Exploring the Low Surface Brightness Universe with LSST/Rubin

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An invitation to explore the LSB Universe: opportunities and challenges

Duc et al., 2018

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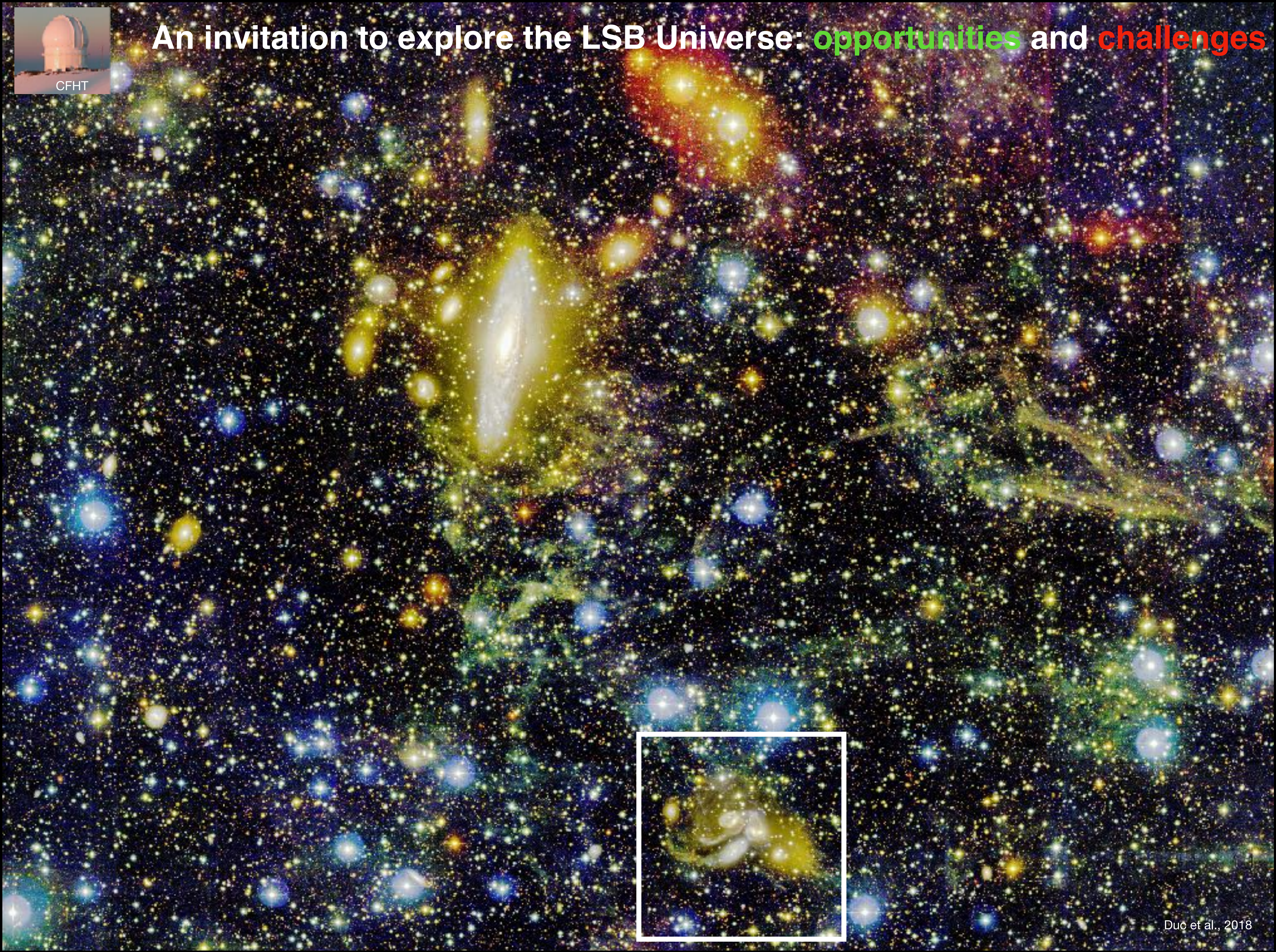

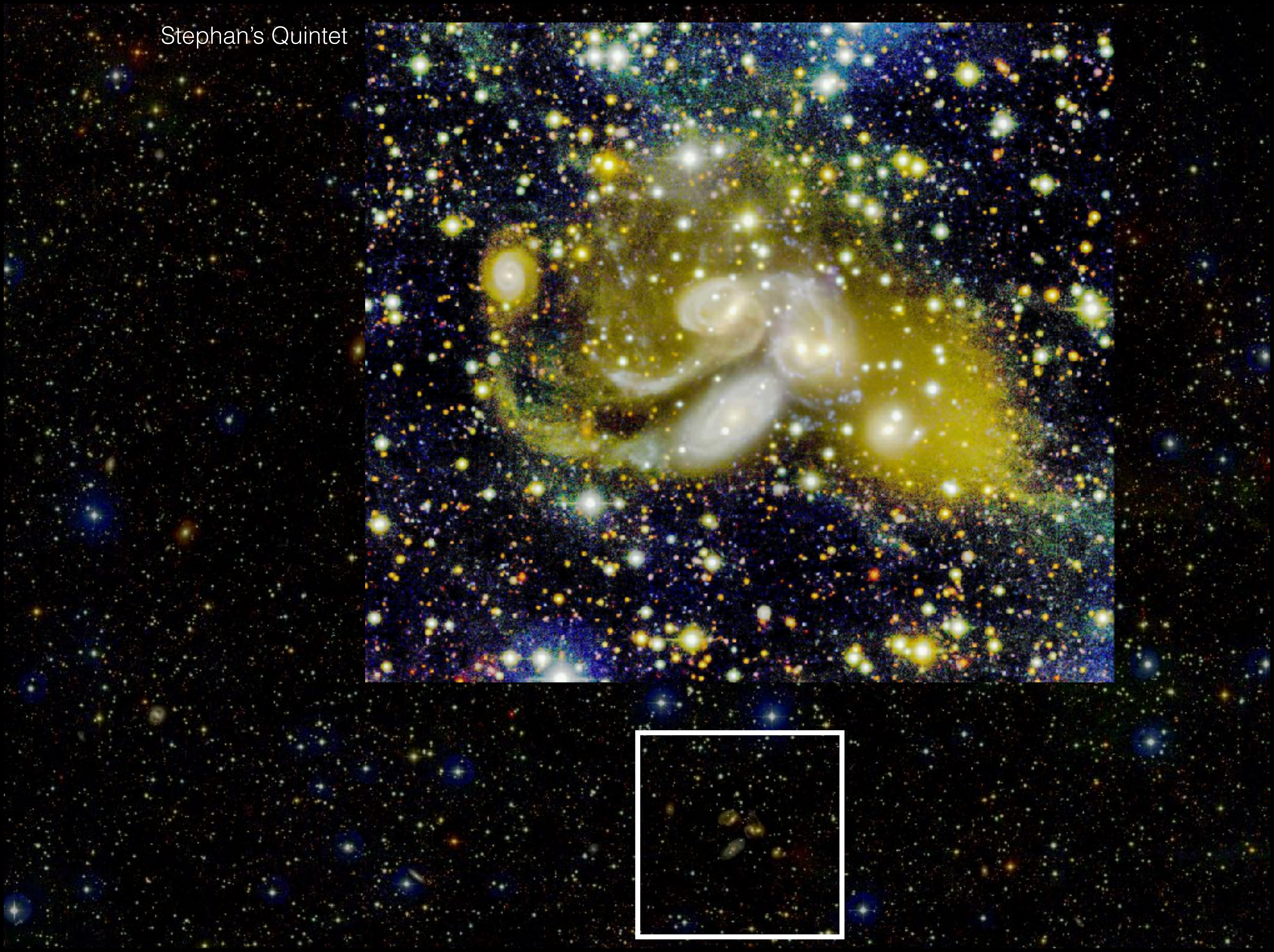
Stephan’s Quintet

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- Tidal features (Tails, plumes, streams, shells) used as tracers of pas collisions.
- Faint and evaporate with time
- Their census allow us to reconstruct the recent mass assembly of galaxies

Renaud et al., 2010

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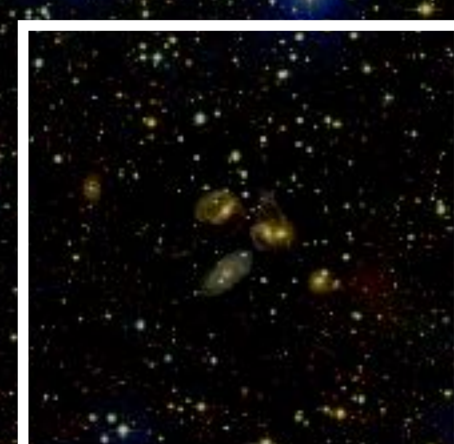

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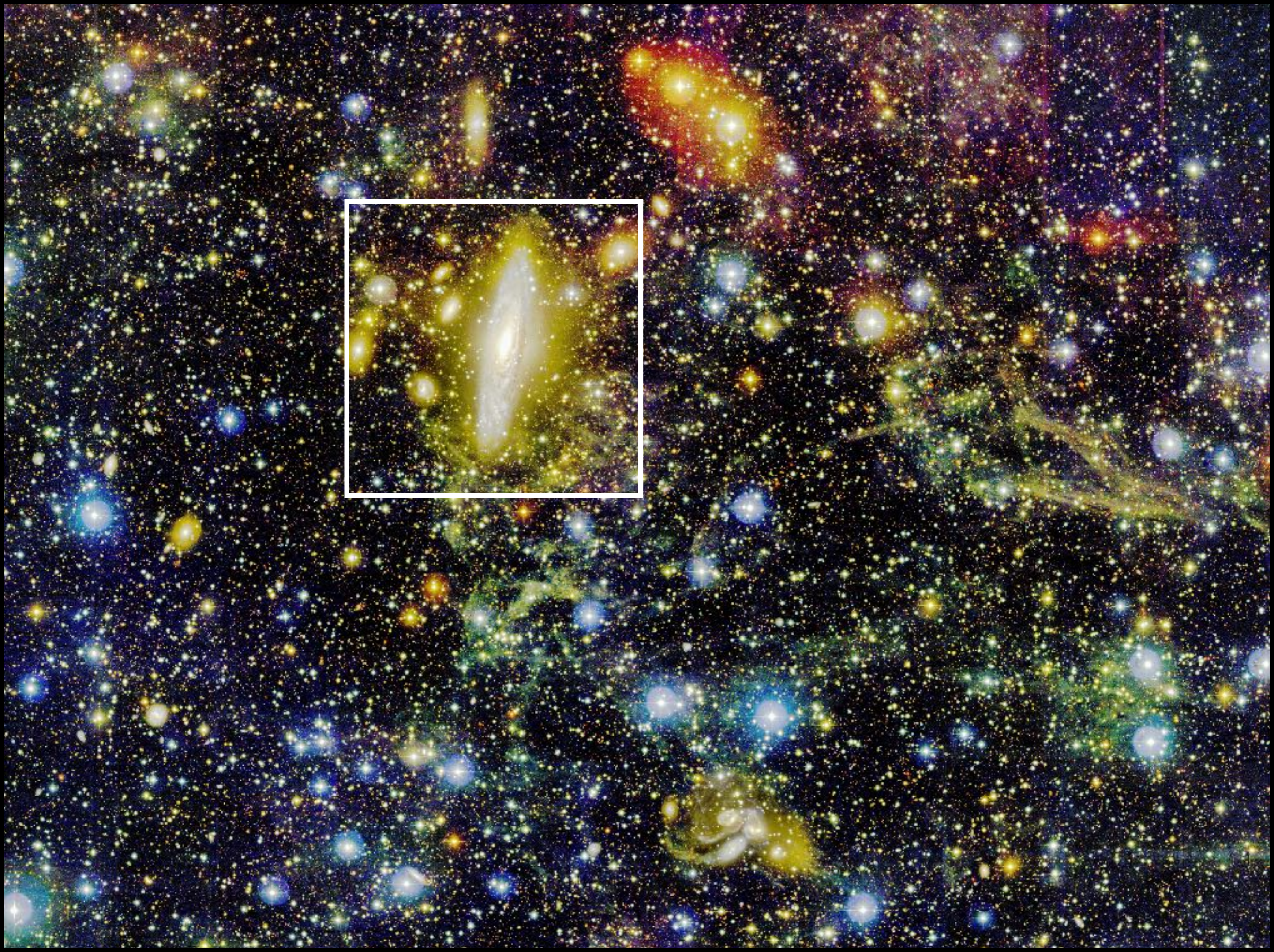
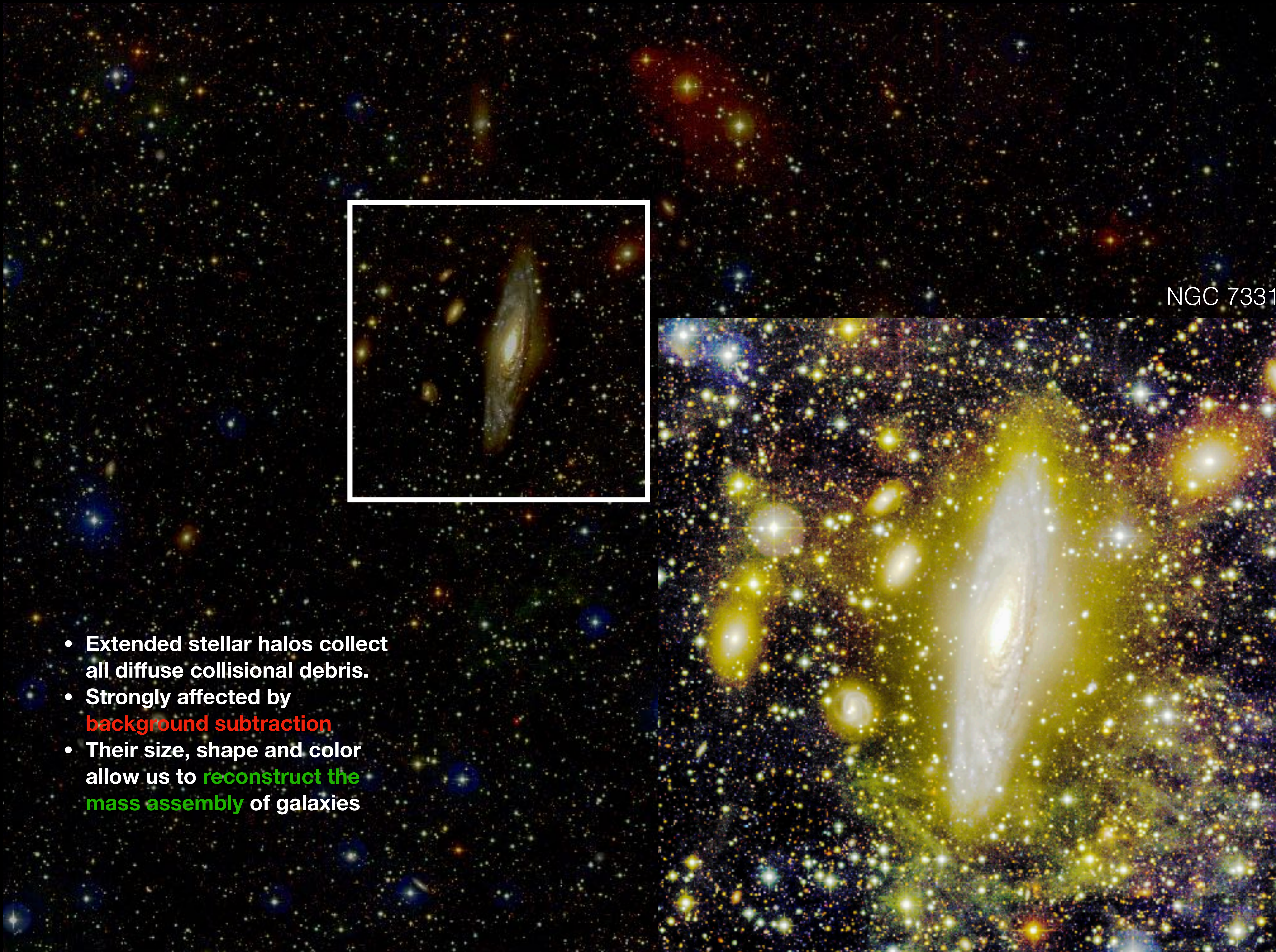
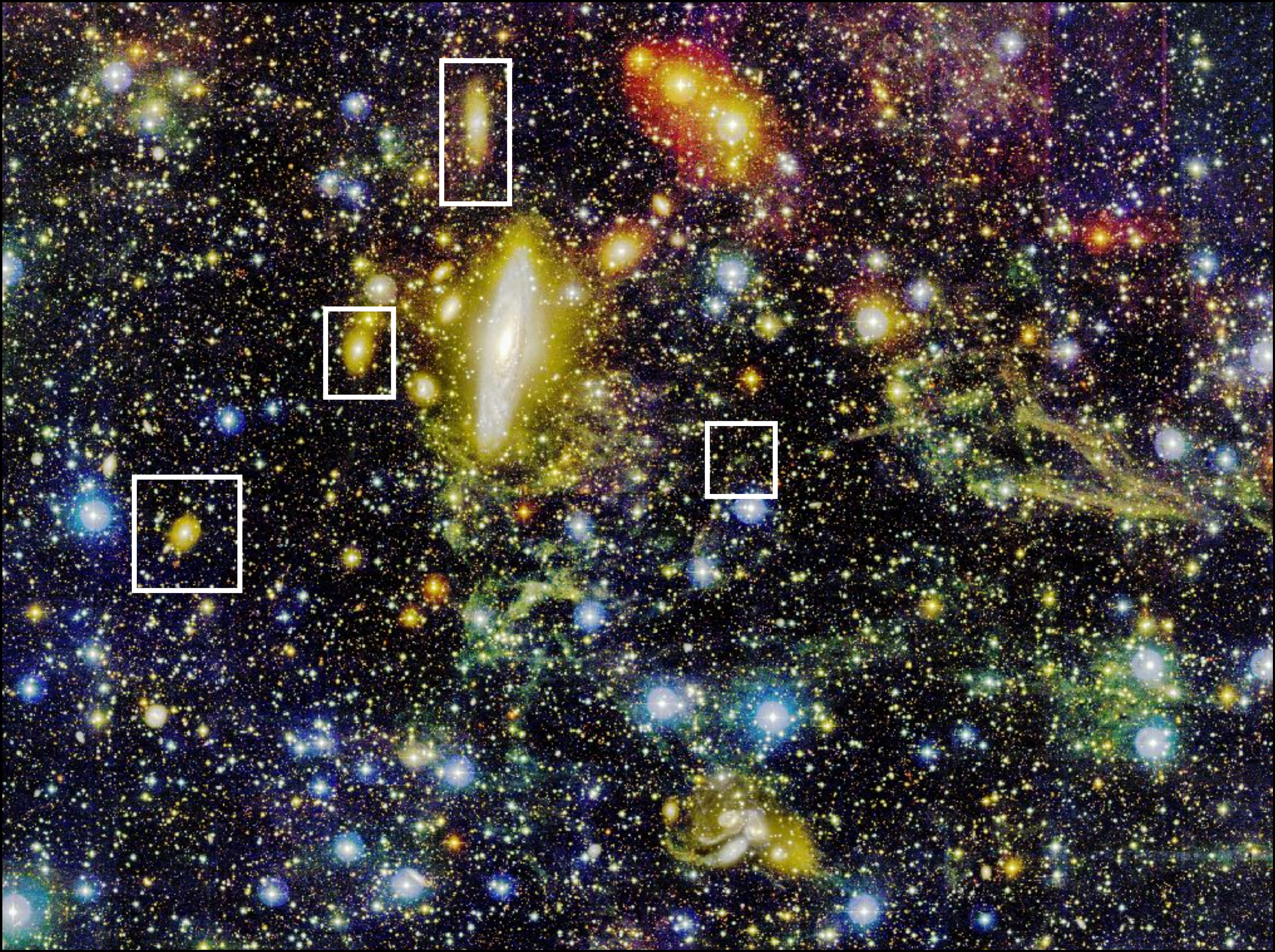
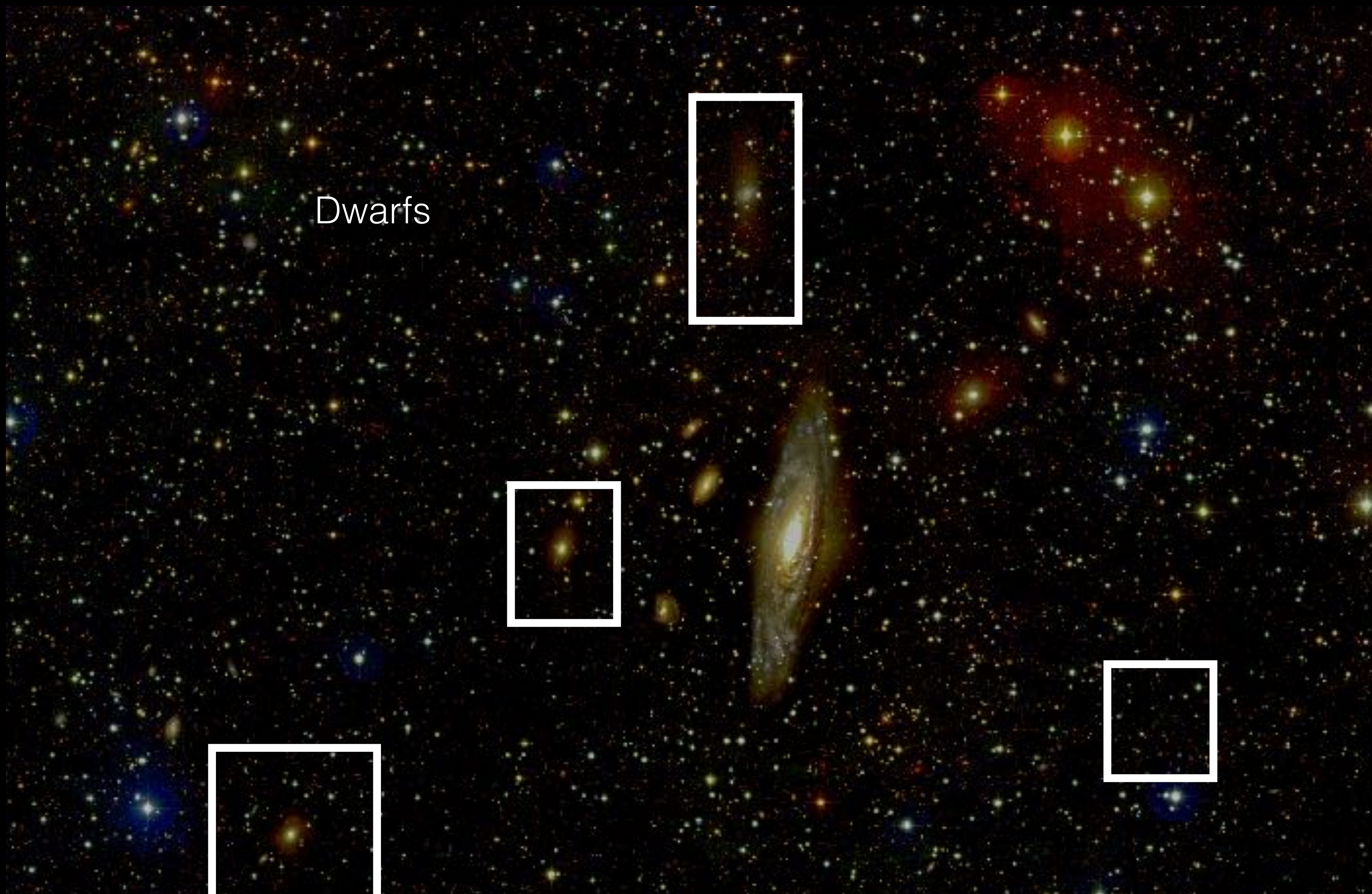
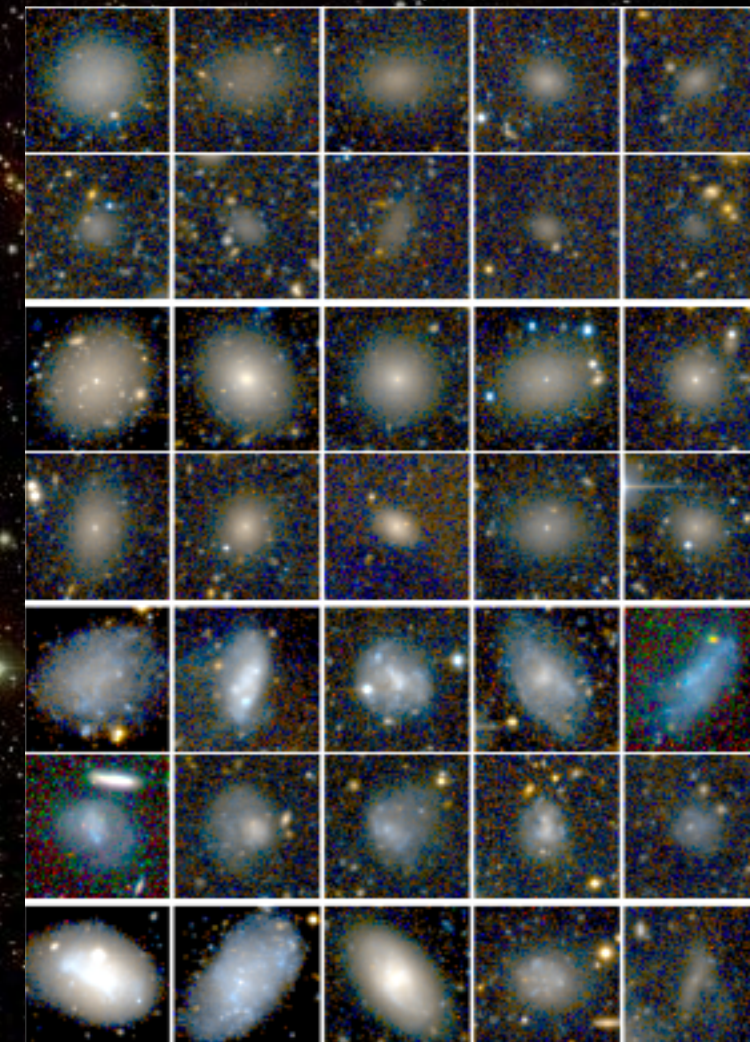



NGC 7331
• Extended stellar halos collect all diffuse collisional debris.
• Strongly affected by background subtraction
• Their size, shape and color allow us to reconstruct the mass assembly of galaxies

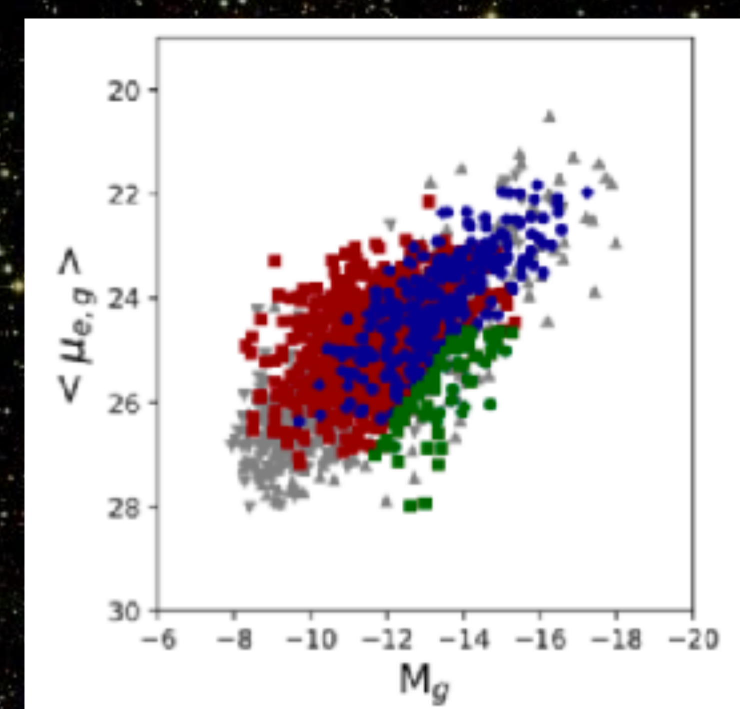


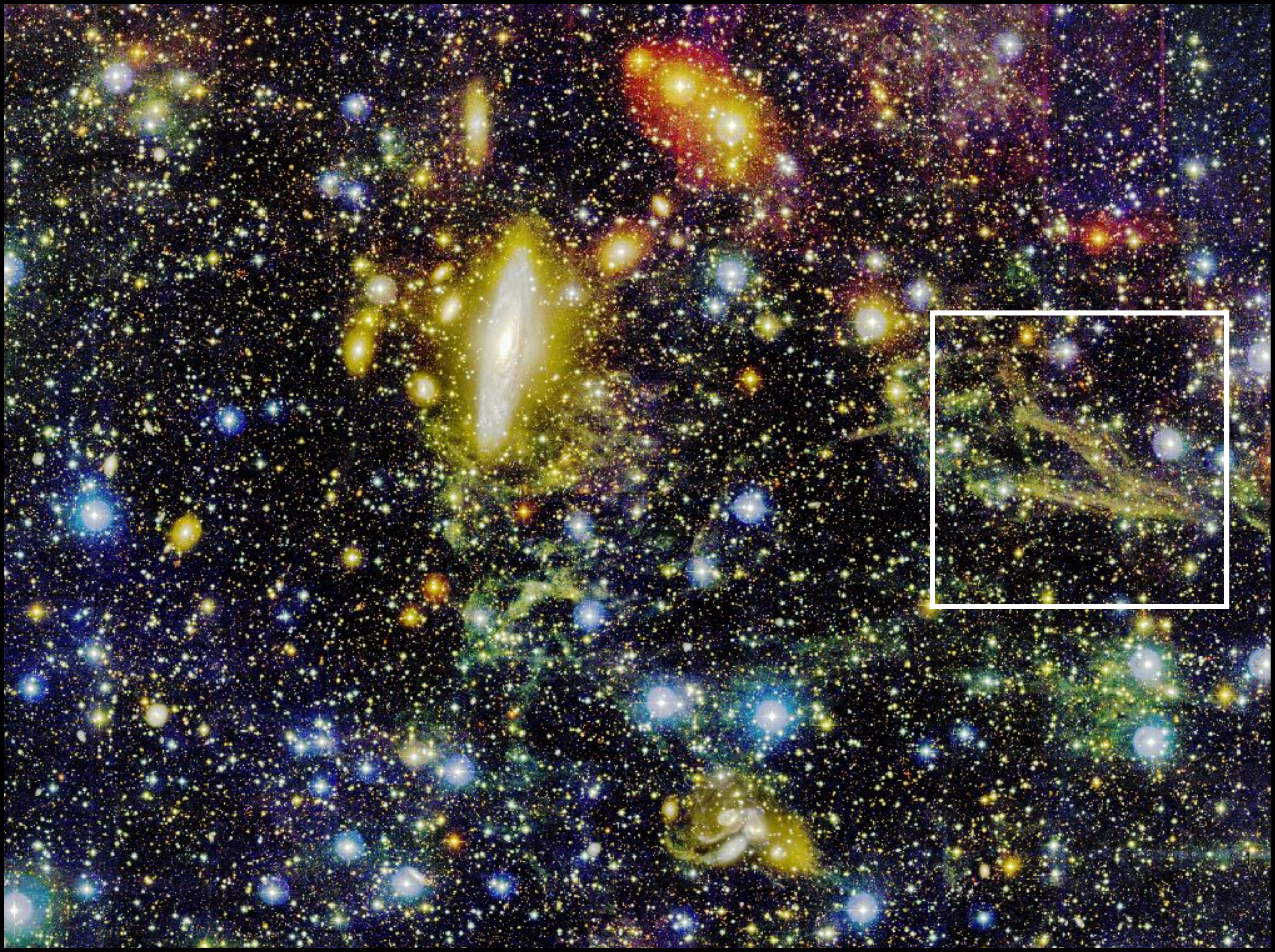


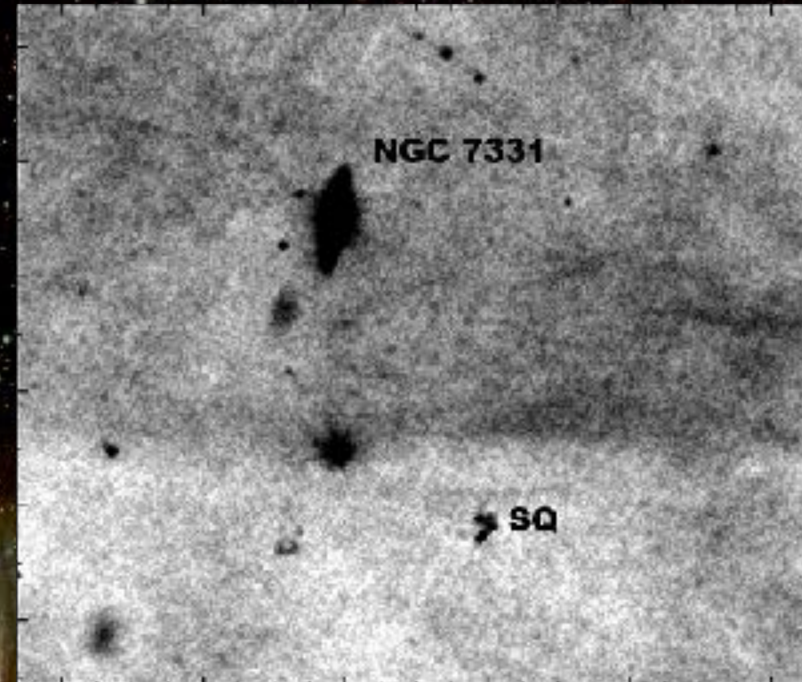


Habas et al., 2019
Marleau et al., 2021

- **Dwarf satellites as tracers of galaxy assembly and cosmological probes**
- **The vast majority is of low surface brightness, and their census is only beginning.**
- **Distance difficult to determine**

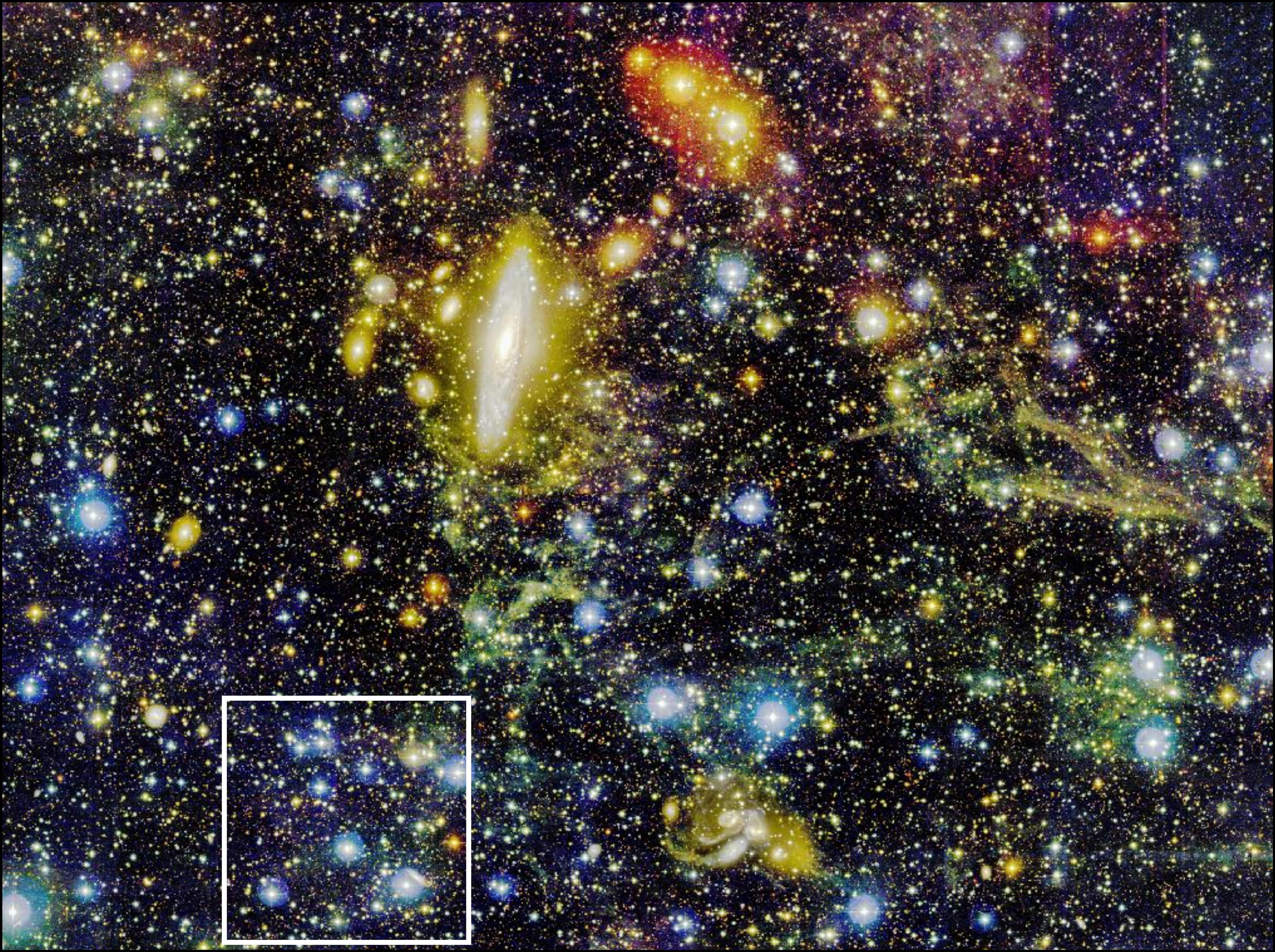






Galactic cirrus

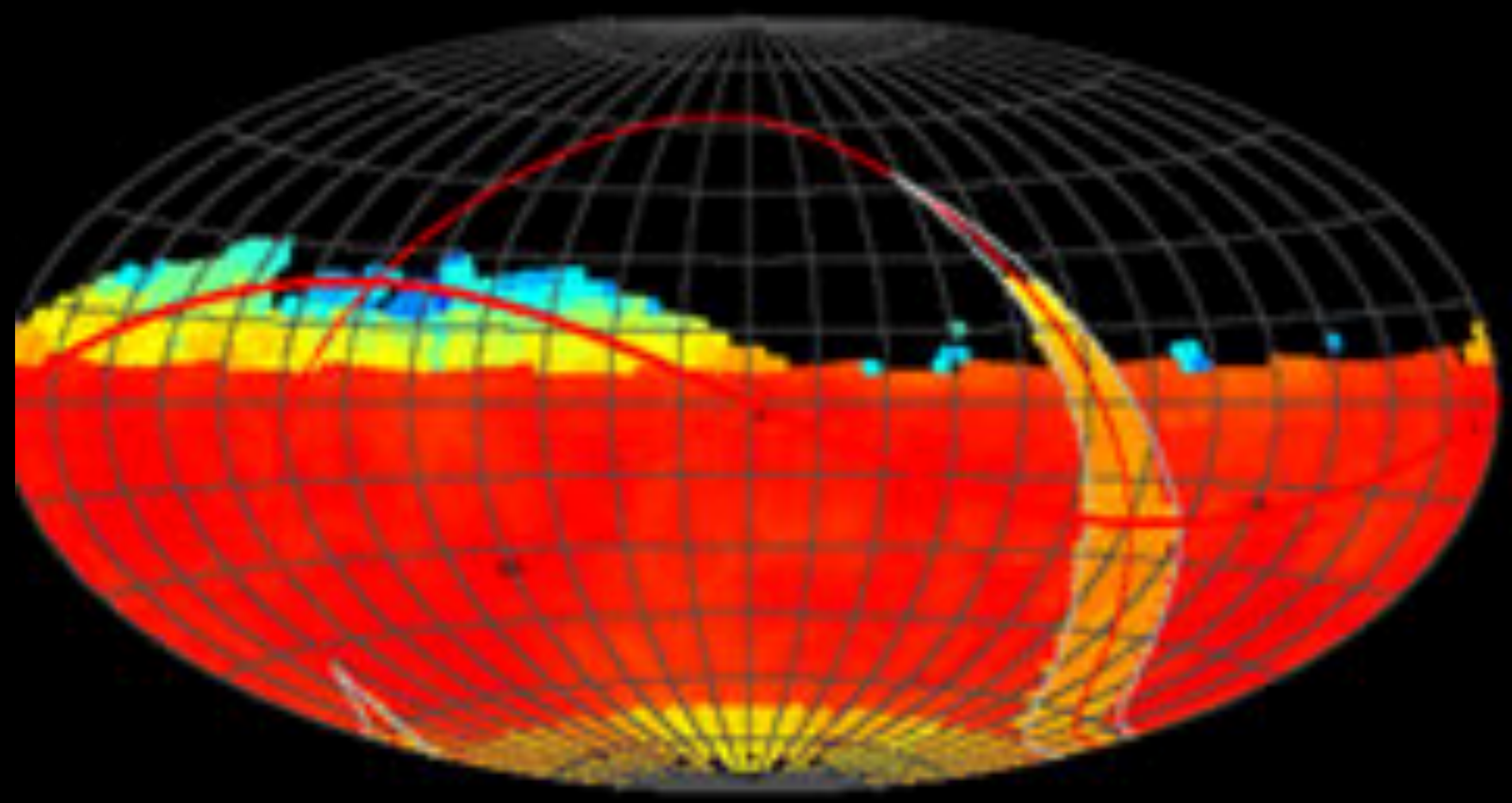
- Dust clouds from the Milky Way visible in the optical with the scattered light
- Shapes and colors similar as tidal features
- Can be identified with multi-lambda studies, but difficult to subtract
- A probe of the ISM structure at very high spatial resolution



Ghosts, PSF

- Prominent ghosts around bright stars (depending on the optical elements)
- Affect the photometry, shape and even detection of LSB structures

Will Rubin/ LSB meet the challenges of the LSB exportation?



- Large sky coverage: about 20 000 square degrees instead of a few hundred square degrees for current deep imaging surveys
- Statistics on thousands of nearby massive systems, 10 thousands of LSB dwarfs, as a function of environment

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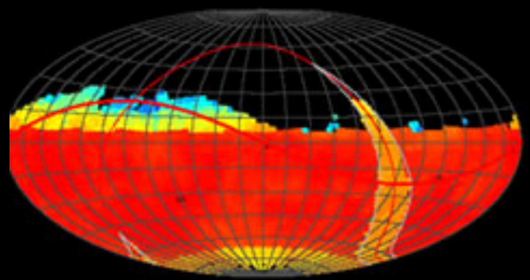
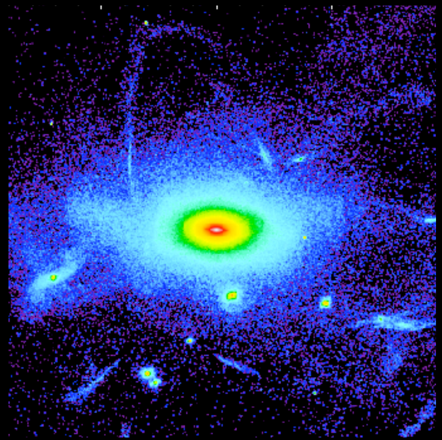
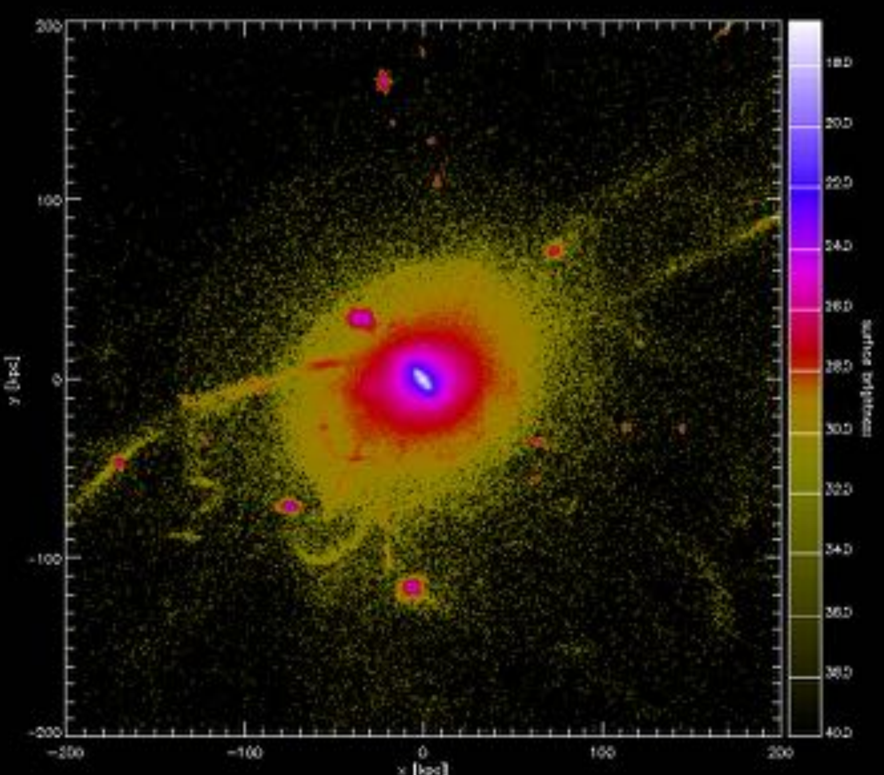




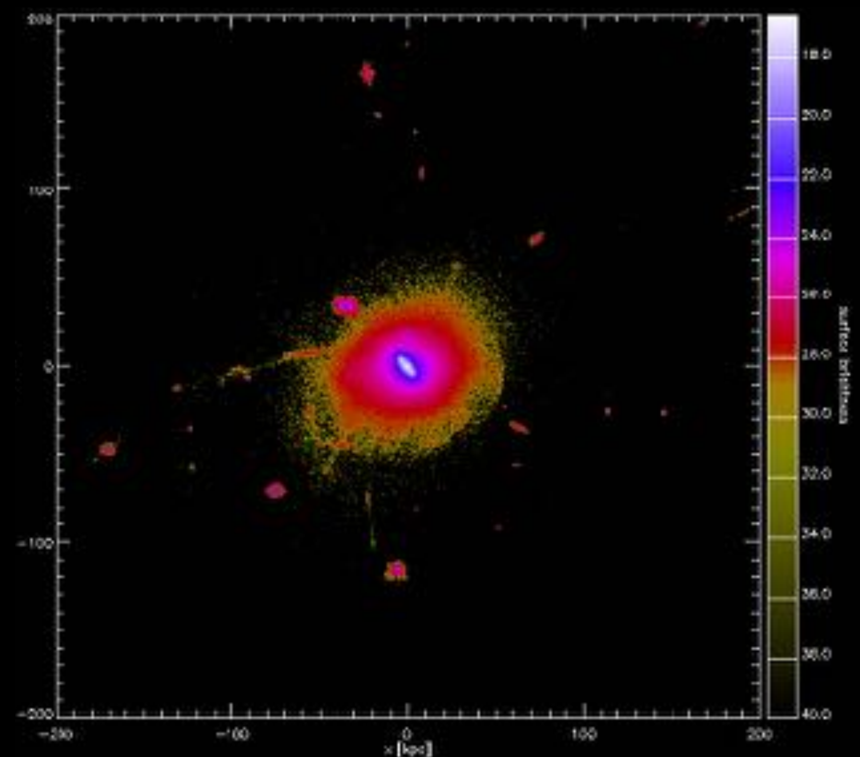
✓ At unlimited sensitivity

- *Simulated surface brightness maps*

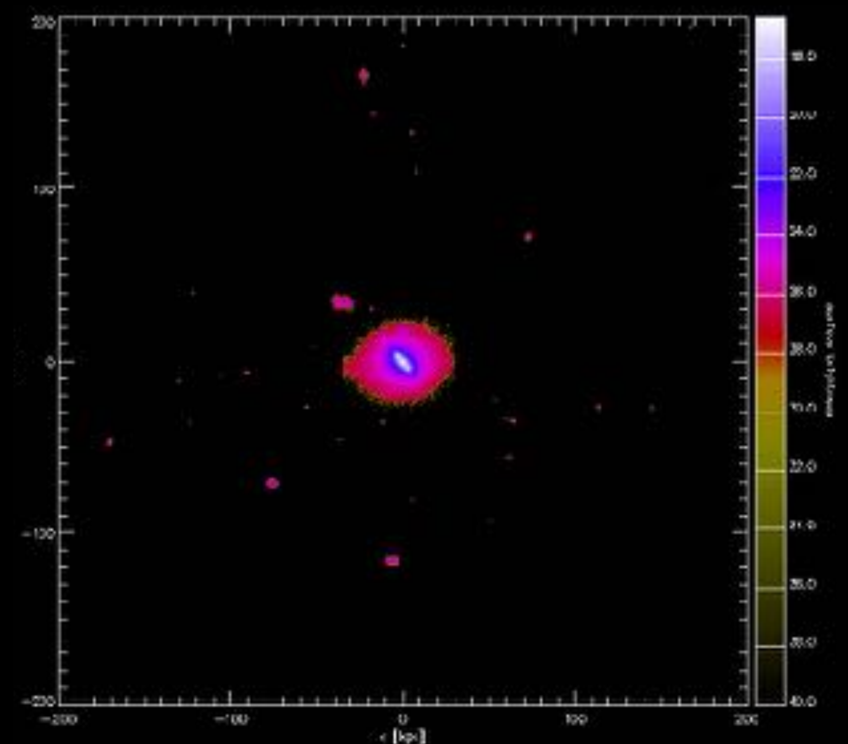
Mancillas et al, 2019



✓ At 31 mag/arcsec^2



✓ At 29 mag/arcsec^2



✓ Cutting at 27 mag/arcsec^2

- **Surface brightness maps which are reached from star counts (e.g. PAndAS) for Local Group galaxies only. Achievable with the 10 year LSST depth**

- **Surface brightness limit of on-going ultra-deep surveys probing the integrated diffuse light of nearby galaxies Achievable with 1 year LSST depth**

- **Surface brightness limit of traditional images of nearby galaxies (SDSS, CFHTLS)**

Getting ready to exploit the LSST LSB capabilities

- **Within the Galaxies Science Collaboration**

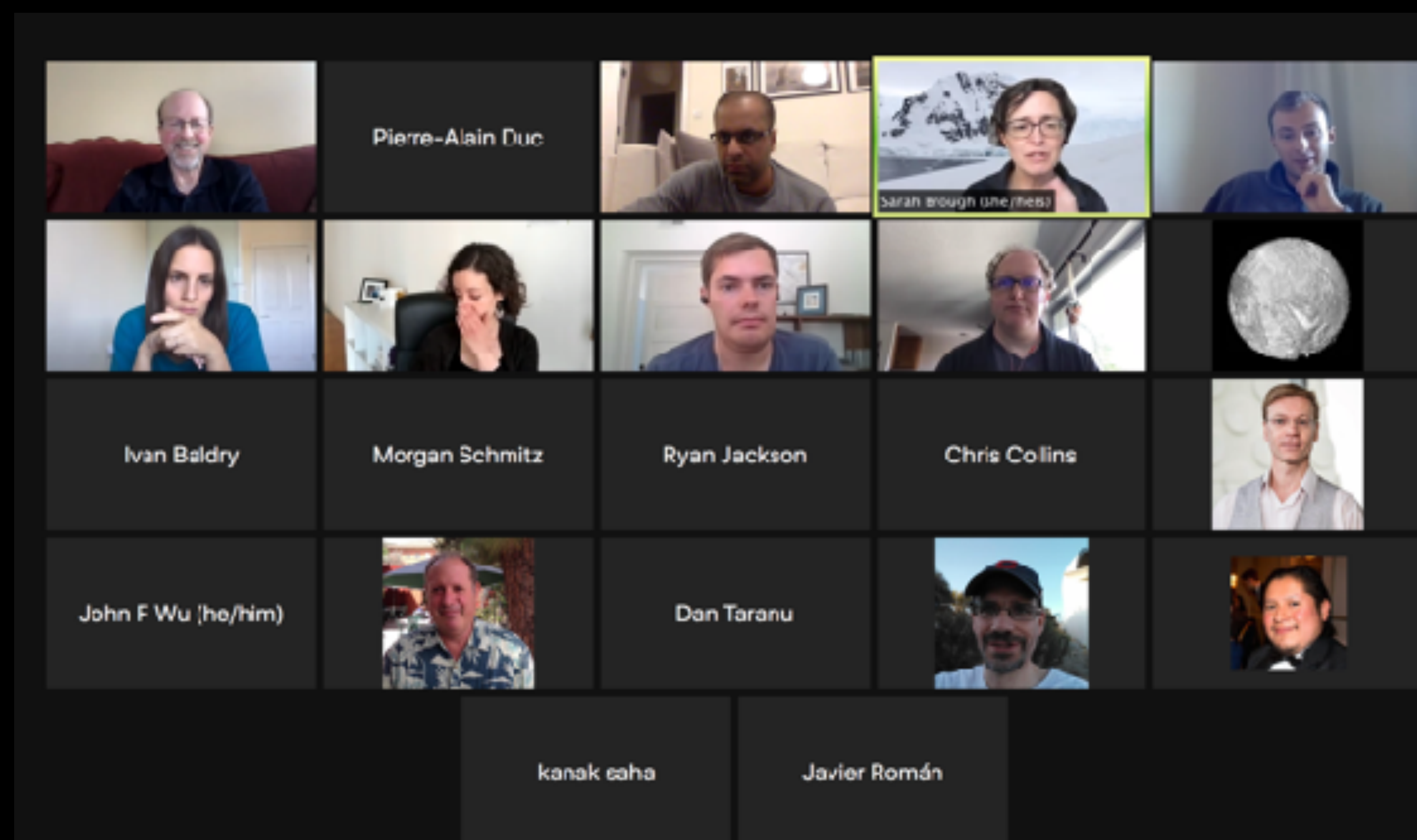
(Sugata Kavirak & Manda Banerji)

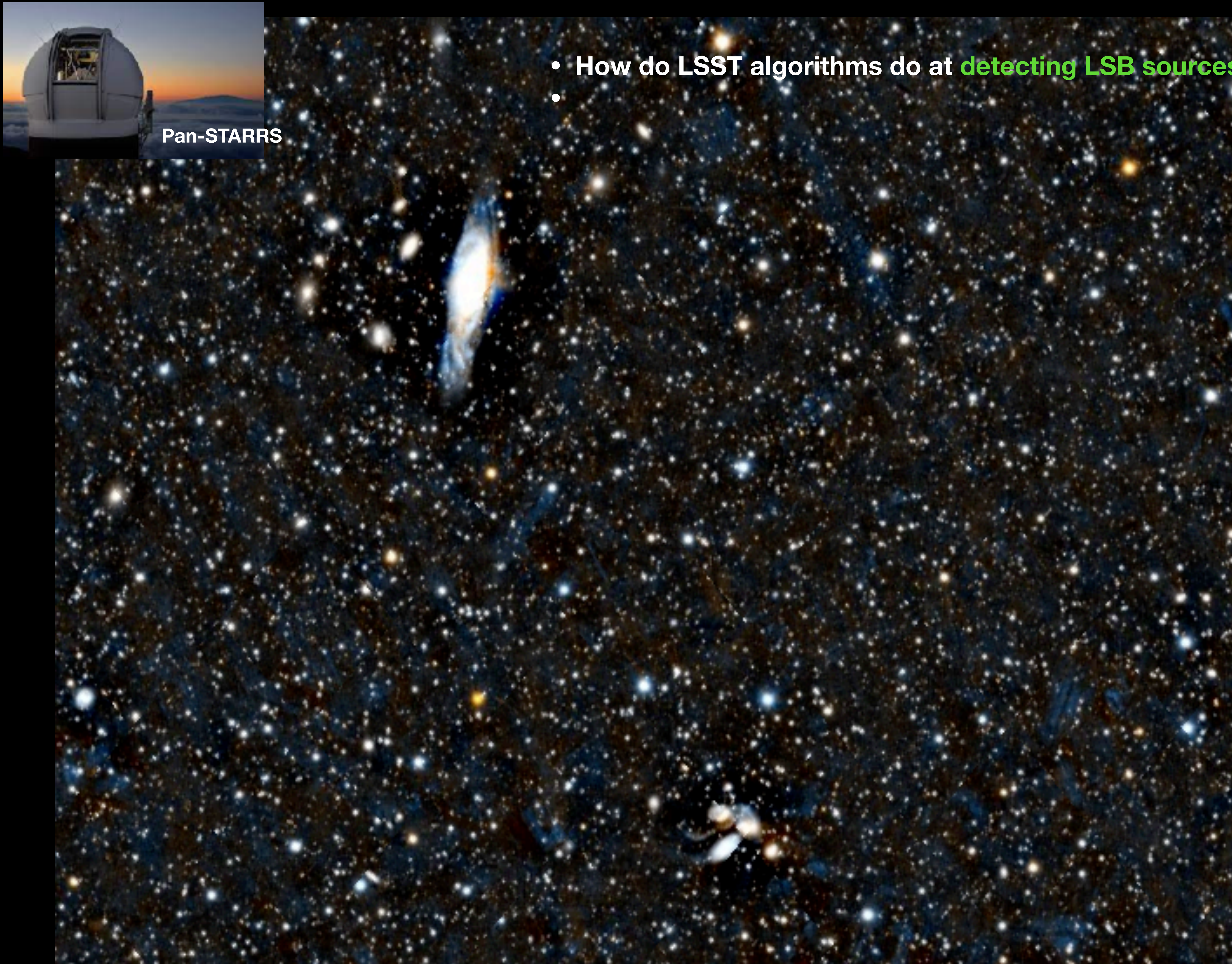
- **LSB science**

(Sarah Brough and Aaron Watkins)

4 challenges

- **How do LSST algorithms do at detecting LSB sources?**
- **What are the best ways to calculate distance for LSB galaxies?**
- **Do observers and simulators measure the same quantity of ICL?**
- **What are the most critical observables/measurables in LSB tidal features that will constrain theory?**





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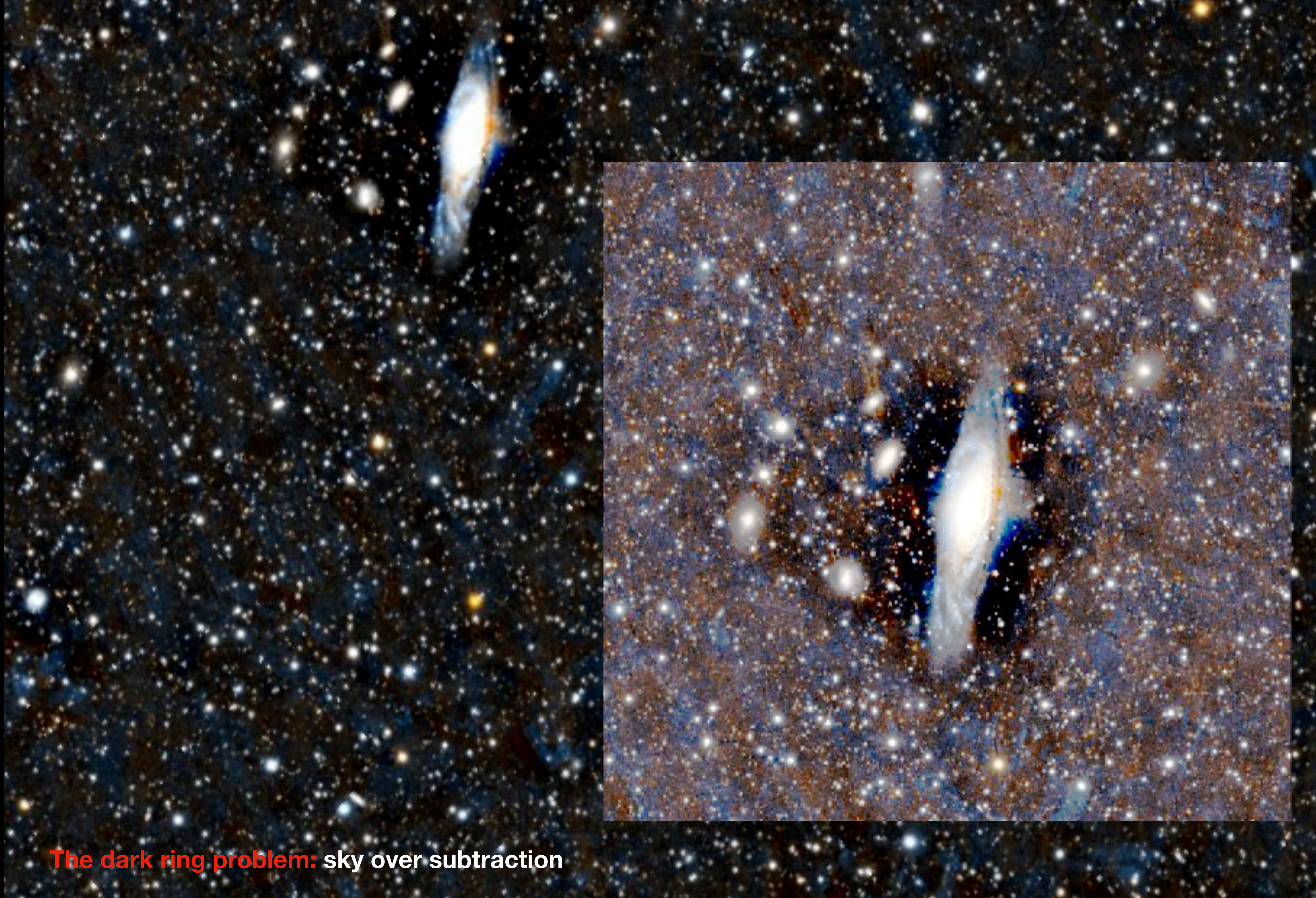
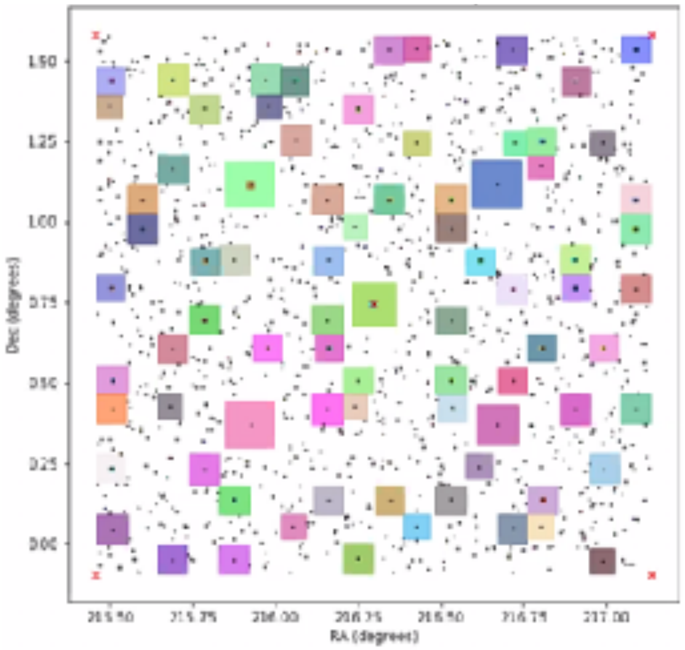


The dark ring problem: sky over subtraction

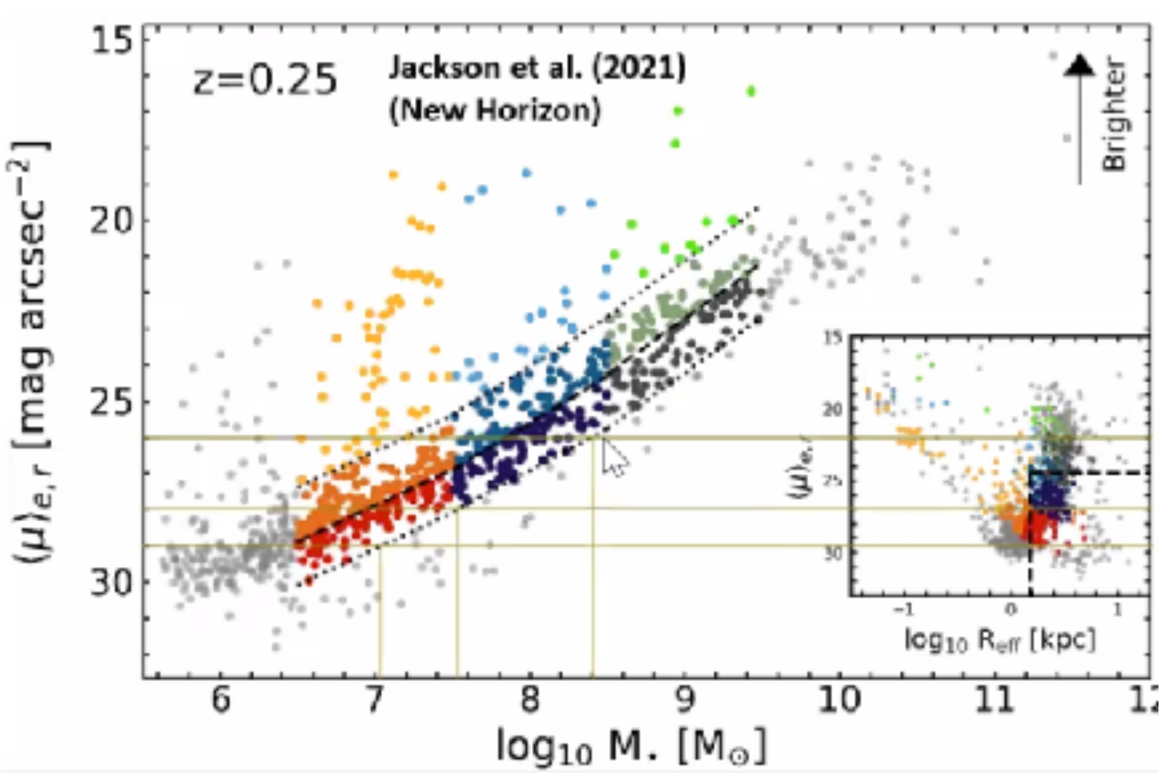


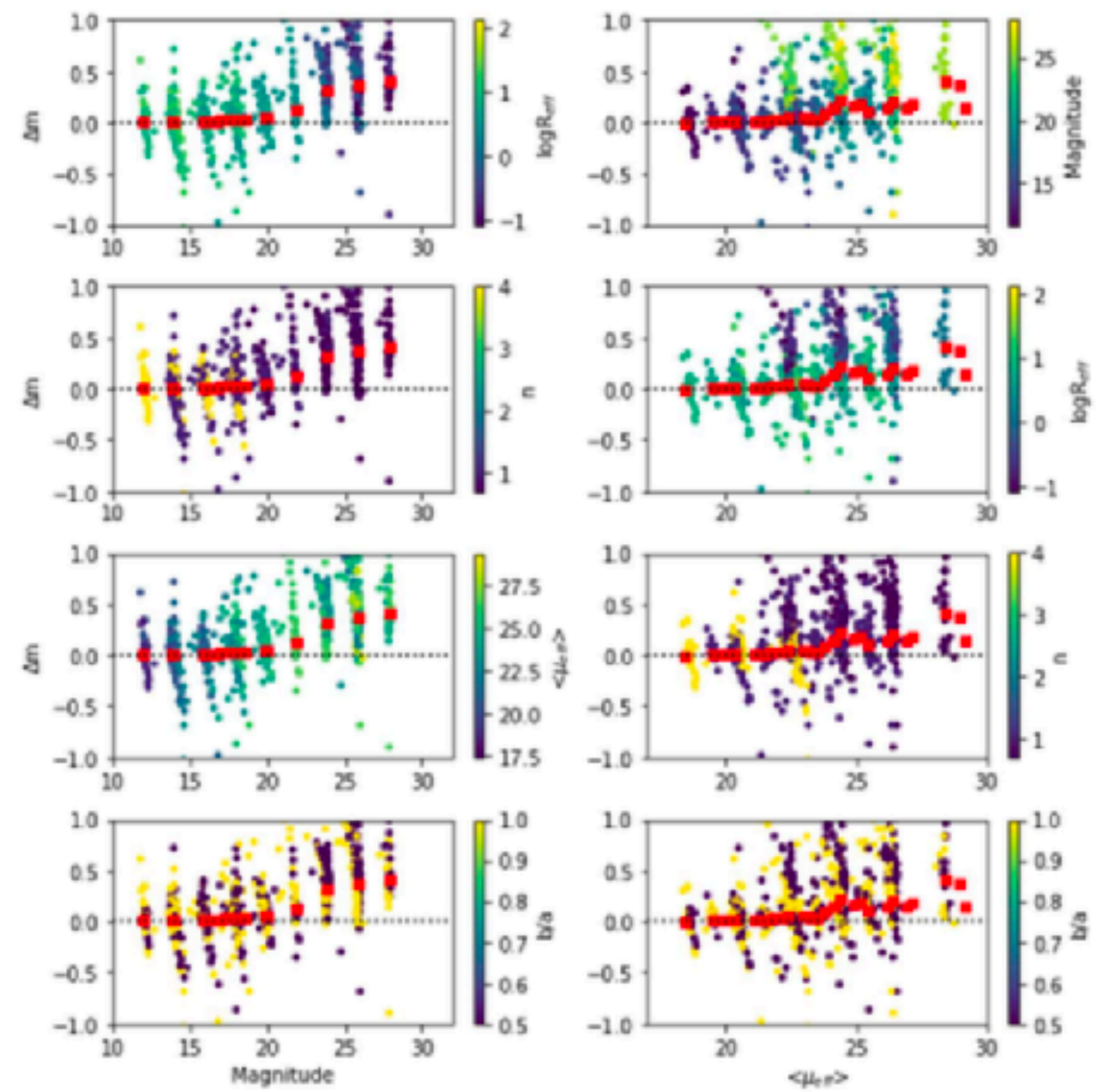
Watkins et al., 2021

Evaluation of the sky subtraction on the LSB performances

- Model galaxy ingestion in the LSST pipeline: Input real galaxies from existing deep imaging surveys (S4G, FDS)

- Serious loss starts at 26 mag/arcsec² while structures if interest have a large part of their flux below the threshold

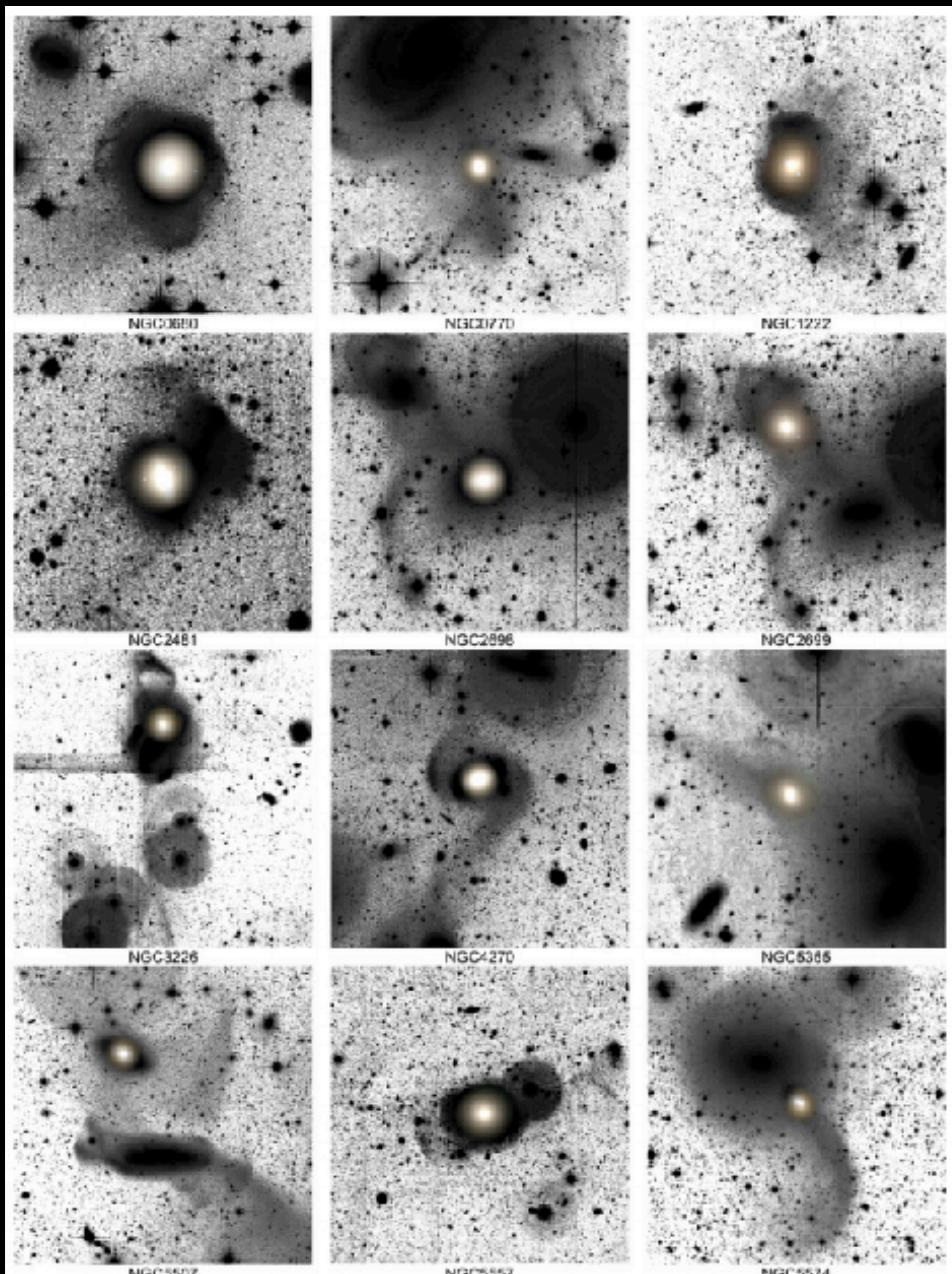


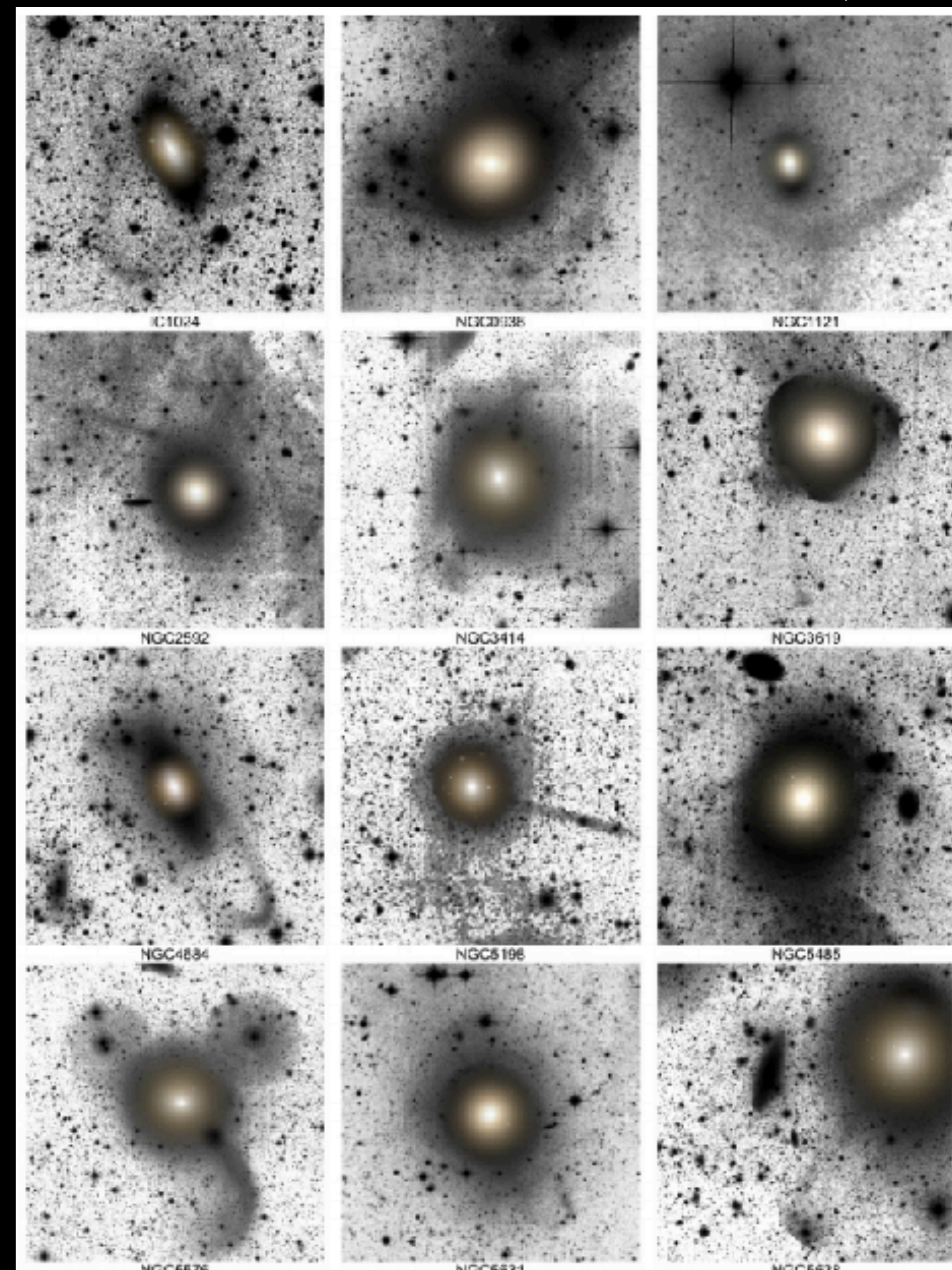


- What are the most critical observables/measurables in LSB tidal features that will constrain theory?

.... and how to automatically detect, classify and annotate them on very large samples?

Bilek et al, 2020





VERA C. RUBIN OBSERVATORY

What is the influence of the survey strategy on the detection of the LSB sources?

The LSST Galaxies Science Collaboration Response to the Survey Cadence Optimization Committee Call

Henry C. Ferguson,[1] Manda Banerji,[2] Sarah Brough,[3] Denis Burgarella,[4] Jeffrey L. Carlin,[5]
Chris A. Collins,[6] Ricardo Demarco,[7] Gaspar Galaz,[8] Eric Gawiser,[9] Nimish Hathi,[1]

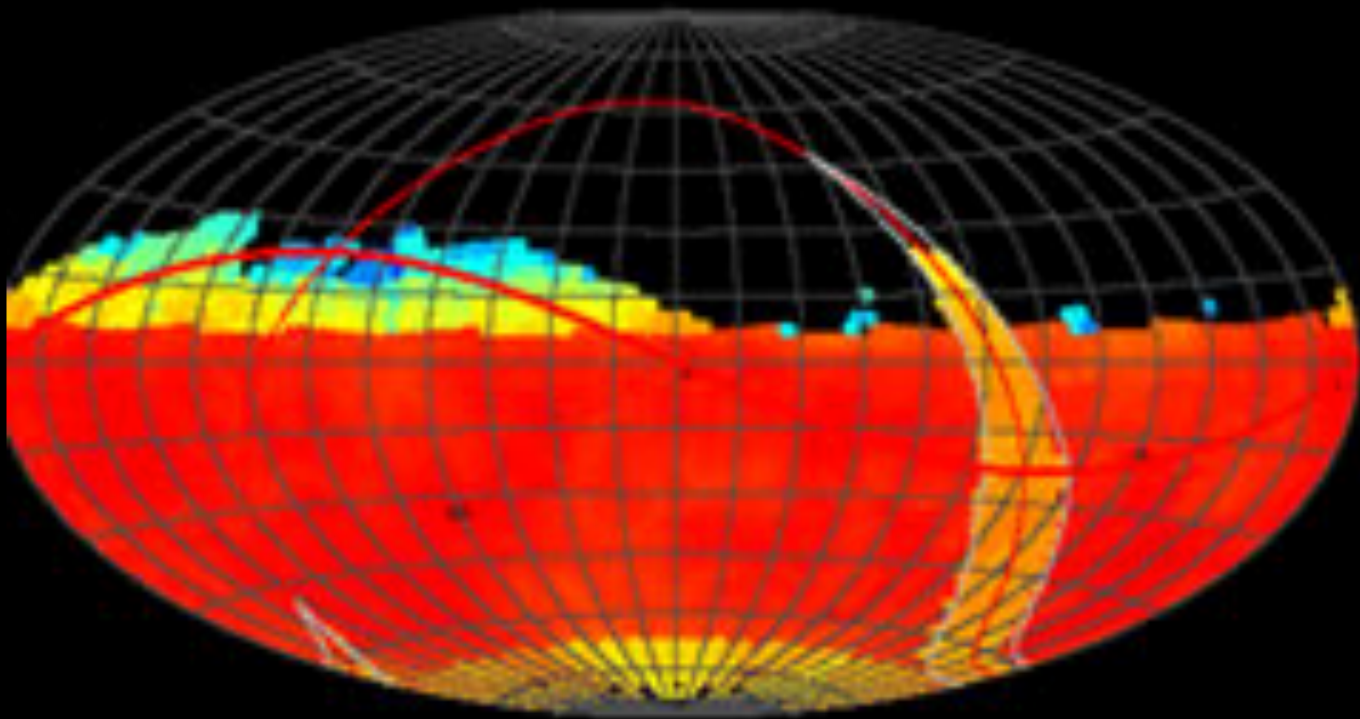
- The scientific goals within the collaboration are focused primarily on the static sky, with a heavy *emphasis on faint, low-surface-brightness objects*. Dithering, seeing, calibration, and sky-background uniformity are all important.

- Interest for a *mini-survey of the Virgo Cluster*: getting 2.5 mag deeper than NGVS

- *Optimizing for good seeing and good photometry* is more important for galaxies science than the timing or spacing of the observations. A priority for homogeneous seeing for the r band

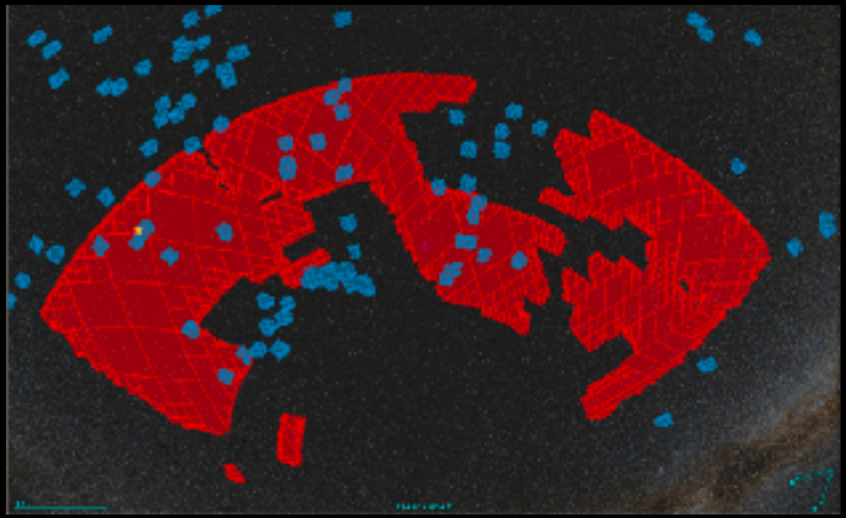
- To average over residual uncertainties in instrumental signatures, galaxies science favors including relatively *large dithers* (many arcminutes to degree scale) over a strategy that would involve only small (arcsecond scale) dithers. Rotational dithers could be advantageous for trying to mitigate the effects of scattered light, but this needs to be verified during commissioning,

LSB science: synergies with other surveys

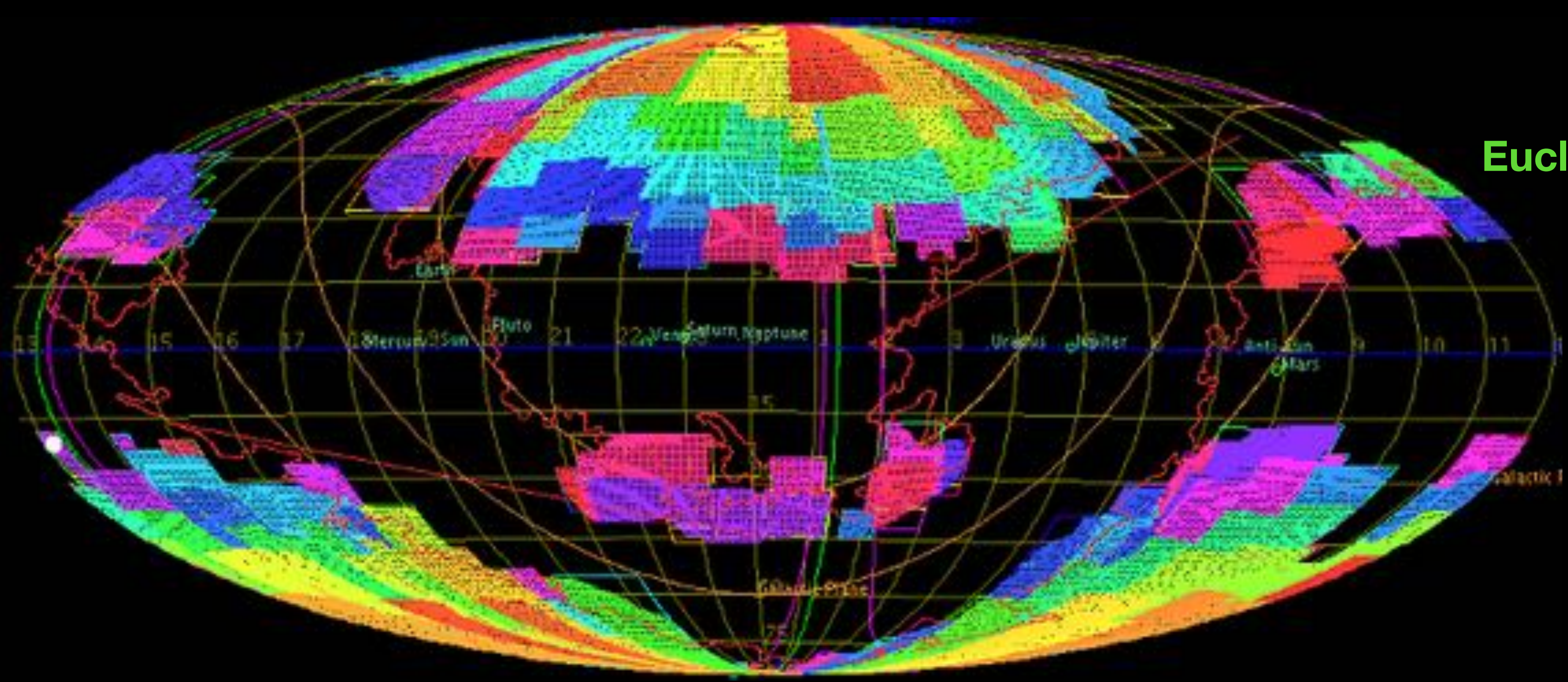


LSST

- A very high sensitivity (10-year data)
- Multi bands



CFHT Large Programmes: CFIS, MATLAS, NGVS



Euclid

- 15 000 square degree
- Surface brightness limit of about 29 mag/arcsec^2 for the Wide
- A wide filter + Near-IR images
- HST resolution: better foreground/ background object separation; GCs follow-ups; SBF distance measurements

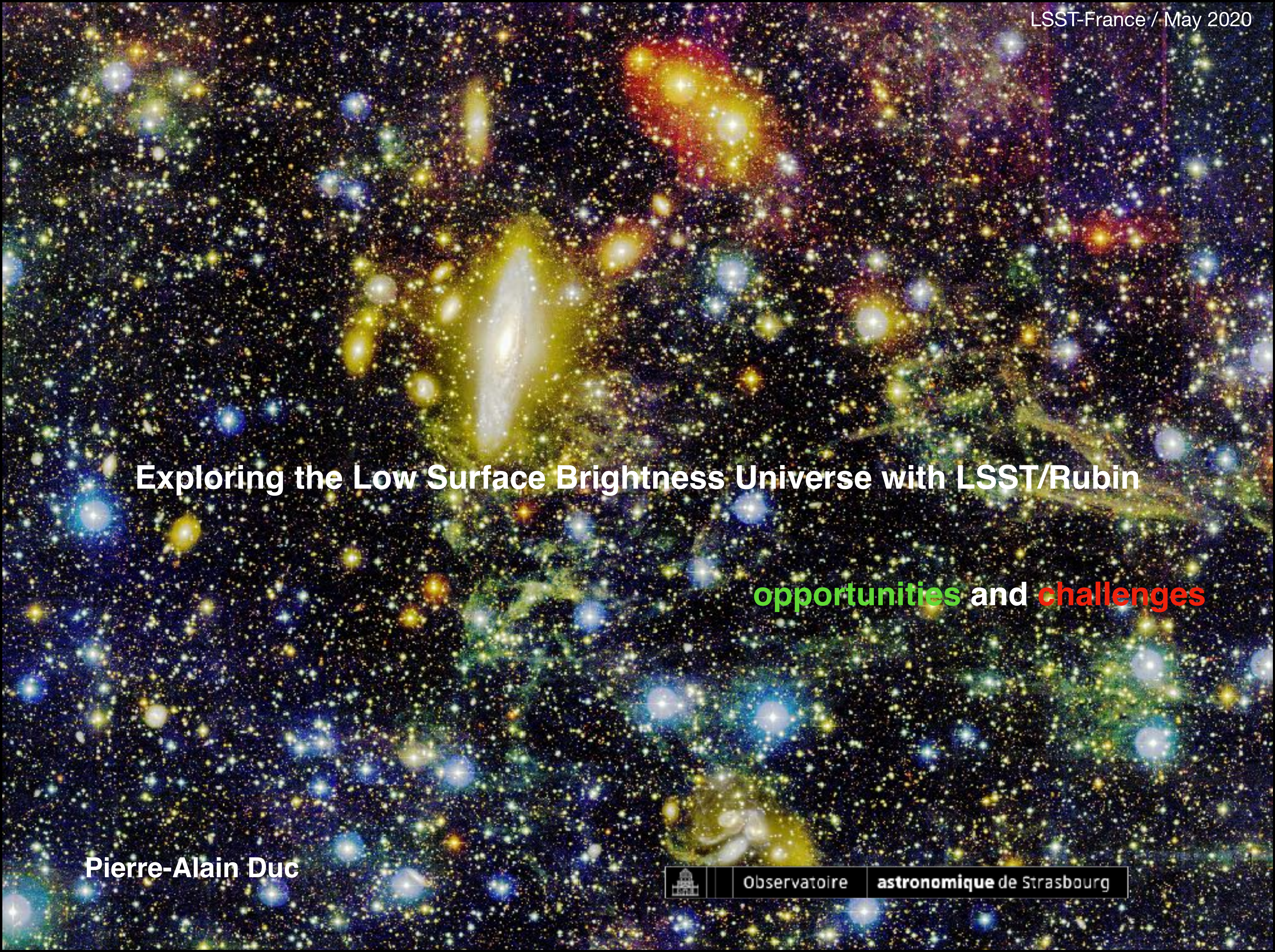
Multiple LSB WPs with the LU Science Working Group

- Enhanced science combining LSST and Euclid data

Question 1: Science

Considering DDPs use cases can be for joint pixel-level processing, or input prior information exchange, or catalog-level processing, what science would be enabled or enhanced with a Rubin-Euclid joint processing?

- Provide a short name and description for your science case.
  - Low Surface Brightness Science: the study of diffuse starlight or other diffuse emission sources, including low surface brightness (LSB) galaxies, ultra-diffuse galaxies, tidal streams, intracluster light, stellar halos, as well as extended emission line regions (e.g., Hanny's Voorwerp), Galactic cirrus, and similar diffuse non-stellar objects.
- Describe the nature and extent of the science gain as compared to using Rubin or Euclid data alone.
  - Enhanced wavelength coverage yields improved SED fitting, thereby improved age/metallicity estimates of LSB sources. Such estimates currently suffer due to the low S/N of LSB detections.
  - LSB at high-redshift: SB dimming effects bias high-z detections toward bright, compact, star-forming regions. Wavelength coverage also introduces time evolution of diffuse structures as a possibility.
  - Euclid will enable detailed studies of the internal structure of faint galaxies (e.g. dwarfs at cosmological distances) which will not be possible using Rubin alone, especially at intermediate redshifts and beyond. These can provide strong constraints on the predictions of the current generation of high resolution hydrodynamical cosmological simulations.
  - Likewise, Euclid's high resolution will help reduce confusion of sources detected in LSST, improving deblending of LSB flux
  - Thanks to its excellent IQ, Euclid will provide catalogs of Globular Cluster candidates associated with the LSB structures, including the dwarfs. They provide key information on their dark matter halo mass and distance (through the GCLF). The u band of LSST (together with the NIR band of Euclid) is most needed to identify GCs among the foreground/background star and galaxy populations.
  - Euclid will (likely) provide a SBF signal, giving another distance indicator.
- Describe as quantitatively as you possibly can how great or significant would the improvement be. (e.g. a back of the envelope type estimate is fine)
  - If both surveys are capable of achieving similarly deep surface brightness limits, then the improvement to the discovery space is constrained by the improvement in the wavelength coverage. Additionally, LSB structures detected in LSST would benefit from higher-resolution Euclid imaging follow-up, allowing for finer physical resolution of, e.g., LSB dwarf galaxy structure, tidal streams, etc.
  - Removal of unresolved contaminants via Euclid also increases accuracy of LSB measurements
  - Confirmation of low-sigma detections are critical: sources detected in multiple filters across two surveys are much less disputable.
  - Additionally, Euclid should suffer less from scattered light and internal reflections, allowing for proper rejection of artifacts and other false LSB detections in both surveys
- Cite relevant papers in support of your science case if they exist already. It is fine if they don't, as papers might be an outcome of this work!
  - Soliciting appropriate citations here, given how broad the topic is. Examples might include: theoretical predictions regarding utility of ICL evolution studies/tidal debris and halo formation, previous LSB science observation results, and theoretical papers on LSB galaxy formation.
    - Suggestions so far: Montes & Trujillo 2019, Montes et al. 2020, Montes et al. 2021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