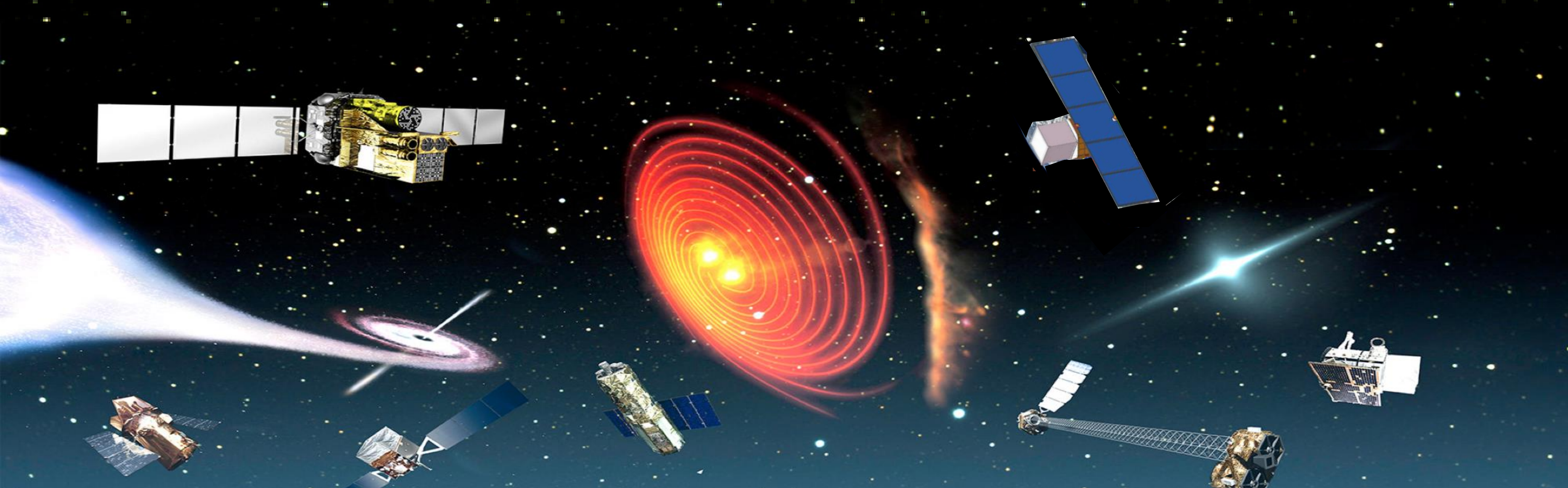
Indirect dark-matter searches with gamma-rays experiments : status and future plans from 300 KeV to 100 TeV



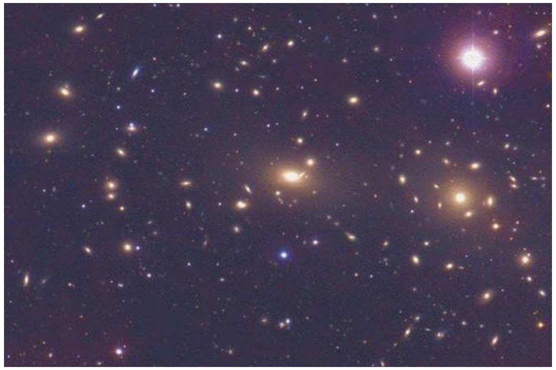
Aldo Morselli

INFN Roma Tor Vergata

8th Heidelberg International Symposium on High-Energy Gamma-Ray Astronomy (γ-2024)

Milano, Sept 4,

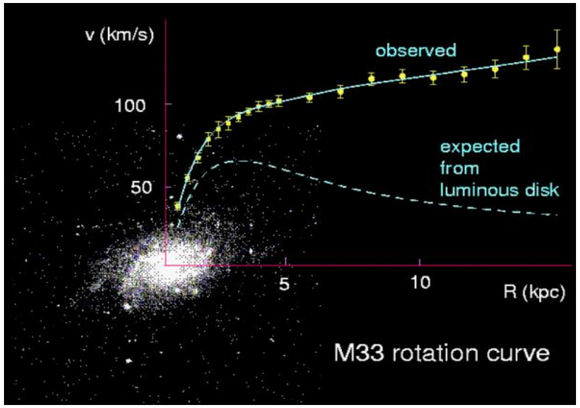
Dark Matter EVIDENCE



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.

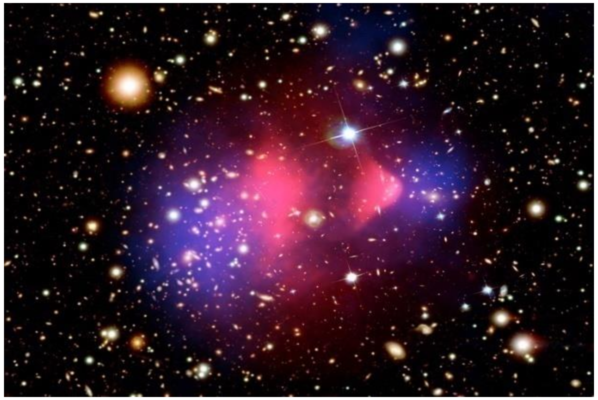
Since then, even more evidence:

Rotation curves of galaxies

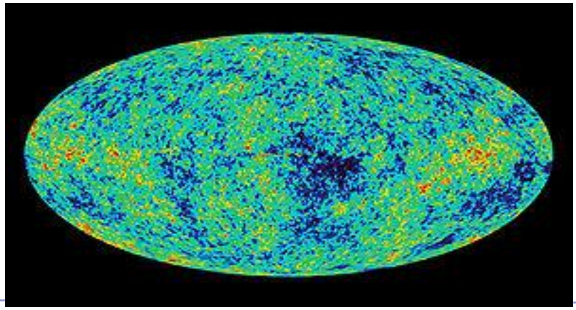


Gravitational lensing

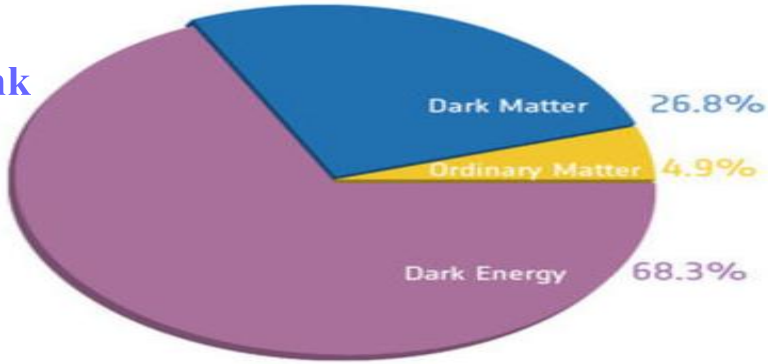
Bullet cluster



Structure formation as deduced from CMB



Data by Plank imply:



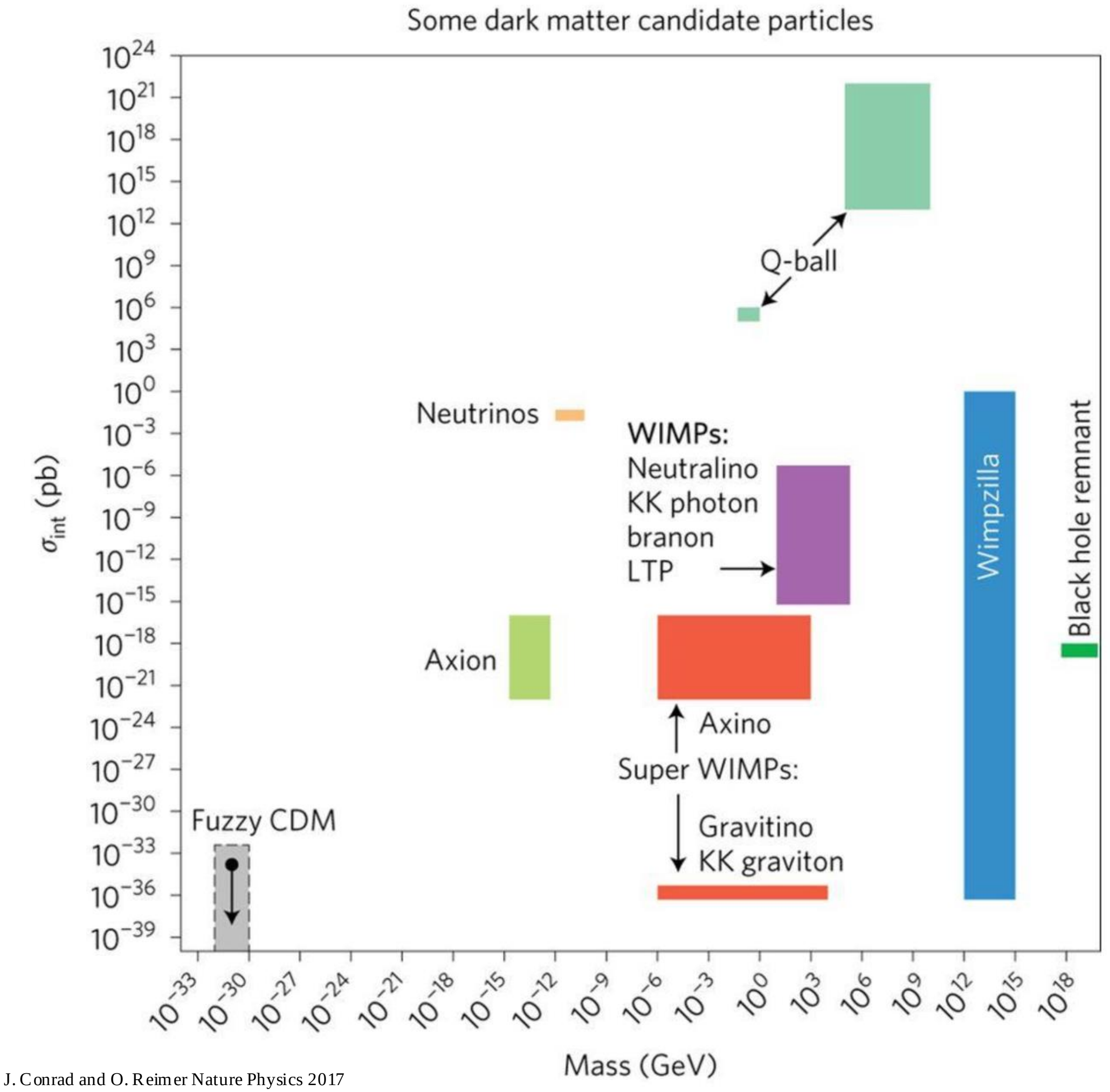
$\Omega_{DM} \approx 26.8\%$

$\Omega_M \approx 4.9\%$


Dark Matter
see the talk by Joseph Silk Thusday

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
- WIMP
- Messenger States in GMSB
- Branons
- Chaplygin Gas
- Split SUSY
- Primordial Black Holes



J. Conrad and O. Reimer Nature Physics 2017

Dark Matter Candidates

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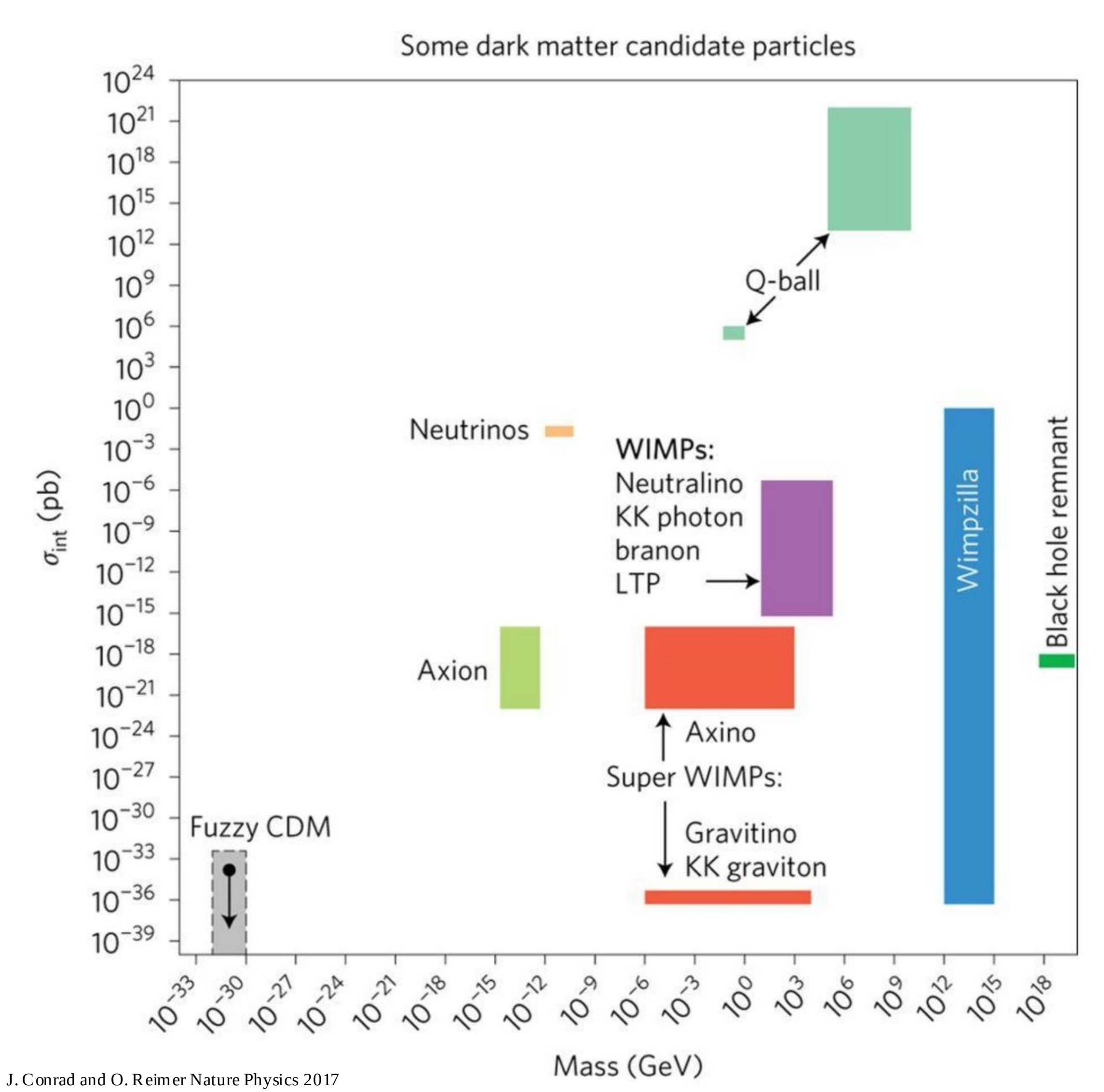
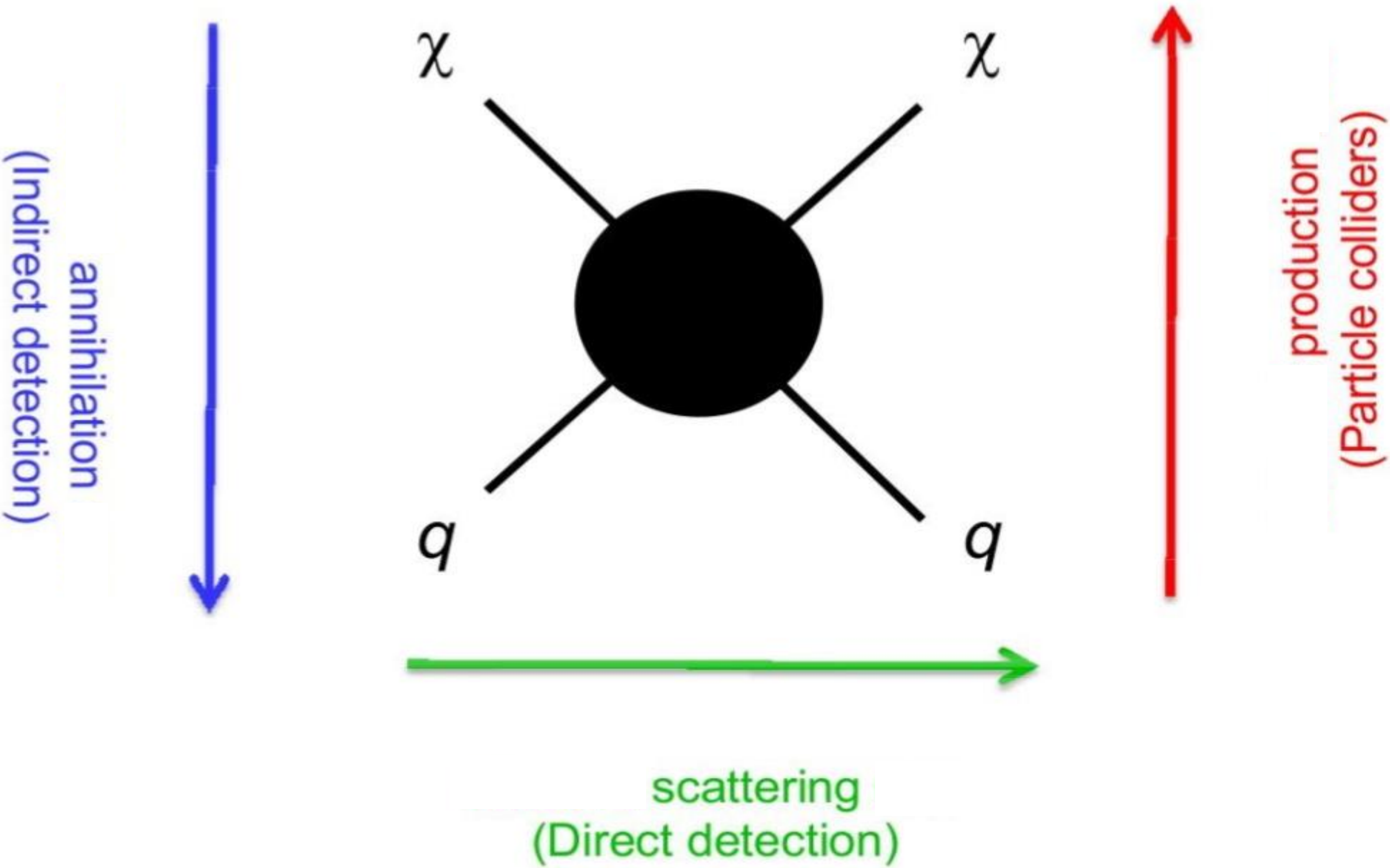
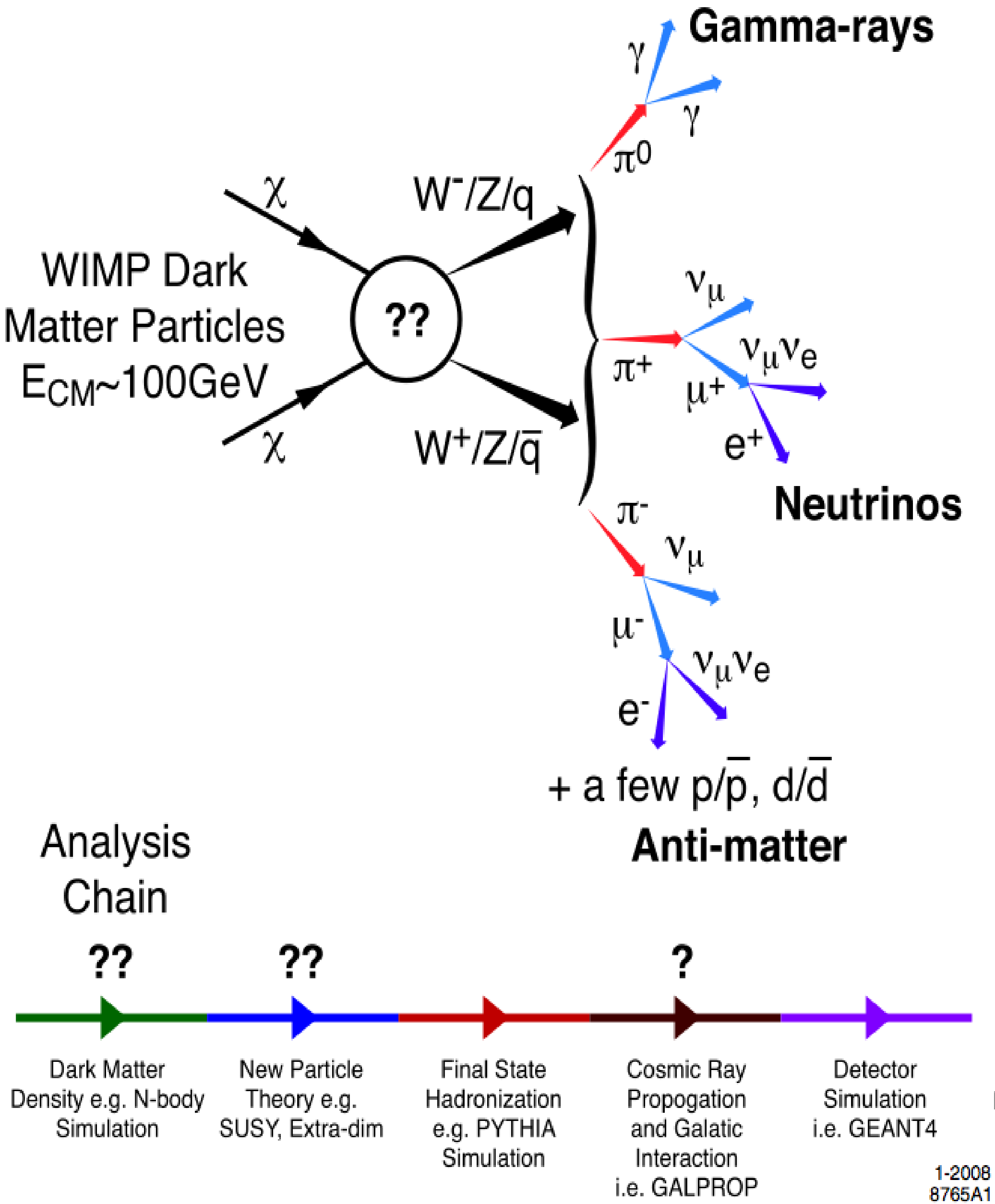
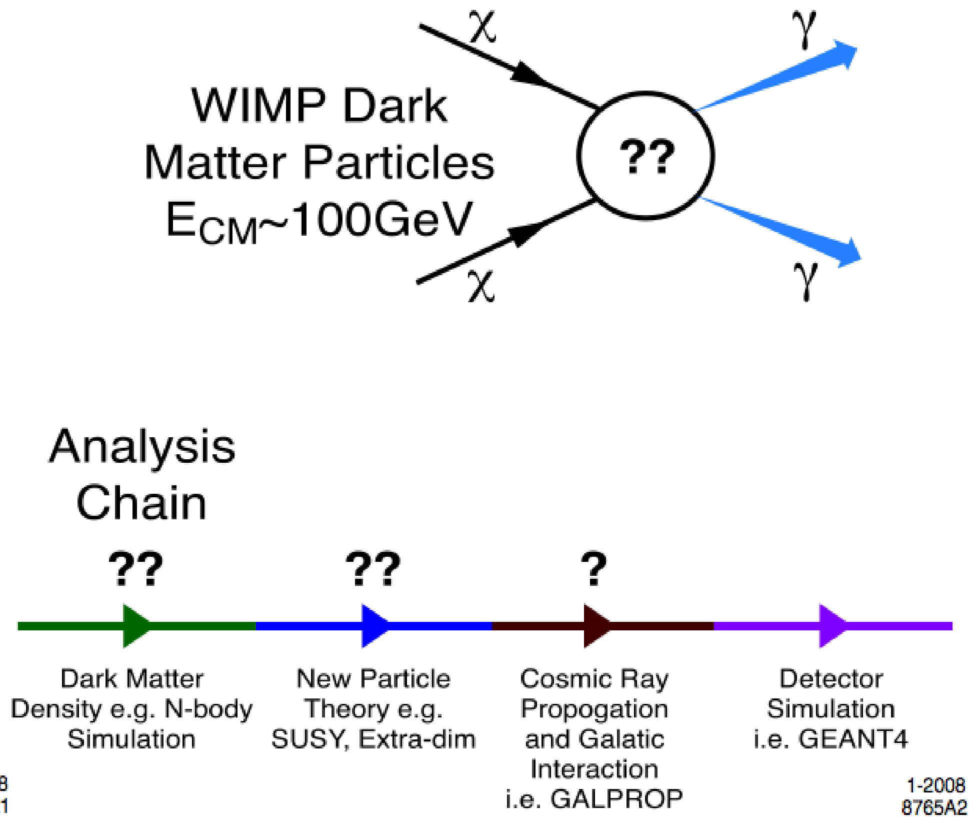


J. Conrad and O. Reimer Nature Physics 2017


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

Annihilation channels





Signal rate from WIMP annihilation

gamma-ray flux from
WIMP annihilation

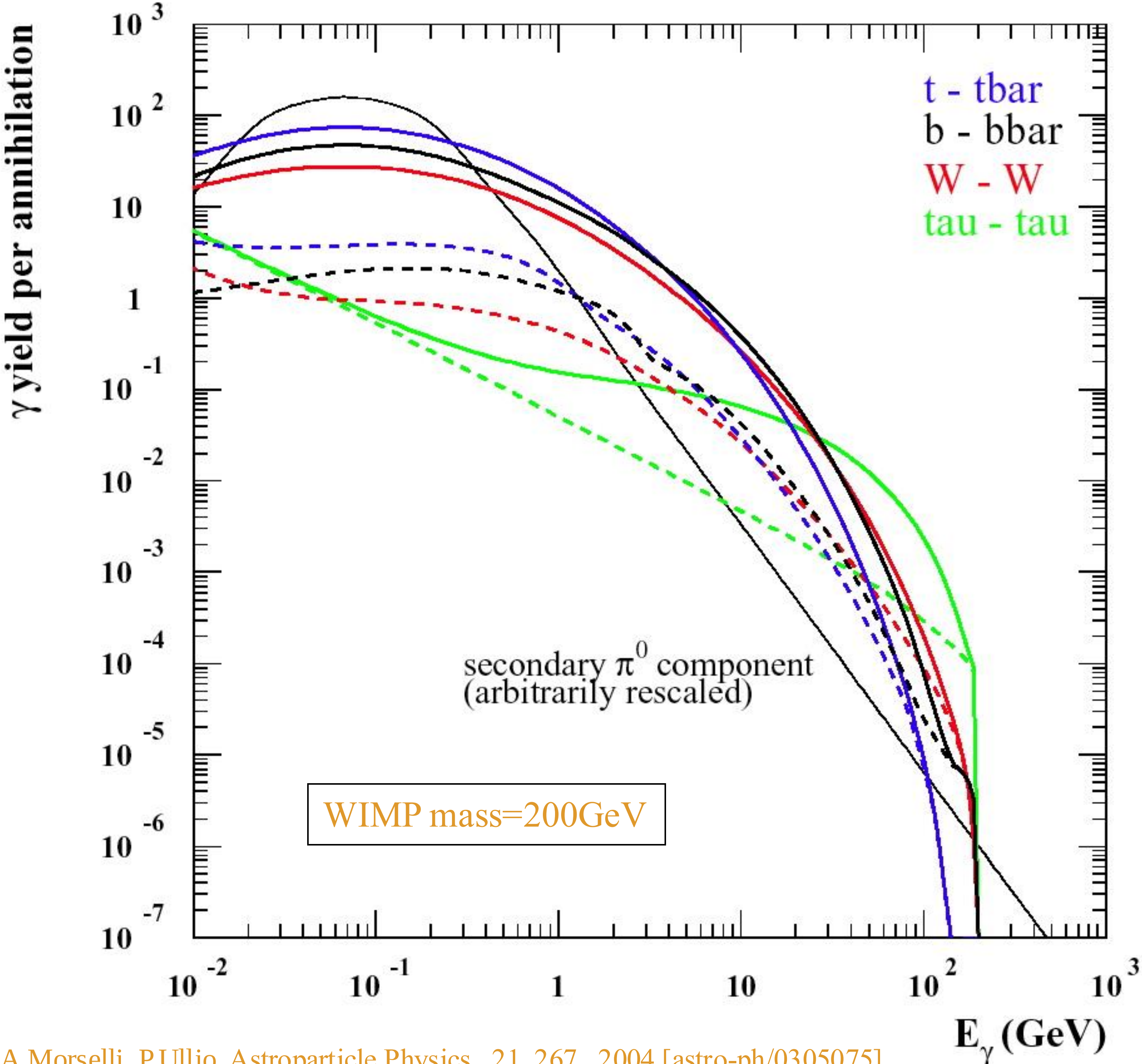
$$\phi(E,\Delta\Omega) \propto \left(\frac{\sigma v}{m_\chi^2}\right) \int_{l.o.s} \int_{\Delta\Omega} \rho^2(l)\, dl\, d\Omega)$$

governed by
particle physics
(supersymmetric
parameters .. etc)

J(φ):

governed by
halo distribution

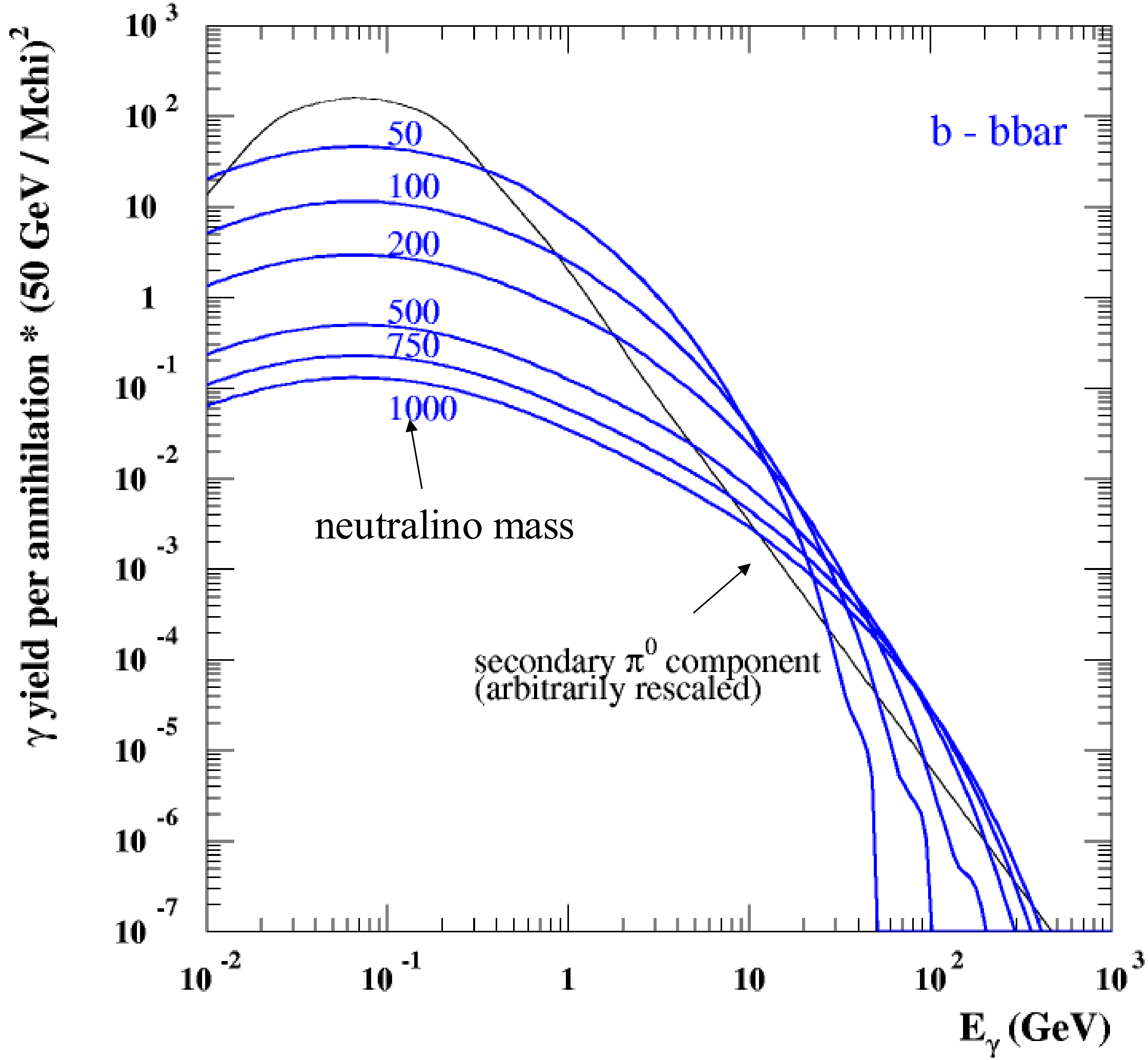
Differential yield for each annihilation channel



dashed lines are components not due to π^0 decay.

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

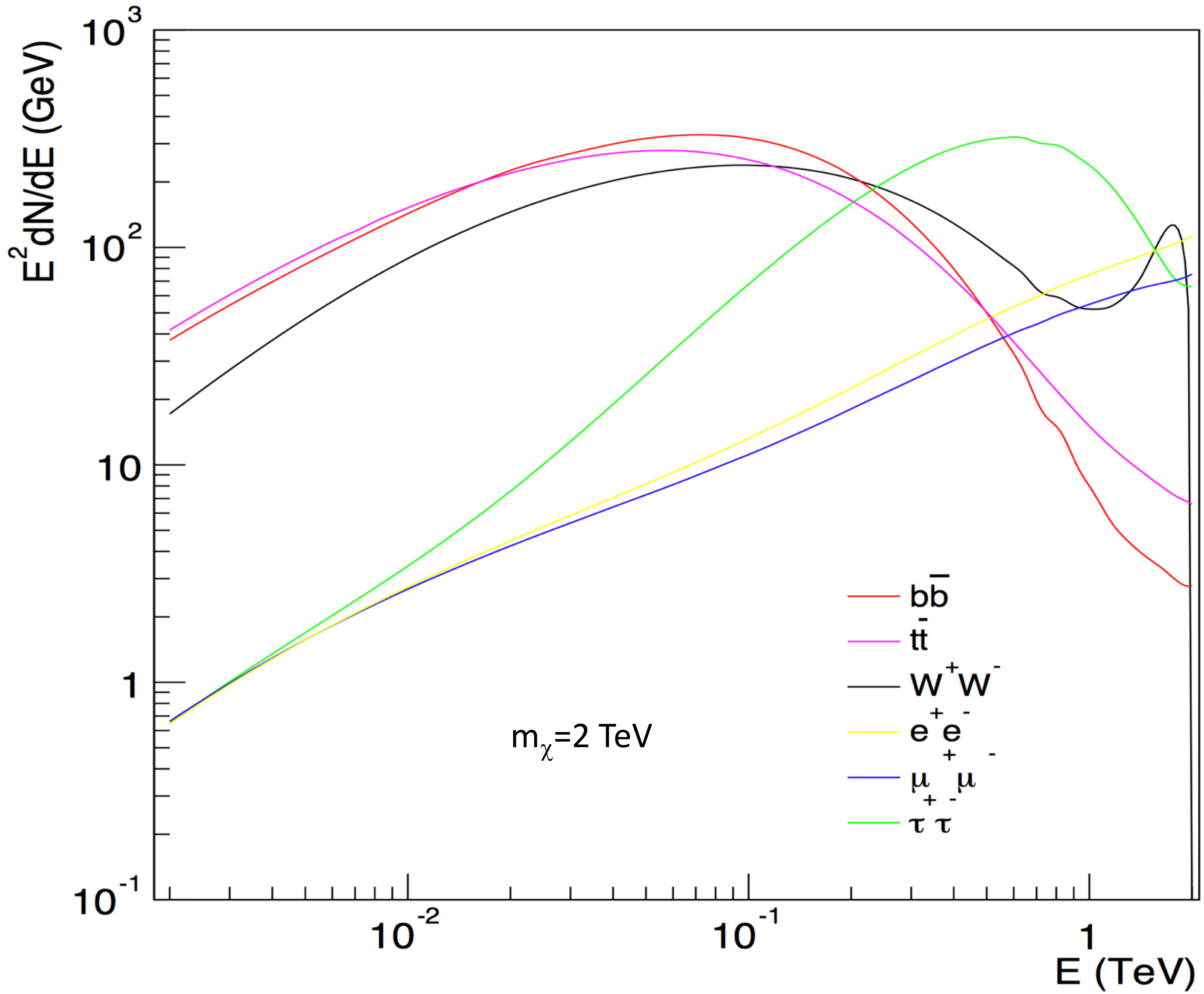
Differential yield for b bar



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

Annihilation spectra for the continuum signal from the quark, lepton and gauge boson primary channels

The line-like feature expected from the virtual internal Bremsstrahlung process contribution is particularly prominent for the W^+W^- channel

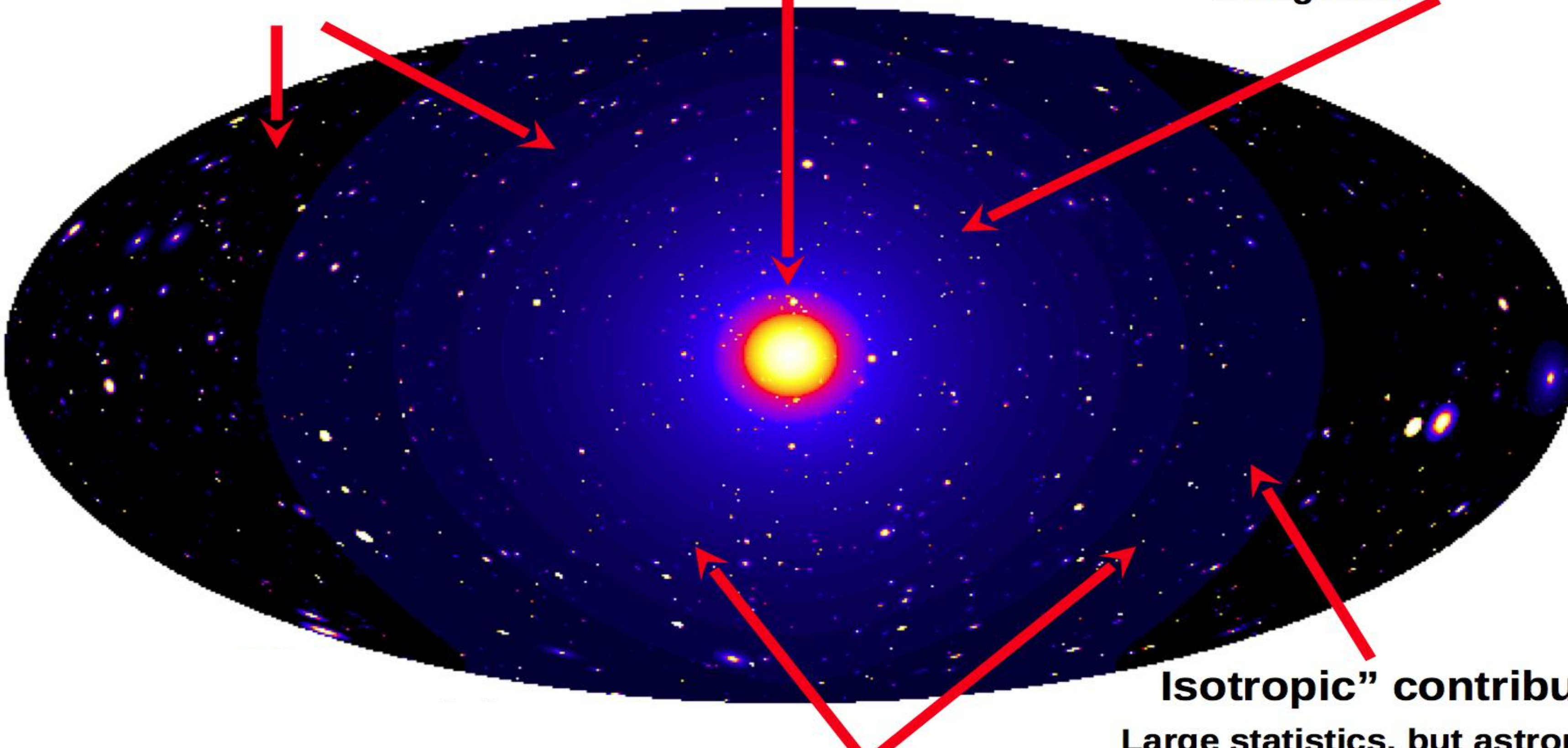


Dark Matter Search: Targets and Strategies

Satellites
Low background and good source id, but low statistics

Galactic Center
Good Statistics, but source confusion/diffuse background

Milky Way Halo
Large statistics, but diffuse background

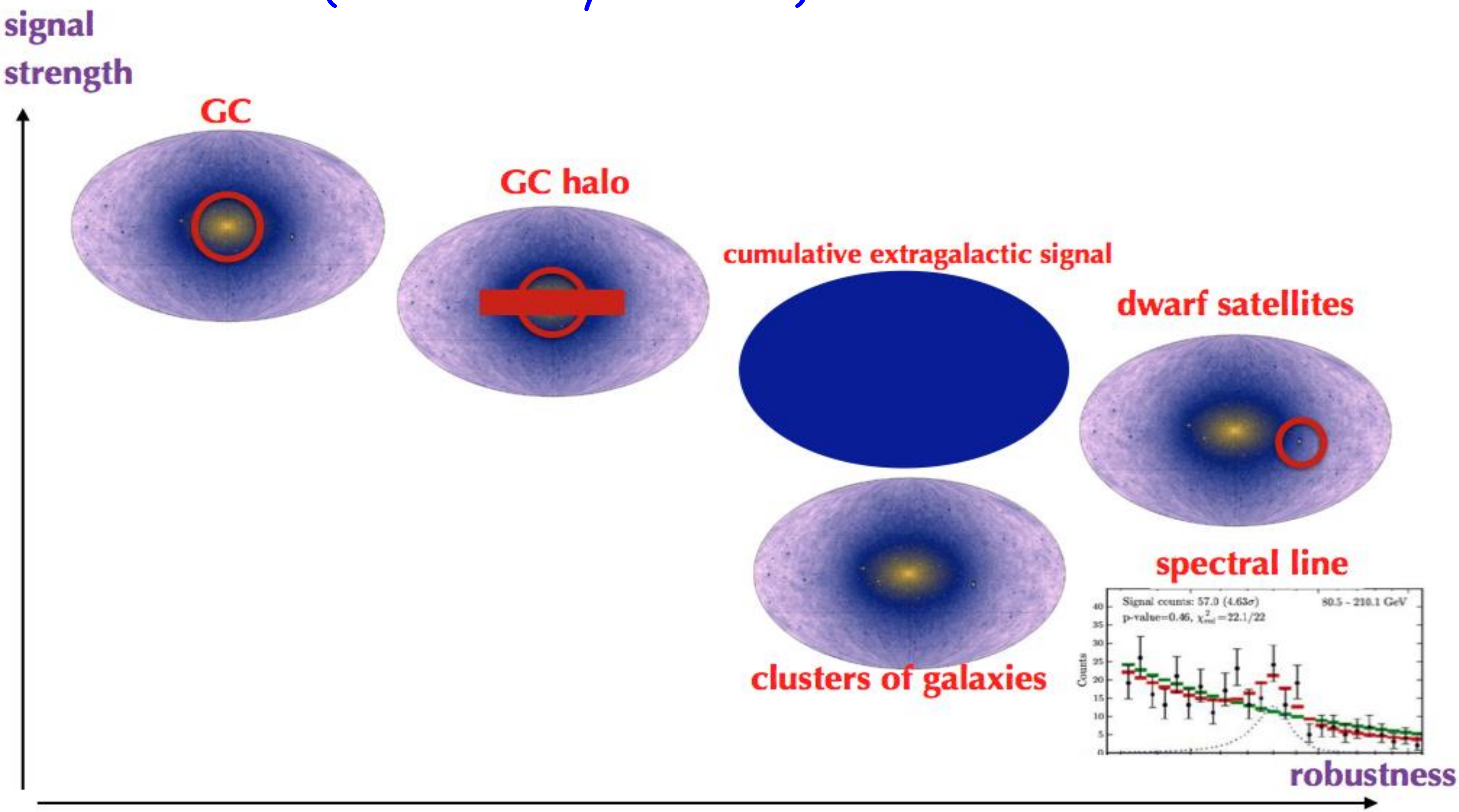


Isotropic" contributions
Large statistics, but astrophysics, galactic diffuse background

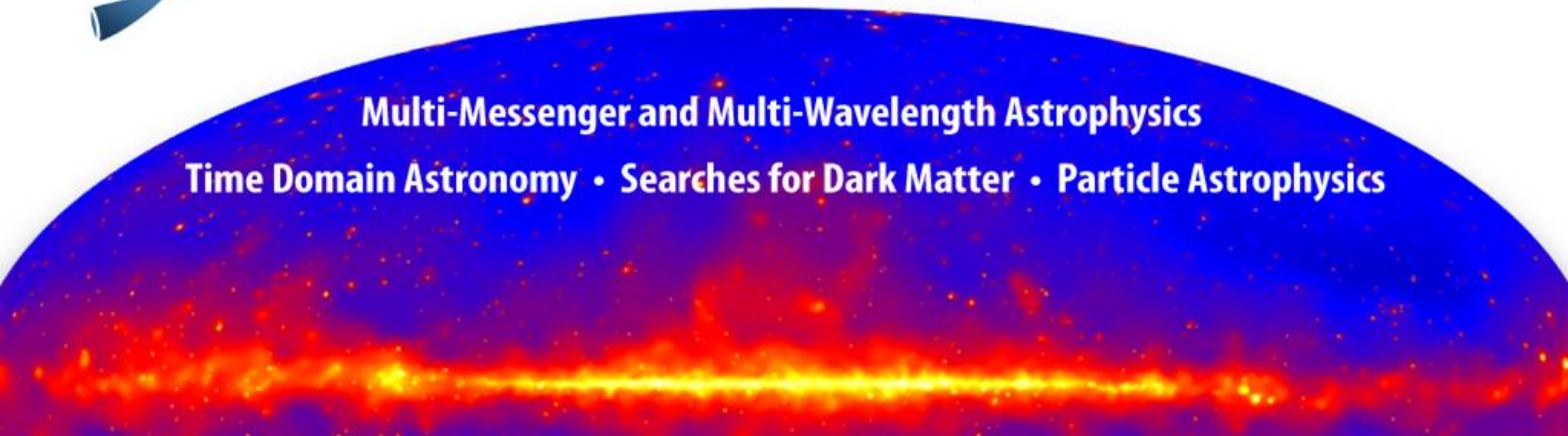
Galaxy Clusters
Low background, but low statistics

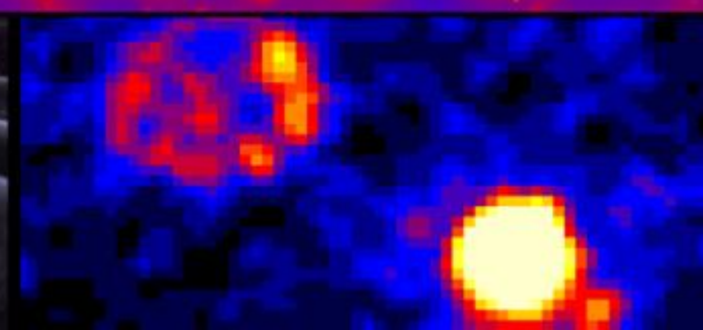
Dark Matter Search: Targets and Strategies

(Another way to see it)



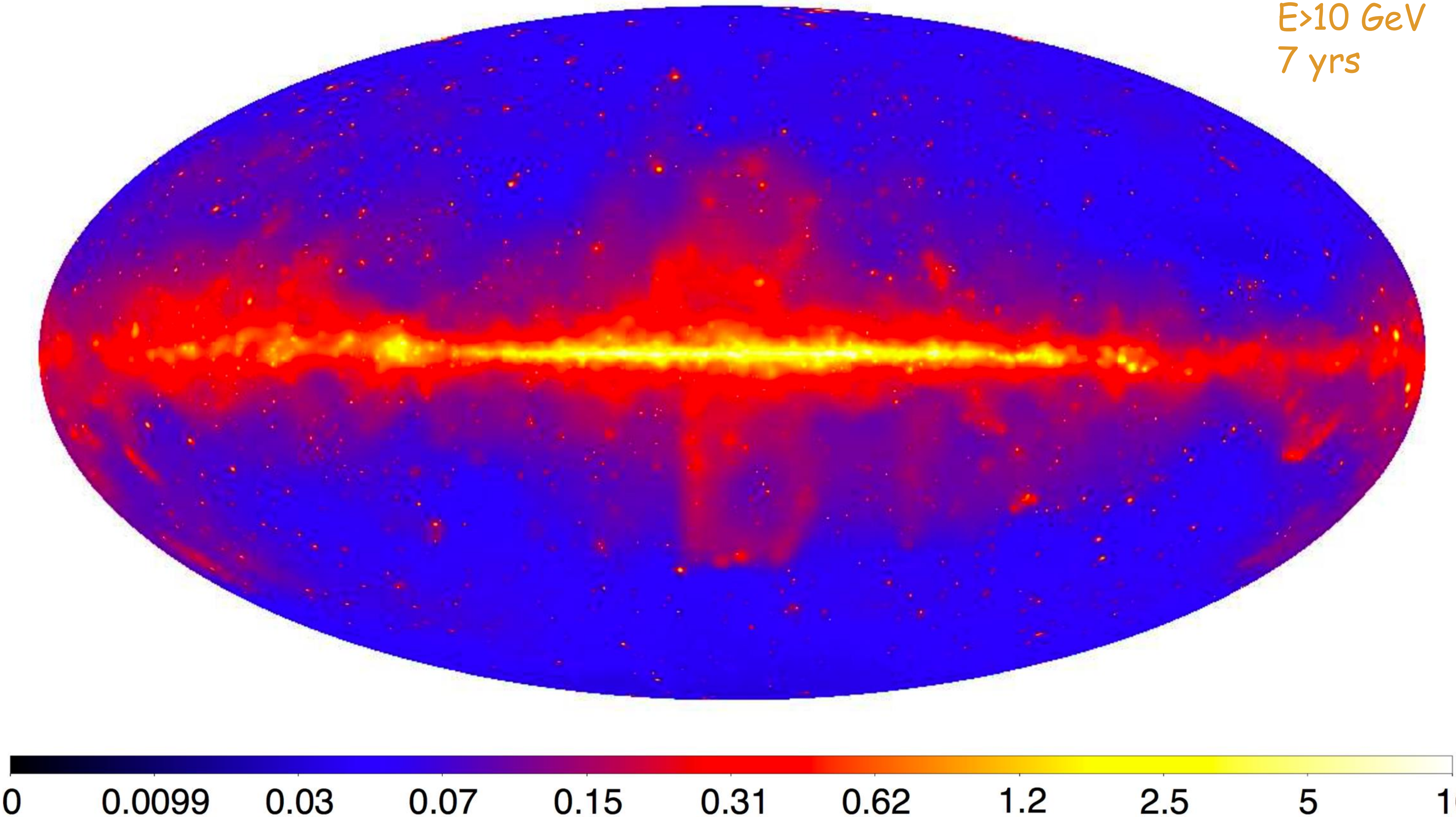
Fermi Gamma-Ray Space Telescope





The sky in gamma-rays

E>10 GeV
7 yrs

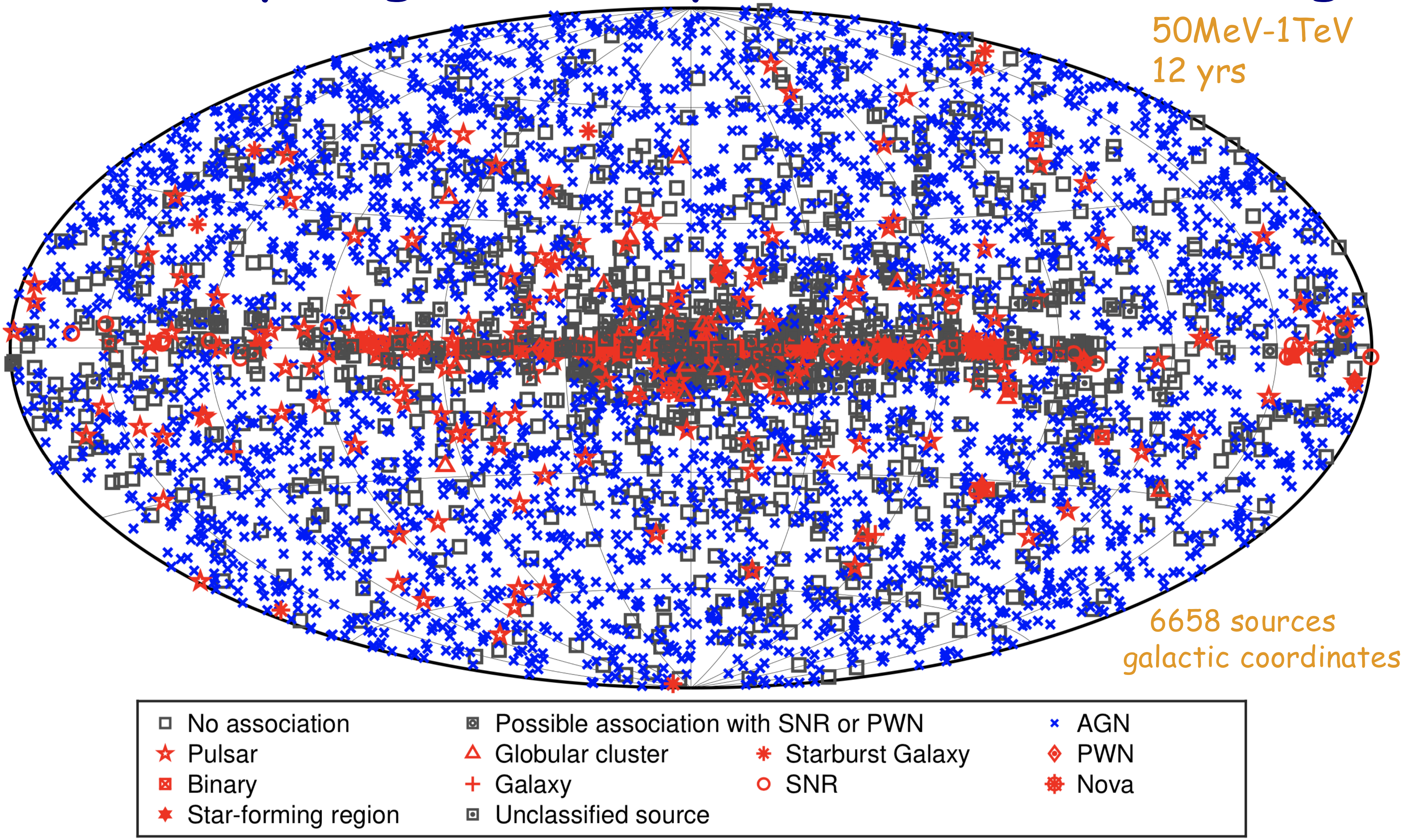


M.Ackermann et al. [Fermi Coll.] 3FHL: The Third Catalog of Hard Fermi-LAT Sources ApJS 2017 232 arXiv:1702.00664

Happy 16th Birthday Fermi !!

11 June 2008

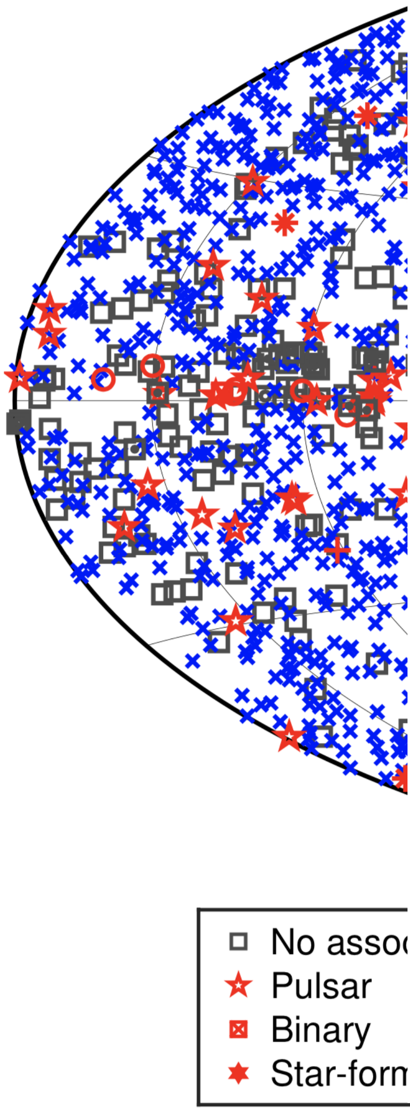
The sky in gamma-rays 4th source catalog



Incremental Fermi Fouth Source Catalog, ApJS 260, 53 (2022) arXiv: 2201.11184

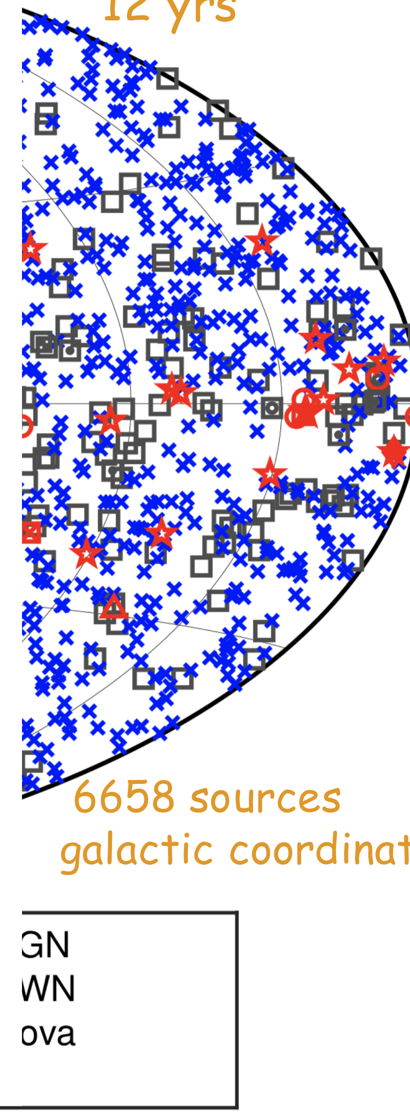
The sky in gamma-rays 4th source catalog

50MeV-1TeV
12 yrs



Description	Identified		Associated	
	Designator	Number	Designator	Number
Galactic center	GC	1	...	...
Young pulsars, identified by pulsations	PSR	135	...	...
Young pulsars, no pulsations seen in LAT yet	...	...	psr	2
Millisecond pulsars, identified by pulsations	MSP	120	...	...
Millisecond pulsars, no pulsations seen in LAT yet	...	...	msp	35
Pulsar wind nebula	PWN	11	pwn	8
Supernova remnant	SNR	24	snr	19
Supernova remnant / Pulsar wind nebula	SPP	0	spp	114
Globular cluster	GLC	0	glc	35
Star-forming region	SFR	3	sfr	2
High-mass binary	HMB	8	hmb	3
Low-mass binary	LMB	2	lmb	6
Binary	BIN	1	bin	6
Nova	NOV	4	nov	0
BL Lac type of blazar	BLL	22	bll	1435
FSRQ type of blazar	FSRQ	44	fsrq	750
Radio galaxy	RDG	6	rdg	39
Nonblazar active galaxy	AGN	1	agn	8
Steep spectrum radio quasar	SSRQ	0	ssrq	2
Compact steep spectrum radio source	CSS	0	css	5
Blazar candidate of uncertain type	BCU	1	bcu	1491
Narrow-line Seyfert 1	NLSY1	4	nlsy1	4
Seyfert galaxy	SEY	0	sey	2
Starburst galaxy	SBG	0	sbg	8
Normal galaxy (or part)	GAL	2	gal	4
Unknown	UNK	0	unk	134
Total	...	389	...	4112
Unassociated	...	...	...	2157

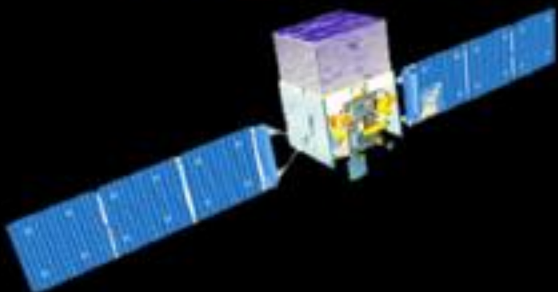
NOTE—The designation 'spp' indicates potential association with SNR or PWN. 'Unknown' are $|b| < 10°$ sources solely associated with the likelihood-ratio method from large radio and X-ray surveys. Designations shown in capital letters are firm identifications; lower-case letters indicate associations.

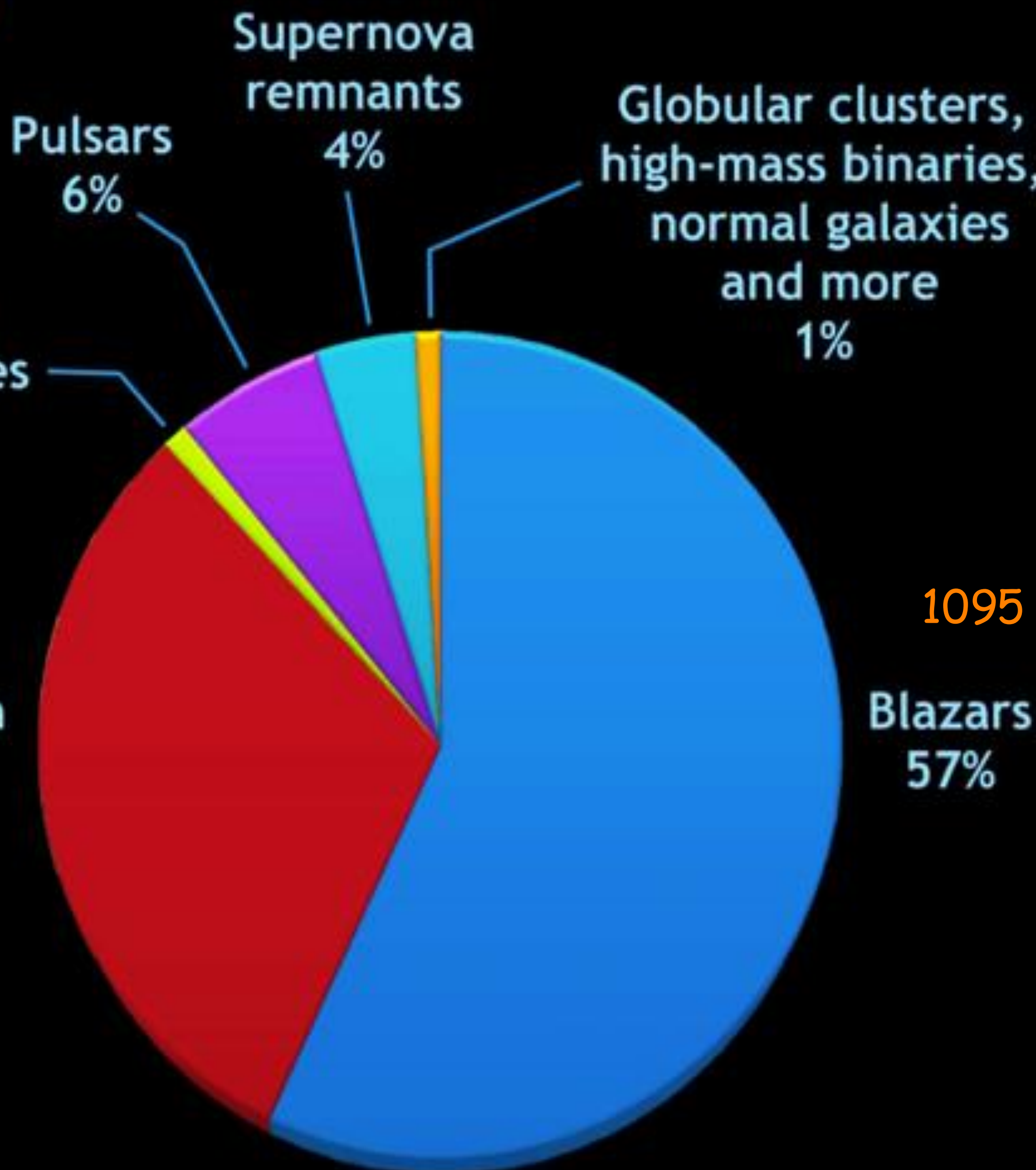


6658 sources
galactic coordinates

Incremental Fermi Fouth Source Catalog, ApJS 260, 53 (2022) arXiv: 2201.11184

What has Fermi found: The LAT two-year catalog

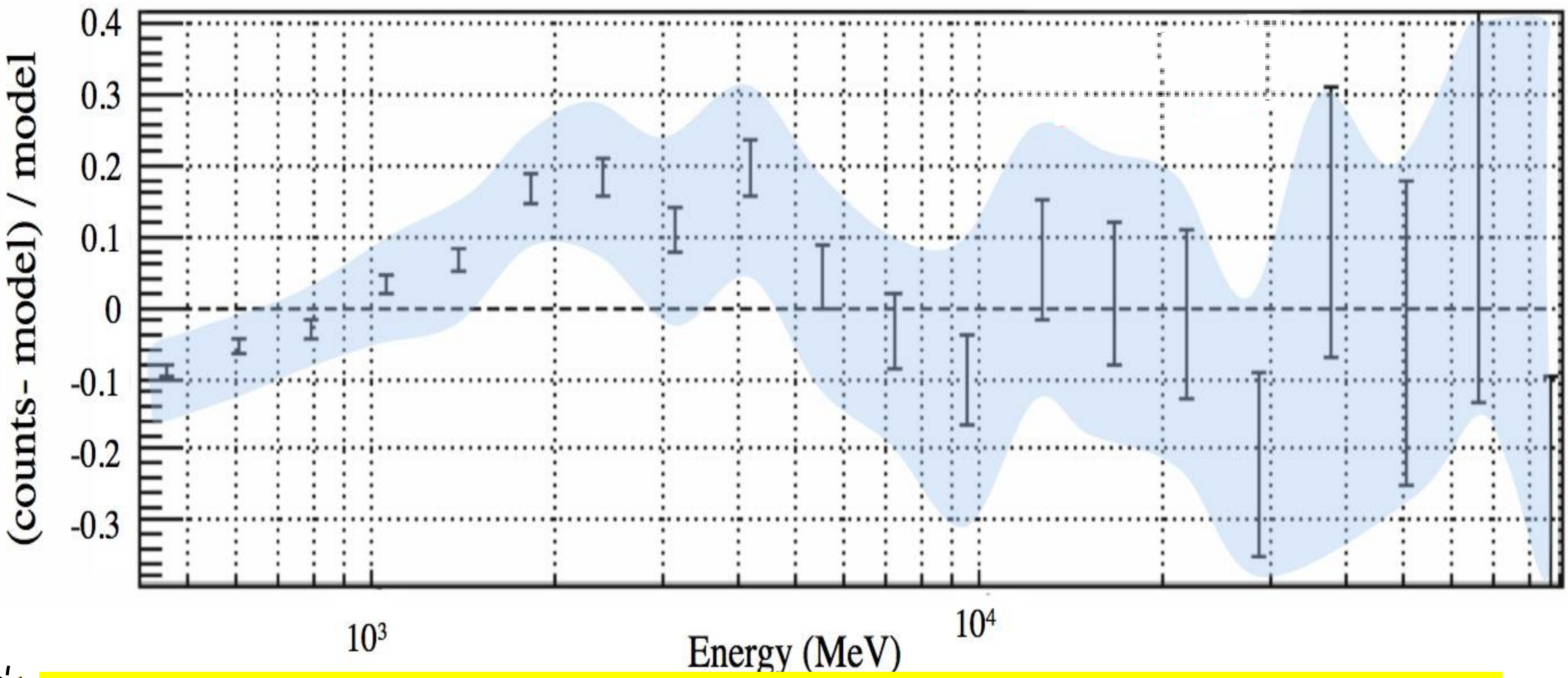




The GeV excess 7° x7° region centered on the Galactic Center

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 :

The Galactic Center as a Dark Matter Gamma-Ray Source
A.Morselli, A. Lionetto, A. Cesarini, F. Fucito, P. Ullio, Nuclear Physics B 113B (2002) 213-220 [astro-ph/0211327]
A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio Astroparticle Physics 21, 267-285, 2004 [astro-ph/0305075]

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**
....

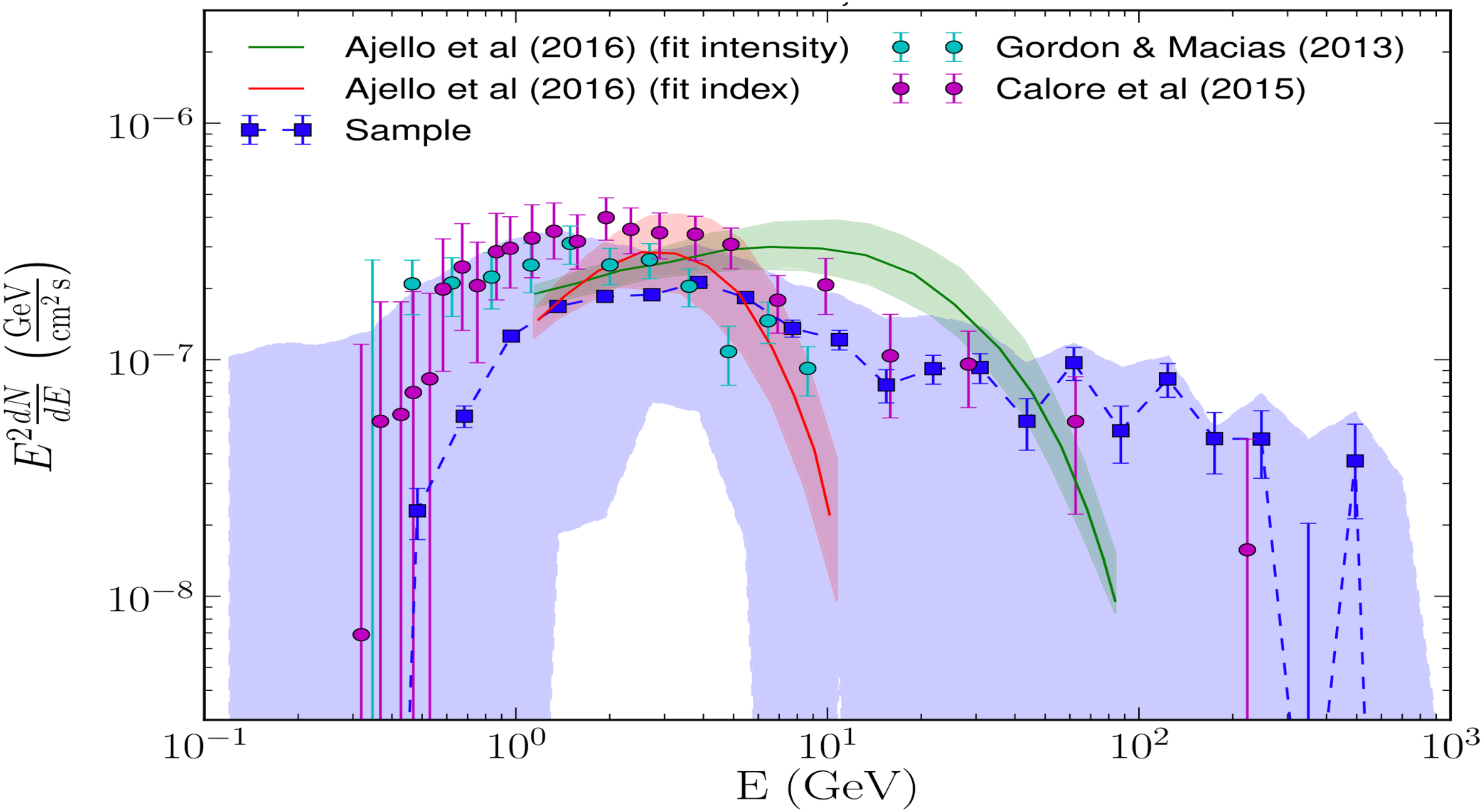
Background model systematics for the Fermi GeV excess
F.Calore, I. Cholis, C. Weniger JCAP03(2015)038 **arXiv:1409.0042v1**

Fermi–LAT observations of high-energy γ-ray emission toward the galactic centre
M. Ajello et al.[Fermi-LAT Coll.] **Apj 819:44 2016 arXiv:1511.02938**

The Fermi galactic center GeV excess and implications for dark matter
M. Ajello et al.[Fermi-LAT Coll.] **Apj 819:44 2016 arXiv:1511.02938**

Revisiting the Gamma-Ray Galactic Center Excess with Multi-Messenger Observations
IC, Zhong, McDermott, Surdutovich, PRD 105, 103023 (2022)

The GeV excess (Pass8 analysis)



following uncertainties have relatively small effect on the excess spectrum

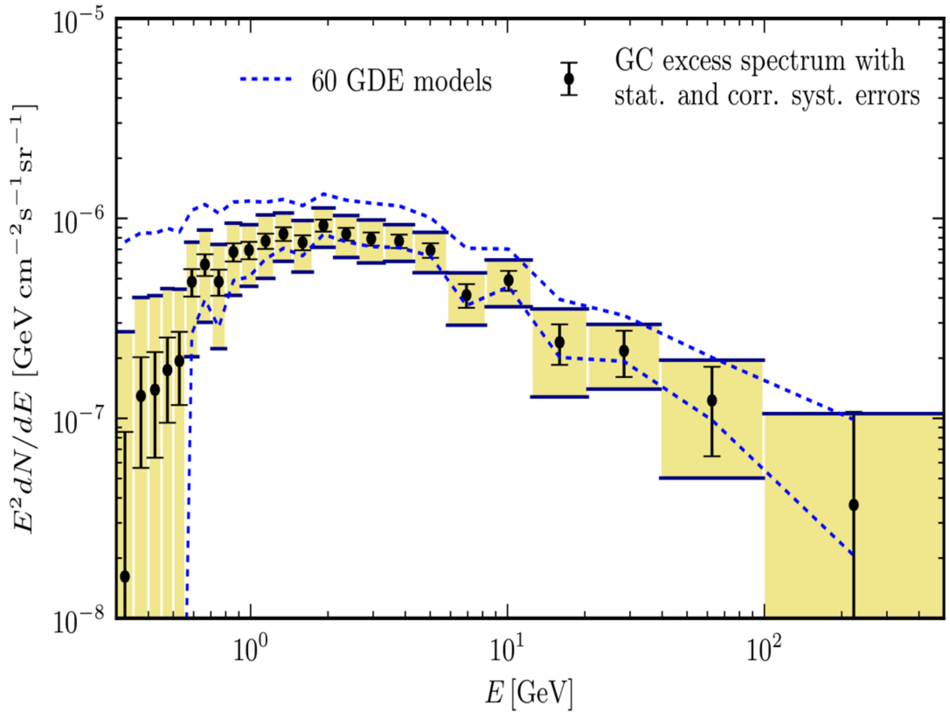
- Variation of GALPROP models – Distribution of gas along the line of sight

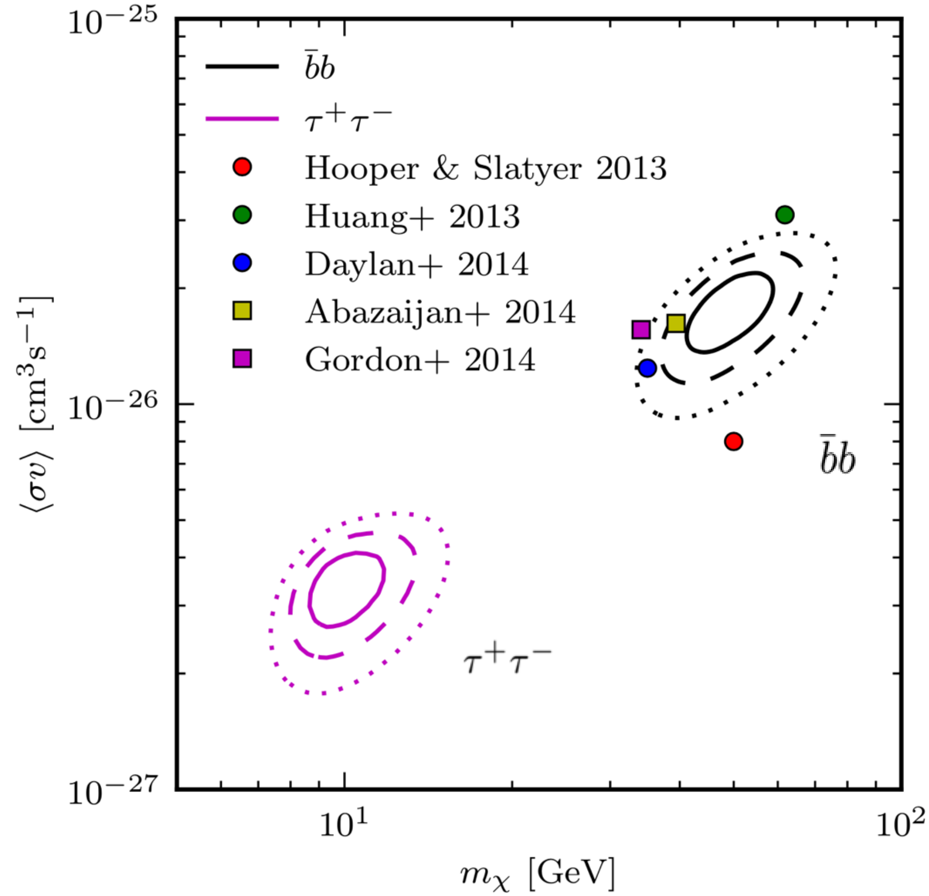
- **Most significant sources of uncertainty are:**

- Fermi bubbles morphology at low latitude – Sources of CR electrons near the GC

Fermi-LAT Collaboration Apj 840:43 2017 May 1 arXiv:1704.03910

The GeV excess





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

Calore et al., arXiv:1409.0042
Cholis et al., Phys. Rev. D 105, 103023 (2022) arXiv:2112.09706

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)

• Series of Leptonic Cosmic-Ray Outbursts

Cholis et al. arXiv:1506.05119

• Stellar population of the X-bulge and the nuclear bulge

Macias et al. arXiv:1611.06644

• Population of pulsars in the Galactic bulge

e.g. , Yuan and Zhang arXiv:1404.2318v1, Lee et al. arXiv:1506.05124, Bartels et.al. 1506.05104

M.Ajello et al. [Fermi-LAT Coll.] Phys. Rev. D 95, 082007 (2017) [arXiv:1704.07195]

....

• Robustness of the Galactic Center Excess

leading explanations being annihilating dark matter or an unresolved population of millisecond pulsars Zhong & Cholis arXiv:2401.02481

How to discriminate between different hypothesis ?

How to discriminate between different hypothesis ?

eROSITA

- Modeling of the Fermi bubbles
- Look for correlated features near the Galactic center

HESS, MAGIC, CTA

- Fermi bubbles near the GC are much brighter
- Possible to see with Cherenkov telescopes?

Radio observations, MeerKAT, SKA

- Search for individual pulsars in the halo around the GC

Radio surveys, Planck

- Look for correlated synchrotron emission near the GC

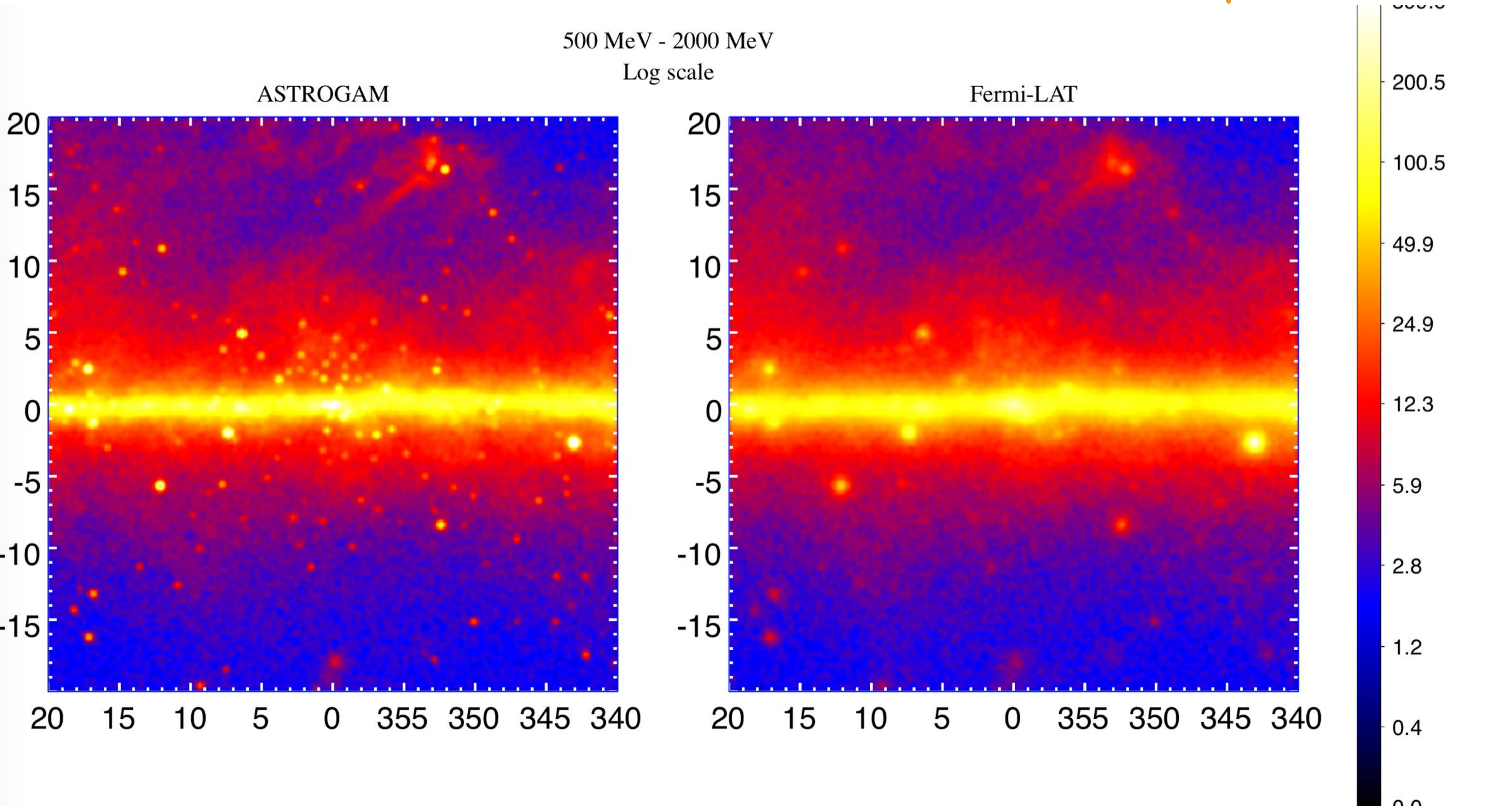
More Fermi LAT analysis

- Diffuse emission modeling
- Analysis of point sources near the GC

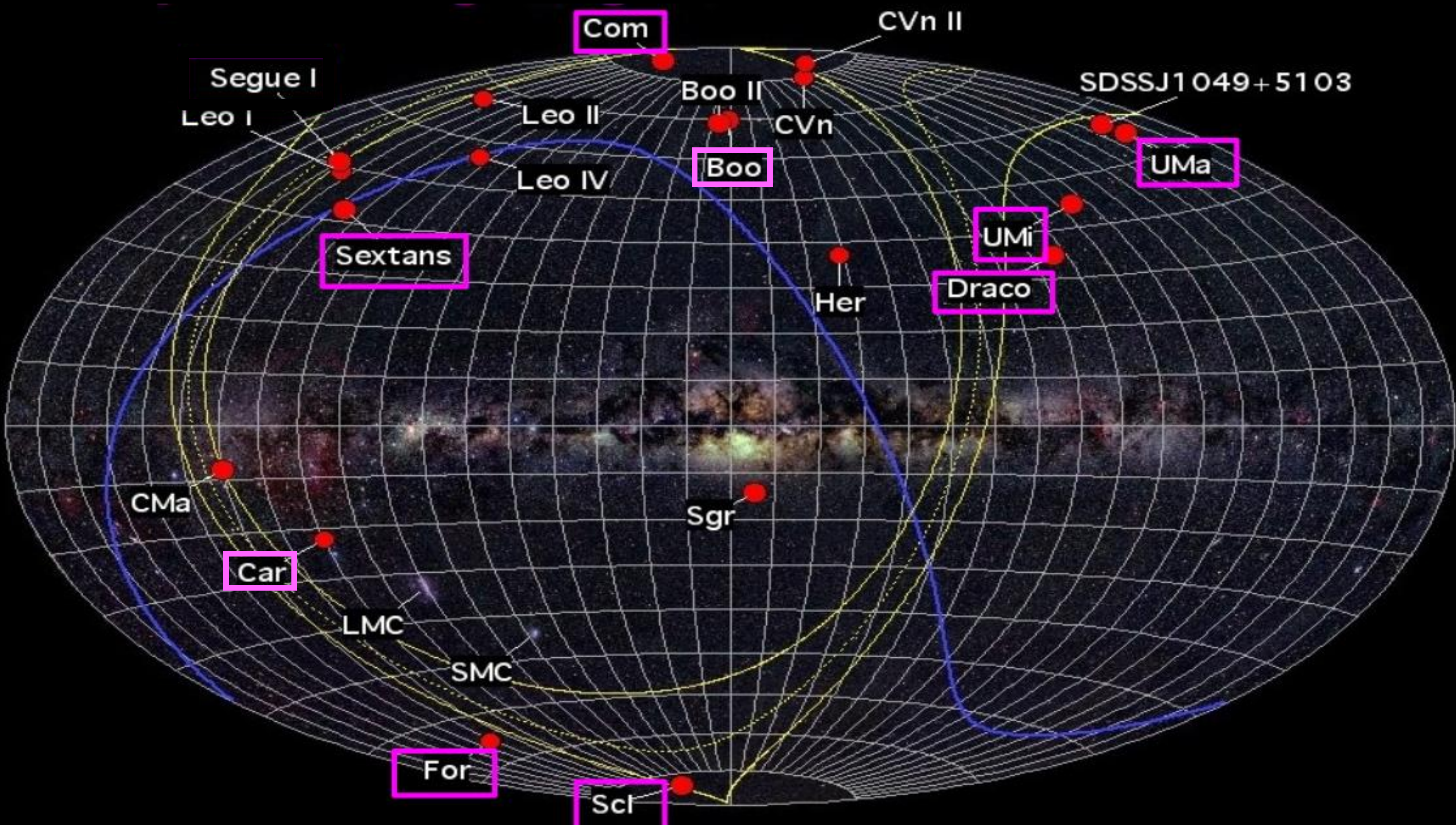
But ultimately We need a new experiment with better angular resolution below 100 MeV

Galactic Center Region 0.5-2 GeV

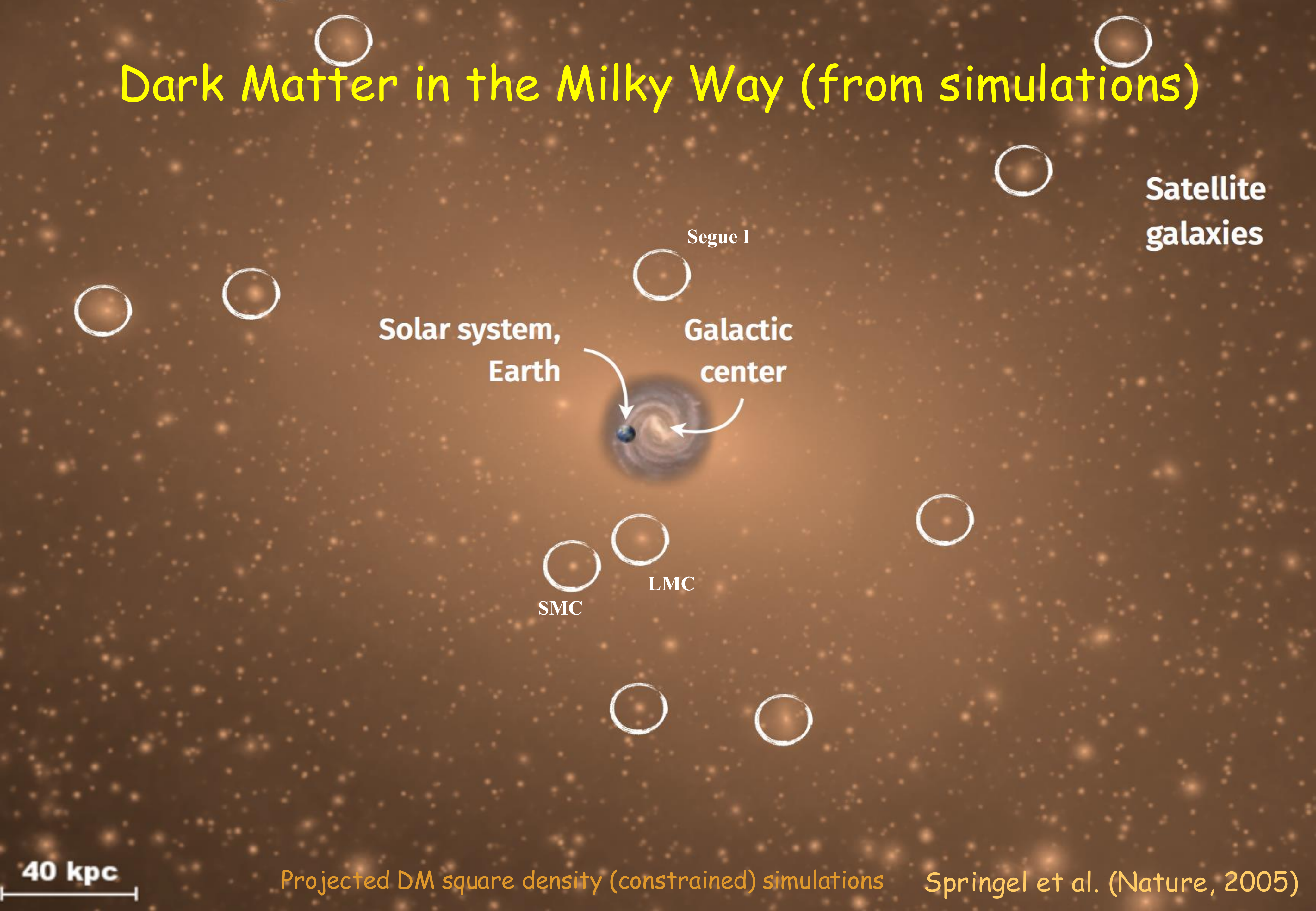
Fermi PSF Pass7 rep v15 source



Classical Dwarf spheroidal galaxies: promising targets for DM detection



Dark Matter in the Milky Way (from simulations)

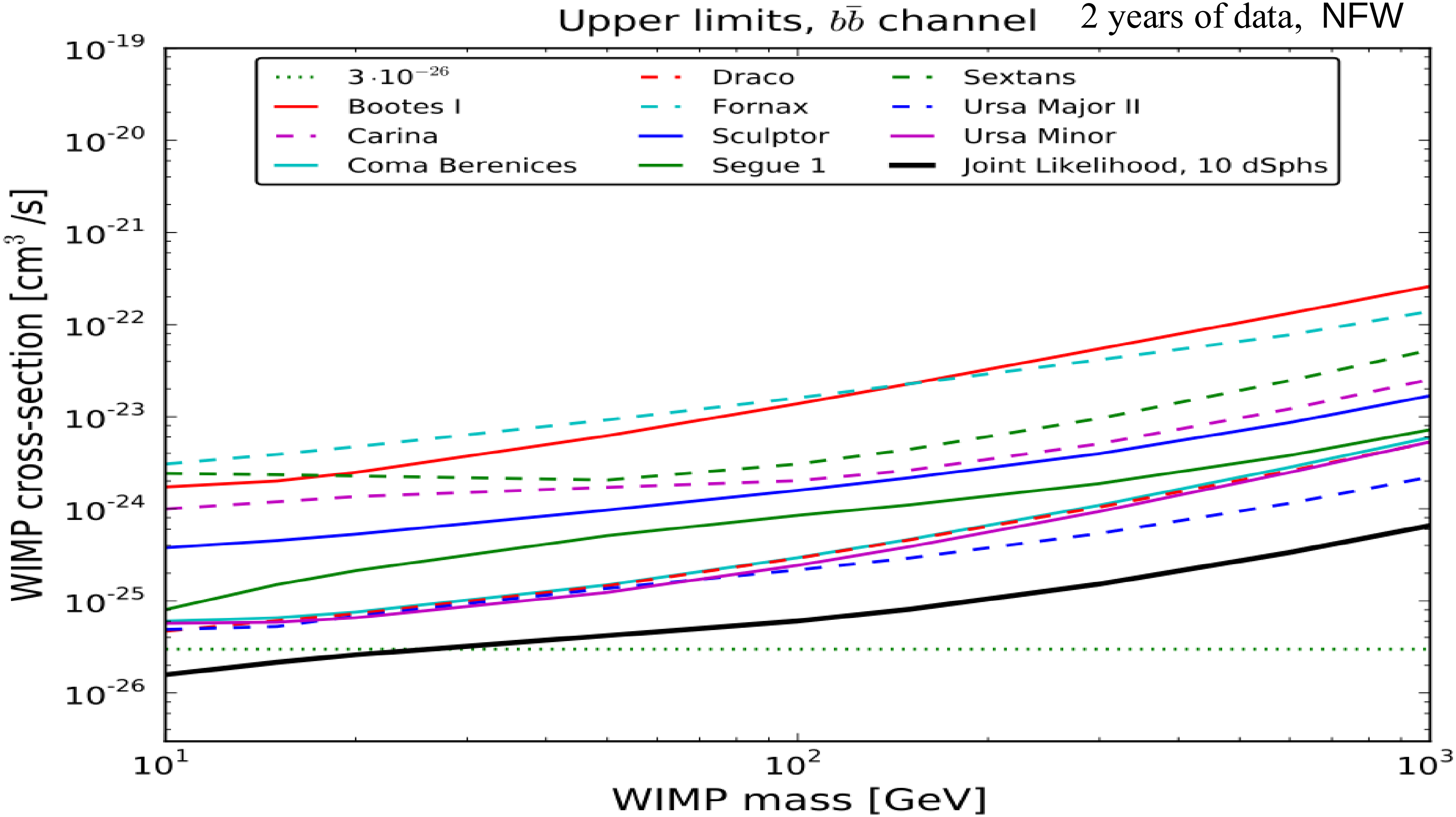


Projected DM square density (constrained) simulations

Springel et al. (Nature, 2005)

Dwarf Spheroidal Galaxies combined analysis

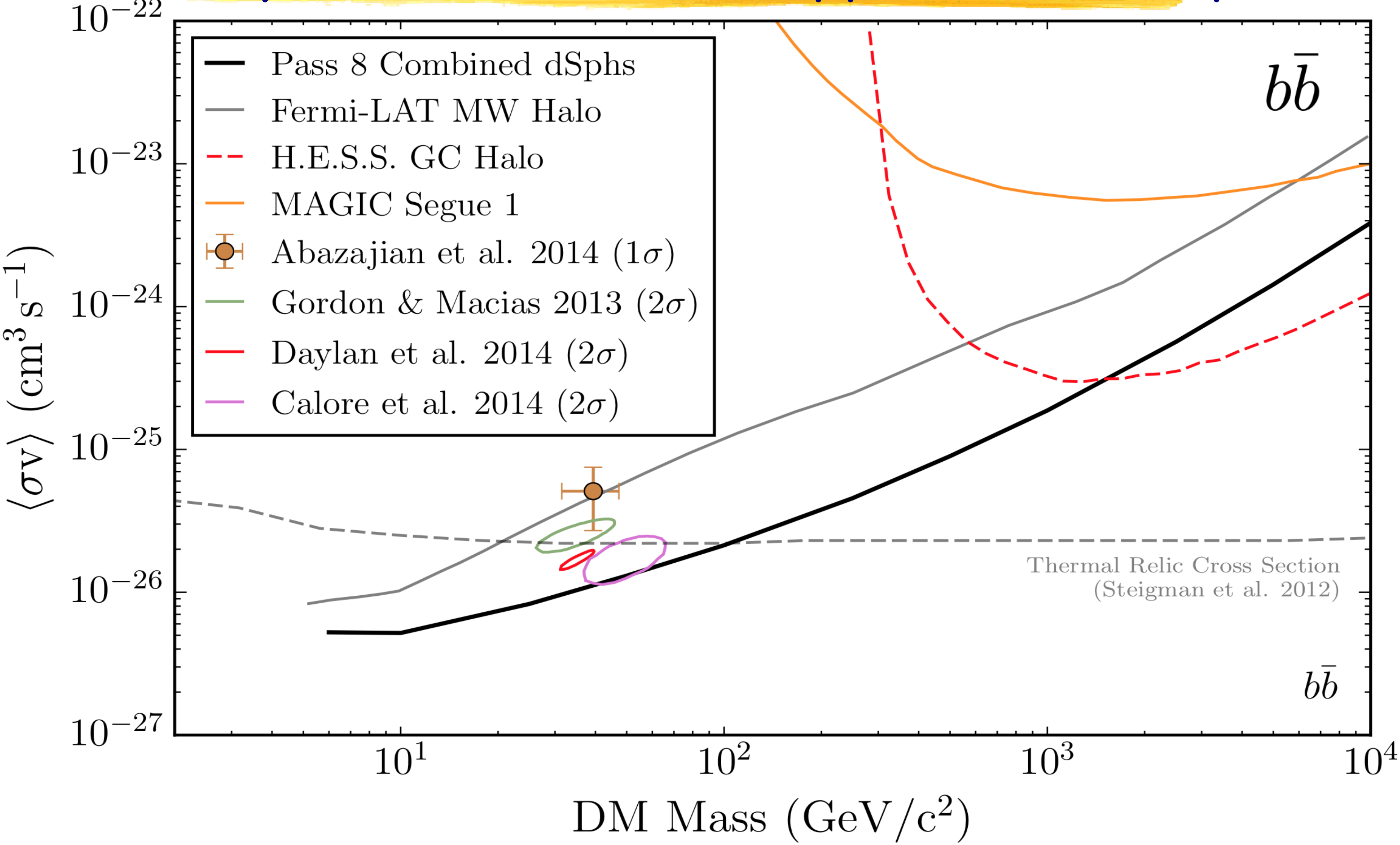
2 years of data, NFW



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

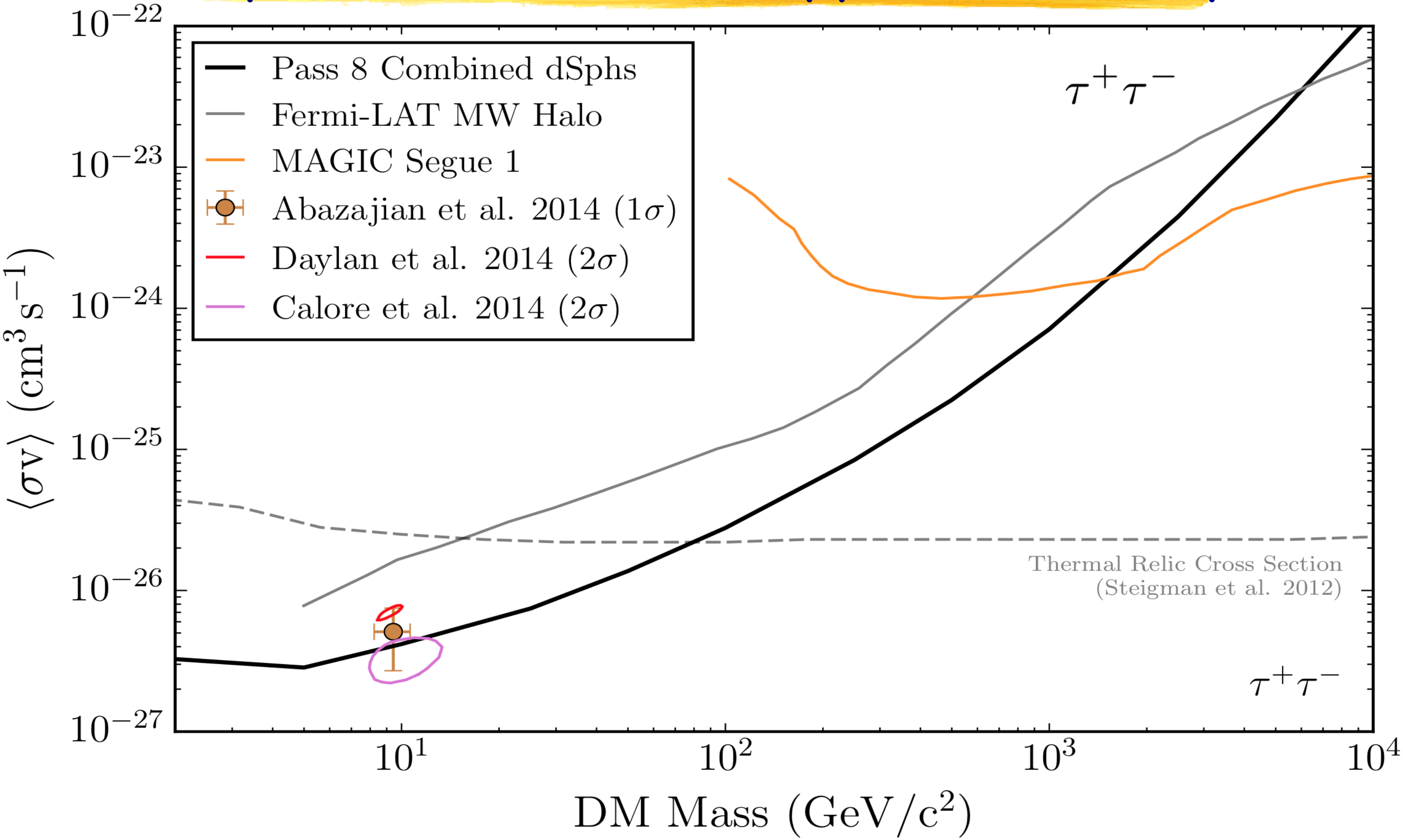
Fermi Lat Coll., PRL 107, 241302 (2011) [arXiv:1108.3546]

Dwarf Spheroidal Galaxies upper-limits (6 years)



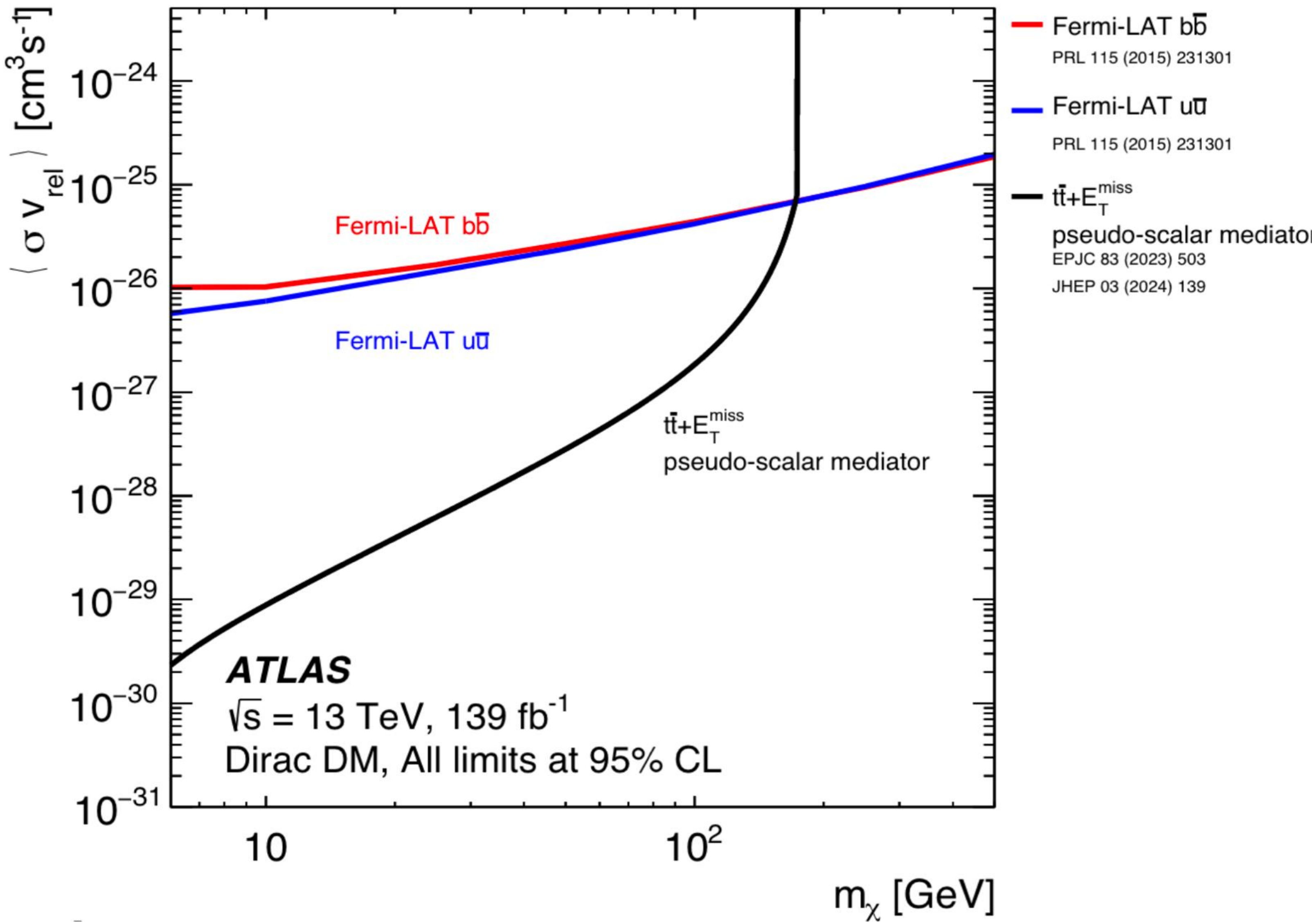
M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

Dwarf Spheroidal Galaxies upper-limits (6 years)



M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

Comparison of ATLAS scalar/pseudo-scalar results with Fermi LAT indire

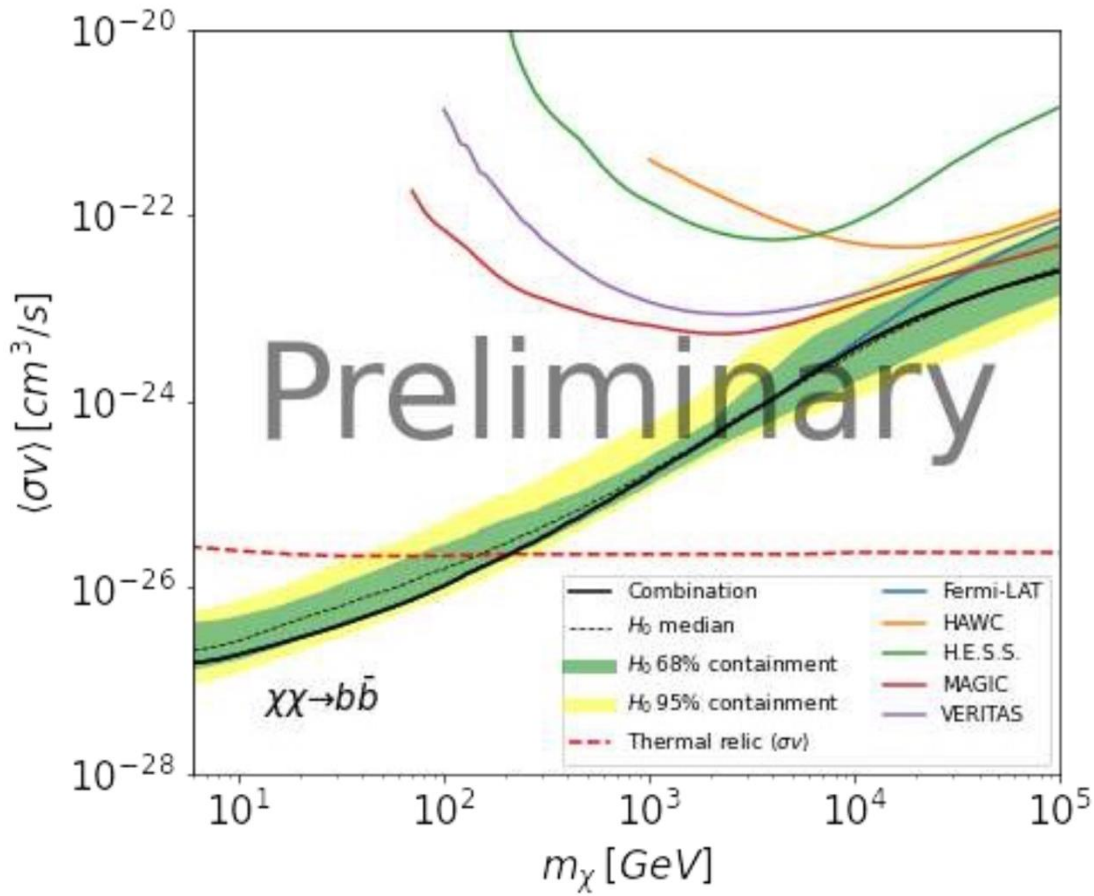


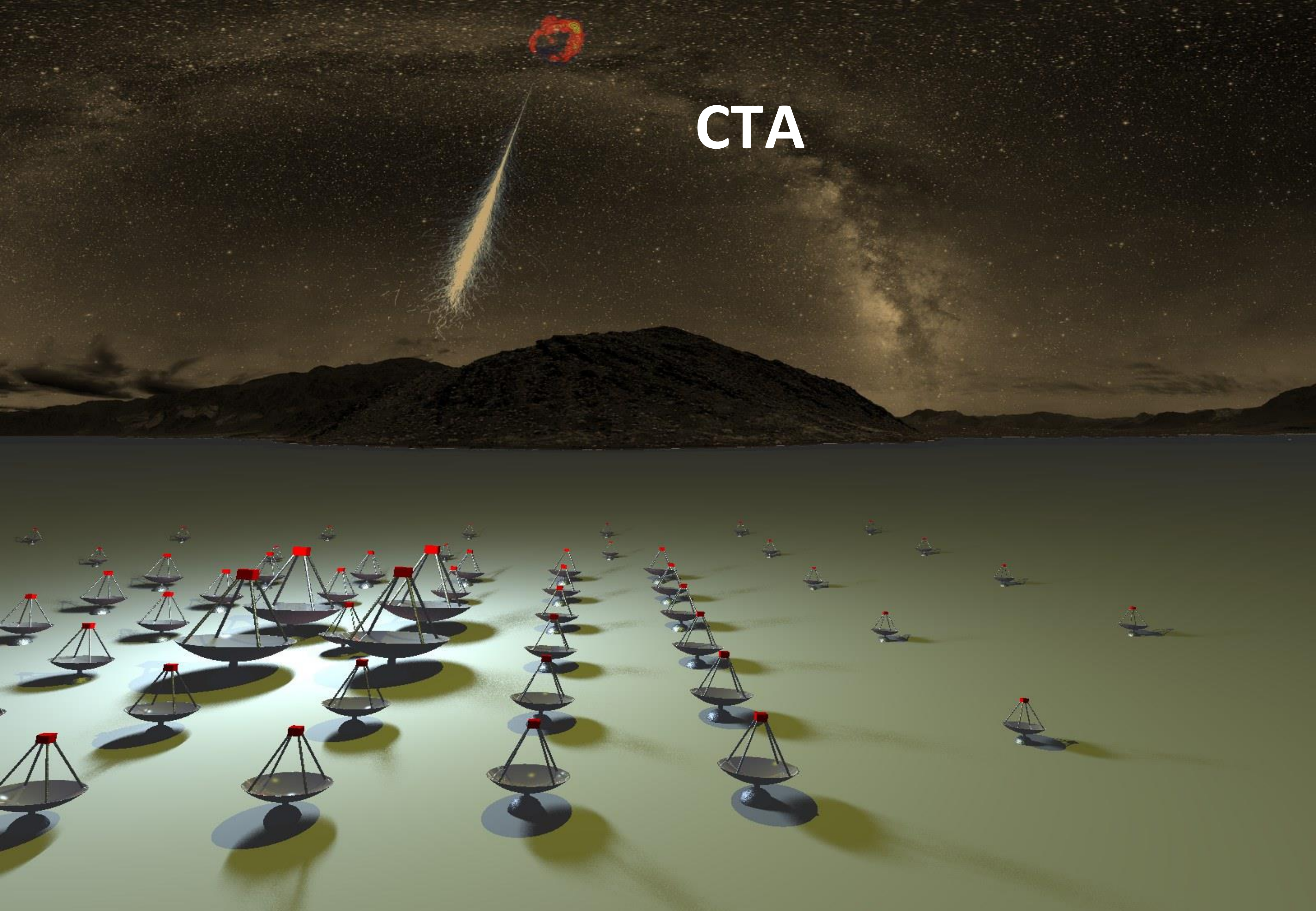
Annihilation cross section** (cross-section x relative velocity v_{rel}) averaged over the DM velocity distribution for a* ***pseudo-scalar mediator

Combining all dSph observations

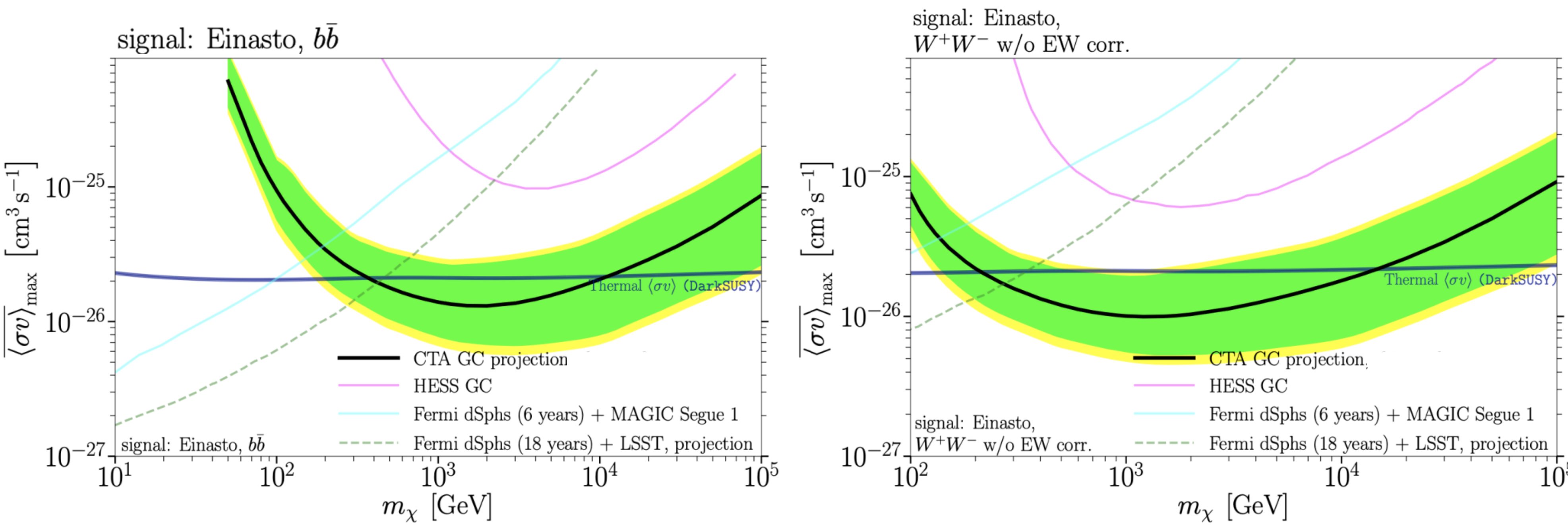
- Combination of the observation results towards 20 dwarf spheroidal galaxies (dSphs)
- Significant increase of the statistics -> Increase the sensitivity to potential dark matter signals
- Cover the widest energy range ever investigated : 20 MeV – 80 TeV

- Common elements :
- Agreed model parameters
- Sharable likelihood table formats
- Joint likelihood test statistic




CTA

Galactic center CTA Sensitivity



- Einasto profile

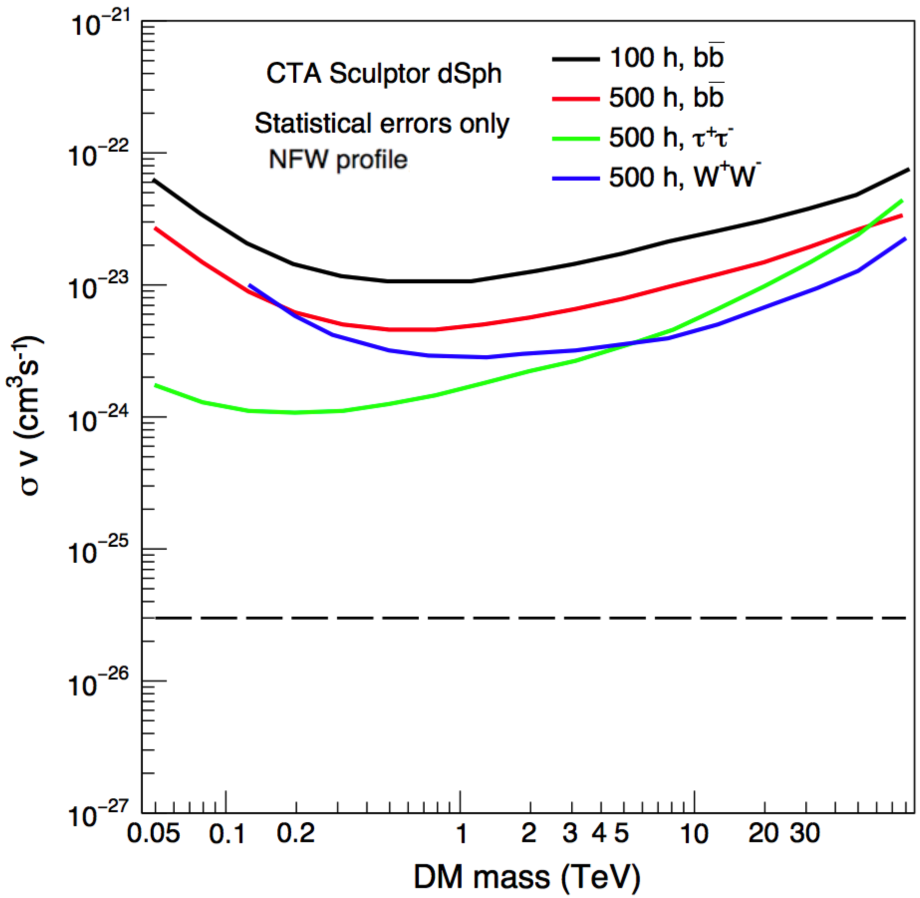
525 h

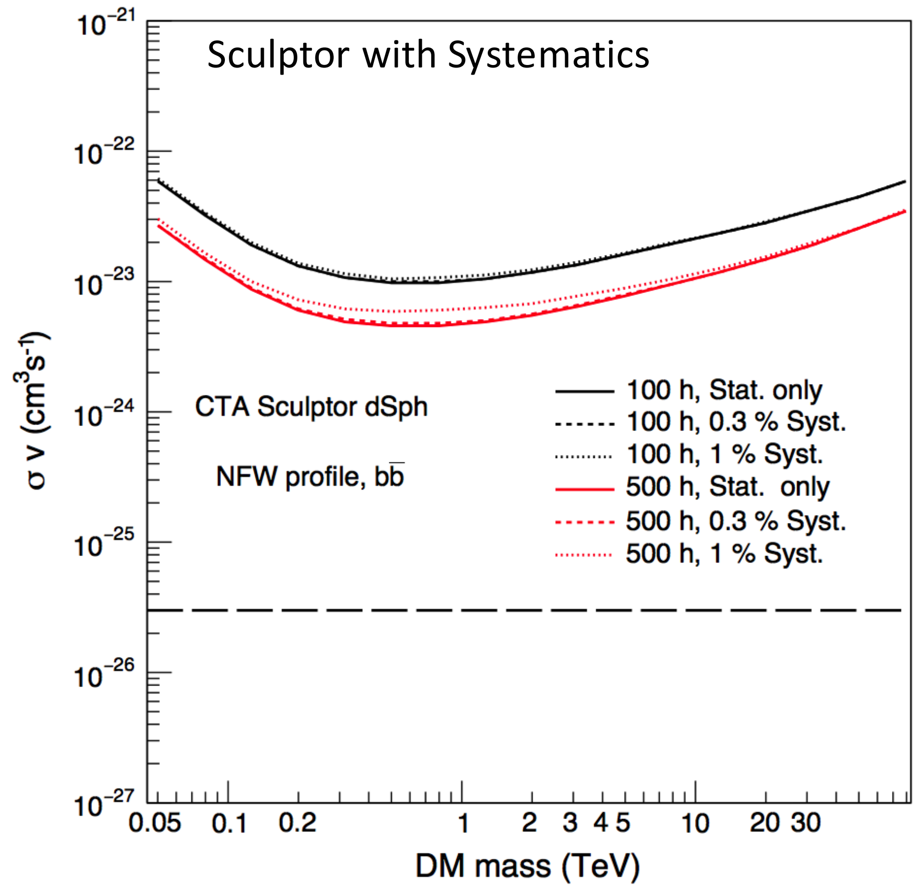
$$\rho_{DM} = \rho_s \exp\left[-\frac{\alpha}{2}\left(\frac{r}{r_s}\right)^{\alpha} - 1\right], \; J \sim 7.1 \times 10^{22}\mathrm{GeV}^2/\mathrm{cm}^5$$

- Main source of background : sources, Fermi Bubble, interstellar γ, residual CR

The CTA Consortium JCAP01(2021) 057 January 27, 2021 [arXiv:2007.16129]

Dwarf Spheroidal Galaxies: CTA Sensitivity





There are several of the newly discovered dSph that have a better case for being a promising target,

Will choose most promising targets before observations with the latest knowledge.

A.M. PoS(ICRC2017)921

Measuring DM densities in dSph halos

Optimal dSphs selected according to:
1. Distance(d<100pc)
2. Culmination zenith angle (ZAmin < 30°)

Targets with no/poor brightness and/ or kinematic data excluded from the MCMC Jeans analysis.

Surviving sample:

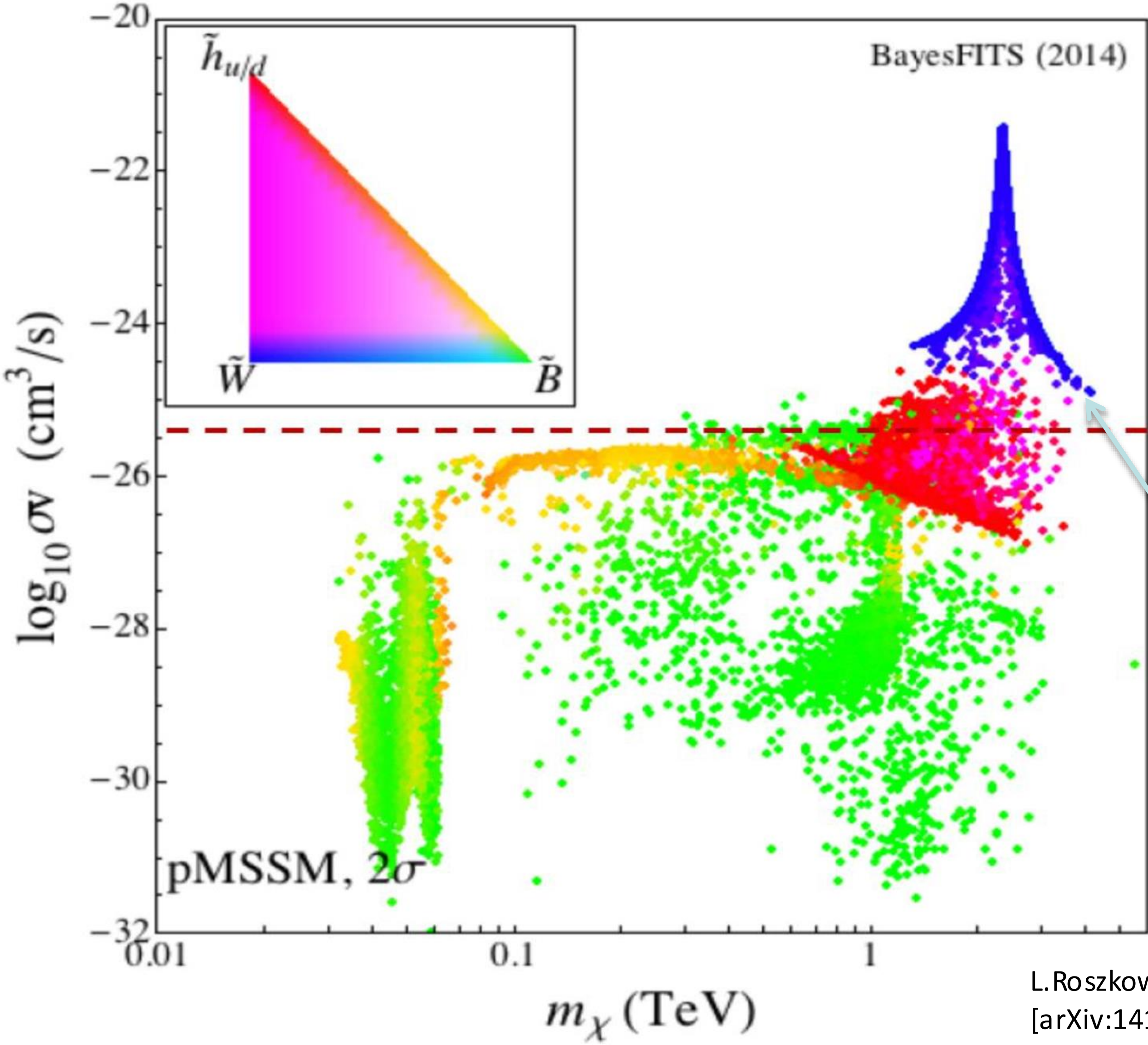
— 6 Northern dSphs (1 classical + 5 ultra-faint)

— 6 Southern dSphs (3 classical + 3 ultra-faint)

Name	Abbr.	Type	R.A. (hh mm ss)	dec. (dd mm ss)	Distance (kpc)	ZA_{culm} N (deg)	ZA_{culm} S (deg)	Month
Andromeda XVIII	AndXVIII	uft	00 02 14.5	+45 05 20	1330 ± 104	16.3	69.7	Sep
Aquarius	Aqr	uft	20 46 51.8	−12 50 53	1030 ± 57	41.6	11.8	Aug
Boötes I	BoöI	uft	14 00 06.0	+14 30 00	65 ± 3	14.3	39.1	Apr
Boötes II	BoöII	uft	13 58 00.0	+12 51 00	39 ± 2	15.9	37.5	Apr
Boötes III	BoöIII	uft	13 57 12.0	+26 48 00	46 ± 2	2.0	51.4	Apr
Canes Venatici I	CVnI	uft	13 28 03.5	+33 33 21	216 ± 8	4.8	58.2	Apr
Canes Venatici II	CVnII	uft	12 57 10.0	+34 19 15	159 ± 8	5.6	58.9	Apr
Carina	Car	cls	06 41 36.7	−50 57 58	106 ± 1	79.7	26.3	Dec
Cetus I	CetI	uft	00 26 11.0	−11 02 40	748 ± 31	39.8	13.6	Sep
Cetus II	CetII	uft	01 17 52.8	−17 25 12	30 ± 3	46.2	7.2	Oct
Columba I	ColI	uft	05 31 26.4	−28 01 48	182 ± 18	56.8	3.4	Dec
Coma Berenices	CBe	uft	12 26 59.0	+23 54 15	42 ± 2	4.9	48.5	Mar
Draco I	DraI	cls	17 20 12.4	+57 54 55	75 ± 4	29.2	82.5	Jun
Draco II	DraII	uft	15 52 47.6	+64 33 55	20 ± 3	35.8	89.2	May
Eridanus II	EriII	uft	03 44 21.5	−43 31 48	330 ± 16	72.3	18.9	Nov
Eridanus III	EriIII	uft	02 22 45.5	−52 16 48	95 ± 27	81.0	27.7	Oct
Fornax	For	cls	02 39 59.3	−34 26 57	146 ± 1	63.2	9.8	Oct
Grus I	GruI	uft	22 56 42.4	−50 09 48	120 ± 17	78.9	25.5	Sep
Grus II	GruII	uft	22 04 04.8	−46 26 24	53 ± 5	75.2	21.8	Aug
Hercules	Her	uft	16 31 02.0	+12 47 30	137 ± 11	16.0	37.4	May
Horologium I	HorI	uft	02 55 28.9	−54 06 36	87 ± 13	82.9	29.5	Oct
Hydra II	HyaII	uft	12 21 42.1	−31 59 07	134 ± 10	60.7	7.4	Mar
Indus I	IndI	uft	21 08 48.1	−51 09 36	69 ± 16	79.9	26.5	Aug
Indus II	IndII	uft	20 38 52.8	−46 09 36	214 ± 16	74.9	21.5	Aug
Laevens 3	Lae3	uft	21 06 54.3	+14 58 48	67 ± 3	13.8	39.6	Aug
Leo I	LeoI	cls	10 08 28.1	+12 18 23	272 ± 10	16.5	36.9	Feb
Leo II	LeoII	cls	11 13 28.8	+22 09 06	240 ± 9	6.6	46.8	Mar
Leo IV	LeoIV	uft	11 32 57.0	−00 32 00	151 ± 4	29.3	24.1	Mar
Leo V	LeoV	uft	11 31 09.6	+02 13 12	169 ± 5	26.5	26.9	Mar
Leo T	LeoT	uft	09 34 53.4	+17 03 05	377 ± 28	11.7	41.7	Feb
Phoenix I	PheI	uft	01 51 06.3	−44 26 41	427 ± 31	73.2	19.8	Oct
Phoenix II	PheII	uft	23 39 57.6	−54 24 36	95 ± 18	83.2	29.8	Sep
Pictor I	PicI	uft	04 43 48.0	−50 16 48	126 ± 24	79.0	25.7	Nov
Pisces II	PscII	uft	22 58 31.0	+05 57 09	182 ± 13	22.8	30.6	Sep
Reticulum II	RetII	uft	03 35 40.9	−54 03 00	32 ± 2	82.8	29.4	Nov
Reticulum III	RetIII	uft	03 45 26.3	−60 27 00	92 ± 13	89.2	35.8	Nov
Sagittarius I	SgrI	dis	18 55 19.5	−30 32 43	31 ± 1	59.3	5.9	Jul
Sagittarius II	SgrII	uft	19 52 40.5	−22 04 05	67 ± 5	50.8	2.6	Jul
Sculptor	Scl	cls	01 00 09.4	−33 42 33	84 ± 2	62.5	9.1	Oct
Segue 1	Seg1	uft	10 07 04.0	+16 04 55	23 ± 2	12.7	40.7	Feb
Segue 2	Seg2	uft	02 19 16.0	+20 10 31	36 ± 2	8.6	44.8	Oct
Sextans	Sex	cls	10 13 03.0	−01 36 53	84 ± 3	30.4	23.0	Feb
Triangulum II	TriII	uft	02 13 17.4	+36 10 42	30 ± 2	7.4	60.8	Oct
Tucana I	TucI	uft	22 41 49.6	−64 25 10	855 ± 35	—	39.8	Sep
Tucana II	TucII	uft	22 52 16.7	−58 33 36	58 ± 6	87.3	33.9	Sep
Tucana III	TucIII	uft	23 56 35.9	−59 36 00	25 ± 2	88.4	35.0	Sep
Tucana IV	TucIV	uft	00 02 55.3	−60 51 00	48 ± 4	89.6	36.2	Sep
Ursa Major I	UMaI	uft	10 34 52.8	+51 55 12	105 ± 2	23.2	76.6	Mar
Ursa Major II	UMaII	uft	08 51 30.0	+63 07 48	35 ± 2	34.4	87.8	Feb
Ursa Minor	UMi	cls	15 09 08.5	+67 13 21	68 ± 2	38.5	—	May
Willman 1	Wil1	uft	10 49 21.0	+51 03 00	38 ± 7	22.3	75.7	Mar

preliminary, in prep. 2024

note:the "thermal" cross section is only a reference value. The real cross section can be higher or lower



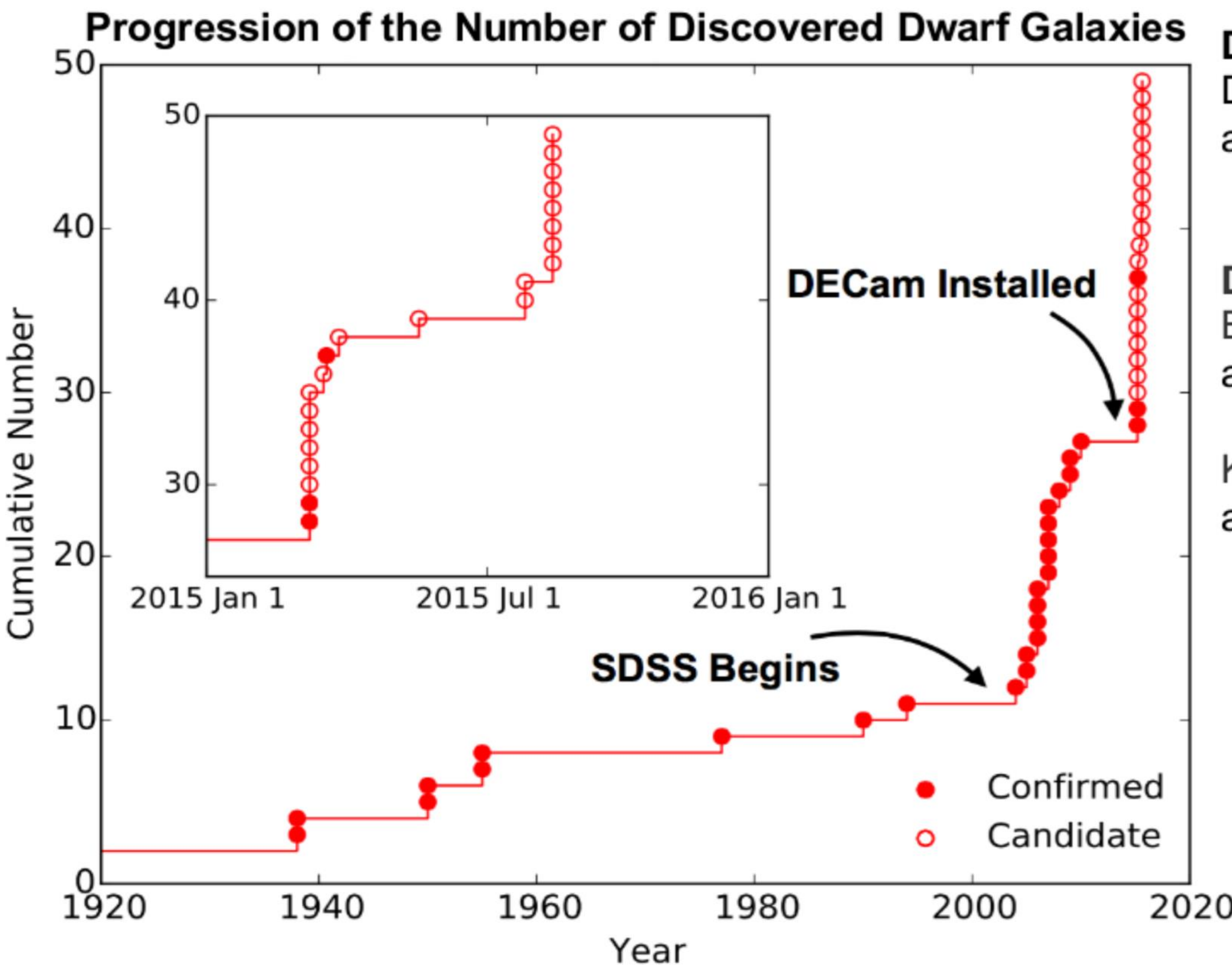
Example: Annihilation cross-section points from a 19 dimensional pMSSM fit

"thermal" cross-section 3×10^{-26} cm^3 s^{-1}

Note that a strong enhancement of the annihilation cross section occurs for winos around 2-3 TeV due to Sommerfeld enhancement.

L.Roszkowski et al., JHEP 1502 (2015) 014 [arXiv:1411.5214]

Dwarf Spheroidal Galaxies: Growing number of known targets

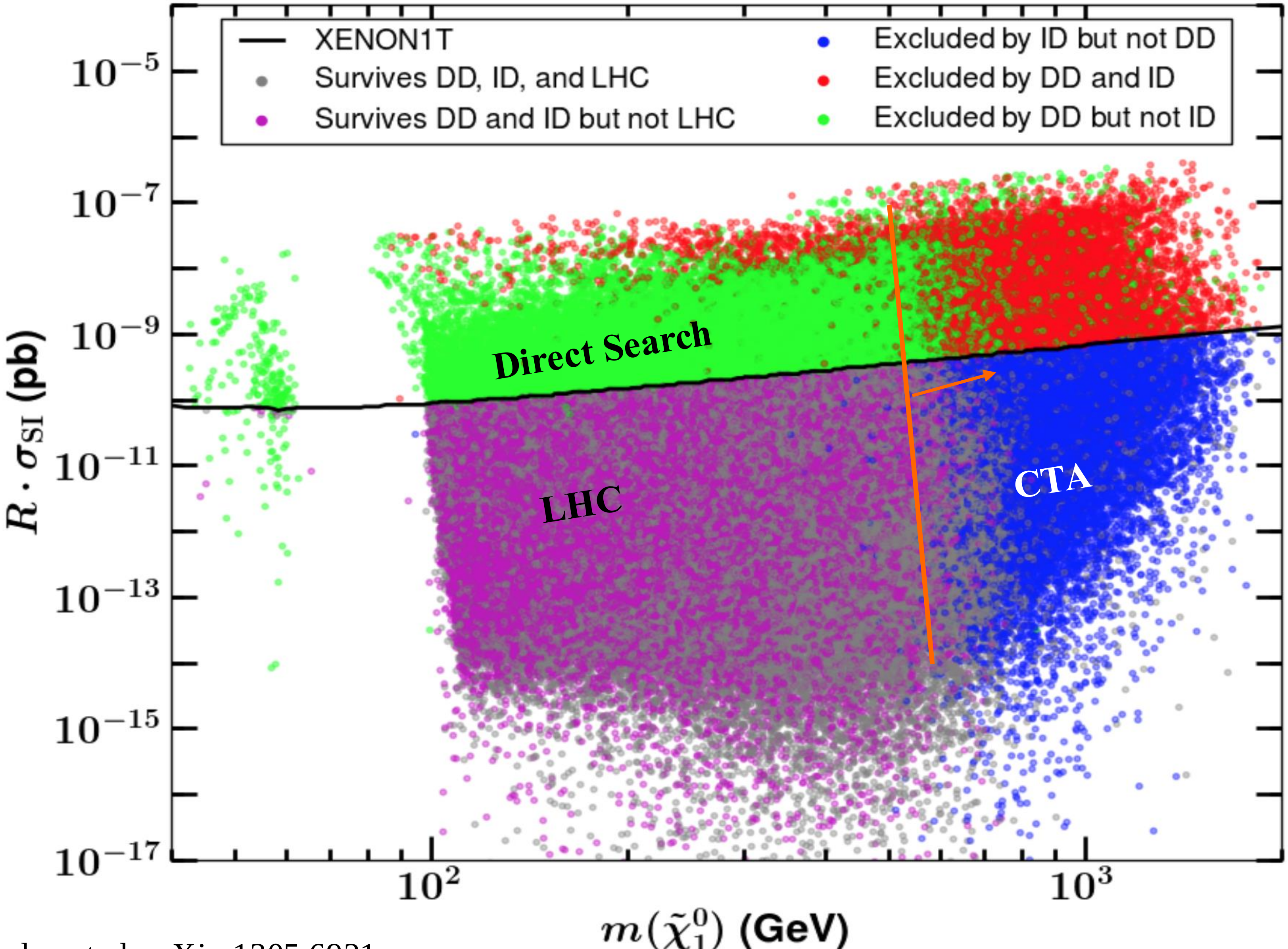


DES Year 2 Data: Drlica-Wagner+, arXiv:1508.03622

DES Year 1 Data: Bechtol+: arXiv:1503.02584

Koposov+: arXiv:1503.02079

Complementarity and Searches for Dark Matter in the pMSSM



Cahill-Rowley et al. arXiv:1305.6921

CTA Search for Dark Matter beyond WIMP

Axion Like Particle (ALP) search prospects

$\gamma + B \rightarrow a + B \rightarrow \gamma' + \ldots$

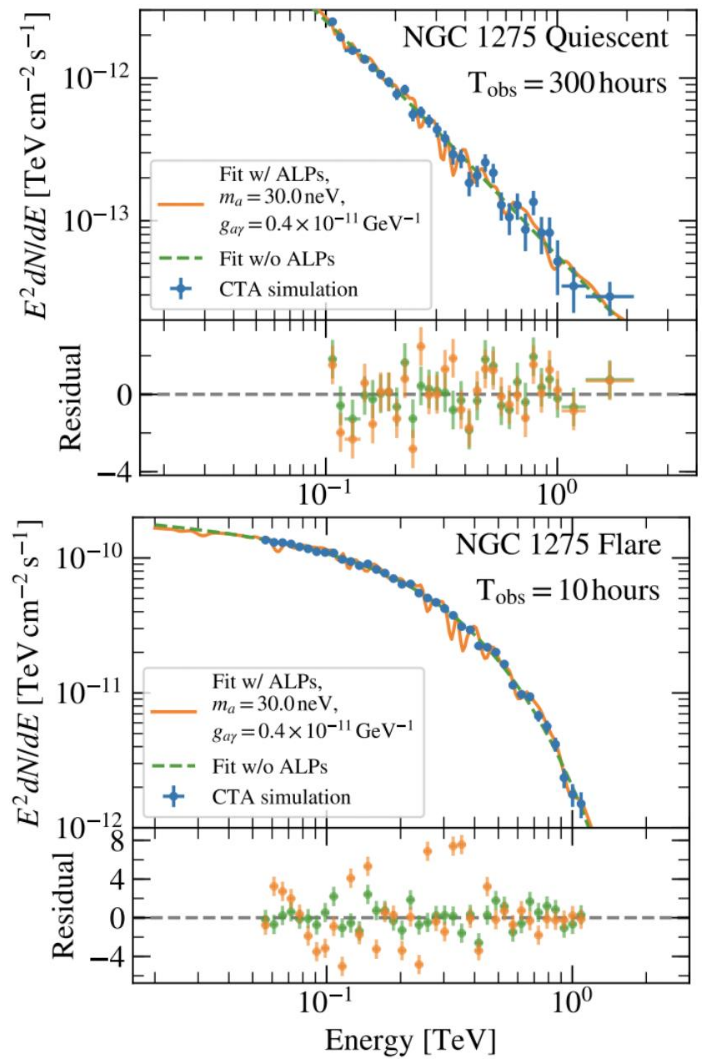
conversion probability ($E > E_{crit}$)

$$P_{a\gamma} \sim \sin^2\left(\frac{g_{a\gamma} B l}{2}\right),$$

$$E_{\rm crit} \sim 2.5\ \mathrm{GeV} \times \left(\frac{|m_a - \omega_{\rm pl}|}{1\,\mathrm{neV}}\right)^2 \left(\frac{B}{1\,\mu\mathrm{G}}\right)^{-1} \left(\frac{g_{a\gamma}}{10^{-11}\,\mathrm{GeV}^{-1}}\right)^{-1}$$

the observation is simulated without an ALP effect and is modeled both without ALPs and with a fixed set of magnetic-field realization and ALP parameters that are excluded at 95 % confidence level by the flaring state simulation

Simulated spectra of the radio galaxy NGC 1275

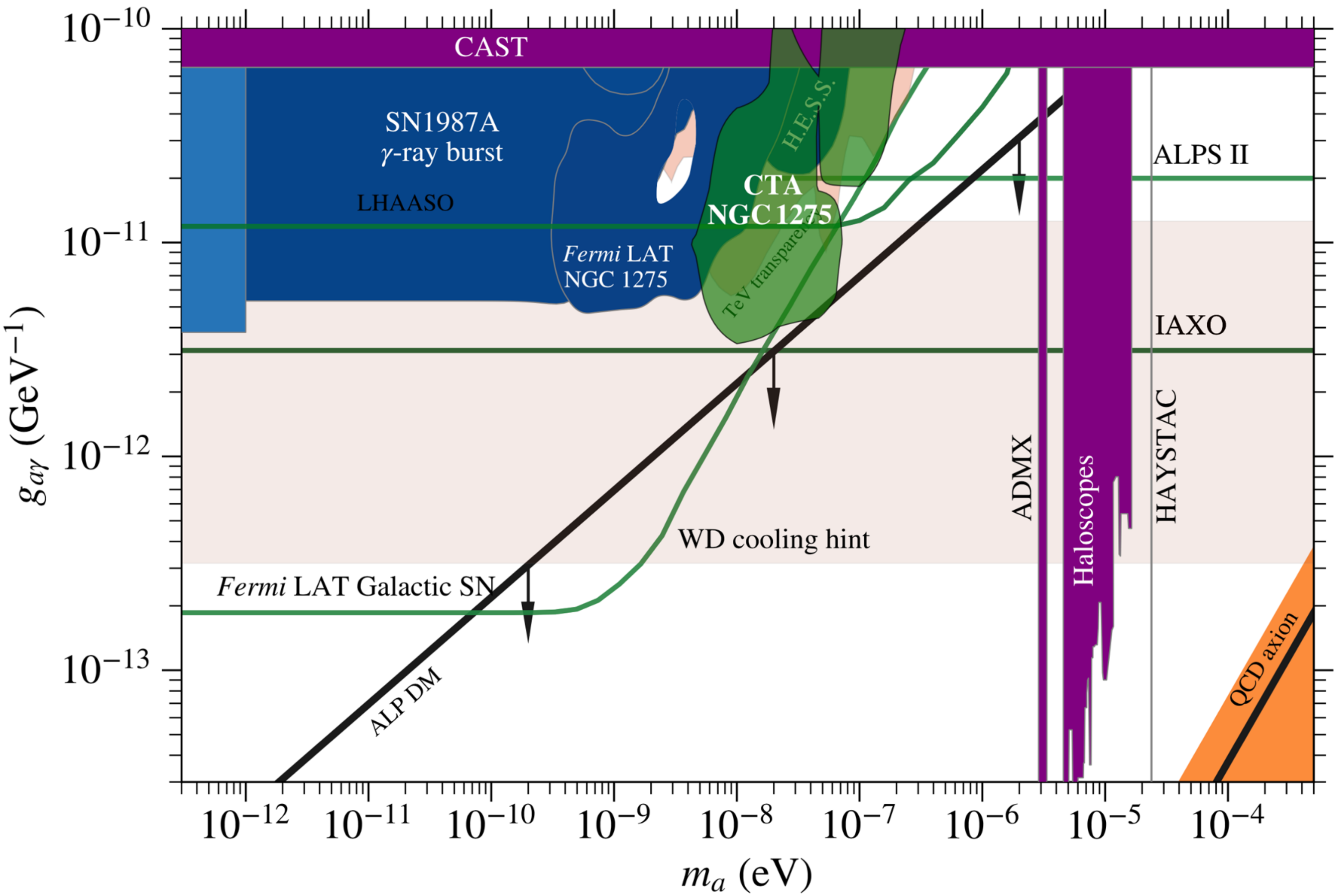


The CTA Consortium, JCAP 02 (2021) 048, 2021 [arXiv:2010.01349]

Search for Dark Matter beyond WIMP

Axion Like Particle (ALP) search prospects

- Observation of a flaring state of the radio galaxy NGC 1275 inside the Perseus cluster



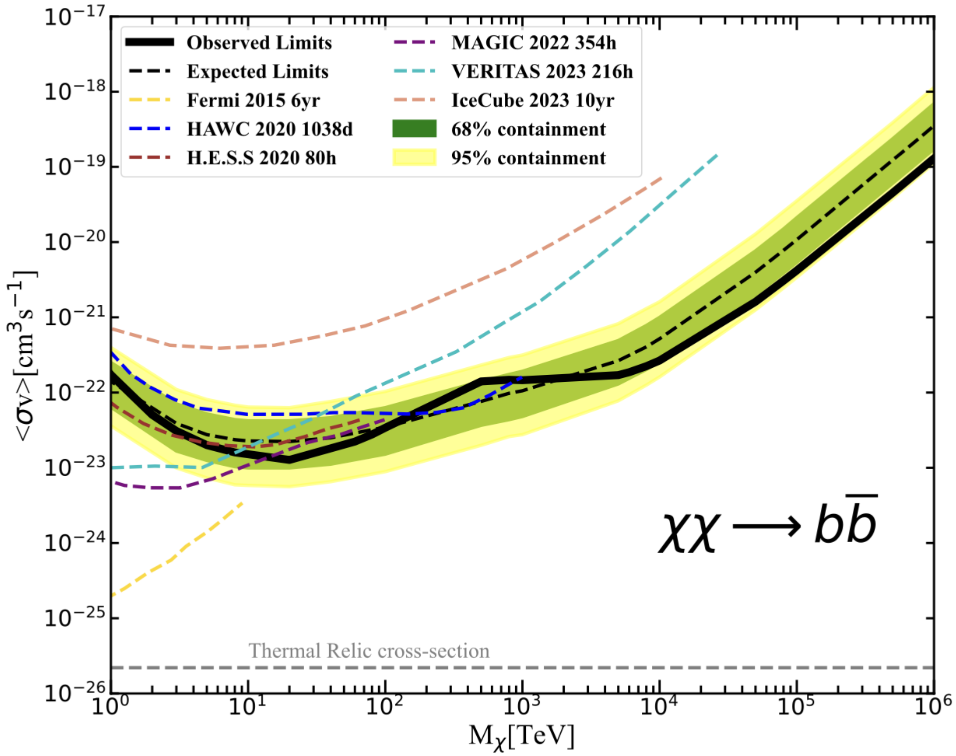
The CTA Consortium, JCAP 02 (2021) 048, 2021 [arXiv:2010.01349]

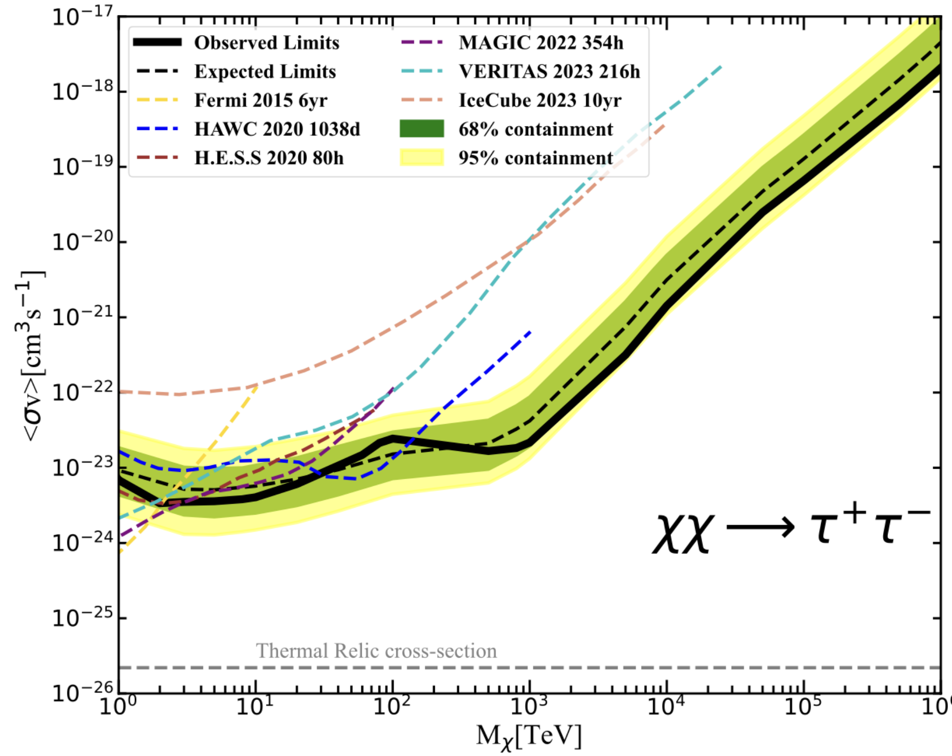
LHAASO

Mt. Haizi 4410 altitude

Constraints on Ultra Heavy Dark Matter Properties from Dwarf Spheroidal Galaxies with LHAASO Observations

DM annihilation cross-section



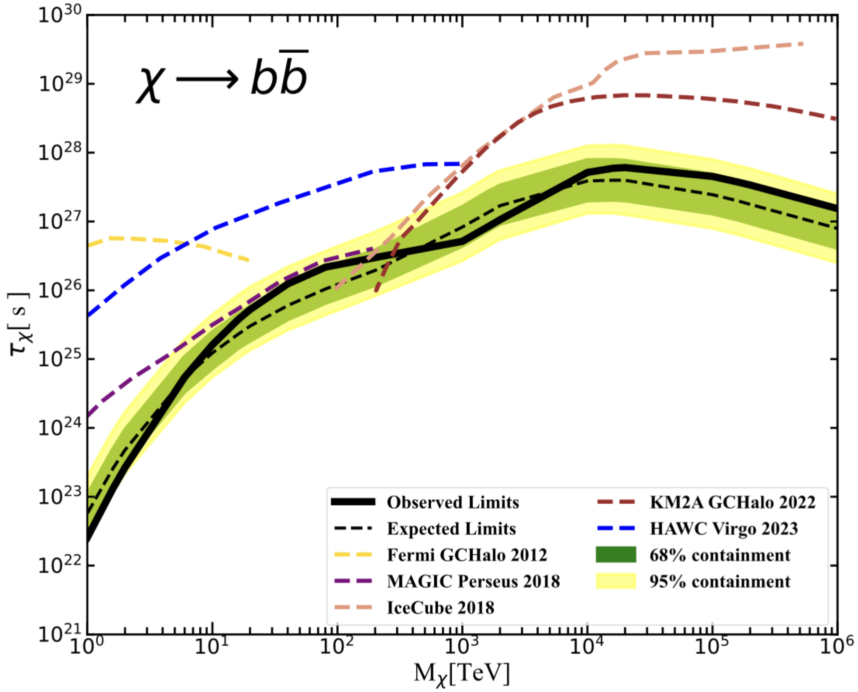


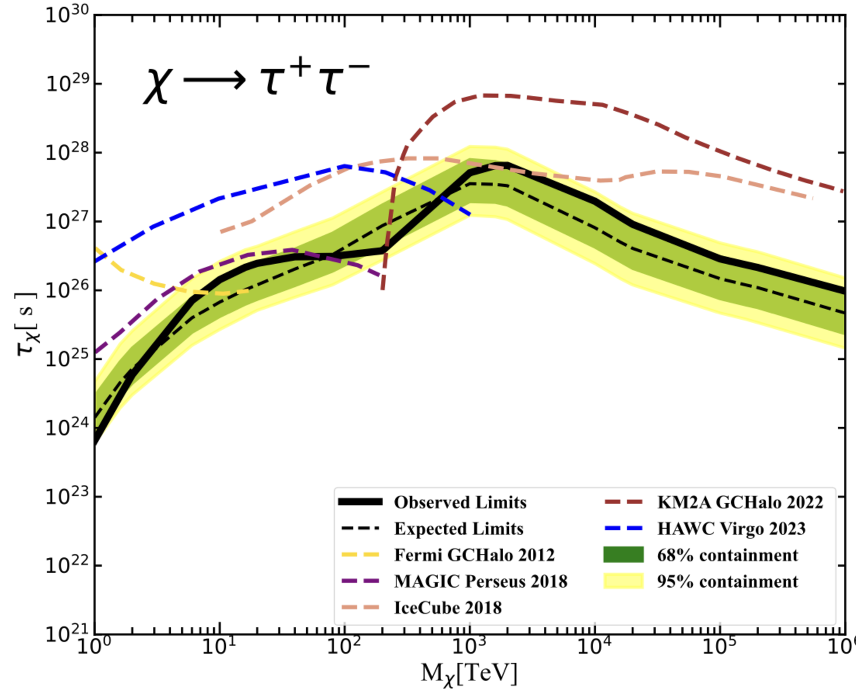
700 days, 16 dwarf spheroidal galaxies

LHAASO Coll. 2406.08698v1

Constraints on Ultra Heavy Dark Matter Properties from Dwarf Spheroidal Galaxies with LHAASO Observations

DM decay lifetime

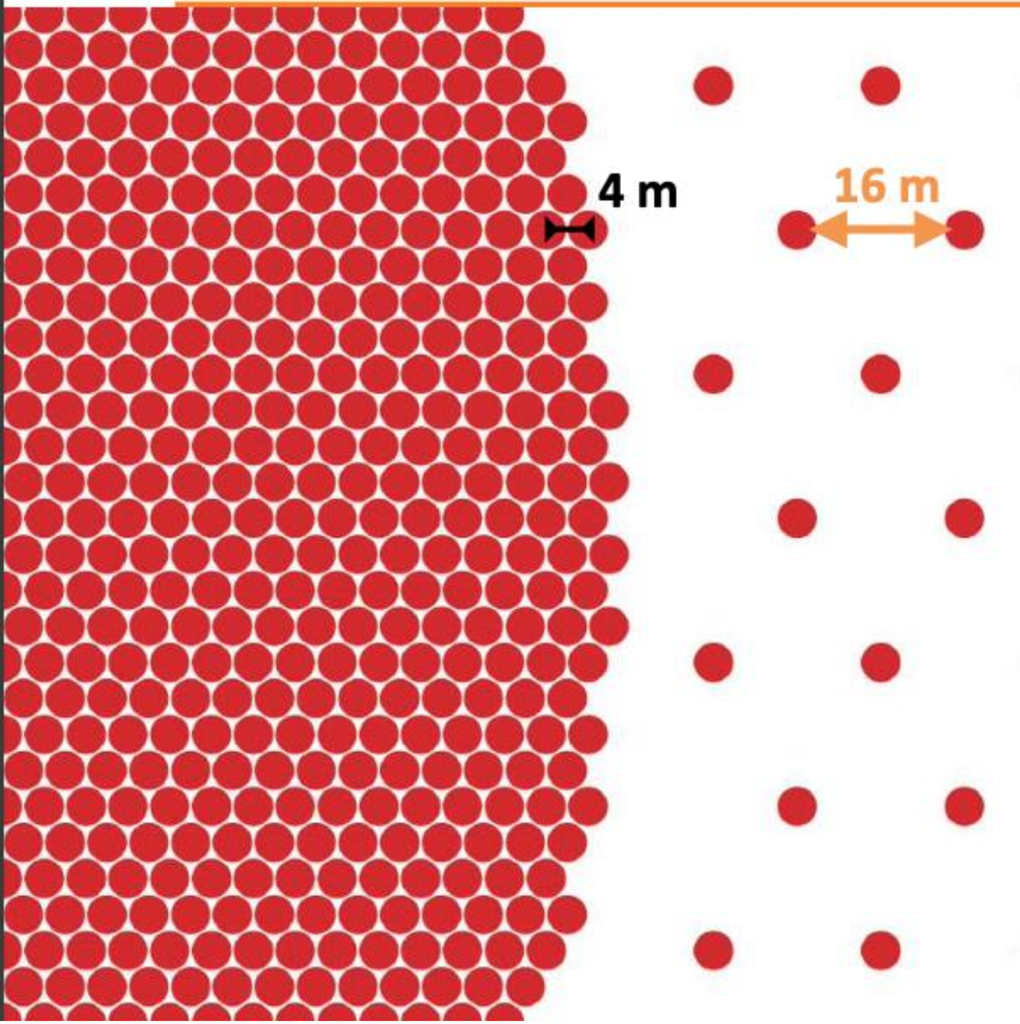




700 days, 16 dwarf spheroidal galaxies

LHAASO Coll. 2406.08698v1

The baseline detector concept

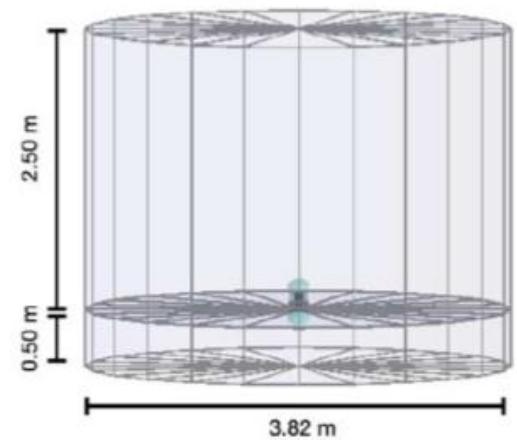


Core: Ø 320 m, FF = 80%
5,700 WCD units

Outer: Ø 600 m, FF = 5%
880 WCD units

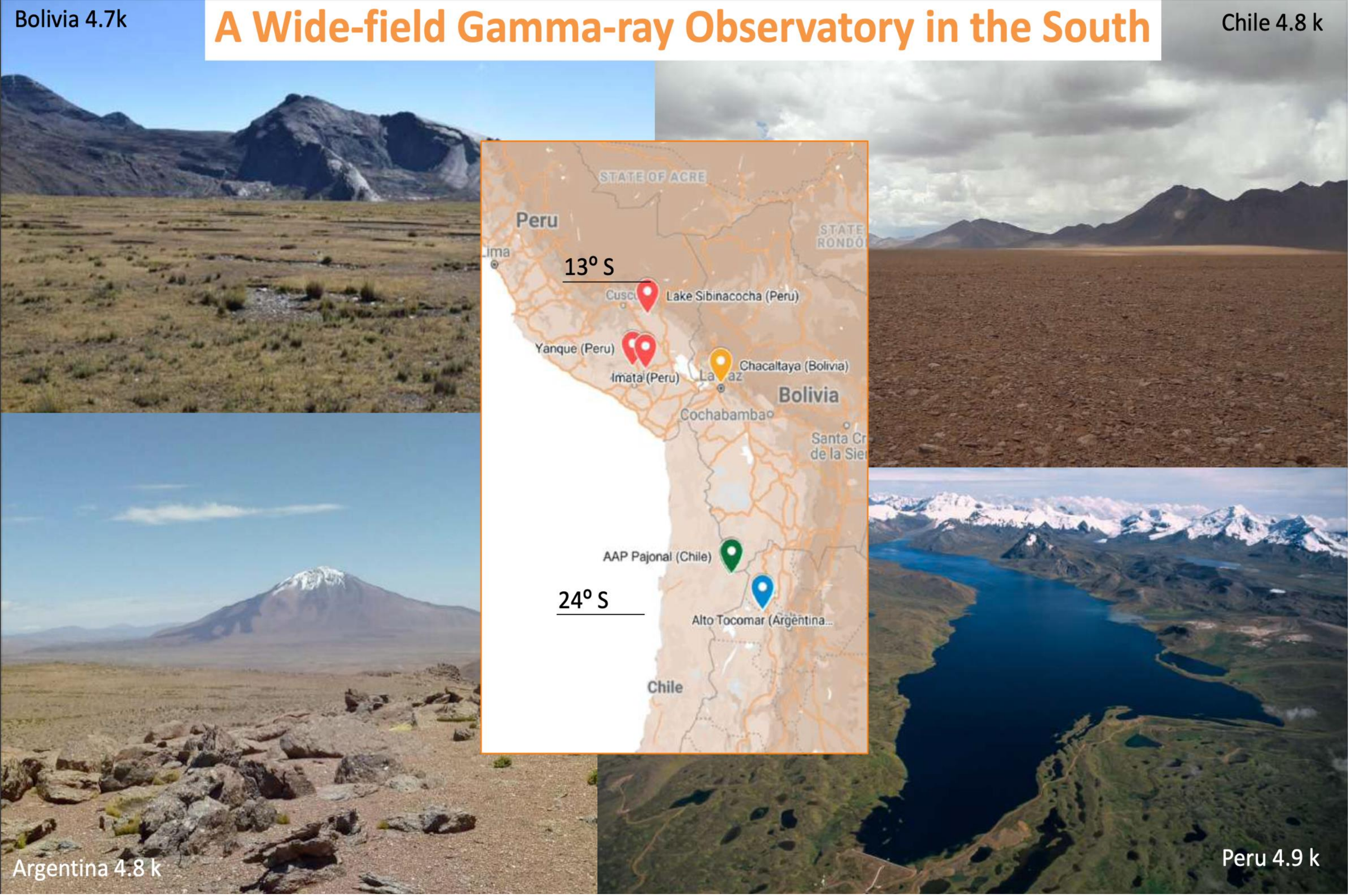
Altitude: 4,700 m a.s.l.

✧ muon counting



SWGO White paper arXiv:1902.08429

A Wide-field Gamma-ray Observatory in the South

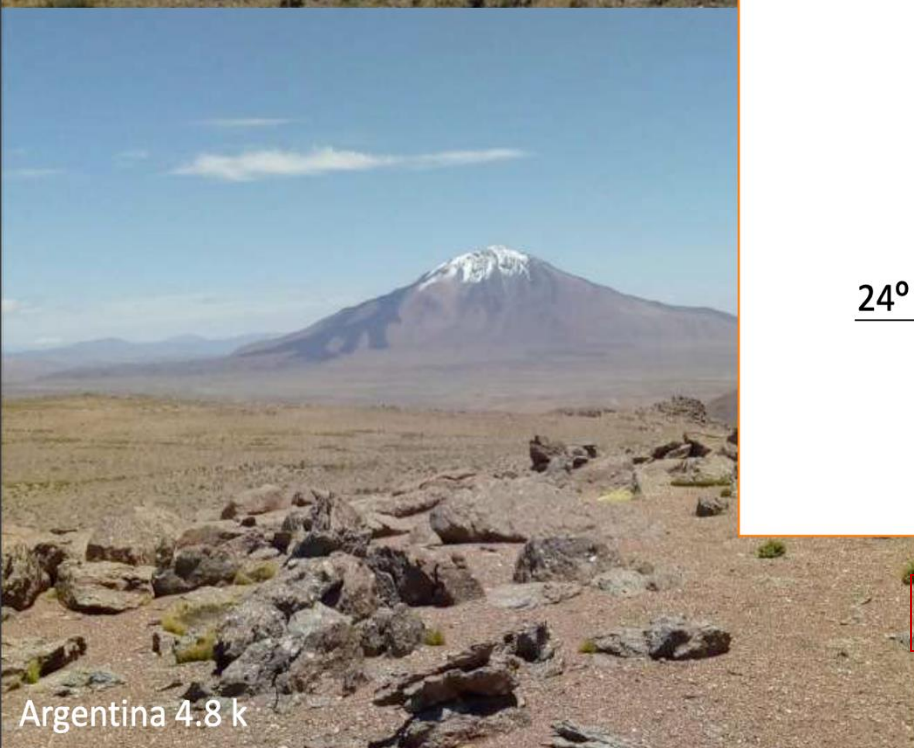


A Wide-field Gamma-ray Observatory in the South

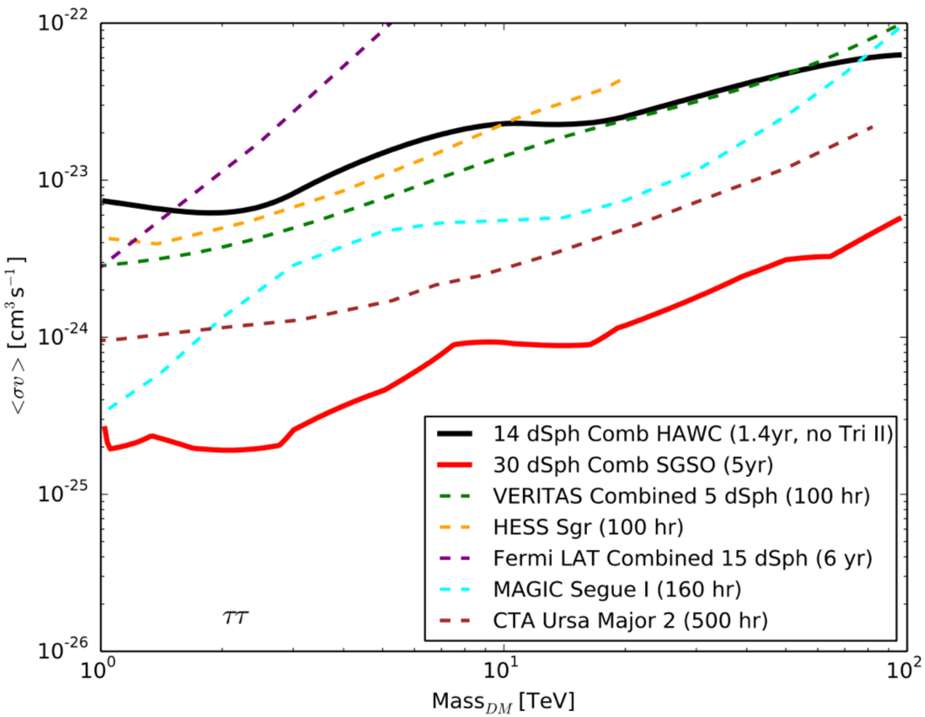
Shortlisting: Fall 2022
Site visits: October
Site selection: Fall 2023

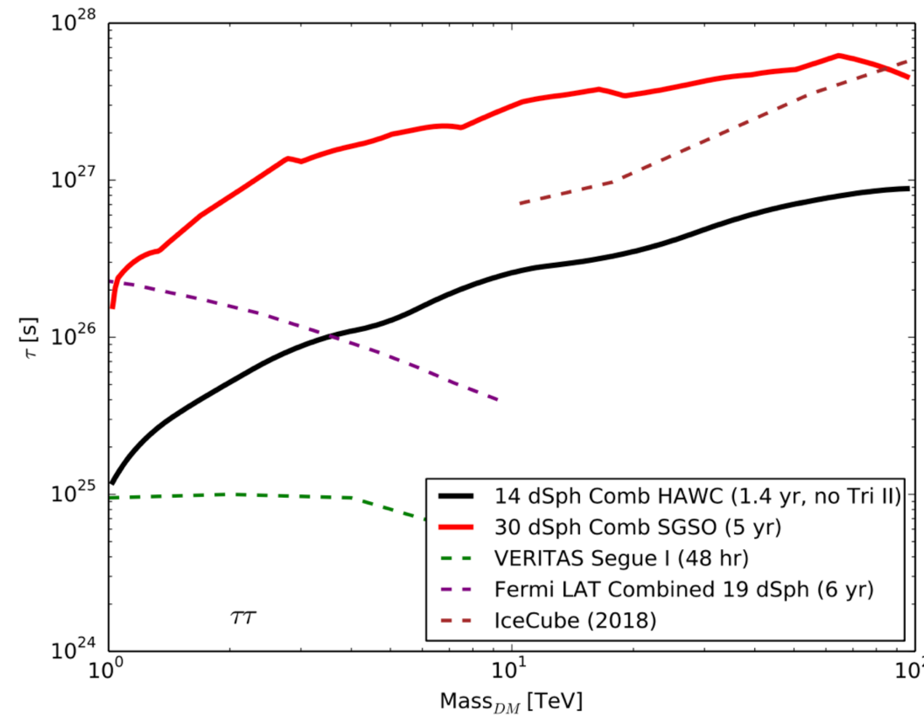
Country	Elevation	Location:
Peru	4900	Laguna Sibinacocha
Peru	4450	Imata
Peru	4450	Yanque
Argentina	4800	Cerro Vecar
Argentina	4450	Alto Tocomar
Chile	4700	ALMA Pampa La Bola
Chile	4400	AAP Pajonales
Bolivia	4700	ALPACA area

Selected as Preferred Site for SWGO Aug.24



SWGO sensitivities

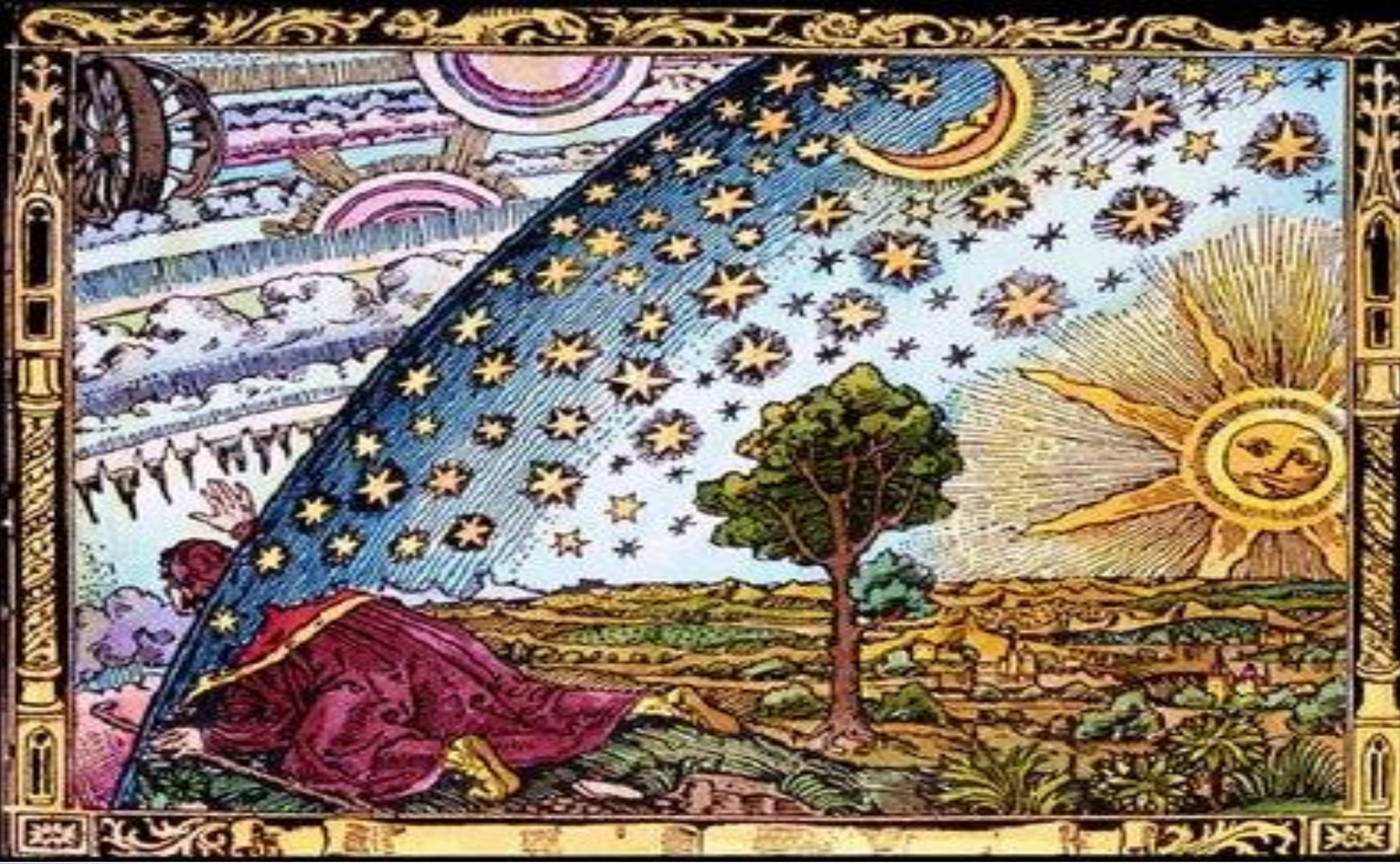




Assumed new dSph discovery and
J-factor and D-factor distributions of the new dSphs matches that of the previously known dSphs

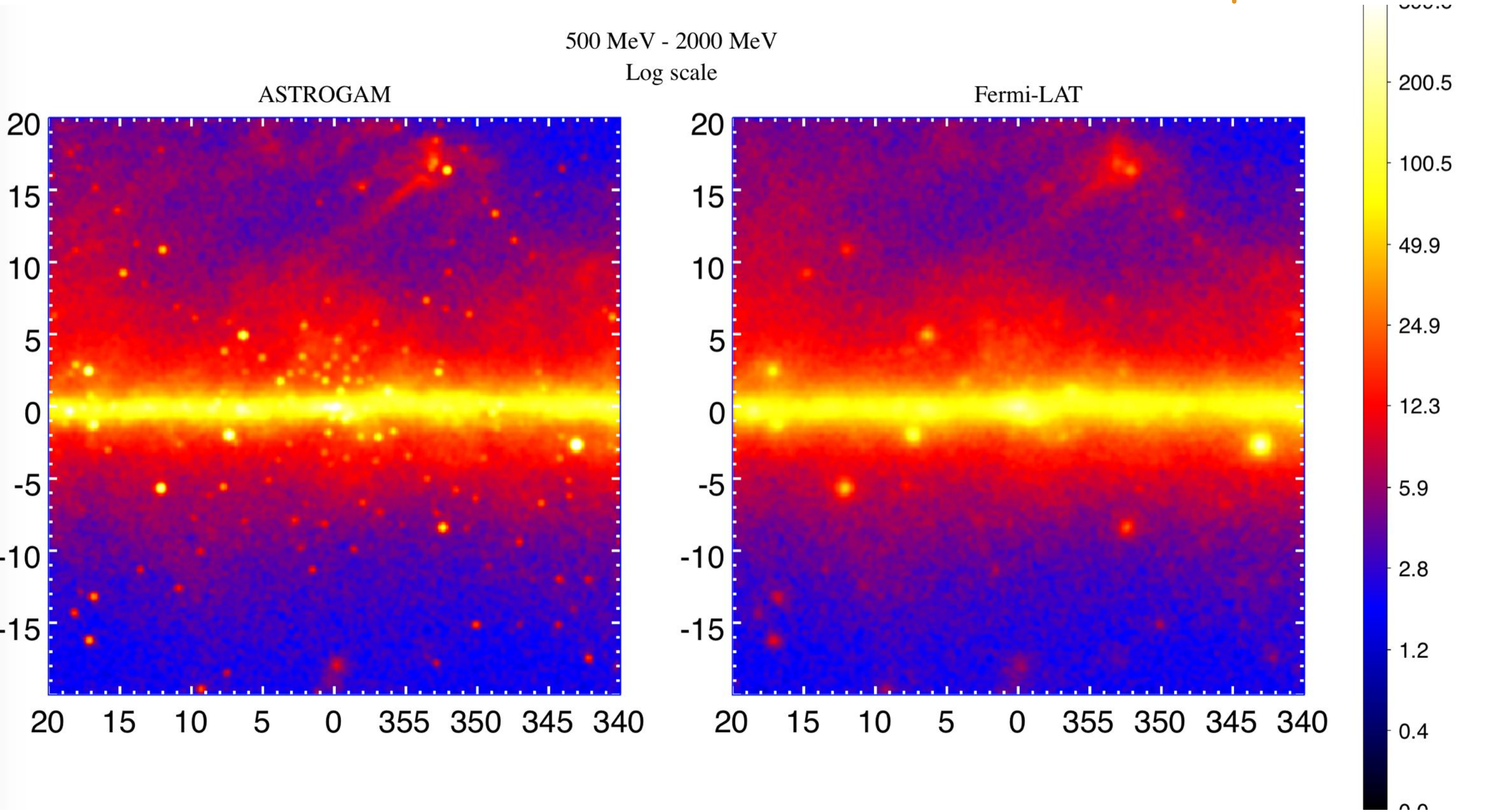
SWGO White paper arXiv:1902.08429

The Low Energy Frontier



Galactic Center Region 0.5-2 GeV

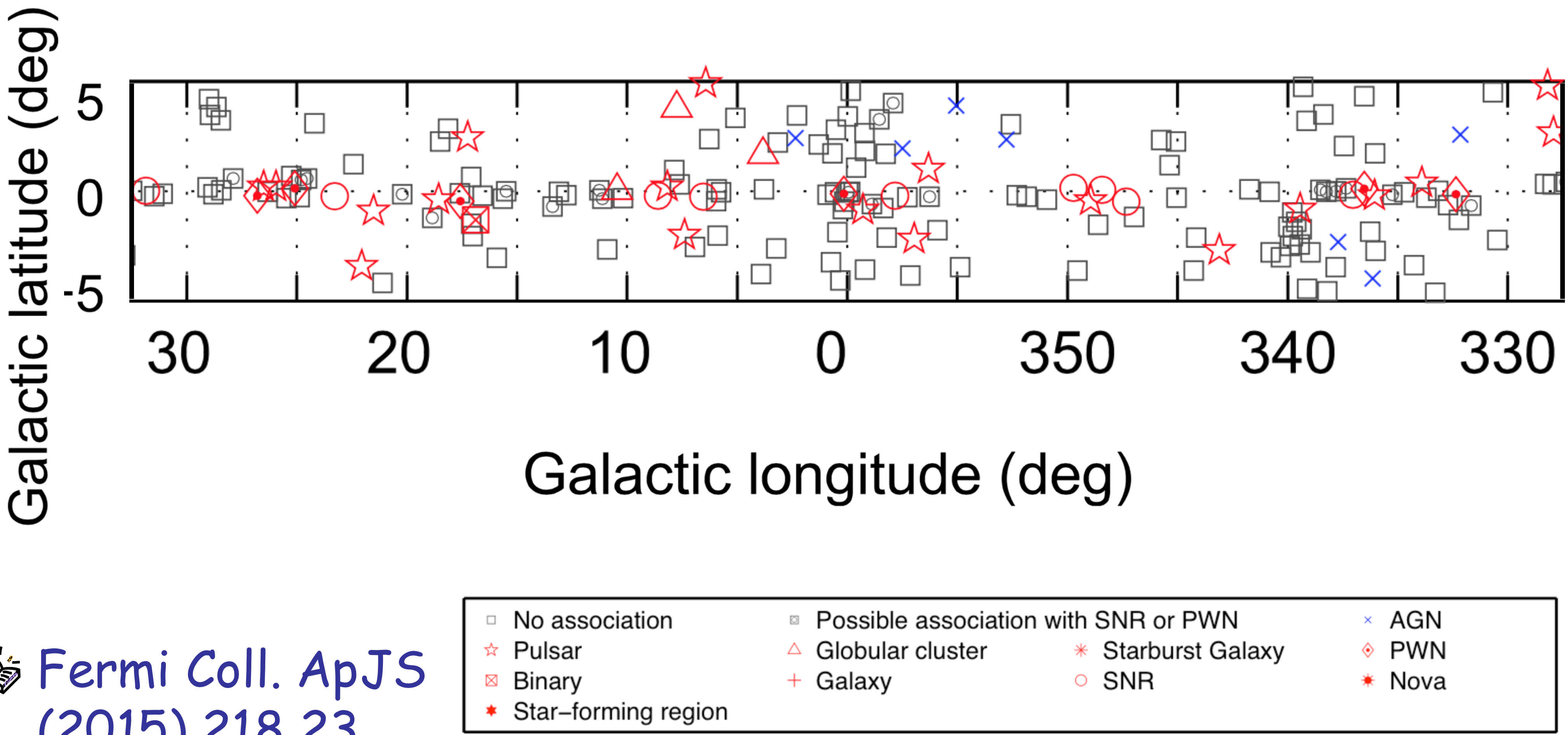
Fermi PSF Pass7 rep v15 source



The Fermi LAT 3FGL Inner Galactic Region

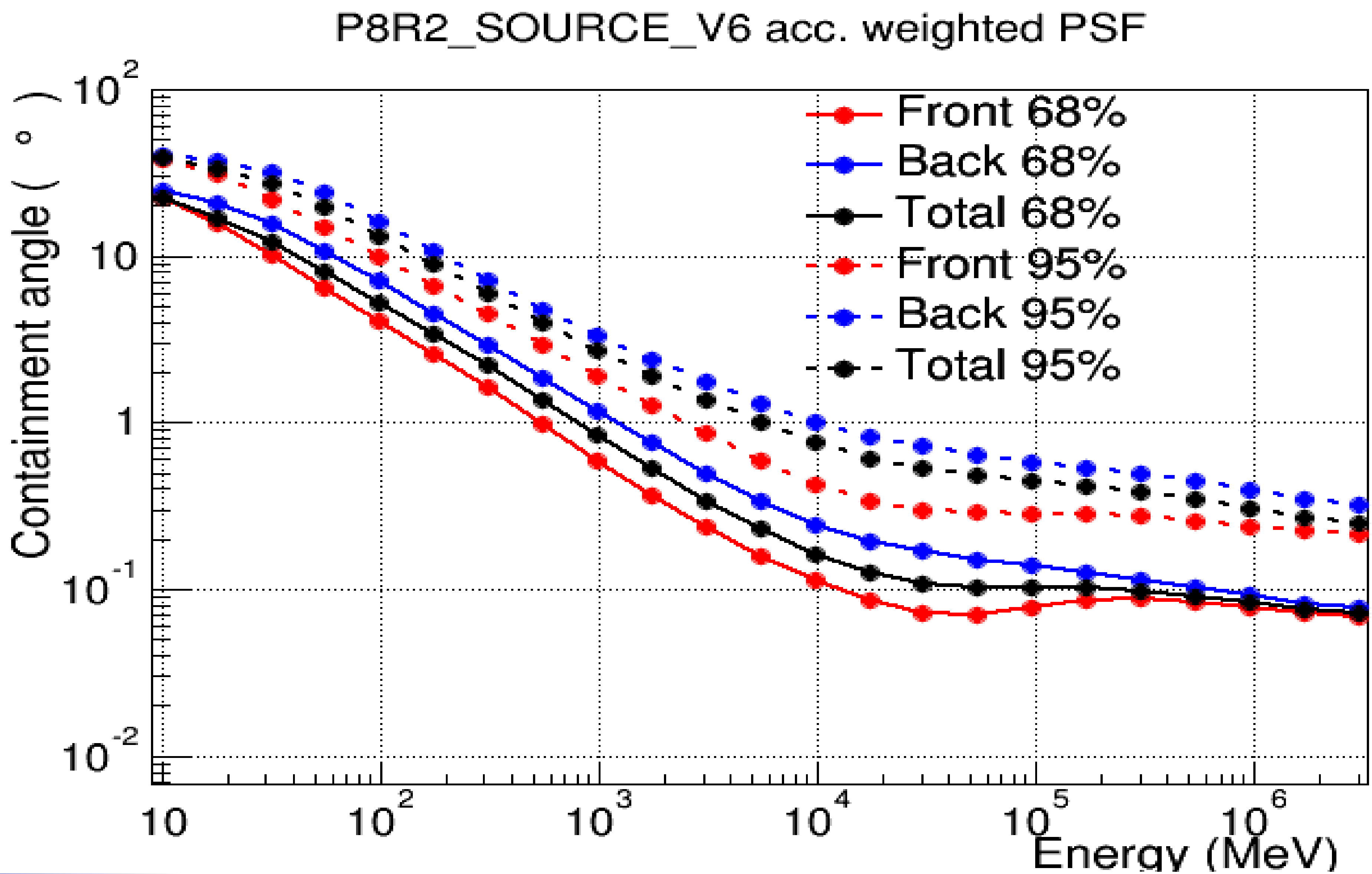
August 4, 2008, to July 31, 2010

100 MeV to 300 GeV energy range

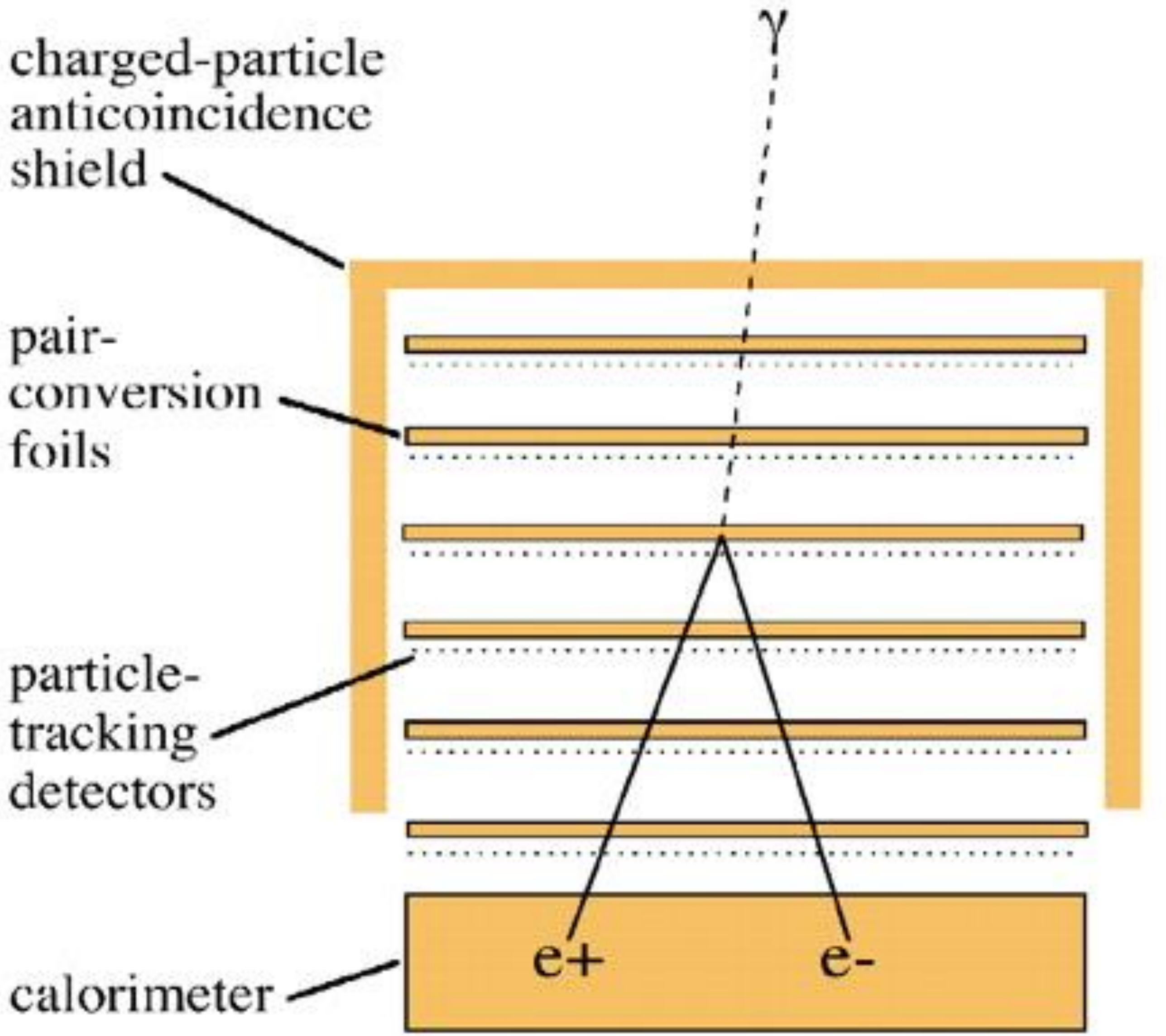


Fermi Coll. ApJS (2015) 218 23 arXiv:1501.02003

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



Elements of a pair-conversion telescope

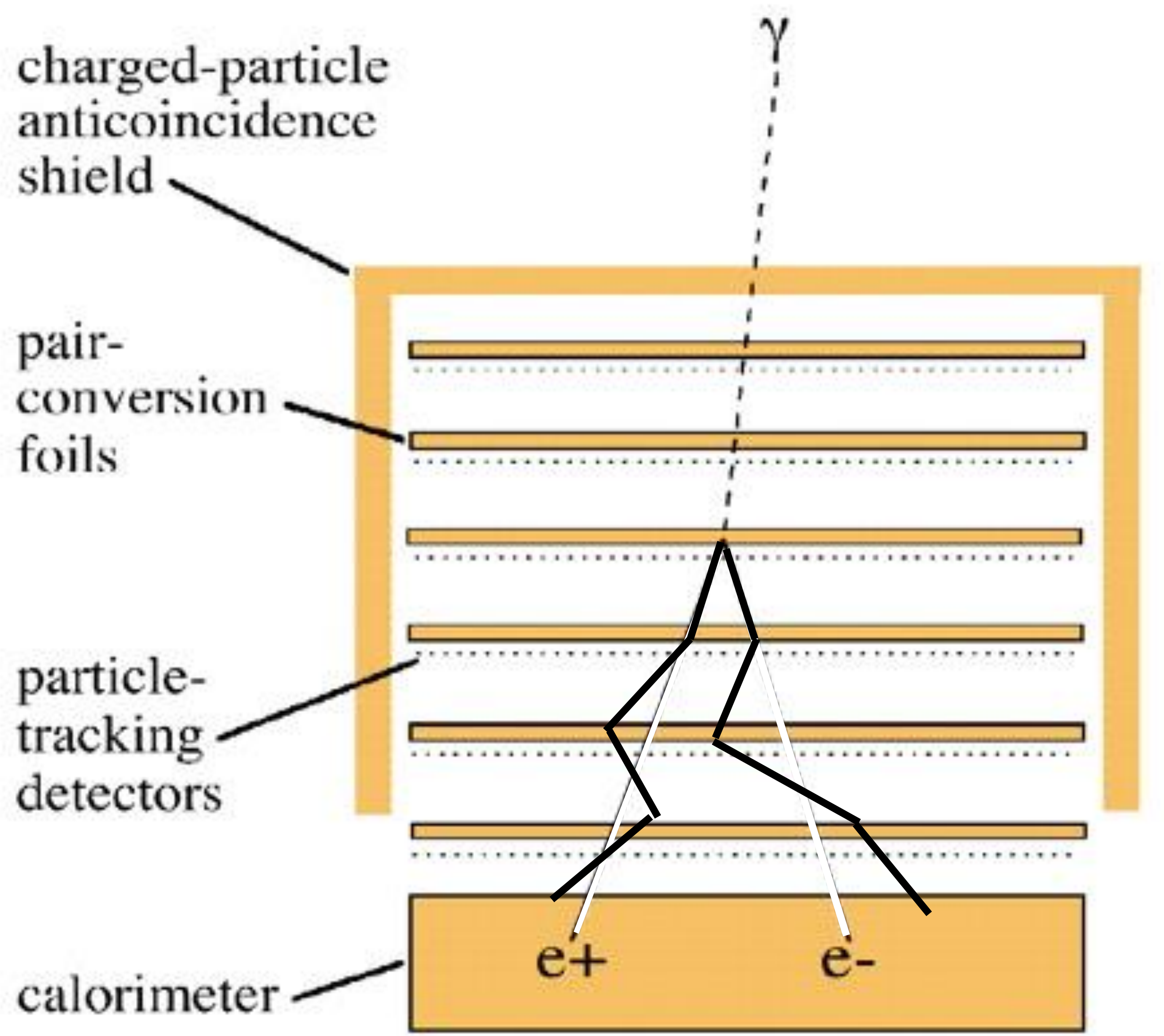


(energy measurement)

- photons materialize into matter-antimatter pairs:
  E_{γ} --> $m_{e^+}c^2 + m_{e^-}c^2$
- electron and positron carry information about the direction, energy and polarization of the γ-ray

Elements of a pair-conversion telescope

(more realistic scheme)



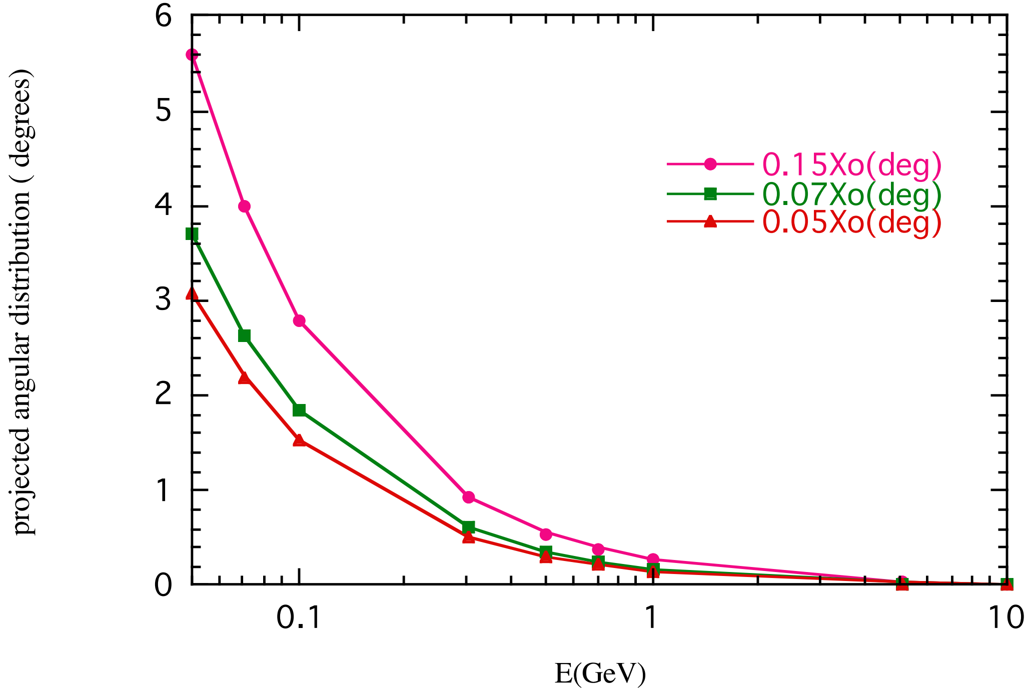
(energy measurement)

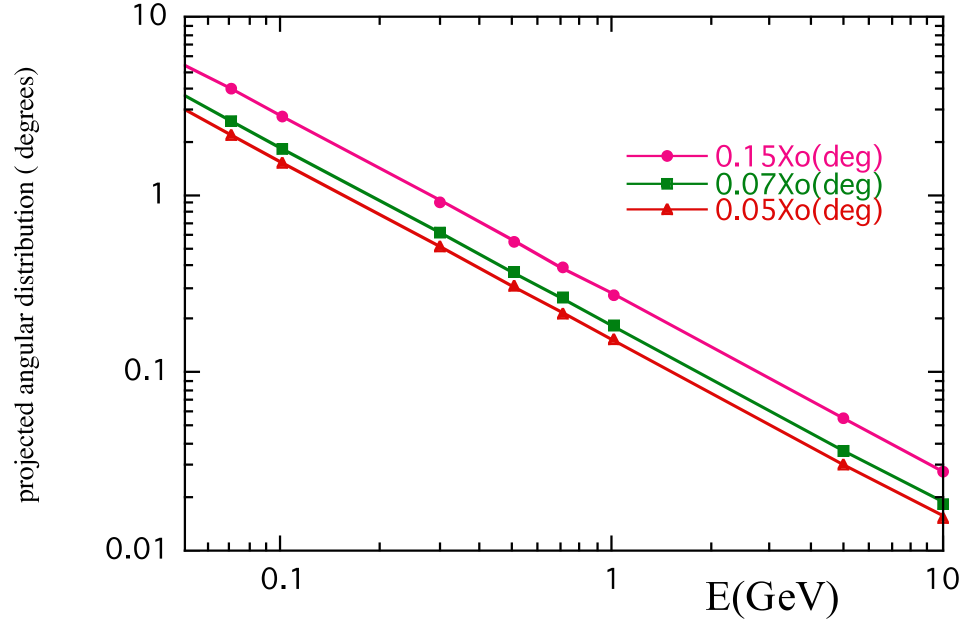
- photons materialize into matter-antimatter pairs:

  E_γ --> $m_{e^+}c^2 + m_{e^-}c^2$

- electron and positron carry information about the direction, energy and polarization of the γ-ray

Multiple Scattering

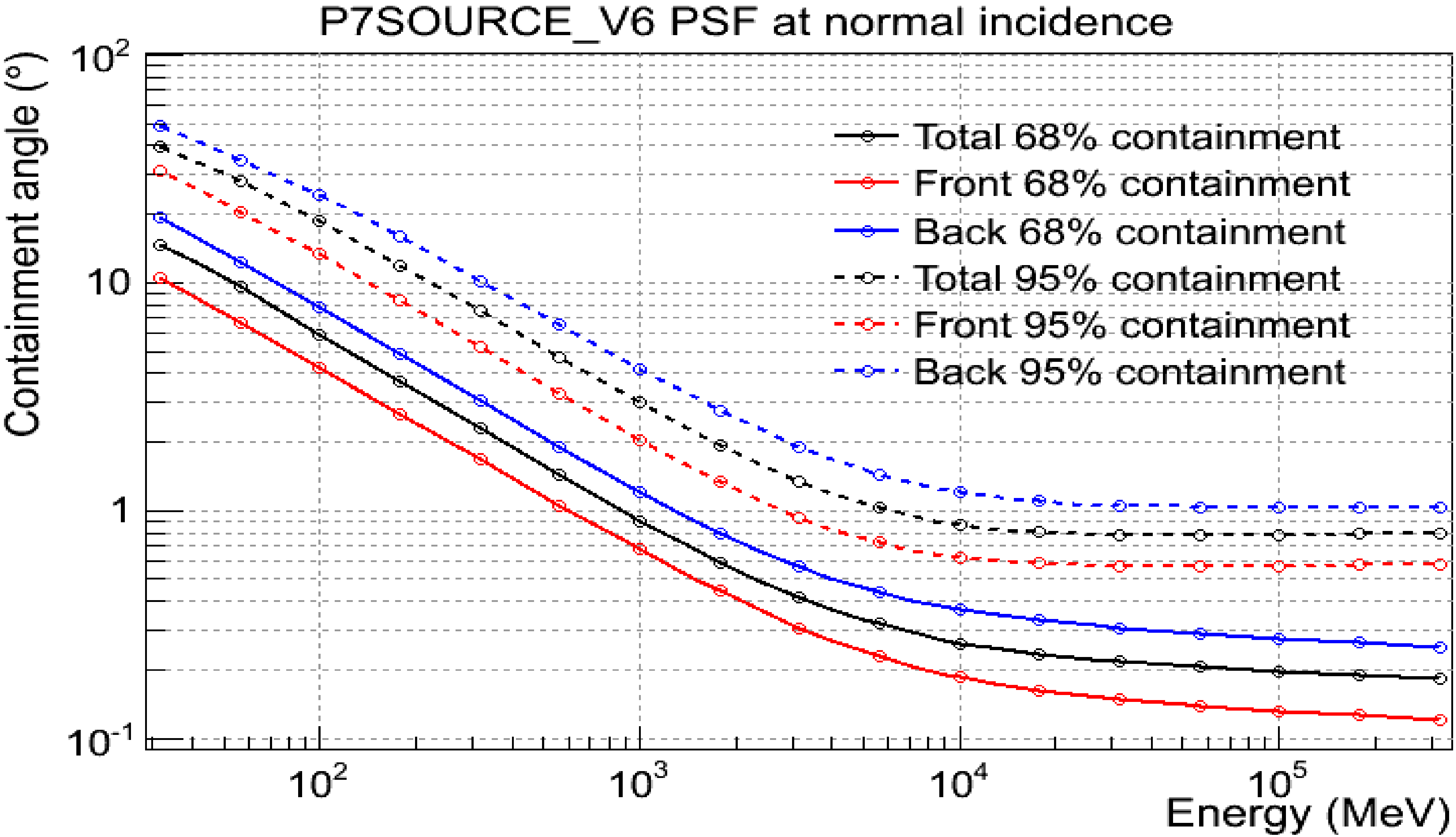




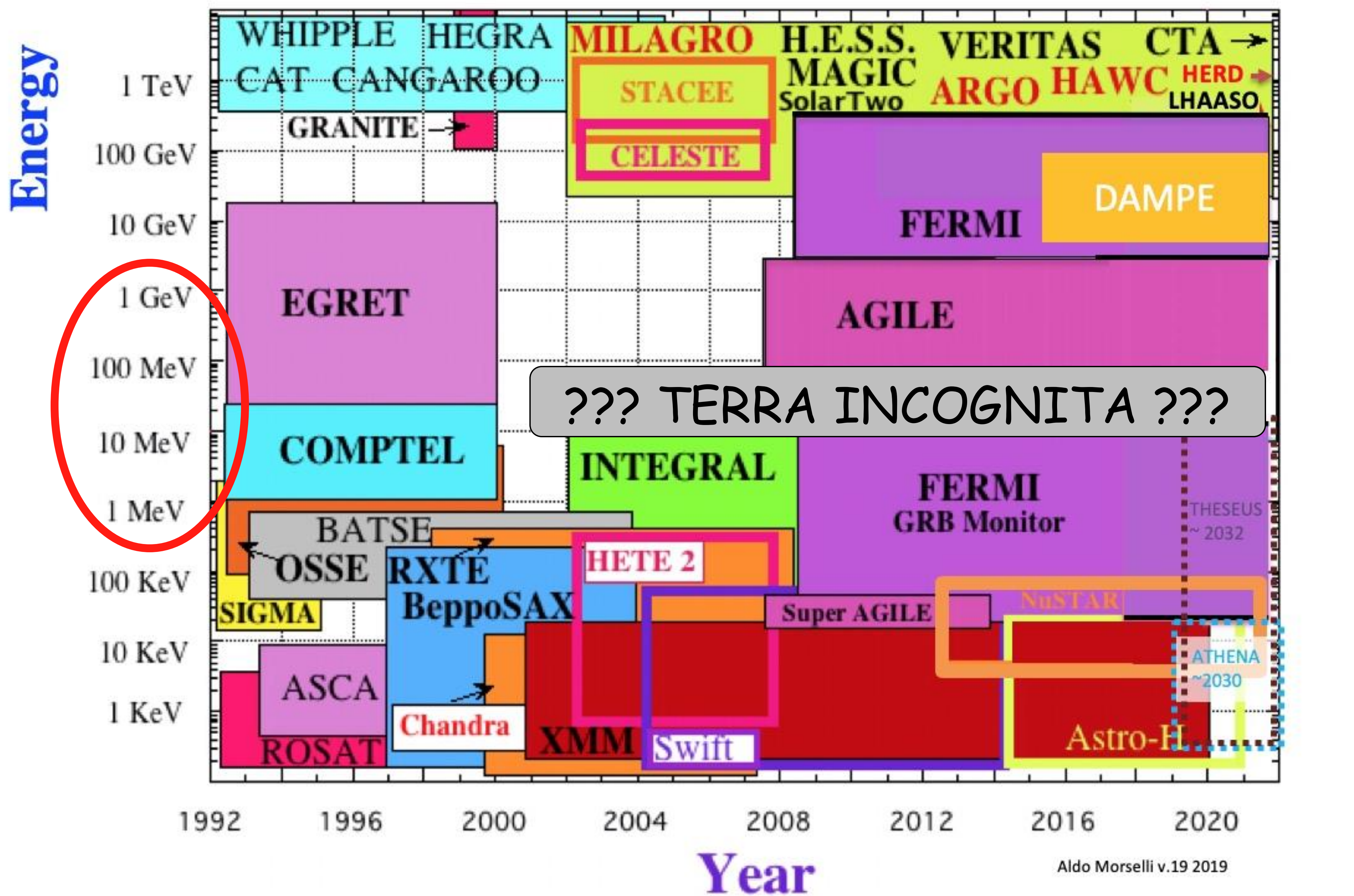
$$\theta_0 = \theta_{plane}^{rms} = \frac{1}{\sqrt{2}}\theta_{space}^{rms}$$

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

Fermi Instrument Response Function



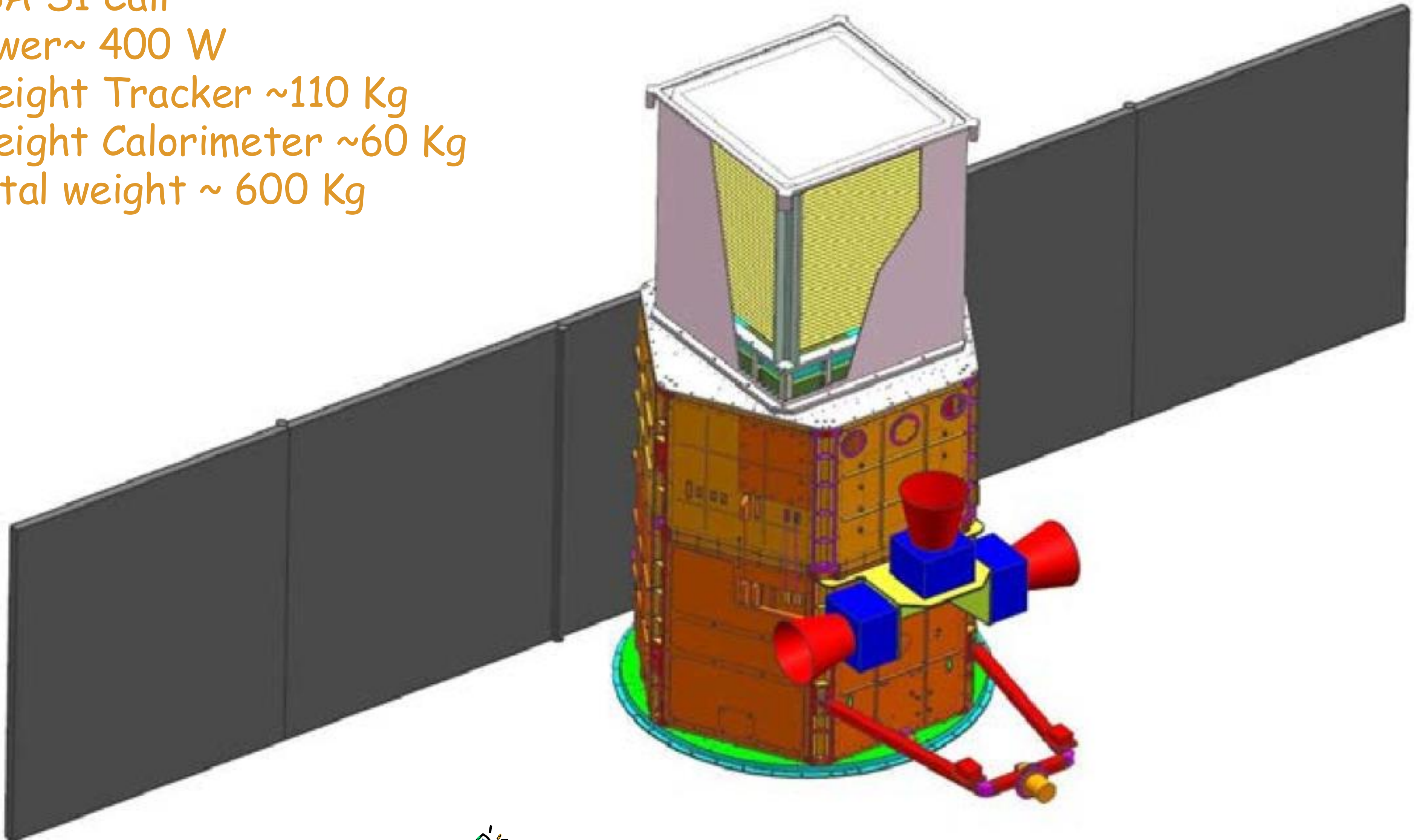
http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm


Energy
1 TeV
100 GeV
10 GeV
1 GeV
100 MeV
10 MeV
1 MeV
100 KeV
10 KeV
1 KeV
WHIPPLE
HEGRA
CAT
CANGAROO
GRANITE
MILAGRO
STACEE
CELESTE
H.E.S.S.
MAGIC
SolarTwo
VERITAS
ARGO
HAWC
CTA
HERD
LHAASO
FERMI
DAMPE
EGRET
AGILE
??? TERRA INCOGNITA ???
COMPTEL
INTEGRAL
FERMI
GRB Monitor
THESEUS
~ 2032
BATSE
OSSE
SIGMA
RXTE
BeppoSAX
HETE 2
Super AGILE
NuSTAR
ATHENA
~2030
ASCA
Chandra
XMM
Swift
Astro-H
ROSAT
1992
1996
2000
2004
2008
2012
2016
2020
Year
Aldo Morselli v.19 2019

- 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

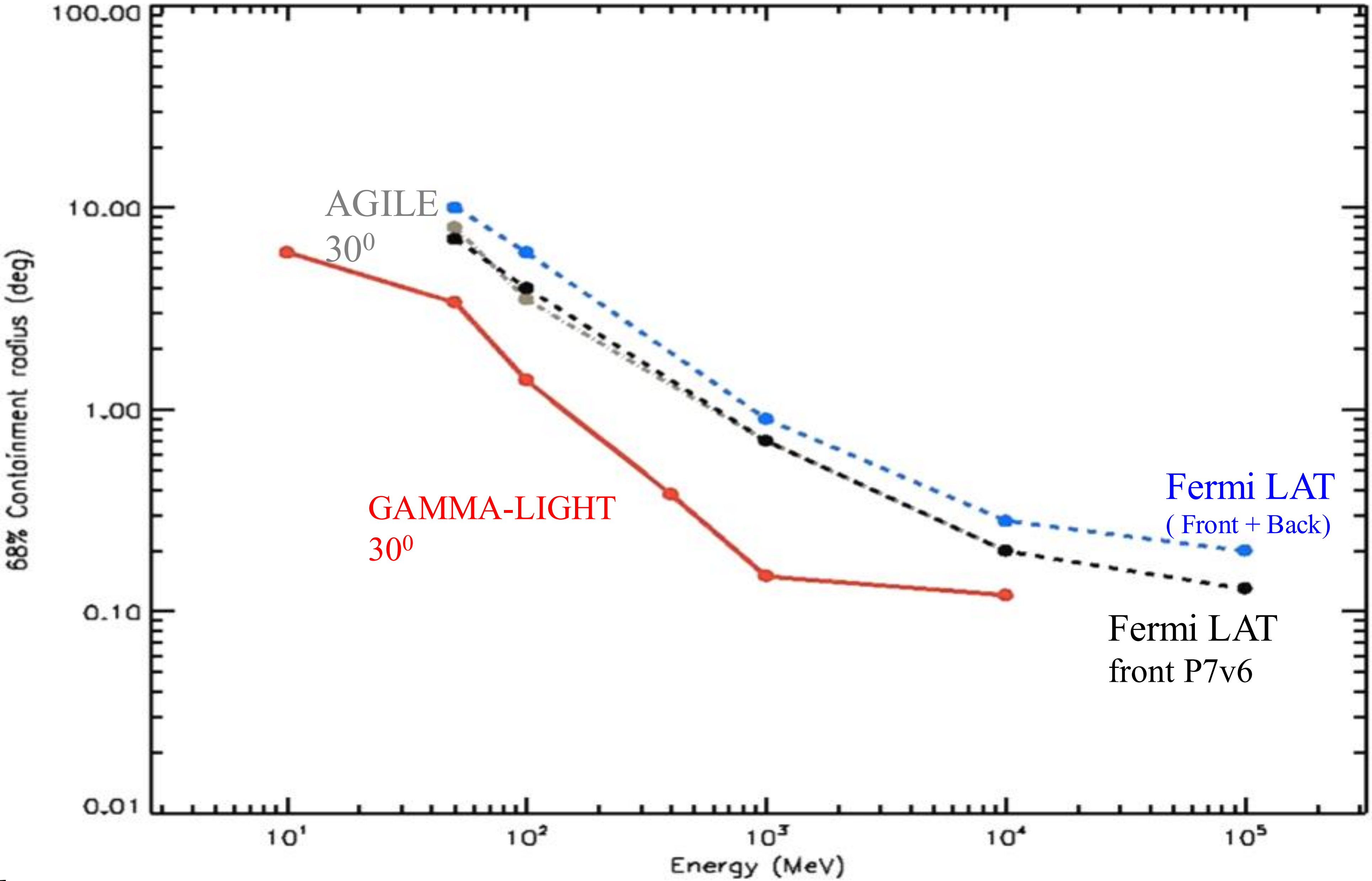
Gamma-light project

ESA S1 Call
Power~ 400 W
Weight Tracker ~110 Kg
Weight Calorimeter ~60 Kg
Total weight ~ 600 Kg



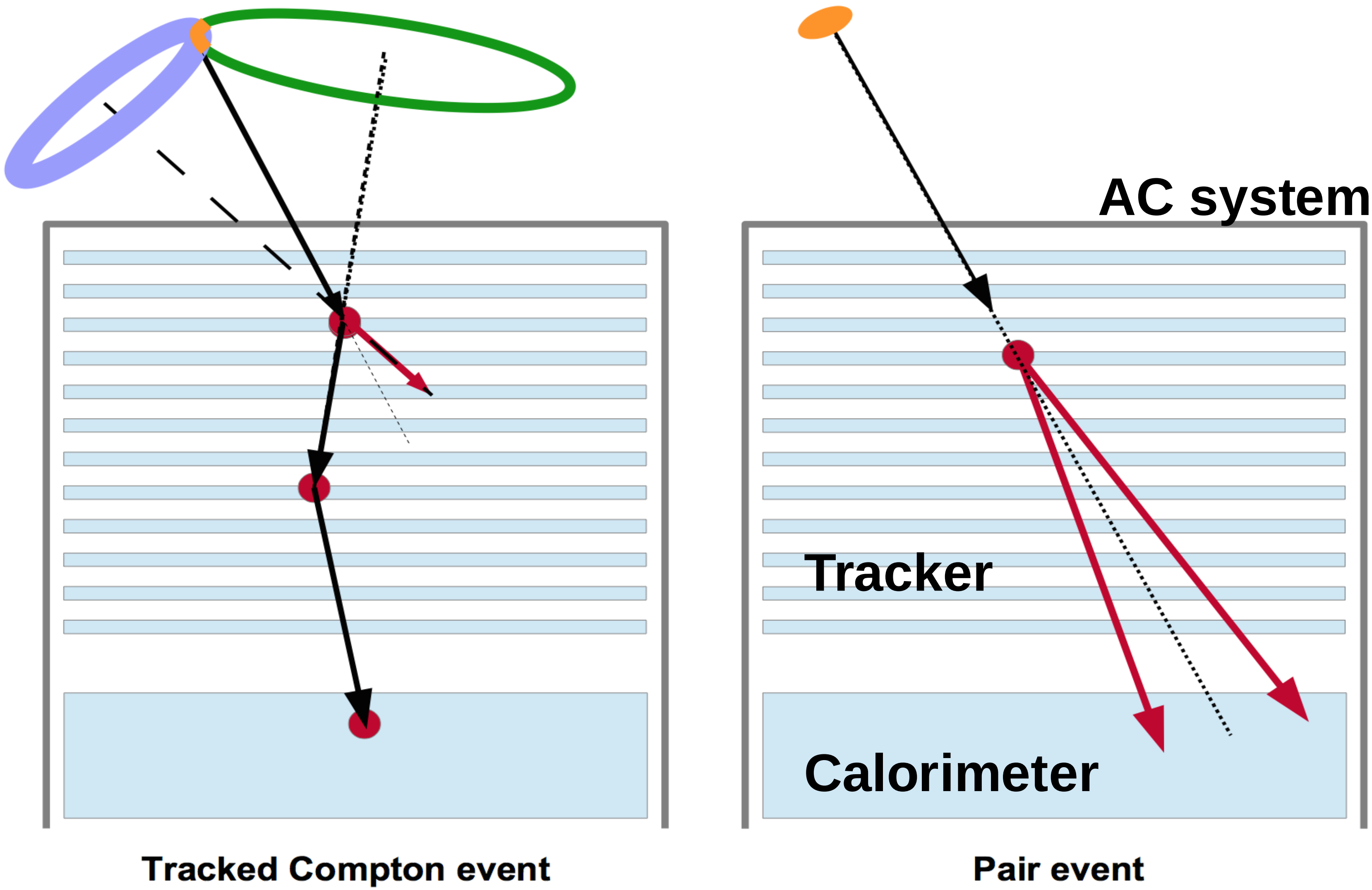
A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198 [arXiv:1406.1071]

Gamma-Light Point Spread Function (angular resolution)



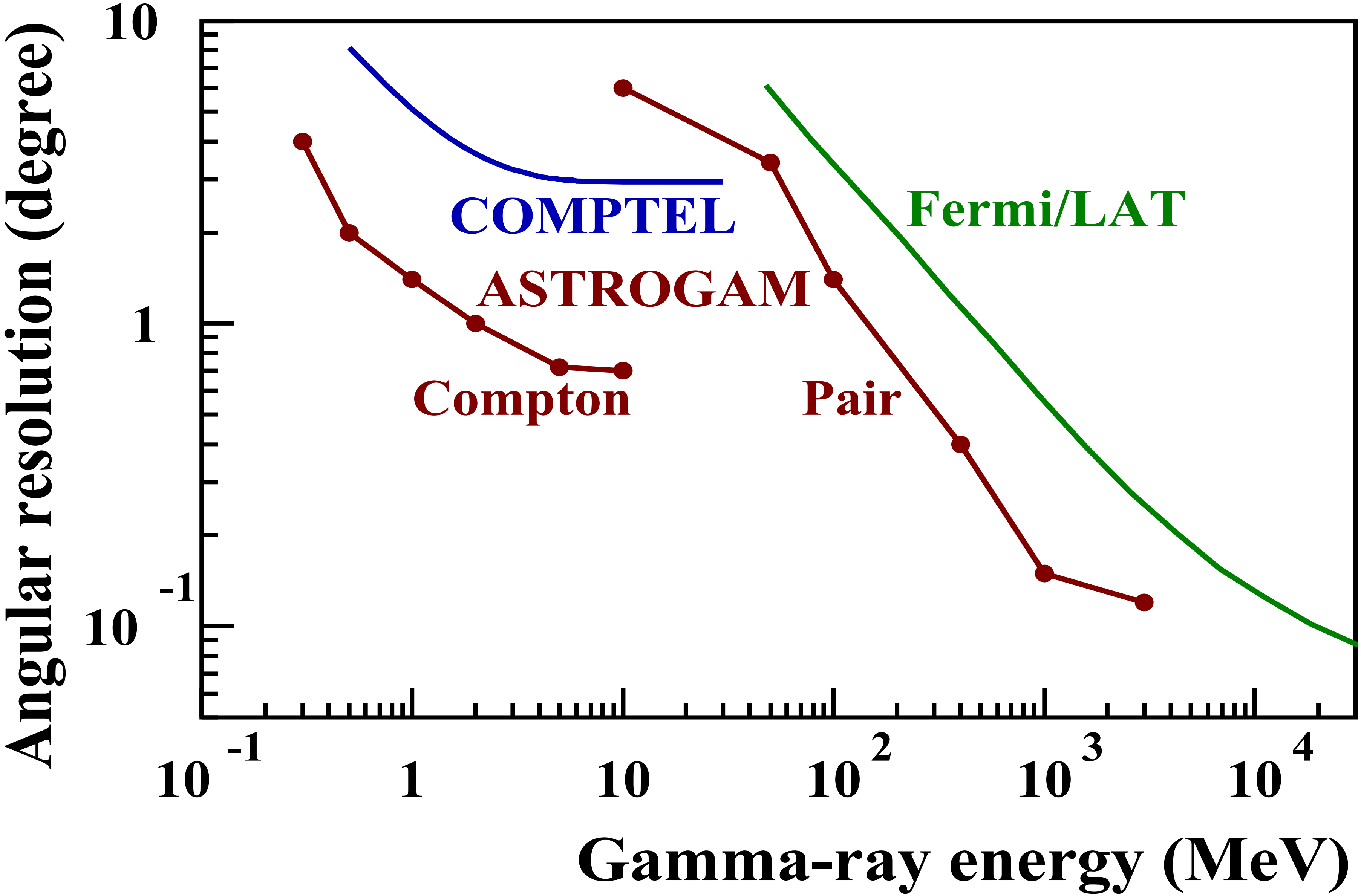
A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198 [arXiv:1406.1071]

An instrument that combine two detection techniques

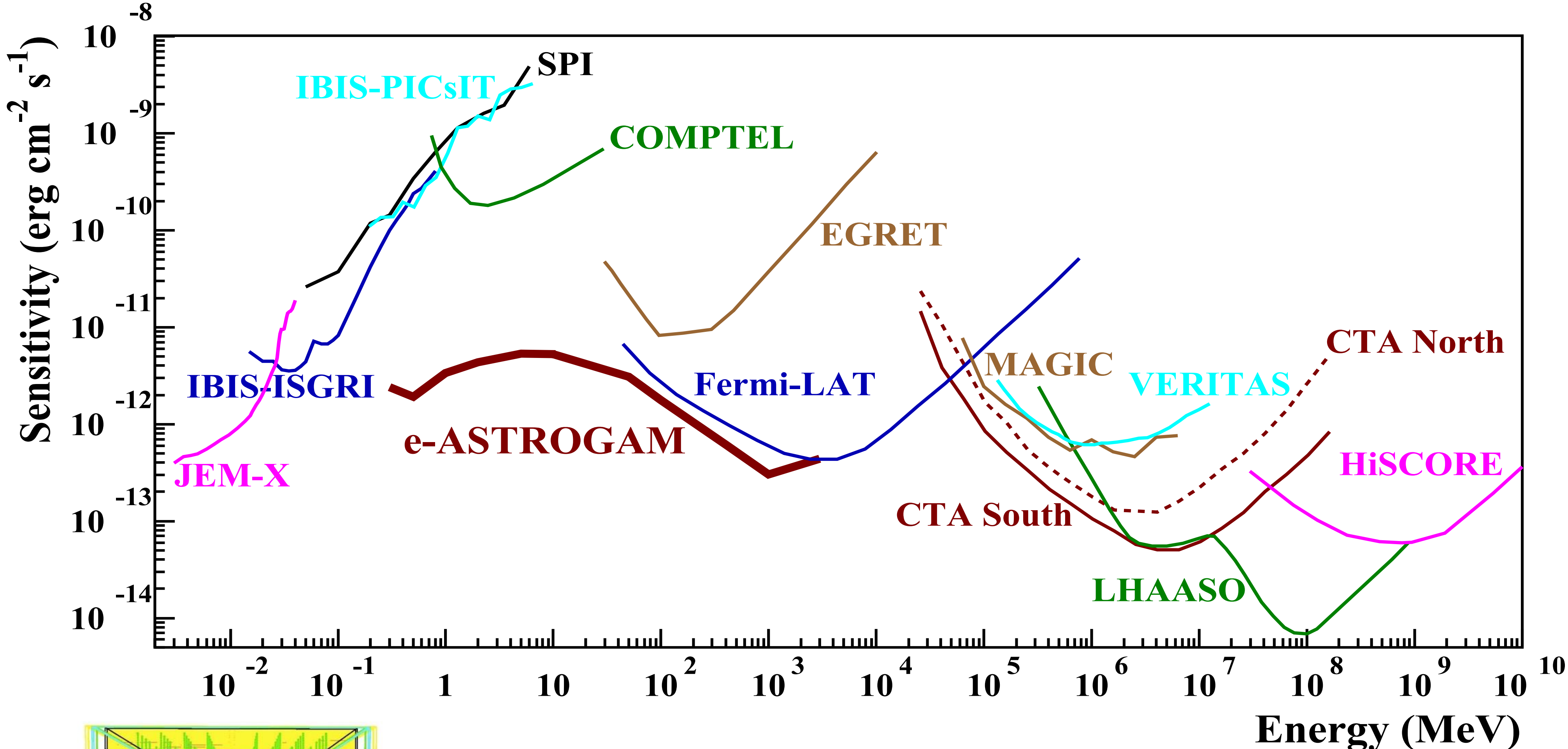


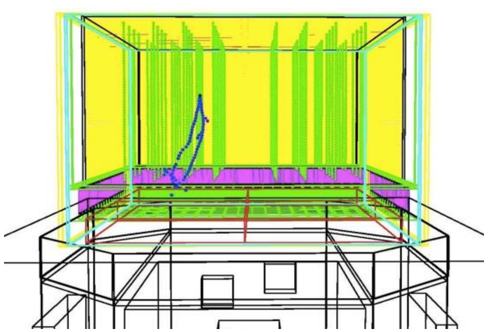

e-ASTROGAM
at the heart of the extreme Universe
An observatory for gamma rays
In the MeV/GeV domain
Detector paper: Exp. Astronomy 2017, 44, 25 arXiv:1611.02232
Science White Book: arXiv:1711.01265 (213 pages)

ASTROGAM Angular Resolution



Performance assessment

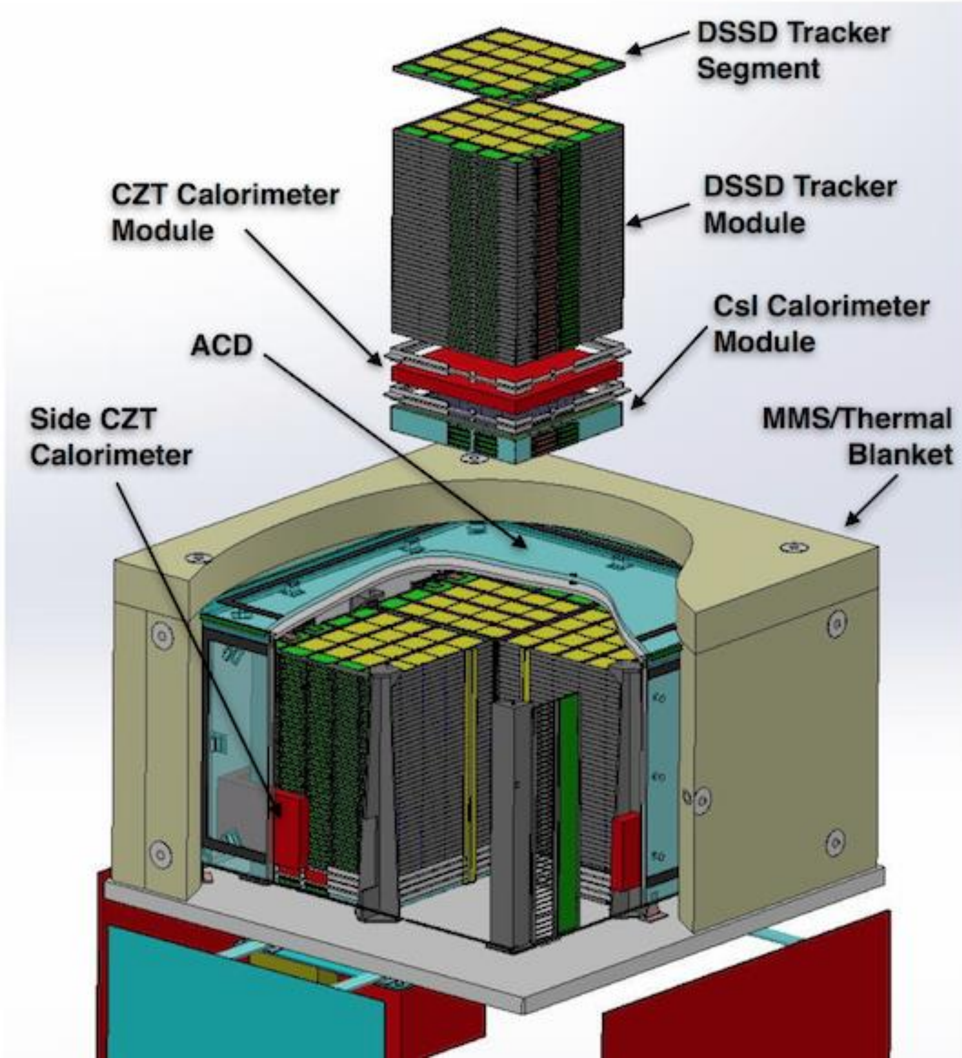


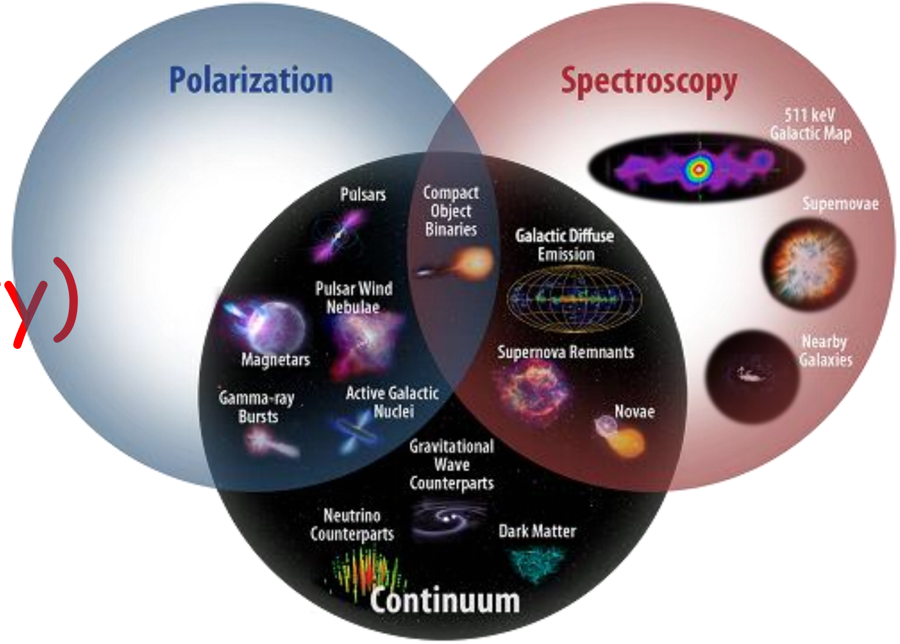


- e-ASTROGAM performance evaluated with **MEGAlib** and – both tools based on Geant4 – and a detailed numerical mass model of the gamma-ray instrument

e-Astrogam: arXiv:1611.02232

Our sister experiment: AMEGO (NASA)
(two brands, one community)

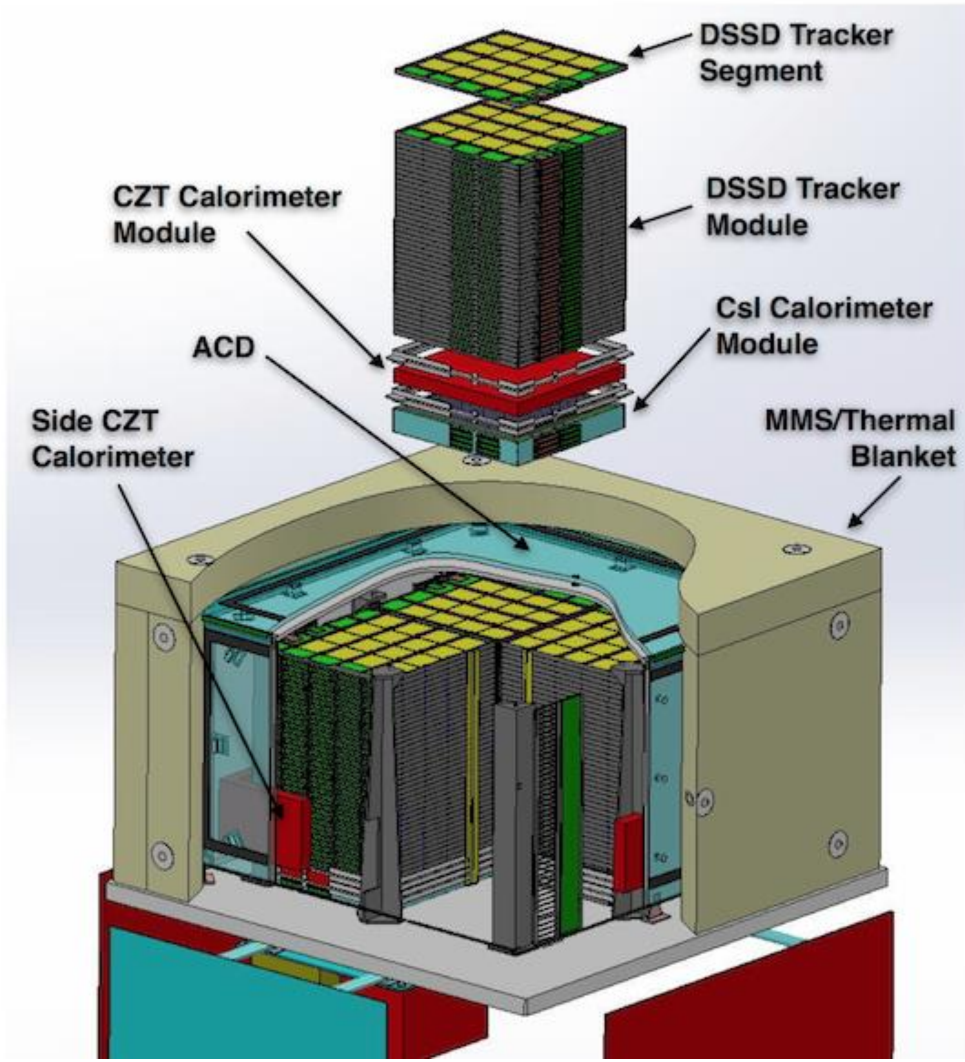




- ~20% smaller tracker
- CZT calorimeter layer

Status and Plans :
Resubmit in the next MIDEX round (~2027)

Our sister experiment: AMEGO (NASA)

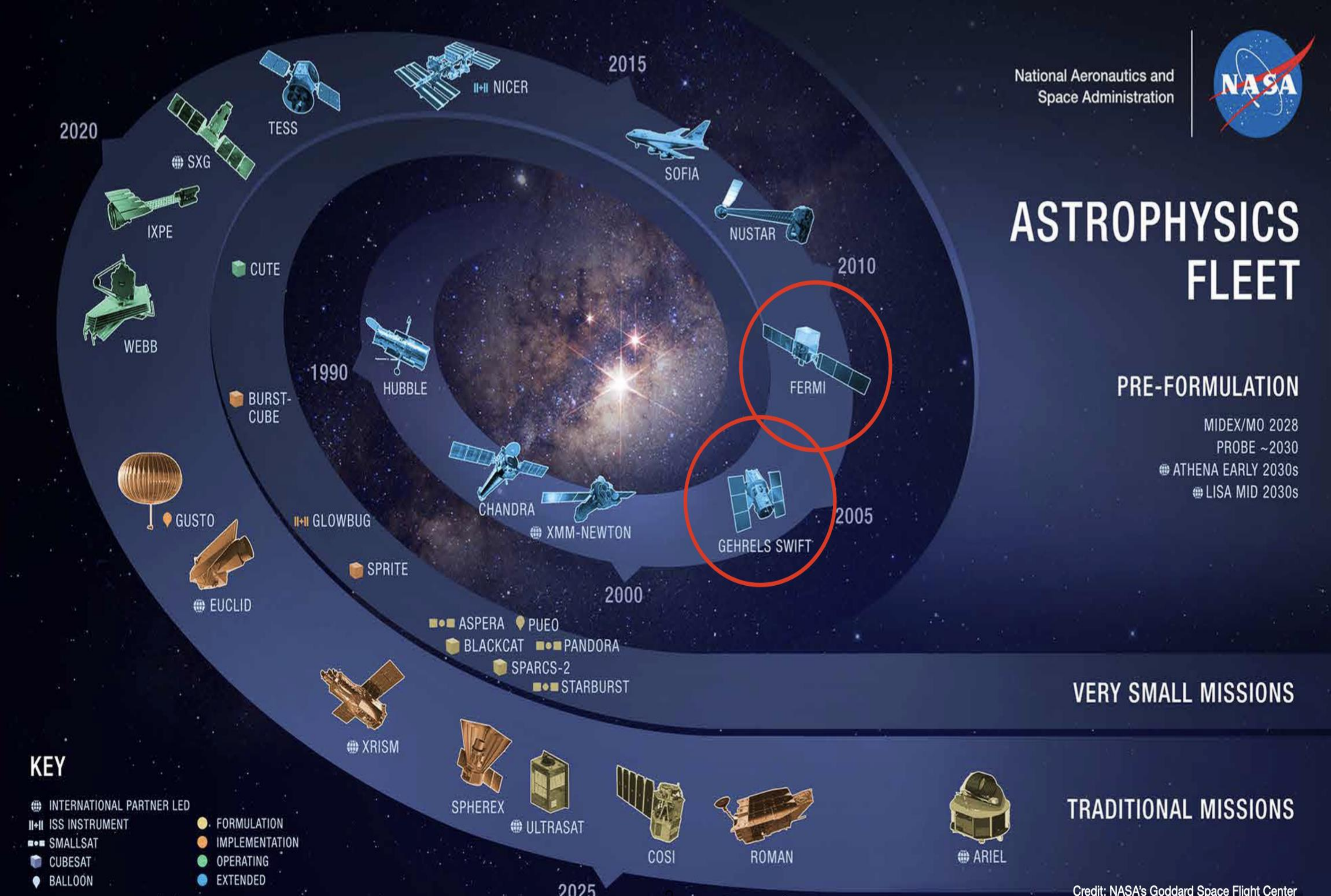


Status and Plans :
Resubmit in the next MIDEX round (~2027)

in the meantime:

Advocate to NASA via the Physics of the Cosmos Program Analysis Group (PhysPAG). This is NASA's link to the community.

- Science gaps: https://pcos.gsfc.nasa.gov/physpag/science-gaps/science-gaps.php
- Technology gaps: https://pcos.gsfc.nasa.gov/news/2024/6_Technology_Gaps_Submissions_Due.php
- Join the Gamma-ray Science Interest Group (GammaSIG)
- https://pcos.gsfc.nasa.gov/sigs/grsig.php



Updated June 2022

COSI The Compton Spectrometer and Imager

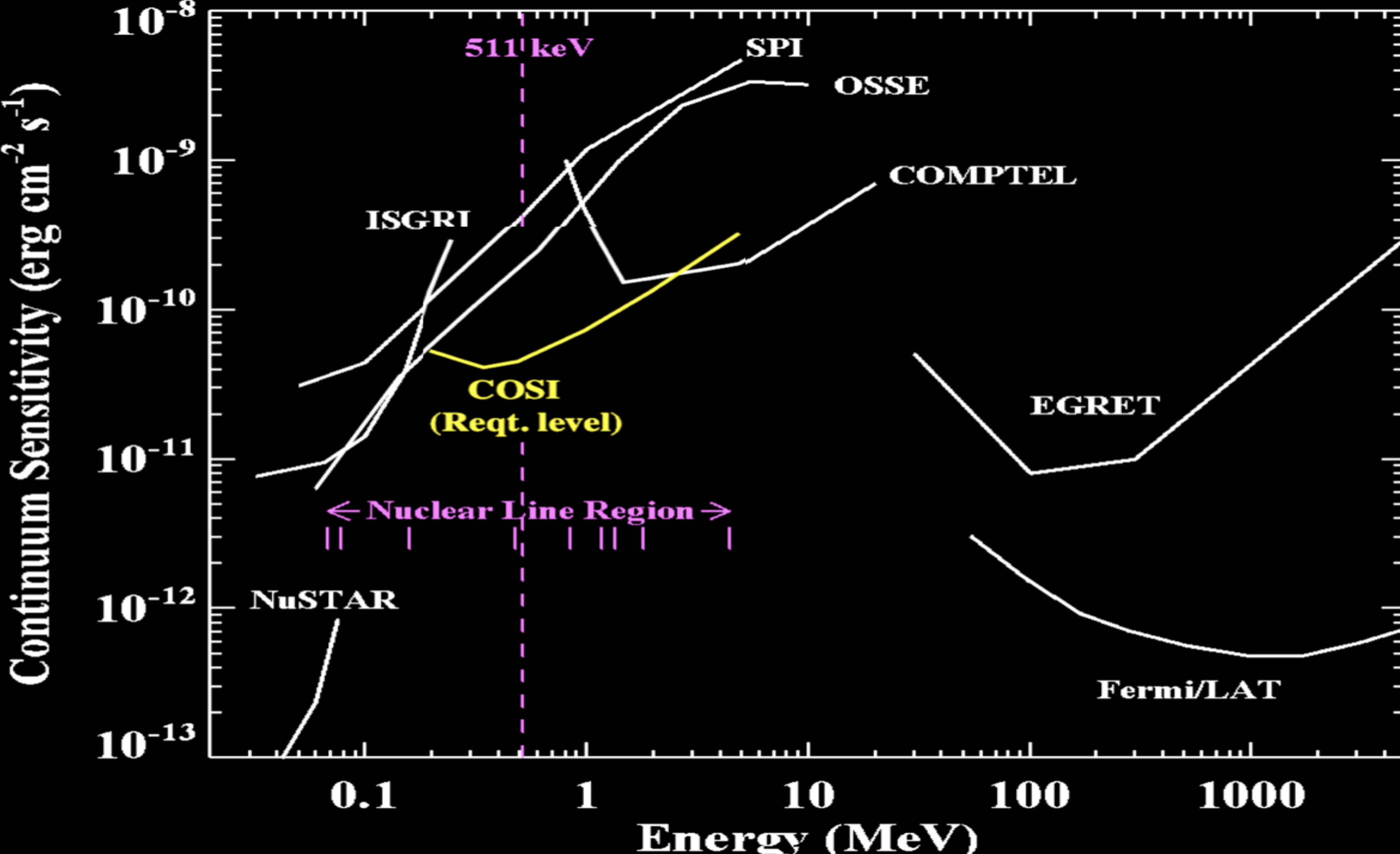
- COSI has been selected by NASA as a SMEX to launch in 2027

- a Compton telescope for observing 0.2-5 MeV gamma-rays

1. Key capabilities
   - Uses cryogenically-cooled germanium detectors (GeDs) to provide energy resolution (~1%)
   - Instantaneous field of view is >25%-sky and covers the whole sky every day

- Goal D emphasizes the connection to gravitational waves
- ▪Detects short gamma-ray bursts (GRBs) from merging neutron stars
  ▪Localizations to ~1° accuracy
  ▪Public alerts in <1 hour

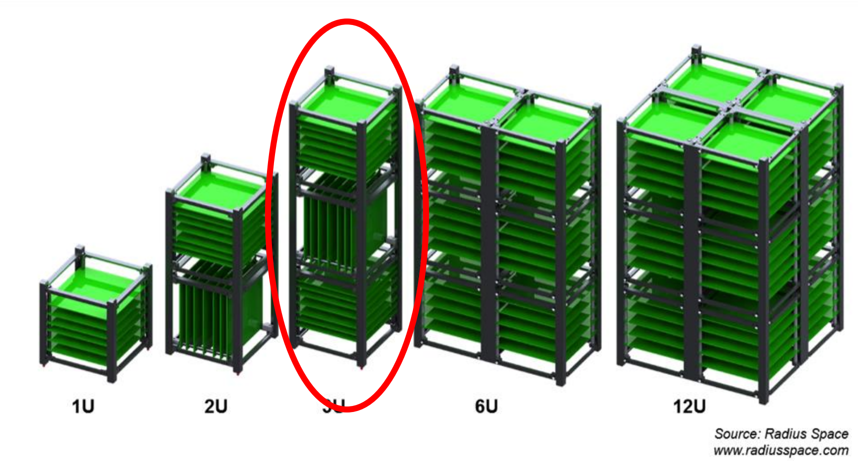
COSI

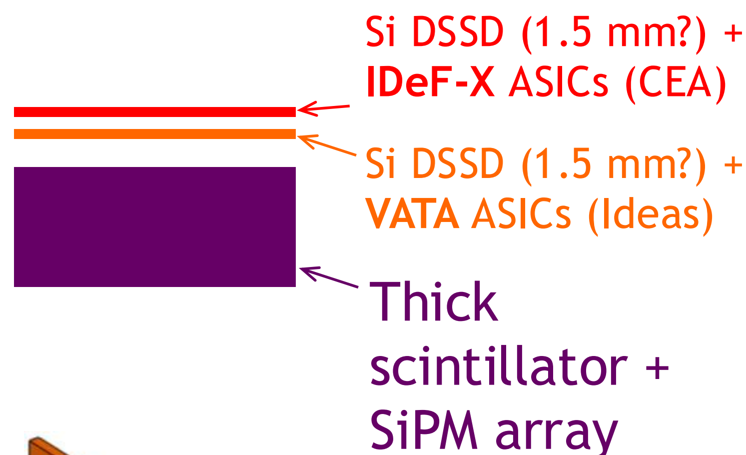


continuum emission sensitivity

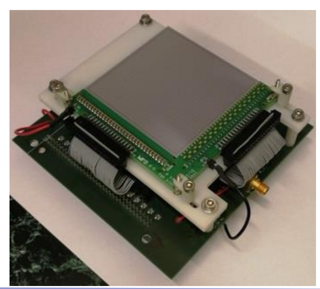
COMCUBE Nanosat sub-WP

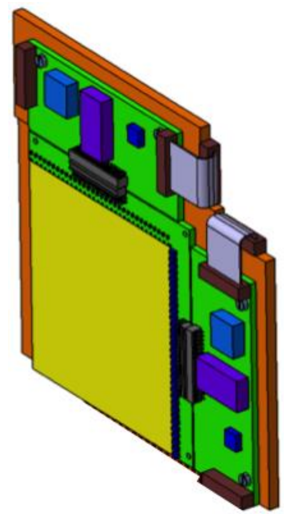
Development of a 3U (?) Compton nanosat for the polarimetry of GRBs + qualification of the e-ASTROGAM technologies



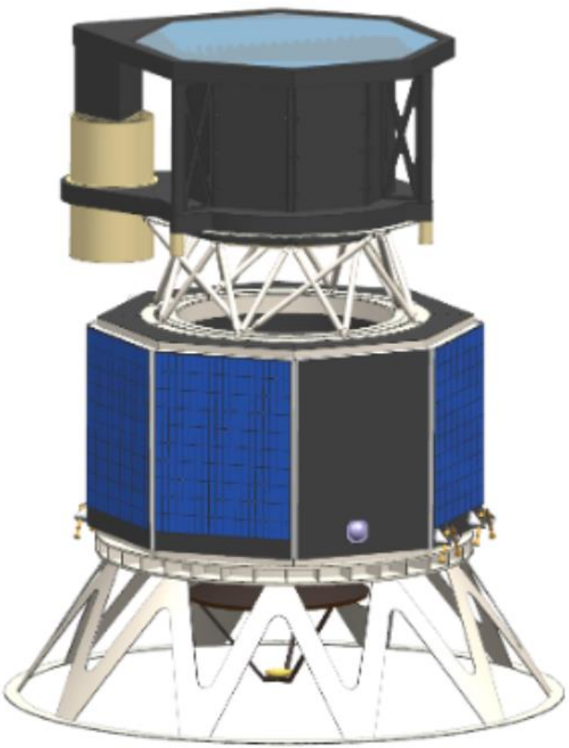


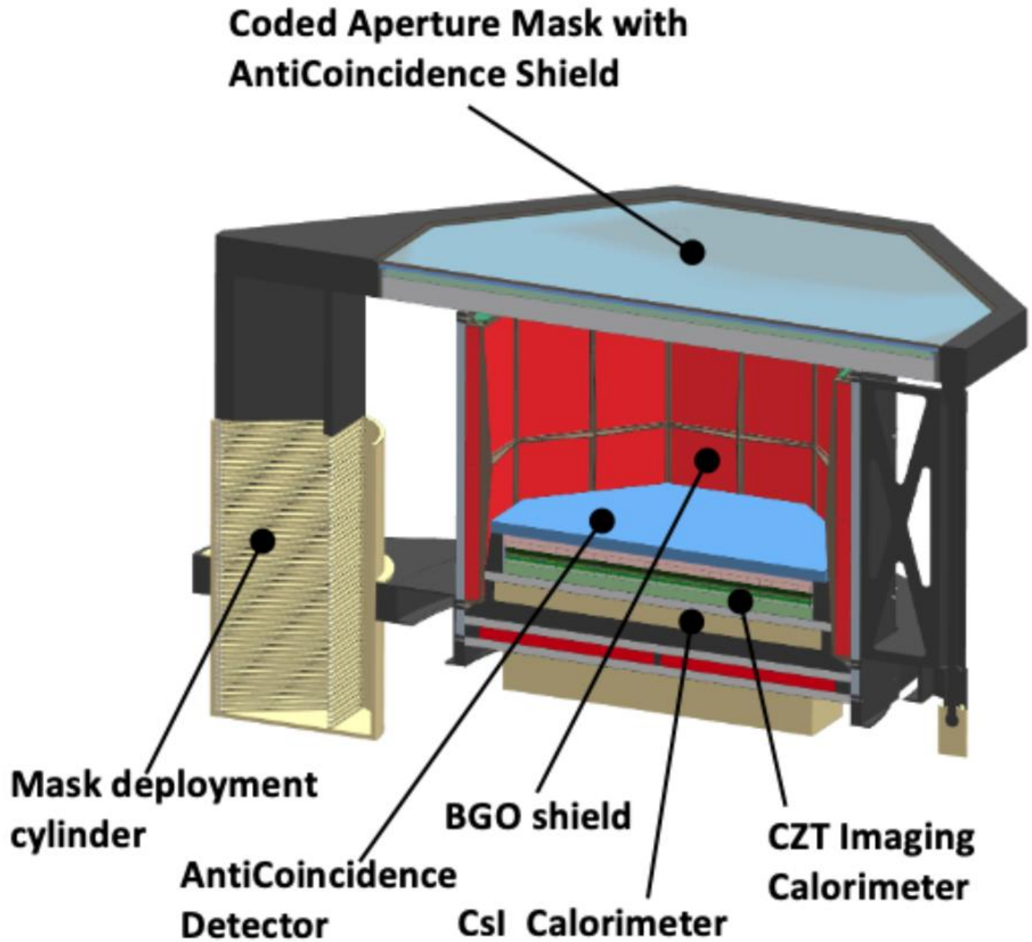
- Cubesat : standard unit ⇒ 1U
- Size : 10 x 10 x 10 cm
- Weight : 1kg
- Power : ~ 1.3 W





GECCO The Galactic Explorer with a Coded Aperture Mask Compton Telescope

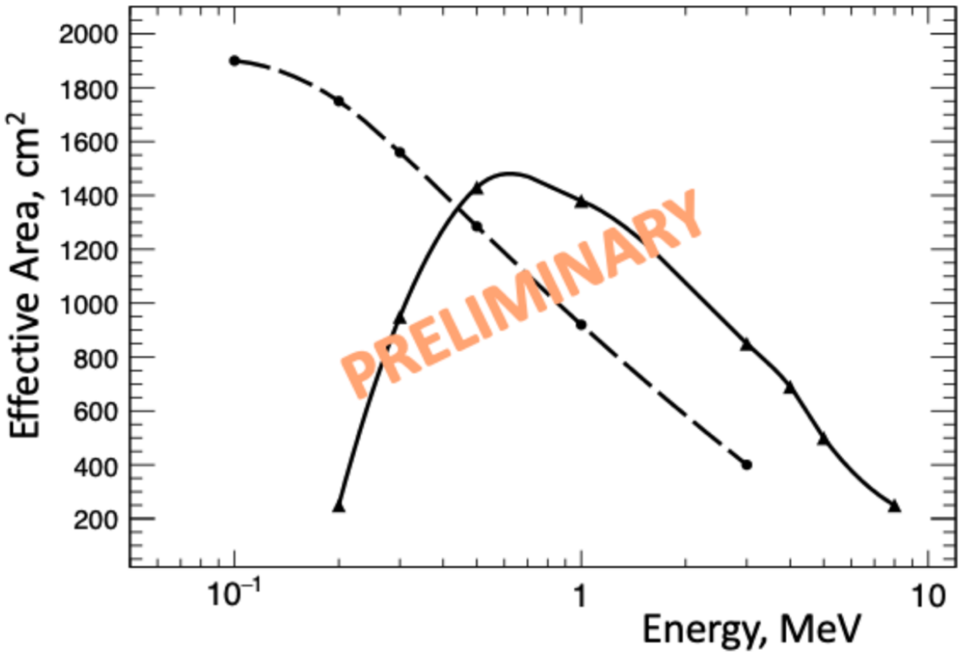




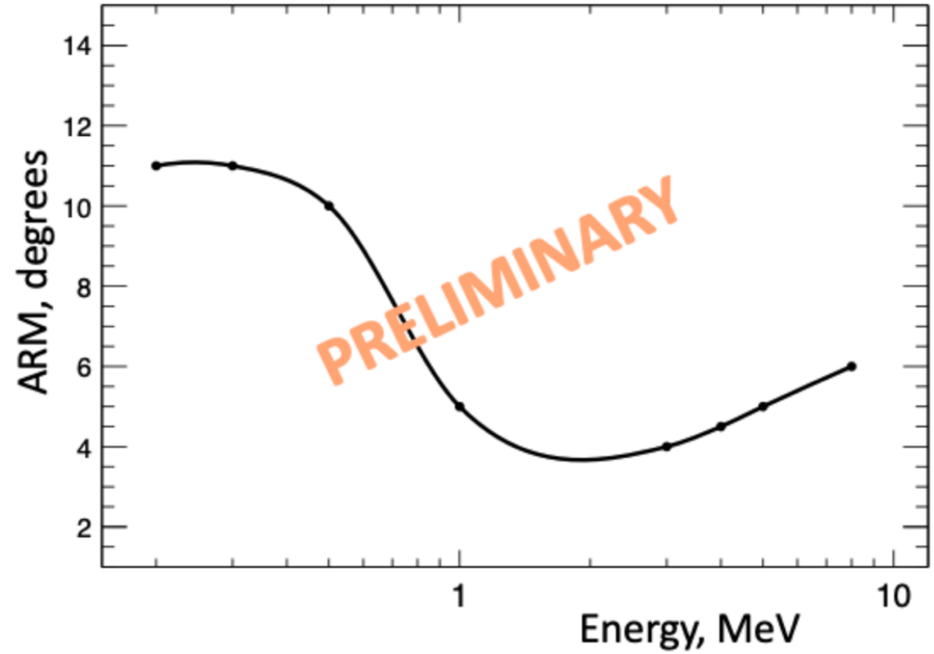
conceptual design mask in stowed position cutaway diameter =90 cm

GECCO Team, JCAP07(2022)036 arXiv:2112.07190

GECCO The Galactic Explorer with a Coded Aperture Mask Compton Telescope



effective area for the CA mask imaging; the solid line is for Compton pointing used, and the dashed line is for classical mask analysis.

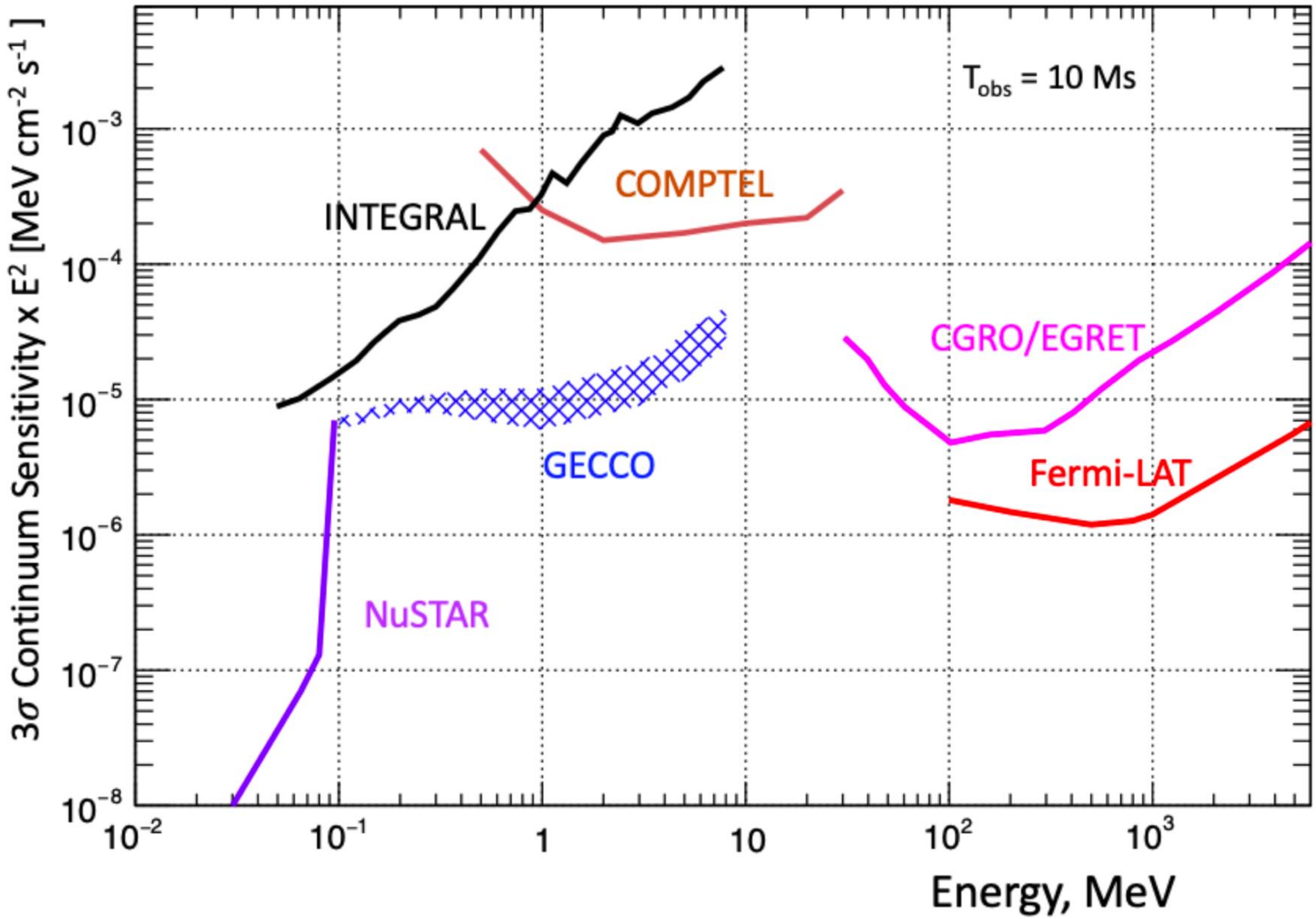


ARM (angular resolution measure) for the ImCal standalone Compton telescope.

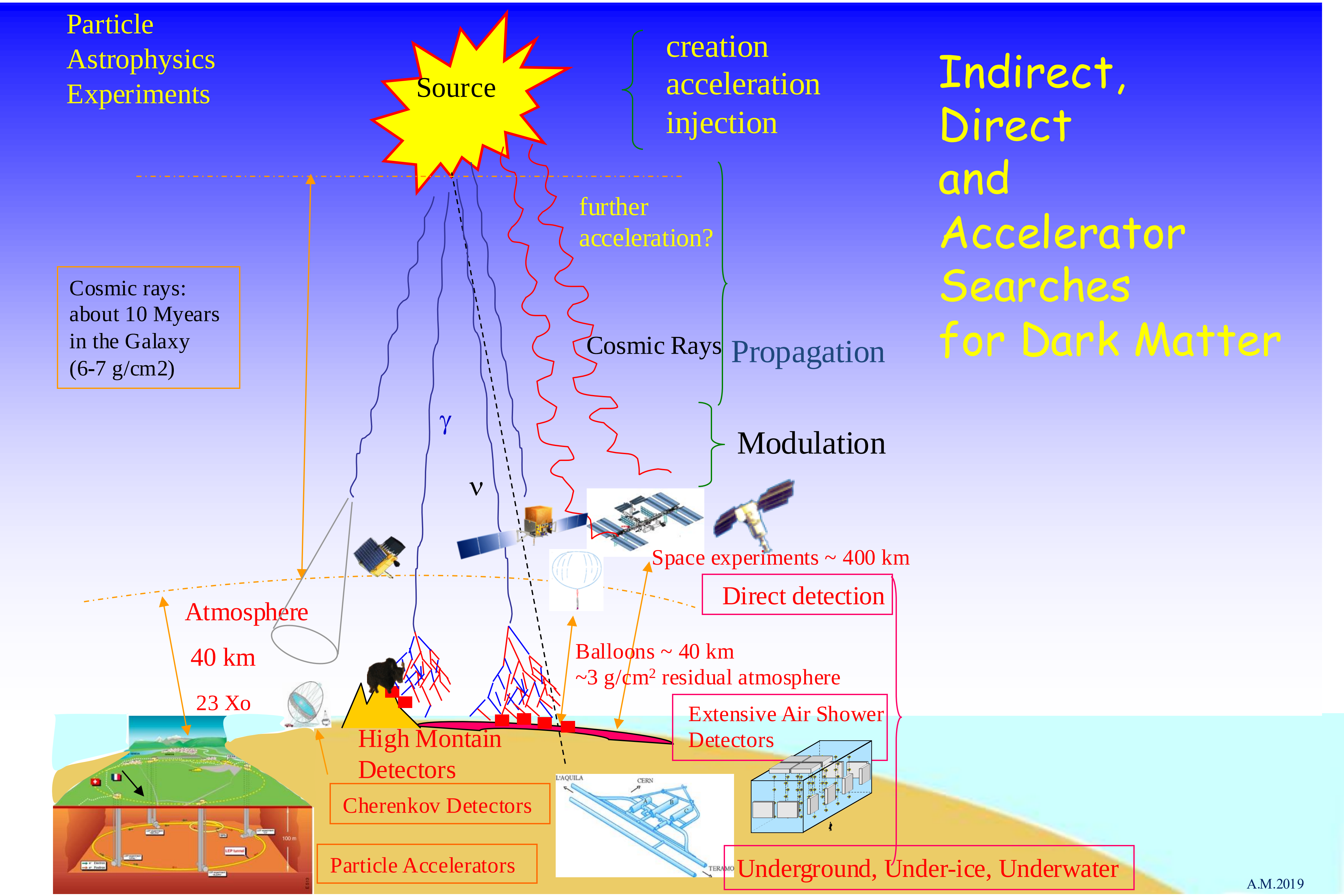
GECCO Team, in preparation

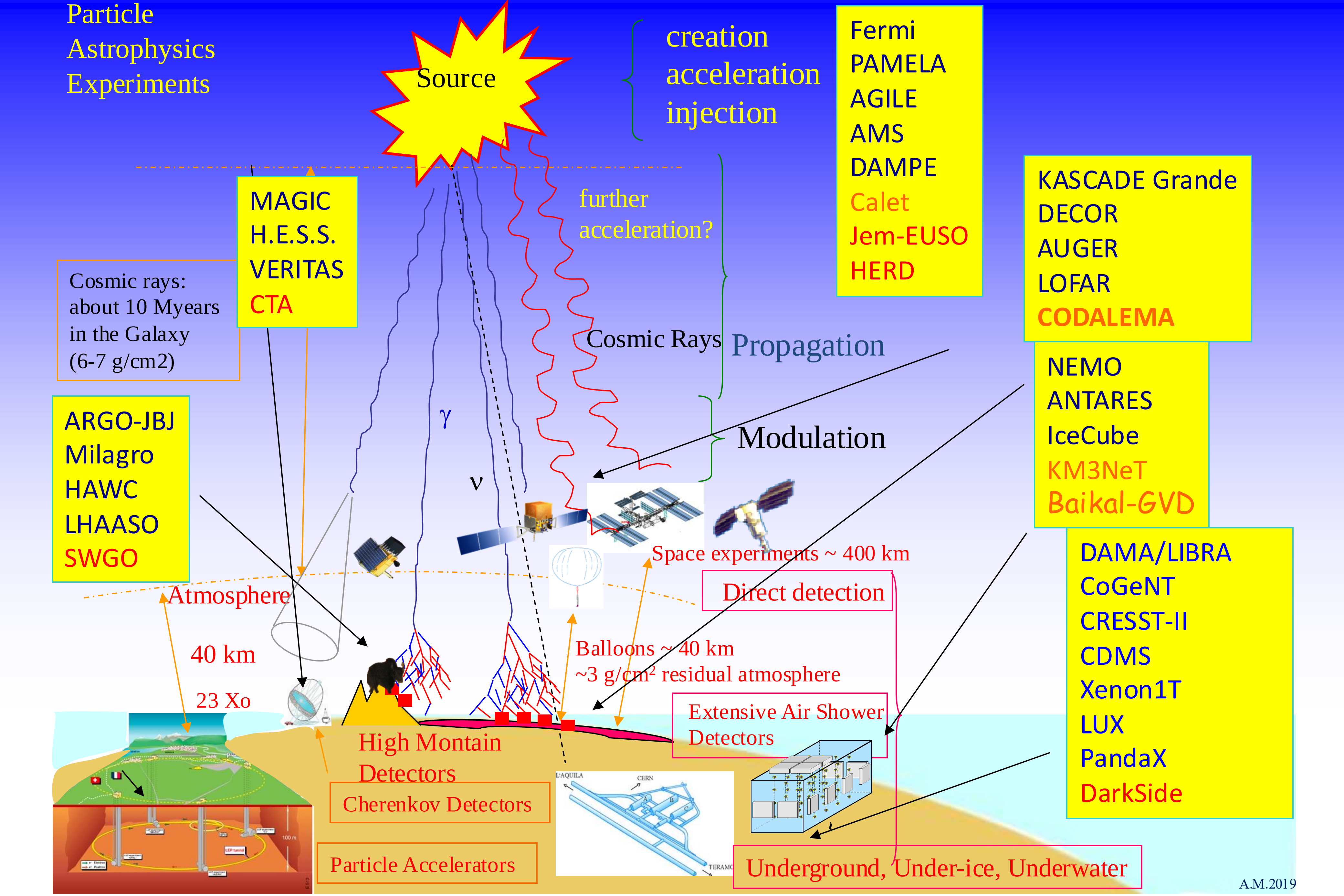
GECCO The Galactic Explorer with a Coded Aperture Mask Compton Telescope

Sensitivity



GECCO Team, JCAP07(2022)036 arXiv:2112.07190


Particle
Astrophysics
Experiments
Source
creation
acceleration
injection
Indirect,
Direct
and
Accelerator
Searches
for Dark Matter
further
acceleration?
Cosmic rays:
about 10 Myears
in the Galaxy
(6-7 g/cm2)
Cosmic Rays
Propagation
γ
Modulation
ν
Space experiments ~ 400 km
Direct detection
Atmosphere
40 km
23 Xo
Balloons ~ 40 km
~3 g/cm2 residual atmosphere
Extensive Air Shower
Detectors
High Montain
Detectors
Cherenkov Detectors
Particle Accelerators
Underground, Under-ice, Underwater
A.M.2019



Particle Astrophysics Experiments
Source
creation
acceleration
injection
Fermi
PAMELA
AGILE
AMS
DAMPE
Calet
Jem-EUSO
HERD
MAGIC
H.E.S.S.
VERITAS
CTA
further acceleration?
KASCADE Grande
DECOR
AUGER
LOFAR
CODALEMA
Cosmic rays: about 10 Myears in the Galaxy (6-7 g/cm2)
Cosmic Rays
Propagation
NEMO
ANTARES
IceCube
KM3NeT
Baikal-GVD
ARGO-JBJ
Milagro
HAWC
LHAASO
SWGO
γ
ν
Modulation
Space experiments ~ 400 km
Direct detection
DAMA/LIBRA
CoGeNT
CRESST-II
CDMS
Xenon1T
LUX
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Particle Accelerators
L'AQUILA
CERN
TERAMO
Underground, Under-ice, Underwater
A.M.2019

Summary

- Indirect search of Dark Matter with gamma rays is complementary to all other research in the underground laboratories and at LHC
- CTA, SWGO and LHAASO can explore the high -energy domain
- Fermi is still in orbit but we need a new mission with a focus in the low energy range (below 100 MeV)
- Because the flux is high it can be at the AGILE scale (like Gamma-Light) i.e. also a National Space Agency (or two) can support the development and launch

thank you !