Solving the nature of dark matter from seven dwarf satellites: Ultimate goal of Subaru/PFS

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& PFS/GA team

Small-scale issues in ΛCDM

- Missing satellites problem
  - Theory: many dark subhalos, Obs: ~50 MW satellites
- Core/cusp problem
  - Theory: cuspy density halo, Obs: cored dwarf galaxies

+ several other issues

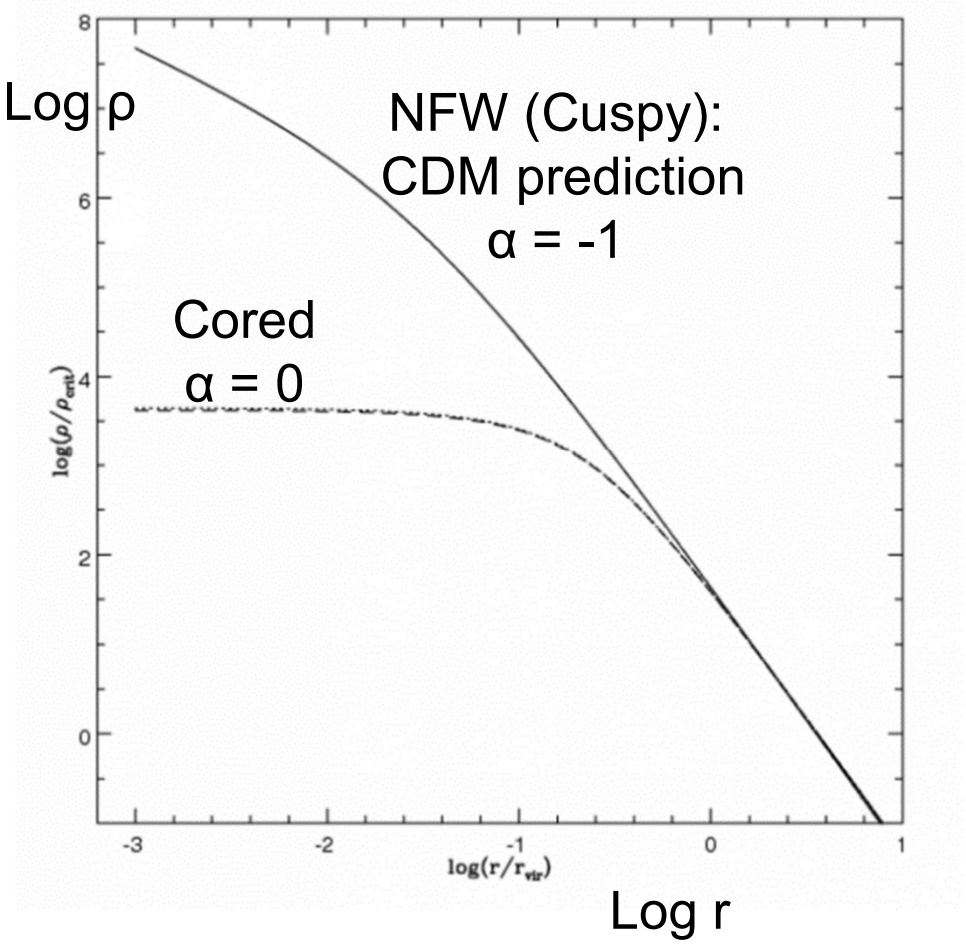
Solutions ・Alternative DM models?
・Baryonic effects?

Dwarf galaxies provide clues to these issues

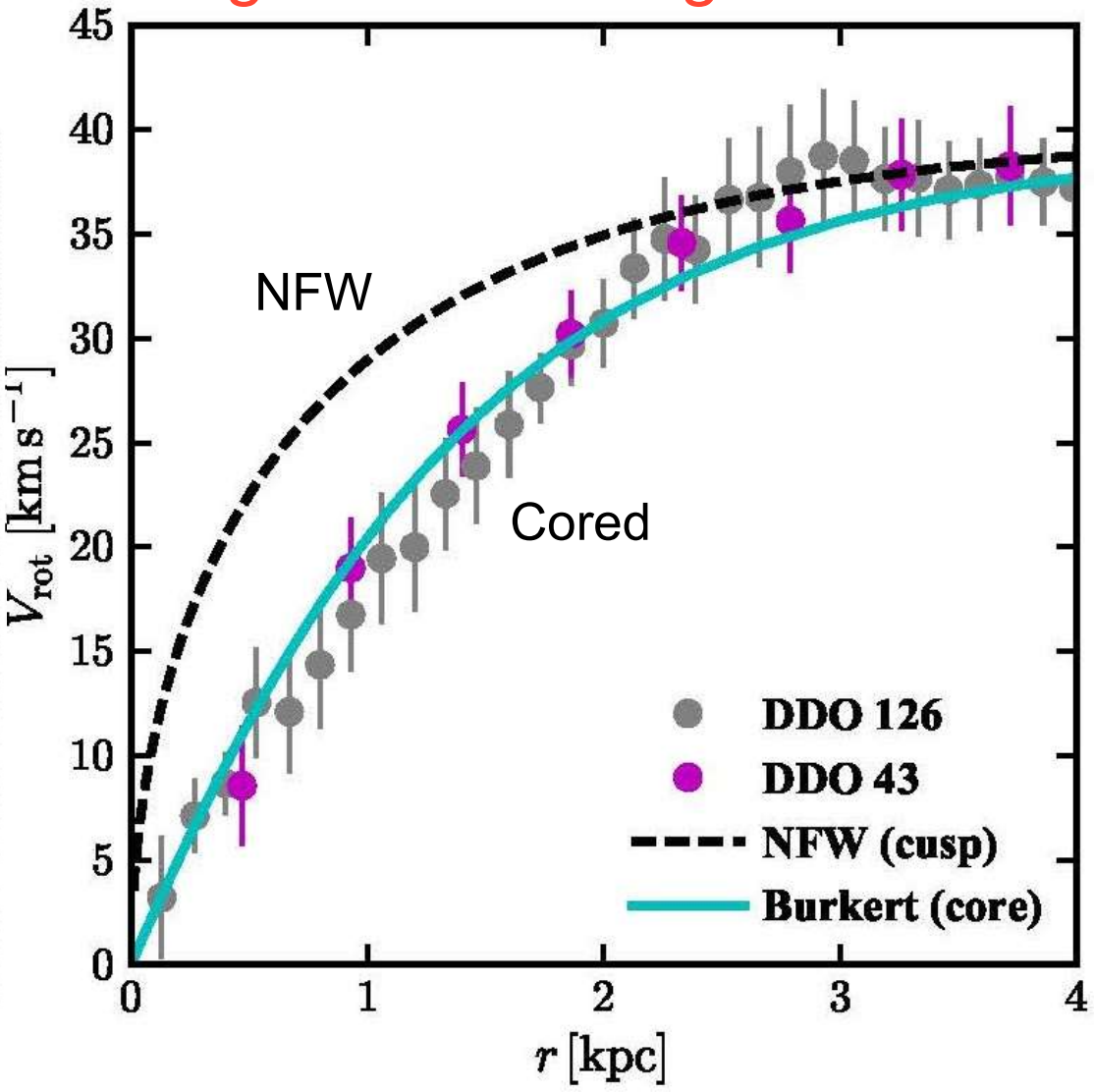
Core/cusp problem

Density distribution of a dark halo

Inner profile: $\rho(r) \propto r^{\alpha}$



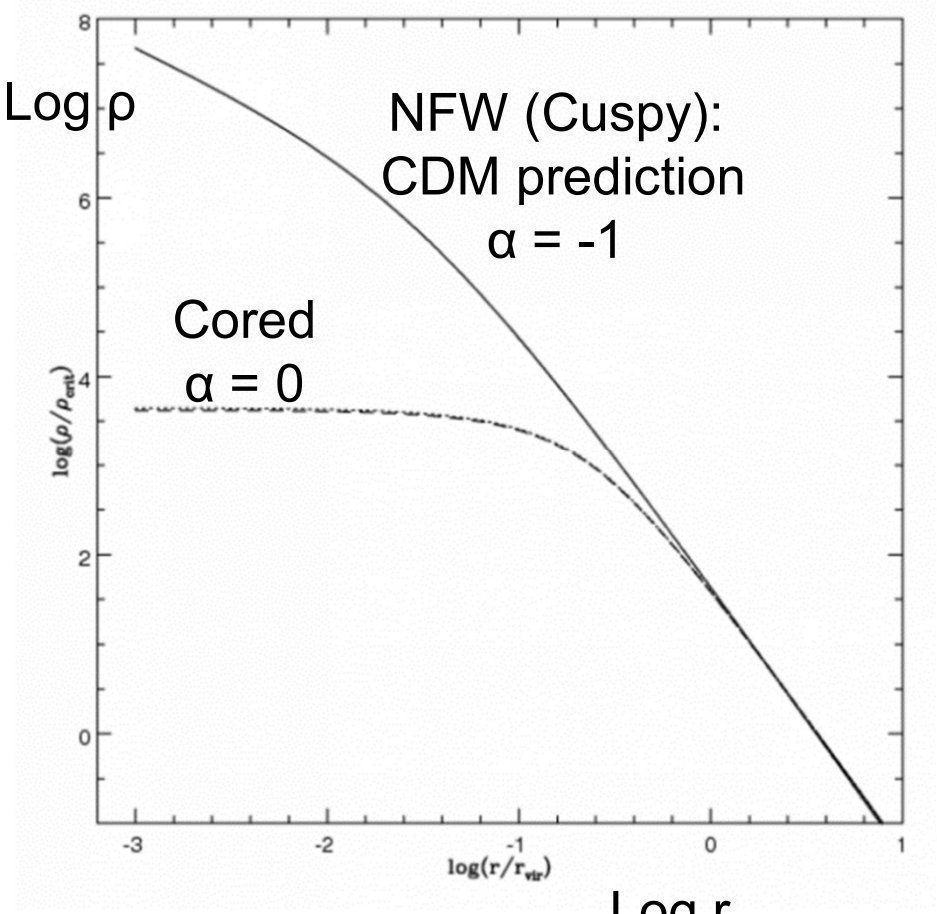
Rotation curves of (external) gas-rich dwarf galaxies



Core/cusp problem

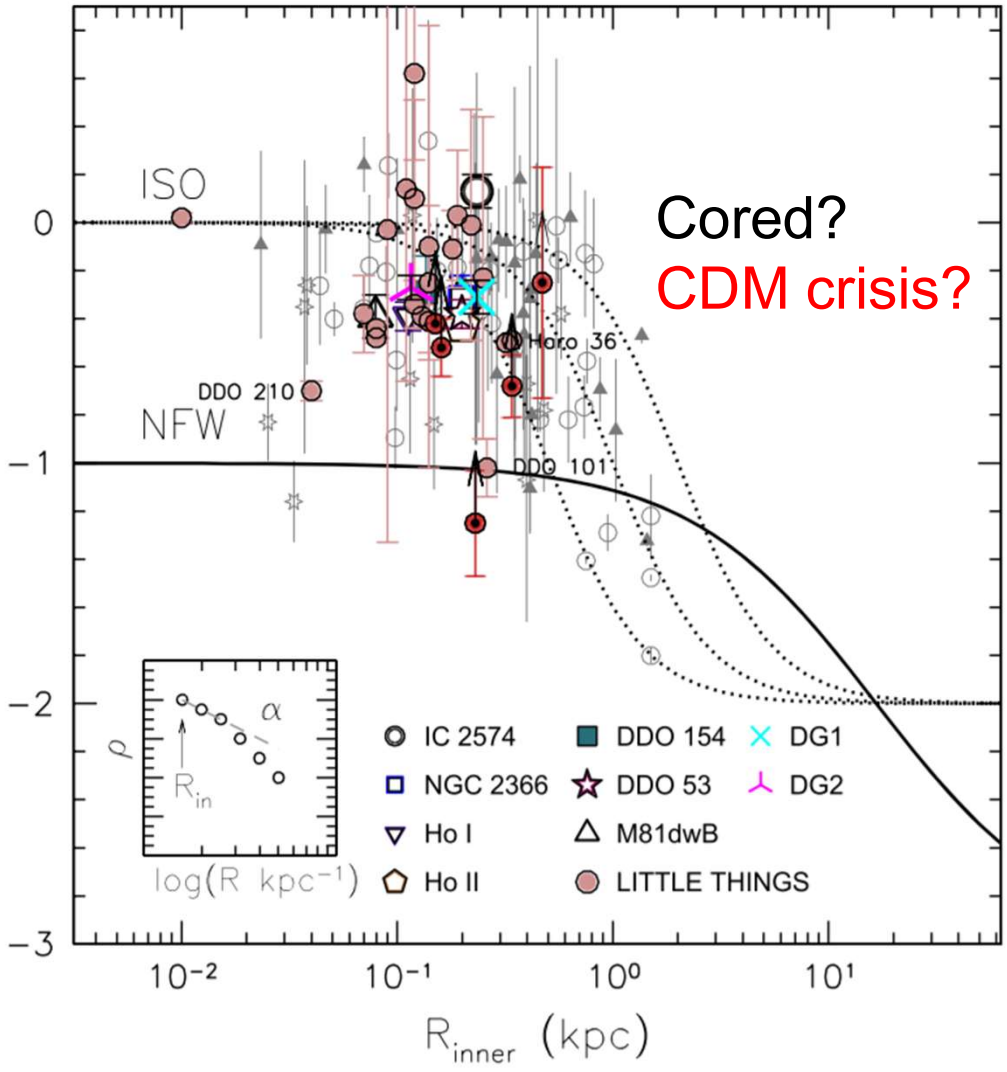
Density distribution of a dark halo

Inner profile: $\rho(r) \propto r^{\alpha}$

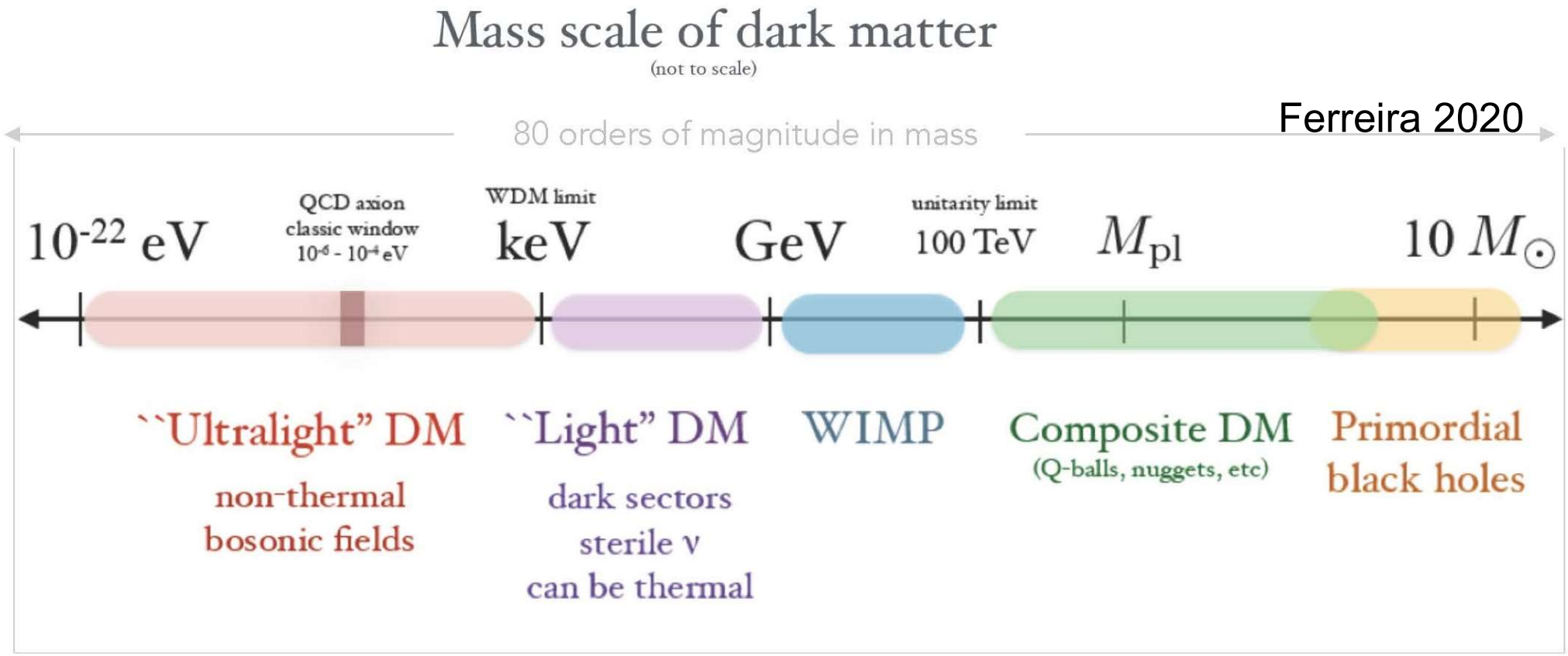


α

Oh et al. 2015



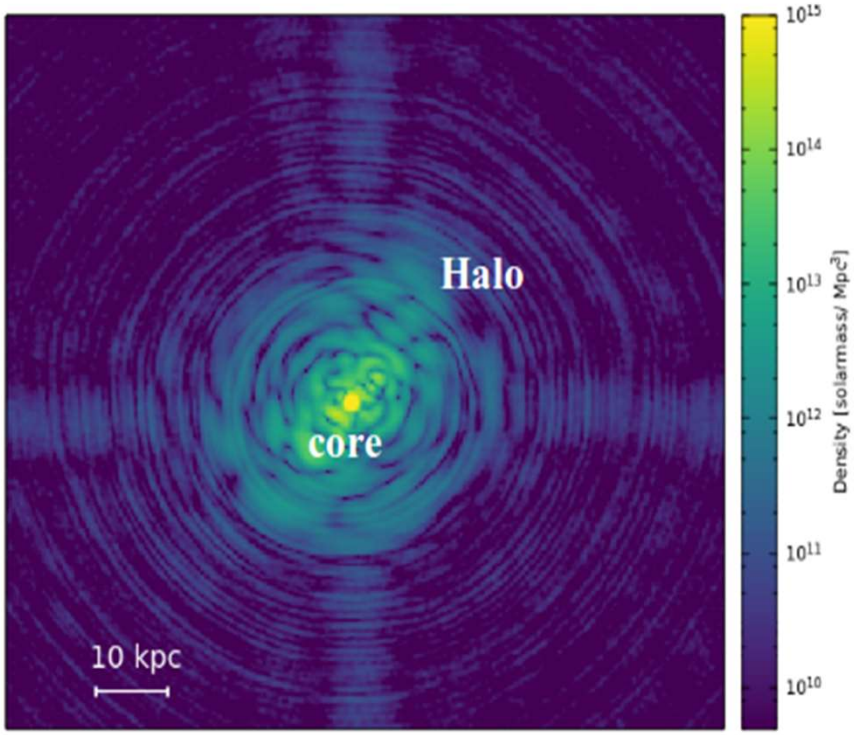
Dark matter candidates



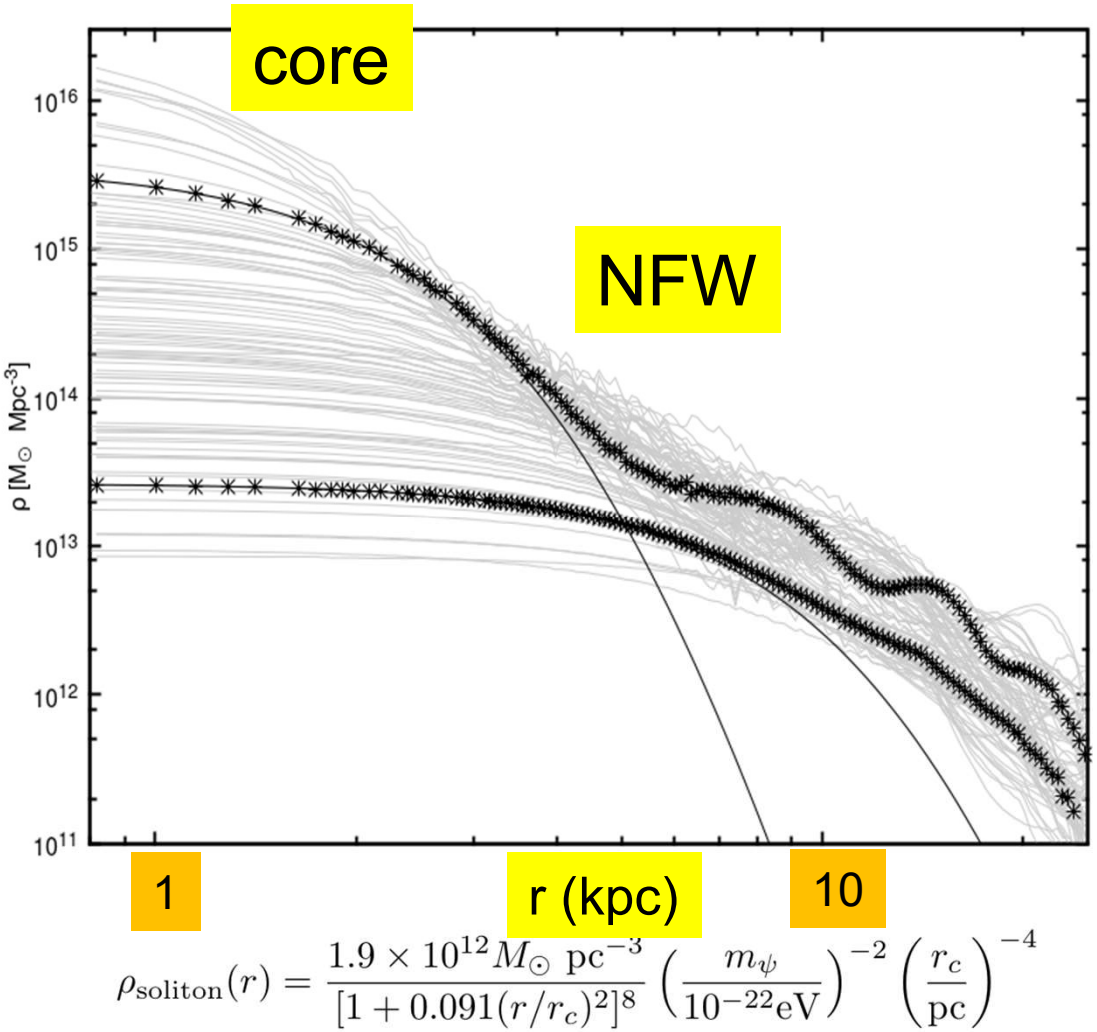
Unsolved, big issue!

The case of ultralight DM (FDM)

$m = 1 \times 10^{-22}$ eV



Simulated halo
by Jowett Chan (Tohoku U.)

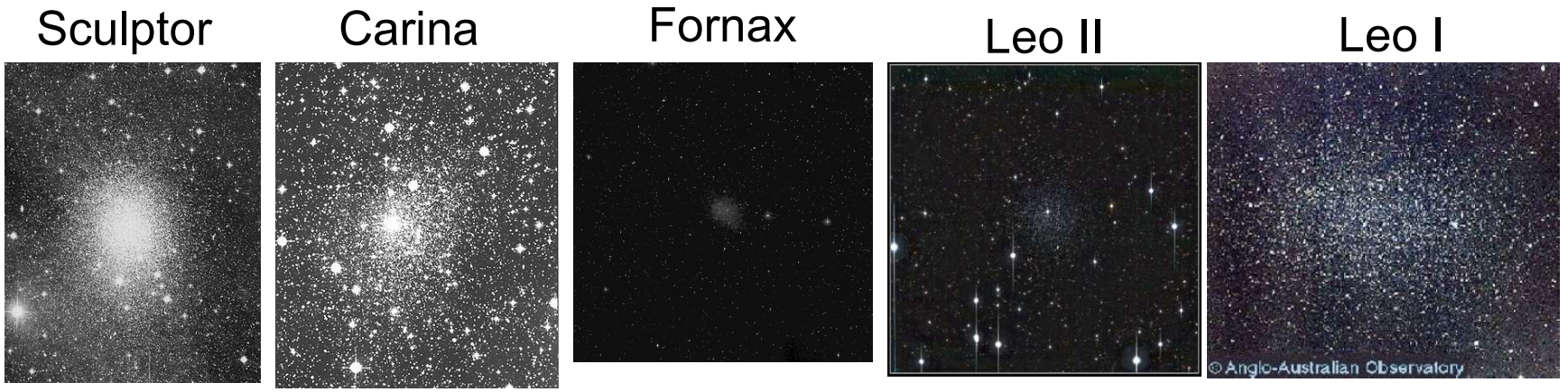


$$\rho_{\rm soliton}(r) = \frac{1.9\times10^{12} M_\odot\ {\rm pc}^{-3}}{[1+0.091(r/r_c)^2]^8}\left(\frac{m_\psi}{10^{-22}{\rm eV}}\right)^{-2}\left(\frac{r_c}{\rm pc}\right)^{-4}$$

Issue solved? Dwarf galaxy scale is a key!

Dwarf spheroidal galaxies (dSphs)

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



- Dark matter dominated
  - Velocity dispersion supported ⇒ Stellar Dynamics

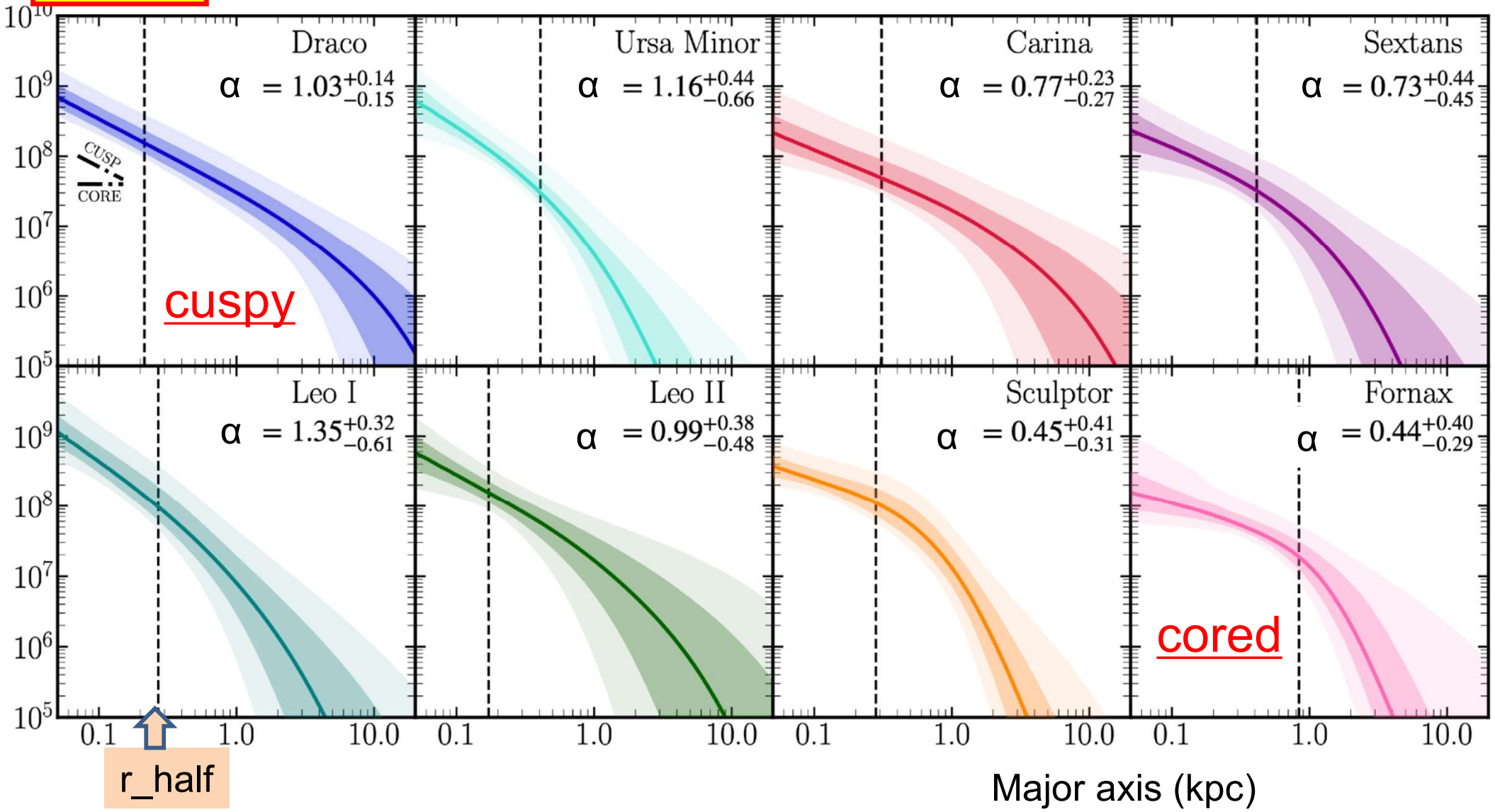
  ⇒ $(M/L)_{tot}$ = 10～10000 or more ⇒ Largely DM dominates!
  - Best sites for studying the nature of DM

Diversity in DM density profiles using currently available, limited RVs

(Hayashi et al. 2020)

$\rho \propto r^{\alpha}$

$\Delta\alpha \sim 0.45$



Why diversity?
Baryonic feedback effects on a CDM cusp

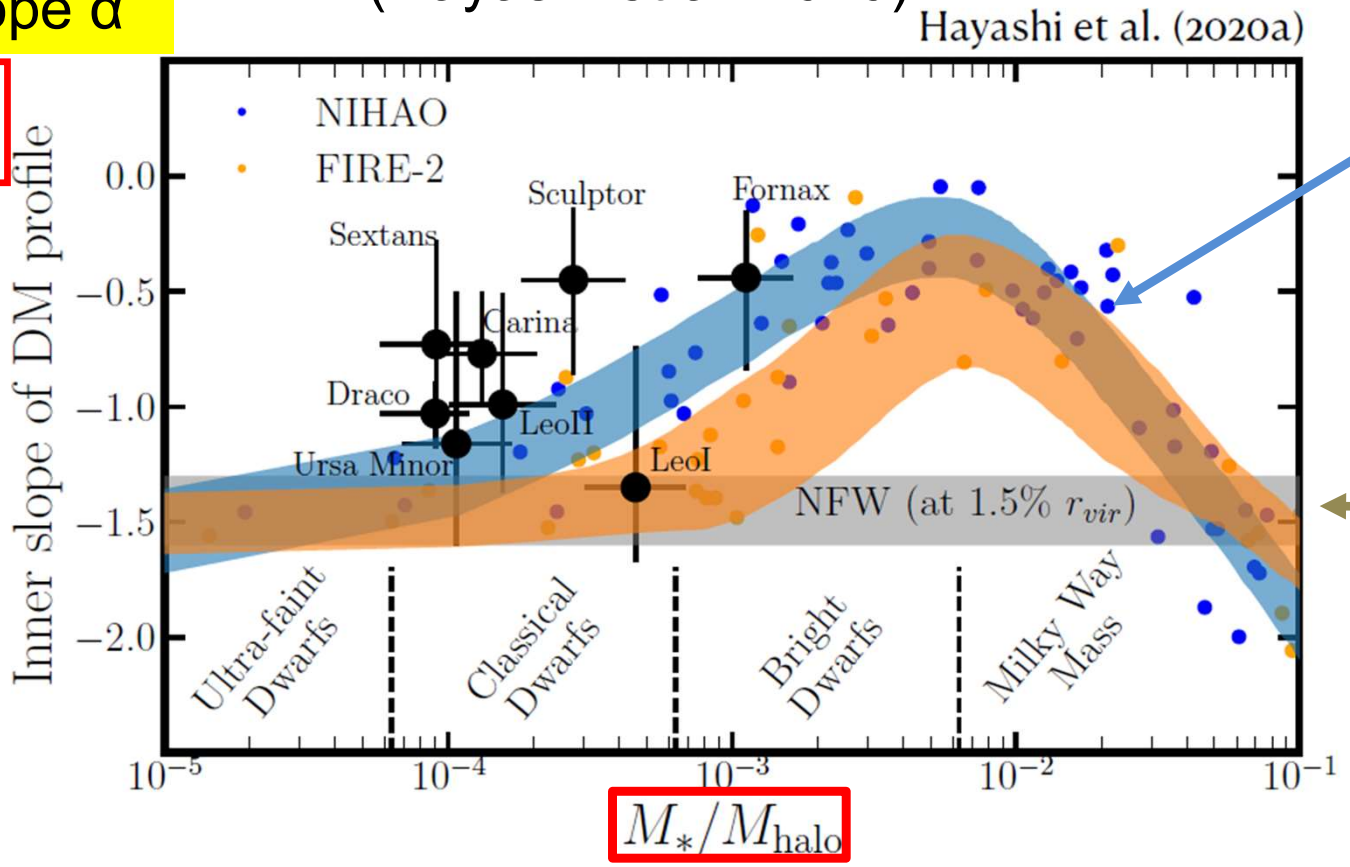
Change of inner density slope α

$\rho \propto r^{\alpha}$

core

cusp

(Hayashi et al. 2020)



after

ΛCDM-based prediction

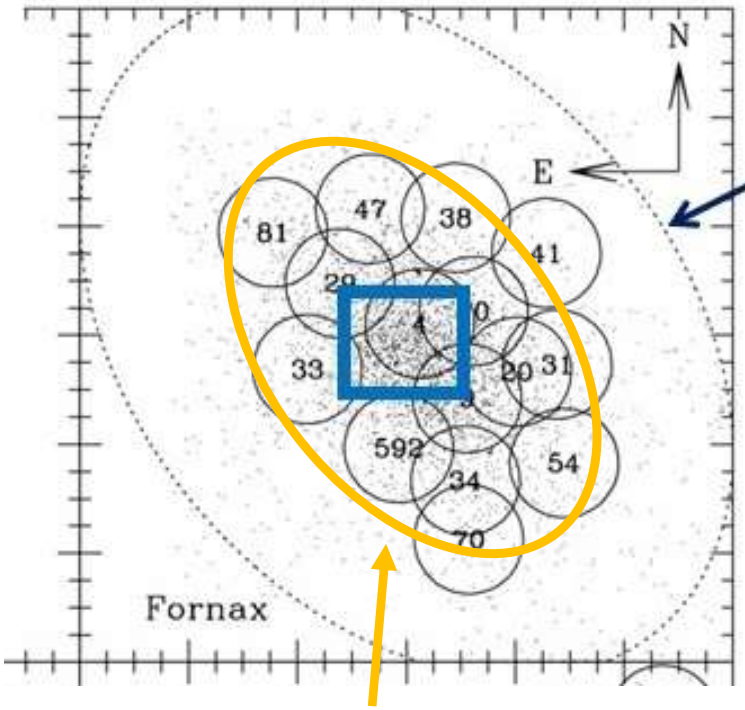
before

Some trend is seen,
but yet inconclusive due to large errors

What's the matter?

Fornax dSph

Walker et al. 2009



tidal radius

$r_t \sim 71'$

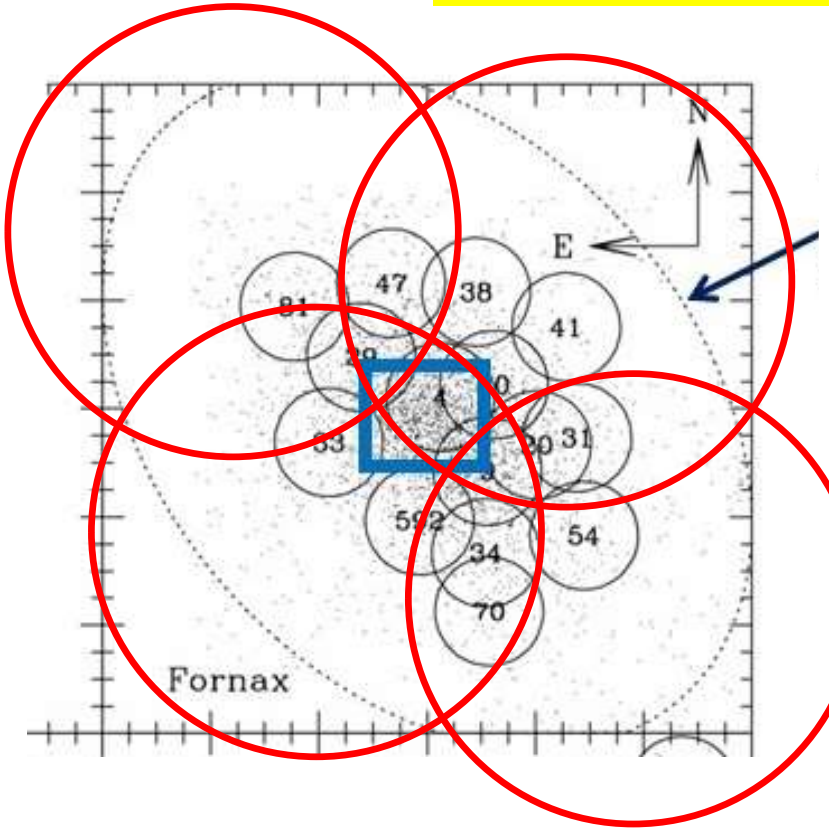
previous range for measuring dark halo profiles

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

Previous RV measurements with MMFS (Walker+)

RV data are confined only in inner parts

PFS pointings



Mapping dark matter

Nature of dark matter

Power of PFS for DM science!

Selection of the 7 MW dwarf satellites

(~ 1 deg extent, varieties in several aspects)

Fornax

(long SF time scale)

Sculptor

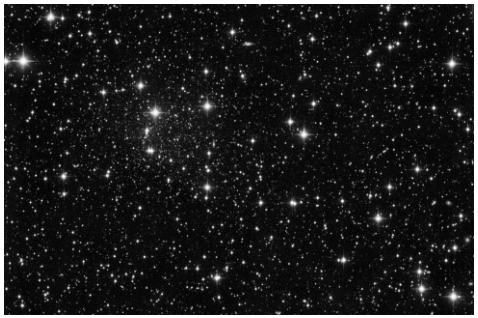
Ursa Minor

(same M_v but different SF time scale)

Sextans

(large r_half~700pc)

Draco



(nearly circular orbit)

Bootes I

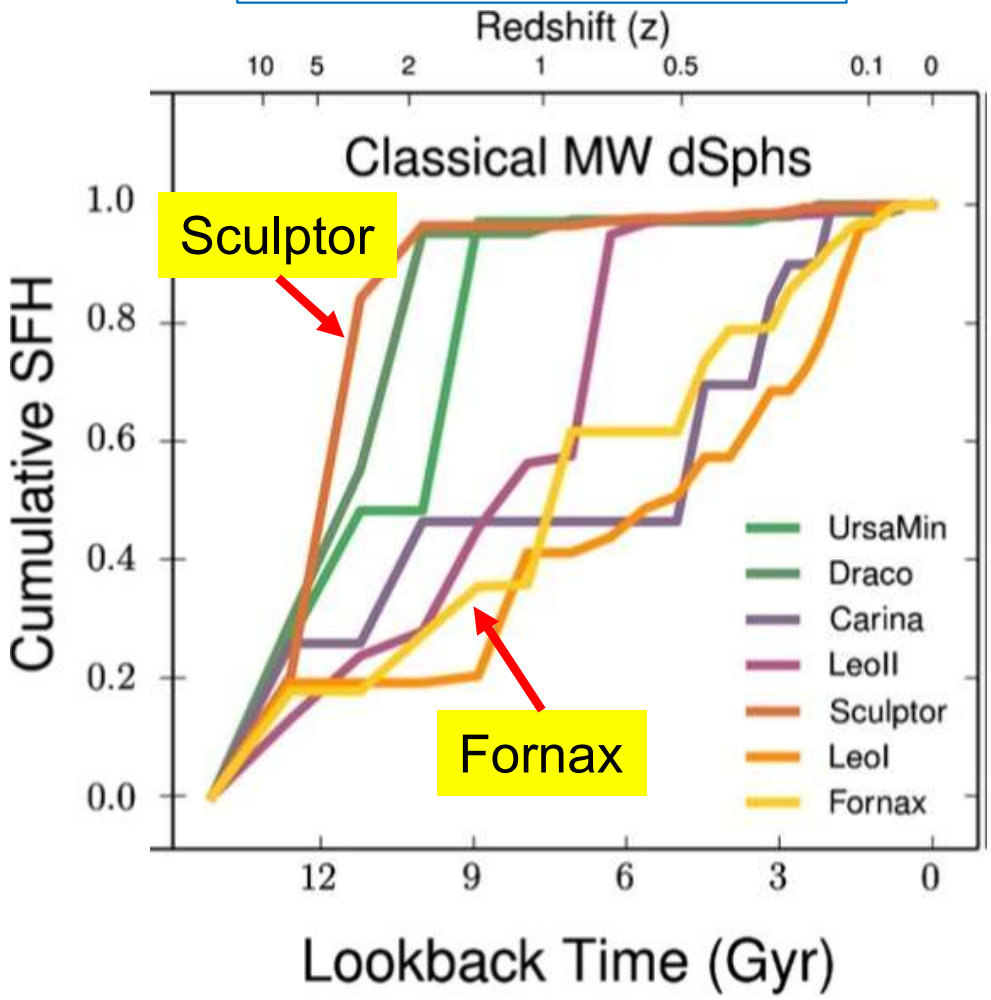
(UFD: M_v=-6.3)

NGC6822

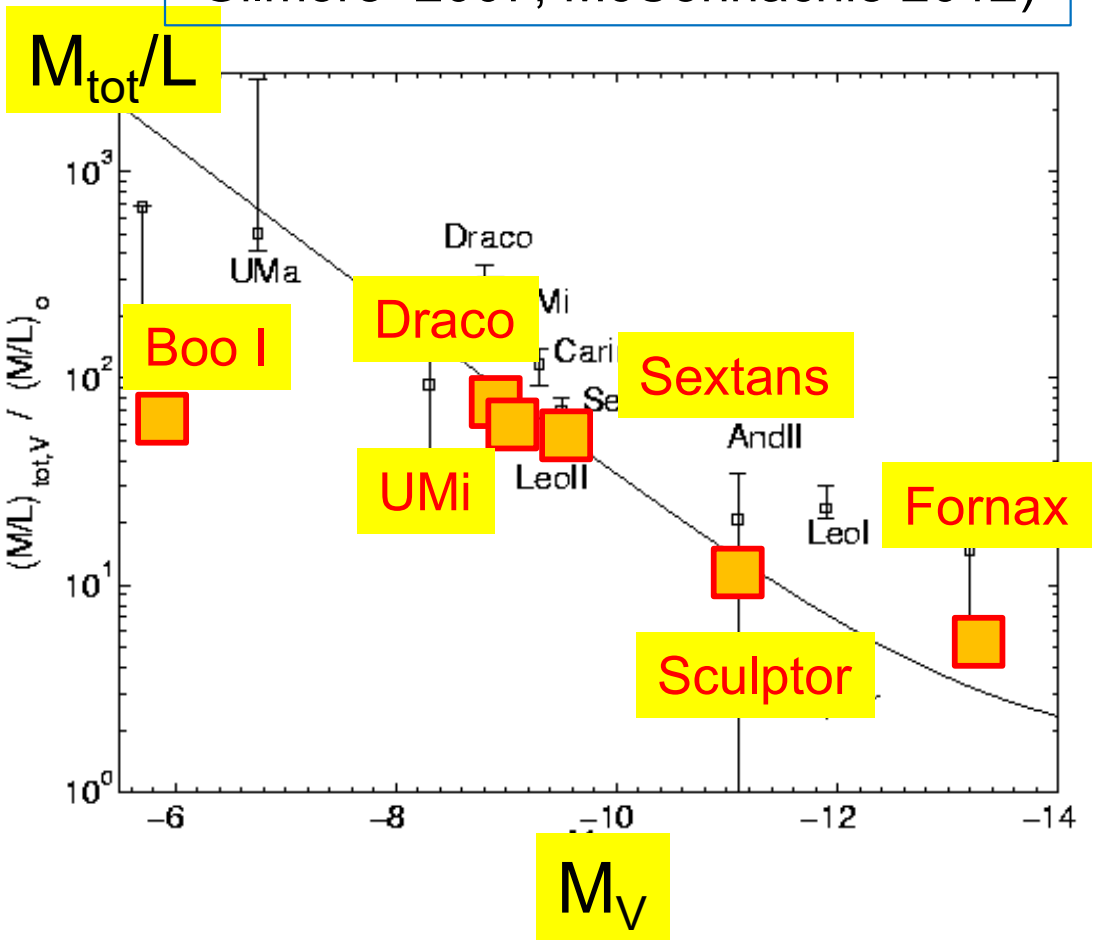
(dIrr, D=460kpc)

Varieties in the 7 dwarf satellites

SFH (Weisz et al. 2014)



DM fraction within half-light radius
Gilmore+2007, McConnachie 2012)



What is a key parameter for these varieties?

Why diversity?
Baryonic feedback effects on a CDM cusp

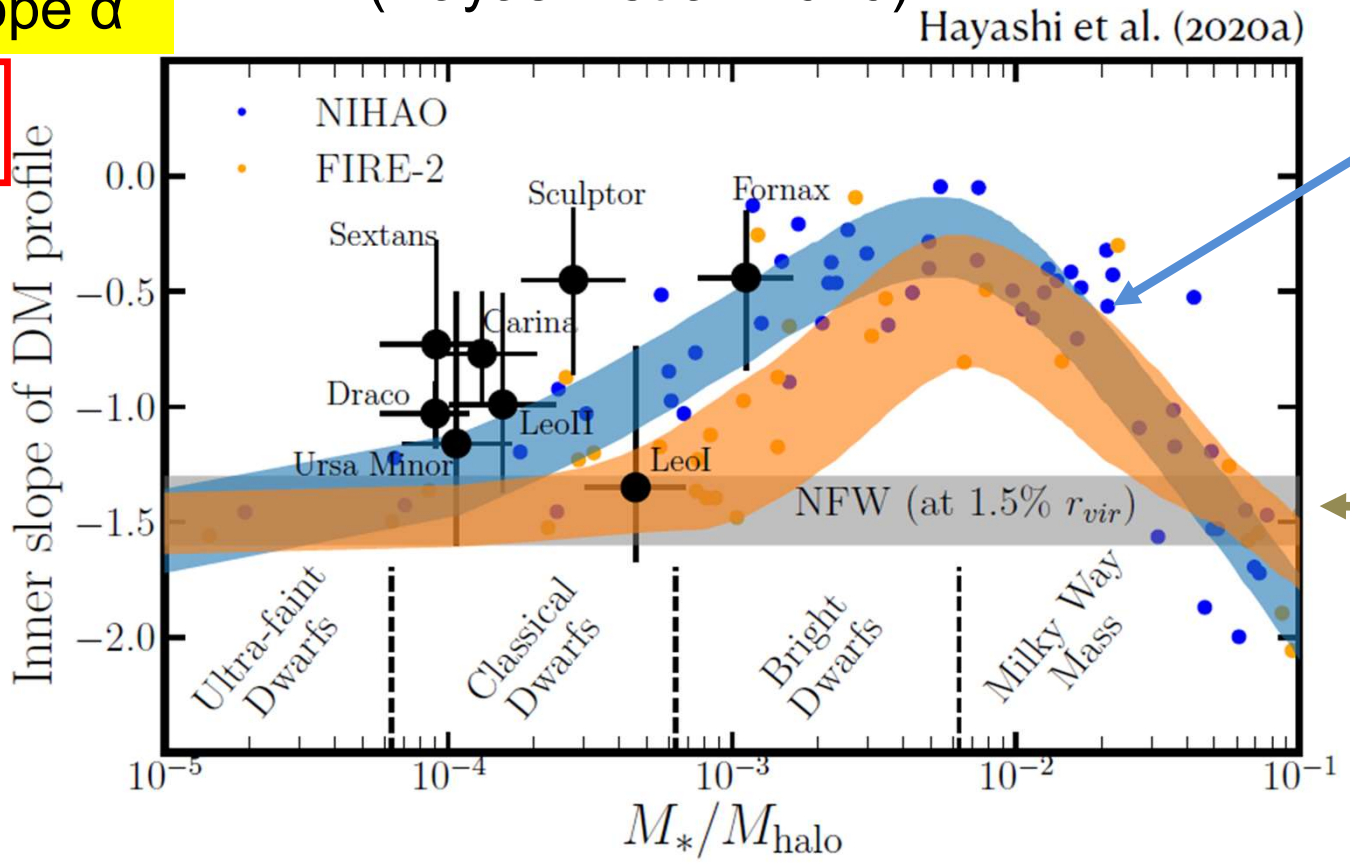
Change of inner density slope α

$\rho \propto r^{\alpha}$

core

cusp

(Hayashi et al. 2020)



after

ΛCDM-based prediction

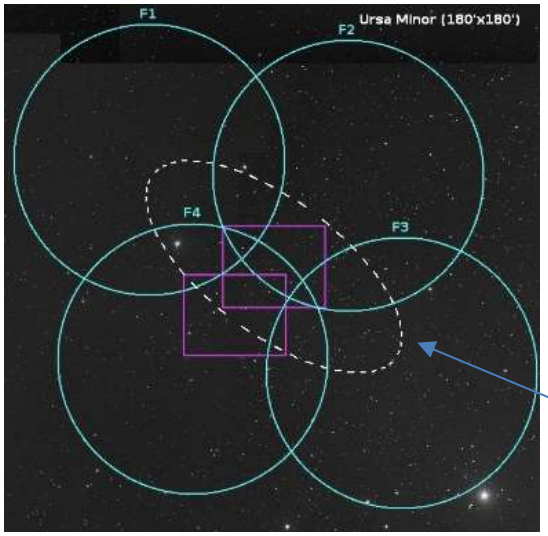
before

Bootes I
Draco
UMi
Sextans
Sculptor
Fornax
N6822

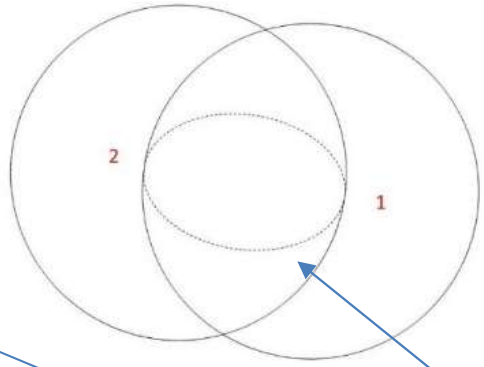
7 dwarfs: HSC+PFS targets

HSC imaging campaign of the 7 MW satellites made over past years ⇒ PFS target selection

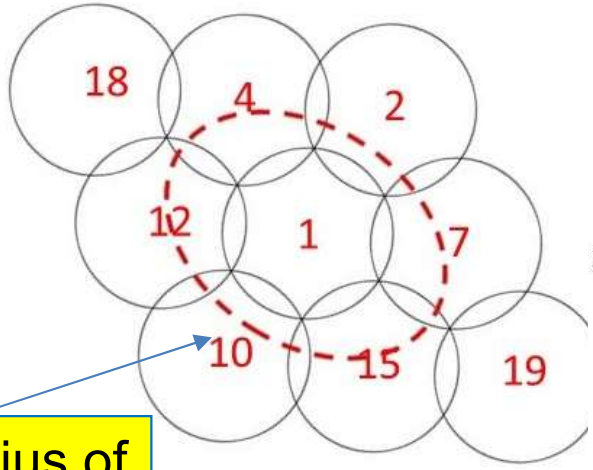
Ursa Minor



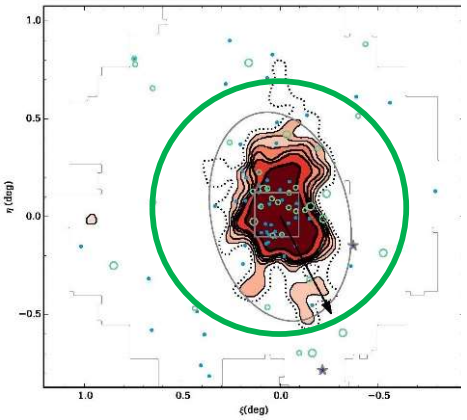
Draco



Sextans

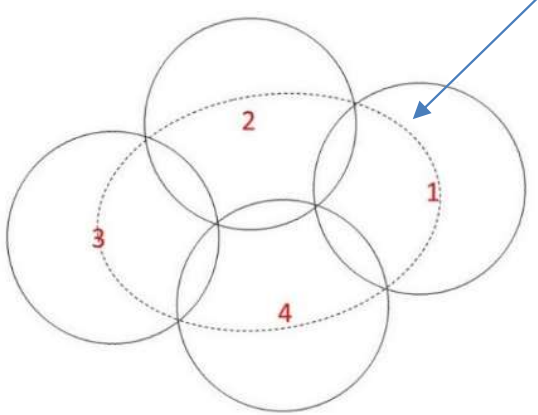


Bootes I

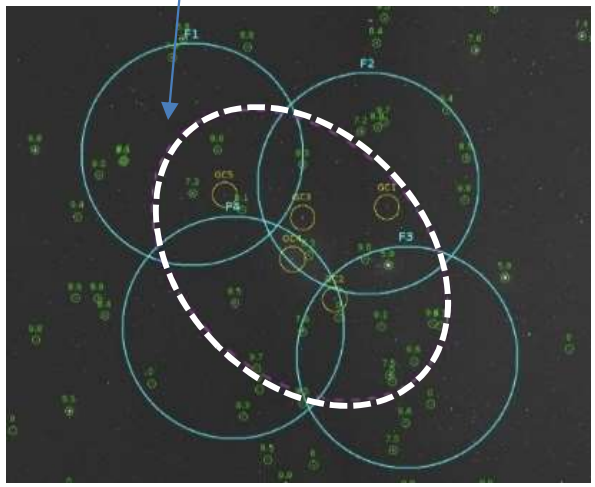


tidal radius of stellar comp.

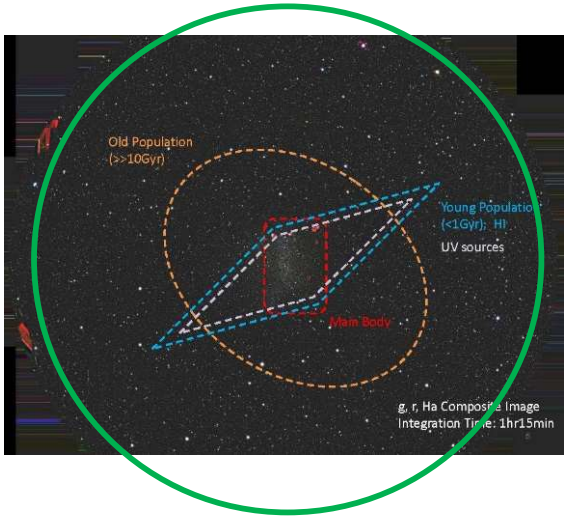
Sculptor



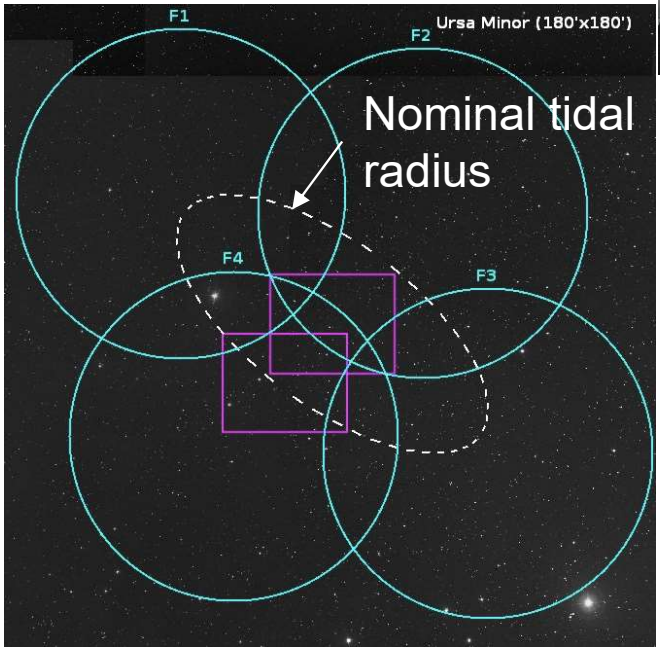
Fornax

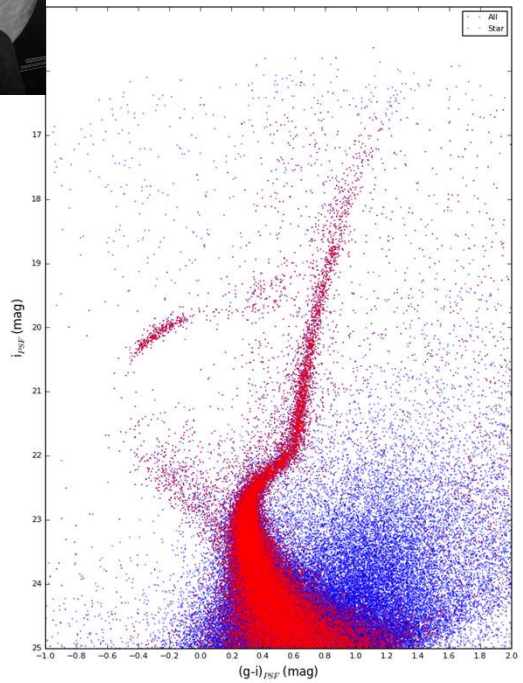


NGC6822

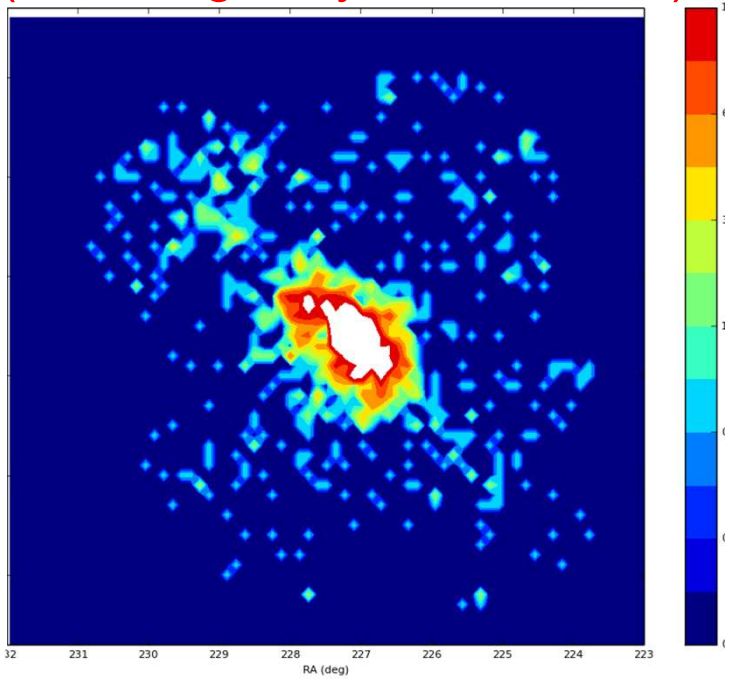


Ursa Minor



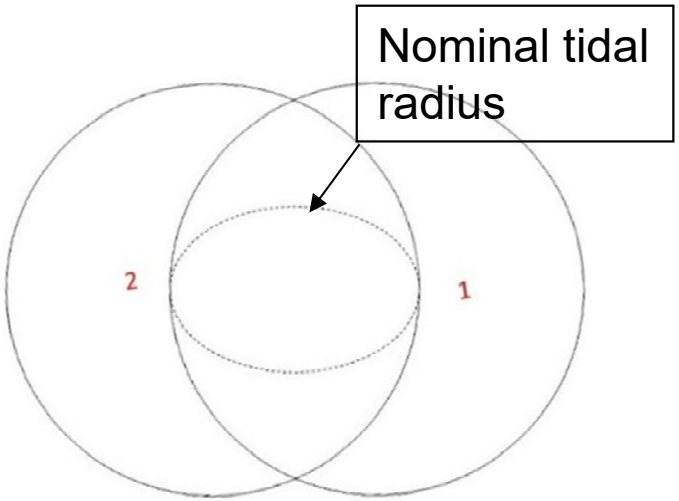


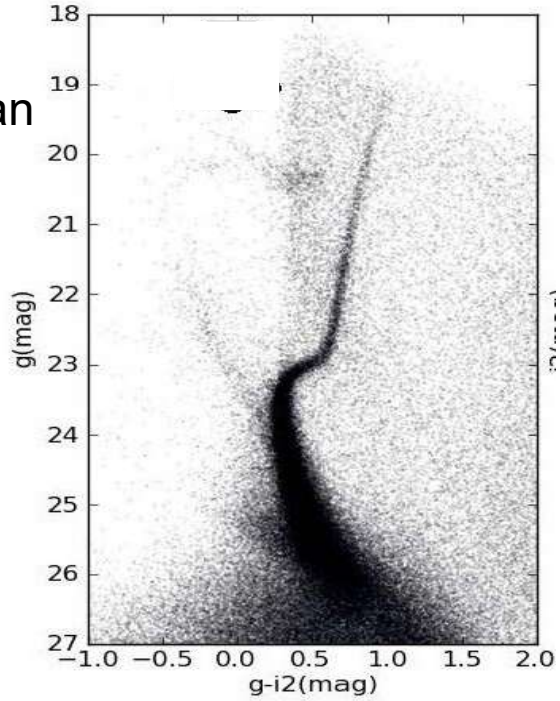
NB515-selected RGBs (surface gravity sensitive NB)



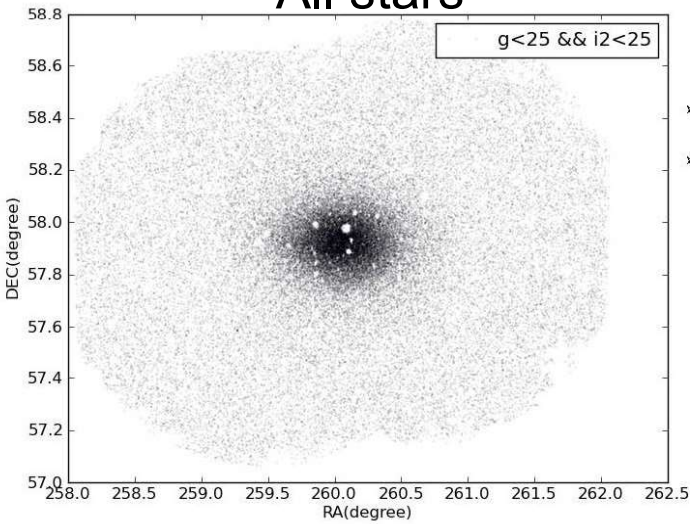
Draco

Sasaki-san



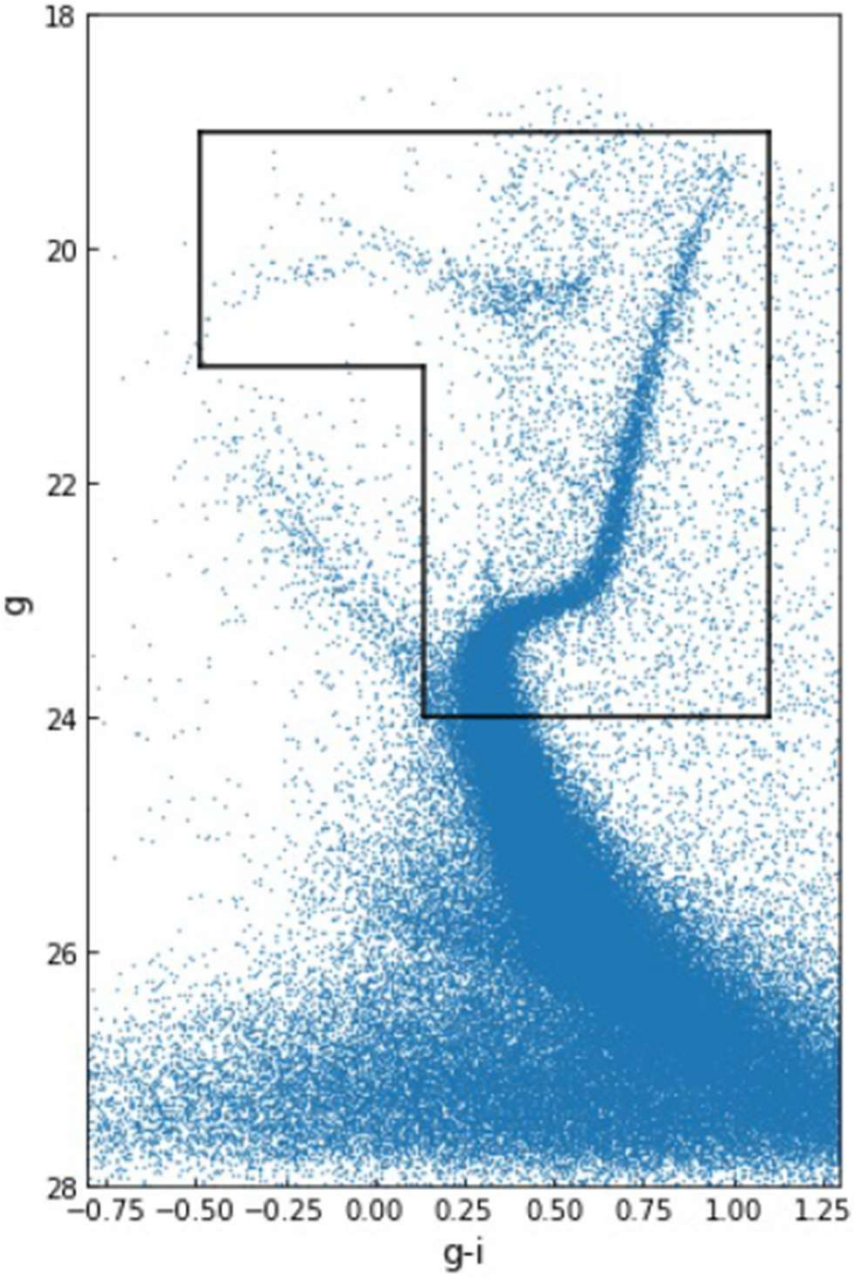


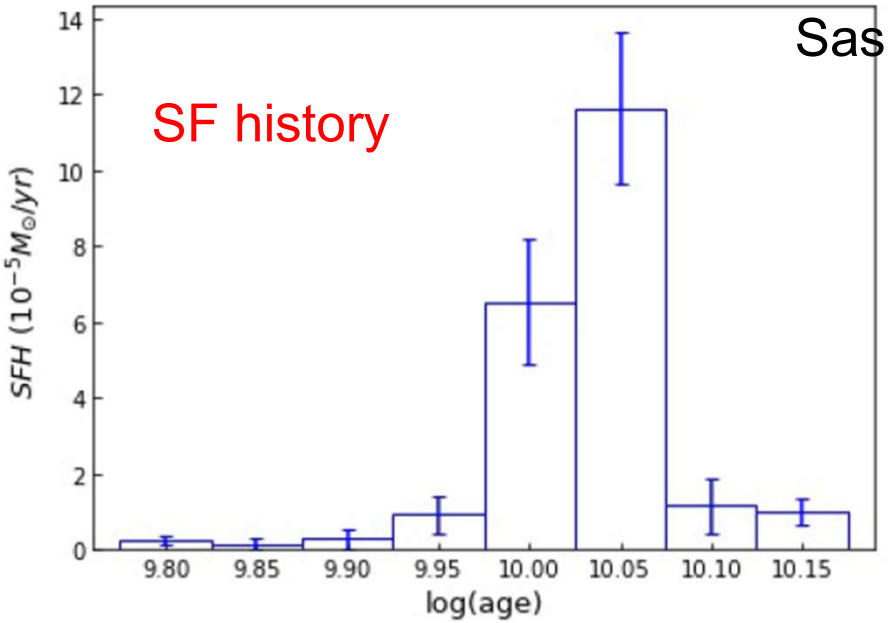
All stars

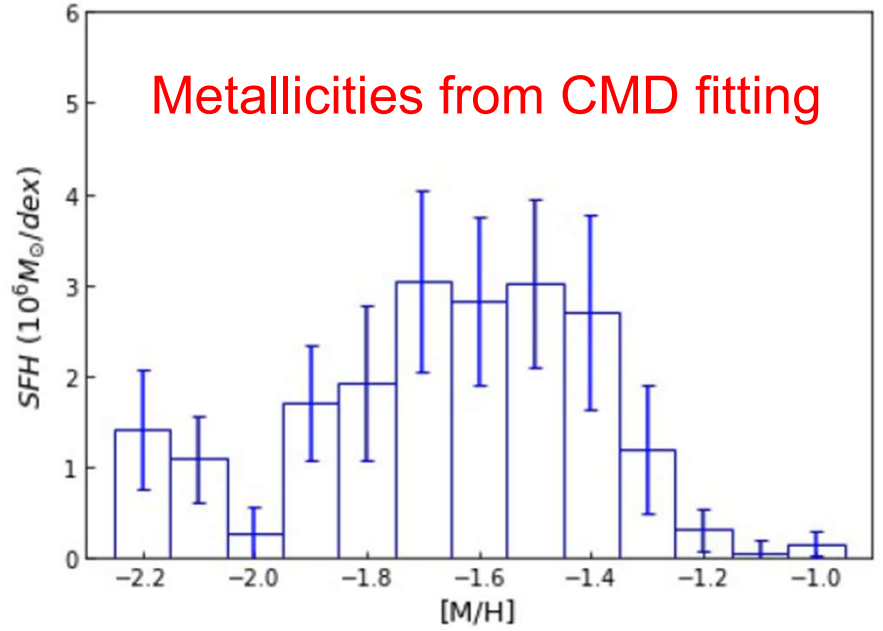


SF History and MDF of Draco

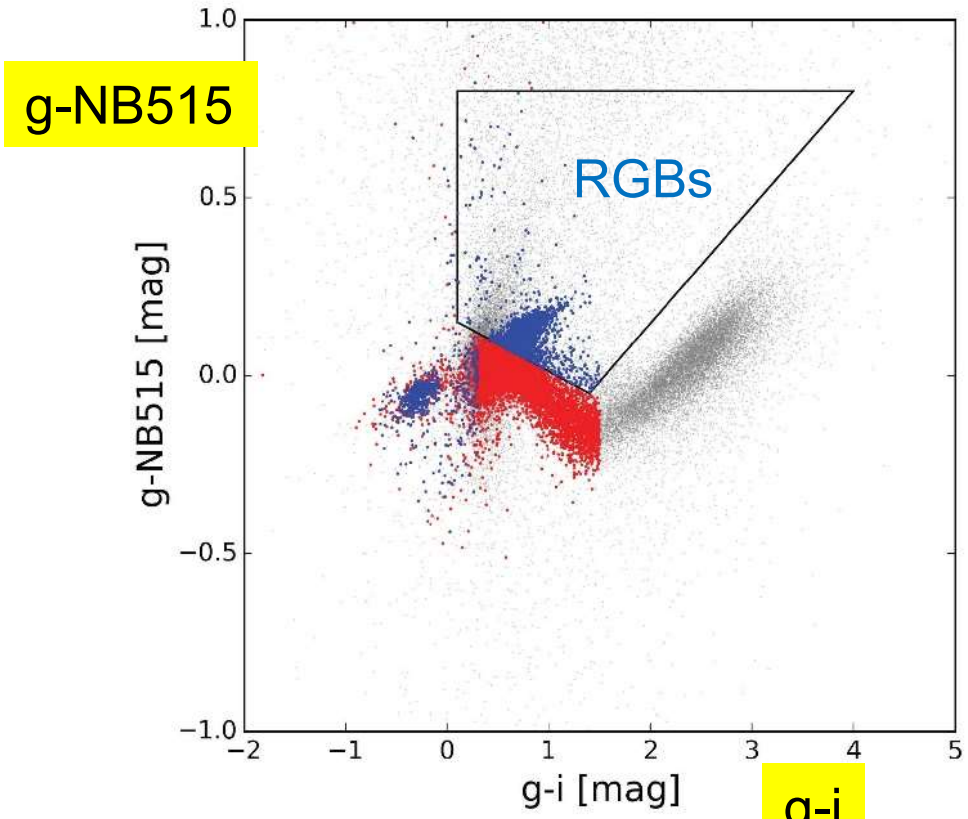
Sasaki-san

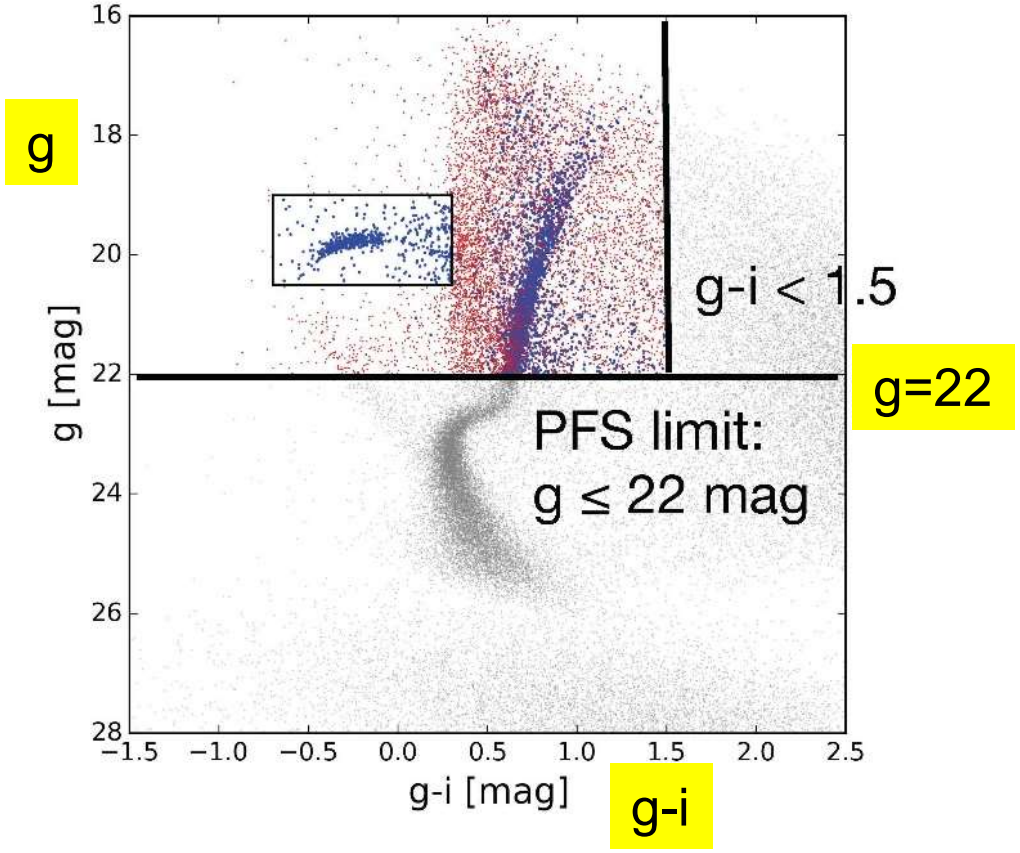


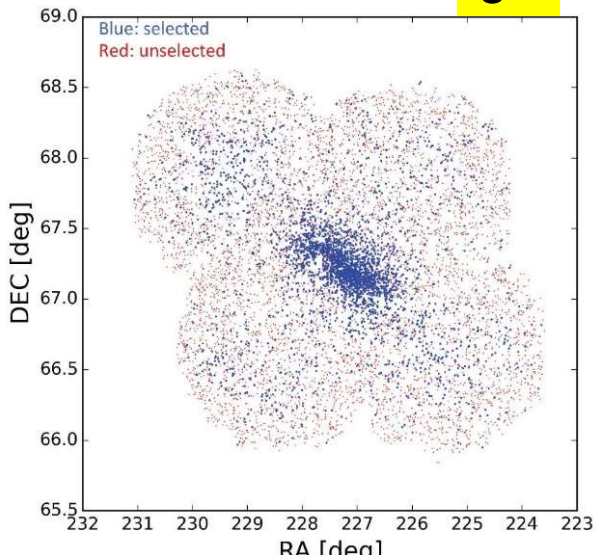




PFS target selection (Ursa Minor)







Blue: NB515 selected RGBs
+ HB stars
= Member stars in UMi
Red: MW field halo stars

Assigning priorities in science targets

(3 hrs x 2 visits) (MR-red)

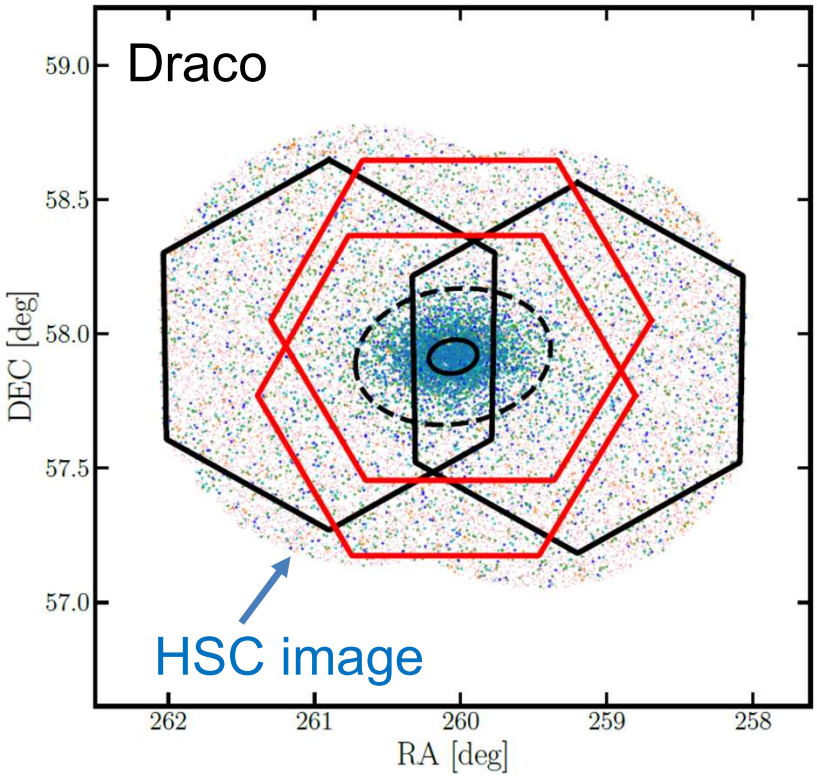
Kohei

Miho

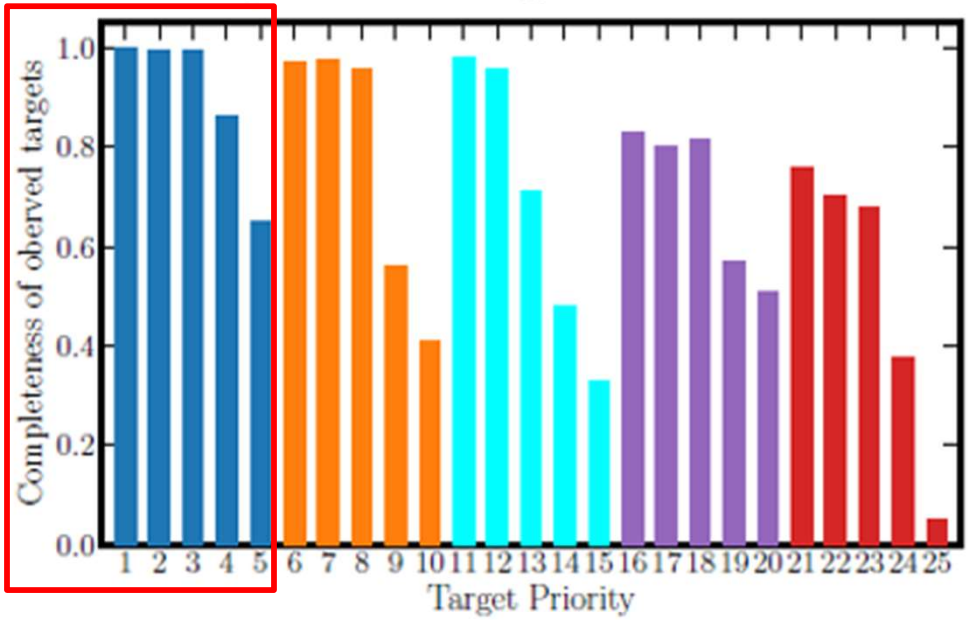
high ↕ low

Priority	Candidate	magnitude	exp. time [s]
1	dSph (K giants)	g≤18	900
2	dSph	18<g≤19	1800
3	dSph	19<g≤20	3600
4	dSph	20<g≤21	3600 (S/N>30)
5	dSph	21<g≤22	10800 (S/N>20)
6	MW halo (G dwarfs)	g≤18	900
7	MW halo	18<g≤19	900(S/N>35)
8	MW halo	19<g≤20	900(S/N>20)
9	MW halo	20<g≤21	900(S/N>20)
10	MW halo	21<g≤22	10800 (S/N>10)

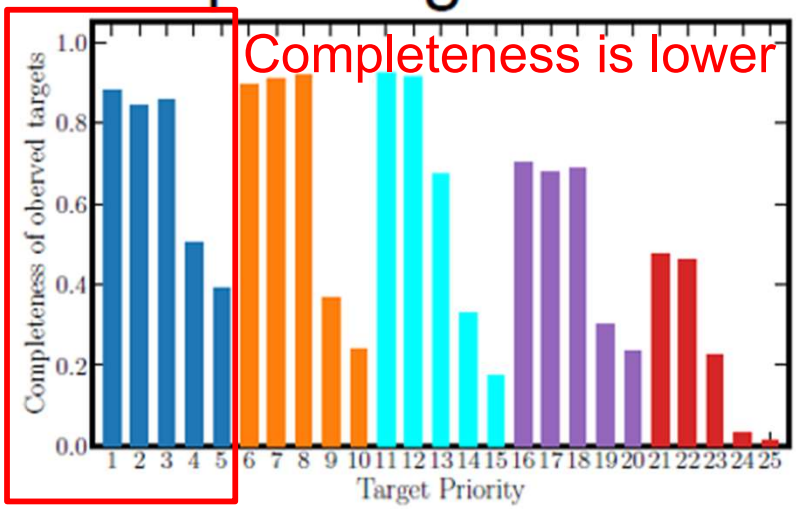
Survey simulation for Draco

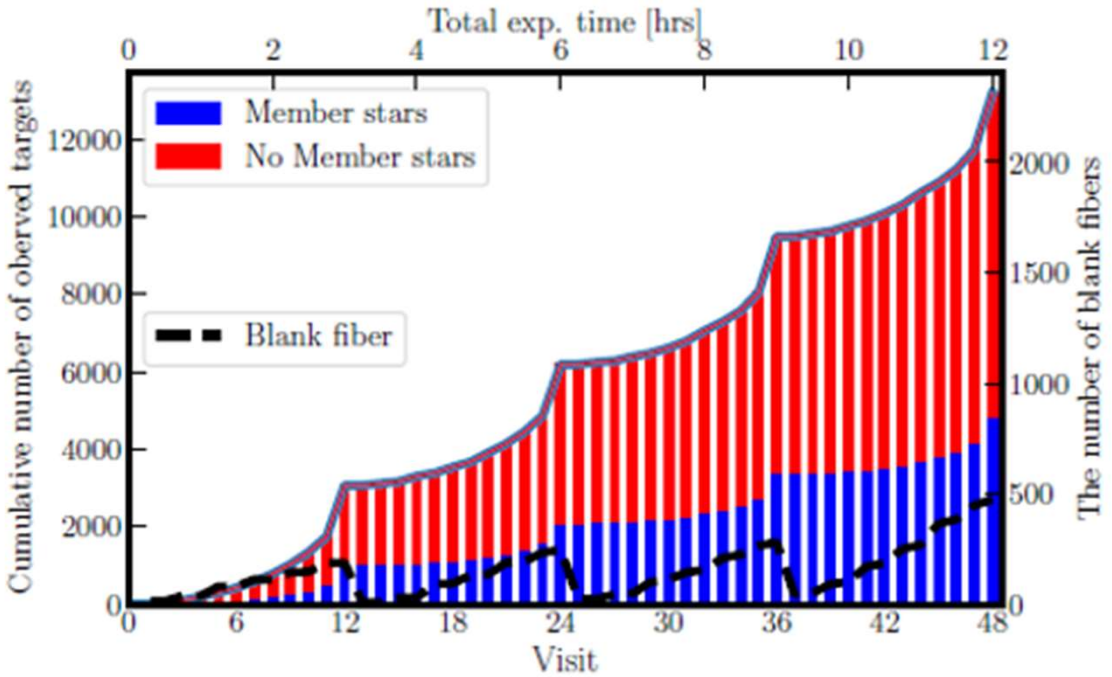


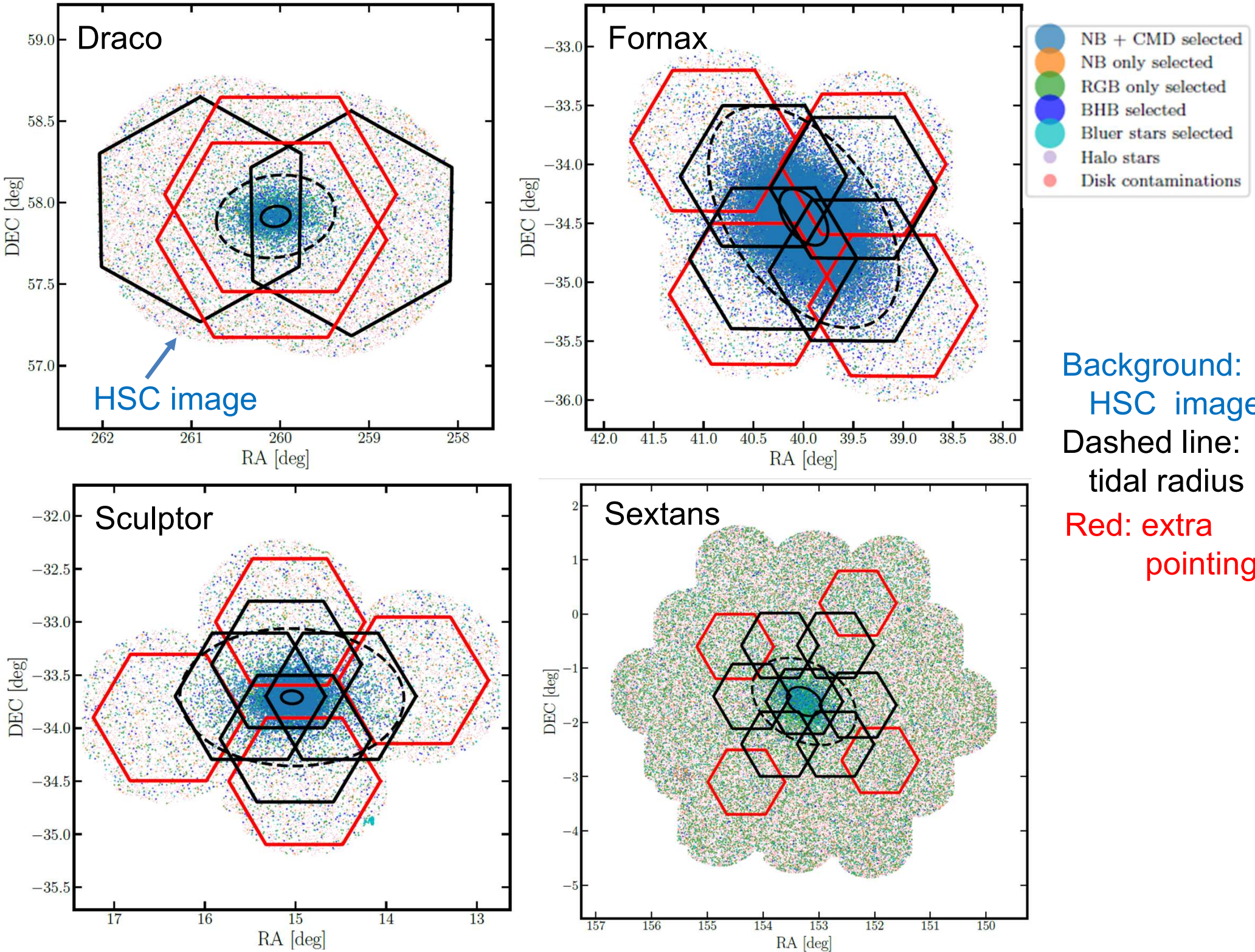
- 4 pointings



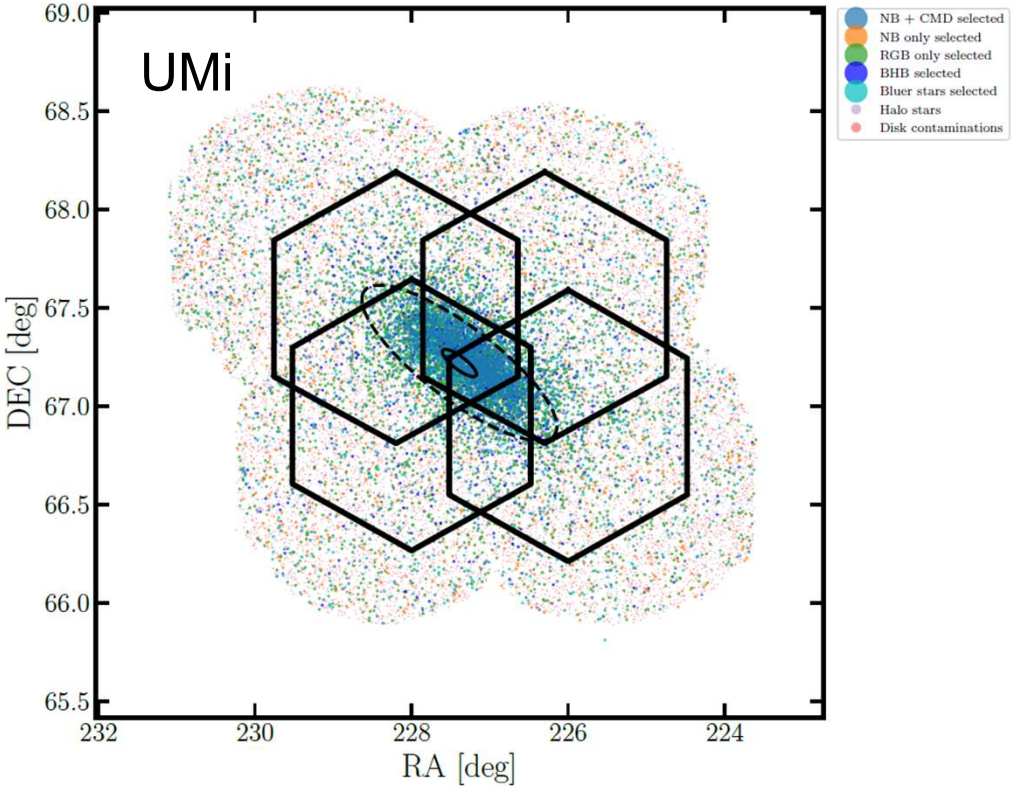
- 2 pointings

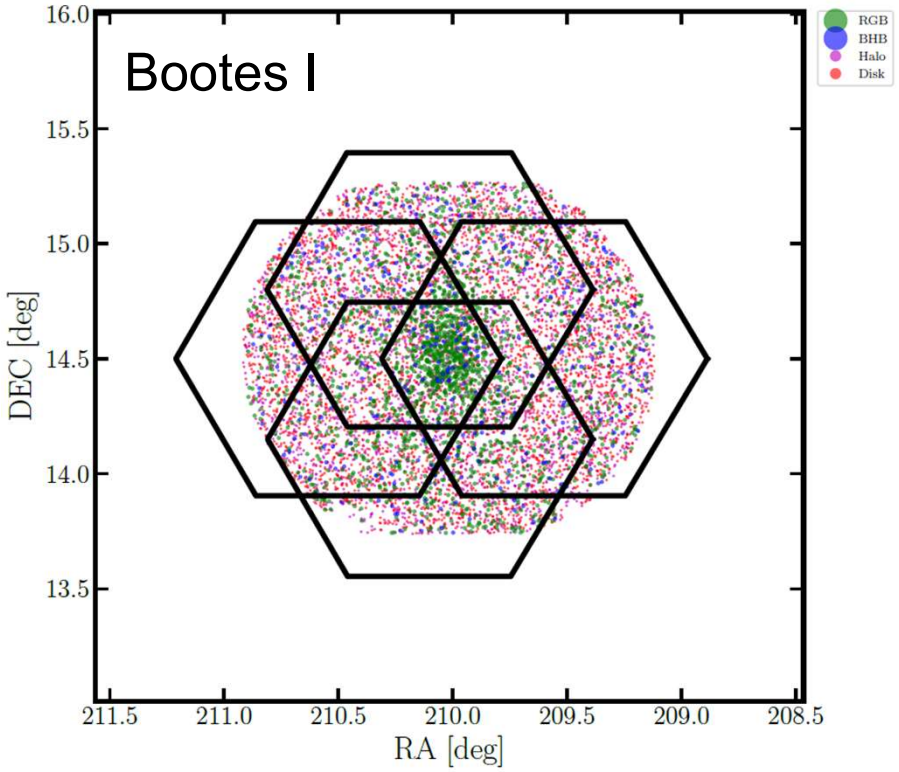




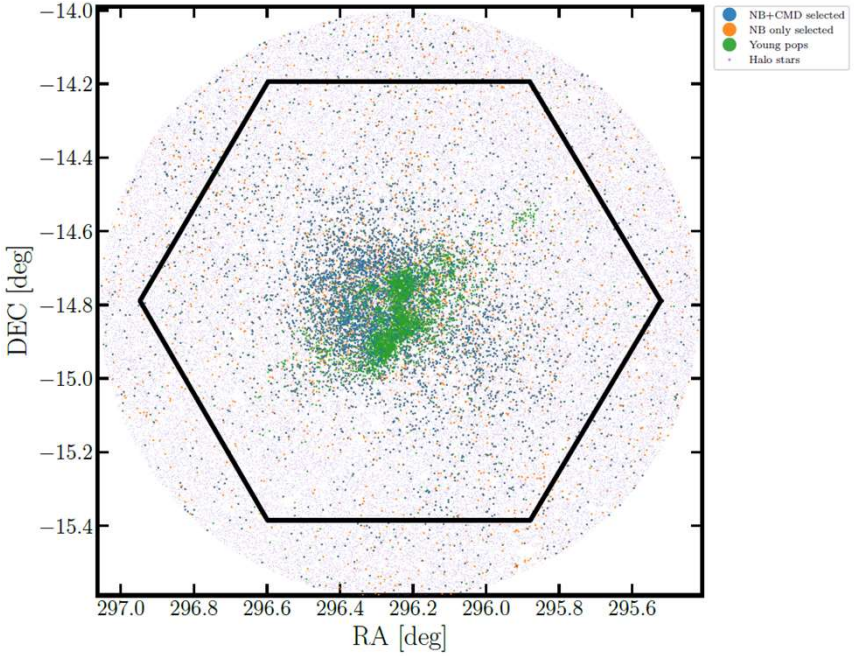


Background:
HSC image
Dashed line:
tidal radius
Red: extra
pointings

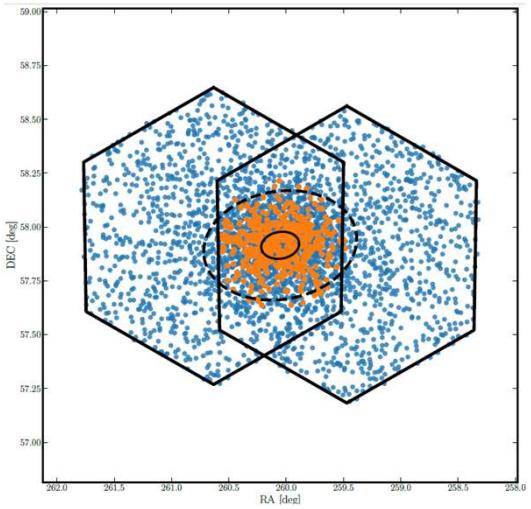

UMi
NB + CMD selected
NB only selected
RGB only selected
BHB selected
Bluer stars selected
Halo stars
Disk contaminations
DEC [deg]
RA [deg]
69.0
68.5
68.0
67.5
67.0
66.5
66.0
65.5
232
230
228
226
224


Bootes I
RGB
BHB
Halo
Disk
DEC [deg]
RA [deg]
16.0
15.5
15.0
14.5
14.0
13.5
211.5
211.0
210.5
210.0
209.5
209.0
208.5

NGC6822


NB+CMD selected
NB only selected
Young pops
Halo stars
DEC [deg]
RA [deg]
−14.0
−14.2
−14.4
−14.6
−14.8
−15.0
−15.2
−15.4
297.0
296.8
296.6
296.4
296.2
296.0
295.8
295.6

Power of PFS for deriving dSph's DM

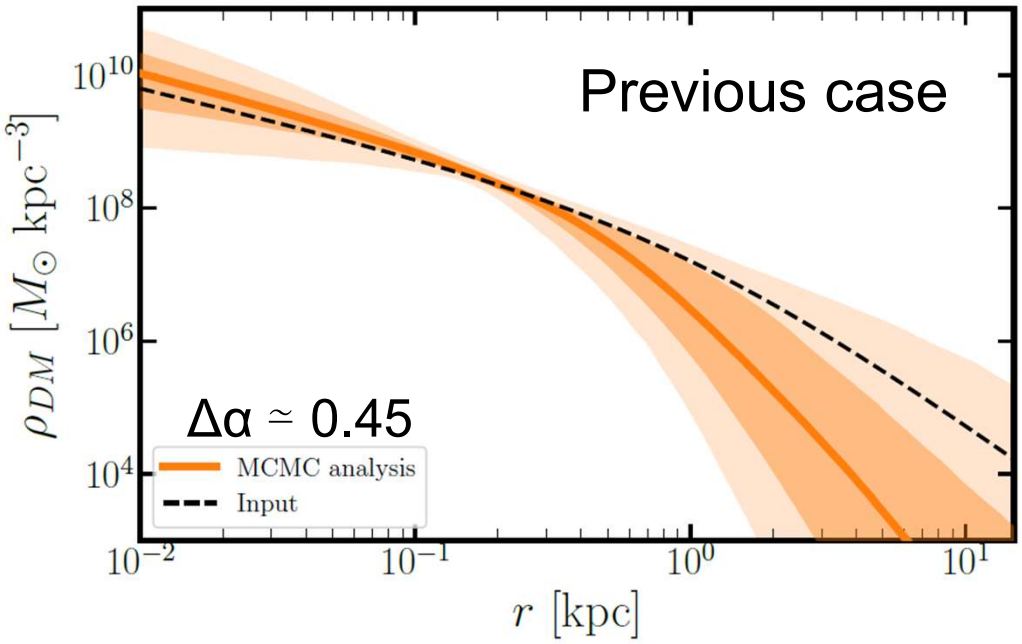


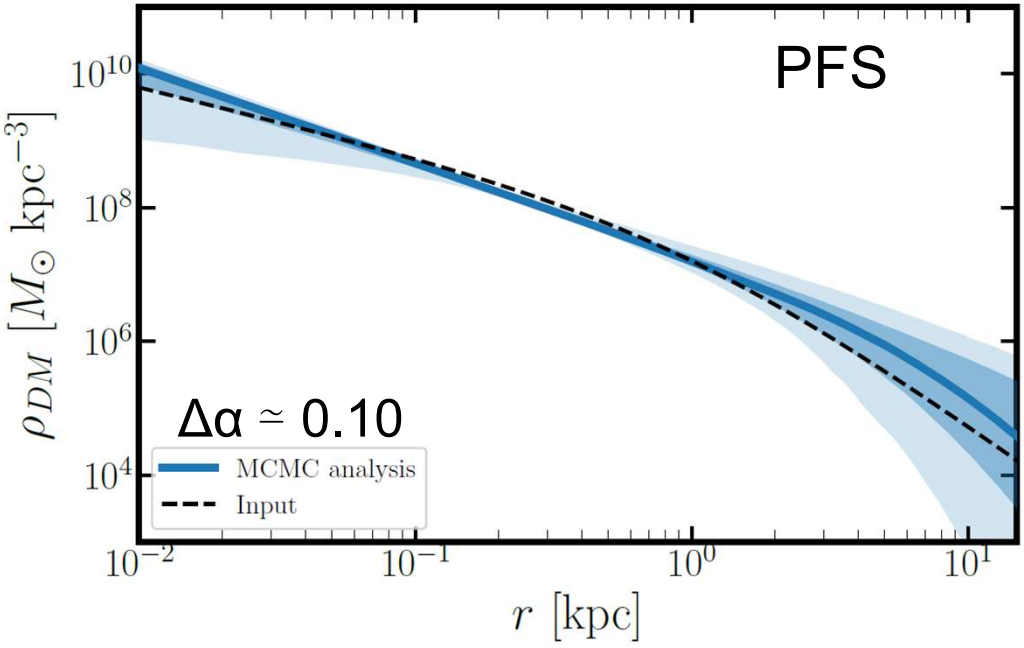
Test for
Draco Mock
(with 2 pointings)


Kohei


Evan
Kirby

$\rho \propto r^{\alpha}$





More analysis is now underway

A Bayesian model
for fiber assignment to stars


Alex

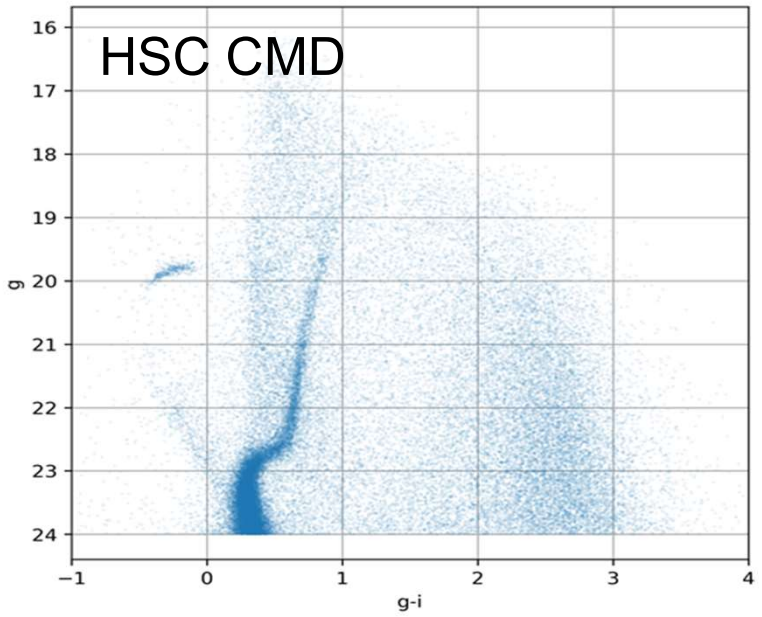

Laszlo

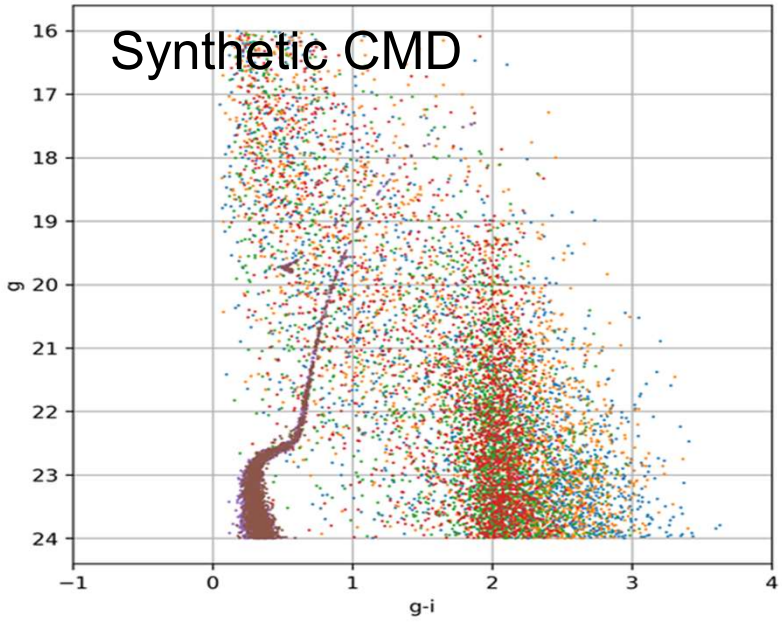

Carrie

JHU group

- Build a Bayesian model for a probably that a given star is a member or not
- MCMC techniques to sample the posterior by repeatedly simulating CMDs and evaluating the likelihood
- Posterior distributions for stellar parameters
- Model a CMD as a mixture of the MW foreground and satellite targets

Example: Ursa Minor





Best method for prioritization for all the target stars!

Summary and Prospects

- These 7 MW dwarfs is a unique set for constraining the nature of dark matter + chemo-dynamics
  - This is a key science and goal in PFS-SSP
  - This will be the Subaru community's dataset, so you are always welcome to join us for collaboration!
- Would like to request to protect these 7 MW dwarfs in PFS-SSP (at least in their spectroscopic observing mode) and get the community's understanding and permission for this
  - Protection within 1 deg from each center (except TOOs)
  - To avoid scoop from others