Nearby Stars as Gravity Detectors

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Outline

- Modern Particle Physics of today : the current status of Cosmology/Particle Physics/Astrophysics (Introduction)
- Dark Matter and Stars
- Conclusion

Modern Particle Physics of today

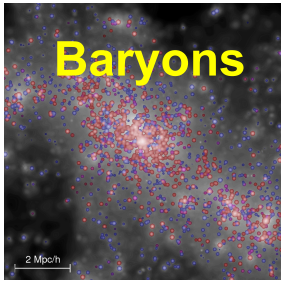
Gravity . Matter . Particle Physics

Formation of structure in the Universe

- **27% Dark Matter** creates the Gravitational web for the formation of structures with **5% of baryons**.

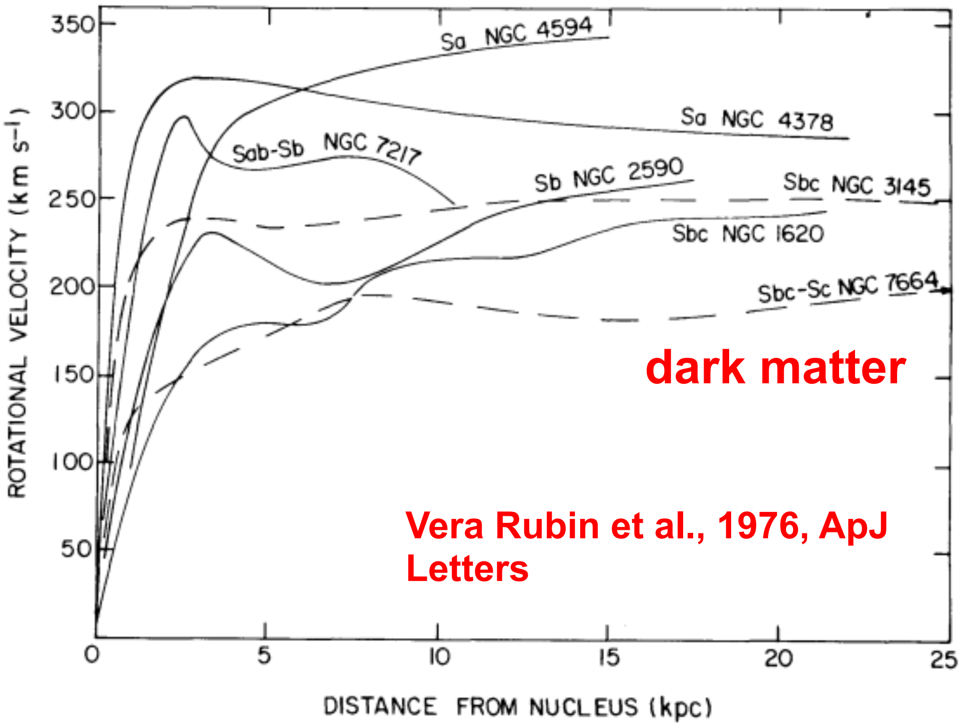
The Nature of Dark Matter: Cold dark matter weakly interacting particles

Reproduce the observed present baryonic structure: stars, stellar clusters, galaxies, galaxy clusters



Confirmed by observations

Rotation curves for 7 spiral galaxies



Vera Rubin et al., 1976, ApJ Letters

Bullet Cluster (two colliding clusters of galaxies)

Modern Particle Physics of today

Einstein's Equation (ignoring constants):

$$G_{\mu\nu} = T_{\mu\nu}^{sp} + T_{\mu\nu}^{DM} + T_{\mu\nu}^{DE}$$

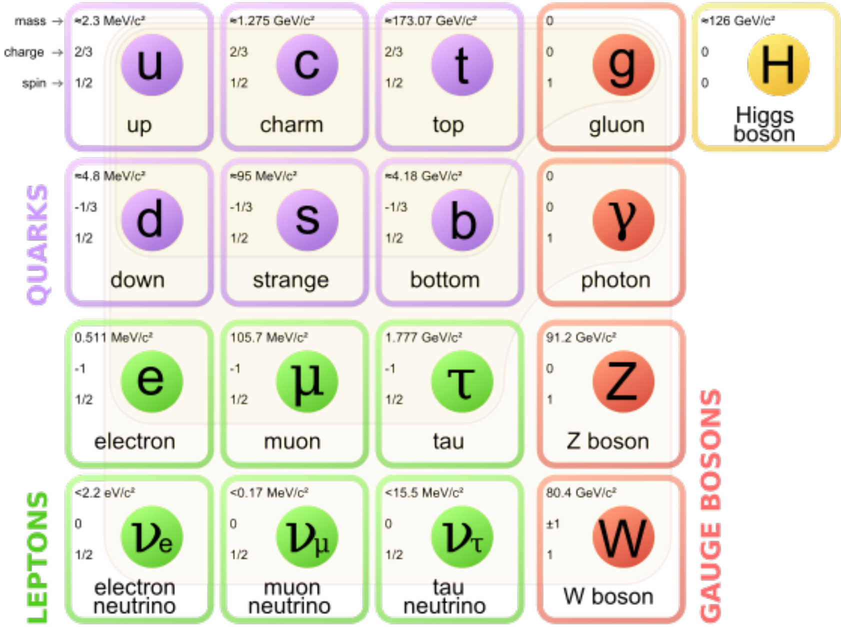
5% 27% 68%

$G_{\mu\nu}$ - Einstein tensor describing the curvature of space-time (and hence the effect of gravity)

$T_{\mu\nu}^{sp}$ – standard particles (baryons, photons and neutrinos)

$T_{\mu\nu}^{DM}$ – dark matter

$T_{\mu\nu}^{DE}$ – dark energy

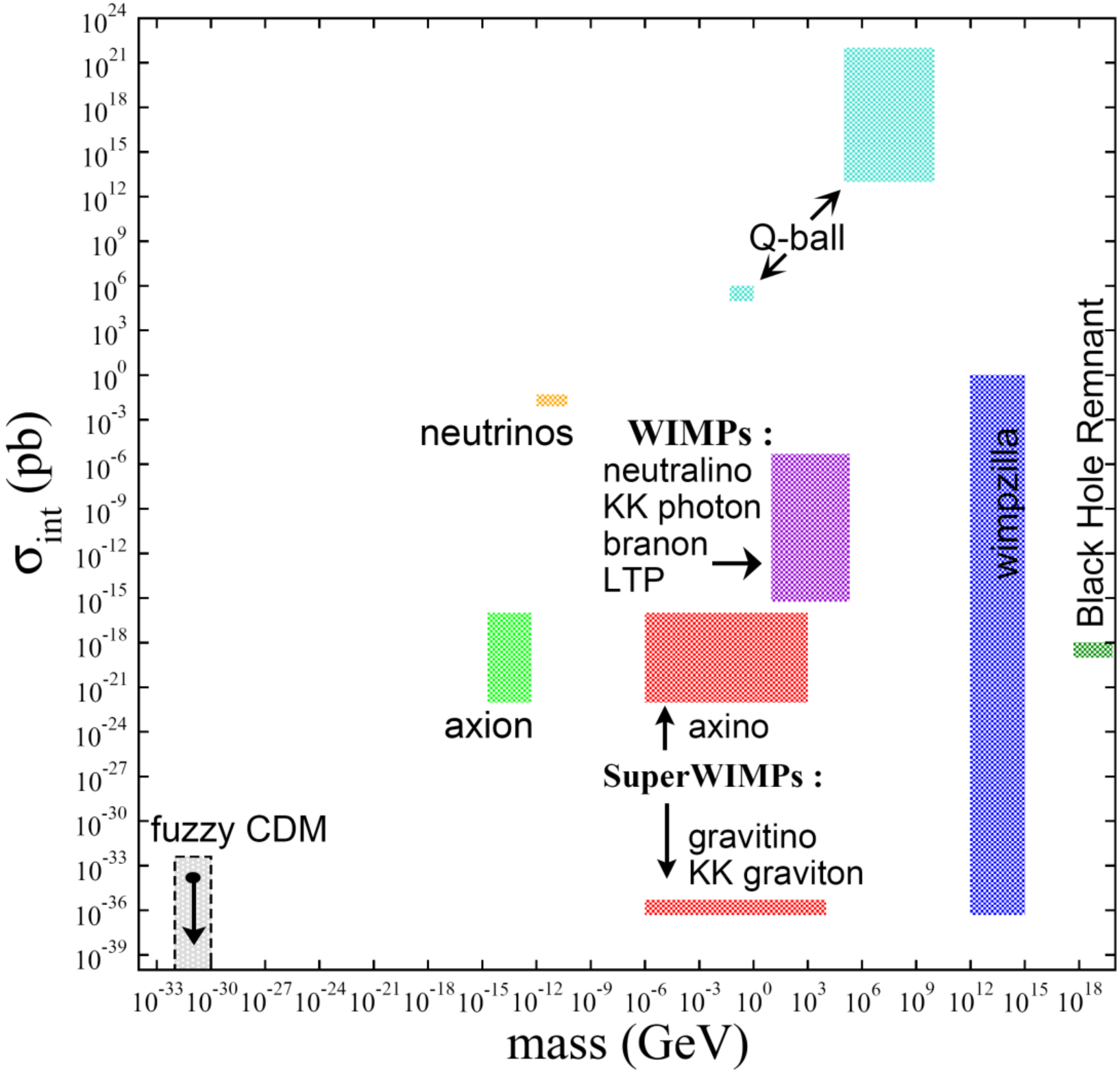


≈2.3 MeV/c² 2/3 1/2 u up	≈1.275 GeV/c² 2/3 1/2 c charm	≈173.07 GeV/c² 2/3 1/2 t top	0 0 1 g gluon	≈126 GeV/c² 0 0 H Higgs boson
≈4.8 MeV/c² -1/3 1/2 d down	≈95 MeV/c² -1/3 1/2 s strange	≈4.18 GeV/c² -1/3 1/2 b bottom	0 0 1 γ photon	
0.511 MeV/c² -1 1/2 e electron	105.7 MeV/c² -1 1/2 μ muon	1.777 GeV/c² -1 1/2 τ tau	91.2 GeV/c² 0 1 Z Z boson	
<2.2 eV/c² 0 1/2 ν_e electron neutrino	<0.17 MeV/c² 0 1/2 ν_μ muon neutrino	<15.5 MeV/c² 0 1/2 ν_τ tau neutrino	80.4 GeV/c² ±1 1 W W boson	

Modern Particle Physics of today

WIMPs (Weakly Interacting Massive Particles)

Candidates of dark matter particles



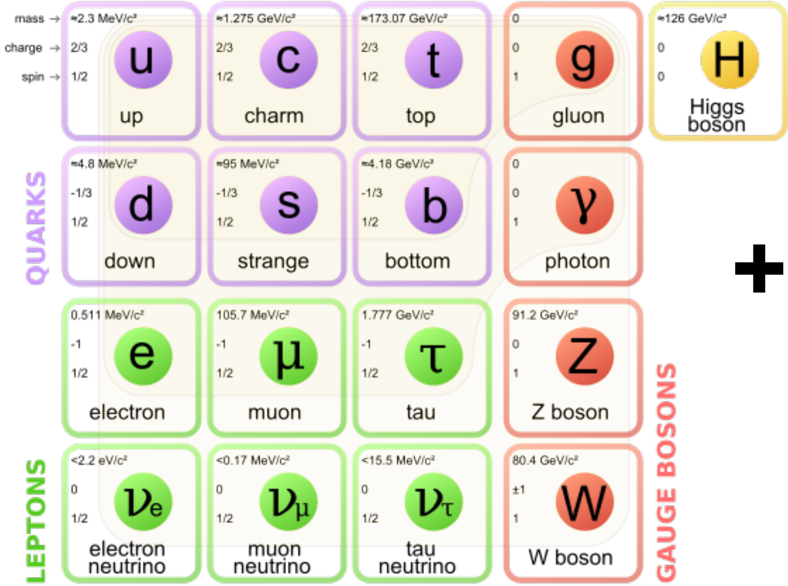
The Early Universe – dark matter particles

Following the evidence, let us now consider that our dark matter is somehow identical to the standard particles.

The obvious choice is to consider that dark matter (27%) is a mirror world of the standard particles (5%).

Nevertheless, we choose to keep the dark matter world simple (dark particle + dark photon). The connection between the standard world and the dark world is done by a kinematic coupling term.

Lopes, Painci, Silk 2014 ApJ



+ Coupling.+

(dark particle + dark photon)

standard particles

mirror particles

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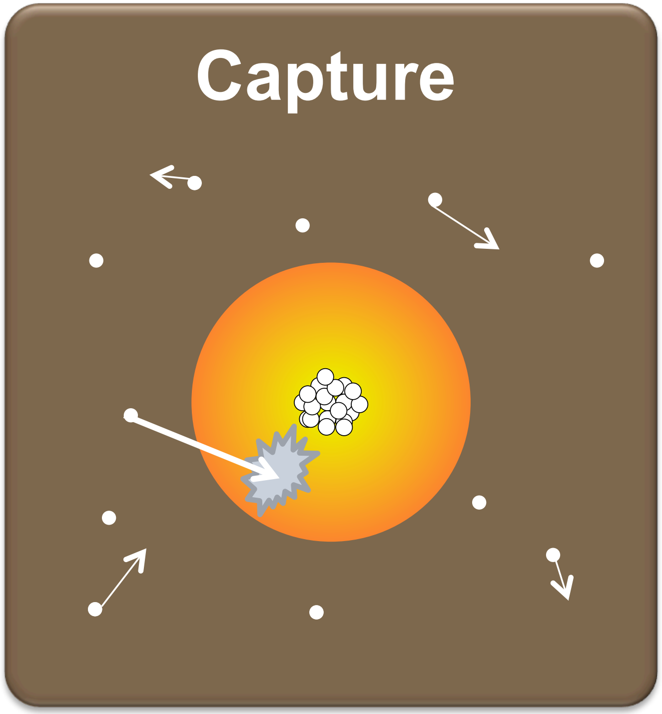
Dark Matter and Stars

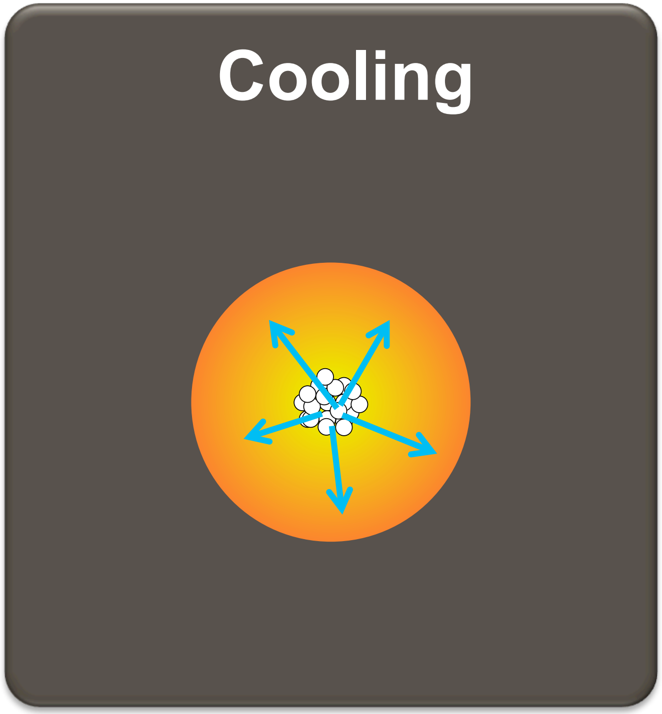
Gravity . Matter . Particle Physics

How does Dark Matter influence stars?



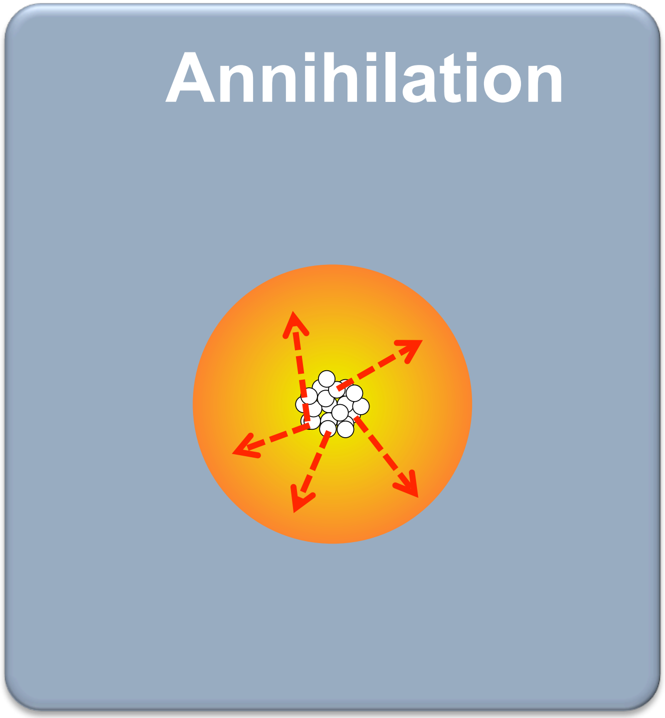
$C_{\chi} \propto f(\chi, \star)$

[Gould, ApJ 321 (1987)]



$L_{transp,\chi} \propto f(C_{\chi}, m_{\chi})$

[Gould & Raffelt ApJ 352 (1990)]



$L_{prod,\chi} = f_{\chi} \cdot C_{\chi} \cdot m_{\chi}$

[Salati & Silk ApJ 338 (1989)]

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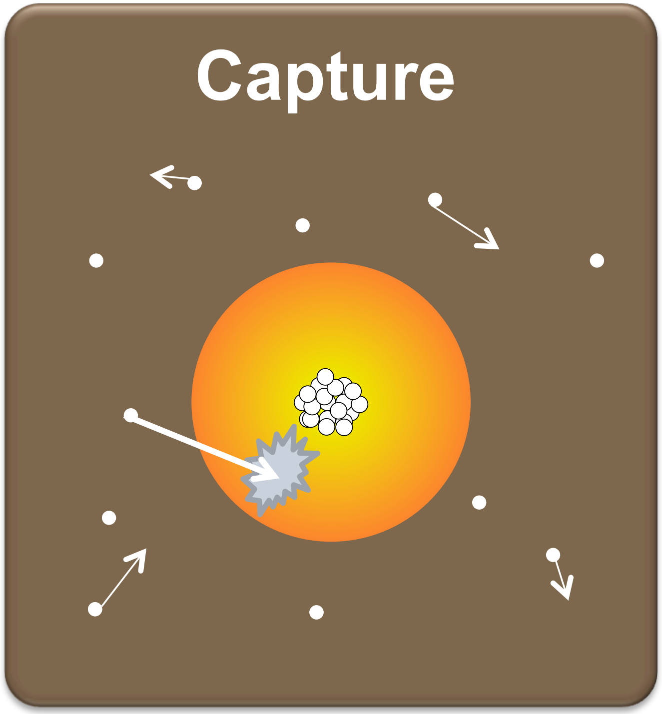
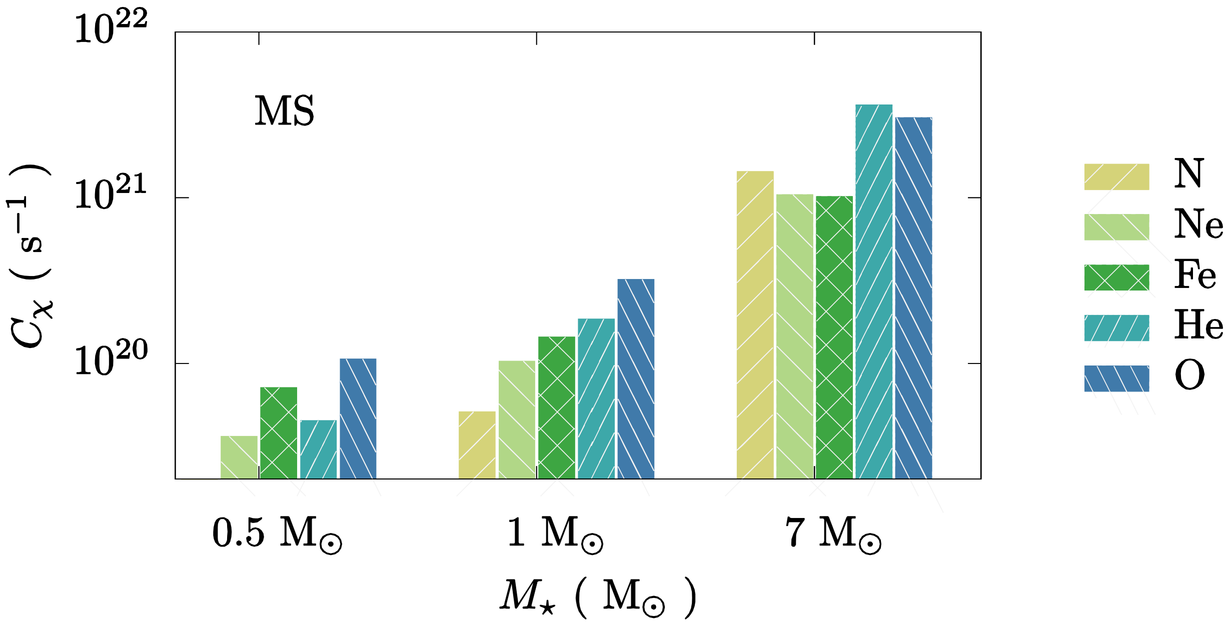
How does Dark Matter influence stars?



$$C_\chi(t) = \int_0^{R_\star} 4\pi r^2 \int_0^\infty \frac{f(u)}{u} w\Omega_v^-(w)\,\mathrm{d}u\,\mathrm{d}r$$

[Gould, ApJ 321 (1987)]

σ_χ m_χ ρ_χ $\bar{v}_\chi$ $V_\star$ n_i



[Lopes, Casanellas & Eugénio, PhysRevD 83 (2011)]

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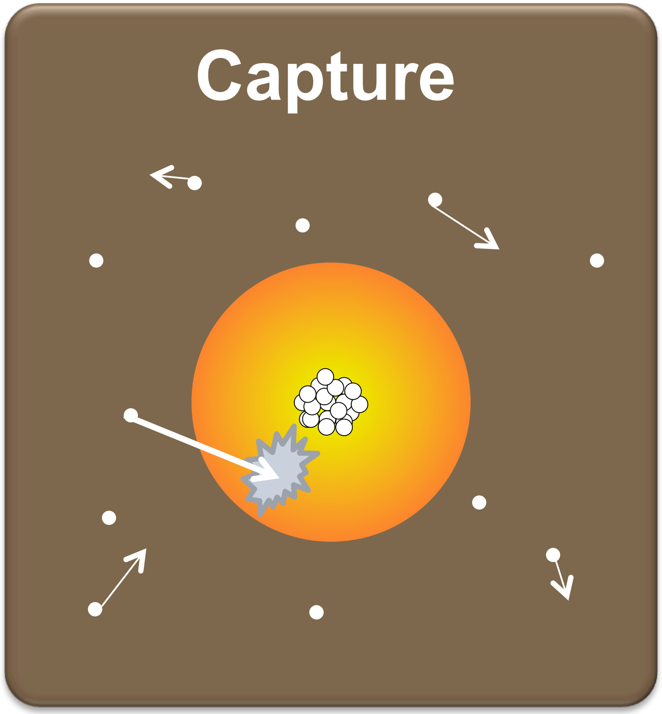
How does Dark Matter influence stars?



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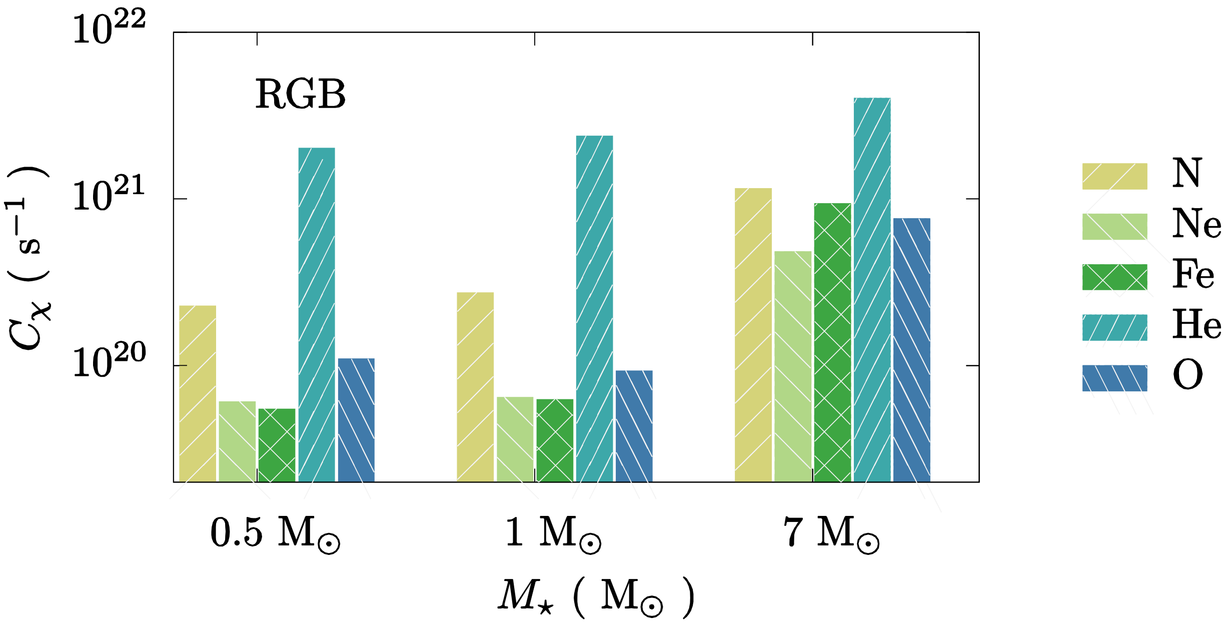


[Lopes, Casanellas & Eugénio, PhysRevD 83 (2011)]

Dark Matter and Stars (few examples)

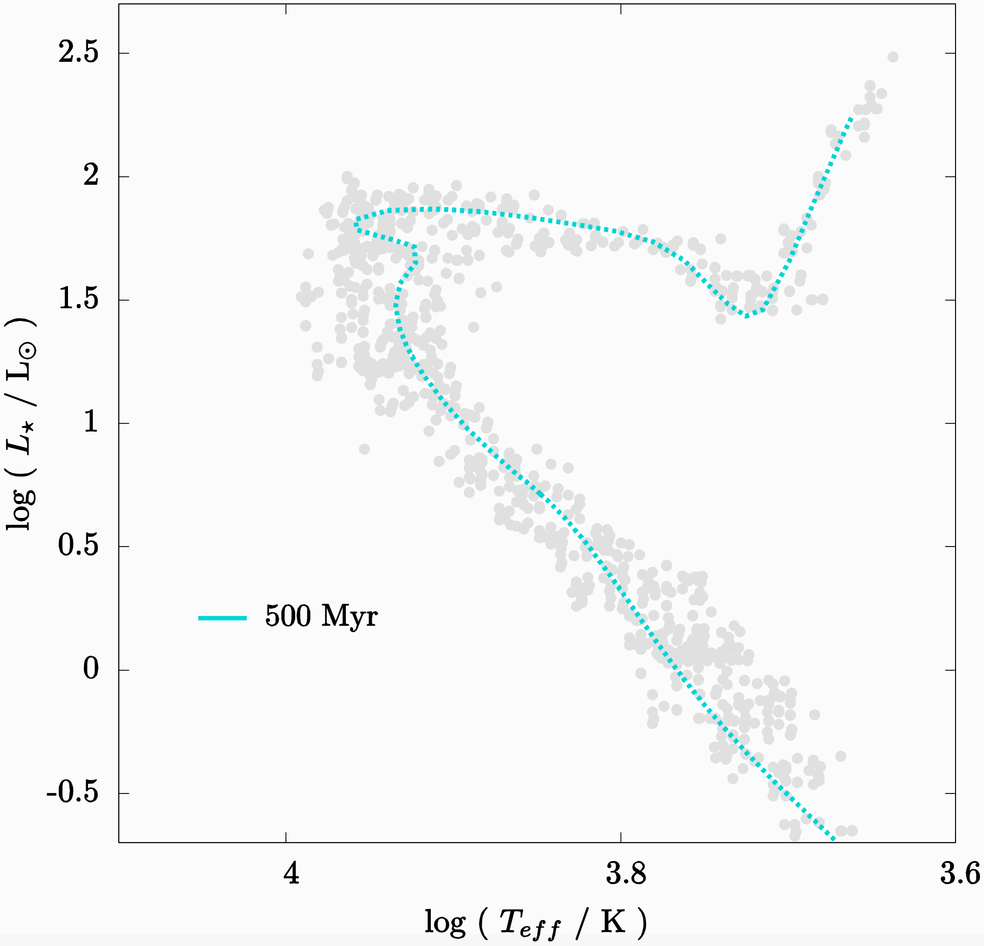
Gravity . Matter . Particle Physics

Prediction: dark matter effect on Population II stars

Stars form in the dense dark matter halos (primordial Universe and core of galaxies) have their lives extended (slower evolution in the HD diagram), due to the energy produced by dark matter.

Observational prediction: The main sequence of these stars in the HR diagram will be different from the one known for population I stars.

- DM particles with a $m_x \sim 100$ GeV and σ_{SD} (with protons) $\sim 10^{-38}$ cm^2
- For a cluster of stars (0.7-3.5 $M_\odot$) in DM halo ($\rho_x \sim 10^{10}$ GeV cm^{-3}, continuous lines) and classical scenario (dashed lines).



Stellar Cluster

Casanellas & Lopes (ApJ Letters 2011)

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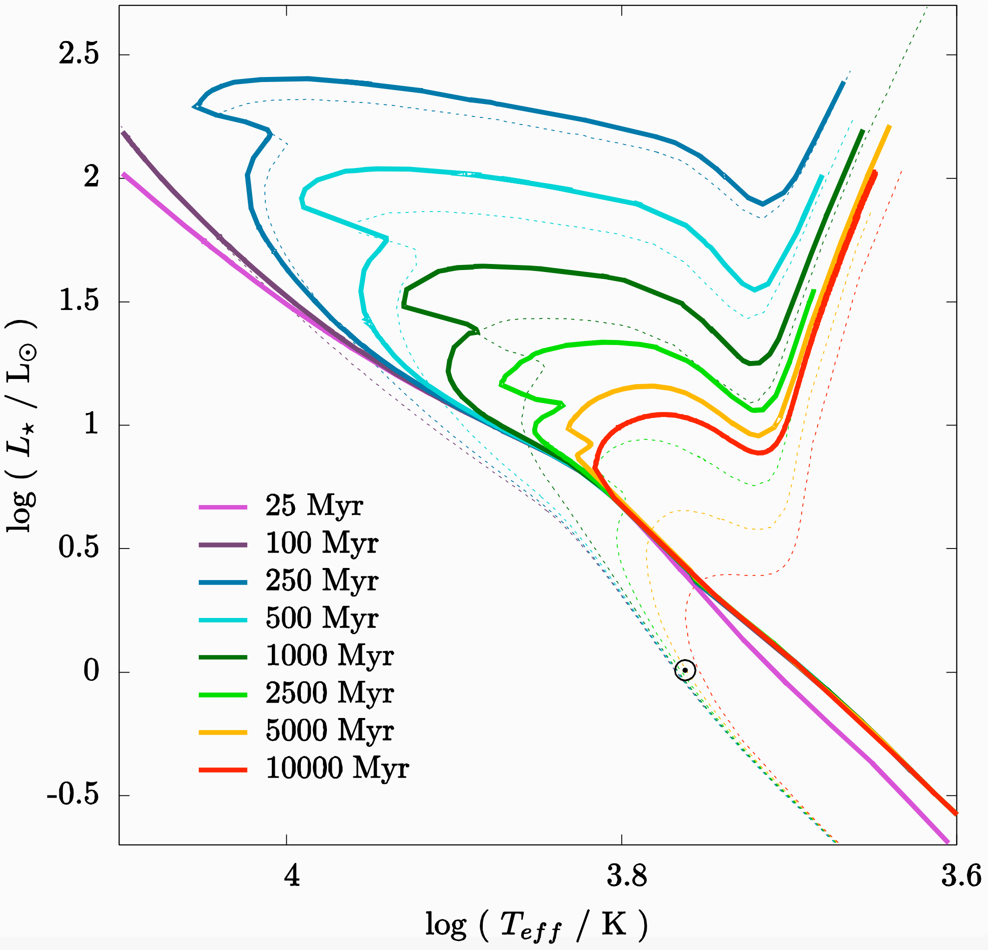
- DM particles with a m_x ~ 100 GeV and σ_{SD} (with protons) ~ 10^{-38} cm^2
- For a cluster of stars (0.7-3.5 $M_\odot$) in DM halo (ρ_x ~ 10^{10} GeV cm^{-3}, continuous lines) and classical scenario (dashed lines).



Stellar Cluster

Casanellas & Lopes (ApJ Letters 2011)

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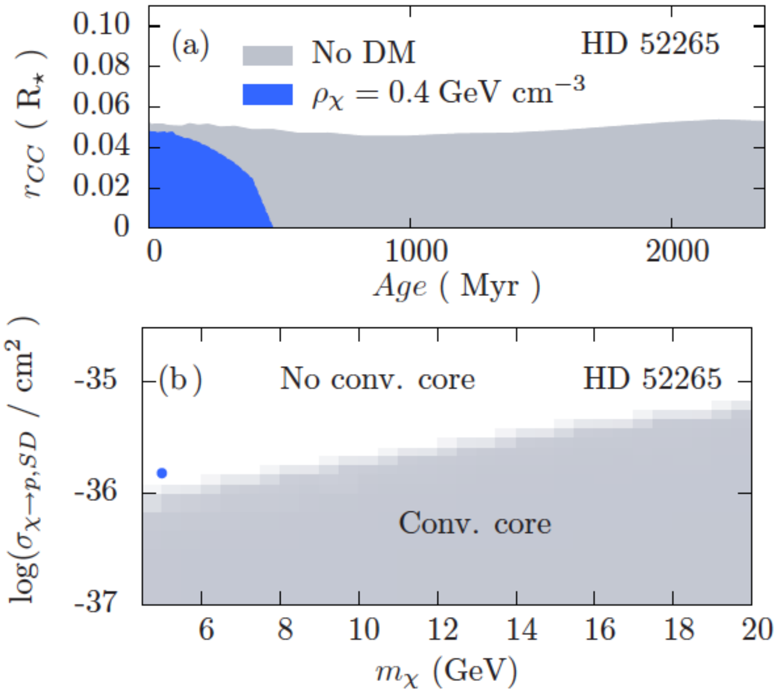
Prediction: dark matter effect on Population I stars

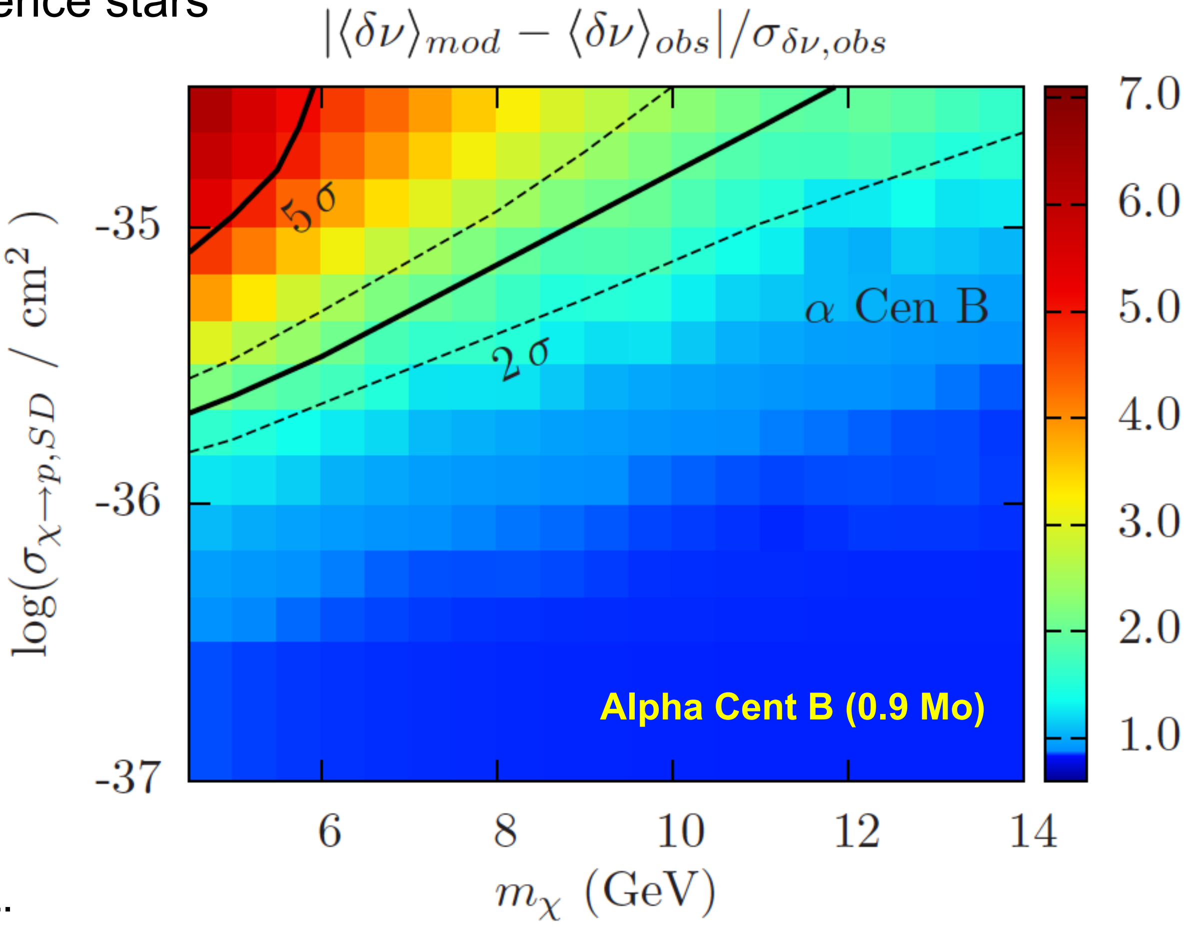
Dark matter (asymmetric) changes the transport of heat energy inside these stars (decreasing the central temperature).

Observational prediction: Suppression of the convective core in 1.1-1.3Mo Main sequence stars



Asymmetric dark matter (with $m_x \sim 5$ GeV, $\sigma_{SD} > 3\ 10^{-36}$ cm^2) are excluded at 95% CL.

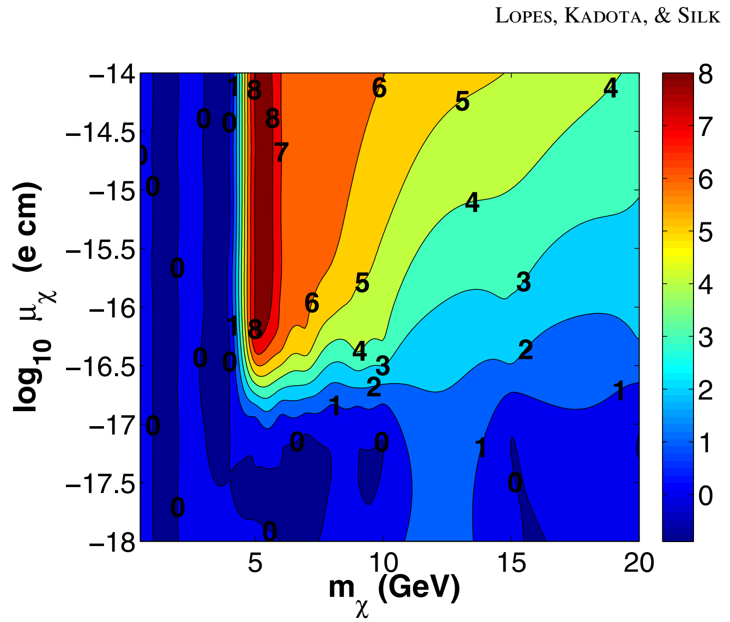
Asteroseismology

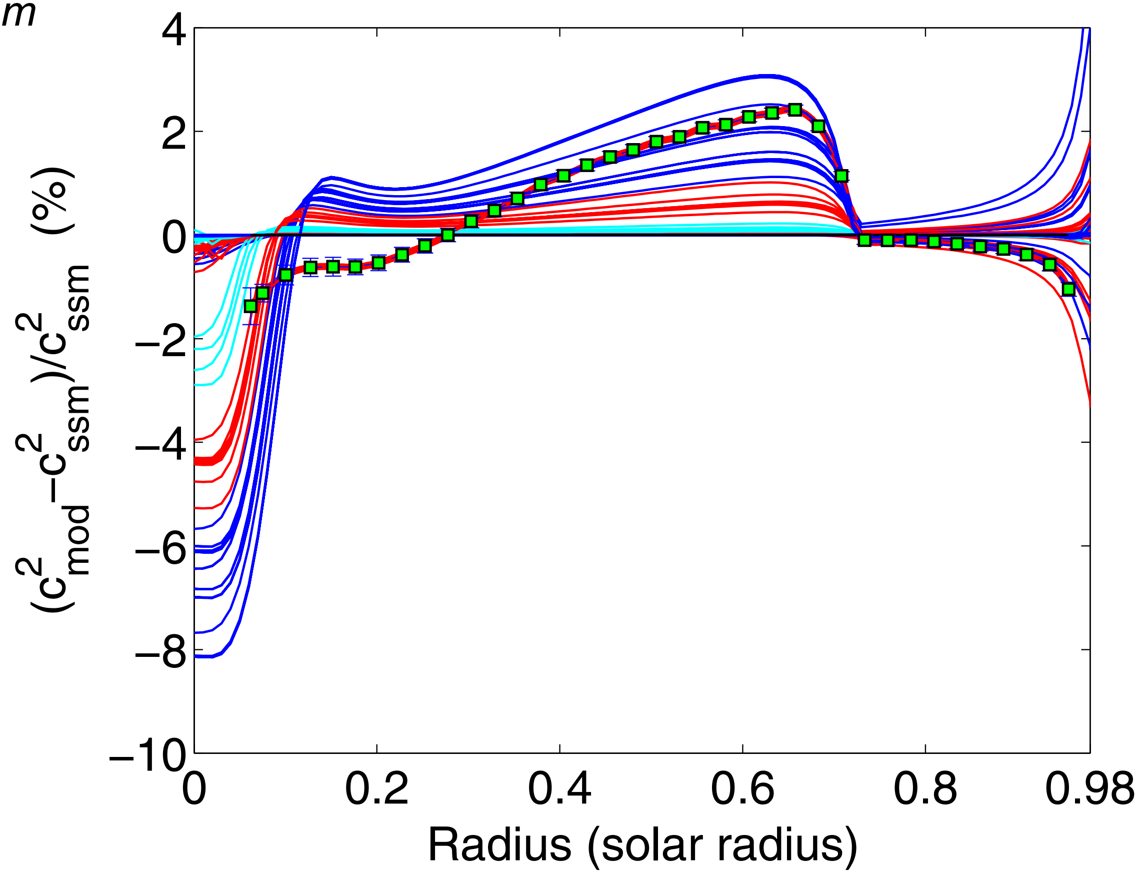


Casanellas & Lopes (ApJ Letters, 2013)

Prediction: dipole dark matter effect on the Sun

Constraint on Light Dipole Dark Matter from Helioseismology", Lopes, Kadota & Silk , ApJ Letters 2014)



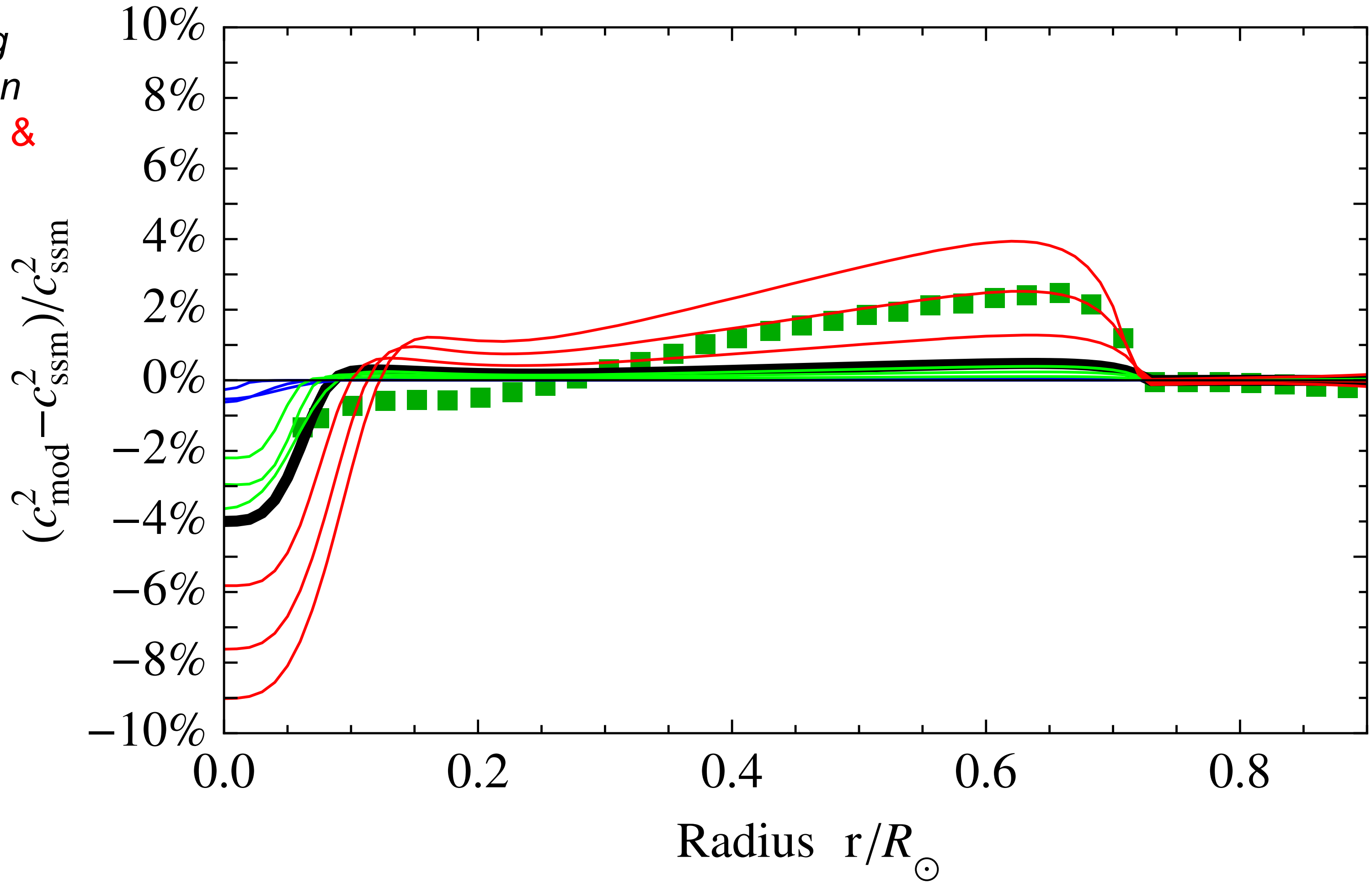


Helioseismology: The dipole interaction can lead to a sizable DM scattering cross section even for light DM, and asymmetric DM can lead to a large DM number density in the Sun. We find that solar model precision tests, using as diagnostic the sound speed profile obtained from helioseismology data, exclude dipolar DM particles with a mass larger than 4.3 GeV and magnetic dipole moment larger than 1.6×10^{-17} e cm.

Prediction: asymmetric dark matter effect on the Sun

The Astrophysical Journal, 795:162 (11pp), 2014 November 10

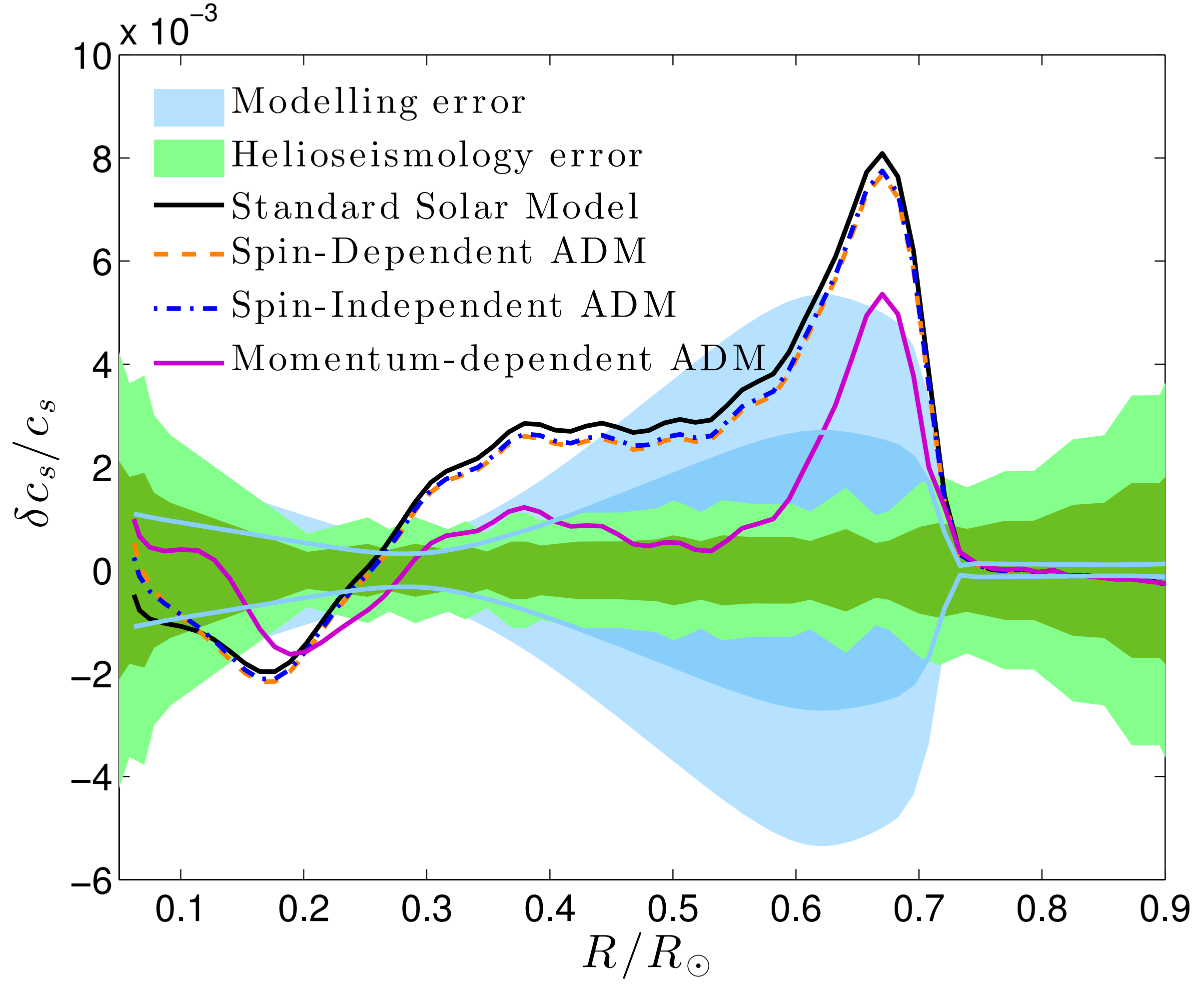
Helioseismology with Long Range Dark Matter Baryon Interaction ", Lopes, Panci & Silk, ApJ 2014)



Helioseismology: DM particles with a mass of 10 GeV and a long–range interaction with ordinary matter mediated by a very light mediator (below roughly a few MeV), can have an impact on the Sun's sound speed profile without violating the constraints coming from direct DM searches.

Prediction: asymmetric dark matter effect on the Sun

(A. Vincent et. al., PRL 2015)



Asymmetric dark matter coupling to nucleons. Agreement with **sound speed profiles**, neutrino fluxes, small frequency separations, surface helium abundances, and convective zone depths for a number of models. The best solat model correspond to a dark matter particle with a mass 3 GeV and reference dark matter-nucleon cross-section (10^{-37} cm^2 at q_0 = 40 MeV).

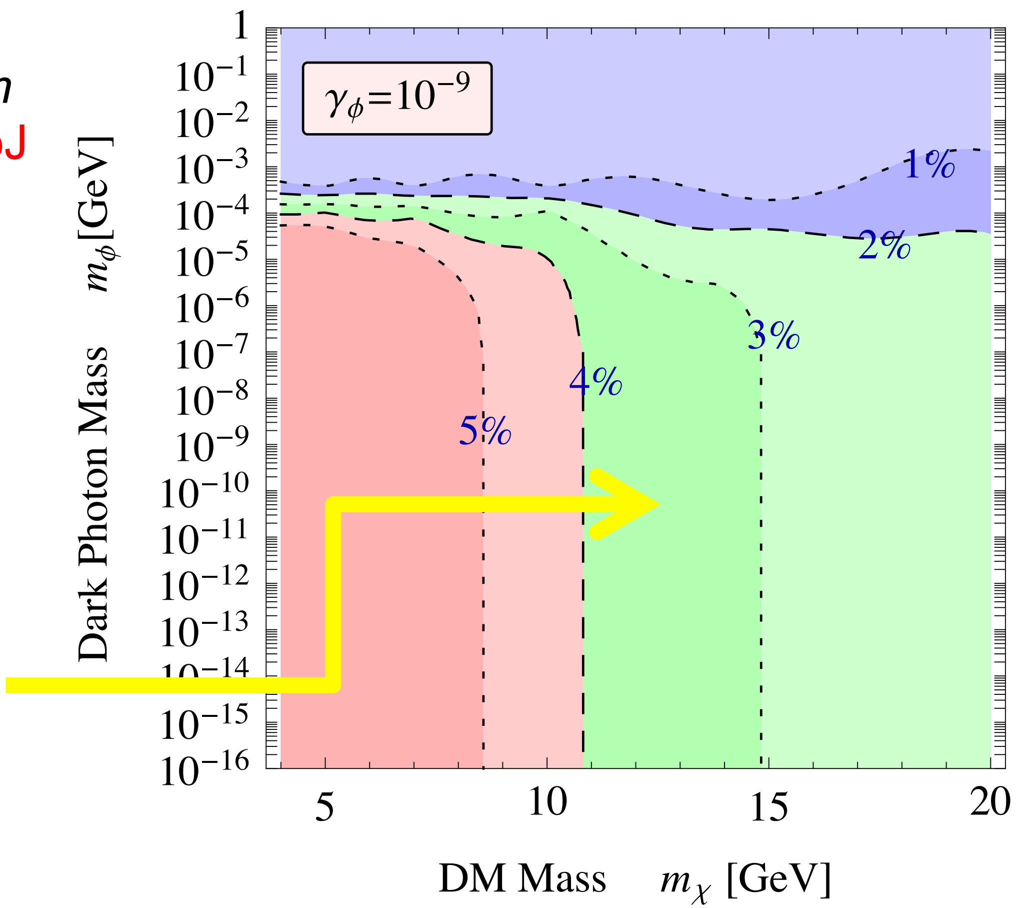
Prediction: asymmetric dark matter effect on the Sun

"*Constraint on Light Dipole Dark Matter from Helioseismology*", Lopes, Kadota & Silk , ApJ Letters 2014)

Helioseismology with Long Range Dark Matter Baryon Interaction ", Lopes, Panci & Silk, ApJ 2014)

$$(c^2_{dm}-c^2_{ssm})/c^2_{ssm} \sim$$

$$(c^2_{obs}-c^2_{ssm})c^2_{ssm} \approx 4\% - 3\ \%$$



Helioseismology: DM particles with a mass of 10 GeV and a long–range interaction with ordinary matter mediated by a very light mediator (below roughly a few MeV), can have an impact on the Sun's sound speed profile without violating the constraints coming from direct DM searches.

Prediction: Solar models for which the DM particles have a mass of 10 GeV and the mediator a mass smaller than 1 MeV, improve the agreement with helioseismic data.

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Thank you

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