ダークハローの平均面密度を用いたダークマター理論への新たな制限手法の提案

KH & Chiba 2015, ApJL, 803, 11 (arXiv: 1503.05279)

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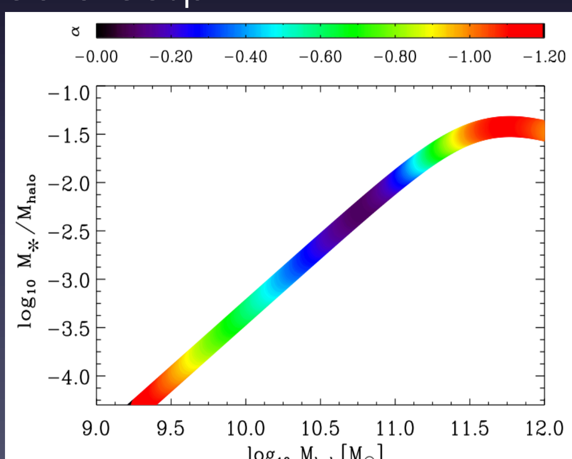
イントロダクション

Cold Dark Matter theory
~ small scale crisis ~

- ❖ Cusp-core problem (Burkert+ 1995, Gilmore+ 2007)
- ❖ Missing satellite problem (Moore+ 1999, Klypin+ 1999)
- ❖ Too-big-to-fail problem (Boylan-Kolchin+ 2012, Garrison-Kimmel+ 2014)

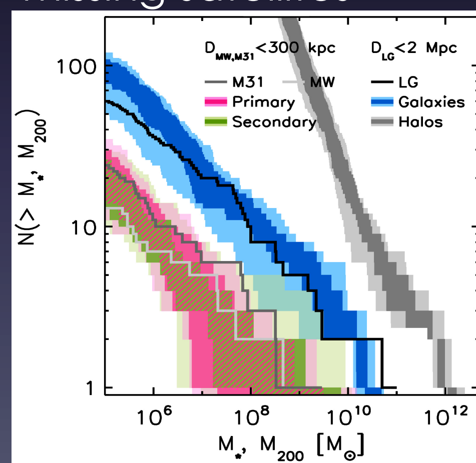
N-body + Baryon feedback + UV background

core-cusp



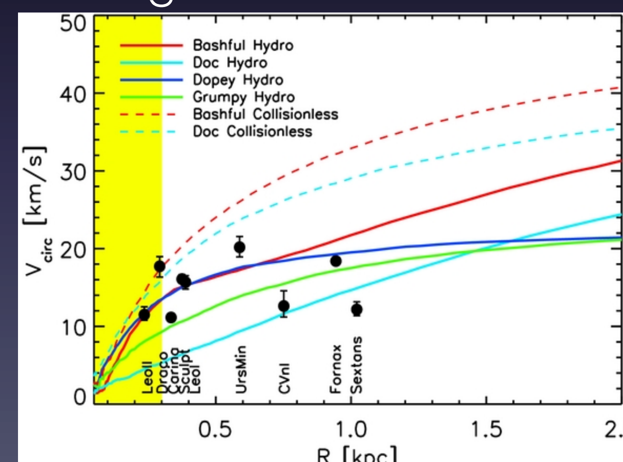
di Cintio+ 2014

missing satellites



Sawala+ 2014

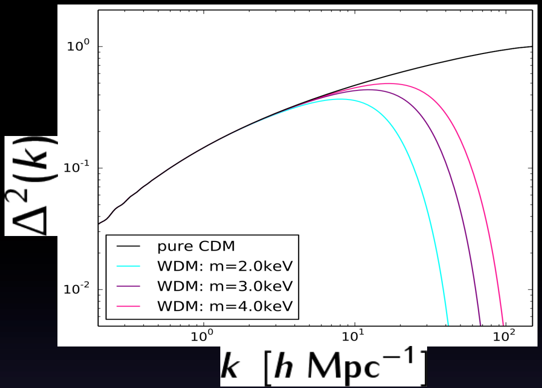
Too-big-to-fail



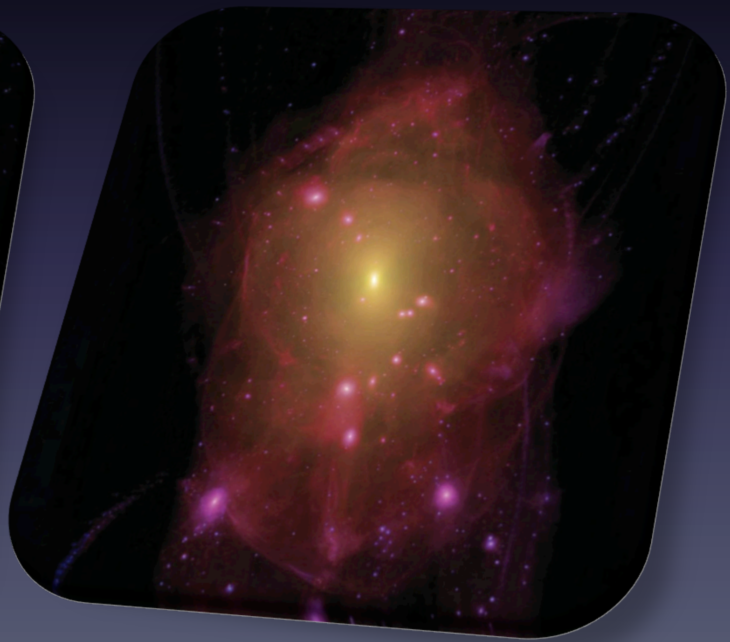
Madau+ 2014

Warm Dark Matter theory ~ another possible solution ~

✓ WDM particles have a free-streaming motion, giving rise to a cut-off matter power spectrum at larger wave number corresponding to small spatial scale.



CDM



WDM

Constraints on WDM particle mass from low mass scales

✓ With Lyman-alpha forest

- ❖ first constraint $m_{WDM} \geq 0.75$ keV (Narayan+ 2000)
- ❖ Newest $m_{WDM} \geq 3.3$ keV (Viel+ 2013)

✓ With Milky Way satellites

- ❖ Missing satellites $m_{WDM} \geq 2.3$ keV (Polisensky & Ricotti 2011)
- ❖ Too-big-to-fail $m_{WDM} \geq 1.1$ keV (Lovell+ 2012)
- ❖ LF & MW mass $m_{WDM} \geq 2.0$ keV (Kennedy+ 2014)

The above tests largely rely on the Mass of the MW halo,
where the estimate of the MW halo is still very uncertainty...

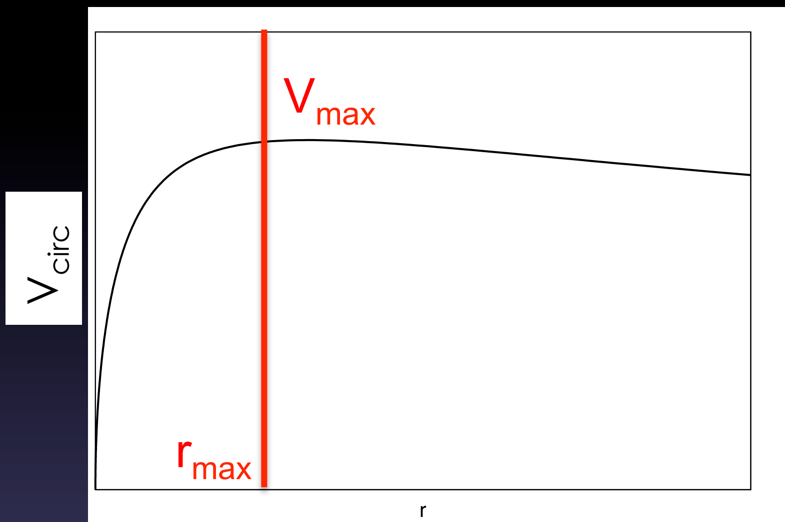
The purpose of this study

In an attempt to place an explicit constraint on dark matter models, especially particle mass of warm dark matter,
we define and estimate the mean surface density of a dark halo with respect to various galaxies, and compare it to predicted ones from DM theories.

ダークハローの平均面密度

Dark matter surface density within a radius of maximum circular velocity

✓ Maximum circular velocity



We suppose that a test particle perform circular motion in a DM halo potential.

$$V_{\mathbf{circ}}(r) = \sqrt{\frac{GM(<r)}{r}}$$

r_{max} indicates the radius of the maximum value of circular velocity, V_{max}.

✓ DM surface density within r_{max}

$$\Sigma_{V_{\mathbf{max}}} = \frac{M(r_{\mathbf{max}})}{\pi r_{\mathbf{max}}^2}$$

$$M(r_{\mathrm{max}}) = \int_0^{r_{\mathrm{max}}} 4\pi\rho(r')r'^2 dr'$$

any DM profiles

Sample and assumed DM profile

Galaxy type	Assumed dark halo profile	Reference
Late- and early-type spirals	pseudo-isothermal profile	de Blok+ 2008 Spano+ 2008
dwarf irregulars	Burkert profile	Gentile+ 2005, 2007
spirals and ellipticals	Burkert profile	Donato+ 2009
MW and M31 dwarf spheroidals	double power law (any slope) profile	KH & Chiba 2015, in prep

$$\rho(r) = \frac{\rho_0}{\left[1+\left(\frac{r}{r_0}\right)^2\right]^{3/2}}$$

pseudo-isothermal

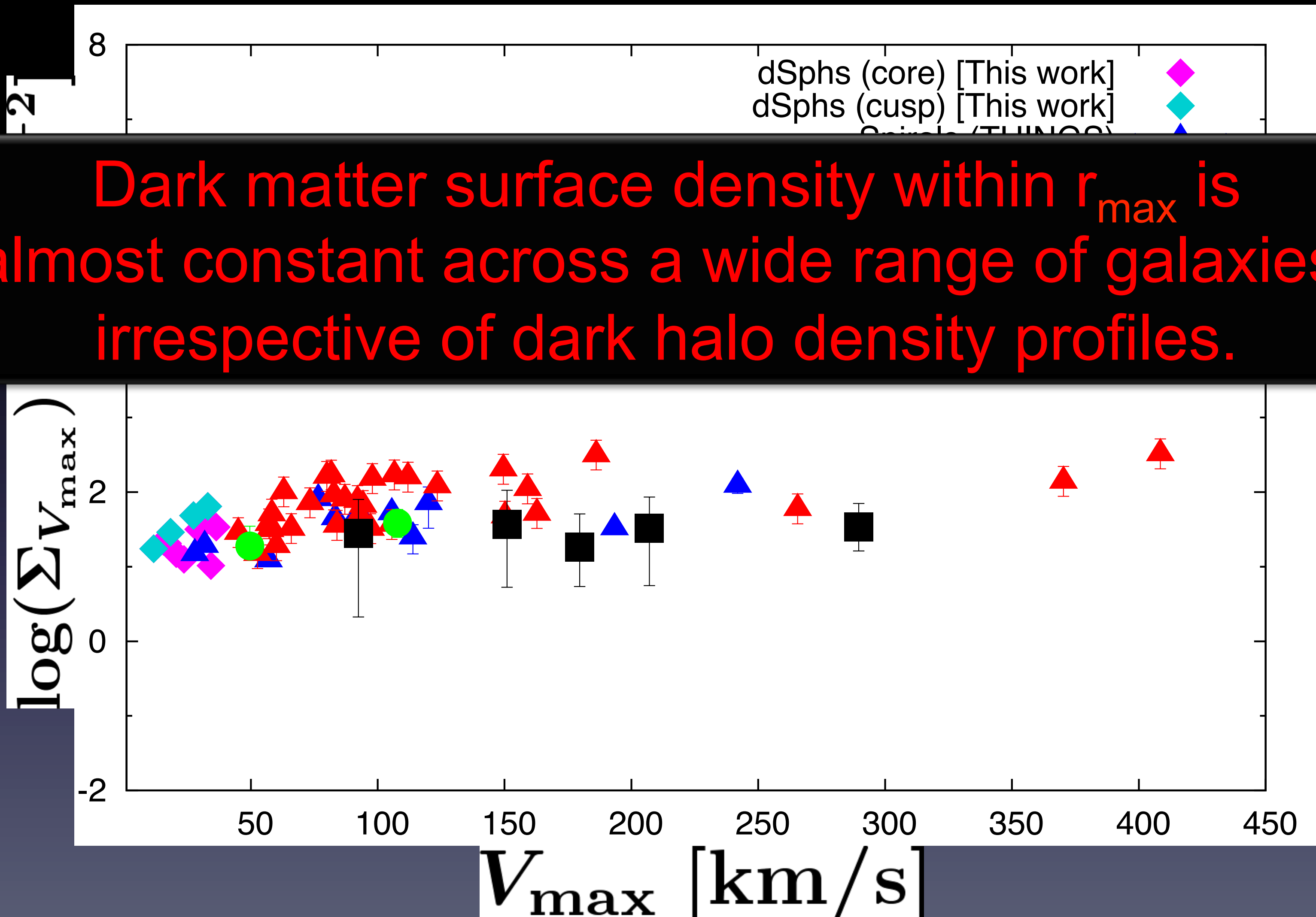
$$\rho(r) = \frac{\rho_0\, r_0^3}{(r+r_0)\left(r^2+r_0^2\right)}$$

Burkert

$$\rho(r) = \rho_0\left(\frac{r}{r_s}\right)^{\alpha}\left[1+\left(\frac{r}{r_s}\right)\right]^{-(\alpha+3)/2}$$

Double power-law

DM surface density vs. Vmax



Dark matter surface density within r_{max} is almost constant across a wide range of galaxies, irrespective of dark halo density profiles.

ダークマター理論との比較

DM surface density from CDM and WDM

- Dark matter density profile

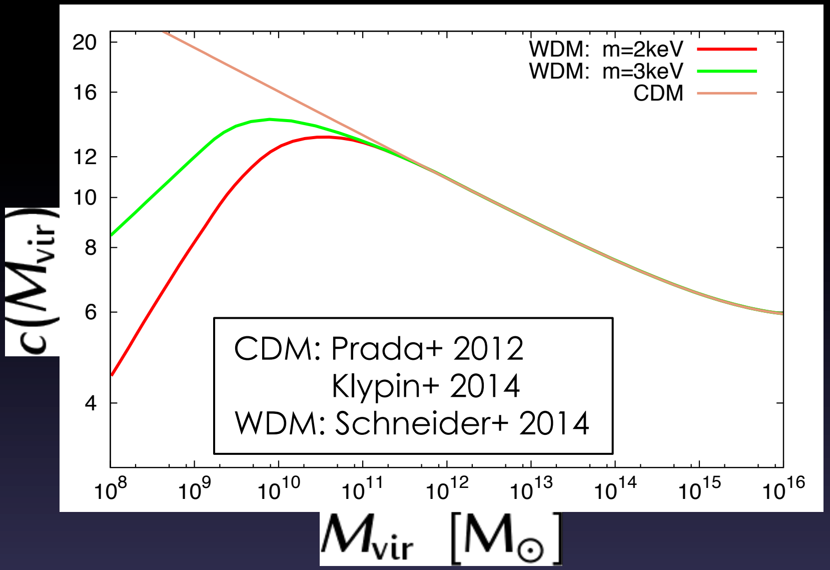
$$\rho(r) = \frac{\rho_s}{(r/r_s)(1+r/r_s)^2}$$

- The scale density and scale radius

$$\rho_s = \frac{\rho_{\rm crit}\Delta_m}{3}\frac{c^3}{\ln(1+c) - c/(1+c)}$$

$$r_{\rm vir} = \left(\frac{3M_{\rm vir}}{4\pi\rho_{\rm crit}\Delta_m}\right)^{1/3}$$

- Concentration

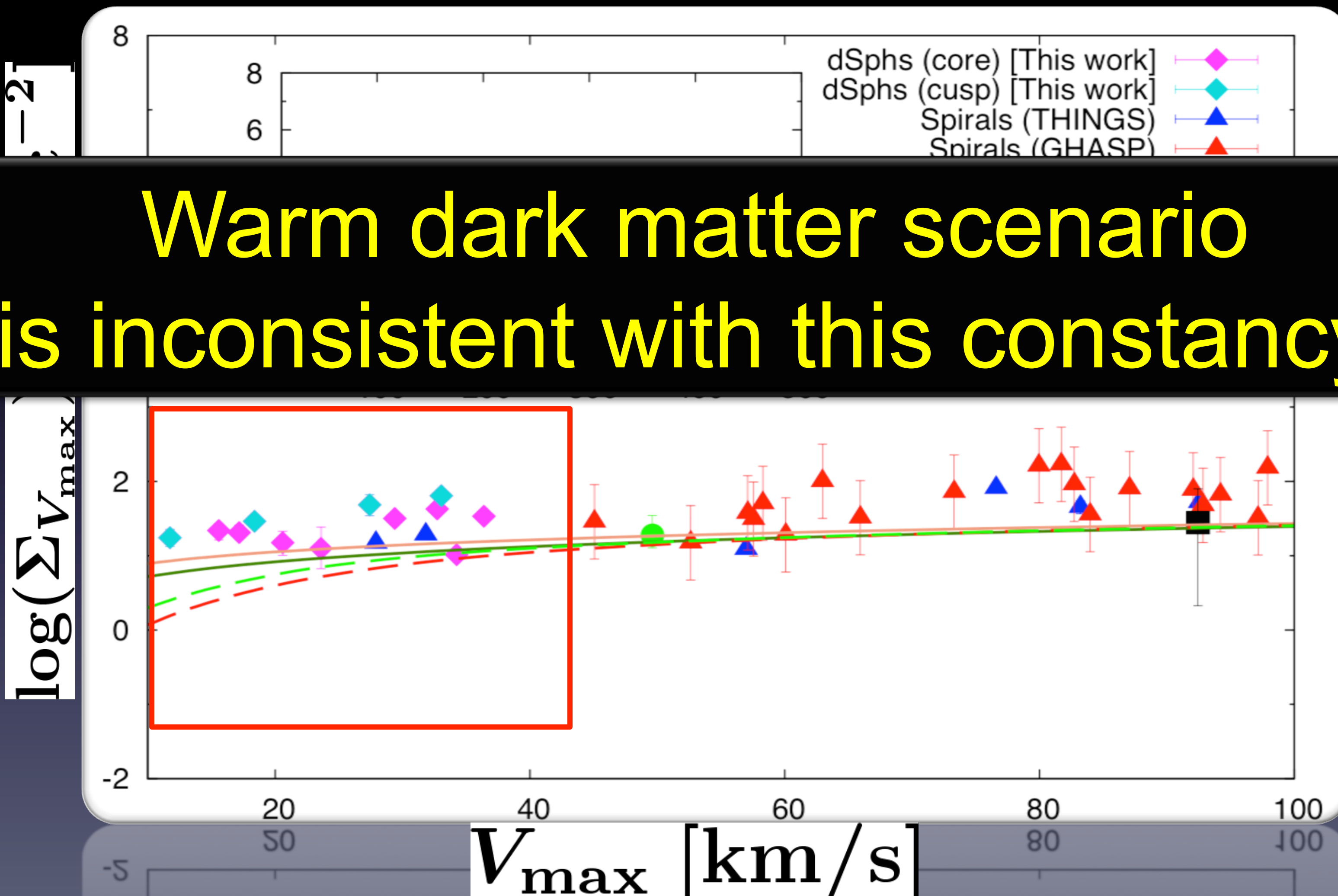


- Mean surface density

$$\Sigma_{V_{\rm max}} = \frac{M(r_{\rm max})}{\pi r_{\rm max}^2}$$

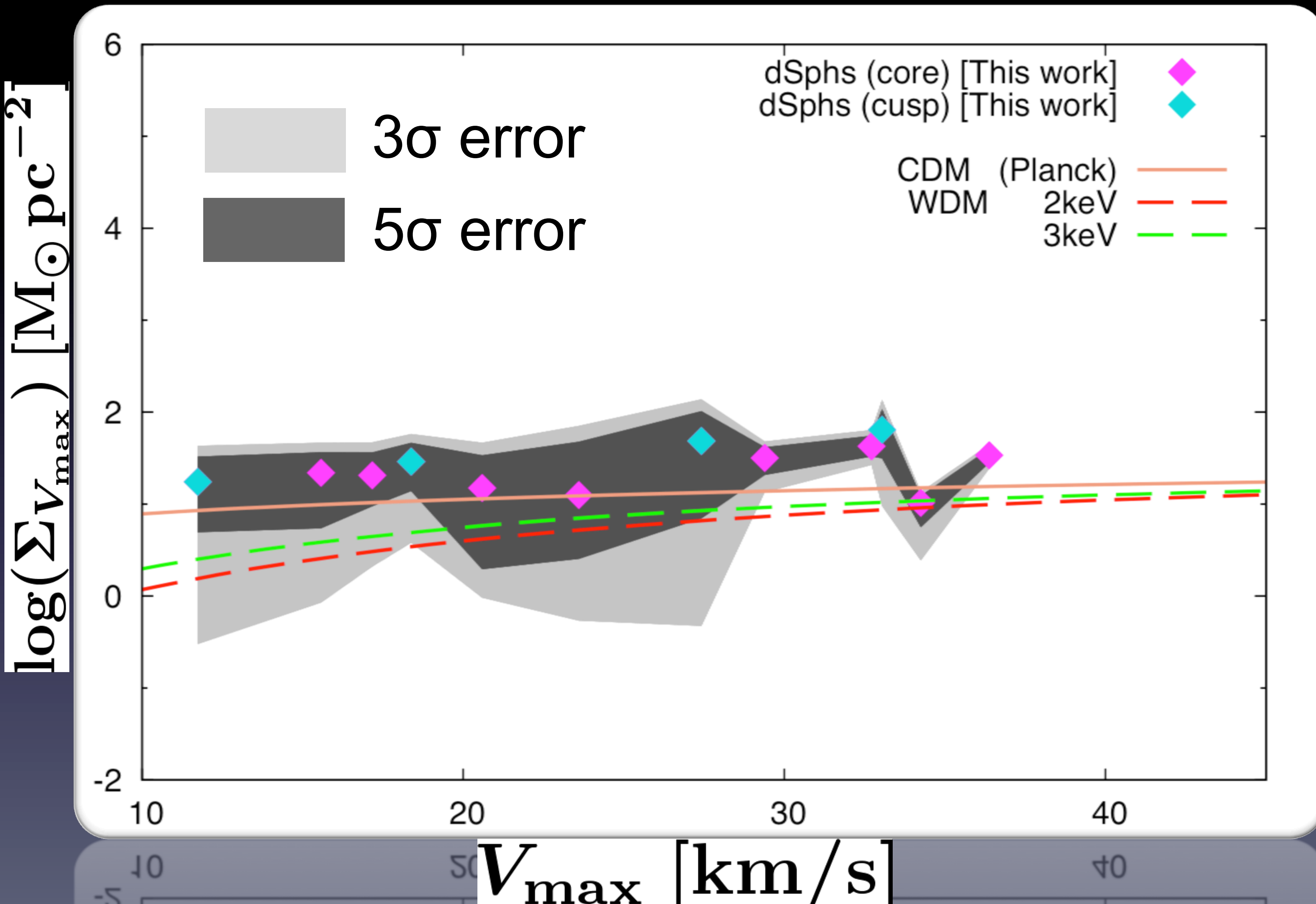
$$M(r_{\rm max}) = \int_0^{r_{\rm max}} 4\pi\rho(r')r'^2 dr'$$

Comparison with dark matter scenario

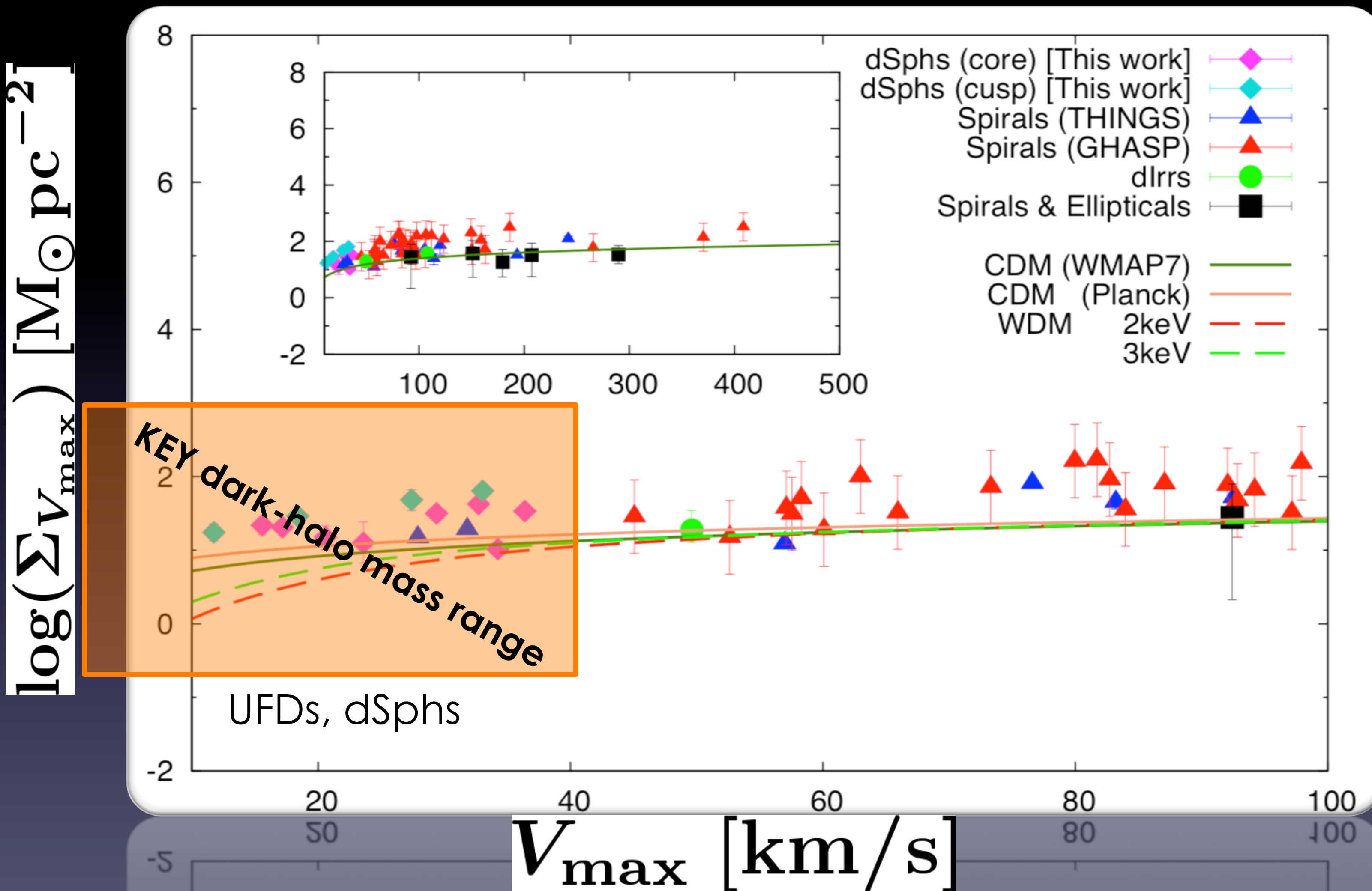


Warm dark matter scenario is inconsistent with this constancy.

How cold is dark matter?



将来展望

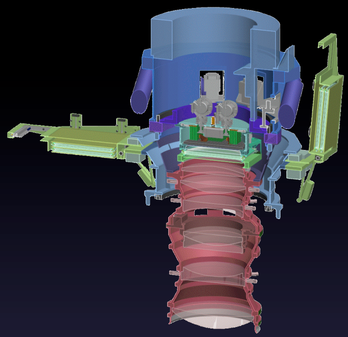


dSphs (core) [This work]
dSphs (cusp) [This work]
Spirals (THINGS)
Spirals (GHASP)
dIrrs
Spirals & Ellipticals
CDM (WMAP7)
CDM (Planck)
WDM 2keV
3keV
KEY dark-halo mass range
UFDs, dSphs
$\log(\Sigma_{V_{max}})$ [$M_\odot pc^{-2}$]
V_{max} [km/s]

Future perspective of dark matter halo in the dSphs

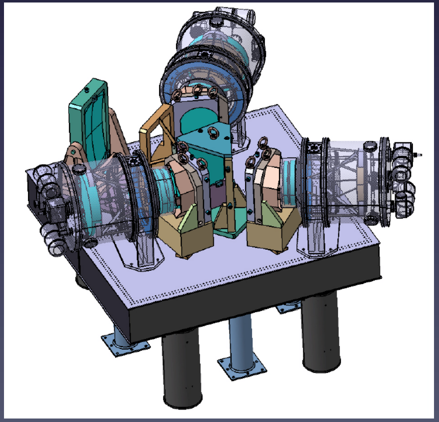
Subaru/HSC

- Discovery of New UFD
- Hunting a number of faint stars in MW and M31 satellites



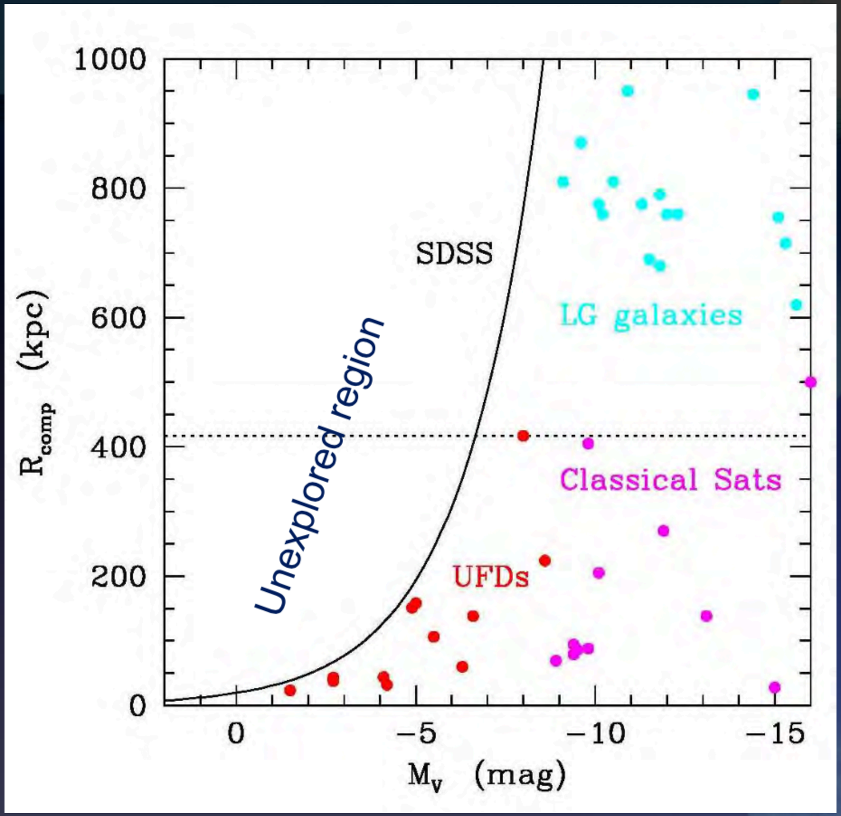
Subaru/PFS

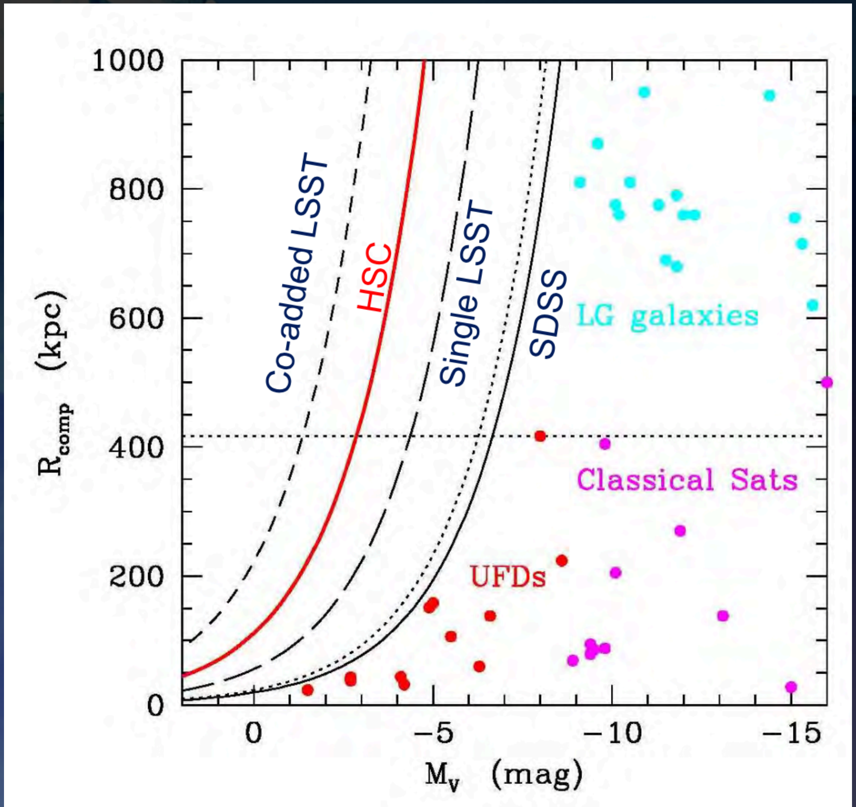
- Determining better radial velocities for many faint stars over large area of dSphs via PFS with MR (R~5,000).



HSC survey for UFD satellites

Tollerud+ 2008



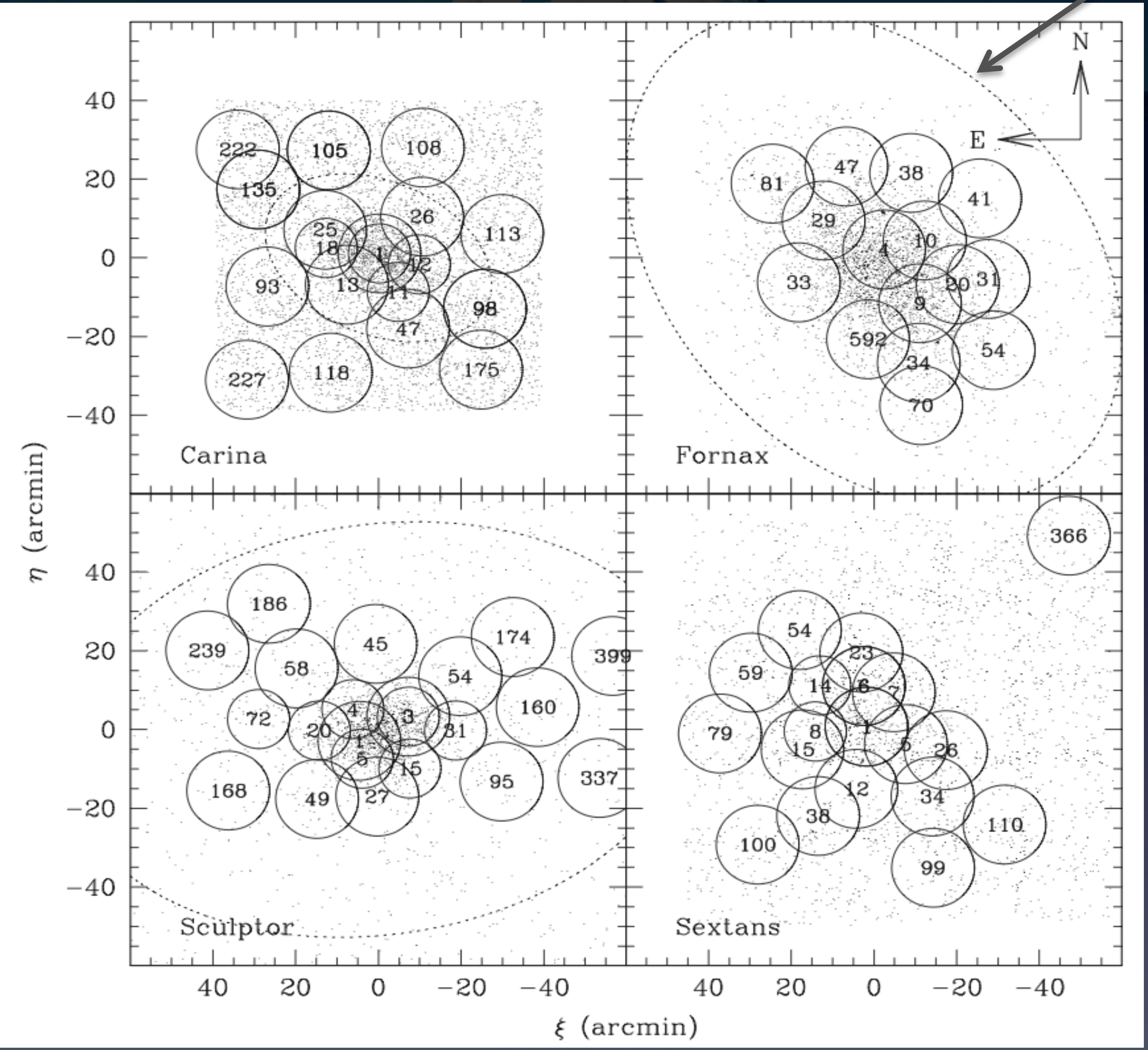


SDSS: ~ 22 mag
HSC wide field survey: r_{lim} ∼ 26 mag

PFS survey for dwarf spheroidal satellites

Walker et al. 2009

tidal radius

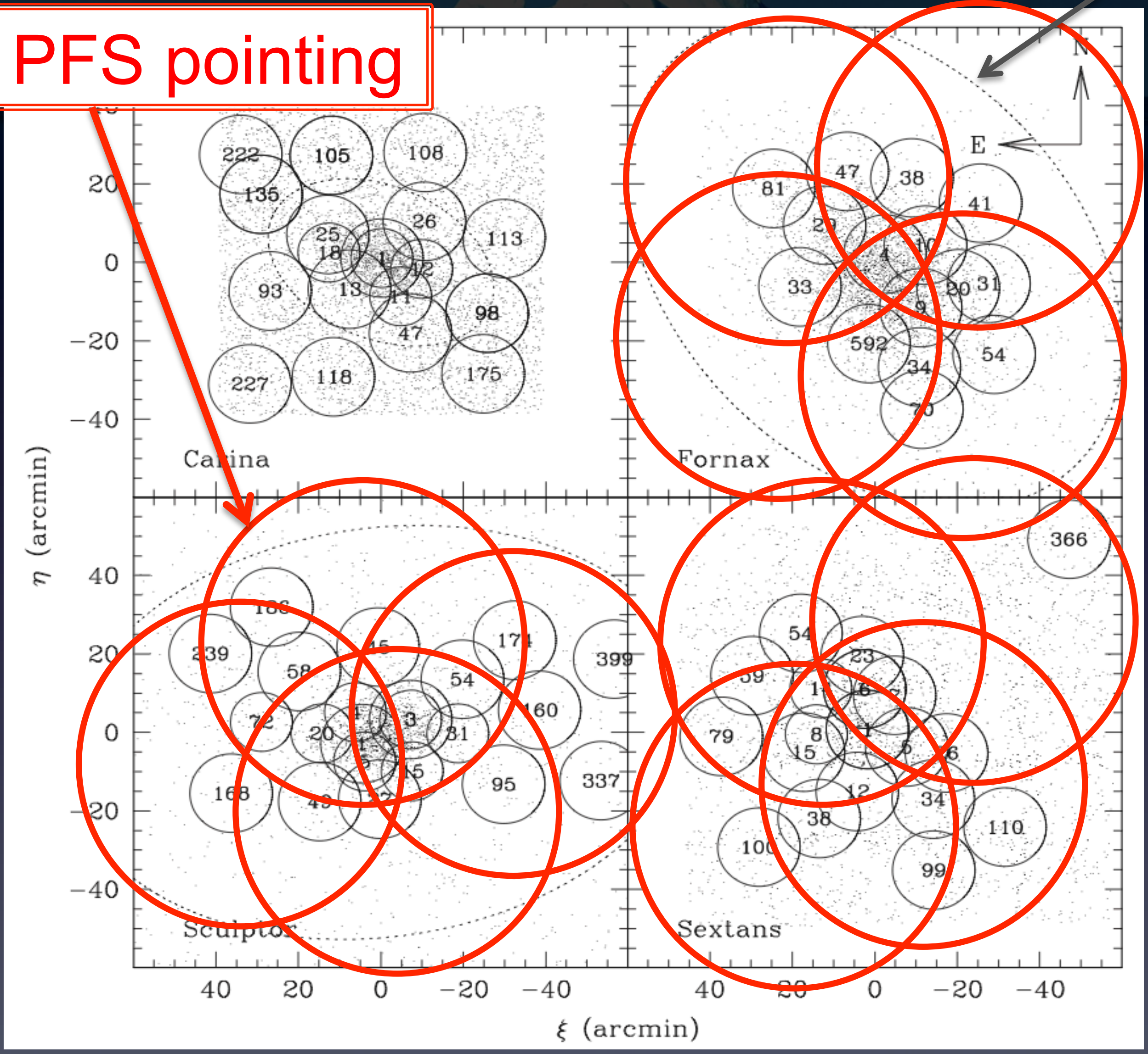


PFS survey for dwarf spheroidal satellites

Takada et al. 2014

Subaru PFS pointing

tidal radius



Summary

- In order to be constraint on dark matter models, we define and estimate the mean surface density of a dark halo within the radius of maximum circular velocity, which is derivable for various galaxies with any dark matter density profiles.
- It is found that this density is nearly constant across a wide range of galaxies, and this constancy is enable us to obtain the limits on particle masses of WDM scenario.
- This study proposes a new astrophysical test on the nature of dark matter.
- The key dark-halo mass range to distinguish dark matter models in this test is the lowest halo mass scales such as classical and ultra faint dwarf galaxies.

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