SEARCHES OF DARK MATTER WITH TEV GAMMA-RAYS AND CTA

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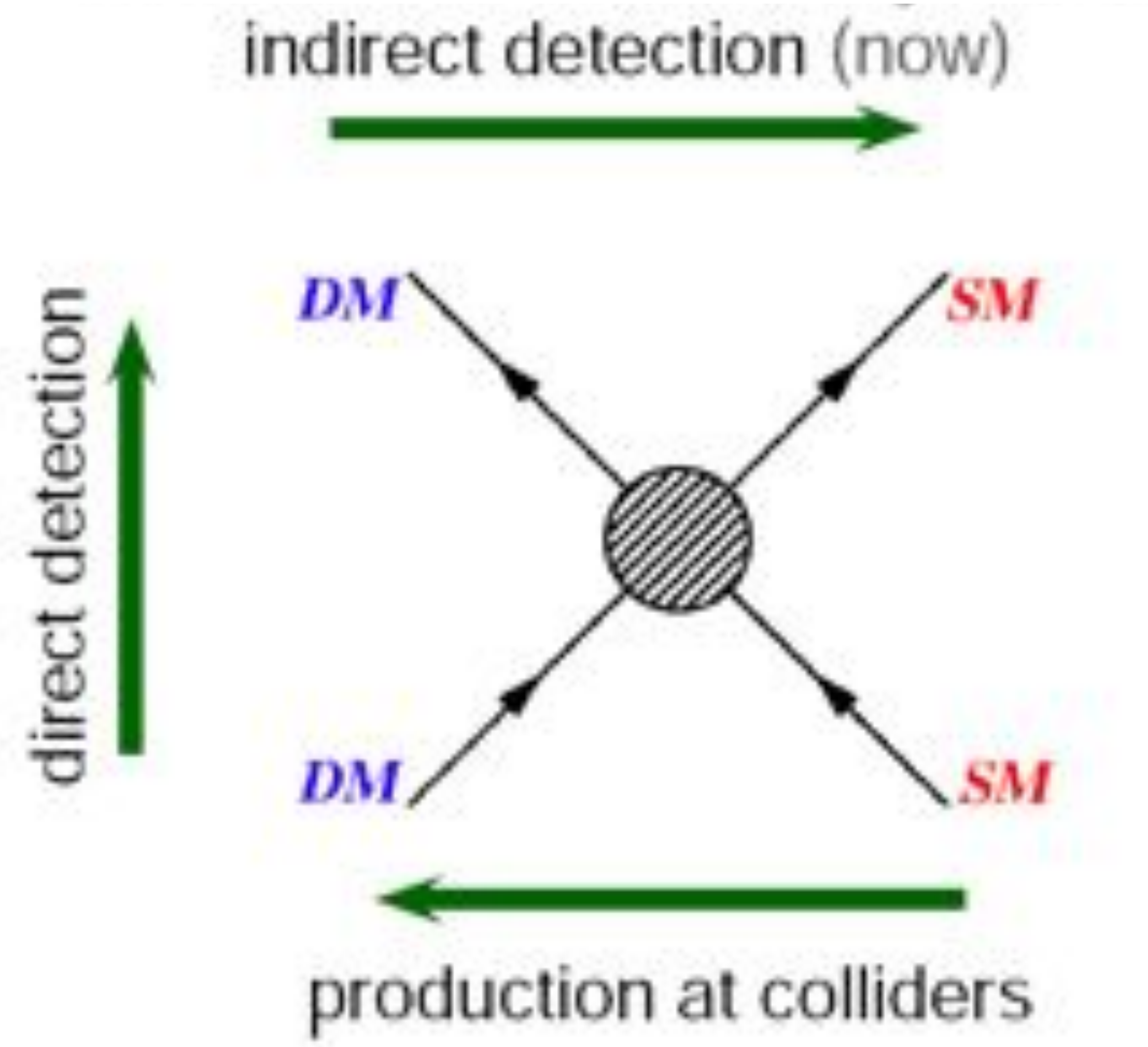
Strategy Workshop for AstroParticle in Switzerland, 2014/06/11-13

cta
cherenkov telescope array

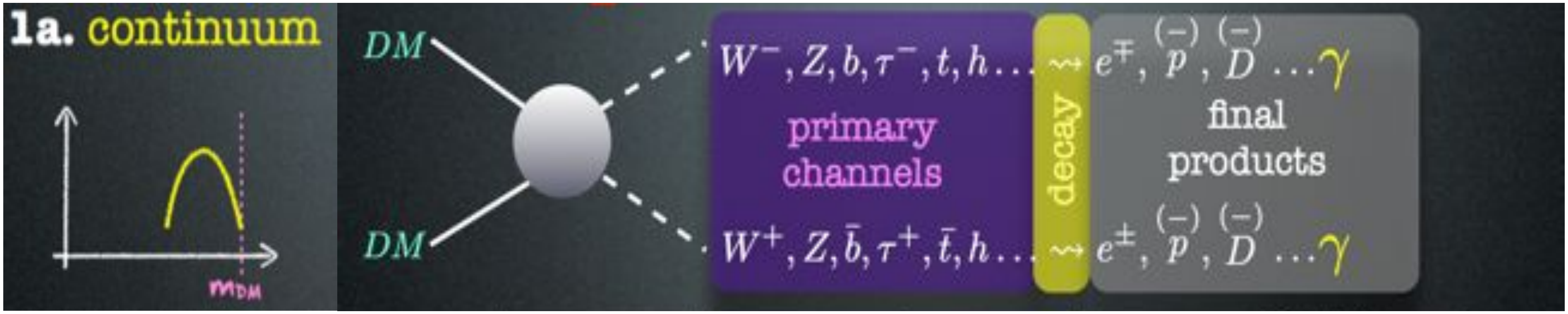
WHY GAMMA-RAYS ARE IMPORTANT

(for DM searches)

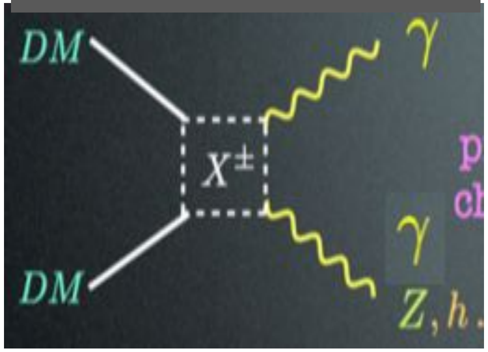
Three ways to rule them all



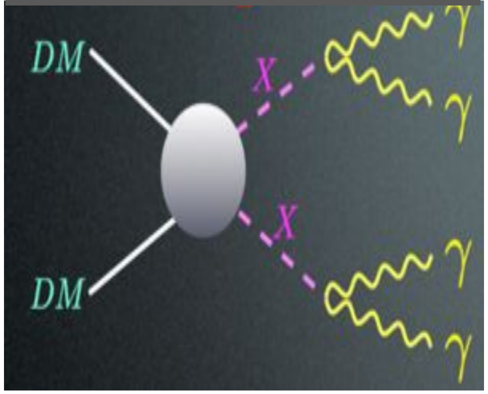
Gammas in the final products

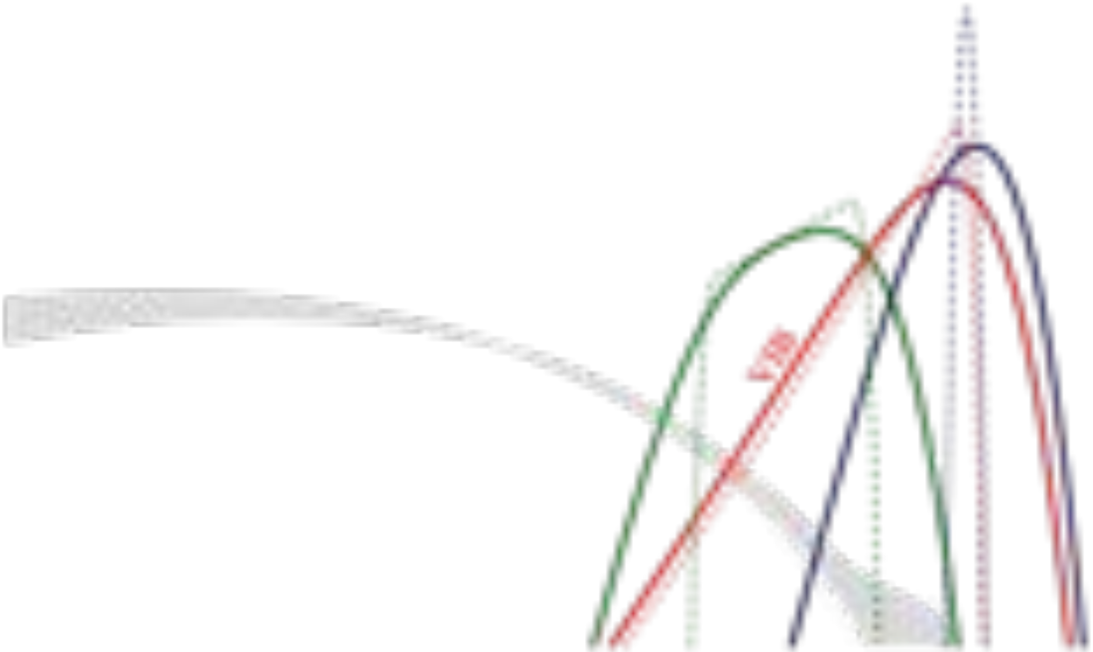


2. Lines



3. Other features





Gamma rays provide smoking gun

- **Universal**: they do not depend on the target
- **Peculiar features**: clearly identifiable (but: energy resolution)
- Gamma-ray are **neutral**: we can point the telescope where we know DM is
- **Identification** of dark matter with gamma rays is possible (besides detection!)
  - Measurement of dark matter mass
  - Measurement of dark matter nature

Worth fighting for!

Flux at the earth

Annihilation

Rico 2013

Kolb 2013

Particle Dark Matter Taxonomy

• neutrinos (WIMPs exist!!!)	(hot)		thermal relics or decay of or oscillation from thermal relics
• sterile neutrinos, gravitini	(warm)		thermal relics or decay of or oscillation from thermal relics
• Lightest supersymmetric particle	(cold)		thermal relics or decay of or oscillation from thermal relics
• Lightest Kaluza-Klein particle	(cold)		thermal relics or decay of or oscillation from thermal relics
• Bose-Einstein condensates		coherent state of a scalar field	nonthermal relics
• axions, axion clusters		coherent state of a scalar field	nonthermal relics
• solitons (Q-balls, B-balls, …)		coherent state of a scalar field	nonthermal relics
• supermassive wimpzillas		from inflation	nonthermal relics

Mass

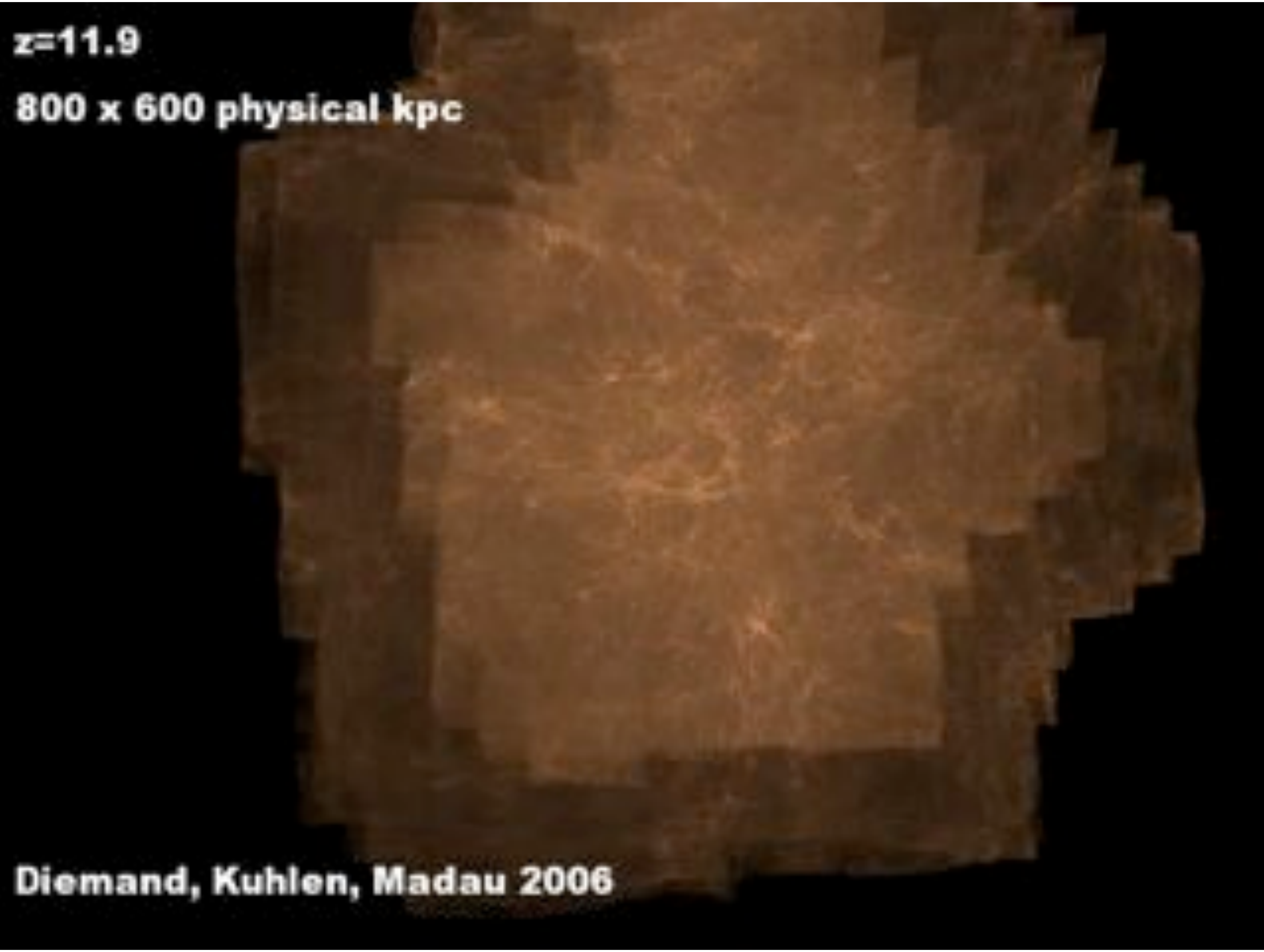
10^{-22} eV (10^{-56} g) Bose-Einstein

$10^{-8} M_{\odot}$ (10^{+25} g) axion clusters

Interaction Strength

only gravitational: wimpzillas

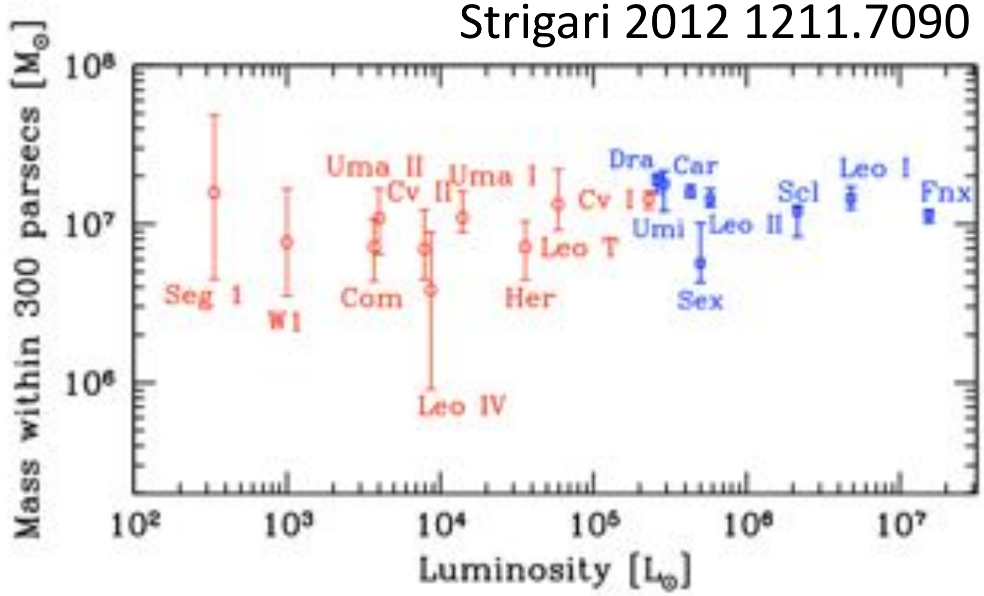
strongly interacting: B balls


z=11.9
800 x 600 physical kpc
Diemand, Kuhlen, Madau 2006

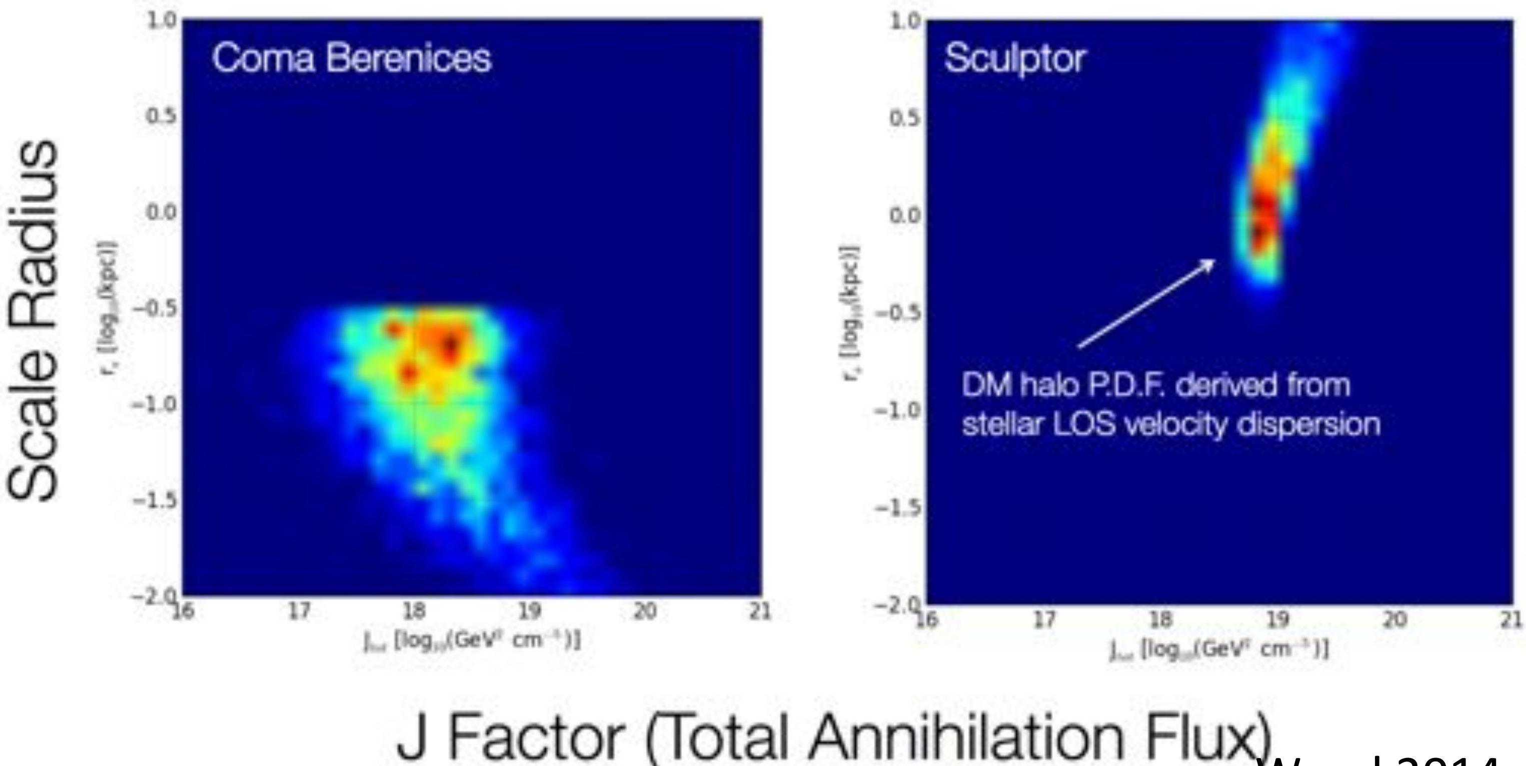
Astrophysical factor

- Uncertainties about factor 10
- Core/cups is less an issue for IACTs

Strigari 2012 1211.7090

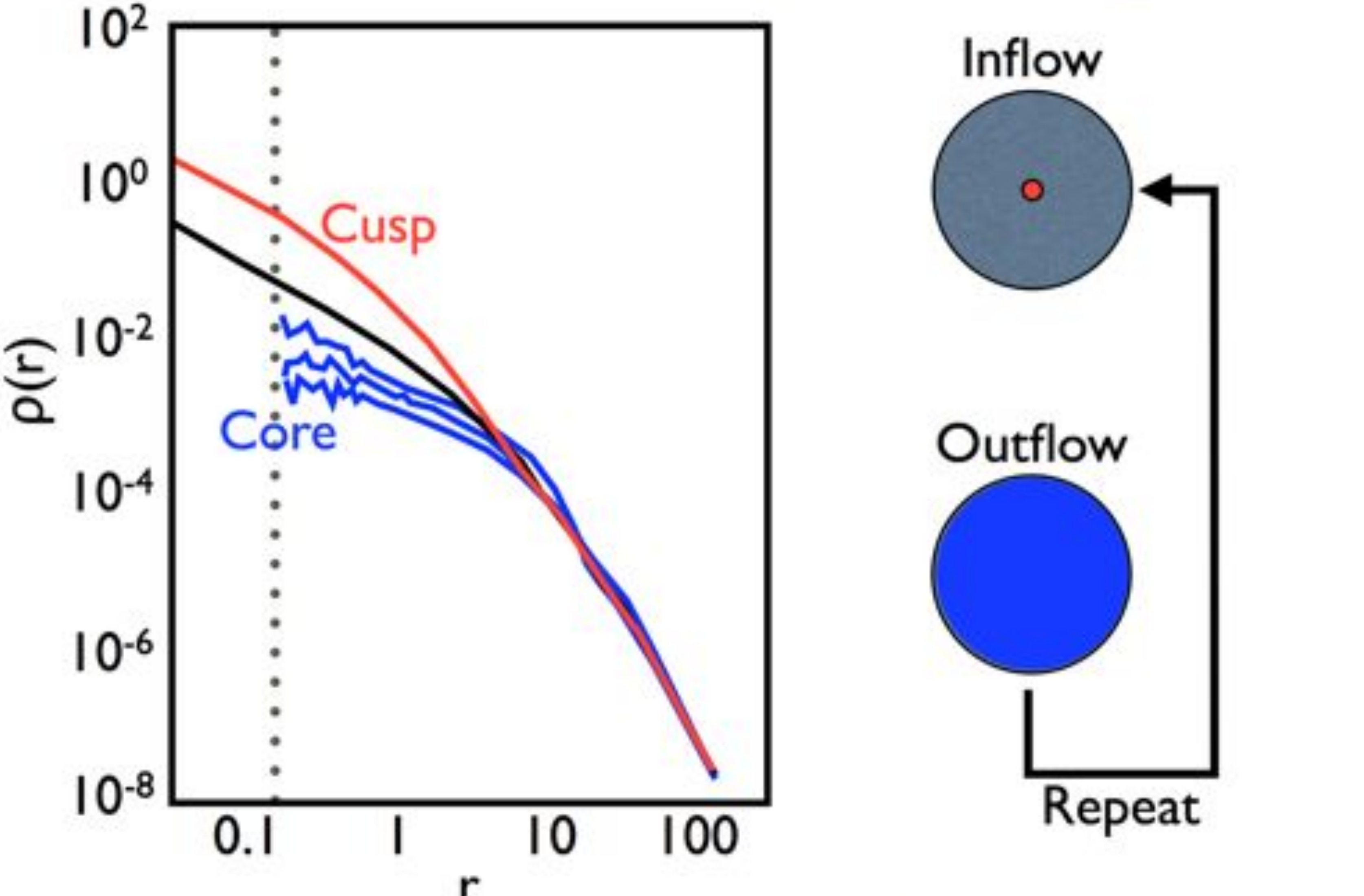


DM Halo Constraints



Wood 2014

Core and cusp/ baryons



Read & Gilmore 2005; Navarro et al. 1996

J. Read. Nordita Conference. Stockholm 2014

HESS, MAGIC AND VERITAS

Current telescopes

Current major IACT experiments

Array 2 telescopes
17m diameters
2200 m asl
>2004

VERITAS (Arizona, USA)

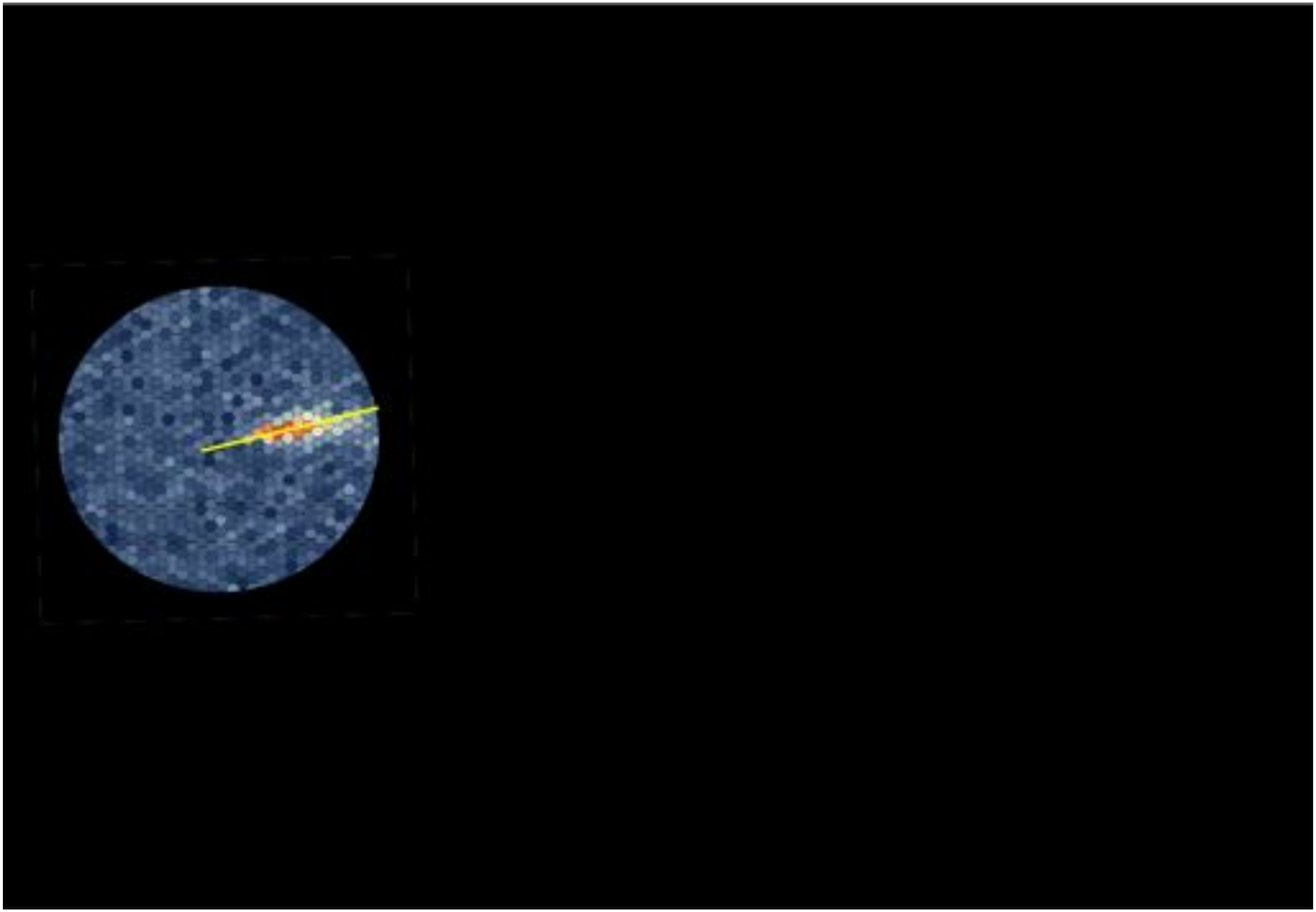
Array 4 telescopes of 12m diam.
Central mast mounting
1800 m asl
>2007

HESS (Namibia)

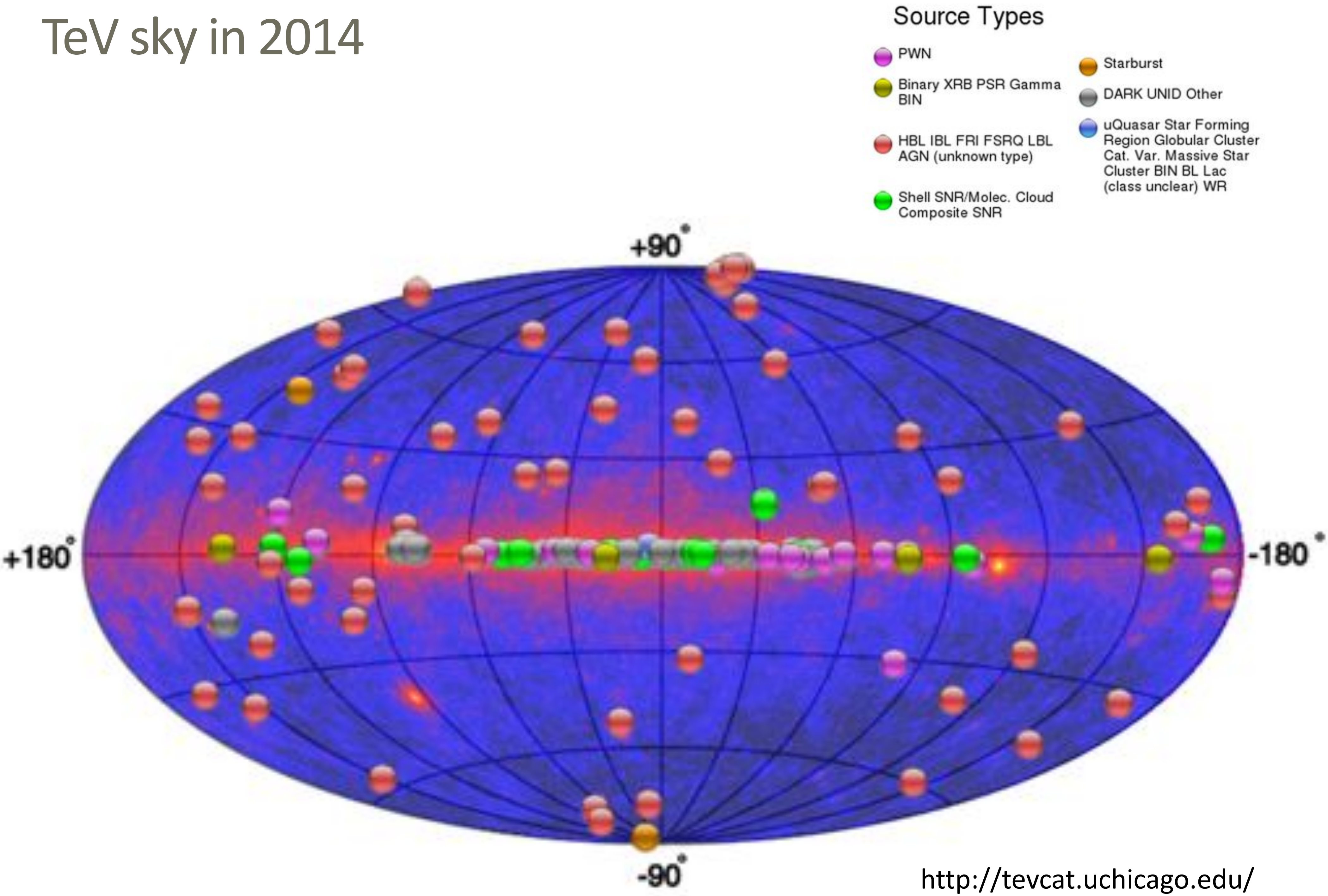
HESS I: Array 4 tel. of 12m
HESS II: 28m diameter (2013)
1800 m asl
> 2003

Cherenkov Telescope Array (CTA)

The IACT technique



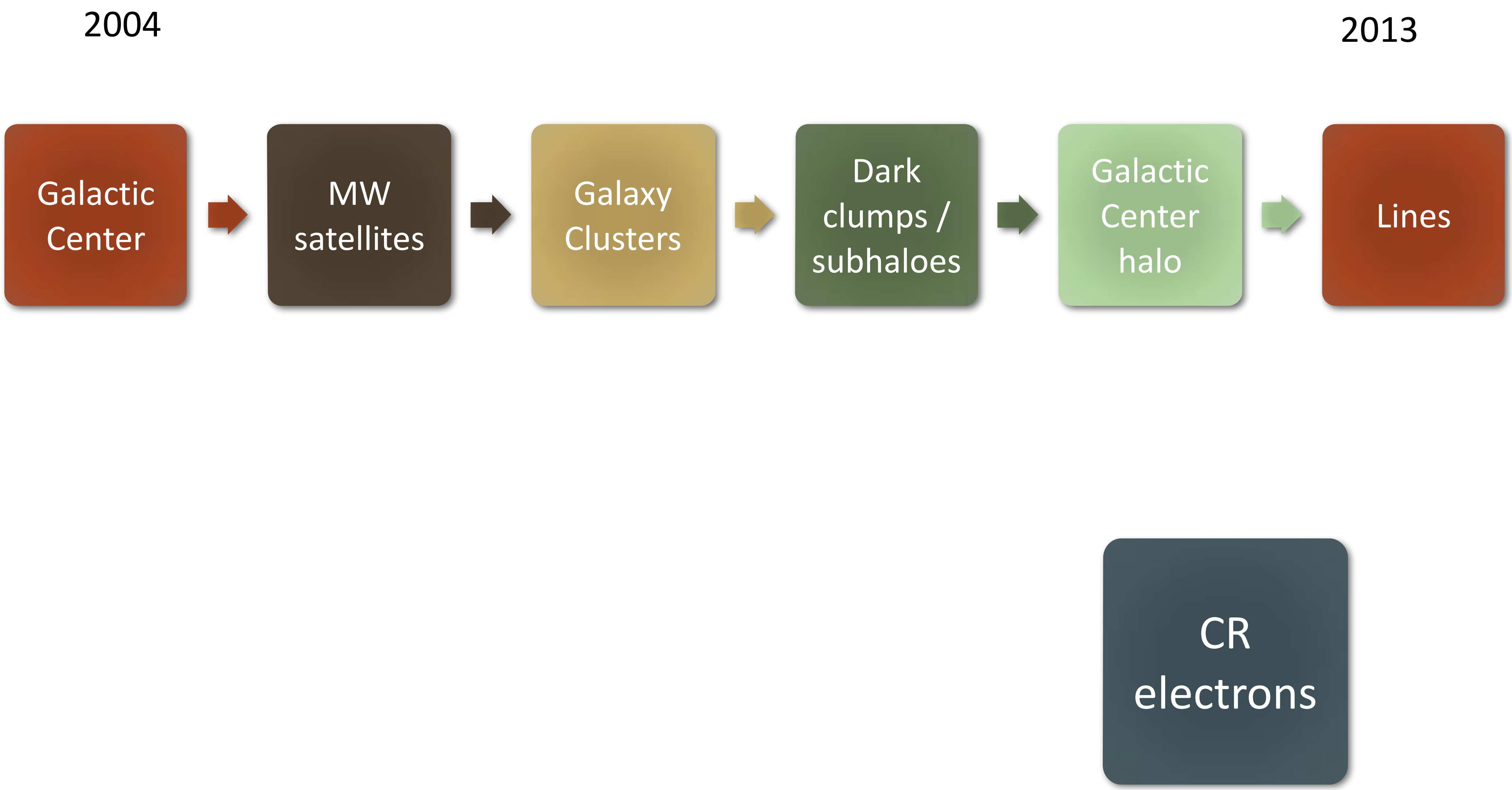
TeV sky in 2014



http://tevcat.uchicago.edu/

DARK MATTER SEARCHES

(approx.) History of a hunt



Our dark "catalog"!

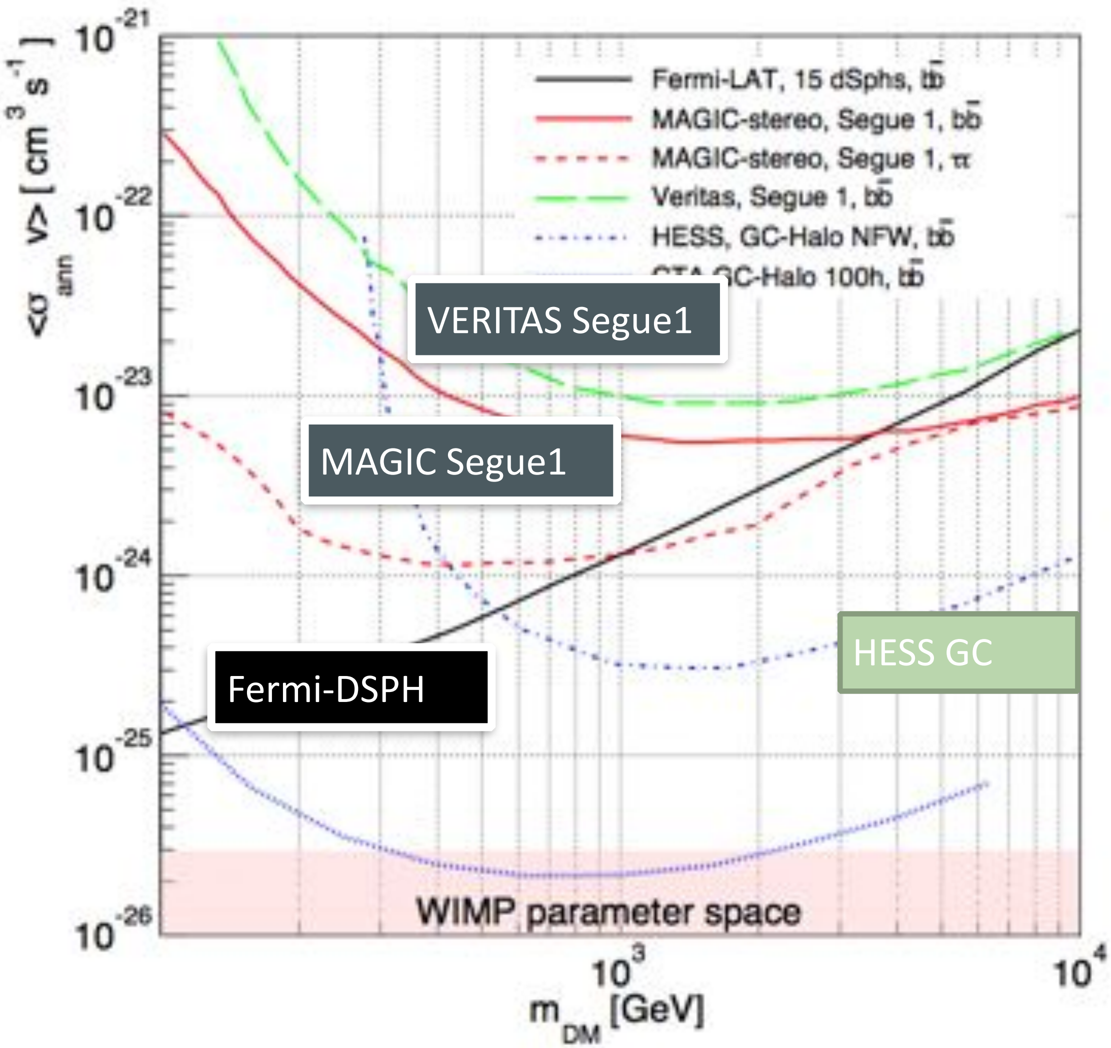
- Several target classes, tens of sources, hundreds hour observation
- No hint so far… shall we stop? *See next slides*

Target	Year	Time	Experiment
Globular Clusters			
M15	2002	0.2	Whipple
	2006–2007	15.2	H.E.S.S.
M33	2002–2004	7.9	Whipple
M32	2004	6.9	Whipple
NGC 6388	2008–2009	27.2	H.E.S.S.
Dwarf Satellite Galaxies			
Draco	2003	7.4	Whipple
	2007	7.8	MAGIC
	2007	18.4	VERITAS
Ursa Minor	2003	7.9	Vhipple
	2007	18.9	VERITAS
Sagittarius	2006	11	H.E.S.S.
Canis Major	2006	9.6	H.E.S.S.
Willman 1	2007–2008	13.7	VERITAS
	2008	15.5	MAGIC
Sculptor	2008	11.8	H.E.S.S.
Carina	2008–2009	14.8	H.E.S.S.
Segue 1	2008–2009	29.4	MAGIC
	2010–2011	48	VERITAS
	2010–2013	158	MAGIC
Boötes	2009	14.3	VERITAS

Target	Year	Time	Experiment
Galaxy Clusters			
Abell 2029	2003–2004	6	Whipple
Perseus	2004–2005	13.5	Whipple
	2008	24.4	MAGIC
Fornax	2005	14.5	H.E.S.S.
Coma	2008	18.6	VERITAS
The Milky Way central region			
MW Center	2004	48.7	H.E.S.S.
MW Center Halo	2004–2008	112	H.E.S.S.
Other searches			
IMBH	2004–2007	400	H.E.S.S.
	2006–2007	25	MAGIC
Lines	2004–2008	112	H.E.S.S.
	2010–2013	158	MAGIC
UFOs	–	–	MAGIC
	–	–	VERITAS
All-electron	2004–2007	239	H.E.S.S.
	2009–2010	14	MAGIC
Moon-shadow	–	–	MAGIC

Doro, NIM A742 (2014) 99

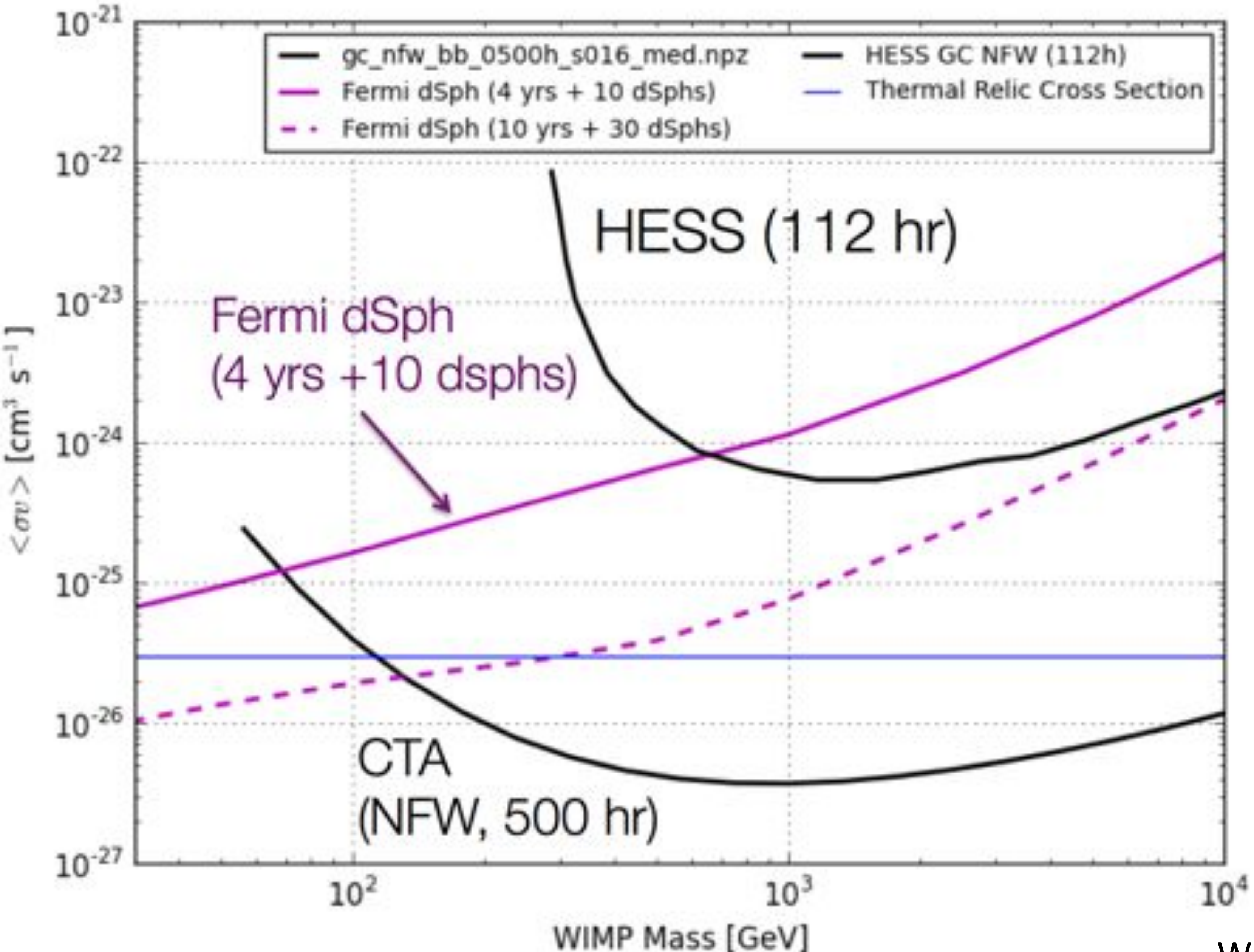
Where are we now



Doro, NIM A742 (2014) 99

- Fermi is more sensitive below few hundreds GeV
- Observation at dSph needs large boost factor for detection
- Galactic Center observation are promising
- *Are we close or far?*

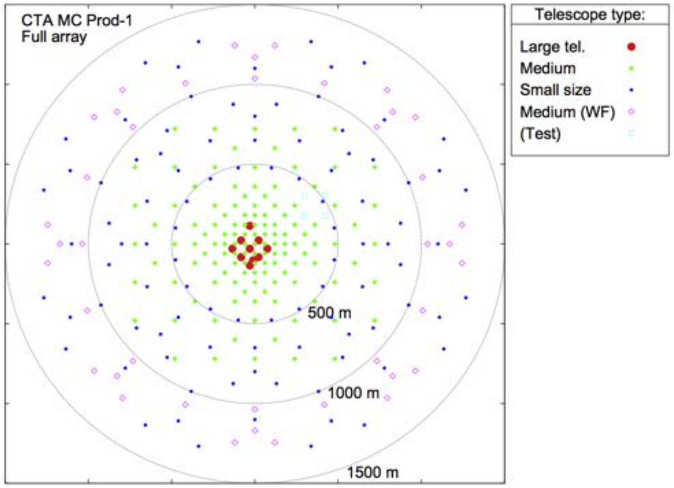
CTA: where we are headed



Wood 2014

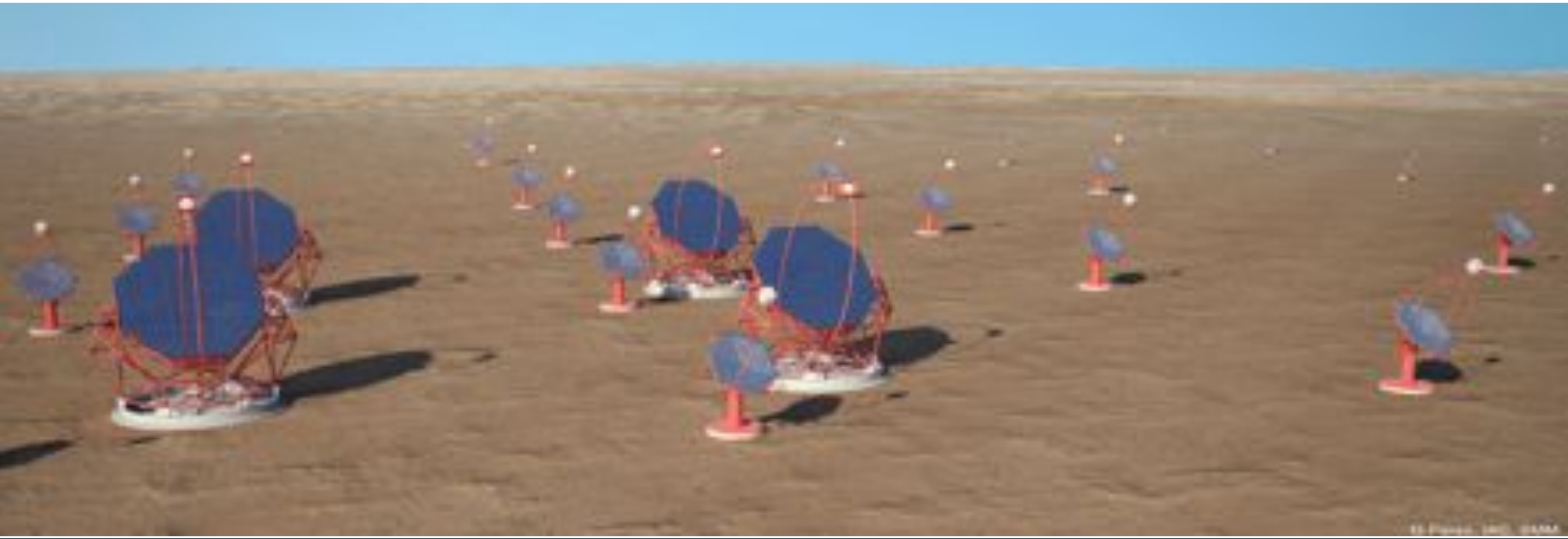
WHAT IS CTA?

Cherenkov Telescope Array

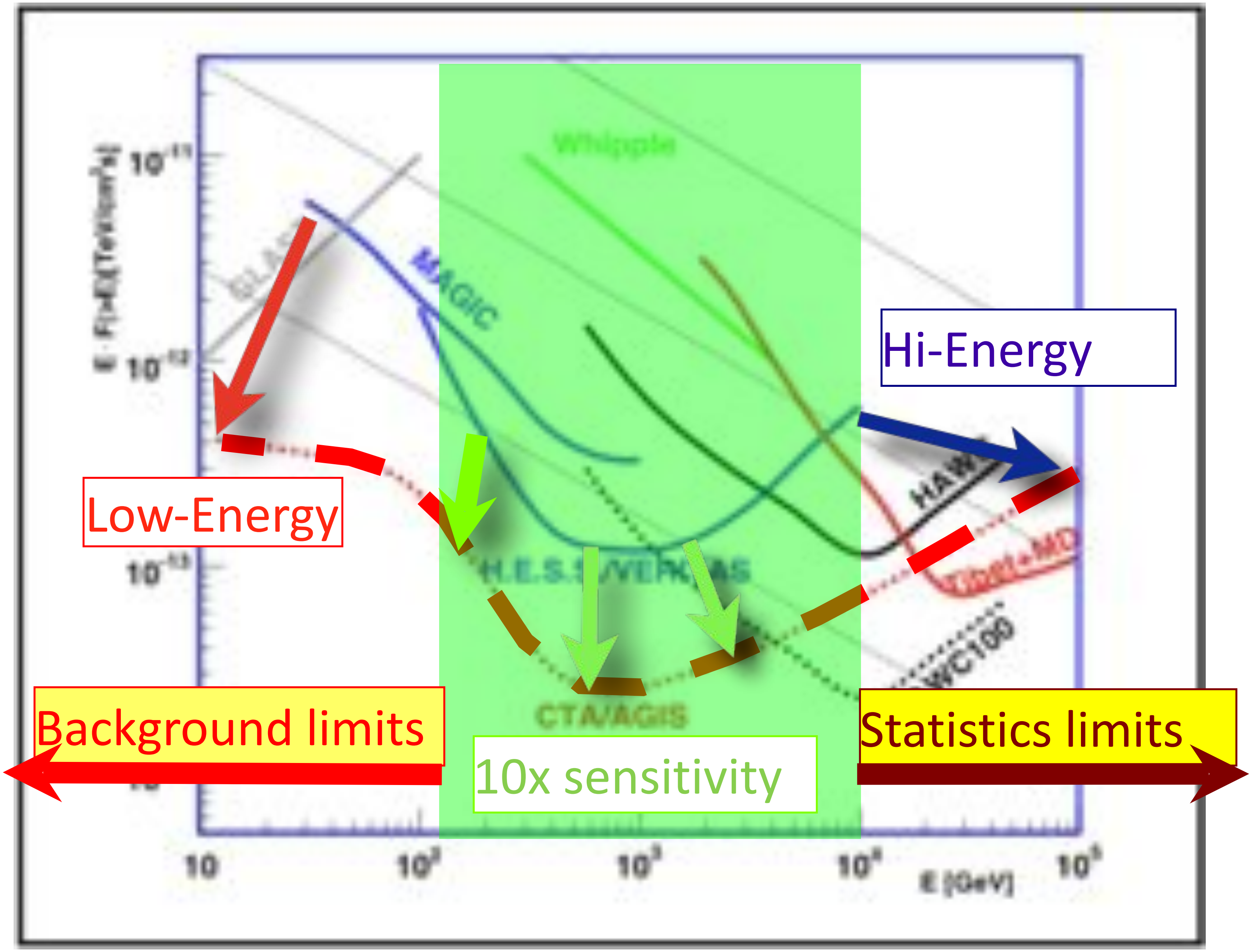


- A project for a new generation of Cherenkov Telescopes
- Gamma-ray precision astronomy and astrophysics from **few tens of GeV to >100 TeV**
- **Two sites**: one Southern and one Northern
- **Hundred telescopes** in total

http://www.cta-observatory.org/

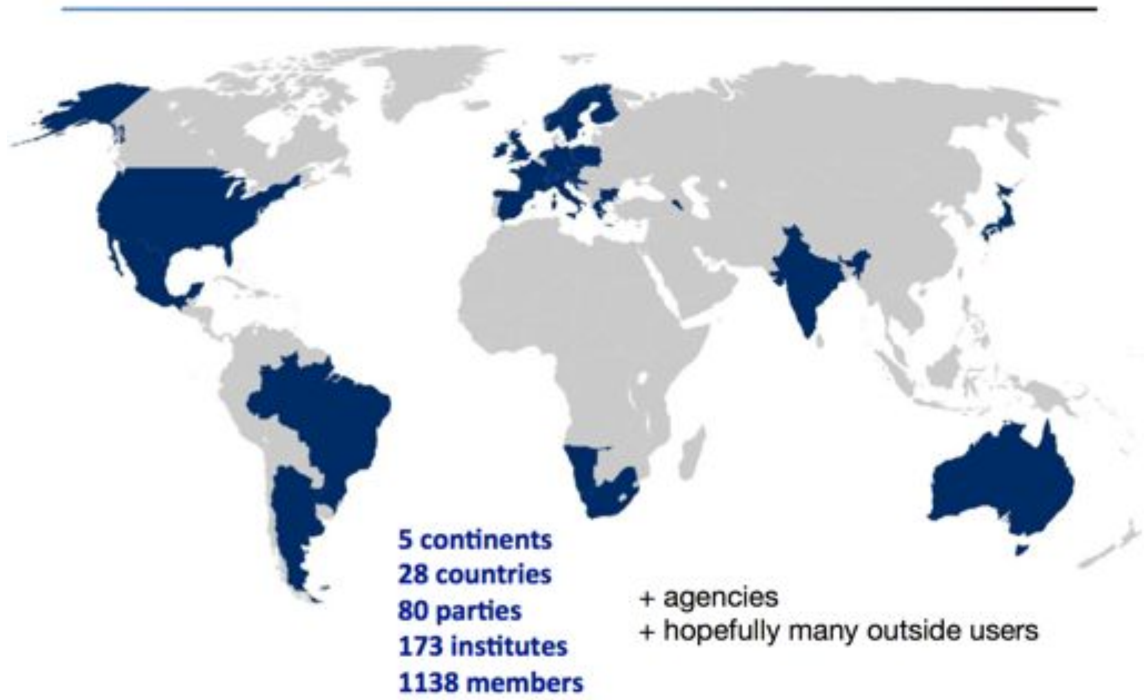


CTA sensitivity runs on 3 regimes (sketch)



A collaboration that grows

* HESS+MAGIC+VERITAS merged
* New communities joined
* Worldwide interest
* About 170 institutes, 28 countries (1100 scientists)
* Regular meetings since 2007.

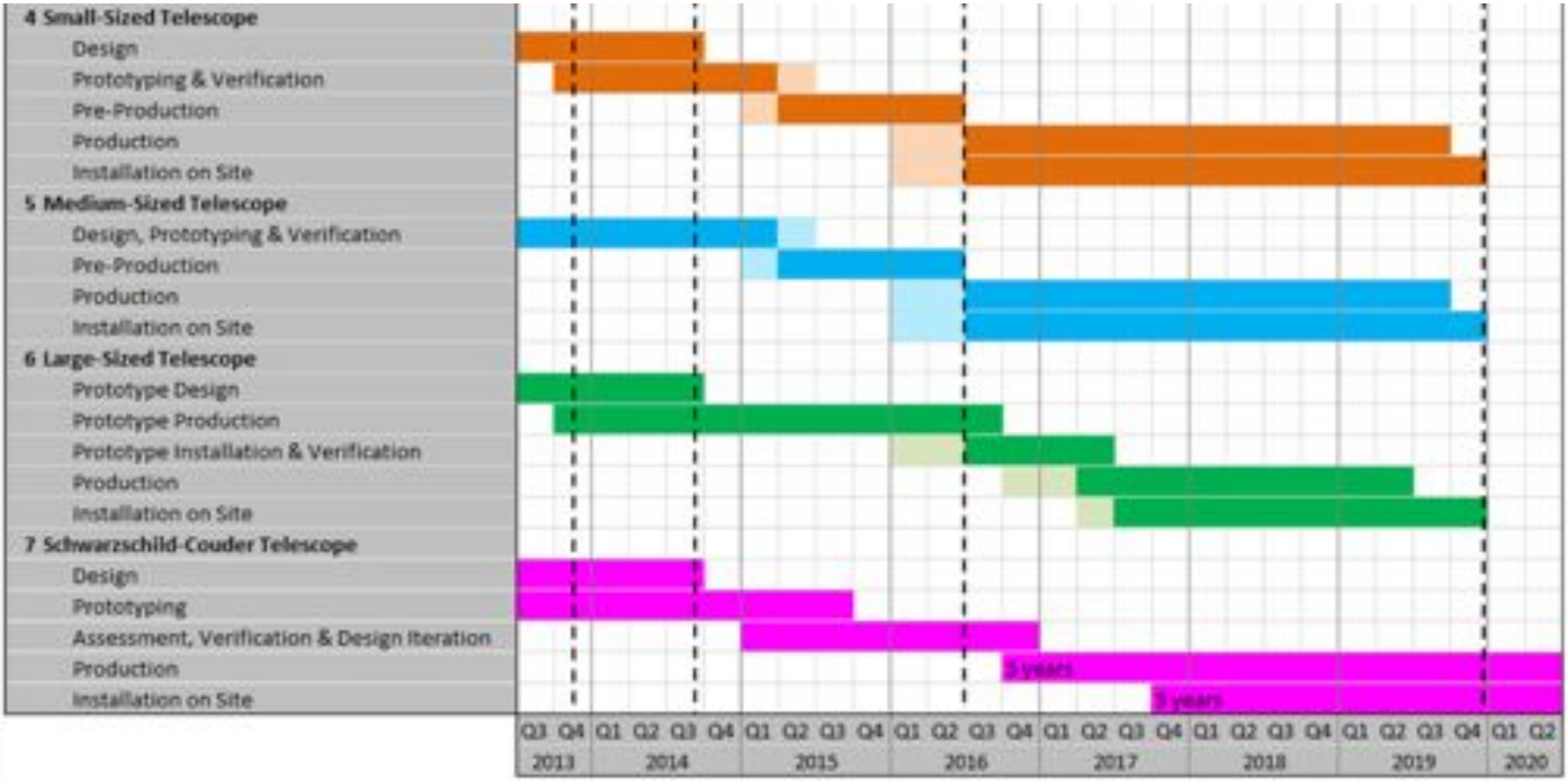


Candidate sites

S-array decision before 2014, N-array 2015

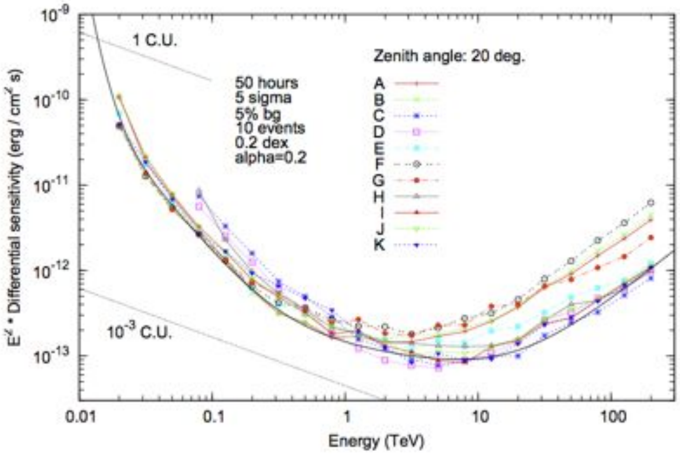
Telescopes (preliminary)

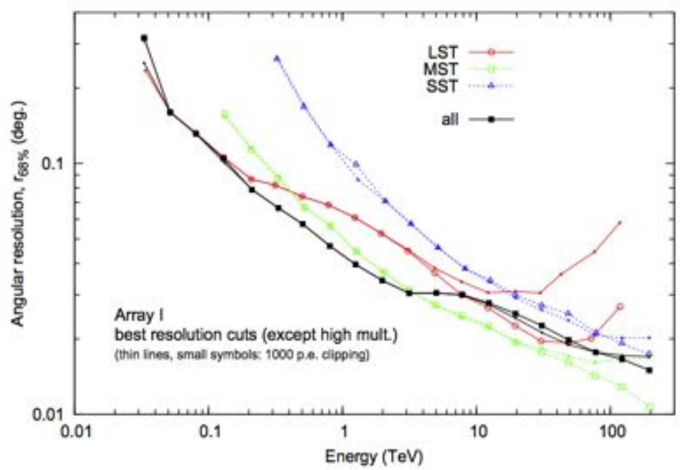
Prototyping started, deploy 2015, completion 2019

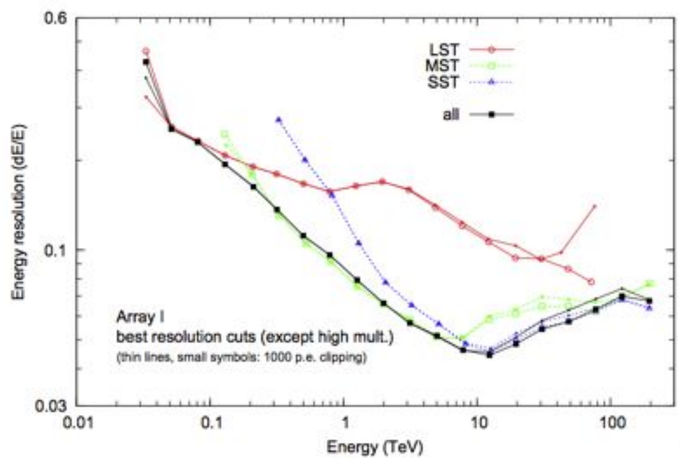


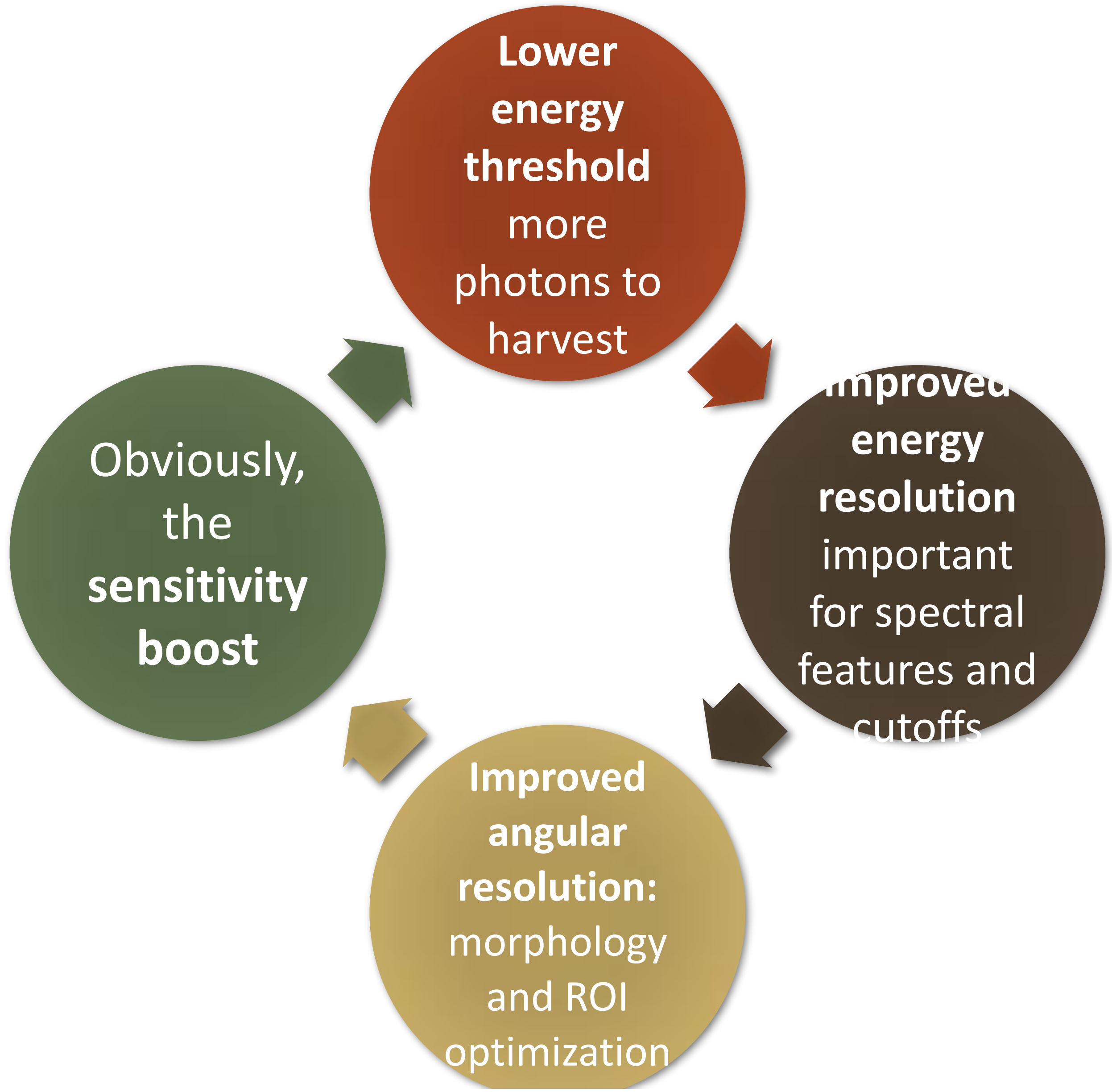
2019

CTA is well-suited for DM searches









K. Bernlöhr et al. / Astroparticle Physics 43 (2013) 171–188

Dark Matter and Fundamental Physics with CTA

- Prospects published in 2013 by CTA
- Dark matter, Lorentz Invariance Violation, Axion-like particles, and more
- Tests capabilities of different array layouts

Astroparticle Physics 43 (2013) 189–214

Contents lists available at SciVerse ScienceDirect

Astroparticle Physics

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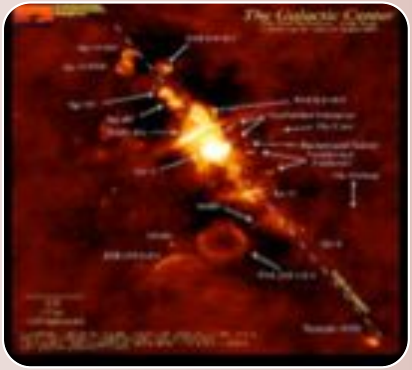
Dark matter and fundamental physics with the Cherenkov Telescope Array

CrossMark

M. Doro[k,*], J. Conrad[h,i,*], D. Emmanoulopoulos[l], M.A. Sànchez-Conde[r,s,t], J.A. Barrio[a], E. Birsin[b], J. Bolmont[c], P. Brun[d], S. Colafrancesco[e,f], S.H. Connell[g], J.L. Contreras[a], M.K. Daniel[j], M. Fornasa[m,n], M. Gaug[k], J.F. Glicenstein[d], A. González-Muñoz[m,n], T. Hassan[a], D. Horns[o], A. Jacholkowska[c], C. Jahn[p], R. Mazini[q], N. Mirabal[a], A. Moralejo[n], E. Moulin[d], D. Nieto[a], J. Ripken[h], H. Sandaker[u], U. Schwanke[b], G. Spengler[b], A. Stamerra[v], A. Viana[d], H.-S. Zechlin[o], S. Zimmer[h], for the CTA Consortium.

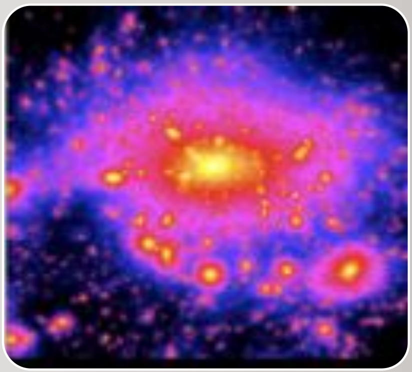
Best targets to point with CTA



GALACTIC CENTER+GALACTIC HALO

Possible observation time: 300-500h

Very good prospects if profile is cusp, i.e. baryons do not reduce the DM density



GALATIC SUBHALOS (DSPH, DARK CLUMPS…)

Possible observation of 100 h per year

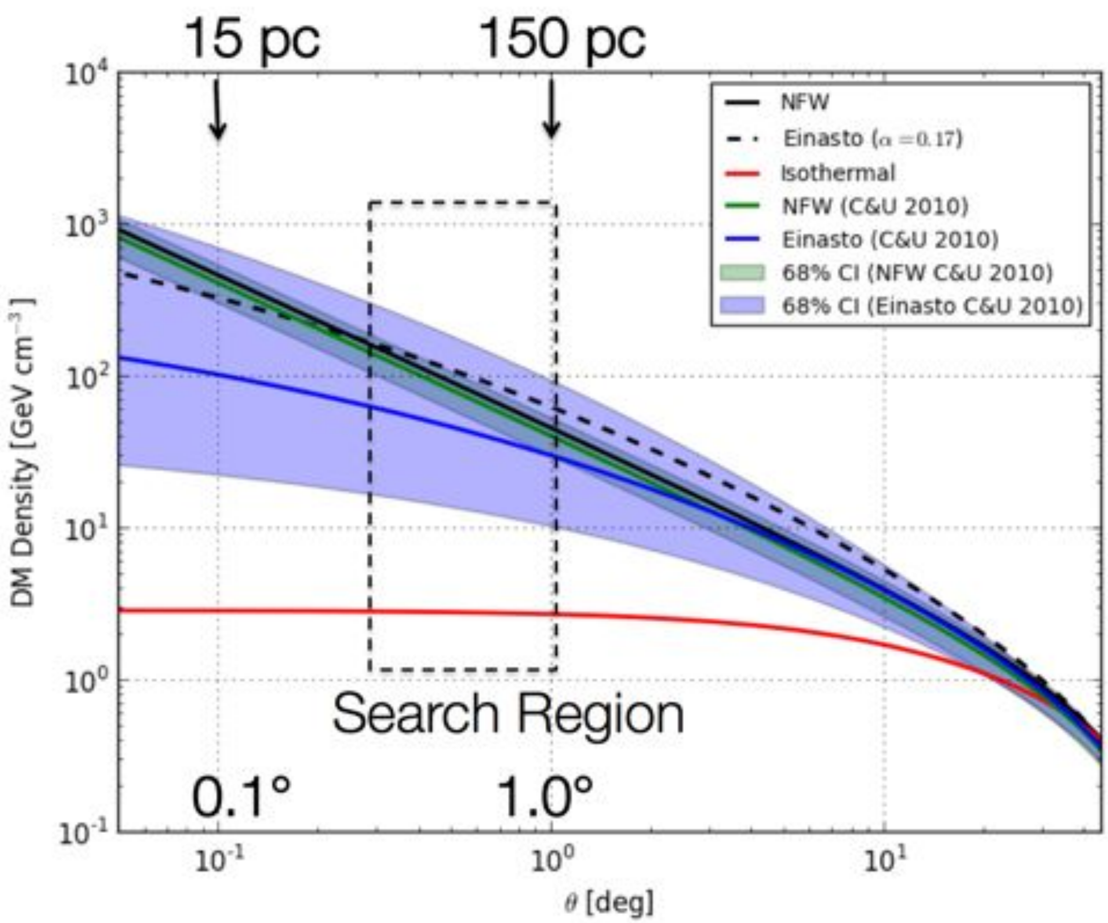
- Cleanest from astrophysical sources and less background systematics
- News expected in next years

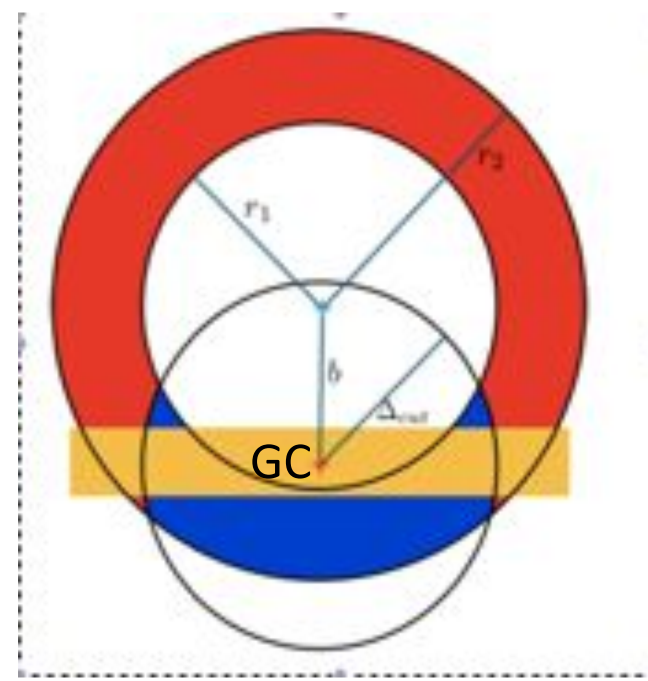
GALAXY CLUSTERS

- Expectations for annihilating DM are low
- Promising targets for **decaying** DM

Galactic Halo

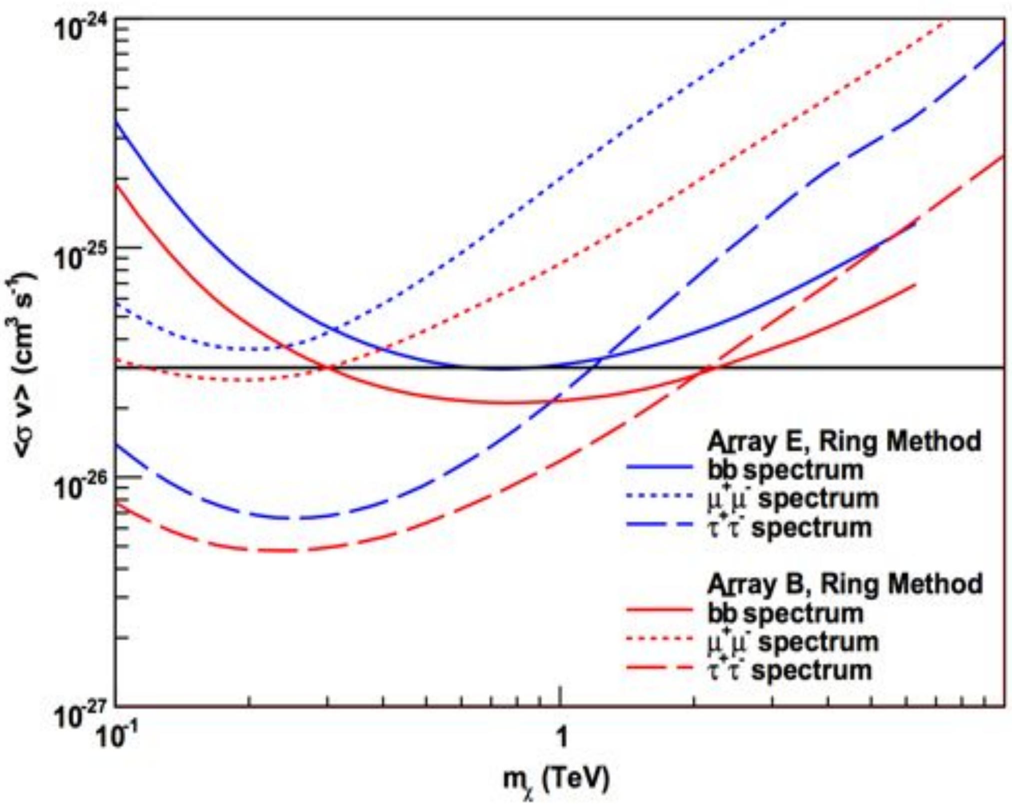
- Galactic center obvious target for DM searches, but crowded region
- Galactic halo at short distance from GC is well-defined
- Top priority for CTA in the first years of observation

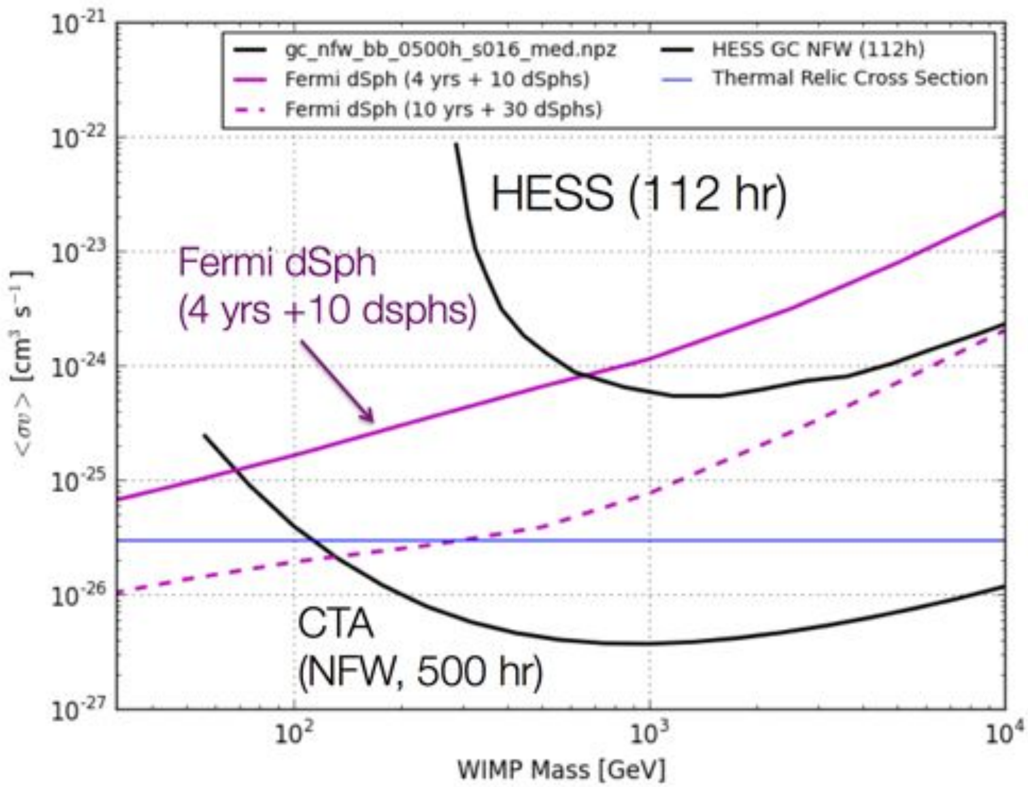




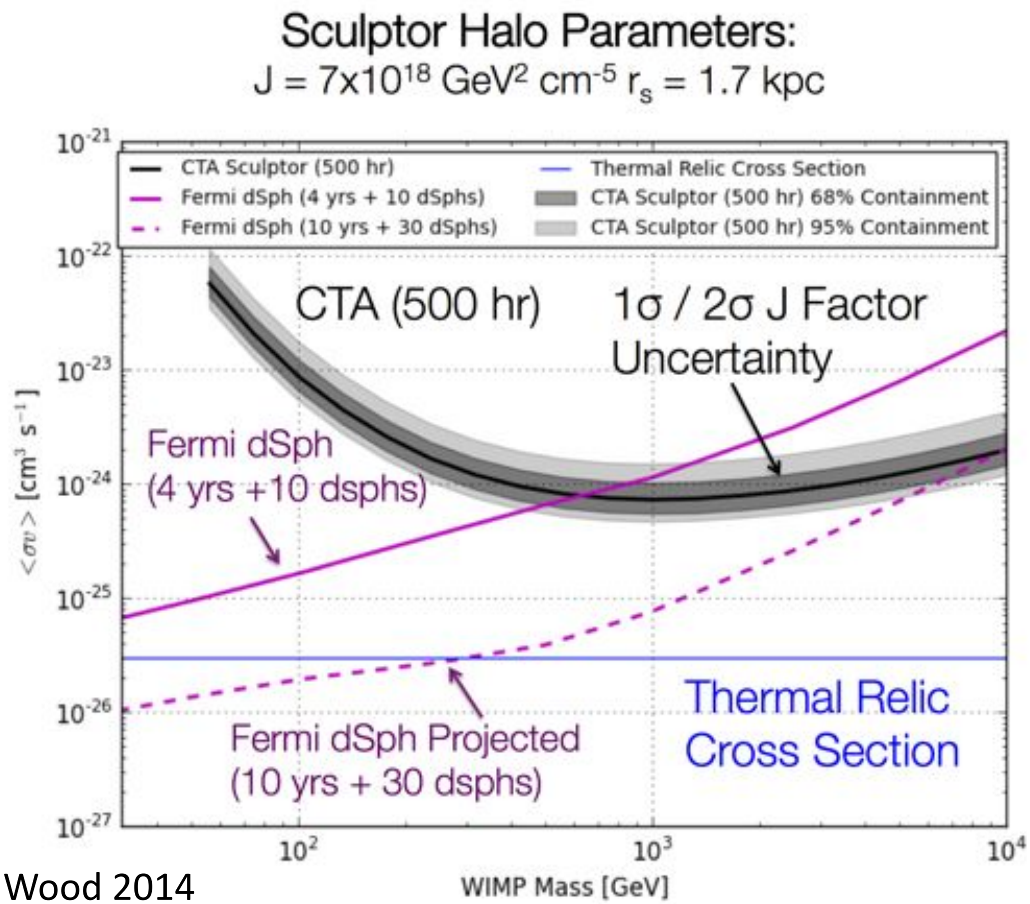
CTA prospects

- Careful selection of the **signal and background region**
- Control of **diffuse gamma-ray background**
- Control of background **systematics**
- Results are robust for **cusp** profile, but are not valid for **core** profiles





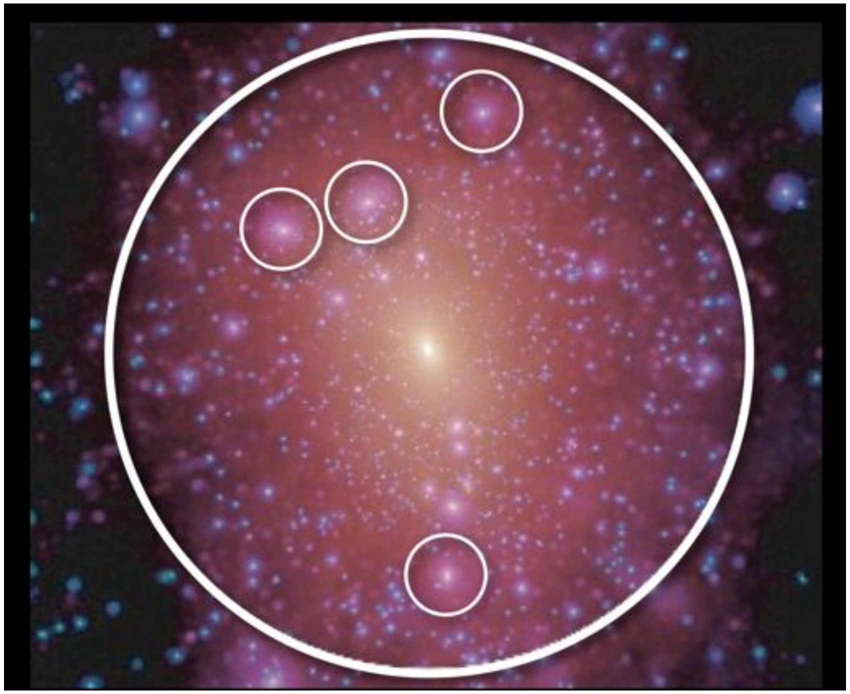
dSphs



Wood 2014

- Prospects based on current dSphs expectations needs very large boost factors to reach detection
- However:
  - Southern-Hemisphere dSphs to be discovered soon
  - Better knowledge of profiles and better determination of J-factor in the future
- Worth not to throw the “towelino” already

Dark clumps



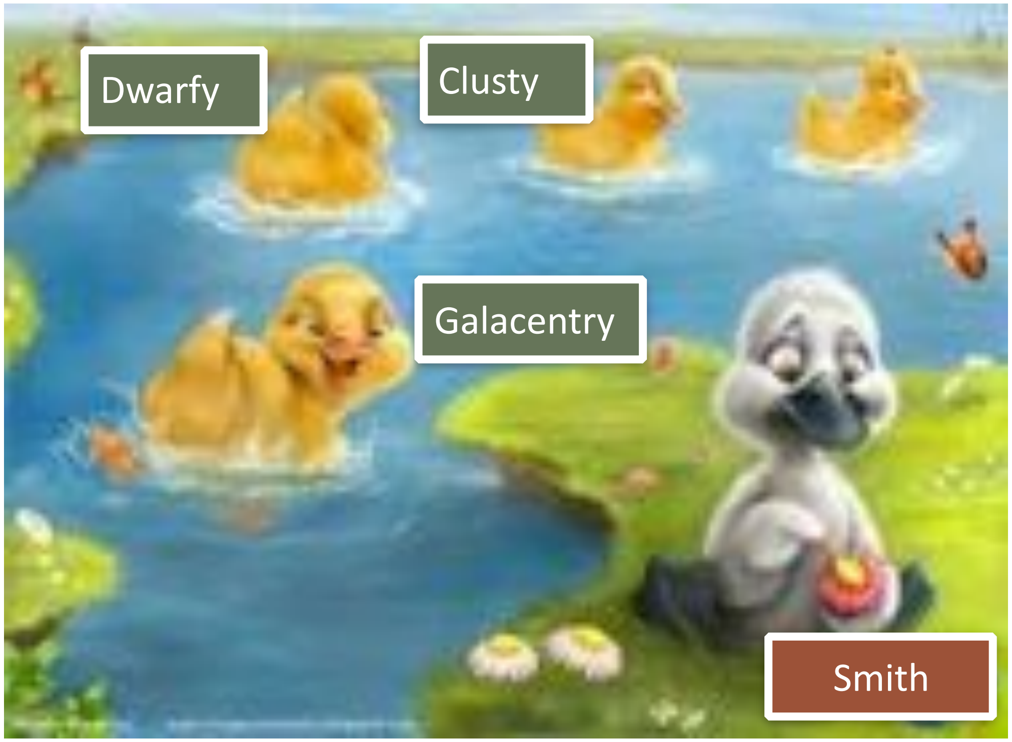
- **Clumps of DM could be dark emitter (only gamma-ray)**
- Some of them could Unidentified Fermi sources, or Fermi could be blind to them if DM is above few hundreds GeV

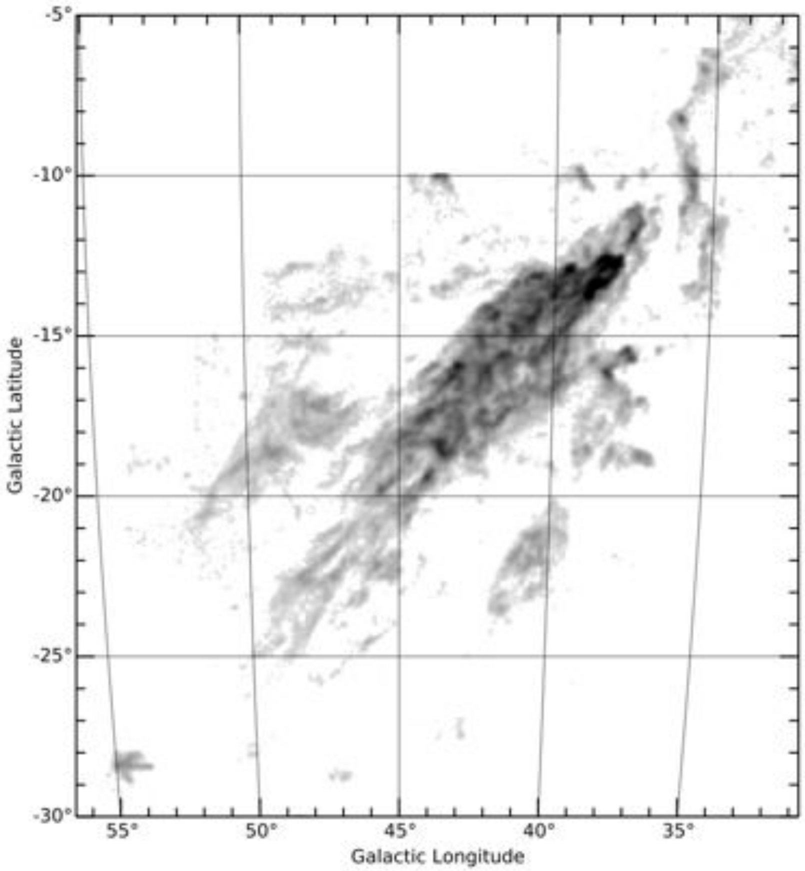
$$N = \int_{M_I} dM \int_{D_I} dD\, D^2 \int_{c_I} dc \int_{b_I} db\, \cos b \int_0^{2\pi} dl\, P(c, \bar{c})\, \frac{dn_{sh}(D_{gc}, M)}{dM}$$

Survey [mCrab]	Boost $\langle\sigma v\rangle / \langle\sigma v\rangle_{th}$	$N(\Delta M, \lvert b\rvert \geq 10^\circ)$ $\chi\chi \to b\bar{b}$ 0.5 TeV	1.0 TeV	5.0 TeV	$\chi\chi \to \tau\bar{\tau}$ 0.5 TeV	1.0 TeV	5.0 TeV
5	≤ 10	0.00	0.01	0.00	0.19	0.05	0.00
	≤ 100	0.31	0.74	0.26	6.91	2.63	0.03

H. Zechlin (very very preliminary)

The ugly duckling



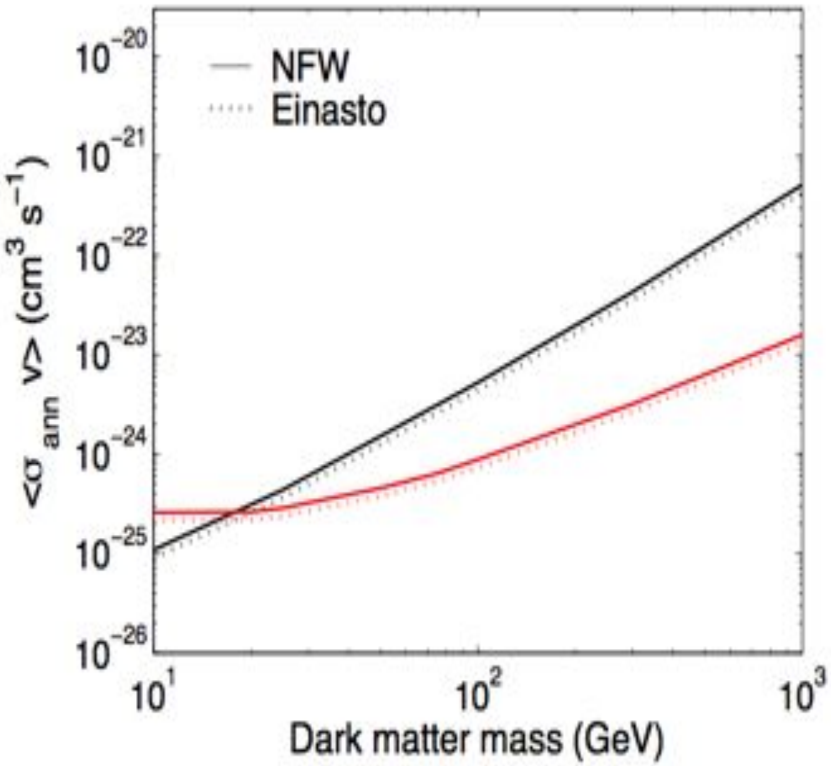


- The Smith Cloud is an exceptionally massive HVC
- If not encapsulated by a DM halo, stellar content should be disrupted by passage through the Galactic disk
- Expected large J-factor (Nichols+ 2014, Drlica-Wagner+ 2014)

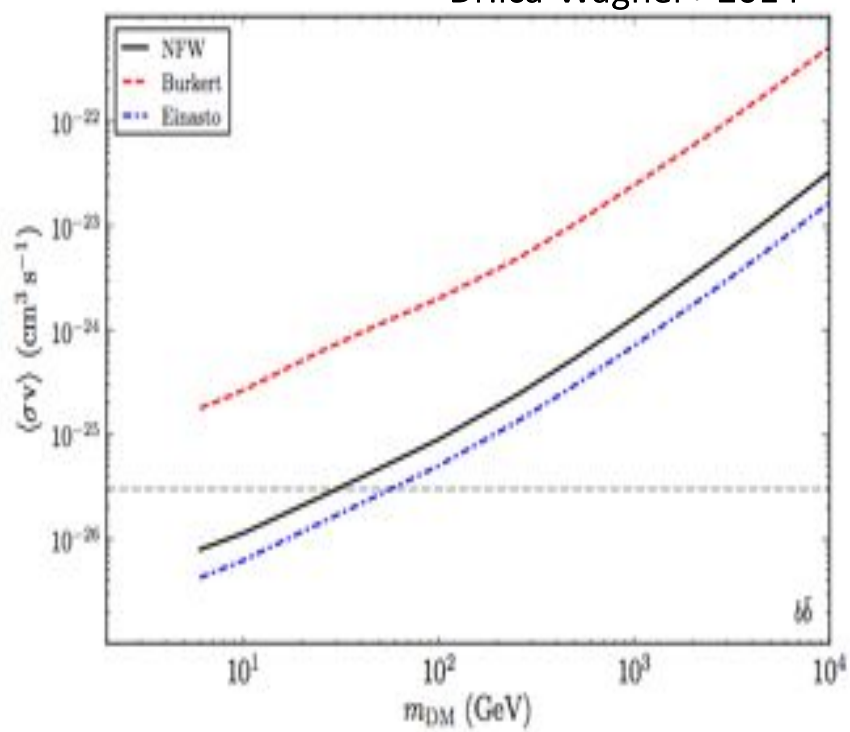
Why not

- "Upcoming experiments such as the Cherenkov Telescope Array (CTA) will be able to achieve improved angular resolution and sensitivity around the Smith Cloud for energies above 100 GeV" Nichols+ 2014

Nichols+ 2014



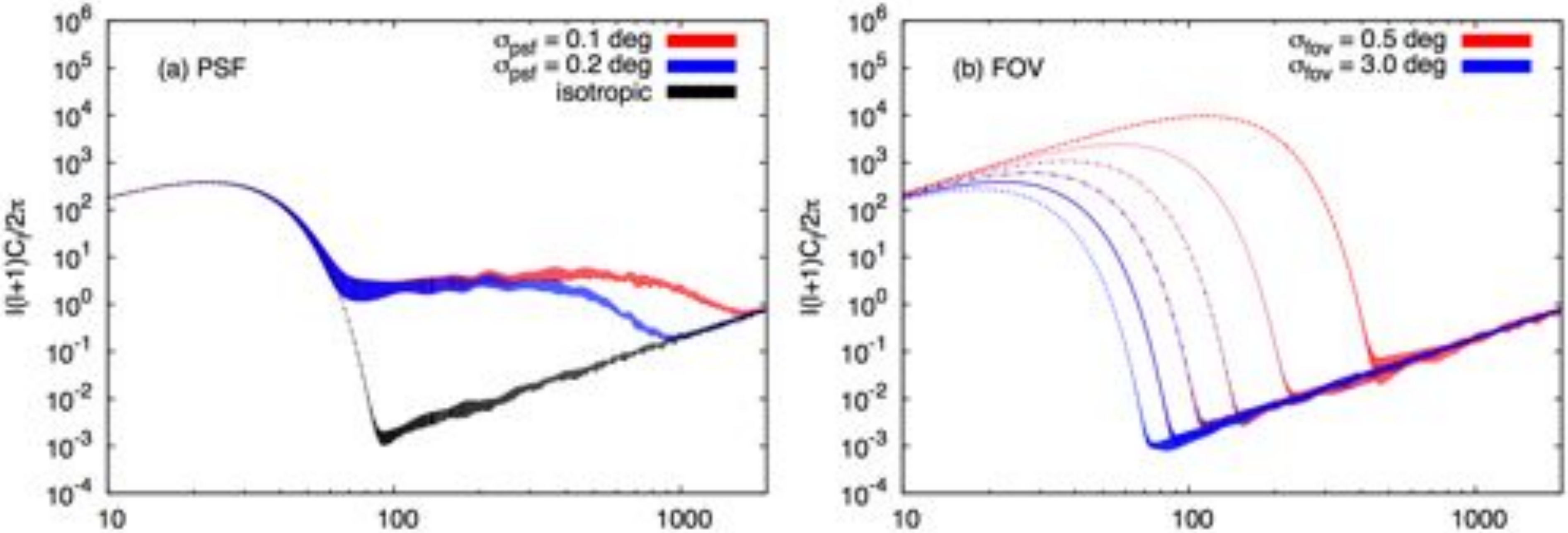
Drlica-Wagner+ 2014



OTHER MEANS: ANISOTROPIES AND LINES

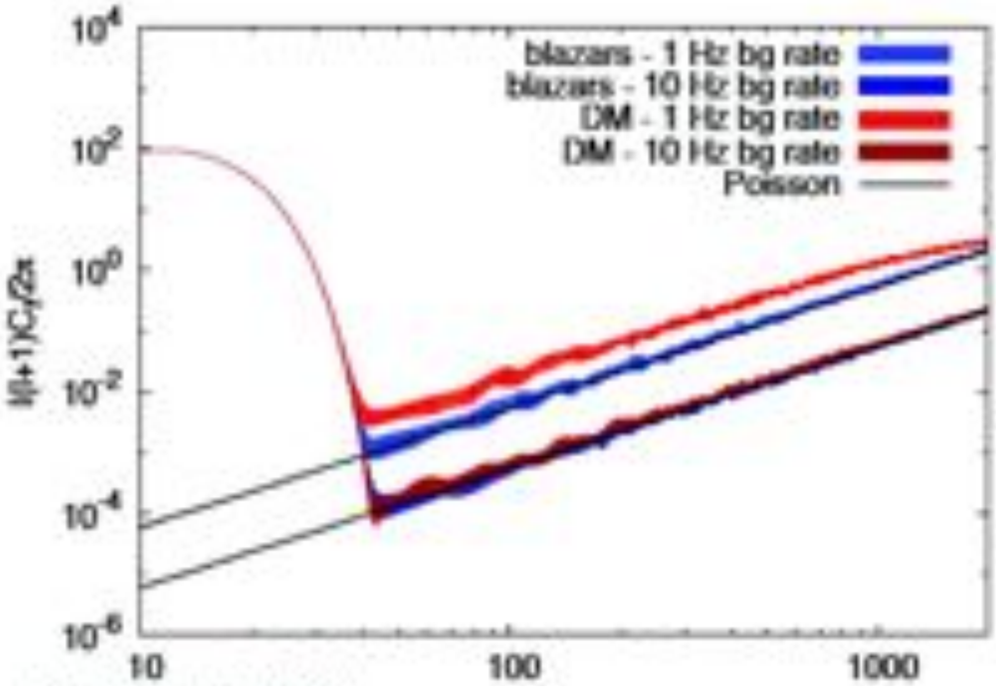
IACT can play that game

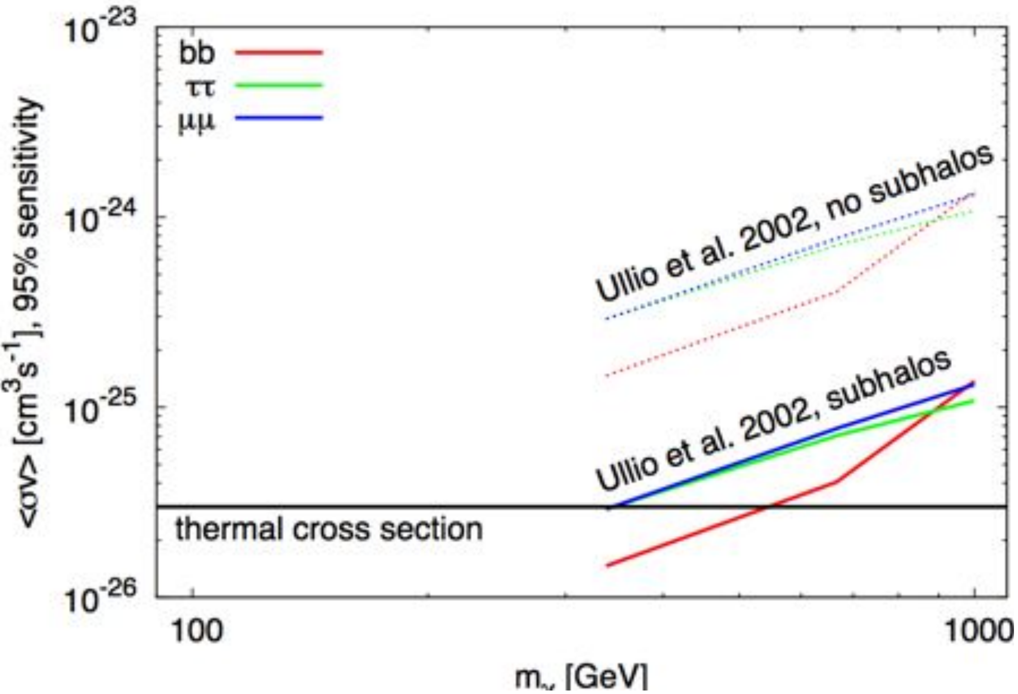
- Self-annihilating DM could leave its signature in the angular power spectrum of the EGDB
- PSF and FOV of the IACTs are not killer: multipoles in the range between 100 and 1000 can be probed
- At the same time, the background is expected to be isotropic at small scales and therefore no fundamental obstacle either.



JCAP01(2014)049

A novelty with chances



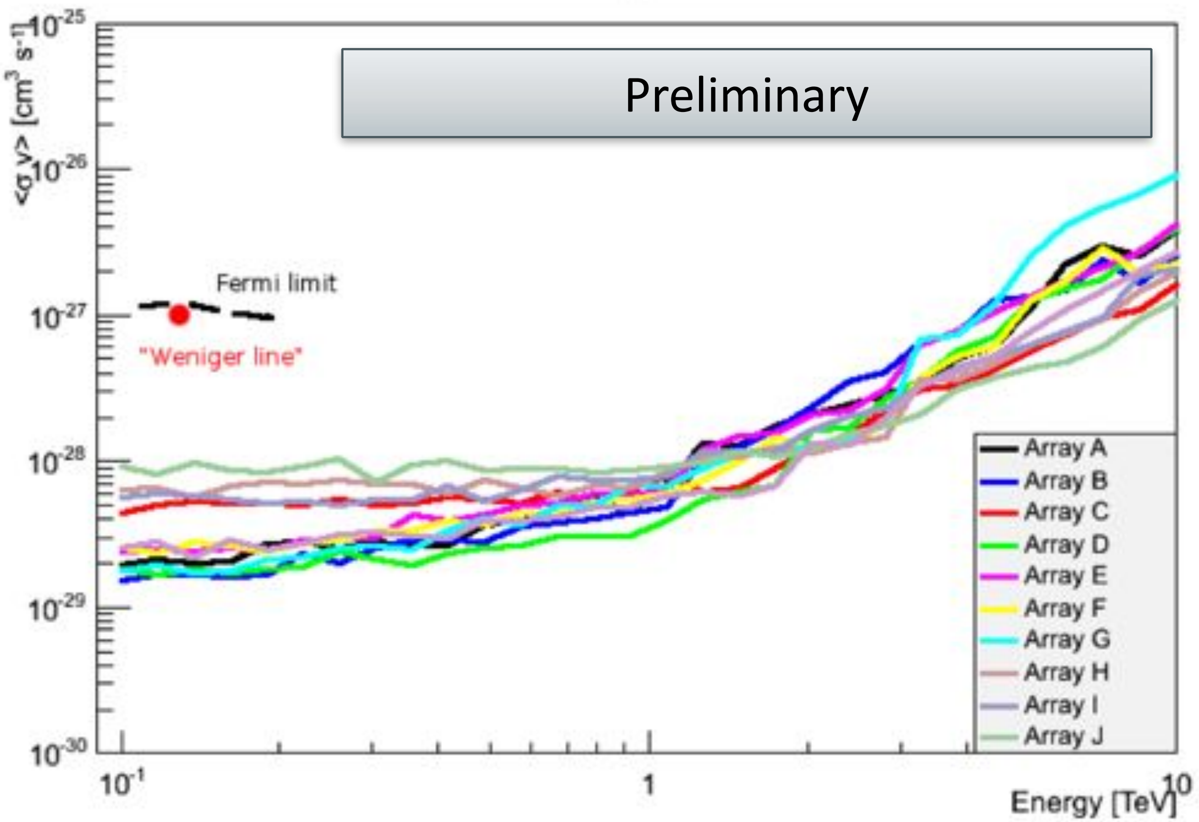


JCAP01(2014)049

- All depends on
  - DM real anisotropy level and photon yield
  - background suppression capability of CTA
- **Best strategy**: multiple ROI obtained from standard extragalactic observation (e.g. 10x100h) above 300 GeV.

Line searches

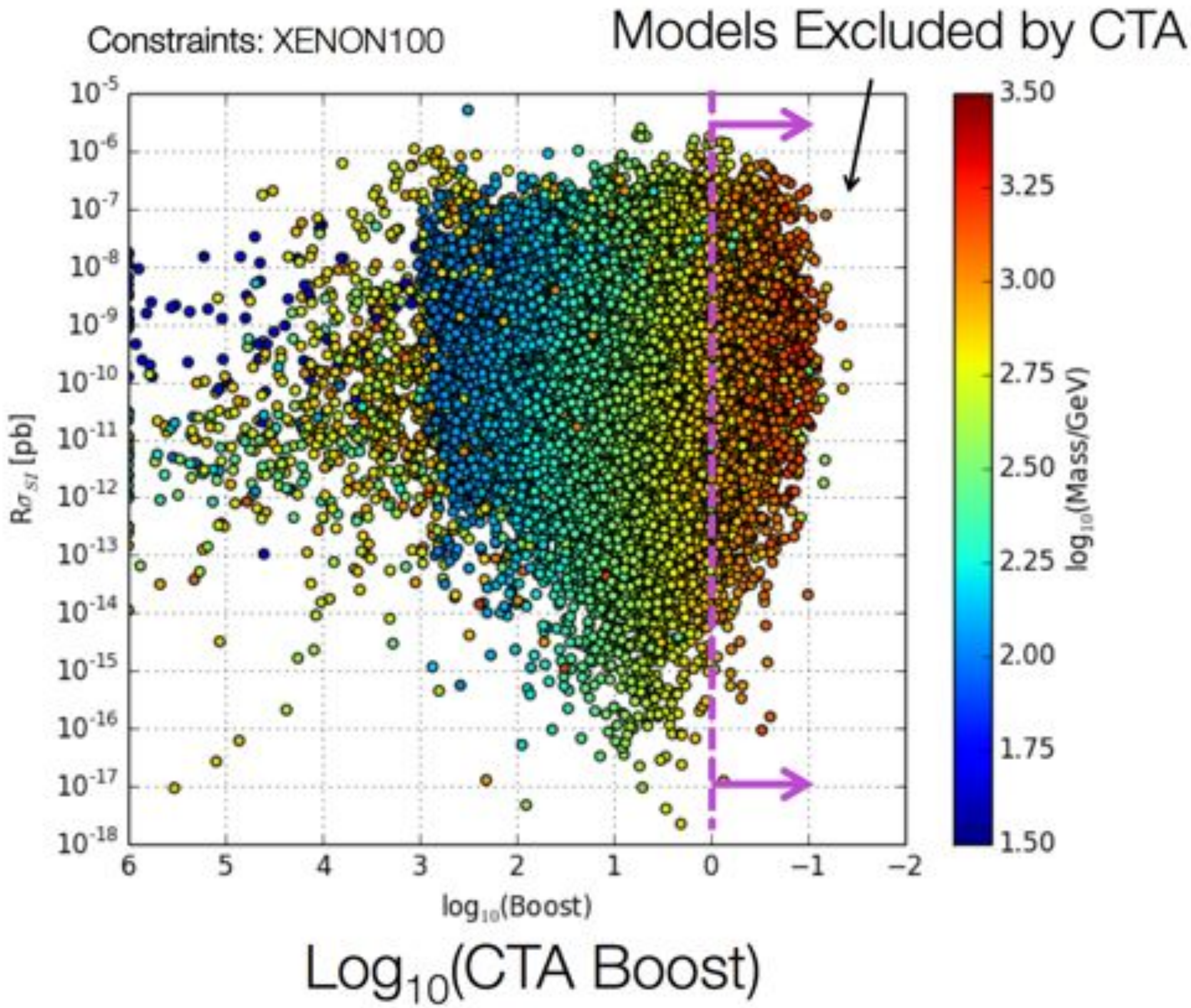
- A large effort is currently at place in CTA to improve the energy resolution and bias through through instrument and atmospheric calibration
- Low-energy threshold and larger sensitivity go along well with line searches
- GC is the best target
- Basically every CTA array under discussion will have sensitivity to the Bringmann-Weniger line



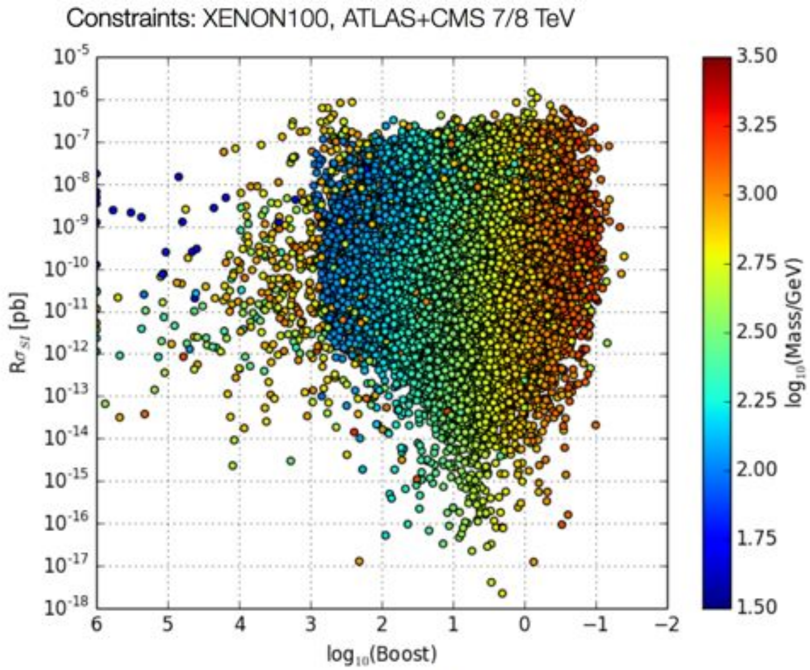
WILL CTA BE COMPETITIVE?

Complementarity with other experiments

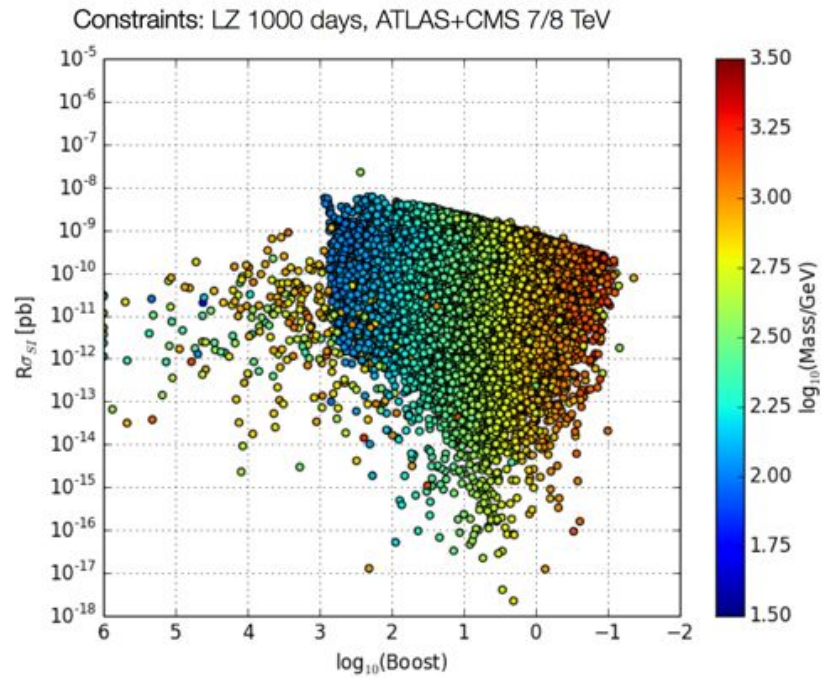
pMSSM



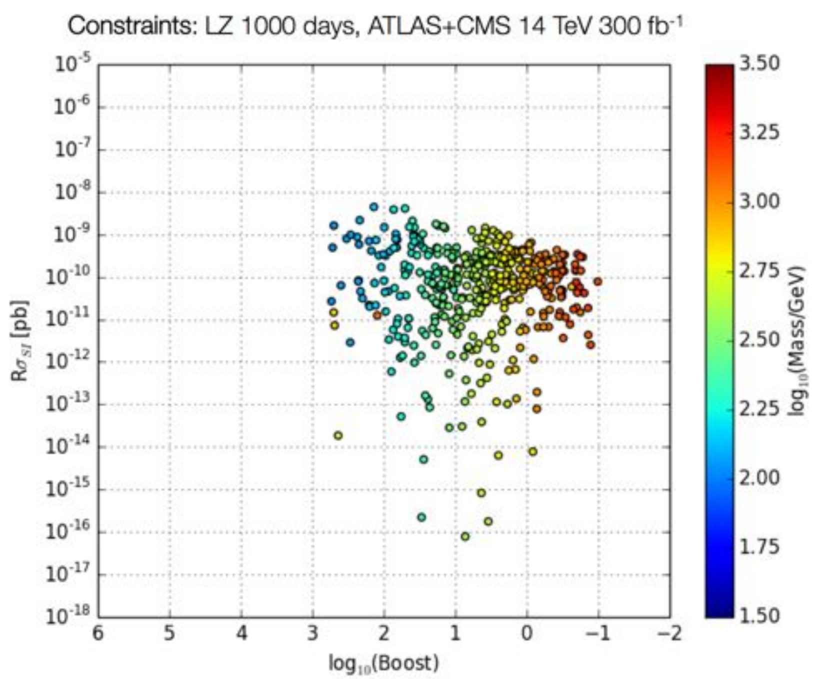
Cahill-Rowley+ 2014



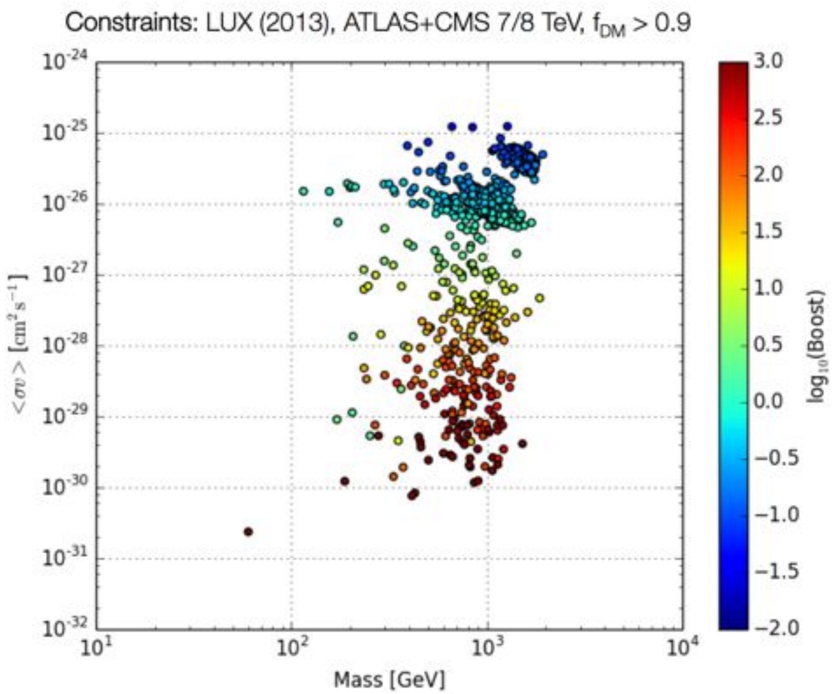
Log_{10}(CTA Boost)



Log_{10}(CTA Boost)

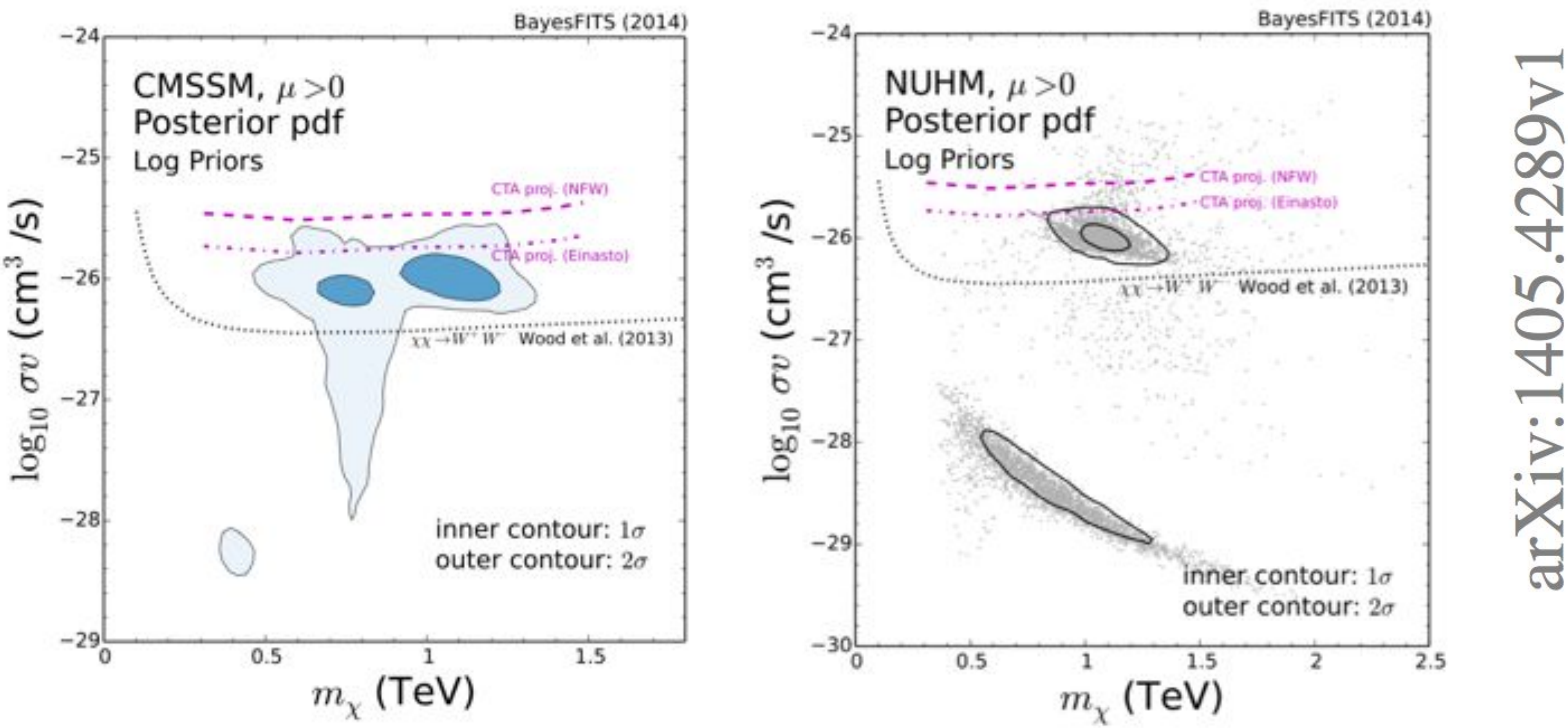


Log_{10}(CTA Boost)



pMSSM

cMSSM and NUHM

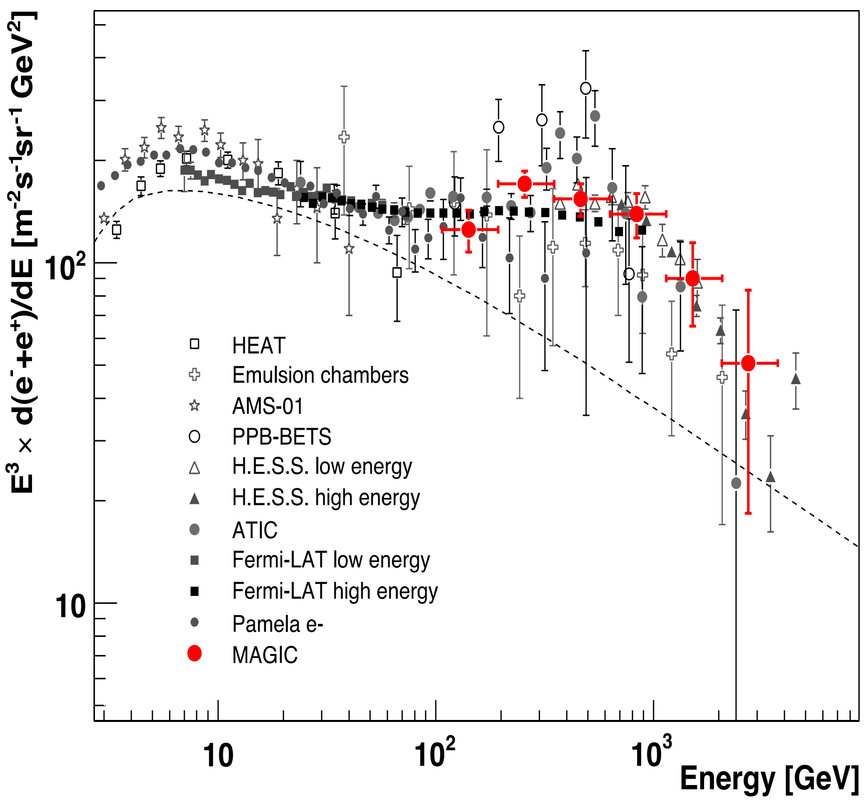


Roszkowski+ 2014i

A DM FLIRT:

DOING IT WITH THE ELECTRONS

DM searches via CR electron(s)

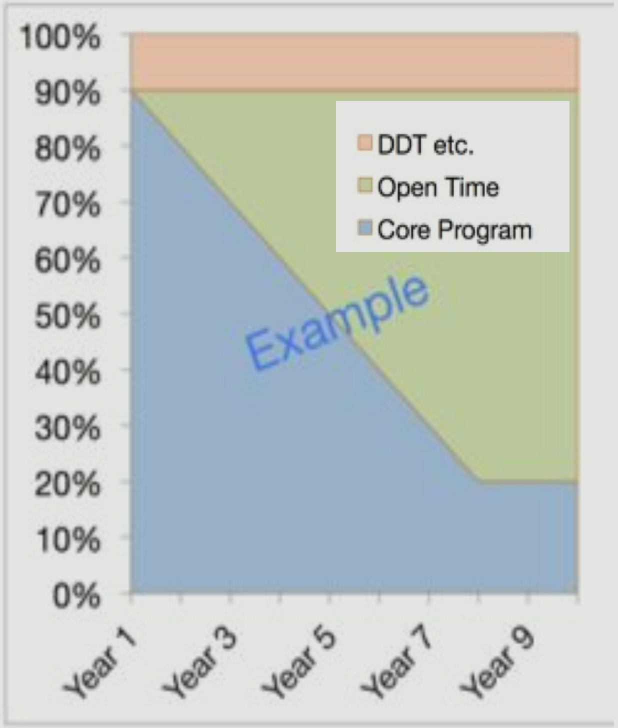


- Many experiments find anomalies in CRs fluxes
  - PAMELA, AMS+: rising e+/e± ratio above 10 GeV
  - Fermi, HESS: rising e± spectrum above 100 GeV
- Explanations: nearby astrophysics sources, Dark Matter annihilation/decay, different CR propagation
- CTA so precise that electrons are suggested as absolute calibrating method

COMMENTS AND CONCLUSIONS

Do you believe in CTA?

1. We have shown that there is at least a part (for now) of the **parameter space** that we can curb with CTA (DM at the GC-halo)
2. In case LHC-14 do not discover DM, CTA has still chance if **DM is heavy**
3. CTA can be the **sole player** if DM is heavy for 2020-2030.
4. CTA can make **identification**



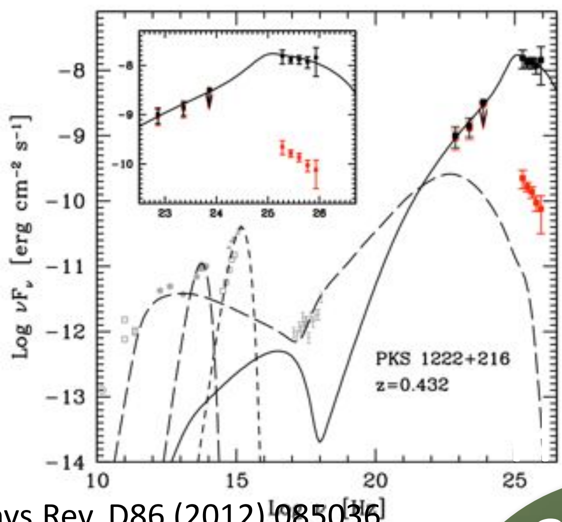
- CTA science community is currently working on Key-Science Projects definitions:
  - To define core program
  - To secure proprietary time
  - To define schedule
- Guest time relevant and photons will be distributed along with analysis tools a-la Fermi
- First time of a **Cherenkov *observatory***!

Summary

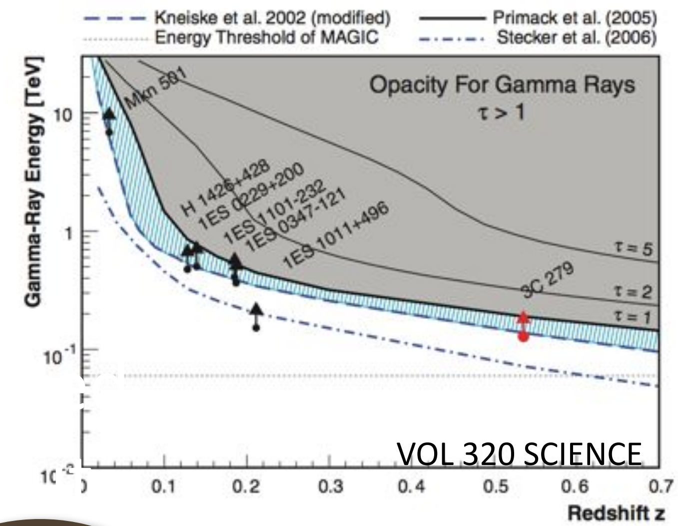
- CTA has good prospects for reaching WIMP models with thermal relic cross section and **mass > 100 GeV**
- **Galactic Center**: Fraction of parameter space finally accessible with CTA – particularly at high LSP masses (>1 TeV)
- **Dwarf Galaxies:** need high boost factor or new sources discovered (possibly dark clumps, HVC?)
- **Other probes** (electrons, anisotropy) are viabl
- CTA will **be complementary** to LHC and direct detection searches and can be unique player in some regions of the parameter space
- CTA is the first ground-based Cherenkov telescopes observatory

THANKS!

Some results



Phys.Rev. D86 (2012) 085036



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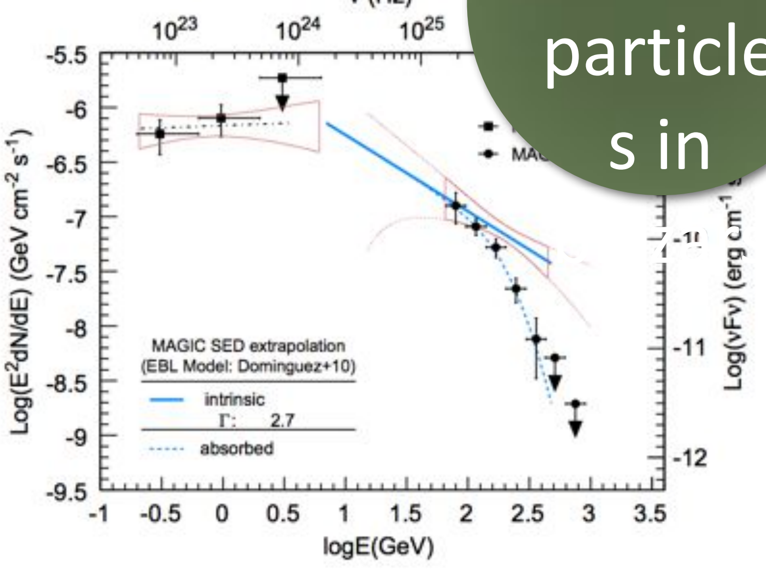
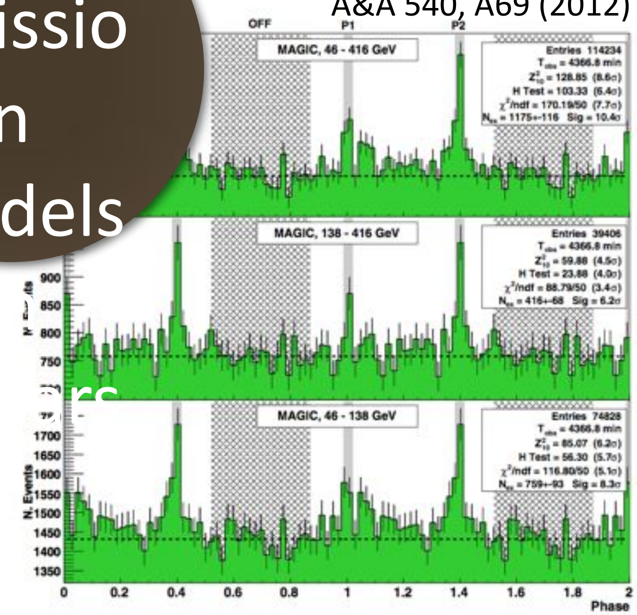
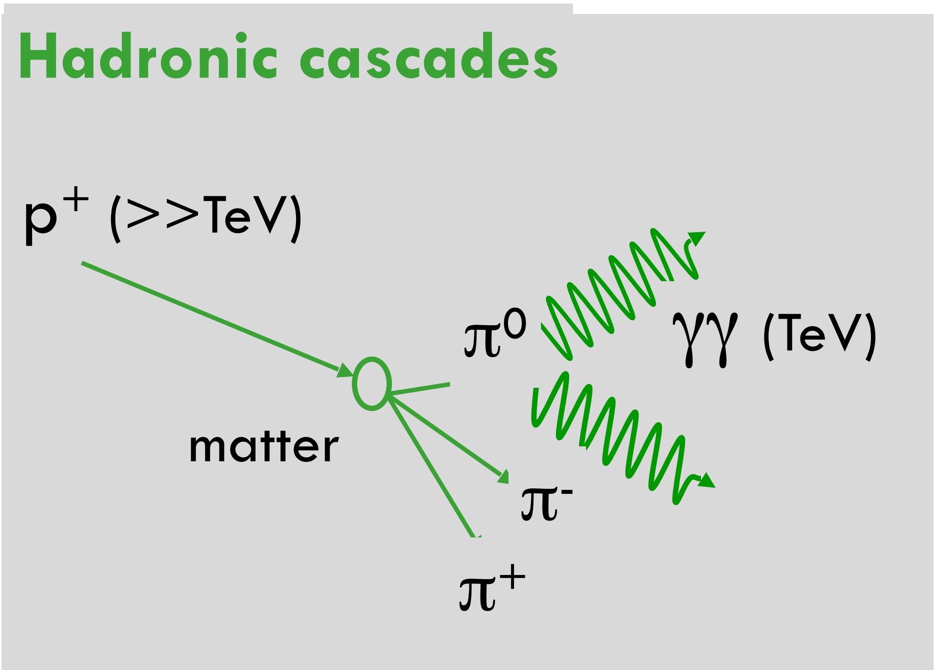


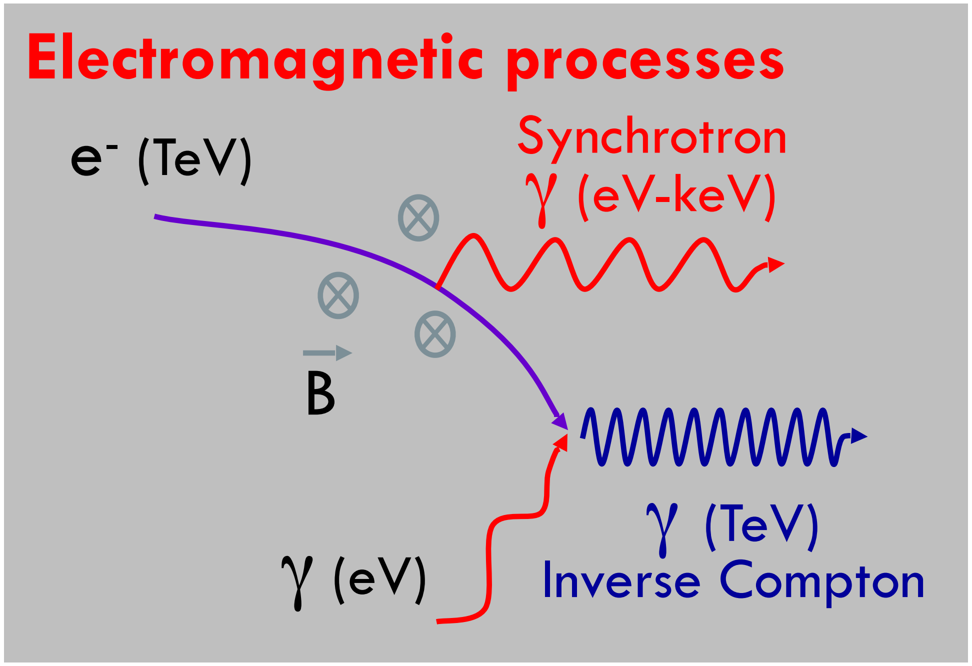
A&A 540, A69 (2012)



Gamma rays trace cosmic rays

- Gamma rays trace charged cosmic rays

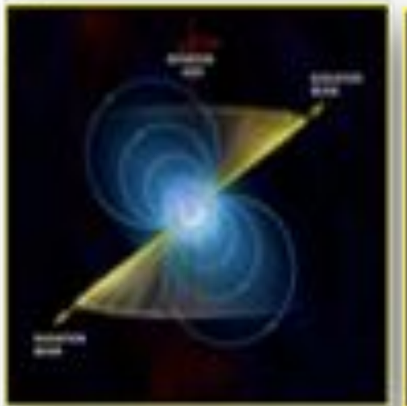




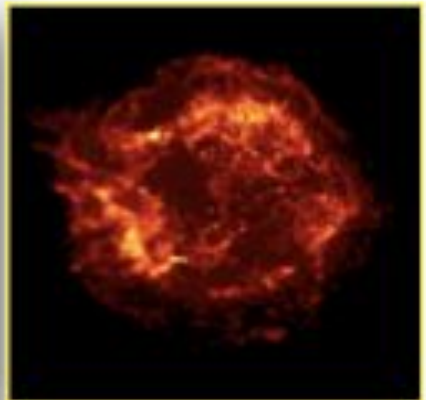
- Cosmic-ray physics (origin, mechanisms)
- Jet physics, magneto hydrodynamics, magnetic turbulence, etc.
- Fundamental physics (DM, ALPs, LIV)

targets

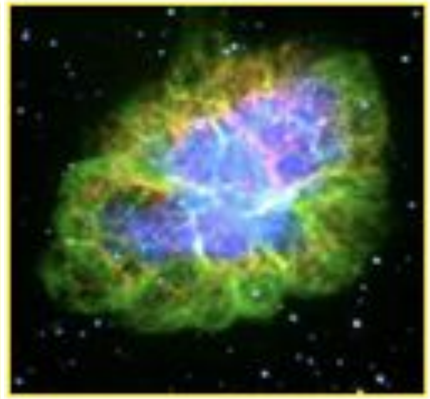
- Galactic targets



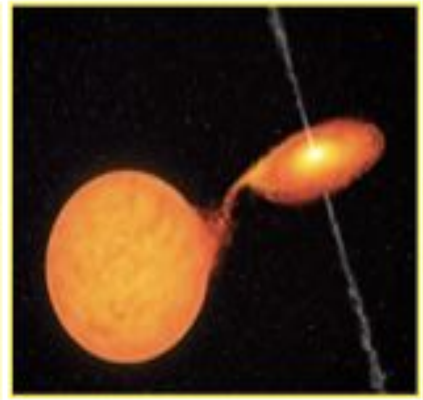
Pulsar



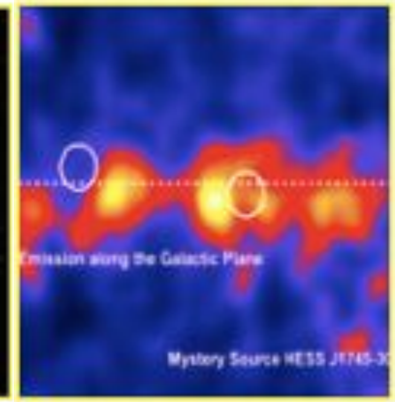
Supernova Remnants



Pulsar wind nebulae



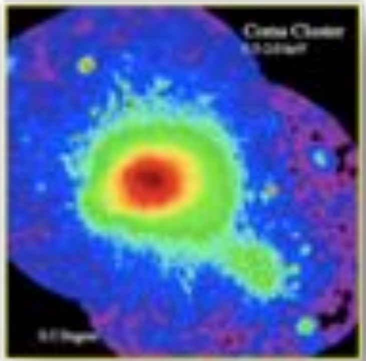
Micro-quasars



Galactic center

- Extragalactic targets

Active Galactic Nuclei



Galaxy Cluster

Starburst galaxies

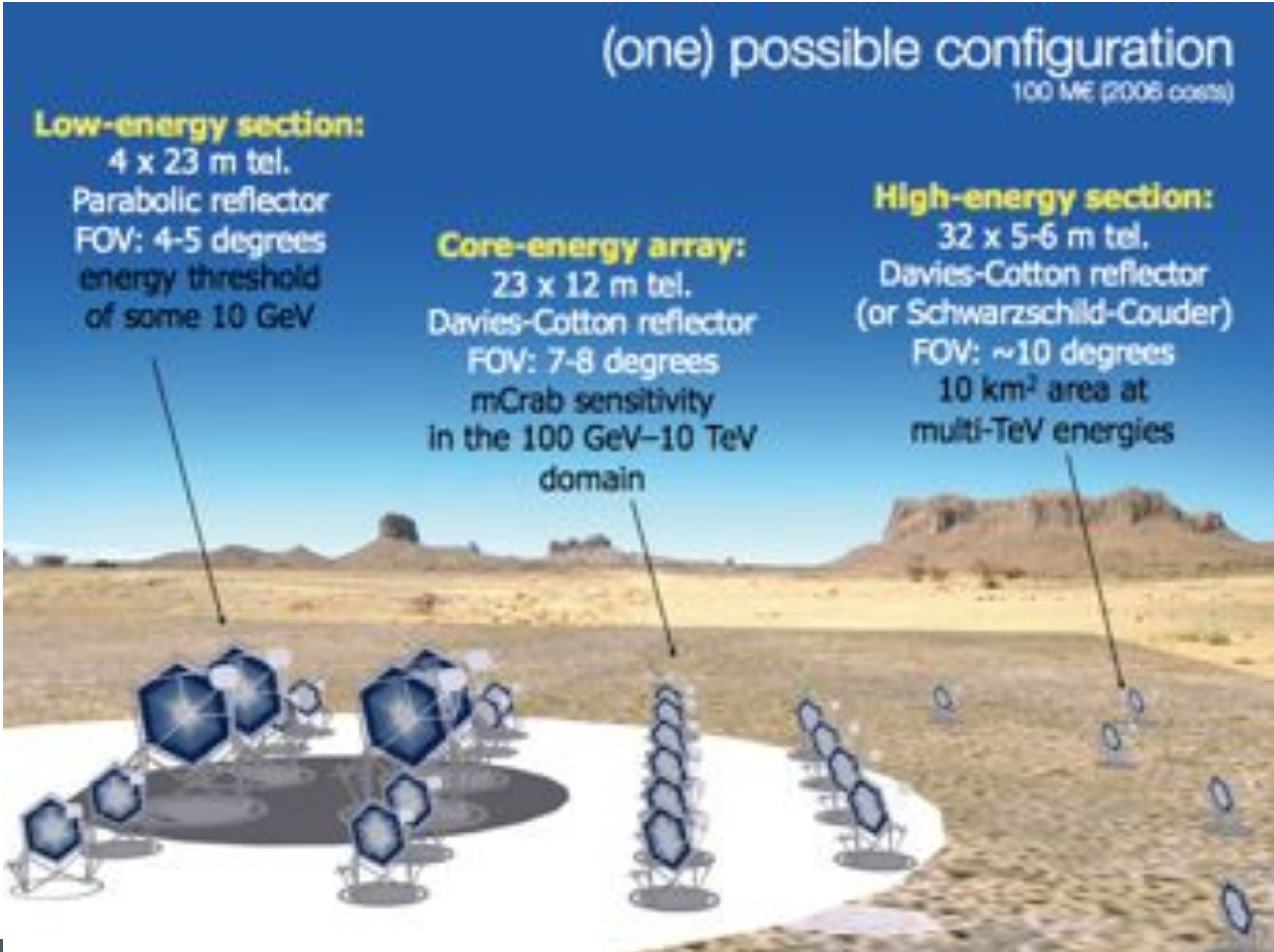
Merging Galaxies

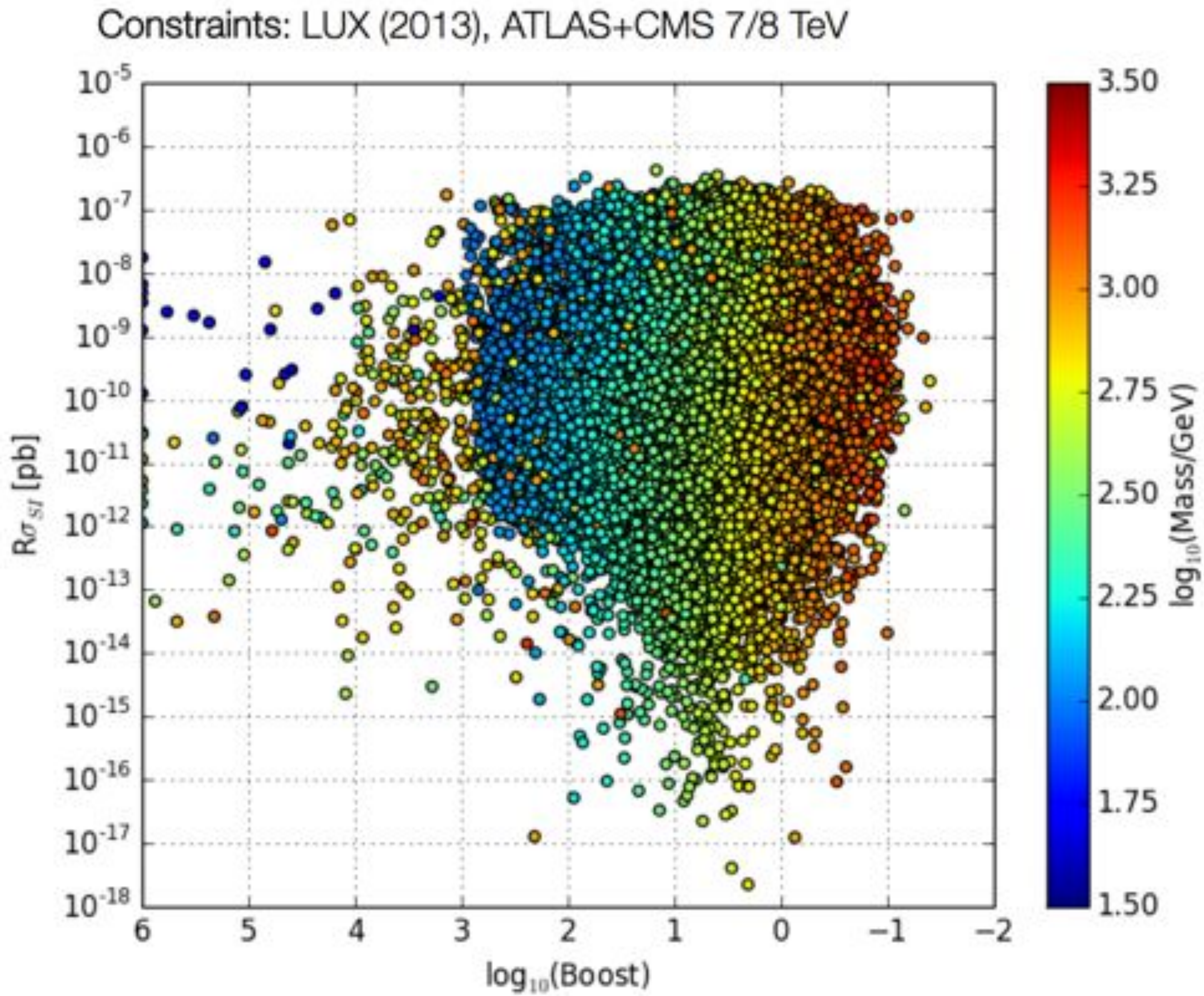
Gamma-ray Bursts

Design concepts and status

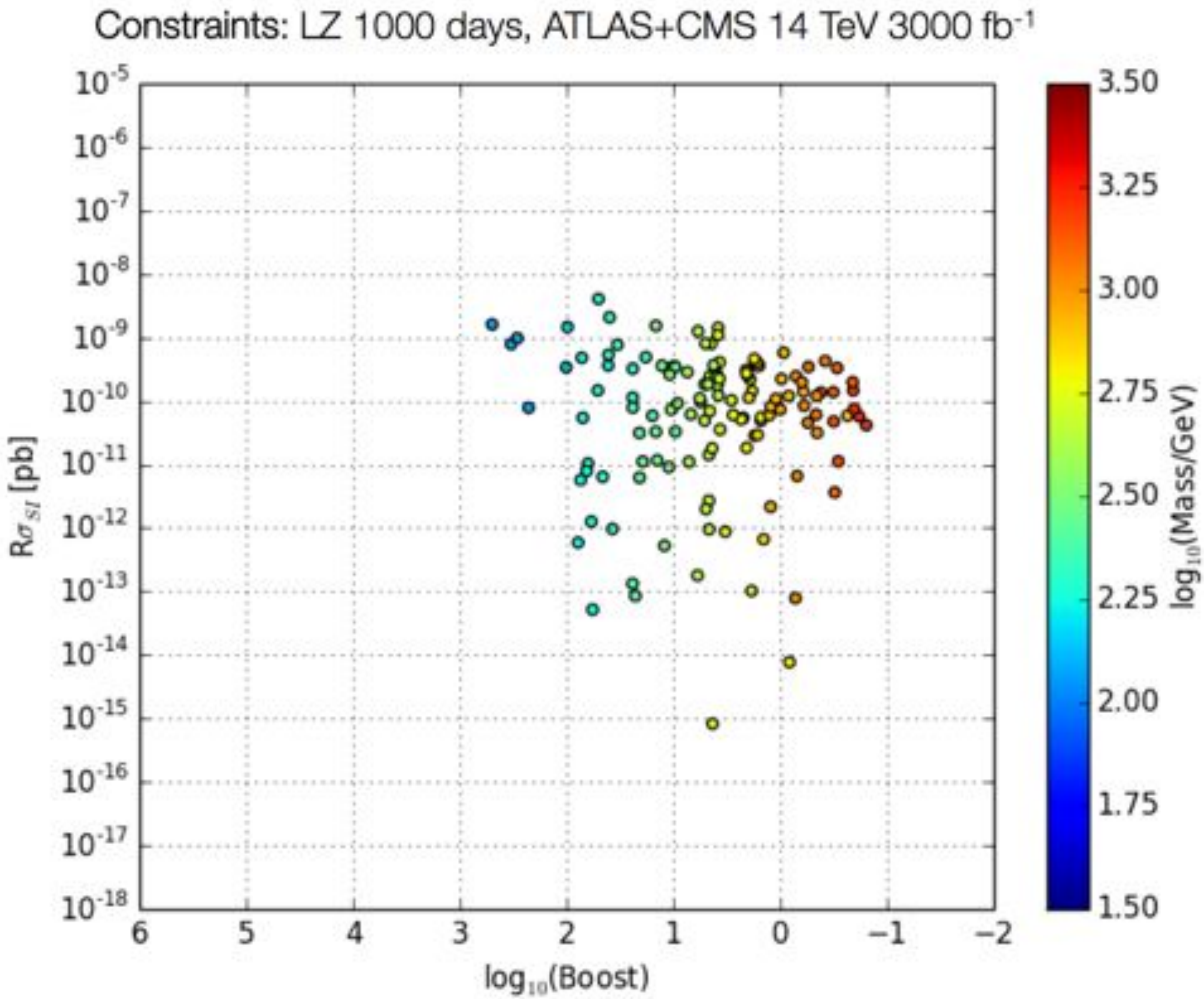
FP7-supported Preparatory Phase: Fall 2010 – Fall 2013
➜ Technical design, sites, construction and operation cost
➜ Legal, governance and finance schemes
➜ Small + medium-sized telescope prototypes

We are entering the Pre-Construction Phase

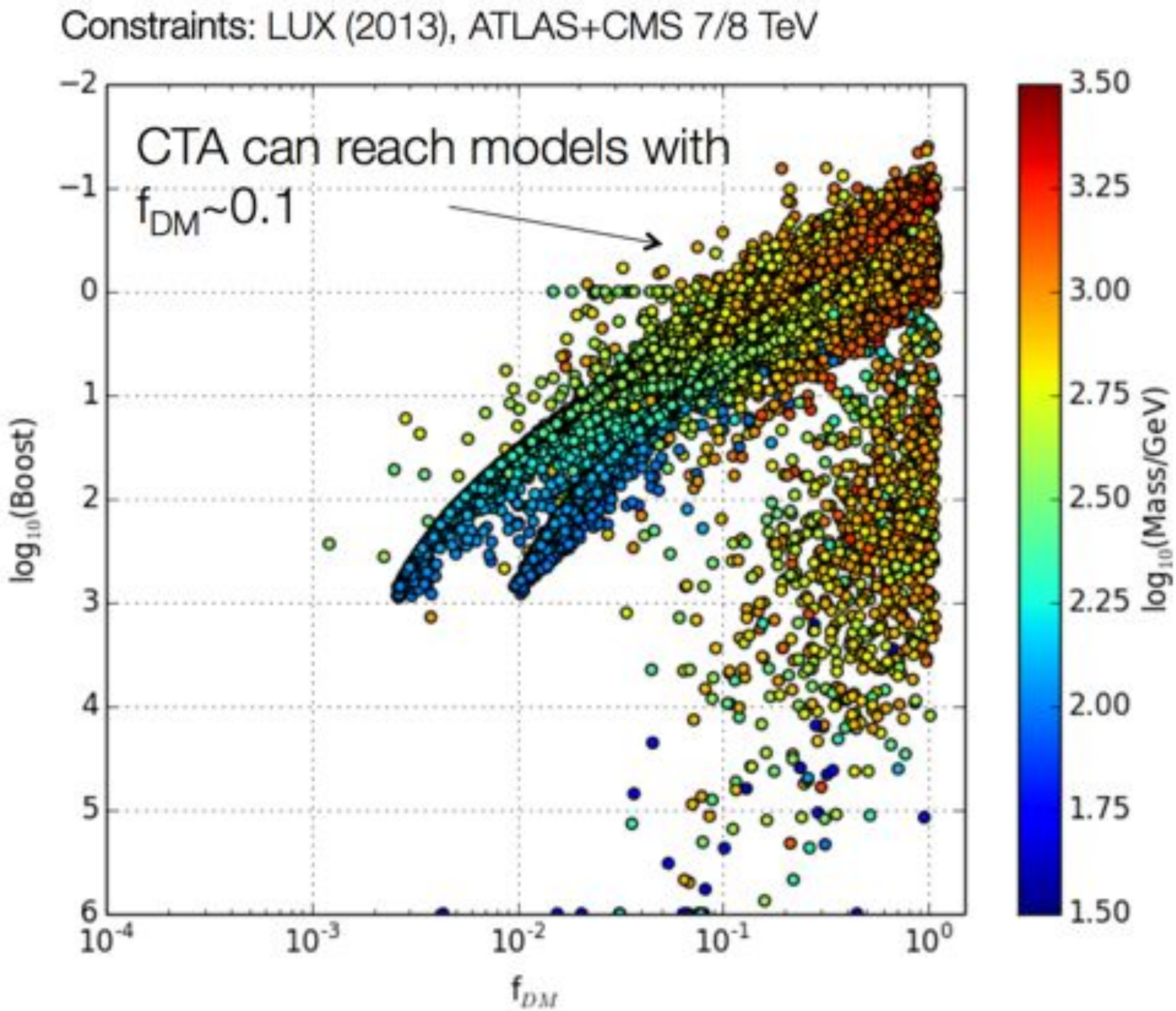

(one) possible configuration
100 M€ (2006 costs)
Low-energy section:
4 x 23 m tel.
Parabolic reflector
FOV: 4-5 degrees
energy threshold
of some 10 GeV
Core-energy array:
23 x 12 m tel.
Davies-Cotton reflector
FOV: 7-8 degrees
mCrab sensitivity
in the 100 GeV–10 TeV
domain
High-energy section:
32 x 5-6 m tel.
Davies-Cotton reflector
(or Schwarzschild-Couder)
FOV: ~10 degrees
10 km² area at
multi-TeV energies



Log_{10}(CTA Boost)



Log$_{10}$(CTA Boost)



$$f_{DM}=\Omega h^2/\Omega_{DM}h^2$$

We can point the telescopes!