LPSC Journal Club, 17/03/10

Dark matter substructure modelling
and
sensitivity of the Cherenkov Telescope Array to Galactic dark halos

Hütten, M.; Combet, C.; Maier, G.; Maurin, D.

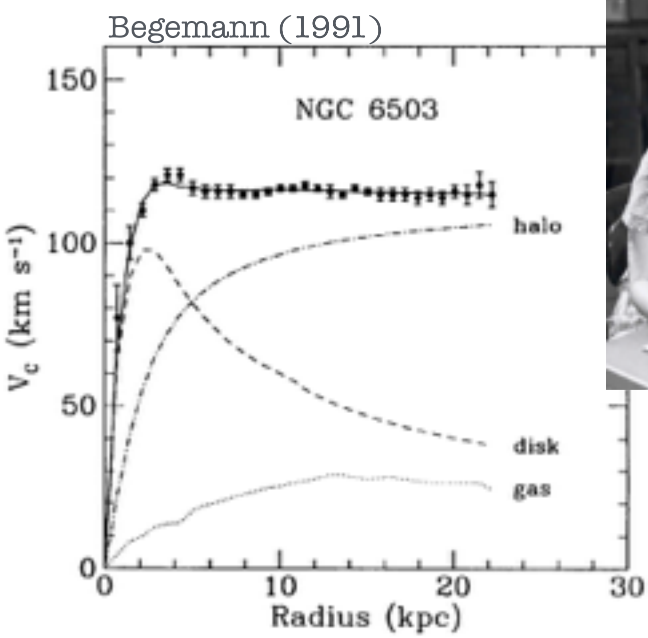
JCAP09(2016)047, arXiv:1606.04898

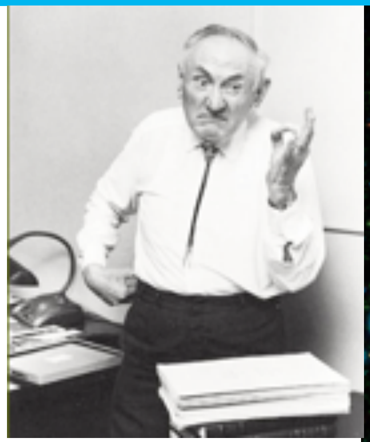
DESY

Enigmass

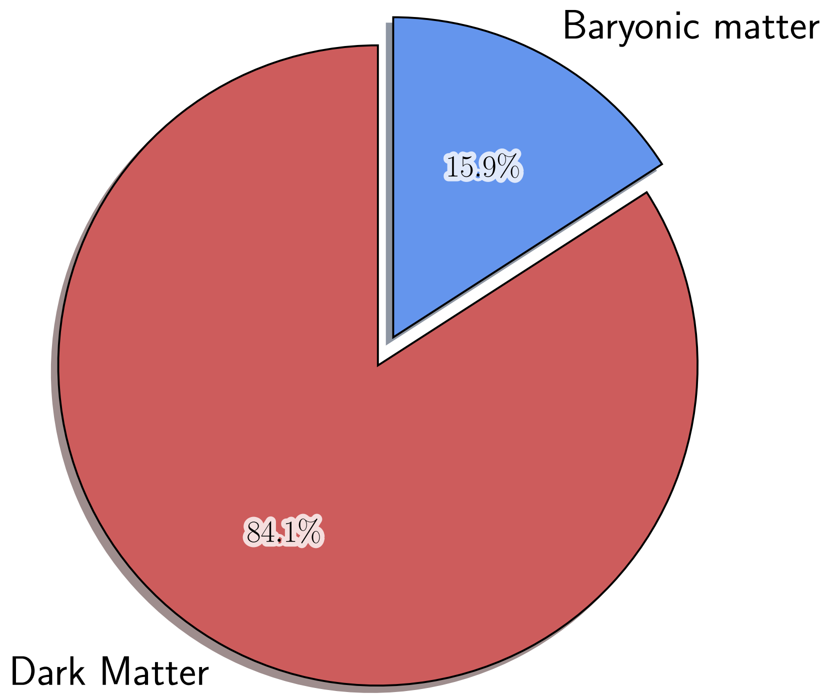
The enigma of mass

What’s the (dark) matter?



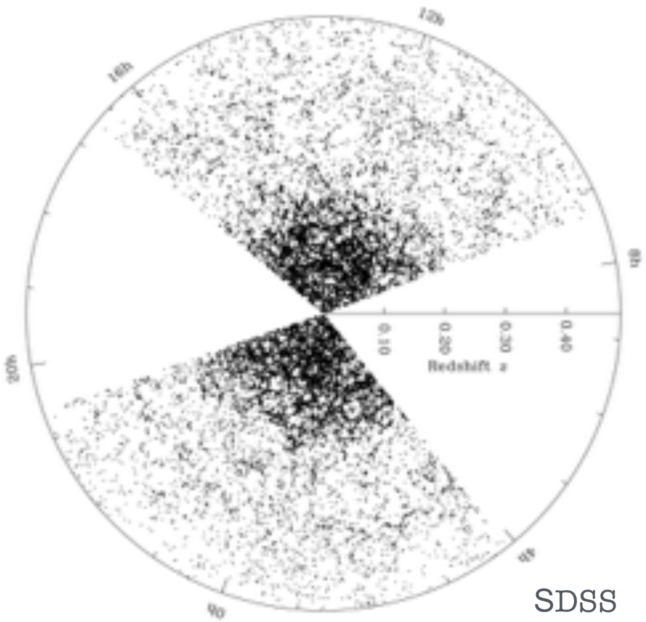


Galaxies

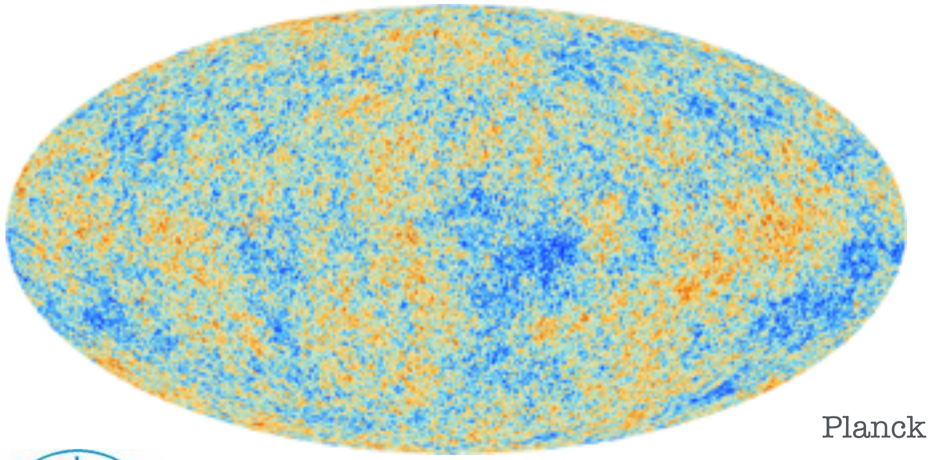


Galaxy clusters

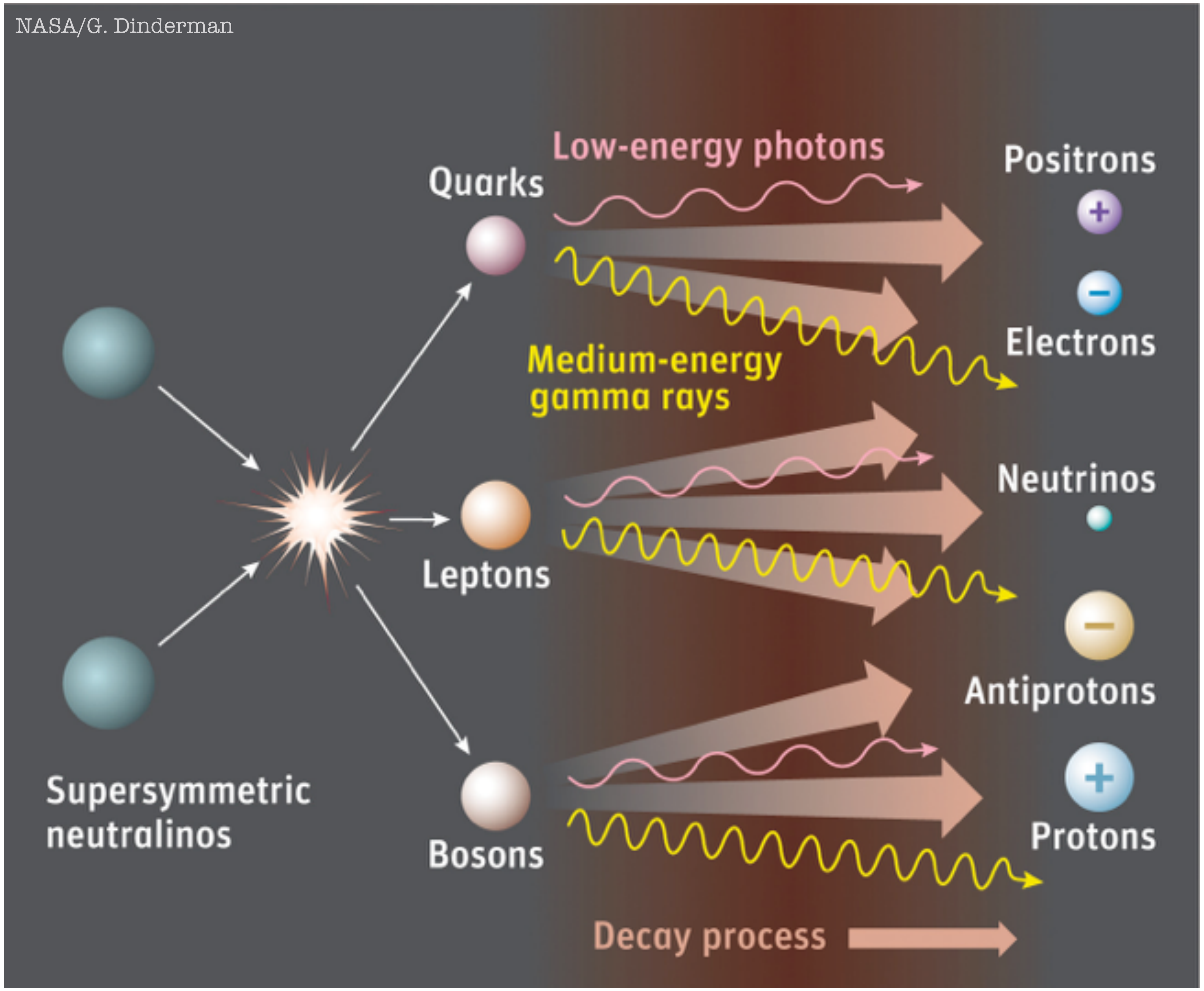
Large Scale Structure



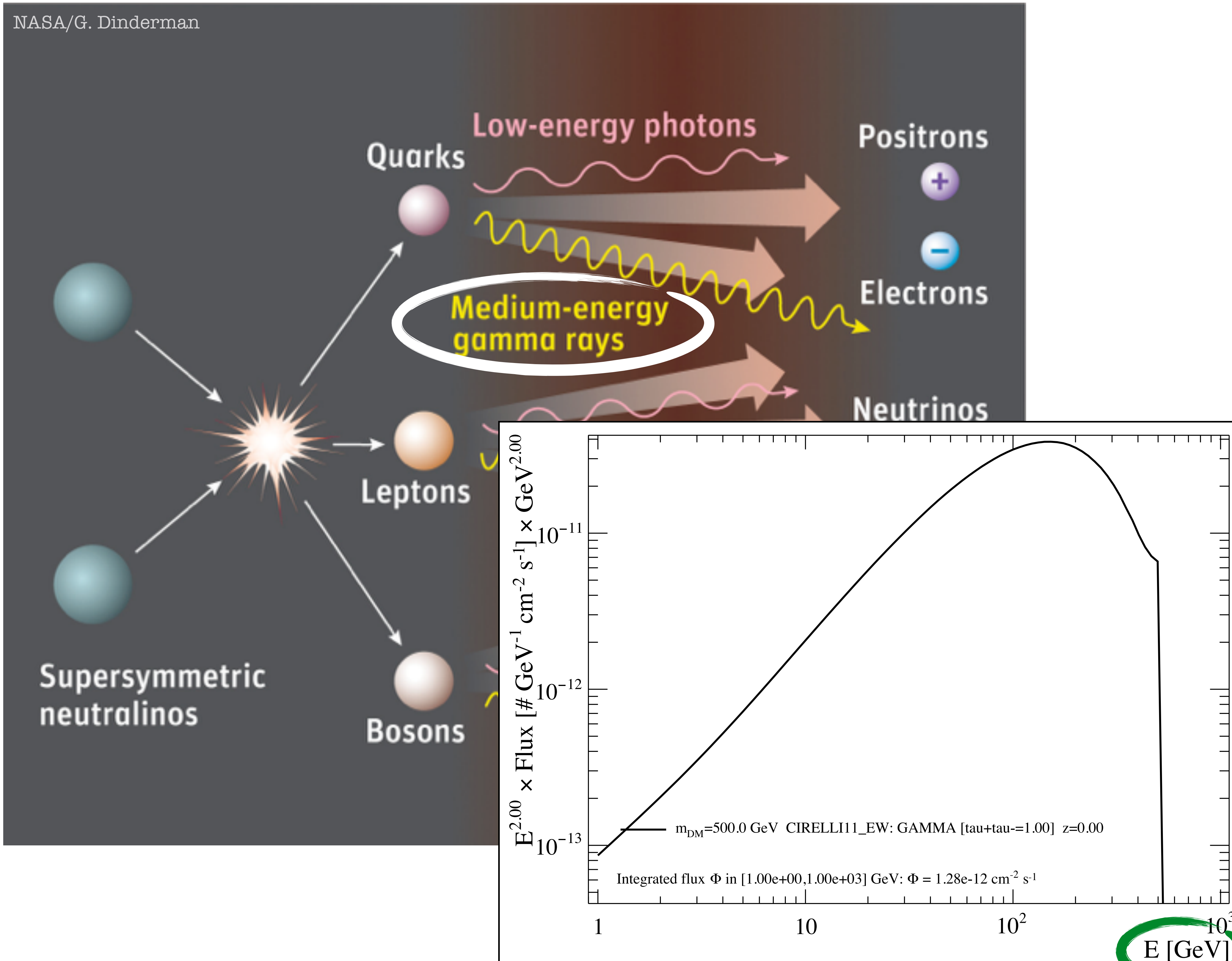
Cosmic Microwave Background



The Dark Matter ↔ γ-ray connection



The Dark Matter ↔ γ-ray connection



DESY

The Dark Matter ↔ γ-ray connection

annihilation cross section

$$\frac{\mathrm{d}\Phi_\gamma^{\mathrm{ann.}}}{\mathrm{d}E_\gamma} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_\chi^{\ 2}} \cdot \sum_i^{\mathrm{chann.}} b_i \frac{\mathrm{d}N_\gamma^i}{\mathrm{d}E_\gamma} \cdot \int_{\Delta\Omega}\int_{l.o.s.} \rho_{\mathrm{DM}}^2[r(l,\Omega)]\,\mathrm{d}l\,\mathrm{d}\Omega$$

spectrum

$= J$: Astrophysical factor

DM particle mass

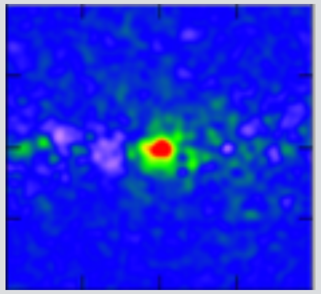
The higher the DM particle mass (yet unknown!), the more energetic the γ-ray spectrum

Astrophysical dark matter γ-ray targets

> Remote galaxies & galaxy clusters

Abell 1689

> Galactic center and vicinity

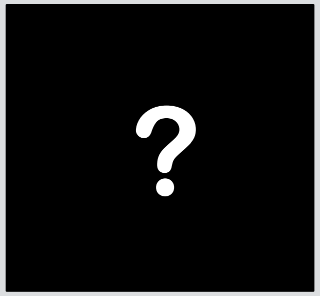


1402.6703

> Dwarf Galaxies

Sculptor dSphG

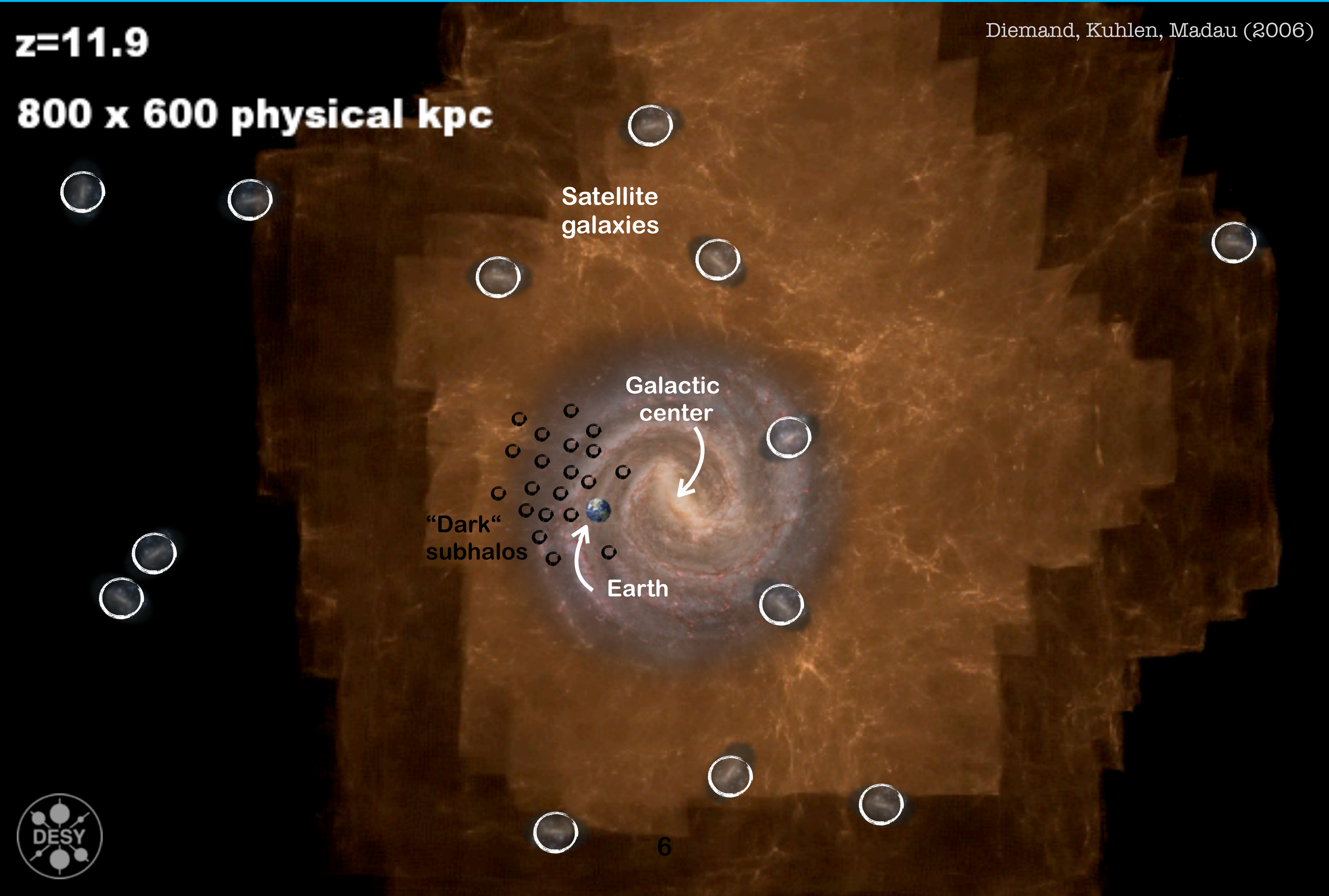
> Dark Galactic subhalos



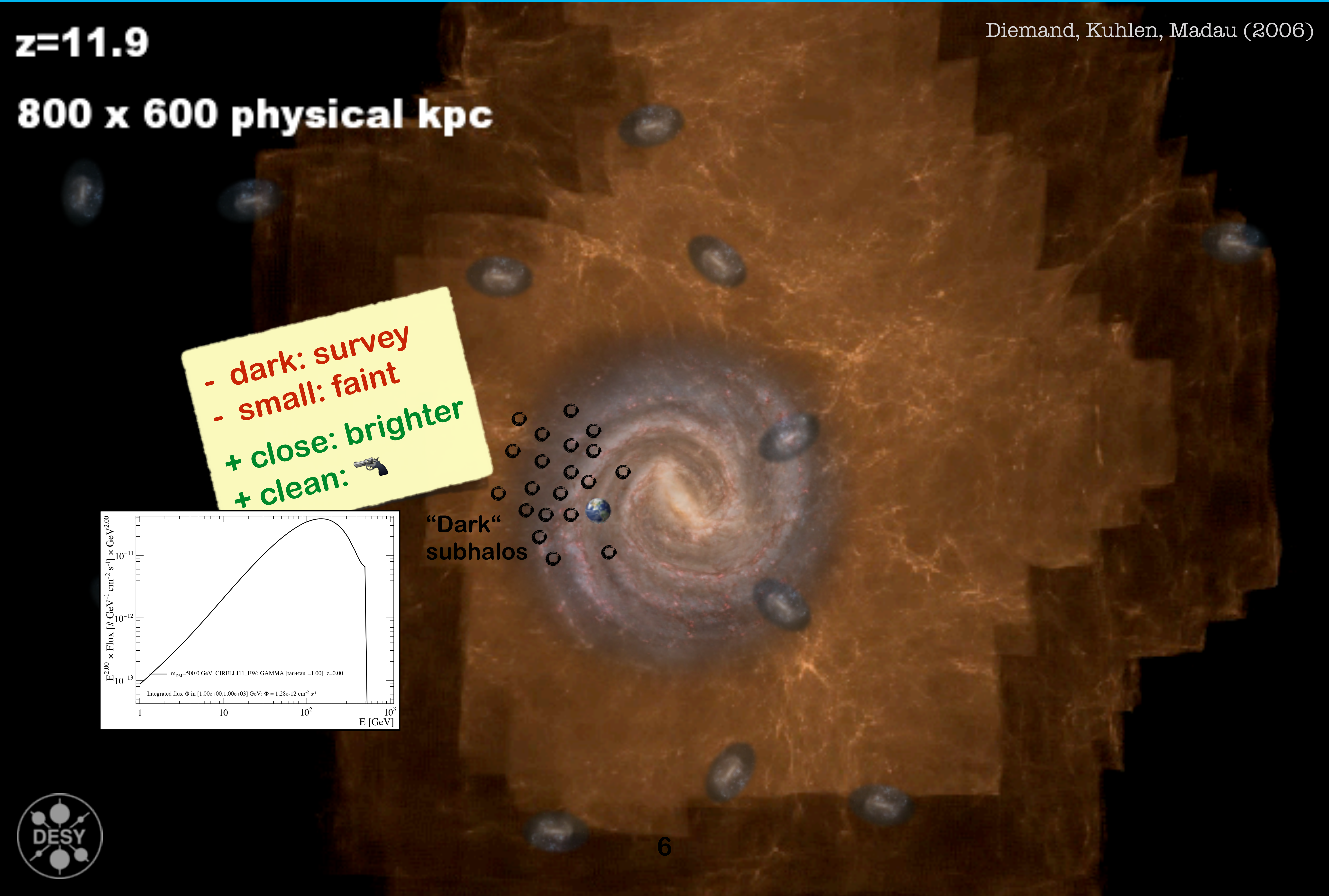
extra-galactic

Galactic targets

Dark Matter in the Galaxy

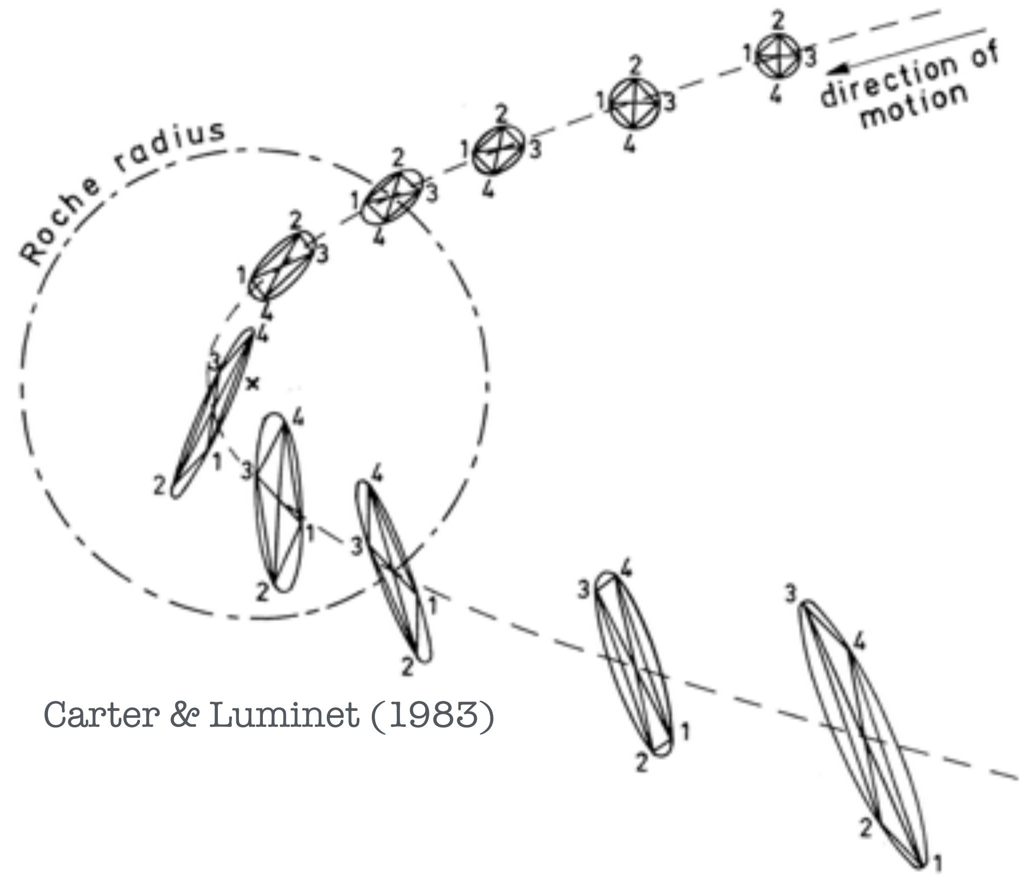


Dark Matter in the Galaxy

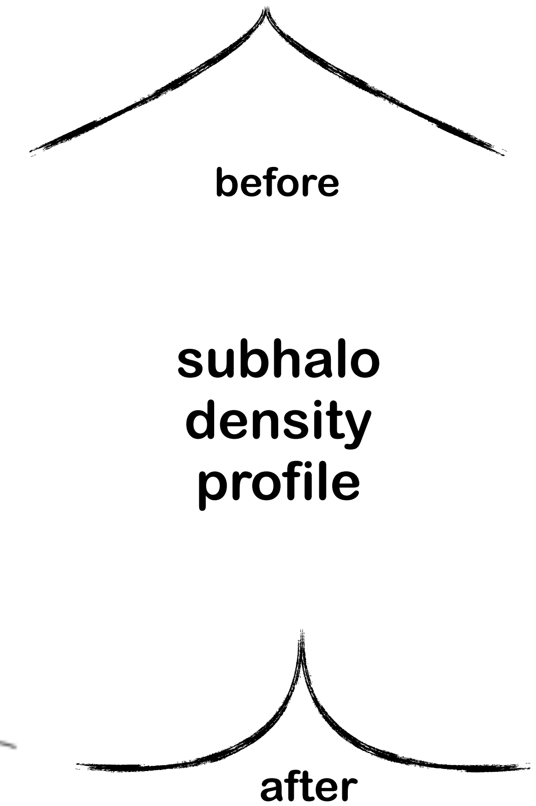


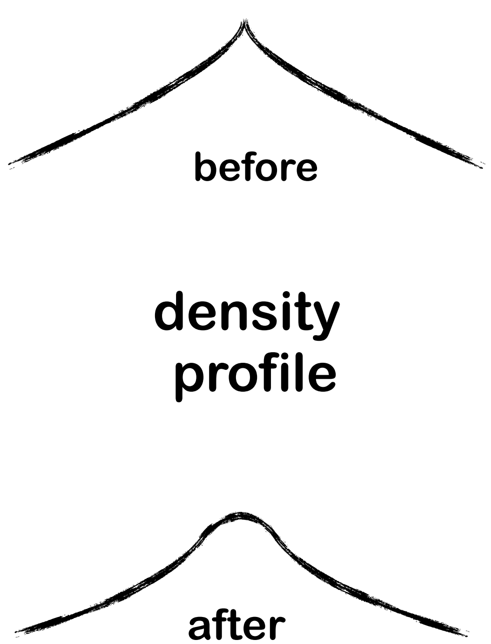
Modelling the Galactic DM substructure distribution

> **Tidal disruption**



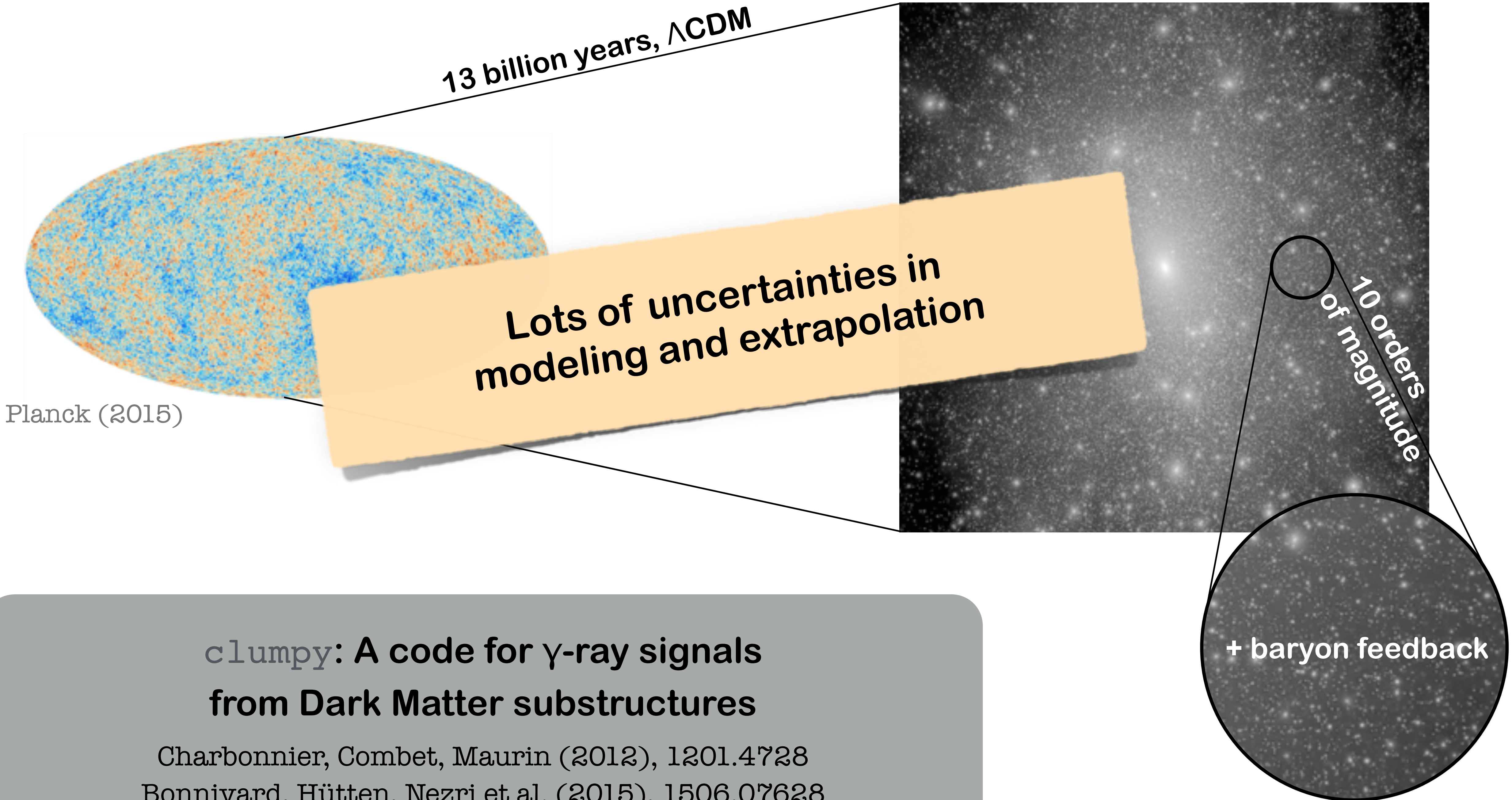
Carter & Luminet (1983)





> **Baryonic (supernova) feedback**

Modelling the Galactic DM substructure distribution



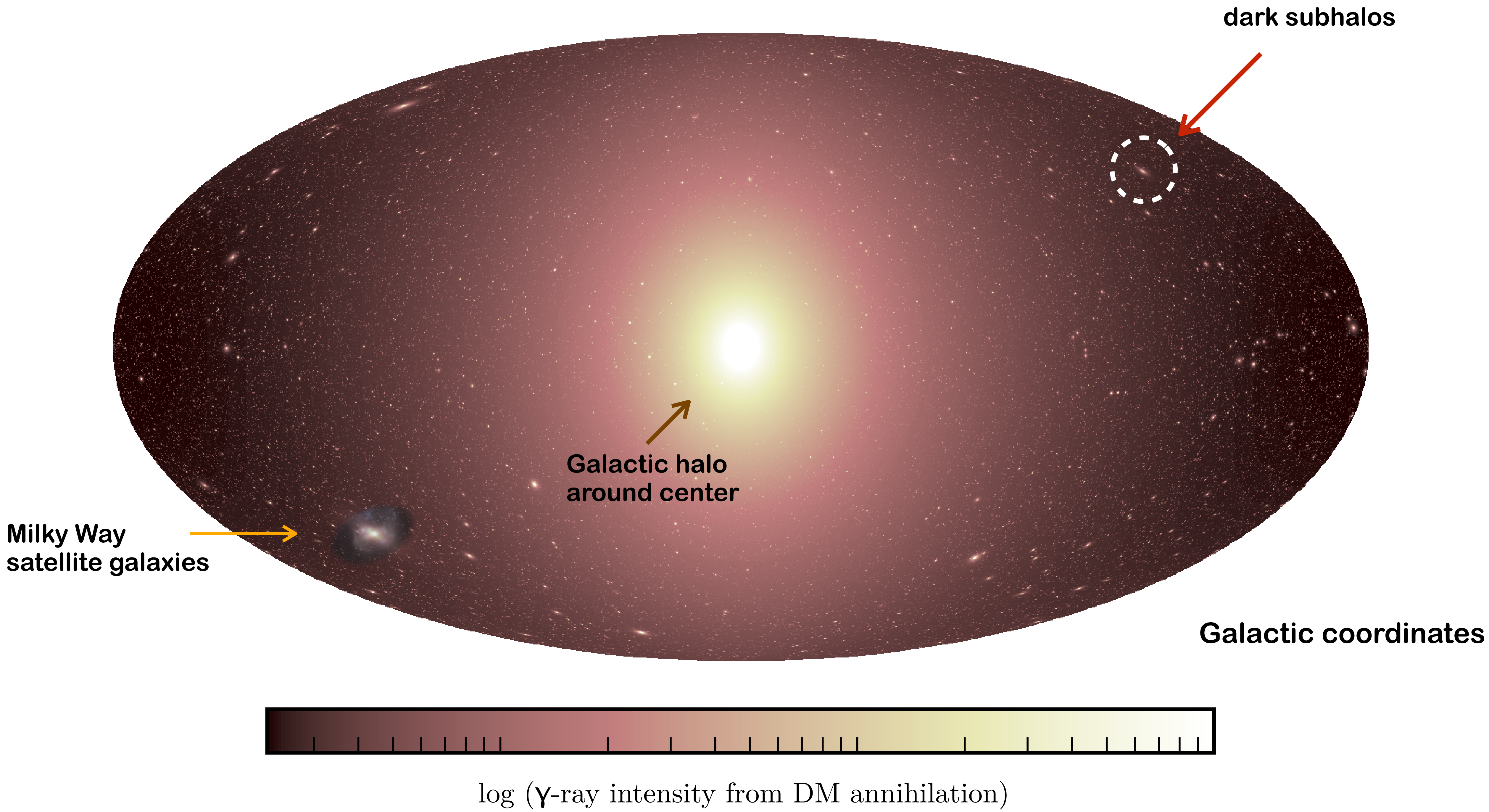
`clumpy`: **A code for γ-ray signals from Dark Matter substructures**

Charbonnier, Combet, Maurin (2012), 1201.4728

Bonnivard, Hütten, Nezri et al. (2015), 1506.07628

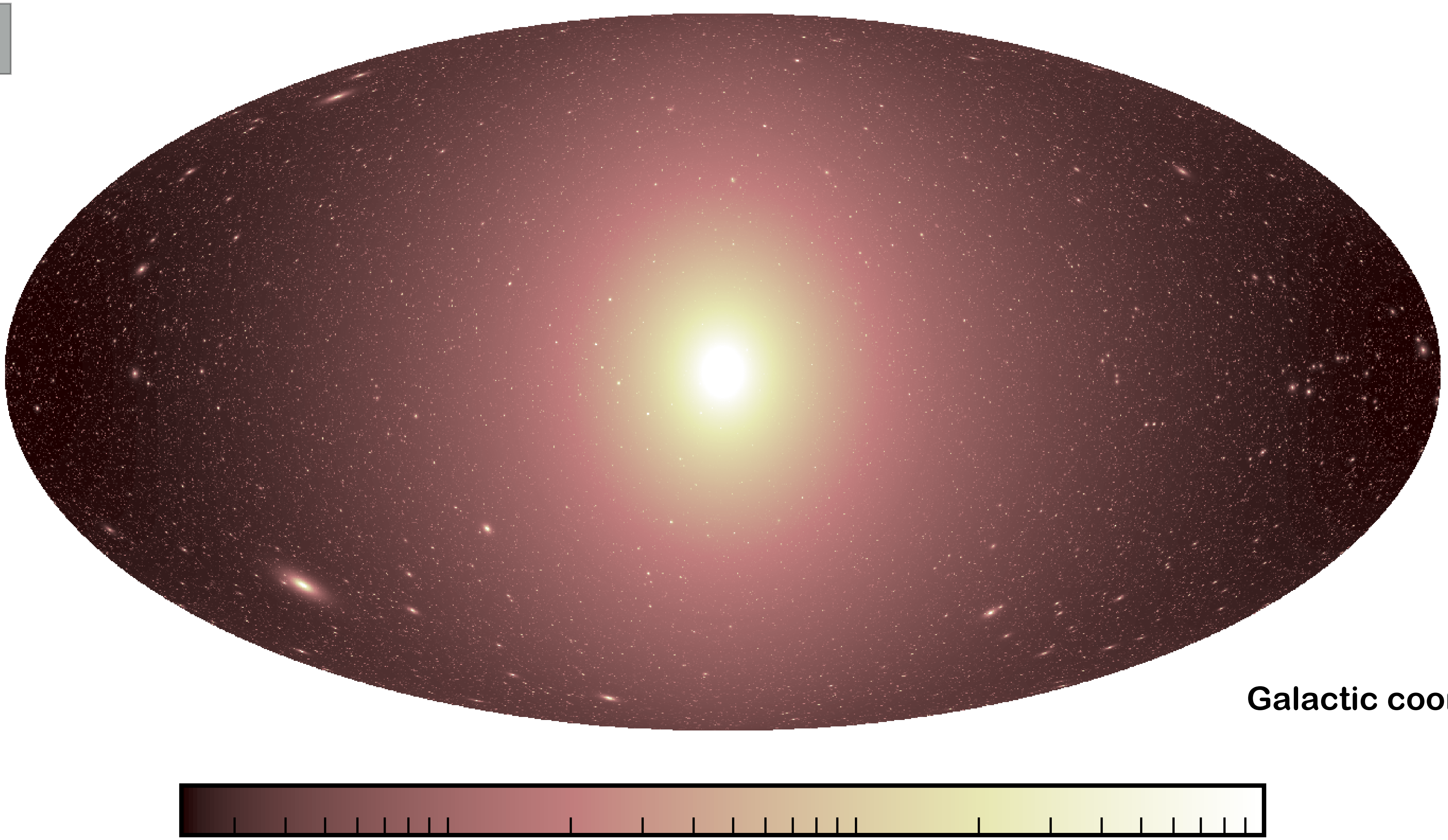
versatile tool to study parametrized N-body results

The Galactic Dark Matter sky from Earth



The Galactic Dark Matter sky from Earth

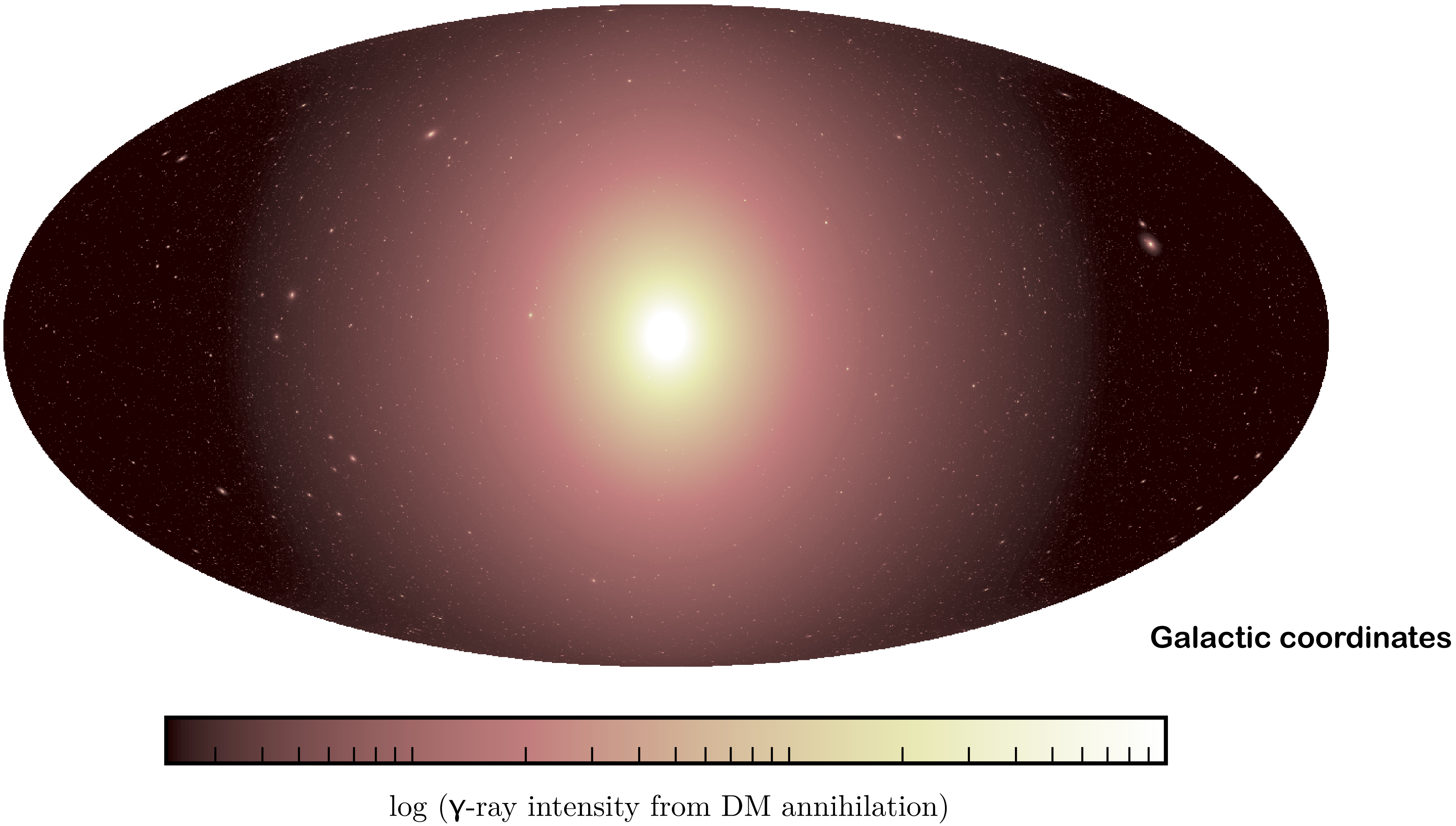
HIGH



Matching DM only simulations (Via Lactea I + II, Aquarius,…)

The Galactic Dark Matter sky from Earth

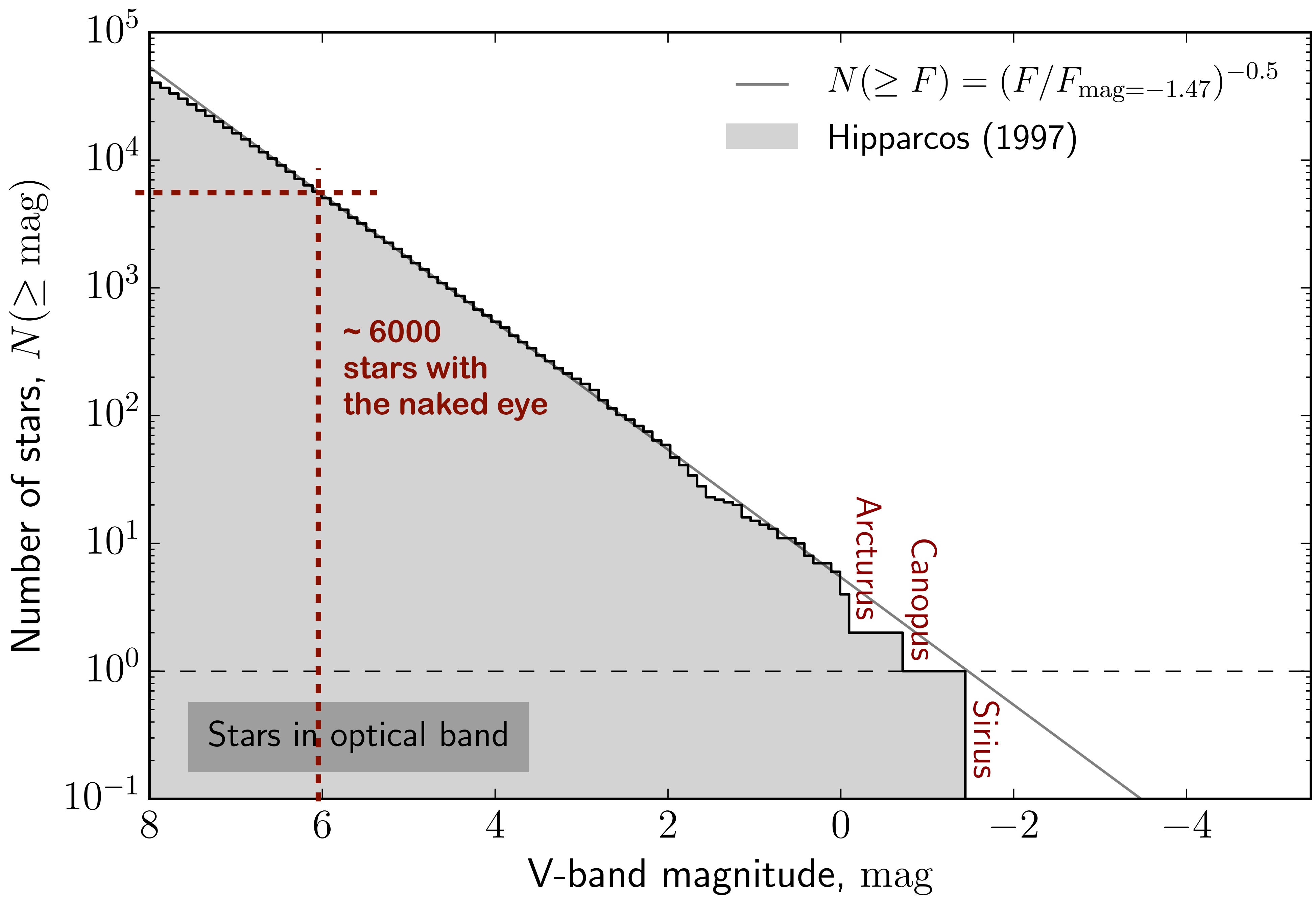
LOW



Accounting for baryonic feedback, less subhalos surviving tidal disruption

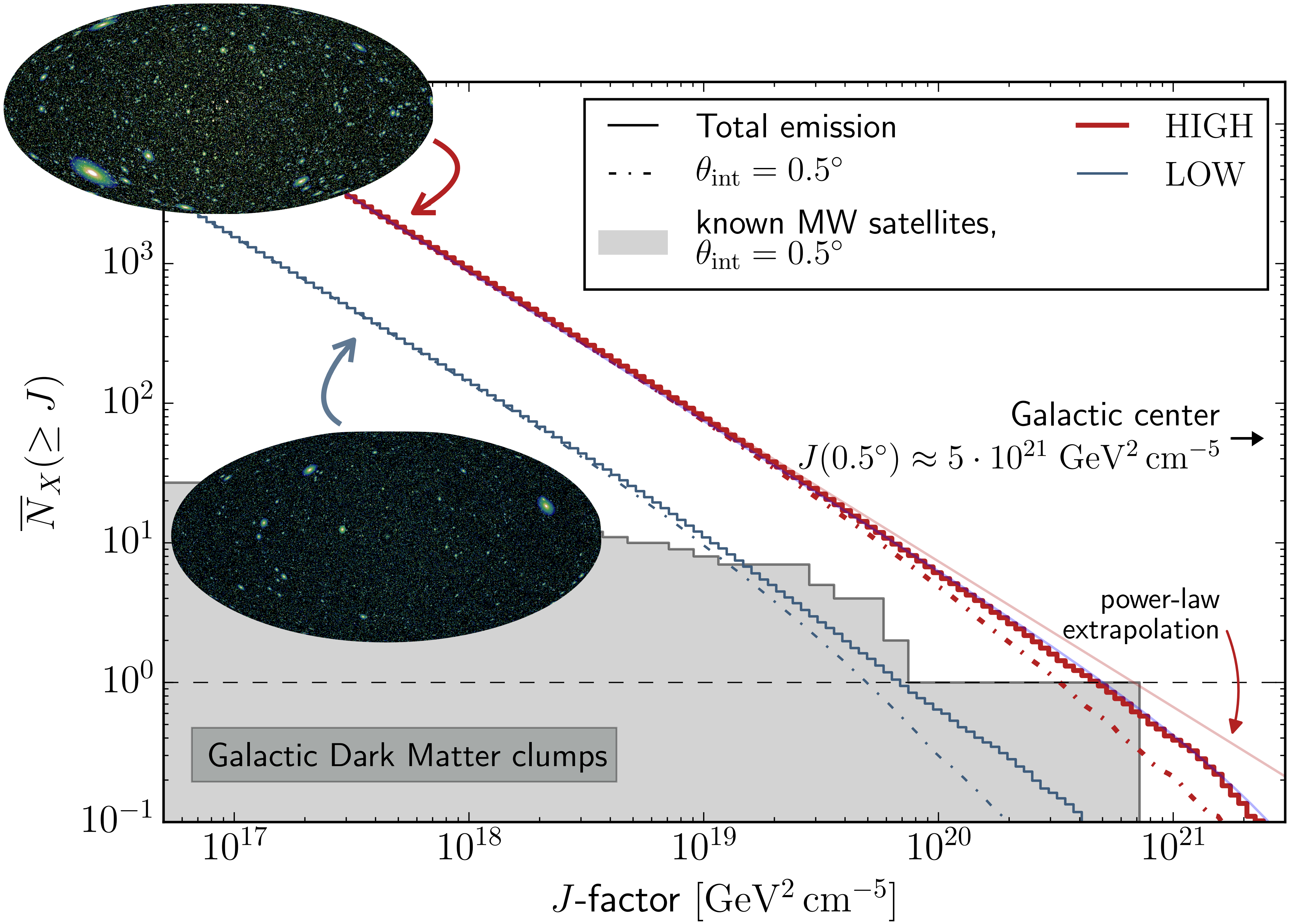
Excursion: Source flux count distributions

> **How many stars shine on Earth?**



Back to Dark Matter

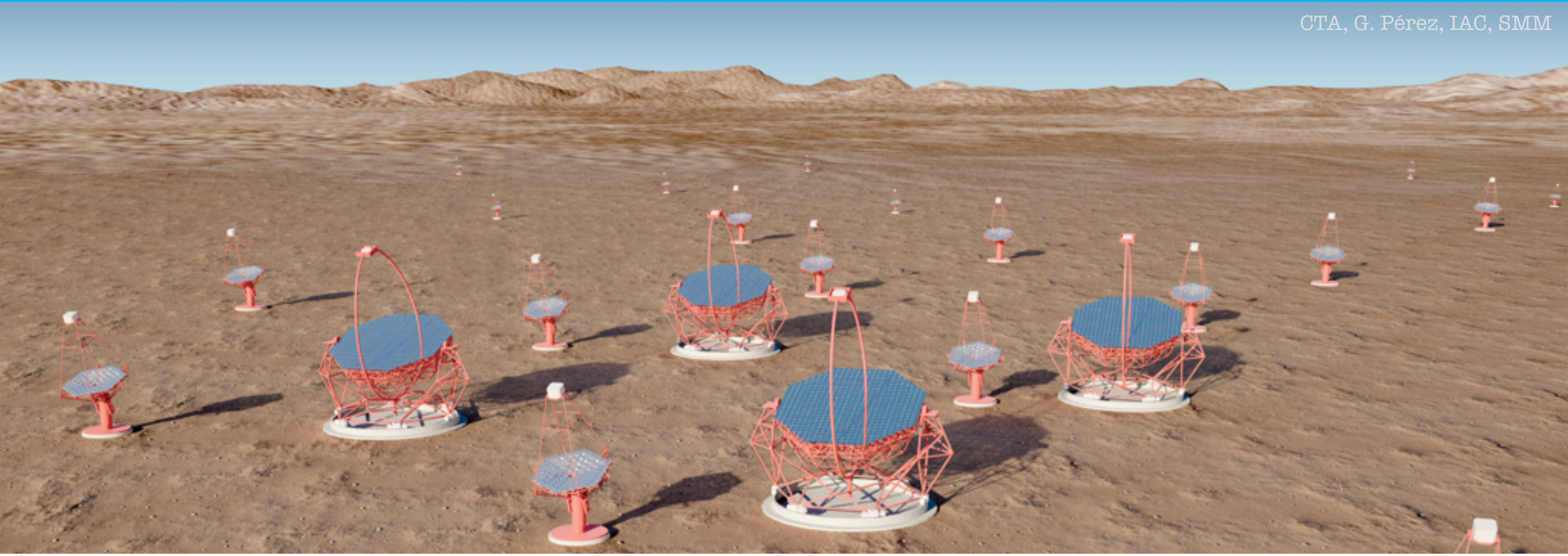
> **Galactic Dark Matter subhalo brightness distribution**



DM subhalos with the Cherenkov Telescope Array

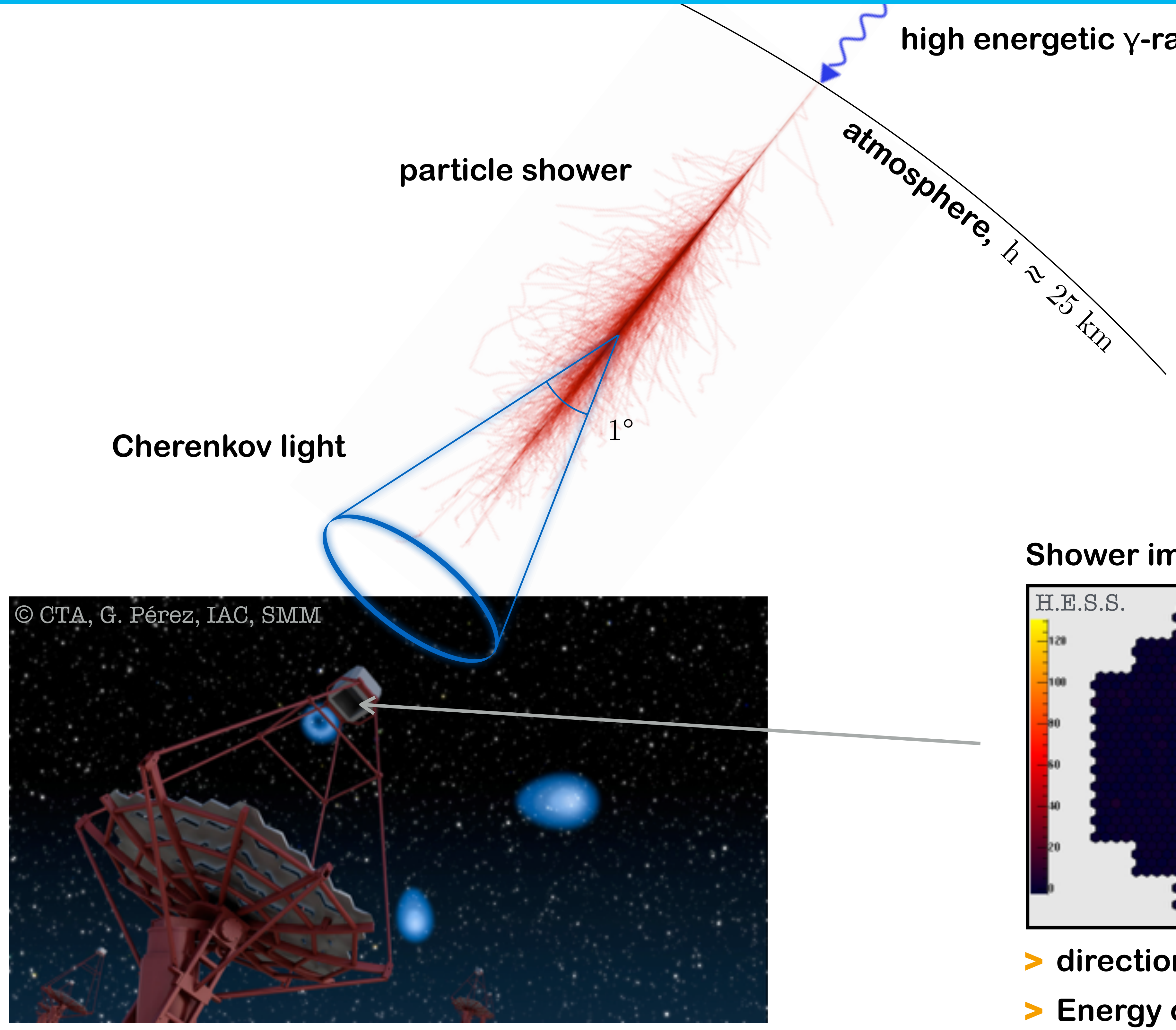
Is CTA sensitive to detect dark satellites in γ-rays > 100 GeV?

The Cherenkov Telescope Array (CTA)

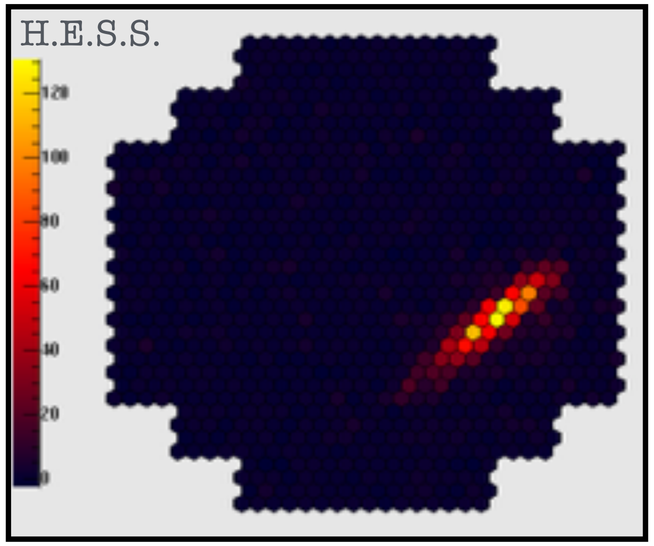


- The next generation Earth-bound γ-ray telescope
- Two arrays of 99 / 19 Cherenkov telescopes in Chile / La Palma.
- γ-ray energy range: $20\ \mathrm{GeV} - 300\ \mathrm{TeV}$.
- Angular resolution: $< 0.1°$, $< 0.05°$ above $1\ \mathrm{TeV}$.
- Point-source sensitivity: 1% Crab-flux in $1\ \mathrm{h}$

Some remarks on Earth-bound γ-ray astronomy



Shower image in the camera

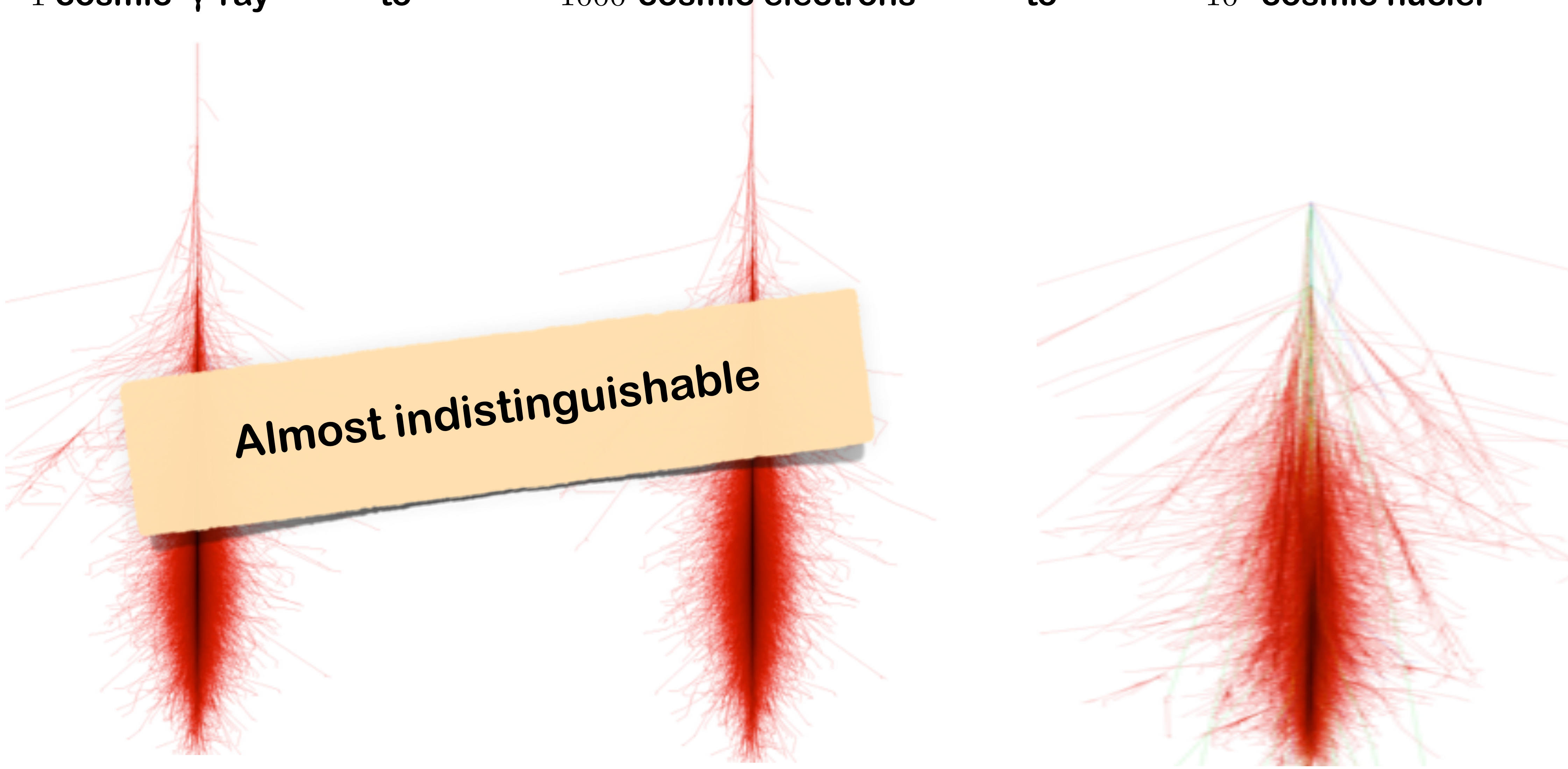


- direction of primary γ-ray
- Energy of primary γ-ray

Some remarks on Earth-bound γ-ray astronomy

- **not only γ-rays create atmospheric particle showers…**

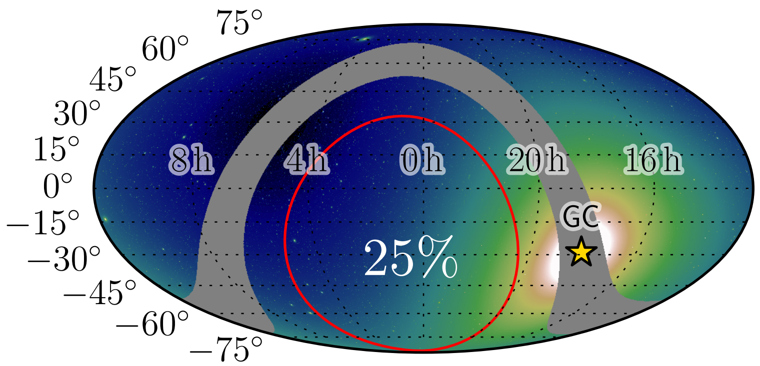
1 **cosmic γ-ray** **to** ~ 1000 **cosmic electrons** **to** $\sim 10^5$ **cosmic nuclei**



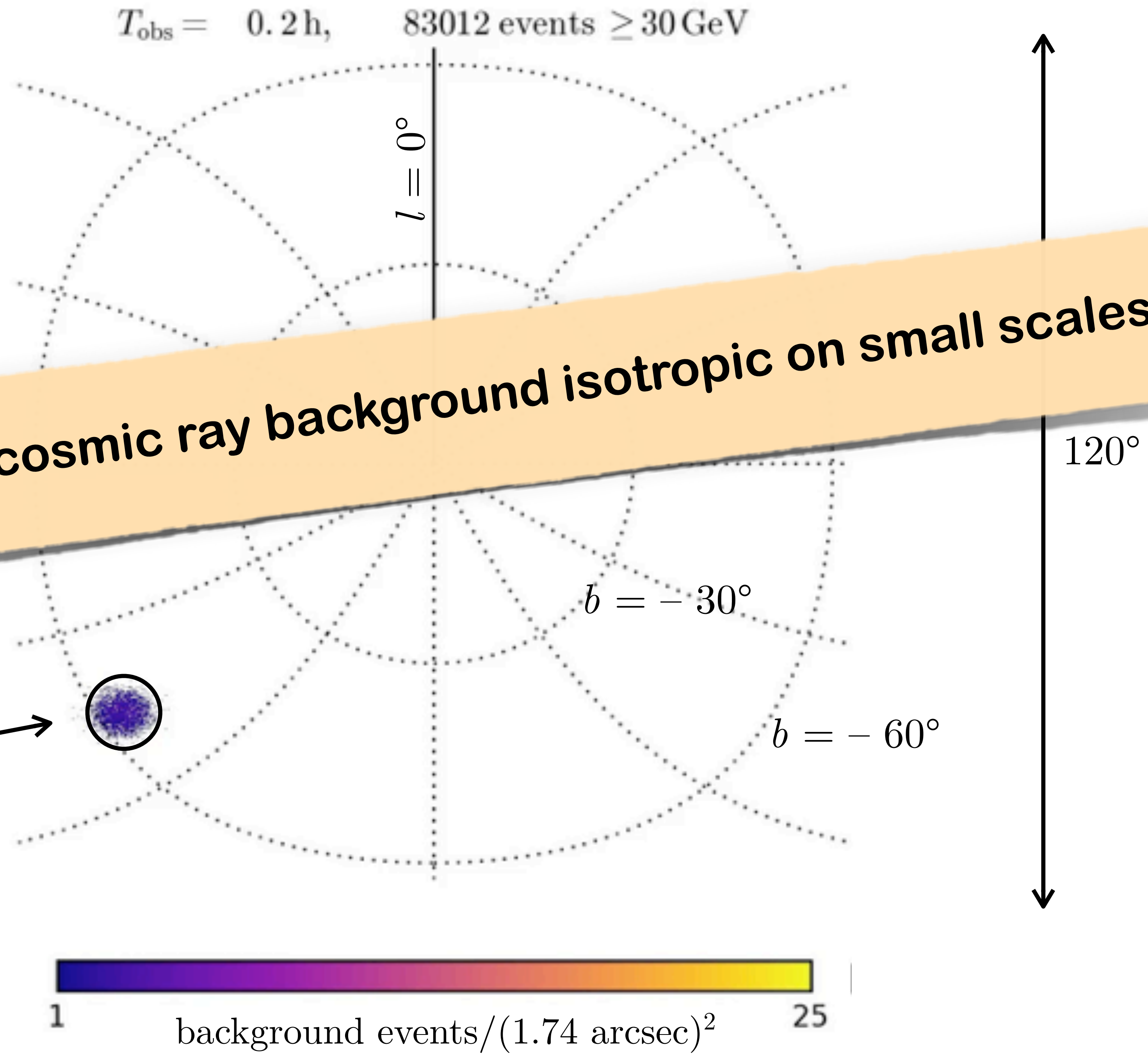
1 TeV **γ-ray shower** 1 TeV **electron shower** 1 TeV **proton shower**

Shower images: Fabian Schmidt, University of Leeds

A model for the CTA extragalactic survey



2880 observations à 10.4 min



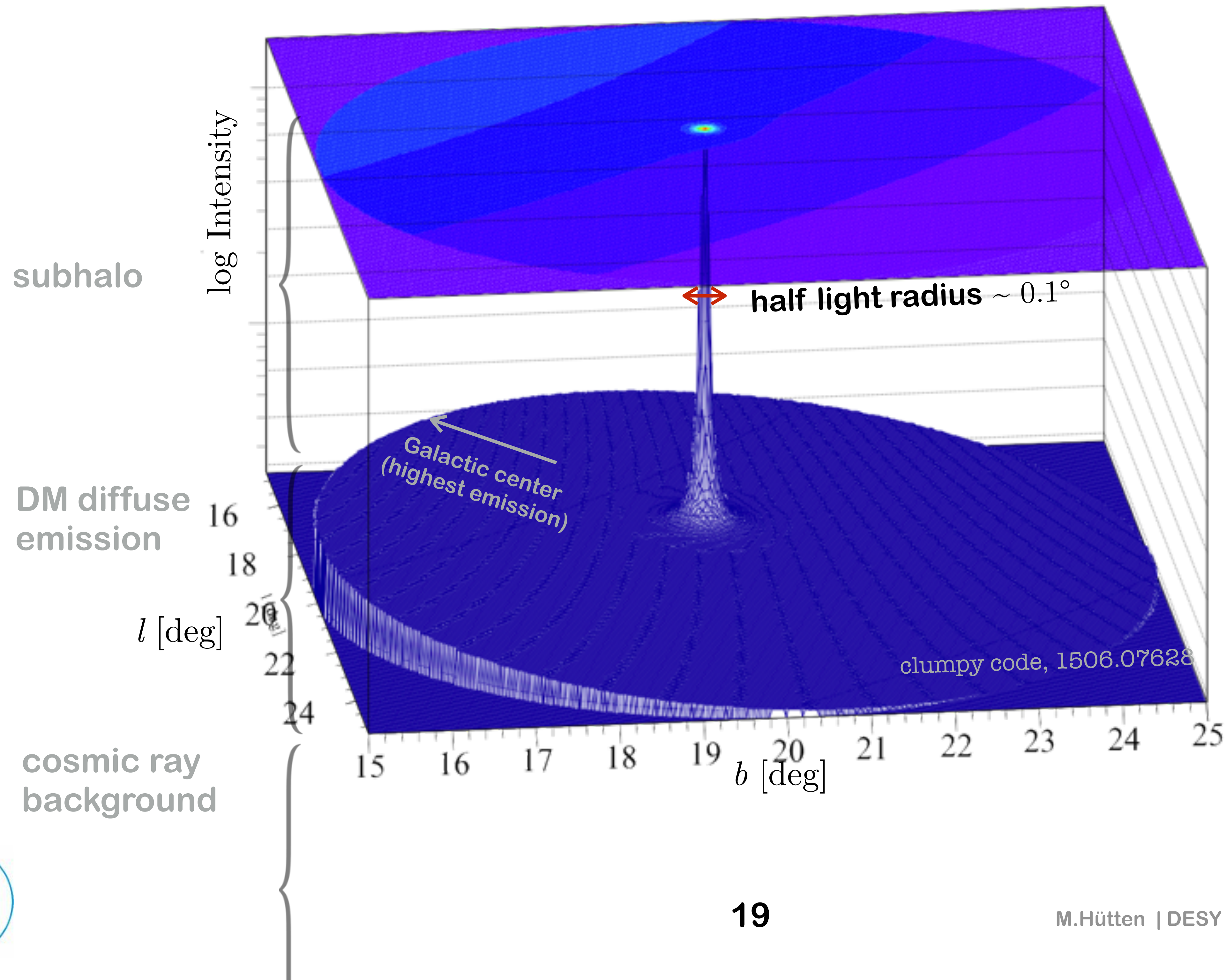
charged cosmic ray background isotropic on small scales

CTA
field of view
$\sim 7°$ **diameter**
at 500 GeV
moon: ∘

Gammalib
Knödlseder
et al. (2016)

Likelihood analysis to find the brightest subhalo

> **Slightly extended, but very steep annihilation profile**



Likelihood analysis to find the brightest subhalo

> **Unbinned likelihood function for N_{obs} recorded events**

$$L(\mathcal{M}\,|\,N_{\mathrm{obs}},\, E_{\mathrm{R},\,1\ldots N_{\mathrm{obs}}},\, \vec{k}_{\mathrm{R},\,1\ldots N_{\mathrm{obs}}}) = p(N_{\mathrm{obs}}\,|\,N_{\mathrm{pred}}(\mathcal{M}))\times\prod_{1}^{N_{\mathrm{obs}}} p(E_{\mathrm{R,\,i}},\, \vec{k}_{\mathrm{R,\,i}}\,|\,\mathcal{M}).$$

$$p(E_{\mathrm{R}},\, \vec{k}_{\mathrm{R}}\,|\,\mathcal{M}) = \int\limits_{E,\,\Omega,\,A_{\mathrm{eff}}(E)} p(E_{\mathrm{R}}\,|\,E,\,\vec{k})\times p(\vec{k}_{\mathrm{R}}\,|\,E,\,\vec{k})\times\frac{d\Phi_{\mathcal{M}}}{dE\,d\Omega}(E,\,\vec{k})\;\; dA\,dE\,d\Omega$$

Energy resolution (neglected in this work)

Angular resolution (Gauss assumed in this work)

Extended DM halo profile + energy spectrum from annihilation

$$\frac{\mathrm{d}\Phi_{\gamma}^{\mathrm{ann.}}}{\mathrm{d}E_{\gamma}} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\chi}^{2}}\cdot\sum_{i}^{\mathrm{chann.}} b_i\,\frac{\mathrm{d}N_{\gamma}^{i}}{\mathrm{d}E_{\gamma}}\cdot\int_{\Delta\Omega}\int_{l.o.s.}\rho_{\mathrm{DM}}^{2}[r(l,\Omega)]\,\mathrm{d}l\,\mathrm{d}\Omega$$

Likelihood analysis to find the brightest subhalo

> **Unbinned likelihood function for N_{obs} recorded events**

$$L(\mathcal{M} \,|\, N_{\mathrm{obs}},\, E_{\mathrm{R},1\ldots N_{\mathrm{obs}}},\, \vec{k}_{\mathrm{R}} \ldots \mathcal{M}).$$

ctools
cherenkov telescope array

ctlike **Likelihood fitter from** ctools

Knödlseder et al. (2016)

$$p(E_{\mathrm{R}}, \ldots = \int_{E,\,\Omega,\,A_{\mathrm{eff}}(E)} p(E_{\mathrm{R}} \,|\, E,\, \vec{k}) \times p(\vec{k}_{\mathrm{R}} \,|\, E,\, \vec{k}) \times \frac{d\Phi_{\mathcal{M}}}{\ldots}(E, \vec{k}) \ldots d\Omega$$

+ accounting for trials in a blind survey search

Energy resolution
(neglected in this work)

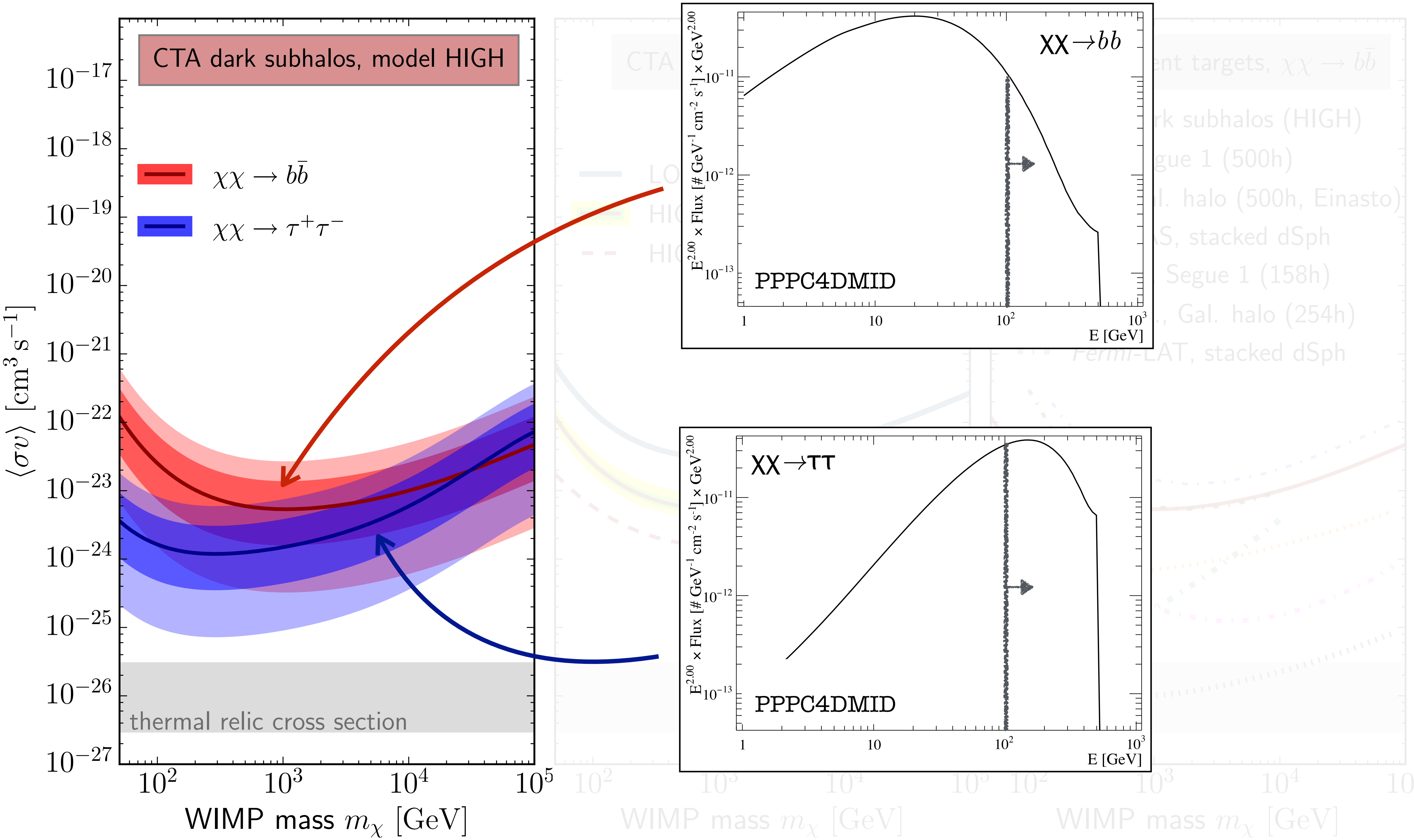
Angular resolution
(Gauss assumed in this work)

Extended DM halo profile
+ energy spectrum from annihilation

$$\frac{\mathrm{d}\Phi_\gamma^{\mathrm{ann.}}}{\mathrm{d}E_\gamma} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_\chi^2} \cdot \sum_i^{\mathrm{chann.}} b_i \frac{\mathrm{d}N_\gamma^i}{\mathrm{d}E_\gamma} \cdot \int_{\Delta\Omega}\int_{l.o.s.} \rho_{\mathrm{DM}}^2[r(l,\Omega)]\,\mathrm{d}l\,\mathrm{d}\Omega$$

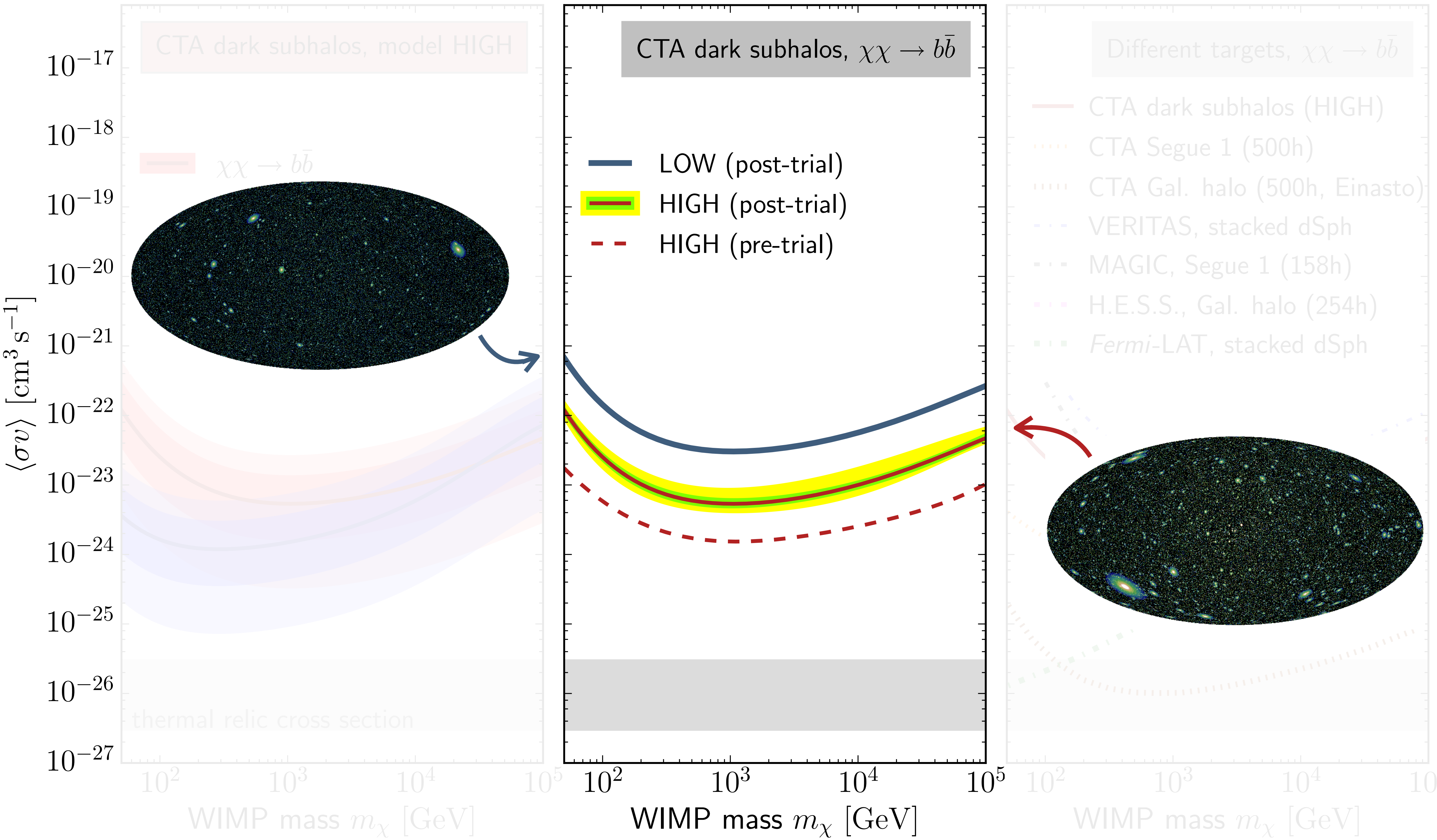
DESY

Results

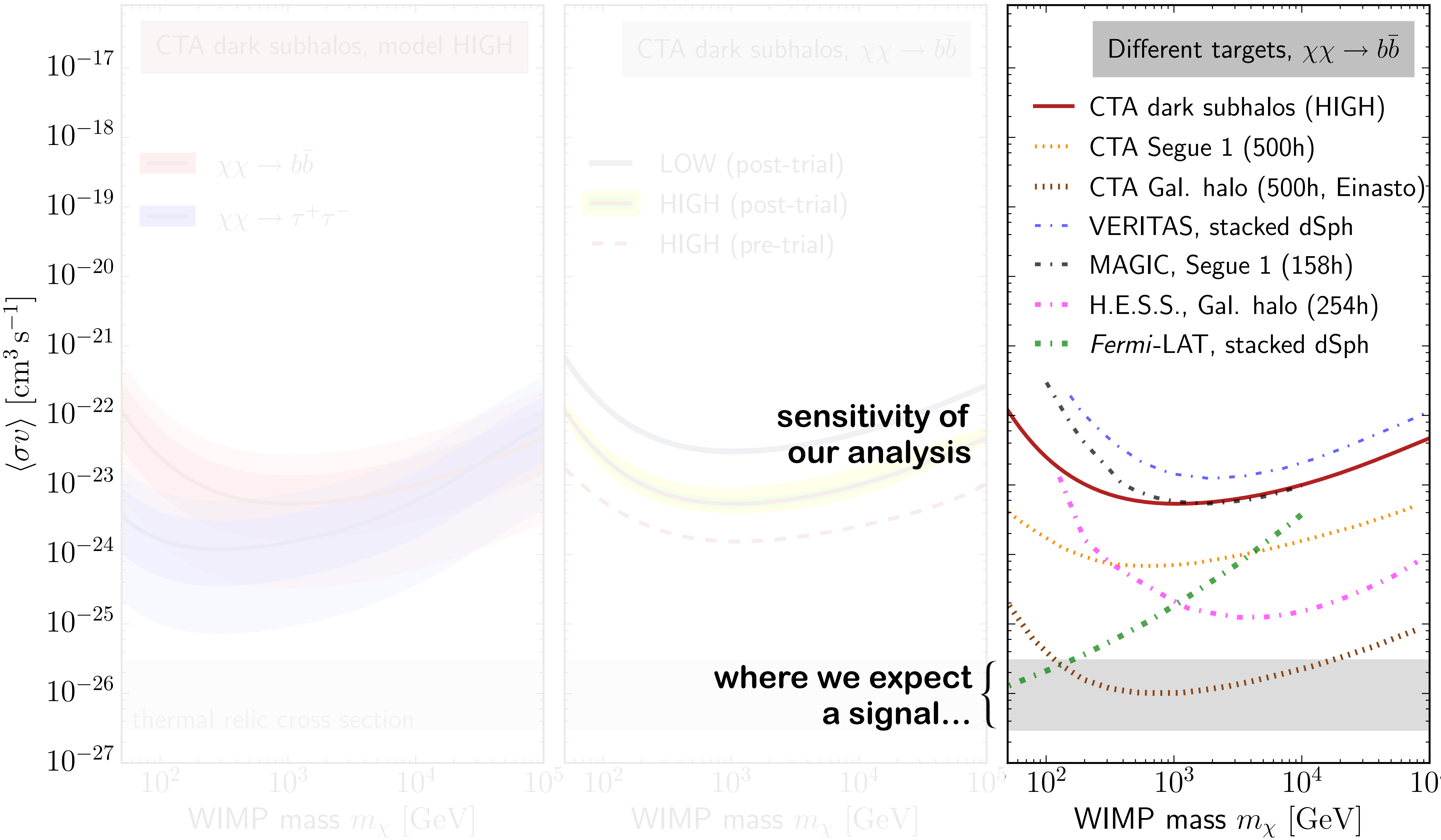


CTA dark subhalos, model HIGH
$\chi\chi \rightarrow b\bar{b}$
$\chi\chi \rightarrow \tau^+\tau^-$
thermal relic cross section
$\langle \sigma v \rangle$ [$\mathrm{cm^3 s^{-1}}$]
WIMP mass m_χ [GeV]
$\chi\chi \rightarrow bb$
PPPC4DMID
E [GeV]
$E^{2.00} \times$ Flux [# $\mathrm{GeV^{-1}\,cm^{-2}\,s^{-1}}$] $\times$ $\mathrm{GeV^{2.00}}$
$\chi\chi \rightarrow \tau\tau$
PPPC4DMID
E [GeV]

Results


CTA dark subhalos, $\chi\chi \rightarrow b\bar{b}$
LOW (post-trial)
HIGH (post-trial)
HIGH (pre-trial)
$\langle \sigma v \rangle$ [cm^3 s^{-1}]
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^2
10^3
10^4
10^5
WIMP mass m_χ [GeV]

Results



sensitivity of our analysis

where we expect a signal…