WIMPs @ CTA

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MONASH University

special thanks to:
Torsten Bringmann (Oslo)
Christopher Eckner (Annecy)
Sergio Cadena Hernández (Mexico City)

image: https://www.cta-observatory.org/the-dark-side-of-the-matter/

outline

WIMPs as gamma ray sources

projected CTA sensitivity for generic WIMPs

Bayesian backbone of our toolchain

prelim results

WIMPs

weakly interacting massive particles

many beyond the standard model theories predict WIMP-like particles

WIMP-like particles are still perfect dark matter candidates

our GAMBIT studies repeatedly prove this

most WIMP-like particles are their own antiparticles

they self-annihilate into energetic standard particles

energetic charged particles copiously produce gamma rays

WIMPs producing cosmic gamma rays

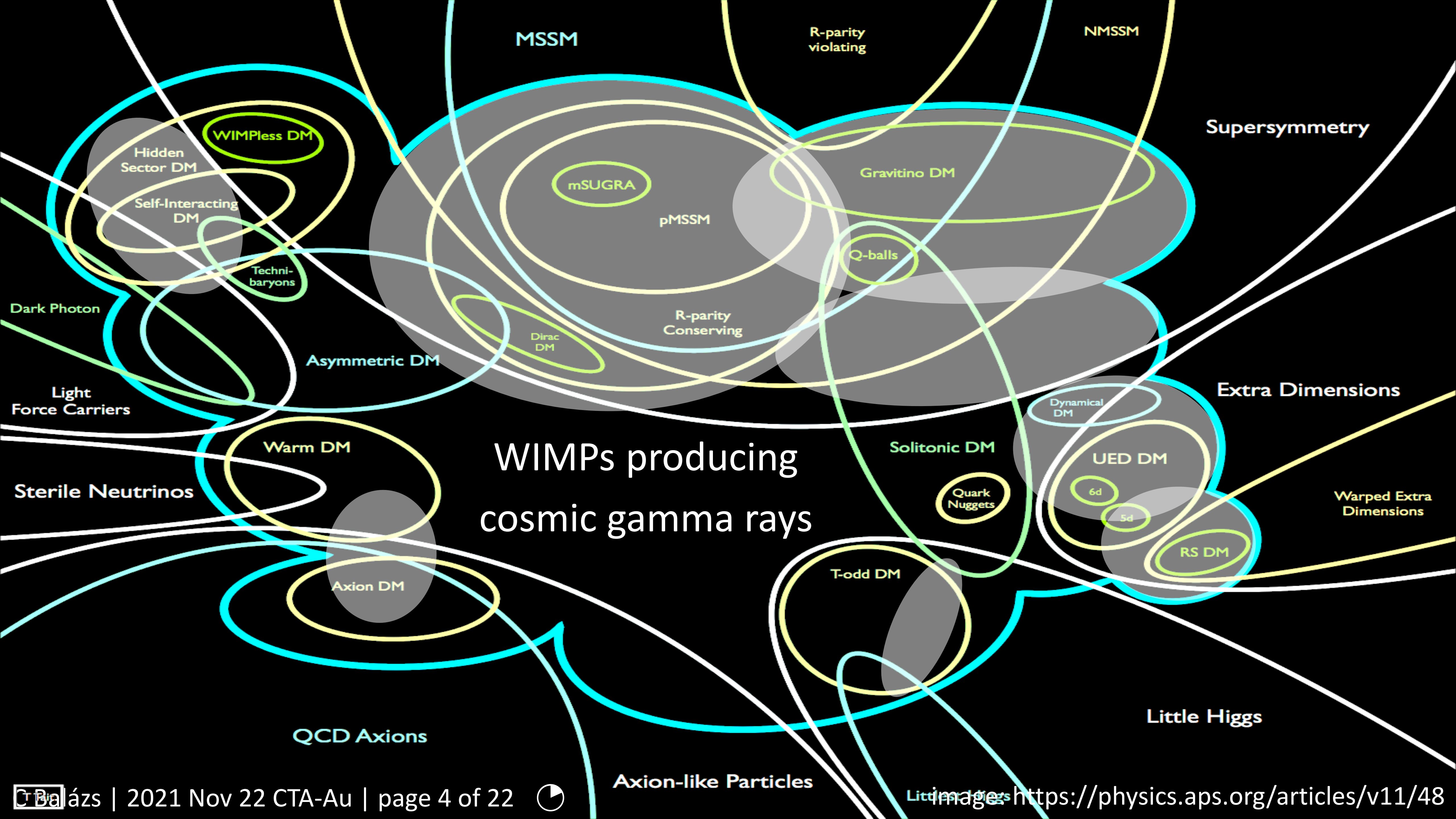
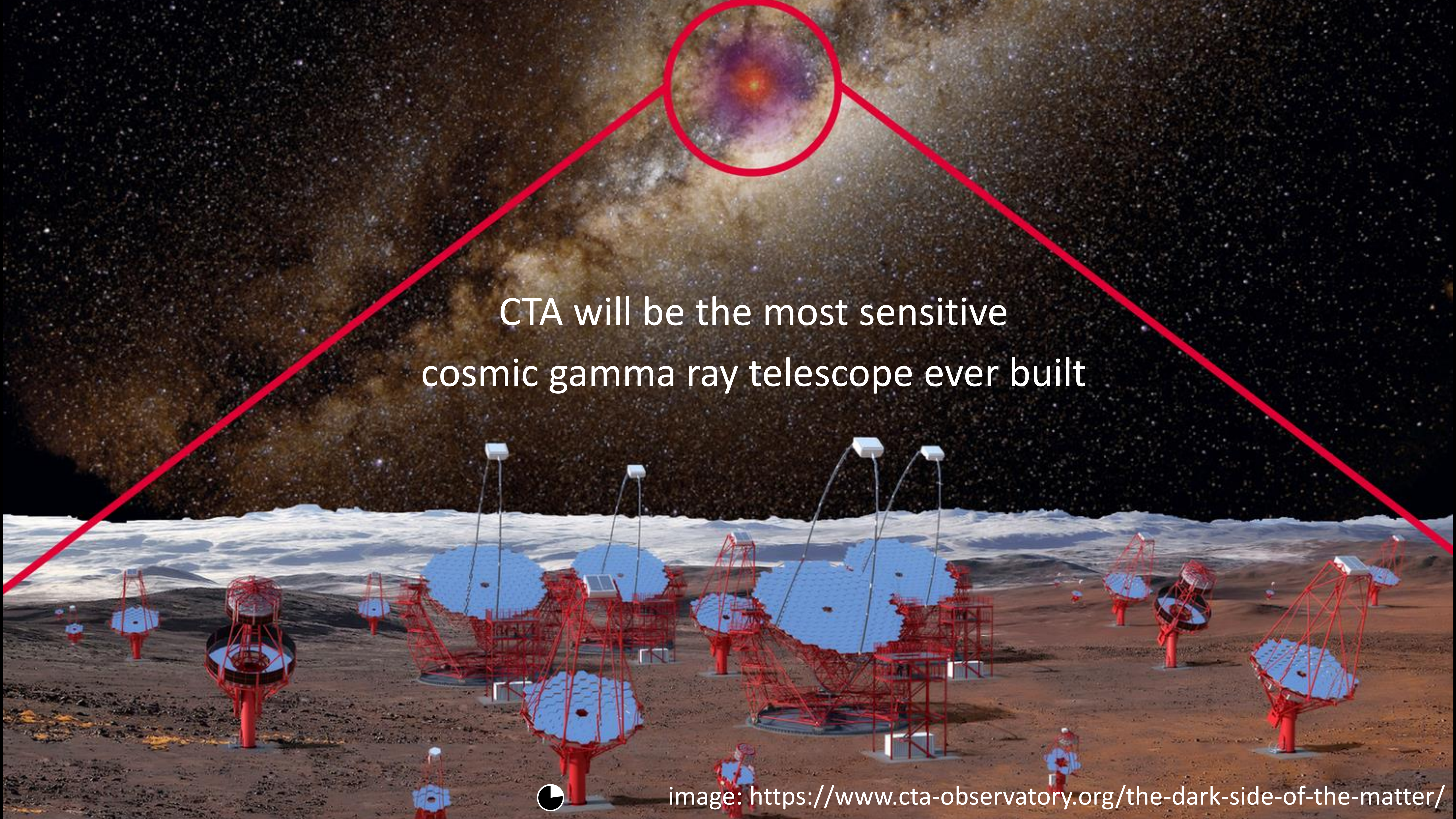
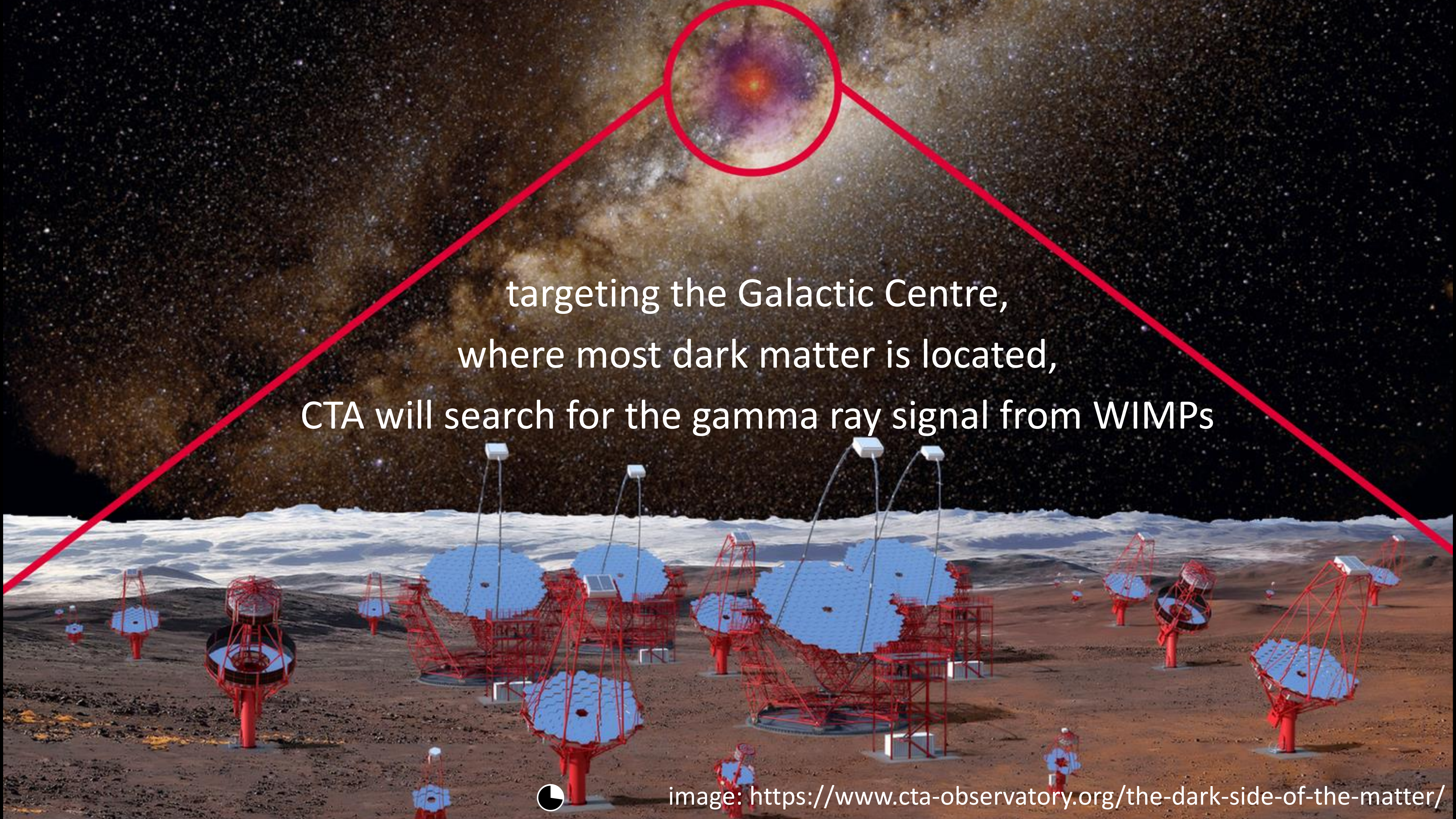


image: https://physics.aps.org/articles/v11/48


CTA will be the most sensitive
cosmic gamma ray telescope ever built
image: https://www.cta-observatory.org/the-dark-side-of-the-matter/



targeting the Galactic Centre,
where most dark matter is located,
CTA will search for the gamma ray signal from WIMPs

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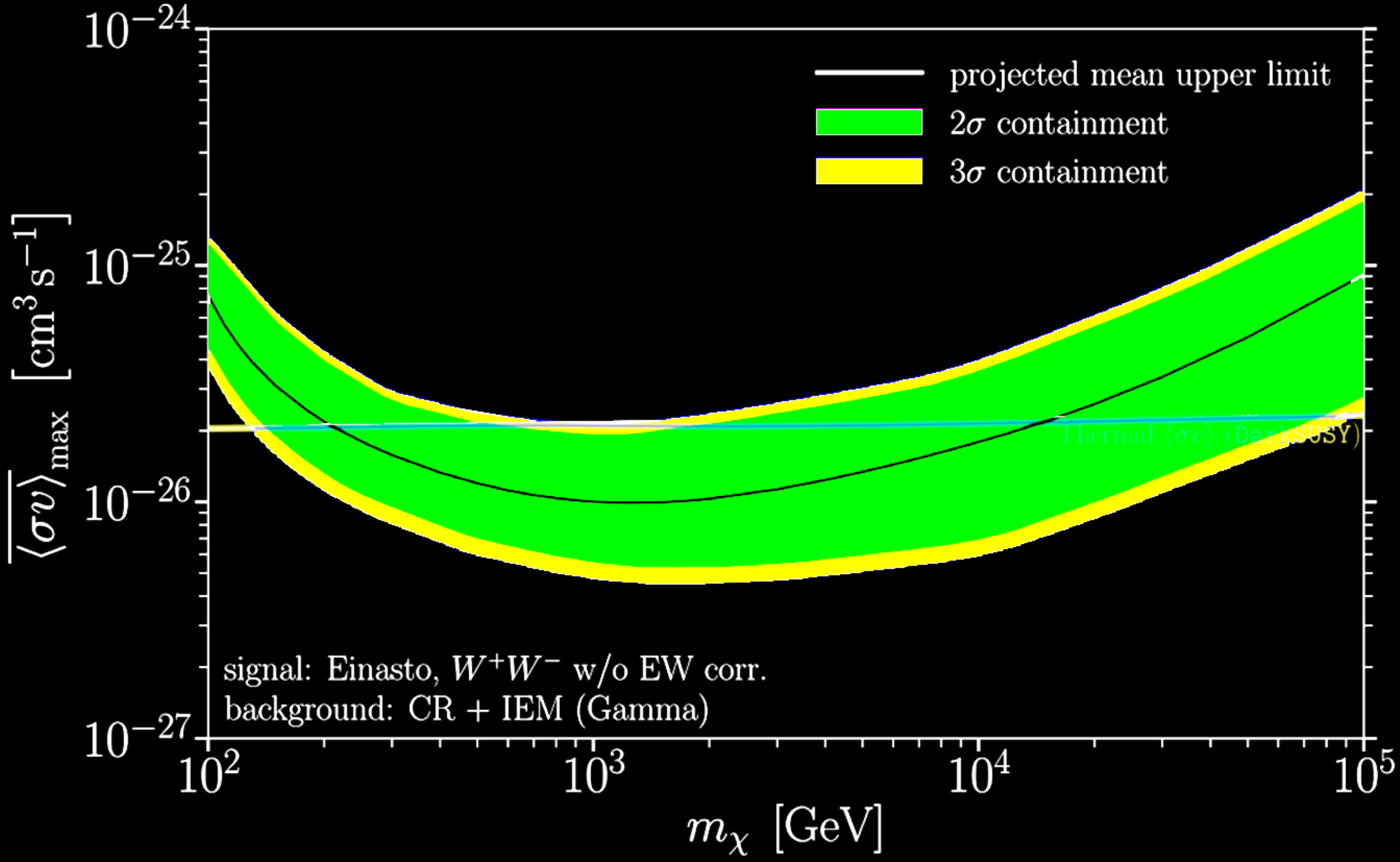
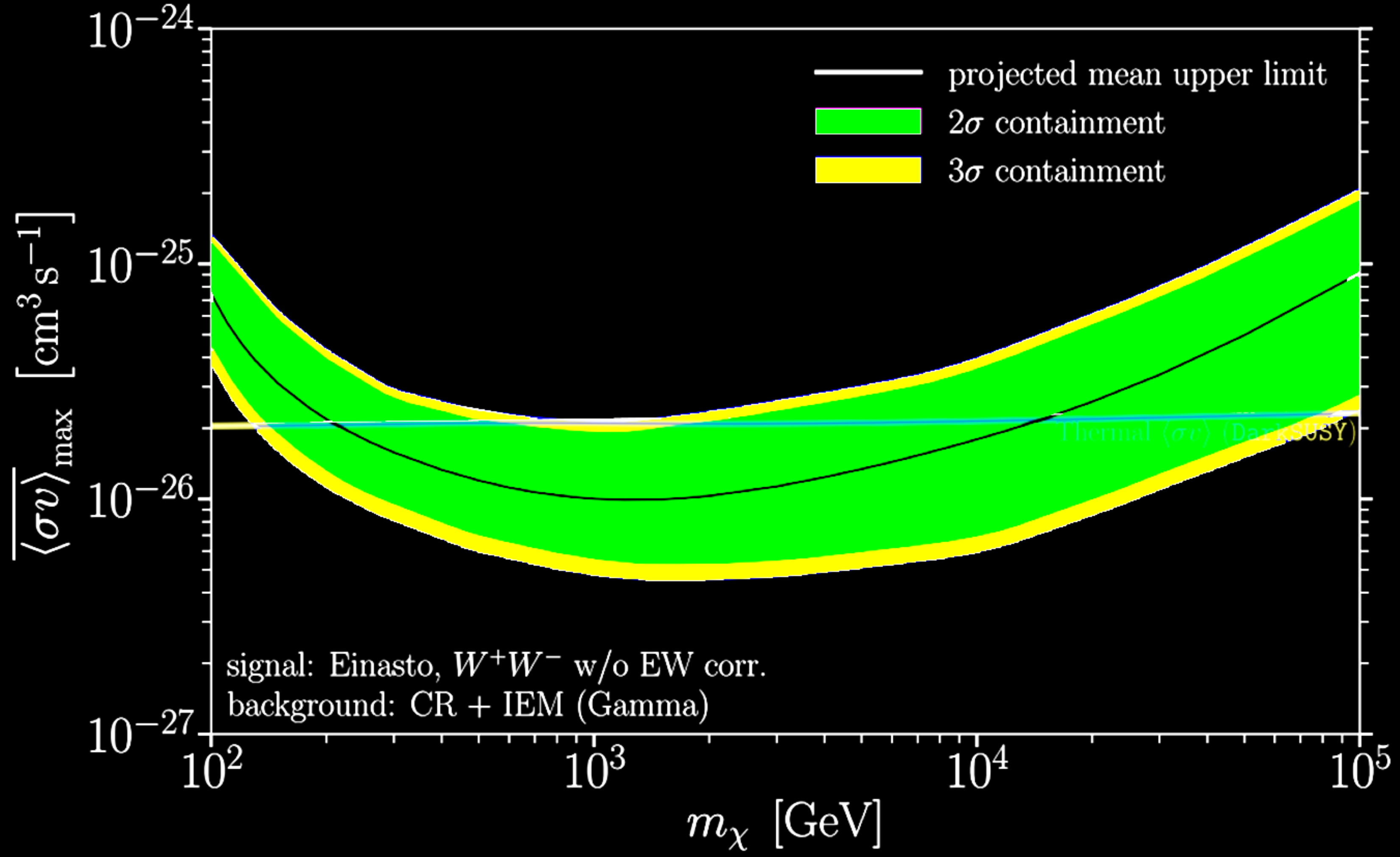


the DM WG published sensitivity of CTA for a generic WIMP

WIMP annihilating into W^+W^-; region above solid curve is observable by CTA

image: C. Balazs et al. based on arXiv:1512.02801



our goal is to generalize these limits for specific DM models

image: C. Balazs et al. based on arXiv:1512.02801

CTAAnalysis

we attempted to use the already existing code CTAAnalysis

PHS3350 Final Report: Sensitivity of the Cherenekov Telescope Array for dark matter from the galactic centre under the Scalar Singlet Model

Liam Pinchbeck
Superisor: Csaba Balazs

November 2021

Abstract

The Cherenkov Telescope Array will be a leap forward in searches for dark matter. The question is then whether it will be sensitive *enough* to eliminate a significant number of dark matter models currently proposed. In this investigation we modified the pipeline ctaAnalysis to develop cross-sections for dark matter under the generic WIMP models for single channel self-annihilation from the galactic centre. In part trying to replicate the results of Acharyya et al. (2021). We also start the initial investigation to modifications to the pipeline to include non-trivial branching factors in the calculations for dark matter. Our findings suggest that by doing so, we can create more accurate estimations of annihilation cross-sections for different dark matter masses and thus estimations on the sensitivity of the Cherenkov telescope array in future investigations.

1 Introduction

One of the major questions plaguing physicists today is the mystery of what is dark matter (DM)? This is not for a lack of possible explanations such as Axion particle candidates, super symmetric candidates such as Sneutrinos and many more [2]. The main issue is the inability to *eliminate* these models. Under most models DM is, almost by definition, hard to detect due to it only weakly interacting with standard model particles of which we would use to detect DM [3, 4].

Another problem with these searches is that candidate particles can typically go to extreme ends of the mass scale. For example under some models for the Axion candidates it is predicted that these particles could be less than $10^{-5} eV$ [5] (10^{10} times smaller than an electron, leading some to postulate the DM is

Sensitivity of The Cherenkov Telescope Array to Dark Matter

Kieran Rule
Supervised by Csaba Balasz

Abstract

Pre-construction estimates of the Cherenkov Telescope Array's sensitivity to dark matter in the galactic centre indicate that it will be sensitive to dark matter with velocity weighted cross section below the thermal relic cross section for dark matter masses between approximately 10^2 and 10^5 GeV, with a 2σ confidence interval [1]. In this investigation, we attempted to replicate these dark matter sensitivity estimates using the Cherenkov Telescope Array data analysis pipeline ctaAnalysis. We found that ctaAnalysis was able to produce similar dark matter annihilation fluxes to that of Acharyya et al. However, none of our sensitivity results for three dark matter annihilation models were in agreement with the estimates of Acharyya et al. We suggest this was due to ctaAnalysis' poor background estimation, particularly for galactic centre surveys. Furthermore, we suggest improvements that future works could implement on Cherenkov Telescope Array dark matter sensitivity estimates to increase accuracy, as well as improvements in ctaAnalysis to increase utility.

1. Introduction

Many observations indicate that dark matter has been a dominant driver of change throughout the universe, yet little is known about it [2]. The following introduce some motivations for the existence of dark matter, as well as an introduction to theoretical candidates and dark matter detection

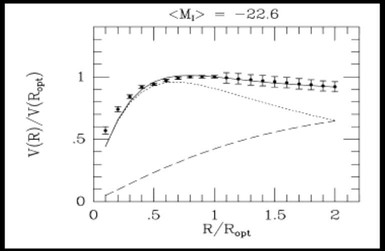


Figure 1. The points show data measuring the average velocity curve of a spiral galaxy, with the solid line being the line of best fit. The dotted line shows the extent due to the disc and the dashed line shows the extent due to the halo. The horizontal axis shows the radius as a fraction of the optical radius [2].

disk. These sum to the dashed line, which is the line of best fit for the data points shown. According to general relativity, the rotation curve should drop off with approximately $r^{-\frac{1}{2}}$ when the radius is greater than the optical radius, since for sufficiently low speeds we have that,

$$v = \sqrt{\frac{GM}{R}} \quad (1)$$

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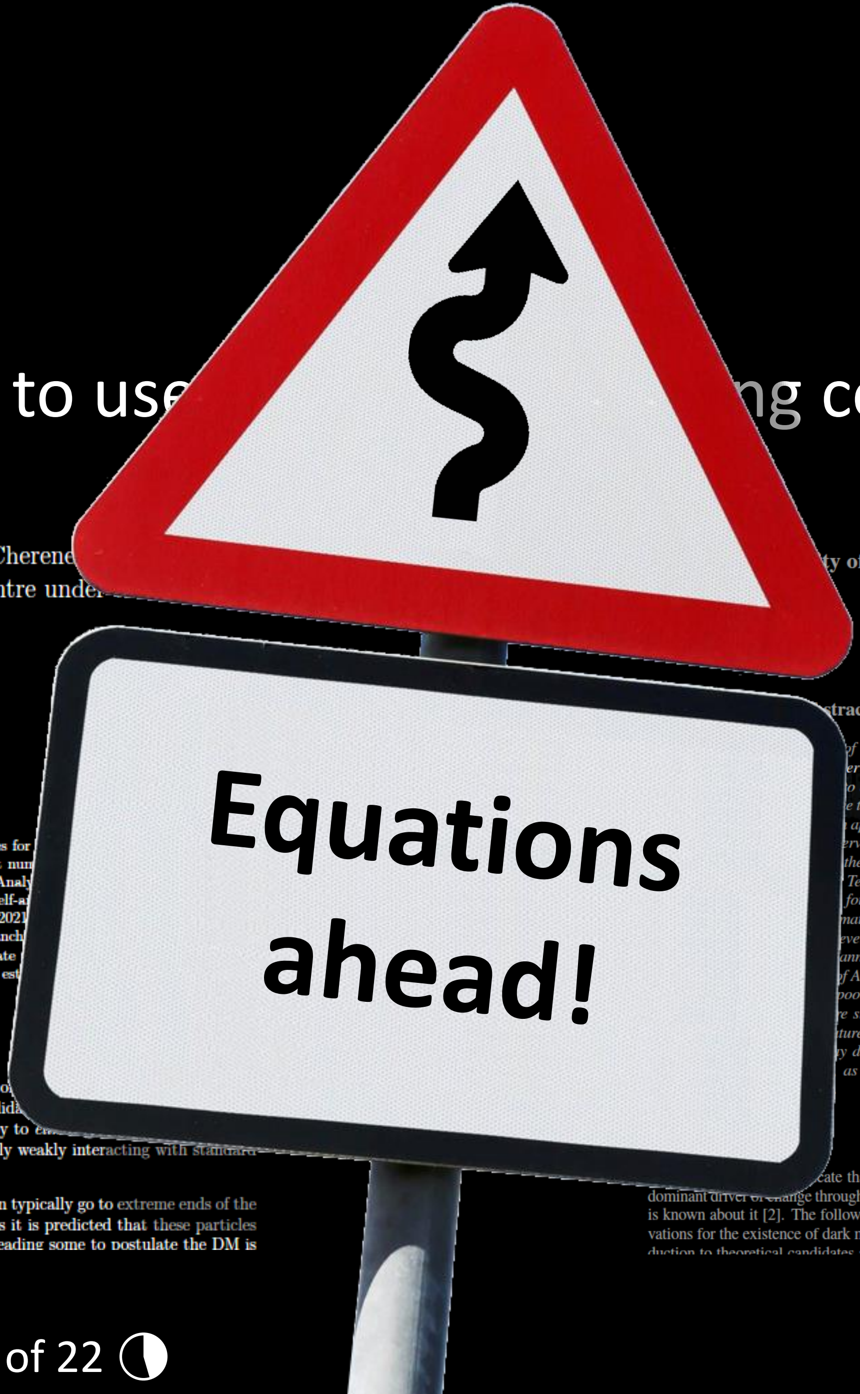

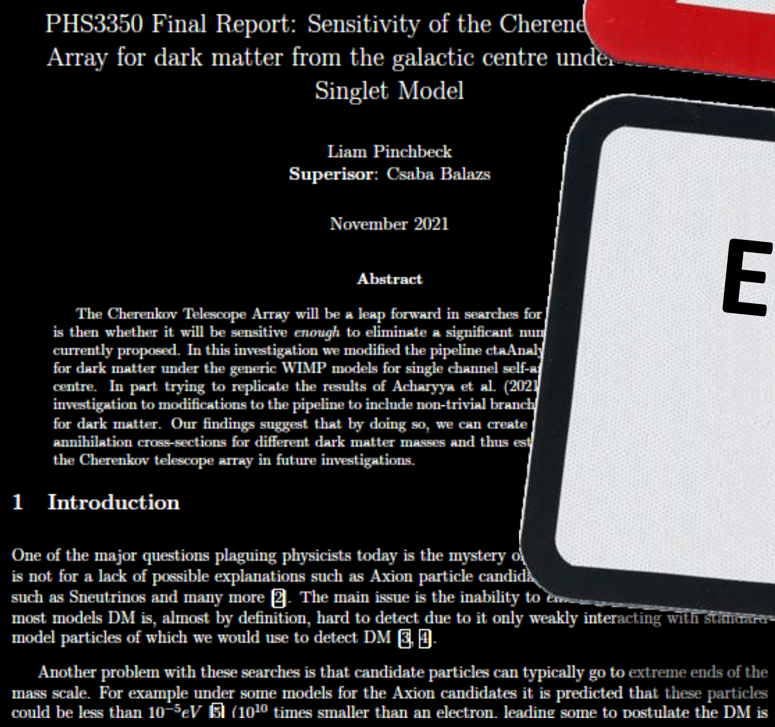

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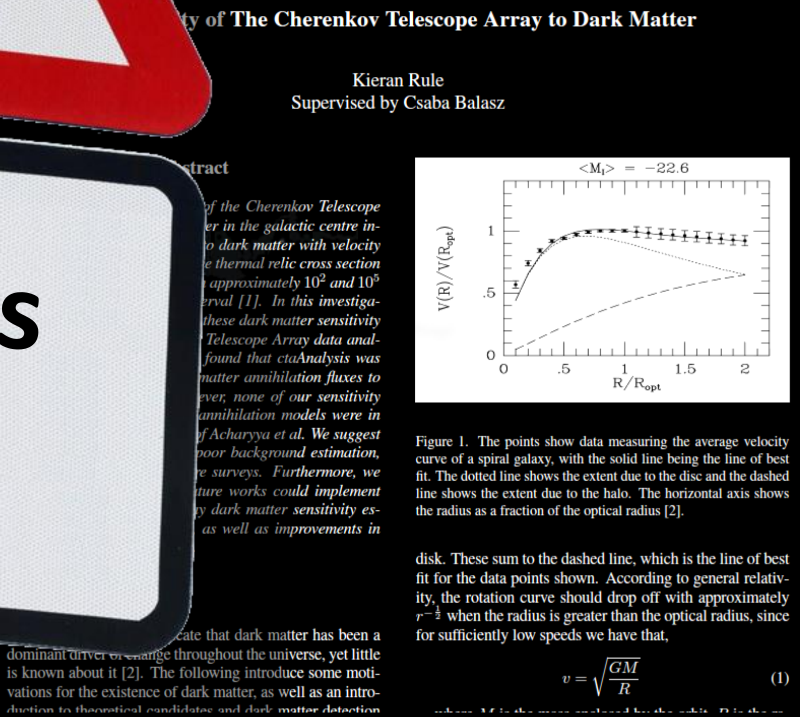

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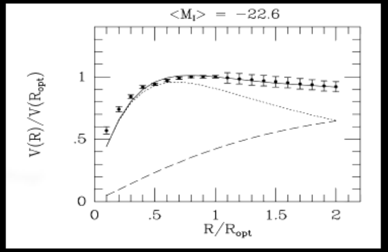

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likelihood of an event

CTA data: measured sky location and energy of each gamma ray events

$$d^i = \{\hat{\Omega}^i_m E^i_m\}$$

each event is characterized by a likelihood function

$$\mathcal{L}(d^i|\hat{\Omega}^i, E^i) = \mathcal{L}(E^i_m|E^i)\,\mathcal{L}(\hat{\Omega}^i_m|\hat{\Omega}^i, E^i_m)$$

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the likelihood is a "point spread function":

it relates the measured sky location and energy (subscript m) to the true sky location and energy (no subscripts)

posteriors

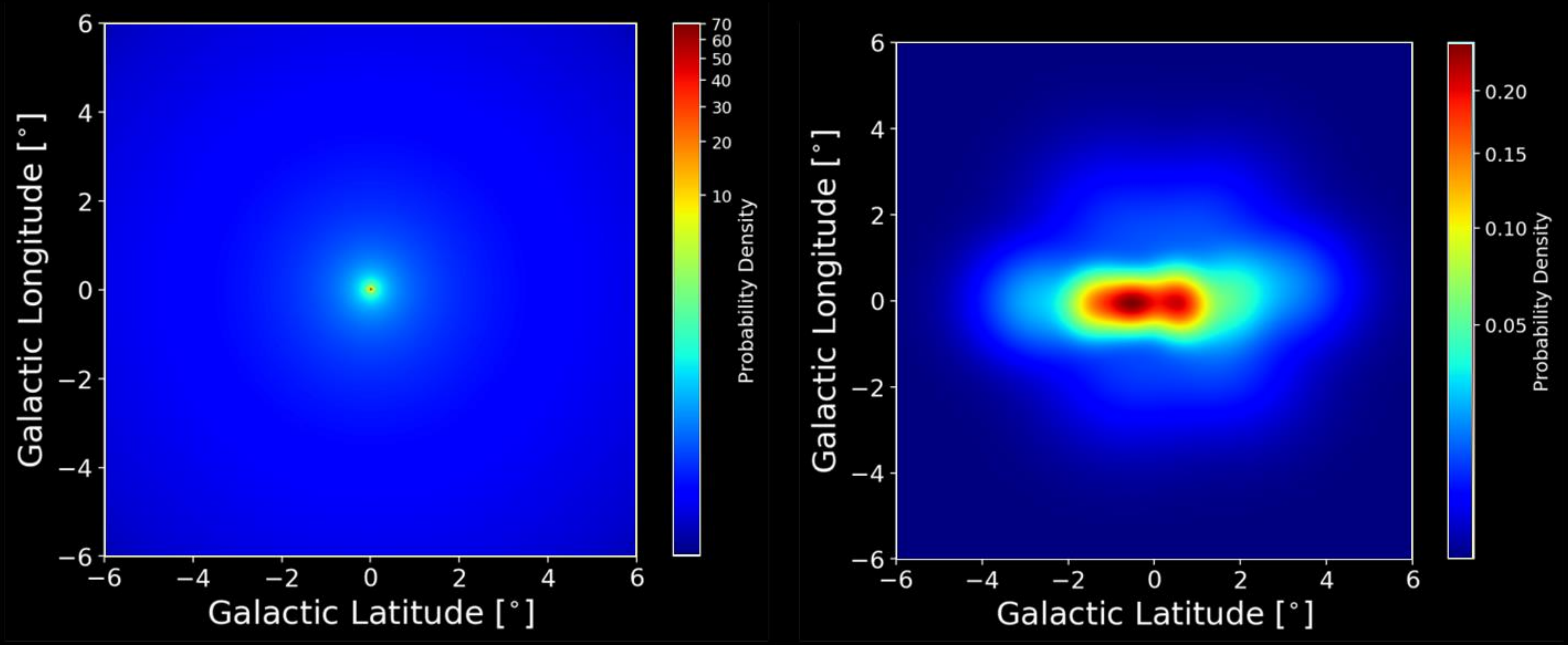
for each event we calculate two posteriors, one given the signal hypothesis

$$\mathcal{L}(d^i|\mathcal{S}) = \int d\hat{\Omega}^i \int dE^i \, \mathcal{L}(d_i|\Omega^i E^i) \, \pi(\Omega^i, E^i|\mathcal{S})$$

and one given the background hypothesis

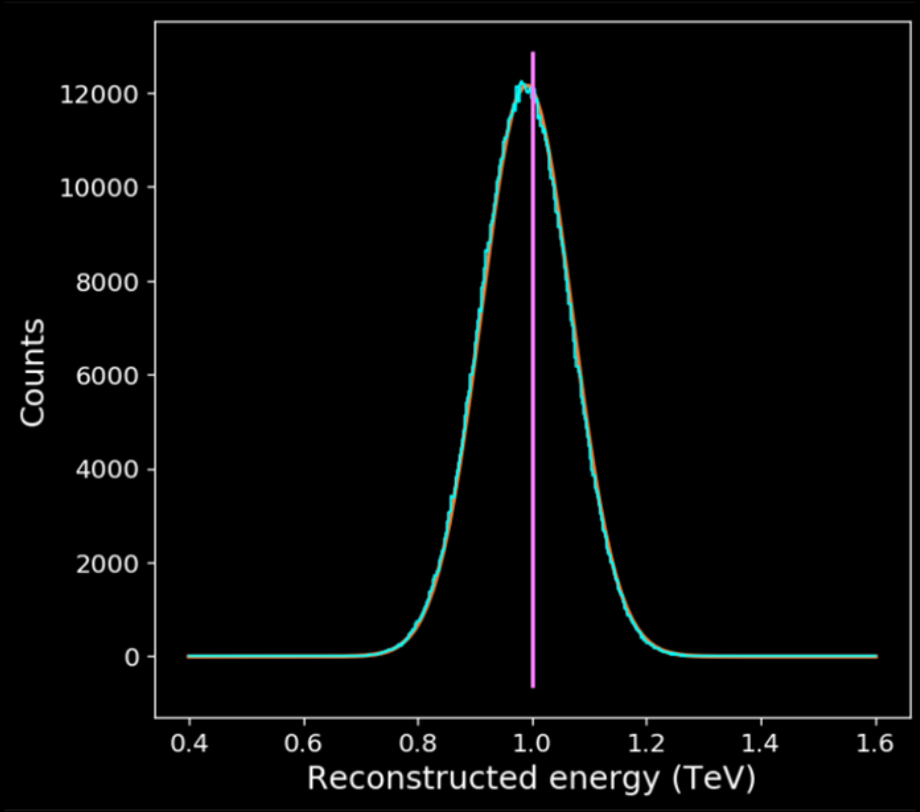
$$\mathcal{L}(d_i|\mathcal{B}) = \int d\hat{\Omega}_i \int dE_i \, \mathcal{L}(d_i|\Omega^i E^i) \pi(\Omega^i, E^i|\mathcal{B})$$

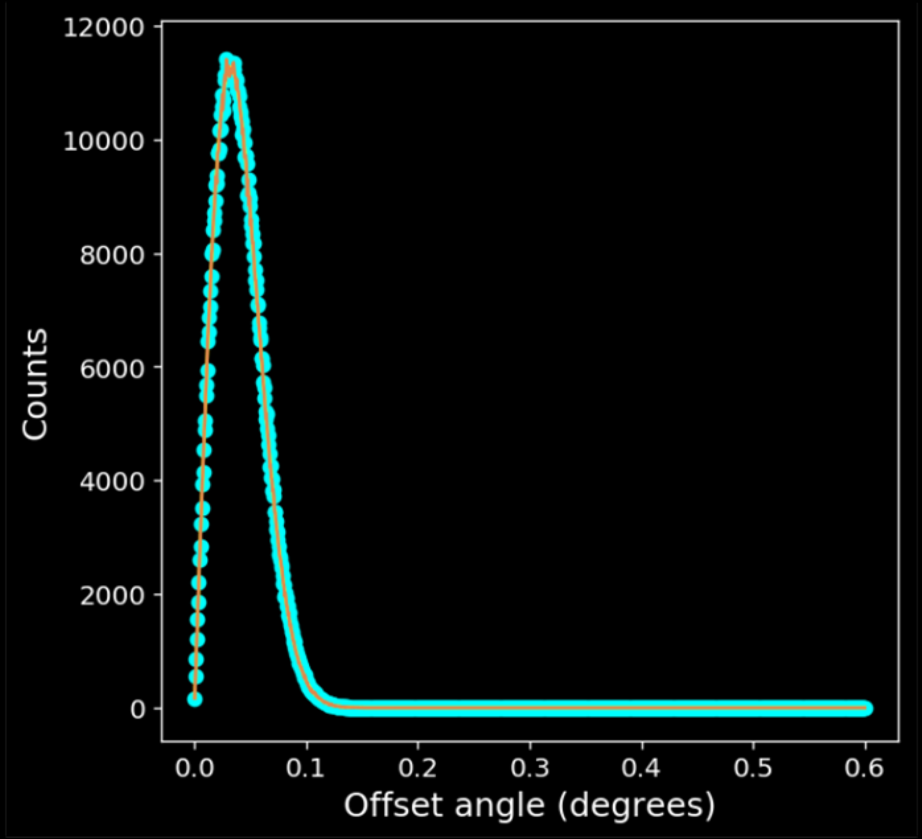
likelihoods



sky location priors for signal and background hypotheses

priors





likelihood functions for energy and sky location

likelihood of full dataset

the likelihood of the complete dataset is

$$\mathcal{L}(\vec{d}|\lambda) = \prod_{i}^{N} \lambda\mathcal{L}(d_i|\mathcal{S}) + (1-\lambda)\mathcal{L}(d_i|\mathcal{B})$$

λ is the probability that an event is drawn from the signal population

equivalently, λ is the proportion of events drawn from the signal hypothesis

$$\lambda = \frac{N_{\mathcal{S}}}{N} \approx \frac{N_{\mathcal{S}}}{N_{\mathcal{B}}}$$

number of signal events

the number of signal events is proportional to the gamma ray flux

$$N_S = T \int \frac{d\Phi}{d\Omega dE}(E,\psi) A(E) dE d\Omega$$

which is proportional to the annihilation cross section

$$\frac{d\Phi}{d\Omega dE}(E,\psi) = \frac{1}{4\pi} \int_{l.o.s} dl(\psi) \rho_\chi^2(\mathbf{r}) \left(\frac{\langle \sigma v \rangle}{2m_\chi^2} \sum B_f \frac{dN}{dE} \right)$$

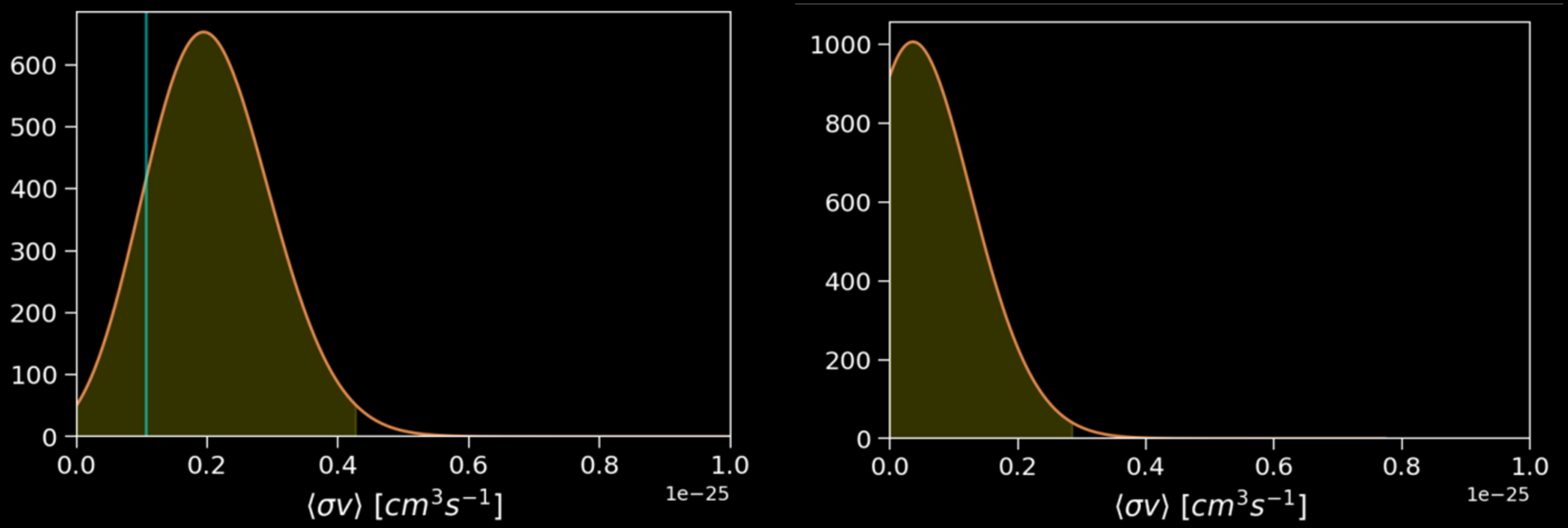
Bayesian posterior for annihilation cross section

using Bayes theorem, we can invert the likelihood

$$\mathcal{L}(\vec{d}|\lambda) = \prod_{i}^{N} \lambda \mathcal{L}(d_i|\mathcal{S}) + (1-\lambda)\mathcal{L}(d_i|\mathcal{B})$$

to obtain a probability distribution for the annihilation cross section

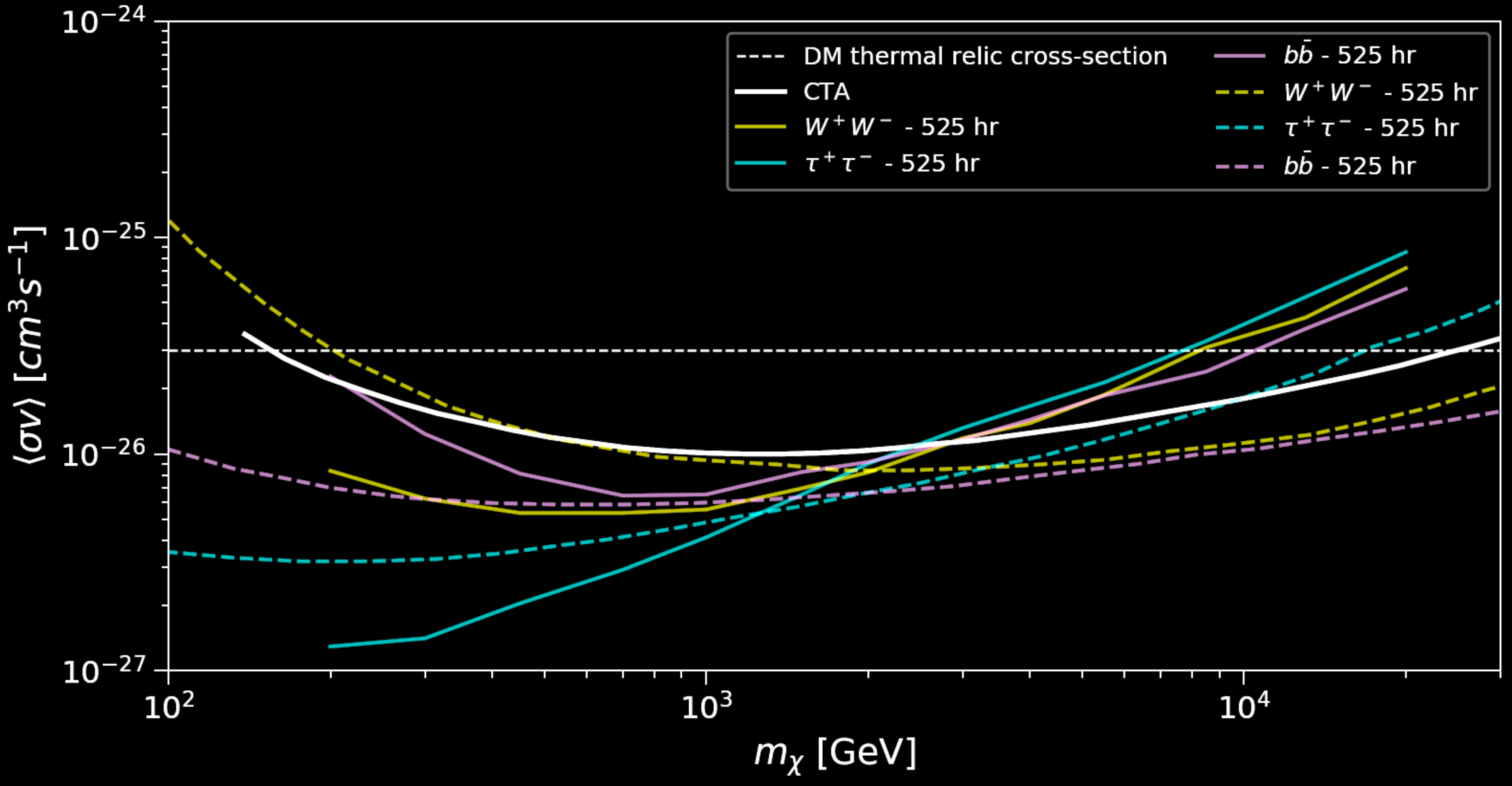
Bayesian posterior for annihilation cross section



sample detection (left) and exclusion (right) at 99% C.L.

shaded region indicating credible interval (vertical line at true value)

prelim limits for annihilation cross section



CTA will be a powerful tool to hunt for WIMPs.

It will be able to discover or rule out various WIMP candidates.

We're working on a generic numerical framework to determine the sensitivity of CTA for various WIMP models.

Interesting results are coming soon!