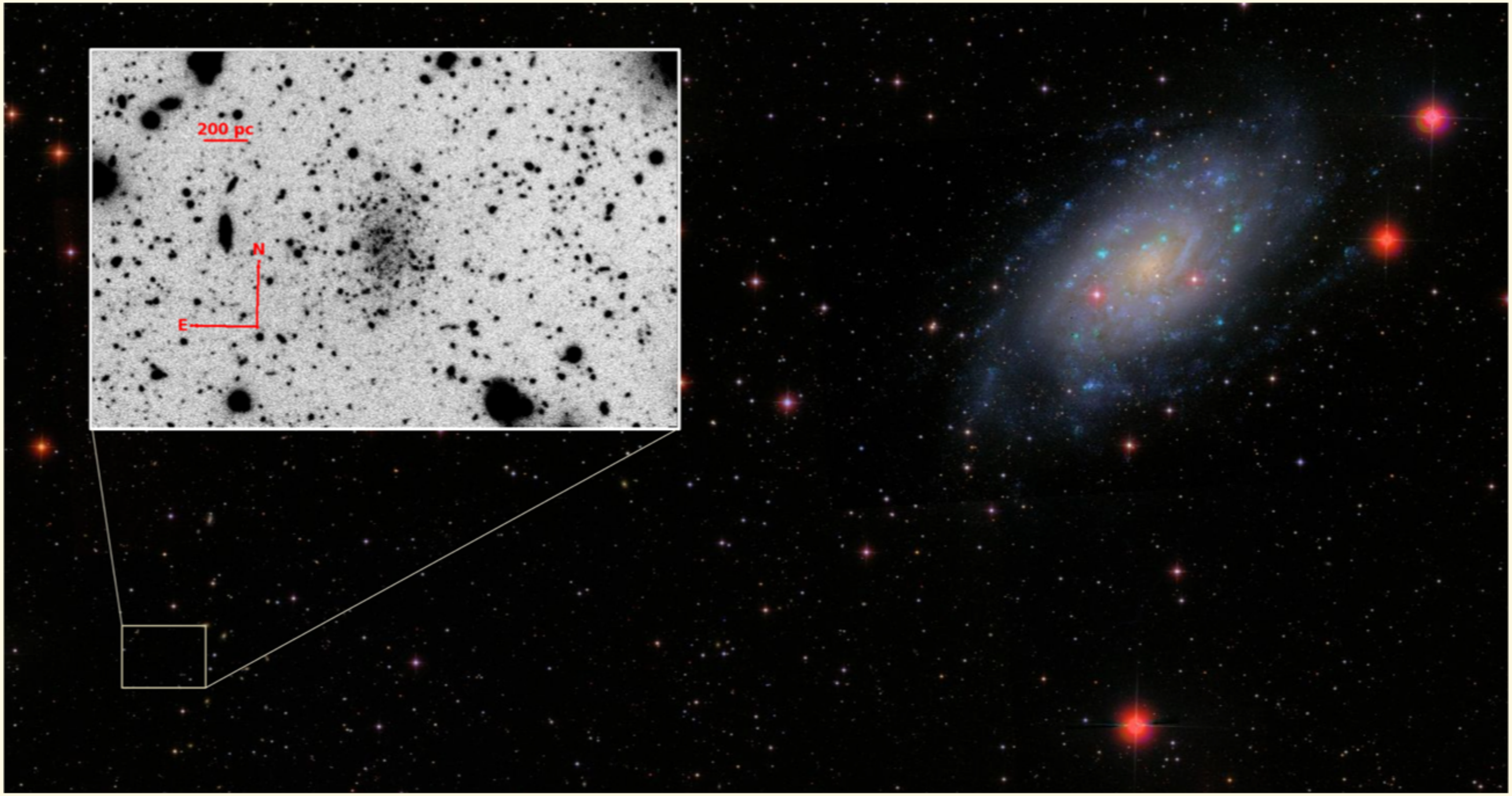
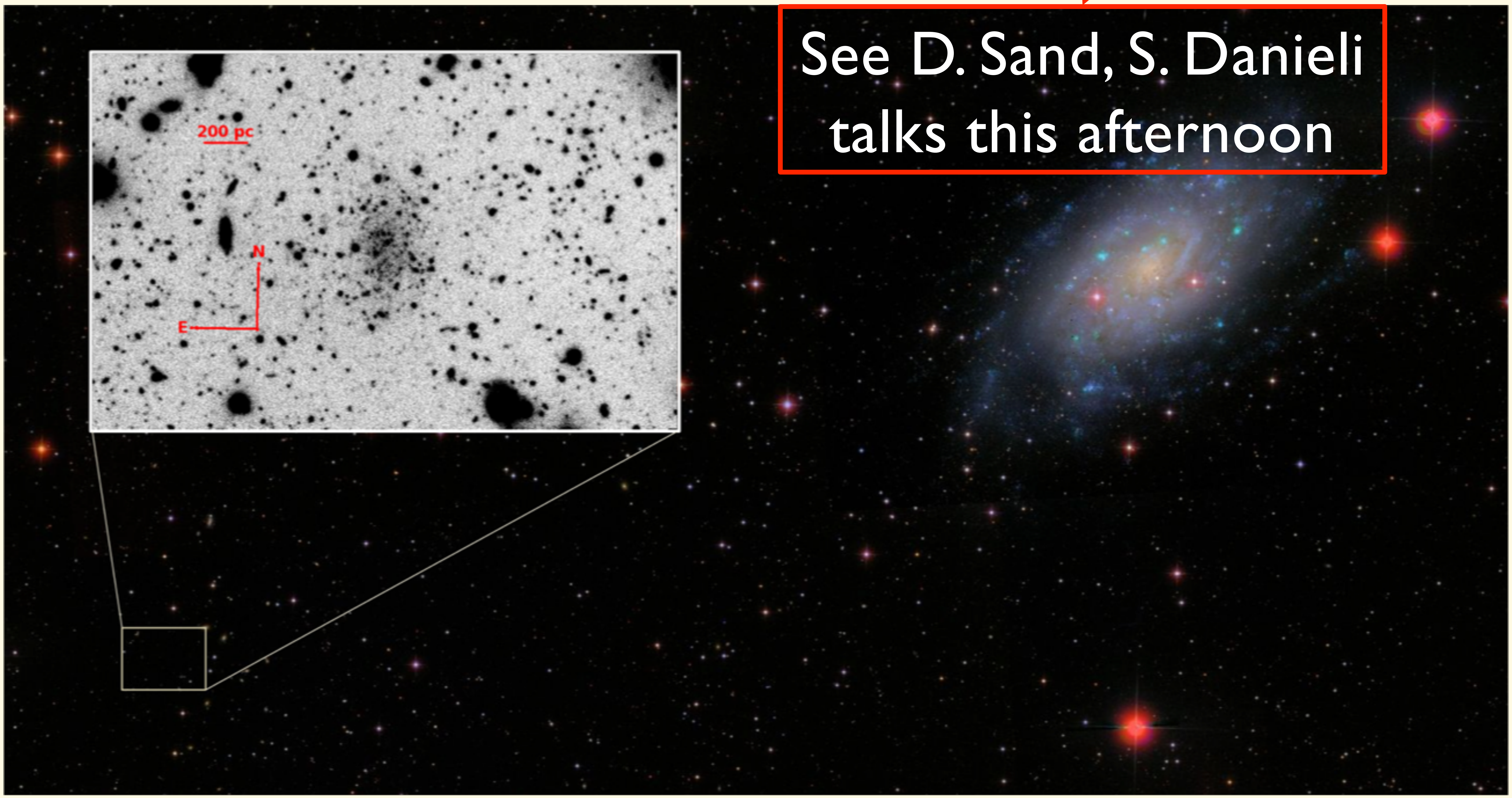
Near-field cosmology with resolved and unresolved stellar populations around low-mass Local Volume galaxies



Jeff Carlin (LSST)

+ Keith Bechtol, Jean Brodie, Denija Crnojević, Greg Dooley, Duncan Forbes, Anna Frebel, Jonathan Hargis, Ananthan Karunakaran, Evan Kirby, Robert Lupton, Ricardo Muñoz, Annika Peter, Paul Price, Ragadeepika Pucha, Aaron Romanowsky, **Dave Sand**, Kristine Spekkens, Jay Strader, **Beth Willman**

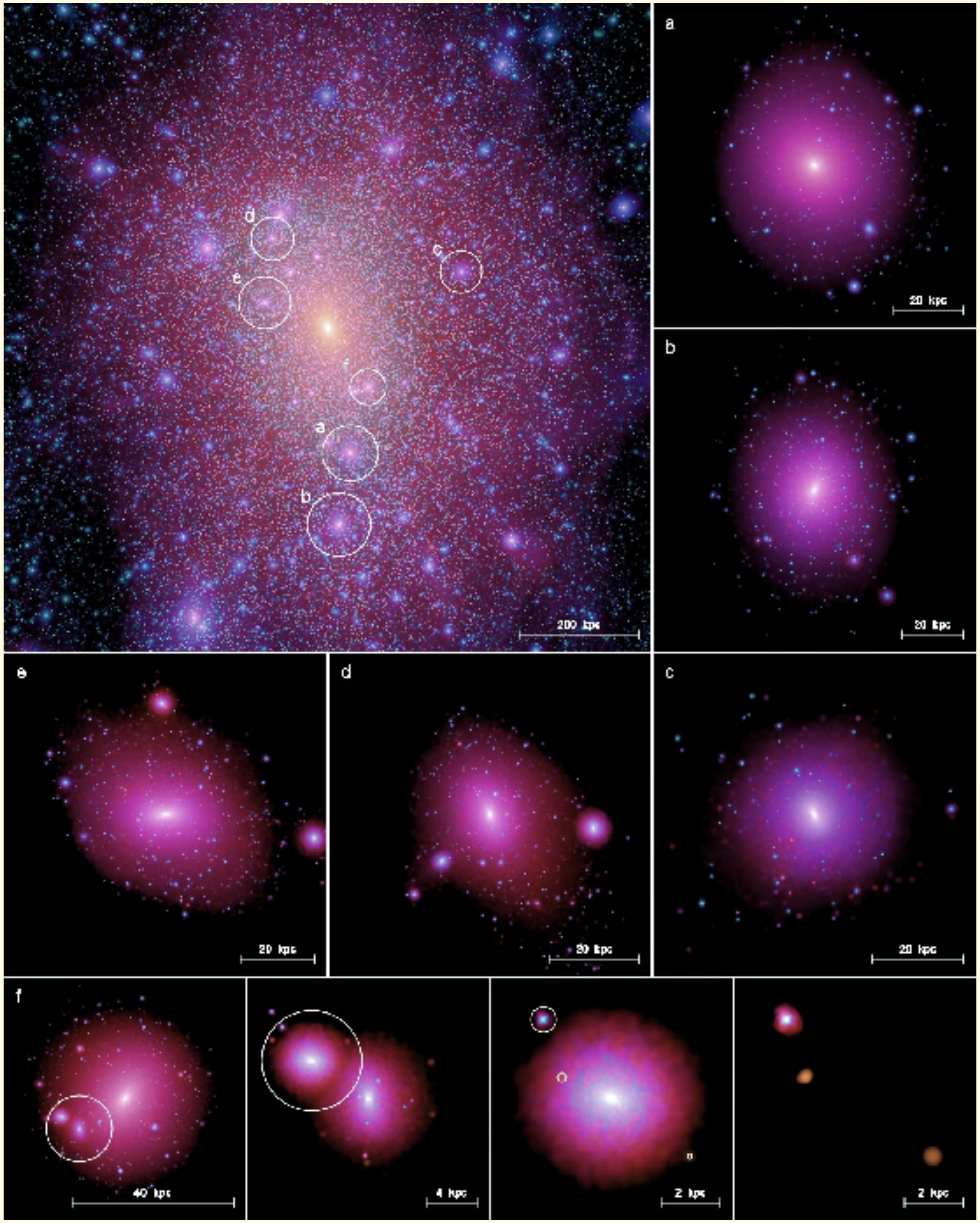
Near-field cosmology with resolved ~~and unresolved~~ stellar populations around low-mass Local Volume galaxies

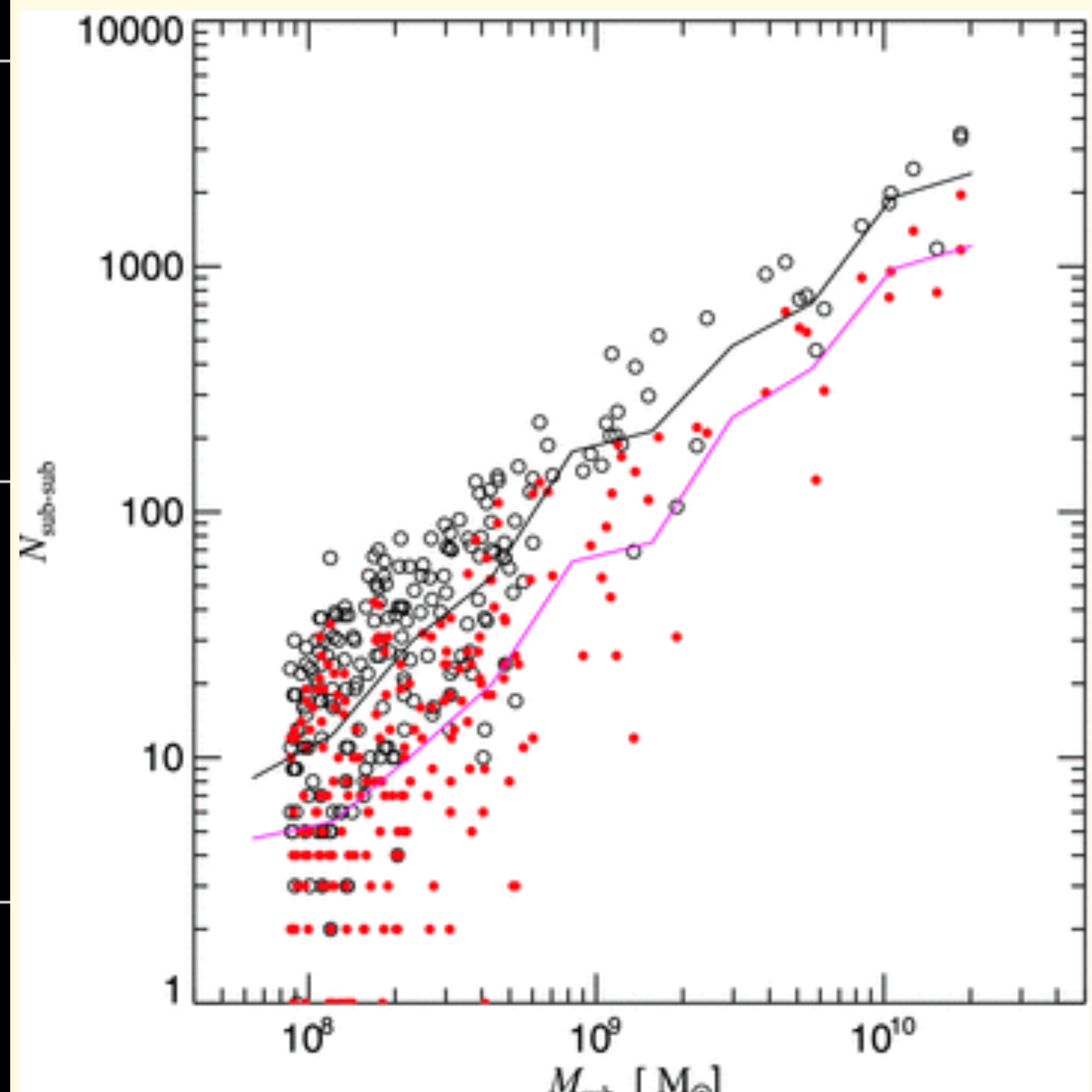


Jeff Carlin (LSST)

+ Keith Bechtol, Jean Brodie, Denija Crnojević, Greg Dooley, Duncan Forbes, Anna Frebel, Jonathan Hargis, Ananthan Karunakaran, Evan Kirby, Robert Lupton, Ricardo Muñoz, Annika Peter, Paul Price, Ragadeepika Pucha, Aaron Romanowsky, **Dave Sand**, Kristine Spekkens, Jay Strader, **Beth Willman**

(Sub)substructure – structure formation is essentially scale-free

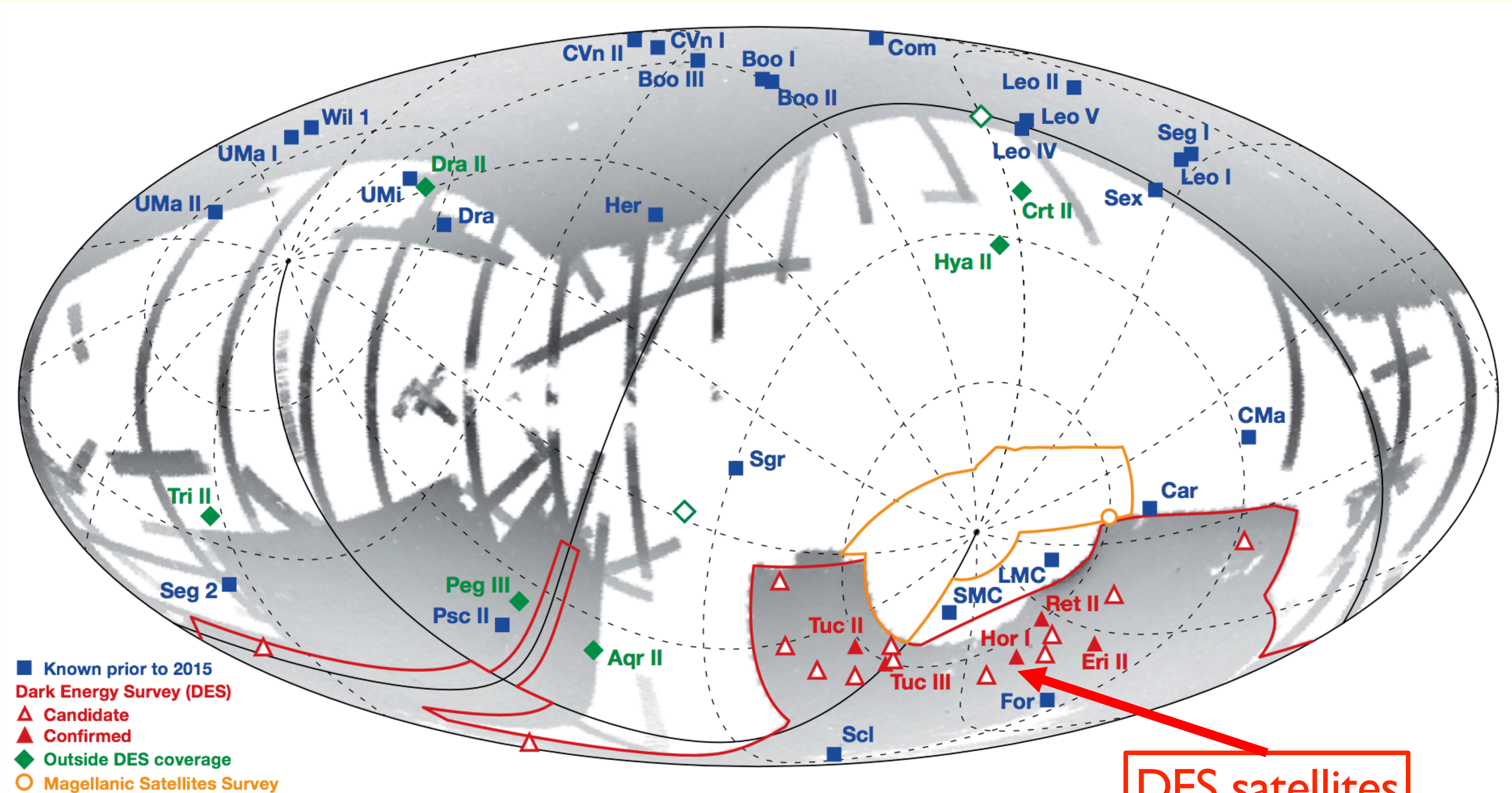




Aquarius simulations – Springel+2008, MNRAS, 391, 1685

LMC/SMC satellites?

Satellites discovered in DES are not isotropically distributed
→ associated with Magellanic Clouds?*



* see, e.g., Deason+2015; Drlica-Wagner+2015;
Koposov+2015; Yozin & Bekki 2015; Jethwa+2016; Sales+2016

Do Local Volume ~SMC/LMC stellar mass dwarfs host their own dwarf galaxy satellites (and if so, what are their properties)?

NGC 3109 and NGC 2403 now have confirmed satellites – more soon!

What do dwarfs-around-dwarfs tell us about fundamental galaxy formation physics?

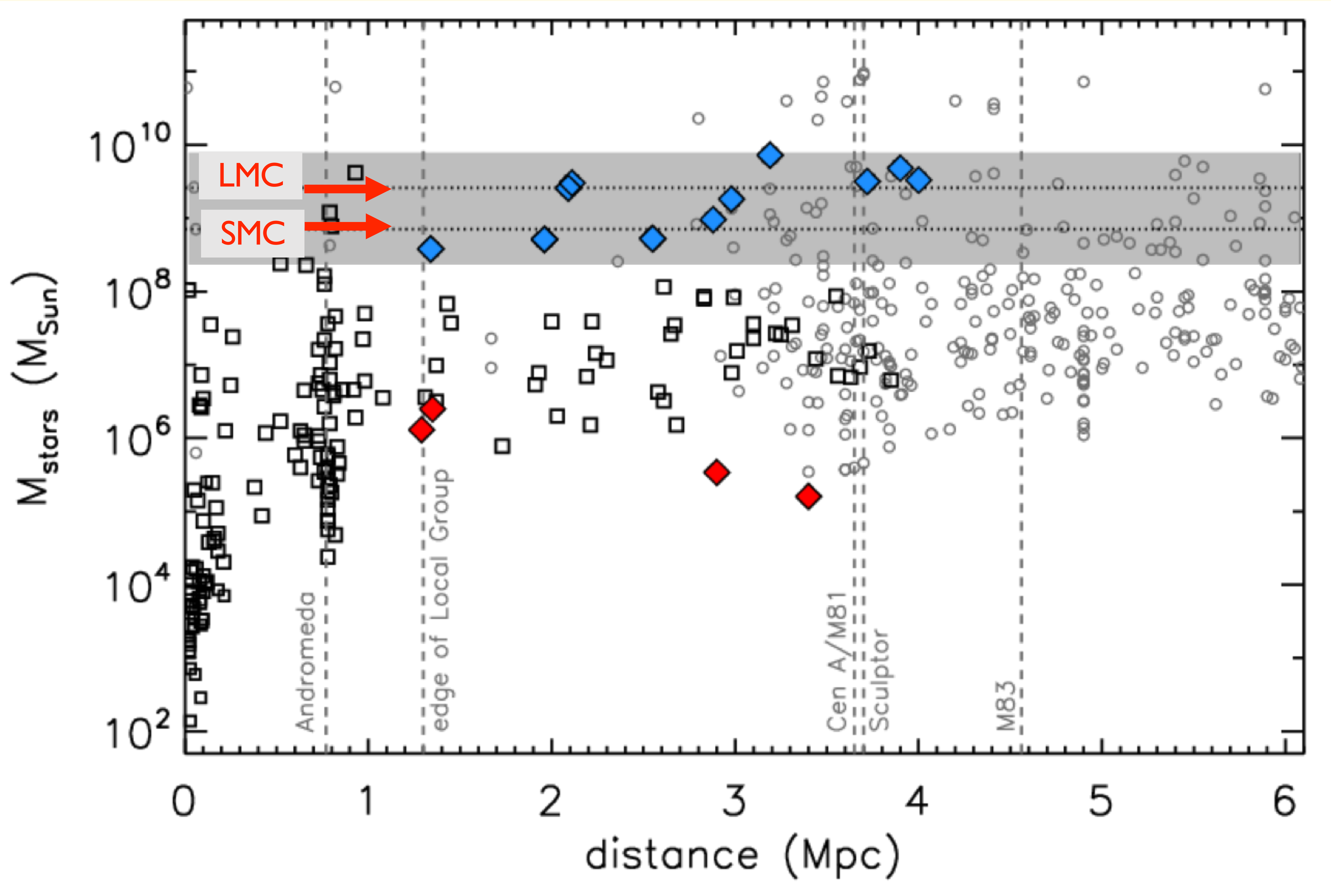
Number distribution and properties (luminosity function, total mass, metallicity, etc.) tell us about competing effects of galaxy formation efficiency, reionization, and environment.

What is the impact of environment on dwarf galaxy formation?

Do dwarf galaxies have stellar halos? Is there appreciable stellar substructure (i.e., satellite remnants) in the halos of LMC analogs?

MADCASH survey observations of Local Volume galaxies will provide systematic measurements of stellar halos and dwarf satellites in sub-MW environments.

Stellar mass vs. distance; Local Volume galaxies



*Data from Karachentsev+2013 Local Volume galaxies catalog, available at: https://relay.sao.ru/lv/lvgdb/, plus more recent MW dwarfs

MADCASH observing program

Distant, > SMC stellar mass

Galaxy	M_* (10^9 M_{Sun})	D (Mpc)	
NGC 4214	1.0	2.9	Subaru+HSC: 5/7 fields; ~69% of virial volume
~~NGC 404~~	~~1.8~~	~~3.0~~	
NGC 300	2.6	2.1	
NGC 55	3.0	2.1	
NGC 247	3.2	3.7	Subaru+HSC: 3/7 fields; ~50% of virial volume
NGC 4244	3.3	4.0	Subaru+HSC: 2/7 fields; ~45% of virial volume
NGC 4449	4.8	3.9	
NGC 2403	7.2	3.2	Subaru+HSC: ~13 sq. deg.; 7/7 fields

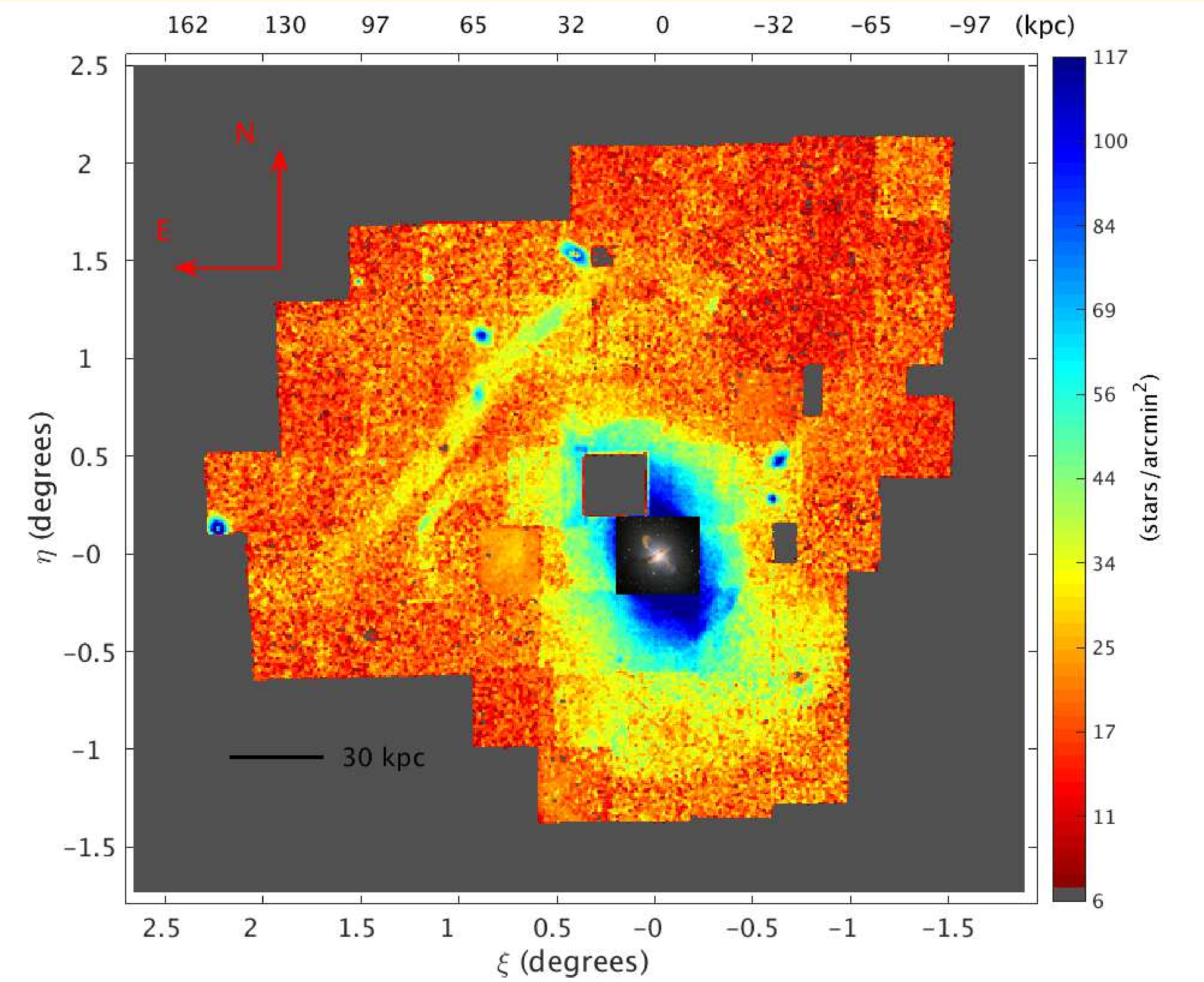
sub-SMC stellar mass

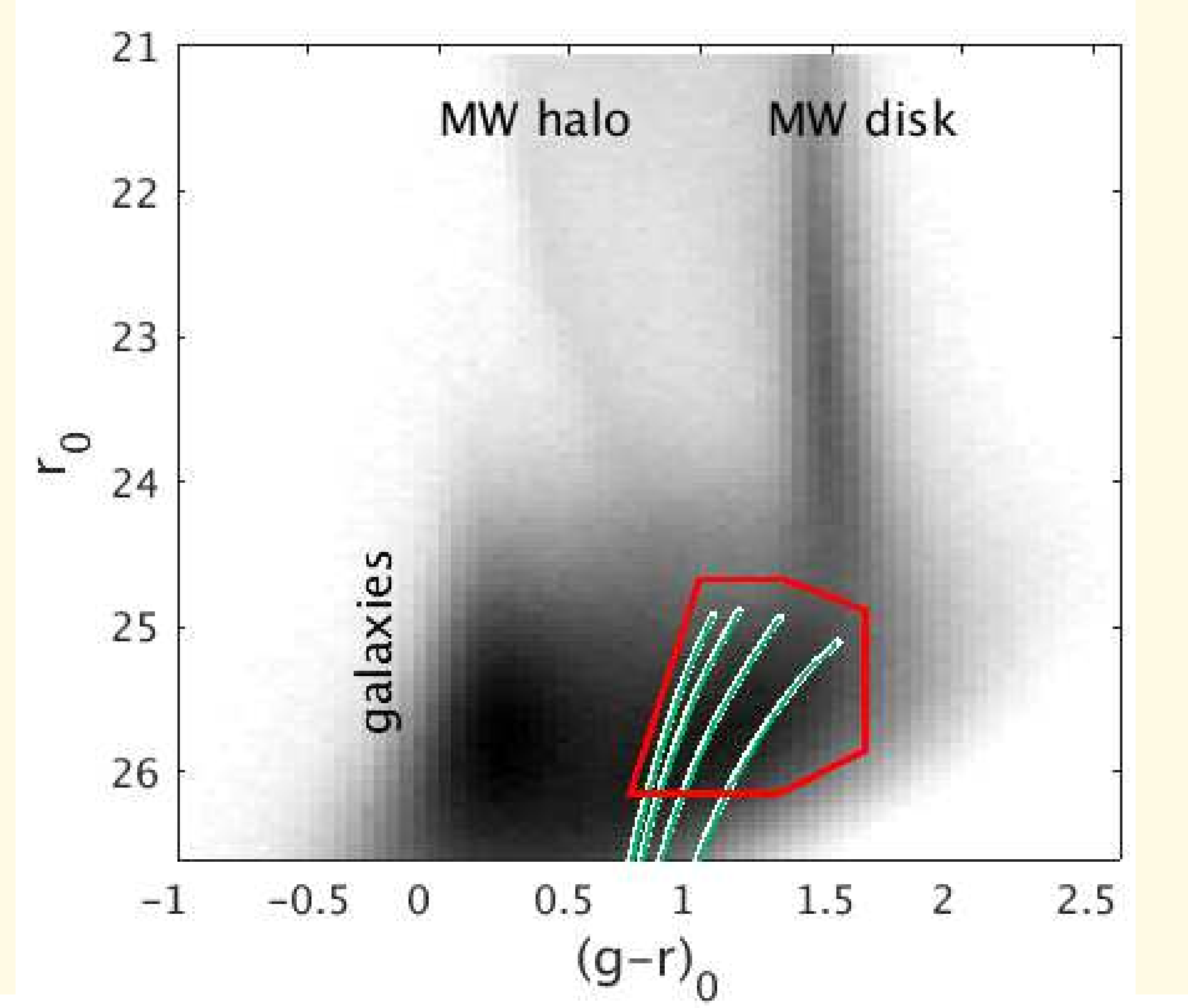
Galaxy	M_* (10^8 M_{Sun})	D (Mpc)	
Sextans A	0.3	1.3	CTIO+DECam: ~27 sq. deg.
Sextans B	0.6	1.4	CTIO+DECam: ~12 sq. deg.; 4/9 fields
IC 1613	1.2	0.73	Subaru+HSC: 4 fields; ~7 sq. deg., 6% of volume
NGC 3109	3.7	1.3	CTIO+DECam: ~40 sq. deg.
IC 4662	4.9	2.4	CTIO+DECam: ~18 sq. deg.; 6/7 fields
IC 5152	5.2	2.0	CTIO+DECam: ~6 sq. deg.; 2/7 fields

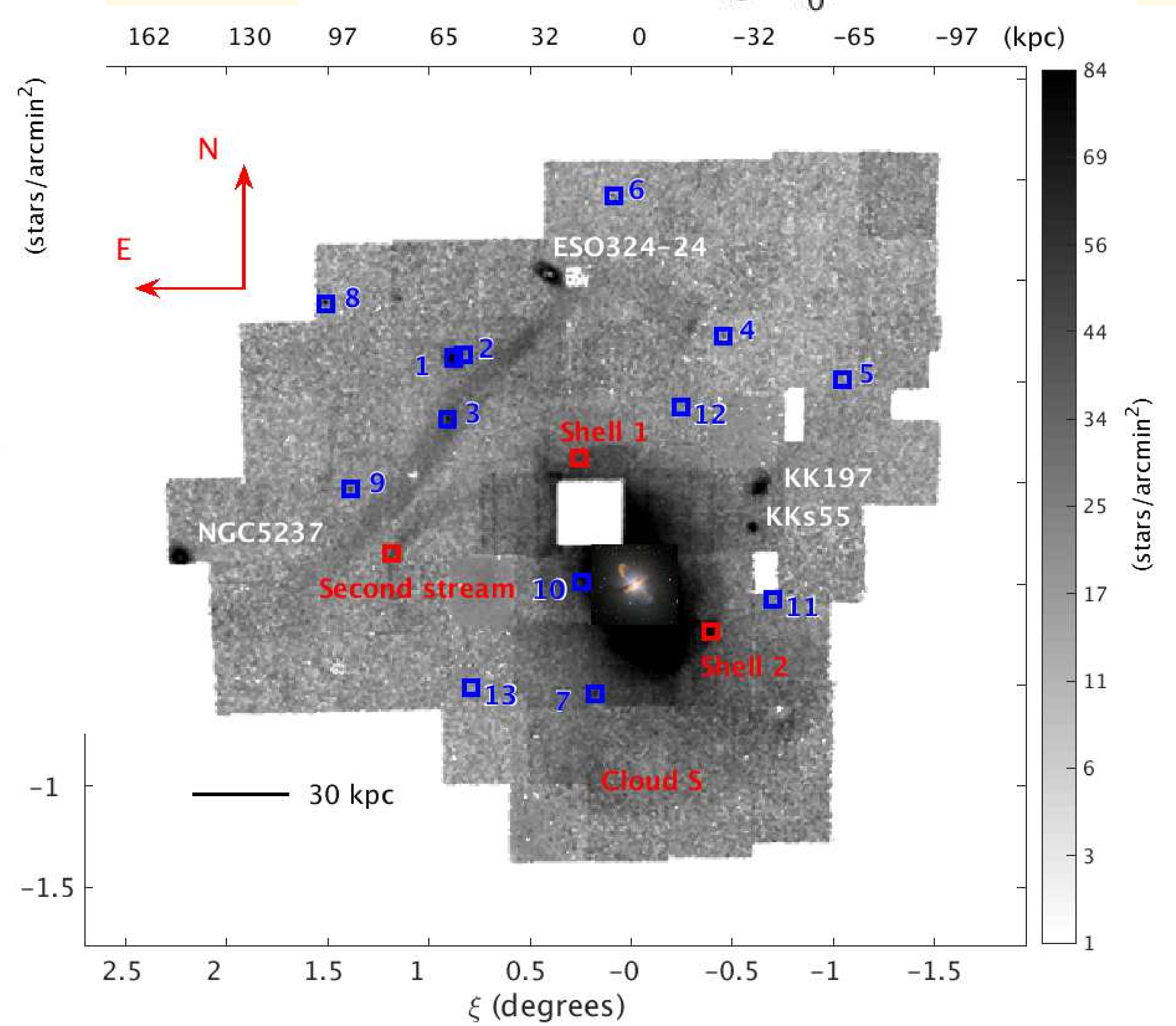
$M_{*,LMC} \sim 2.6\times10^9\ M_{Sun}$; $M_{*,SMC} \sim 7.1\times10^8\ M_{Sun}$

Stellar substructure (tidal remnants) in PISCeS:

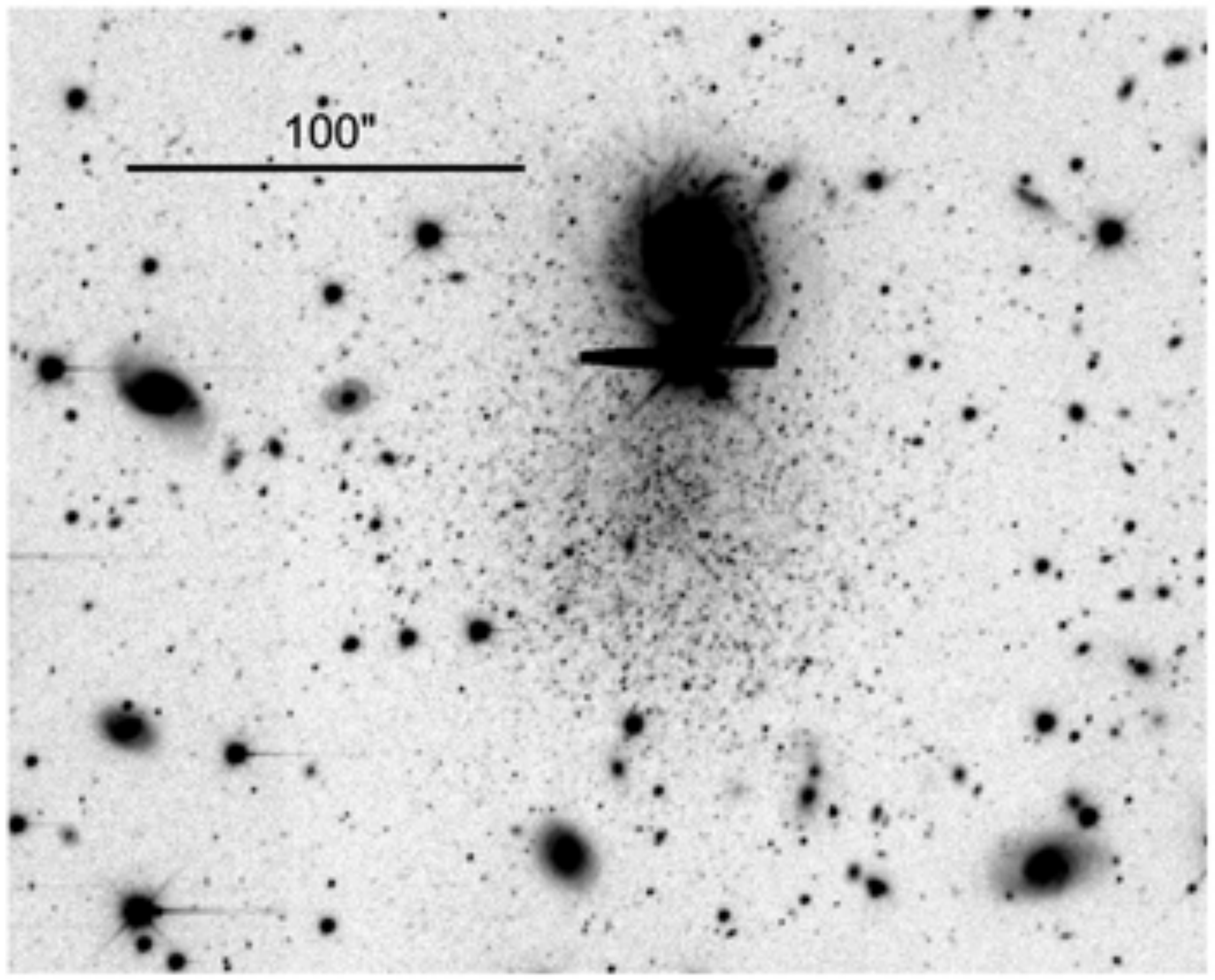
Resolved substructure around Centaurus A (D~3.7 Mpc): Crnojević+2016, ApJ, 823, 19







Dwarfs around dwarfs with CTIO/DECam: NGC 3109

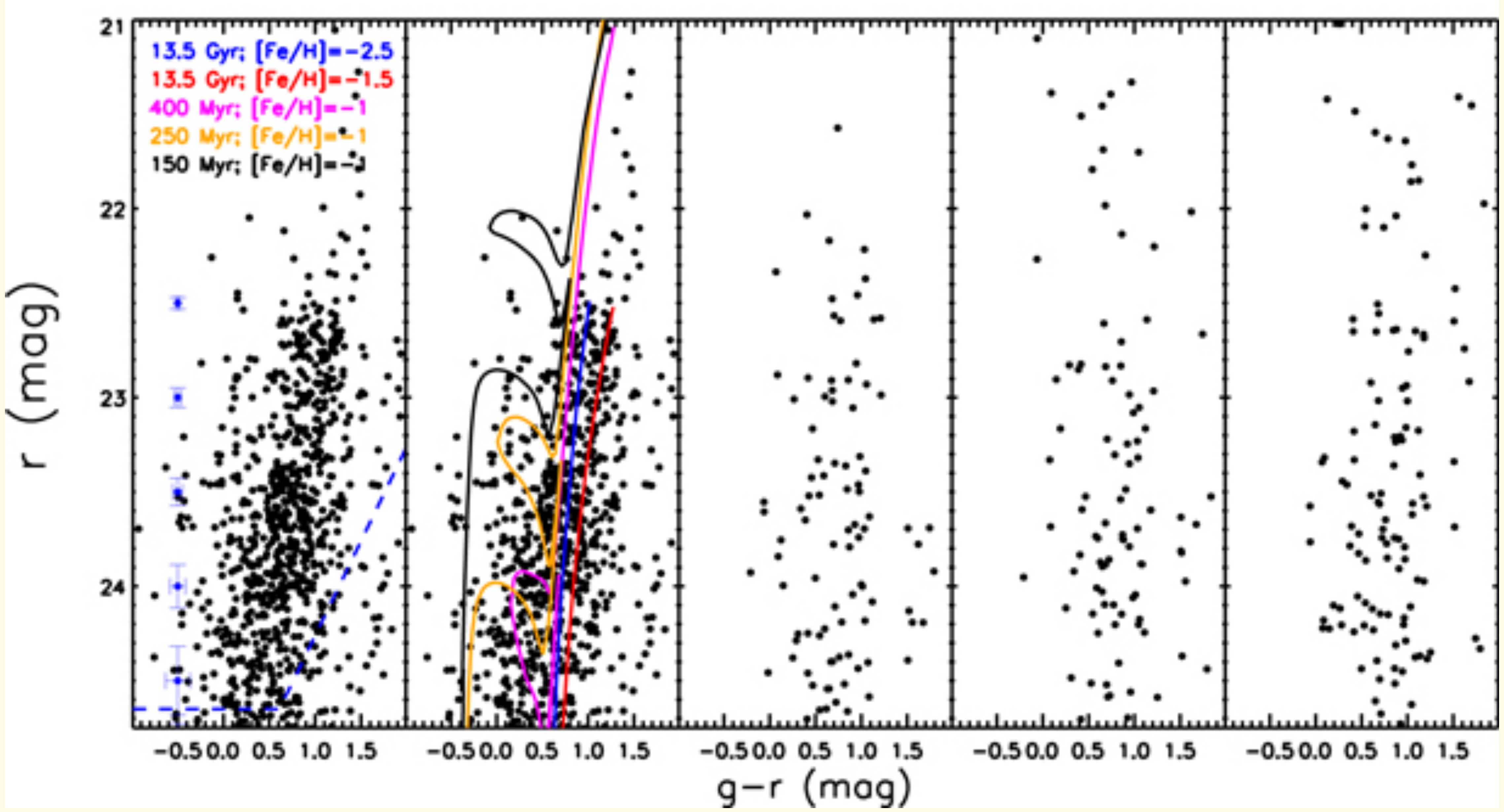


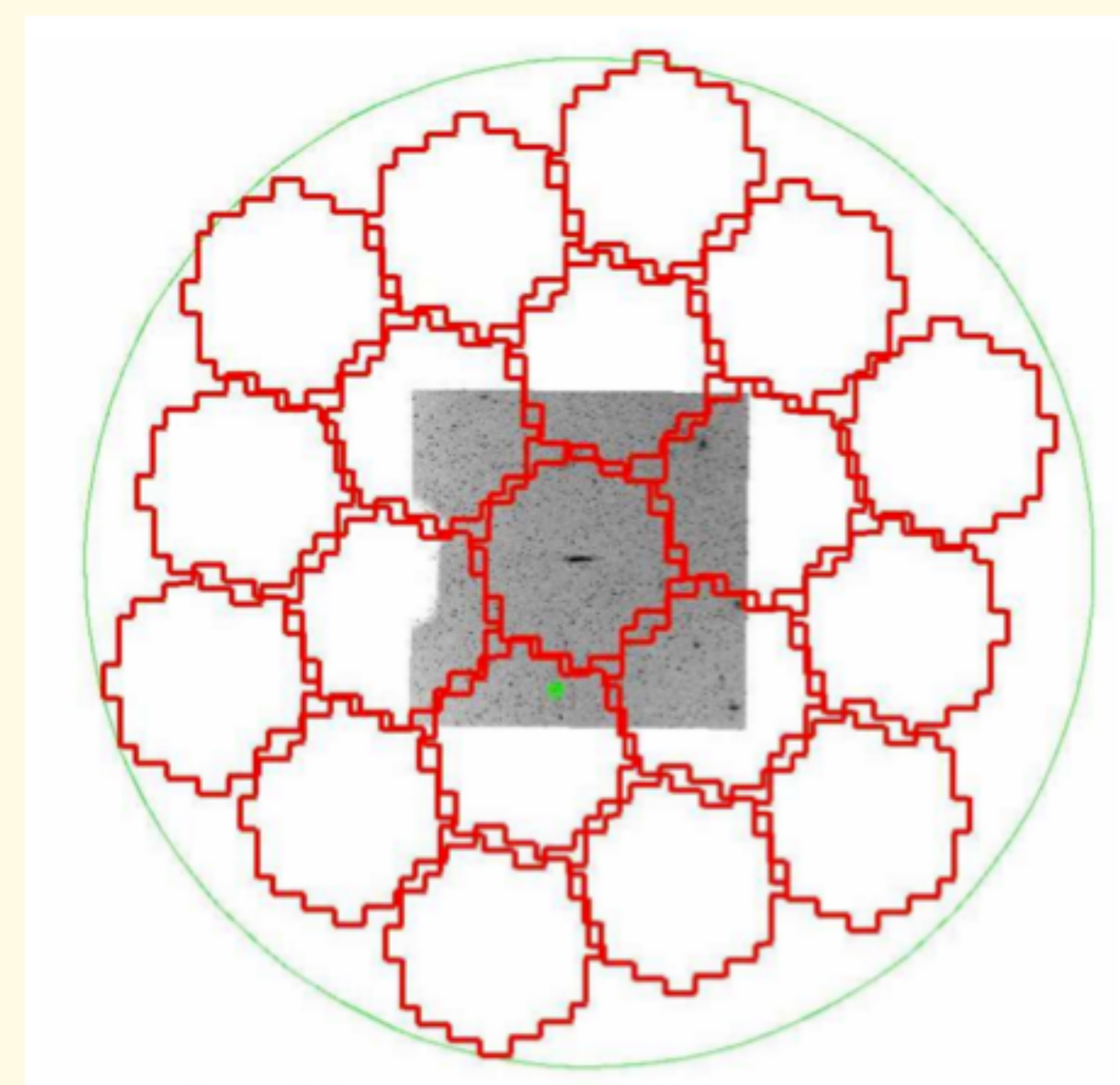
NGC 3109: M_V ~ -15 dwarf (M_{star} ~$3x10^8$ M_{sun}) at 1.3 Mpc

Discovery of a new dwarf galaxy, **Antlia B:**

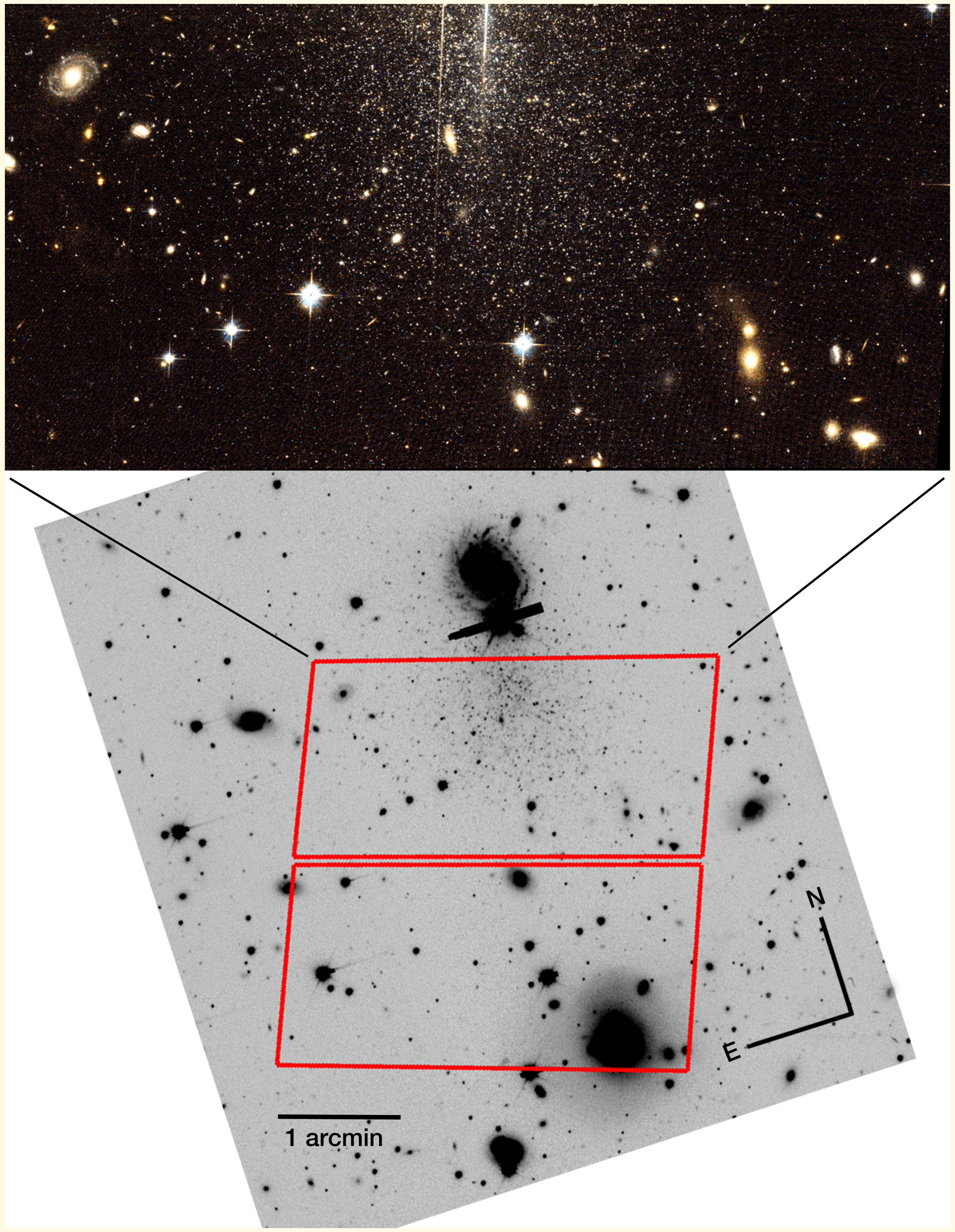
- M_V ~ -9.7, r_{half} ~ 270 pc

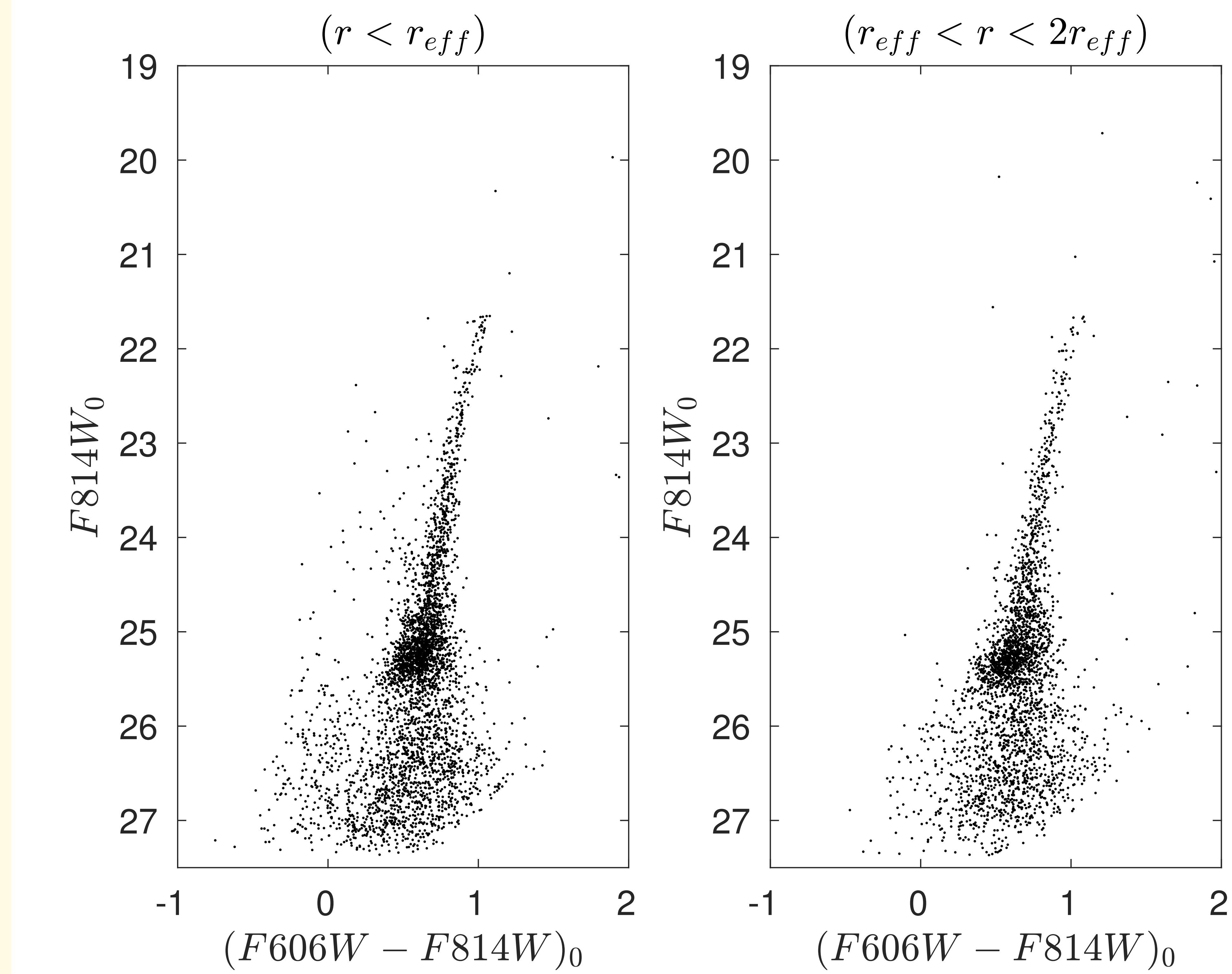
(Sand+2015, ApJL, 812, 13)





Dwarfs around dwarfs with CTIO/DECam: NGC 3109





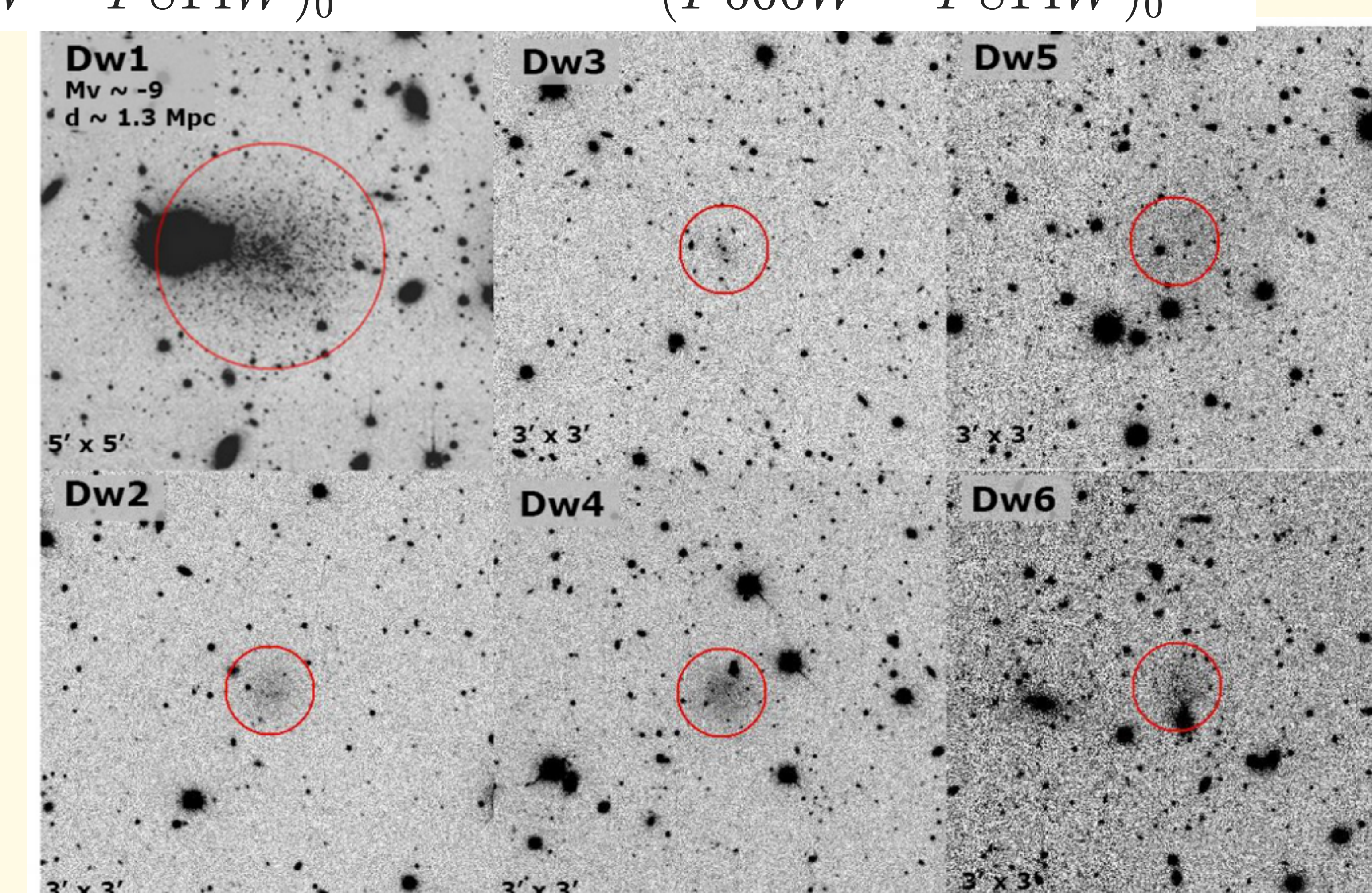
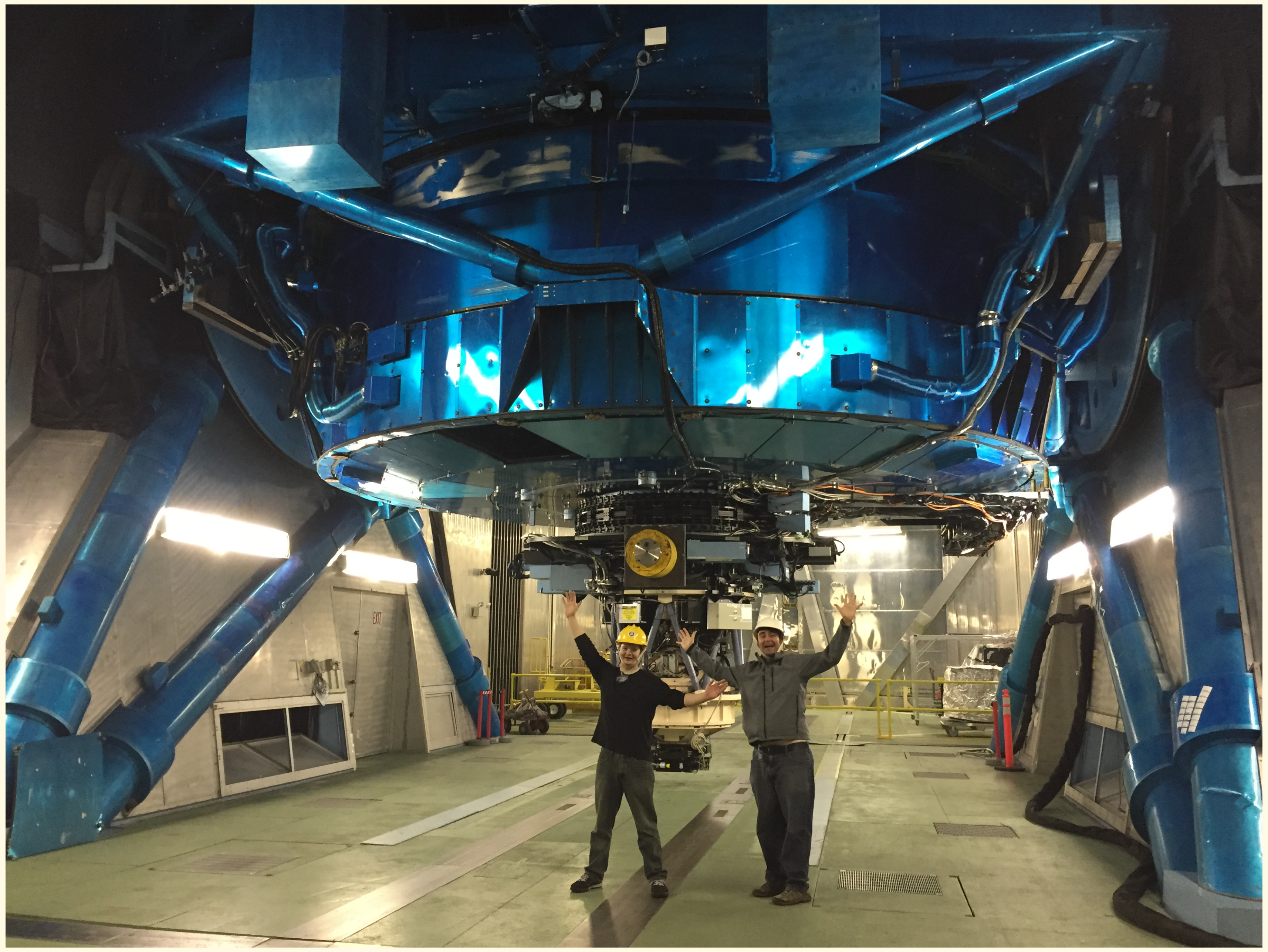


Image: D. Crnojevic

Several candidate Mv ~ -6 dwarfs, a confirmed Mv ~ -9 dwarf (Antlia B, Sand+15), and a candidate stream. HST Cycle 23 analysis ongoing (PI: J. Hargis).

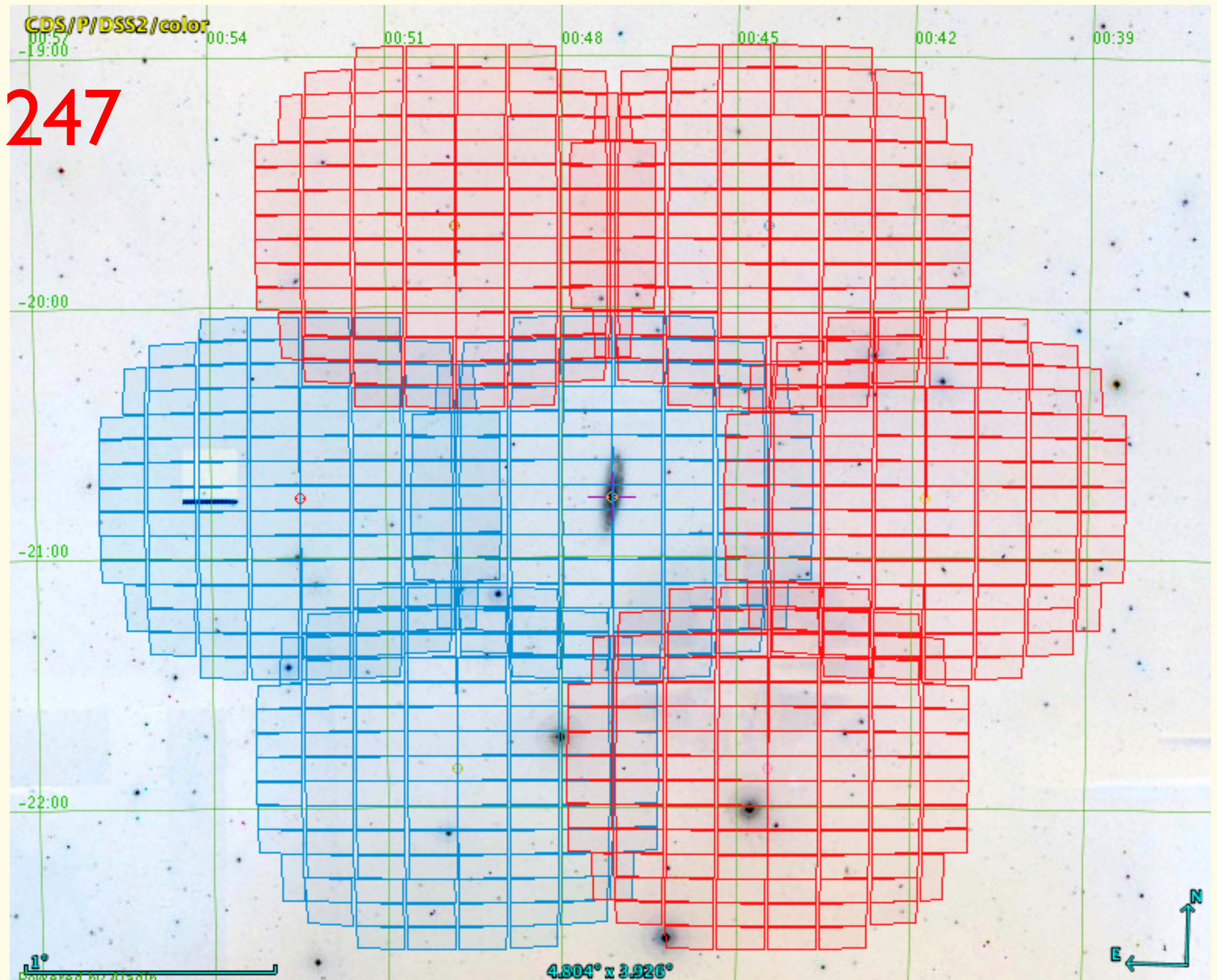
Magellanic Analog Dwarf Companions And Stellar Halos (MADCASH) survey:

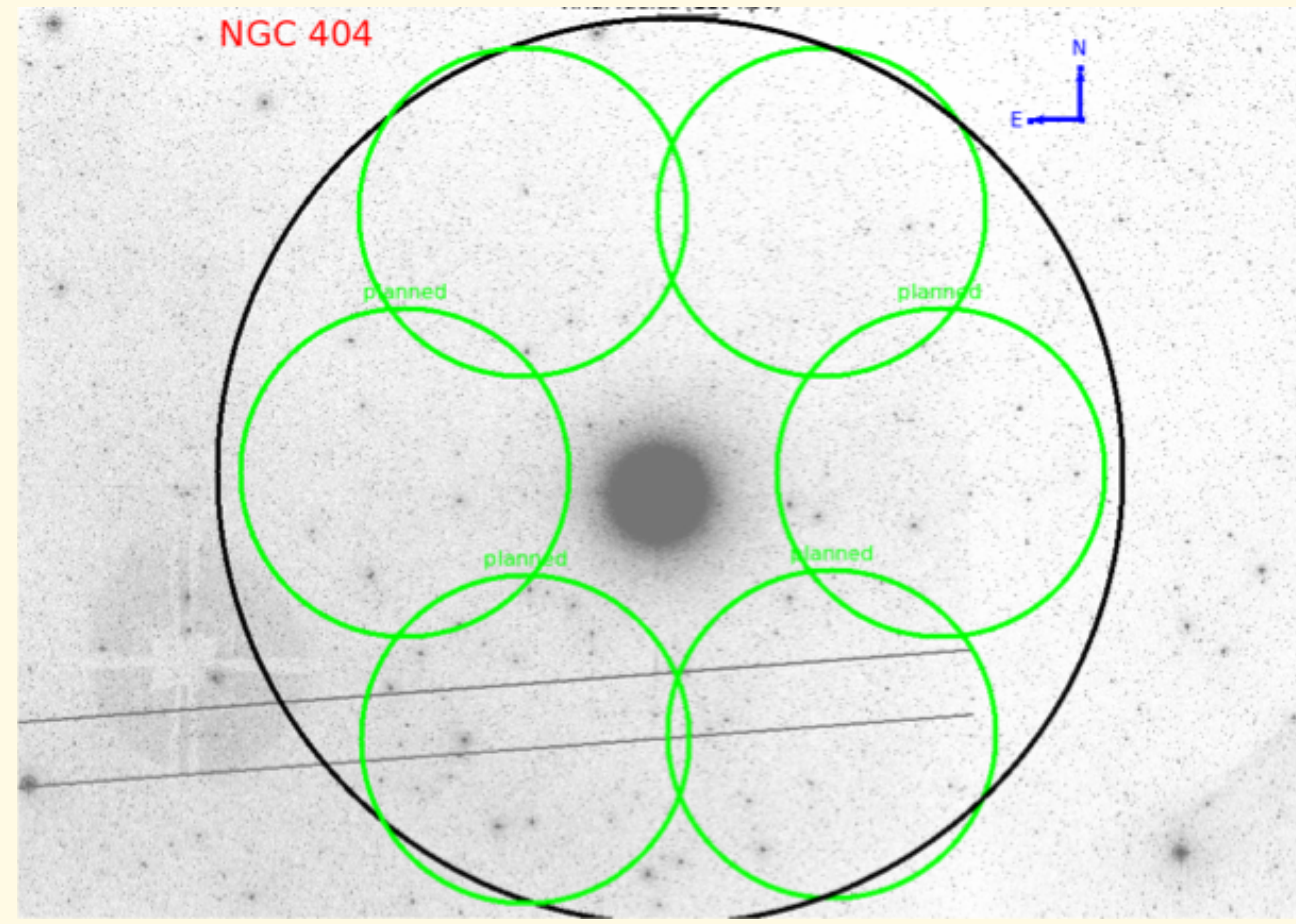
- Ongoing Subaru+HyperSuprimeCam (HSC) and DECam program
- 7 galaxies with ~LMC stellar mass (M_{star} = 1-7 x 10^9 M_{Sun}) between 2-4 Mpc of MW
- 6 sub-SMC stellar mass galaxies at D<2.5 Mpc
- 5σ point source depths: *g*~27.4, *i*~26.2 (~1.5 mags below the TRGB at 3.2 Mpc)



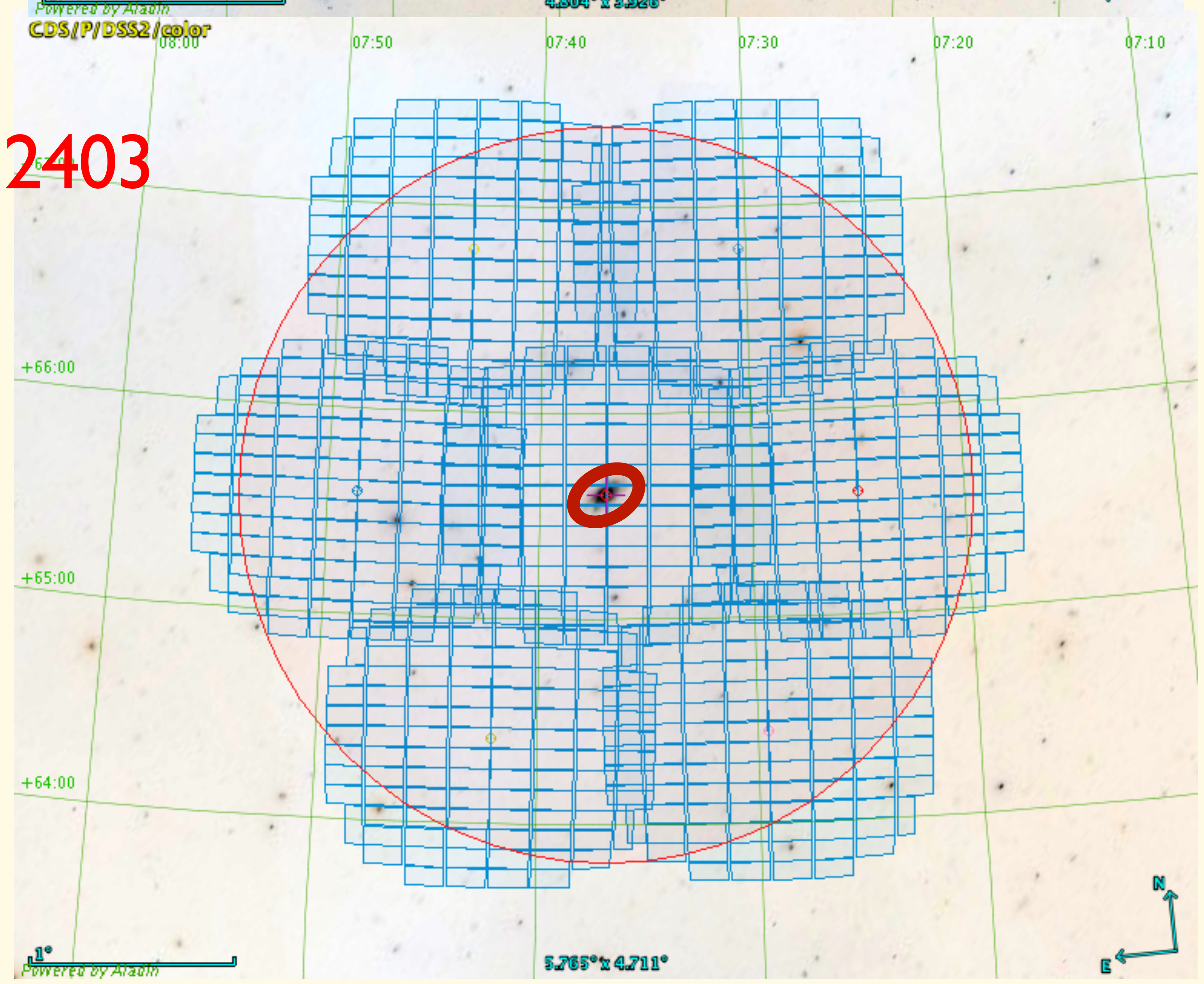
Subaru/HSC observing plans/progress

NGC 247

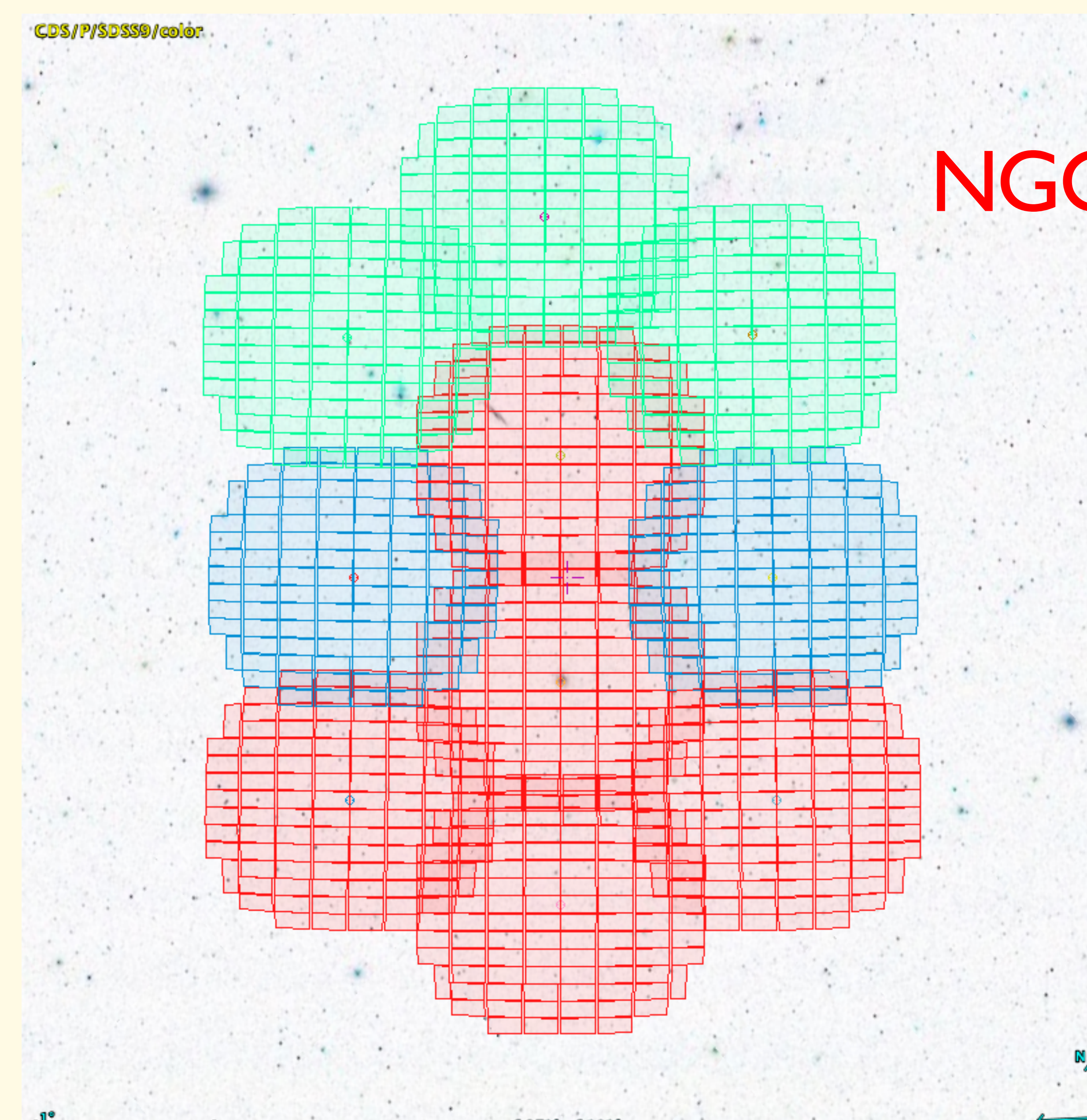




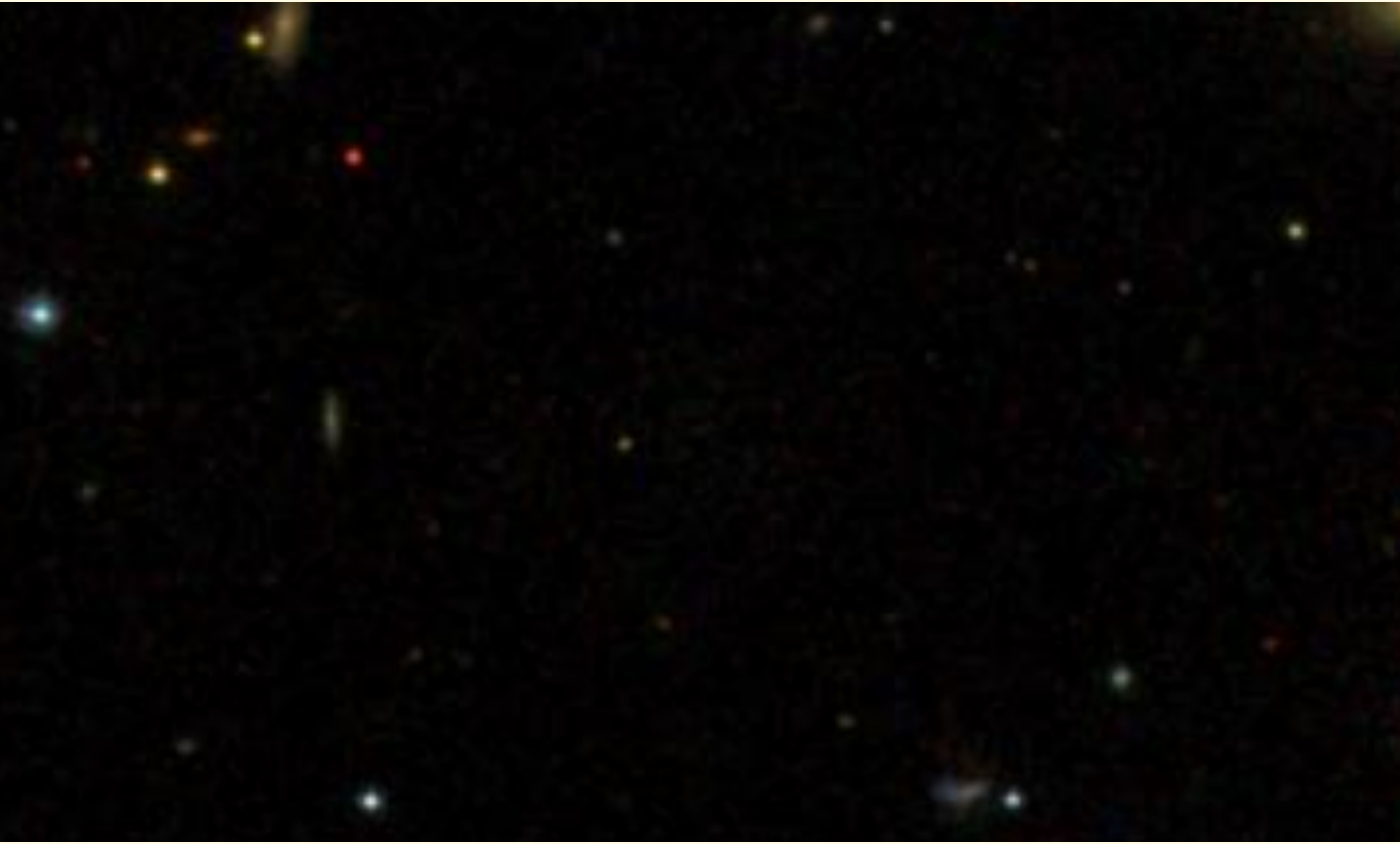
NGC 2403



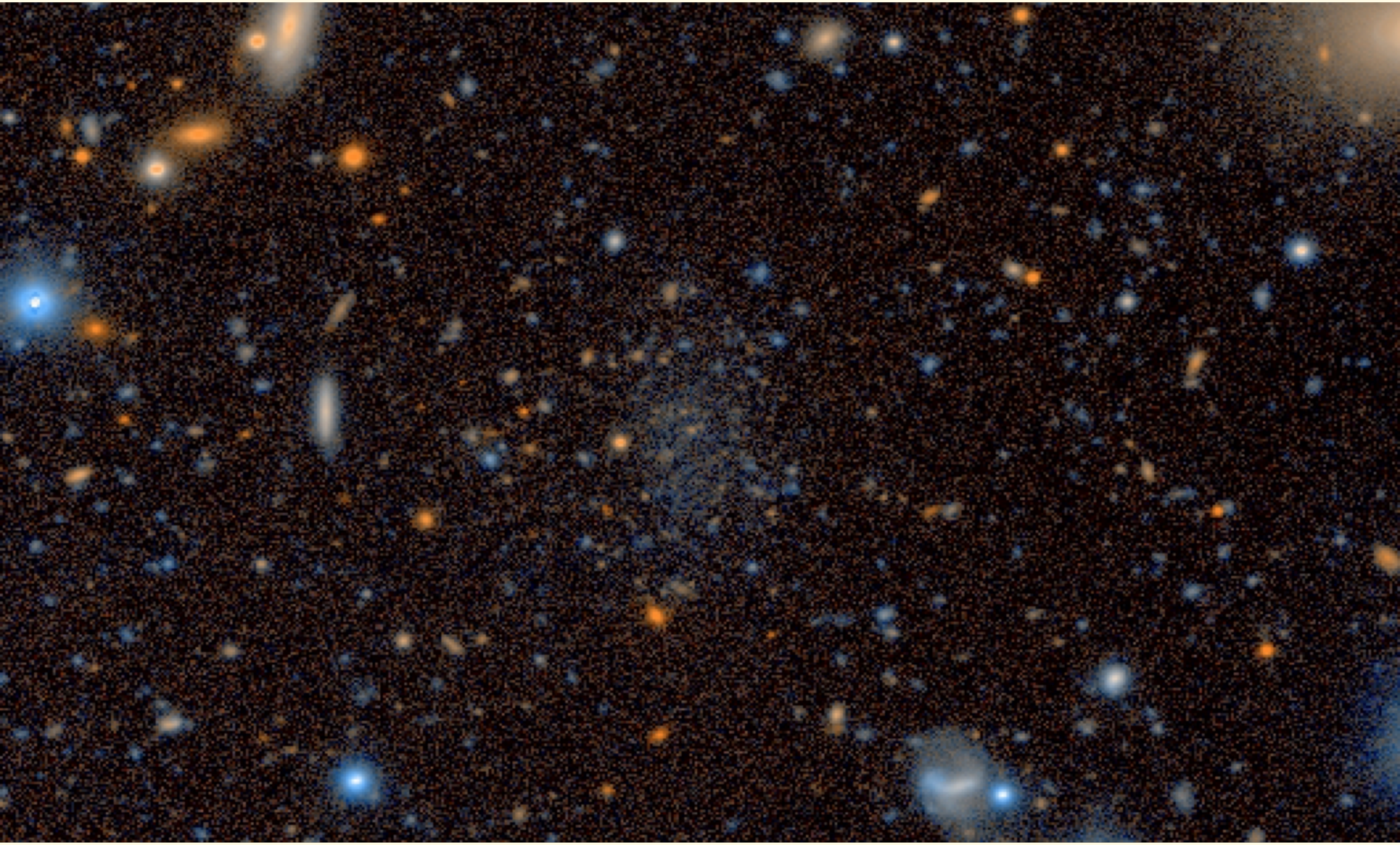
NGC 4214/4244



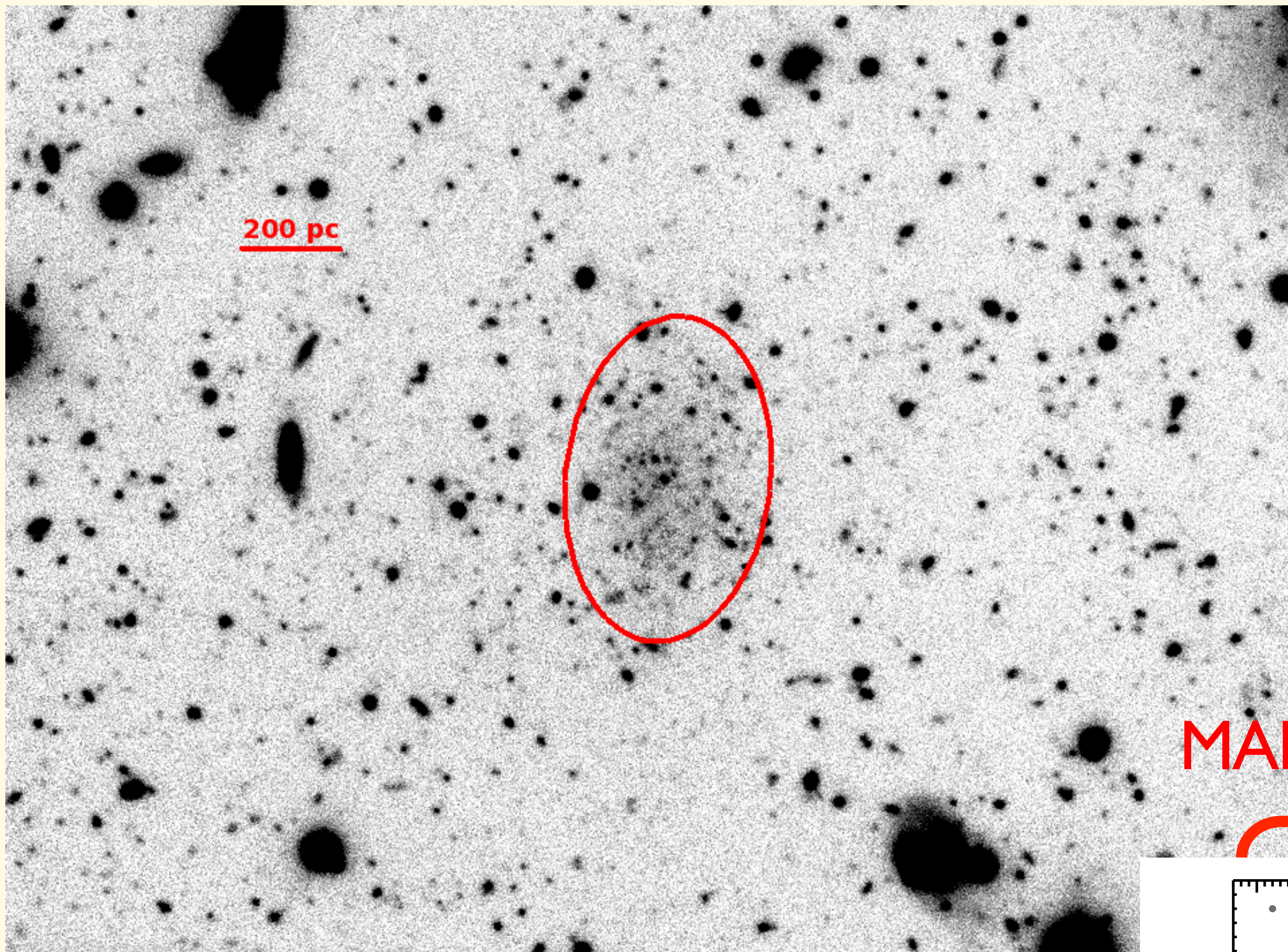
SDSS vs. HSC



SDSS vs. **HSC**



New dwarf galaxy near NGC 2403
(D~3.2 Mpc, $M_* \sim 7\times10^9\ M_{Sun}$; ~2.5 $M_{*,LMC}$)



MADCASH J074238+652501-dw

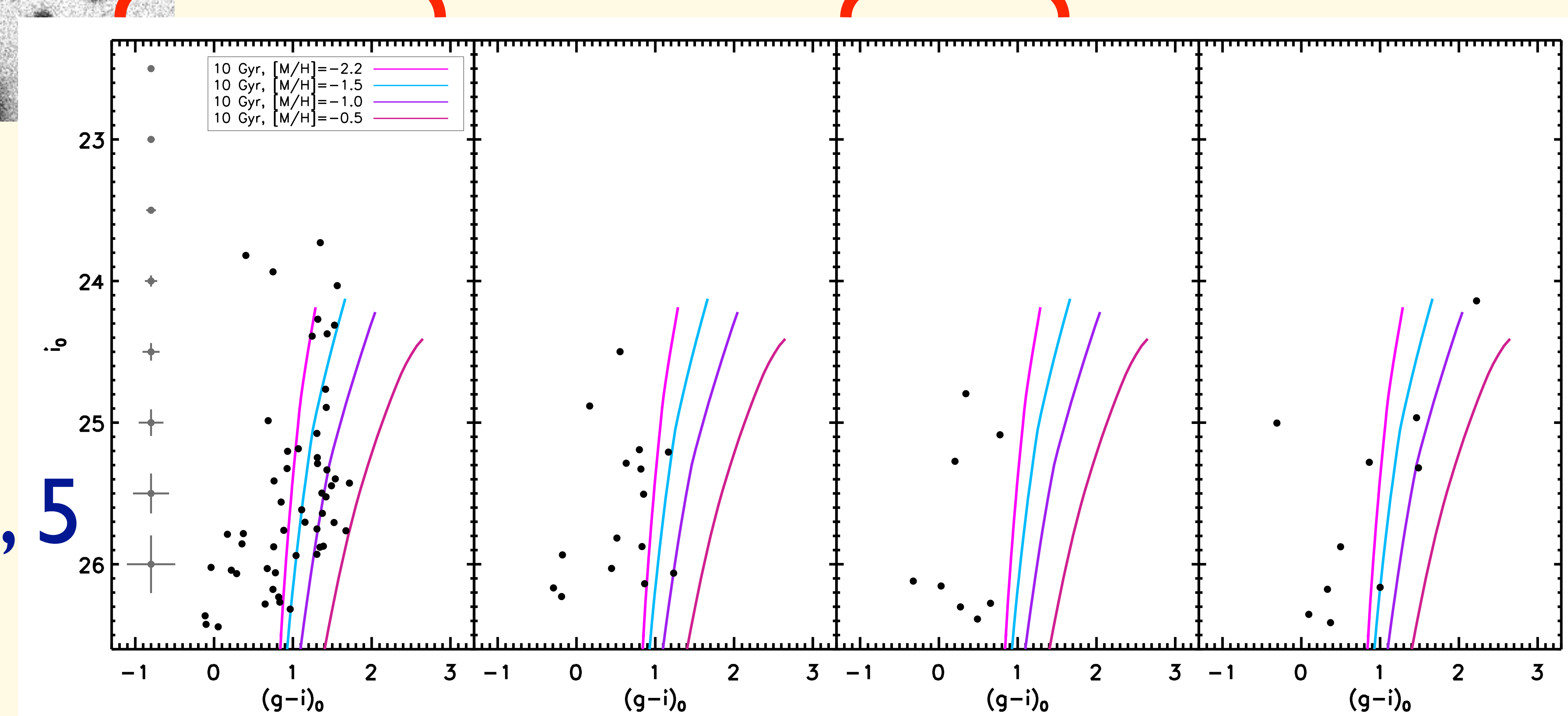
$M_V \sim -7.7$

size: ~200x70 pc

R~35 kpc from NGC 2403

MADCASH-dw1

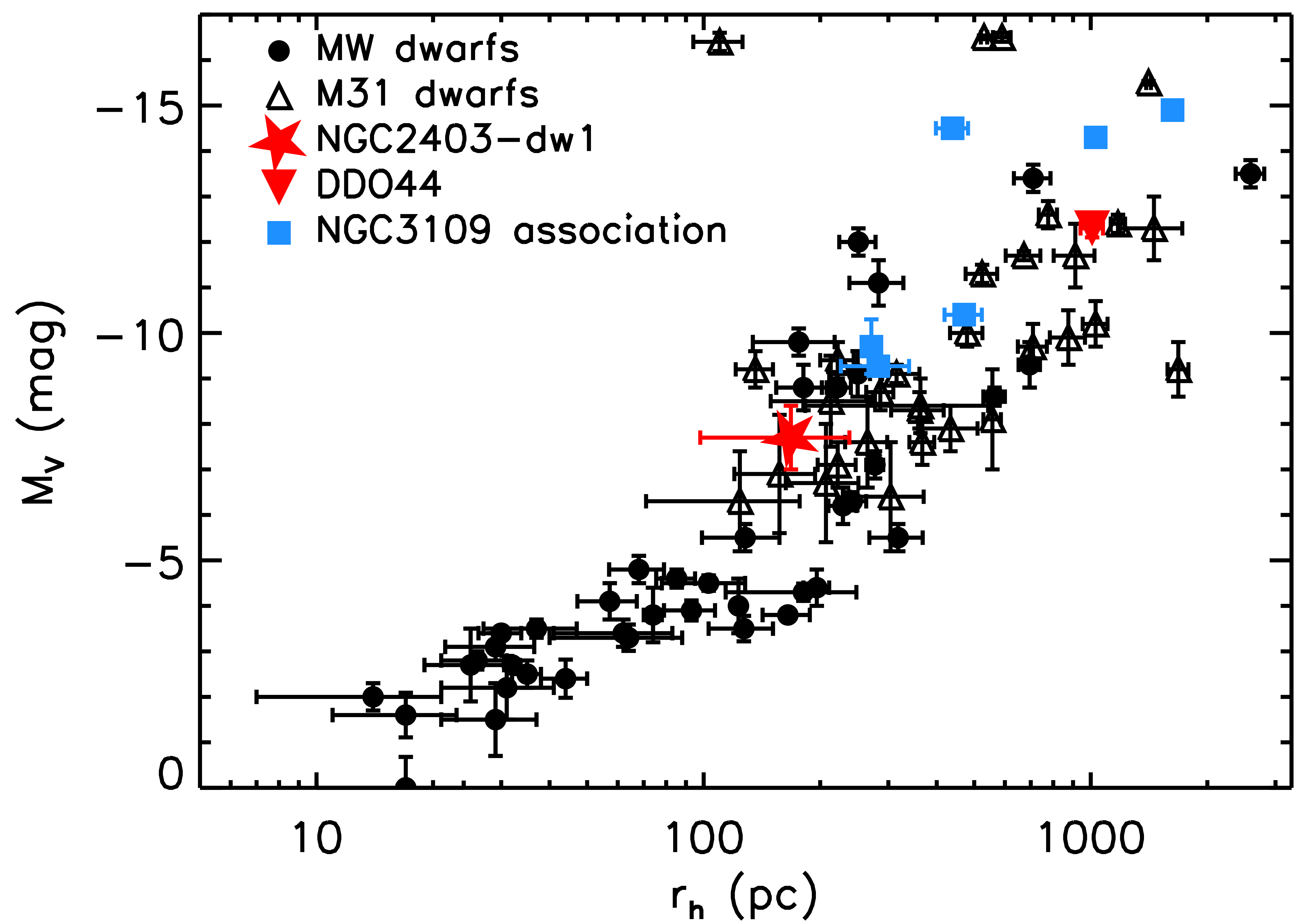
background



* Carlin et al. (2016), ApJL, 828, 5

Properties of MADCASH-1 in comparison to Local Group dwarfs

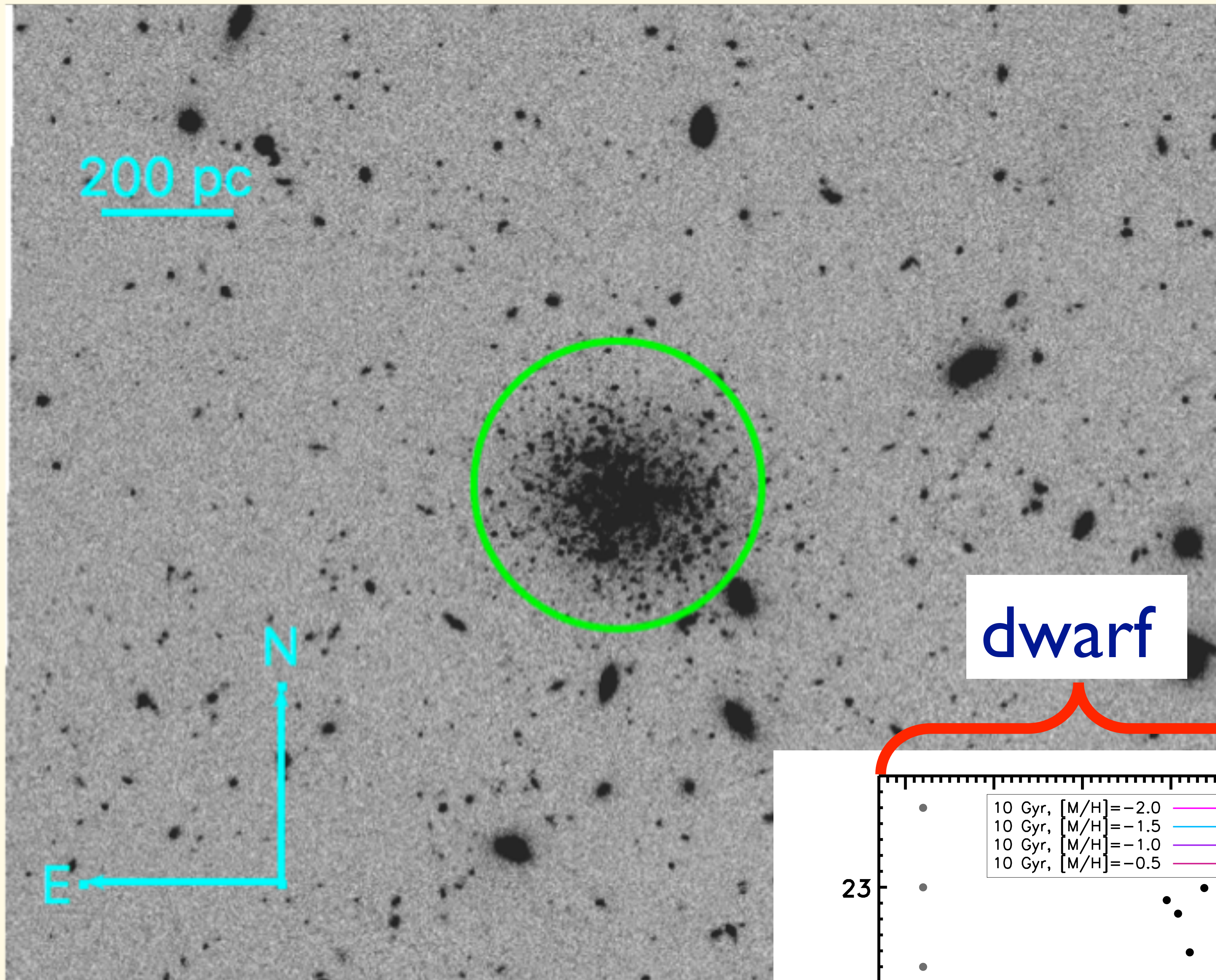
Parameter	Value
RA (hh:mm:ss)	$07:42:38.887 \pm 2.6''$
Decl (dd:mm:ss)	$+65:25:01.89 \pm 3.2''$
$m - M$ (mag)	27.65 ± 0.26
D (Mpc)	3.39 ± 0.41
M_g (mag)	-7.4 ± 0.4
M_V (mag)	-7.7 ± 0.7
$r_{\rm h}$ (arcsec)	10.2 ± 3.0
$r_{\rm h}$ (pc)	168 ± 70
ϵ	< 0.42 (68% CL)
θ (deg.)	29°(unconstrained)
μ_0 (mag arcsec^{-2})	25.9 ± 0.7
$M_{\rm star}(M_\odot)$	$\sim 1 \times 10^5$
$M_{\rm HI}/L_V(M_\odot/L_\odot)$	< 0.69
$M_{\rm HI}(M_\odot)$	$< 7.1 \times 10^4$
SFR ($M_\odot$/yr)	$\leq 4.4 \times 10^{-6}$



Faint (M_V ~ -7.7) companion of LMC analog NGC 2403, with old (>10 Gyr), metal-poor ([M/H] ~ -2) stellar pops, no appreciable HI or UV emission

* Carlin et al. (2016), ApJL, 828, 5

New dwarf galaxy near NGC 4214?
(D~2.9 Mpc, $M_* \sim 1\times10^9\ M_{Sun}$; ~0.4 $M_{*,LMC}$)



MADCASH Jxxxxxx+xxxxxx-dw

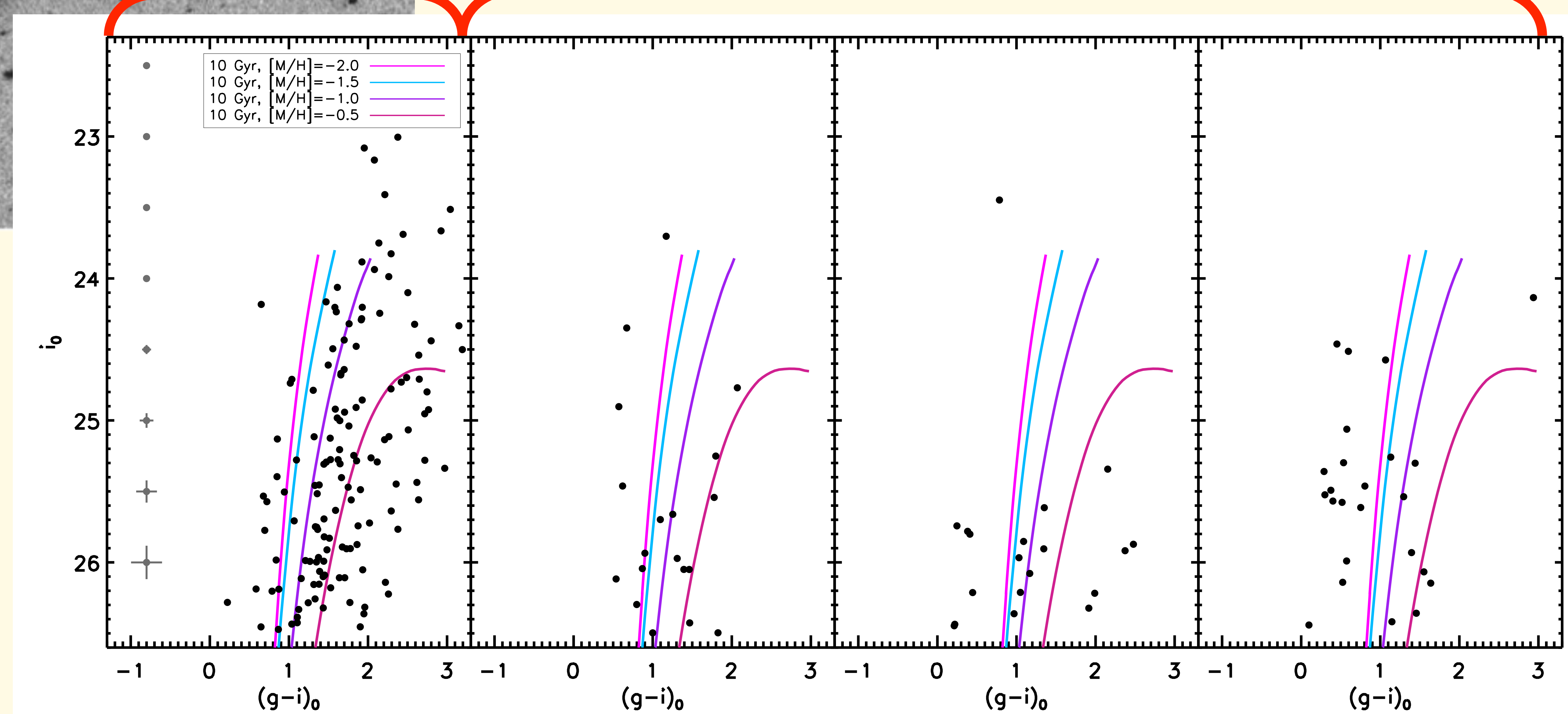
$M_V \sim -8.5$(?)

$r_{half} \sim 200$ pc

R_{proj}~70 kpc from NGC 4214

dwarf

background

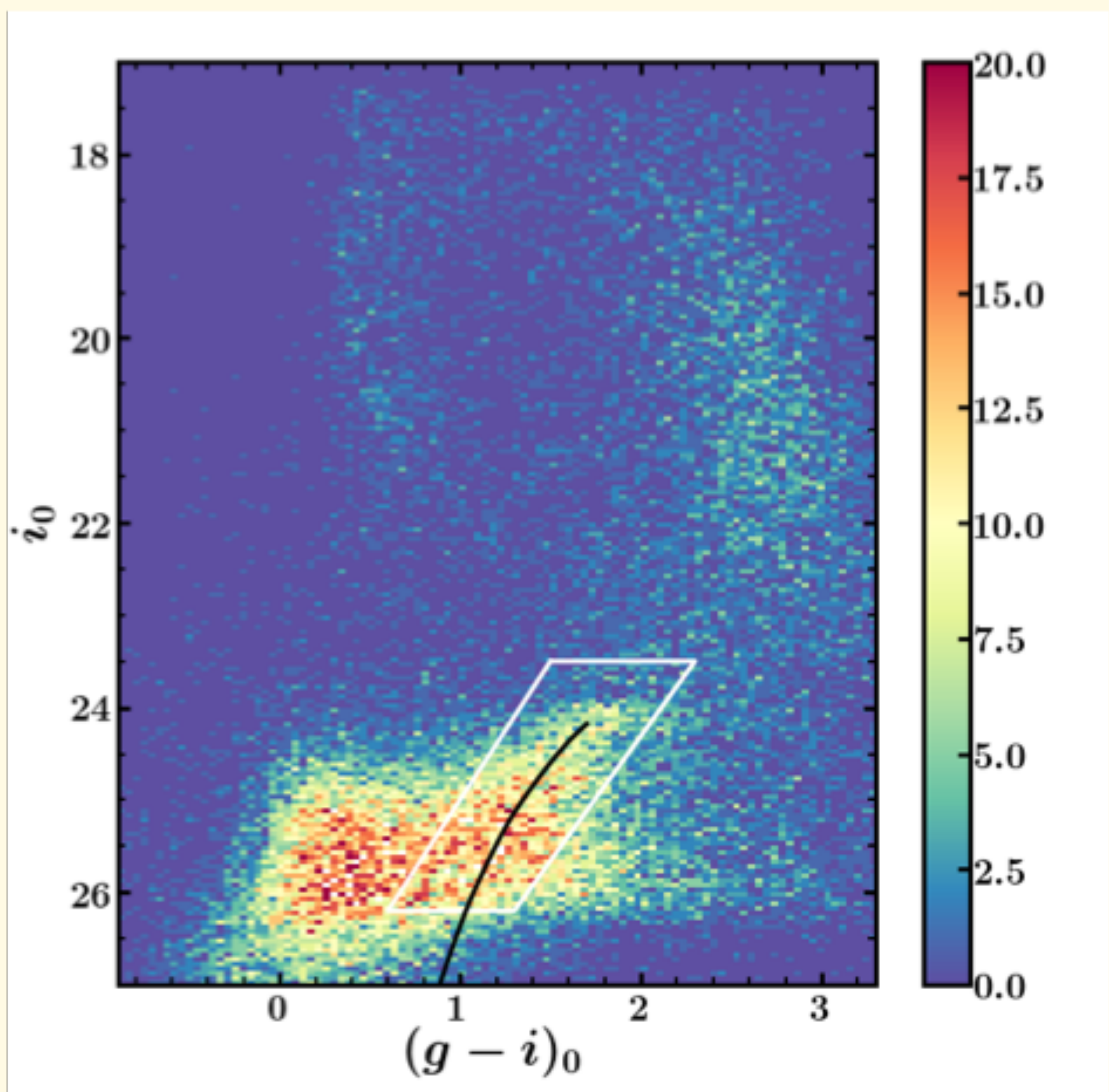


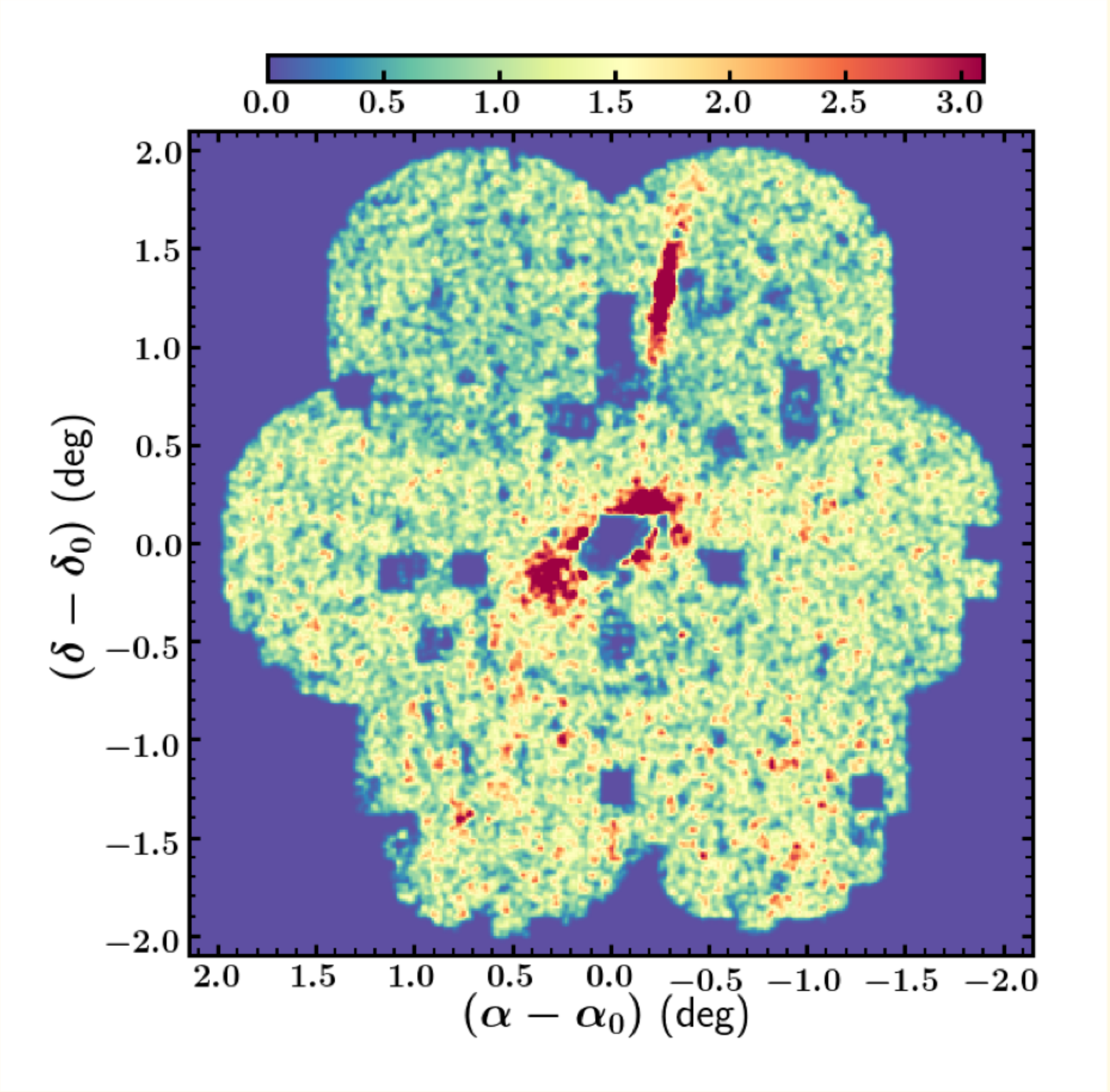
*** preliminary

J. Carlin, *Near-field Cosmology with the Dark Energy Survey's DR1 and Beyond*, Chicago, June 2018

Density of RGB stars around NGC 2403

-- Disrupting dwarf satellite with Leo I-like luminosity



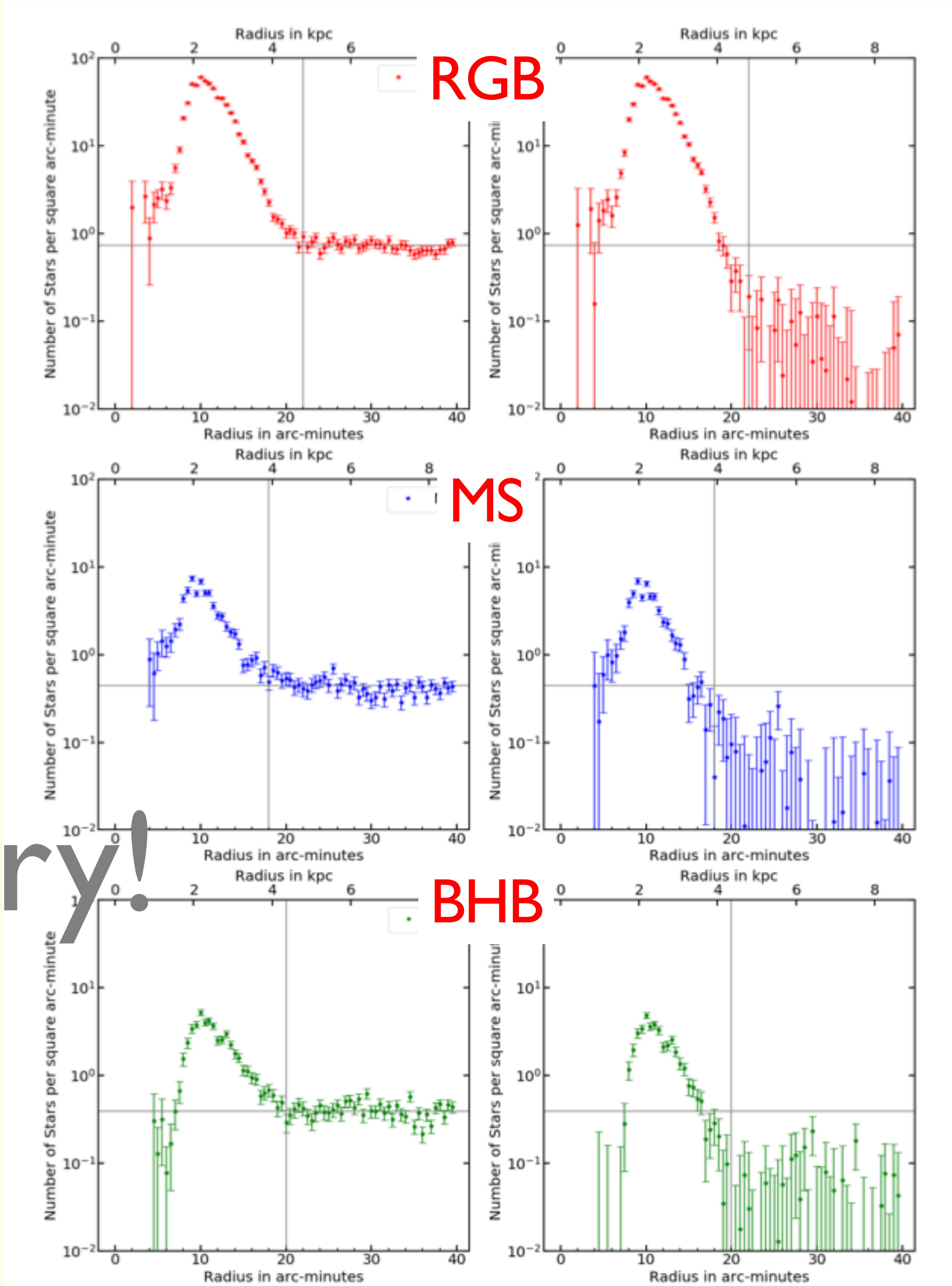


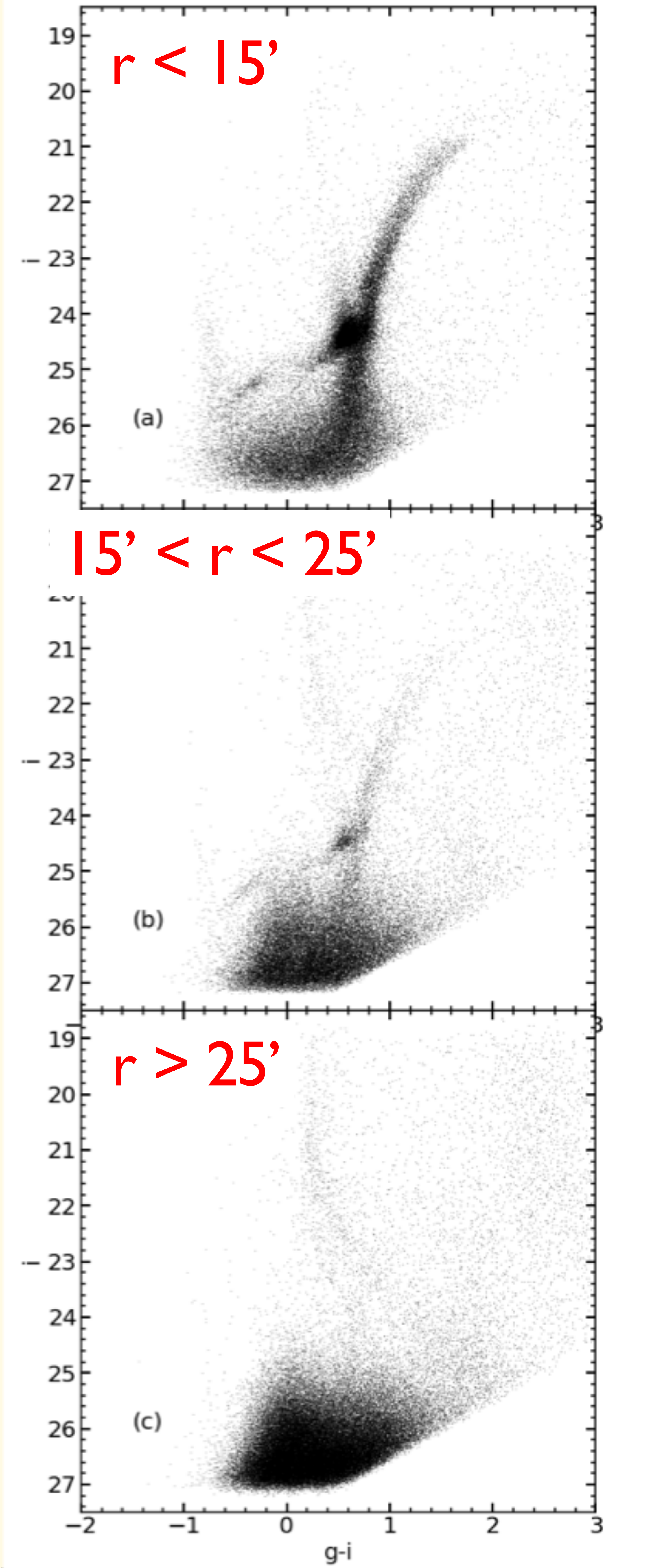
Carlin+2018, *in prep.*

***preliminary!

IC 1613:
$M_* \sim 0.5\ M_{*,SMC}$; d ~ 730 kpc

Evidence of an extended stellar component





preliminary!

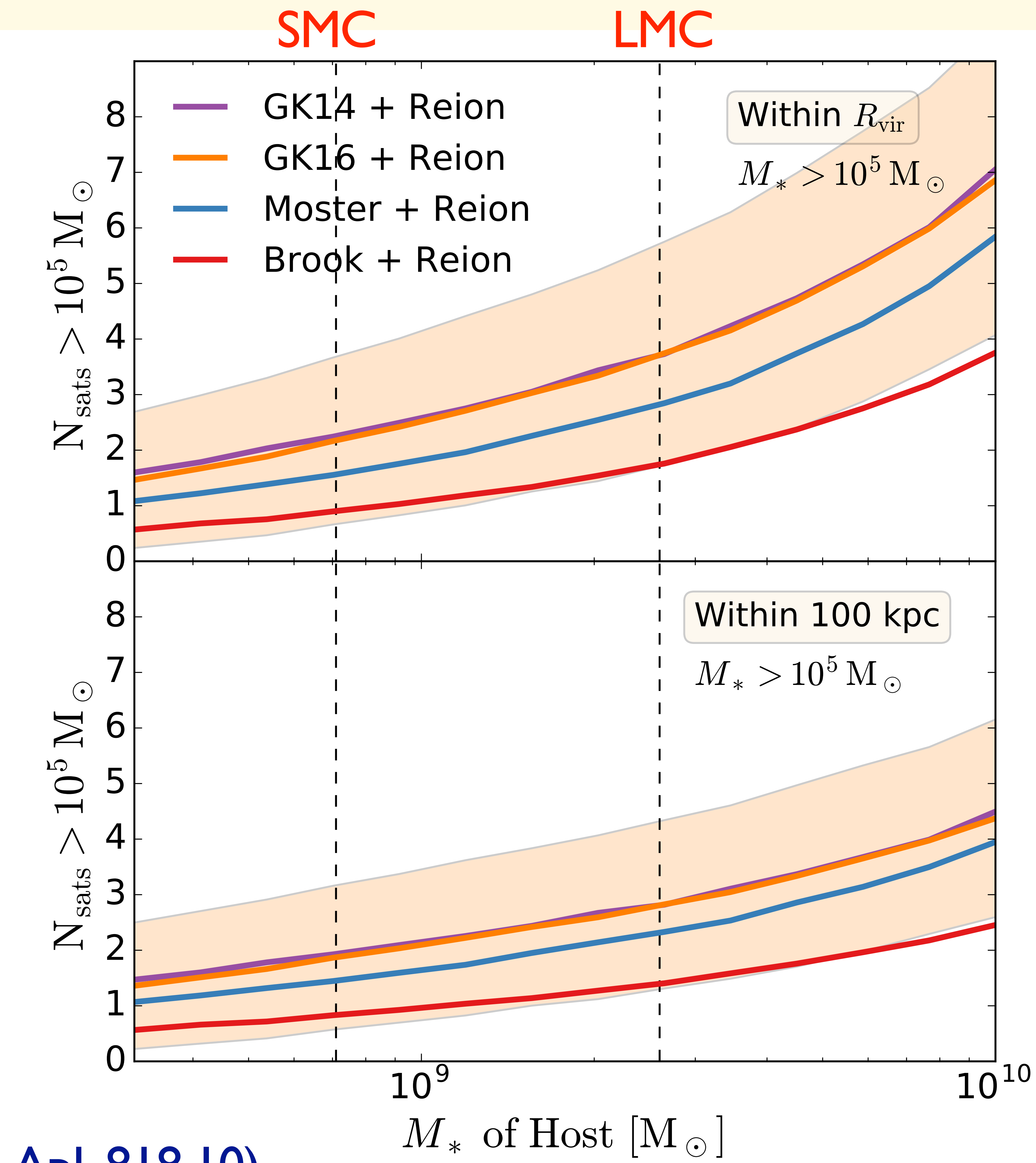
*work by Ragadeepika Pucha et al.; in prep.

How many satellites do we expect to find around isolated LMC/SMC stellar-mass galaxies?

[Dooley+2017(MNRAS, 471, 4894)]

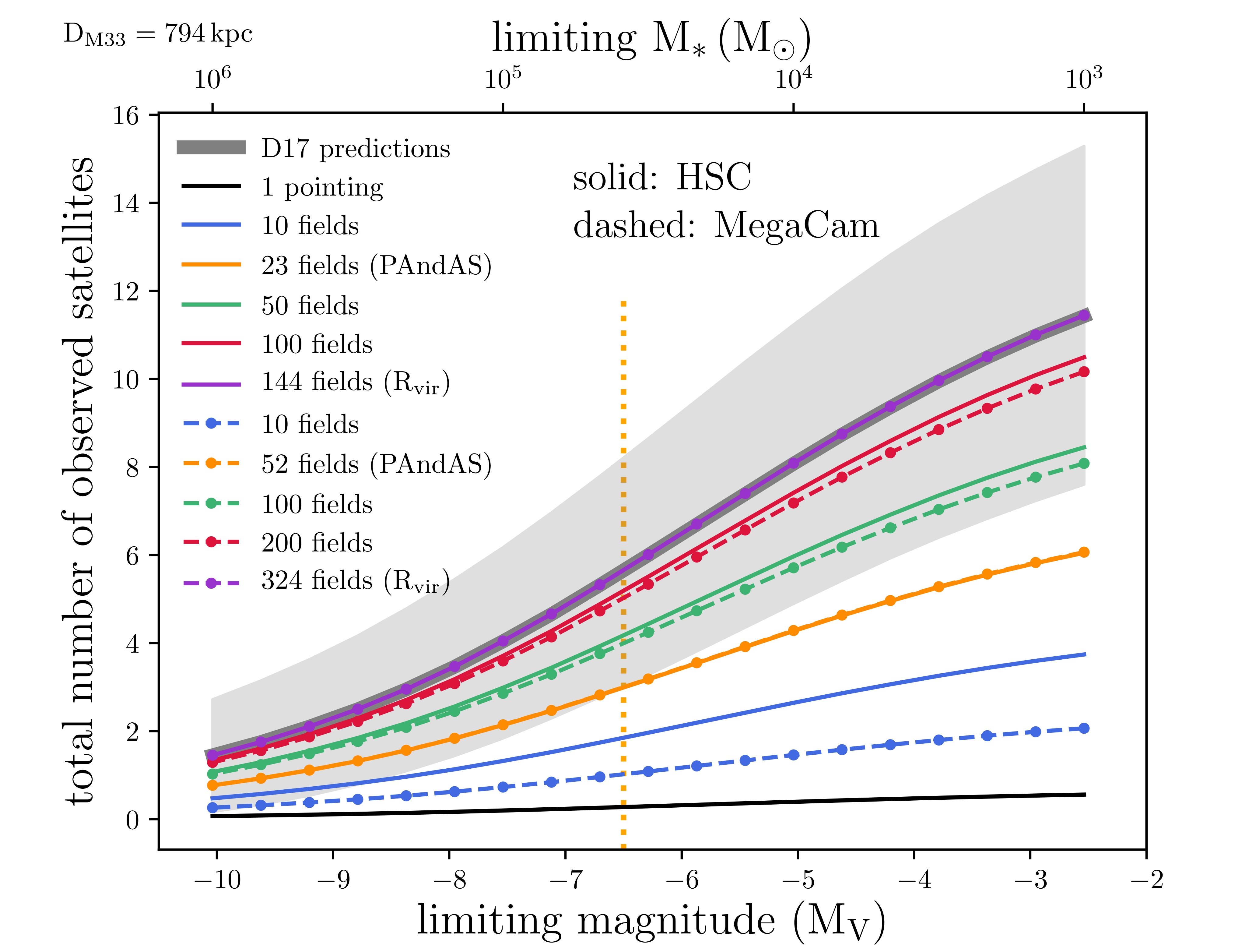
Galaxy	M_* (10^9 M_{Sun})	N_{sat} (>10^5 M_{Sun})
SMC	0.7	1-3
NGC 4214	1.0	1-4
NGC 404	1.8	2-5
NGC 300	2.6	2-5
LMC	2.6	2-5
NGC 55	3.0	2-6
NGC 247	3.2	2-6
NGC 2403	7.2	4-8

Note: $M_*=10^5$ M_{Sun} → M_V ~ -7.2



see also Dooley+2017 (MNRAS, 472, 1060); based on Caterpillar simulations (Griffen+2016, ApJ, 818, 10)

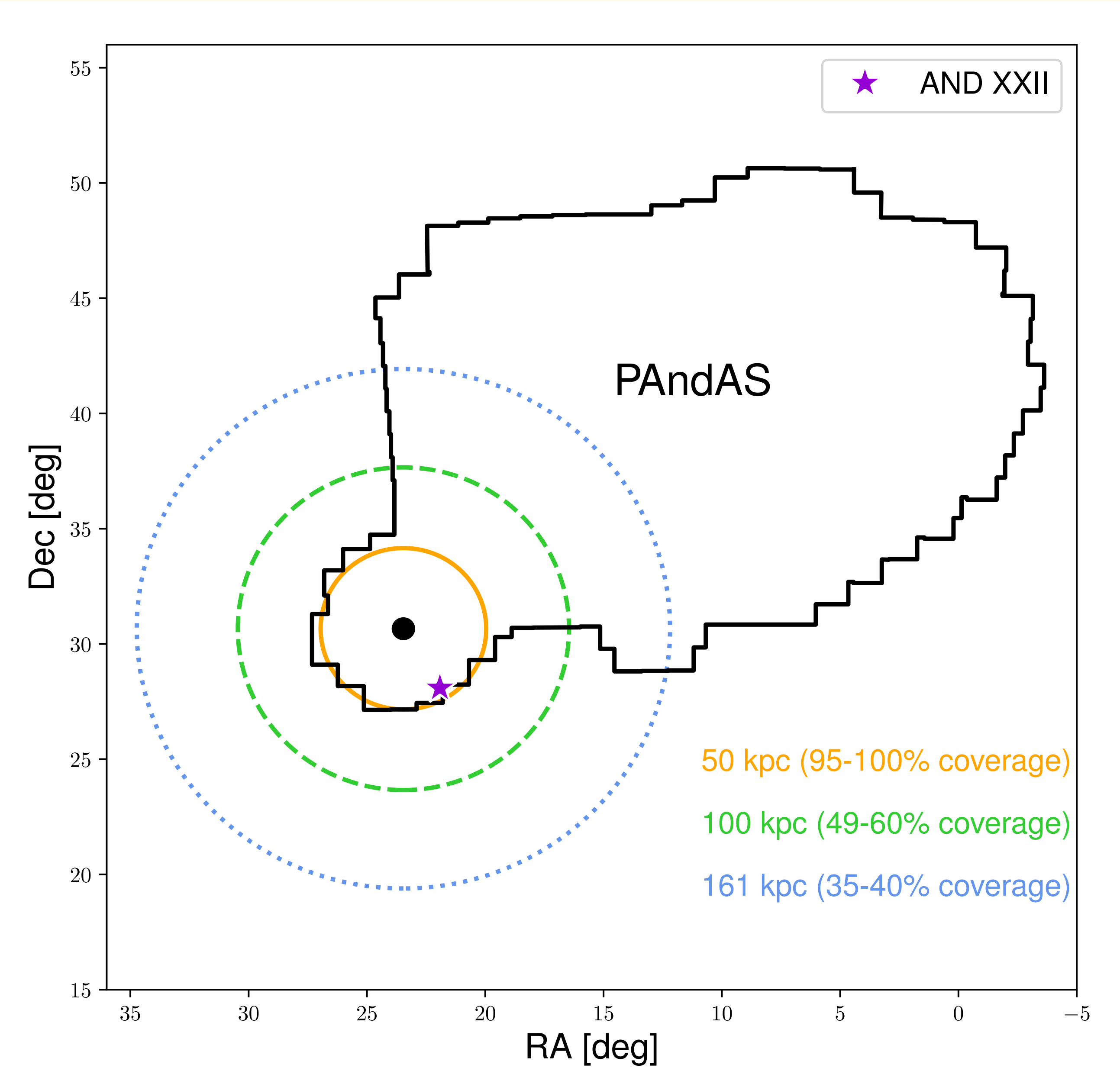
How many satellites do we expect to find around M33 ($M_* \sim M_{*,LMC}$)?



Patel+2018 (MNRAS, *submitted*):

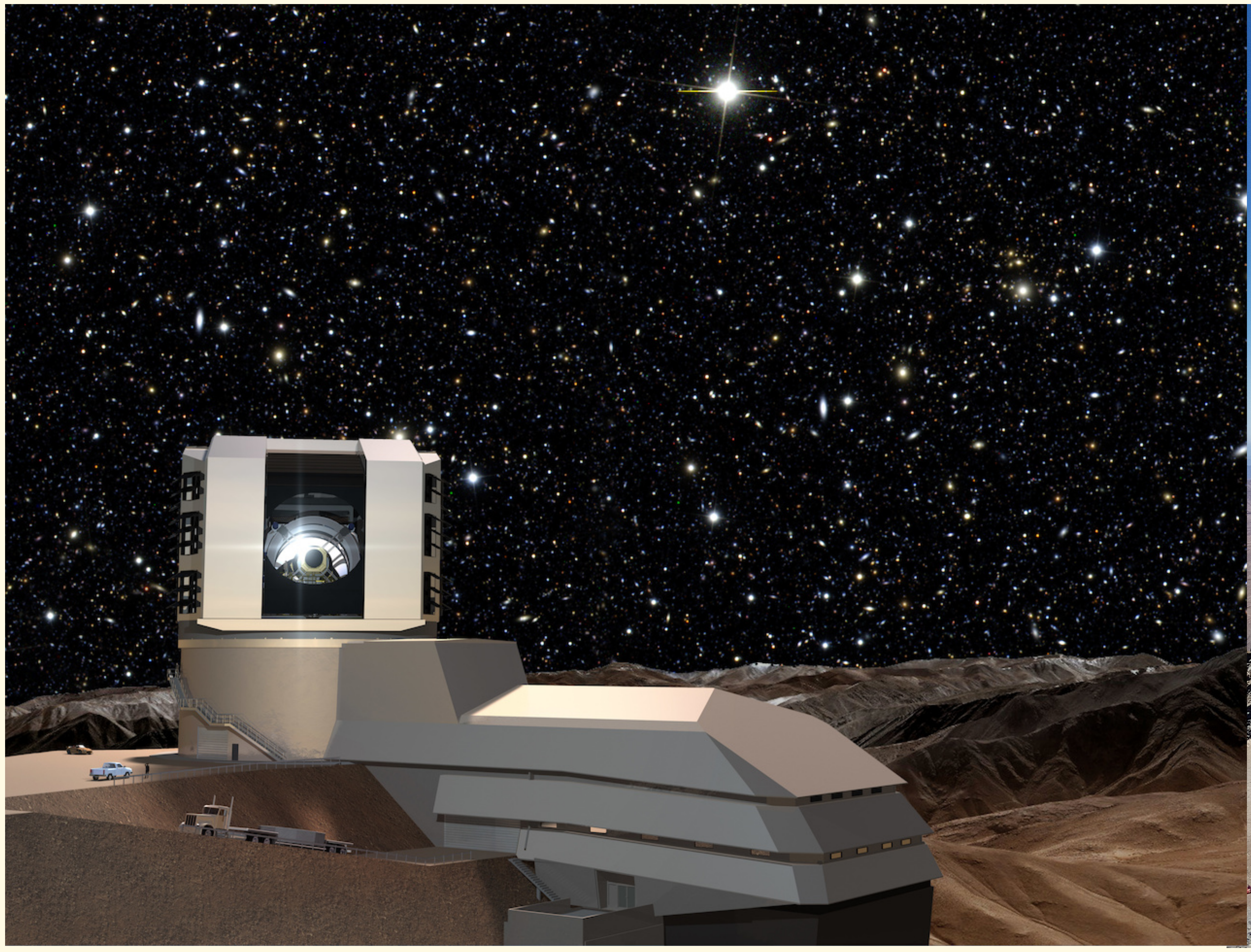
ΛCDM predictions:
~4 satellites with $M_* > 10^5$ M_{Sun}, and ~11 with $M_* > 10^3$ M_{sun}

(only 1 possible M33 sat. known – And XXII; $M_* \sim 4x10^4$ M_{sun})



Using method of Dooley+2017(MNRAS, 471, 4894)

The Large Synoptic Survey Telescope
will again revolutionize our picture of our own cosmic backyard



The LSST system will include:

(i) an 8.4-meter optical telescope, a 3.5-degree diameter field-of-view, a 3.2 billion pixel camera, and 6 broad-band, optical filters that **will observe more than half the sky hundreds of times over 10 years**

(ii) a data facility that will process, archive, and distribute survey images, associated transient alerts, and calibrated catalogs.

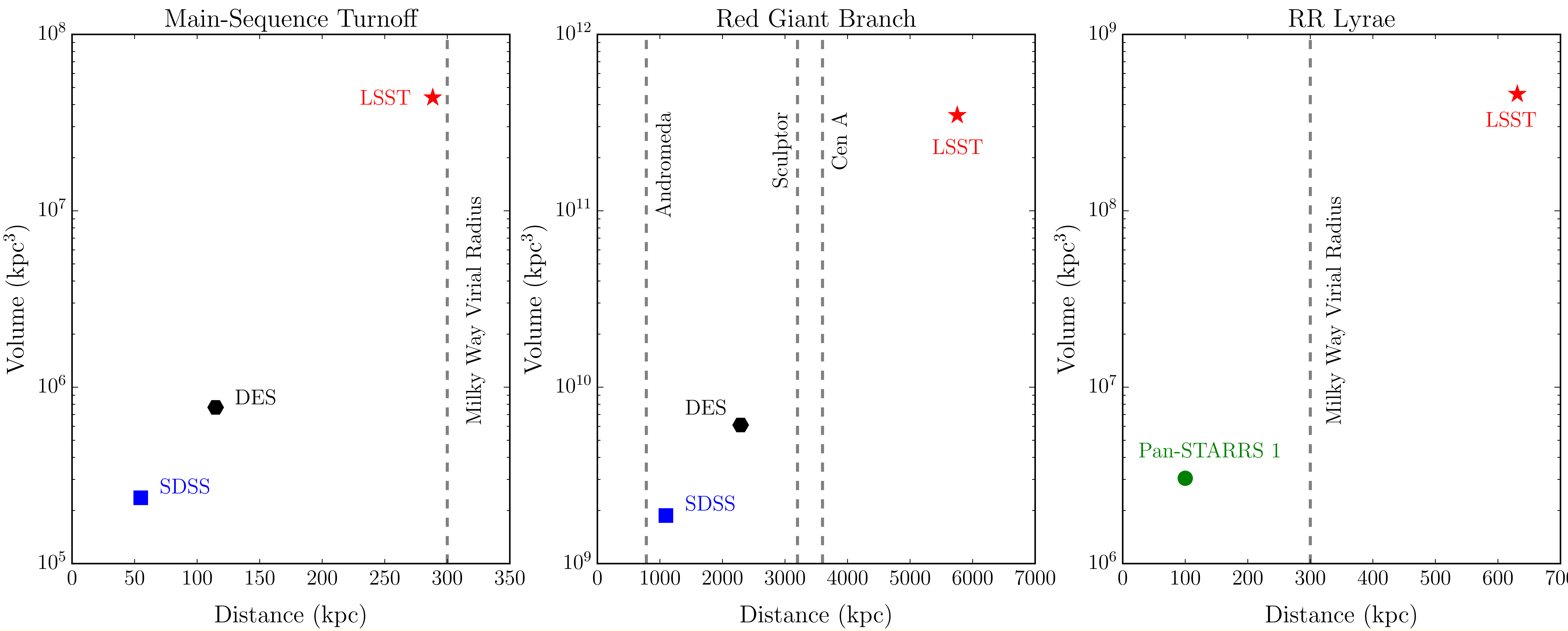
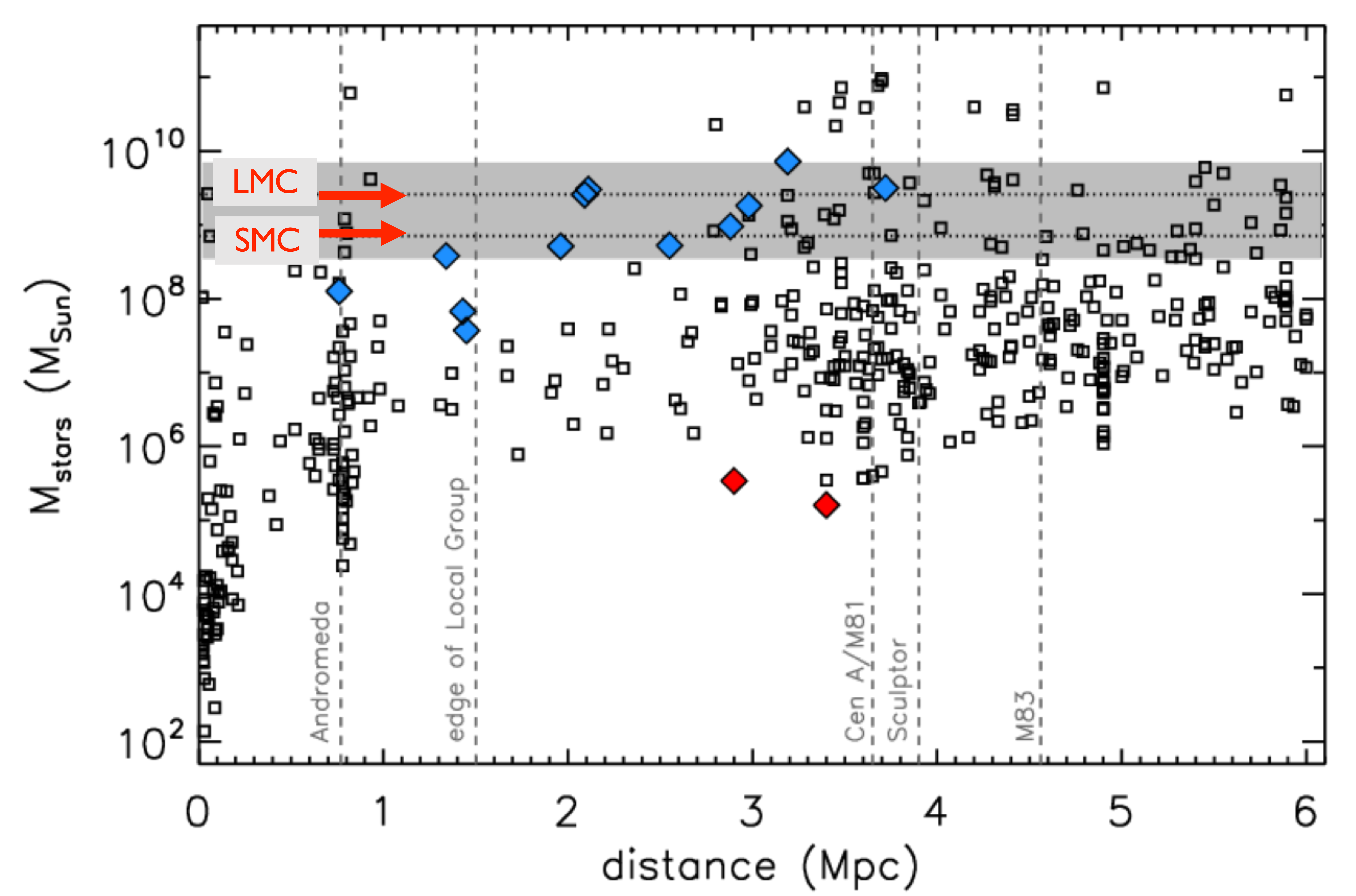


Figure: Keith Bechtol

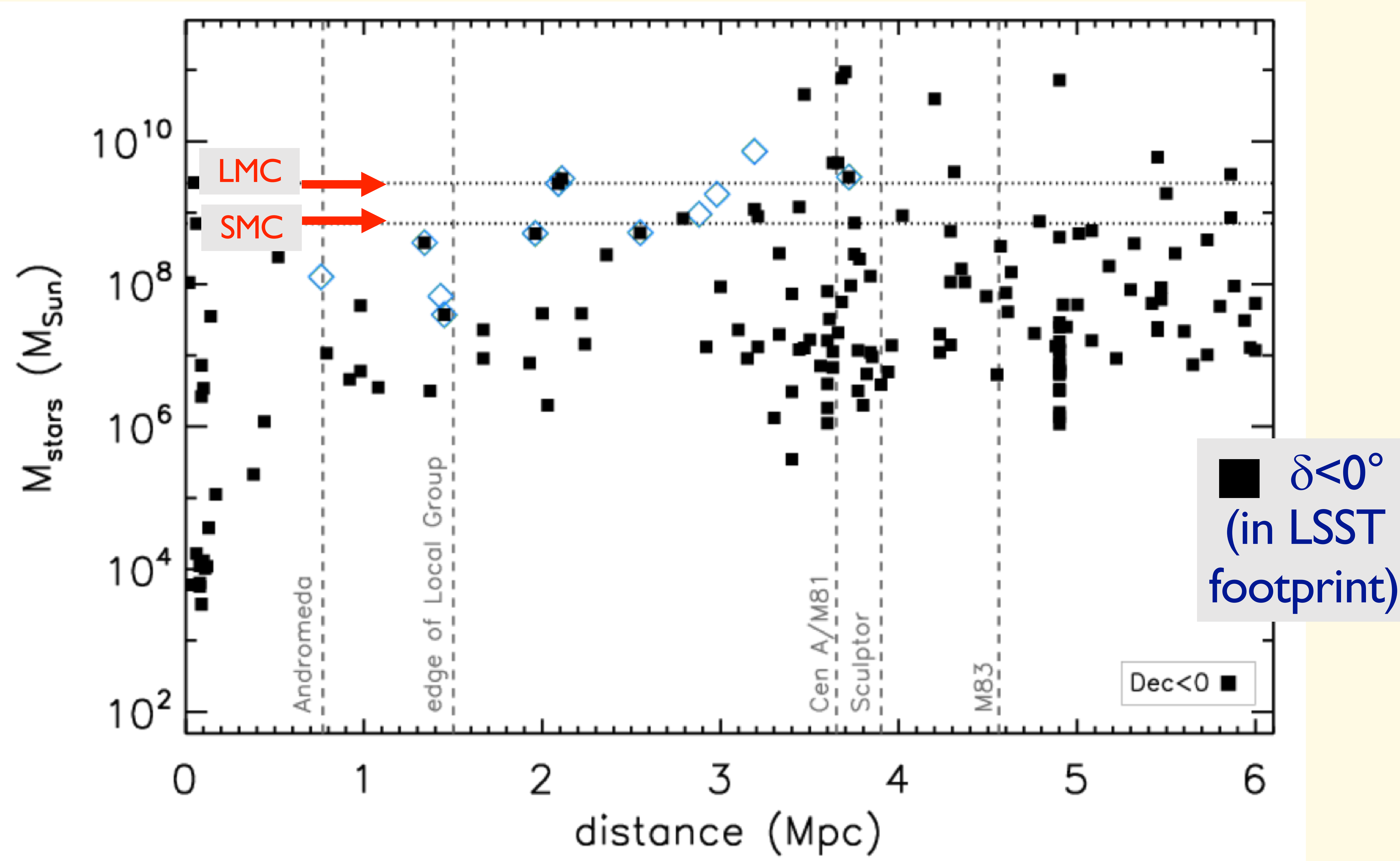
LSST will open ~1,000 times the volume for studying the Local Universe with resolved stars compared to SDSS

Stellar mass vs. distance; Local Volume galaxies



*Data from Karachentsev+2013 Local Volume galaxies catalog, available at: https://relay.sao.ru/lv/lvgdb/, plus more recent MW dwarfs

Stellar mass vs. distance; Local Volume galaxies



*Data from Karachentsev+2013 Local Volume galaxies catalog, available at: https://relay.sao.ru/lv/lvgdb/, plus more recent MW dwarfs

Summary -- Magellanic Analog Dwarf Companions and Stellar Halos (MADCASH):

We (Carlin et al. 2016) have discovered the faintest dwarf galaxy companion of an LMC-mass host in the Local Volume -- MADCASH J074238+652501-dw.

Many more dwarfs-around-dwarfs are likely to be discovered soon.

Still to come:

- Systematic search for overdensities of resolved RGB stars in LMC-mass galaxy halos
- (Resolved) surface brightness maps, halo density profiles
- Explore as a function of environment
- Interpret in context of predictions from cosmological models
- LSST!

(Possible) future avenues (with DECam and/or other instruments):

- Bright dwarfs may be visible around Local Volume hosts in DES
- Unresolved, low surface-brightness systems
- For cosmological context, need (poorly known) host masses – use globular clusters as mass tracers
- Spectroscopic follow-up of newly-discovered resolved/unresolved dwarfs?