What are the interactions of Dark Matter?

Camilo Garcia Cely

12 December, 2017

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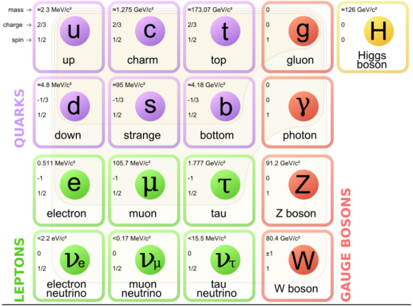
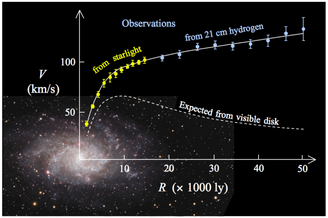
  Advisor : Prof. Alejandro Ibarra.
- Postdoctoral researcher at Université Libre de Bruxelles
- DESY theory fellow

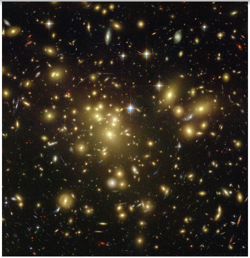
- The last piece of the Standard Model was discovered at the LHC in the summer of 2012 (shortly after the start of my PhD)

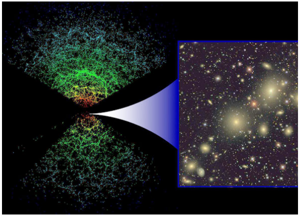


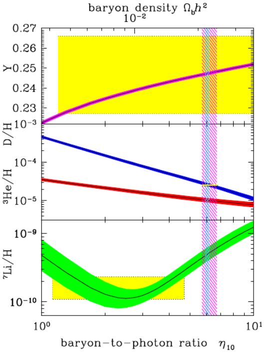
- The SM does not explain Dark Matter: incorporate it in the previous table.
- What are the interactions of Dark Matter?

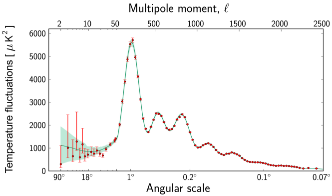
What are the interactions of DM? Gravitational





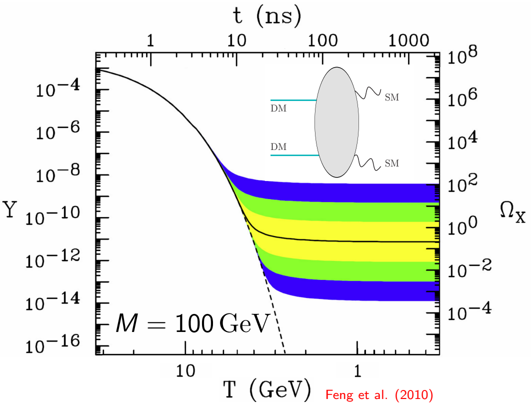






WIMP Paradigm

Lee and Weinberg (1977)

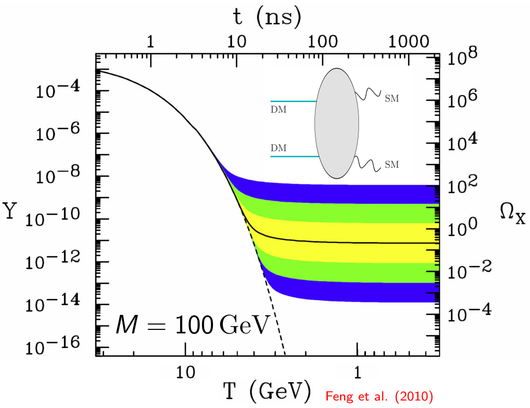


Feng et al. (2010)

What are the interactions of DM? Electroweak?

WIMP Paradigm

Lee and Weinberg (1977)



Feng et al. (2010)

$$\Omega h^2 = \frac{0.1\,\mathrm{pb}}{\sigma v}$$

$$\sigma v \sim \frac{g^4}{M^2} \sim 1\,\mathrm{pb}$$

$$M \sim 100\,\mathrm{GeV} \text{ to } 200\,\mathrm{TeV}$$

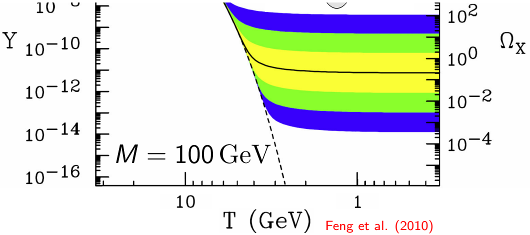
Griest and Kamionkowski(1990)

What are the interactions of DM? Electroweak?

WIMP Paradigm

Lee and Weinberg (1977)

We must look at the TeV scale!



Feng et al. (2010)

$M \sim 100\,\mathrm{GeV}$ to $200\,\mathrm{TeV}$

Griest and Kamionkowski(1990)

Multi-TeV DM scenarios

Simple assumption: extend the SM with an electroweak multiplet

Quantum Numbers			
$SU(2)_L$	$U(1)_Y$	Spin	
2	1/2	0	Inert doublets [1] 0.5-20 TeV
	1/2	1/2	Higgsino DM $\sim$ 1 TeV
3	0	0	
	0	1/2	Wino DM $\sim$ 2.9 TeV
	1	0	
	1	1/2	
4	1/2	0	
	1/2	1/2	
	3/2	0	
	3/2	1/2	
5	0	0	
	0	1/2	Fermionic 5-plet $\sim$ 10 TeV
7	0	0	Scalar 7-plet $\sim$ 25 TeV

Cirelli, Fornengo, Strumia (2005)

[1] PhD Thesis

Multi-TeV DM scenarios

Quantum Numbers			
$SU(2)_L$	$U(1)_Y$	Spin	
2	1/2	0	Inert doublets 0.5-20 TeV
	1/2	1/2	Higgsino DM $\sim$ 1 TeV
	0	0	

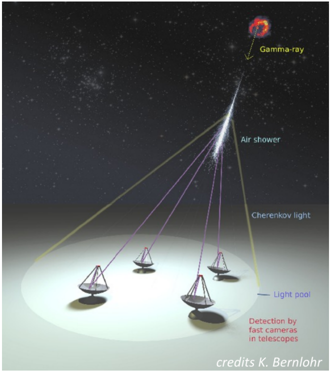
How do we test these models?

Indirect Dark Matter searches: Gamma-ray telescopes

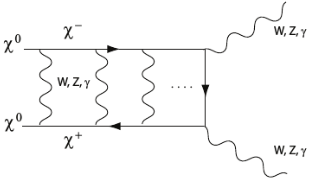
4	3/2	0	
	3/2	1/2	
5	0	0	
	0	1/2	Fermionic 5-plet $\sim$ 10 TeV
7	0	0	Scalar 7-plet $\sim$ 25 TeV

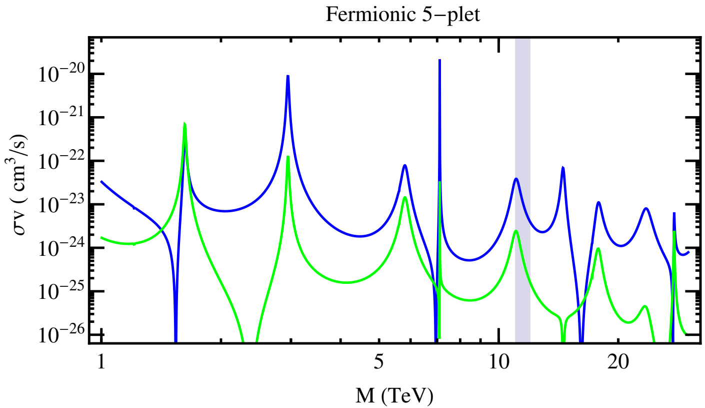
Cirelli, Fornengo, Strumia (2005)

The H.E.S.S. Experiment (High Energy Stereoscopic System)



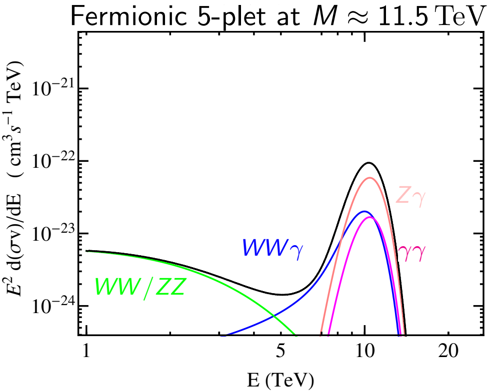
In the early Universe
$\sigma v \sim 1\,\mathrm{pb} \approx 3 \times 10^{-26}\,\mathrm{cm}^3/\mathrm{s}.$
Sommerfeld Effect

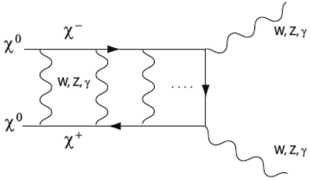




GGC, Ibarra, Lamperstorfer, Tytgat (2015)

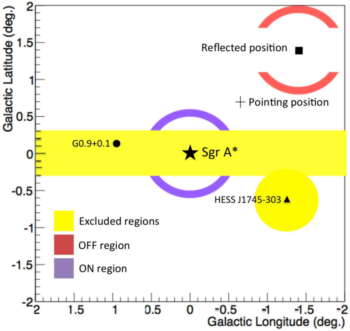
Gamma-ray spectrum

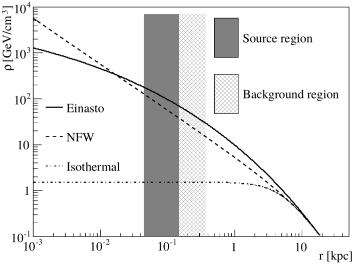




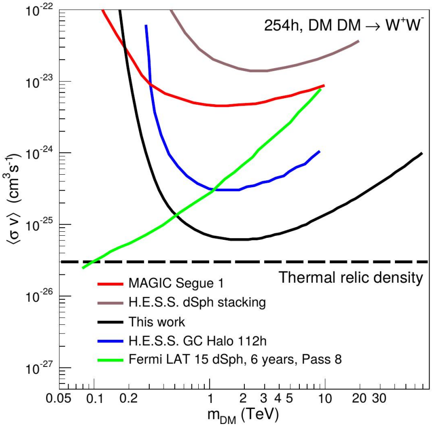
GGC, Ibarra, Lamperstorfer, Tytgat (2015)

H.E.S.S. searches for a continuum of photons

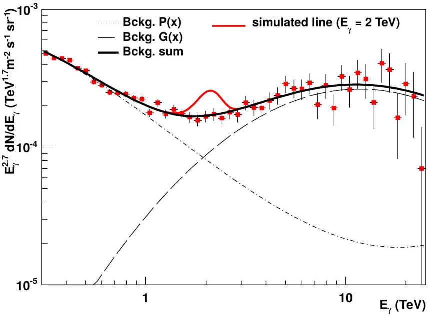


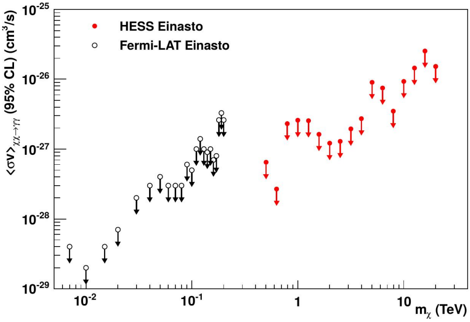


It only works for cuspy profiles!



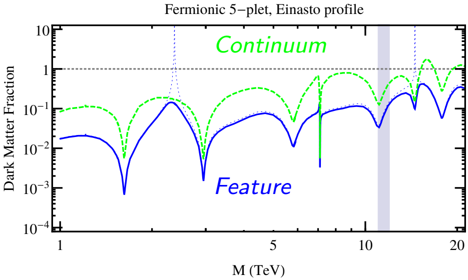
H.E.S.S. searches for line-like features

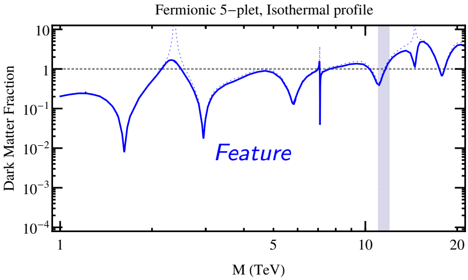




It makes use of the spectral feature and works for any profile

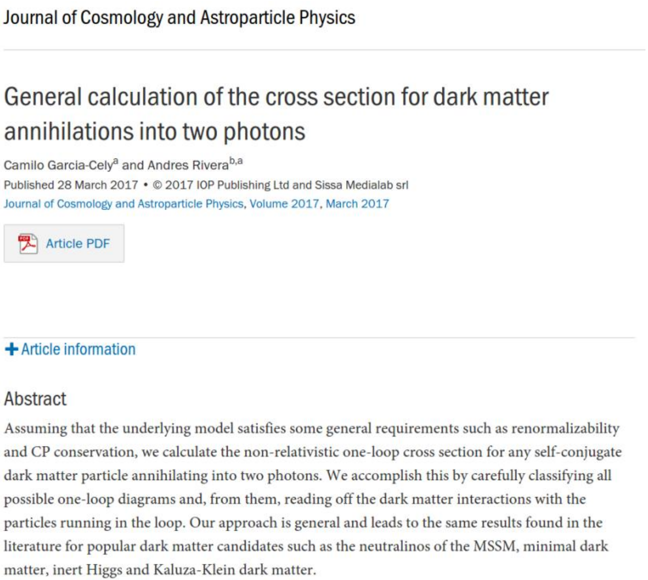
H.E.S.S. Limits from the Galactic Center





Spectral features are very important to study these models.

Irony: DM DM $\to \gamma\gamma$ is the best channel


Journal of Cosmology and Astroparticle Physics

General calculation of the cross section for dark matter annihilations into two photons

Camilo Garcia-Cely[a] and Andres Rivera[b,a]

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Journal of Cosmology and Astroparticle Physics, Volume 2017, March 2017

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Abstract

Assuming that the underlying model satisfies some general requirements such as renormalizability and CP conservation, we calculate the non-relativistic one-loop cross section for any self-conjugate dark matter particle annihilating into two photons. We accomplish this by carefully classifying all possible one-loop diagrams and, from them, reading off the dark matter interactions with the particles running in the loop. Our approach is general and leads to the same results found in the literature for popular dark matter candidates such as the neutralinos of the MSSM, minimal dark matter, inert Higgs and Kaluza-Klein dark matter.

DM DM $\to \nu\nu$ is also good

Prospects for discovering a neutrino line induced by dark matter annihilation

Chaimae El Aisati, Camilo Garcia-Cely, Thomas Hambye and Laurent Vanderheyden

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Abstract

In the near future, neutrino telescopes are expected to improve their sensitivity to the flux of monochromatic neutrinos produced by dark matter (DM) in our galaxy. This is illustrated by a new limit on the corresponding cross section that we derive from public IceCube data. In this context, we study which DM models could produce an observable flux of monochromatic neutrinos from DM annihilations. To this end, we proceed in two steps. First, within a set of simple and minimal assumptions concerning the properties of the DM particle, we determine the models that could give rise to a significant annihilation into monochromatic neutrinos at the freeze-out epoch. The list of models turns out to be very limited as a result of various constraints, in particular direct detection and neutrino masses at loop level. Given the fact that, even if largely improved, the sensitivities will be far from reaching the thermal annihilation cross section soon, a signal could only be observed if the annihilation into neutrinos today is boosted with respect to the freeze-out epoch. This is why, in a second step, we analyze the possibility of having such a large enhancement from the Sommerfeld

What are the interactions of DM? Self-interactions?

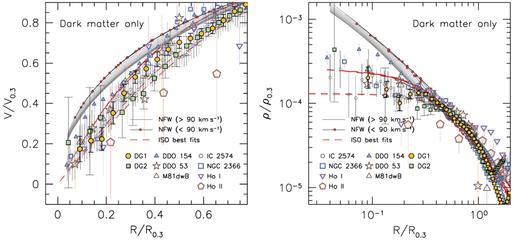
Core vs. cusp problem

dwarf galaxies exhibit a core while N-body simulations predict a cusp at their center

Moore (1994)

Flores et al. (1994)

Naray et al. (2011)



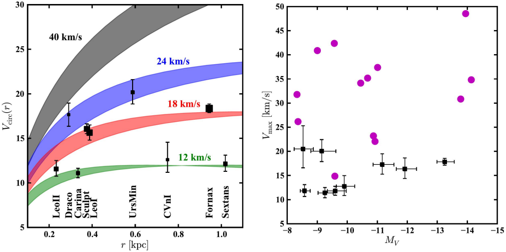
Oh et al.(2010)

Too big to fail problem

simulations of the Milky Way predict subhalos too massive and too dense to host the brightest observed satellites

Boylan-Kolchin et al.(2011)

Ferrero et al. (2014)



Boylan-Kolchin et al.(2011)

What are the interactions of DM? Self-interactions?

Astrophysical possible solutions:

- Including baryons on the simulations
- Supernova feedback
- Tidal effects
- Low star-formation rates

Particle physics solution:

- postulate dark matter interactions that become relevant at small scales, without modifying the physics at large scales.

"..To be more specific, we suggest that the dark matter particles should have a mean free path between 1 kpc to 1 Mpc at the solar radius in a typical galaxy."

Spergel, Steinhardt (1999)

$$\text{Mean Free Path} \sim \left(\frac{\rho}{m_{\text{DM}}}\sigma_{\text{scattering}}\right)^{-1}$$

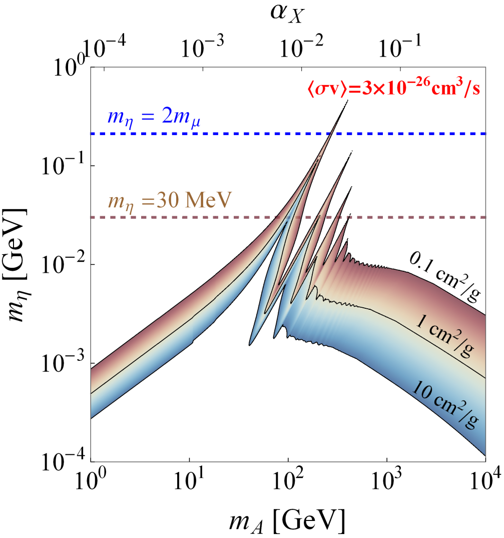
$$\frac{\sigma_{\text{scattering}}}{m_{\text{DM}}} \sim 1\text{cm}^2/g \quad \text{at the scale of galaxies } (v \sim 10 \text{ - } 100 \text{ km/s})$$

Simulations show that this is indeed a solution

Wandelt, et.al (2000), Vogelsberger et.al (2012)
Peter et.al (2012), Rocha et.al (2013),Zavala et.al (2012)
Elbert et.al (2014), Kaplinghat (2015), Vogelsberger et.al (2015)
Francis-Yan Cyr-Racine (2015)

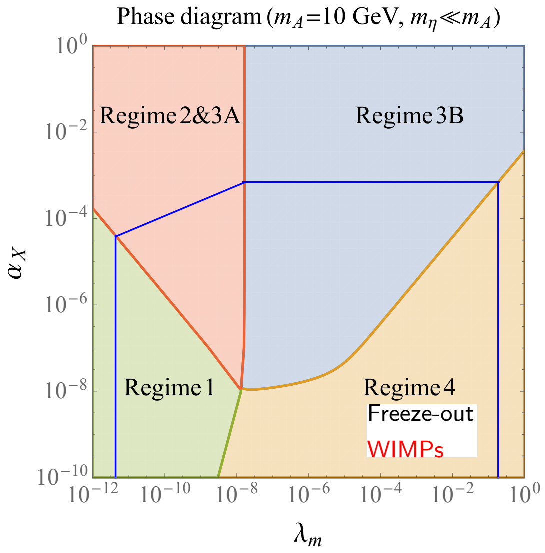
Self-interacting DM

Introduce a light particle inducing self-interactions.



Bernal, Chu, GGC, Hambye, Zaldivar (JCAP 2016)

Production Regimes for self-interacting DM



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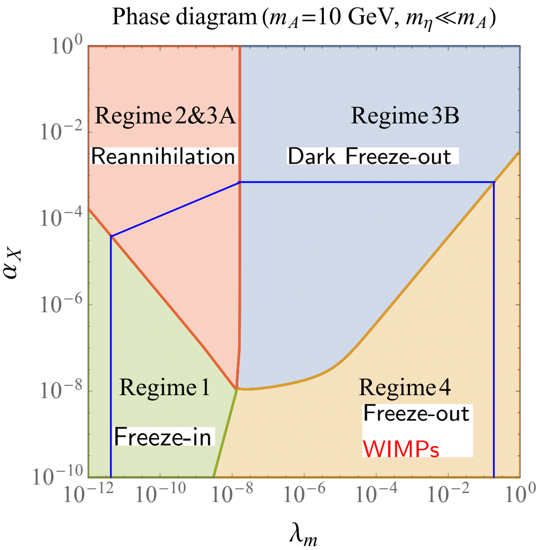
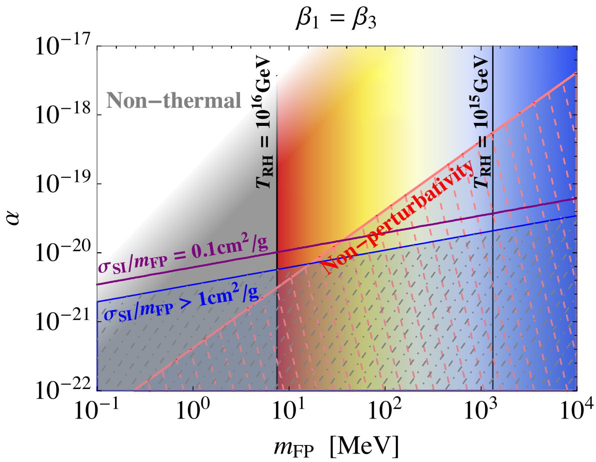
Production Regimes for self-interacting DM



Bernal, Chu, GGC, Hambye, Zaldivar (JCAP 2016)

Spin-2 DM (Bigravity)



How can we produce DM? Regime 3A

Thanks for your attention!