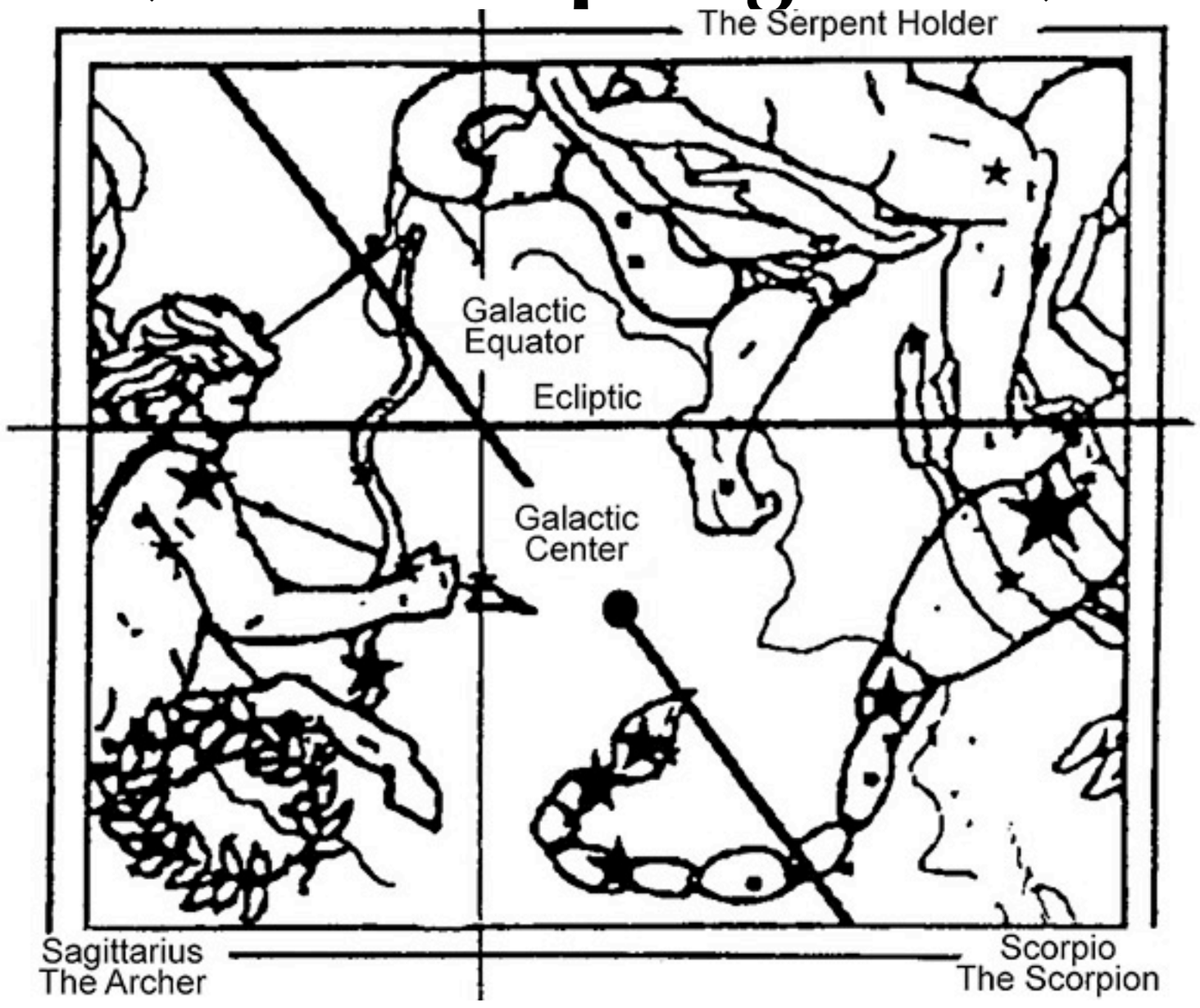
Indirect DM (→WIMP) searches (status ~ Spring 2015)



Gabrijela Zaharijas

University Nova Gorica

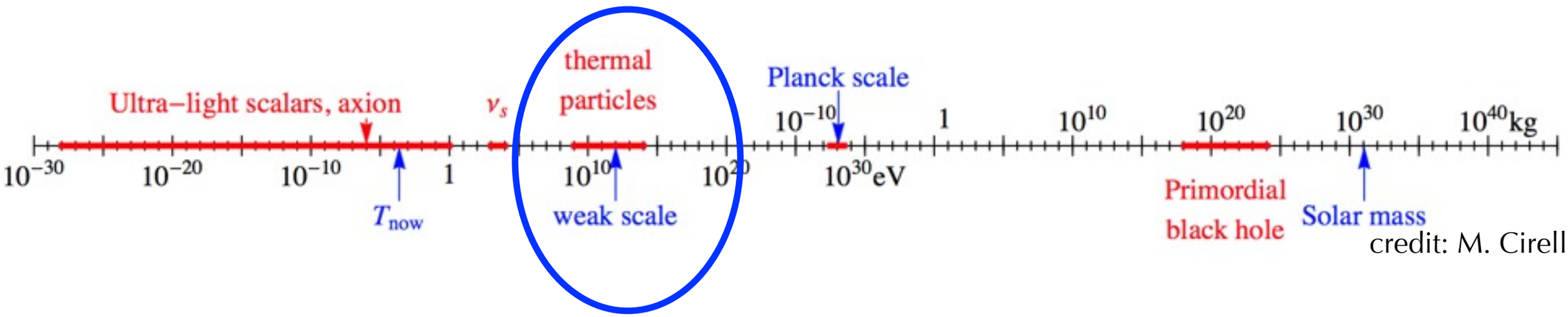
Portotoz2015: Particle phenomenology from early Universe to high energy colliders

Focus on WIMPs

weak-scale mass + weak interactions → if in thermal equilibrium have automatically the correct abundance + the right properties for DM
(caveats...)

- **theoretical bias**: "a simple, elegant, compelling explanation for a complex physical phenomenon" (R. Kolb)

- ***Large experimental effort and bulk of this talk -*** *Disclaimer: the field is much richer.*



credit: M. Cirelli

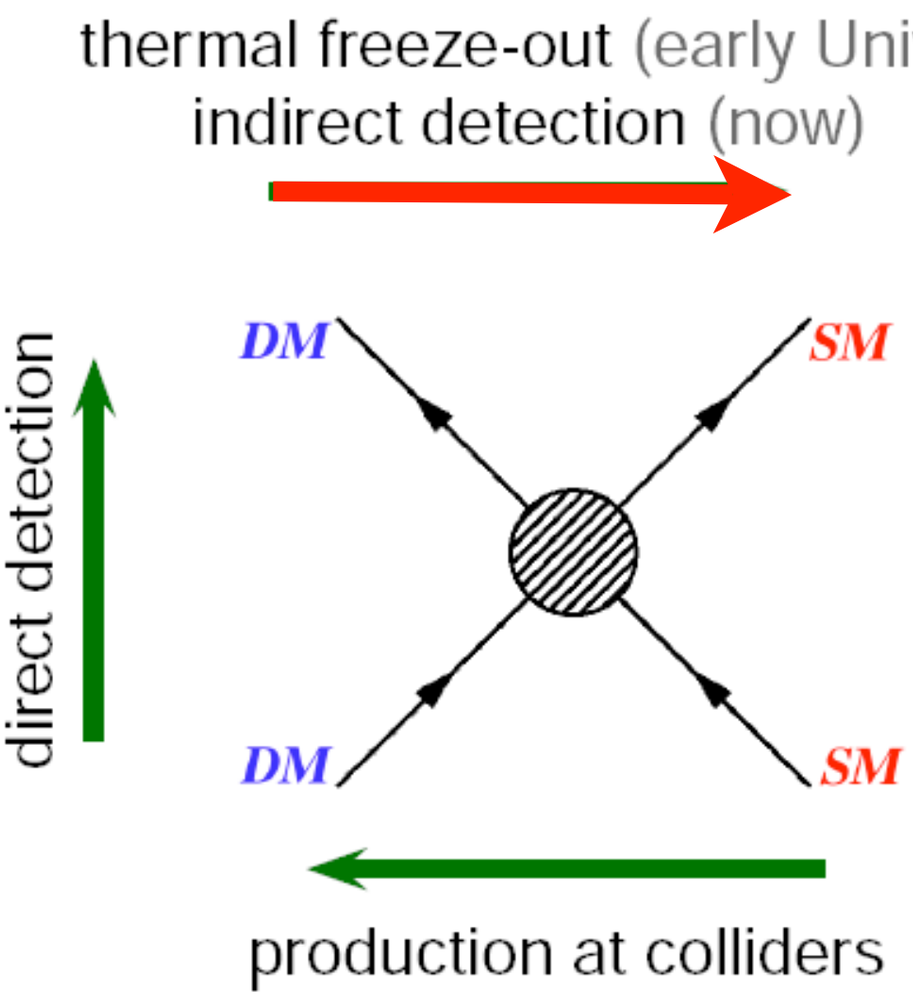
- WIMP hypothesis is **predictive**:

Dark Matter Abundance from Thermal Production

$$\Omega_{dm} = 0.23 \times \left(\frac{10^{-26}\ \mathrm{cm}^3 \cdot \mathrm{s}^{-1}}{\langle \sigma v \rangle} \right)$$

Cosmological Measurement

Weak Scale Physics



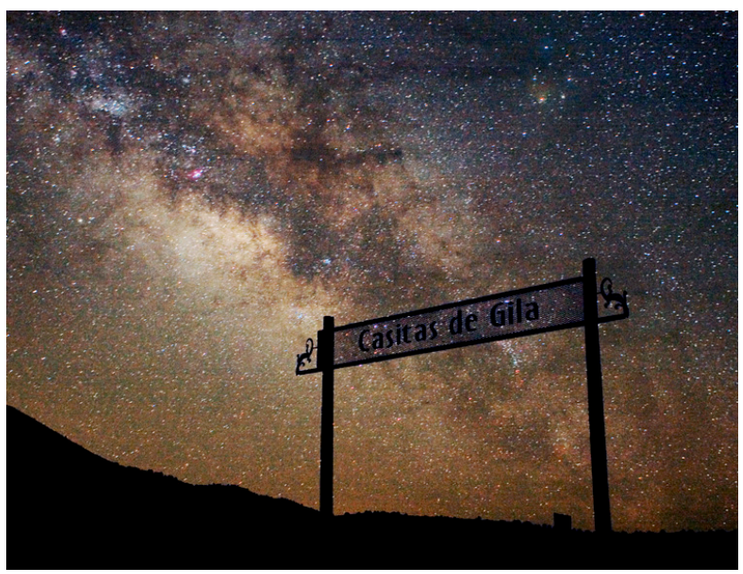
decay →

γ,
ν,
$e^{\pm}$,
$p^{\pm}$
D^{-}

In the Early Universe: DM kept in equilibrium w SM by self-annihilations $\langle \sigma v \rangle_{thermal}$.

Today, *DM expected to annihilate with the same* $\langle \sigma v \rangle_{thermal}$, *in places where its* **density is enhanced**!

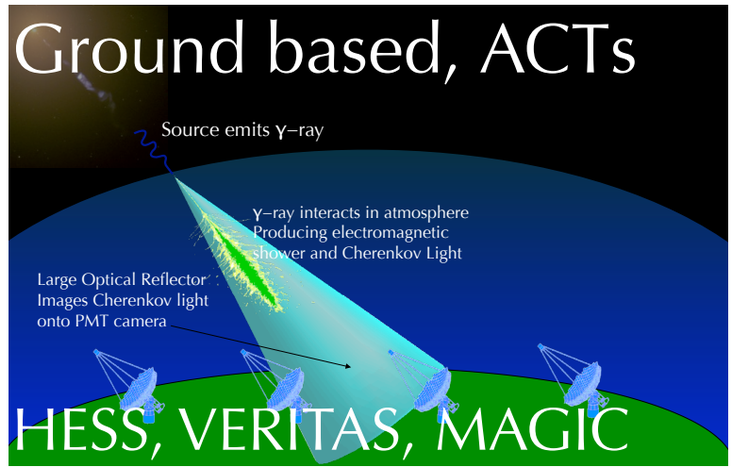
@ $\leq M_Z$



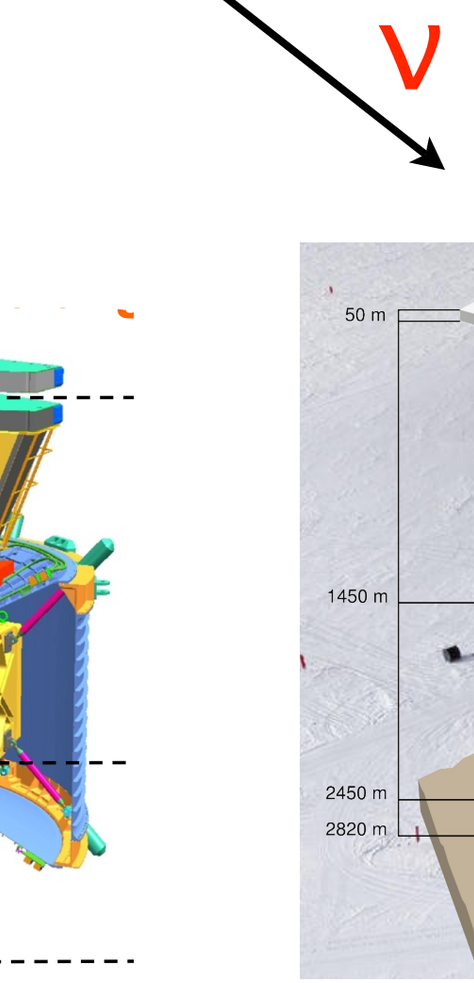
in astrophysical systems - *remotely*

and now we have powerful tools

@ M_Z

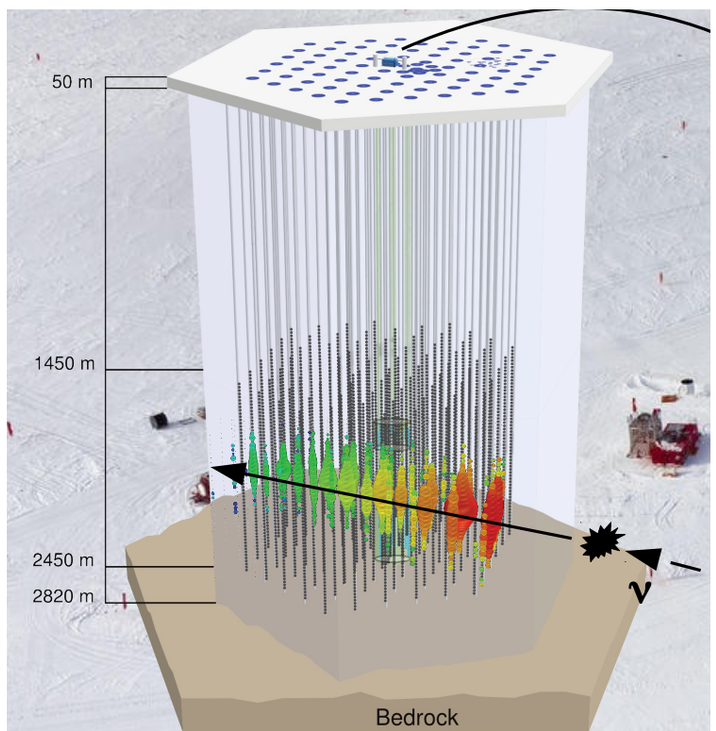


$e^{\pm}$, $p^{\pm}$, D^{-}



PAMELA, AMS02

ν



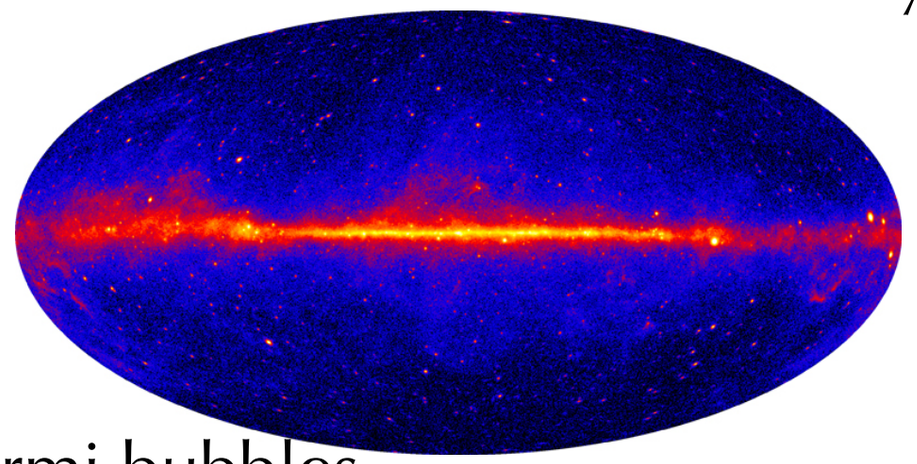
Ice Cube, ANTARES

Astrophysical experiments: multipurpose experiments w rich scientific program

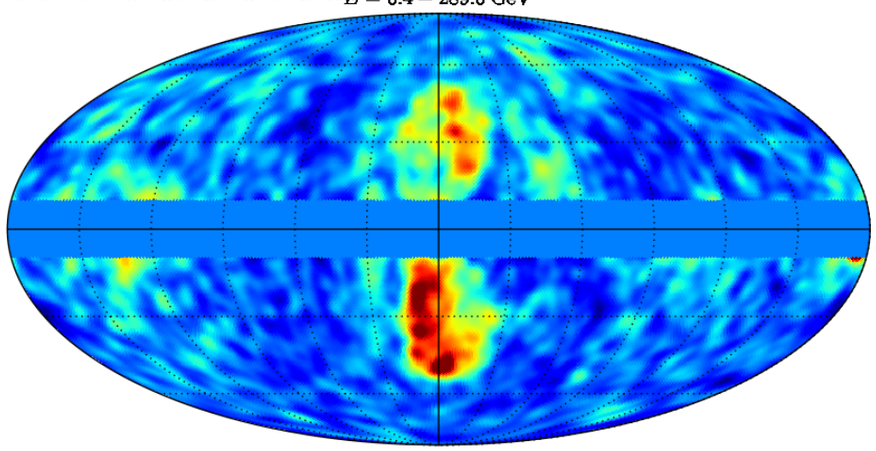
→ discovering the sky @>~Mz energies!

γ

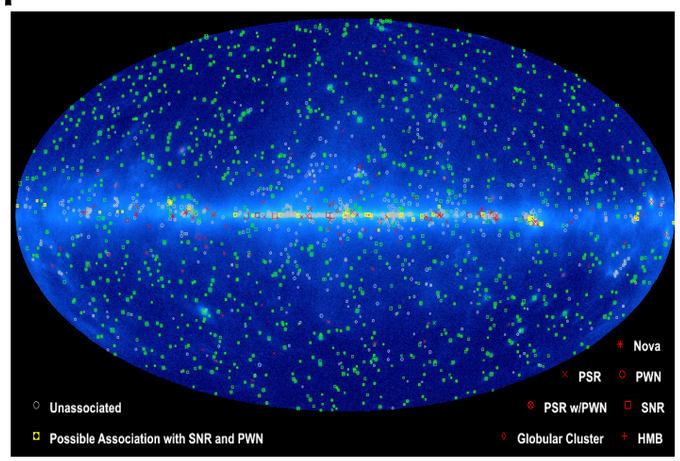
diffuse emission from our Galaxy:



Fermi bubbles

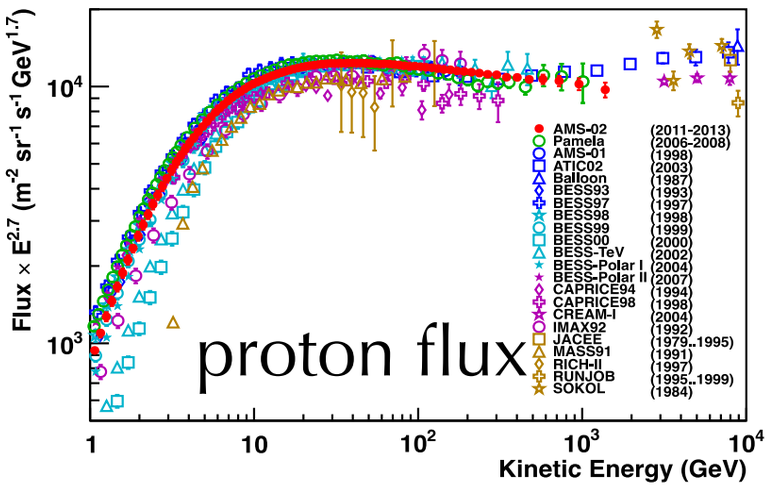


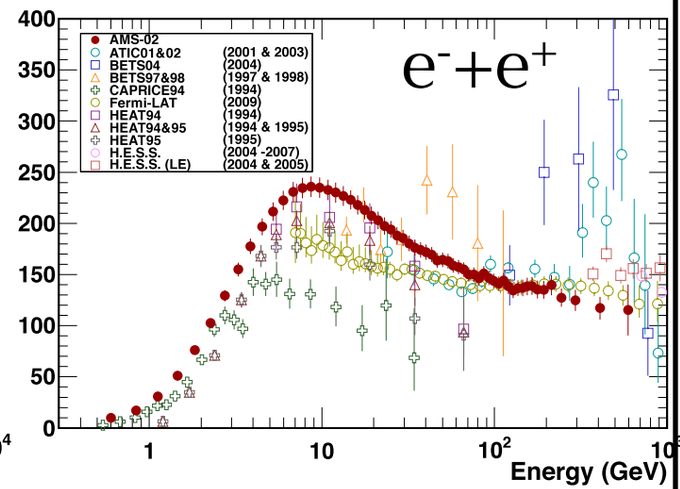
~3000 point sources



charged cosmic rays

New AMS results:



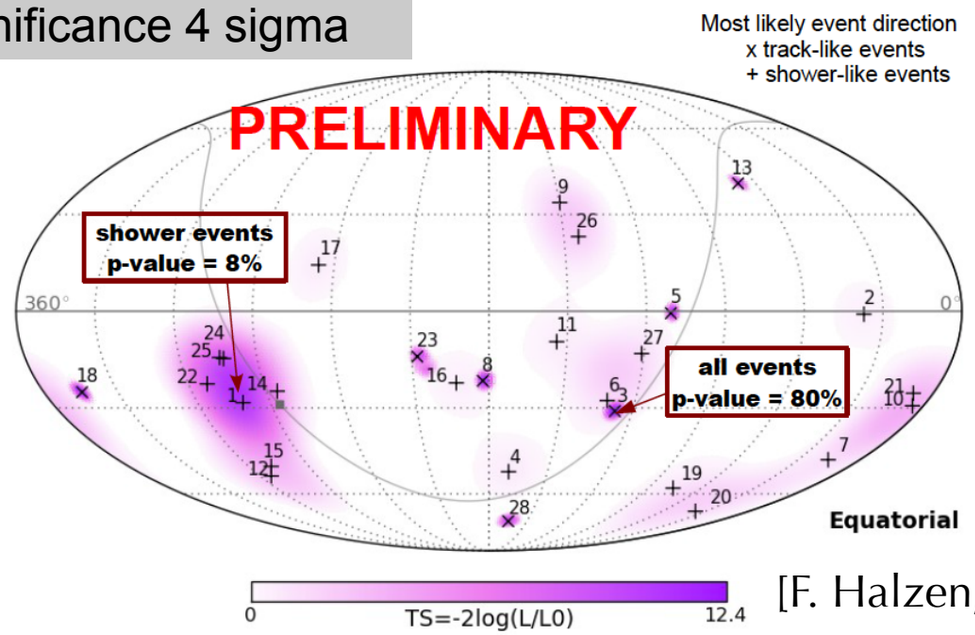


[S. Ting, ICRC 2013]

ν

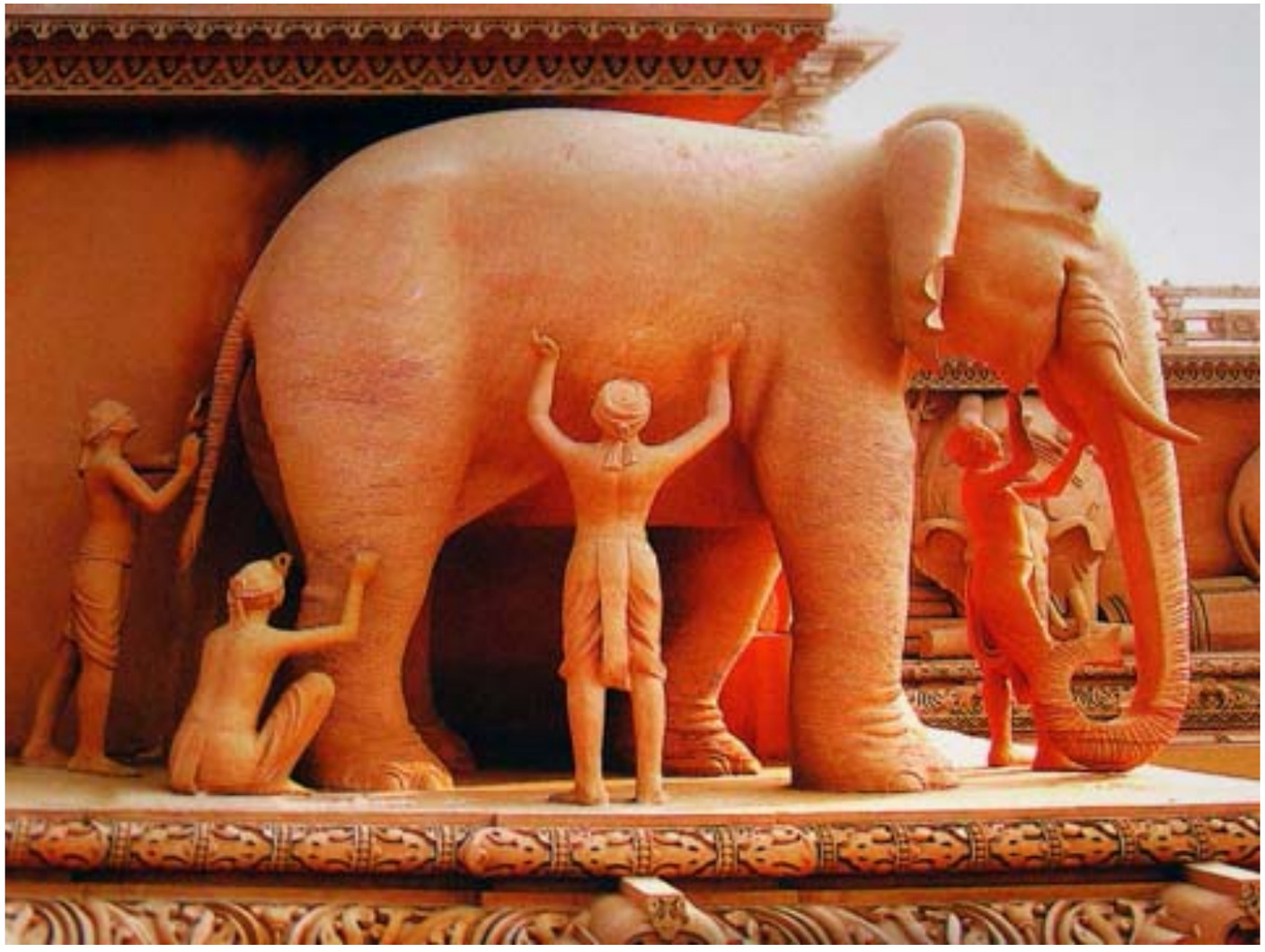
First detection of astrophysical neutrinos!

- 28 events above 10 TeV
- significance 4 sigma



[F. Halzen, ICRC 2013]

- **Why** indirect searches?
  - direct detection and collider searches are cleaner environments with ~'controlled' backgrounds
- **Important**:
  - to detect/measure DM **remotely**/in places where it was discovered
  - direct **link to early universe physics**
  - ideally: detect it in the Lab AND astrophysical objects → **multiple handle**.



- What are we after:

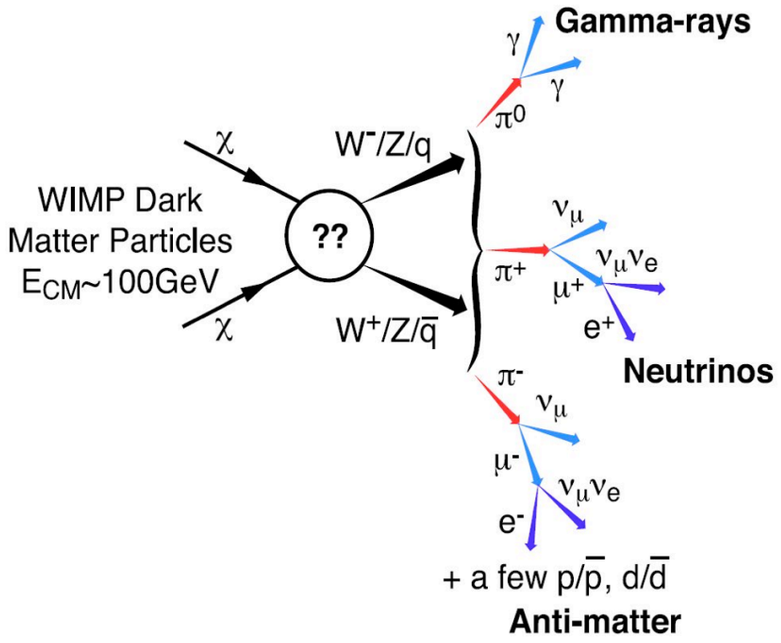
$$\frac{\mathrm{d}\Phi(\Delta\Omega, E_\gamma)}{\mathrm{d}E_\gamma} = \frac{1}{4\pi}\frac{(\sigma_{\mathrm{ann}}v)}{2\,m_\chi^2} \mathrm{X} \sum_i \mathrm{BR}_i \frac{\mathrm{d}N_\gamma^i}{\mathrm{d}E_\gamma} \quad \mathrm{X} \quad \int_{\Delta\Omega} d\Omega \int_{\mathrm{los}} \mathrm{d}s\, \rho^2(s, \Omega)$$

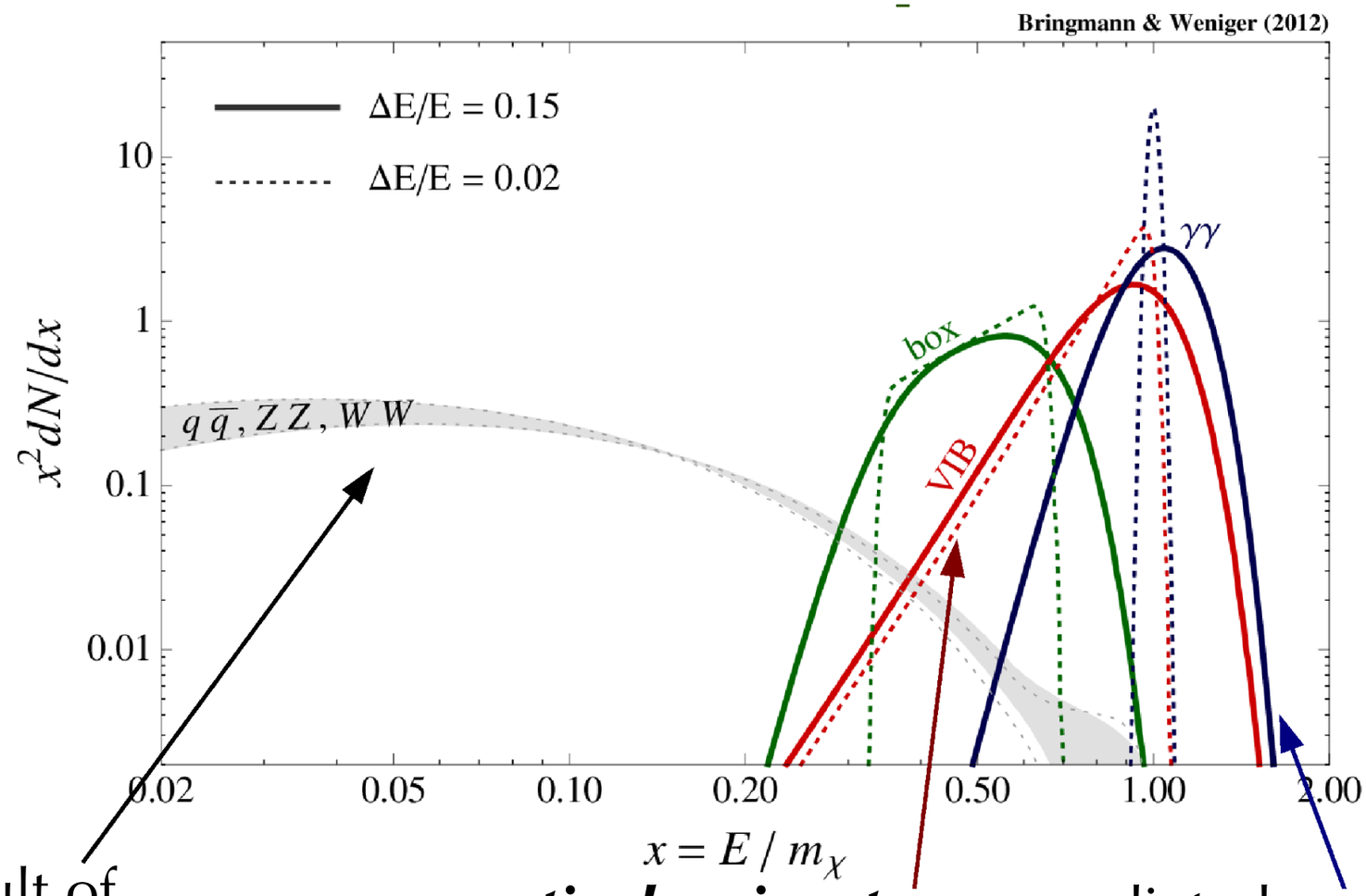
Particle physics: sets **spectrum** and ***overall normalization***

DM clustering: **morphology** and ***overall normalization***

- What are we after:

$$\frac{\mathrm{d}\Phi(\Delta\Omega, E_\gamma)}{\mathrm{d}E_\gamma} = \frac{1}{4\pi}\frac{(\sigma_{\mathrm{ann}} v)}{2\, m_\chi^2} \mathrm{X} \sum_i \mathrm{BR}_i \frac{\mathrm{d}N_\gamma^i}{\mathrm{d}E_\gamma} \quad \mathrm{X} \quad \int_{\Delta\Omega} d\Omega \int_{\mathrm{los}} \mathrm{d}s\, \rho^2(s, \Omega)$$





quasi-universal spectra as a result of fragmentation/hadronization and subsequent pion decays.

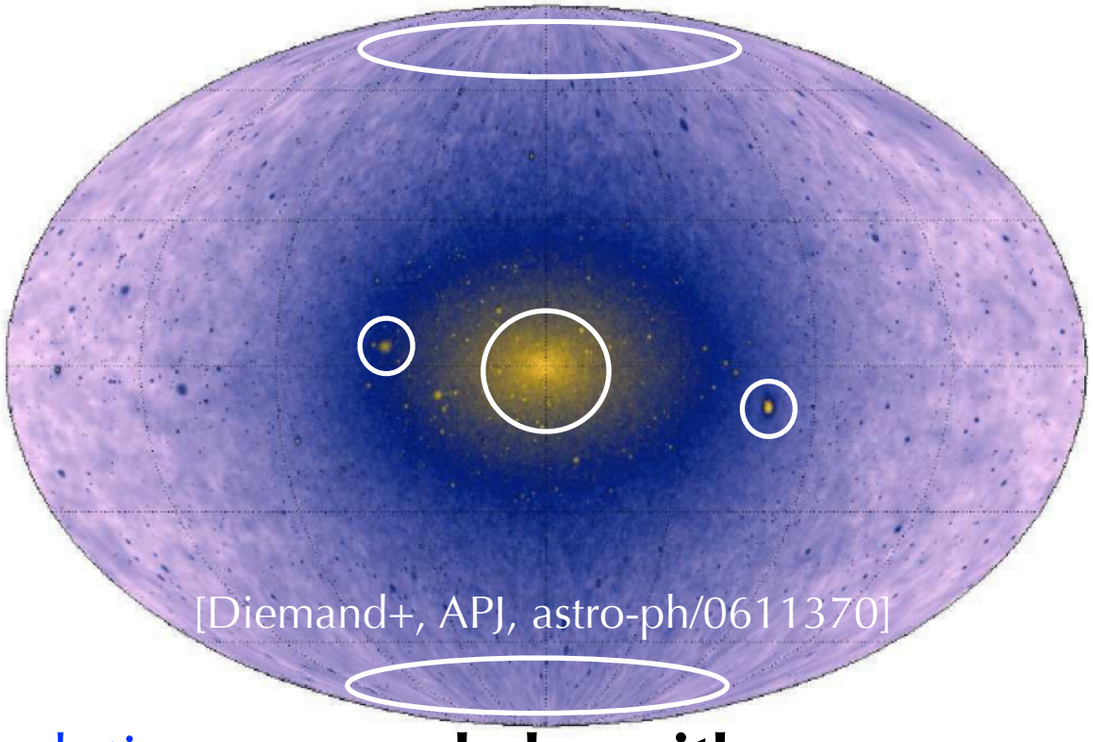
Determines early universe decoupling.

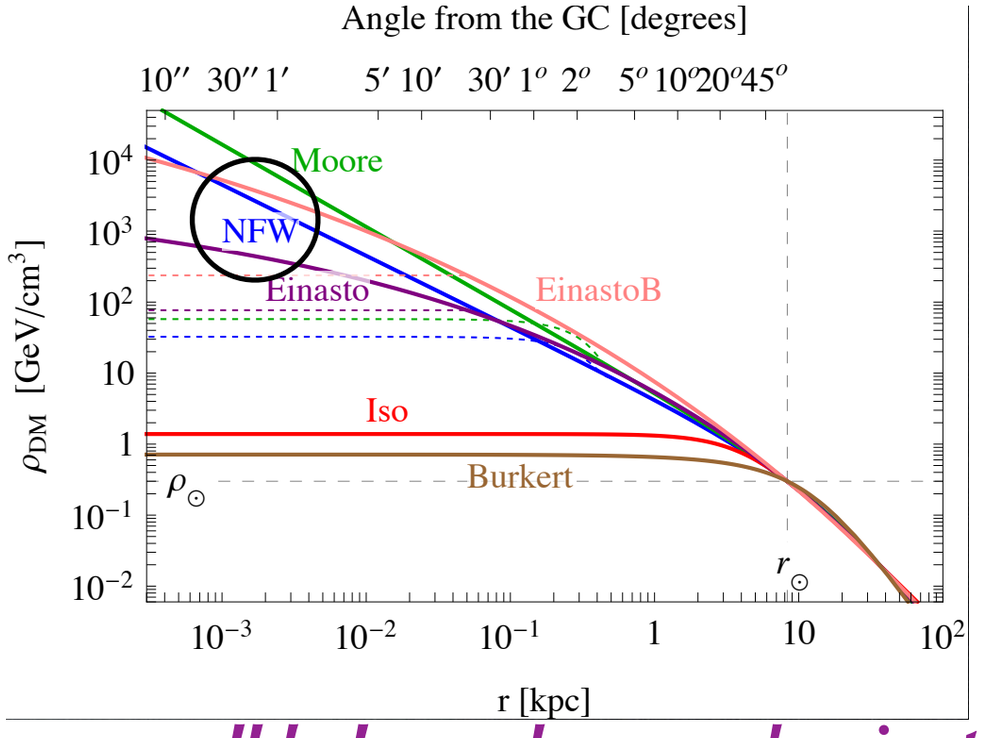
particular signatures predicted intensity model dependent, but hard to mimic with astrophysics.

- What are we after:

$$\frac{\mathrm{d}\Phi(\Delta\Omega, E_\gamma)}{\mathrm{d}E_\gamma} = \frac{1}{4\pi}\frac{(\sigma_{\mathrm{ann}}v)}{2\,m_\chi^2} \mathrm{X} \sum_i \mathrm{BR}_i \frac{\mathrm{d}N_\gamma^i}{\mathrm{d}E_\gamma} \quad \mathrm{X} \int_{\Delta\Omega} d\Omega \int_{\mathrm{los}} \mathrm{d}s\, \rho^2(s, \Omega)$$

-> **Where to look?** γ and ν propagate in a straight line, unaffected by Galaxy - DM clustering map is a good guide to observational targets.





Simulations: **cuspy halos with numerous substructure**; ***small halos or baryon dominated regions* cannot (yet) be probed reliably.**

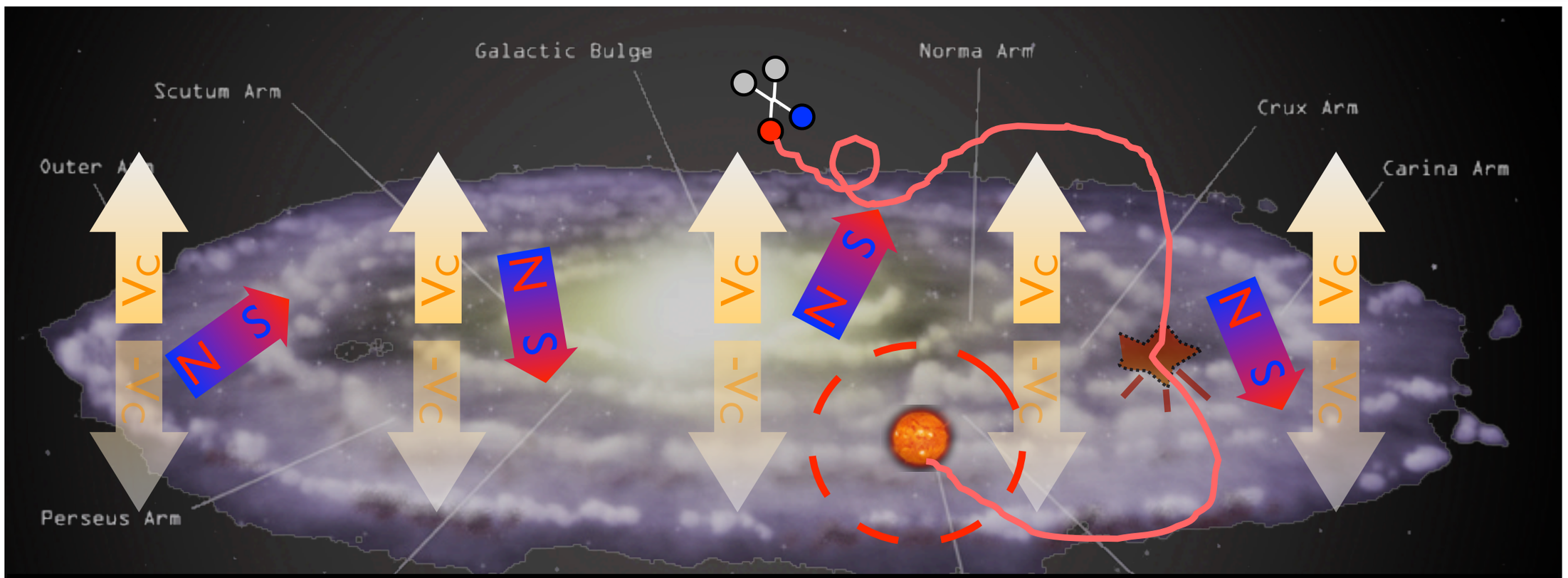
Observations: measure tracers of gravitational potential: fail in ***small halos or baryon dominated regions.***

Considerable uncertainties for most of searches.

- charged CR:
- a more complicated story/ less ‘clean’ channel
- CRs propagate diffusively entangled in Galactic magnetic fields - signal depends also on *diffusion/energy losses/* in the Galaxy - probe **local volume**.

$$\frac{\mathrm{d}\Phi(\Delta\Omega, E_\gamma)}{\mathrm{d}E_\gamma} = \left(\frac{1}{4\pi} \frac{(\sigma_{\mathrm{ann}} v)}{2\, m_\chi^2} \mathrm{X} \sum_i \mathrm{BR}_i \frac{\mathrm{d}N_\gamma^i}{\mathrm{d}E_\gamma} \quad \mathrm{X} \int_{\Delta\Omega} d\Omega \int_{\mathrm{los}} \mathrm{d}s\, \rho^2(s, \Omega) \right)$$

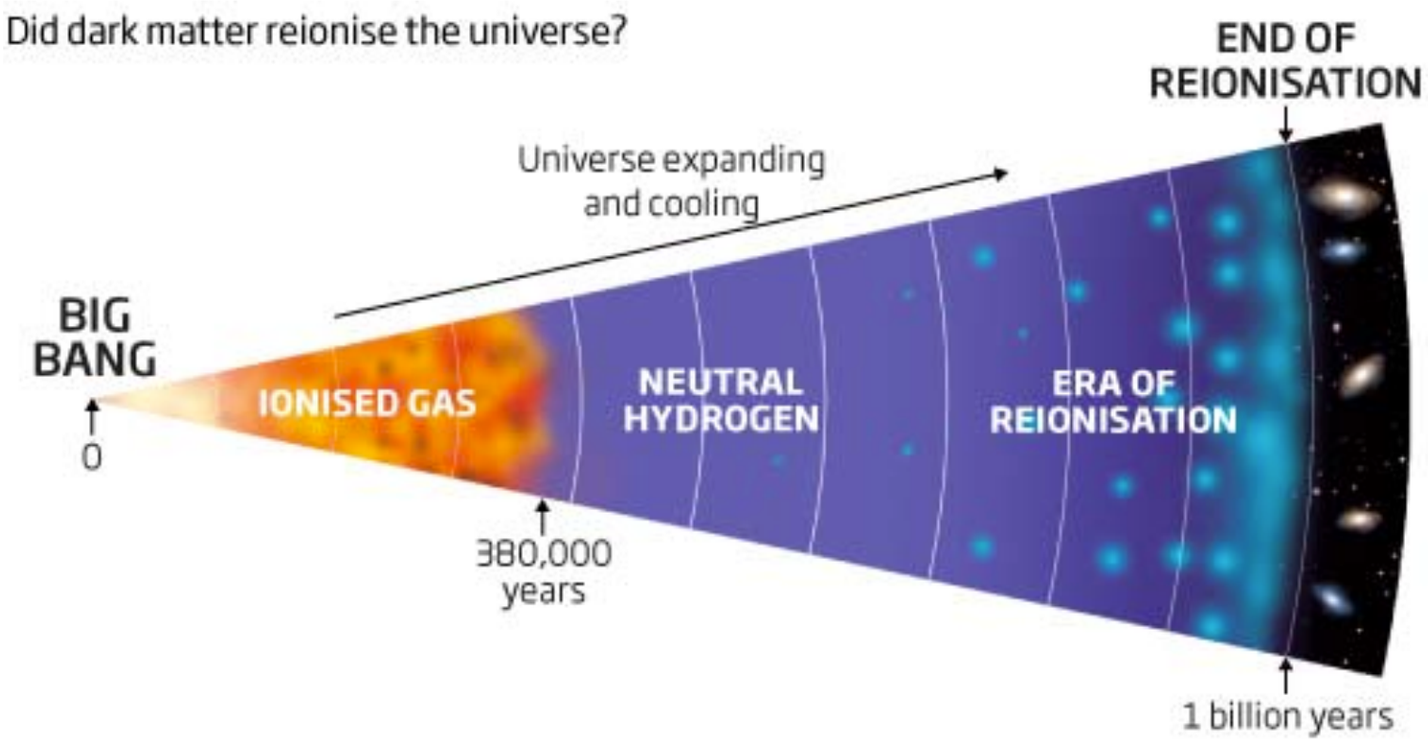
astrophysics

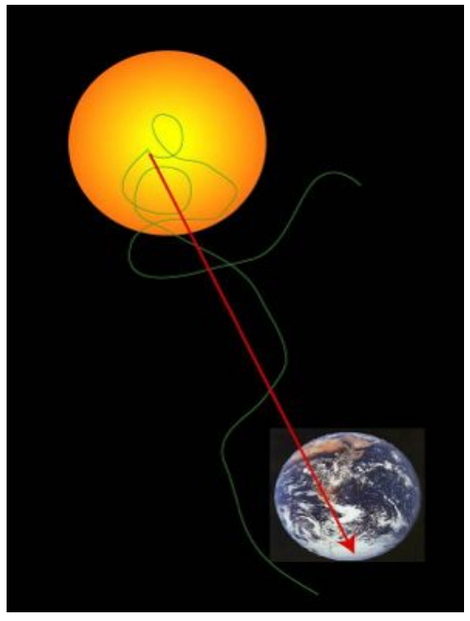


- Strategy: *look for **anti particles** as the backgrounds are lower!*

-> Where (else) to look?

- **back in time:** DM ann/decays inject energy and charge particles in the early universe and could affect its evolution:
  - ***BBN*** (T~1 MeV): energy injections could destroy formed nuclei
  - ***CMB*** (z ~ 1000): The increased ionization fraction leads to a broadening of the last scattering surface.
  - ***re-ionization*** ($6 < z < 20$): ionization and heating after recombination and during the epoch of structure formation affect optical depth of the Universe.
- **inside of stars:** ν can escape from systems in which other messengers are trapped. i.e. Sun or Earth! Note: relevant also for axions: light/weakly coupled/neutral degrees of freedom.
- **...**



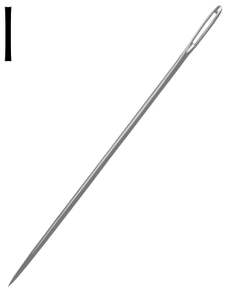


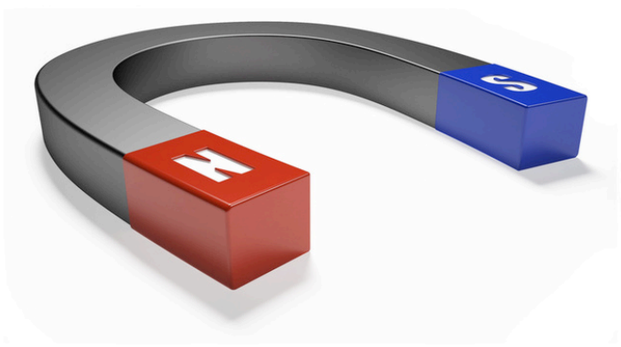
Bigger picture:

(most of) the astro-signals we measure DO NOT look like the ones expected from DM.

Challenge:

look for an uncertain signal swapped in the uncertain backgrounds.





[J. Siegal-Gaskins talk@Sackler colloquium 2012]

Possible detection paths:

A) look for ***smoking guns***:

➡ 'zero' astro backgrounds, but need luck -- expected signals (for vanilla DM) low

- **Milky Way dwarf spheroidal galaxies**
- spectral line features
- anti-deuterium
- Sun (neutrinos) - elastic cross section

B) search for ***most promising WIMP signatures*** and ***use rich astro data to model the backgrounds***

➡ current experimental **sensitivity in the right ballpark for vanilla models, but due to confusion with astro backgrounds possible hints NEED confirmation** across the range of ***wavelengths/messengers/targets***

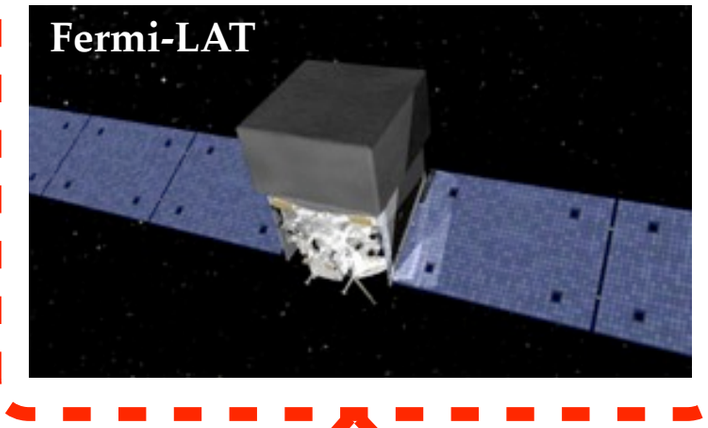
- **Galactic Center GeV excess and 'multi' constraints**

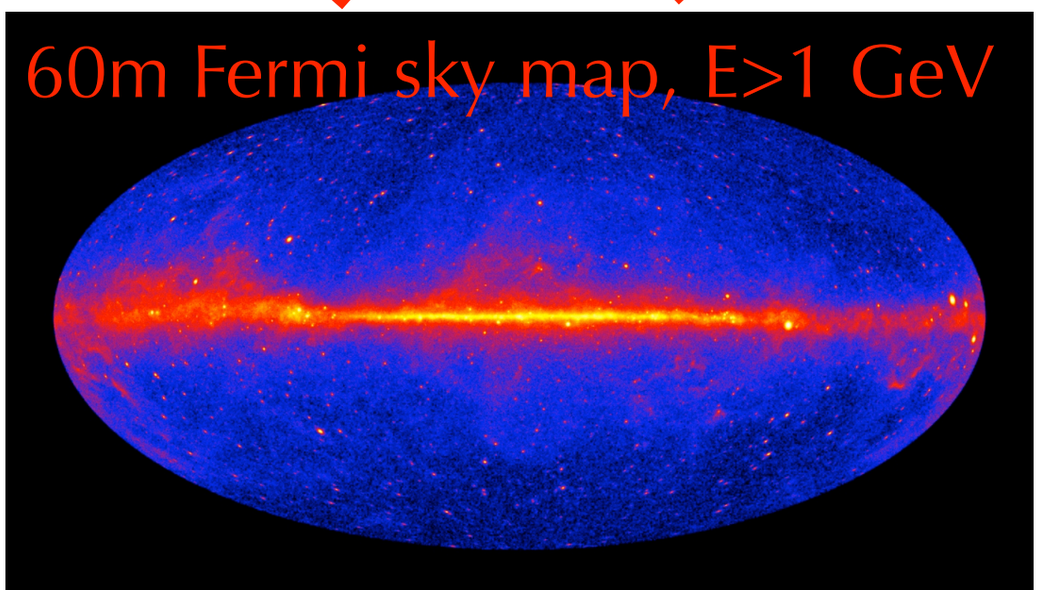
Galactic center gamma ray GeV excess

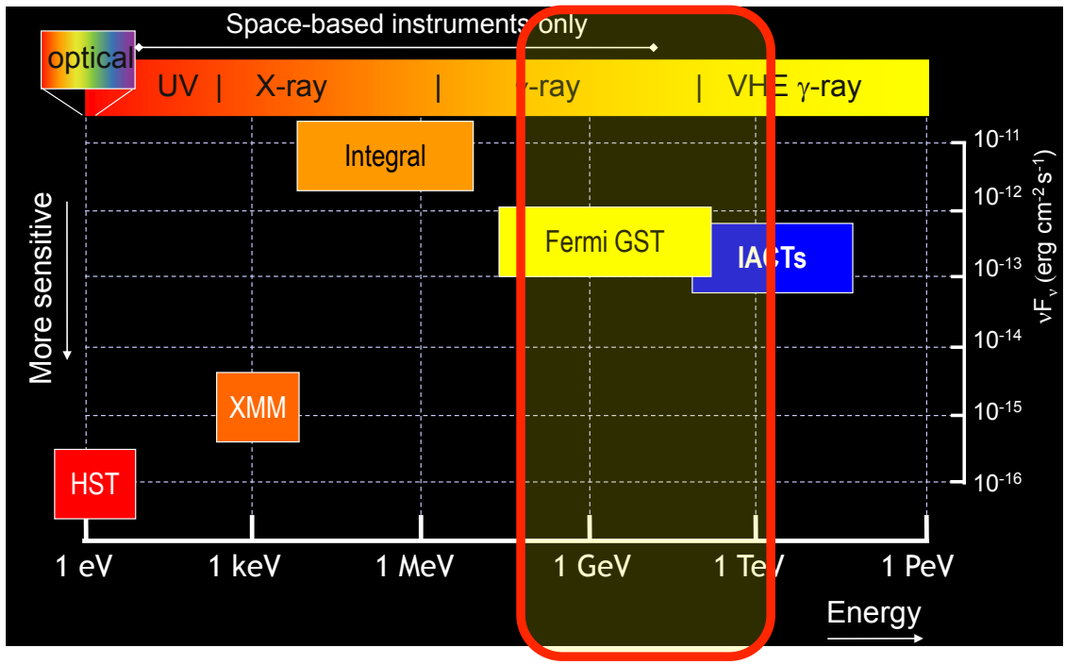
Fermi LAT - key features:

Large field of view: 20% of the sky at any instant!

Energy range: 20 MeV to >300 GeV (~M_Z), -ideally suited for WIMP searches.





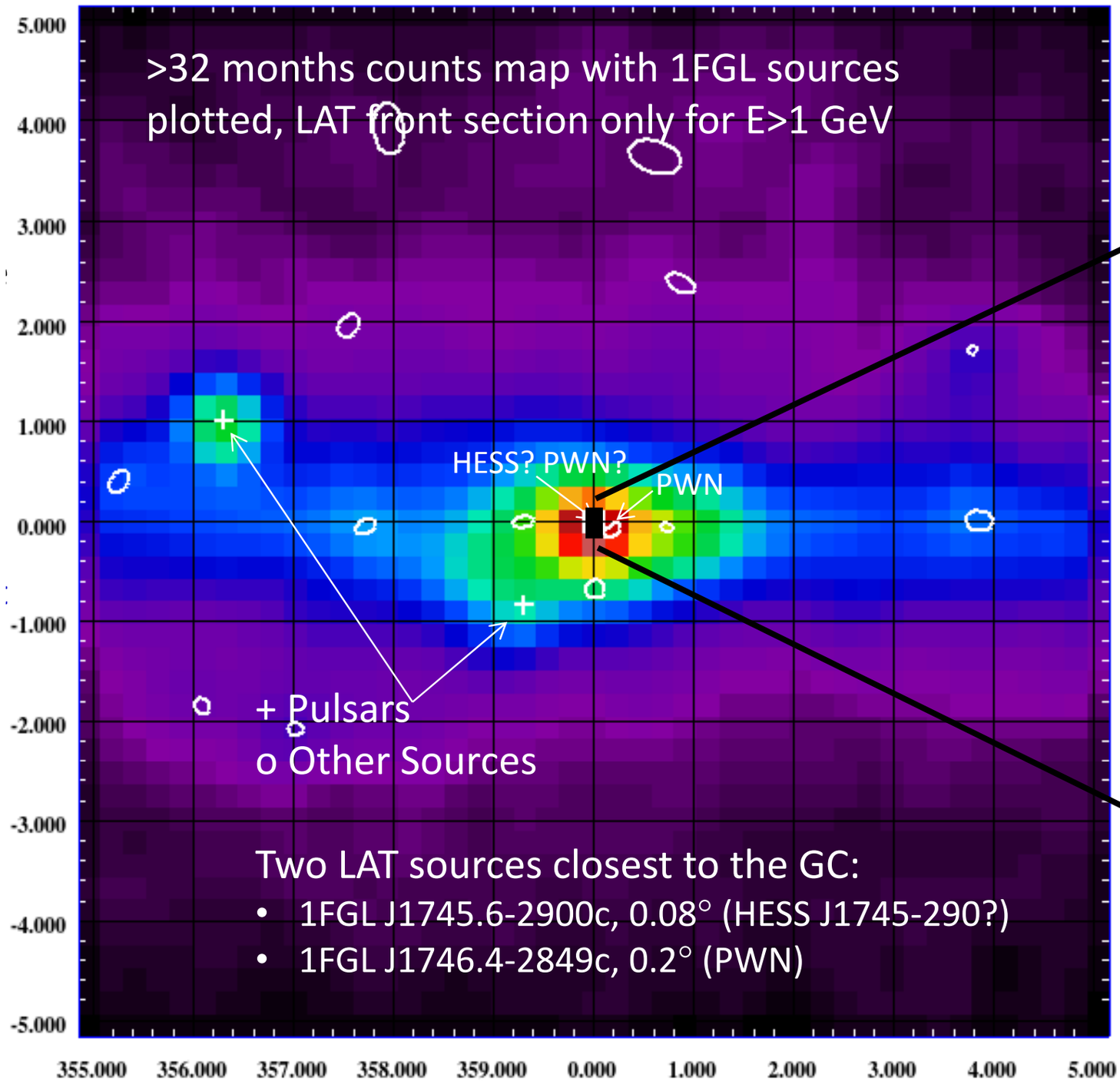


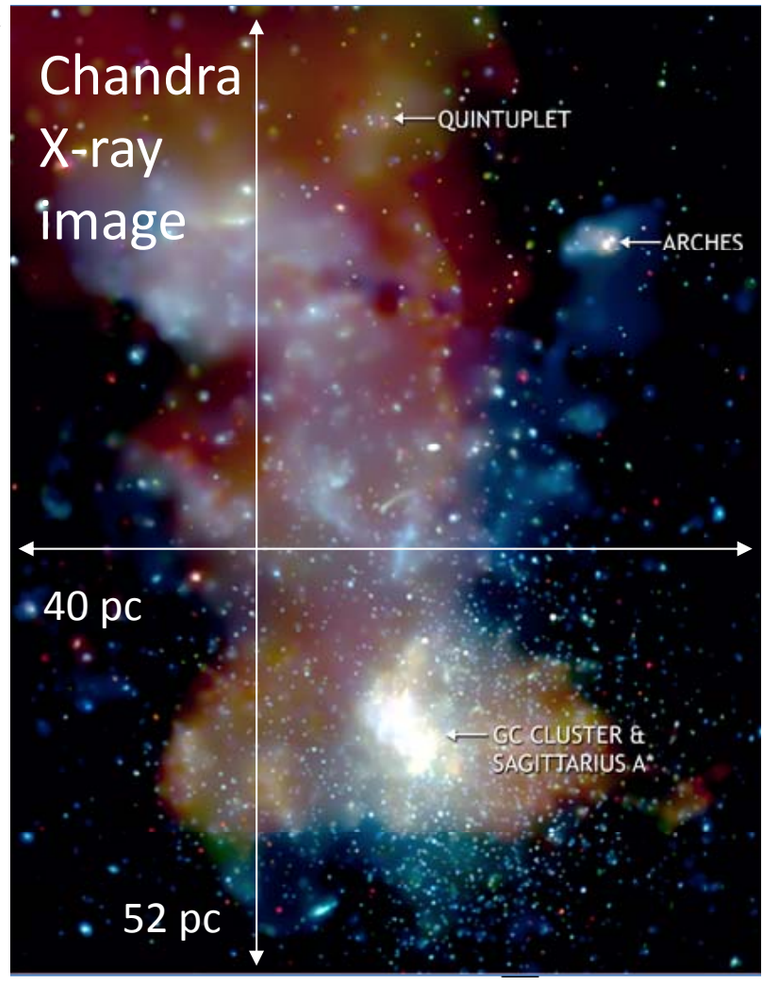
WIMP Mass Range

Good angular resolution ~ 0.1 deg (>10GeV) (radio telescopes arcsec!).

Galactic center GeV excess

- Galactic center - an obvious place to look for DM annihilation (potentially the highest J factors)!
- But this region also has the most complex astrophysical background.





[R. Johnson, TeVPA 2013.]

Galactic center GeV excess

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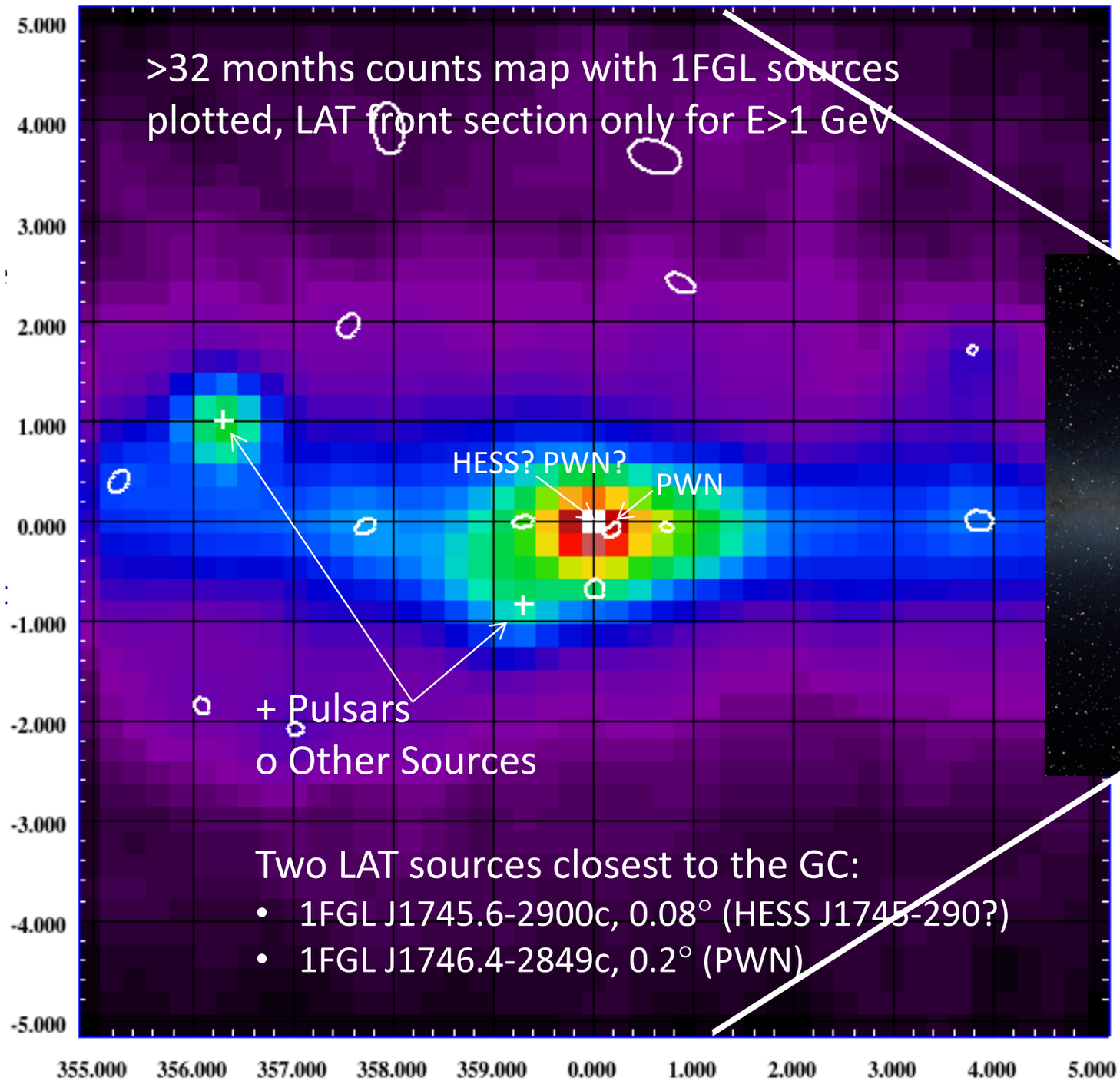
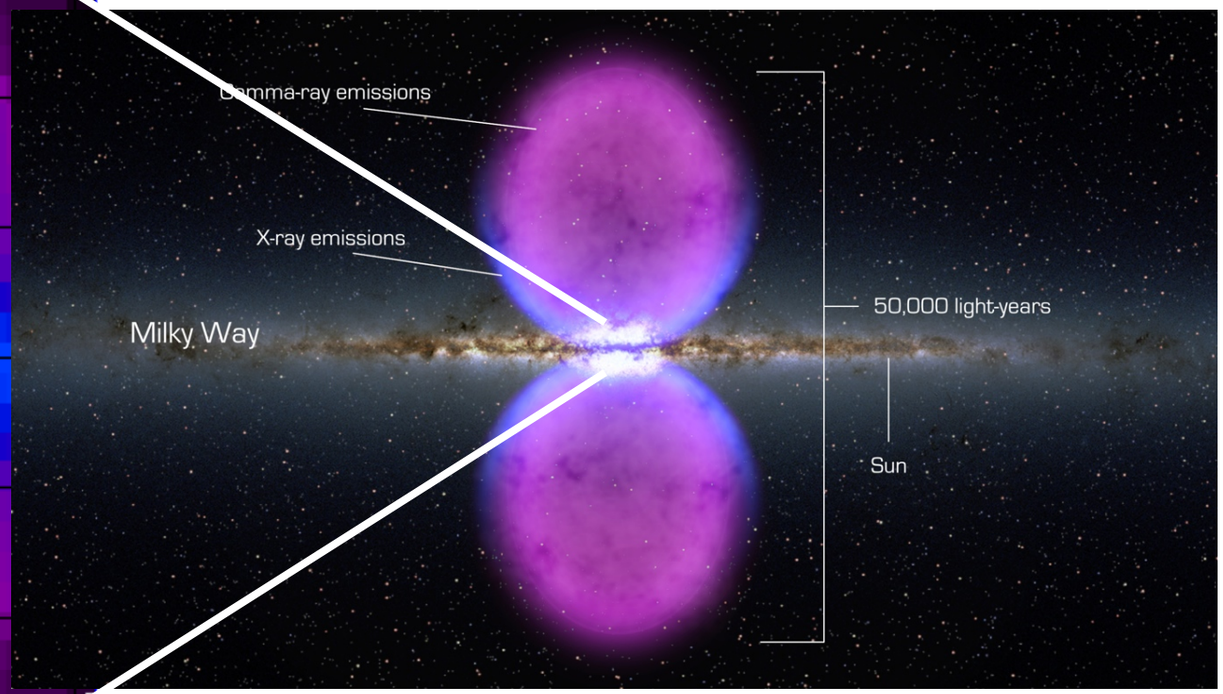
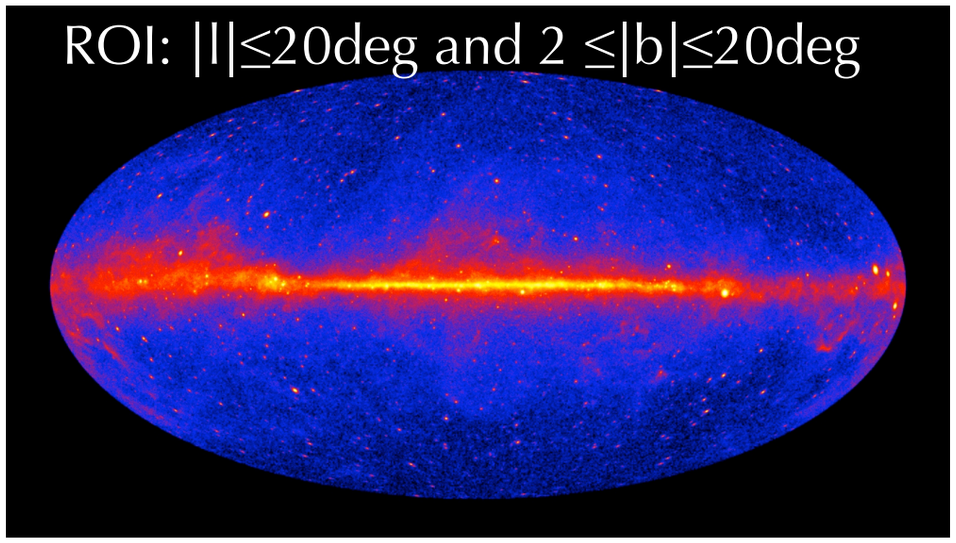




Galactic center GeV excess

Excess, with respect to what?



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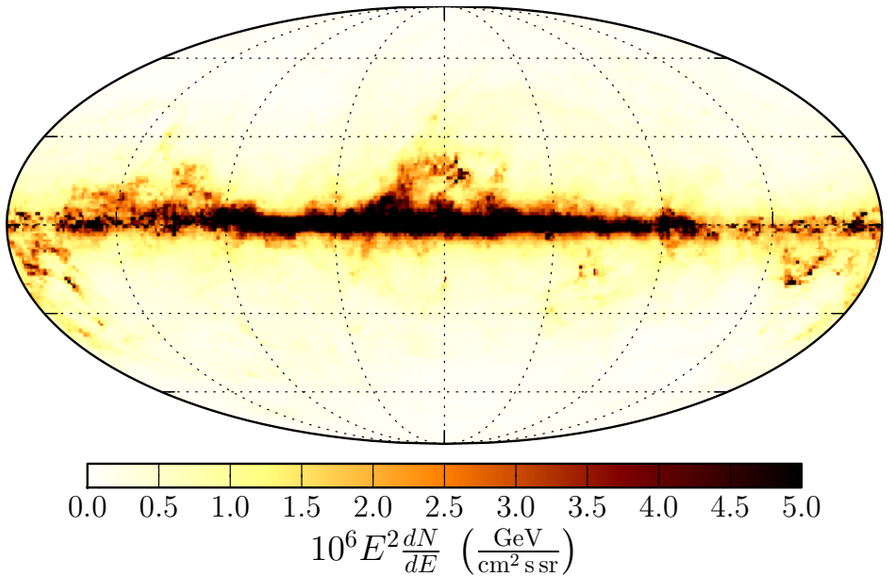
Milky Way plane emission -
modeled by sampling the parameter space of cosmic ray propagation



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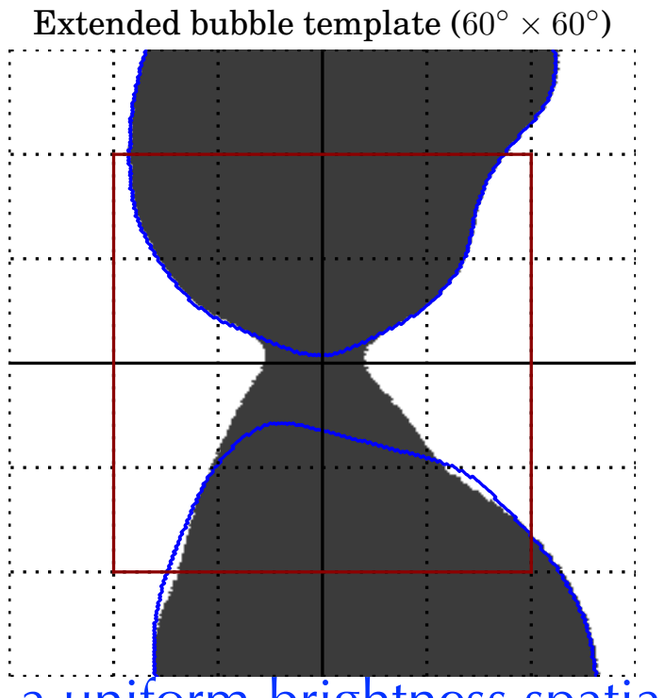
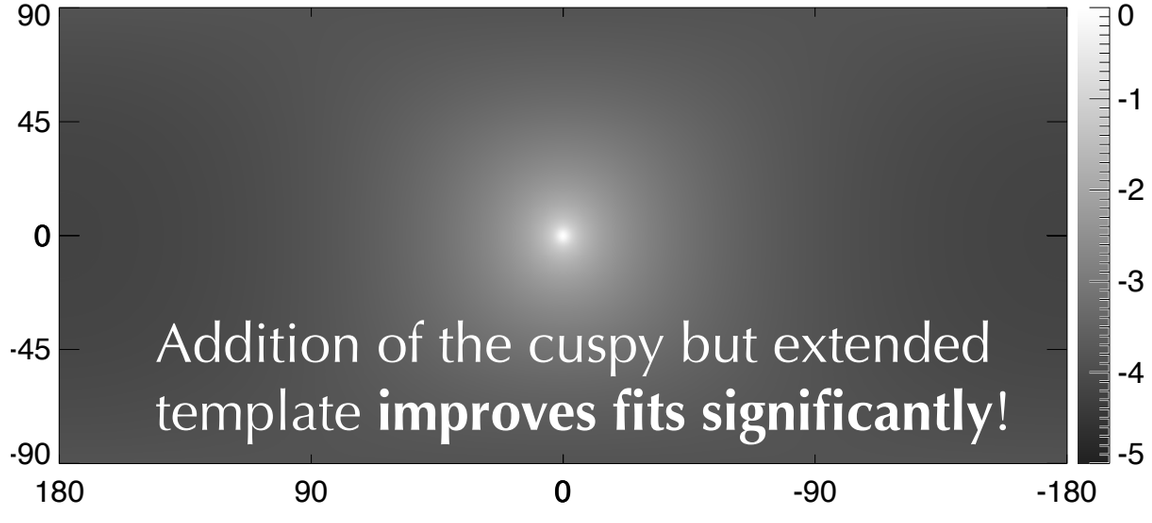


+ a uniform-brightness spatial template for the Fermi Bubbles

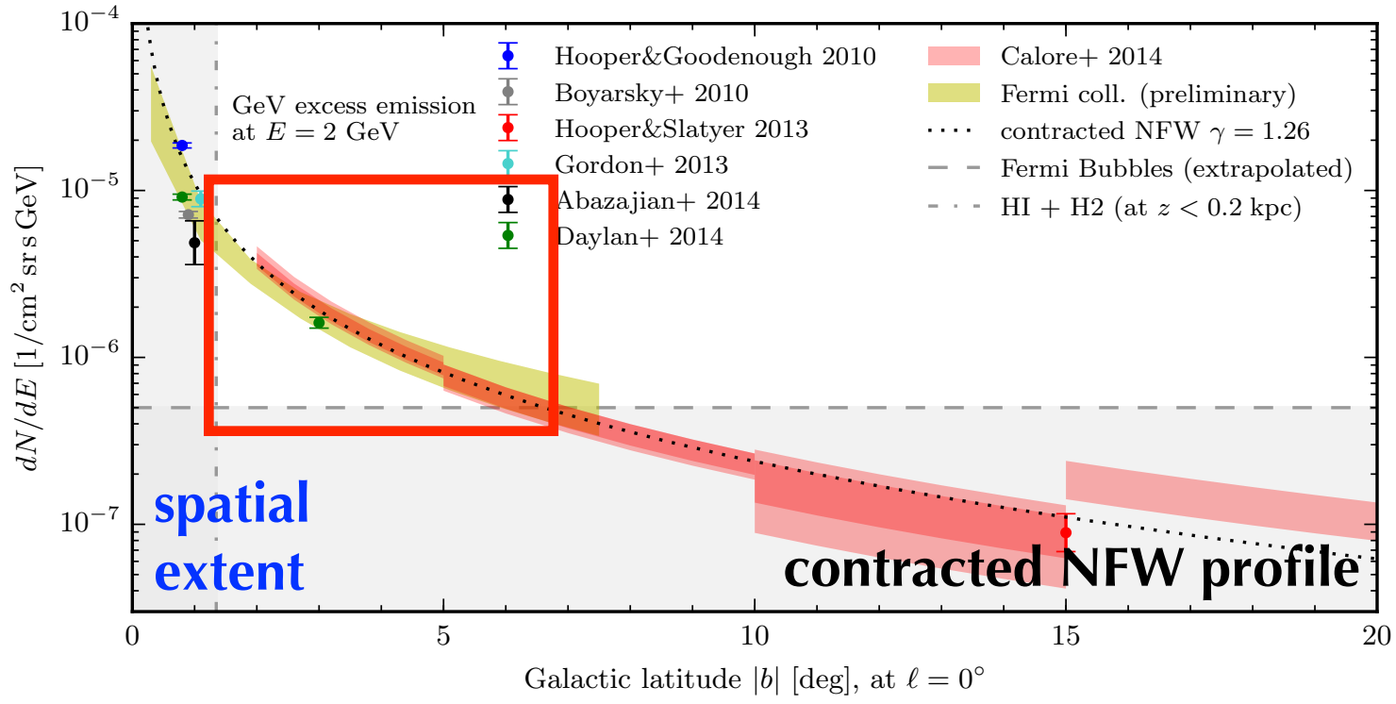
+



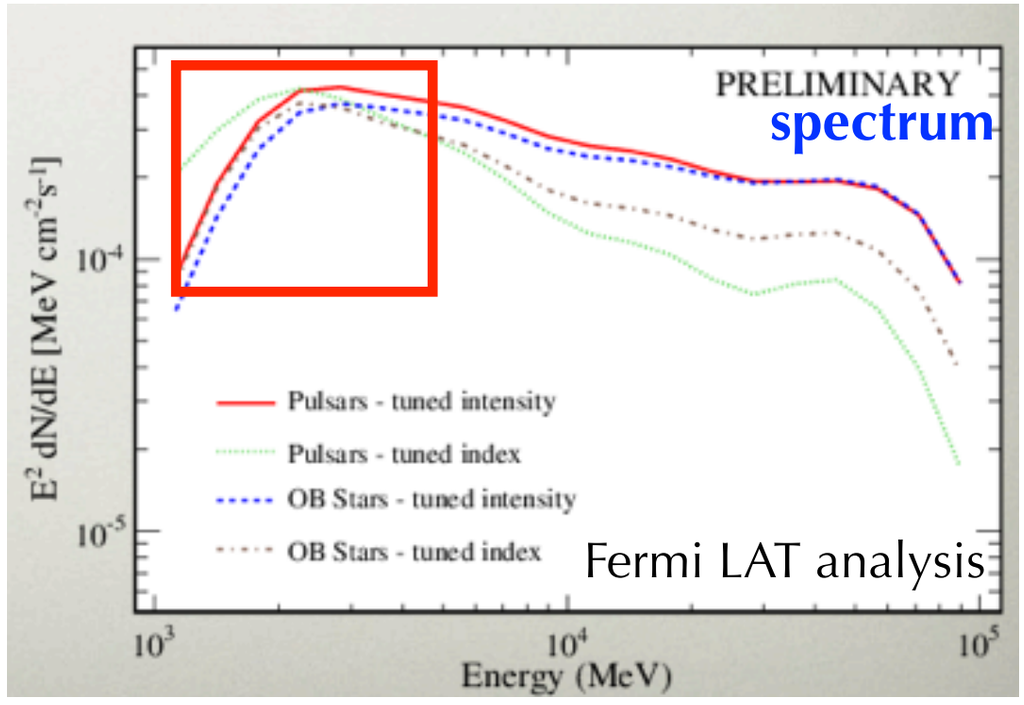
Calore+, 1409.0042

Galactic center GeV excess

Features: Spectra peaking at few GeV and extending up to 10 deg (~2 kpc)

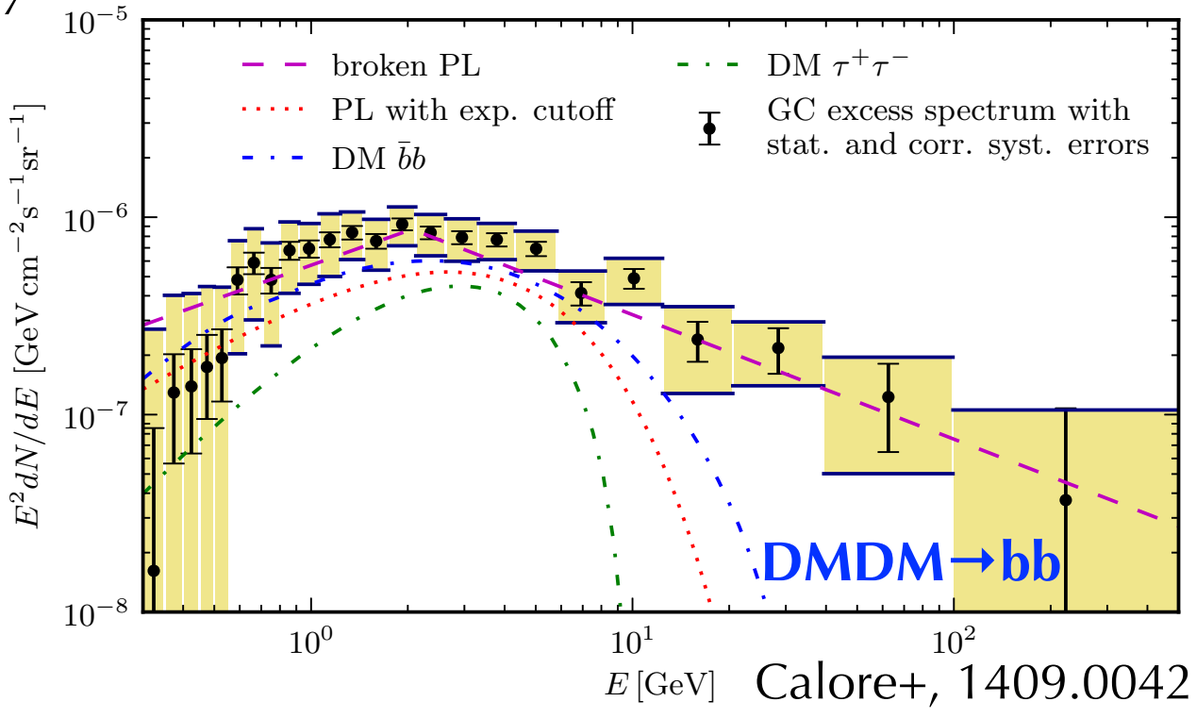


Calore+, 1411.4647



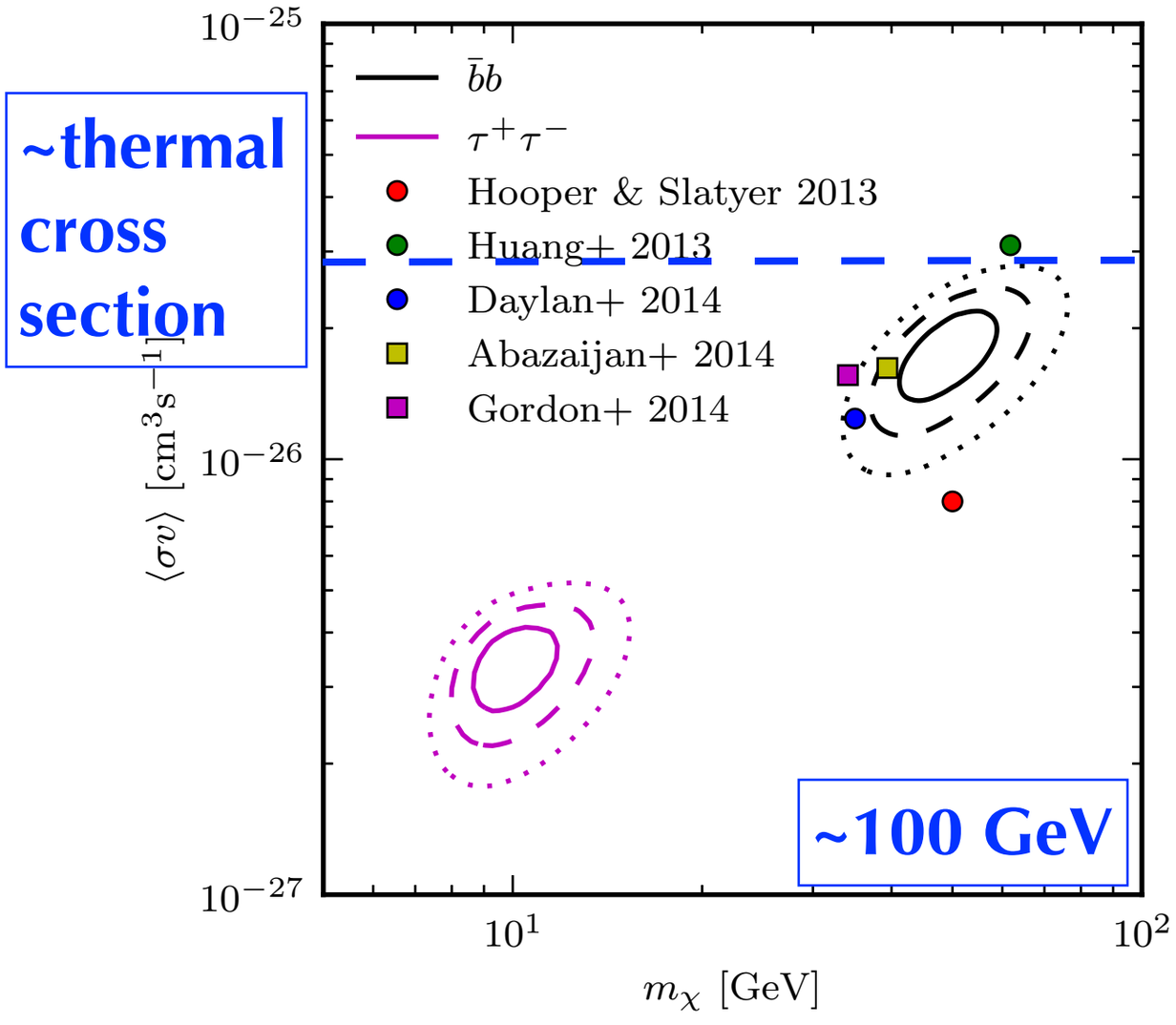
Many works reaching similar results:

Goodenough & Hooper (2009), Hooper & Goodenough (2011, PLB 697 412), Hooper & Linden (2011, PRD 84 12), Abazajian & Kaplinghat (2012, PRD 86 8), 1207.6047, Hooper & Slatyer (2013, PDU 2 118), 1302.6589 Gordon & Macias (2013, PRD 88 8) 1306.5725 Macias & Gordon (2014, PRD 89 6) 1312.6671, Abazajian et al. (2014, PRD 90 2) 1402.4090, Daylan et al. (2014) 1402.6703, 1407.5583 1407.5625 1410.1527



Calore+, 1409.0042

Galactic center GeV excess



Right on the spot where WIMP DM is supposed to be!

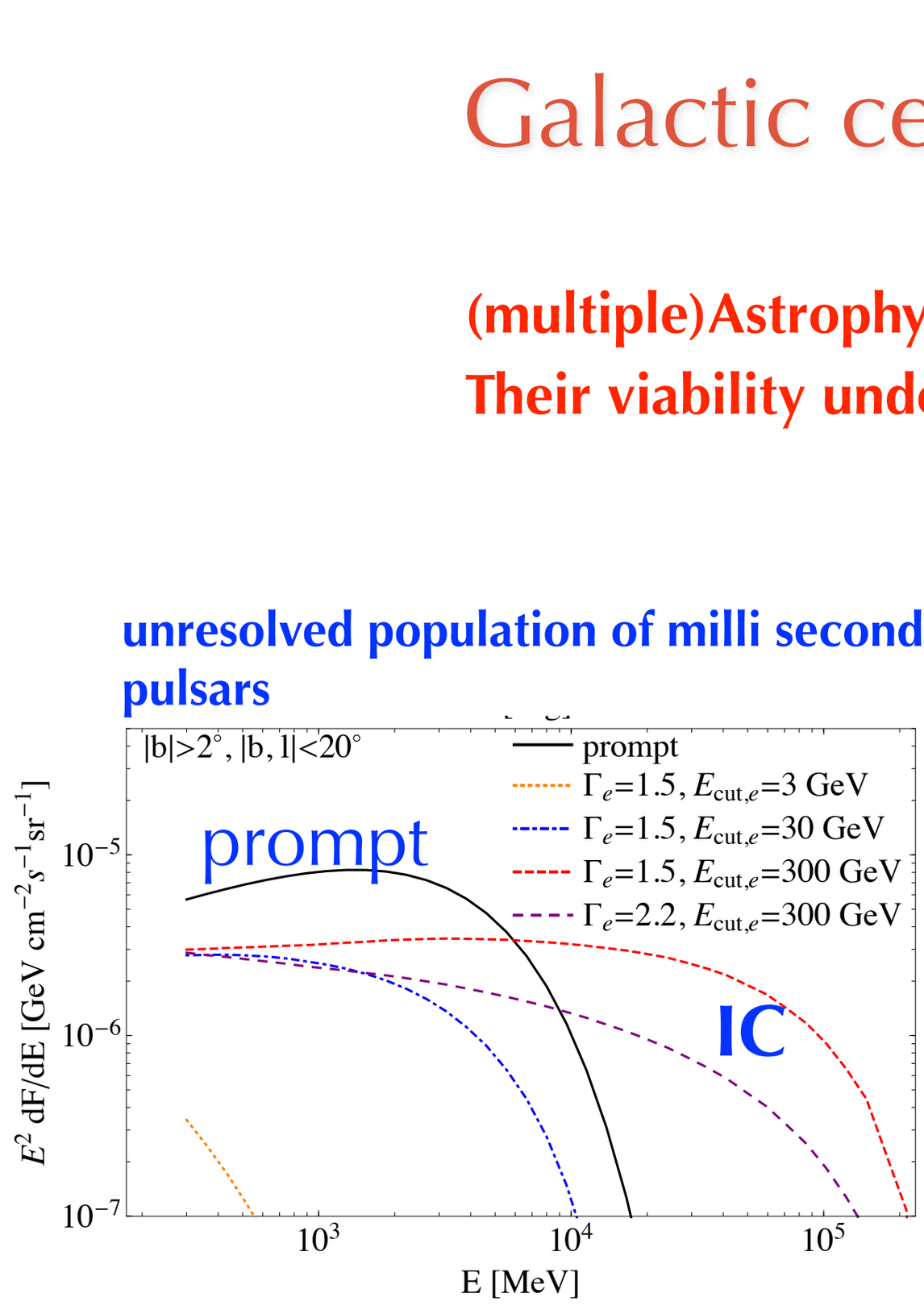
Thermal cross section & <~100 GeV & at the Galactic center

Galactic center GeV excess

(multiple)Astrophysical explanation do exist!

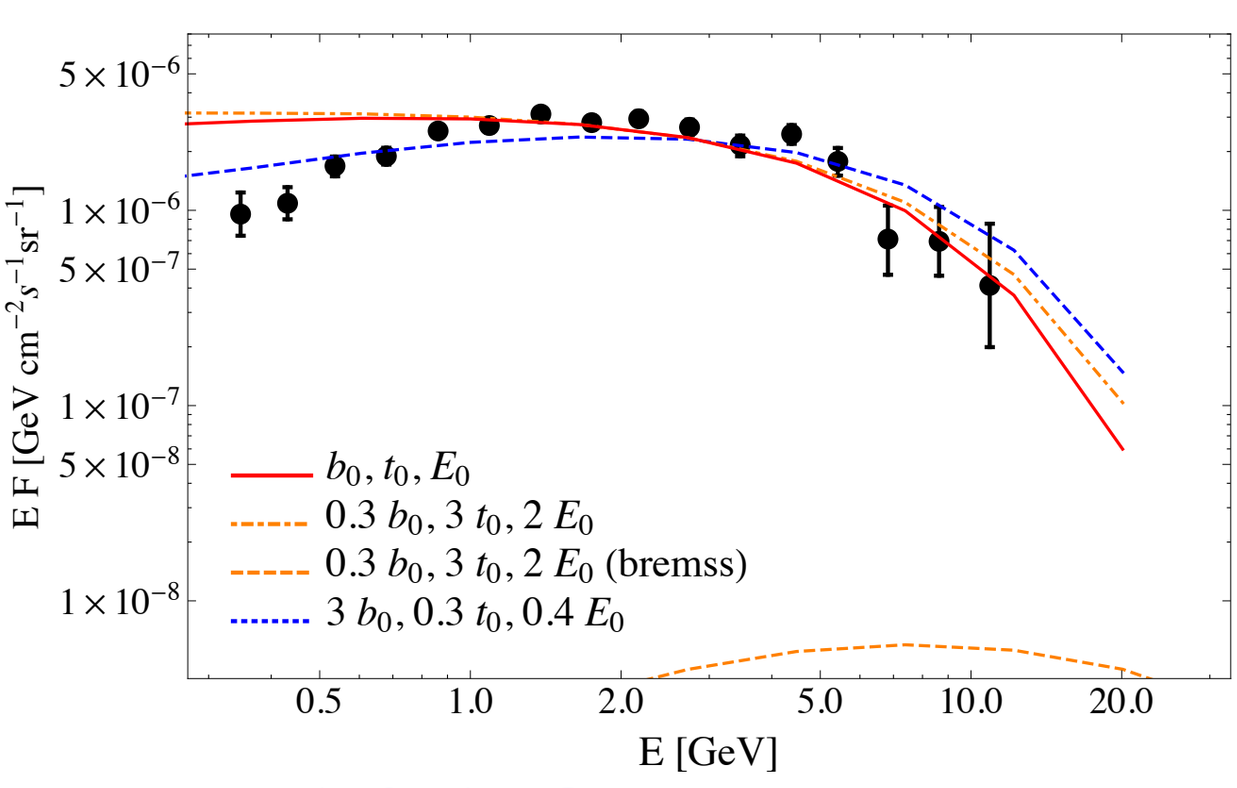
Their viability under debate.

unresolved population of milli second pulsars



Petrovic, Serpico, GZ,
JCAP,1405.7928

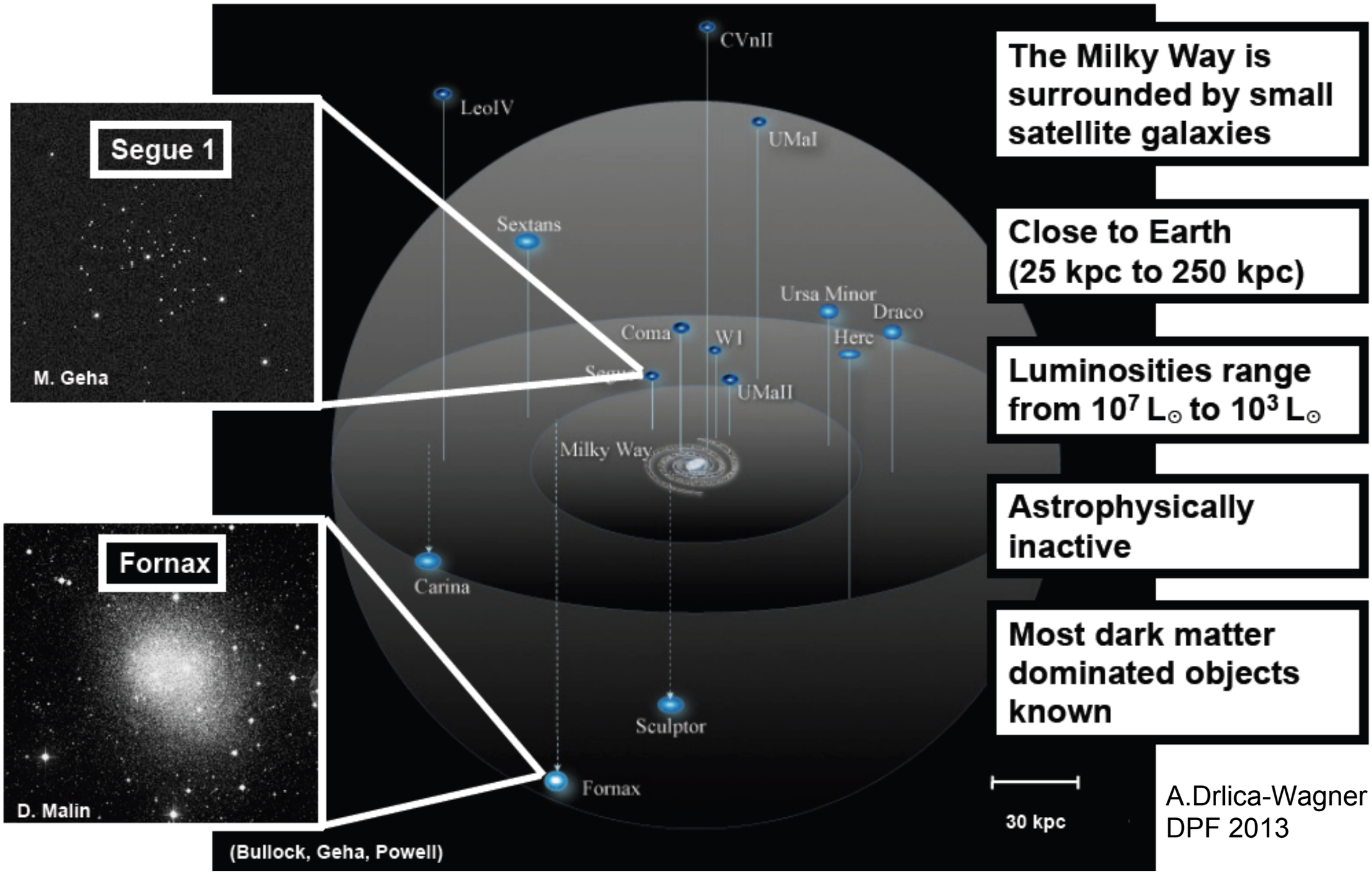
large energy injection of electrons in a bursting event ~Myr ago



Petrovic, Serpico, GZ,
JCAP,1405.7928

Is the excess consistent with other gamma ray observations?

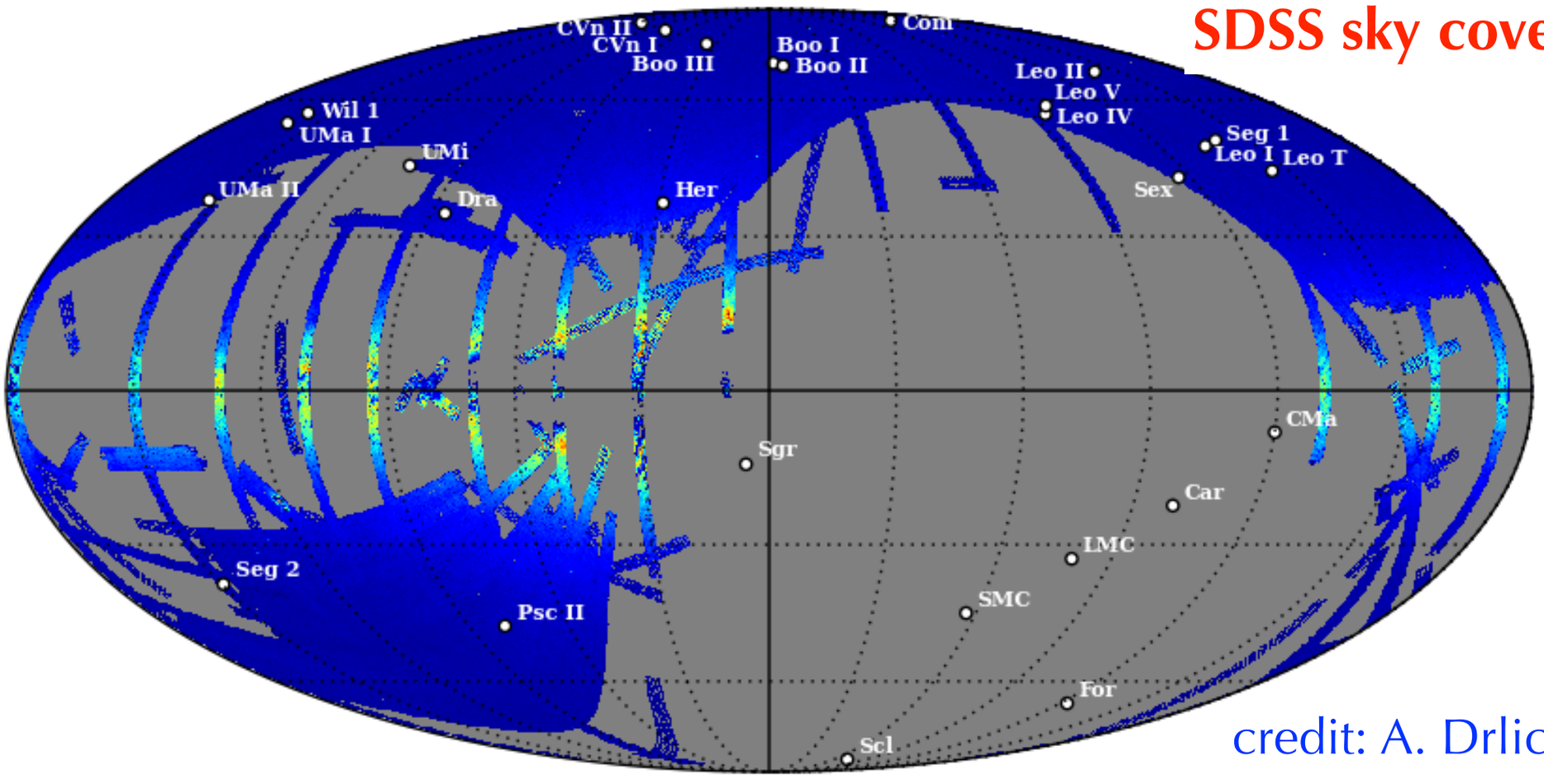
Search in MW Dwarf Spheroidal Galaxies



A.Drlica-Wagner
DPF 2013

Search in MW Dwarf Spheroidal Galaxies with gamma-rays

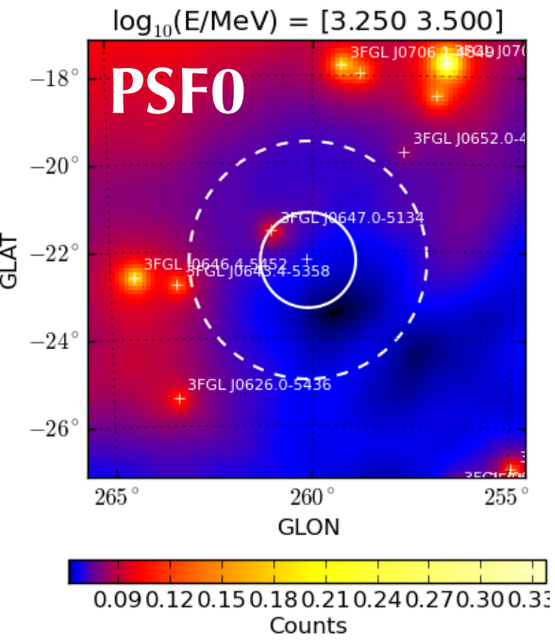
Fermi LAT data within SDSS sky coverage

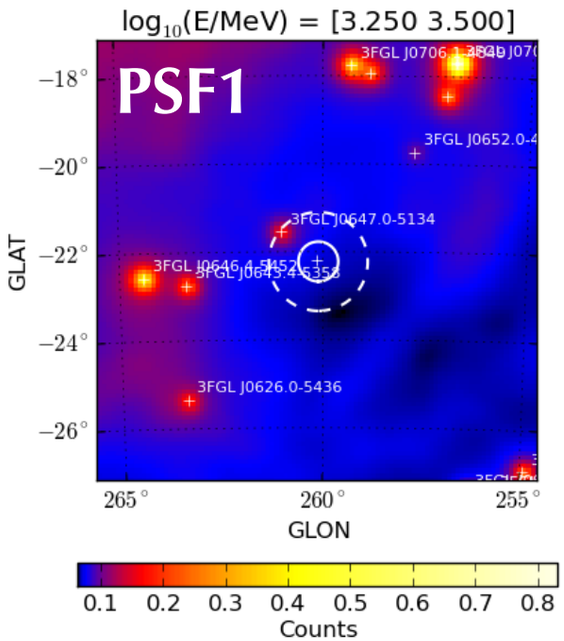


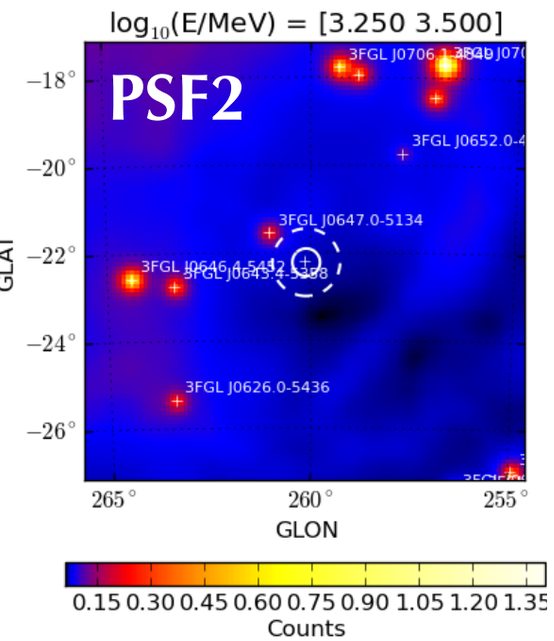
credit: A. Drlica-Wagner

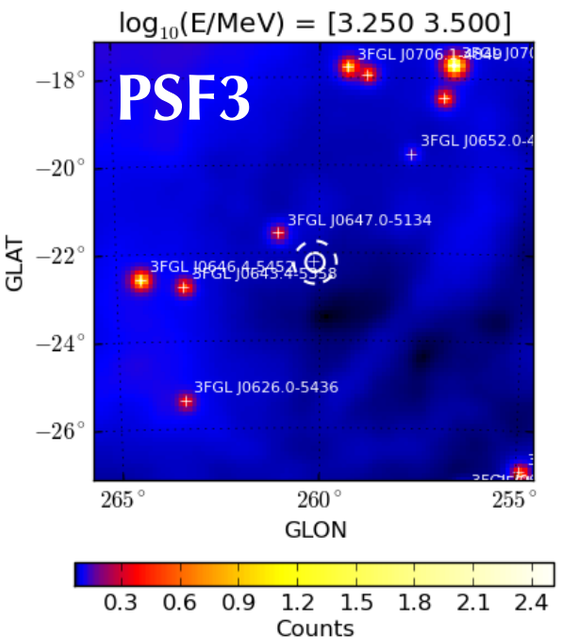
Sloan Digital Sky Survey - 15 dSphs with well-determined dark matter content. Located in quiet regions of the Fermi LAT sky.

Search in MW Dwarf Spheroidal Galaxies with gamma-rays









- newest event selection: **Pass8SOURCE**

500 MeV-500 GeV - scheduled for release end of April!

- 15 ROI: **10x10 deg** centered at each dSph
- DM profile of each dwarf modeled with **extended NFW profile**

Input:

- overall DM content from each target dSph and its uncertainty (**'J' factors**)

- data in each **angular resolution class** (PSF 0-3)

[Ackermann+, 1503.02641]

Search in MW Dwarf Spheroidal Galaxies with gamma-rays

statistical framework

EFFECTIVE LIKELIHOOD (bin-by-bin)

(term accounts for uncertainty in J-factor)

$$L_2(\mathcal{D}|\boldsymbol{\mu},\boldsymbol{\theta_t}) = L_t^{\mathrm{LAT}}(\mathcal{D}_t|\boldsymbol{\mu},\boldsymbol{\theta_t}) \times \frac{1}{\ln(10)\mathrm{J_t}\sqrt{2\pi}\sigma_\mathrm{t}} e^{-(\log_{10}(\mathrm{J_t})-\overline{\log_{10}(\mathrm{J_t})})^2/2\sigma_\mathrm{t}^2}$$

$$L_3(\mathcal{D}|\boldsymbol{\mu},\{\boldsymbol{\theta_t}\}) = \prod_{targets} L_2(\mathcal{D}|\boldsymbol{\mu},\boldsymbol{\theta_t})$$

← *(combine information from all targets)

$$L_4(\mathcal{D}|\boldsymbol{\mu},\{\boldsymbol{\theta_t}\}) = \prod_{classes} L_3(\mathcal{D}_c|\boldsymbol{\mu},\{\boldsymbol{\theta_t}\})$$

← (combine information from all psf classes)

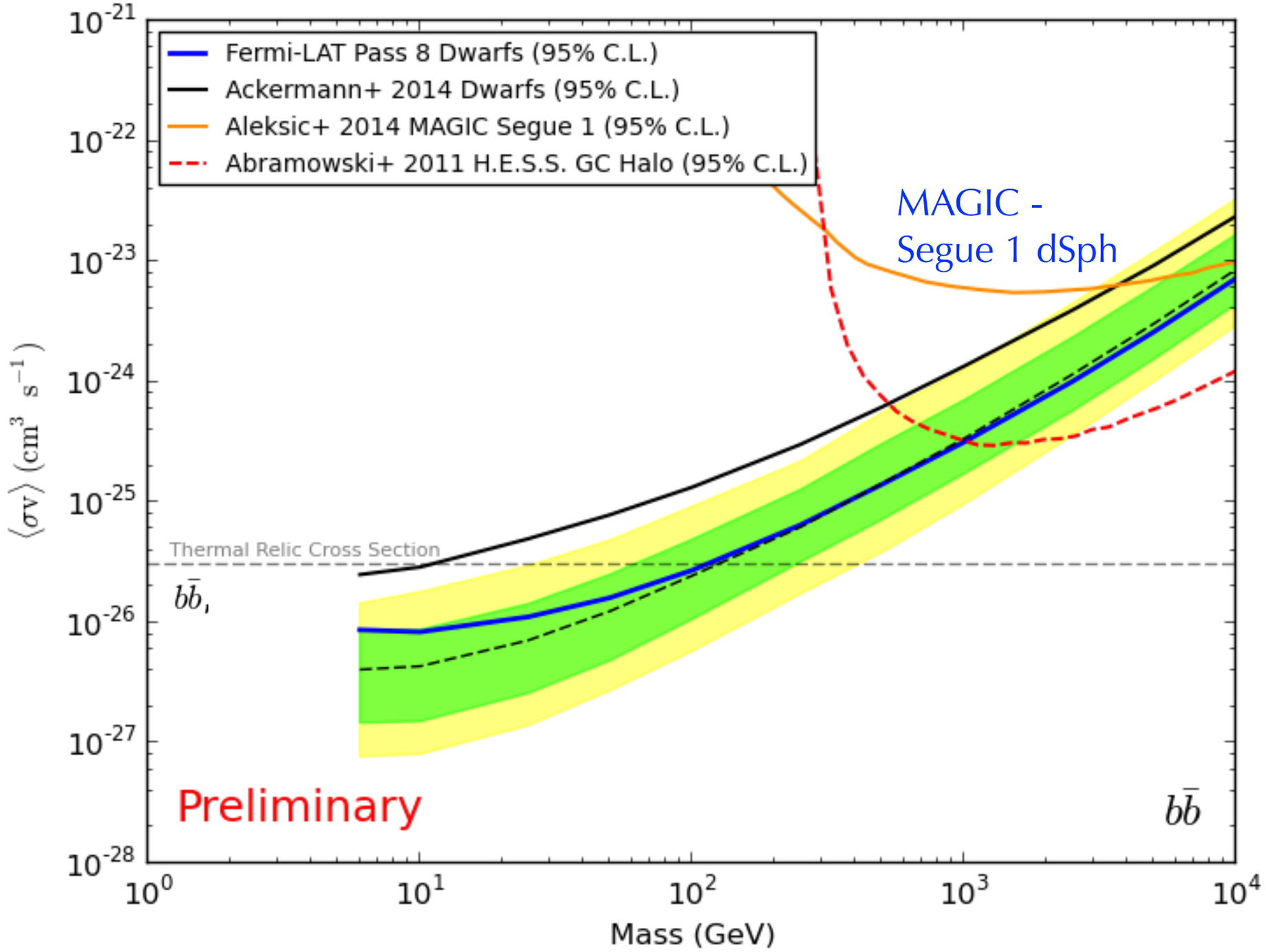
FOURTH GENERATION

arXiv	irf	time	targets	joint?
1001.4531	P6	11 mo.	10	no
1108.3546	P6	24 mo.	10	yes
1310.0828	P7	48 mo.	15	yes
	P8	60 mo.	15	yes x2!

Events are weighted according to the quality of their angular reconstruction
four PSF event types

[Ackermann+, 1503.02641]

Search in MW Dwarf Spheroidal Galaxies with gamma-rays

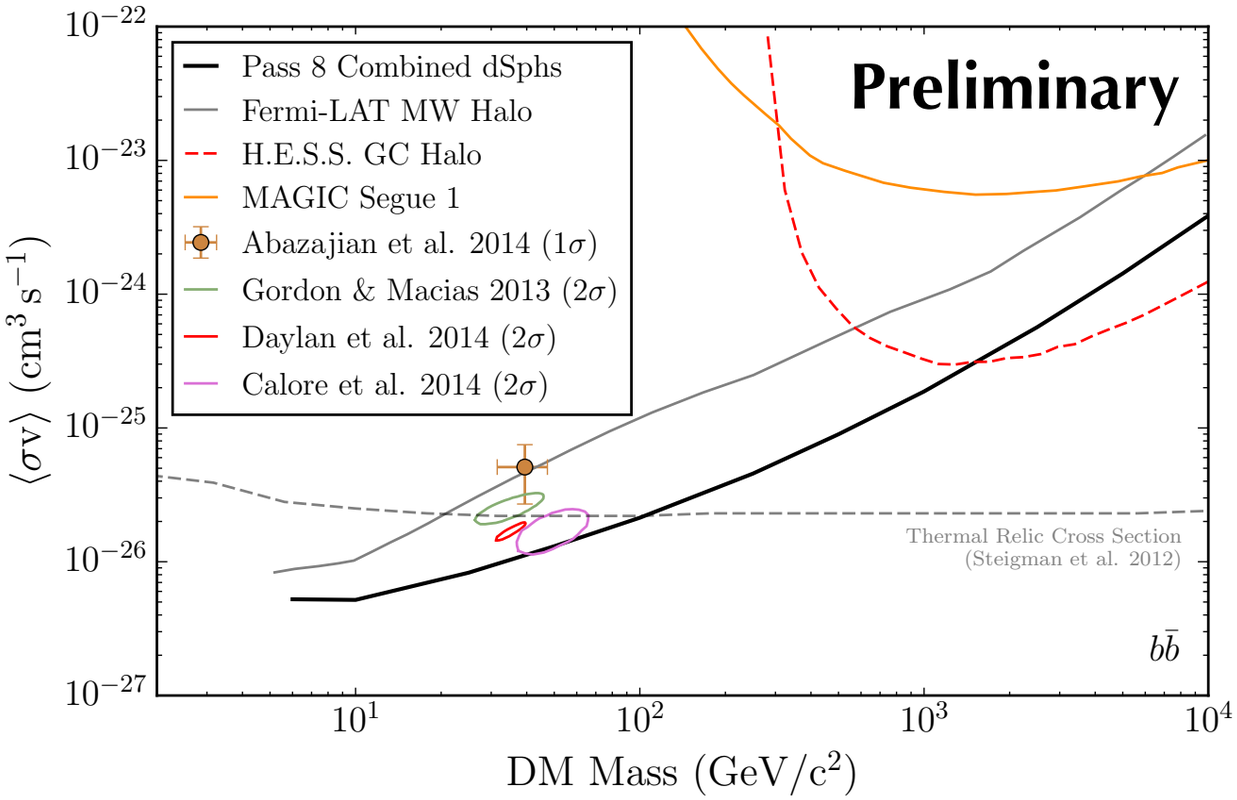


Thermal cross section excluded below 100 GeV!

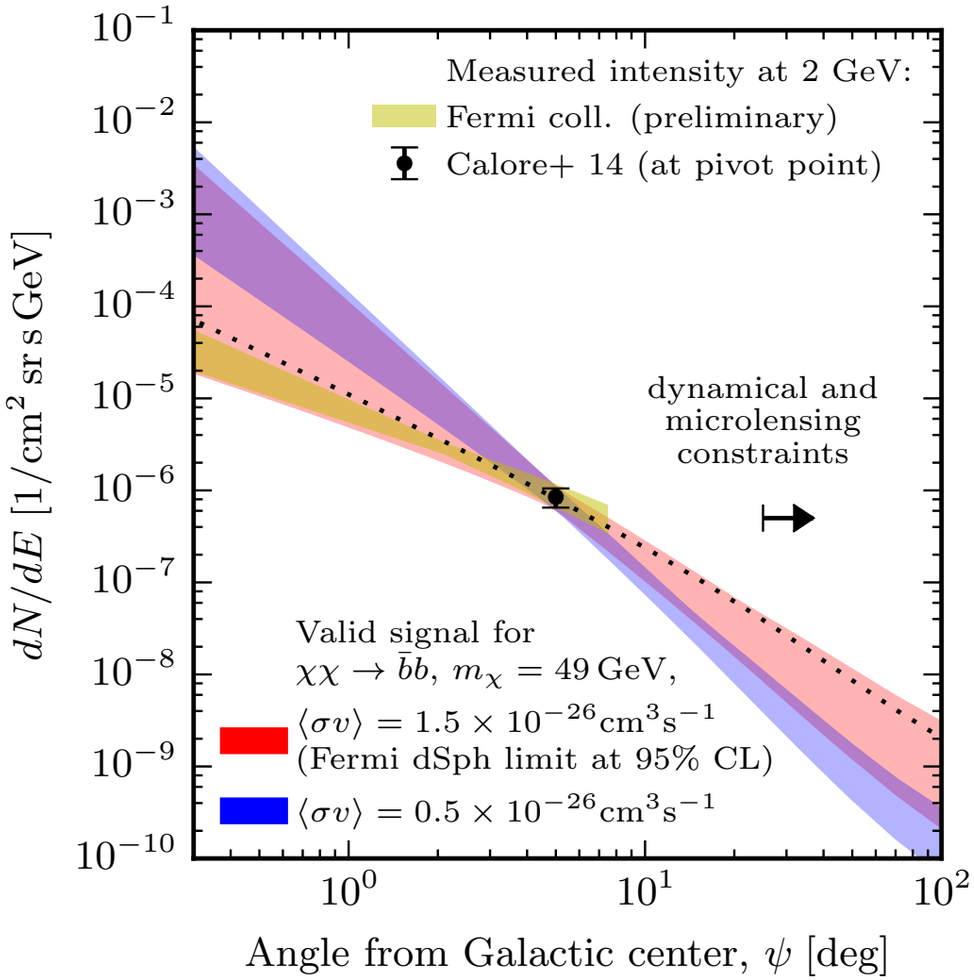
[Ackermann+, 1503.02641]

Search in MW Dwarf Spheroidal Galaxies with gamma-rays

Is the excess consistent with other gamma ray observations?



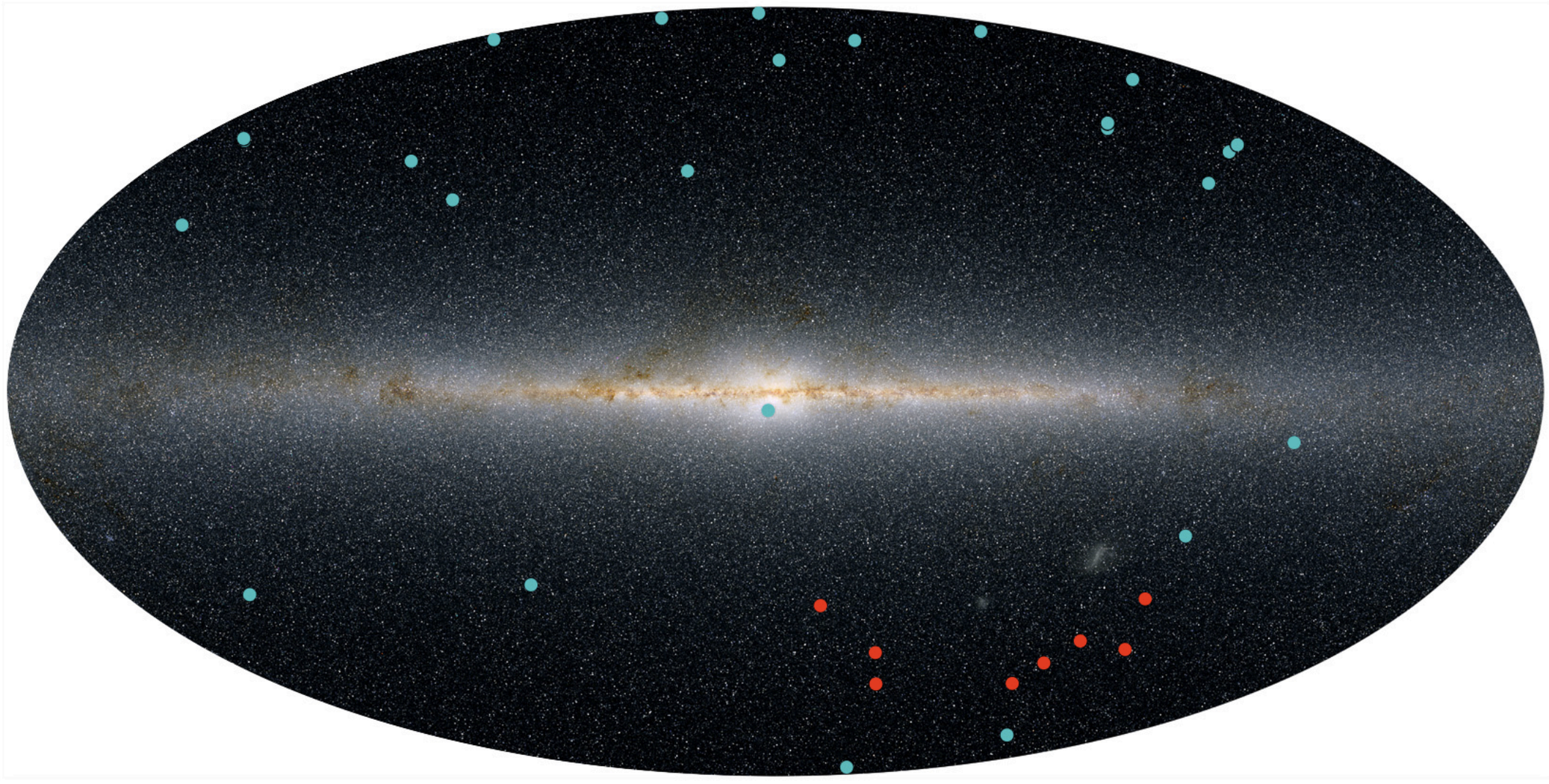
[Ackermann+, 1503.02641]



[Calore+, 1411.4647]

~Tension with complementary gamma ray observations.

Things are getting more exciting!

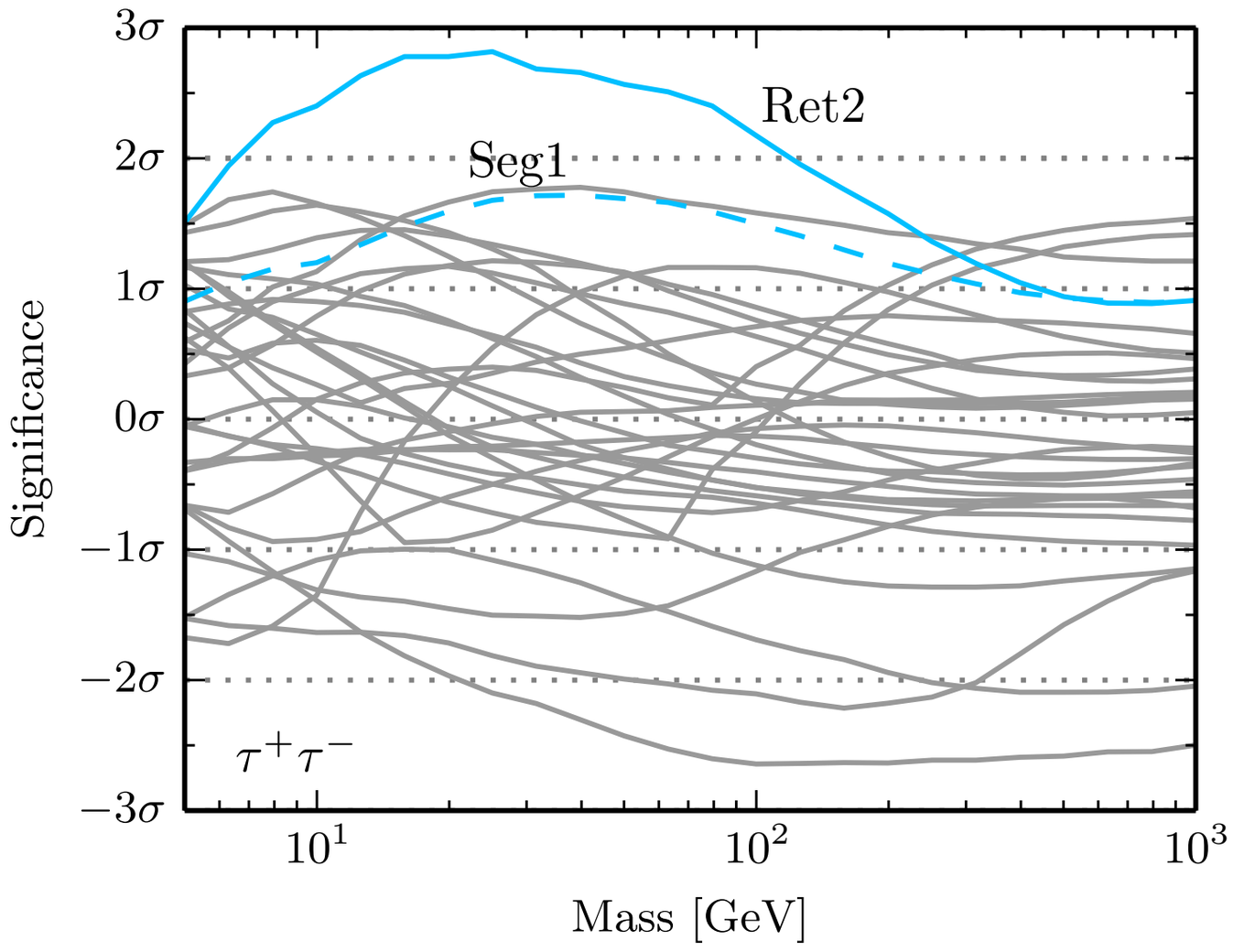


DES: 8 new dSph candidates in 1st year data! + SMASH and Pan-STARRS recently claimed ultra-faint dwarf discoveries.

Fermi LAT analysis finds NO sign of gamma rays in the direction of the new dSphs.

(Bechtol+ 1503.02584, Belokurov+, 1403.3406, Laevens+, 1503.05554)

Things are getting more exciting!

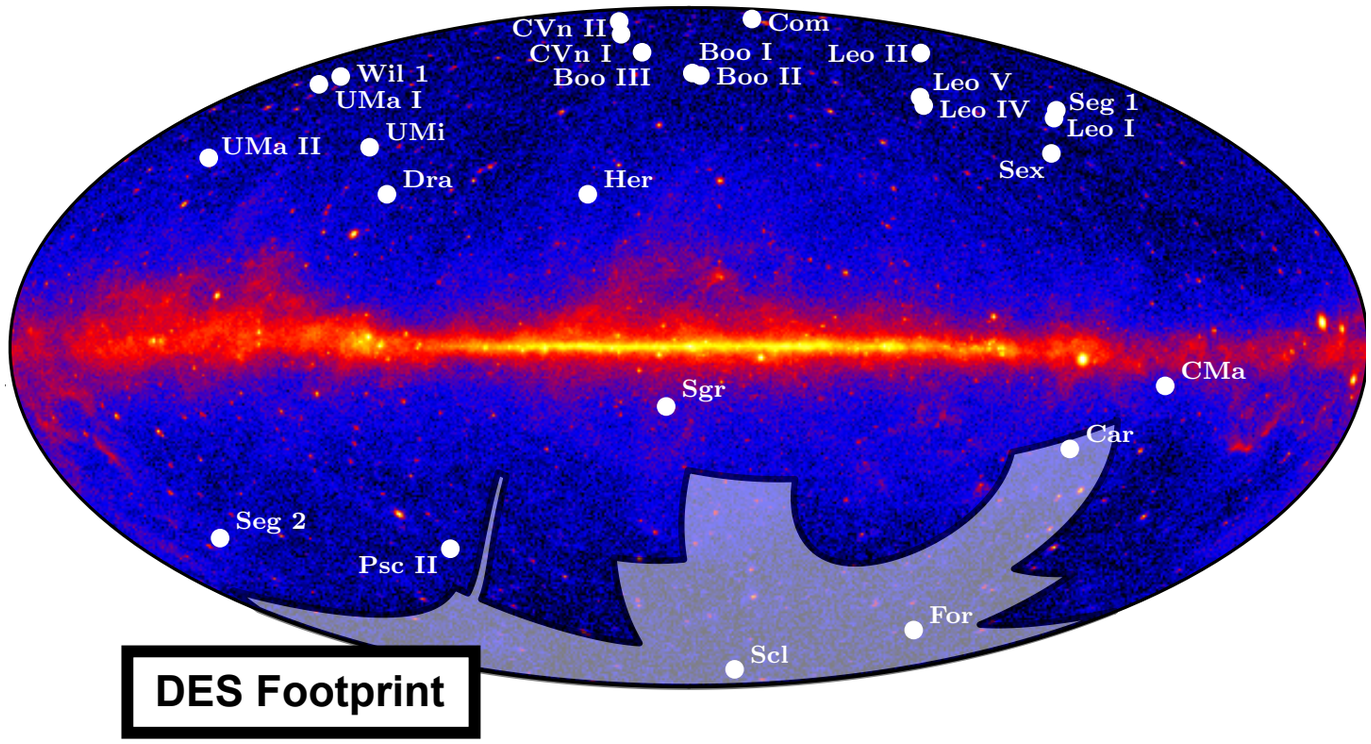


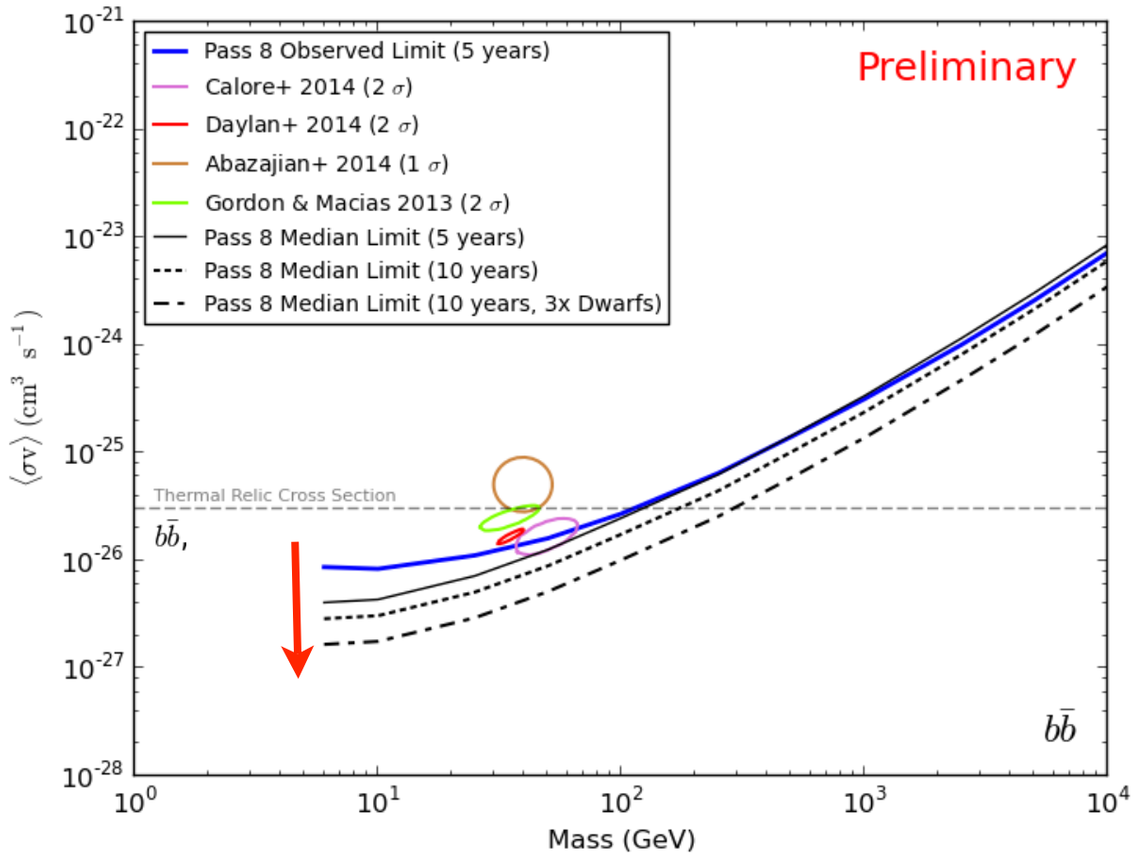
Slight significance for the closest dwarfs ~2 ‘astrosigma’ (local).

(Geringer-Sameth+, 1503.02320; Hooper+, 1503.06209)

Significance drops with the Pass8 analysis.

Things are getting more exciting!



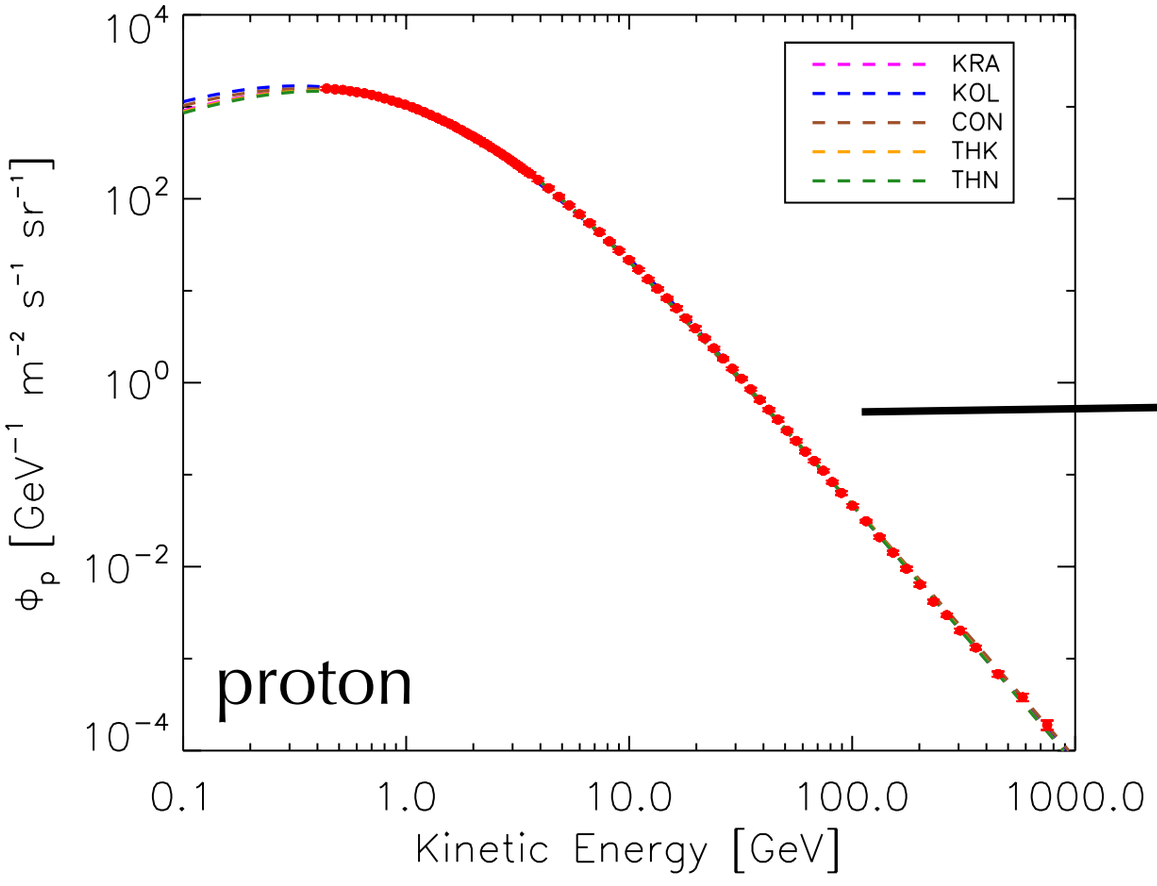


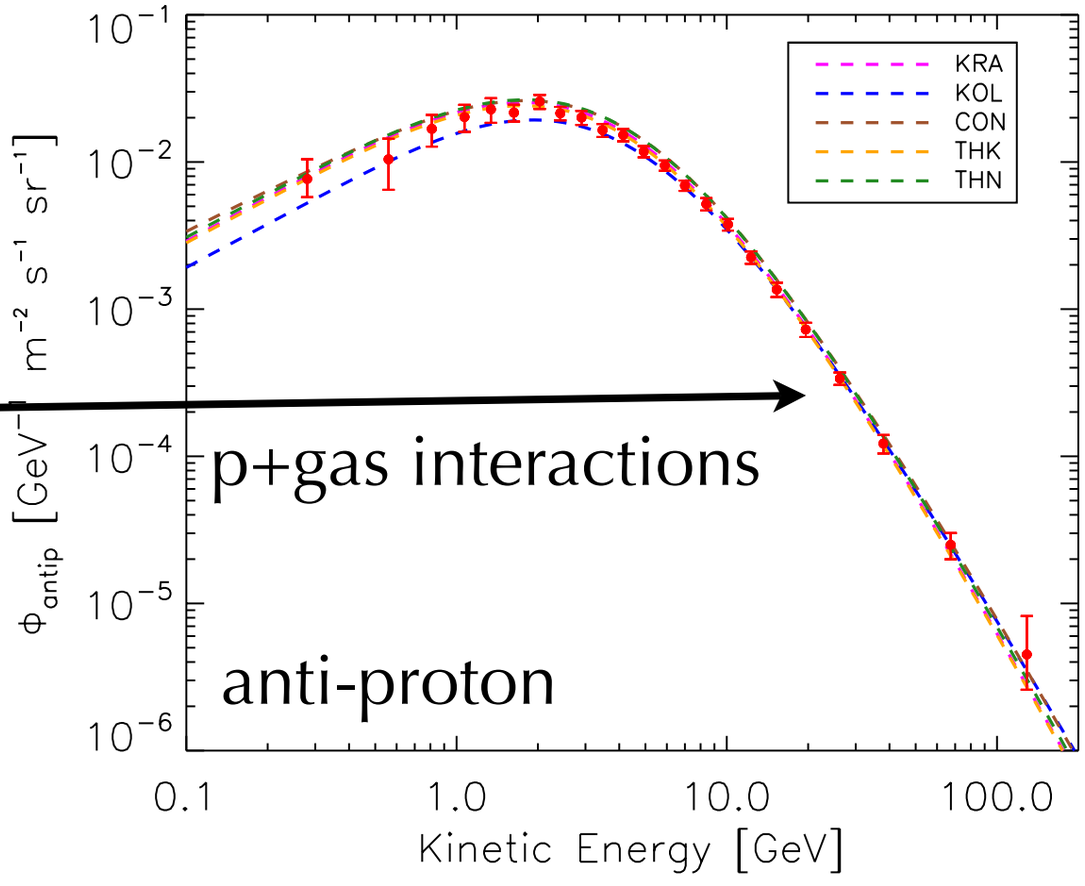
DES: will cover 5000deg2, reaching magnitude 24 stars (SDSS magnitude 22).
LSST will be much deeper + 50% of the sky (started construction end 2014).

Is the excess consistent with other astro messengers?

Anti-protons

- astrophysical background is relatively under control: anti-protons are mainly produced in pp or pHe interactions and constrained by measured p fluxes
- excess hadronic origin - antiprotons should also be produced in annihilations

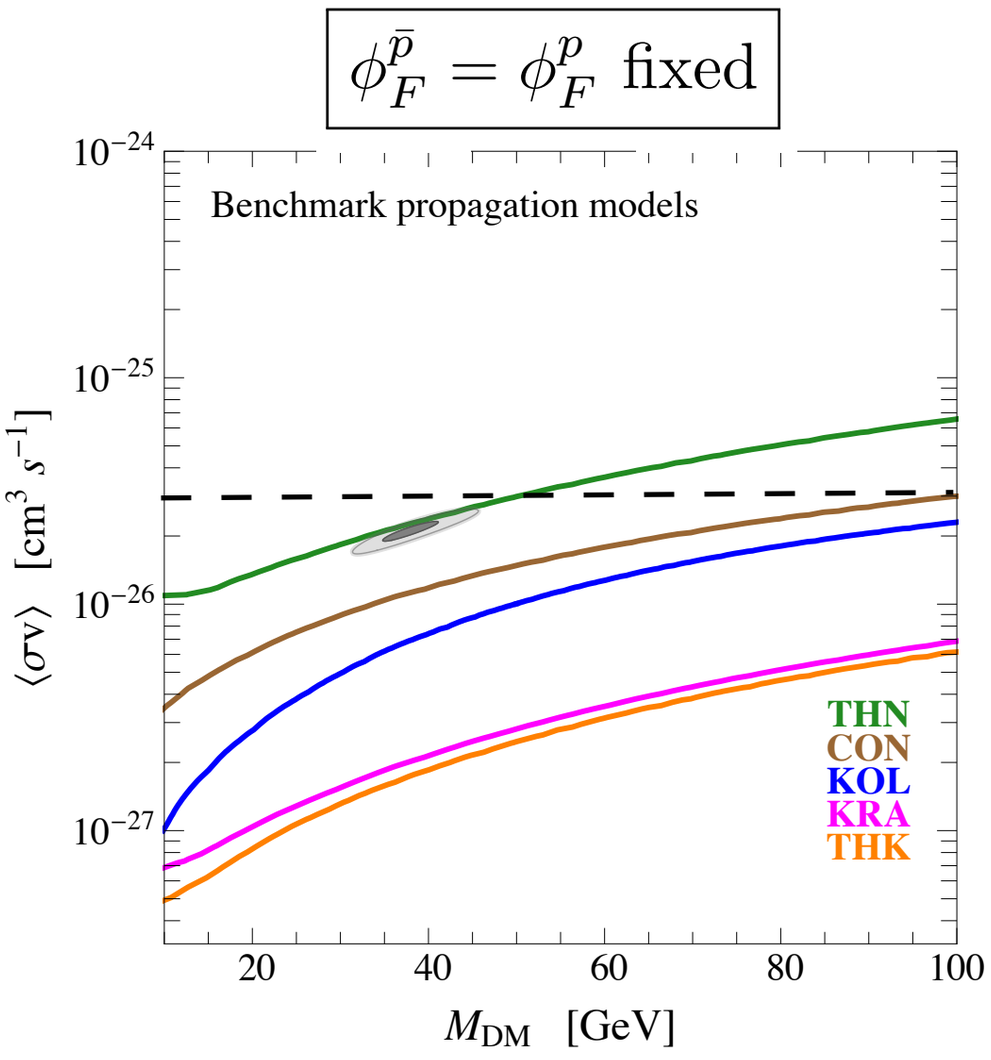


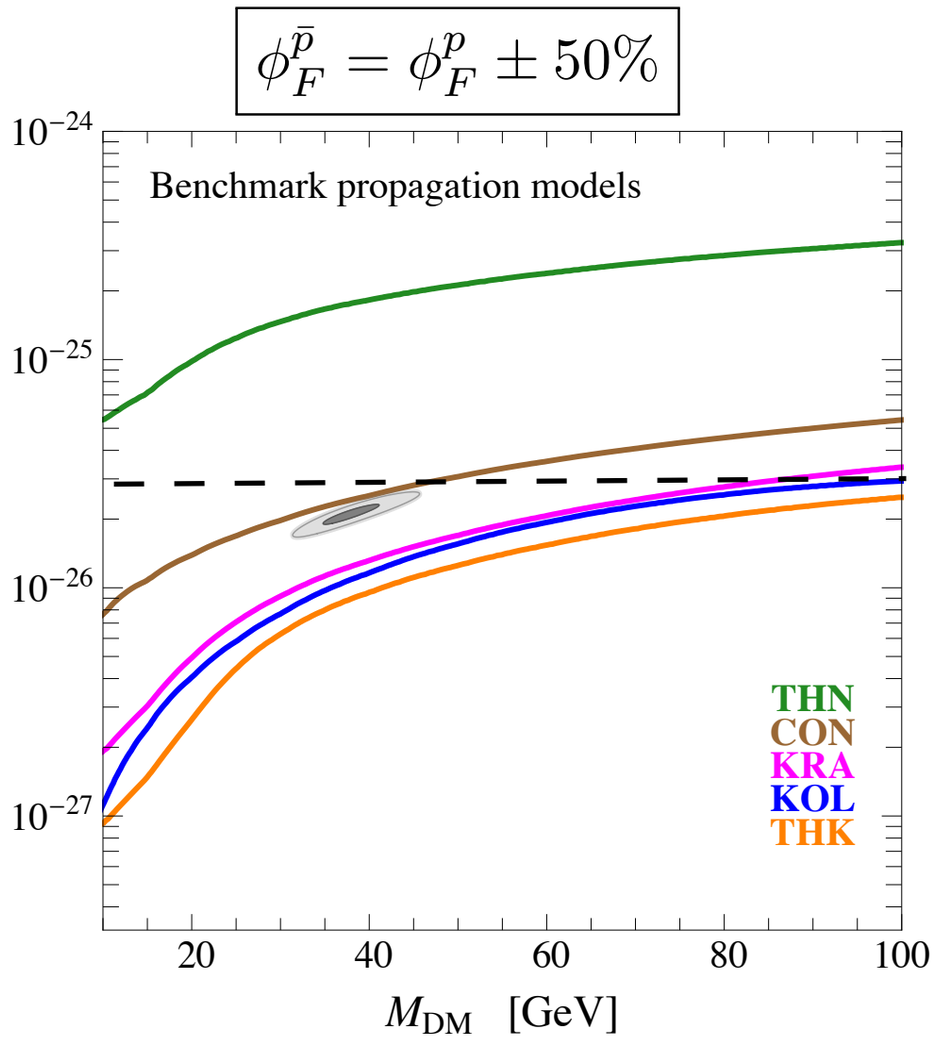


Is the excess consistent with other astro messengers?

Anti-protons

anti-p very constraining for standard astro set-up, but not robust yet.





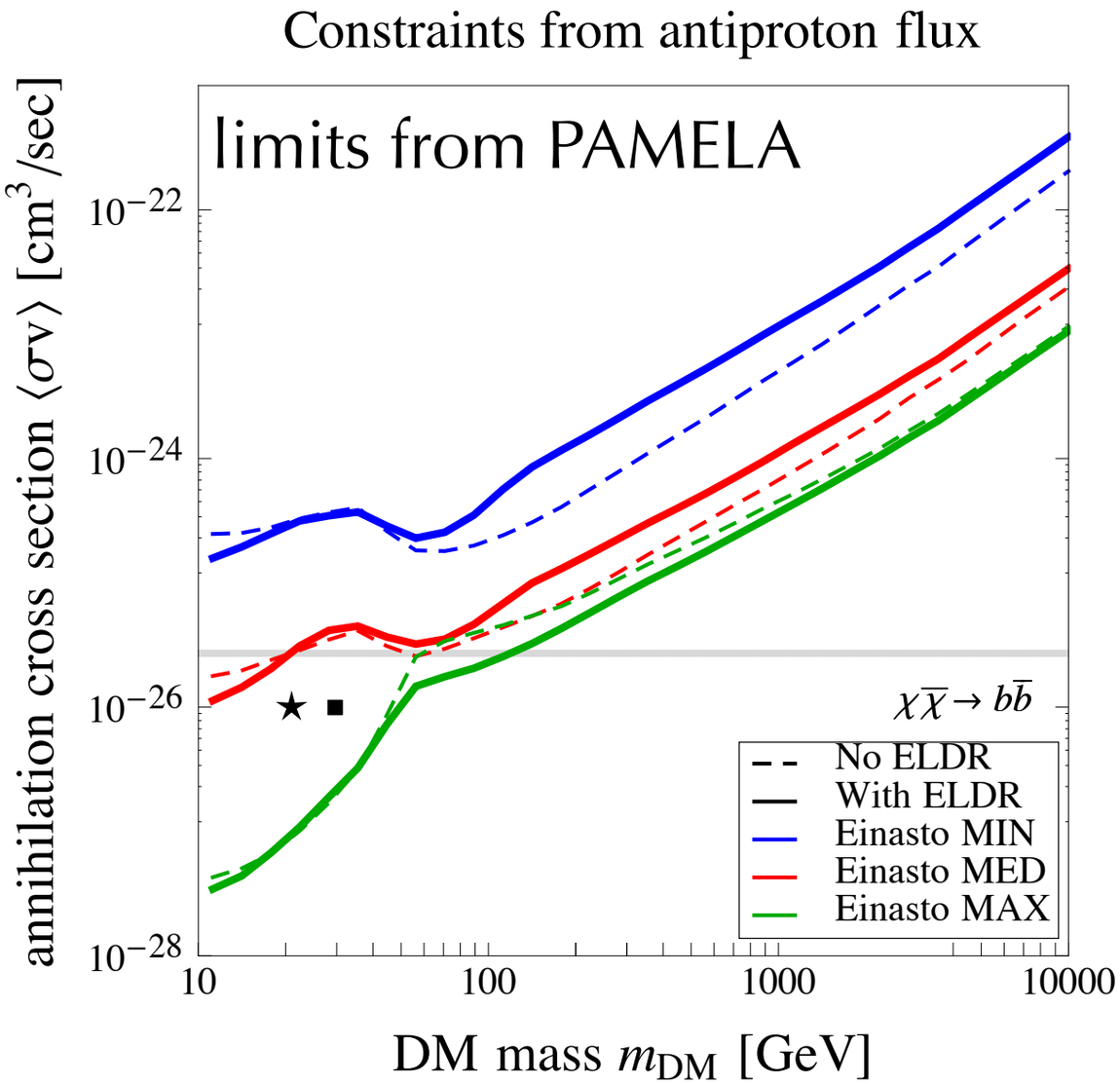
[Cirelli+, 1407.2173]

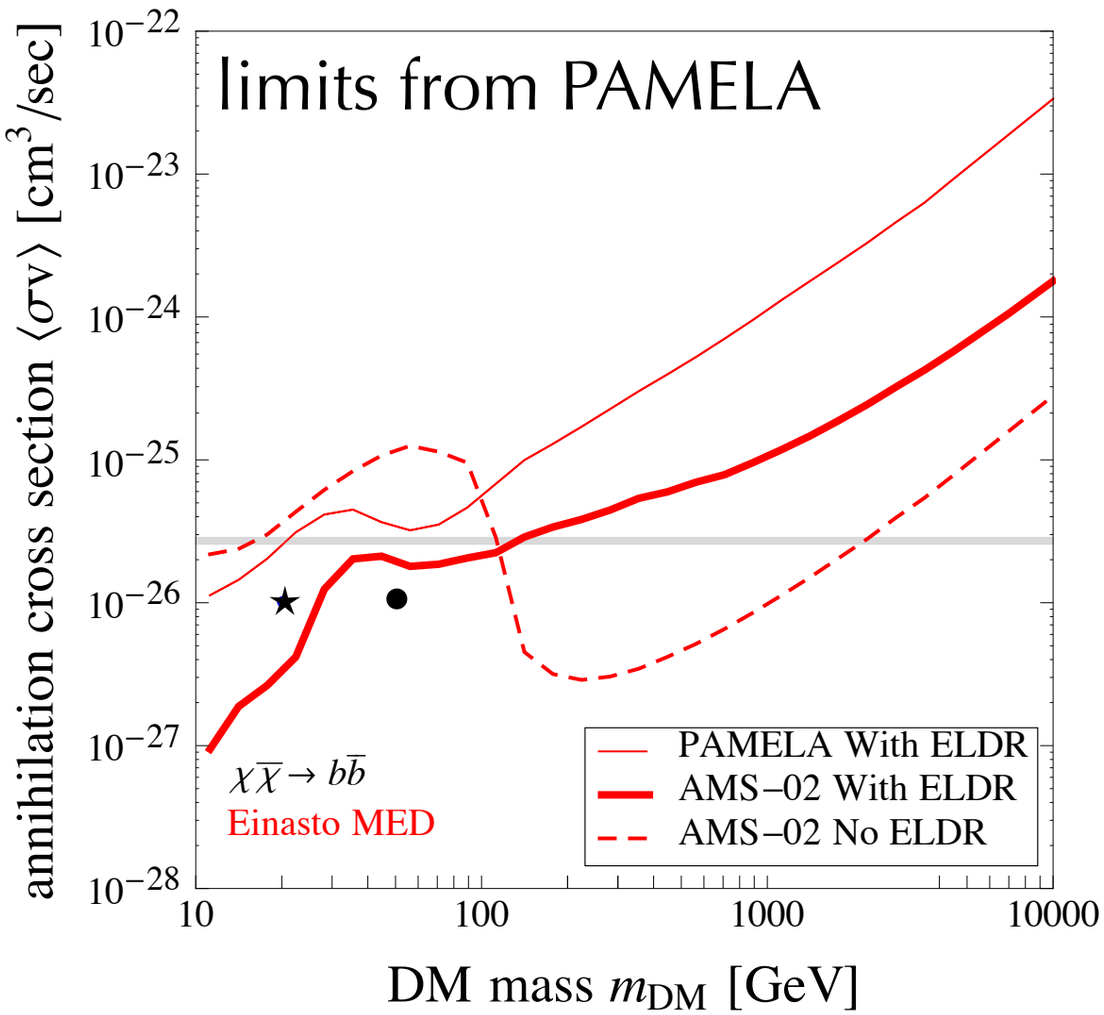
Is the excess consistent with other astro messengers?

Anti-protons

anti-p very constraining for standard astro set-up, but not robust yet.

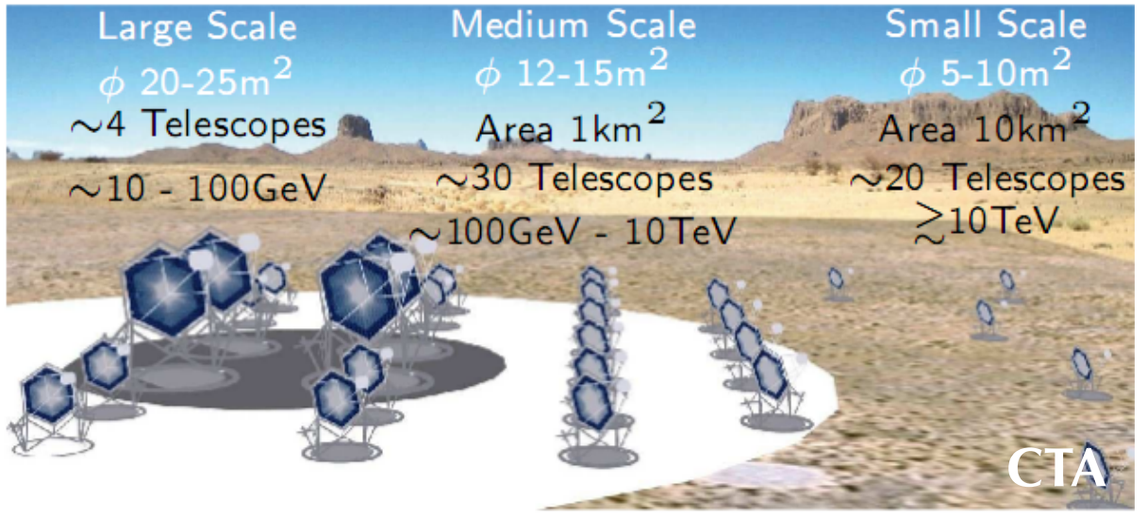
→ limits changed if energy losses due to tertiary anti-p production and re-acceleration taken into account



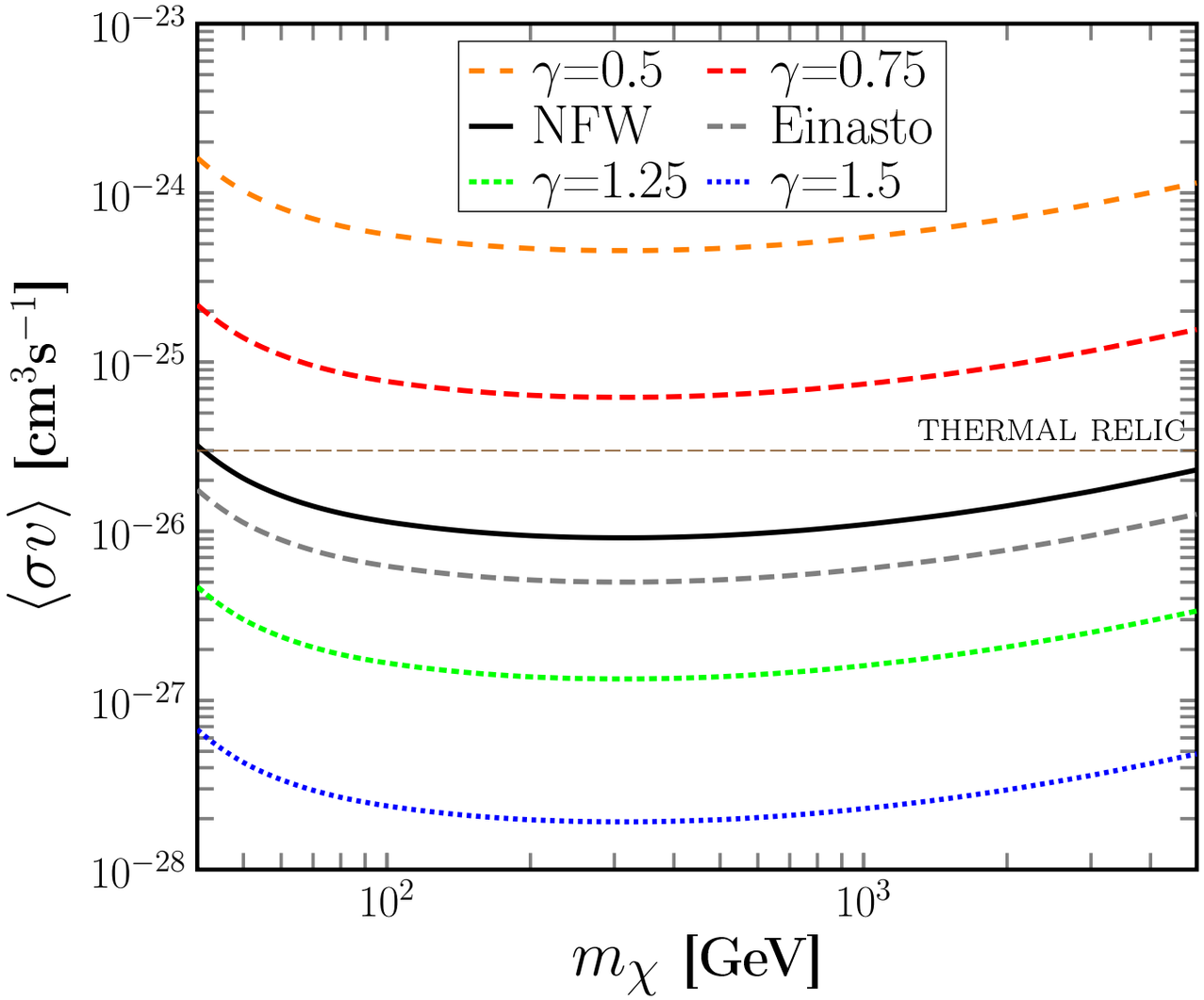


[Cirelli+, 1412.5696]

Future:

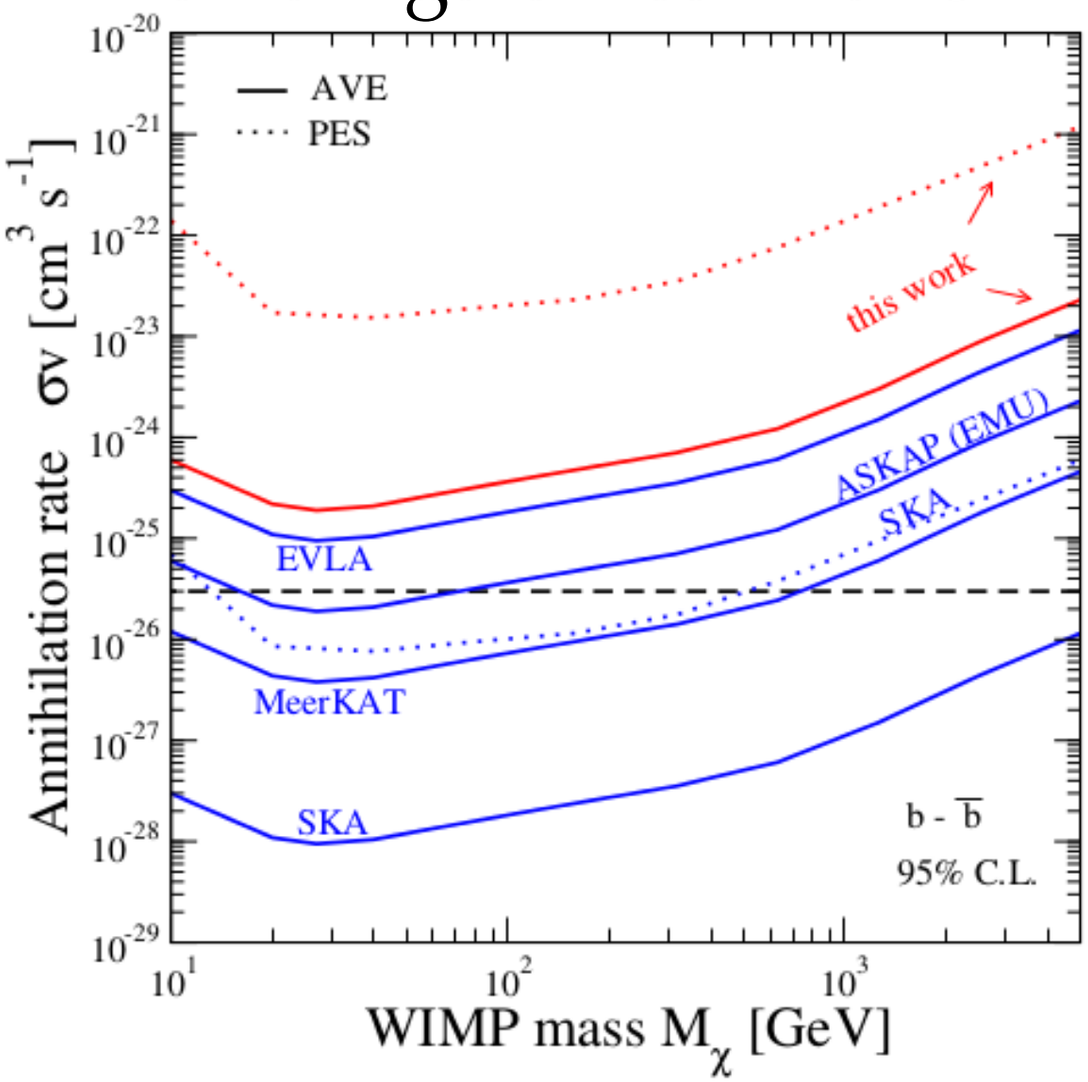


Galactic Center with CTA



[Pierre+, JCAP 2013]

dwarf galaxies with SKA

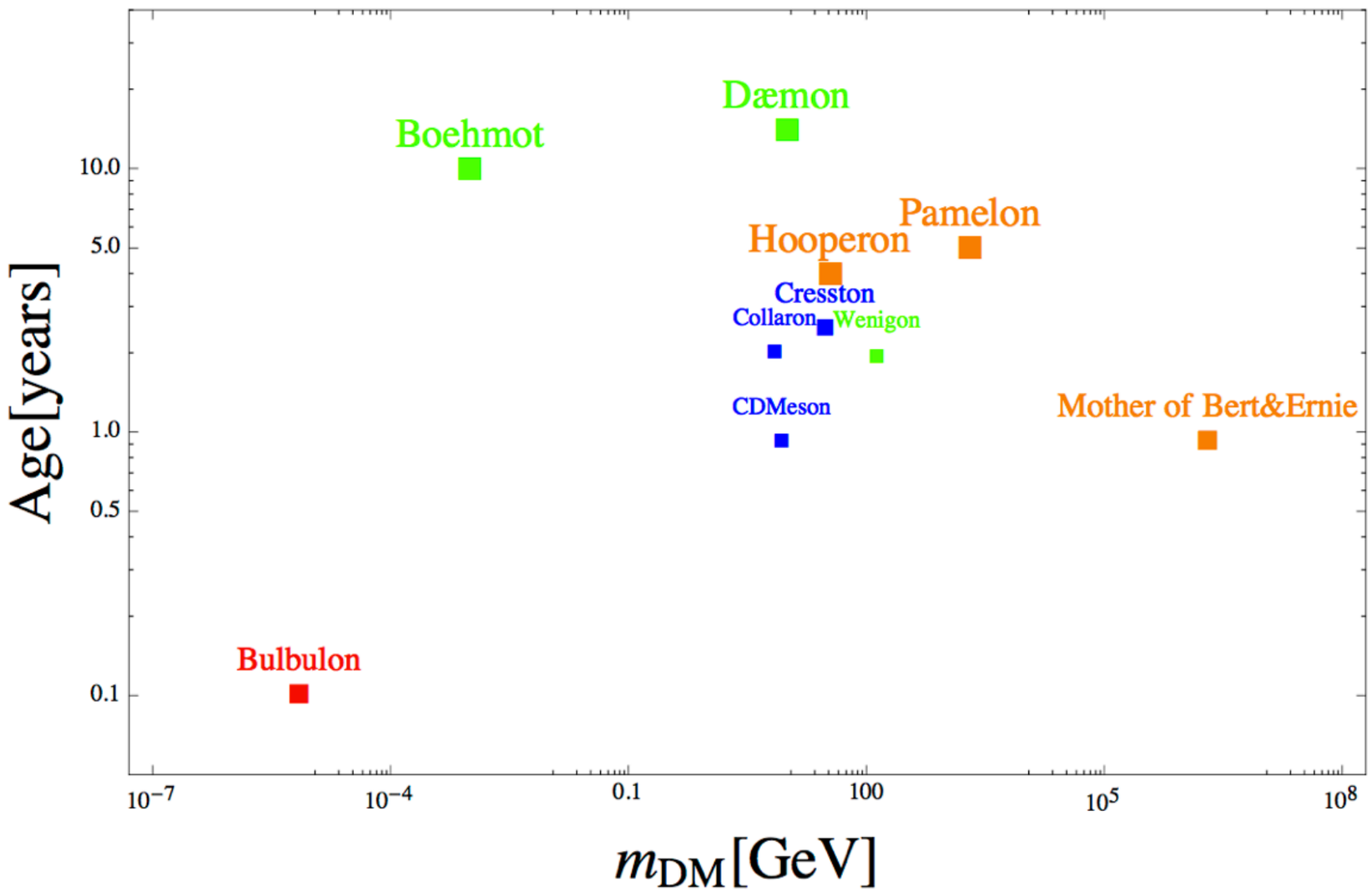


[M. Reggis, APP Conference, 2014]

Summary:

- The field of astrophysics is being re-defined by high-quality data, extending over a larger dynamical range.
- DM search is an outstanding effort for over 50 years: the tools are now in the right region!
- Great times for good high-energy astrophysics!

  → DM signal might show up along the way.

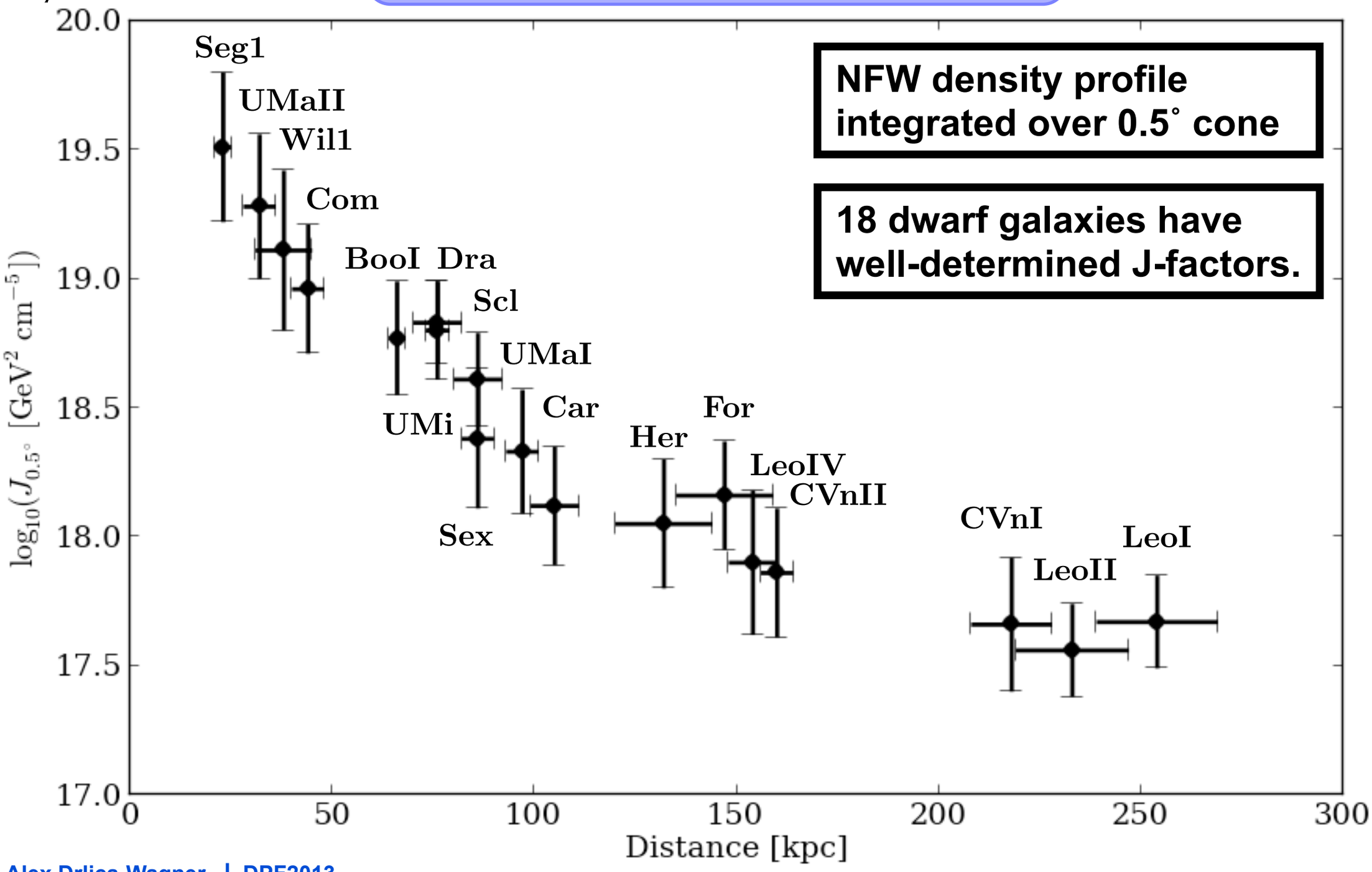


[RESONAANCES: http://resonaances.blogspot.it/]

Extra slides

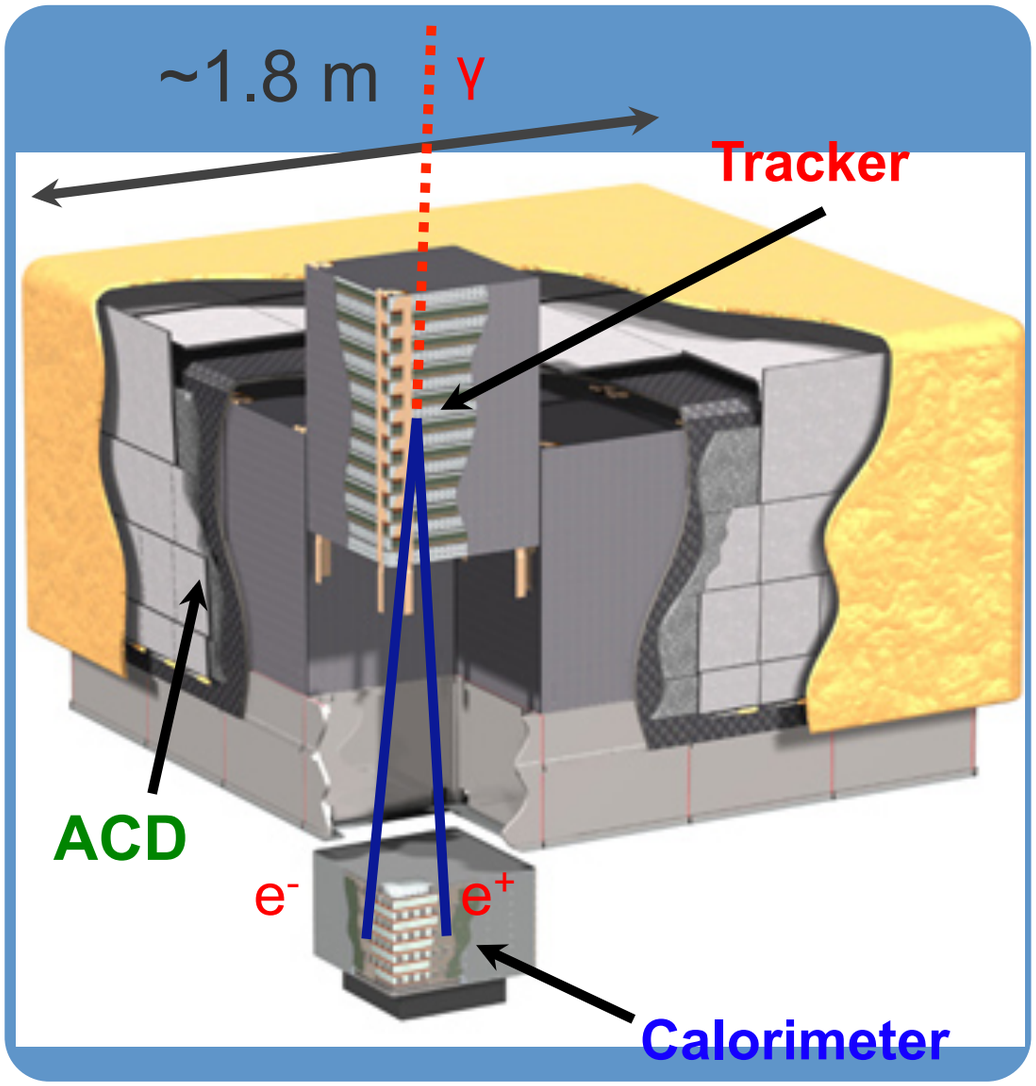
'J-factor' - proportional to expected gamma-ray intensity

$$\int_{\Delta\Omega(\phi,\theta)} d\Omega' \int_{los} \rho^2(r(l,\phi'))dl(r,\phi')$$



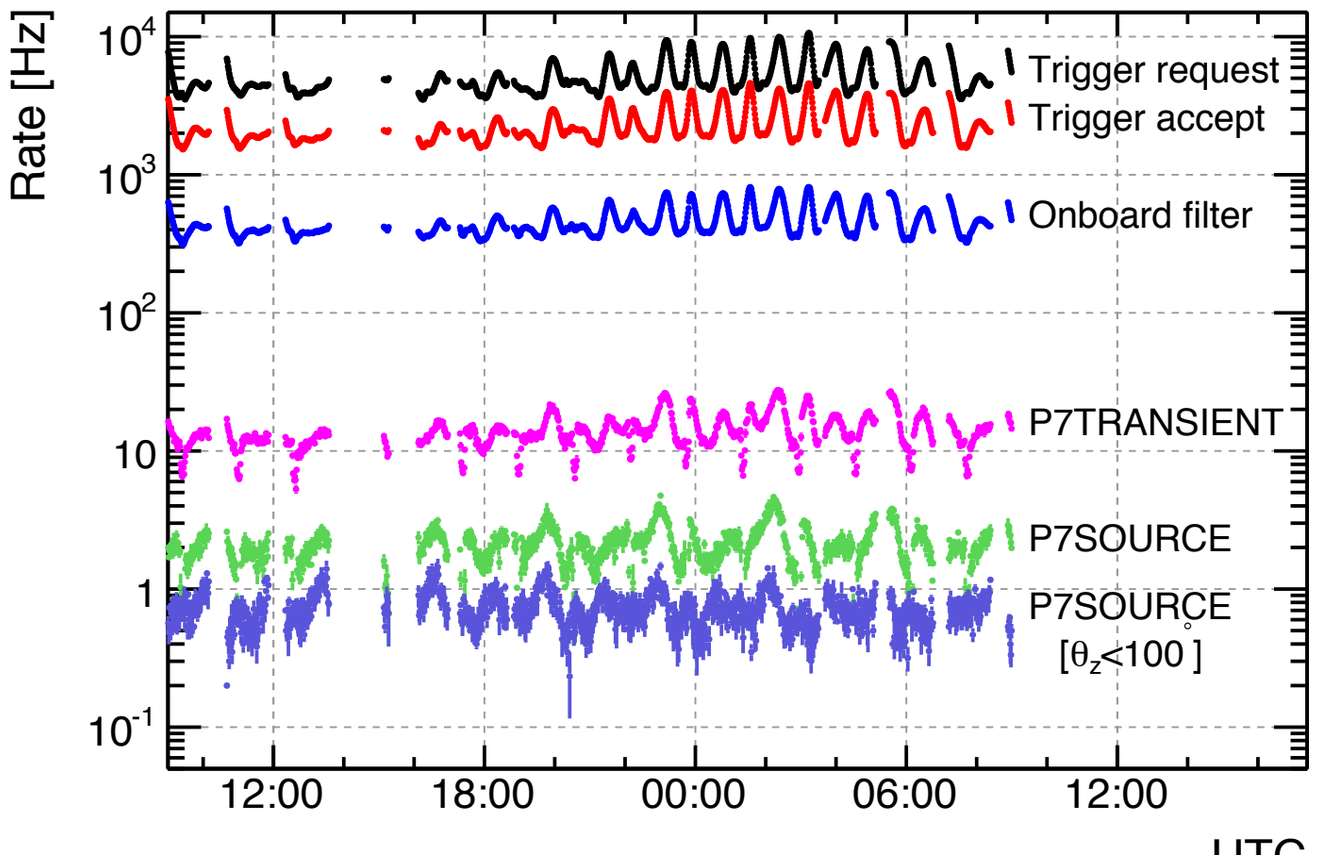
NFW density profile integrated over 0.5˚ cone

18 dwarf galaxies have well-determined J-factors.



The Fermi LAT is a **e^+e^- pair-conversion** telescope:
- individual γ rays convert to **e^+e^-** pairs
- their tracks (direction!) measured in the **tracker**
- and energy deposition in the **calorimeter**.

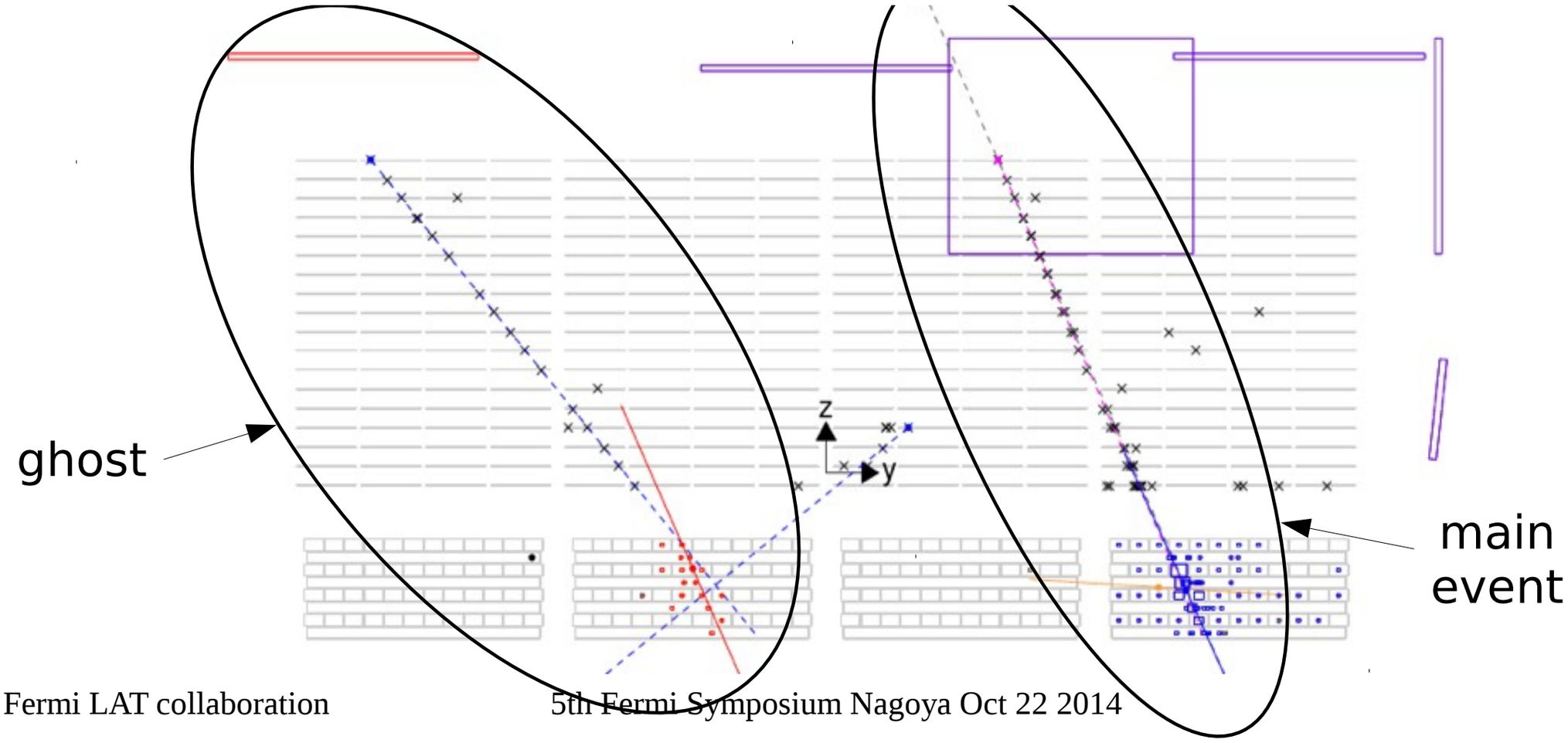
The flux of charged particles passing through the LAT is several thousand times larger than the γ-ray flux → **anti-coincidence** detector, vetoes charged cosmic rays.



Photon samples are prepared based on **event-by-event analyses**.

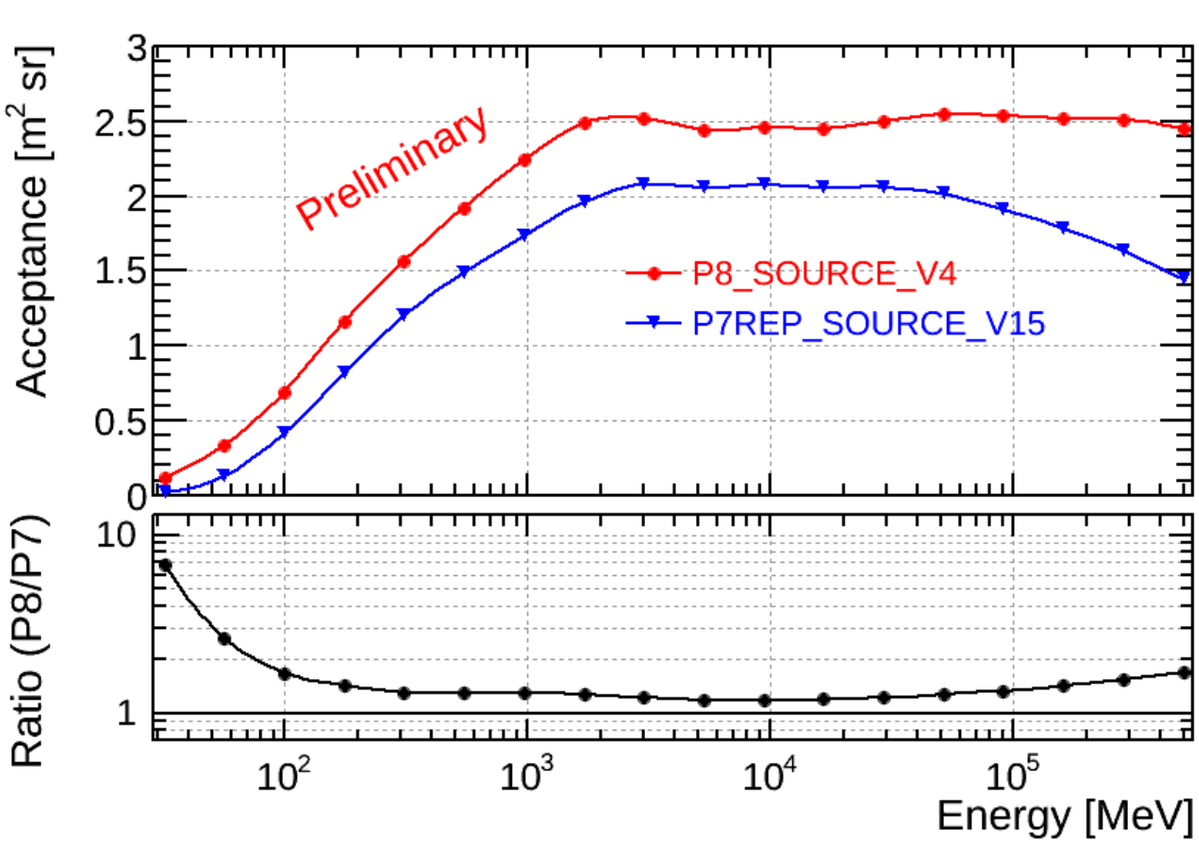
Pass 6 -> the event analysis scheme designed prior to launch.
Pass 7 -> accounts for known on-orbit effects based on the real events collected in 2 yrs.
Pass8 - incorporates so far gained experience - deals with issues of ghosts events, incorporates better clustering reconstruction.

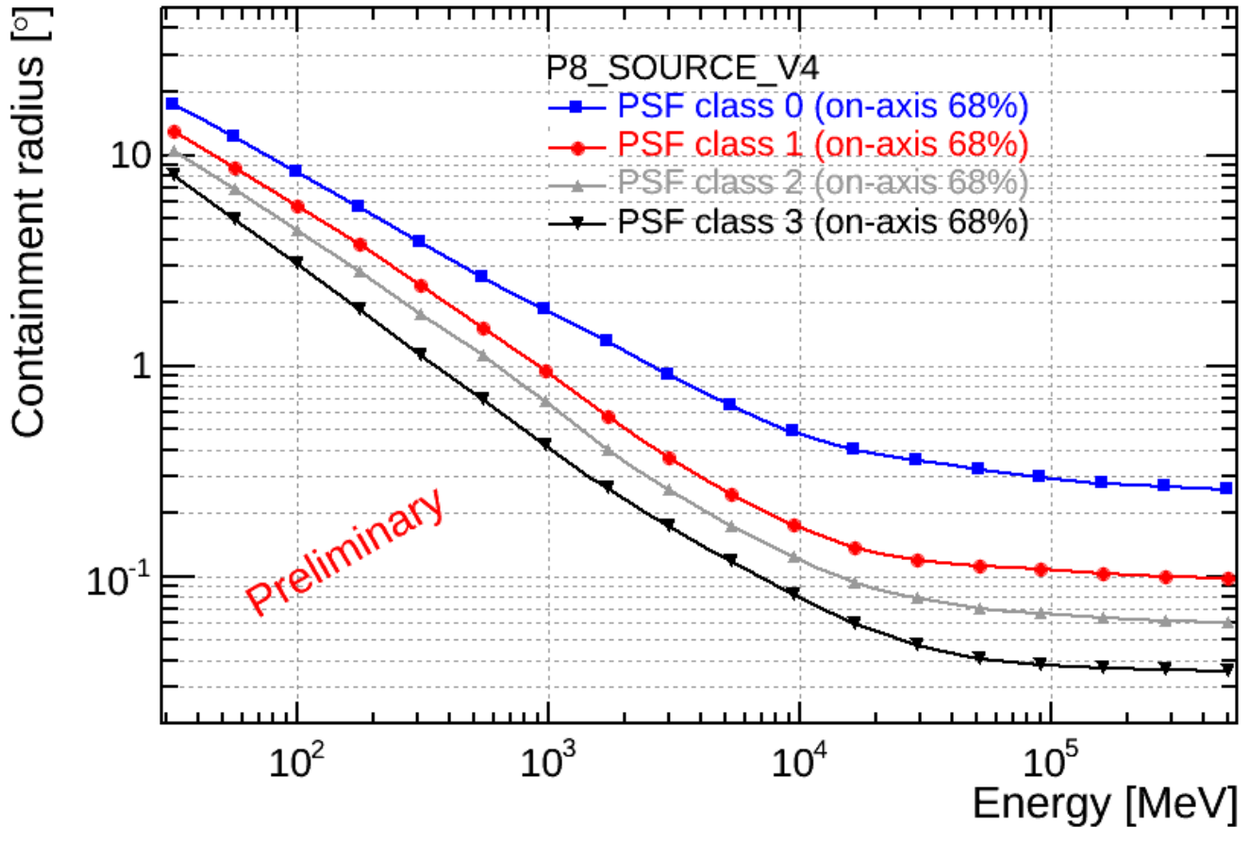
Changes in the event-level analysis can result in individual events being assigned slightly different directions and/or energy estimates between Passes -> ~independent data sets.



Commercial break → Pass 8

Some analysis already published. **Data release scheduled for April!**

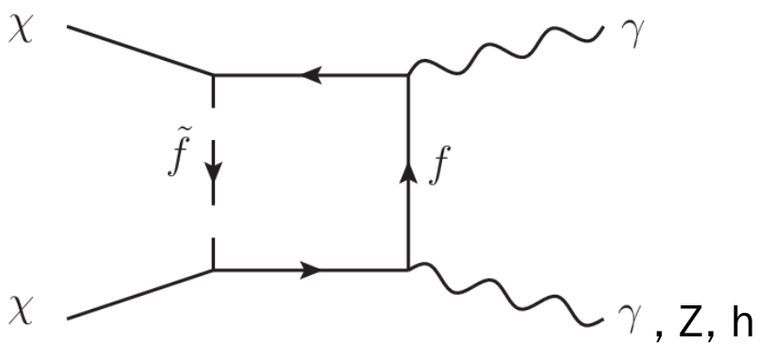


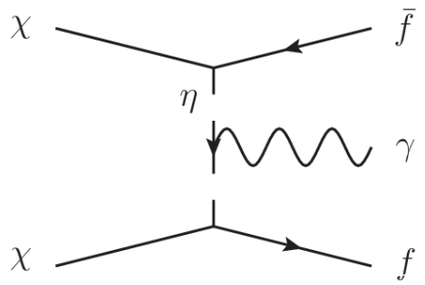


Acceptance ratio >~2 at the edges of energy range

Angular resolution several (~10) times better in the best event class (PSF3) -- lower effective area but narrower PSFs.

Smoking guns: **Gamma ray** line

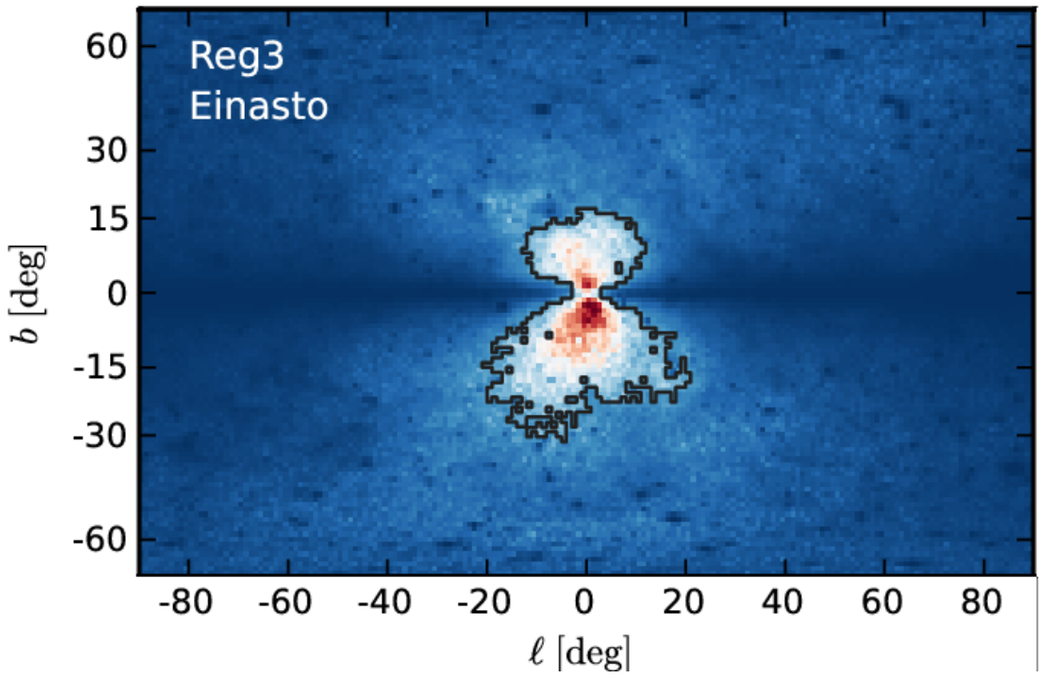




t-channel annihilation

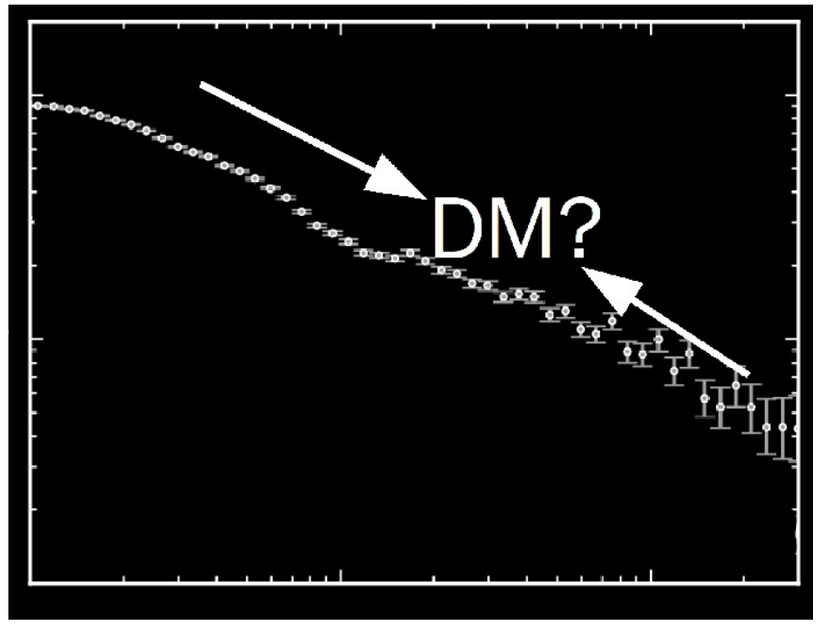
How to look for a spectral feature?

I) Identify target region



blind or maximize S/N assuming a DM density profile

II) Spectral analysis



extrapolate measured spectrum from a larger energy range and look for ‘line-like’ features.

Smoking guns 01: **Gamma ray** line - **LOW energy line search:**

Search for DM lines from 100 MeV to 10 GeV, for annihilation ($\chi\chi \rightarrow \gamma\gamma$) and decay ($\Psi 3/2 \rightarrow \nu\gamma$)

[Fermi LAT: Albert+, 1406.3430; + external authors: M. Grefe, C. Muñoz, C. Weniger]**:**

- previously unexplored region with the Fermi LAT
- in the case of decay, constrains models of Gravitino decay ($\Psi_{3/2} \rightarrow \nu\gamma$)

Challenge:

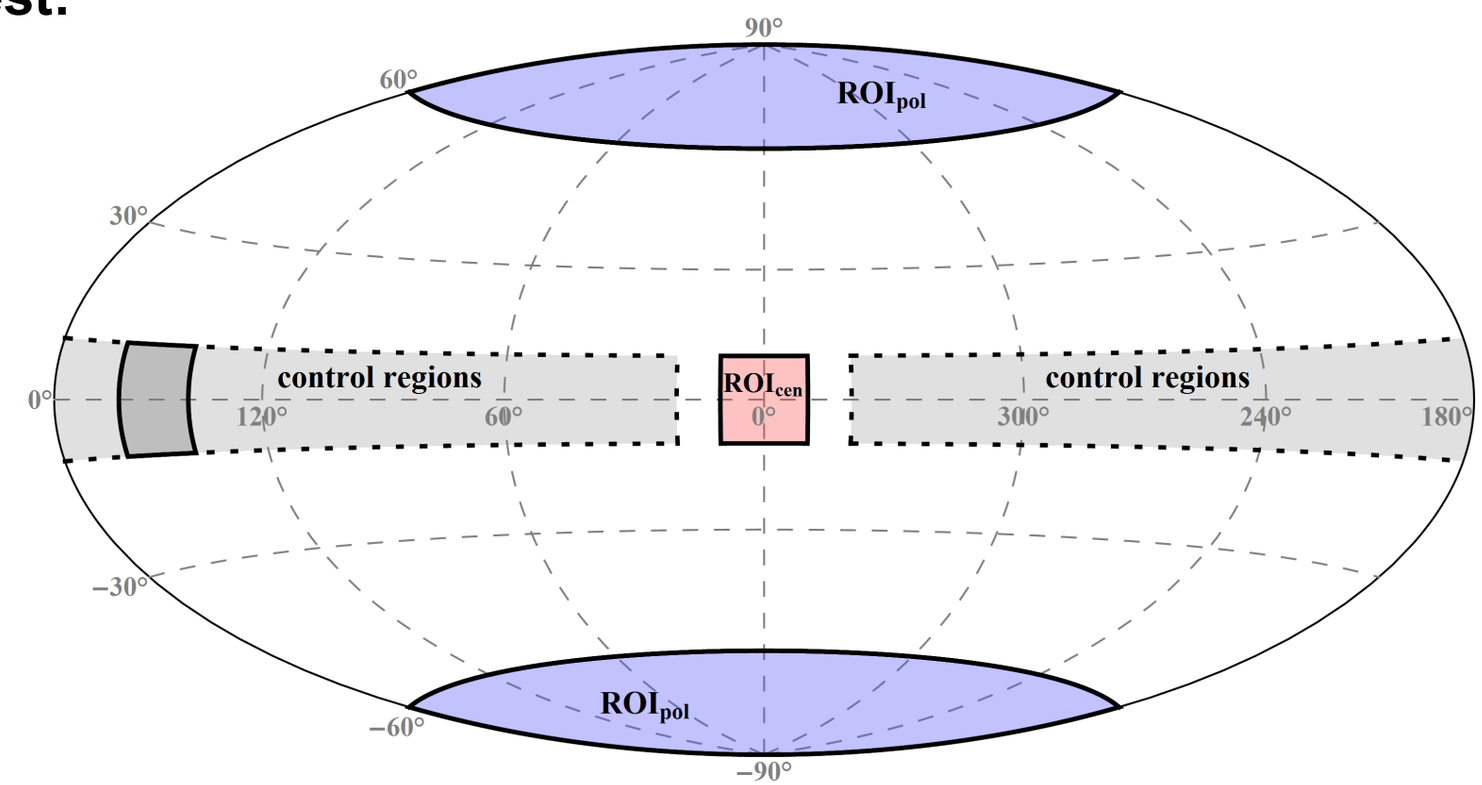
at low energies the statistical uncertainty gets very small (<1%) and the systematic uncertainties dominate - important to model them properly

Data:

P7 REP Clean, ZA < 100°, 5.2 years

Fit for lines from 100 MeV to 10 GeV ($\pm 2\sigma_E$ windows -> 56.5 MeV to 11.5 GeV)

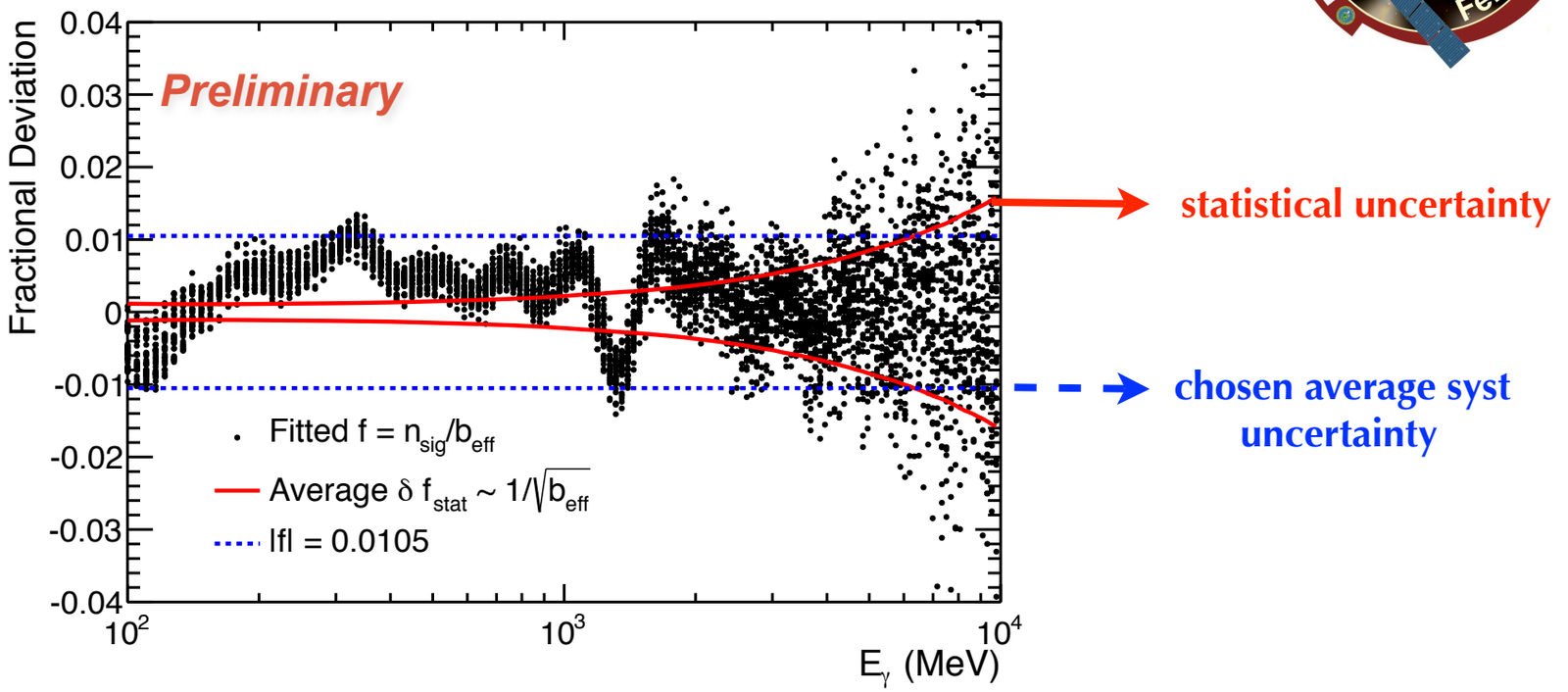
Region of interest:



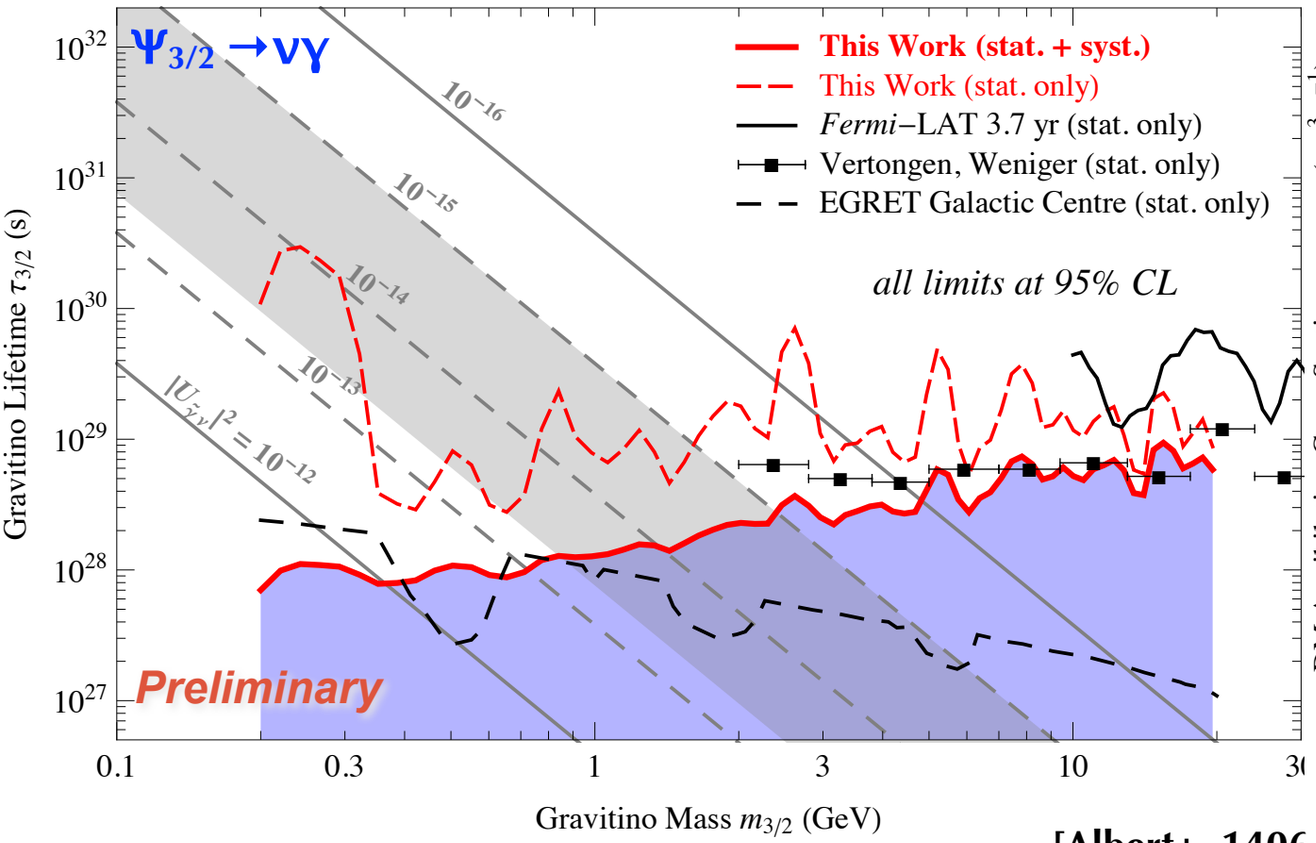
Smoking guns 01: **Gamma ray** line - **LOW energy line search:**

Systematic uncertainty:

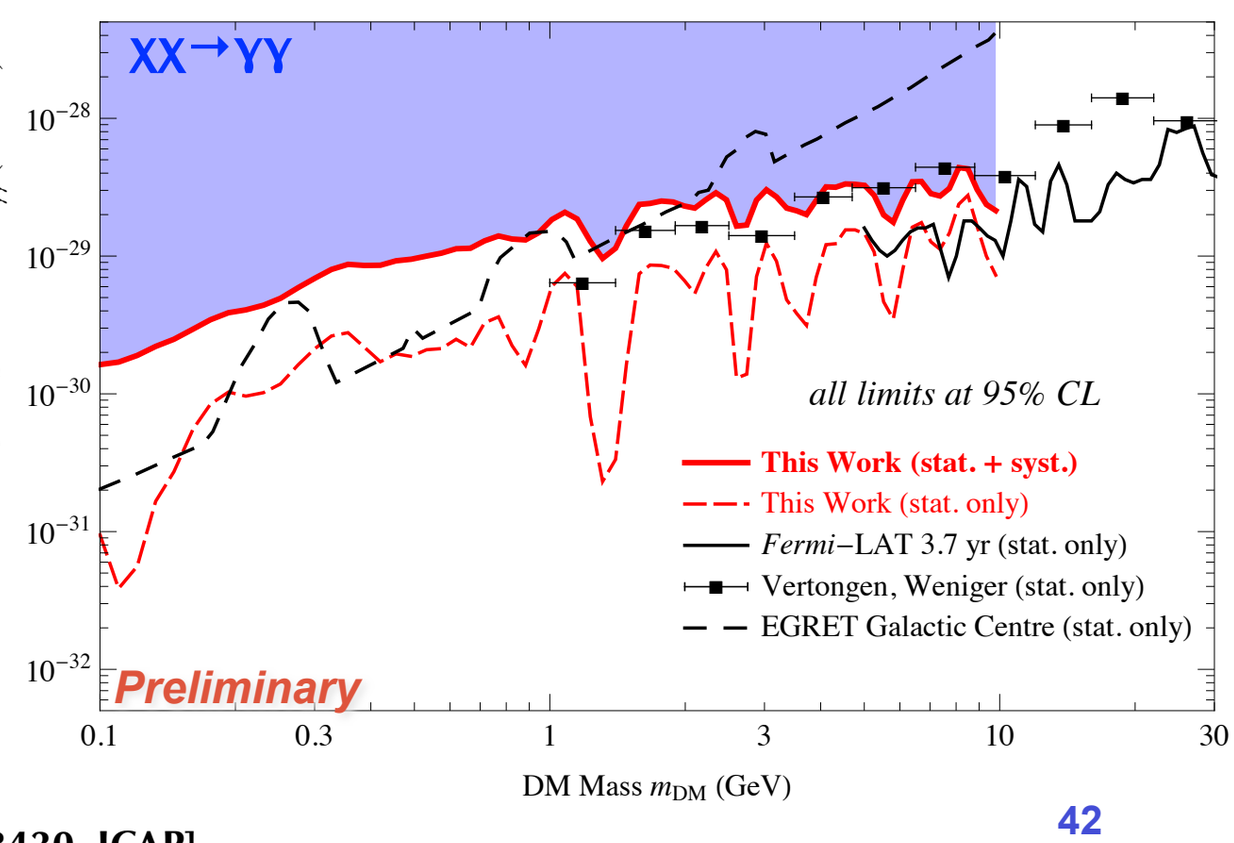
obtained in fits along the Galactic plane dominates below ~3 GeV



Limits, decaying DM:



Limits, annihilating DM:



[Albert+, 1406.3430, JCAP]

Low energy line search: fitting method

Include nuisance parameter (n_{sys}) for systematically-induced line-like features:

- only consider the true signal events to be those that remain after subtracting the expected systematic offset, $n_{sig}' = n_{sig} - n_{syst}$
- We add a Gaussian constraint on n_{sys} to the likelihood fit

f_{sys} determined by control regions fits (i.e. off-center Galactic Ridge)

Similar technique used to incorporate J-factor systematic uncertainties in LAT Collaboration dSph analysis

Can be applied whenever accounting for systematic uncertainties is important

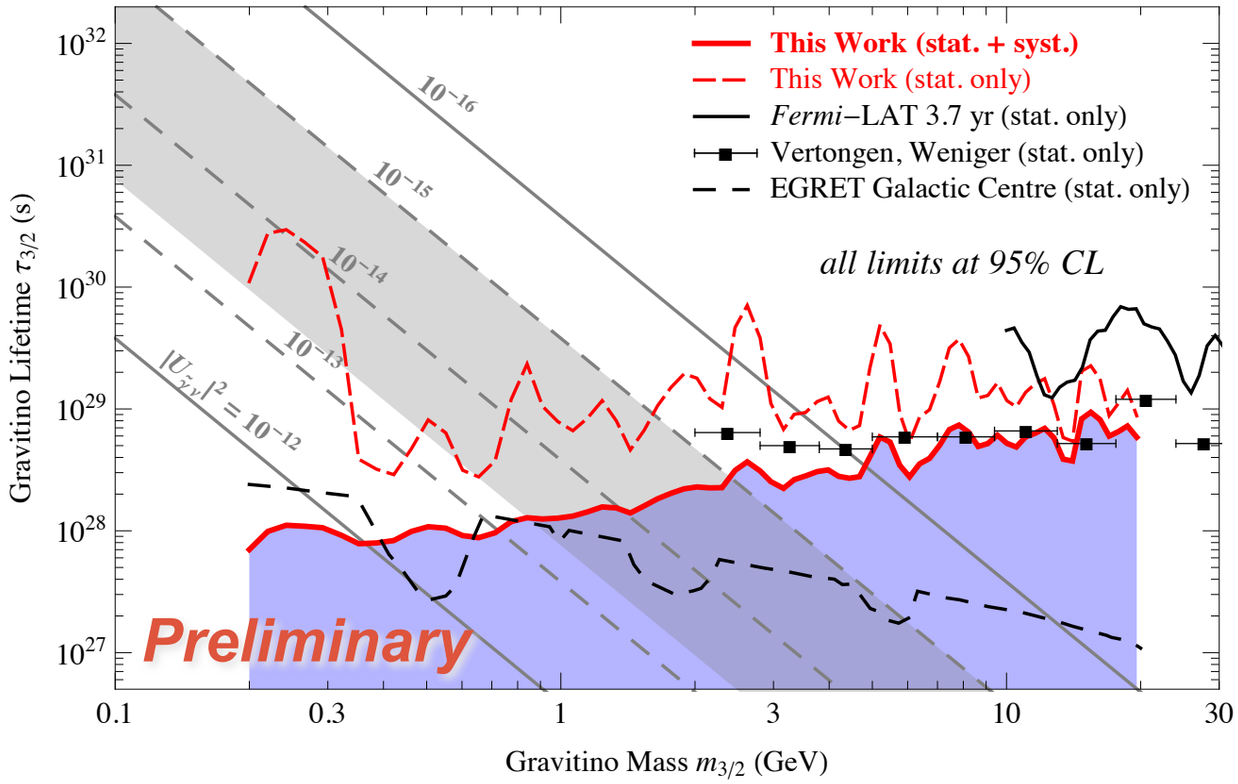
- the full likelihood function

$$\mathcal{L}(\alpha, \Gamma, n_{\rm sig}, n_{\rm syst}) = P_{\mathcal{F}}(n_{\rm syst}, b_{\rm eff}) \prod_i P(c_i | \mu_i(\alpha, \Gamma, n_{\rm sig} + n_{\rm syst}))$$

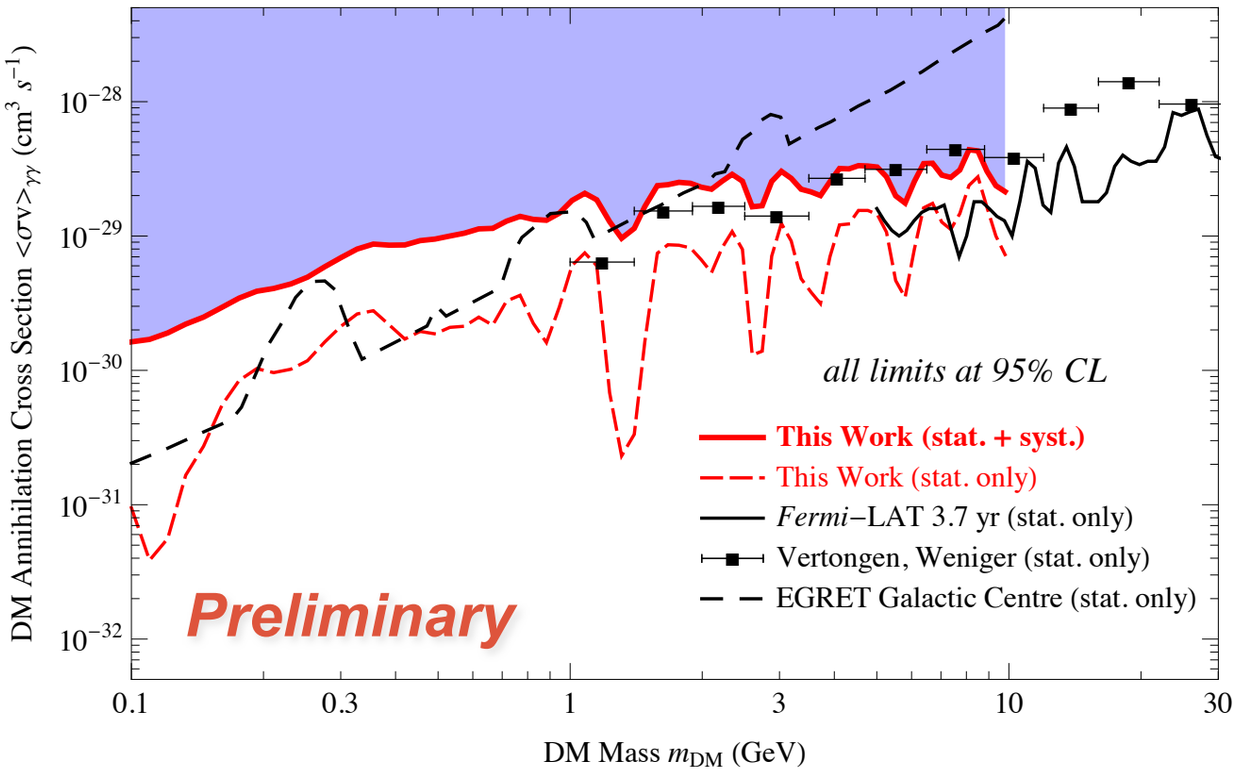
$$P_{\mathcal{F}}(n_{\rm syst}, b_{\rm eff}) = \frac{1}{\sigma_{\rm syst}\sqrt{2\pi}} \exp\left(-\frac{(n_{\rm syst} - \mu_{\rm syst})^2}{2\sigma_{\rm syst}^2}\right) \qquad \sigma_{\rm syst} = \delta f_{\rm syst} b_{\rm eff}$$

Low energy line search: limits

$\Psi_{3/2} \rightarrow \nu\gamma$



$XX \rightarrow \gamma\gamma$



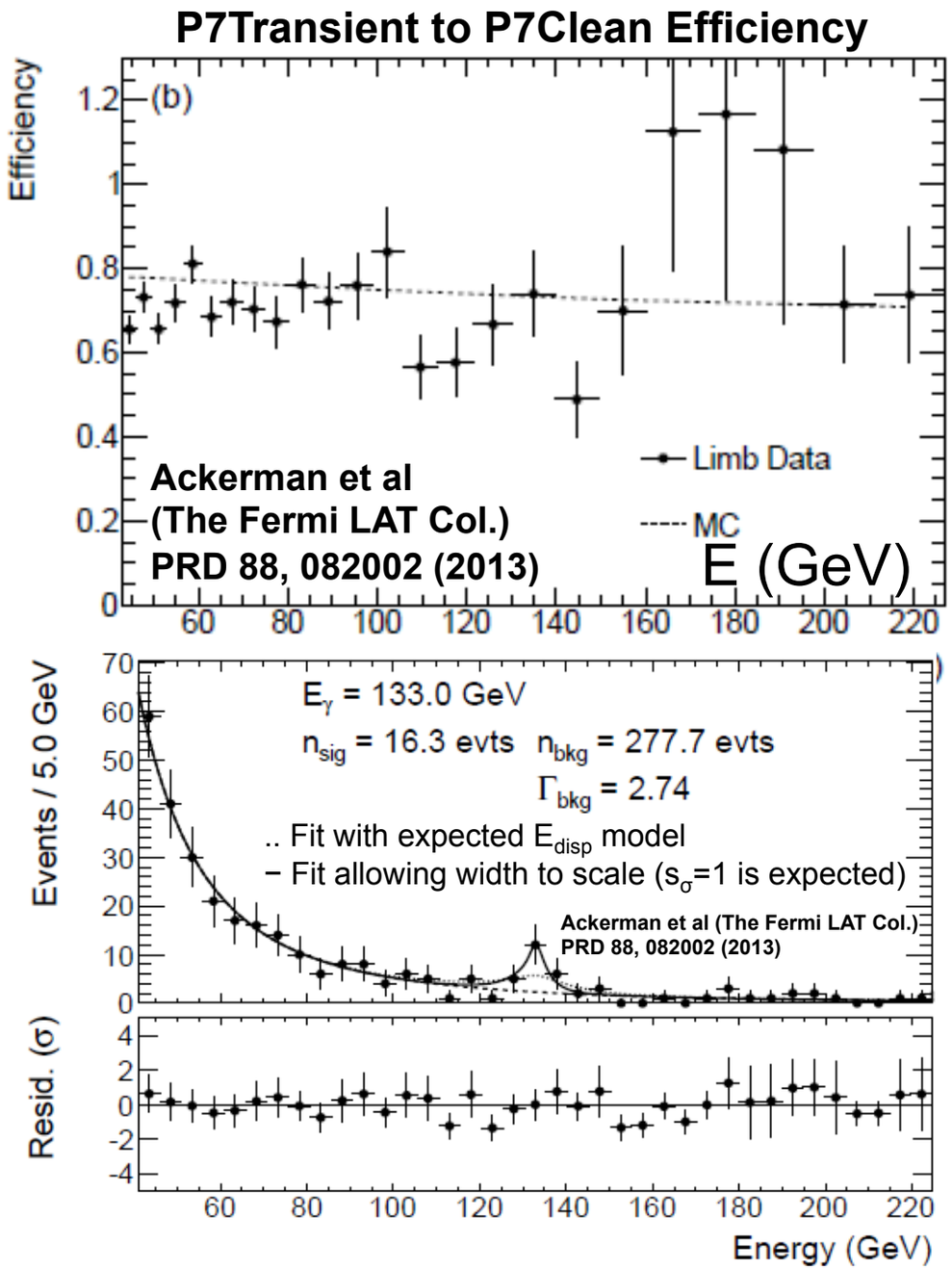
[Albert+, 1406.3430, JCAP submitted]

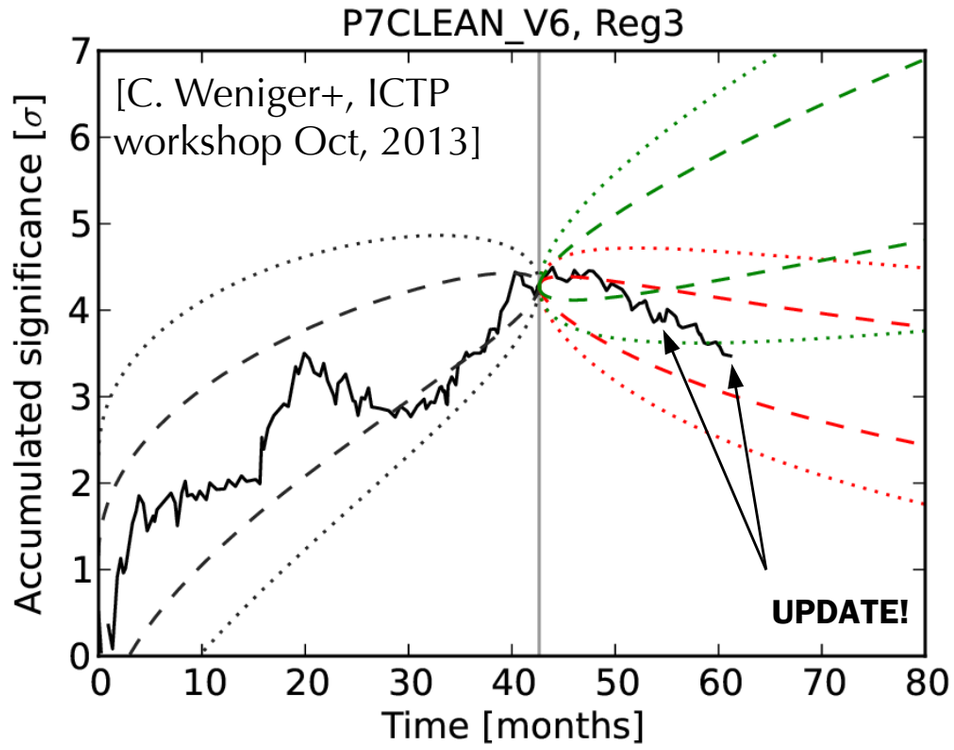
High energy line search: update

- this analysis statistics dominated.
- curious hint for a 133 GeV line being followed up by the LAT team and community

Weak line signal appears in the control sample (Earth limb ($|\theta r|<52^0$)

-Not large enough to explain all the GC signal (f=0.14, in GC would be 0.8σ).





→ Behaves like expected for a statistical fluke

Since spring 2012, feature has decreased.

Bkg fluctuation?

-Decreasing with more data

-Much narrower than expected energy resolution

- **Let width scale factor float in fit (while preserving shape)**
- $s_\sigma = 0.32^{+0.22}_{-0.07}(95\%CL) \quad \Delta TS = 9.4$

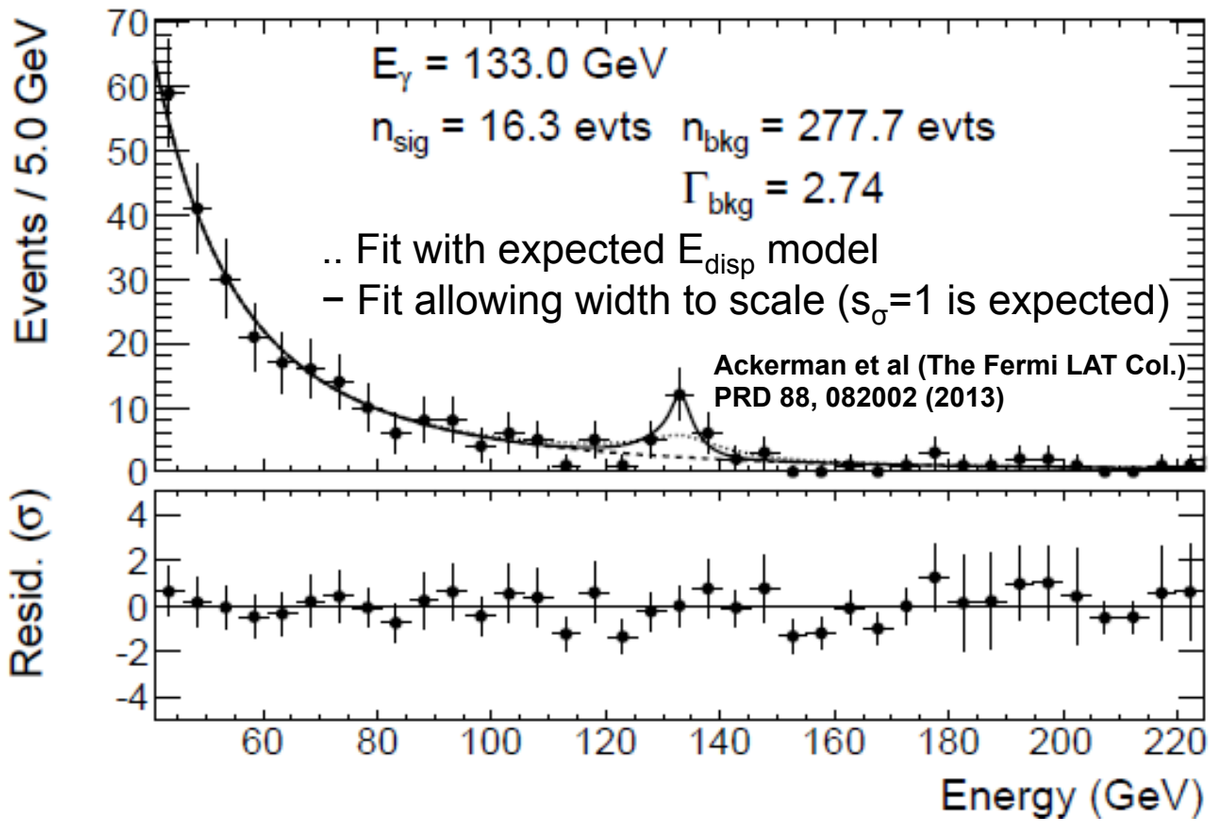
Smoking guns 01: **Gamma ray** line - update

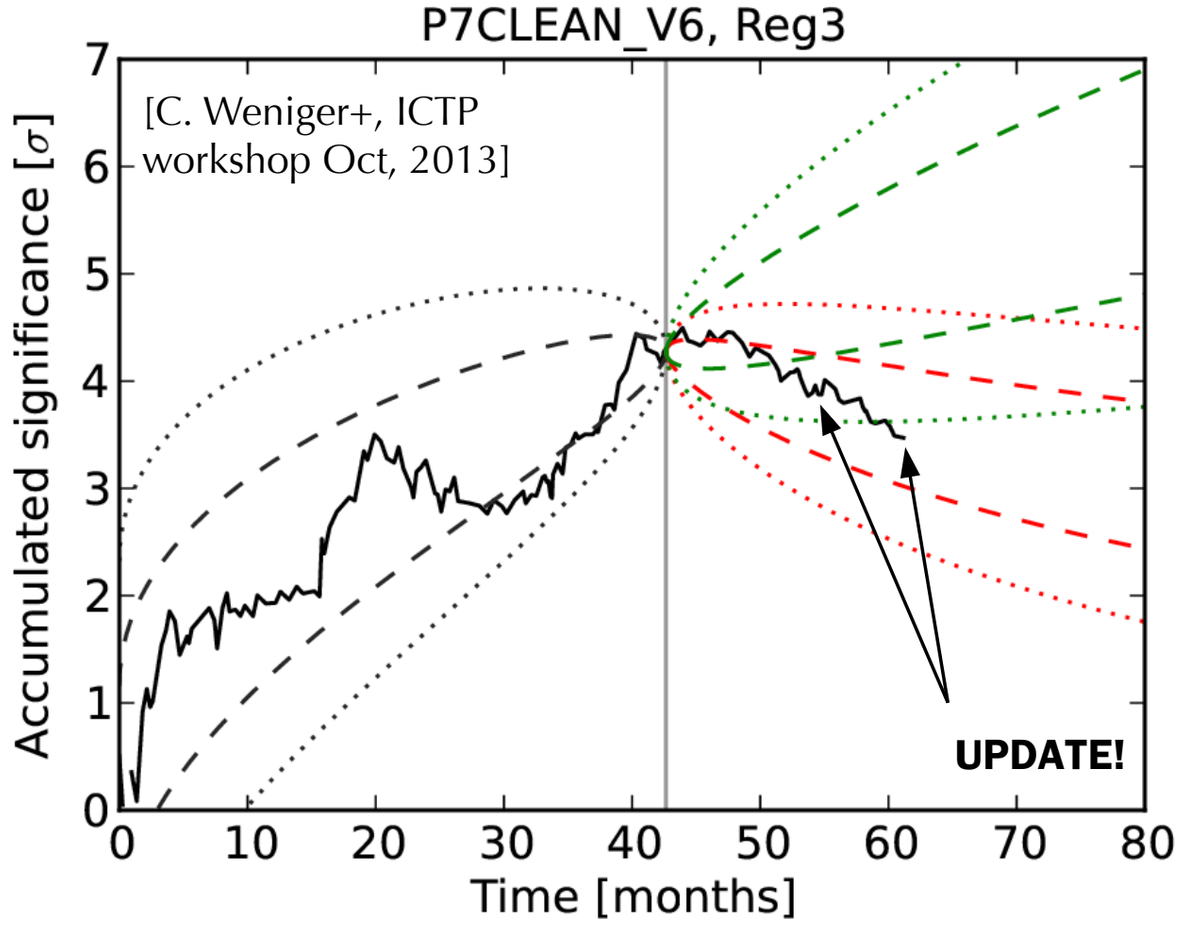
Since spring 2012, feature has decreased.

Bkg fluctuation?

-Decreasing with more data

-Much narrower than expected energy resolution



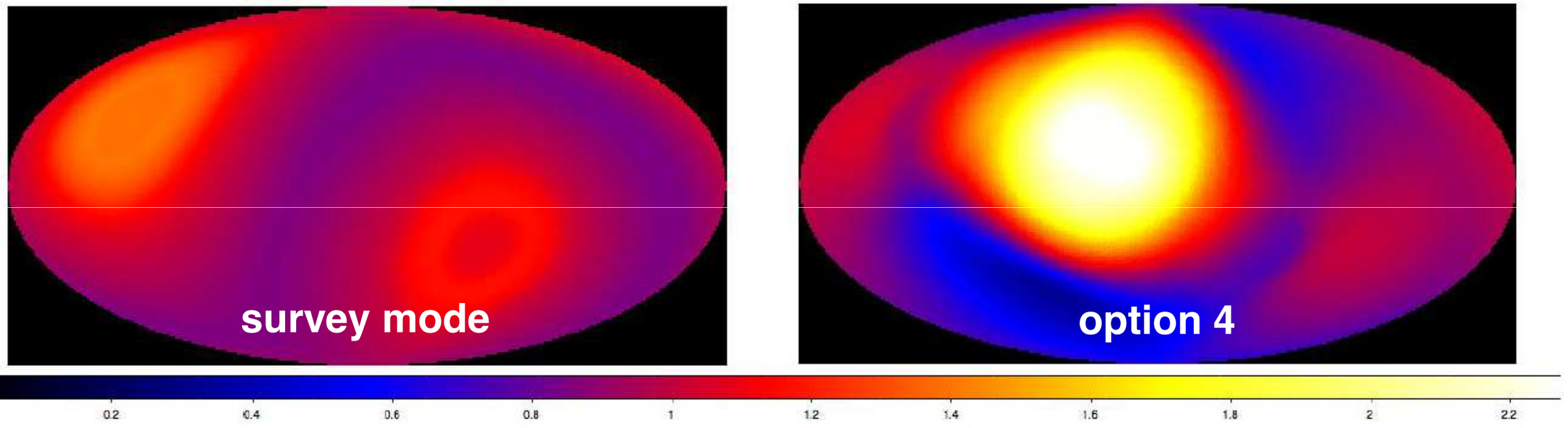


- **Let width scale factor float in fit (while preserving shape)**
- $s_\sigma = 0.32^{+0.22}_{-0.07}(95\%CL) \quad \Delta TS = 9.4$

→ Behaves like expected for a statistical fluke

Smoking guns: **Gamma ray** line

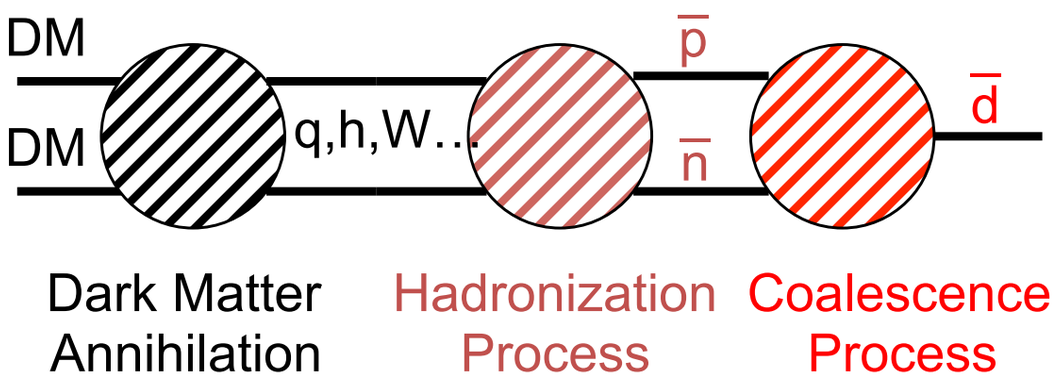
- **increase statistics** through a **change in observational strategy** (to favor the GC region). Started December 2013, ended January 2015.
- New event reconstruction scheme of the Fermi LAT events (**Pass 8**) with independent systematics will be available soon.
- **HESS 2** telescope should be able to say the final word by the end of the year.



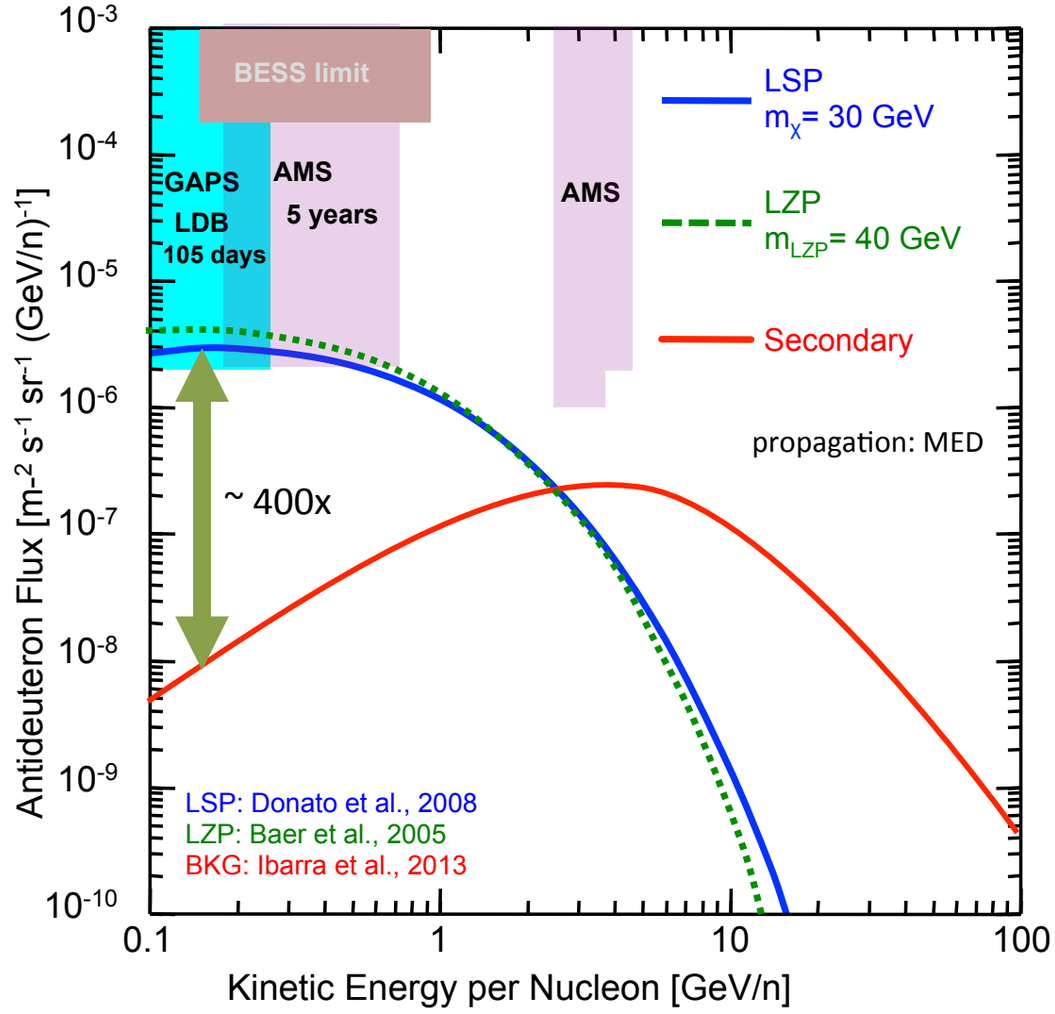
exposure maps

Smoking guns 03: anti-deuterons ($\bar{p}$ $\bar{n}$)

- not detected yet;
- in DM ann/decays produced via the coalescence of anti-p and -n, originating from an annihilation event
- astro: spallation of high energy cosmic ray protons on the interstellar gas at rest pH or pHe
- ***DM signals*** flatter than astro backgrounds for ***<2,3 GeV/n***: detection of ~1 pn at <1 GeV a smoking gun -- A generic signature with essentially zero conventional astrophysical background



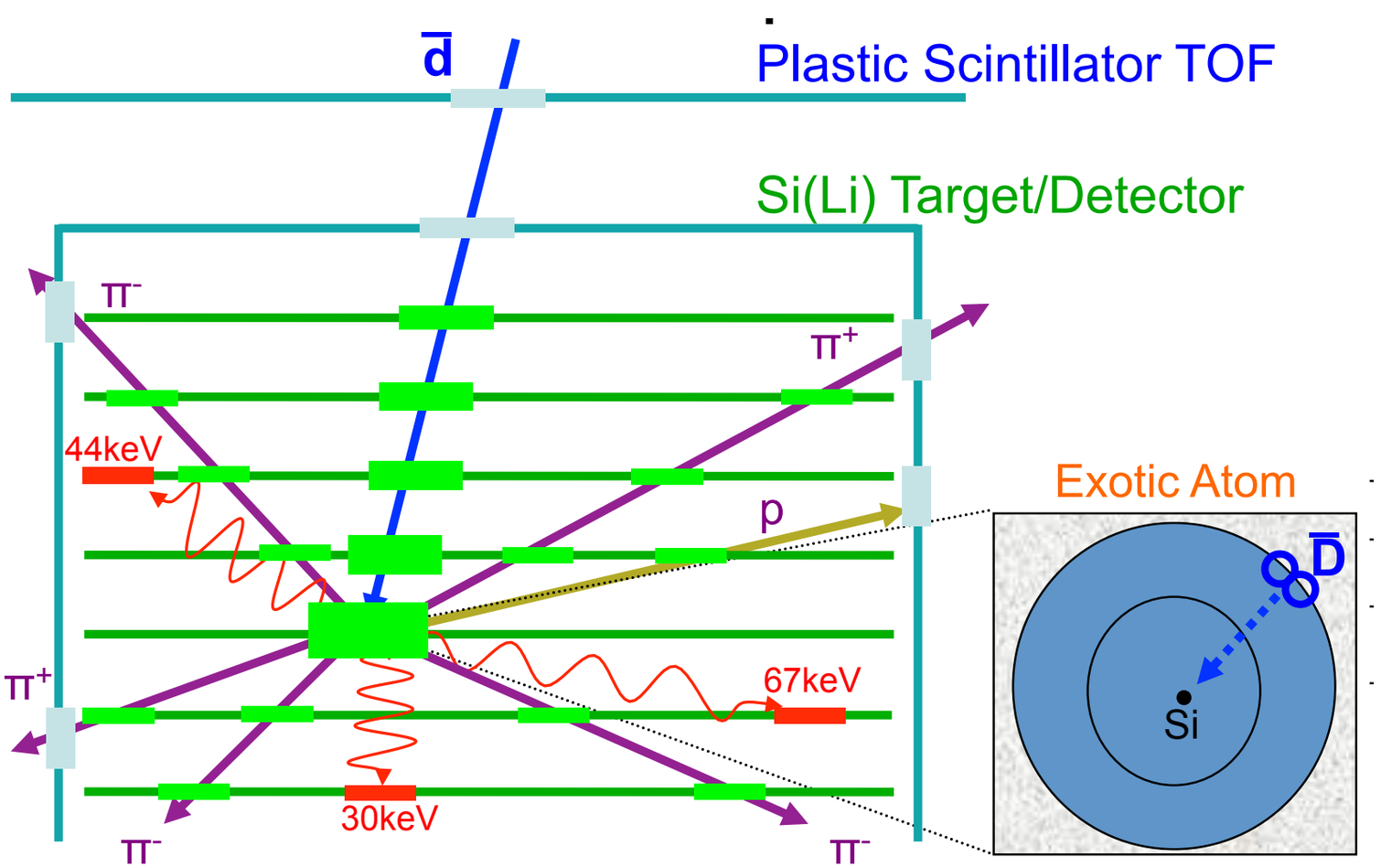
[Ibarra+, 1301.3820, Fornengo+, 1306.4171]



Smoking guns 03: anti-deuterons ($\bar{p}$ $\bar{n}$)

- GAPS detects atomic X-rays and annihilation products from exotic atoms
- AMS in its second year & pGAPS finished a prototype flight! Plan for an initial GAPS flight in winter 2017/2018.
- Exciting time coming up for anti-deuteron searches!

Taiki, Japan



[T. Aramaki's talk at TeVPA 2014]

[K. Perez's talk at ICRC & arXiv:1303.1615]

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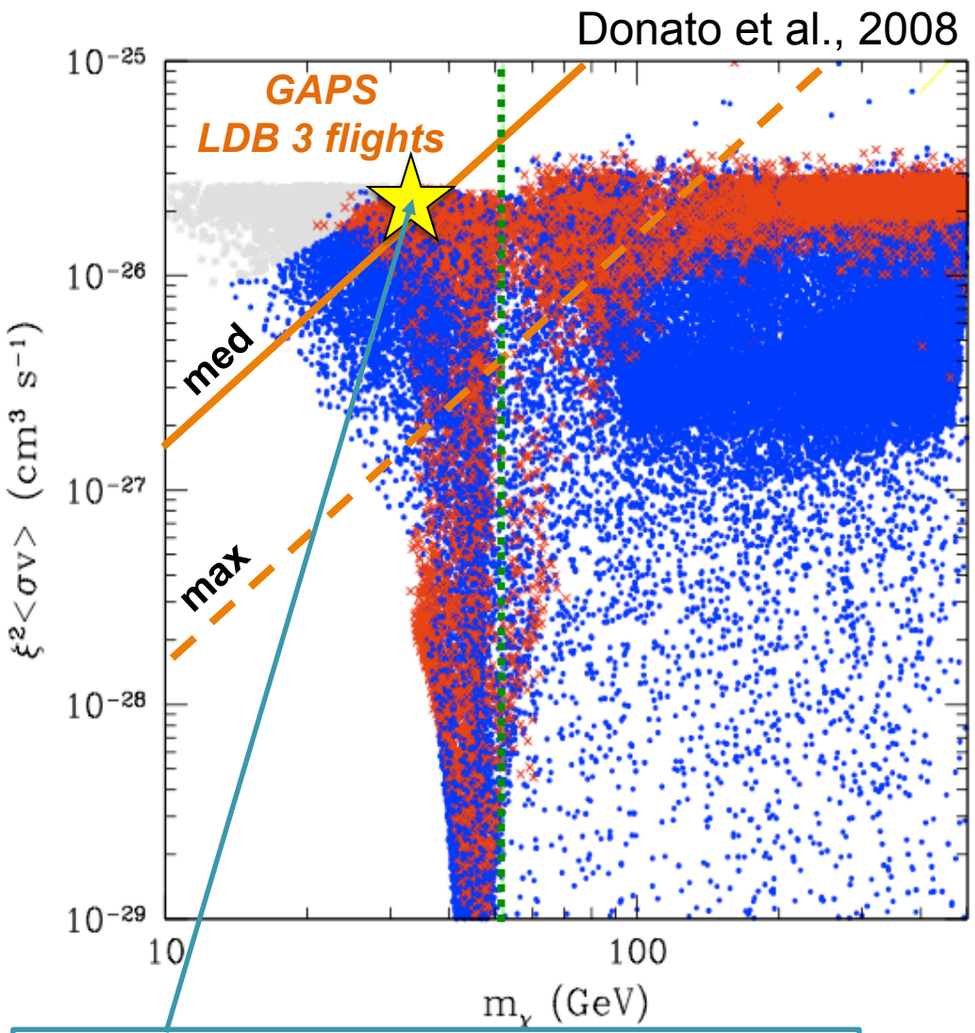
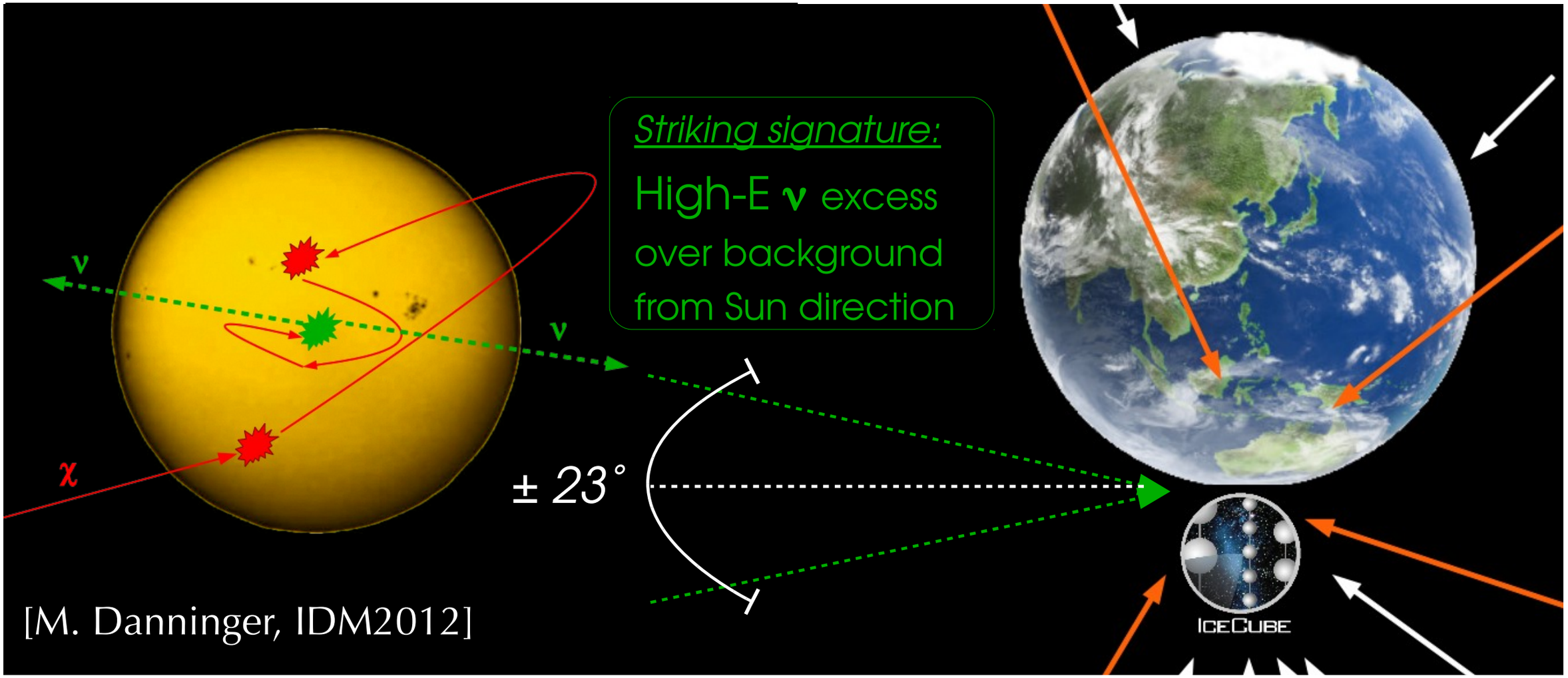


neutralino DM with m ~ 30-40 GeV
suggested by the Fermi-LAT observation

[K. Perez's talk at ICRC & arXiv:1303.1615]

Smoking guns 04: high energy neutrinos from the Sun



Use off-source data to estimate the CR related backgrounds.

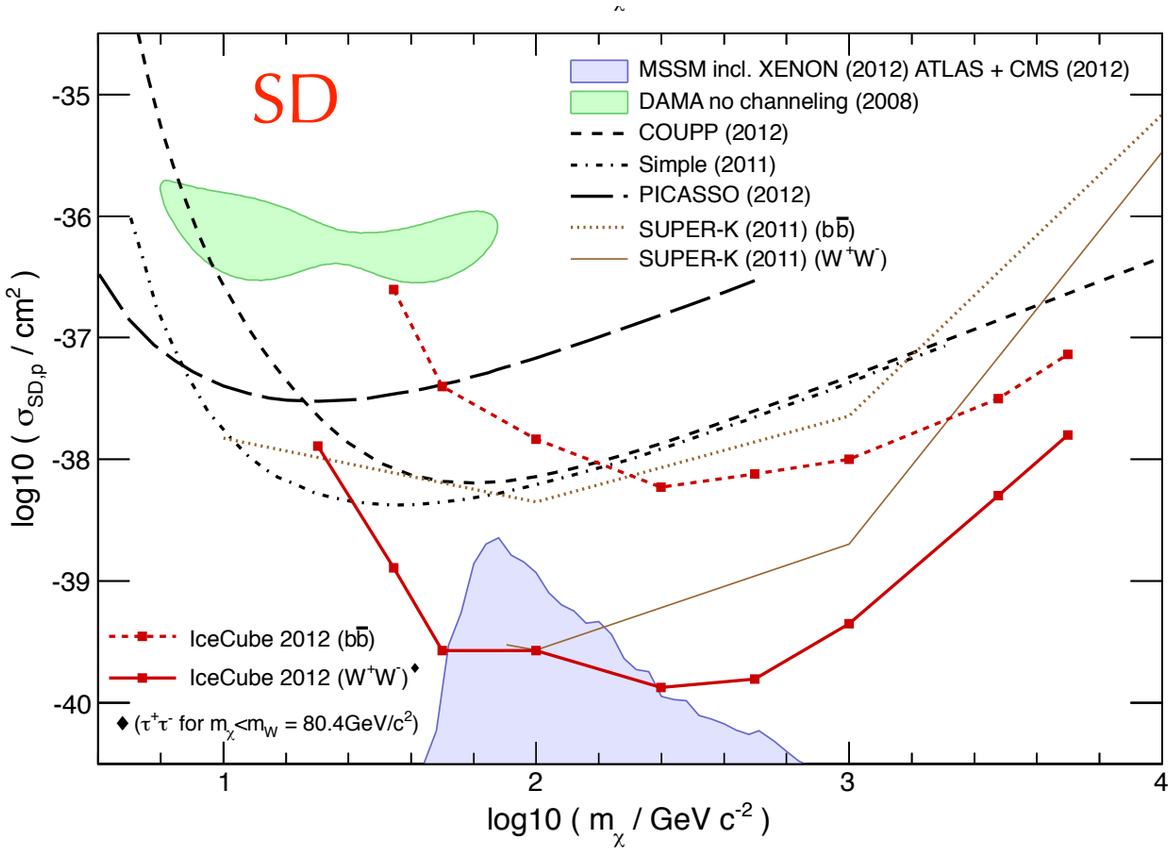
Solar neutrino fluxes low >1 GeV energies - detection of a signal- **smoking gun**.

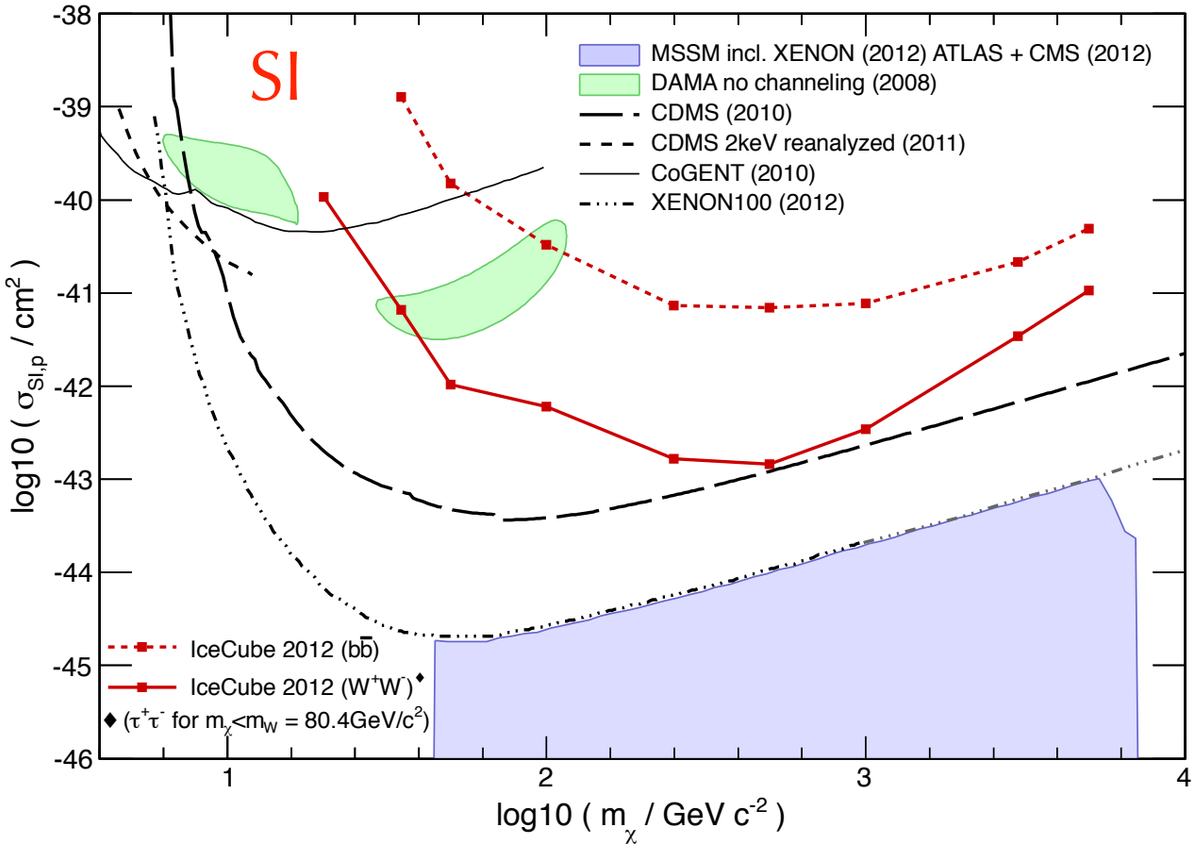
In equilibrium all captured DM particles annihilate, **by constraining Γ_A we constrain elastic cross sections**!

Smoking guns 04: high energy neutrinos from the Sun

Sun is made of p! Limits on spin dependent cross section stronger wrt direct detection experiments!

- New results from ***79-string*** data (~1y livetime)
- First Dark Matter analysis including ***DeepCore*** -> constrain low masses >20 GeV and use ***full year***-round IceCube data!



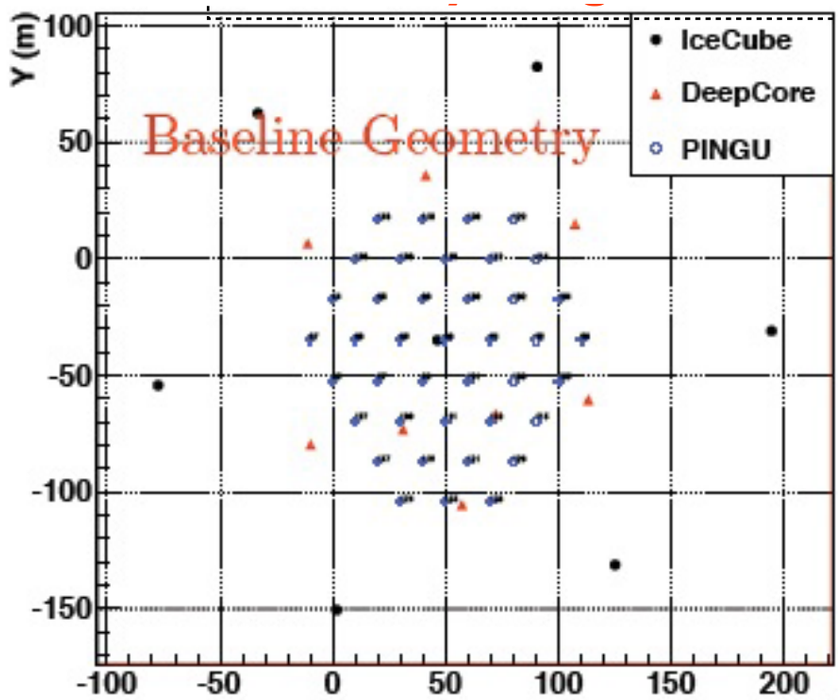


[ICE CUBE collab., PRL 2013, 1212.4097]
(see also 0905.2316, ANTARES)

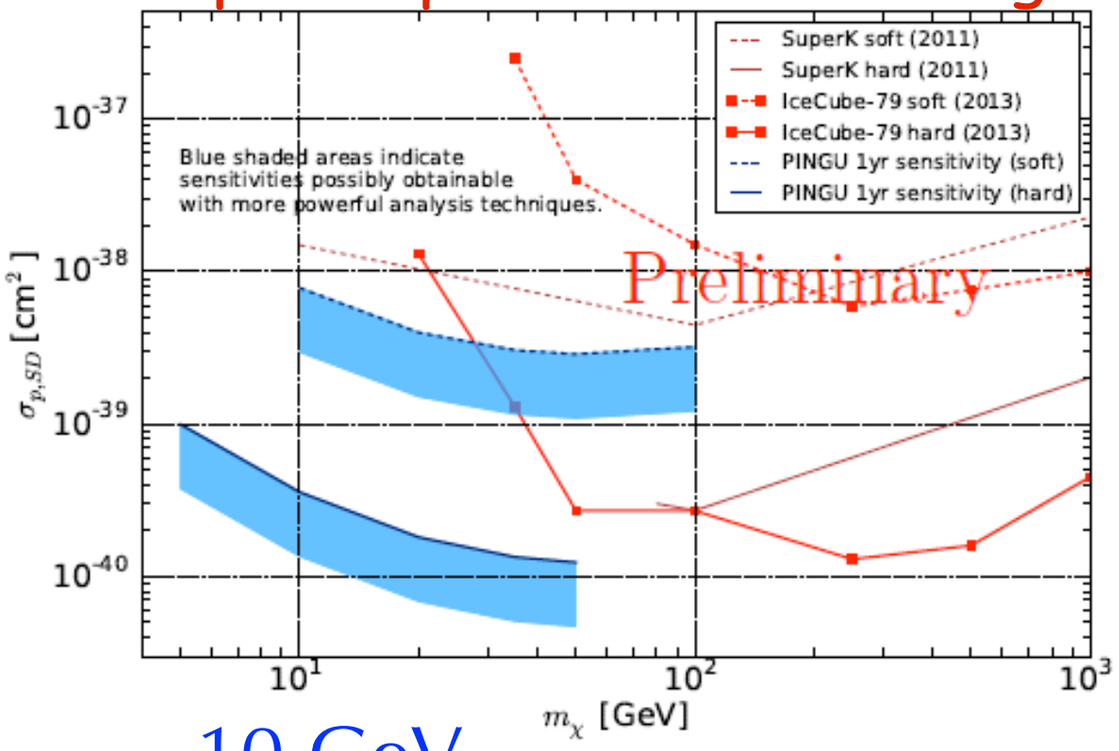
Smoking guns 04: high energy neutrinos from the Sun

Precision **I**ceCube **N**ext **G**eneration **U**pgrade

- High density instrumentation:
  - baseline geometry: 40 strings with 60 DOMs each)
  - Threshold ~ 1GeV
- Test low mass WIMP region -- capable to comfortably test DAMA/Libra

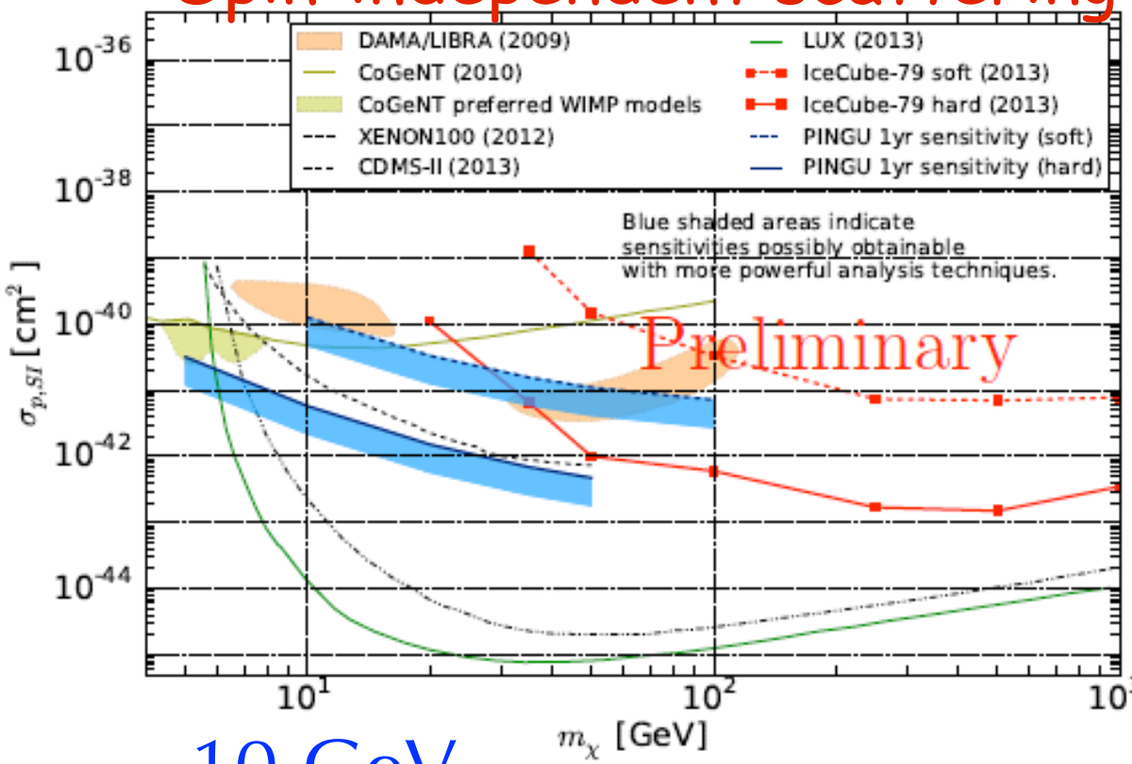


Spin-dependent scattering



10 GeV

Spin-independent scattering



10 GeV

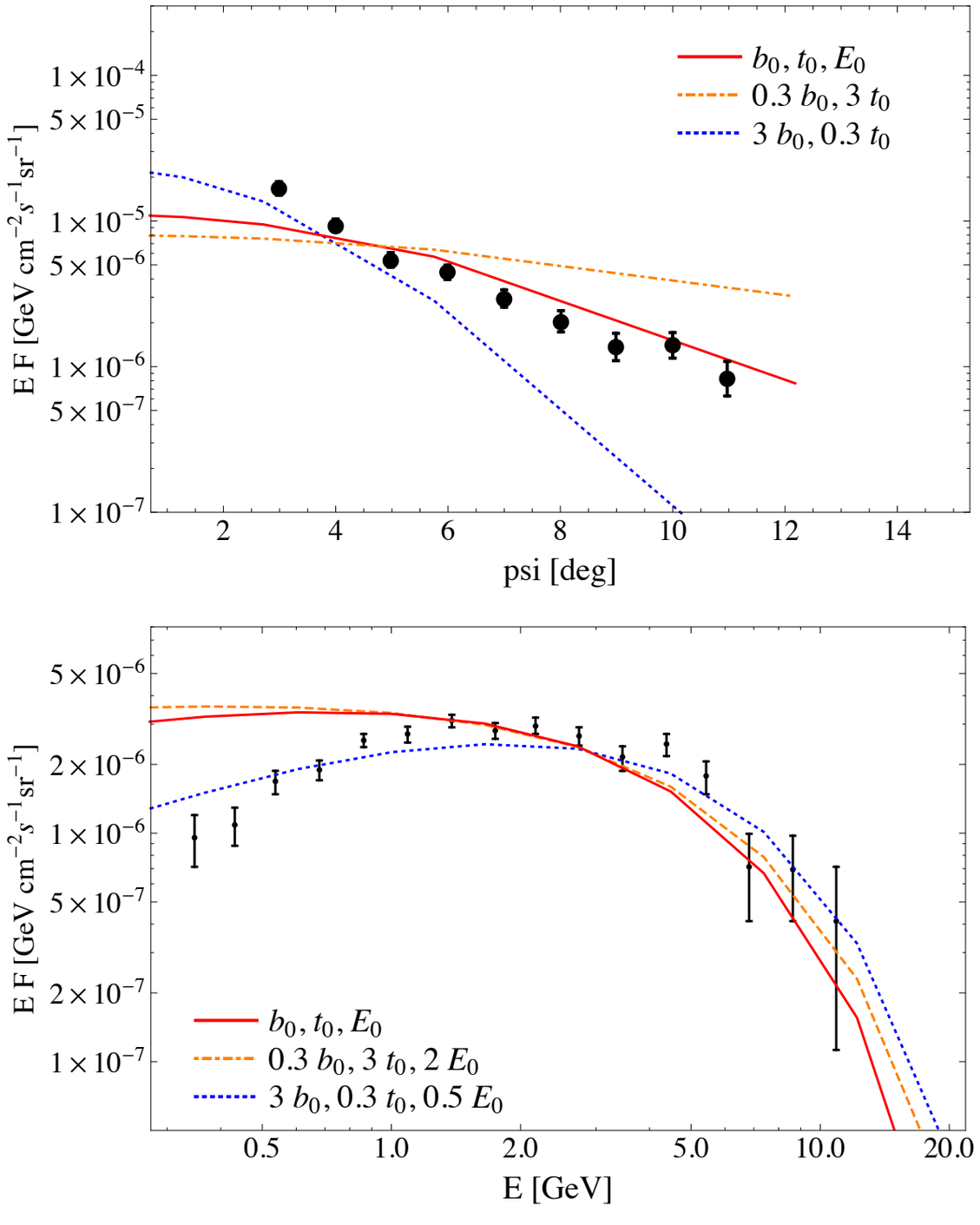
[C. Rott, APP Conference, 2014]

Galactic Center gamma ray signal

Astrophysical explanations:

electrons injected in a bursting episode (~1 Myr ago, 10^{53} erg):

- pros: energy cut-off set by energy losses, many flaring episodes known in that region from independent evidence
- cons: **simple burst cannot explain all the details within statistical errors published so far**.



[Petrovic+, 1405.7928]

Future:

- The field of astrophysics is being re-defined by high-quality data, extending over a larger dynamical range.

Optical surveys: DM density profiles, discovery of dwarf Galaxies, Galactic dust maps

- pan-STARRS: Hawaii, PS1 started operating in 2008.
- DES: Chile, started 2012.
- Gaia: launched October 2013.

X-ray: GC environment, Fermi bubbles, pulsars, AGNs, star burst Galaxies

- nuSTAR: launched 2012.

Radio: pulsars, CR propagation, DM signatures

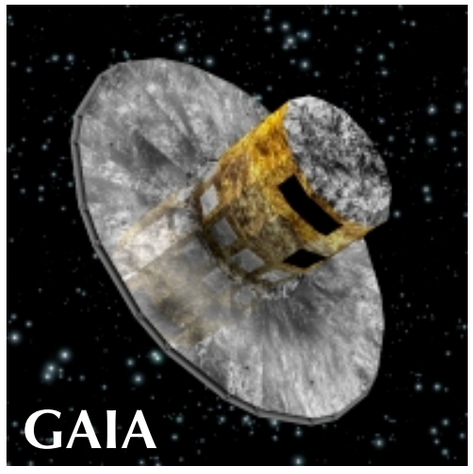
- SKA: construction 2016; to be built in South Africa and Australia.

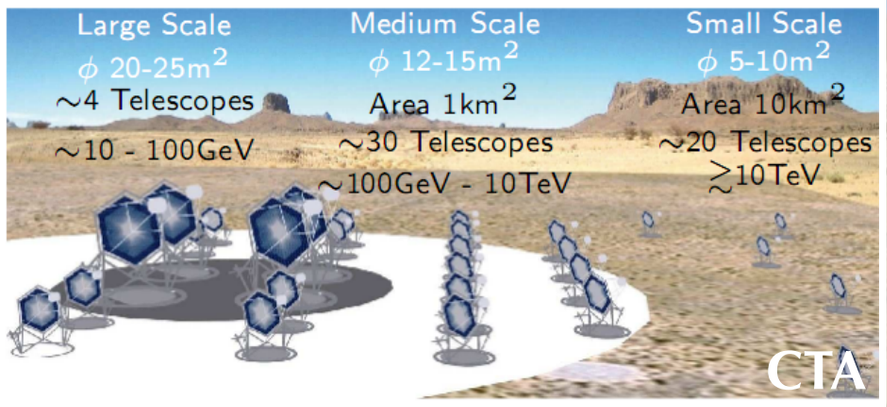
Gamma rays/charged CRs:

- CTA
- Gamma-400

Neutrinos:

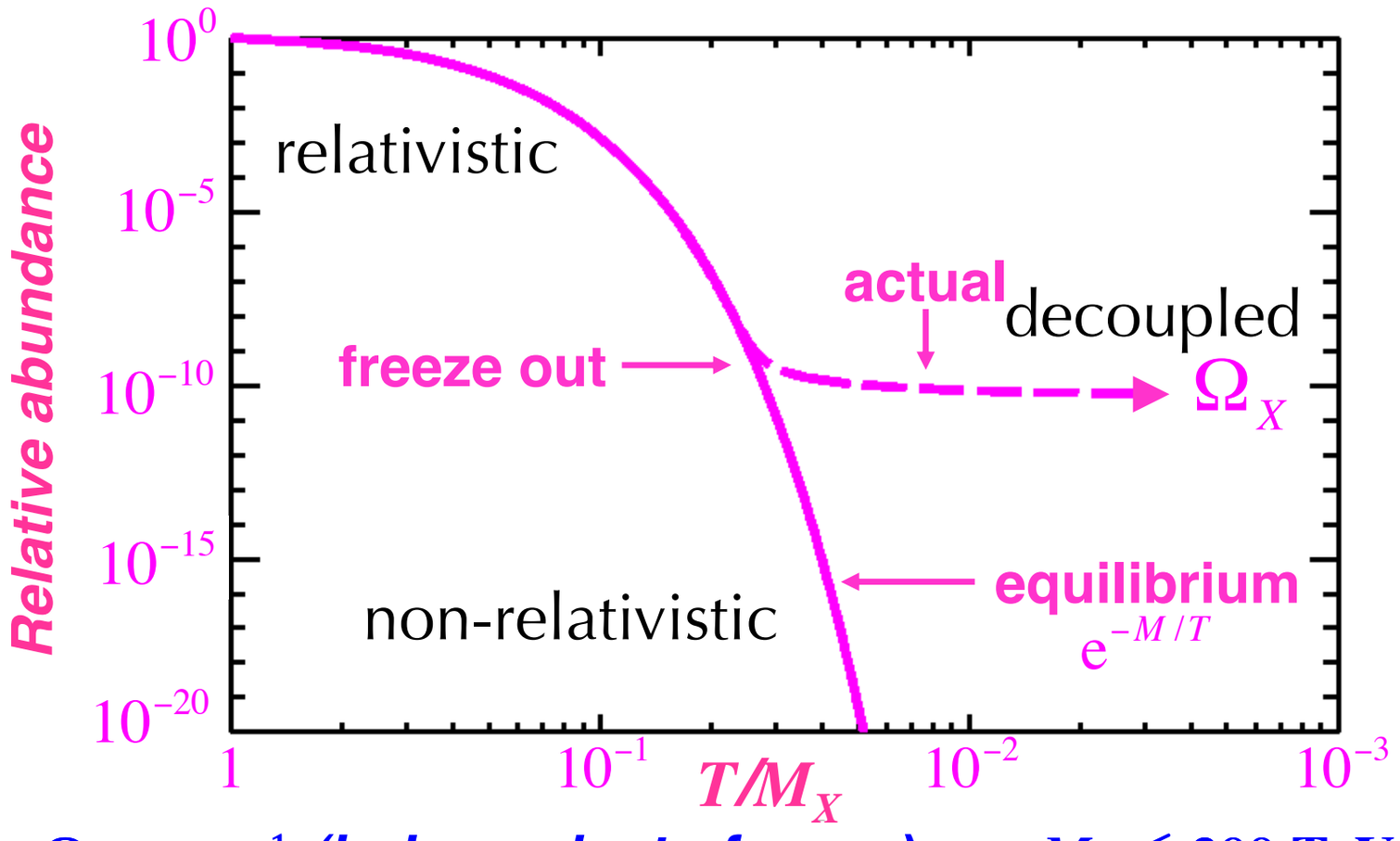
- Ice Cube/PINGU
- km3net





Focus on WIMPs

weak-scale mass + weak interactions → give automatically the correct abundance + have all the right properties for DM (caveats...)



$\Omega_X \propto \sigma_A^{-1}$ ***(independent of mass)*** $M_X \lesssim 200$ **TeV**

- **theoretical bias**: "a simple, elegant, compelling explanation for a complex physical phenomenon" (R. Kolb)
- ***Large experimental effort and bulk of this talk!*** *(Disclaimer: the field is richer: stellar neutrinos, axions...)*