Robust J-factor estimation of ultra-faint dwarf galaxies

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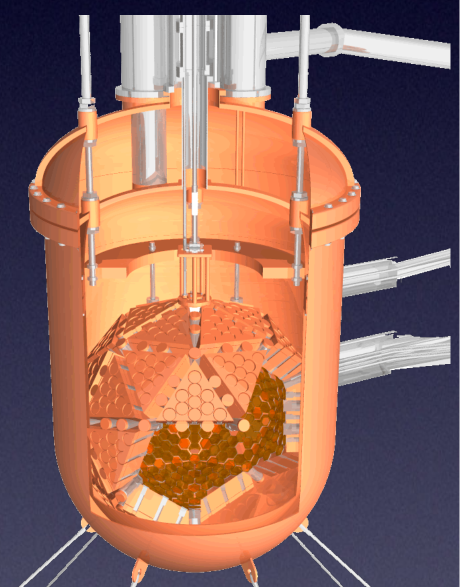
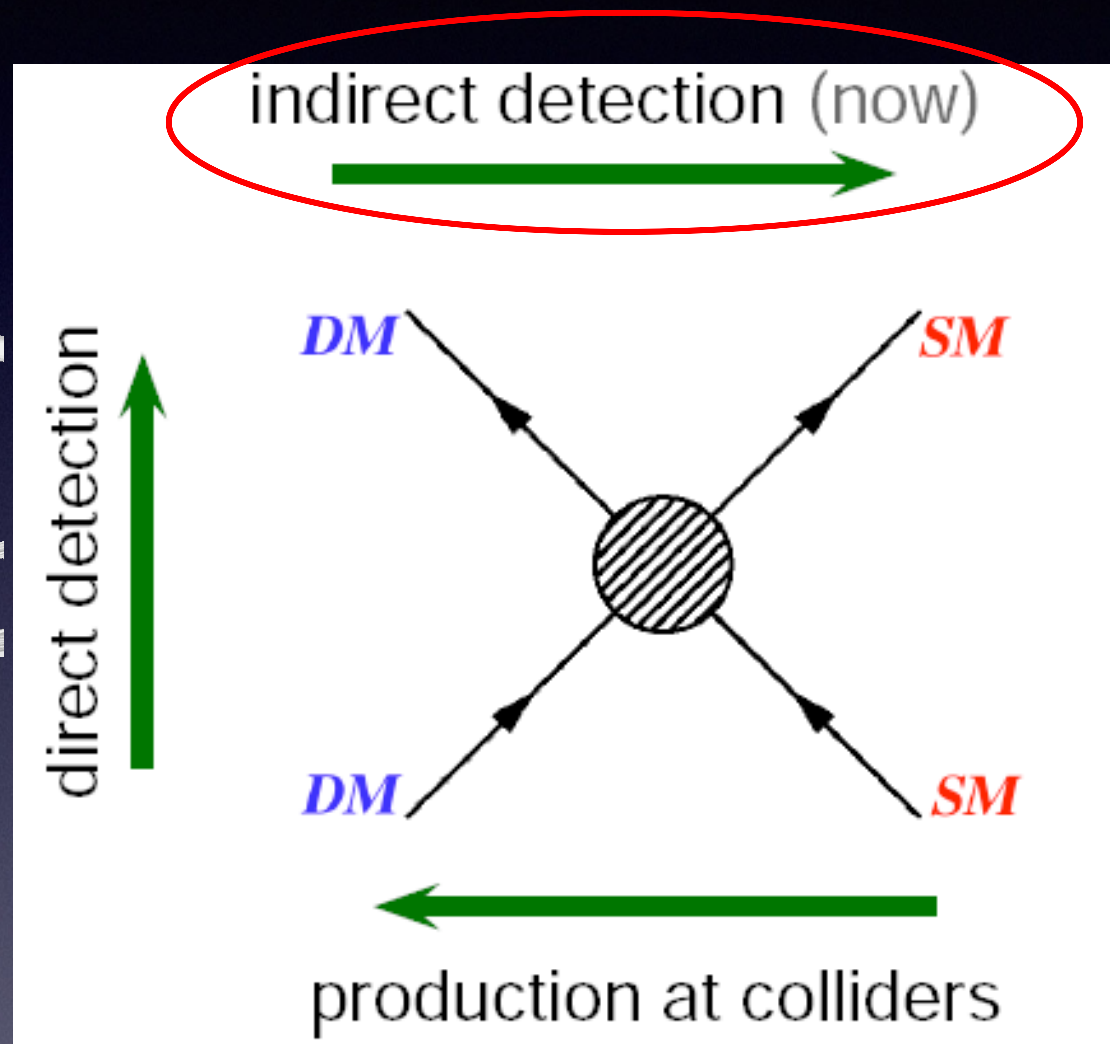
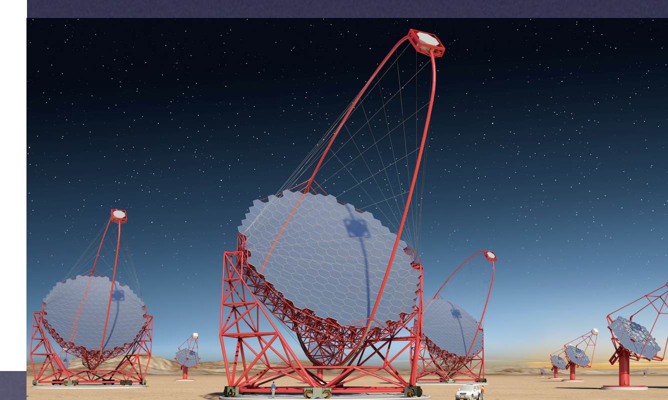
Dark Matter Search

M_{DM} ~ 50-2000GeV







Indirect search for dark matter

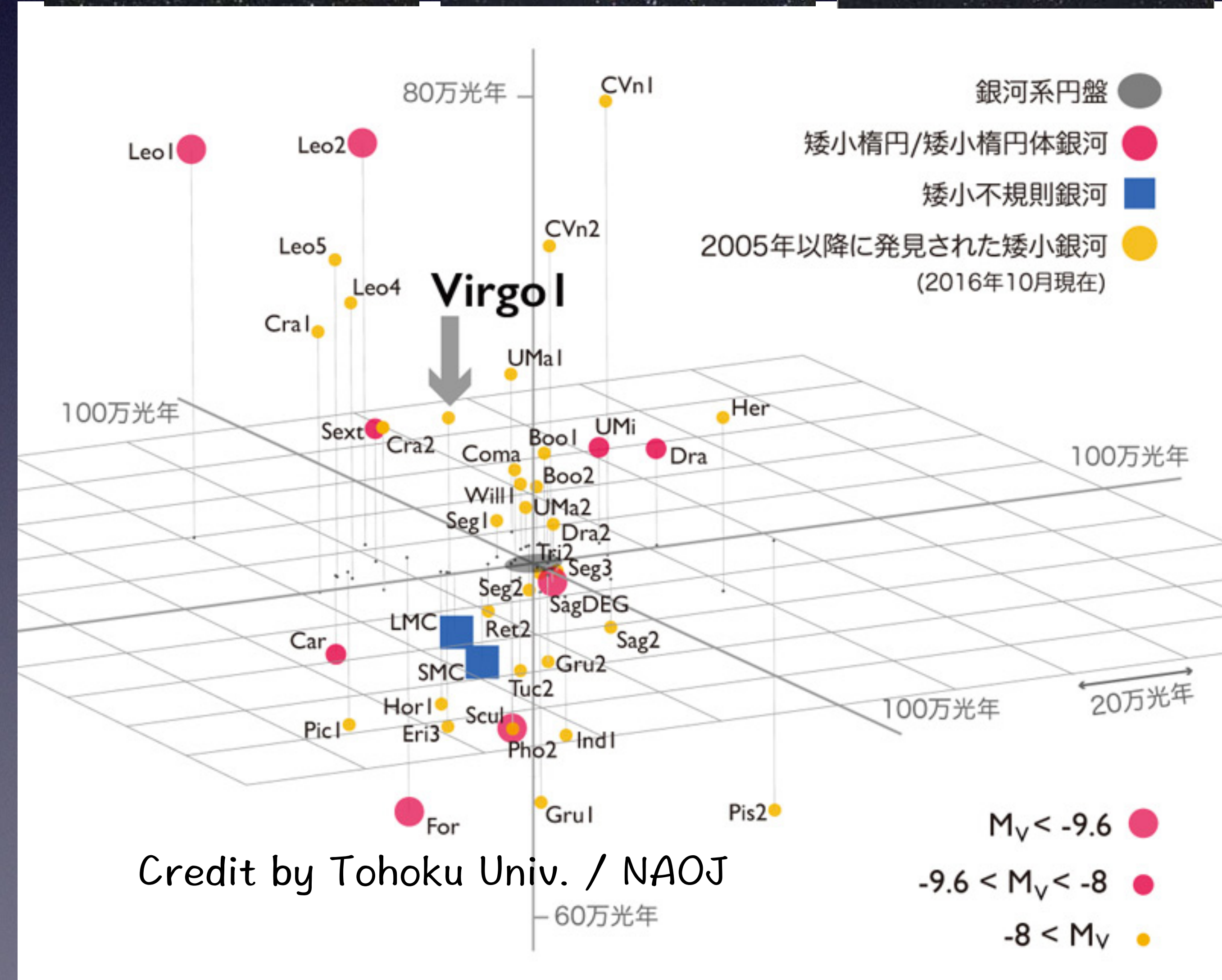
Galactic dSphs are ideal sites for studying properties of dark matter!

Galactic dSphs:

- DM rich (M/L~10 to 1000)
- Proximity (D ~ 20 - 100 kpc)
- Clean (no gas & no star formation)

Type of dSph galaxy

	Classical	Ultra-faint
# of dSphs	8	>30
M/Ls	10-100	100-1000
# of stars	500-2500	10-100

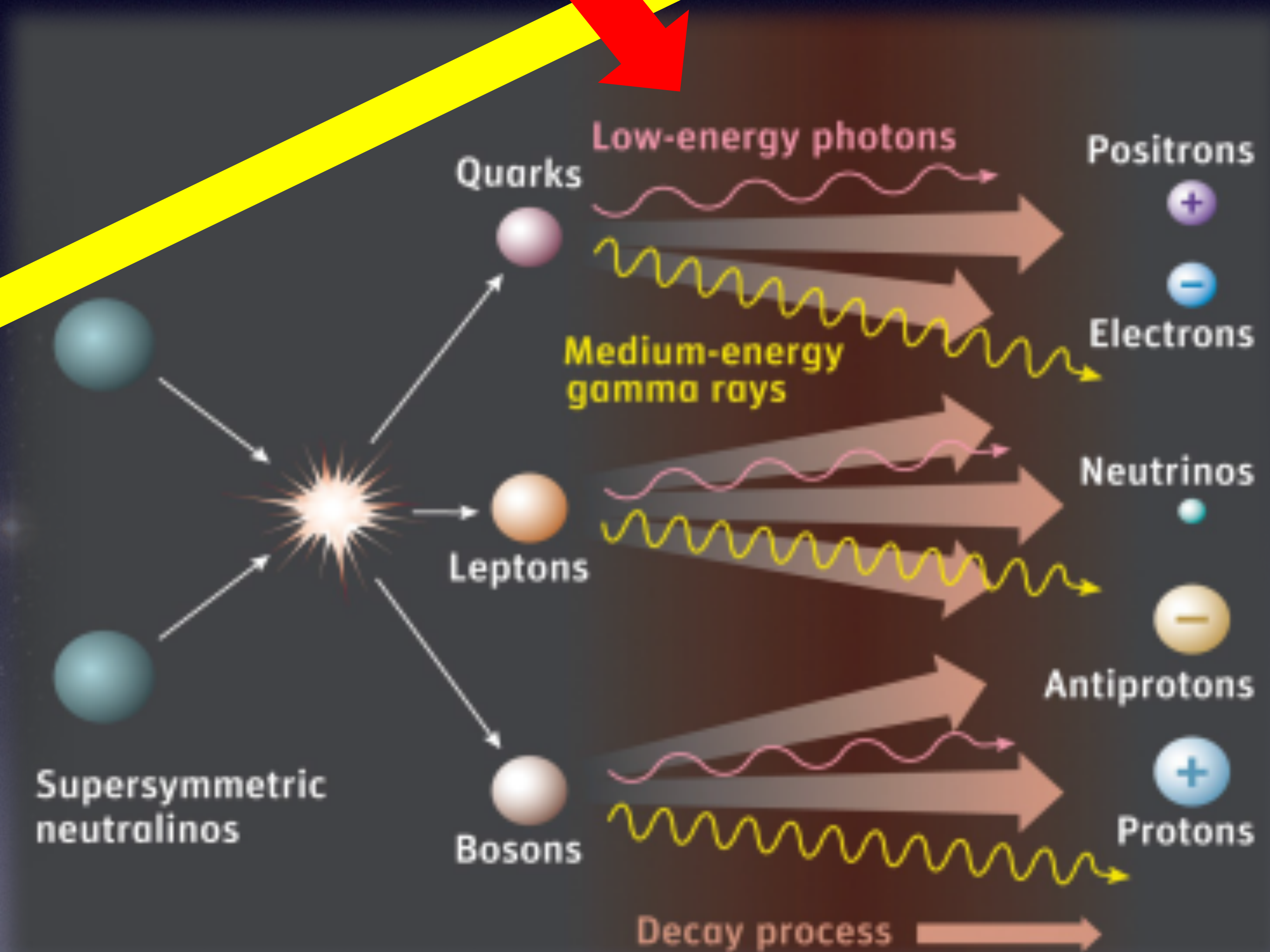


Indirect search for dark matter

$$\Phi(E,\Delta\Phi) = \left[\frac{\langle\sigma v\rangle}{8\pi m_{\rm DM}^2}\sum_f b_f \frac{dN_\gamma}{dE}\right] \times \int_{\Delta\Omega}\int_{\rm l.o.s} d\ell d\Omega\, \rho^2(\ell,\Omega)$$

Observable | Particle physics | Astrophysics (J-factor)

dSph galaxy



γ-ray detector

To robust estimate J-factor value,
revealing the dark halo structure of the dSphs is of importance!

Major systematic uncertainties on J-factor

- Non-spherical dark halo (Hayashi et al. 2016)

  Most previous works estimated J-values by assuming spherical mass models, even though the distributions of luminous and dark components in dSph are actually not spherical.

- Foreground contaminations (Ichikawa (inc. KH) et al. 2017a,b)

  Foreground contaminations have largely impact on determining dark halo profiles, especially ultra faint dwarf galaxies.

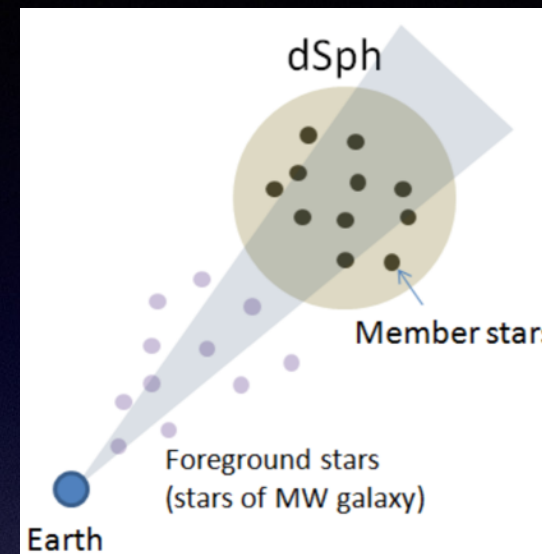
- Velocity anisotropy (Hayashi et al. in prep)

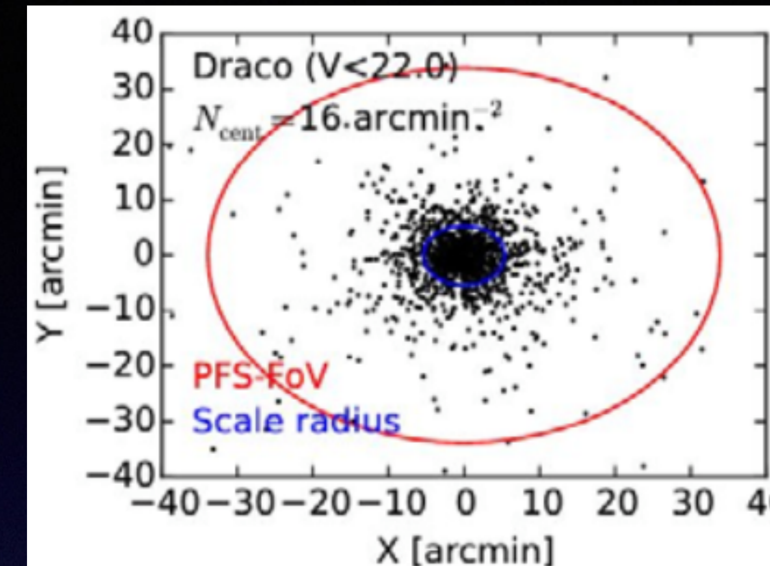
  Velocity anisotropy as commonly parameter is strongly degenerated with mass profile of dark halo. Therefore, studies of dark matter is dSphs have been hampered by this degeneracy.

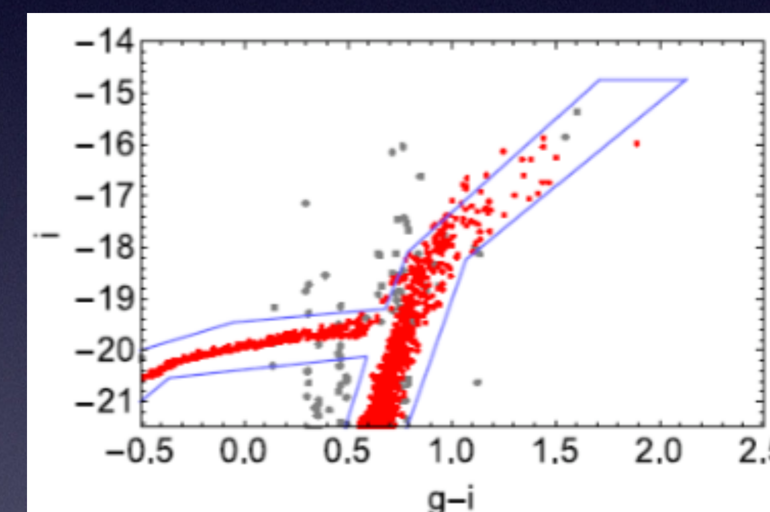
Foreground contaminations

Big efforts to reduce contaminations…

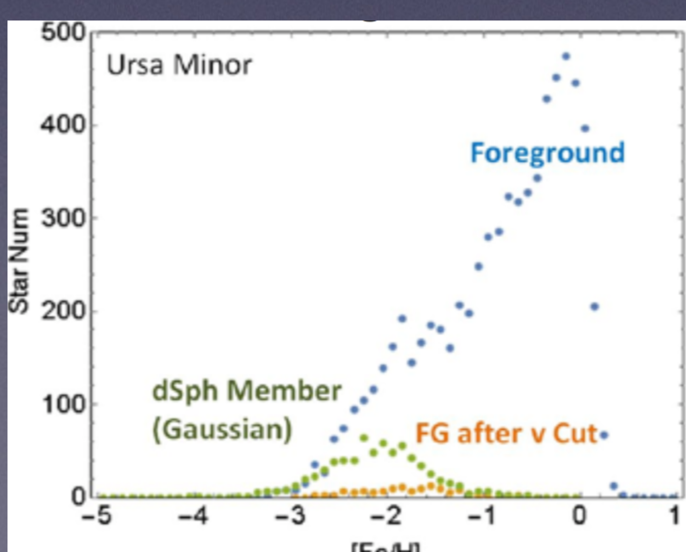
1. Region of interest cut
2. Color-magnitude cut
3. Velocity cut
4. Surface gravity cut
5. Effective temperature cut
6. Metallicity cut

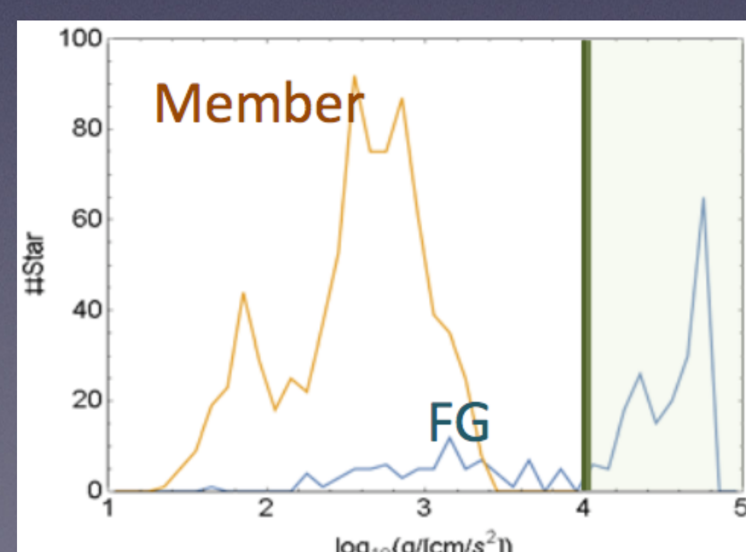


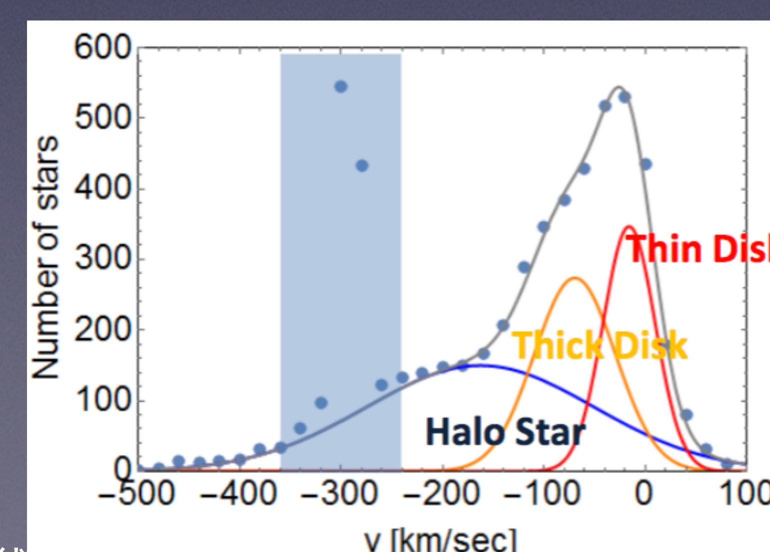




<u>Indistinguishable contaminations still remain…</u>







New fitting function including FG contaminations

Ichikawa (incl. KH) et al. (2017a)

$$-2\ln\mathcal{L} = -2\sum_i \ln(s f_{\rm Mem}(v_i,R_i) + (1-s) f_{\rm FG}(v_i,R_i))$$

- Membership fraction parameter

$$s = \frac{N_{\rm Mem}}{N_{\rm Mem}+N_{\rm FG}}$$

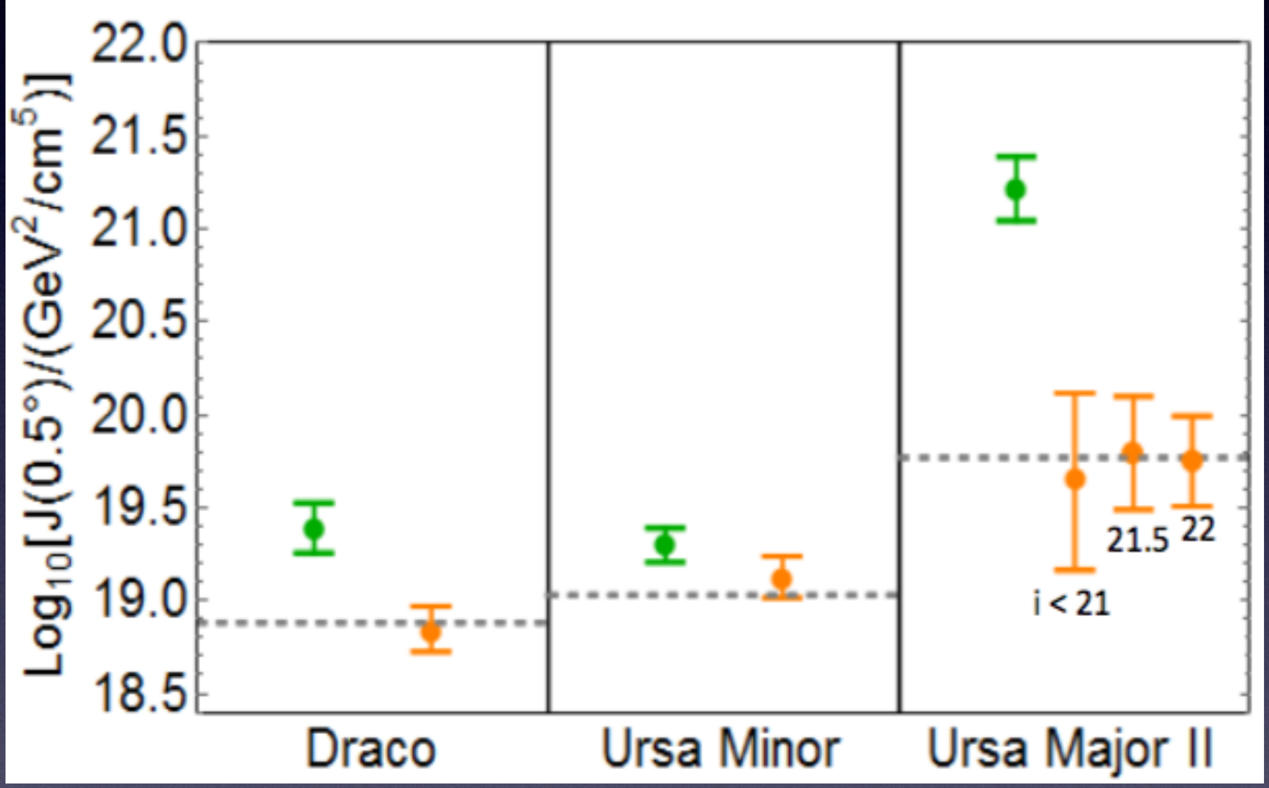
- Distribution Functions

$$f_{\rm FG}(v,R) = 2\pi R N_{\rm FG}\exp\left[-\frac{(v-v_{\rm FG})^2}{2\sigma_{\rm FG}^2}\right]$$

$$f_{\rm Mem}(v,R) = \frac{2\pi R\Sigma_*(R)}{\sqrt{2\pi\sigma_{\rm l.o.s}^2(R)}}\exp\left[-\frac{(v-v_{\rm Mem})^2}{2\sigma_{\rm l.o.s}^2(R)}\right]$$

Green: Contaminated (regard FG as member stars)

Orange: Our new fit

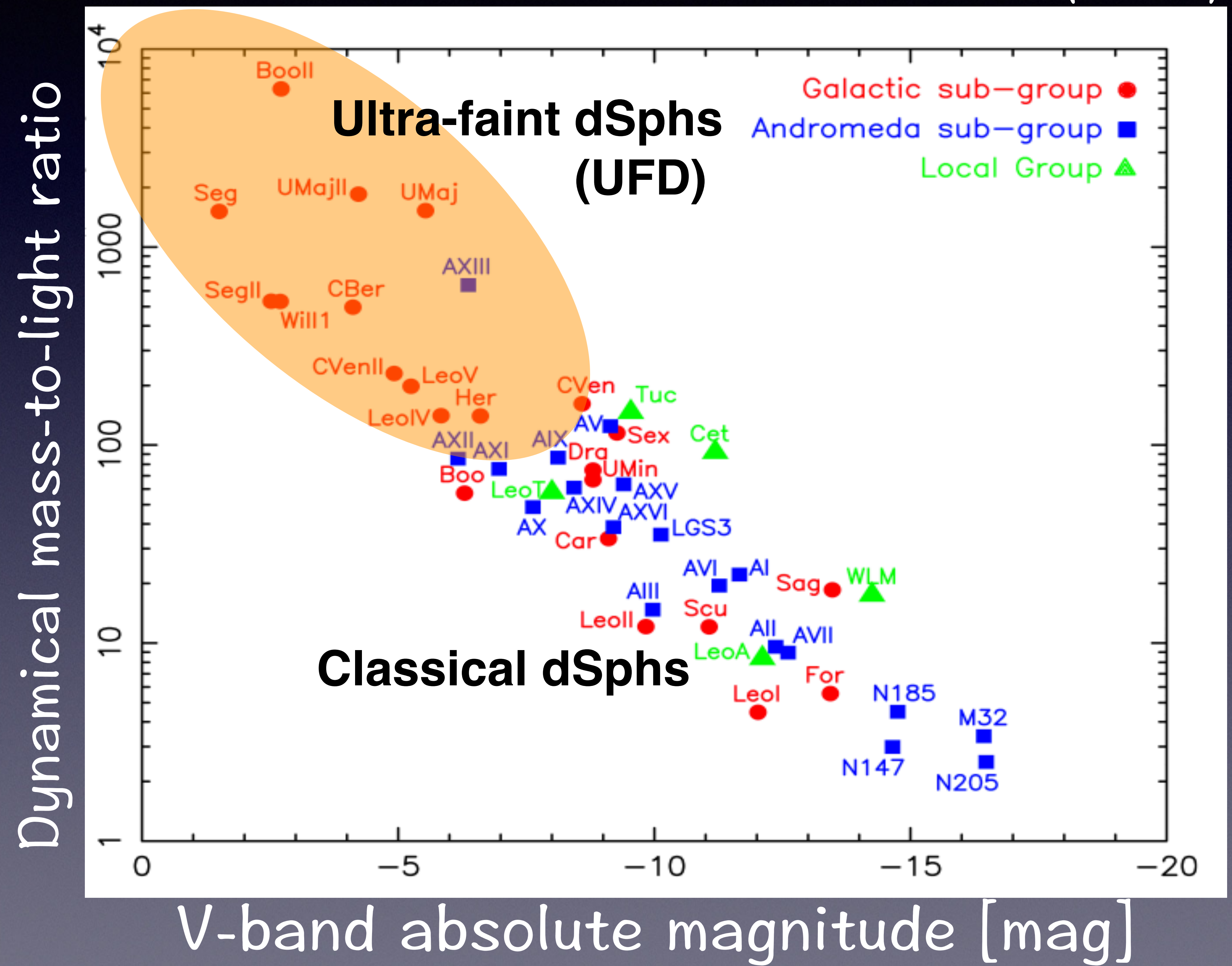


Our new likelihood reproduces successfully the input J-factor values.

To treat contaminations more accurately, we require a number of stellar spectra of FG stars as well as member stars in outer region.

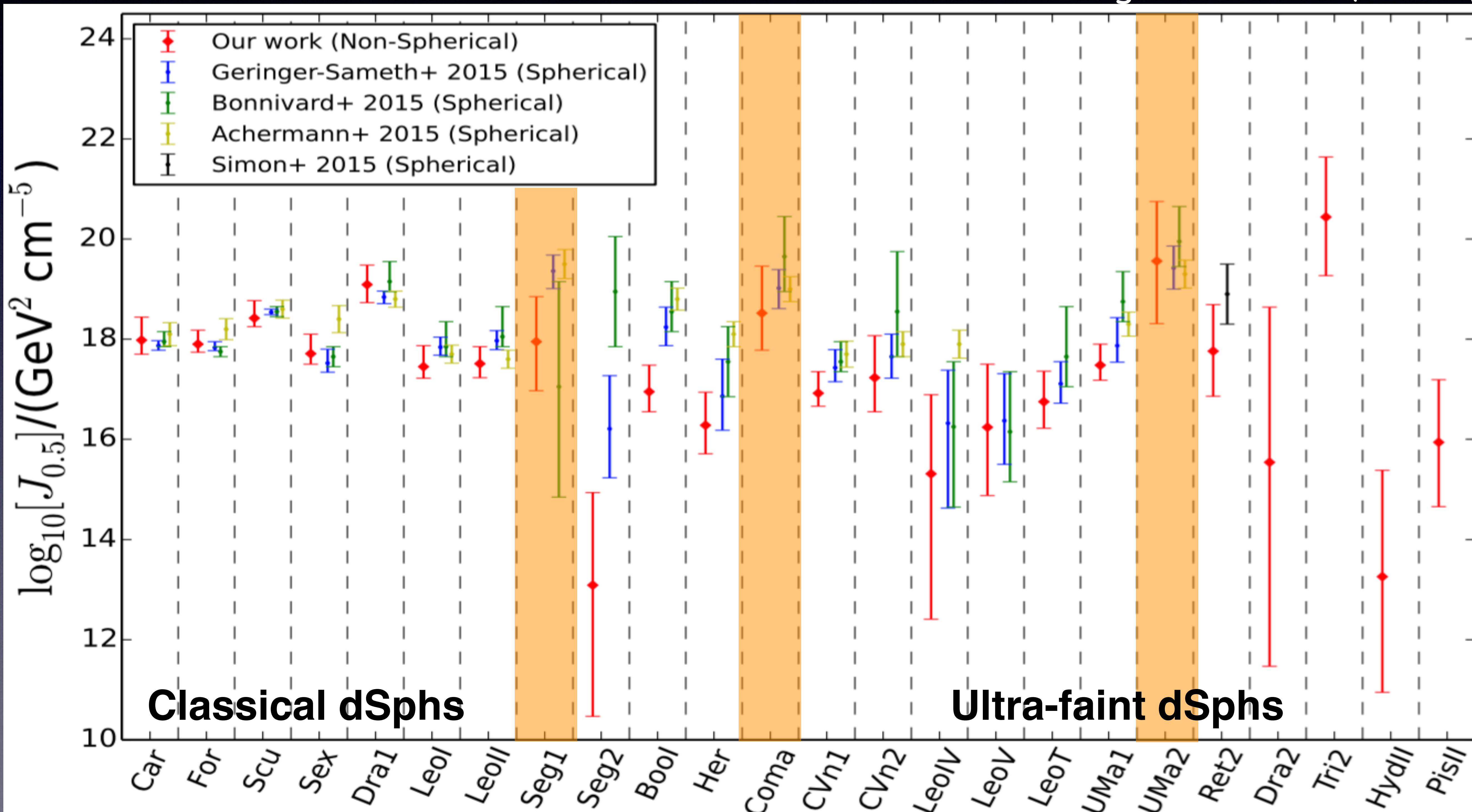
The most promising target: Ultra-faint dwarf galaxy

McConnachie et al. (2012)



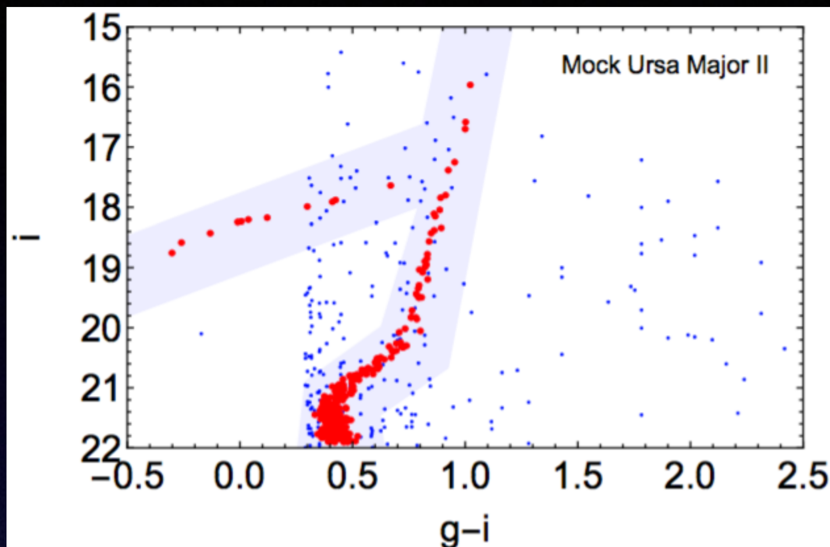
The most promising target: Ultra-faint dwarf galaxy

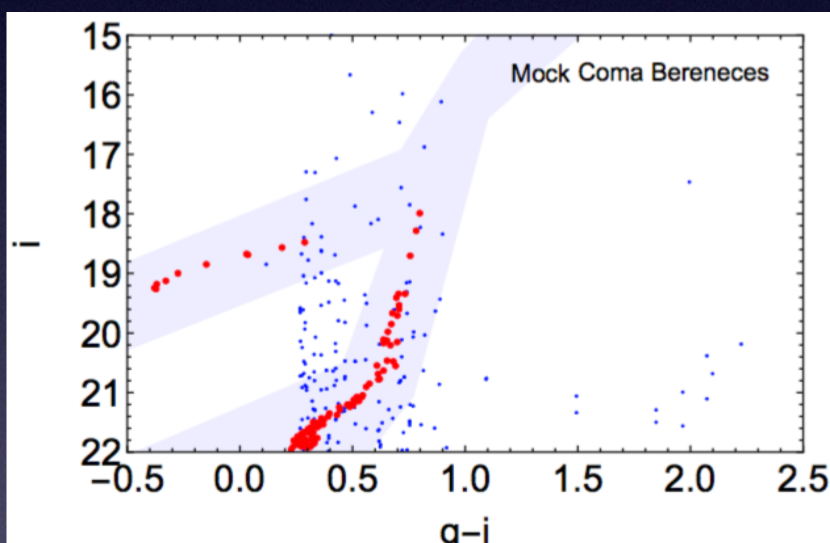
Hayashi et al. (2016)

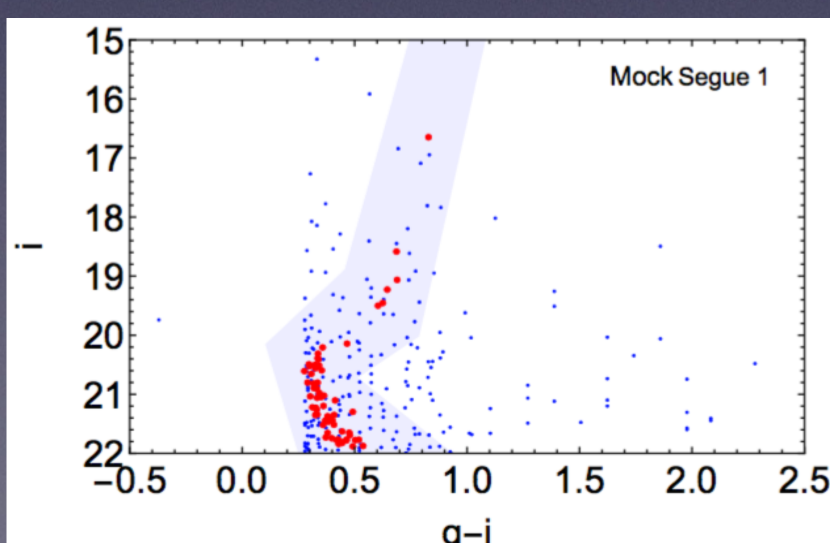


Data selection from mock data

Ichikawa (incl. KH) et al. (2017b)







※ i_{max} = 22 [mag] corresponds to the limiting magnitude of Subaru-PFS.

Condition			Raw		Naive cut	
dSph	θ_{ROI} [degree]	i_{max} [mag]	N_{Mem}	N_{FG}	N_{Mem}	N_{FG}
Ursa Major II	0.65	21	80	829	76	75
		21.5	150	988	141	103
		22	233	1149	214	132
Coma Berenices	0.65	21	35	579	34	58
		21.5	58	743	55	85
		22	92	898	85	110
Segue 1	0.65	21	26	585	23	65
		21.5	46	704	40	86
		22	66	922	58	130

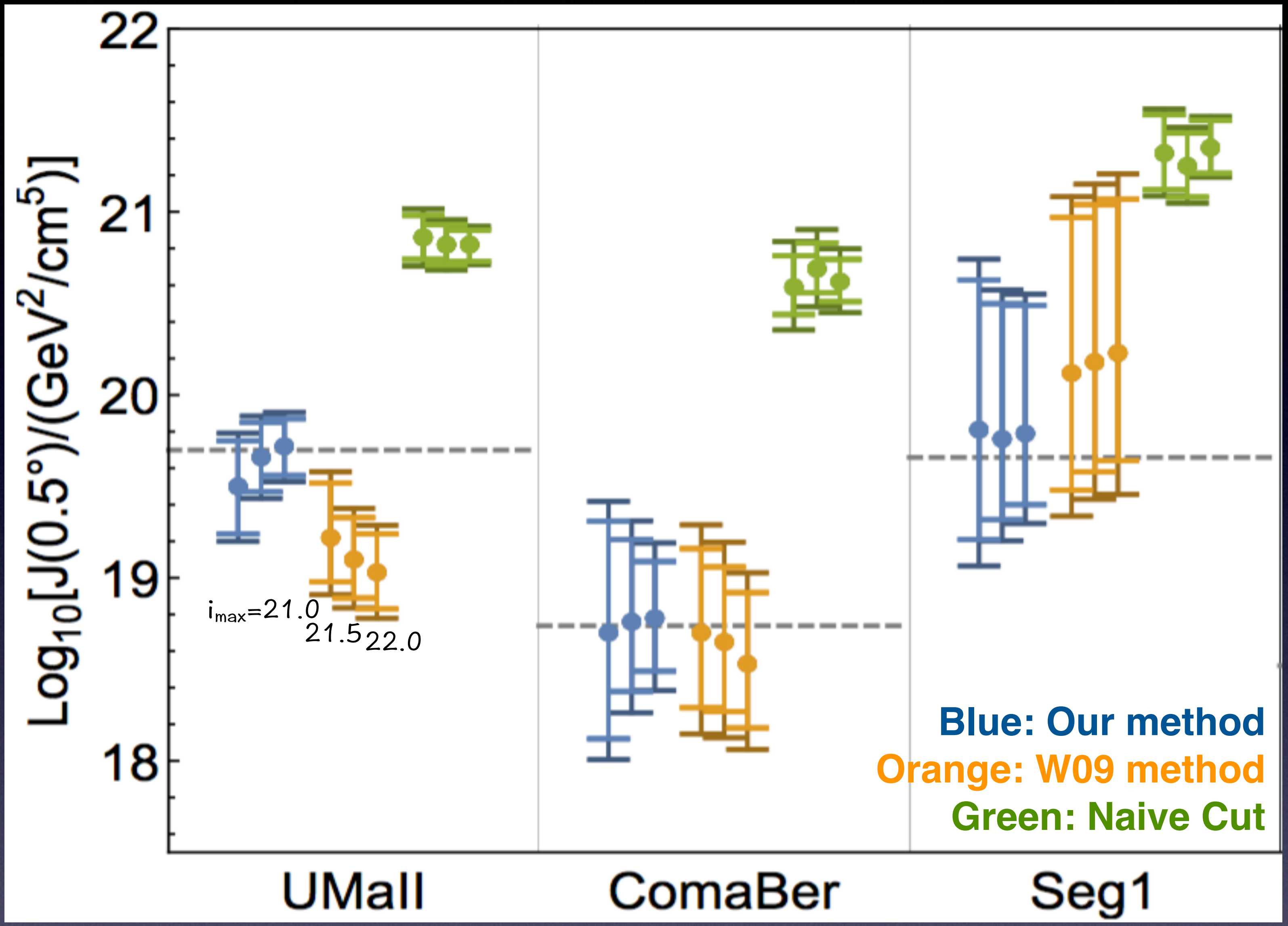
Raw: After CMD selection

Naive Cut: After CMD, [Fe/H], velocity, surface gravity

Although after doing "Naive Cut" selection, contamination stars still remain…

We inspect the effects of contaminations on J-factor values of UFD, using our new method and the previous method developed by Walker et al. (2009).

Foreground effect on the J-factor estimation



Our method:
considers distribution functions of FG stars as well as member stars.

Walker+'09 method:
assumes the constant velocity dispersion profile for the membership probability calculation.

Naive Cut:
selection from CMD, [Fe/H], velocity distribution, and surface gravity only.

- **Our method can treat correctly and statistically the effect of the foreground contamination for the observational data.**
- **It should become powerful tool for the J-factor estimate of the MW dSphs in the PFS-era and it is worthwhile to calculate the sensitivity of WIMP DM.**

Summary

- The MW dSphs, especially ultra-faint dwarfs, are ideal targets in the indirect dark matter searches.
- However, three major hidden systematic uncertainties are still remain.
- In order to reduce the foreground contamination, we develop a new likelihood method.
- Our method can treat correctly and statistically the effect of the foreground contamination for the observation data.
- The future investigation of the stellar kinematics via PFS will play a crucial role.

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