The SAGA Project: Satellites Around Galactic Analogs

Marla Geha (Yale)
Risa Wechsler, Yao-Yuan Mao

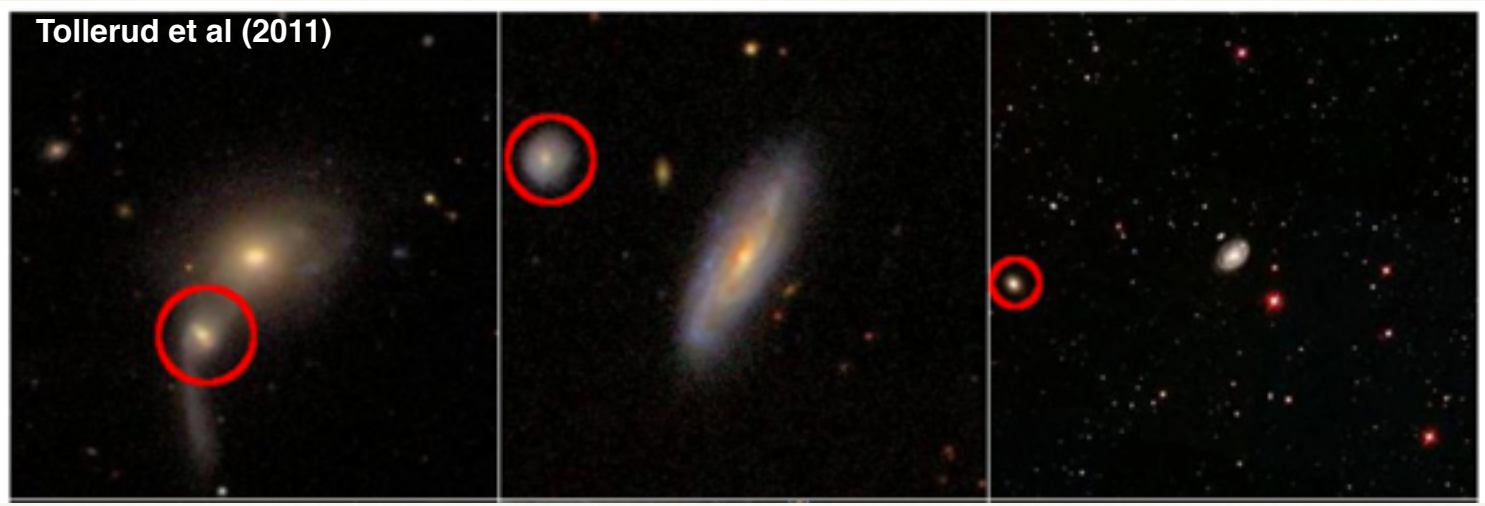
Erik Tollerud, Ben Weiner, Ben Hoyle
and the SAGA team

Paper and pretty images available at sagasurvey.org

Submitted on astro-ph 29.96 minutes ago.

The Milky Way's Brightest Satellites

Liu et al 2011, Tollerud et al 2011, Guo et al 2011, Wechsler & Strigari 2012:
SDSS spectroscopic survey allows identification of LMC/SMC satellites around Milky Way analogs out to 50 Mpc.



Liu et al (2011)
SDSS suggests LMC/SMC are unusual for a MW-mass halo, but not uncomfortably so (~4%).

The SAGA Project (Satellites Around Galactic Analogs)

SAGA Overall Goal:
Characterize the satellite populations down to $M_r = -12.3$ around 100 Milky Way-like galaxies.

LMC: $M_r = -18.5$ SMC: $M_r = -17.1$ Sgr: $M_r = -13.8$ For: -13.7 Leo I: -12.3





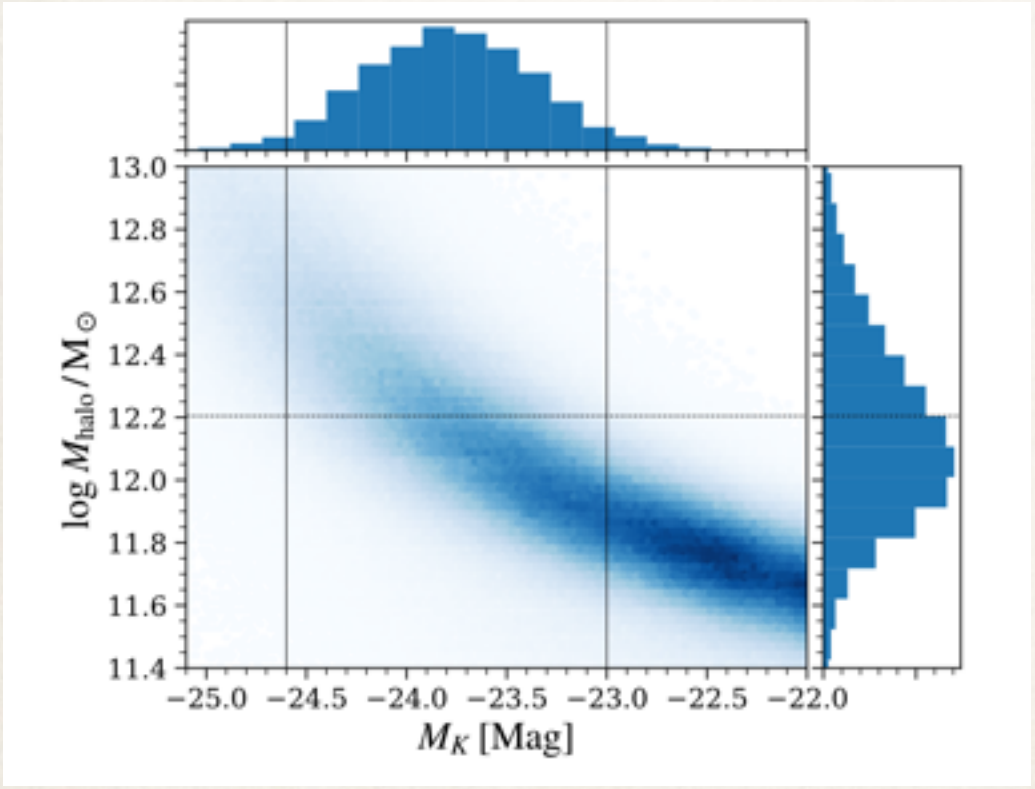
Inside the Milky Way viral radius of 300 kpc, there are 5 satellites to $M_r = -12.3$
LMC/SMC are only star formation satellites.

The SAGA Project: How to Define the Milky Way?

How to Define a Milky Way?

Assuming Milky Way halo mass of 1.6 x 10^{12} M_{sun} and a stellar-halo mass relationship with 0.15 dex scatter. This suggest a range of K-band luminosities:

$-23.0 < M_K < -24.6$.



Milky Way analog Definition:

Stellar mass:

$-24.6 < M_K < -23$

Environment:

No $M_K + 1$ within viral radius

Outside of 2MASS group

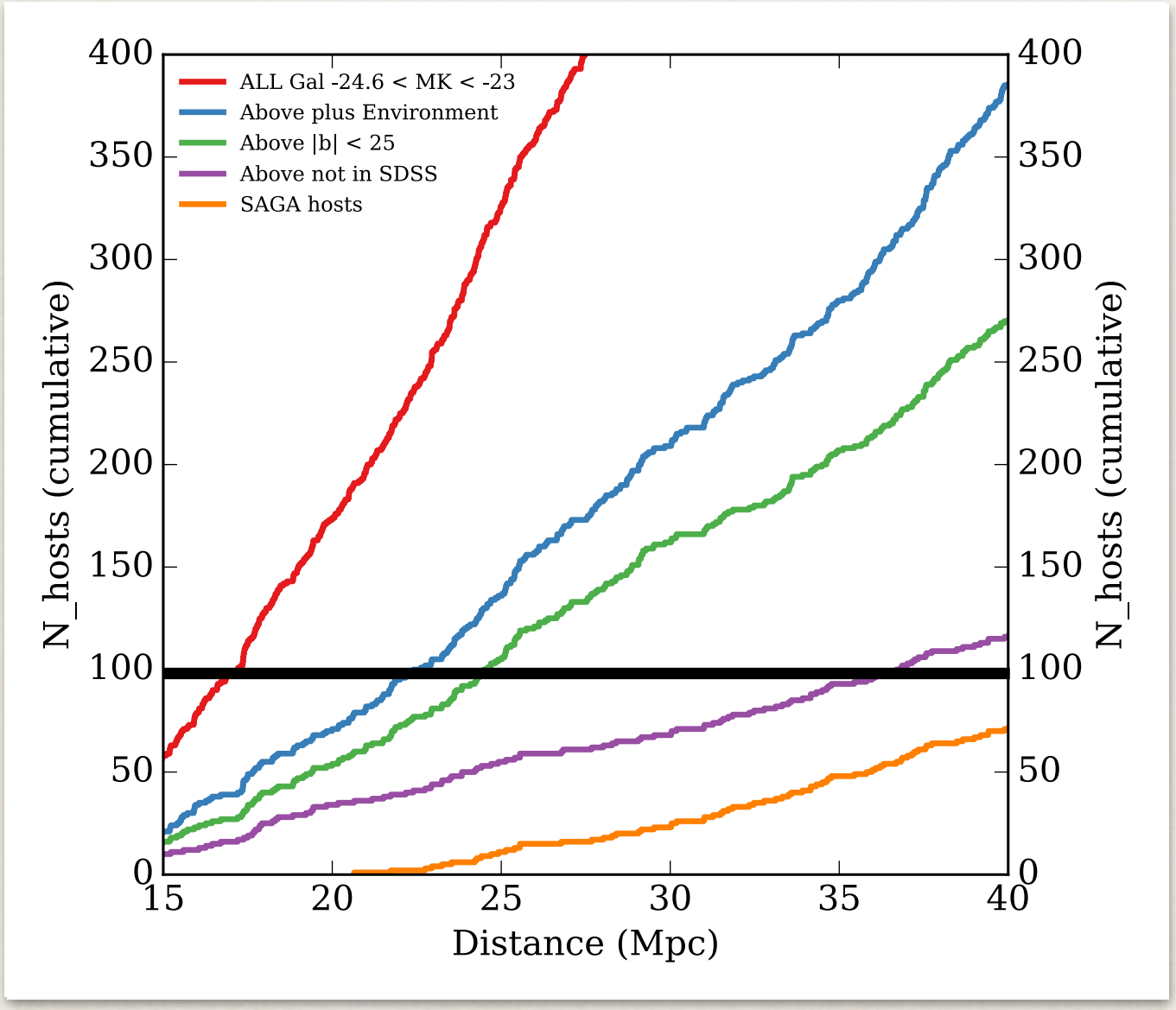
Practical:

b > 25 deg from Galactic plane

20 Mpc < D < 40 Mpc

The SAGA Project: Defining a Milky Way Analog

How to Define a Milky Way?



Milky Way analog Definition:

Stellar mass:

$-24.6 < M_K < -23$

Environment:

No $M_K + 1$ within viral radius

Outside of 2MASS group

Practical/Resources:

b > 25 deg from Galactic plane

20 Mpc < D < 40 Mpc

Majority of hosts are NGC galaxies

The SAGA Project: Defining a Milky Way Analog

The virial radius of the Milky Way is **300 kpc**. Want to survey satellites inside this radius.

At 20 Mpc, a physical radius of 300 kpc is equivalent to ~ 1 degree

The SAGA Project: Defining a Milky Way Analog

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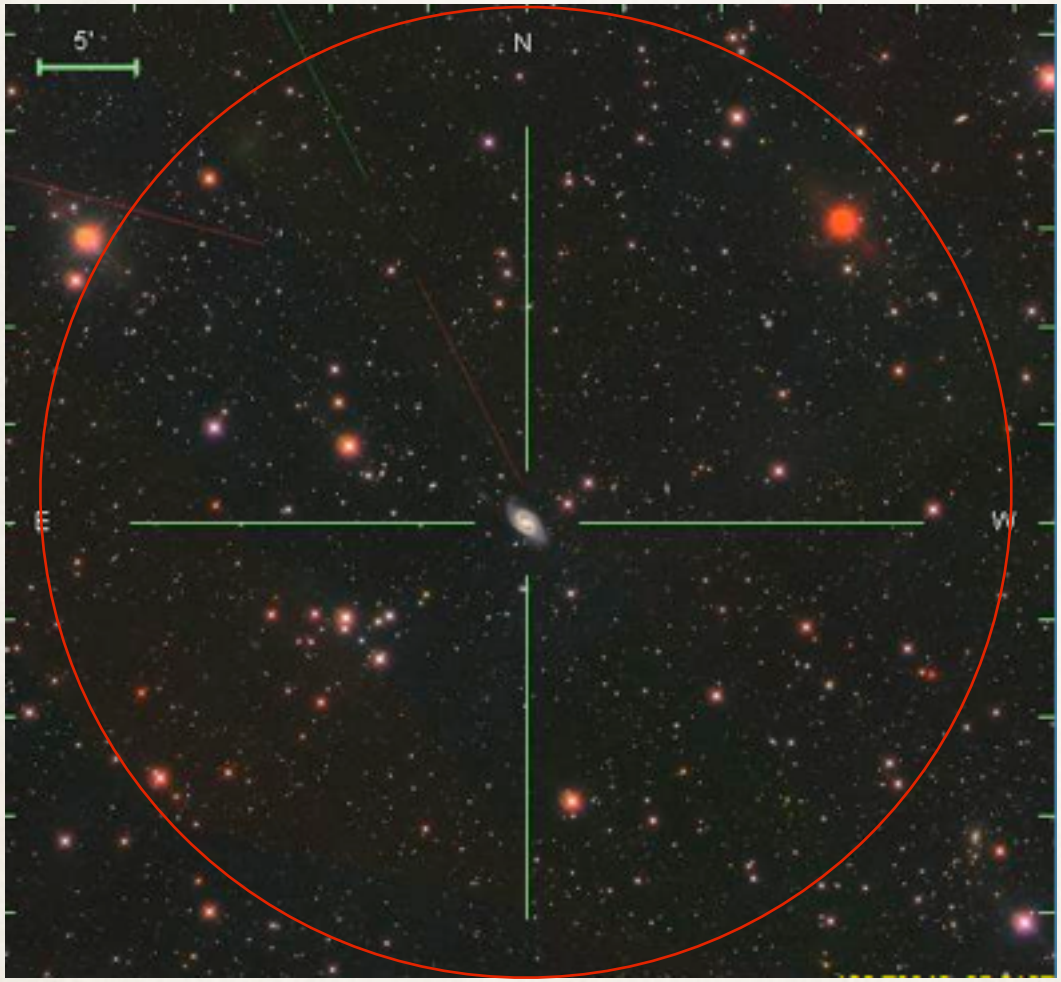
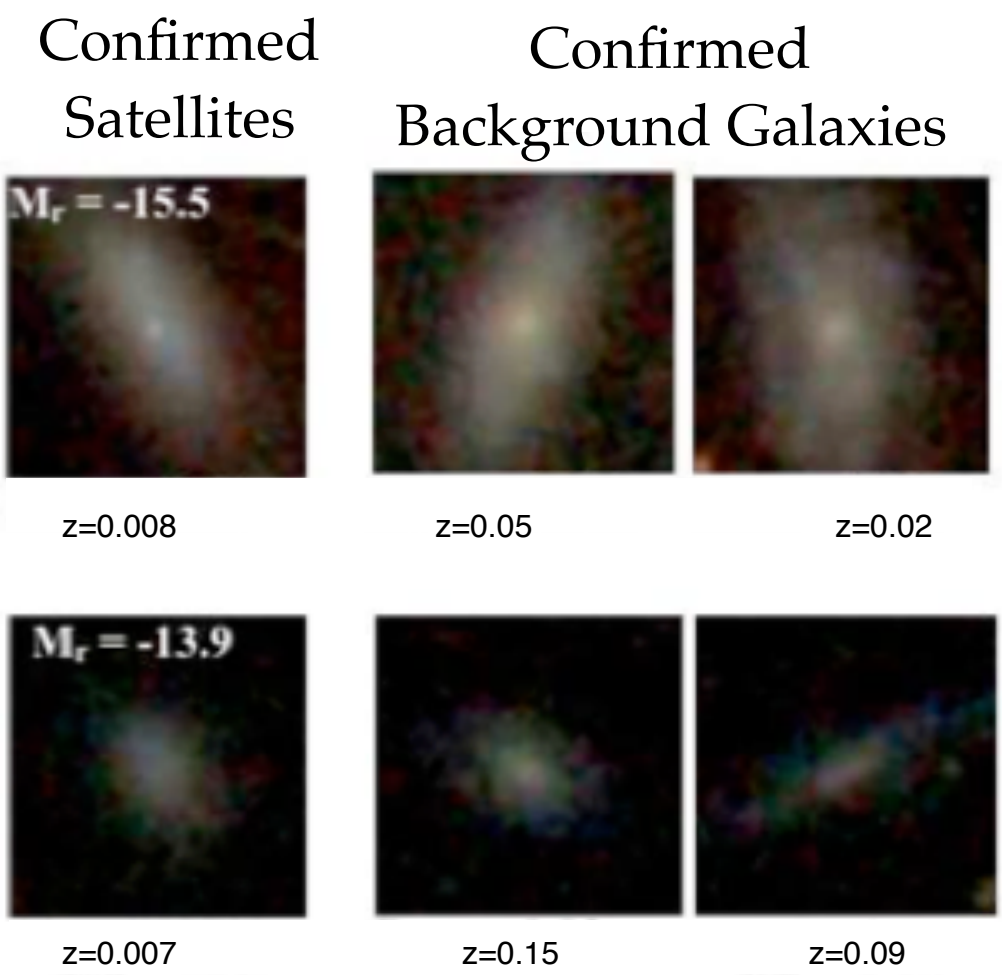


At 20 Mpc, a physical radius of 300 kpc is equivalent to ~ 1 degree

At 40 Mpc, r = 21 is equivalent to $M_r = -12.3$

Within 1 deg, there are typically 10,000 objects down to r = 21

The SAGA Project: Photometric Redshifts @ Low-z



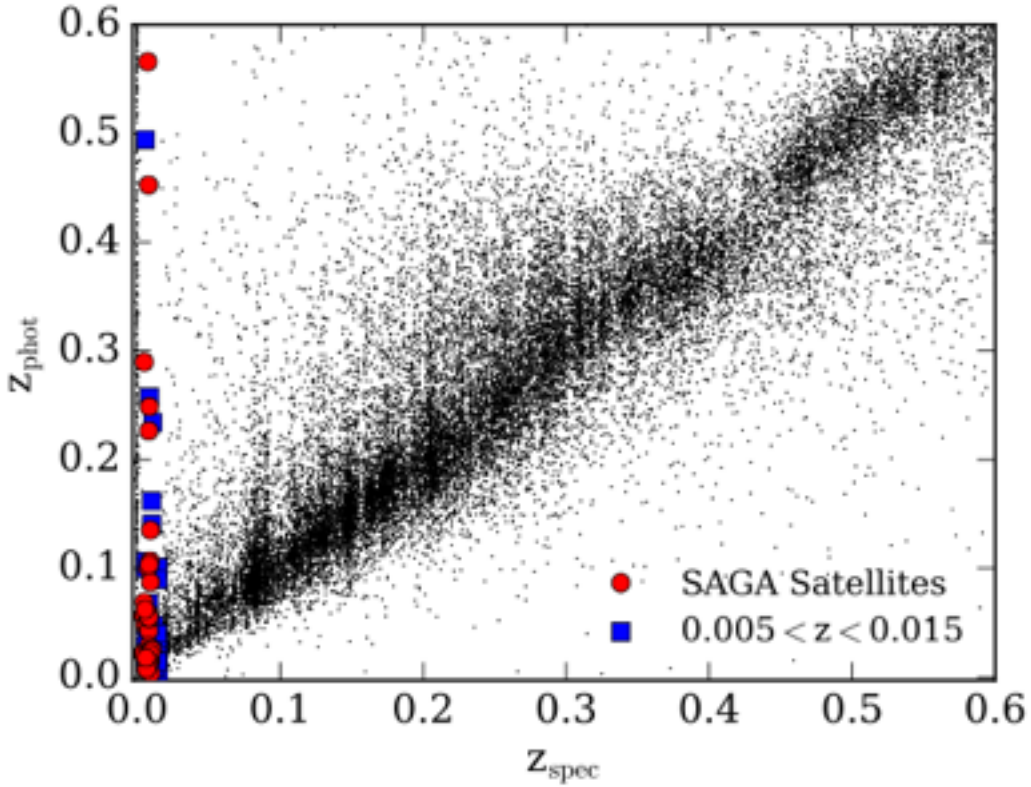
Photometric redshifts are not very informative at these redshifts.

D = 20 - 40 Mpc

z = 0.005 - 0.01

The SAGA Project: Photometric Redshifts $z < 0.02$

SDSS DR12 photo-zs (Beck et al 2006)



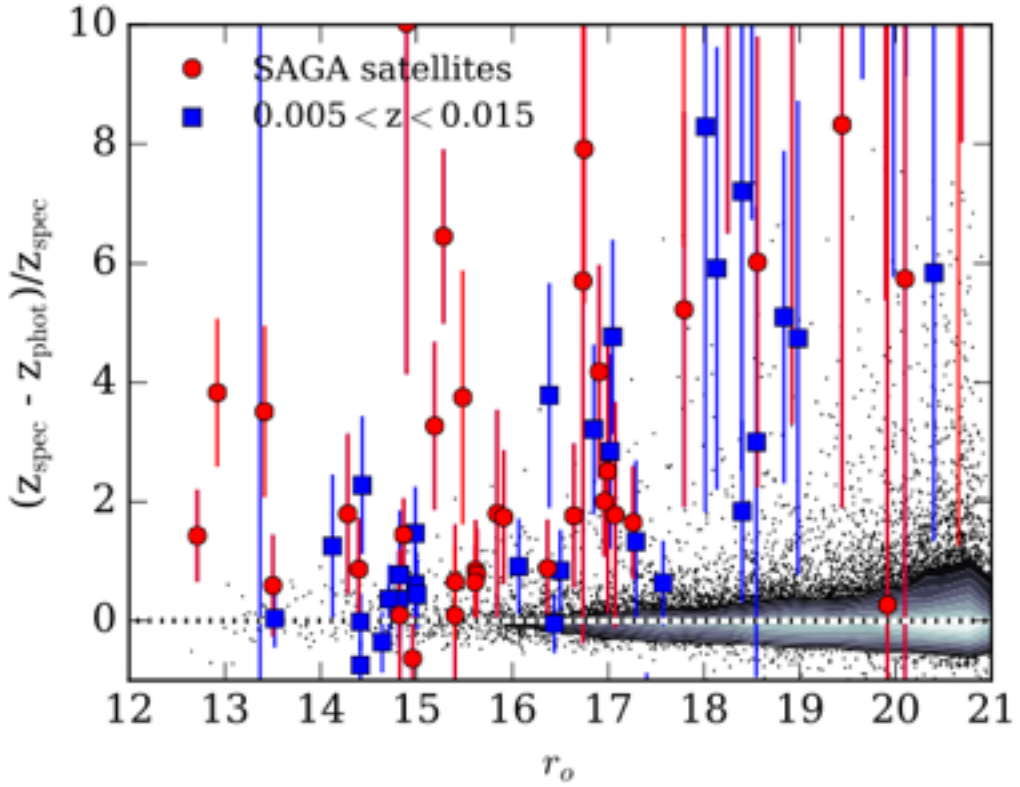
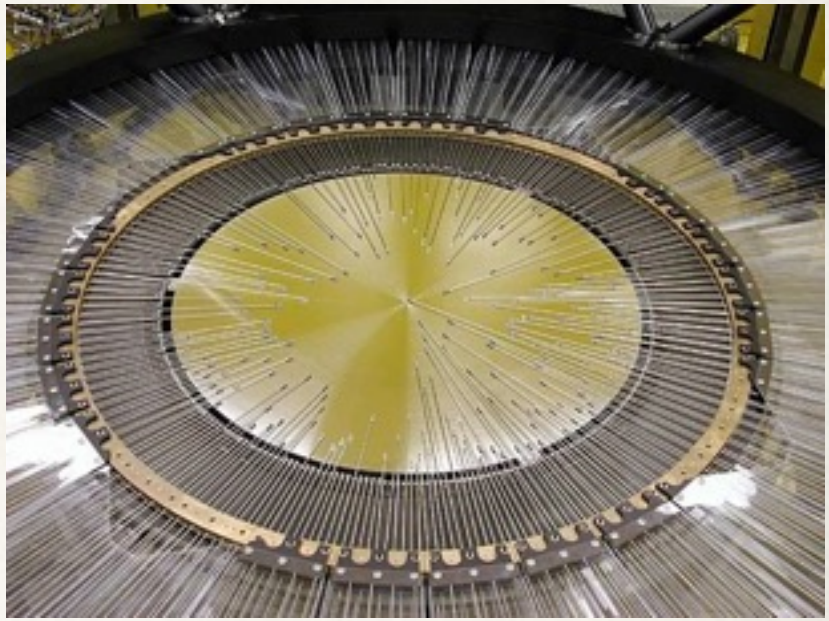


Photo-zs are neither accurate nor precise.

We place a premium on completeness, tail of photo-zs to large redshift means these cannot be used to reduce target density.

The SAGA Project: Spectroscopic Follow-up

Given lack of reliable photo-z, we require spectroscopy to identify satellites.



We need large FOV, multi-object spectrographs:

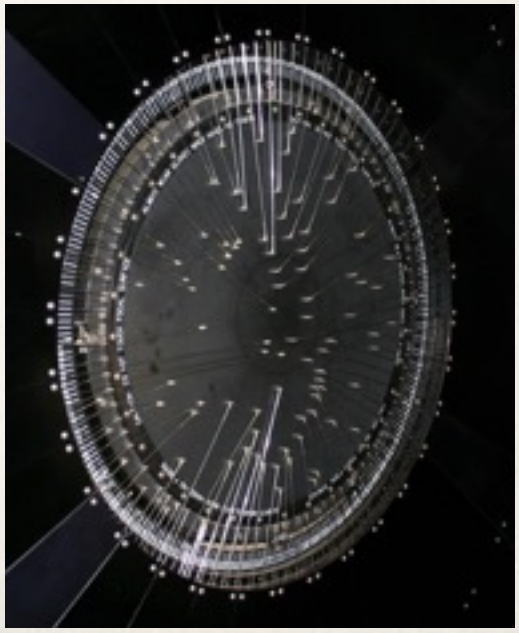
- MMT/Hectospec (1 deg, 300 fibers)
- AAT/AOmega+2dF (2 deg, 400 fibers)
- Magellan/IMACS

SAGA progress to date:

17,000 redshifts for galaxies $17.7 < r < 21$

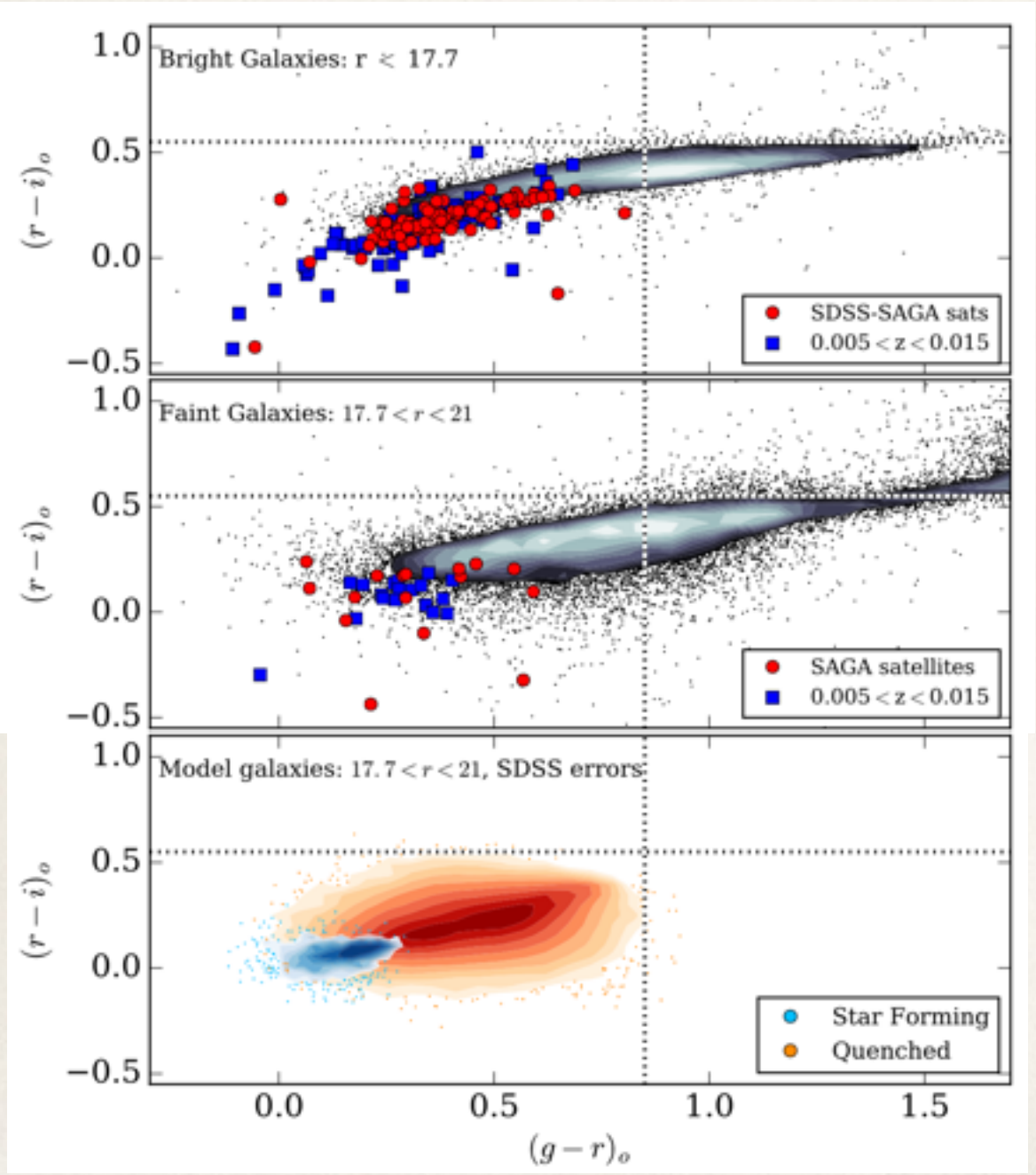
300 redshift for galaxies $r < 17.7$

3000 redshifts for galaxies $r > 21$



Note that upcoming spectroscopic surveys will not fulfill our requirements (DESI, 4MOST).

The SAGA Project: gri Color Cuts



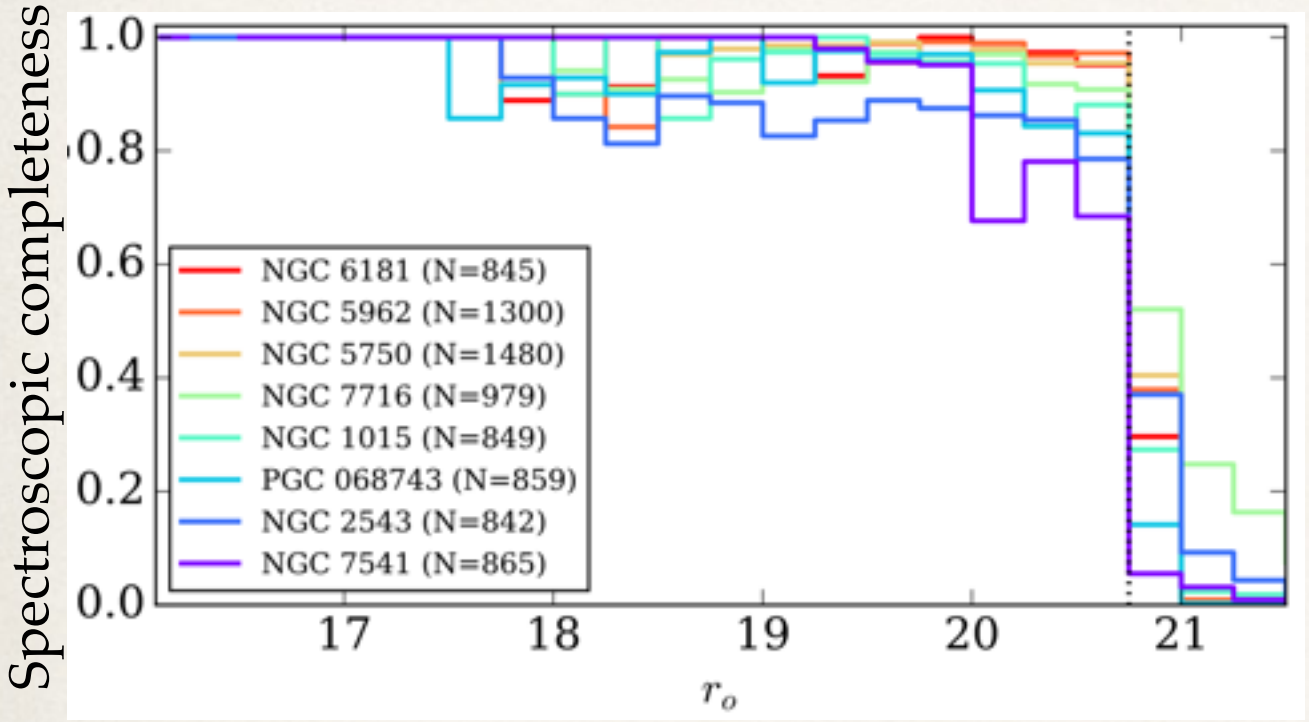
gri color cuts

$$(g_o - r_o) - 2\sqrt{\sigma_g^2 + \sigma_r^2} < 0.85$$

$$(r_o - i_o) - 2\sqrt{\sigma_r^2 + \sigma_i^2} < 0.55$$

Color cuts reduce number of candidate satellites by factor of two.

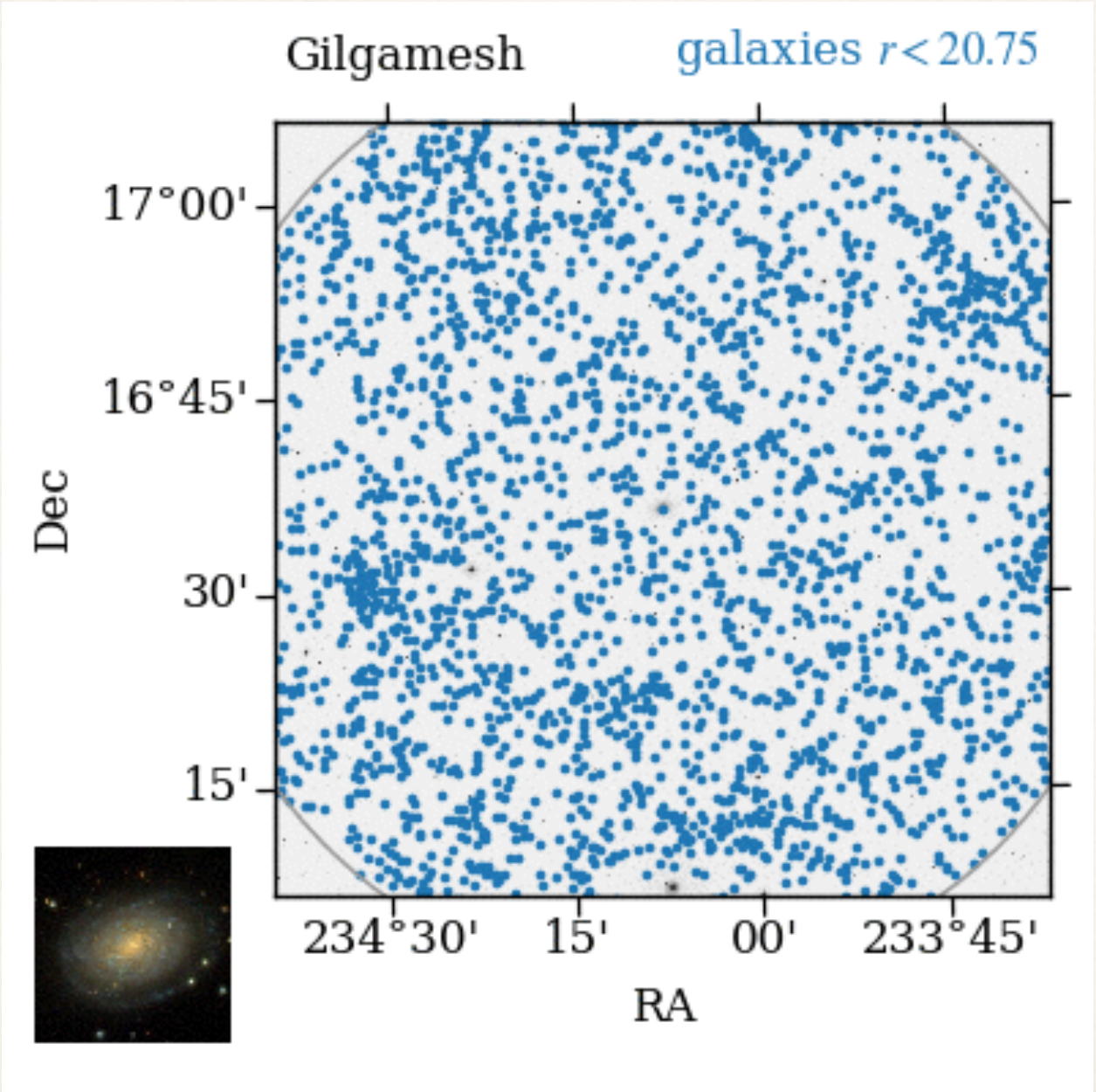
The SAGA Project: Completeness



8 MW hosts
with > 82% gri
completeness to $r_o < 20.75$

(1) SAGA Name	(2) NGC Name	(9) N_{sats}	(10) N_{tot} $r_o < 20.75$	(11) N_{gri} $r_o < 20.75$
Gilgamesh	NGC 5962	2	2995	98% (1271/1300)
Odyssey	NGC 6181	9	1850	97% (819/845)
Dune	NGC 5750	1	3557	97% (1433/1480)
AnaK	NGC 7716	2[1]	2356	94% (917/979)
Narnia	NGC 1015	2	1976	92% (778/849)
OBrother	PGC 068743	4	1740	90% (770/859)
StarTrek	NGC 2543	2	1719	85% (716/842)
Catch22	NGC 7541	5[2]	2198	82% (706/865)

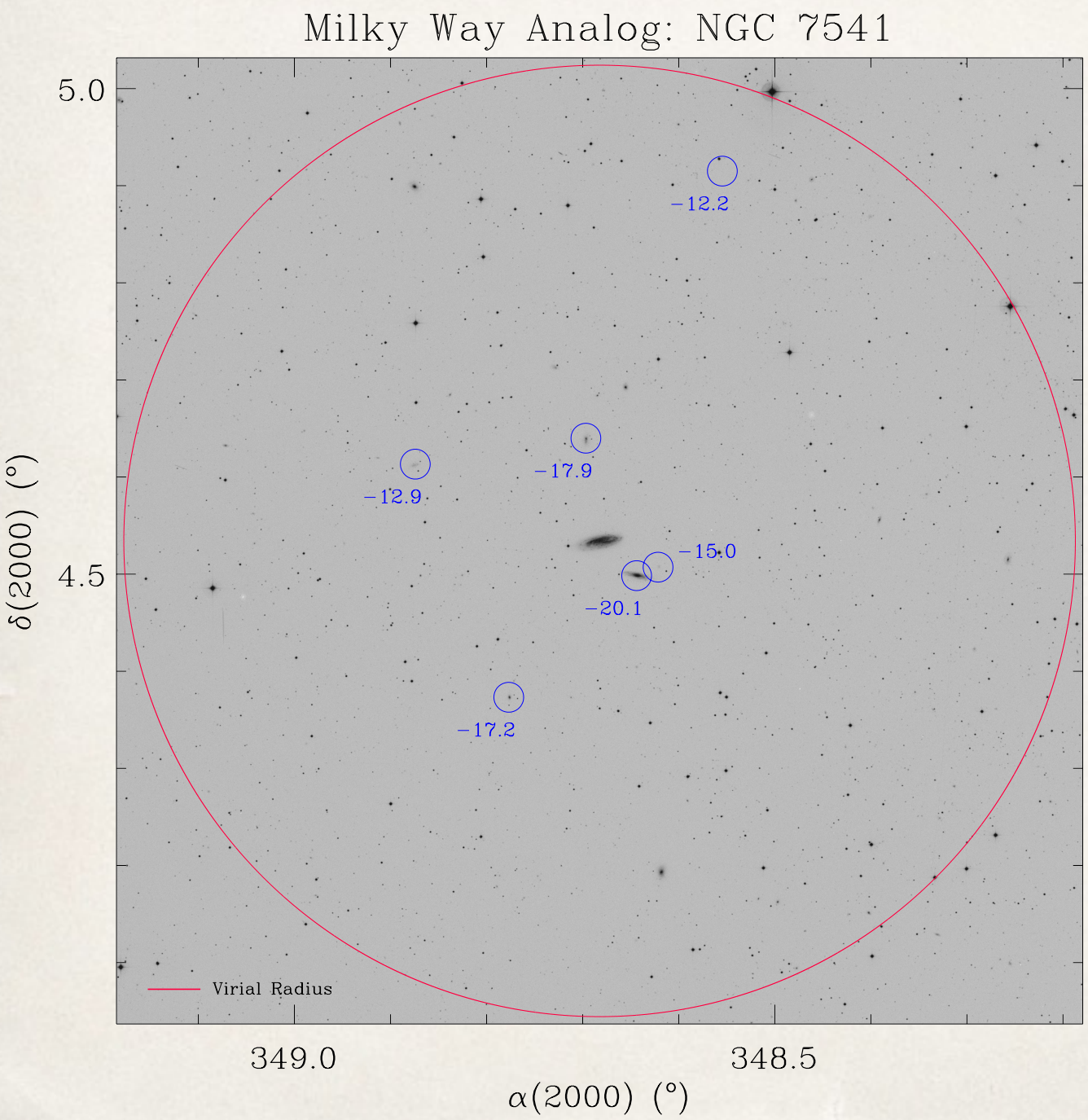
The SAGA Project: gri Color Cuts

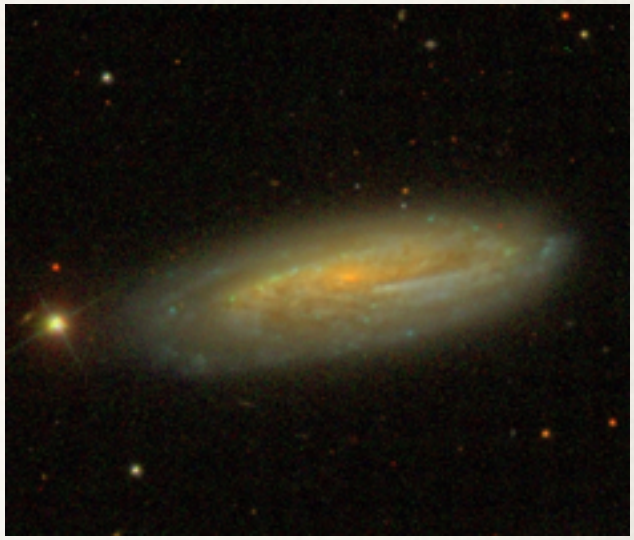


Color cuts reduce number of candidate satellites by factor of two.

Thanks to Yao for the animation!

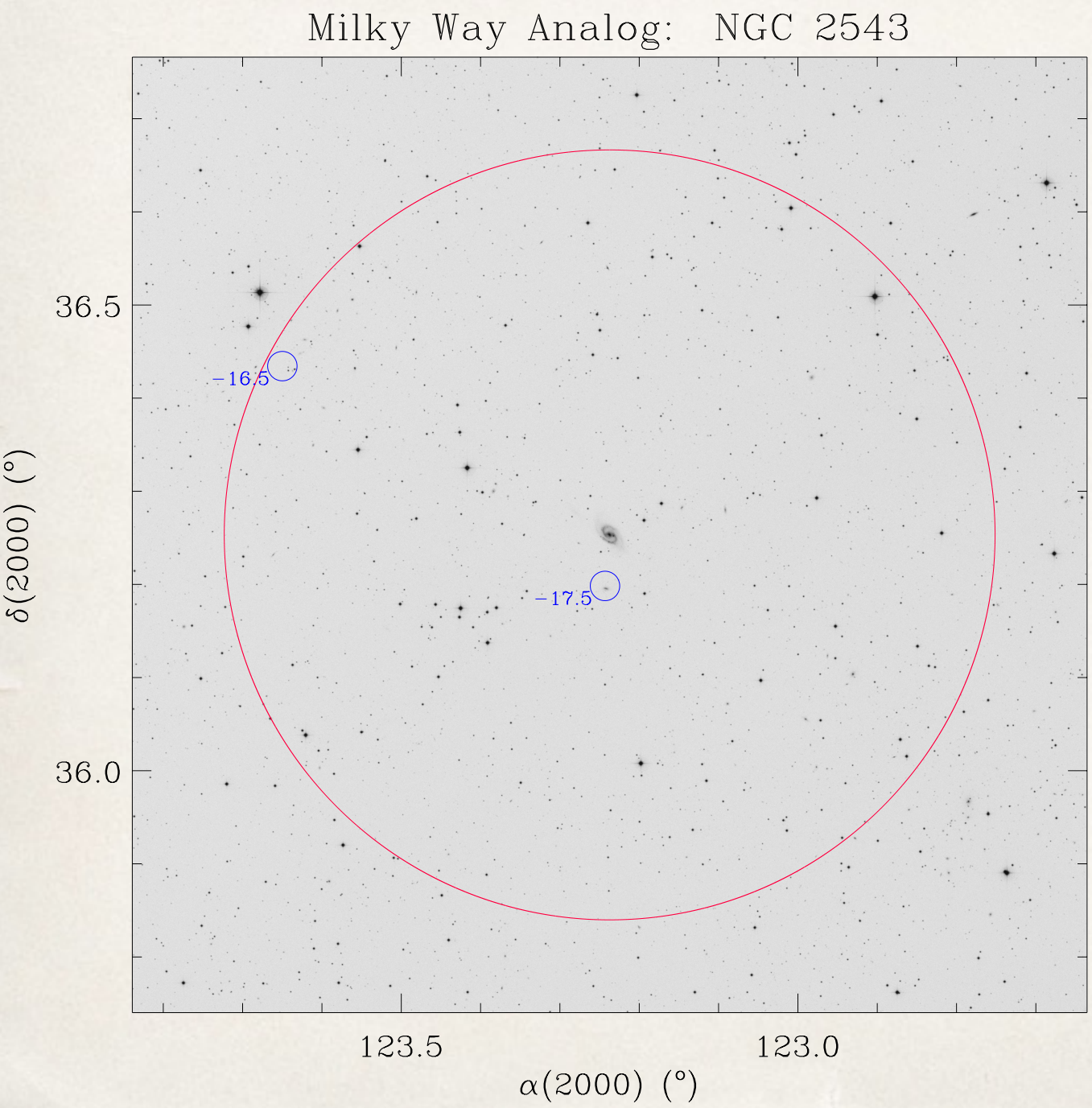
The SAGA Project

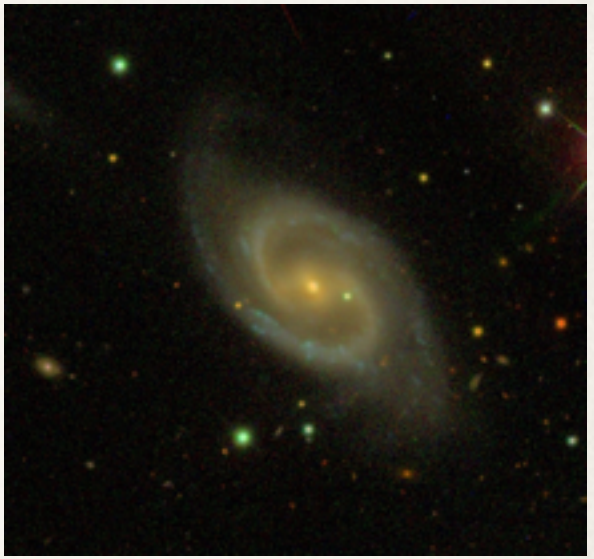




6 satellites
(3 discovered)

The SAGA Project

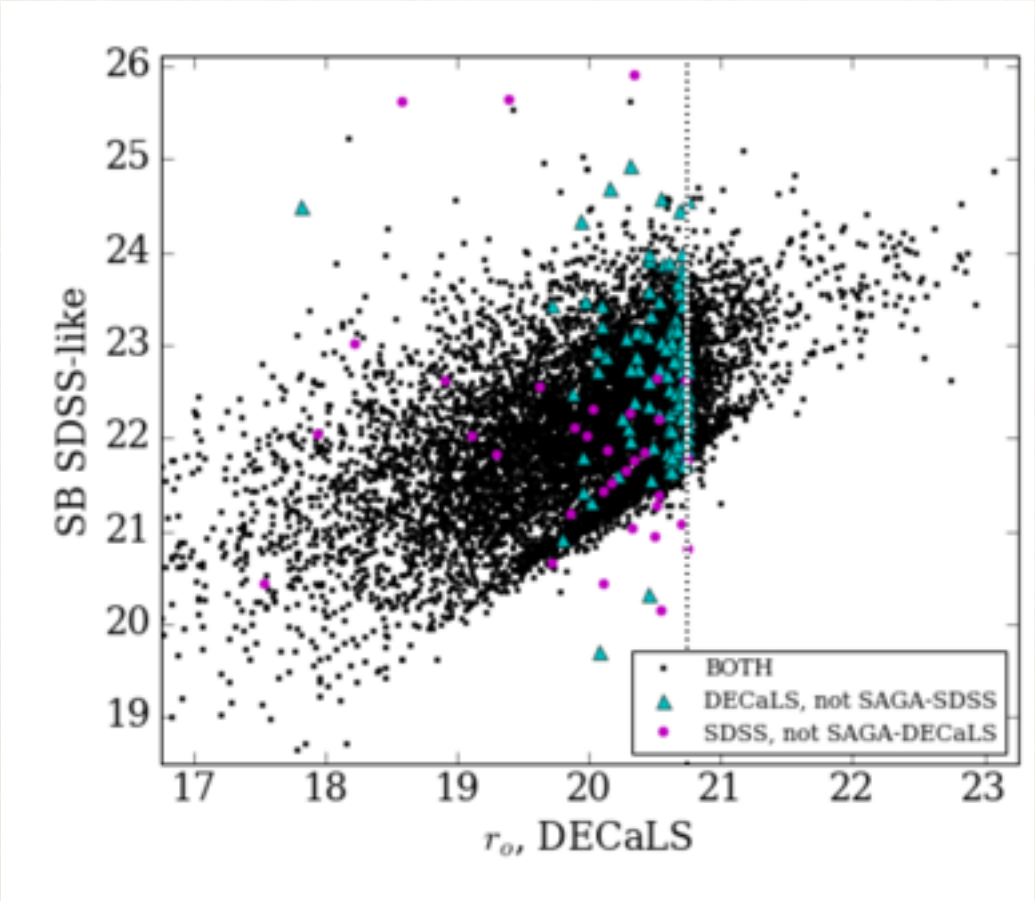




2 satellites
(1 discovered)

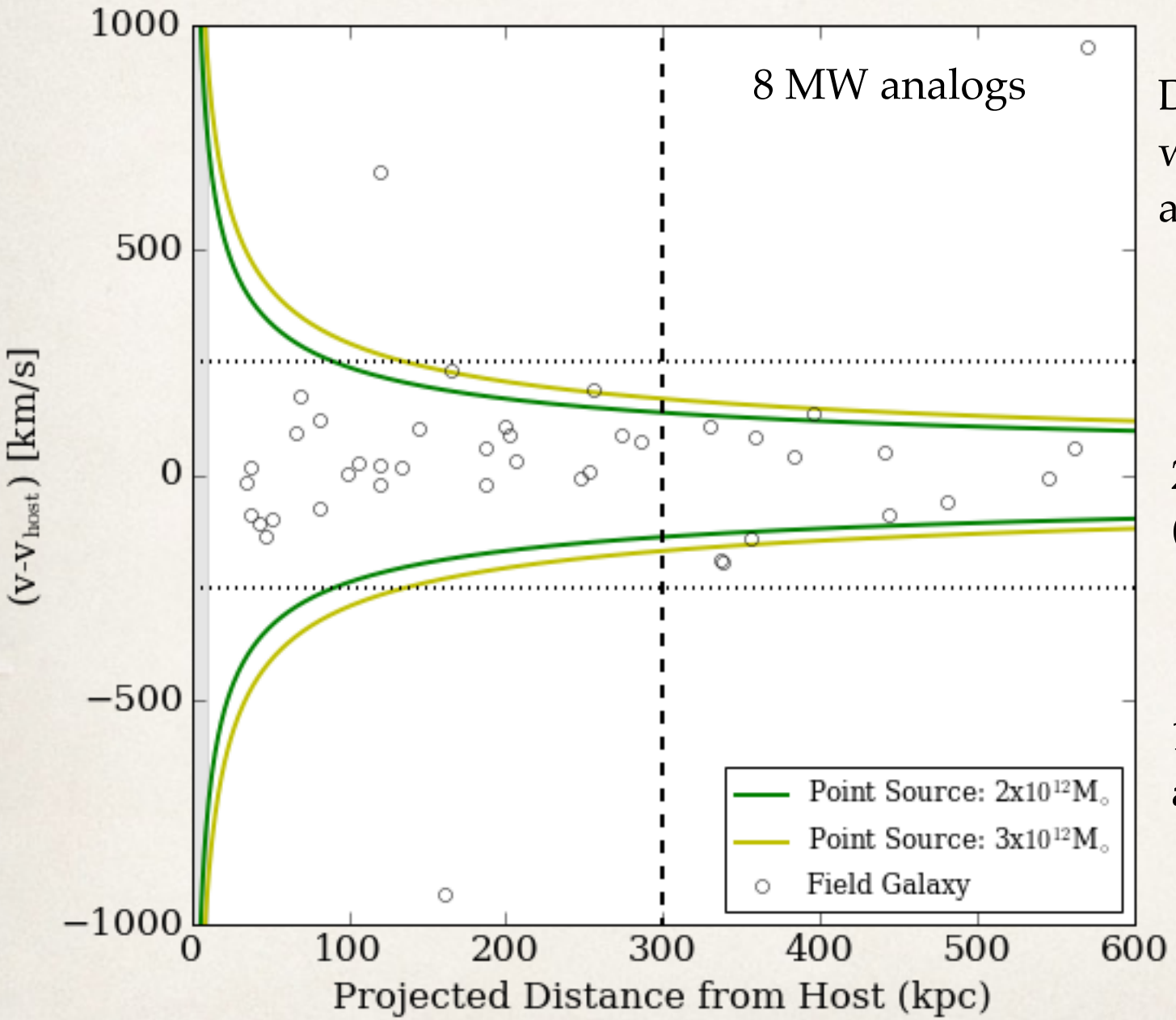
The SAGA Project: Completeness

Compare an overlapping photometry btw SDSS and DECaLS.



We are not missing a large number of low surface brightness galaxies.

The SAGA Project: Satellite Radial Distribution

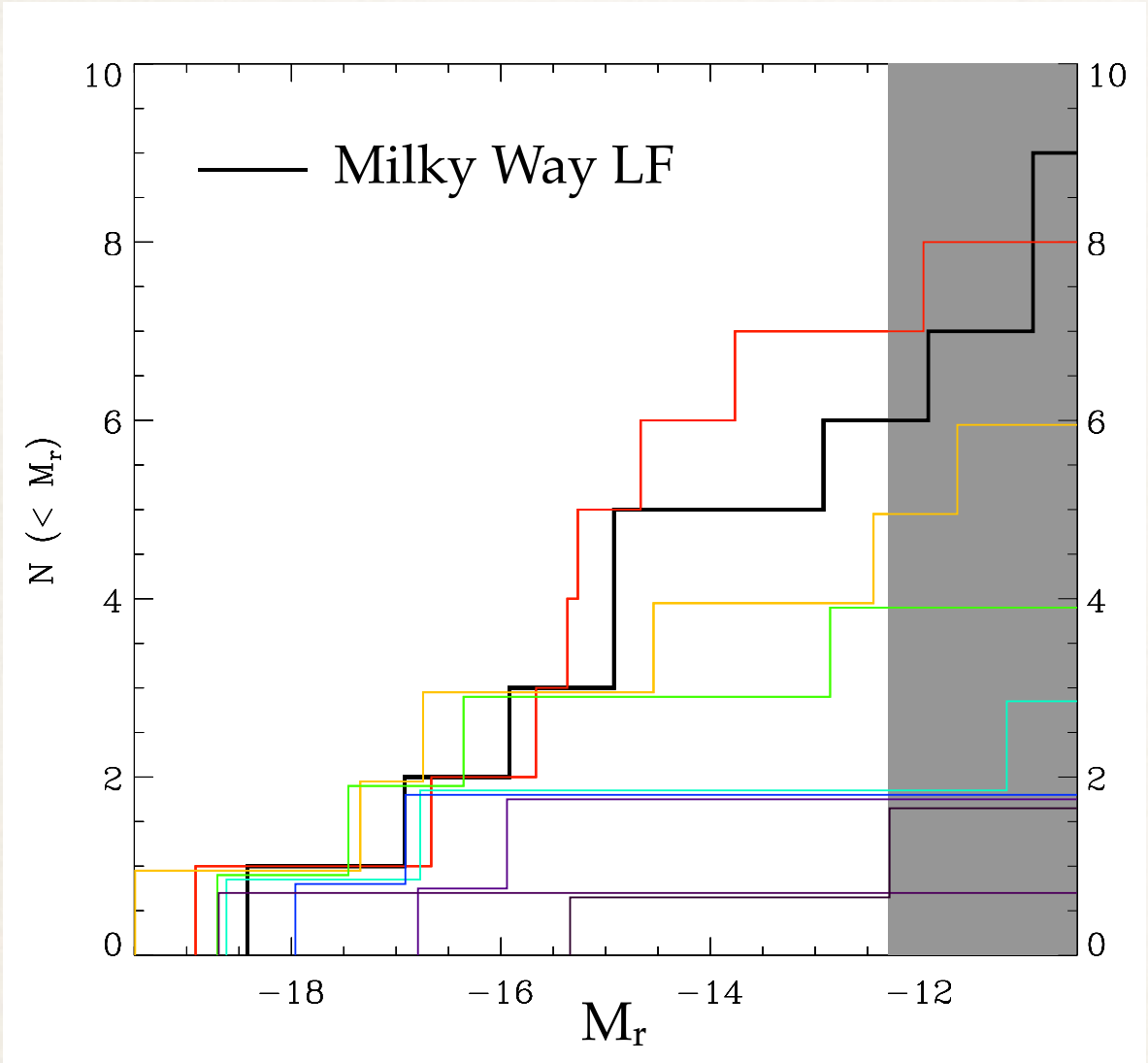


Define satellite as galaxy w/in projected virial radius and +/- 250 km/s

27 satellites around 8 hosts (14 new satellites)

11 new satellites in 8 additional incomplete hosts.

The SAGA Project: Satellite Luminosity Function



NGC 6181

NGC 7461

PGC 68743

NGC 7716

NGC 5962

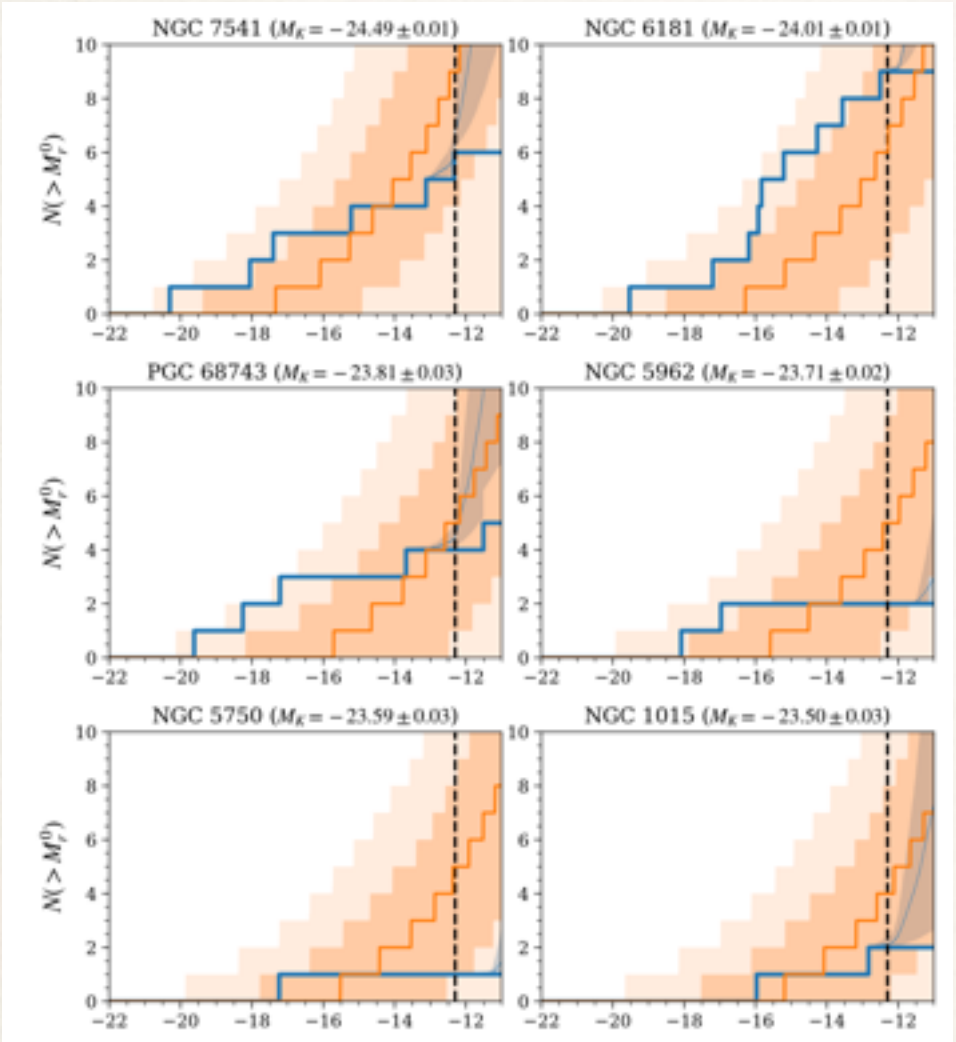
NGC 1051

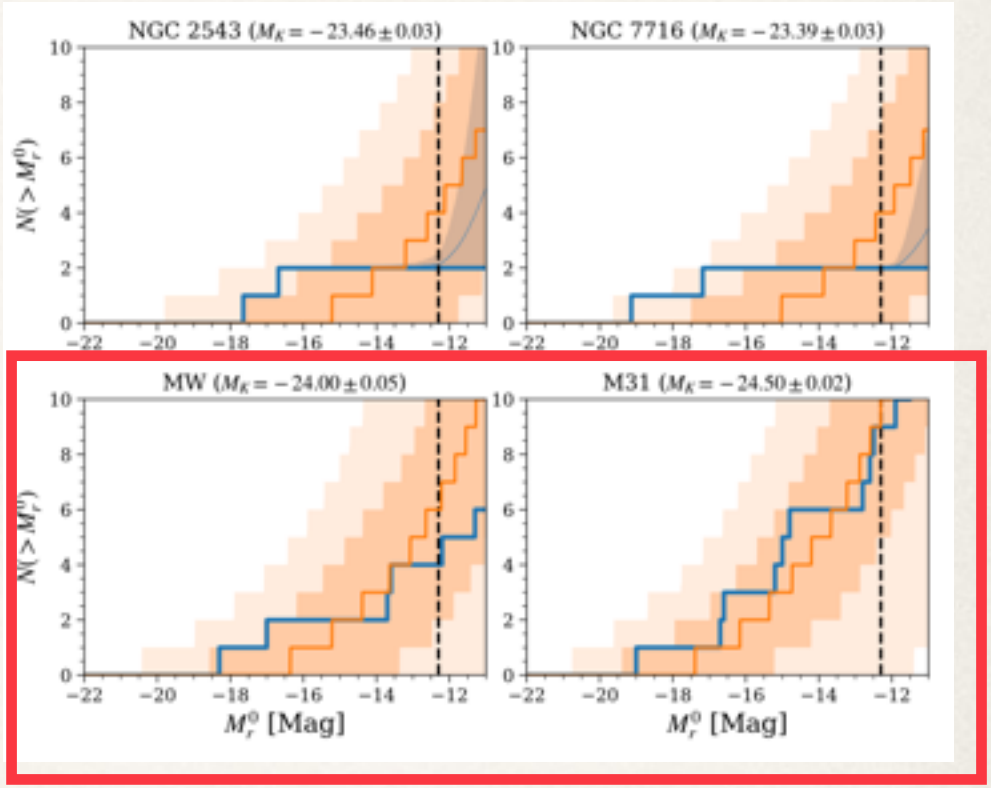
NGC 2541

NGC 5750

The SAGA Project: Satellite Luminosity Function

8 SAGA hosts, corrected for gri incompleteness

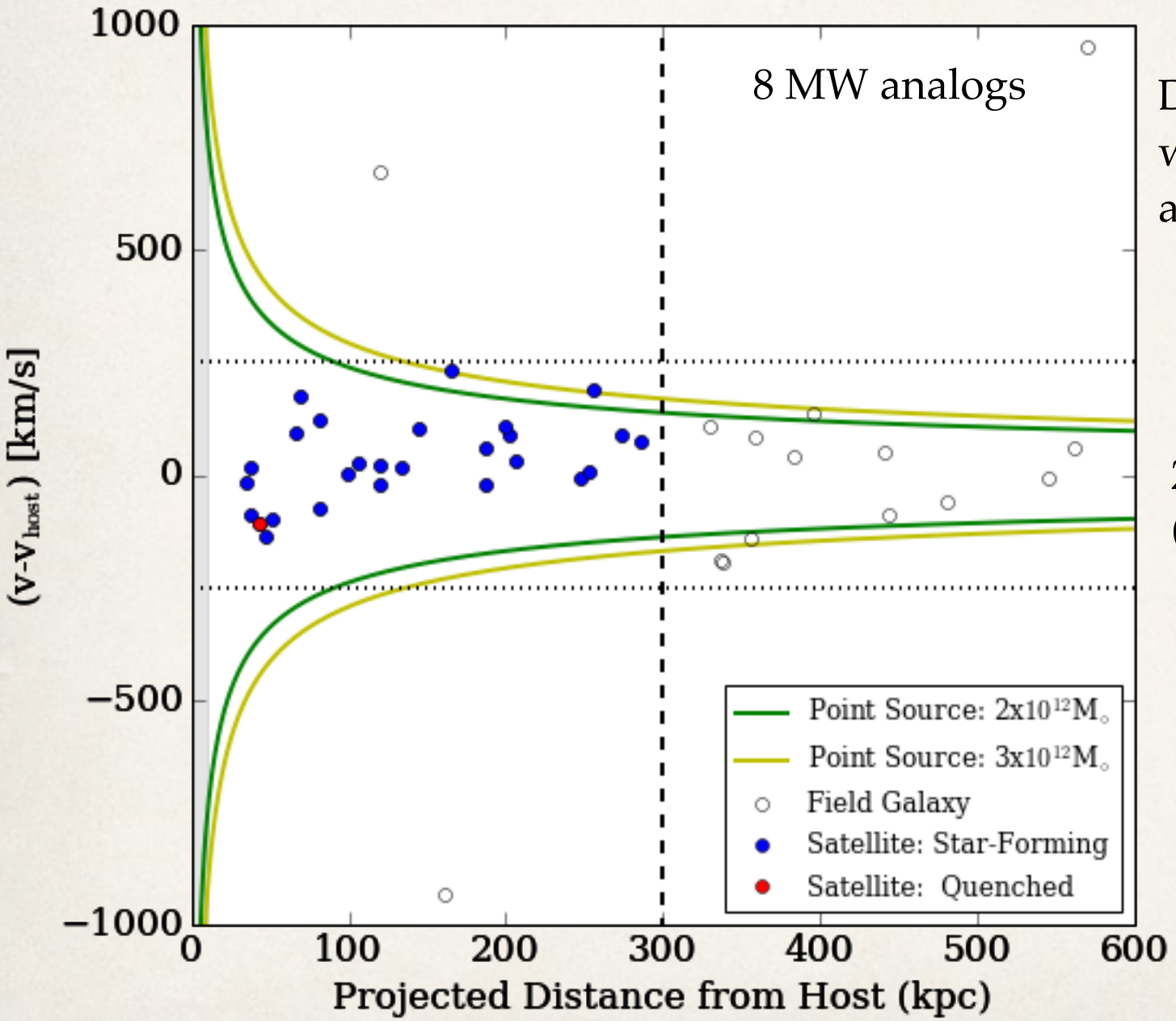




subhalo model based on 50 MW resimulations
+ simple abundance matching
Mao et al 2015

Luminosity functions are generally in 2-sigma agreement,
but shapes are shallower than predicted.

The SAGA Project: Satellite Radial Distribution

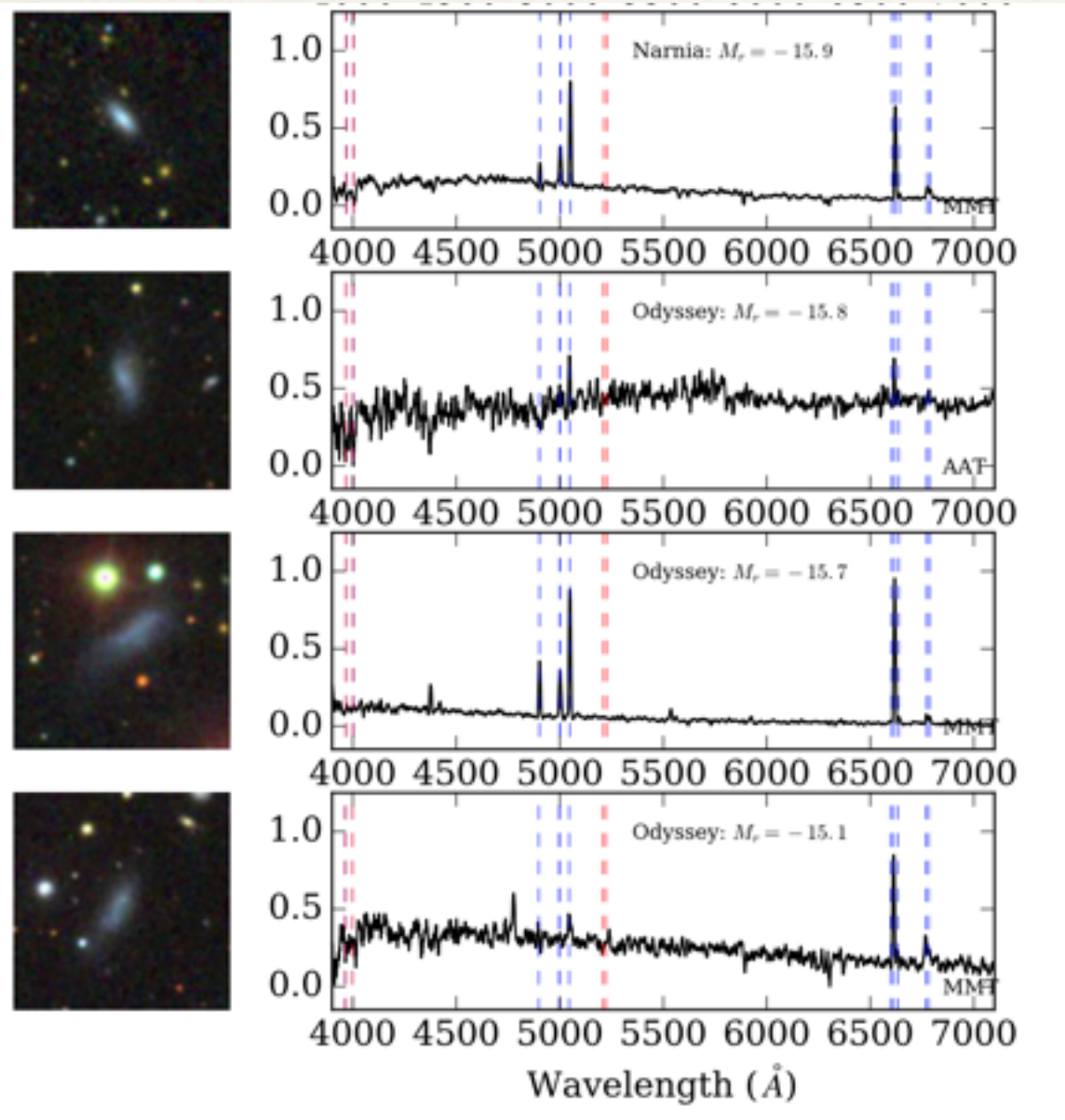


Define satellite as galaxy w/in projected virial radius and +/- 250 km/s

27 satellites around 8 hosts (14 new satellites)

26 of 27 satellites are star forming

The SAGA Project: Star Forming Satellites



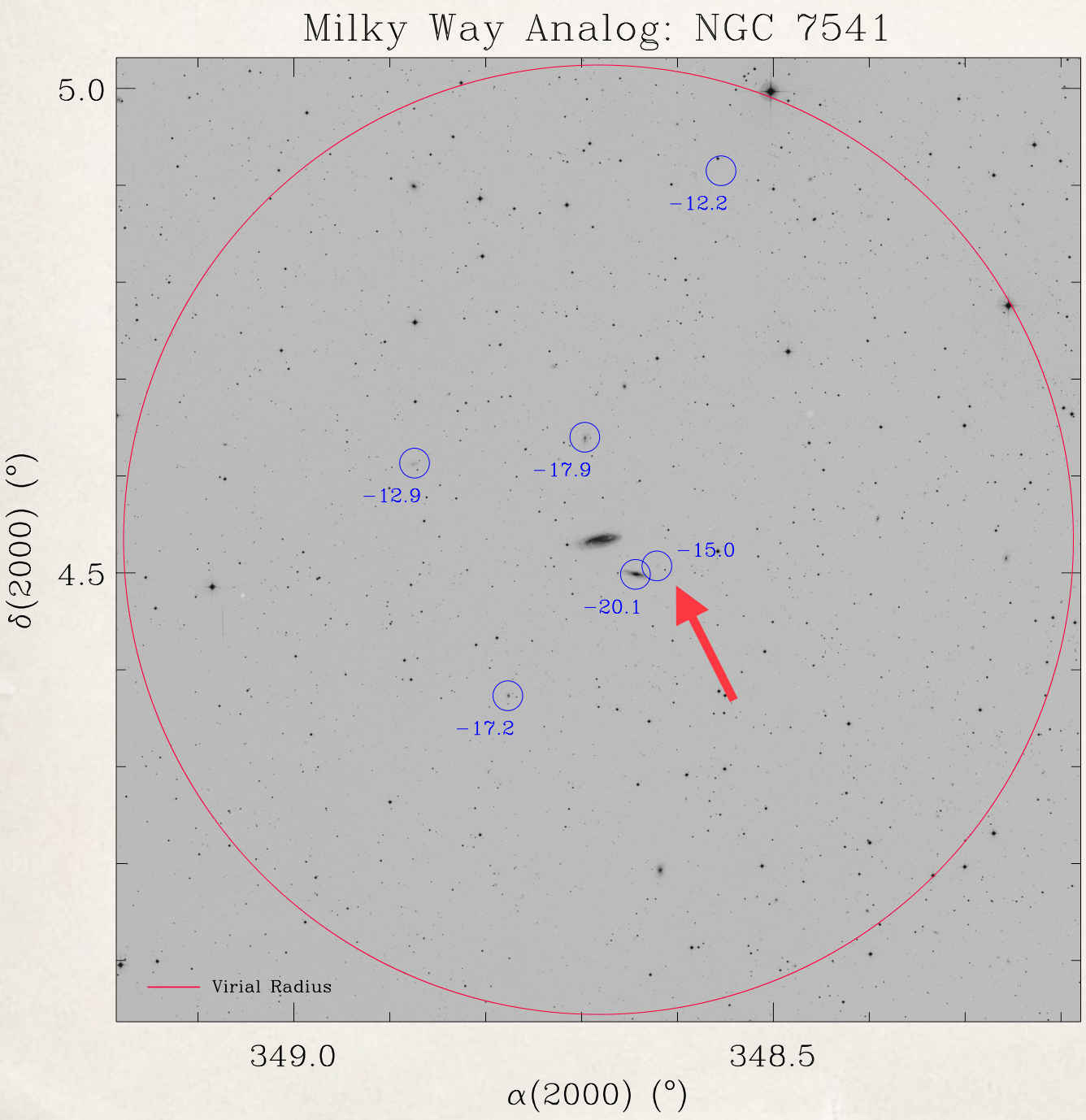
Spectra are high S/N.

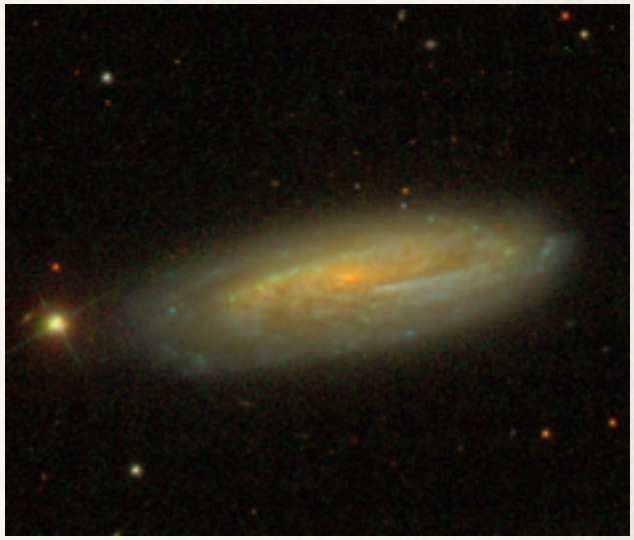
Able to detect absorption or emission line spectra.

26 out of 27 satellites are star-forming (96%).

Compared to 2 out of 5 (40%) in Milky Way.

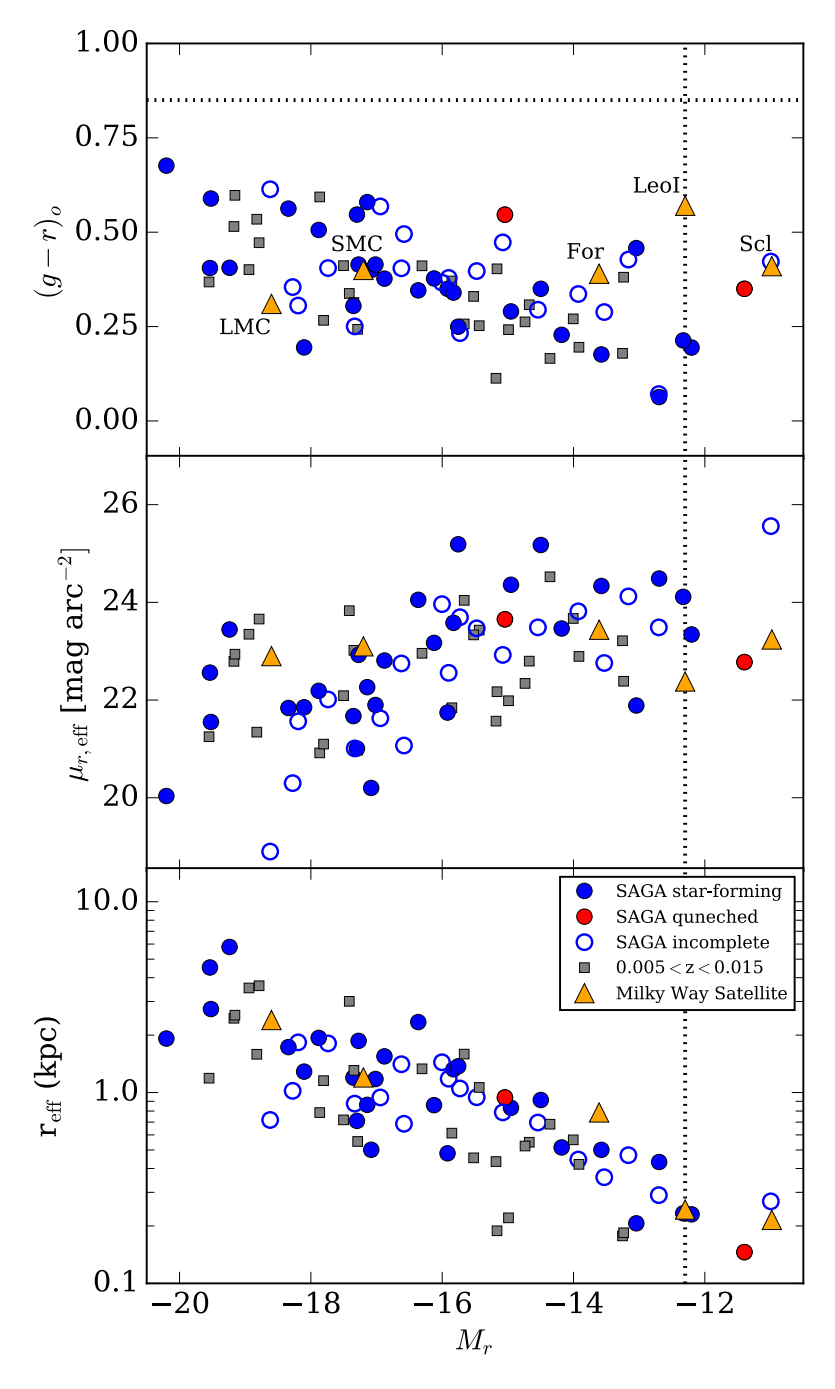
The SAGA Project



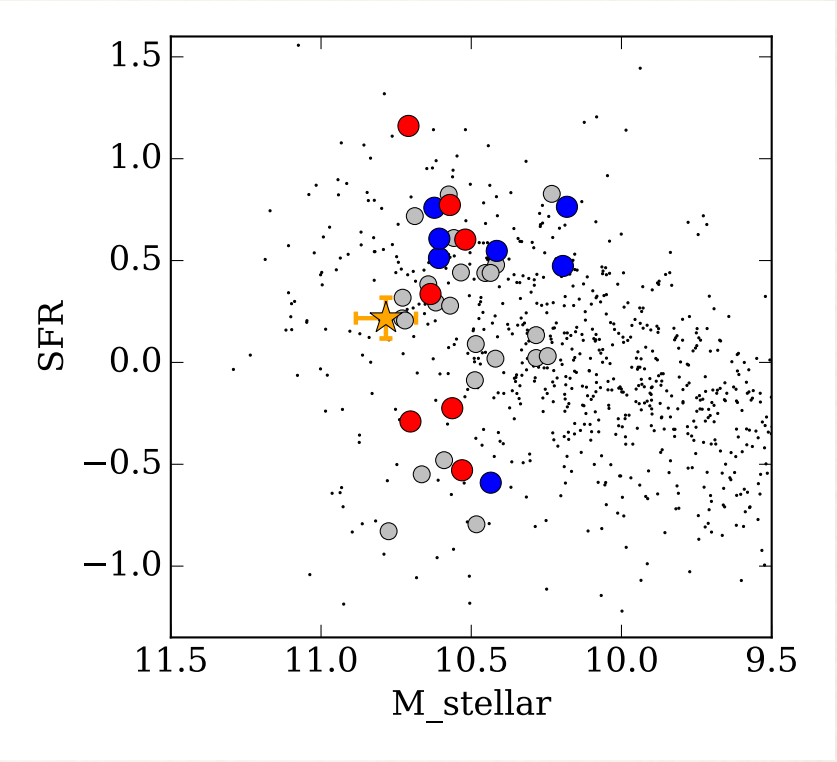


6 satellites
(3 discovered)

The SAGA Project: Star Forming Satellites



SFR of Hosts



Unlikely to be a conformity issue, maybe due to isolation criteria?

Need to revisit efficiency of quenching satellites?

The SAGA Project: Towards 100 Milky Ways

SAGA Overall Goal:
Characterize the satellite populations down to $M_r = -12.3$ around 100 Milky Way-like galaxies.

Near Future: We will/have measured dynamical masses and HI gas mass for all satellites.

To achieve goal of 100 Milky Way satellite luminosity functions we need:

1. A lot more telescope time (AAT, MMT access anyone?)
2. Substantially reduce candidate target number density without sacrificing completeness.

Conclusions

The SAGA project goal is to characterize the satellite populations around 100 Milky Way-like galaxies to determine the underlying satellite distribution around a Milky Way-mass halo.

The SAGA results so far:

— 17,000 redshifts taken between $17.7 < r < 21$

— 25 new satellites across 16 Milky Way analogs

— 8 Milky Way analogs with complete LF

— Significant variation in luminosity function, somewhat consistent with predictions, but shapes are generally shallower.

— **26 out of 27 satellites are star forming**

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