Direct and Cosmological characterization of dark matter

LAM & CPPM

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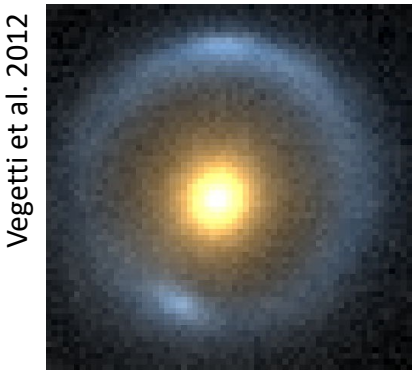
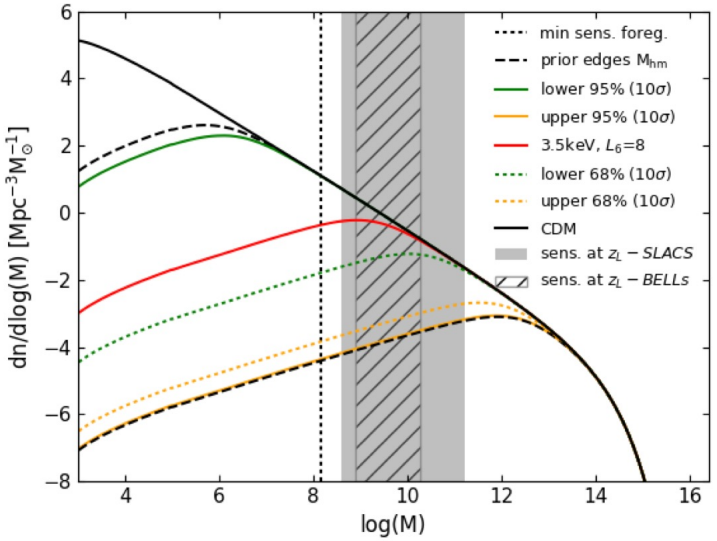
Problematic


Vegetti et al. 2012

SL current constraints



1) Gravitational lenses

=> WIMP & axion: galactic scale CDM behavior => unable to distinguish WIMP & axion?

2) Detection of DM particles

=> Sensitivity depends on the density model of the Galaxy and subhalos
=> use of simulations, observations (lensing, galaxy rotation curves, etc.)

In the 2 cases

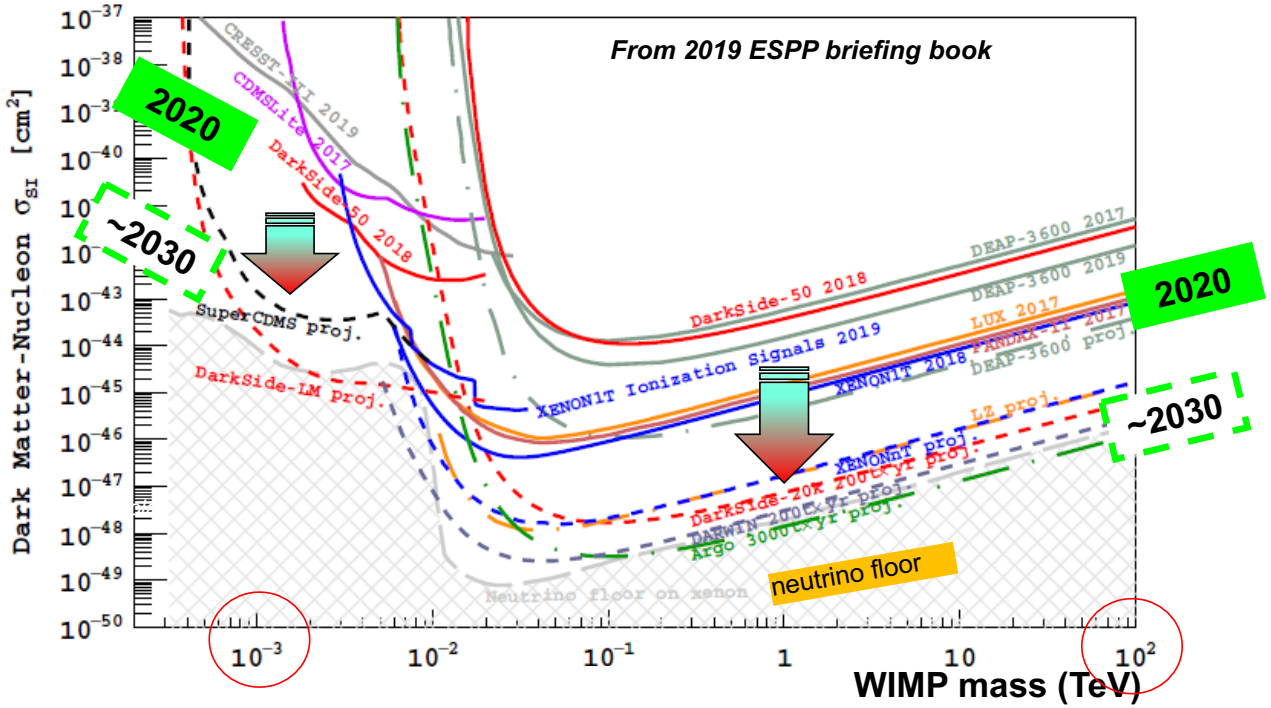
- Use of hydrodynamical simulations

Much to gain by exchanging/joining efforts between communities 1) and 2), especially at the level of simulations

Simulation (Springel et al. 2008)

Direct detection sensitivities

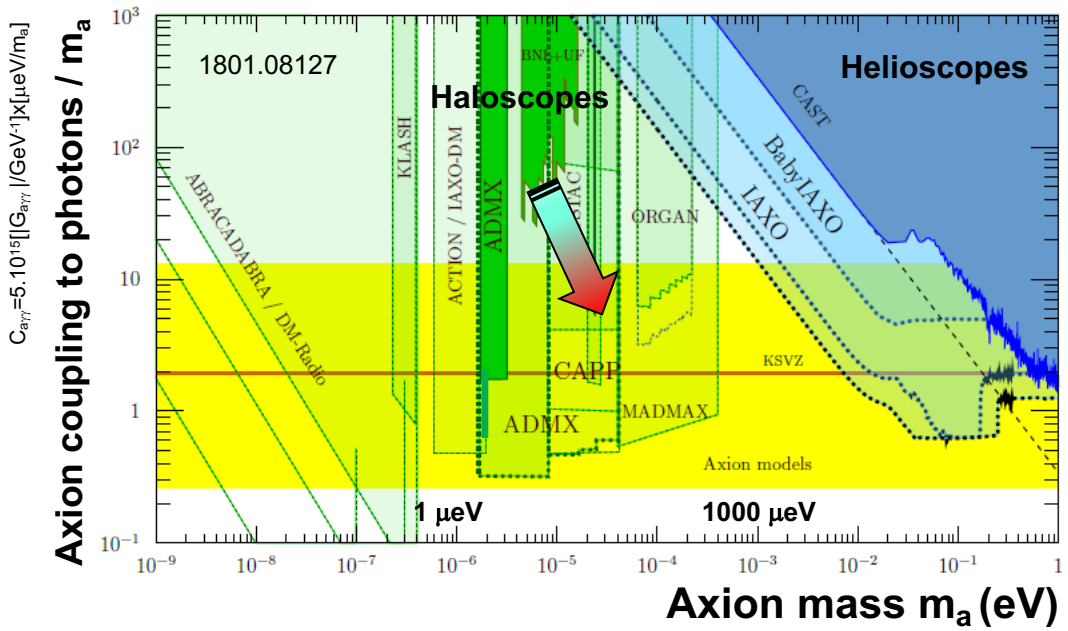
Experiments / prototypes in preparation at CPPM:



DarkSide-20k

➔TPC with noble liquid (Xe, Ar): best limits 1 GeV - 100 TeV

➔Next decade decisive to probe WIMPs down to neutrino floor



MADMAX

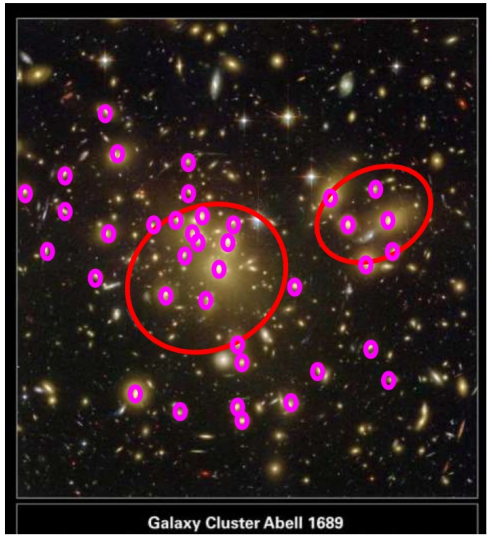
➔ Targets “high mass” DM axions: **m_a~40-400 μev**

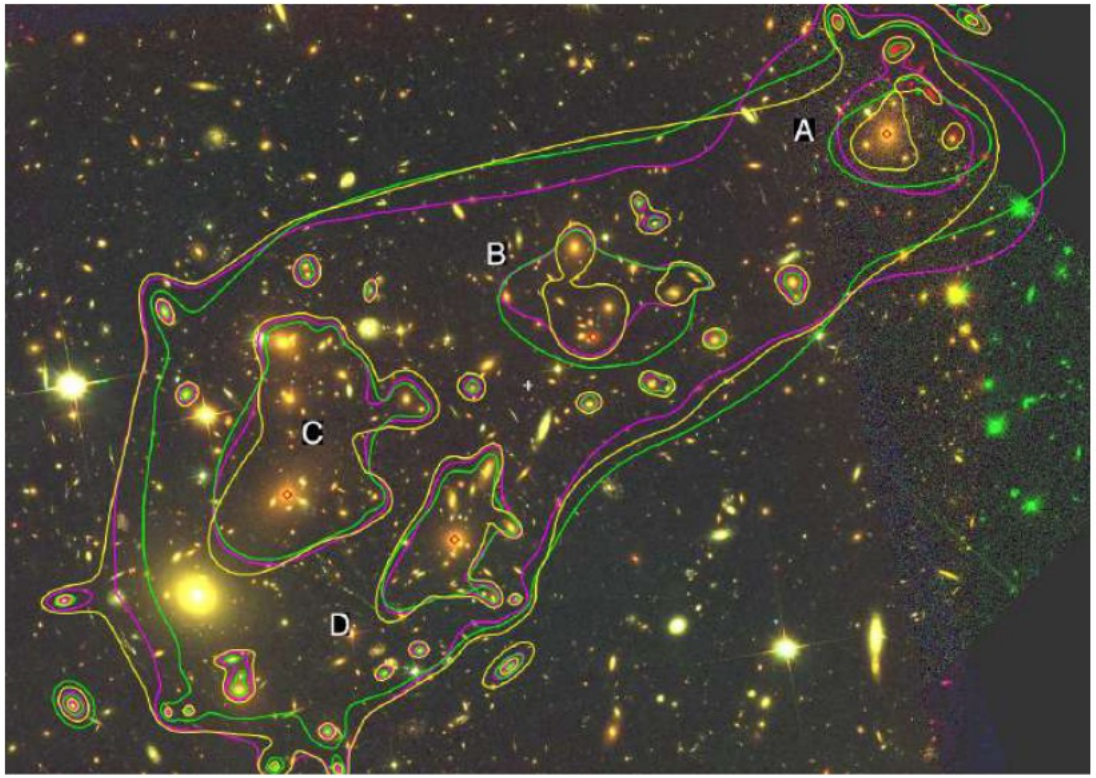
➔ R&D program to improve signal sensitivity

Strong lensing recent progress

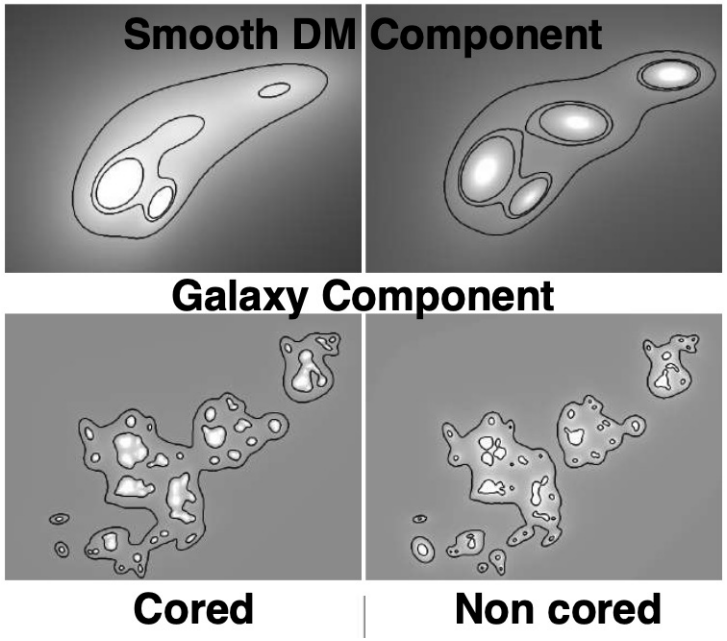
Better modelling thanks to

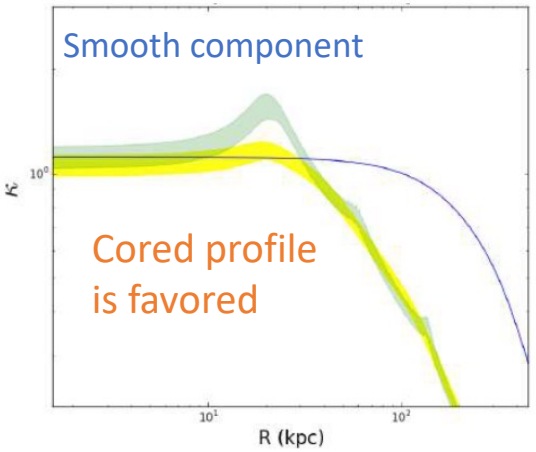
- More multiple images constraints with deep HST observations (HFF program, JWST)
- Integral field spectroscopy data to constrain galaxy kinematics (MUSE)





Limousin et al. 2017





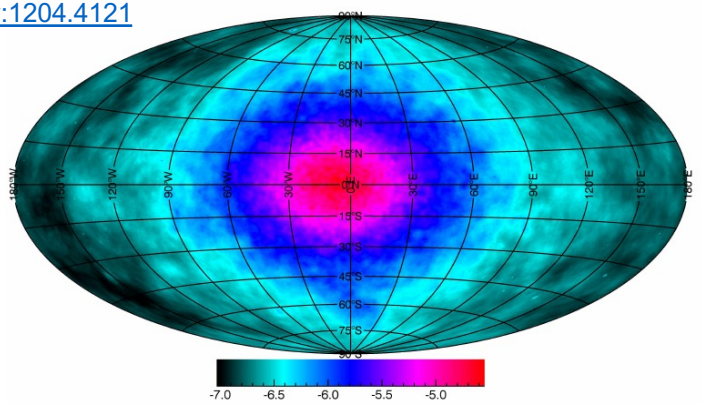
Limousin et al. 2022

=> Self-Interacting DM can produce a cored inner profile

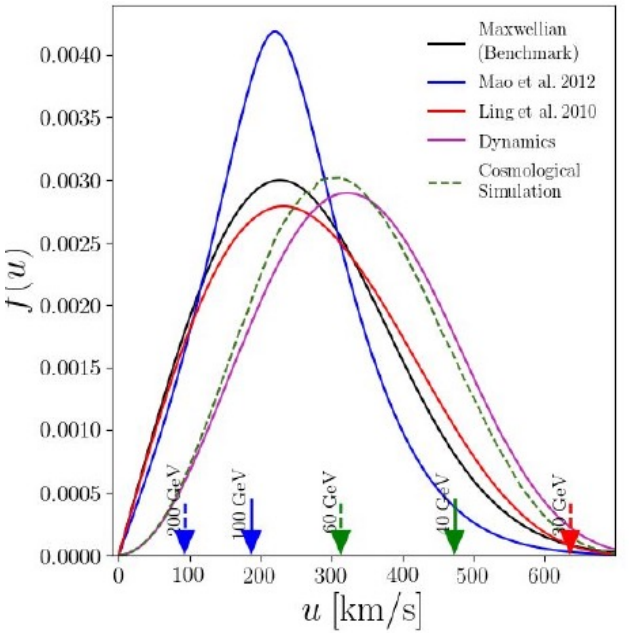
Milky Way modelling

1. Hydrodynamical N-body (zoom-in) simulations including subhalos
2. Connecting cosmo simulations with astroparticles and dark matter detection
3. Phase space distribution beyond the Maxwellian distribution of the Standard Halo Model

Nezri et al. 2012
arXiv:1204.4121



Petač et al. 2021
arXiv:2106.01314



Nuñez et al. 2023
arXiv:2301.06189

- Velocity distribution is more complex than analytical models
- Observations with grav. lenses can constrain halo models and simulation

Project objective (3 years)

Interdisciplinarity: Combining diverse scientific disciplines to foster creativity and achieve a common goal through different approaches

Common goal: to characterize the nature of dark matter

Approach 1: Gravitational lensing in cosmology

- Able to measure density profile and number of subhalos in galaxies

Approach 2: Direct and indirect detection in (astro-)particle physics

- Able to distinguish DM particles

Project Milestones

=> Show that the nature of DM (WIMP or axion) modifies macro observables (lensing and baryon properties)

Quality and Ambition of the project

- 2 well-established CPPM & LAM teams: Recognized for their analysis expertise
  - Tools: Lenstool Jullo et al. 2007, Clumpy Nezri et al. 2012, RAMSES Nuñez et al. 2021
- CPPM & LAM involved in international projects
  - WIMP: **ANTARES**: 1st neutrino telescope in the sea, data taking 2006-2012
    KM3NeT: new generation neutrino telescope in the Mediterranean sea, 2 complementary detectors under construction (ORCA in France, ARCA in Sicily)
  - **DarkSide**: proven technology with innovative design → DS-20k (2027-)
  - Axion: **MadMax**: innovative concept → prototyping phase for validation (2021-25)
  - **Euclid, HST+JWST**: High Resolution Detection and Imaging of Gravitational Lenses
  - **VLT & ELT-HARMONI**: Gravitational lens spectroscopy (redshifts)
- Ambition:
  - Challenge simulations: impact of micro DM physics at the macro level. Analogy with baryon physics (Nuñez et al. 2021)
  - Lens profile measurement (Limousin et al. 2016, 2022) + detection of substructures in gravitational lenses (Natarajan et al. 2017)

Implementation modality

- WP1: Common language for modeling DM halos, tidal effects, tidal streams

=> The modelling of DM halos is the common object of the DM search & gravitational probe communities
=> Implementation of consistent models in Lenstool & Clumpy & Simulations
=> Analysis of lens systems and measurement of density profiles and number of subhalos

- WP2: Impact of baryons+DM on the morphology and evolution of (sub)halos

=> Run of hydrodynamic cosmological simulations with the same properties of DM and baryon physics

Challenge: Find consistent recipes despite the different simulation scales (Mpc → sub-pc)

- WP3: Using WP1 and WP2 results to estimate uncertainties in detections

=> Prediction of direct & indirect detection rates from models (MD+baryons), simulation results, observational results

Funding status

- AMIDEX funded 100k€
- Request to IPhU
  - 4k€ to reach the salary for a >3 years experience postdoc for 24 months
  - 5k€ for laptop and travel for the postdoc
- Adminitrative question
  - Possible to spend for salary on 2 EOTP
  - Is this spending allowed by the IPhU maquette?