

Dark matter on small scales ～dwarf galaxies and J factor～

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新学術領域シンポ 2017.03.08

Small-scale issues in Λ CDM

- **Missing satellite problem**
 - Overabundance of dark subhalos (vs. ~ 50 MW satellites)
- **Too big to fail problem**
 - Too concentrated massive subhalos
- + **other issues** (anisotropic distribution, core/cusp)

Solutions

- Other DM models?
- Baryon effects?
- Limitations in observations?

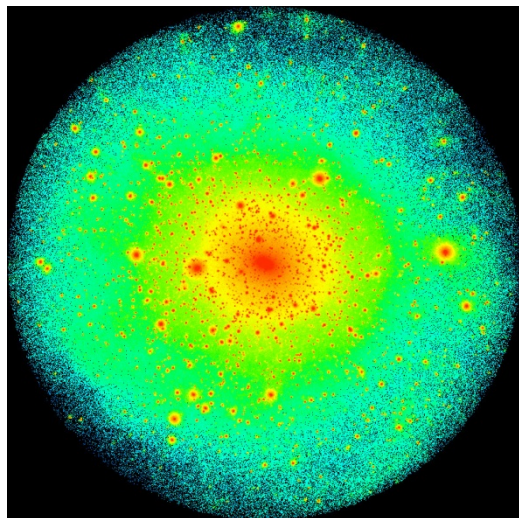
Dwarf spheroidal galaxies (dSphs) in the Local Group provide clues to these issues

Milky Way sized dark halo

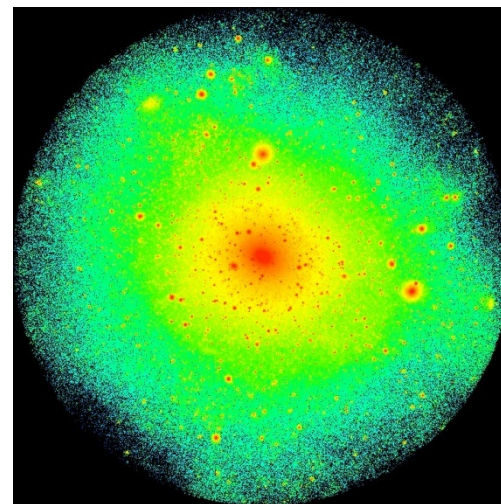
Anderhalden+12

Too many
subhalos

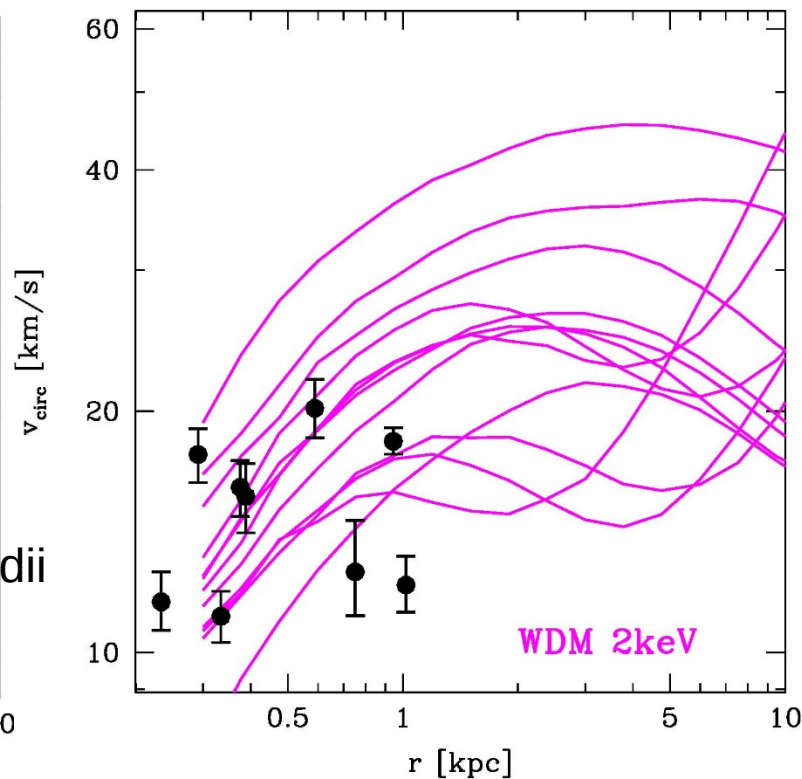
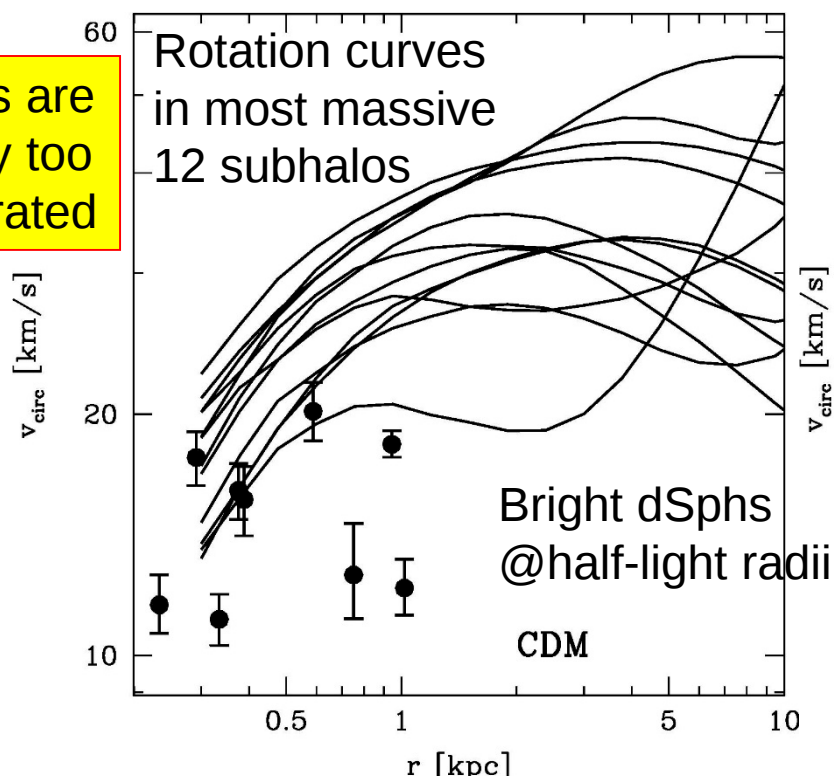
CDM



WDM
2 keV



subhalos are
internally too
concentrated



Dwarf spheroidal galaxies (dSphs)

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

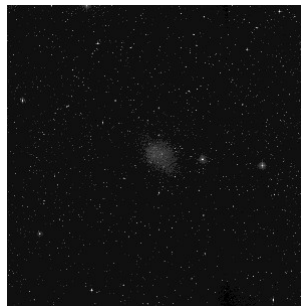
Sculptor



Carina



Fornax



Leo II



Leo I



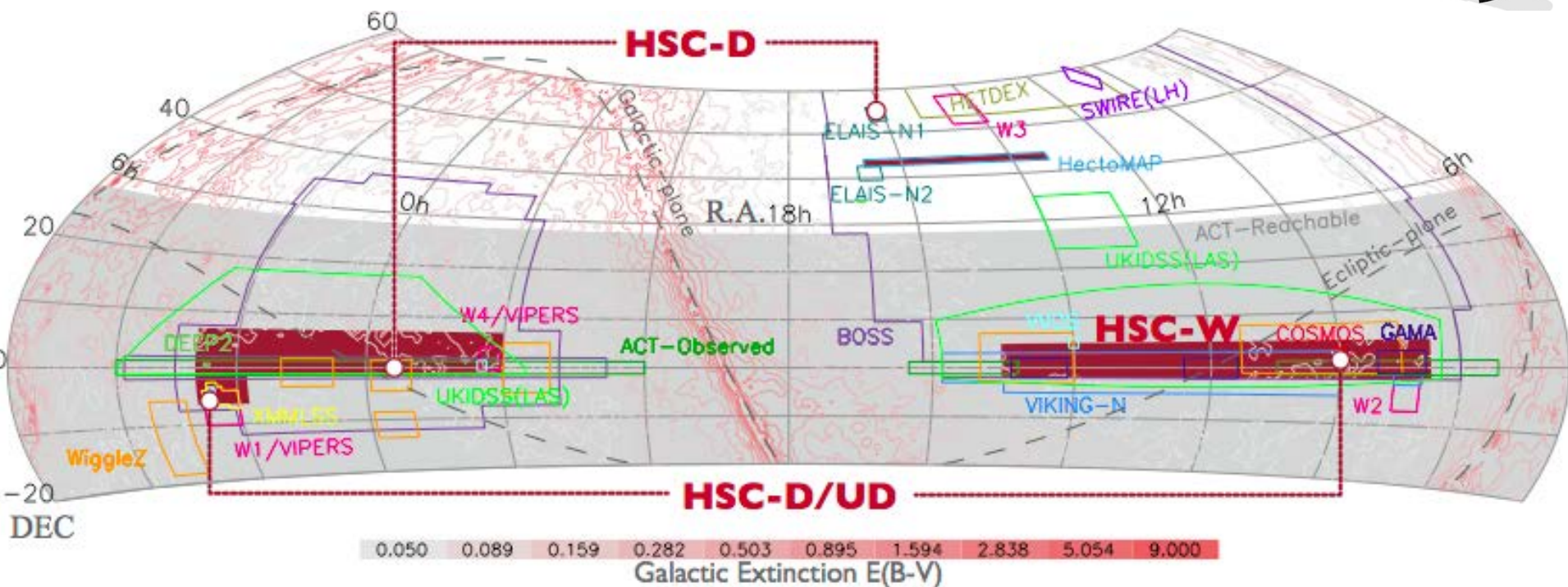
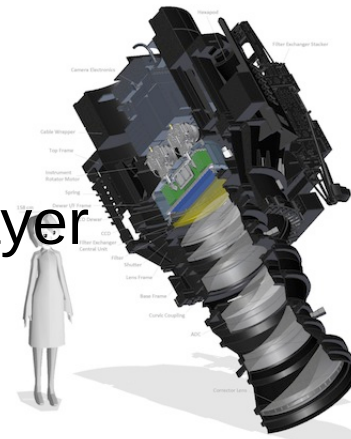
- Dark matter dominated
 - $(M/L)_{\text{tot}} = 10 \sim$ a few thousands
 - Ideal site for studying DM $\Rightarrow$ more details, Kohei's talk

This talk

- M. Chiba: recent progress on dwarf galaxies
 - Discovery of new dSphs in the Milky Way halo from Subaru/HSC survey
 - Discovery of a dusty dark dwarf galaxy with ALMA in a quadruple lens system
- K. Hayashi: models for getting J-factor

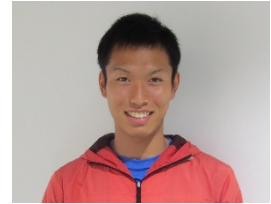
HSC Subaru Strategic Program (SSP)

- Wide, Deep, Ultra-deep layers
 - dSphs search from 1st 2 year data of Wide layer
 - (~ 300 deg² / 1,400 deg²)



A new dwarf galaxy: Virgo I discovered

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

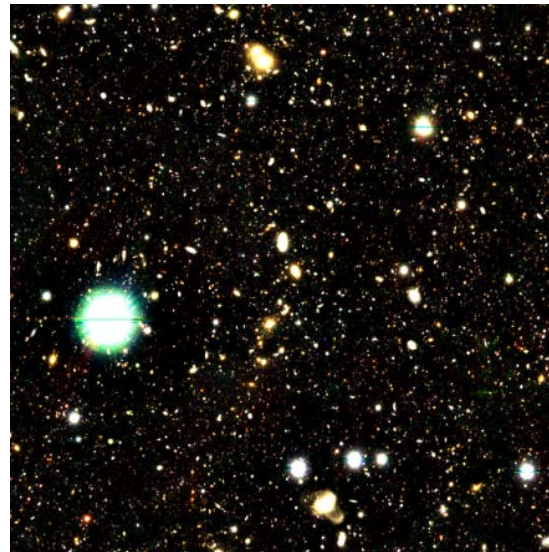


Coordinates : $(\alpha, \delta) = (180^\circ.04, -0^\circ.68)$

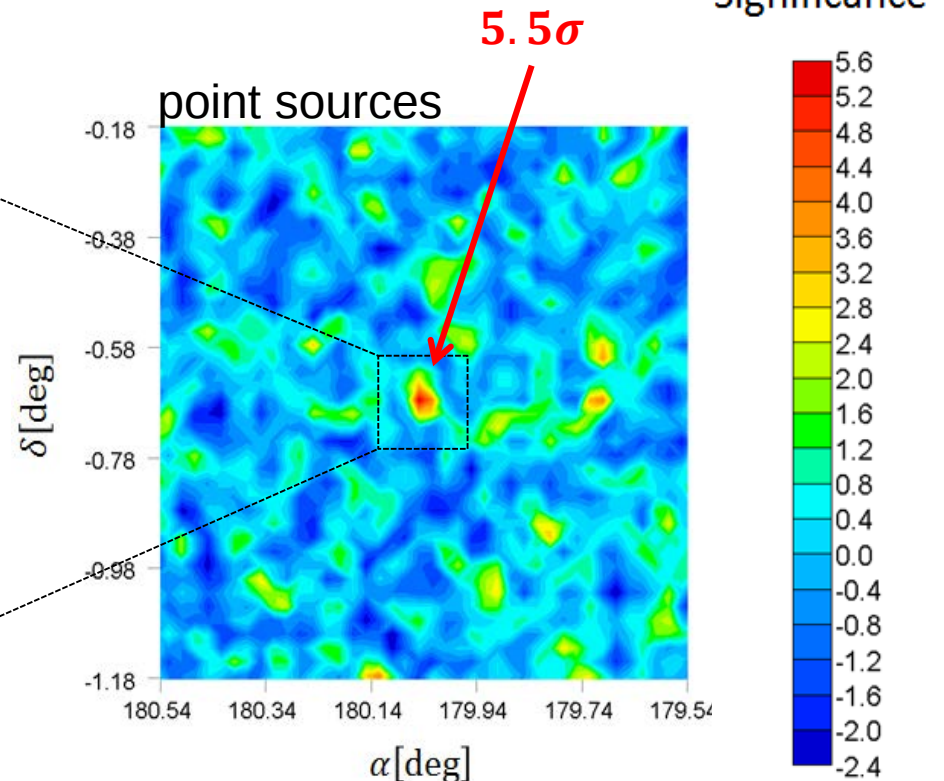
Absolute magnitude : $M_V = -0.33$ mag

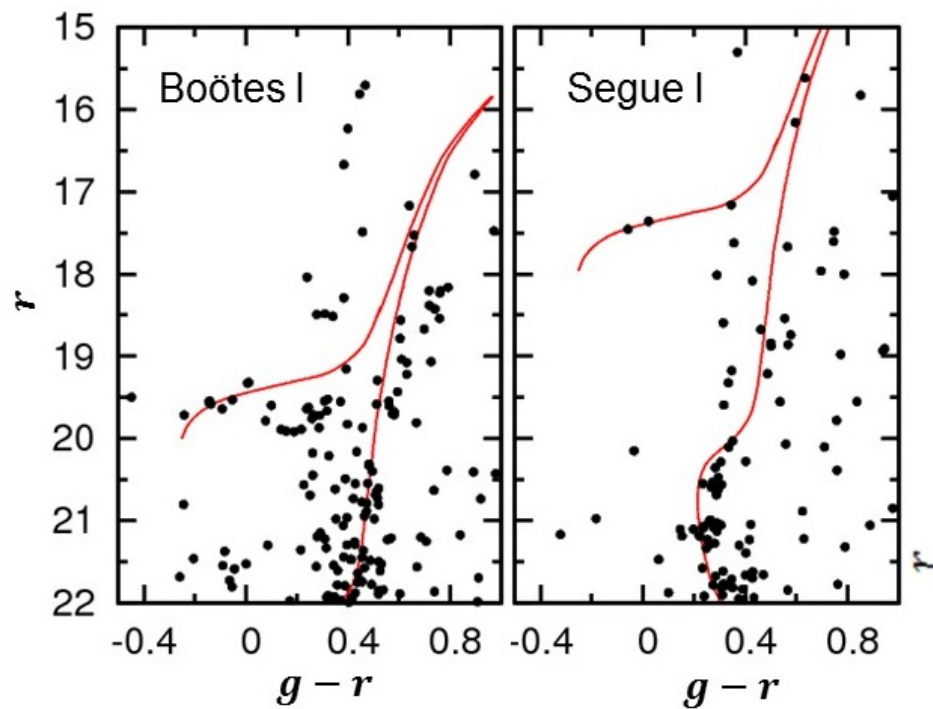
Heliocentric distance : $D = 87_{-8}^{+13}$ kpc

Half light radius : $r_h = 38_{-11}^{+12}$ pc

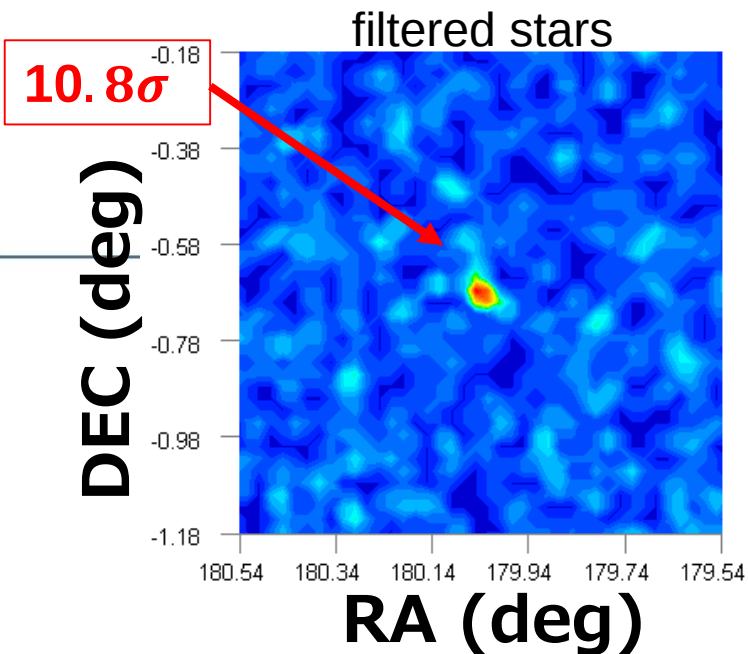
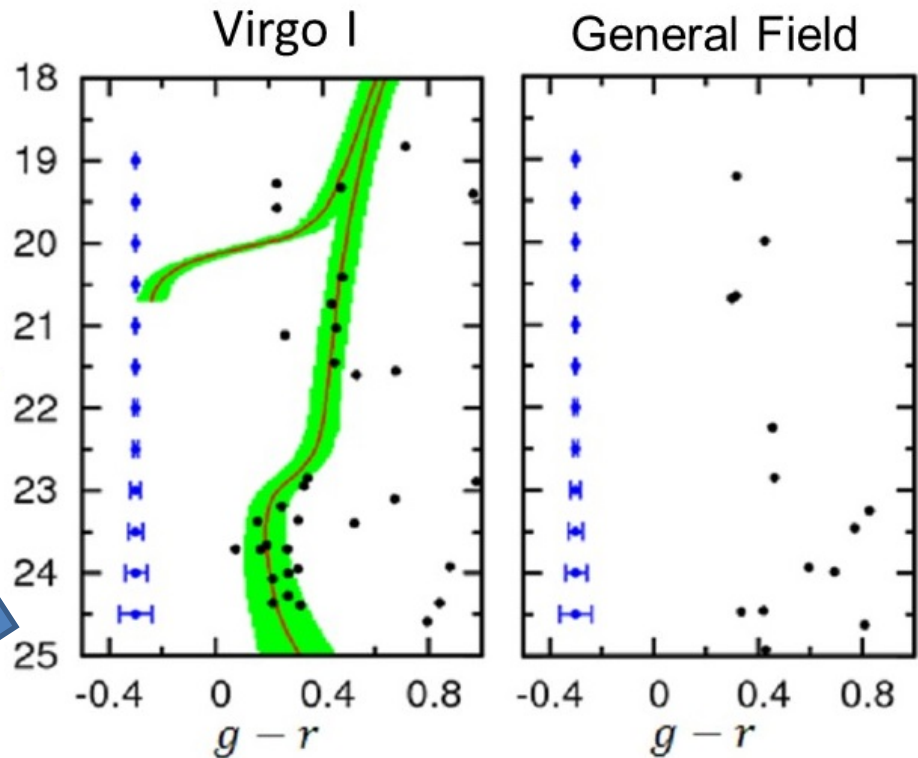


$10' \times 10'$ *gri* image of Virgo I





Stellar distribution
in the color-magnitude diagram



Stars passing the Isochrone filter
(green shaded envelope)

10.8σ overdensity

$M_V = -0.33$ mag (faintest dSphs)

Advertisement

Many media over the world reported our discovery

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DAILY NEWS 4 October 2016

Super-dim galaxy may be one of hundreds orbiting the Milky Way



The Milky Way, as seen from the ISS
NASA/Reid Wiseman

By Ken Crowell



Descubren la galaxia más oscura, justo al lado de la Vía Láctea

Dwarf galaxy discovered next to our own Milky Way



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science

Astronomers detect a faint dwarf galaxy relatively close to our own

NOVEMBER 23, 2016 4:51PM



Astronomers have detected a faint dwarf galaxy relatively close to our own.

Nick Whigham news.com.au

Crean una m
digital capaz
sobrevivir a
humana

52... Lee la entrada

Publicidad

“今回で2足目ですが、も
140年続く老舗靴屋の新

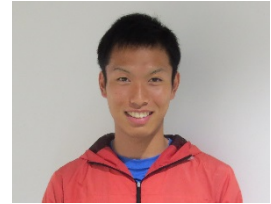


Categorías:

Technology | Creative

One more: Cetus III discovered

Homma, Chiba, et al. 2017, in prep



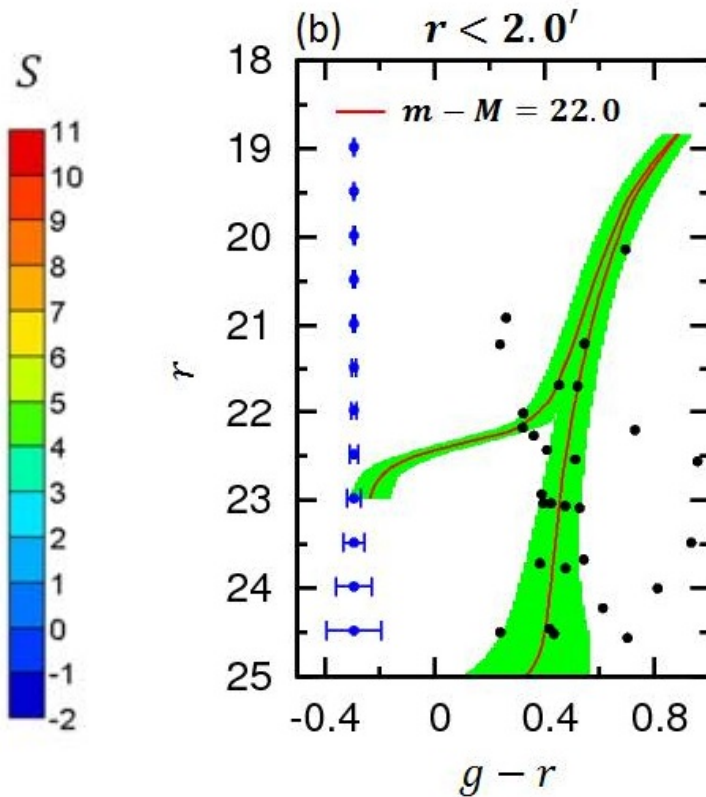
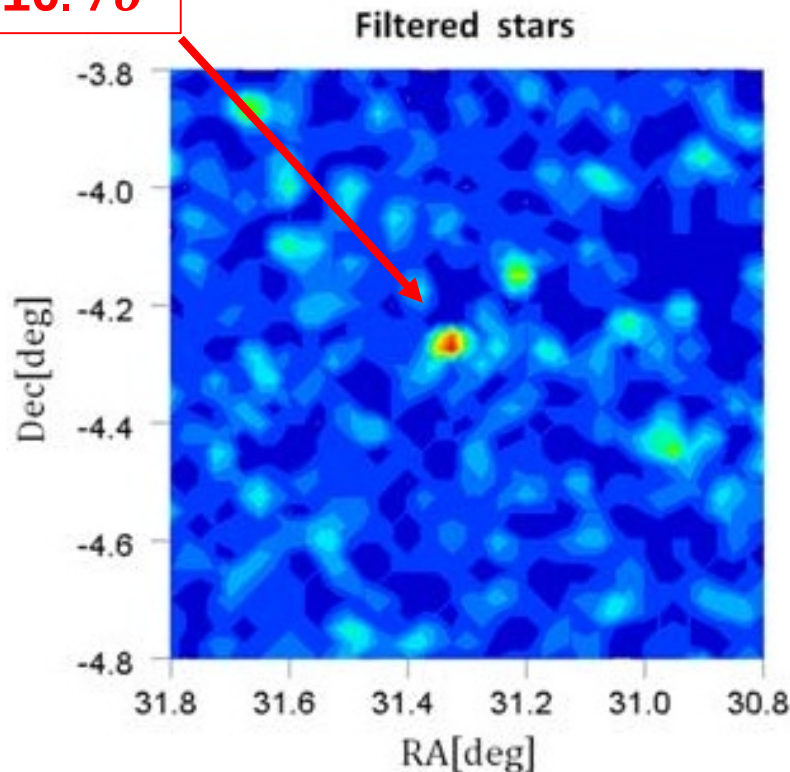
Coordinates : $(\alpha, \delta) = (31^\circ.331, -4^\circ.270)$

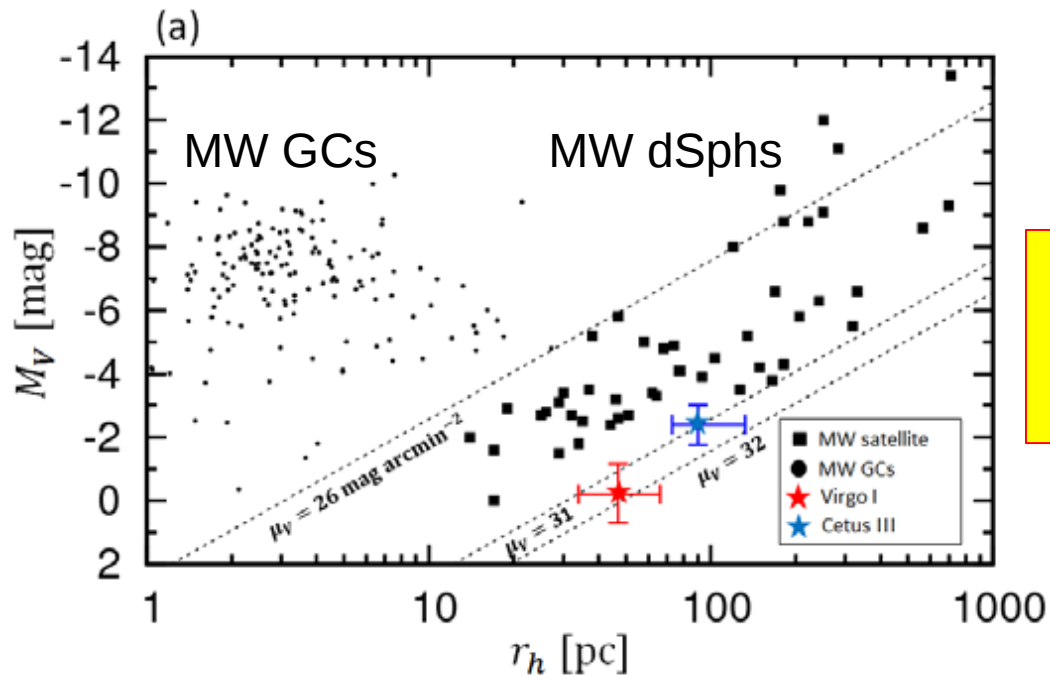
Absolute magnitude : $M_V = -2.45$ mag

Heliocentric distance : $D = 251_{-11}^{+24}$ kpc

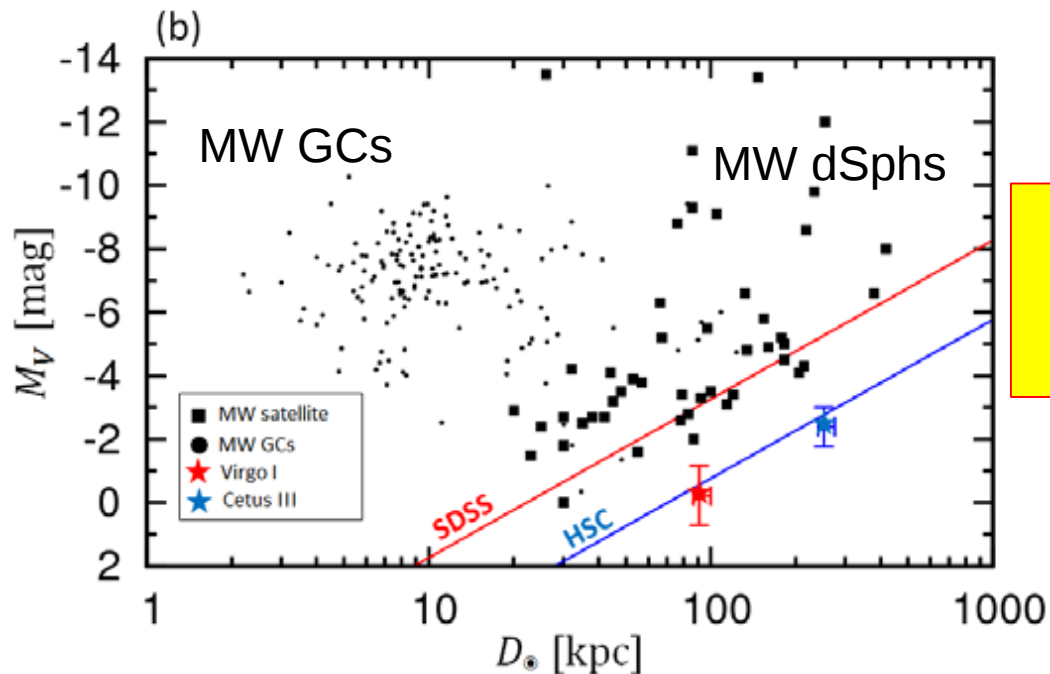
Half light radius : $r_h = 90_{-17}^{+42}$ pc

10.7 σ





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



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



Subaru Telescope
National Astronomical Observatory of Japan

Semester	S17B
Proposal ID	PROPIDTMP
Received	RECEIVETMP

Application Form for Telescope Time (Subaru $\Rightarrow$ Gemini)

1. Title of Proposal

Spectroscopy of a new Milky Way satellite discovered in the HSC survey I.

2. Principal Investigator

Name: Chiba Masashi

Institute: Tohoku Univ.

Mailing Address: Sendai 980-8578, Japan

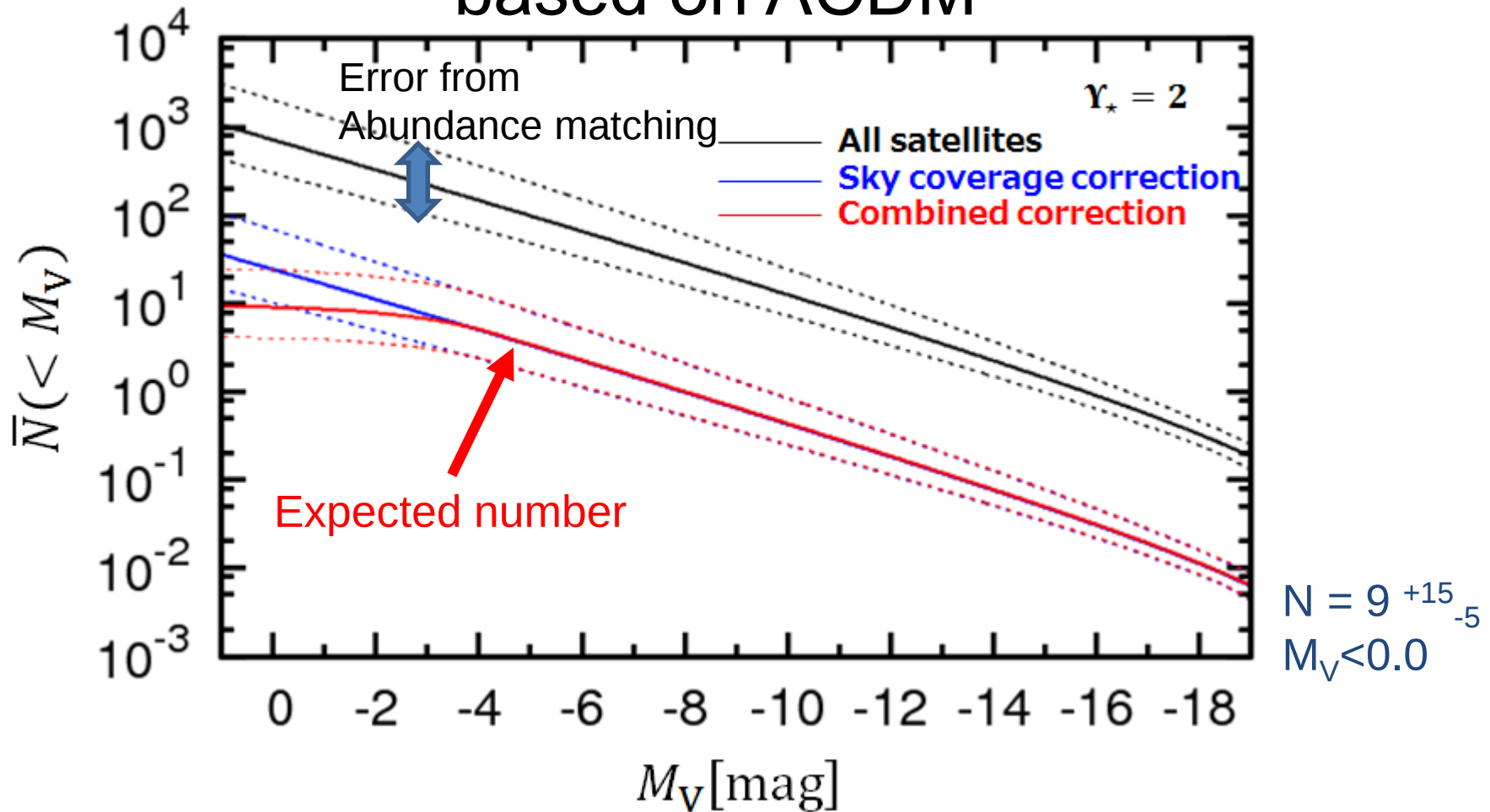
E-mail Address: chiba@astr.tohoku.ac.jp Phone: 022-795-6505

3. Scientific Category

**Will be happy if you would approve
just one (Gemini) night...**

We launch a spectroscopic follow-up campaign for new ultra-faint dwarf galaxies in the Milky Way discovered by our group from the Hyper Suprime-Cam (HSC) survey data. This proposal intends to target one of these new ultra-faint dwarf galaxies being observable in S17B, named Cetus III (Homma et al. 2017). This galaxy is located at a heliocentric distance of 251^{+24}_{-11} kpc with a most likely absolute magnitude of $M_V = -2.4 \pm 0.6$ mag, namely beyond the reach of SDSS but within the detection limit of Subaru/HSC. Medium resolution spectroscopy of candidate bright member stars in Cetus III, including red giant branch and asymptotic giant branch stars, as well as candidate field halo stars in the same direction,

Expected number of dSphs in HSC-SSP based on Λ CDM



HSC-wide survey over $\sim 1,400 \text{ deg}^2$

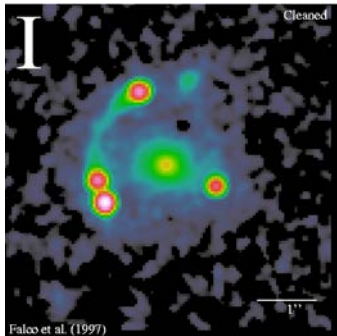
- ~ 9 new UFDs @ $M_V < 0.0$
- 2 new UFDs over $\sim 300 \text{ deg}^2$

So far
 Λ CDM looks okay

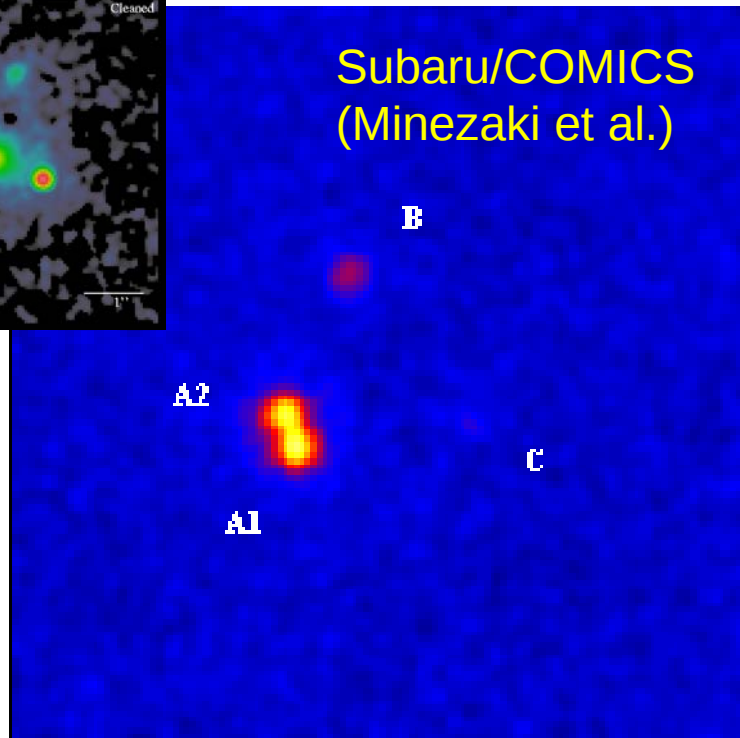
Discovery of a dusty dark dwarf galaxy with ALMA

(Inoue, K.T. et al. incl. MC 2016)

MG0414+0534

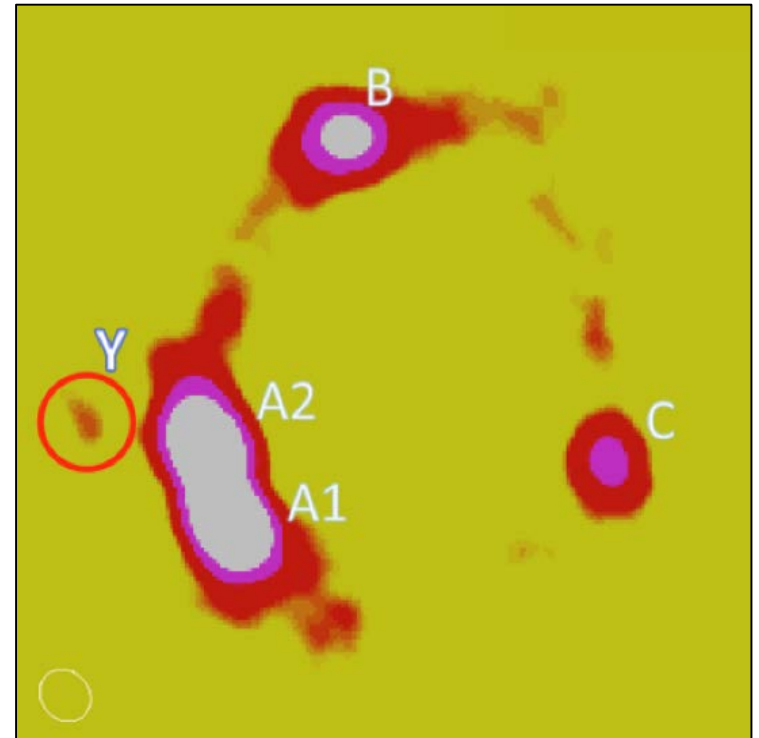


Subaru/COMICS
(Minezaki et al.)



$z_L=0.96$
 $z_S=2.64$

ALMA image ($\lambda=0.88\text{mm}$)



$A2/A1$ (Mid-IR) = 0.90 ± 0.04

$A2/A1$ (smooth lens model) = 1.063 ± 0.001

$\Rightarrow$ **Anomalous flux ratio**

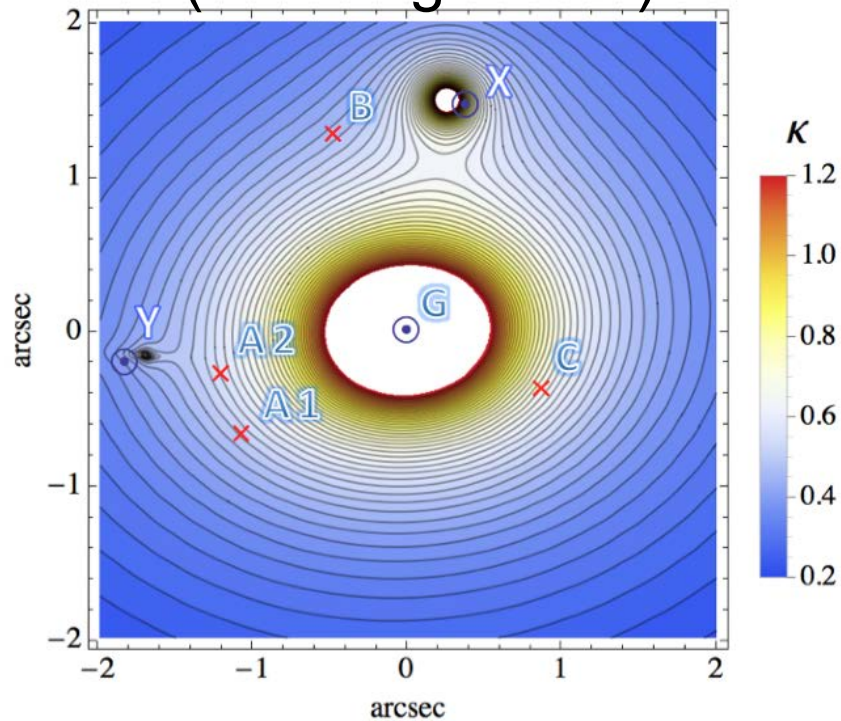
due to dark satellites (subhalos)?

Image Y (dusty dwarf galaxy)
can yield the observed $A2/A1$

Discovery of a dusty dark dwarf galaxy with ALMA

(Inoue, K.T. et al. incl. MC 2016)

Mass density
(Convergence κ)



κ from Y only

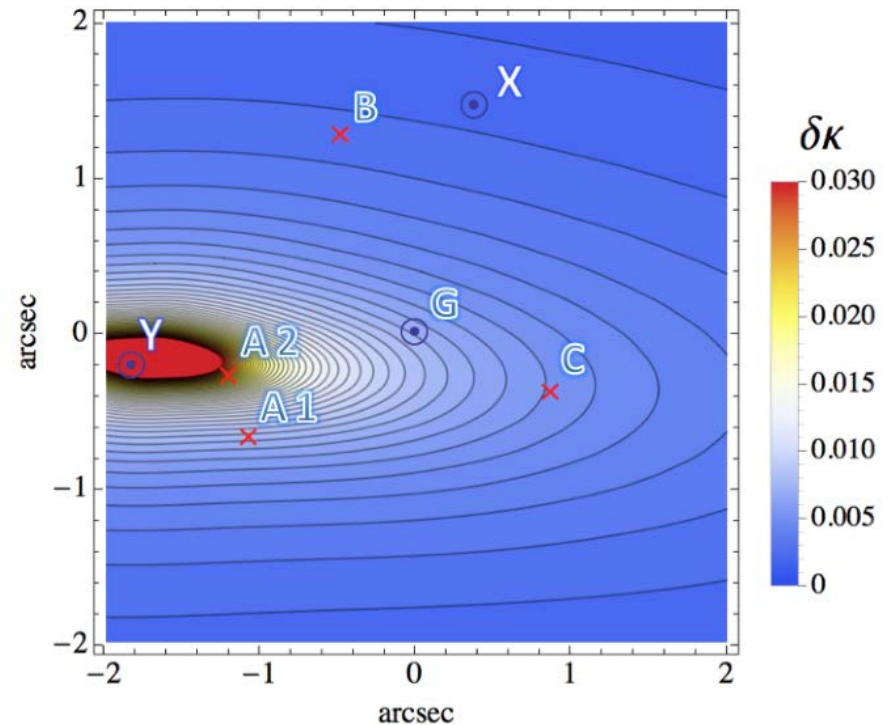


Image Y is a dark subhalo with $10^9 M_{\text{sun}}$ and an ellipticity of 0.7 at $z = 0.5\sim 1.0$

Summary

- We have discovered new MW satellites from HSC-SSP data
 - This discovery rate so far is in agreement with Λ CDM models.
 - Further search will increase this statistical significance.
- We have discovered a dusty dark satellite with ALMA in the quadruple lens showing anomalous flux ratio
 - Further search of dusty dark satellites with ALMA is important.
- TBTF problem $\Rightarrow$ Subaru/PFS will be important.