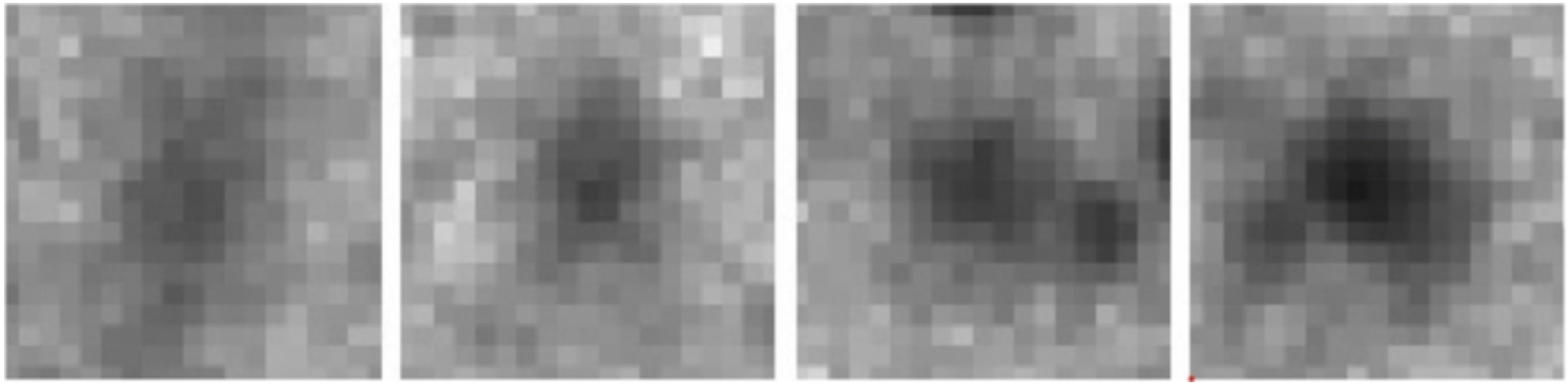
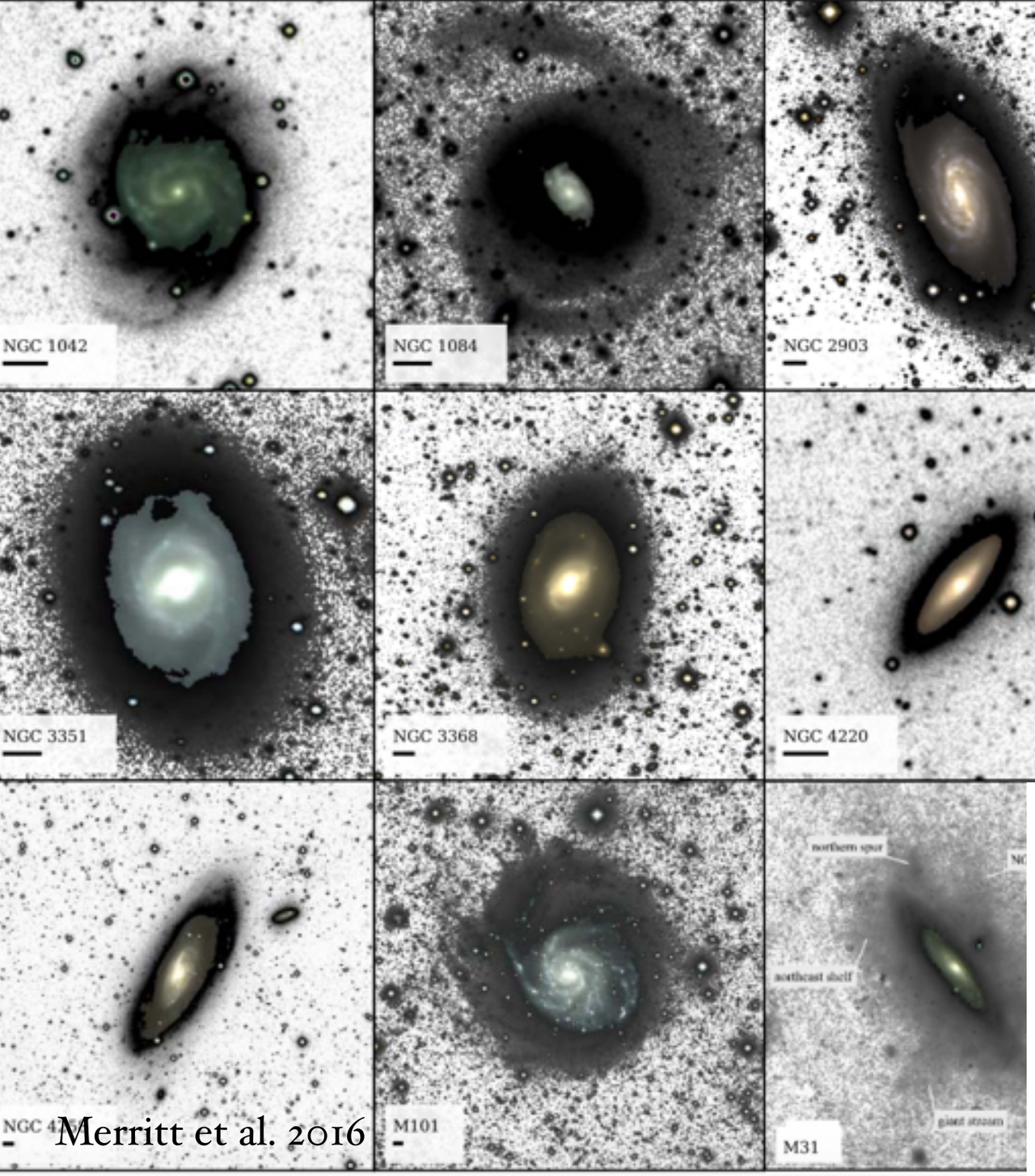


Hunting Low Surface Brightness Galaxies with the Dragonfly Telephoto Array

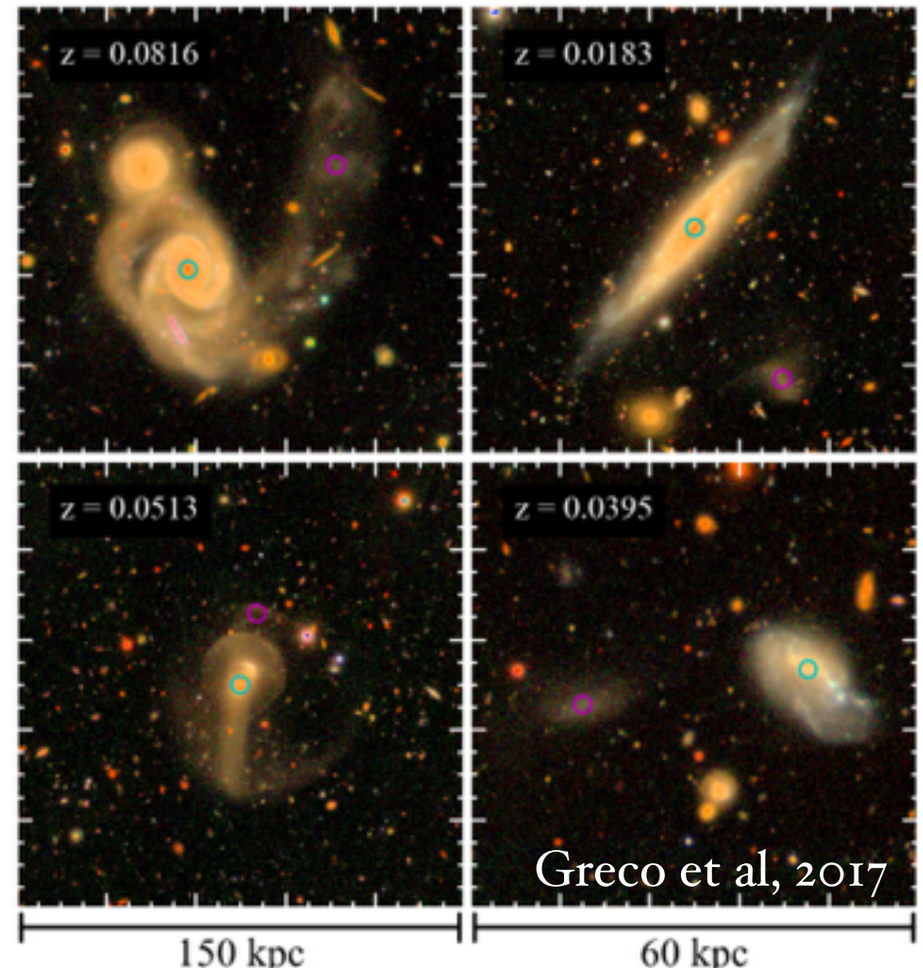
Shany Danieli (Yale)

Near-Field Cosmology with the DES DR1
Thursday, June 28th 2018

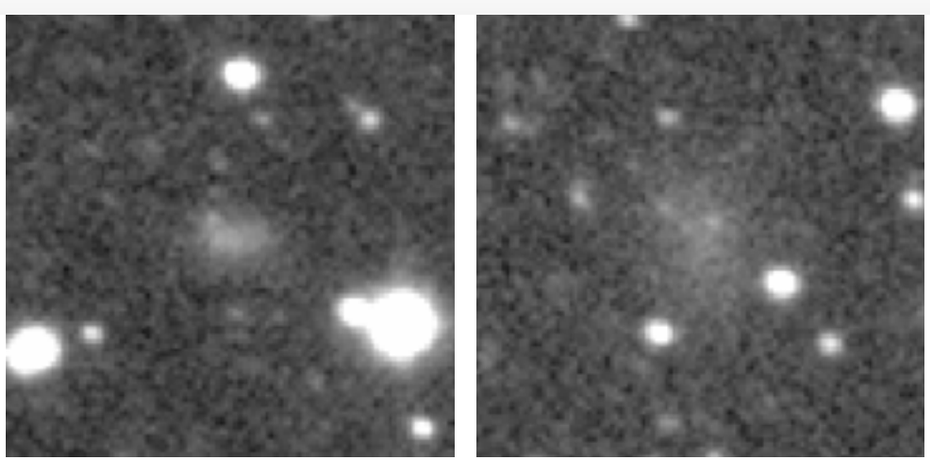
Pieter van Dokkum (Yale), Roberto Abraham (Toronto), Charlie Conroy (Harvard, CfA), Lamiya Mowla, Yotam Cohen (Yale), Allison Merritt (MPIA), Jielai Zhang, Deborah Lokhorst & Colleen Gilhuly (U Toronto)



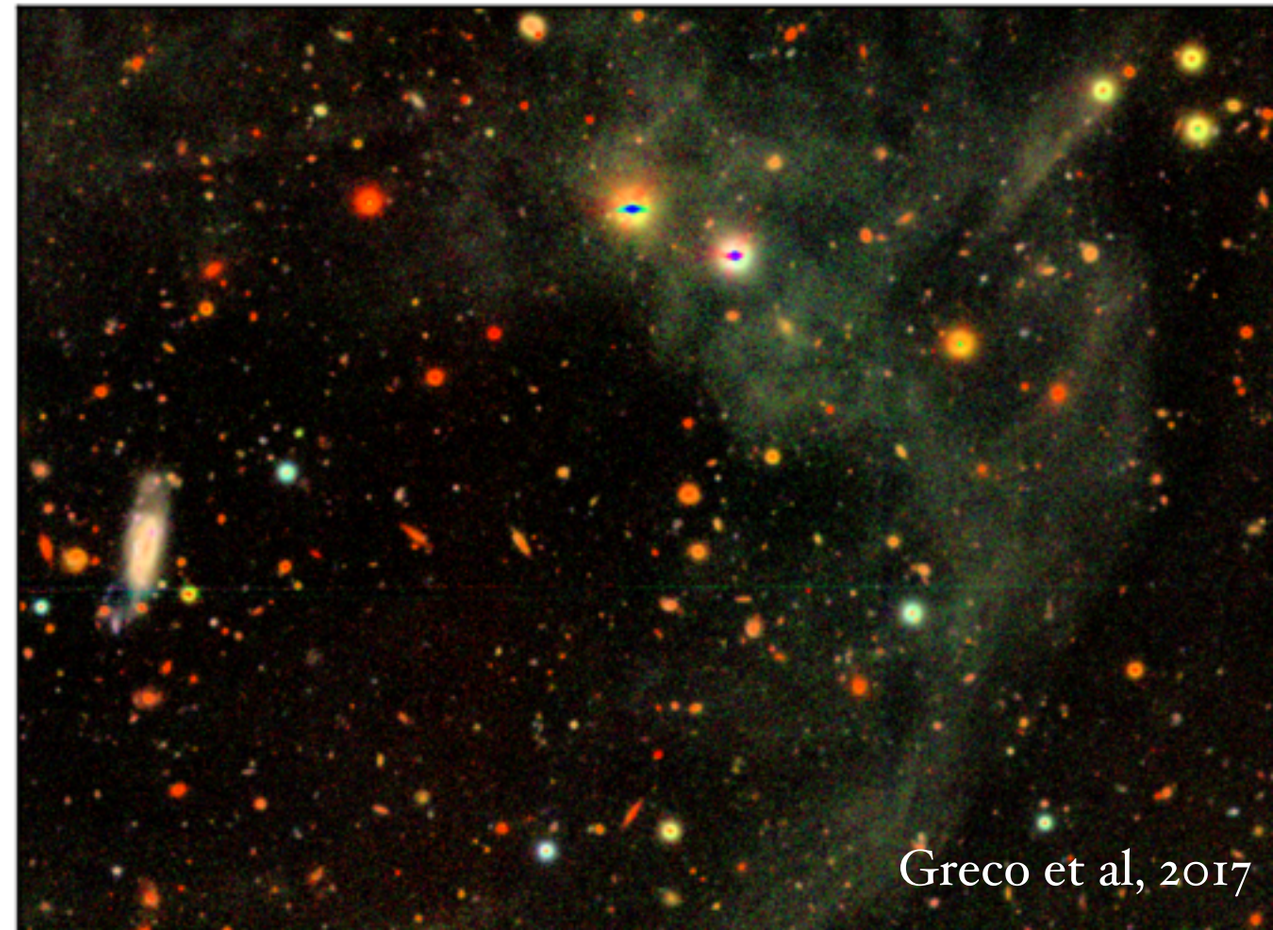
Merritt et al. 2016



Greco et al, 2017

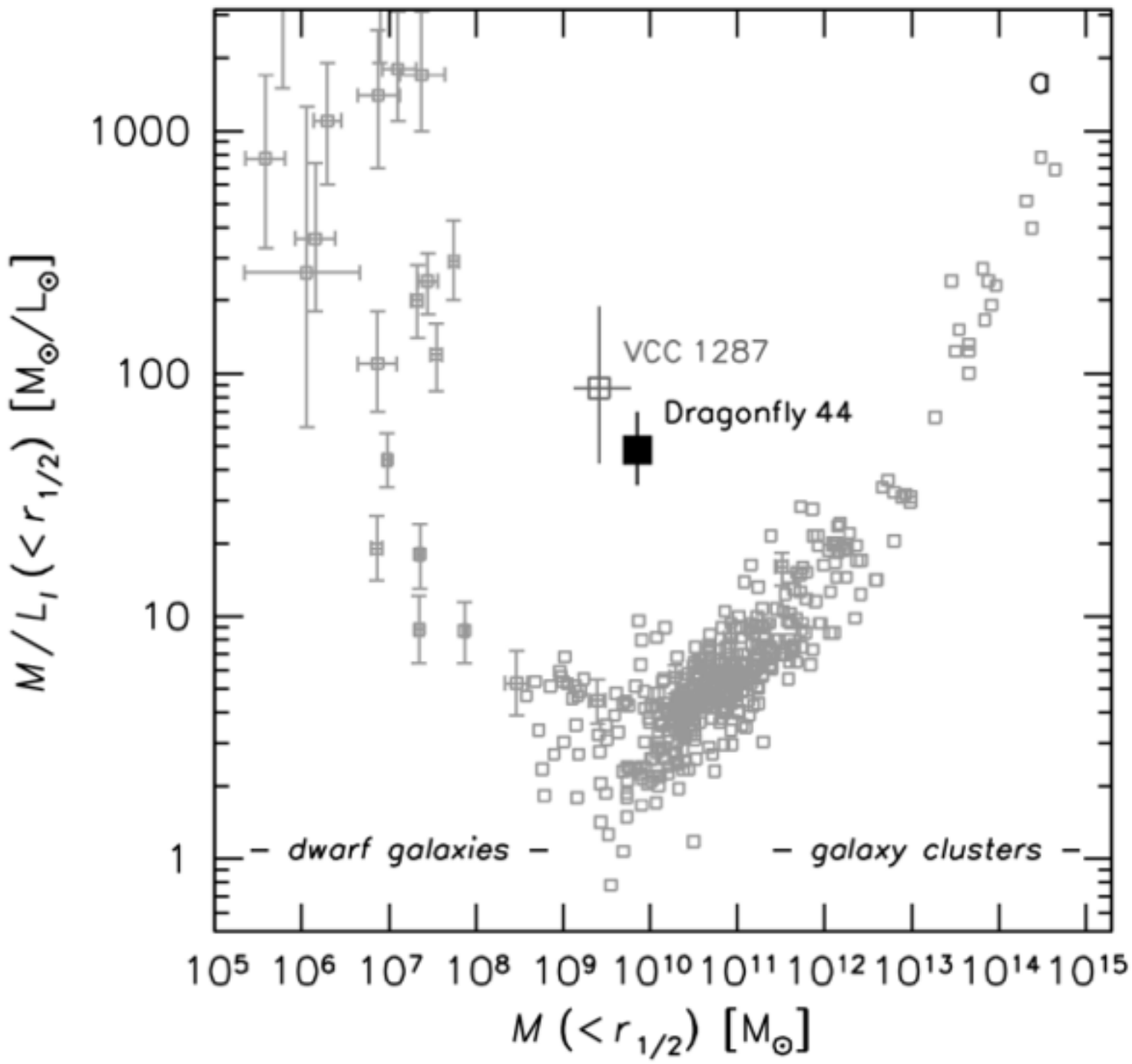


Danieli et al. 2016



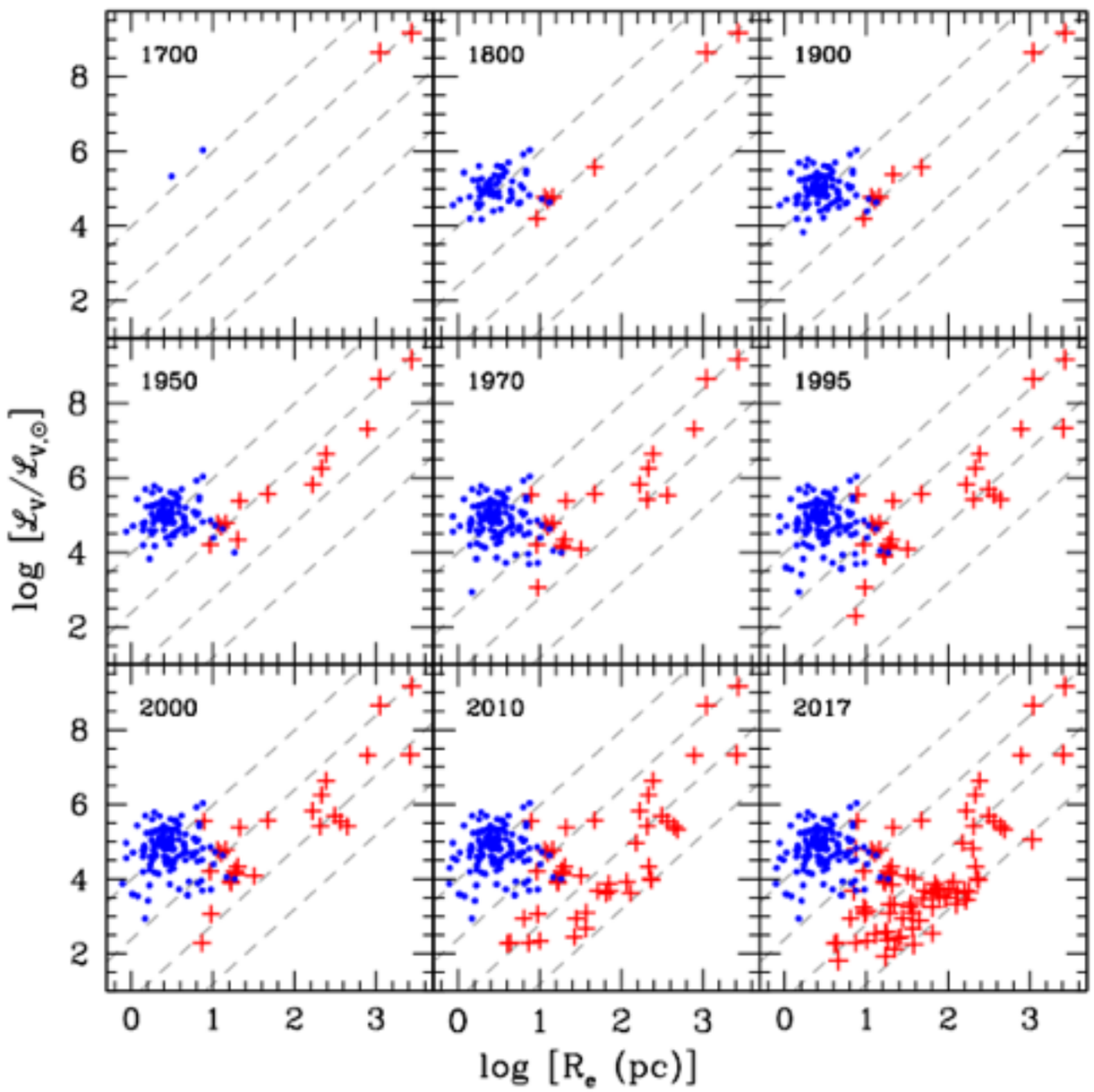
Greco et al, 2017

Mass to light Ratio



van Dokkum et al. 2016

Dwarf galaxies are low surface brightness



Munoz et al. 2018

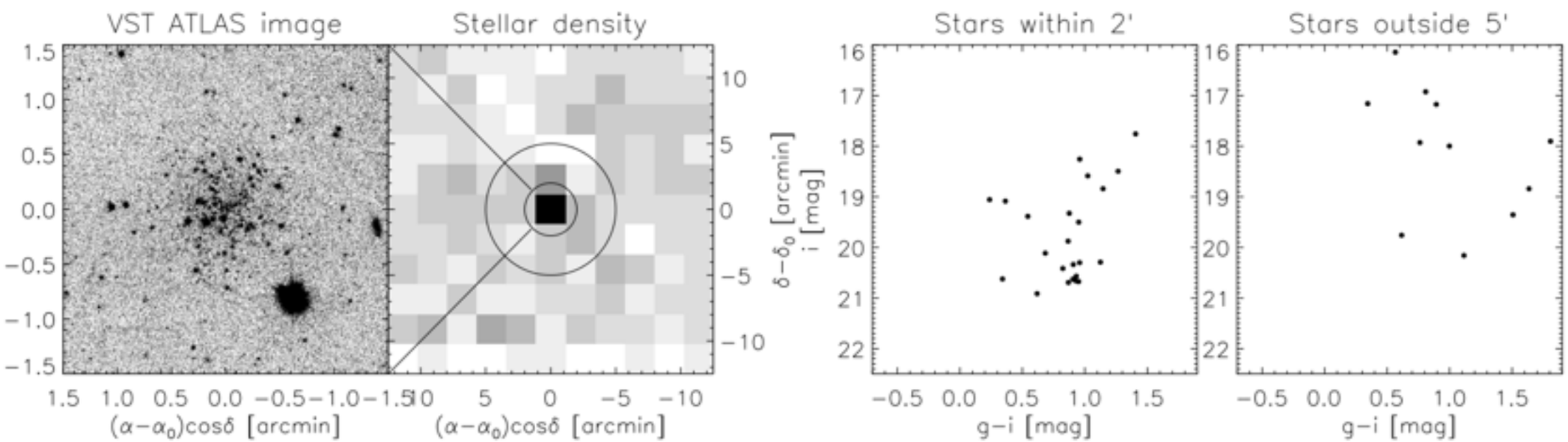
The discovery of galactic satellites as a function of time

blue points: GCs
red crosses: satellites

Local Group dwarfs are low surface brightness

Star count methods

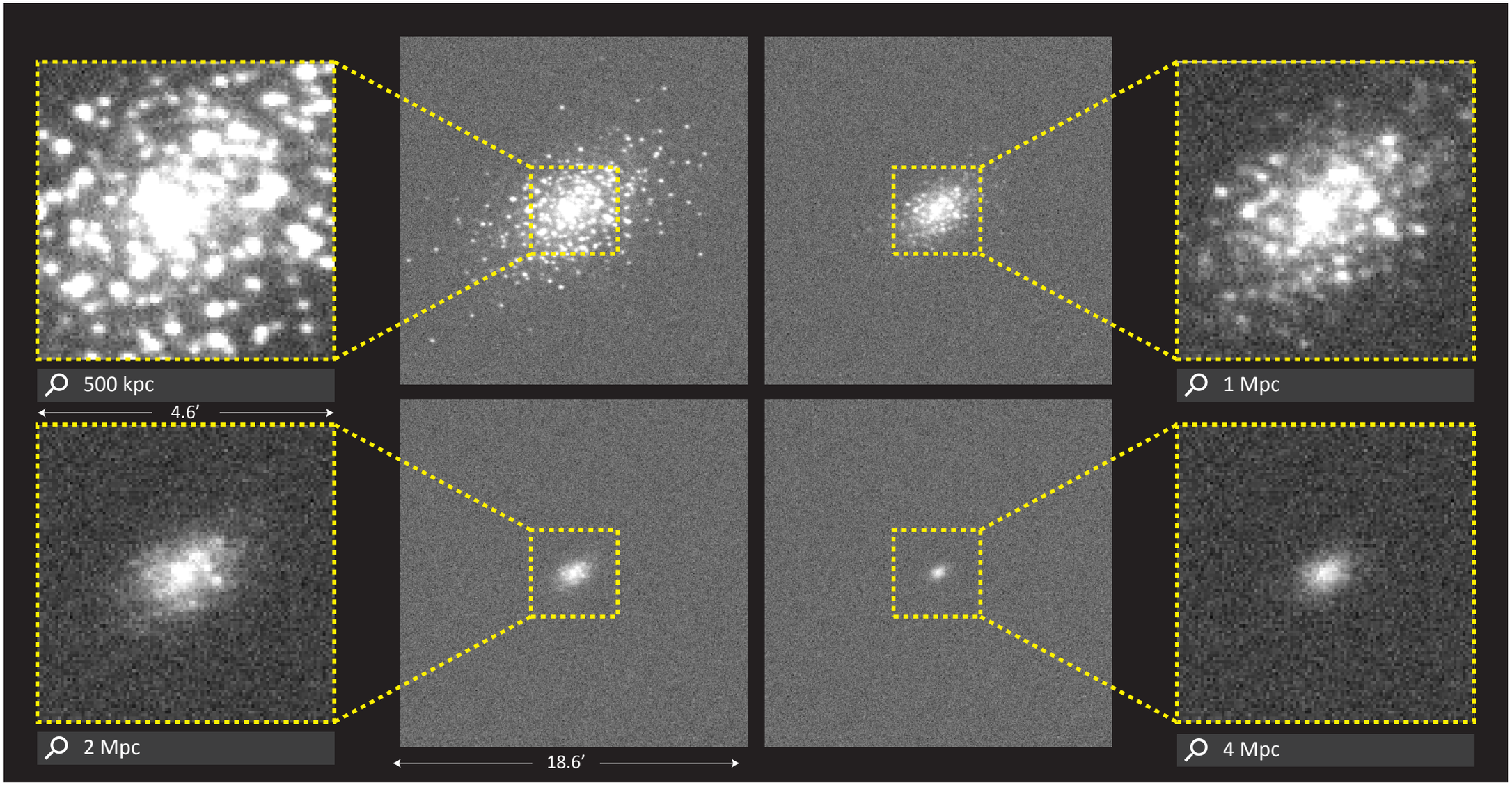
Discovery of a New Milky Way satellite in Crater



Belokurov et al. 2014

Star count methods → Integrated light detections

$$M_* = 10^5 M_\odot$$



ArtPop, Danieli et al. 2018

So... how do we go from here?

THE ASTRONOMICAL JOURNAL VOLUME 79, NUMBER 6 JUNE 1974

Faint envelopes of galaxies

John Kormendy
Hale Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena, California 91109

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Institute for Advanced Study, Princeton, New Jersey 08540
(Received 30 October 1973; revised 22 March 1974)

Photographic surface photometry is presented for 12 fields containing small and moderately rich groups of galaxies, as well as isolated galaxies of various morphological types. Surface brightnesses of 26–28 green mag per square arcsec are reached using isodensity tracings with small density steps. Star images provide the magnitude calibrations. Observations confirm the existence of faint envelopes $\gtrsim$ 100 kpc in diameter previously reported for elliptical galaxies by de Vaucouleurs (1969) and Arp and Bertola (1969, 1971). *When measured at the same surface brightness, spiral galaxies are not substantially smaller than ellipticals of the same luminosity.* Some groups of galaxies dominated by ellipticals are imbedded in common luminous envelopes up to 1.3 Mpc in diameter. In the Coma cluster there is evidence for more luminosity than would be produced by overlapping galaxy halos. The NGC 383 grouping of ellipticals, and the NGC 3623 group of spirals show no definite intergalactic matter at 27 green mag per square arcsec. If intergalactic matter is present with a mass at least equal to that in visible galaxies, it must have a mass to light ratio $\gtrsim$ 3(M/L) galaxies. The isodensity tracing technique is examined in detail in an Appendix. Various photographic and optical effects that might produce spurious halos are shown to be negligible. However, plate background variations are important, and make 103a emulsions more suitable for tracing than the baked IIIa-J emulsion. Generally, isodensity tracing is found to be suitable for rapid survey work at faint light levels, but is insufficiently accurate for precise photometry.

INTRODUCTION

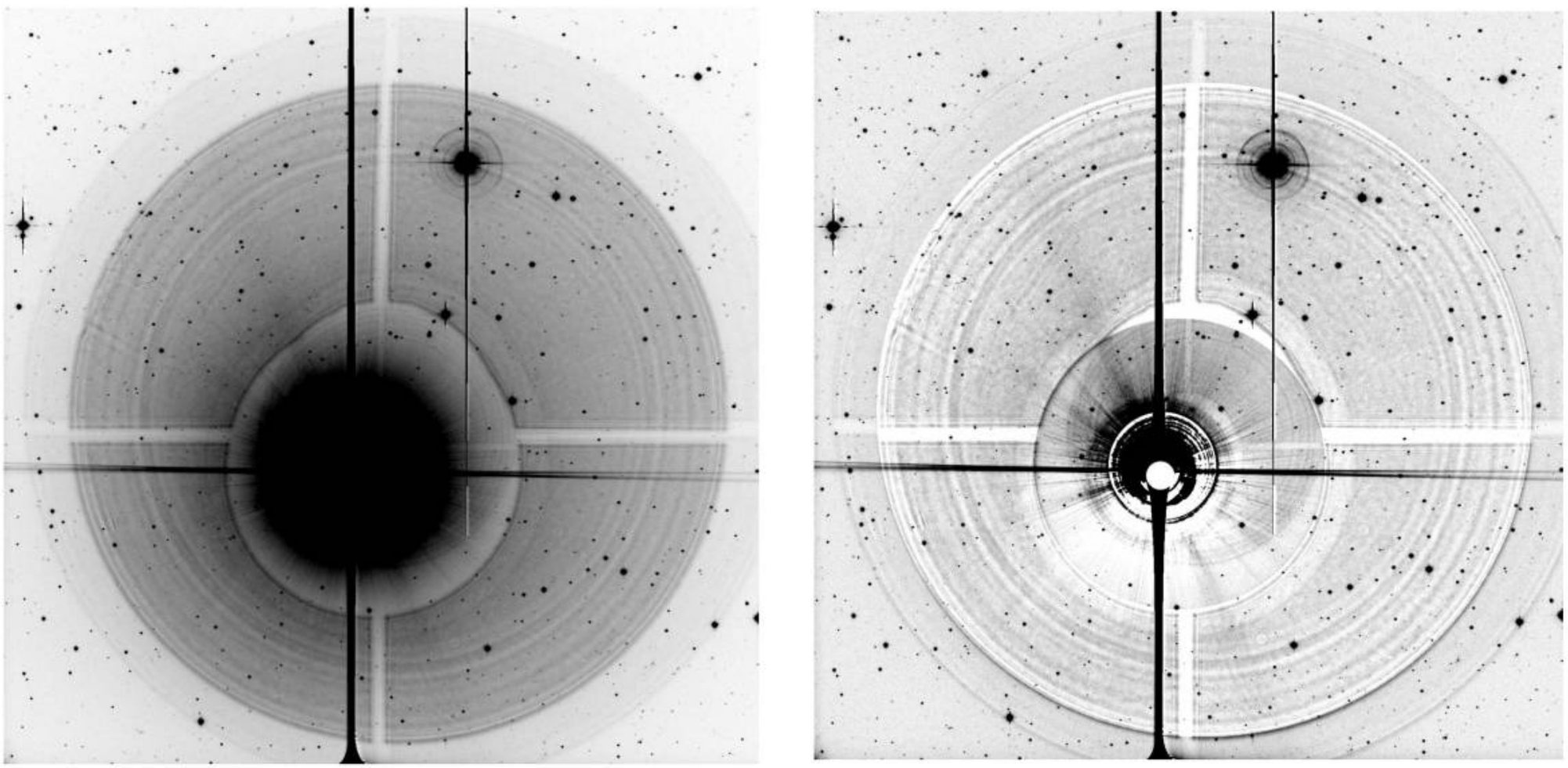
IN recent years, several authors have presented

the objects studied in AB were centered in the field, so that effects symmetric about the optic axis, such as vignetting and certain ghost images, could affect the

No progress in 40 years!

PSF of conventional telescope

- Reflecting telescopes produce complex PSFs, which limit low surface brightness studies to ~29 mag/arcsec^2



Slater, Harding, & Mihos 2009

Deep imaging with conventional telescope

Not galaxy light!
Optical "ghosts" from nucleus

3.6m Canada France Hawaii Telescope

Duc et al 2015

Ideal telescope

- Ideal telescope has no mirrors and an unobstructed light path → refractor!
- Problems: optically slow, no longer in active development for astronomy

$$\Phi \approx a f^{-2} \frac{\bar{E}\bar{S}_\lambda}{hc} \bar{\lambda}\, \Delta\lambda$$

Φ = number of photons per pixel
S = surface brightness
f = focal ratio
E = throughput of instrument
a = pixel area

Telephoto lenses

- In the real world, refractors are alive and well - could telephoto lenses be used for low surface brightness astronomy?

Canon 400/2.8 L IS II USM telephoto lenses

The Dragonfly Telephoto Array

$$D_{\text{eff}} = \sqrt{N_{\text{lens}}} \cdot D$$

$$f/_{\text{eff}} = f/D_{\text{eff}}$$

$$f/_{\text{eff}} = f/\sqrt{N_{\text{lens}}}$$

$f = 400$ mm

$D = 0.143$ m

$f/2.8$

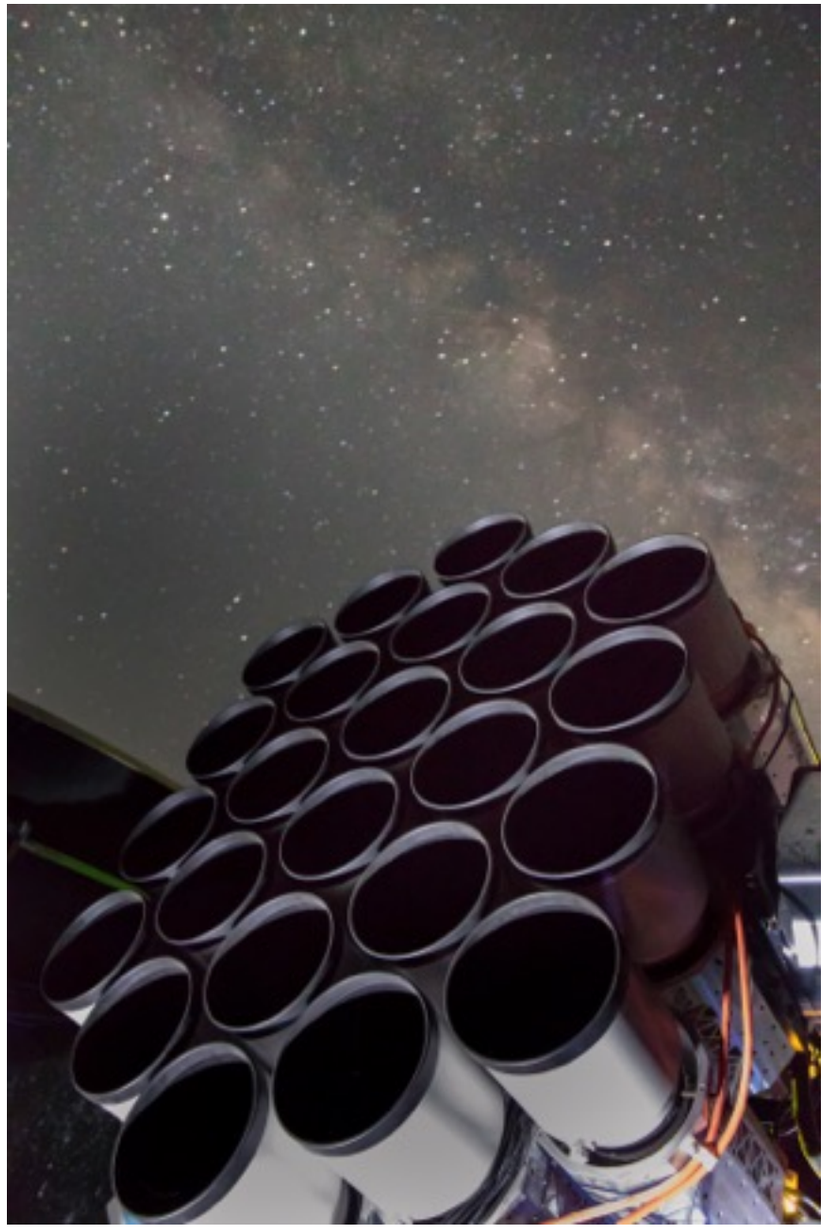
$f = 400$ mm

$D_{\text{eff}} = 0.4$ m

$f_{\text{eff}}/1.0$

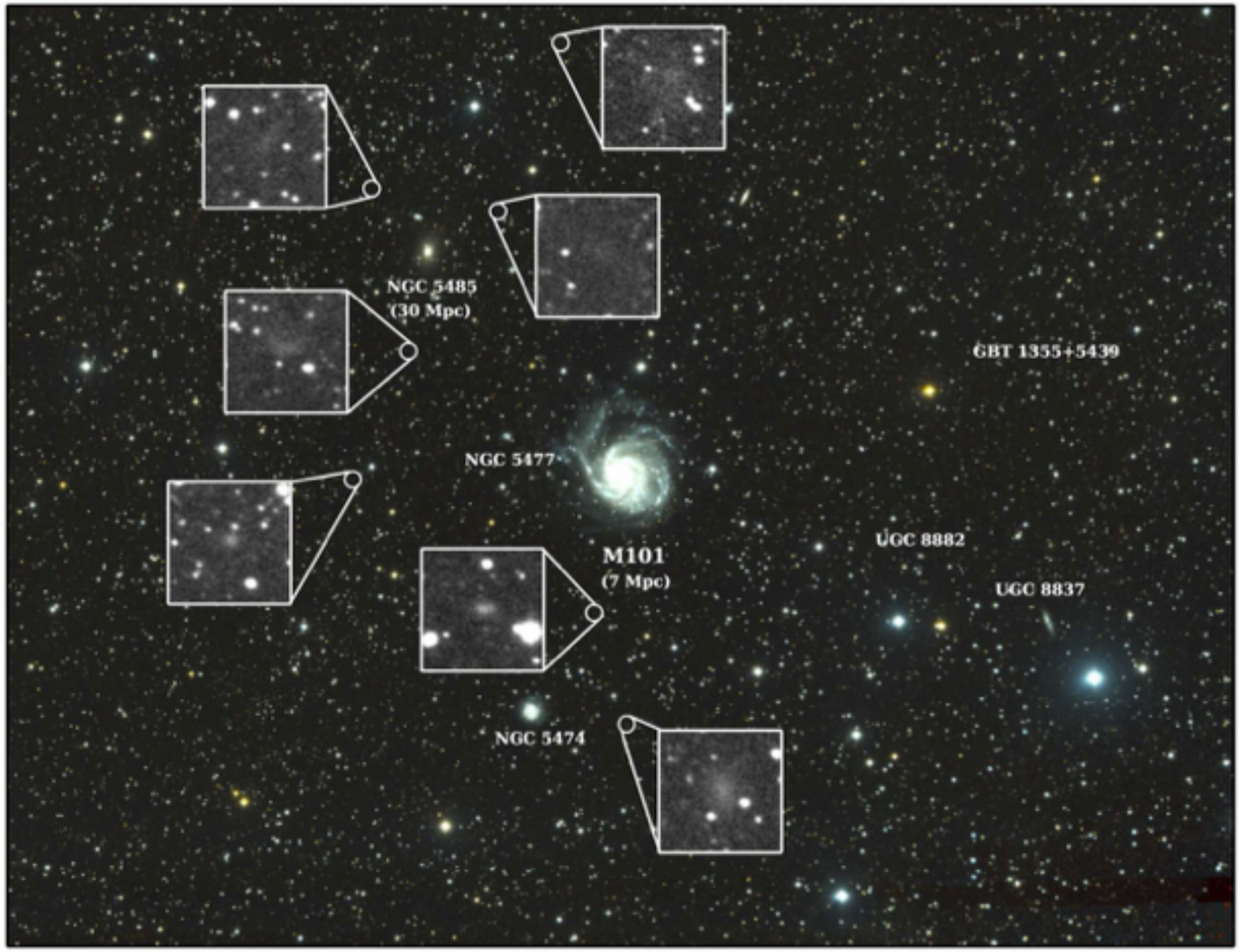
The Dragonfly Telephoto Array

- 2x24 Canon Telephoto lenses
- Effectively a 1.0m f/0.4 refractor
- 2x3 degree^2 field of view
- 2.9" pixels
- Fully robotic - operates every clear night



PC: Pieter van Dokkum

Early results - LSB galaxies in the field of M101



Merritt et al. 2014

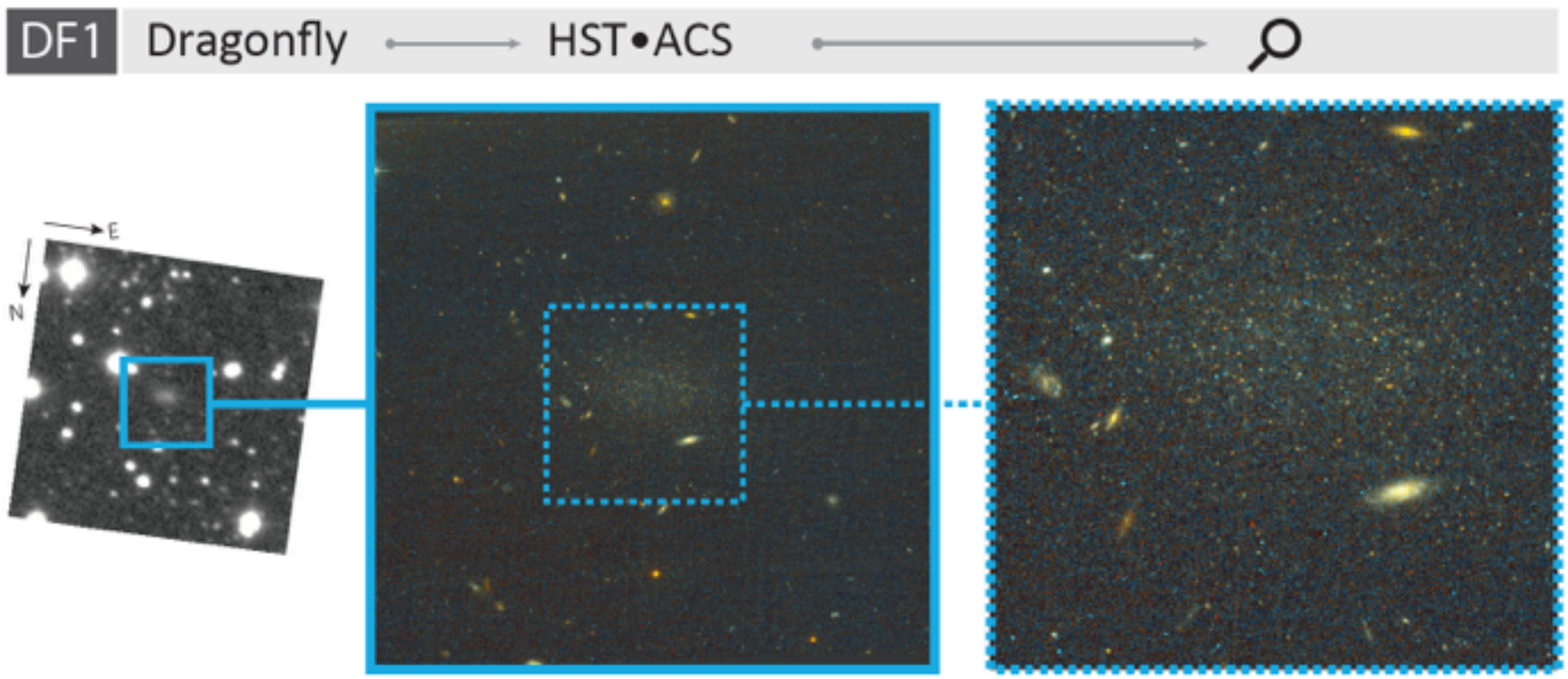
- 7 large LSB galaxies near the spiral galaxy M101 (7 Mpc)

$$\mu_g = 25.5 - 27.5 \text{ mag arcsec}^{-2}$$

$$R_{\text{eff},\theta} = 10 - 30 \text{ arcsec}$$

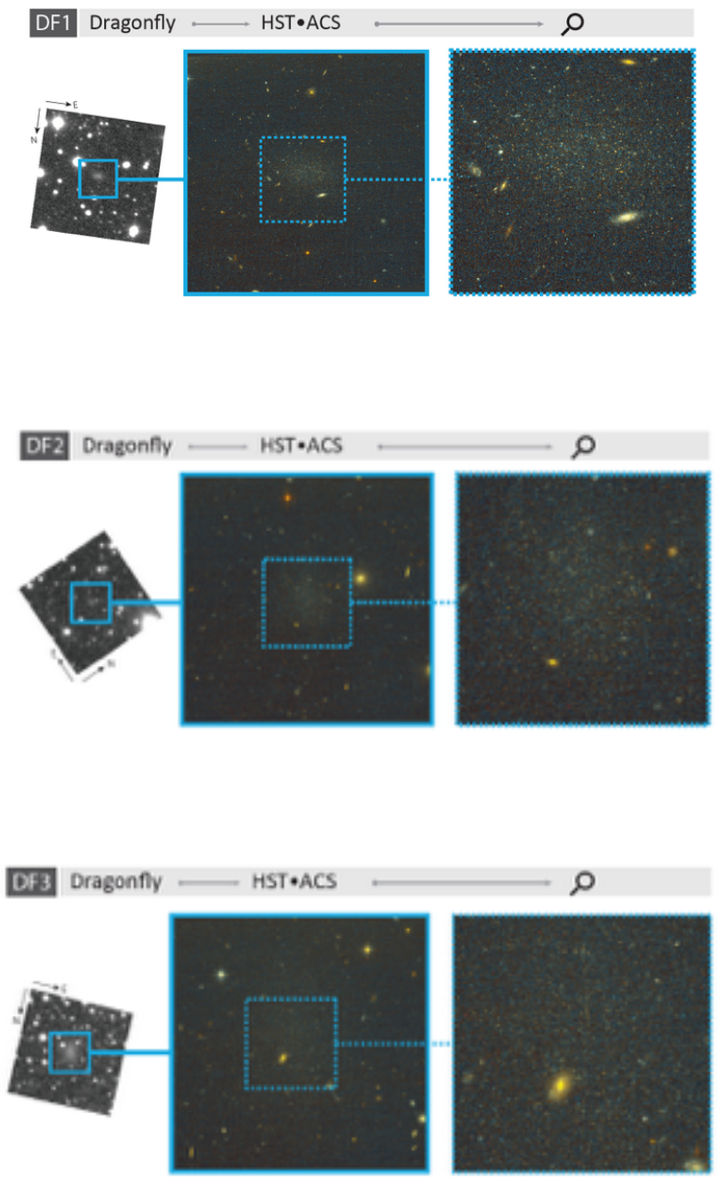
- Need higher resolution data for measuring distance

HST Imaging resolved the blobs into stars

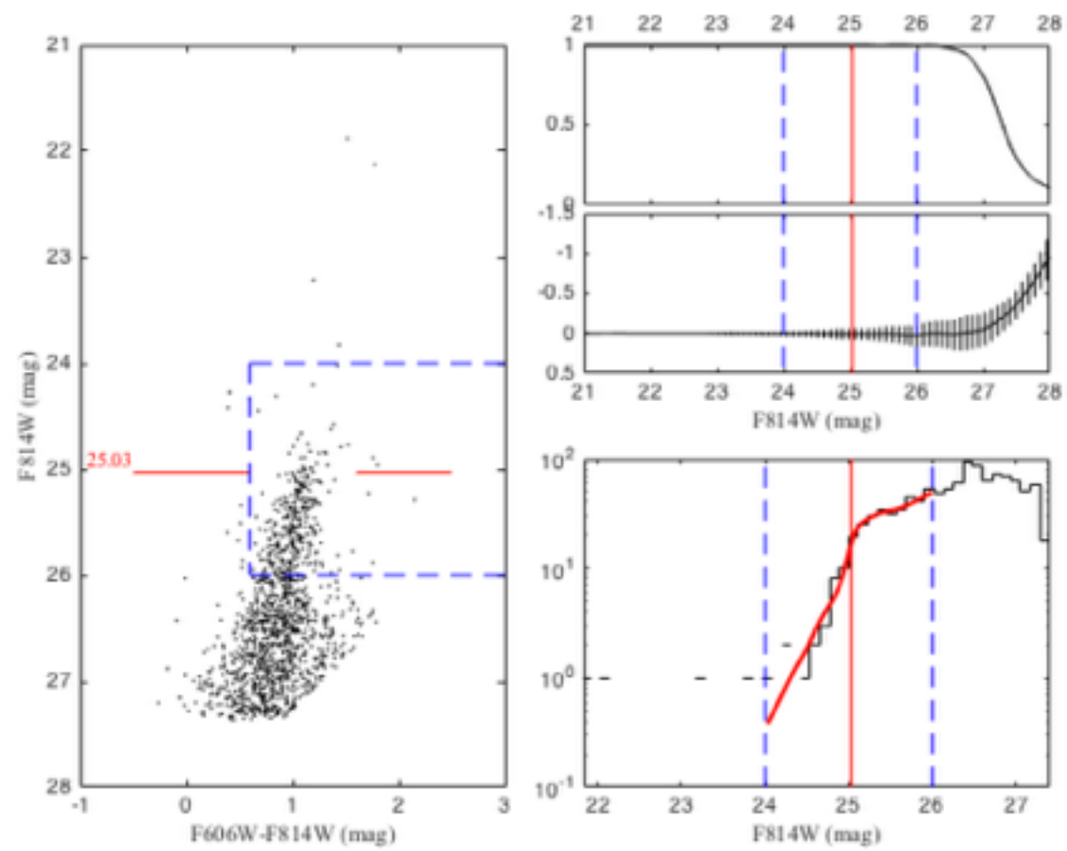


Danieli et al. 2016

Distance measured using the TRGB method

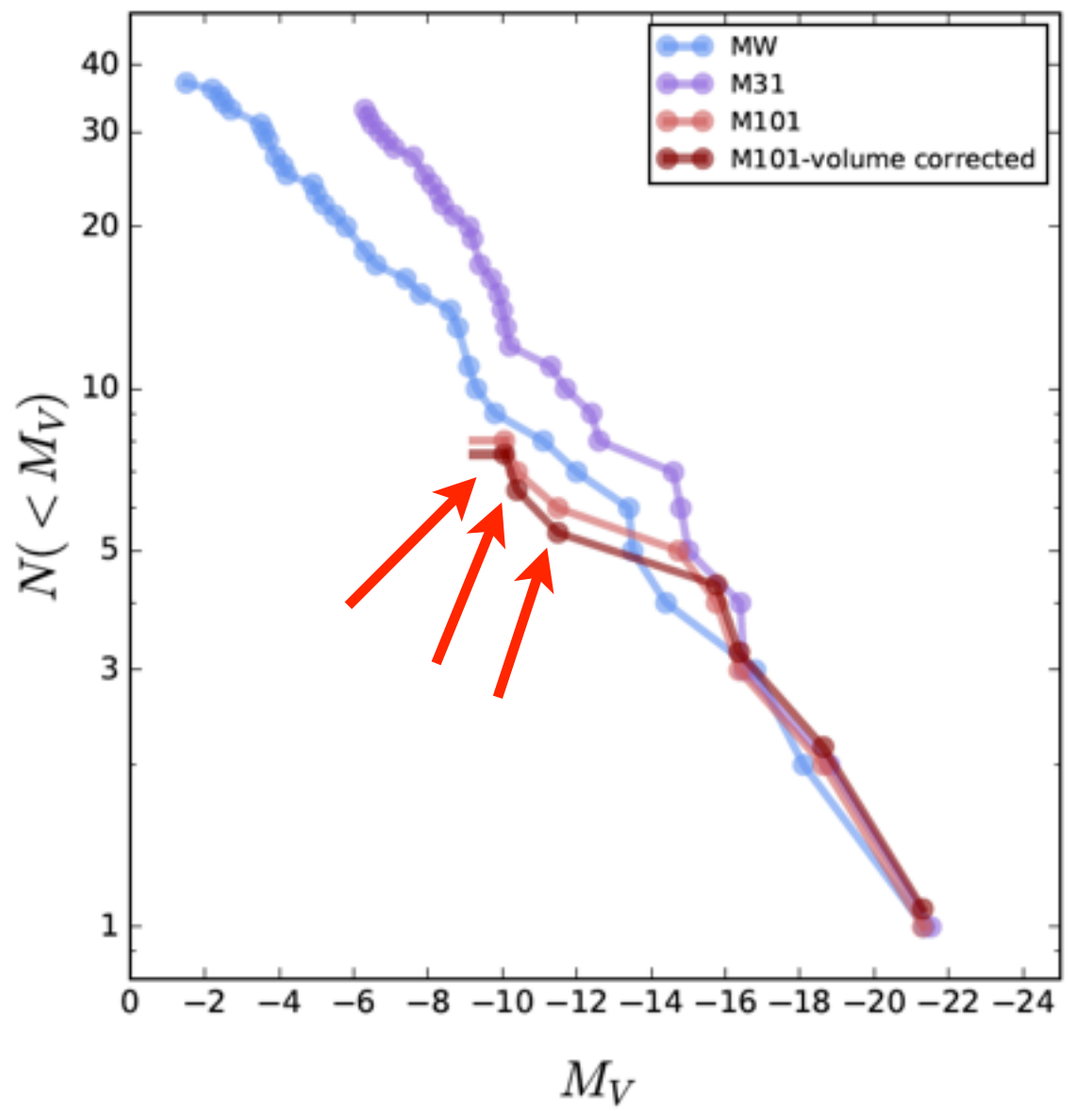


3/7 galaxies were resolved into stars including the Red Giant Branch



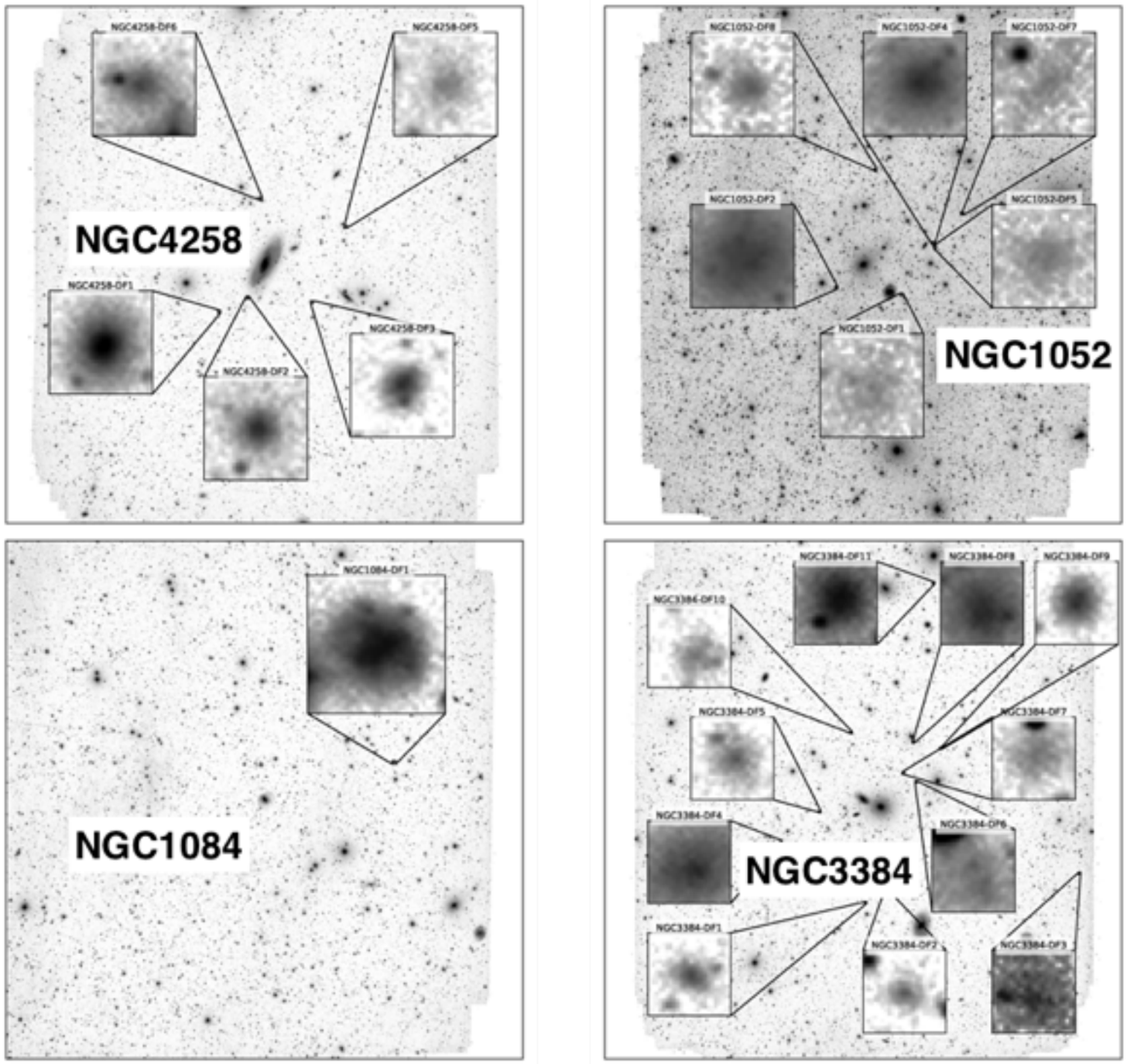
Danieli et al. 2016

Observed cumulative luminosity function



Danieli et al. 2016

And around 4 more central galaxies



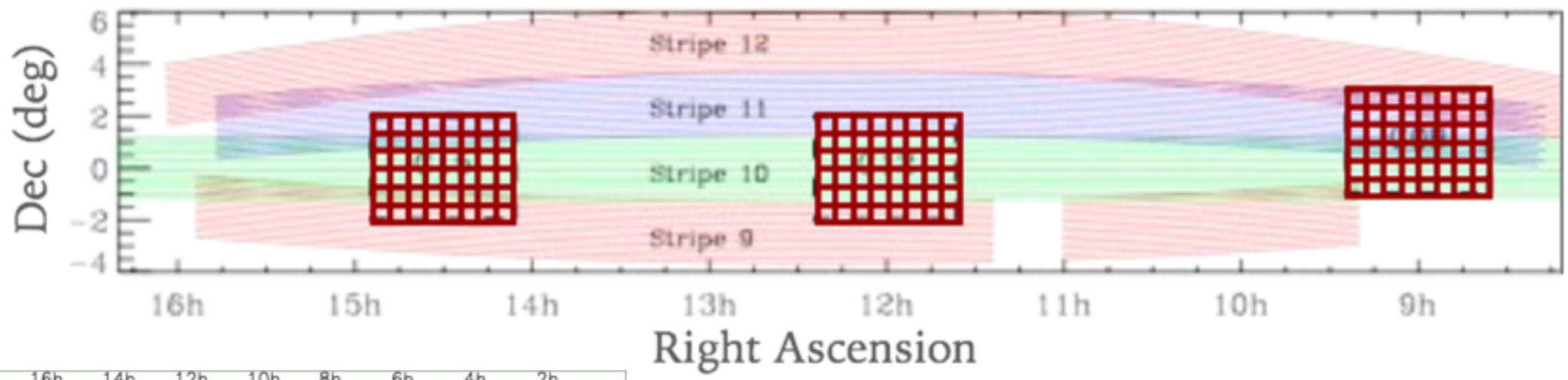
Cohen et al. 2018

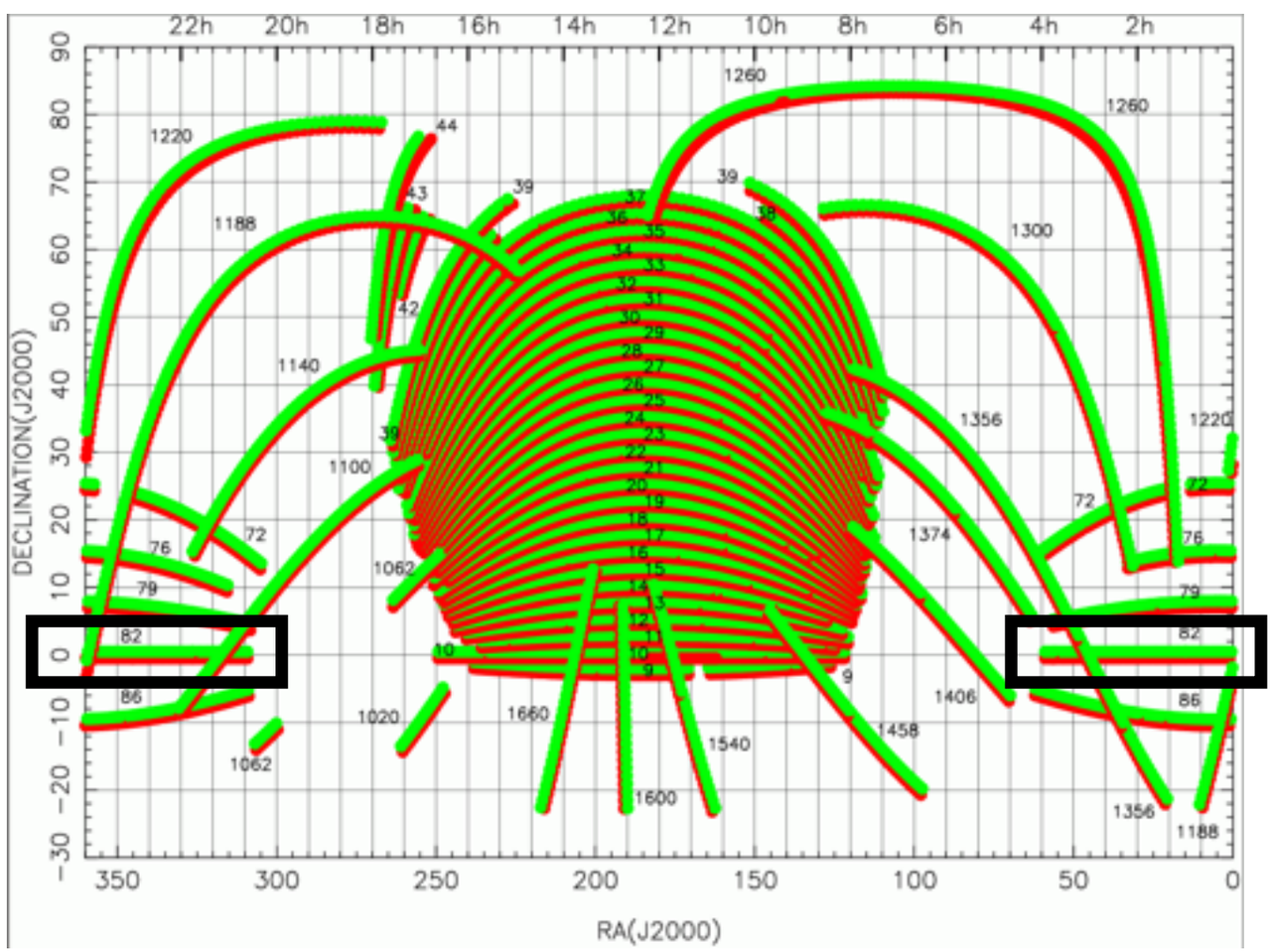
The Dragonfly Wide Field Survey

- A wide field survey covering 300-500 square degrees at the lowest surface brightness levels (30-32 mag/arcsec^2)
- Imaging in g and r bands
- Looking for: dwarf galaxies, UDGs, ICL, IGL, stellar halos, tidal features, etc.
- Covering the SDSS Stripe 82 and the GAMA fields
- Overlap with deep high-res optical imaging and spectroscopy

The Dragonfly Wide Field Survey - Coverage

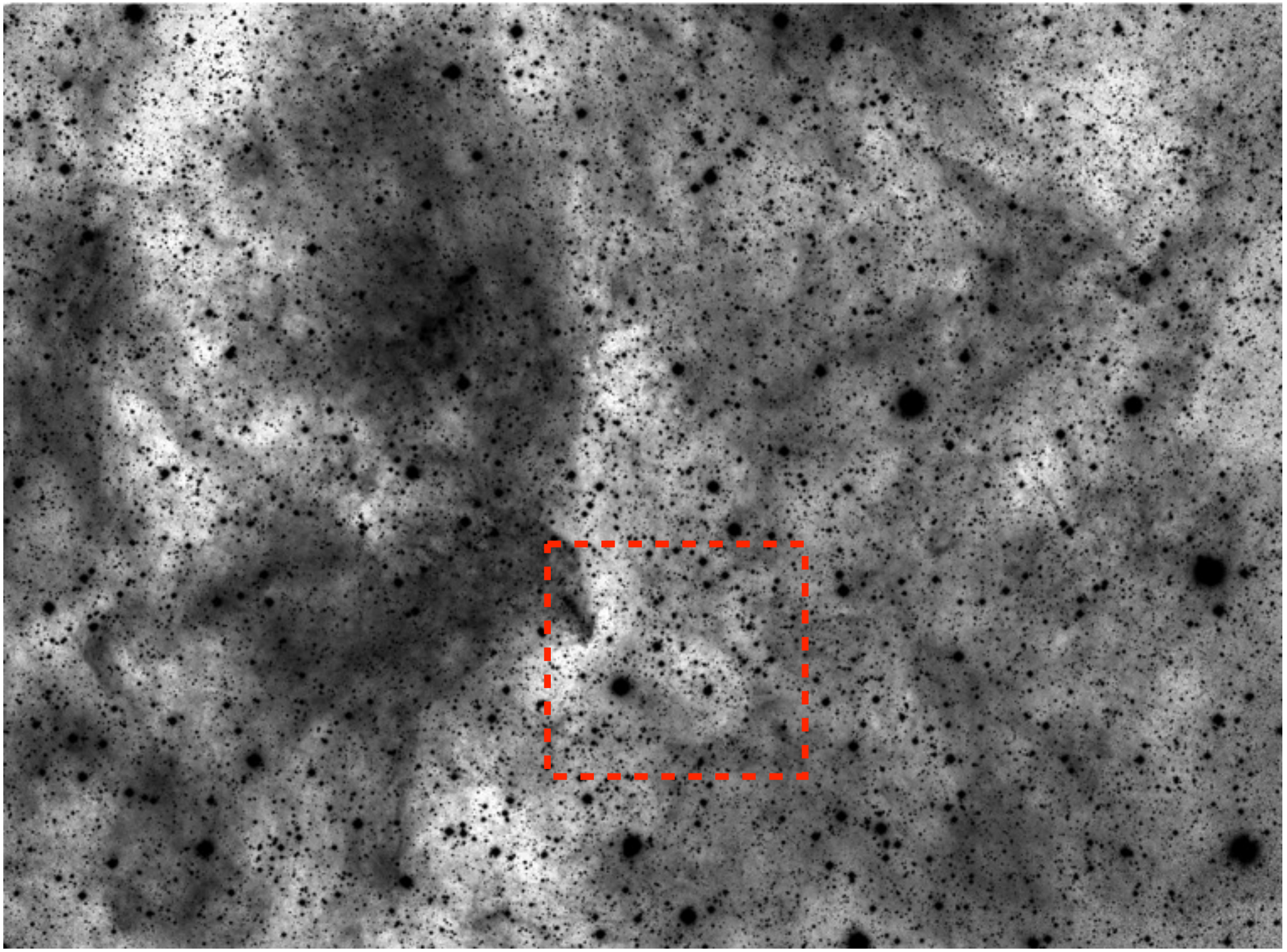
GAMA

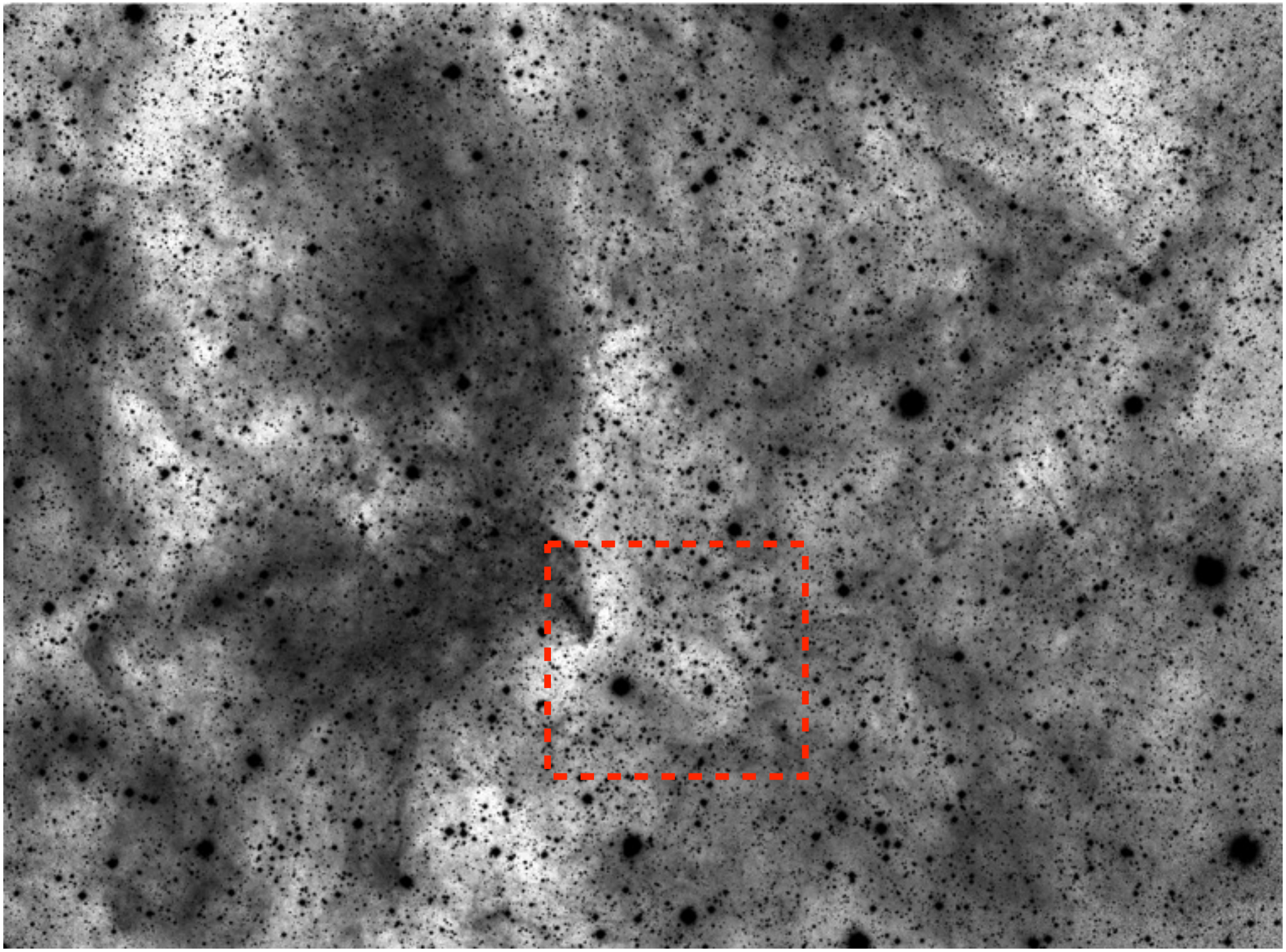


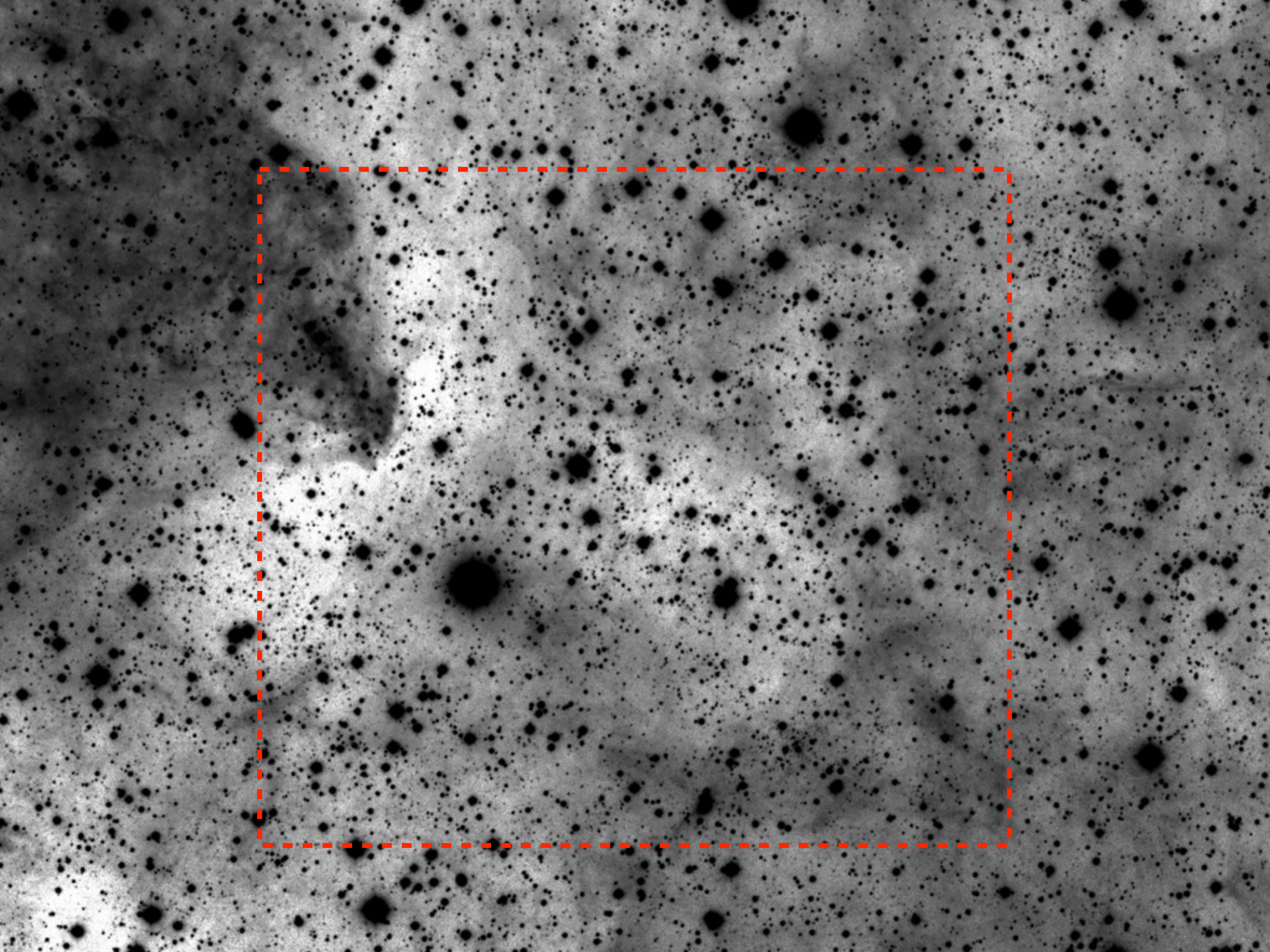


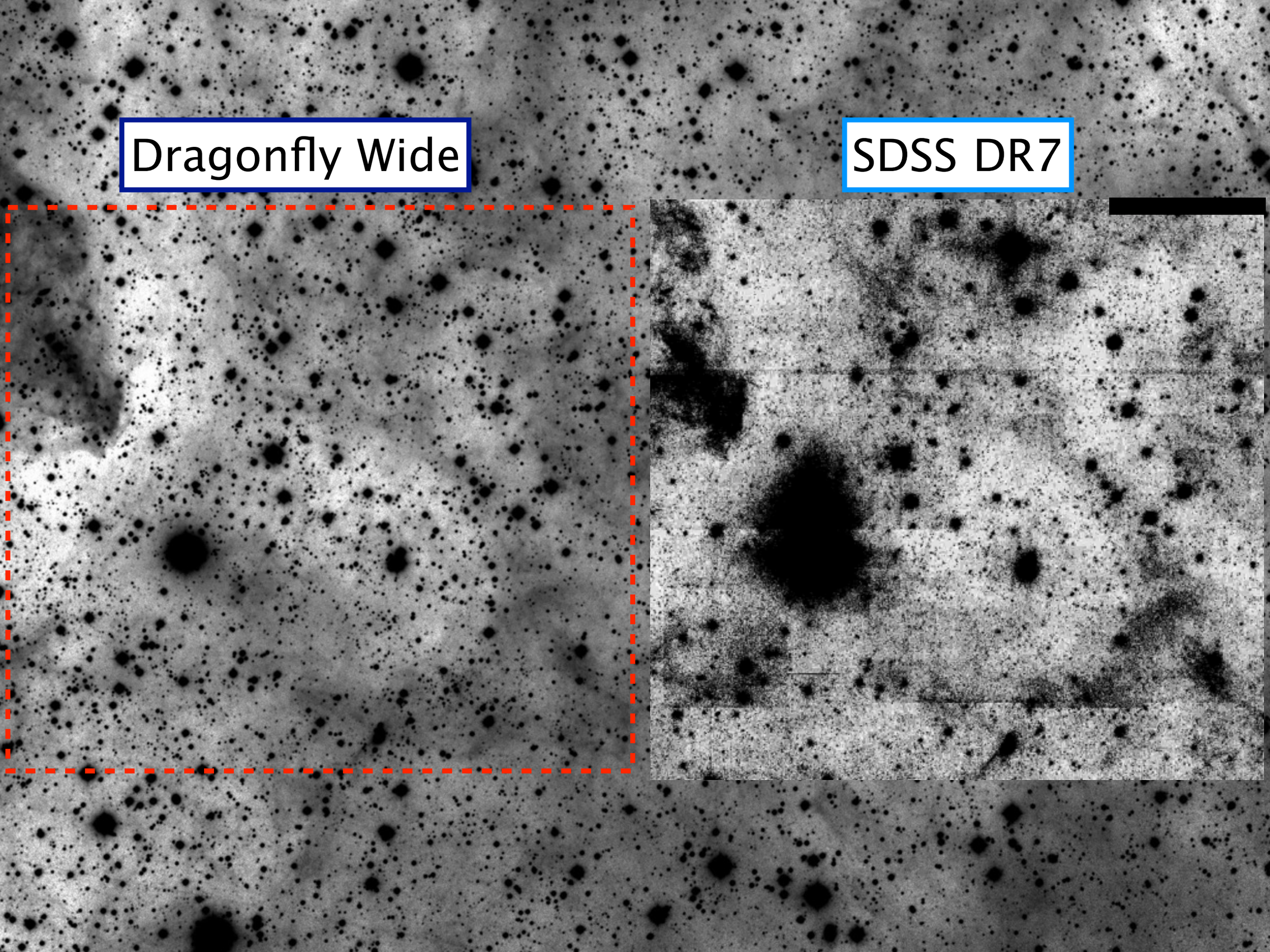
Stripe82

First Reduced Image








Dragonfly Wide
SDSS DR7

Summary

Integrated light techniques are sensitive enough to allow dwarfs to be detected beyond the Local Group, allowing a statistical probe of the low mass dwarf population

The Dragonfly Wide Field Survey is predicted to reveal a new rich discovery space, reaching ultra low surface brightness levels