# Dark Matter Detection Prospects for the Cherenkov Telescope Array

13th TAUP Conference
Asilomar / Sep., 2013

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

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For the CTA Consortium

# Outline

- **The Cherenkov Telescope Array**
- **Dark Matter Detection Prospects**

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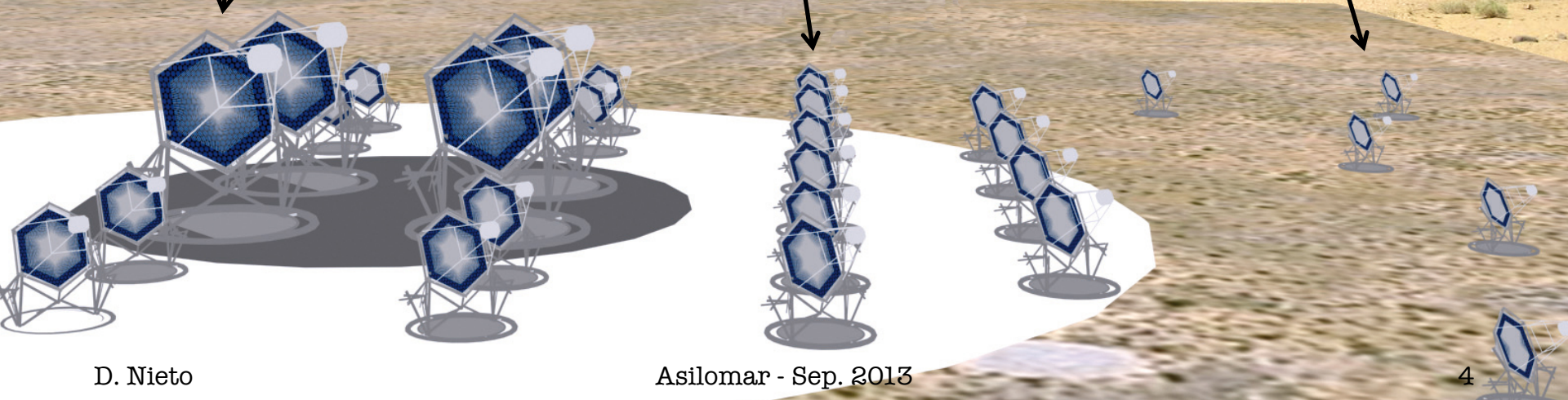
- **<u>The Cherenkov Telescope Array</u>**
- **Dark Matter Detection Prospects**

- 10 fold sensitivity of current instruments
- 4 decades of energy coverage: tens of GeV to >100 TeV
- Improved angular resolution
- Two asymmetric arrays (North/South)

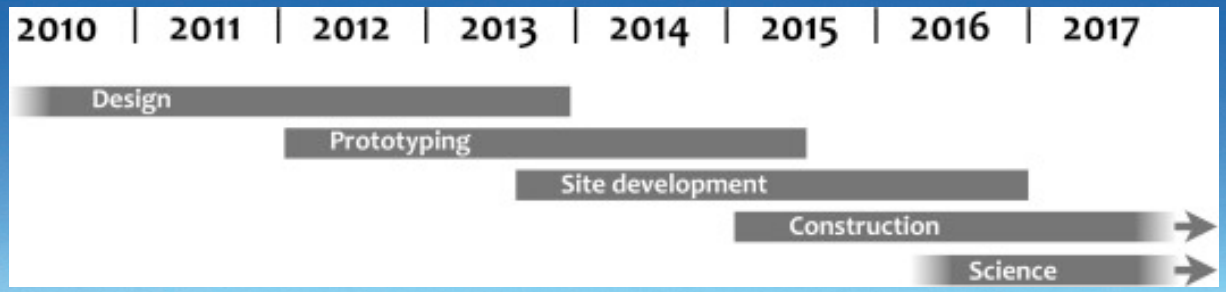
**Low energy range:**
23 m ø
Parabolic reflector
4° - 5° FoV
**Energy threshold ~tens GeV**

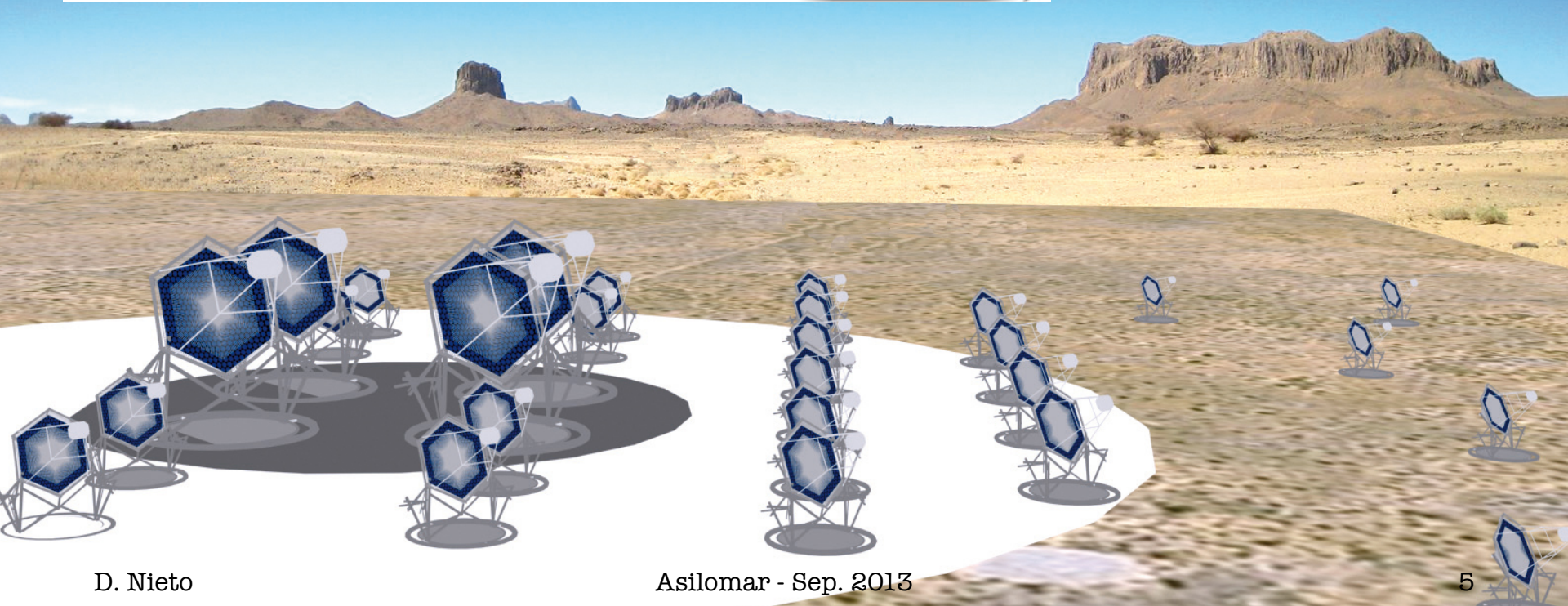
**Mid energy range:**
12 m ø
Davies-Cotton reflector
9 m ø
Schwarzschild-Couder reflector
7° - 8° FoV
**mCrab sensitivity in the 100 GeV – 10 TeV range**

**High energy range:**
4 m ø
Davies-Cotton reflector
(or Schwarzschild-Couder)
9 - 10° FoV
**Several km$^2$ area at multi-TeV energies**

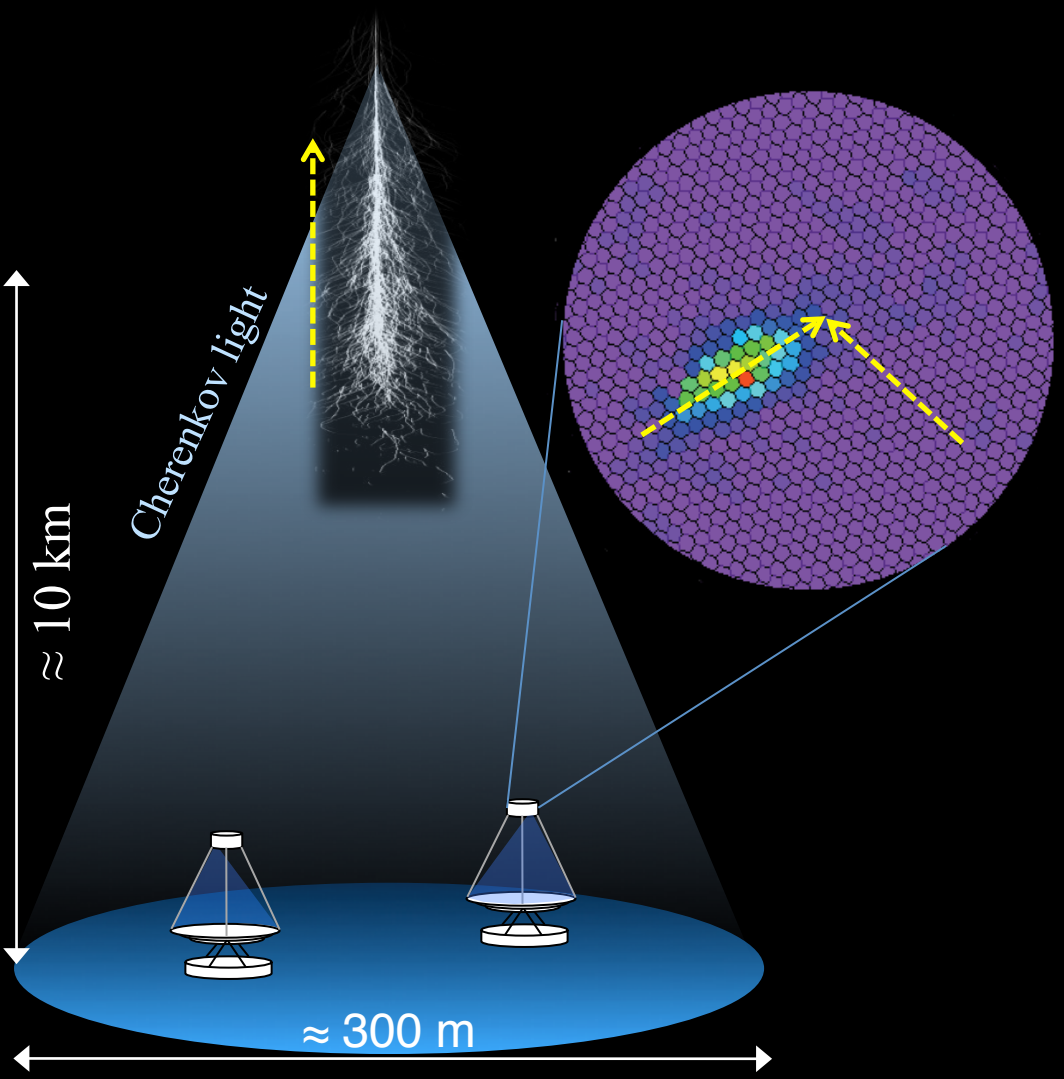


- Worldwide initiative:
  - **>1000** researchers
  - **171** institutions
  - **27** countries



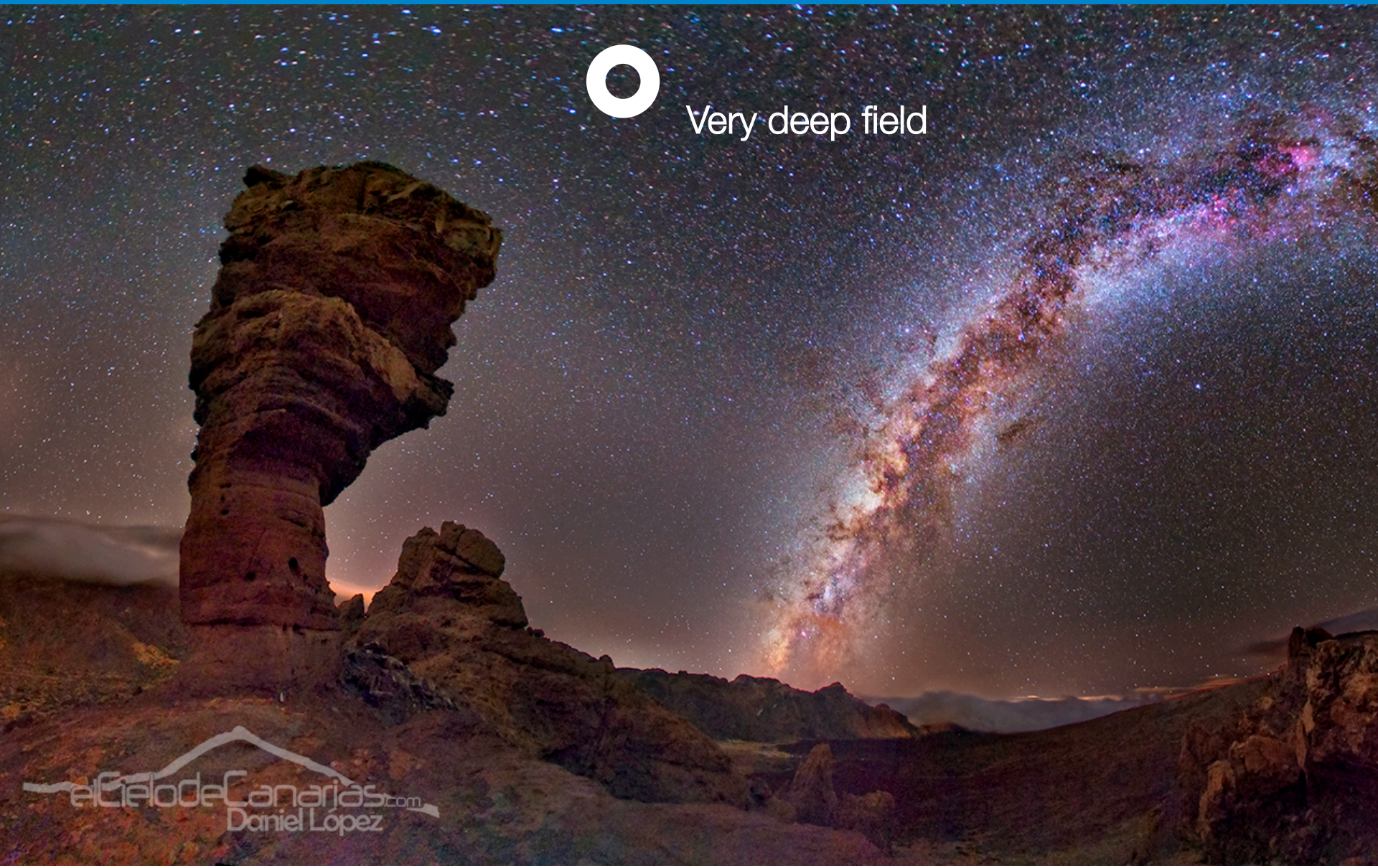



# Detection Technique

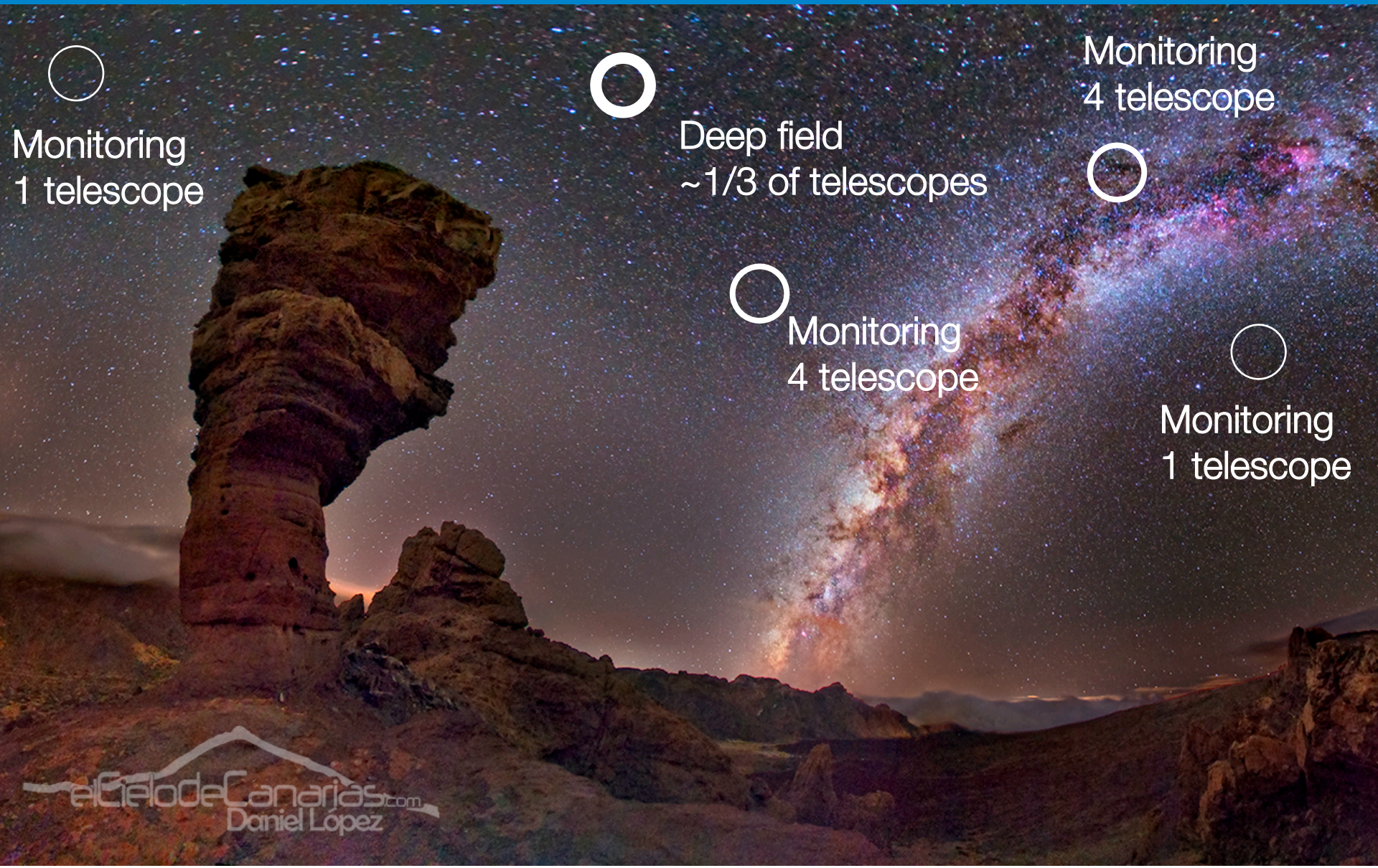



- Detection of extended air showers (EAS) using the atmosphere as a calorimeter
- Huge γ–ray collection area (~$10^5$ $m^2$)
- Large background from charged CR
- Energy window: tens GeV - tens TeV
- Event reconstruction from EAS image:
  - Type of primary event
  - Primary energy estimation
  - Primary arrival direction

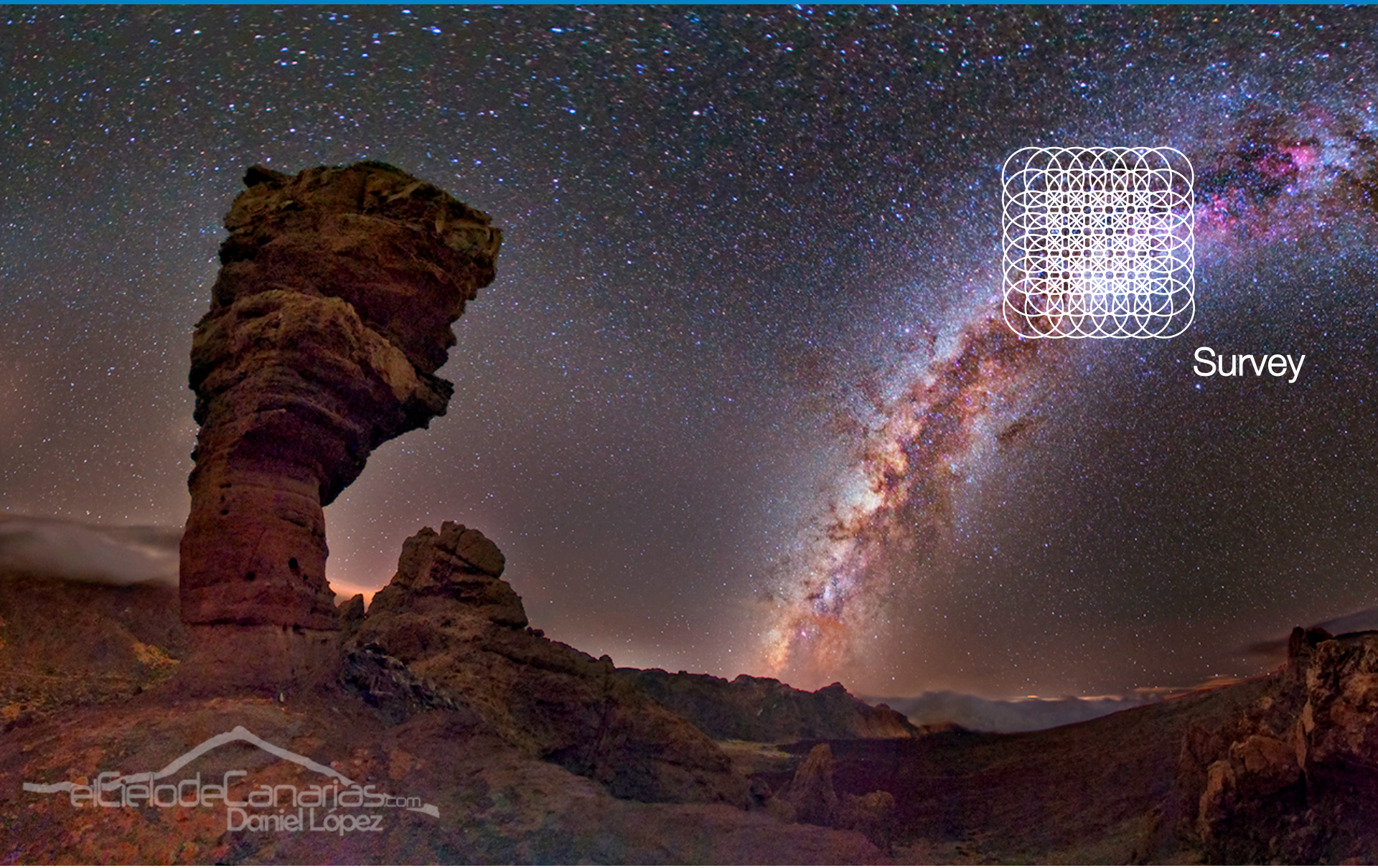
# Observation Modes



# Observation Modes



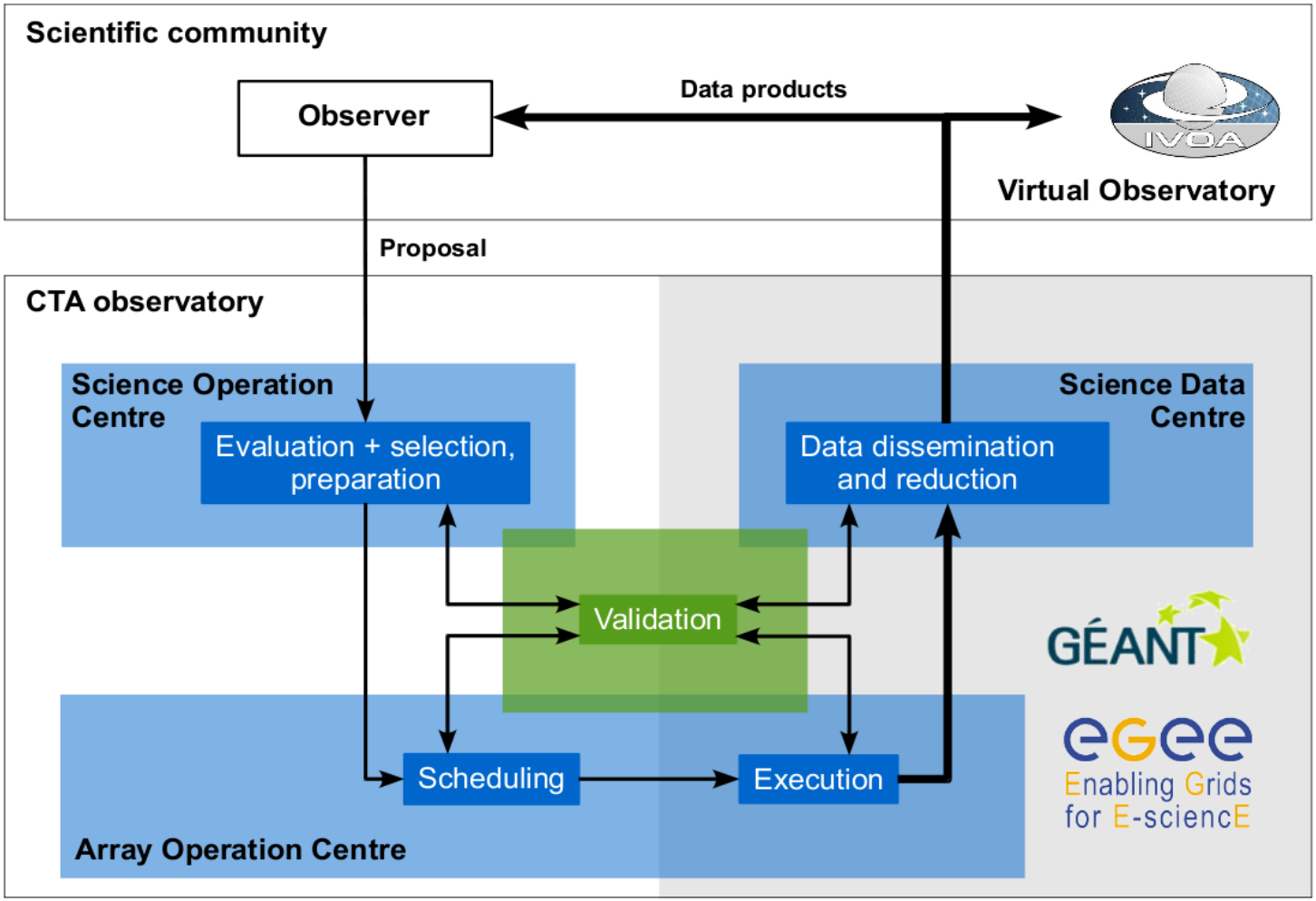
# Observation Modes



# Candidate Sites

# CTA Observatory

The first **open observatory** in the field of IACTs



# Astroparticle Physics Special Issue

**Seeing the High-Energy Universe with the Cherenkov Telescope Array**
**–**
**The Science Explored with the CTA**

## Invited Reviews

- Introducing the CTA concept
- Evolution of ground-based gamma-ray astronomy from the early days to the Cherenkov Telescope Arrays
- **Dark matter and imaging air Cherenkov arrays**
- Probes of Lorentz violation
- Cosmic ray acceleration
- Gamma rays from supernova remnants
- High energy $\gamma$-ray emission from compact galactic sources in the context of observations with the next generation Cherenkov Telescope Arrays
- Studies of active galactic nuclei with CTA
- The extragalactic background light and the gamma-ray opacity of the universe
- Gamma ray bursts
- Multiwavelength Astronomy and CTA: X-rays
- Pionic photons and neutrinos from cosmic ray accelerators
- Multi messenger astronomy and CTA: TeV cosmic rays and electrons

## Detailed Case Studies

- Monte Carlo design studies for the Cherenkov Telescope Array
- **Dark matter and fundamental physics with the Cherenkov Telescope Array**
- Active Galactic Nuclei under the scrutiny of CTA
- Potential of EBL and cosmology studies with the Cherenkov Telescope Array
- Gamma-ray burst science in the era of the Cherenkov Telescope Array
- Gamma-ray signatures of cosmic ray acceleration, propagation, and confinement in the era of CTA
- Prospects for observations of pulsars and pulsar wind nebulae with CTA
- Binaries with the eyes of CTA
- Surveys with the Cherenkov Telescope Array
- Optical intensity interferometry with the Cherenkov Telescope Array
- Comparison of Fermi-LAT and CTA in the region between 10–100 GeV

http://www.sciencedirect.com/science/journal/09276505/43

# Outline

- **The Cherenkov Telescope Array**
- **<u>Dark Matter Detection Prospects</u>**

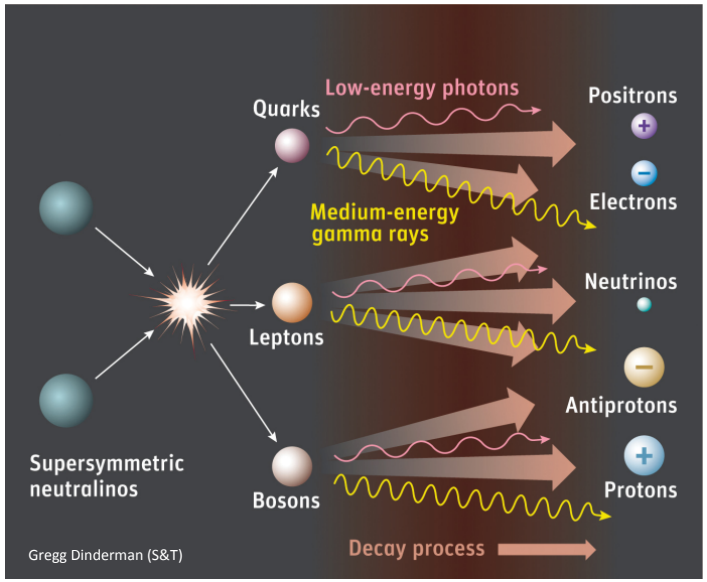
# Indirect Dark Matter Searches

- Basis: Detection of DM annihilation or decay products (SM particles)

- In most cases, entangled with CR and subdominant

- Photons are privileged messengers
  - No deflection by B-fields, trace back to source
  - Observation of astrophysical targets

- Assumptions:
  - DM particle is a WIMP with mass in the few tens of GeV – TeV range.
  - Annihilating DM:




$$\frac{d\Phi}{dE} = J(\Delta\Omega) \times \frac{d\Phi^{PP}}{dE} = \int_{l.o.s,V} \rho_{DM}^2(l)\, d\Omega\, dl \times \frac{1}{4\pi} \frac{\langle \sigma_{ann} v \rangle}{2 m_{DM}^2} \sum_i B_i \frac{dN_i^\gamma}{dE}$$

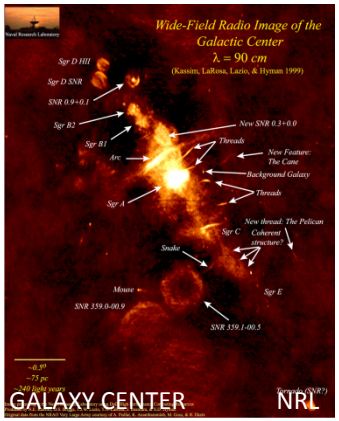
# DM Targets for CTA

$$\frac{d\Phi}{dE} = J(\Delta\Omega) \times \frac{d\Phi^{PP}}{dE} = \int_{l.o.s,V} \rho_{DM}^2(l)\, d\Omega\, dl \times \frac{1}{4\pi} \frac{\langle \sigma_{ann} v \rangle}{2 m_{DM}^2} \sum_i B_i \frac{dN_i^\gamma}{dE}$$

Key concepts: $\rho_{DM}$, distance, background

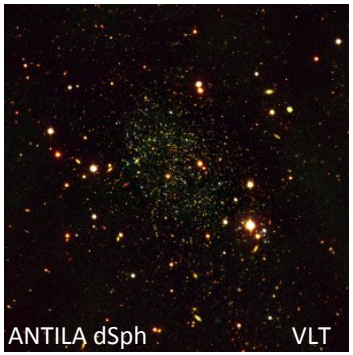
Galactic Center & Halo

- High flux
- Background Issues



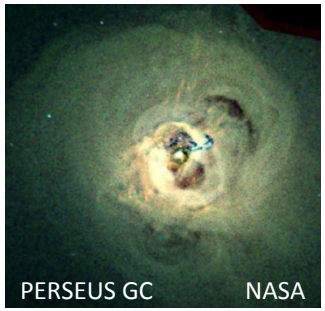

Dwarf Galaxies

- Large M/L
- No background
- Low flux




Galaxy Clusters

- Huge DM content
- Large distance
- High background

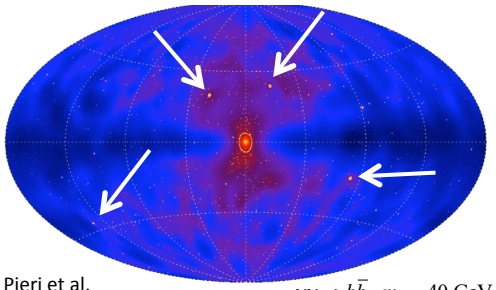



Unassociated HE Sources:

- DM Subhalos?

**Poster Session**

**ID 90**



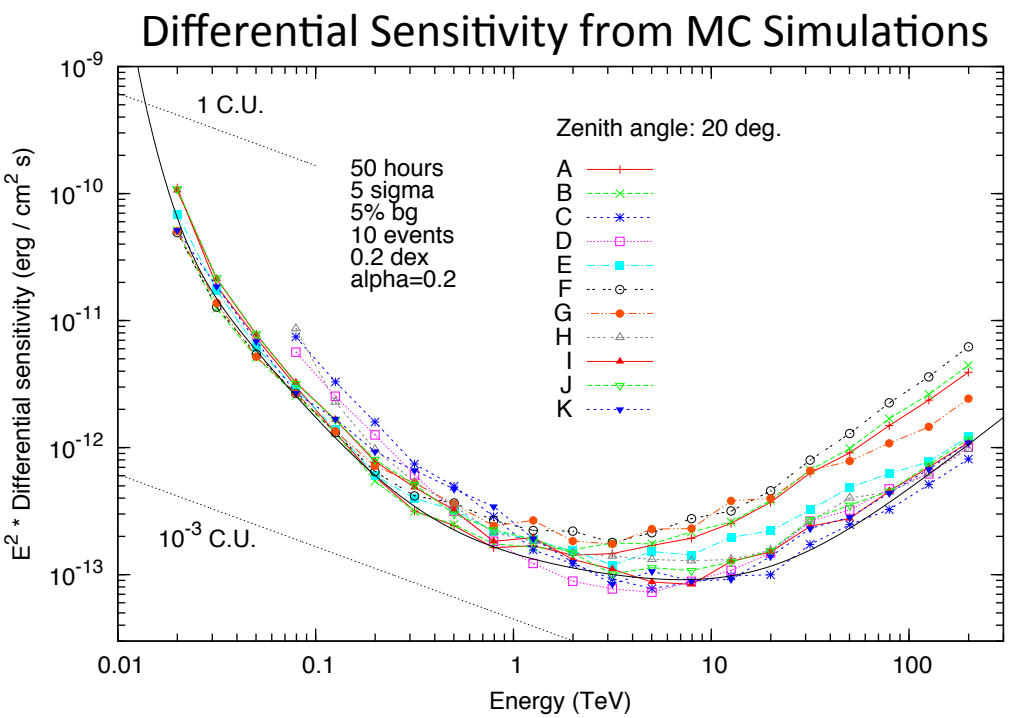
Pieri et al.
PRD 83:0235,

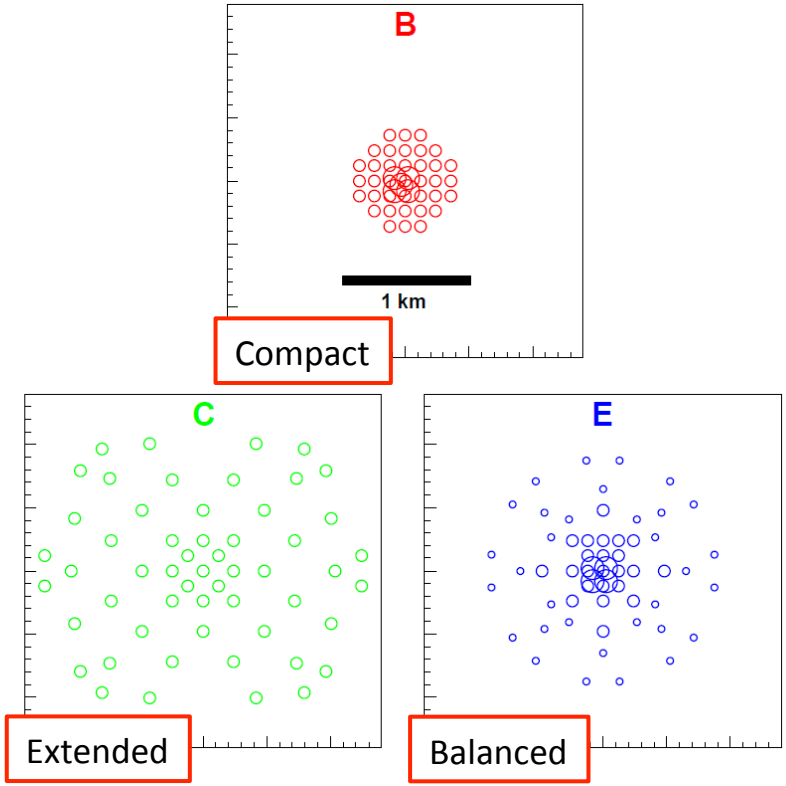
$\chi\chi \to b\bar{b},\ m_\chi = 40$ GeV

# CTA Layout Performance Evaluation

$$\frac{d\Phi}{dE} = J(\Delta\Omega) \times \frac{d\Phi^{PP}}{dE} = \int_{l.o.s,V} \rho_{DM}^2(l)\, d\Omega\, dl \times \frac{1}{4\pi} \frac{\langle \sigma_{ann} v \rangle}{2 m_{DM}^2} \sum_i B_i \frac{dN_i^\gamma}{dE}$$

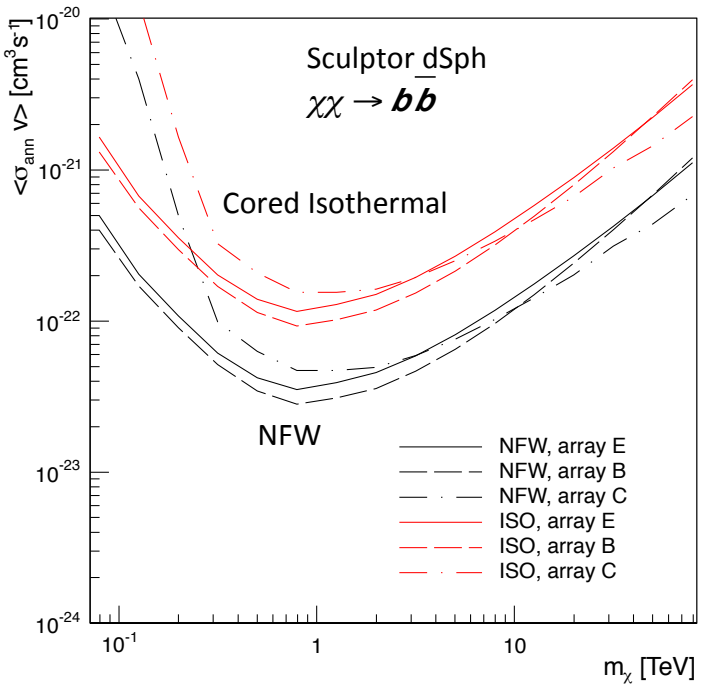
DM Targets: dSph Galaxies, Galaxy Clusters, Galactic Halo



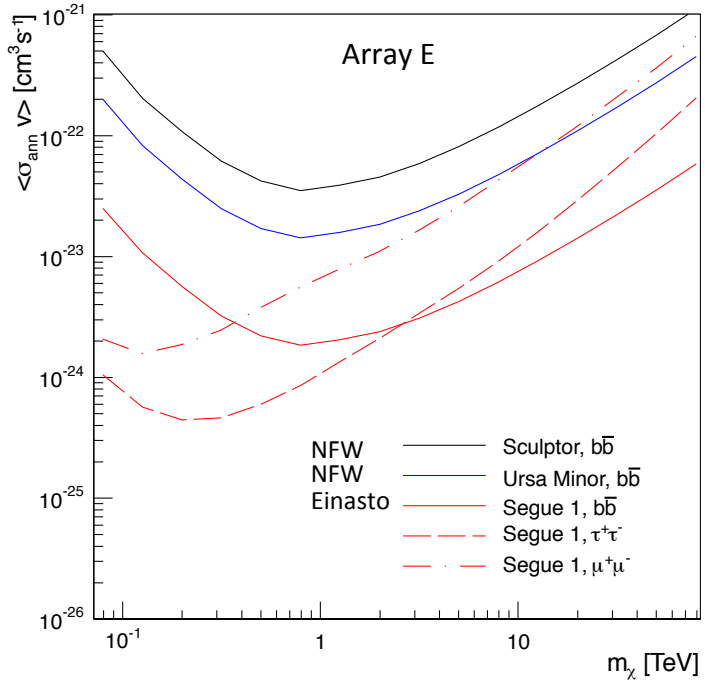



# dSph Galaxies

## Prospects vs. Profile




## Classical vs. Ultra-Faint




| dSph | Dec. [deg] | D [kpc] | $\tilde{J}$ [GeV$^2$ cm$^{-5}$] | Profile |
|---|---|---|---|---|
| Ursa Minor | +44.8 | 66 | $2.2 \times 10^{18}$ | NFW |
| Draco | +34.7 | 87 | $7.1 \times 10^{17}$ | NFW |
| Sculptor | −83.2 | 79 | $8.9 \times 10^{17}$ | NFW |
| | | | $2.7 \times 10^{17}$ | ISO |
| Carina | −22, 2 | 101 | $2.8 \times 10^{17}$ | NFW |
| Segue 1 | +16.1 | 23 | $1.7 \times 10^{19}$ | Einasto |
| Willman 1 | +51.1 | 38 | $8.4 \times 10^{18}$ | NFW |
| Coma Berenices | +23.6 | 44 | $3.9 \times 10^{18}$ | NFW |

100h obs.
$\Delta\Omega = 10^{-5}$ sr (0.1° FoV)
Integral flux U.L., 95% C.L.

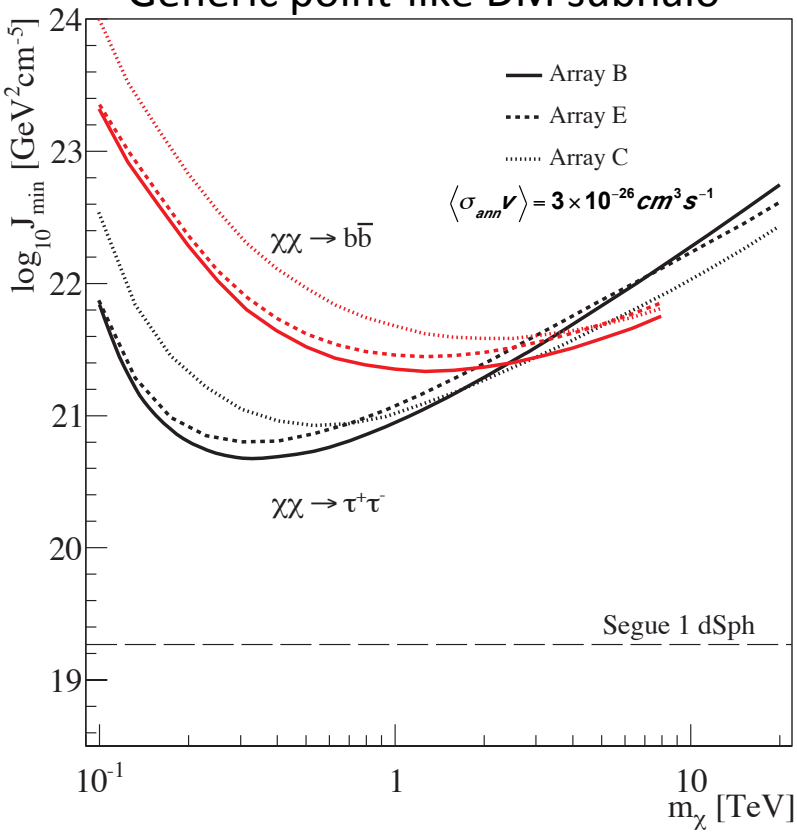
# dSph Galaxies

Boost factors required for detection

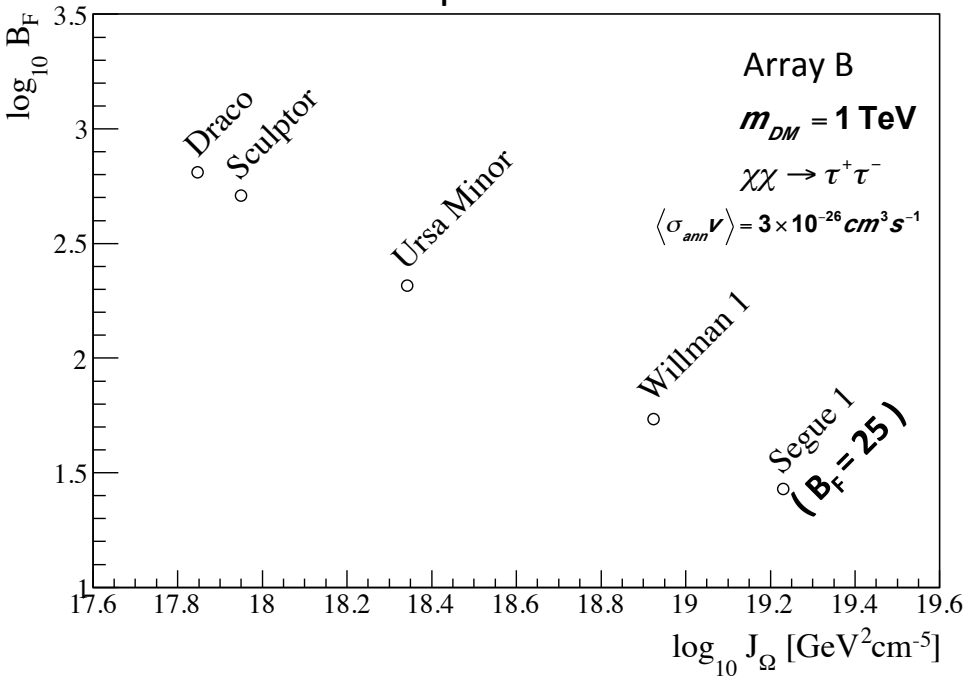
$$\frac{d\Phi}{dE} = B_F \times J(\Delta\Omega) \times \frac{d\Phi^{PP}}{dE}$$

5σ detection in 100h obs.

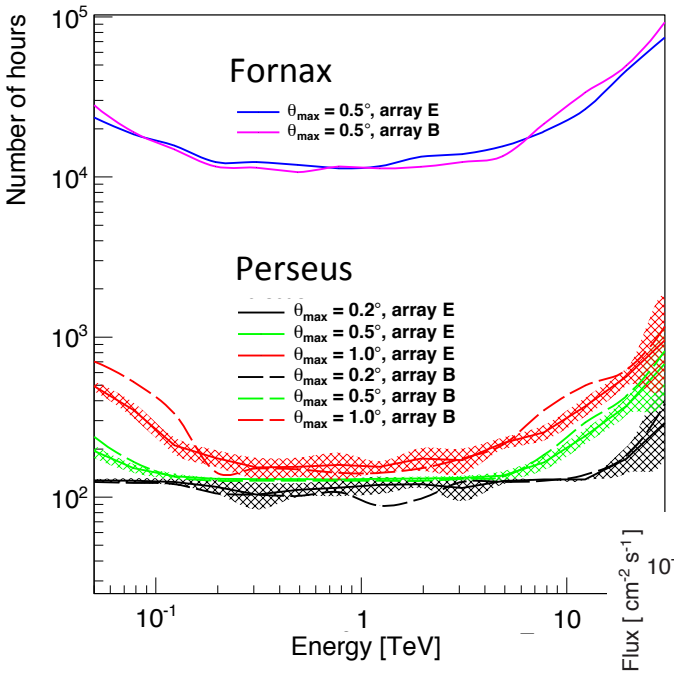
Generic point-like DM subhalo




dSph Galaxies



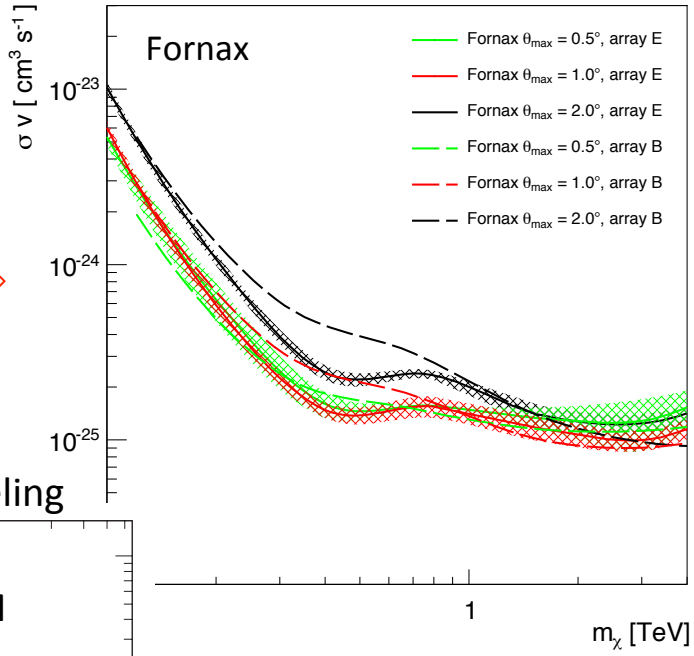
# Cluster of Galaxies




Required obs. time for 5σ detection

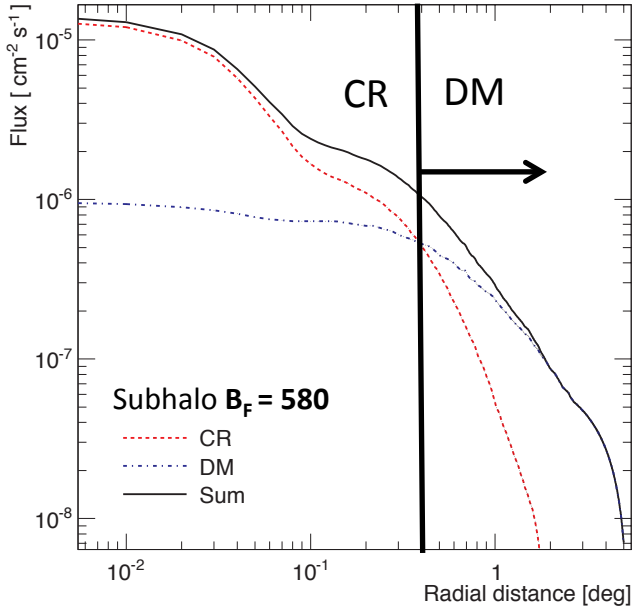
**Cosmic rays only**

**Dark matter only**




100h obs.
Integral flux U.L., 95% C.L.

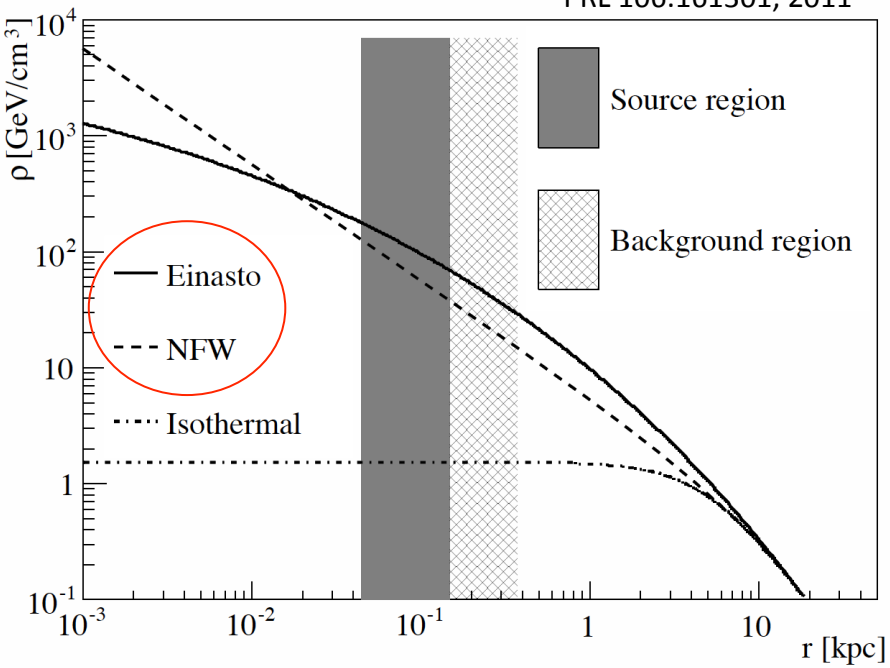
Fornax cluster modeling




Model adapted from Pinzke et al. 2011

# Galactic Halo

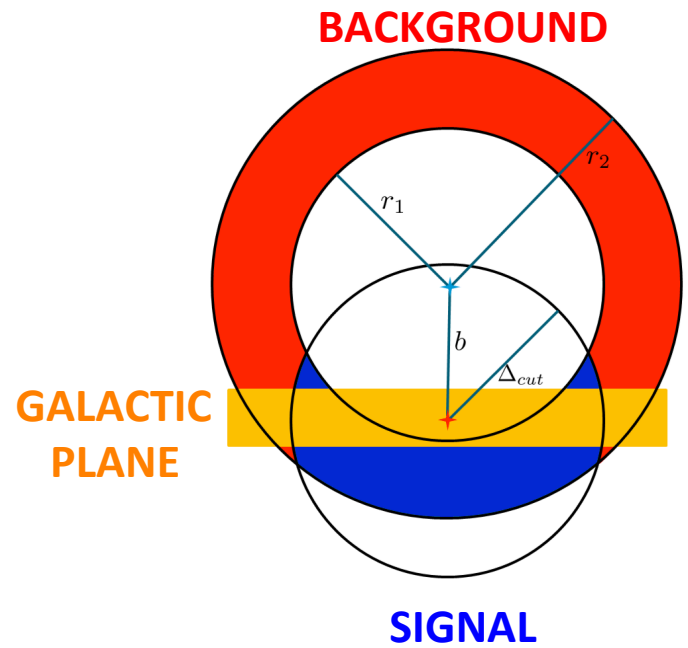
PRL 106:161301, 2011




| Method | Array (TeV) | $m_\chi$ | $\tilde{J}_s$ ($10^{22}$ GeV$^2$ cm$^{-5}$) | $\Delta\Omega$ (sr) |
|---|---|---|---|---|
| Ring | $E$ | Any | 4.68 | 0.00117 |
| | $B$ | Any | 4.43 | 0.00104 |
| On–off | $E$ | 0.1 | 16.4 | 0.00751 |
| | | 1 | 19.7 | 0.01044 |
| | | 10 | 28.7 | 0.02211 |
| On–off | $B$ | 0.1 | 16.4 | 0.00751 |
| | | 1 | 22.8 | 0.01384 |
| | | 10 | 28.7 | 0.02211 |

## Observational Strategies

a) Ring Method:
(ring of same instrumental acceptance)

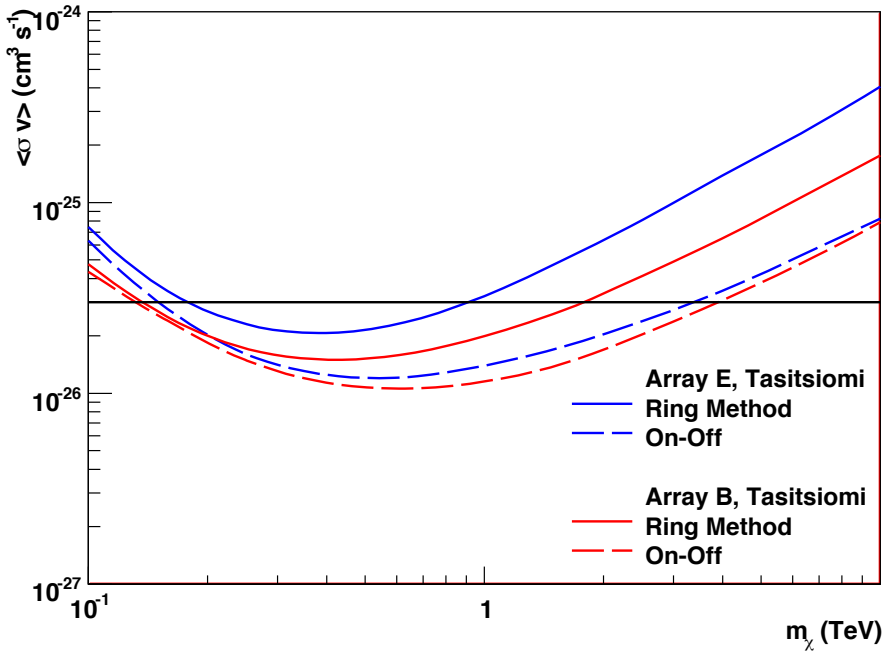



b) On-Off Method:

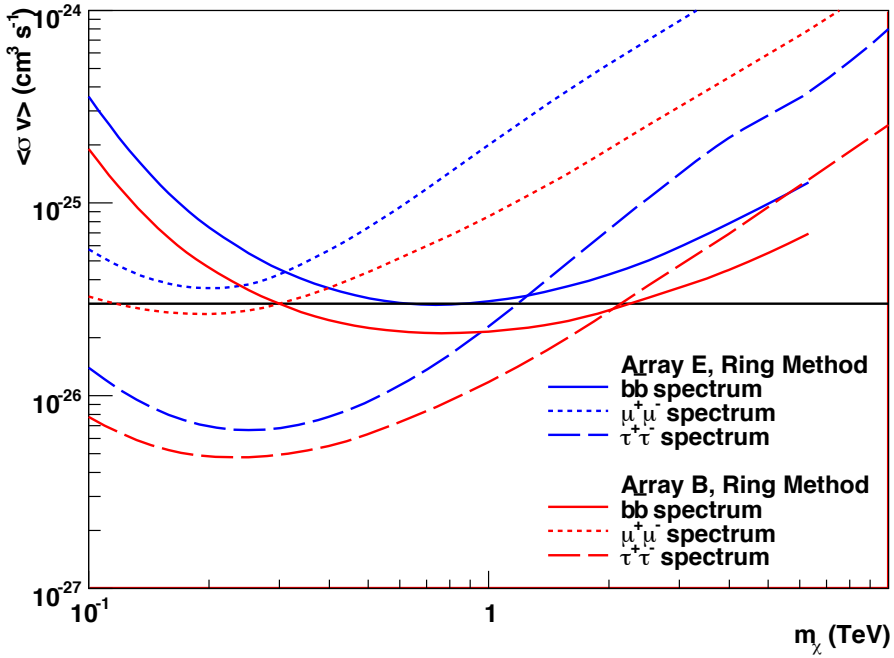
- More sensitive
- Challenging background control

# Galactic Halo

On-Off method vs. Ring method




Ring method, channel dependence

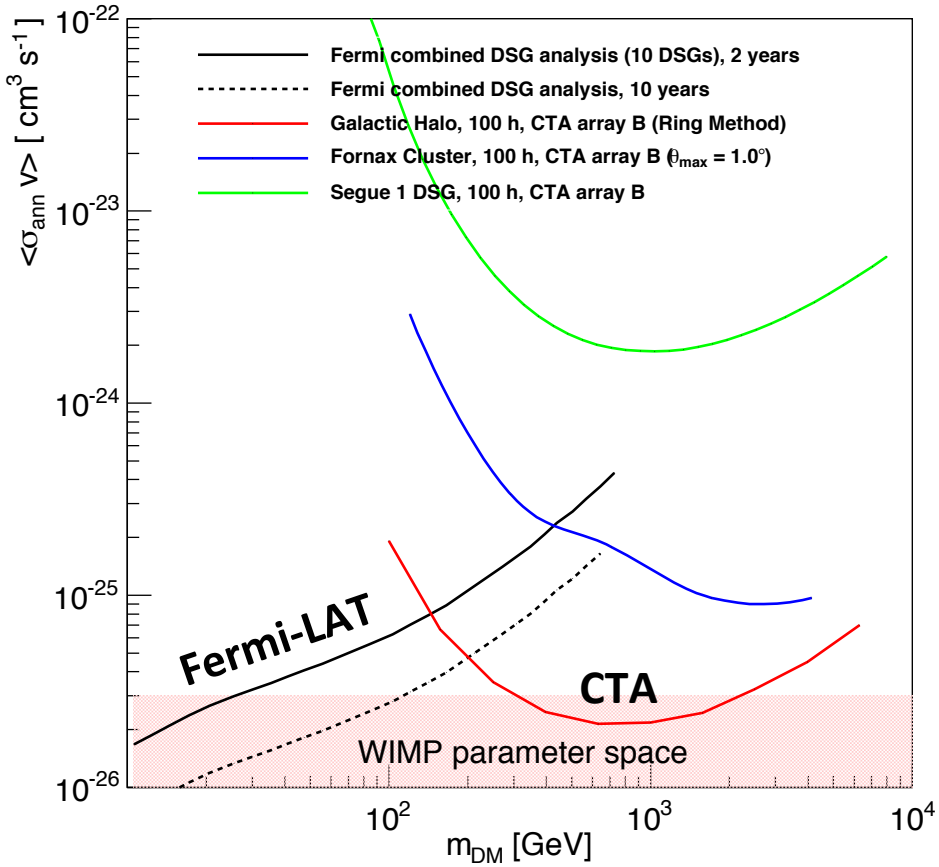



Ring Method: 100h obs.
On-Off Method: 50h+50h obs.

**Probing canonical annihilation cross-section sector!**

# CTA Prospects & Complementarity

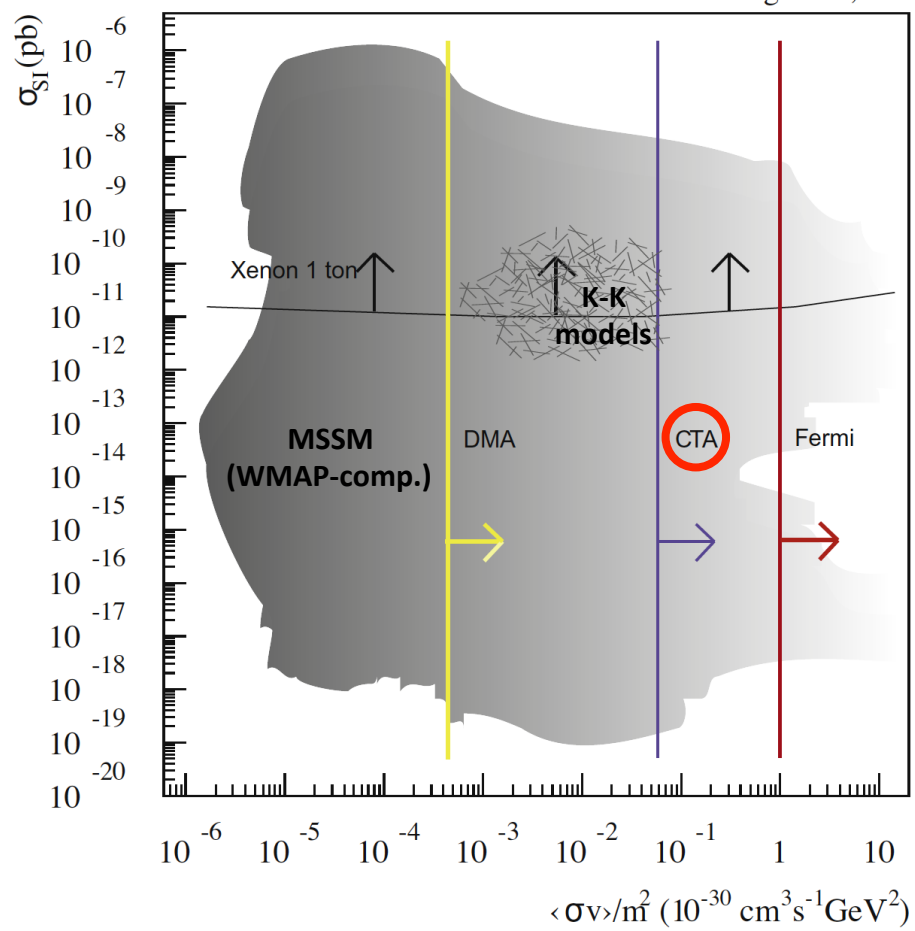
## Indirect Searches in the γ-Ray Band




## Indirect vs. Direct Searches

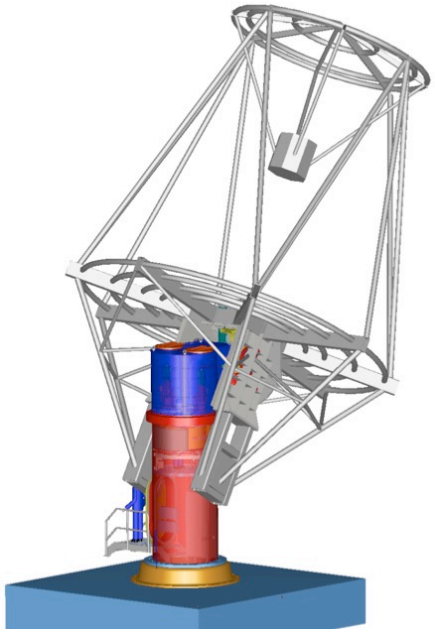
(Galactic Center, NFW)

L. Bergström, 2011

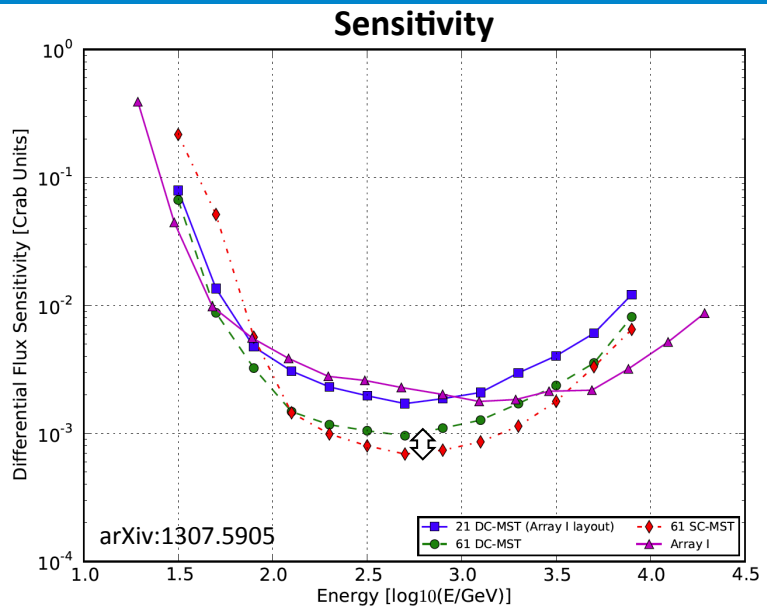


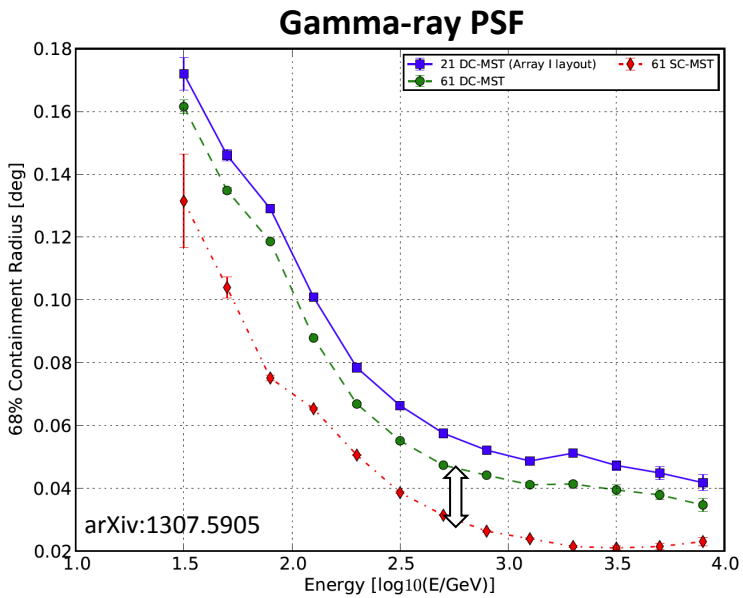
# US Contribution to CTA

**Schwarzschild-Couder Mid-Size Telescope**
(28 units)



- Double-mirror optics, novel design
- Wide FoV (8°) with a good optical PSF
- More compact plate scale: finer pixelization
- Enhancing CTA in the core-energy range
- Prototype funded by MRI Program (NSF)



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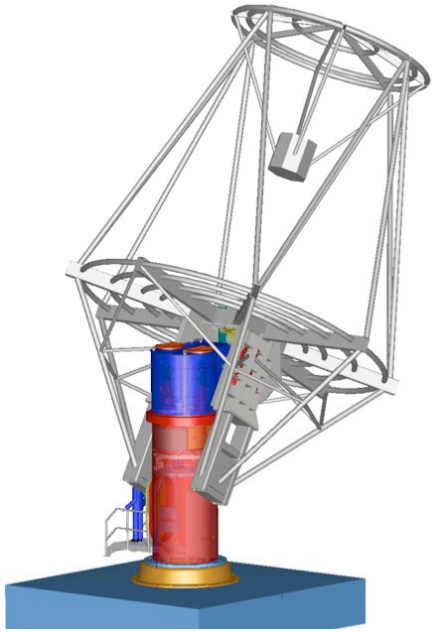
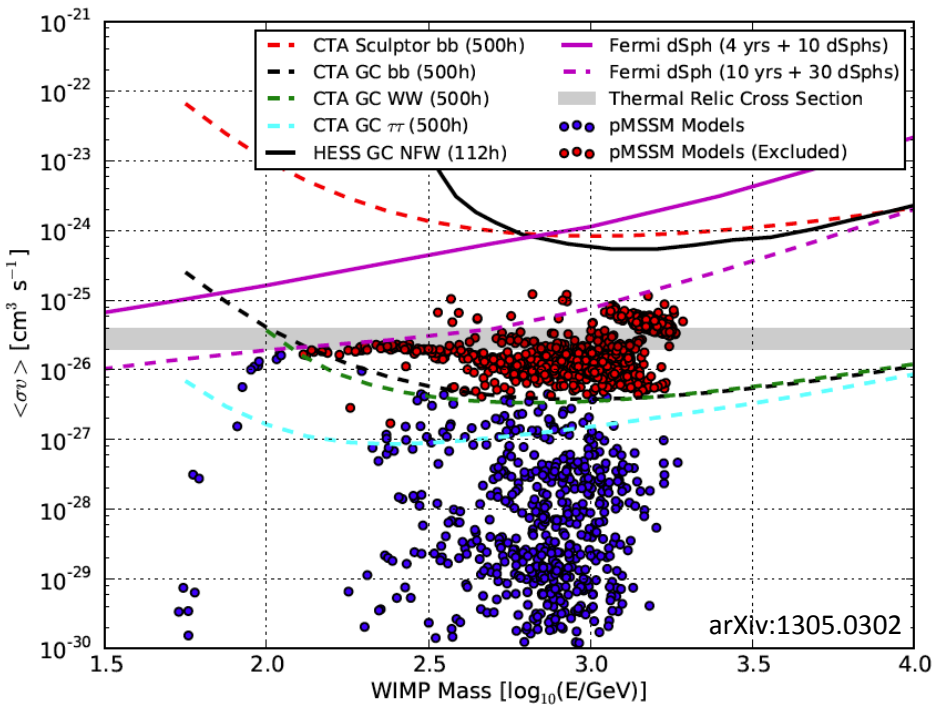


Impact on dark matter searches

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- Wide FoV (8°) with a good optical PSF
- More compact plate scale: finer pixelization
- Enhancing CTA in the core-energy range
- Prototype funded by MRI Program (NSF)

500h obs.
61 MST Array
(25 DCs + 36 SCTs)

# Conclusions

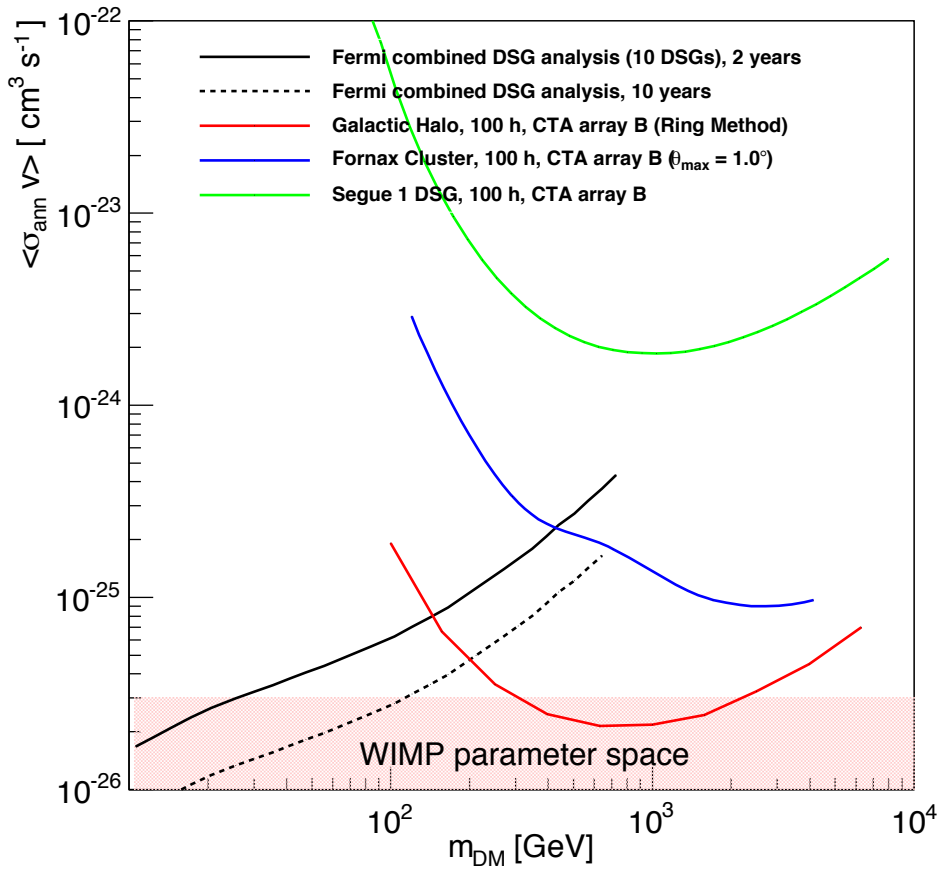
- CTA is the worldwide project for a future VHE gamma-ray **open observatory**, heading towards starting **construction by 2014**.
- dSph Galaxies:

  $\langle \sigma_{ann} v \rangle \sim 10^{-24} cm^3 s^{-1}$

  BF=25 (Segue 1)
- Galaxy Clusters

  $\langle \sigma_{ann} v \rangle \sim 10^{-25} cm^3 s^{-1}$

  CR background, extended emission
- **Galactic Halo**

  $\langle \sigma_{ann} v \rangle \sim 10^{-26} cm^3 s^{-1}$

  **Probing the WIMP parameter space!**
- **Complementarity** with Fermi-LAT and direct searches
- **US-contribution**: Remarkable enhancement in **sensitivity** and **angular resolution**