Searches for new Milky Way satellites and implications for the nature of dark matter

Masashi Chiba (Tohoku Univ)

With D. Homma, Y. Komiyama, Masayuki/Mikito Tanaka, M.N. Ishigaki, and MW/HSC-SSP team

新学術領域シンポ 2018.02.10

Small-scale issues in ΛCDM

- Missing satellite problem
  - Overabundance of dark subhalos (vs. ~50 MW satellites)
- Core/cusp, too big to fail problems
  - Cuspy + Too concentrated massive subhalos (vs. cored..)

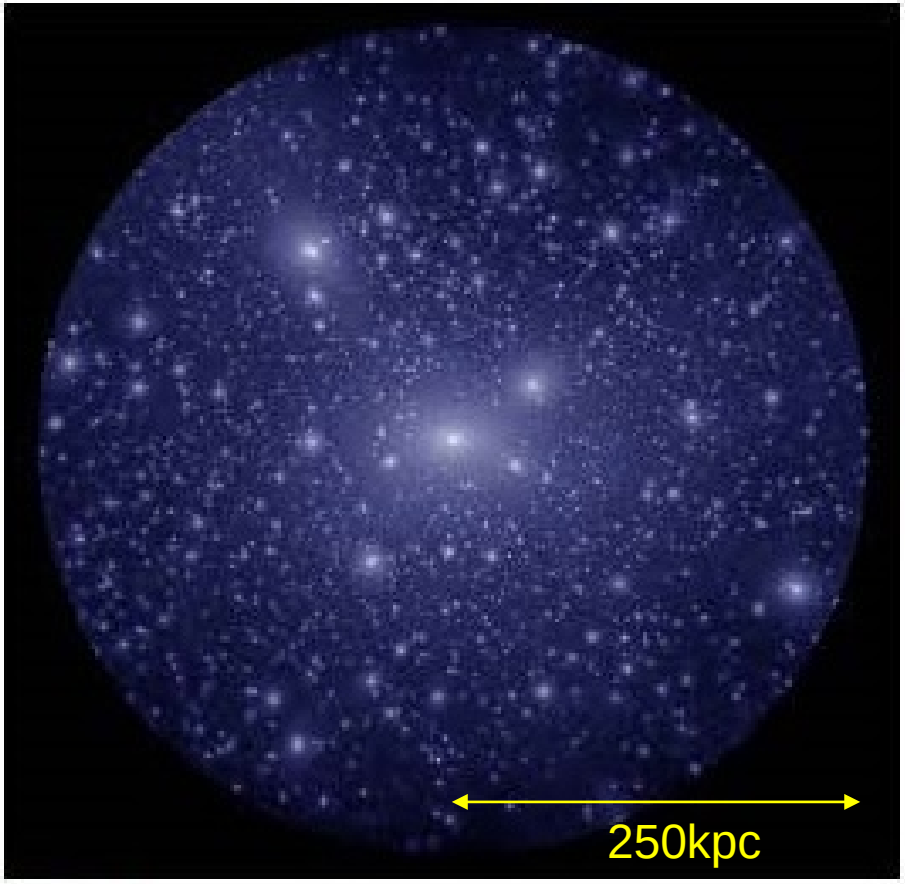
+ other issues (anisotropic distribution)

Solutions
- Alternative DM models?
- Baryon effects?
- Limitations in observations?

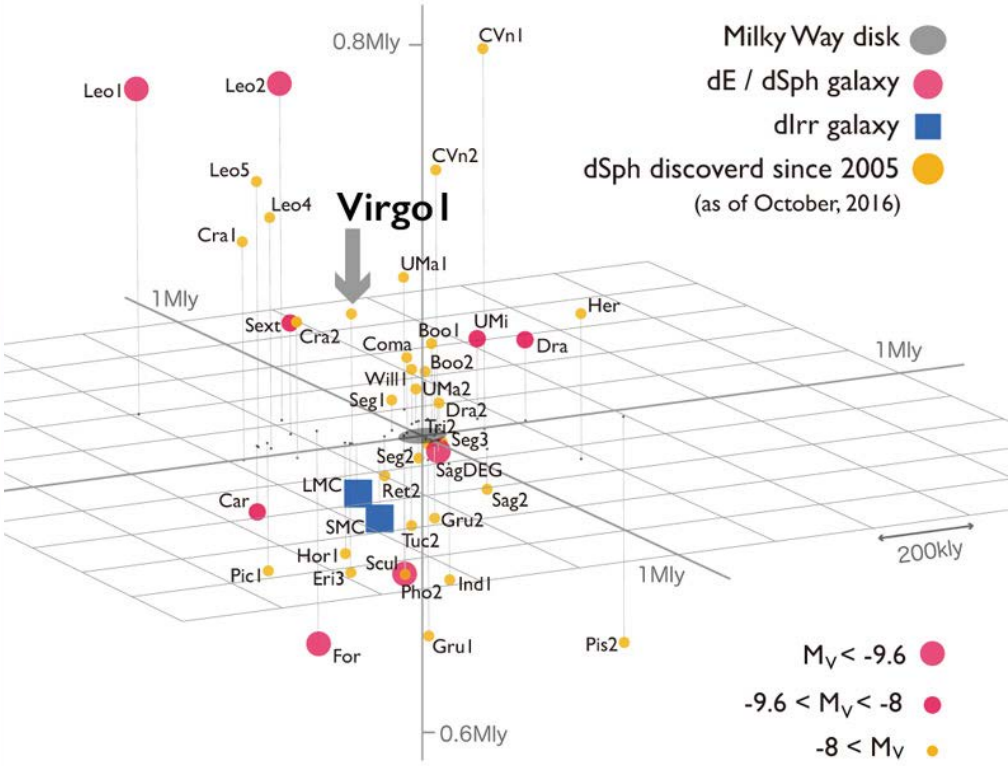
Dwarf spheroidal galaxies (dSphs) in the Local Group provide clues to these issues

Missing satellite problem

ΛCDM simulation for a MW-sized halo
(Bullock & Boylan-Kolchin 2017)



Observed satellites in the MW
(as of 2016)

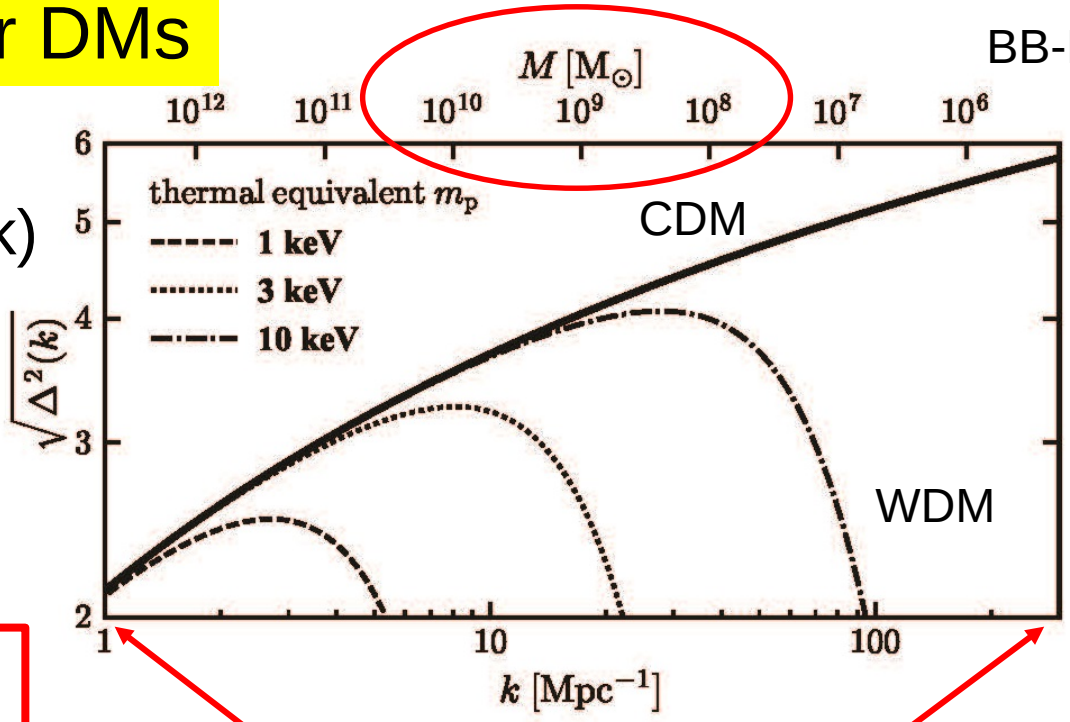


~ 50 satellites identified

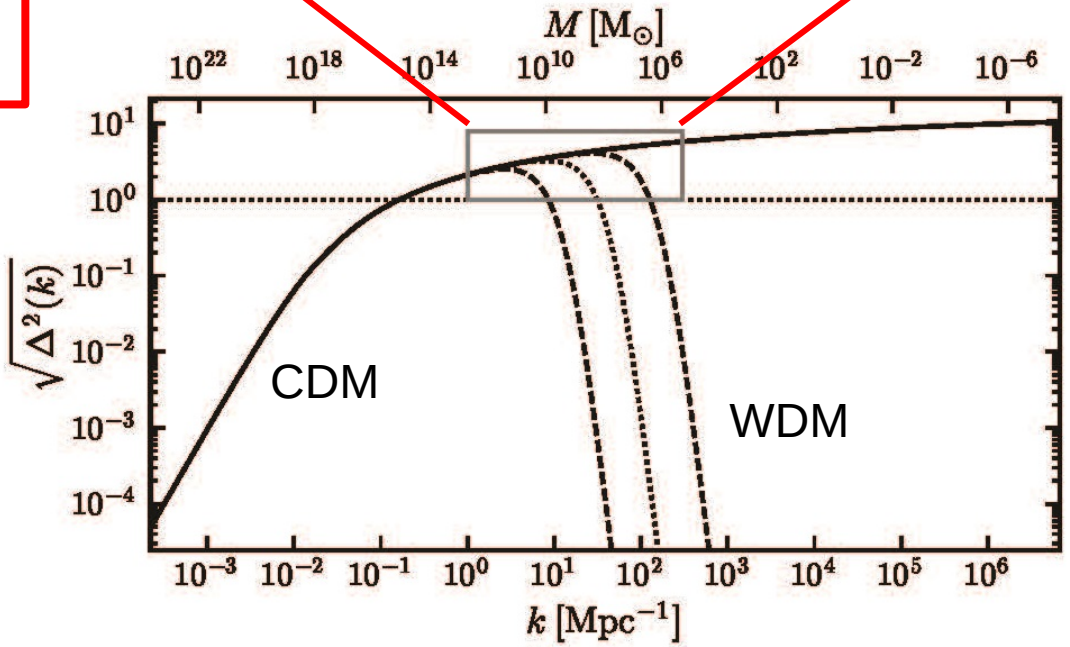
Power spectrum for DMs

BB-K2017

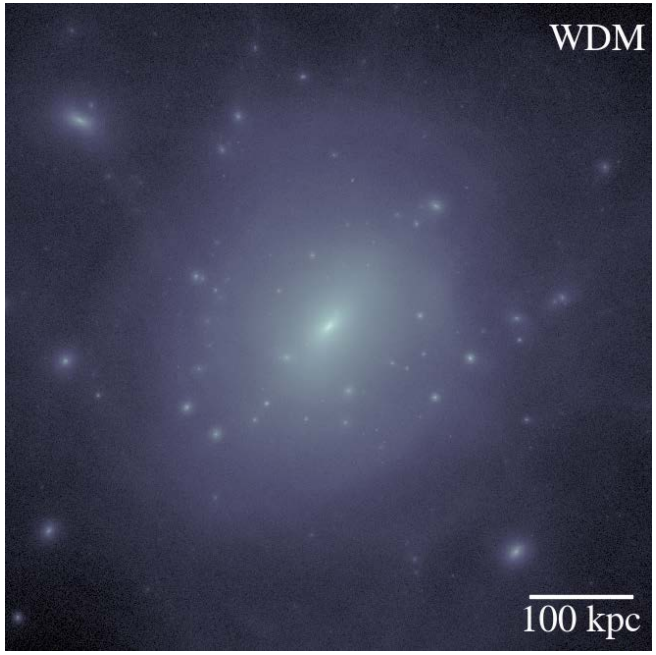
$$\Delta^2(k) \propto \frac{k^3}{2\pi} P(k)\, T^2(k)$$



Dark halos on scales of dwarf galaxies are most important keys

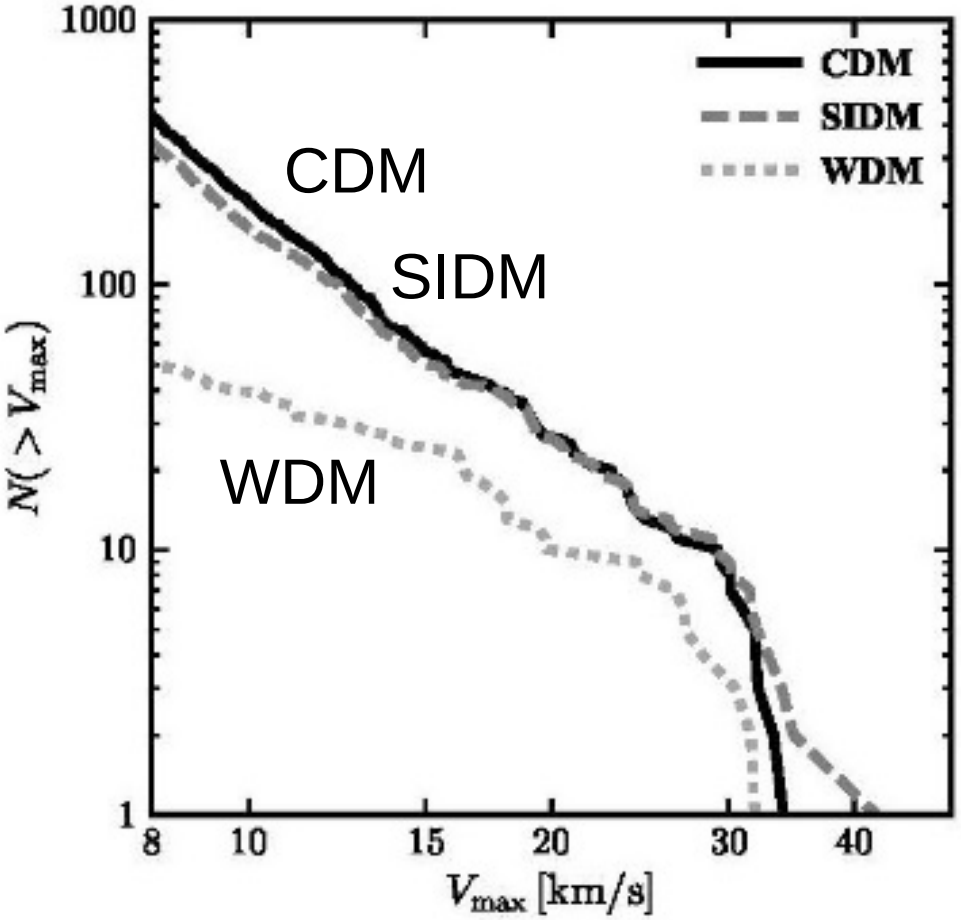


WDM



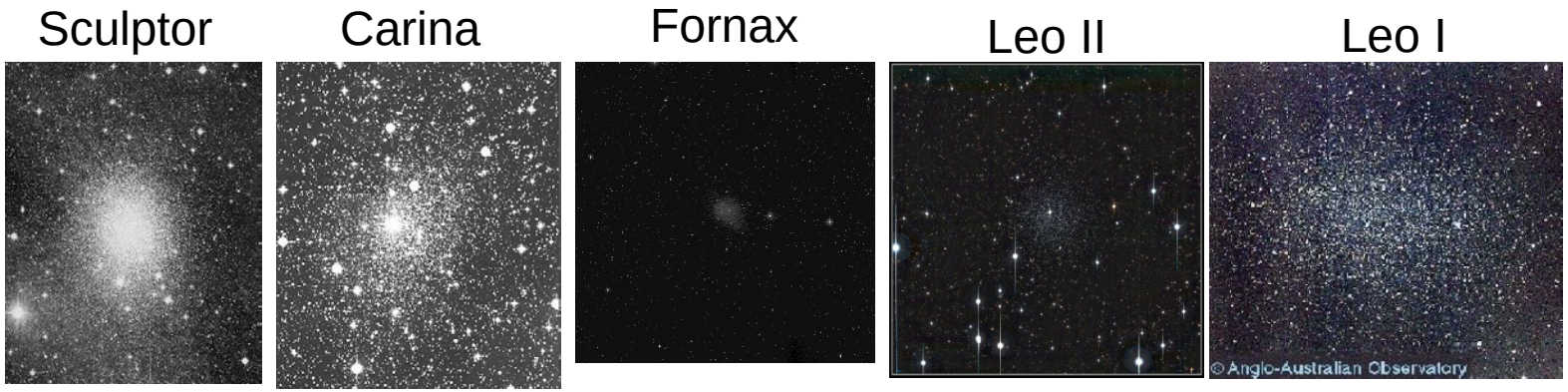
SIDM

Mass functions of subhalos



Dwarf spheroidal galaxies (dSphs)

- Dominant satellites in the Milky Way and M31
  - No gas, diffuse and faint stellar systems

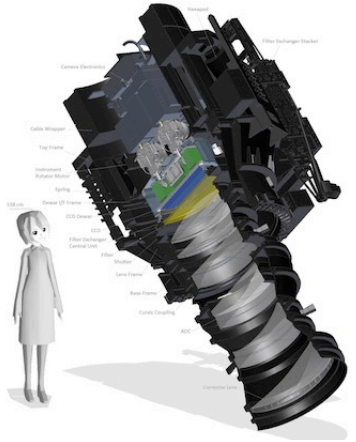


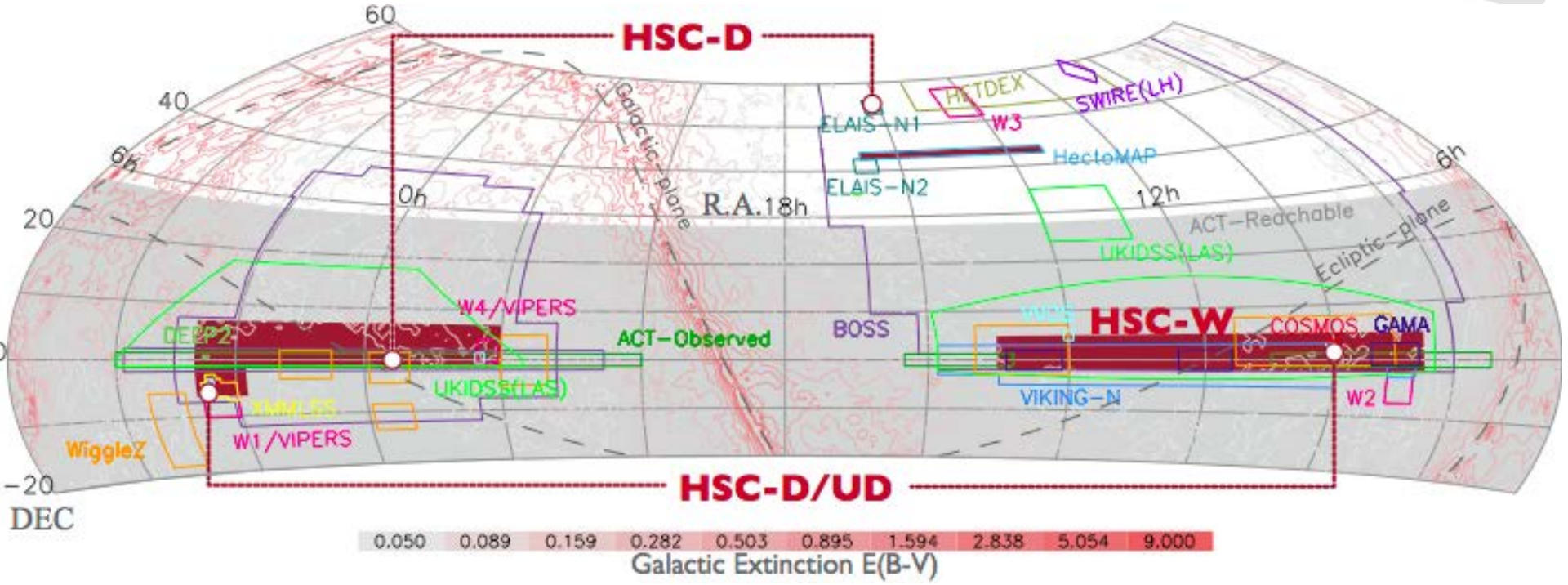
- Dark matter dominated
  - $(M/L)_{tot} = 10 \sim$ a few thousands or more
  - Ideal site for the study of DM

HSC Subaru Strategic Program (SSP)

- Search for new MW dSphs from the wide-layer data

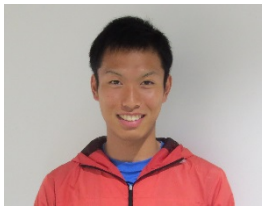
  (S17A: ~ 580 deg^2 / 1,400 deg^2)



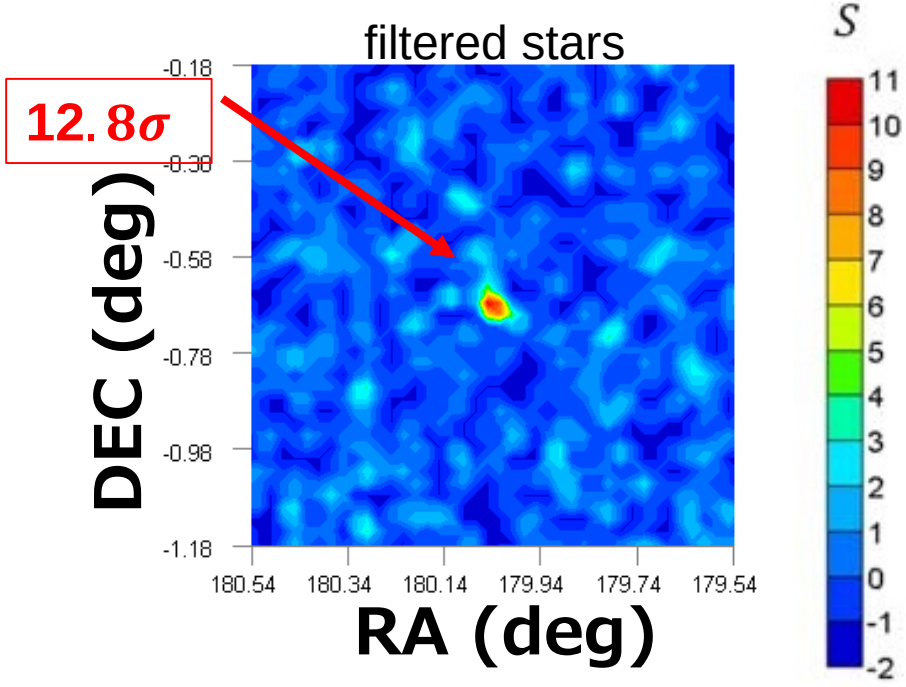


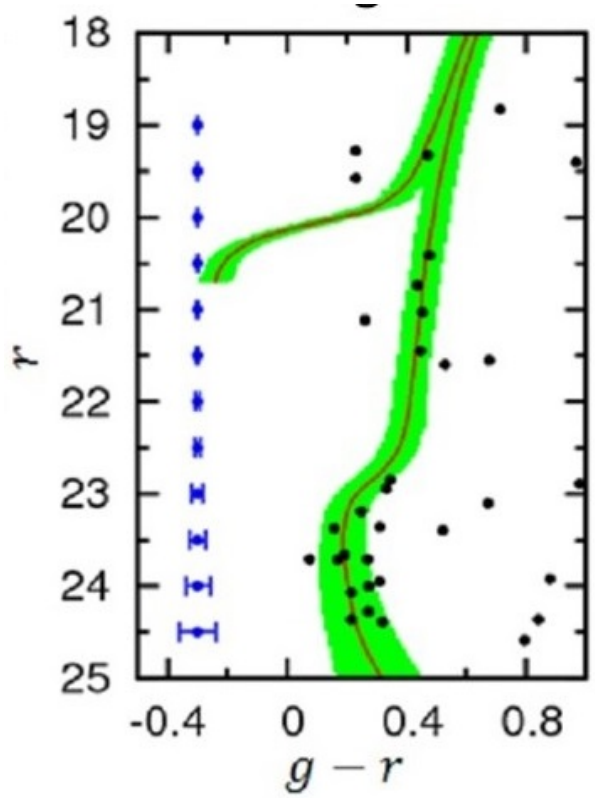
1st new dwarf galaxy discovered: Virgo I

Homma, Chiba, et al. 2016, ApJ, 832, 21



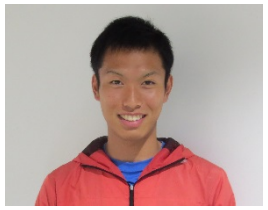
Coordinates : $(\alpha, \delta) = (180°.04, -0°.68)$
Absolute magnitude : $M_V = -0.33$ mag
Heliocentric distance : $D = 87^{+13}_{-8}$ kpc
Half light radius : $r_h = 38^{+12}_{-11}$ pc



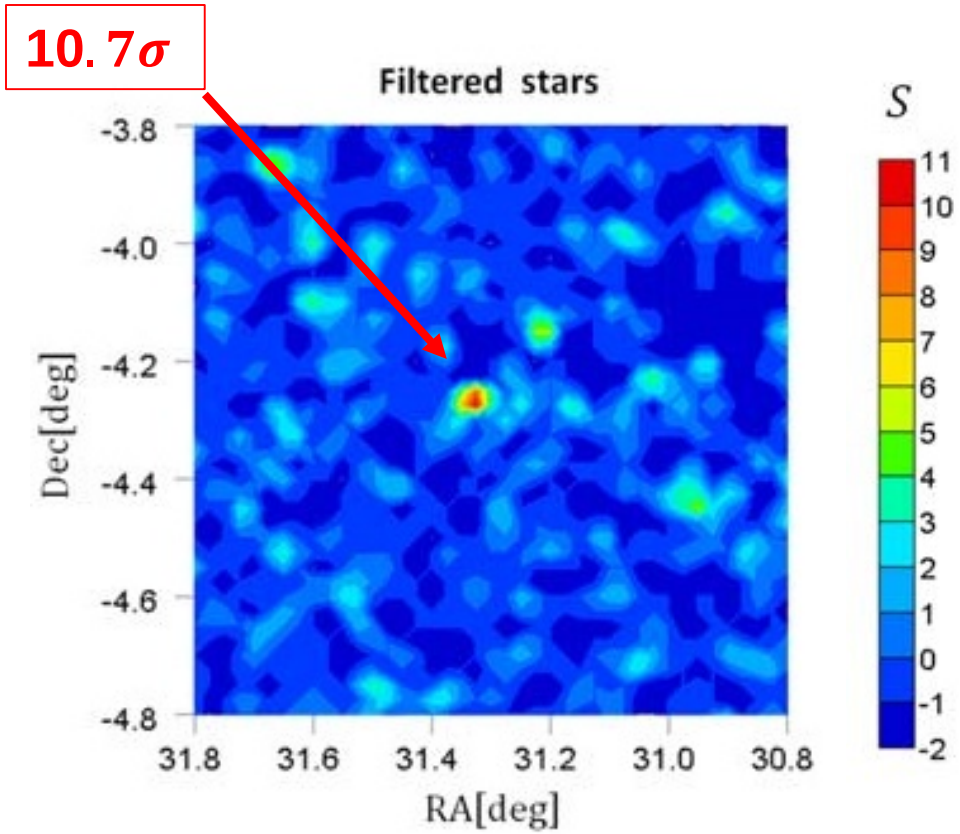


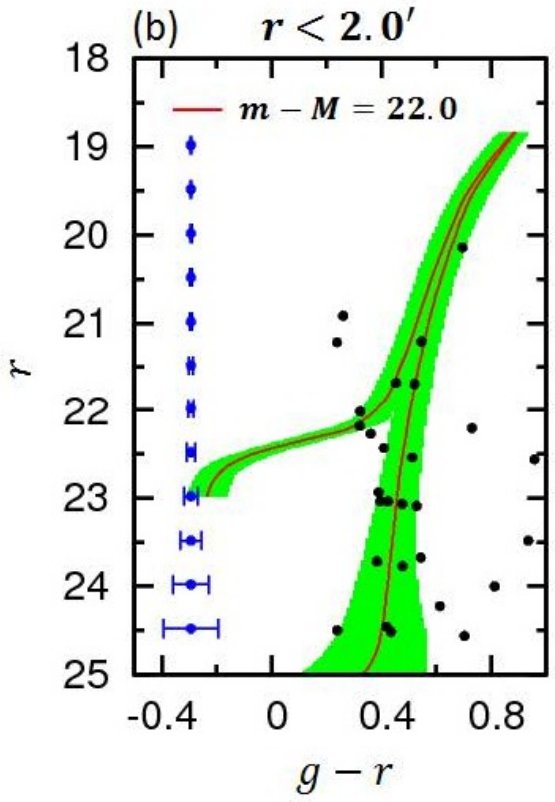
2nd new dwarf galaxy: Cetus III

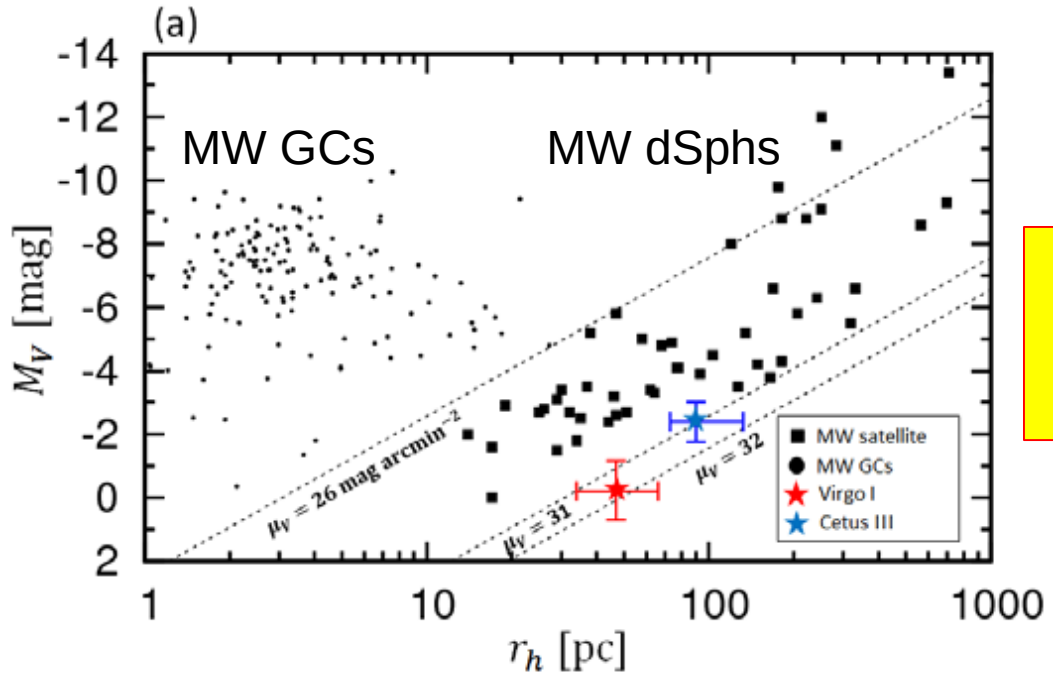
Homma, Chiba, et al. 2017, PASJ, HSC special issue



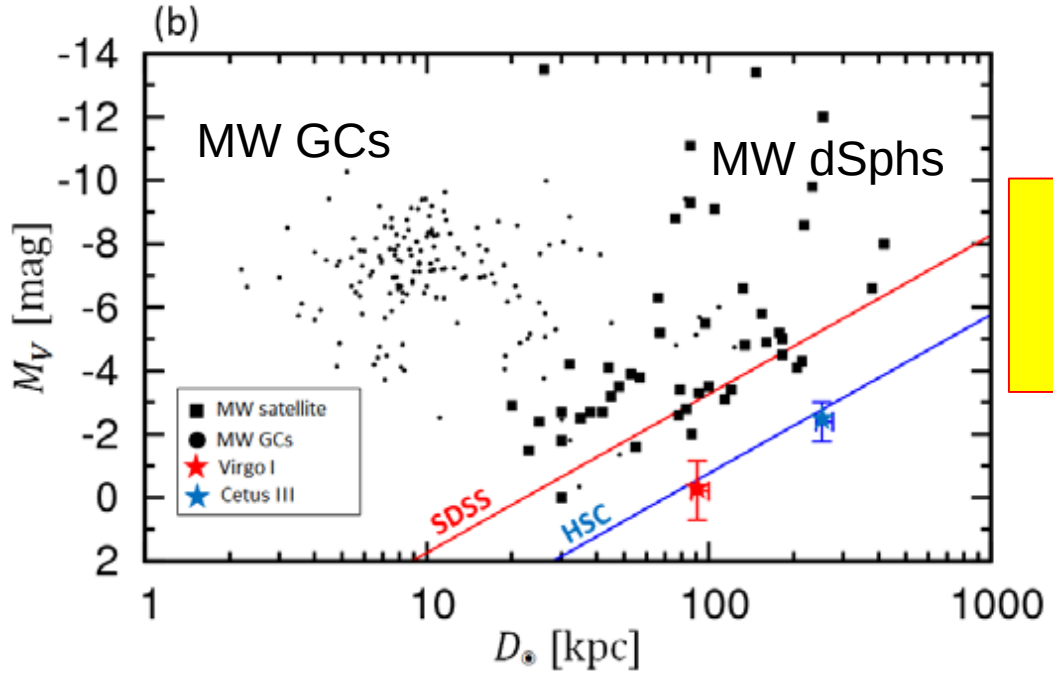
Coordinates : $(\alpha, \delta) = (31°.331, -4°.270)$
Absolute magnitude : $M_V = -2.45$ mag
Heliocentric distance : $D = 251^{+24}_{-11}$ kpc
Half light radius : $r_h = 90^{+42}_{-17}$ pc





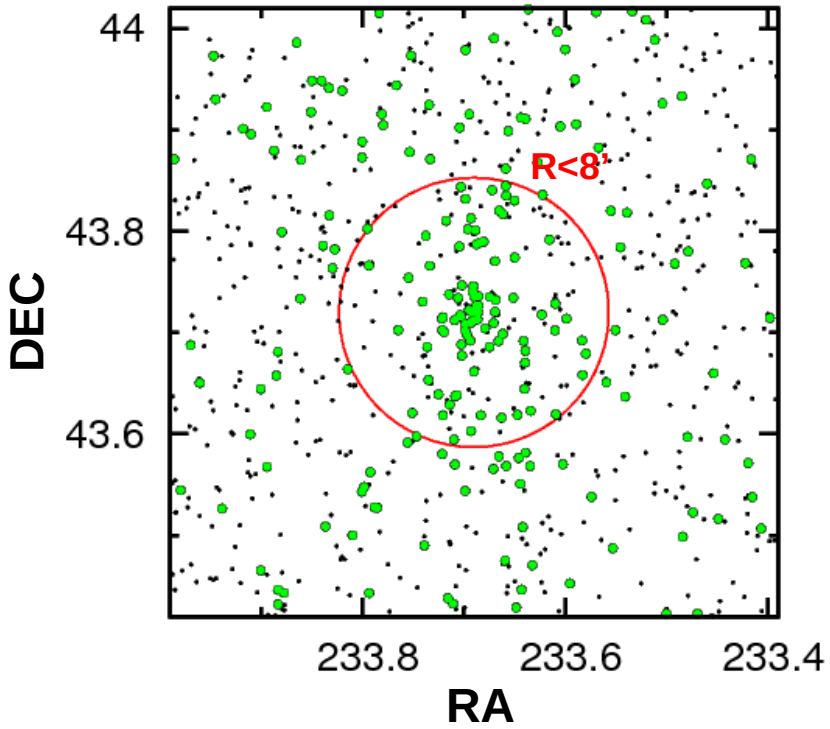


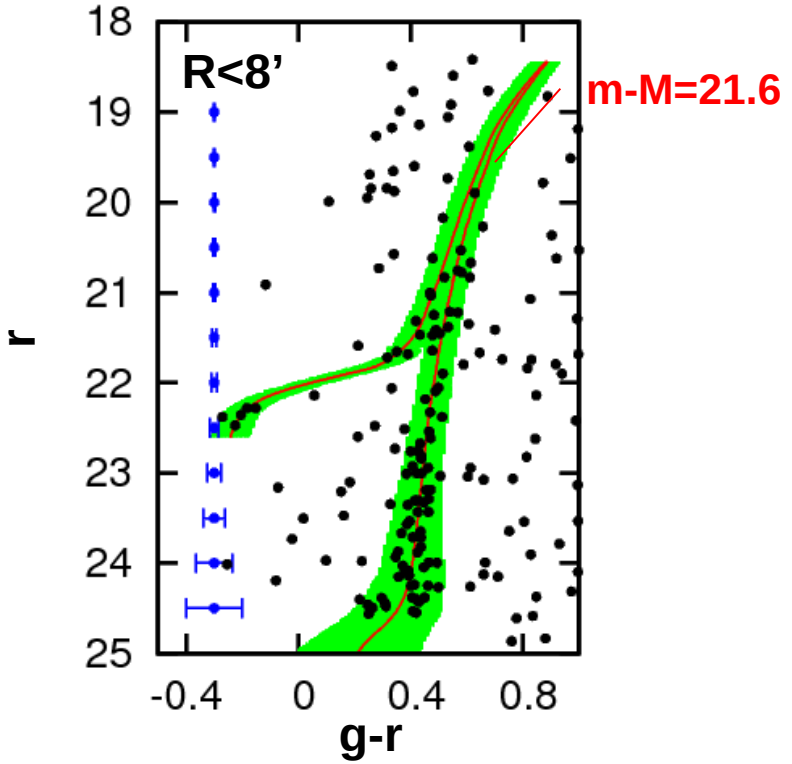
Virgo I and Cetus III have larger sizes than globular clusters.



HSC-SSP is powerful to identify very faint dwarf satellites.

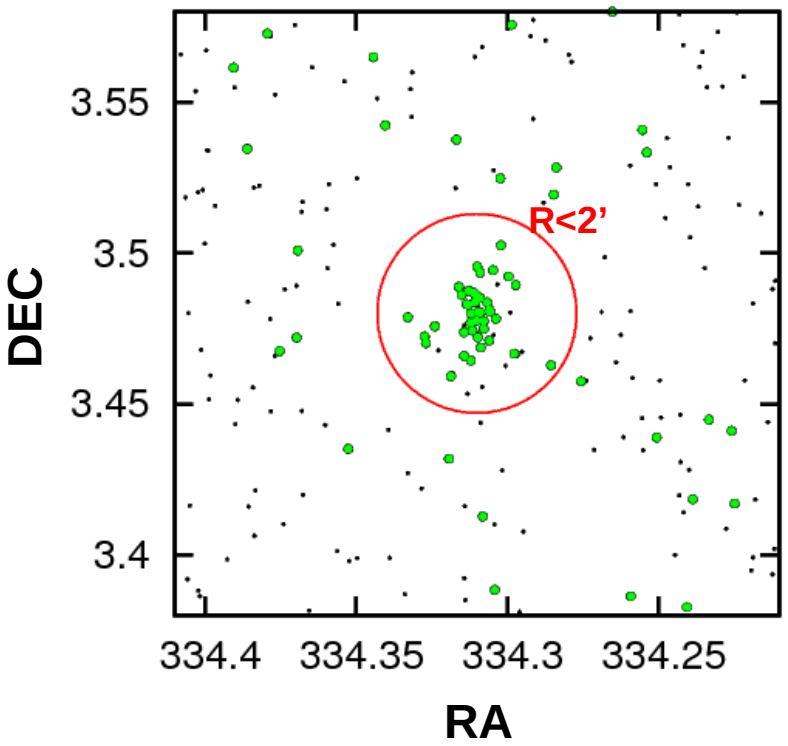
3rd new dwarf galaxy (Bootes IV) discovered!

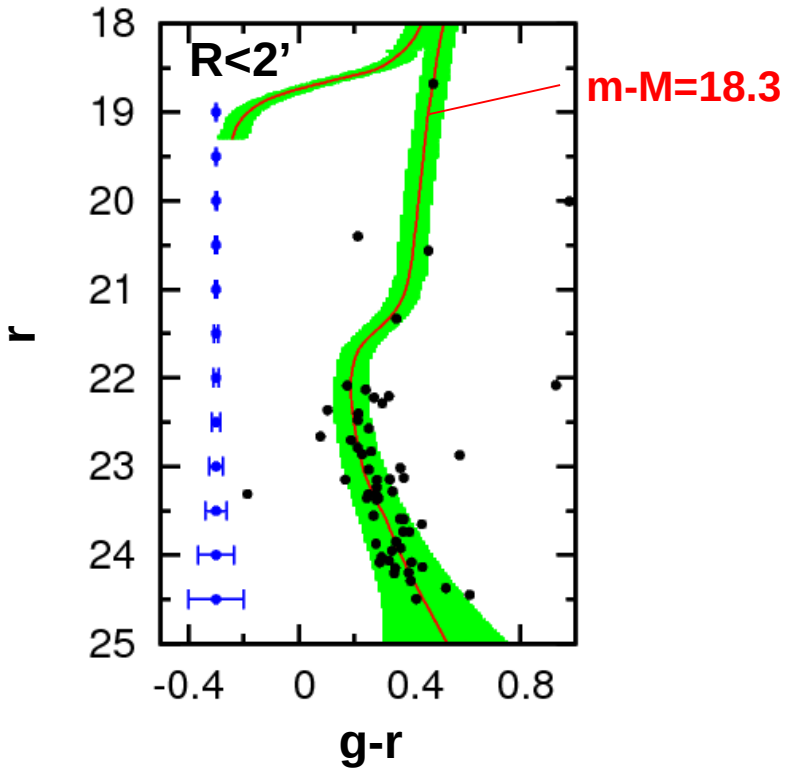




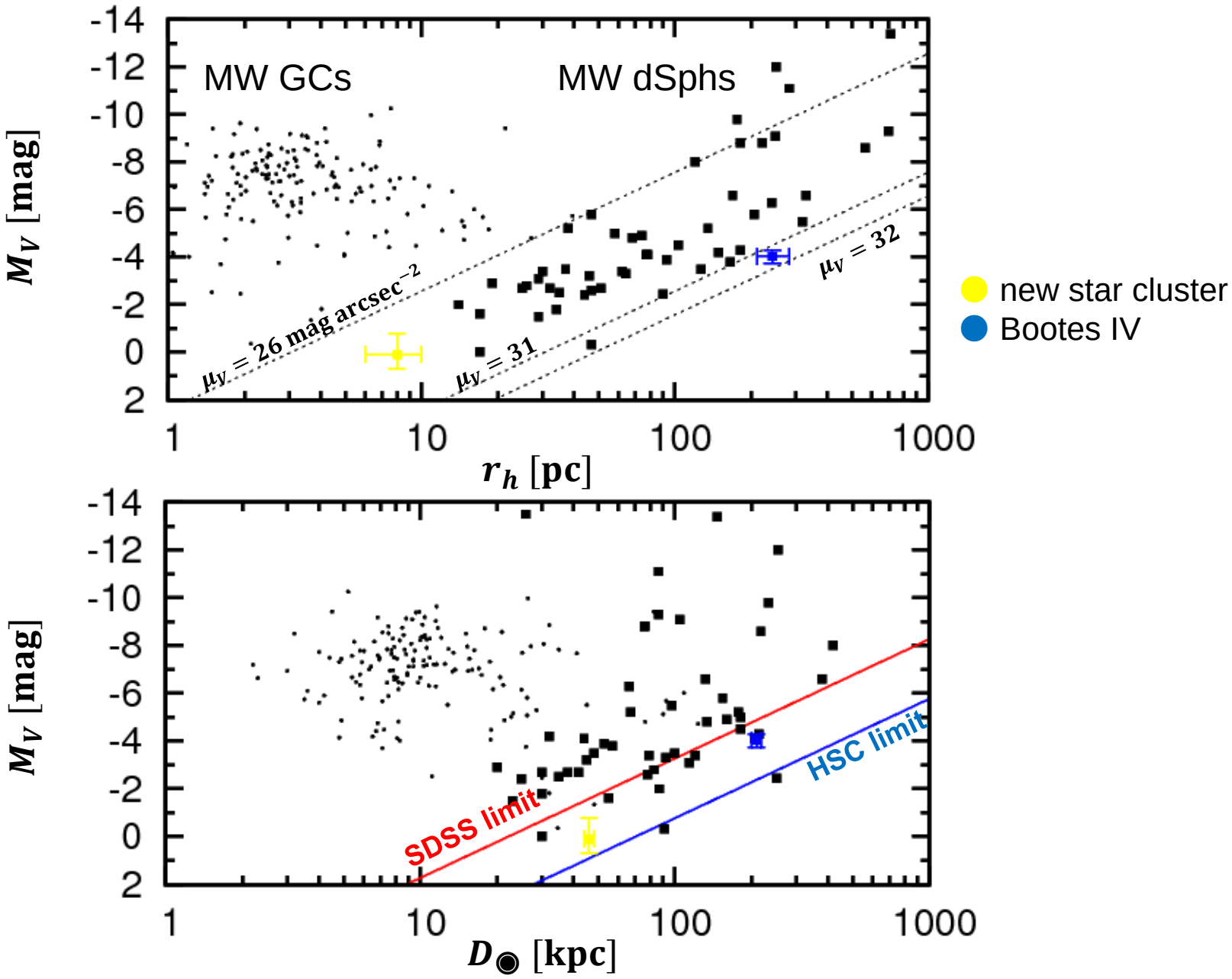
Parameter	Value
Coordinates(J2000)	$(233°.69, 43°.72)$
Ellipticity	$0.68^{+0.05}_{-0.05}$
Heriocentric distance, $D_{\odot}$	209^{+10}_{-9} kpc
Half light radius, $r_{\rm h}$	$4'.00^{+0'.44}_{-0'.36}$ *or* 243^{+40}_{-31} pc
$M_{\rm tot,V}$	$-4.03^{+0.28}_{-0.26}$ mag

A new (globular?) cluster discovered

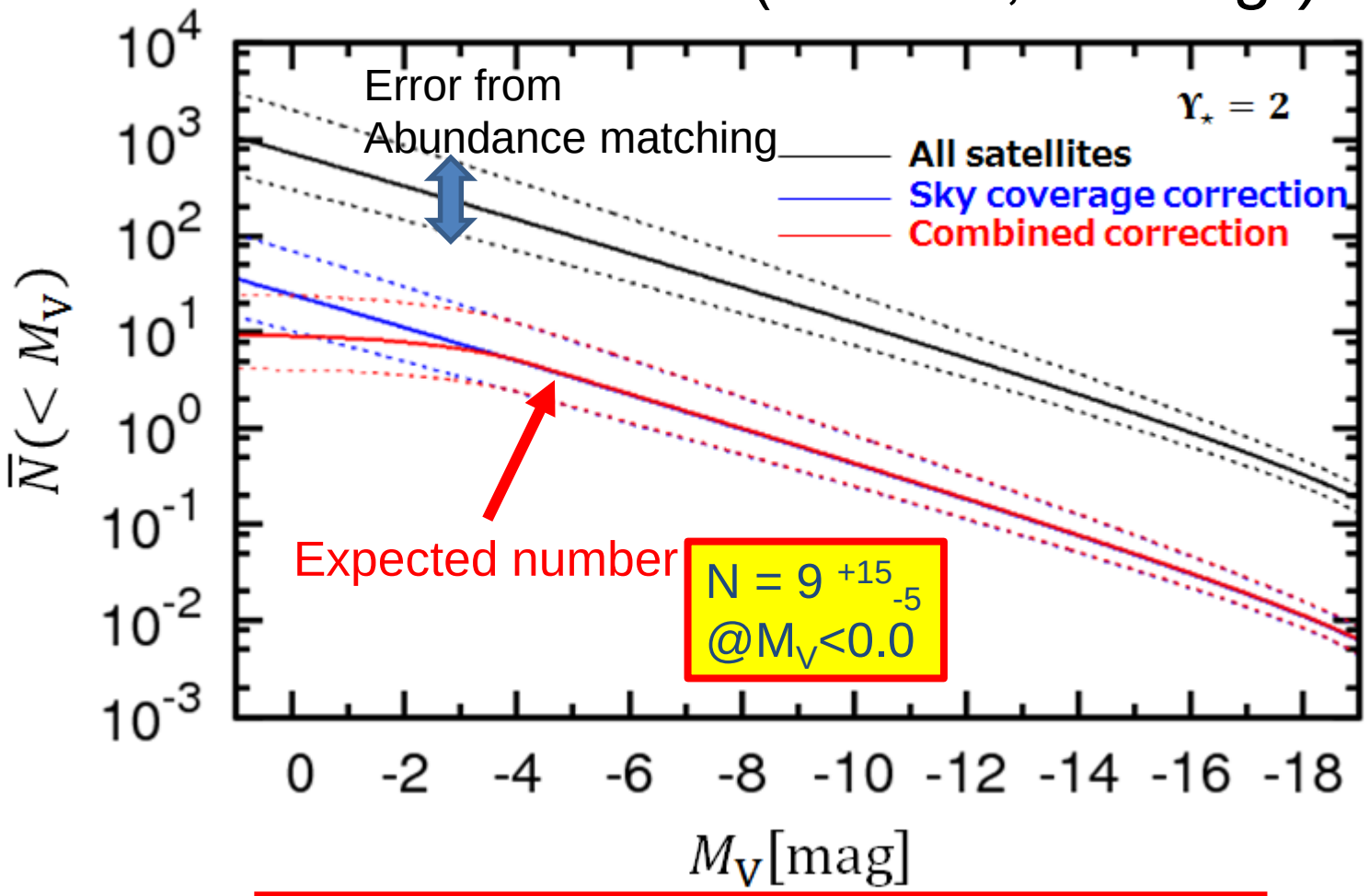




Parameter	Value
Coordinates(J2000)	$(334°.31, 3°.48)$
Ellipticity	$0.45^{+0.10}_{-0.10}$
Heriocentric distance, $D_{\odot}$	46^{+2}_{-2} kpc
Half light radius, $r_{\rm h}$	$0'.63^{+0'.10}_{-0'.99}$ *or* 8^{+2}_{-2} pc
$M_{\rm tot,V}$	$0.10^{+0.58}_{-0.87}$ mag


MW GCs
MW dSphs
$\mu_V = 26$ mag arcsec^{-2}
$\mu_V = 31$
$\mu_V = 32$
M_V [mag]
r_h [pc]
$D_\odot$ [kpc]
SDSS limit
HSC limit
new star cluster
Bootes IV

Expected number of dSphs in HSC-SSP based on ΛCDM (over ~1,400 deg^2)

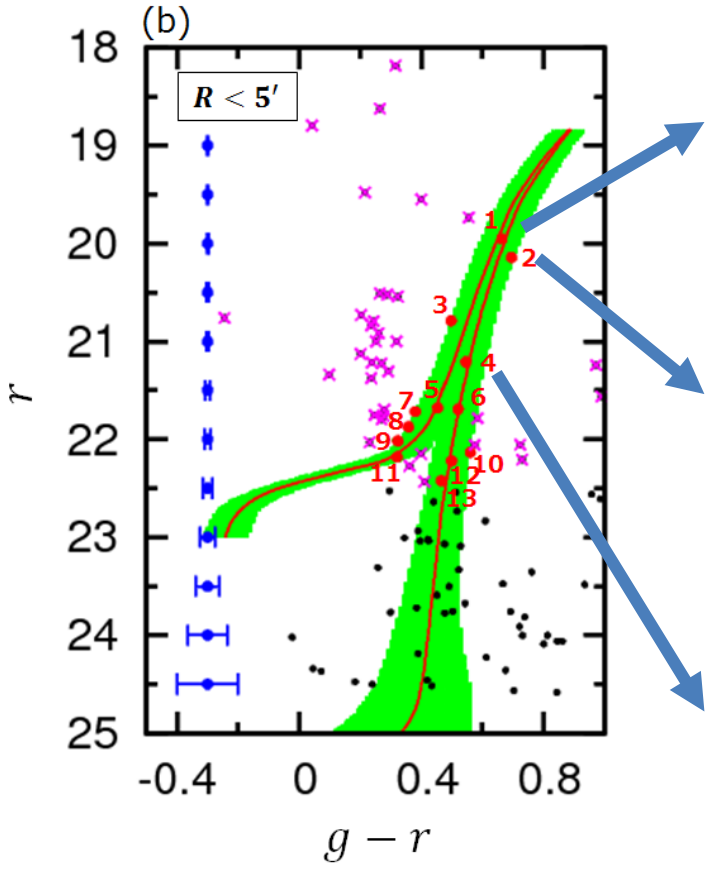


HSC-wide survey over ~580 deg^2
⇒ 4^{+6}_{-2} UFDs @ Mv<0.0 predicted
⇒ 3 new + 2 known UFDs identified

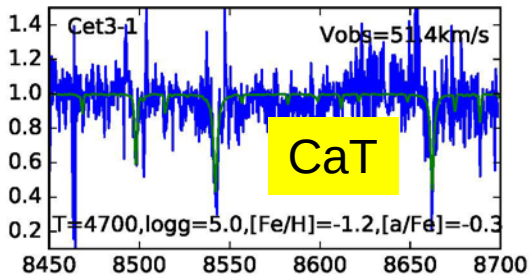
So far ΛCDM looks reasonable!

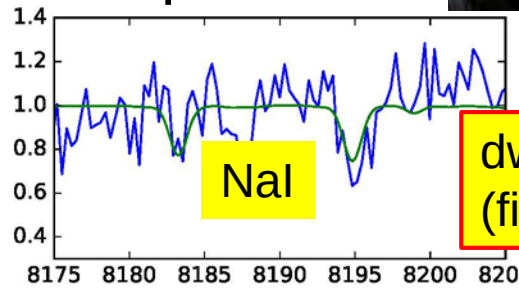
Spectroscopic follow-ups are on going
(Chiba+, Ishigaki+)

Cetus III

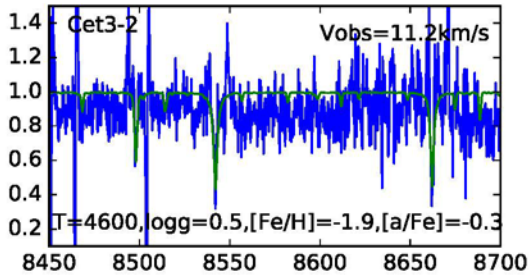


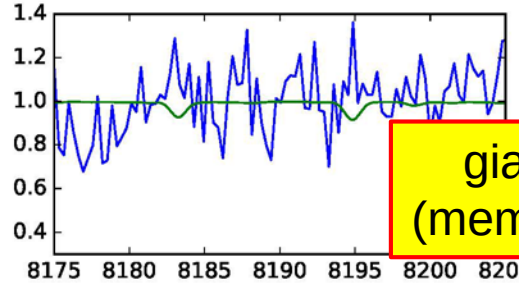
DEIMOS/Keck spectra



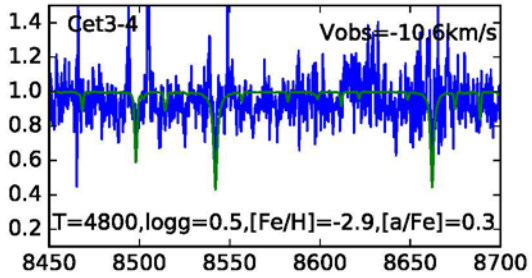


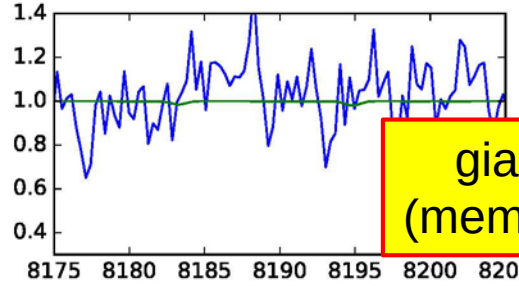
dwarf (field)





giant (member)





giant (member)

FOCAS/Subaru observation of Virgo I is scheduled on Feb 23 and Mar 23.

⇒ membership, mass of dark halo, metallicity distribution

Summary

- We have discovered new MW satellites from HSC-SSP data
  - This discovery rate so far is in agreement with ΛCDM models. ⇒ rule out WDM !?
  - Further search for new satellites will increase this statistical significance.
  - Spectroscopic follow-ups are ongoing to tighten membership and derive chemo-dynamics.
- What about the limit on SIDM?
  - PFS-GA survey will do this !