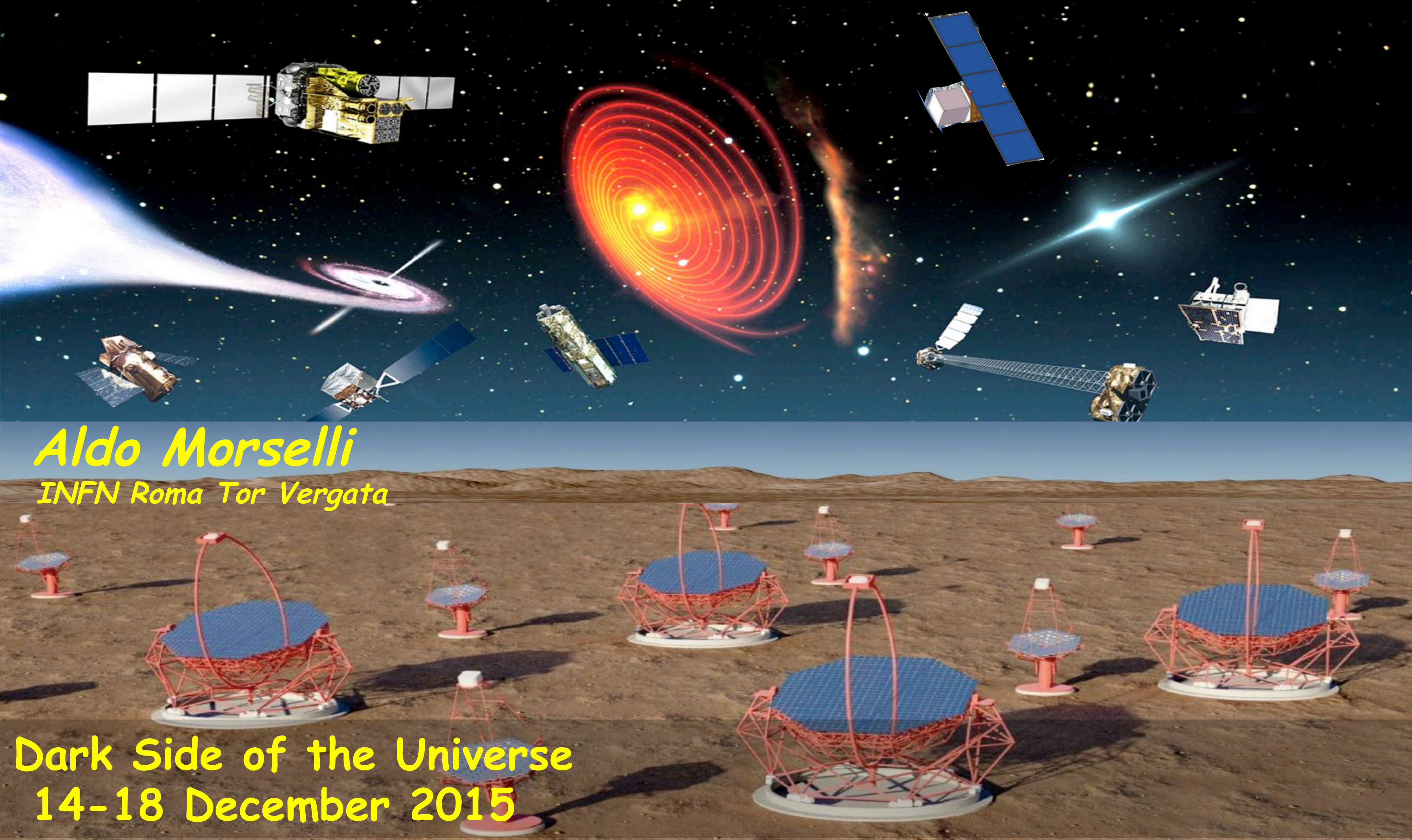
Indirect dark-matter searches with gamma-rays: Current and future gamma-ray observations from KeV to TeV



Aldo Morselli

INFN Roma Tor Vergata

Dark Side of the Universe

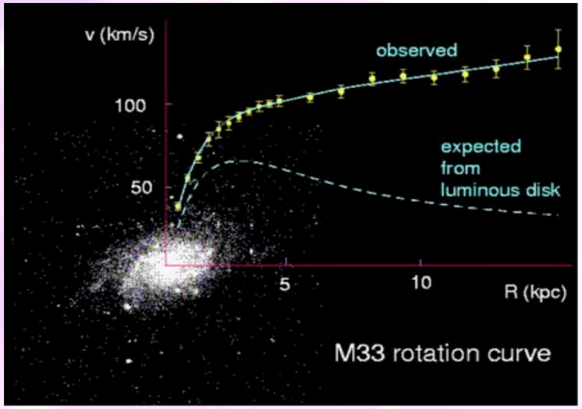
14-18 December 2015

Dark Matter EVIDENCES

- In 1933, the astronomer Zwicky realized that the mass of the luminous matter in the Coma cluster was much smaller than its total mass implied by the motion of cluster member galaxies:

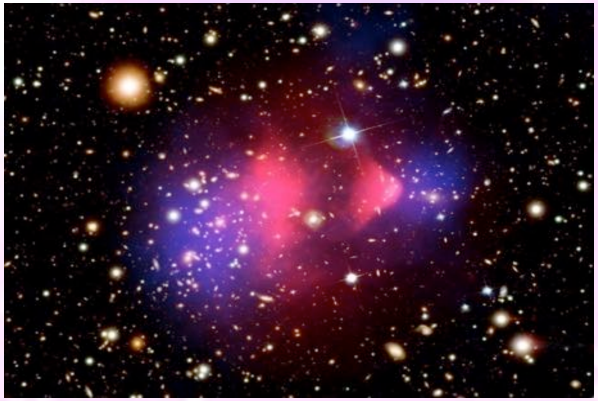
- Since then, many other evidences:

Rotation curves of galaxies

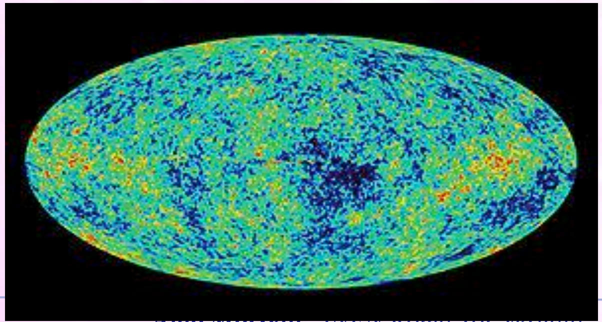


Gravitational lensing

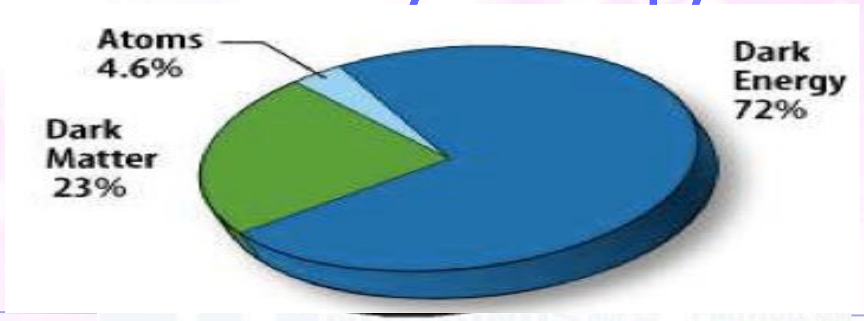
Bullet cluster



Structure formation as deduced from CMB



Data by WMAP imply:

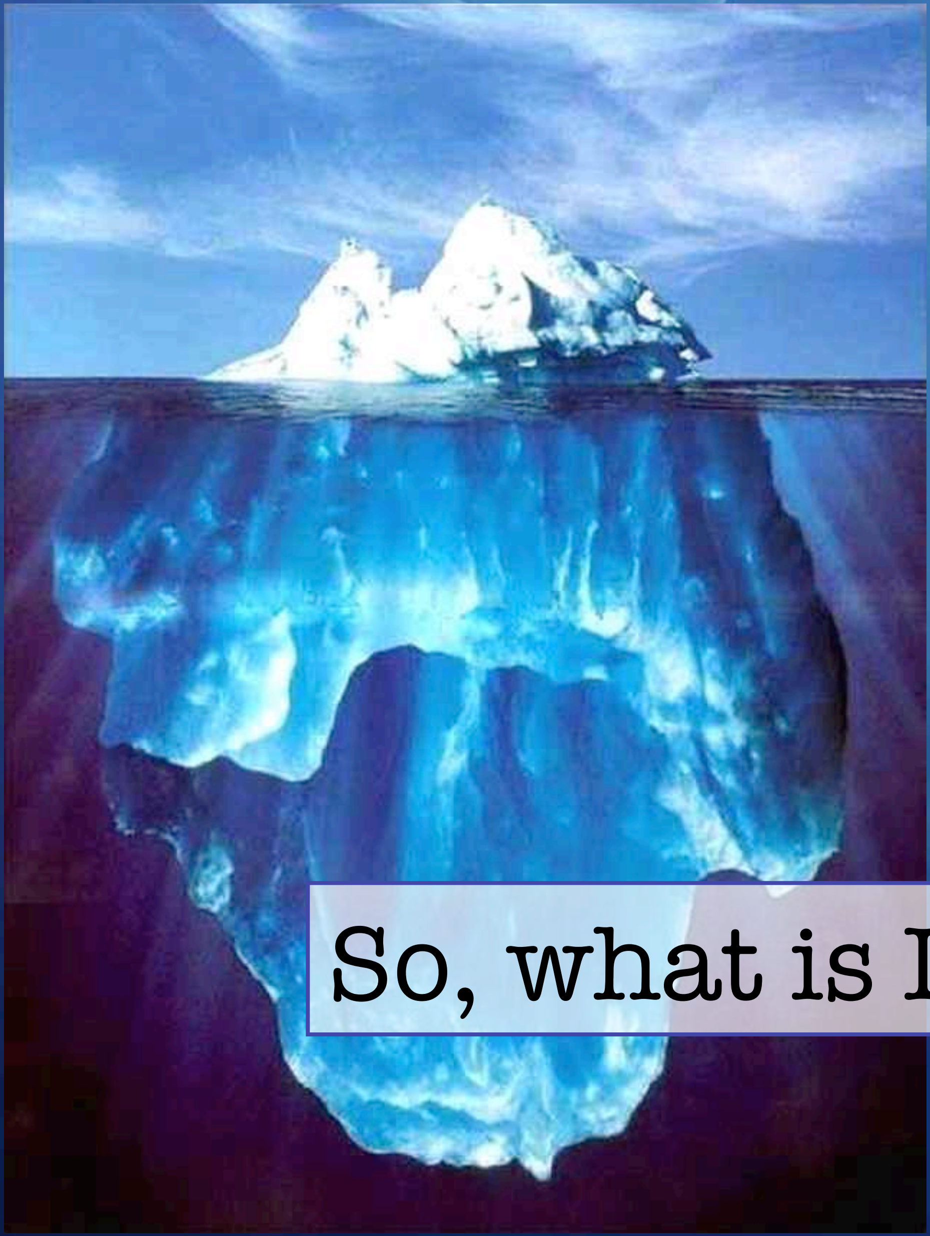


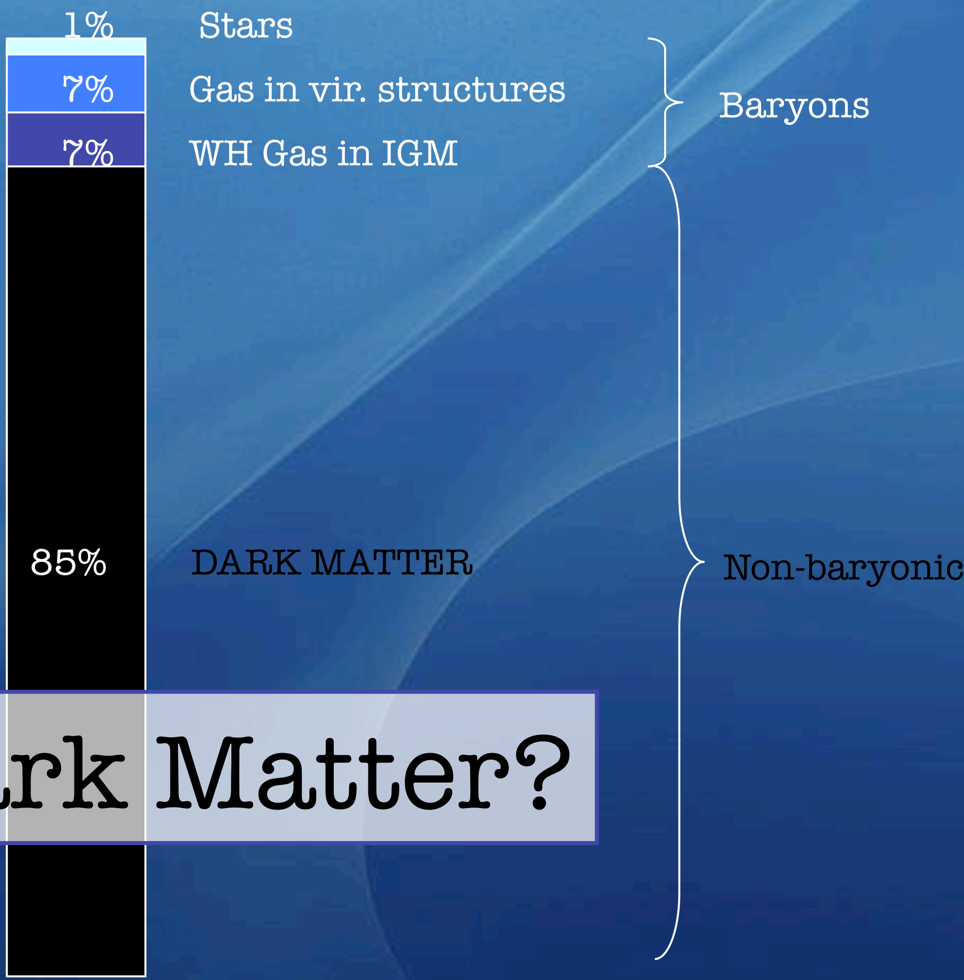
$\Omega_b h^2 \approx 0.02$

$\Omega_{DM} h^2 \approx 0.1$

Dark Matter

An Inventory of Matter in the Universe

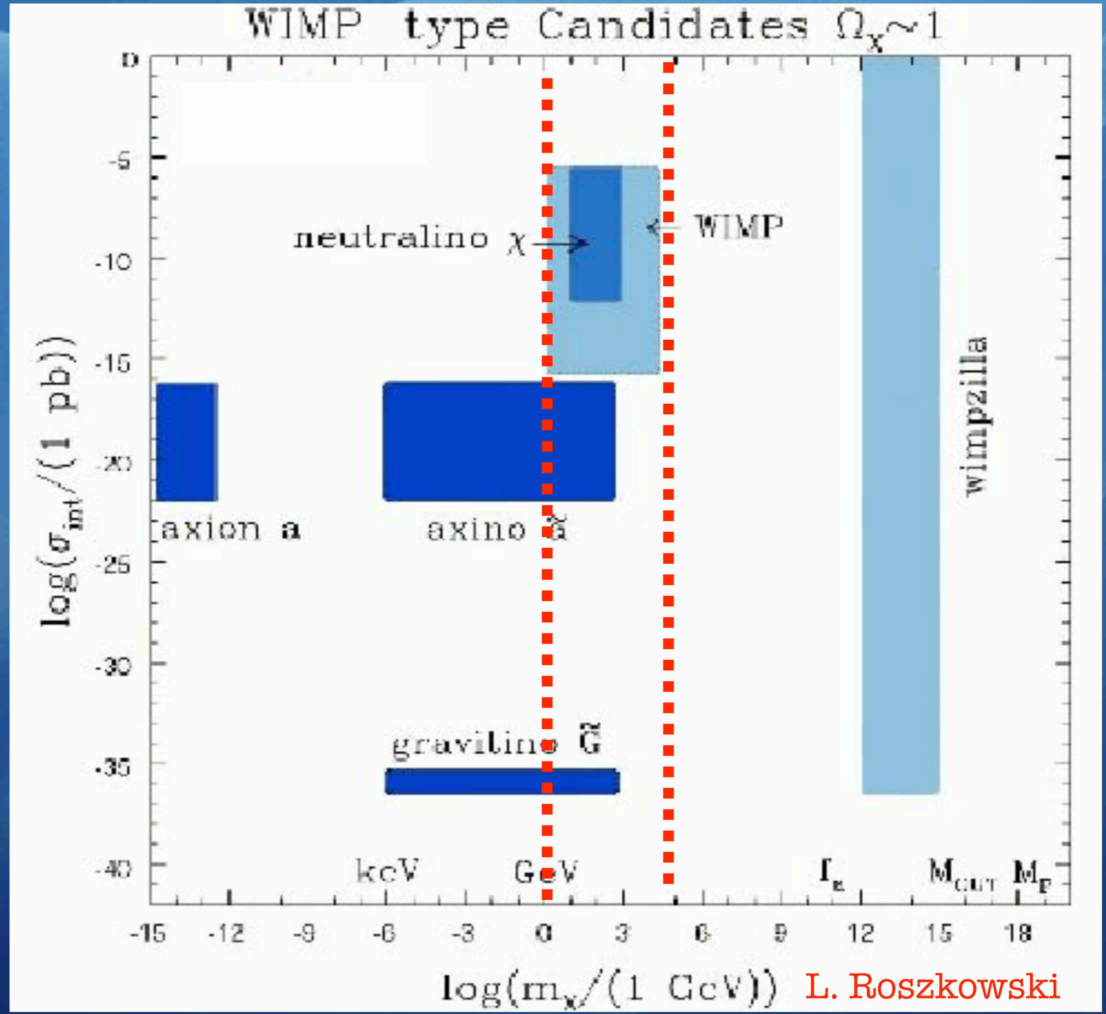




So, what is Dark Matter?

Dark Matter Candidates

- Kaluza-Klein DM in UED
- Kaluza-Klein DM in RS
- Axion
- Axino
- Gravitino
- Photino
- SM Neutrino
- Sterile Neutrino
- Sneutrino
- Light DM
- Little Higgs DM
- Wimpzillas
- Q-balls
- Mirror Matter
- Champs (charged DM)
- D-matter
- Cryptons
- Self-interacting
- Superweakly interacting
- Braneworld DM
- Heavy neutrino
- NEUTRALINO
- Messenger States in GMSB
- Branons
- Chaplygin Gas
- Split SUSY
- Primordial Black Holes



Dark Matter Candidates

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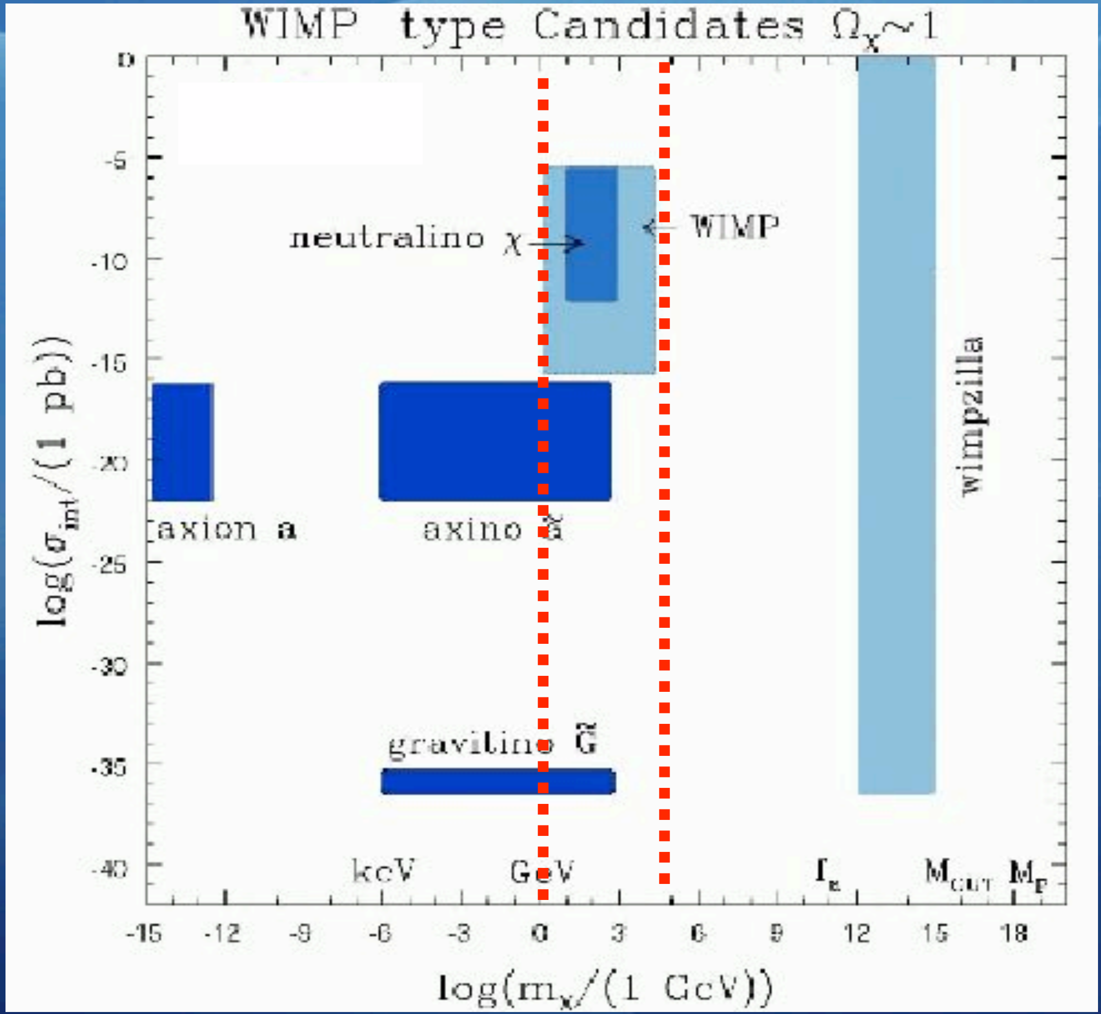
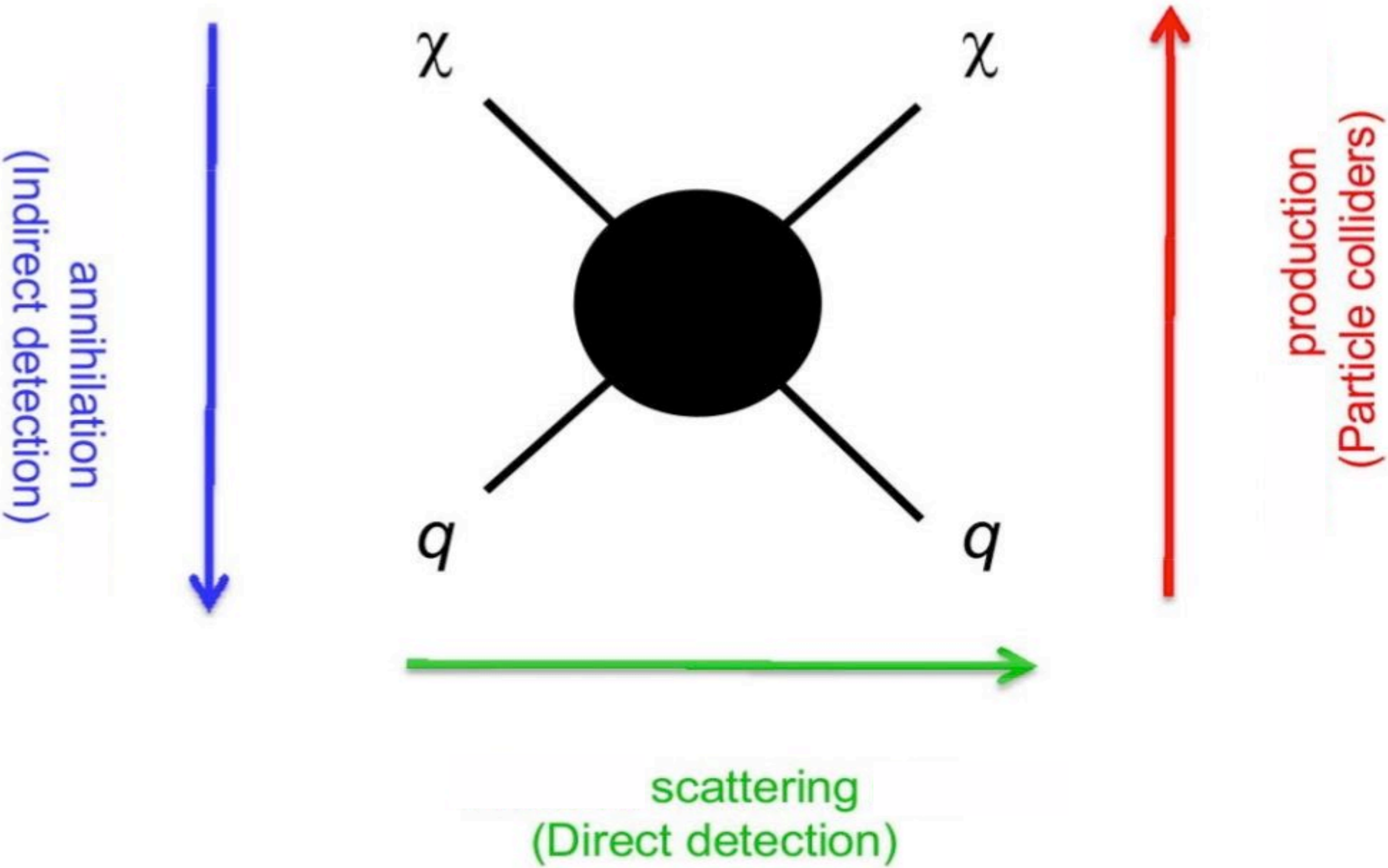


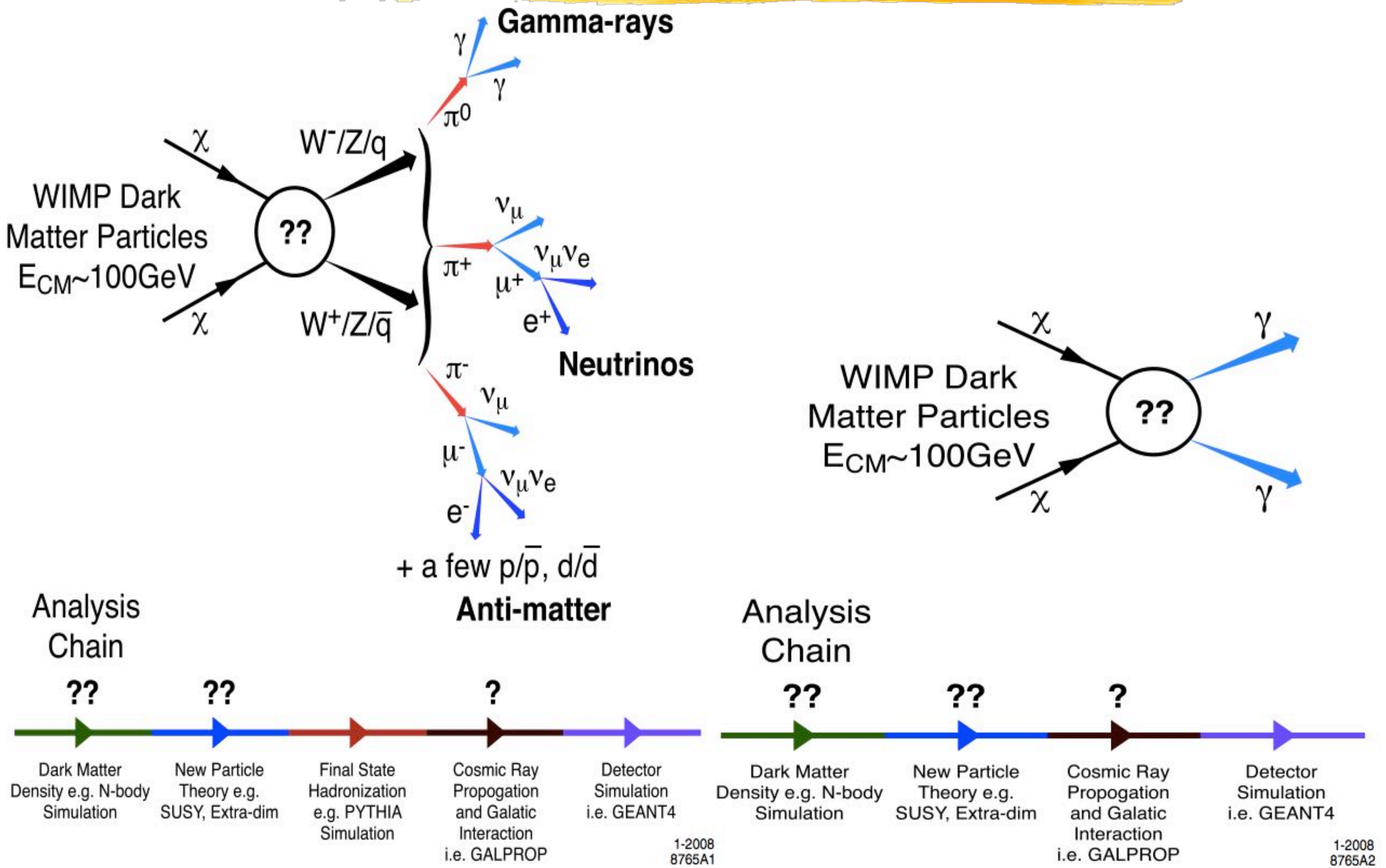

χ
χ
q
q
annihilation
(Indirect detection)
production
(Particle colliders)
scattering
(Direct detection)

Neutralino WIMPs

Assume χ present in the Galactic halo

- χ is its own antiparticle **=>** can annihilate in galactic halo producing gamma-rays, antiprotons, positrons….
- Antimatter not produced in large quantities through standard processes (secondary production through p + p **-->** anti p + X)
- So, any extra contribution from exotic sources (χ χ annihilation) is an interesting signature
- ie: χ χ --> anti p + X
- Produced from (e. g.) χ χ **-->** q / g / gauge boson / Higgs boson and subsequent decay and/ or hadronisation.

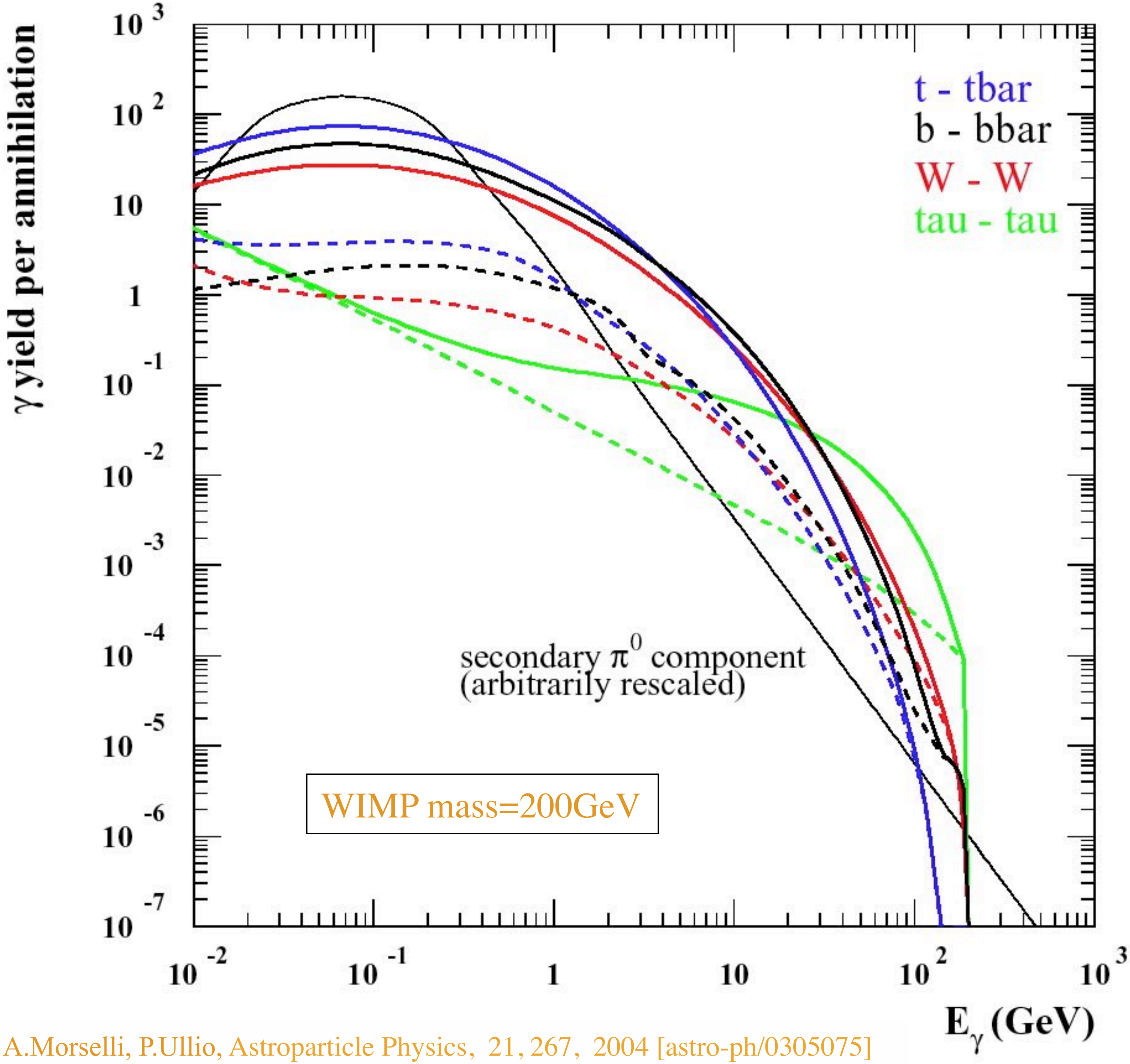
Annihilation channels



Differential yield for each annihilation channel

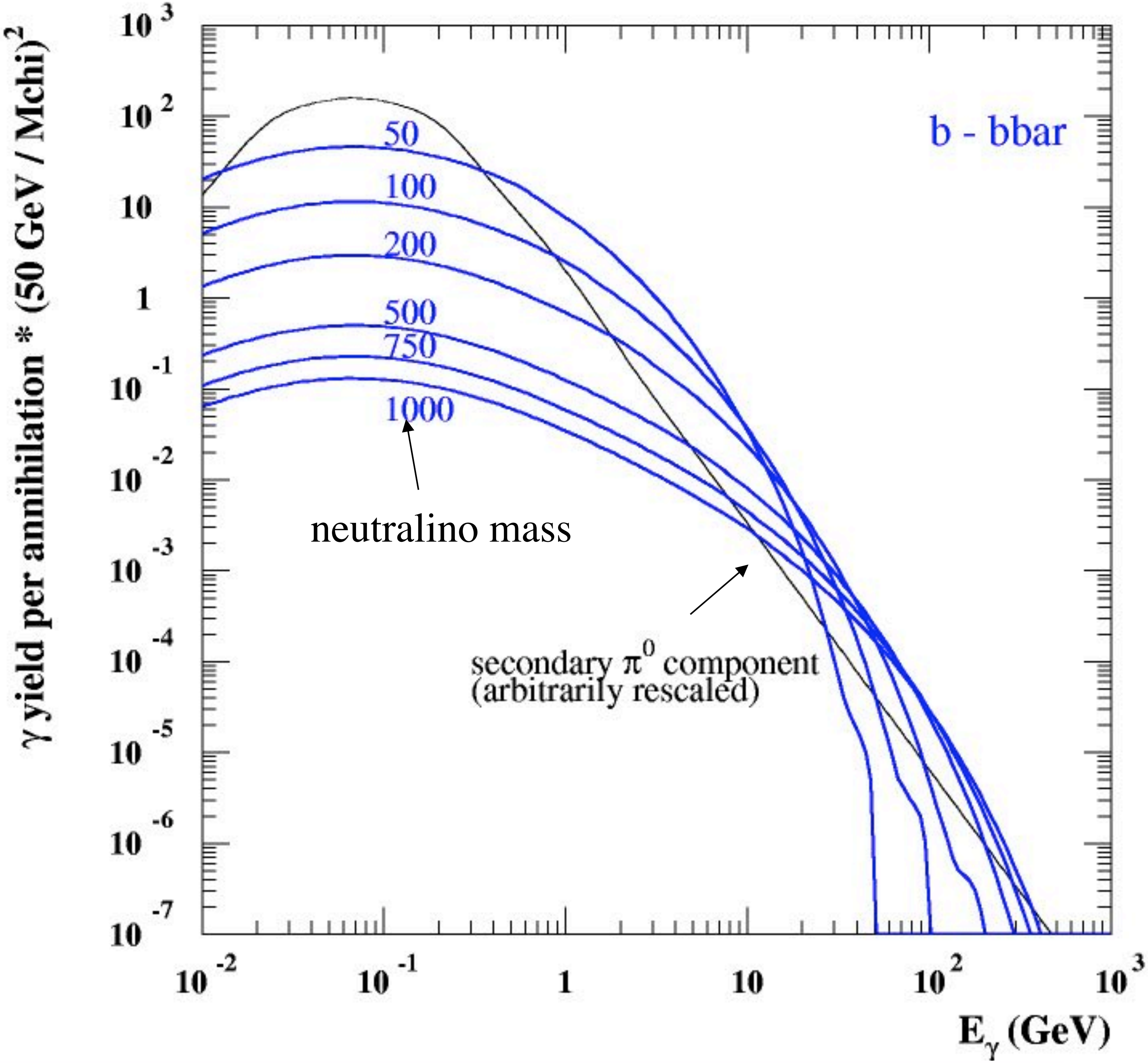
•Quite distinctive spectrum
(no power-law)

•solid lines are the total yields, while the dashed lines are components not due to π^0 decays

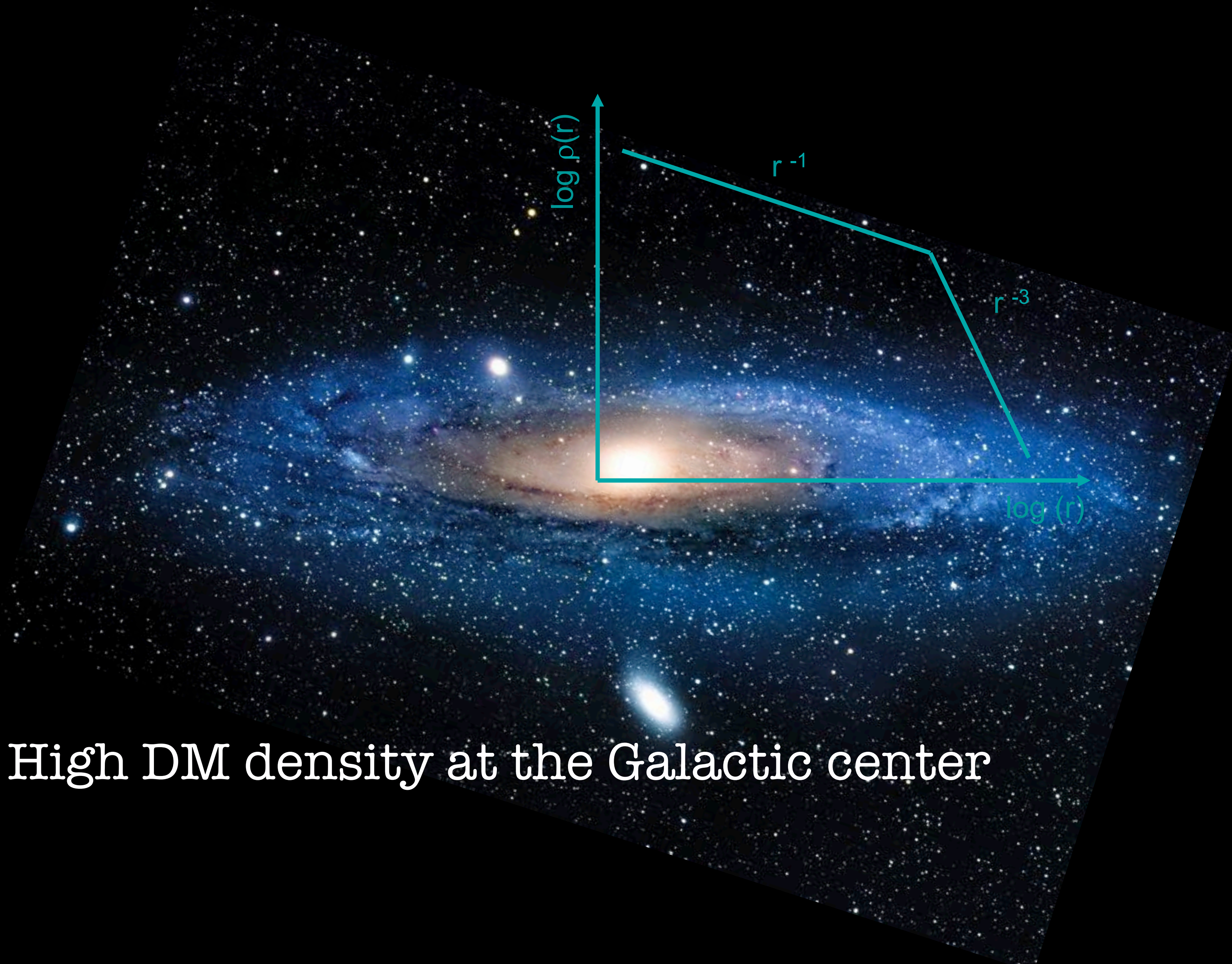


A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267, 2004 [astro-ph/0305075]

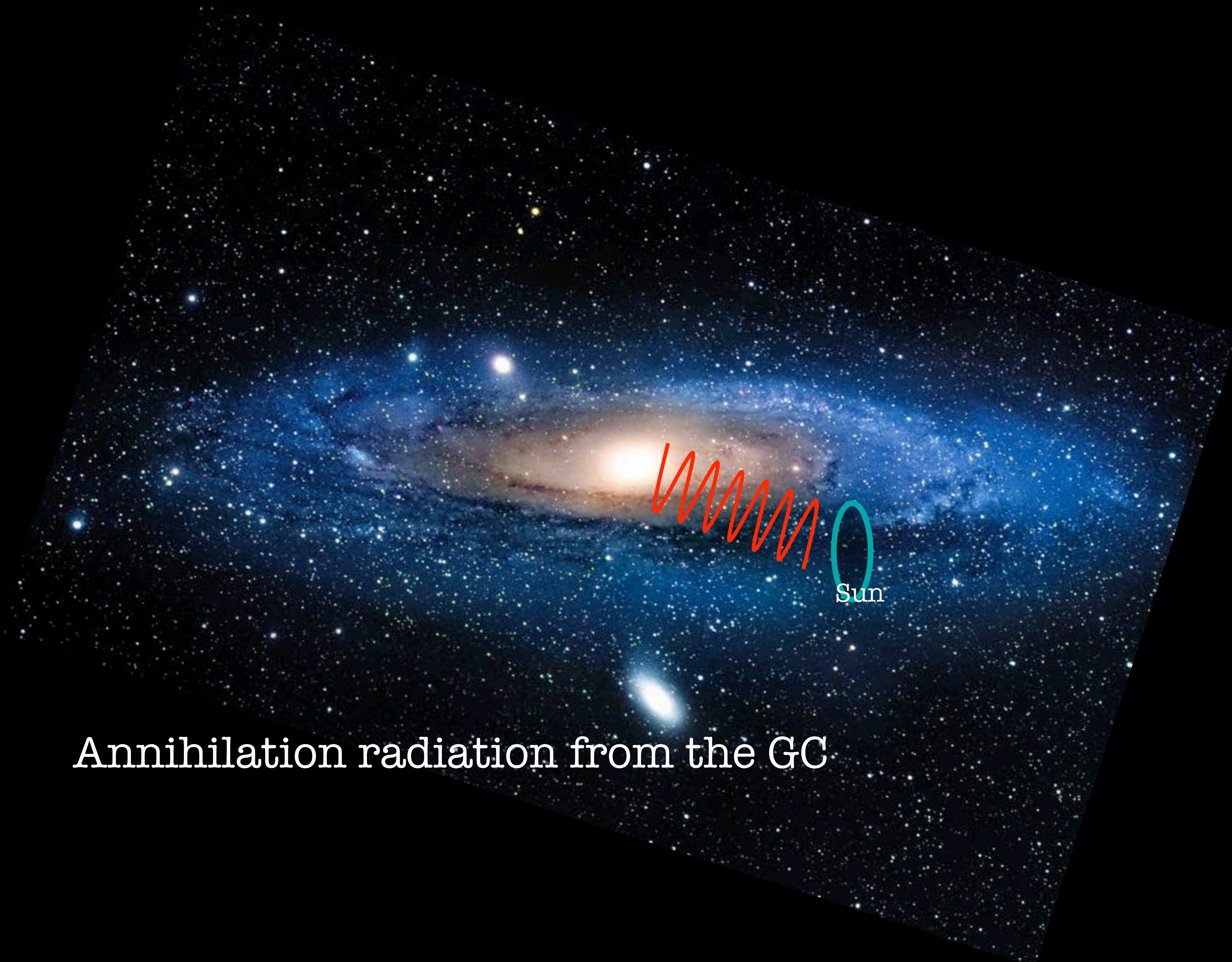
Differential yield for b bar for different neutralino mass



A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267-285, 2004 [astro-ph/0305075]



High DM density at the Galactic center



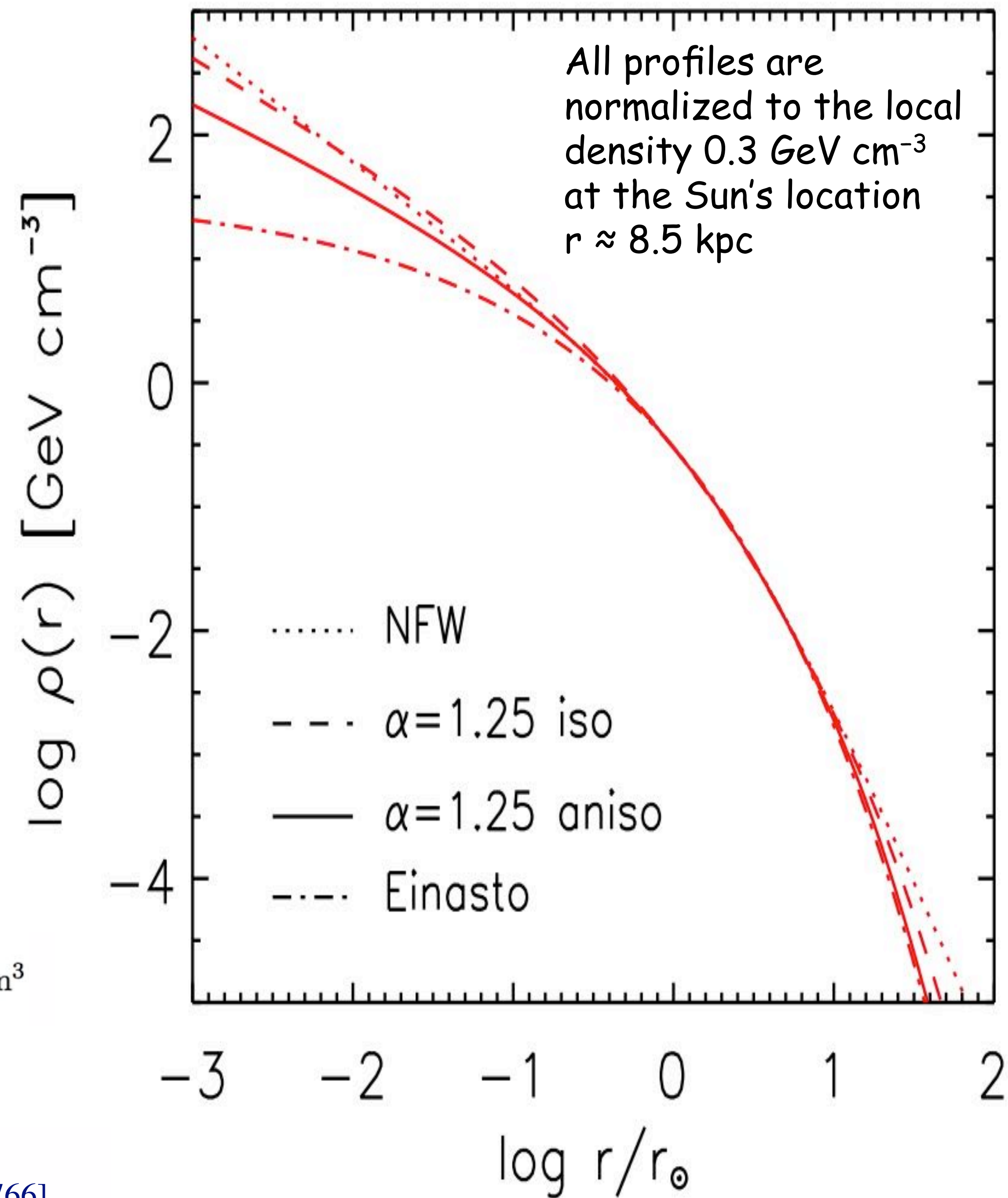
Annihilation radiation from the GC

Milky Way Dark Matter Profiles

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

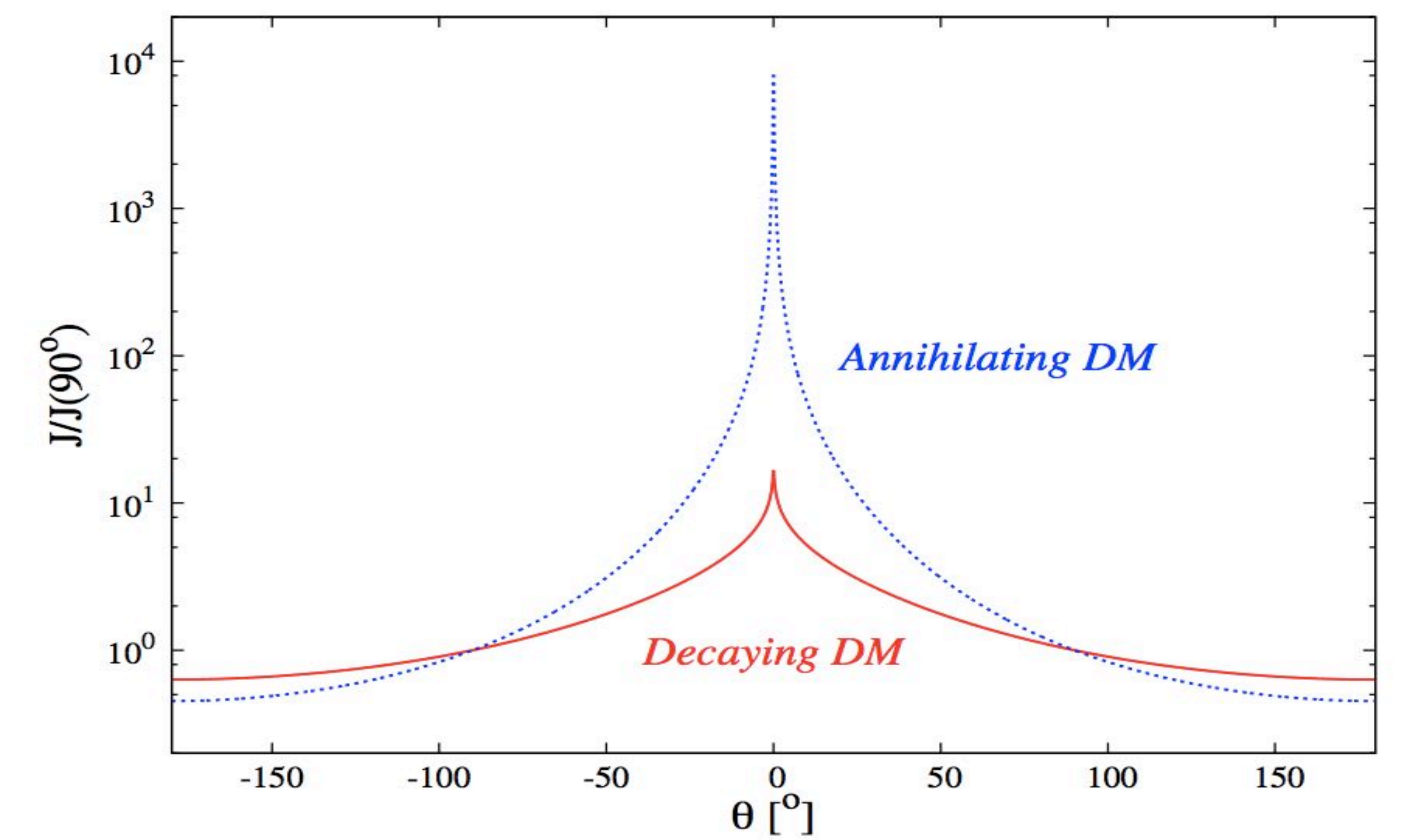
Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

Einasto | $\alpha = 0.17$ $r_s = 20\,\text{kpc}$ $\rho_s = 0.06\,\text{GeV/cm}^3$



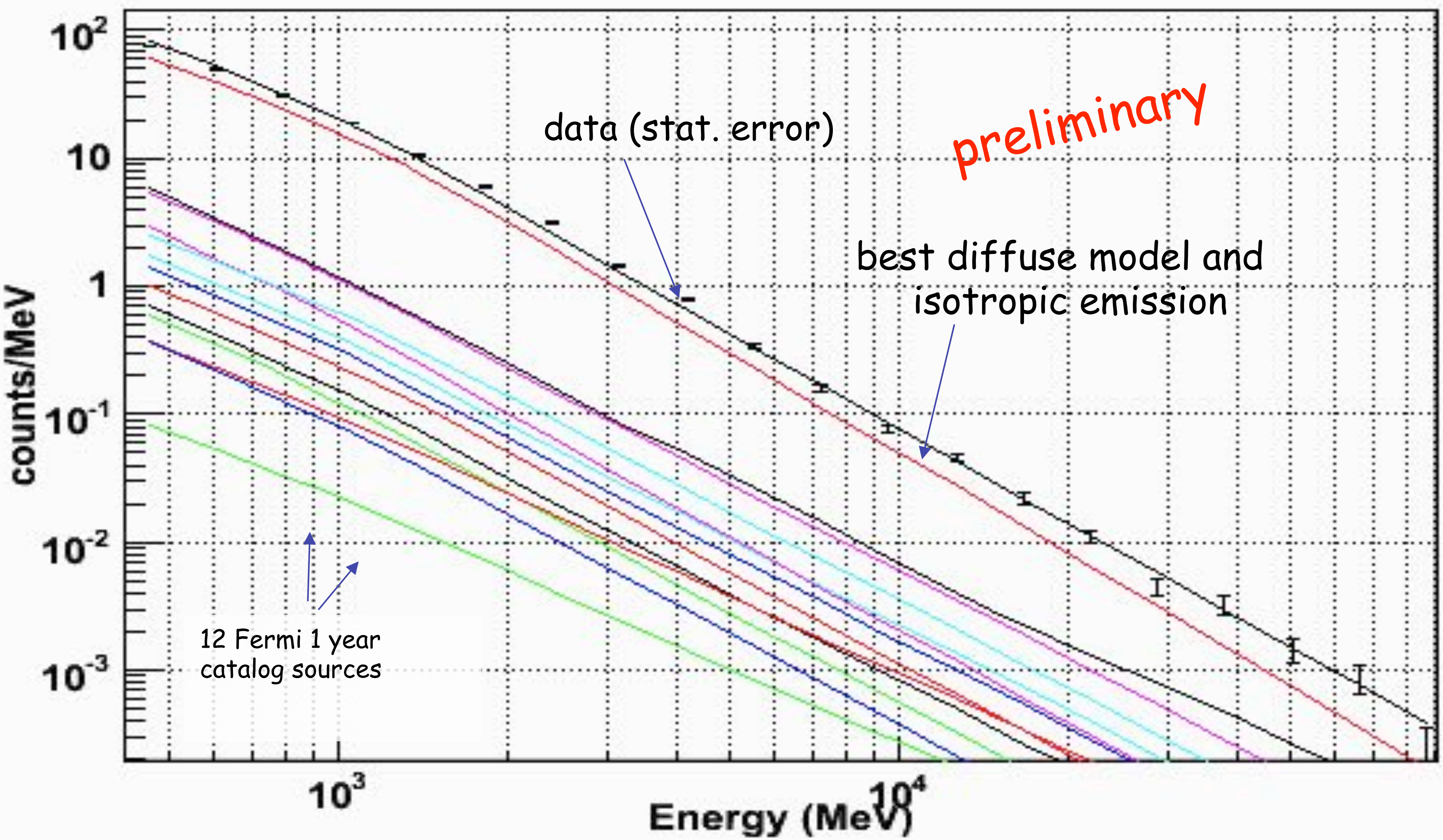
A.Lapi, A.Paggi, A.Cavaliere, A.Lionetto, A.Morselli, V.Vitale. A&A 510, A90 (2010) [arXiv:0912.1766]

Different spatial behaviour for decaying or annihilating dark matter



The angular profile of the gamma-ray signal is shown, as function of the angle θ to the centre of the galaxy for a Navarro-Frenk-White (NFW) halo distribution for decaying DM, solid (red) line, compared to the case of self-annihilating DM, dashed (blue) line

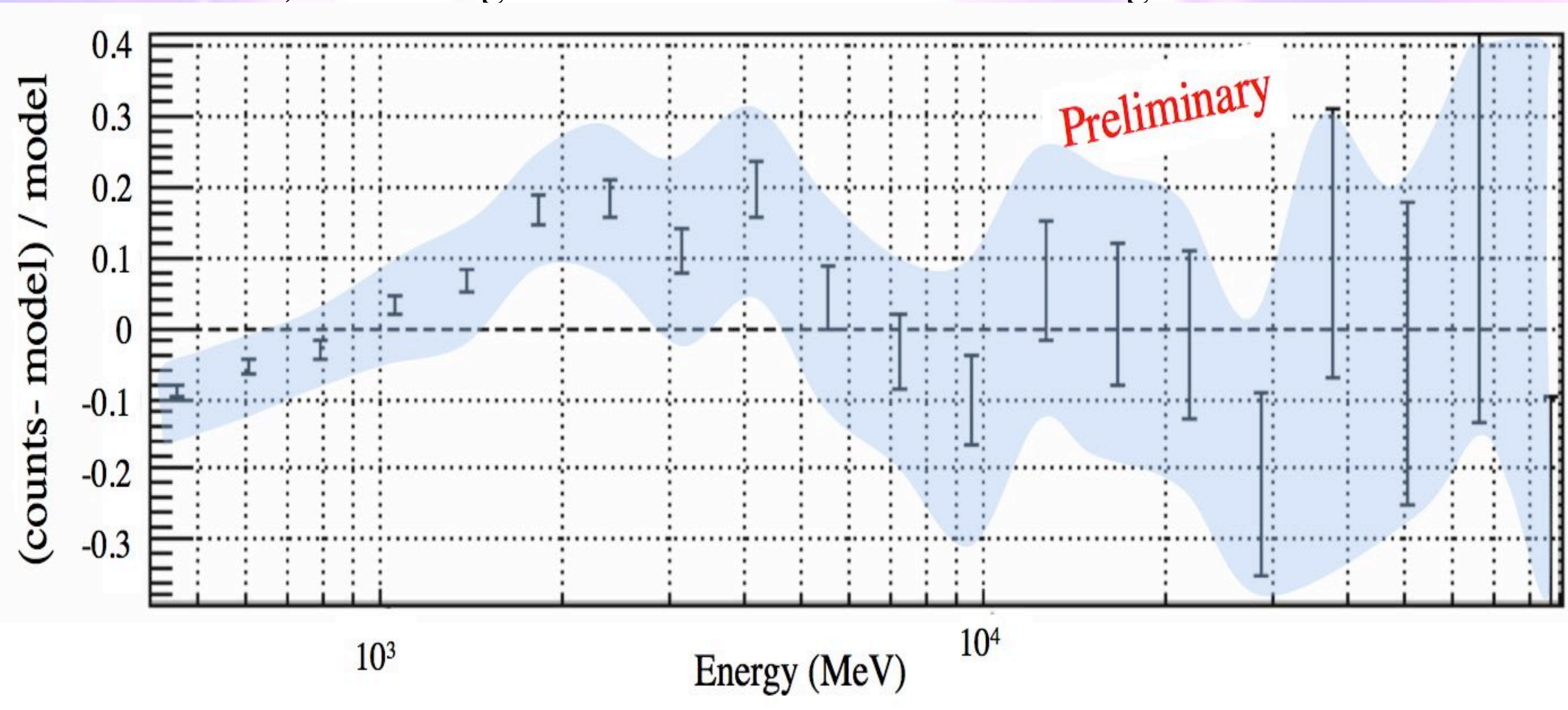
Spectrum (E> 400 MeV, 7°x7° region centered on the Galactic Center analyzed with binned likelihood analysis)



The GeV excess 7°x7°region centered on the Galactic Center

11 months of data, E >400 MeV, front-converting events analyzed with binned likelihood analysis)

- The systematic uncertainty of the effective area (blue area) of the LAT is ~10% at 100 MeV, decreasing to 5% at 560 MeV and increasing to 20% at 10 GeV



V.Vitale, A.Morselli, Fermi Coll. 2009 arXiv:0912.3828 Fermi Symposium eConf Proceedings C091122

the GALACTIC CENTER : any hints of Dark Matter?

the beginning of the history :

Possible Evidence For Dark Matter Annihilation In The Inner Milky Way From The Fermi Gamma Ray Space Telescope
Lisa Goodenough, Dan Hooper arXiv:0910.2998

Indirect Search for Dark Matter from the center of the Milky Way with the Fermi-Large Area Telescope
Vincenzo Vitale, Aldo Morselli, the Fermi/LAT Collaboration
Proceedings of the 2009 Fermi Symposium, 2-5 November 2009, eConf Proceedings C091122 **arXiv:0912.3828 21 Dec 2009**

Search for Dark Matter with Fermi Large Area Telescope: the Galactic Center
V.Vitale, A.Morselli, the Fermi-LAT Collaboration NIM A 630 (2011) 147–150 (Available online 23 June 2010)

Dark Matter Annihilation in The Galactic Center As Seen by the Fermi Gamma Ray Space Telescope
Dan Hooper , Lisa Goodenough . (21 March 2011). 21 pp. **Phys.Lett. B697 (2011) 412-428**

On The Origin Of The Gamma Rays From The Galactic Center
Dan Hooper , Tim Linden. Oct 2011. 13 pp. **Phys.Rev. D84 (2011) 123005**

Detection of a Gamma-Ray Source in the Galactic Center Consistent with Extended Emission from Dark Matter Annihilation and Concentrated Astrophysical Emission Kevork N. Abazajian, Manoj Kaplinghat **Phys.Rev. D86 (2012) 083511**

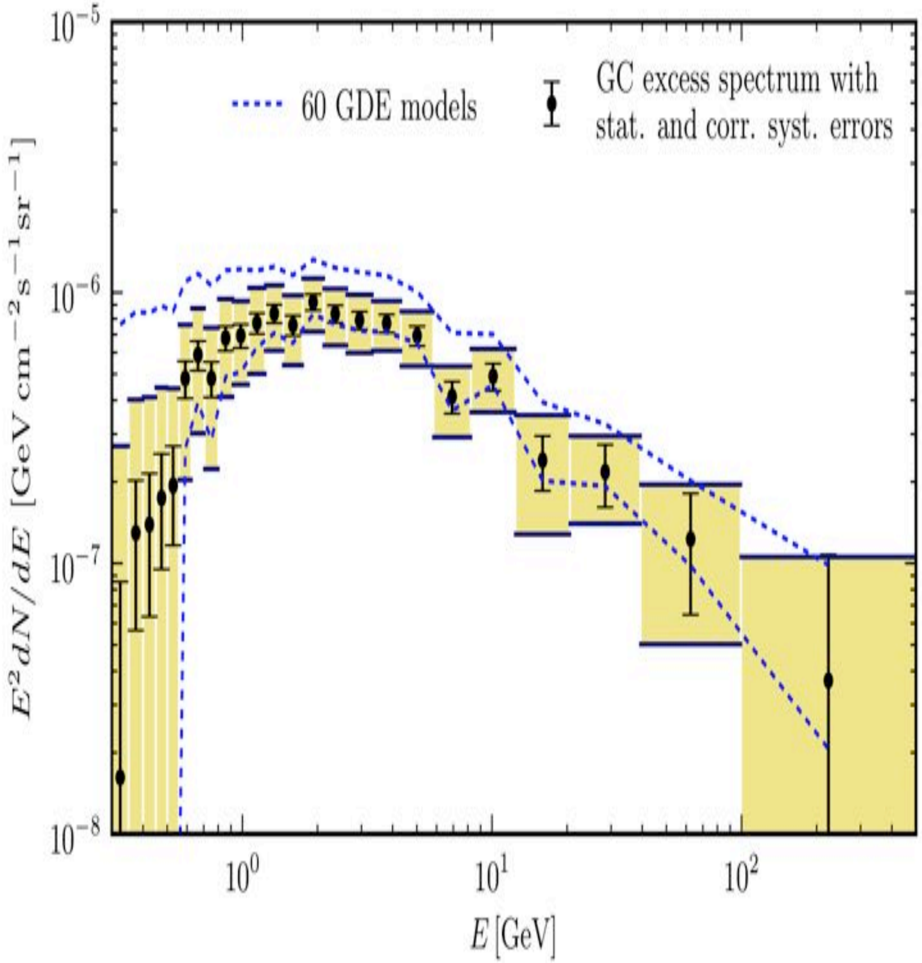
Dark Matter and Pulsar Model Constraints from Galactic Center Fermi-LAT Gamma Ray Observations
Chris Gordon, Oscar Macías. Jun 24, 2013. 20 pp. **Phys.Rev. D88 (2013) 083521**

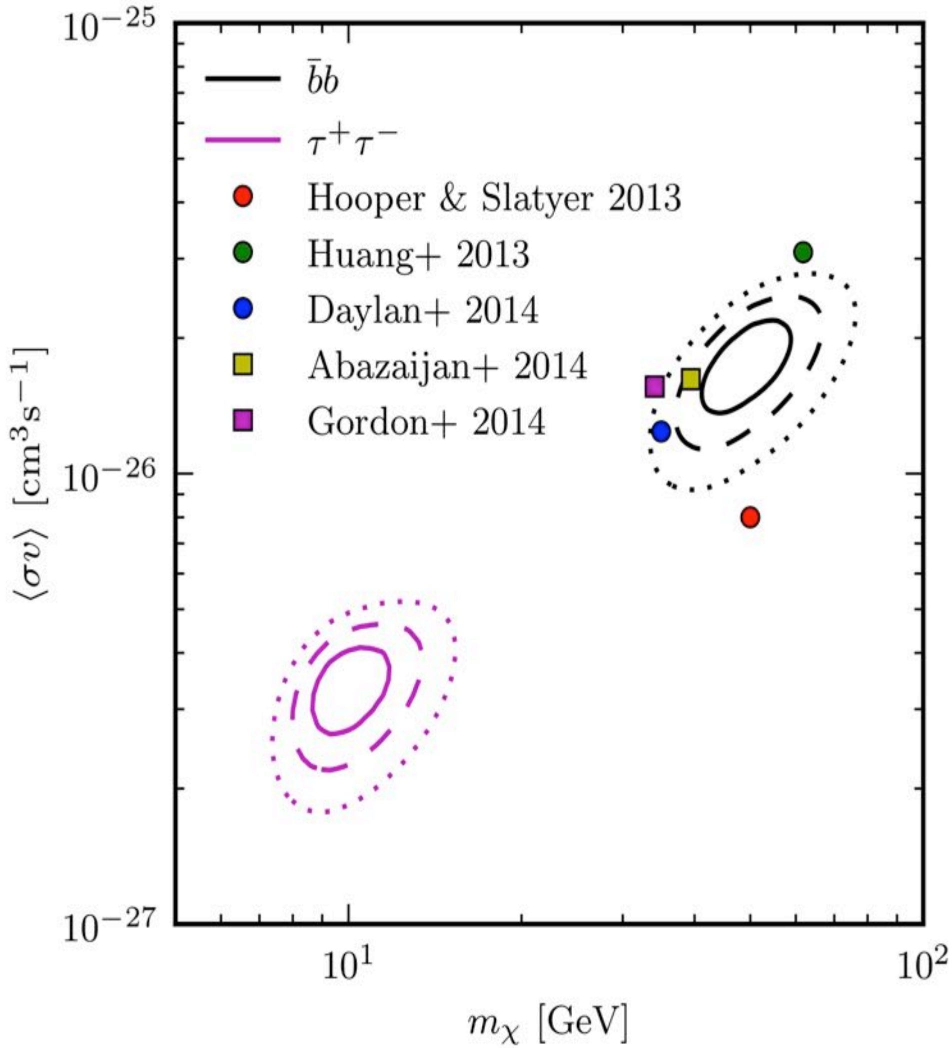
The Characterization of the Gamma-Ray Signal from the Central Milky Way: A Compelling Case for Annihilating Dark Matter
Tansu Daylan, Douglas P. Finkbeiner, Dan Hooper, Tim Linden, Stephen K. N. Portillo, Nicholas L. Rodd , Tracy R. Slatyer . Feb 26, 2014. 26 pp. e-Print: **arXiv:1402.6703 [astro-ph.HE]**

Background model systematics for the Fermi GeV excess
F.Calore, I. Cholis, C. Weniger JCAP03(2015)038 **arXiv:1409.0042v1**

Fermi–LAT observations of high-energy γ-ray emission toward the galactic centre
M. Ajello et al.[Fermi-LAT Coll.] **Apj accepted arXiv:1511.02938 (using Pass7,Pass8 analysis in progress,see Fermi Symp.15)**

The GeV excess





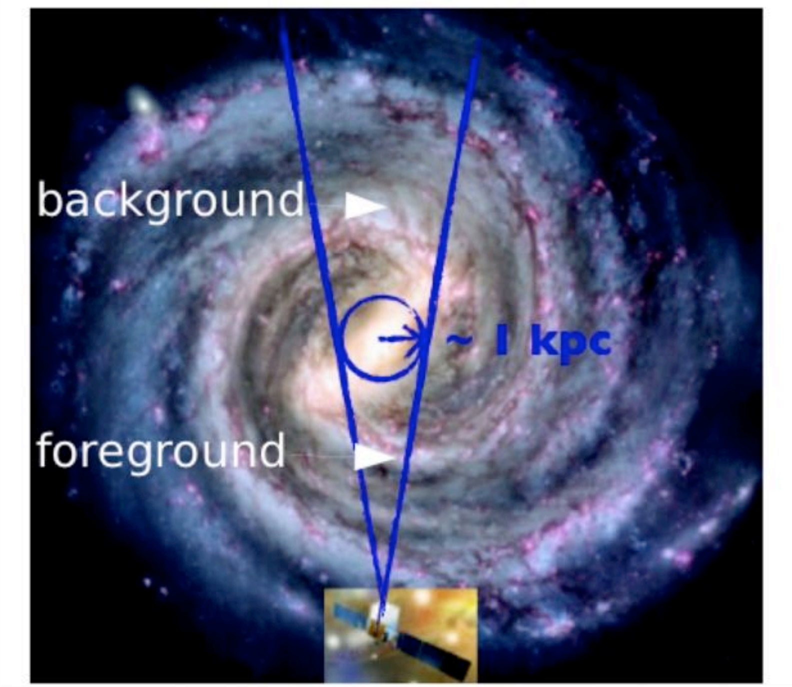
A lot of activity outside the Fermi collaboration with claims of evidence for dark matter in the Galactic Center

i.e. Calore et al, arXiv:1409.0042v1

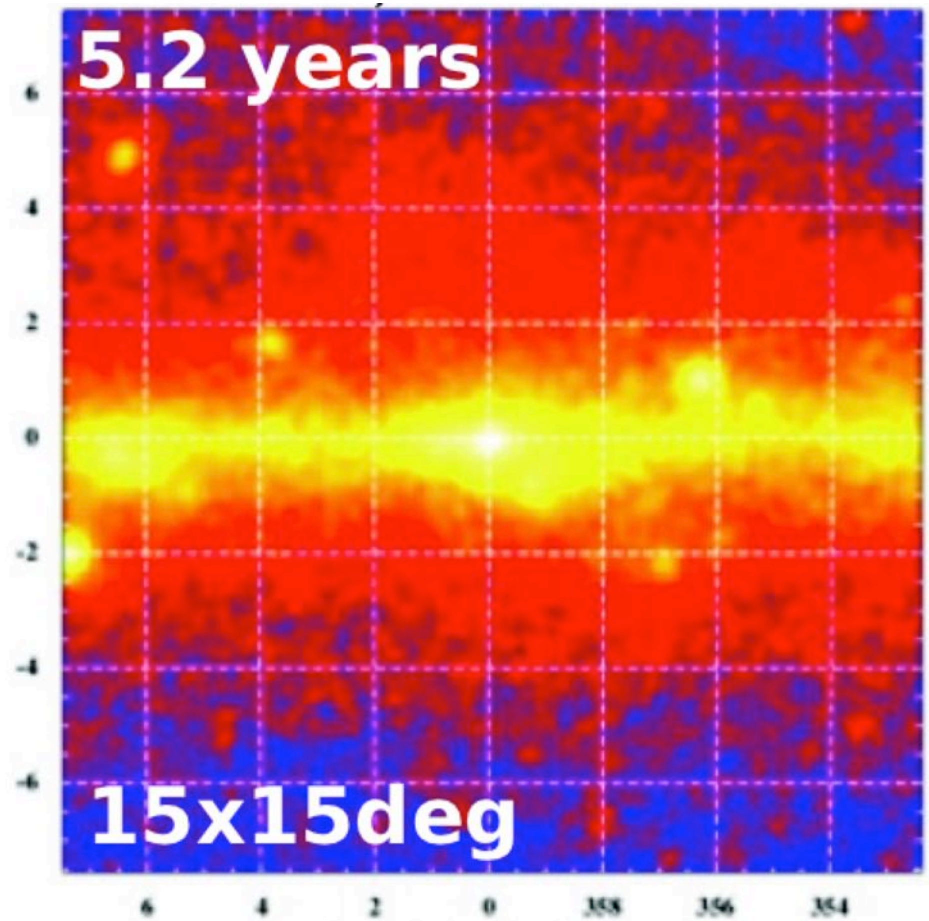
The Galactic Center with Fermi-LAT

LAT counts = sum of:

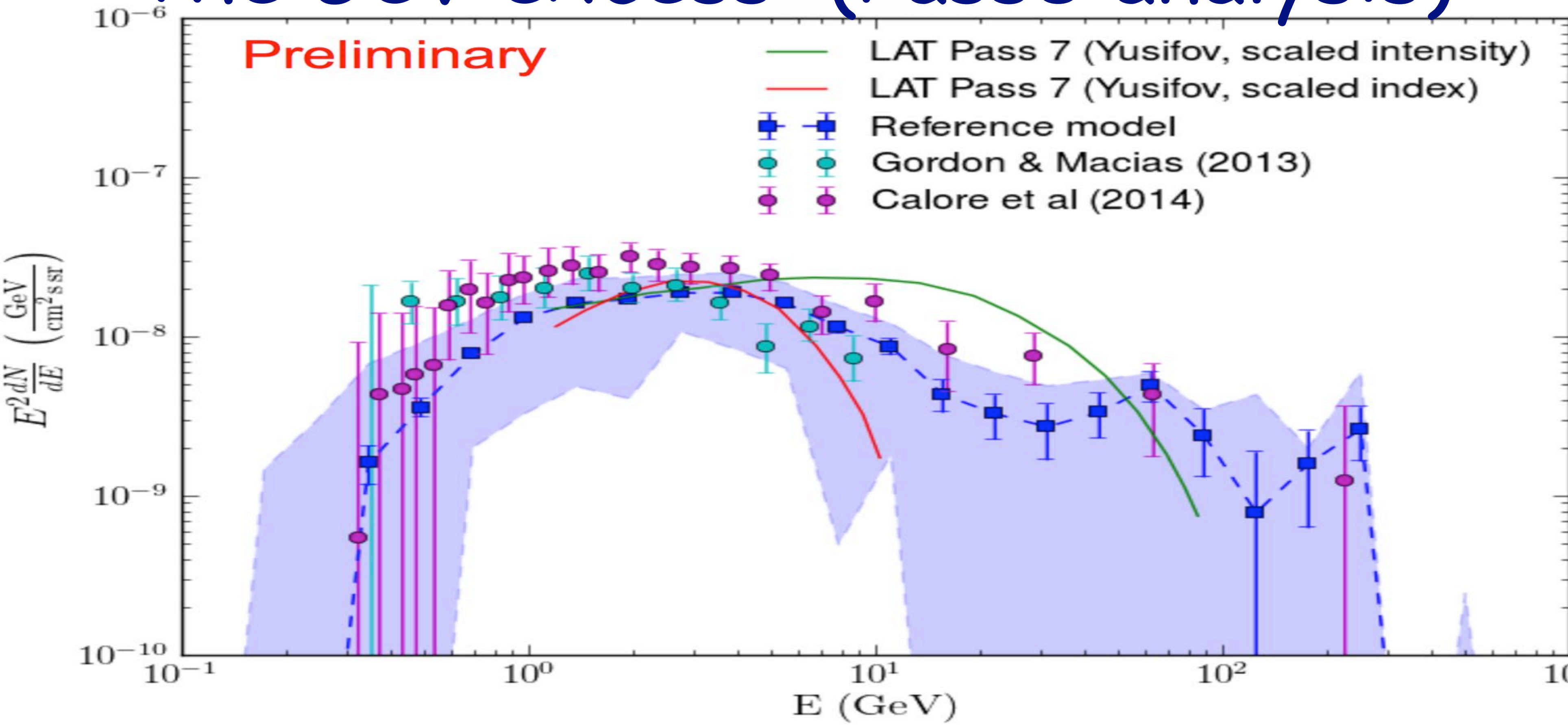
- Galactic Center diffuse emission
  - Interaction of Cosmic Rays (density?) with gas (distribution?) and interstellar radiation fields (intensity?)
- Foreground/background (all-sky analysis)
  - Interaction of Cosmic Rays with gas and interstellar radiation fields
- Individual sources (~catalog analysis)
- Additional components ?



Fermi LAT 1-100 GeV



The GeV excess (Pass8 analysis)



following uncertainties have relatively small effect on the excess spectrum

- Variation of GALPROP models
- Distribution of gas along the line of sight

- **Most significant sources of uncertainty are:**

- Fermi bubbles morphology
- Sources of CR electrons near the GC

Pass 7 analysis:
M. Ajello et al.[Fermi-LAT Coll.]
arXiv:1511.02938 Apj accepted

D. Malyshev al.[Fermi-LAT Collaboration] **Fermi Symposium 2015**

The GeV excess : Other explanations exist

- past activity of the Galactic center

(e.g. Petrovic et al., arXiv:1405.7928, Carlson & Profumo arXiv:1405.7685)

- Population of millisecond Pulsars around the Galactic Center

(e.g. , Yuan and Zhang arXiv:1404.2318v1 , Lee et al. arXiv:1506.05124)

- Series of Leptonic Cosmic-Ray Outbursts

Cholis et al. arXiv:1506.05119

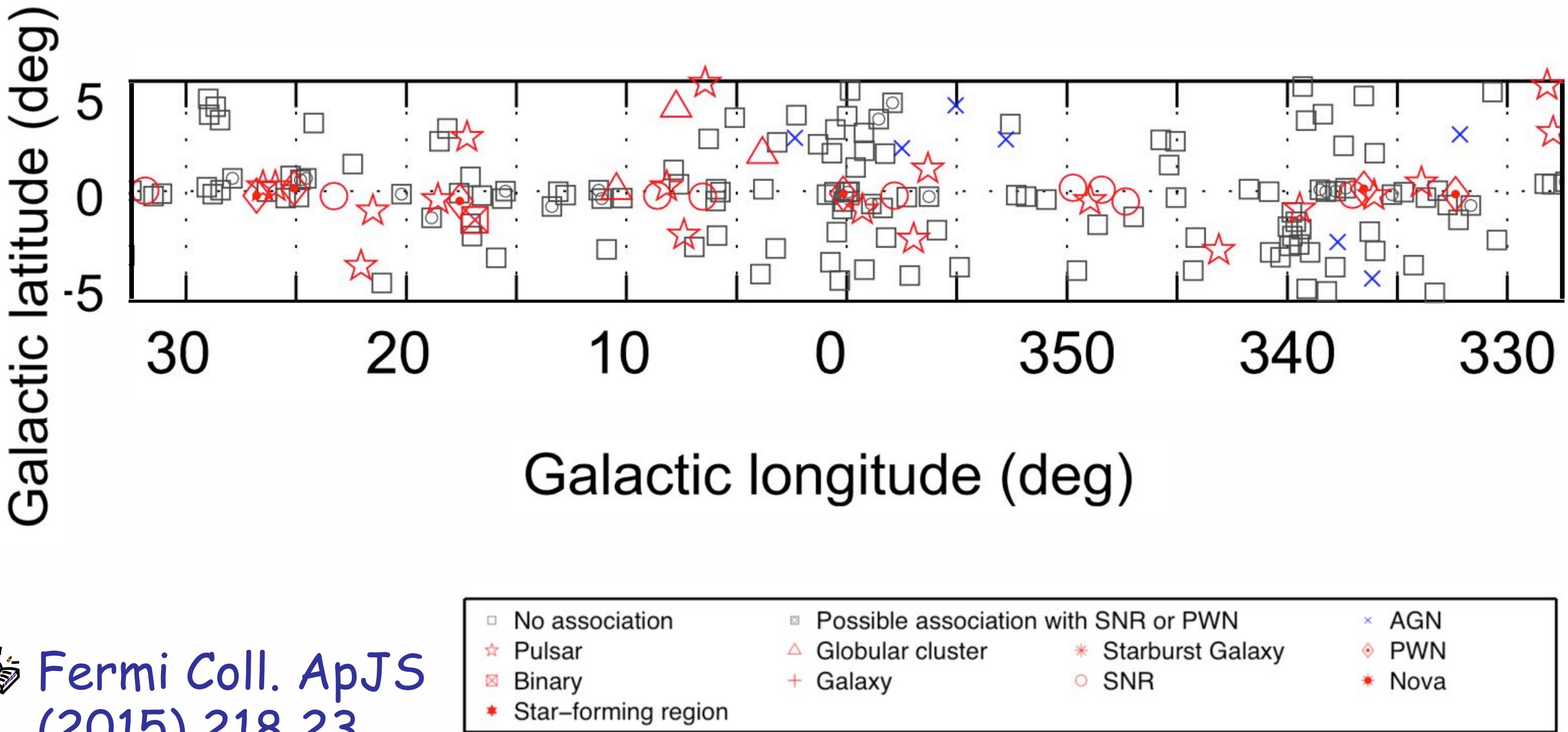
- Different diffusion coefficent in the GC region
- ....

How to discriminate between different hypotesis ?

The Fermi LAT 3FGL Inner Galactic Region

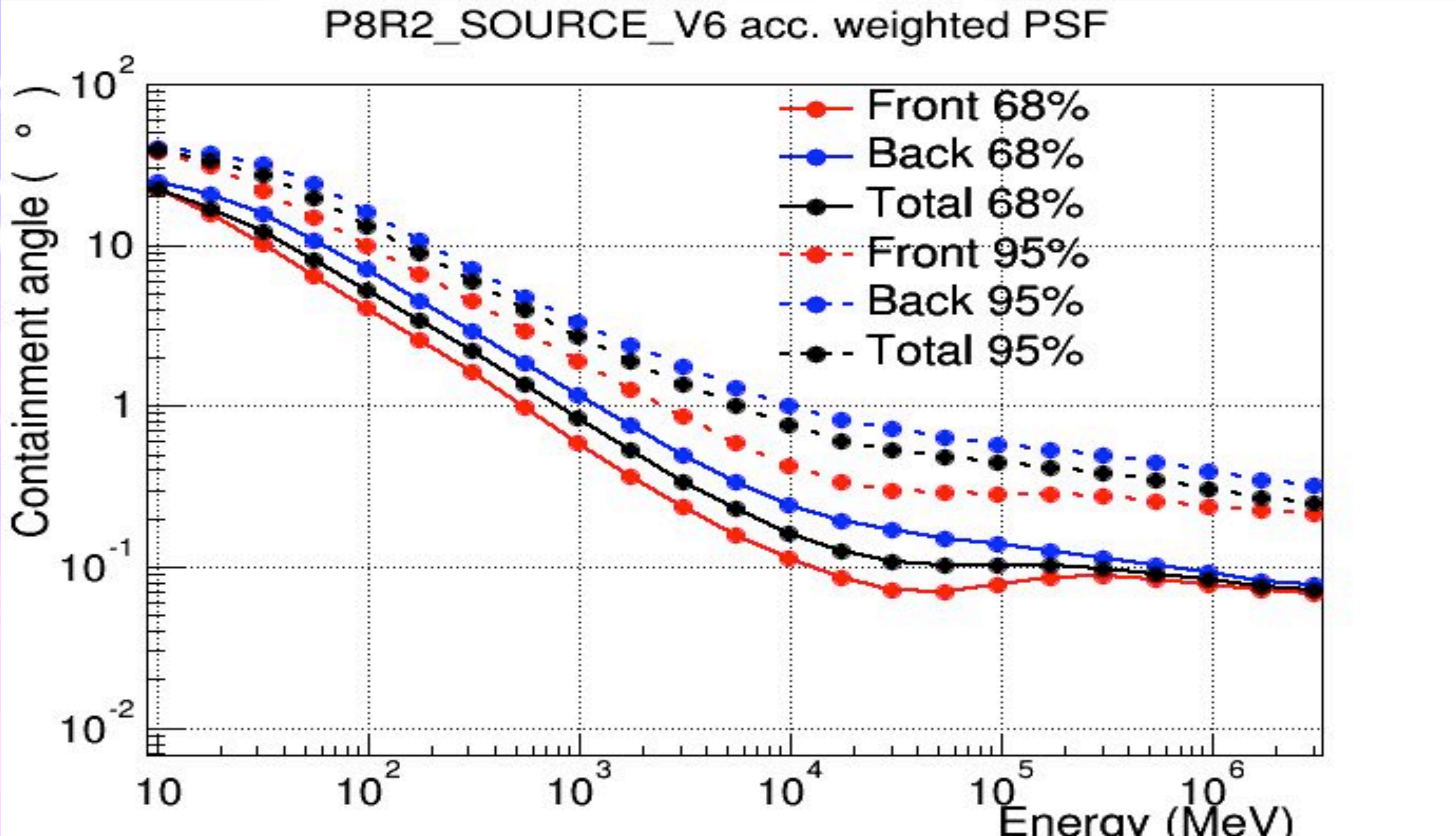
August 4, 2008, to July 31, 2010

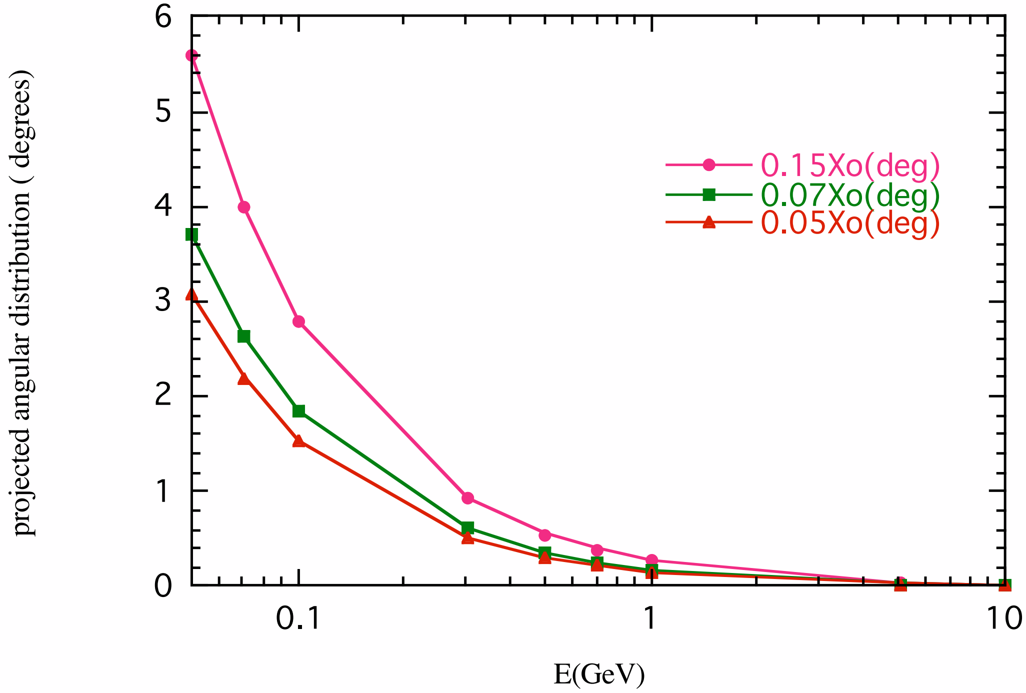
100 MeV to 300 GeV energy range



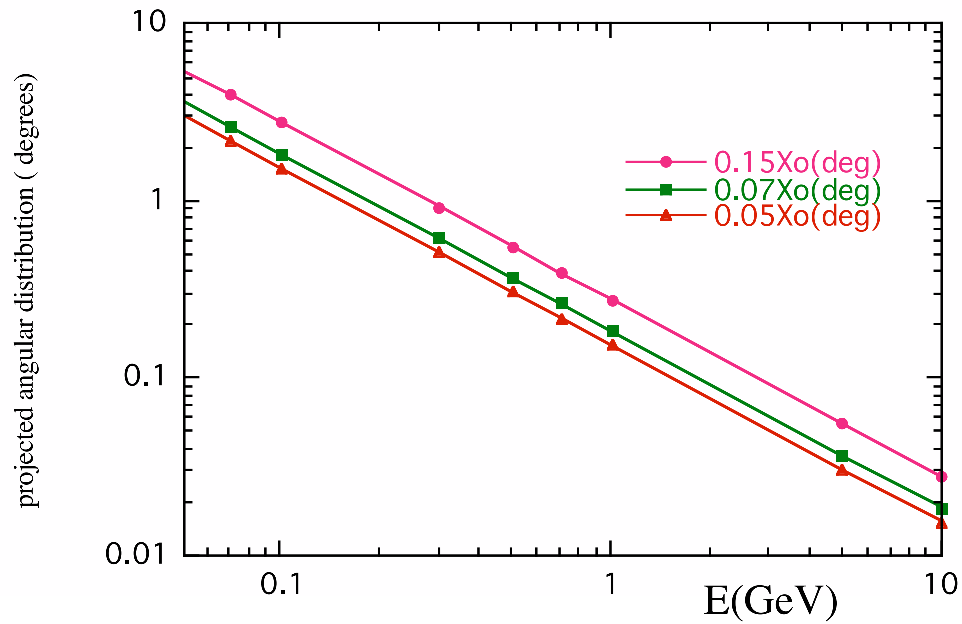
Fermi Coll. ApJS (2015) 218 23
arXiv:1501.02003

Fermi-LAT Instrument Response Functions (Pass 8) Angular Resolution





Multiple Scattering



$$\theta_0 = \theta^{rms}_{plane} = \frac{1}{\sqrt{2}}\theta^{rms}_{space}$$

$$\theta_0 = \frac{13.6MeV}{\beta cp} z\sqrt{x/X_0}\left[1 + 0.038\ln\left(x/X_0\right)\right]$$

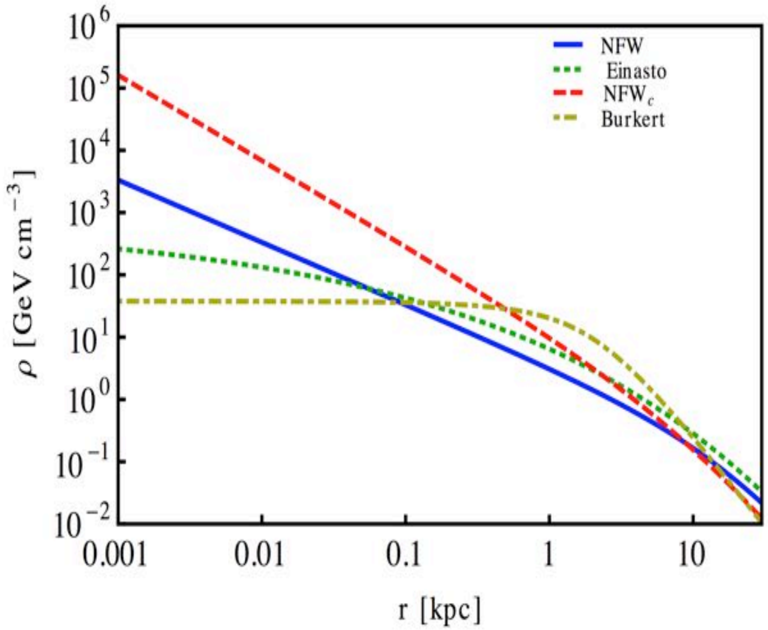
ARE WE SEEING DARK MATTER WITH THE FERMI-LAT IN A REGION AROUND THE MILKY WAY CENTER?

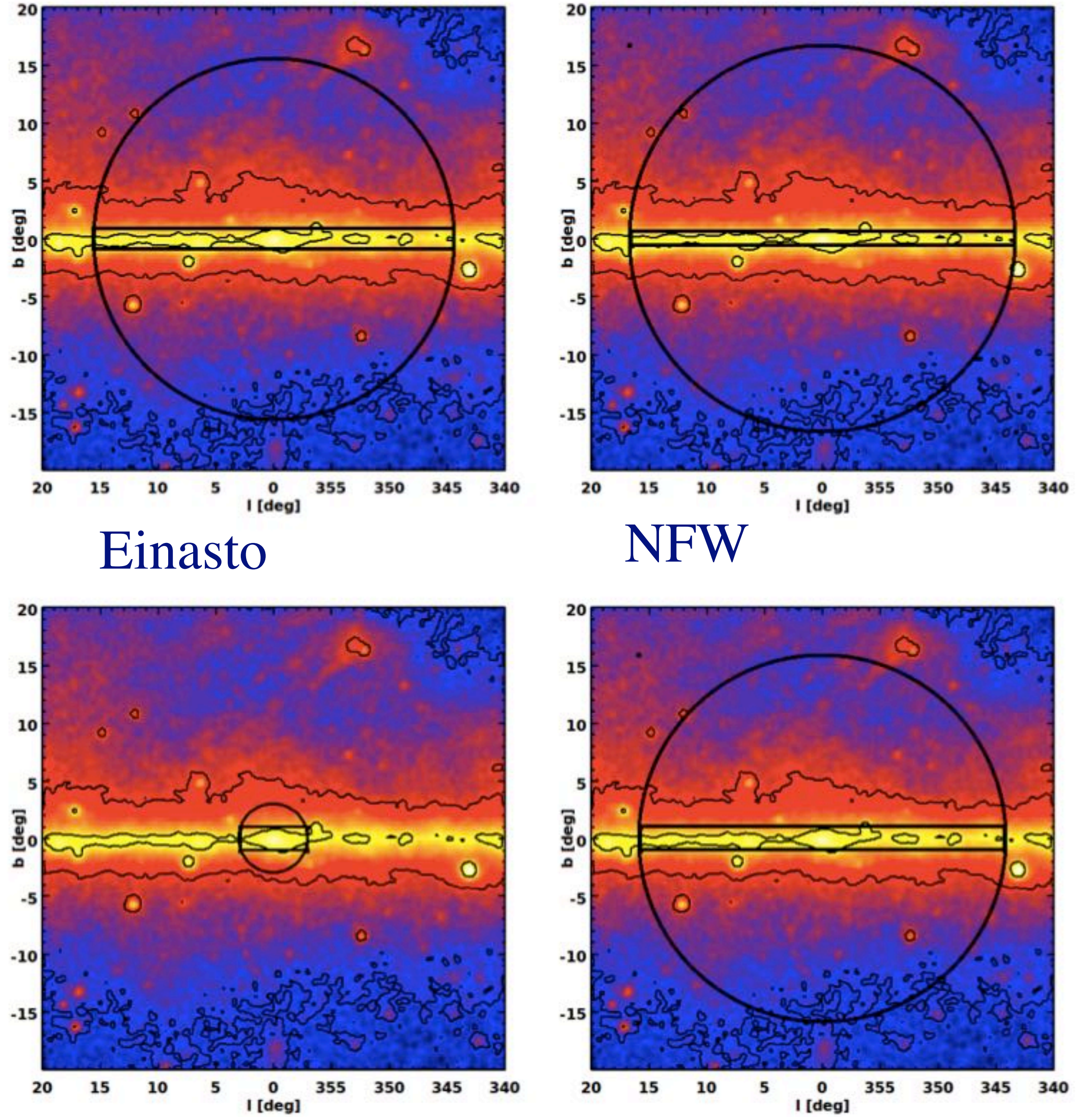
- Maybe yes, but we can't be sure as far as we don't understand the background at the level needed for disentangle a DM-induced γ-ray flux in this interesting region.

It would be really very nice to have a new experiment with better angular resolution at energies below 100 MeV

Constraints from the inner Galaxy

Optimized ROI for each profile





Einasto NFW

NFWc Burkert

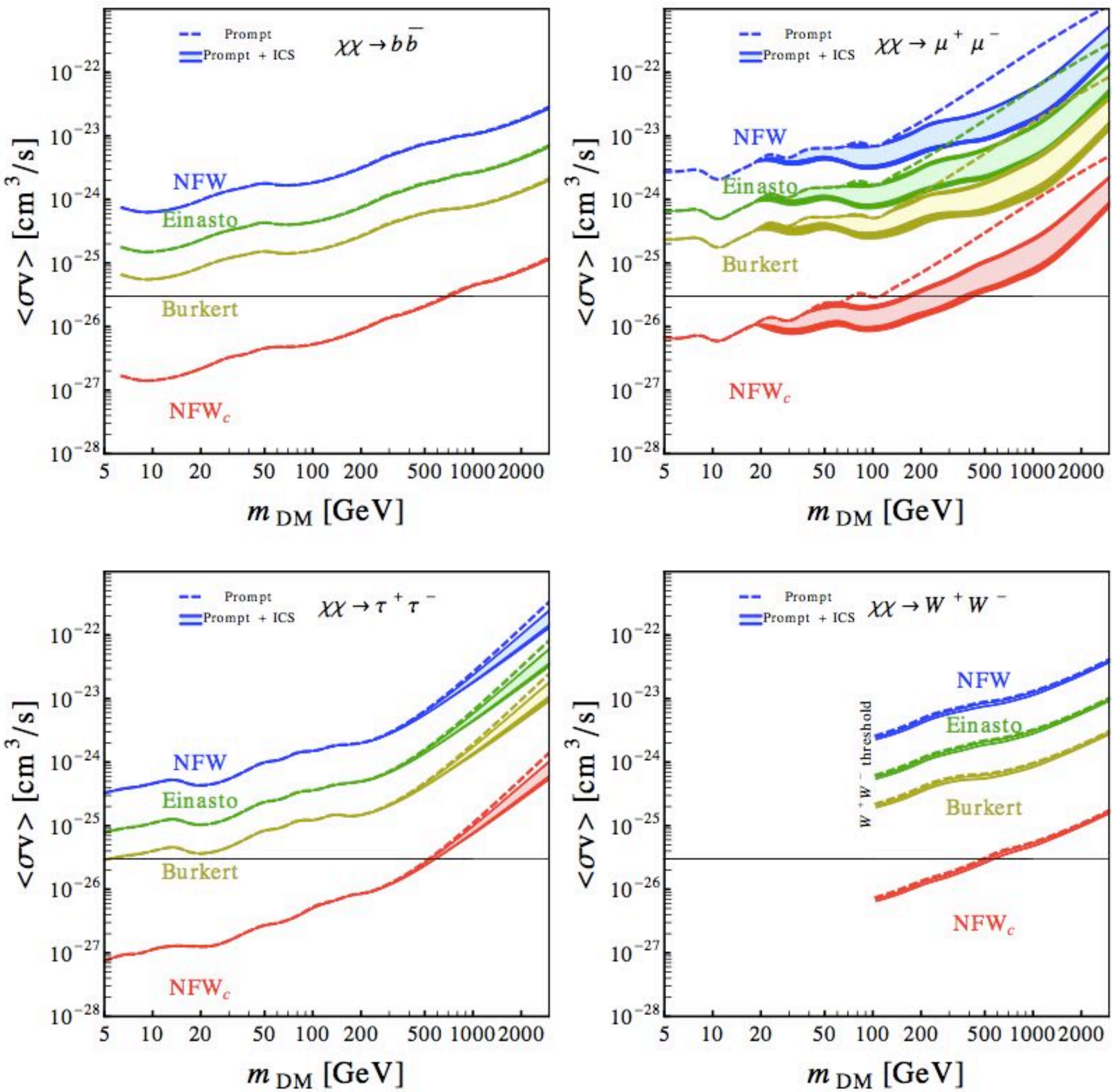
JCAP 10 (2013) 029 [arXiv:1308.3515]

Constraints from the inner Galaxy

3 σ upper limits on the annihilation cross-section for different channels and halo profiles

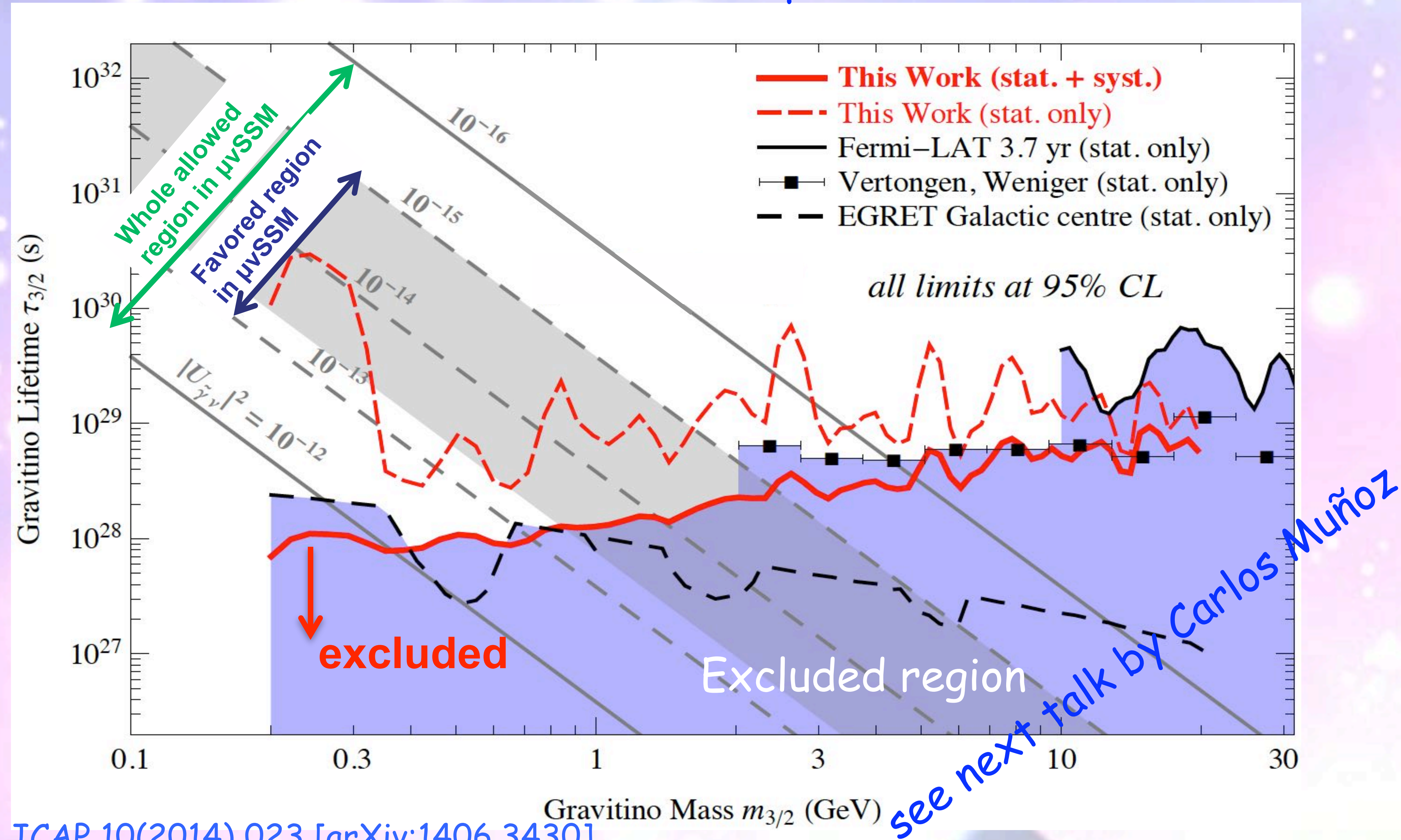
No assumption on background

very robust result



JCAP 10 (2013) 029
arXiv:1308.3515

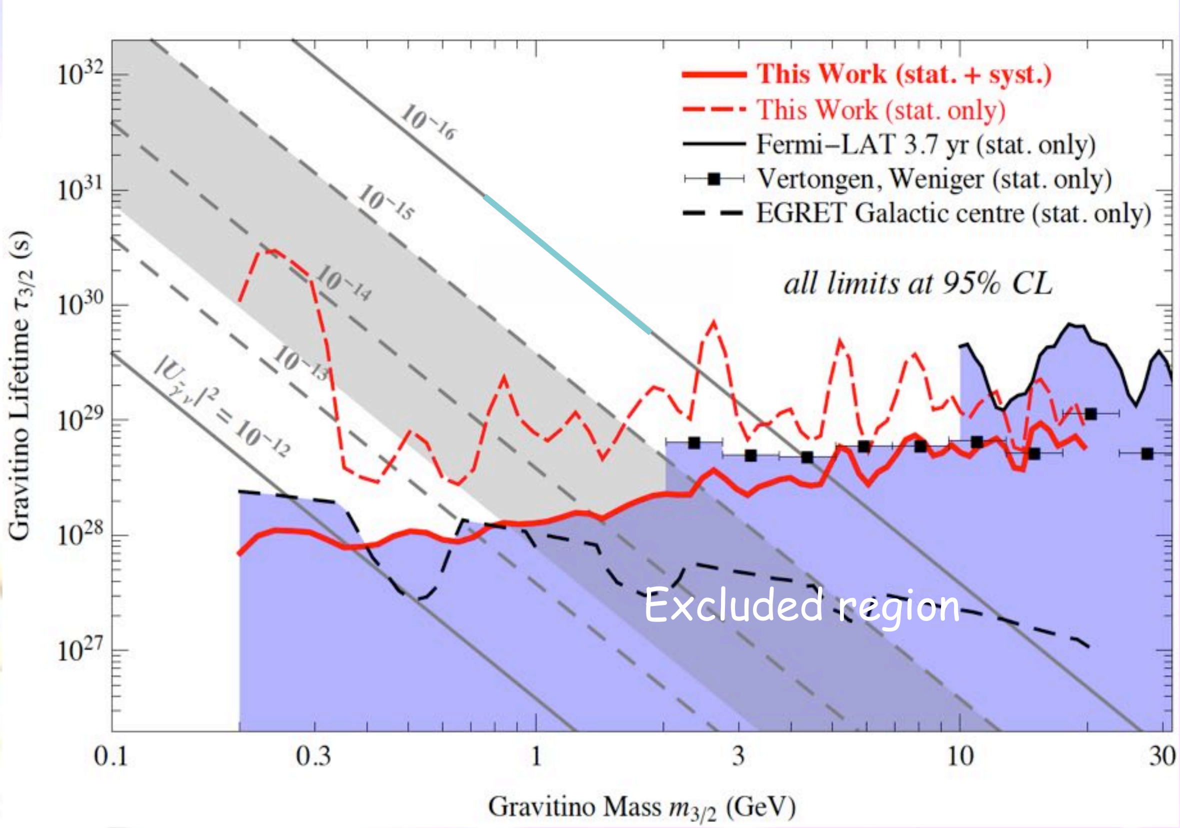
Low energy lines limits and implications for gravitino dark matter in the μνSSM



JCAP 10(2014) 023,[arXiv:1406.3430]

New Low Energy Line Search

- *Modeling effective area*
- *background emission*
- *not masking known point sources*: because the broad PSF of the LAT at low energies.

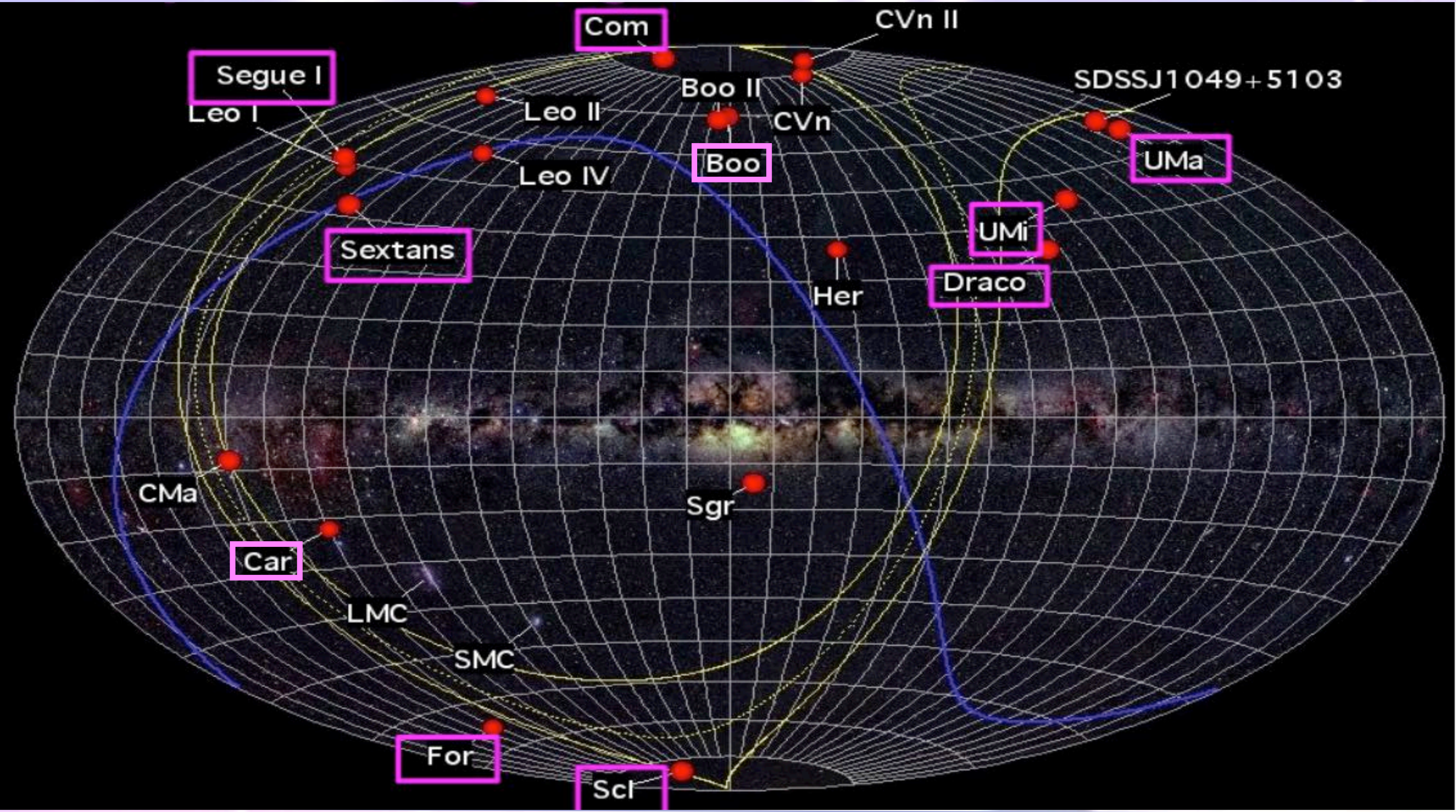


This Analysis is Systematics Limited

JCAP 10(2014) 023,[arXiv:1406.3430]

To improve this search better energy and angular resolutions at energies below 100 MeV are needed

Dwarf spheroidal galaxies (dSph) : promising targets for DM detection

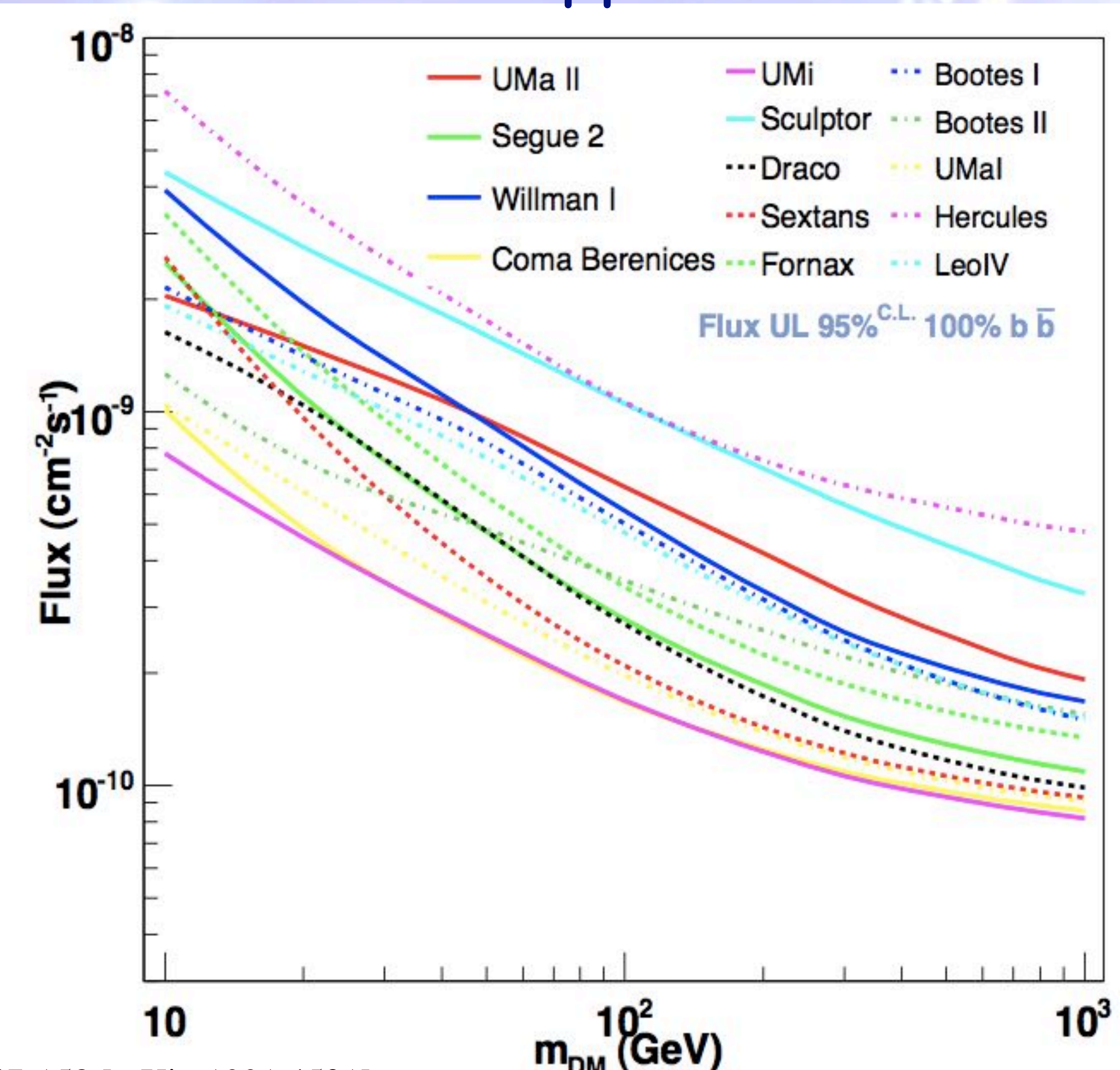


Dwarf Spheroidal Galaxies upper-limits

No detection by Fermi with 11 months of data. 95% flux upper limits are placed for several possible annihilation final states.

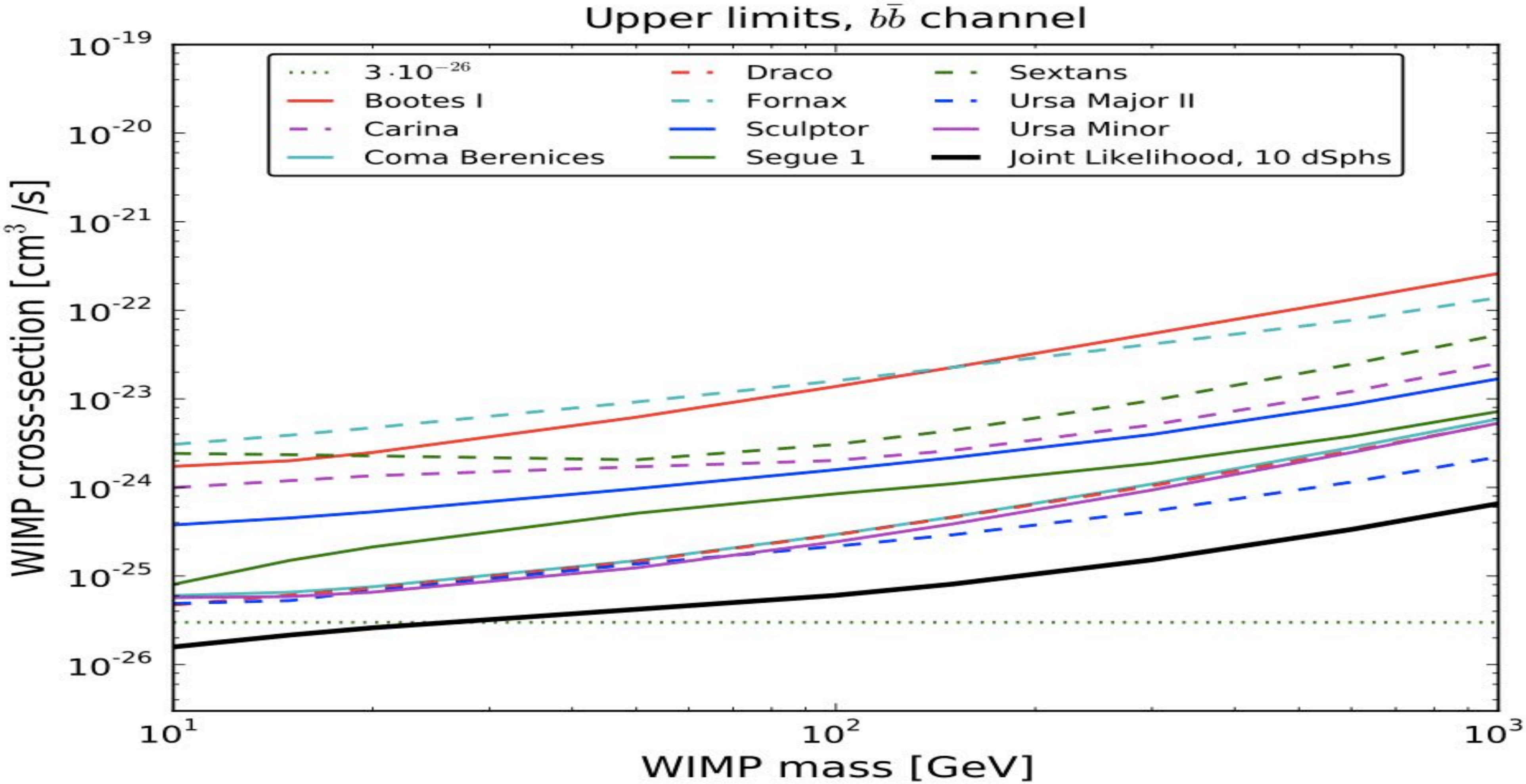
- Flux upper limits are combined with the DM density inferred by the stellar data(*) for a subset of 8 dSph (based on quality of stellar data) to extract constraints on < σ v> vs WIMP mass for specific DM models

(*) stellar data from the Keck observatory (by Martinez, Bullock, Kaplinghat)



Fermi Coll. ApJ 712 (2010) 147-158 [arXiv:1001.4531]

Dwarf Spheroidal Galaxies combined analysis

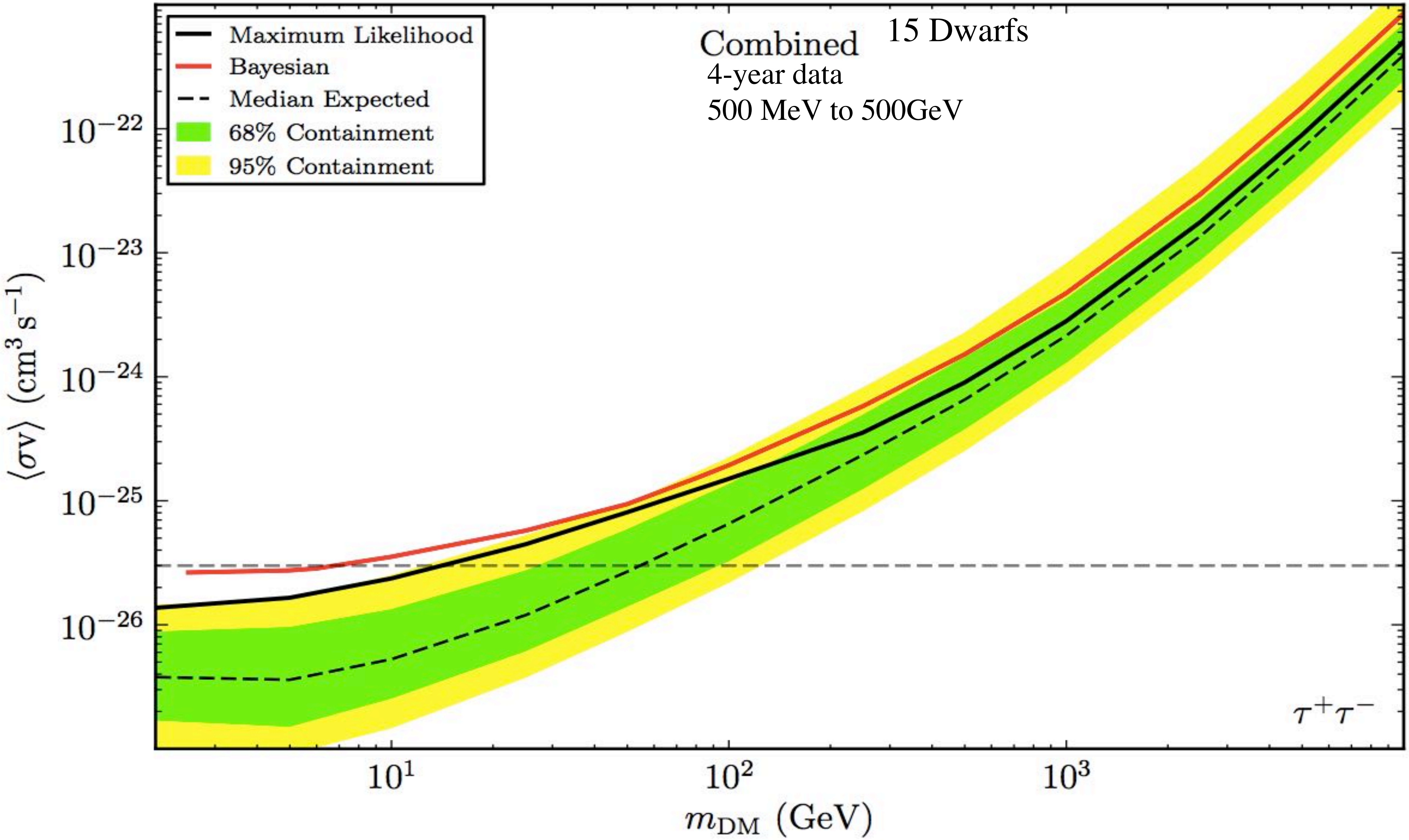


robust constraints including J-factor uncertainties from the stellar data statistical analysis

NFW. For cored dark matter profile, the J-factors for most of the dSphs would either increase or not change much

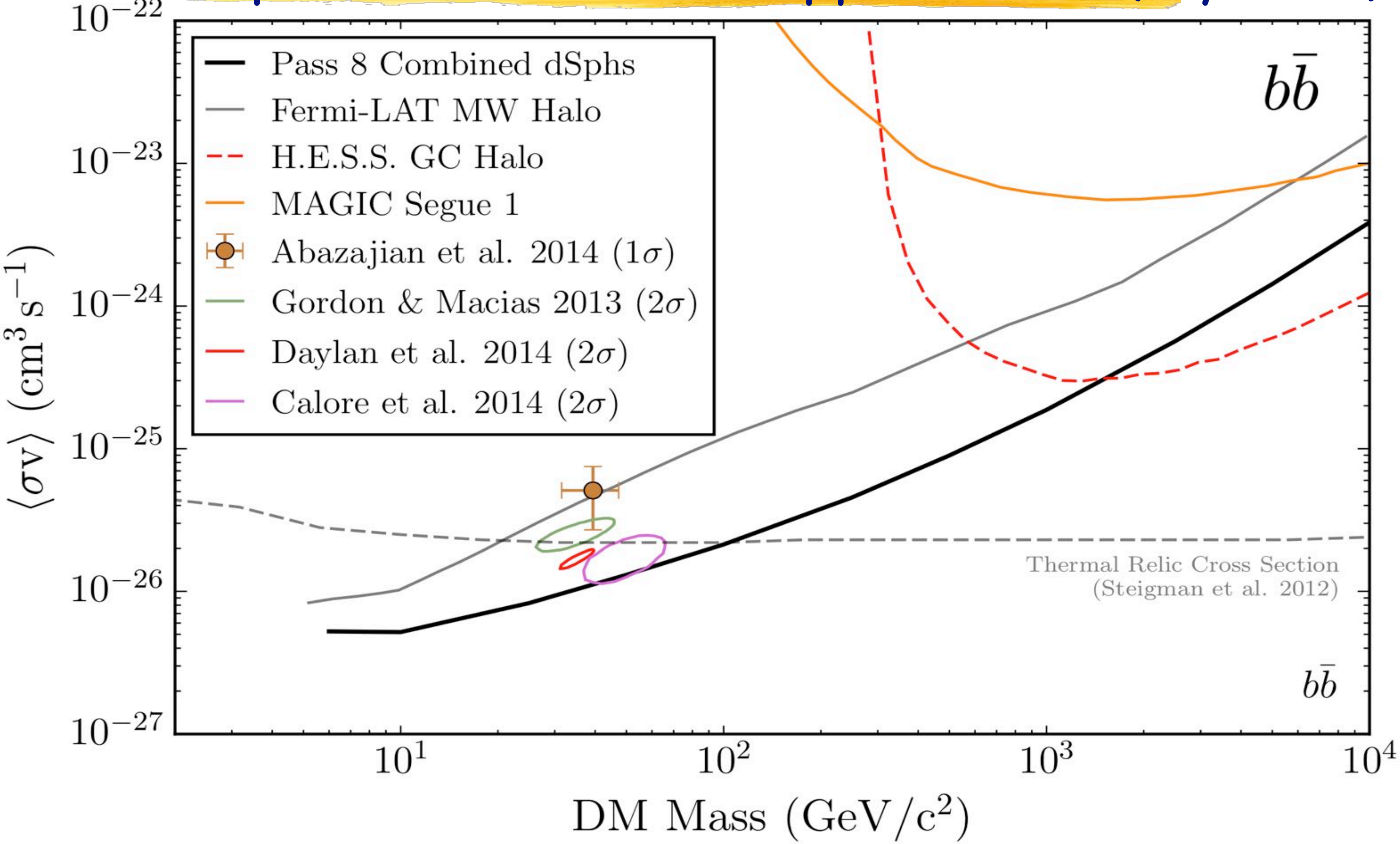
Fermi Lat Coll., PRL 107, 241302 (2011) [arXiv:1108.3546]

Dwarf Spheroidal Galaxies upper-limits



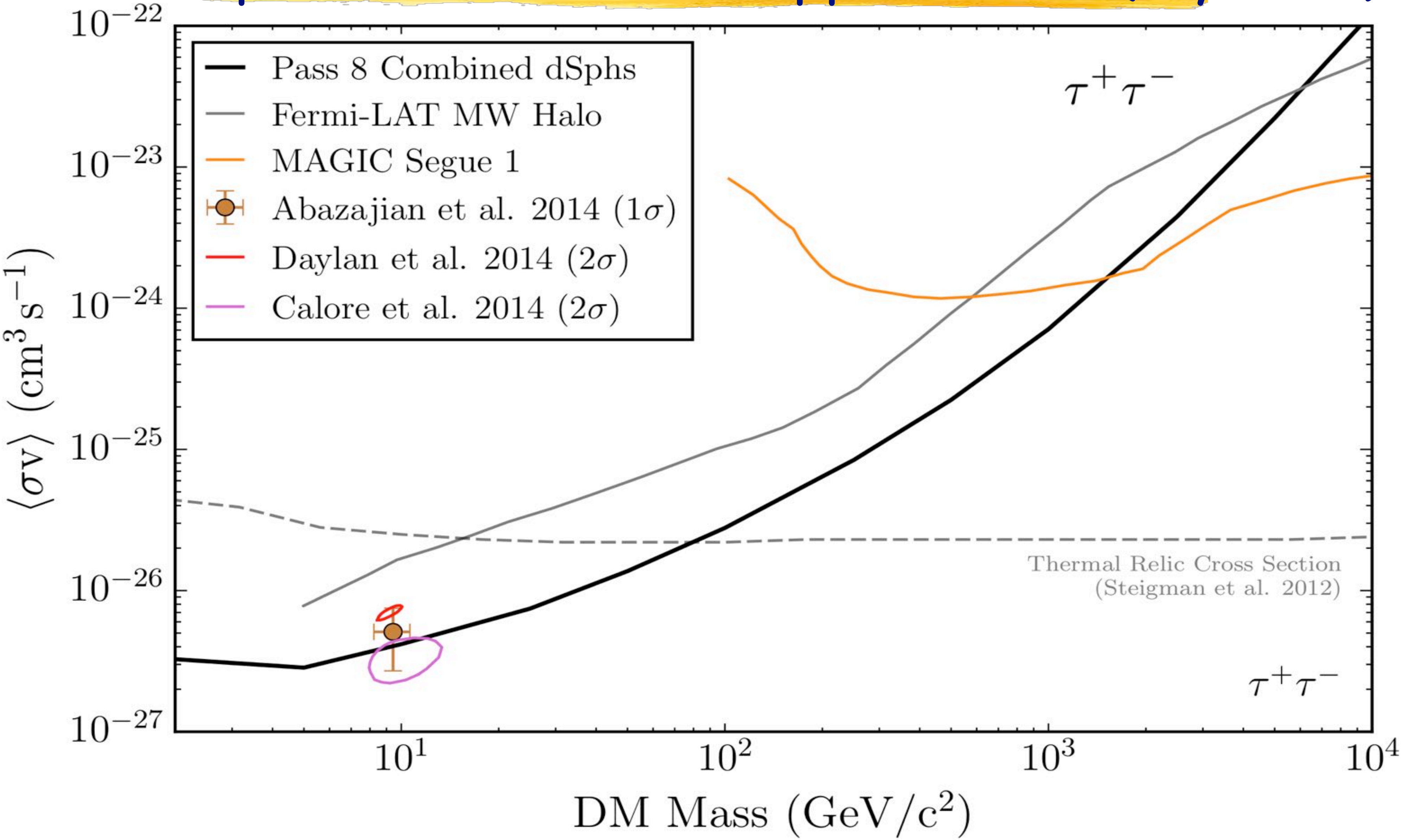
M.Ackermann et al., [Fermi Coll.] Phys.Rev.D 89, 042001 (2014)[arXiv:1310.0828]

Dwarf Spheroidal Galaxies upper-limits (6 years)



M.Ackermann et al., [Fermi Coll.] PRL accepted [arXiv:1503.02641]

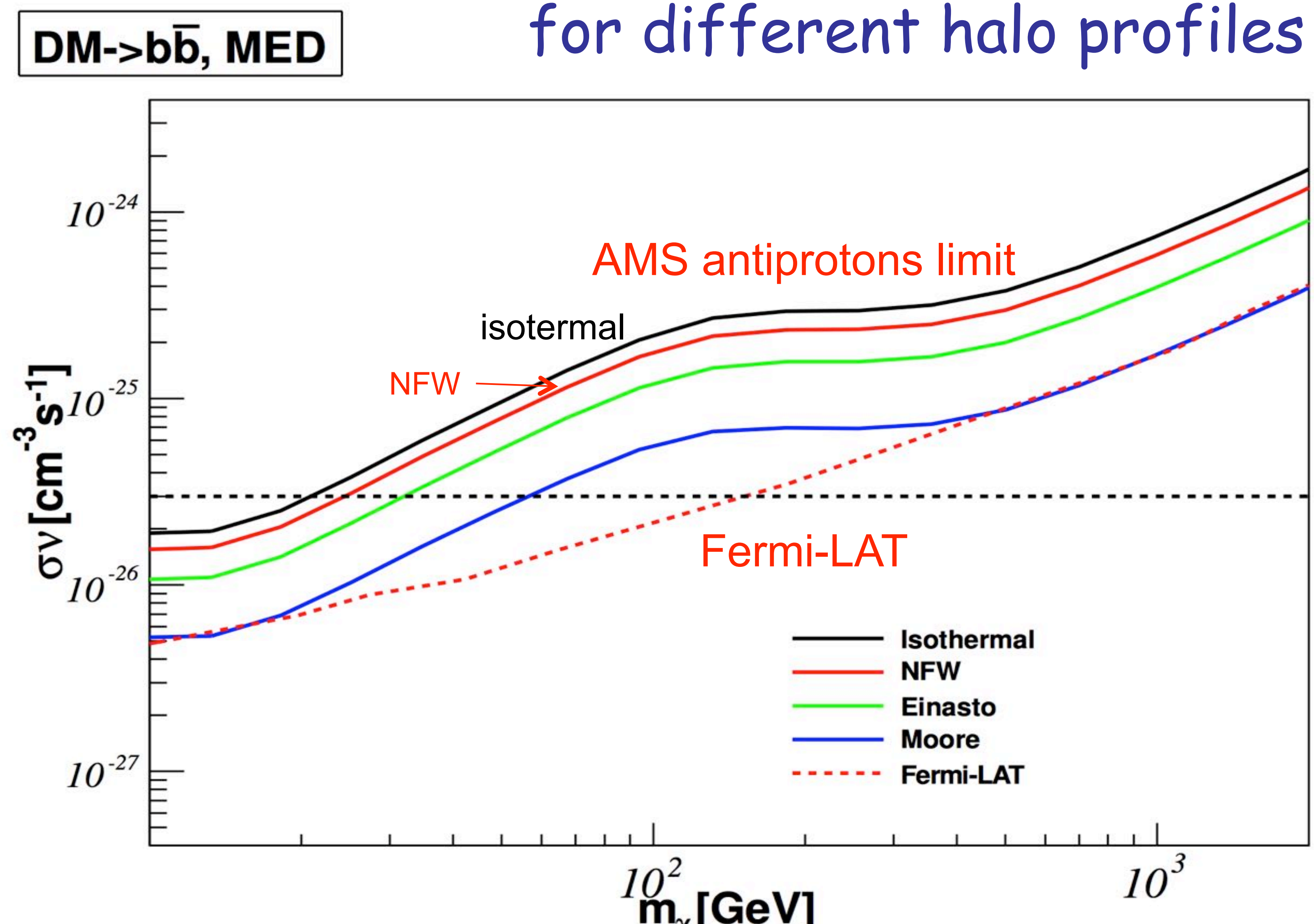
Dwarf Spheroidal Galaxies upper-limits (6 years)



M.Ackermann et al., [Fermi Coll.] PRL accepted [arXiv:1503.02641]

Upper limits from AMS antiprotons and Fermi LAT

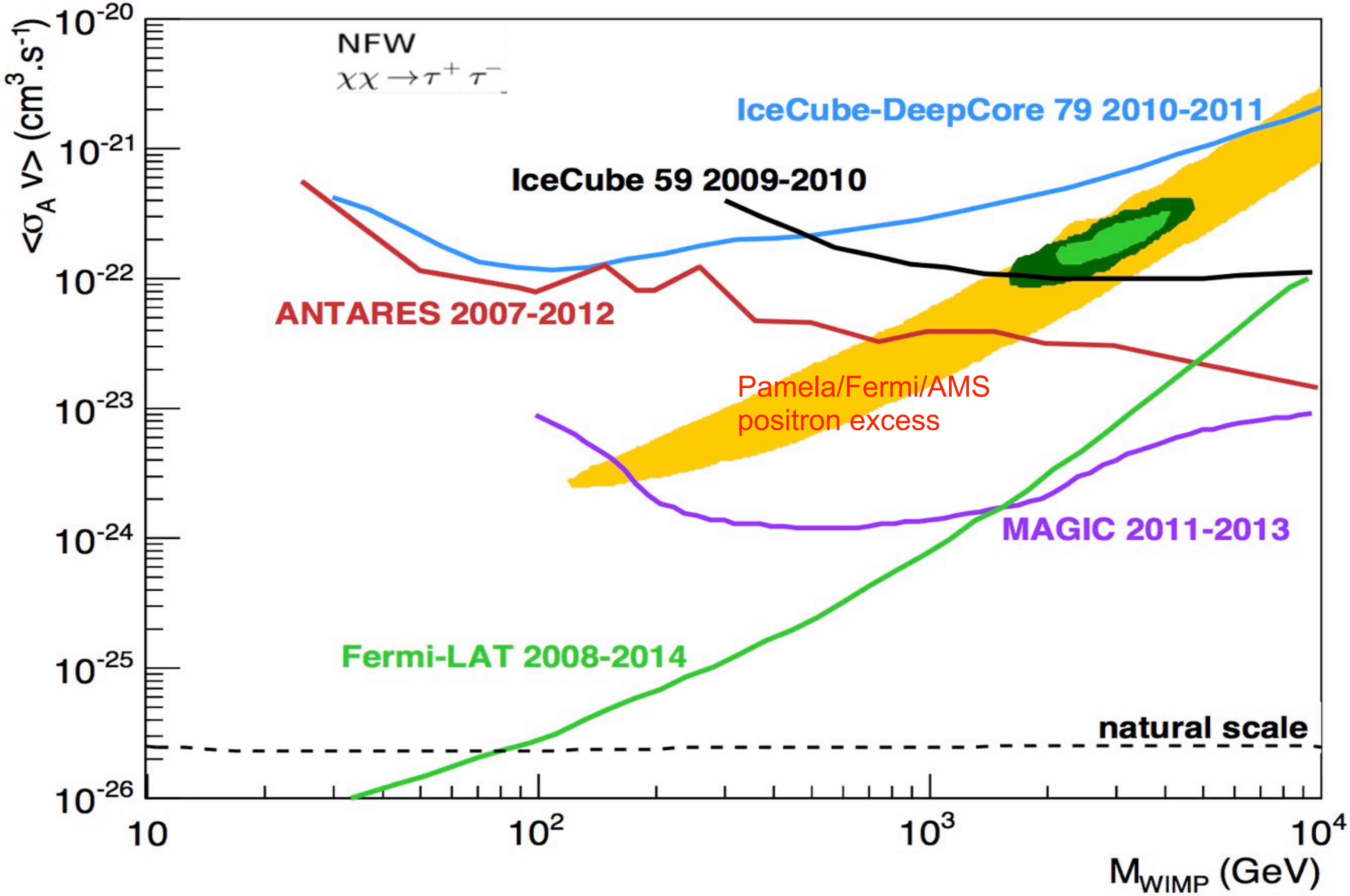
for different halo profiles



Jin et al., arXiv:1504.04604

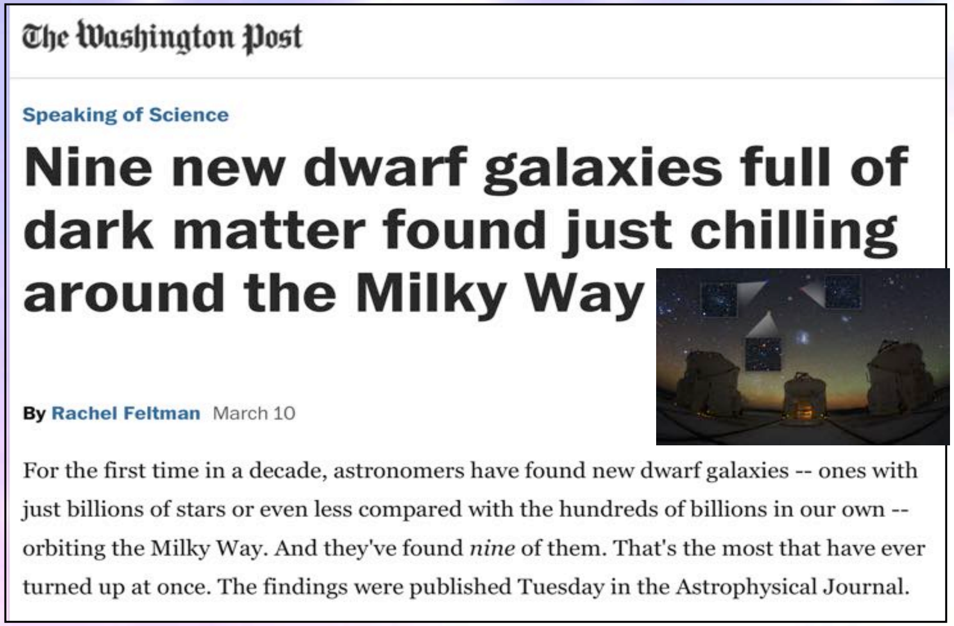
Fermi data from M.Ackermann et al., [Fermi Coll.] PRL accepted [arXiv:1503.02641]

Upper limits from Fermi LAT, Antares, IceCube, Magic



Antares Coll. arXiv:1505.04866 IceCube Coll. arXiv:1505.07259

2015: New DES Dwarf Spheroidal Galaxy Candidates



The Washington Post

Speaking of Science

Nine new dwarf galaxies full of dark matter found just chilling around the Milky Way

By Rachel Feltman March 10

For the first time in a decade, astronomers have found new dwarf galaxies -- ones with just billions of stars or even less compared with the hundreds of billions in our own -- orbiting the Milky Way. And they've found *nine* of them. That's the most that have ever turned up at once. The findings were published Tuesday in the Astrophysical Journal.

LAT Collaboration – DES Collaboration agreement – Feb 2015

- first joint paper “Search for Gamma-Ray Emission from DES Dwarf Spheroidal Galaxy Candidates with Fermi-LAT Data” arXiv:1503.02632

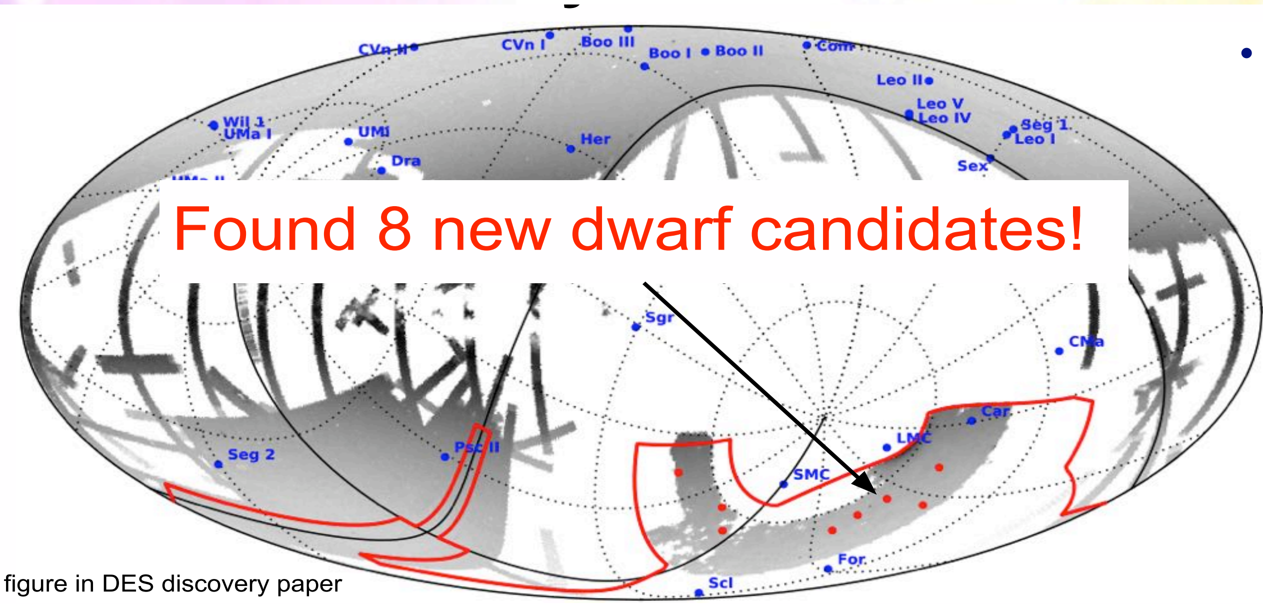


figure in DES discovery paper

- analysis of observations of 8 new Dwarf Spheroidal Galaxies found by DES:

  Bechtol, et al. arXiv:1503.02584

  also found by Koposov, et al. arXiv:150302079

New DES Dwarf Spheroidal Galaxy Candidates

Name	$(\ell, b)^{a}$	Distance[b]	$\log_{10}(\mathrm{Est.J})^{c}$
	deg	kpc	$\log_{10}(\frac{\mathrm{GeV}^2}{\mathrm{cm}^5})$
DES J0222.7−5217	(275.0, −59.6)	95	18.3
DES J0255.4−5406	(271.4, −54.7)	87	18.4
DES J0335.6−5403	(266.3, −49.7)	32 (Reticulum II)	19.3
DES J0344.3−4331	(249.8, −51.6)	330	17.3
DES J0443.8−5017	(257.3, −40.6)	126	18.1
DES J2108.8−5109	(347.2, −42.1)	69	18.3
DES J2251.2−5836	(328.0, −52.4)	58	18.8
DES J2339.9−5424	(323.7, −59.7)	95	18.4

A.Drlica-Wagner et al. [Fermi and DES Coll.] ApJ Letters Submitted [arXiv:1503.02632]

New DES Dwarf Spher… …alaxy Candidates

The New York Times The New York Times http://nyti.ms/1KTQHM7

SCIENCE

Gamma Rays May Be Clue on Dark Matter

By DENNIS OVERBYE MARCH 10, 2015

A small, newly discovered galaxy orbiting the Milky Way is em… amount of electromagnetic radiation in the form of gamma… reported Tuesday. The finding may be the latest in a lon… alarms, they said, or it might be that the mysterious… the universe is finally showing its face.

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Latest Headlines Science Pictures

Have we finally found DARK MATTER? Gamma rays hint at the presence of the mysterious material in nearby dwarf galaxy

- Dark matter is the missing material making up 80% of universe's mass
- Gamma rays from a dwarf galaxy are considered a sign of dark matter
- They were spotted in direction of 'Reticulum 2' 98,000 light-years away
- Scientists say this is the most convincing signal of dark matter yet

By ELLIE ZOLFAGHARIFARD FOR DAILYMAIL.COM

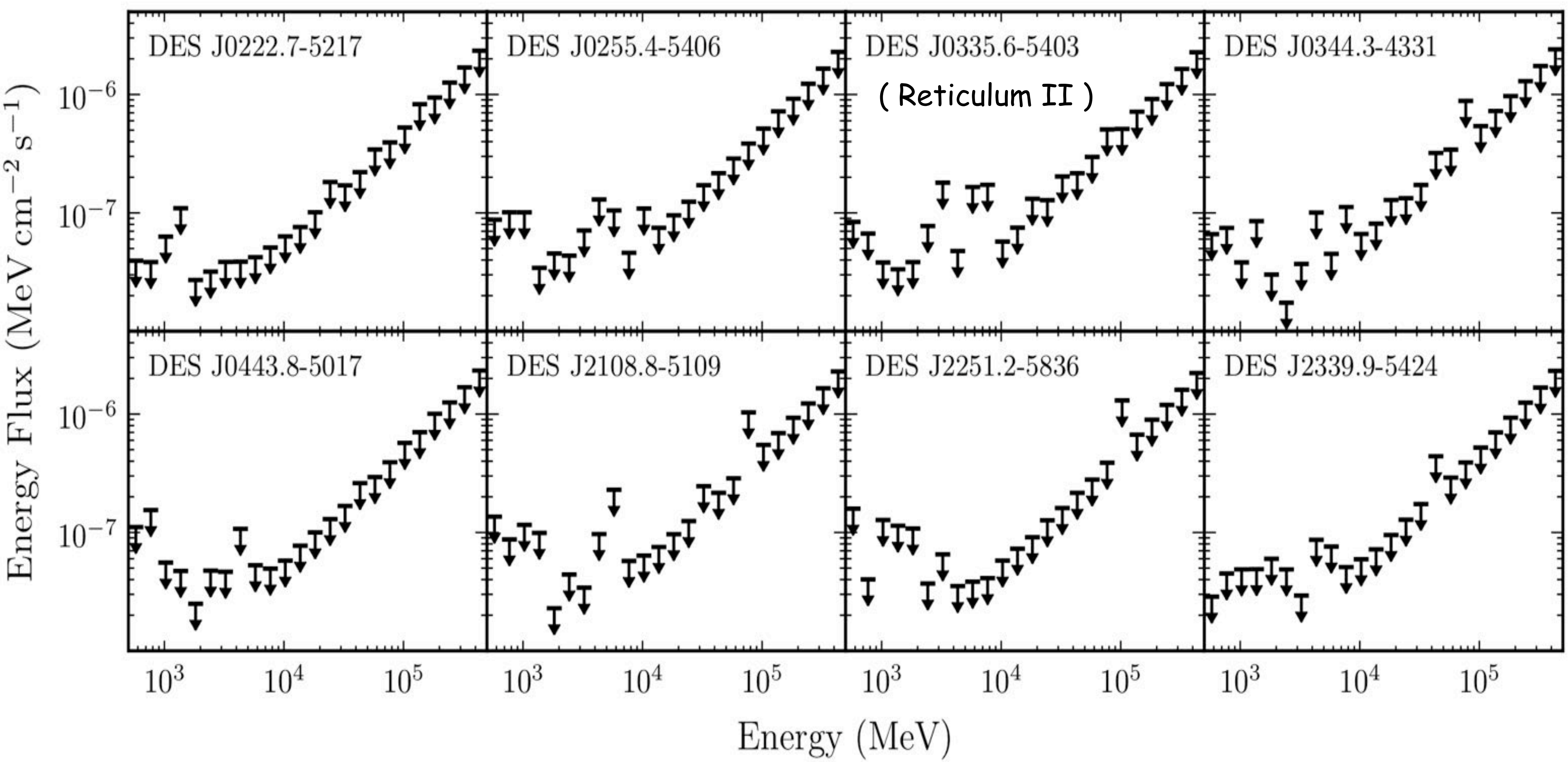
PUBLISHED: 18:03 GMT, 25 March 2015 | UPDATED: 20:17 GMT, 25 March 2015

Scroll down for video

Scroll down for video !

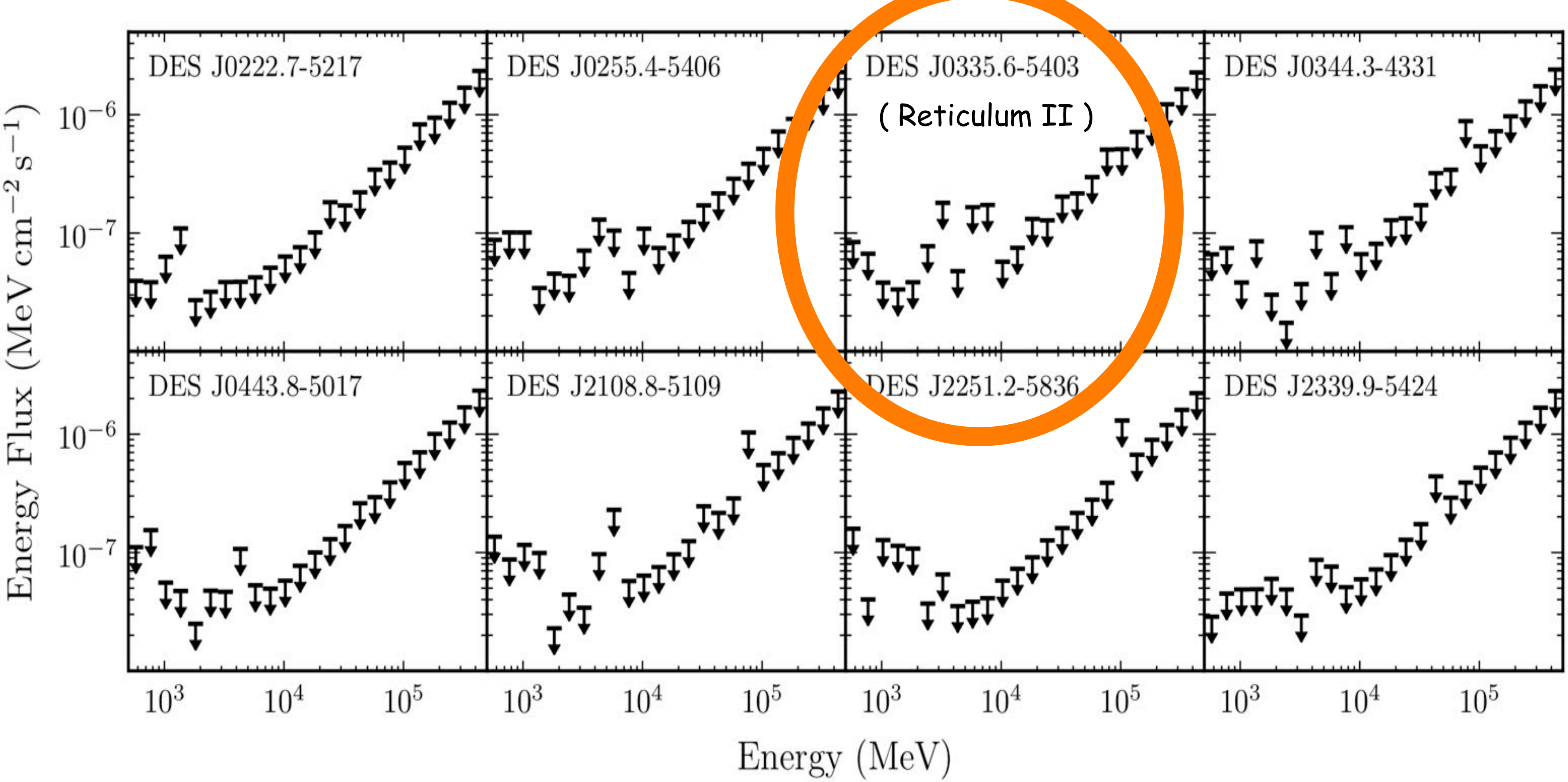
Based on arXiv:1503.02320 and arXiv:1503.06209

New DES Dwarf Spheroidal Galaxy Candidates



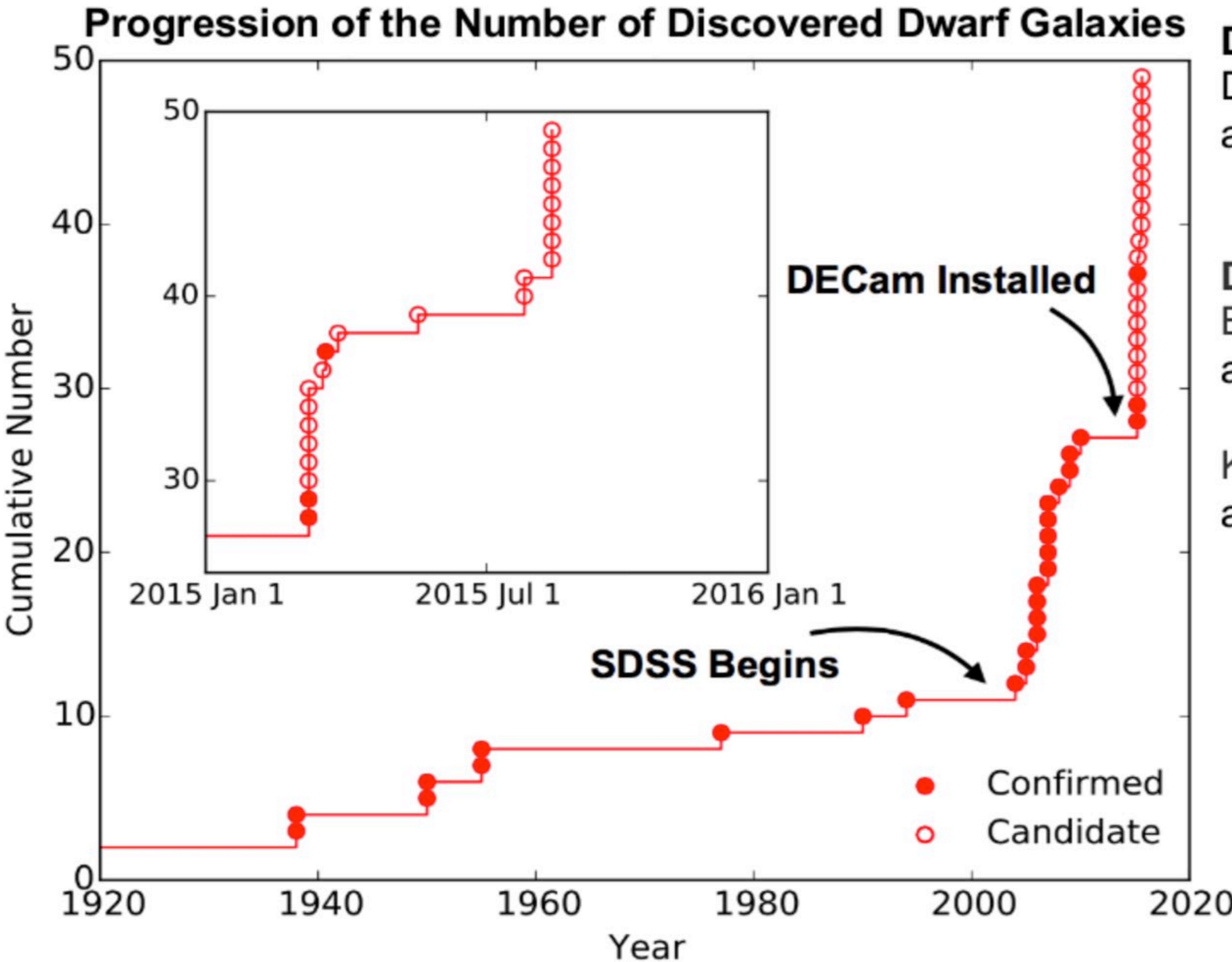
A.Drlica-Wagner et al. [Fermi and DES Coll.] ApJ Letters Submitted [arXiv:1503.02632]

New DES Dwarf Spheroidal Galaxy Candidates



A.Drlica-Wagner et al. [Fermi and DES Coll.] ApJL 2015, 809, L4 [arXiv:1503.02632]

Dwarf Spheroidal Galaxy: Growing number of known targets

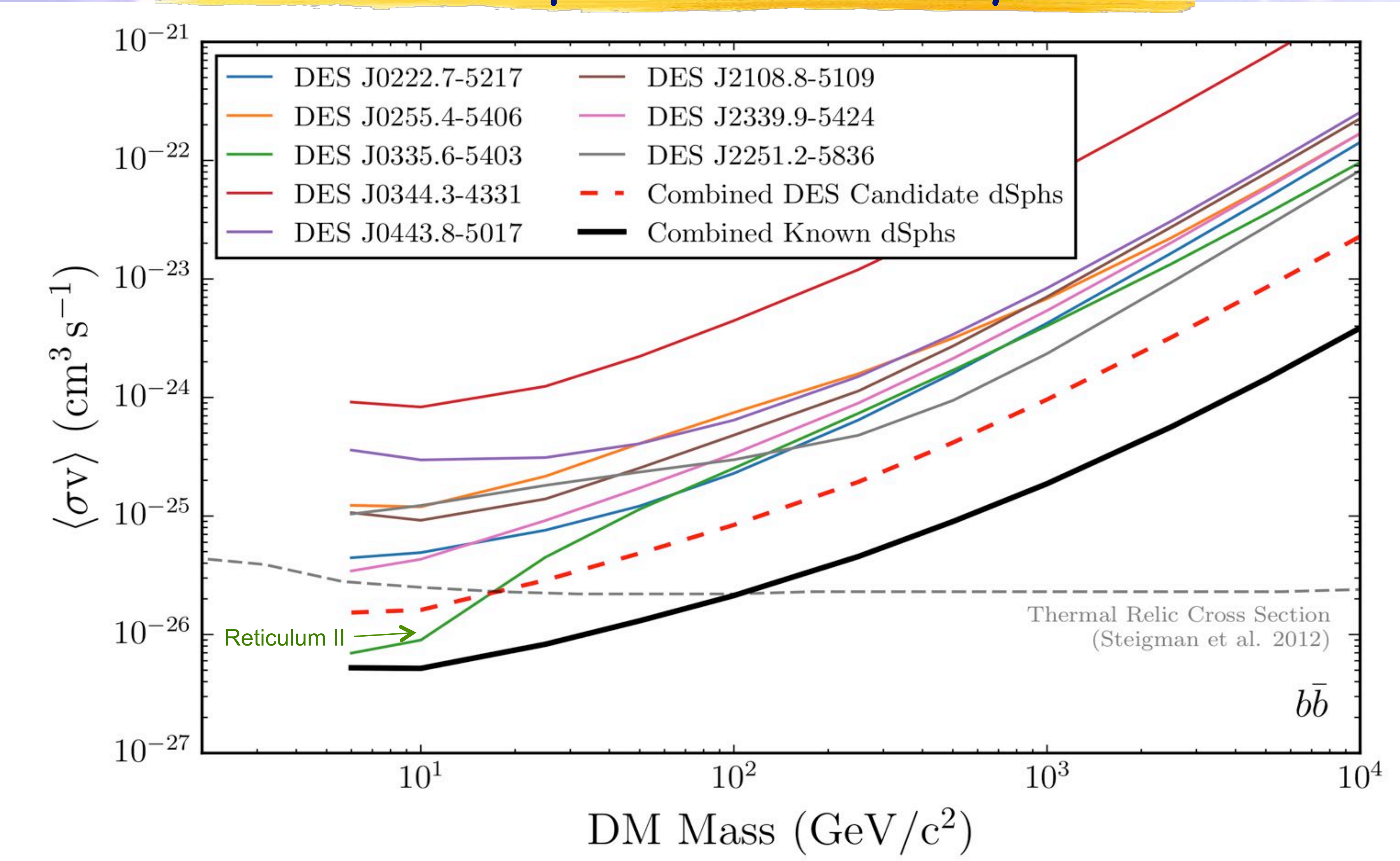


DES Year 2 Data:
Drlica-Wagner+,
arXiv:1508.03622

DES Year 1 Data:
Bechtol+:
arXiv:1503.02584

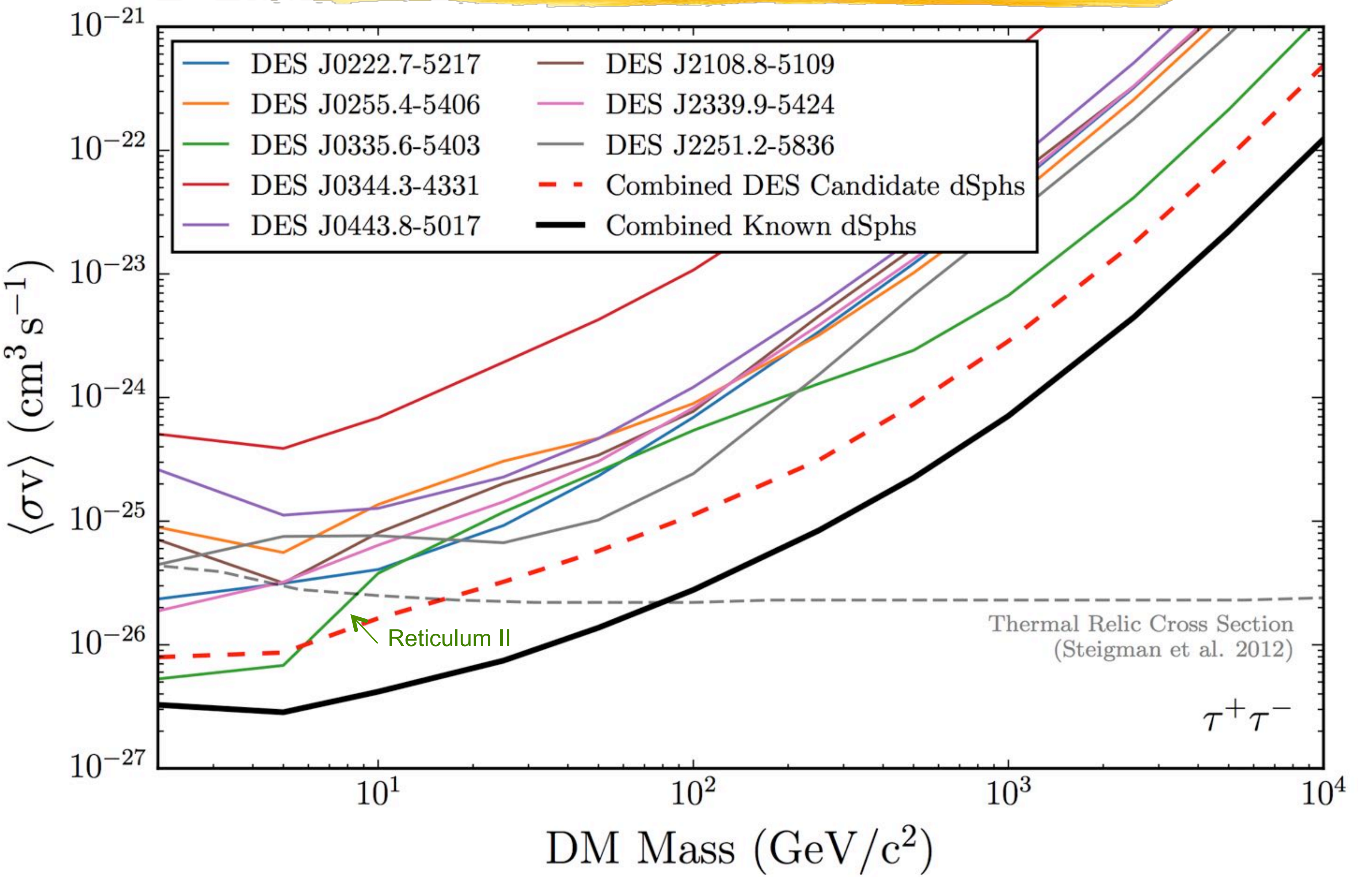
Koposov+:
arXiv:1503.02079

New DES Dwarf Spheroidal Galaxy Candidates



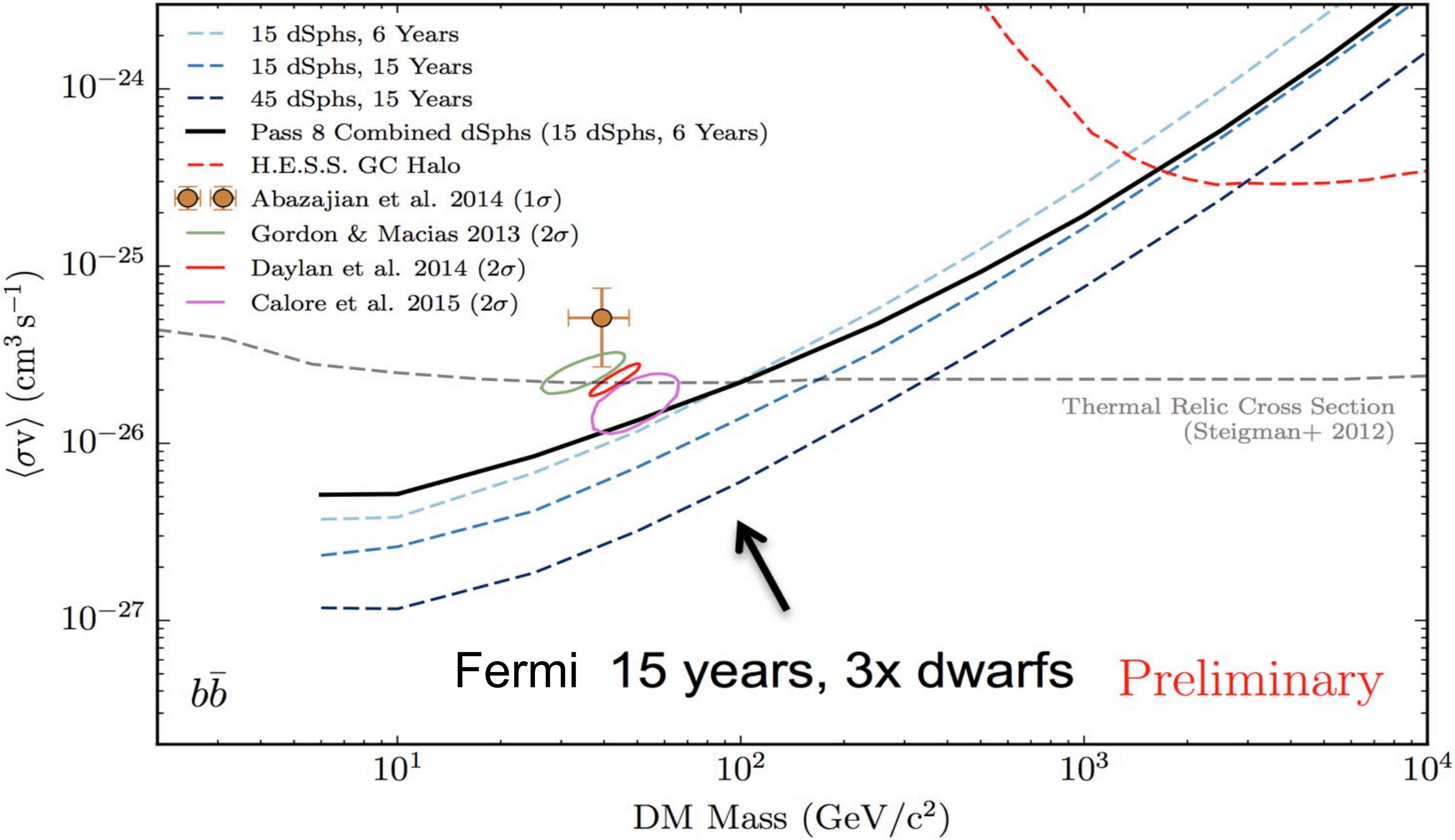
A.Drlica-Wagner et al. [Fermi and DES Coll.] ApJL 2015, 809, L4 [arXiv:1503.02632]

New DES Dwarf Spheroidal Galaxy Candidates



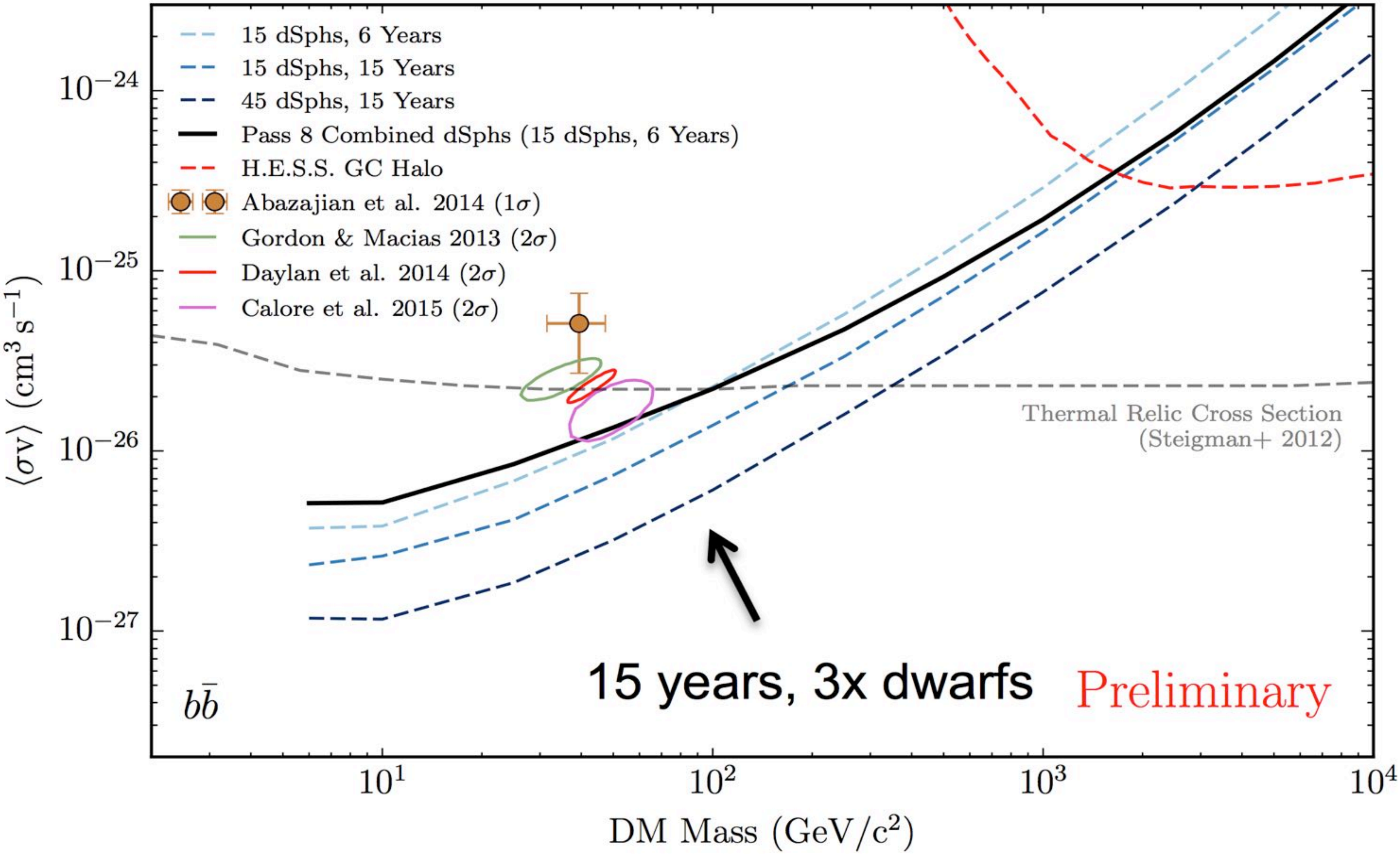
A.Drlica-Wagner et al. [Fermi and DES Coll.] ApJL 2015, 809, L4 [arXiv:1503.02632]

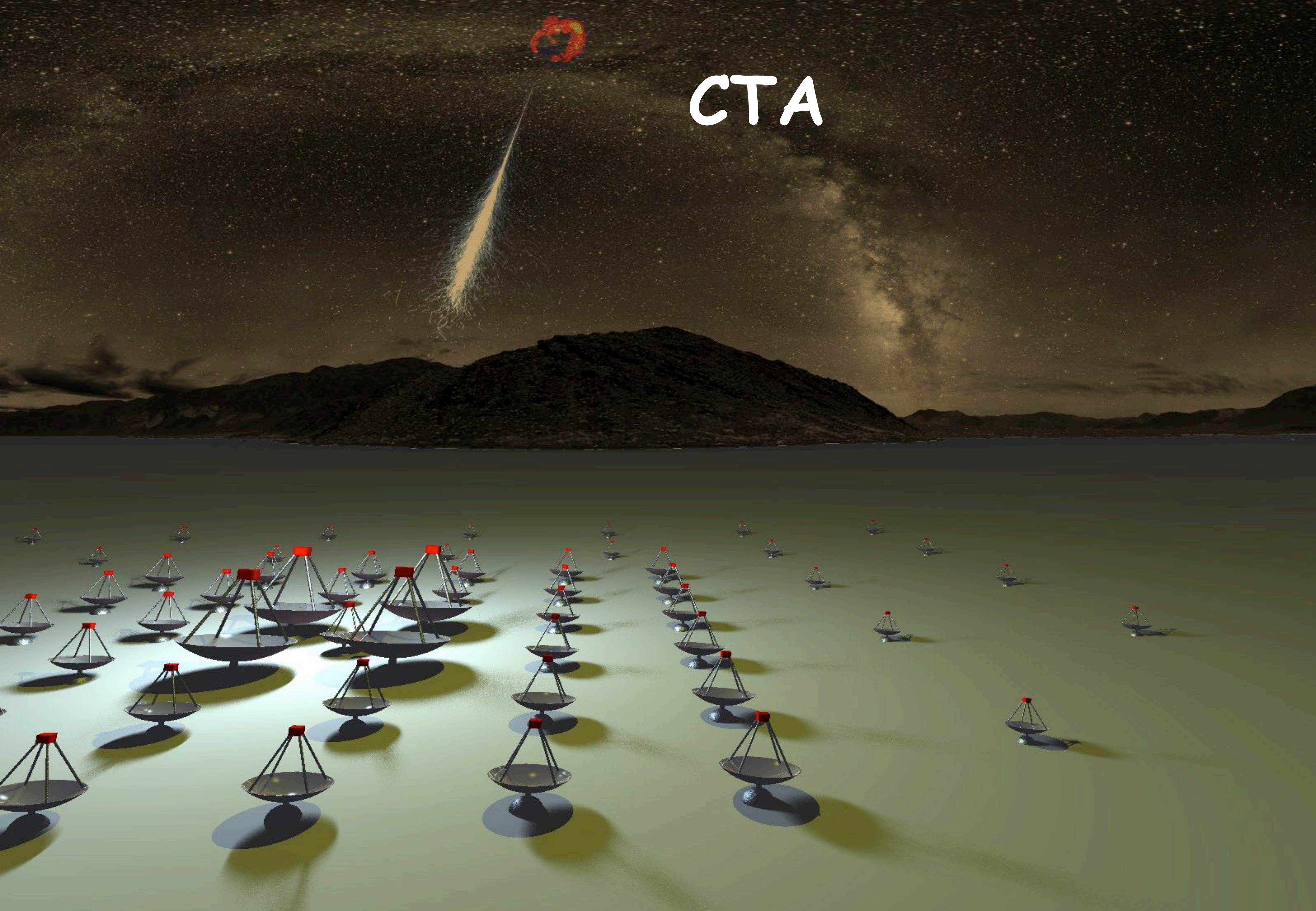
DM limit improvement estimate in 15 years with the composite likelihood approach (2008- 2023)



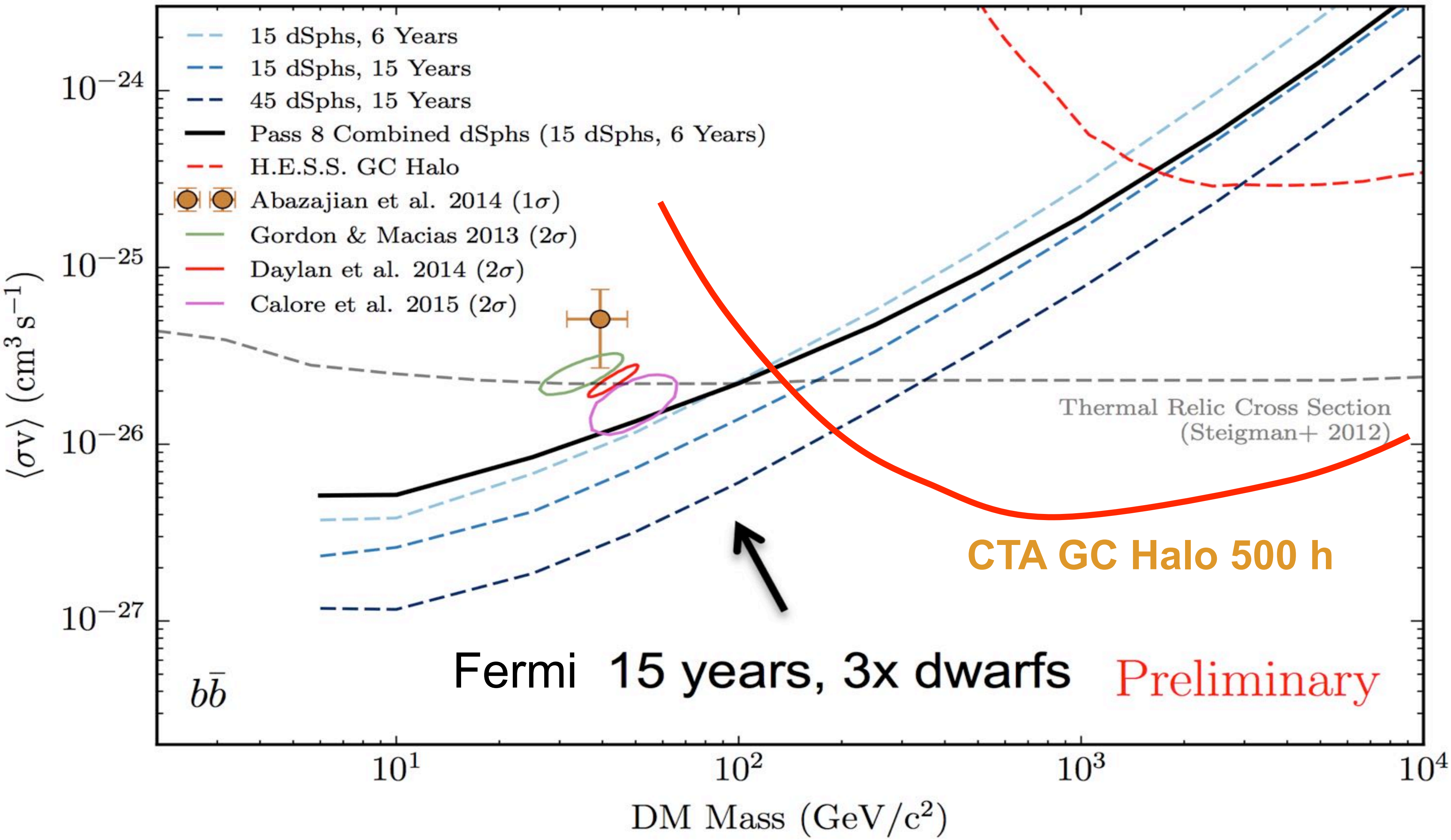
Together Fermi and CTA will probe most of the space of WIMP models with thermal relic annihilation cross section

DM limit improvement estimate in 15 years with the composite likelihood approach (2008- 2023)



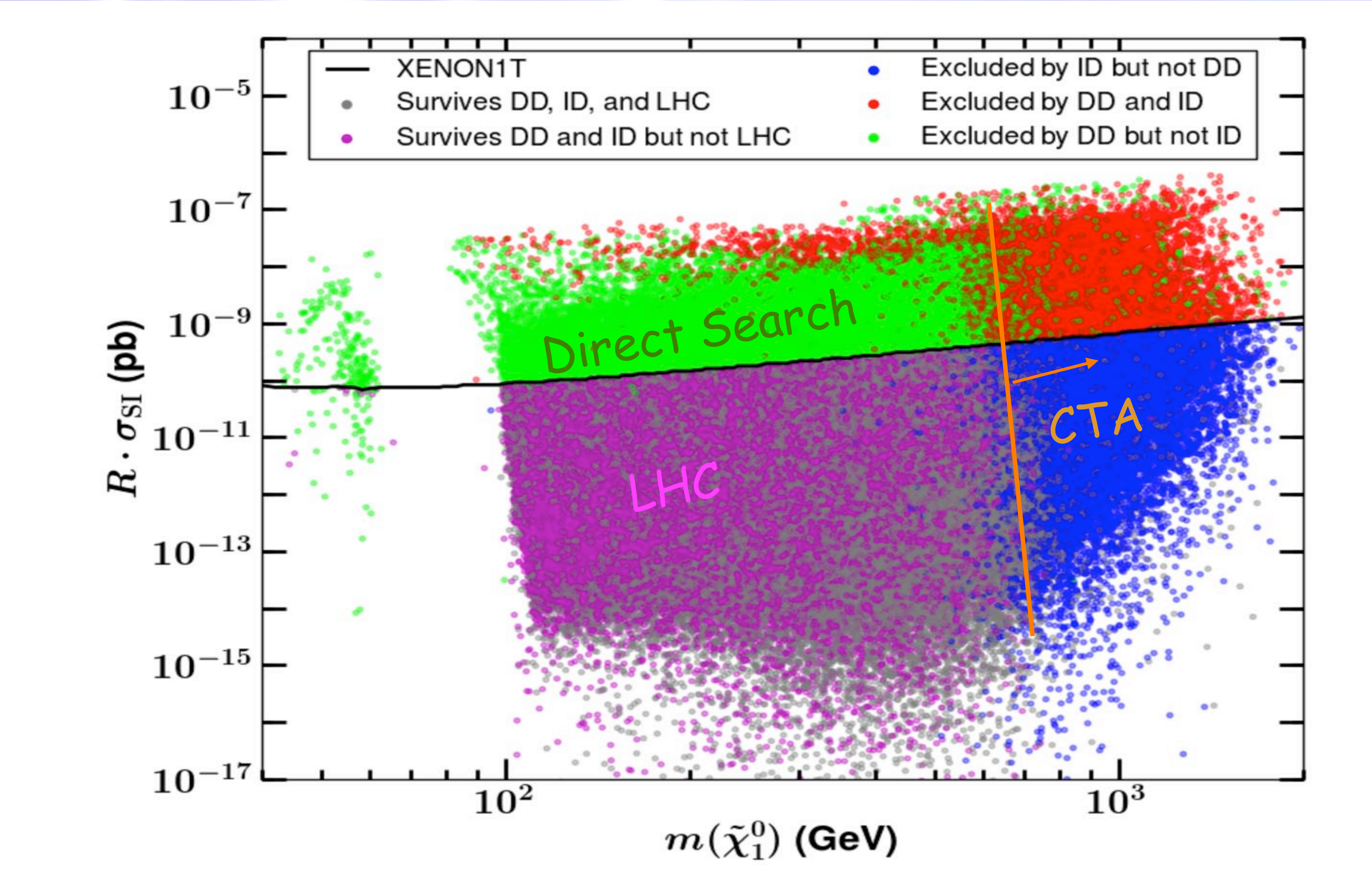

CTA

DM limit improvement estimate in 15 years with the composite likelihood approach (2008- 2023)



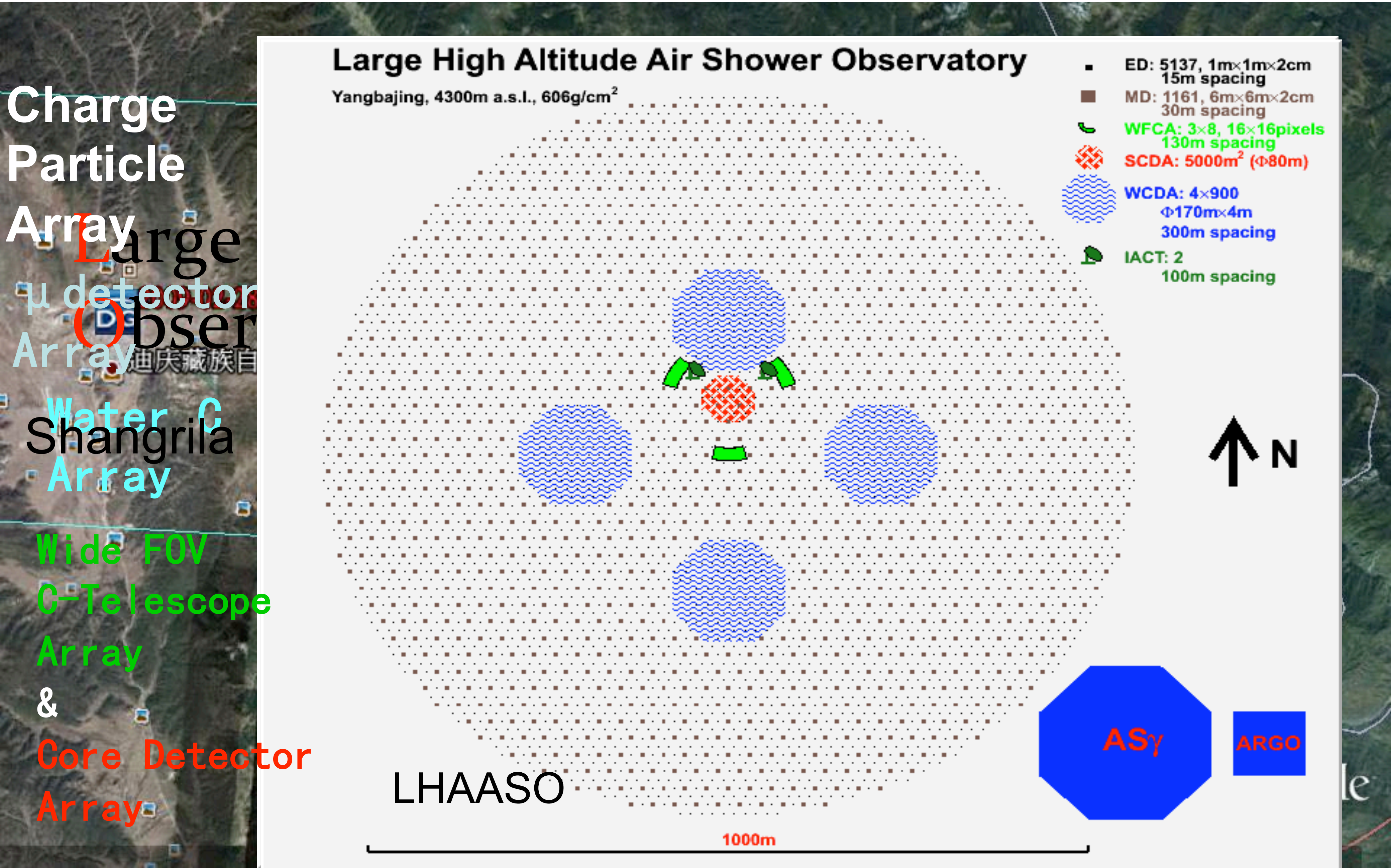
Together Fermi and CTA will probe most of the space of WIMP models with thermal relic annihilation cross section

Complementarity and Searches for Dark Matter in the pMSSM

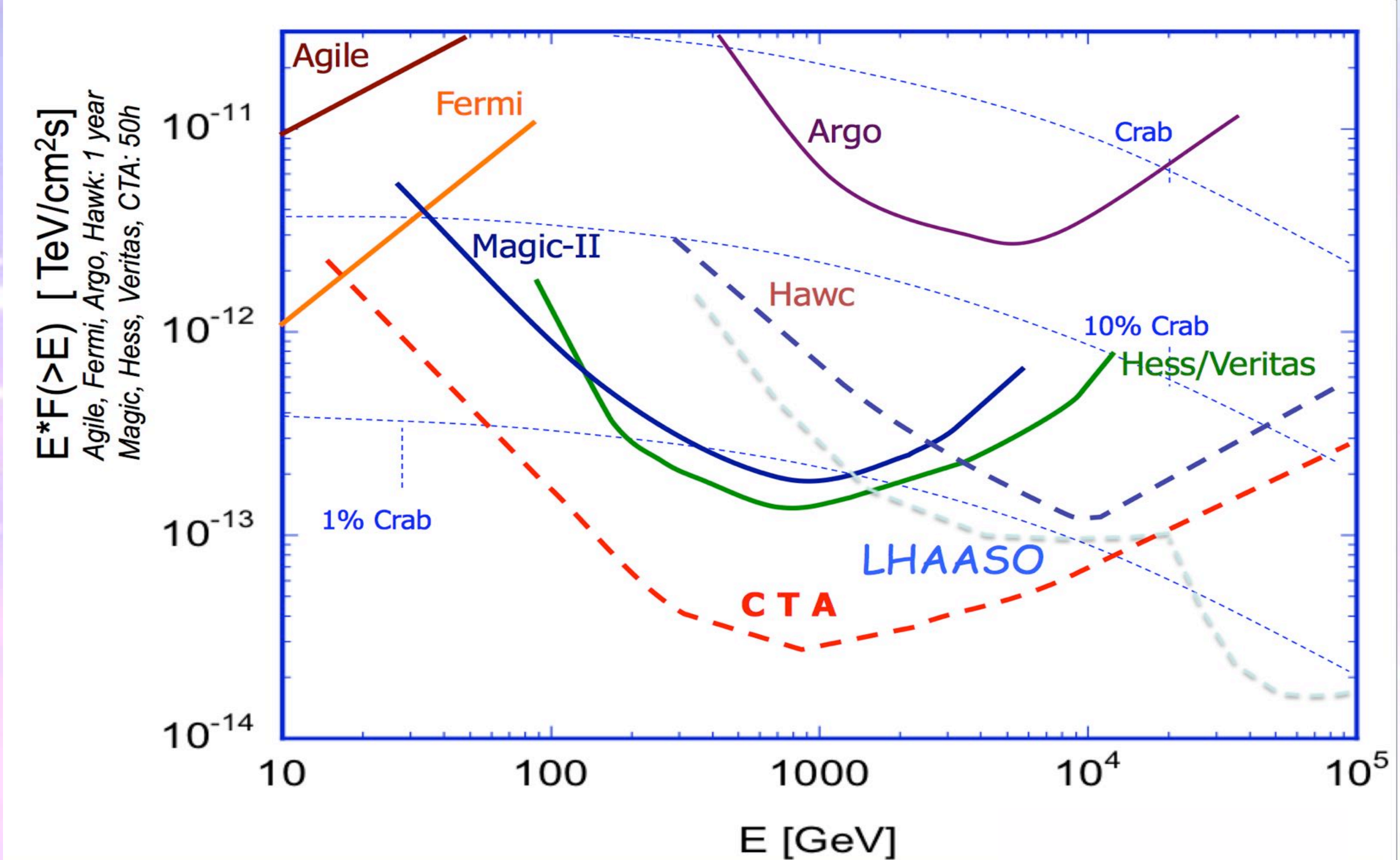


Cahill-Rowley et al. arXiv: 1305.6921

LHAASO Project: γastronomy and origin of CR

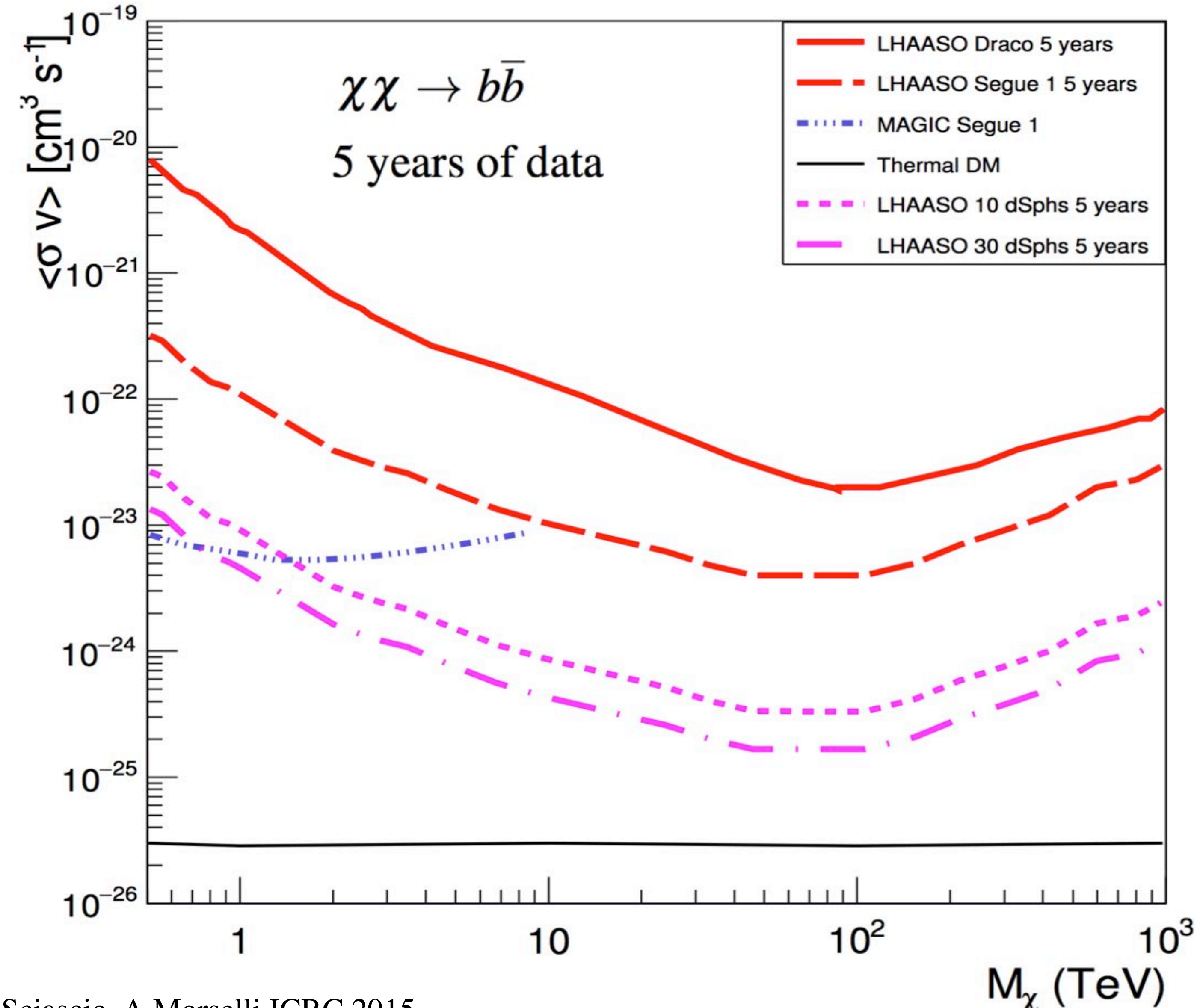


Sensitivity of present and future experiments



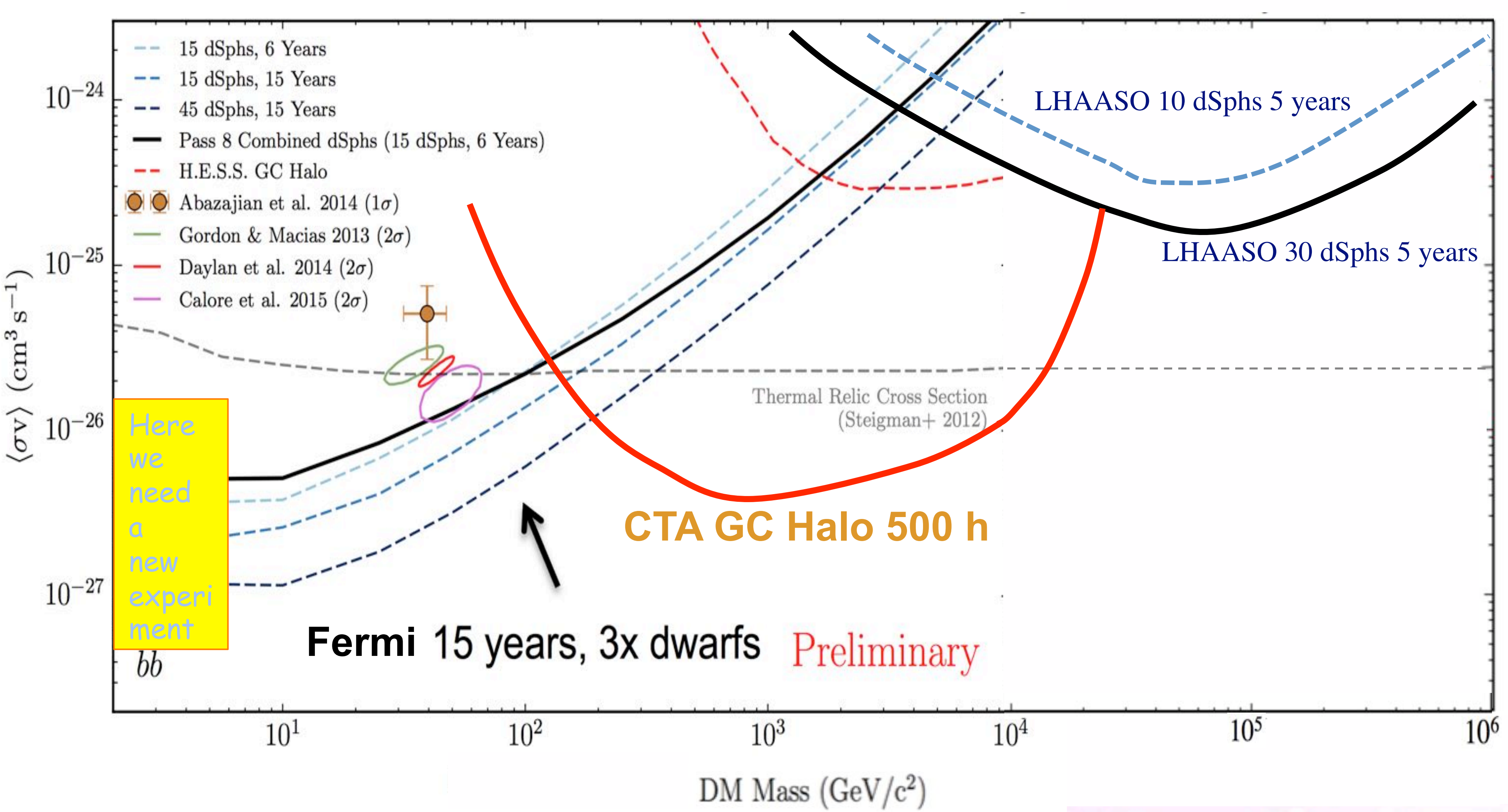
LHAASO and Dark Matter Search

LHAASO advantage: combined analysis of different dwarf galaxies observed at the same time



G.Di Sciascio, A.Morselli ICRC 2015

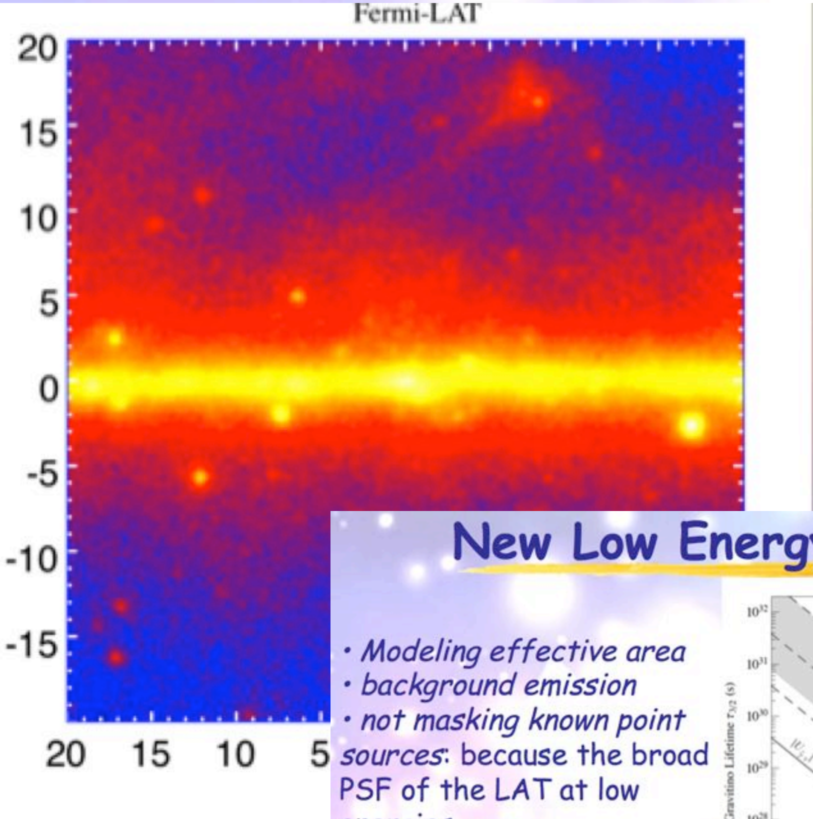
DM limit improvement estimate in 15 years with the composite likelihood approach (2008- 2023)



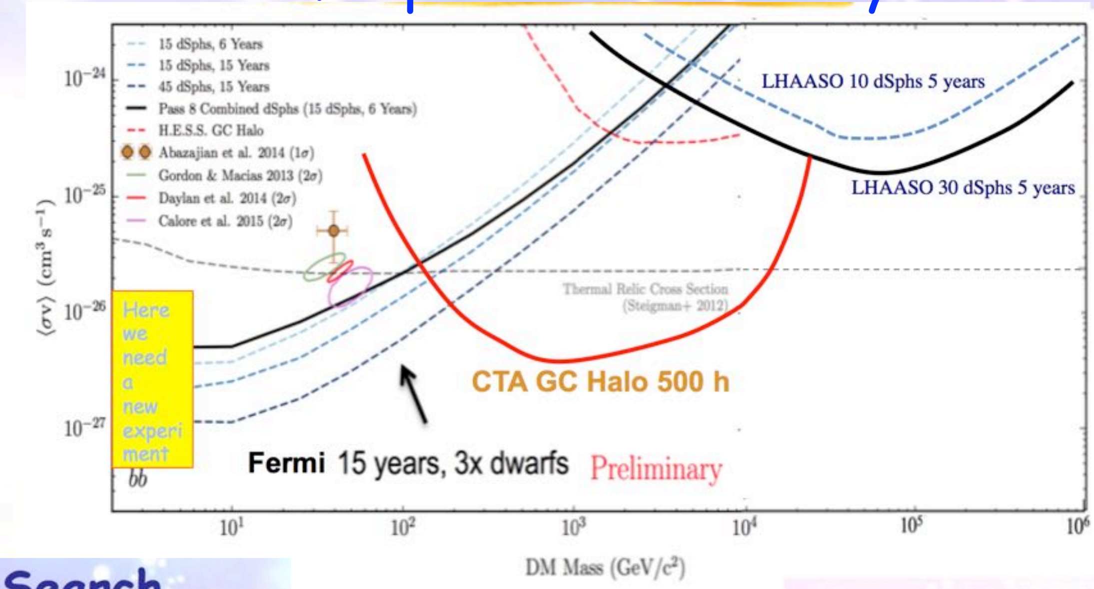
Together Fermi and CTA will probe most of the space of WIMP models with thermal relic annihilation cross section

we saw at least three reasons for a low energy experiment

Galactic Center

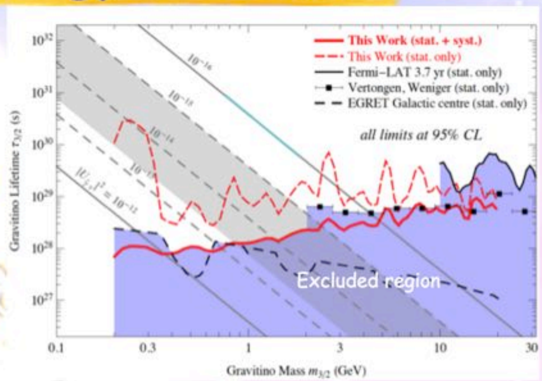


Dwarf Spheroidal Galaxy



New Low Energy Line Search

- *Modeling effective area*
- *background emission*
- *not masking known point sources*: because the broad PSF of the LAT at low energies.



This Analysis is Systematics Limited

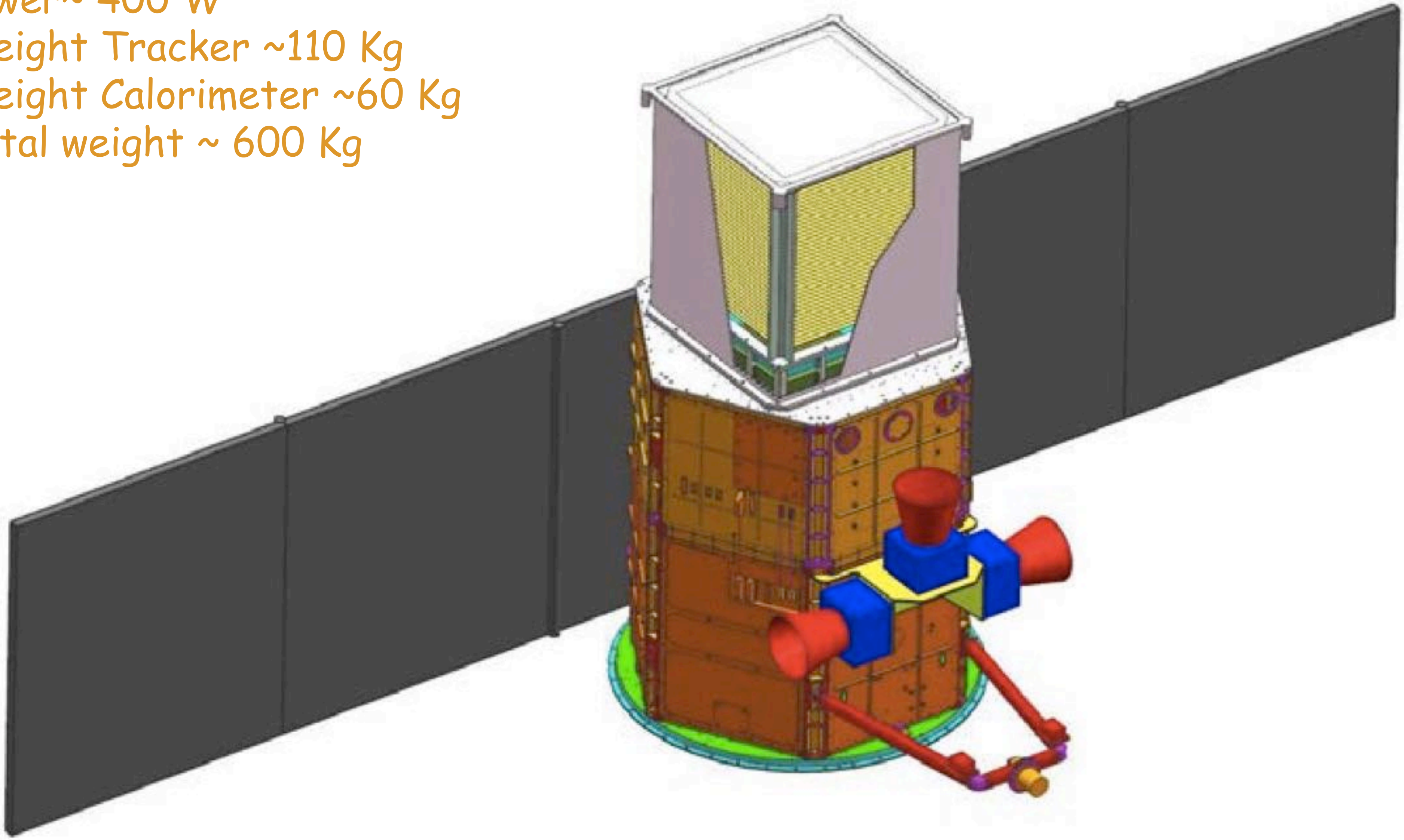
JCAP 10(2014) 023,[arXiv:1406.3430]

To improve this search better energy and angular resolutions at energies below 100 MeV are needed

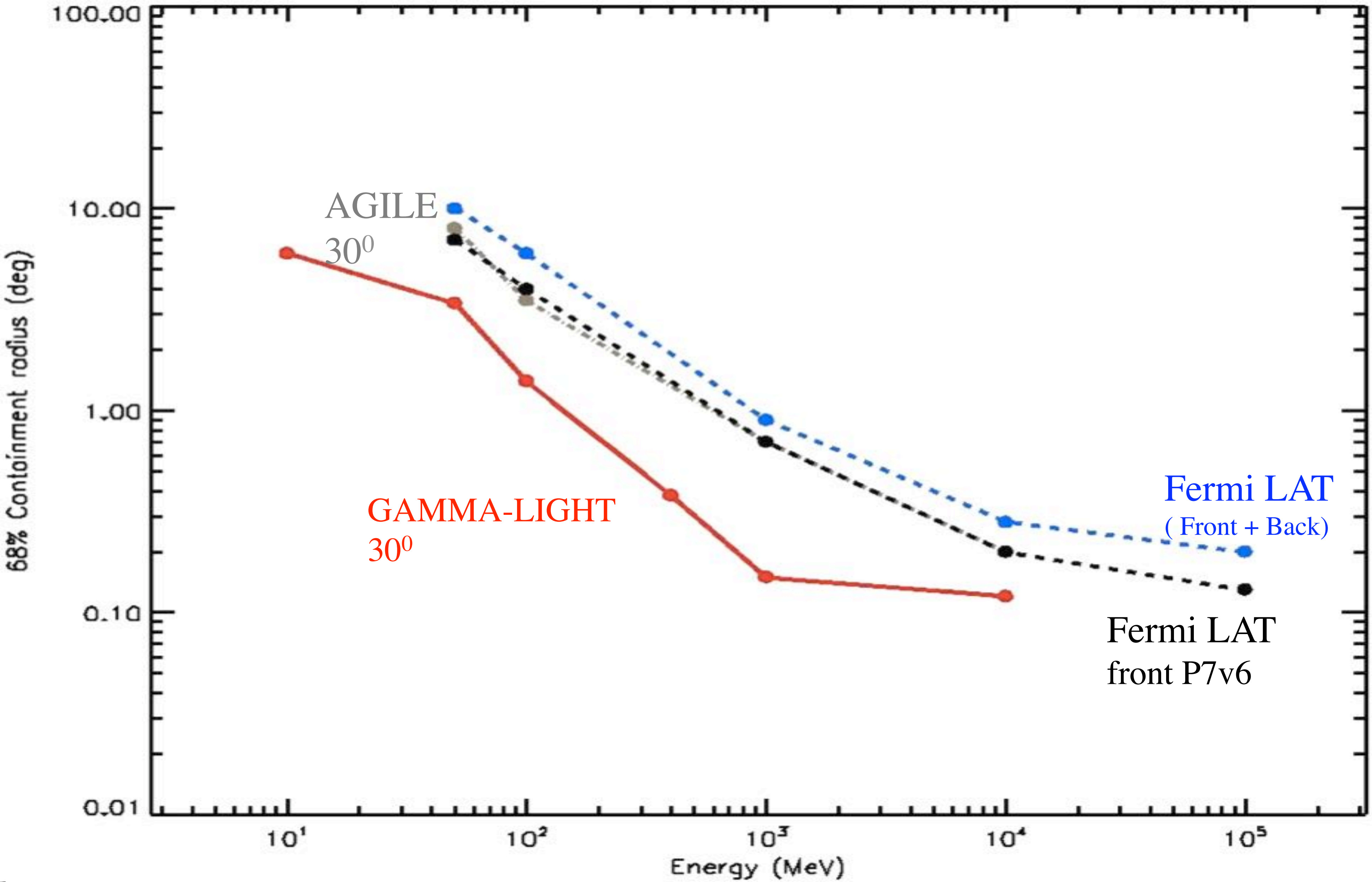
- 1-100 MeV unexplored domain for
  - Dark Matter searches
  - Galactic compact stars and nucleosynthesis
  - Cosmic rays
  - Relativistic jets, microquasars
  - Blazars
  - Gamma-Ray Bursts
  - Solar physics
- and…
  - Terrestrial Gamma-Ray Flashes

Gamma-light project

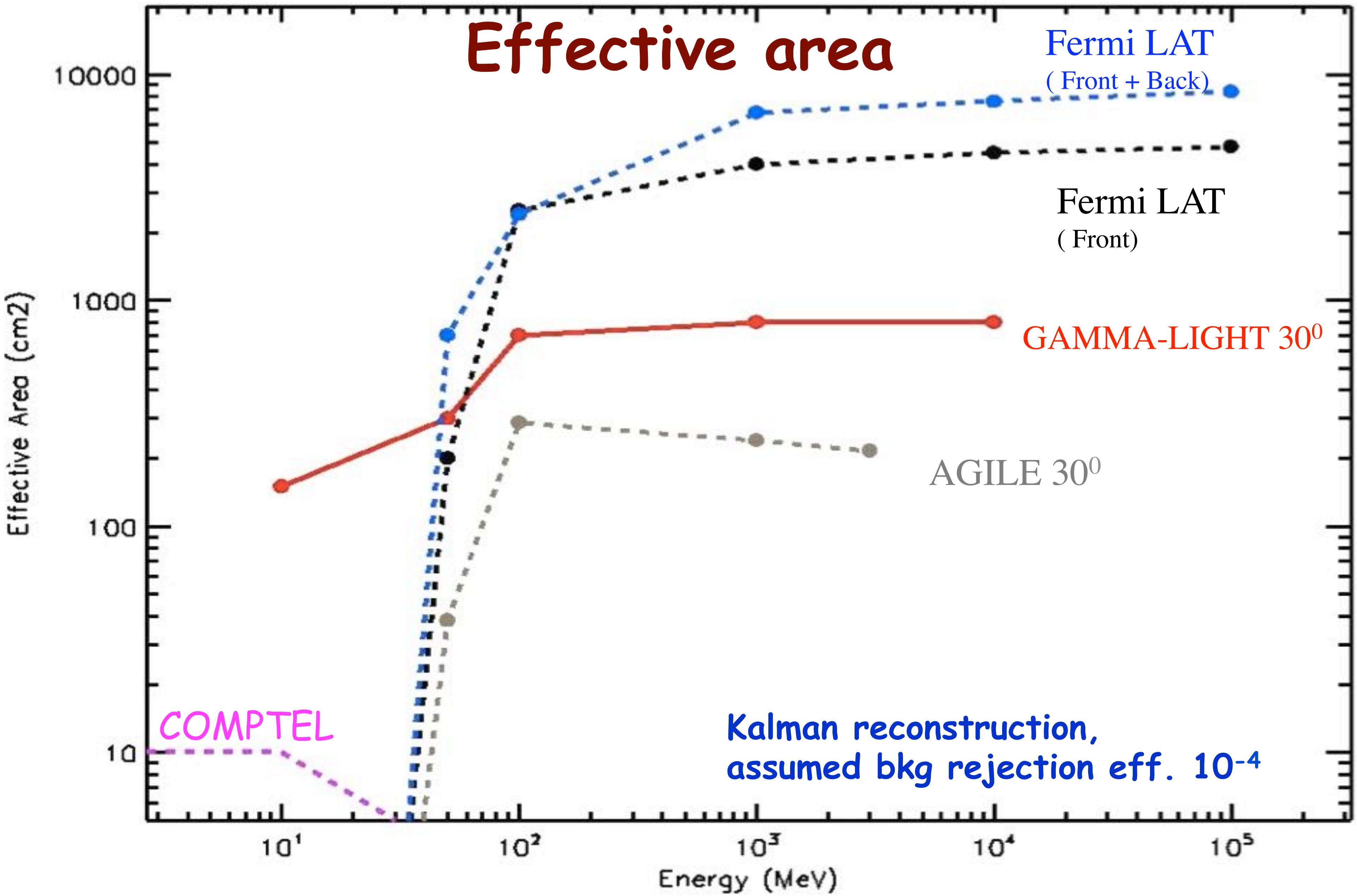
Power~ 400 W
Weight Tracker ~110 Kg
Weight Calorimeter ~60 Kg
Total weight ~ 600 Kg



Gamma-Light Point Spread Function (angular resolution)



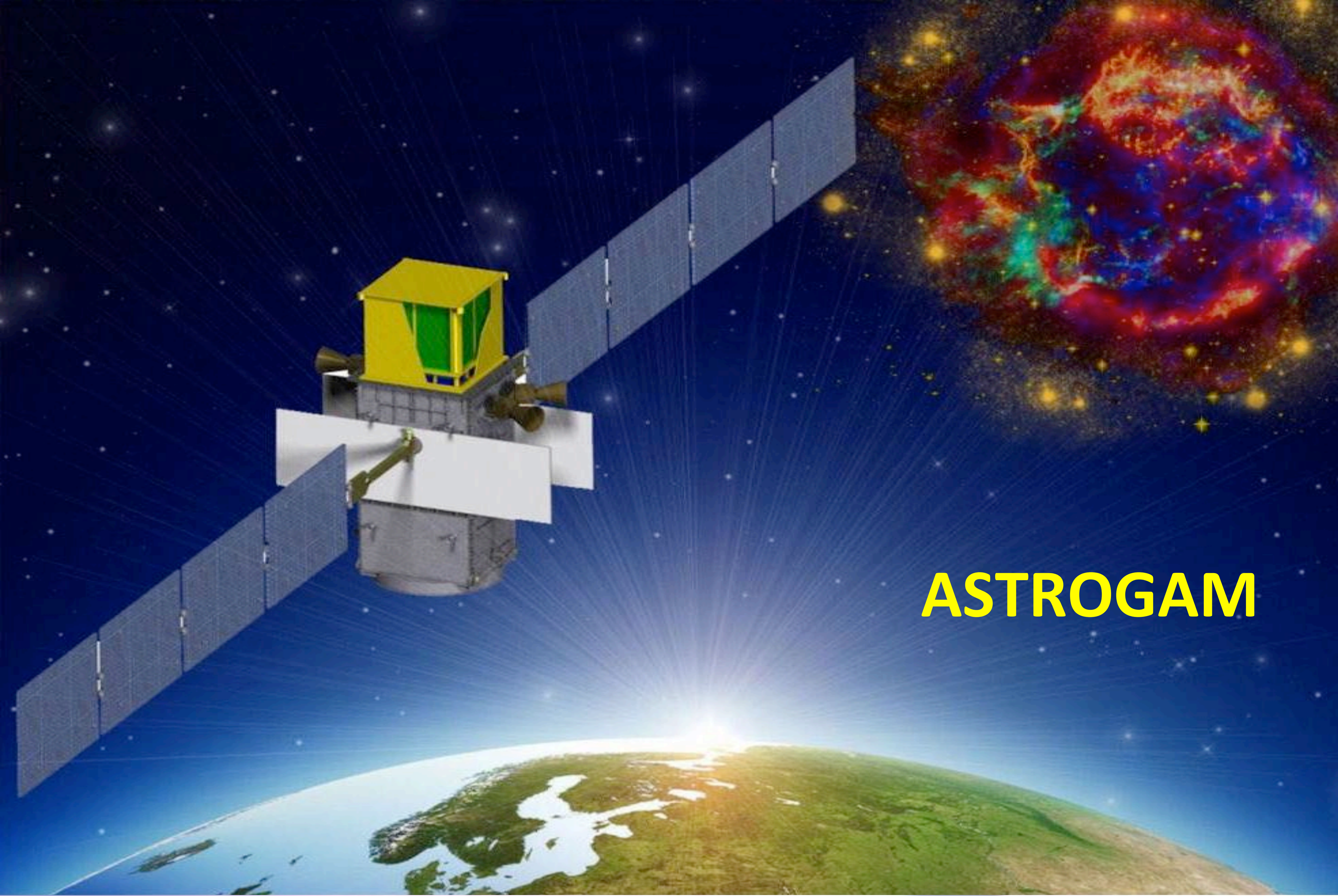
A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198 [arXiv:1406.1071]



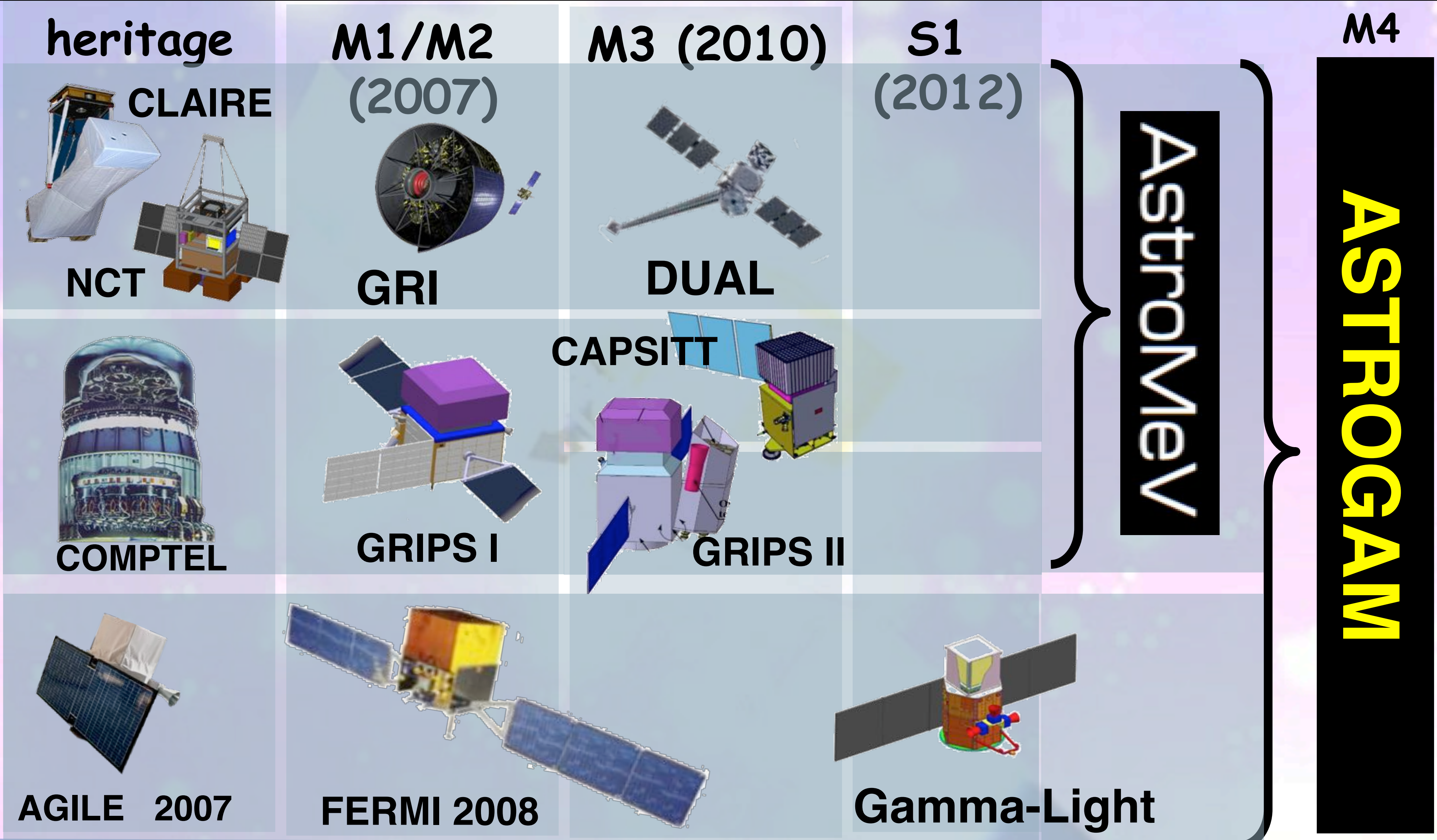
A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198 [arXiv:1406.1071]

ESA M-4 Call

- quite different from previous Medium-sized Mission Calls (Solar Orbiter, EUCLID, PLATO);
- total ESA budget: 450 Meuro.
- guidelines for an ''ESA-only'' mission:
  - Payload mass: 300 kg;
  - total spacecraft mass: 800 kg.

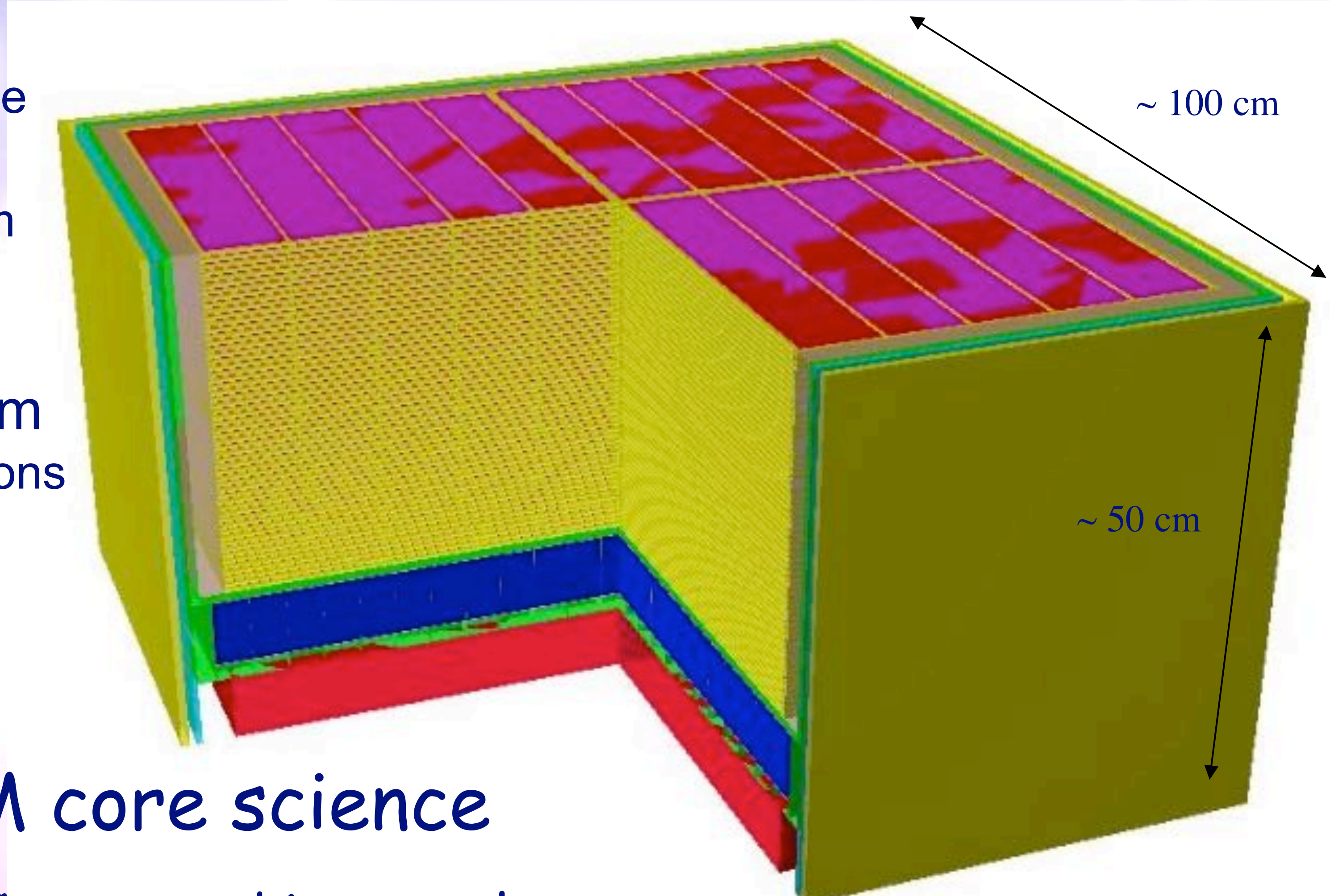

ASTROGAM

ASTROGAM a unified proposal from the entire gamma-ray community



e-ASTROGAM

- 4 towers
- 50 layers of 5*5 double sides Si strip detectors
- Read-out pich 240 μm
- Spacing of Si layers 7.5 mm
- Si thickness 400 μm
- Payload Weight ~ 2 Tons
- Power: 1-5-2 KW



e-ASTROGAM core science

1. The Galactic Center and inner galaxy the central black hole, compact stars, the beginning of Fermi bubbles, DM search
2. Nucleosyntesis throughout the Galaxy and beyond
3. The extragalactic and cosmic gamma-ray background

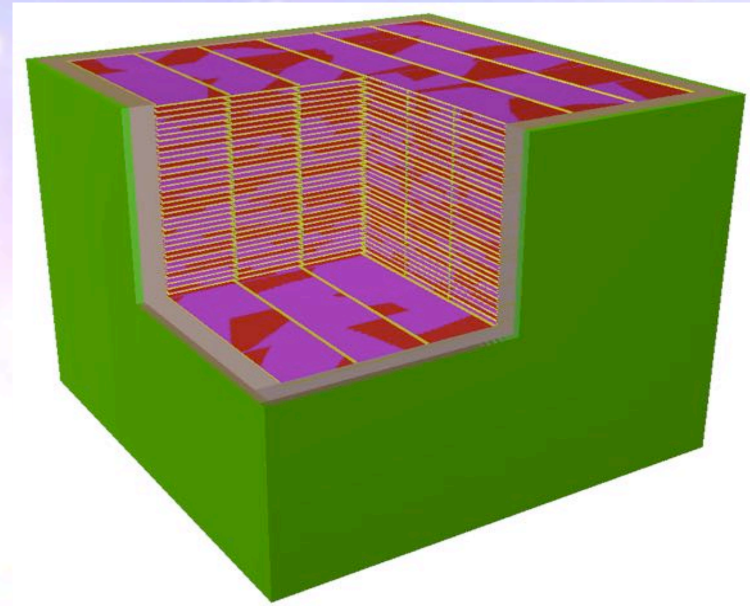
ASTROGAM Silicon Tracker

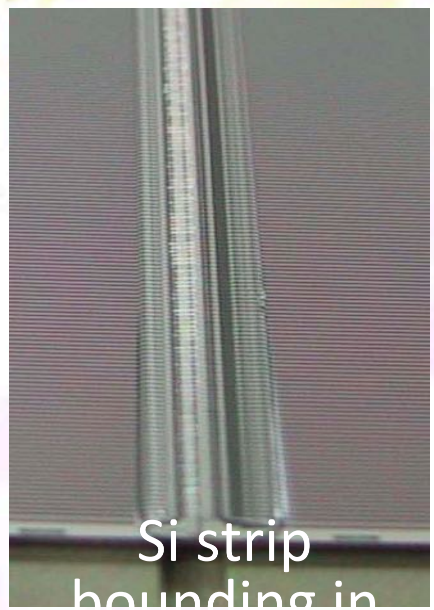
- 70 layers of 6×6 double sided Si strip detectors = 2520 DSSDs
- Each DSSD has a total area of 9.5×9.5 cm^2, a thickness of 400 μm, a strip width of 100 μm and pitch of 240 μm (384 strips per side), and a guard ring of 1.5 mm
- Spacing of the Si layers: 7.5 mm
- The DSSDs are wire bonded strip to strip to form 2-D ladders

⇒ 322 560 electronic channels

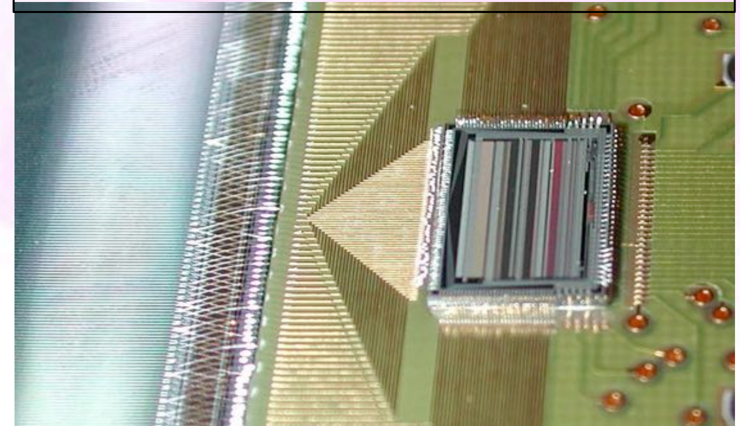
- DSSD strips connected to ASICs (32 channels each) through a pitch adapter (DC coupling)
- 144 ASICs (IDeF-X HD) per layer (72 per DSSD side)

⇒ 10 080 ASICs total

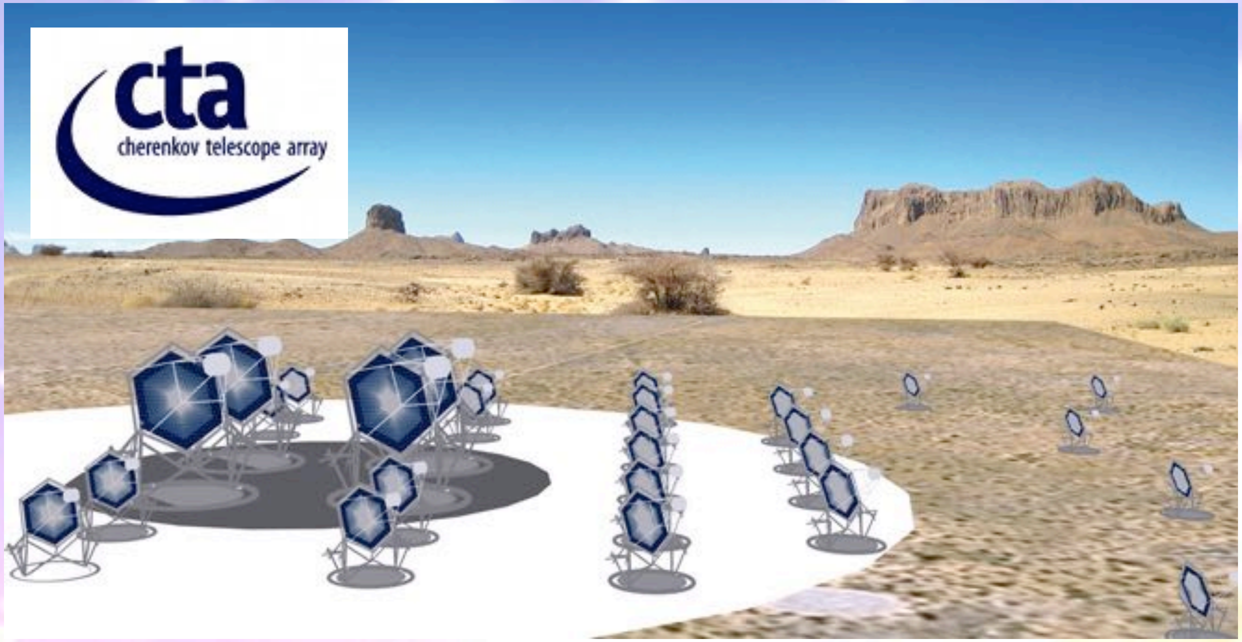




Detail of the detector-ASIC bonding in the AGILE Si Tracker

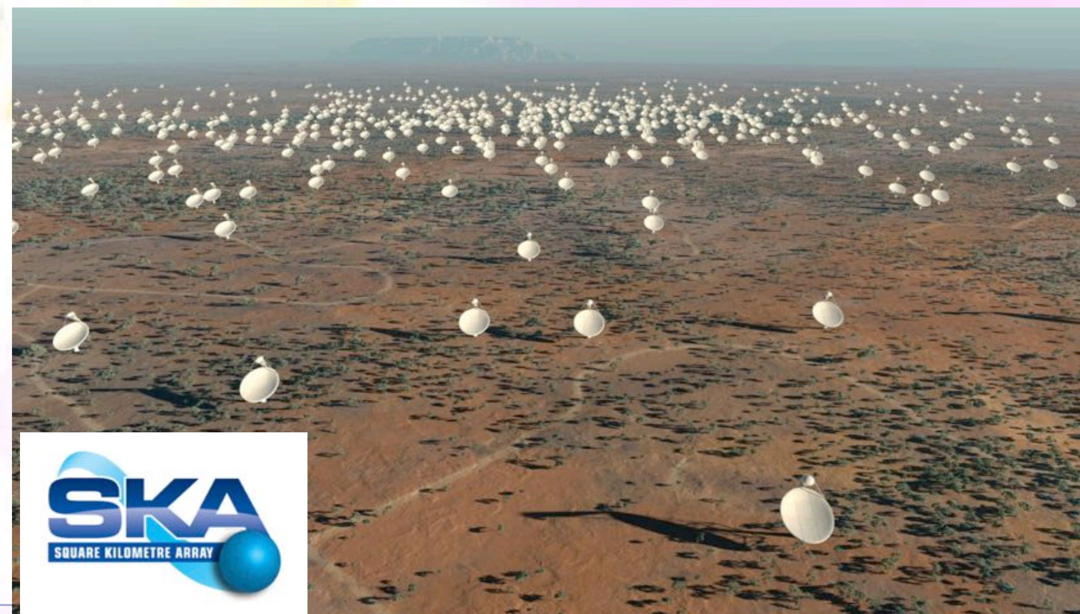


ASTROGAM Complementary to CTA and SKA !

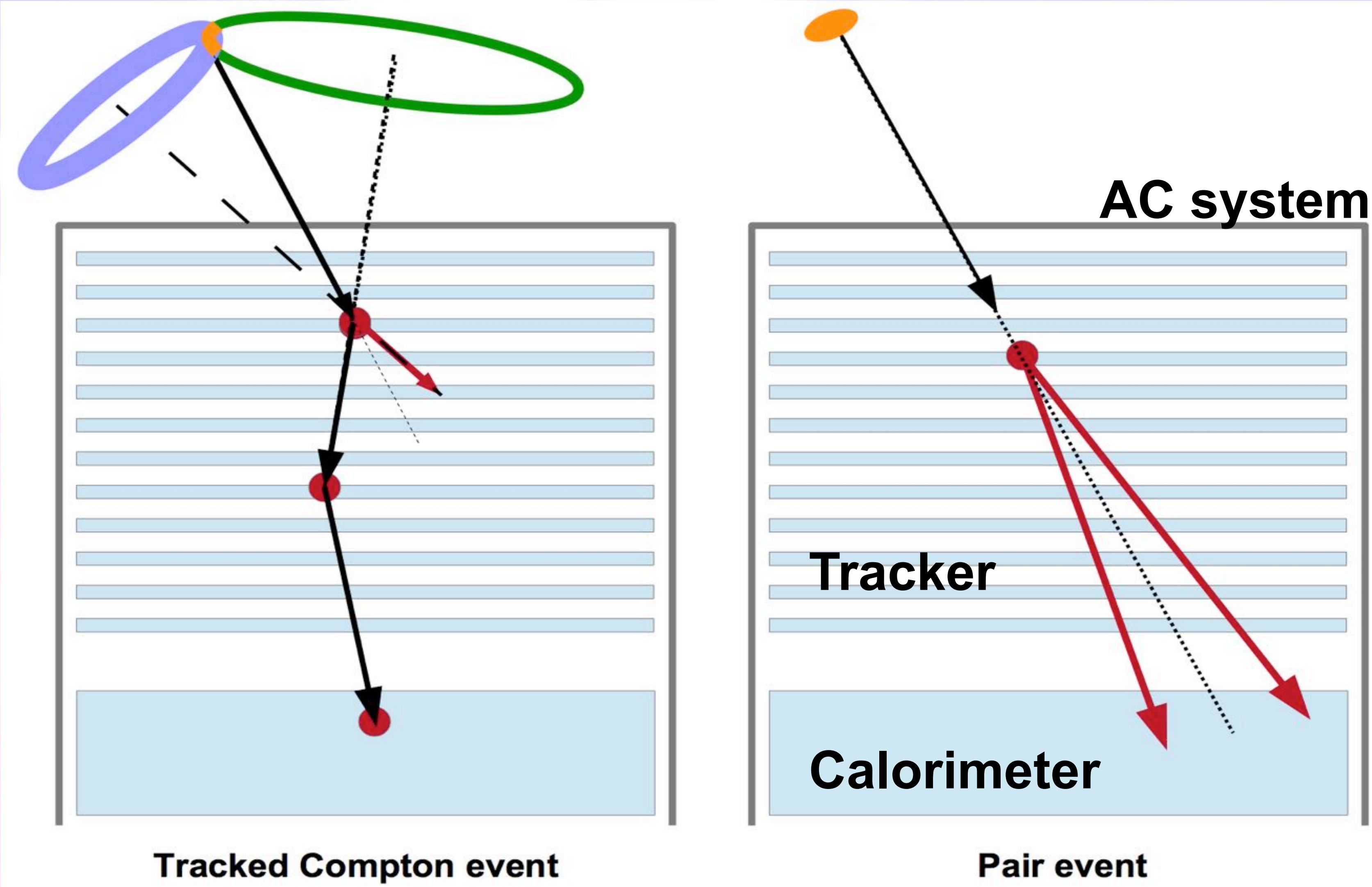


CTA science related to variable sources will need a coverage of the γ-ray sky at lower energies to trigger Target-of-Opportunity observations

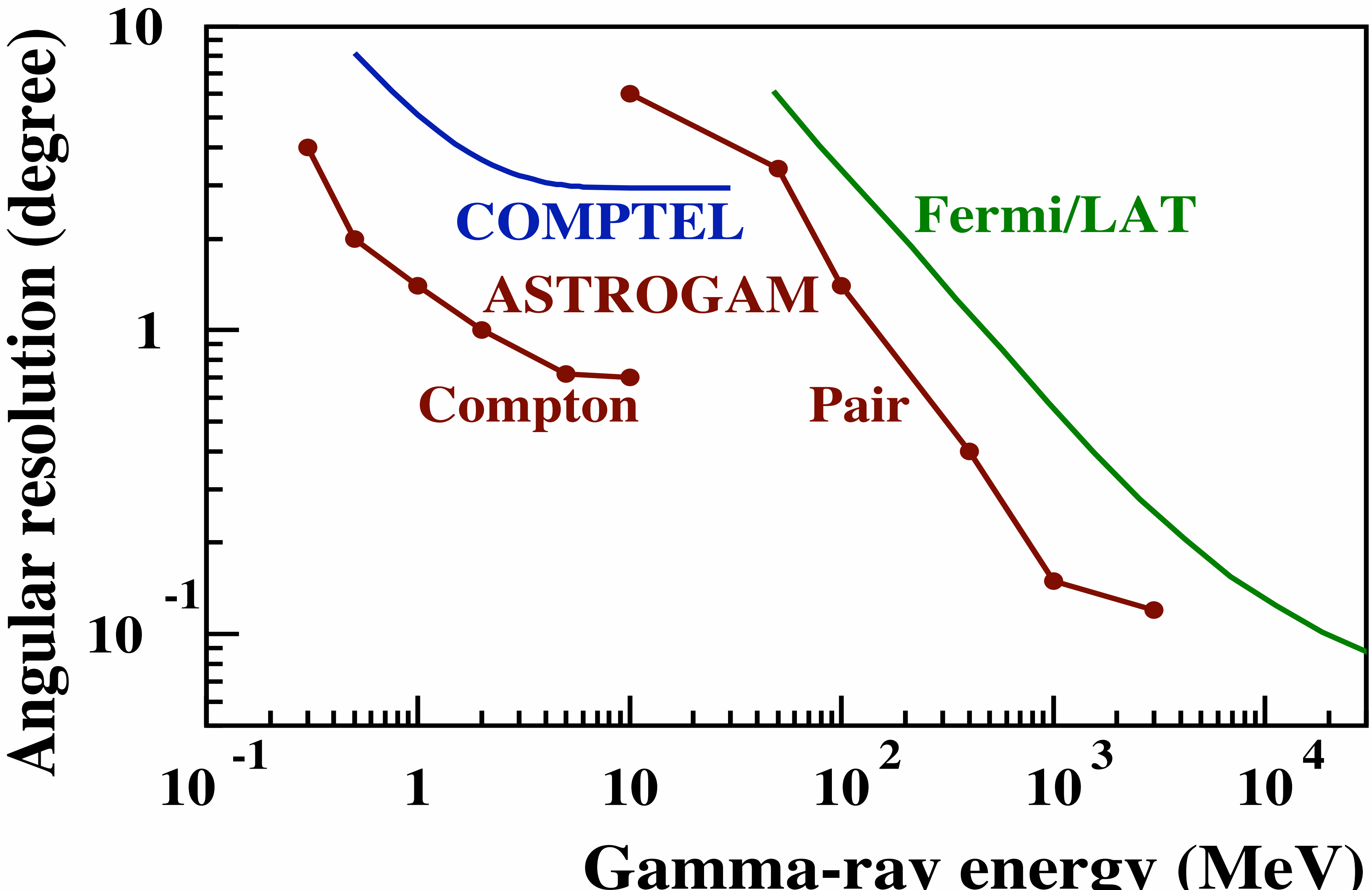
A wide-field γ-ray observatory operating at the same time as facilities like LSST and SKA will give a more coherent picture of the transient sky.



An instrument that combine two detection techniques

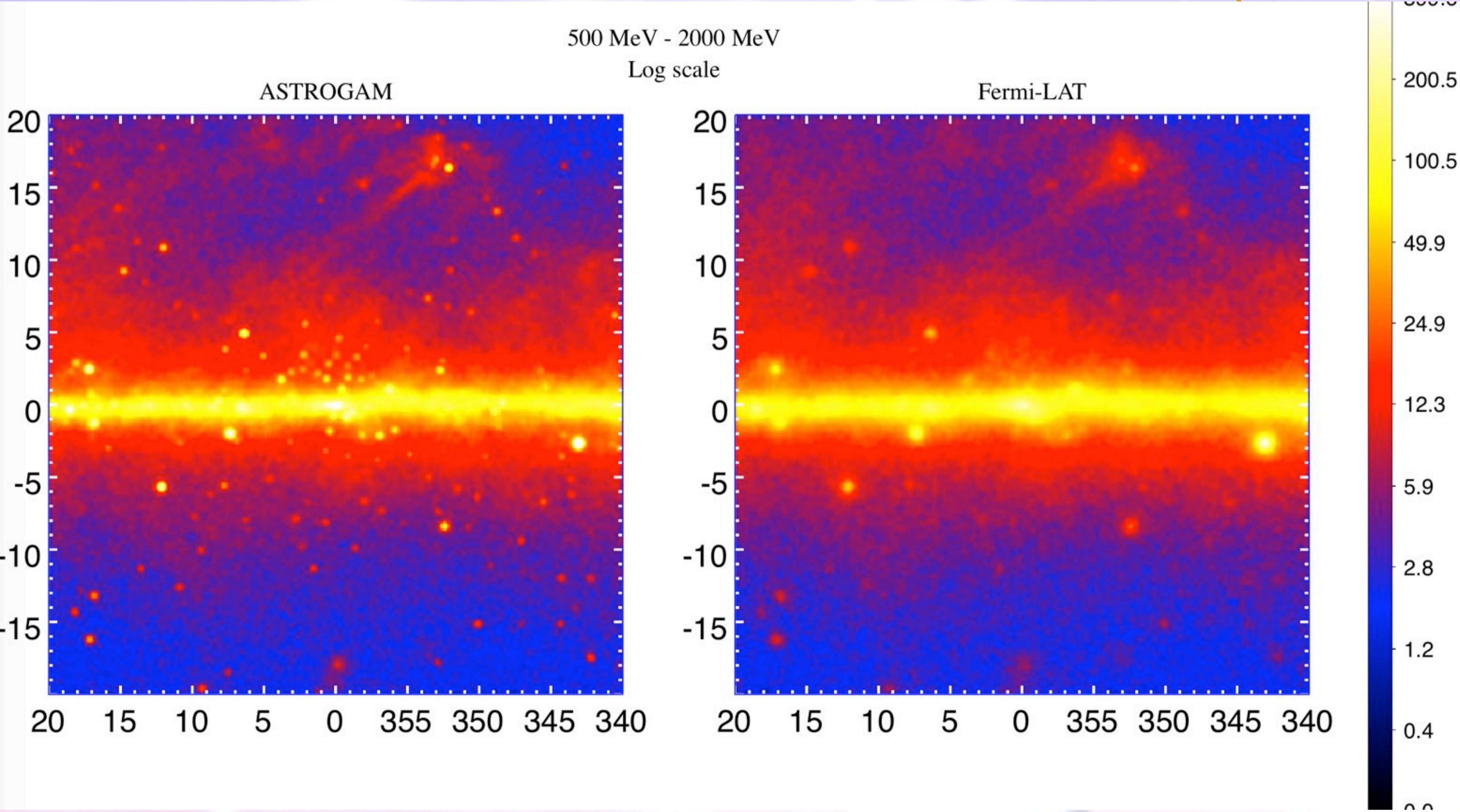


ASTROGAM Angular Resolution



Galactic Center Region 0.5-2 GeV

Fermi PSF Pass7 rep v15 source



Morselli, Gomez Vargas, preliminary

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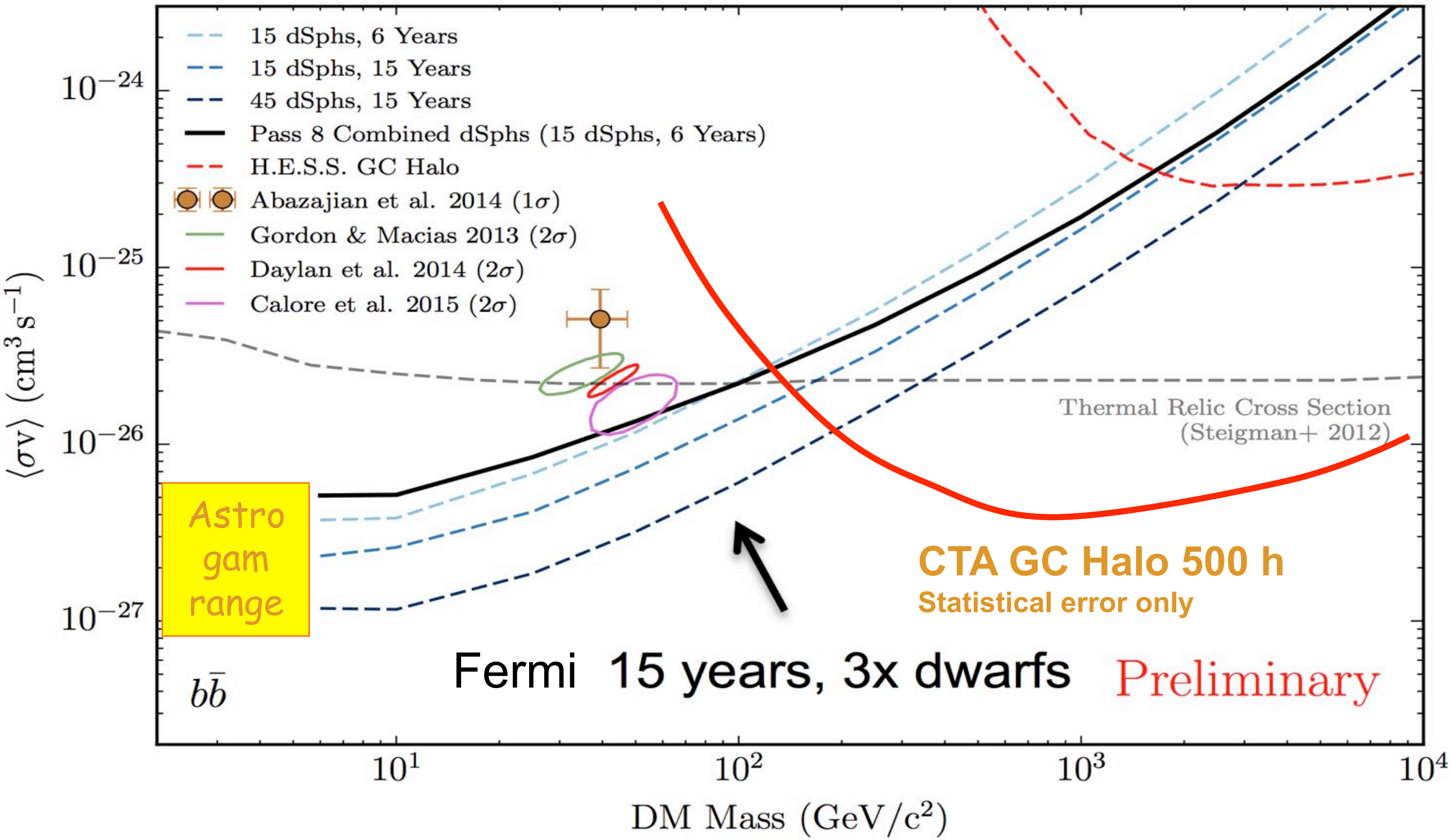
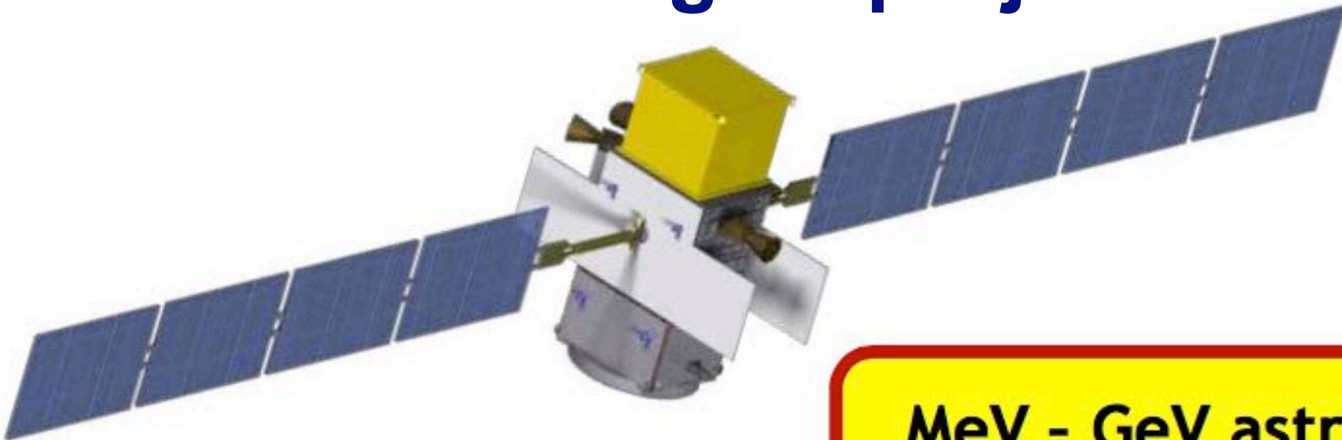


Together Fermi and CTA will probe most of the space of WIMP models with thermal relic annihilation cross section

The next gamma-ray MeV-GeV mission:

the e-Astrogam project



MeV - GeV astrophysics
MeV - GeV community

Proposed for the ESA M4 call; currently under study for enhancement and reconfiguration for the ESA M5 call. ASTROGAM is **focused on gamma-ray astrophysics in the range 0.3-100 MeV** with excellent capability also at GeV energies.

see Carlotta Pittori talk

New gamma projects in space

- **AstroGam** 300 KeV- GeV (Proposal to ESA for M4 and now M5)
- **ComPair** similar to Astrogam concept for a proposal to NASA
- **Gamma-light** (Proposed to ESA for S1)

A.Morselli et al. arXiv:1406.1071

- **Gamma-400** launch foreseen by 2020

Science with Gamma-400 Workshop http://cdsagenda5.ictp.it/full_display.php?ida=a1311

Performance are under revision

- **DAMPE**: Chinese γ-ray satellite with INFN participation

Planned launch **18/12/2015.** 5 GeV- TeV G.F. 0.3 m^2 sr (Fermi ~1)

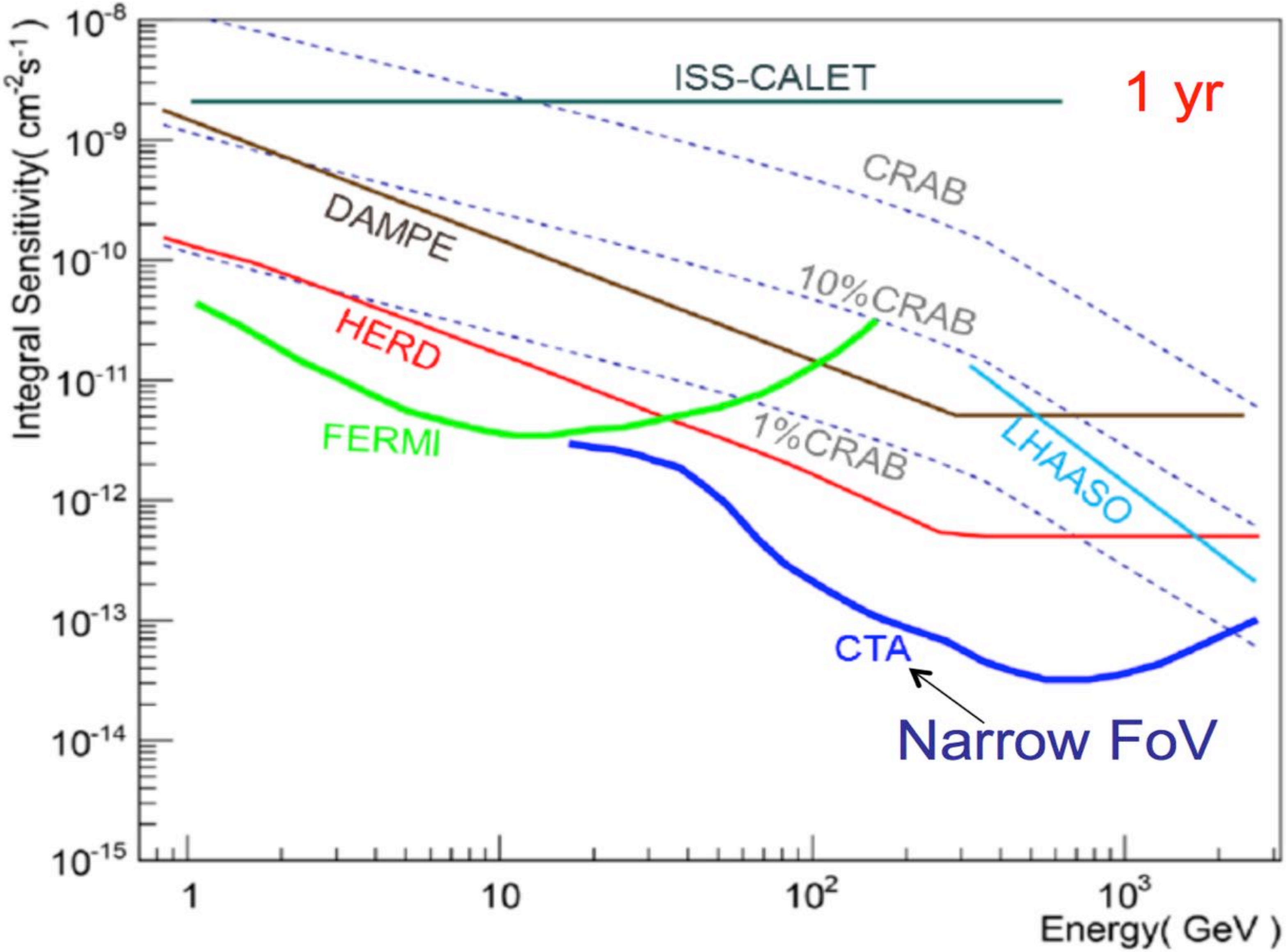
- **HERD**: Instrument on the planned Chinese Space Station.

Energy resolution (100 GeV) ~ 1 %. Effective area ~ 1 - 2 m^2.

Angular resolution (100 GeV) ~ 0.01°. Planned launch around 2020.

- **PANGU**: suggested as a candidate for the joint small mission between the European Space Agency (ESA) and the Chinese Academy of Science (CAS)

Gamma-ray Sky Survey Sensitivity



Conclusions

Detection of gamma rays from the annihilation or decay of dark matter particles is a promising method for identifying dark matter, understanding its intrinsic properties, and mapping its distribution in the universe (in synergy with the experiments at the LHC and in the underground laboratories).

In the future it would be extremely important to extend the energy range of experiments at lower energies (compared to the Fermi energies) (AstroGAM) and higher energies (HAWC, Dampe, HERD, CTA, LHAASO)

Thank you !

The 6 th Roma International Conference on Astro-Particle Physics

June 21-24 2016

All of you are invited to the sixth edition of RICAP 2016 that will be hosted by INFN & Roma Tor Vergata University


Thank you !