

Pegasus Dwarf

# A New Milky Way Satellite Discovered In The Subaru/Hyper Suprime-Cam Survey

Canis Major Dwarf

Virgo I

Sculptor Dwarf

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(Homma et al.2016,ApJ,832,21H)

Magellanic Cloud

# Summary

- We have discovered a new Milky Way satellite 'Virgo I' in the Subaru/HSC survey.
- Virgo I is one of the faintest satellite galaxies ( $M_V \sim -0.8\text{mag}$ ).
- HSC-SSP is very powerful to search for missing satellites.
- We expect more new satellites in the next data release.
- In the future, more satellite discoveries will be very important to understand galaxy formation and nature of dark matter.

# Missing satellite problem

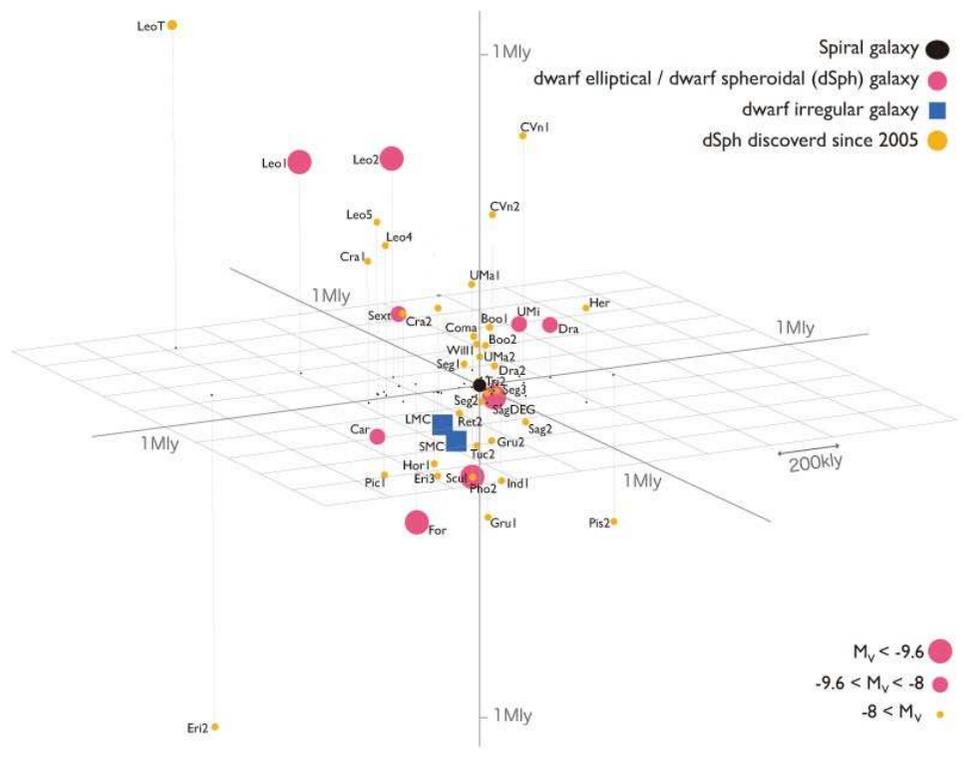
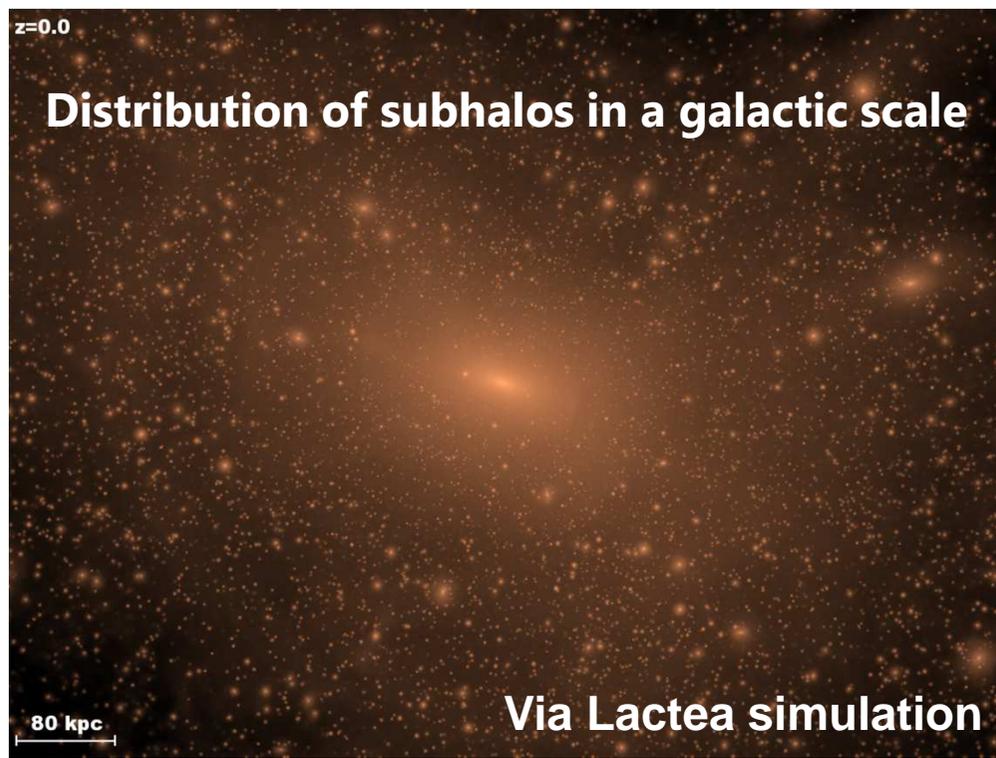
**$\Lambda$ CDM theory**

Hundreds of sub-halos

**Observation**

~50 satellites

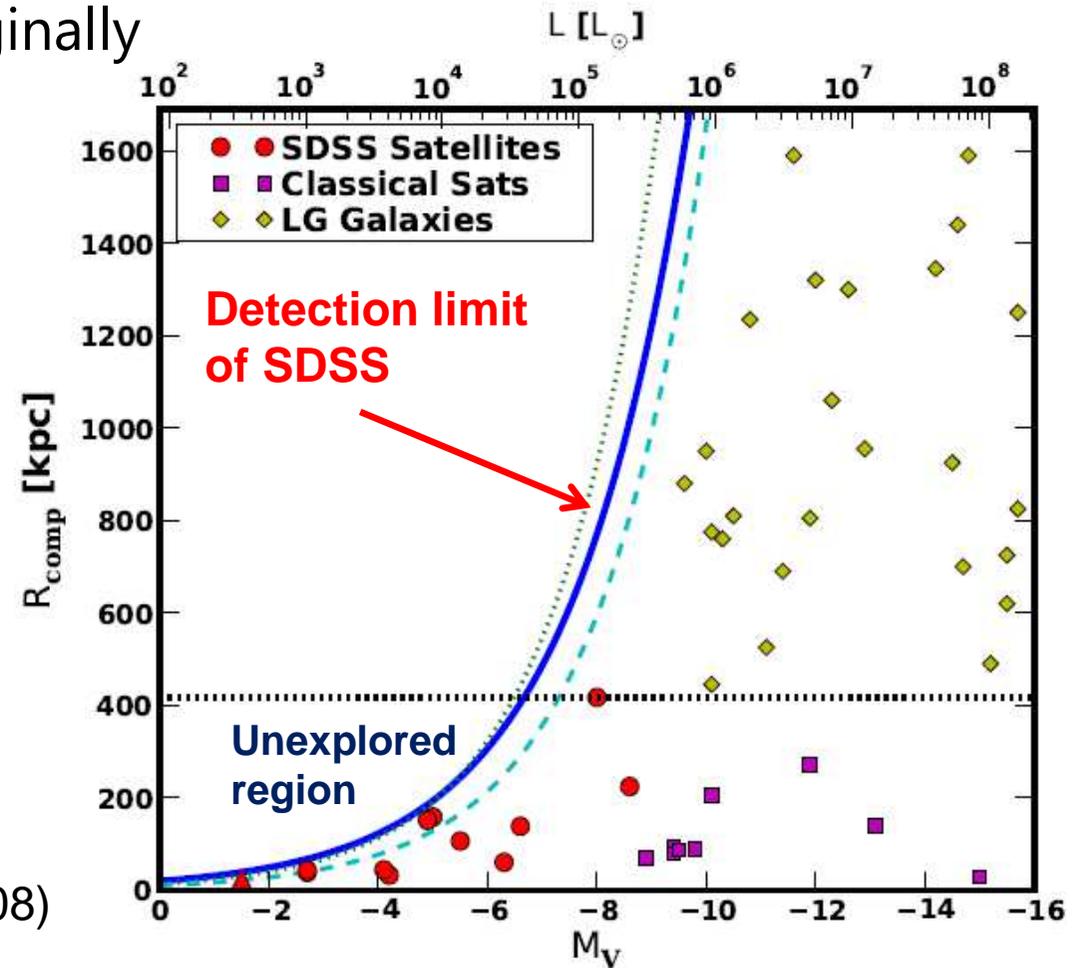
Discrepancy



# Missing satellite problem

## Proposed solutions

- Few (or no) baryons in small sub-halos  
Stellar feedback and ionization suppress star formation in small sub-halos
- There are not so many sub-halos originally  
Other types of dark matter particle  
(WDM, not CDM)
- **Observational bias**  
Faint or distant satellites  
have not been discovered

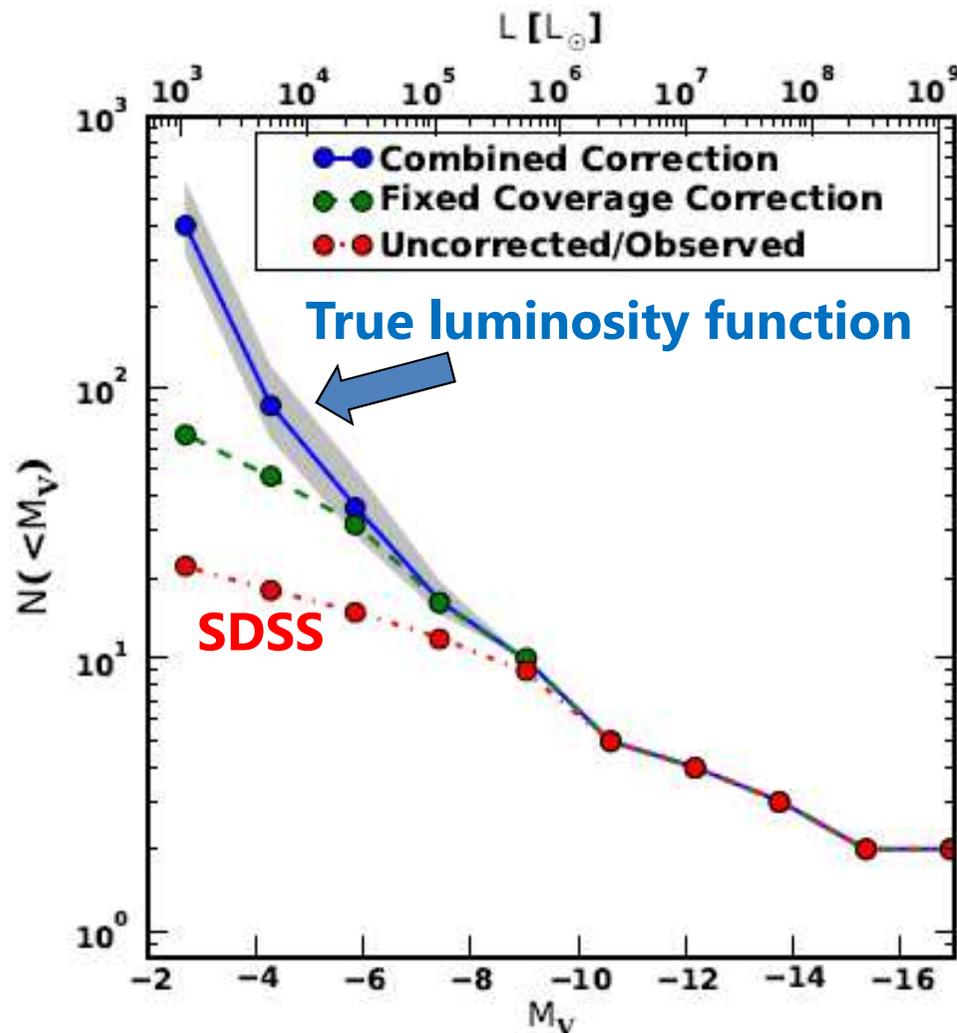


(Tollerud et al.2008)

# Luminosity function of satellites

• 2005~2012 : 15 satellites discovered by SDSS

Many of them are ultra-faint dwarfs (UFDs;  $M_V \leq -8 = L < 10^5 L_\odot$ )

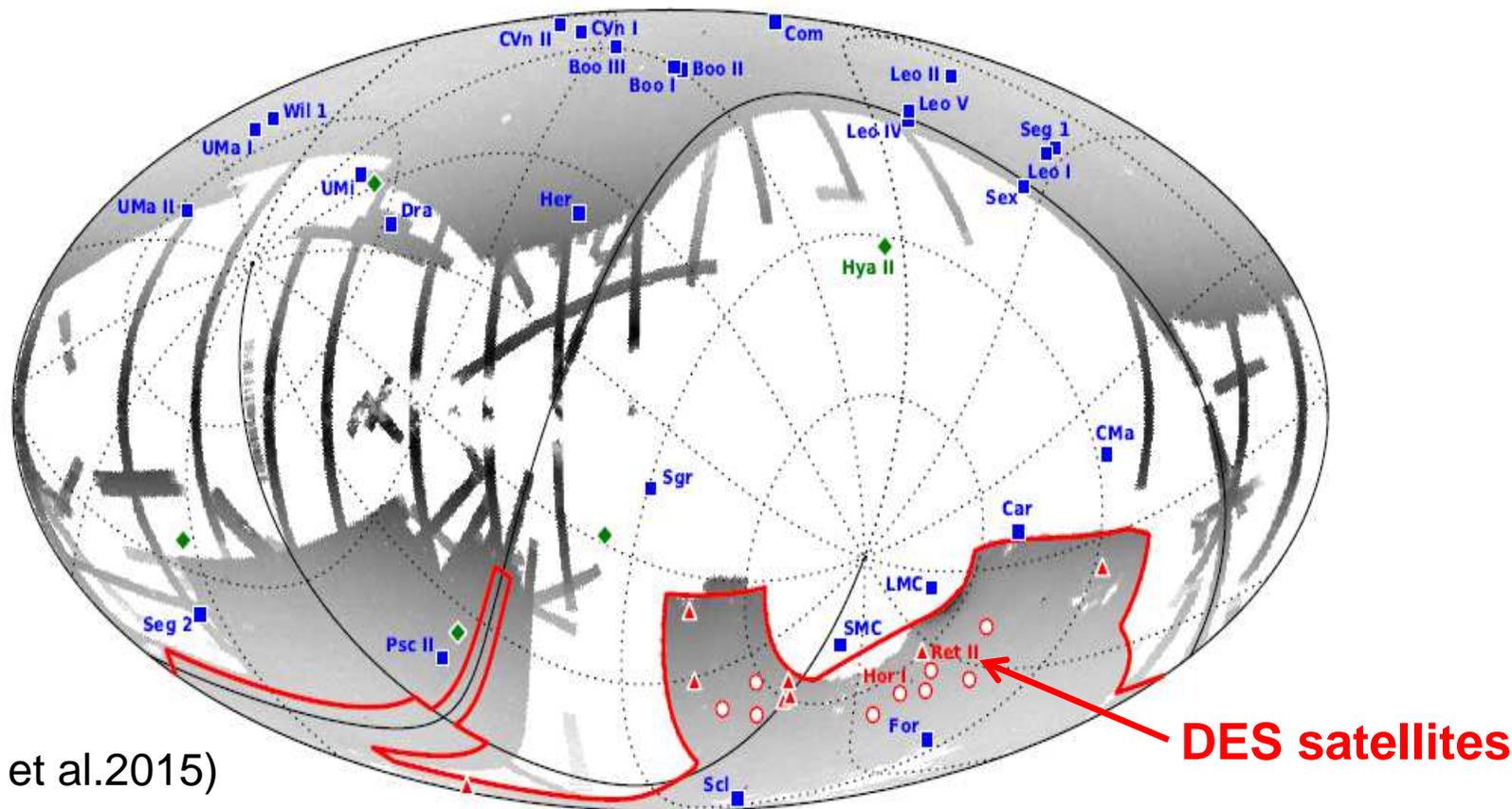


SDSS discoveries predict  
~400 satellites @  $M_V < -3$

(Tollerud et al.2008)

# Recently satellite discoveries

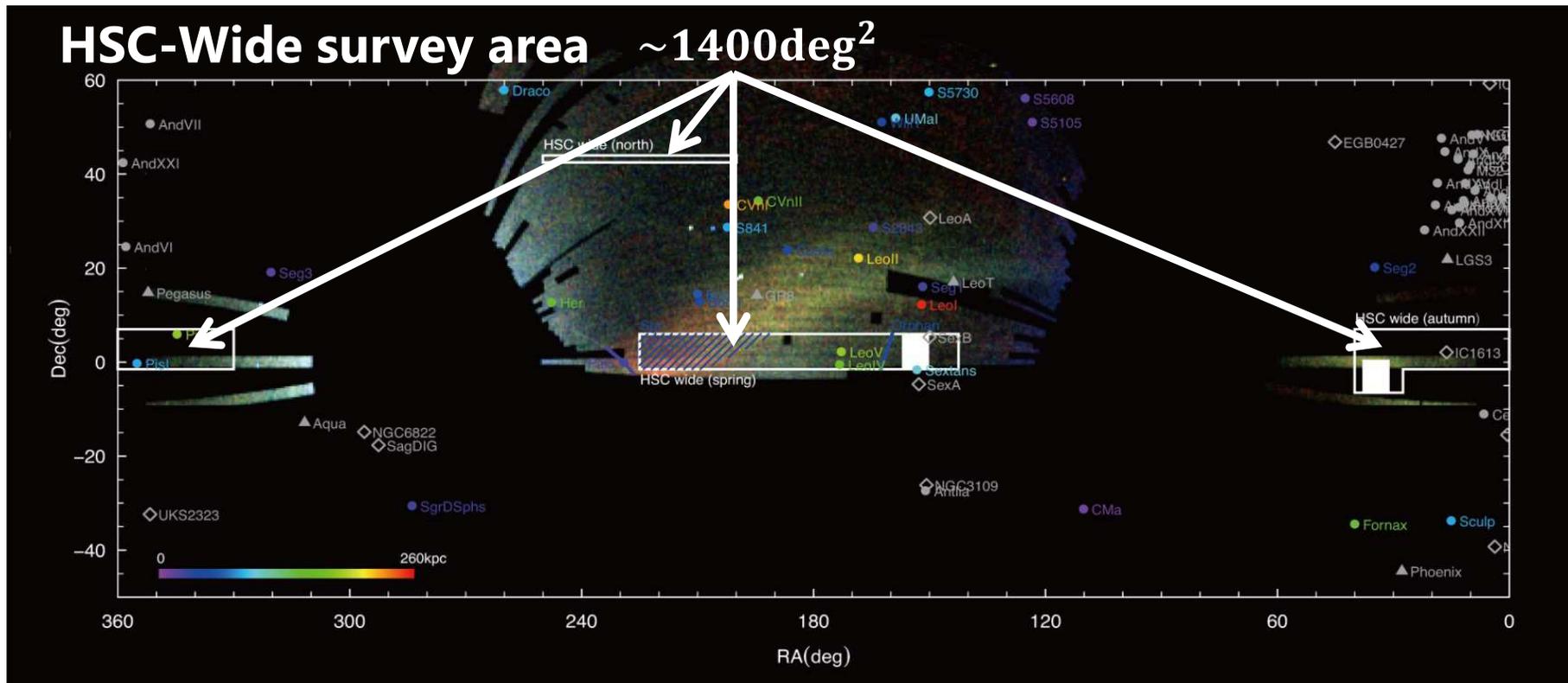
- 2005~2012 : 15 satellites discovered by SDSS  
Many of them are ultra-faint dwarfs (UFDs;  $M_V \leq -8 = L < 10^5 L_\odot$ )
- **2015~** : **~20 satellites discovered by DES, Pan-STARRS, and so on**  
**Some of them are "hyper faint" galaxies ( $M_V \leq -2.7 = L < 10^3 L_\odot$ )**



# Search for missing satellites with Subaru/HSC

HSC-SSP survey is...

**Wide** and **Deep**  
 ( $\sim 1400 \text{deg}^2$ ) ( $r_{\text{lim}} = 26 \text{mag}$ )

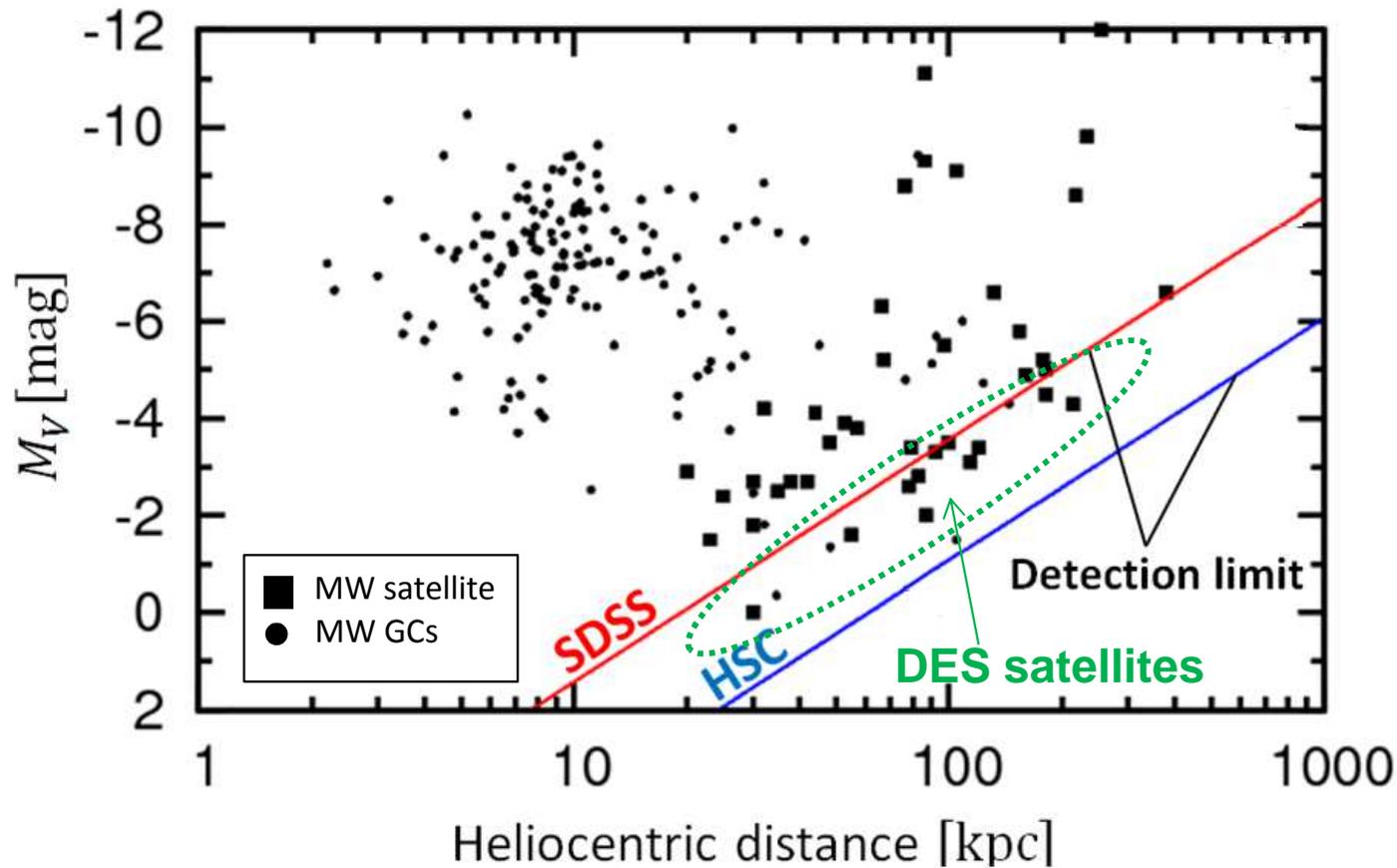


Search for satellites in the HSC-Wide survey area has been already done by previous surveys such as SDSS and Pan-STARRS, but...

# Search for missing satellites with Subaru/HSC

Subaru/HSC-SSP survey is...

**Wide** and **Deep**  
( $\sim 1400 \text{deg}^2$ ) ( $r_{\text{lim}} = 26 \text{mag}$ )

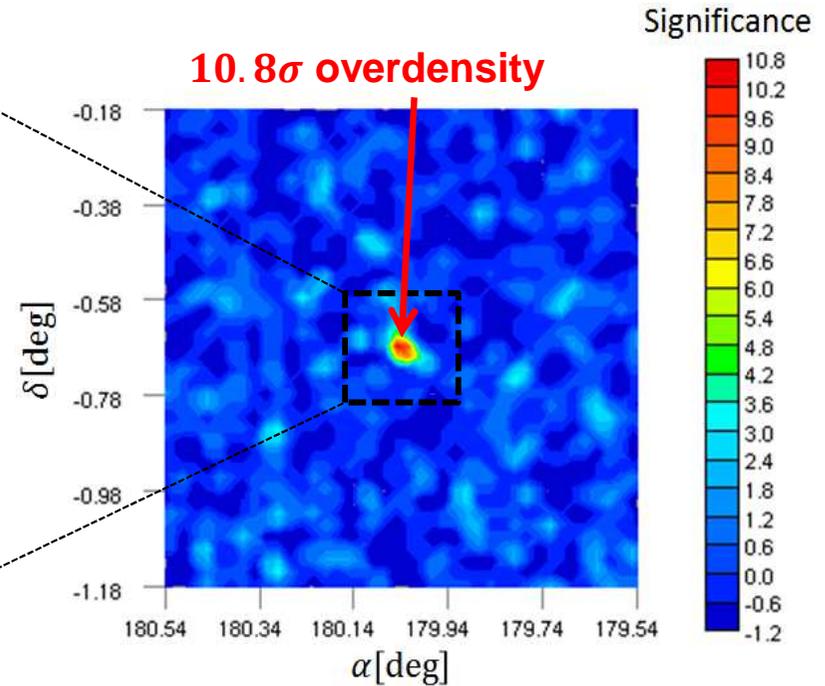


New satellites can be discovered by HSC-SSP !!

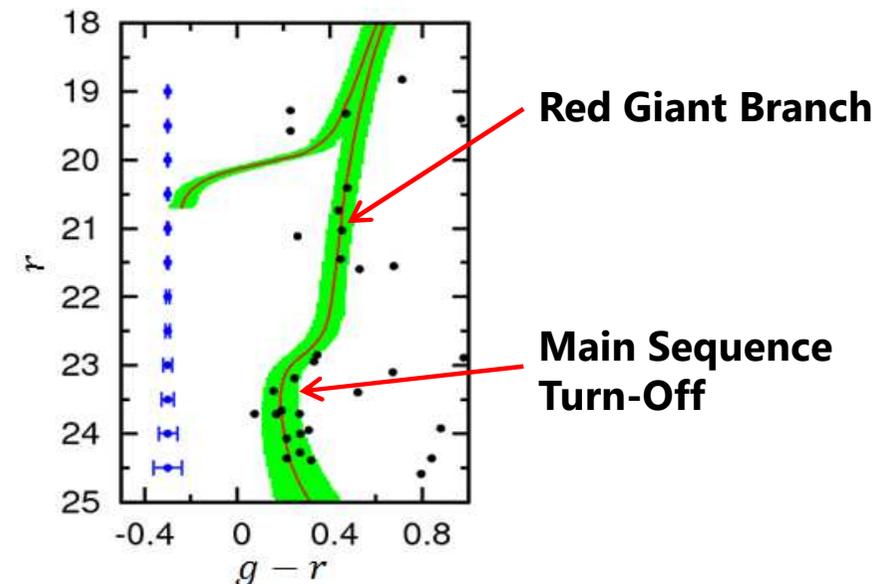
# A new MW satellite 'Virgo I' discovered



0.2° × 0.2° g,r,i image of Virgo I



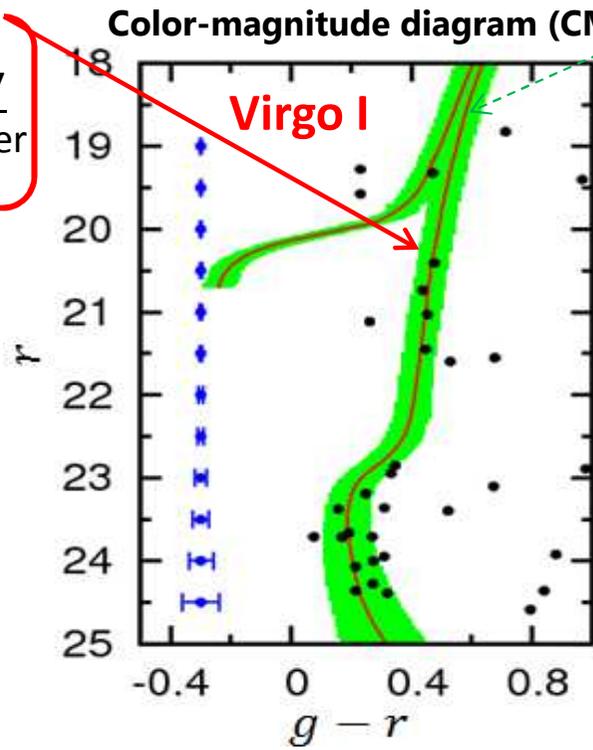
Parameter <sup>a</sup>	Value
Coordinates (J2000)	12 <sup>h</sup> 00 <sup>m</sup> 09 <sup>s</sup> .6, -0° 40' 48''
Galactic Coordinates ( <i>l</i> , <i>b</i> )	276°.94, 59°.58
Position angle	+51 <sup>+18</sup> <sub>-40</sub> deg
Ellipticity	0.44 <sup>+0.14</sup> <sub>-0.17</sub>
$A_V$	0.066 mag
$(m - M)_0$	19.7 <sup>+0.3</sup> <sub>-0.2</sub> mag
Heliocentric distance	87 <sup>+13</sup> <sub>-8</sub> kpc
Half light radius, $r_h$	1'.5 ± 0'.4 or 38 <sup>+12</sup> <sub>-11</sub> pc
$M_{\text{tot},V}$	<u>-0.8 ± 0.9 mag</u>



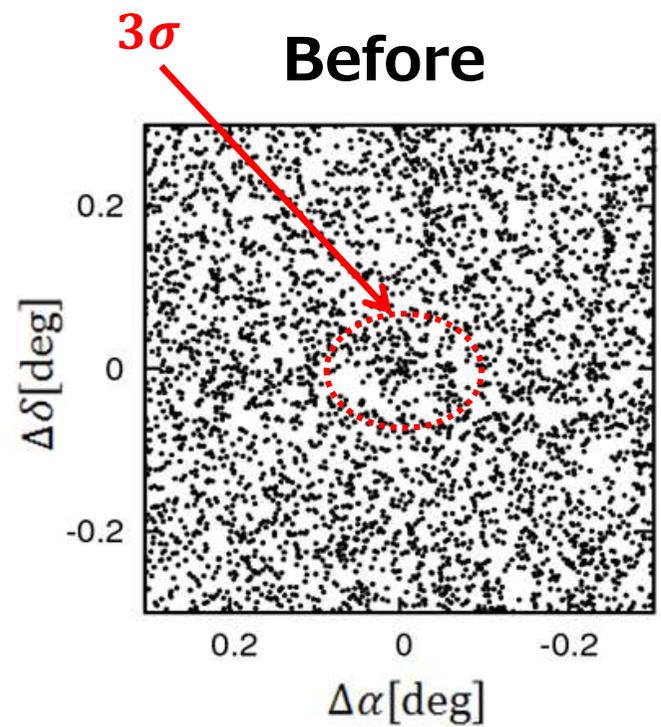
# Detection algorithm

- UFDs are very old and metal-poor systems
- So, stellar overdensities of UFDs are sensitive to the **CMD filtering**

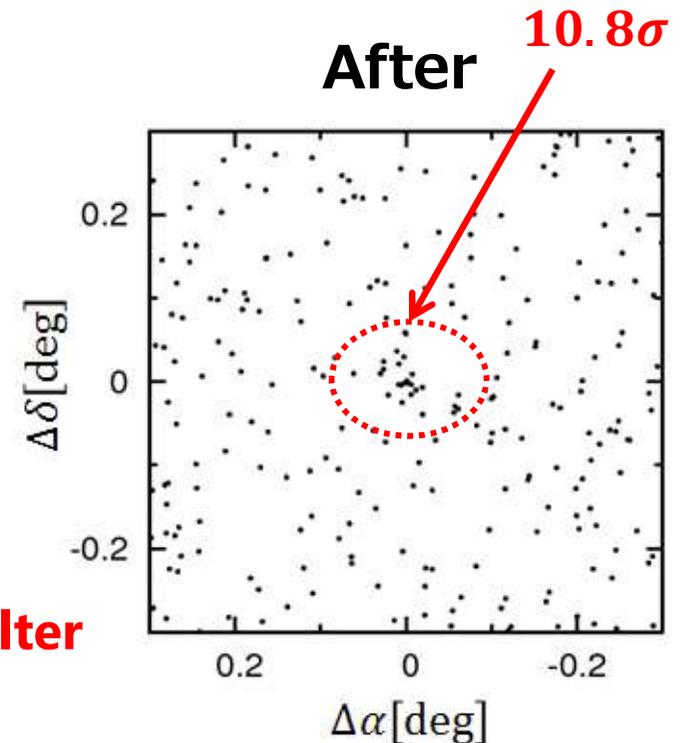
**Fiducial isochrone**  
 Age:13Gyr, [Fe/H]=-2.2,  $m-M=19.7$   
 Free parameter



**(Green shaded region)**

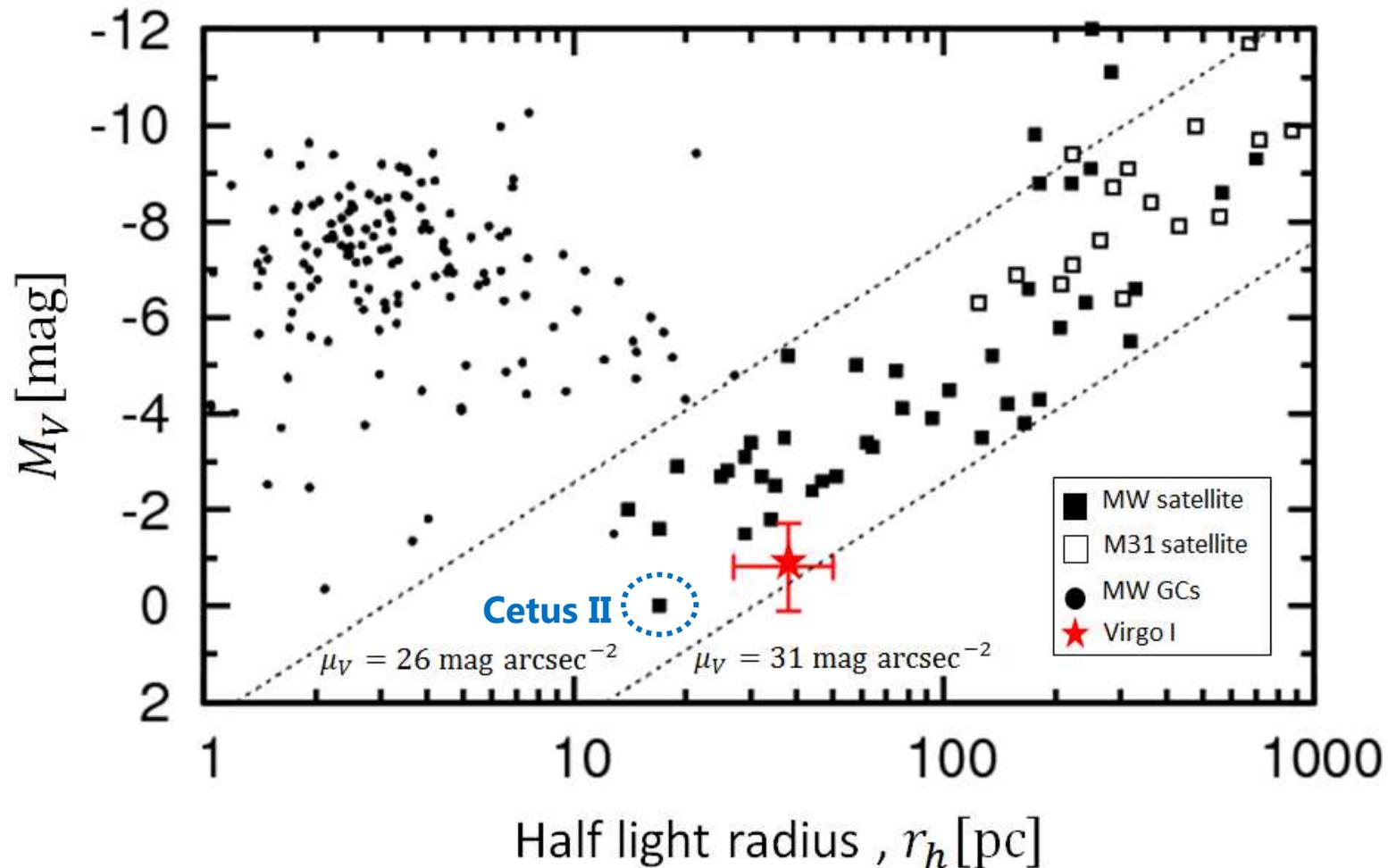


**Selection within the CMD filter**



# Virgo I is the 1<sup>st</sup> or 2<sup>nd</sup> faintest satellite

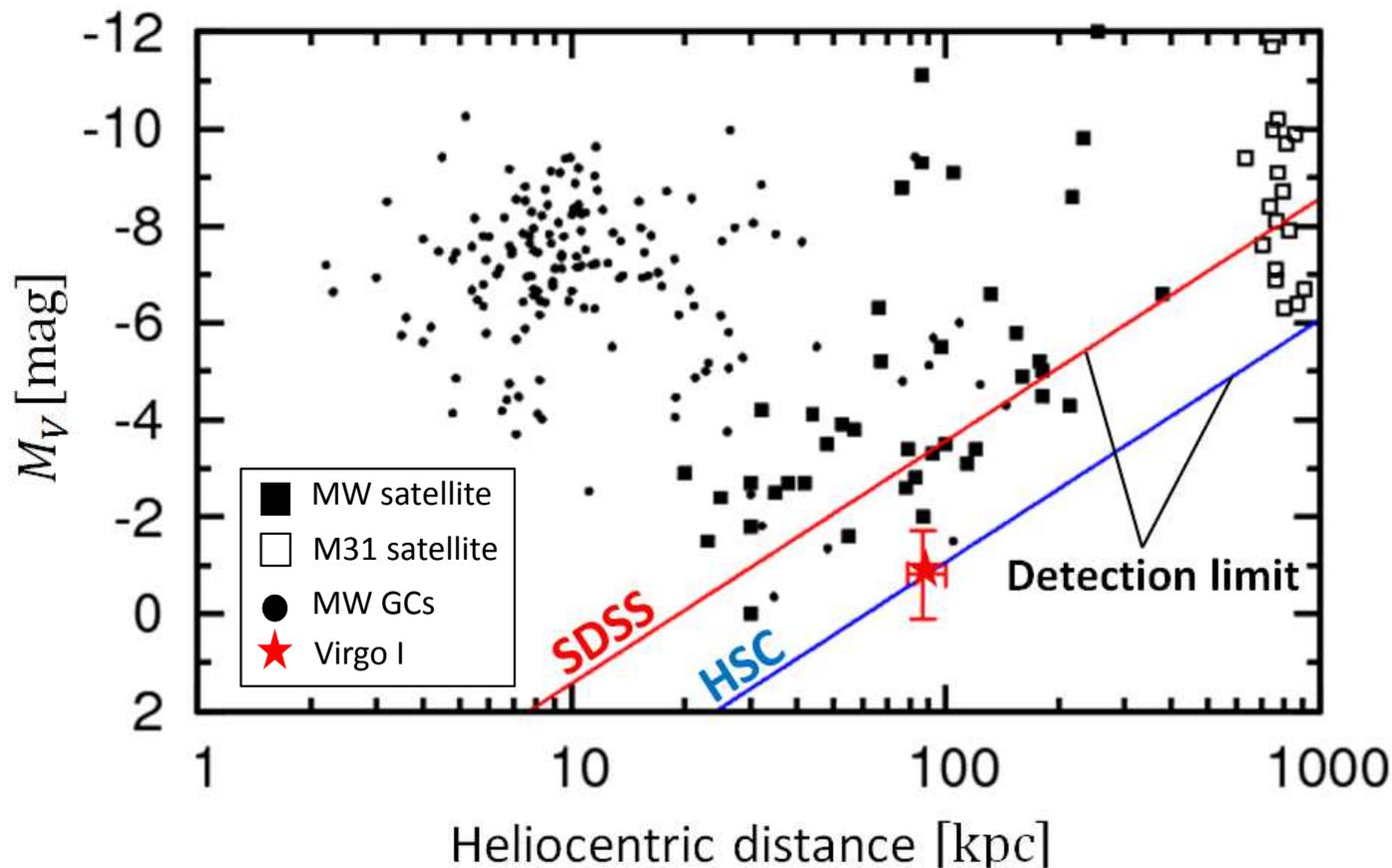
$$M_V \sim 0.8 \text{ mag} = L \sim 200 L_\odot$$



Where is the faintest end of the galaxy luminosity ??

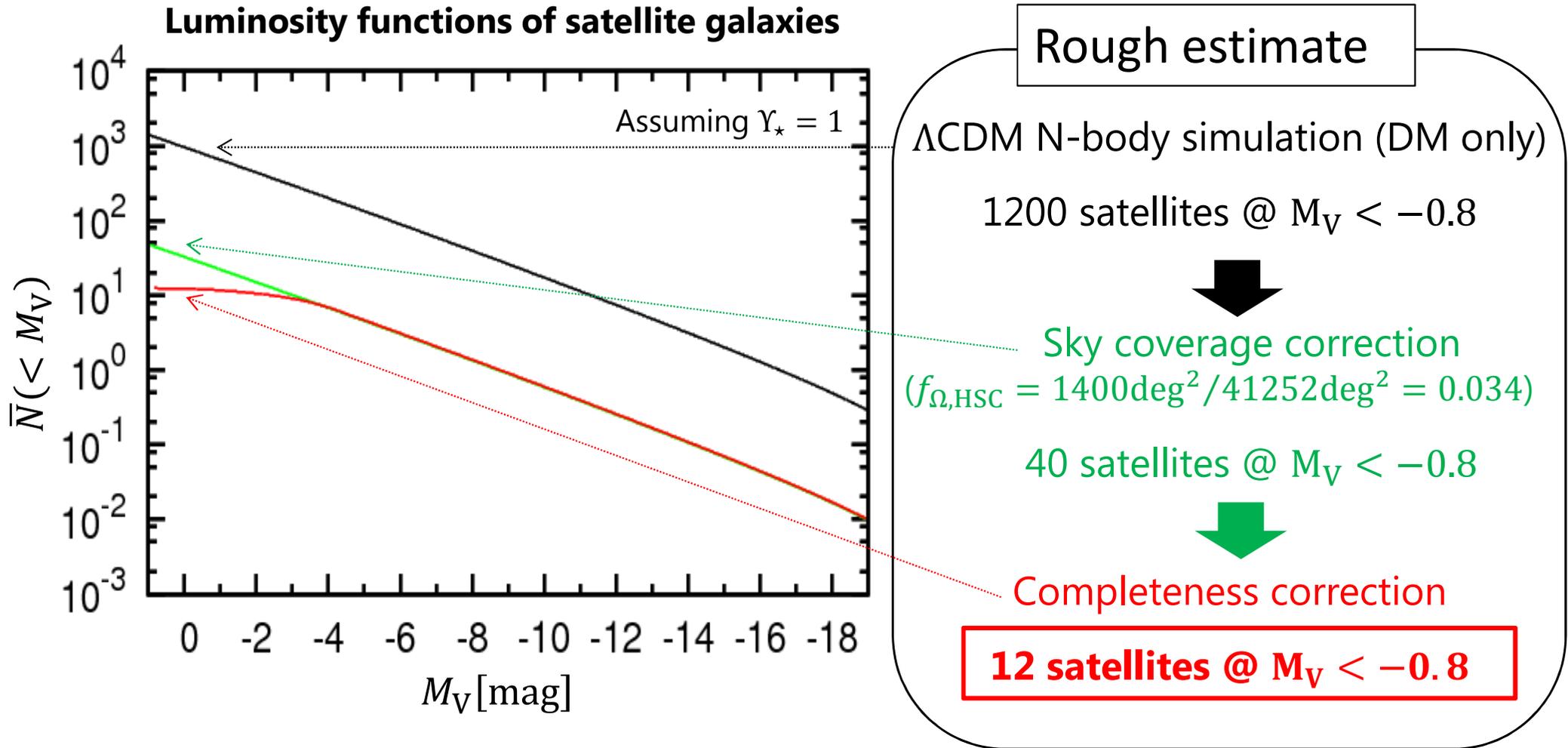
# Virgo I is the 1<sup>st</sup> or 2<sup>nd</sup> faintest satellite

Virgo I is beyond the detection limit of SDSS  
(~87kpc)



**Subaru/HSC is very powerful**  
**We expect more new satellites in the next data release**

# The likely number of detectable satellites in the HSC-SSP survey

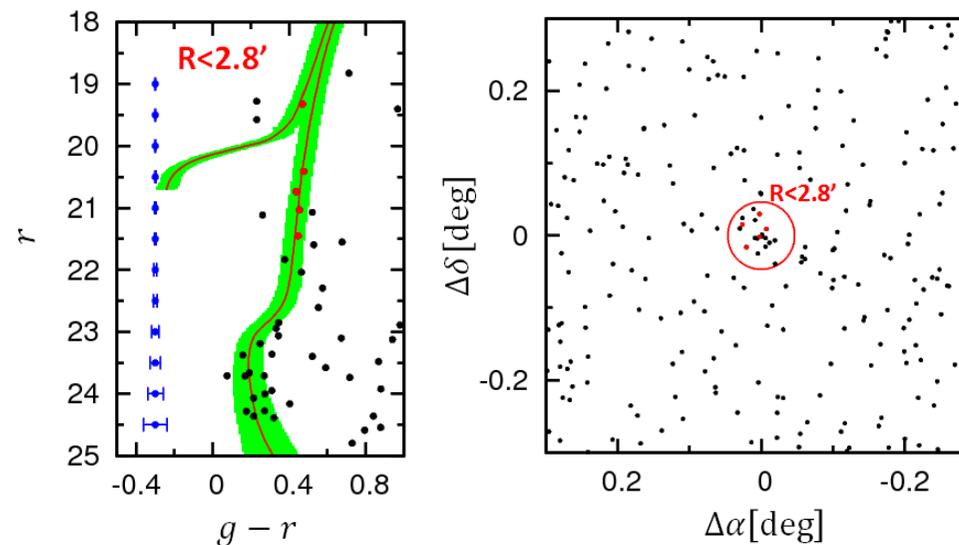


**$\Lambda$ CDM model predicts 1 satellite per  $120 \text{ deg}^2$  in the HSC-SSP survey**

# What's next ?

## I. Follow-up spectroscopy has been proposed to **Gemini**

- Radial velocity, dark matter mass, and metallicity
- Kinematically confirmed as a satellite galaxy



## II. Comparison with $\Lambda$ CDM model

- Luminosity function, radial distribution, kinematics, mass, ...

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