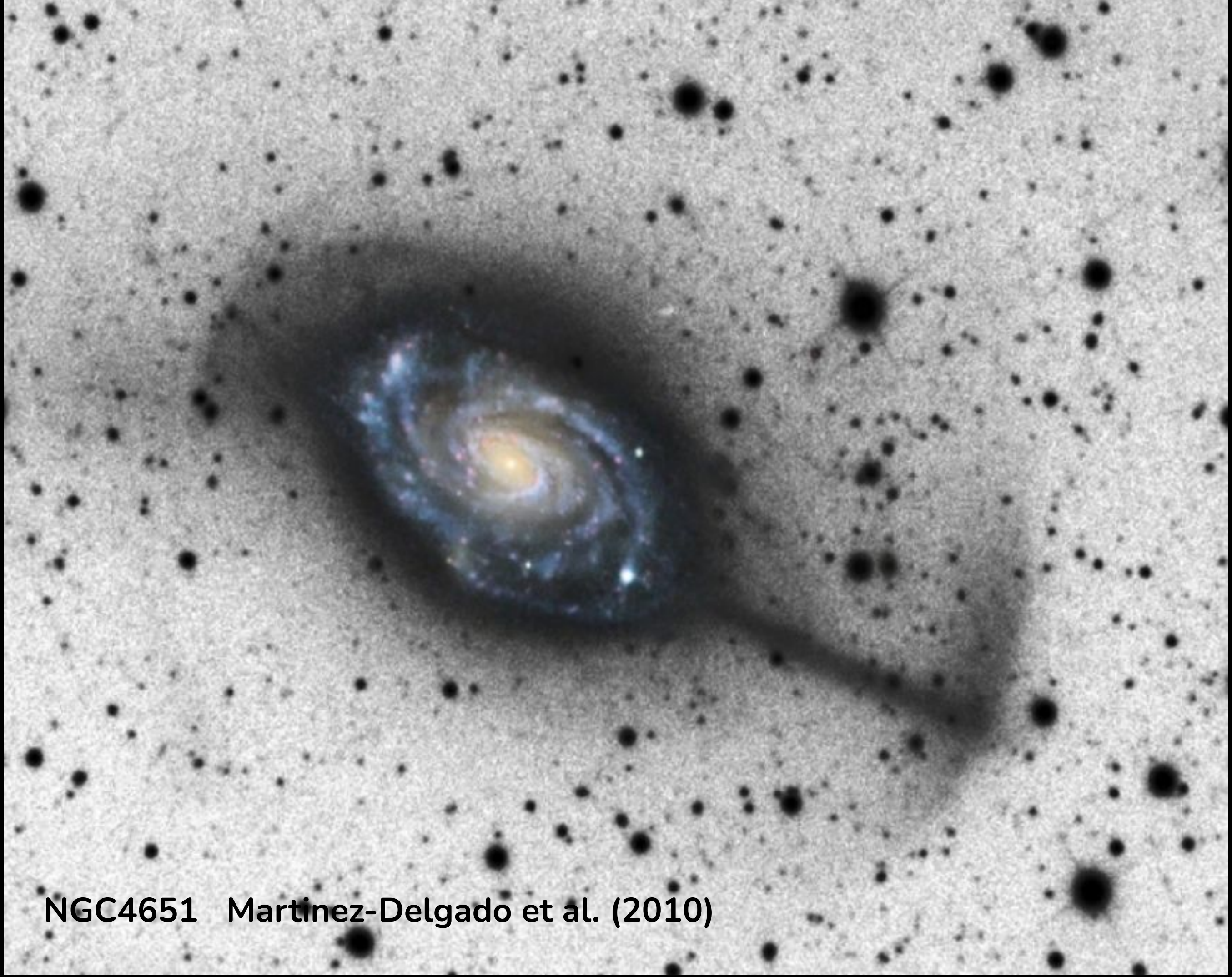


Courtesy of S. Eskandarlou, R. Infante-Sainz, and M. Akhlaghi

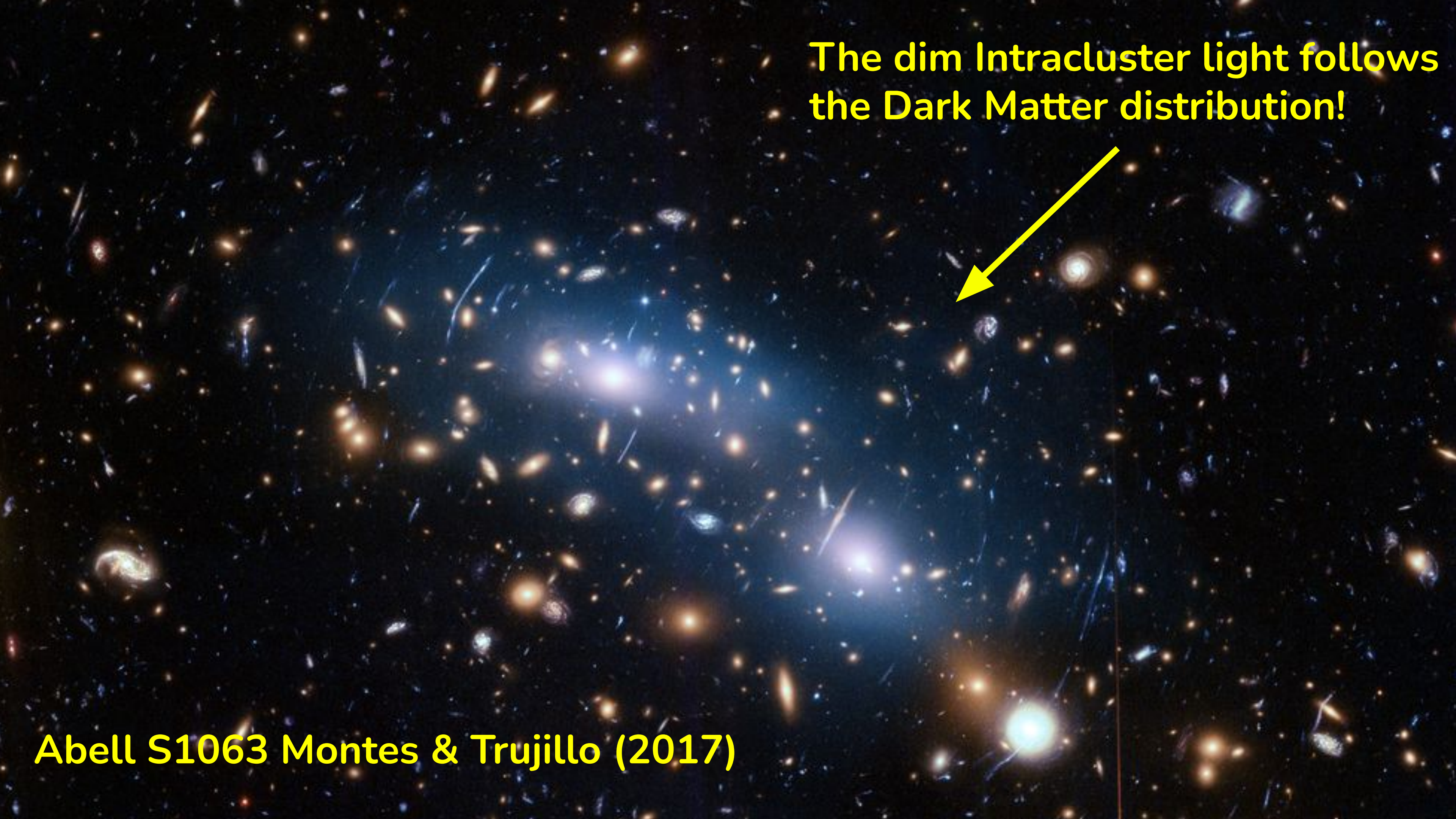


Galaxies are like icebergs and what is seen above the sky background may be no reliable measure of what lies underneath - Michael Disney, 1976

NGCC3628 - Hanson Astronomy Photos

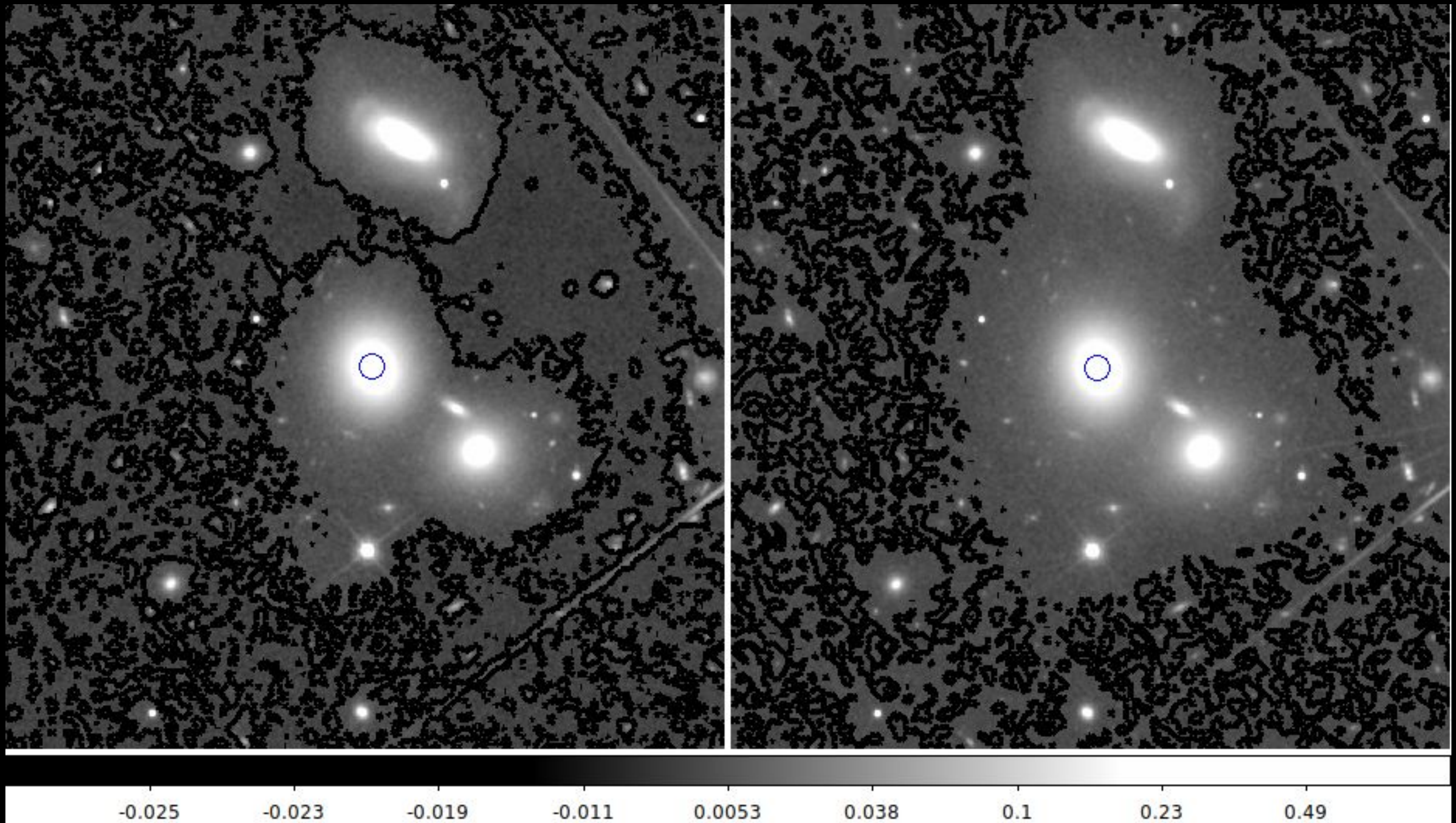

NGC4651 Martinez-Delgado et al. (2010)

NGC474 Bilek et al. (2022)


The dim Intracluster light follows the Dark Matter distribution!
Abell S1063 Montes & Trujillo (2017)

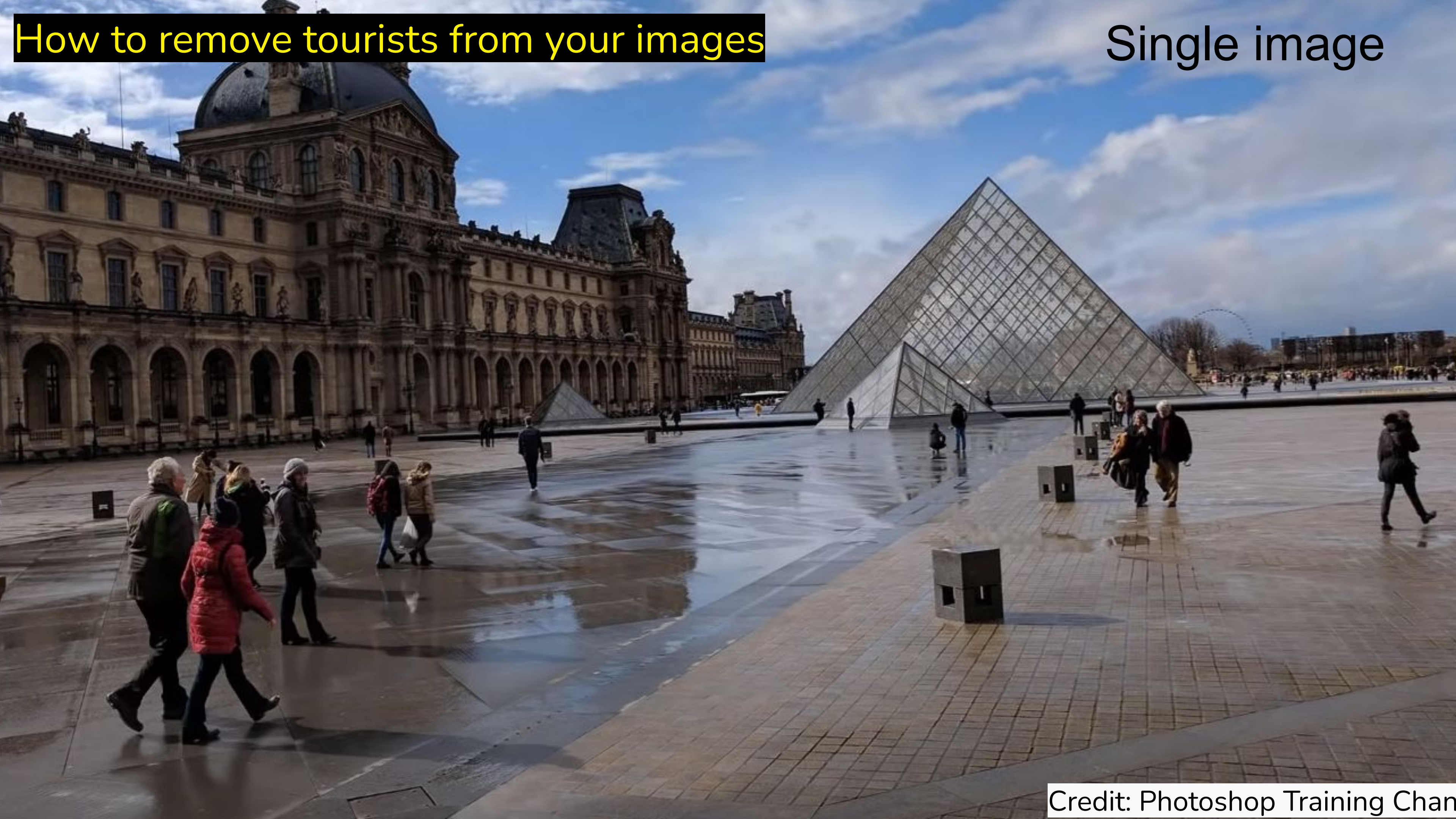

CS COSMOS 3D-HST Skelton et al. (2014)

HST/ACS COSMOS 3D-HST Skelton et al. (2014) Improved pipeline (Borlaff et al. in prep)



How to remove tourists from your images

Single image



Credit: Photoshop Training Chan

How to remove tourists from your images

15x averaged images

Euclid Collaboration XVI - A. S. Borlaff et al. 2022

Zodiacal background emission is enough to calibrate Euclid/VIS flat-field every 10 days over scales > 0.5 arcsec²

Euclid can flat-calibrate itself using the Zodiacal light

Ice-contamination!