Expectation from the gamma-ray sky of the next decade

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Barolo Astroparticle Meeting

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INFN Istituto Nazionale di Fisica Nucleare

https://www.darkmatterwines.com/

DARK MATTER

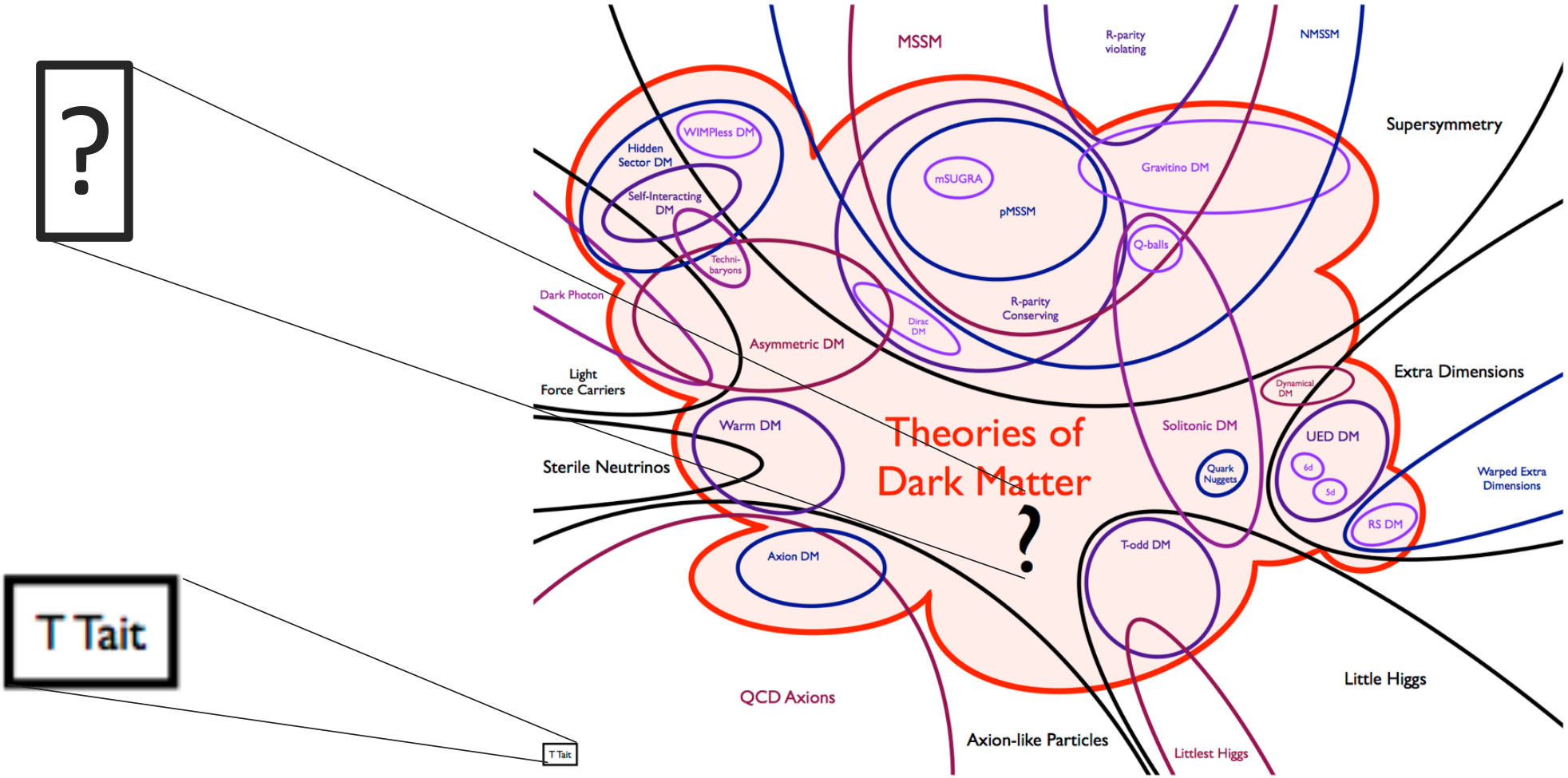
VINEYARDS

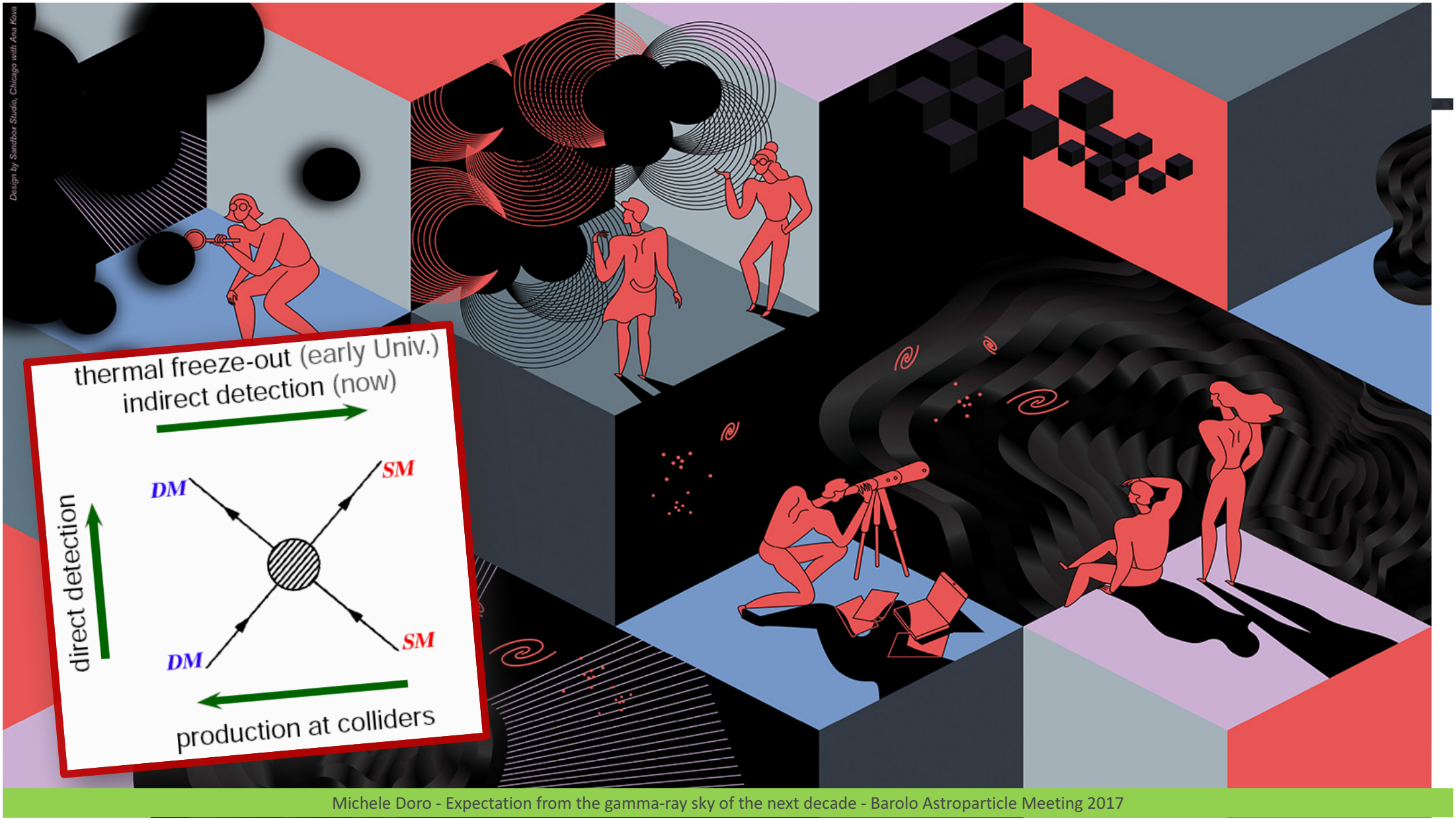
CONTACT

2013 DARK MATTER LIMITLESS CABERNET SAUVIGNON

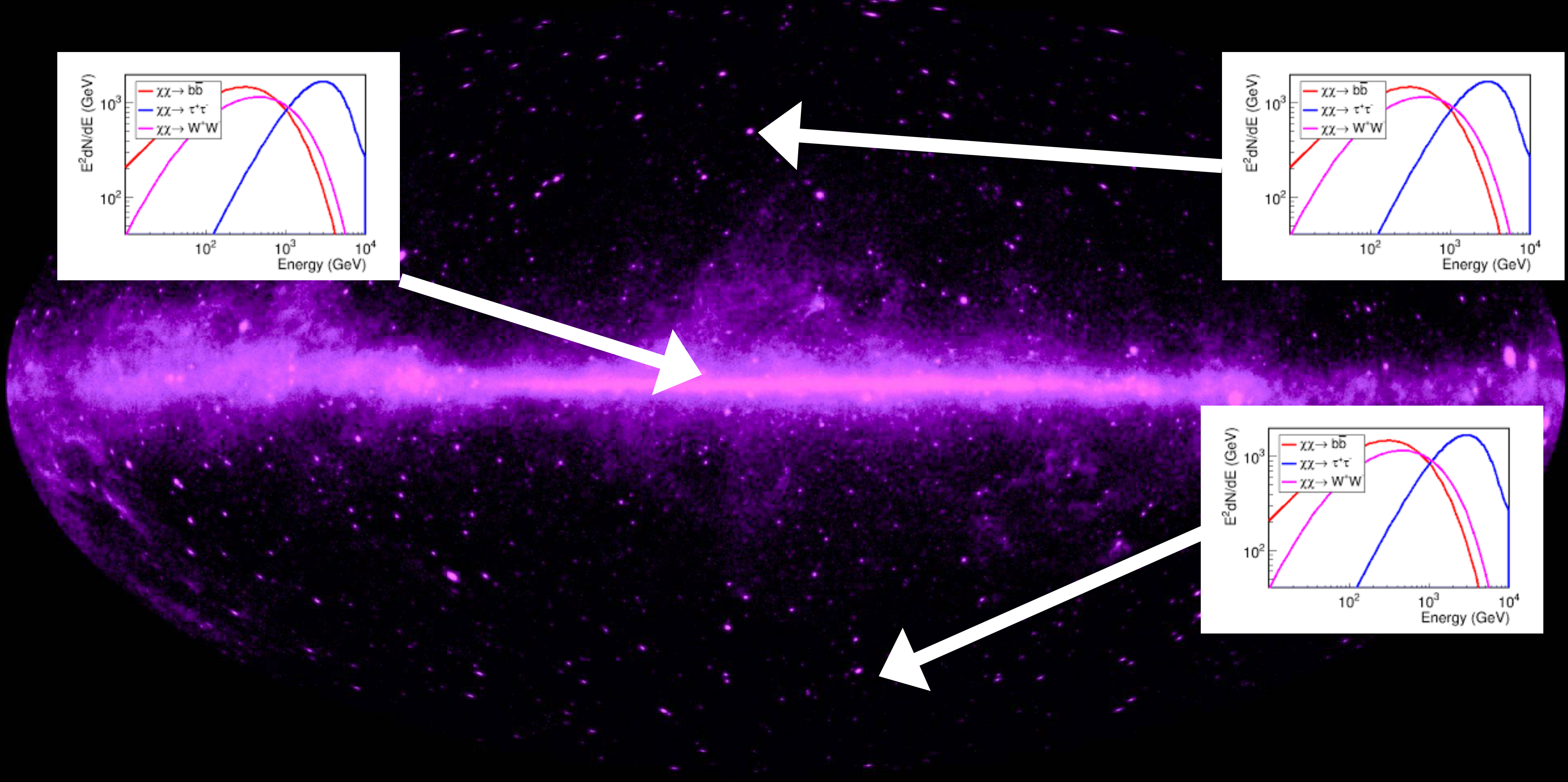
Introduction

Our heads in the clouds

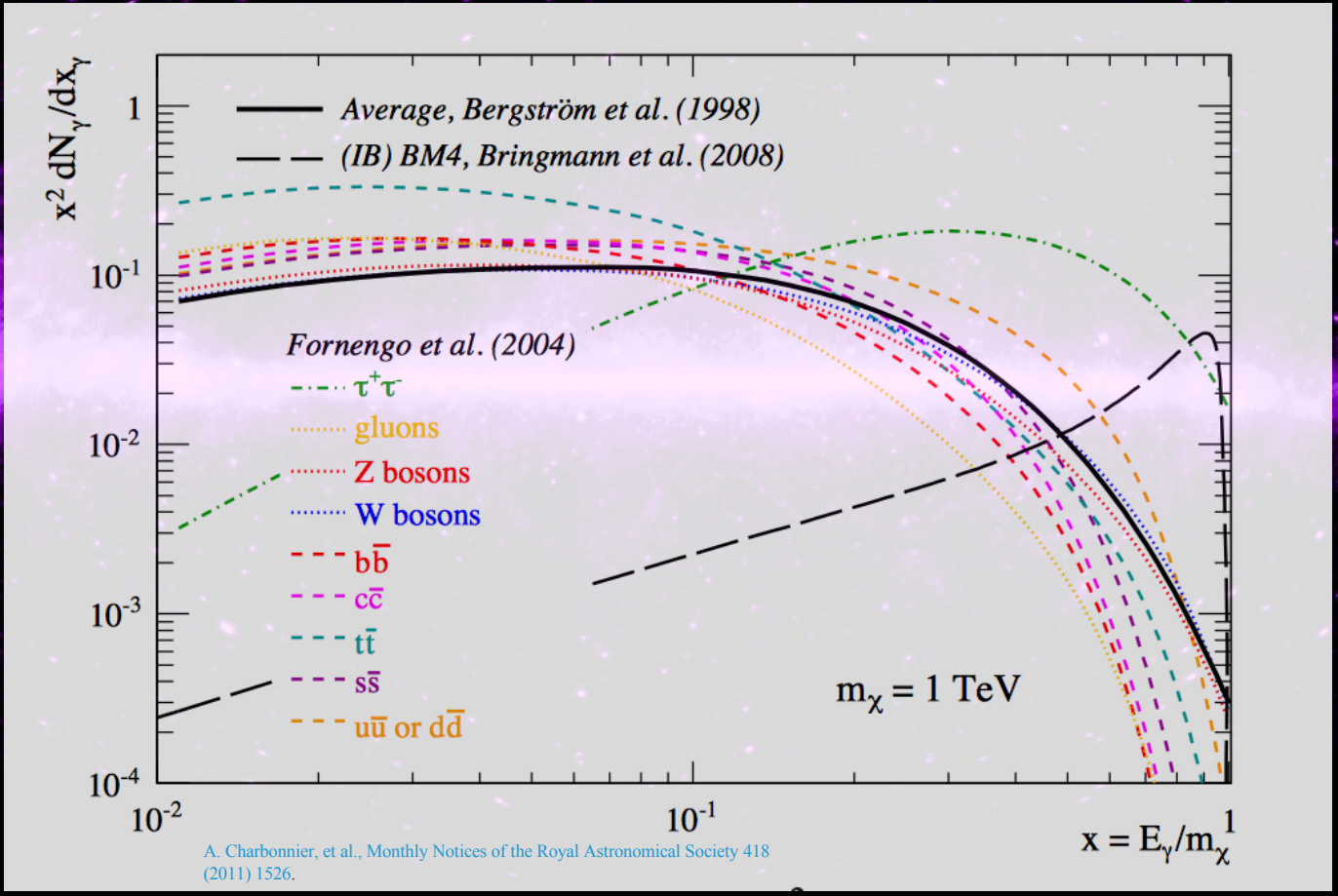



Design by Sandbox Studio, Chicago with Ana Kova
thermal freeze-out (early Univ.)
indirect detection (now)
DM
SM
direct detection
DM
SM
production at colliders

1/ Universality of Dark Matter Spectra

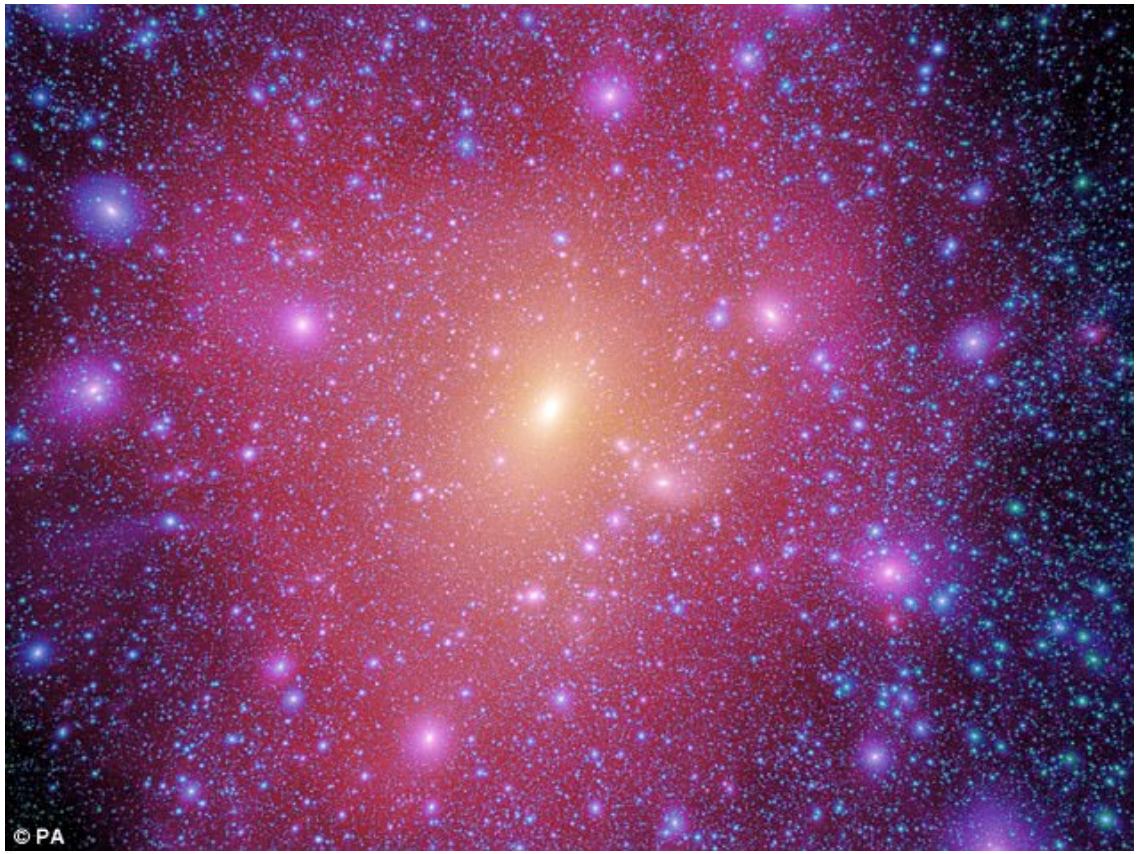


2/ Dark Matter mass (cutoff position) & Dark matter branching ratios (spectral shape)



A. Charbonnier, et al., Monthly Notices of the Royal Astronomical Society 418 (2011) 1526.

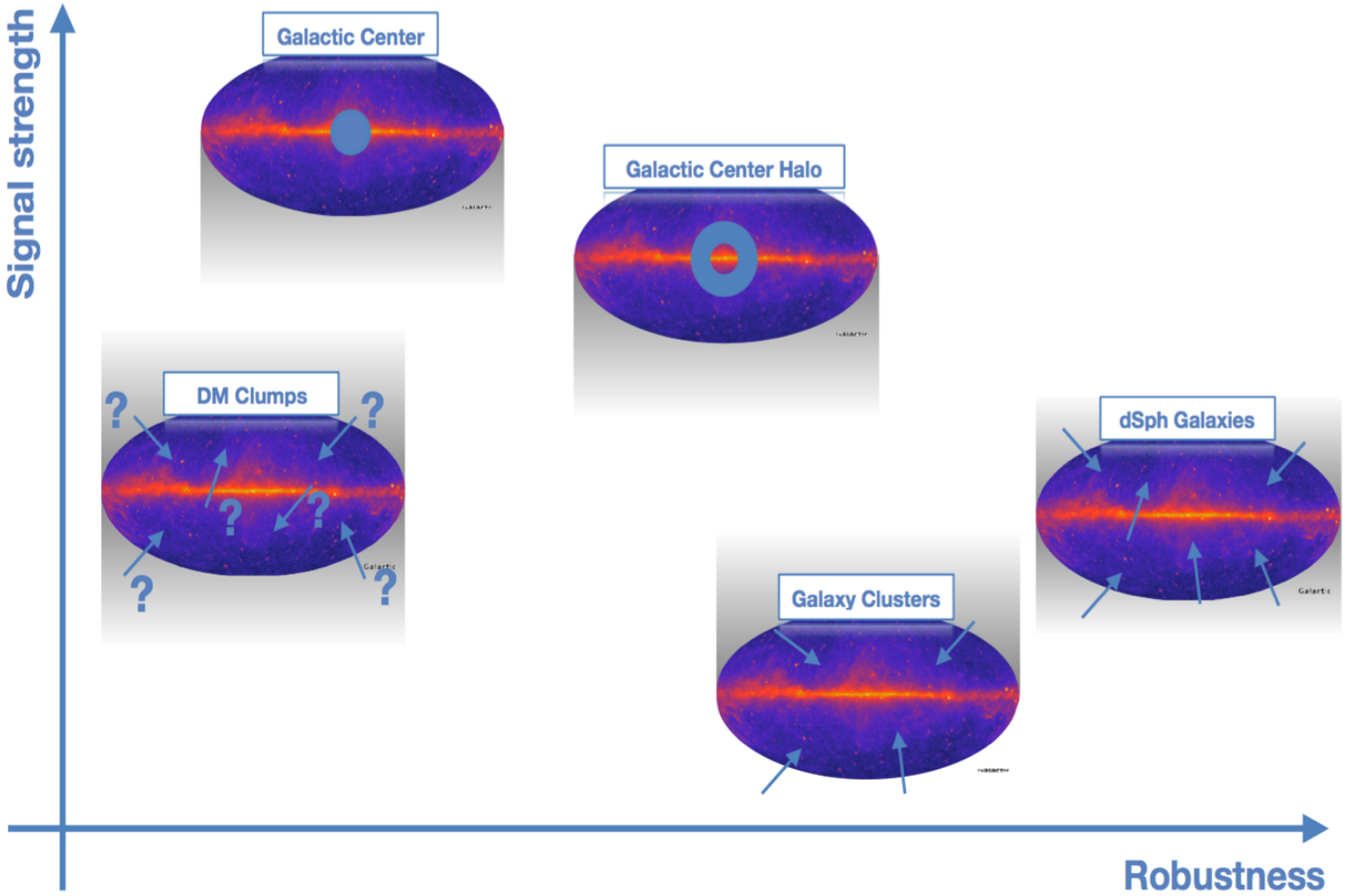
Golden channel



- Important to look where DM is
- Gamma-rays can do it (Neutrinos too)

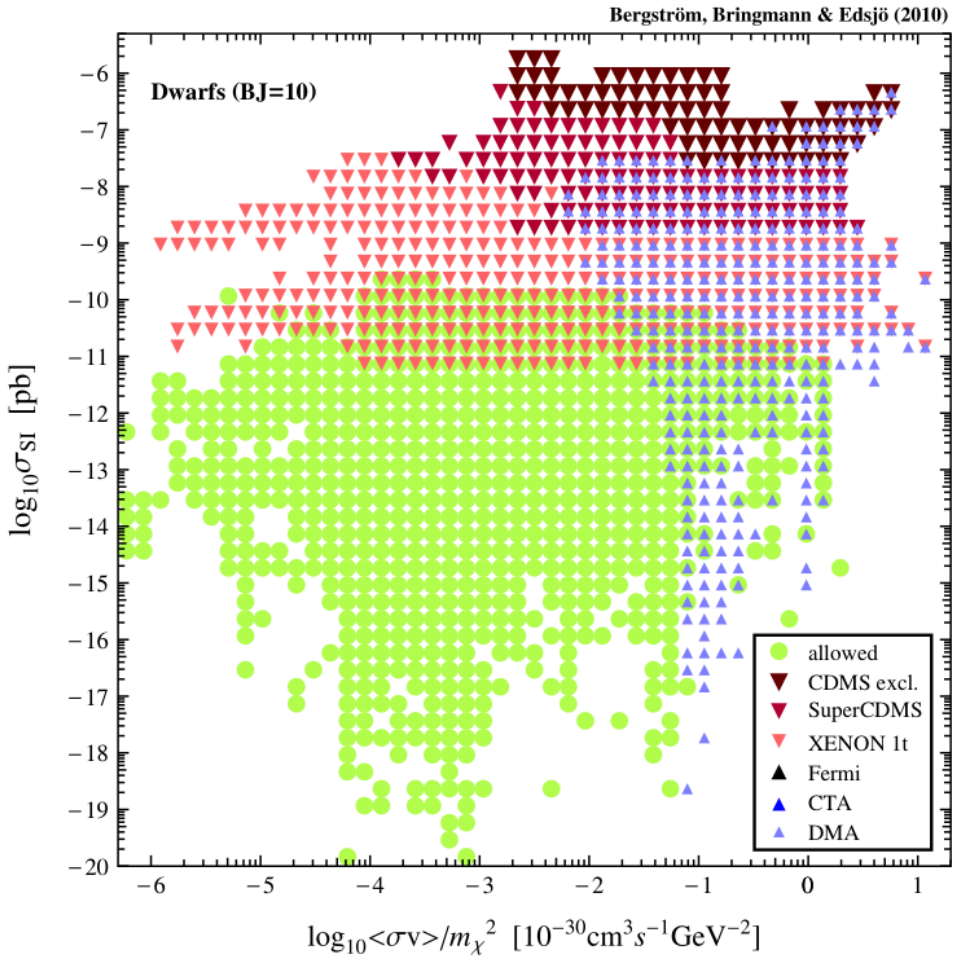
What other probe can give us that?

If you need to point, where to point?

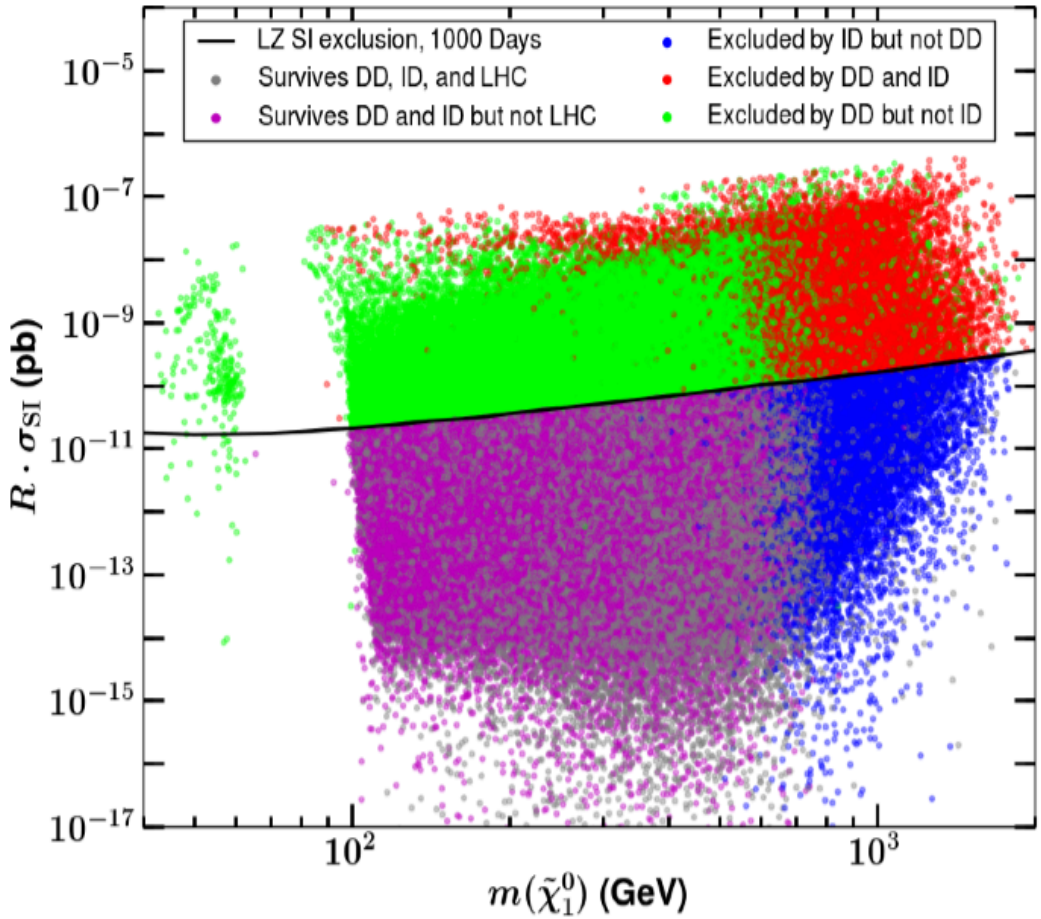


Zechlin+

Complementarity



M. Cahill-Rawley 1411.3353

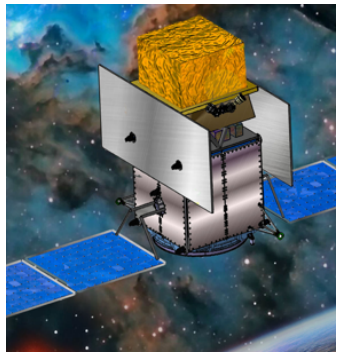
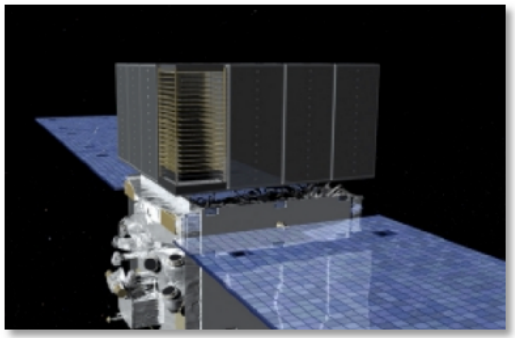


✶ DARK MATTER ✶

Do gamma-rays provide a good path toward DM discovery?

Let's first briefly see what we've accomplished

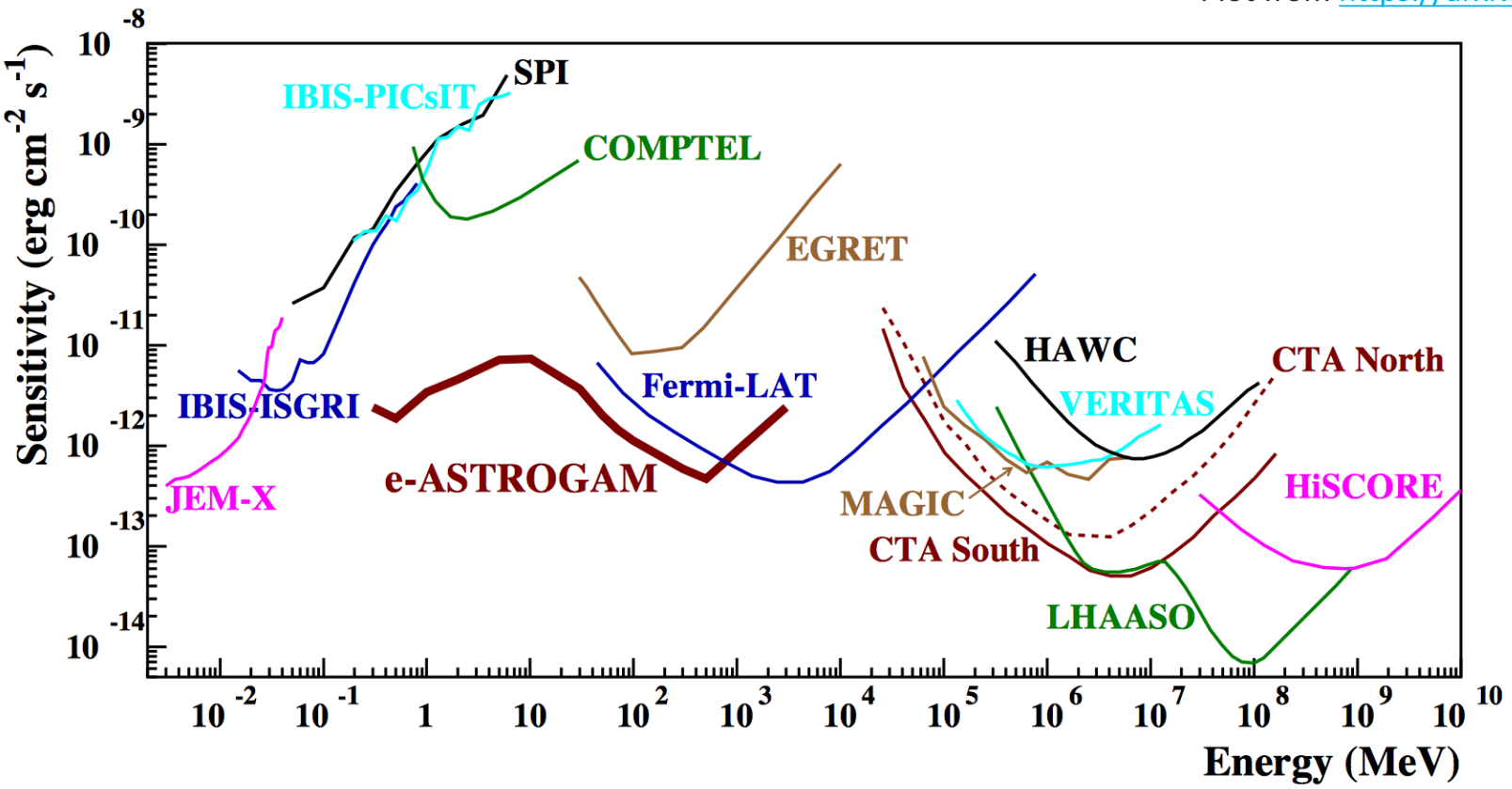
Techniques

Compton (in space) 10 MeV→	Pair-production (in space) 100 MeV—100 GeV	Cherenkov (ground) 10 GeV—100 TeV	Shower front (ground) 1 TeV—100TeV+
			
Small area Background-free Large field of view High duty cycle Bad angular pos.	Small area Background-free Large field of view High duty cycle	Large area Excellent bg rejection Small field of view Low duty cycle	Large area Good bg rejection Large field of view Large duty cycle

Modified from: Hofmann 2012

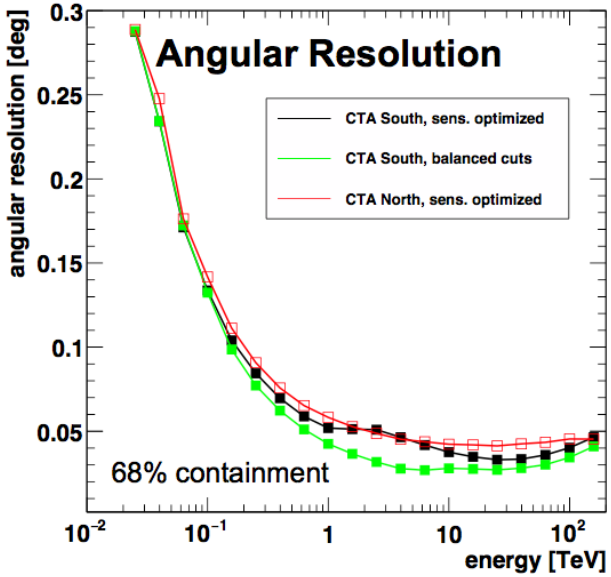
Comparing experiments

Plot from https://arxiv.org/abs/1611.02232

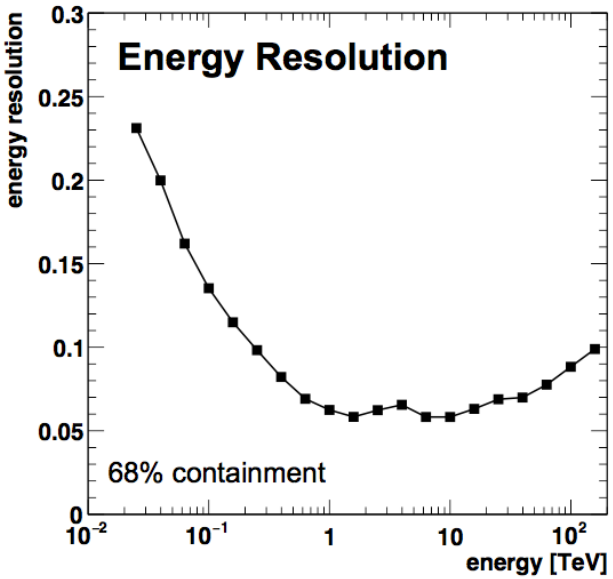


Sensitivity is not the only thing that matters

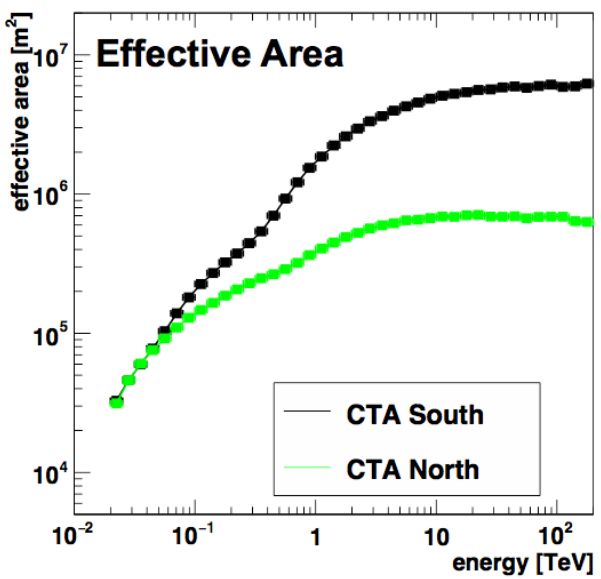
Ingredients to discovery



- Compton: 10 deg
- Lat/MeV: >1 deg
- Lat/GeV: 0.5 deg
- IACT: <0.1 deg
- EAS: 0.5-1deg



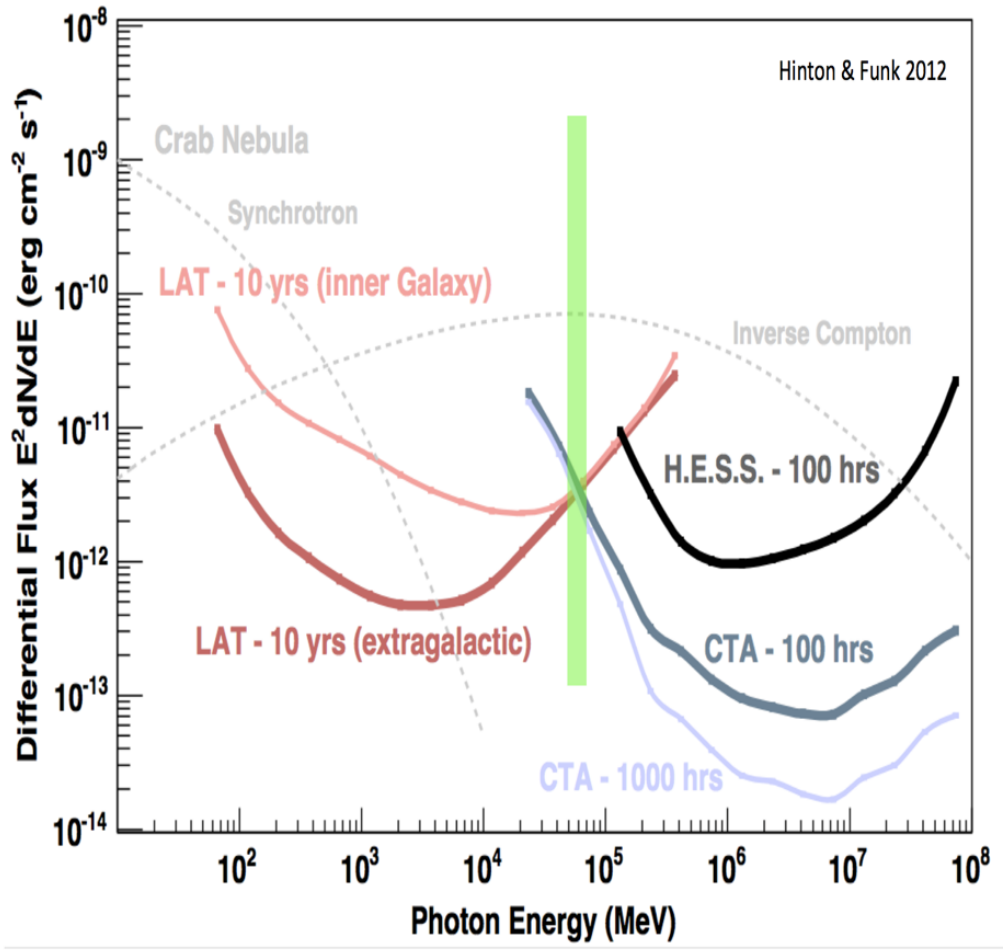
- Compton:
- Lat/MeV:
- Lat/GeV:
- IACT: 10-20%
- EAS: 100%

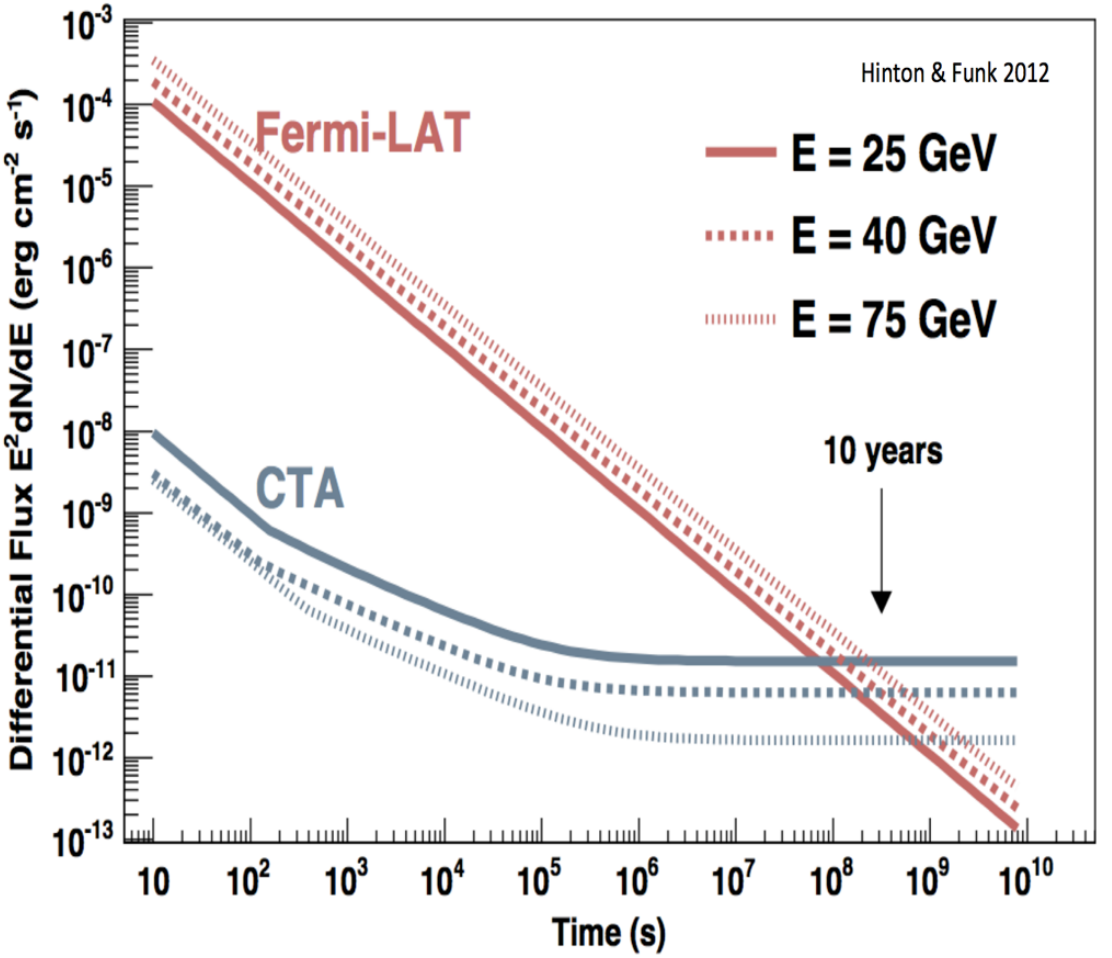


- Similar information than sensitivity for non-transient sources
- Do not take constant eff. area

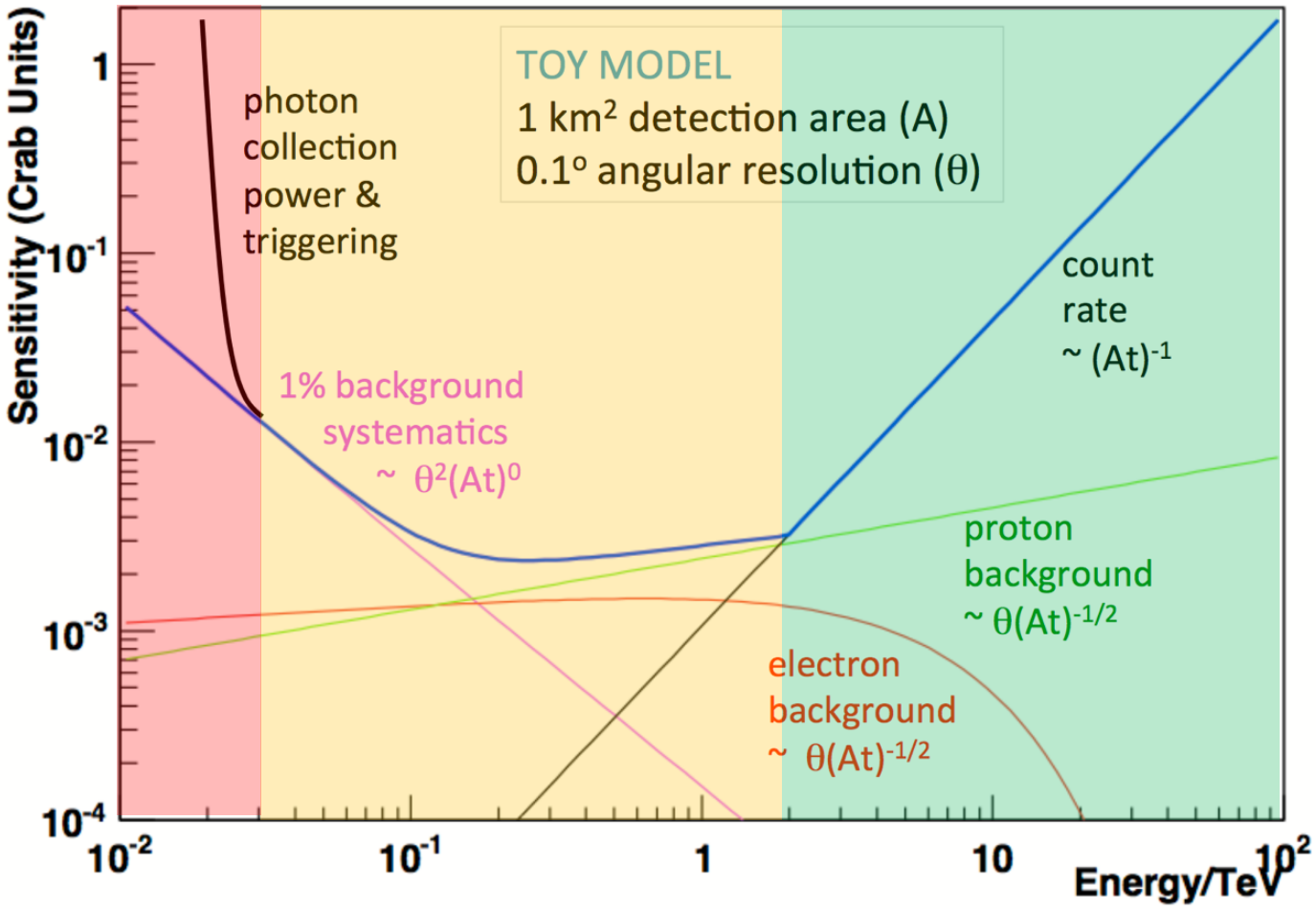
And also FOV & Duty cycle

Steady or not





Performance limitations in IACTs



You can use some brute force

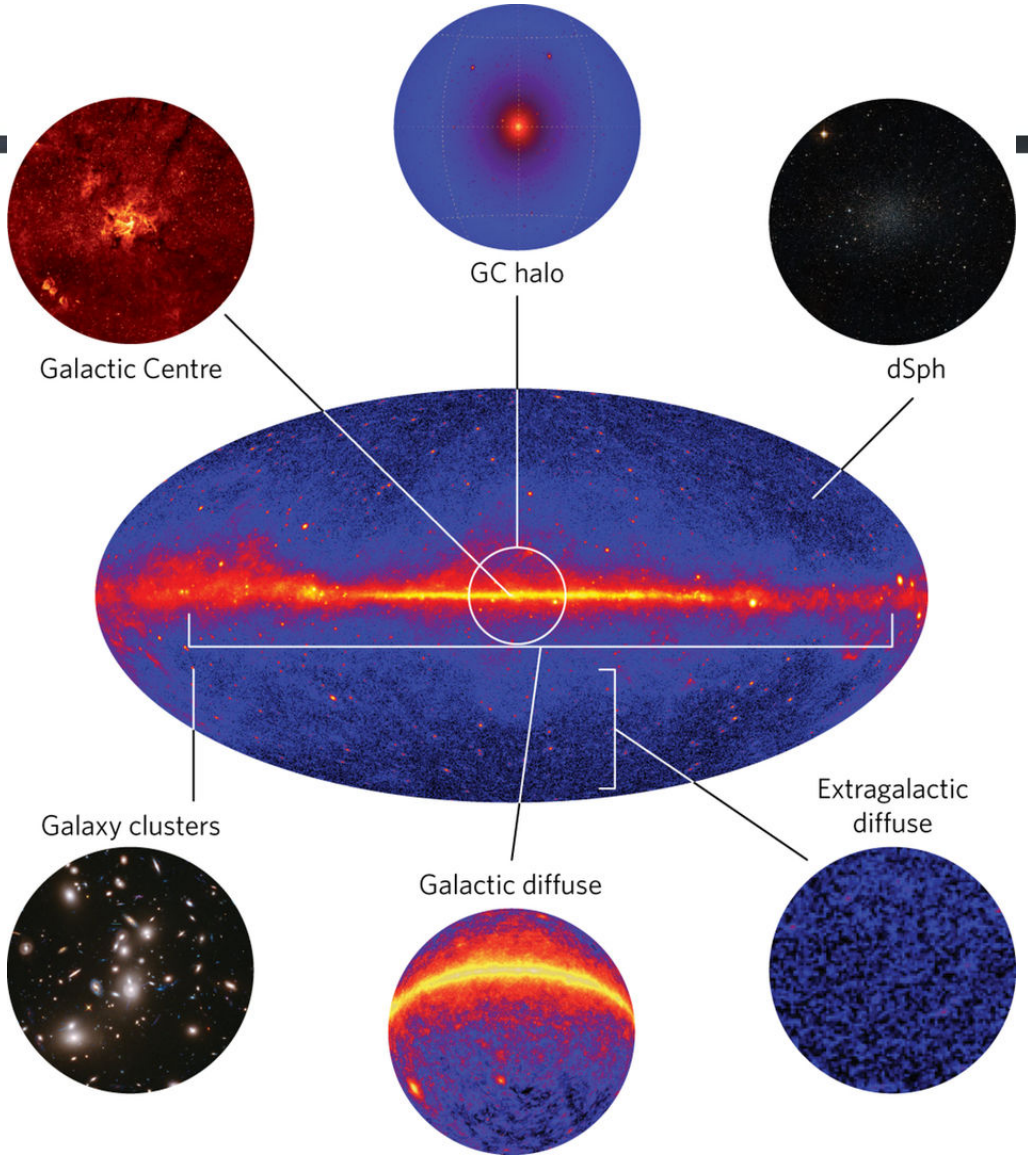
You need to use your brain

You are not (a) God

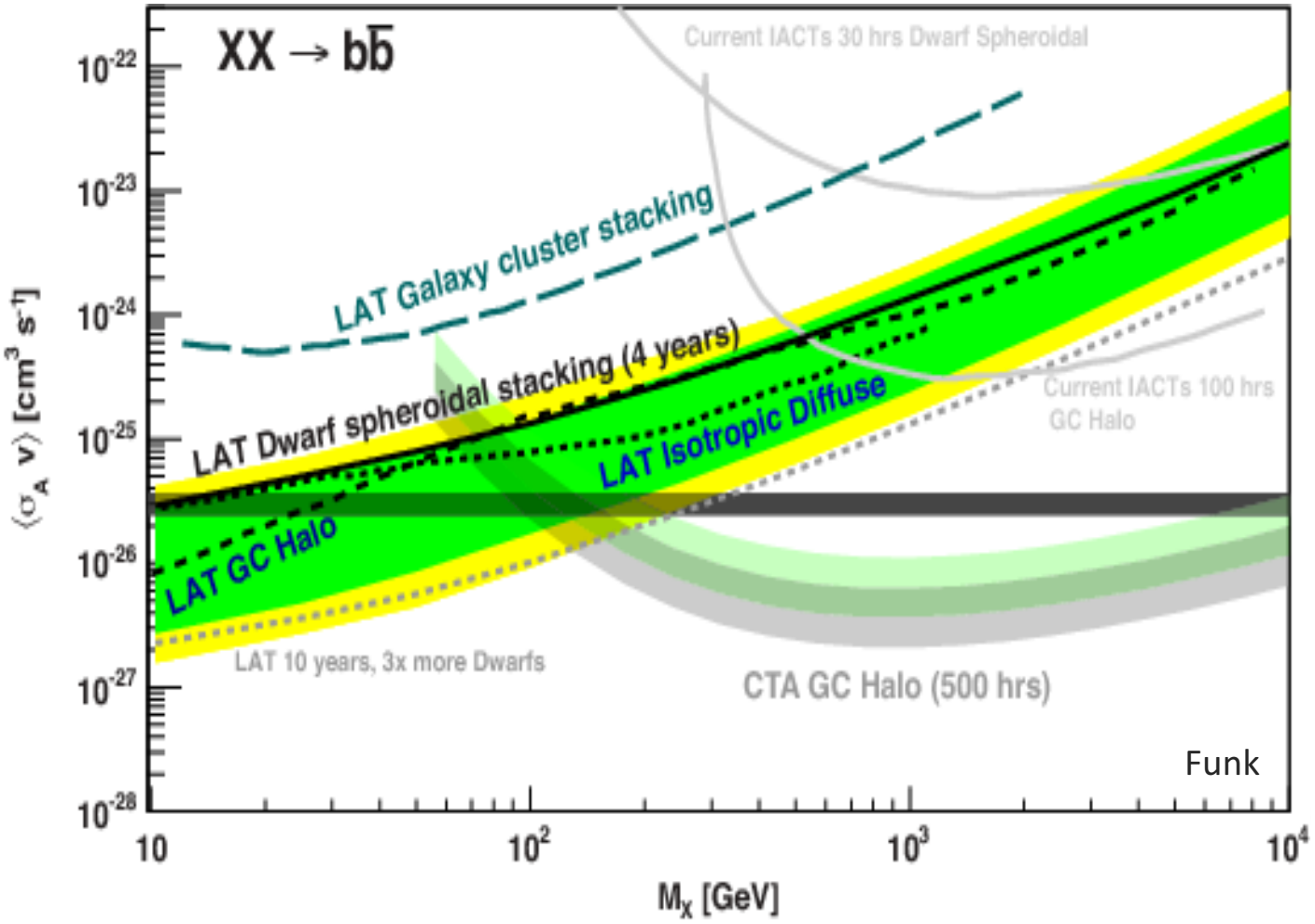
Hofmann 2012

Fermi/LAT (& AGILE)

- Fermi is always looking at DM



Compilation of Fermi Dark Matter UL



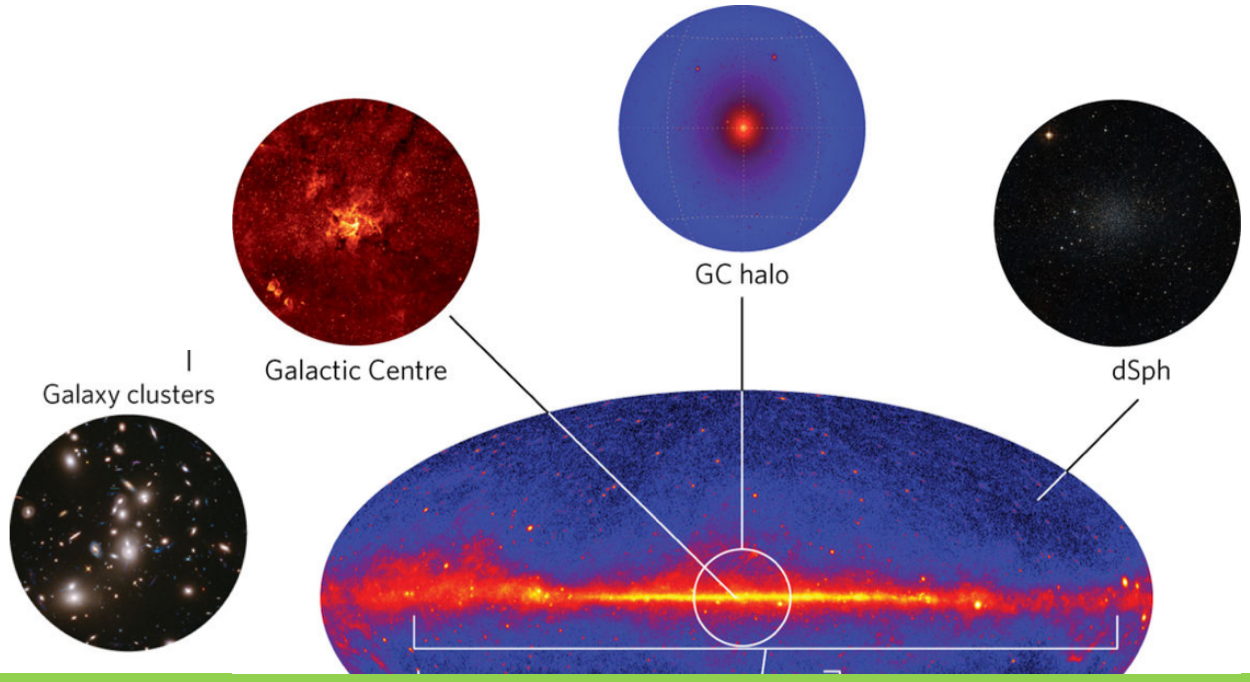
- dSphs stacking provide strongest constraints

IACTs (FOV <5x5)

HESS, MAGIC and VERITAS (in 2012)

IACT	Year	Nr. tels & diameter	Location
Whipple	1968	1×12 m	Arizona, USA
H.E.S.S.	2003	4×12 m+1×28 m	Gambserg, Namibia
MAGIC	2004	2×17 m	La Palma, Spain
VERITAS	2007	4×12 m	Arizona, USA

Table 1: Current major operating ground-based Cherenkov telescopes. Given are the starting year, the array multiplicity and dish diameter *in the latest configuration*, and the location.



IACTs: tested several target classes

Target	Year	Time	Experiment	Ref.
Globular Clusters				
M15	2002	0.2	Whipple	[5]
	2006 – 2007	15.2	H.E.S.S.	[6]
M33	2002 – 2004	7.9	Whipple	[5]
M32	2004	6.9	Whipple	[5]
NGC 6388	2008 – 2009	27.2	H.E.S.S.	[6]
Dwarf Satellite Galaxies				
Draco	2003	7.4	Whipple	[5]
	2007	7.8	MAGIC	[7]
	2007	18.4	VERITAS	[8]
Ursa Minor	2003	7.9	Whipple	[5]
	2007	18.9	VERITAS	[8]
Sagittarius	2006	11	H.E.S.S.	[9]
Canis Major	2006	9.6	H.E.S.S.	[10]
Willman 1	2007 – 2008	13.7	VERITAS	[8]
	2008	15.5	MAGIC	[11]
Sculptor	2008	11.8	H.E.S.S.	[12]
Carina	2008 – 2009	14.8	H.E.S.S.	[12]
Segue 1	2008 – 2009	29.4	MAGIC	[13]
	2010 – 2011	48	VERITAS	[14]
	2010 – 2013	158	MAGIC	[15]
Boötes	2009	14.3	VERITAS	[8]
Galaxy Clusters				
Abell 2029	2003 – 2004	6	Whipple	[16]
Perseus	2004 – 2005	13.5	Whipple	[16]
	2008	24.4	MAGIC	[17]
Fornax	2005	14.5	H.E.S.S.	[18]
Coma	2008	18.6	VERITAS	[19]
The Milky Way central region				
MW Center	2004	48.7	H.E.S.S.	[20]
MW Center Halo	2004 – 2008	112	H.E.S.S.	[21]
Other searches				
IMBH	2004 – 2007	400	H.E.S.S.	[22]
	2006 – 2007	25	MAGIC	[23]
Lines	2004 – 2008	112	H.E.S.S.	[24]
	2010 – 2013	158	MAGIC	[15]
UFOs	–	–	MAGIC	[25]
	–	–	VERITAS	[26]
All-electron	2004 – 2007	239	H.E.S.S.	[27, 28]
	2009 – 2010	14	MAGIC	[29]
Moon-shadow	–	–	MAGIC	[30]

MD, NIM A 742 (2014)

Time devoted

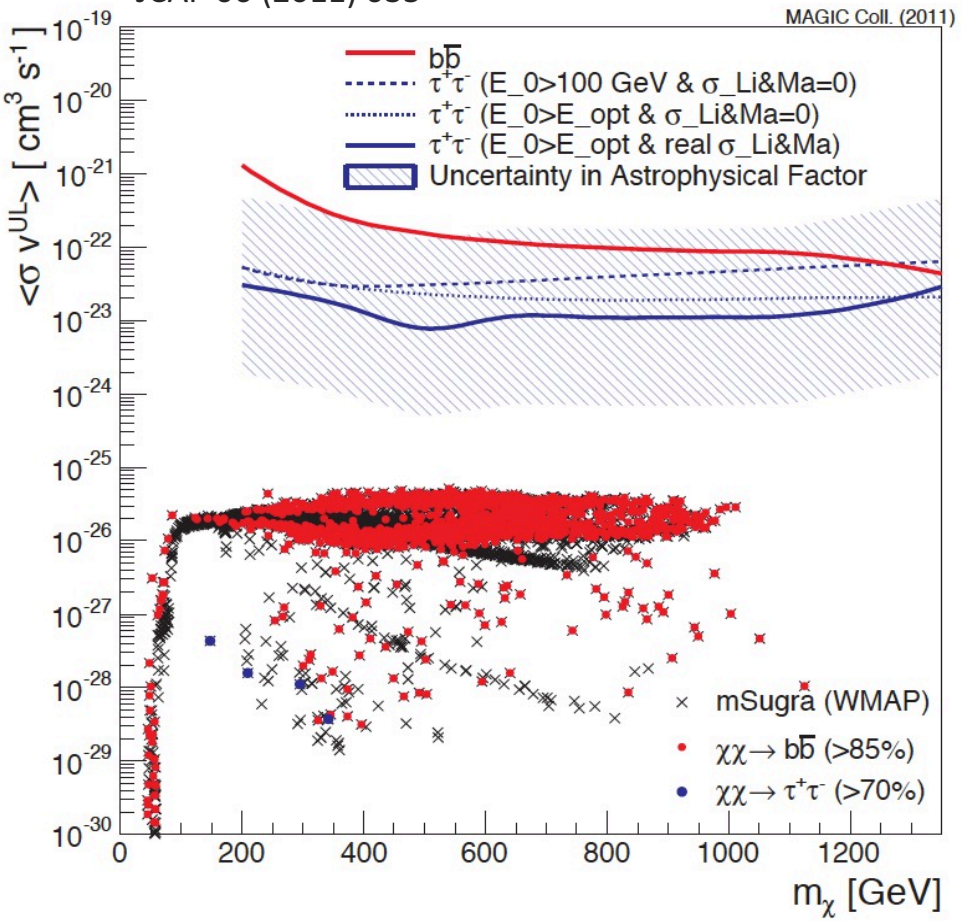
MAGIC	Class	Target	Year	Obs. Time	Ann.	Decay	Ref.	Comments
Mono	MW	Galactic Center	2006/07	25	-	-	[33]	
	DSG	Draco	2007	7.8	X	-	[19]	
		Willman 1	2008	15.5	X	-	[20]	
		Segue 1	2008/09	29.4	X	-	[21]	
	Unid	3EG1835	2007	25	X	-	[11]	
	GC	Perseus	2008	24.4	-	-	[15]	
	CR	All-electrons	2009/10	14	-	-	[17]	
Stereo	Unid	Many	2009/12	71.3	F	-	[31]	Paper in prep.
	DSG	Segue 1	2010/13	158	X	X	[34]	
	GC	Perseus	2009/14	253	F	F	[30]	Paper in prep.
	CR	All-electrons	2012/14	40	-	-	[18]	
		Positrons			F	-	[22]	Paper in prep.
	MW	Galactic Center	2012/16	67	F	F	[32]	Paper in prep.

About 1000 h in a decade ←

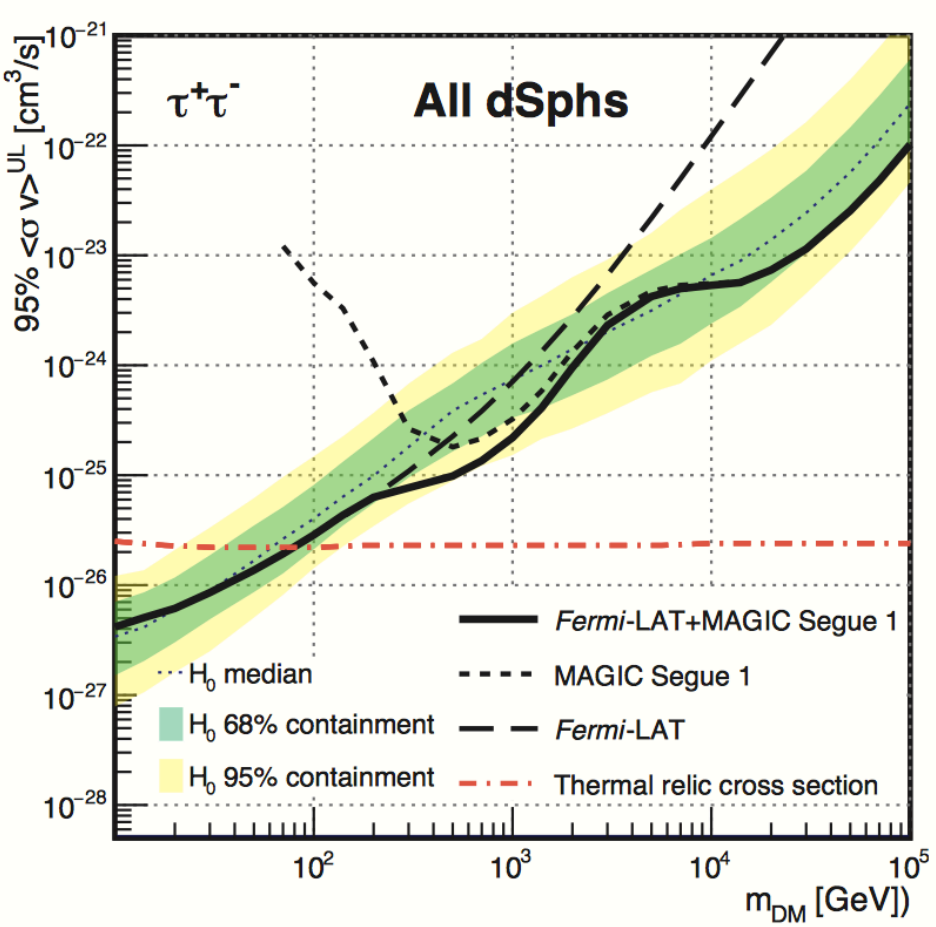
MD XXV ECRS 2016 Proceedings

We learnt some things

JCAP 06 (2011) 035



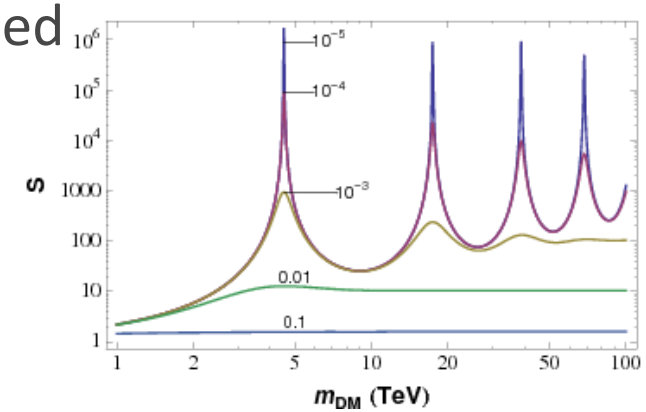
JCAP 1602 (2016) no.02, 039

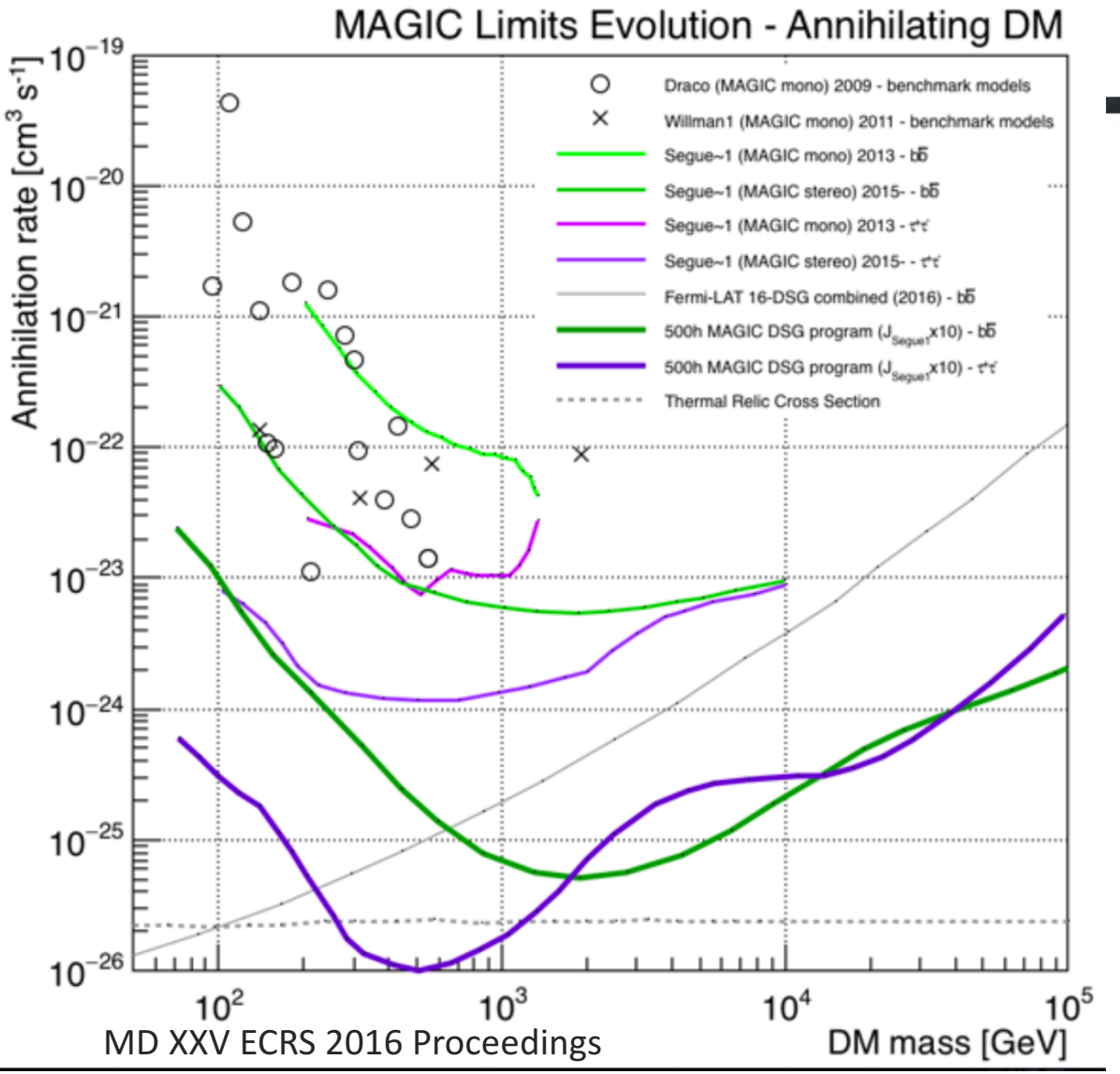


Are we close or far?

- If we find a dSph with J=10x J_Segue, in 500h we barely start to enter the holy region

- Useless? I believe as experimentalist we need to provide those limits
- Some intrinsic boost cannot be excluded

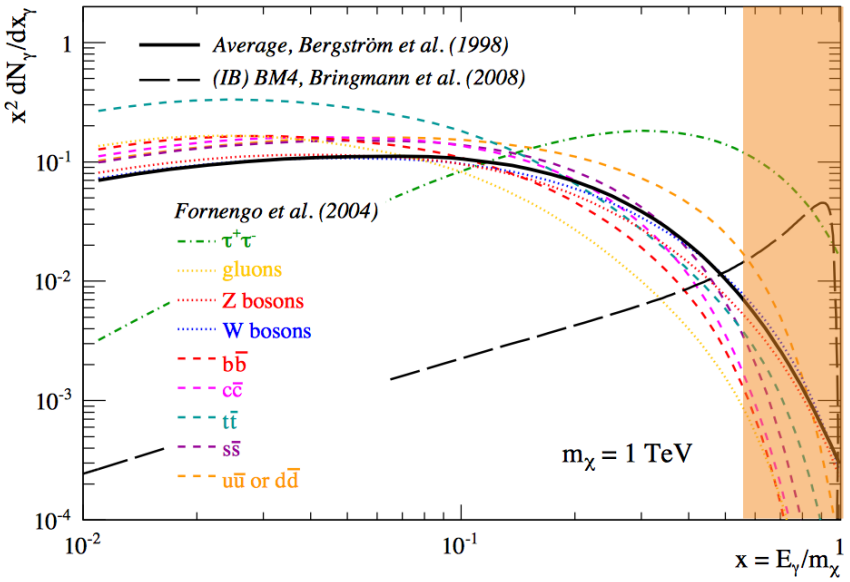


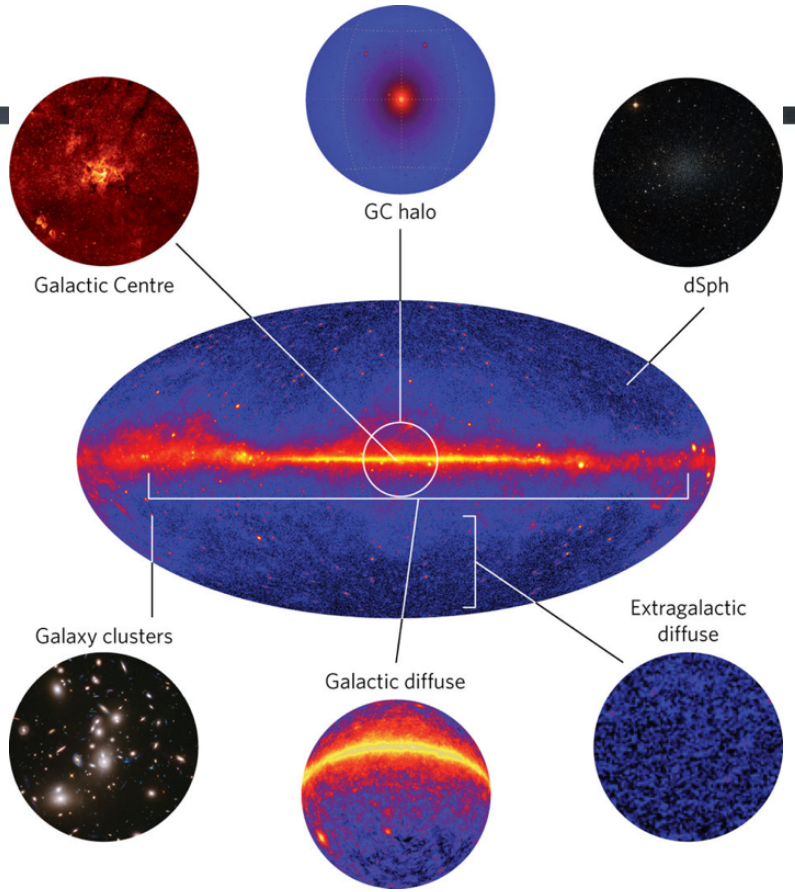


MD XXV ECRS 2016 Proceedings

Shower front detectors

if m=10 TeV





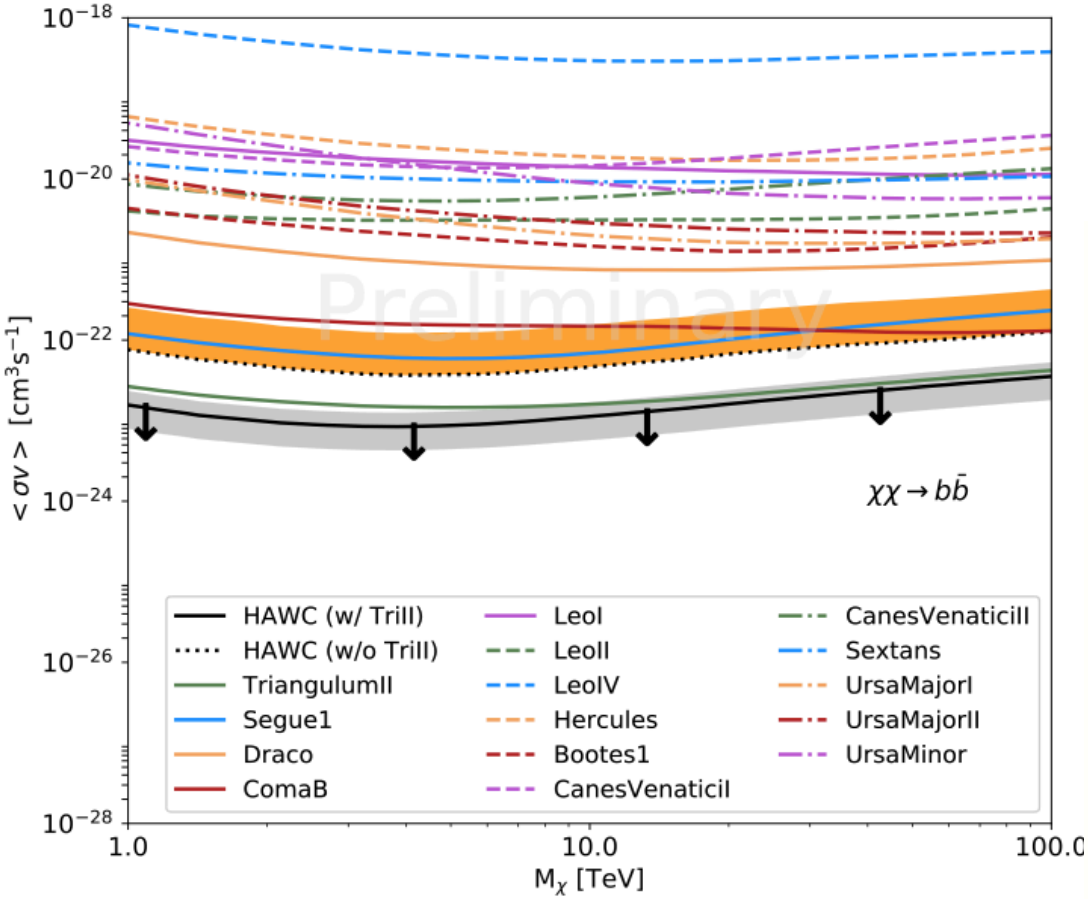
HAWC (left)

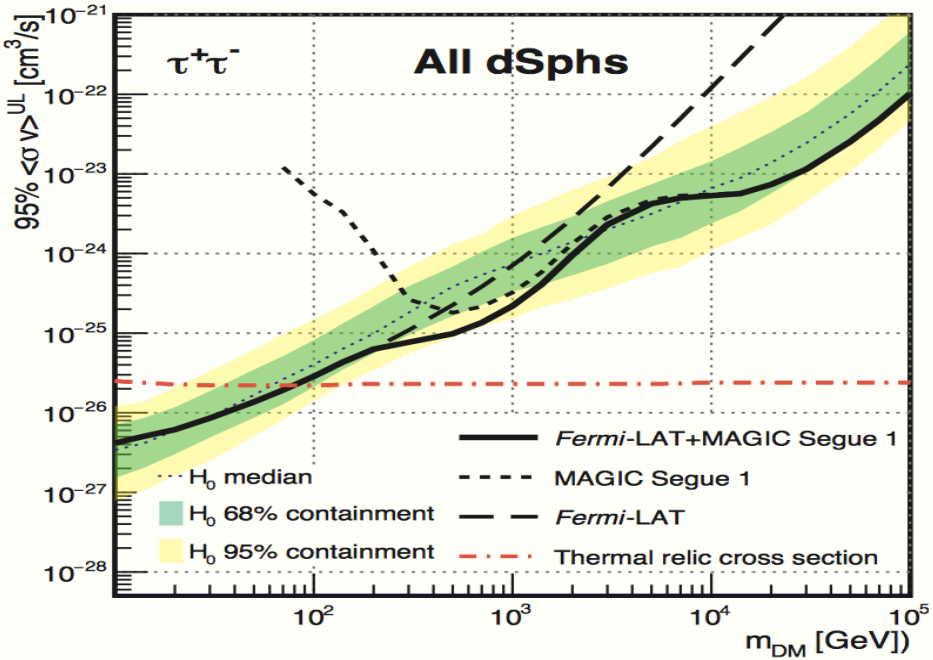
→ 2015

LHAASO (right)

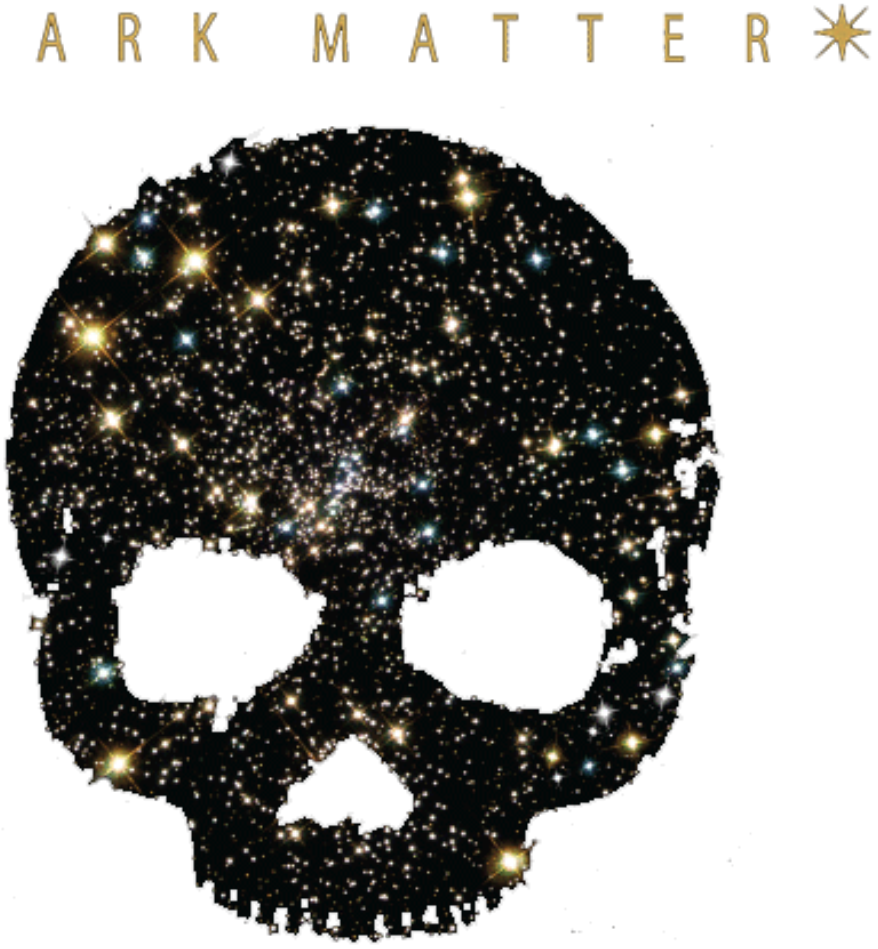
→ in construction (2019?)

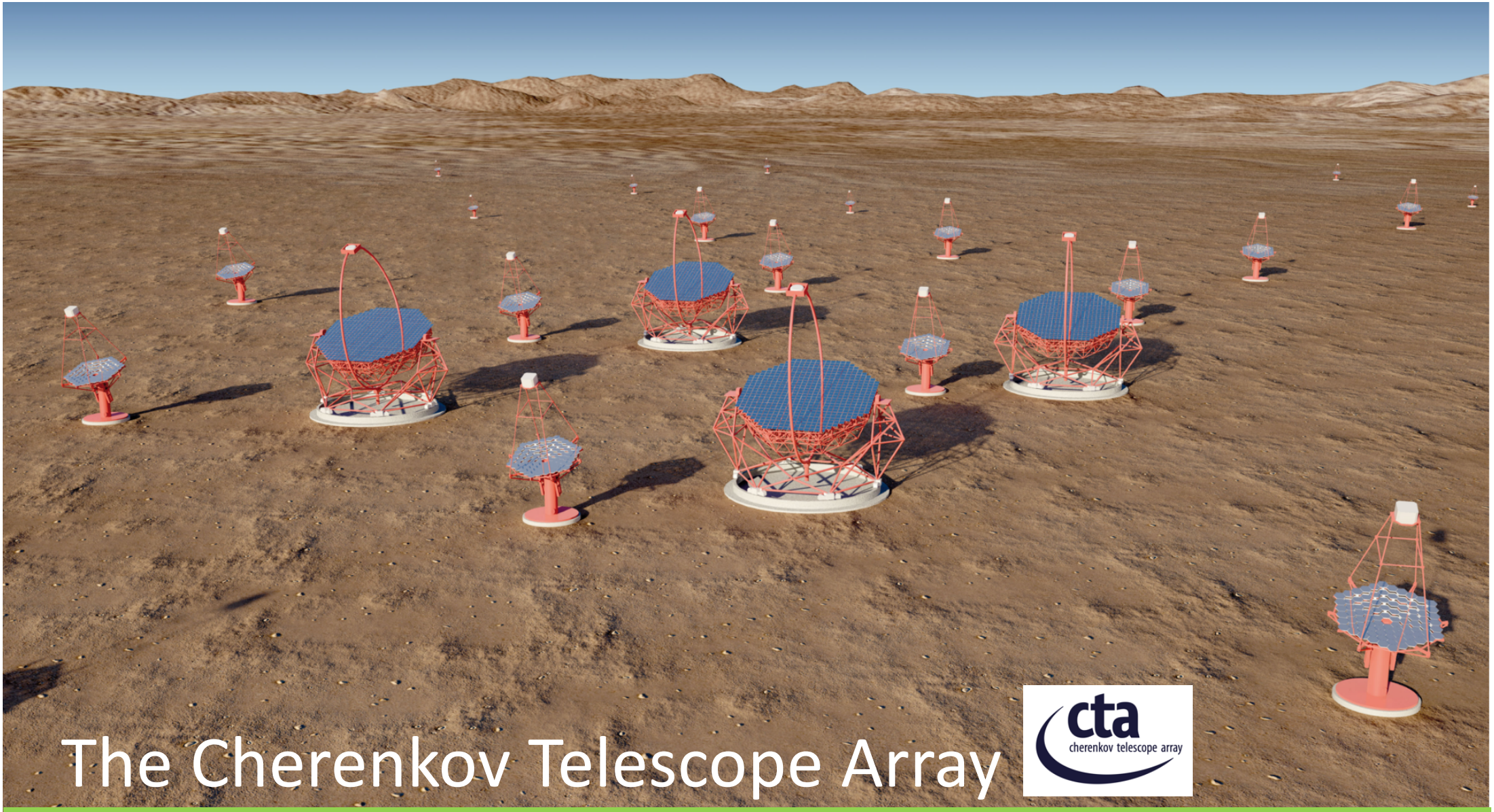
HAWC


Preliminary
$\chi\chi \to b\bar{b}$
HAWC (w/ TrIII)
HAWC (w/o TrIII)
TriangulumII
Segue1
Draco
ComaB
LeoI
LeoII
LeoIV
Hercules
Bootes1
CanesVenaticiI
CanesVenaticiII
Sextans
UrsaMajorI
UrsaMajorII
UrsaMinor
$< \sigma v >$ [cm^{3}s^{-1}]
M_χ [TeV]

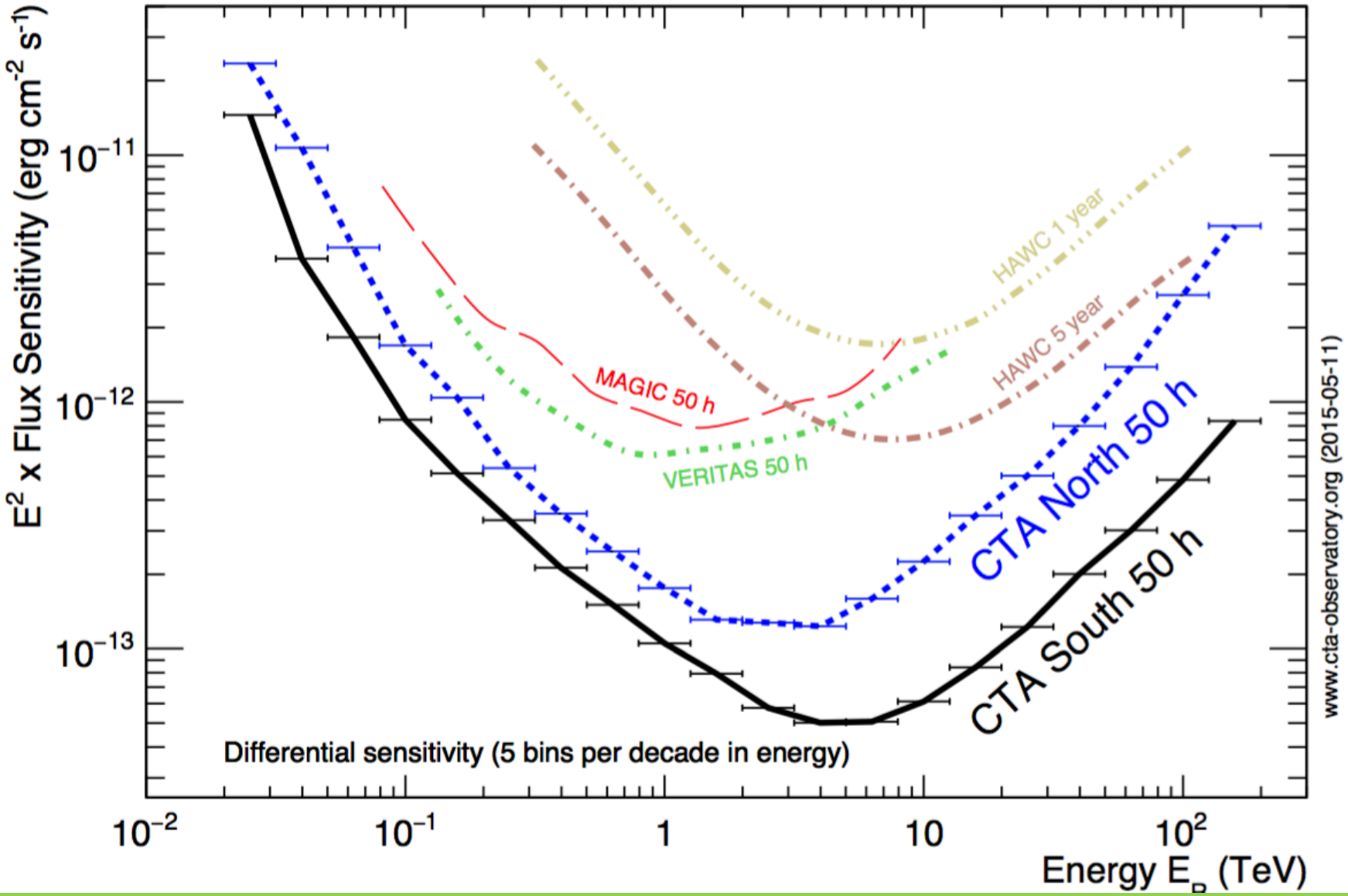

$\tau^+\tau^-$
All dSphs
H_0 median
H_0 68% containment
H_0 95% containment
Fermi-LAT+MAGIC Segue 1
MAGIC Segue 1
Fermi-LAT
Thermal relic cross section
95% $<\sigma v>^{UL}$ [cm^3/s]
m_{DM} [GeV])

A look ahead: CTA, HAWC and CONDORs, e-Astrogam





The Cherenkov Telescope Array


E² x Flux Sensitivity (erg cm⁻² s⁻¹)
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻²
10⁻¹
1
10
10²
Energy E_R (TeV)
HAWC 1 year
HAWC 5 year
MAGIC 50 h
VERITAS 50 h
CTA North 50 h
CTA South 50 h
Differential sensitivity (5 bins per decade in energy)
www.cta-observatory.org (2015-05-11)

Dark Matter on CTA television

Featuring:

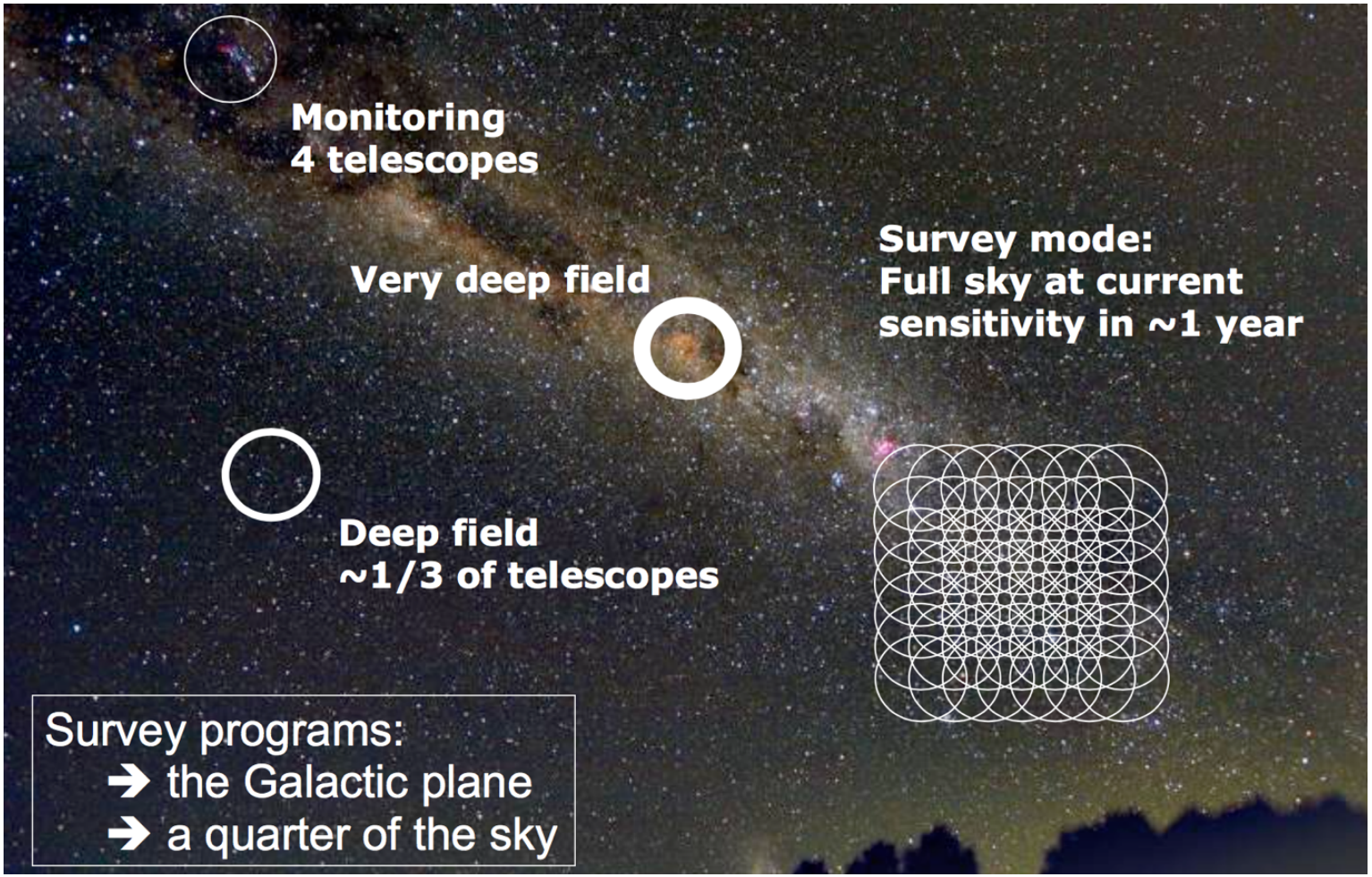
Improved sensitivity
Better energy and angular resolution
Two hemispheres for hunt
Open observatory

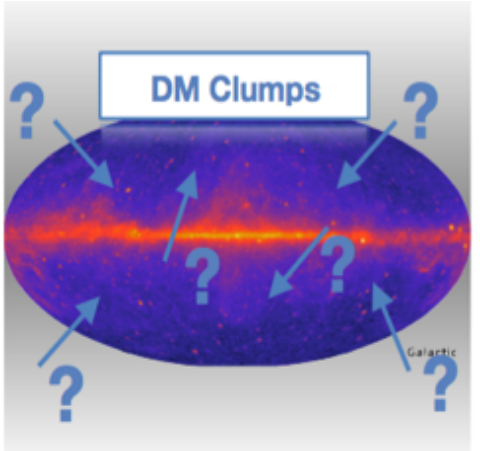
Plot:

500h on the GC region (first year(s))
100h/dSph/year?
LMC

Can CTA make a change?

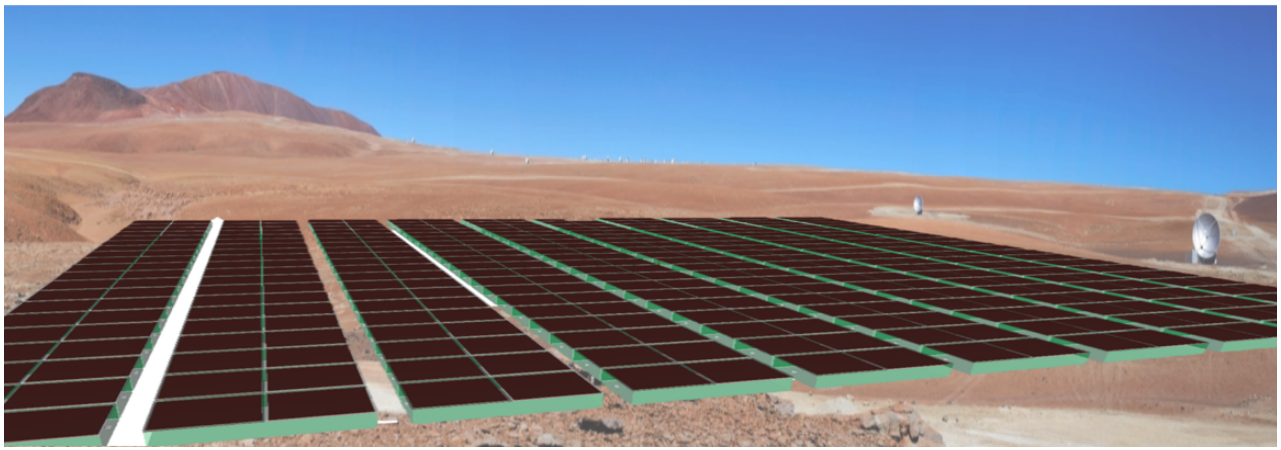
CTA with in survey mode (divergent pointing)

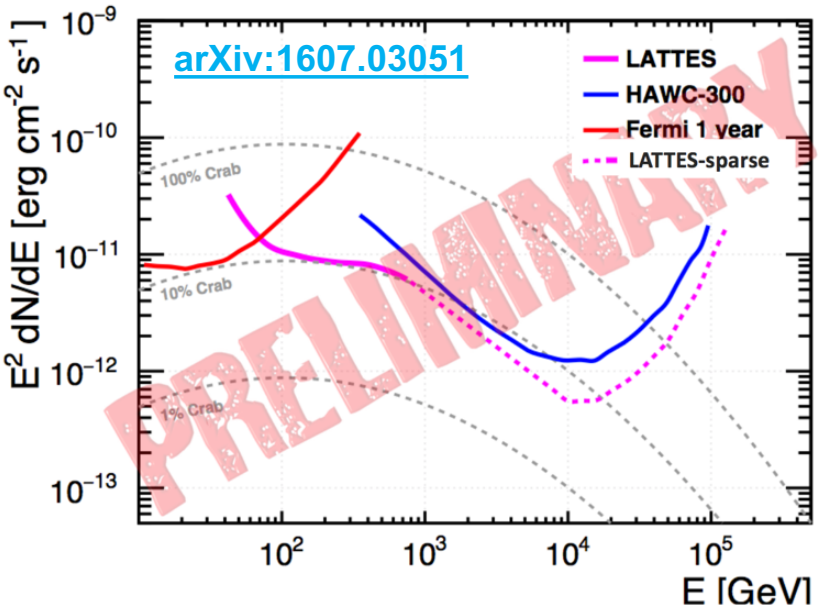




Particle Shower Detectors @ Southern Hemisphere

LATTES concept

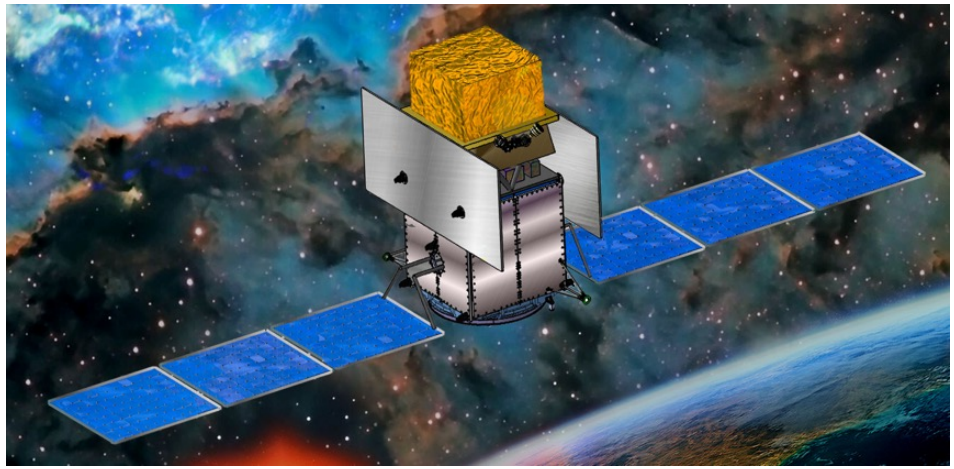


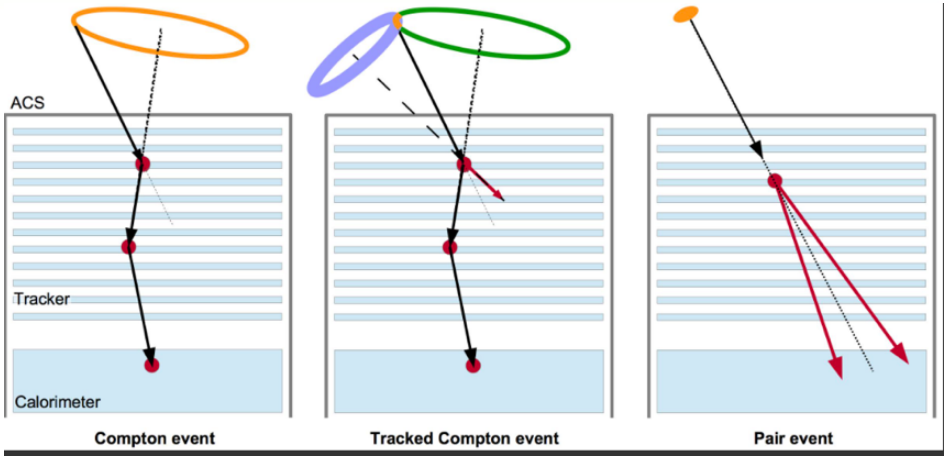


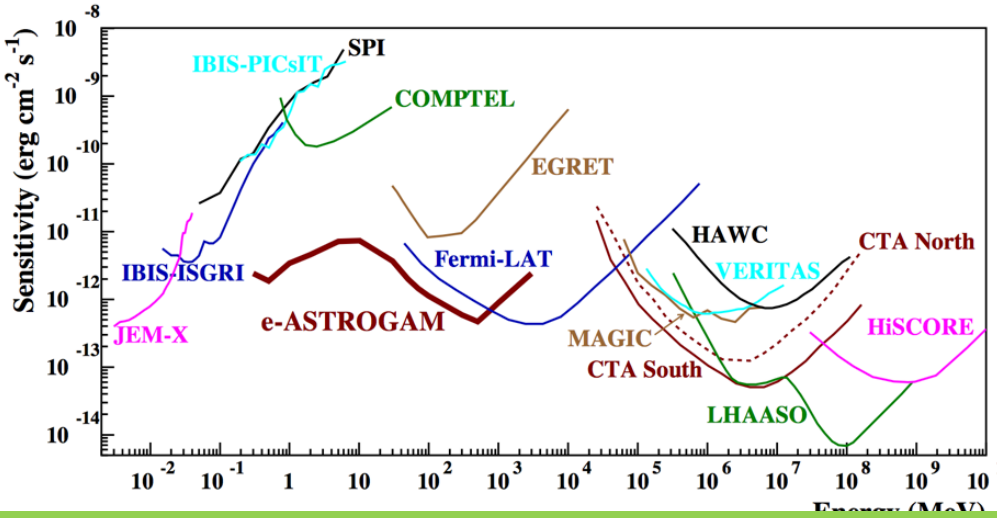
ALTO

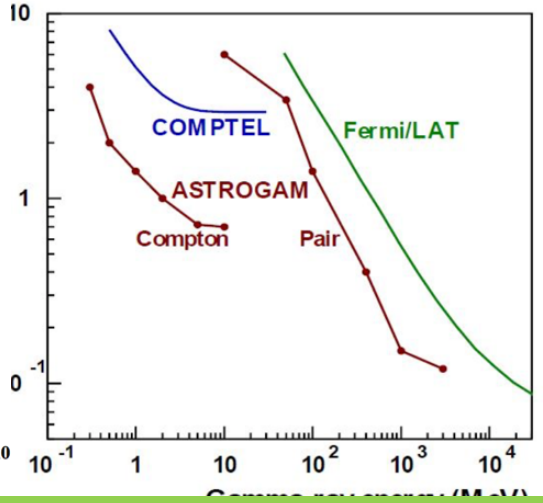
e-Astrogam

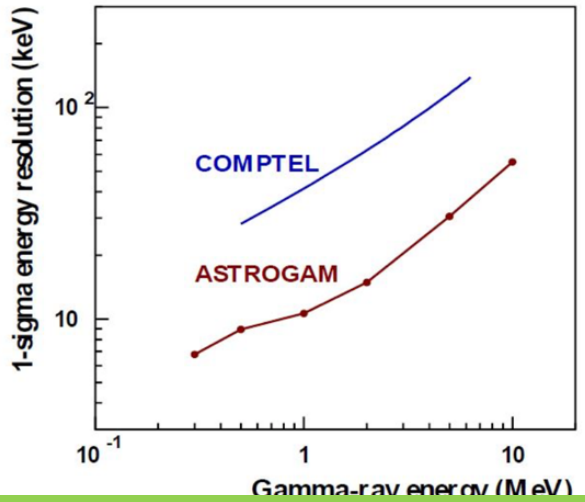
http://astrogam.iaps.inaf.it, https://arxiv.org/abs/1611.02232





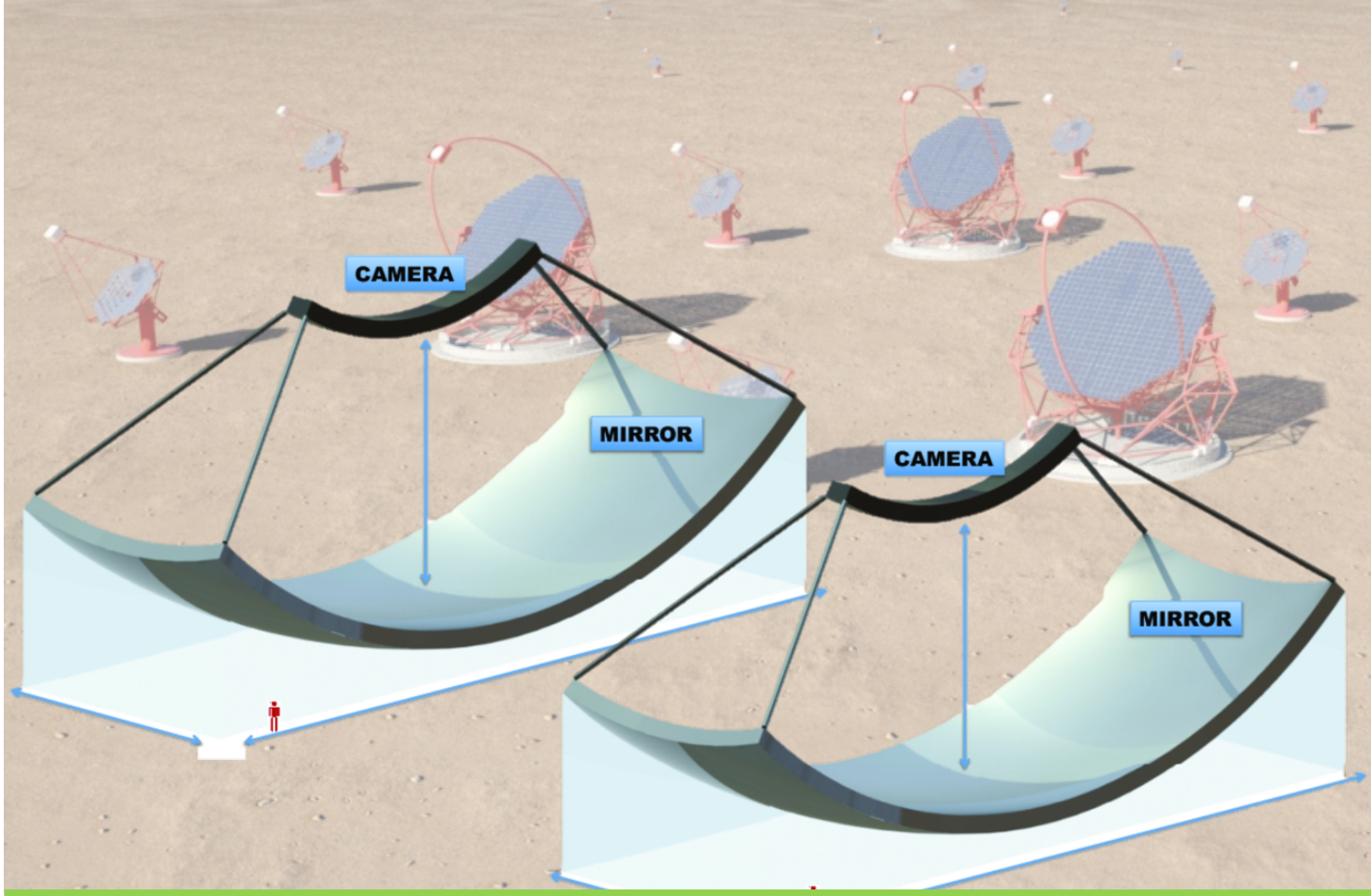






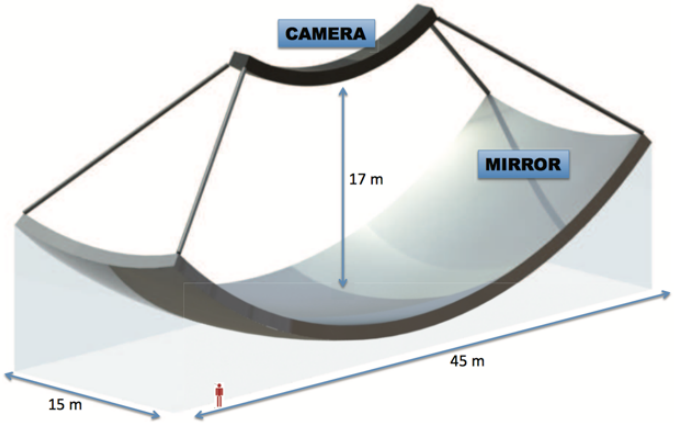
Machete (Meridian Atmospheric CHErenkov TElescope)

Astropart.Phys. 72 (2016) 46-54

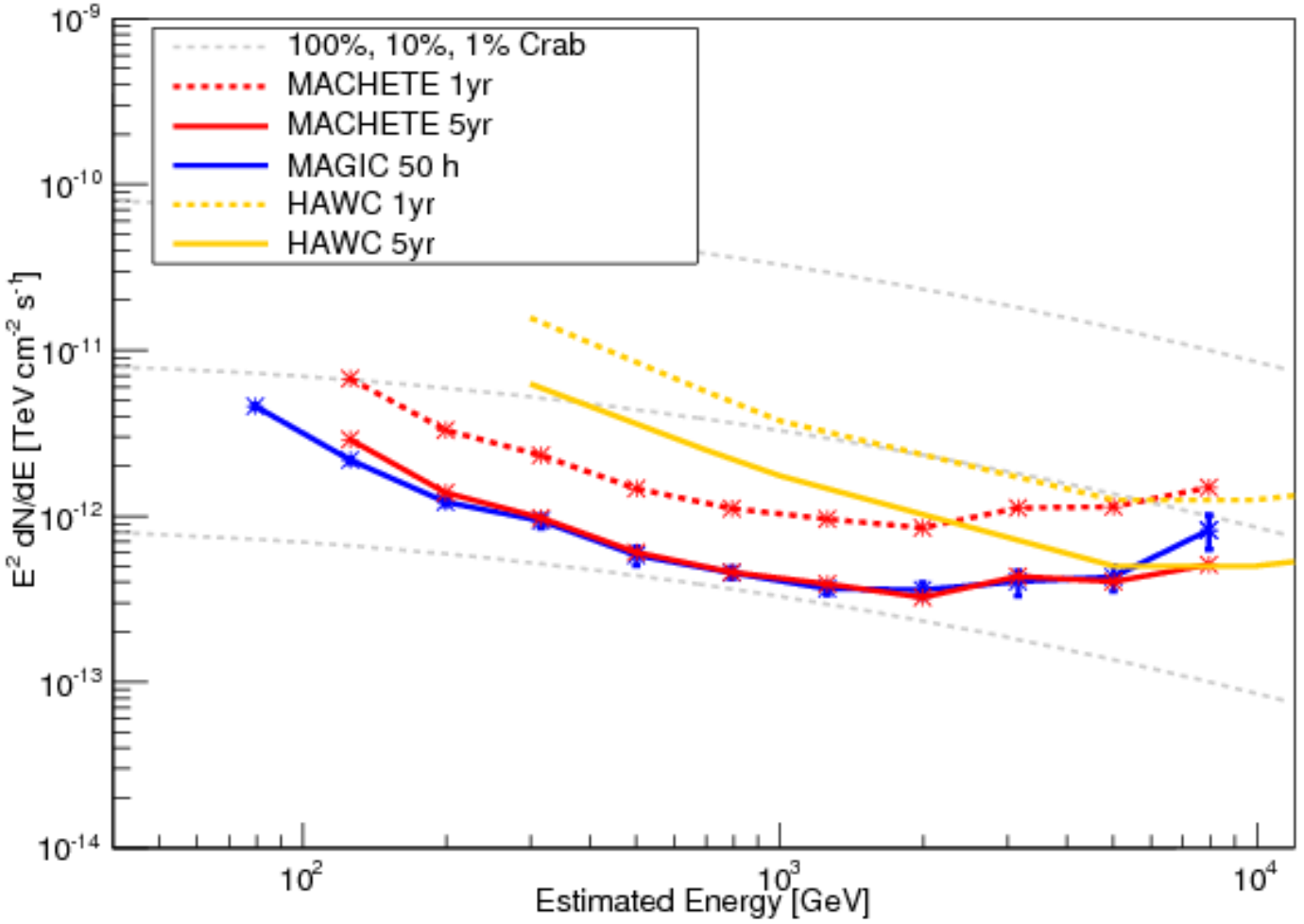


- Fixed (no steering)
- Elongated: 45m x 17m
- FOV: strip of 60 square deg
- Energy threshold and sensitivity similar to MAGIC (<100 GeV)

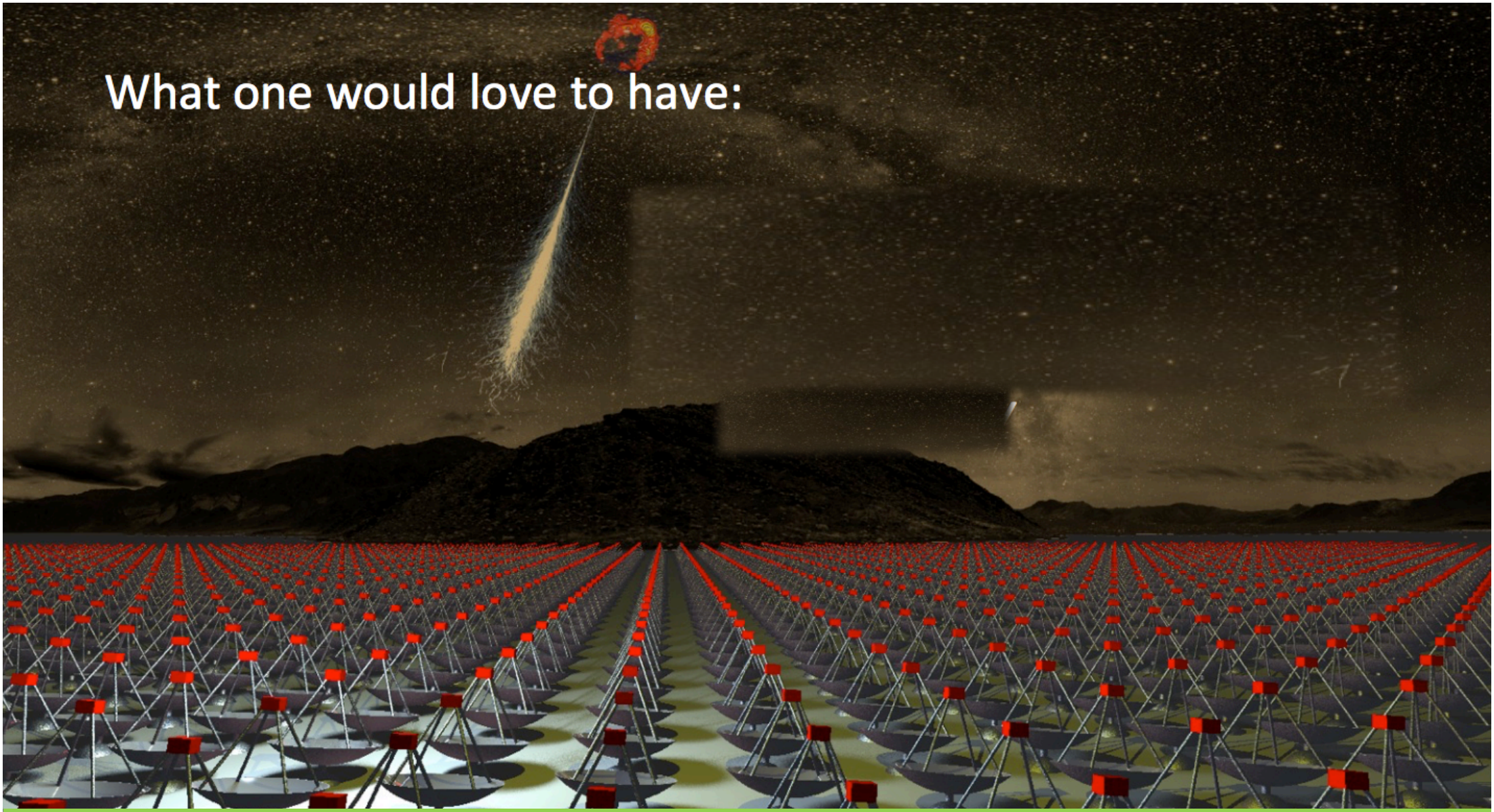
Sensitivity



- Current design, a source in the FOV for 20min/day.
- 1500 h on target reached in 5y…

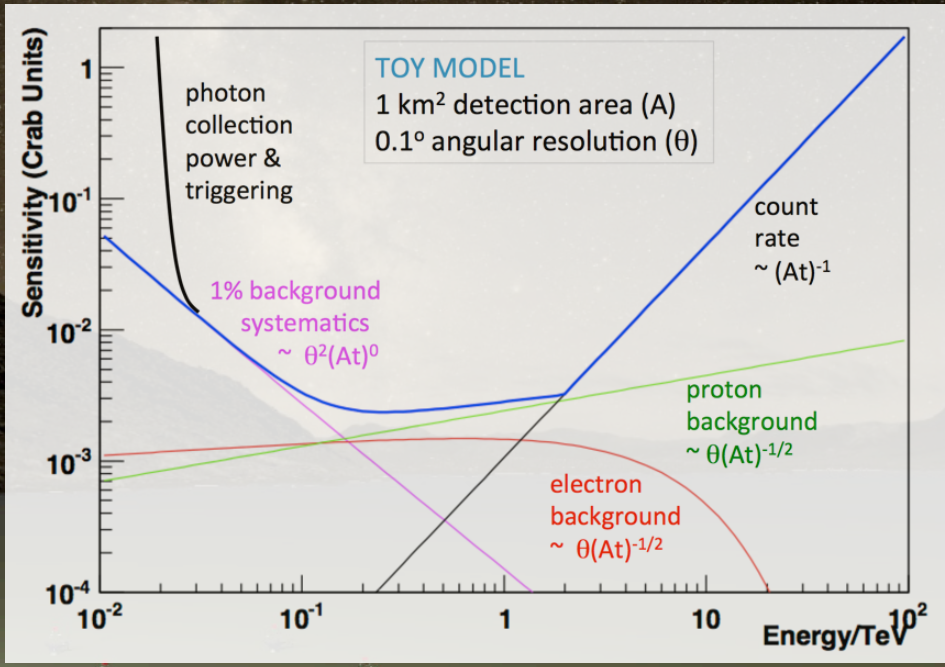


Is there a better (or dedicated) gamma-ray instrument for dark matter?

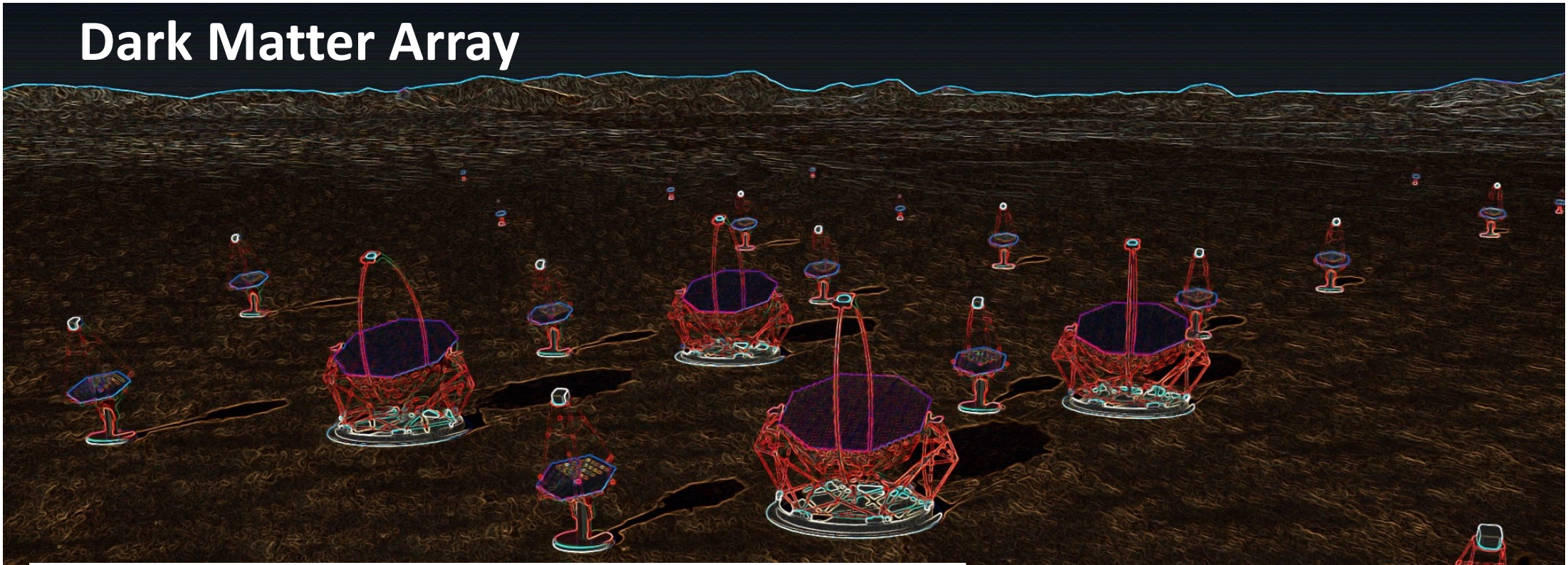

What one would love to have:

What one can (hopefully) afford:

What one should remember

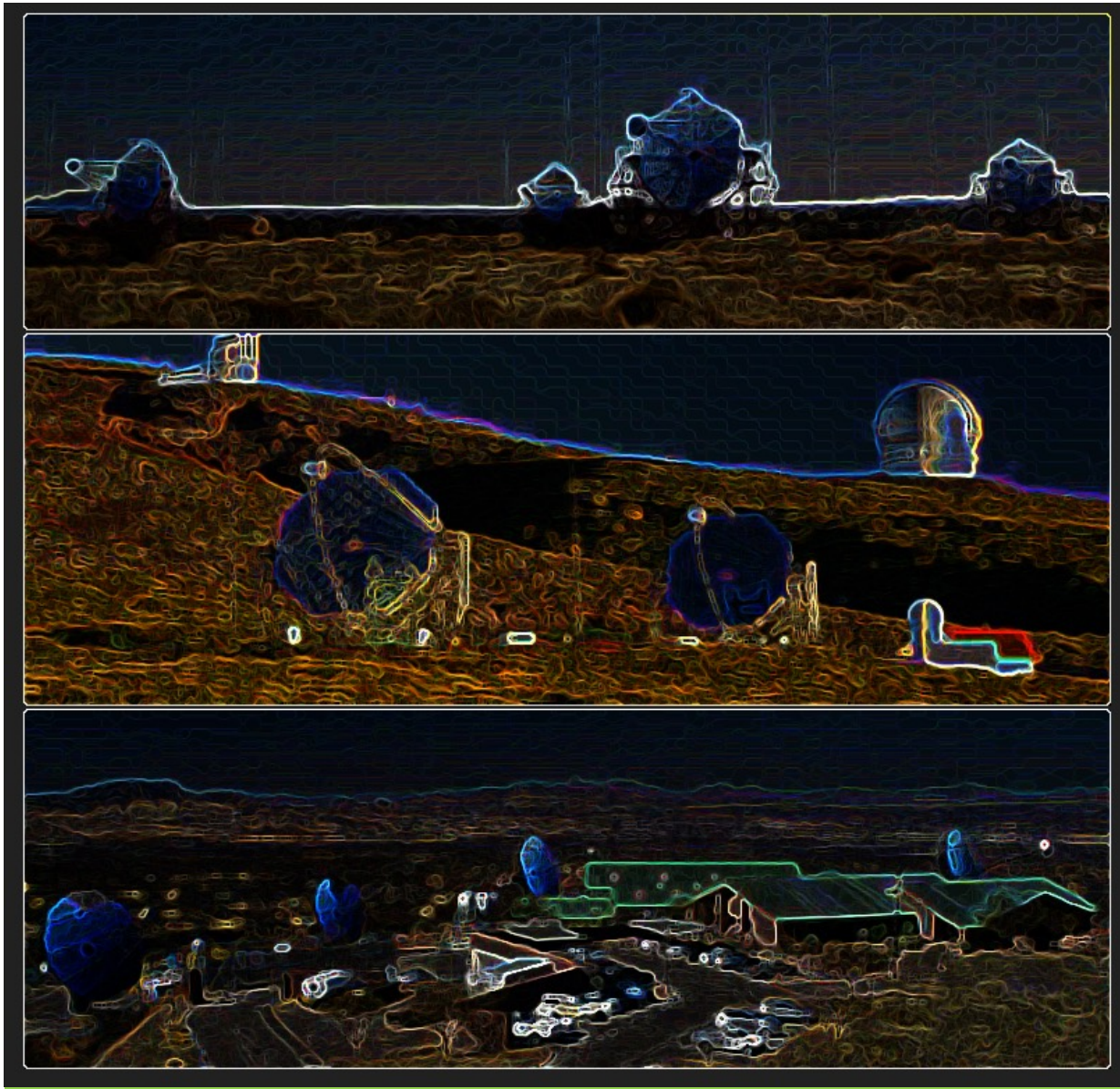


Dark Matter Array



Phys.Rev.D83:045024,2011	Fermi	CTA	DMA
Energy resolution	0.1	0.1	0.1
Angular resolution [sr]	10^{-4}	$4 \cdot 10^{-7}$	$4 \cdot 10^{-7}$ (10^{-5} for $E_\gamma < 40$ GeV)
Energy threshold [GeV]	1	40	10
Effective Area [m^2]	0.7	10^6	10^7
Observation time [h]	10^4	50	5000

Did this make sense?



Before their death…

Use MAGIC VERITAS and HESS for dSph deep field?

Conclusions

Contact

Dark Matter is not open to the public;
therefore we do not offer tours or tastings.

Gamma rays are a powerful probe, but so far nothing

Still one of best, maybe unique, messenger toward dark matter discovery and identification

We need to orientate this future, with CTA and other instruments

Thanks