cta cherenkov telescope array

Fundación BBVA

Dark Matter Searches with Cherenkov Telescope Array

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On behalf of the CTA consortium

Project supported by a 2018 Leonardo Grant for Researchers and Cultural Creators, BBVA Foundation

CIEMAT / UPM, Madrid

Outline

Very-High-Energy Gamma-ray astronomy

Cherenkov Telescope Array (CTA)

Expectations on Indirect Dark Matter Searches

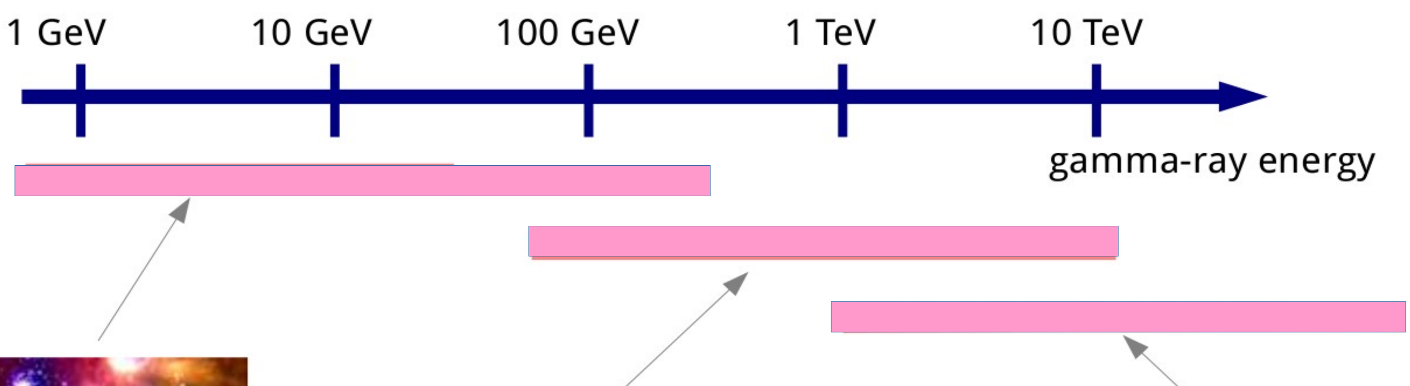
- **Galactic Center**
- **Dwarf Spheroidal Galaxies**
- **Large Magellanic Cloud**

Conclusion

Gamma-Rays Instruments

Earth's atmosphere is opaque for gamma-rays

Direct detection in space ⟷ Indirect detection from ground



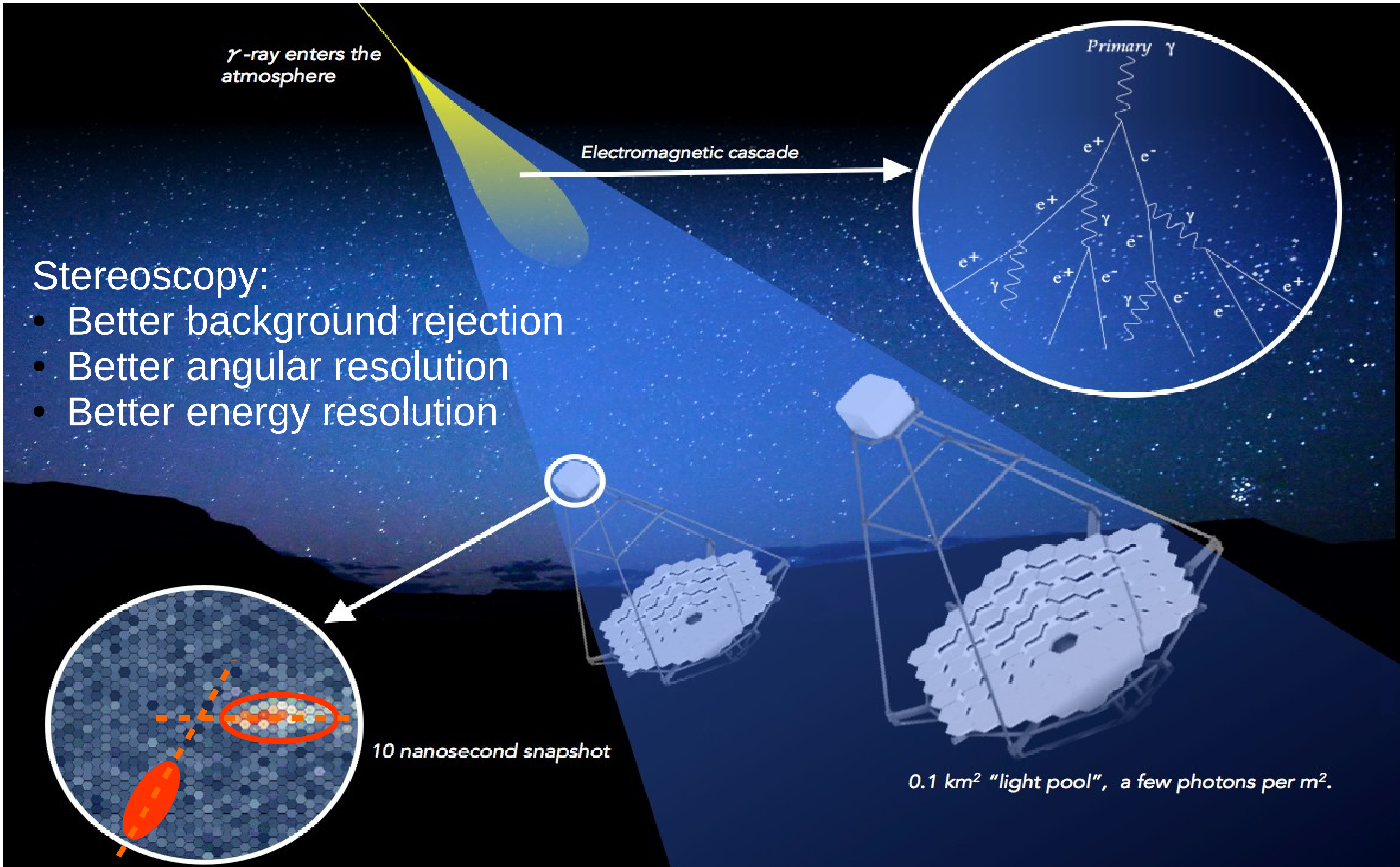
Satellites

Cherenkov telescopes

Water Cherenkov detectors

Stereoscopic Detection

Stereoscopy:
- Better background rejection
- Better angular resolution
- Better energy resolution



Objective of CTA Project

Objective of CTA with respect to current instruments

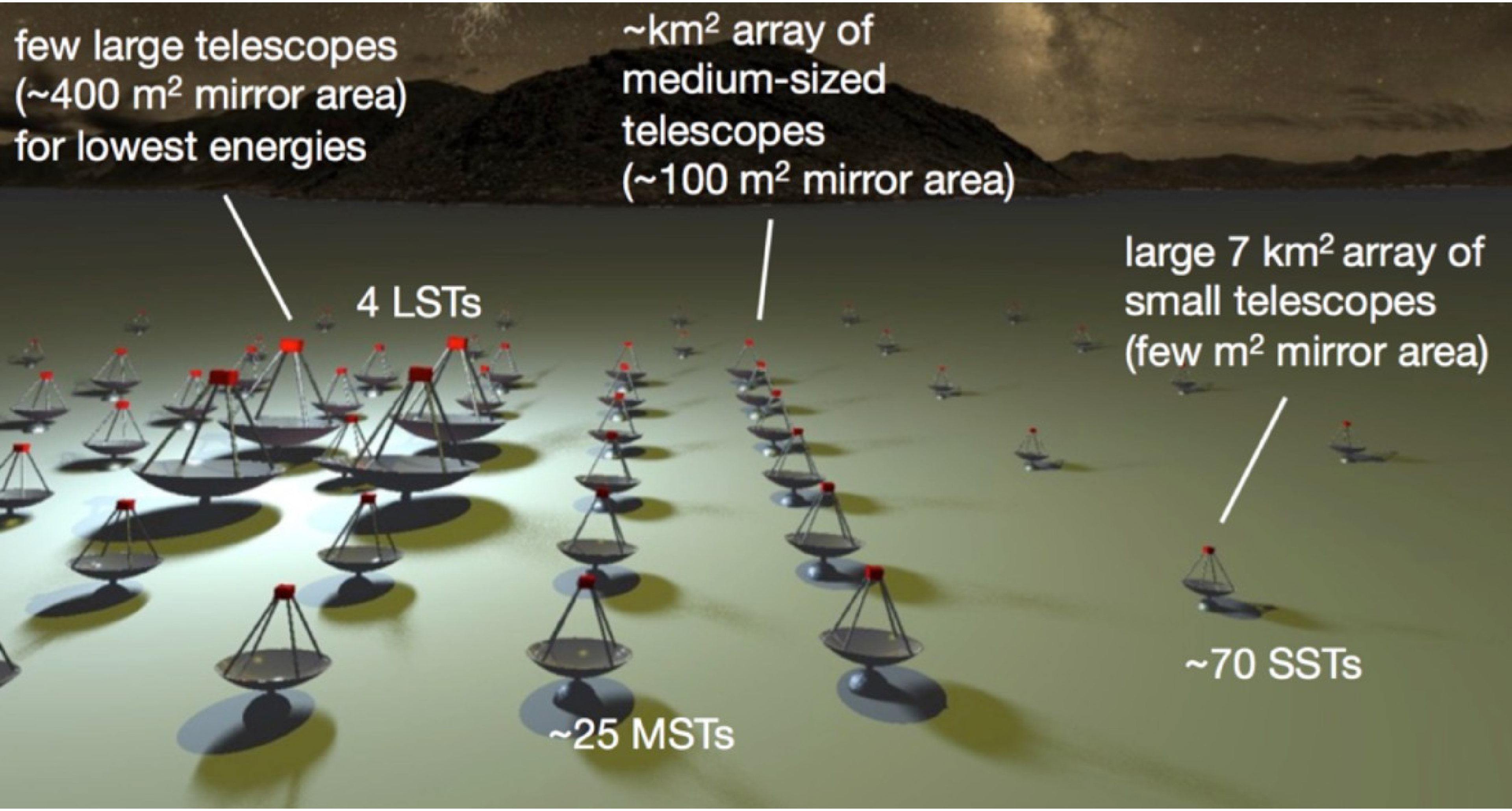
- Improve sensitivity by an order of magnitude
- Extend energy range ~20 GeV to ~300 TeV
- Improve resolution: energy (10% @ 1TeV), angular (0.1° @ 1TeV)
- Survey full sky
- Observe fast transient phenomena
- Operate as open observatory (accept proposal)

Allow VHE gamma-ray astronomy to
transit from source discovery to detailed source investigation

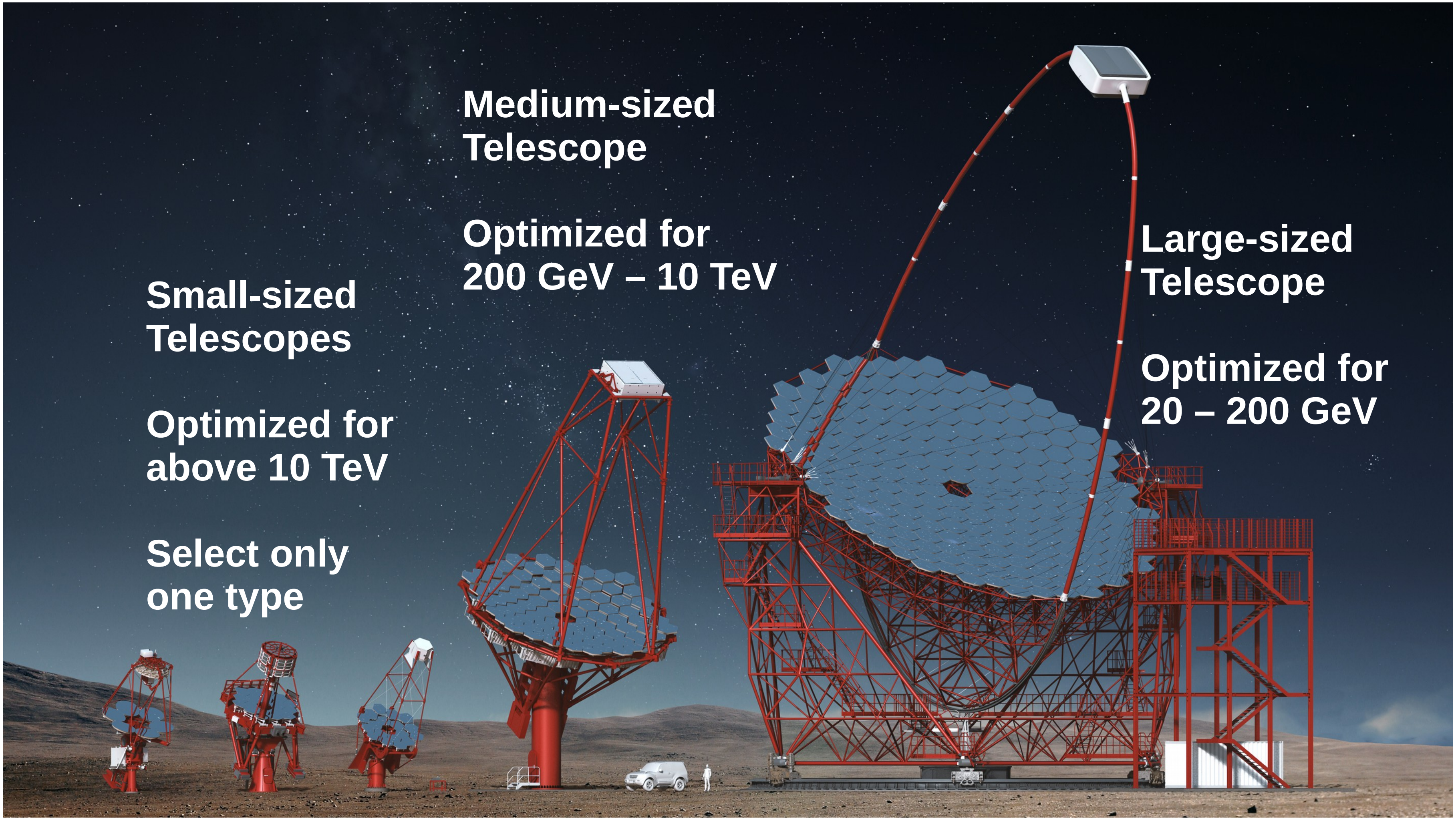
How to reach objective

- Build array of telescopes
- Use different telescope sizes
- Operate on sites in both hemispheres
- Improve collection area

CTA Concept


few large telescopes
(~400 m² mirror area)
for lowest energies
4 LSTs
~km² array of
medium-sized
telescopes
(~100 m² mirror area)
large 7 km² array of
small telescopes
(few m² mirror area)
~70 SSTs
~25 MSTs

CTA Telescope Types

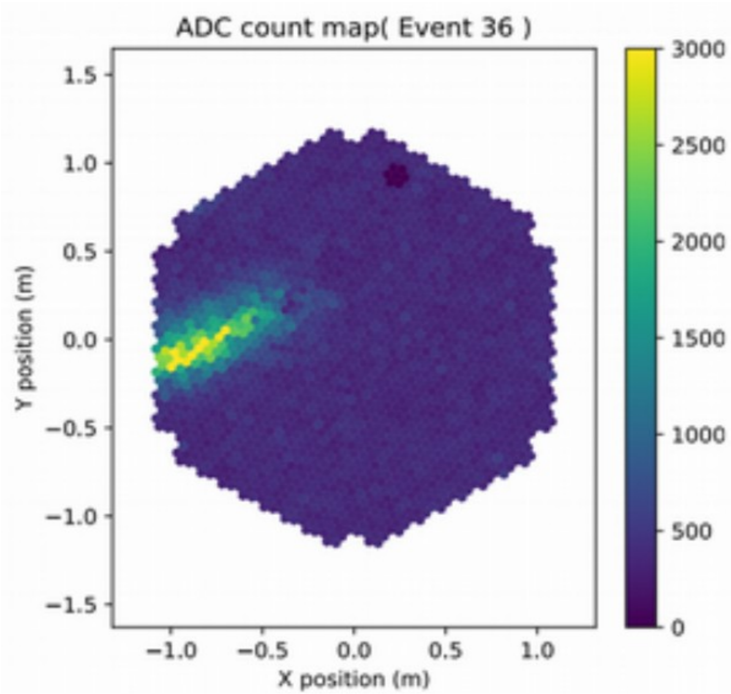


Three different sizes of telescope optimized for three different energy ranges

Large Size Telescope Status

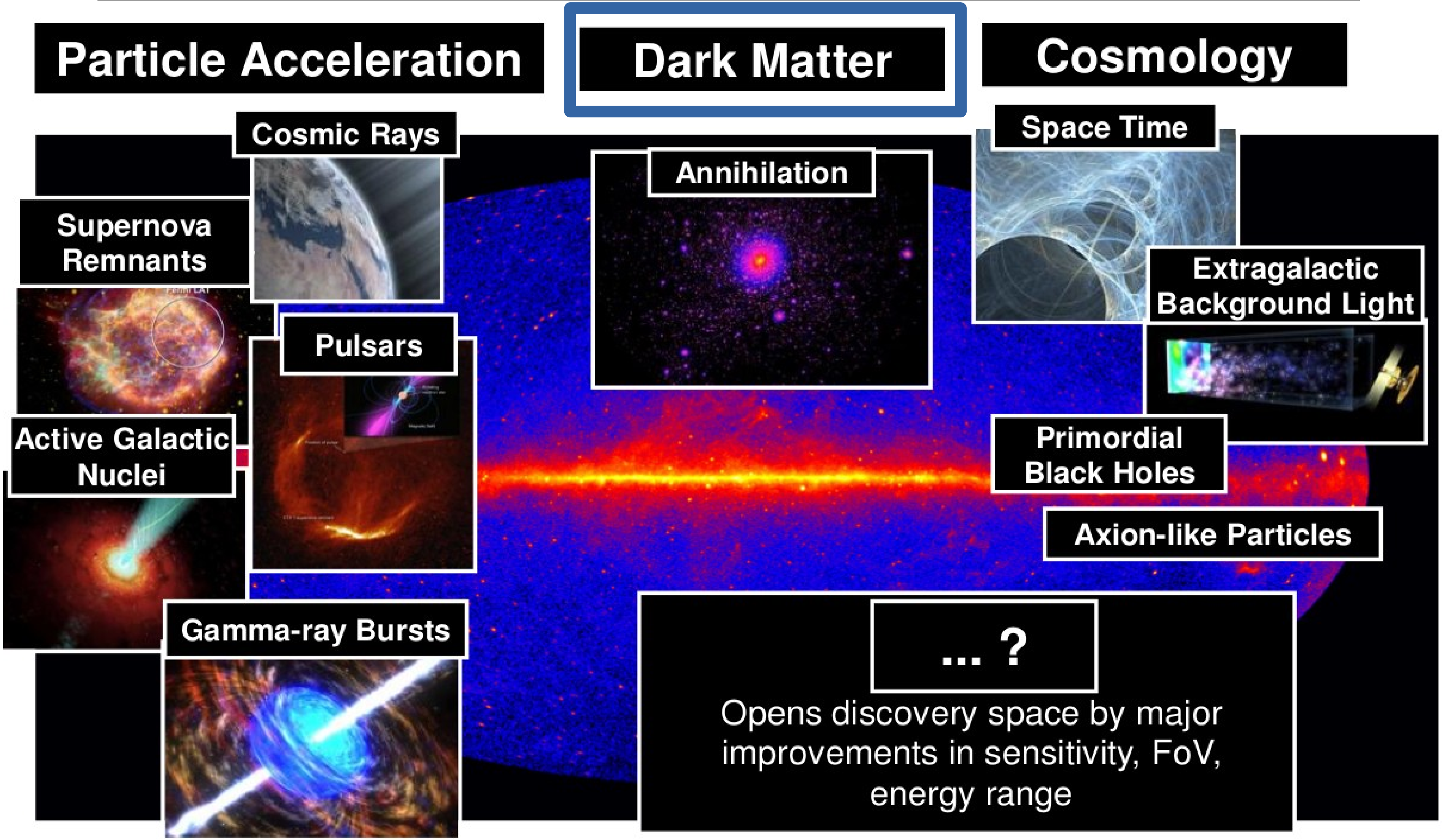
Inauguration October 2018

Events December 2018



1st Large size telescope is in commissioning phase
Small and medium size telescope prototypes exist
Construction expected to be ready at northern site around 2022-2023

Science Themes: Dark Matter



Dark Matter Evidence

Fritz Zwicky (1933, “dunkle Materie”)

Missing mass (at different scales):

- **Rotation curves, galactic dynamics**
- **Cluster dynamics**
- **Gravitational lensing**
- **Cluster collision, Bullet Cluster**

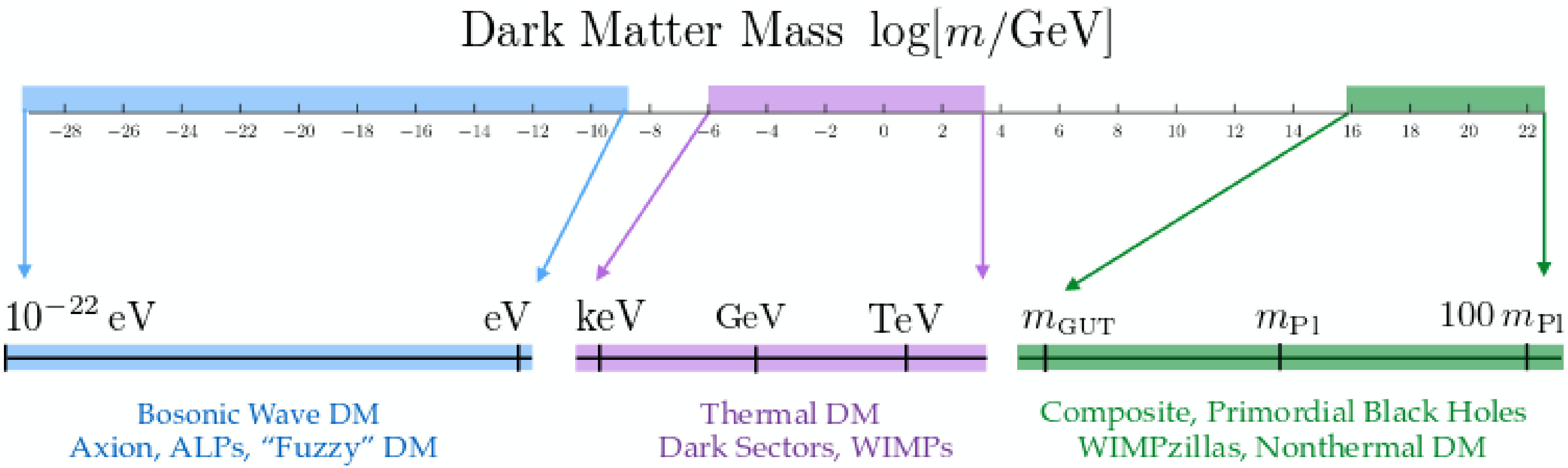
Cosmic microwave background

Formation and evolution of galaxies

Etc.

Dark Matter Models

Classification of dark matter models according to mass

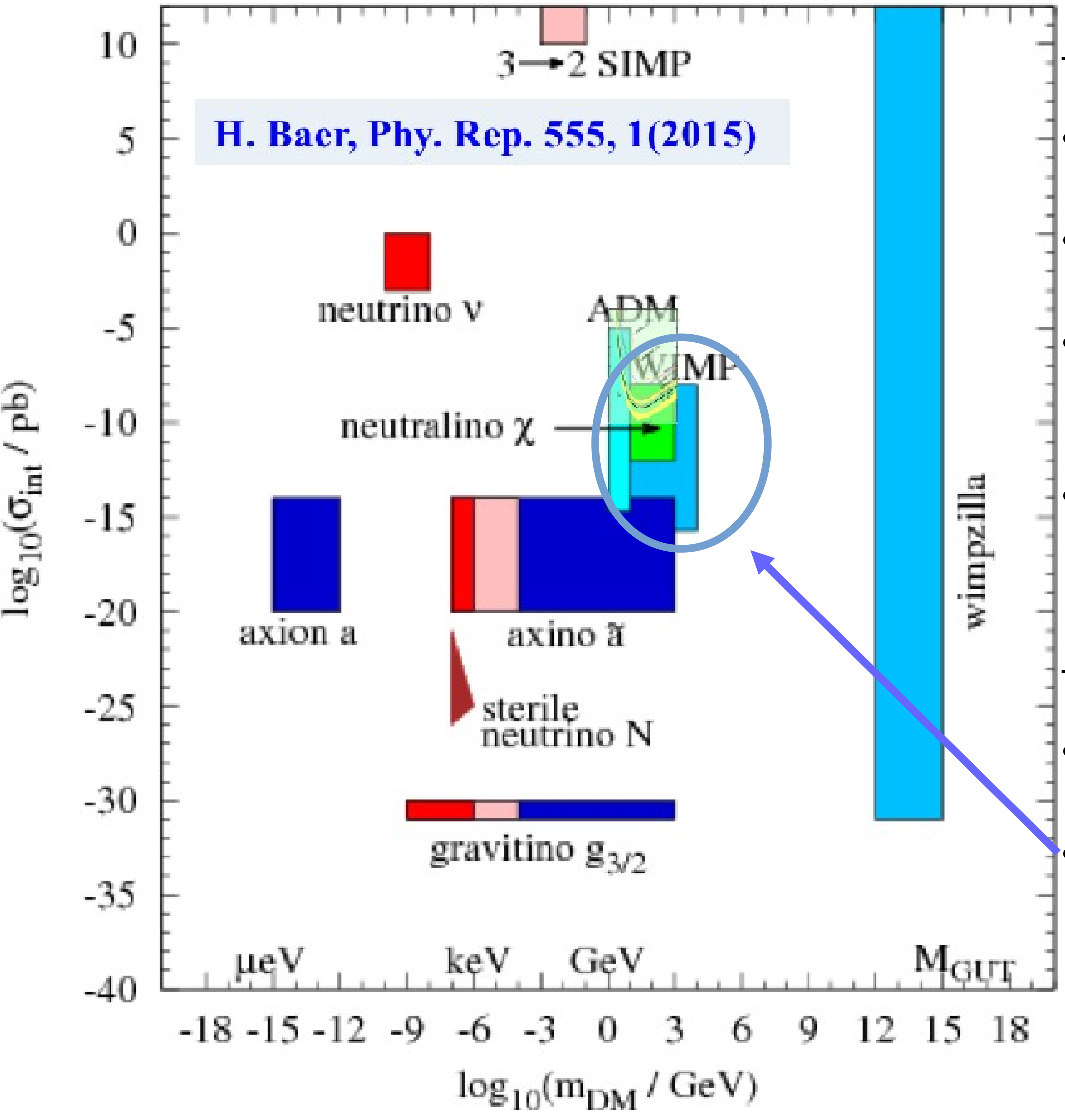


< 10^{-22} eV
DM wavelength
too large
to fit inside ~kpc
dwarf galaxies

keV – 100 TeV range
DM in thermal
equilibrium with
SM in early universe

Taken from arxiv:1903.00492

Dark Matter Models



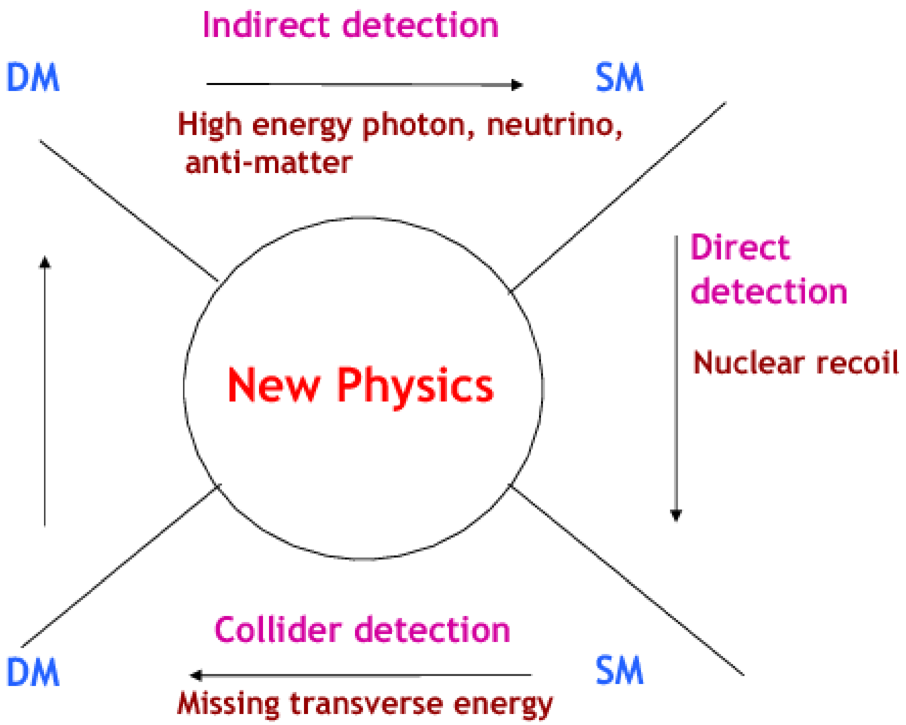
Dark matter seems to be:

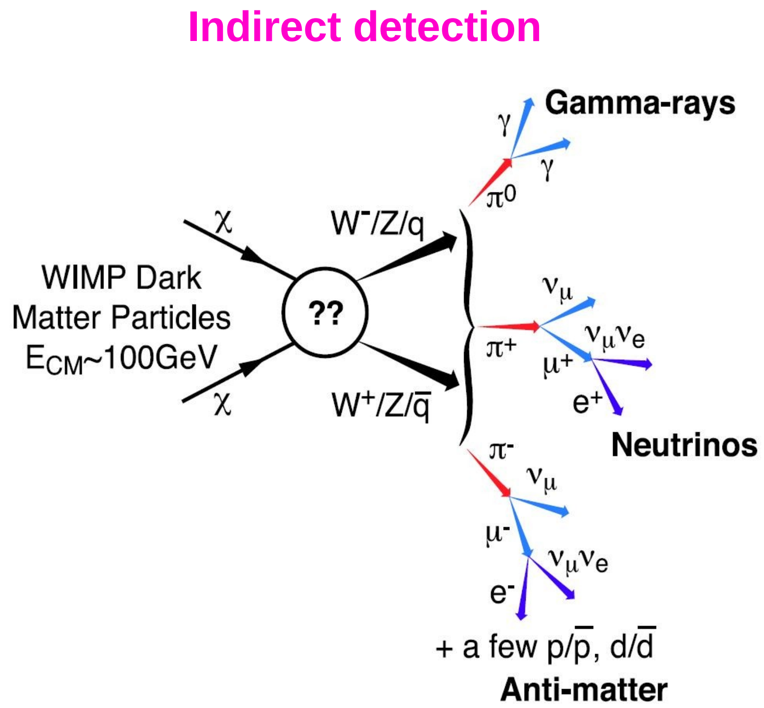
- Massive, gravitational attraction
- Dark, no (tiny) interaction with γ
- Non or (very weak) interaction with standard model particles
- Cold, slow-moving, build structure

Primary dark matter candidate:

- Undiscovered particle(s)
- **W**eakly **I**nteracting **M**assive **P**artilces (WIMPs)

Indirect Dark Matter Detection





Methods of dark matter search
Multidisciplinary approach: Synergy of
(1) direct
(2) indirect
(3) accelerator
Goal: Identify DM

DM annihilation

SM channels: b, W, Z, τ, etc
↓
Hadronization,decay,radiation
↓
Final state: γ, ν, e, p

Annihilation of Dark Matter

Astrophysics

spectrum

$$\frac{d\Phi(b,\ell)}{dE_\gamma} = \boxed{\frac{\langle \sigma v \rangle_{b\bar{b}}}{8\pi m_\chi^2}} \frac{dN_\gamma}{dE_\gamma} \boxed{\int_{\text{los}} dx\, \rho^2 \left(r_{\text{gal}} \left(b, \ell, x\right)\right)}$$

Particle Physics

Particle physics input from extension of Standard Model

Astrophysics (J-factor):

DM density distribution obtained from N-body simulations of DM clustering (Need to specify distribution of DM along line of sight)

Annihilation ~ ρ·ρ
Decay ~ ρ

Indirect Dark Matter Searches

<u>Difficult to distinguish between:</u>

- **Dark Matter content**
- **Astrophysical background**

<u>Targets with different systematics:</u>

- **Galactic Halo**
  + large DM statistics
  – diffuse astrophysical background
  – astrophysical source confusion

- **Dwarf Spheroidal Galaxies**
  – low DM statistics
  + low astrophysical background
  with small uncertainty

- **Spectral Lines**
  + No background => smoking gun
  – very low DM statistics

- **Galaxy Clusters**
  + independent crosscheck
  – astrophysical background

Observation in Key Science Projects

Key science projects:

Galactic Center Survey
500 h (center)
+300 h (10º * 10º)

Dwarf Spheroidal Galaxies (dSph):
100 h (each)

Large Magellanic Cloud (LMC):
300 h (in six pointings)

Etc.

DM search strategy (program of 10 years)

First 3 years
- **Observation of galactic halo (~500 h)**
- **Additional obs. of best dSph (~300 h)**

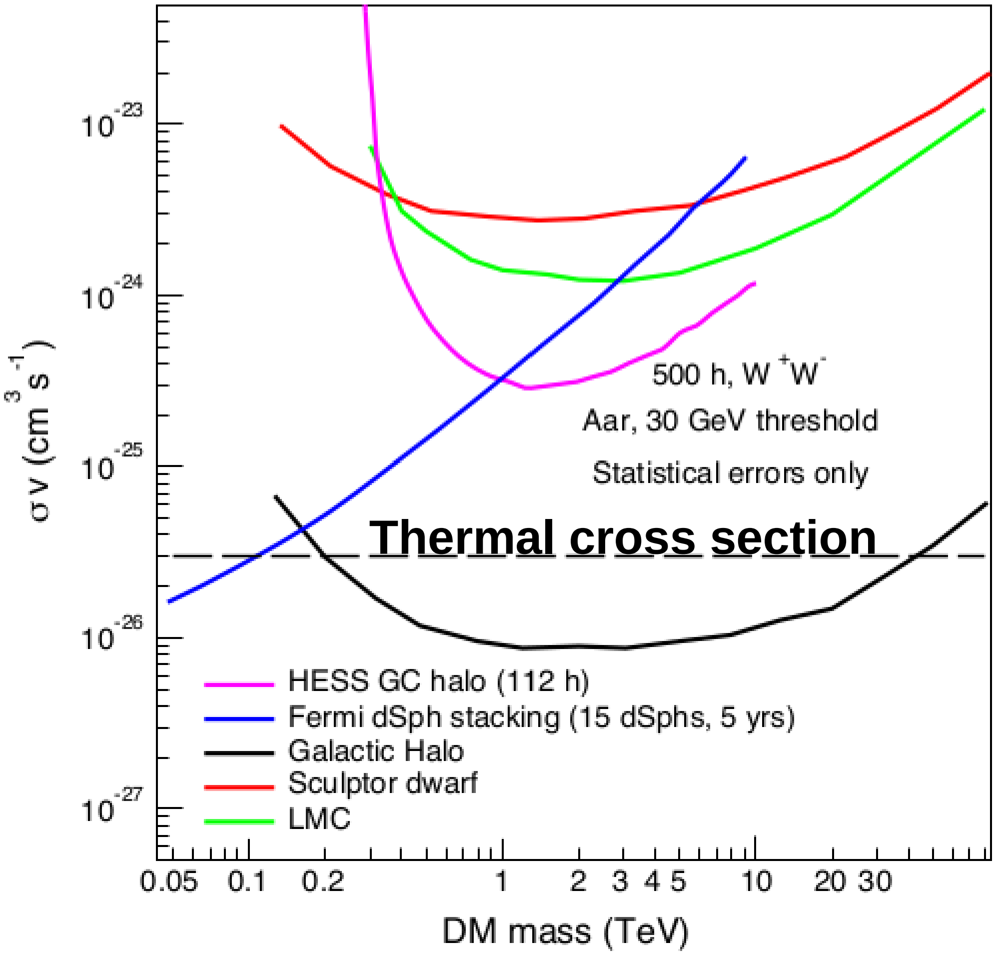
Follow-up observation:
- **Case of detection**
  if cross section large enough
  check DM signal with dSph
- **Case of no detection:**
  choose best target to produce limits

Year	1	2	3	4	5	6	7	8	9	10
Galactic halo	175 h	175 h	175 h							
Segue 1 (or best) dSph	100 h	100 h	100 h							
				in case of detection at GC, large σv						
Segue 1 (or best) dSph				150 h	150 h	150 h	150 h	150 h	150 h	150 h
Galactic halo				100 h	100 h	100 h	100 h	100 h	100 h	100 h
				in case of detection at GC, small σv						
Galactic halo				100 h	100 h	100 h	100 h	100 h	100 h	100 h
				in case of no detection at GC						
Best Target				100 h	100 h	100 h	100 h	100 h	100 h	100 h

Taken from arXiv: 1709.07997

Galactic Halo

Taken from arXiv: 1709.07997



Galactic Halo
Deep exposure 500 h

Avoid inner region
with astrophysical sources

Close by

Strong DM signal expected

Highly uncertain DM profile

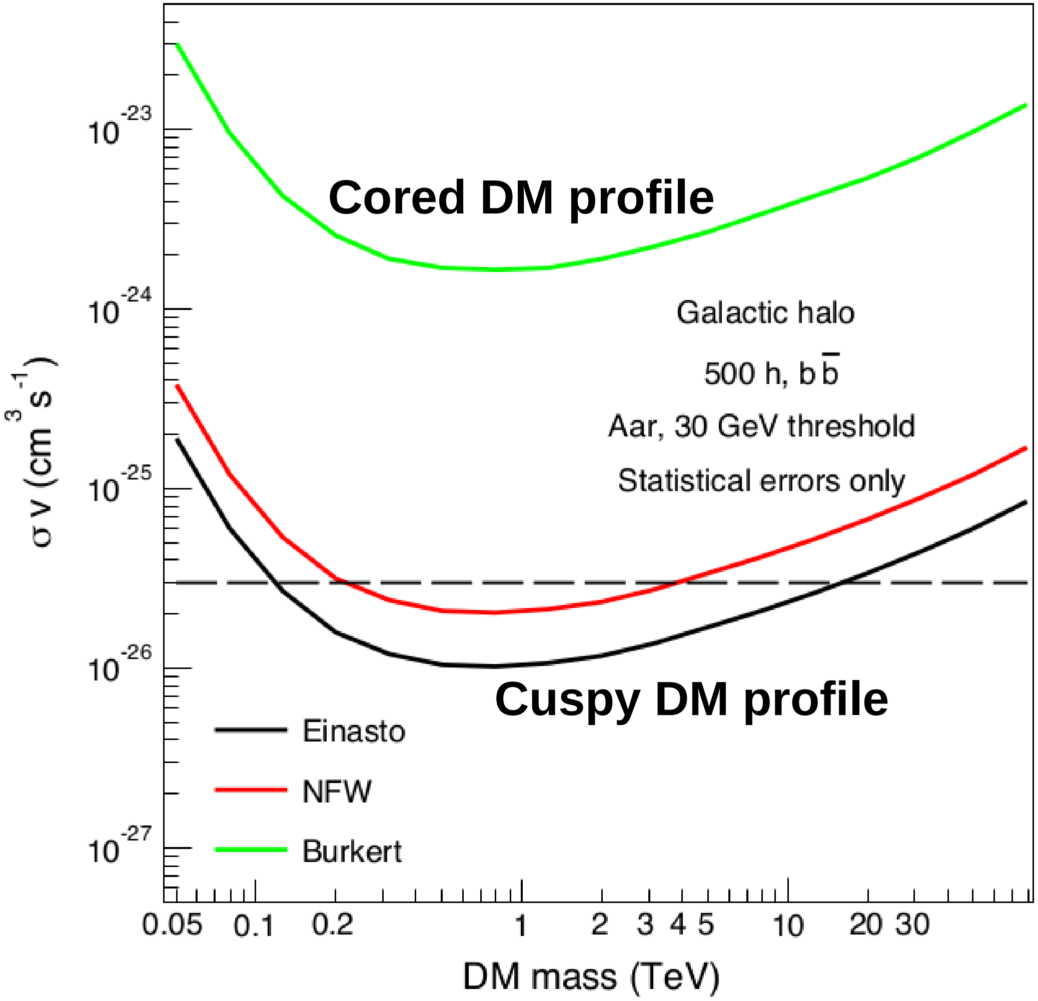
Careful control of systematic effects

CTA perfectly suited:
- **sensitivity**
- **energy resolution**
- **spatial resolution**

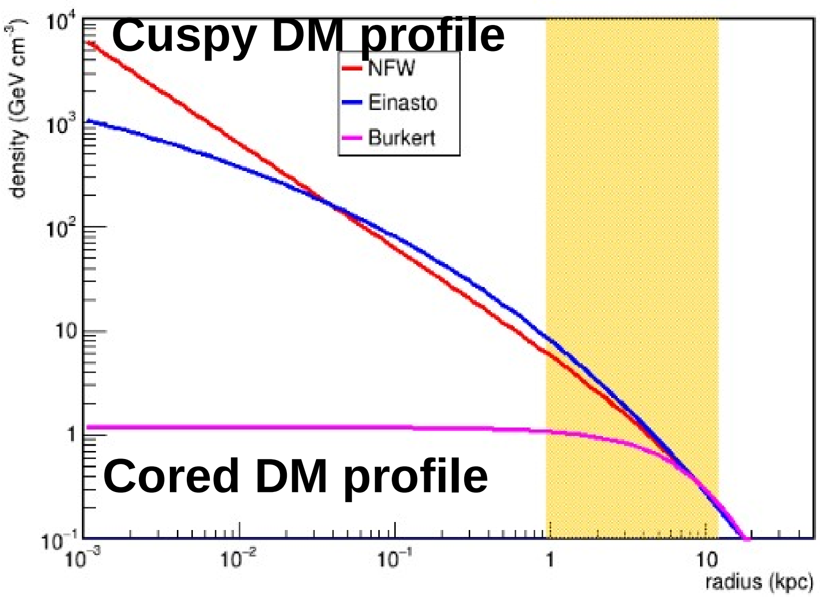
Sensitivity to thermal cross section for WIMP masses between ~200 GeV to ~20 TeV

Galactic Halo DM Profile Uncertainity

Taken from arXiv: 1709.07997

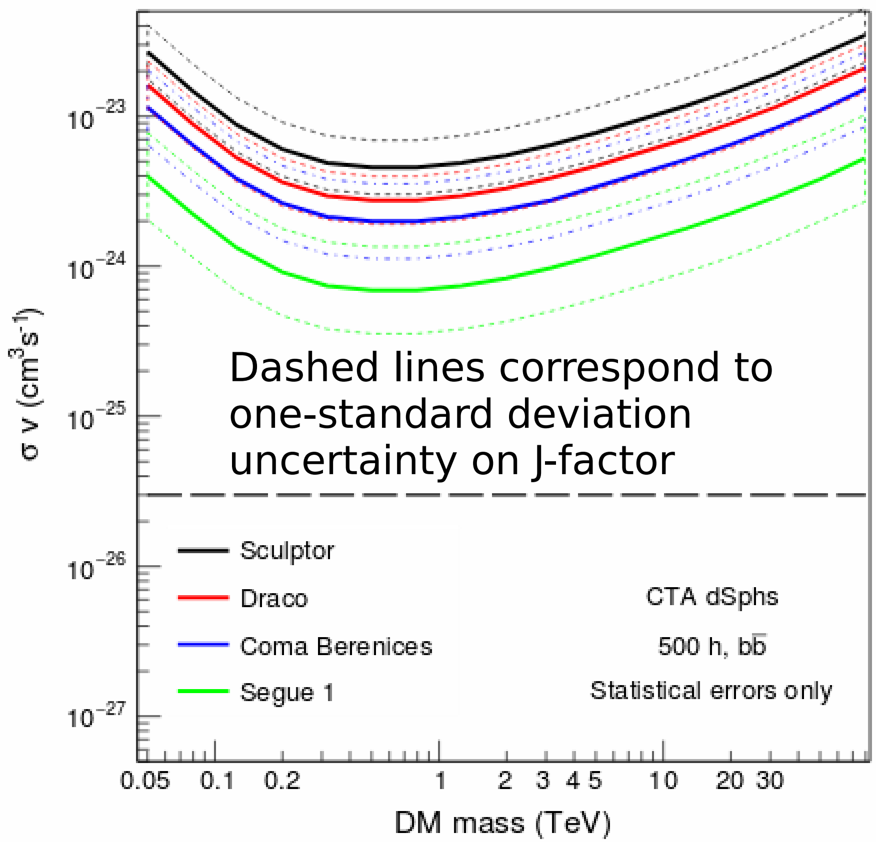


Cored DM profile still at level of dwarf spheroidal galaxies



Dwarf Spheroidal Galaxies

Taken from arXiv: 1709.07997



DM distribution fitted to reproduce observed stellar kinematics

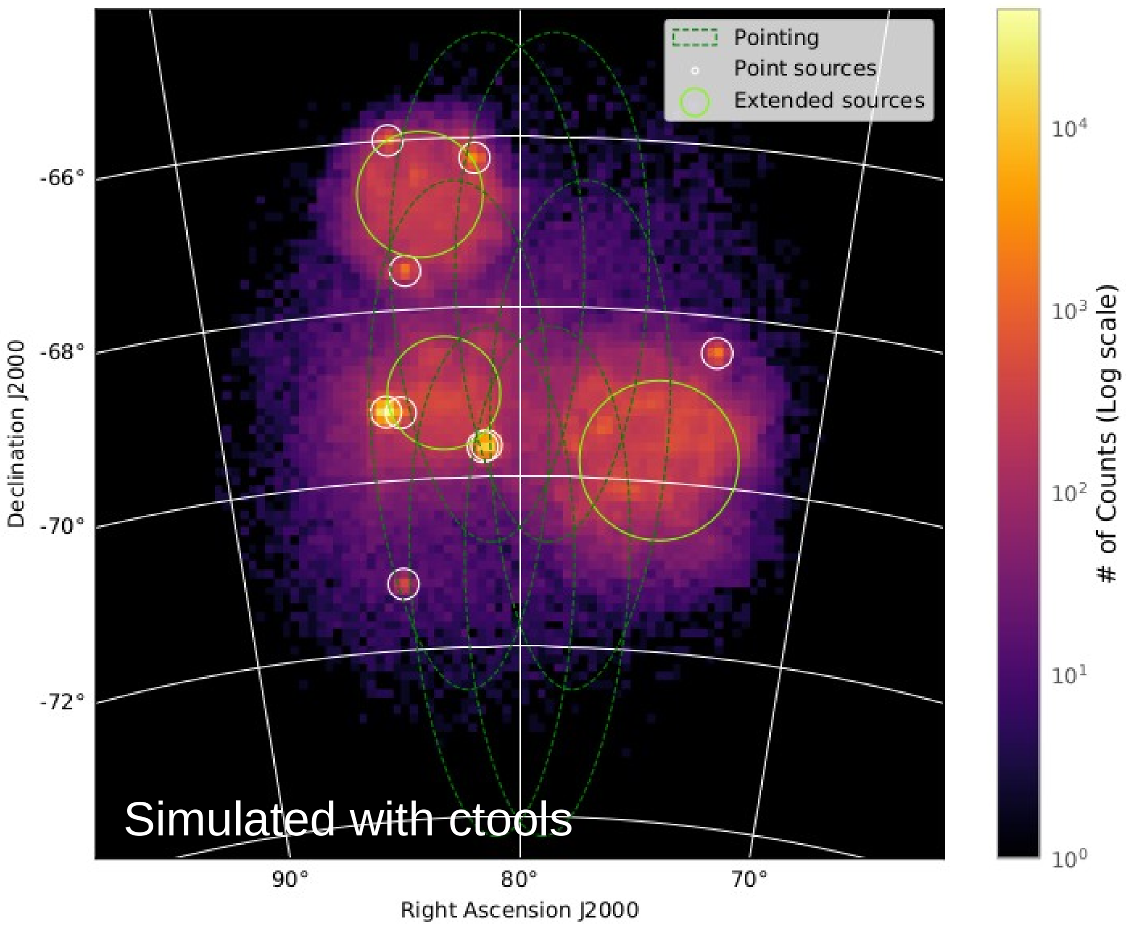
- O(20) objects known
- O(1000) mass in dark matter / visible matter
- Large J-factor uncertainty on ultra-faint dwarfs

Main properties

- Large expected DM annihilation luminosity
- Low astrophysical background
- Combine analysis to improve sensitivity

Results from dwarf spheroidal galaxies (point-like for CTA) less constraining than galactic halo but have less systematic uncertainty

Simulated LMC Skymap



Large Magellanic Cloud (LMC) is key science project

Build emission model:
- Point sources
- Extended sources
- Diffuse emission (hadronic and leptonic emission)

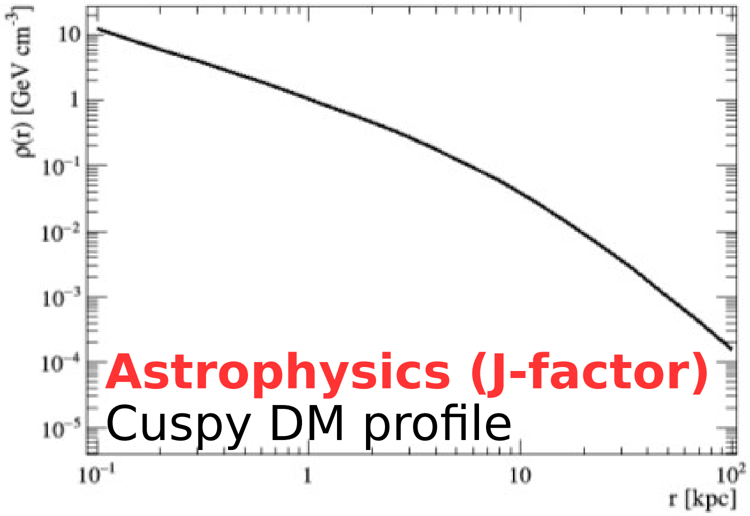
Include knowledge/extrapolation:
- Fermi LAT
- HESS

Expected observation mode:
- 6 pointing around LMC center
- 50 h each, total 300 h

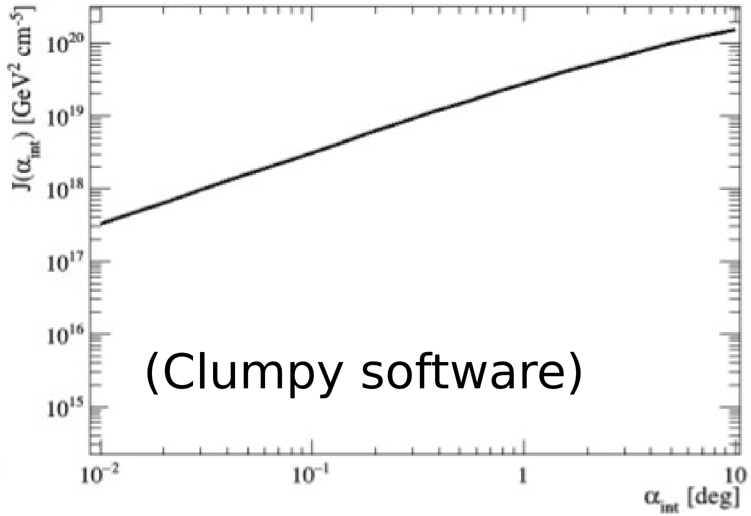
Analysis method:
- Likelihood method

Preparing consortium publication:
Maria Isabel Bernardos, Fabio Iocco, Pierrick Martin at al.

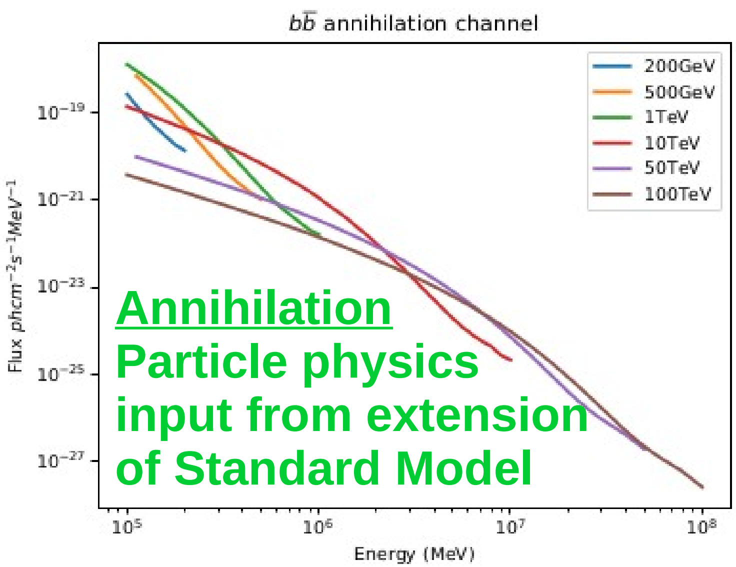
LMC Dark Matter Ingredients



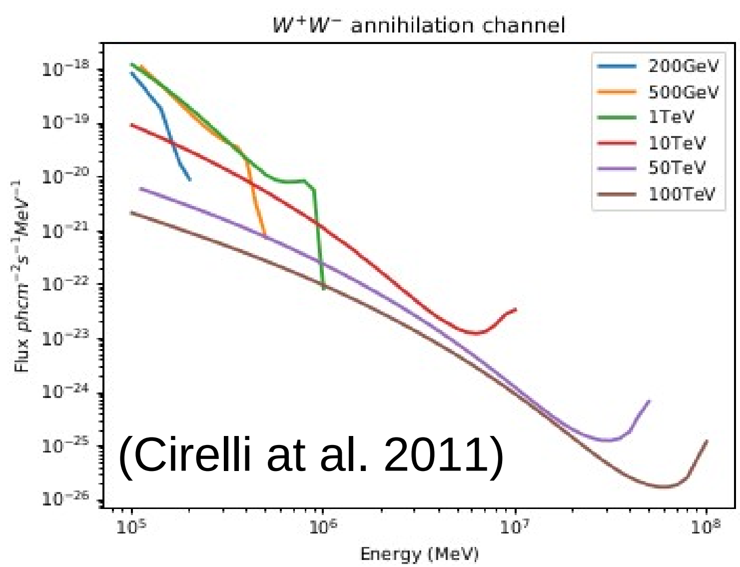
Astrophysics (J-factor)
Cuspy DM profile



(Clumpy software)



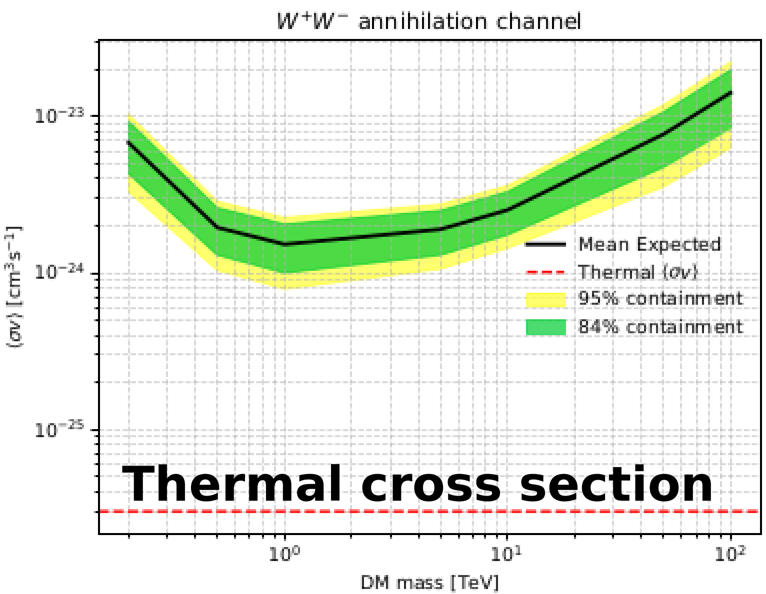
Annihilation
Particle physics input from extension of Standard Model

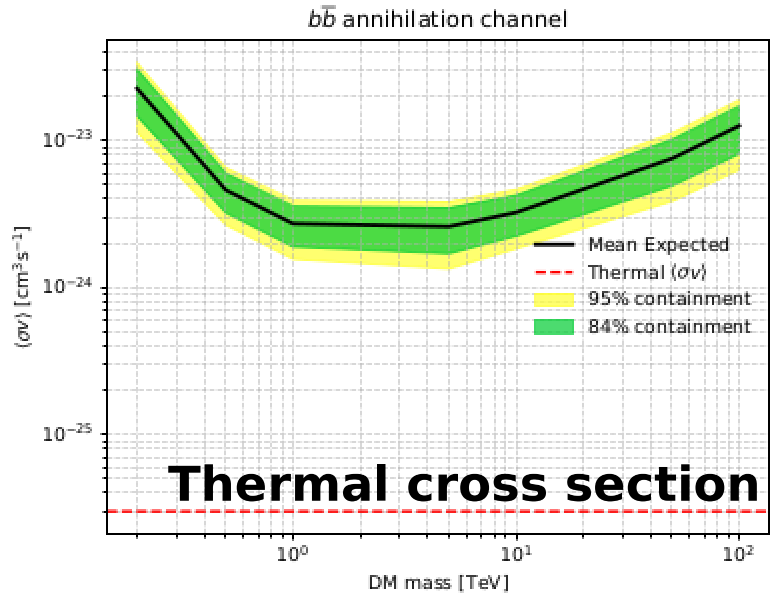


(Cirelli at al. 2011)

LMC Dark Matter Sensitivity

Constraints on LMC DM annihilation cross section for two channels





Results in agreement with previous studies
Not competitive with Galactic Halo (other interesting searches)
Results obtained with standard pipeline
Enhance DM sensitivity with machine learning
(Seen @ Daniel's Nieto talk on Monday)

Conclusion

CTA will open up high energy gamma-ray window to DM community in near future

- Science scope very ample
- Construction started, expected to be ready around 2022-2023
- First science run this year

CTA will devote significant observation time for DM searches with multiple strategies and targets

- Galactic Center (high DM flux, large uncertainty)
- Dwarf satellite galaxies (low DM flux, low uncertainty)
- Large Magellanic Cloud (independent cross check)
- More objects and analysis strategies (apply machine learning)

CTA has possibility to search for DM signal below thermal cross section for DM mass around TeV range

Fundación BBVA
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MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
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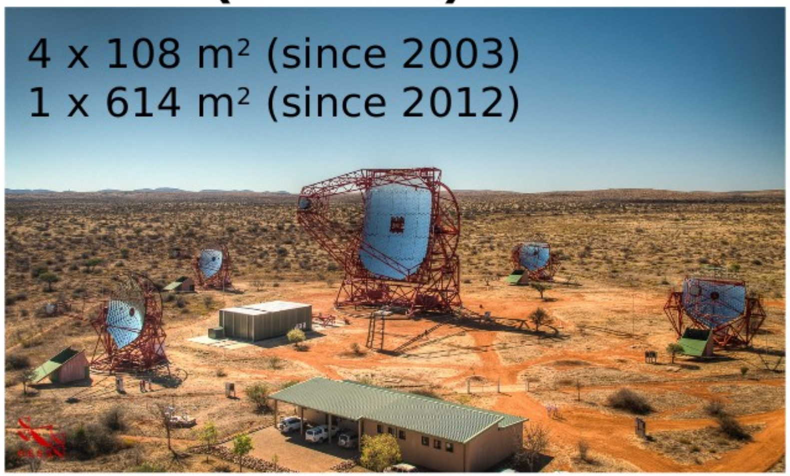
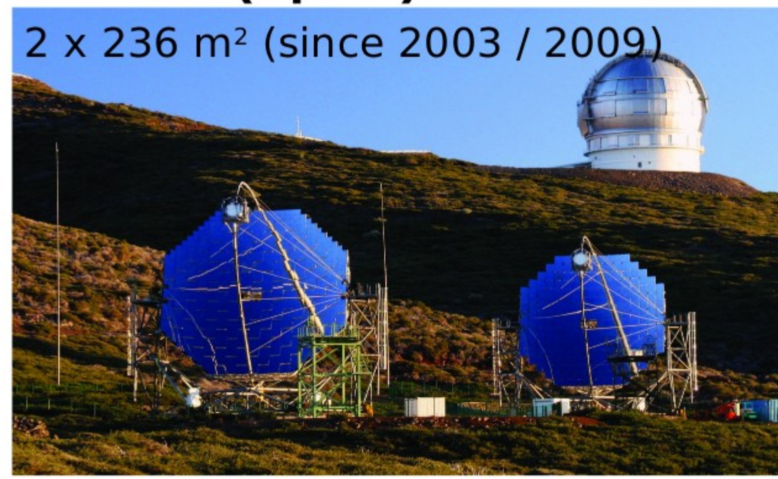
Backup

Present Cherenkov Telescope Arrays

HESS (Namibia)

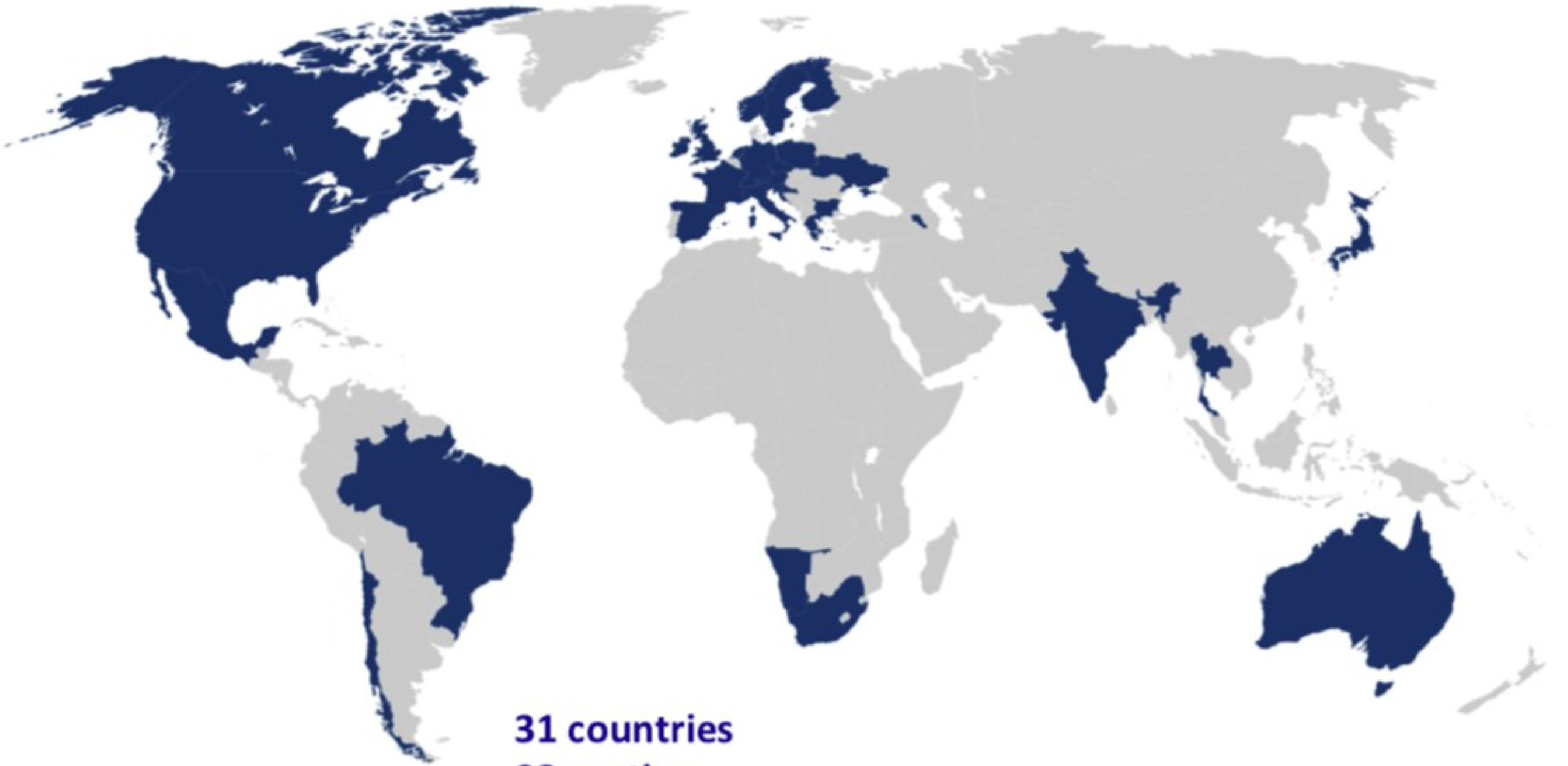


MAGIC (Spain)



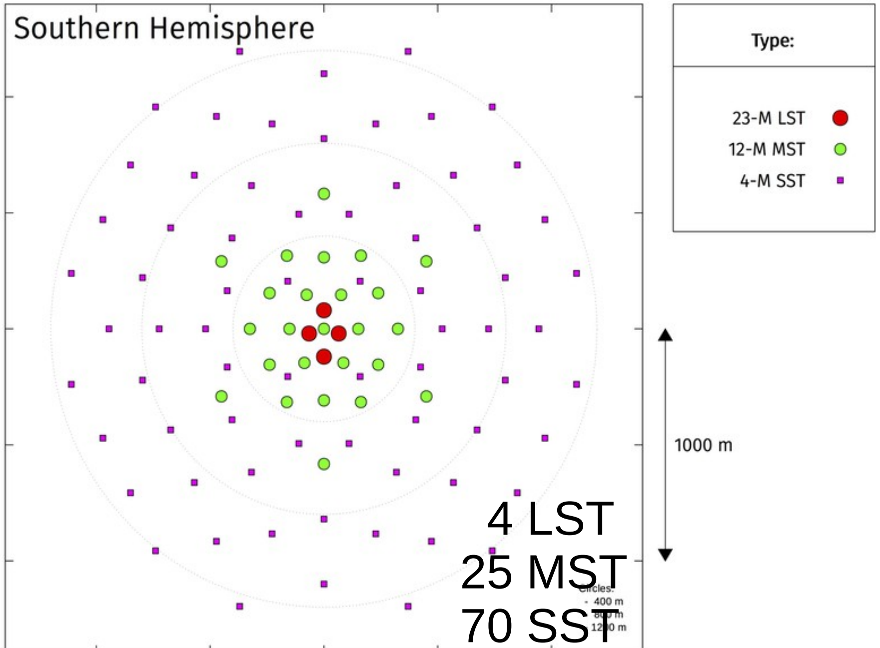
VERITAS (Arizona)

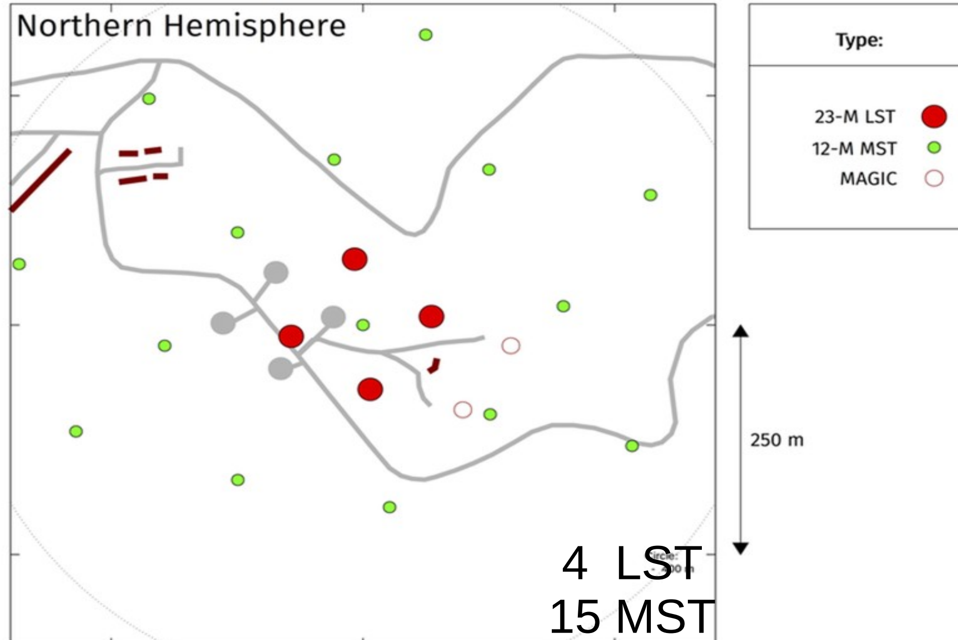
World-Wide Cooperation



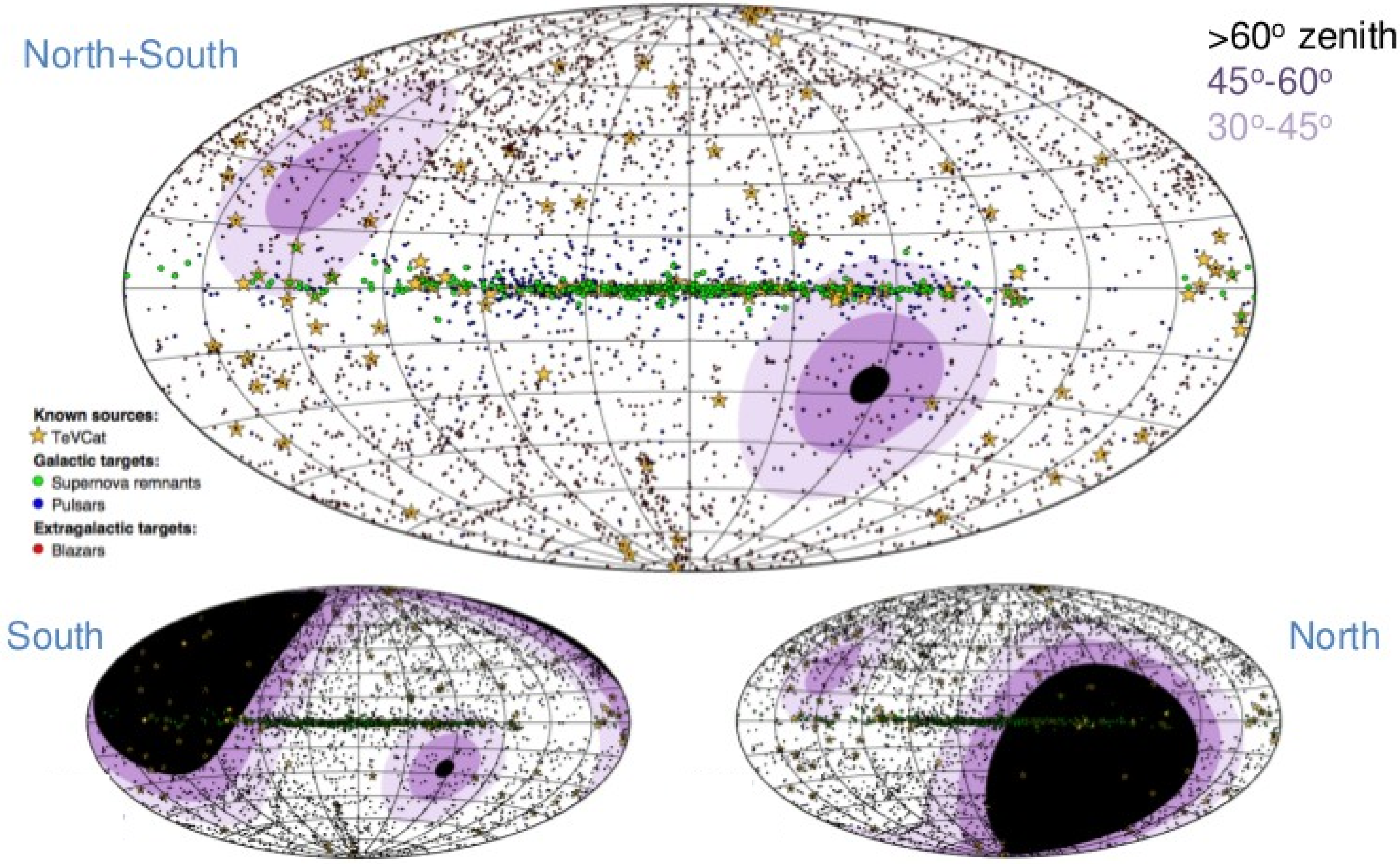
31 countries
92 parties
202 institutes
1451 members

Possible Arrays Layout





Full Sky Survey



Galactic plus extragalactic science

Mainly extragalatic science

Sensitivity