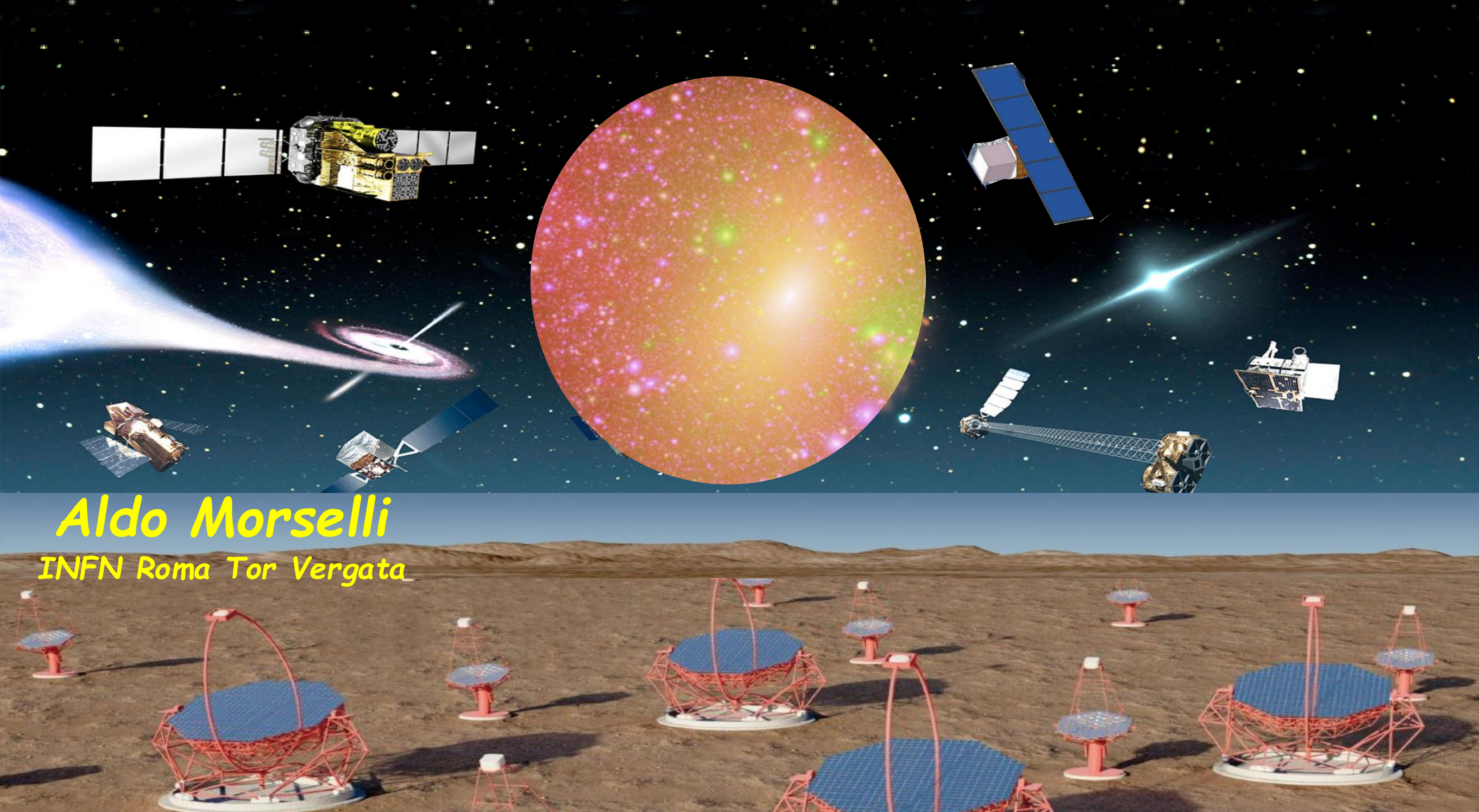
Multimessenger searches for Dark Matter



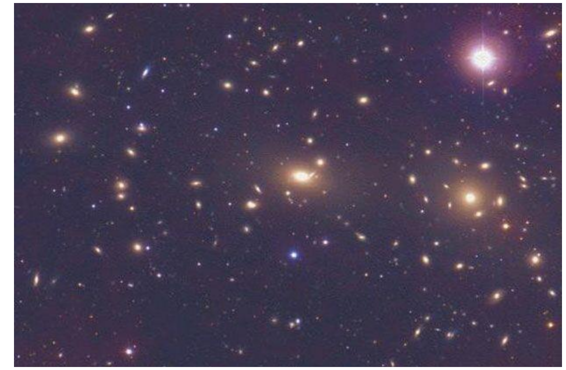
Aldo Morselli

INFN Roma Tor Vergata

ADVANCES IN MODELING HIGH-ENERGY ASTROPHYSICAL SOURCES

Sexen Center for Astrophysics, 2 July 2025

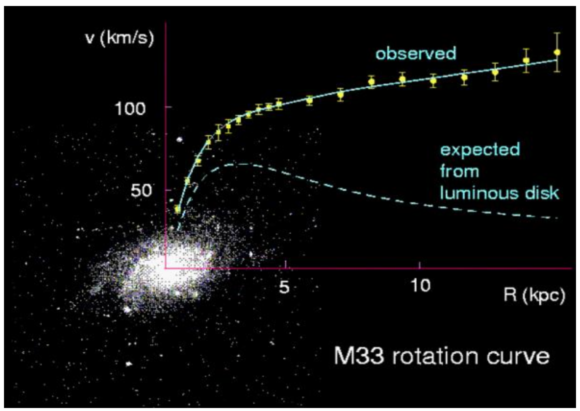
Dark Matter EVIDENCE



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.

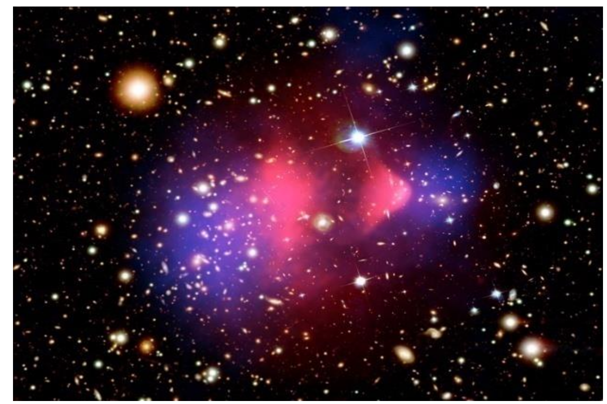
Since then, even more evidence:

Rotation curves of galaxies

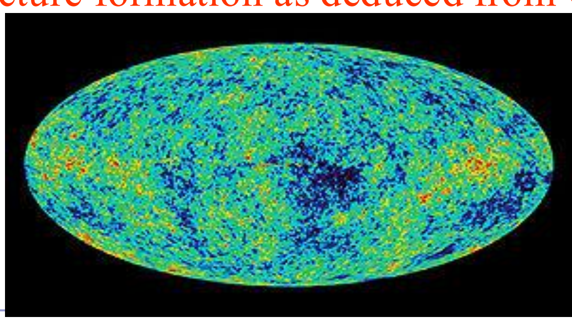


Gravitational lensing

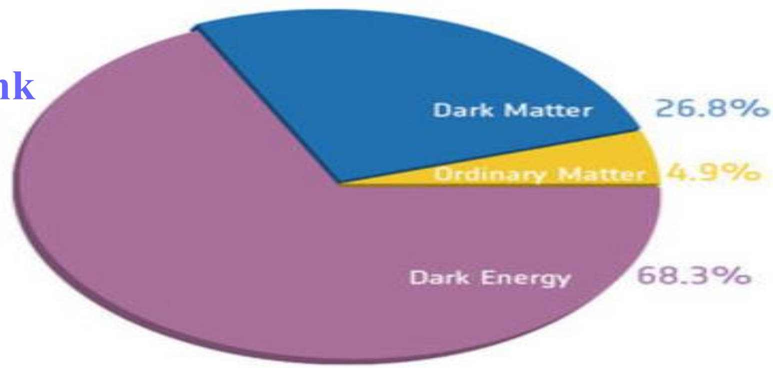
Bullet cluster



Structure formation as deduced from CMB



Data by Plank imply:



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

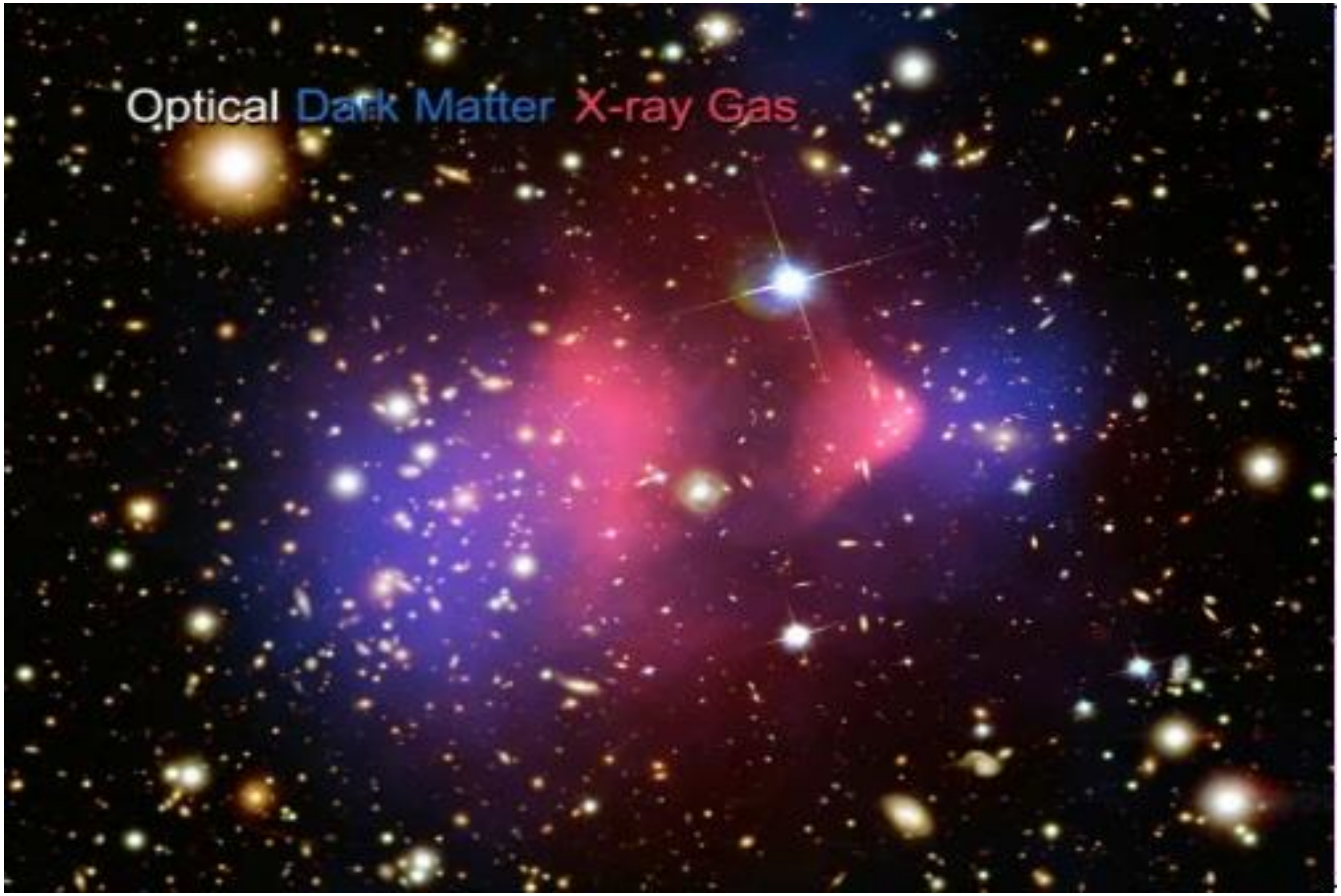
$\Omega_{M} \approx 4.9\%$

Dark Matter really exist ?

astro:ph/0608407

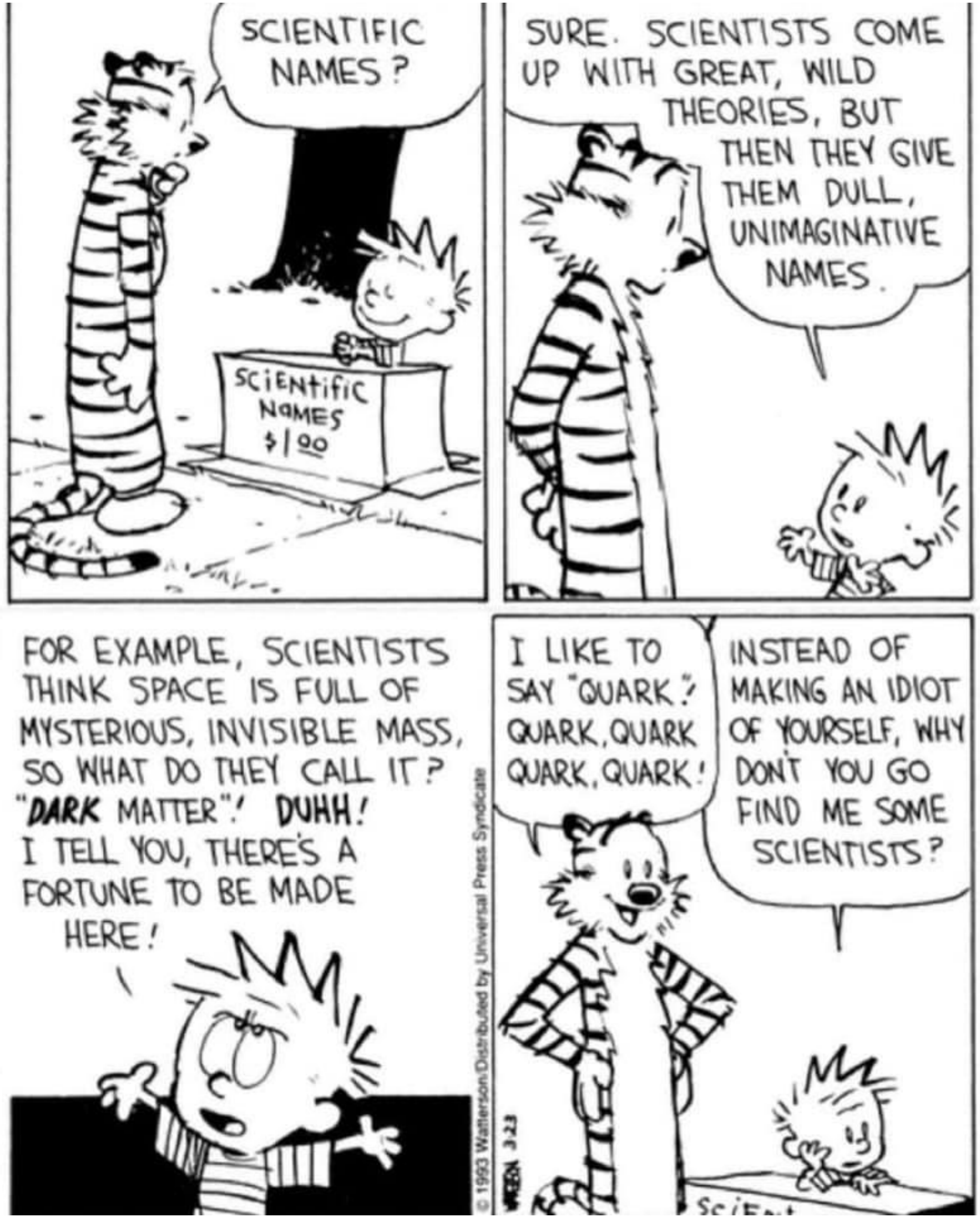
color image from the Magellan images of the merging cluster 1E0657−558

Chandra image of the cluster



200 kpc

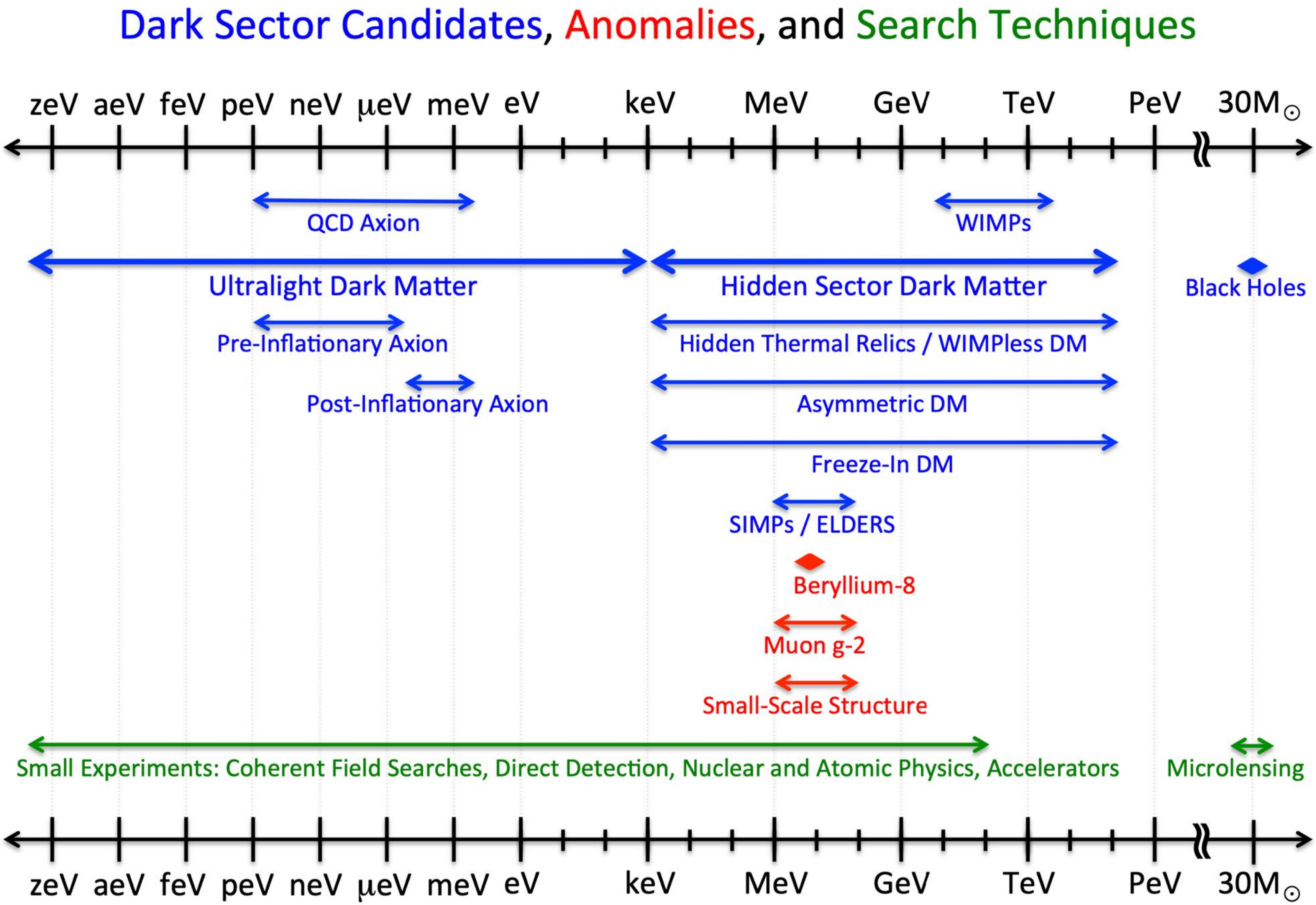
Due to the collision of two clusters, the dissipationless stellar component and the fluid-likeX-ray emitting plasma are spatially segregated


SCIENTIFIC NAMES?
SCIENTIFIC NAMES $1.00
SURE. SCIENTISTS COME UP WITH GREAT, WILD THEORIES, BUT THEN THEY GIVE THEM DULL, UNIMAGINATIVE NAMES.
FOR EXAMPLE, SCIENTISTS THINK SPACE IS FULL OF MYSTERIOUS, INVISIBLE MASS, SO WHAT DO THEY CALL IT? "DARK MATTER"! DUHH! I TELL YOU, THERE'S A FORTUNE TO BE MADE HERE!
I LIKE TO SAY "QUARK." QUARK, QUARK QUARK, QUARK!
INSTEAD OF MAKING AN IDIOT OF YOURSELF, WHY DON'T YOU GO FIND ME SOME SCIENTISTS?
© 1993 Watterson/Distributed by Universal Press Syndicate

Dark Matter

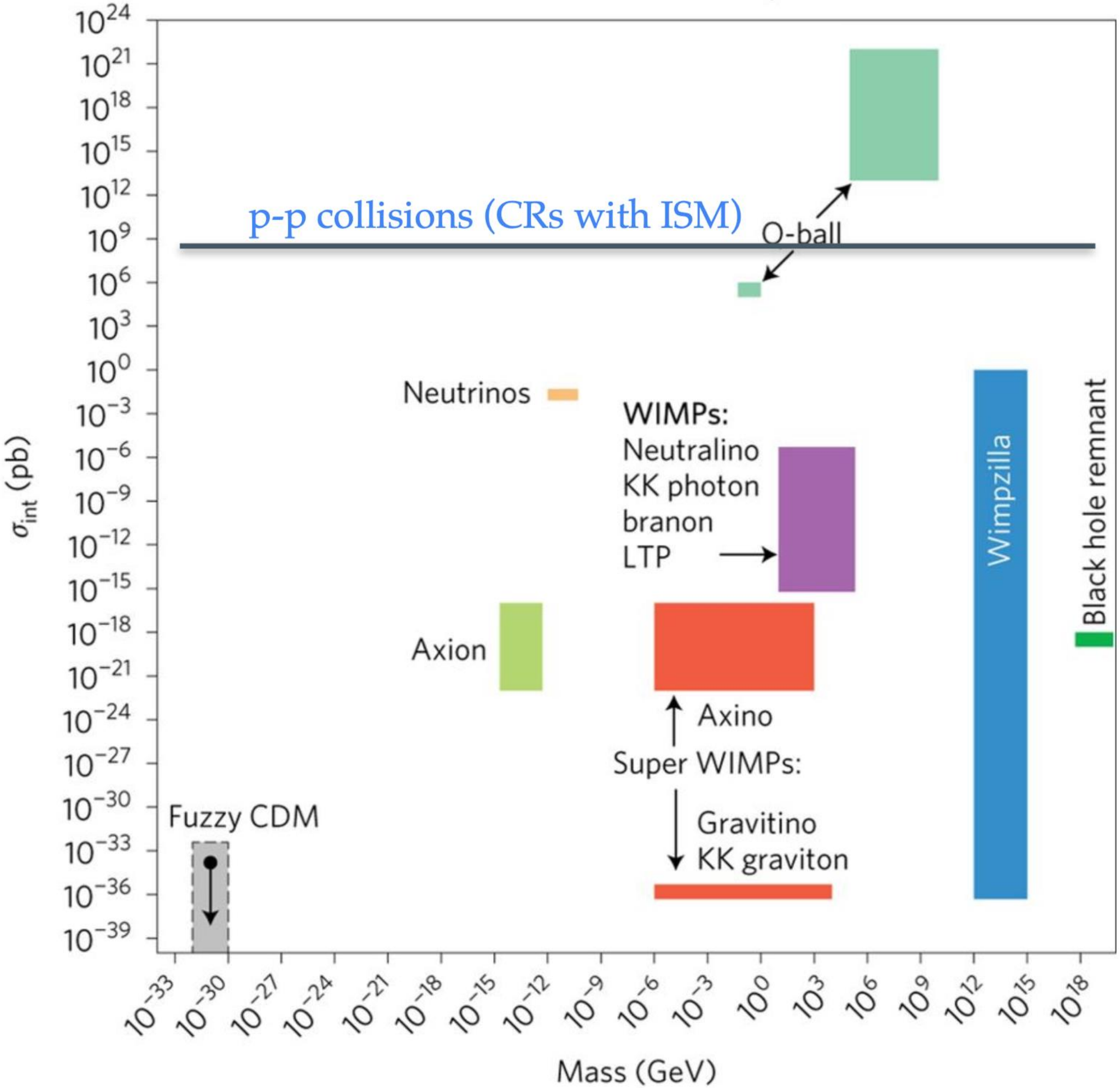
What is dark matter made of ?

Dark Sector Candidates, Anomalies, and Search Techniques



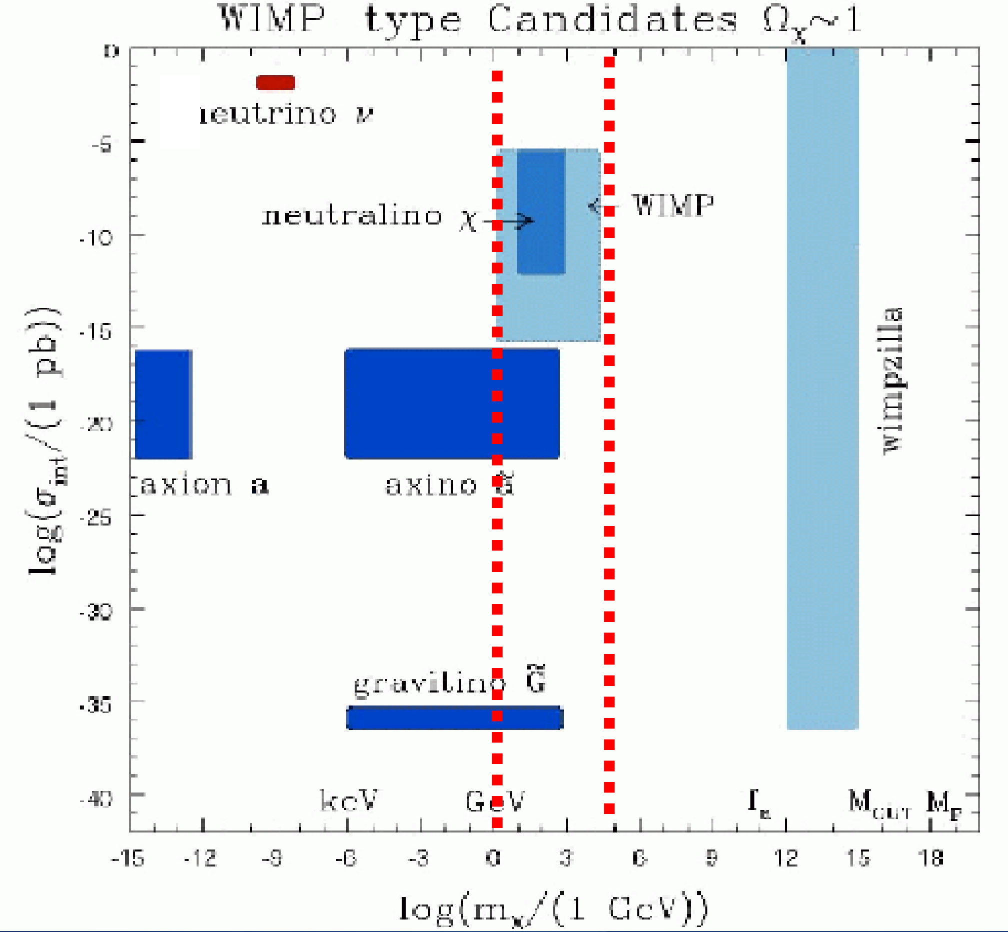
New Ideas in Dark Matter 2017 : Community Report arXiv:1707.04591

Some particle dark matter candidates



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

- Kaluza-Klein DM inUED
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- **NEUTRALINO**
- Messenger States in GMSB
- Branons
- Chaplygin Gas
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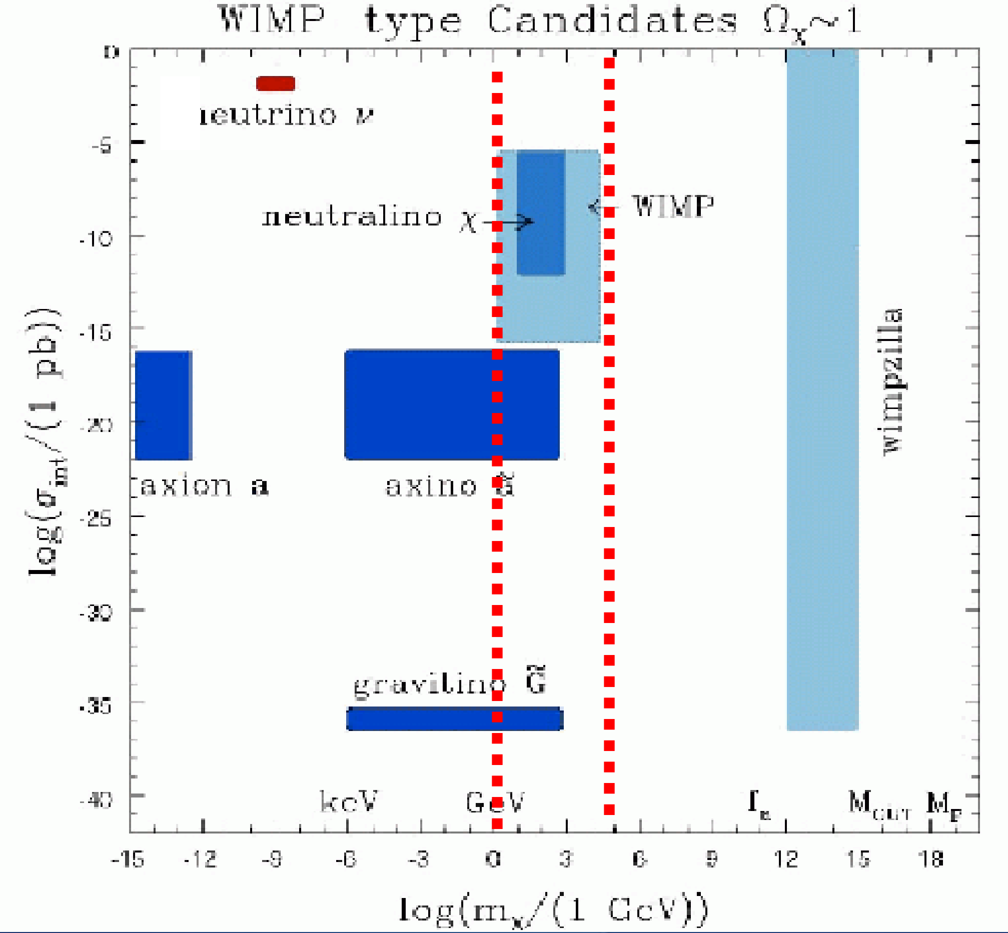
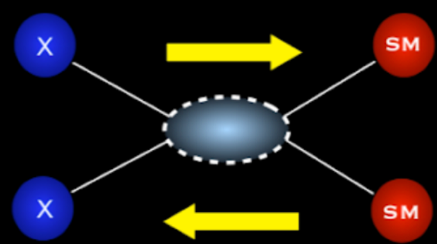



THIS IS WHERE YOU LOST YOUR WALLET?
NO, I LOST IT IN THE PARK. BUT THIS IS WHERE THE LIGHT IS.

WIMPs

By far the most studied class of dark matter candidates.

The WIMP paradigm is based on a simple yet powerful idea:



$$\frac{dn_\chi}{dt} - 3Hn_\chi = -\langle\sigma v\rangle \left[n_\chi^2 - (n_\chi^{eq})^2\right]$$

Weak-scale cross sections can reproduce observed relic density

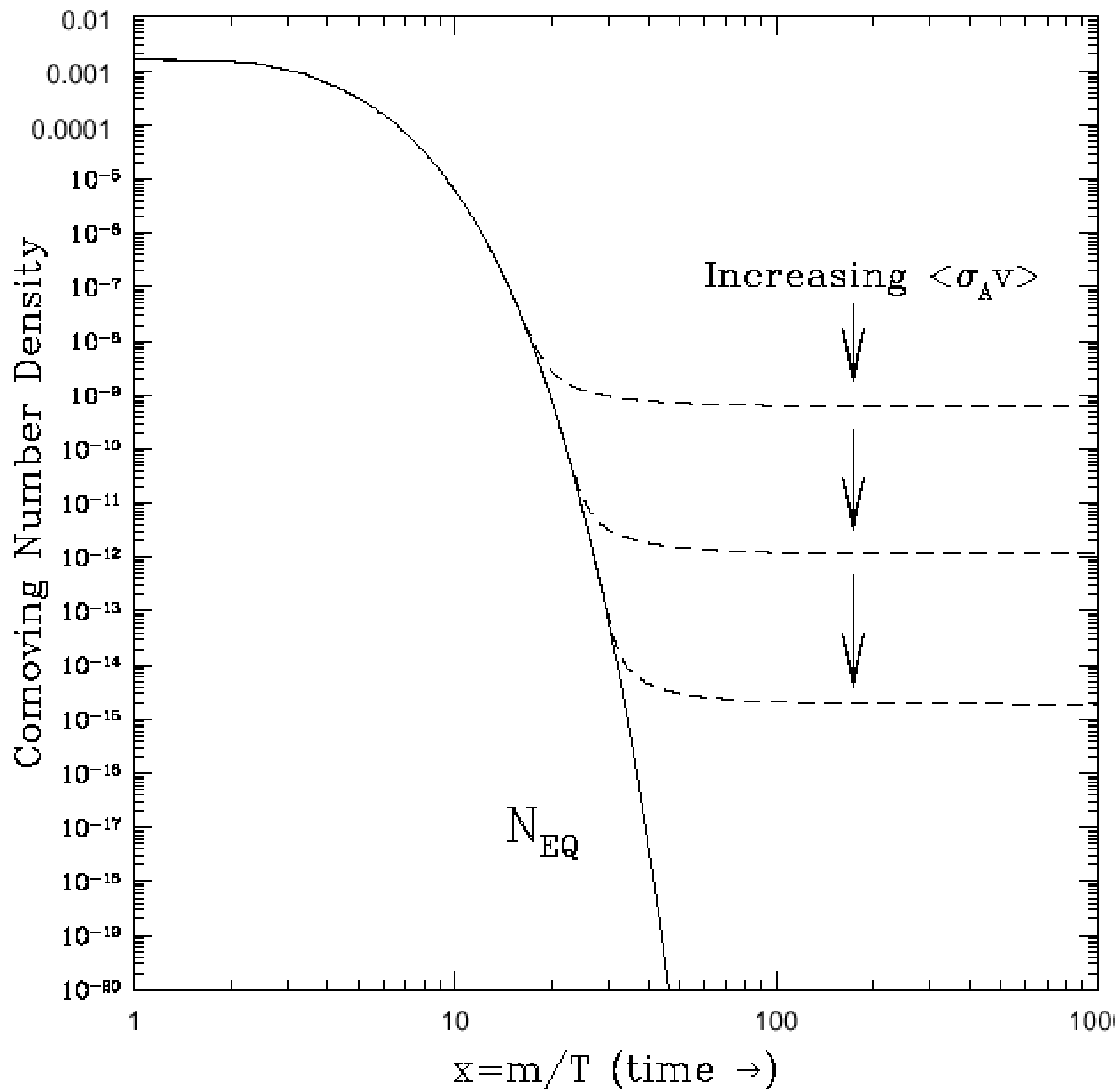
$$\Omega h^2 \approx \frac{3 \times 10^{-27} cm^3 s^{-1}}{< \sigma v >}$$

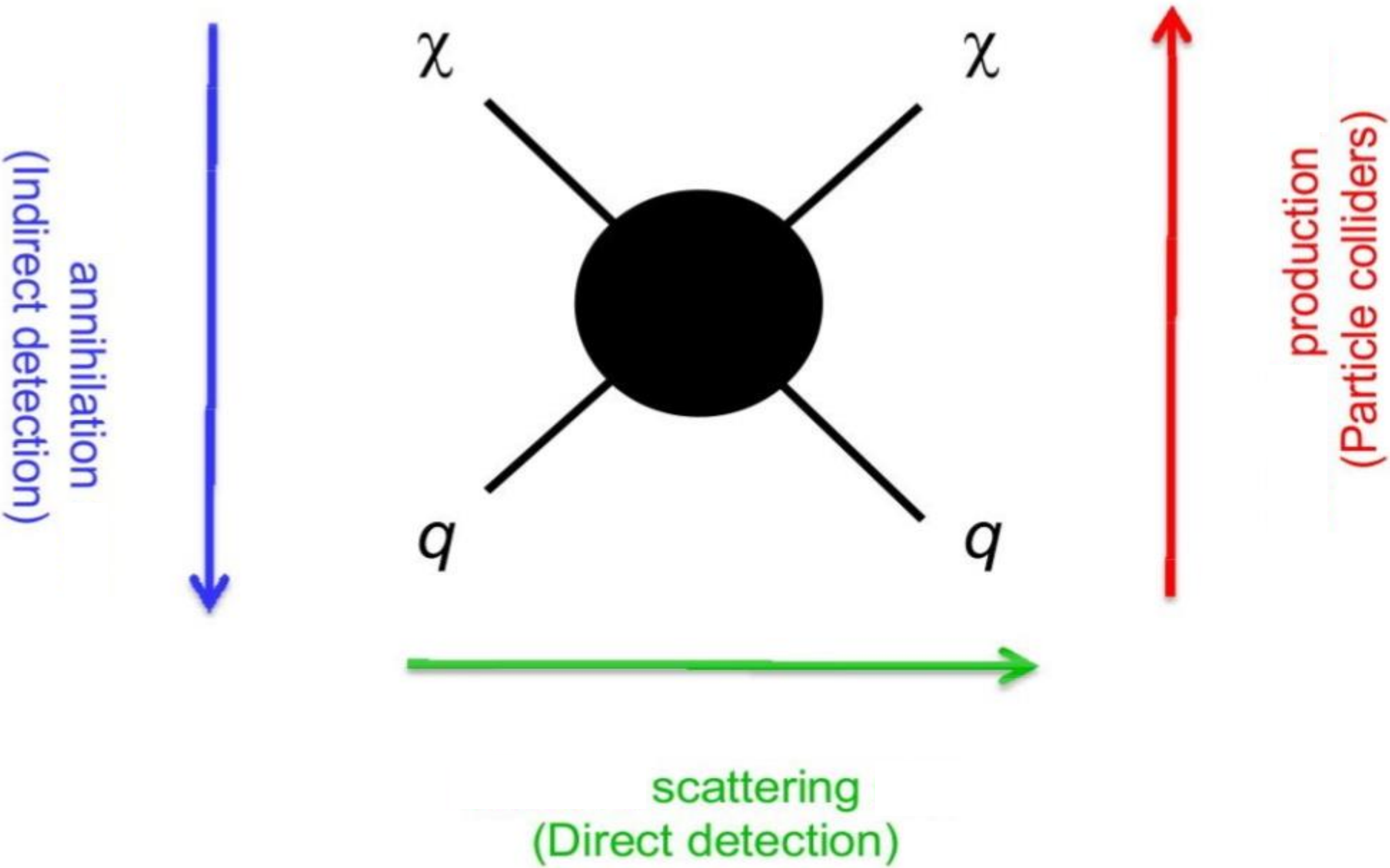
‘WIMP miracle’: new physics at ~1 TeV solves at same time fundamental problems of particle physics (*hierarchy problem*) AND DM

Termal relics

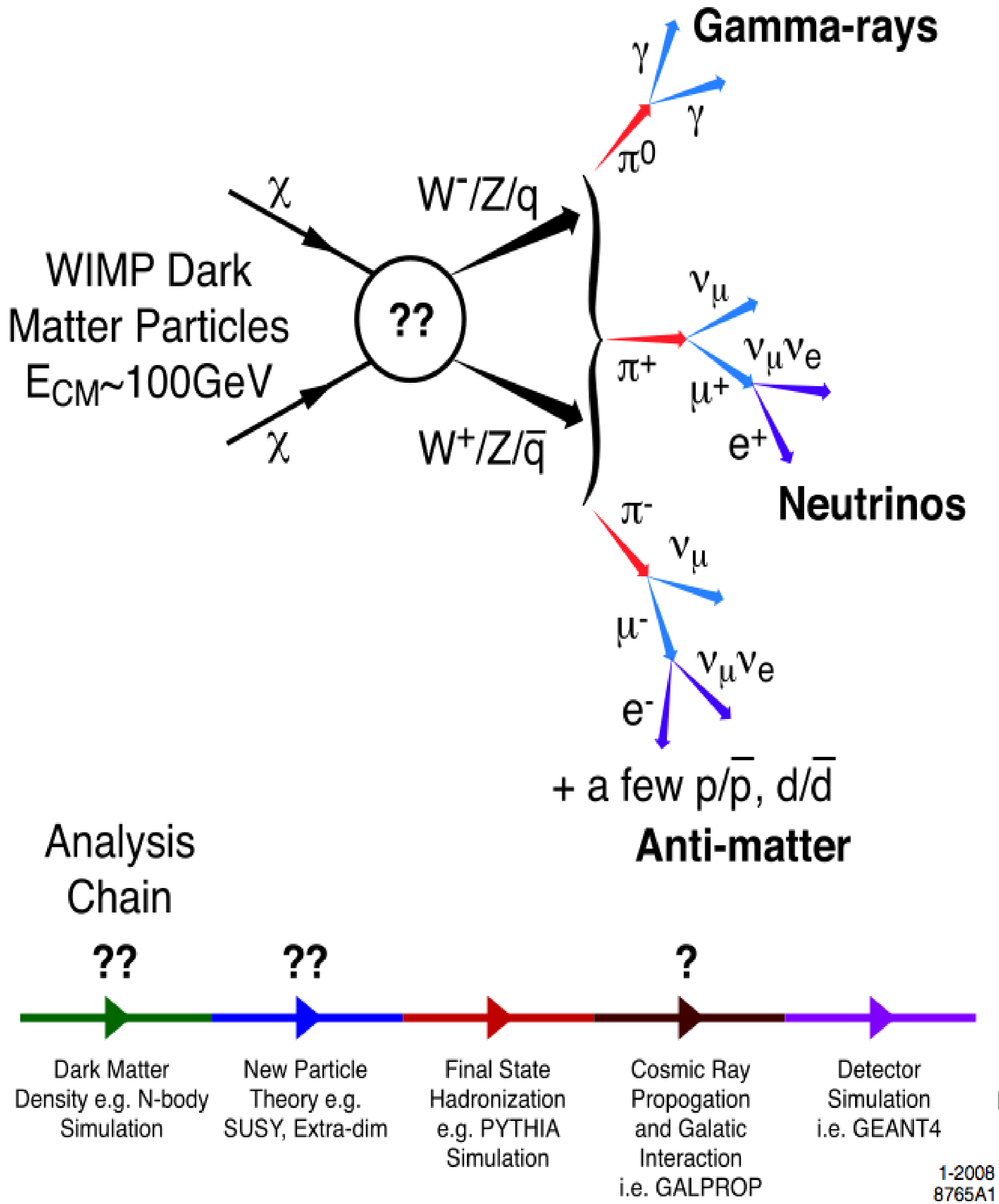
Freeze out at $\Omega_\chi h^2 = \frac{m_\chi n_\chi}{\rho_c}$

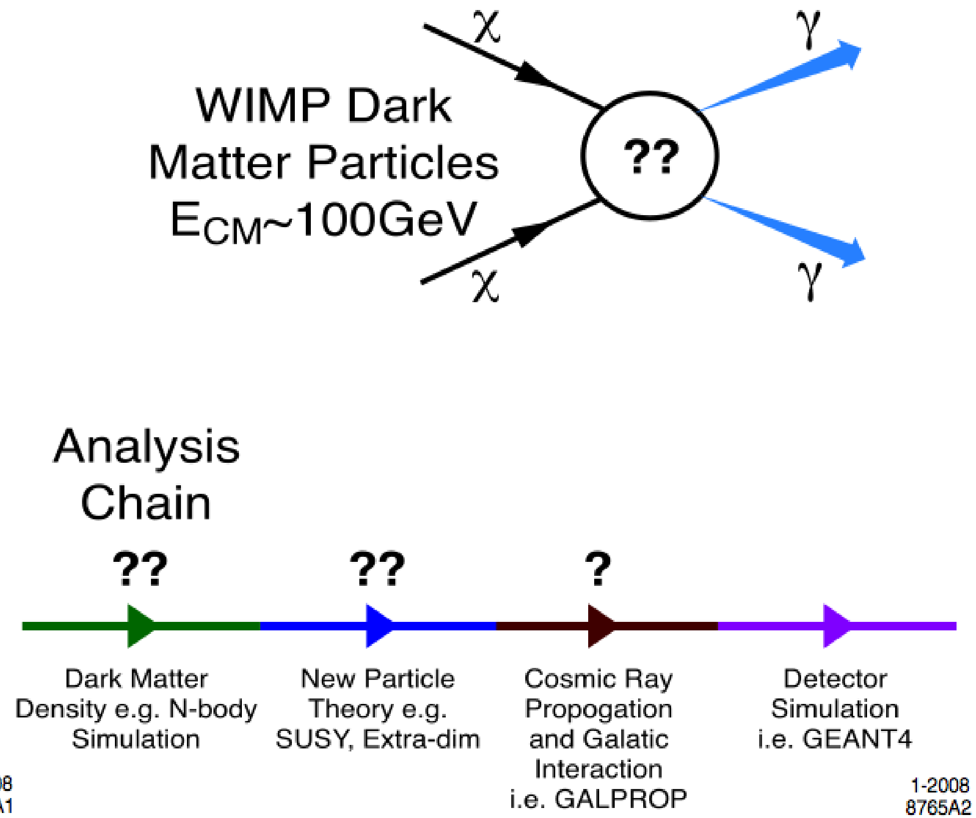
$$\approx \frac{3\ 10^{-27}\ \mathrm{cm}^3\ \mathrm{sec}^{-1}}{\sigma_a\, v}$$




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

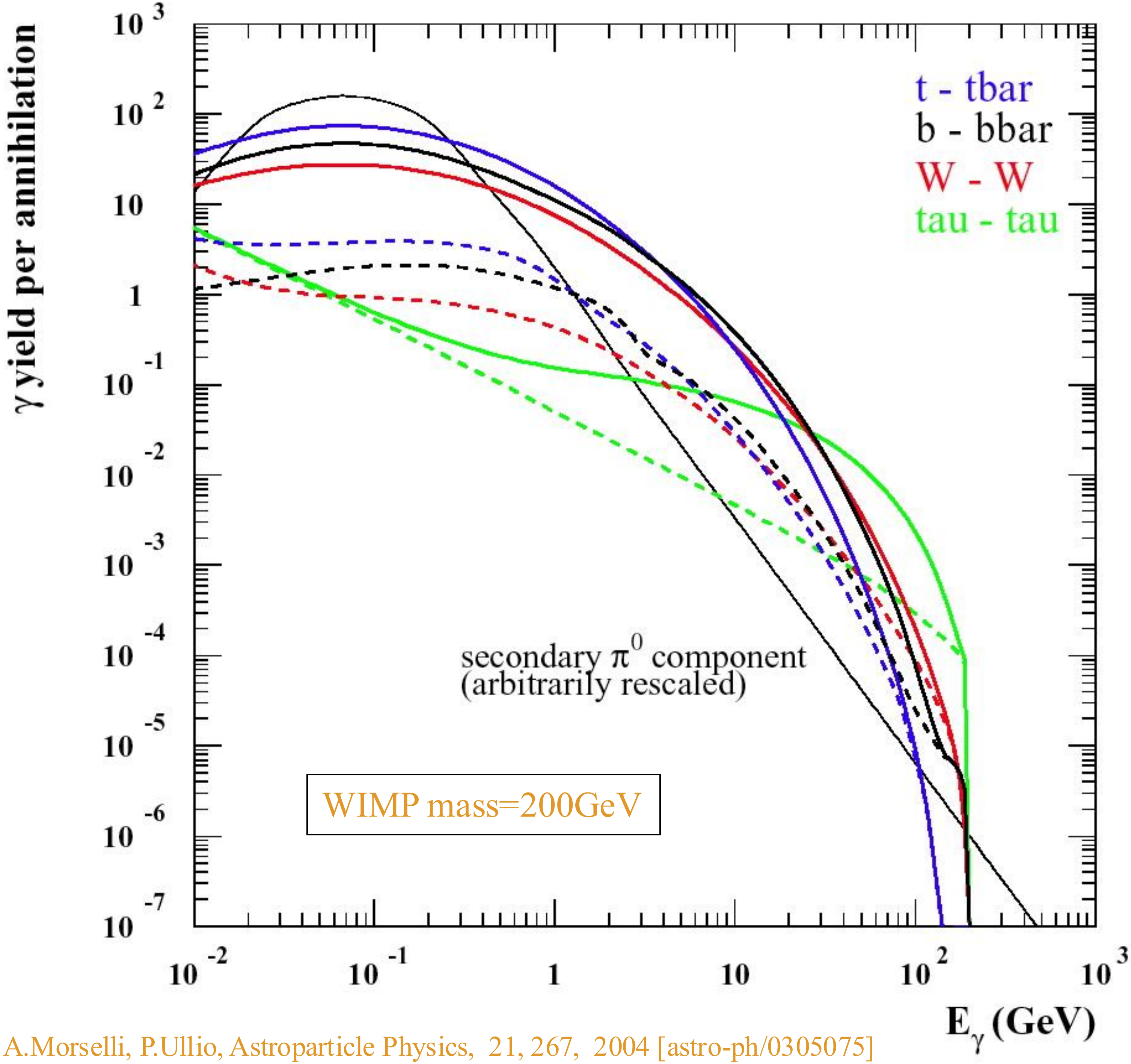
$$\phi(E,\Delta\Omega) \propto \left(\frac{\sigma v}{m_\chi^2}\right) \int_{l.o.s}\int_{\Delta\Omega} \rho^2(l)\,dl\,d\Omega)$$

governed by
particle physics
(supersymmetric
parameters .. etc)

J(φ):

governed by
halo distribution

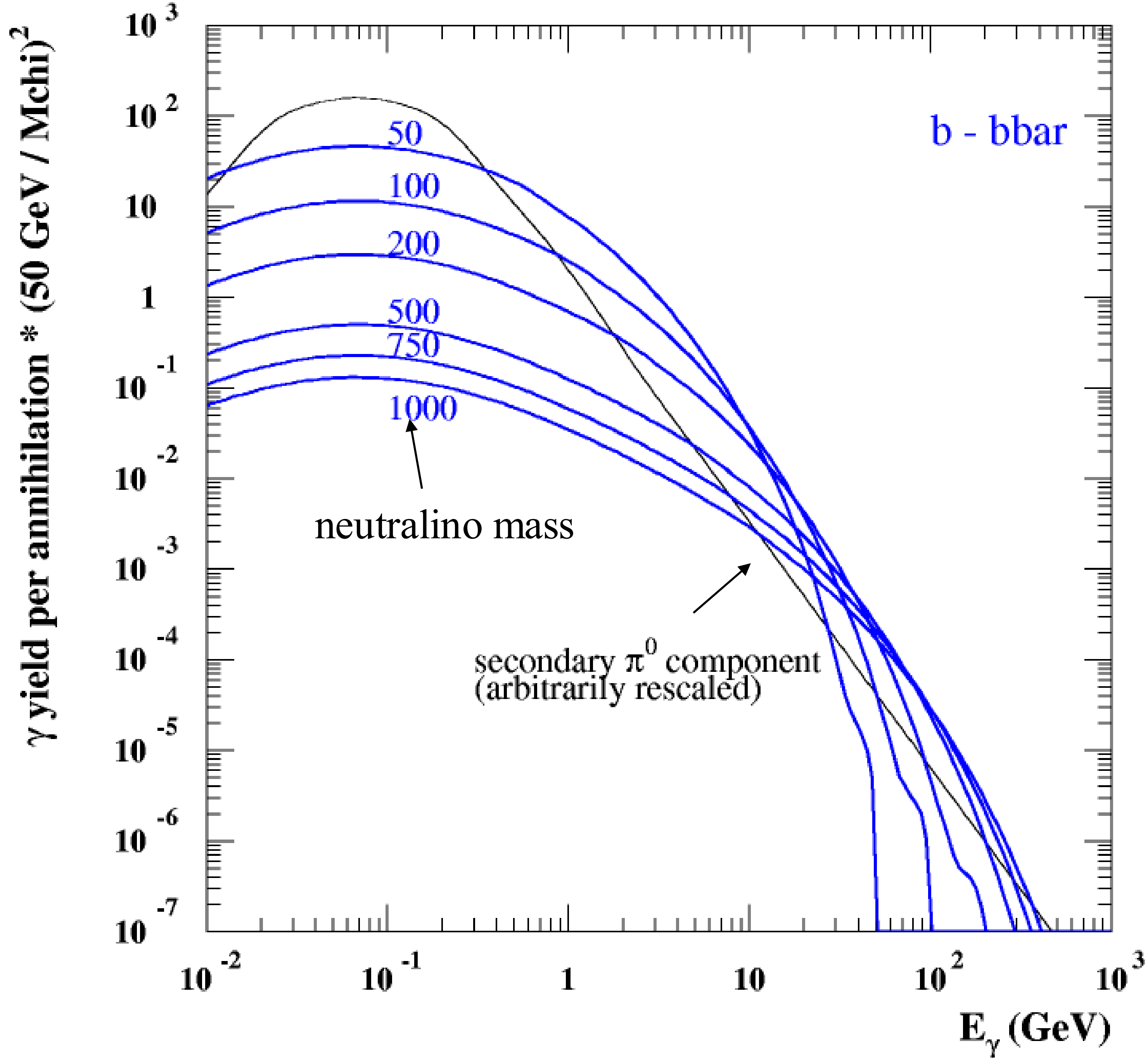
Differential yield for each annihilation channel



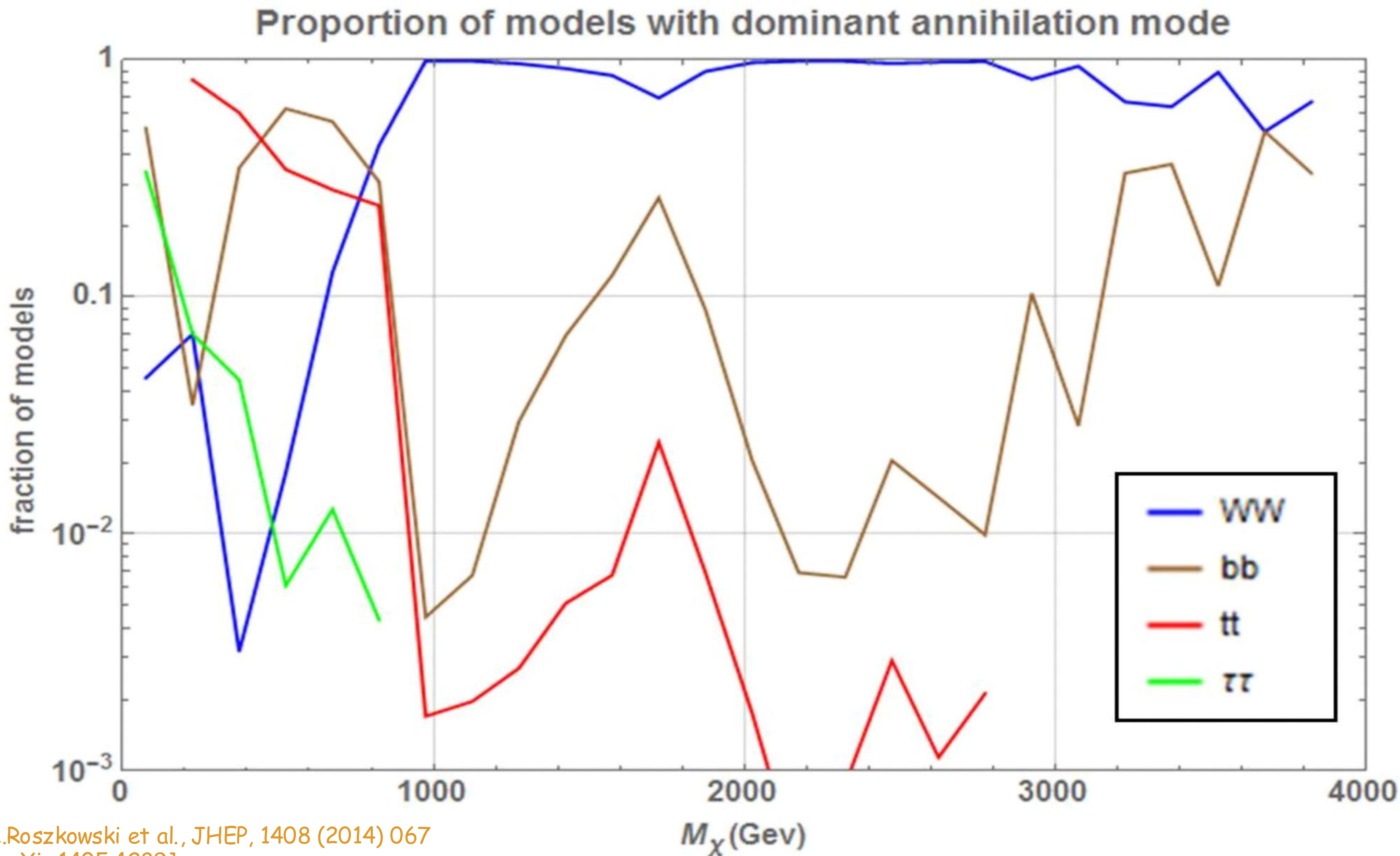
dashed lines are components not due to π^0 decay.

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

Differential yield for b bar



Which channel to choose?
Example: The dominant annihilation modes in the pMSSM scan



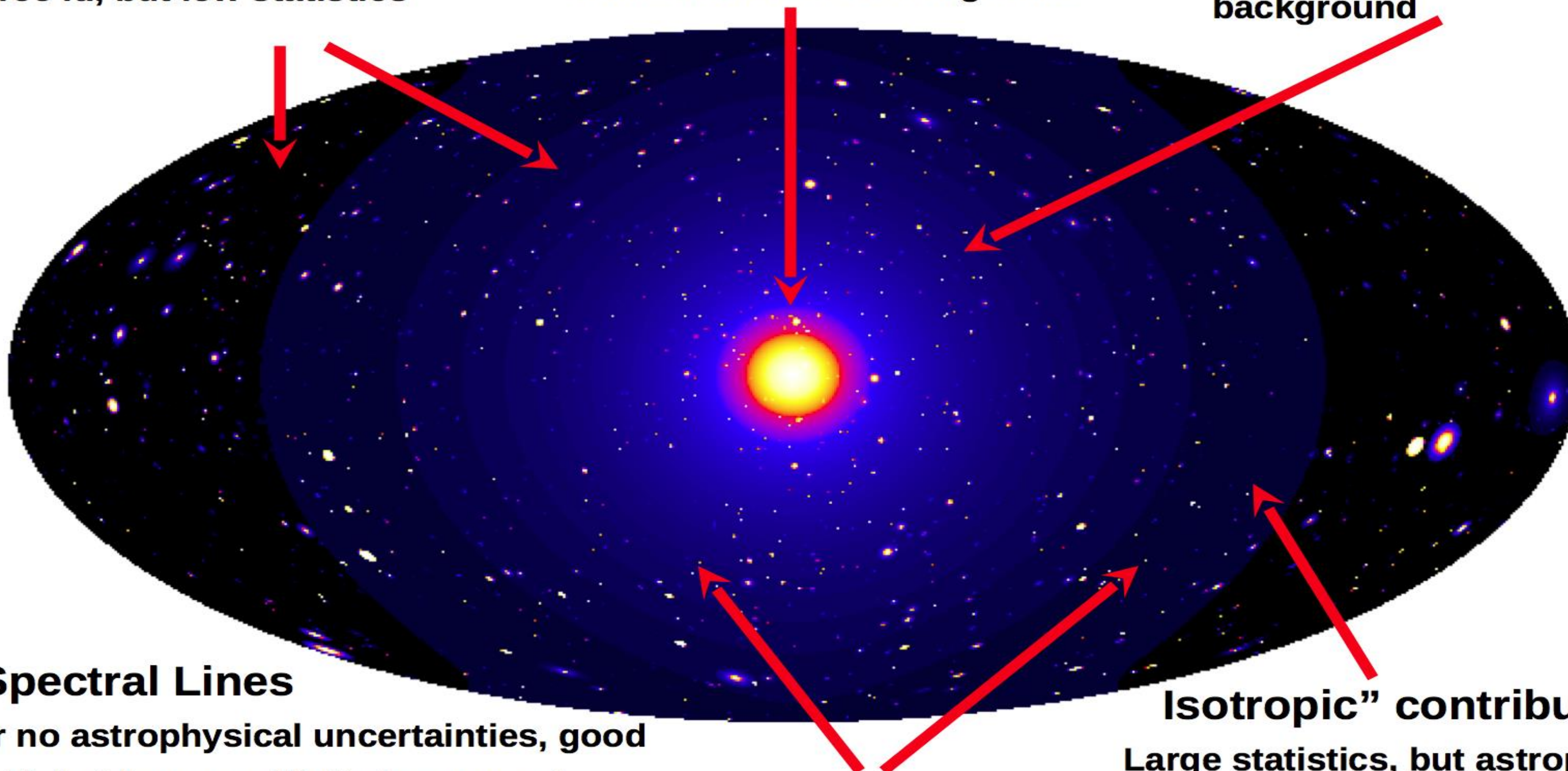
L.Roszkowski et al., JHEP, 1408 (2014) 067
[arXiv:1405.4289]

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



Spectral Lines
Little or no astrophysical uncertainties, good source id, but low sensitivity because of expected small branching ratio

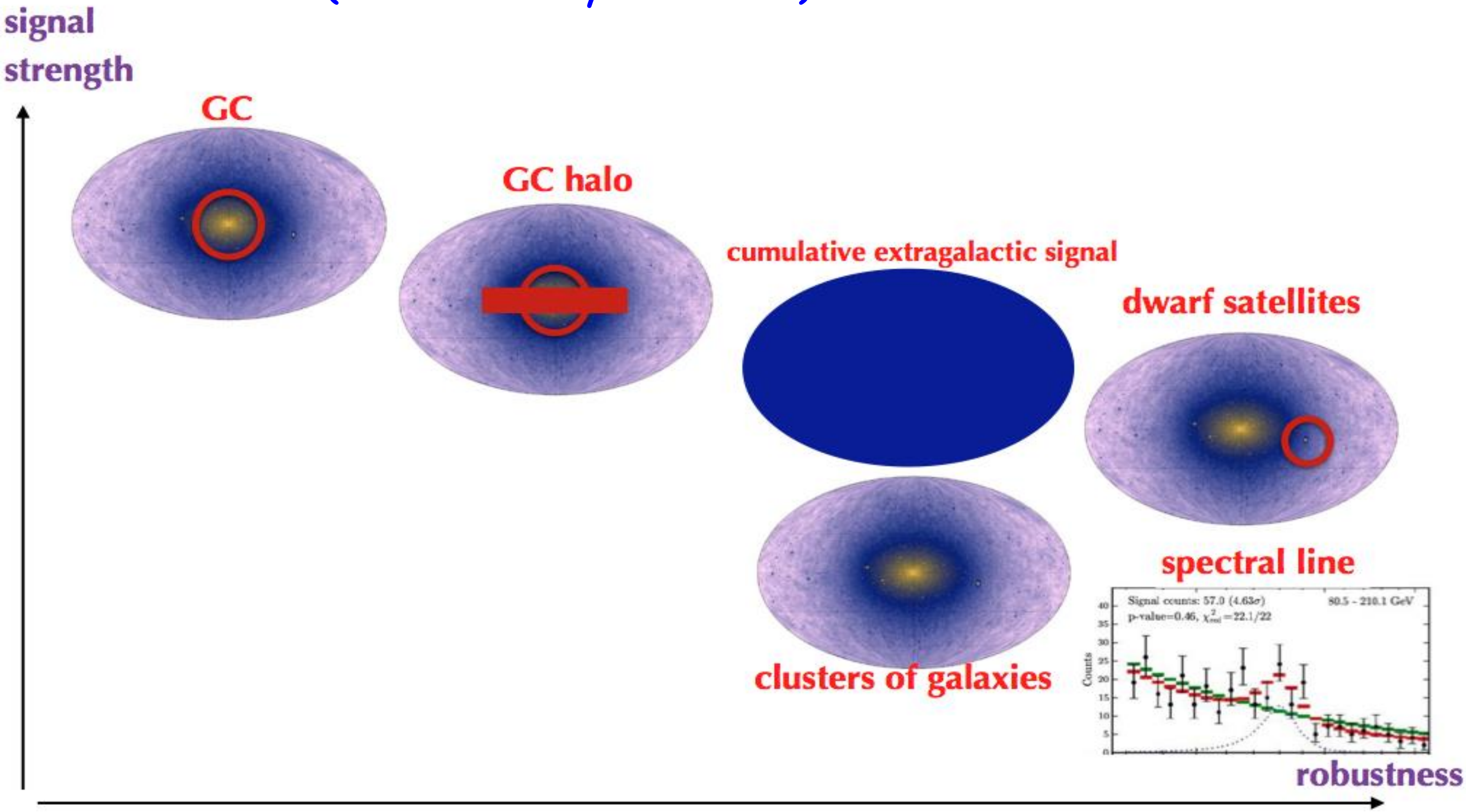
Galaxy Clusters
Low background, but low statistics

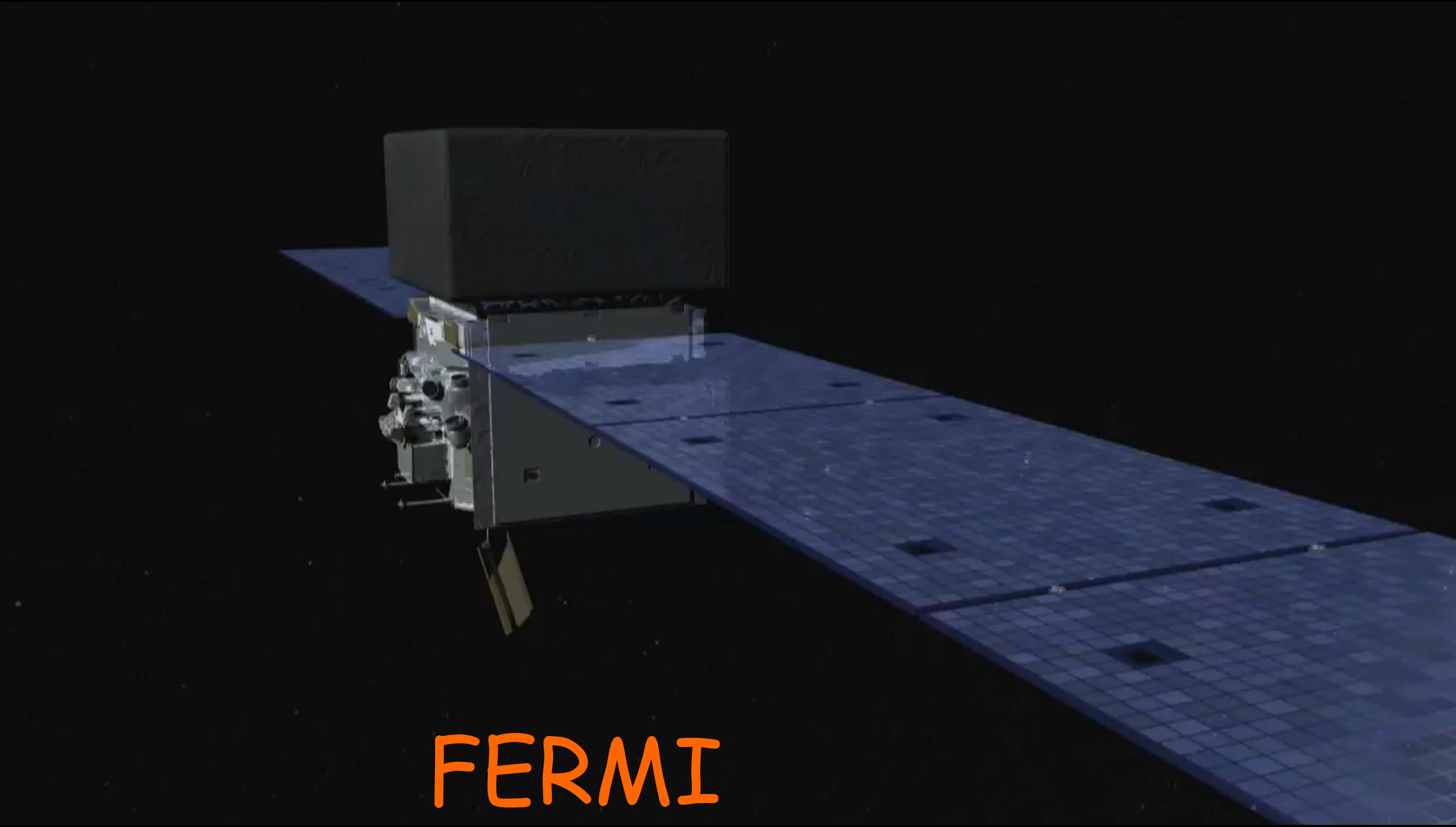
Isotropic" contributions
Large statistics, but astrophysics, galactic diffuse background

Dark Matter simulation: Pieri+(2009) arXiv:0908.0195

Dark Matter Search: Targets and Strategies

(Another way to see it)





FERMI

Large Area Telescope

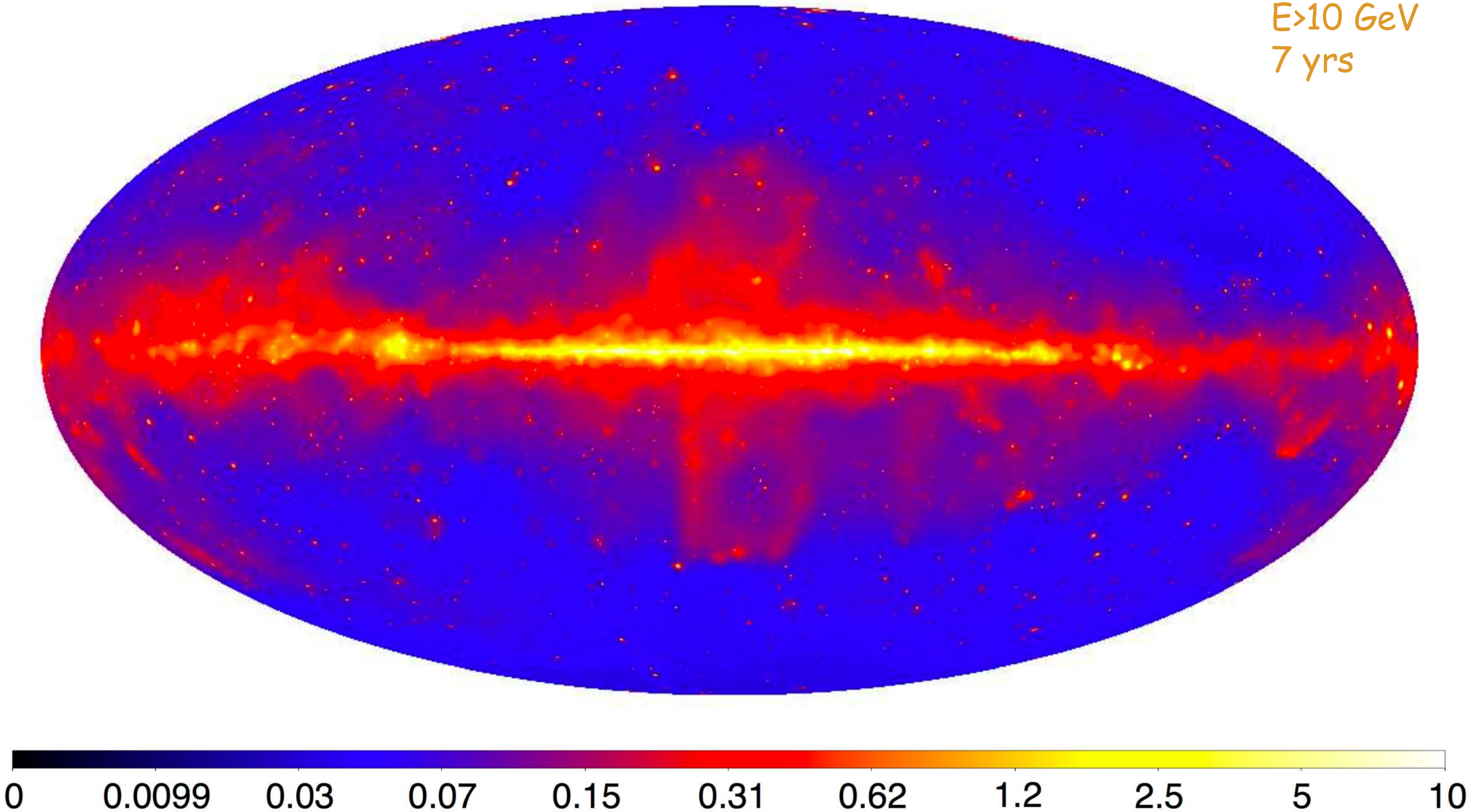
Fermi
Gamma-ray Space Telescope

11 June 2008


Fermi
Gamma-ray
Space Telescope
Happy 17th Birthday Fermi !!
11 June 2008

The sky in gamma-rays

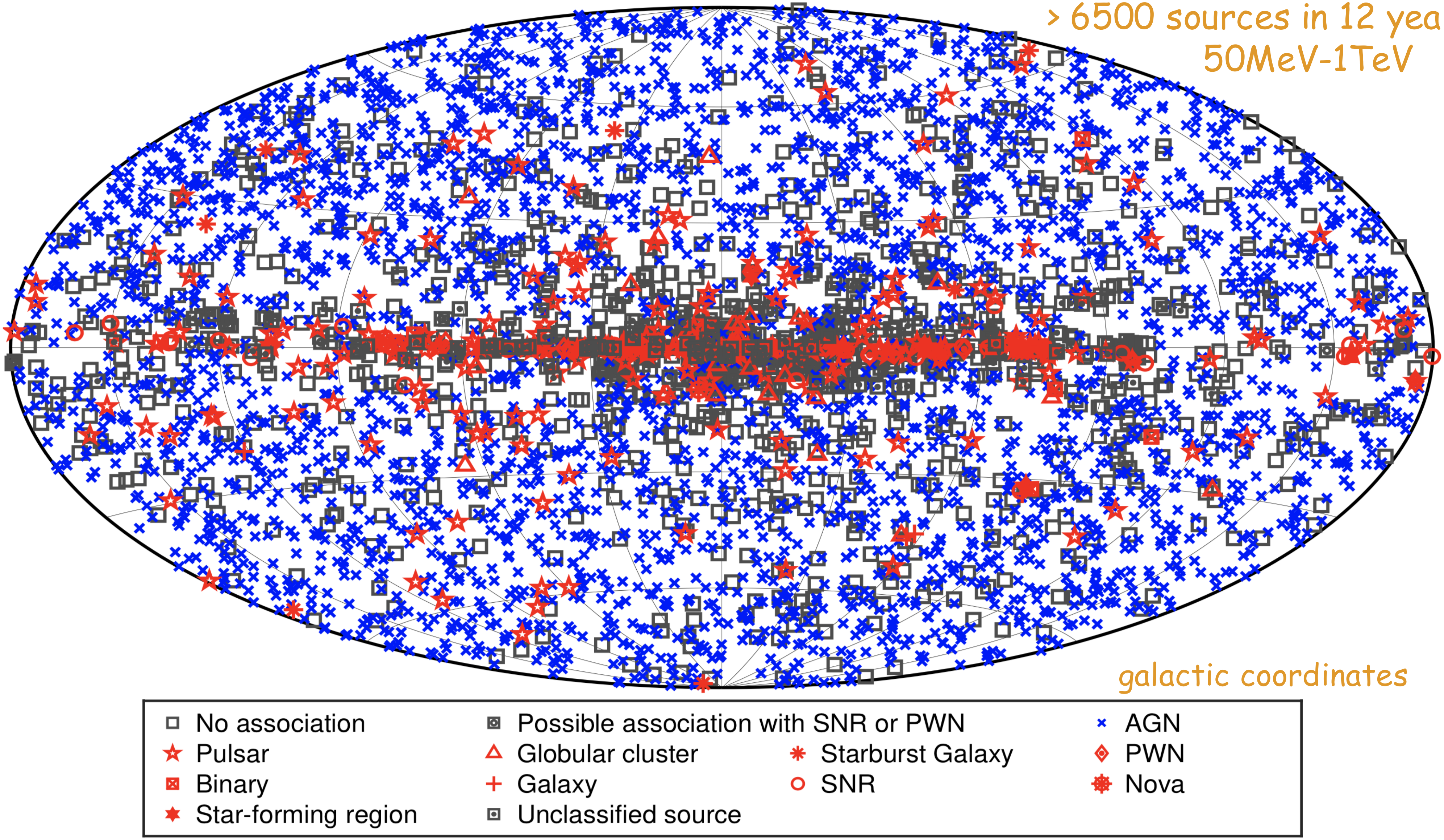
E>10 GeV
7 yrs



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

The sky in gamma-rays 4th source catalog

> 6500 sources in 12 years
50MeV-1TeV

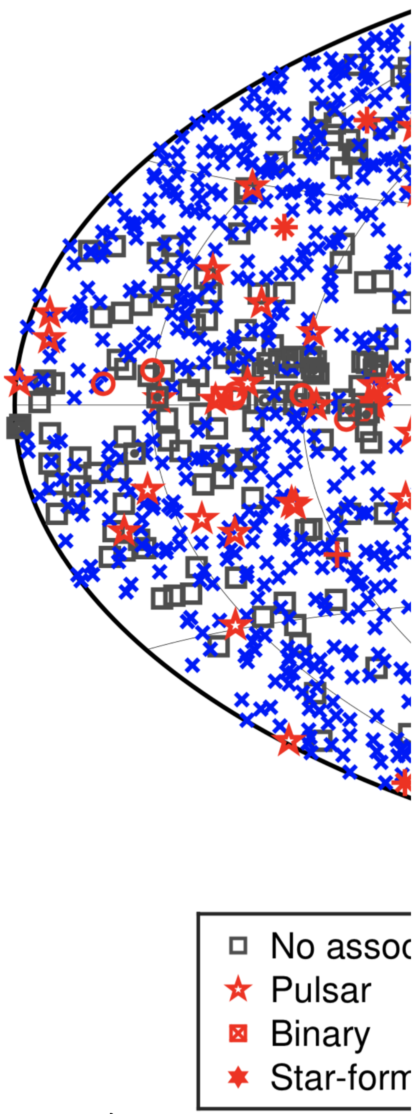


galactic coordinates

Fermi Fourth Source Catalog, The Astrophysical Journal ss, 247; 33 March 2020 [arXiv:1902.10045]
+ Incremental Fermi Large Area Telescope Fourth Source Catalog arXiv:2201.11184

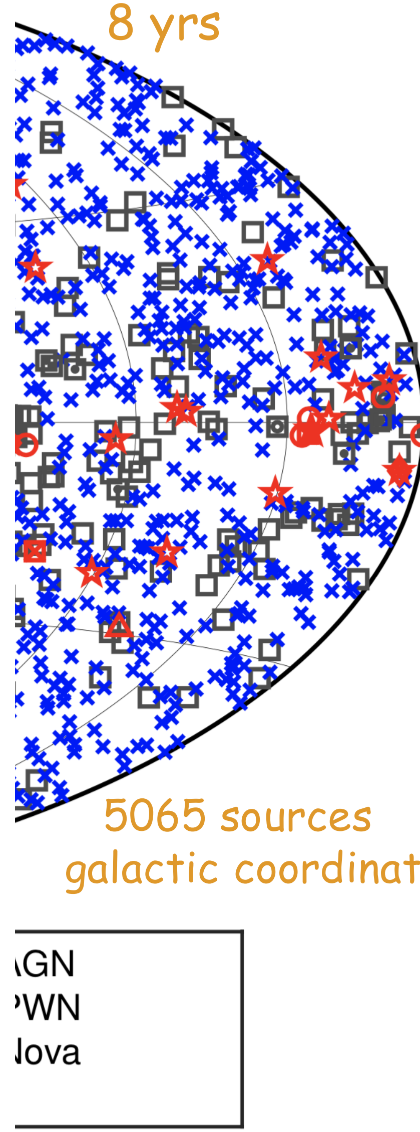
The sky in gamma-rays_ 4^{th} source catalog

50MeV-1TeV
8 yrs



Description	Identified		Associated	
	Designator	Number	Designator	Number
Pulsar, identified by pulsations	PSR	229	...	...
Pulsar, no pulsations seen in LAT yet	...	...	psr	10
Pulsar wind nebula	PWN	12	pwn	6
Supernova remnant	SNR	24	snr	16
Supernova remnant / Pulsar wind nebula	SPP	0	spp	90
Globular cluster	GLC	0	glc	30
Star-forming region	SFR	3	sfr	0
High-mass binary	HMB	5	hmb	3
Low-mass binary	LMB	1	lmb	1
Binary	BIN	1	bin	0
Nova	NOV	1	nov	0
BL Lac type of blazar	BLL	22	bll	1094
FSRQ type of blazar	FSRQ	42	fsrq	644
Radio galaxy	RDG	6	rdg	36
Non-blazar active galaxy	AGN	1	agn	17
Steep spectrum radio quasar	SSRQ	0	ssrq	2
Compact Steep Spectrum radio source	CSS	0	css	5
Blazar candidate of uncertain type	BCU	3	bcu	1327
Narrow line Seyfert 1	NLSY1	4	nlsy1	5
Seyfert galaxy	SEY	0	sey	1
Starburst galaxy	SBG	0	sbg	7
Normal galaxy (or part)	GAL	2	gal	2
Unknown	UNK	0	unk	92
Total	...	356	...	3388
Unassociated	...	...	...	1323

NOTE—The designation 'spp' indicates potential association with SNR or PWN. Designations shown in capital letters are firm identifications; lower case letters indicate associations.



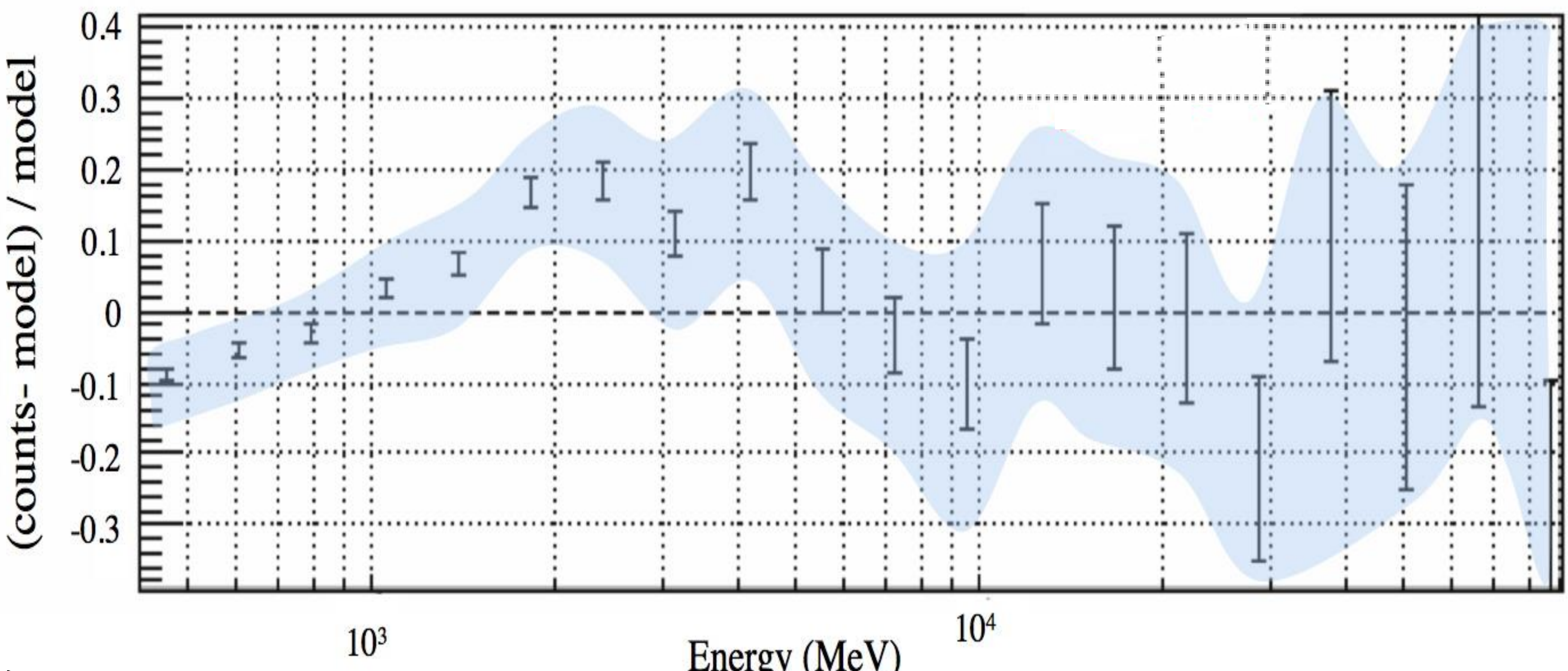
5065 sources
galactic coordinates

Fermi Fourth Source Catalog, The Astrophysical Journal ss, 247; 33 March 2020 [arXiv:1902.10045]

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

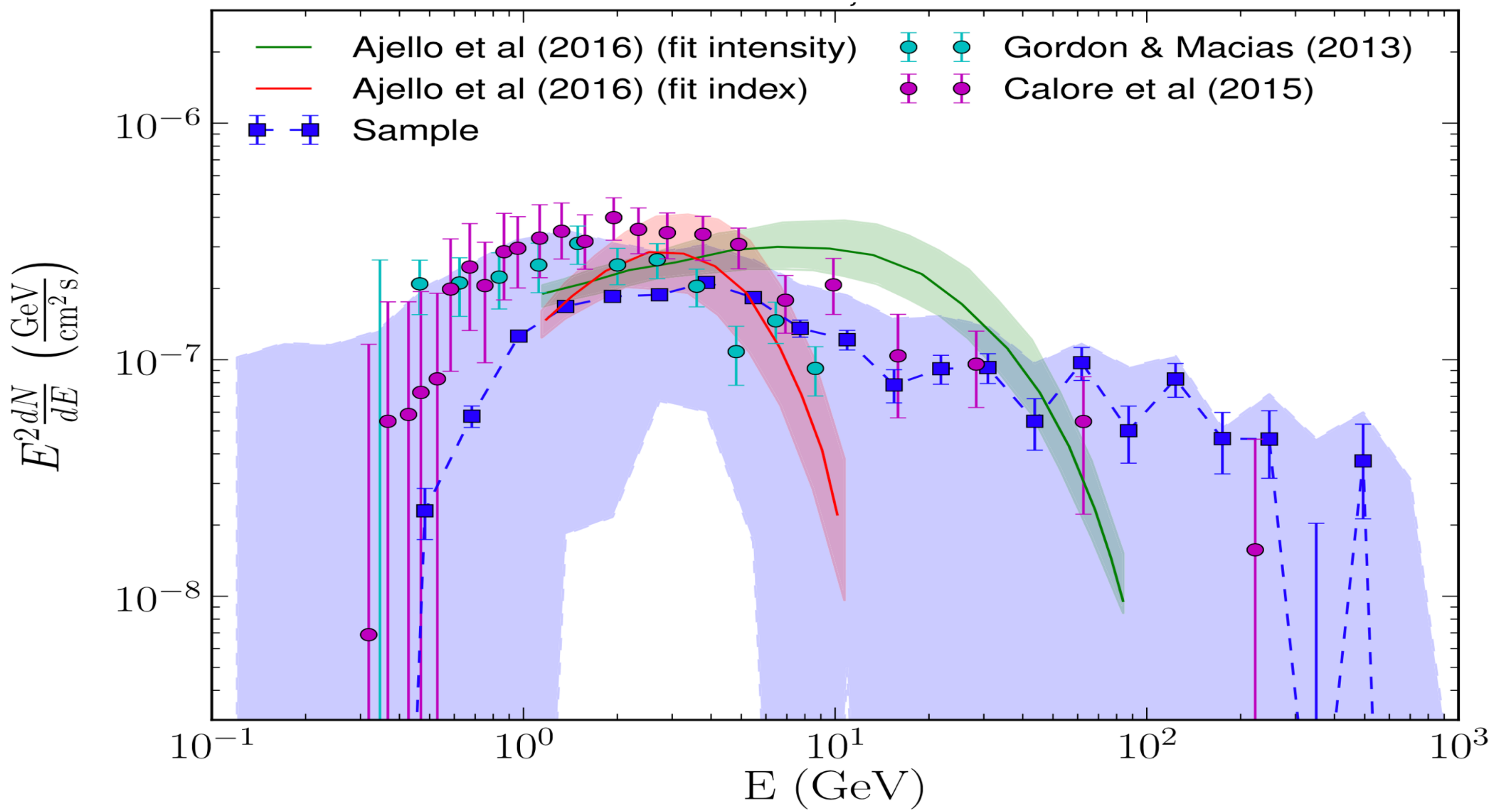
11 months of data, E >400 MeV, front-converting events analyzed with binned likelihood analysis)

- 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 GeV excess (Pass8 analysis)



following uncertainties have relatively small effect on the excess spectrum

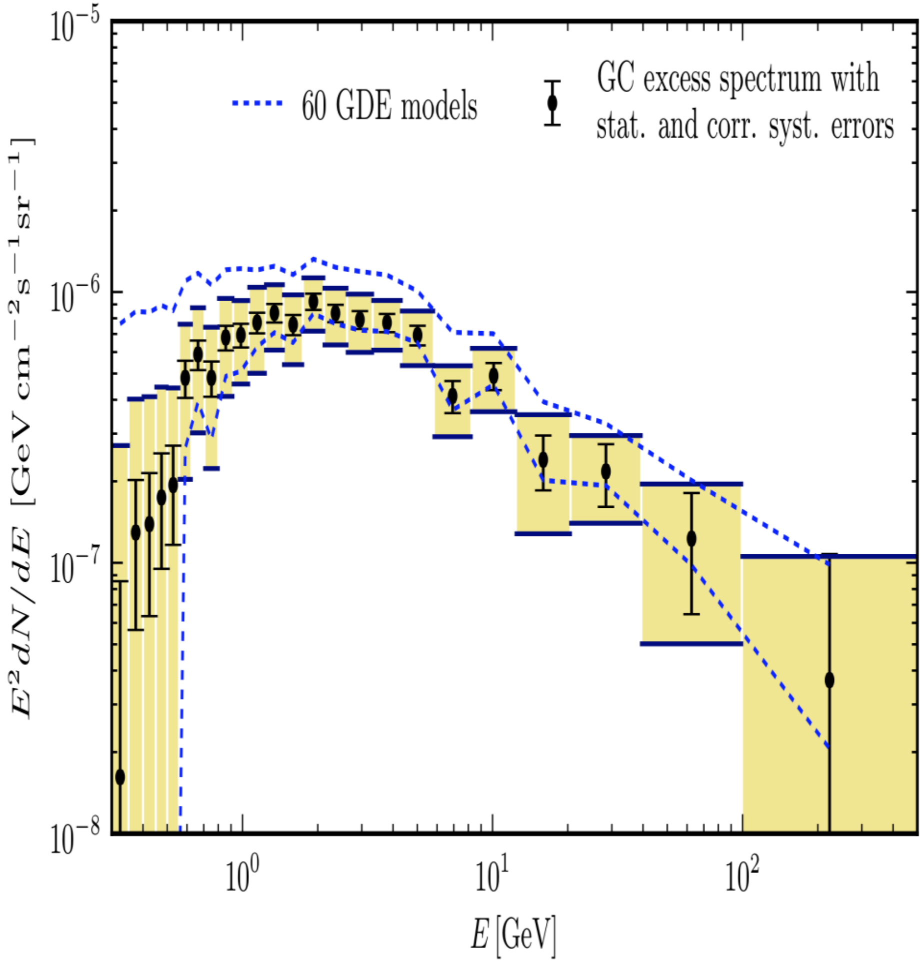
– Variation of GALPROP models – Distribution of gas along the line of sight

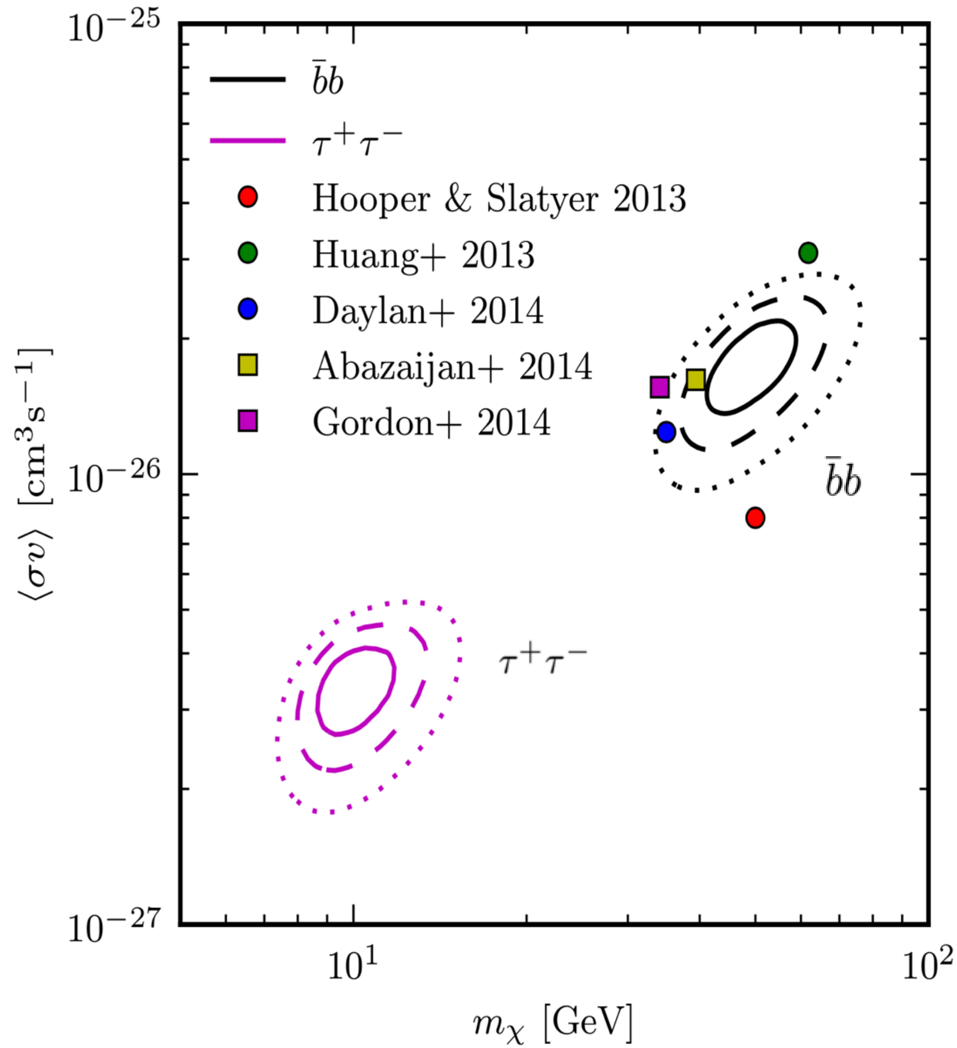
- **Most significant sources of uncertainty are:**

– 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:1409.0042v1

se non e' vero e' ben trovato (if it's not true it's well thought out)

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

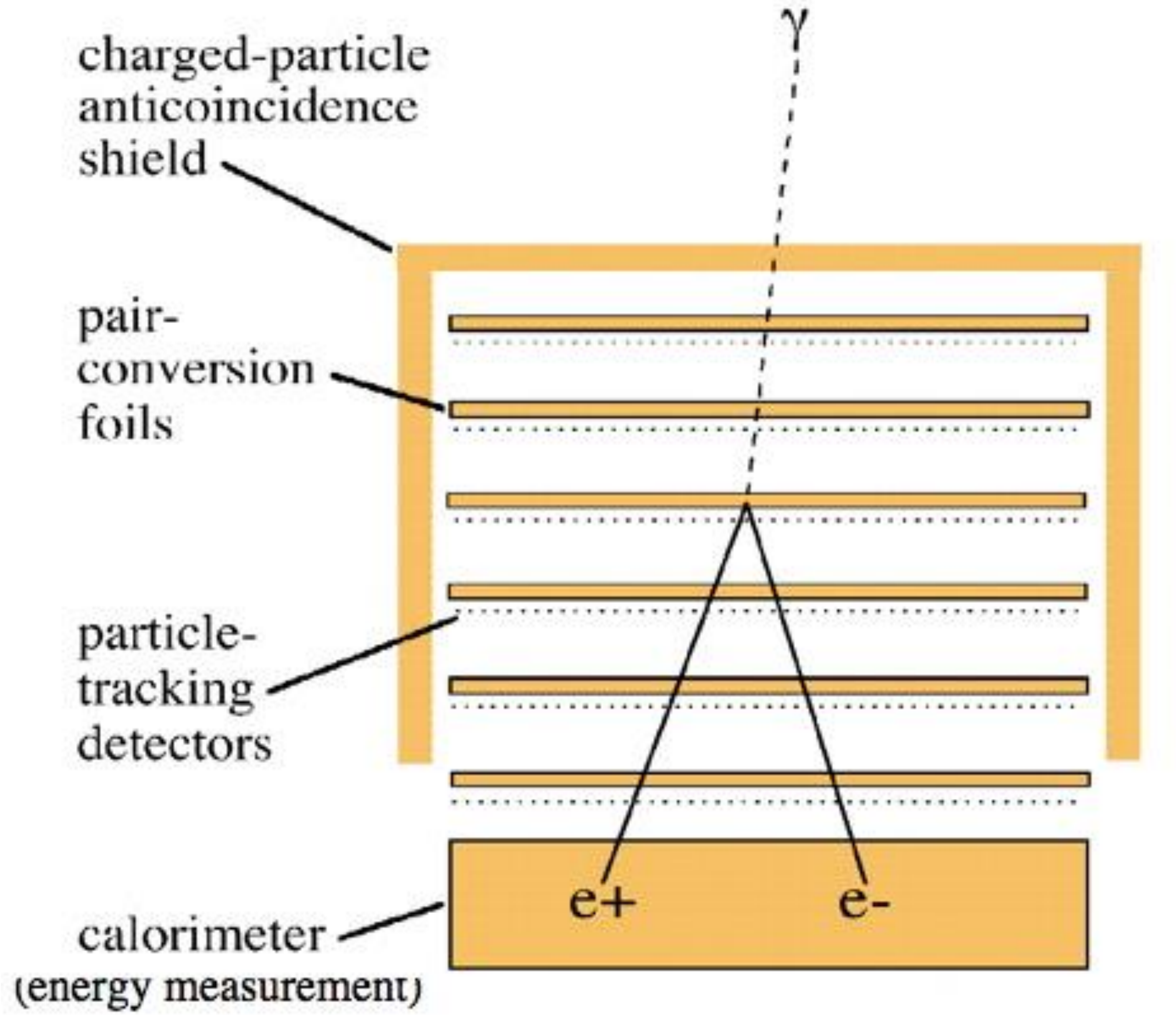
- Look for correlated synchrotron emission near the GC

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

Elements of a pair-conversion telescope



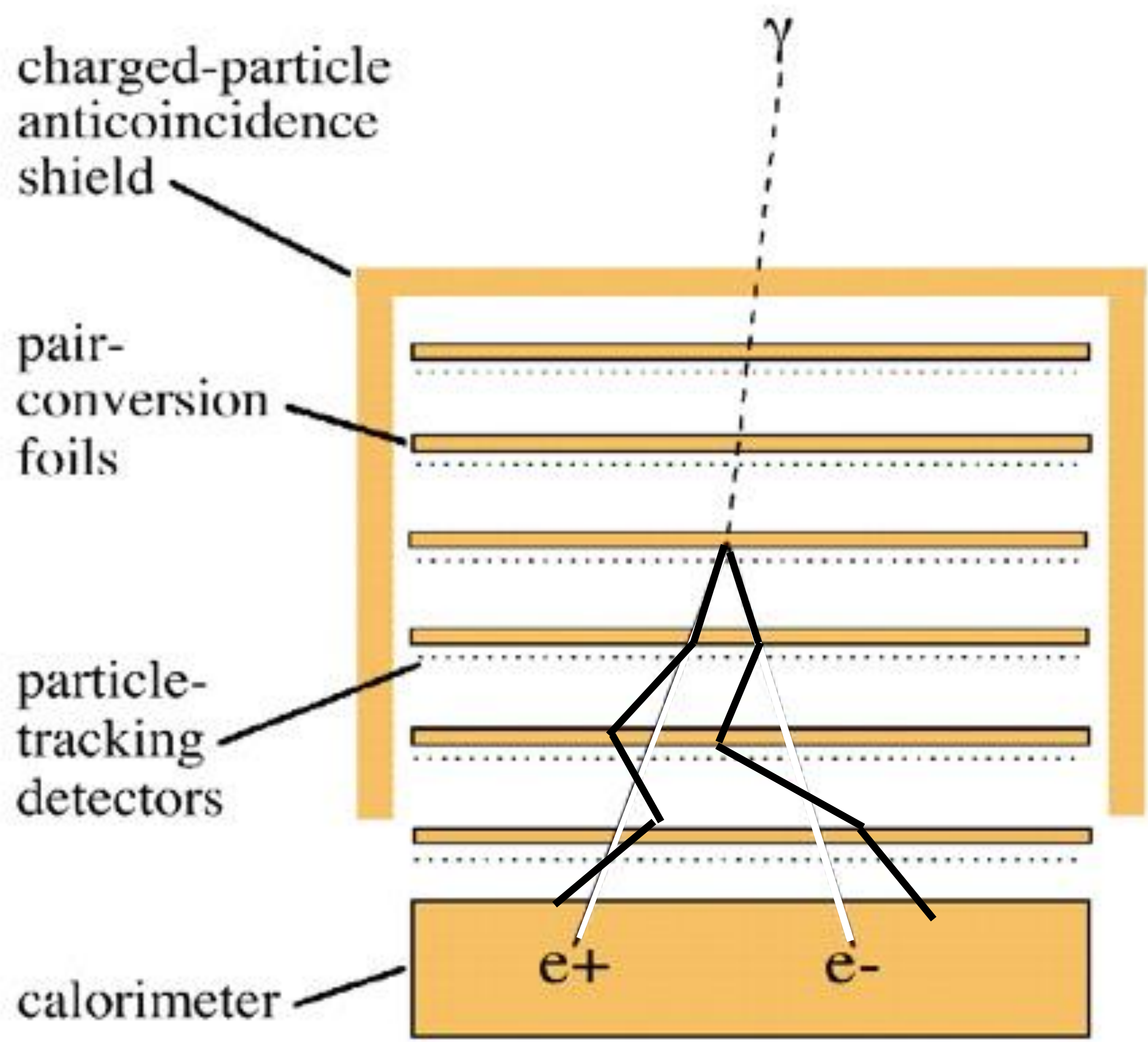
- photons materialize into matter-antimatter pairs:

  $E_\gamma \; \text{-->} \; m_{e^+}c^2 + m_{e^-}c^2$

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

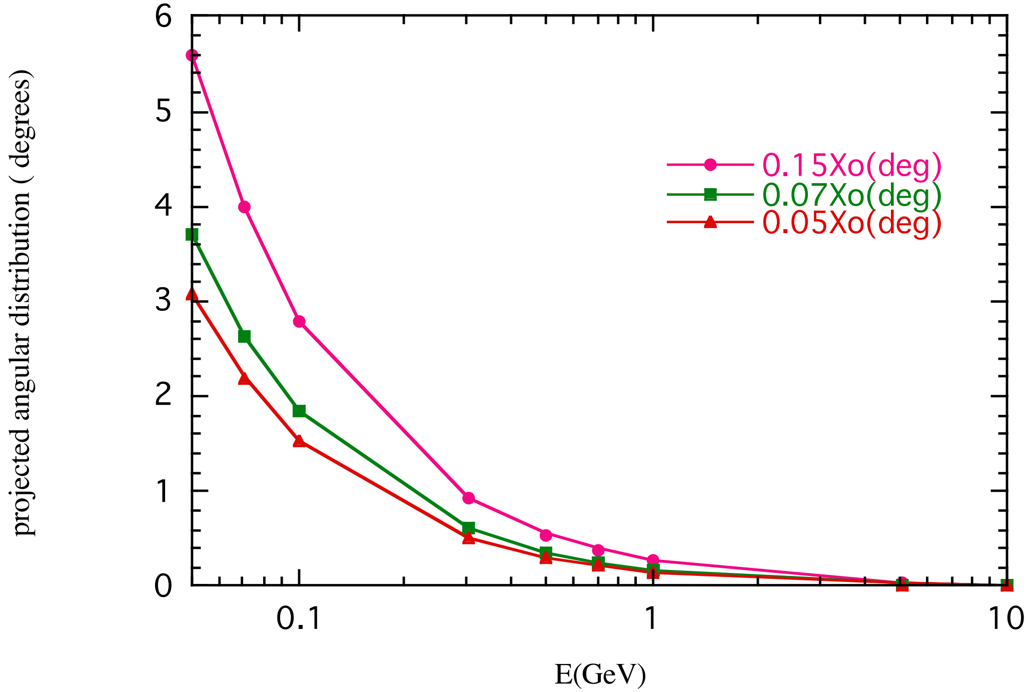
Elements of a pair-conversion telescope

(more realistic scheme)

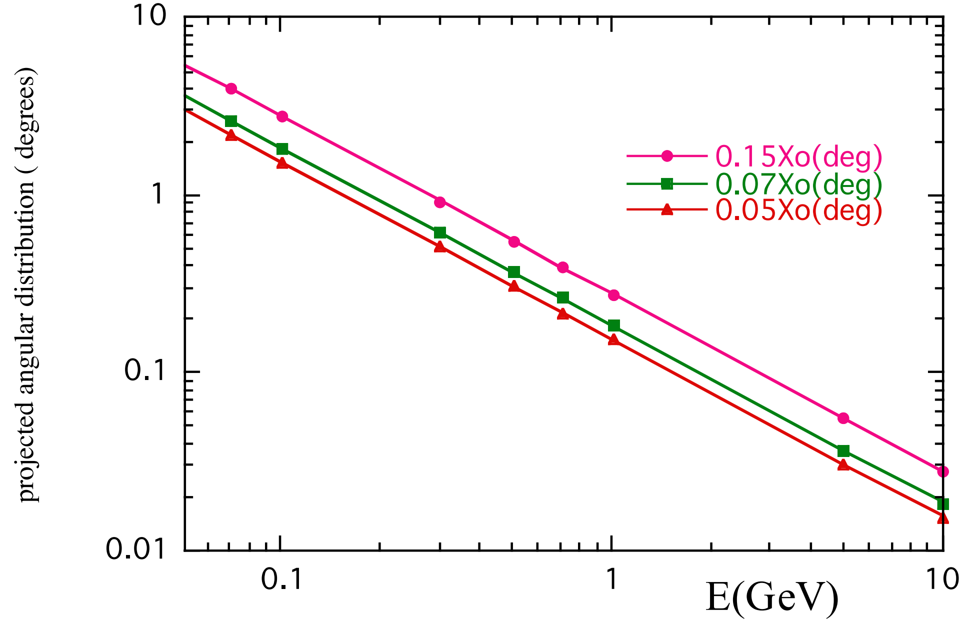


(energy measurement)

- 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



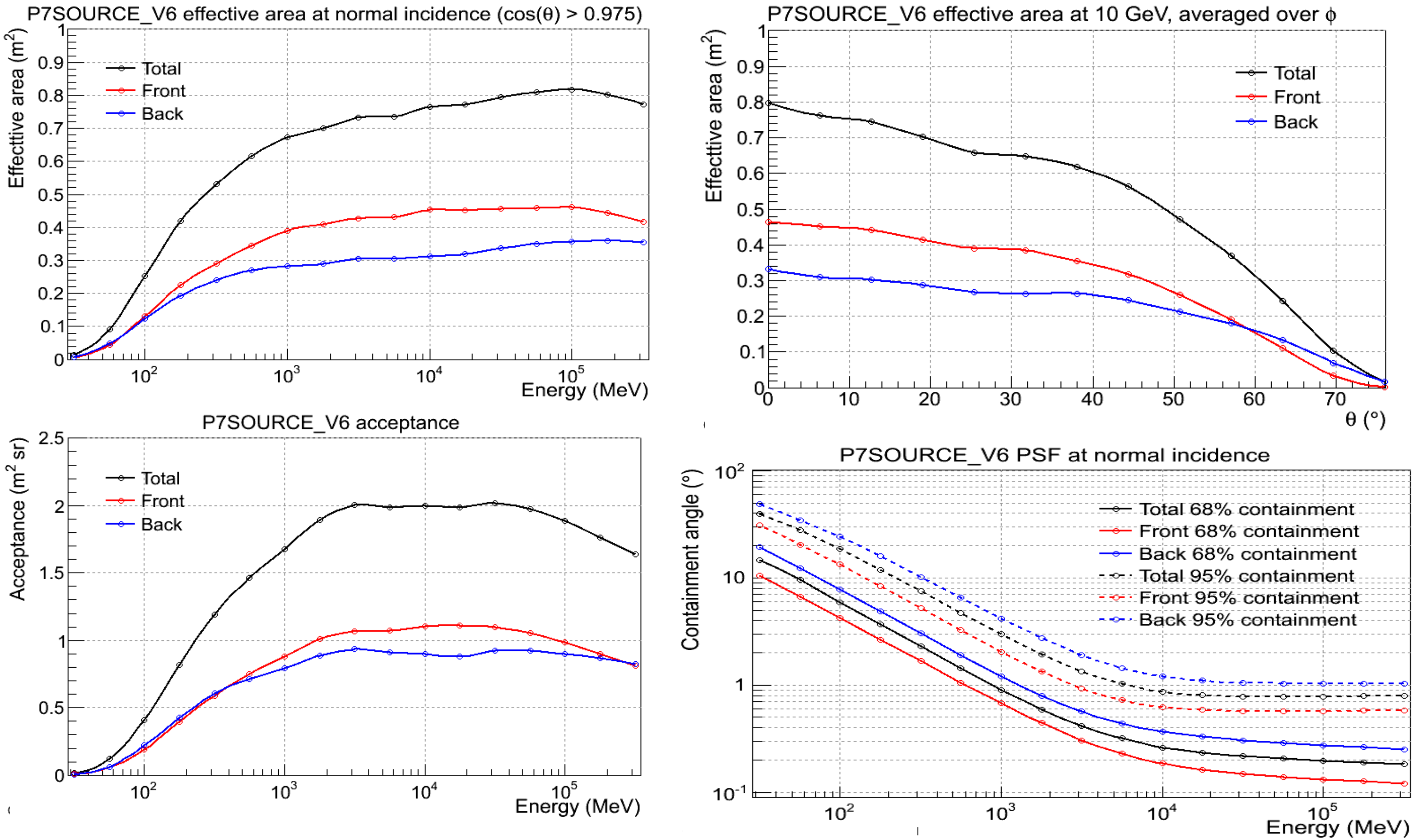
Multiple Scattering



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

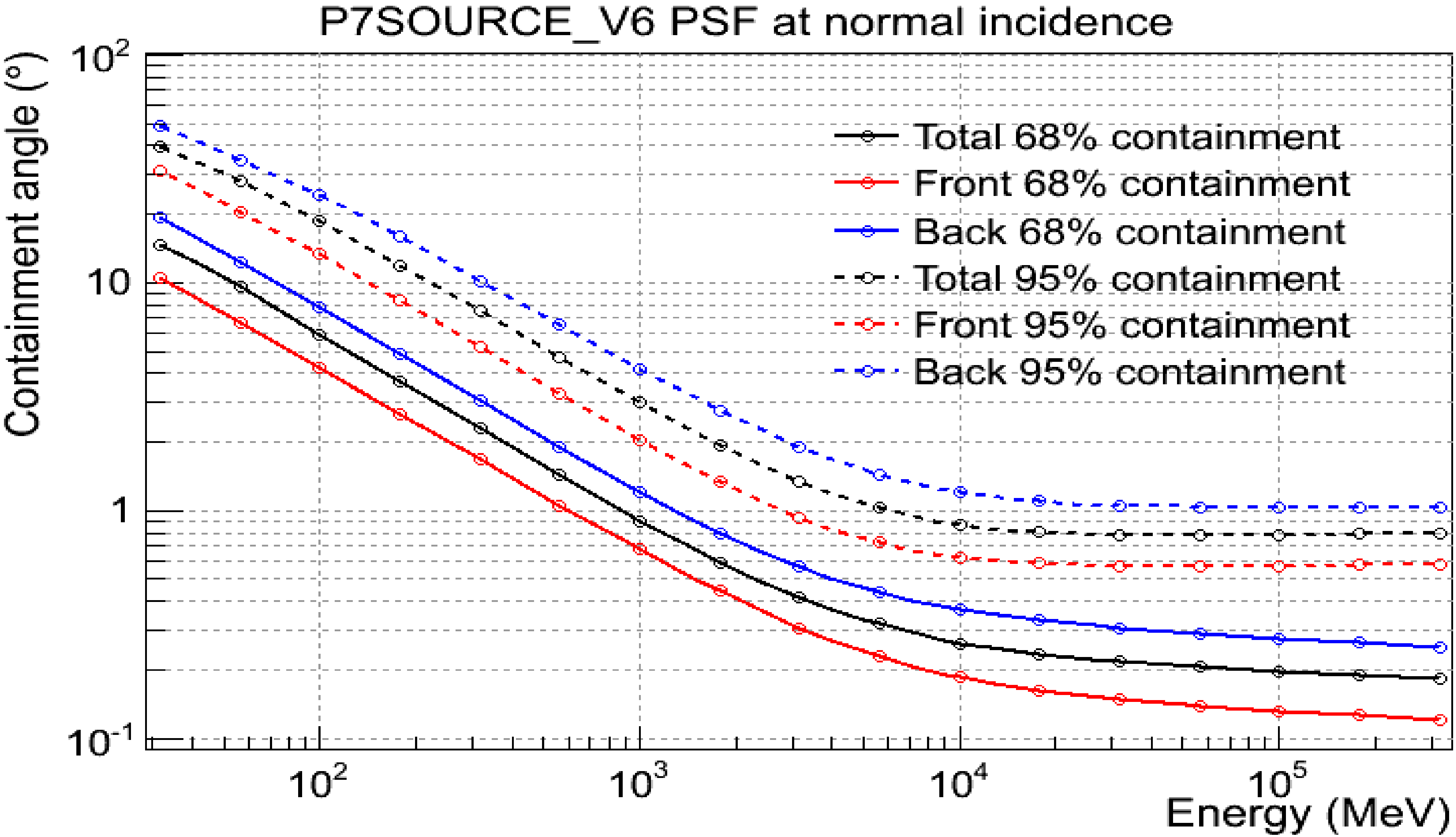
$$\theta_0 = \frac{13.6MeV}{\beta cp} z\sqrt{x/X_0}\,[1 + 0.038\ln(x/X_0)]$$

Fermi Instrument Response Function



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

Fermi Instrument Response Function

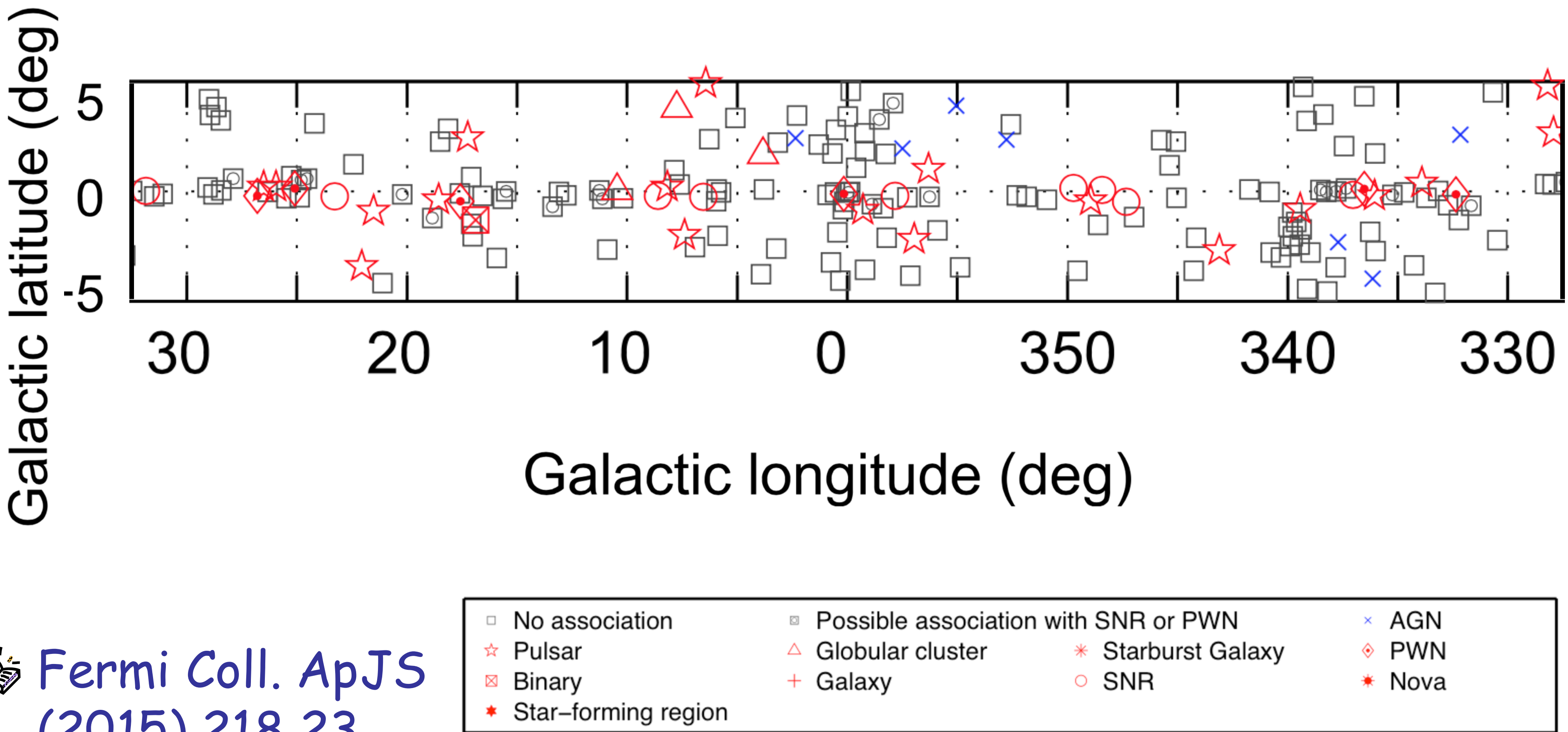


http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

The Fermi LAT 3FGL Inner Galactic Region

August 4, 2008, to July 31, 2010

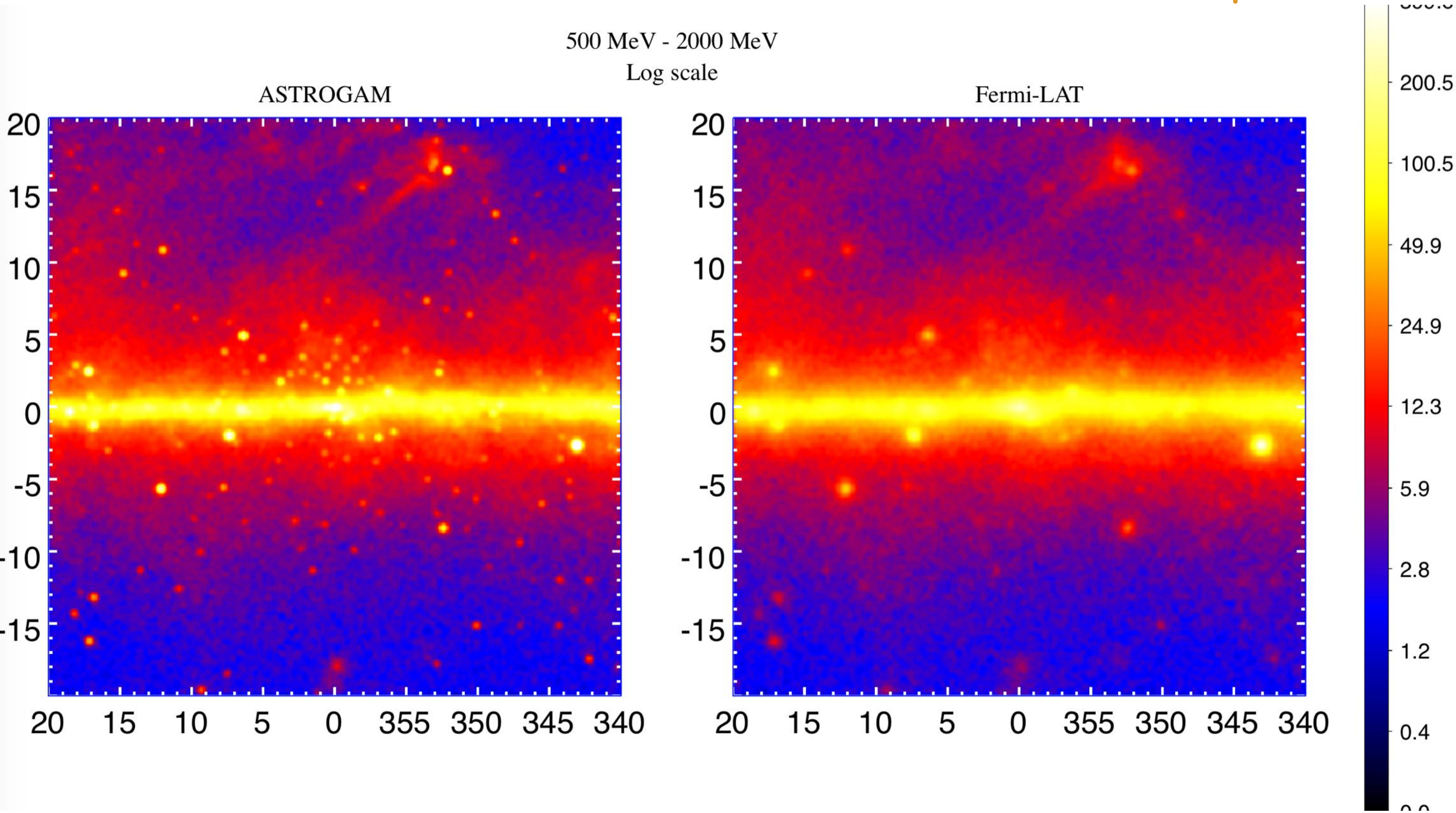
100 MeV to 300 GeV energy range



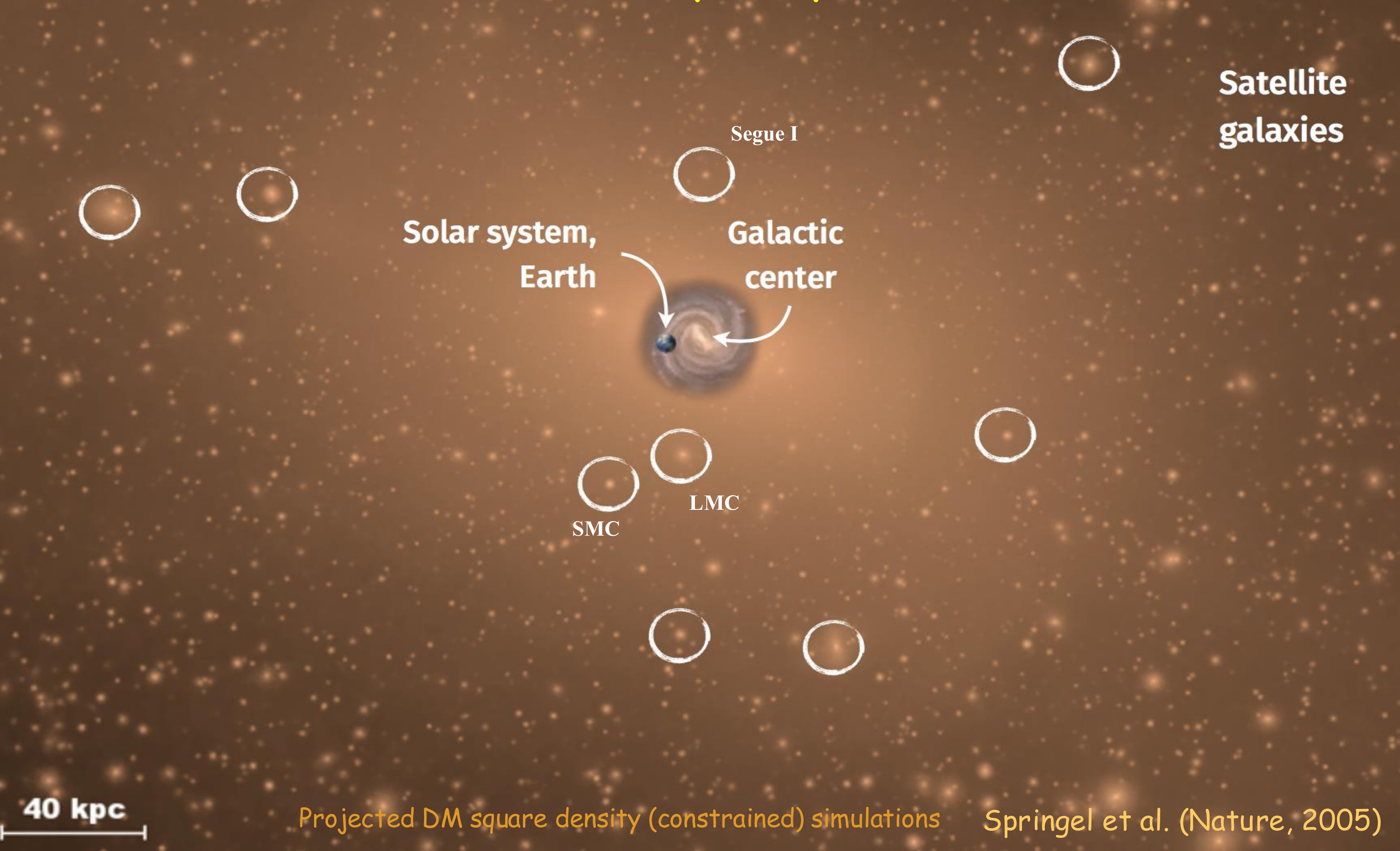
Fermi Coll. ApJS (2015) 218 23
arXiv:1501.02003

Galactic Center Region 0.5-2 GeV

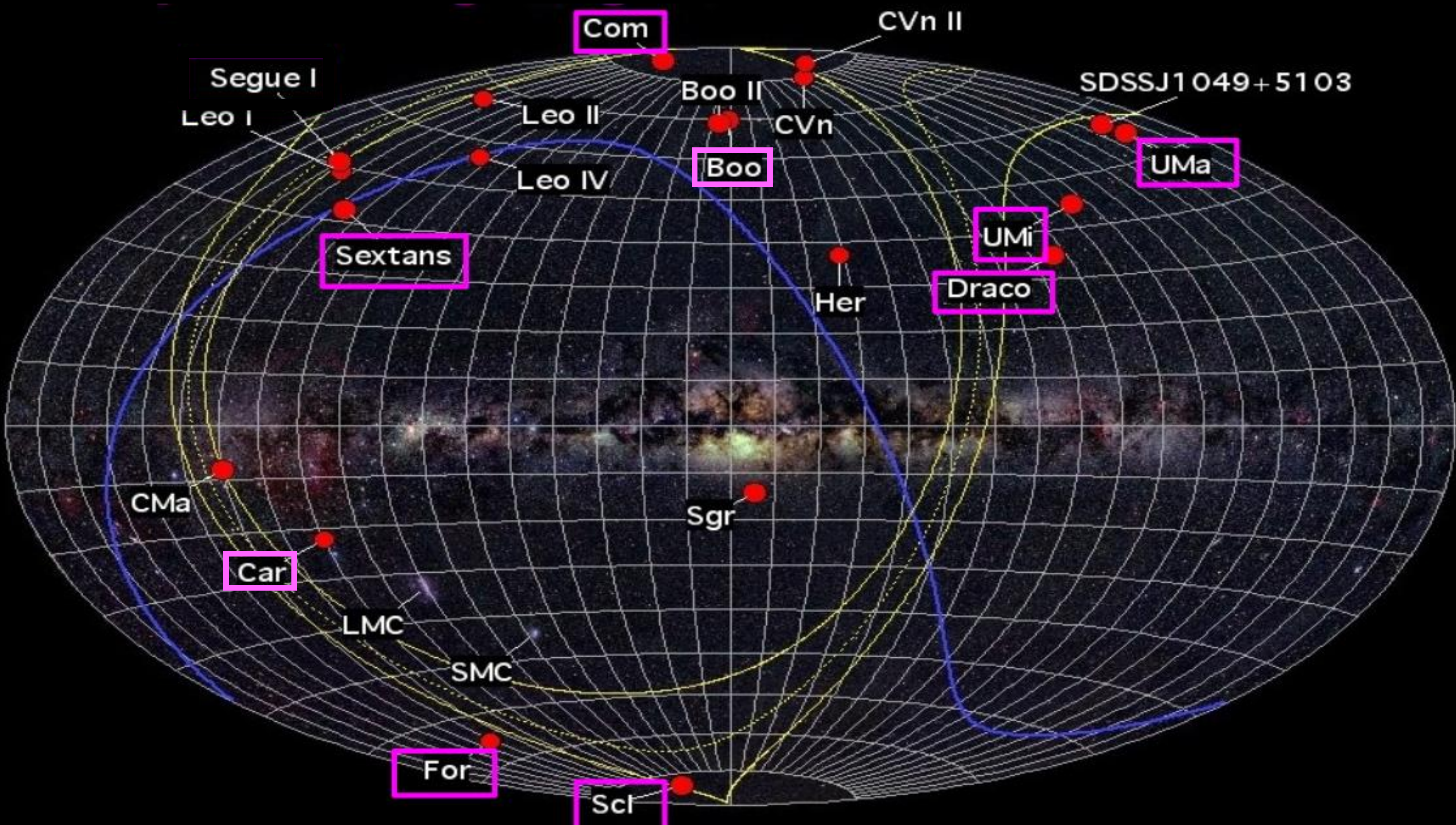
Fermi PSF Pass7 rep v15 source



Dark Matter in the Milky Way (from simulations)

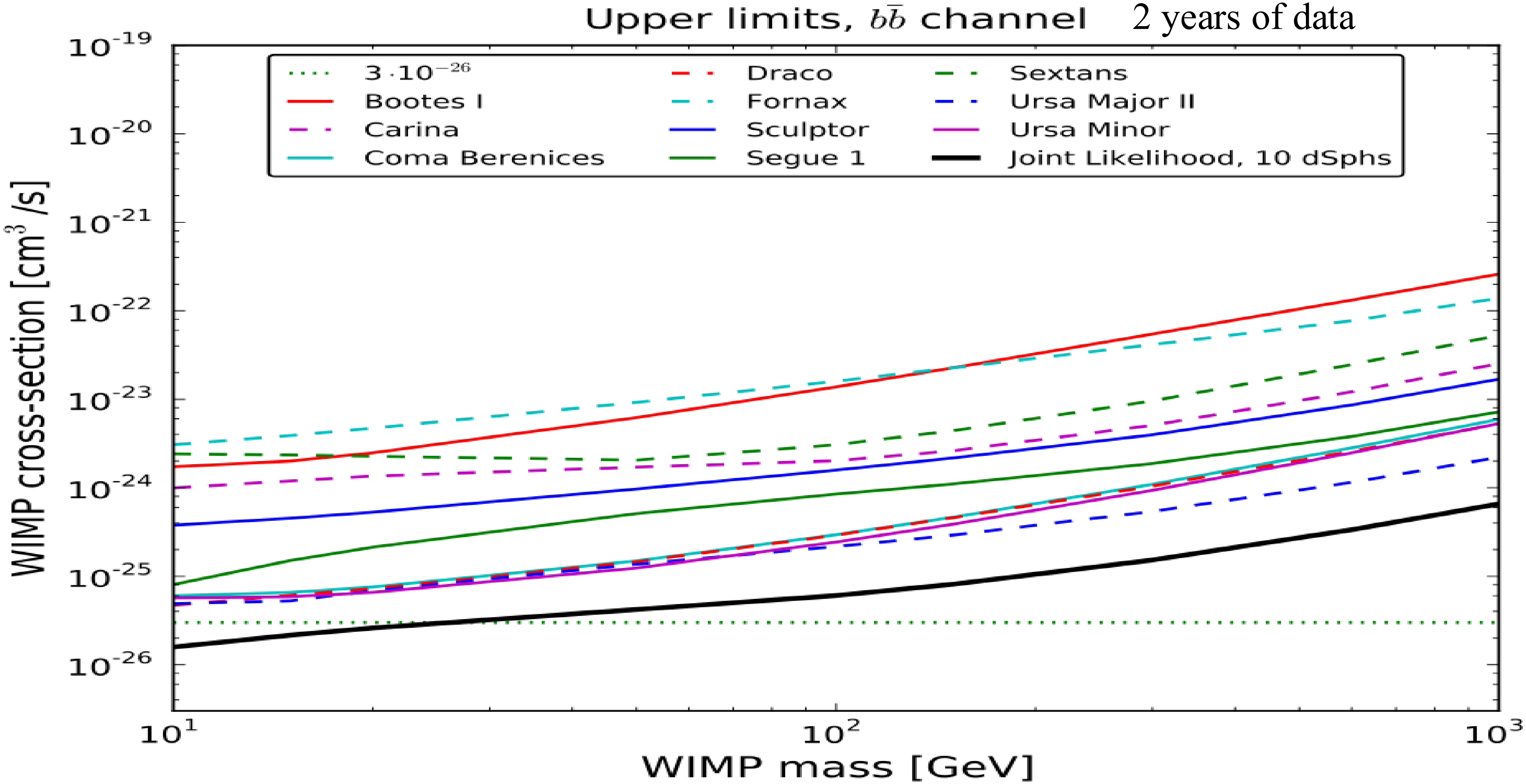


Classical Dwarf spheroidal galaxies: promising targets for DM detection



Dwarf Spheroidal Galaxies combined analysis

2 years of data

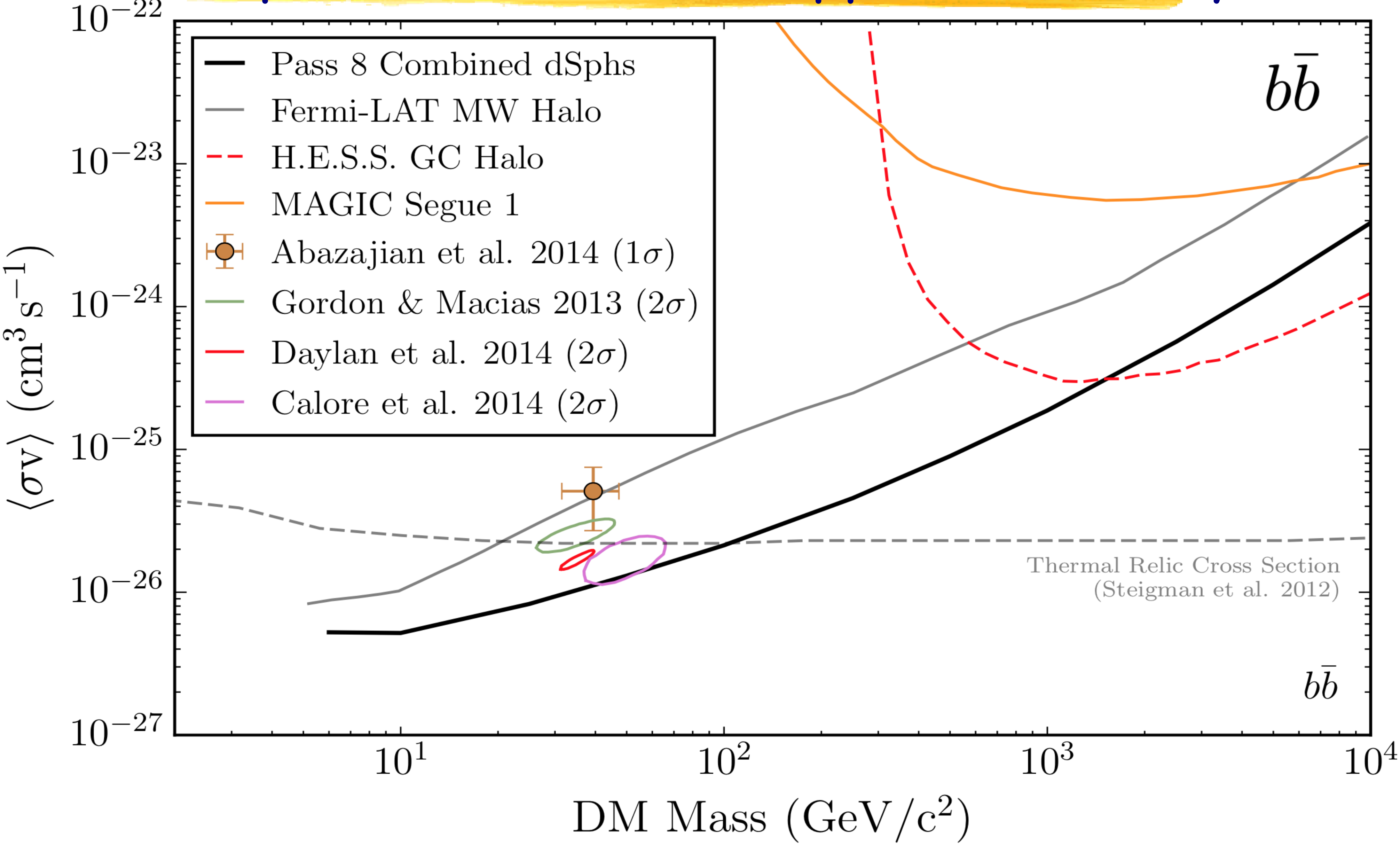


robust constraints including J-factor uncertainties from the stellar data statistical analysis

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

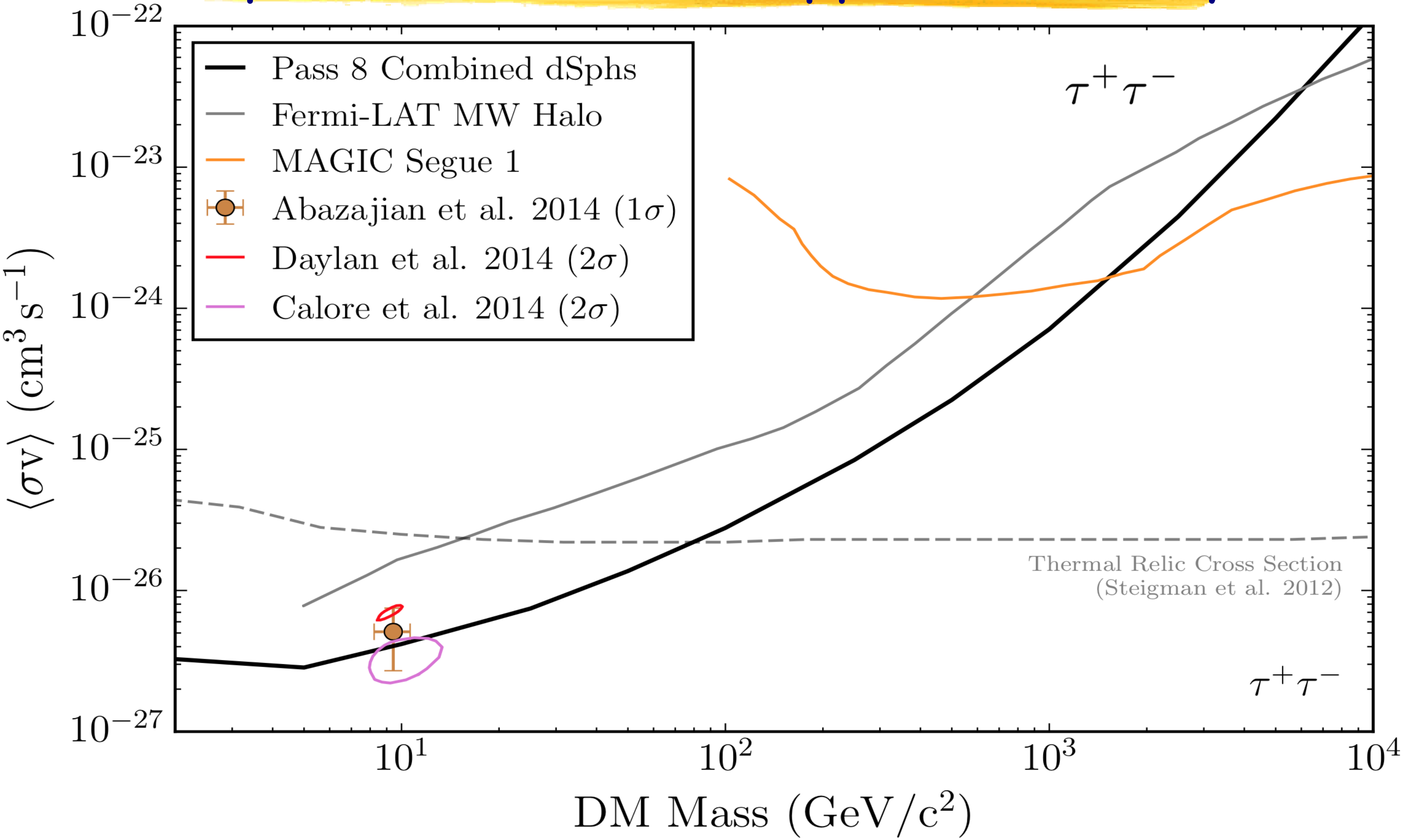
Fermi Lat Coll., PRL 107, 241302 (2011) [arXiv:1108.3546]

Dwarf Spheroidal Galaxies upper-limits (6 years)

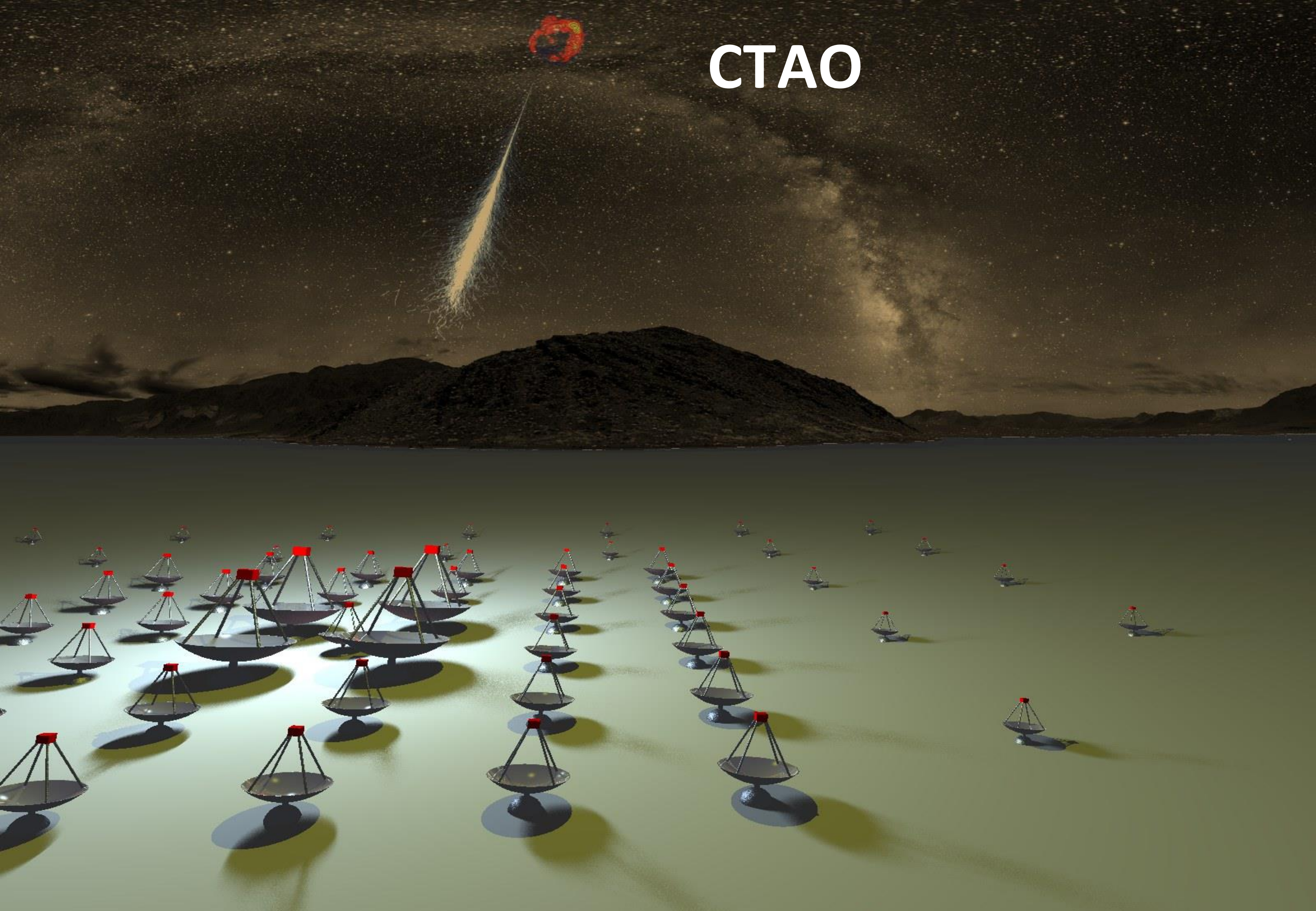


M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

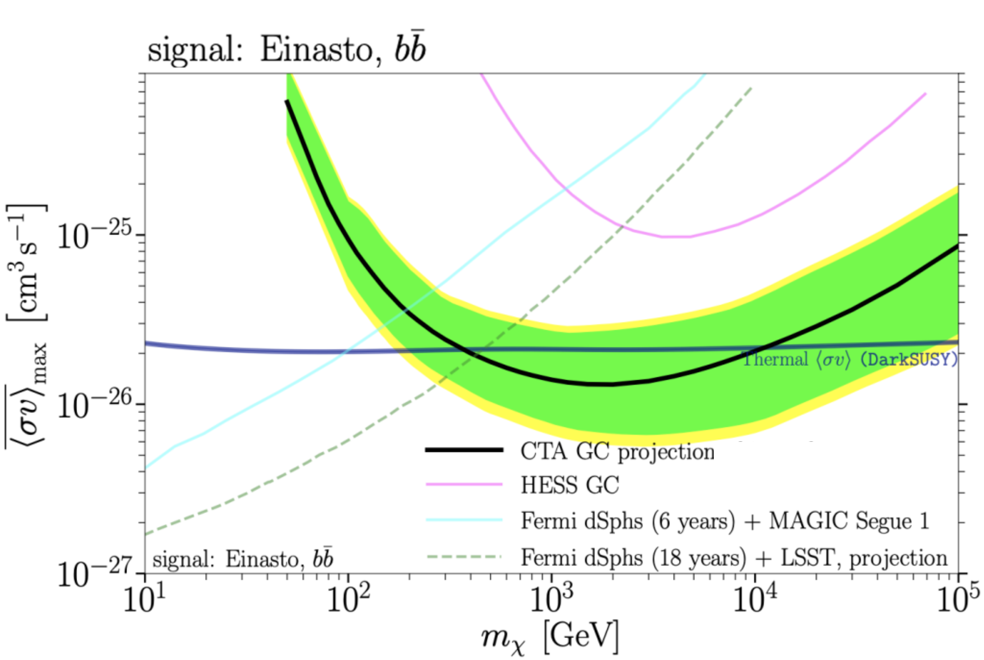
Dwarf Spheroidal Galaxies upper-limits (6 years)

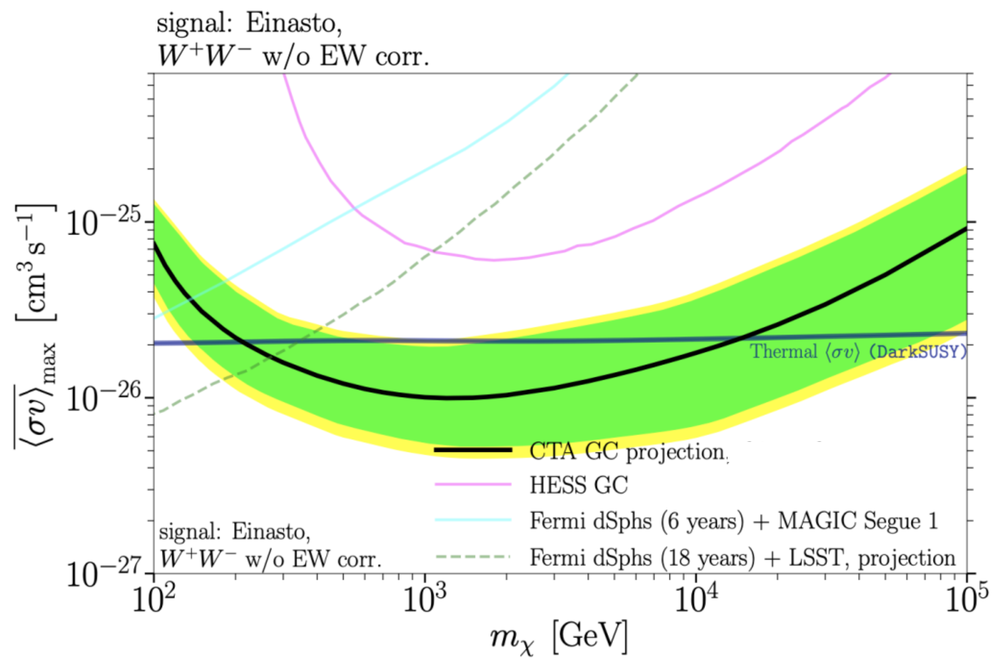


M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]


CTAO

Galactic center CTAO Sensitivity





- Einasto profile

520 h

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

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

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

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:

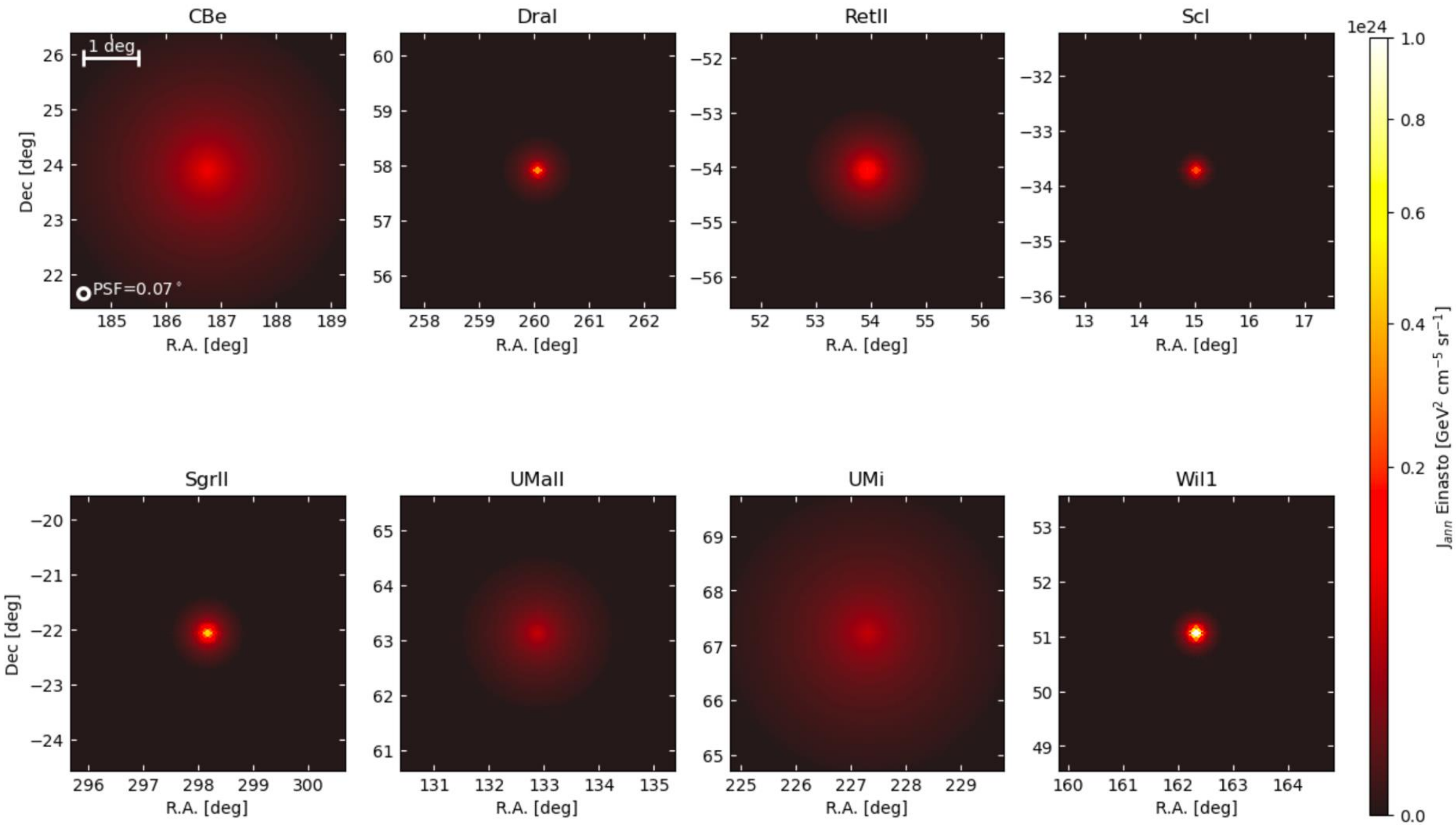
— 5 Northern dSphs (1 classical + 5 ultra-faint)

— 3 Southern dSphs (1 classical + 2 ultra-faint)

CTAO Coll. in preparation

Name	Abbr.	Type	R.A. (hh mm ss)	dec. (dd mm ss)	Distance (kpc)	ZA_{culm} N (deg)	ZA_{culm} S (deg)	Month	Ref.
CTAO-N candidate dSphs									
Boötes I	BoöI	uft	14 00 06.0	+14 30 00	65 ± 3	14.3	39.1	Apr	1,2
Boötes II	BoöII	uft	13 58 00.0	+12 51 00	39 ± 2	15.9	37.5	Apr	1,3
Boötes III	BoöIII	uft	13 57 12.0	+26 48 00	46 ± 2	2.0	51.4	Apr	1,3
Coma Berenices	CBe	uft	12 26 59.0	+23 54 15	42 ± 2	4.9	48.5	Mar	1,4
Draco I	DraI	cls	17 20 12.4	+57 54 55	75 ± 4	29.2	82.5	Jun	1,5
Draco II	DraII	uft	15 52 47.6	+64 33 55	20 ± 3	35.8	89.2	May	6
Laevens 3	Lae3	uft	21 06 54.3	+14 58 48	67 ± 3	13.8	39.6	Aug	7
Segue 1	Seg1	uft	10 07 04.0	+16 04 55	23 ± 2	12.7	40.7	Feb	1,8
Segue 2	Seg2	uft	02 19 16.0	+20 10 31	36 ± 2	8.6	44.8	Oct	1,9
Triangulum II	TriII	uft	02 13 17.4	+36 10 42	30 ± 2	7.4	60.8	Oct	10
Ursa Major II	UMaII	uft	08 51 30.0	+63 07 48	35 ± 2	34.4	87.8	Feb	1,11
Ursa Minor	UMi	cls	15 09 08.5	+67 13 21	68 ± 2	38.5	—	May	1,12
Willman 1	Wil1	uft	10 49 21.0	+51 03 00	38 ± 7	22.3	75.7	Mar	1,8
CTAO-S candidate dSphs									
Carina II	CarII	uft	07 36 26.3	−58 00 00	36 ± 1	86.7	33.3	Jan	13
Carina III	CarIII	uft	07 38 31.2	−57 54 00	28 ± 2	86.7	33.3	Jan	13
Cetus II	CetII	uft	01 17 52.8	−17 25 12	30 ± 3	46.2	7.2	Oct	14
Eridanus III	EriIII	uft	02 22 45.5	−52 16 48	95 ± 27	81.0	27.7	Oct	15
Grus II	GruII	uft	22 04 04.8	−46 26 24	53 ± 5	75.2	21.8	Aug	14
Horologium I	HorI	uft	02 55 28.9	−54 06 36	87 ± 13	82.9	29.5	Oct	15
Horologium II	HorII	uft	03 16 26.4	−50 03 00	78 ± 8	77.5	26.7	Nov	16
Hydrus I	HyiI	uft	02 29 33.7	−79 18 36	28 ± 1	—	53.3	Oct	17
Indus I	IndI	uft	21 08 48.1	−51 09 36	69 ± 16	79.9	26.5	Aug	15
Phoenix II	PheII	uft	23 39 57.6	−54 24 36	95 ± 18	83.2	29.8	Sep	15
Pictor II	PicII	uft	06 44 43.1	−59 54 00	45 ± 5	88.3	35.8	Jan	18
Reticulum II	RetII	uft	03 35 40.9	−54 03 00	32 ± 2	82.8	29.4	Nov	15
Reticulum III	RetIII	uft	03 45 26.3	−60 27 00	92 ± 13	89.2	35.8	Nov	19
Sagittarius I	SgrI	cls	18 55 19.5	−30 32 43	31 ± 1	59.3	5.9	Jul	1,20
Sagittarius II	SgrII	uft	19 52 40.5	−22 04 05	67 ± 5	50.8	2.6	Jul	7
Sculptor	Scl	cls	01 00 09.4	−33 42 33	84 ± 2	62.5	9.1	Oct	1,21
Sextans	Sex	cls	10 13 03.0	−01 36 53	84 ± 3	30.4	23.0	Feb	1,22
Tucana II	TucII	uft	22 52 16.7	−58 33 36	58 ± 6	87.3	33.9	Sep	15
Tucana III	TucIII	uft	23 56 35.9	−59 36 00	25 ± 2	88.4	35.0	Sep	14
Tucana IV	TucIV	uft	00 02 55.3	−60 51 00	48 ± 4	89.6	36.2	Sep	14
Tucana V	TucV	uft	23 37 23.9	−63 16 12	55 ± 9	—	38.3	Sep	23
Virgo I	VirI	uft	12 00 09.1	−00 40 52	87 ± 11	40.0	24.2	Mar	24

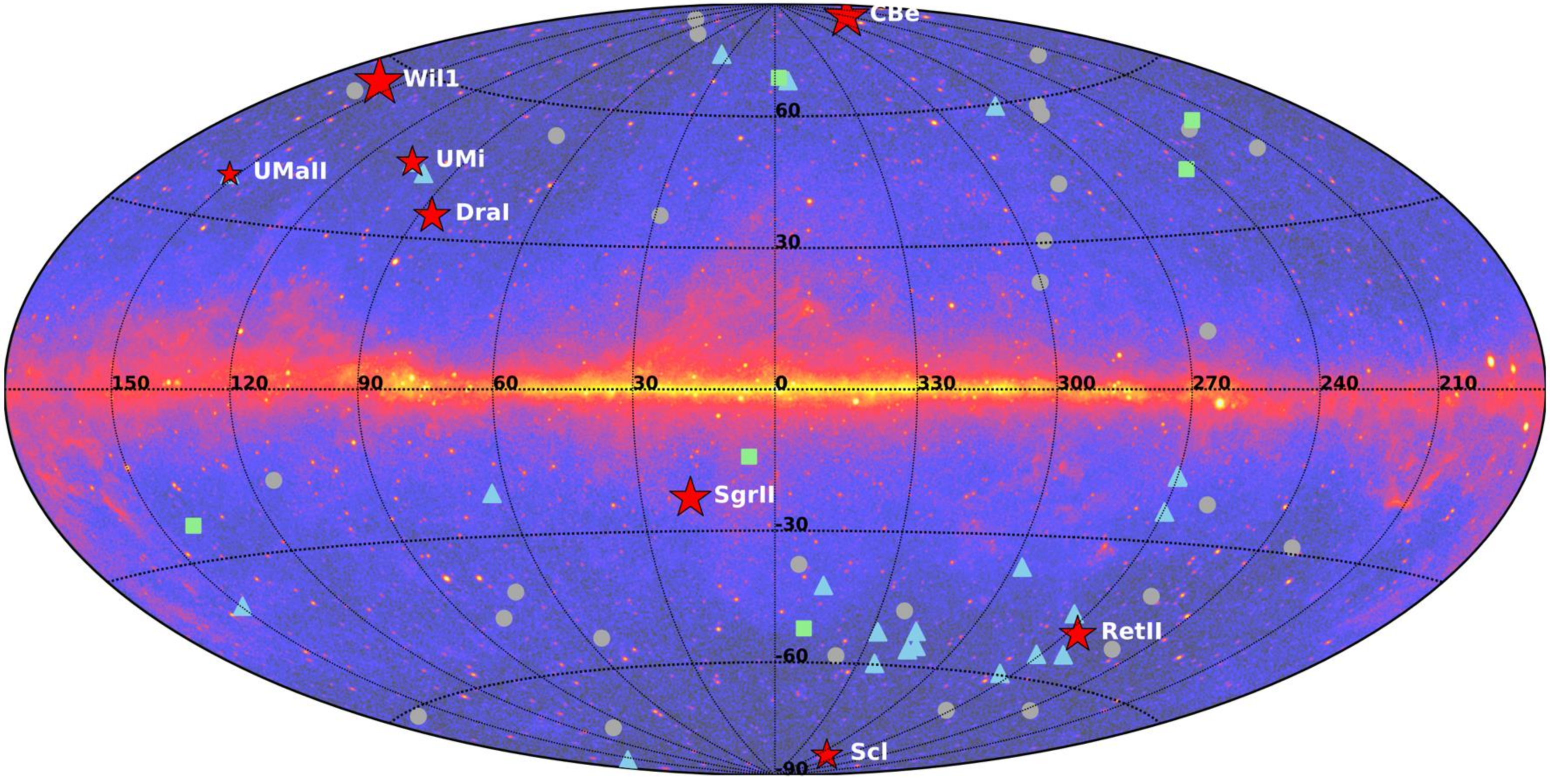
Dark matter density of the selected dSphs



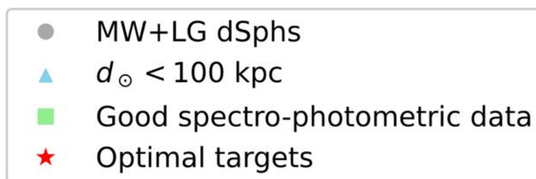
2D distributions of the astrophysical factors of the selected dSphs obtained with CLUMPY for an Einasto profile. The CTAO PSF (white circle) is indicated in the first panel

CTAO Consortium paper in prep. by the dSph task force

Dwarf Spheroidal Galaxies: Selection of optimal candidates for CTAO



The optimal targets (red stars) are highlighted with symbols of increasing size, proportional to the value of their dark matter content

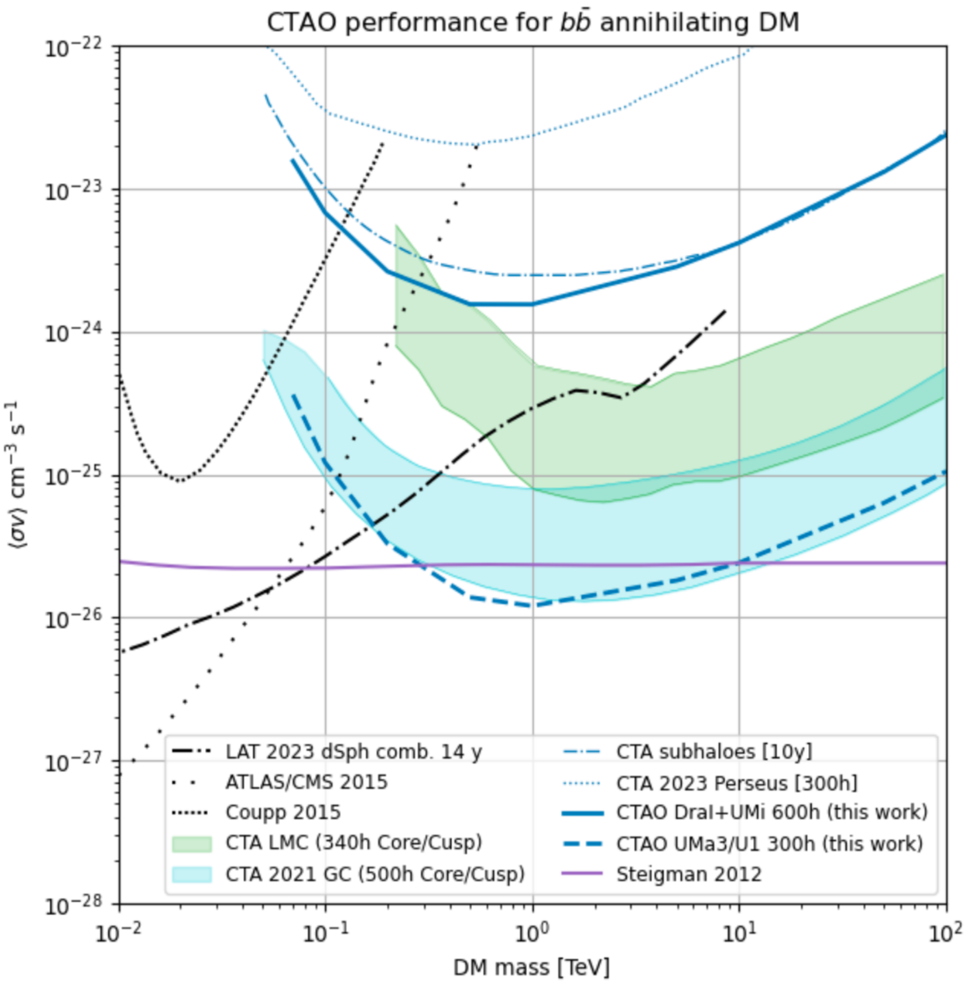


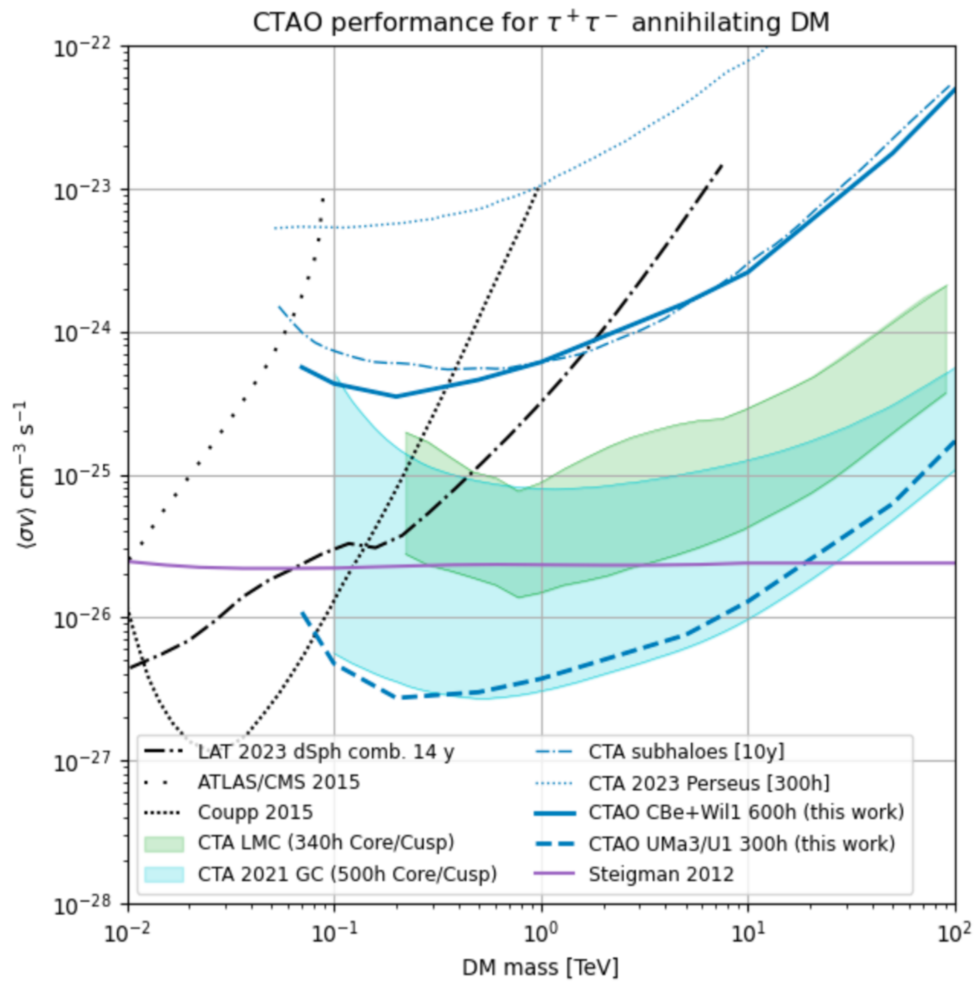
MNRAS **000**, 1–34 (2025)   Preprint 26 May 2025   Compiled using MNRAS LATEX style file v3.2

Prospects for dark matter observations in dwarf spheroidal galaxies with the Cherenkov Telescope Array Observatory

CTAO Consortium paper in prep. by the dSph task force M. Doro, A. Morselli, G. Rodríguez-Fernández, F. G. Saturni

Dwarf Spheroidal Galaxies: CTAO Sensitivity compared with other targets and experiments





CTAO Consortium paper in prep. by the dSph task force M. Doro, A. Morselli, G. Rodríguez-Fernández, F. G. Saturni

CTAO Search for Dark Matter beyond WIMP

Axion Like Particle (ALP) search prospects

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

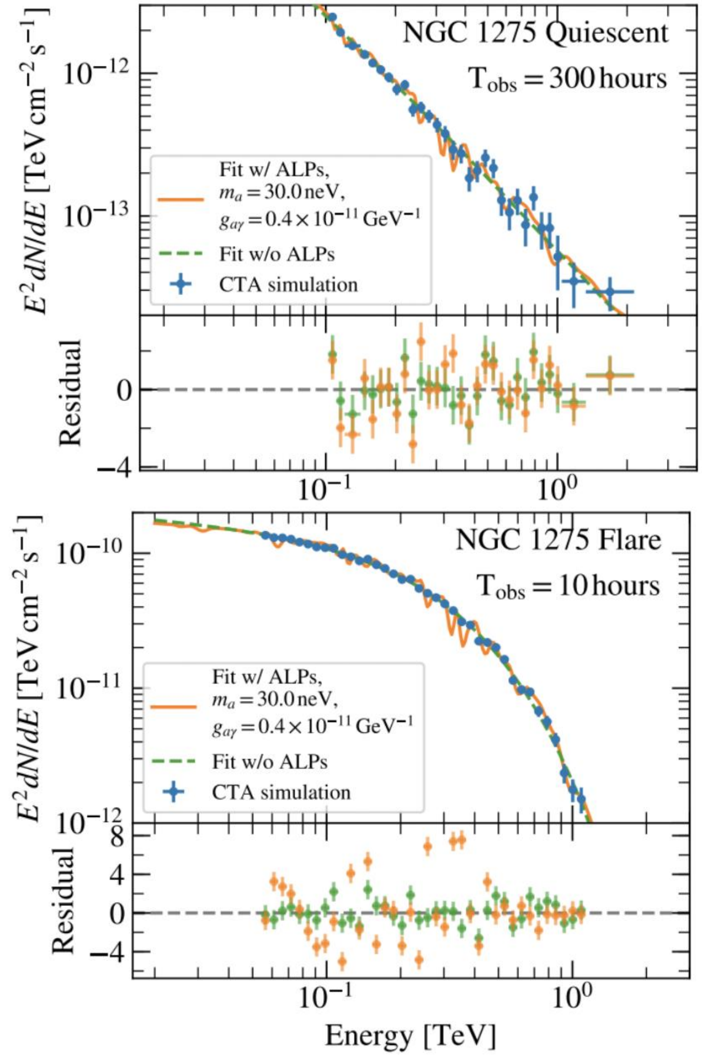
conversion probability ($E > E_{crit}$)

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

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

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



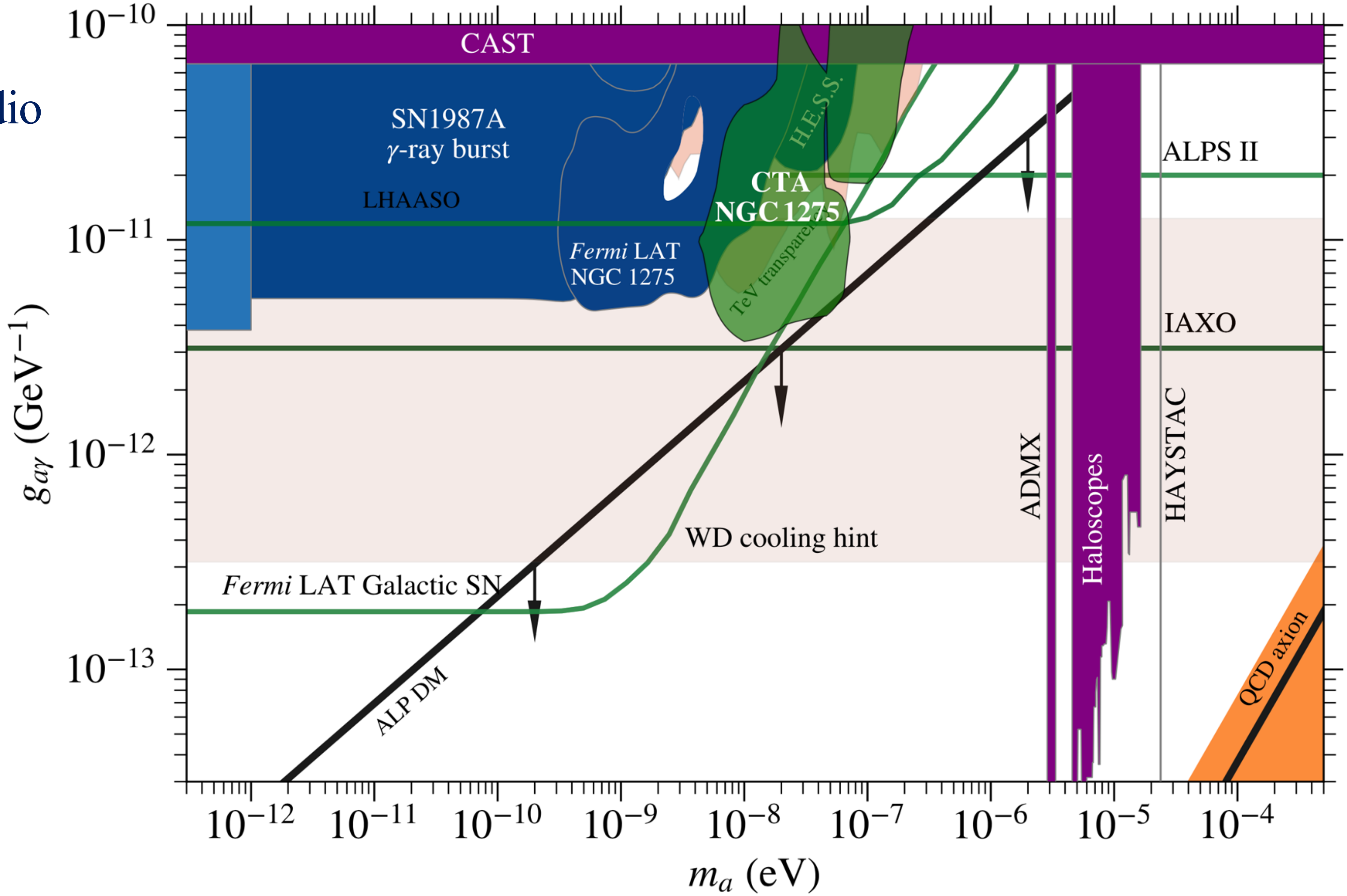
The CTA Consortium, JCAP 02 (2021) 048, 2021 [arXiv:2010.01349]

CTAO Search for Dark Matter beyond WIMP

Axion Like Particle search prospects

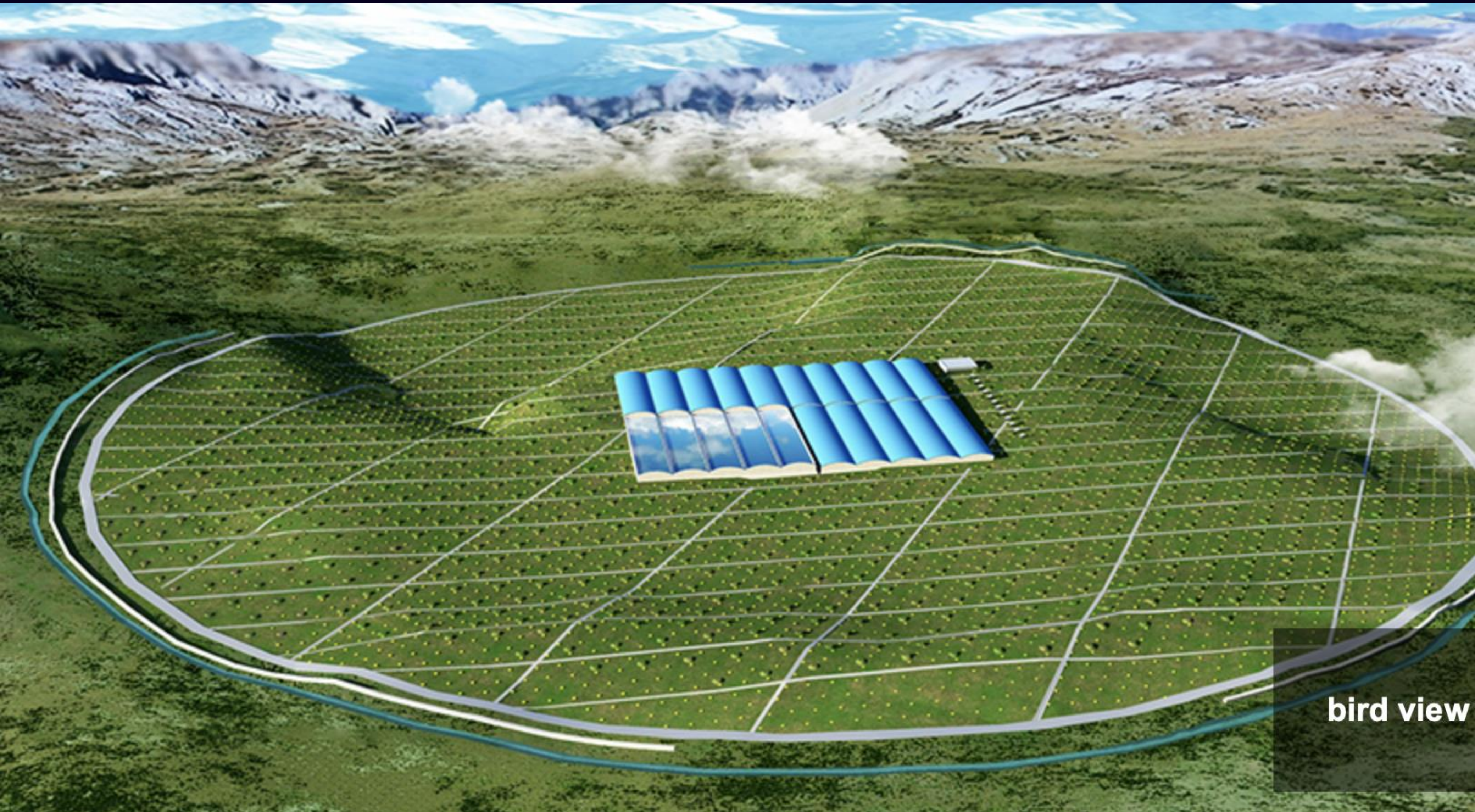
- Observation of a flaring state of the radio galaxy NGC 1275 inside the Perseus cluster

- Observations of several AGN can be combined to further improve the CTA sensitivity.

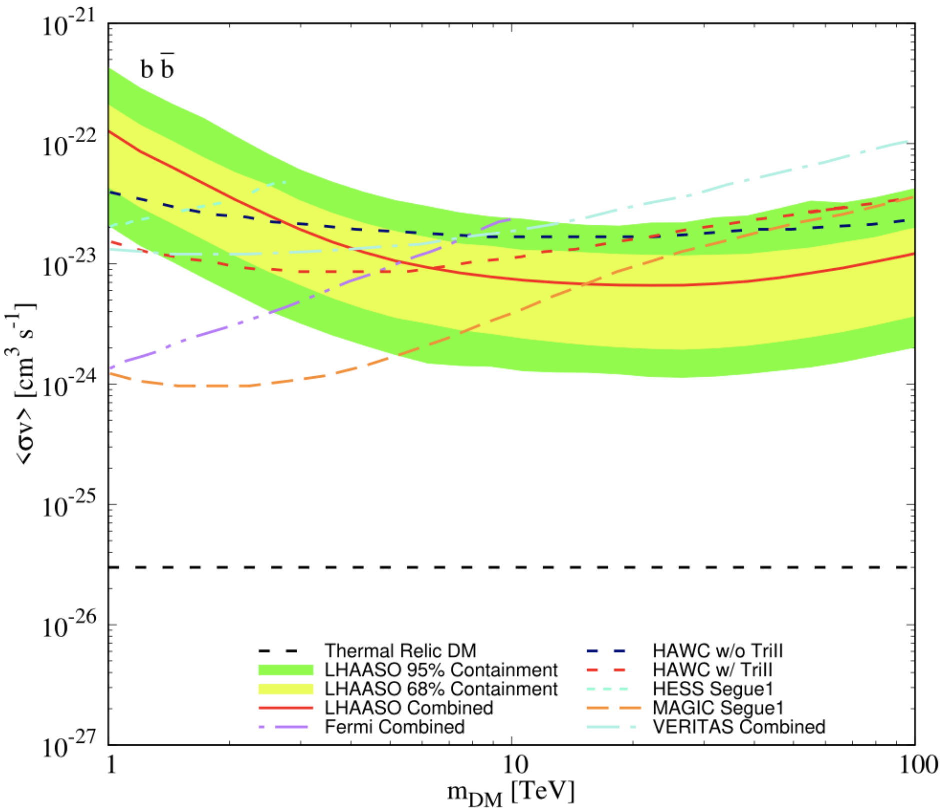


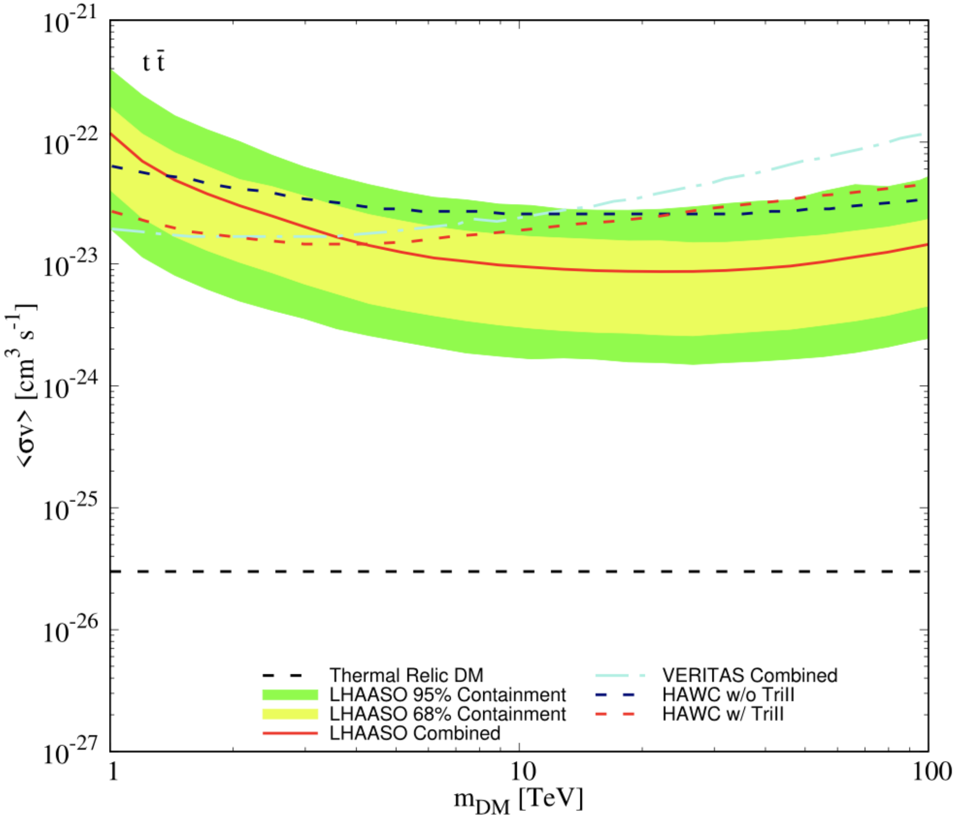
The CTA Consortium, JCAP 02 (2021) 048, 2021 [arXiv:2010.01349]

LHAASO



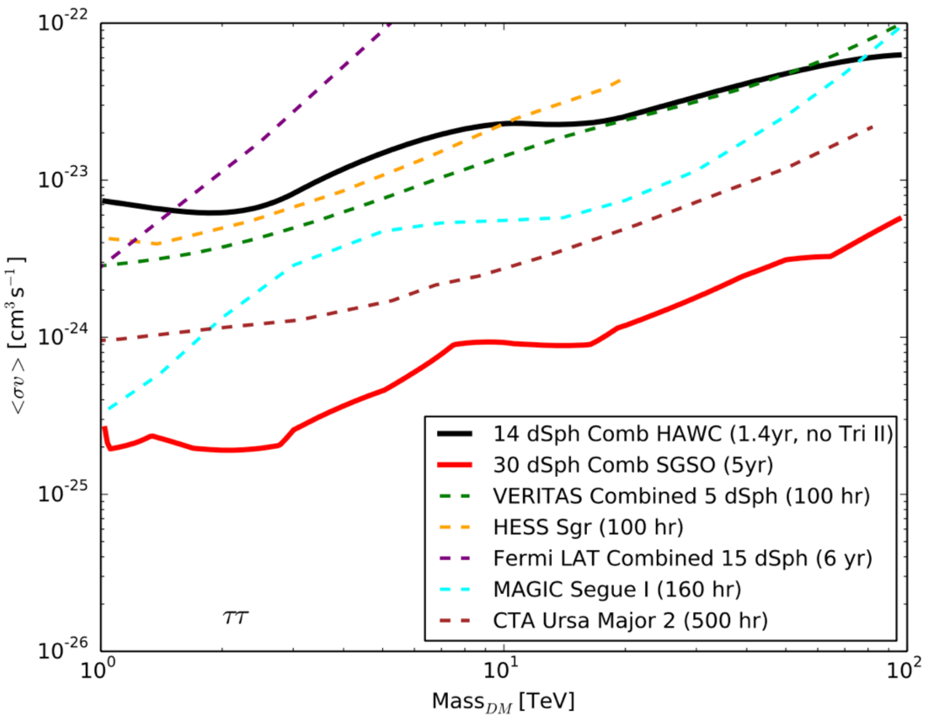
Combined one-year LHAASO sensitivities

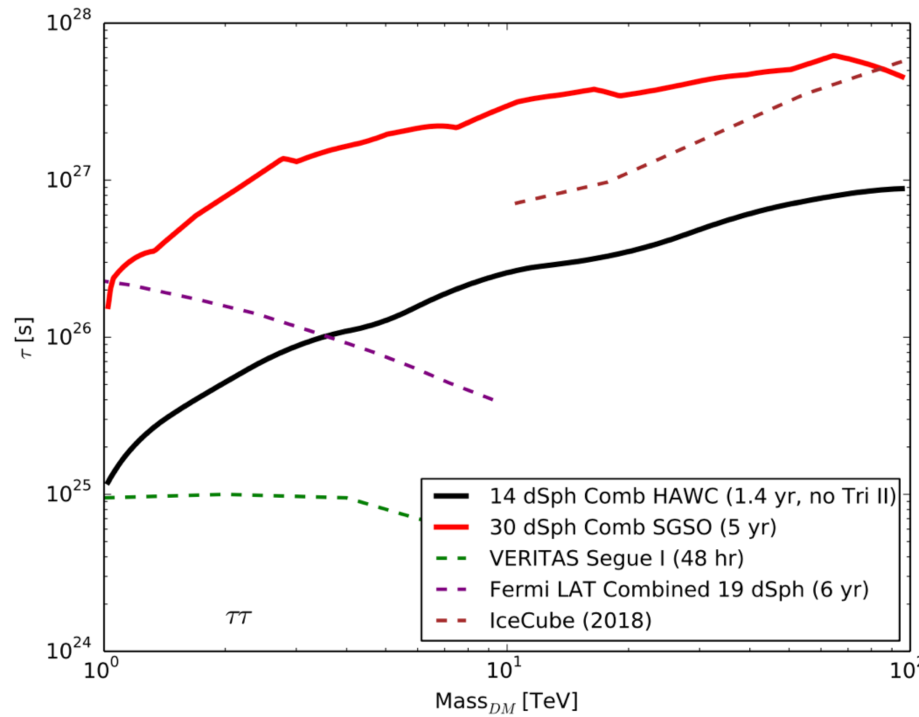




Dong-Ze He et al., Phys. Rev. D 100, 083003 (2019)

SWGO sensitivities

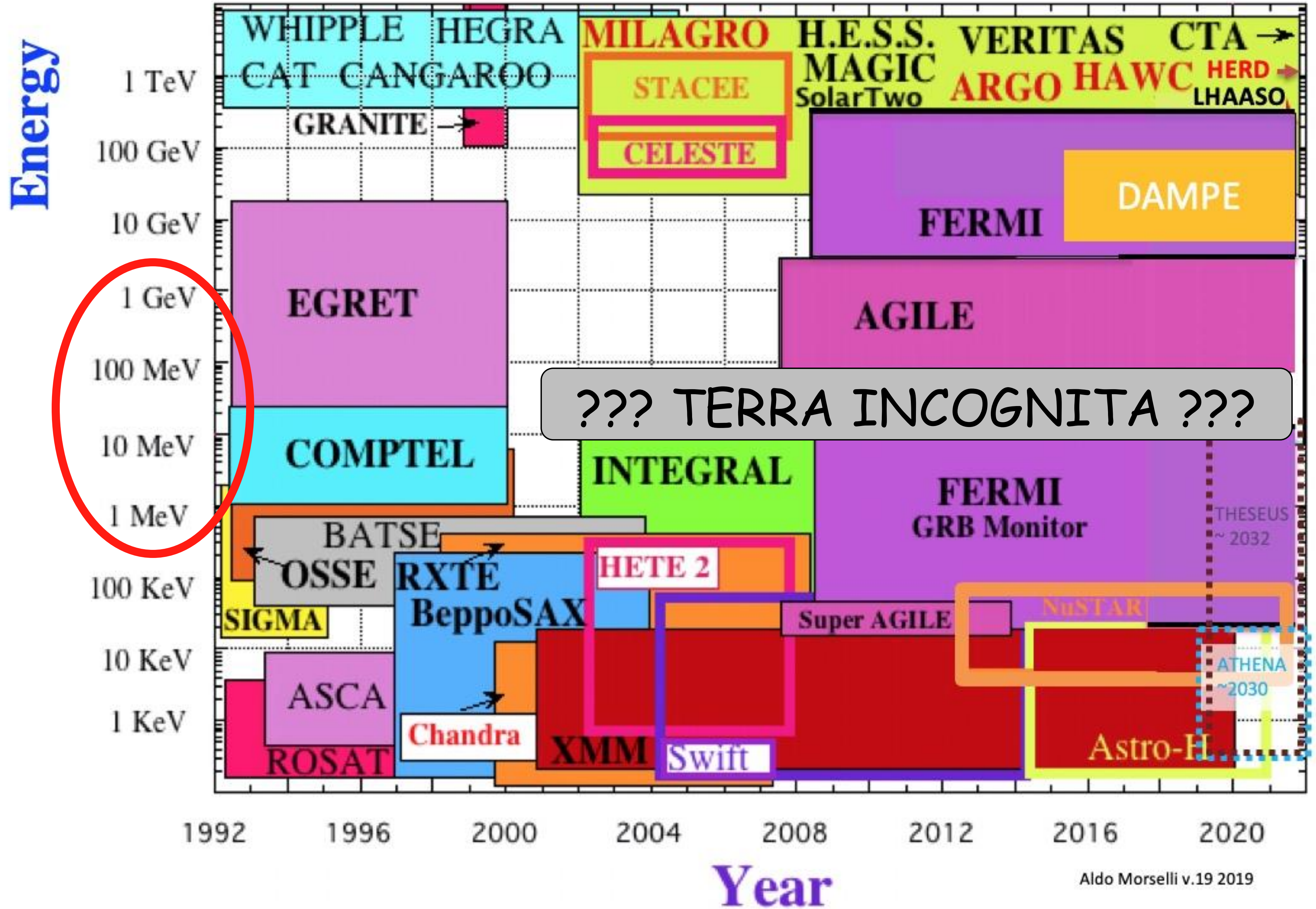




Assumed new dSph discovery and
J-factor and D-factor distributions of the new dSphs matches that of the previously known dSphs

SWGO White paper arXiv:1902.08429

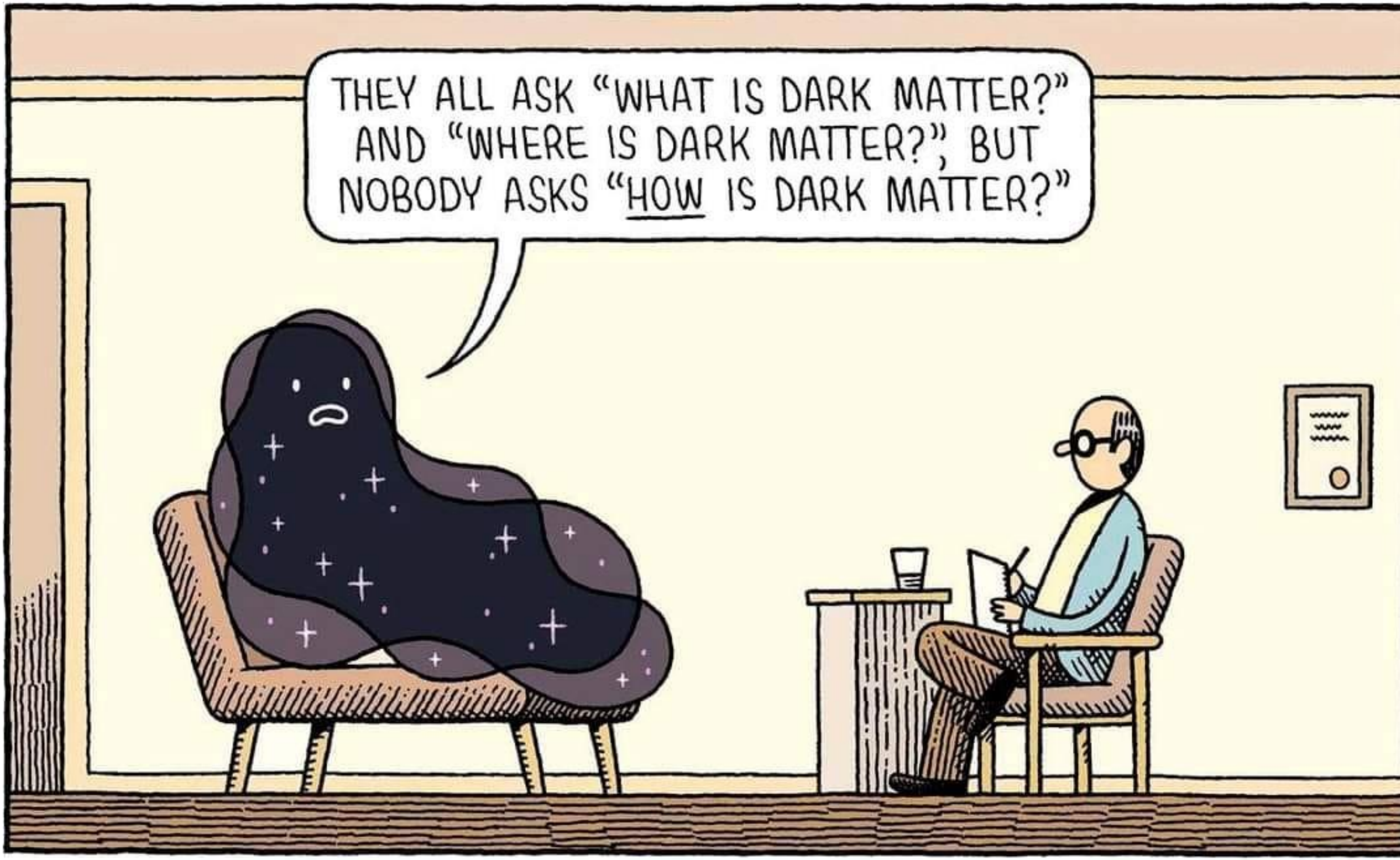
The Low Energy Frontier


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
CTA
ARGO
HAWC
HERD
LHAASO
FERMI
DAMPE
EGRET
AGILE
??? TERRA INCOGNITA ???
COMPTEL
INTEGRAL
FERMI
GRB Monitor
THESEUS
~ 2032
BATSE
OSSE
RXTE
BeppoSAX
HETE 2
SIGMA
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

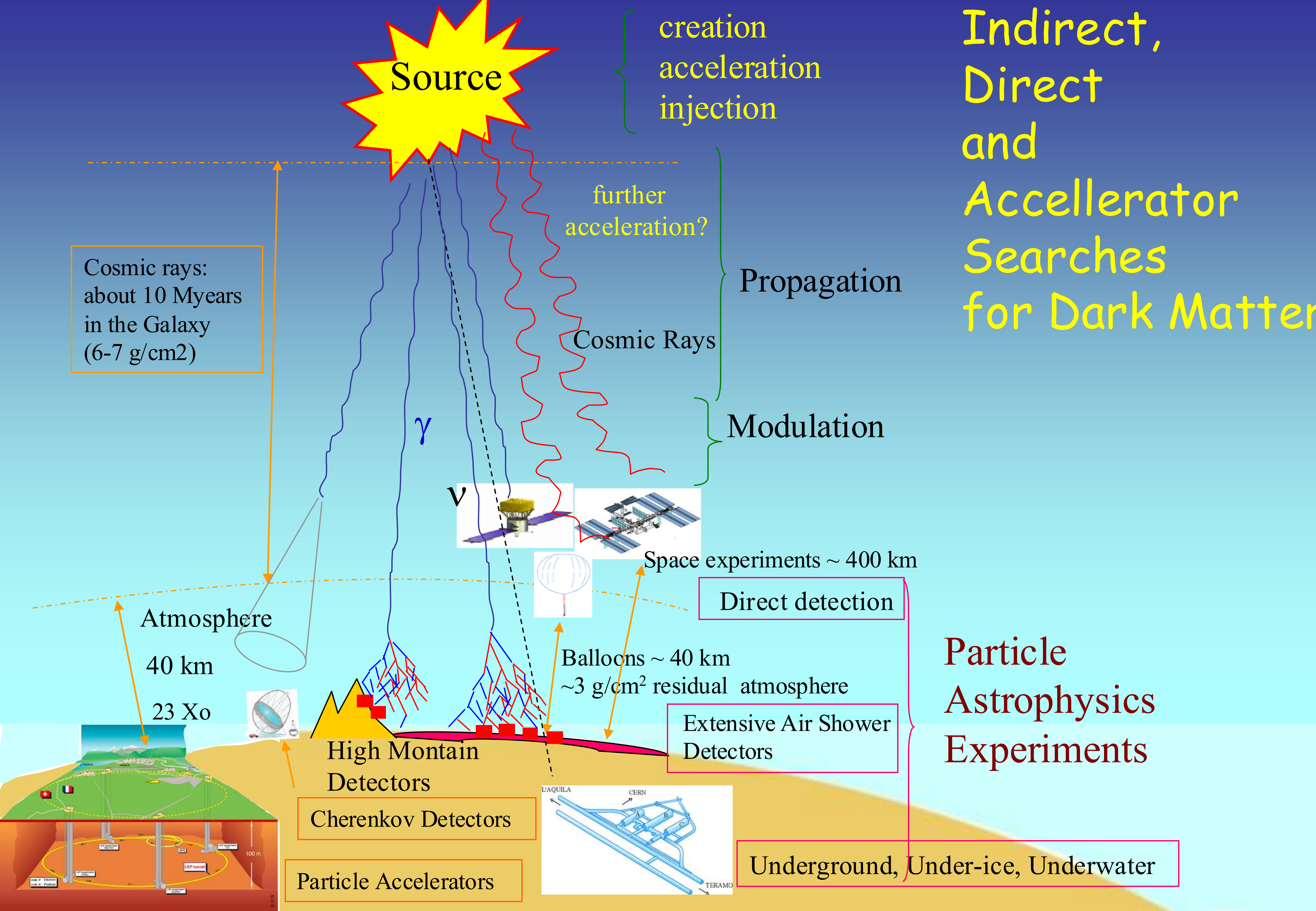
newASTROGAM

Proposed for ESA M8 Call

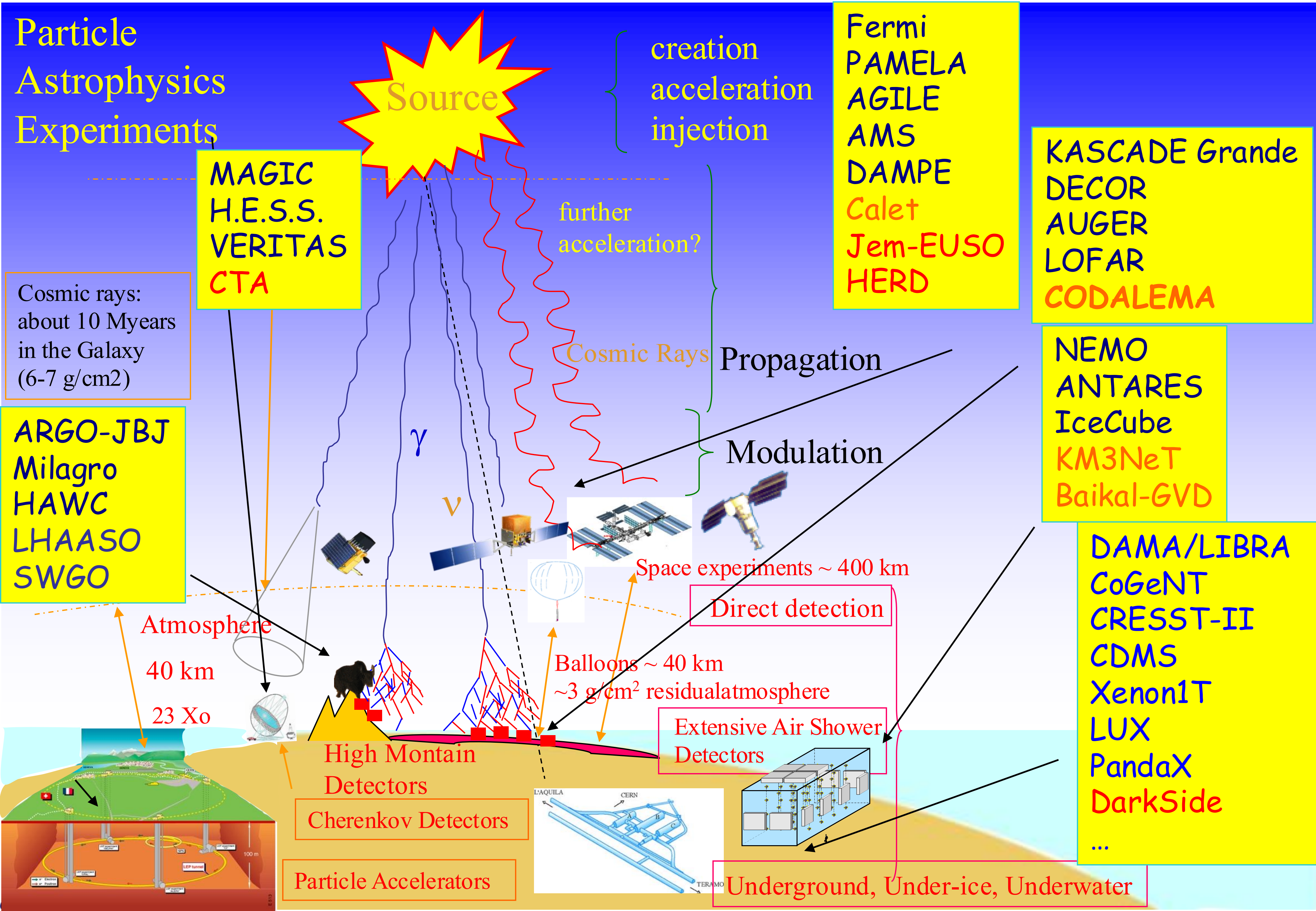
Detector paper: Exp. Astronomy 2017, 44, 25 arXiv:1611.02232
Science White Book: arXiv:1711.01265 (213 pages)



TOM GAULD for NEW SCIENTIST



Indirect, Direct and Accellerator Searches for Dark Matter
Source
creation
acceleration
injection
further acceleration?
Propagation
Cosmic Rays
Modulation
Cosmic rays: about 10 Myears in the Galaxy (6-7 g/cm2)
γ
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
Particle Astrophysics Experiments
L'AQUILA
CERN
TERAMO



Particle Astrophysics Experiments
Source
creation
acceleration
injection
Fermi
PAMELA
AGILE
AMS
DAMPE
Calet
Jem-EUSO
HERD
KASCADE Grande
DECOR
AUGER
LOFAR
CODALEMA
MAGIC
H.E.S.S.
VERITAS
CTA
further acceleration?
Cosmic rays: about 10 Myears in the Galaxy (6-7 g/cm2)
Cosmic Rays
Propagation
Modulation
NEMO
ANTARES
IceCube
KM3NeT
Baikal-GVD
ARGO-JBJ
Milagro
HAWC
LHAASO
SWGO
γ
ν
Space experiments ~ 400 km
Direct detection
DAMA/LIBRA
CoGeNT
CRESST-II
CDMS
Xenon1T
LUX
PandaX
DarkSide
...
Atmosphere
40 km
23 Xo
Balloons ~ 40 km
~3 g/cm² residualatmosphere
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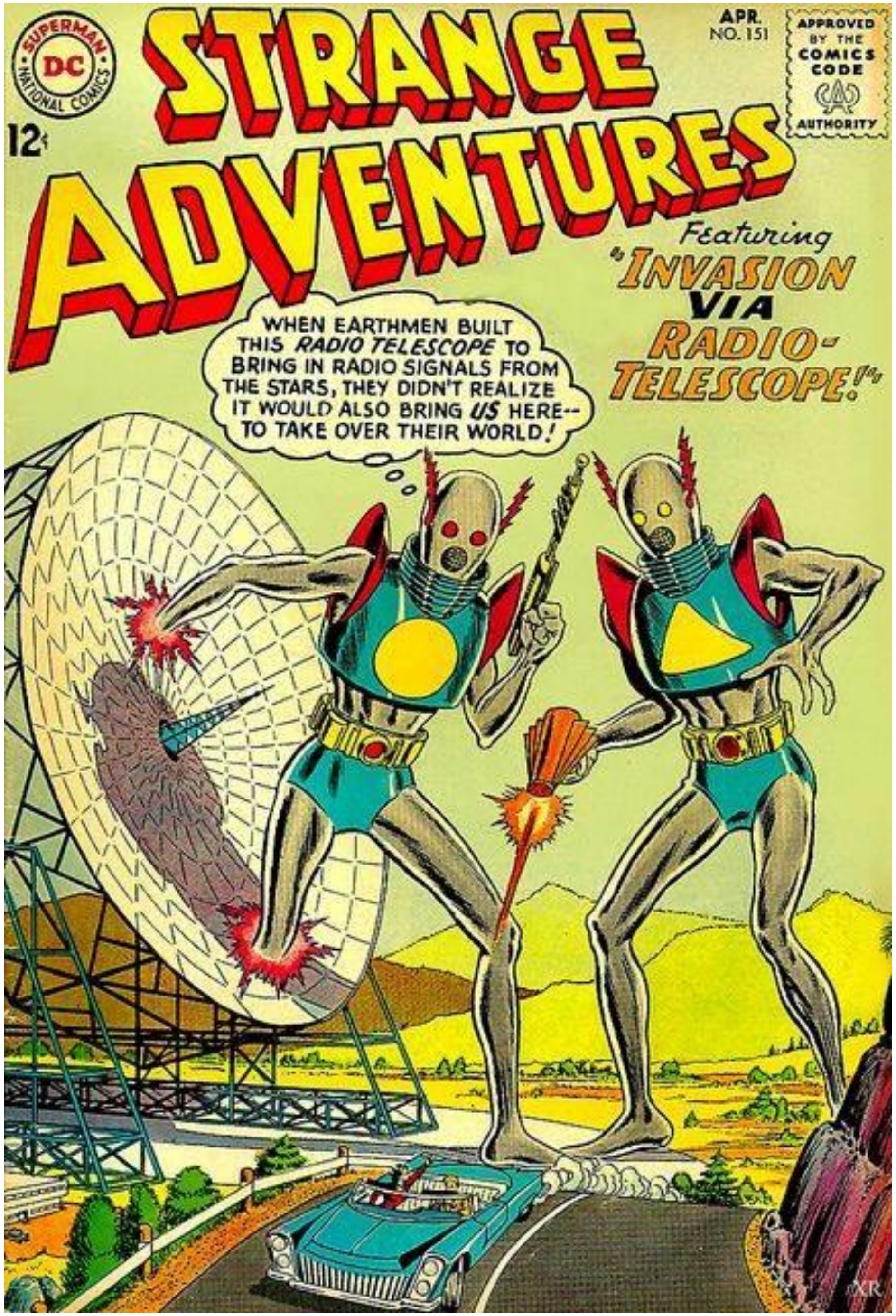
High Montain Detectors
Cherenkov Detectors
Particle Accelerators
L'AQUILA
CERN
TERAMO
Underground, Under-ice, Underwater

there is always
a risk ..



Thanks !!

but hopefully this will not happen
even with the new telescopes..