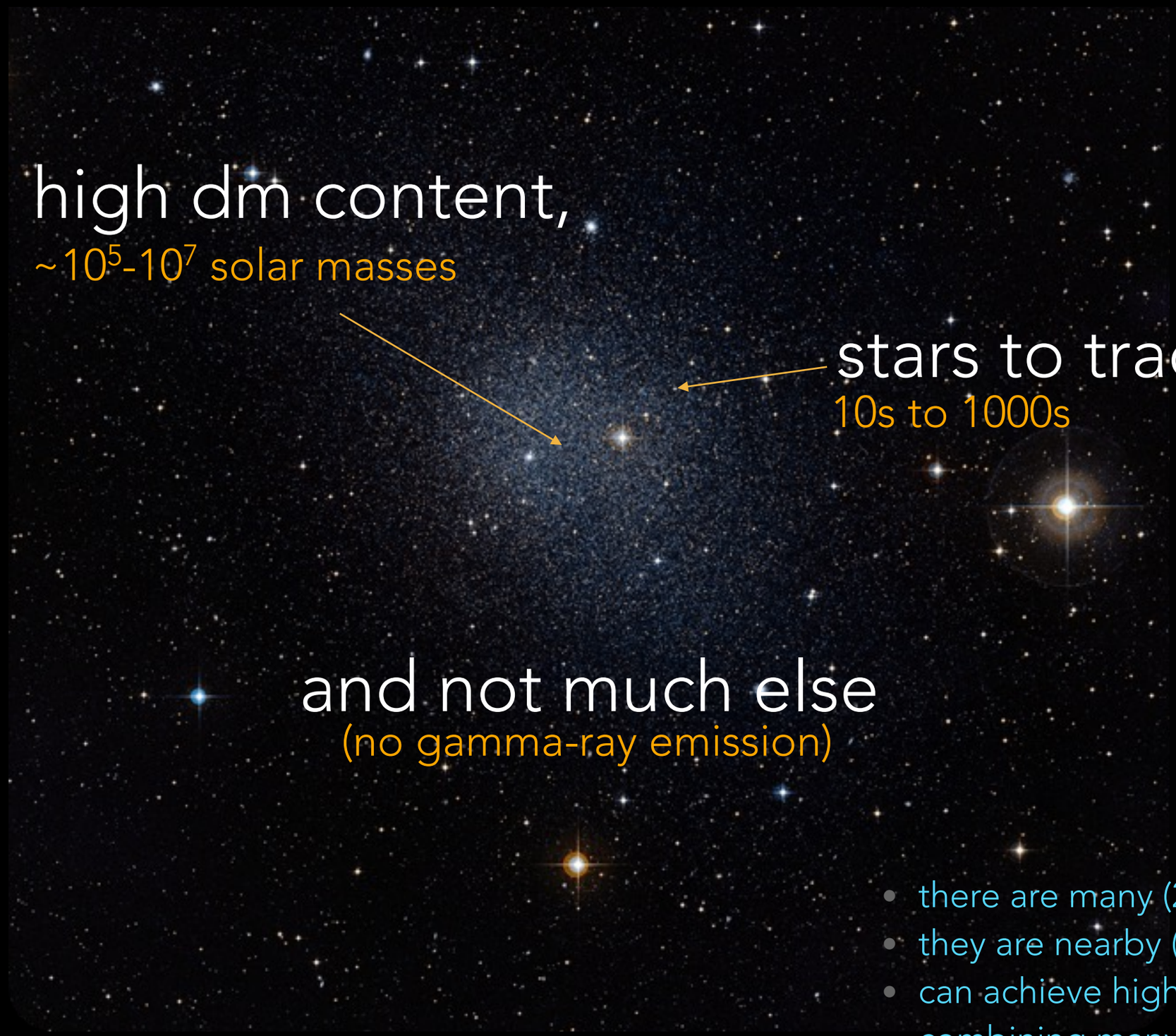
SEARCHING FOR DM IN DWARF SPHEROIDAL GALAXIES

Brandon Anderson
on behalf of the Fermi-LAT Collaboration
Dec. 9, 2015

dwarf spheroidals
as DM laboratories

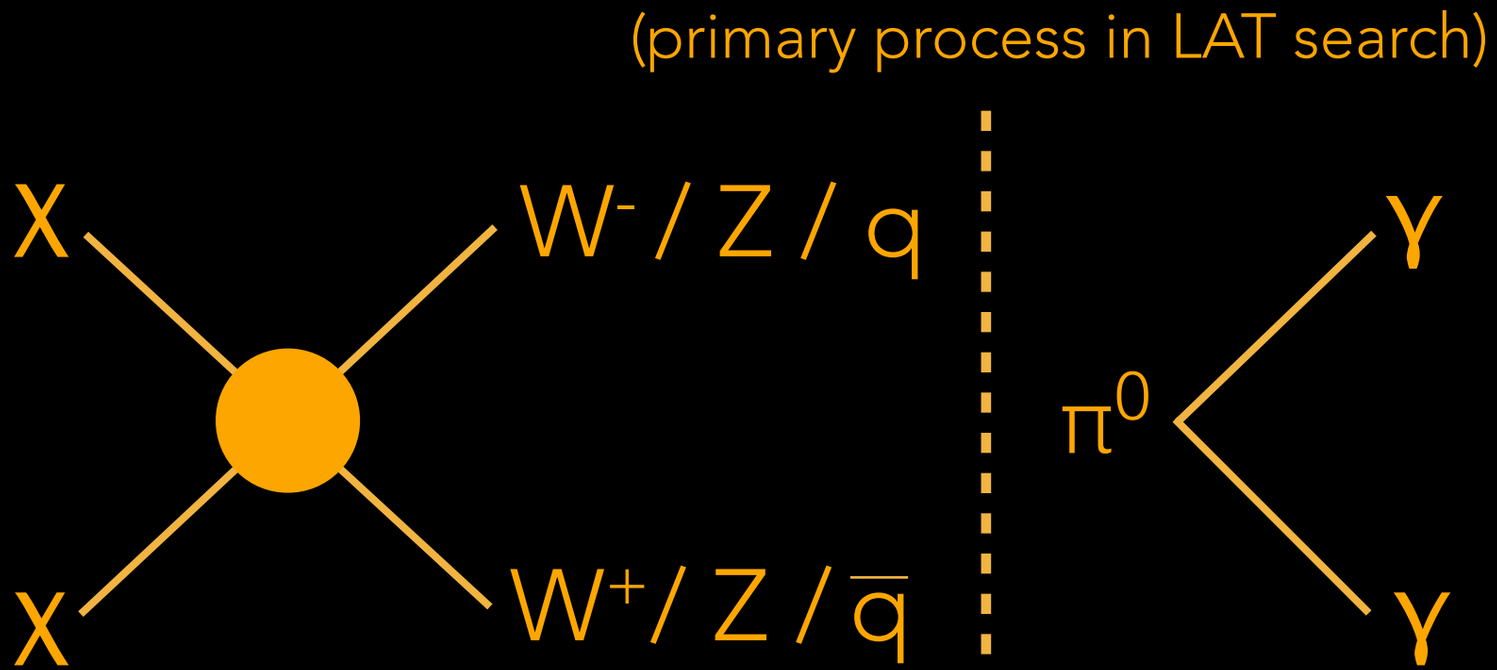
ESO DSS2



- there are many (20+ so far)
- they are nearby (<250 kpc)
- can achieve high sensitivity by combining many of them

WIMP paradigm

abundance + observability



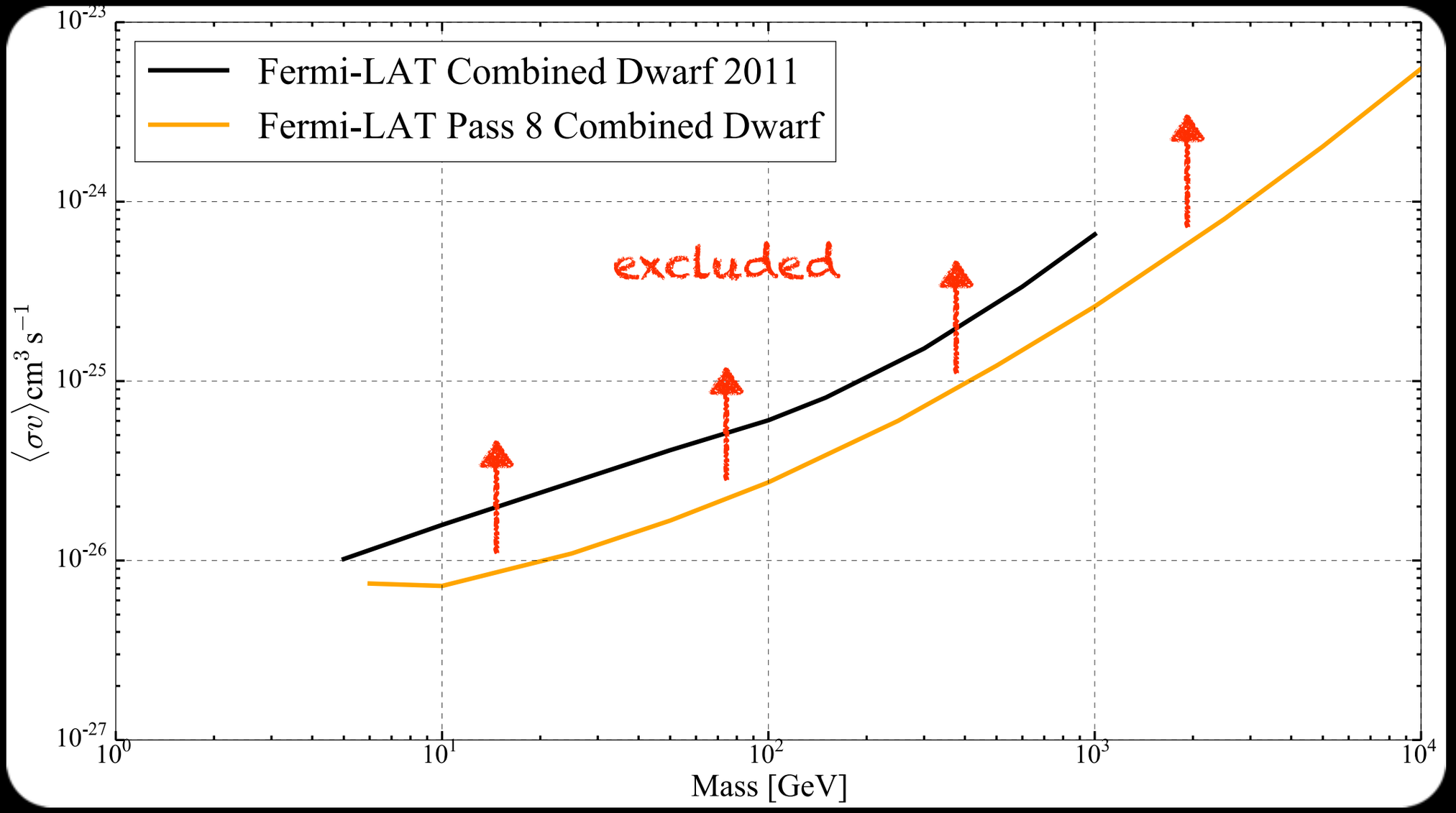
- annihilation with weak cross section (~2e-26 $cm^3\ s^{-1}$) gives Ω_{DM}
- same process would make it visible in high density areas today

$$\frac{d\Phi_\gamma}{dE_\gamma} = \underbrace{\frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_\chi^2}\sum_f \frac{dN_\gamma^f}{dE_\gamma}B_f}_{\Phi_{PP}} \times \underbrace{\int_{\Delta\Omega}\int_{l.o.s.}\rho^2(r)dl\ d\Omega'}_{\mathrm{J-factor}}$$

motivation

what keeps this interesting?

arXiv:1111.0320
arXiv:1503.02641
b-quark channel



- no significant detections
- very low systematics —>
- factor of 2-3 drop in upper limits over the last years

J-factor	Diffuse	IRFS
33%	8%	9%

@ 100 GeV
WIMP Mass

motivation

what keeps this interesting?

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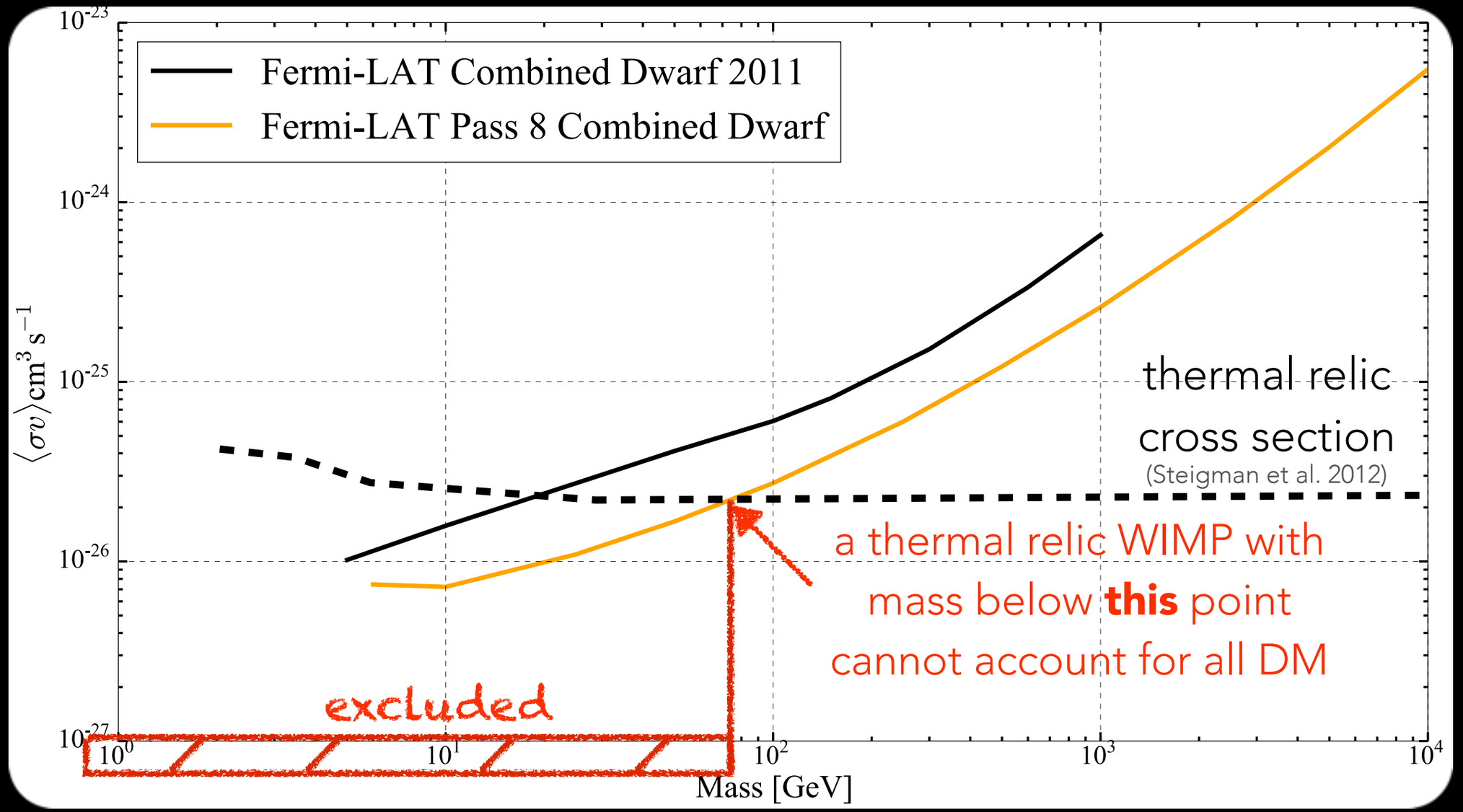

constrains critical theoretical parameter space

motivation

what keeps this interesting?

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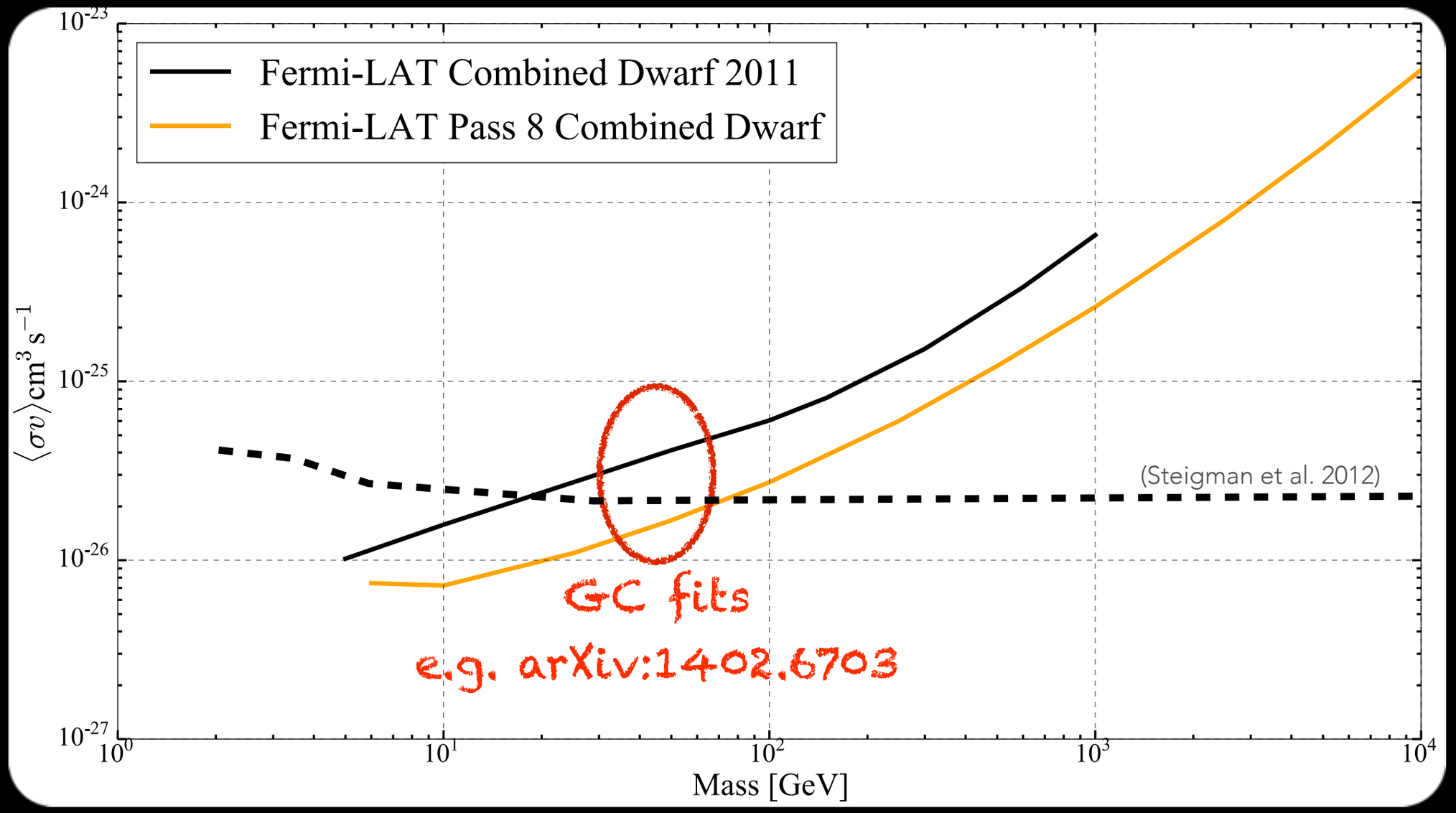


(similar for τ)

constrains critical theoretical parameter space
&
cross-checks phenomenological models

sensitivity
improvements

Statistics $\sqrt{N}$

- observation time
- additional targets
- instrument response (effective area)

Systematics σ_{sys}

- dm mass profile
- background model
- instrument response (point spread function)

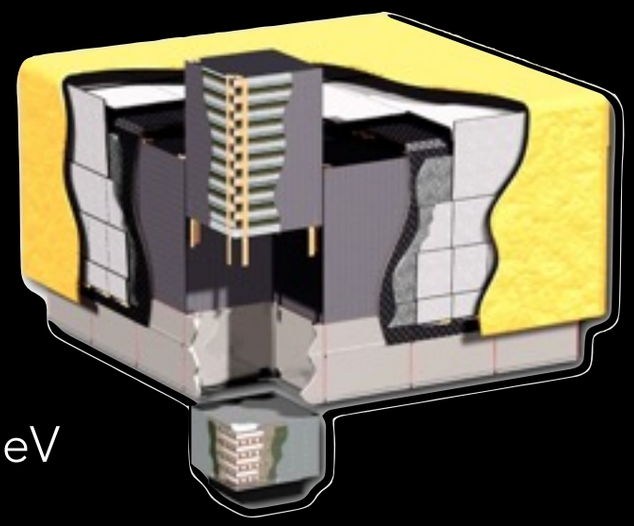
the LAT
upgraded

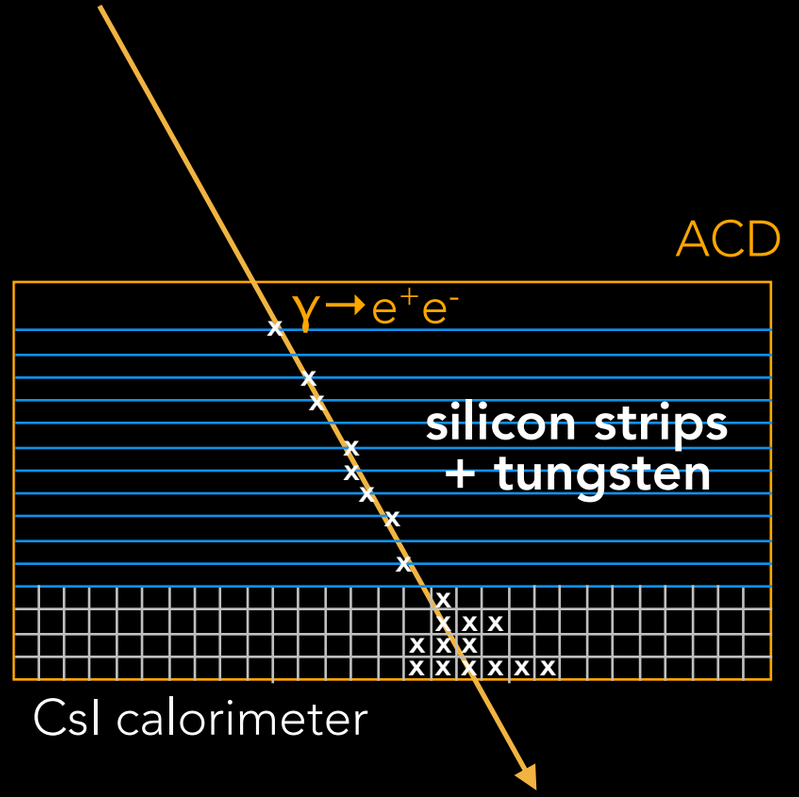
$\sqrt{N}$

σ_{sys}

Fermi Large Area Telescope

- all-sky gamma-ray monitor
- public data
- ~1 m^2 effective area
- 6+ years of observation
- energies from 30 MeV to over 300 GeV





Pass 8

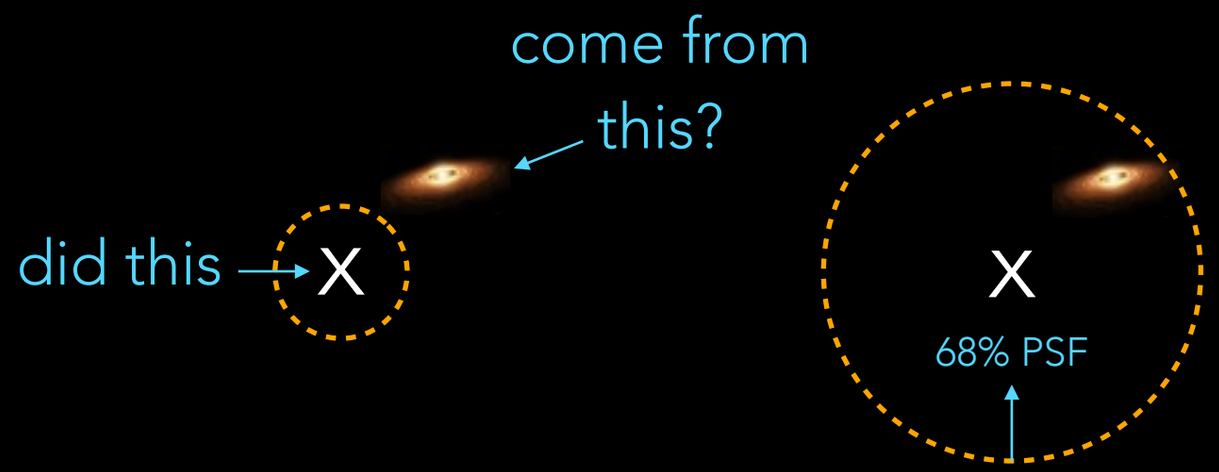
- complete event reconstruction
- applied to all prior data
- available to use!

Effective Area	Angular Resolution	Point-Source Sensitivity
+25%	+10-15%	+40%
> 1 GeV	> 1 GeV	@ 1-10 GeV

spatial information

event types

σ_{sys}



each event PSF is a parameterized function of

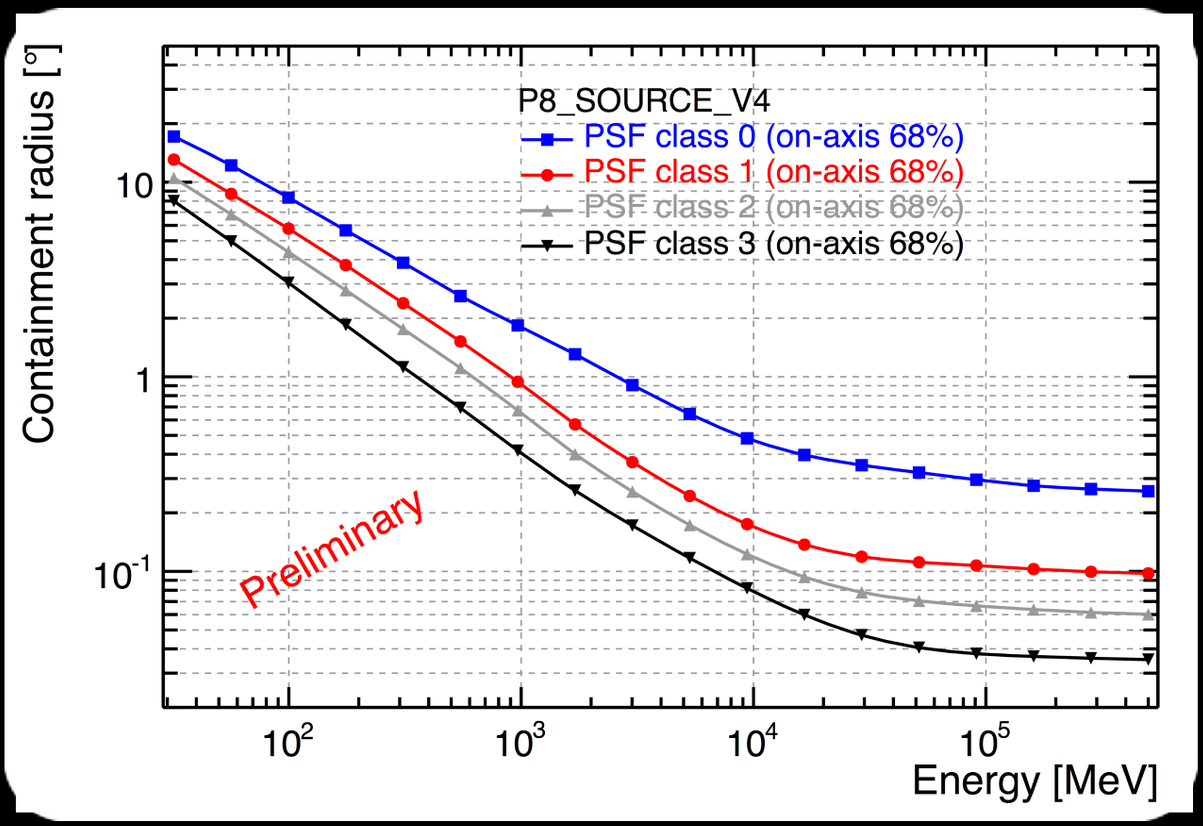
- energy
- incoming angle
- event class (probability to be a photon)

averaged over, e.g.

- what tracker layer it converted in
- if it passed through any gaps/cracks

new feature, PSF types

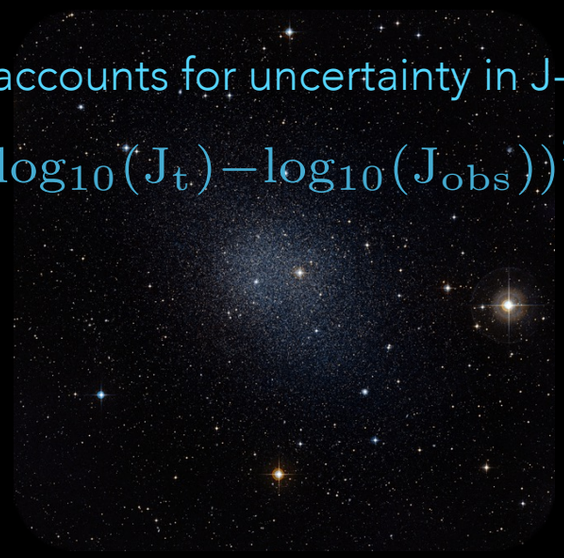
- uses deeper instrument info to subdivide events by angular uncertainty
- each set (4) gets its own PSF



implementation
joint likelihood

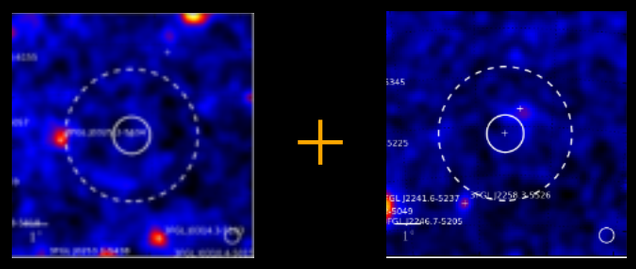
$$\mathcal{L}_2(\mathcal{D}|\boldsymbol{\mu}, \boldsymbol{\theta_t}) = \mathcal{L}_t^{\mathrm{LAT}}(\mathcal{D}_t|\boldsymbol{\mu}, \boldsymbol{\theta_t}) \times \frac{1}{\ln(10)\mathrm{J}_{\mathrm{obs}}\sqrt{2\pi}\sigma_{\mathrm{t}}} e^{-(\log_{10}(\mathrm{J_t})-\log_{10}(\mathrm{J_{obs}}))^2/2\sigma_{\mathrm{t}}^2}$$

(term accounts for uncertainty in J-factor)



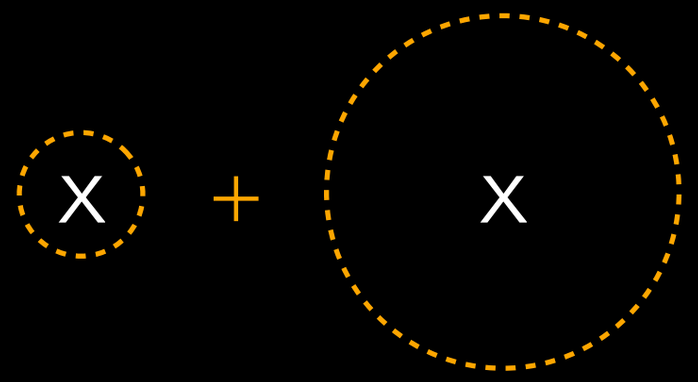
$$\mathcal{L}_3(\mathcal{D}|\boldsymbol{\mu}, \{\boldsymbol{\theta_t}\}) = \prod_{\mathrm{targets}} \mathcal{L}_2(\mathcal{D}|\boldsymbol{\mu}, \boldsymbol{\theta_t})$$

(combine information from all targets)



$$\mathcal{L}_4(\mathcal{D}|\boldsymbol{\mu}, \{\boldsymbol{\theta_t}\}) = \prod_{\mathrm{types}} \mathcal{L}_3(\mathcal{D}_c|\boldsymbol{\mu}, \{\boldsymbol{\theta_t}\})$$

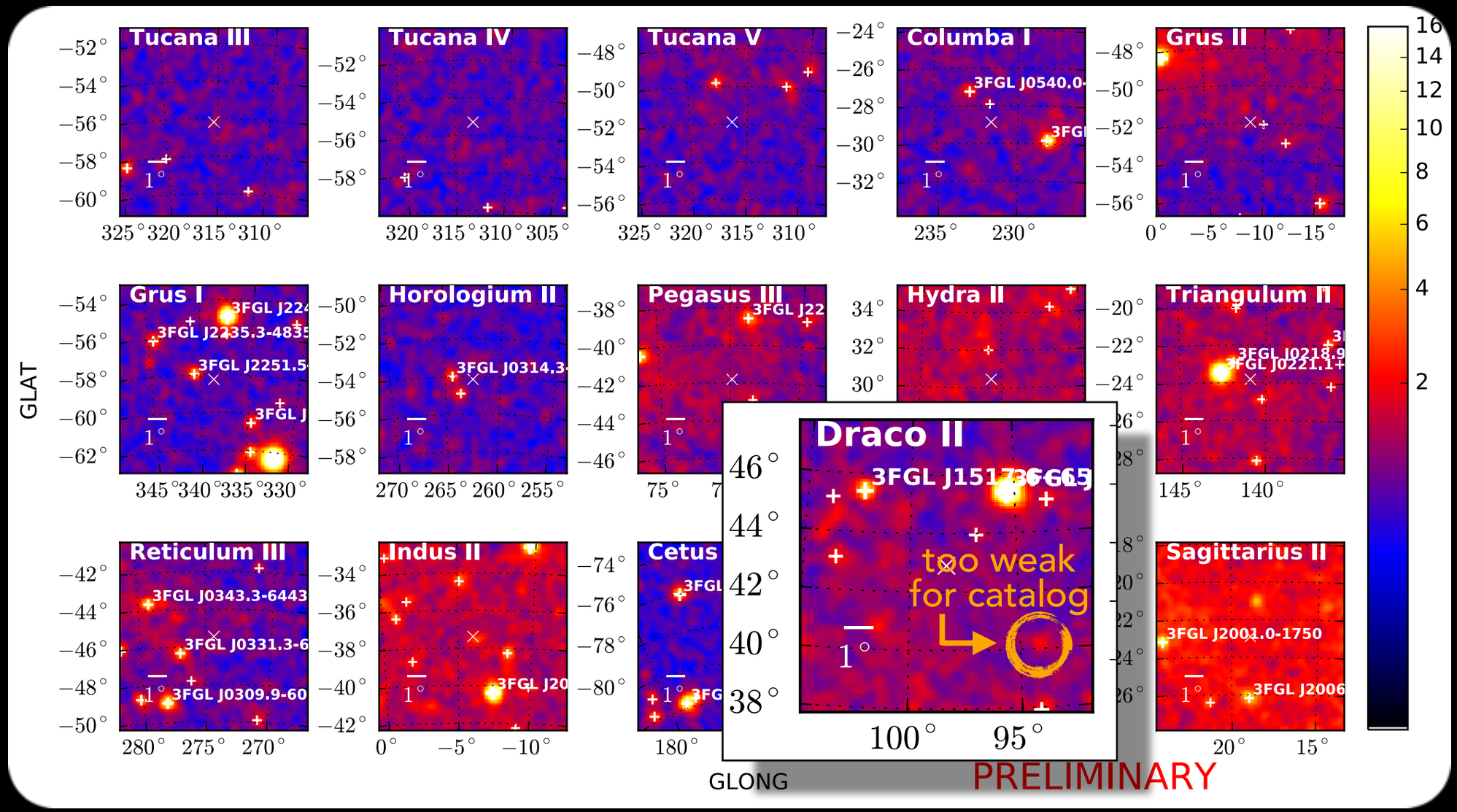
(combine information from all PSF types)



background model

sub-threshold sources

σ_{sys}



visual inspection (latest candidates)

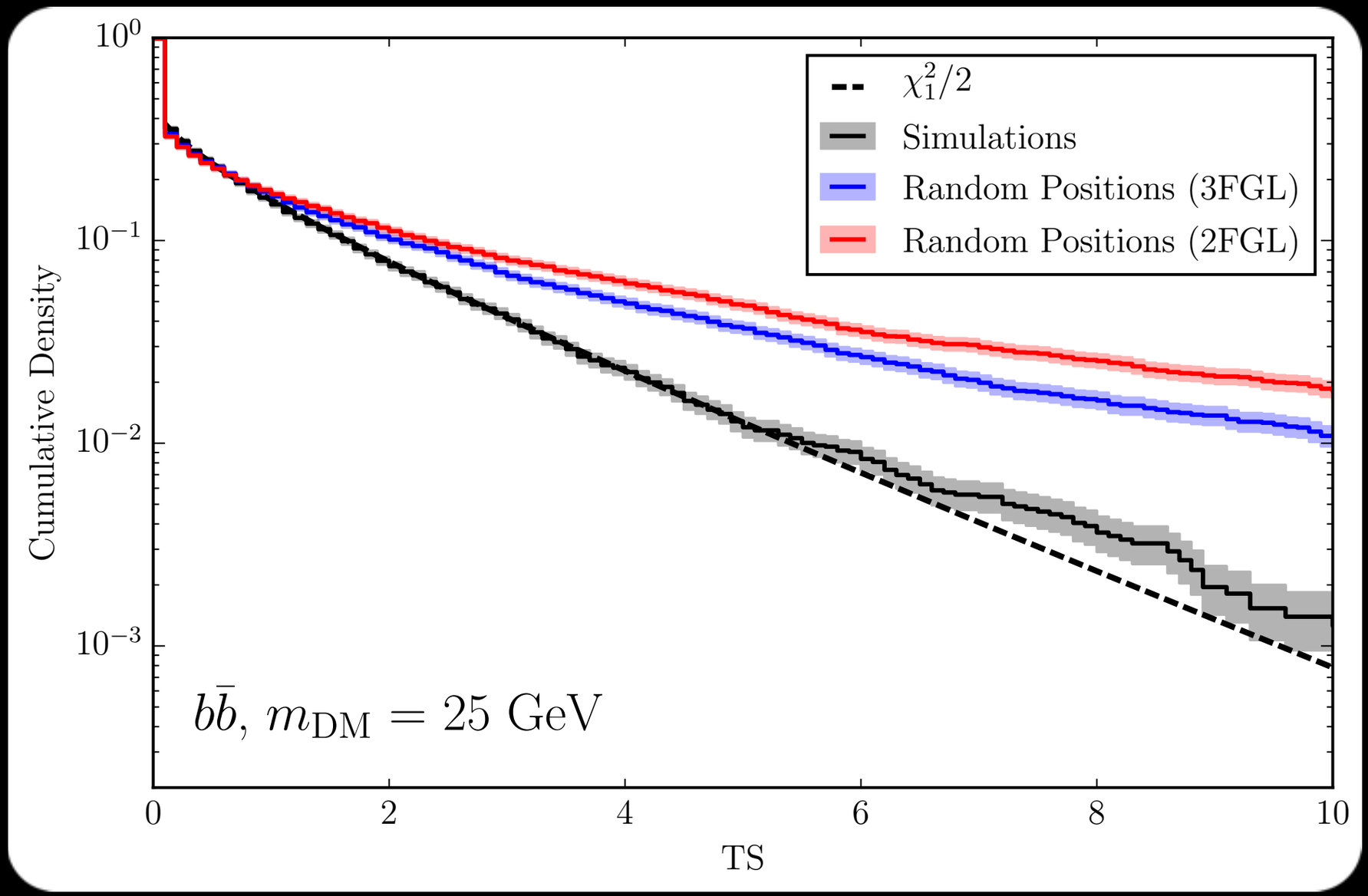
- no stand-out targets
- 3FGL sources marked with +
- can spot a few potential sub-threshold sources

background model

sub-threshold sources

σ_{sys}

arXiv:1503.02641



- blank field analysis. number of type I errors decreases with updated catalog
- implies we had some un-modeled background (could still be more)
- direct increase in sensitivity

j-factors
levels of certainty

σ_{sys}

Gold (prior-independent spectroscopic)

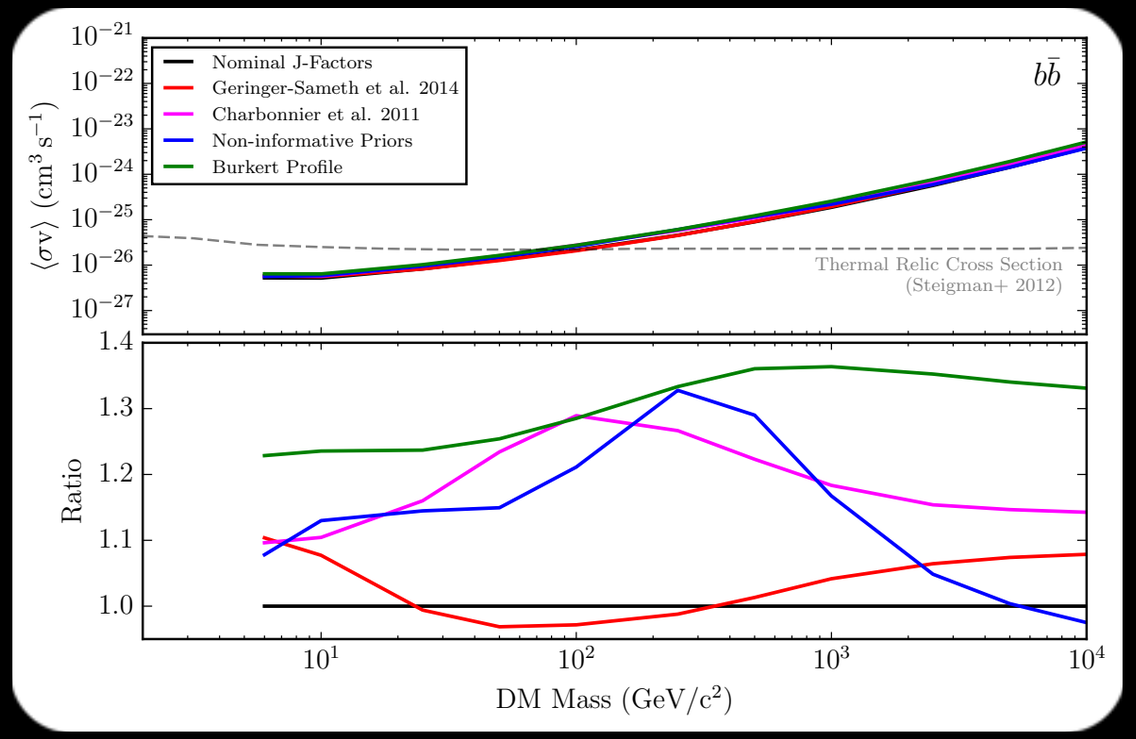
- fewest possible assumptions
- maximum likelihood: profile everything

Silver (spectroscopic)

- determine stellar velocity distribution
- fit mass distribution with NFW profile
- priors on scale radius/density

Bronze (photometric)

- assume all dphs have similar DM properties
- scale J-factor with distance



arXiv:1503.02641

priors affect constraints by up to 40%

dsph classes

- classical: up to 1000s of stars
- ultra-faint: can be just a handful

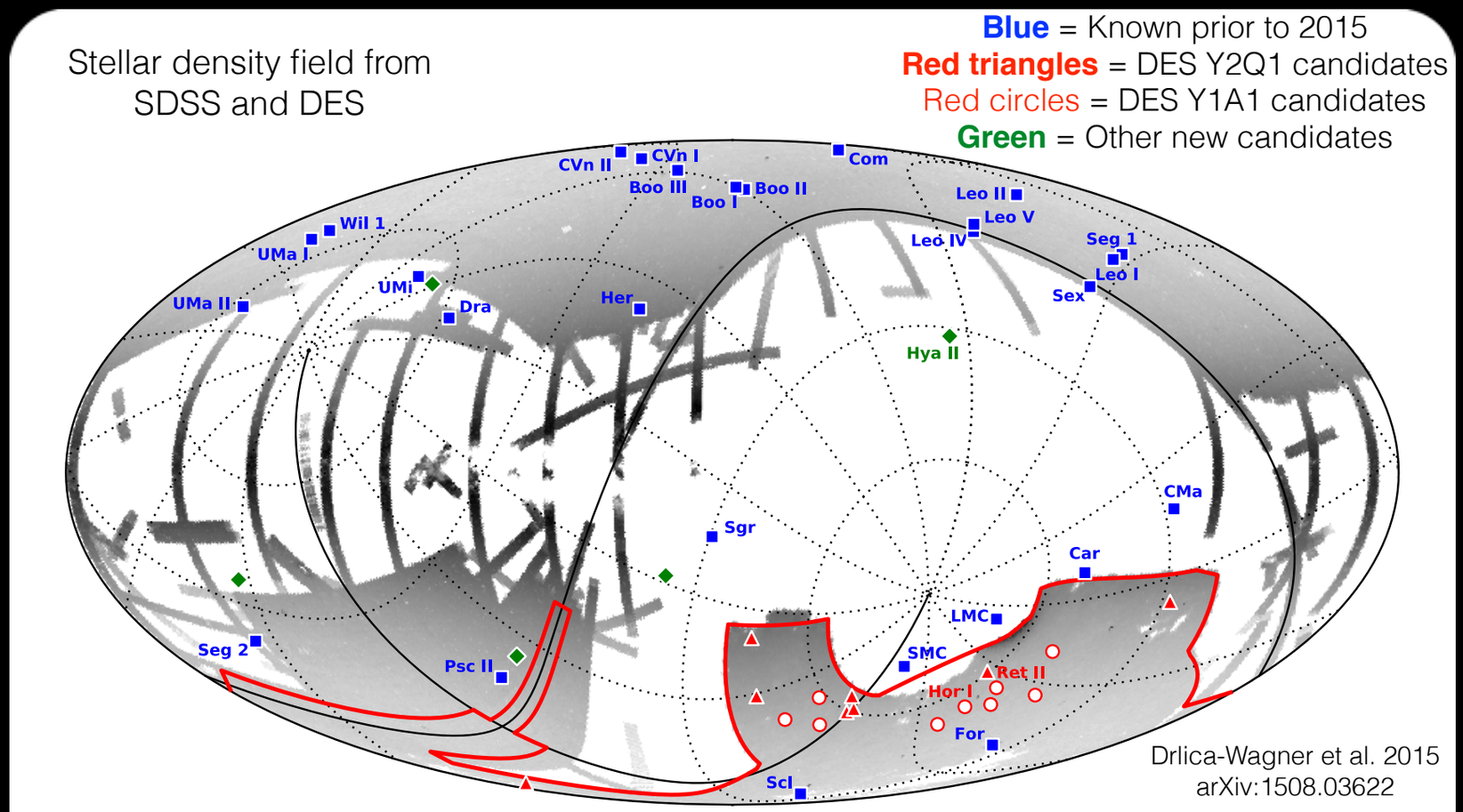
new targets
des overview

SDSS

- expanded on 12 ‘classical’ dsphs
- added 15 in a ~14,000 deg^2 patch
- 95% complete to r=22 mag
- can see faintest dsphs out to 50 kpc

DES

- will cover 5,000 deg^2
- sensitive to r=24 mag
- faintest to 120 kpc
- 1,600 deg^2 so far



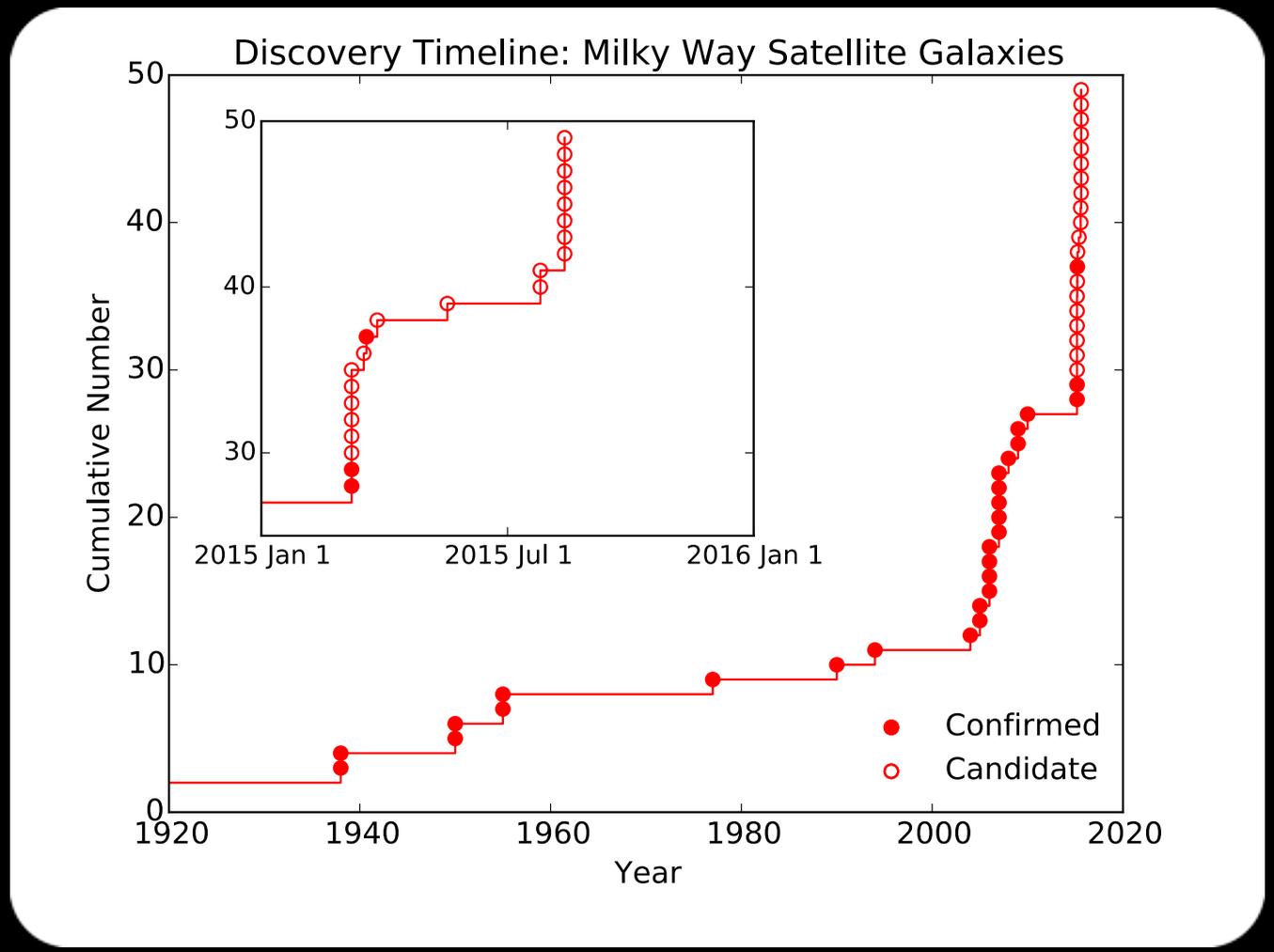
DES footprint in Galactic coordinates (~5000 deg^2)

12

new targets
recent additions

SDSS
- expanded on 12 ‘classical’ dsphs
- added 15 in a ~14,000 deg^2 patch
- 95% complete to r=22 mag
- can see faintest dsphs out to 50 kpc

DES
covers!
- ~~will cover~~ 5,000 deg^2
- sensitive to r=24 mag
- faintest to 120 kpc
- ~~1,600 deg^2 so far~~



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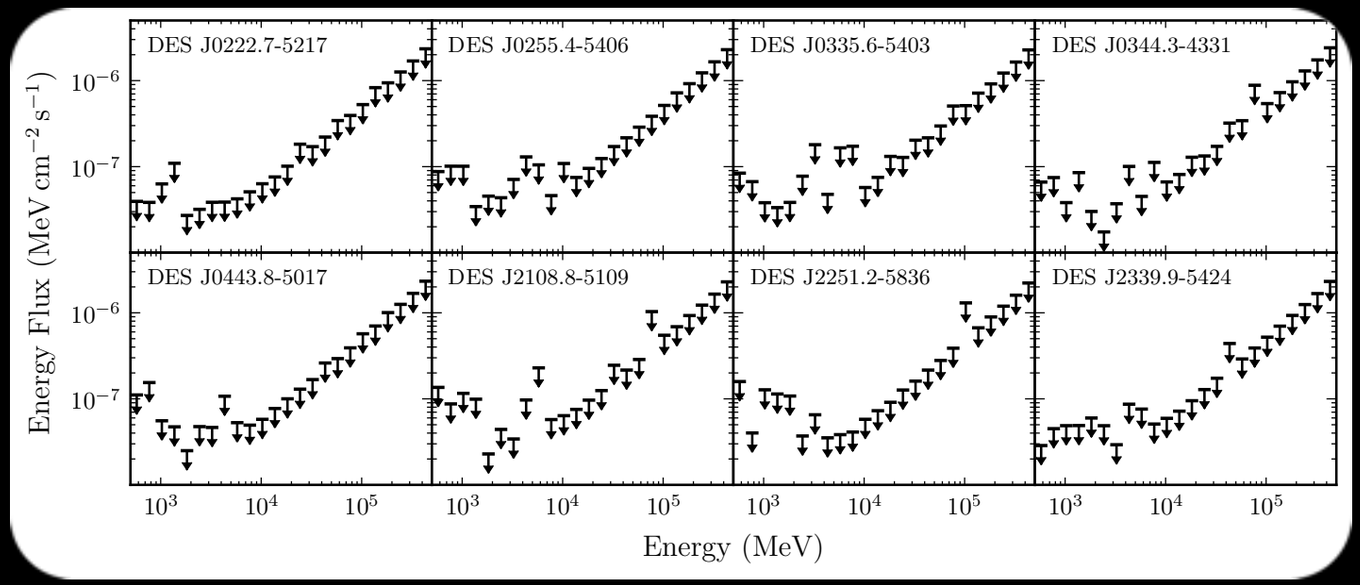
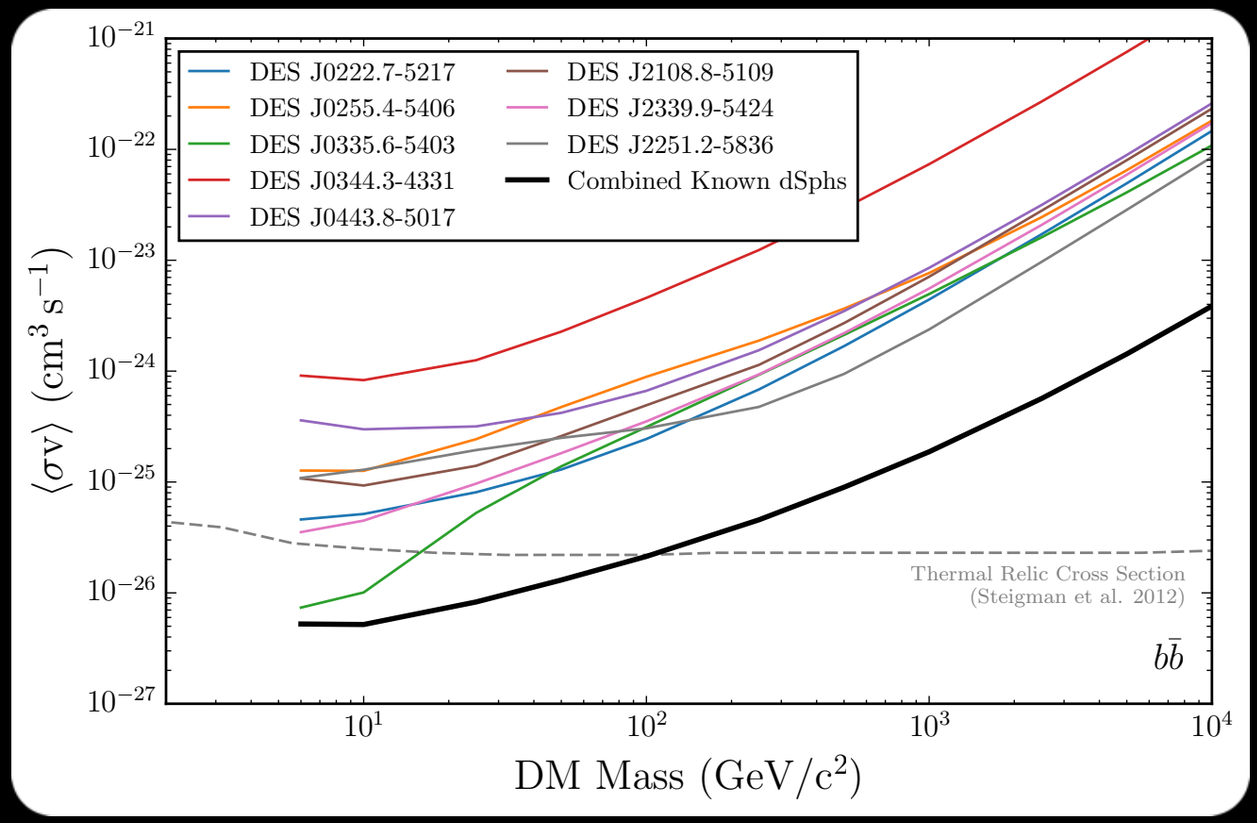
as of year two

new targets
des year 1 results



8 Candidates

- nothing statistically significant in either individual or joint analyses
- 3 confirmed dsphs
- reticulum II has the highest TS



arXiv:1503.02632

A Guess at Limits

- use photometric J-factors
- none seem likely to significantly improve (or worsen) current limits

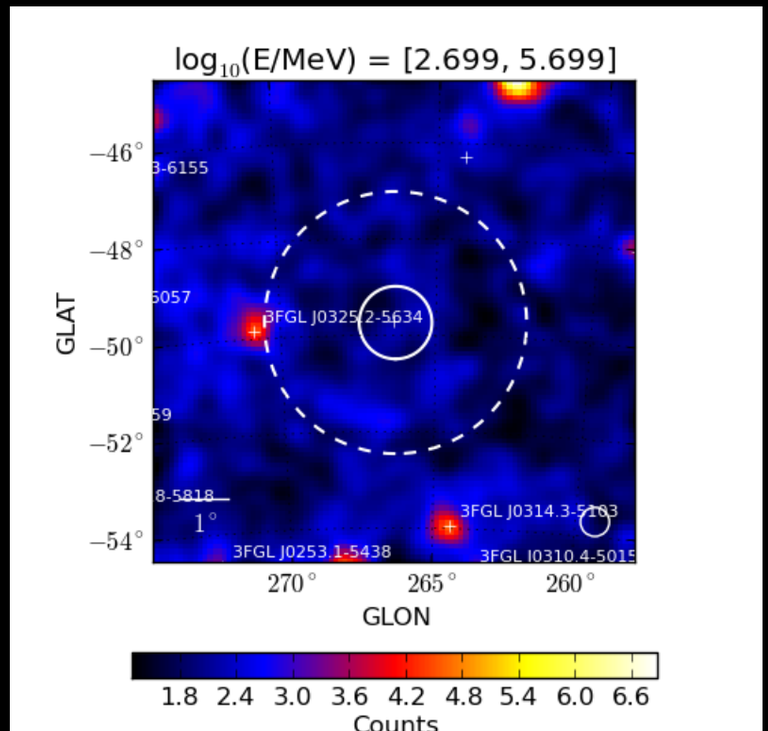
new targets
reticulum II

why all the attention?

- *nearby – 32 kpc.
- means high J-factor ~ 19
- most significant DM fits

relevant facts

- blazar PMN J0335-5046 is a hard spectrum emitter 15′ away
- there is a comparable TS from a candidate with 1/10 the J-factor
- Segue I has TS=0.33 for this WIMP



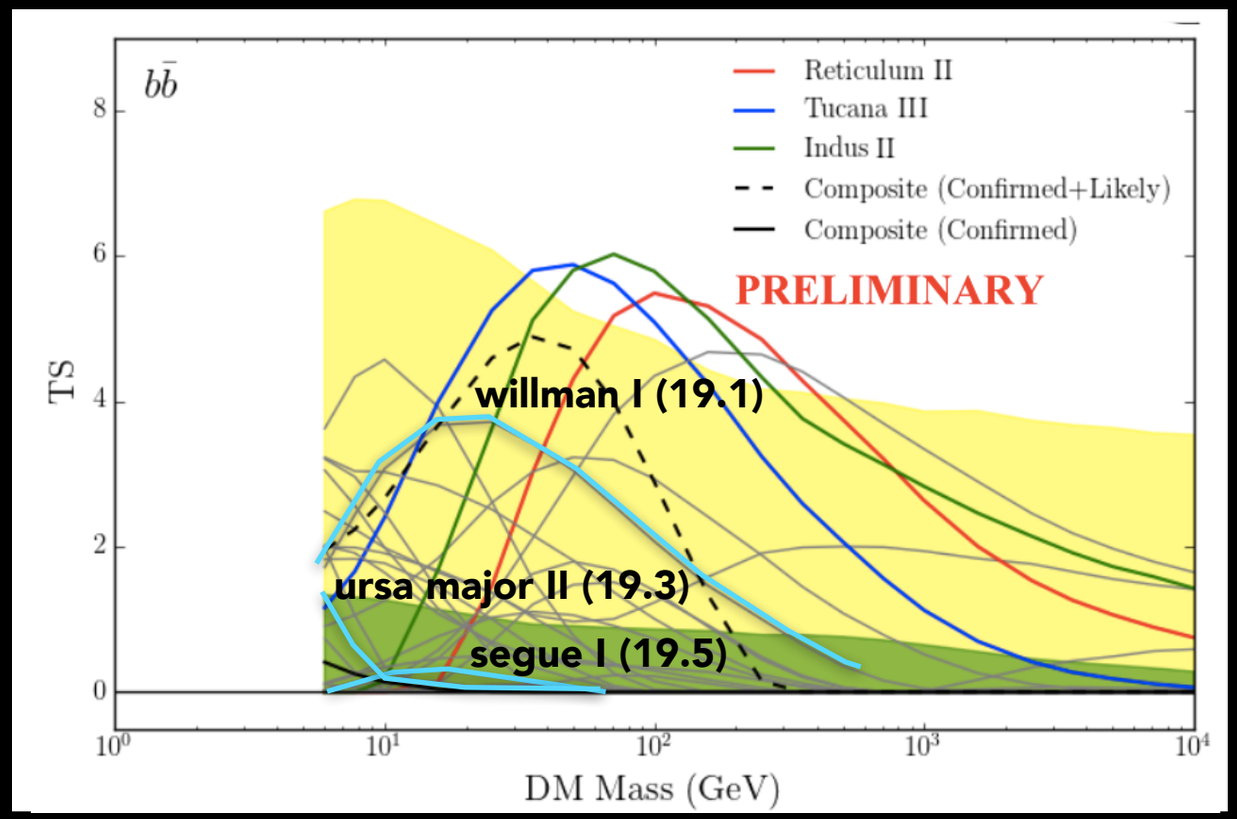
~15 GeV -> τ+τ-	Local Significance	Post-Trials	Global Significance	Data Version
Fermi+DES (arXiv:1503.02632)	2.3 σ	1.66 σ	~0 σ	**8**
Geringer-Sameth (arXiv:1503:02320)	2.8 σ	2.3 σ	Ret II Only	7
Hooper-Linden (arXiv:1503.06209)	3.2 σ	No Trials (Use GC)	Depends On Relative J-Factor	7

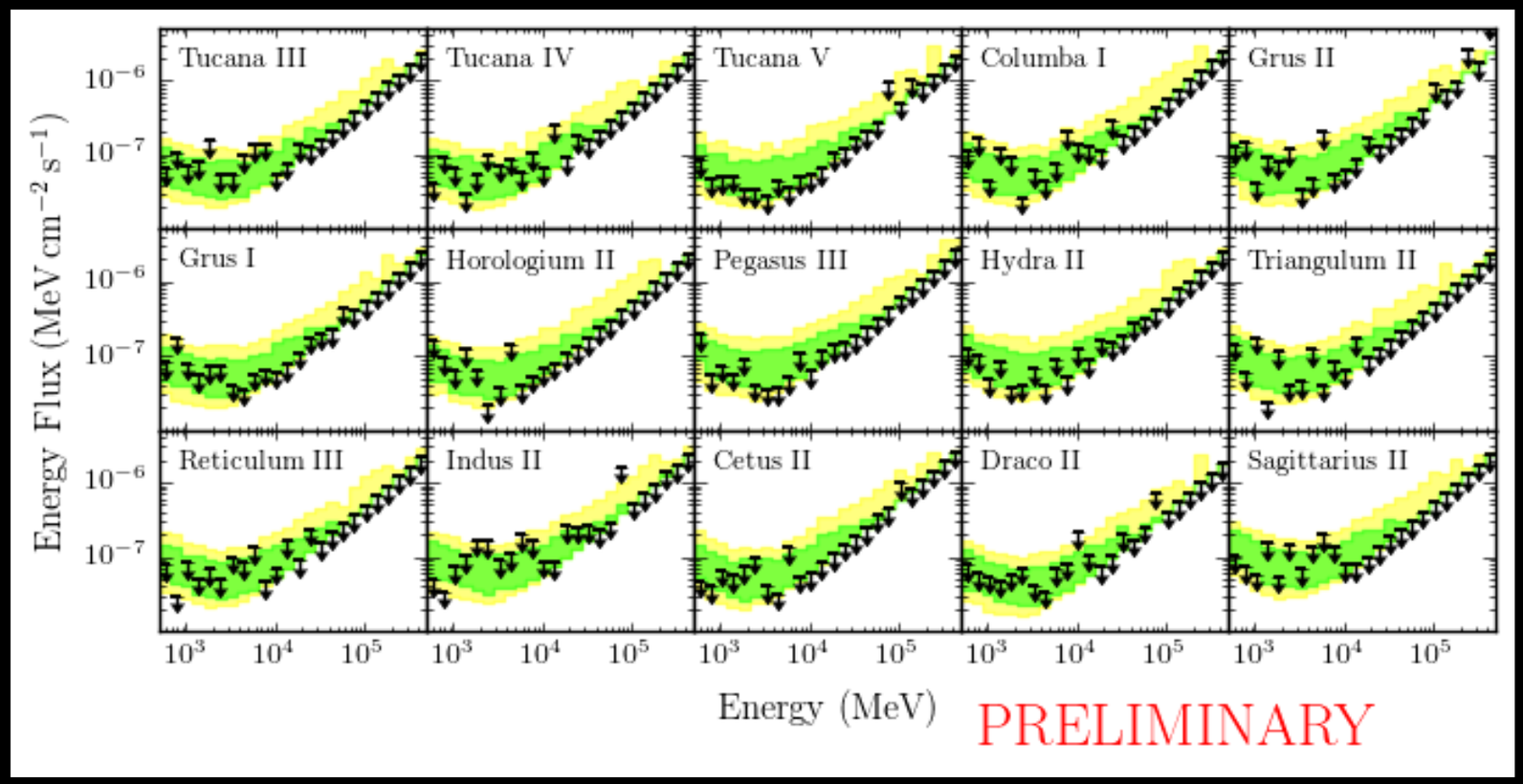
* Segue I is 23 kpc

new targets
year 2 des+panSTARRS

15 New Candidates

- nothing statistically significant in either individual or joint analyses
- a few with 2-3σ local significance
- none spectroscopically confirmed yet

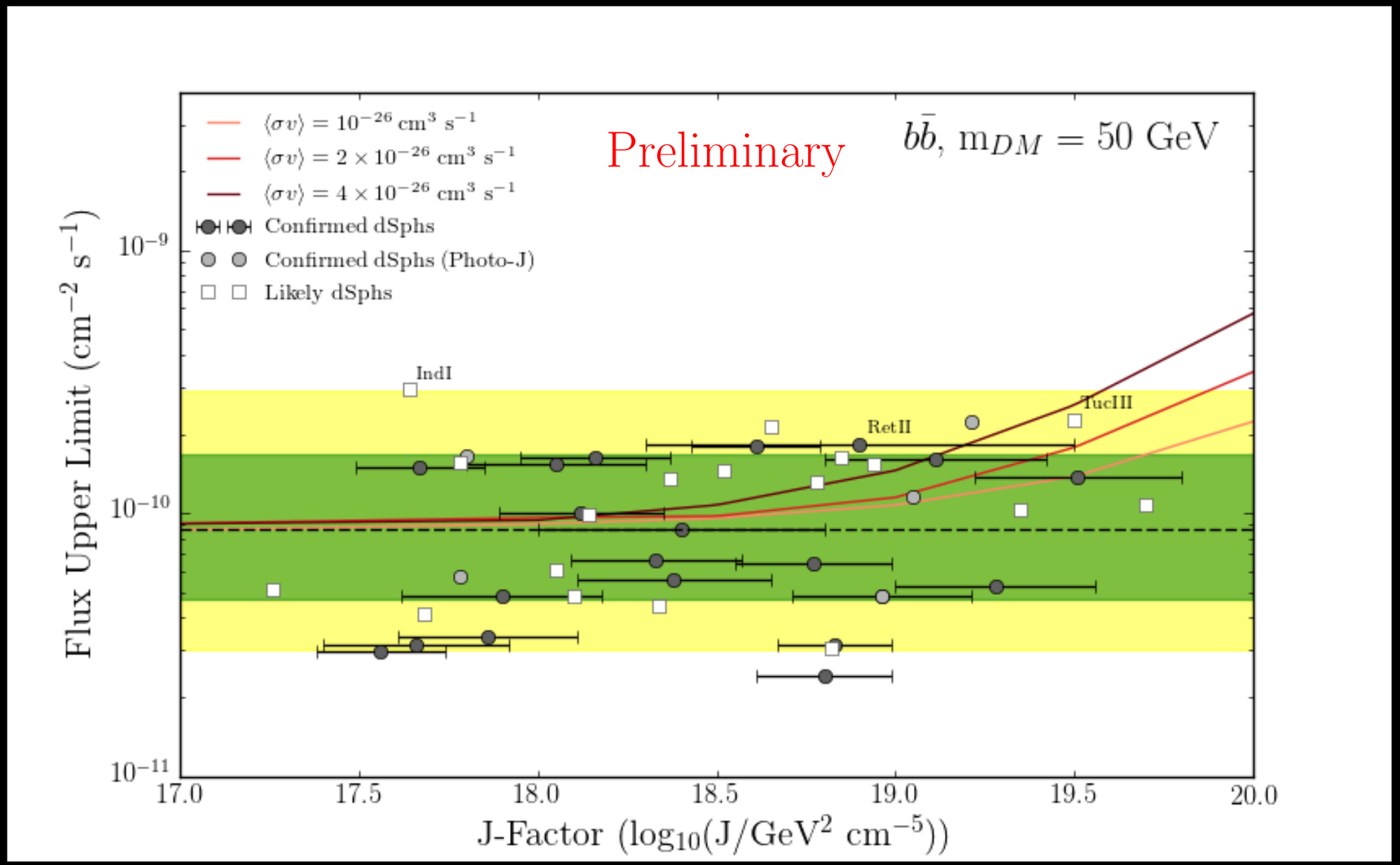




new targets
year 2 des+panSTARRS

The Importance of Context

- cannot evaluate dSphs outside of the continuum
- a guess at new J-factors can indicate if we are trending



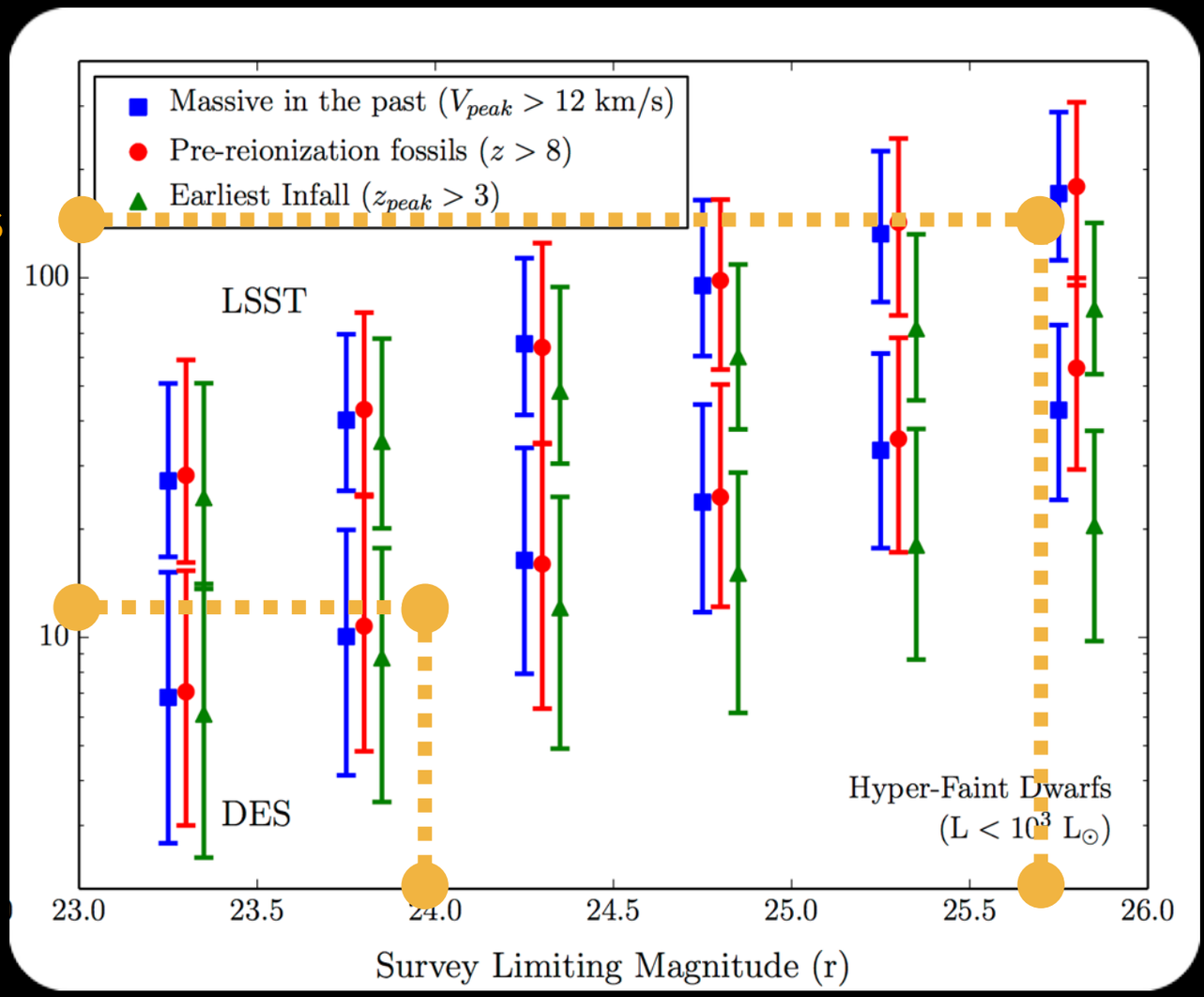
outlook
time+targets

How Many Can We Expect?

- combination of increased sky coverage and sensitivity
- DES will be done in 3 more years. some time afterwards needed for spectroscopy
- LSST should be a ~complete survey

LSST: 100s

DES: 10s

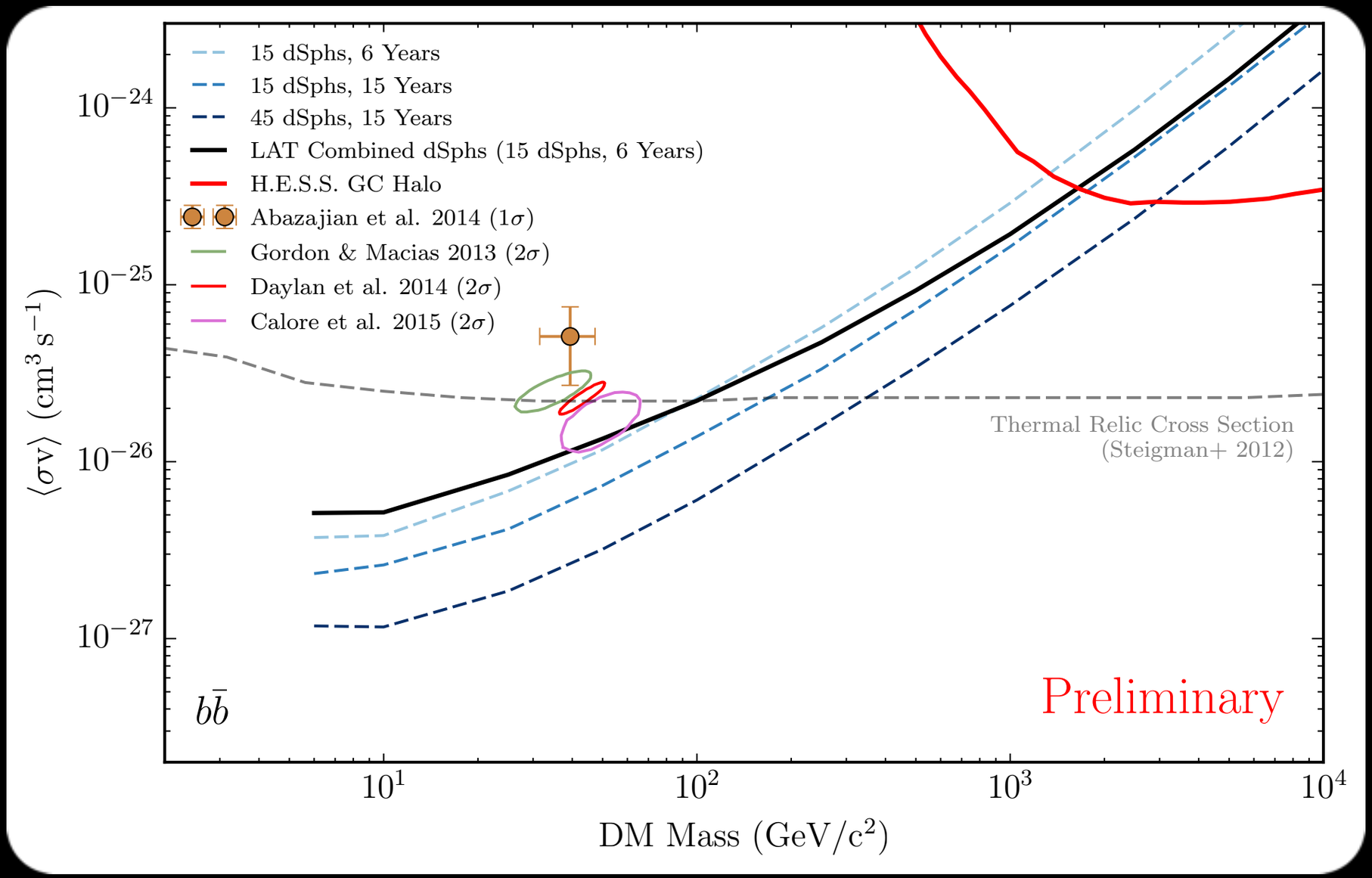


hargis et al. 2014
arXiv:1407.4470

In lieu of detection

we can realistically hope to:

- confirm / refute GC models

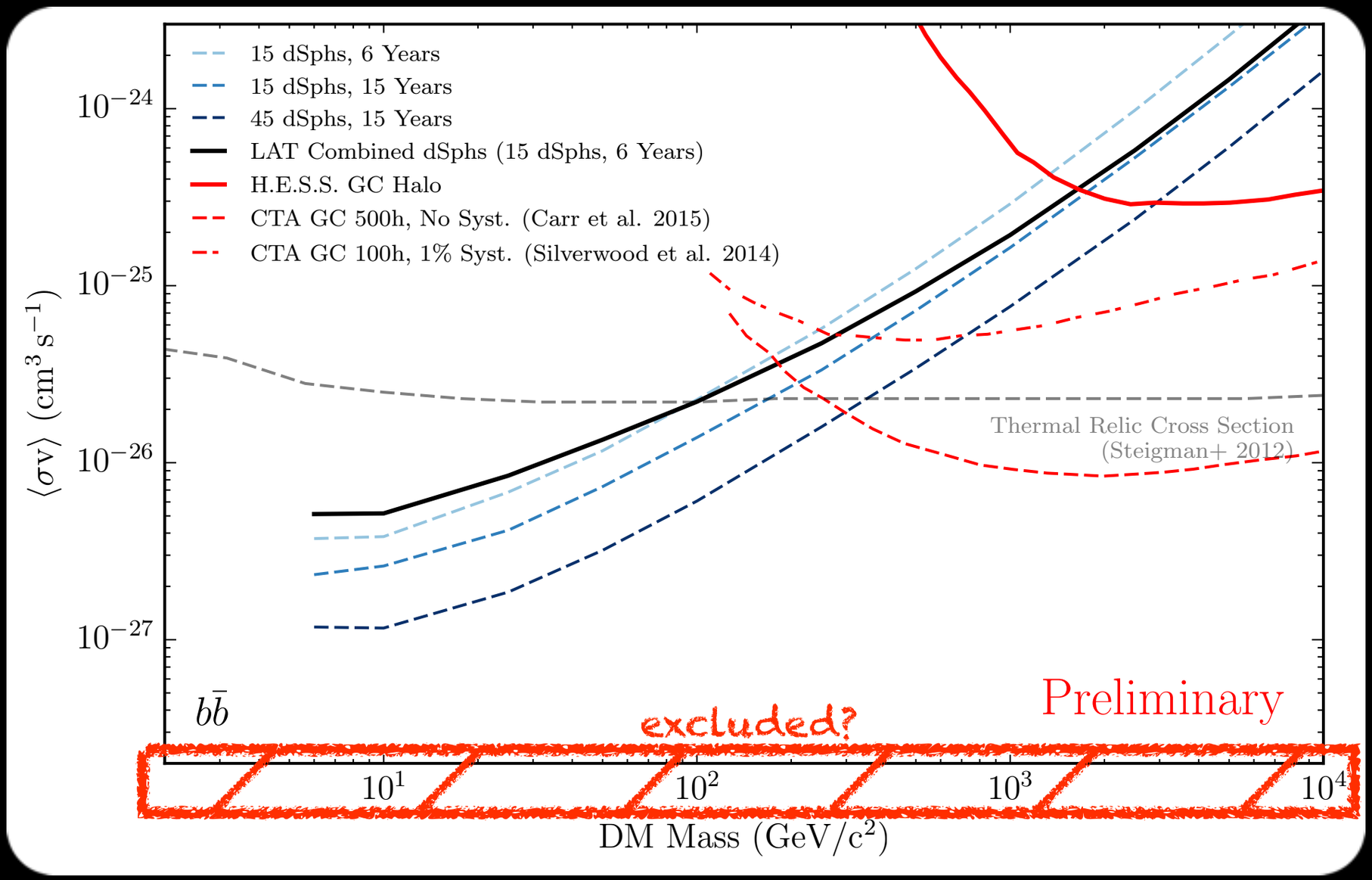


outlook
time+targets

In lieu of detection

we can realistically hope to:

- confirm / refute GC models
- exclude thermal production for WIMP masses 10 GeV – 100's of TeV (with the aid of ACT's)



summary

dsphs are great DM labs

- few uncertainties involved
- yield some of the most robust constraints to date

the list is growing!

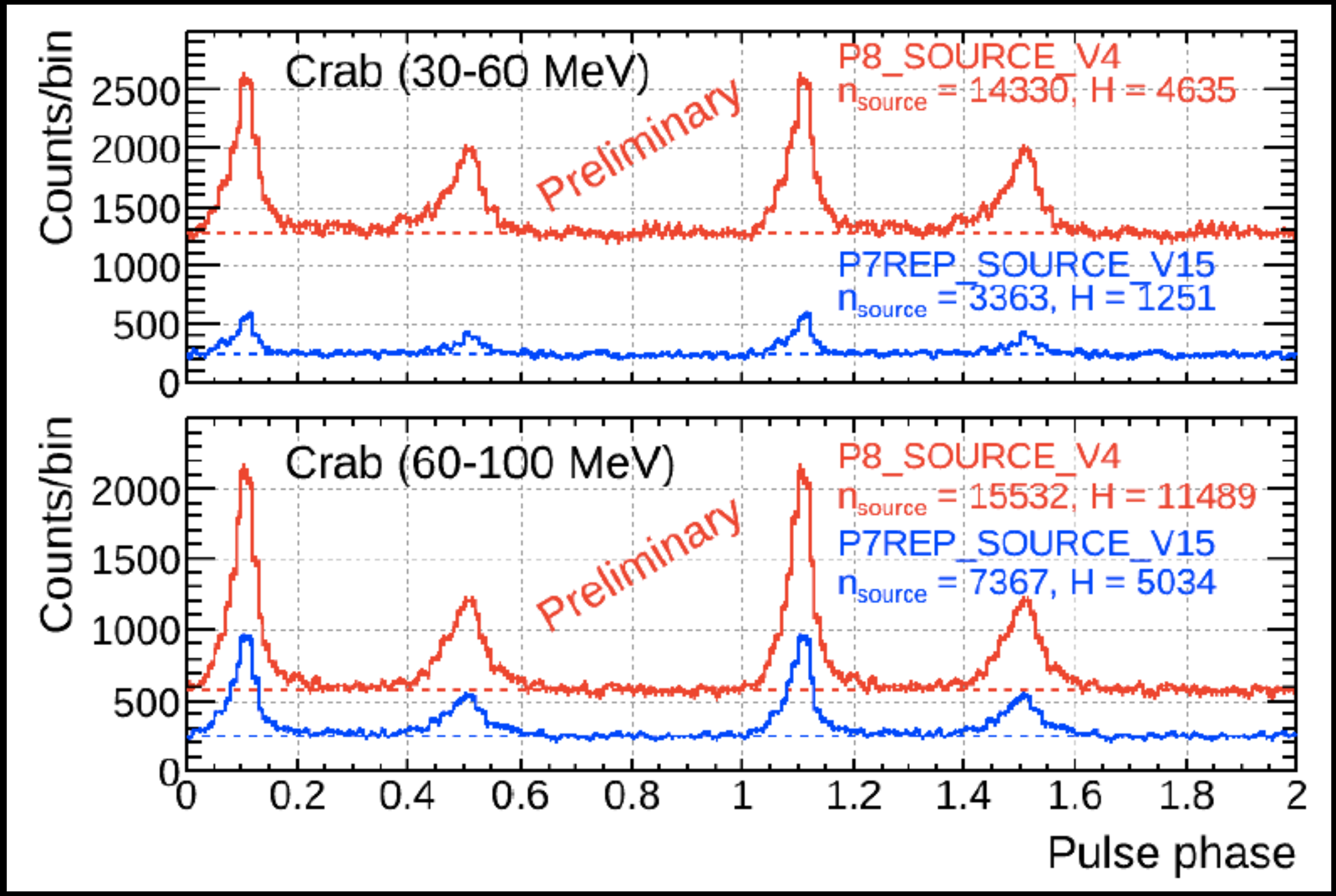
- new surveys are rapidly increasing the number of known targets
- gives a big boost to sensitivity

milestones approaching

- possible to exclude a huge swath of DM masses with thermal cross section (when combined with CTA)
- could always get lucky and find a very nearby dsph with detectable signal

BACKUP

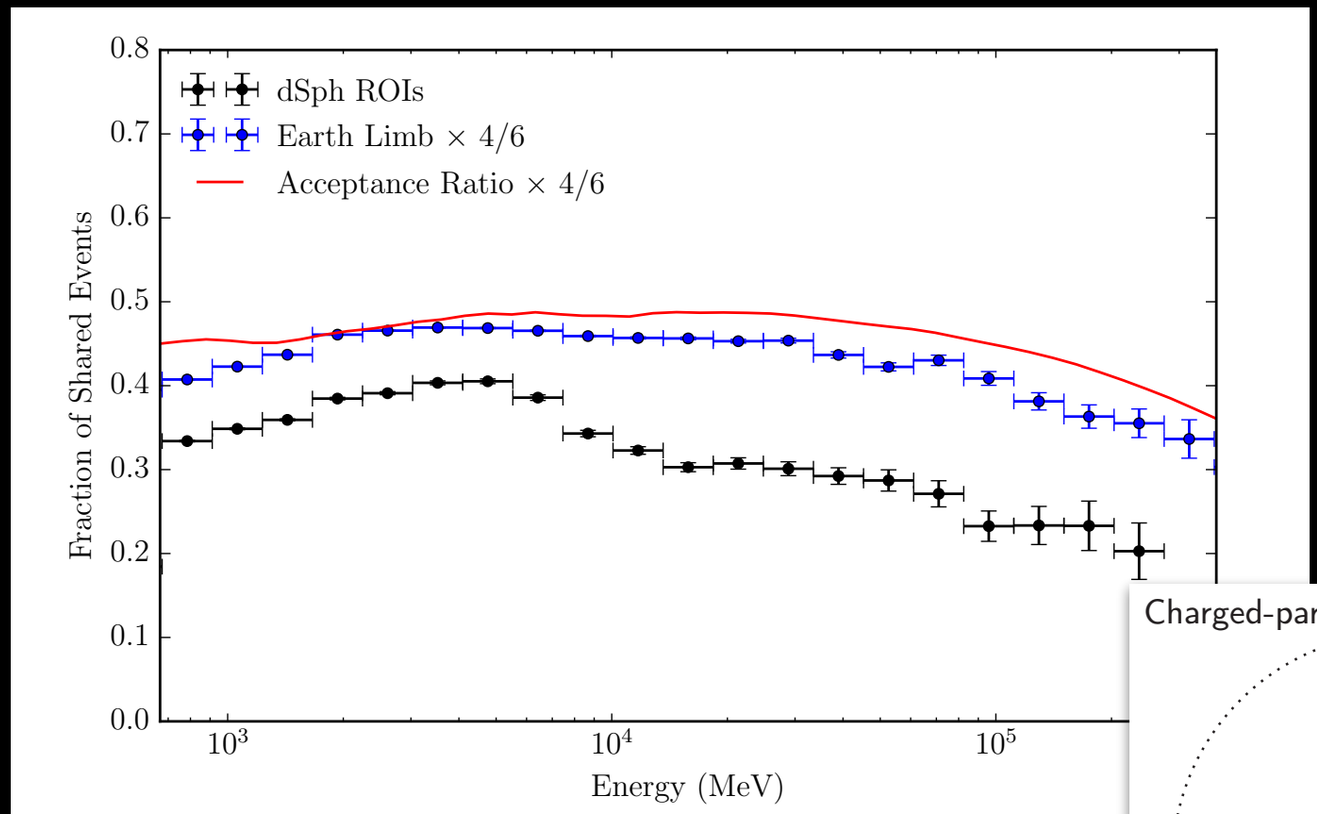
pass 8
improvement



consistency

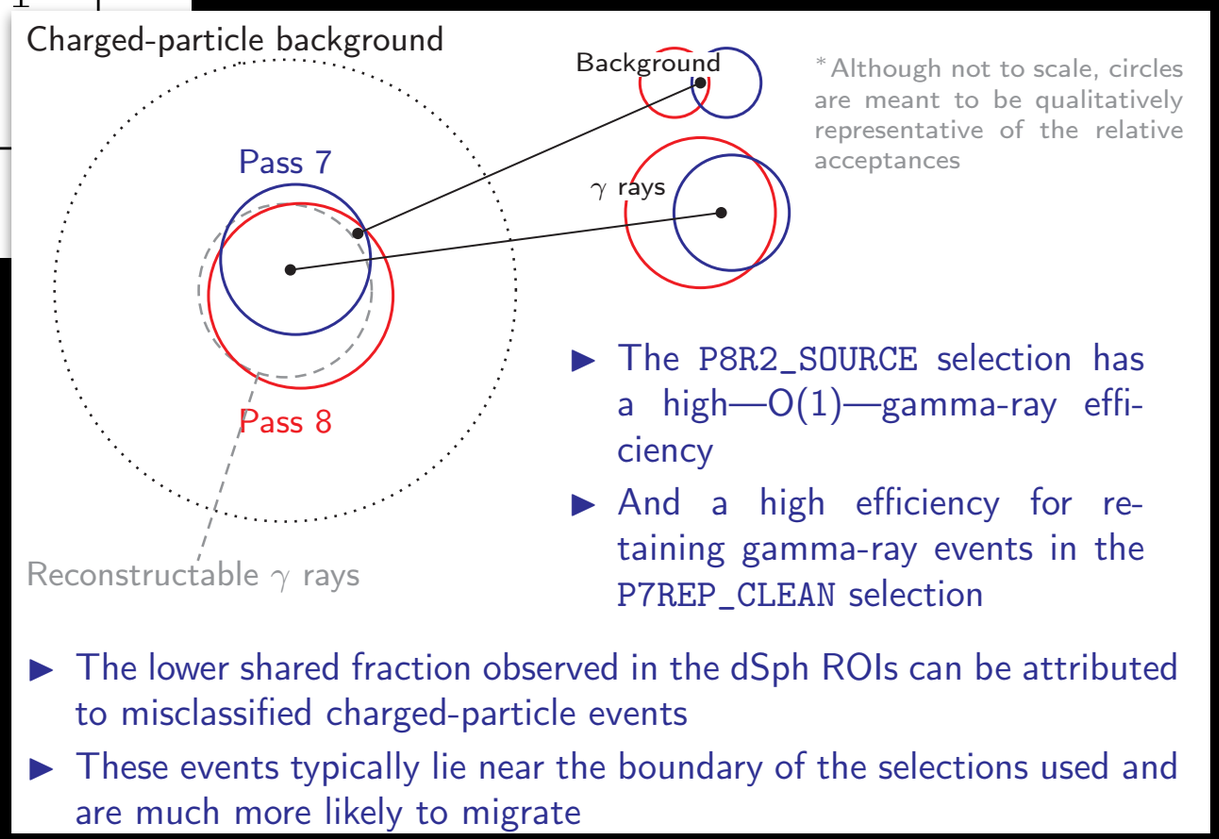
event overlap

arXiv:1503:02641



missing events?

- we expect 35-50% from pass acceptance ratios and observation times
- bulk remaining difference comes from event class migration (likely of charged-particle events)



Baldini, Fermi Symposium 2015

Status of 2015 Milky Way Companions

THE DARK ENERGY SURVEY

Object	Classification	Photometry	Spectroscopy	arXiv
Reticulum II	**dSph**	DECam (DES)	Magellan/M2FS, Gemini South/GMOS, VLT/GIRAFFE	1503.02079, 1503.02584, 1504.02889, 1504.03060, 1504.07916
Horologium I	**dSph**	DECam (DES)	VLT/GIRAFFE	1503.02079, 1503.02584, 1504.07916
Hydra II	**dSph**	DECam (SMASH)	Keck/DEIMOS	1503.06216, 1506.01021
Kim 2 / Indus I / DES J2108.8–5109	Star cluster?	DECam (Stromlo Milky Way Satellite Survey, DES)		1502.03952, 1503.02079, 1503.02584
Eridanus II	dSph?	DECam (DES)		1503.02079, 1503.02584
Tucana II	dSph?	DECam (DES)		1503.02079, 1503.02584
Pictor / DES J0443.8 –5017	?	DECam (DES)		1503.02079, 1503.02584
Phoenix II / DESJ2339.9–5424	?	DECam (DES)		1503.02079, 1503.02584
Eridanus III / DESJ0222.7–5217	?	DECam (DES)		1503.02079, 1503.02584
Grus I	?	DECam (DES)		1503.02079
Pegasus III	dSph?	SDSS + DECam		1503.08268
Laevens 2 / Triangulum II	?	PanSTARRS, Large Binocular Camera		1503.05554

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Status of 2015 Milky Way Companions

Object	Classification	Photometry	Spectroscopy	arXiv
Horologium II	dSph?	DECam (DES)		1505.04948
Laevens 3	Star cluster?	Pan-STARRS		1507.07564
Draco II / Laevens 4	?	Pan-STARRS		1507.07564
Sagittarius II / Laevens 5	?	Pan-STARRS		1507.07564
DES 1	Star cluster?	DECam (DES)		1508.02381
Grus II	dSph?	DECam (DES)		1508.03622
Tucana III	dSph?	DECam (DES)		1508.03622
Columba I	dSph?	DECam (DES)		1508.03622
Tucana IV	dSph?	DECam (DES)		1508.03622
Reticulum III	dSph?	DECam (DES)		1508.03622
Tucana V / DES J2337-6316	?	DECam (DES)		1508.03622
Indus I	dSph?	DECam (DES)		1508.03622
Cetus II / DES J0117-1725	?	DECam (DES)		1508.03622

photometric J-factors

reliability