Dark matter searches with gamma-rays (HESS-II, CTA, Fermi-LAT)

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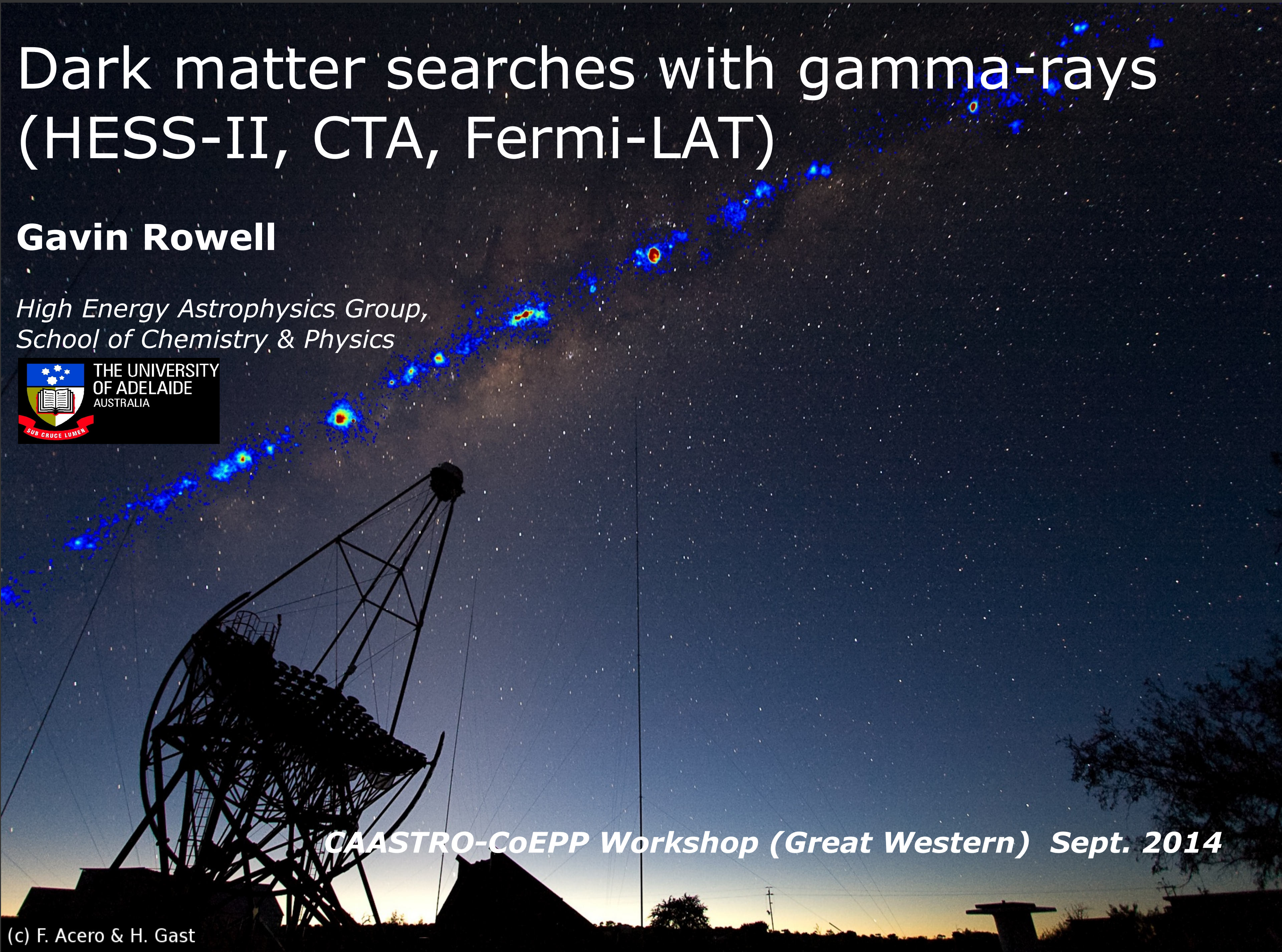
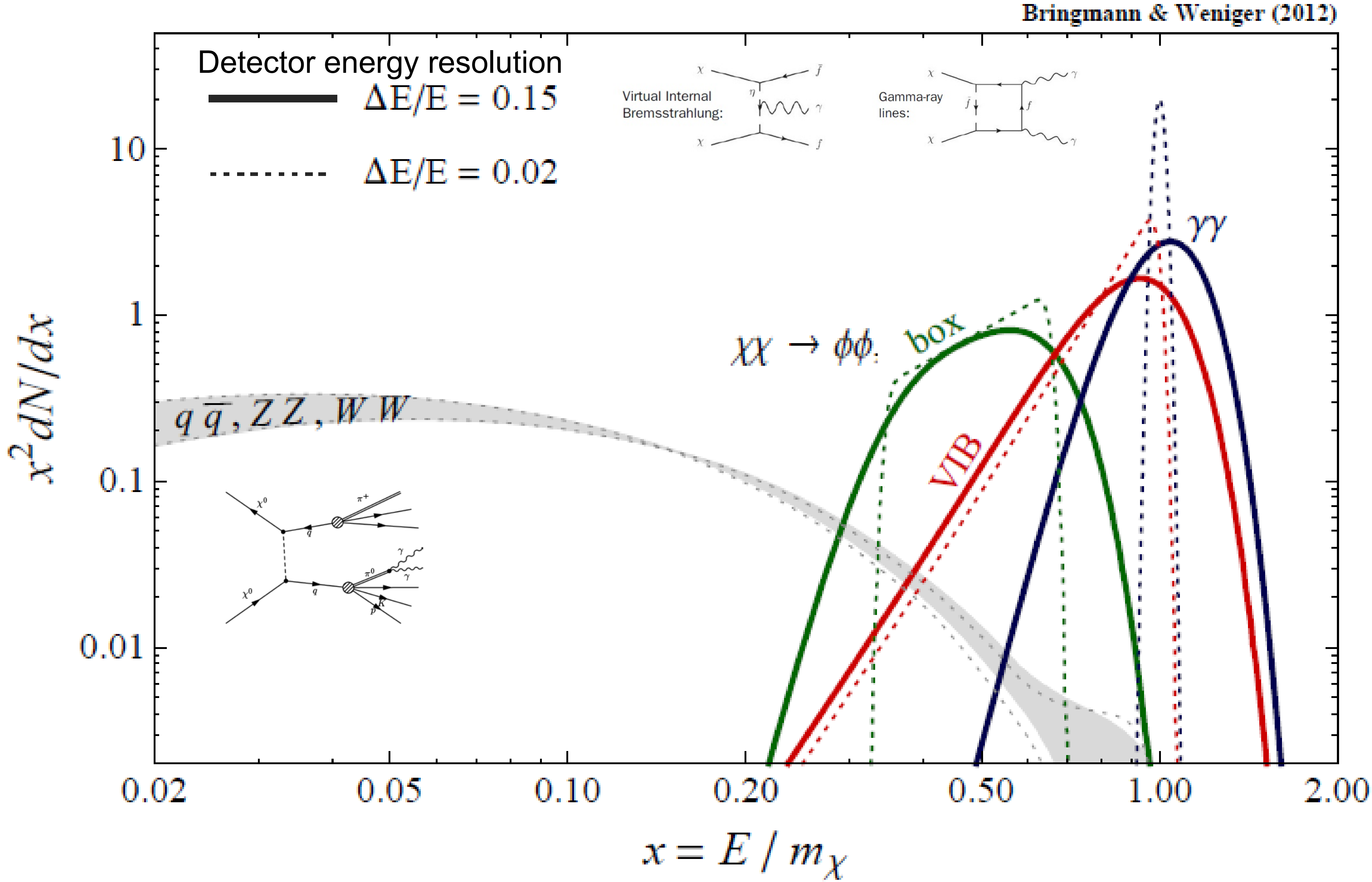
SUB CRUCE LUMEN



CAASTRO-CoEPP Workshop (Great Western) Sept. 2014

Gamma-Ray Annihilation Signatures from (WIMP) Dark Matter



Gamma-Ray Flux from Dark Matter Annihilation

$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = B_F \cdot \underbrace{\frac{1}{4\pi} \frac{(\sigma_{ann} v)}{2\, m_\chi^2} \sum_i BR_i \frac{dN_\gamma^i}{dE_\gamma}}_{Particle\ Physics} \cdot \underbrace{\tilde{J}(\Delta\Omega)}_{Astrophysics}$$

$$\tilde{J} = \int_{\Delta\Omega} d\Omega \int_{los} ds\, \rho^2(s, \Omega)$$

B_F - boost factor
BR_i - branch ratio

Astrophysics term:

- assume density profile of DM ρ (NFW, Einasto..)
- peaking at cores of galaxies, clusters, stars....

→ constraints on <σv>

Prefer astrophysically 'boring' targets

→ ***Dwarf galaxies, globular clusters....***
→ ***But galactic centre region, galaxy clusters are still in favour***

	Time of operation	E-range [GeV]	A_{eff} [m^2]	Sens. [$10^8 m^2 s$]$^{-1}$	$\Delta E/E$ [%]	F.O.V. [sr]	$\Delta\theta$ [°]
Fermi-LAT	2008–2018*	0.2–300	0.8	200	11	2.4	0.2
AMS-02/Ecal	2011–2021*	10–1000	0.2	1000	3	0.4	1.0
AMS-02/Trk	2011–2021*	1–300	0.06	1000	15	1.5	0.02
GAMMA-400	2018*–...	0.1–3000	0.4	100	1	1.2	0.02 (0.006)
MAGIC	2009–...	$\gtrsim 50$	$2\cdot10^4(7\cdot10^4)$	10(0.2)	20(16)	0.003	0.17(0.08)
HESS-II	2012–...	$\gtrsim 30$	$4\cdot10^3(10^5)$	4(0.1)	15(15)	0.003	0.13(0.07)
CTA	2018*–...	$\gtrsim 20$	$5\cdot10^4(10^6)$	1(0.02)	20(10)	> 0.006	0.1(0.06)

* planned

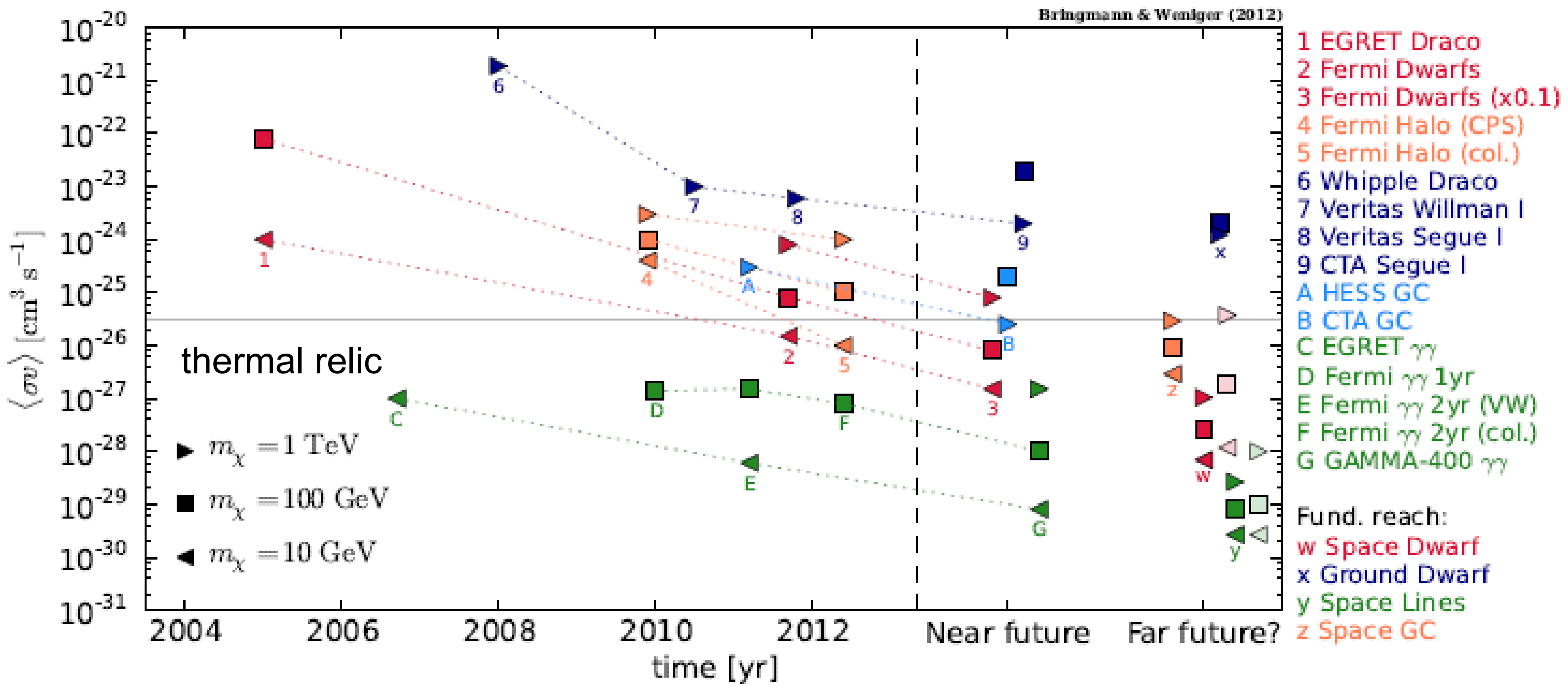
Auger CRs E>10^{18} eV constraints on super-heavy particles (Abraham etal 2009)

Table 1: Rough comparison of basic telescope characteristics relevant for indirect DM searches with gamma rays, for a selection of typical space- and ground-based experiments that are currently operating, shortly upcoming or planned for the future. The quoted sensitivity is for point sources at the 5σ level, after 1yr (50 hrs) of space- (ground-) based observations and assuming typical backgrounds. Where applicable, numbers refer to photon energies at or above $E \simeq 100$ GeV (1 TeV). The angular resolution $\Delta\theta$ denotes the 68% containment radius. More details in Refs. [20] (Fermi-LAT), [21–23] (AMS-02), [24–26] (GAMMA-400), [27] (MAGIC), [28] (HESS-II) and [29] (CTA).

Bringman & Weniger 2012

Gamma-rays & DM : Evolution of limits

Bringman & Weniger 2012



$\chi\chi \rightarrow \gamma\gamma$ $\chi\chi \rightarrow \bar{b}b$ $\chi\chi \rightarrow \bar{b}b$

Figure 6: Time evolution of limits. References: EGRET Draco [312]; Fermi Dwarfs [126]; Fermi Halo (CPS) [143]; Fermi Halo (col.) [191]; Whipple Draco [170]; Veritas Willman I [178]; Veritas Segue I [313]; CTA Segue I and GC [311]; HESS GC [187]; EGRET $\gamma\gamma$ [196]; Fermi $\gamma\gamma$ 1yr [197]; Fermi $\gamma\gamma$ 2yr (VW) [198]; Fermi $\gamma\gamma$ 2yr (col.) [199]; GAMMA-400 [57]. For the dark red, dark green, blue and orange far future 'fundamental' limits, we took only into account systematic limitations (basically assuming that all relevant systematics can be understood at the 1% level); the corresponding observational times can be extremely large in case of space-based telescopes, but are realistic for IACTs. For comparison, the light green and light red symbols show the limits obtained for hypothetical sky exposures about 100 times larger than 10 years Fermi LAT observations in survey mode.

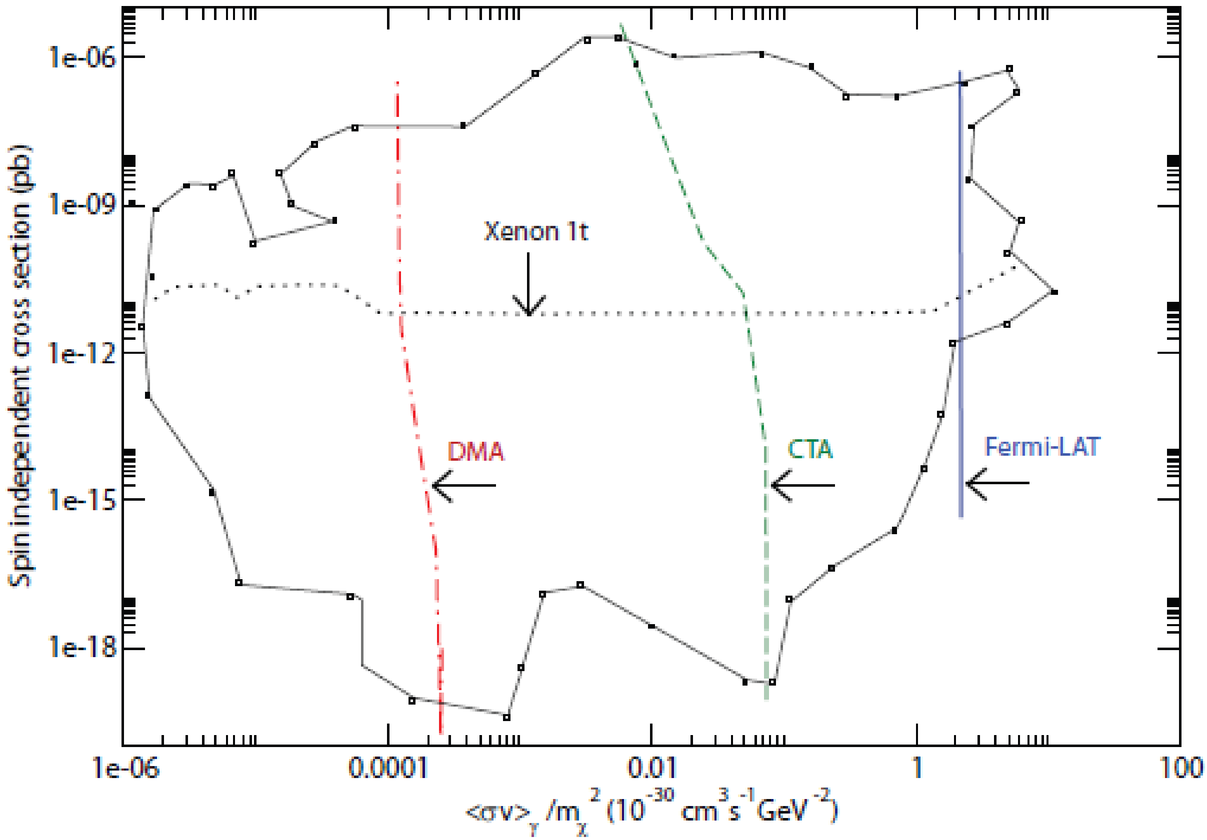
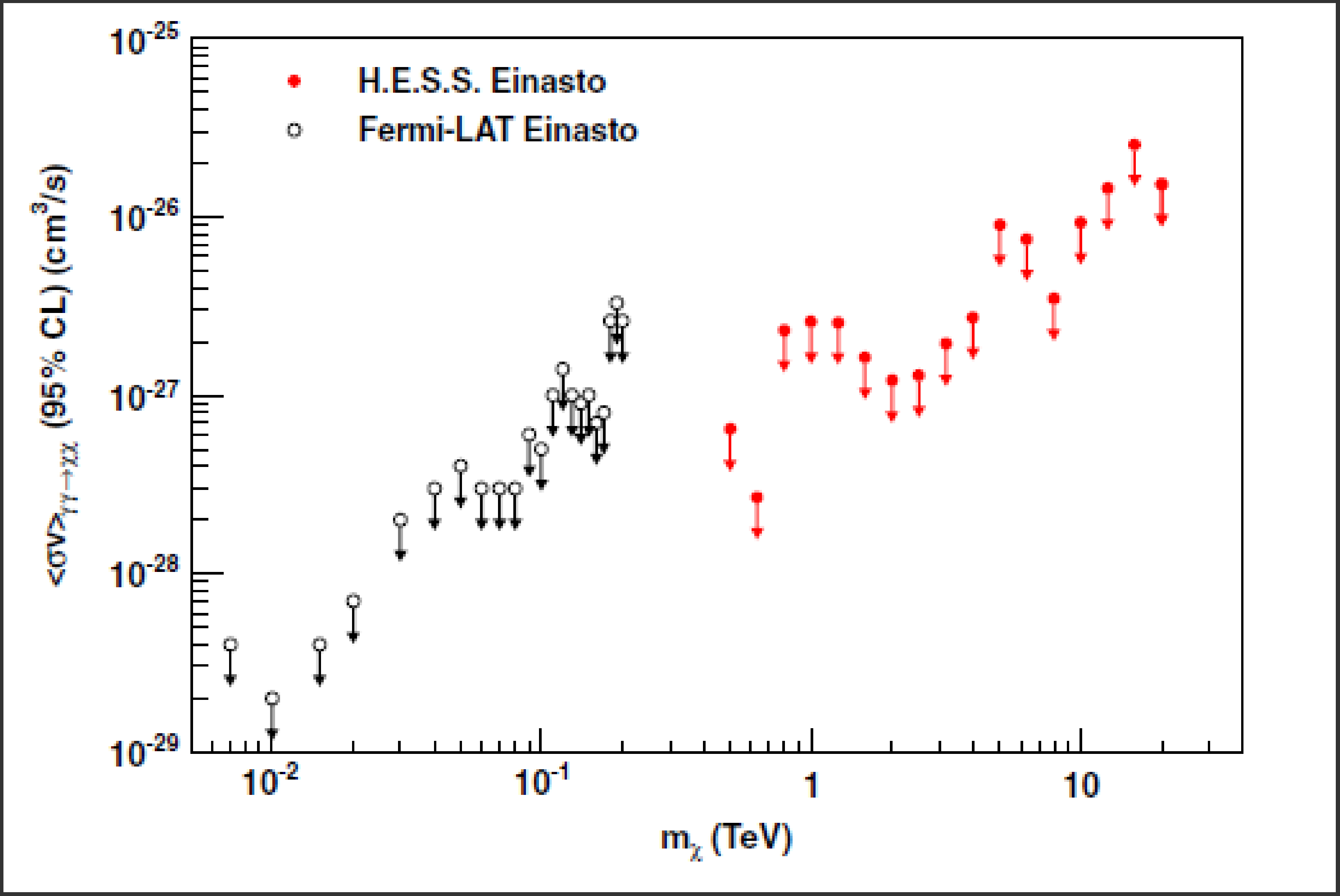


Figure 1: Illustration of the reach of direct and indirect dark matter detection experiments. Here γ-ray detection towards the galactic center with the NFW profile is considered. Shown is the area encompassing the approximate range of WMAP-compatible phenomenological MSSM model space, and the reach of the upcoming Xenon 1t direct detection experiment, and the Fermi-LAT, CTA and DMA indirect detection experiments. For details, see [65].

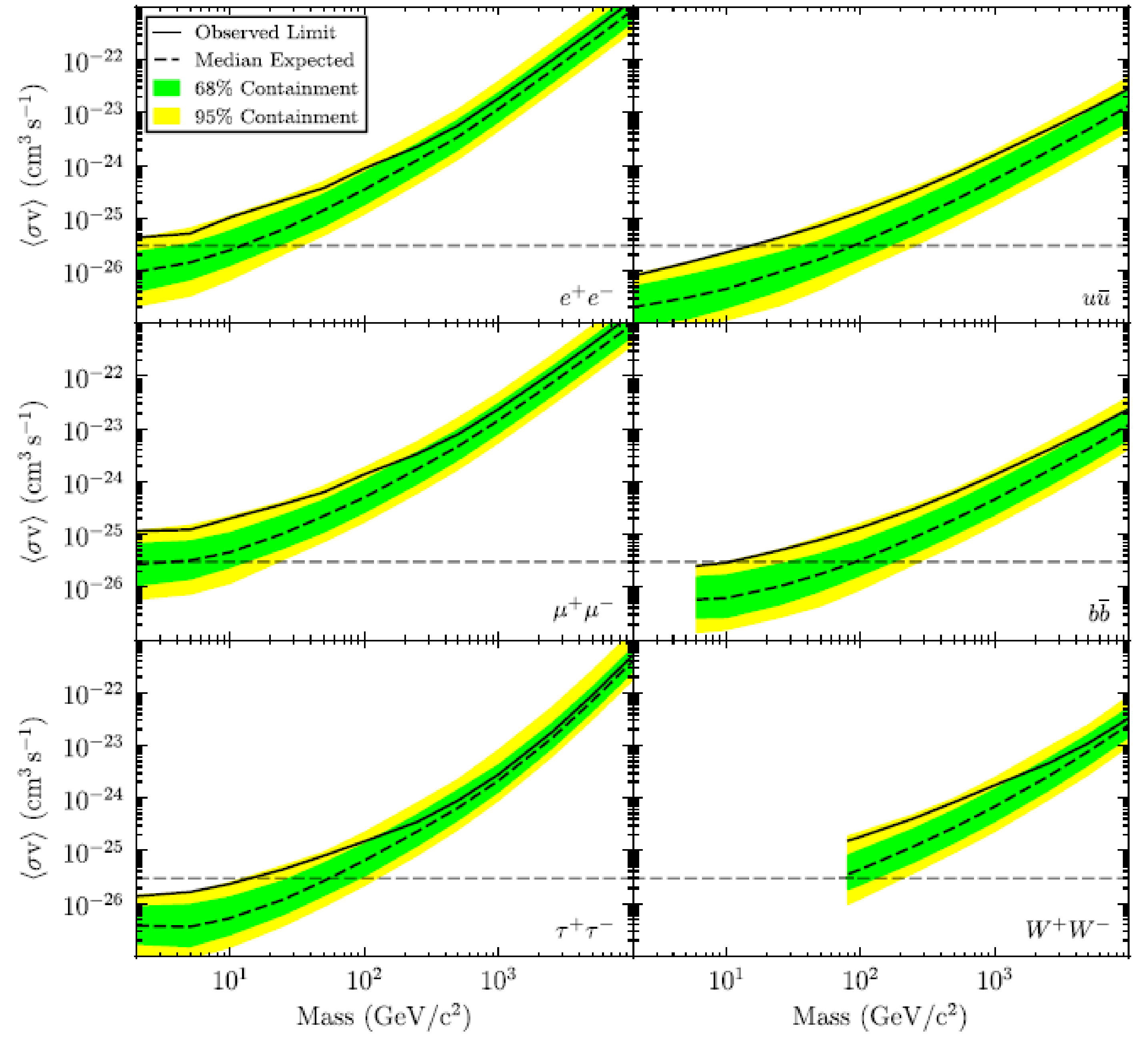
Bergstrom 2012

Galactic Centre Halo $\chi\chi \rightarrow \gamma\gamma$ (r<1 deg, |b|>0.3deg)

HESS Abramowski etal 2013 **Fermi LAT** Ackermann etal 2012



Dwarf Galaxies (x15) Fermi-LAT Ackermann etal 2014

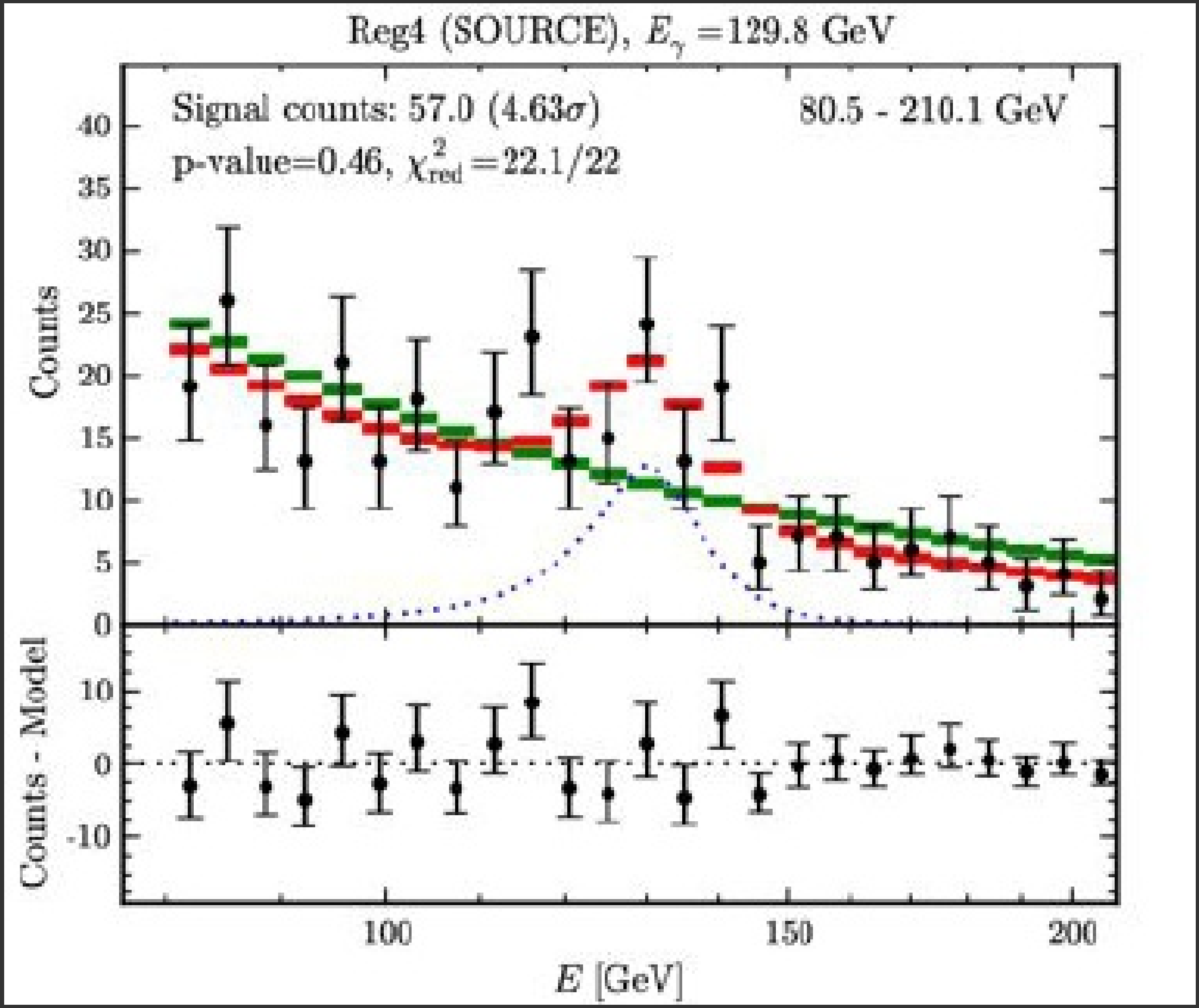


130 GeV Line Feature towards Galactic Centre

Weniger (2012)

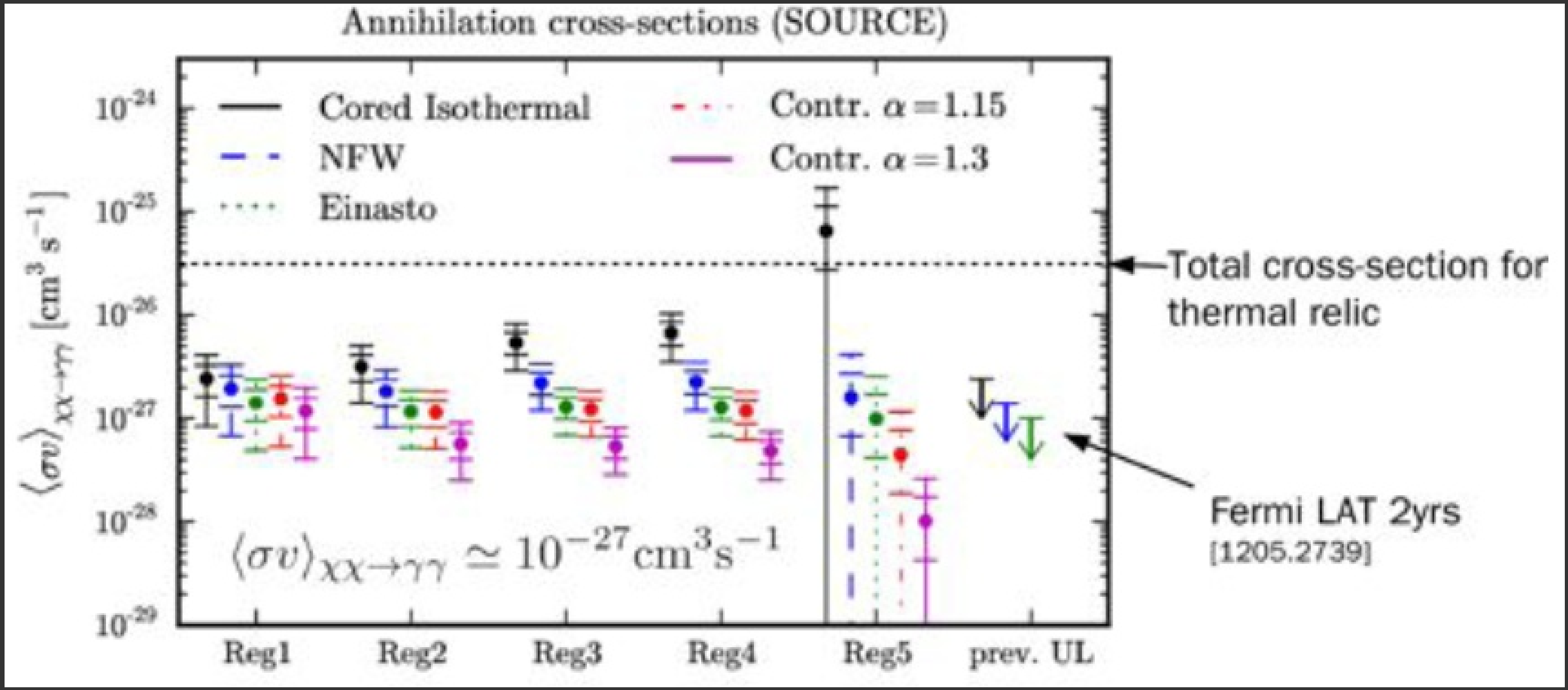
3.2σ significance (post-trial) Einasto profile

Also – Possible VIB signal
Bringmann etal 2012



DM Implications of this 130 GeV line $\chi\chi \rightarrow \gamma\gamma$

Weniger (2012)

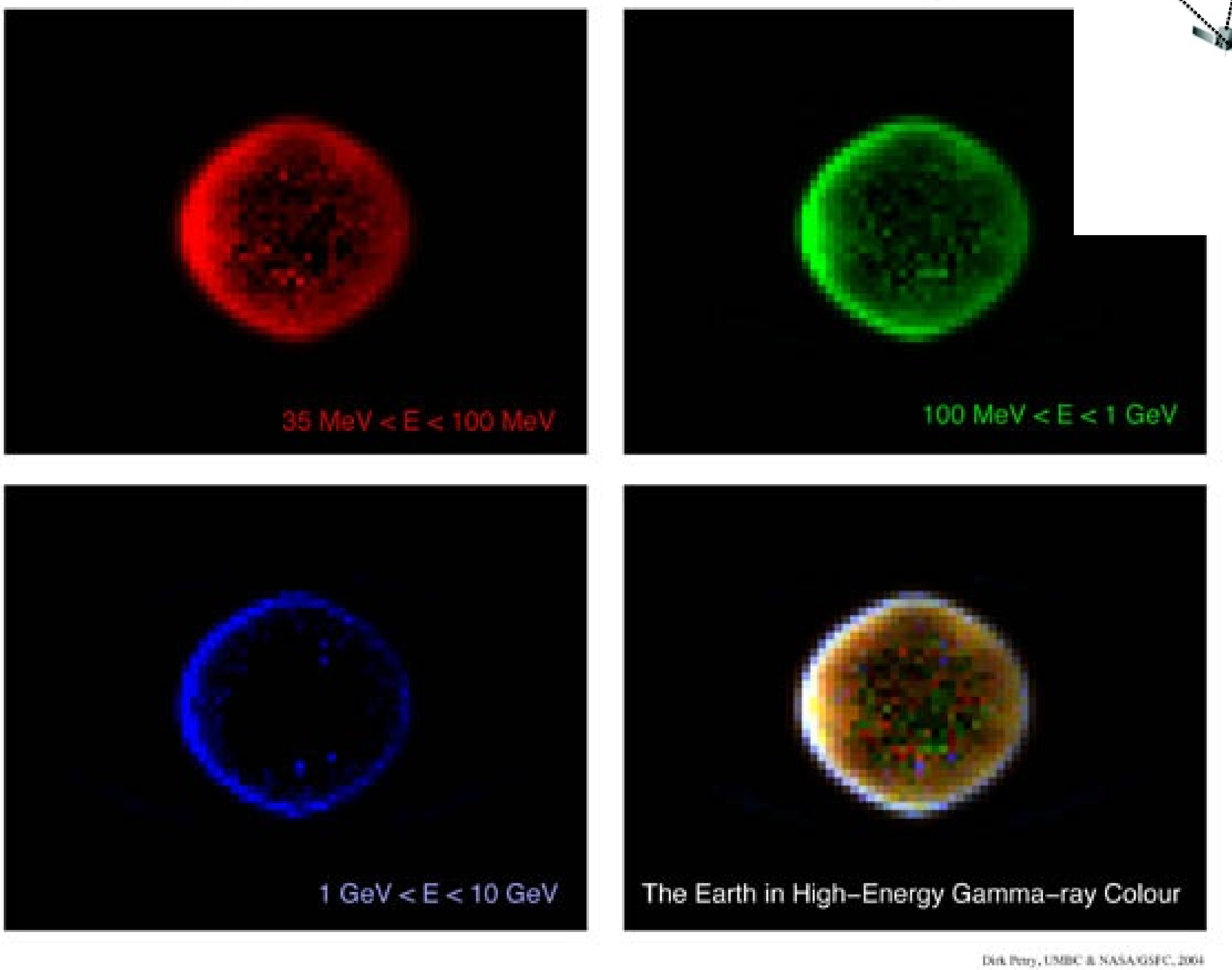


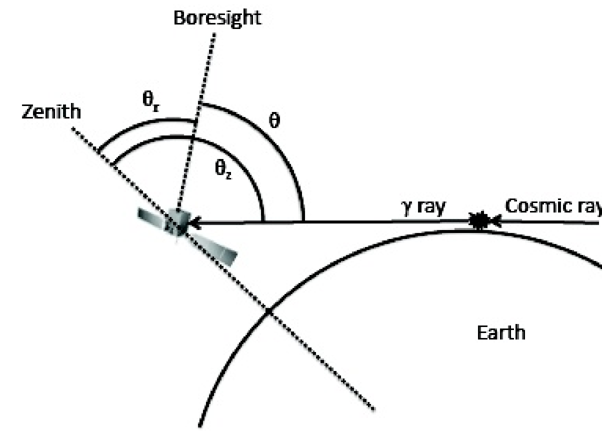
BR ($\chi\chi \rightarrow \gamma\gamma$) ~ 5%   expect ~10^{-4}

<u>But other sources of GeV lines....!?</u>

- Earth limb   Finkbeiner etal 2012, Hektor etal 2012, Ackermann etal 2013
- Sun region Whiteson 2013
- Galaxy Cluster stacking Hektor etal 2012
- UnID Gal. Sources Su&Finkebeiner 2012
- Astrophysical? Inv-Compton KN pile-up Aharonian etal 2012

Earth limb gamma-rays
(from cosmic-ray air-showers)





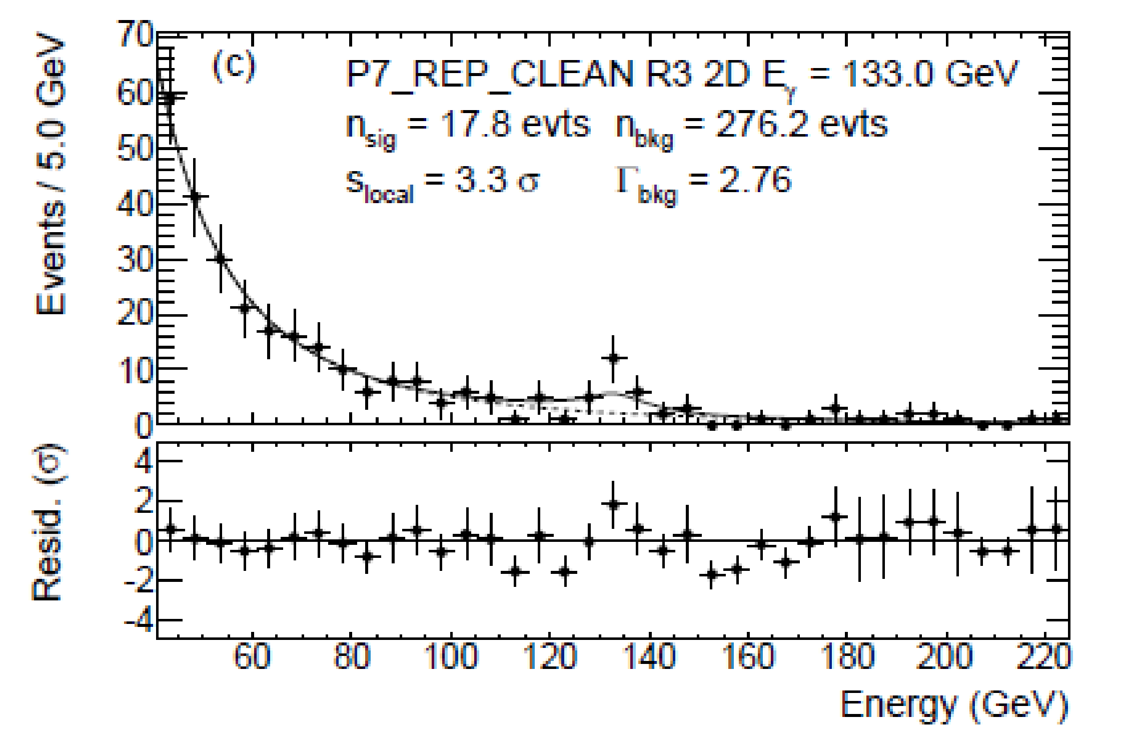
130 GeV line feature seen at ~2σ

Most recent analysis by the Fermi team

Ackermann etal 2013 (pass 7 data)

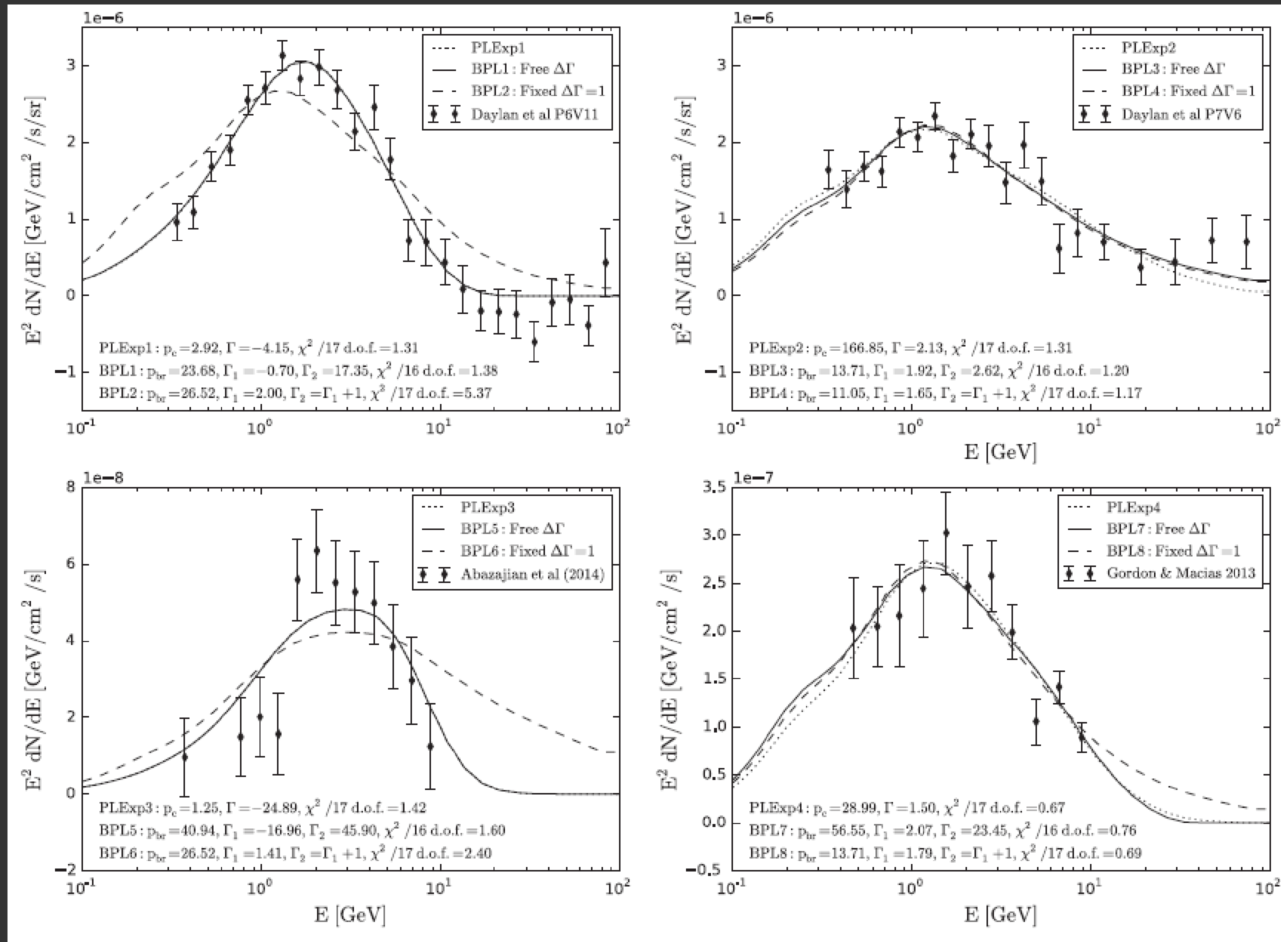
Pass 7 Data → energy resolution depends on incidence angle

- Feature at 133 GeV but <2σ signifance (post-trial or global)
- Still seen in Earth's limb.
- Line feature narrower than Fermi-LAT energy resolution



1-10 GeV 'Excess' towards Galactic Centre (inner 10°)

Dark Matter interpretation (e.g. Daylan et al 2014)



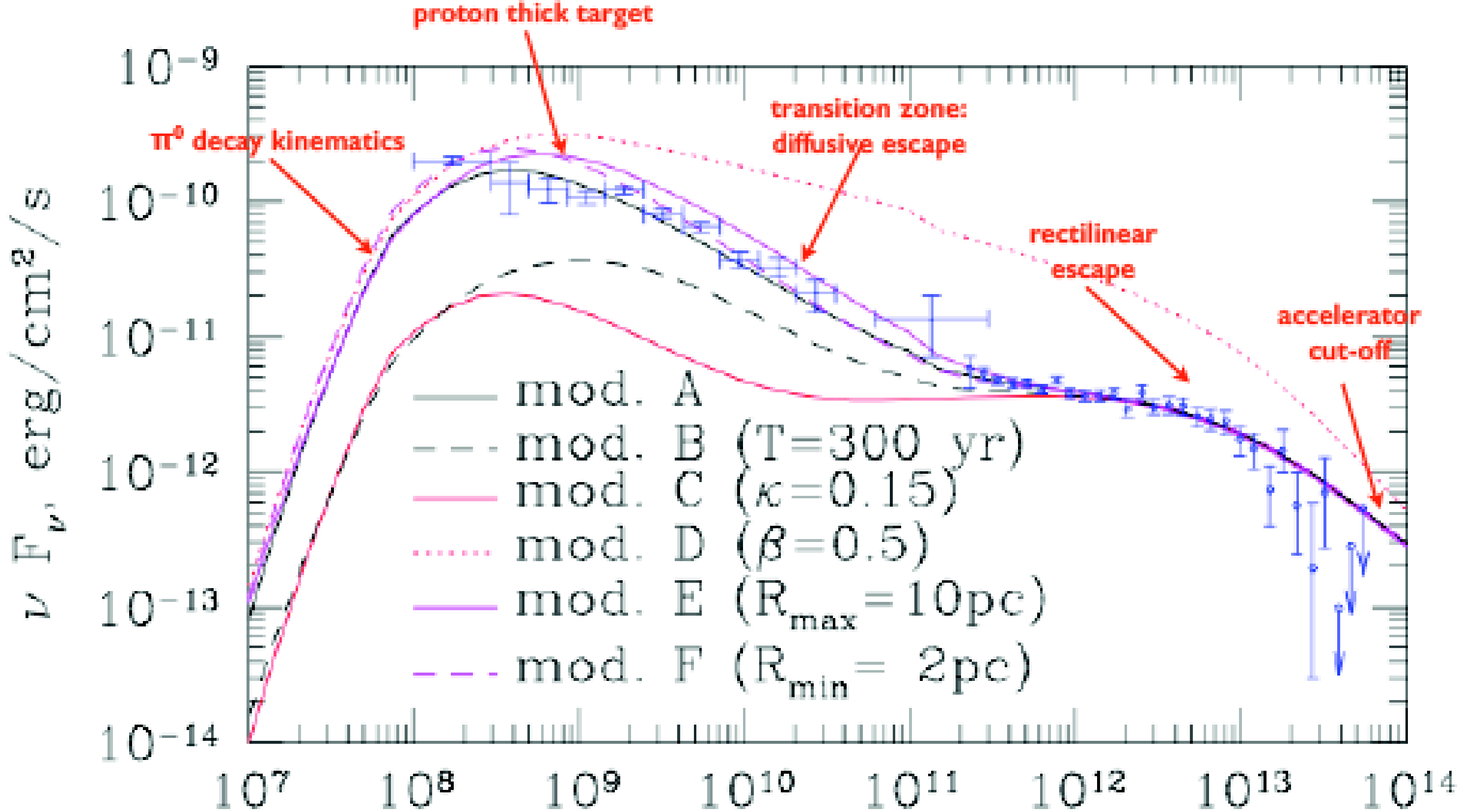
→ **Astrophysical interpretation (Okkam's Razor) instead of Dark Matter** (e.g. Carlson & Profumo et al 2014)

- Current GeV background model inappropriate
- E-dependent cosmic-ray propagation **into** the ISM (e.g. Gabici et al 2007)

Sgr A* in gamma-rays

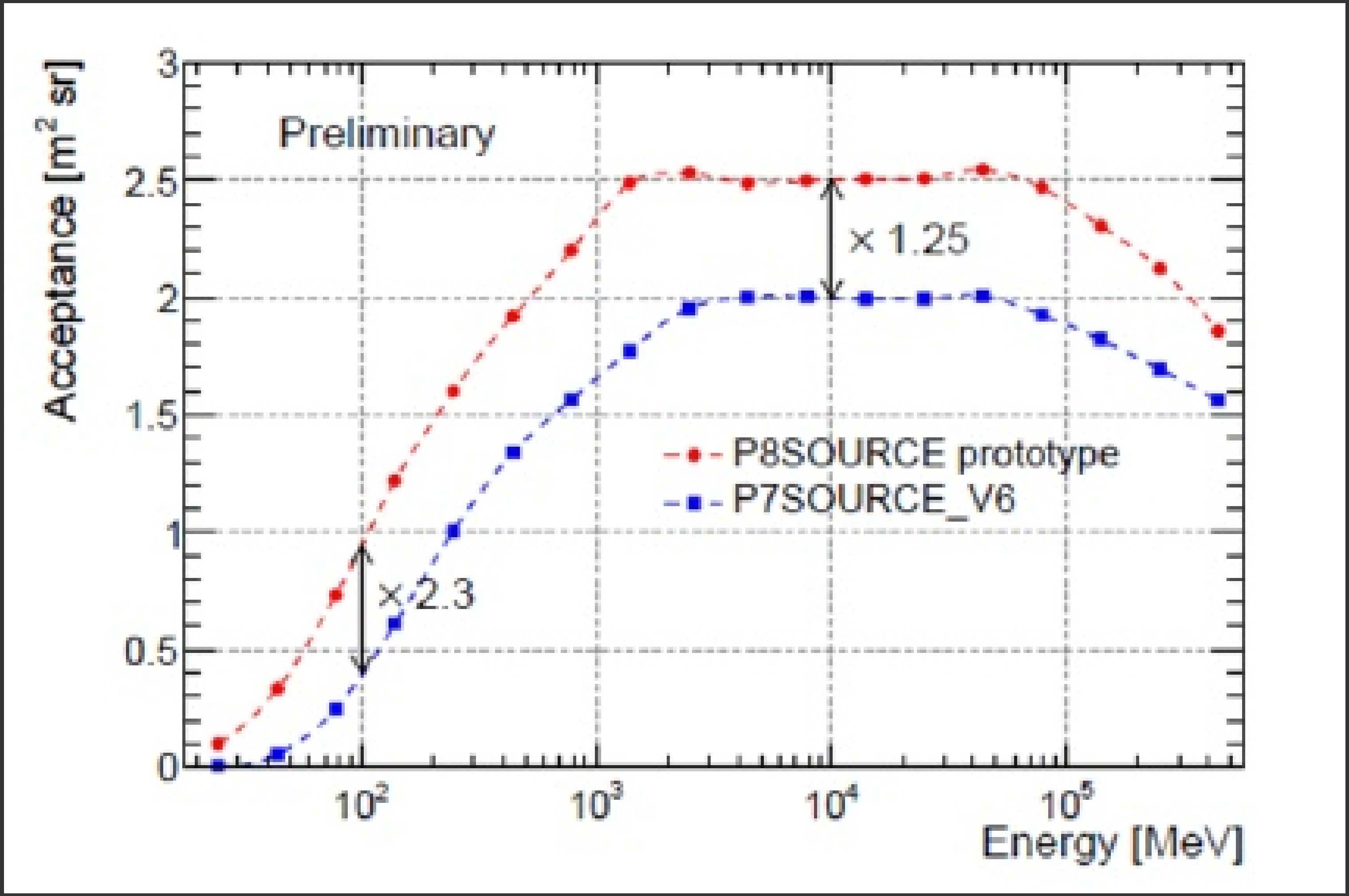
Slide from R. Crocker Recontres du Vietnam 2014)

...but 'astrophysical' explanations for the γ-ray spectrum are also credible



Chernyakova et al. 2011

Pass 8 Data from Fermi LAT – Even better at GeV energies - stay tuned!

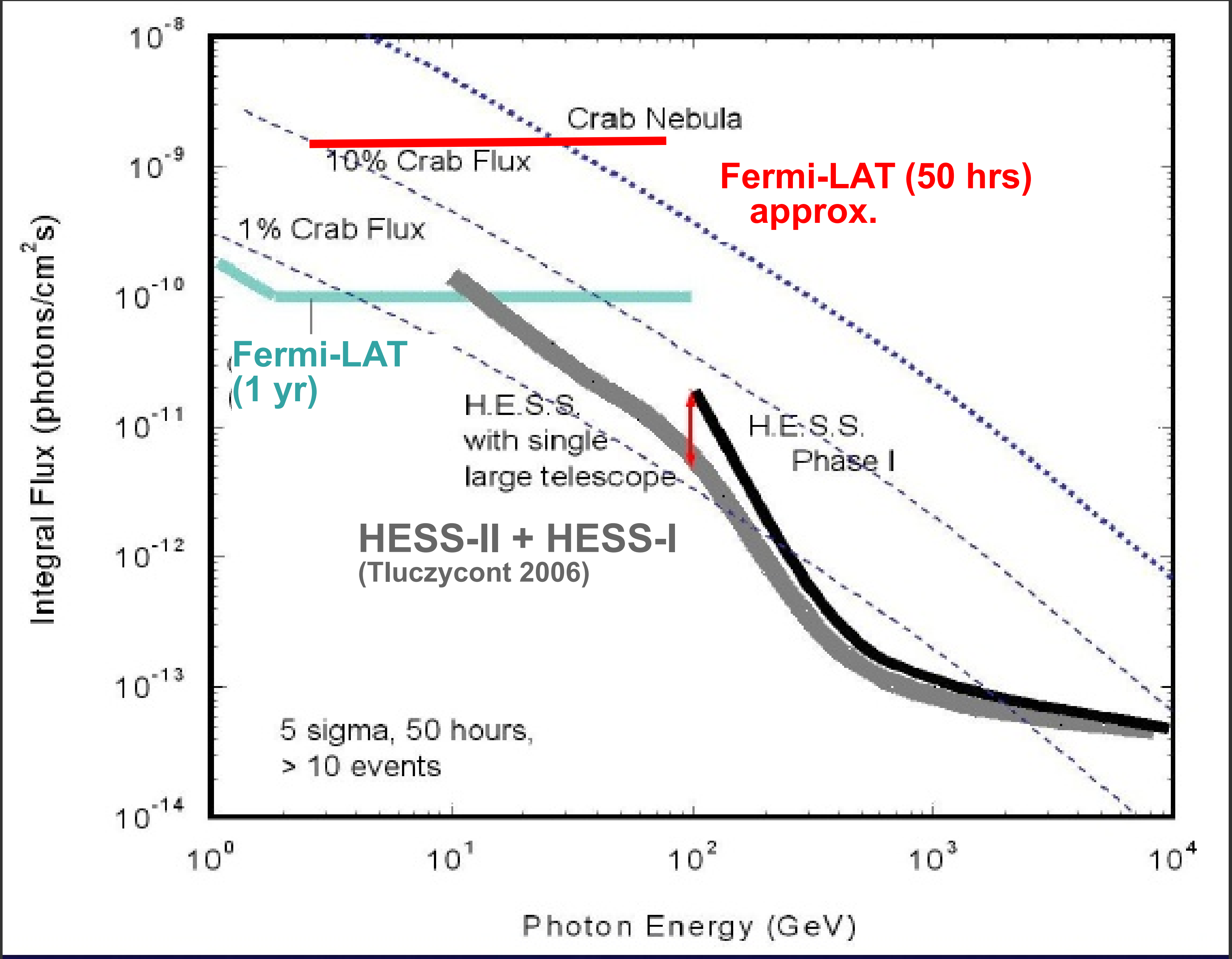


H.E.S.S. 4x12m + 1x28m diam. Cherenkov Imaging Telescopes (22° S 1800m a.s.l. Namibia)

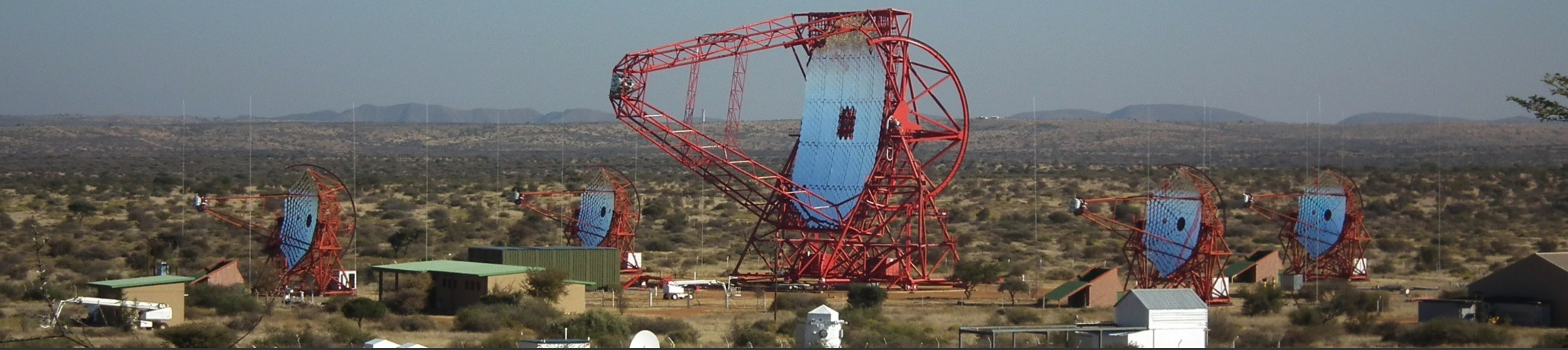
- Full array 0.02 to ~ 20 TeV coverage
- 28m telescope ~0.02 to ~5 TeV now commissioned

- Field of view 3 to 5°
- Angular resolution ~3 to 6 arcmin
- Energy resolution ~0.1 to 0.2 $\Delta E/E$

Flux sensitivity : HESS-II & Fermi-LAT crucial overlap

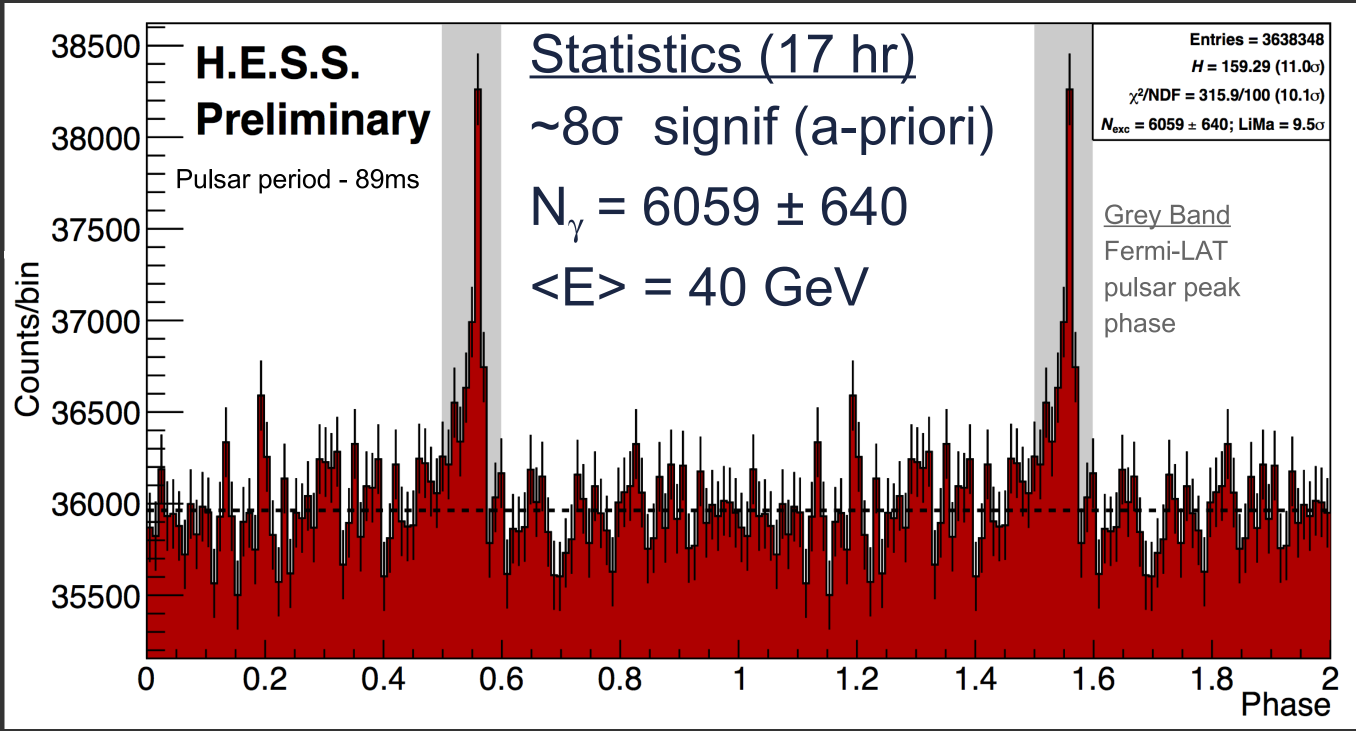


First “Mono” Results from H.E.S.S. II



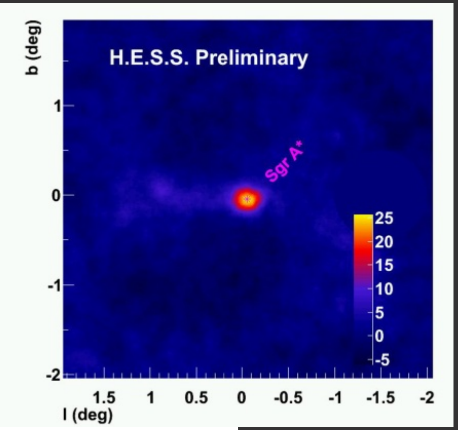
~30 GeV threshold

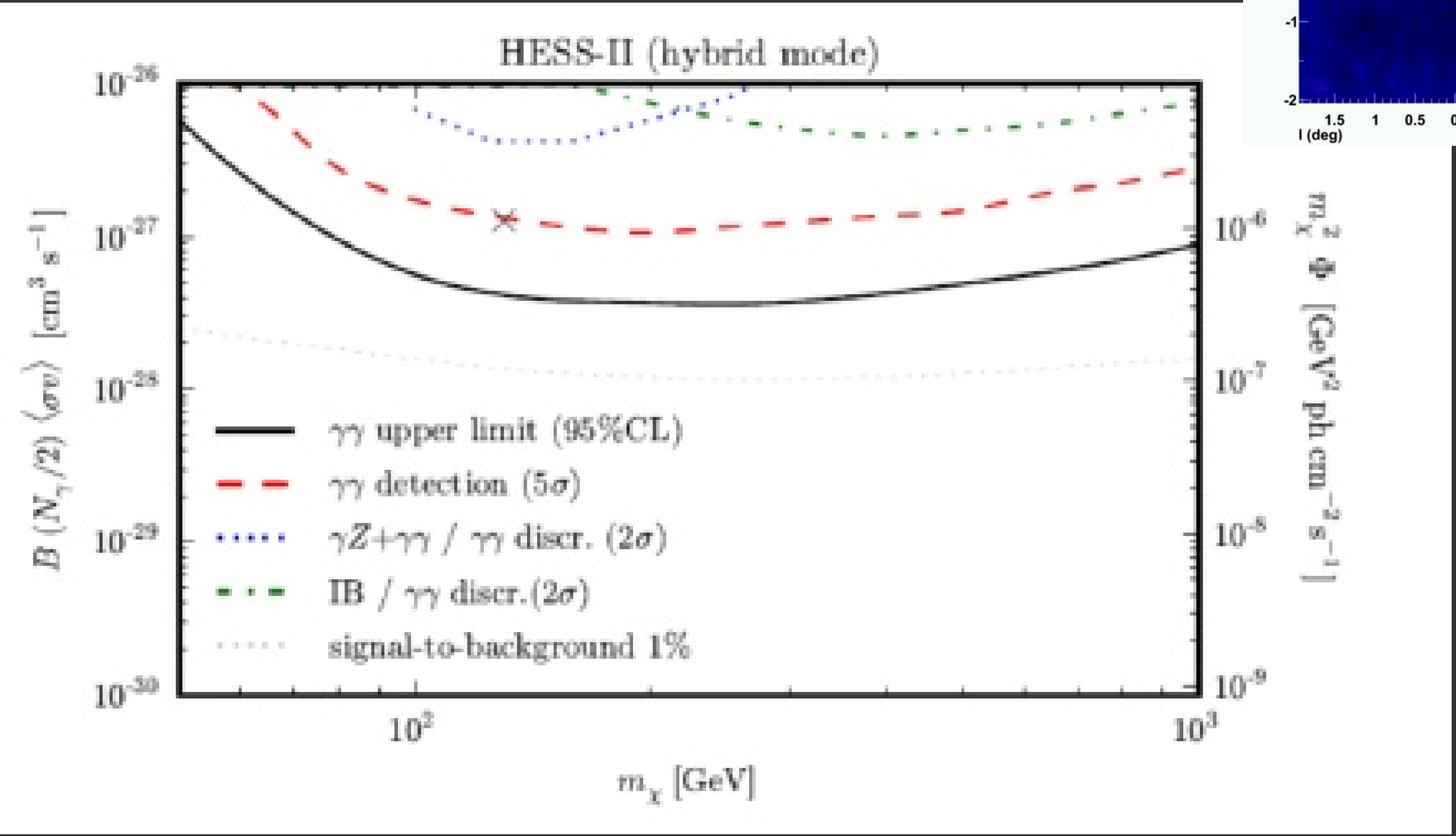
- Vela Pulsar pulsed emission detection
- Crab Nebula
- Gal. Centre
- 2 AGN



HESS II Sensitivity to $\chi\chi \rightarrow \gamma\gamma$

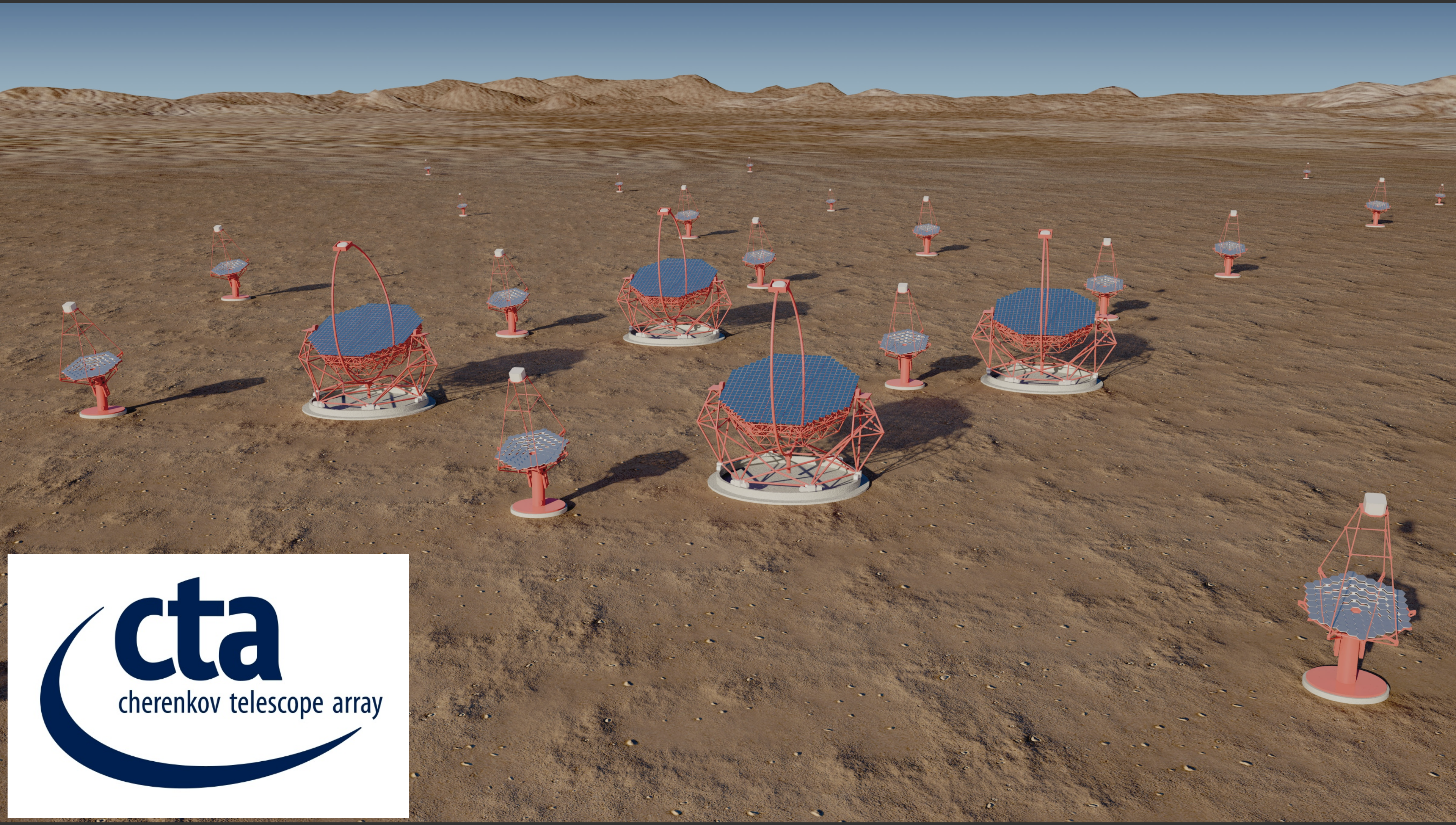
- 50 h Galactic Centre   Bringmann etal 2012

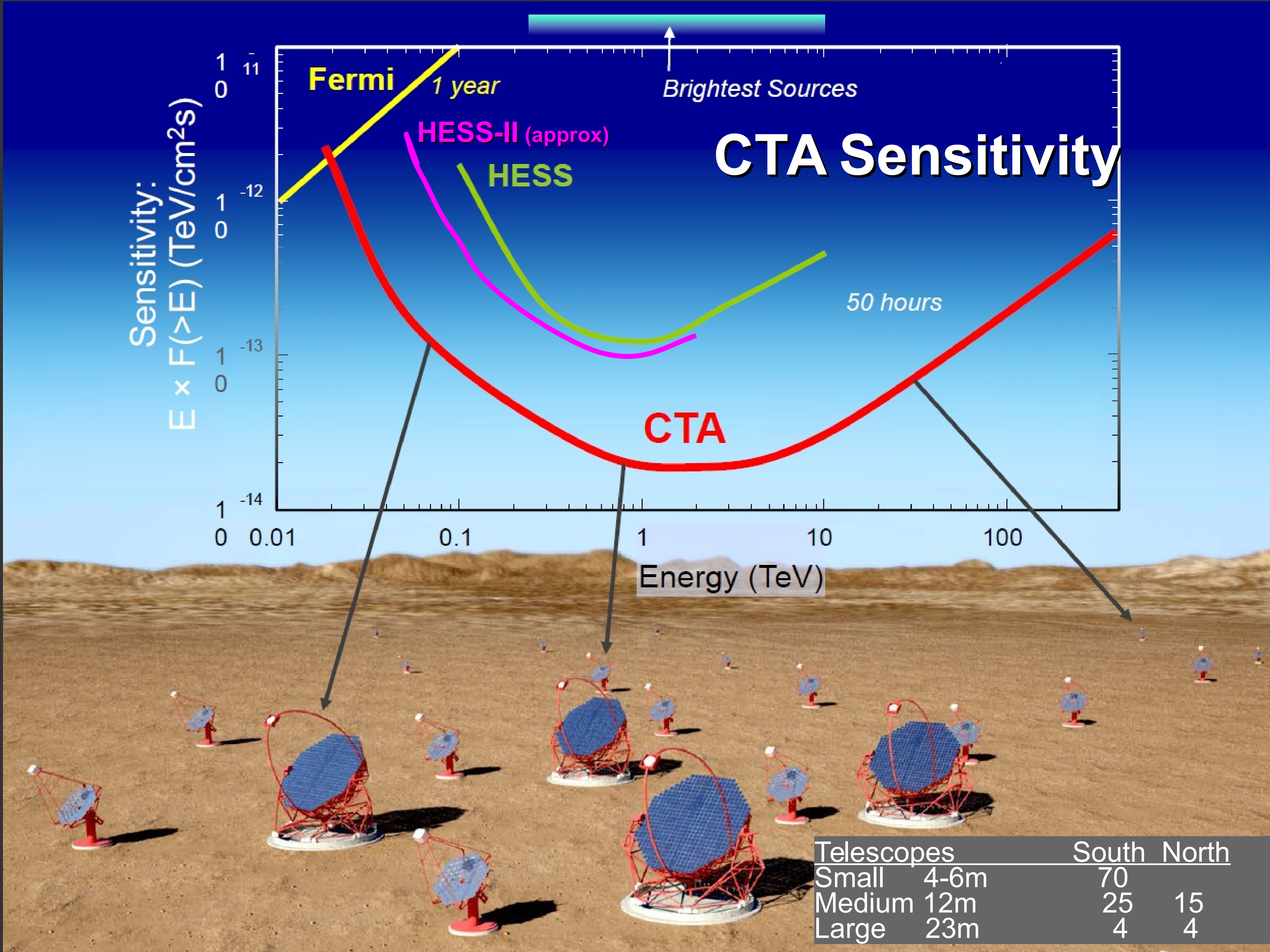




- Expect first results by end of 2014

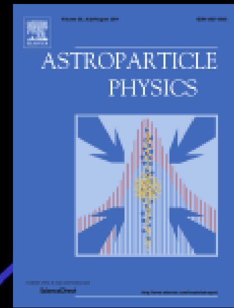
CTA - The Next Step in TeV Gamma-Ray Astronomy





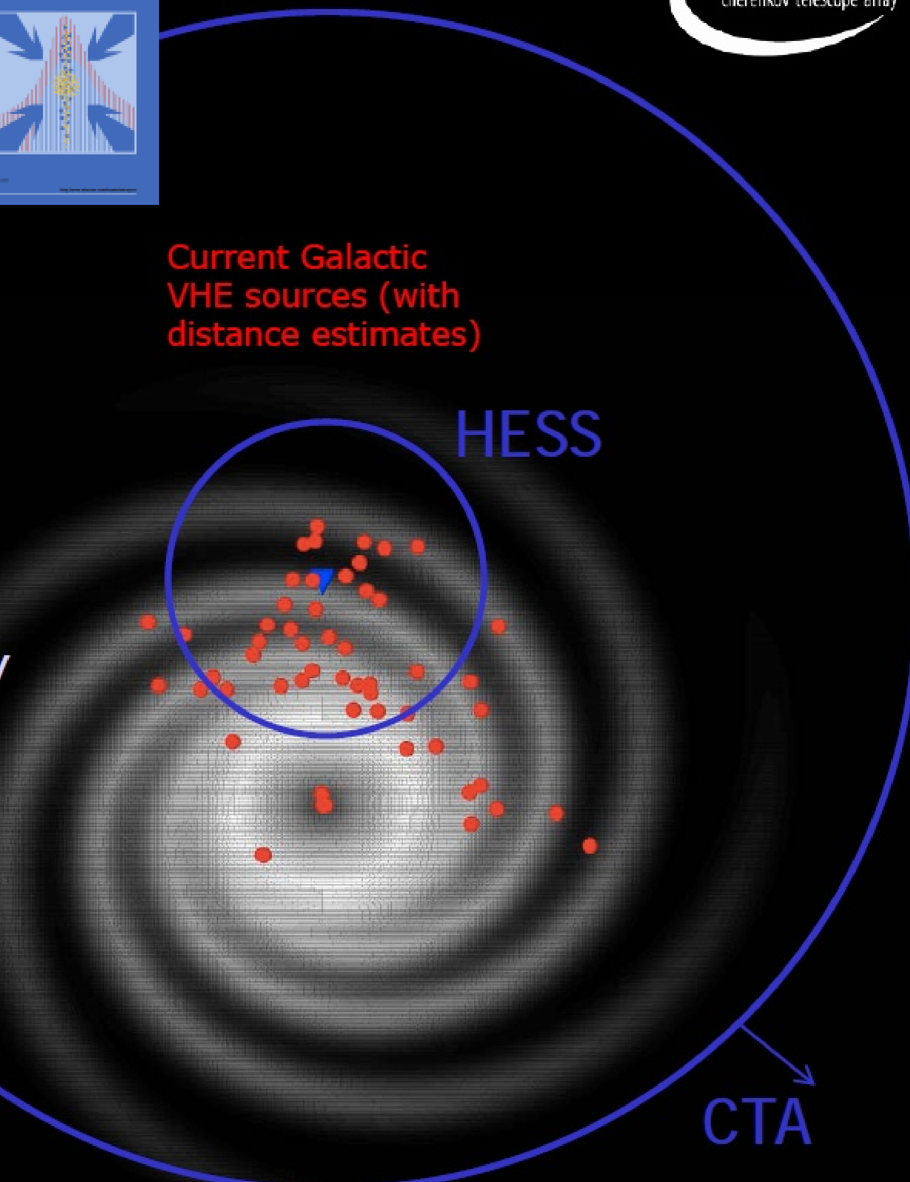
Telescopes		South	North
Small	4-6m	70	
Medium	12m	25	15
Large	23m	4	4

CTA Science



Special Issue Vol 43, Pg 1-356 (Mar 2013)

- e.g. Galactic objects
  - Newly born pulsars and the supernova remnants
    - have typical brightness such that HESS etc can see only relatively local (typically at a few kpc) objects
  - CTA will see **whole** Galaxy
- Survey speed ~300×HESS



Extragalactic

AGN z>0.5, GRBs, Star-bursts, Gal. clusters, AGN haloes..

Astro-particle

Dark matter, Axions, Lorentz invariance....

Optical

Intensity Interferometry

CTA Time-line & Funding

cta
cherenkov telescope array

- Design Study
  - Design development 2006-9
  - CTA appears on *key roadmaps*
- Preparatory Phase > €30M funded
  - EU FP7 funded activity 2010-14
  - Preliminary Design Review 2013
  - Site Selection during 2014
  - Critical Design Rev. early 2015
- Construction Phase
  - Site development and first telescopes on site 2015/16
  - First science 2016/17
  - Completion ~2020
- Operation: aim for 30 years

ASPERA

ASTRONET

ESFRI

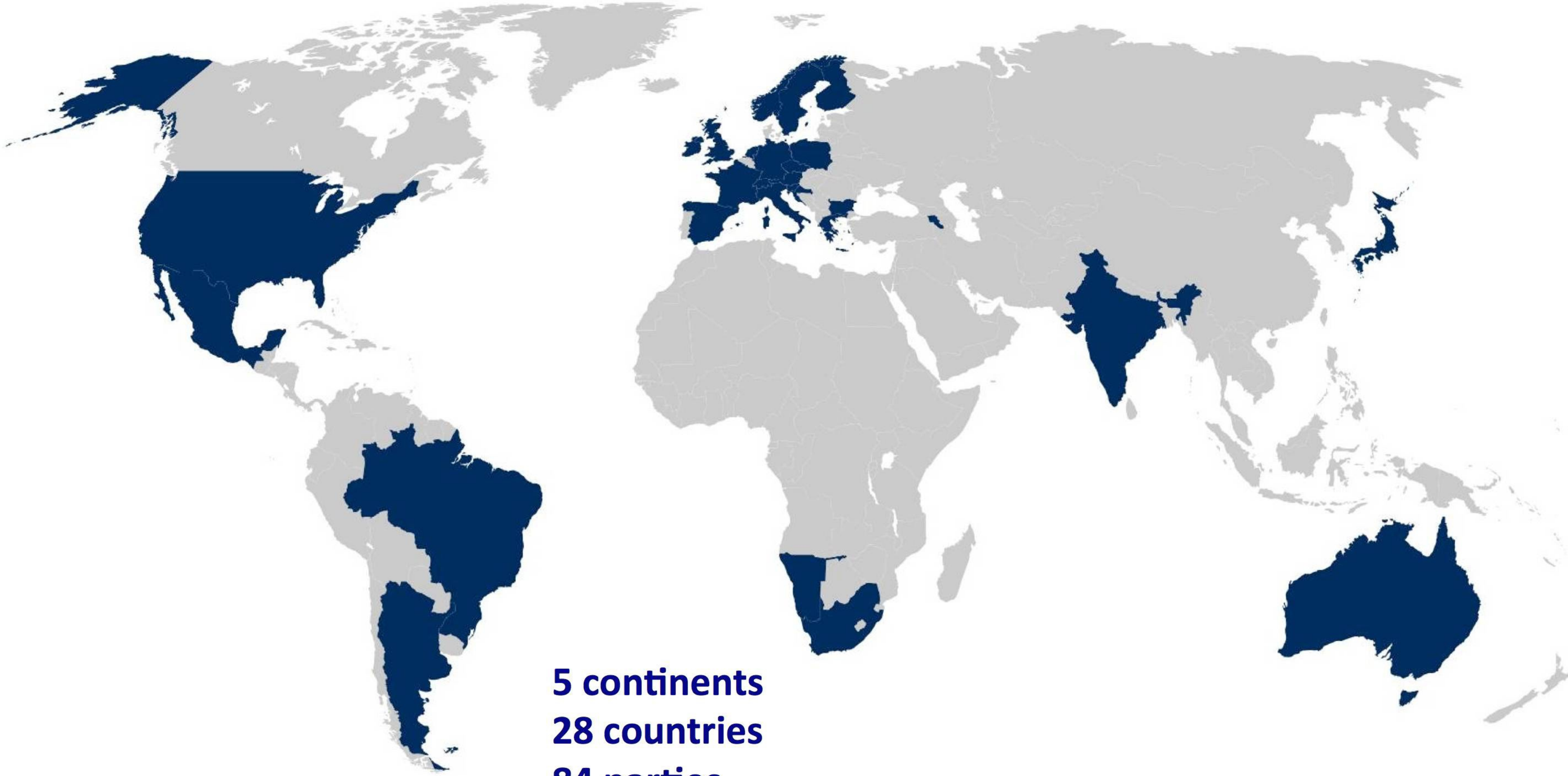
European Strategy Forum on Research Infrastructures

7 April 2014

additional projects which we recommend for support from the Member States and from suitable Horizon 2020 instruments to help reach the Innovation Union target of 60% of projects being in implementation by 2015:

ECCSEL, EISCAT-3D, EMSO, BBMRI, EL, CTA, SKA, CLARIN and DARIAH

CTA Consortium August 2014



5 continents
28 countries
84 parties
173 institutes
1178 members (378 FTE)

CTA – Australia

Six institutes

Institution	Personnel (+ FTE)	Expertise	CTA Work Package(s)
University of Adelaide	Gavin Rowell (0.1), Res.Assoc.[1] (0.1), PhD student[2] (0.1), Bruce Dawson (0.05), Roger Clay (0.1), Neville Wild (technician 0.05), Martin White (0.05), David Ottaway (0.05), Peter Veitch (0.05),	γ-ray, millimetre, CR, neutrino astronomy, astrophysics theory, particle physics, LIDAR systems, atmospheric monitoring, detectors, electronics	MC, PHYS, OBS, ATAC, SITE, FPI
University of New South Wales	Michael Burton (0.1), Catherine Braiding (0.1)	millimetre, sub-millimetre, infrared astronomy, antarctic astronomy	PHYS, ATAC, OBS
University of Sydney	Anne Green (0.05), Sean Farrell (0.05)	radio astronomy	PHYS, OBS
Australian National University	Geoff Bicknell (0.1), Roland Crocker (0.1)	γ-ray, neutrino astrophysics theory	PHYS, OBS
Monash University	Duncan Galloway (0.05), Csaba Balazs (0.05)	X-ray astronomy, particle and astroparticle physics	PHYS, OBS
University of Western Sydney	Miroslav Filipovic (0.05), Nick Tothill (0.05)	γ-ray, X-ray, radio astronomy	PHYS, OBS

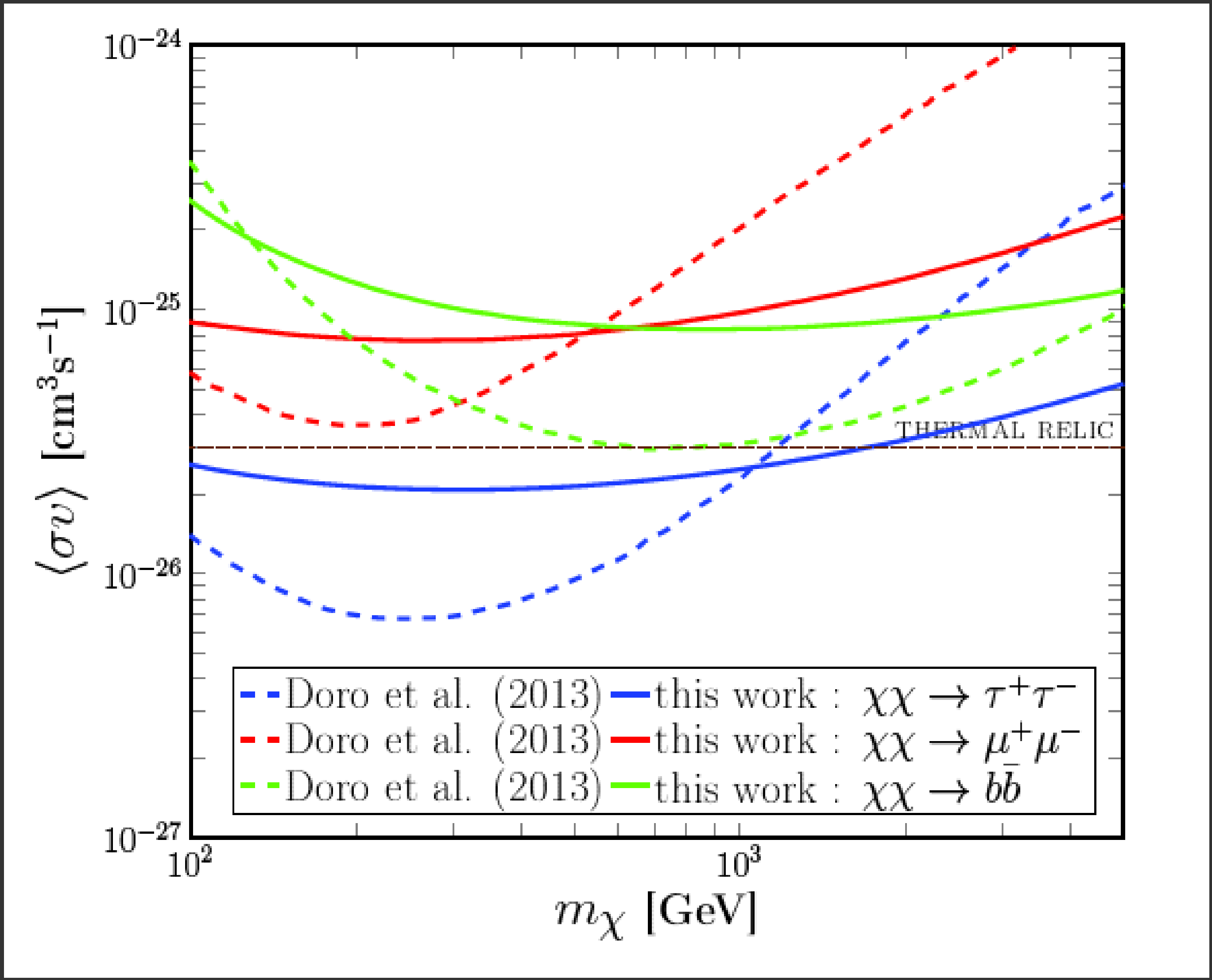
1. Research Associate commencing from Sept. 2013 for $\geq$4 months.
2. Based on current in-kind contributions from 2 PhD students.

Table 1: Australian Consortium for CTA Associated Party Membership. FTE estimates are for 2013+.

- ARC LIEF 2015: First hardware contribution \$550k
  & raise Oz consortium to full member status
- Additional construction costs (LIEF, NCRIS++?, EIF++?) ~ \$1-3M
- Operational cost model under discussion (per person, GDP scaling?)

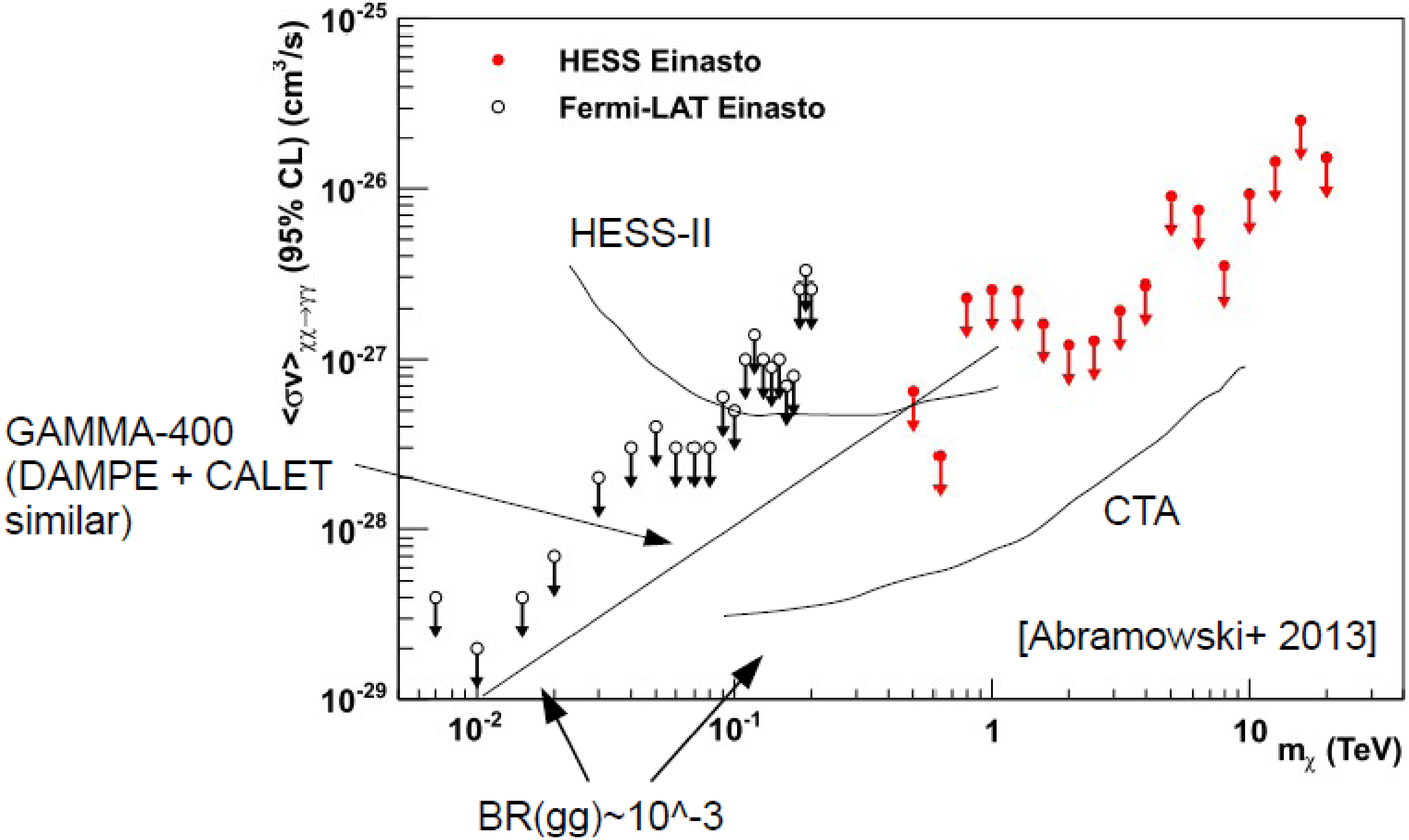
CTA – Effect of Telescope Layout - Galactic Centre 100h

- array E layout (Doro etal 2013) dashed
- array I layout (Pierre etal 2014) solid



Future sensitivities for gamma-ray lines

$\chi\chi \rightarrow \gamma\gamma$

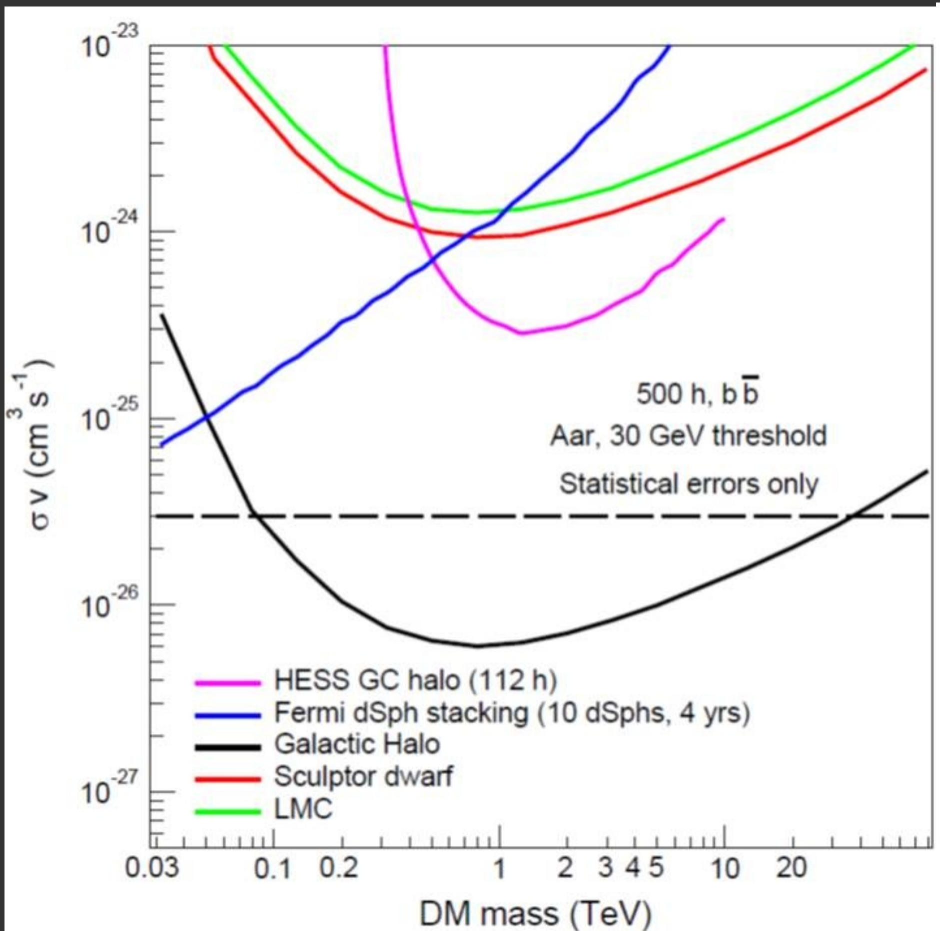


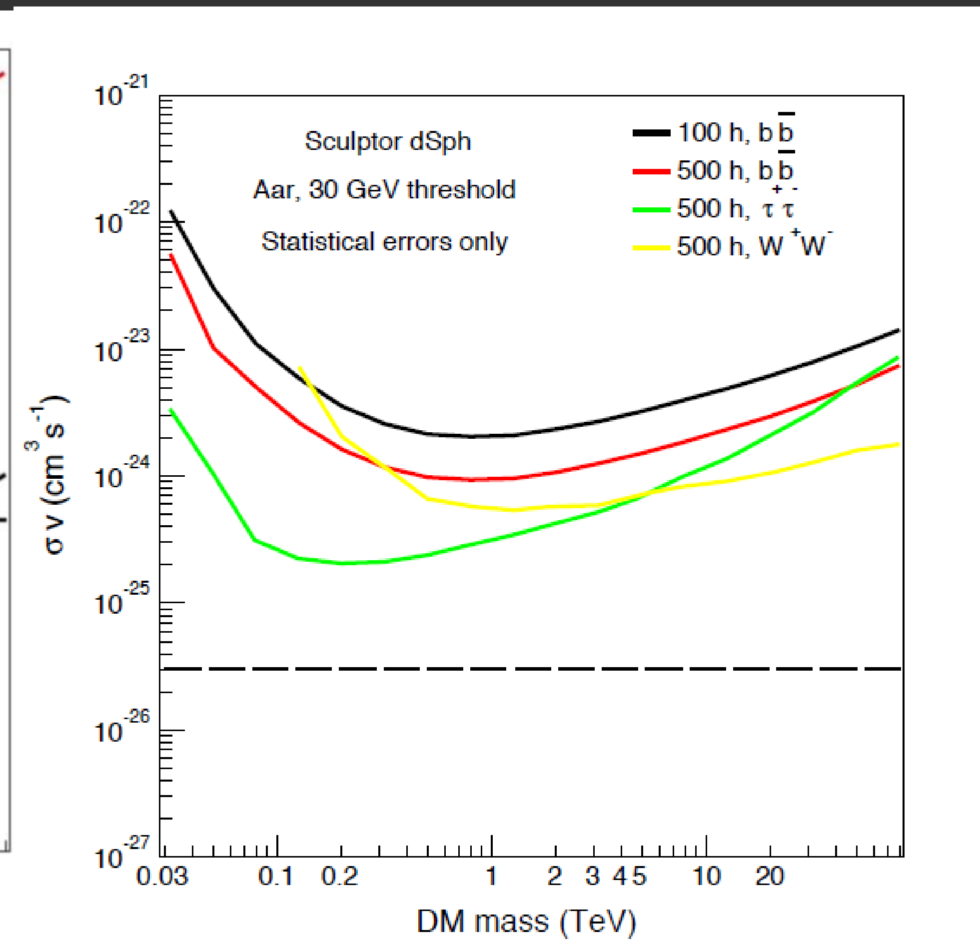
Slide from C. Weniger "Debates on the natue of dark matter" 2014)

CTA: G. Pedaletti, Talk in Trieste Sep 2013
GAMMA-400 & HESS-II: Bergström+ 2012
DAMPE (and CALET) similar to GAMMA-400

CTA – Dark Matter Key Science Programme

CTA Consortium incl C. Balazs (2014) in preparation





Backup

Experiment	Status of claim
DAMA/LIBRA annual modulation[68]	Unexplained at the moment; not confirmed by other experiments [70, 71, 74, 76]
CoGeNT excess events and annual modulation [73]	Tension with other data [70, 71, 74, 76]
CRESST excess events [79]	Tension with other data [70, 71, 74, 76]
EGRET excess of GeV photons [80, 81]	Due to instrument error (?) – not confirmed by Fermi-LAT [82]
INTEGRAL 511 keV γ-line from galactic centre region [83]	Does not seem to have spherical symmetry – shows an asymmetry which follows the disk (?) [84]
PAMELA: Anomalous ratio of cosmic ray positrons/electrons [85]	May be due to DM [86], or pulsars [87] – energy signature not unique for DM
Fermi-LAT positrons + electrons [31]	May be due to DM [86], or pulsars [87] – energy signature not unique for DM
Fermi-LAT GeV γ-ray excess towards galactic centre [88]	Unexplained at the moment – astrophysical explanations possible [89, 90], no statement from the Fermi-LAT collaboration
WMAP radio "haze" [91]	Has a correspondence in "Fermi bubbles" [92] – probably caused by outflow from the galactic centre
γ-ray structure [93] in public Fermi-LAT data [94] from galaxy clusters.	Very weak indication, could be cosmic-ray induced emission?
γ line at 130 GeV [95, 96, 97] in Fermi-LAT public data [94]	$3.3\sigma - 4.6\sigma$ effect, unexplained at the moment. Not confirmed by the Fermi-LAT collaboration [98].

Table 1: Some of the recent experimental claims for possible dark matter detection, and a comment on the present status.

Bergstrom 2012 arXiv:1205.4882
See also: Porter etal 2011 Ann. Rev. Astron. Astrophys. 49, 155
Bringmann, Weniger 2012 arXiv:1208.5481

CTA – Example Telescope Layouts

Bernlohr etal 2013

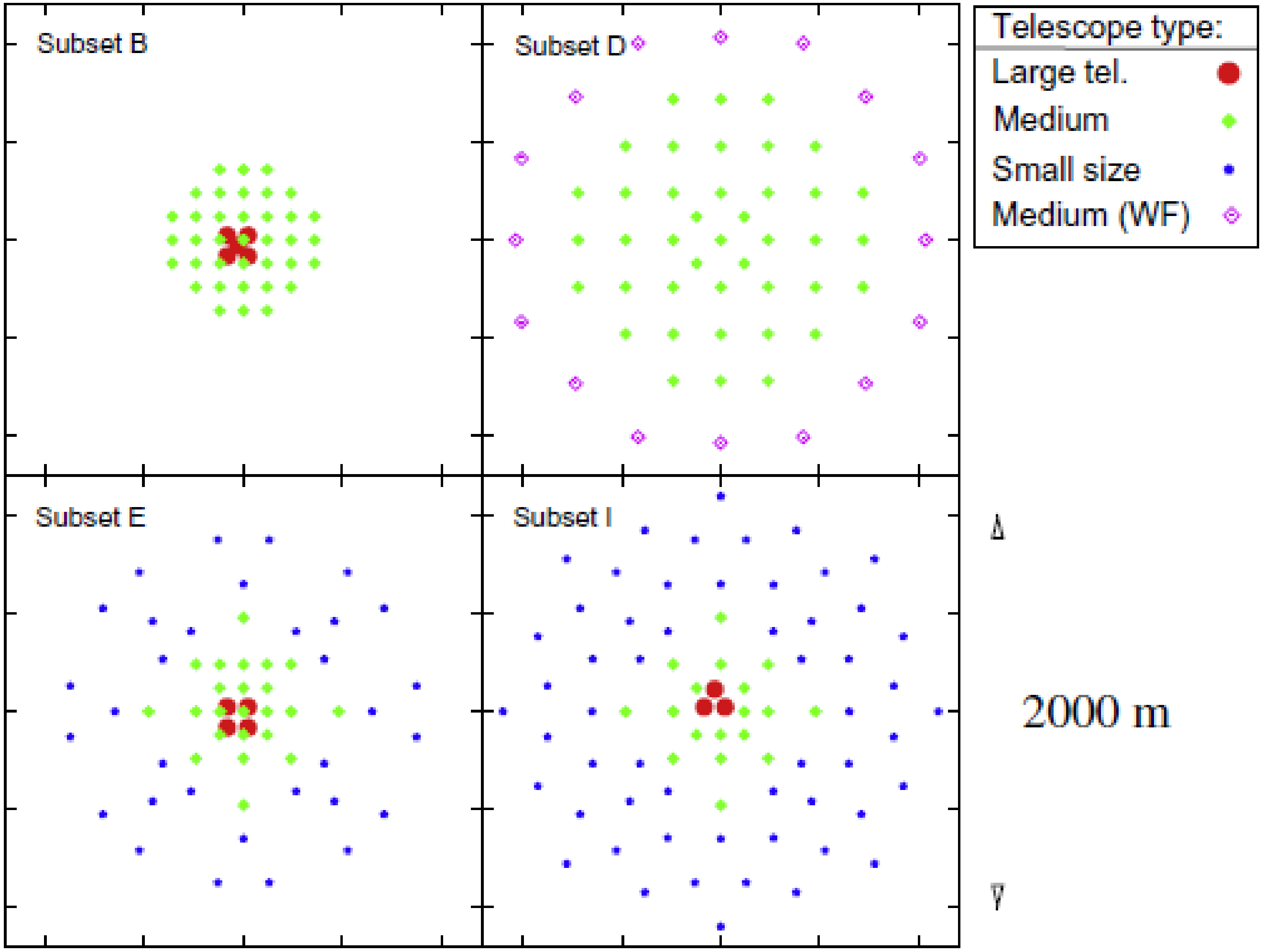
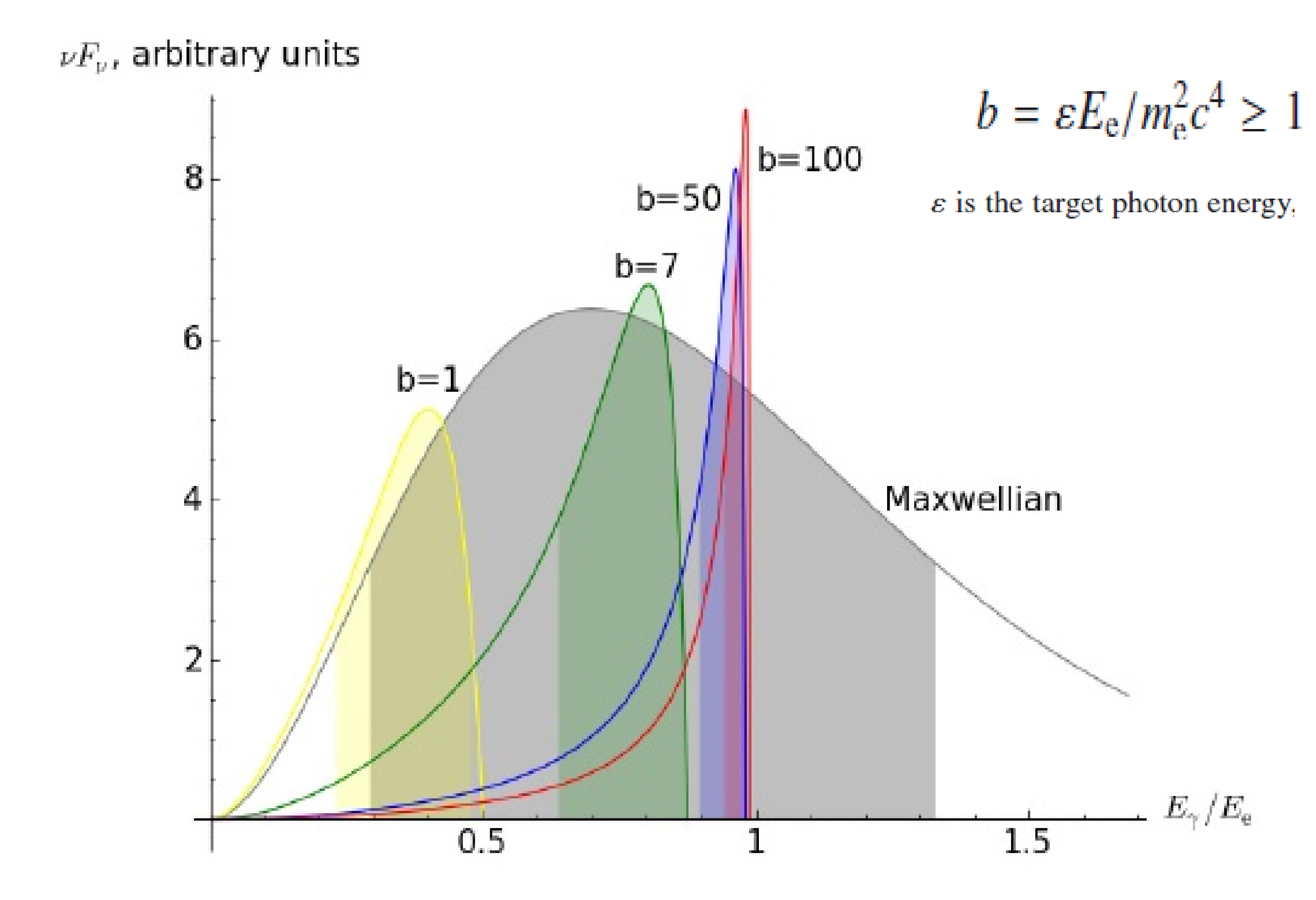


Fig. 7. Layout examples for a compact array layout (B), an extended layout without LSTs (D), as well as two balanced layouts (E and I).

Gamma-ray 'Line' Astrophysical Origin?

e.g. Deep Klein-Nishina inverse-Compton scattering by cold pulsar wind electrons (~monoenergetic) Aharonian eta 2012

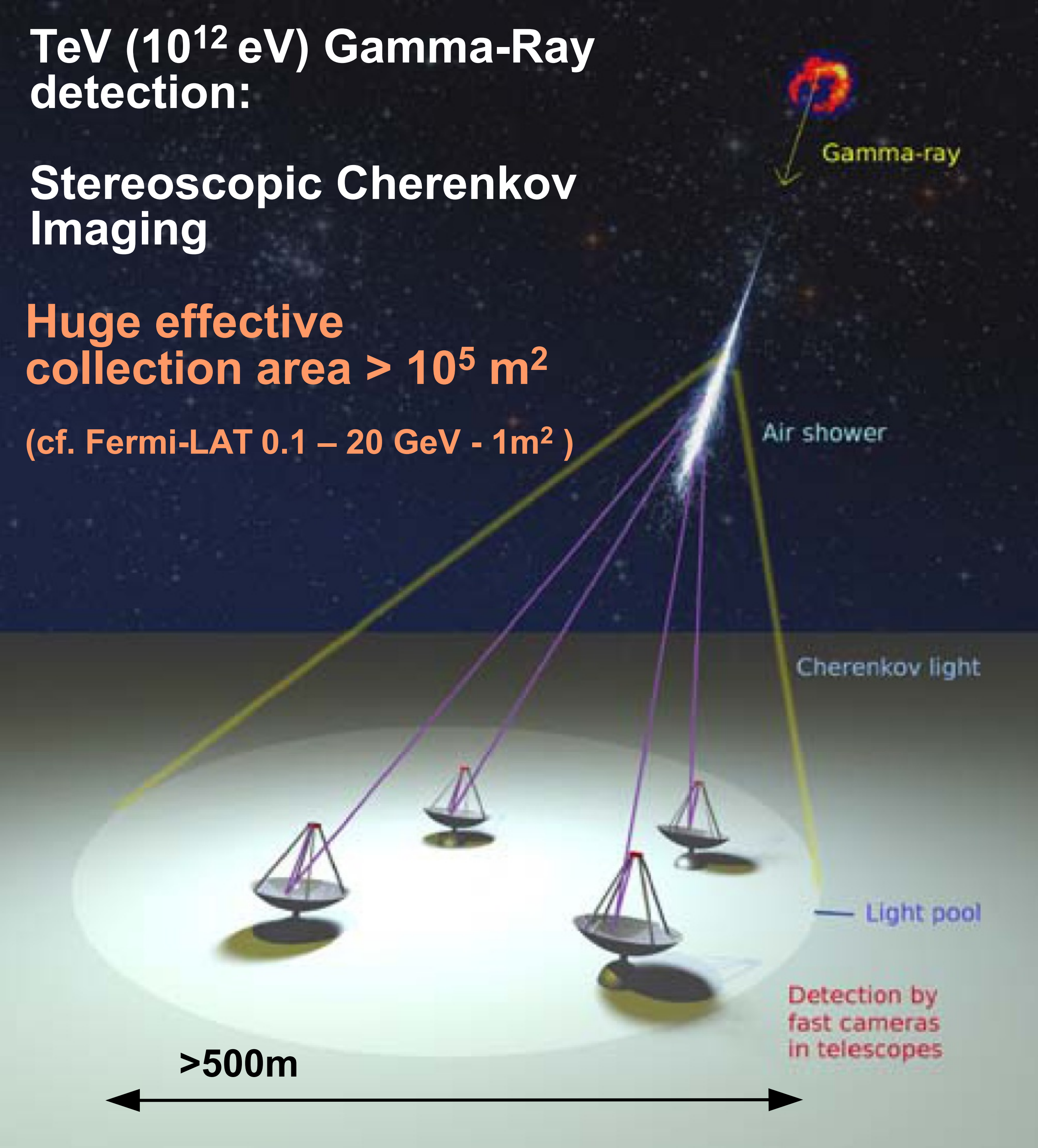


TeV (10^{12} eV) Gamma-Ray detection:

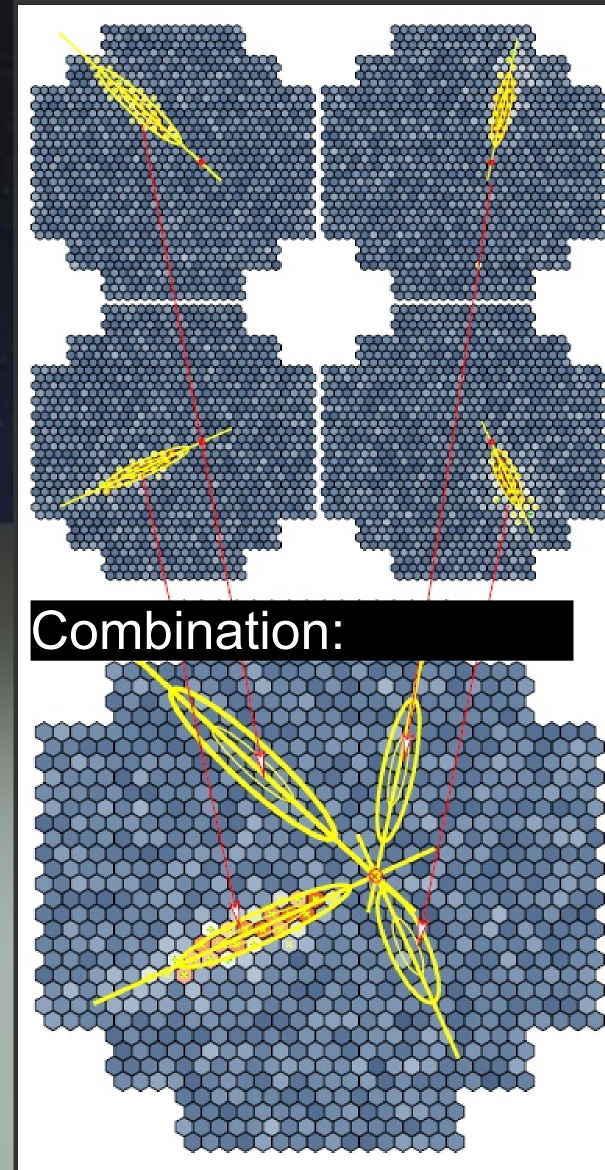
Stereoscopic Cherenkov Imaging

Huge effective collection area > 10^5 m^2

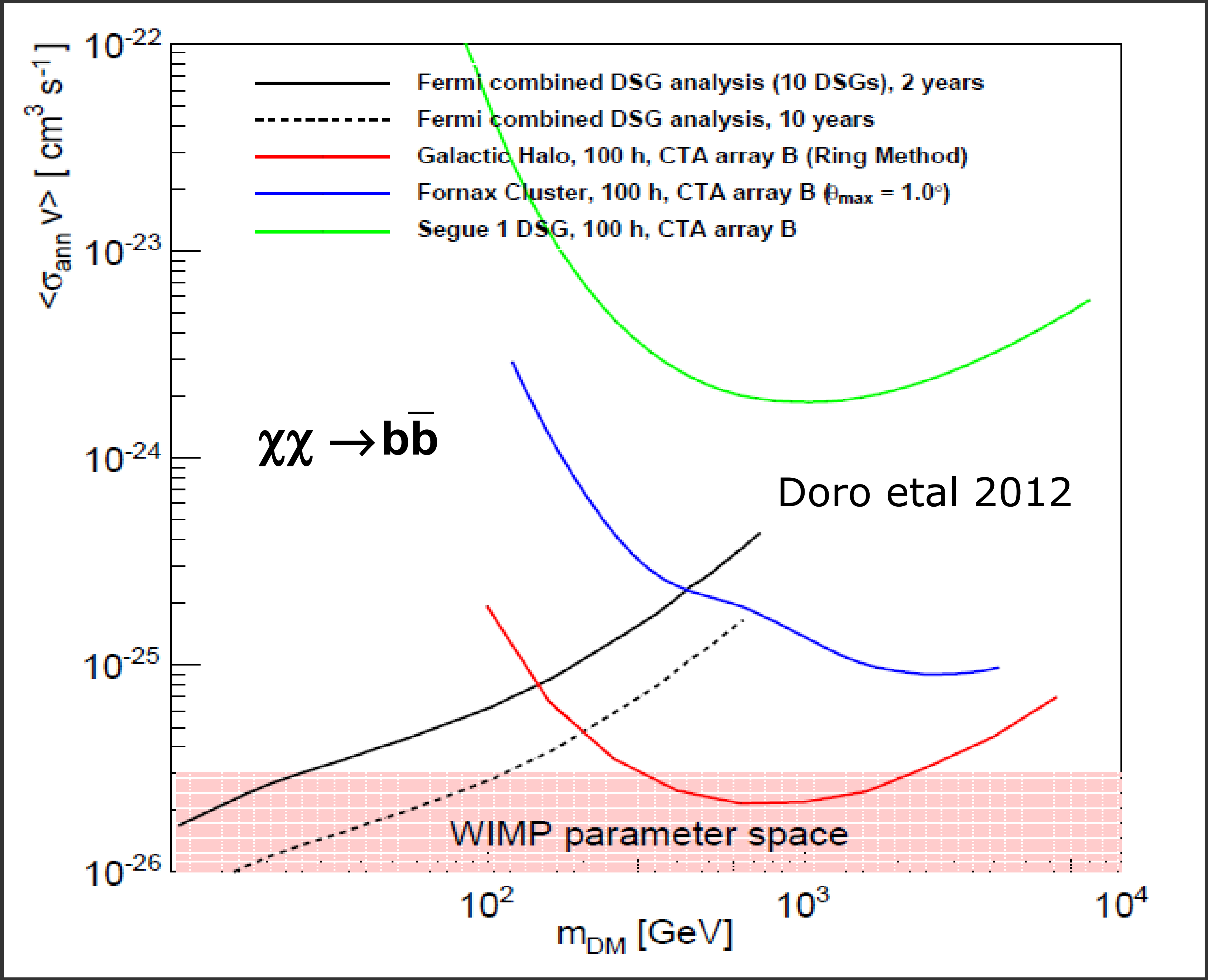
(cf. Fermi-LAT 0.1 – 20 GeV - $1 m^2$)



Cherenkov 'image' as viewed by each telescope



Example Outlook for CTA.... (array B)



CR Diffusion *Into* Molecular Clouds

Gabici etal 2007

R = distance CR travels into molecular cloud core

$$R = 0.62 - \sqrt{6D(E_P, B)[1600 - t_0]} \quad [\mathrm{pc}]$$

$$D(E_P, B(r)) = \chi D_0 \left(\frac{E_P/\mathrm{GeV}}{B/3\,\mu\mathrm{G}} \right)^{0.5} \quad [\mathrm{cm}^2\,\mathrm{s}^{-1}],$$

$$B(n_{H_2}) \sim 100 \sqrt{\frac{n_{H_2}}{10^4\ \mathrm{cm}^{-3}}} \quad [\mu\mathrm{G}]$$

χ=diffusion suppression

→ Low energy CRs can't reach cloud core
→ Expect harder TeV spectra from cores.
→ GeV cutoffs in energy specra
→ Don't expect electrons to penetrate!!
(due to sync. losses)

→ Need to map dense cloud cores