Local Dwarf Galaxies and Near-Field Cosmology in LCDM

Erik Tollerud
University of California, Irvine

Berkeley Cosmology Seminar

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Topics to Cover

- MW Satellites
- M31 dSphs
- LMC Analogs

Fainter | Local | ?

Brighter ↓ “Distant” ↓ LCDM

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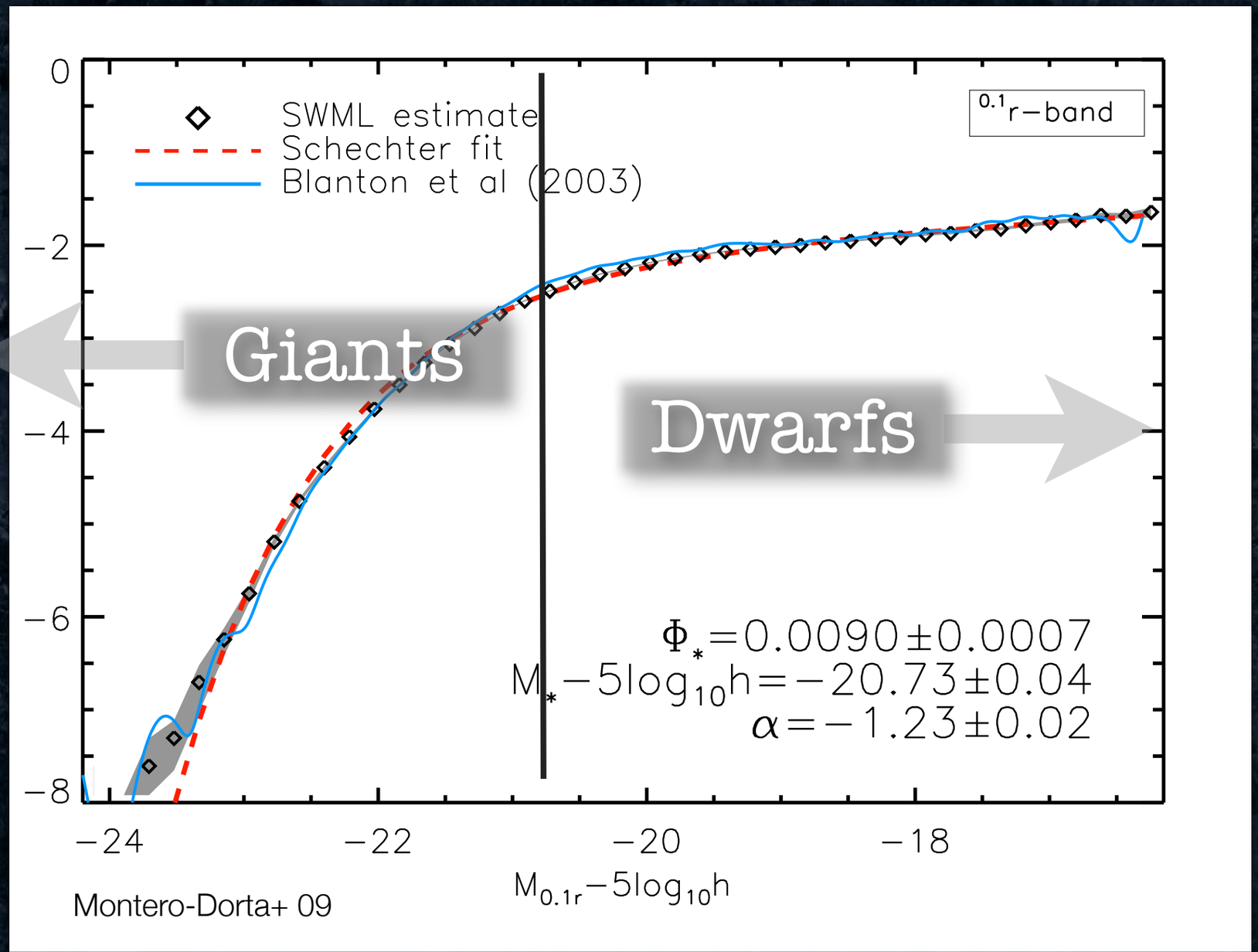
"Dwarf" Galaxies?



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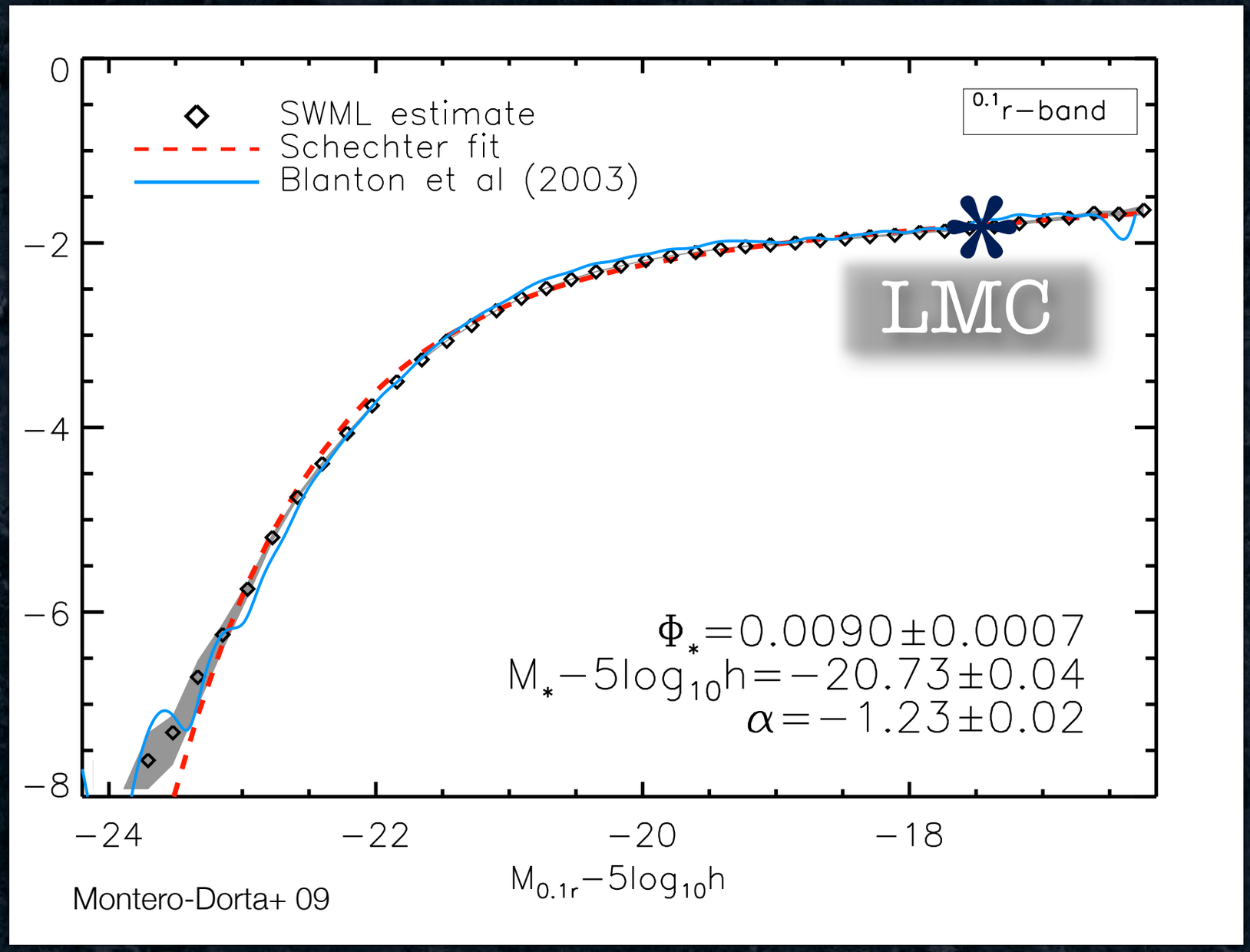
"Dwarf" Galaxies?



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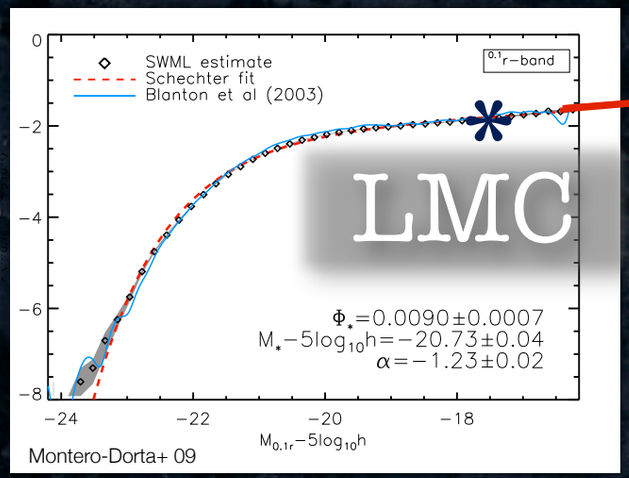
"Dwarf" Galaxies?



M31
dSphs

MW
ultra-
faints

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"Dwarf" Sizes?

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“Dwarf” Sizes?

"Dwarf" Sizes?

Milky Way Satellites

ApJ, 688, 277 (2008)
ApJ, 726, 108 (2011)

In Collaboration with:
James Bullock[1], Genevieve Graves[2], Louie Strigari[3], Beth Willman[4], Joe Wolf

[1]UCI, [2]UCB, [3]Stanford, [4]Haverford

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Image Credit:SDSS

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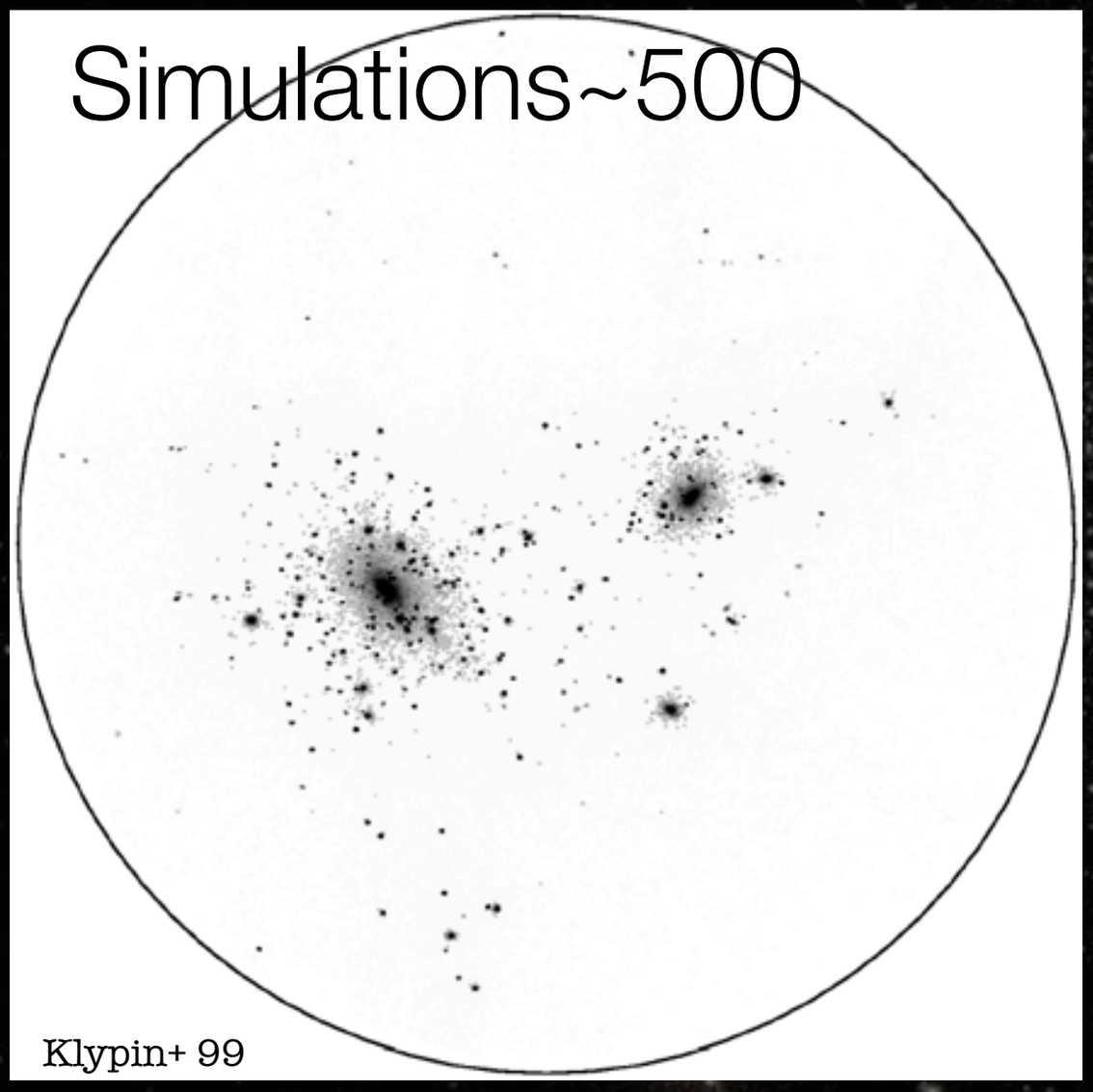
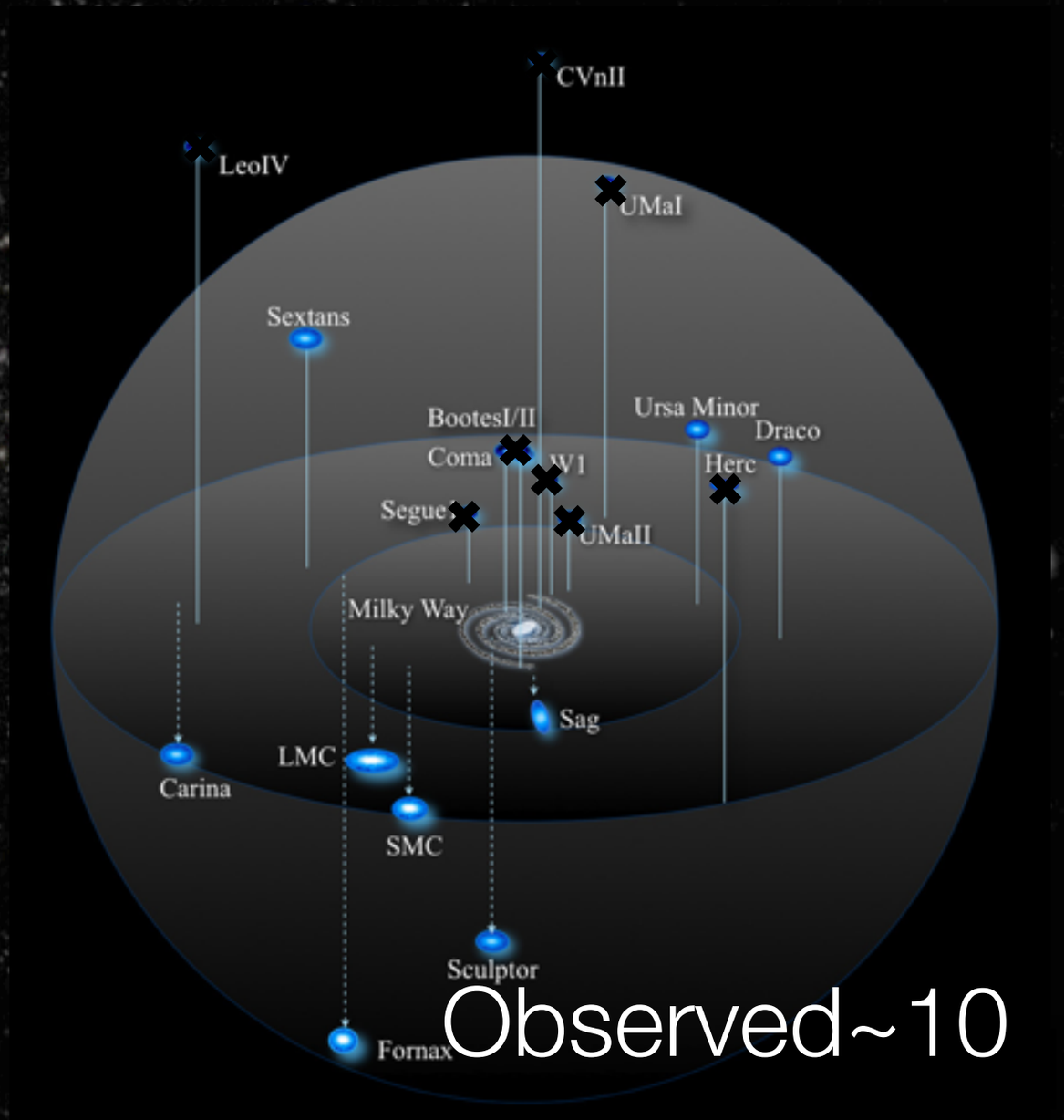
Missing Satellites





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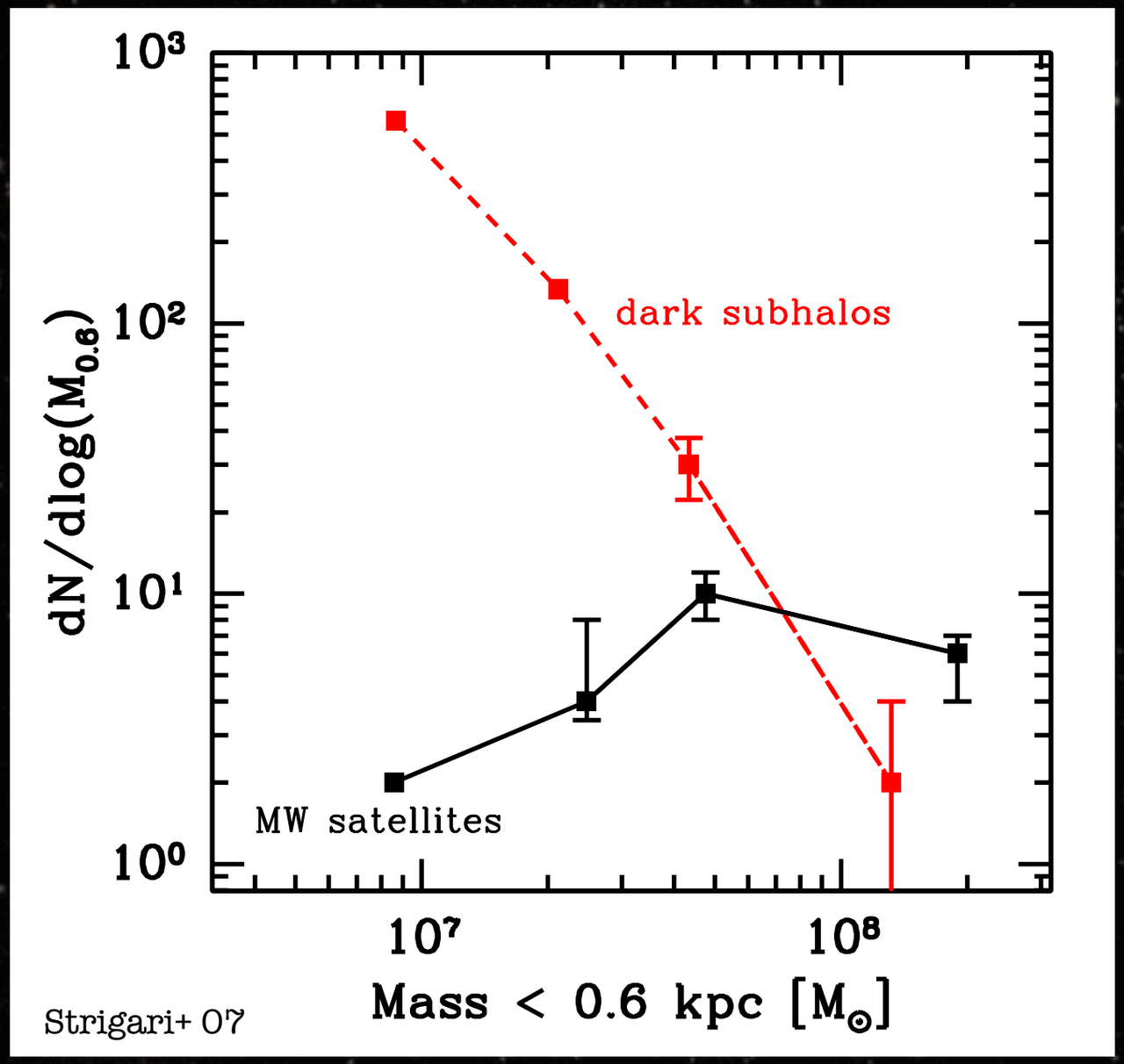

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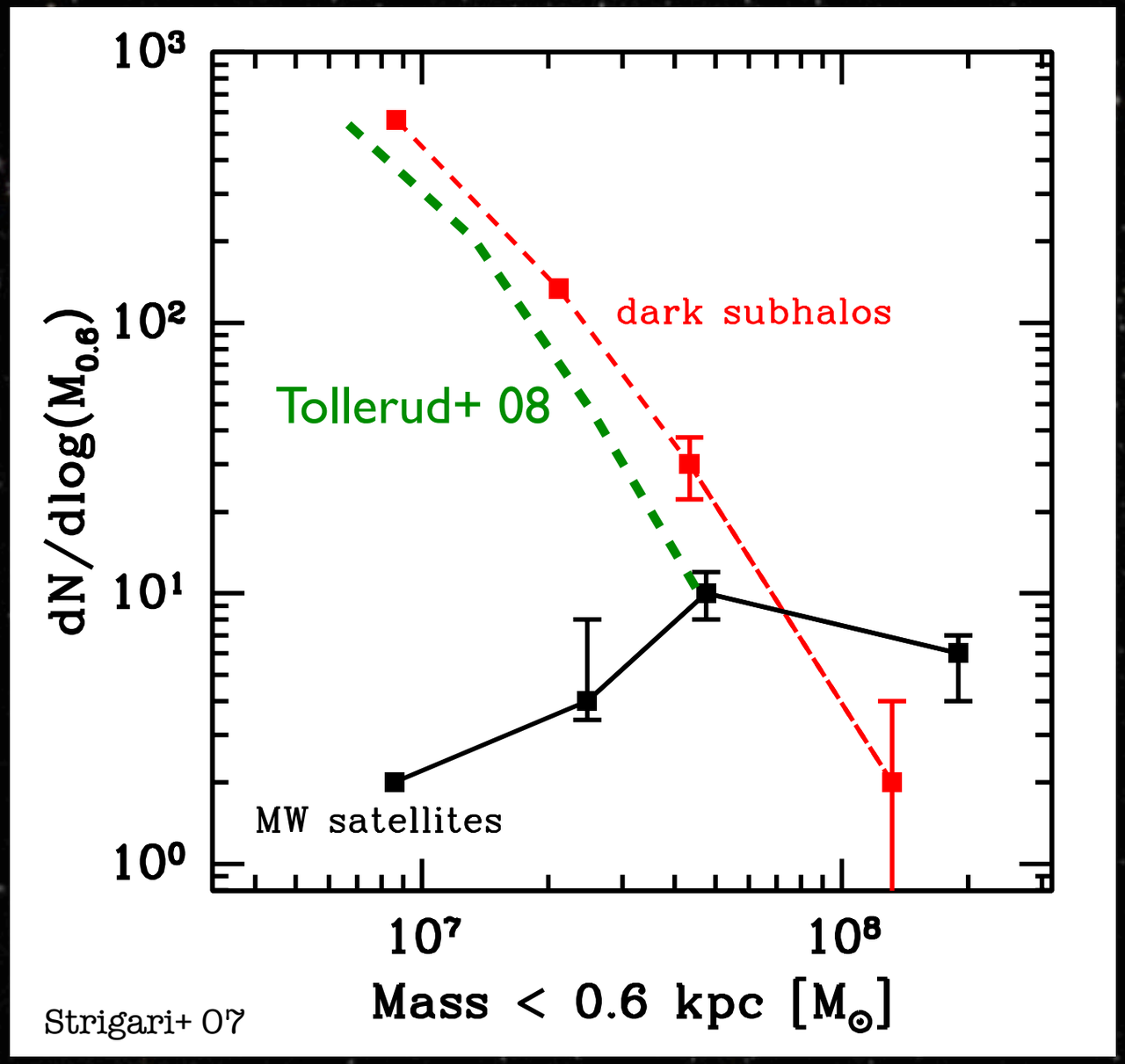
Found?



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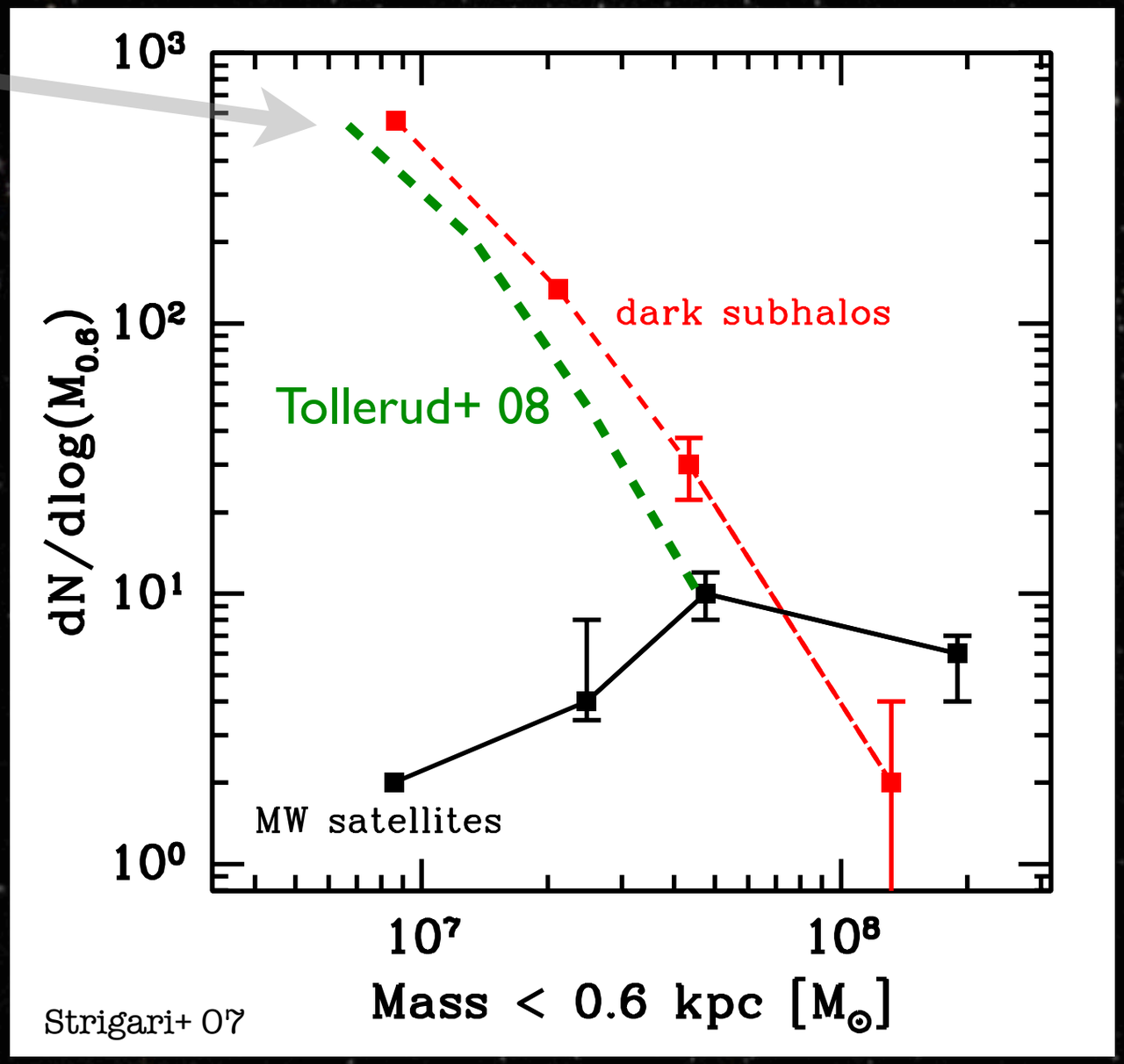
Found?

Hundreds of MW Satellites



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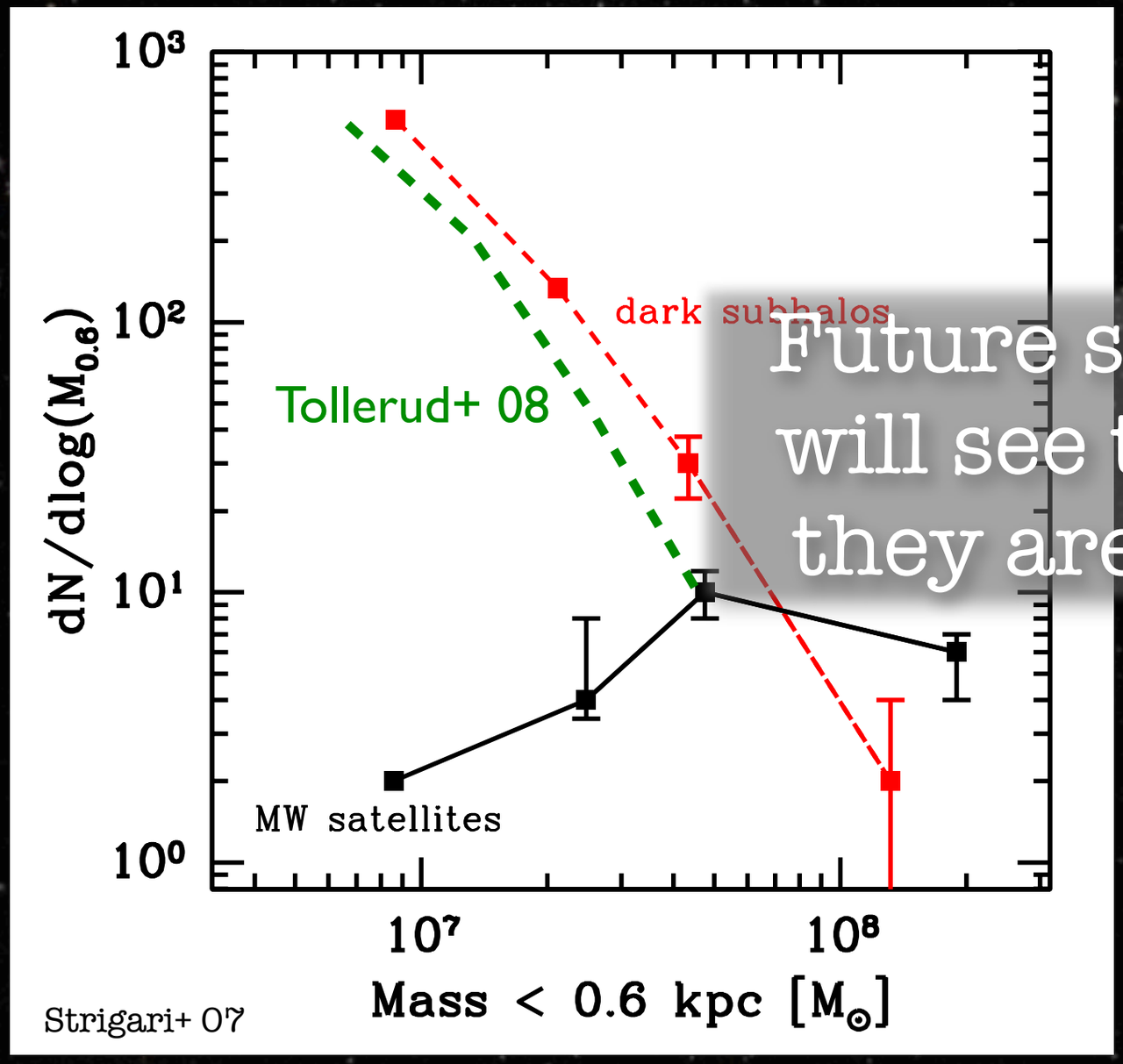
Found?



Future surveys will see them if they are there

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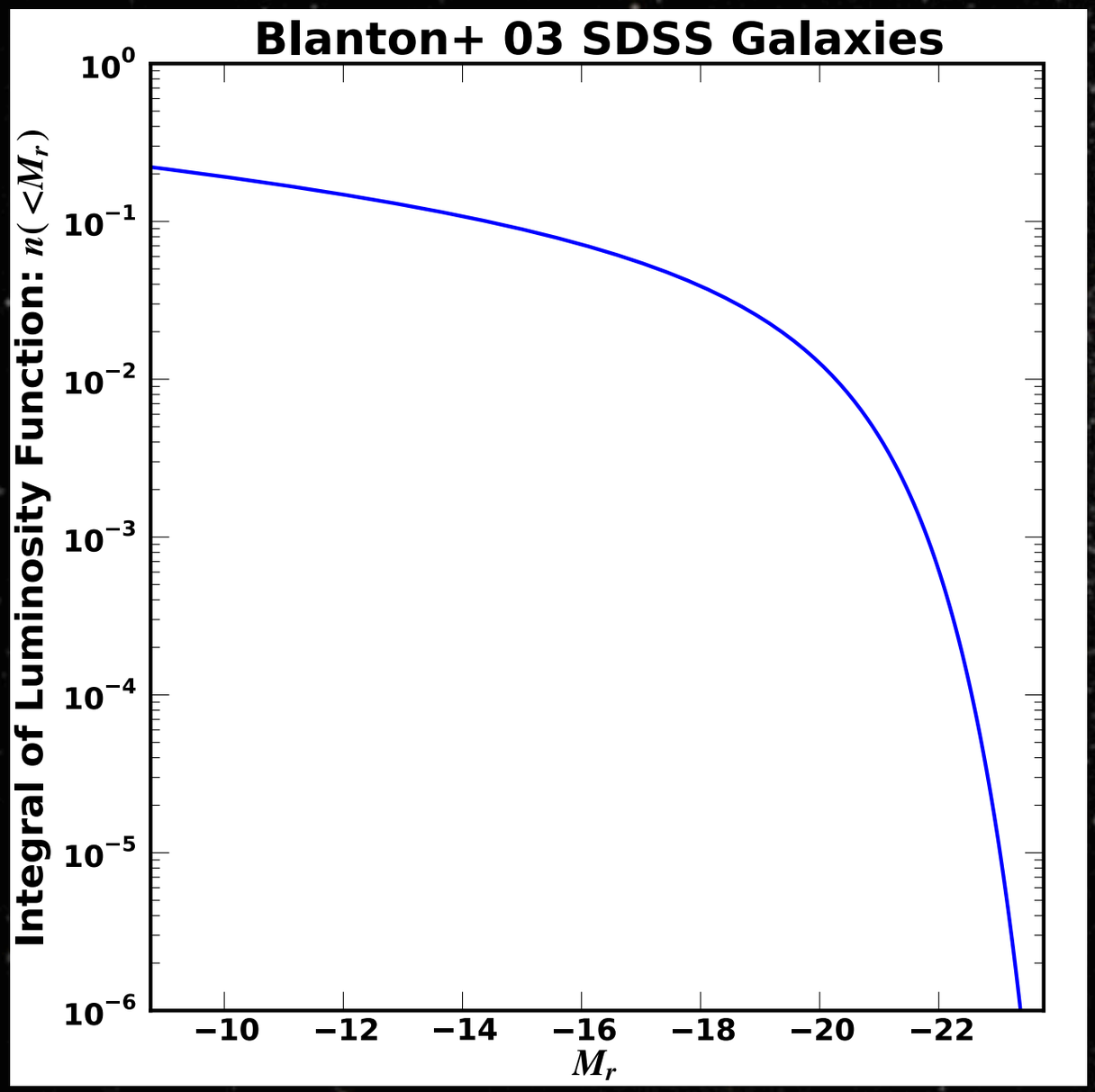
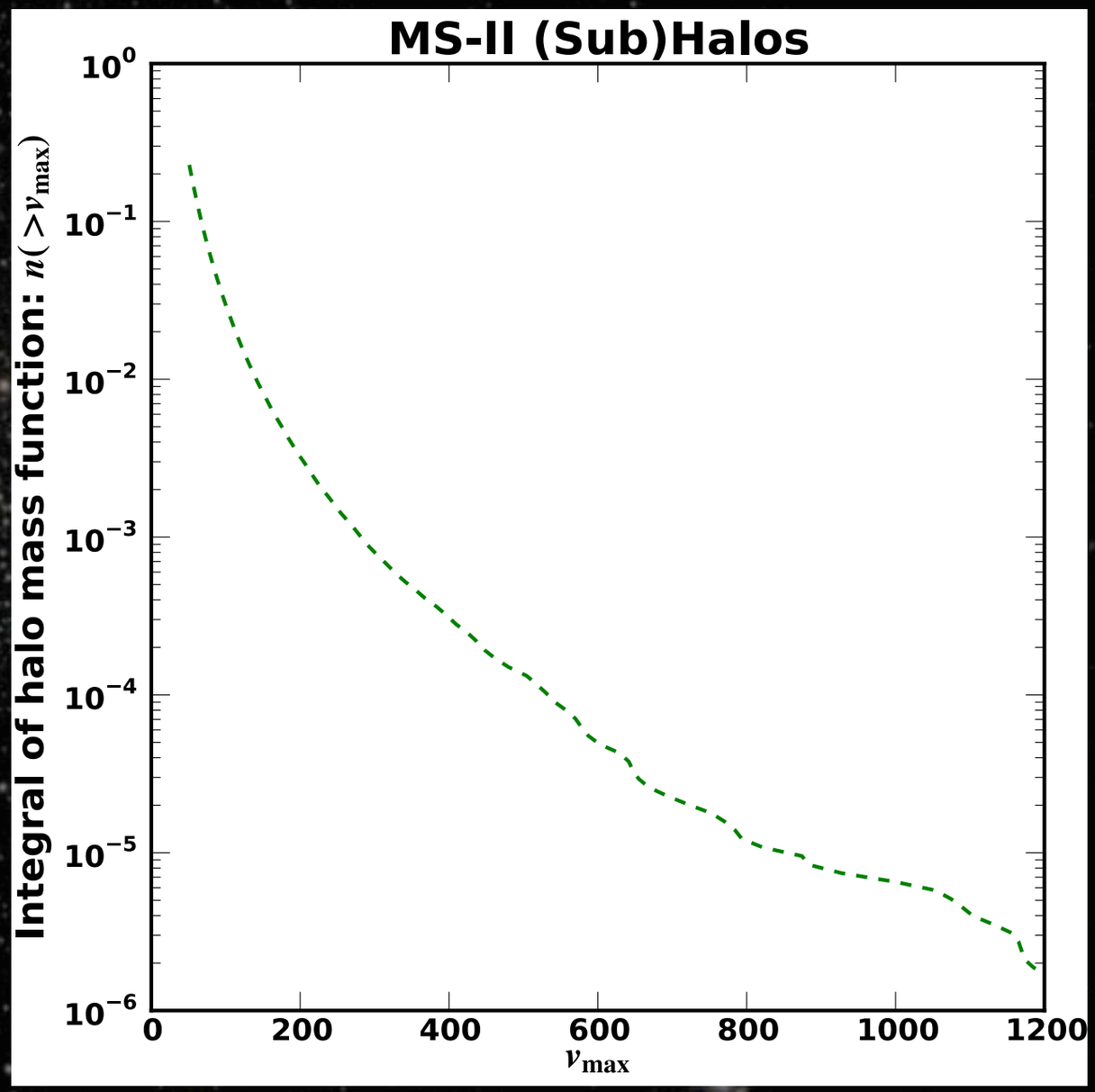
How Are Subhalos Populated By Galaxies?





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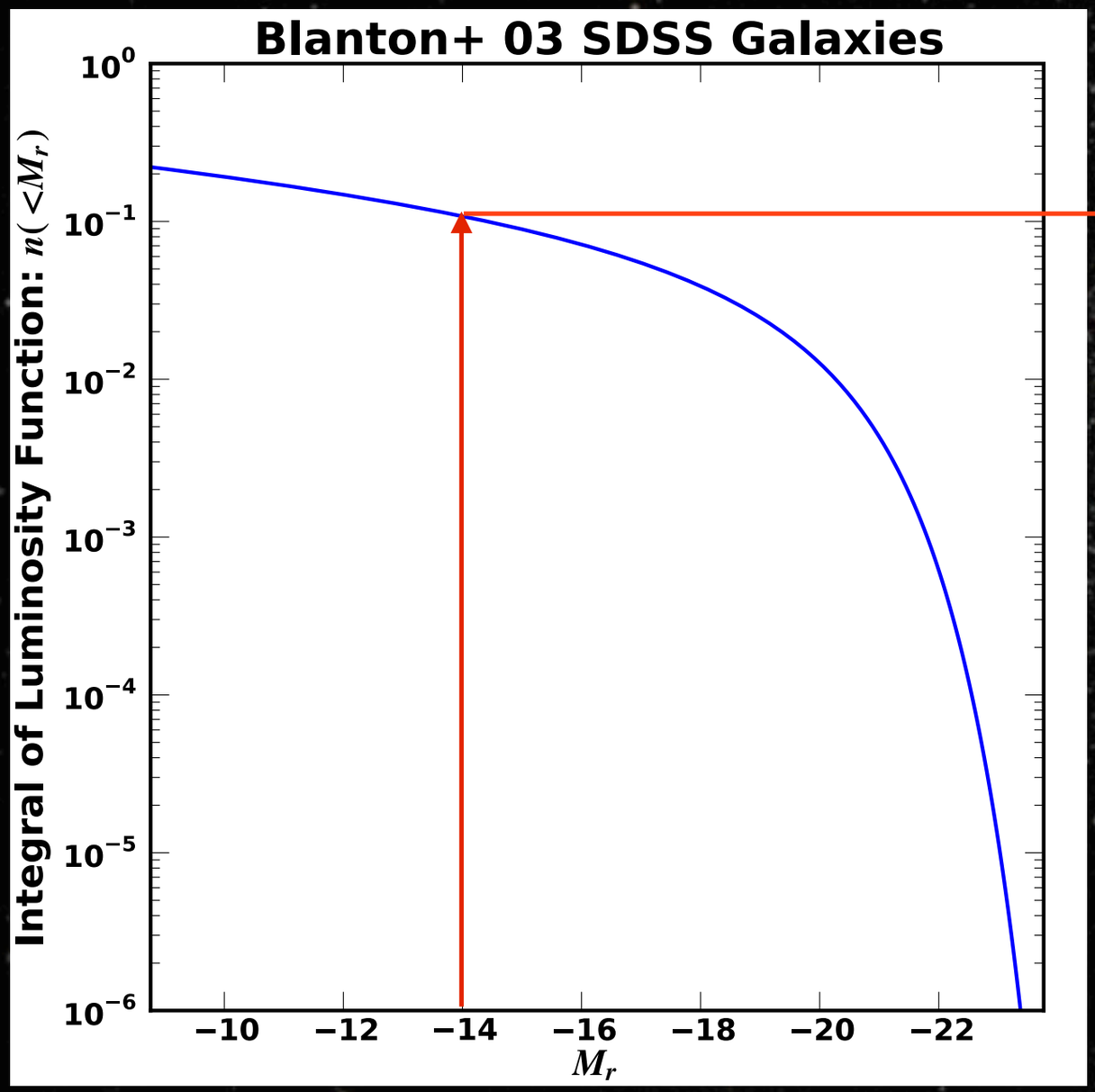
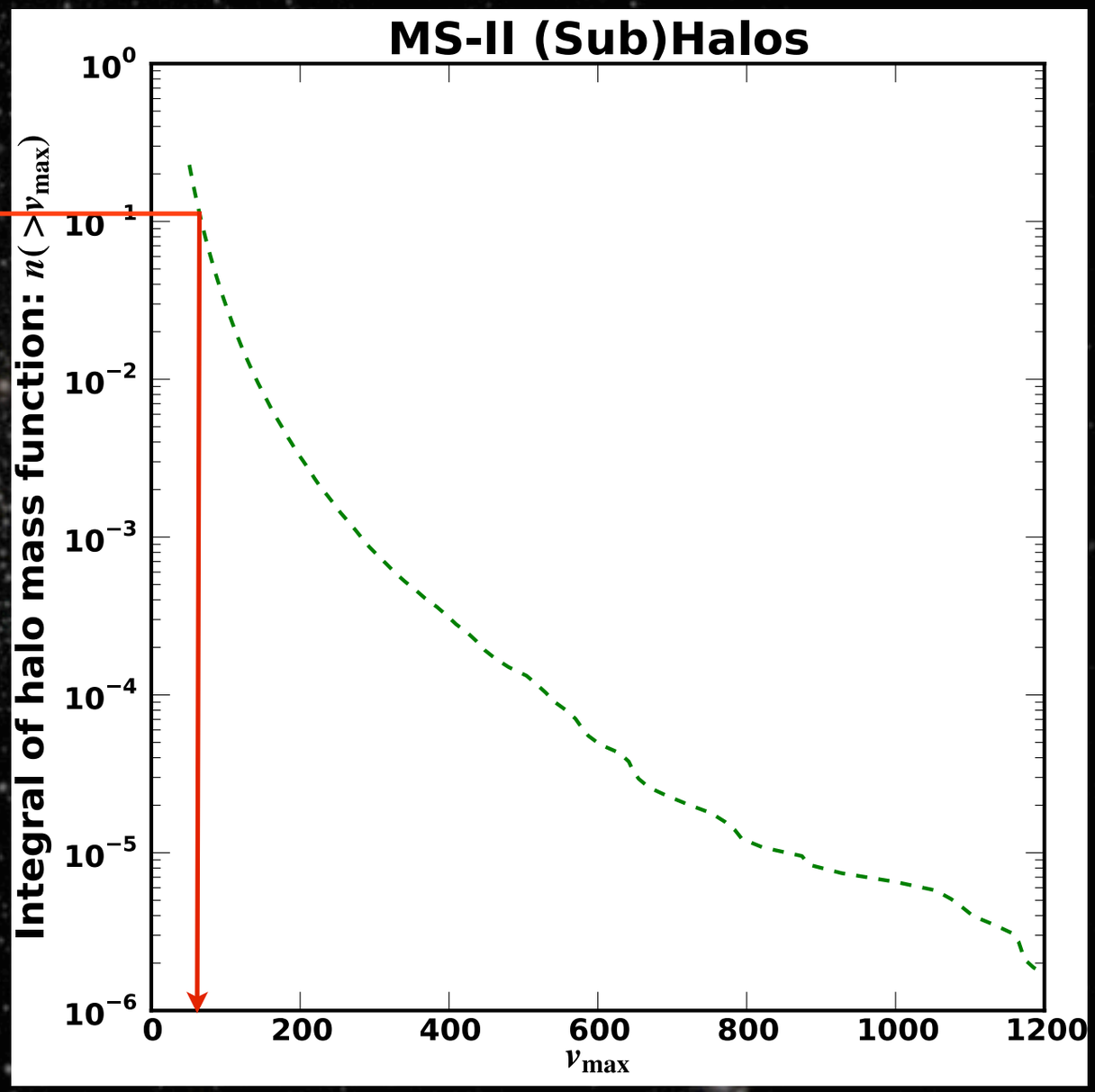
Simplest Approach: Abundance Matching





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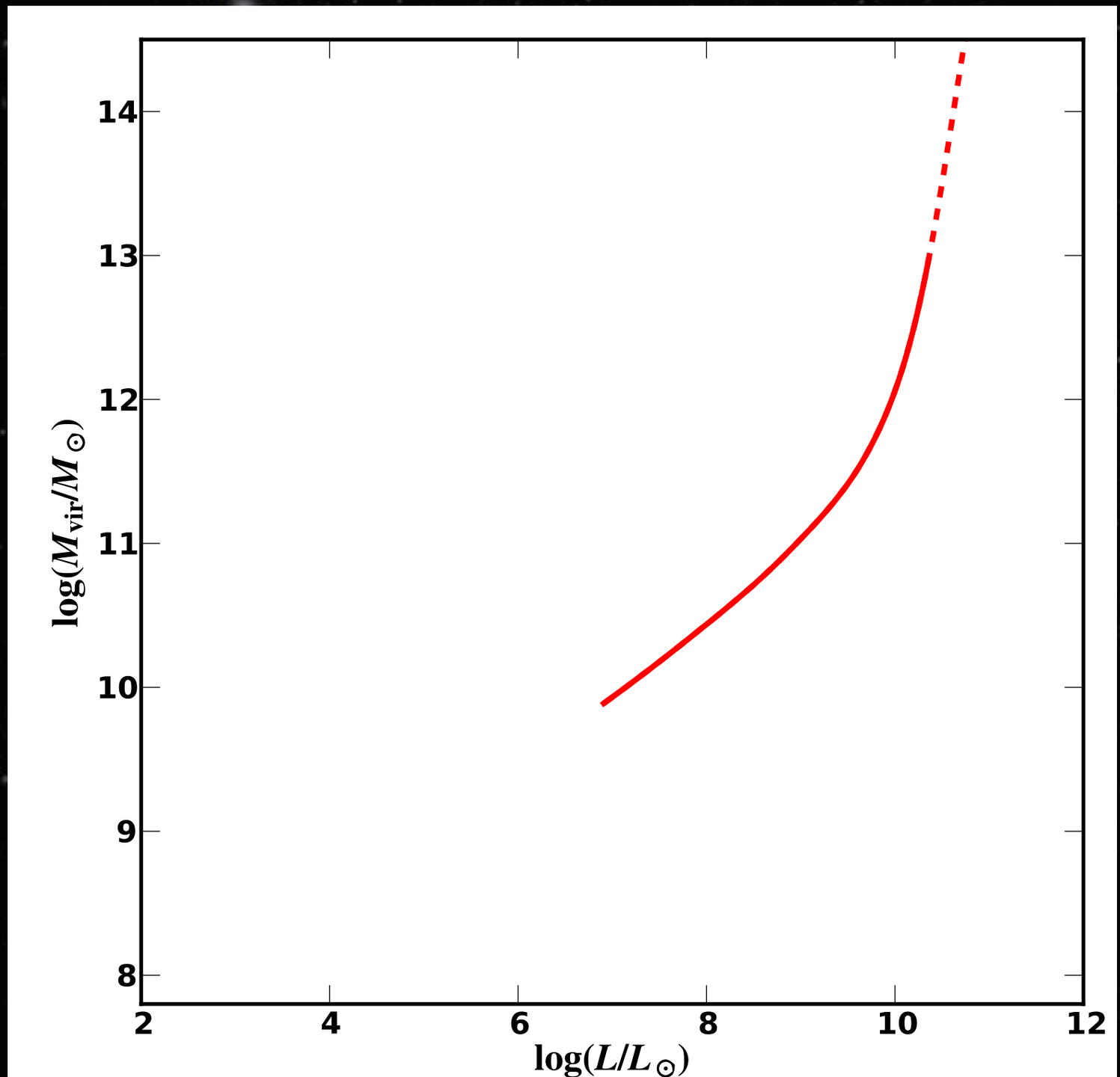
Abundance Matching



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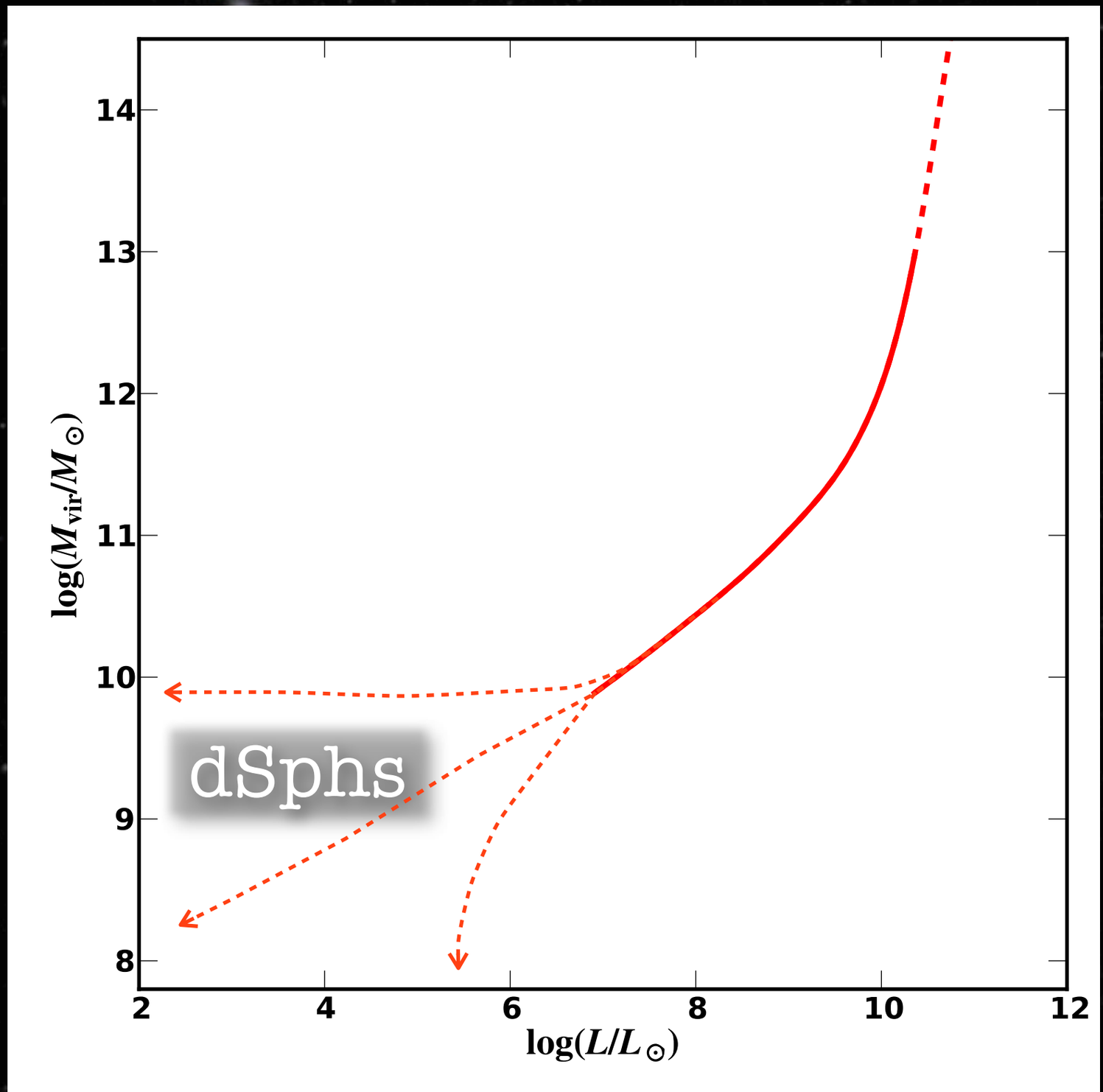
Abundance Matching



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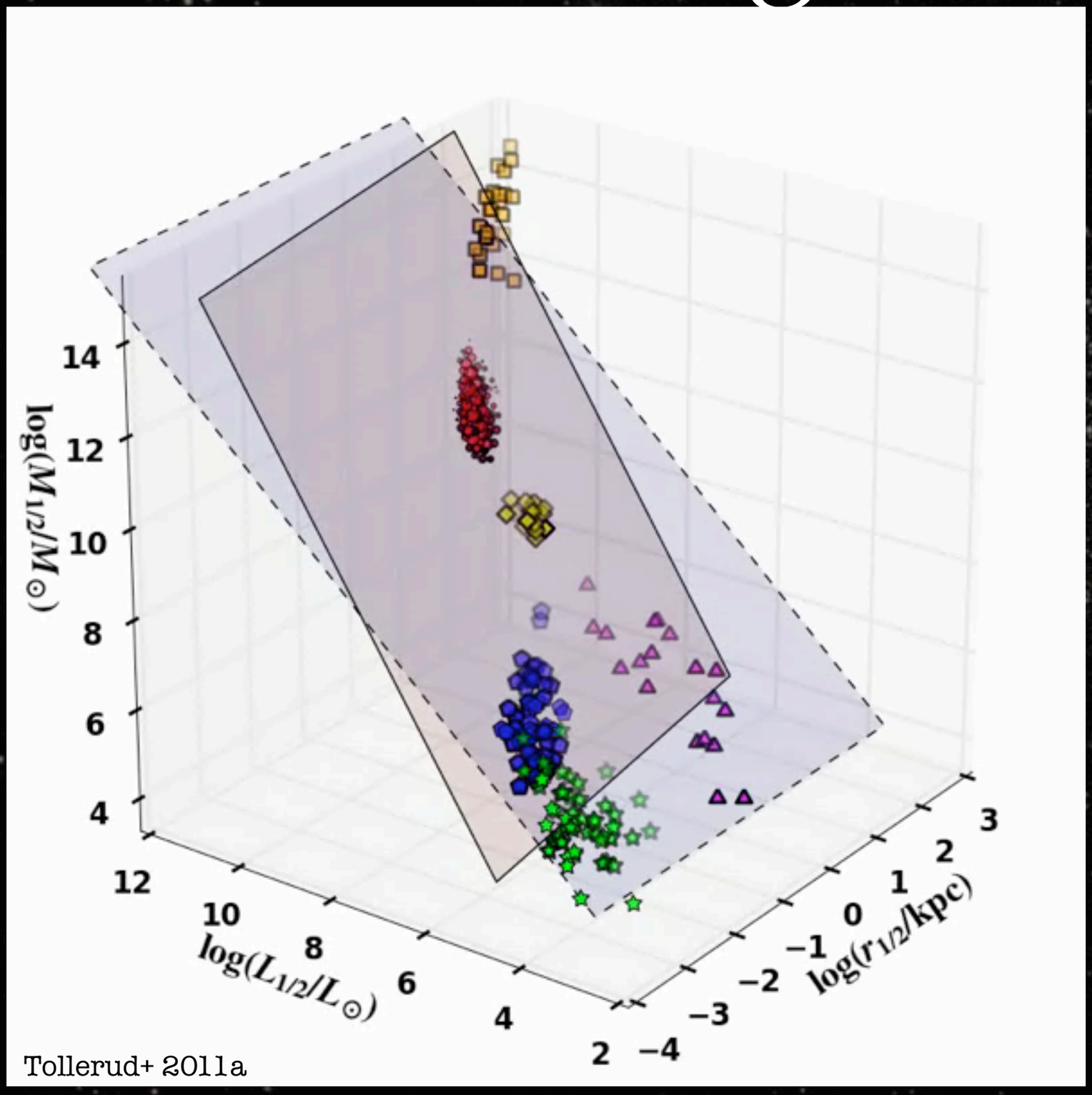
Scaling Relations



Tollerud+ 2011a

dSph

Tollerud+ 11a:

$$M_{1/2} = 3\frac{\langle\sigma^2\rangle r_{1/2}}{G}$$

(Wolf+ 10)

$$r_{1/2} = \frac{4R_{\rm eff}}{3}$$

$$L_{1/2} = L/2$$

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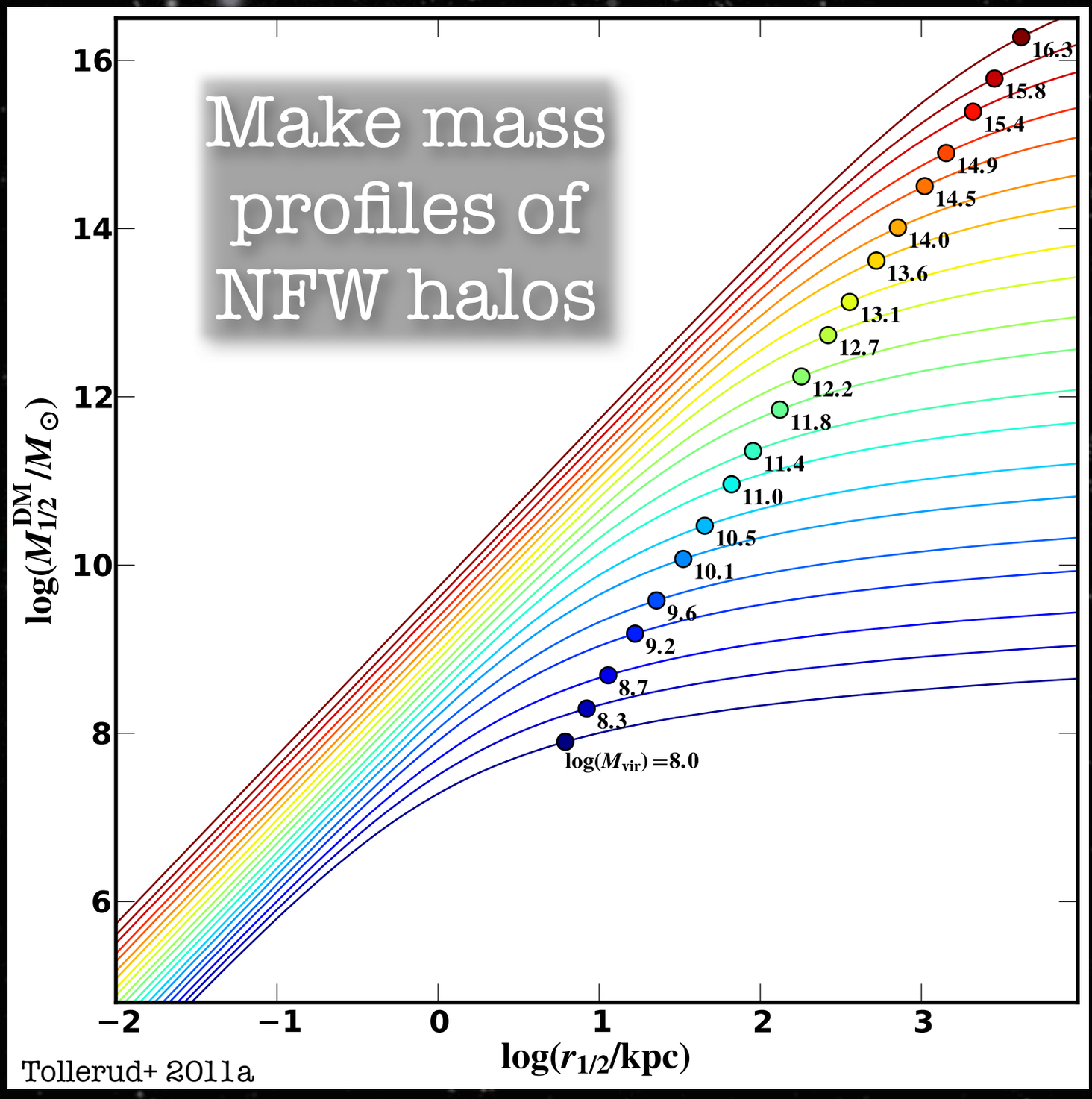
Mapping Scalings to Halos



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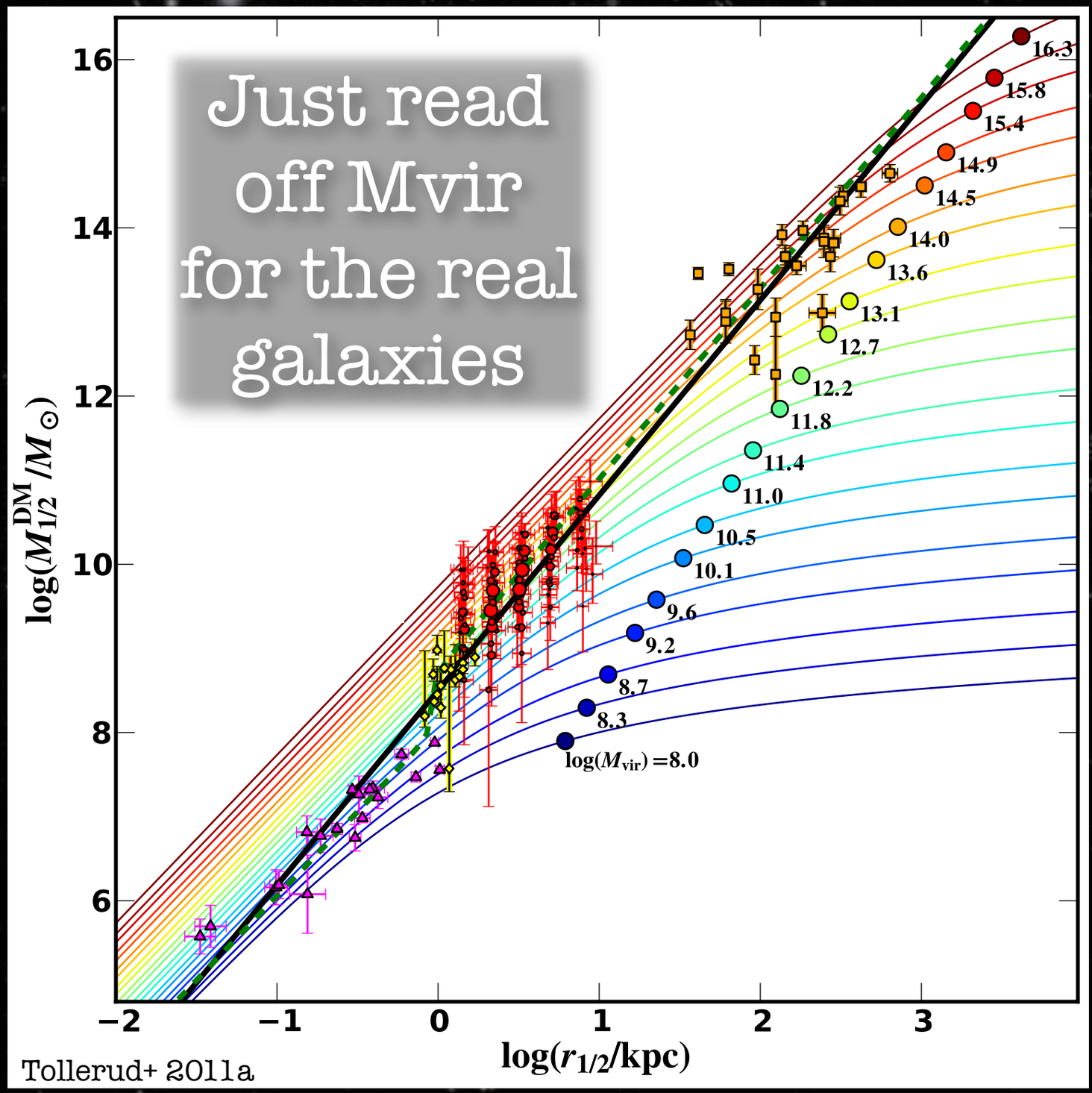
Mapping Scalings to Halos



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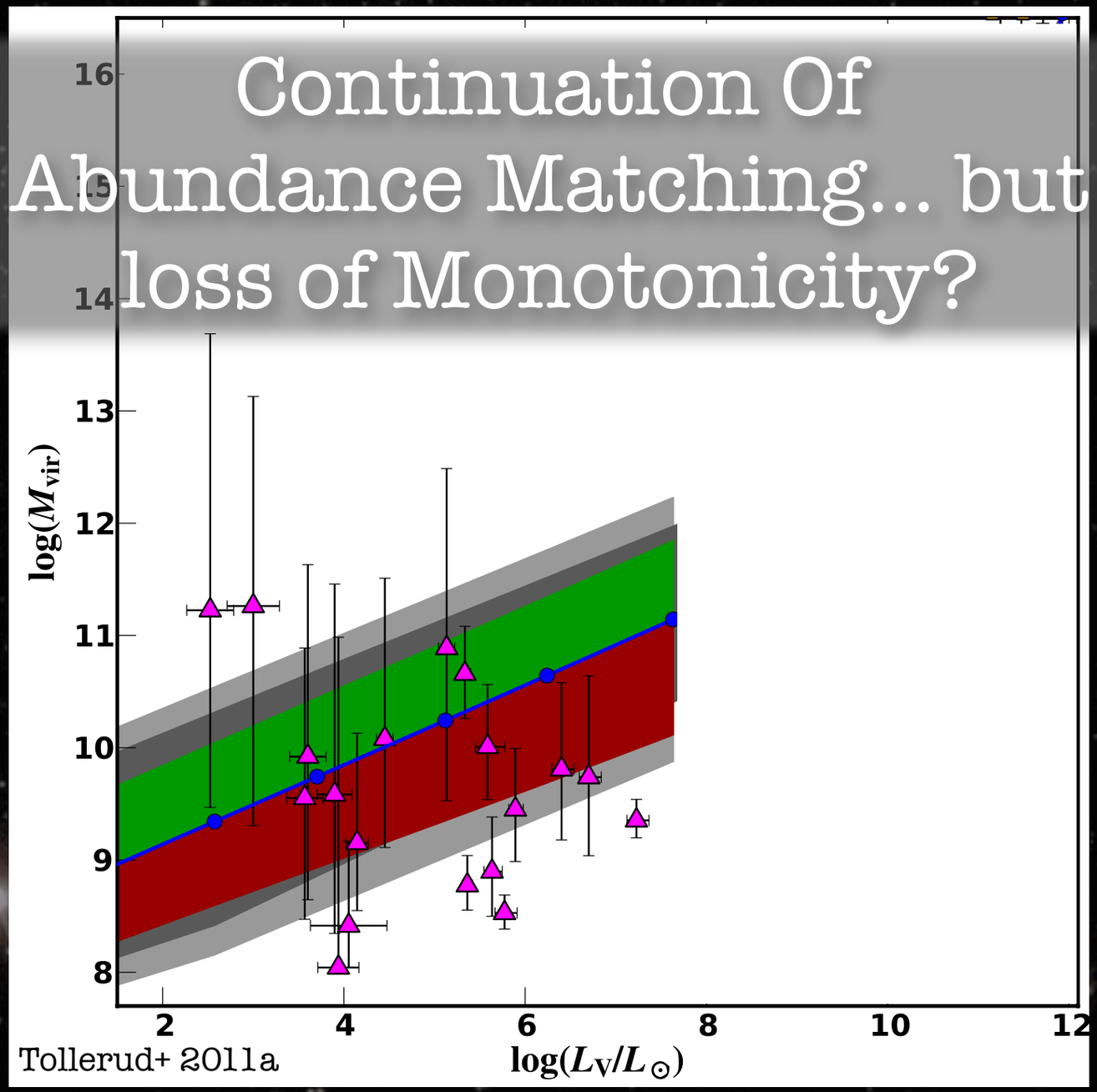
Mapping Scalings to Halos for MW Satellites

Continuation Of Abundance Matching... but loss of Monotonicity?



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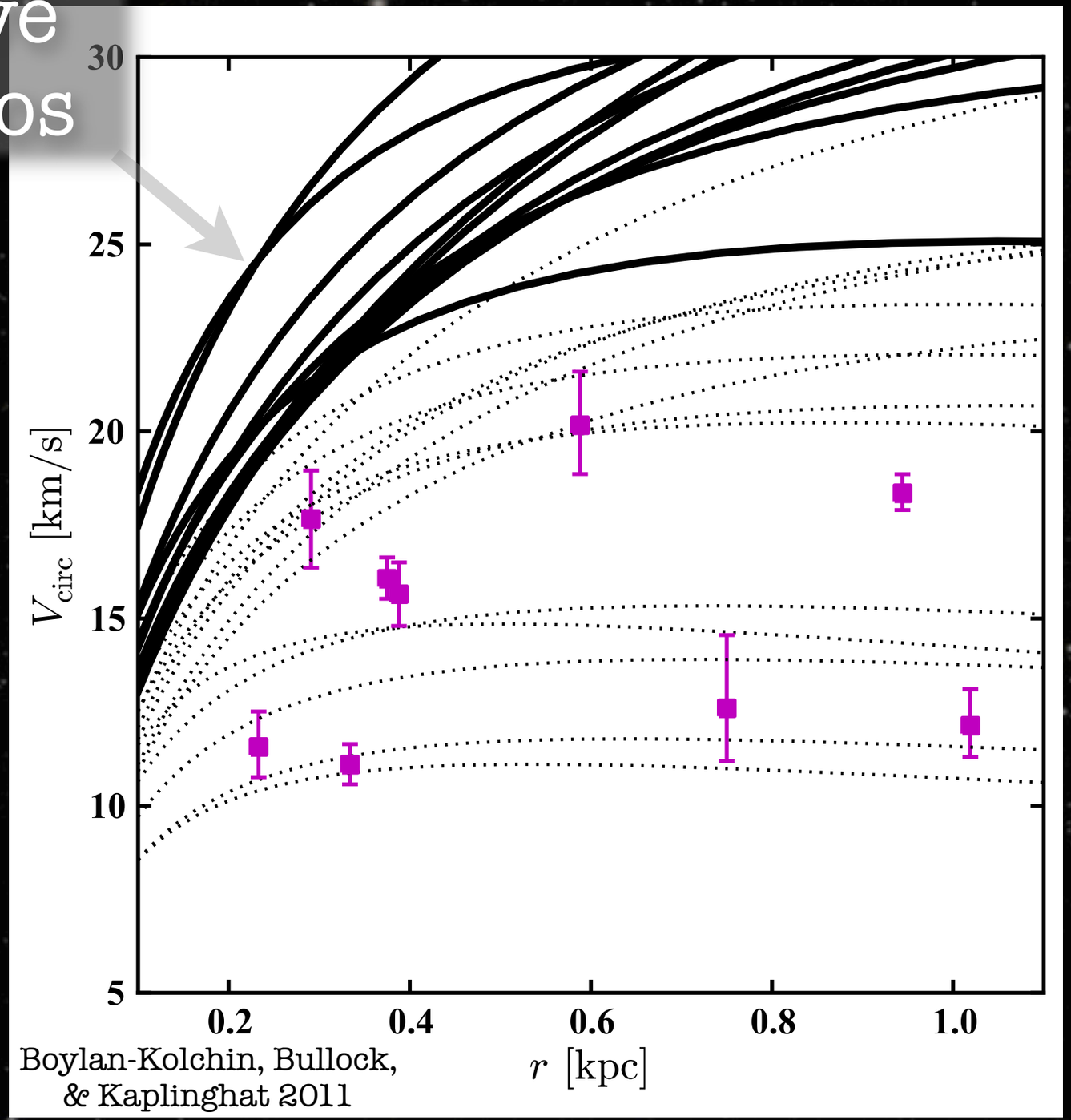
Massive Failures of the MW

Massive Subhalos



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Massive Failures of the MW

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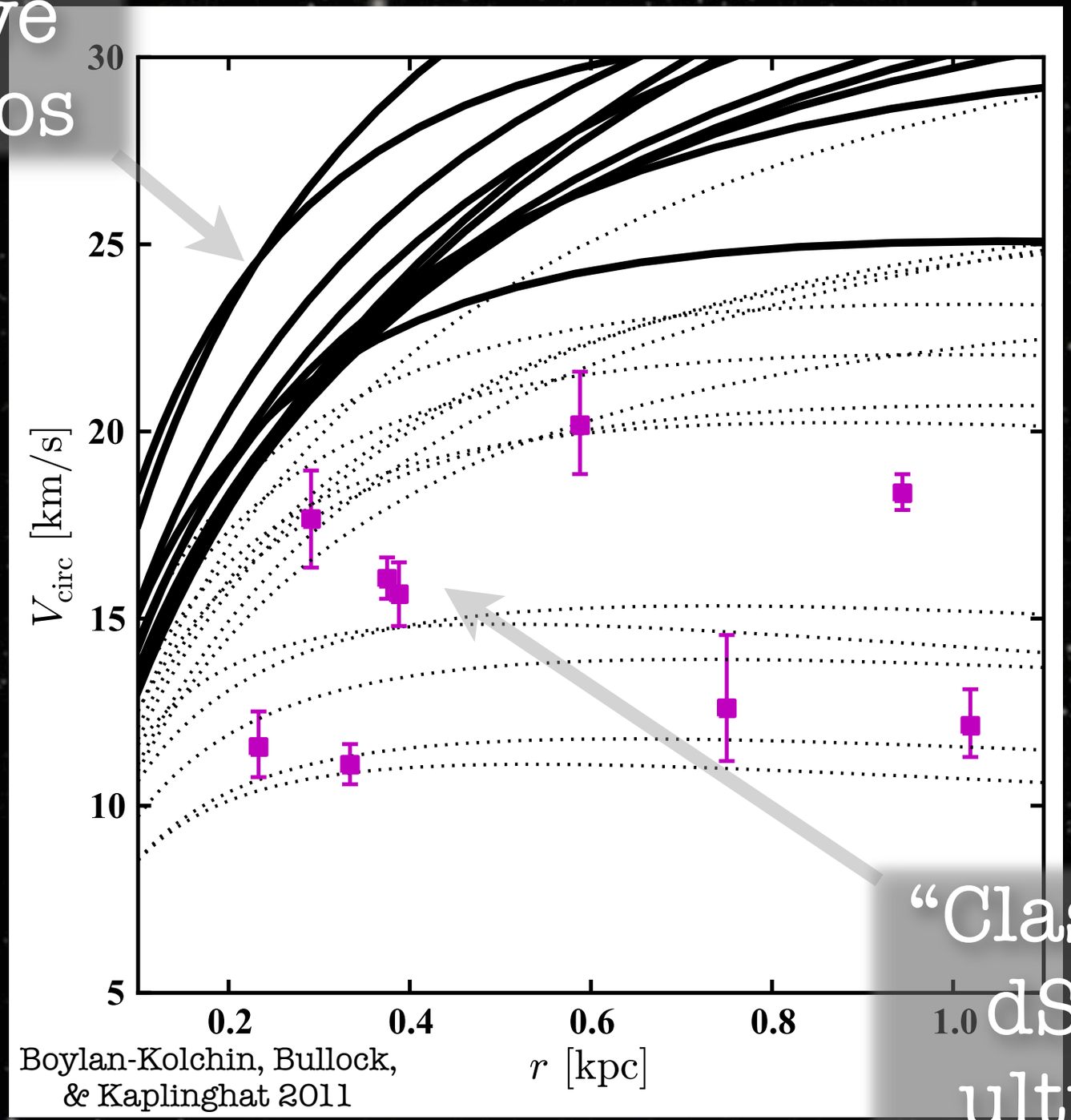

"Classical" MW dSphs (not ultra-faints)

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MW Satellites Summary

- Satellites not necessarily missing - detection bias is crucial.
- Subhalo <-> Galaxy mapping murky for faintest satellites - loss of predictability?
- MW's big subhalos are unpopulated! (or LCDM is wrong at small scales...)

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Unless... The Milky Way is Atypical

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SPLASH Survey: M31 dSph Kinematics

In Collaboration with:
Rachael Beaton[1], James Bullock[2], Raja Guhathakurta[3], Marla Geha[4], Jason Kalirai[5], Evan Kirby[6], Michael Boylan-Kolchin[2]

[1]UVa, [2]UCI, [3]UCSC, [4]Yale, [5]STScI, [6]Caltech

Image Credit: Tony Hallas

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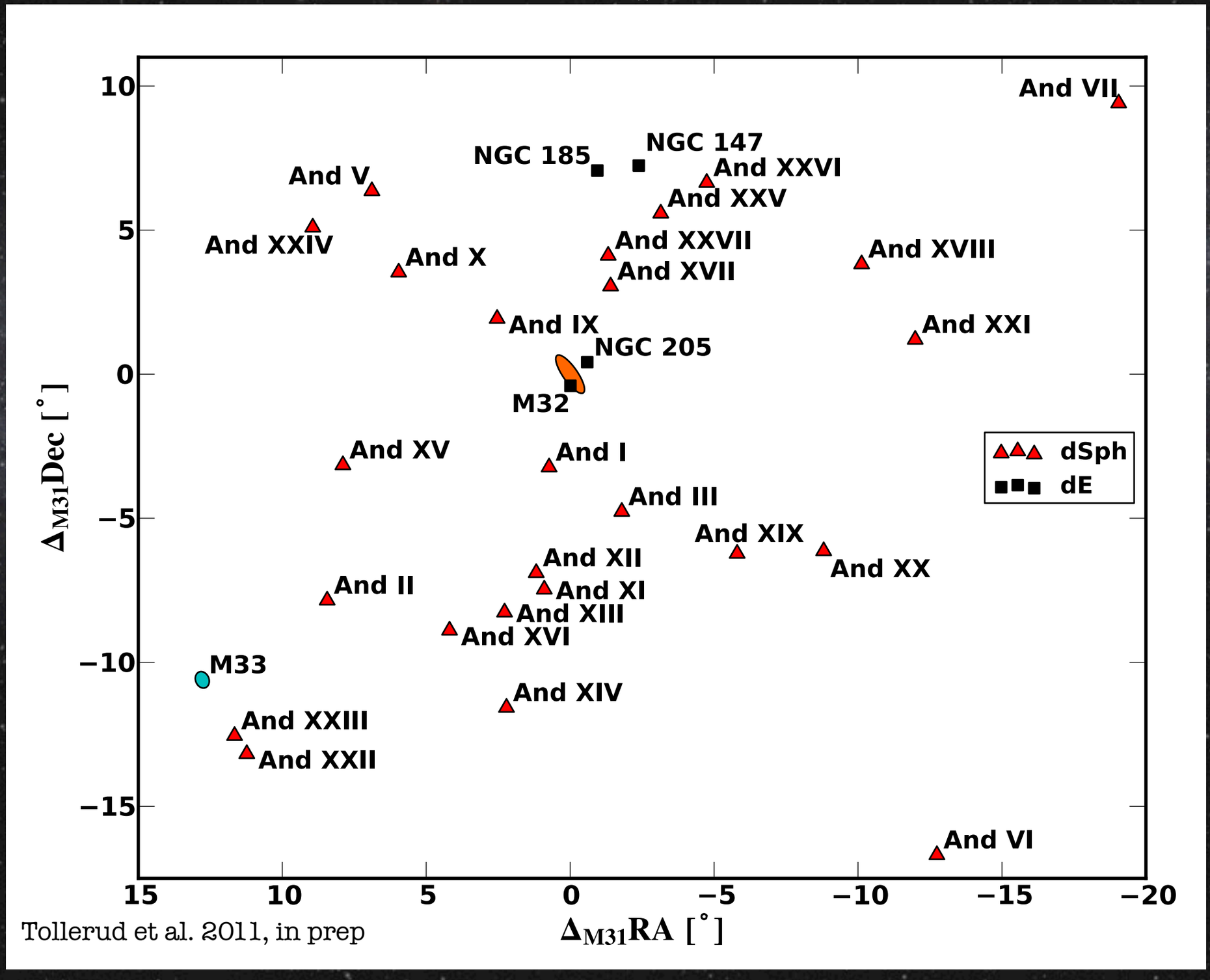
M31 System



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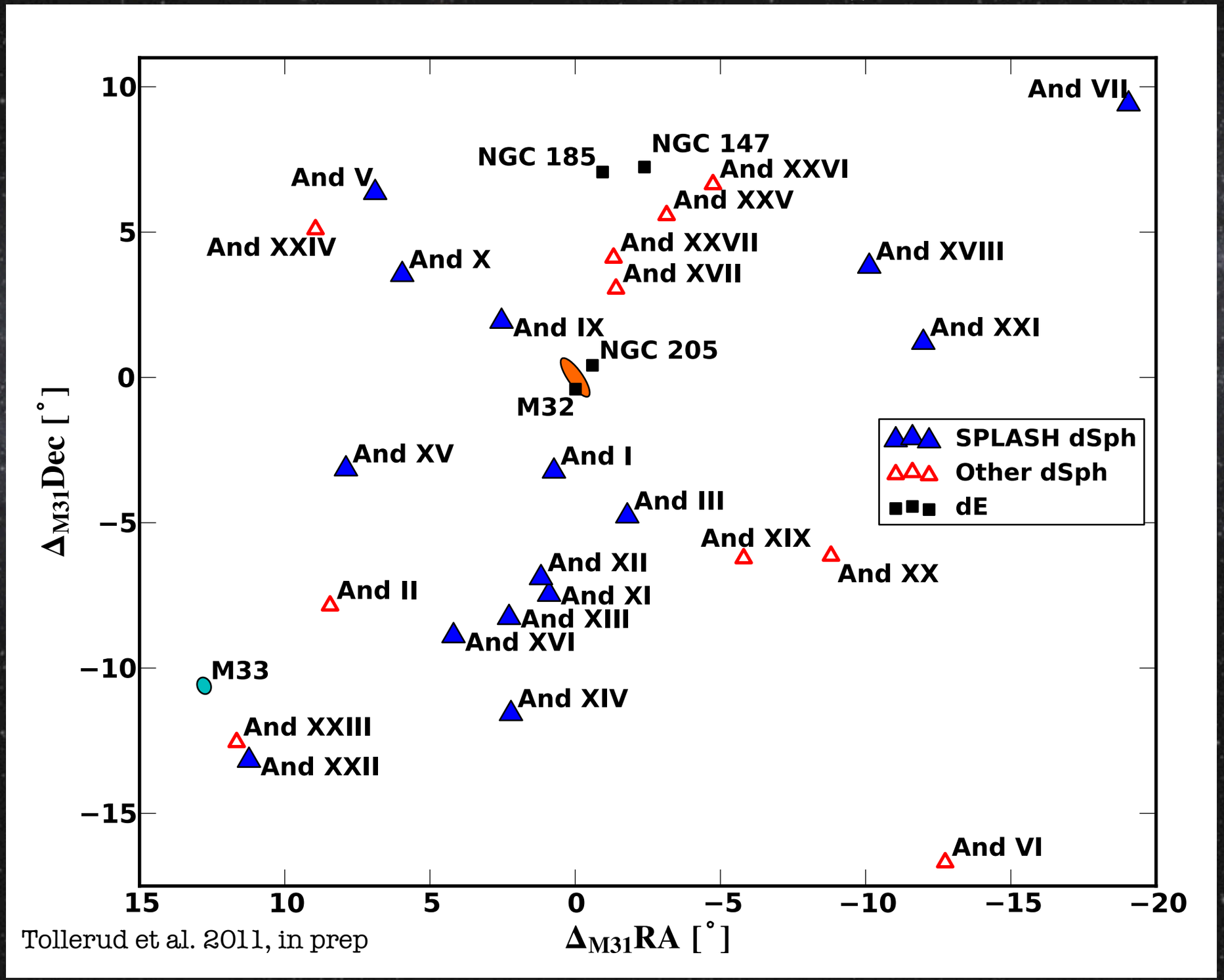
SPLASH dSphs



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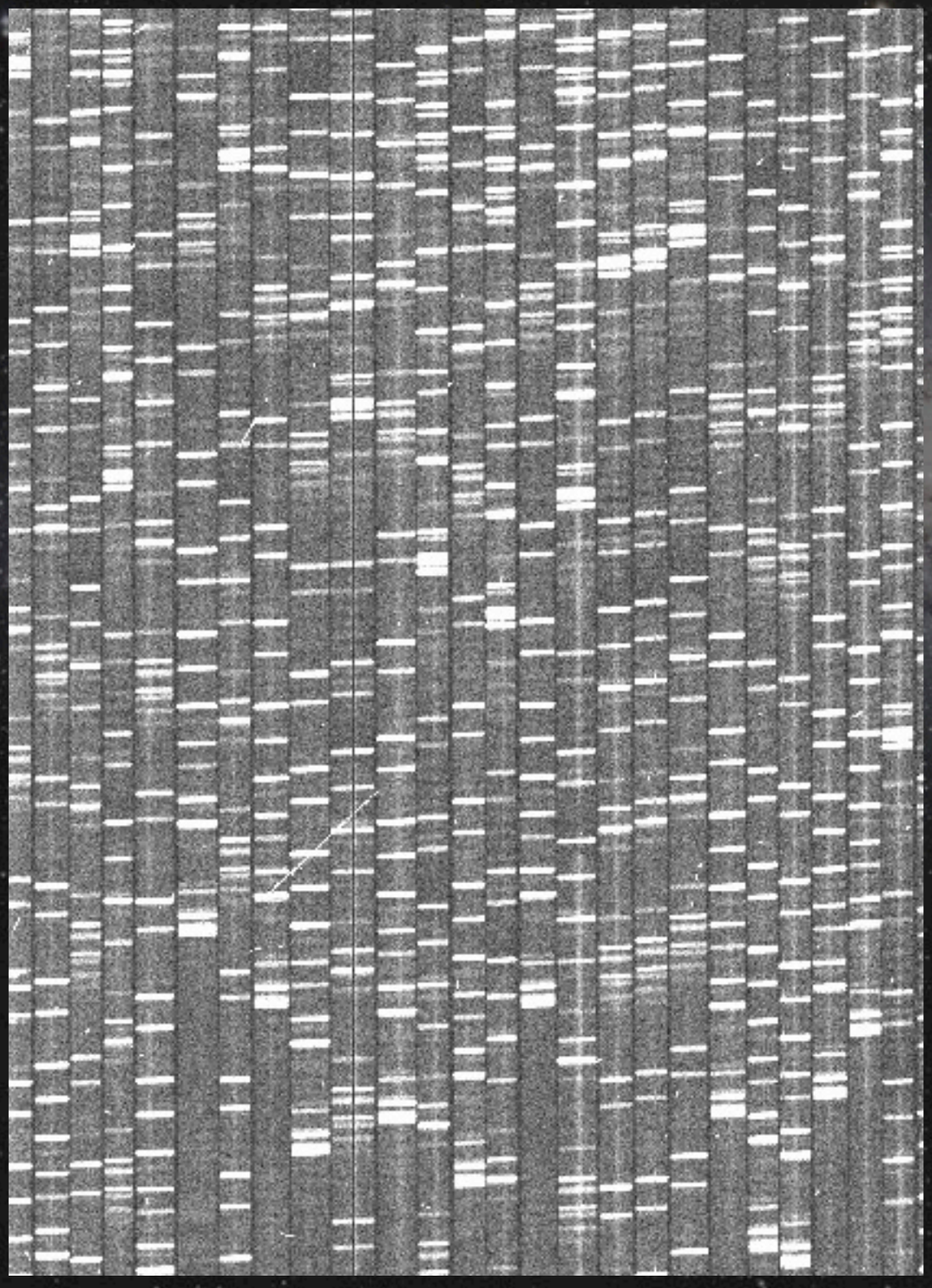
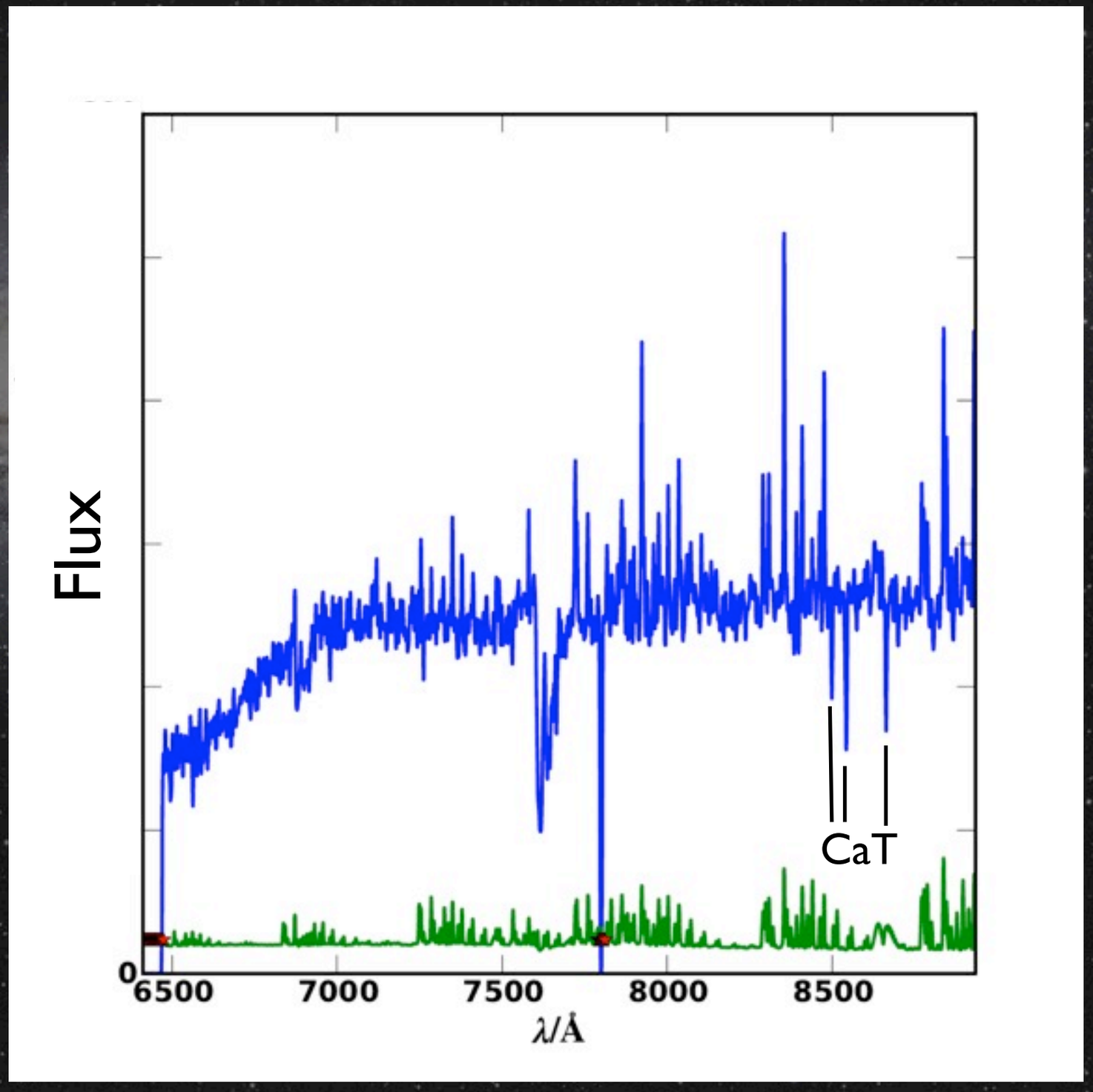
Keck/DEIMOS Spectroscopy





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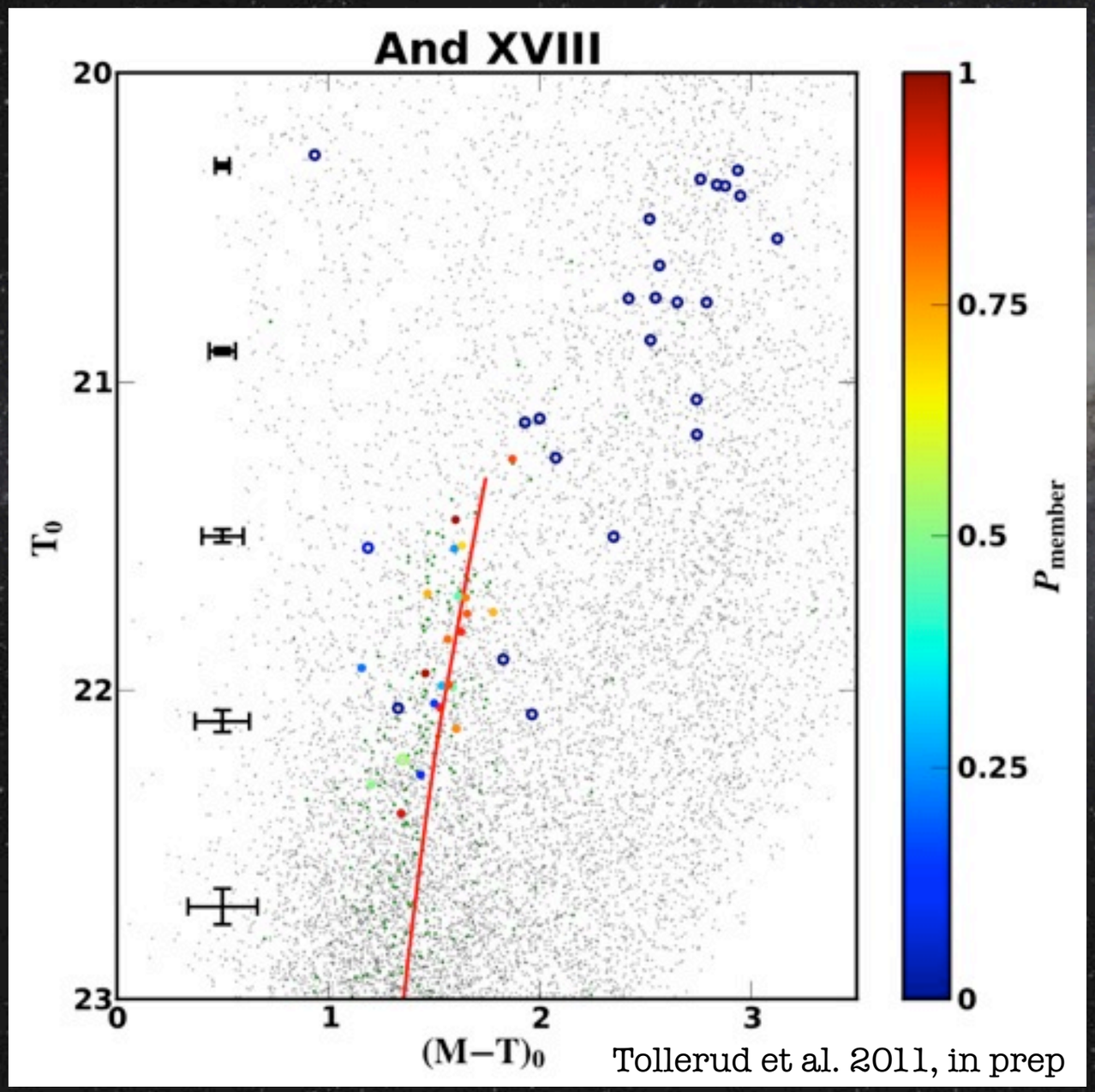
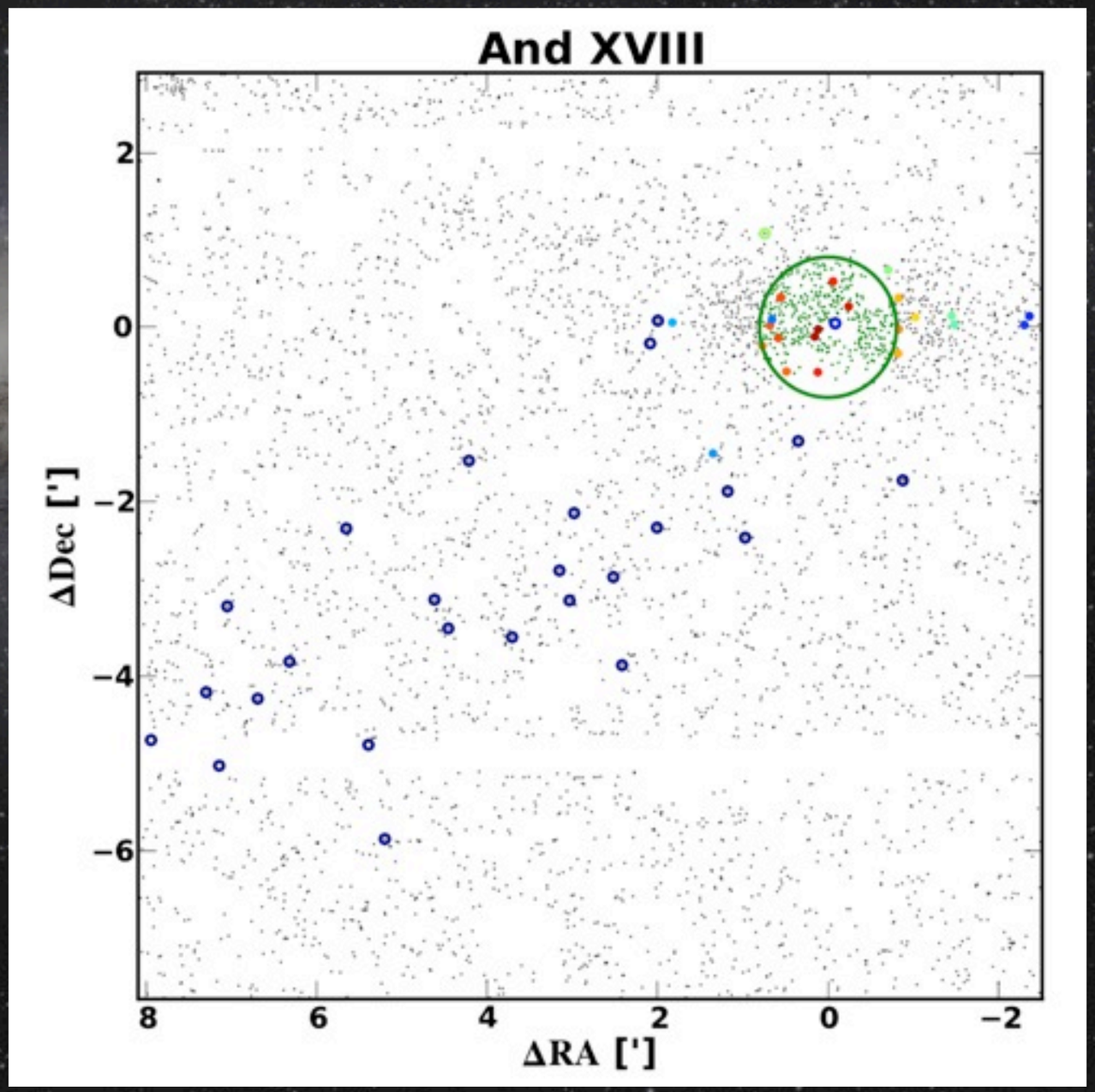
Member Selection



Tollerud et al. 2011, in prep



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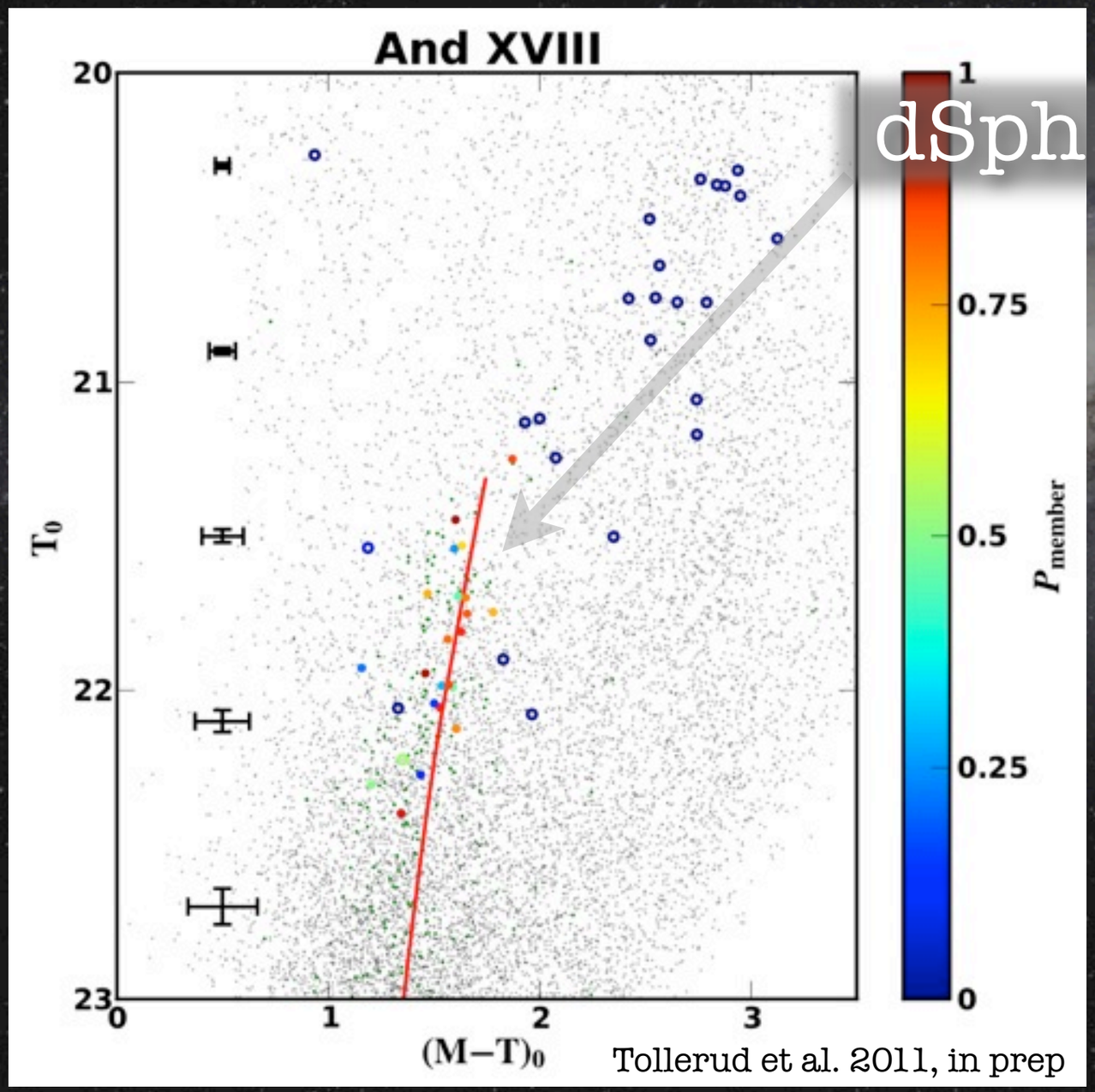
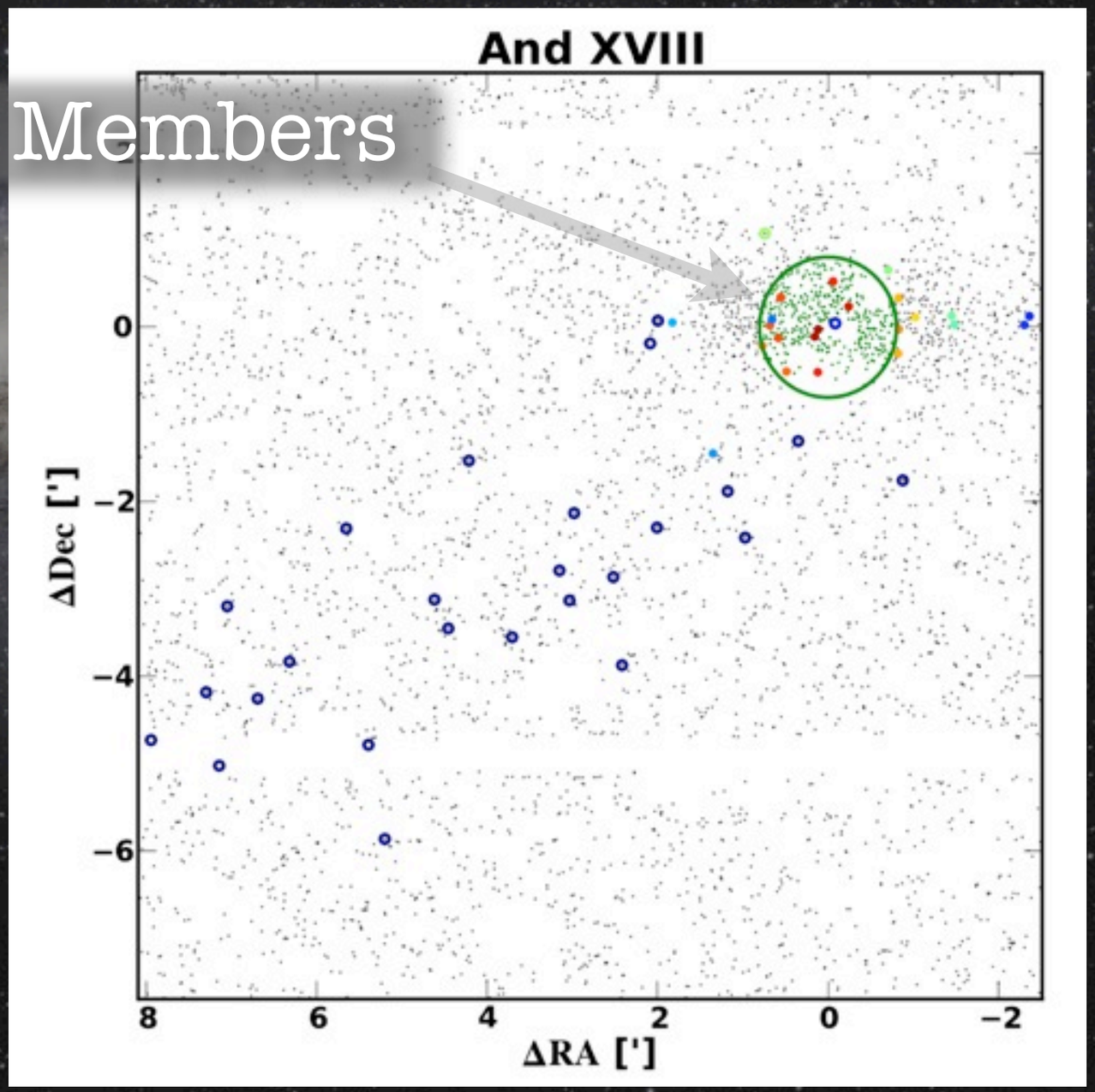


dSph Members

Tollerud et al. 2011, in prep



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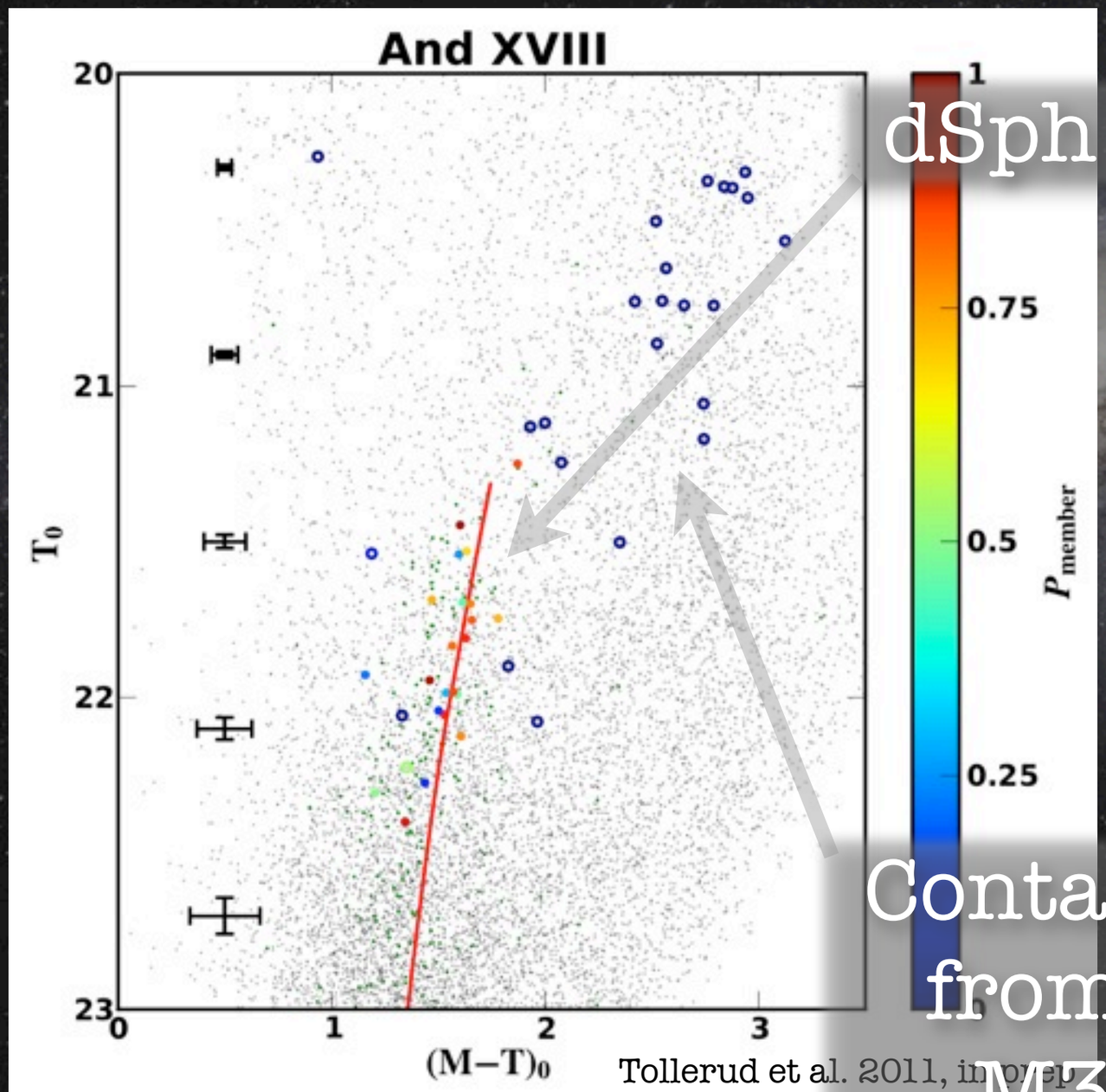
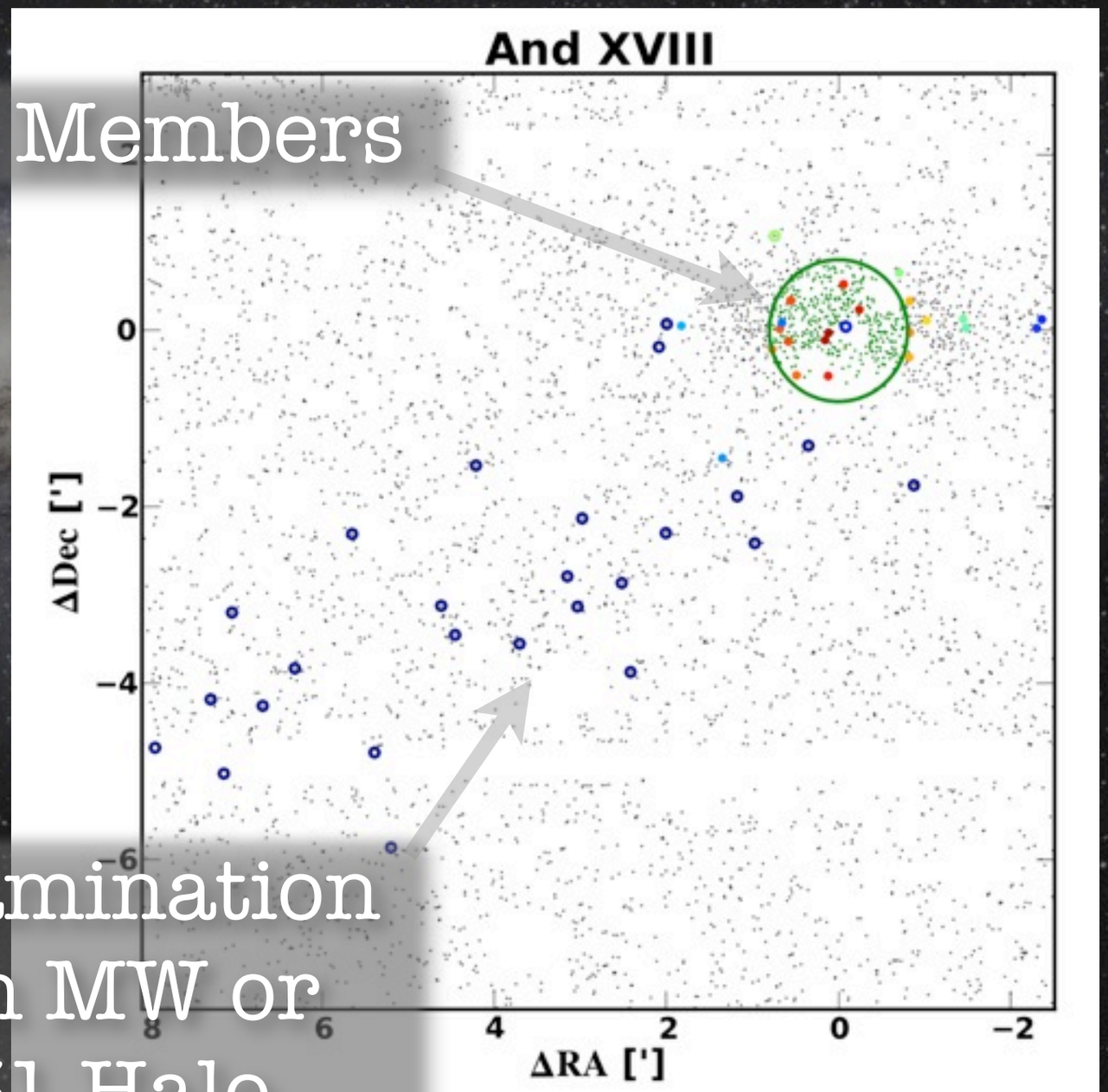
Member Selection



dSph Members



Contamination from MW or M31 Halo

Tollerud et al. 2011, in prep

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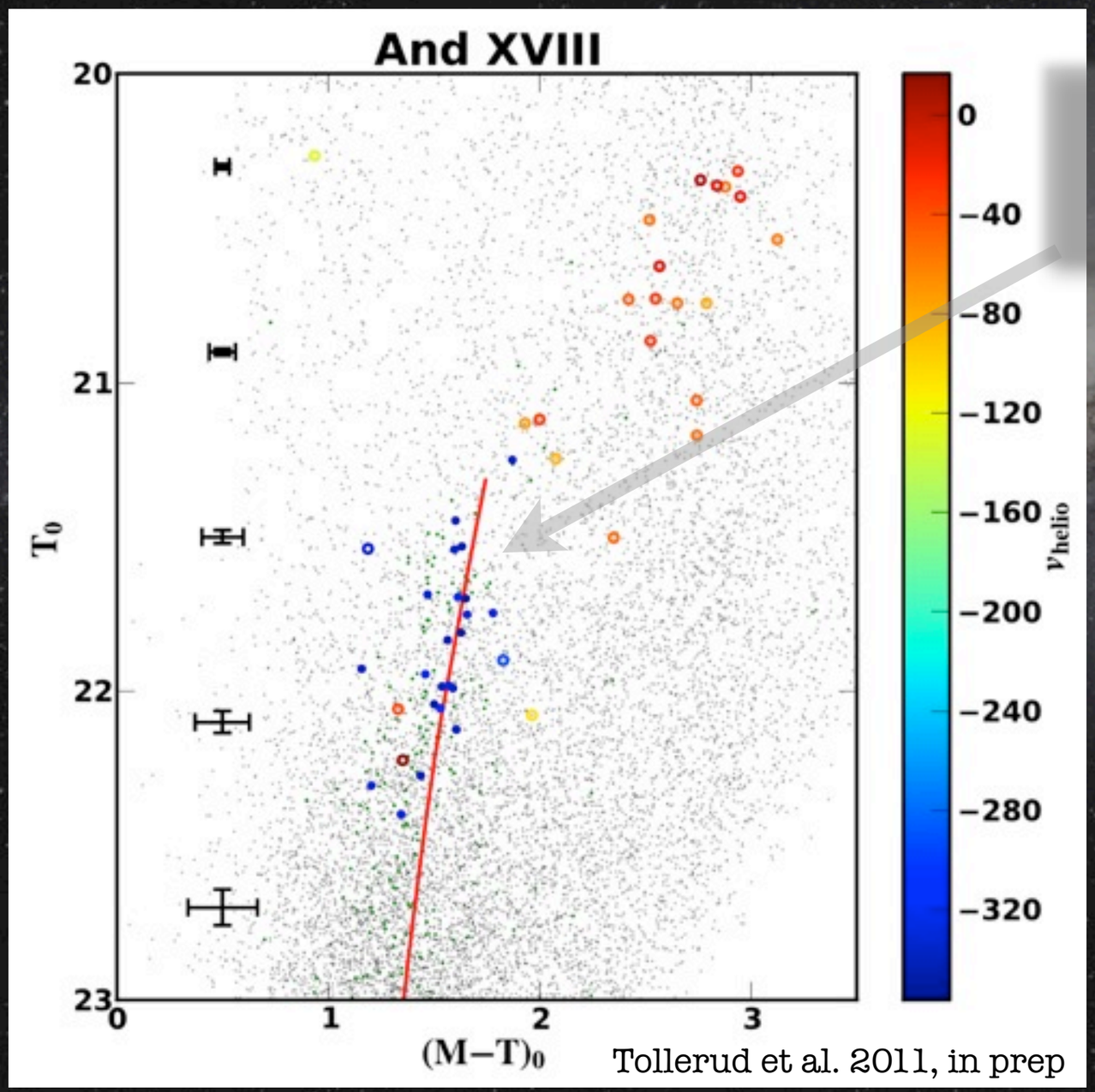
Member Selection



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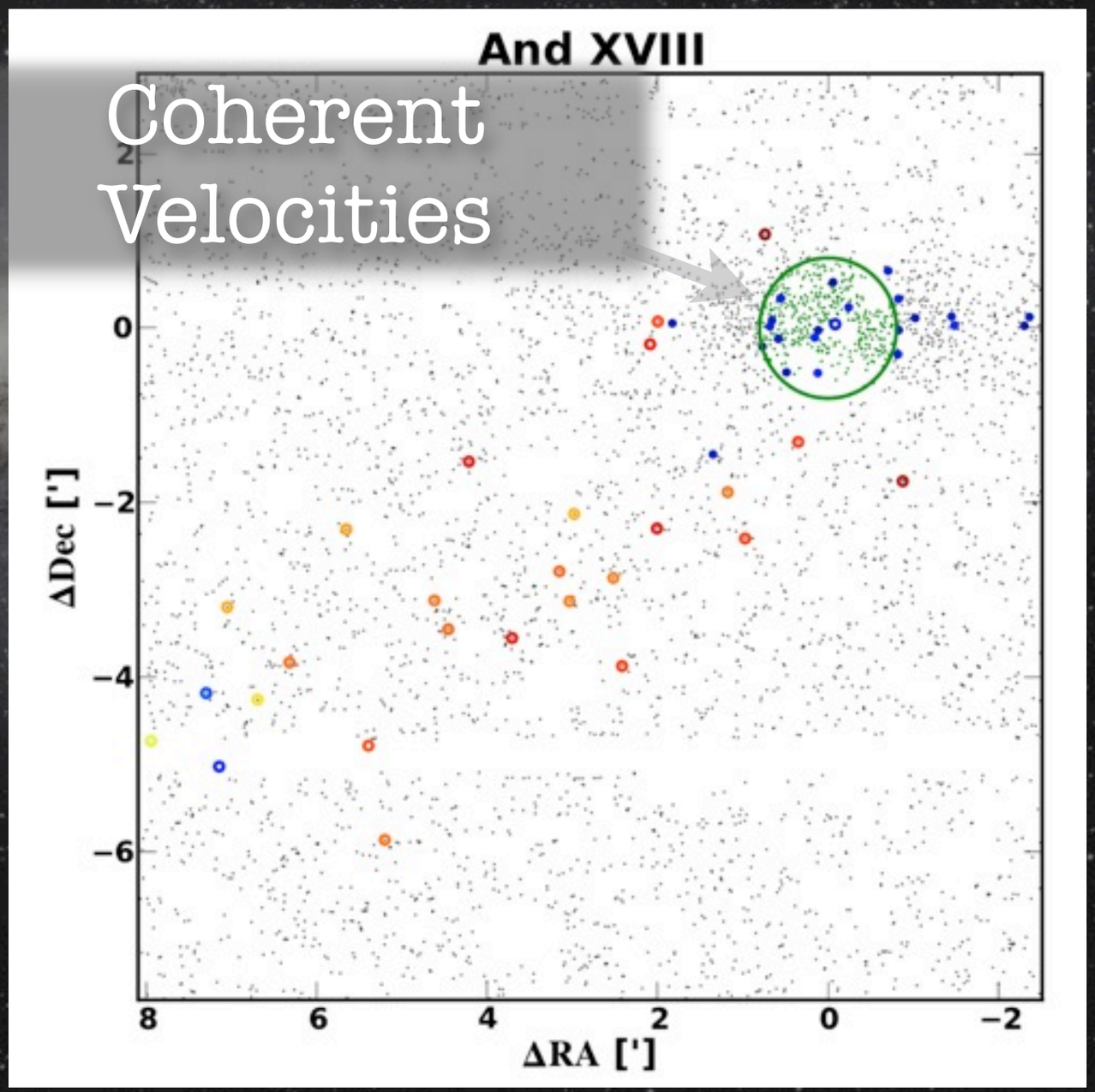

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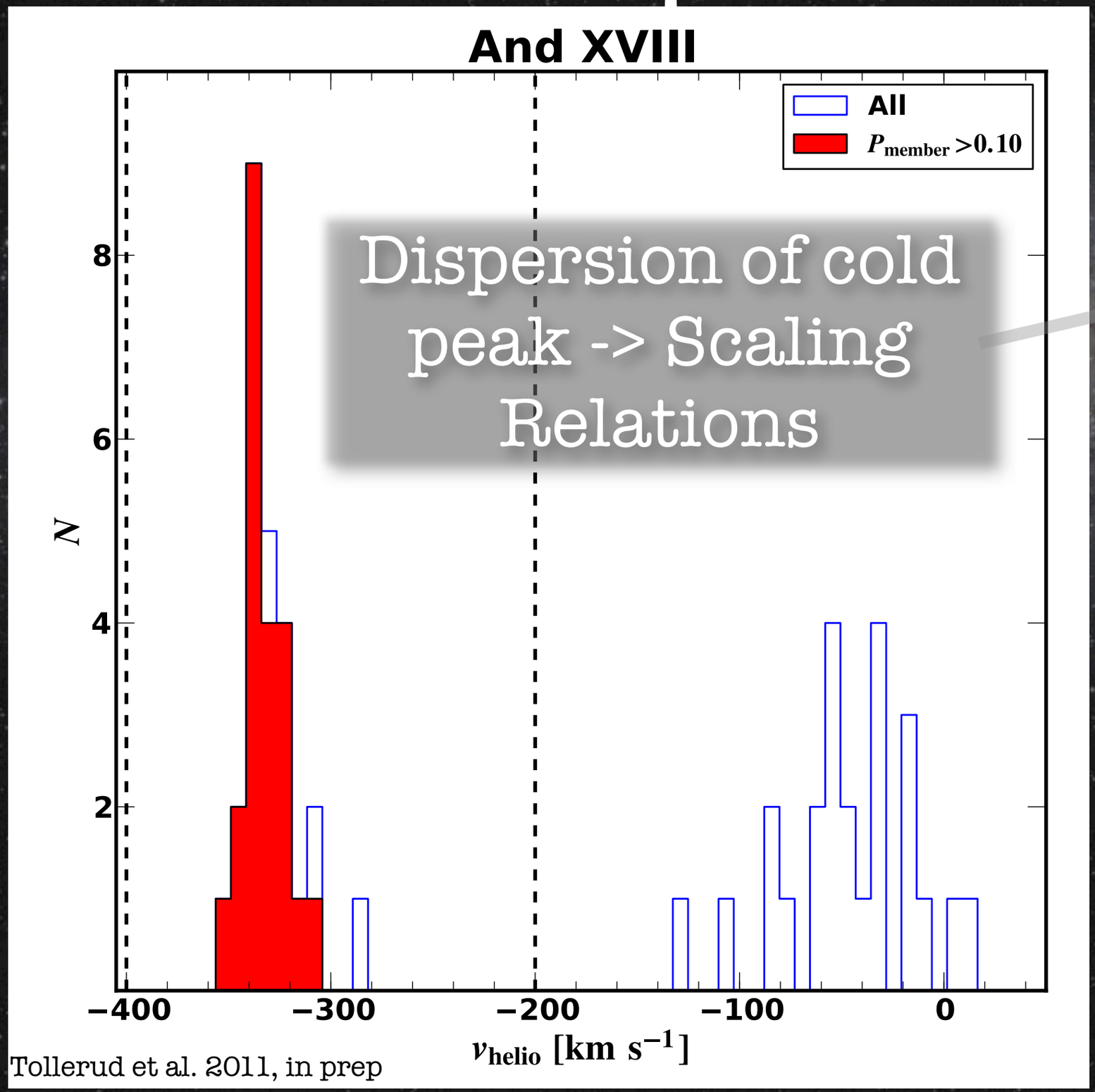
M31 dSph Kinematics



Tollerud et al. 2011, in prep

Dispersion of cold peak -> Scaling Relations

Tollerud+ 11a:

$$M_{1/2} = 3\frac{\langle\sigma^2\rangle r_{1/2}}{G}$$

(Wolf+ 10)

$$r_{1/2} = \frac{4R_{\rm eff}}{3}$$

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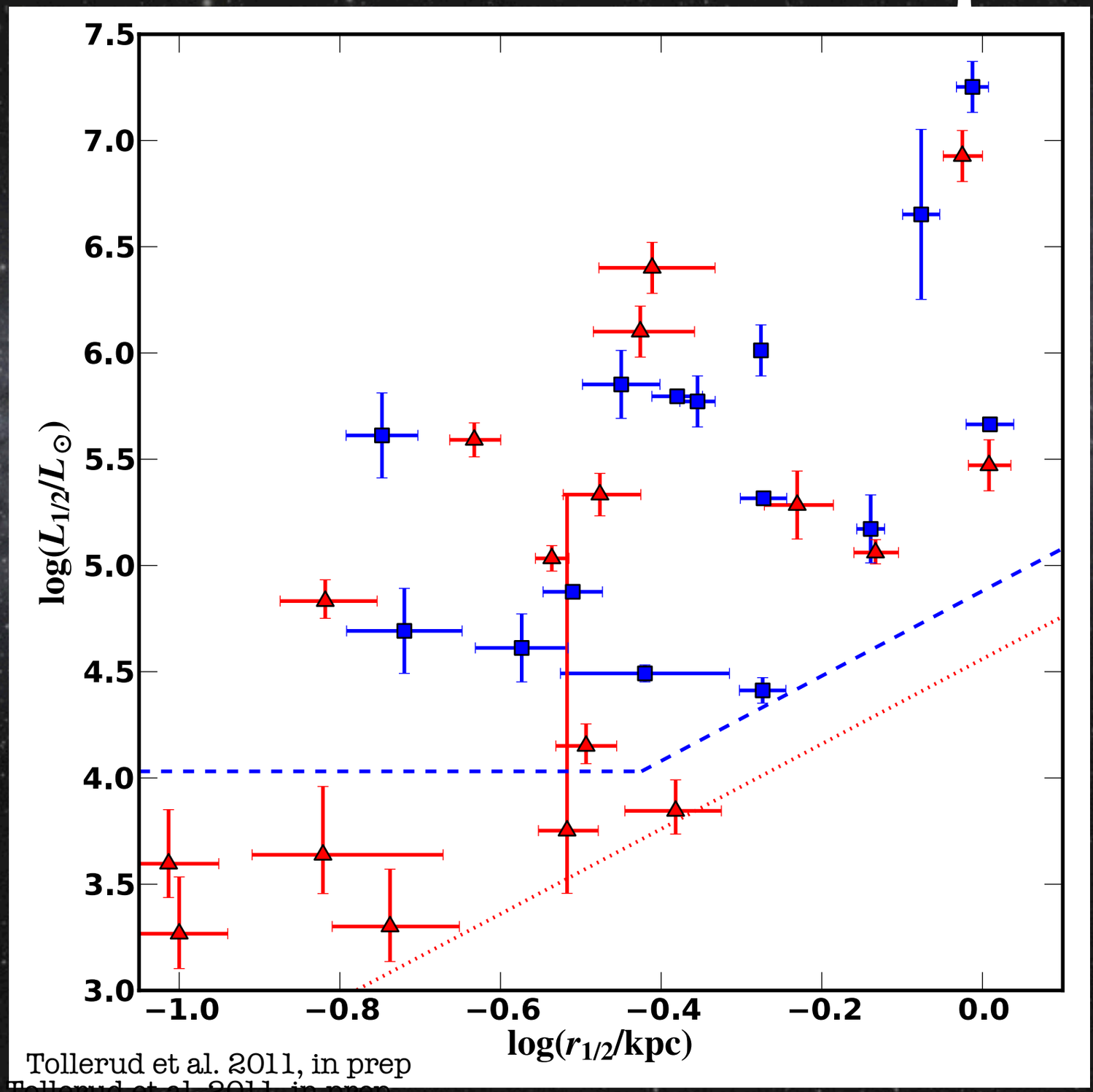
MW vs M31 dSphs



Tollerud et al. 2011, in prep

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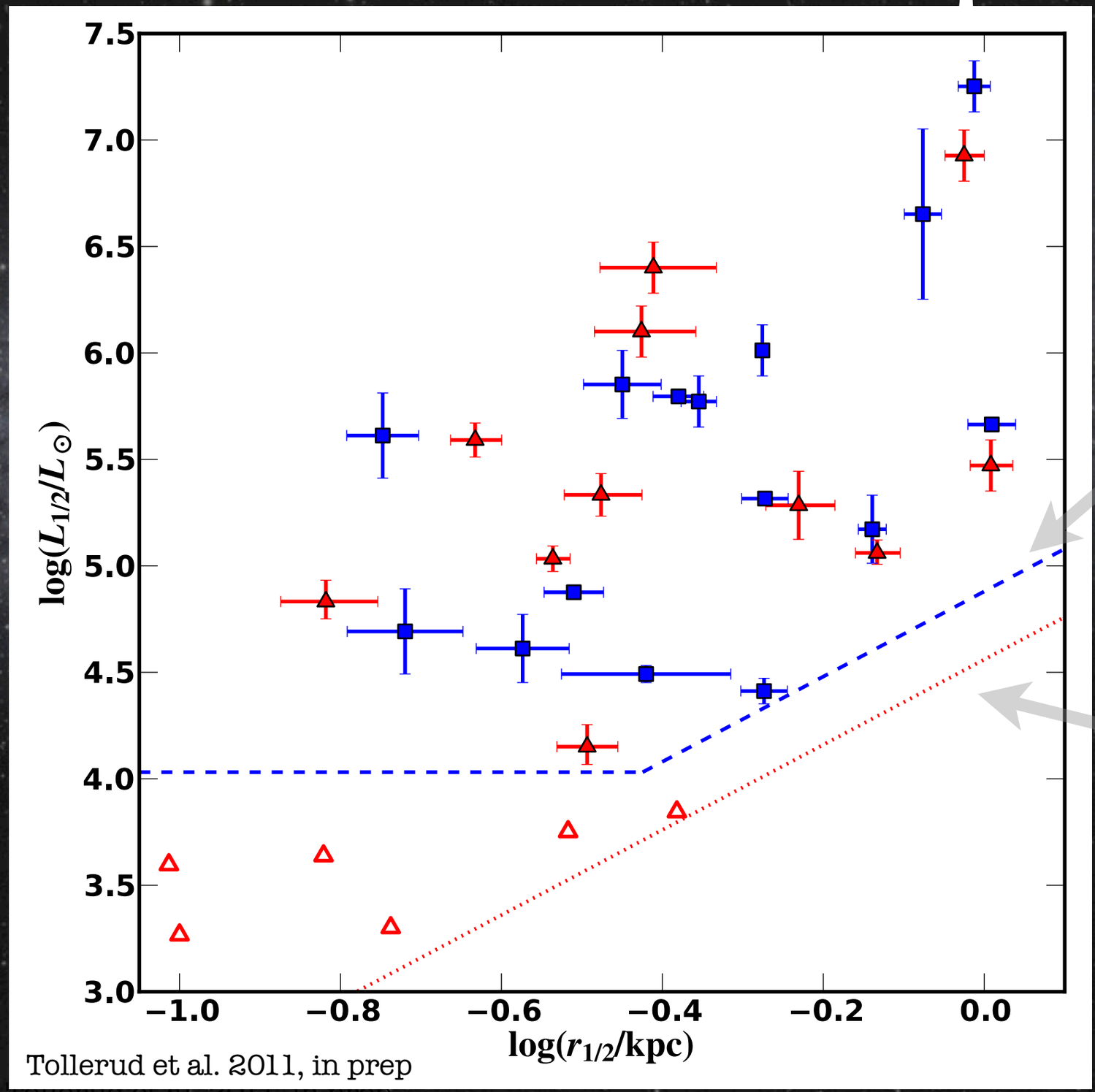
MW vs M31 dSphs



Tollerud et al. 2011, in prep

Tollerud et al. 2011, in prep

PAndAS (M31) Limits

SDSS (MW) Limits

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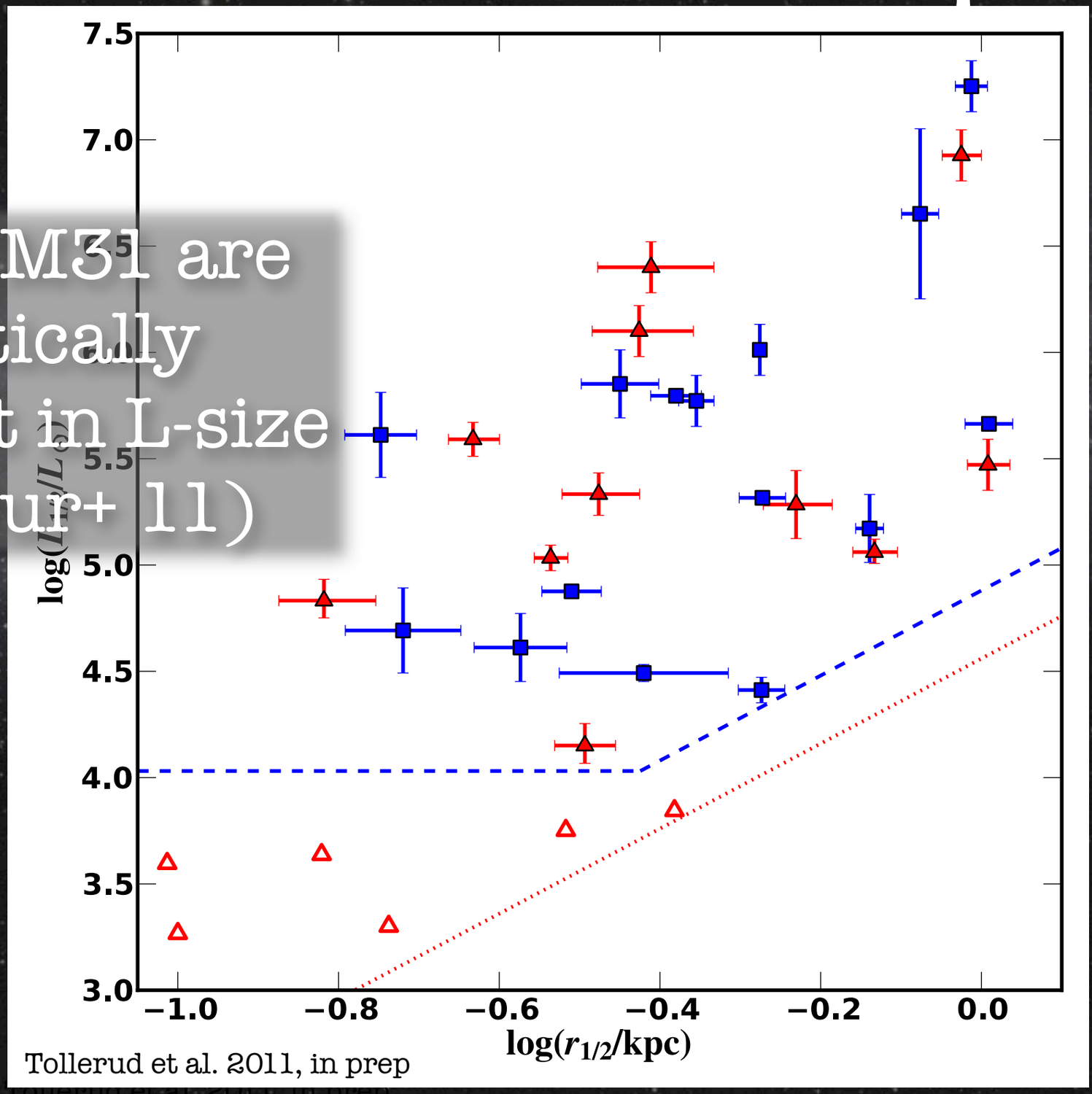
MW vs M31 dSphs

MW and M31 are statistically consistent in L-size (Brasseur+ 11)



Tollerud et al. 2011, in prep

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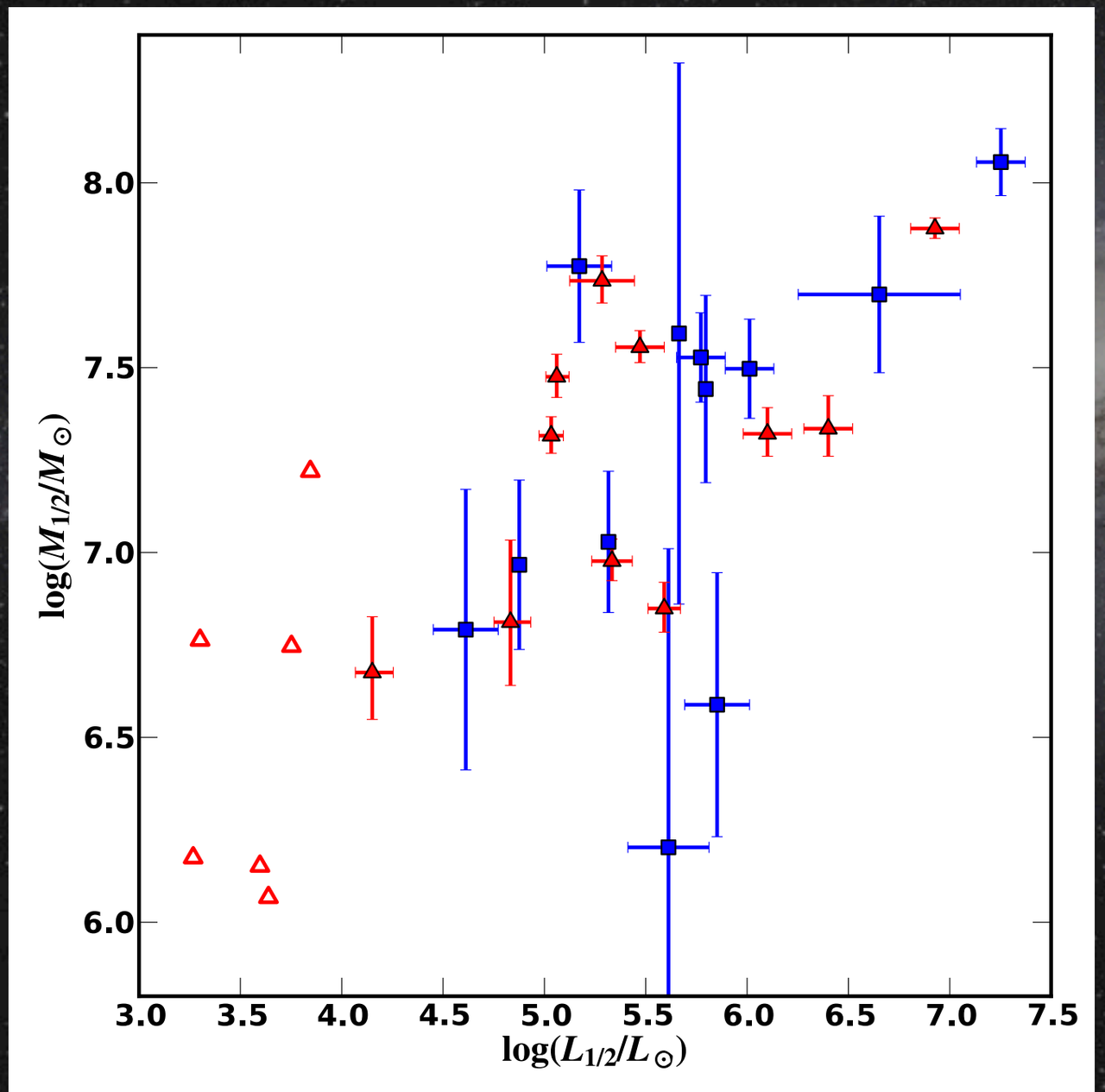
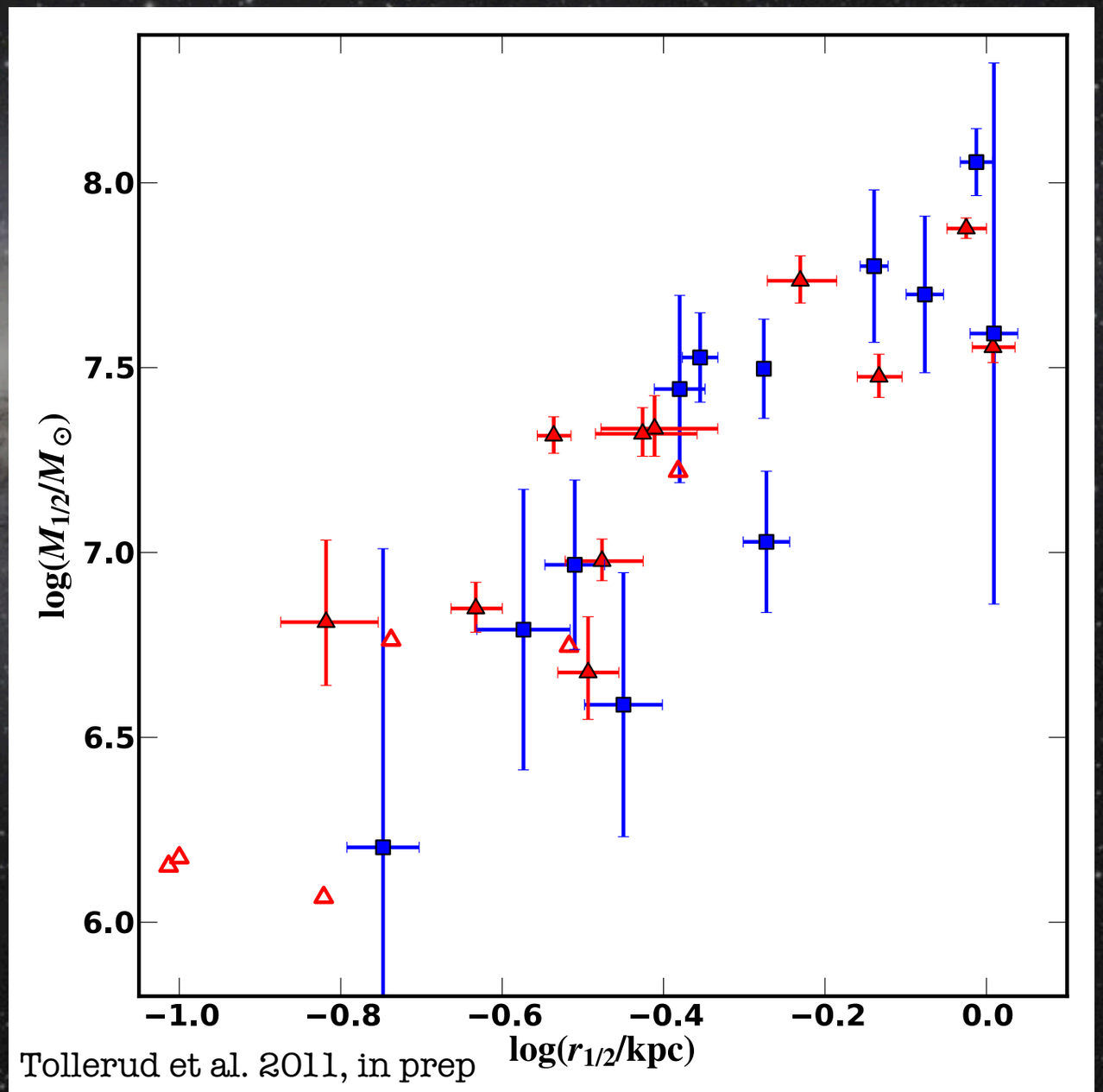
MW vs M31 dSphs





Tollerud et al. 2011, in prep

M31 dSphs
MW dSphs

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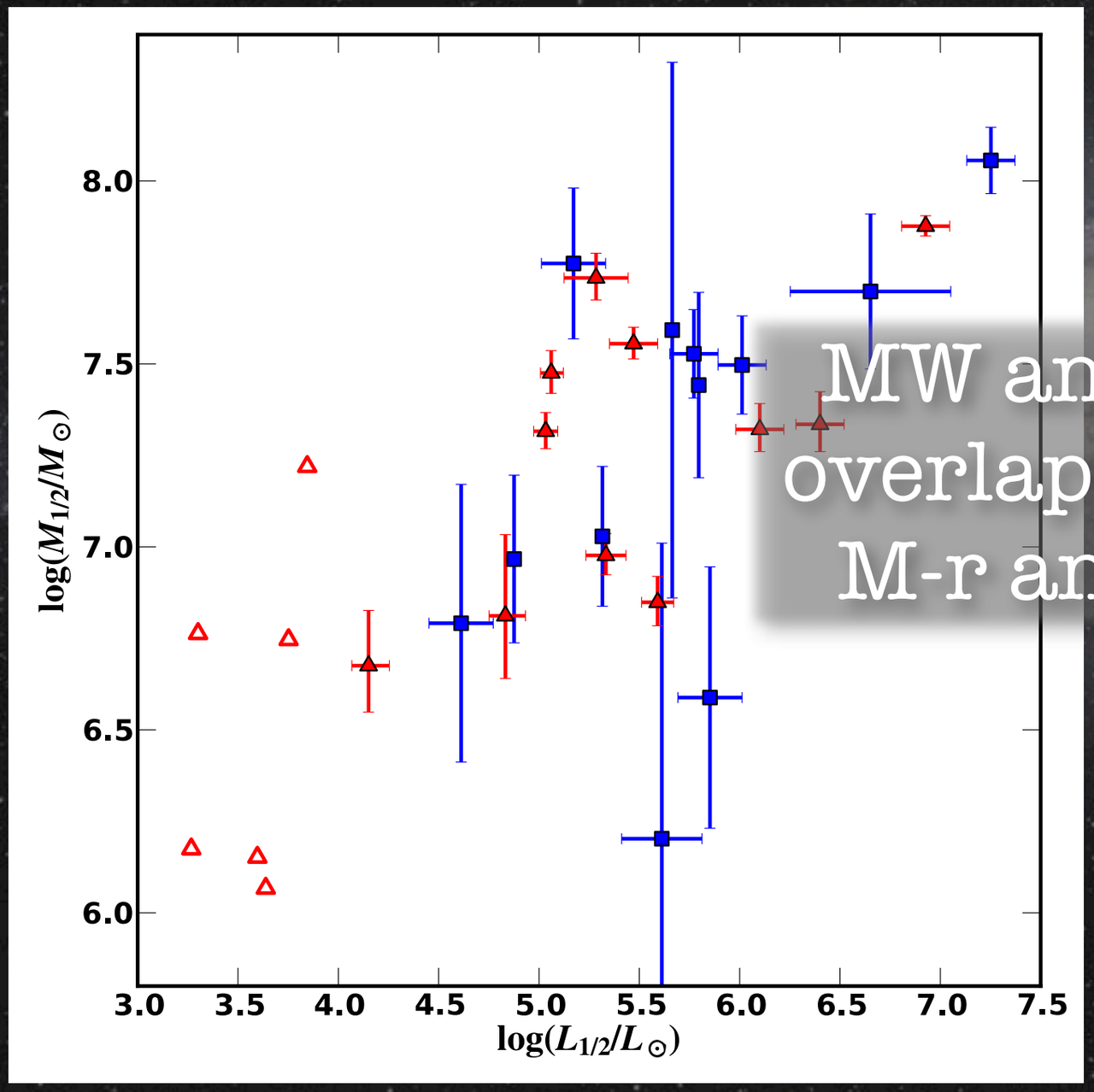
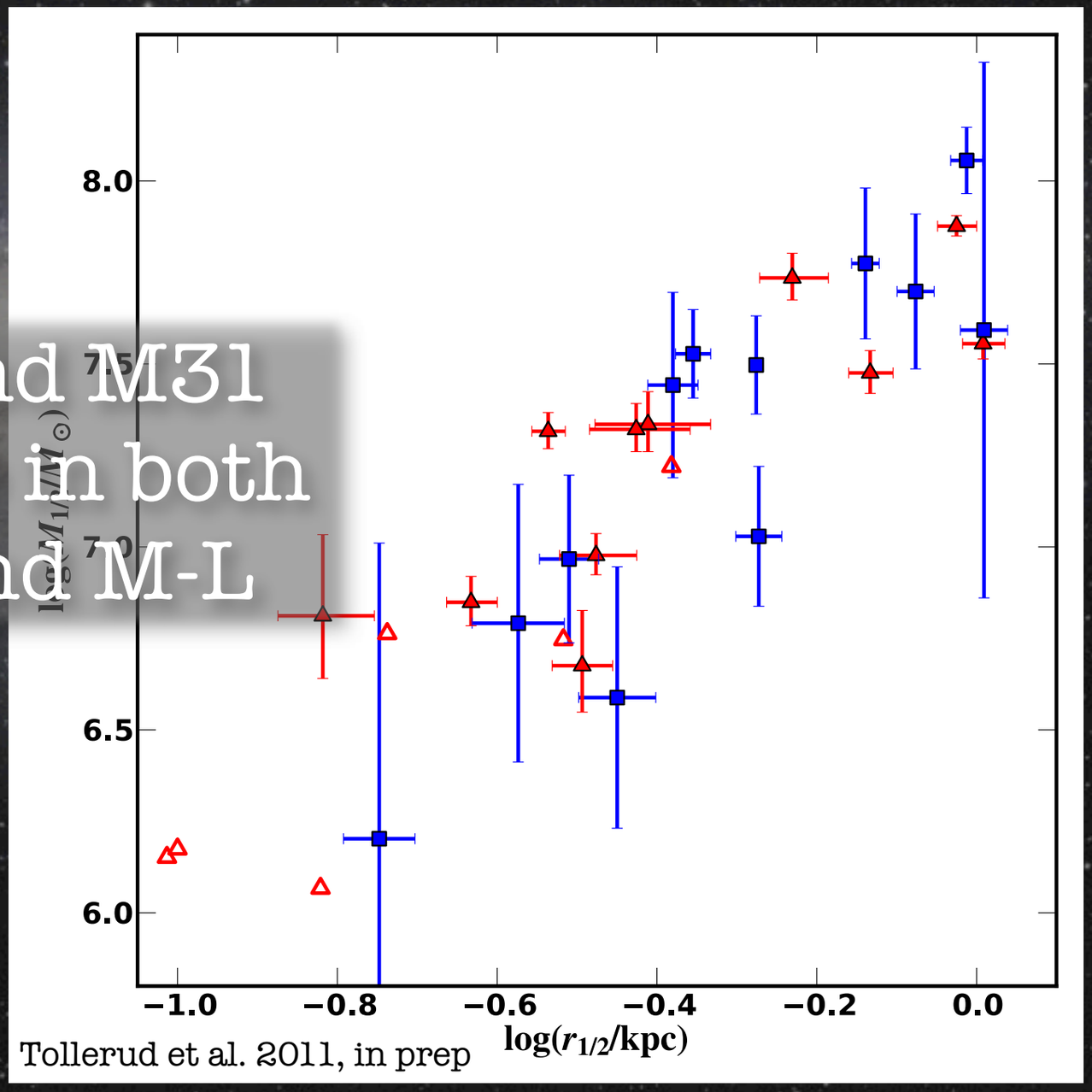
MW vs M31 dSphs





MW and M31 overlap in both M-r and M-L

Tollerud et al. 2011, in prep

M31 dSphs
MW dSphs

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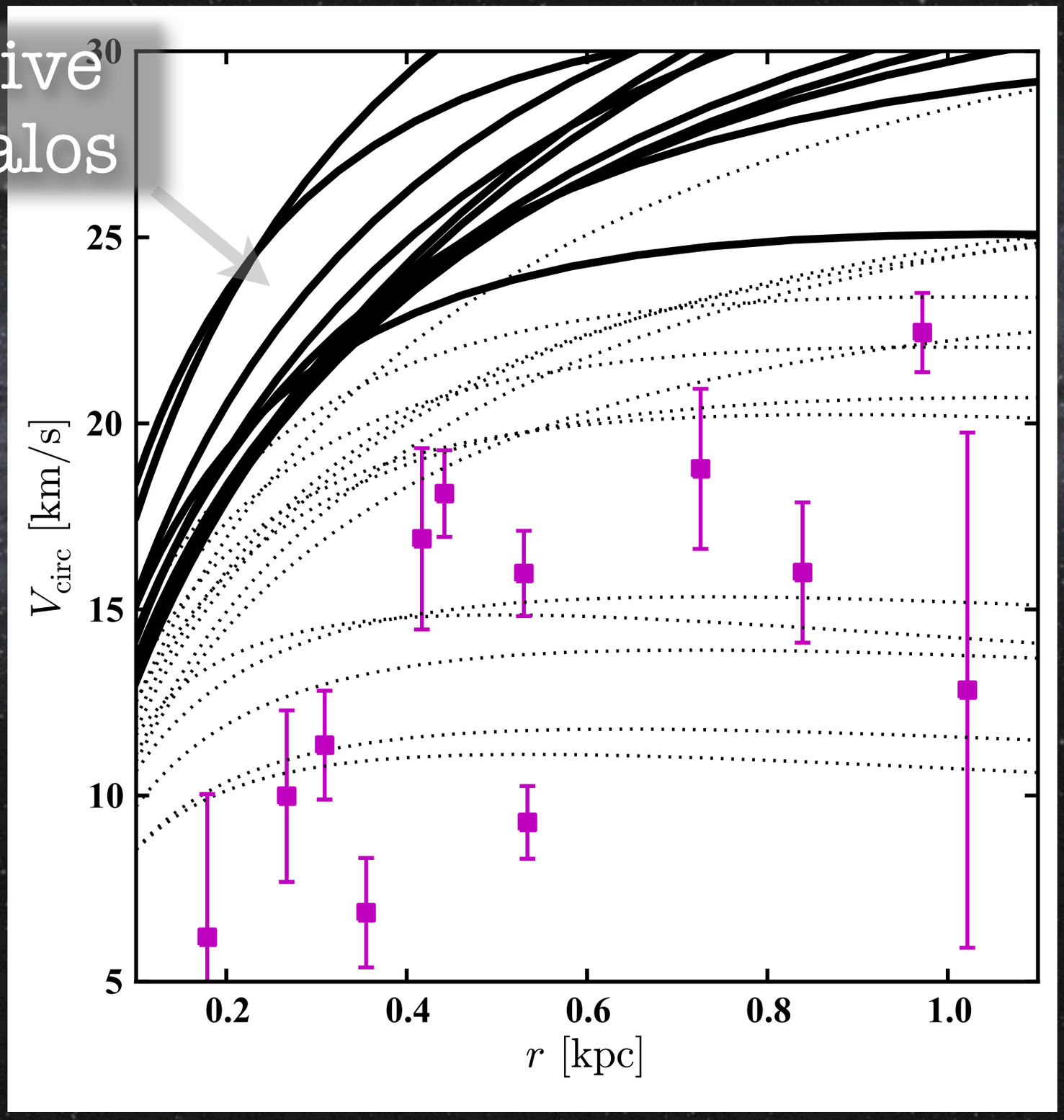
Massive Failures in M31

Massive Subhalos



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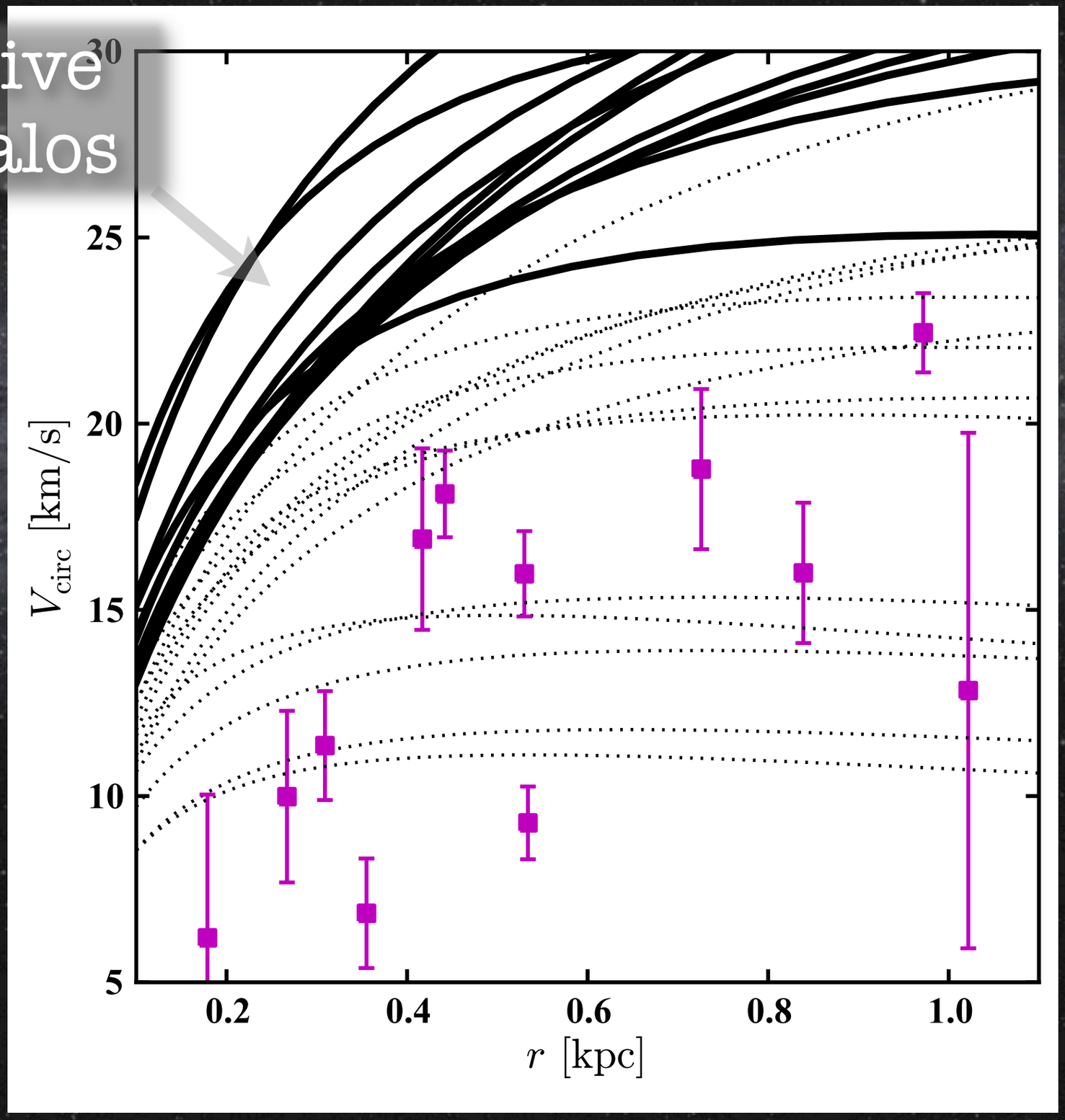
Massive Failures in M31

Massive Subhalos



Massive Subhalos also Fail for M31!

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Summary (SPLASH)

- M31 dSphs scale much like MW sats: “uniqueness” of MW sats not really viable.
  - Is this odd, given different MW/M31 accretion histories/masses?
- M31 (and MW) satellites are too low density for most massive LCDM subhalos. A problem for LCDM, or “just galaxy formation”?

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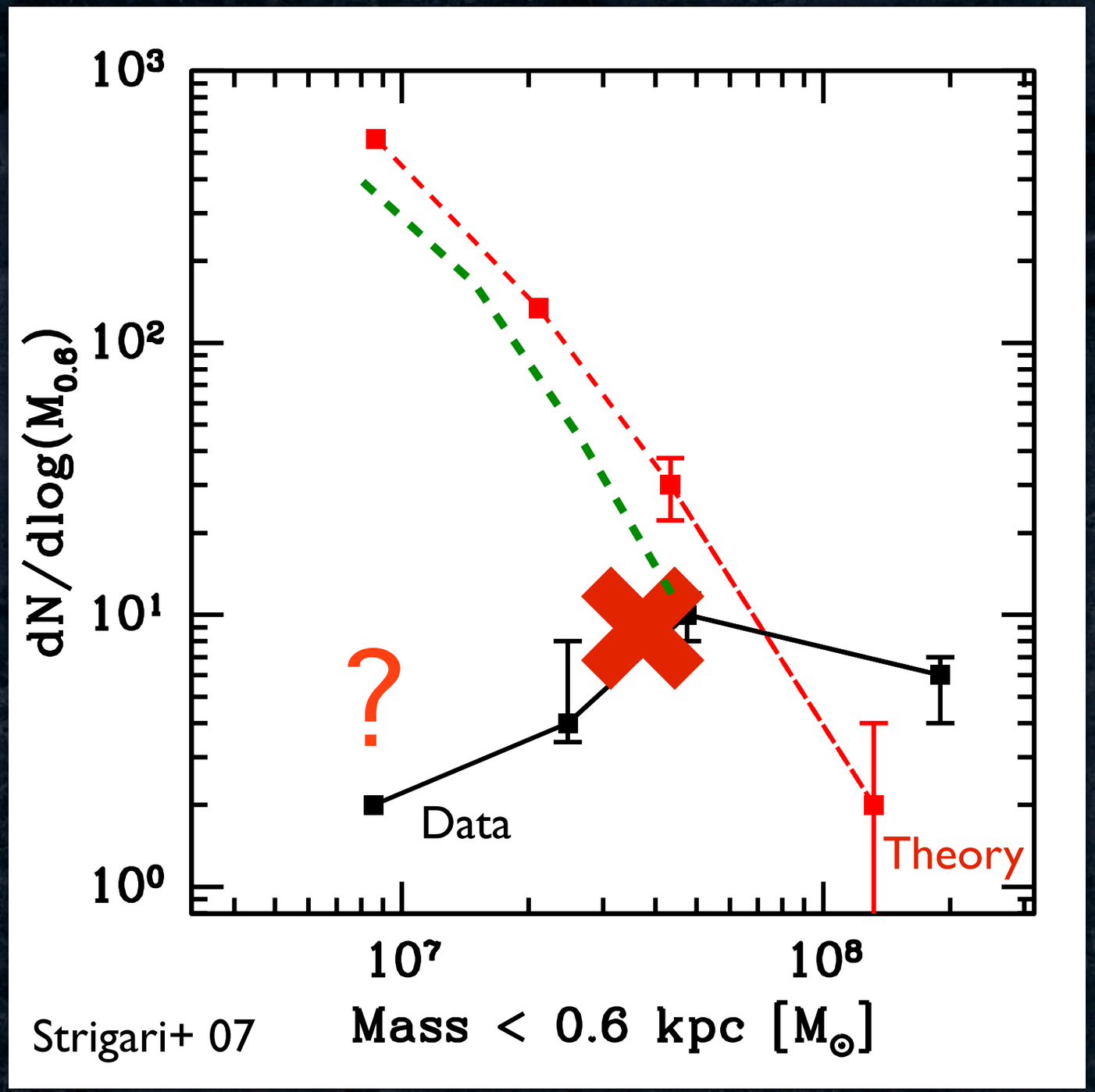
Where'd We Go Wrong?



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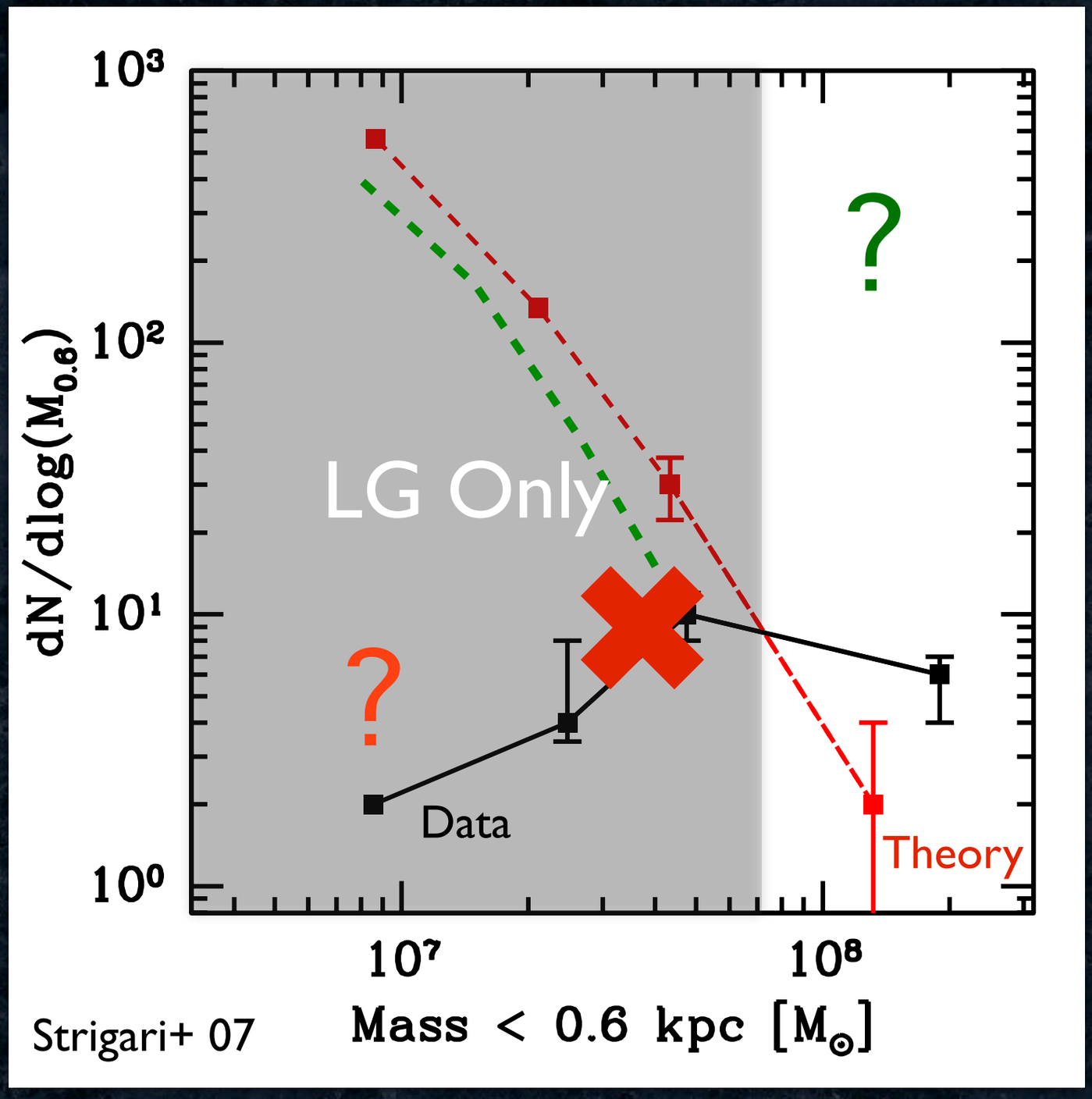
Where'd We Go Wrong?



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Small-Scale Structure and Bright Satellites

ApJ, 738, 102 (2011)

In Collaboration with:
Michael Boylan-Kolchin[1], Betsy Barton[1], James Bullock[1], Chris Trinh[2],John Phillips[1]

[1]UCI, [2]U of Sydney

Image Credit:Robert Gendler

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Two Key Questions

- Does LCDM behave well for brightest satellites of L* galaxies?
- Is the LMC Weird? (Boylan-Kolchin+ 10, James+ 10, Liu+ 10)

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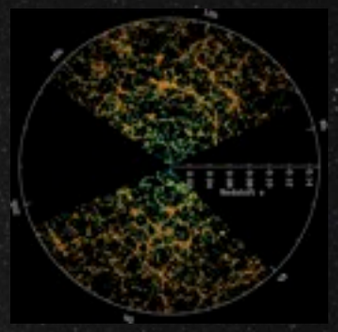
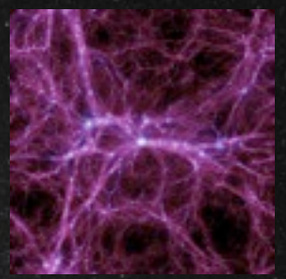
Approach

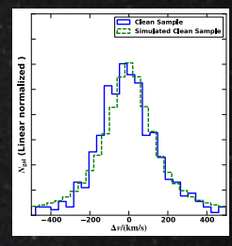
- SDSS Sample of LMC-like Satellites of Isolated L^* galaxies



- Identical Sample from cosmological simulation



- Compare them: $\Delta v_{\rm pair}$ and radial distribution



- Compare the satellites to the LMC

- (Bonus: Study the satellites themselves)

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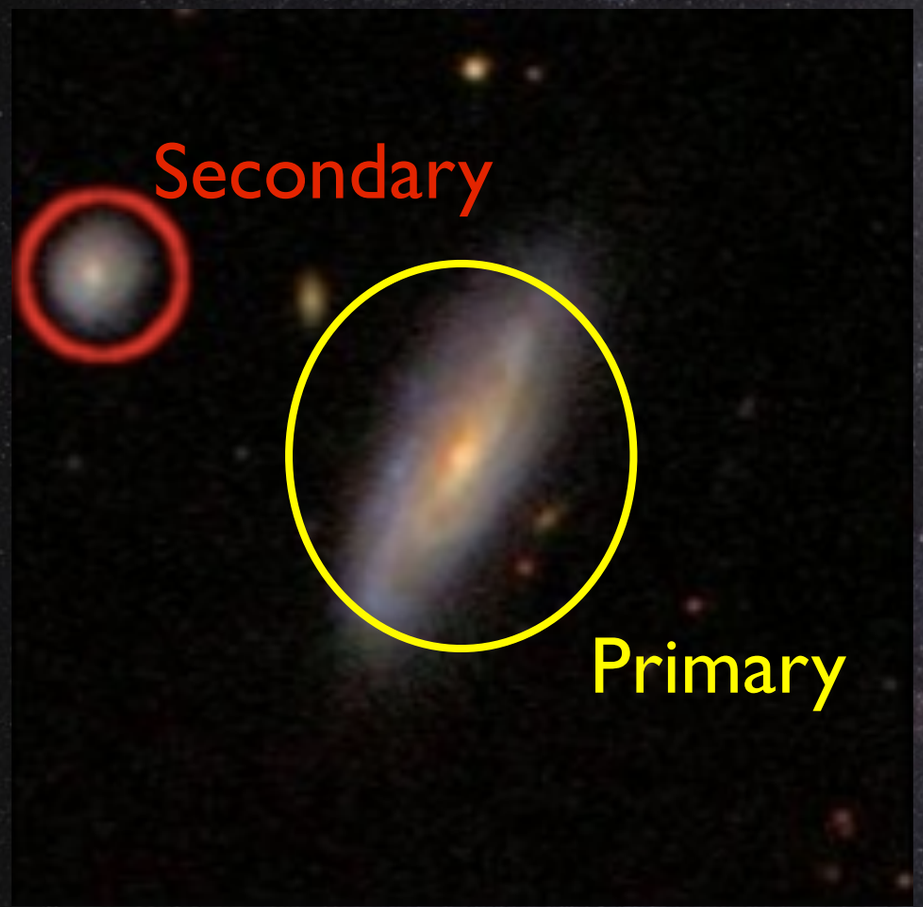
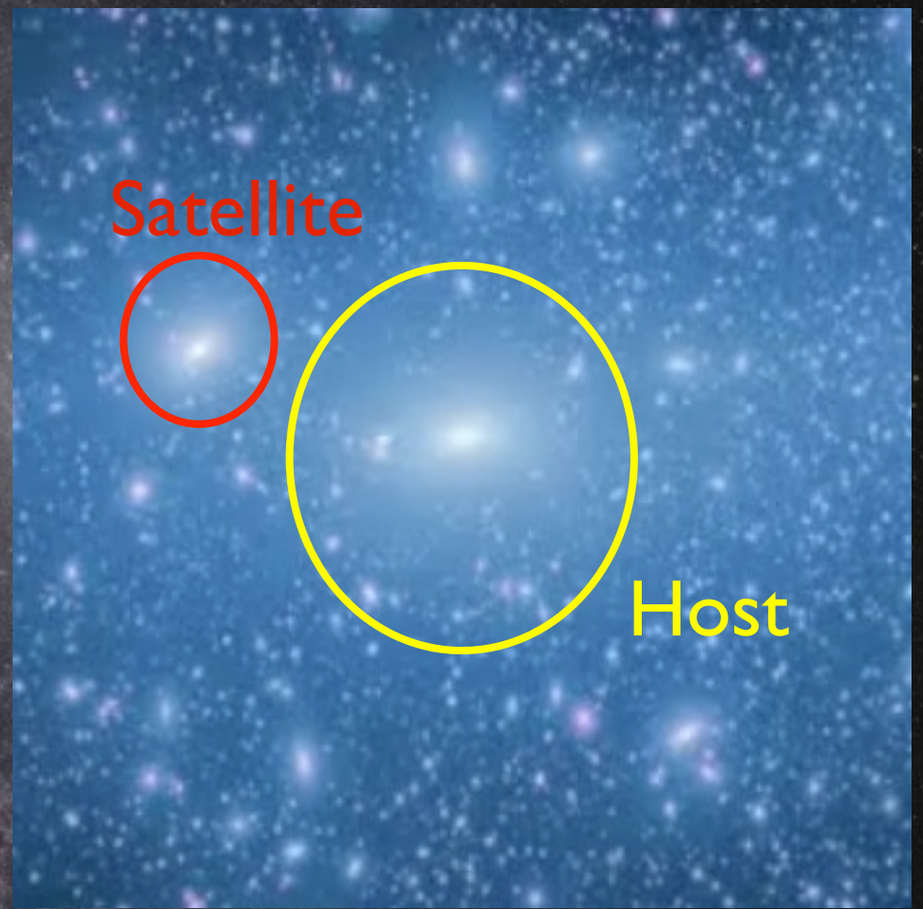
Approach



SDSS



Simulation

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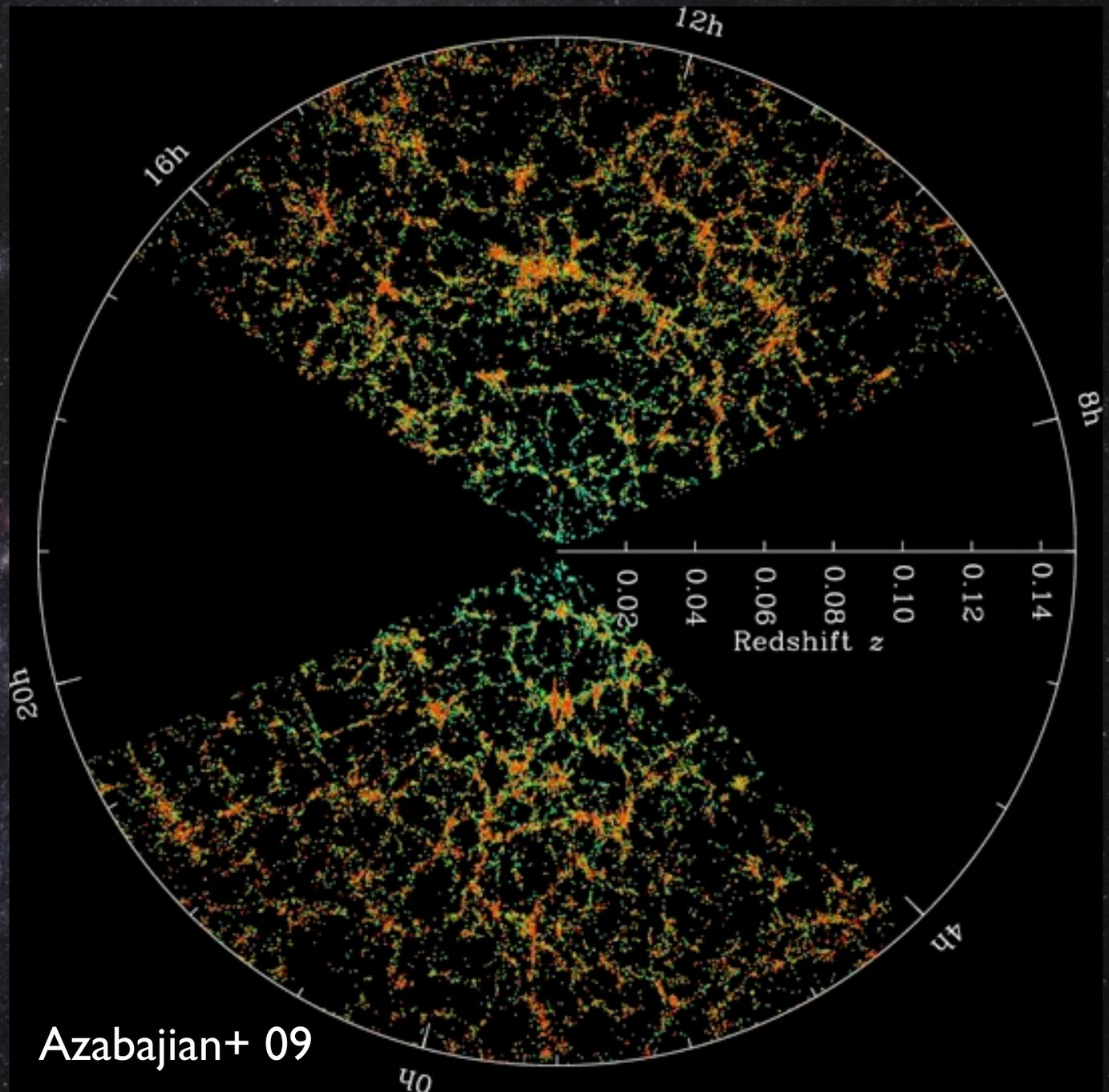
SDSS Galaxy Sample

NYU VAGC
(Blanton+ 05)
DR7



Azabajian+ 09

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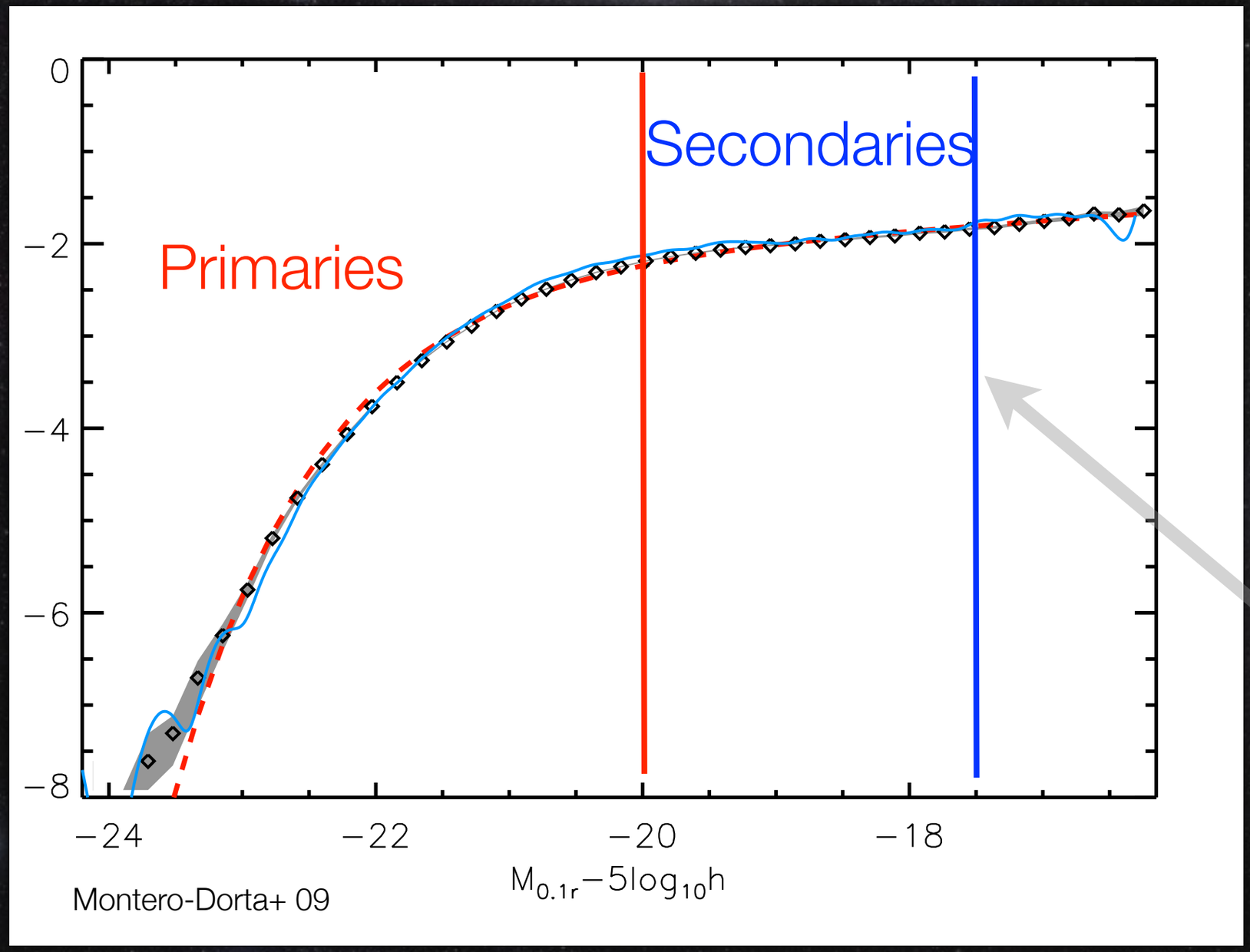
SDSS Primary/ Secondary Selection



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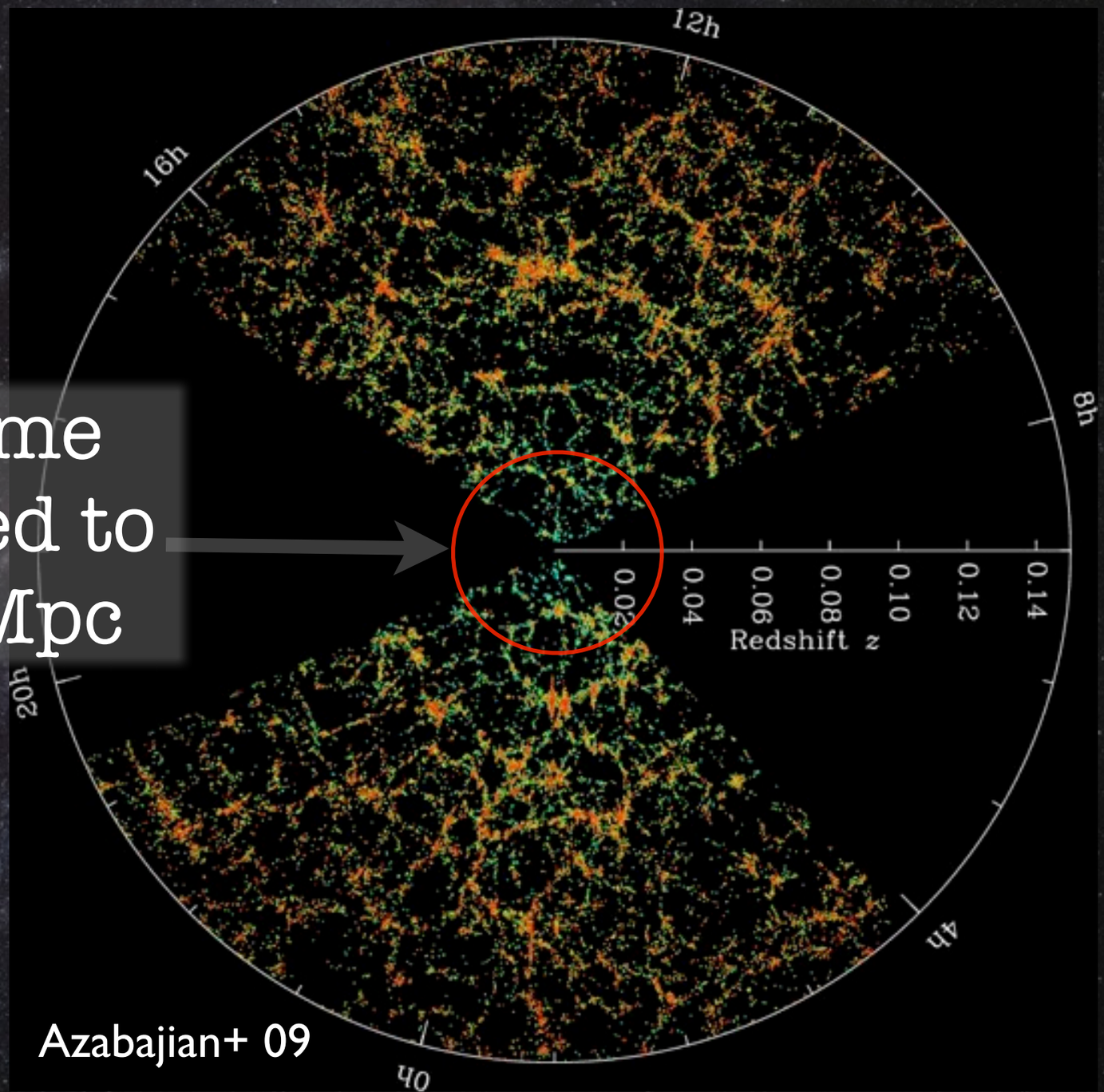
SDSS Galaxy Sample

NYU VAGC
(Blanton+ 05)
DR7

Volume
Limited to
144 Mpc



Azabajian+ 09

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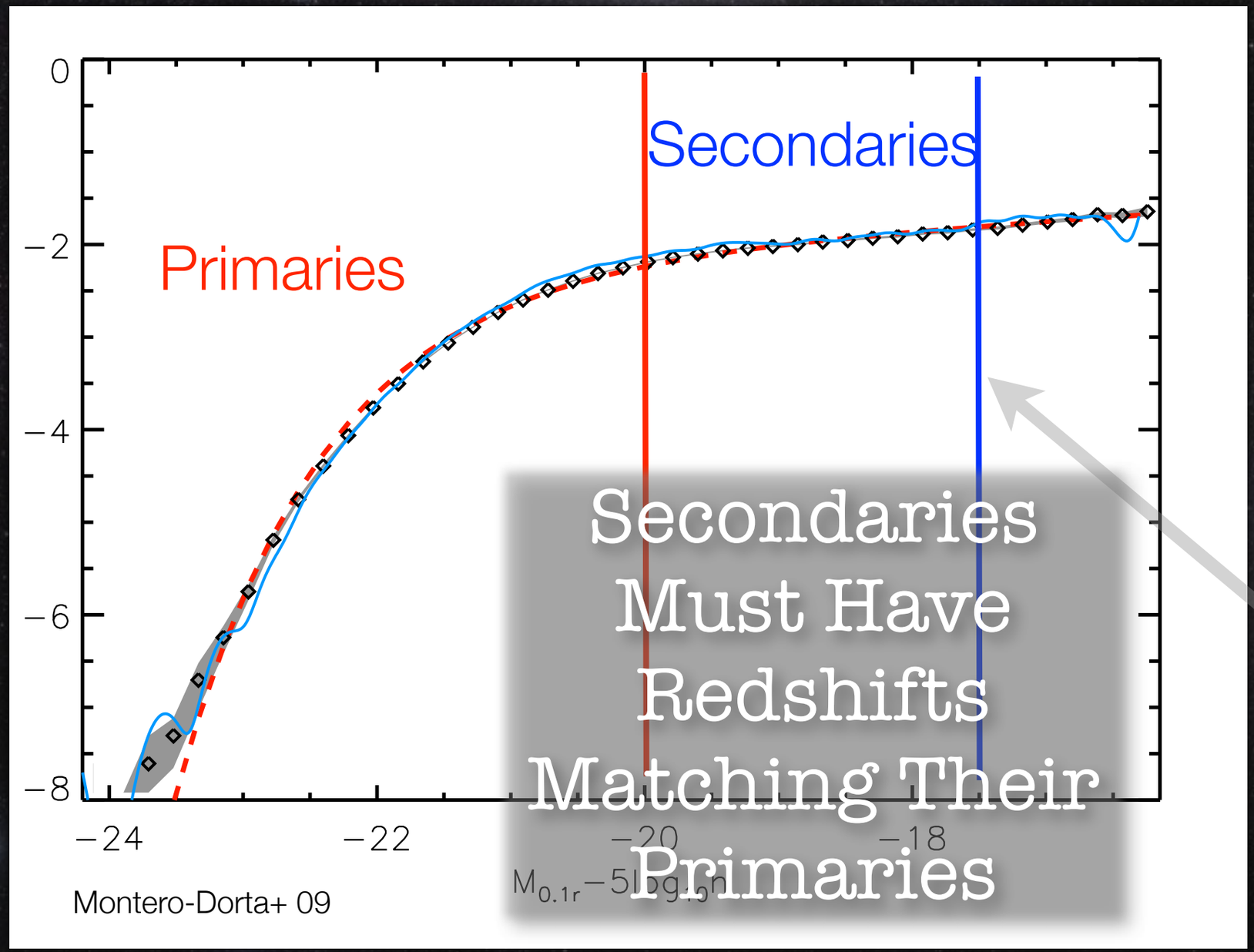
SDSS Primary/ Secondary Selection



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SDSS Primary Isolation

$250 < d_{proj} < 700$ kpc/h

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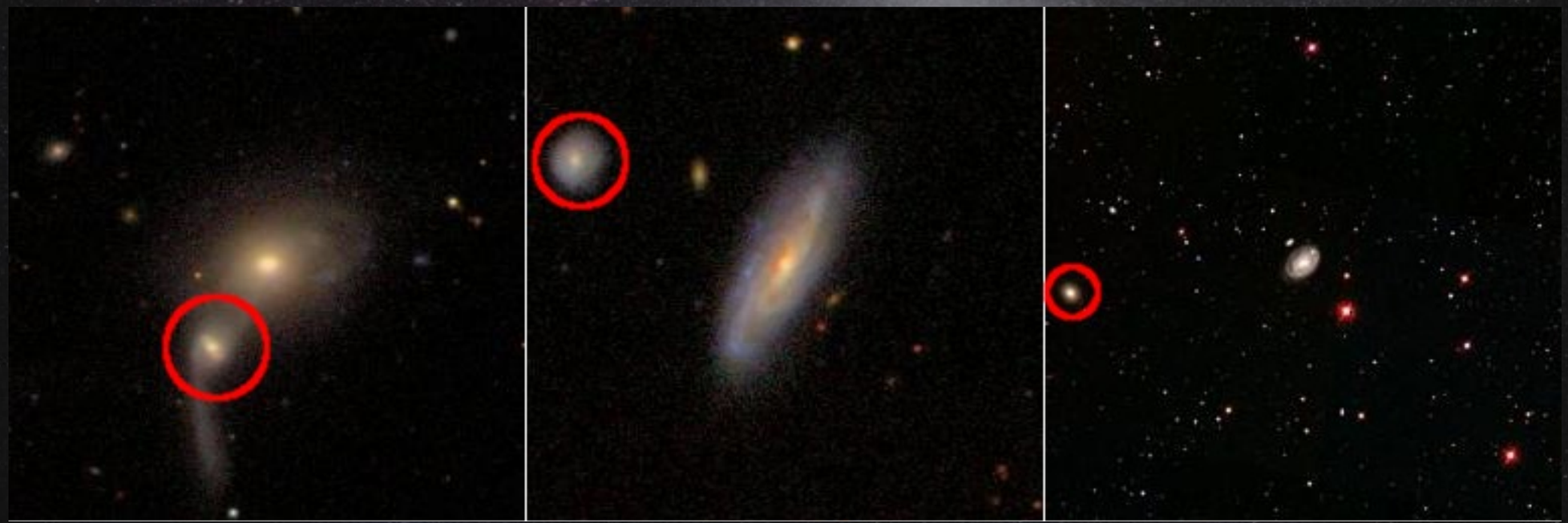
Primary/Secondary Pairs

- 1075 Primaries, 467 Secondaries
- Median Redshift z=.028



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Primary/Secondary Pairs

- 1075 Primaries, 467 Secondaries
- Median Redshift z=.028

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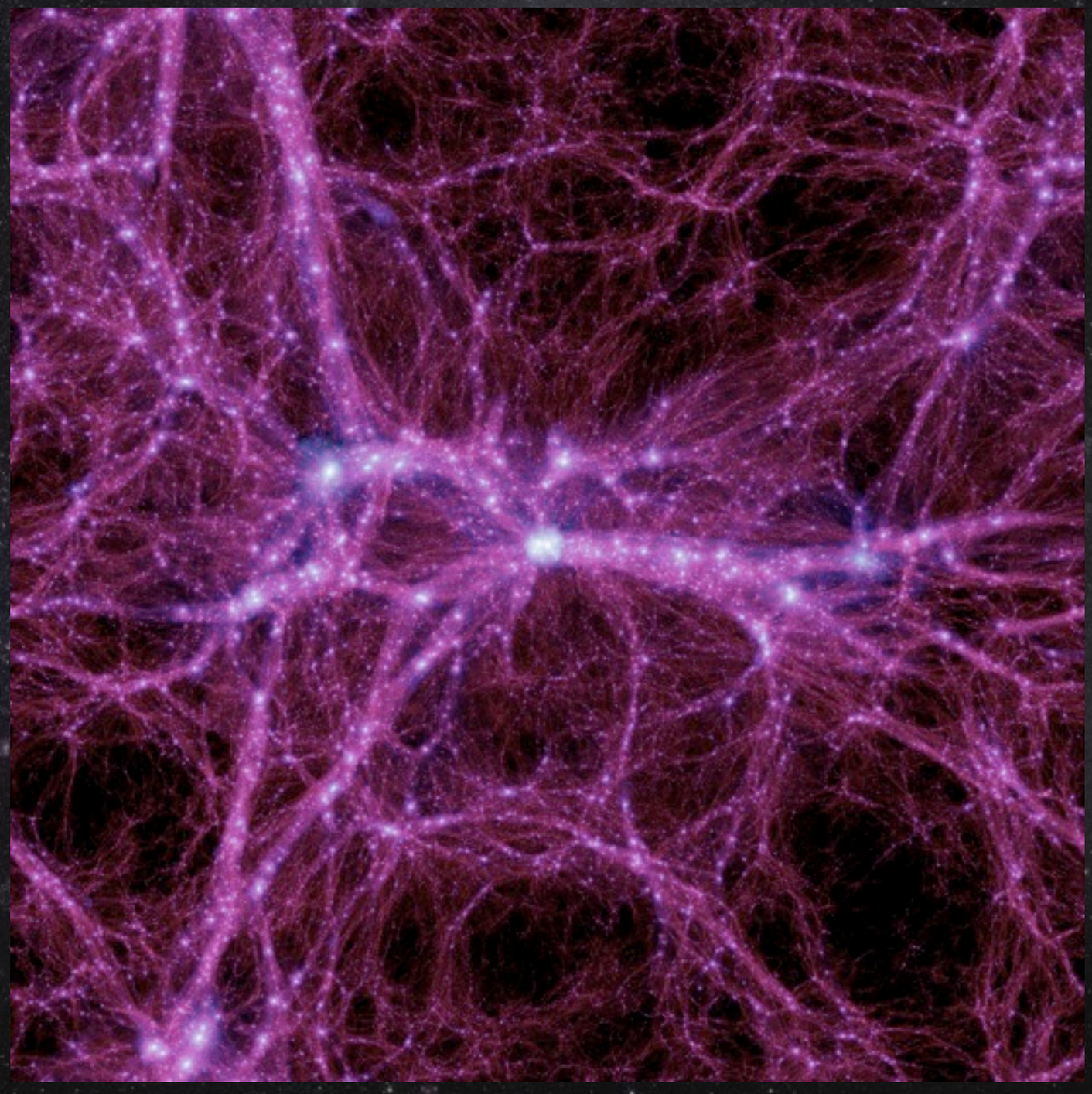
Millennium II Simulation

Boylan-Kolchin+ 09



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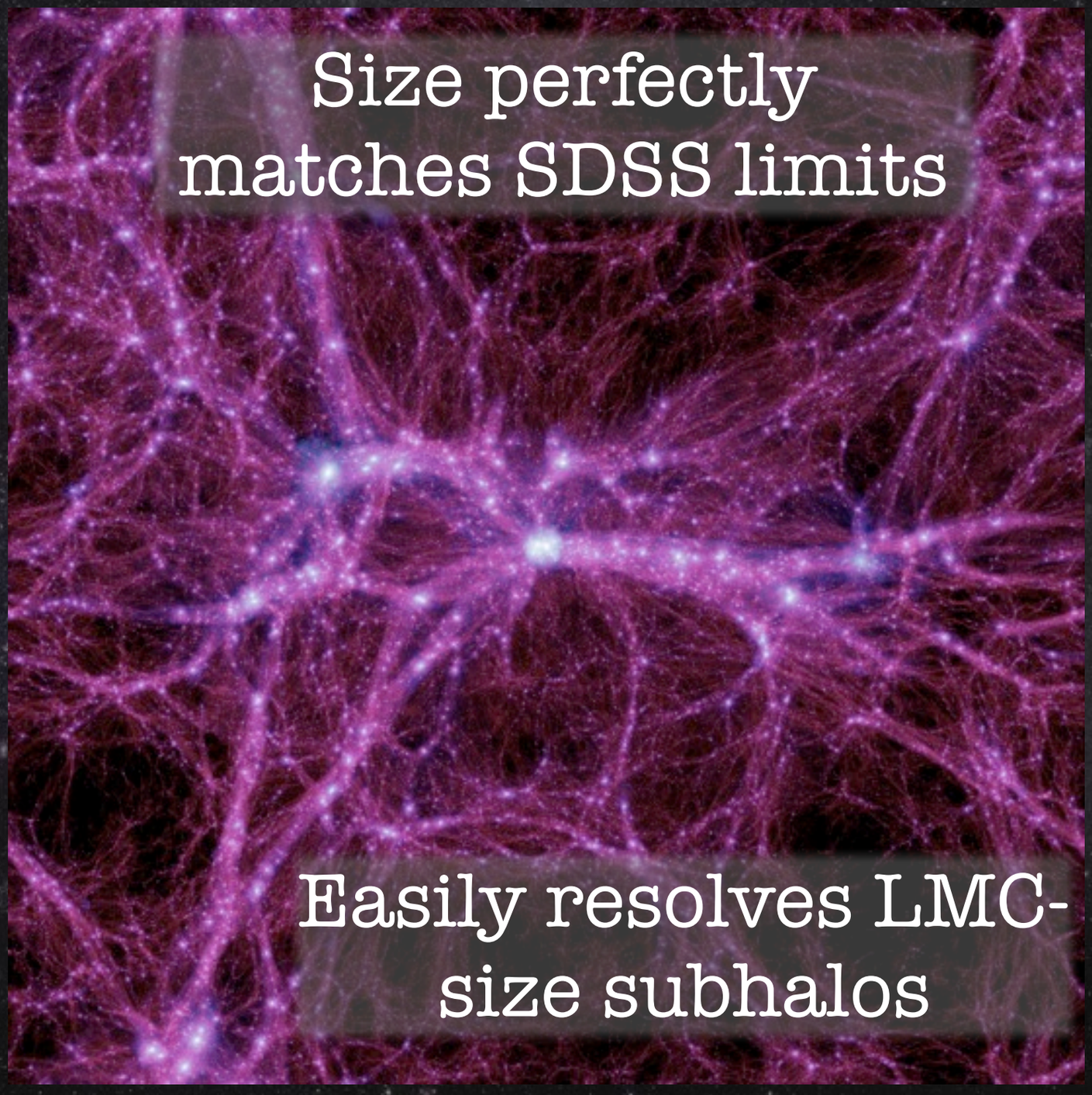
Millennium II Simulation

Boylan-Kolchin+ 09



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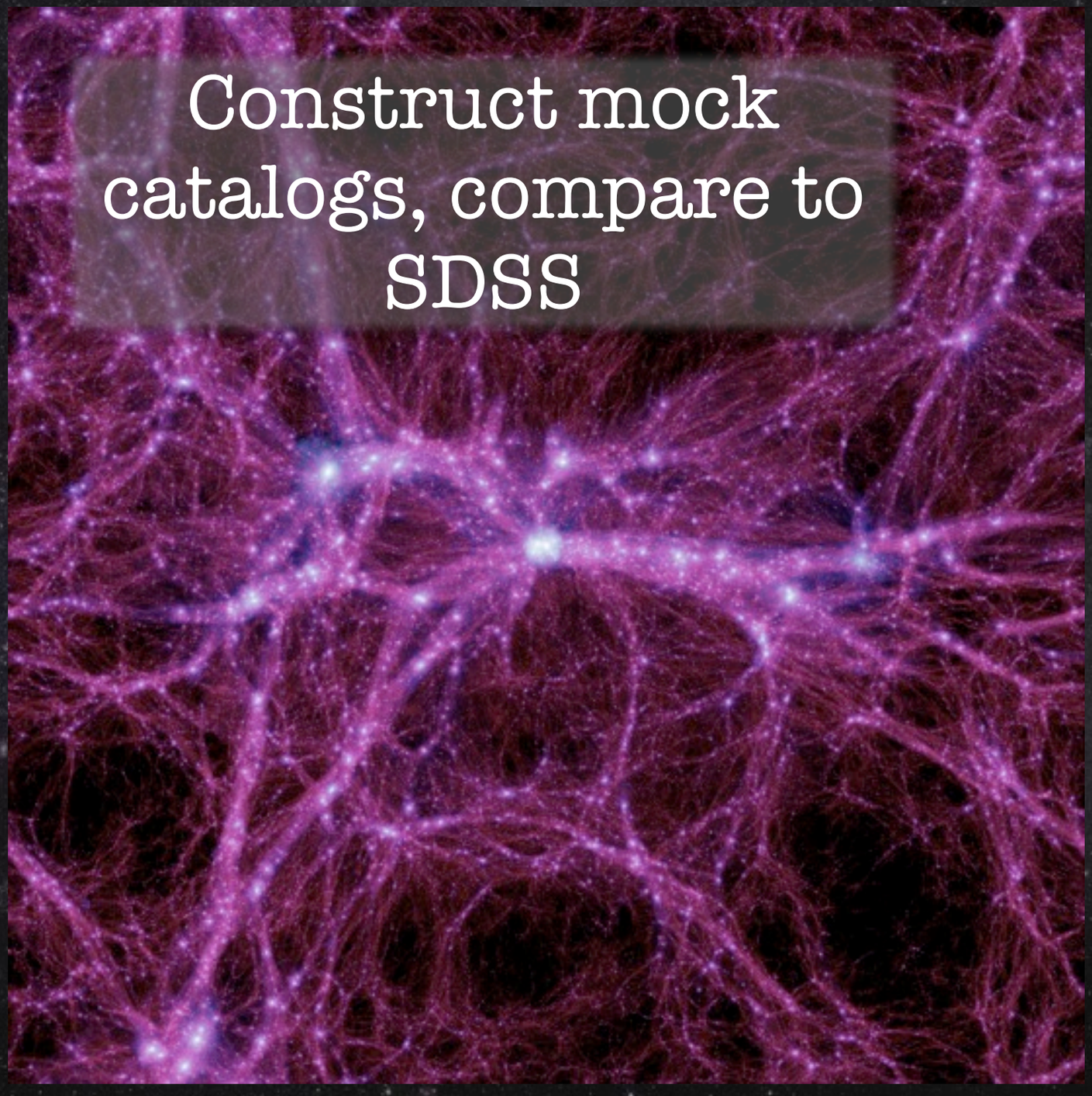
Millennium II Simulation

Boylan-Kolchin+ 09



Construct mock catalogs, compare to SDSS

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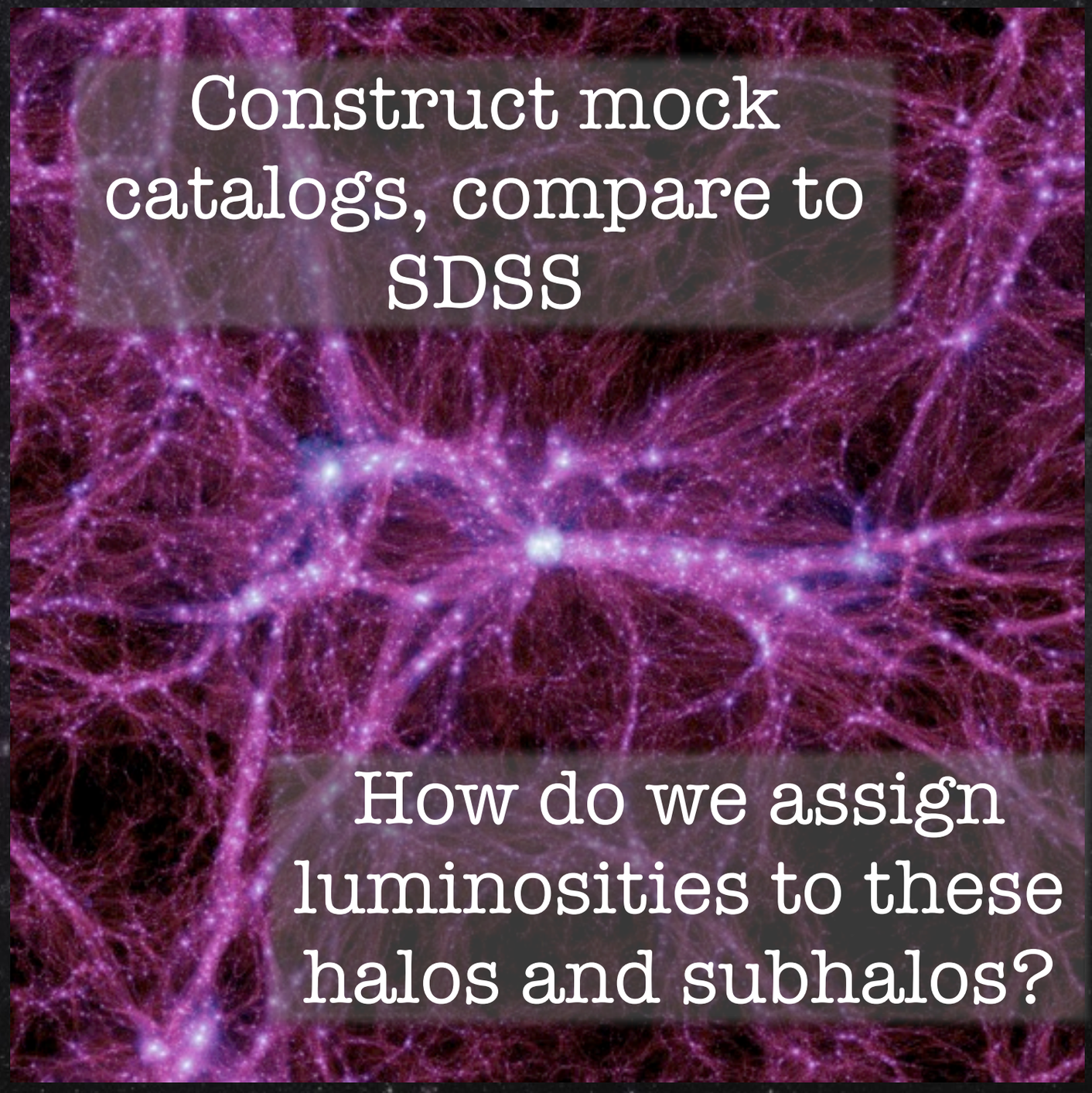
Millennium II Simulation

Boylan-Kolchin+ 09



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Abundance Matching for Luminosities

SDSS

Simulation

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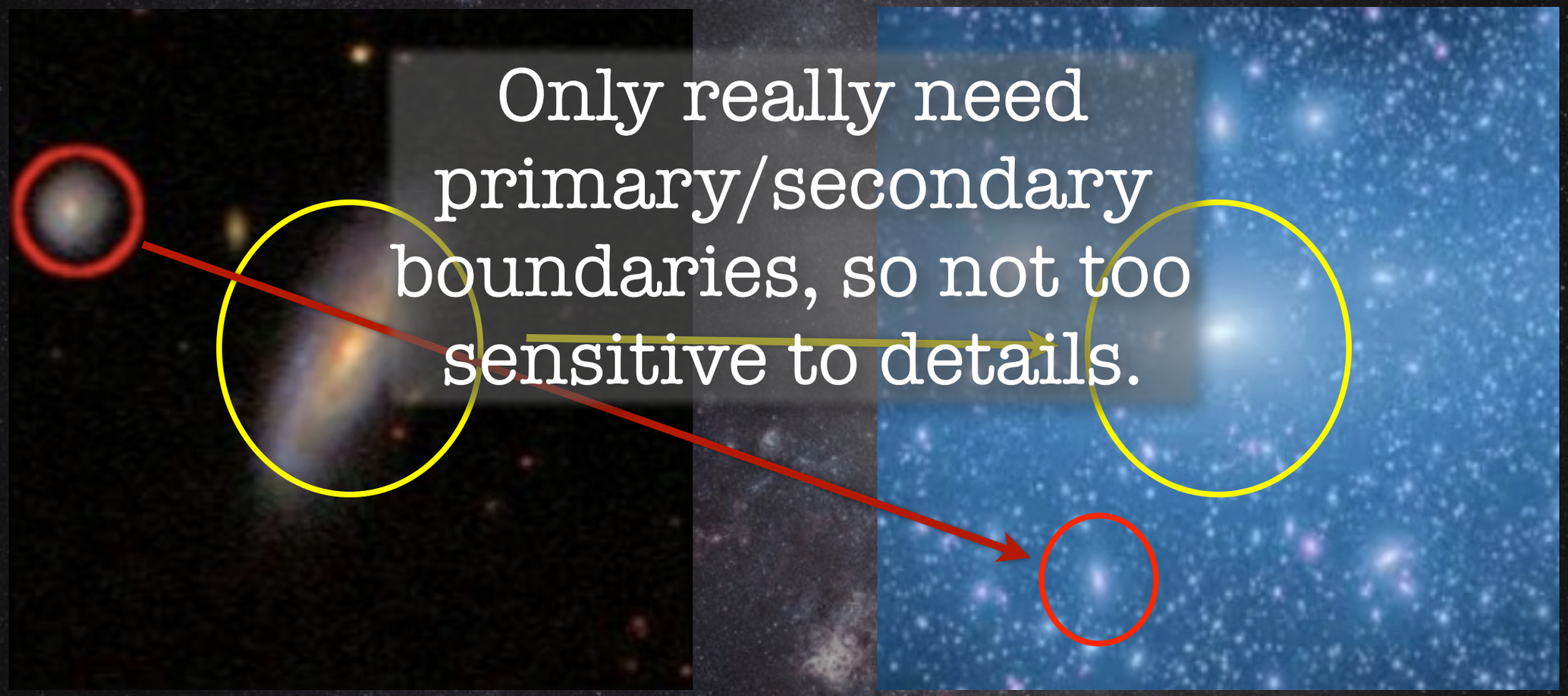
Abundance Matching for Luminosities



SDSS

Simulation

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Only Three Assumptions for MS-II <-> SDSS

- Gravity
- ΛCDM Initial Conditions/Cosmology
- Monotonic Lgalaxy⇔Mhalo

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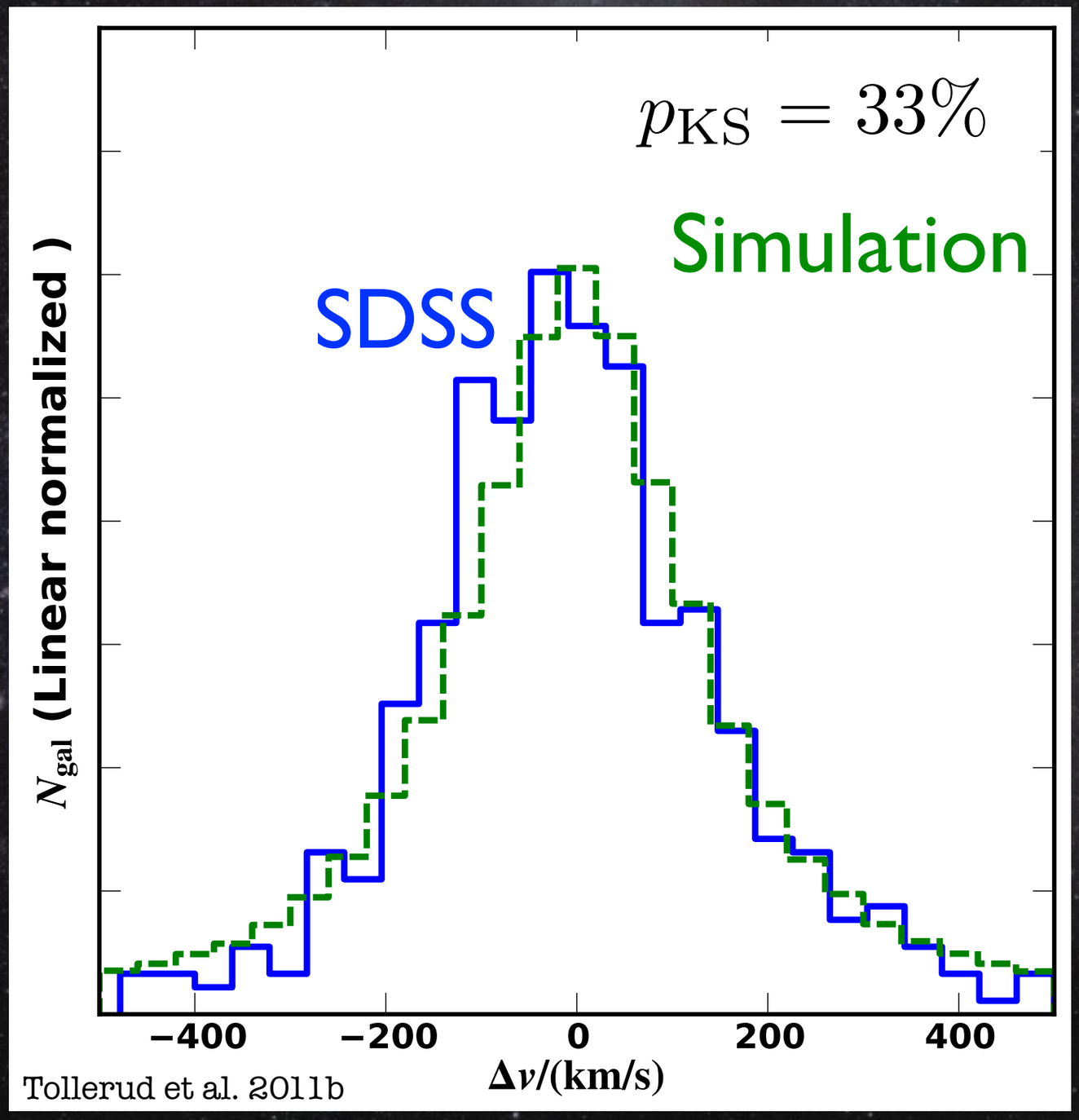
Pairwise Velocity Distribution



Tollerud et al. 2011b

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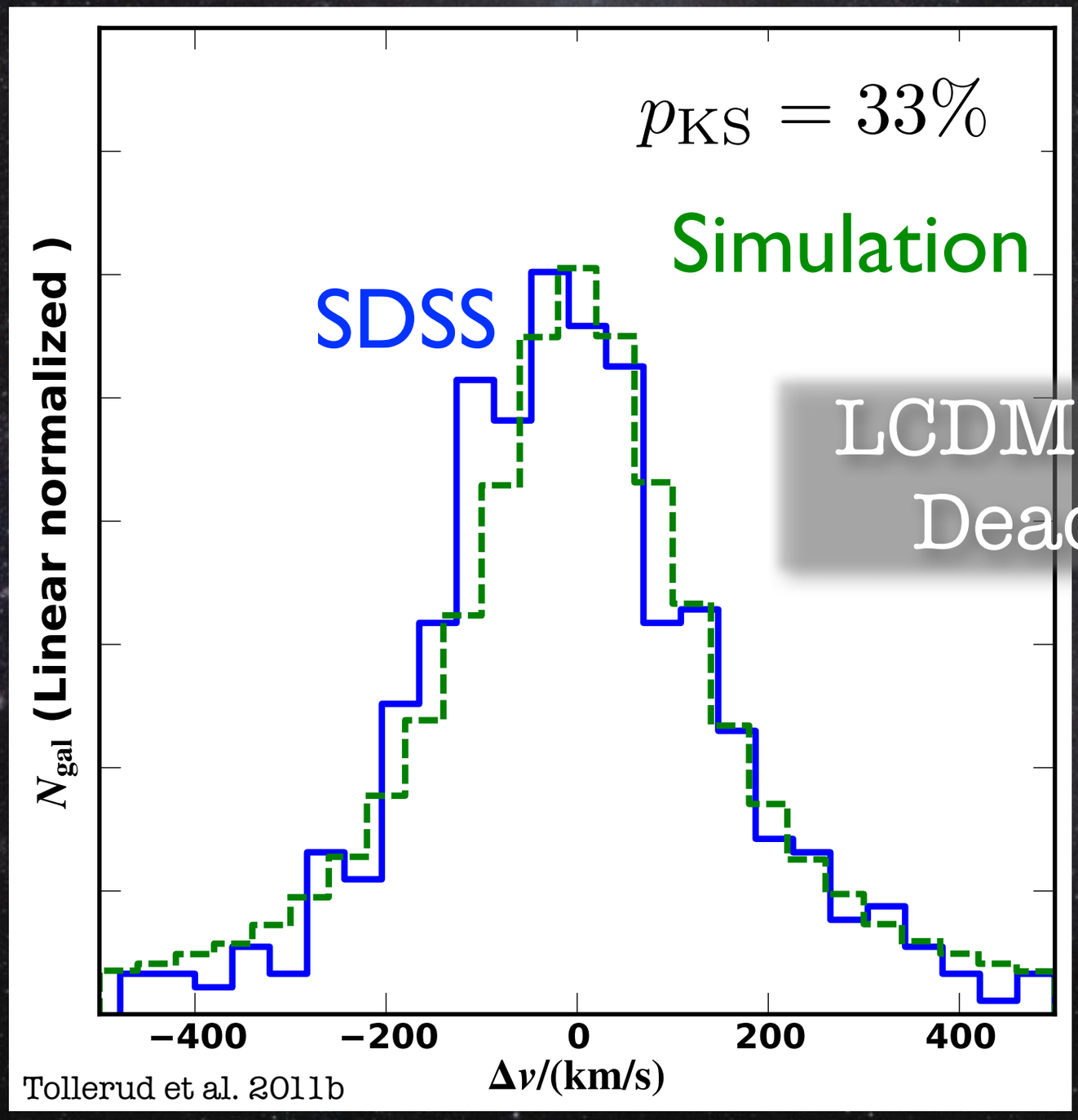
Pairwise Velocity Distribution



LCDM Gets it Dead On!

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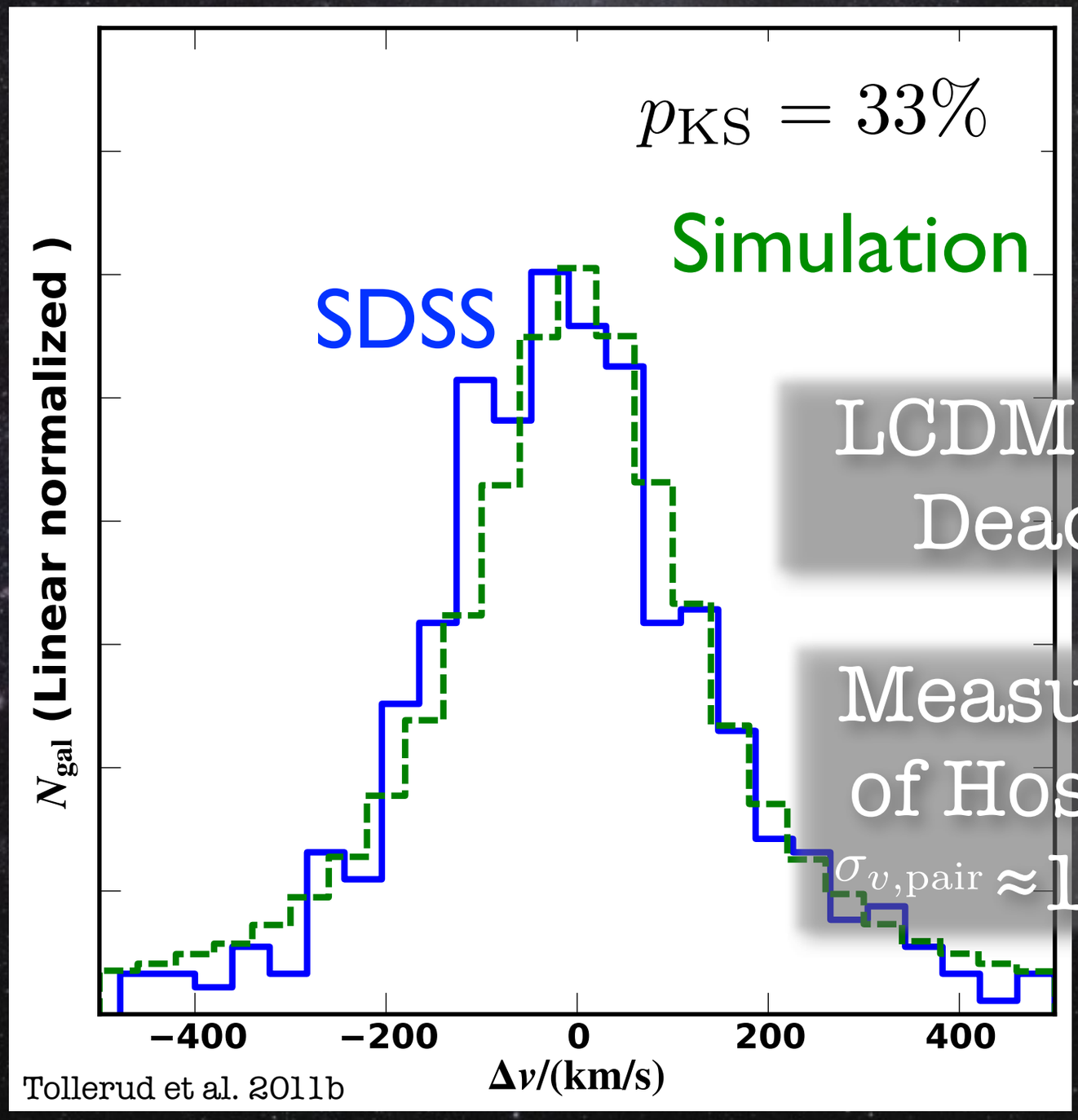
Pairwise Velocity Distribution



LCDM Gets it Dead On!

Measurement of Host Mass:
$\sigma_{v,\rm pair} \approx 150$ km/s

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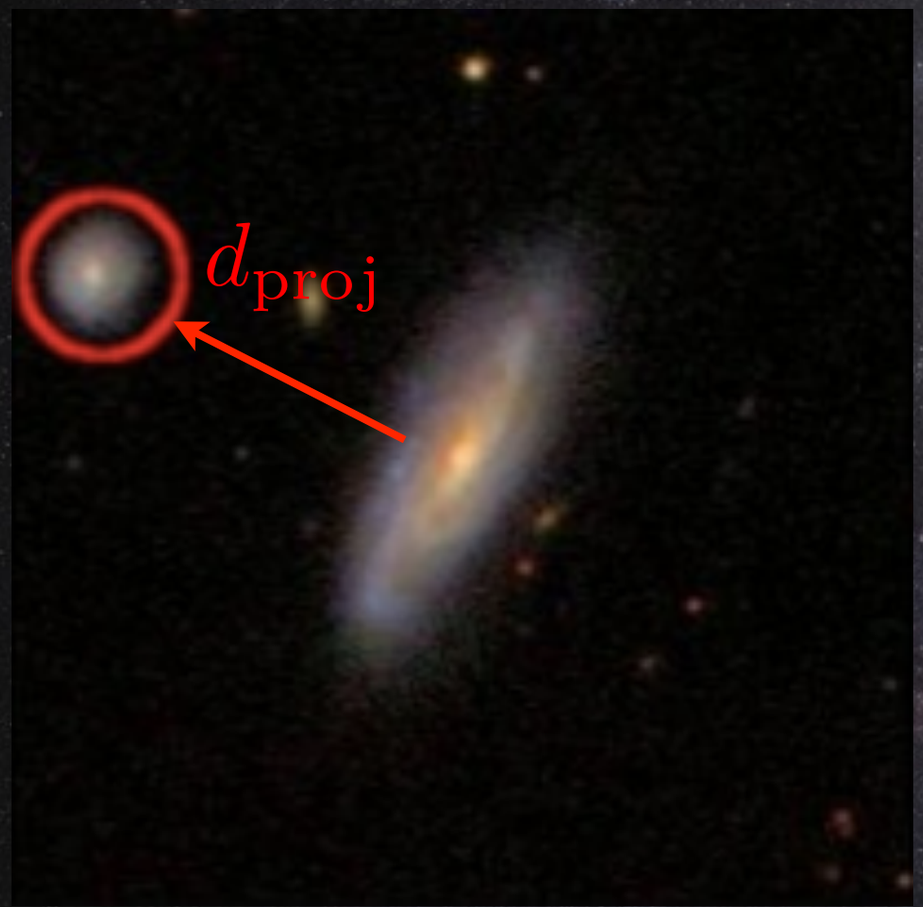
Radial Distribution



SDSS Galaxies

MS-II Halos

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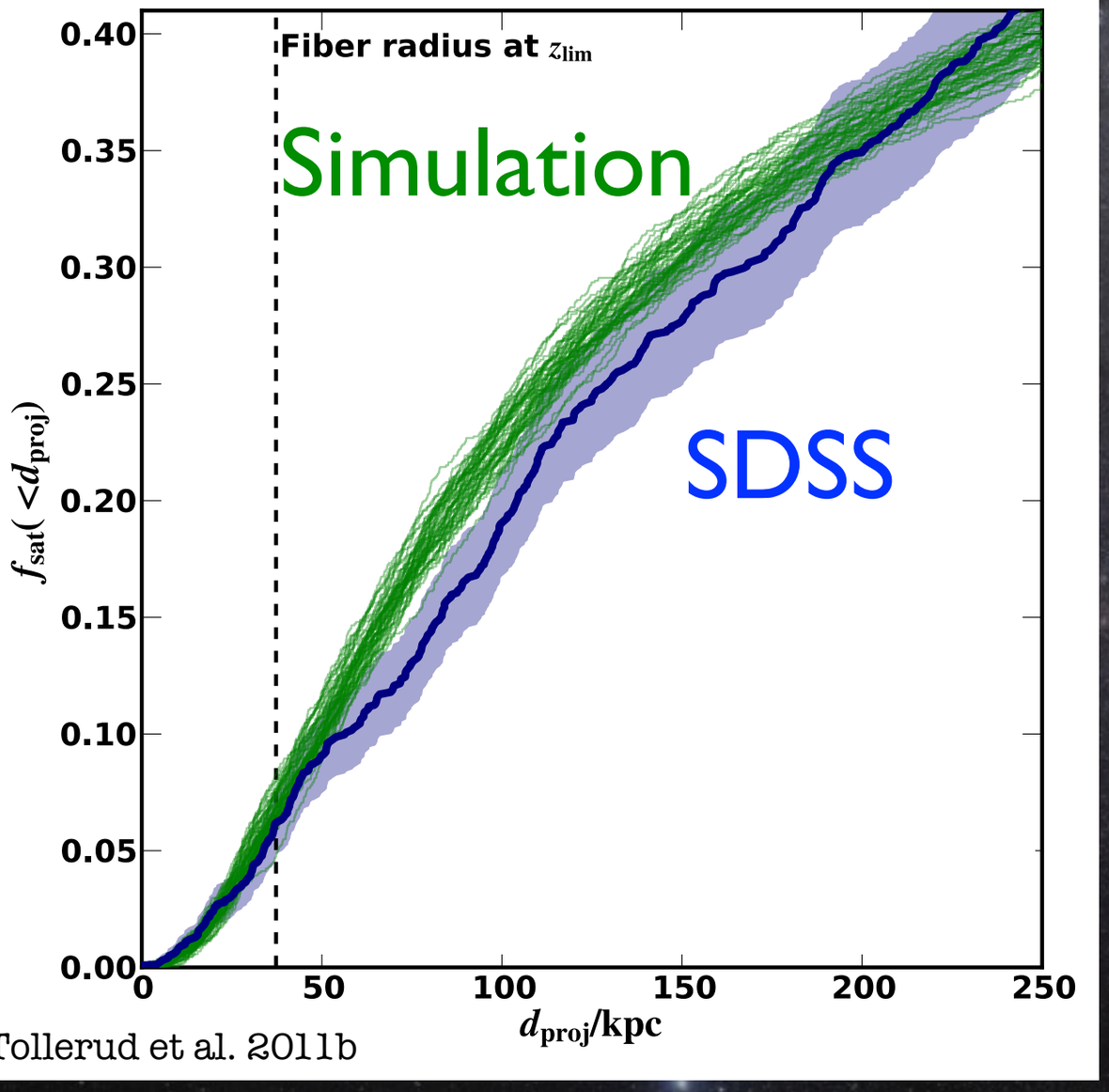
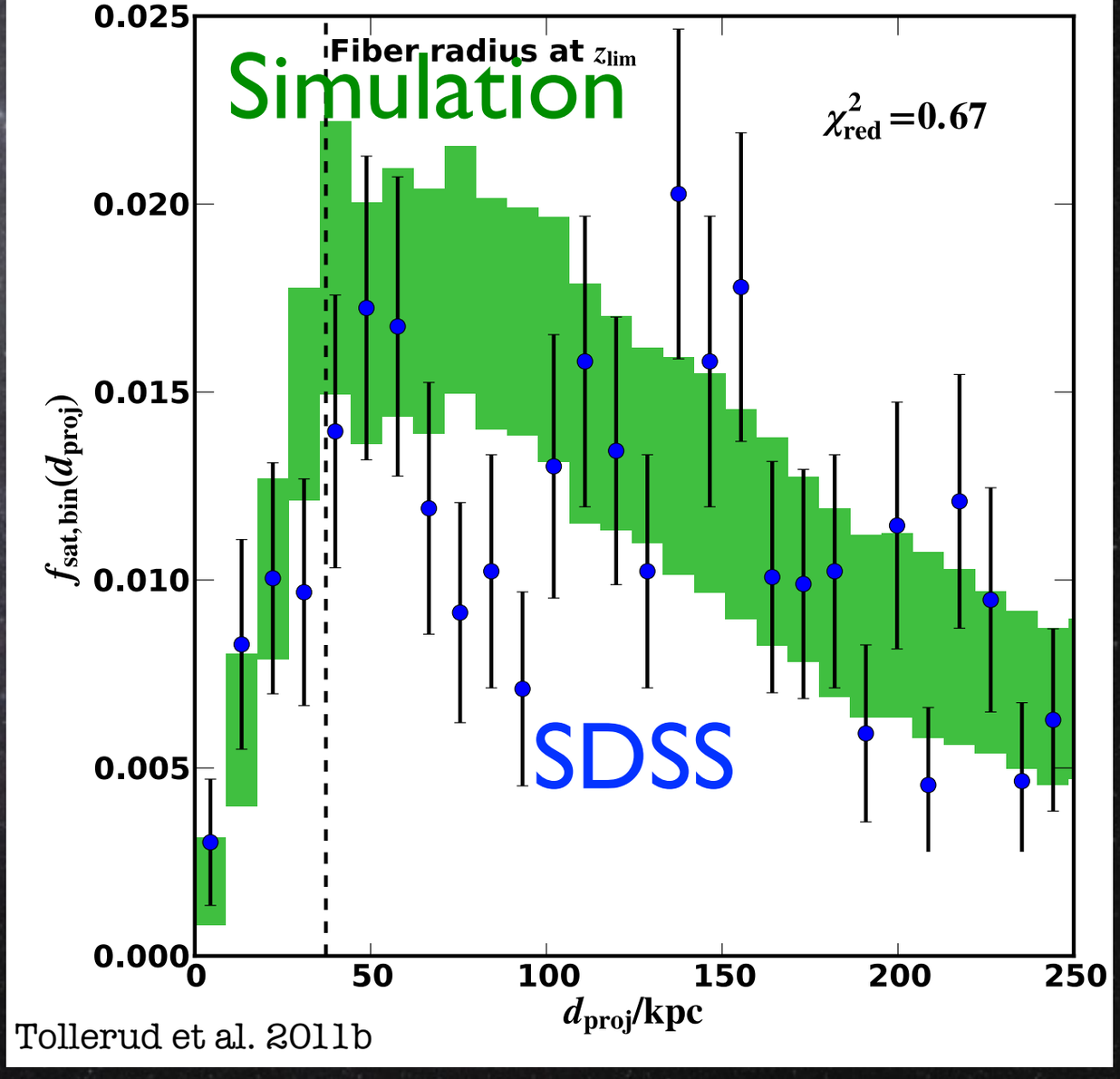
LCDM Gets The Right Radial Distribution!



Tollerud et al. 2011b



Tollerud et al. 2011b

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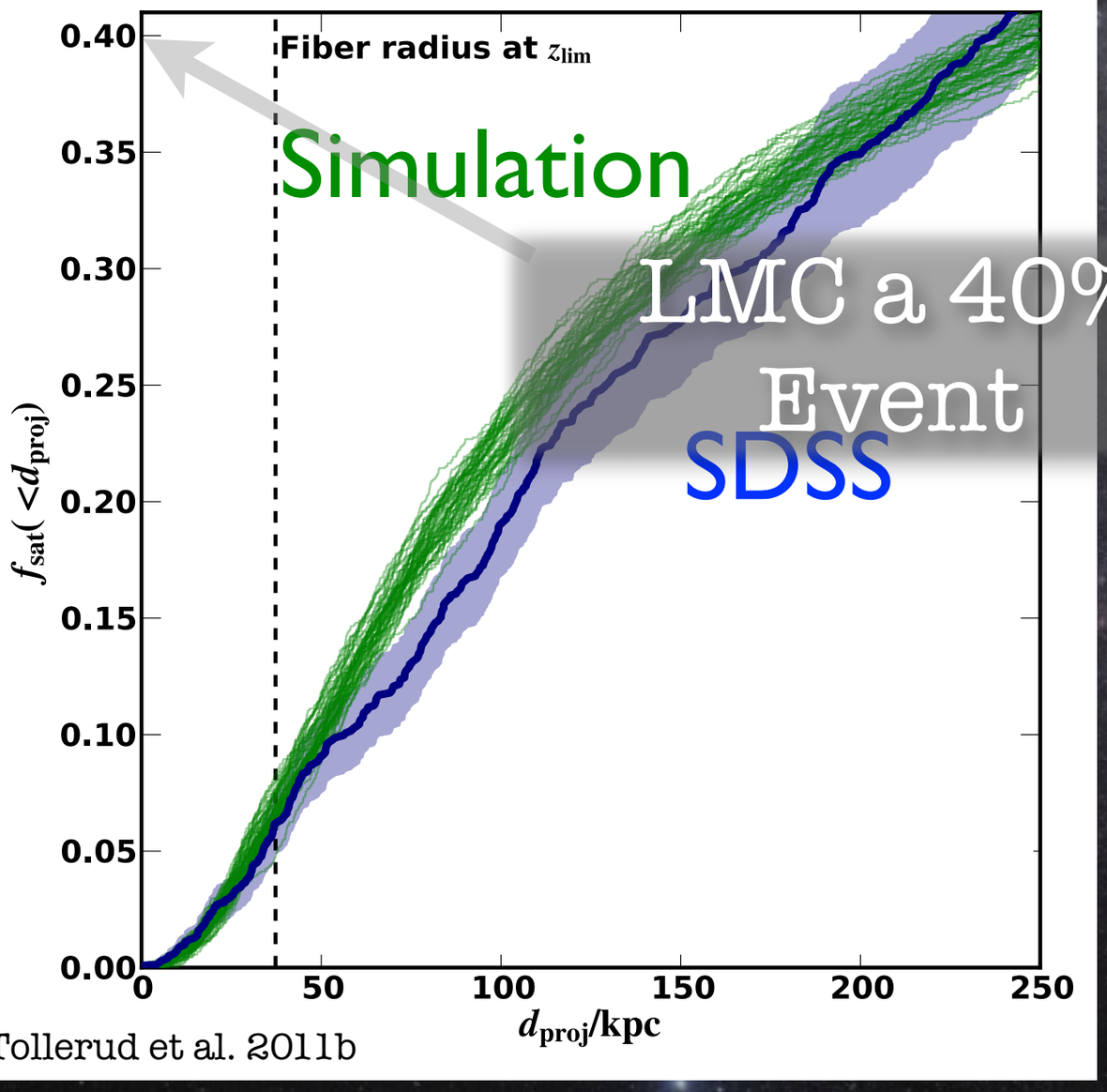
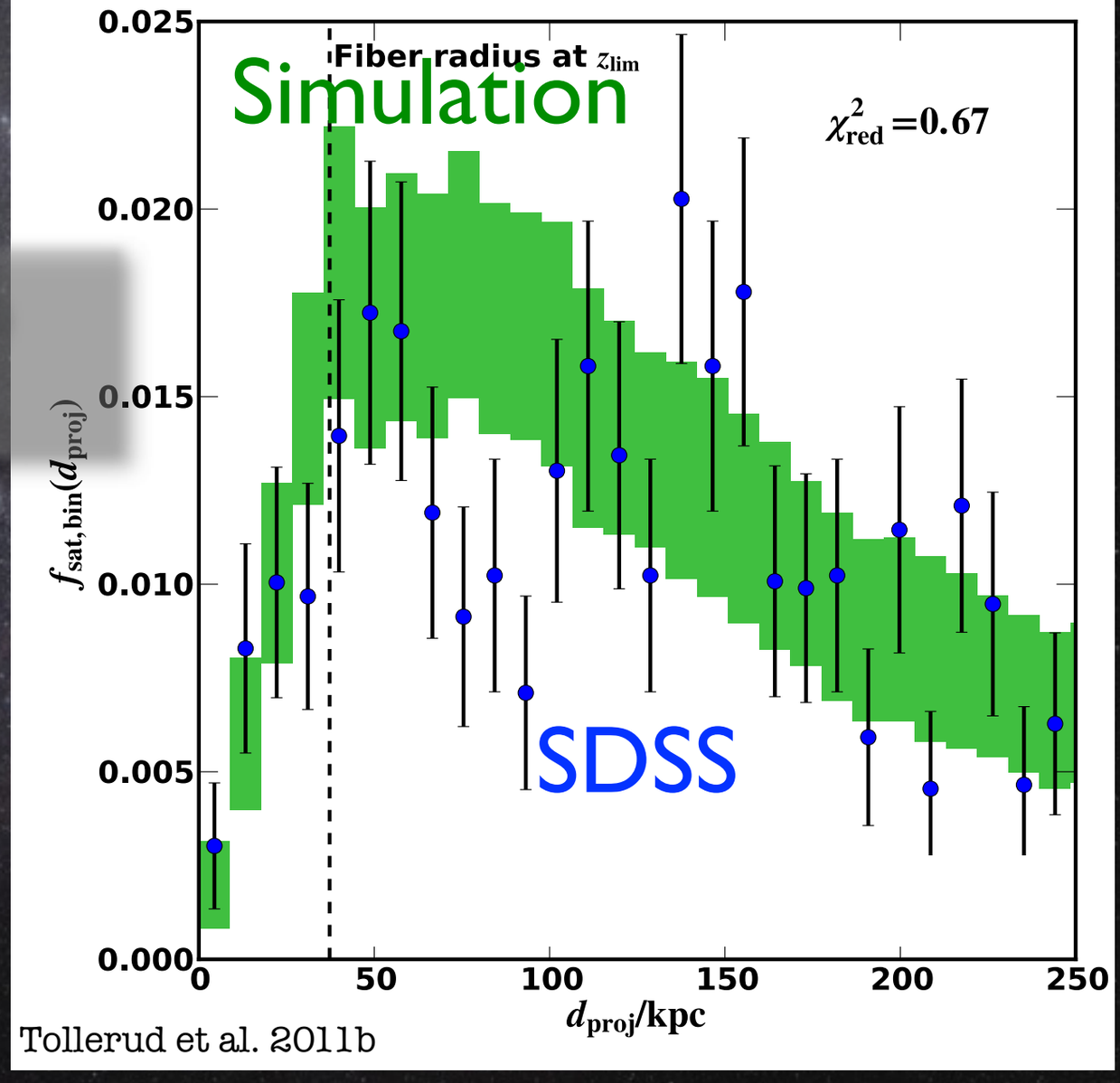
LCDM Gets The Right Radial Distribution!



Tollerud et al. 2011b

LMC a 40% Event



Tollerud et al. 2011b

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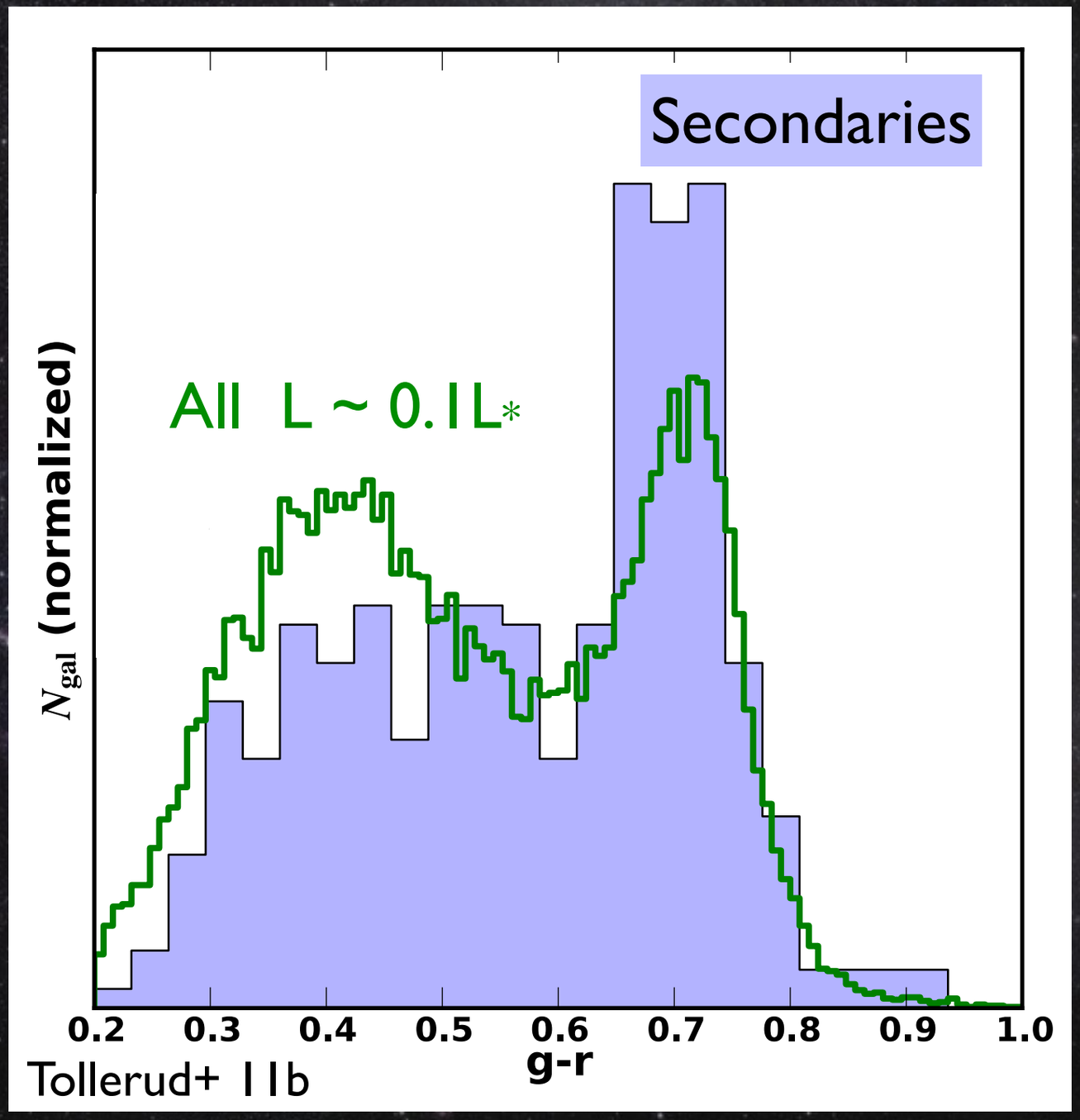
Satellite Colors



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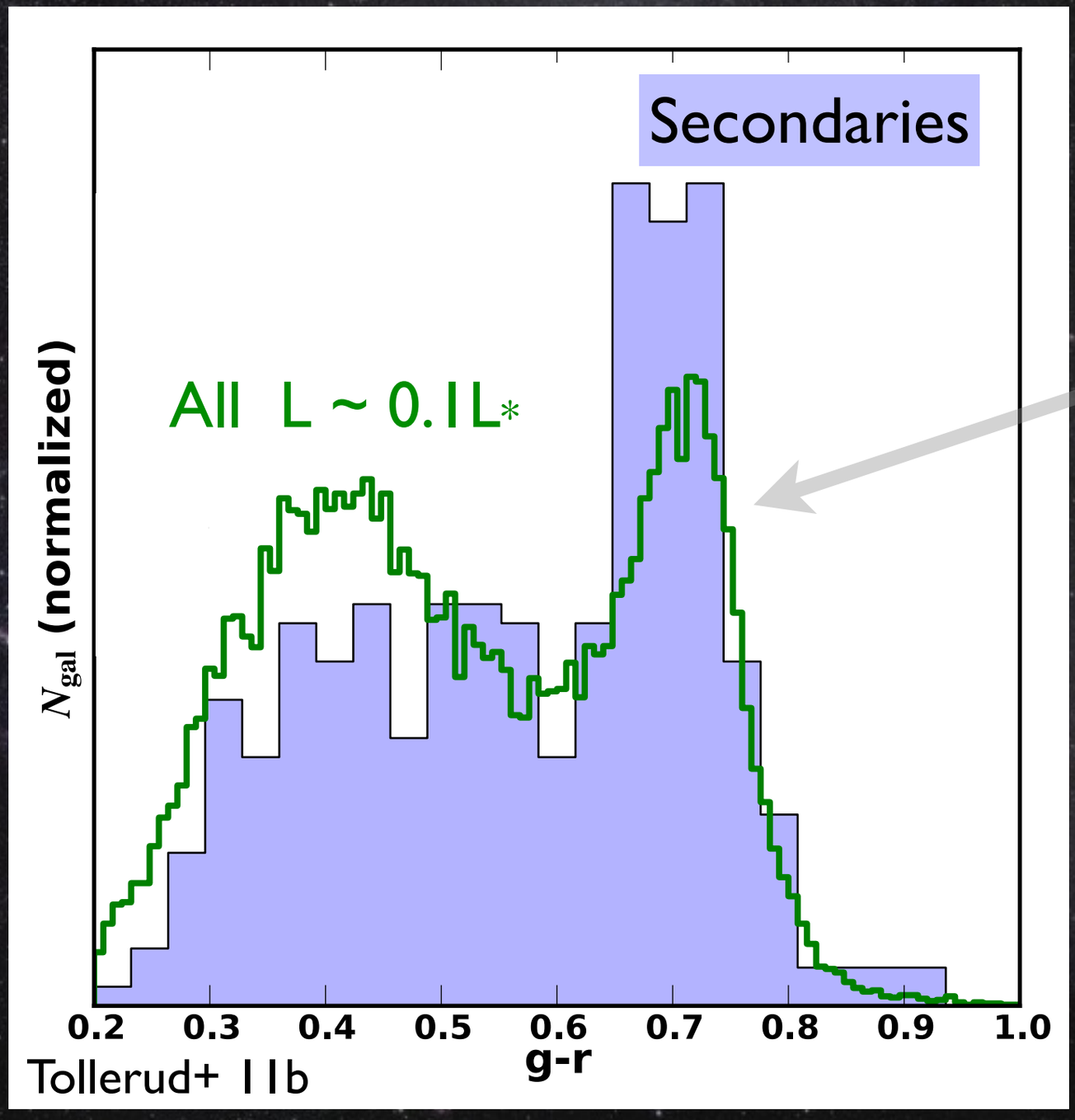
Satellite Colors



Satellites of Isolated L* Galaxies Are Red

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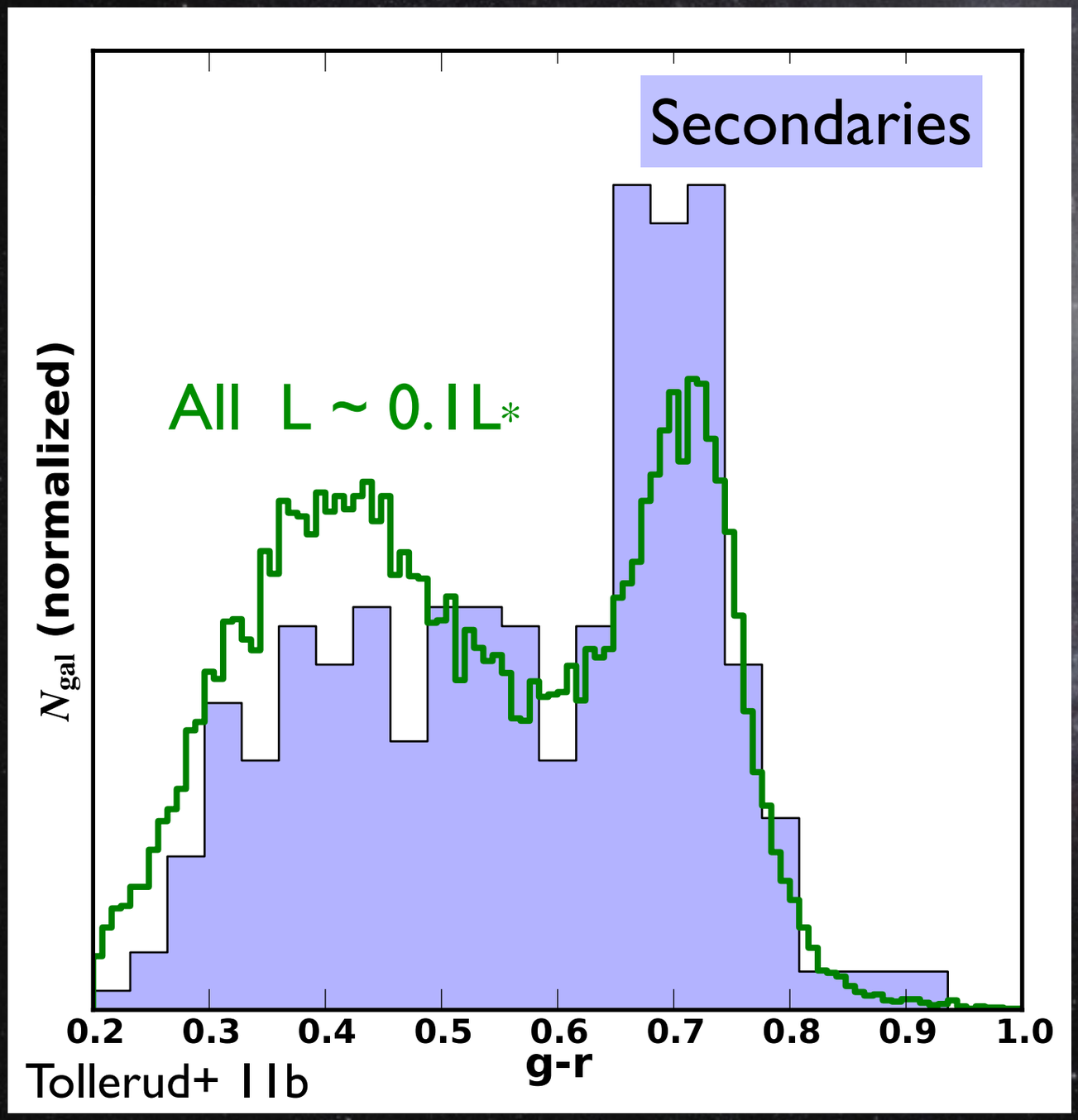
Why Are Secondaries Red?



- Not Harrassment
- Strangulation?
- Ram Pressure Stripping?

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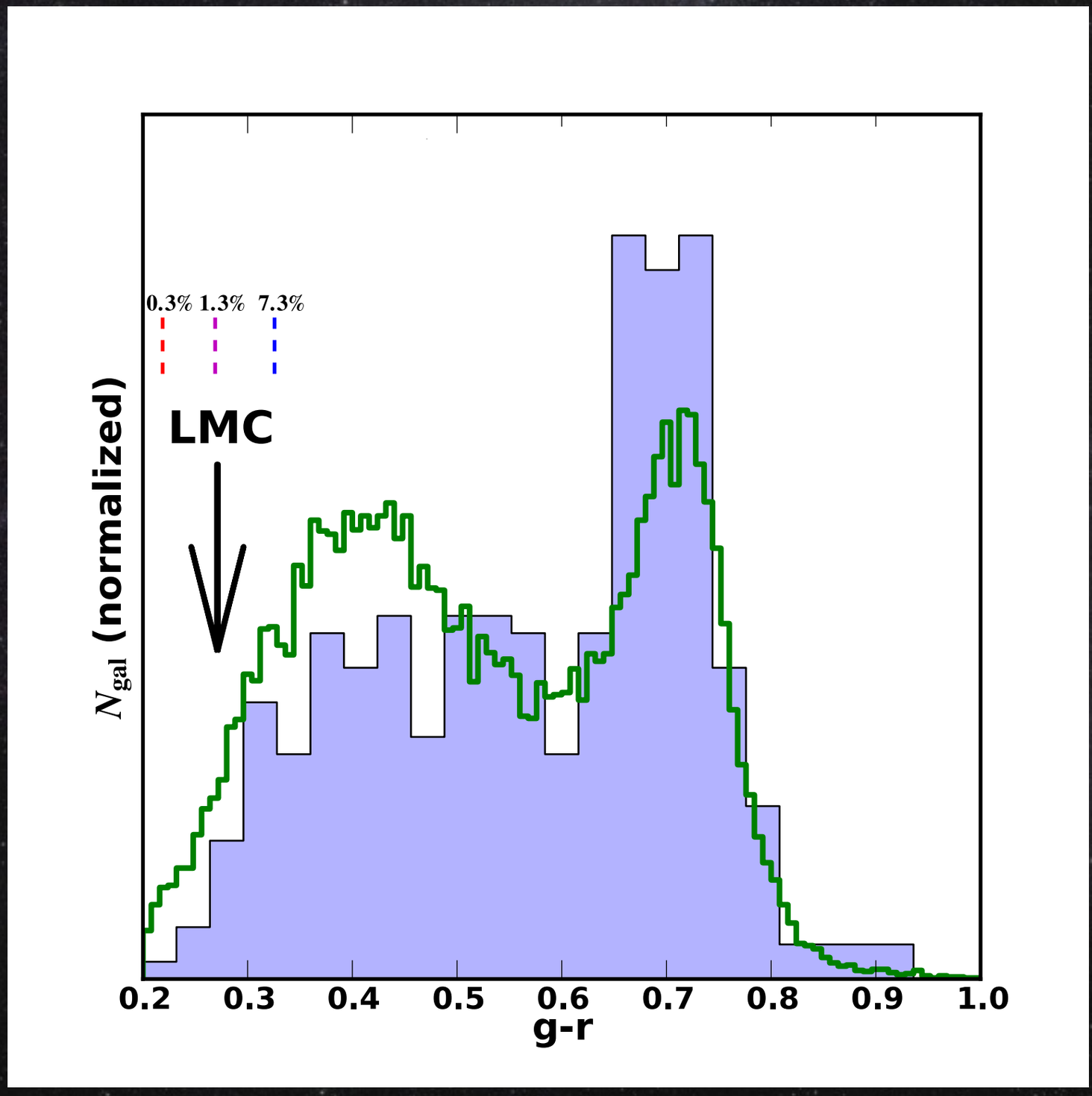
LMC is Very Blue

- RC3
- Eskew& Zaritsky 11
- Bothun& Thompson 88



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LMC is Very Blue

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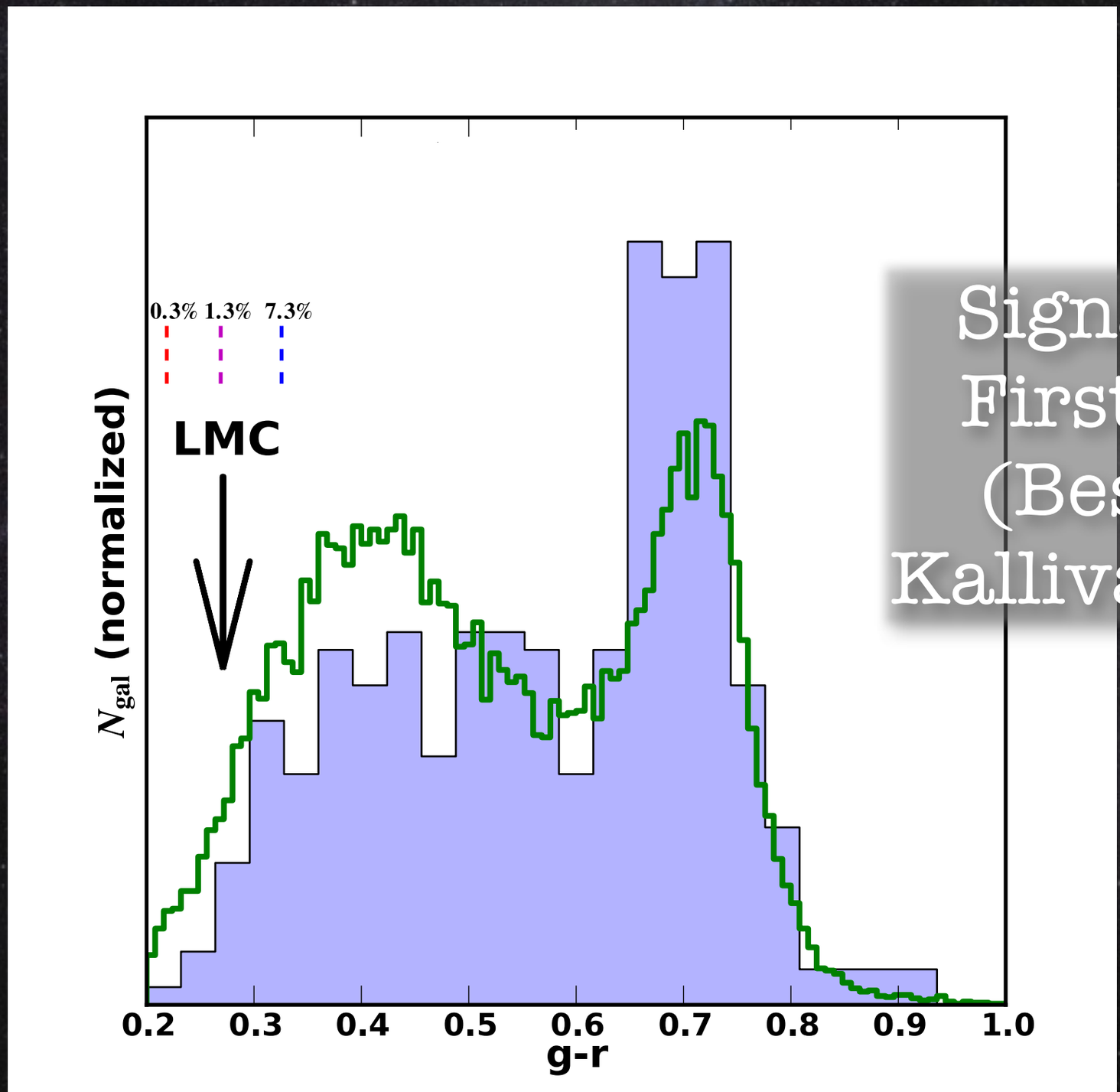

Signature of First Infall? (Besla+ 07, Kallivayalil+ 06

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SSS/LMC Summary

- ΛCDM+Abundance Matching works surprisingly well for bright satellite (~0.1 L*) scales.
  - $\Delta v_{\rm pair}$/Host mass correct: $\sigma_{v,\rm pair}$~ 150 km/s
  - Radial distribution of satellite galaxies match subhalos
  - Fraction of L* galaxies w/ 0.1 L* satellites: ~ 40% (LMC is not weird)
- Empirical bright satellite properties:
  - Satellites of isolated 0.1 L* galaxies are red - squelched!
  - LMC is is very blue/starforming relative to similar objects. (LMC *is* weird) First infall?

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Conclusions

- MW dSphs suggest either a breakdown of LCDM or stochastic galaxy formation.
- M31 Looks a lot like MW - the same problems and solutions hold.
- Bright (~0.1L_*) Satellites *do* match LCDM expectations, which presents interesting Galaxy Formation opportunities.
- Coupling Observations to a theoretical framework provides unexpected new opportunities.

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