New insights into Stellar Components and Dark Halo in the Milky Way

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新学術領域シンポ 2020.02.18

Thank you for supporting the following research works !

- Long-term orbital evolutions of Galactic satellites and the effects on their star formation histories
  - Miyoshi, T. & Chiba, M. 2020, to be submitted to ApJ
- Void formation: does the void-in-cloud process matter?
  - Chan, H.Y.J., Chiba, M., Ishiyama, T. 2019, MNRAS, 490, 2405
- Evidence for the third stellar population in the Milky Way's disk
  - Carollo, D., Chiba, M., Ishigaki, N. M. 2019, ApJ, 887, 22
- Bootes IV: A New Milky Way Satellite Discovered in the Subaru/Hyper Suprime-Cam Survey and Implications for Dark Matter Models
  - Homma, D., Chiba, M. et al. 2019, PASJ, 71, 94
- The stellar halo of the Milky Way traced by blue horizontal-branch stars in the Subaru Hyper Suprime-Cam Survey
  - Fukushima, T., Chiba, M. et al. 2019, PASJ, 71, 72

Milky Way's halo as a probe of dark matter

- Dark halo
  - reflects the nature of dark matter particles
    - Missing satellites problem in ΛCDM
      - Alternative DM models?
      - Limitation in observations?
    - Core-cusp problem in ΛCDM ⇒ Hayashi-san's talk

⇒Searching for new dwarf spheroidal satellites (dSphs) in the Milky Way

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

HSC-Subaru Strategic Program (SSP)

300 nights over 5 years, Wide, Deep & Ultra-deep layers

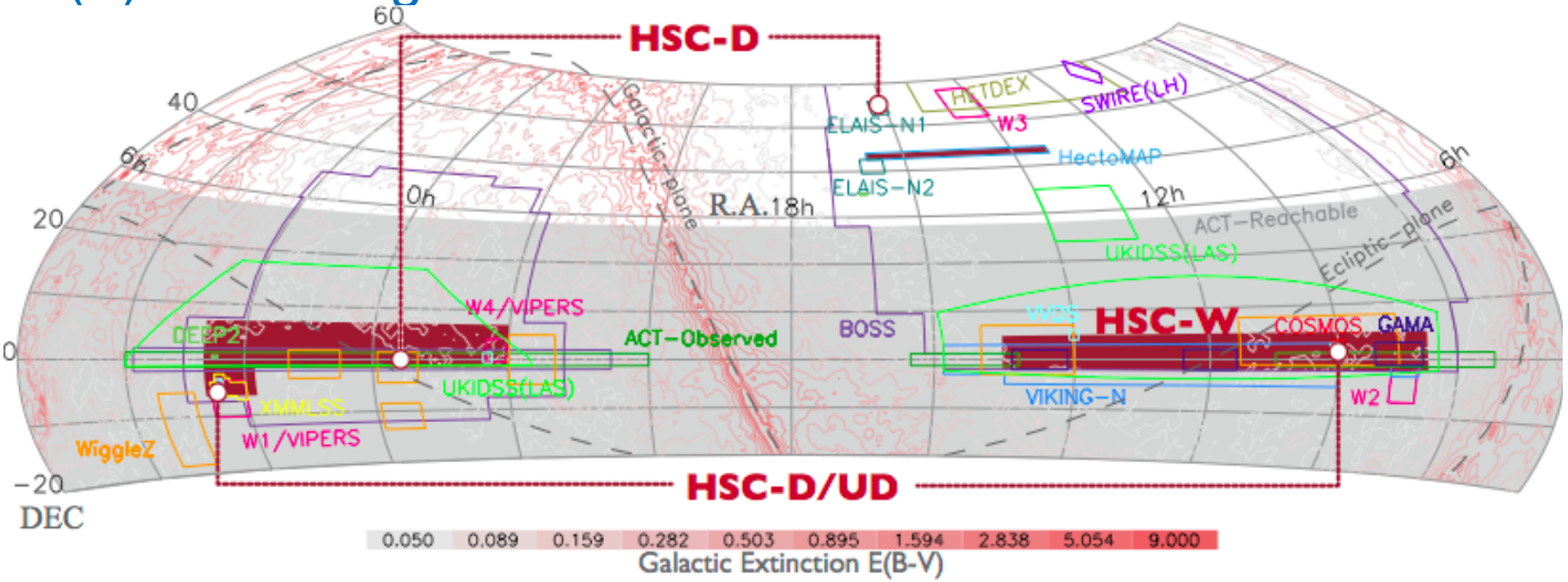
- MW science from the Wide-layer data

  S18A: ~ 680 deg^2 / 1,400 deg^2(goal)

  (1) Searching for new MW dSphs

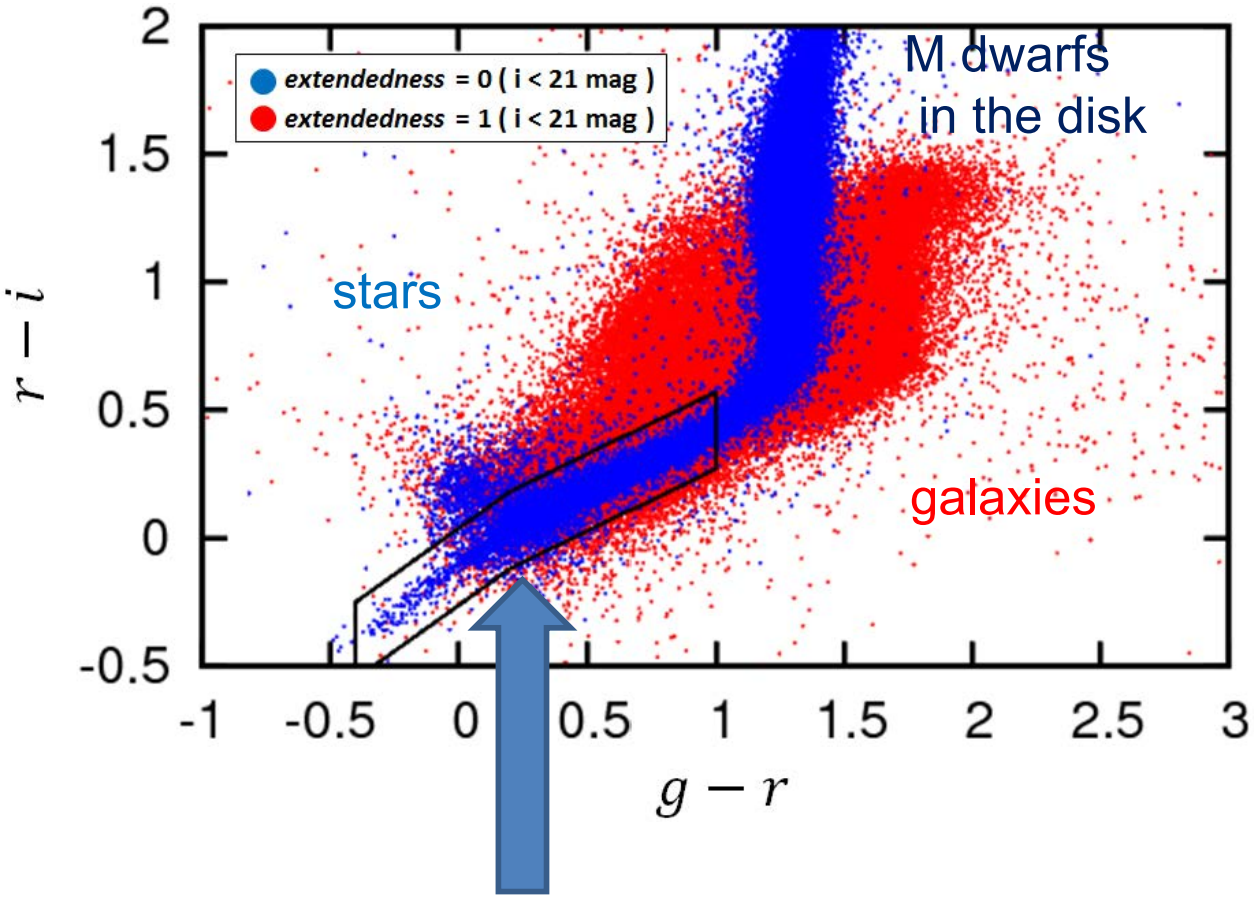
  (2) Mapping Halo with Blue Horizontal-Branch stars

  (3) Searching for new stellar streams …



New MW dSphs from HSC-SSP

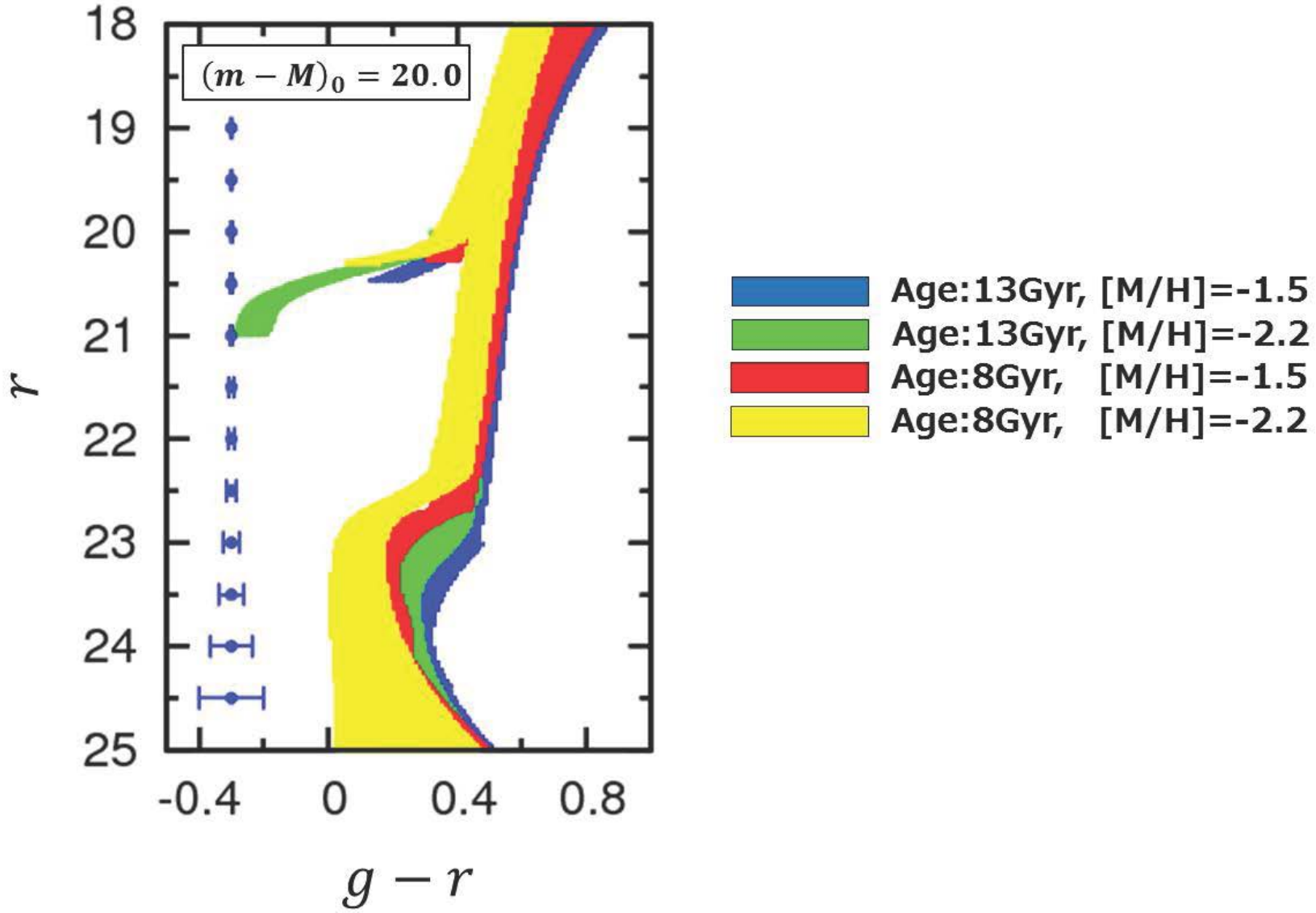
Cf. Koposov et al. (2008), Walsh et al. (2009)



Target halo stars

- Select point sources (*extendedness*=0)
- Remove remaining contaminants from color-color diagram
- Set isochrone filters and count stars in 0.05° x 0.05° bin (80 pc at D=90 kpc)
- Find overdensities with high statistical significance

Isochrone filter

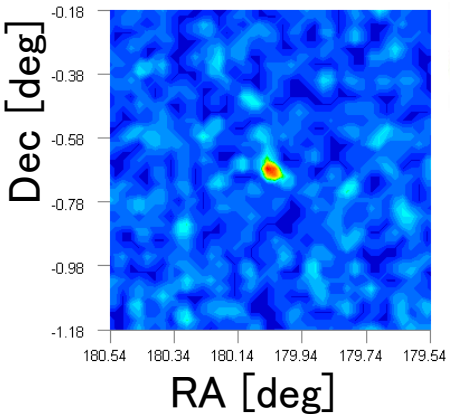


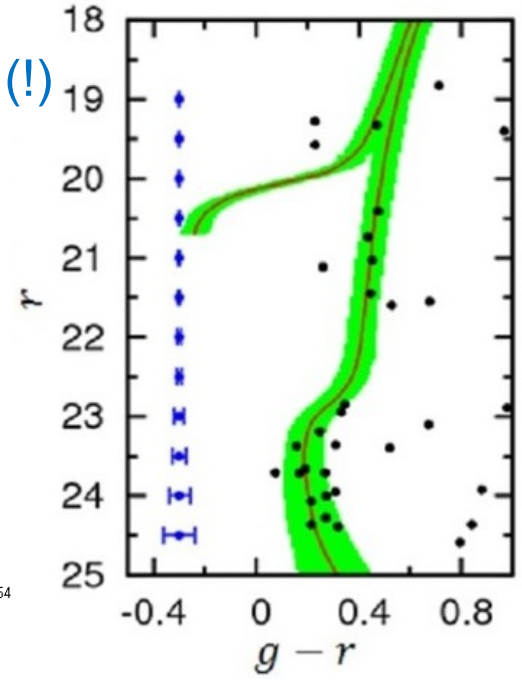
Virgo I

M_V = -0.33 mag (!)

D = 91 kpc

r_h = 47 pc



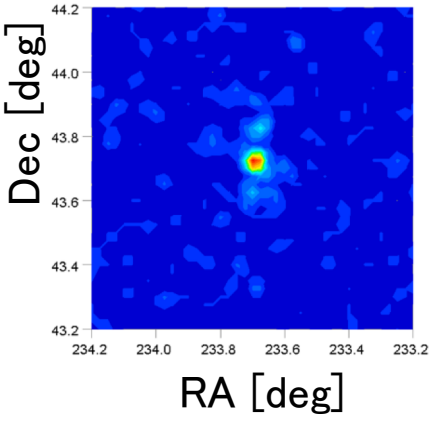


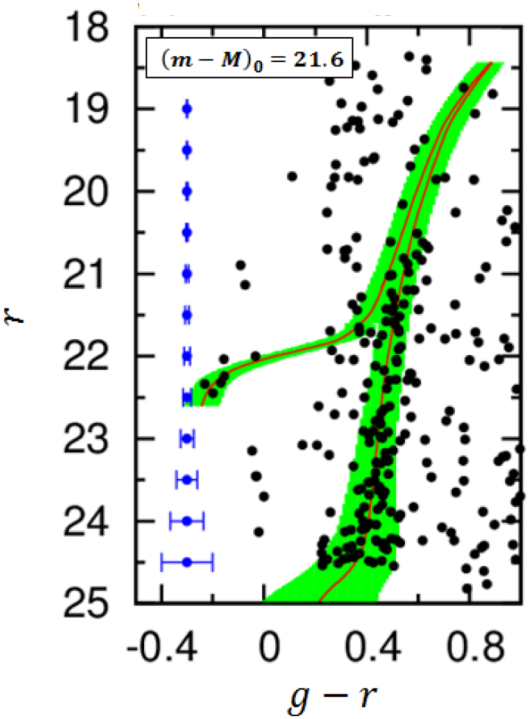
Bootes IV

M_V = -4.53 mag

D = 209 kpc (!)

r_h = 462 pc



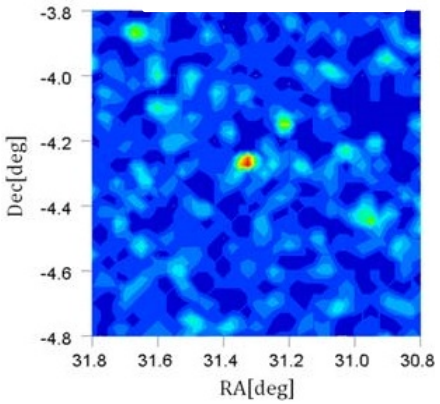


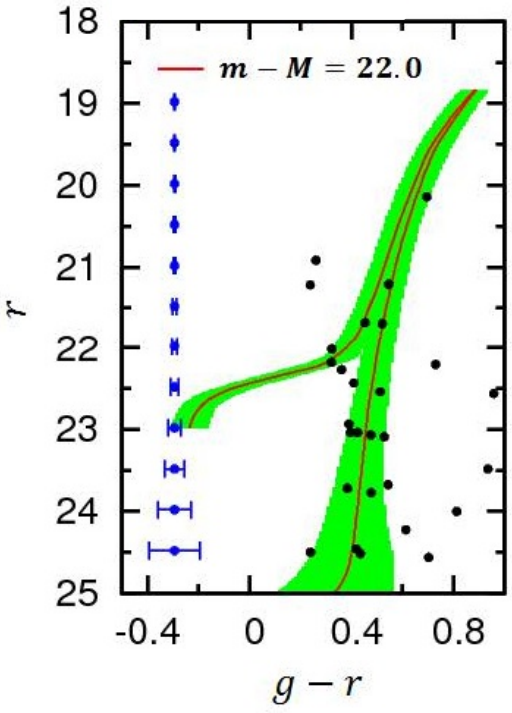
Cetus III

M_V = -2.45 mag

D = 251 kpc (!)

r_h = 90 pc



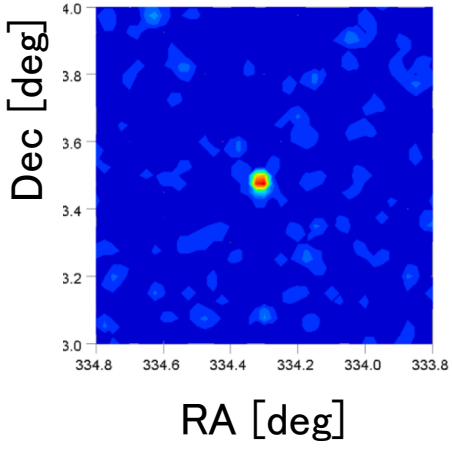


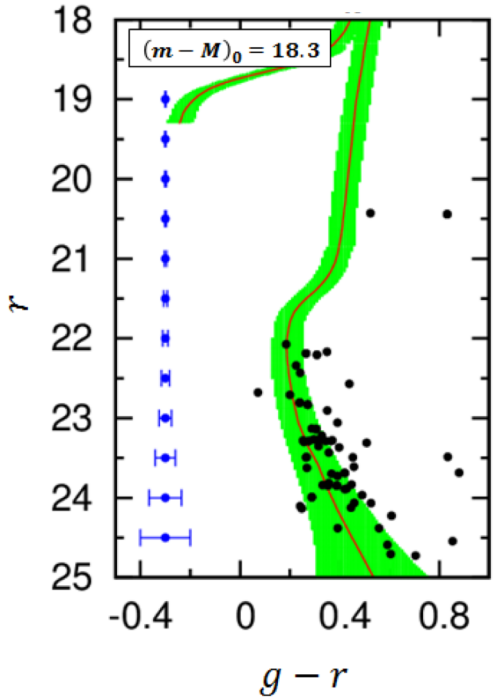
HSC 1

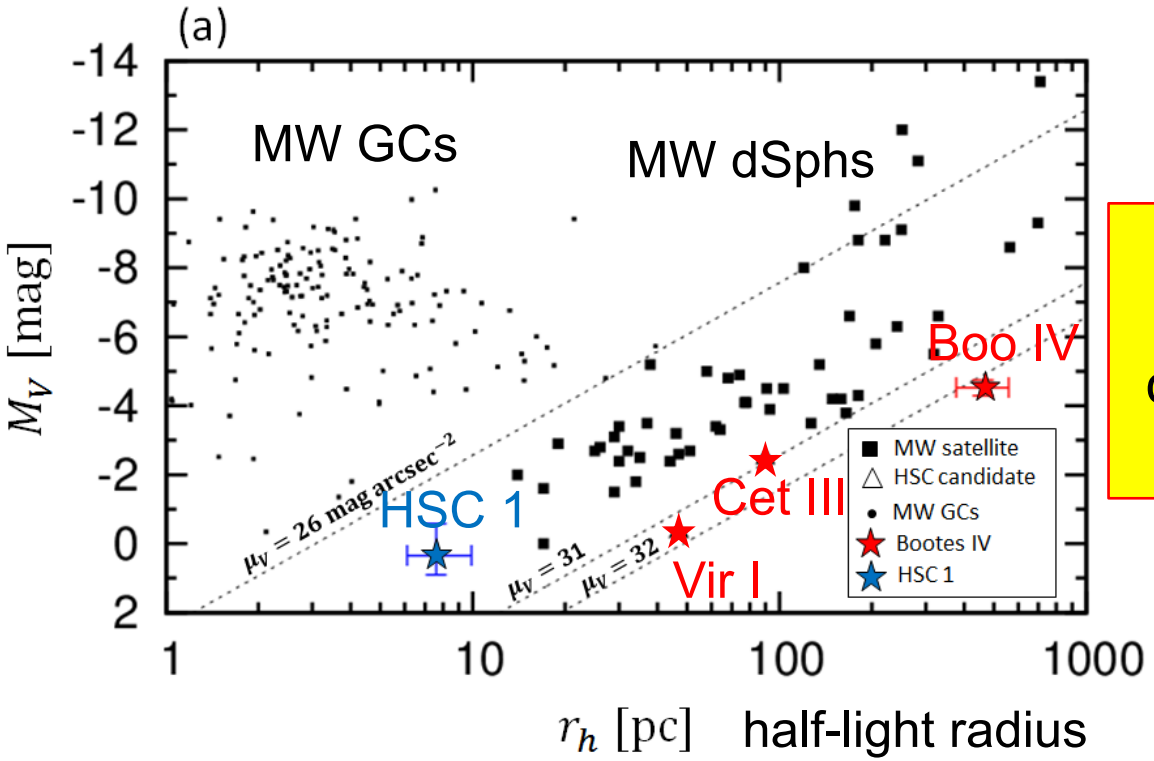
M_V = -0.20 mag

D = 46 kpc

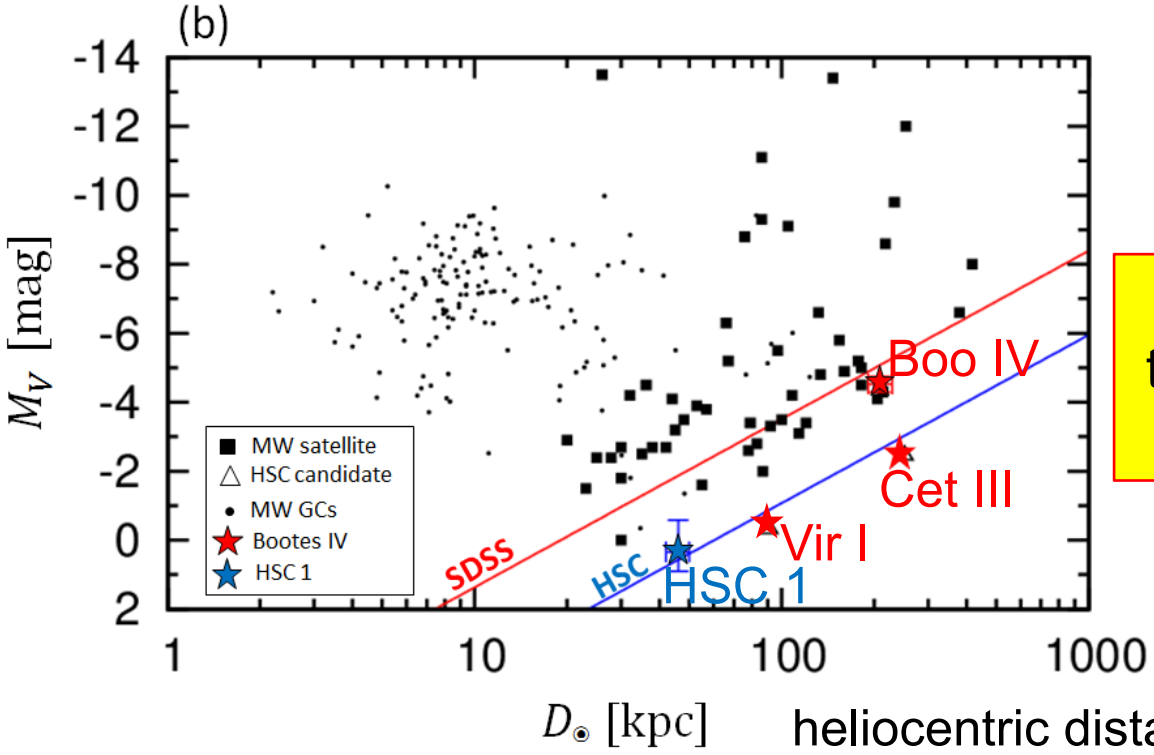
r_h = 5.9 pc





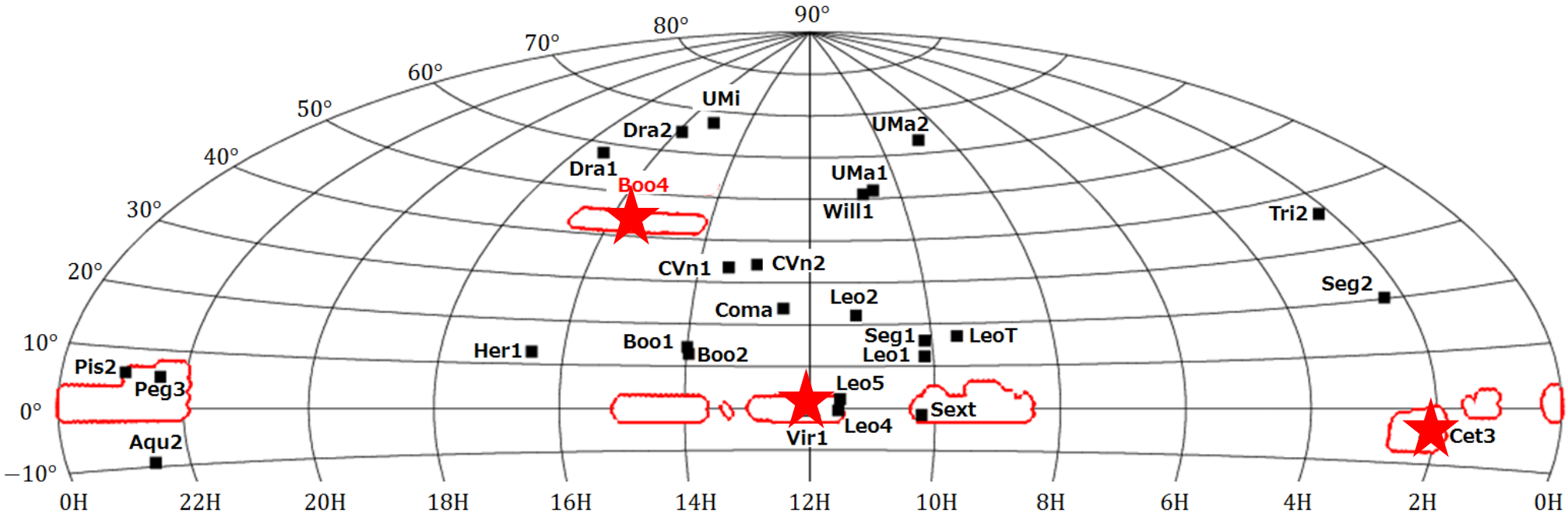


Vir I, Cet III & Boo IV have very large sizes compared to globular clusters.



HSC-SSP is powerful to identify very distant stellar systems.

Implication for the missing satellites problem



HSC-SSP survey area

Known dSphs

New dSphs

Homma, MC, et al. 2016
Homma, MC, et al. 2018
Homma, MC, et al. 2019

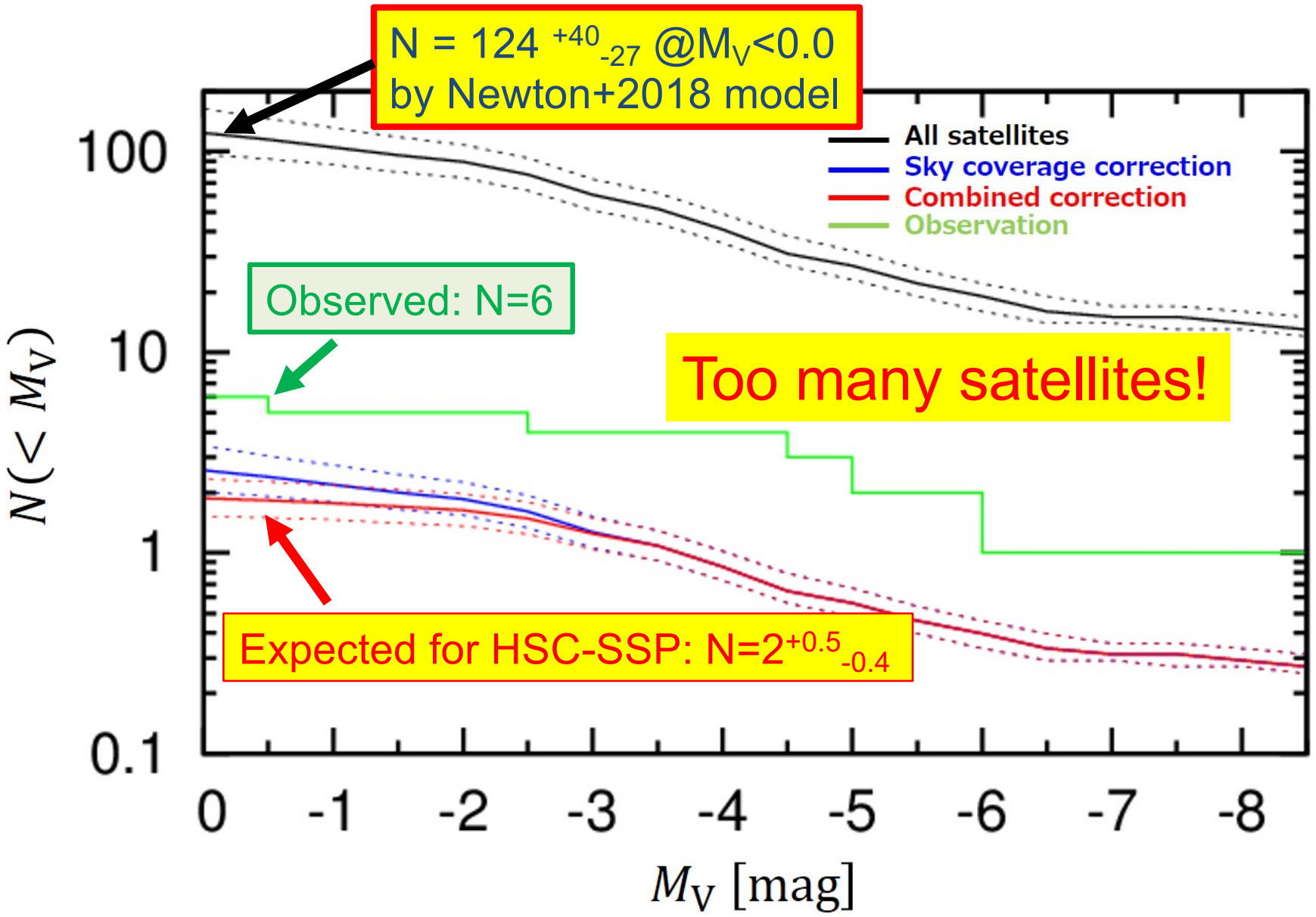
6 dSphs in S18A footprint: 3 known (Sex, Leo IV, Peg III) + 3 new dSphs

Comparison with ΛCDM models (satellite distribution)

- Newton et al. (2018)
  - Number of satellites N(r) follows a centrally concentrated Einasto profile and the total number is scaled to the finding by SDSS + DES, i.e. completeness corrected
  - Total number of satellites $N_{tot} = 124^{+40}_{-27}$ at $M_V < 0$
  - Predicted: $2^{+0.5}_{-0.4}$ vs. observed 6 in HSC-SSP area

    ⇒ Too many satellites!

LFs of MW satellites



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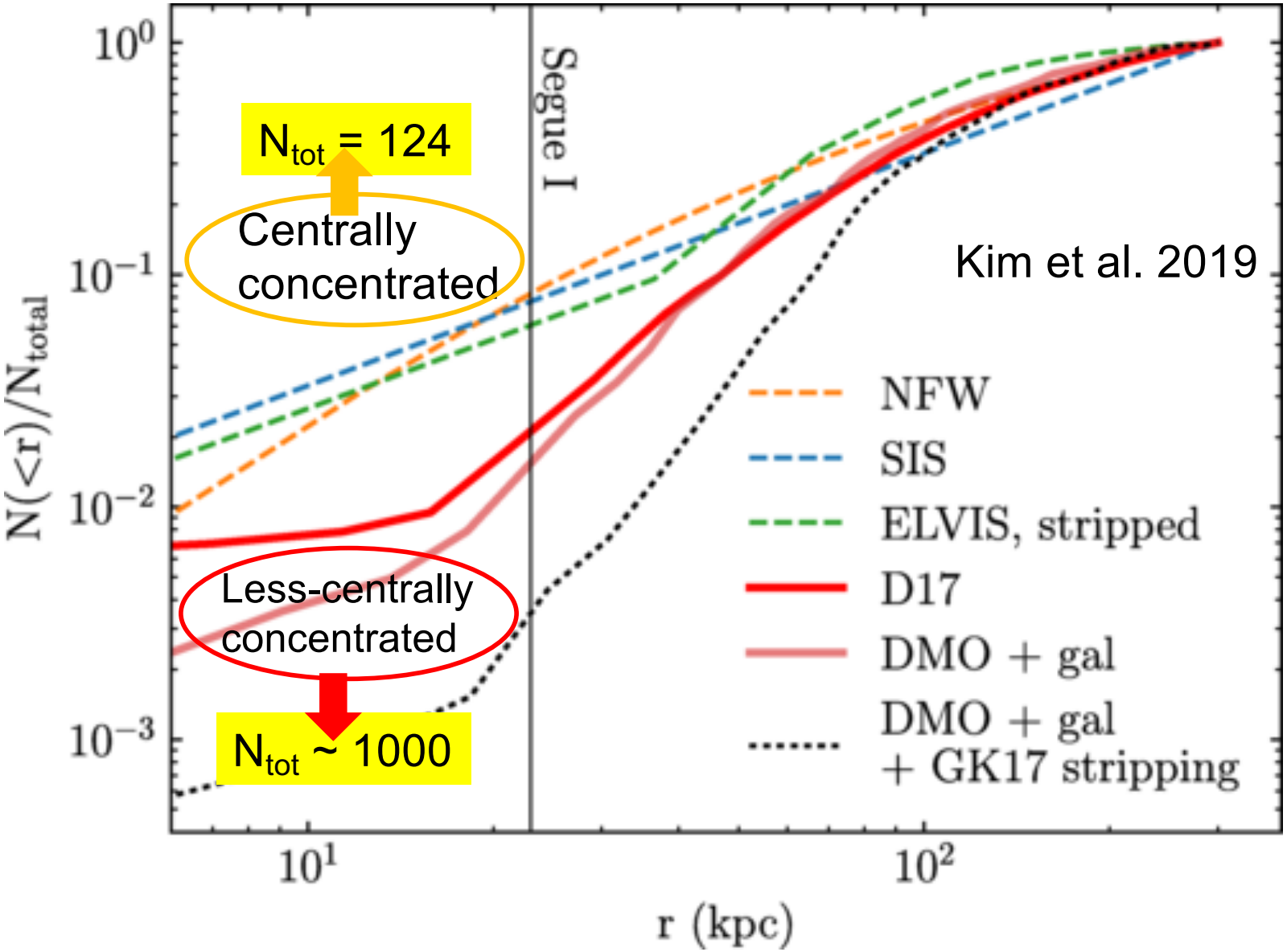
    ⇒ Too many satellites!
- Dooley et al (2017)
  - DM-only simulation + reionization + abundance matching
  - Less centrally concentrated N(r) than Einasto/NFW
  - N_{tot} ~ 1000 at $M_V < 0$ using SDSS

    ⇒ N = 6-12 satellites in HSC-SSP area ⇒ not so bad!

What's the matter?

Completeness corrected satellite counts N_{tot} depend on the radial distribution of satellites

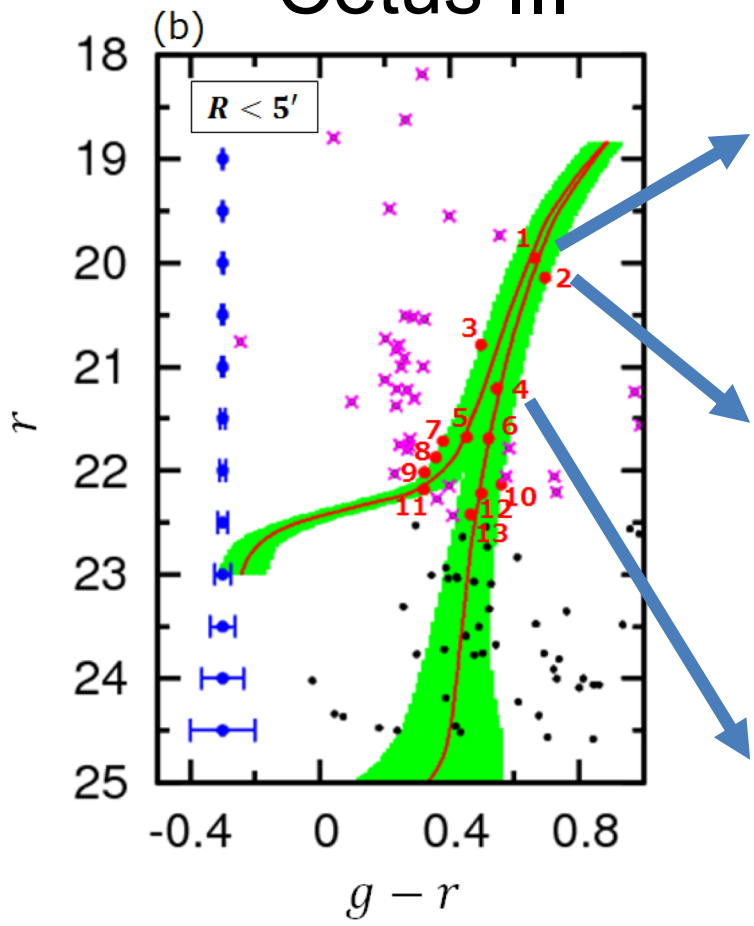


Implication for the missing satellites problem

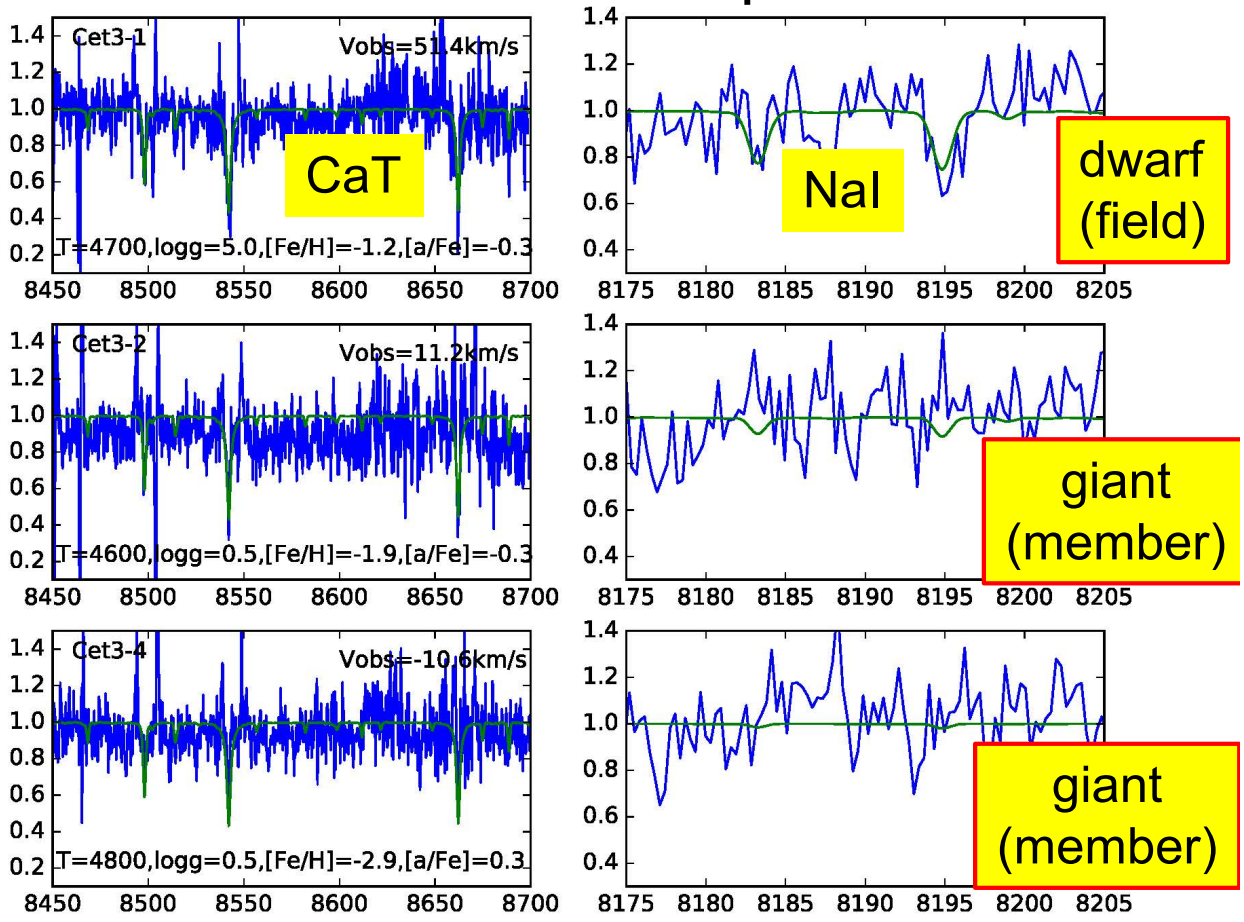
- N_{tot} ~1000: Perhaps the problem is now less serious than previous thought or the problem is solved?
  - The refinement for the relation between subhalos and satellites, incl. N(r) of satellites, is important.
  - WDM with light mass (<4kev), suggesting $N_{tot} < 100$, may be ruled out (Cf. Kim et al. 2018).
- Deep surveys, e.g. HSC-SSP and LSST, are important to constraint N(r) of satellites in the outer parts of the halo.

Spectroscopic follow-up
(Chiba+, Ishigaki+)

Cetus III



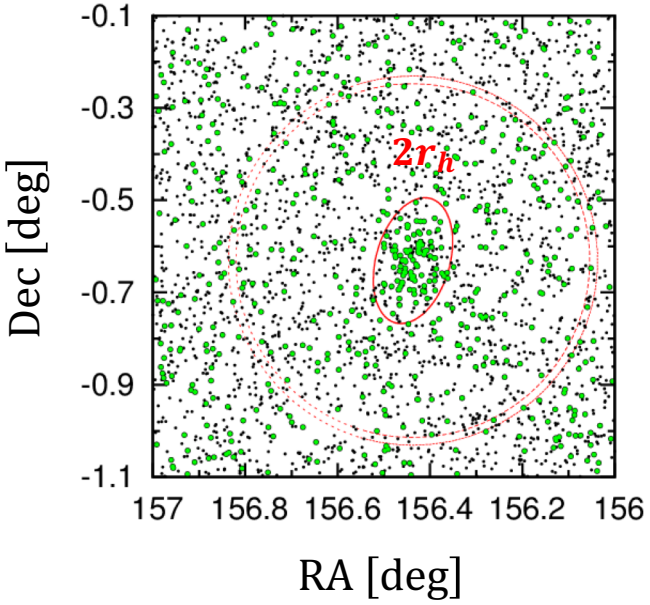
DEIMOS/Keck spectra



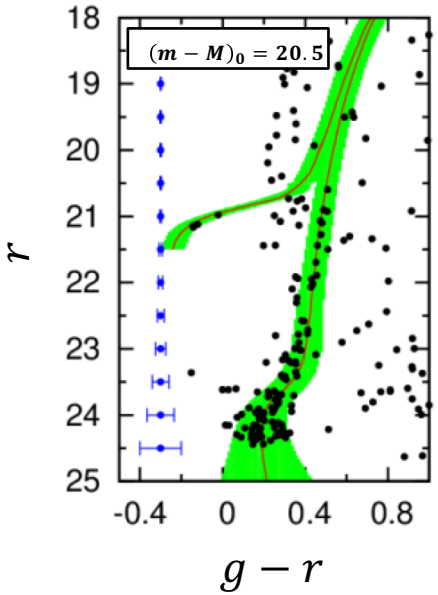
More spectroscopic data have been obtained for other dSphs
⇒ membership, mass of dark halo, metallicity distribution

More UFDs are discovered from S19A data!

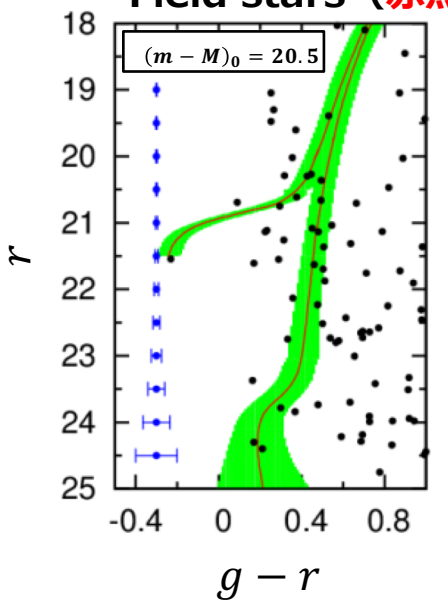
Sextans II



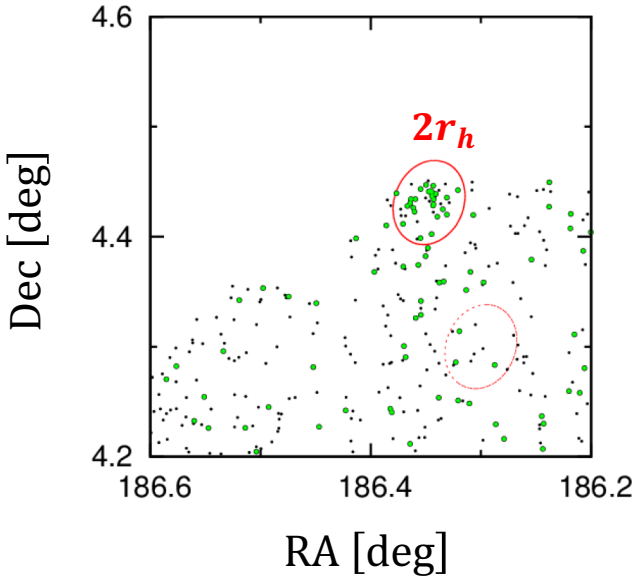
$r < 2r_h$



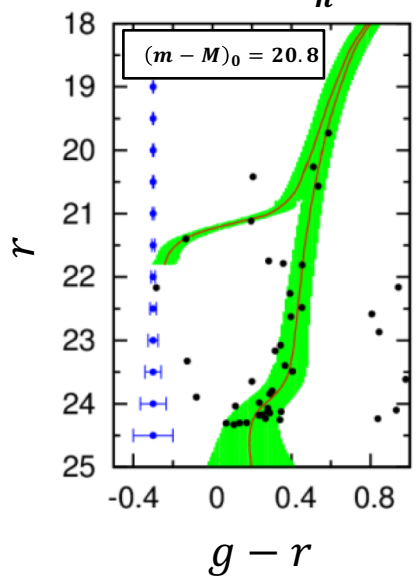
Field stars（赤点線内）



Virgo II



$r < 2r_h$



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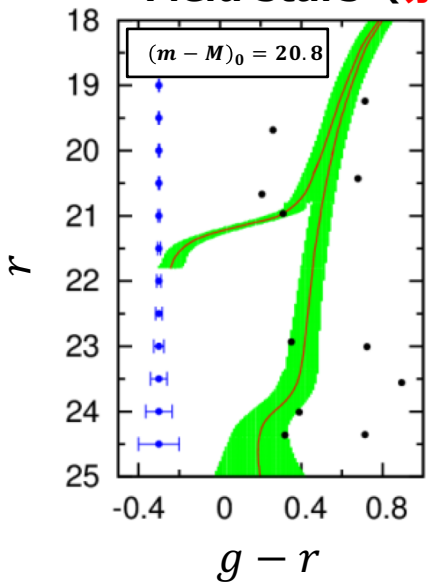
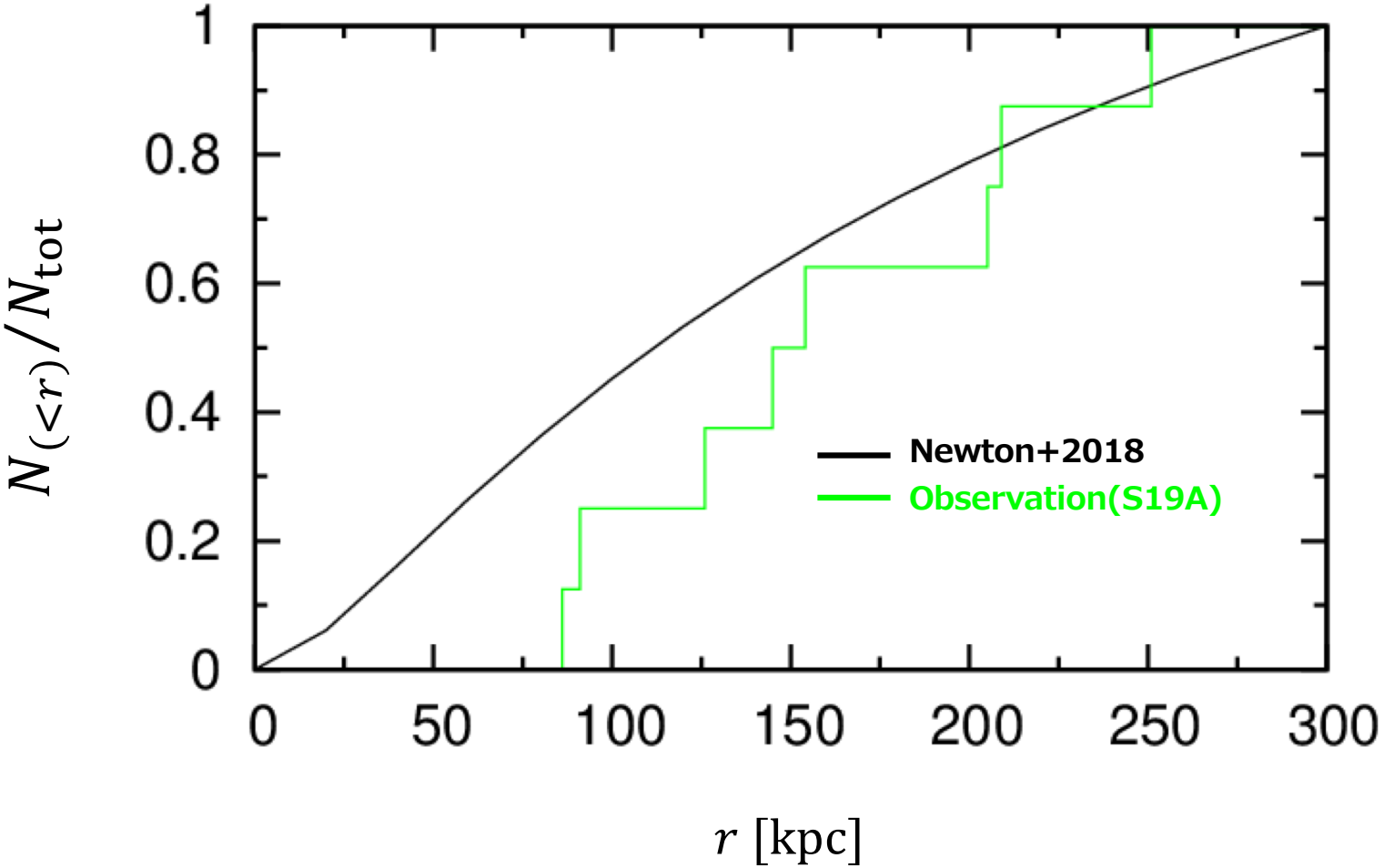
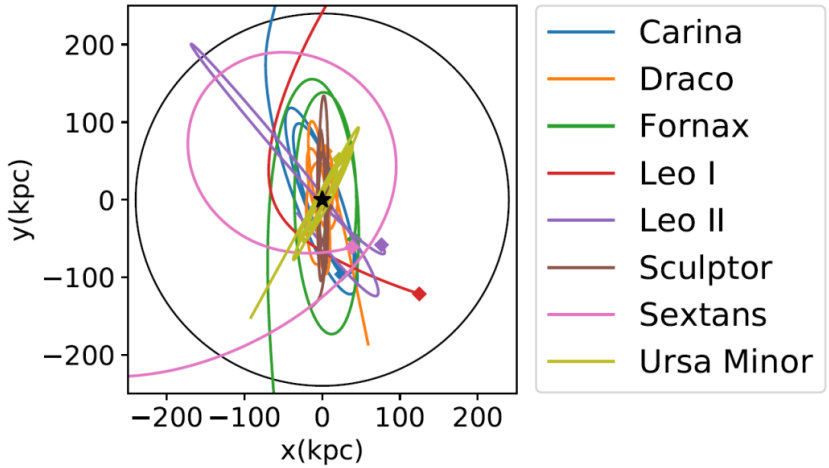


Radial distribution of 8 satellites in S19A (comparison with Newton+ 2018)

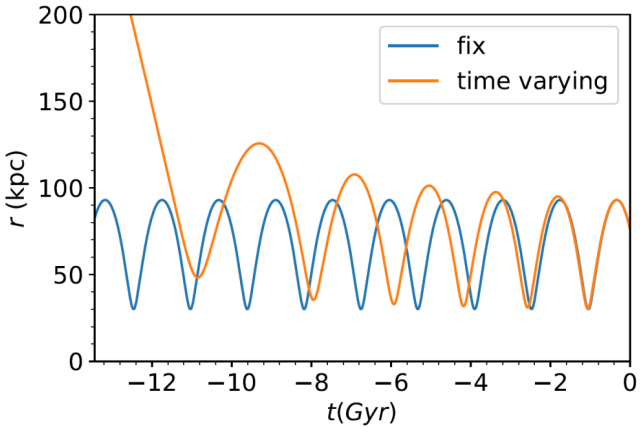


Long-term orbital motions of Galactic satellites in the growing mass of the Galactic halo (Miyoshi 2020, Master Thesis)

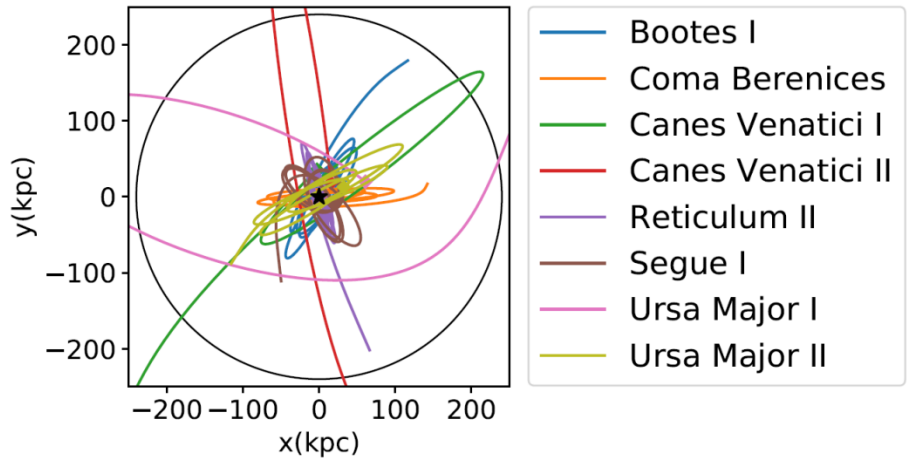
Classical dSphs



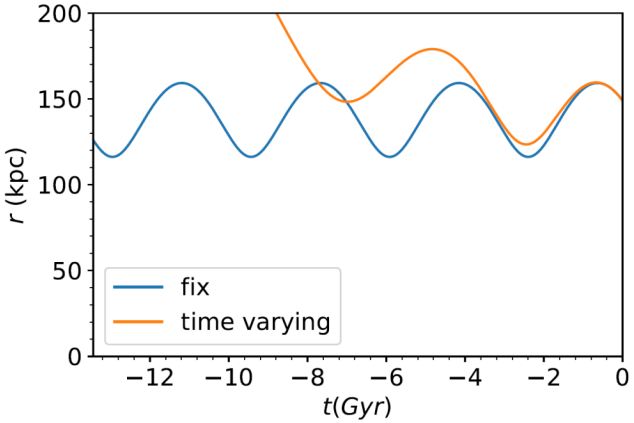
Draco



UFDs



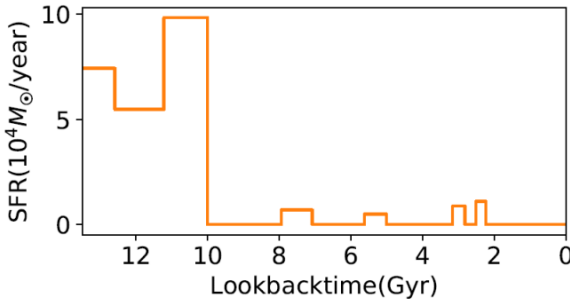
Fornax

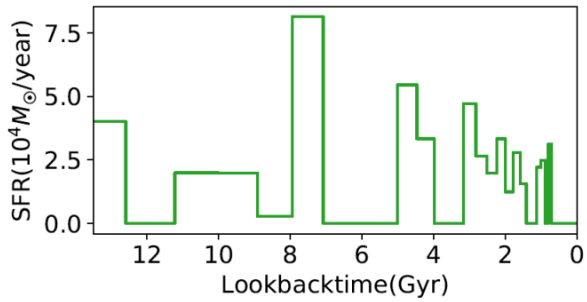


Draco

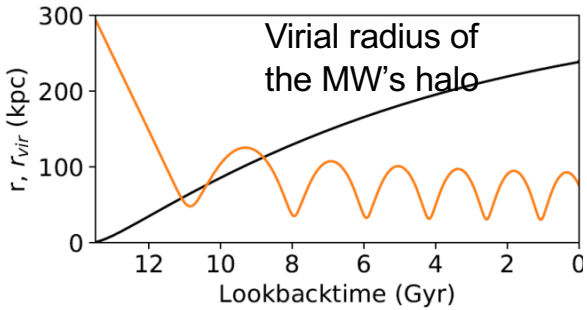
Fornax

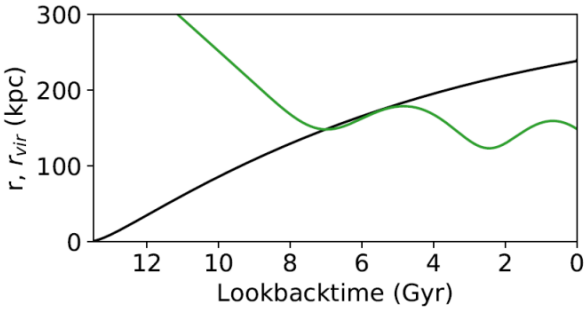
Star formation history





Orbital evolution

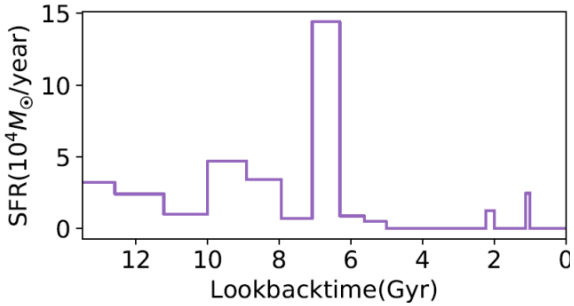


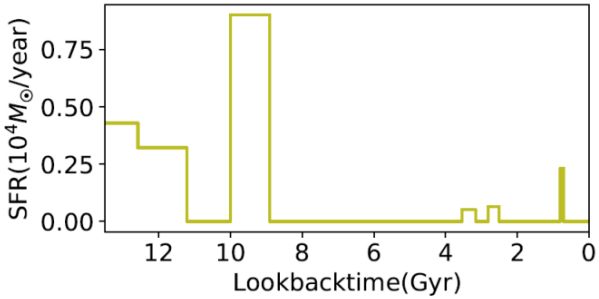


Leo I

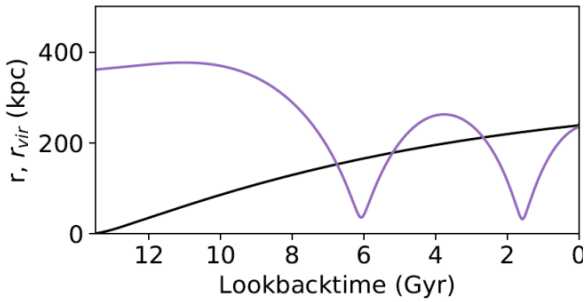
Ursa Minor

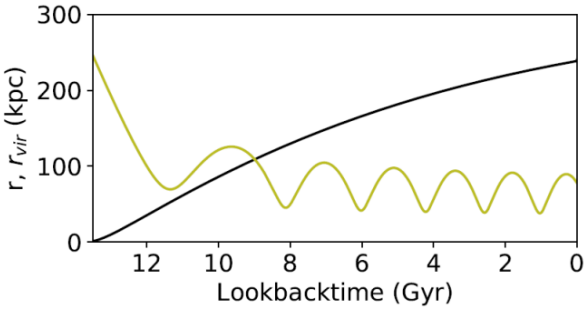
Star formation history





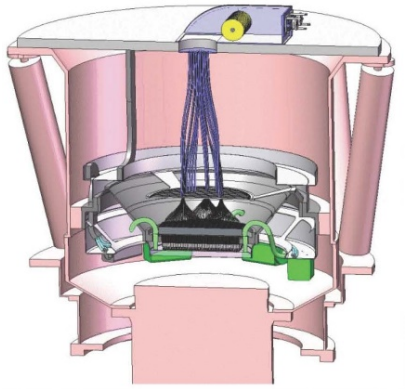
Orbital evolution





First infall time
= time of SF peak
(due to tidal effect, ram-pressure)

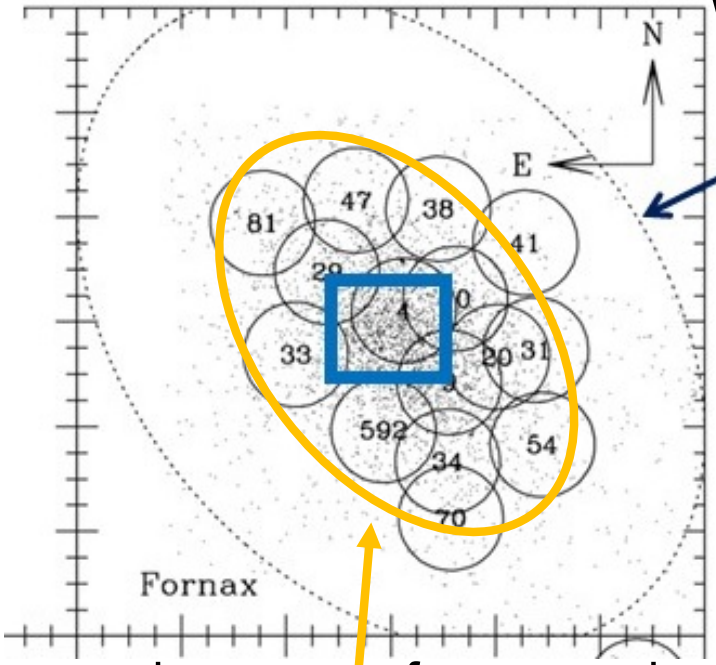
What is the effect on DM structure?
⇒ PFS!



PFS
(Prime Focus Spectrograph)

Prime Focus Spectrograph
SuMIRe

Fornax dSph



Walker et al. 2009

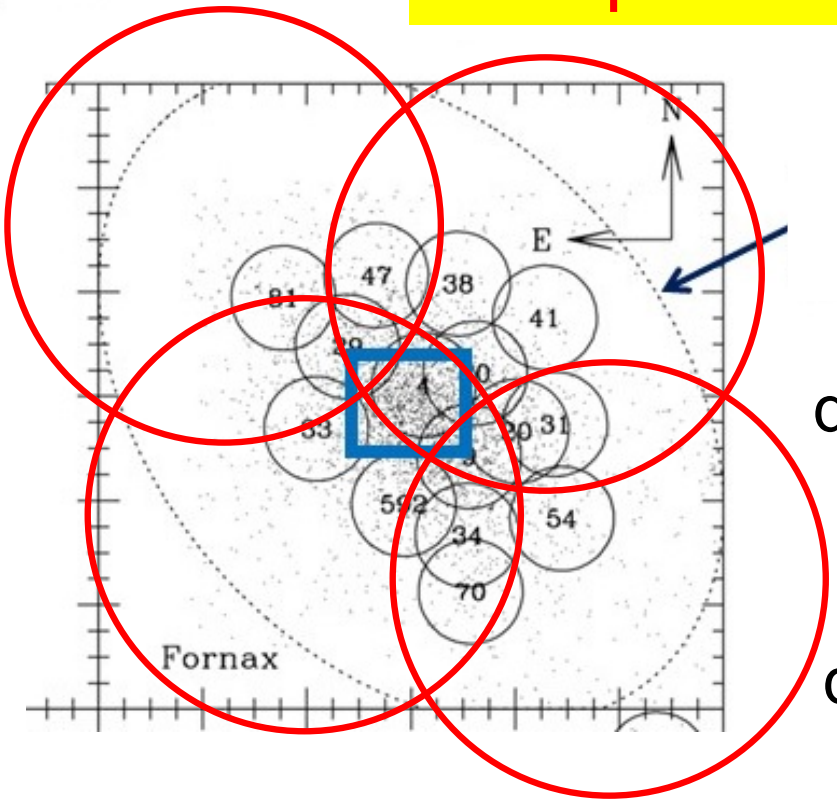
tidal radius
$r_t \sim 71'$

previous range for measuring dark halo profiles

Previous [α/Fe] measurements with DEIMOS (Kirby+)

Previous RV measurements with MMFS (Walker+)

PFS pointings



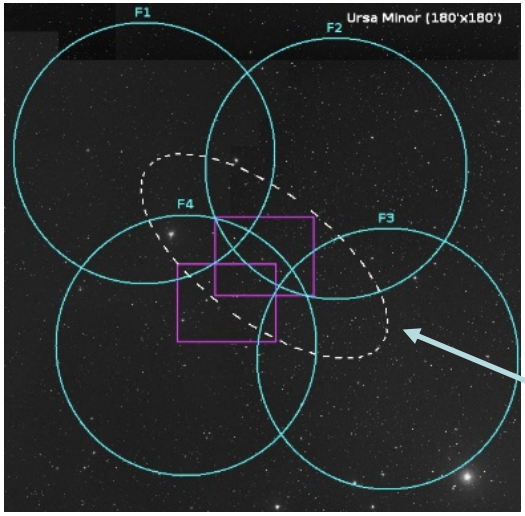
Mapping dark matter

Nature of dark matter

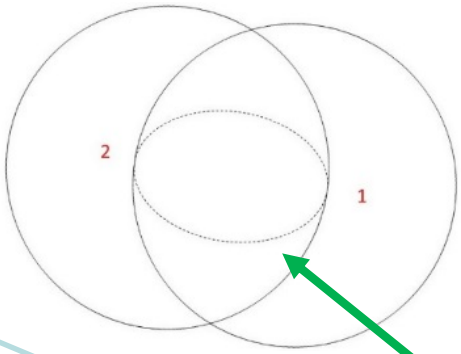
MW's satellites: PFS sample

~ HSC data are available for all these satellites ~

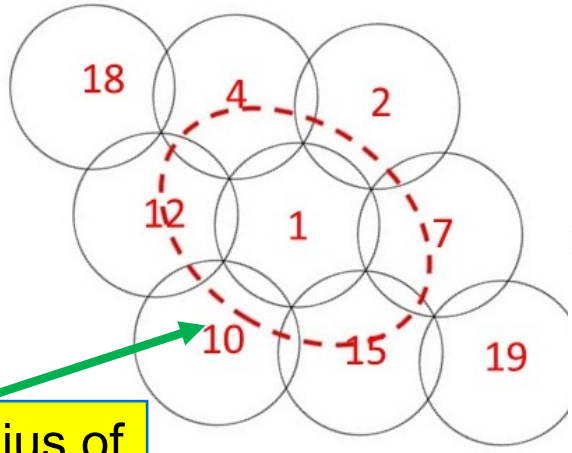
Ursa Minor



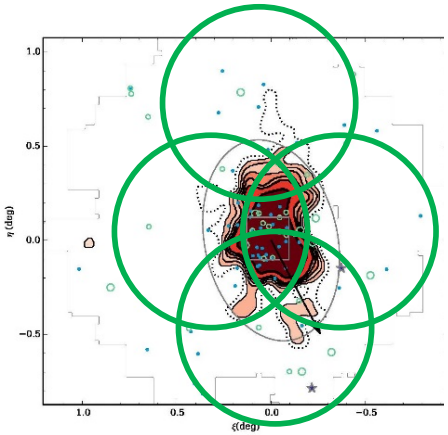
Draco



Sextans

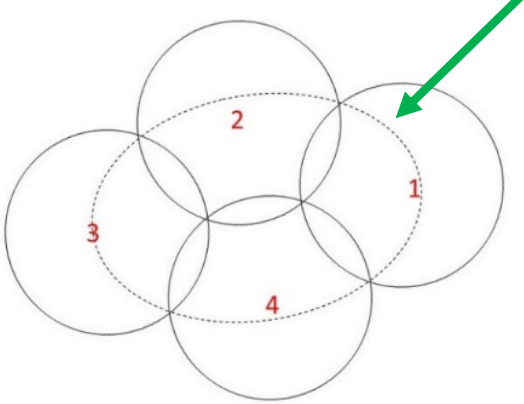


Bootes I

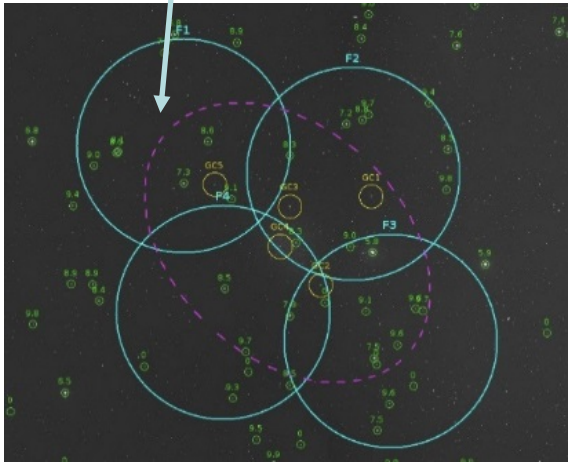


tidal radius of stellar comp.

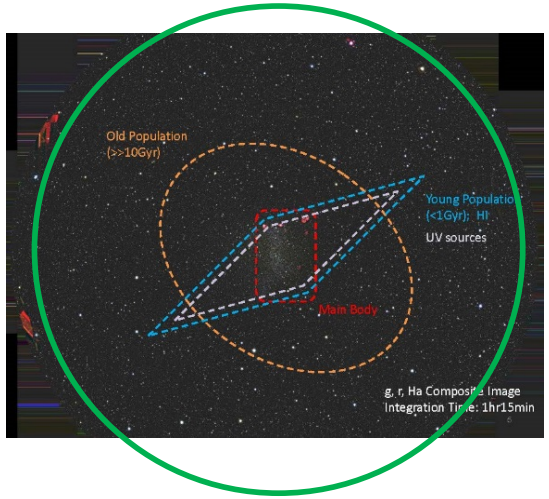
Sculptor



Fornax



NGC6822



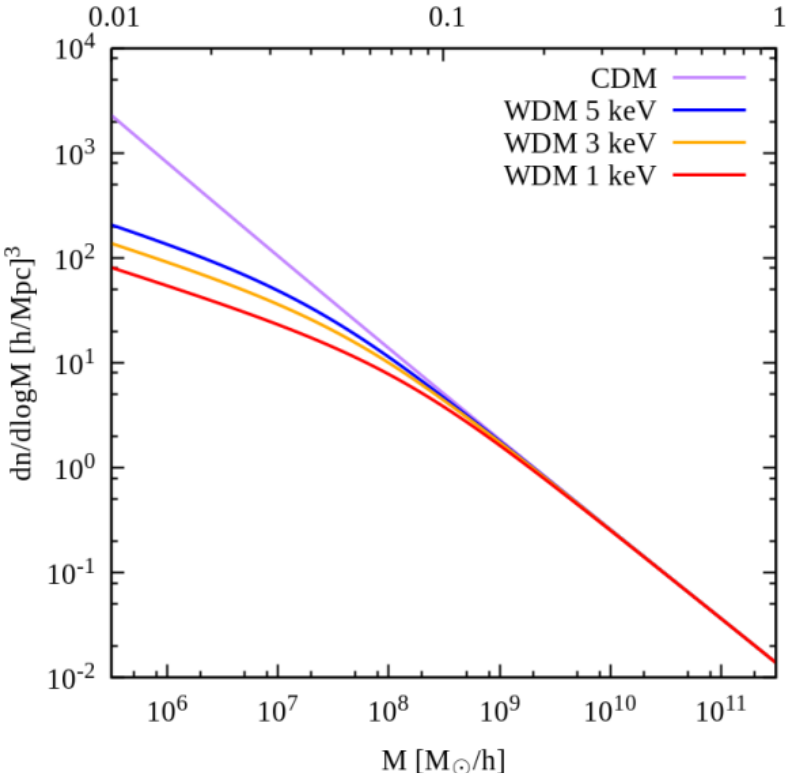
New Insight into Statistics of Void Sizes on Galactic Scales

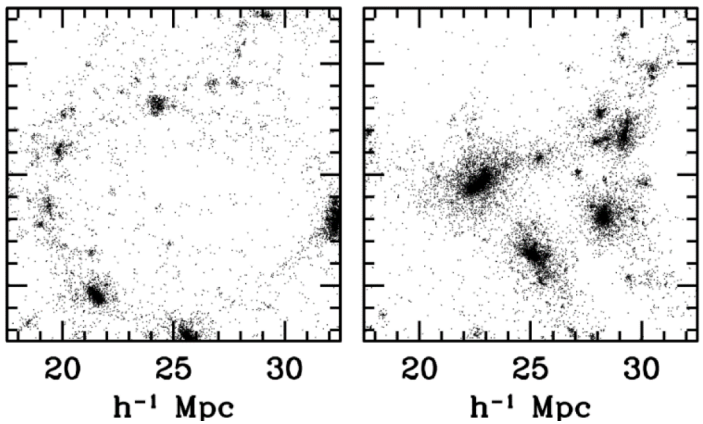
Hei Yin Jowett Chan
Masashi Chiba, Tomoaki Ishiyama

2019, MNRAS, 490, 2405

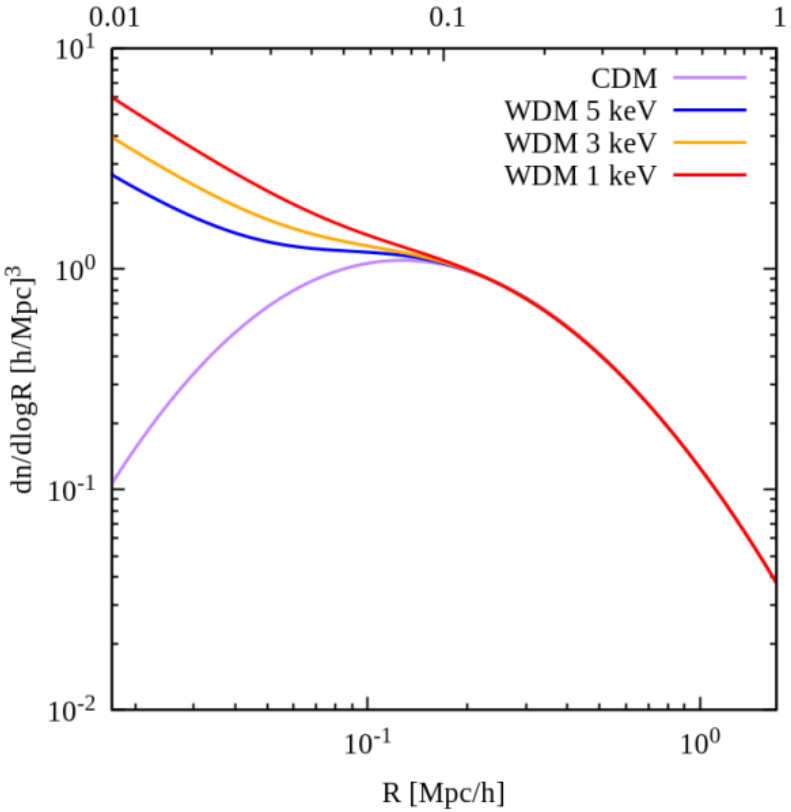
Analytical models

Halo mass function (EPS)





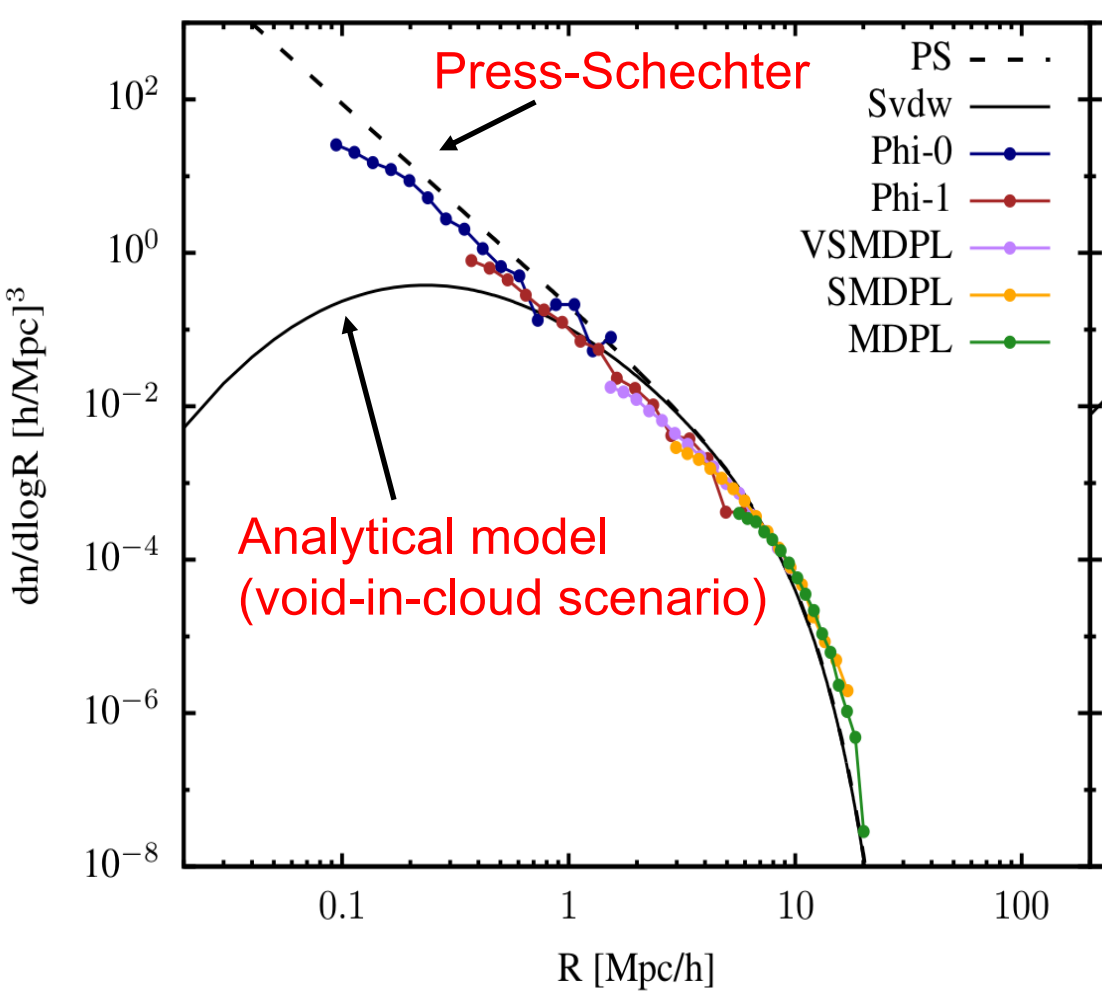
Void size function
(Cf. Sheth & van de Weygaert 2004)
Void-in-cloud scenario



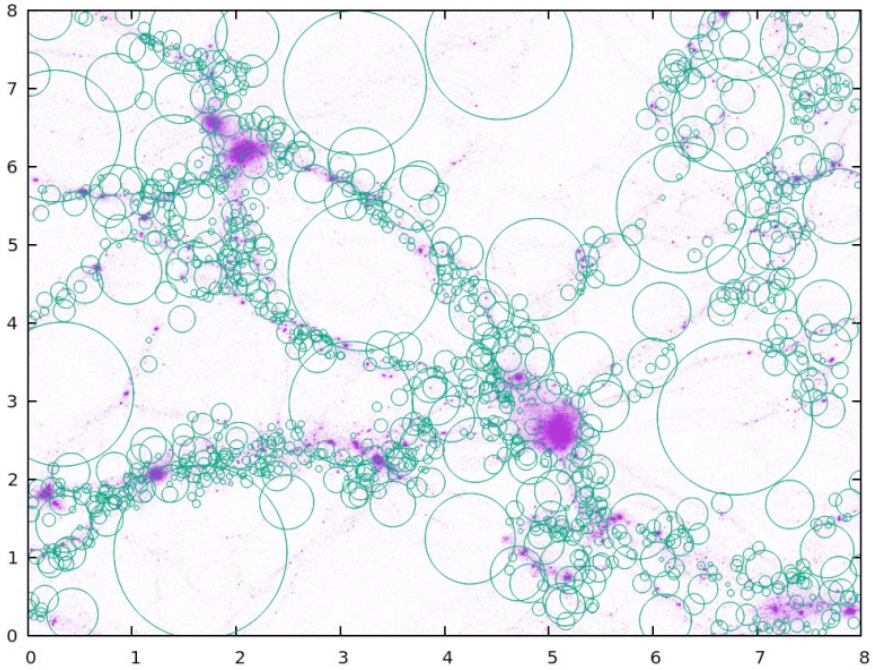
A void is assumed to disappear by the collapse of a larger halo

But is it true?

Void Size Distribution



Void finding for Ishiyama-san's high-resolution simulation



- **Disagreement on small scale at R < 1 Mpc/h**
- **Small voids survive through the void-in-cloud process**

Void-in-cloud scenario is not correct!

Summary

- New Galactic satellites have constantly been discovered from the HSC-SSP data.
- This discovery status may be understood in the frame work of ΛCDM + galaxy formation models