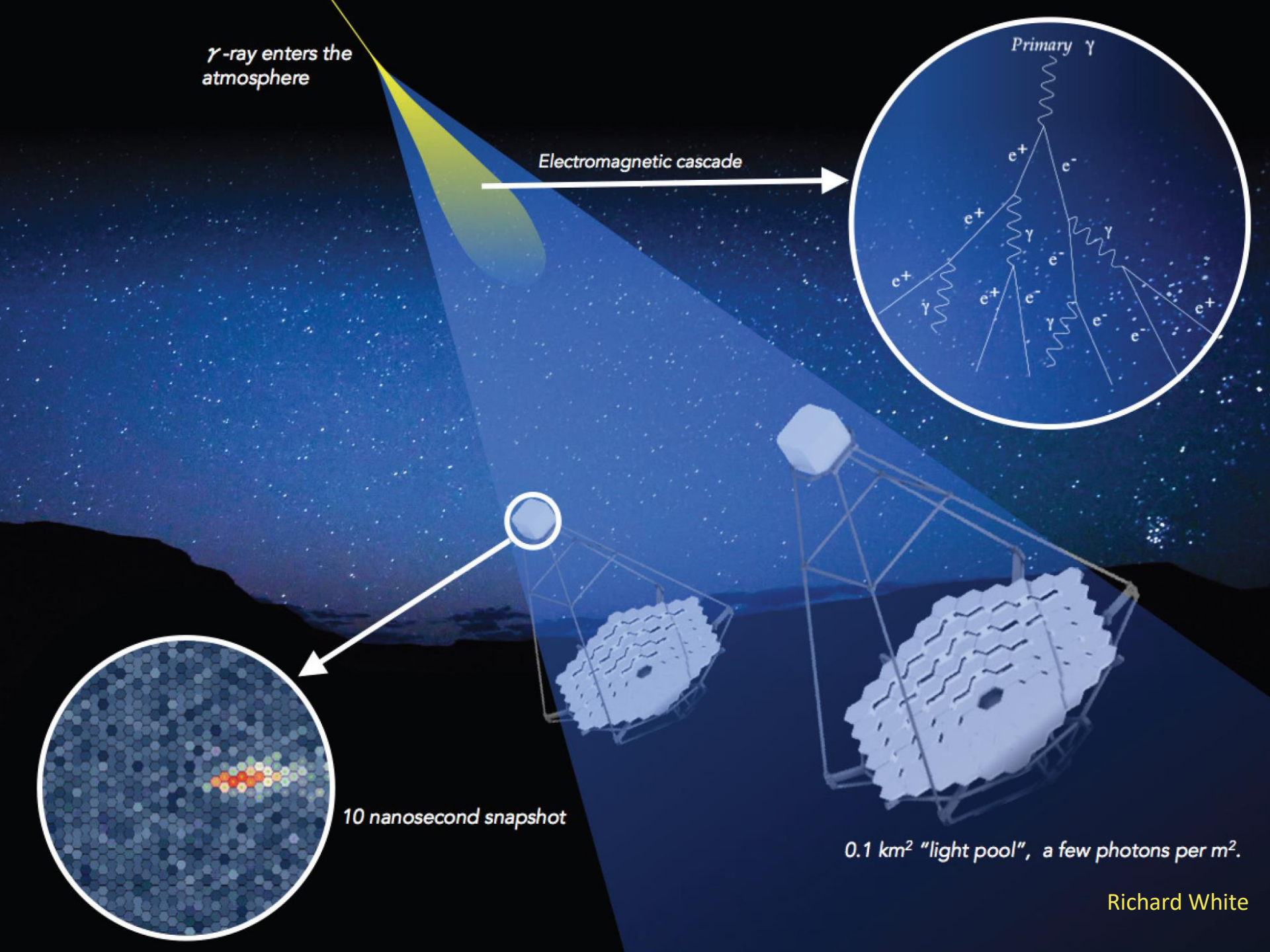
The Cherenkov Telescope Array

Prospects for Dark Matter Studies

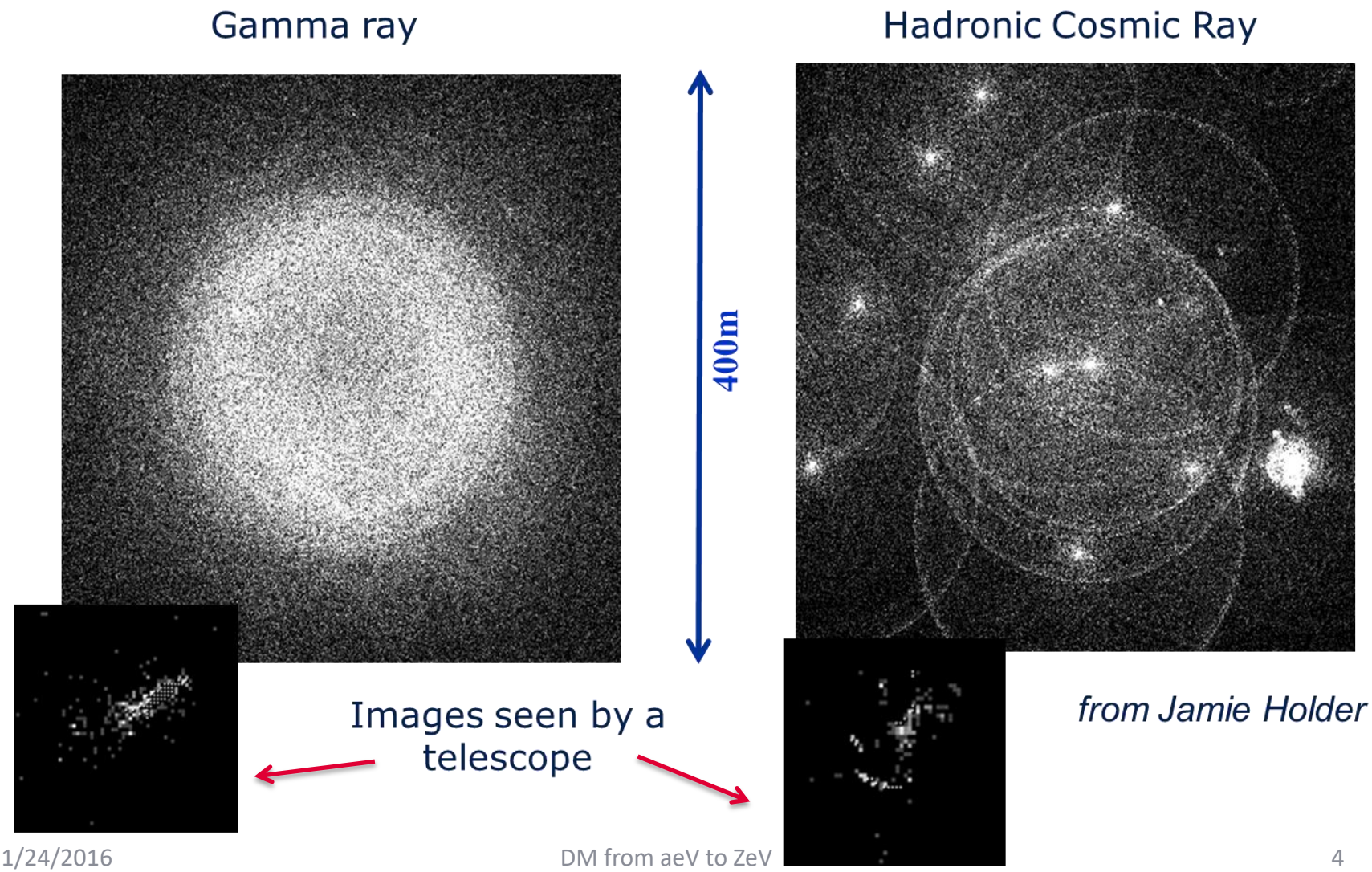
Paula Chadwick, Durham University

Outline

- What is CTA?
  - Basics of the imaging atmospheric Cherenkov technique
  - CTA: How? Where? When?
  - CTA's capabilities & science themes
- Prospects for DM studies
  - The Galactic centre
  - The Large Magellanic Cloud
  - Dwarf spheroidal galaxies

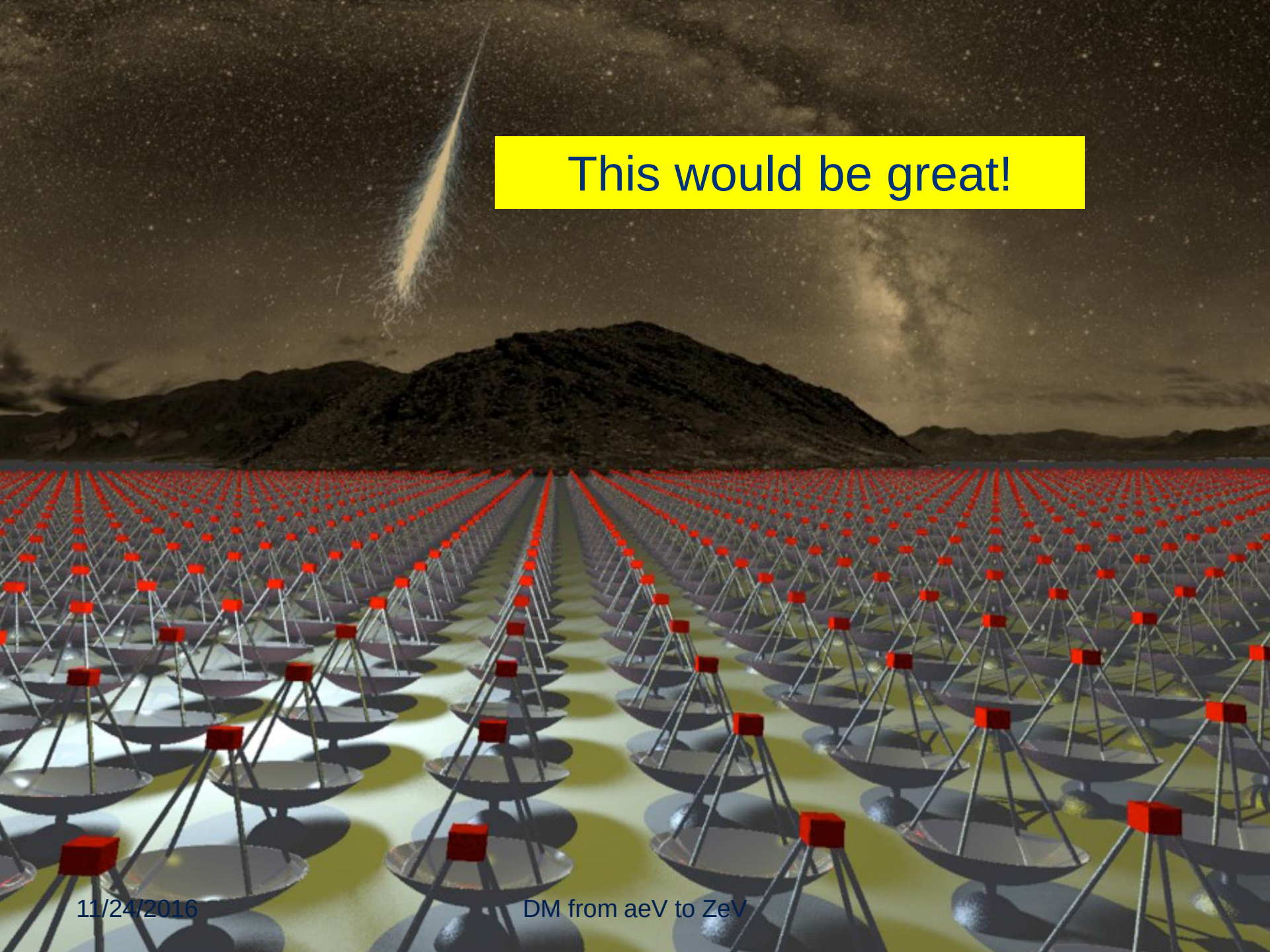

γ-ray enters the atmosphere
Electromagnetic cascade
Primary γ
e+
e-
γ
10 nanosecond snapshot
0.1 km² "light pool", a few photons per m².
Richard White

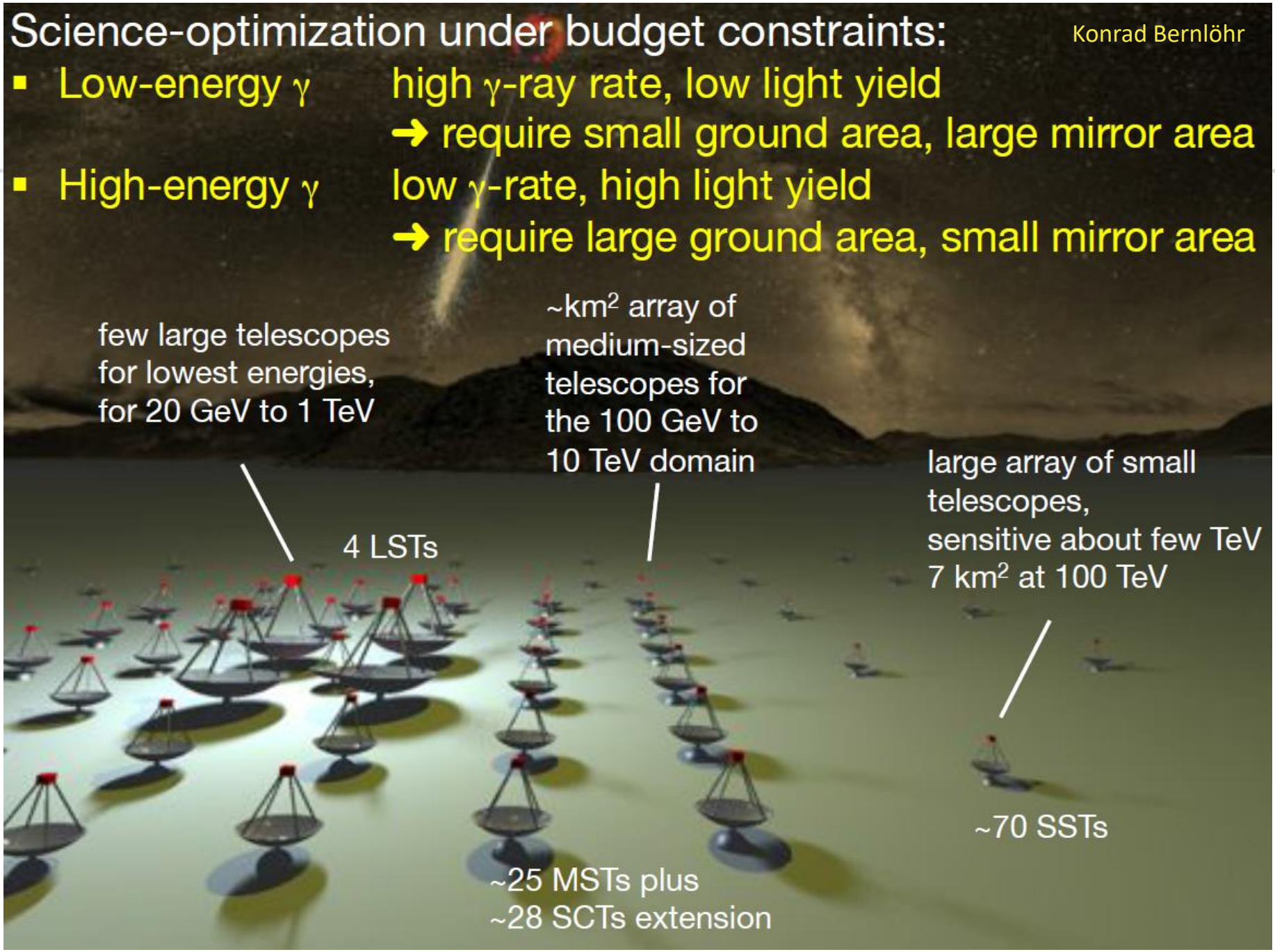
Removing the Background



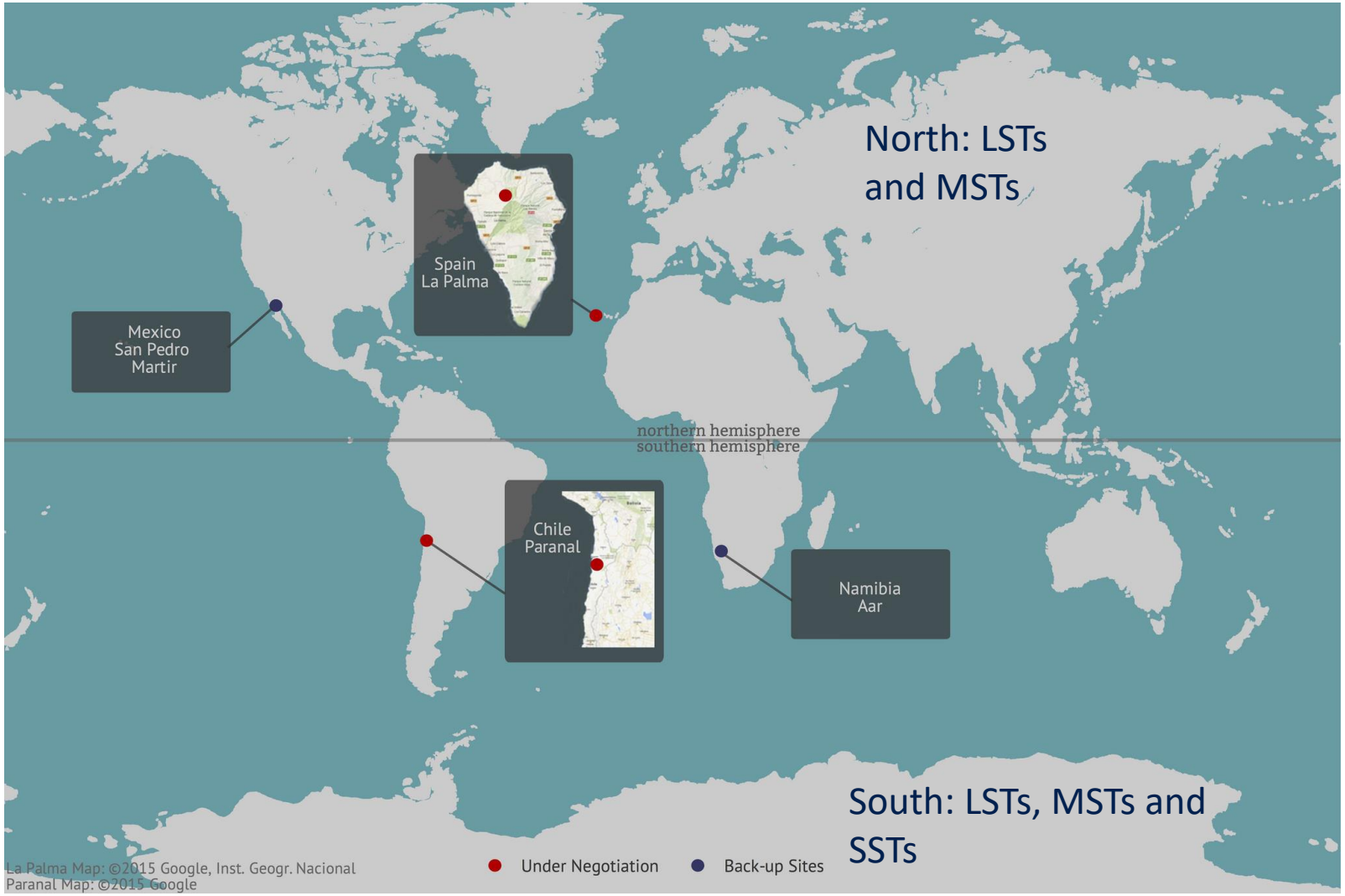
Present Instruments

The current telescopes have opened this new window on the Universe. Now we need to take the next step.


This would be great!

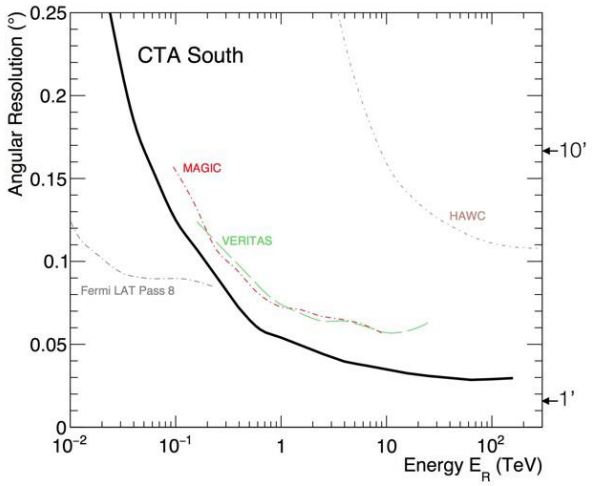

Science-optimization under budget constraints:
Konrad Bernlöhr
Low-energy γ high γ-ray rate, low light yield
➜ require small ground area, large mirror area
High-energy γ low γ-rate, high light yield
➜ require large ground area, small mirror area
few large telescopes for lowest energies, for 20 GeV to 1 TeV
~km² array of medium-sized telescopes for the 100 GeV to 10 TeV domain
large array of small telescopes, sensitive about few TeV 7 km² at 100 TeV
4 LSTs
~25 MSTs plus ~28 SCTs extension
~70 SSTs

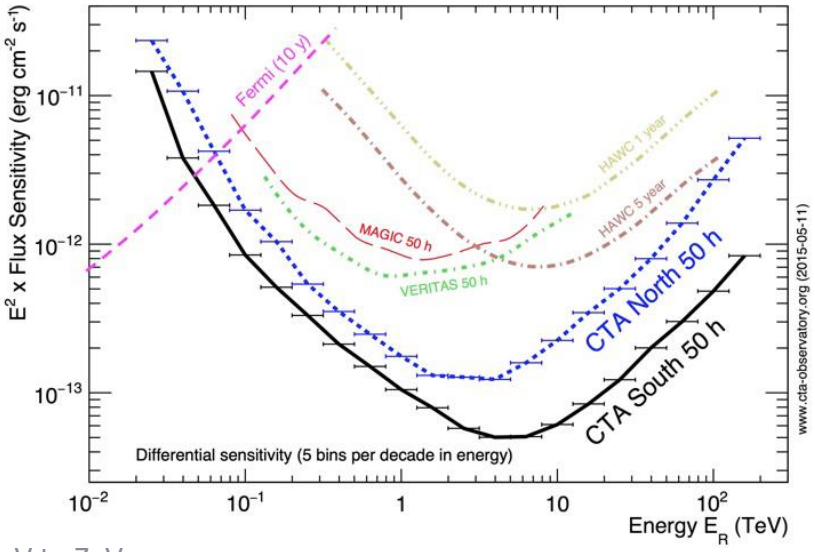
Two Arrays


North: LSTs and MSTs
Spain
La Palma
Mexico
San Pedro
Martir
northern hemisphere
southern hemisphere
Chile
Paranal
Namibia
Aar
South: LSTs, MSTs and SSTs
La Palma Map: ©2015 Google, Inst. Geogr. Nacional
Paranal Map: ©2015 Google
Under Negotiation
Back-up Sites

Performance

- Improved sensitivity
  - Access the entire Galaxy
  - Instantaneous sensitivity (AGN, GRBs)
- Excellent energy ‘reach’
- Field-of-view > 8°
  - Efficient survey instrument
  - Measure diffuse emission
- Arcminute angular resolution
  - Resolve extended sources

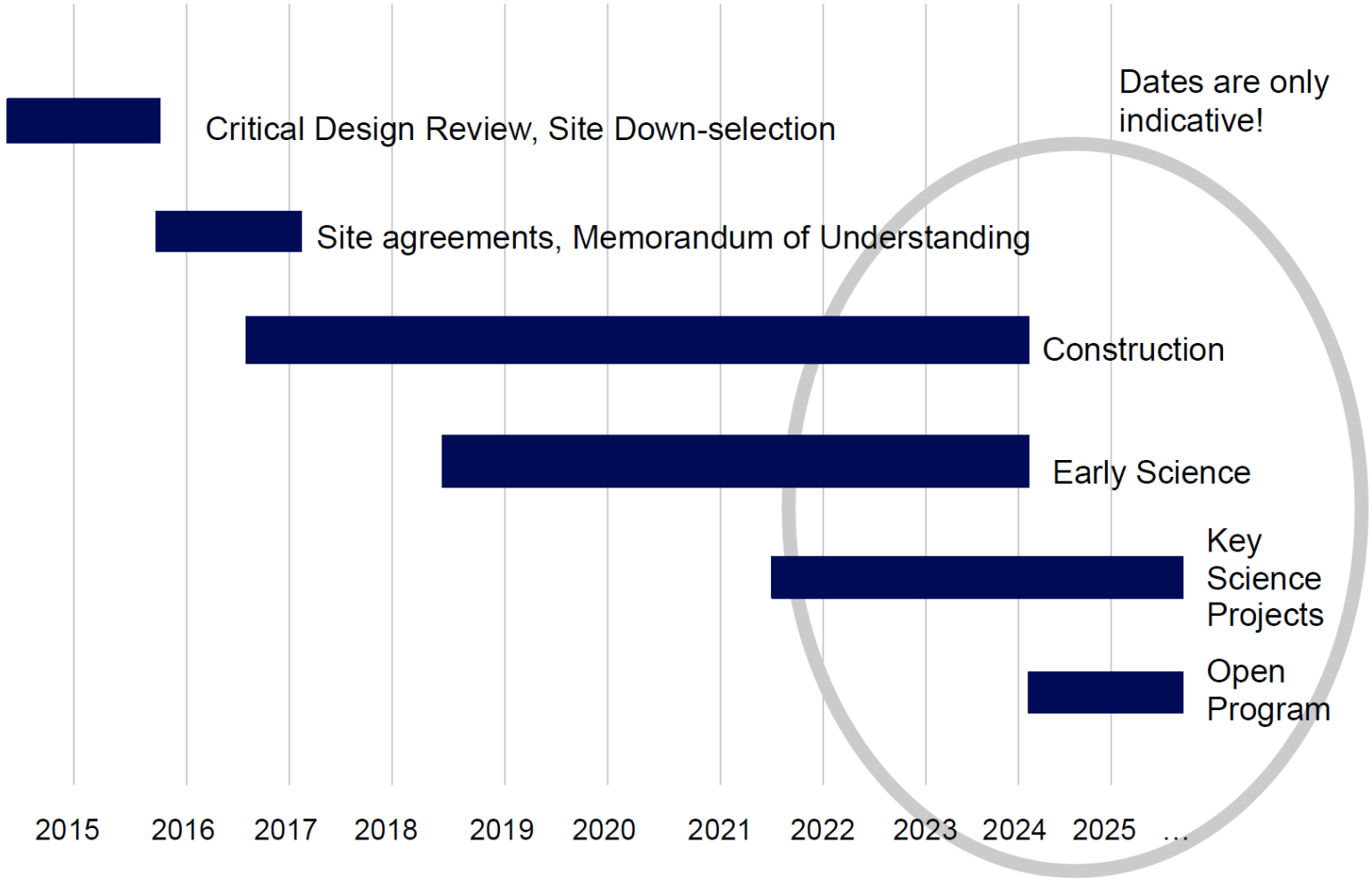




The Consortium (or at least some of it)

1350 scientists & engineers, 209 institutes, 32 countries….1 aim!

Timeline


Dates are only indicative!
Critical Design Review, Site Down-selection
Site agreements, Memorandum of Understanding
Construction
Early Science
Key Science Projects
Open Program
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
…

Science Themes

- Theme 1: Cosmic Particle Acceleration
  - How and where are particles accelerated?
  - How do they propagate?
  - What is their impact on the environment?
- Theme 2: Probing Extreme Environments
  - Processes close to neutron stars and black holes?
  - Processes in relativistic jets, winds and explosions?
  - Exploring cosmic voids
- Theme 3: Physics Frontiers – beyond the SM
  - **What is the nature of dark matter? How is it distributed?**
  - Is the speed of light constant for high energy photons?
  - Do axion-like particles exist?

Indirect Detection of DM via γ-rays

Observation time

DM distribution in source & location relative to observer

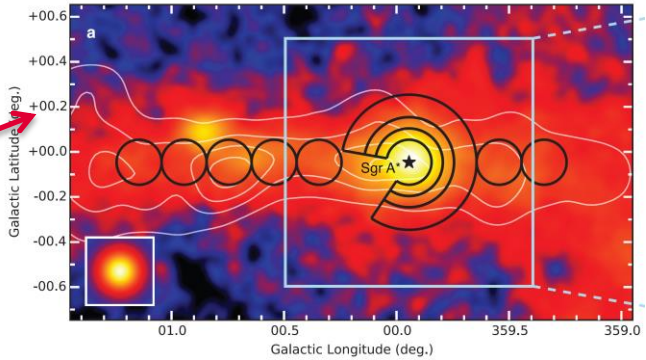
Detector effective area

$$N_{\gamma,DM} = \frac{t_{obs} J_{region} \langle \sigma v \rangle}{8\pi {M_\chi}^2} \int_{E_{min}}^{E_{max}} \frac{dN_{DM}}{dE}(E) A_{eff}(E) dE$$

No. of observed events

Energy spectrum of gamma rays produced in annihilation

So far, so good…but…there are significant astrophysical backgrounds. This is the HESS view of the central 200 pc of the Milky Way



HESS Collaboration: arXiv 1603.07730

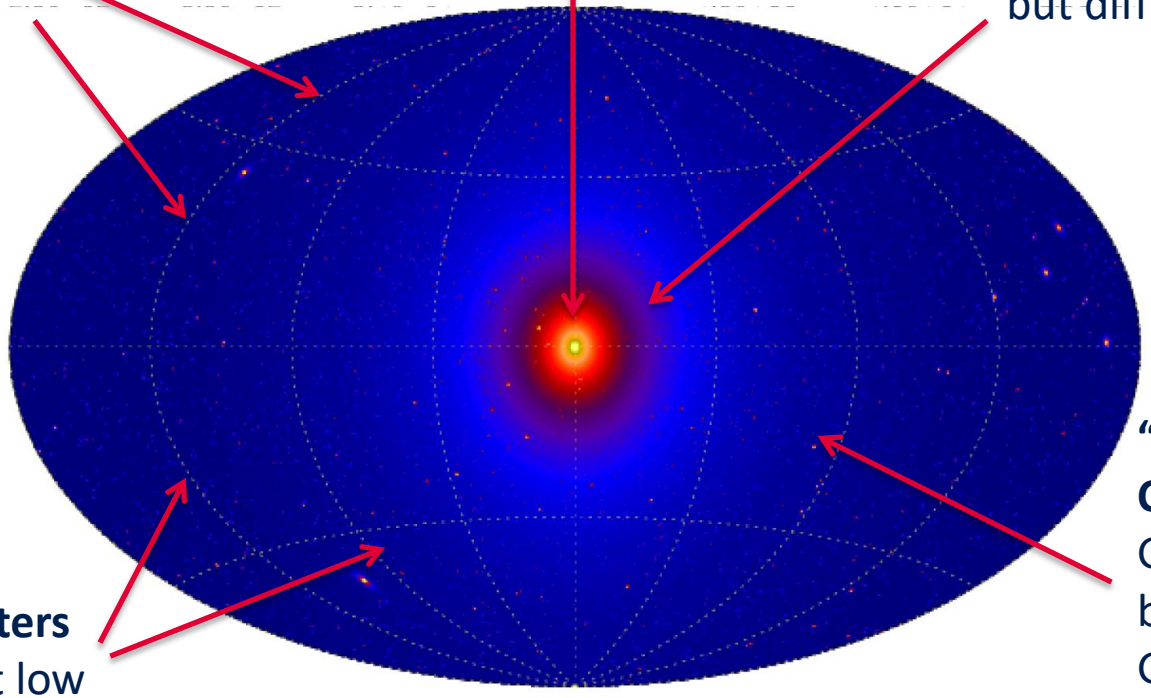
DM Search Targets

Satellite Galaxies
Low BG and good source ID, but low statistics

Galactic Centre
Great statistics, but source confusion/diffuse BG

MW Halo
Good statistics, but diffuse BG

Spectral Lines
Little/no BG but low sensitivity (small branching ratio)

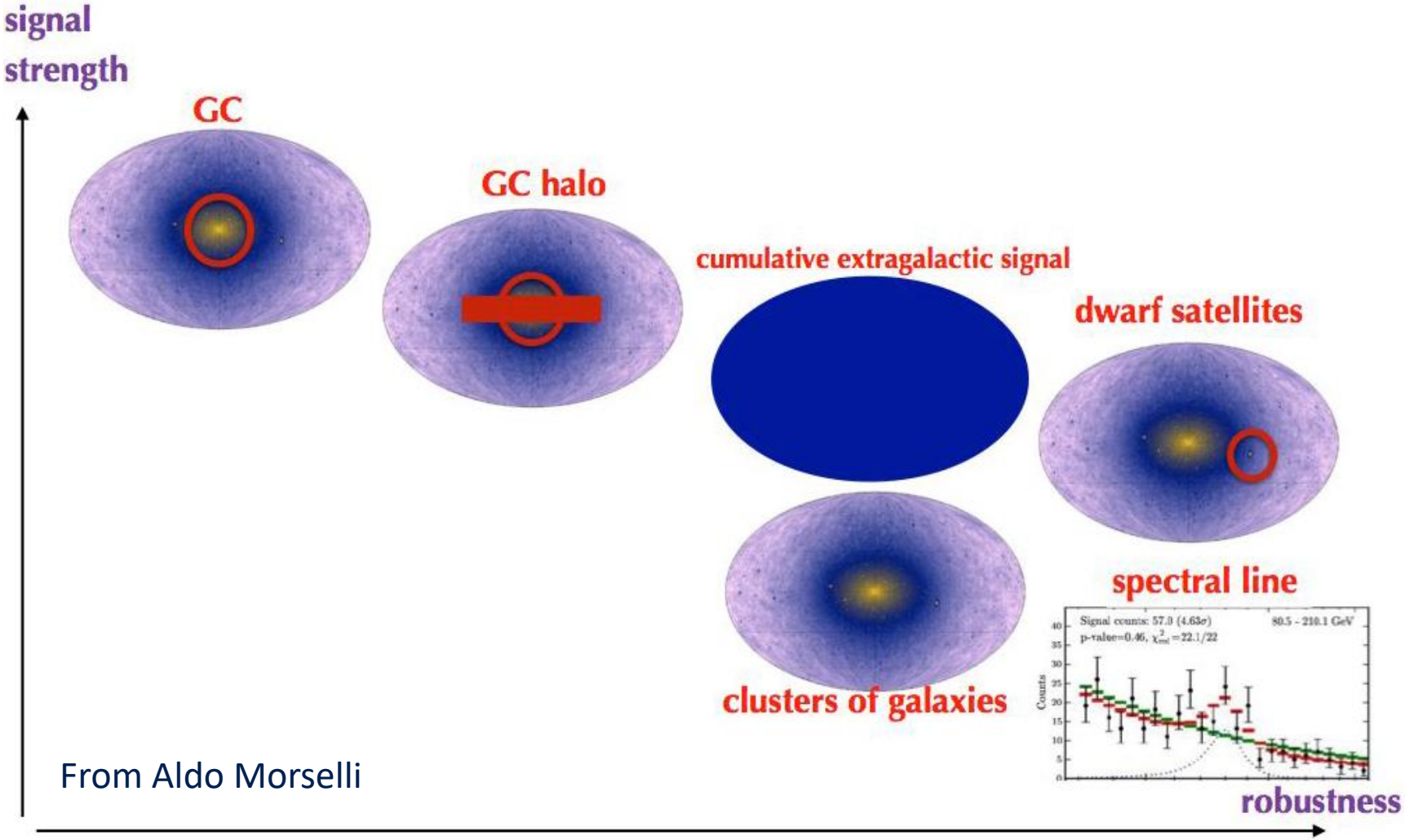


Galaxy Clusters
Low BG, but low statistics

"Isotropic" Contributions
Great statistics, but BG (inc. Galactic diffuse)

DM simulation from Pieri et al., arXiv:0908.0195 (photons > 3 GeV)

To look at it another way…

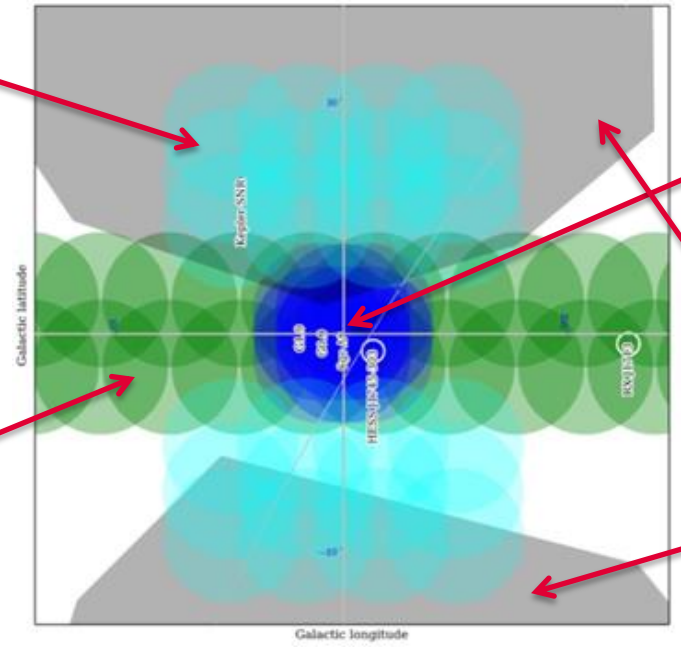


From Aldo Morselli

Galactic Centre observations

300h Galactic bulge extension

525h deep exposure of GC

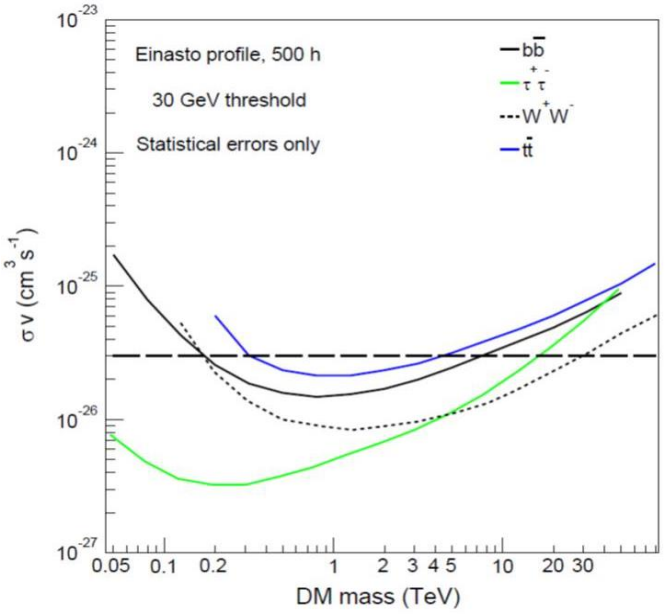


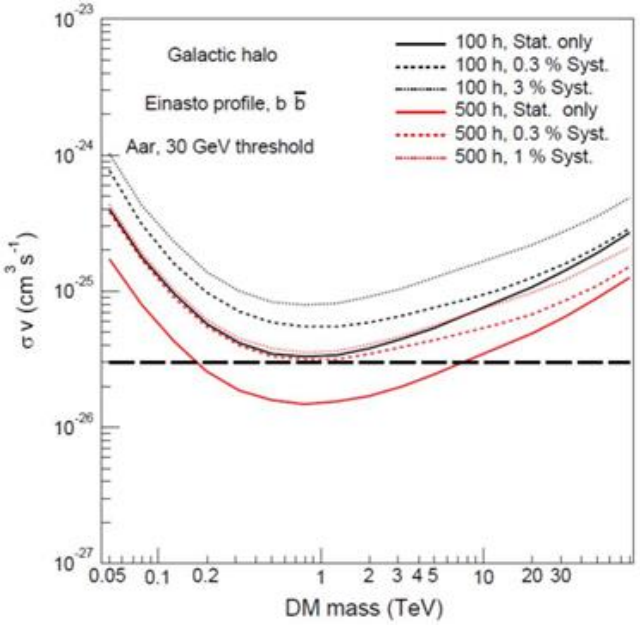
Fermi bubbles

Approx. Galactic plane survey region

Deep and uniform exposure over several degrees around the central BH to allow for spectral & morphological studies, understanding of instrument systematics and of the astrophysical sources. A legacy dataset.

Galactic halo sensitivity





CTA Science TDR

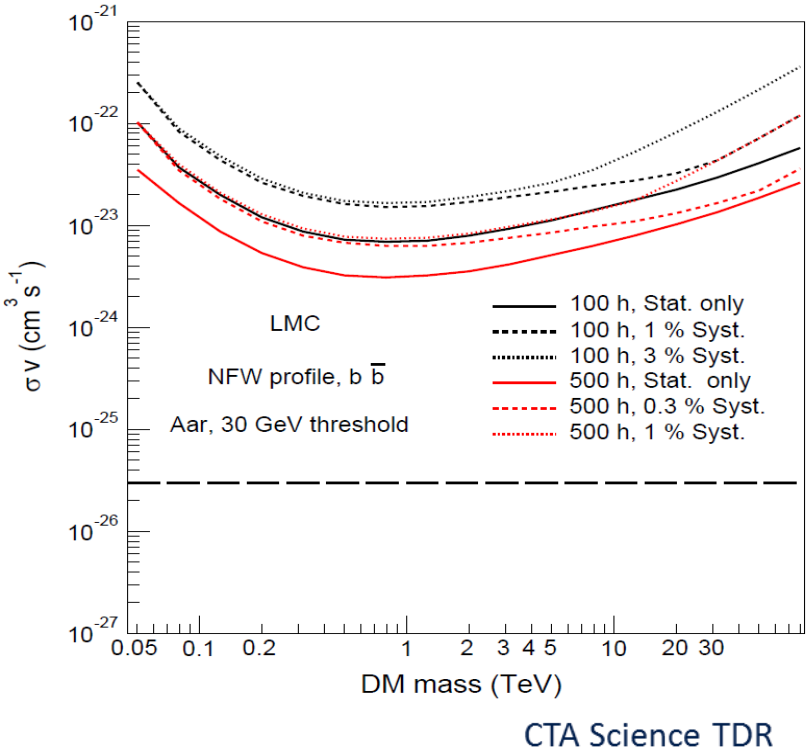
See Carr et al. (CTA Consortium) arXiv:1508.06128 for details on this and following sensitivity curves

The Large Magellanic Cloud

- Milky Way satellite galaxy, about 1% of MW mass
- Expected DM density larger than any dwarf
- J-factor quite well-determined (min. of 5 x 10^{19} GeV^2 cm^{-5})
- DM signal morphology not strongly correlated with known astrophysical background

BUT

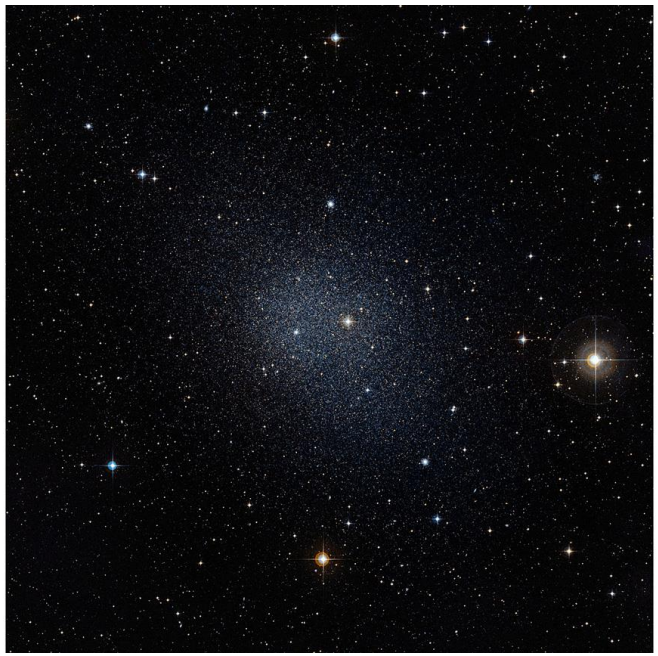
- Extended source
- 6x further away than the GC



CTA Science TDR

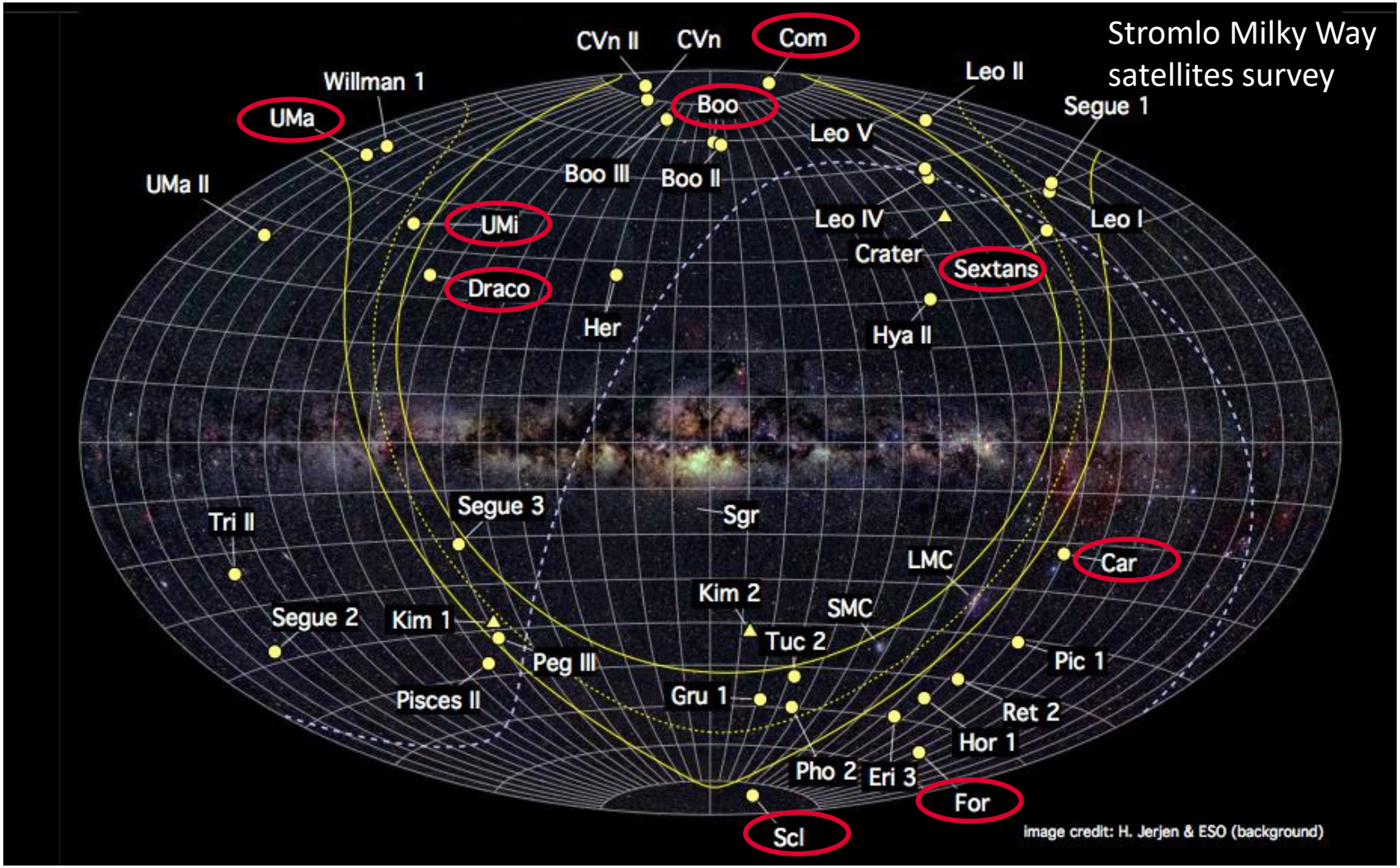
Dwarf spheroidal galaxies

- Gravitationally-bound objects, thought to contain ~10^3 times more DM than visible matter
- Low astrophysical background
- Near point sources in CTA
- DM distribution not well-known
- Much debate about which constitute the best targets

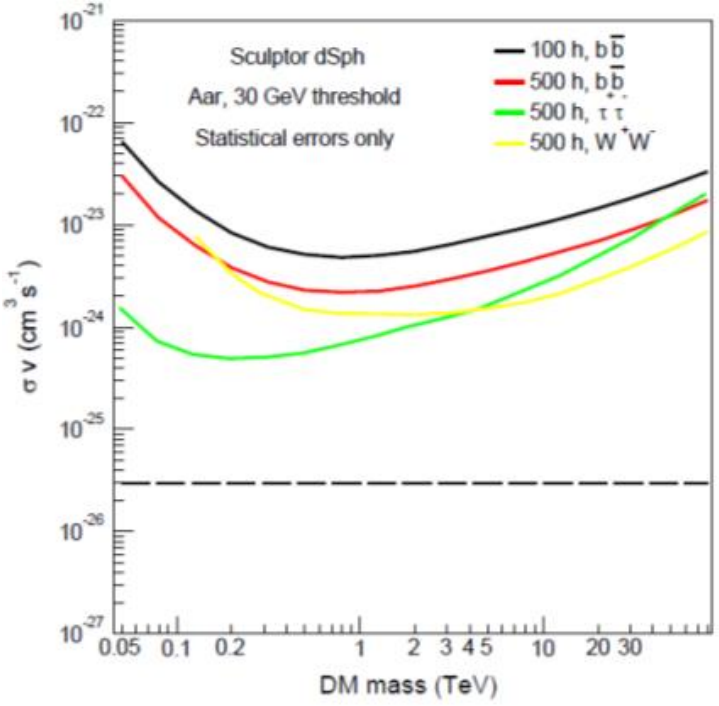


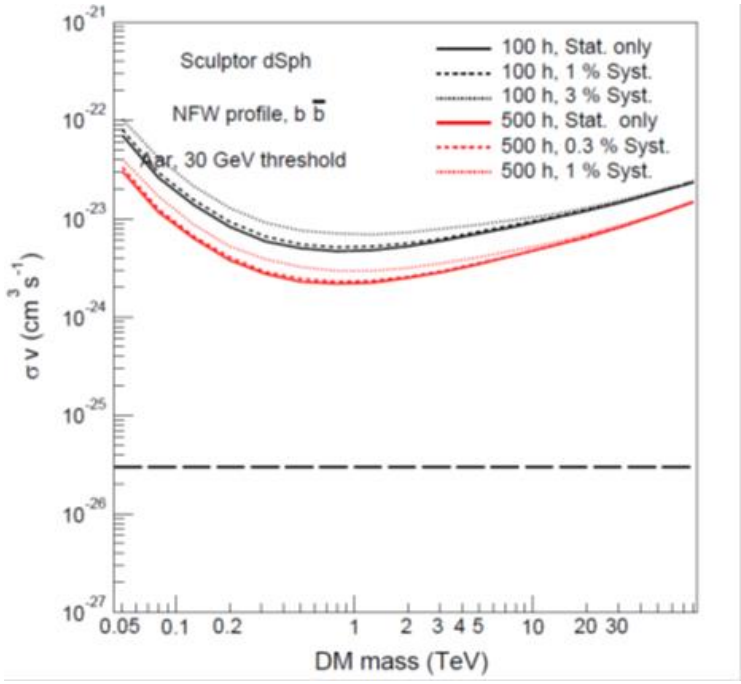
Fornax dwarf spheroidal galaxy, *ESO/Digital Sky Survey 2*

Classical dwarf spheroidal galaxies



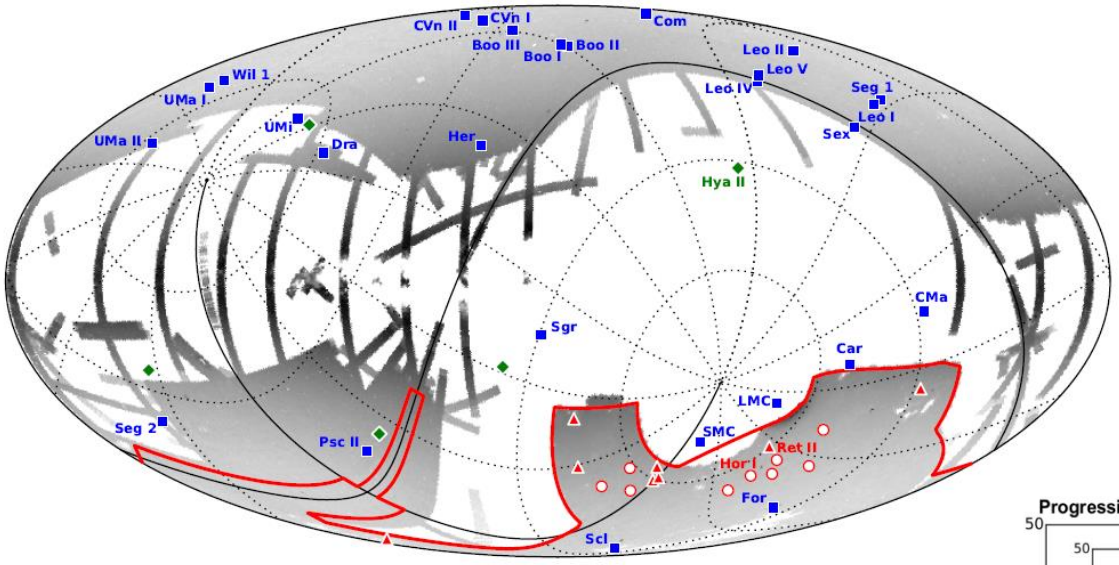
An example dSph: Sculptor





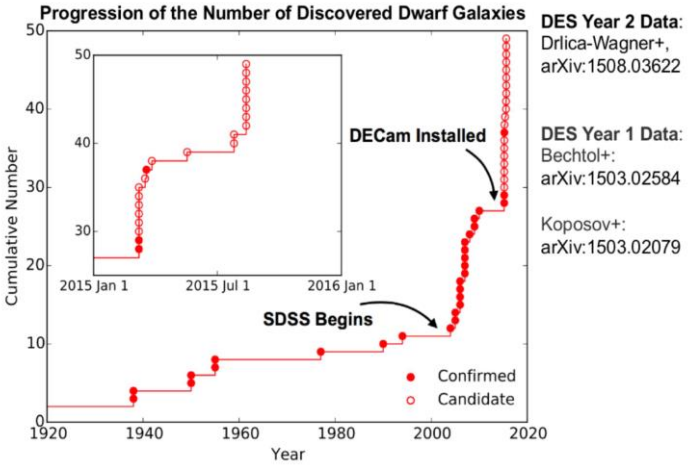
CTA Science TDR

Growing number of known dSphs

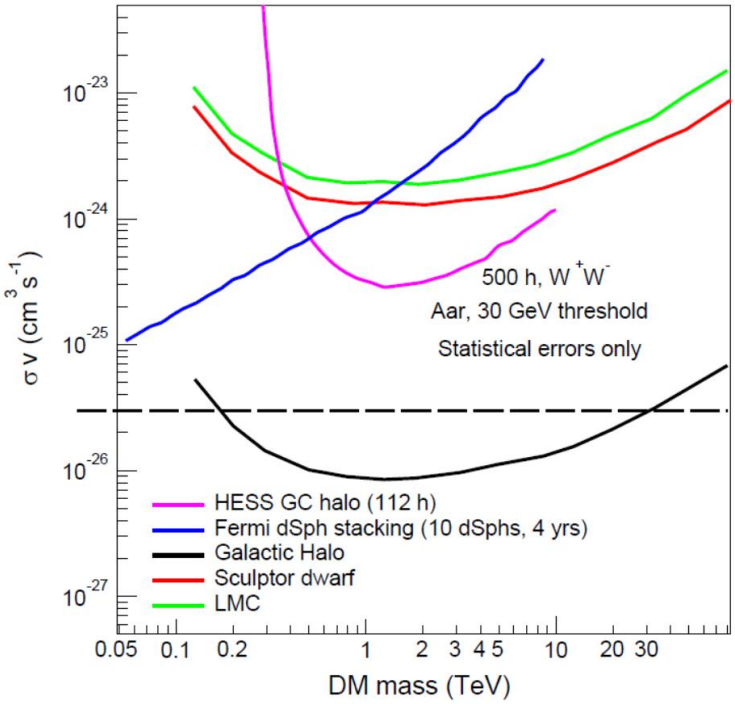


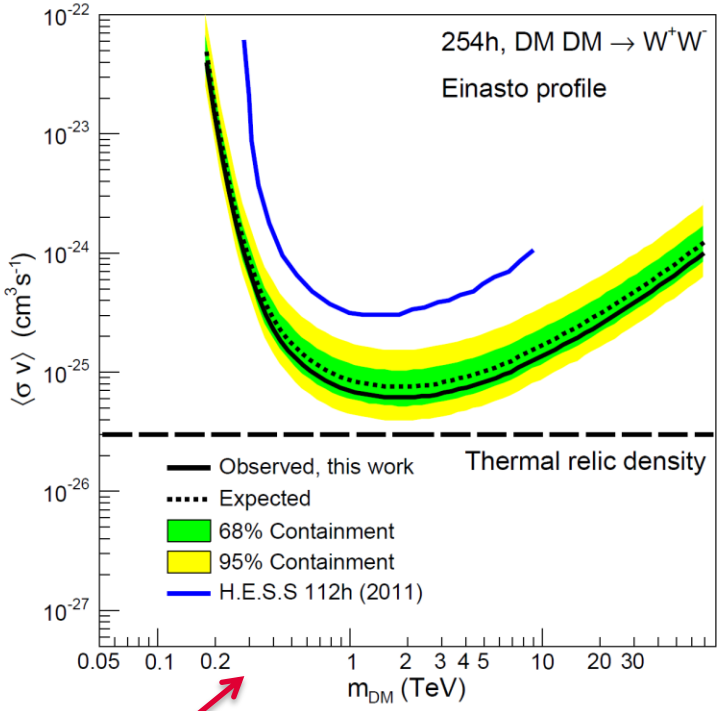
DES in particular is providing many new dSph candidates

CTA will target the most promising, based on the best information available at the time



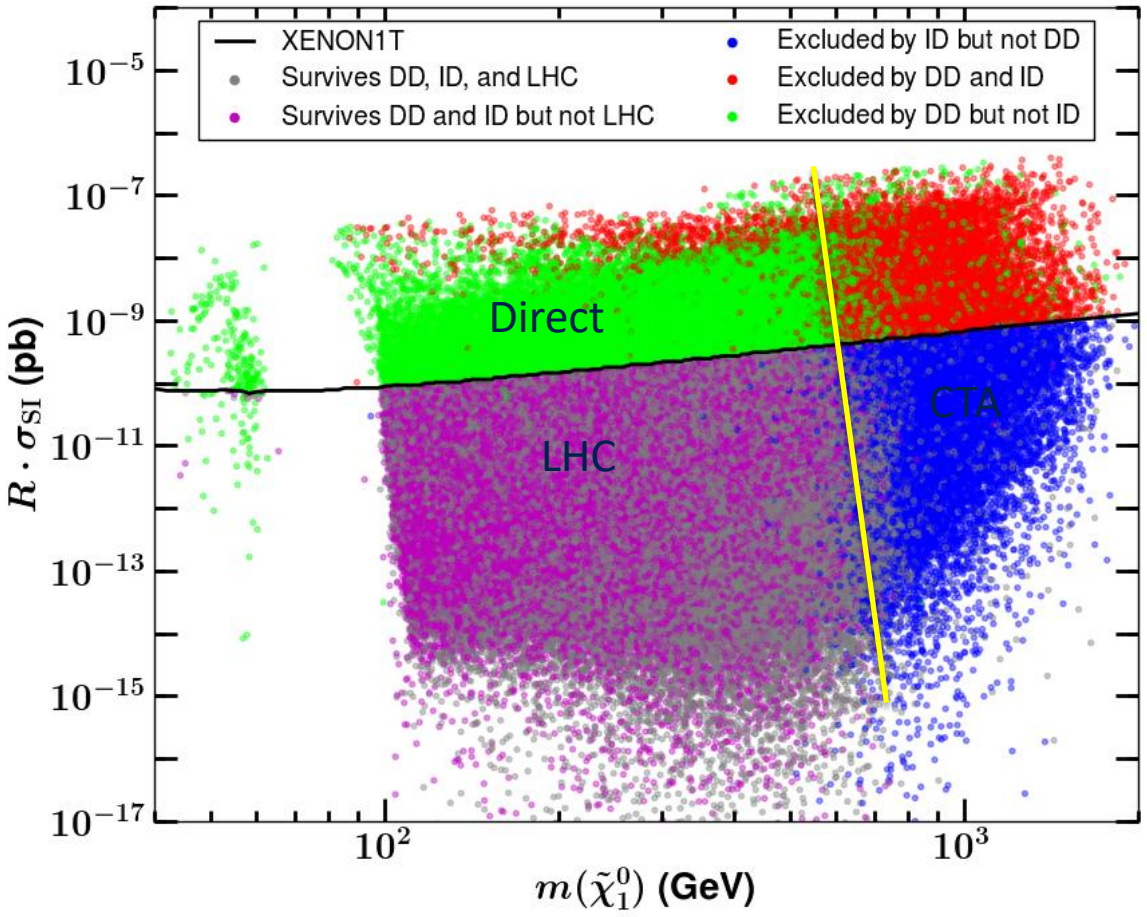
Comparing with Fermi & HESS





Most recent HESS result – 254h of observations: arXiv 1607.08142

Complementarity with other searches



Cahill-Rowley et al. arXiv: 1305.6921

CTA and Dark Matter

- Good prospects to probe WIMP models with thermal relic cross-section and mass above 200 GeV
- Combined with Fermi, CTA will be able to detect (or exclude) thermal WIMPs from a few GeV to a few 10s of TeV
- CTA sensitivity to heavy WIMPS (>TeV) is unique
- Excellent complementarity with direct DM searches and LHC
- A thorough understanding of the instrument and control of systematics is critical
- Better understanding of J-factors is essential
- We also need to understand the astrophysical background, particularly for the GC observations

With thanks to all my colleagues in CTA from whom I stole slides, graphs etc.