Future spectroscopic survey and dark matter constraints from dwarf spheroidal galaxies

(In preparation)

Koji Ichikawa

In collaboration with
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KAVLI IPMU

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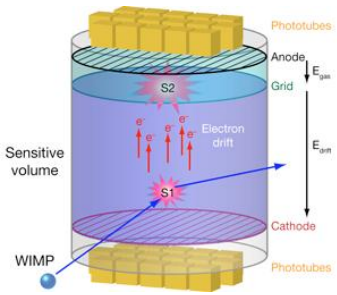
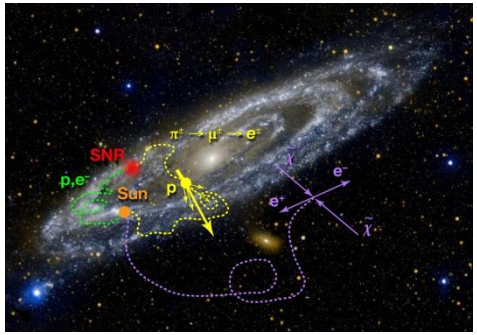
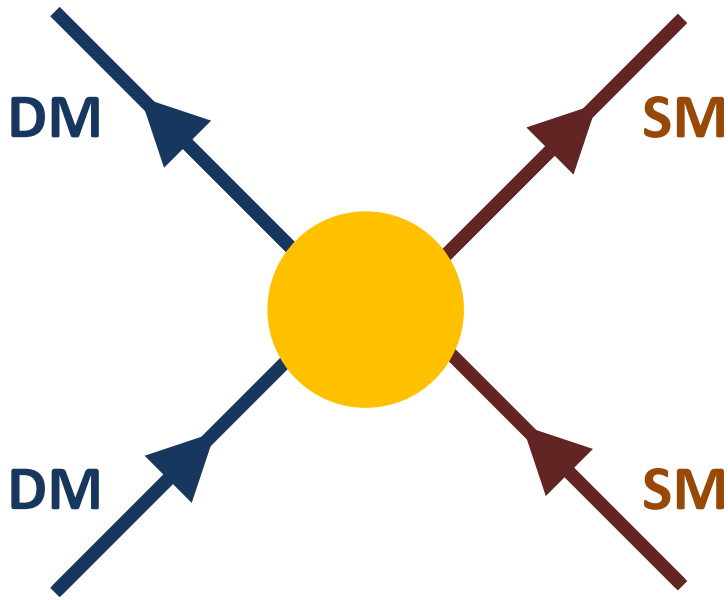
Dark Matter Search



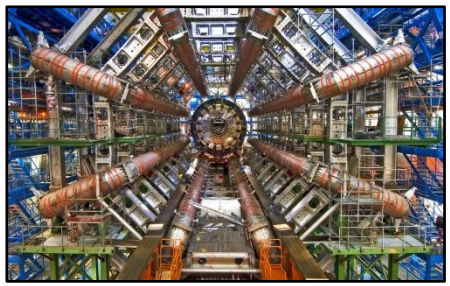
Indirect Detection



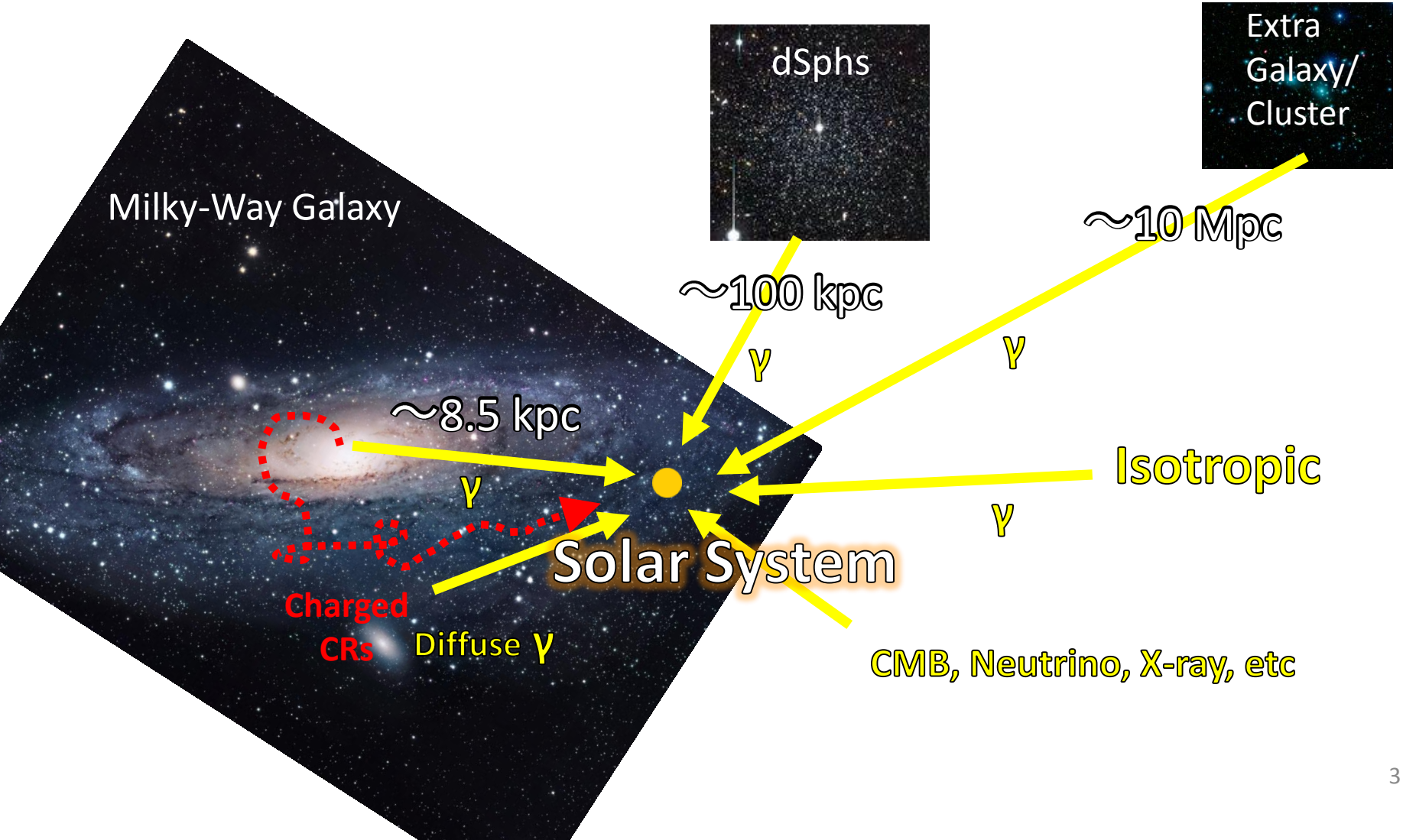
Direct Detection



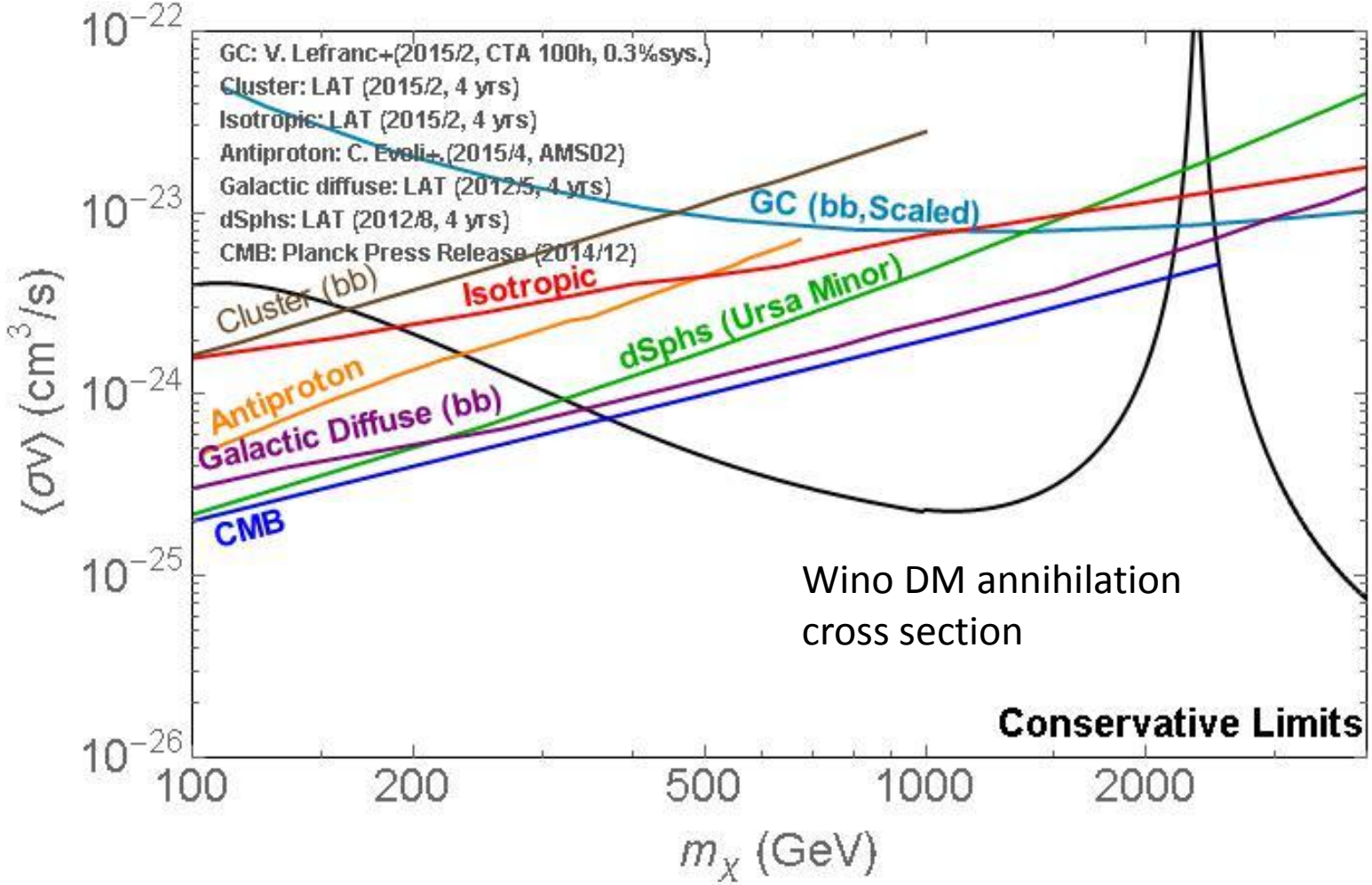
Collider Production



Signal Target



Current(slightly old) observational limit



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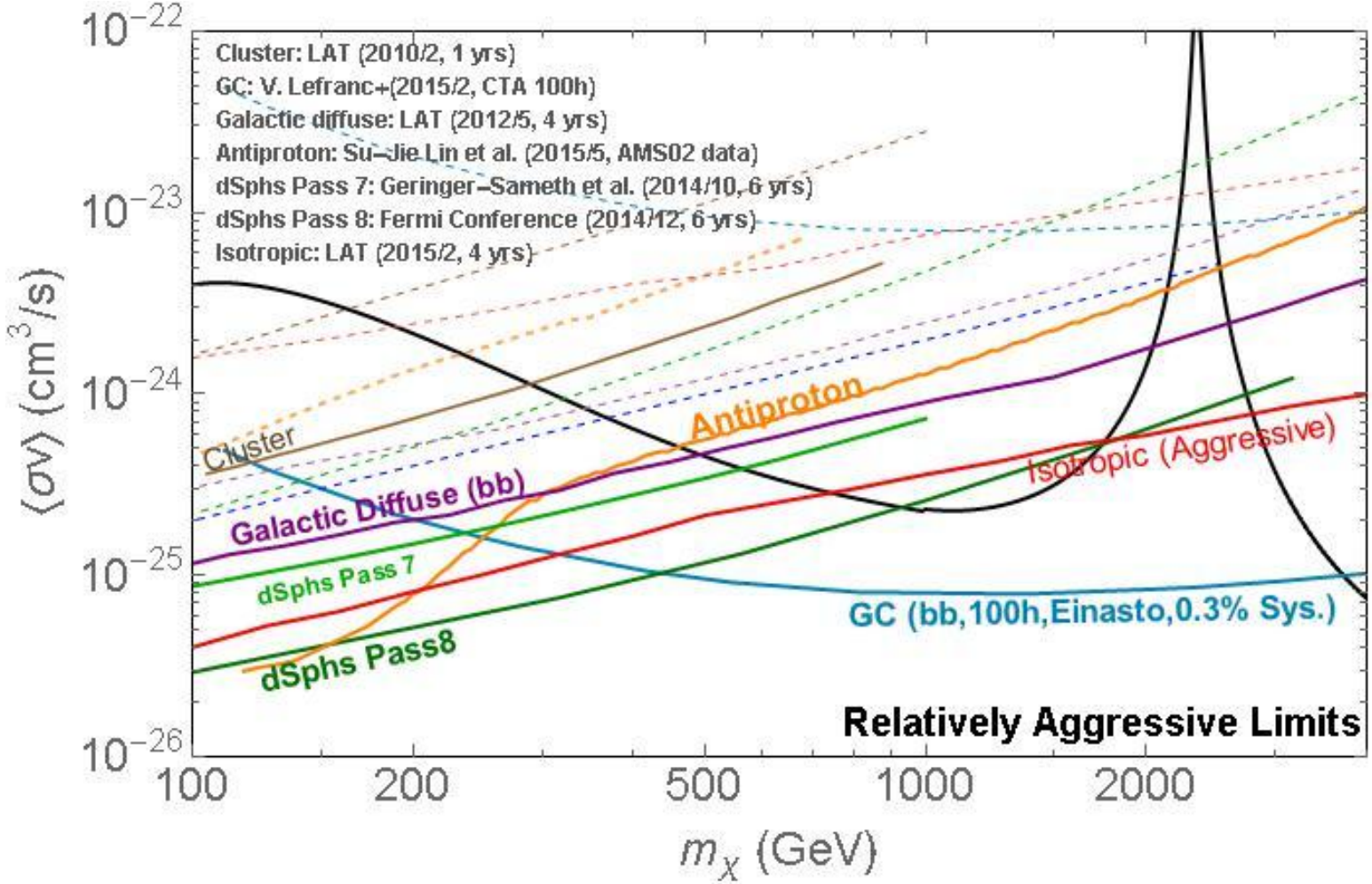

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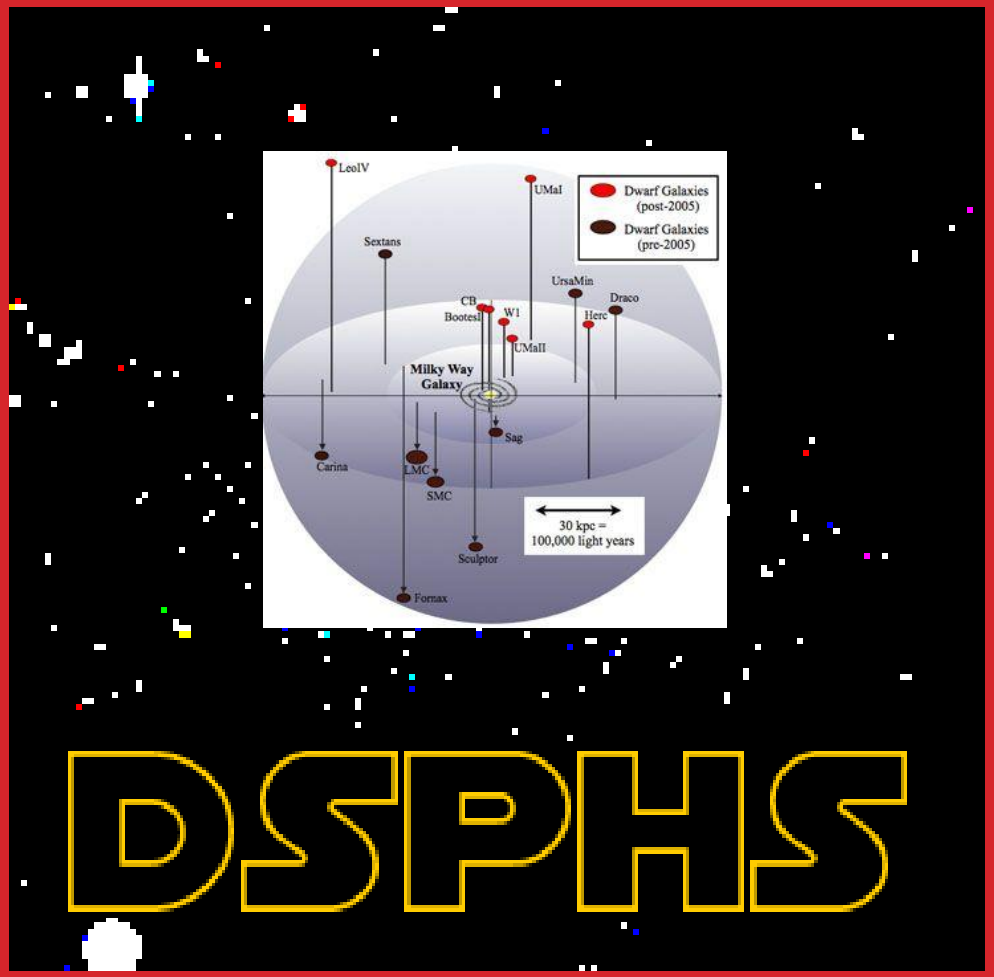
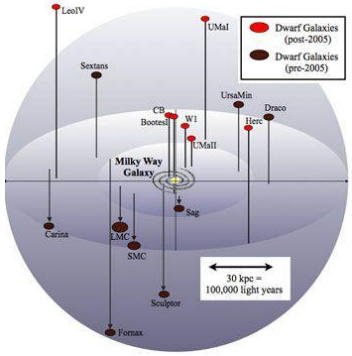


Dwarf spheroidal galaxies

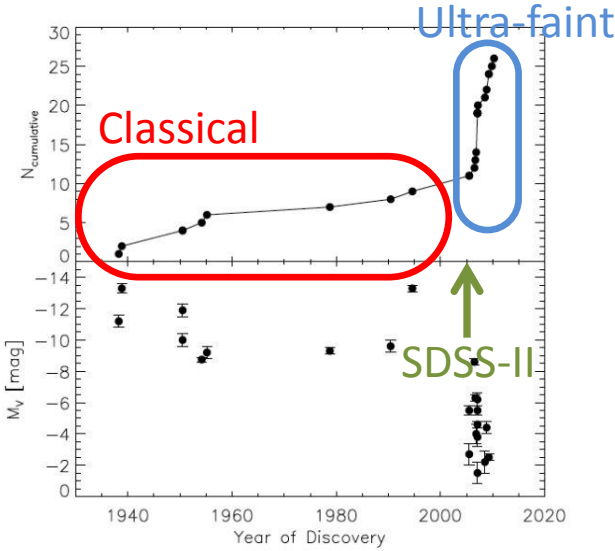
dSphs:

1. **Neighbor** galaxies: 10~100kpc
2. Large Mass to Luminosity ratio = **DM rich**
3. Fewer gas containment



	Classical	Ultra-faint
#dSphs	8	>20
M/L ($M_\odot/L_\odot$)	10-100	100-1000
Distance (kpc)	60-250	10-60
#Obs Stars	150-2500	20-100
Characteristics	Brighter, farther	Darker, closer

See, e.g. Wolf et al (2010)



arXiv:0908.2995v6 [astro-ph.CO]

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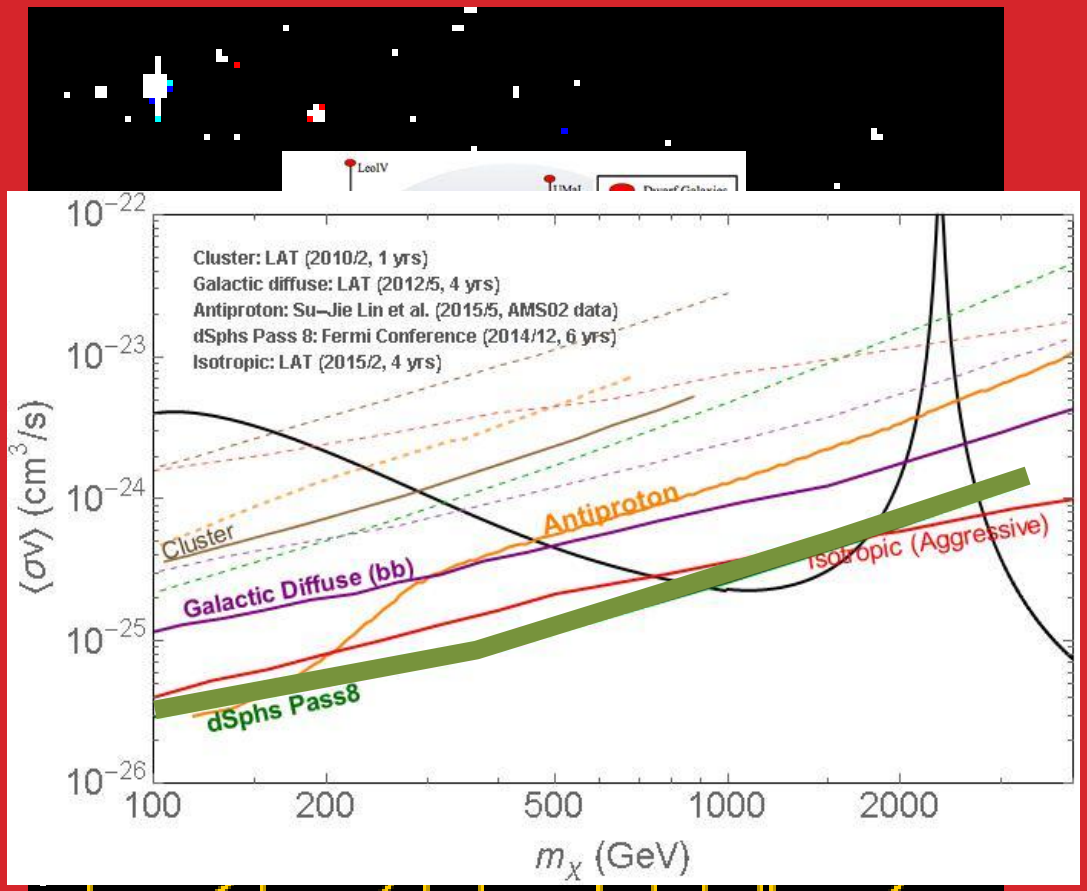

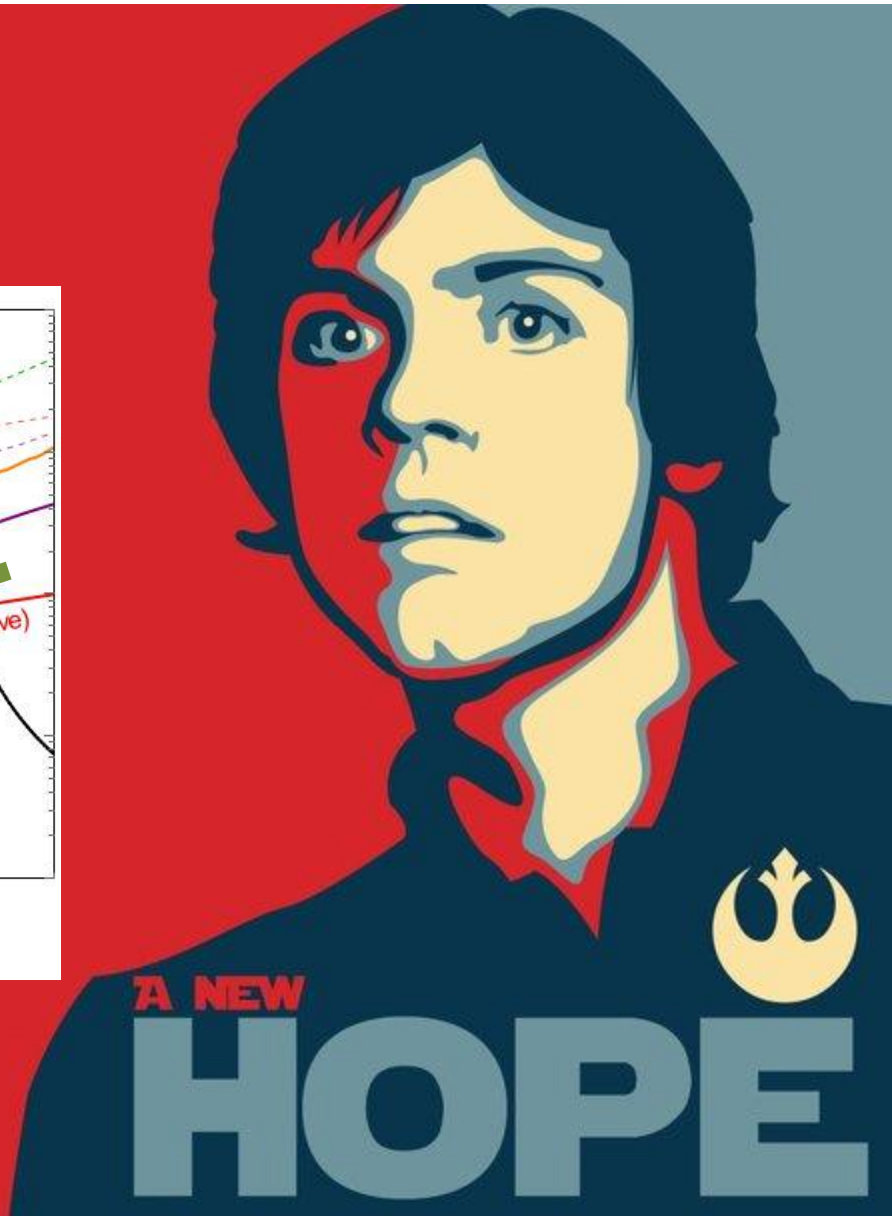

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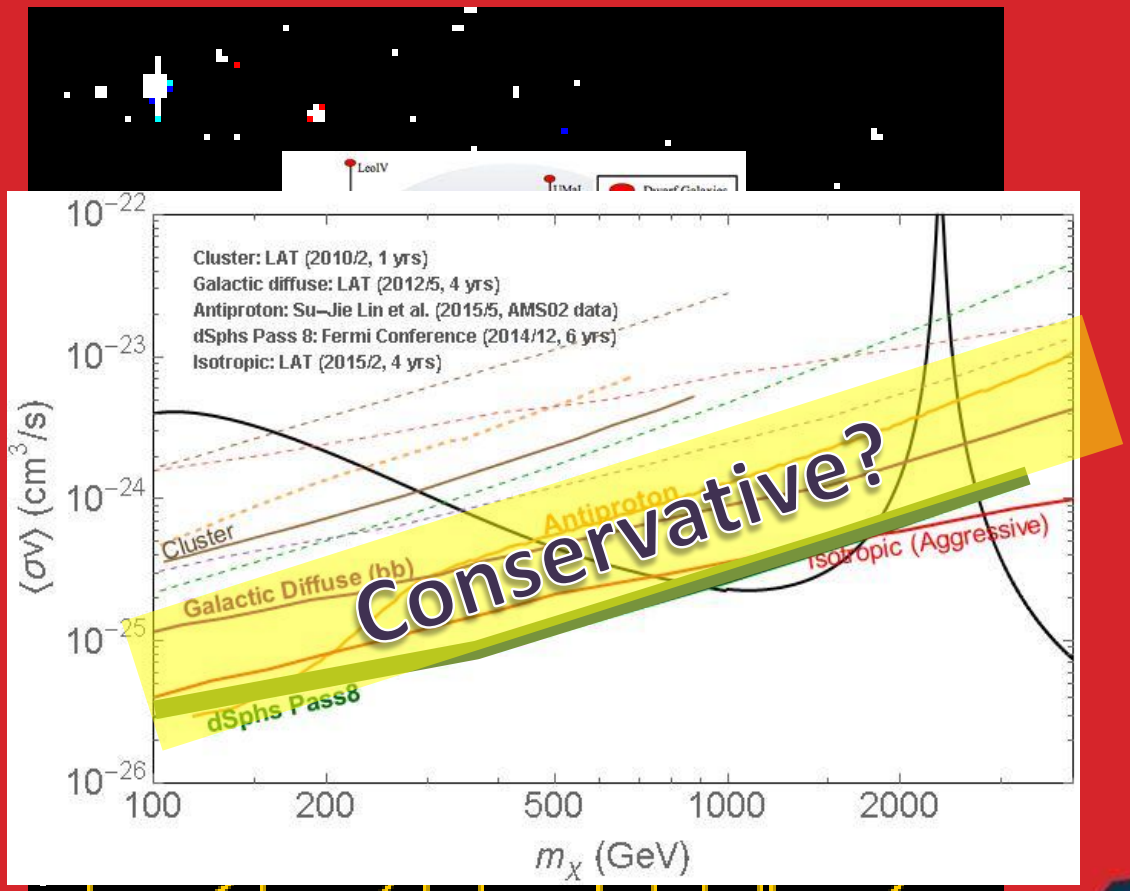
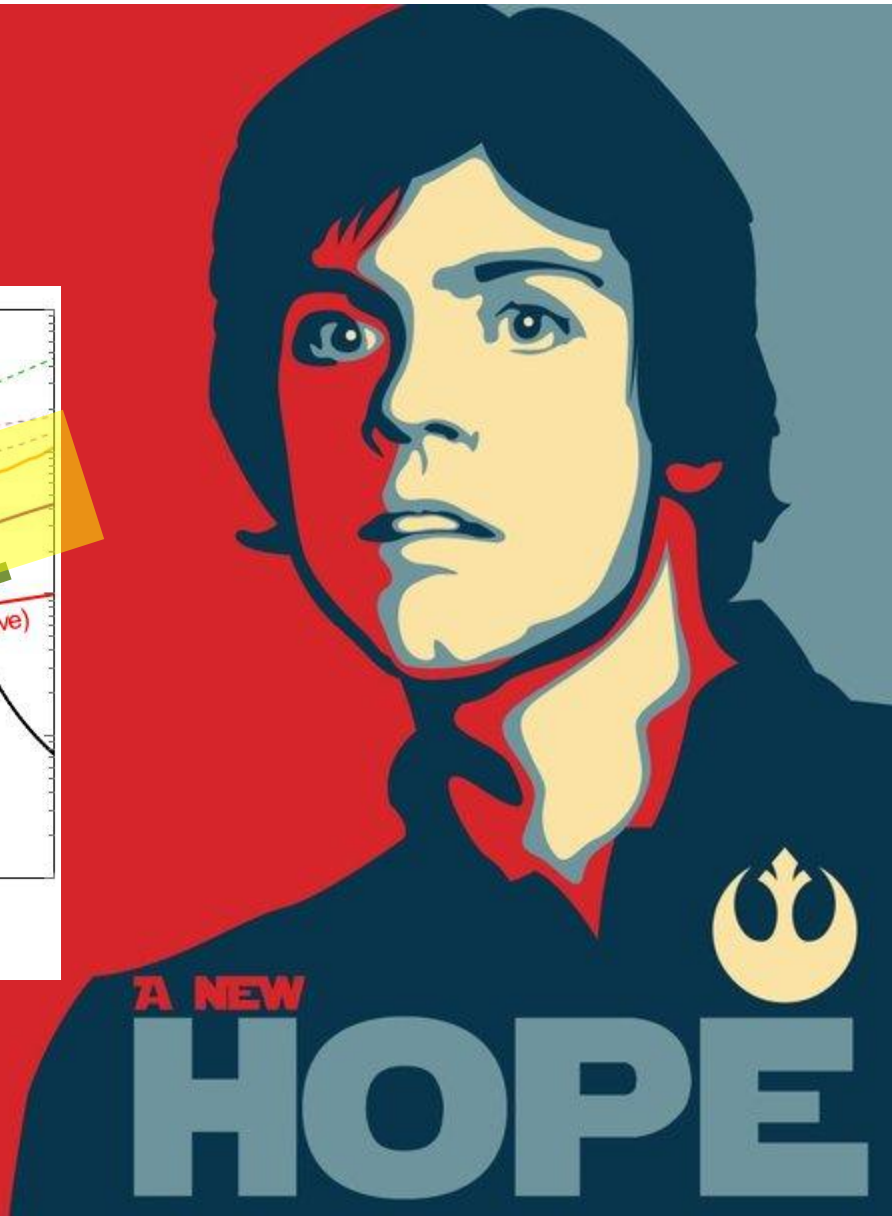




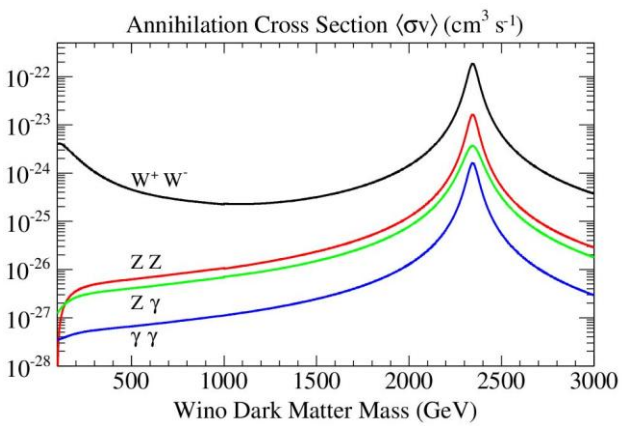
Signal Flux

$$\Phi(E,\Delta\Omega) = \left[\frac{\langle\sigma v\rangle}{8\pi m_{\tilde{w}}^2}\sum_f \mathrm{Br}(\tilde{w}^0\tilde{w}^0 \to f)\left(\frac{dN_\gamma}{dE}\right)_f\right]\left[\int_{\Delta\Omega} d\Omega \int_{l.o.s.} dl\, \rho^2(l,\Omega)\right]$$

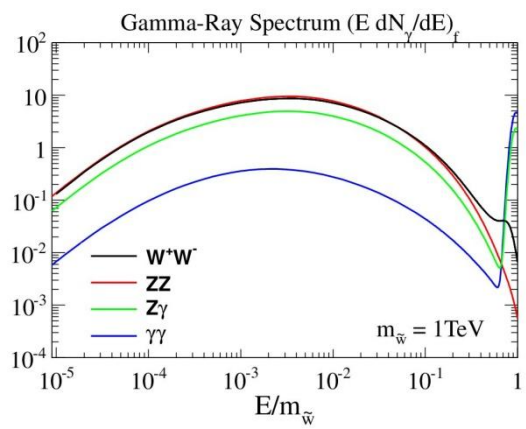
Particle Physics Factor

Astrophysics Factor (J-factor)

$f = WW, ZZ, \gamma\gamma, Z\gamma$ Error: 1-10 % level



Hryczuk and Iengo (2012)
arXiv:1111.2916v4 [hep-ph]



Cirelli et al. (2012)
arXiv:1012.4515 [hep-ph]

Large uncertainty:
Next Slide

$$J \simeq \frac{1}{D^2}\int_{\mathrm{Vol}} r^2\rho^2(r)\mathrm{d}r$$

Astrophysical Factor

DM Density profile

$$\rho(r) = \rho_s \left(r/r_s\right)^{-\gamma} \left[1 + \left(r/r_s\right)^{\alpha}\right]^{(\gamma-\beta)/\alpha}$$

$\rho_s (r/r_s)^{-1}(1+r/r_s)^{-2}$ Cusp

$\rho_s (1+r/r_s)^{-1}(1+r/r_s)^{-2}$ Cored

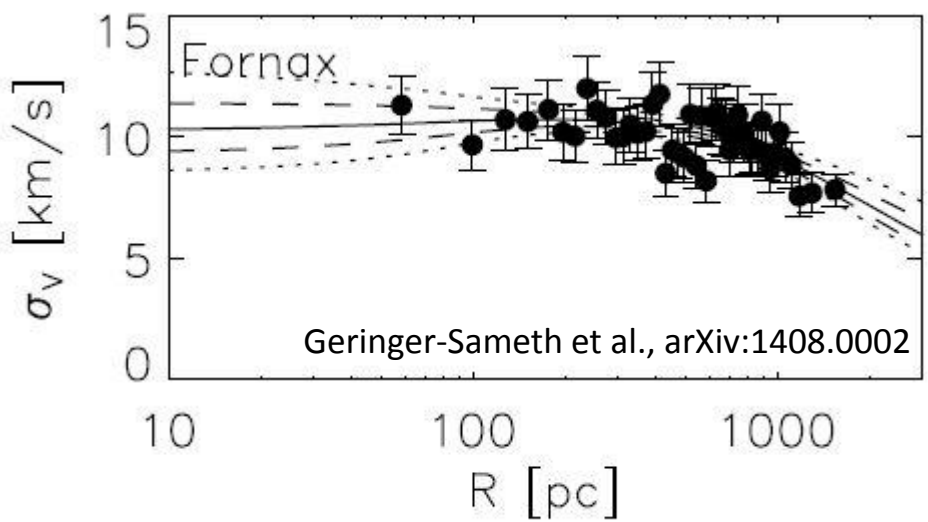
Stellar Density Profile: v(r)

Jeans equation for stars

$$\frac{1}{\nu}\frac{d}{dr}(\nu \bar{v_r^2}) + 2\frac{\beta(r)\bar{v_r^2}}{r} = -\frac{GM(r)}{r^2}$$

$\sigma_{\text{l.o.s}}^{2\,(\text{Theory})}$ ⟷ $\sigma_{\text{l.o.s}}^{2\,(\text{obs})}$

Fit



Geringer-Sameth et al., arXiv:1408.0002

$$P(\theta|D) \propto P(D|\theta)P(\theta)$$

$$\sim \prod_{i}^{\text{samples}} \exp\left[-\frac{(\sigma^2_{\text{obs}}(r_i) - \sigma^2_{\text{theory}}(r_i,\theta))^2}{2\delta^2}\right]$$

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Fit

		long. (deg.)	lat. (deg.)	dist. (kpc)	α_s (deg.)	$\log_{10}[J(0.5°)/(\text{GeV}^2\text{cm}^{-5}\text{sr})]$
Classical: Well-determined	Draco	86.4	34.7	76	$0.25^{+0.15}_{-0.09}$	18.8 ± 0.16
	Ursa Min.	105.0	44.8	76	$0.32^{+0.18}_{-0.12}$	18.8 ± 0.19
	Sculptor	287.5	-83.2	86	$0.25^{+0.25}_{-0.13}$	18.6 ± 0.18
	Sextans	243.5	42.3	86	$0.13^{+0.07}_{-0.05}$	18.4 ± 0.27
Ultra-faint: Not well-determined. Prior dependence	Segue 1	220.5	50.4	23	$0.40^{+0.86}_{-0.27}$	19.5 ± 0.29
	Ursa Maj. II	152.5	37.4	32	$0.32^{+0.48}_{-0.19}$	19.3 ± 0.28
	Willman 1	158.6	56.8	38	$0.25^{+0.54}_{-0.17}$	19.1 ± 0.31
	Coma B.	241.9	83.6	44	$0.25^{+0.54}_{-0.17}$	19.0 ± 0.25

Conservative?

Hidden Systematics…

- **Prior Bias?/Cut?**

$$P(\theta|D) \propto P(D|\theta)P(\theta)$$

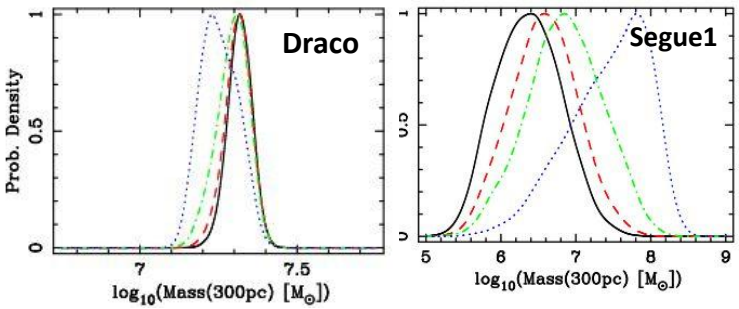
$$\sim \prod_i^{\text{samples}} \exp\left[-\frac{(\sigma^2_{\text{obs}}(r_i) - \sigma^2_{\text{theory}}(r_i,\theta))^2}{2\delta^2}\right]$$

ex: $P(v_{\max}) \propto v_{\max}^{-n} dv_{\max}$

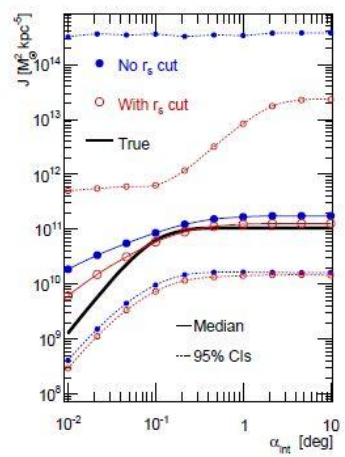
- Non Spherical?

=> 0.2〜0.4 uncertainty

- Foreground Contamination?
- Member Star Sampling Bias?



Martinez et al., arXiv: 0902.4715



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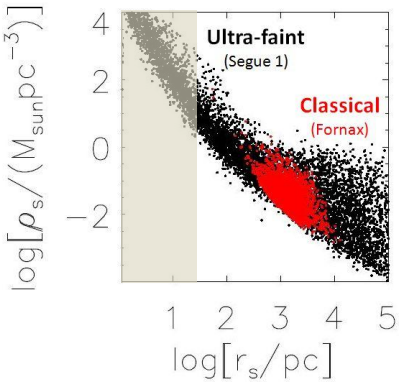

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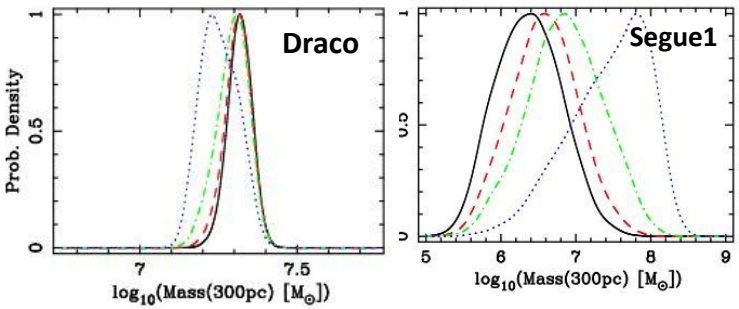

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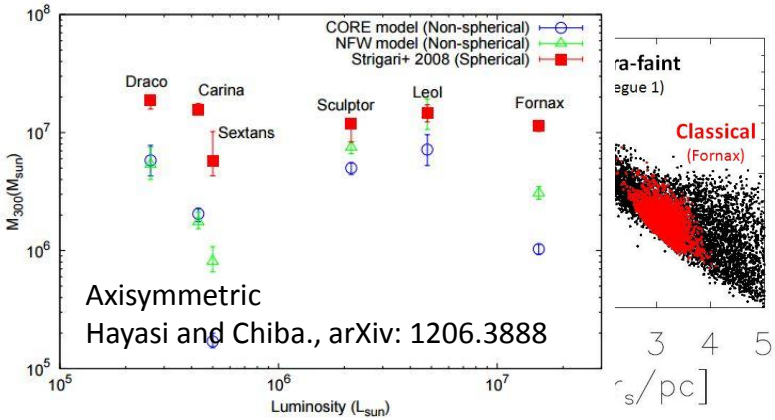

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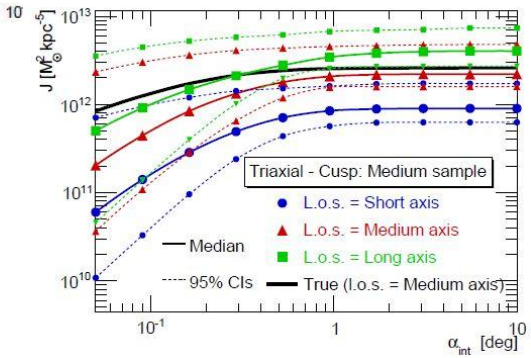

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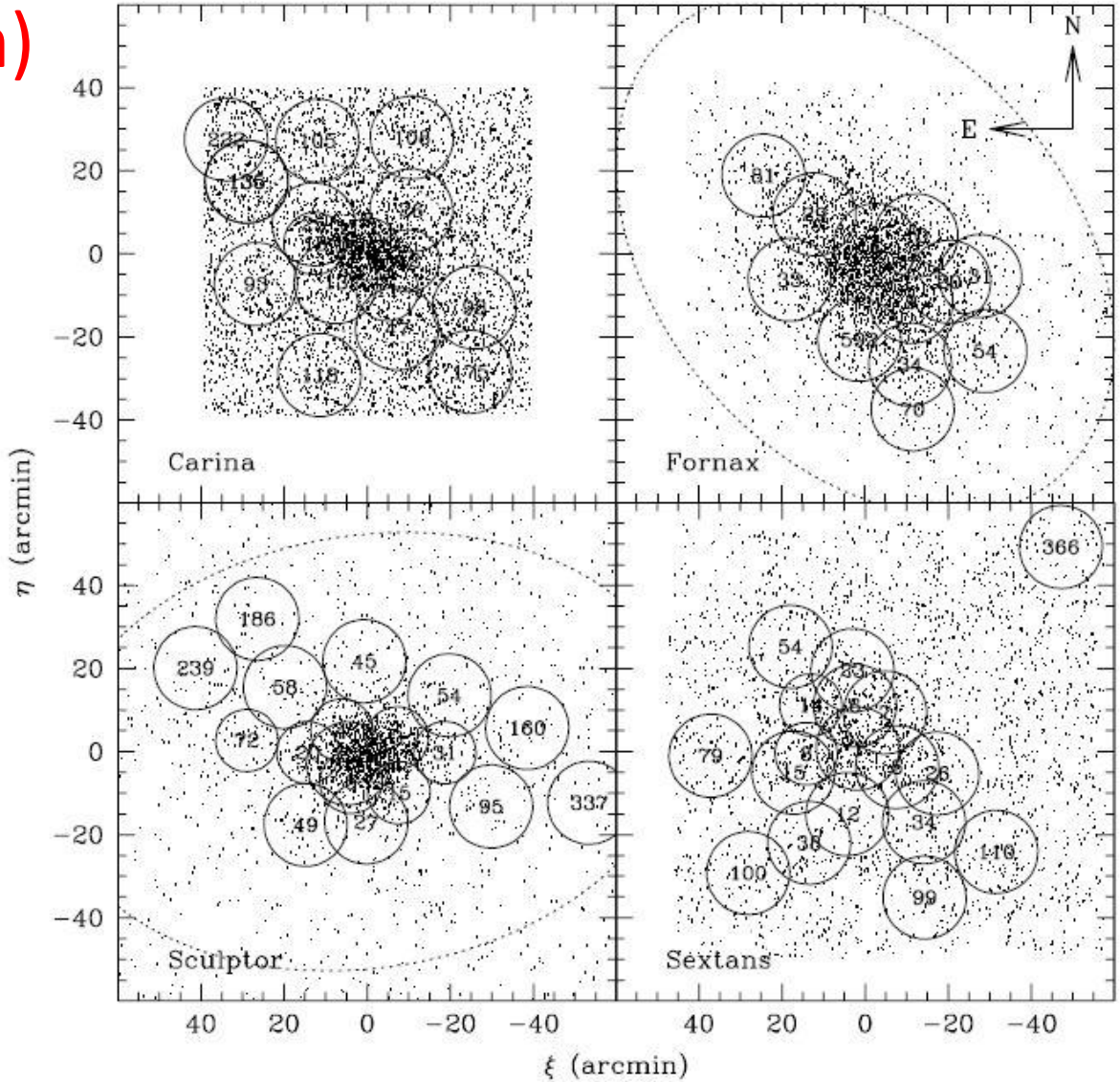
Prime Focus Spectroscopy

FoV 1.3 deg (diam)
with 2394 Fiber



MMFS (M. G. Walker et al,. (2007))

Prime Focus Spectroscopy

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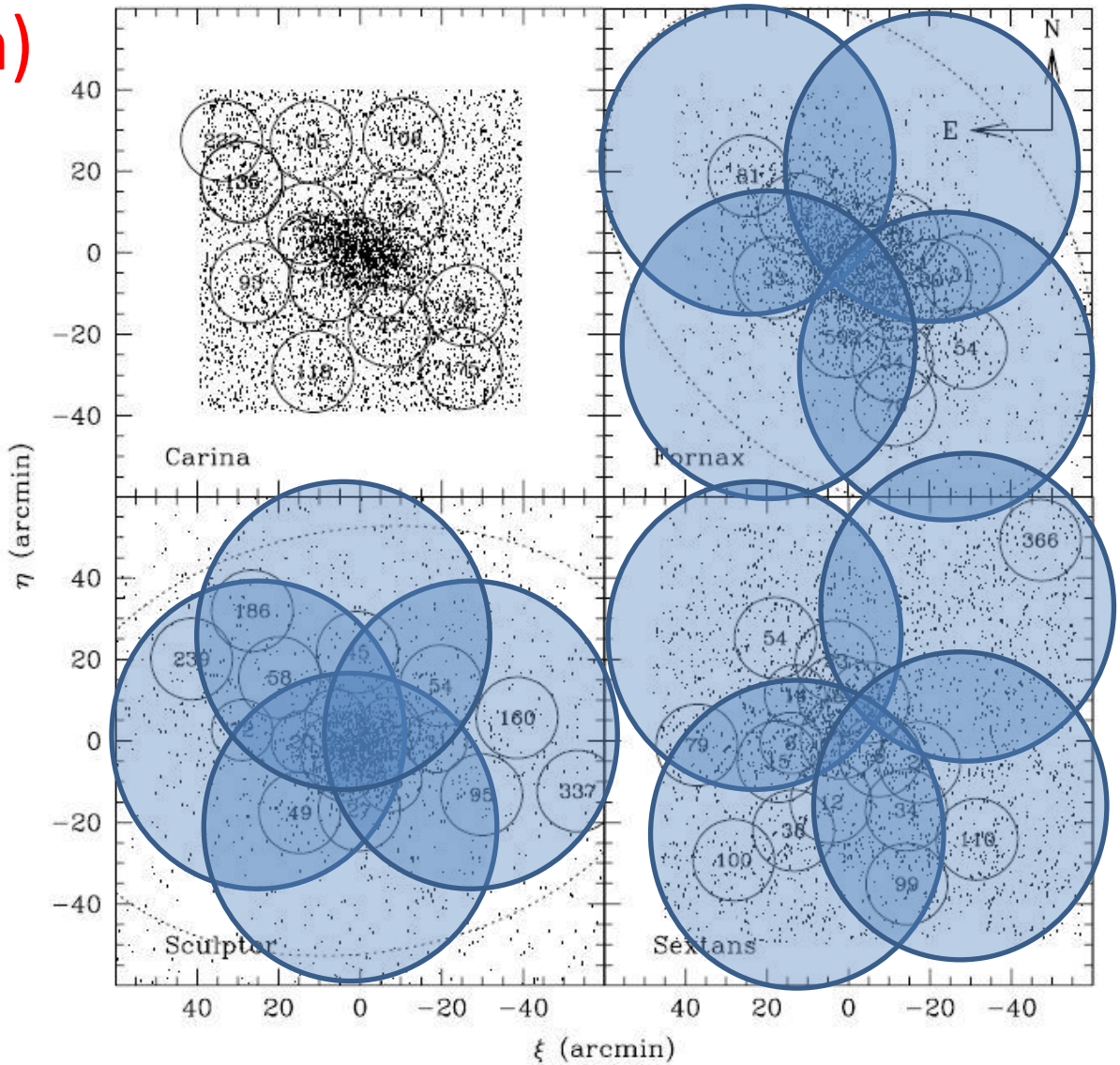

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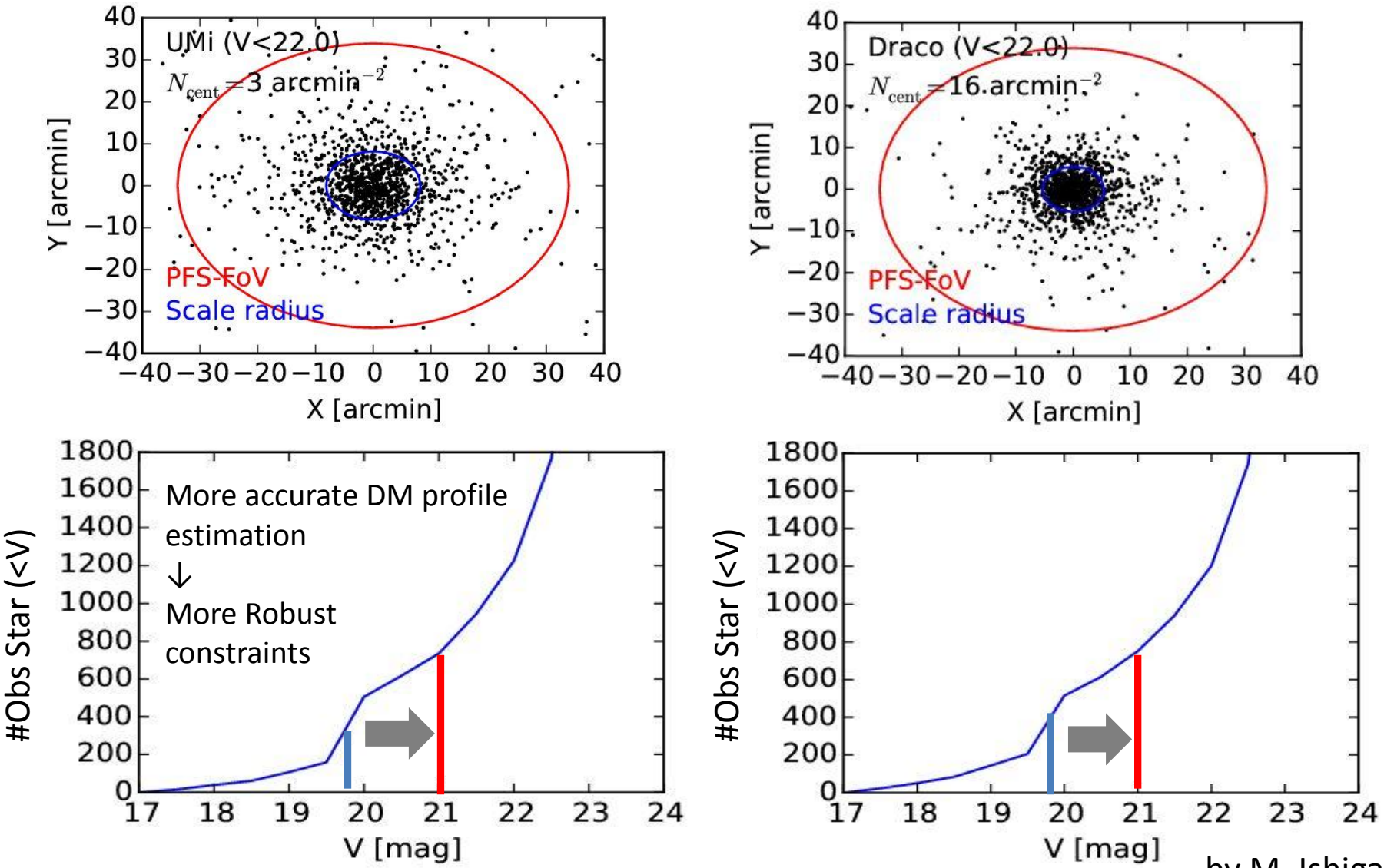


by M. Ishigaki

Strategy

1. Mock Observable:

(R, v, Metalicity, Luminosity)

= dSph Stellar + Foreground

dSph Stellar Mock

⇒Boltzmann Equation under DM profile

Foreground Mock

⇒Besancon Model (Robin+ (2003))

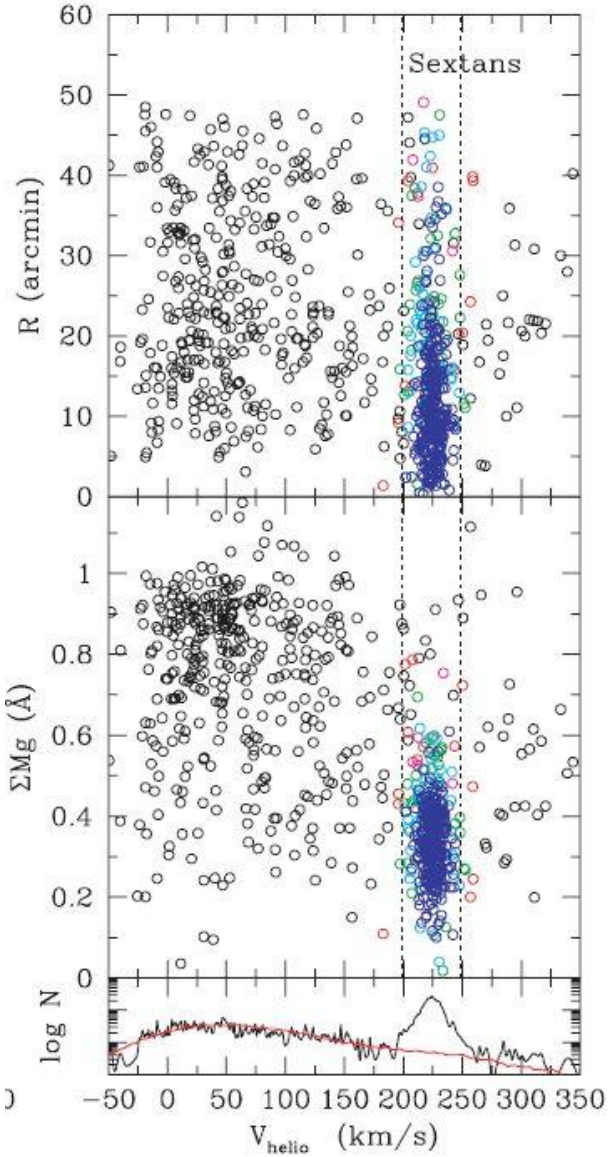
2. Detector Convolution:

⇒1. fix: dv = 3.0km/s

3. Fit:

(DM profile, anisotropy, dSph stellar profile, dSph v, foreground norm + metalicity)

⇒Fit to (v, r) probability density.



Walker+, AJ 137 (2009)

Stra

1. Mod

(R, v, M

= dSph S

dSph Stella

⇒Bolt

Foregroun

⇒Besa

2. Dete

⇒1. fix: dv

3. Fit:

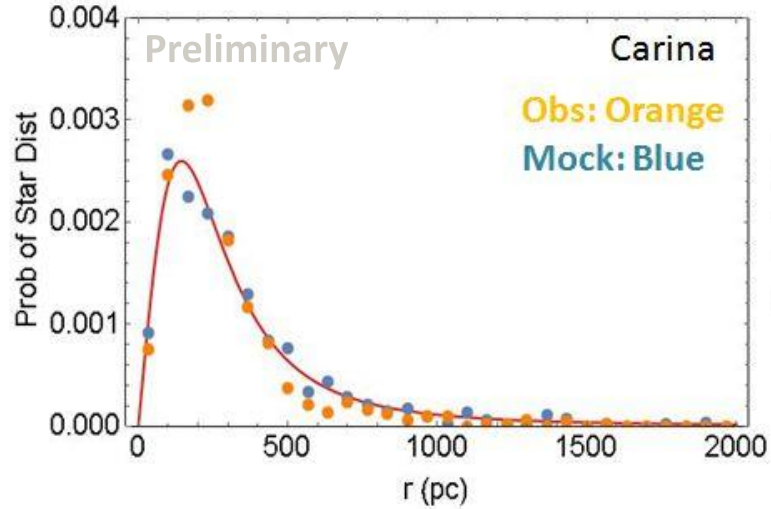
(DM prof

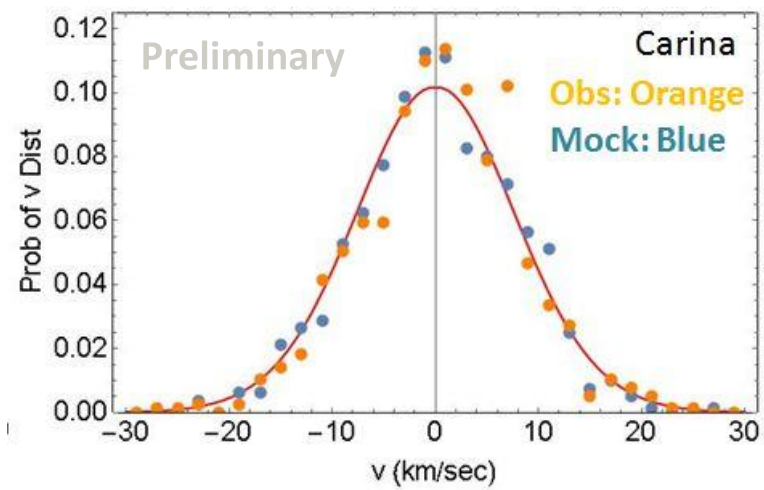
dSph v, f

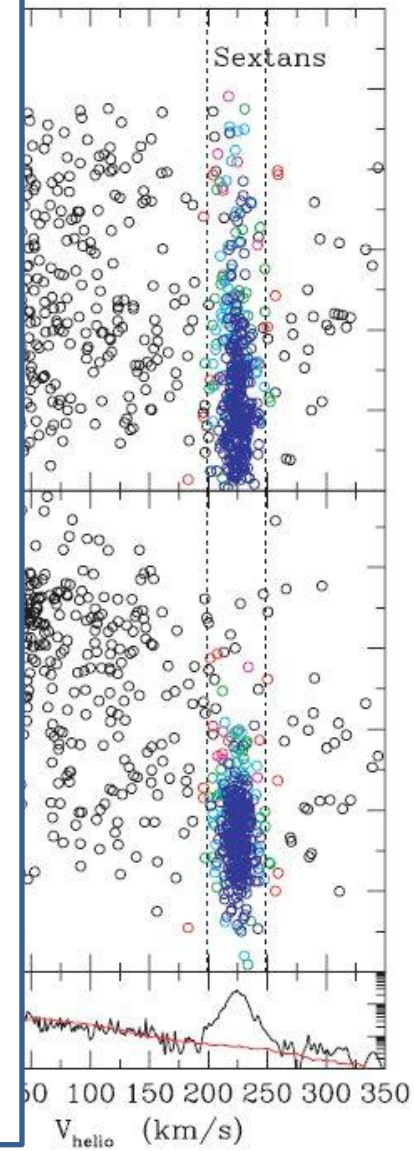
⇒Fit to

1. Mock Samples

$\rho_{DM}(r)$, $v_{star}(r)$ => $f(r,v)$ Cuddeford (1991)







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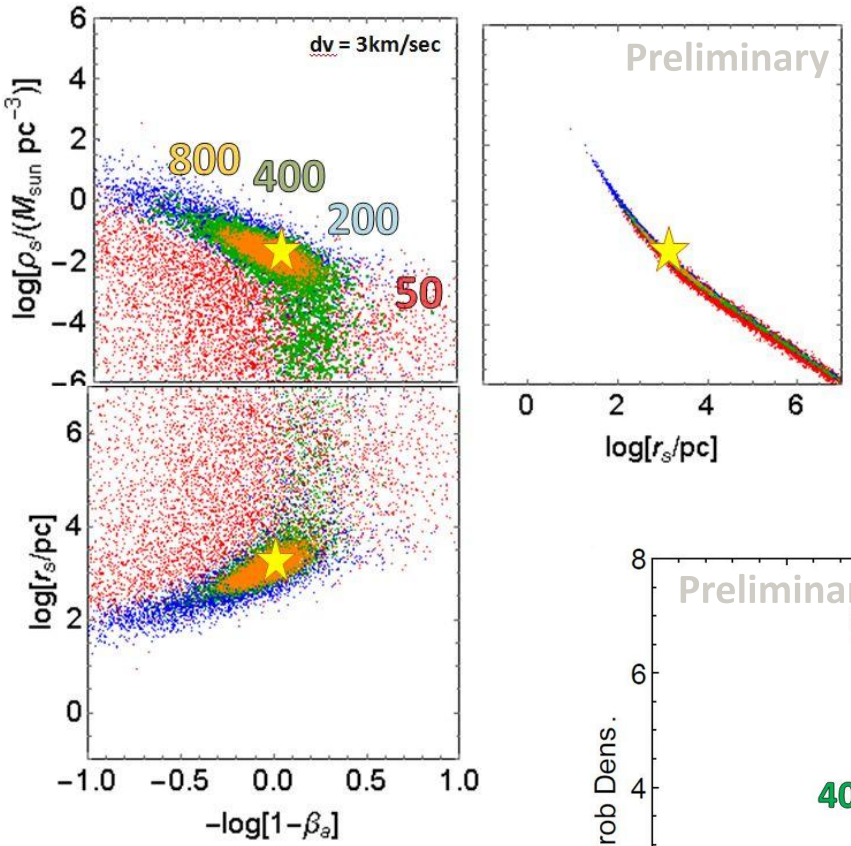
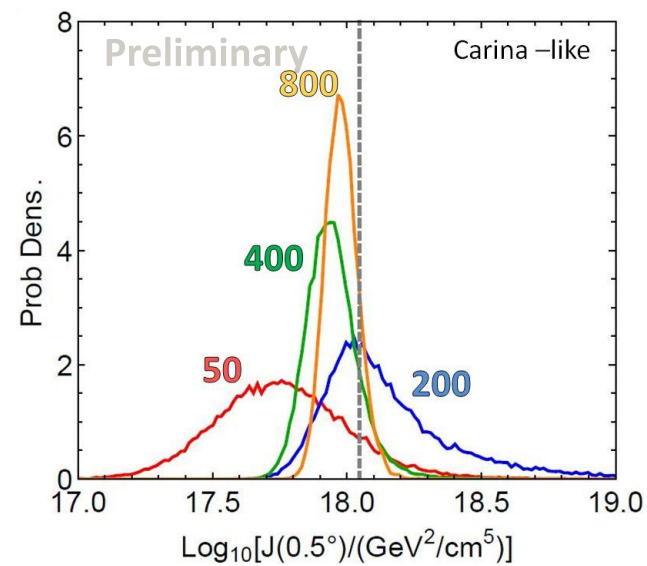
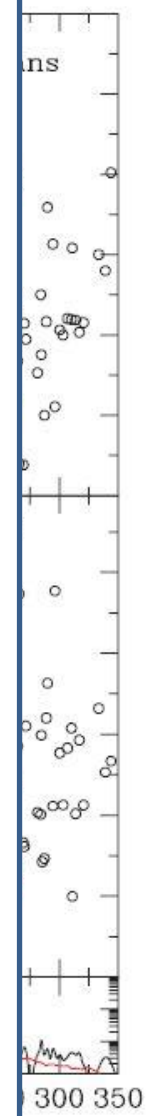
Fit without Foreground







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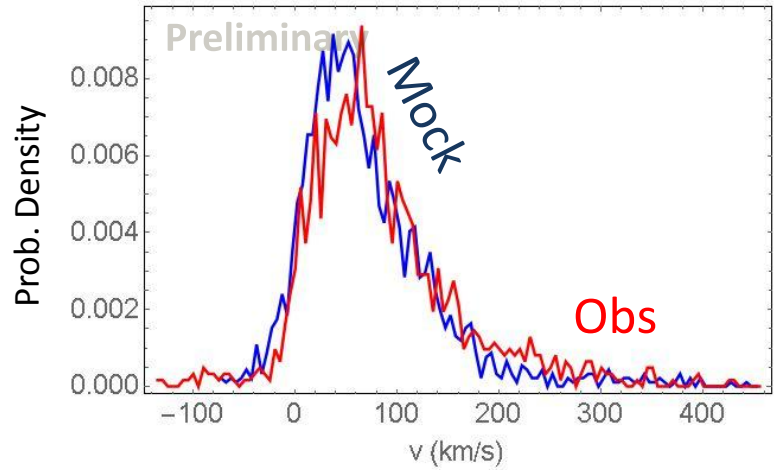
Besancon Model

Robin+ (2003)



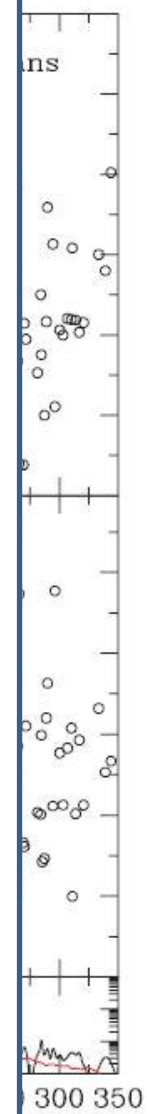
3. Fit

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

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

$$f_{\rm Mem}(v, R) = \frac{2\pi R \Sigma(R)}{\sqrt{2\pi\sigma^2(R)}} e^{-\frac{(v-v_{\rm Mem})^2}{2\sigma^2(R)}}$$

$$f_{\rm FG}(v, R) = 2\pi R N e^{-\frac{(v-v_0)^2}{2(\sigma_0(v-v_0)+\sigma_1)^2}}$$



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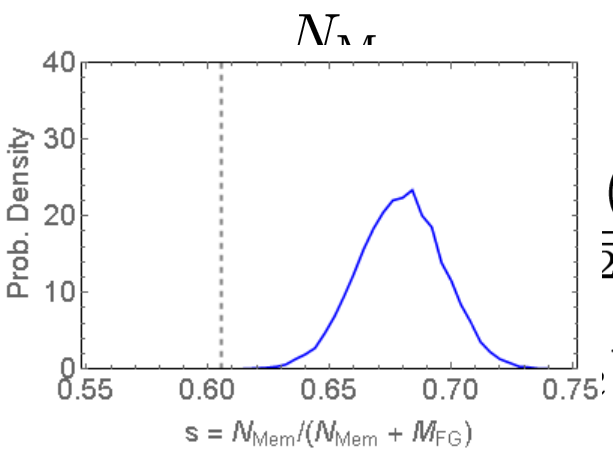
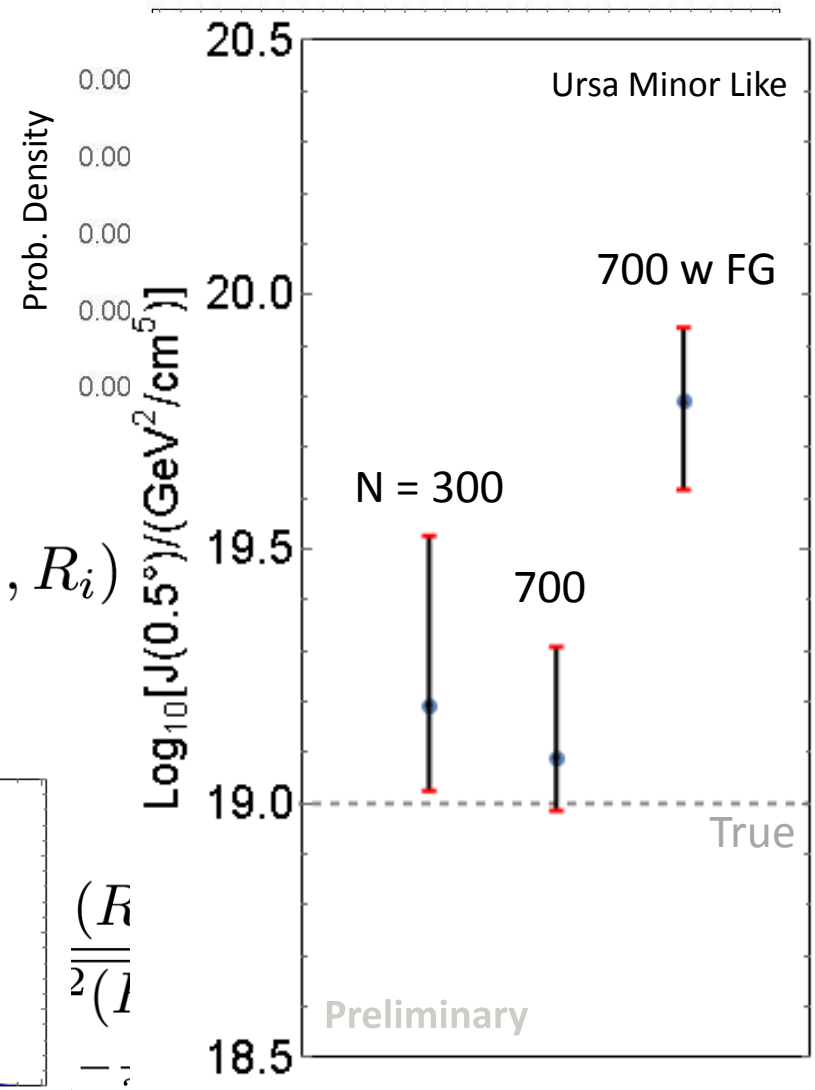
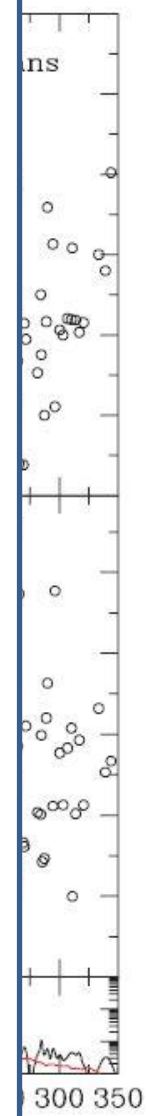


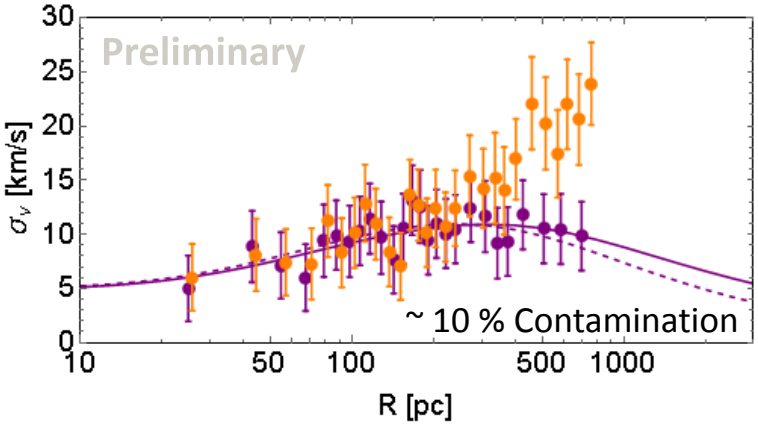




Walker+, AJ 137 (2009)

Foreground Contamination

Outer Region = FG dominant



How to Reduce FG stars?

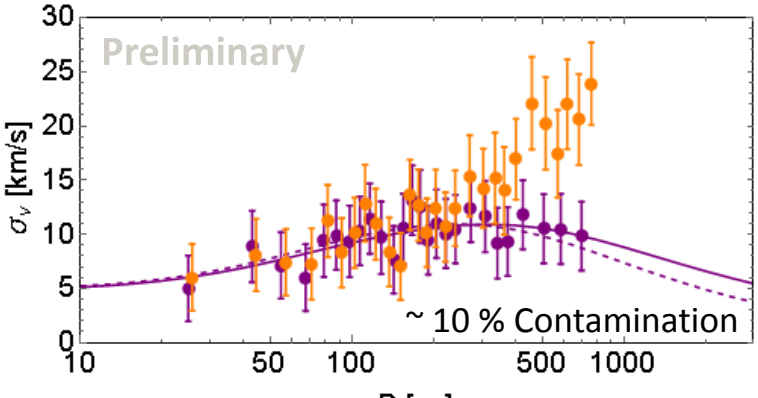
Cut:

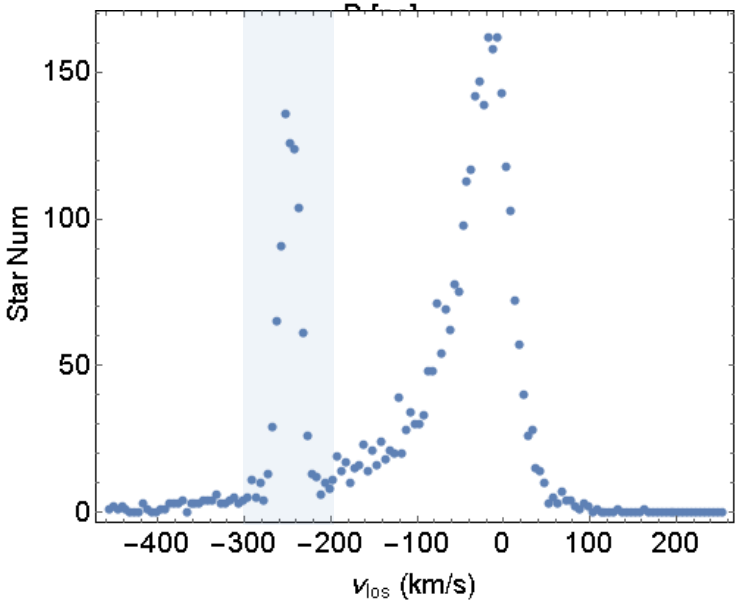
1. Velocity … The most effective
2. Color… Not Bad
3. Chemical Component… Degenerate
4. Others?

Foreground Contamination

Outer Region = FG dominant

How to Reduce FG stars?





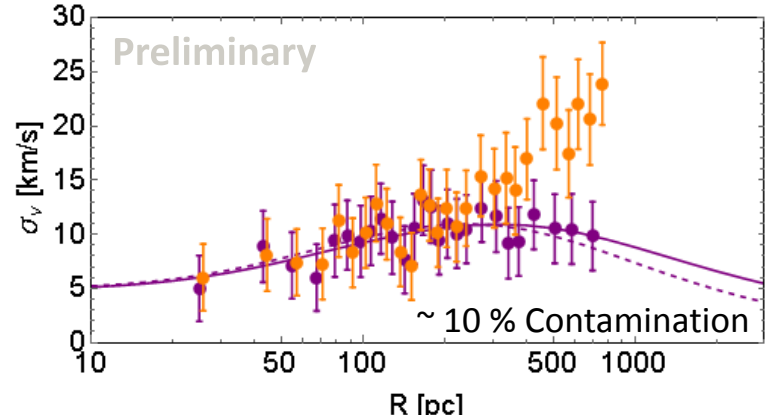
<u>Cut:</u>

1. Velocity … The most effective
2. Color… Not Bad
3. Chemical Component… Degenerate
4. Others?

Foreground Contamination

Outer Region = FG dominant

How to Reduce FG stars?



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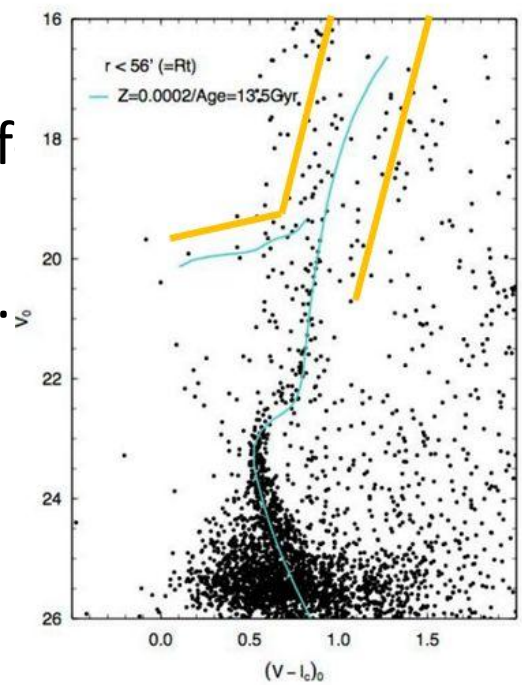

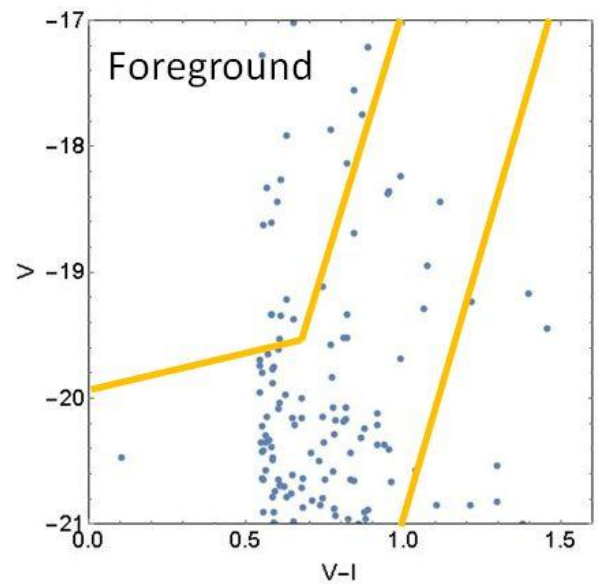

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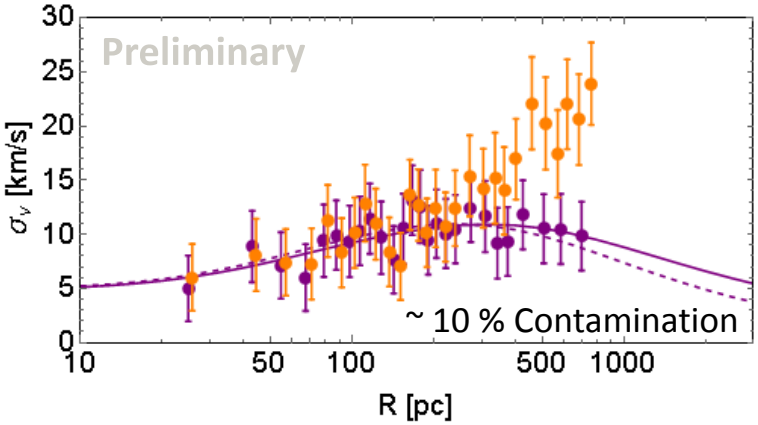
How to Reduce FG stars?



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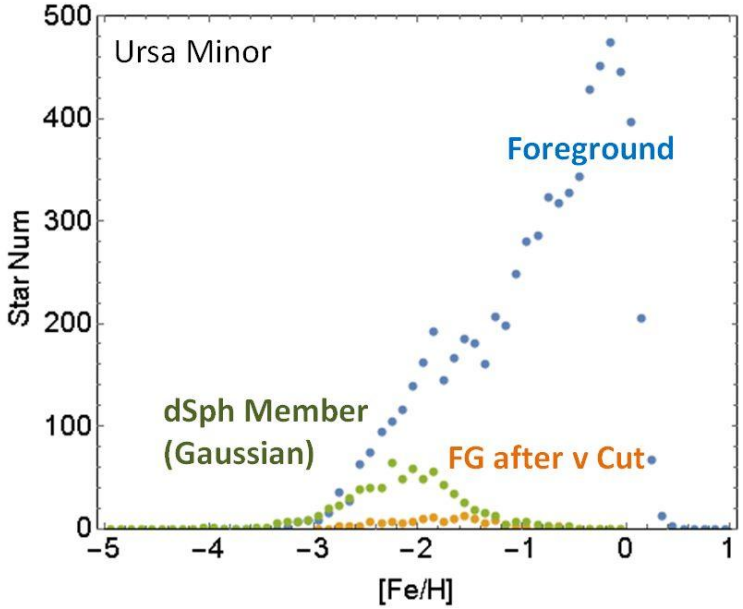

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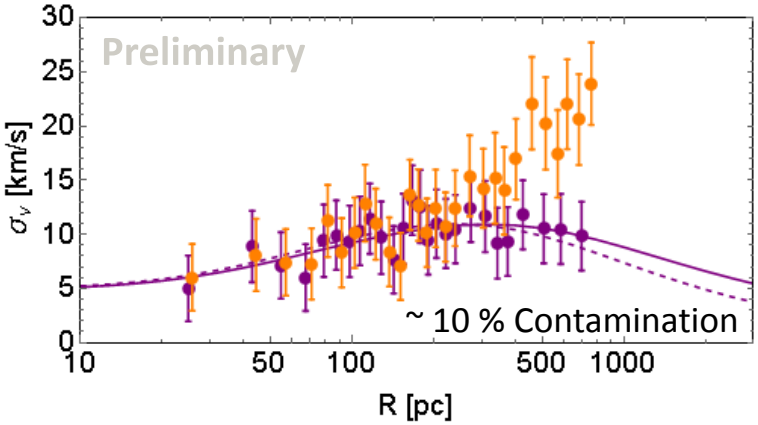

Coming Soon!

Cut:

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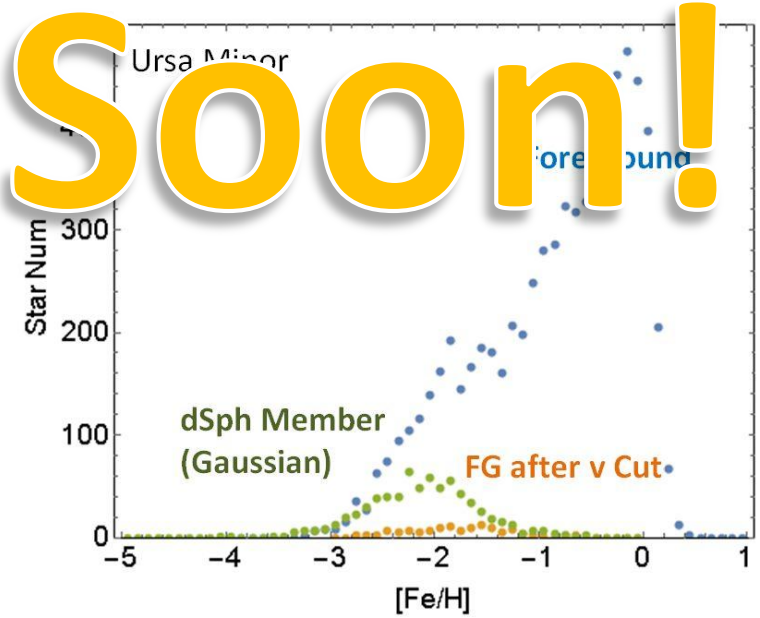
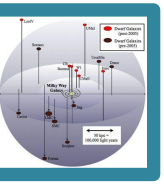


Summary

- Indirect detection is essential for DM search.
- Gamma-ray observation of dSph can give robust constraints on the DM annihilation cross section.
- Investigation of stellar kinematics is important.
- PFS will play a crucial role.

Thank You !



Koji Ichikawa

In collaboration with
Kohei Hayashi , Masahiro Ibe, Miho N. Ishigaki,
Shigeki Matsumoto and Hajime Sugai.

Back up

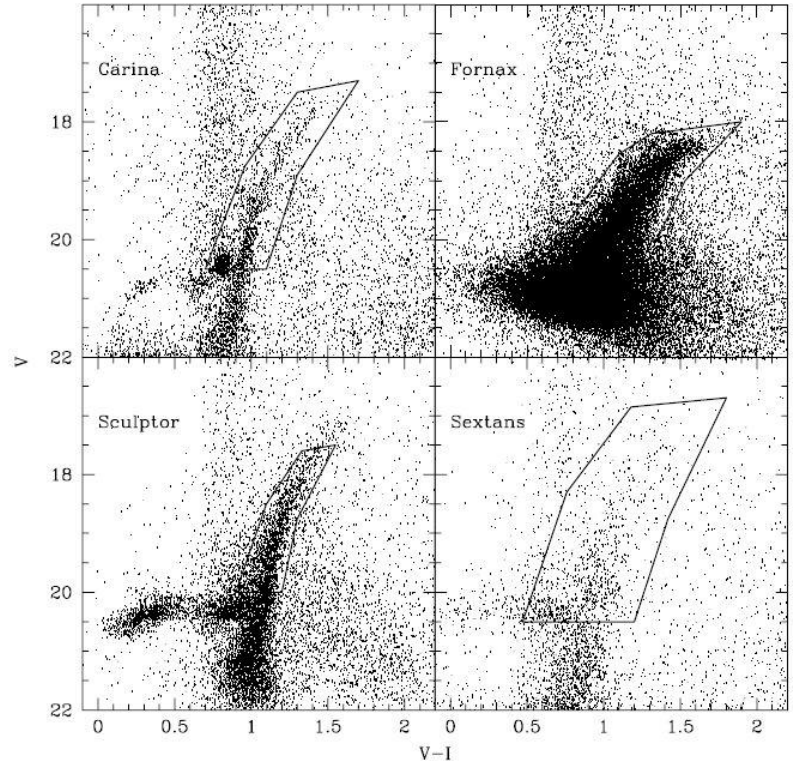
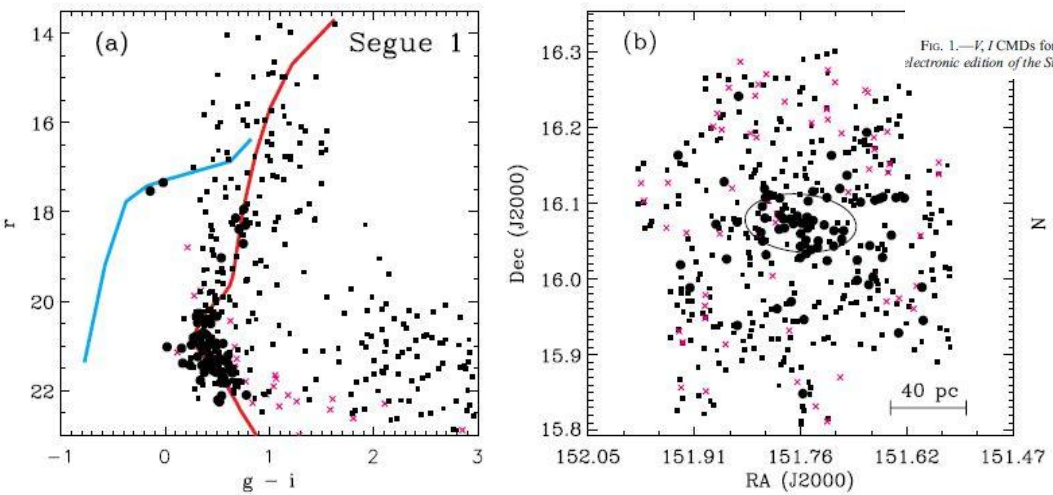


FIG. 1.—V, I CMDs for the four dSph's observed with MMFS. Stars enclosed by polygons are considered red giant candidates and eligible MMFS targets. [See the electronic edition of the Supplement for a color version of this figure.]

M. G. Walker et al,. (2007)



J. D. Simon et al., (2011)

Spectrograph	MMFS	Hectochelle	DEIMOS	FLAMES +GIRAFFE	PFS
Telescope	Magellan/Caly	MMT	Keck	VLT	Subaru
Caliber [m]	6.5	6.5	10	8.2	8.2
FoV (diam)					
[arcmin]	20	60	5×16.6	25	78
[deg]	0.33	1.0	(rectangle)	0.42	1.3
Resolution					
R	Blue: 25000 Red: 20000	25000	6000	6500	2500-5000
Range [Å]	Blue: 3200-5000 Red: 4900-10000	3800 - 9000	6500-9000	8180-9375	3800-12600
Fibler	Blue: 128 Red: 128	224	Slits	130	2394
dSphs	7 Classicals	Leo I, V	8 UFs	Hercules, Bootes I	—
Refs	URL1, URL2	URL1, URL2	URL1	[8] [9]	URL1