# GRAPPA Student Seminar

## Session 3:
## Direct Detection

### First part:

*Basics and status: G. Bertone (g.bertone@uva.nl)*

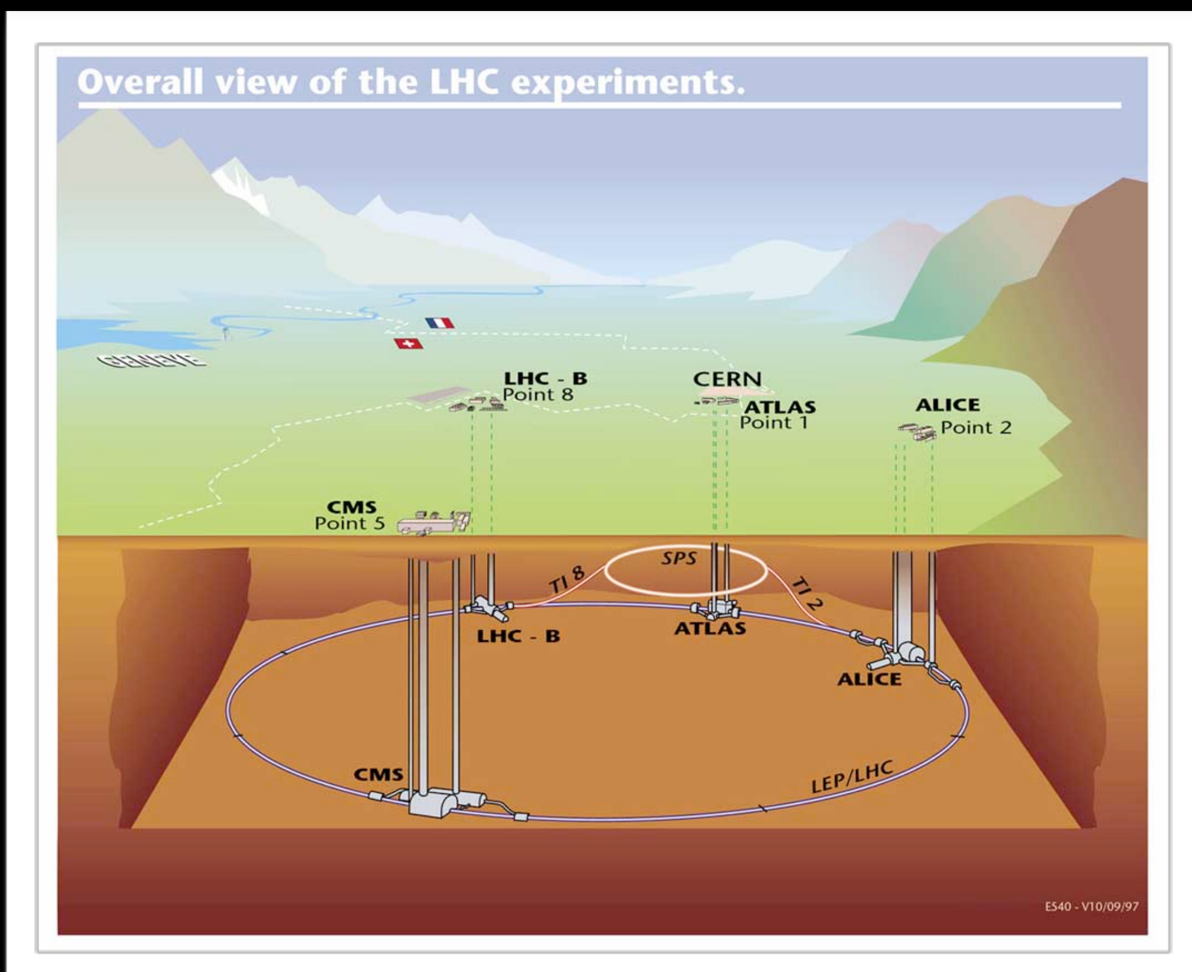
### Second part:

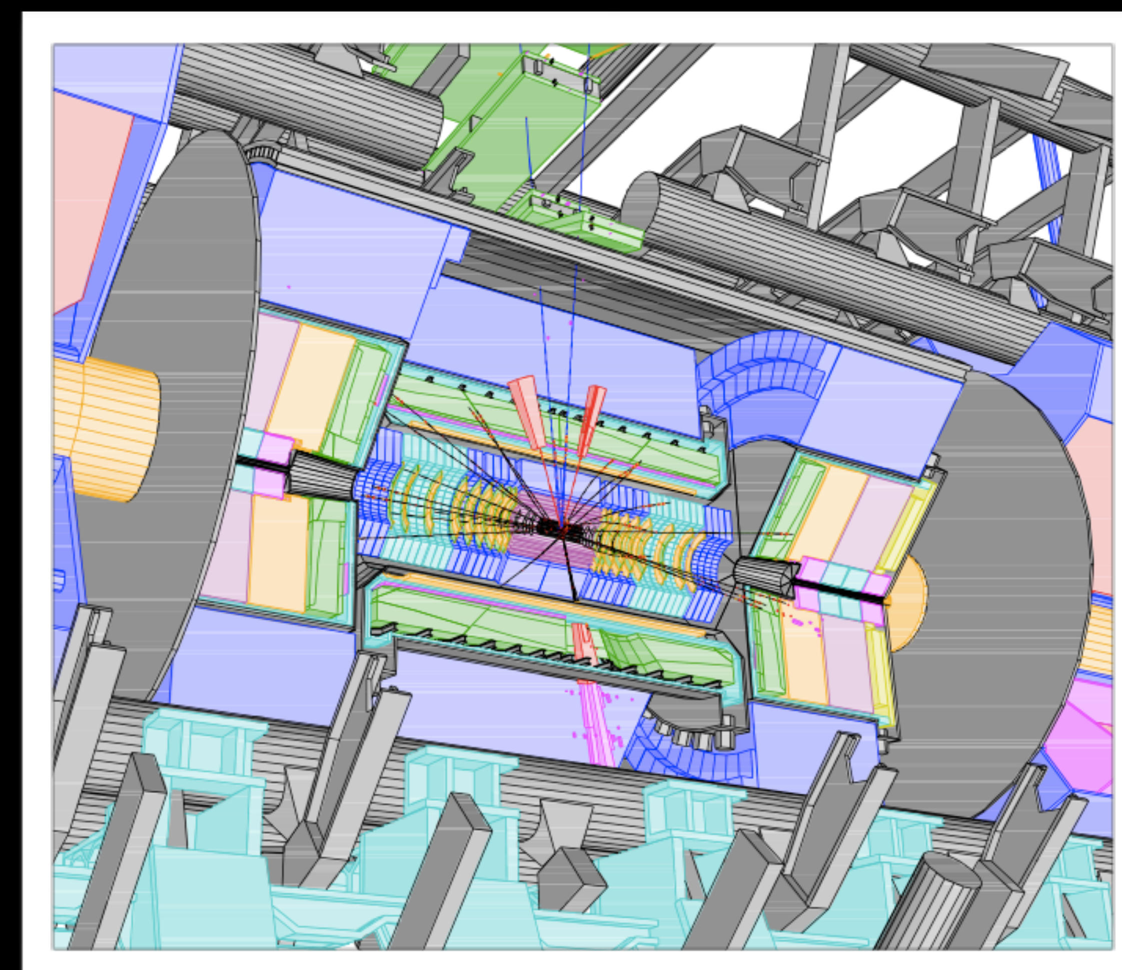
*Interpreting experimental results: C.Weniger (c.weniger@uva.nl)*

# What is dark matter?

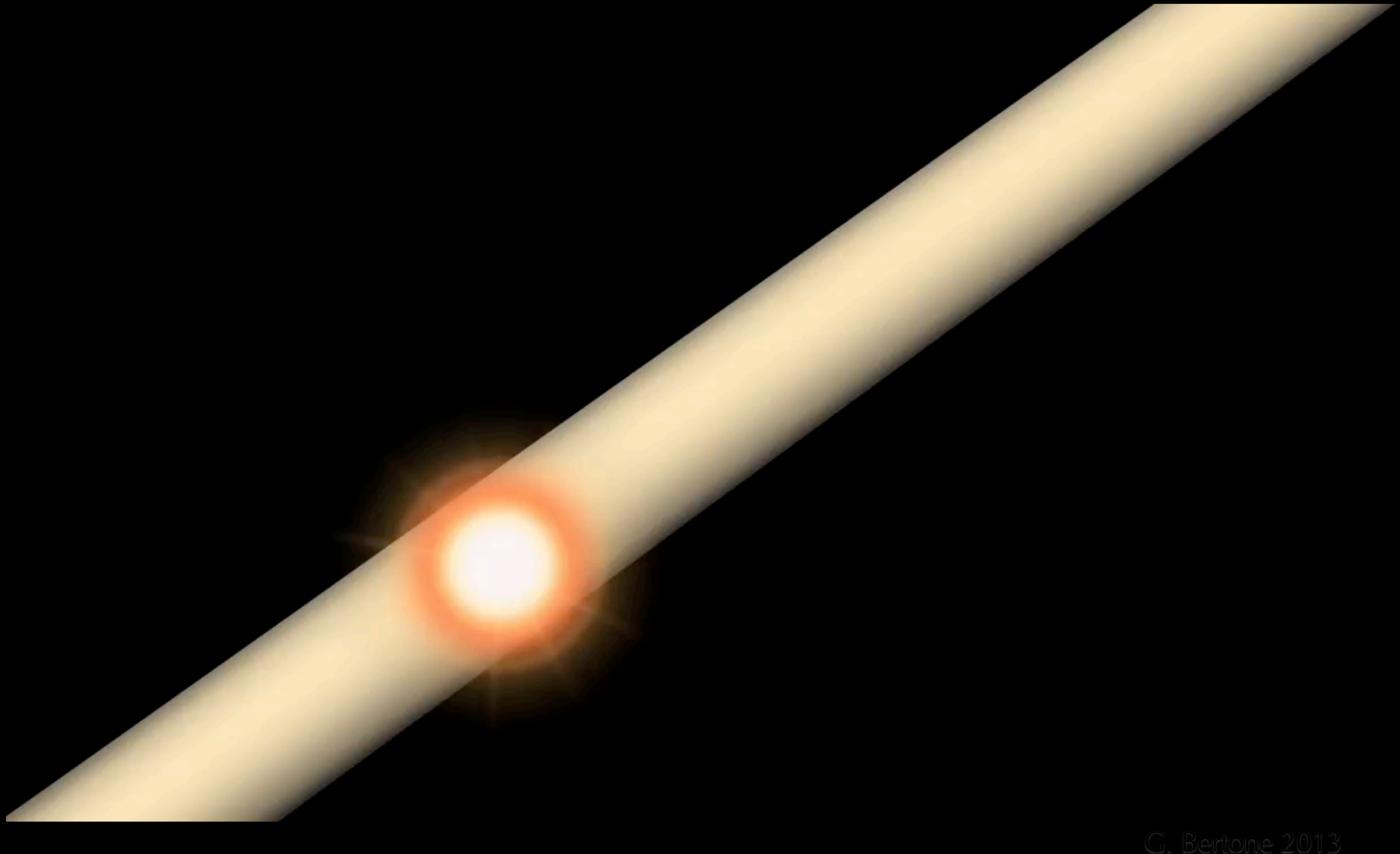

GB & Tait 1810.01668

# Dark Matter Searches at the LHC



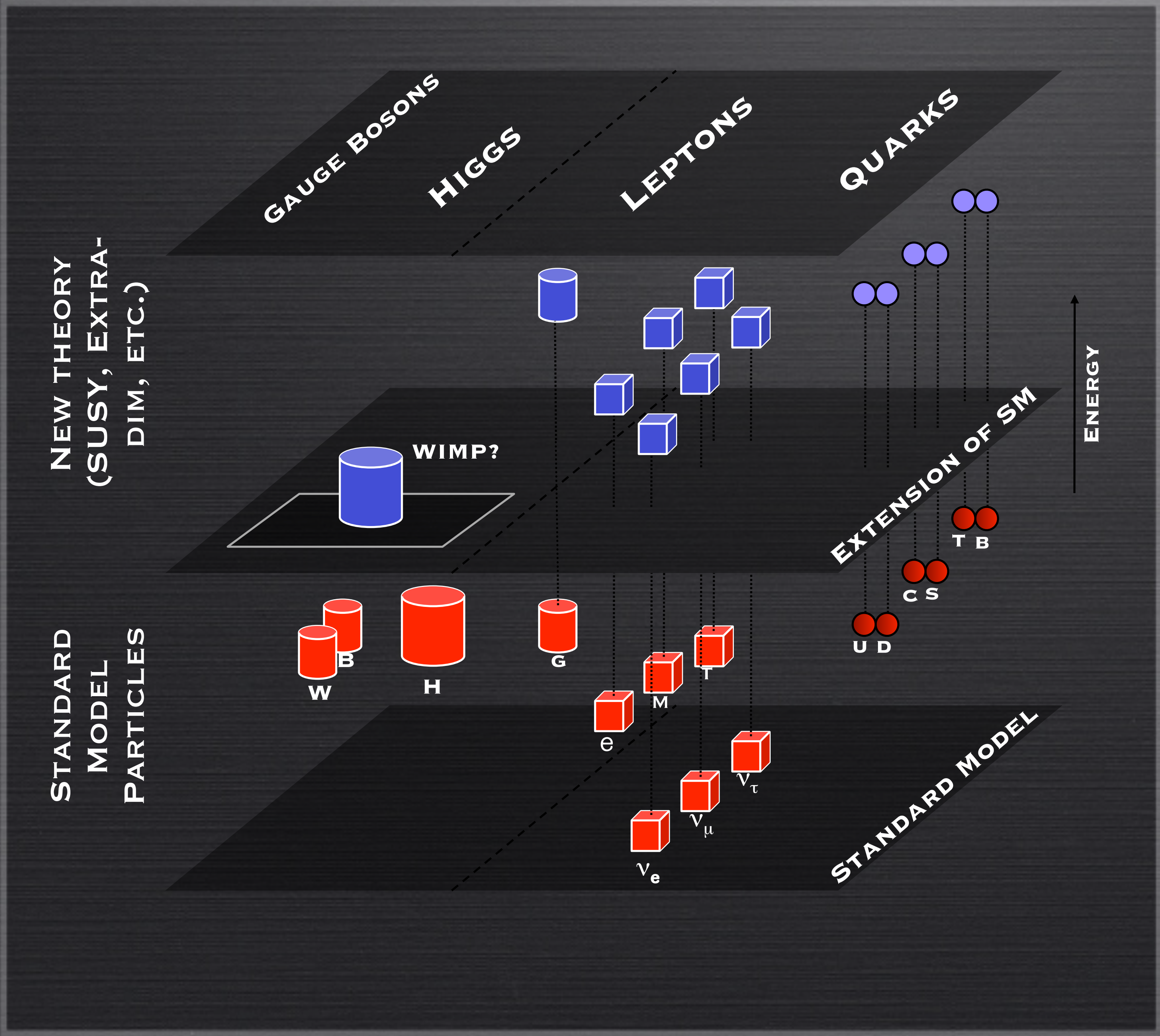



# Colliding protons at the LHC



# Beyond the Standard Model

The Standard Model provides an accurate description of all known particles and interactions, however there are good reasons to believe that the Standard model is a low-energy limit of a more fundamental theory




To explain the origin of the weak scale, extensions of the standard model often postulate the existence of new physics at ~100 GeV

On the left, schematic view of the structure of possible extensions of the standard model

# Beyond the Standard Model

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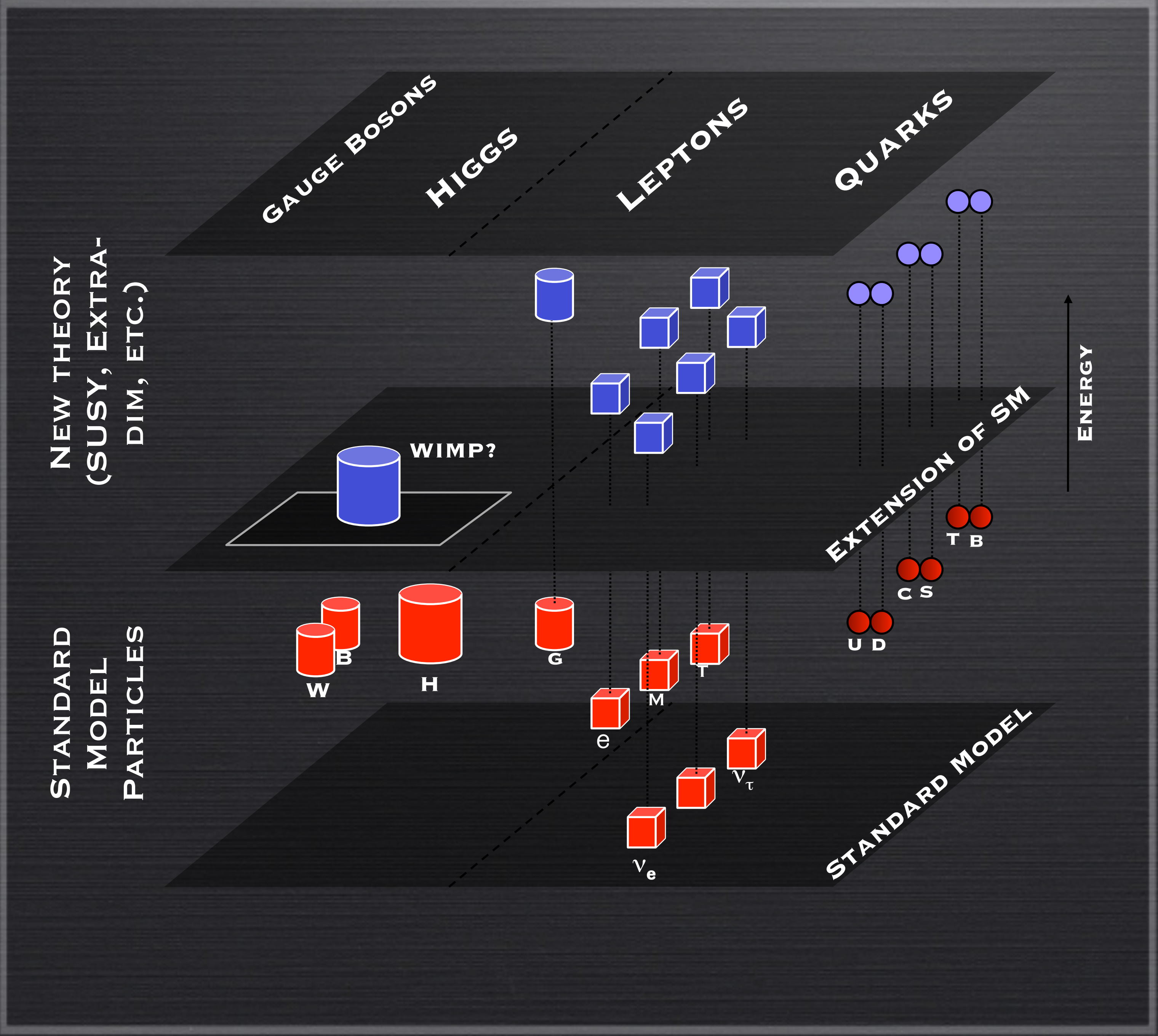
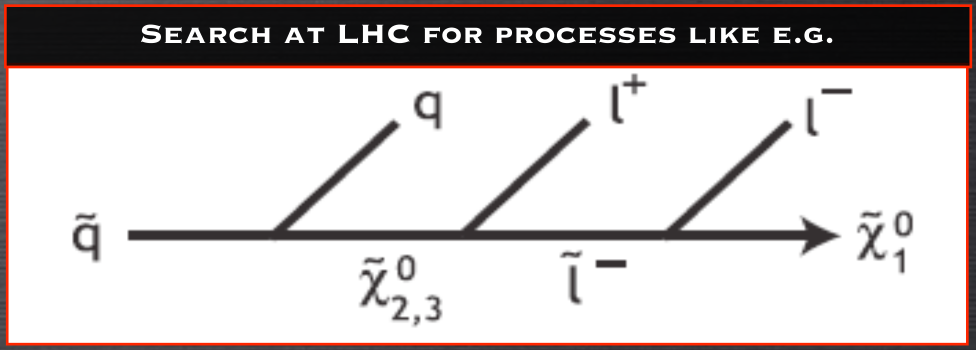
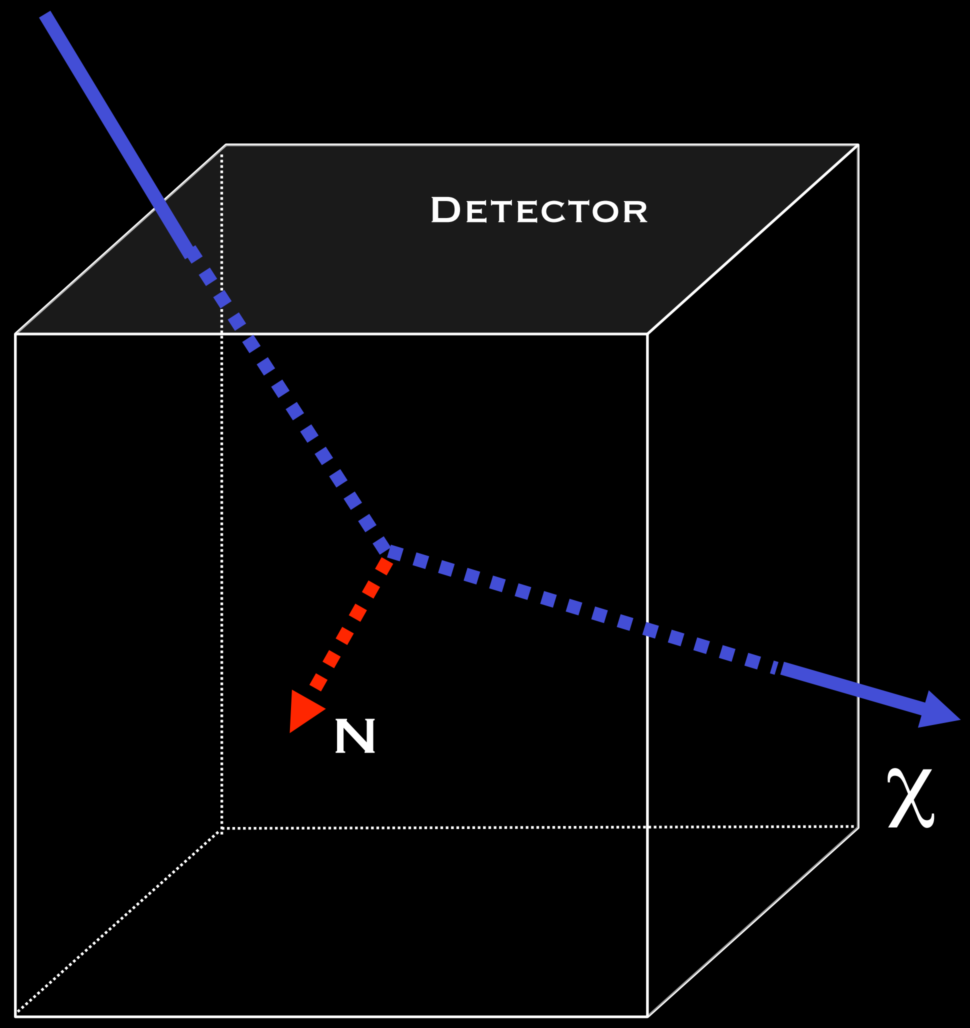
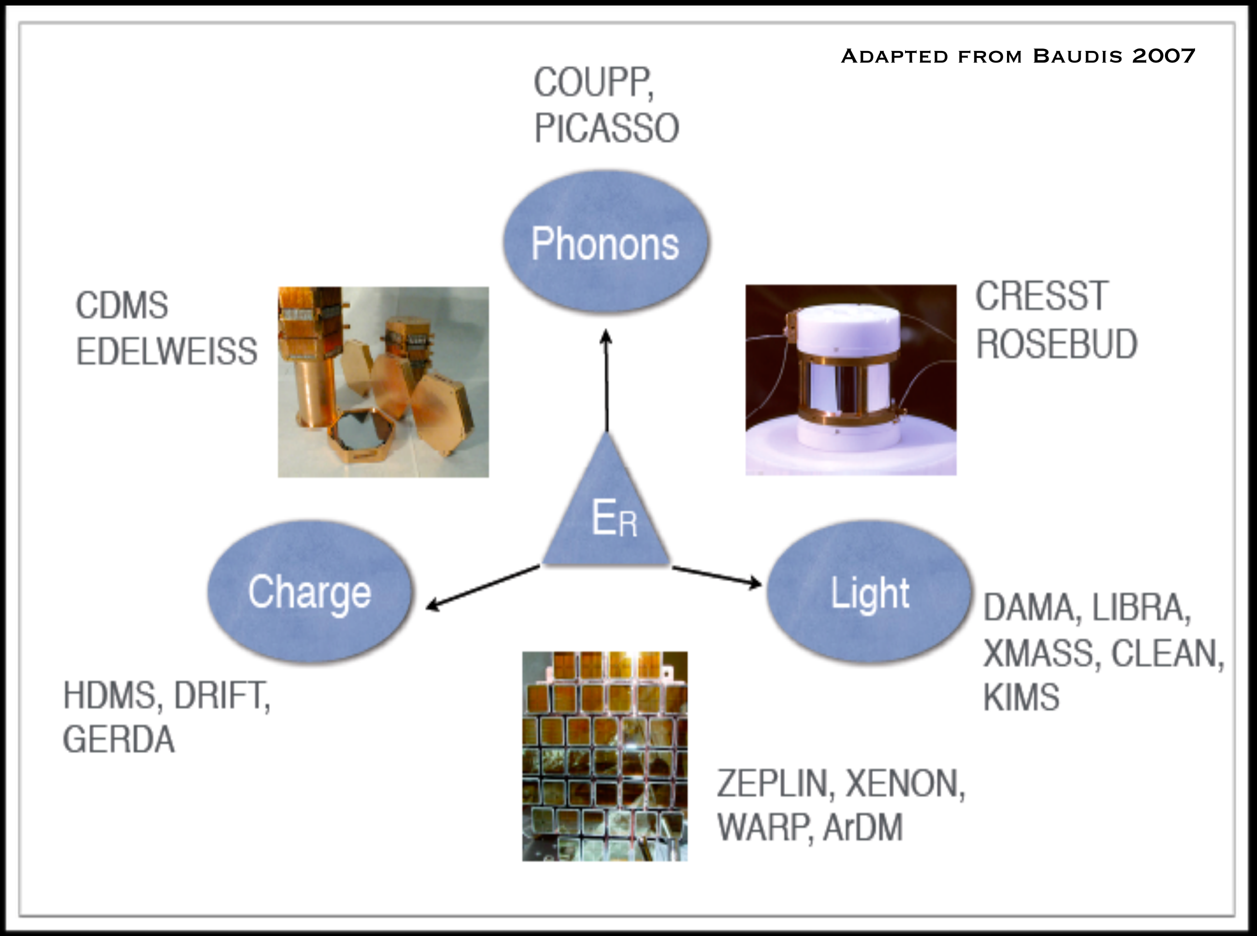


# Direct Detection

## Principle and Detection Techniques




DM Scatters off nuclei in the detector

Detection of recoil energy via ionization (charges), scintillation (light) and heat (phonons)

# Direct Detection

Event Rate

$$R \propto (\rho_0 v)\, \sigma_{\chi N}$$

Differential Event Rate

$$\frac{dR}{dE_R}(E_R) = \frac{\rho_0}{m_\chi m_N} \int_{v>v_{min}} v f(\vec{v} + \vec{v_e}) \frac{d\sigma_{\chi N}}{dE_R}(v, E_R) d^3\vec{v}$$

# Direct Detection

This expression can be recast as (see the lecture notes)

$$\frac{dR}{dE_R}(E_R) = \frac{\sigma_{SI}^p}{2\mu_p^2 m_\chi} \times A^2 F^2(A, E_R) \times \rho_0 \int_{\mathscr{V}} d^3\vec{v}\, \frac{f(\vec{v})}{v}$$

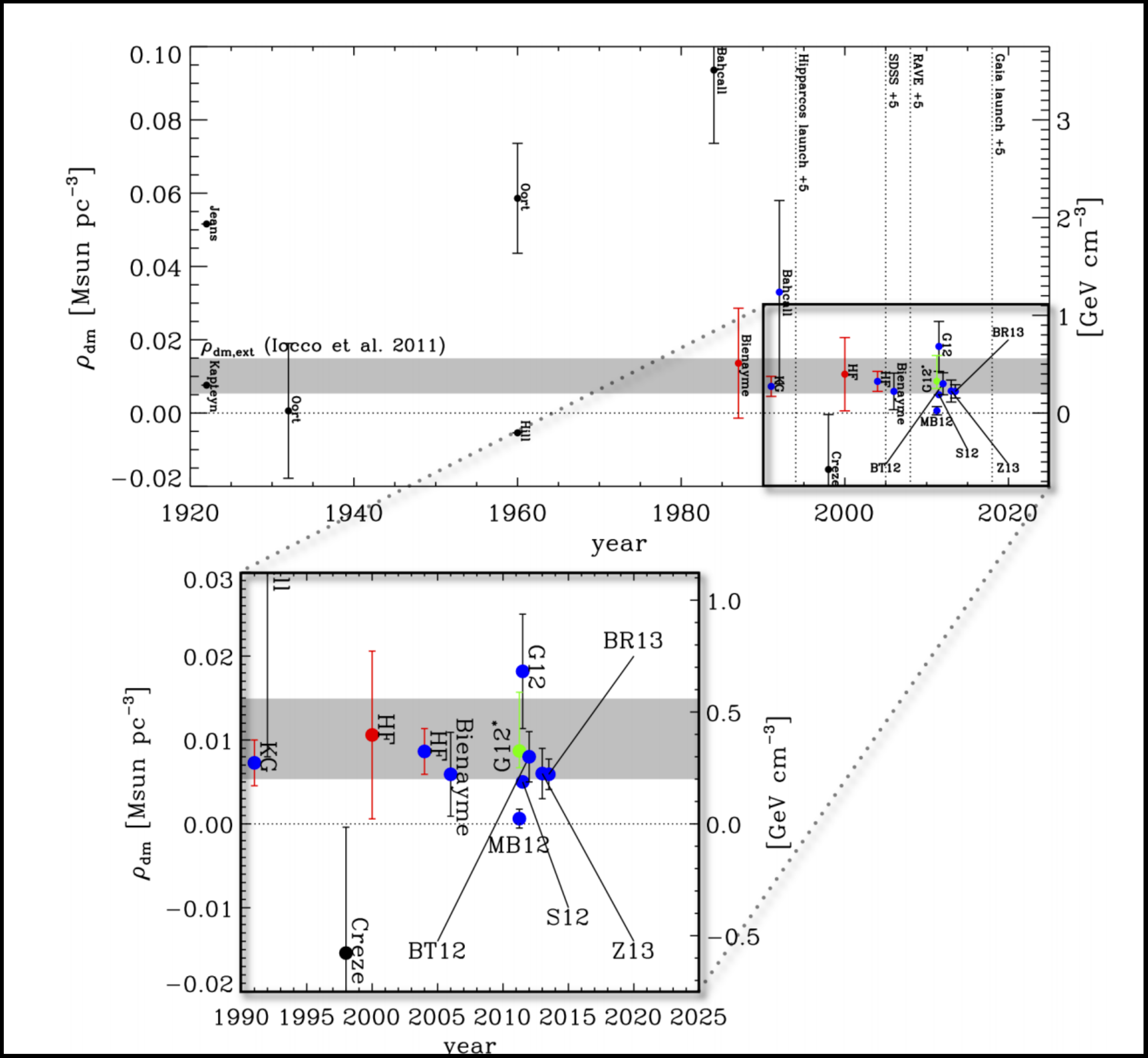
where

- $\sigma_{SI}$ is so-called spin-independent cross-section
- F(A,E_R) is the "form factor" that accounts for the fact that the WIMPS interacts coherently with the whole nucleus, instead of individual nucleons

Note the $A^2$ factor: the rate increases with the square of the atomic number!

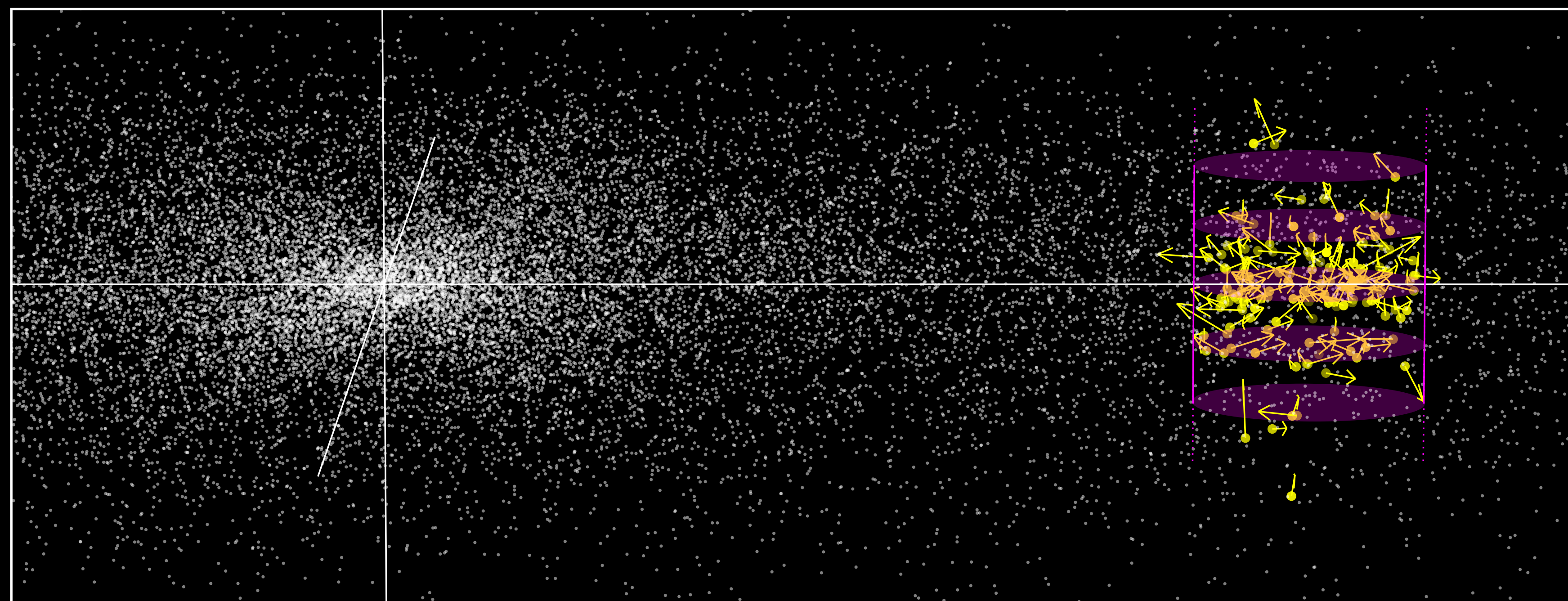
A quintessential astroparticle formula: particle physics, detector, astrophysics

# *Local* dark matter density




*Read, 1404.1938*

# *Local* dark matter density



Under simplifying assumptions (e.g. *Silverwood, GB et al. 2016*), the gravitational potential can be reconstructed from the observed dynamics of tracer stars via the z-Jeans equation:

$$\underbrace{\frac{1}{R\nu}\frac{\partial}{\partial R}\left(R\nu\sigma_{Rz}\right)}_{\text{'tilt' term: }\mathcal{T}}+\frac{1}{\nu}\frac{d}{dz}\left(\nu\sigma_z^2\right)=\underbrace{-\frac{d\Phi}{dz}}_{K_z}$$

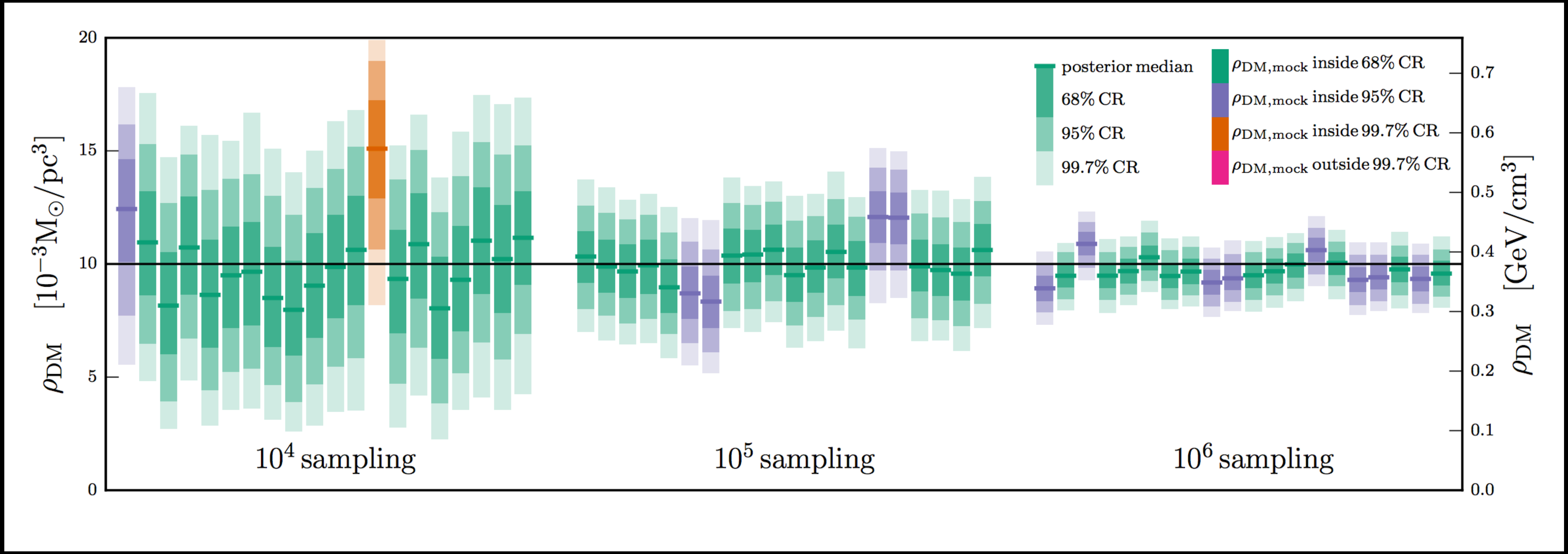
where $\nu$ and $\sigma^2_z$ are the density and vertical velocity dispersion profile of a tracer population, $\sigma_{Rz}$ is the Rz cross term in the velocity dispersion tensor

# *Local* dark matter density

ESA Gaia satellite launched in 2013, will soon provide a precise 3d map of the Milky Way, including 3d velocities.

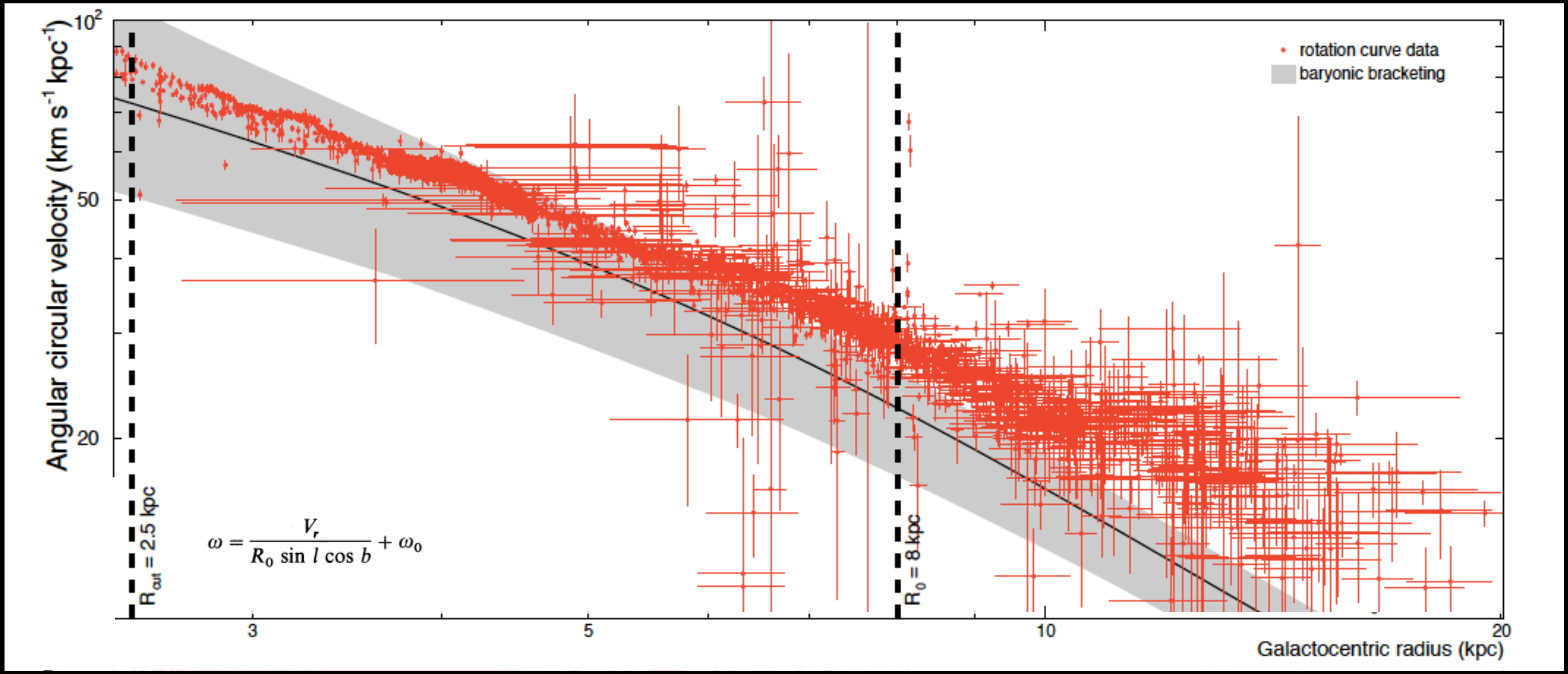
This will allow to substantially improve the statistical error on the determination of the local dark matter density.

Next challenge: systematic errors!



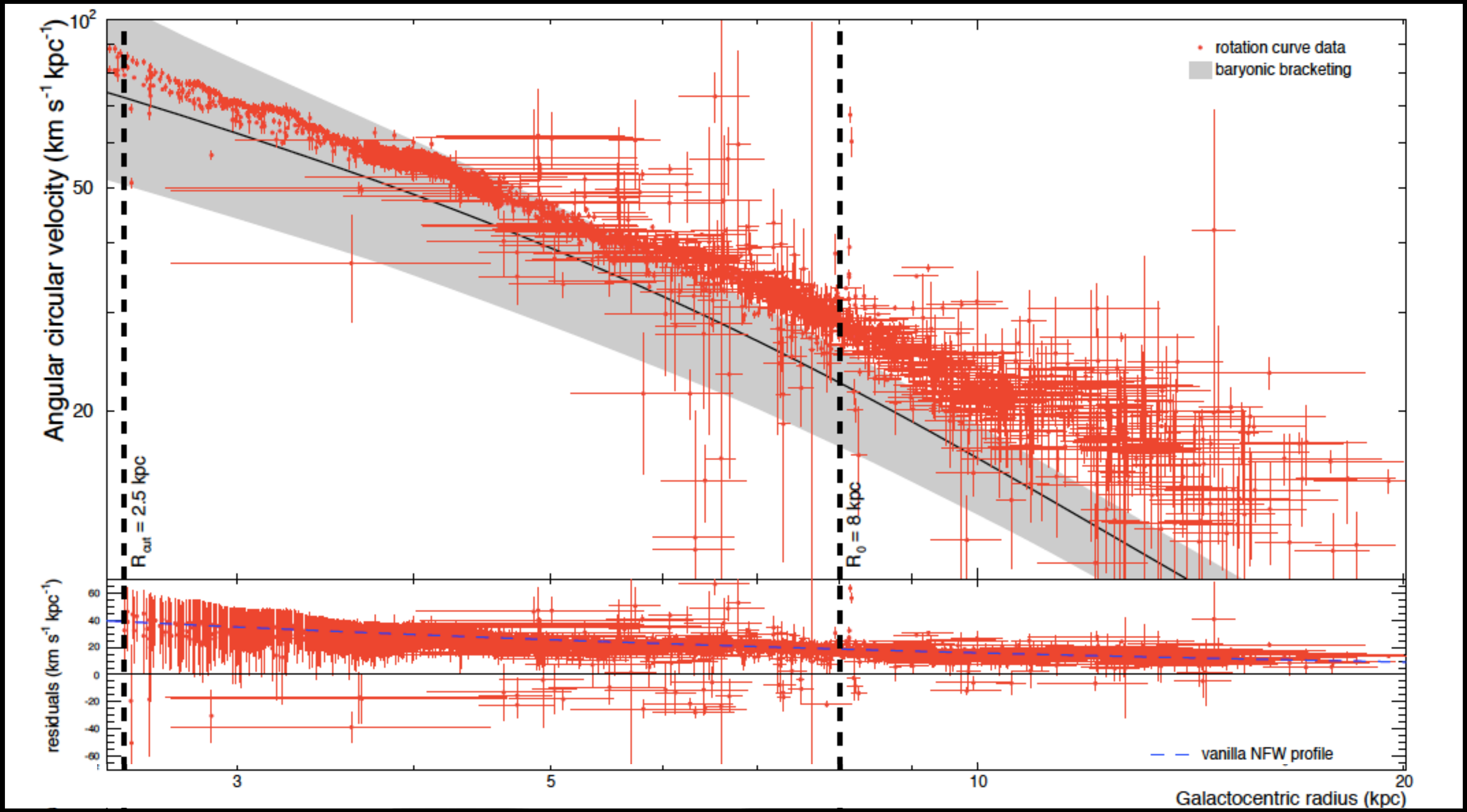

*Silverwood, GB et al. 2016*

# Global modelling: Rotation curve of the Milky Way



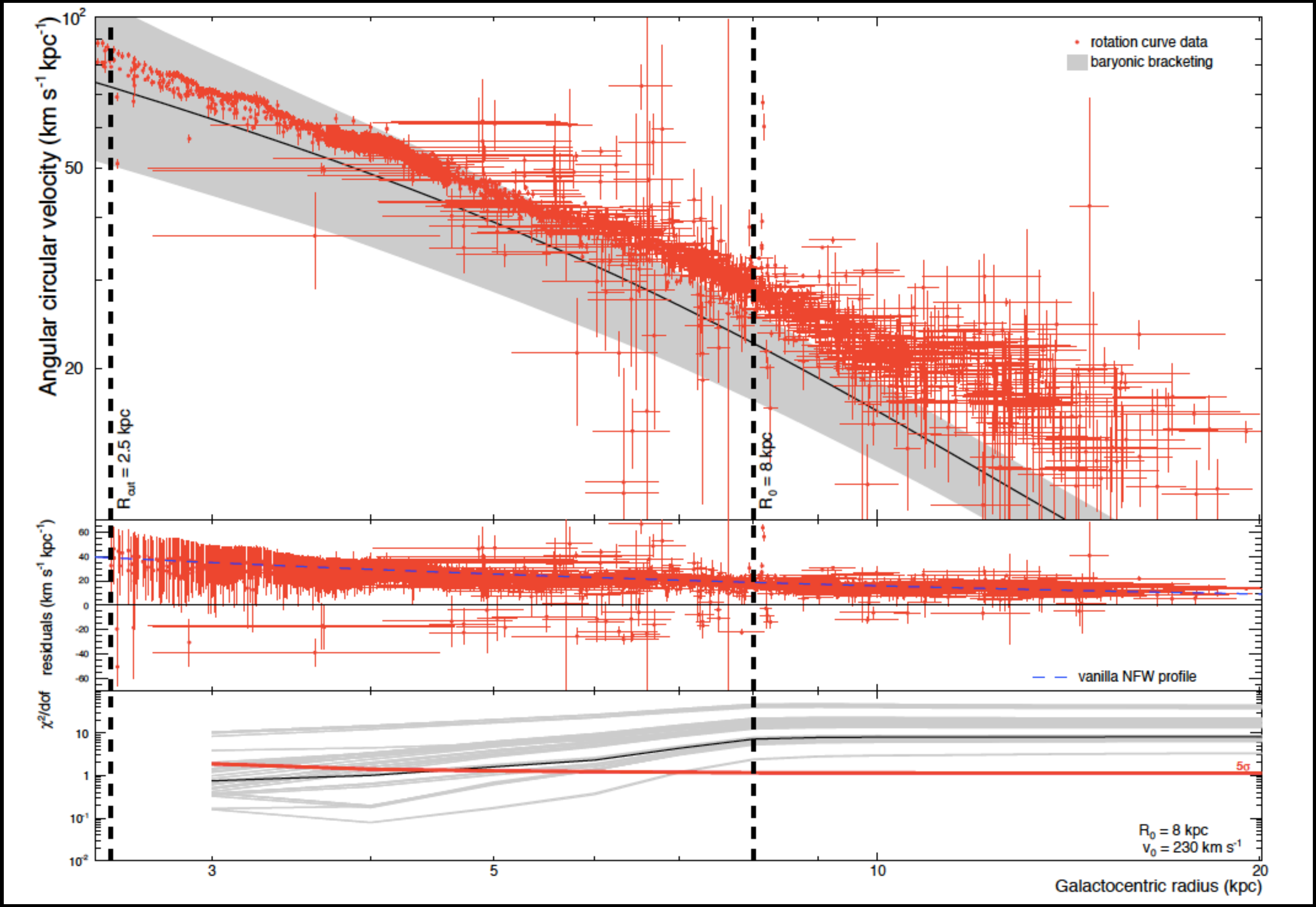

*Iocco, Pato, GB, Nature Physics, arXiv:1502.03821*

# Rotation curve of the Milky Way



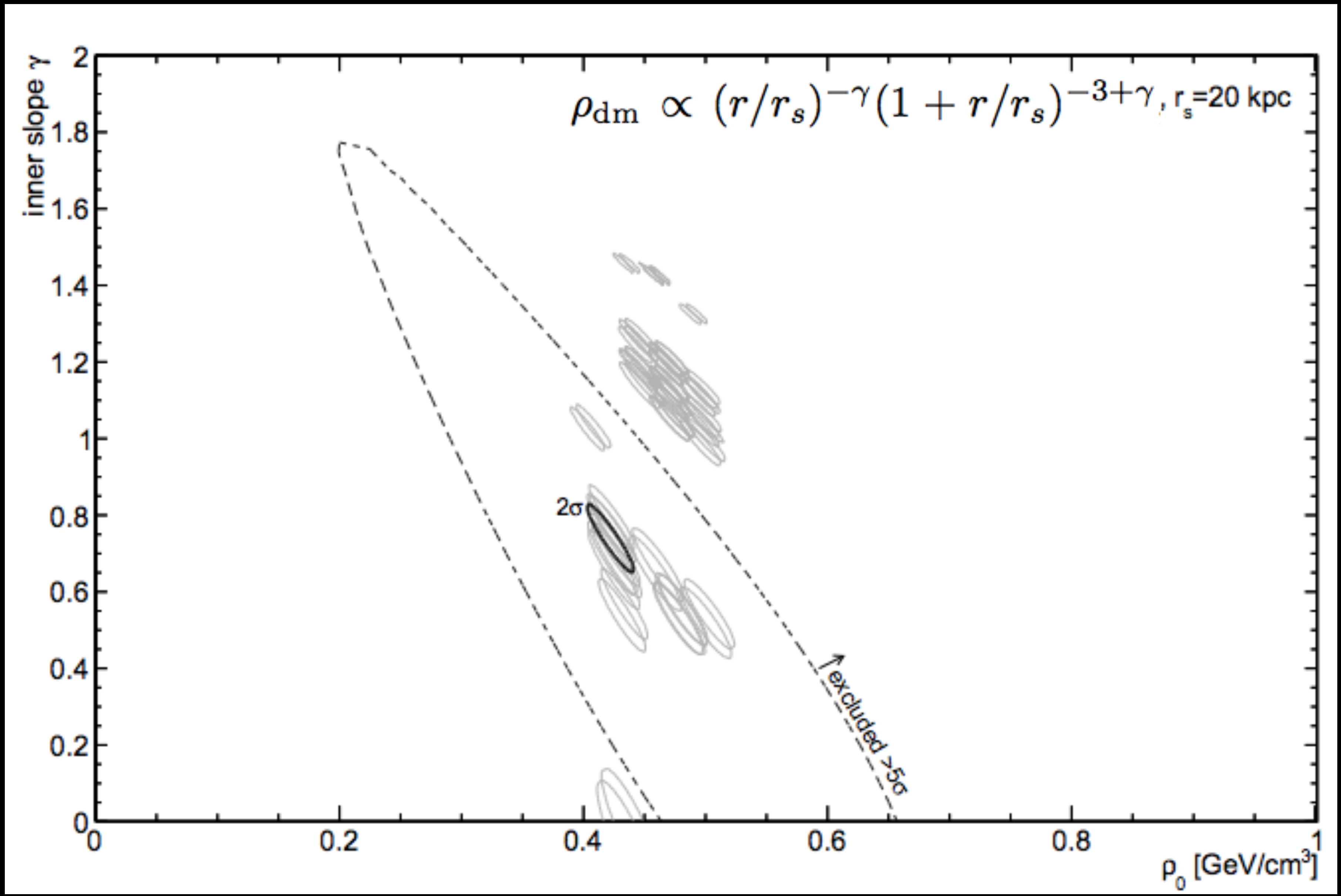

*Iocco, Pato, GB, Nature Physics, arXiv:1502.03821*

# A tool to study DM distribution in the MW




*Iocco, Pato, GB, Nature Physics, arXiv:1502.03821*

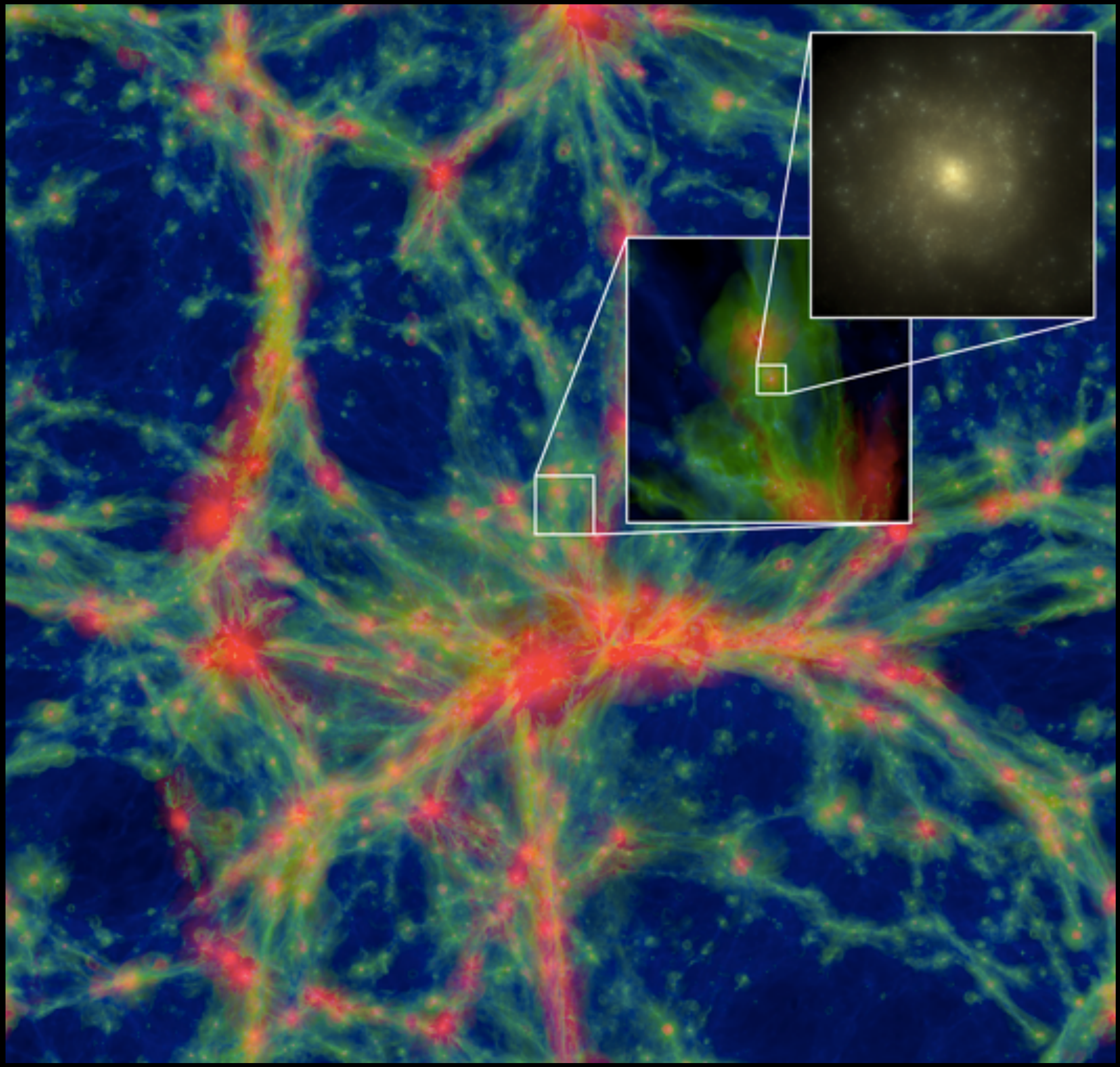
# Constraints on MW DM profile




*Pato, Iocco, GB 1504.06324*

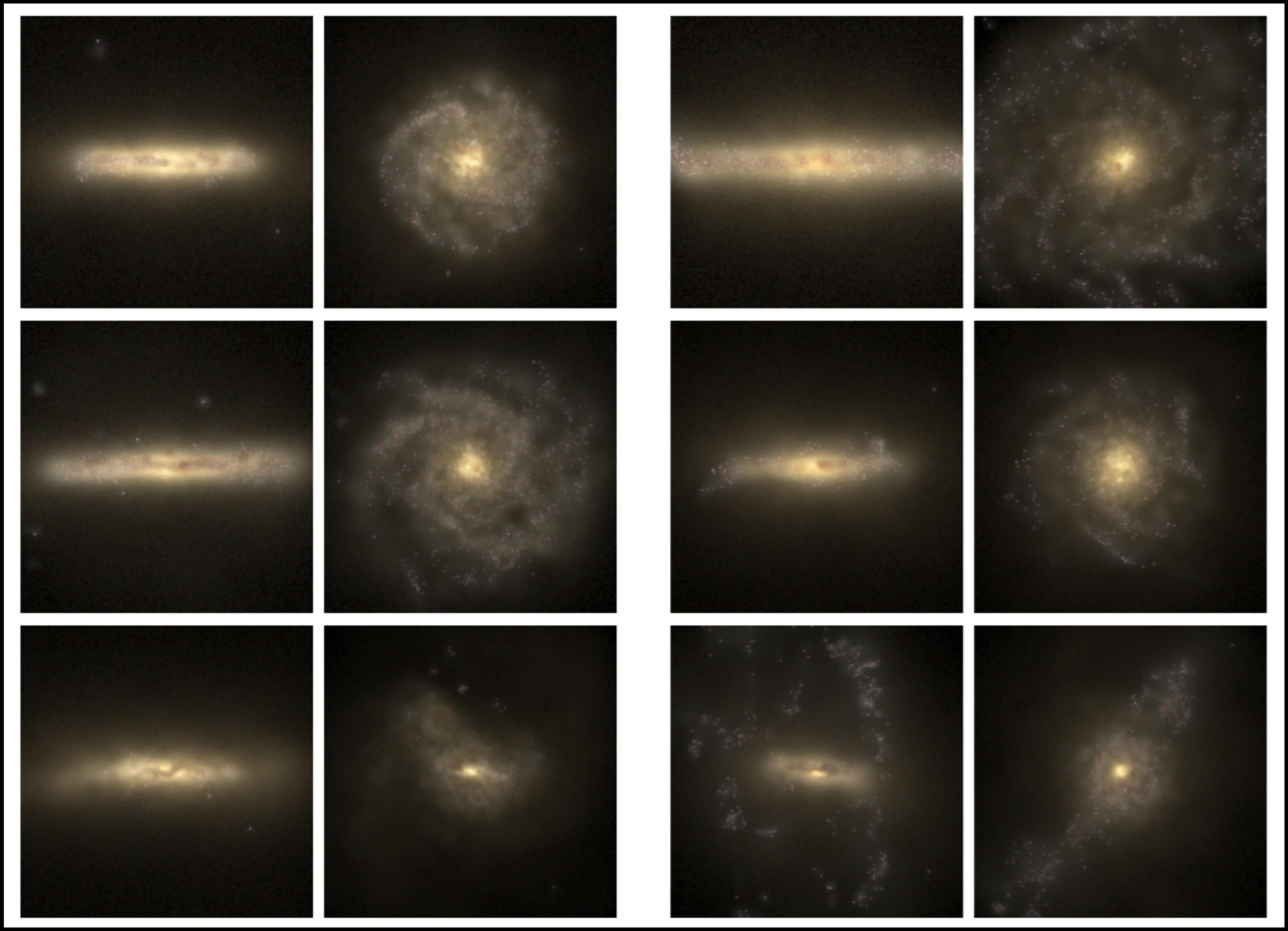
# Numerical simulations frontier

# The Eagle simulation



- One of the largest cosmological hydrodynamical simulations (7 billion particles)
- 1.5 months on 4000 cores DiRAC-2 supercomputer in Durham
- Runs a modified version of the GADGET-2 simulation code

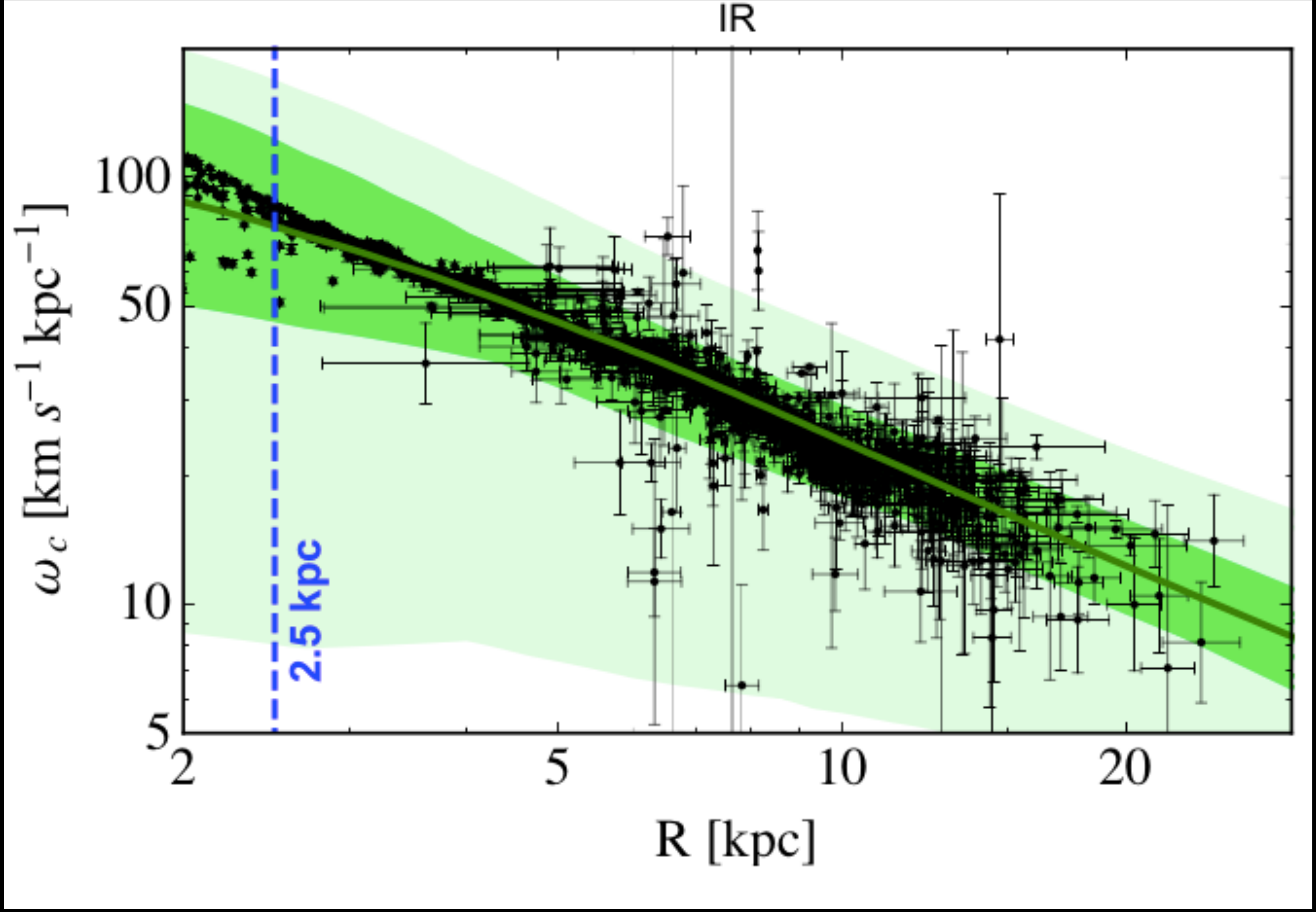
# Identifying MW-like galaxies



Calore, Bozorgnia, GB+ arXiv:1509.02164

Visualisation of MW-like galaxies in the Eagle simulation.

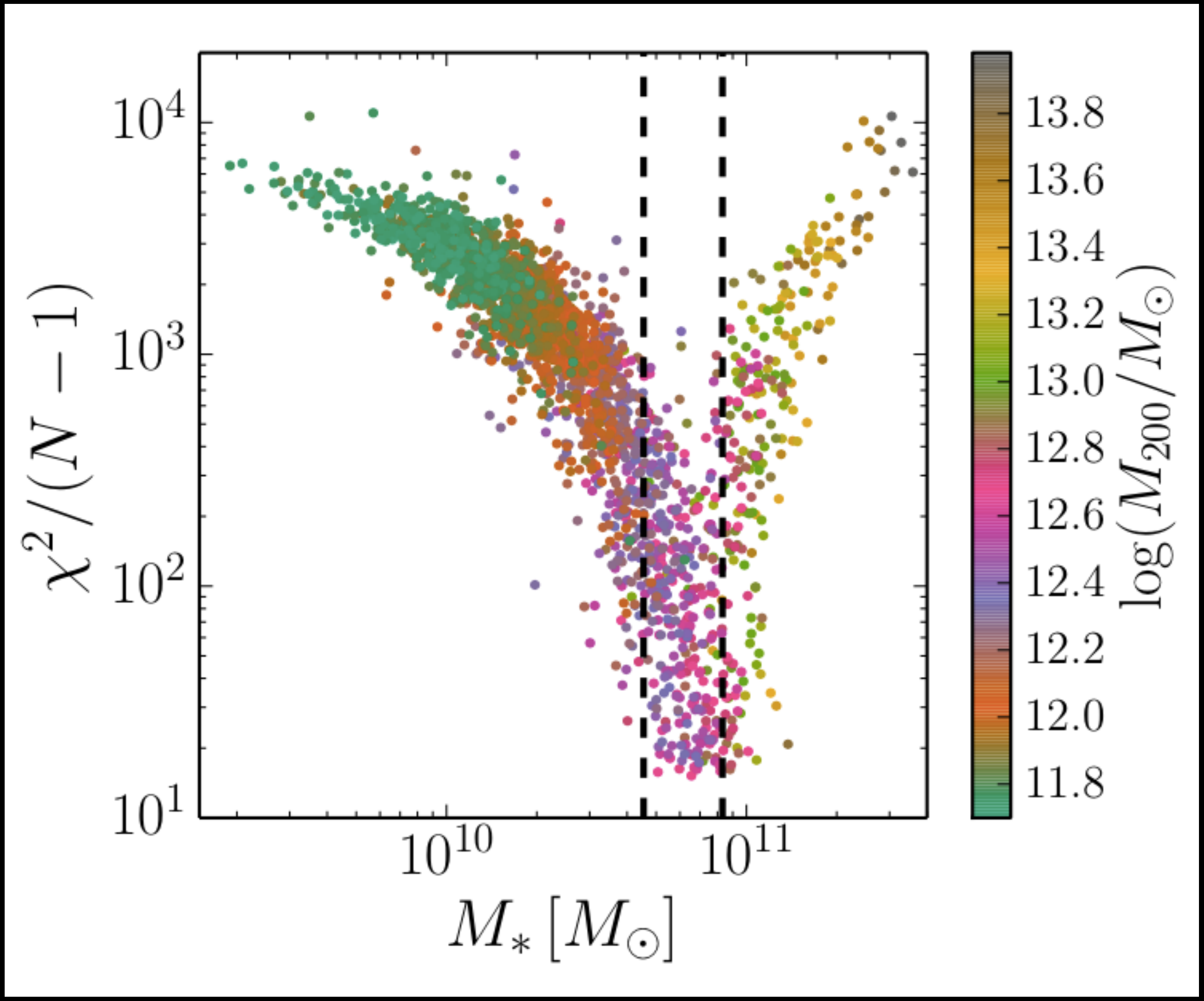
# Identifying MW-like galaxies




Calore, Bozorgnia, GB+ arXiv:1509.02164

What does MW-like mean? Only a small fraction of the halos that satisfy halo mass constraints, have rotation curves compatible with observations.

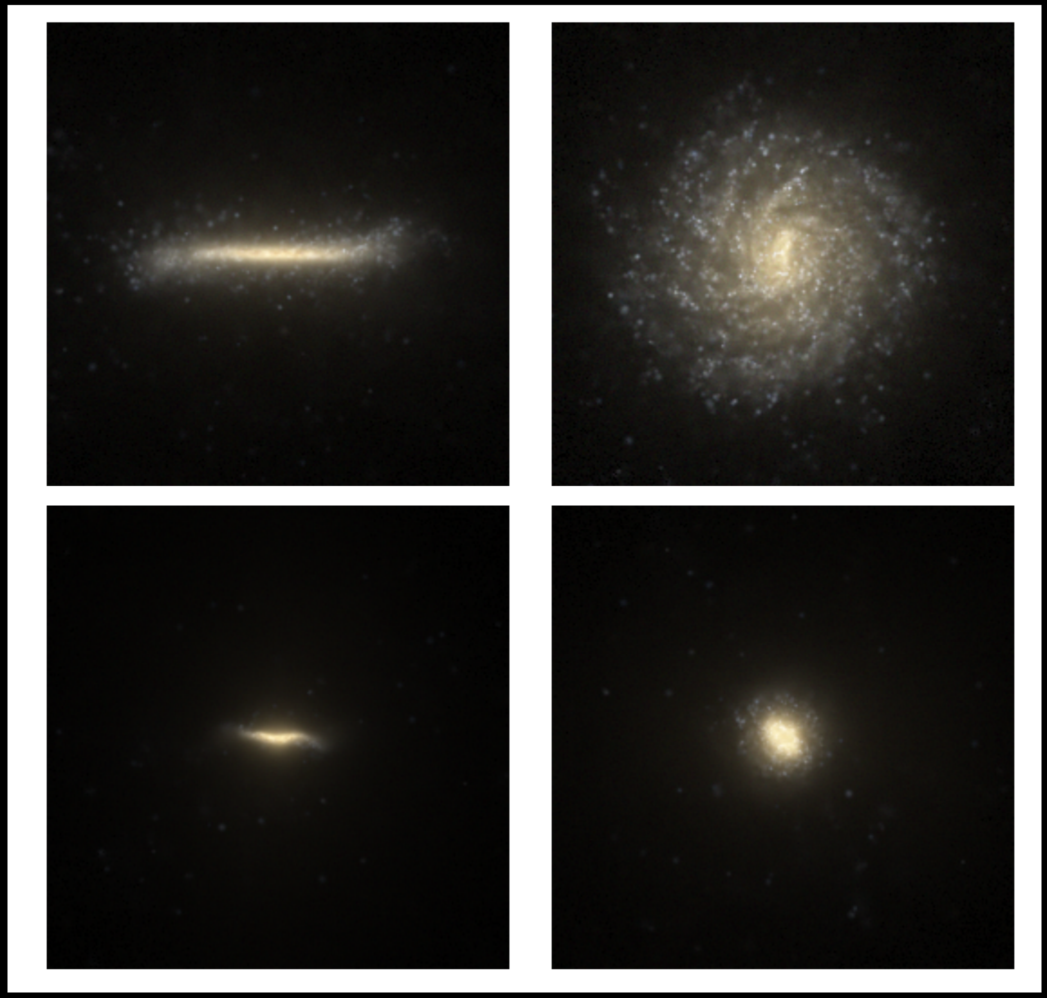
# Identifying MW-analogues




Calore, Bozorgnia, GB+ arXiv:1509.02164

We identify halos morphologically and dynamically similar to the MW as MW-analogues. Simulated halos with ‘good’ rotation curves tend to have a mass *in stars* that closely matches the MW observed one.

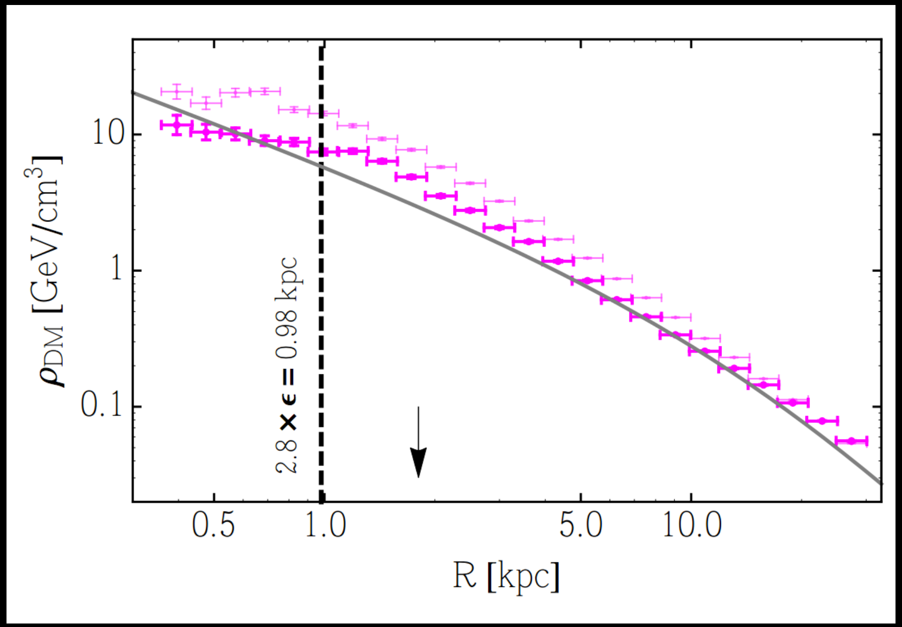
# Understanding the impact of baryons on the dark matter distribution



Selection of halos that satisfy rotation curve constraints in the Eagle High-resolution hydrodynamic simulation

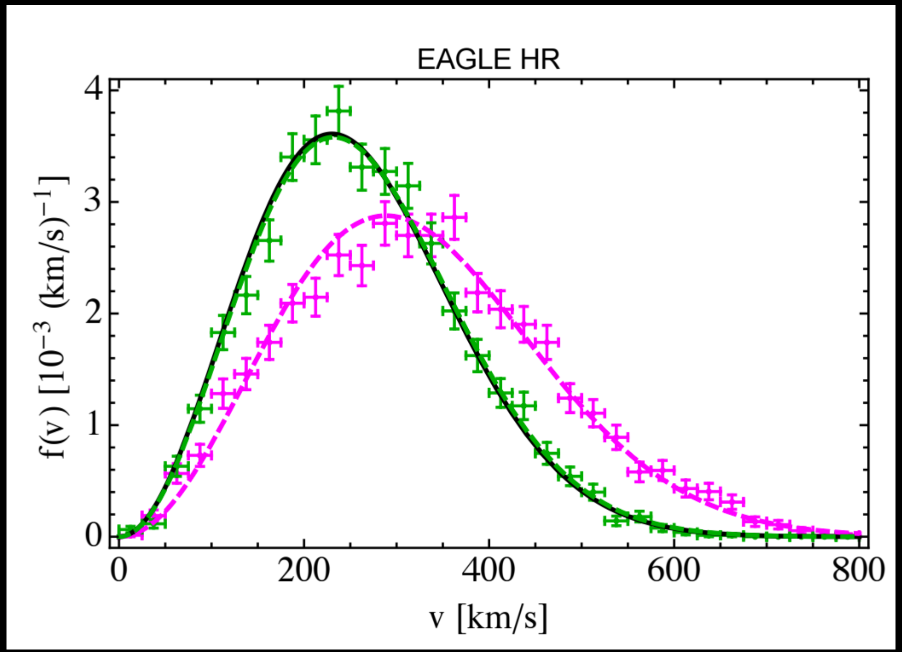
*(GRAPPA + Eagle collab.:1509.02164, 1601.04707)*

Density profiles




*1509.02164*

Velocity distribution




*1601.04707*

# Xenon detectors

## (e.g. Xenon1T)

# Evolution of experimental sensitivity

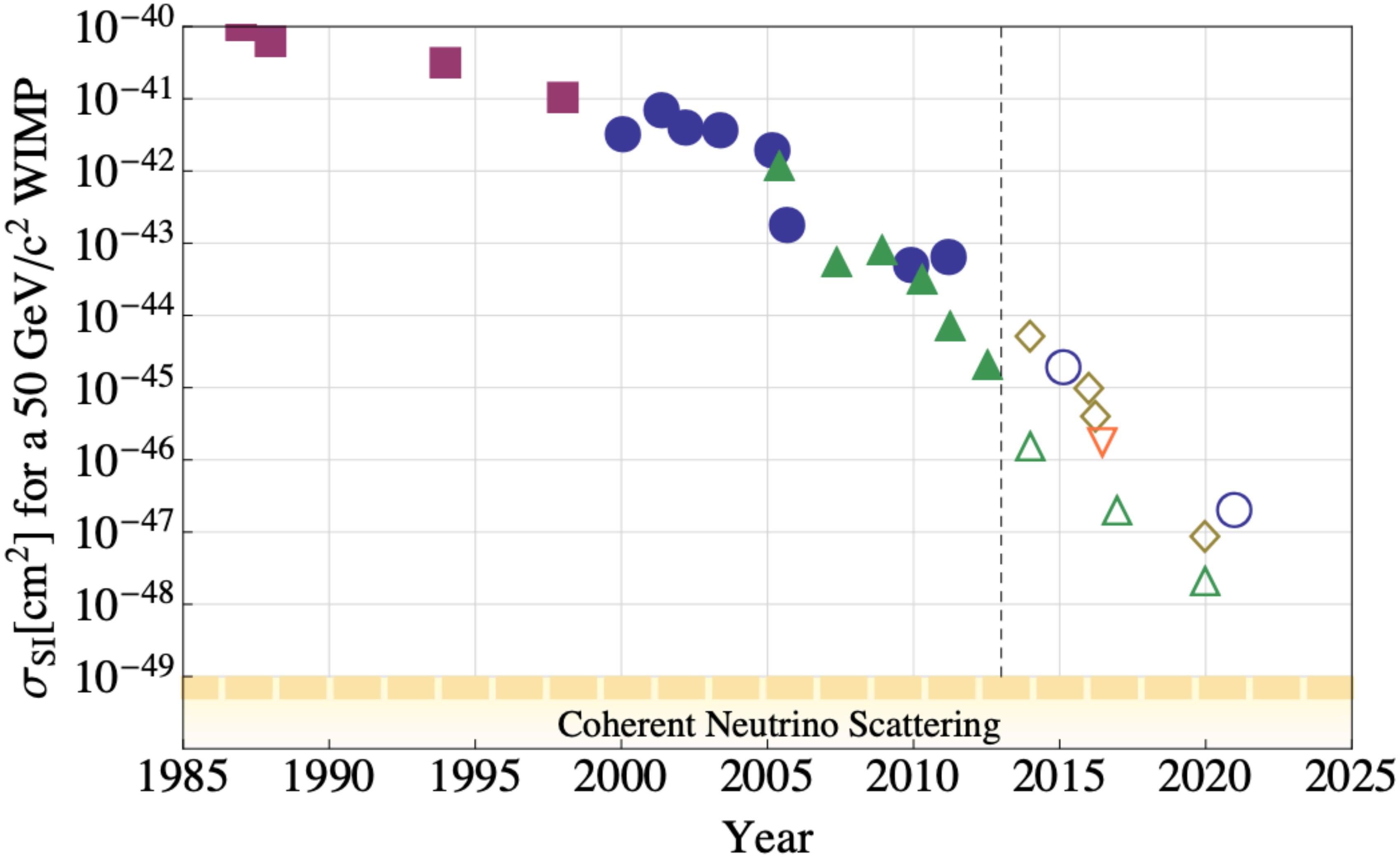



FIG. 8. The past and projected evolution of the spin-independent WIMP-nucleon cross section limits for a 50 GeV dark matter particle. The shapes correspond to limits obtained using different detectors technologies: cryogenic solid state detectors (blue circles), crystal detectors (purple squares), liquid argon detectors (brown diamonds), liquid xenon detectors (green triangles), and threshold detectors (orange inverted triangle). Taken from Ref. [83].

# Sensitivity present and future detectors