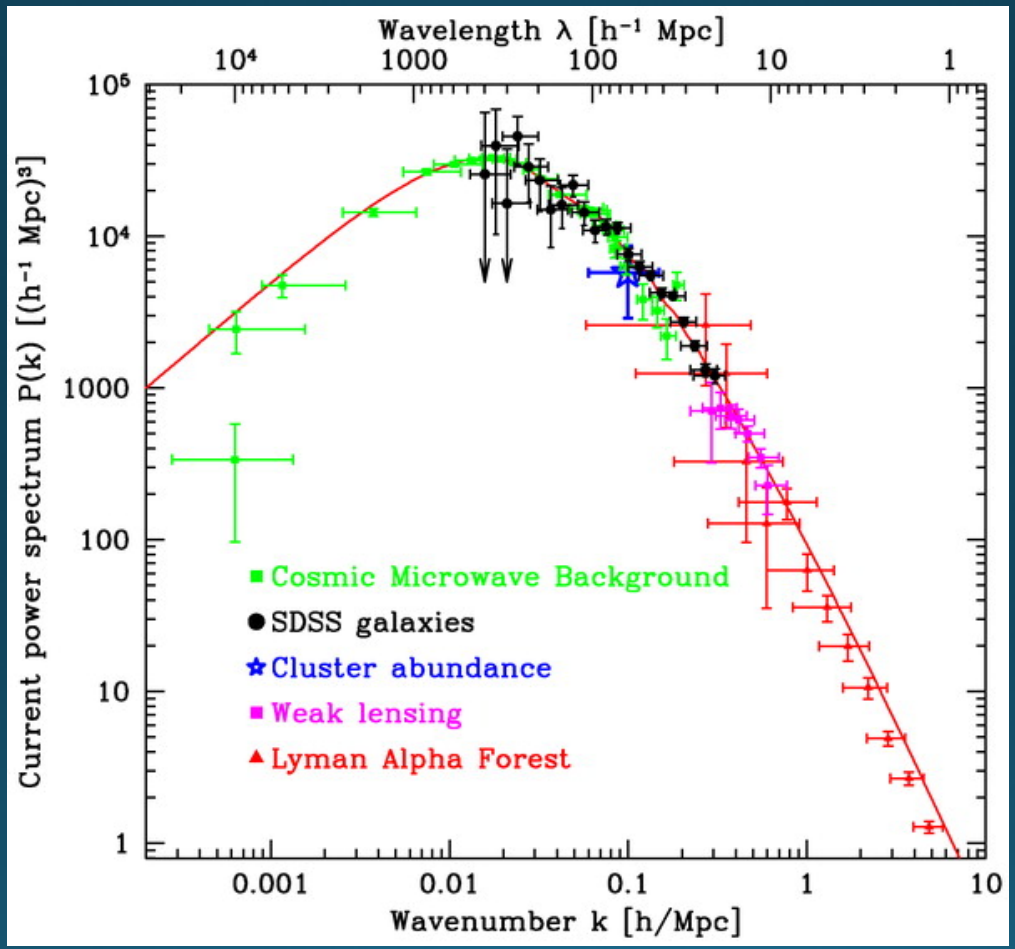
The Missing Satellite Problem Outside of the Local Group

Masayuki Tanaka, Masashi Chiba, Yutaka Komiyama
Mikito Tanaka, Sakurako Okamoto, Takashi Okamoto


Mikito
Komiyama-san
Chiba-sensei
Me

LCDM has been extensively tested on large scales



Tegmark et al 2004 ApJ

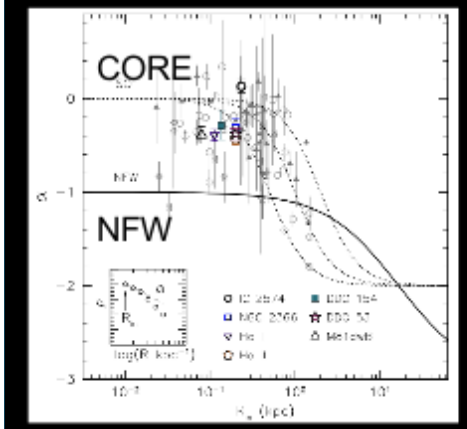
Shamelessly stolen from Hayashi-san's talk at Observational Cosmology Workshop 2015

Current small scale problems in ΛCDM

- ❖ Core-cusp problem
  - Too steep dark matter density profiles of ΛCDM subhalos.
- ❖ Missing satellites problem
  - Overabundance of ΛCDM subhalos.
- ❖ Too-big-to-fail problem
  - Too concentrated most massive ΛCDM subhalos.
- ❖ Satellite plane problem
  - Anisotropic distribution & coherent motion of dwarf satellites

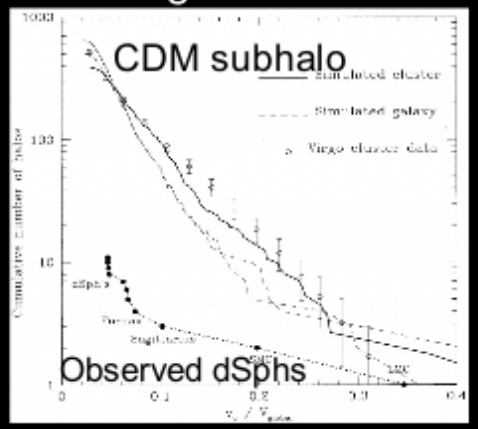
Solutions:
- Baryonic feedbacks?
- Alternative DM models?
- Incomplete observational data?

Core-cusp



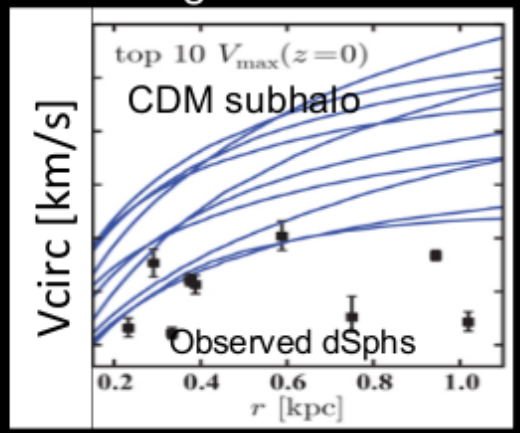
(Oh+ 2011)

Missing satellites



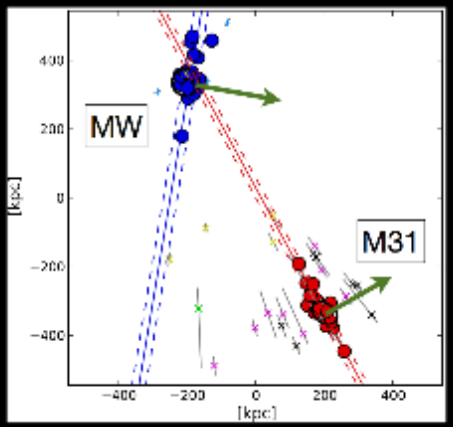
(Moore+ 1999)

Too-big-to-fail



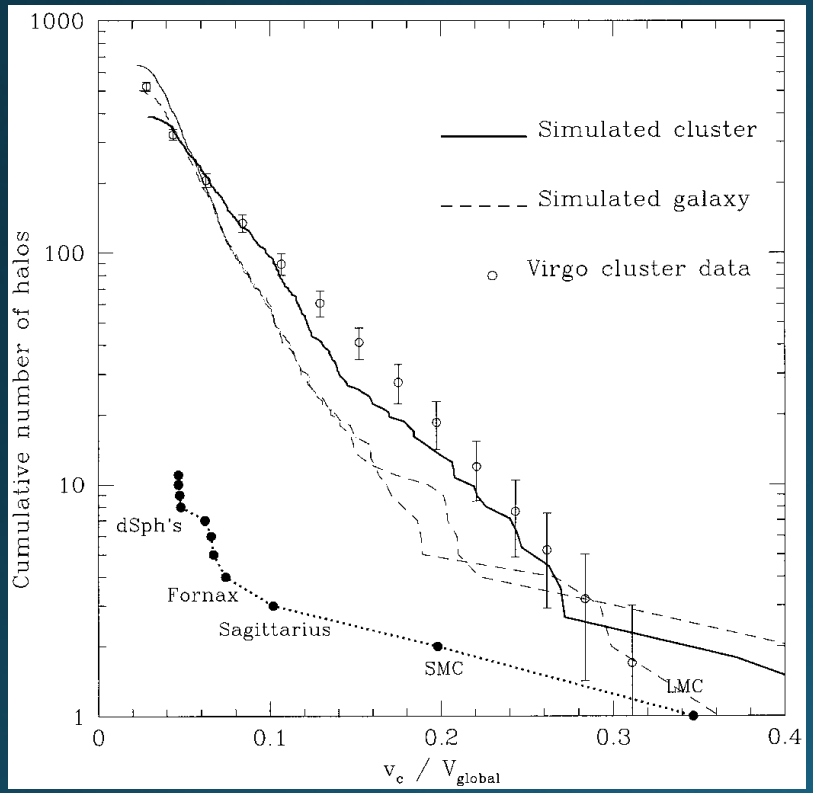
(Boylan-Kolchin+ 2012)

Satellite plane

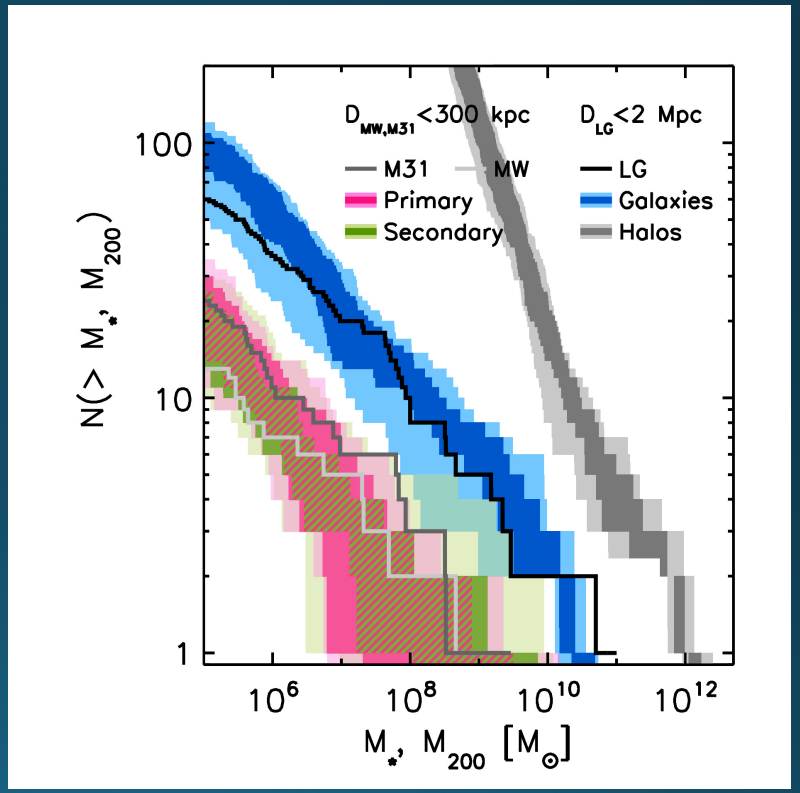


(Pawlowski+ 2013)

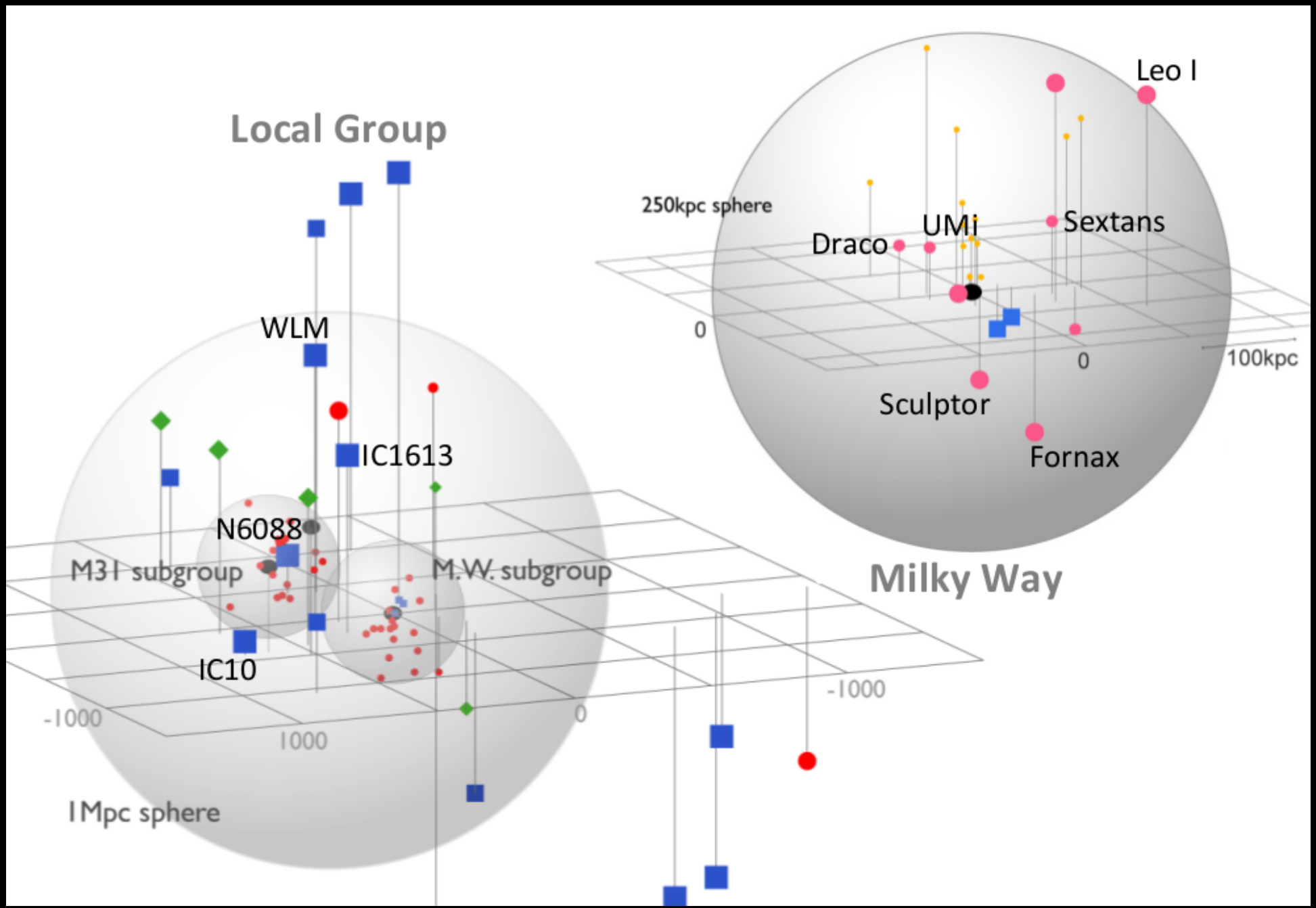
The missing satellite problem



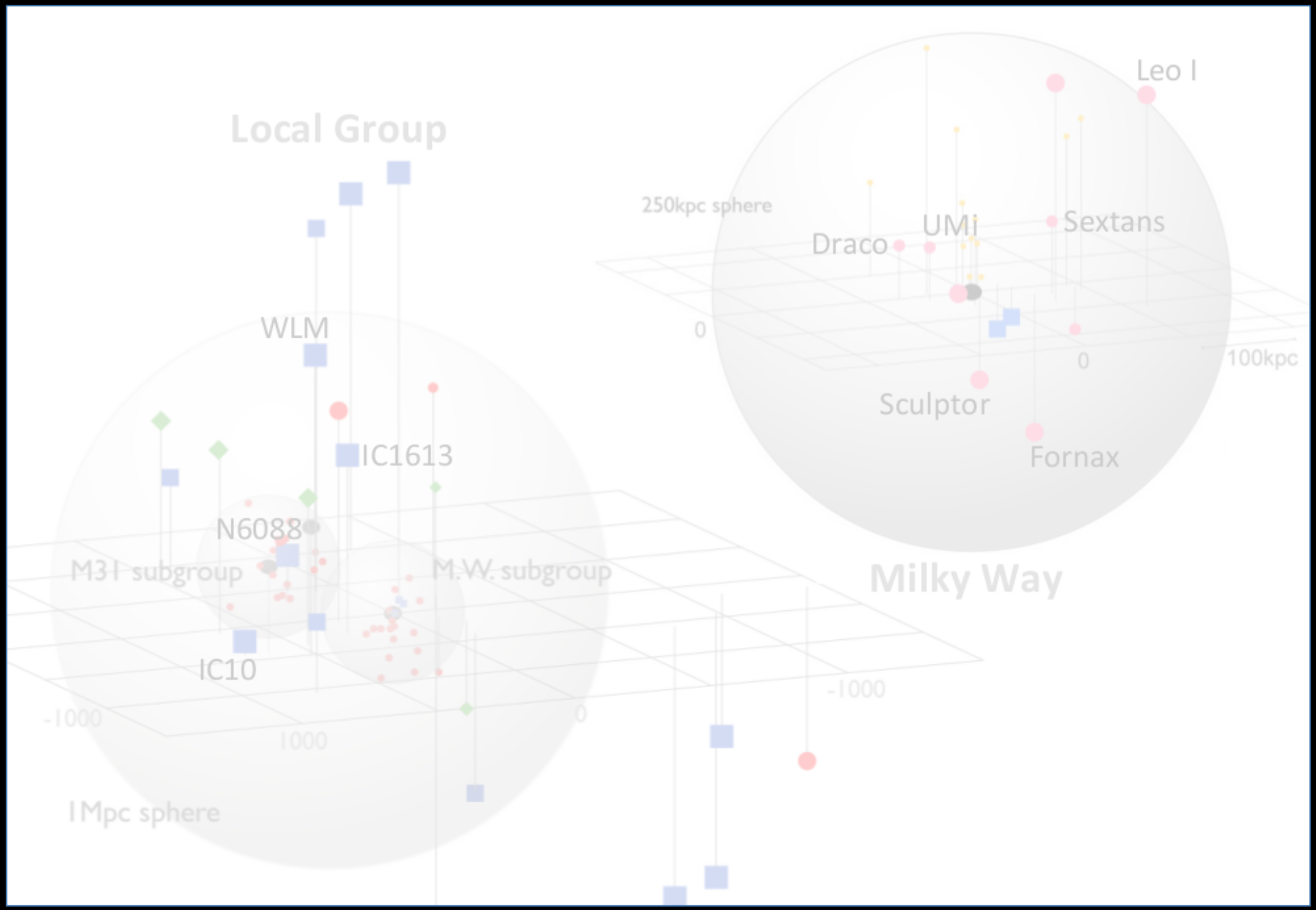
Moore et al. 1999
DM only simulation



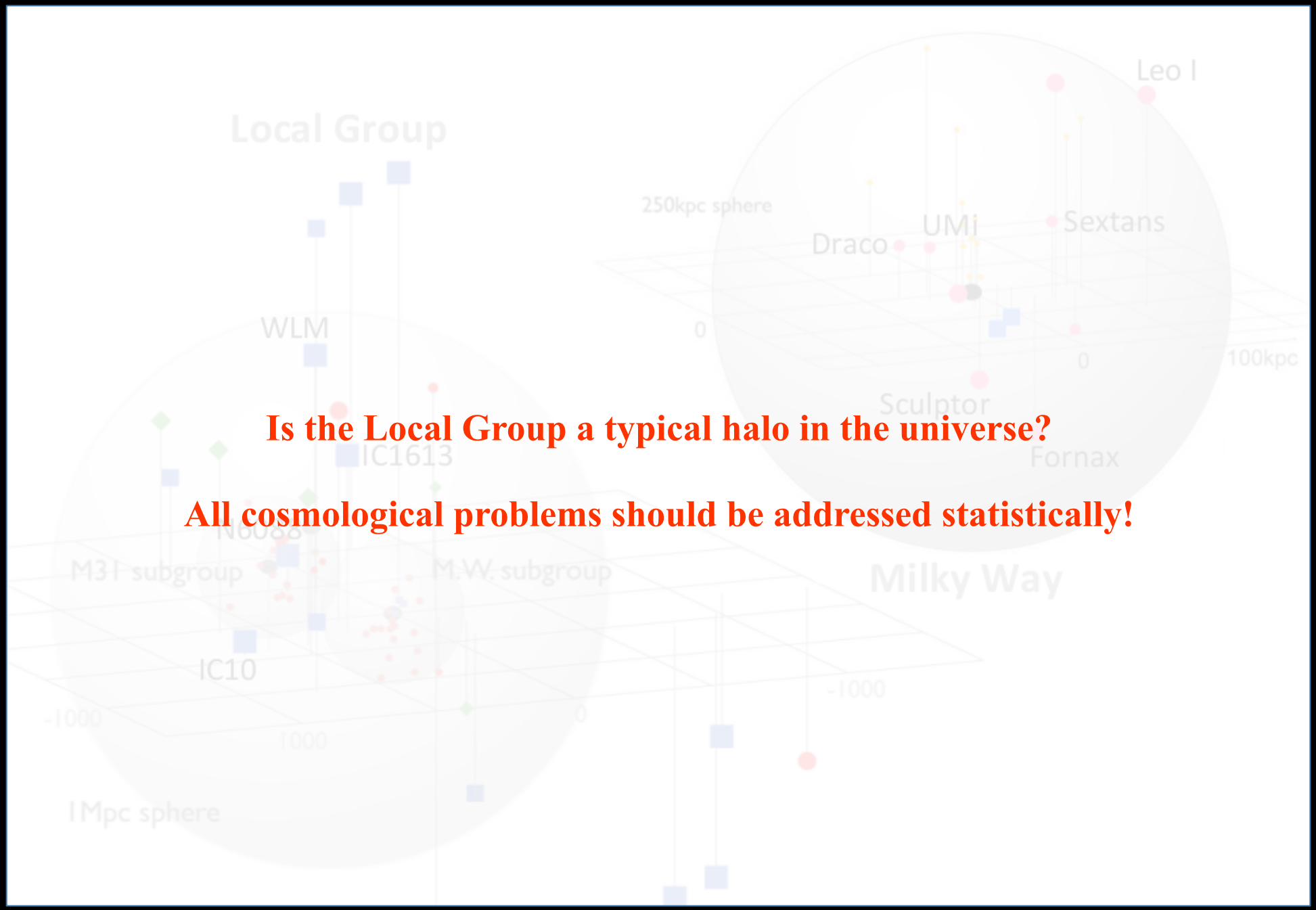
Sawala et al. 2014
DM + Baryon simulation



Courtesy: Sakurako Okamoto



Courtesy: Sakurako Okamoto



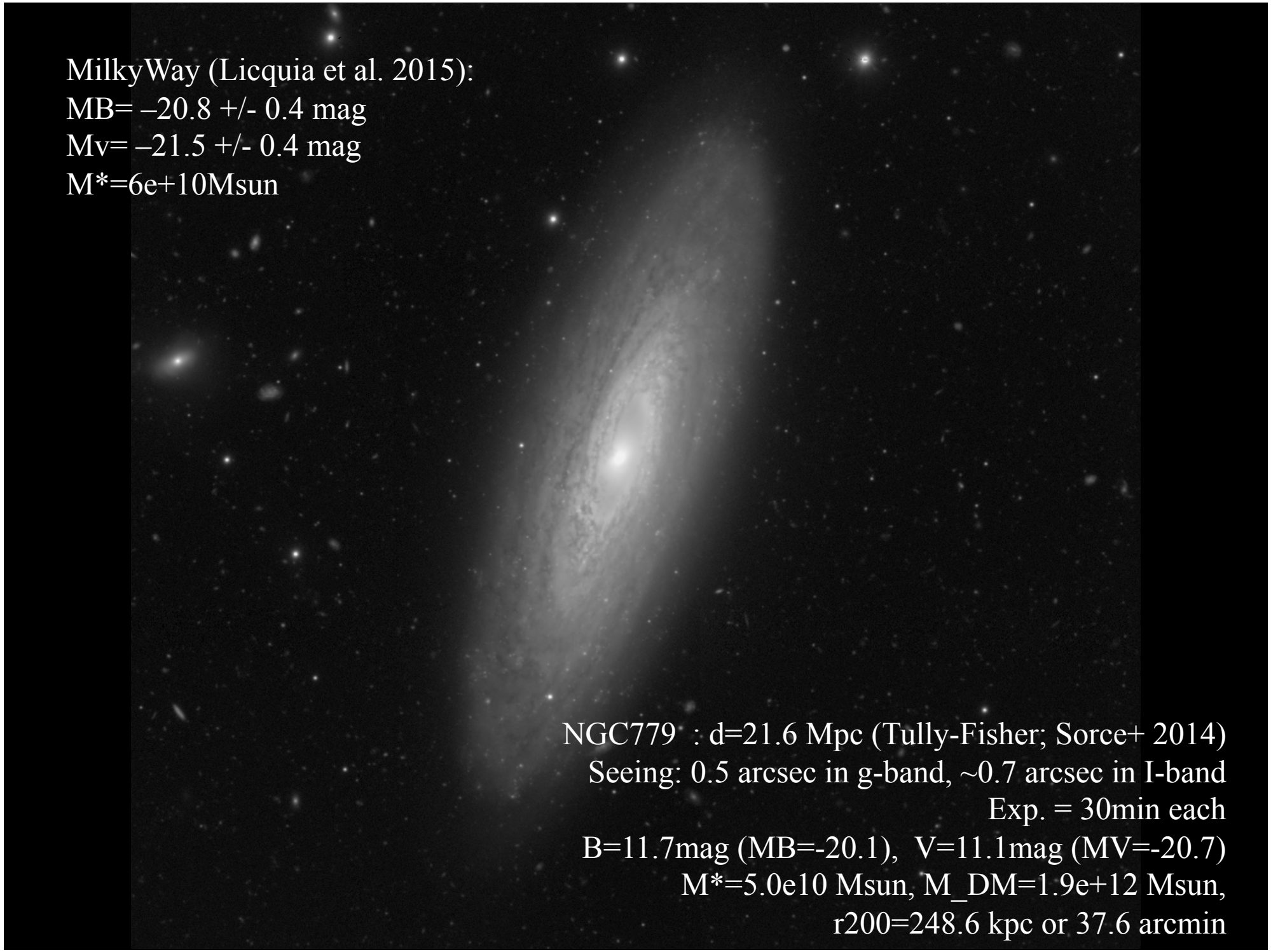
Is the Local Group a typical halo in the universe?

All cosmological problems should be addressed statistically!

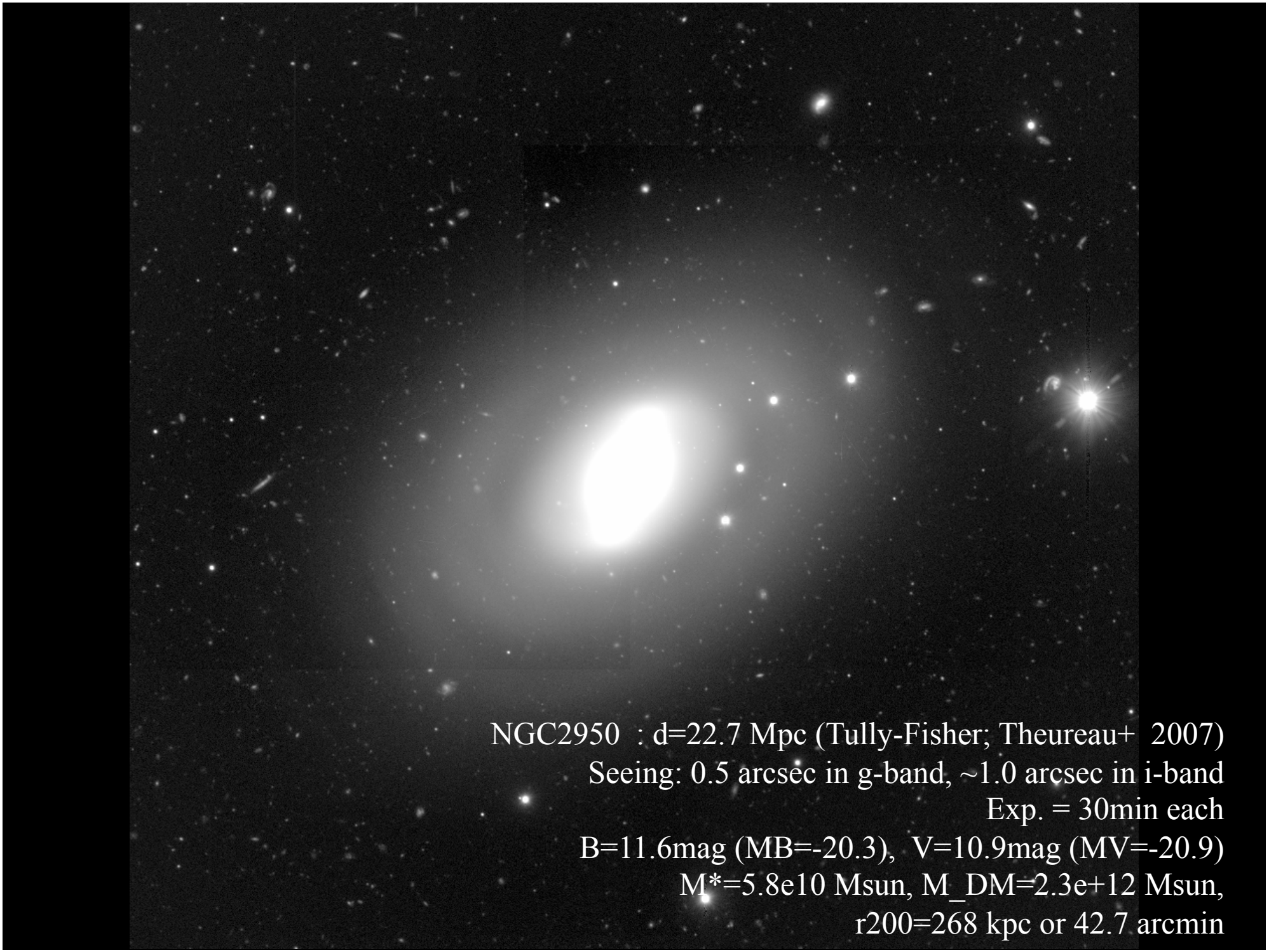
Courtesy: Sakurako Okamoto

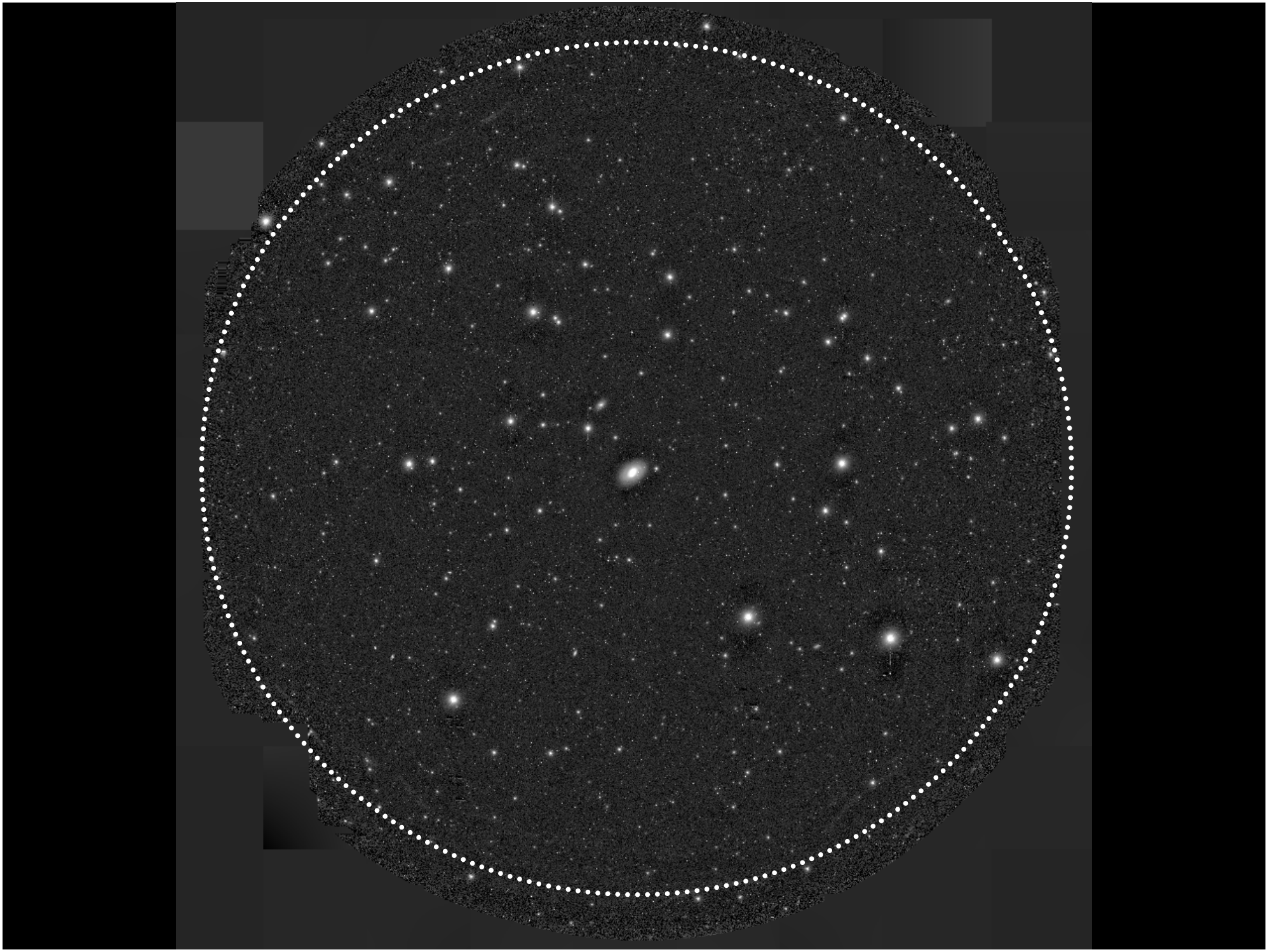
Hyper Suprime-Cam

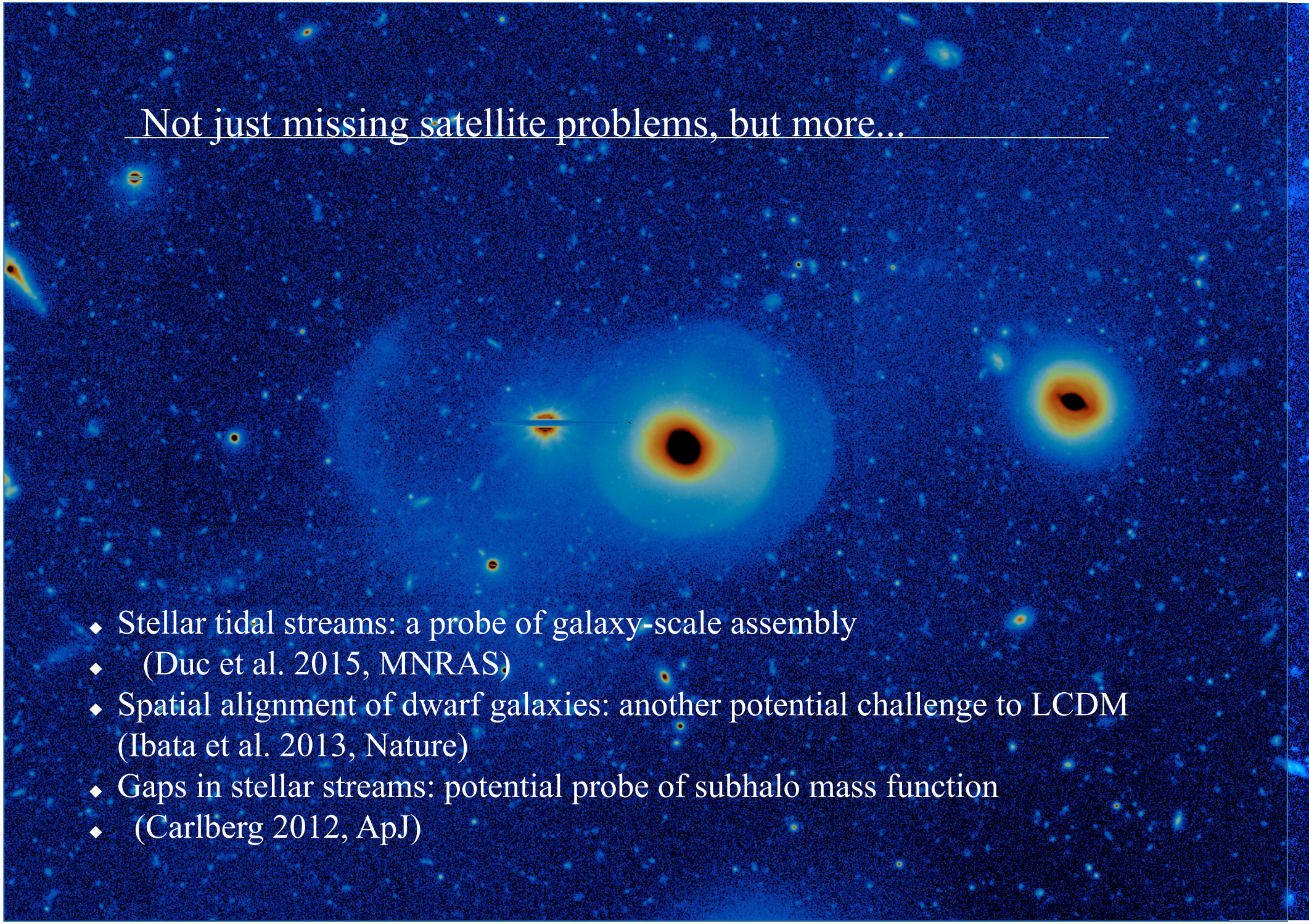
- 1.5 deg phi field of view
-
- Excellent image quality
-
- See Posters #14 (Mineo-sensei) and #16 (Koike-san)


MilkyWay (Licquia et al. 2015):
MB= –20.8 +/- 0.4 mag
Mv= –21.5 +/- 0.4 mag
M*=6e+10Msun
NGC779 : d=21.6 Mpc (Tully-Fisher; Sorce+ 2014)
Seeing: 0.5 arcsec in g-band, ~0.7 arcsec in I-band
Exp. = 30min each
B=11.7mag (MB=-20.1), V=11.1mag (MV=-20.7)
M*=5.0e10 Msun, M_DM=1.9e+12 Msun,
r200=248.6 kpc or 37.6 arcmin

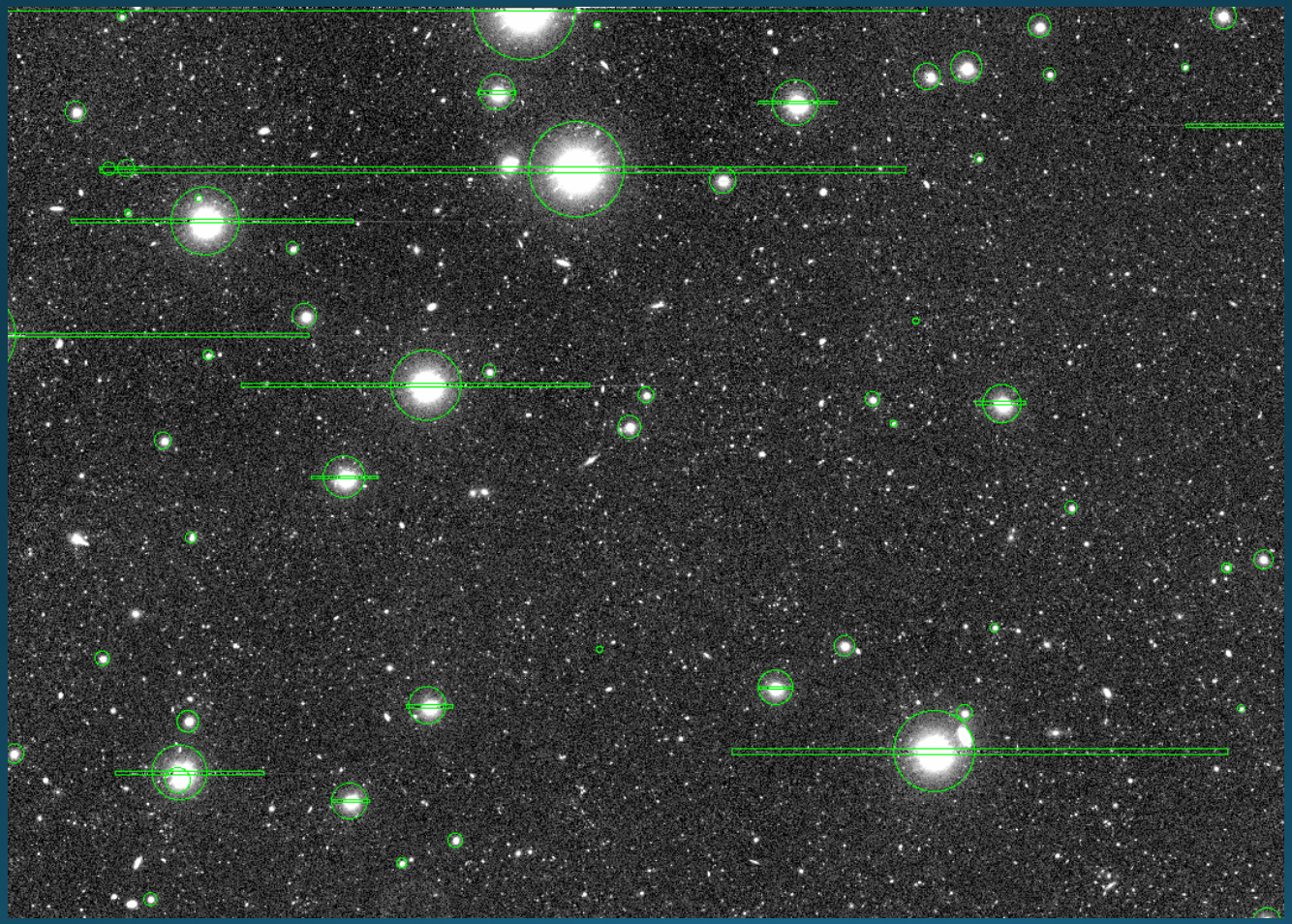

(a) the wide field of view of HSC
(b) the light collecting power of Subaru


NGC2950 : d=22.7 Mpc (Tully-Fisher; Theureau+ 2007)
Seeing: 0.5 arcsec in g-band, ~1.0 arcsec in i-band
Exp. = 30min each
B=11.6mag (MB=-20.3), V=10.9mag (MV=-20.9)
M*=5.8e10 Msun, M_DM=2.3e+12 Msun,
r200=268 kpc or 42.7 arcmin



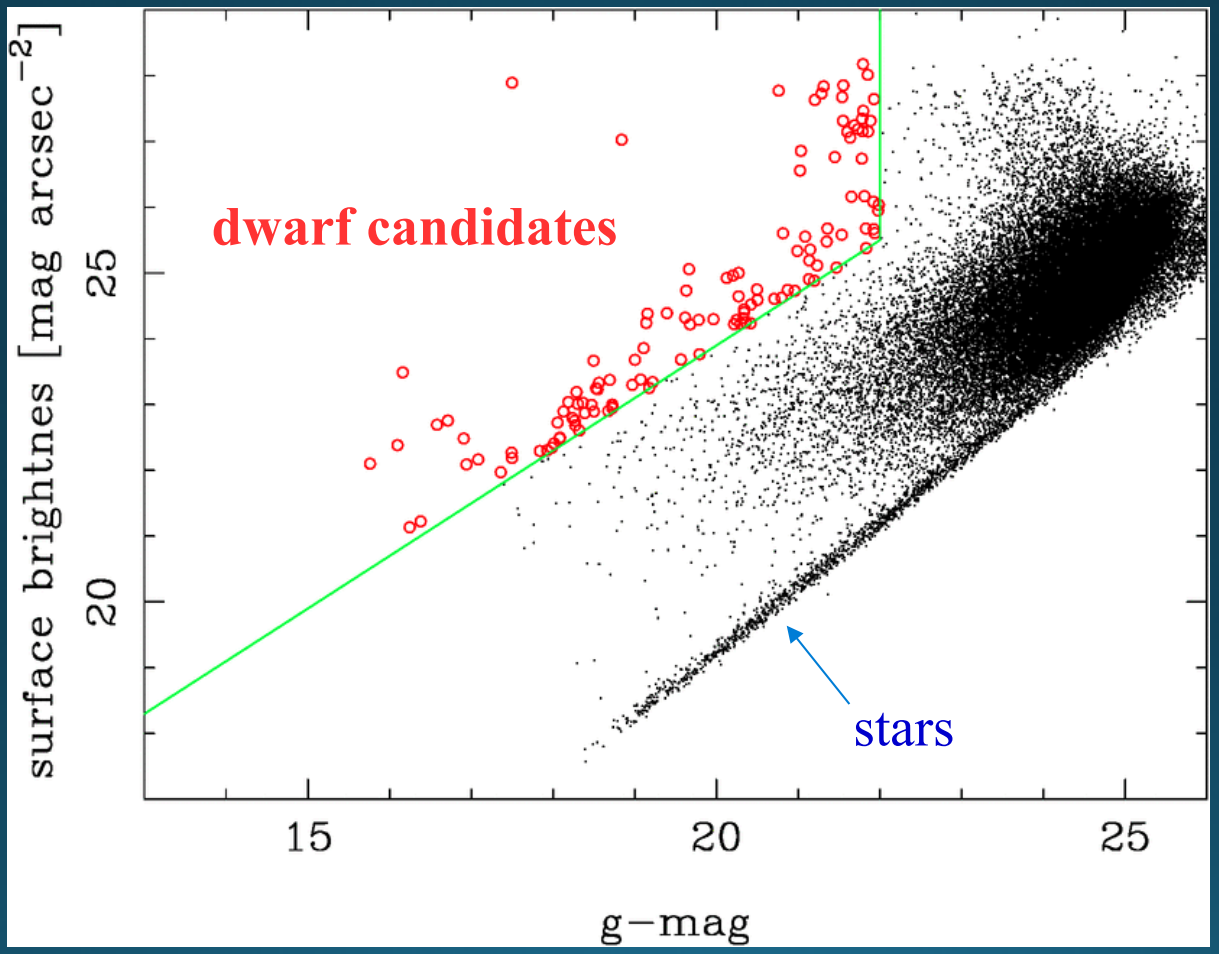

Not just missing satellite problems, but more...
Stellar tidal streams: a probe of galaxy-scale assembly
(Duc et al. 2015, MNRAS)
Spatial alignment of dwarf galaxies: another potential challenge to LCDM
(Ibata et al. 2013, Nature)
Gaps in stellar streams: potential probe of subhalo mass function
(Carlberg 2012, ApJ)

Masks and junks

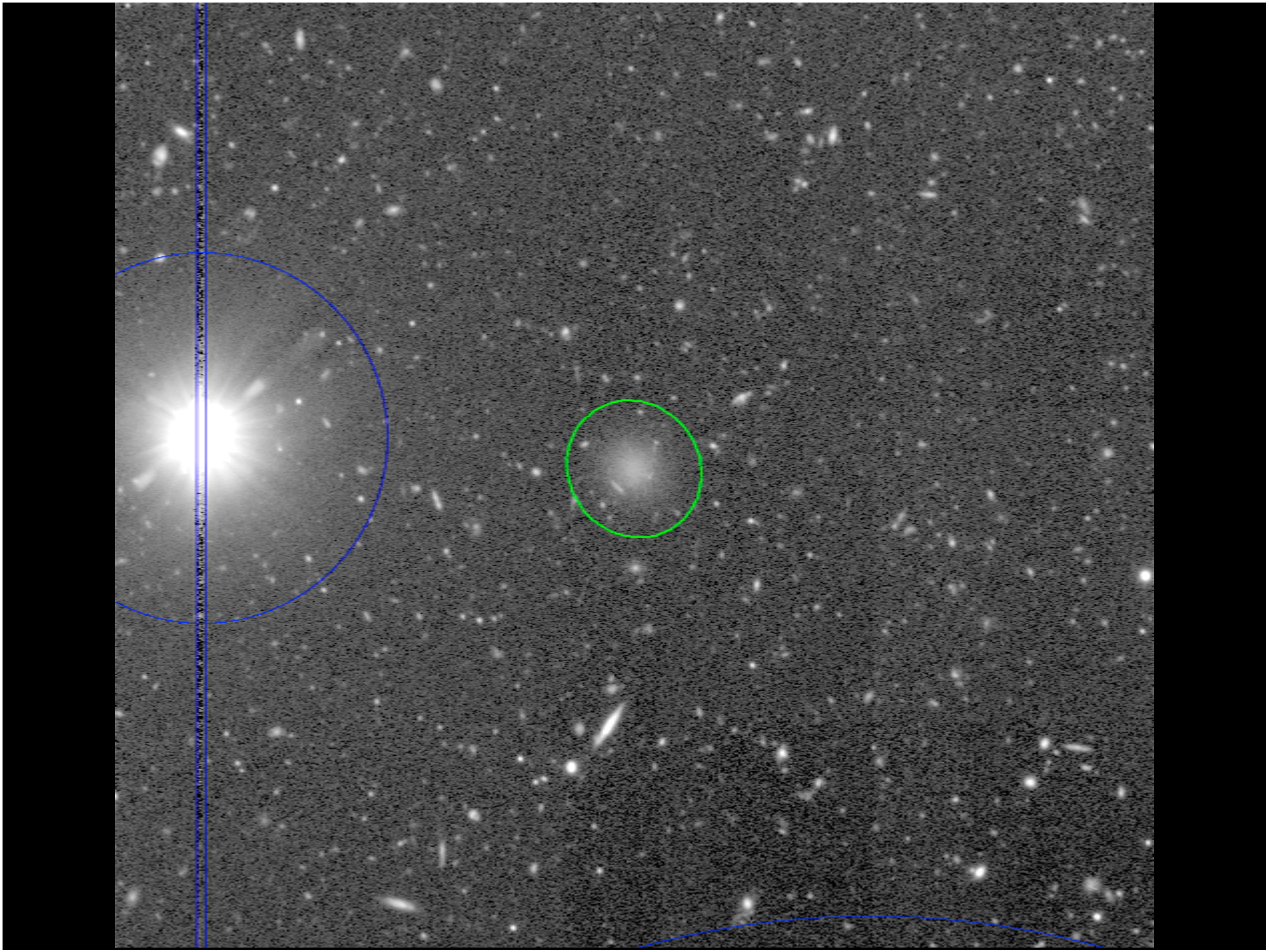


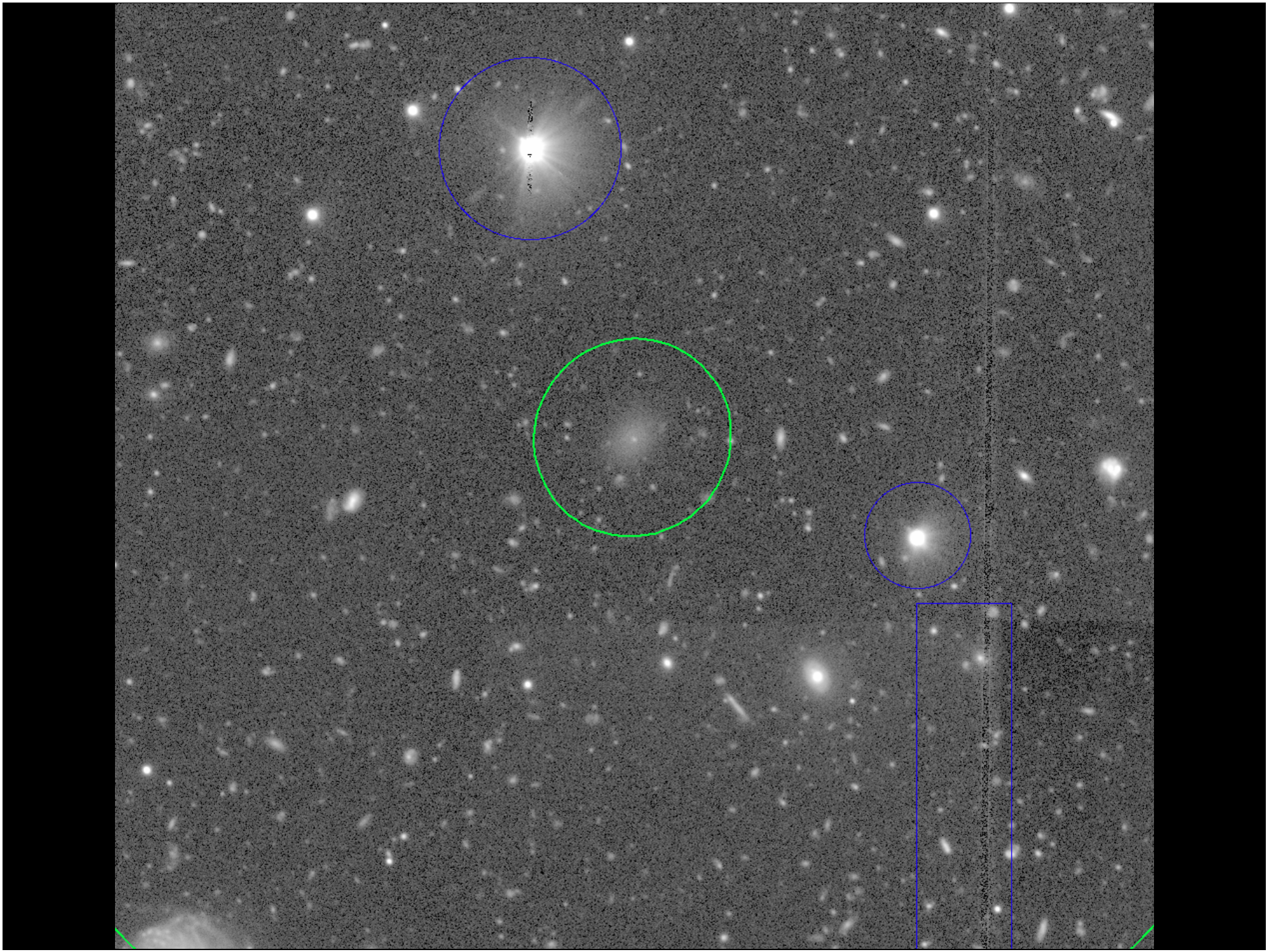
We mask stars, bleeding trails, ghosts, as well as (approximate) virial radii of near-field background galaxies.

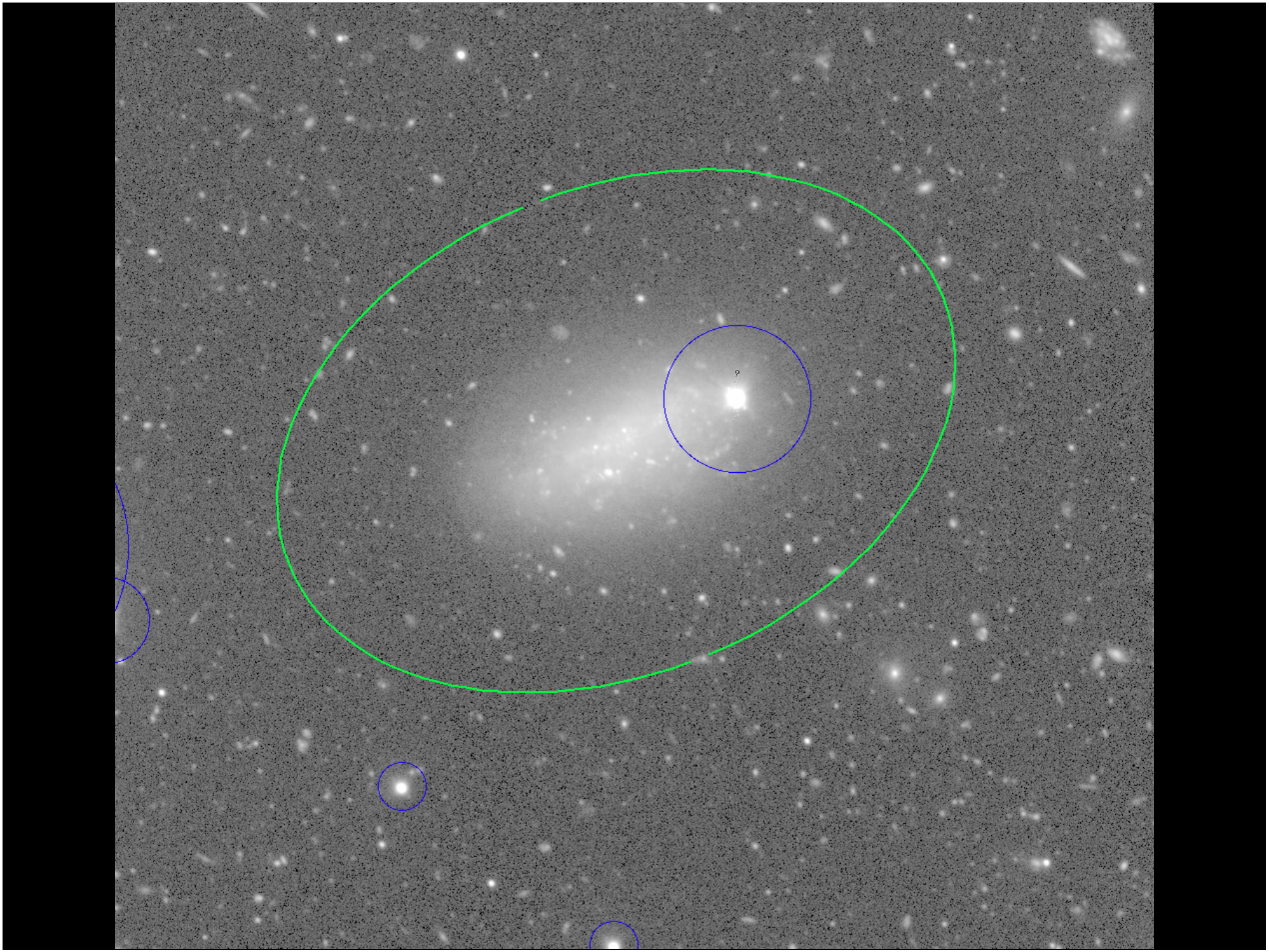
Dwarf galaxy selection



Dwarf candidates (~100 objects per HSC field of view) are visually inspected.





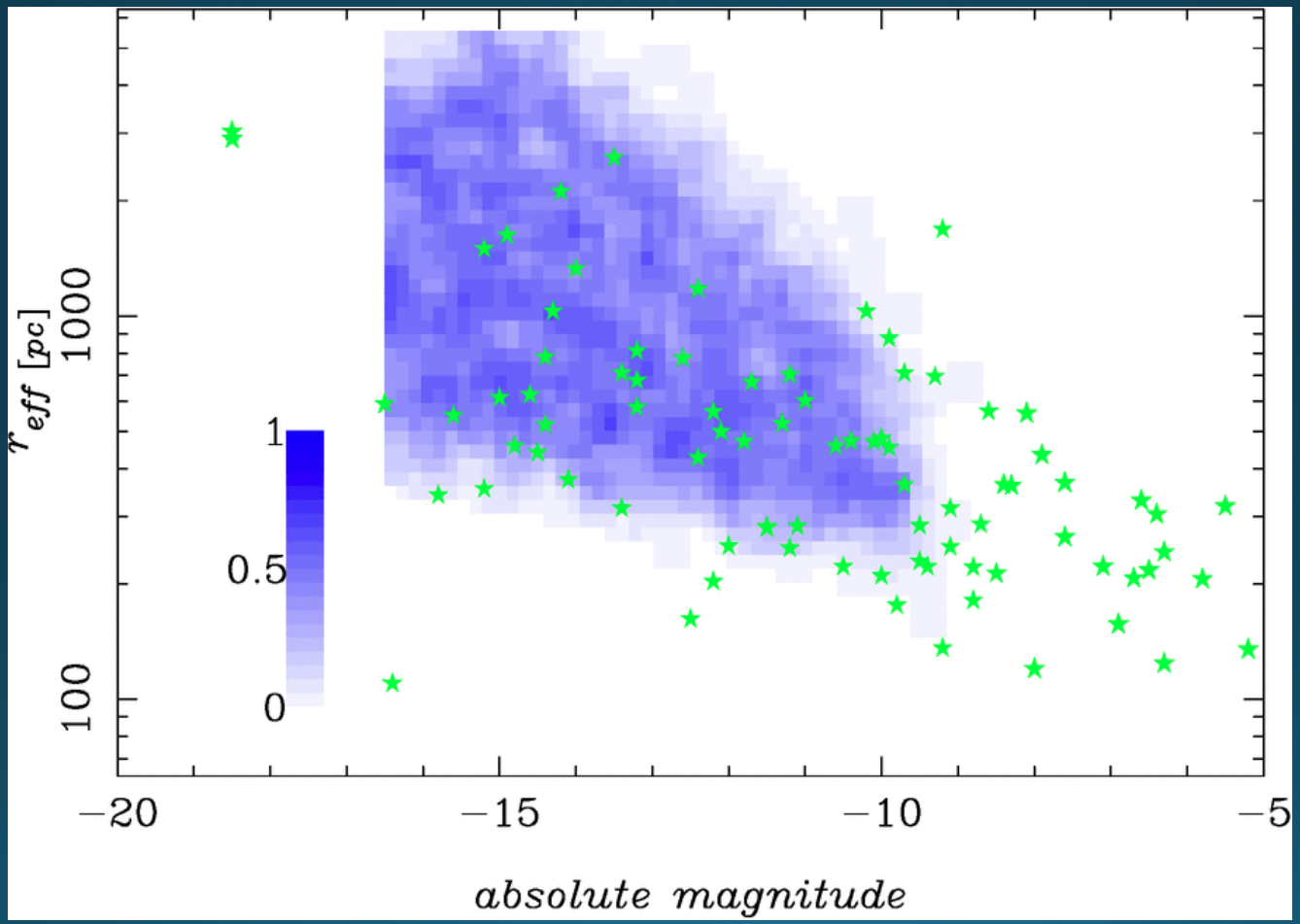


Simulations: detection completeness and flux biases

1. Assume dwarf galaxies have an exponential profile
2. Add artificial sources with a range of sizes and magnitudes to the real image
3. Detect objects
4. Apply masks
5. Match the input and output catalogs
6. Repeat the above procedure
7. Measure the detection completeness and biases in measured fluxes
8. Statistically correct for the incompleteness and flux bias

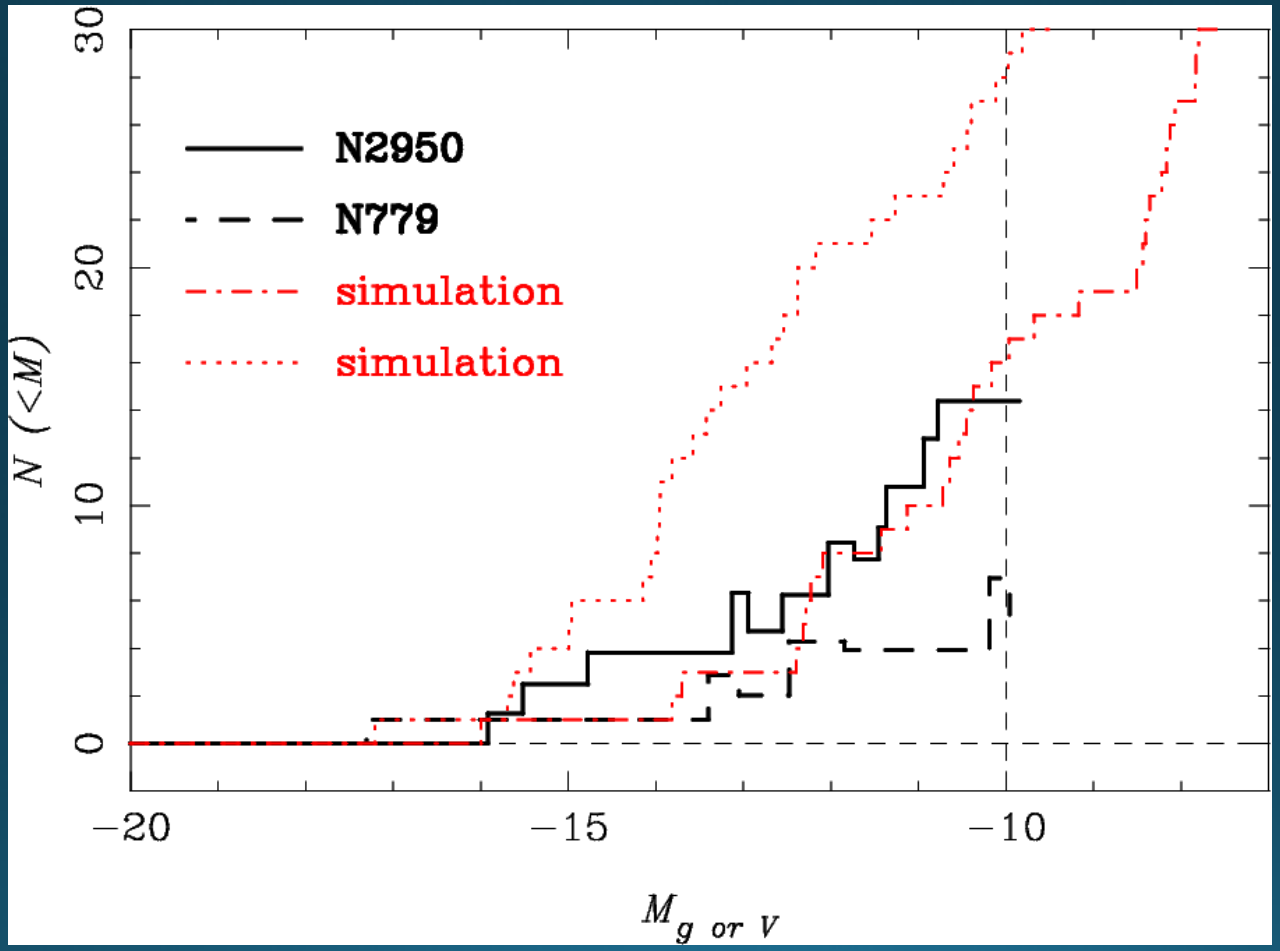
Simulations: detection completeness and flux biases

Detection completeness



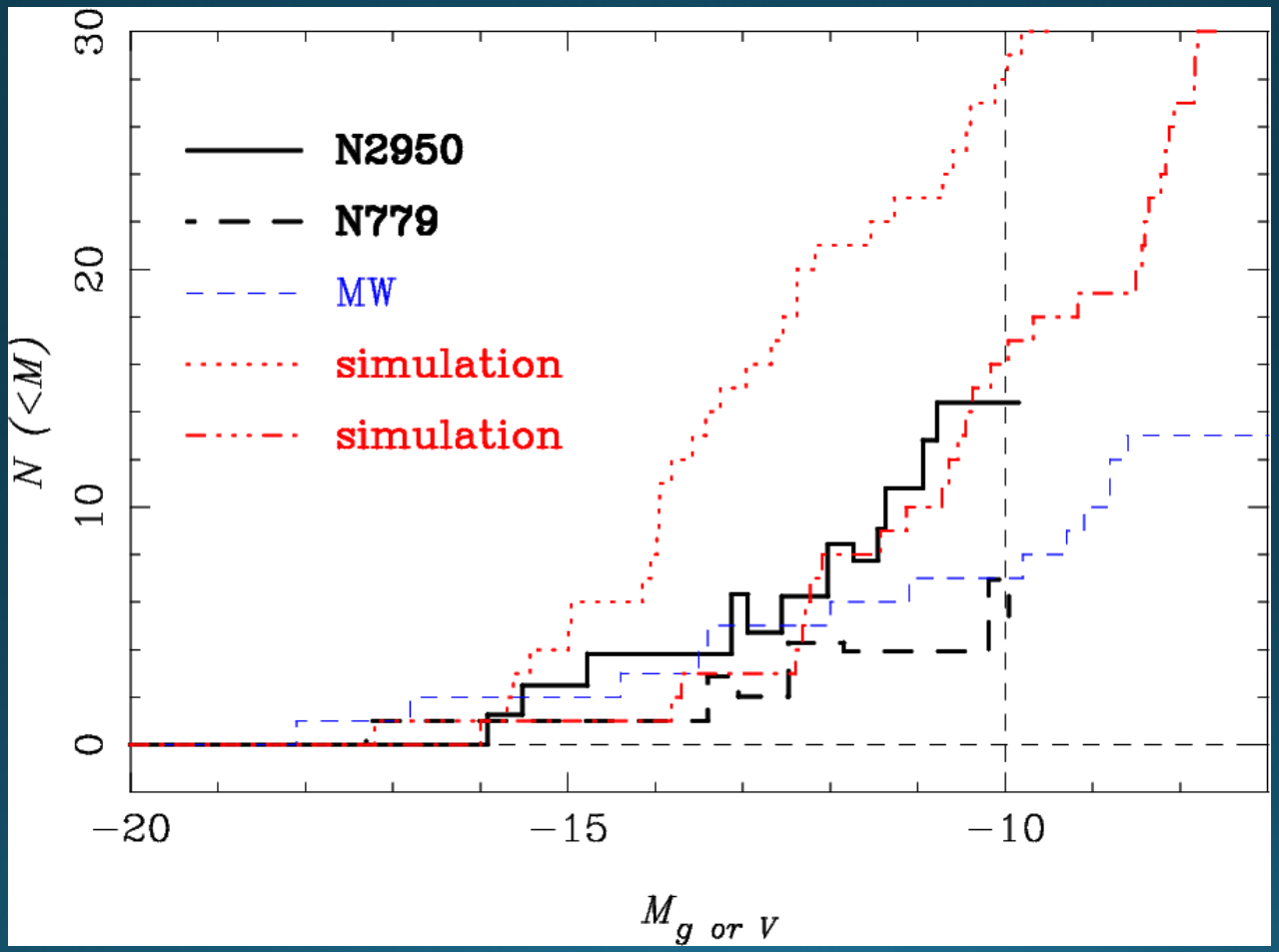
Dwarf galaxies in the Local Group

Preliminary results – cumulative luminosity function



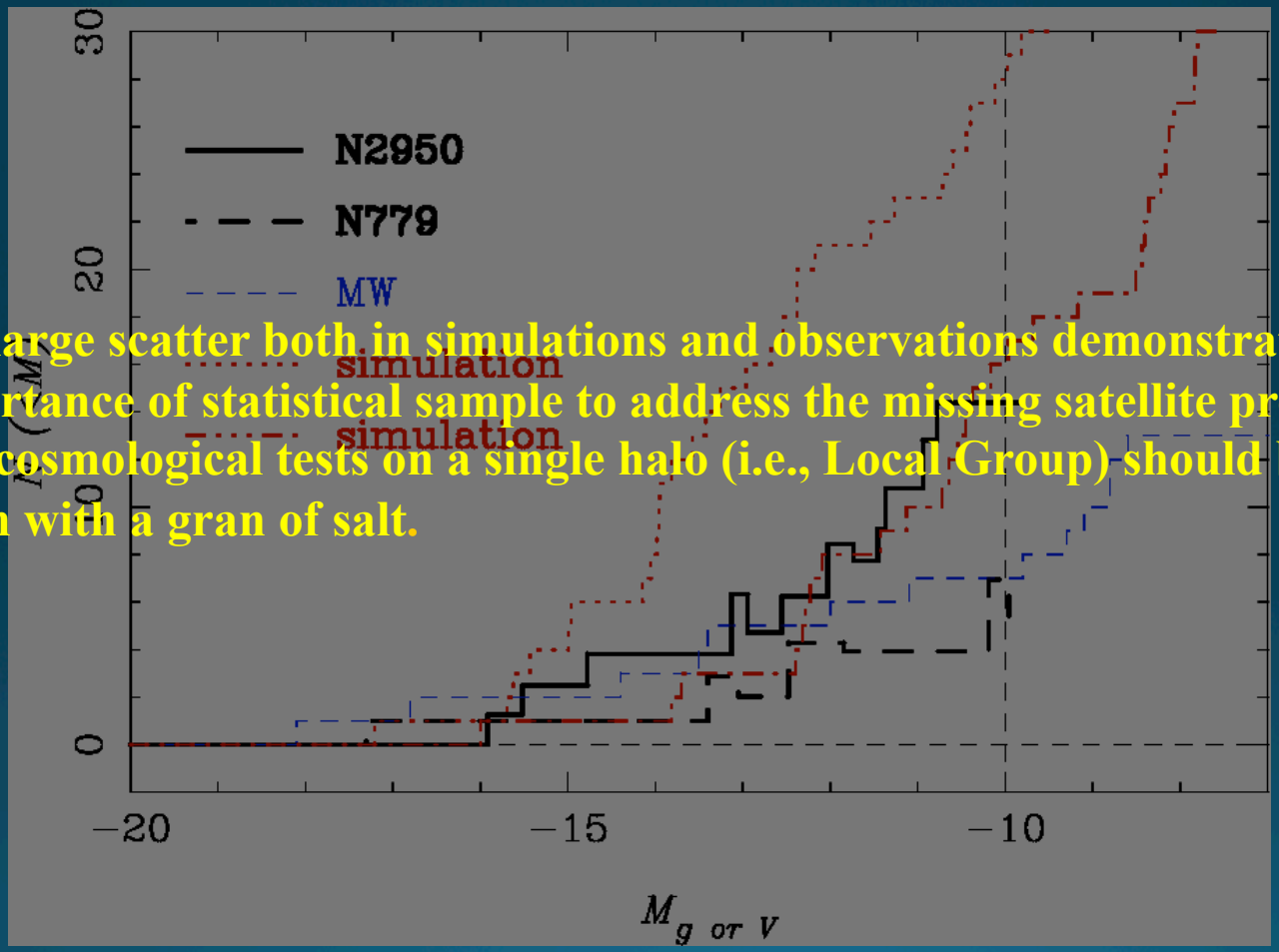
Simulations are from Okamoto (2013, MNRAS, 428, 718).

Preliminary results – cumulative luminosity function



Simulations are from Okamoto (2013, MNRAS, 428, 718).

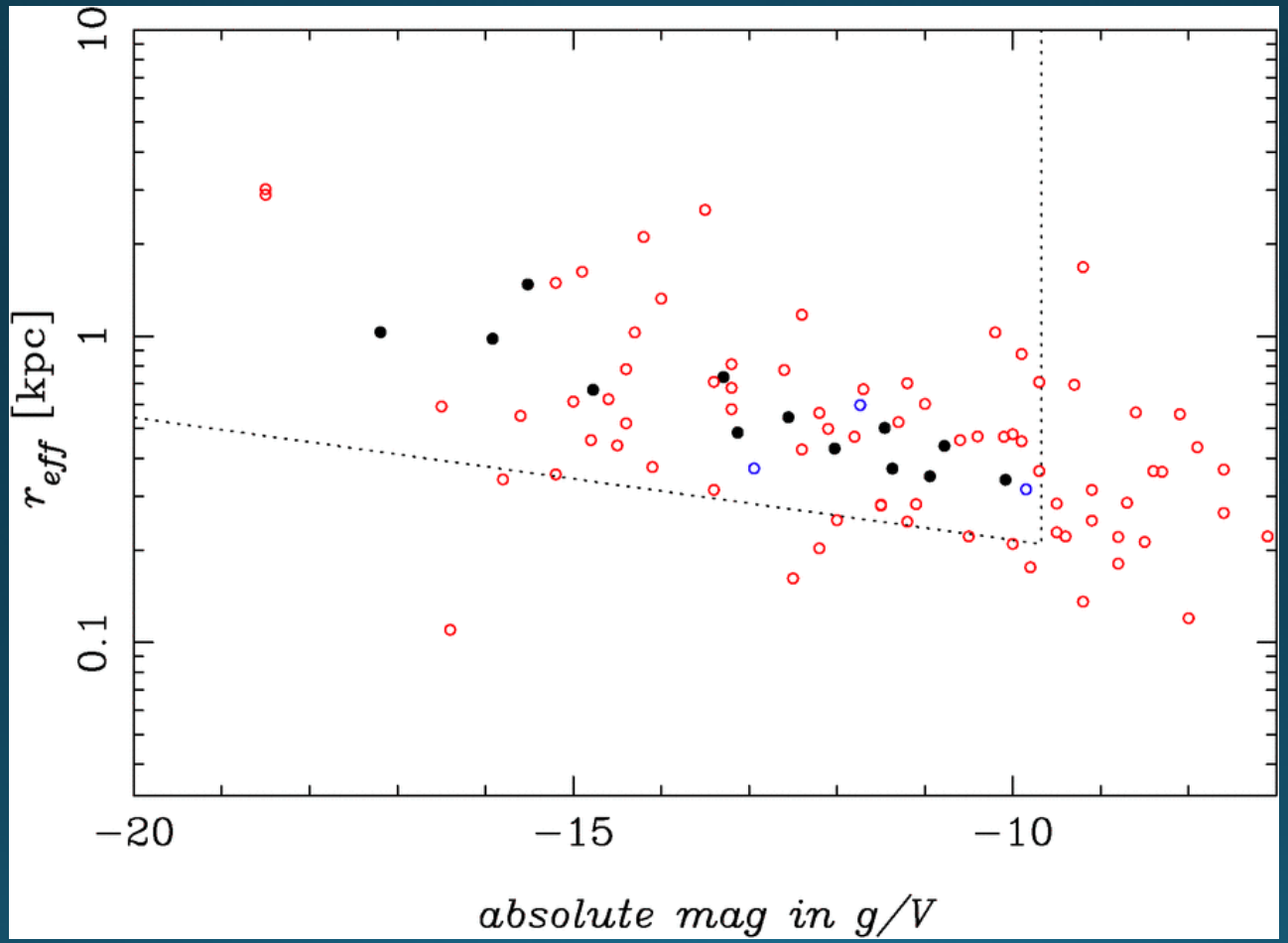
Preliminary results – cumulative luminosity function



The large scatter both in simulations and observations demonstrates the importance of statistical sample to address the missing satellite problem. Any cosmological tests on a single halo (i.e., Local Group) should be taken with a gran of salt.

Simulations are from Okamoto (2013, MNRAS, 428, 718).

Preliminary results – size-luminosity relation:

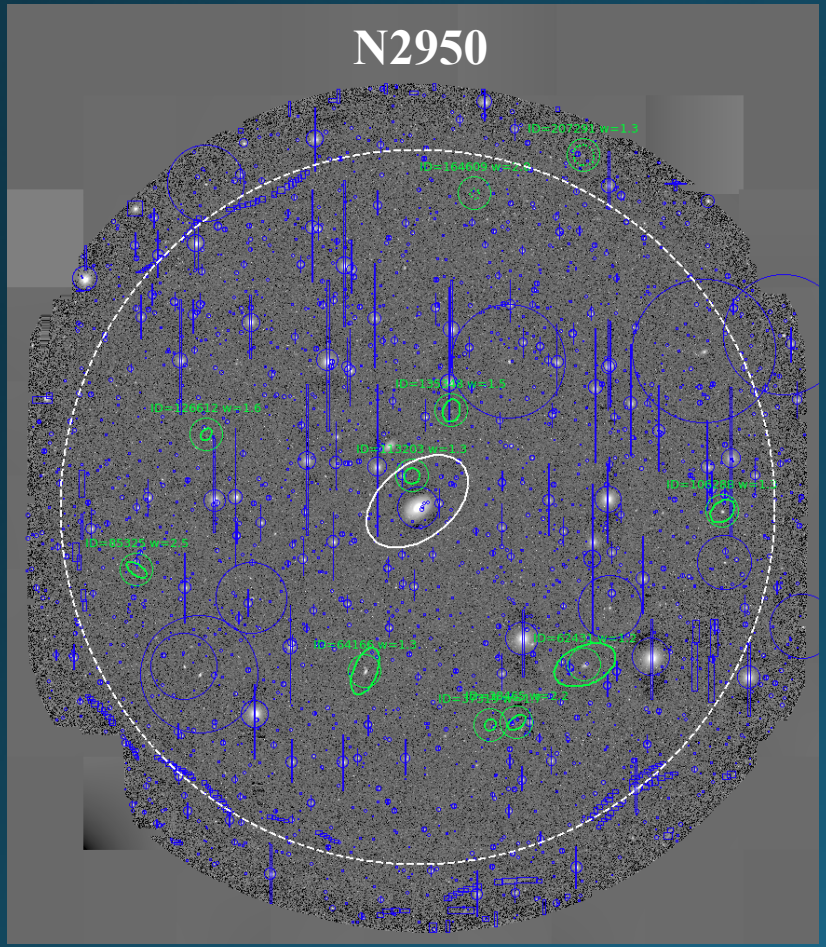


Dwarf galaxies in the Local Group

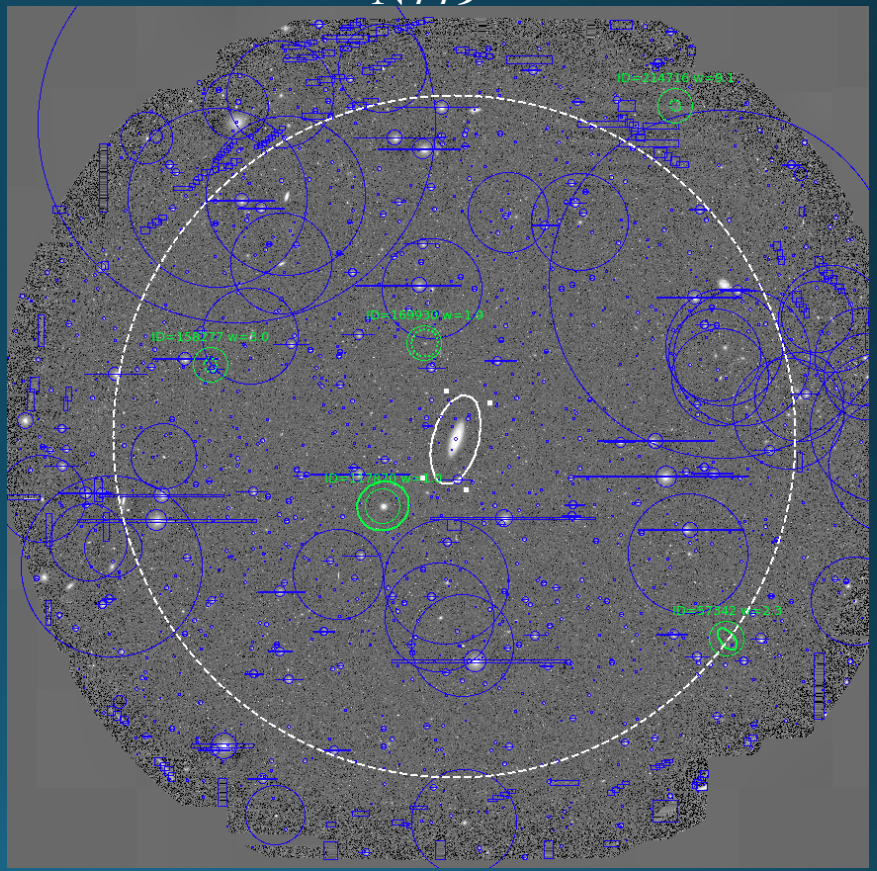
Dwarf galaxies around N779 + N2950

Preliminary results – spatial distribution

N2950



N779



Hm… OK, let's wait for a larger sample.

Summary

We started a survey to statistically address the missing satellite problem with Hyper Suprime-Cam on Subaru.

Our pilot observation shows:

– LFs of dwarf galaxies around N779 and N2950 show a factor of ~2 scatter.

– Okamoto et al. models seem to overpredict the abundance of dwarfs.

Our pilot observation was successful and we learned a lot of lessons. Note our current statistics is already comparable to the state-of-the-art work in the field! We now move on to construct a statistical sample of nearby galaxies.