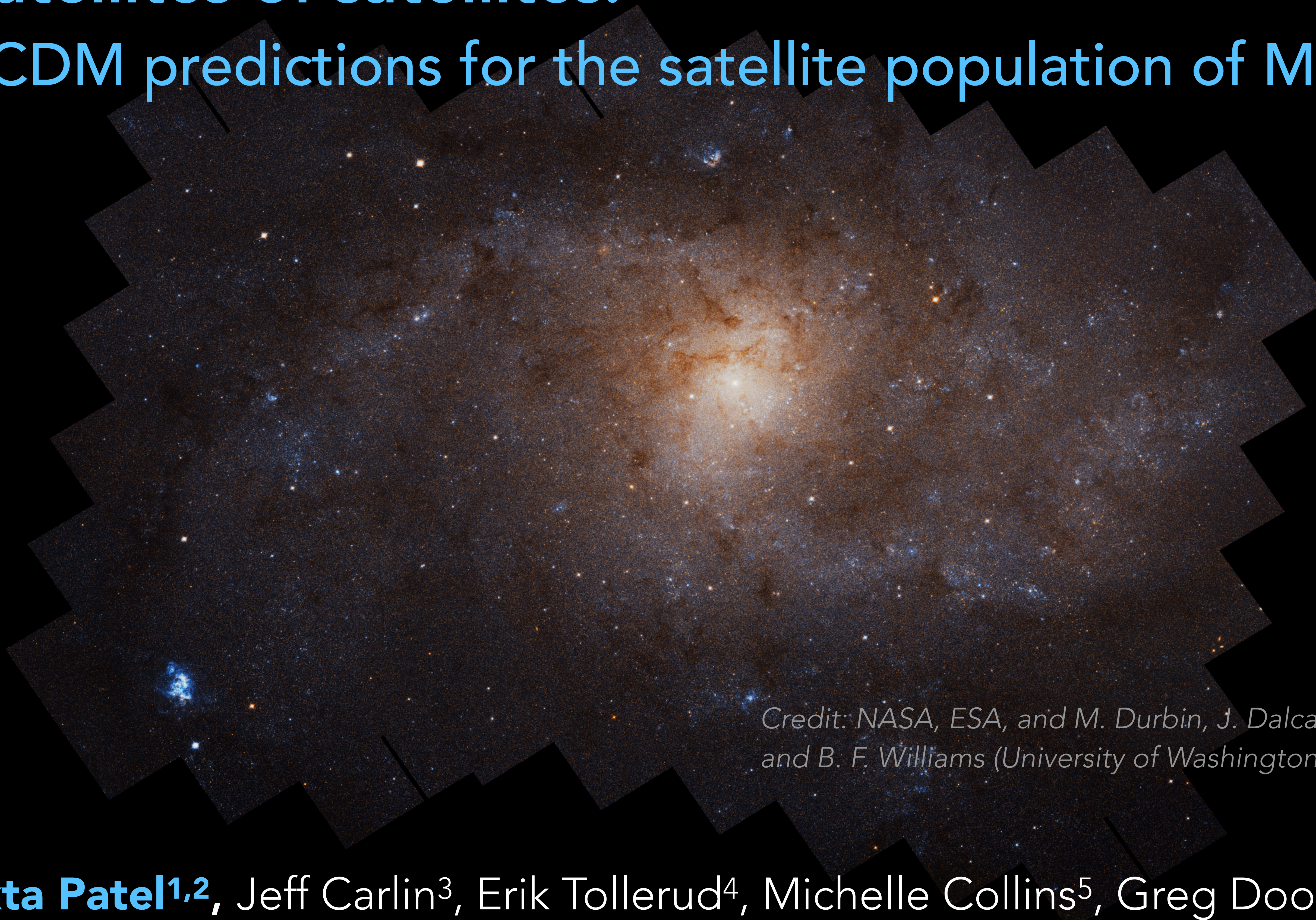
Satellites of satellites:
LCDM predictions for the satellite population of M33



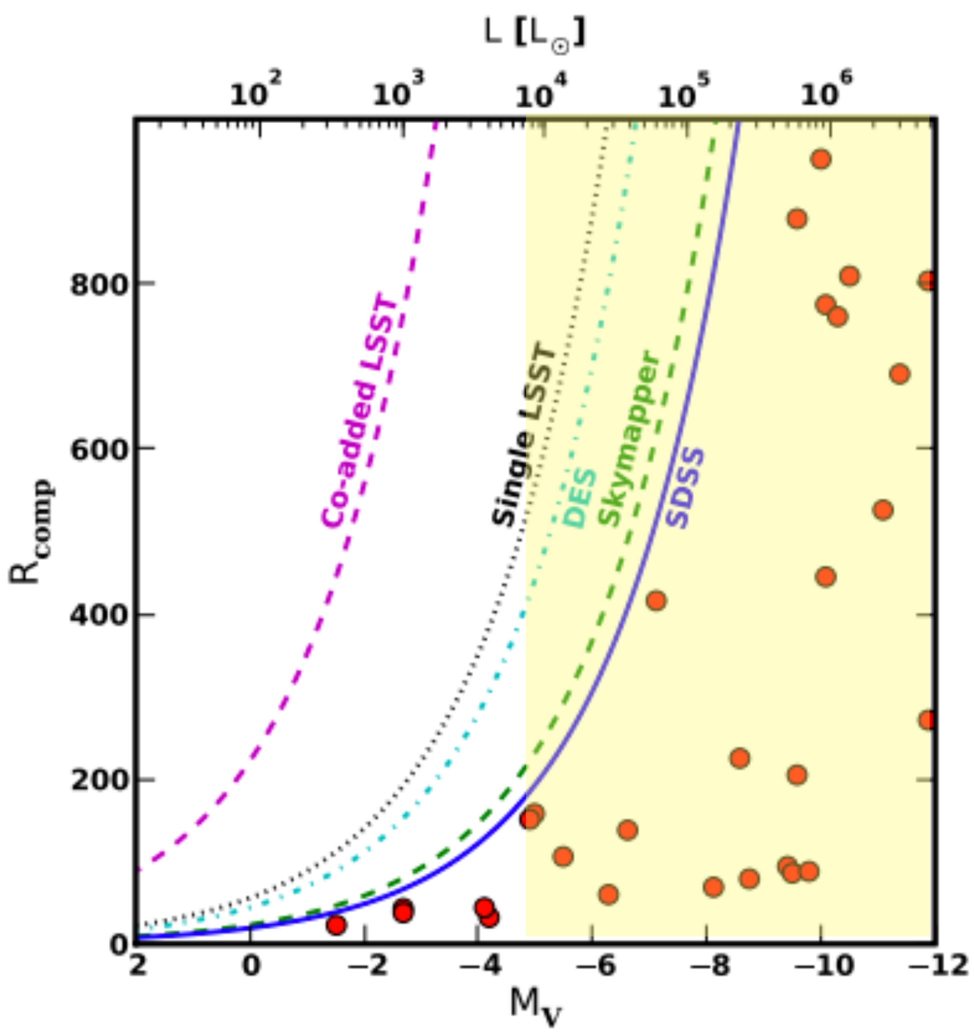
Credit: NASA, ESA, and M. Durbin, J. Dalcanton, and B. F. Williams (University of Washington)

Ekta Patel[1,2], Jeff Carlin[3], Erik Tollerud[4], Michelle Collins[5], Greg Dooley[6]

[1] U. Arizona, [2] UC Berkeley - Miller Institute, [3] LSST, [4] STScI, [5] U. Surrey, [6] Google

Satellites in MW-Mass Halos

theory



Single LSST: 93-179 sats

DES: 19-37 sats

Tollerud+08; see also Newton+18

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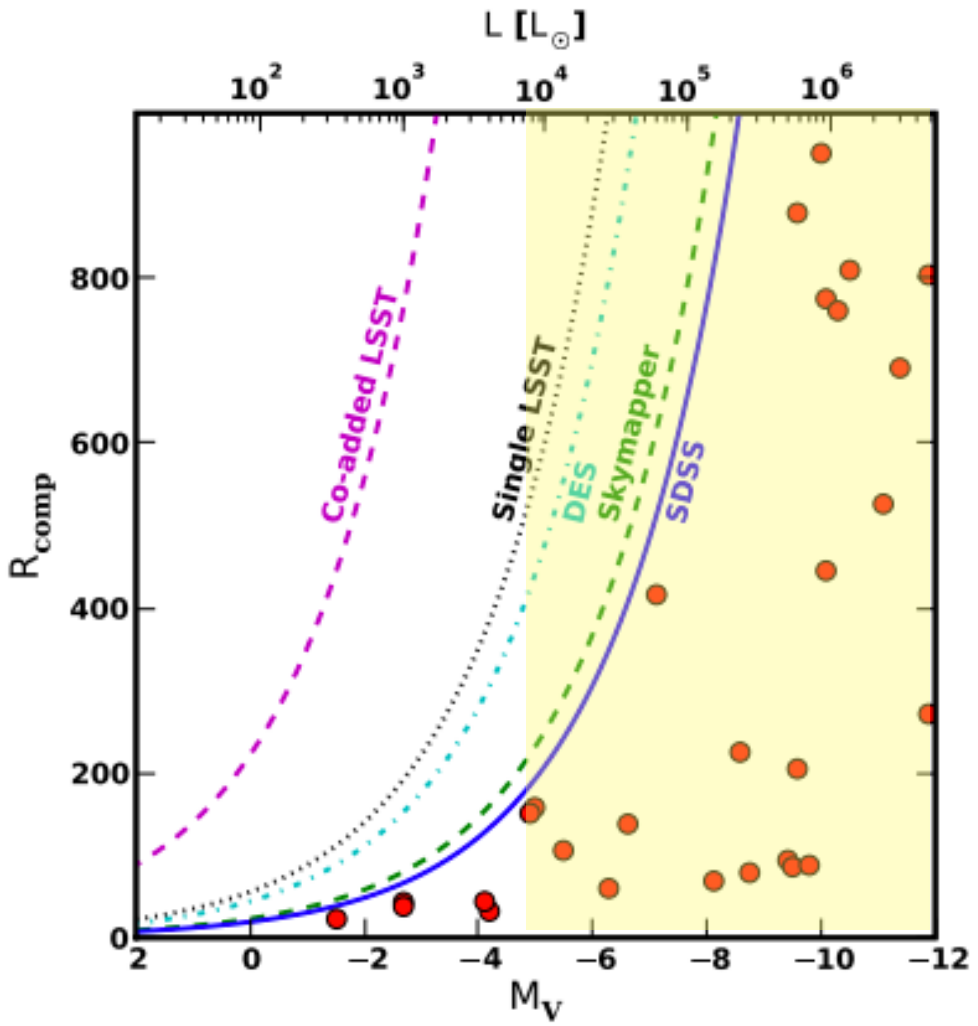
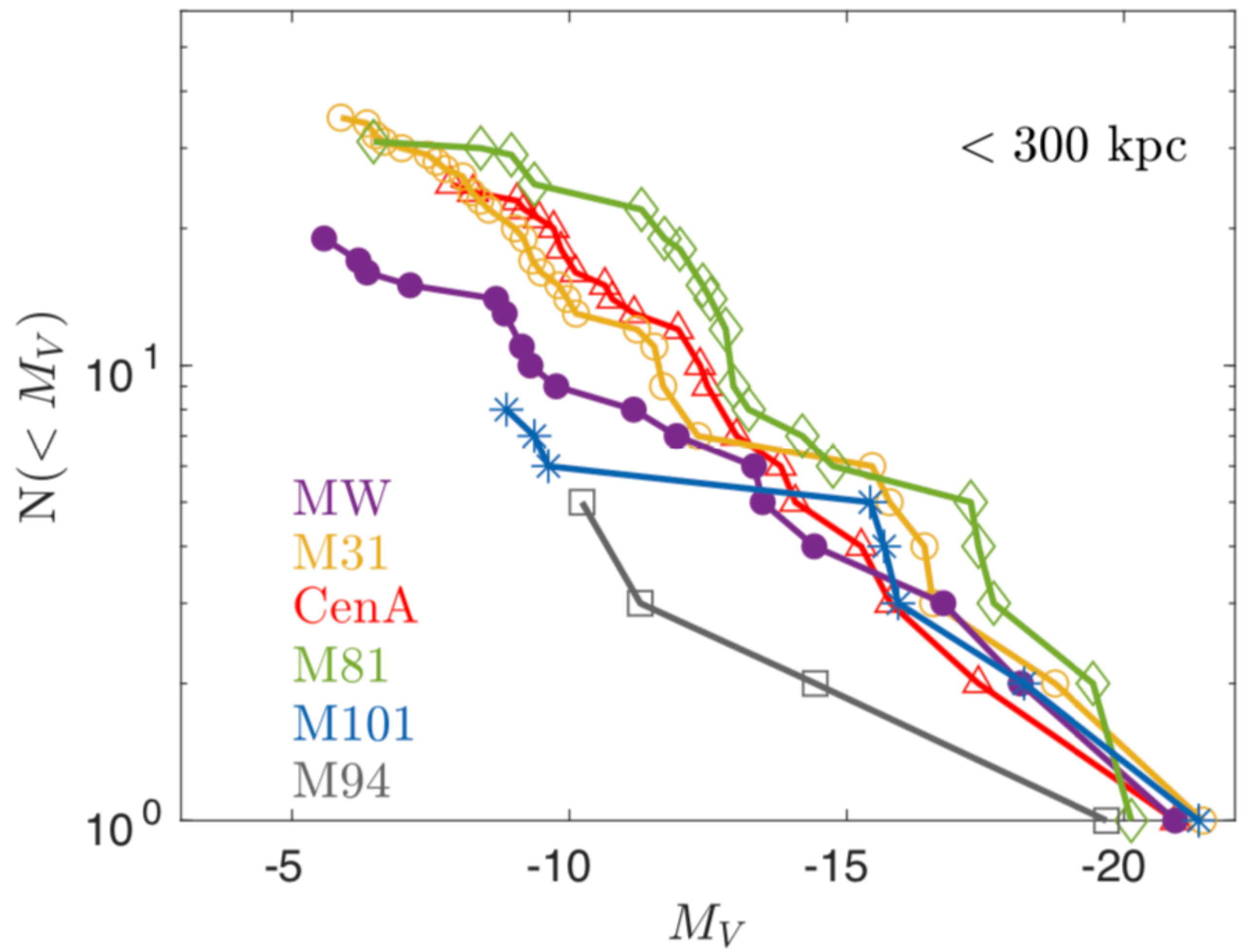


observations



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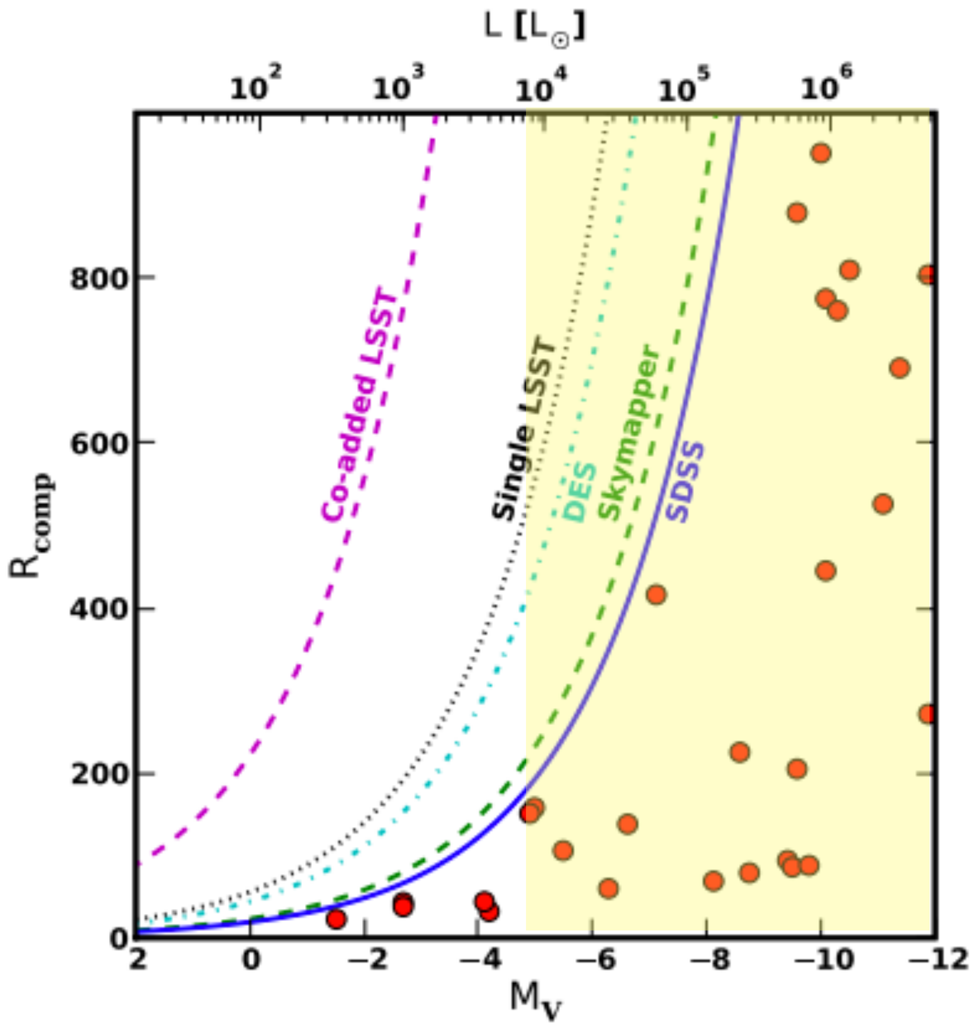

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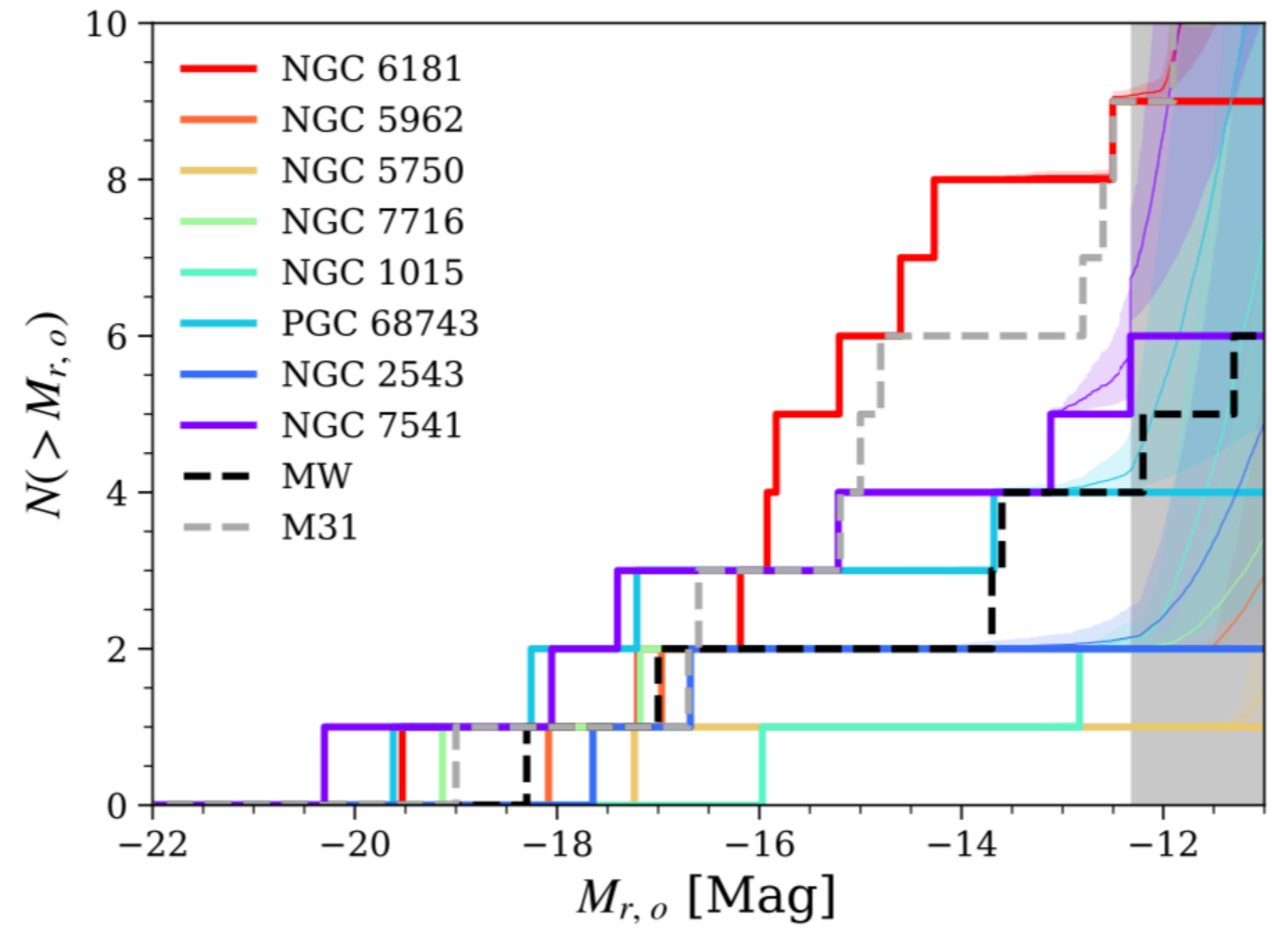

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100 MW-mass analogs at completion!

Tollerud+08; see also Newton+18

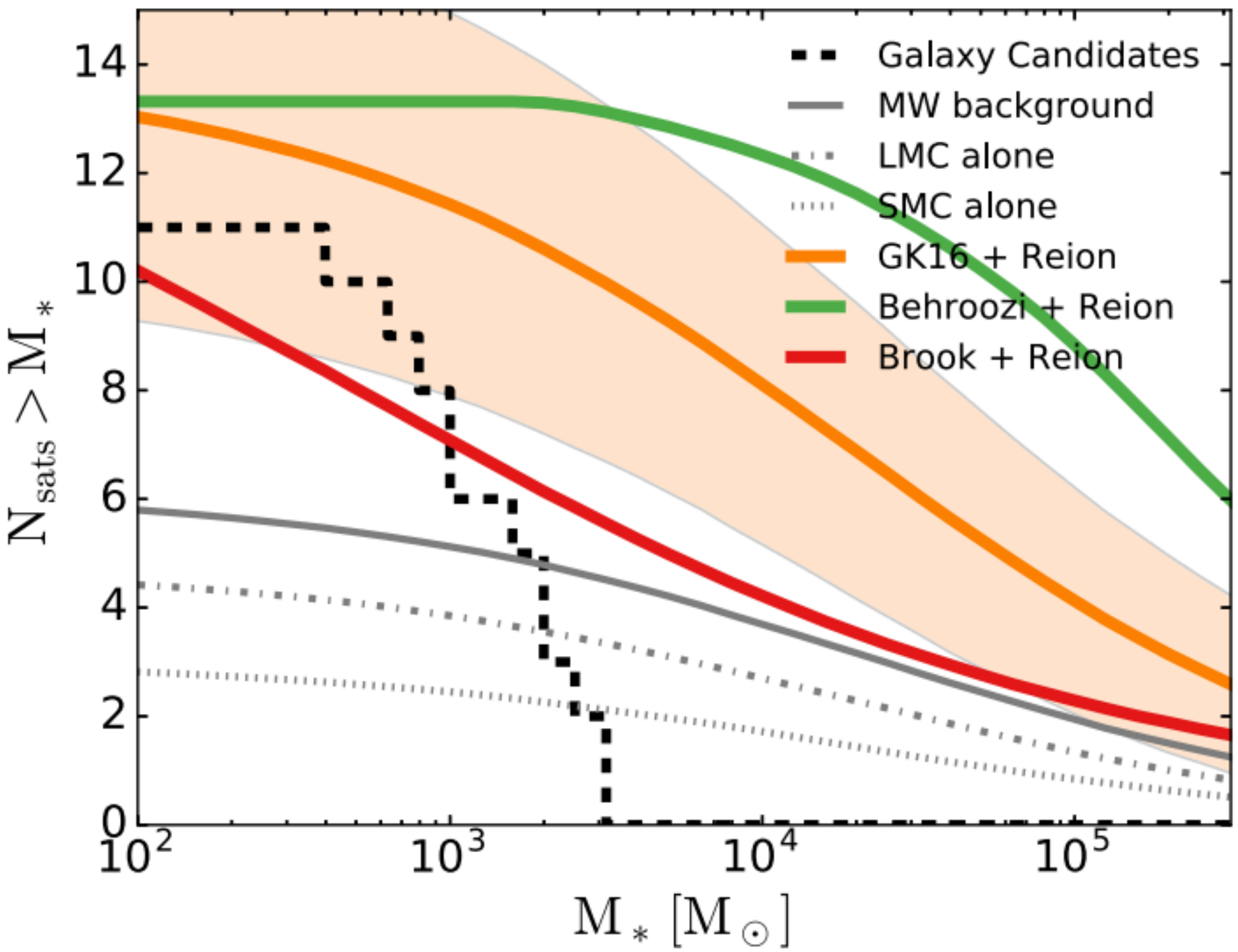
SAGA; Geha+17

Satellites in 10^{11} $M_\odot$ Halos

It becomes increasingly difficult to search for satellites around sub-MW mass haloes (< 10^{11} $M_\odot$) as many satellites are in the ultra-faint regime.

The LMC(+SMC) is the nearest example to test predictions.

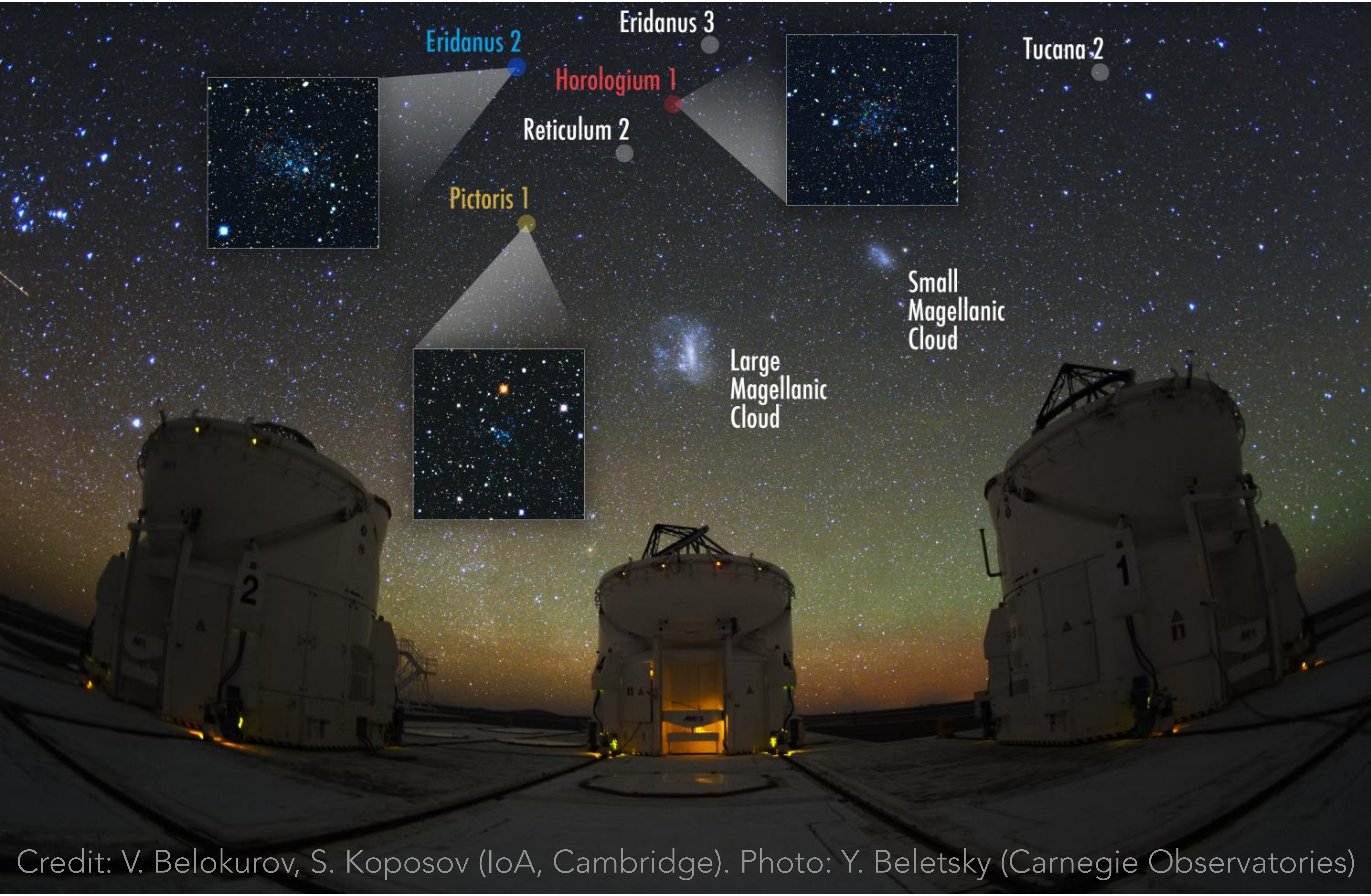
Dooley+17b



Sales+13: 1 SMC, 5-40 ultra-faint dwarf galaxies (UFDs): $M_\bigstar \sim (0.1–1) \times 10^4\ M_\odot$

Dooley+17b: 2-12 UFDs with $M_\bigstar > 10^4\ M_\odot$

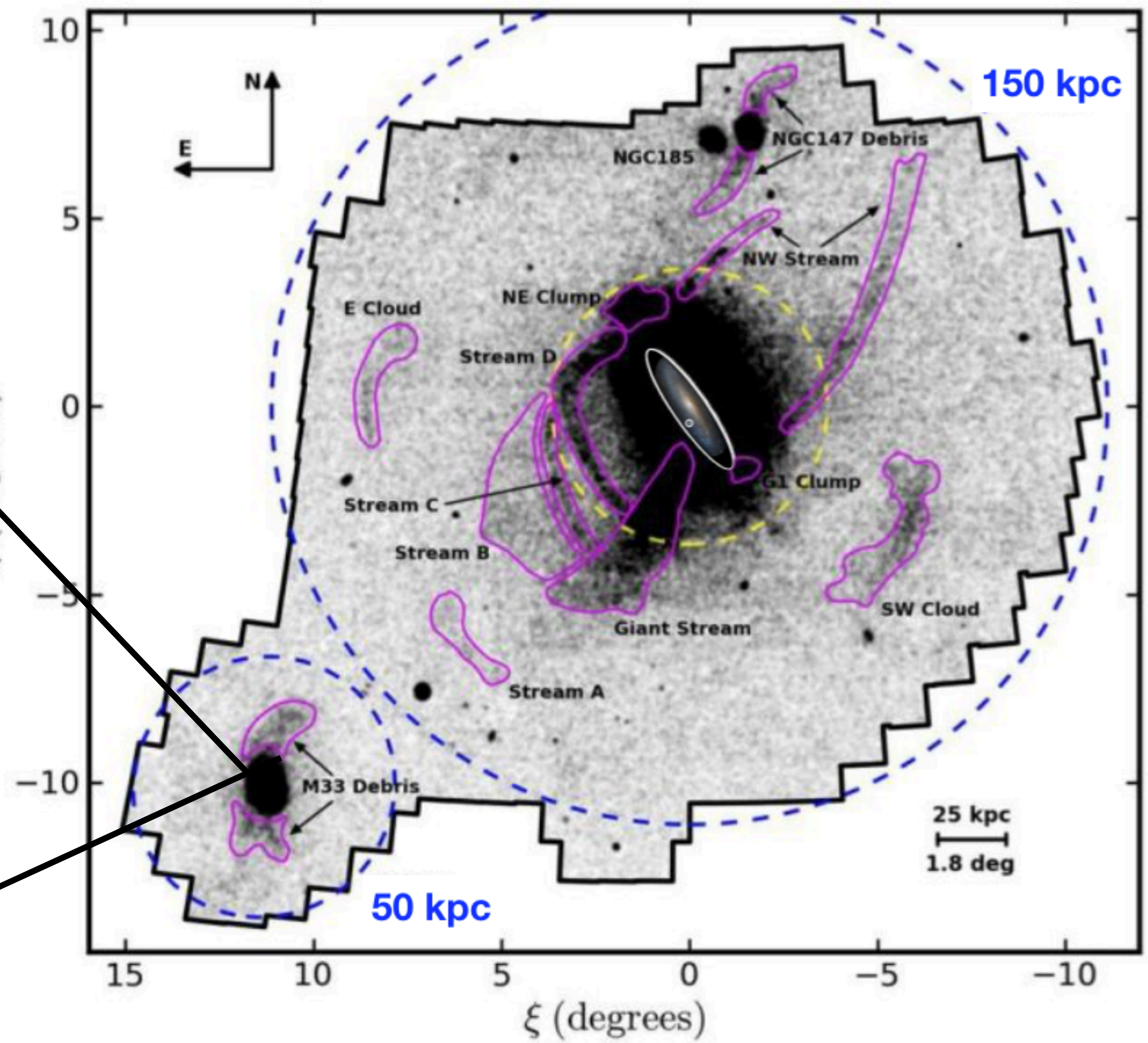
See also Jethwa+16, Kallivayalil+18 (and reference within)



Credit: V. Belokurov, S. Koposov (IoA, Cambridge). Photo: Y. Beletsky (Carnegie Observatories)

M33: M31's Most Massive Satellite Galaxy

(adapted from Ferguson & Mackey 2016)

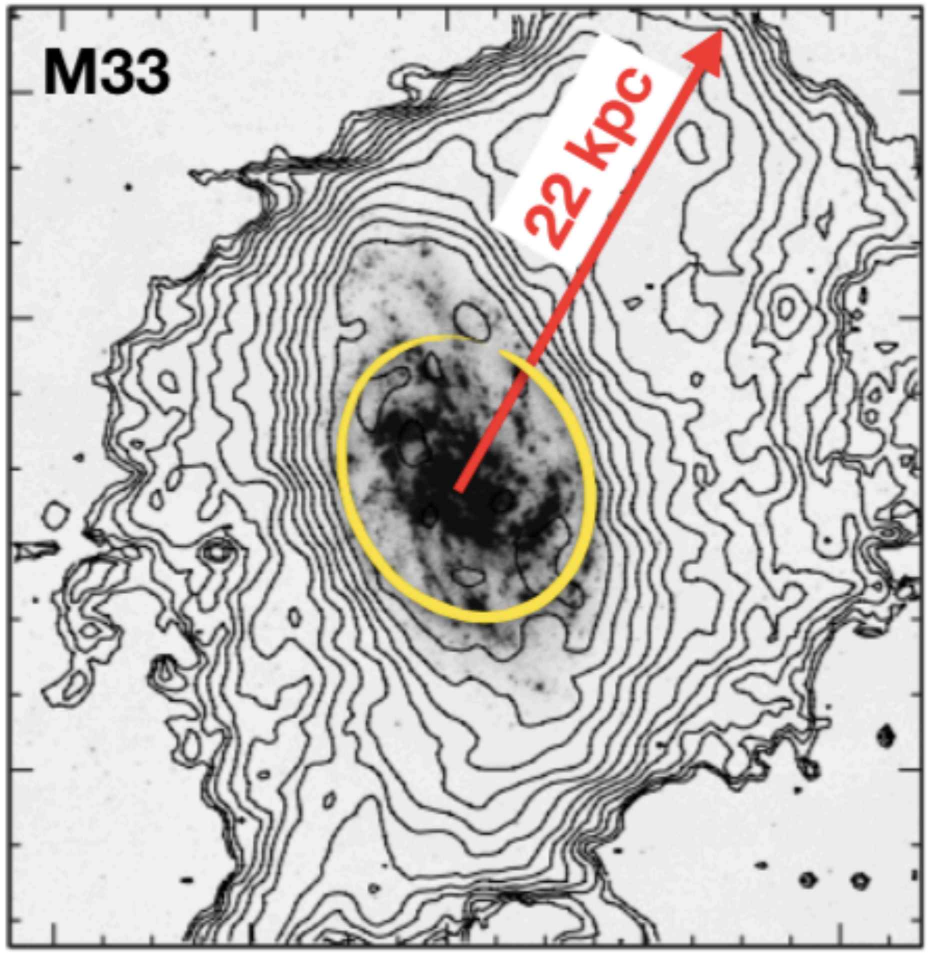


M33: M31's Most Massive Satellite Galaxy

- $M_\star = 3.2 \times 10^9\, M_\odot \rightarrow M_{halo} \sim 10^{11}\, M_\odot$
- *isolated* LMC counterpart
  - 200 kpc from M31
  - ~10% of M31's mass
- morphology shows hints of previous interaction(s) in gas and stars: M31 or satellite companions?

M33: M31's Most Massive Satellite Galaxy

FUV GALEX overlaid with HI density



(Figure adapted from Putman+09)

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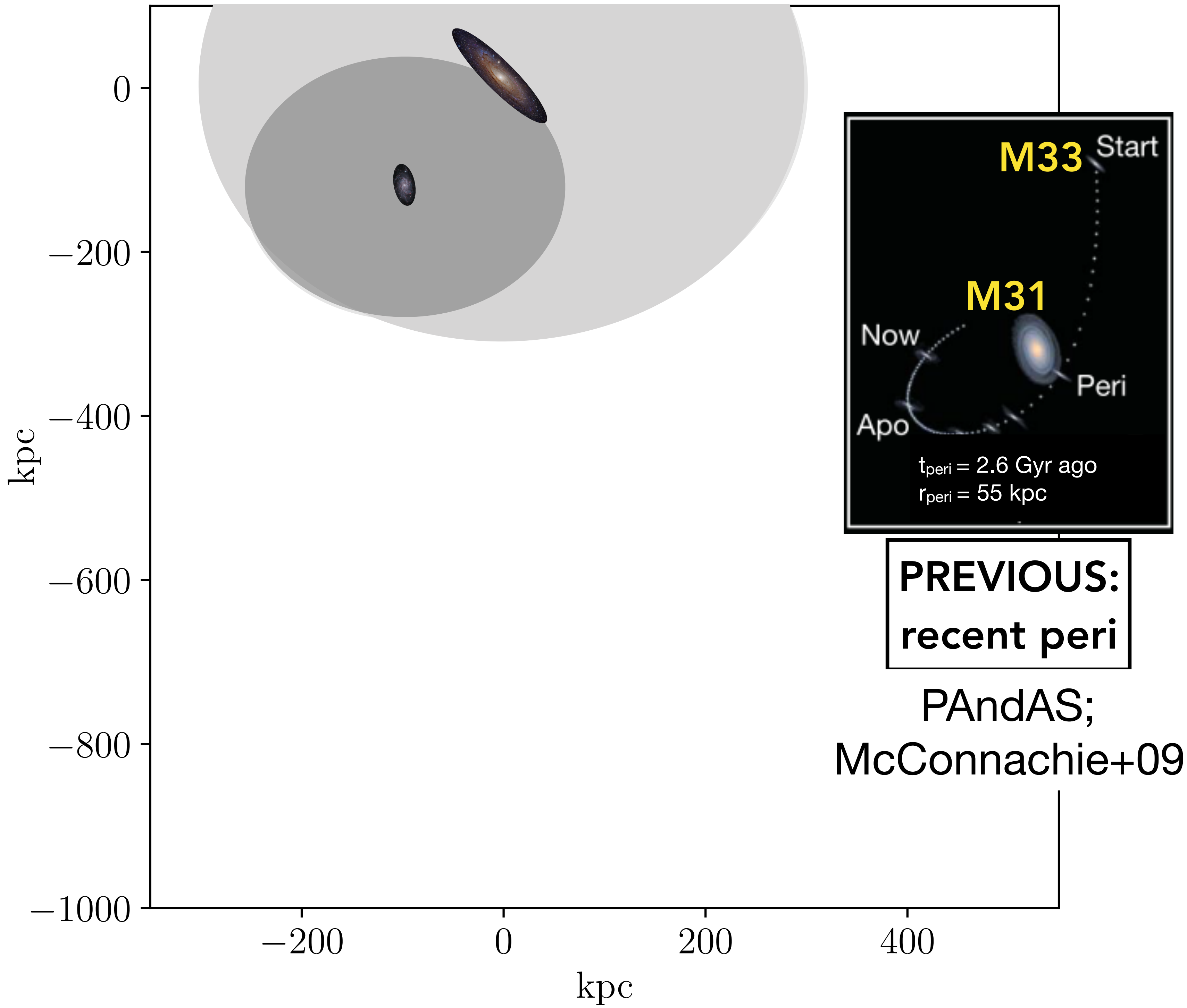


PREVIOUS: recent peri

PAndAS; McConnachie+09

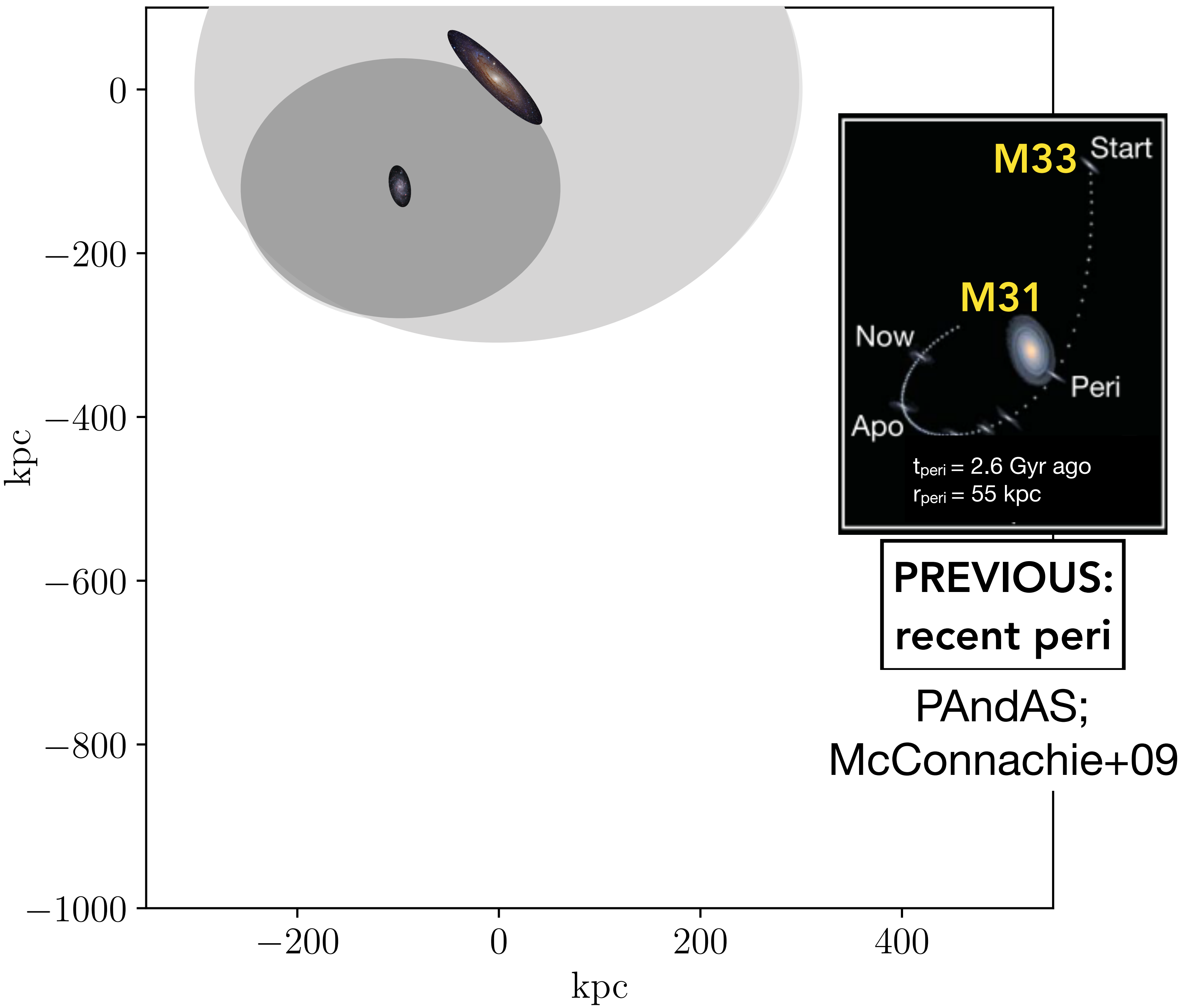
M33's Conventional Orbital History:

Prior to 2012, M31's proper motion (i.e. its tangential motion) was **unknown**.

What orbital history best reproduces M33's current morphology?

A New Orbital History for M33

Which orbital histories are allowed within the measured phase space?



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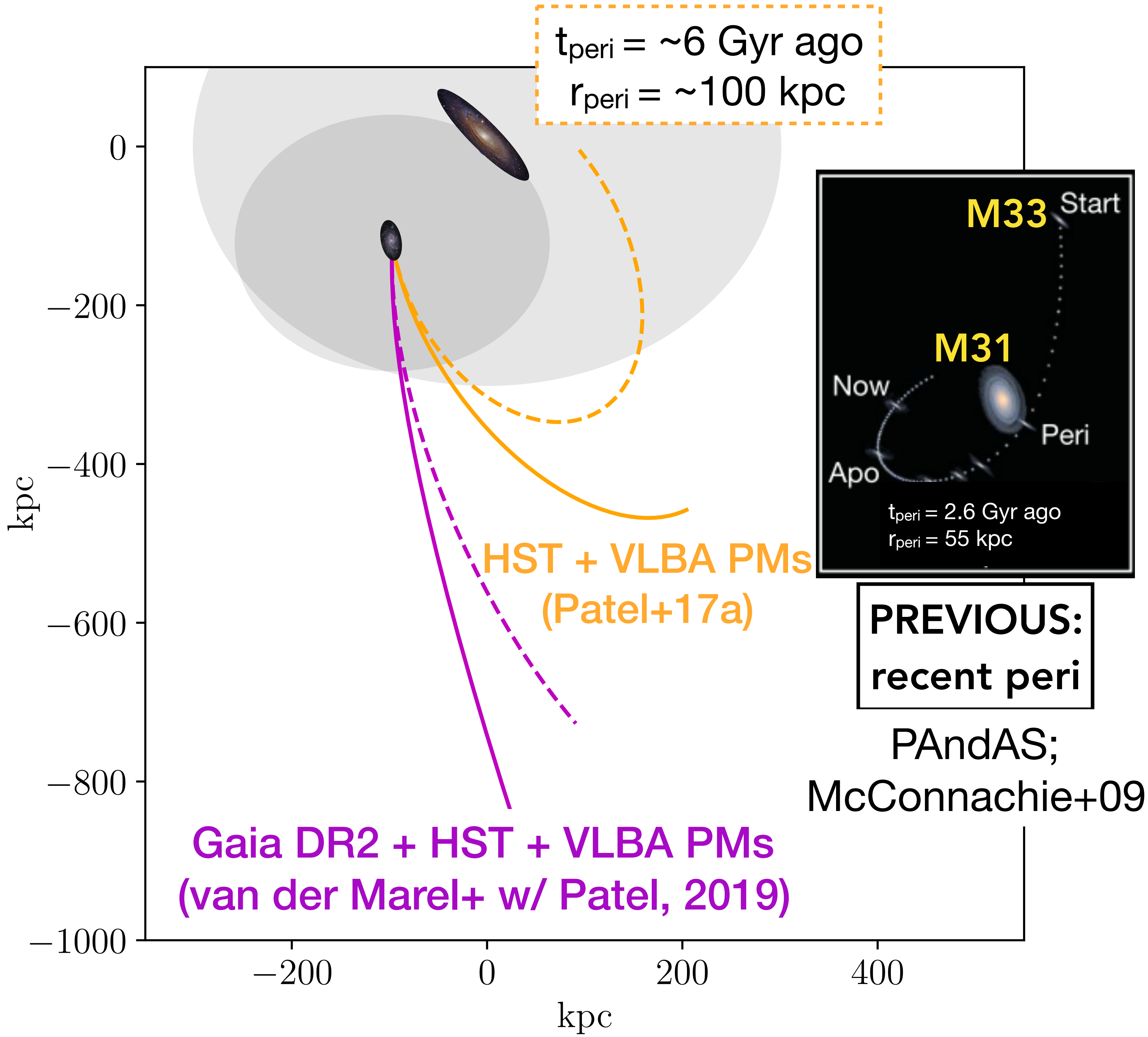

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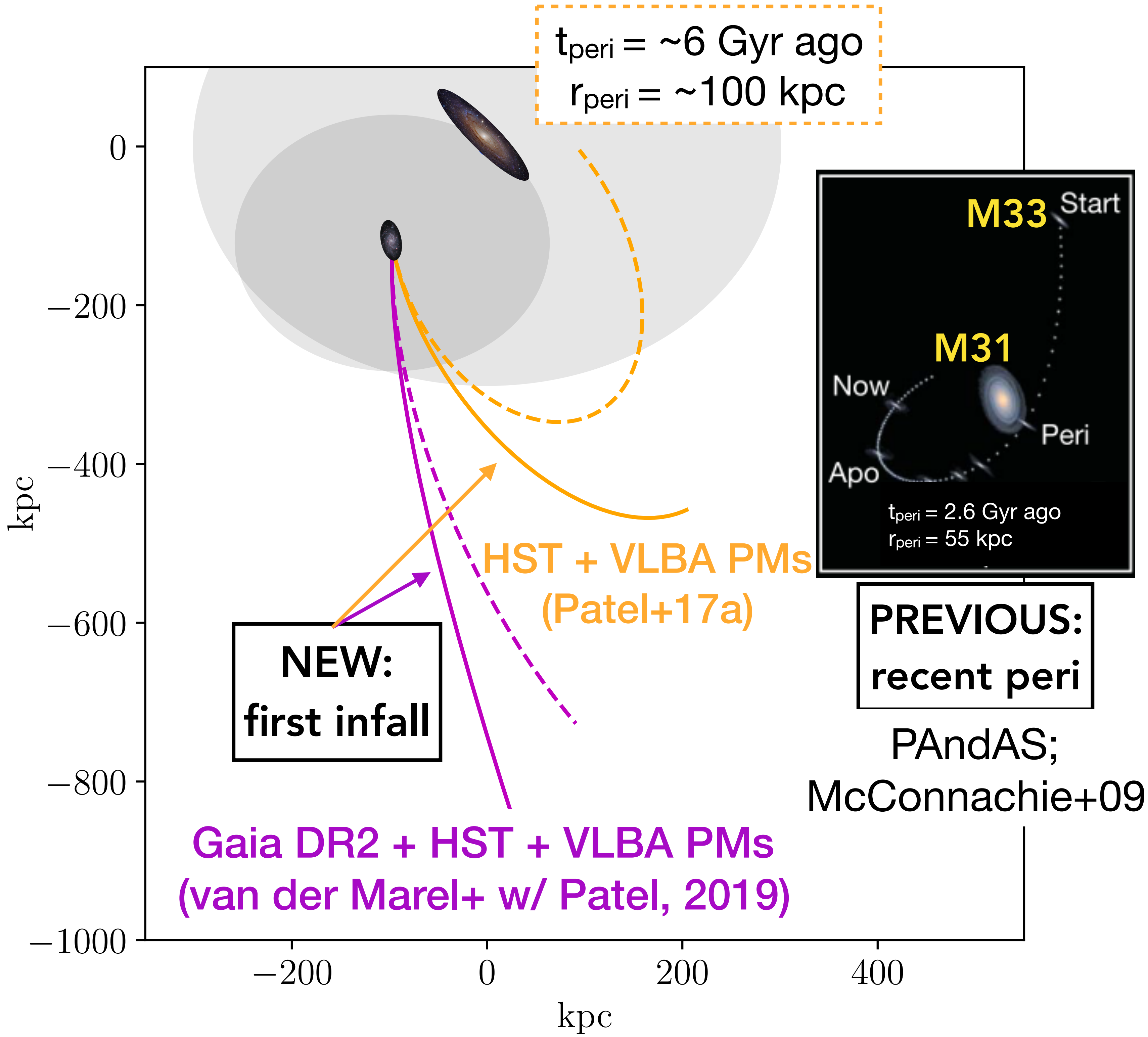
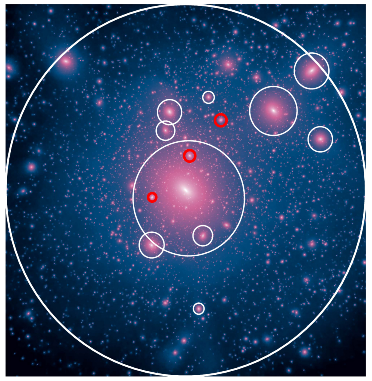


- 10,000 backwards numerical integrations x 6 different mass models
- < 1% of M33 orbits reach R_{peri} = 55-100 kpc with t_{peri} ≤ 3 Gyr
- Gaia DR2 PMs further support **first infall**

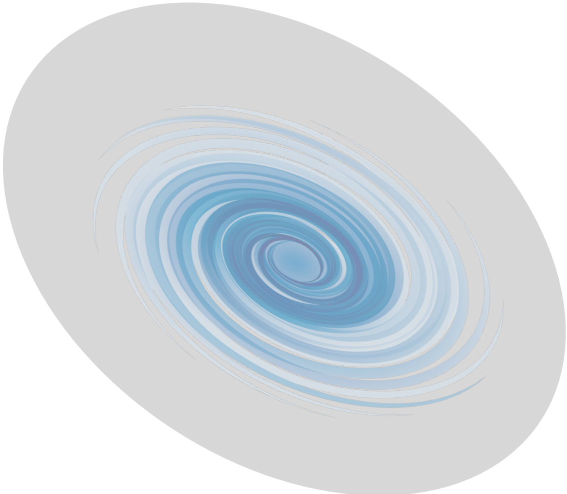
LCDM Predictions for M33's Satellite Population

Applying techniques of Dooley+17a,b



Dark matter only Caterpillar suite: 33 MW-mass zooms ($m_p \sim 10^4 M_\odot$)

host galaxy



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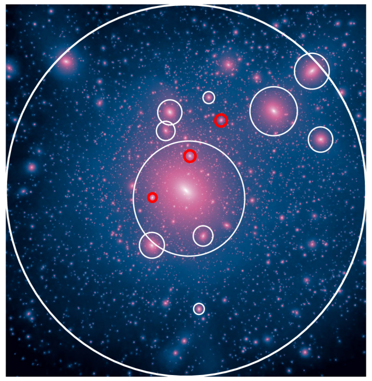

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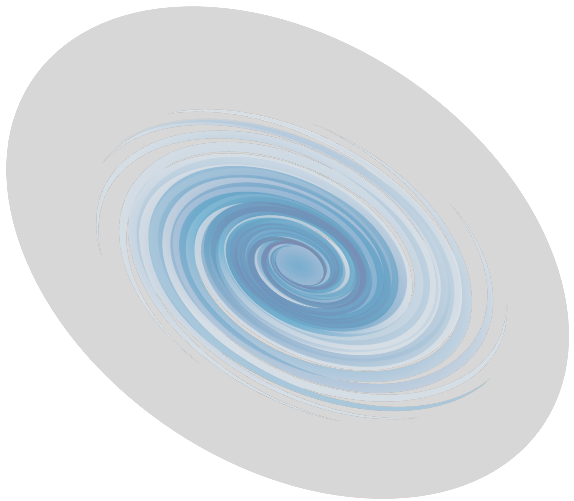
1. Determine the subhalo mass function (SHMF) for host galaxies



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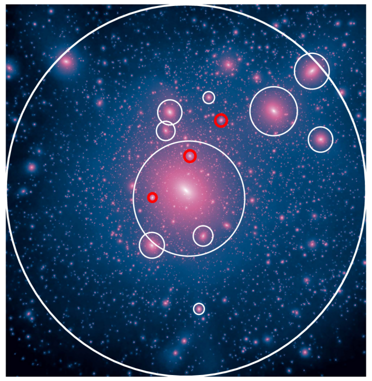

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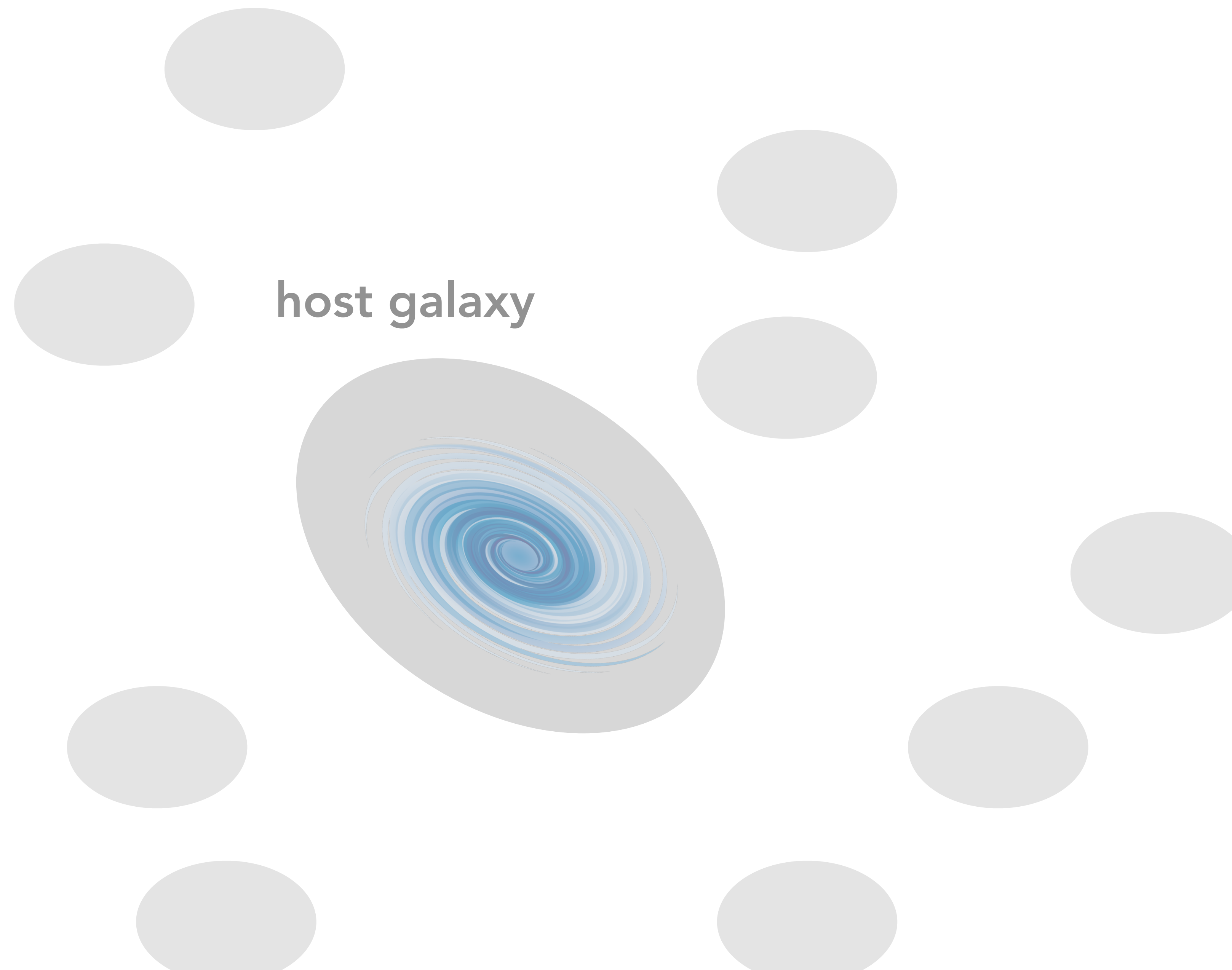
2. Sample SHMF to generate random realization of DM subhalos for host



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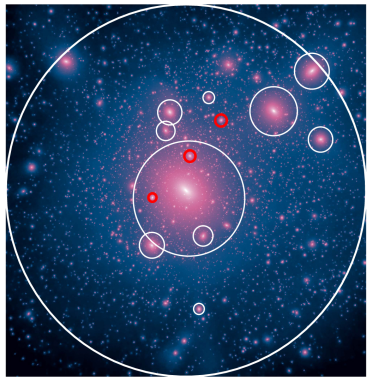

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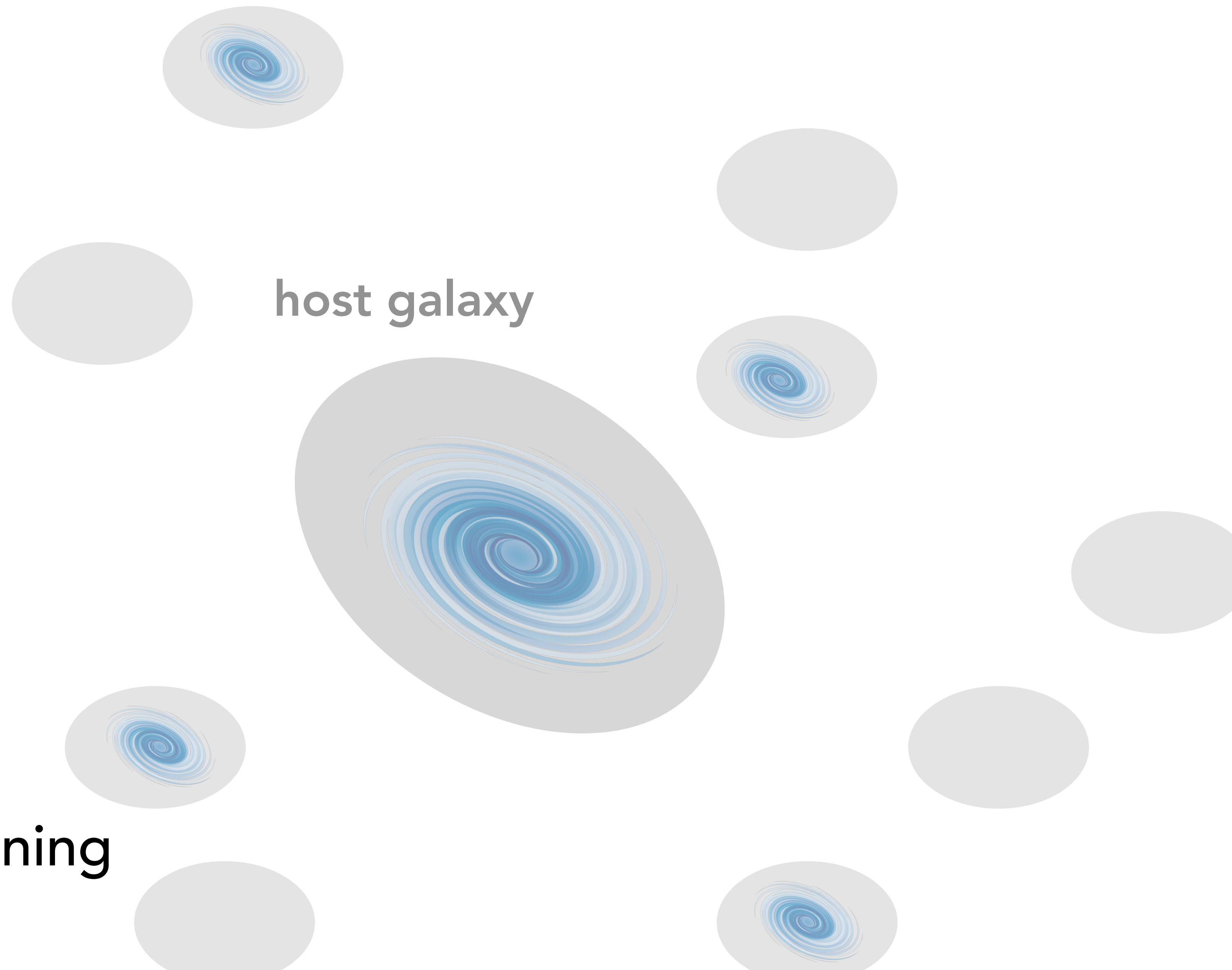

Ekta Patel U. Arizona/Berkeley

LCDM Predictions for M33's Satellite Population

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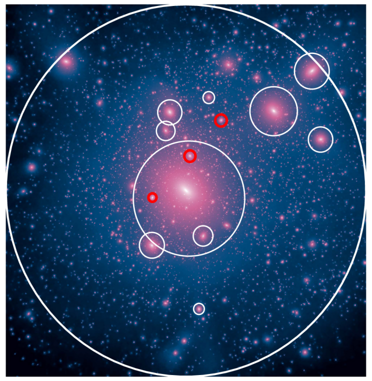

Dark matter only Caterpillar suite: 33 MW-mass zooms ($m_p \sim 10^4\,M_\odot$)

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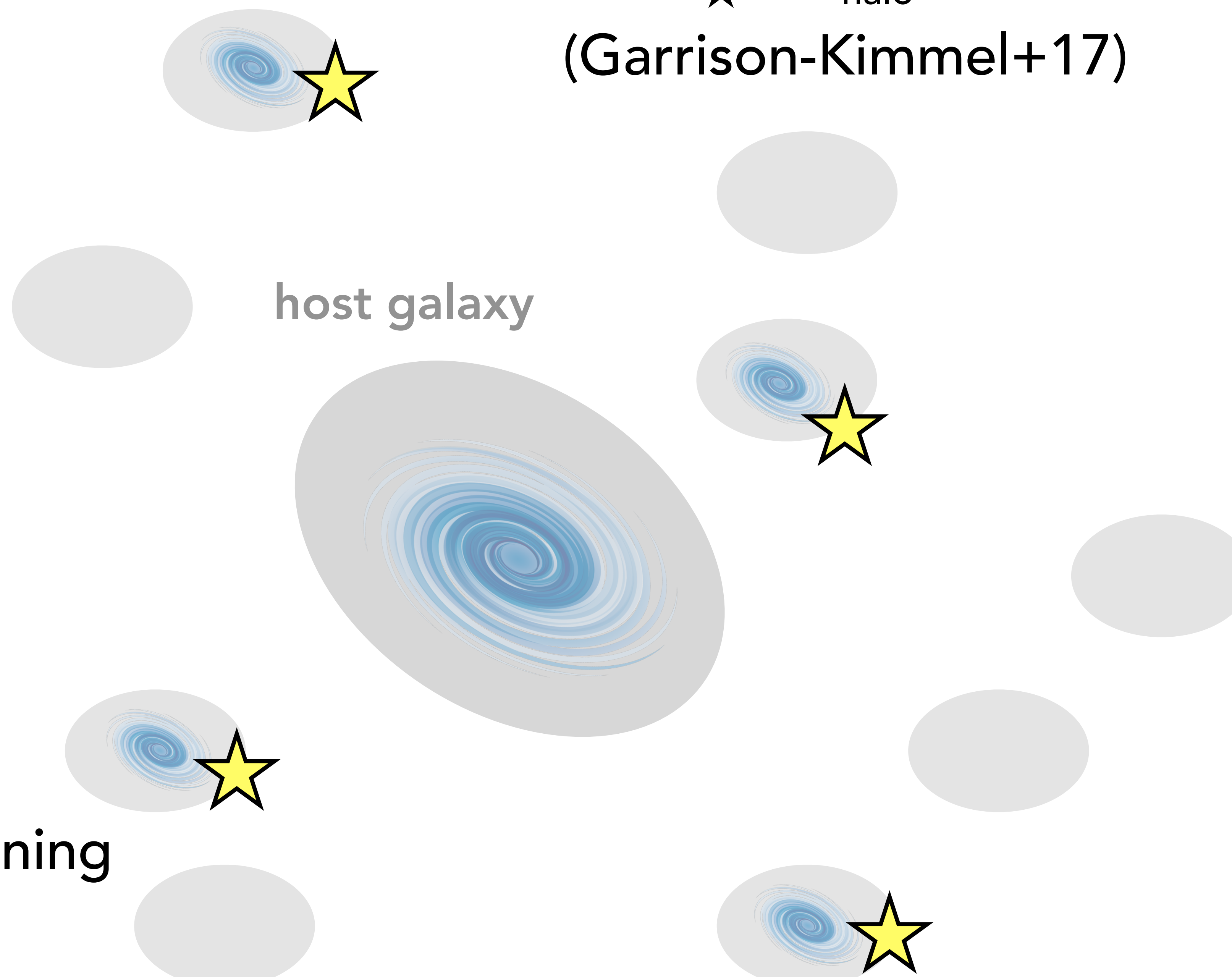

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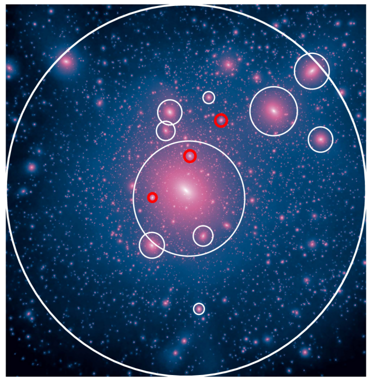

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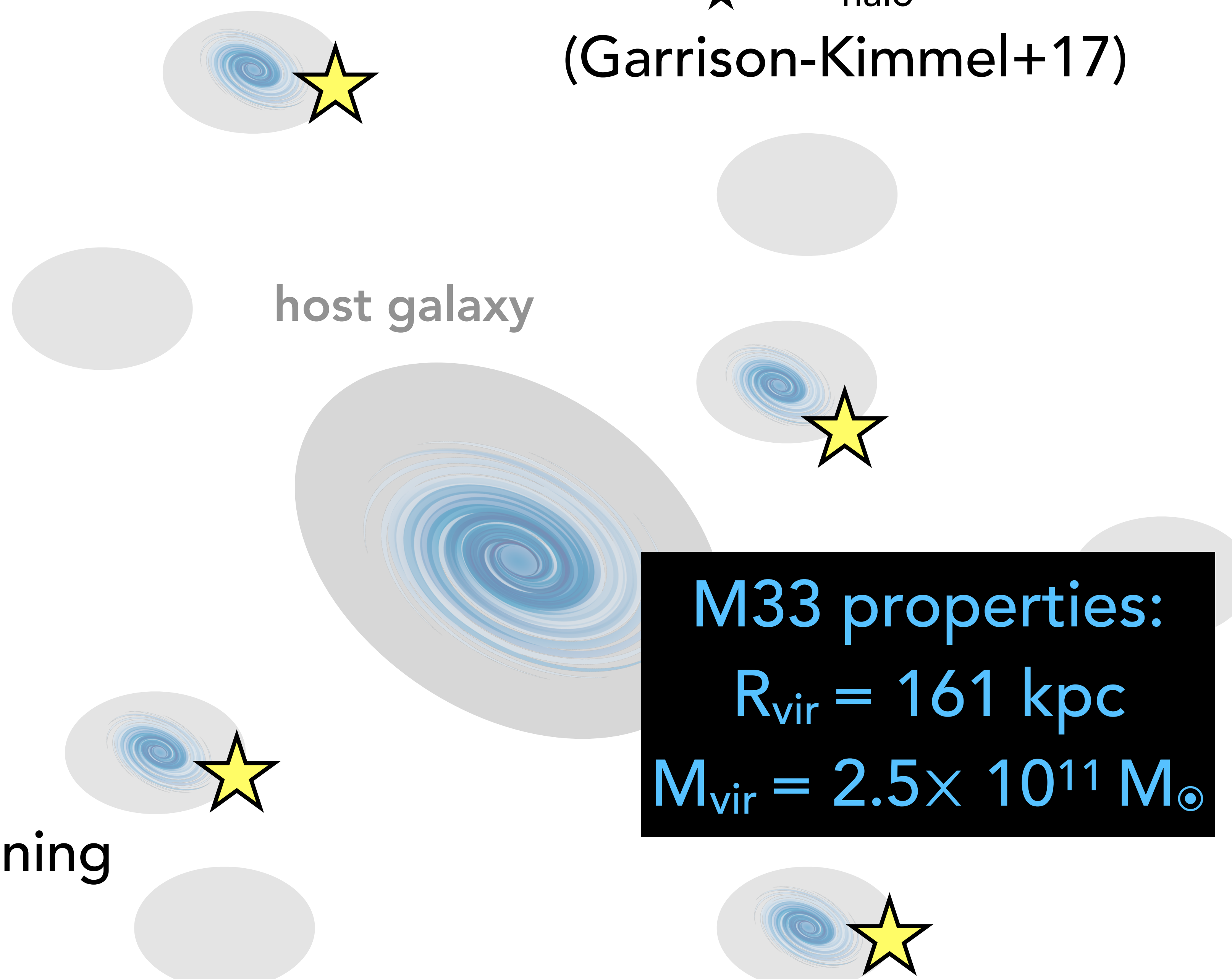


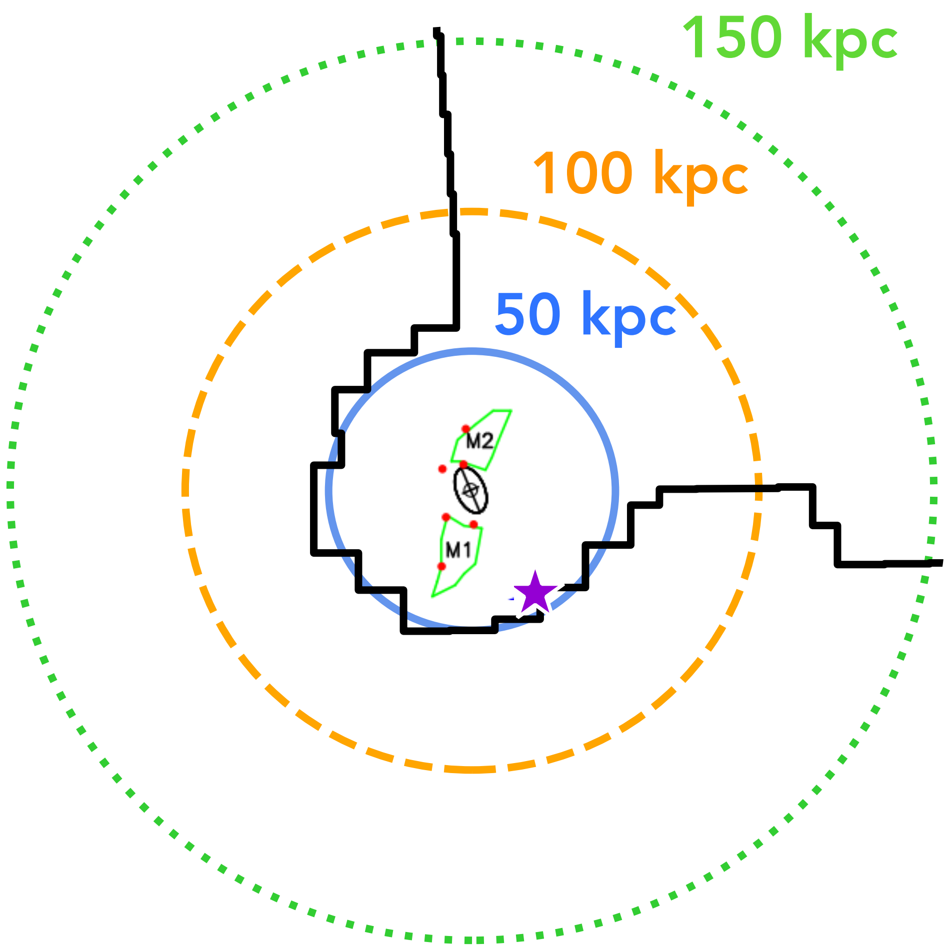
M33 properties:

R_{vir} = 161 kpc

$M_{vir} = 2.5\times 10^{11} M_\odot$

LCDM Predictions for M33's Satellite Population*

***corrected for geometric effects**



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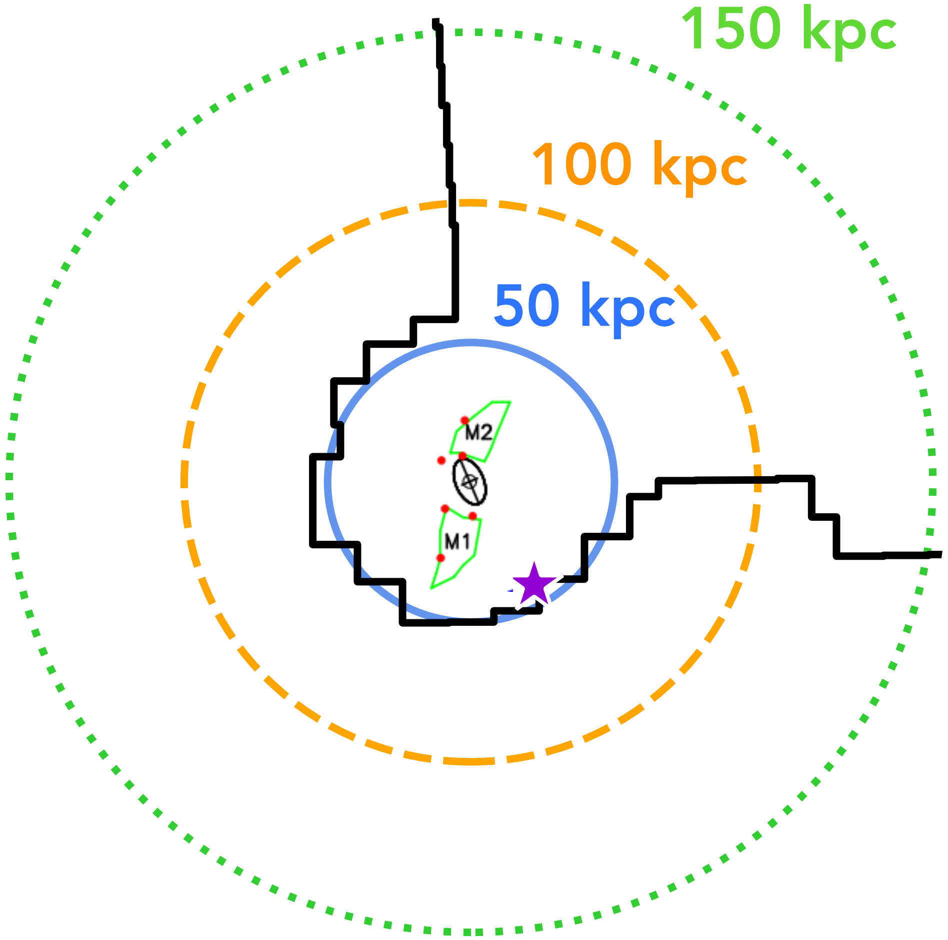

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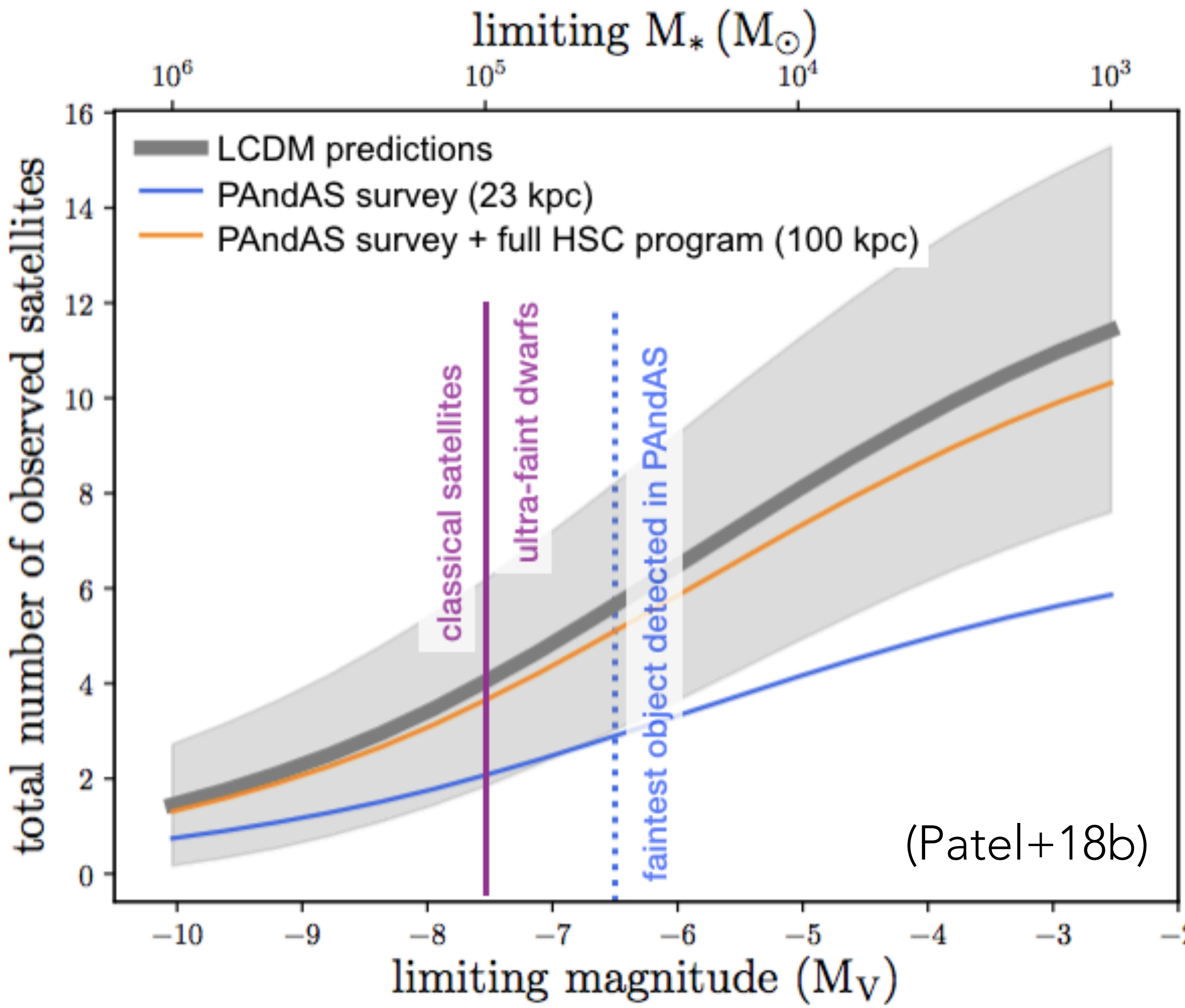

8±4 satellites at $M_\bigstar \geq 10^4\ M_\odot$

Predictions for *Surviving* M33 Satellites

If M33 really is on first infall (as suggested by Gaia and HST) all of the satellites that fell into M31's halo with M33 should survive until today.

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$$r_t = r_{peri} \left[\frac{m(r_t)/M_{host}(r_{peri})}{2 - \frac{d\ln M}{d\ln R}|_R} \right]^{1/3}$$

van den Bosch+18

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van den Bosch+18

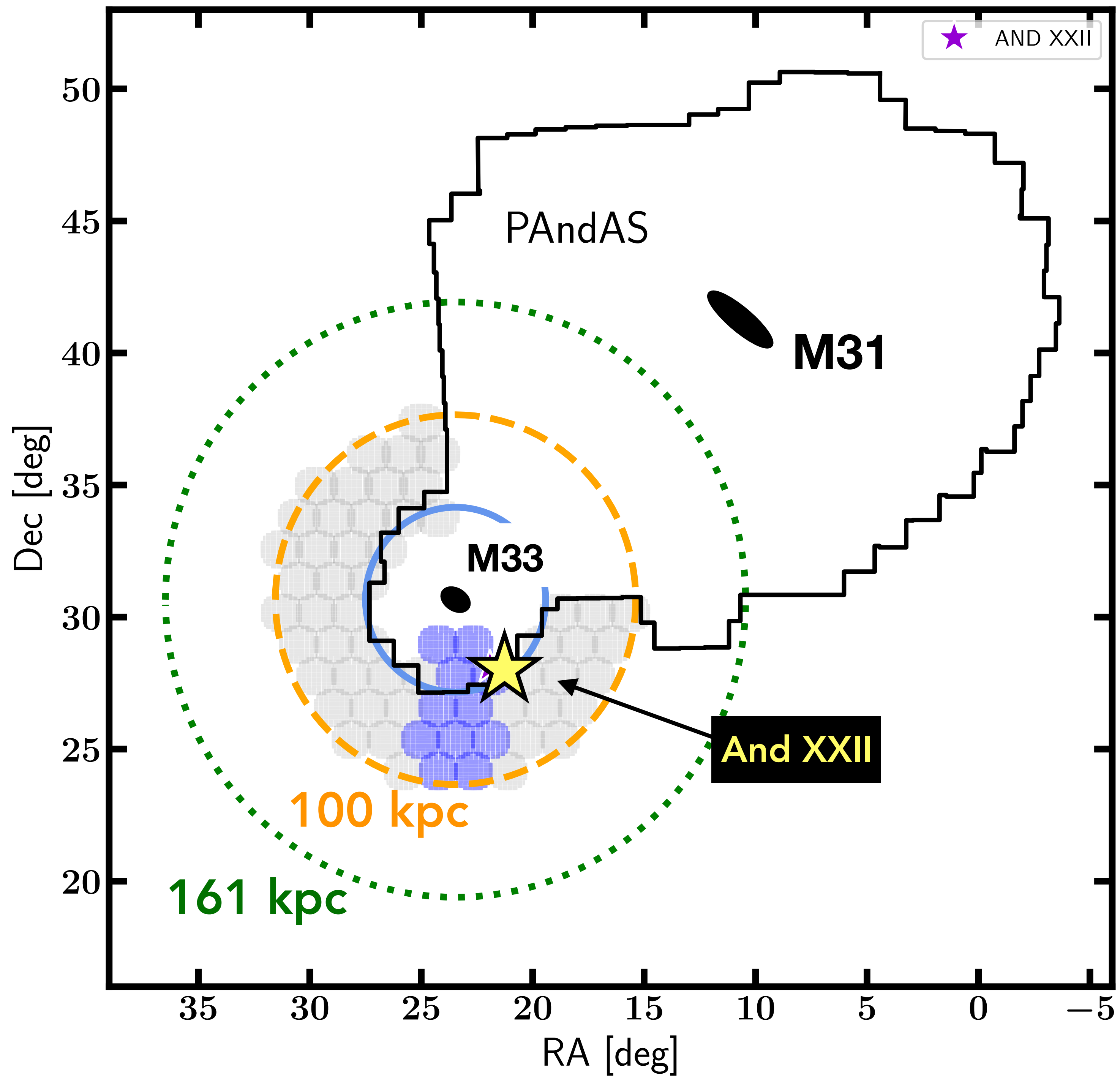
R_{peri}	R_{tidal}	# surviving satellites ($M_\star \geq 10^4\, M_\odot$)
100 kpc	49-53 kpc	4±3
150 kpc	68-73 kpc	6±3

Hunting for Satellites of M33

To reach *g*~27 and *i*~26.3 (HSC-SSP Deep):

11 fields/2 nights on HSC

50 fields/8.5 nights on HSC



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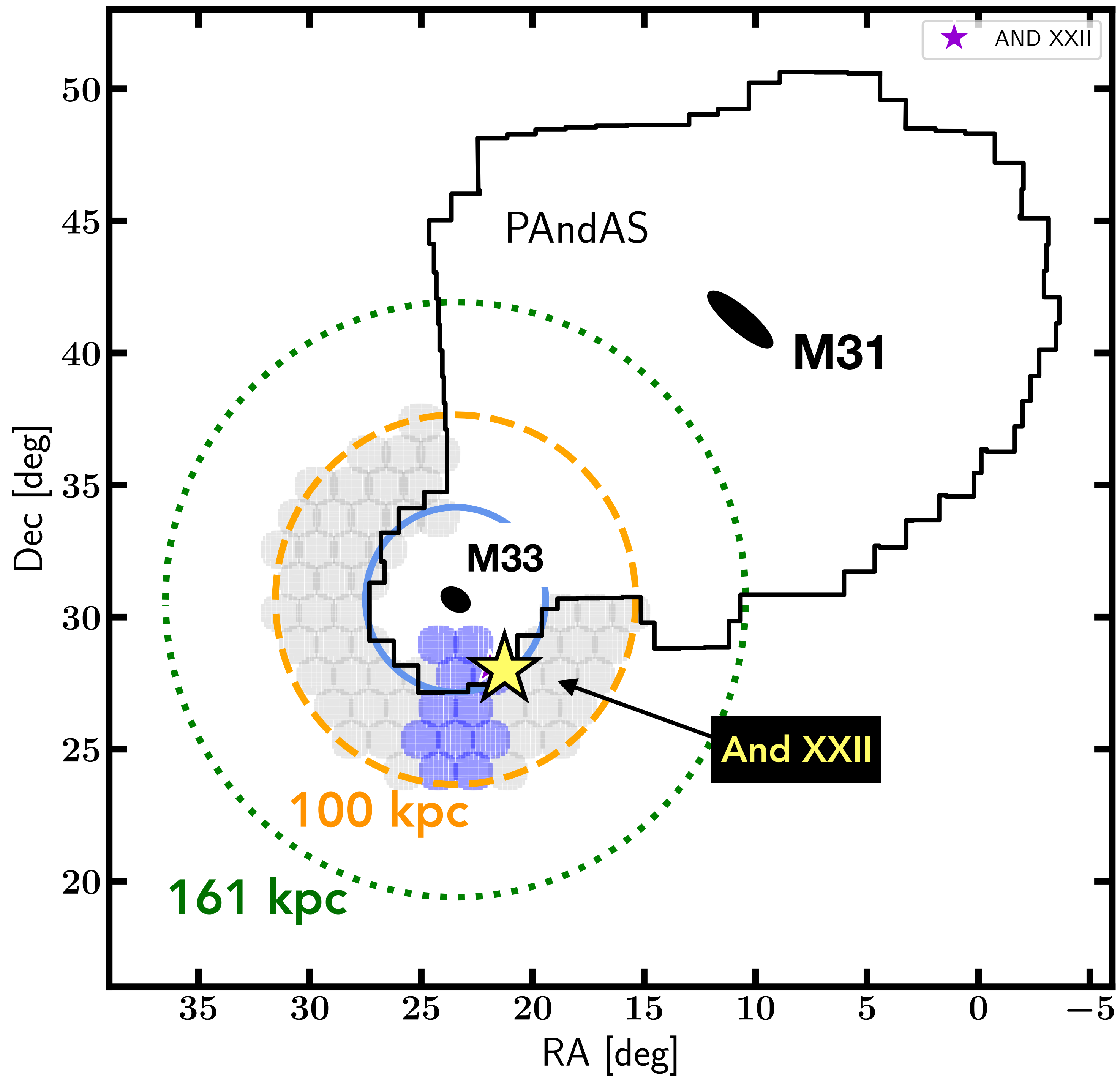
WFIRST could observe all 50 fields in ~4 hours!



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Summary

- M33 is expected to host 8±4 satellites at $M_\star \geq 10^4\ M_\odot$ (90% within 100 kpc survey) if it's on first infall and fewer if it had a recent interaction with M31.

- A census of M33's satellite population will help constrain its orbital history and provide a direct test for small-scale LCDM predictions.

- Deep observations of M33's halo will additionally characterize the stellar "warps" in M33's outer disk, help determine if it has a stellar halo, provide an improved distance to And XXII, and reveal remnant stellar streams.

See Patel et al. 2018b, MNRAS, 480, 1883

ektapatel@email.arizona.edu