

An Overview of Dark Matter Candidates

Leszek Roszkowski

Univ. of Sheffield, England and
Soltan Institute for Nuclear Studies, Warsaw, Poland

Dark Matter Programme at GGI

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- venue: Galileo Galilei Institute, Florence
- dates: 26 April - 19 June 2010
- organizers: H. Baer, L. Covi, L. Roszkowski and P. Ullio

The Galileo Galilei Institute for Theoretical Physics
Arcetri, Florence

**Dark Matter:
Its Origin, Nature and Prospects for Detection**
April 26, 2010 - June 19, 2010

Galileo Galilei

Precise cosmology data identify dark matter as the main building block for all structures in the Universe, however they do not discriminate among the many viable dark matter candidates. Solving this puzzle is certainly one of the greatest challenges in science today.
This program is dedicated to all aspects of dark matter physics: its existence and general properties, astrophysical and cosmological signatures for the various candidates, as well as collider and other experimental searches for the underlying particle physics models. Progress and status for dark matter detection via direct and indirect searches will be critically assessed, also in light of related searches for new physics at the LHC.

The main topics of the workshop include:

- Theoretical models for dark matter
- Cosmology and structure formation
- WIMP dark matter and direct detection
- Indirect dark matter searches
- Dark matter at the LHC

Organizing Committee:
Howard Baer (University of Oklahoma, Norman, OK, USA)
Lars Covi (DESY, Hamburg, Germany)
Leszek Roszkowski (University of Sheffield, Sheffield, UK)
Piero Ullio (SISSA, Trieste, Italy)

GGI - <http://www.ggi.it>

Cosmology After WMAP...

Post WMAP-5yr (April 08)

...+ACBAR+CBI+SN+LSS+...

$$\Omega_i = \rho_i / \rho_{crit}$$

$$\text{Hubble } H_0 = 100 h \text{ km/s/Mpc}$$

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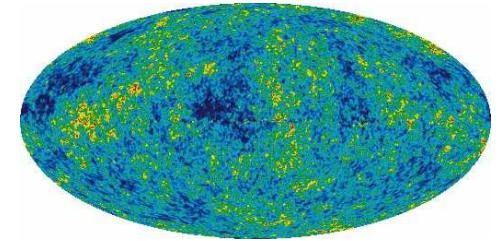
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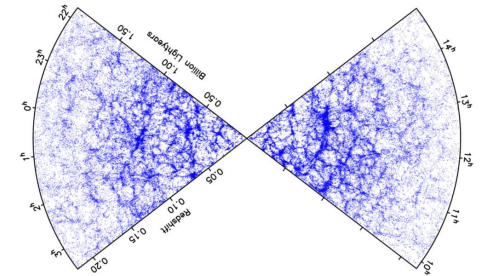
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CMB (WMAP, ACBAR, CBI,...)



LSS (2dF, SDSS, Lyman- α)



assume simplest Λ CDM model

● matter $\Omega_m h^2 = 0.1378 \pm 0.0043$

● baryons $\Omega_b h^2 = 0.02263 \pm 0.00060$

● $\Rightarrow \Omega_{CDM} h^2 = 0.1152 \pm 0.0042$

● $h = 0.696 \pm 0.017$

● $\Omega_\Lambda = 0.715 \pm 0.20 \dots$

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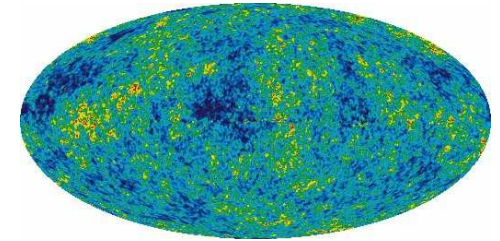
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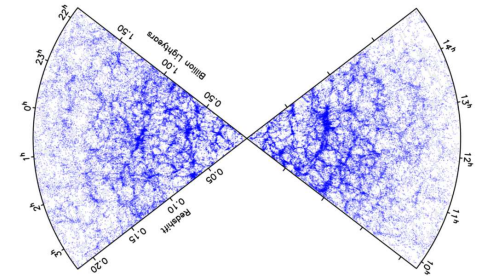
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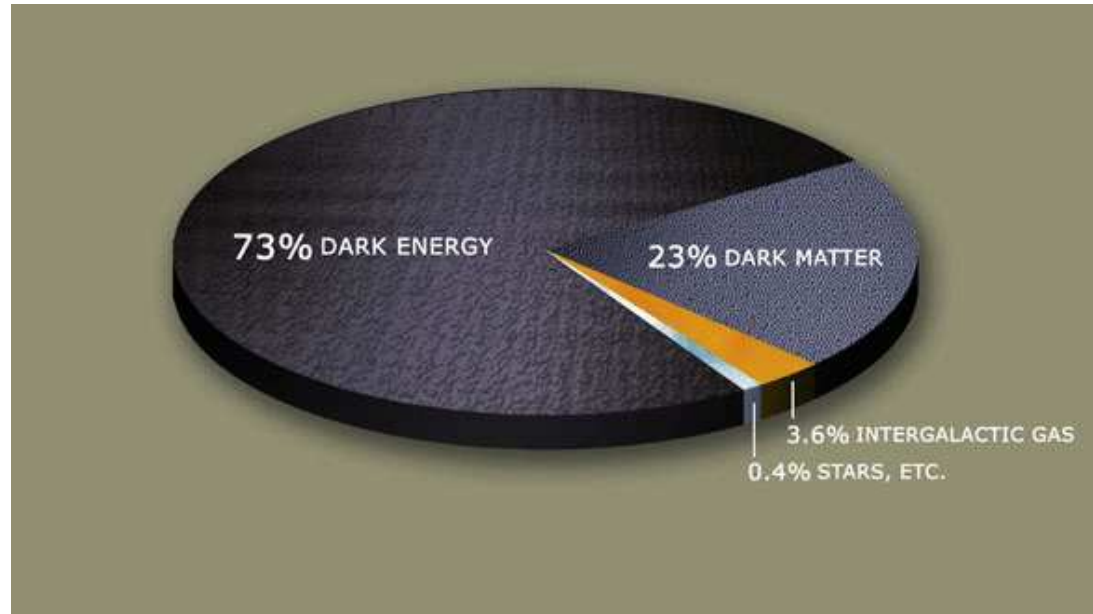
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● concordance model works well

● main components: dark energy and dark matter

factor of 4-10 improvement expected from Planck

Cosmic Pie



Outline

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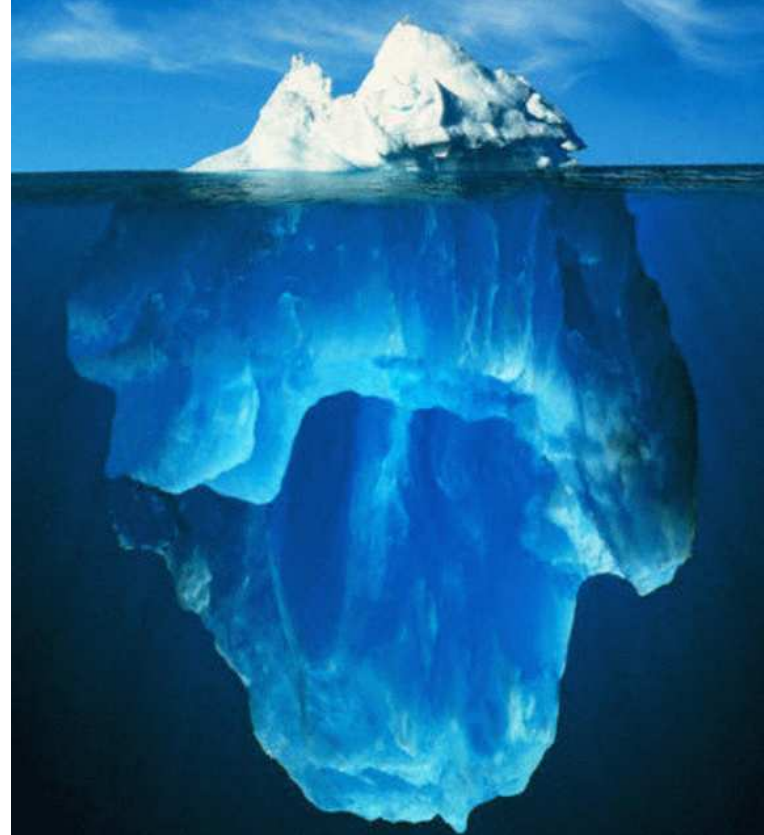
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Some anomalies and hints – DM origin of 'signal' not convincing.

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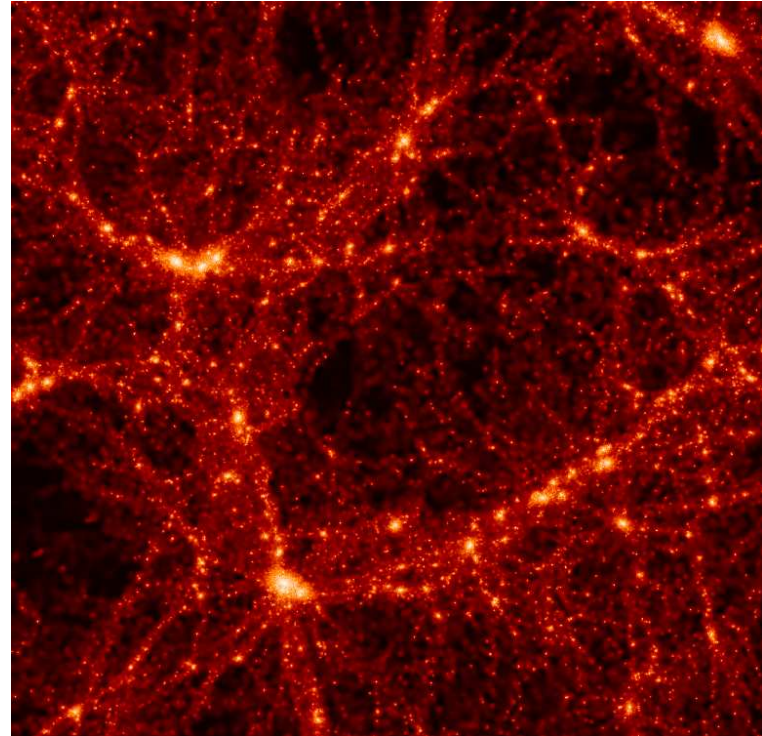


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numerical simulations of LSS



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plausible choice ⇒ **WIMP**

weakly interacting massive particle

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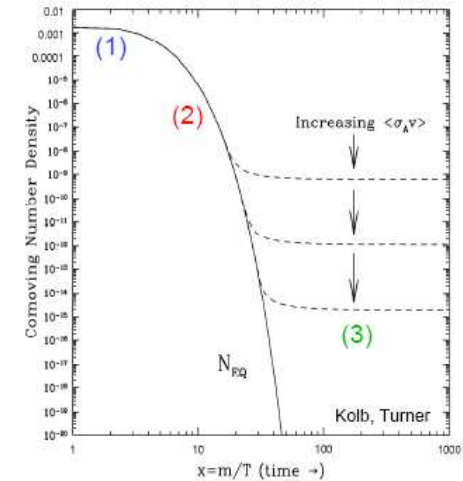
WIMP: some new, unknown particle

...How weak can weak be?

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- WIMPs decouple from thermal equilibrium
- freeze-out when $\Gamma \lesssim H$



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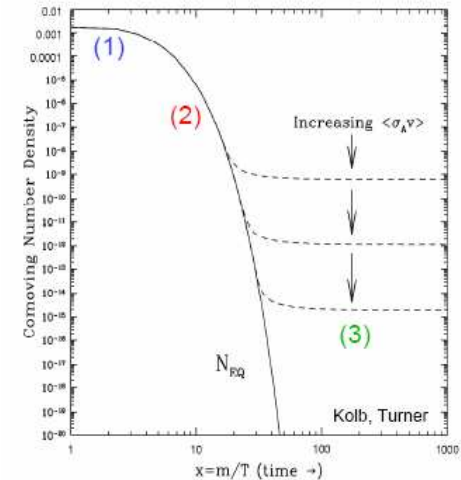
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σ_{ann} – c.s. for WIMP pair-annihilation in the early Universe
 v – their relative velocity, $\langle \dots \rangle$ – thermal average

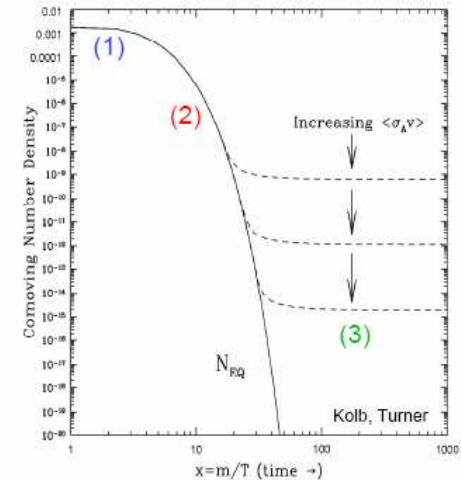
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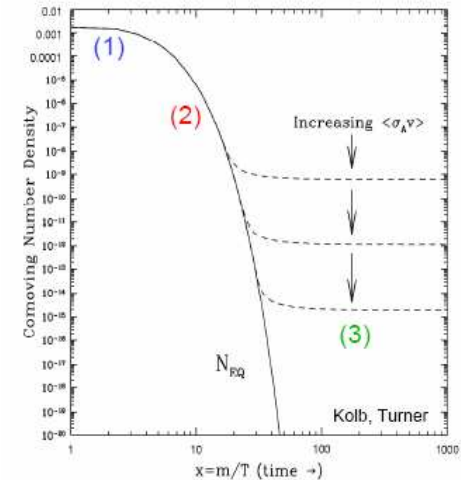
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A hint? Possibly, but...

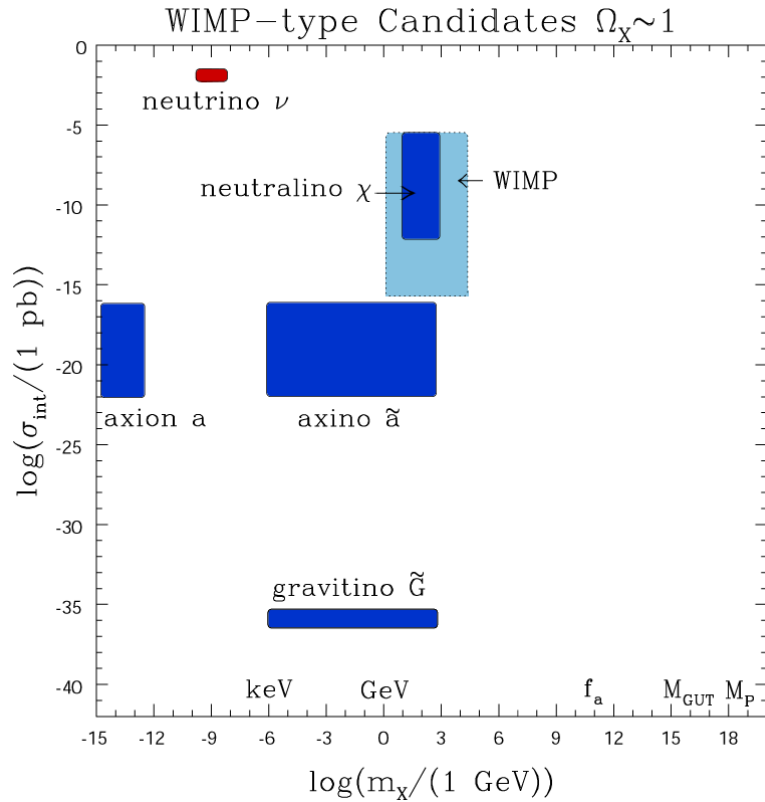
DM: The Big Picture

* – not invented to solve the DM problem

*well-motivated** particle candidates with $\Omega \sim 0.1$

DM: The Big Picture

L.R. (2000), hep-ph/0404052



- neutrino ν – hot DM
- neutralino χ
- “generic” WIMP
- axion a
- axino \tilde{a}
- gravitino \tilde{G}

- vast ranges of interactions and masses
- different production mechanisms in the early Universe (thermal, non-thermal)
- need to go beyond the Standard Model
- WIMP candidates testable at present/near future
- axino, gravitino EWIMPs/superWIMPs not directly testable, but some hints from LHC

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it is much (!) harder to invent a (lasting) model of
'new physics'

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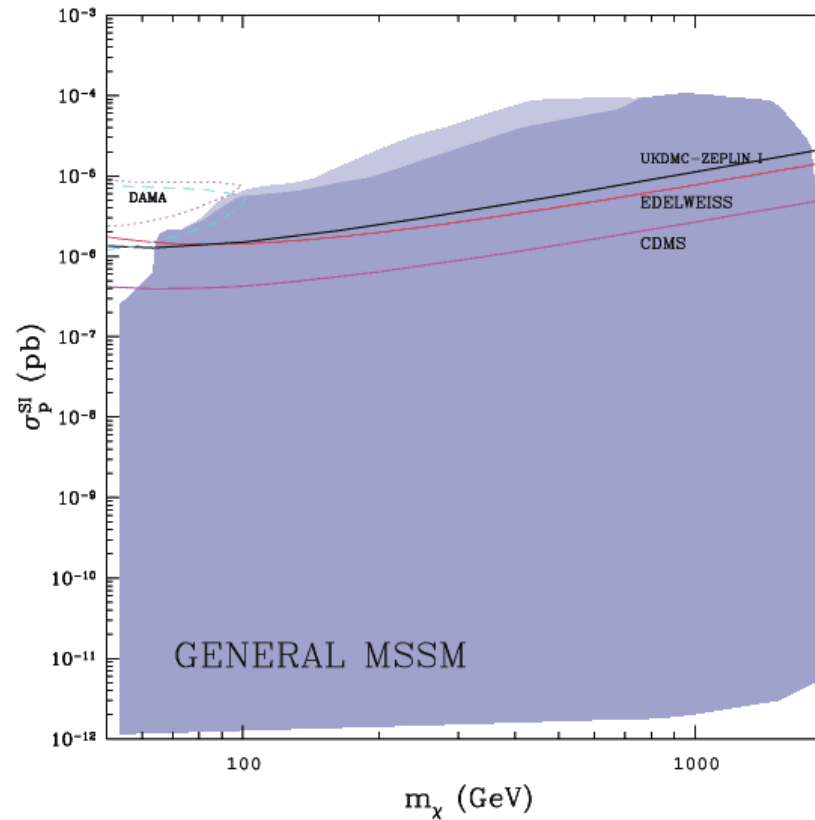
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- other ideas: traces of WIMP annihilation in dwarf galaxies, in rich clusters, etc
 - more speculative

MSSM: Expectations for σ_p^{SI}

general MSSM

$\mu > 0$

Kim, Nihei, LR & Ruiz de Austri (02)



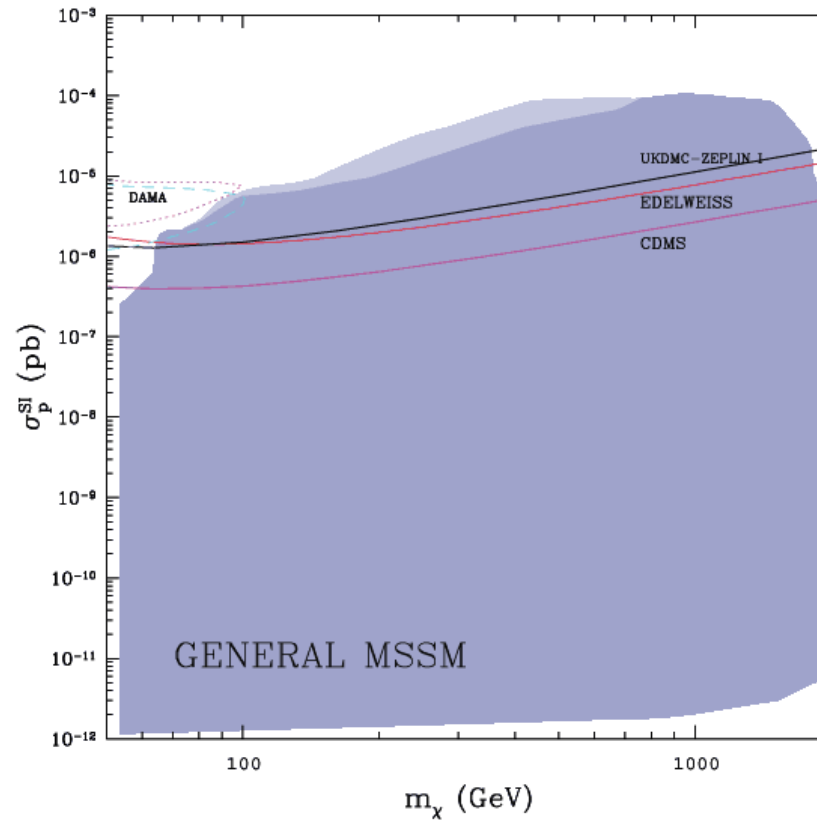
σ_p^{SI} – WIMP–proton SI elastic scatt. c.s.
(elastic c.s. for $\chi p \rightarrow \chi p$ at zero momentum transfer)

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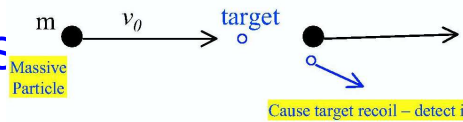
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⇒ **MSSM: vast ranges! Lacks real predictive power!**

SUSY: Prospects for direct detection

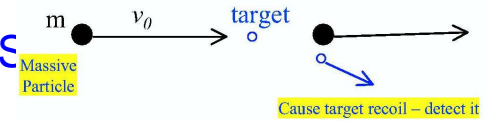
Bayesian analysis, flat priors, MCMC scan of 8 params (4 SUSY+4 S



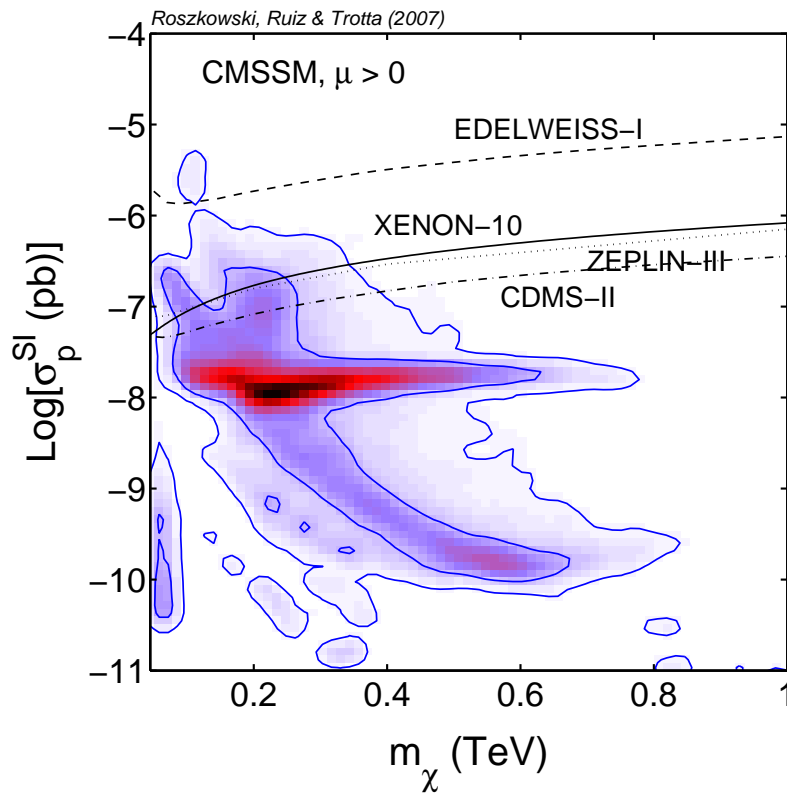
The diagram illustrates a particle collision. On the left, a black dot labeled 'm' represents a 'Massive Particle'. An arrow labeled v_0 points to the right, indicating its velocity. This particle is moving towards a 'target' nucleus, represented by a black dot on the right. A smaller white dot below the target nucleus represents the point of collision. A blue arrow points downwards from the collision point, indicating the recoil of the target nucleus. A yellow box at the bottom right contains the text 'Cause target recoil - detect it'.

SUSY: Prospects for direct detection

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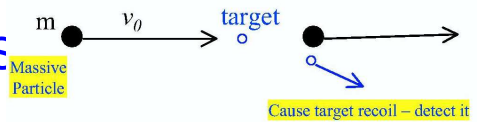
Constrained MSSM (mSUGRA)



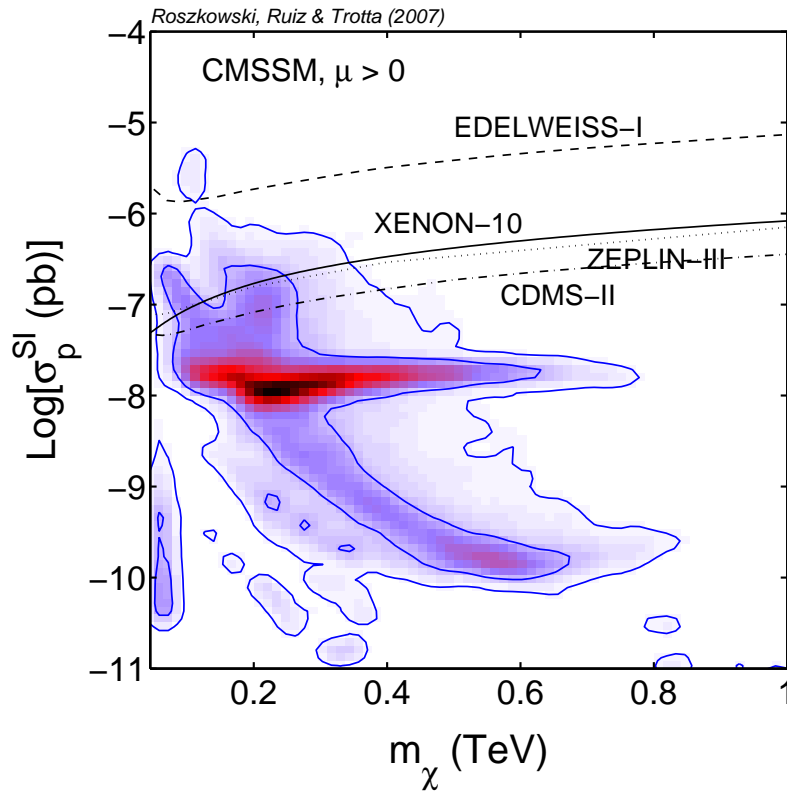
internal (external): 68% (95%) region

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XENON-10, CDMS-II, Zeplin-III:

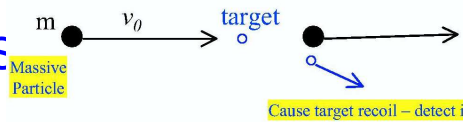
$$\sigma_p^{SI} \lesssim 10^{-7} \text{ pb:}$$

⇒ already explore 68% region

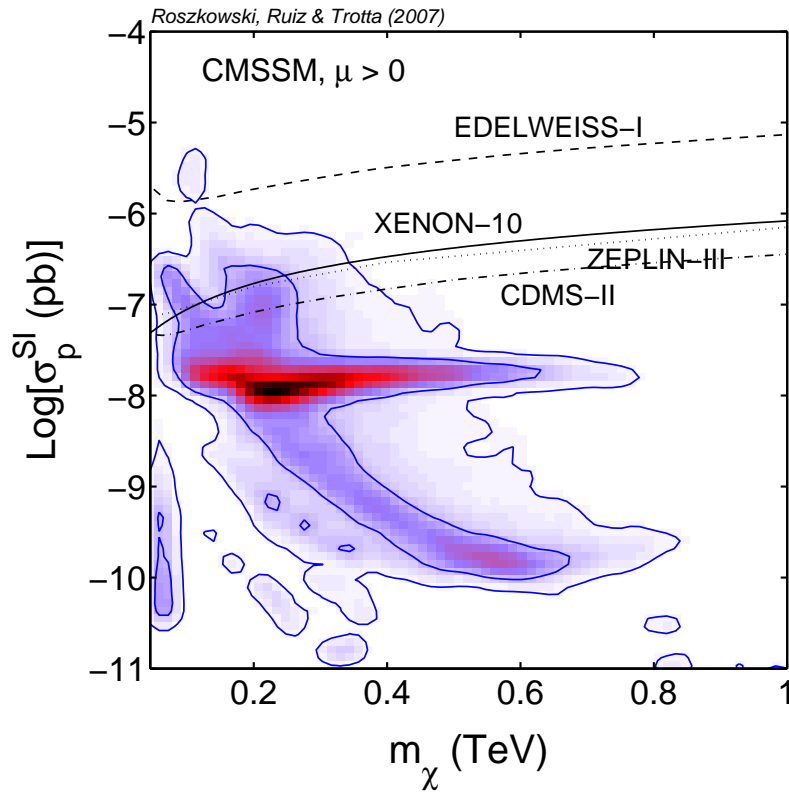
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SUSY: Prospects for direct detection

Bayesian analysis, flat priors, MCMC scan of 8 params (4 SUSY+4 S) 

Constrained MSSM (mSUGRA)



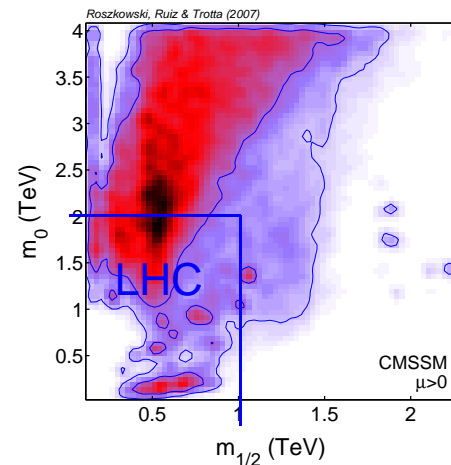
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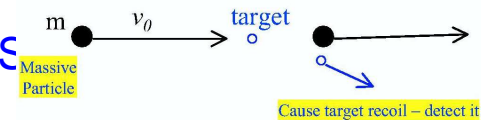
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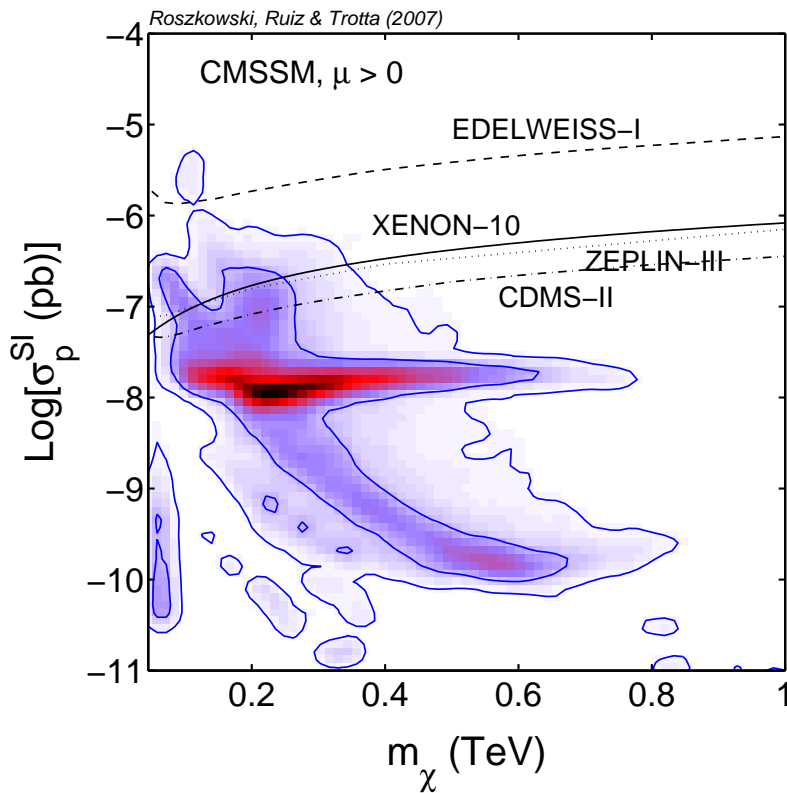


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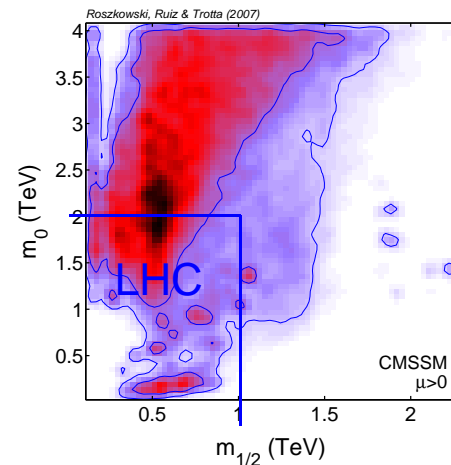


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⇒ **DD: prospects look very good**

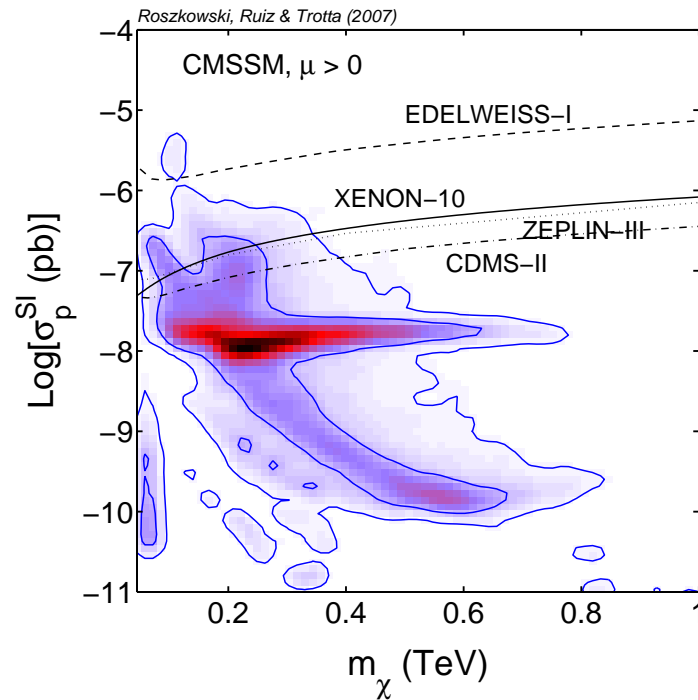
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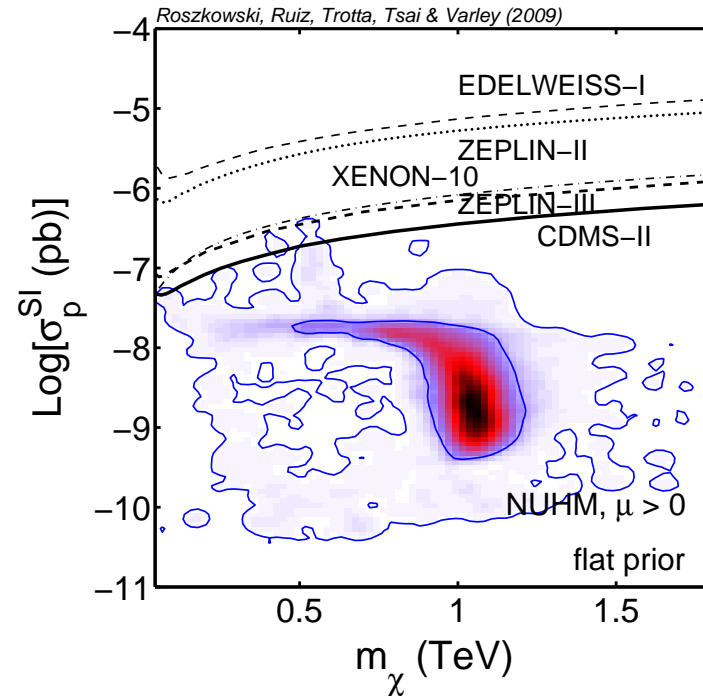
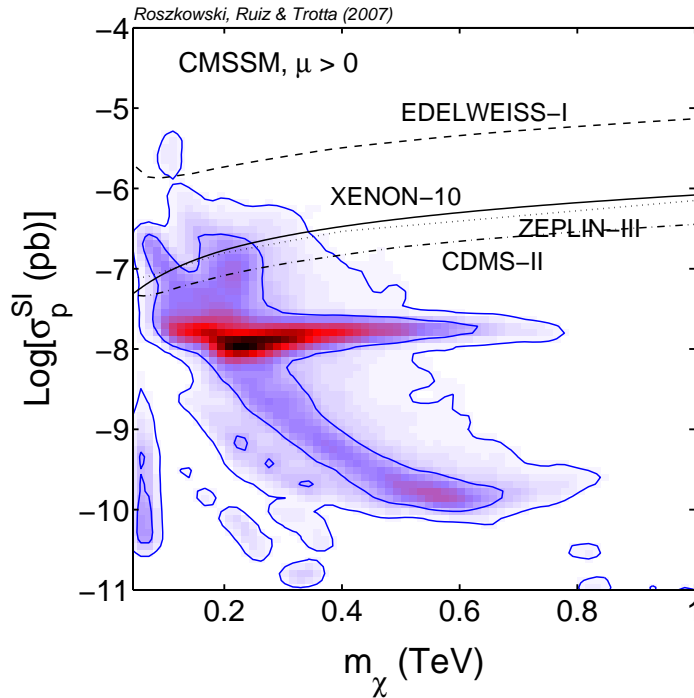
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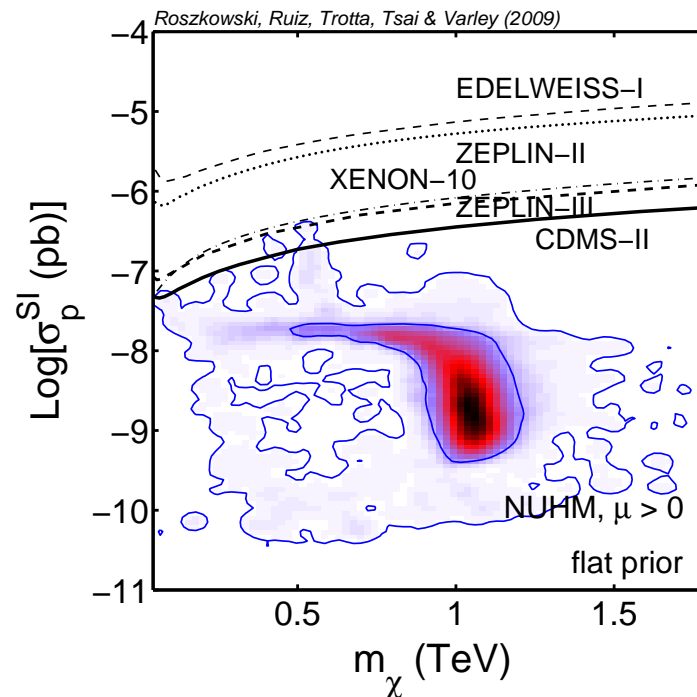
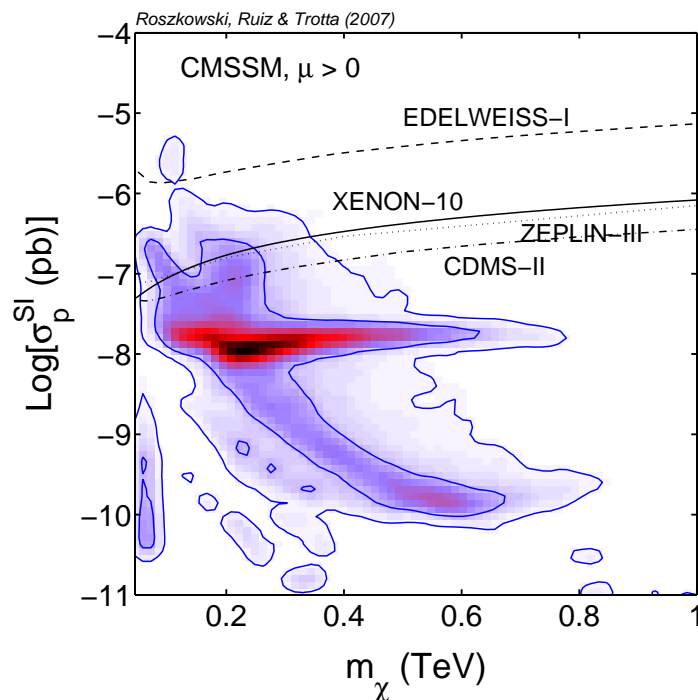
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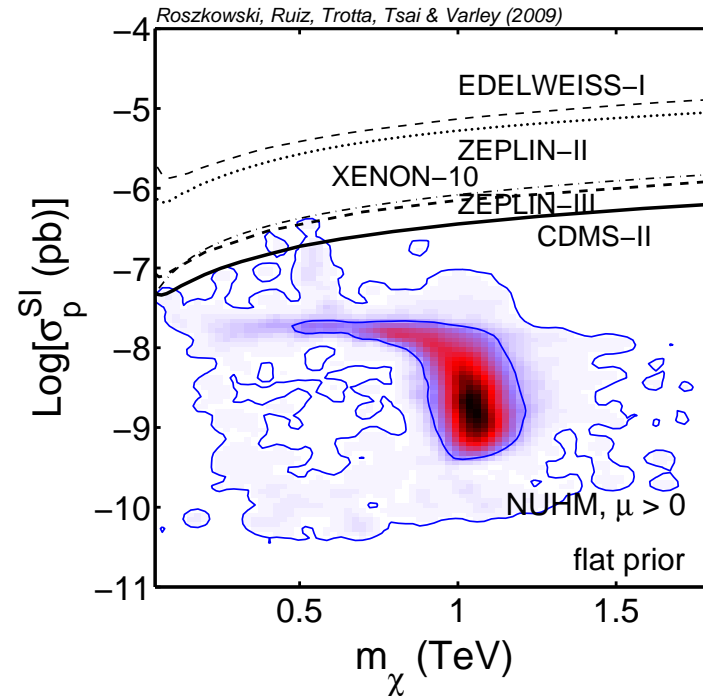
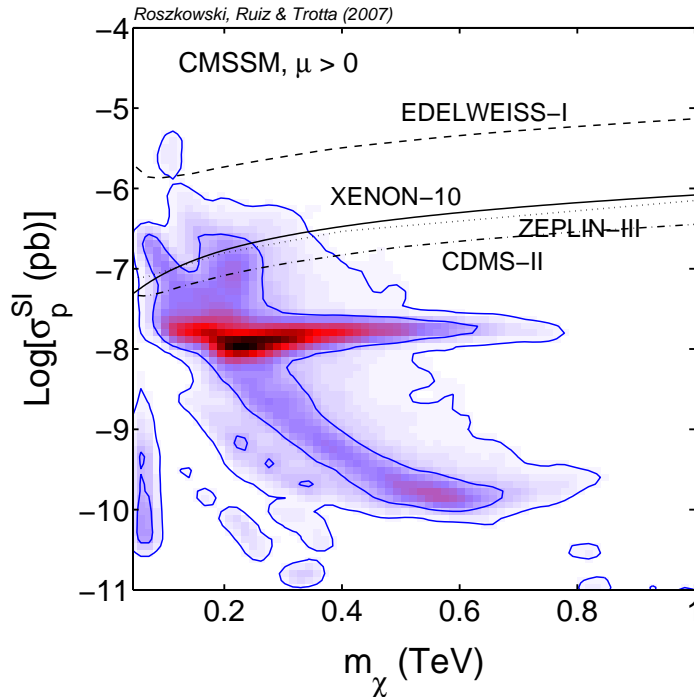
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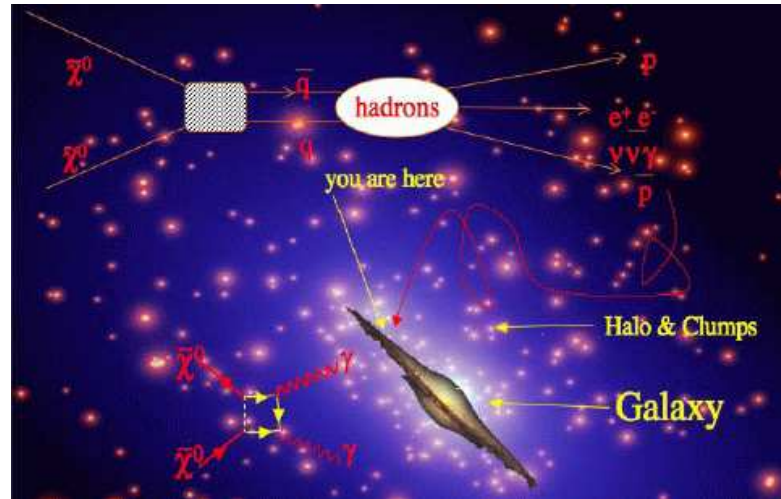
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collider signatures also similar

⇒ LHC, DM: it will be hard to distinguish models

Indirect detection

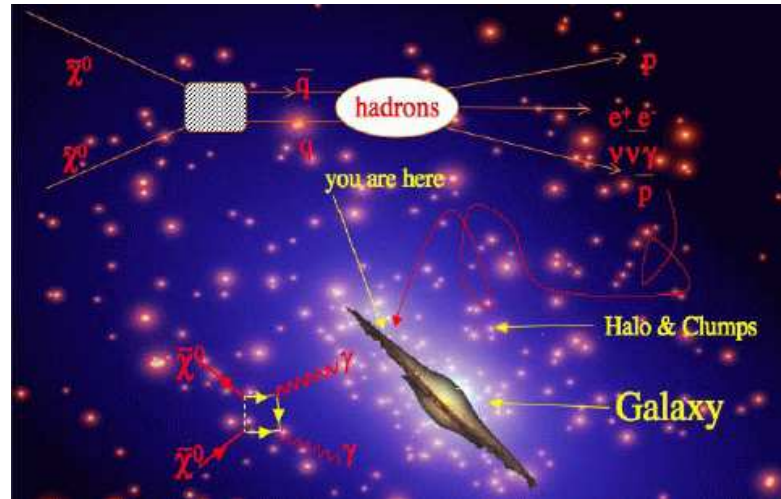
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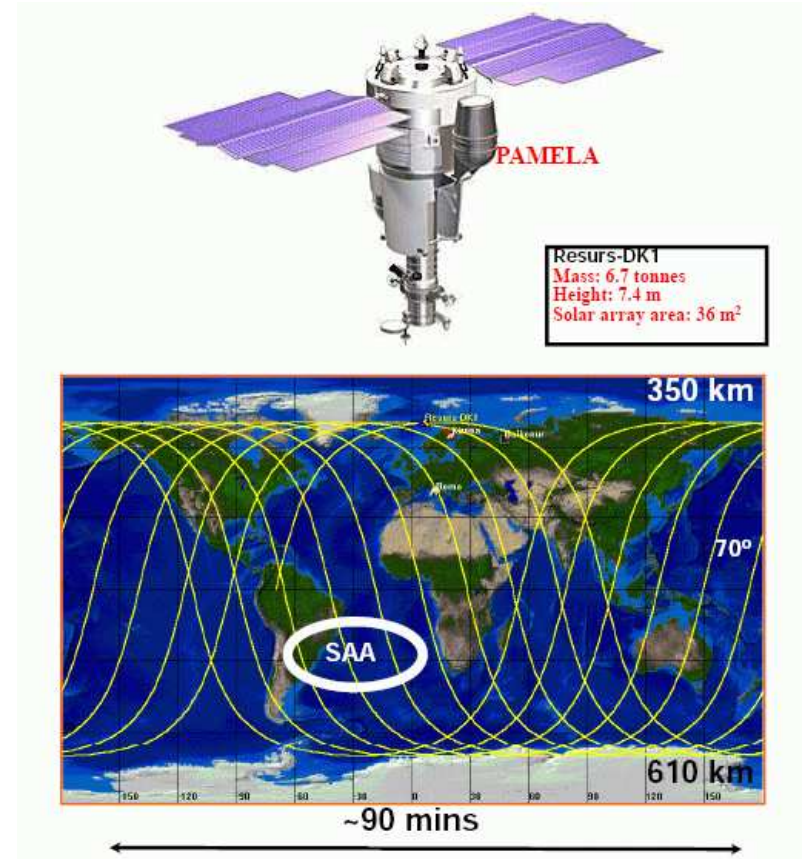
Much activity in connection with:

- PAMELA
- Fermi (GLAST)

e^+ data from PAMELA & DM

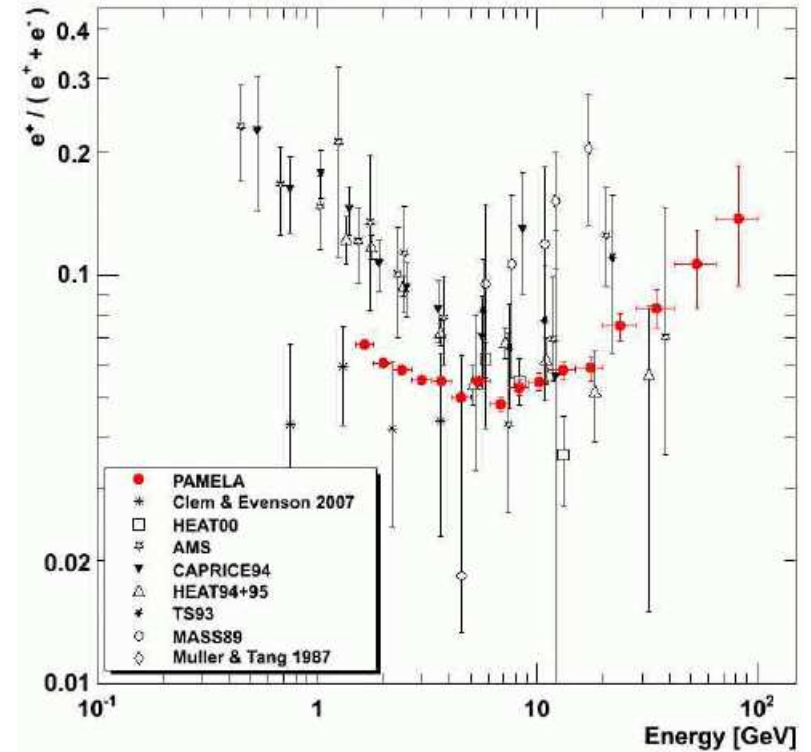
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PAMELA satellite (since 2007)



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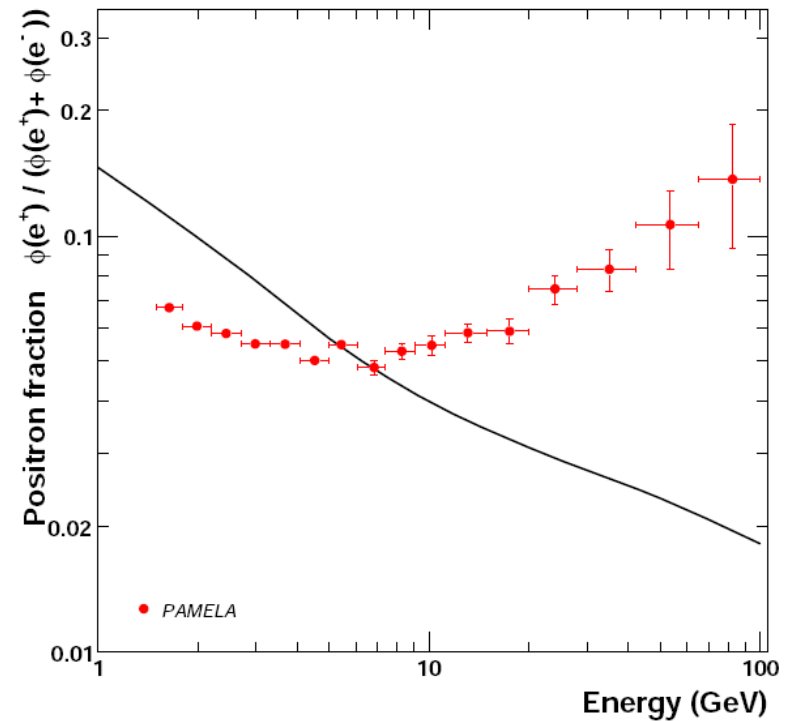
$e^+ / (e^+ + e^-)$ ratio, \bar{p} flux, ...



O. Adriani et al., arXiv:0810.4995

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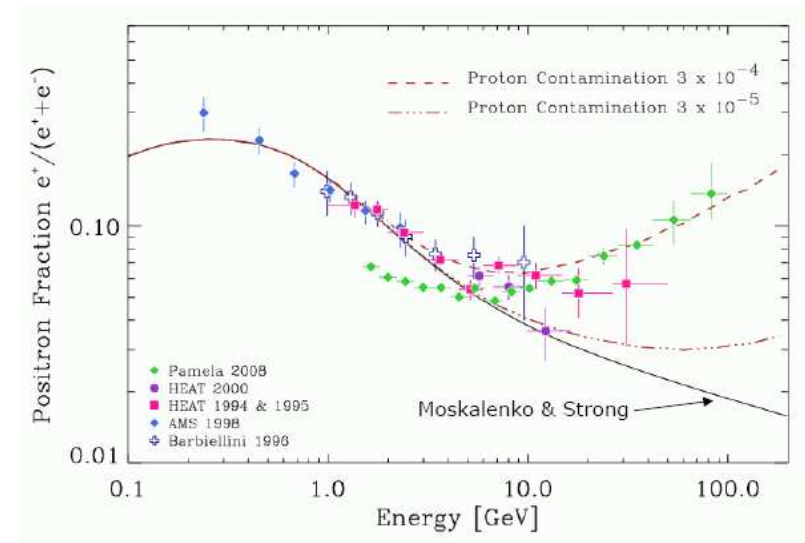
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also indication from ATIC at $\sim 0.7 - 1$ TeV

e^+ : difficult measurement



Schubnell, Feb. 09

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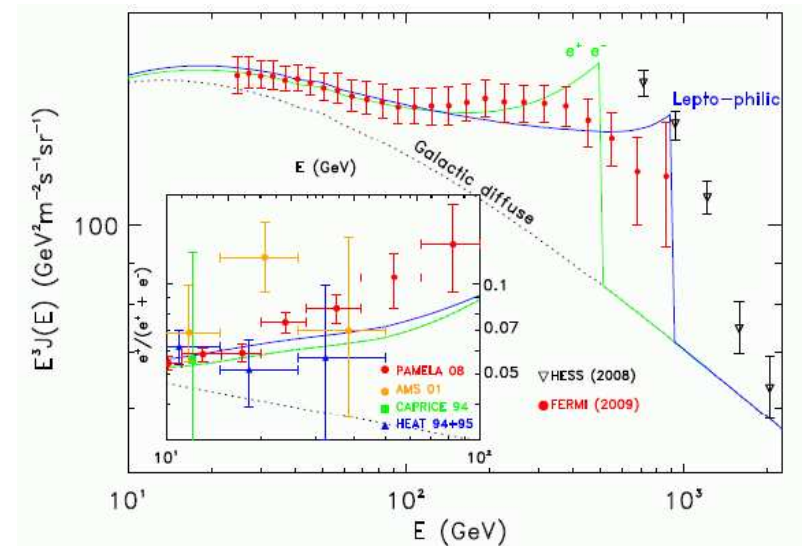
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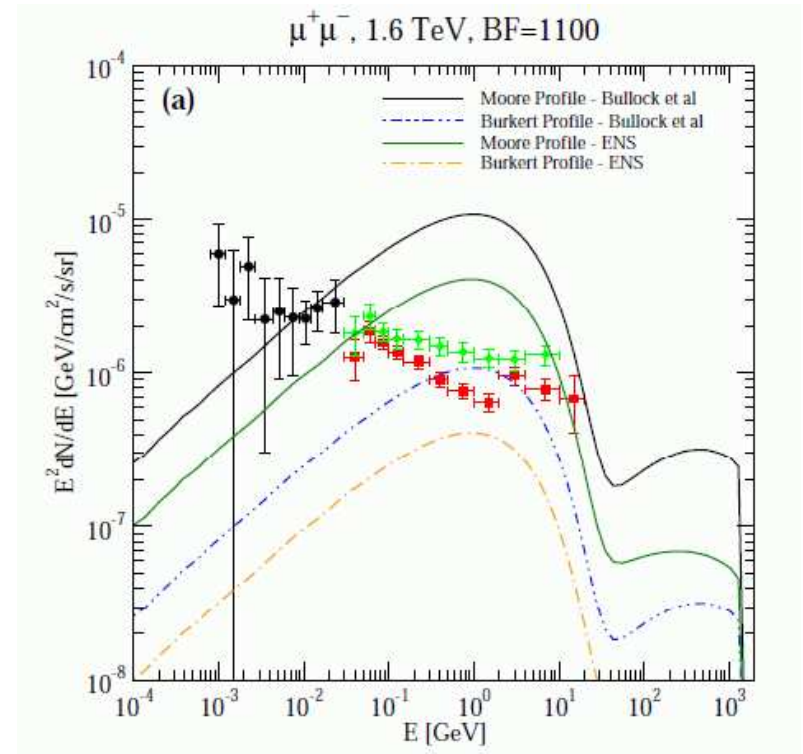
Grasso, et al., May 09

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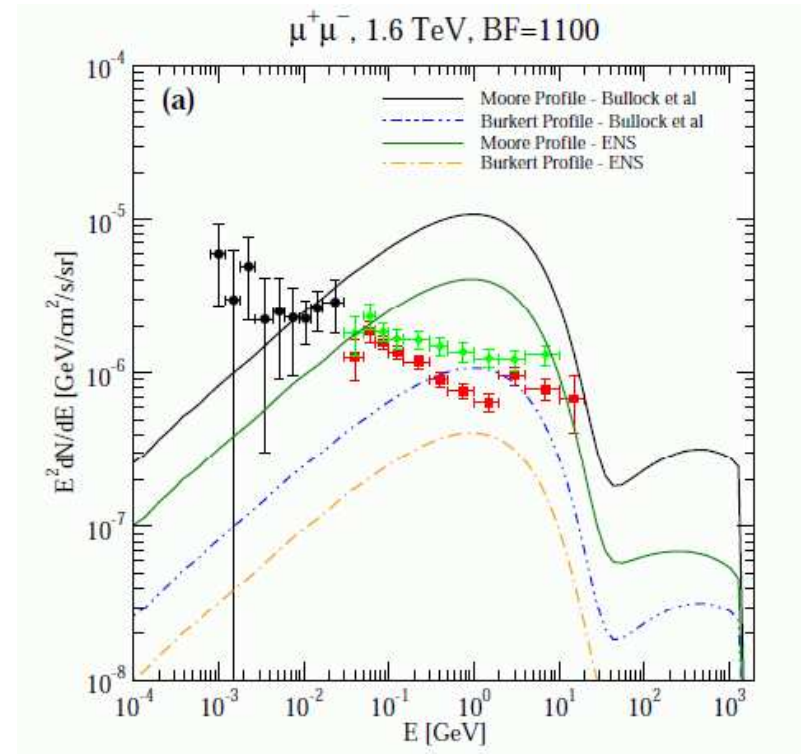
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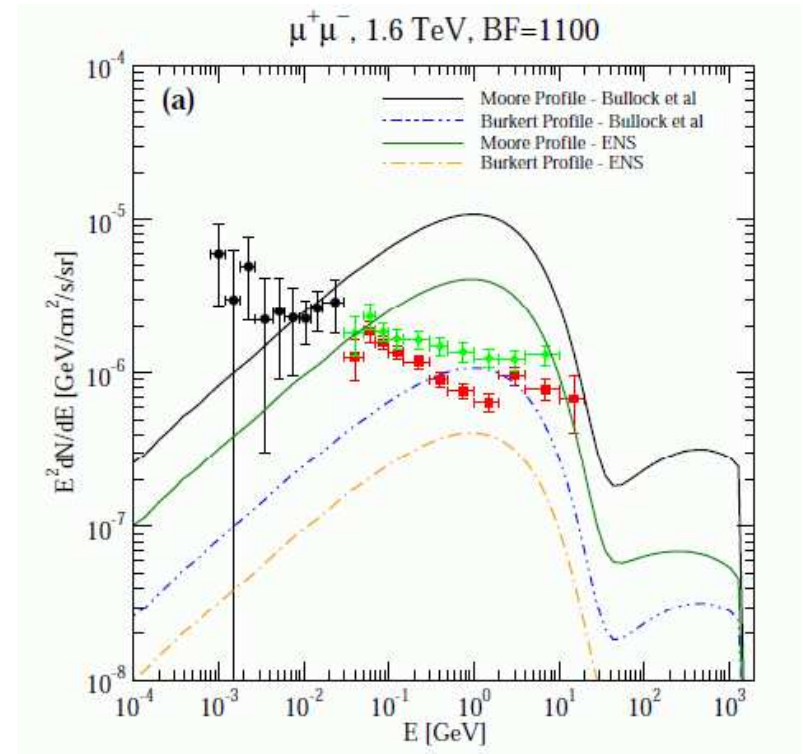
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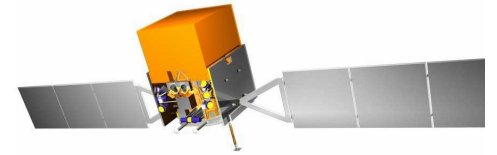


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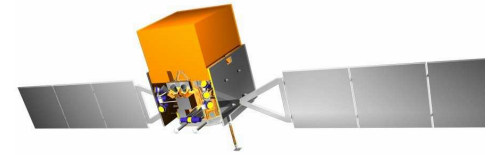
...pulsar explanation likely to be sufficient

Fermi/GLAST



in orbit since 2008

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in orbit since 2008

- full sky map in γ -ray spectrum, ~ 20 MeV to ~ 300 GeV
- superior energy and angular resolution
- improve accuracy/energy range of EGRET by an order of magnitude
- 1st year data to be released in August 09

...stay tuned

SUSY DM at Fermi and/or Pamela?

e.g. CMSSM

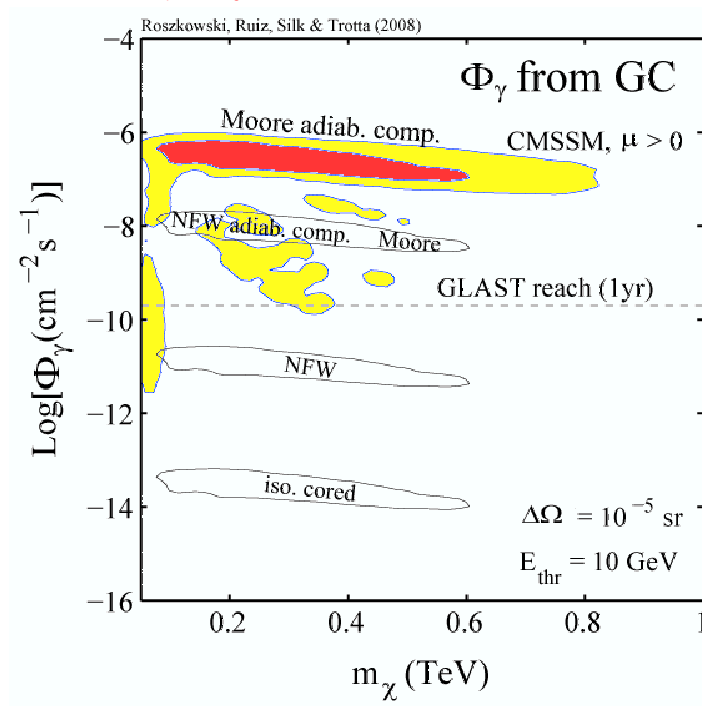
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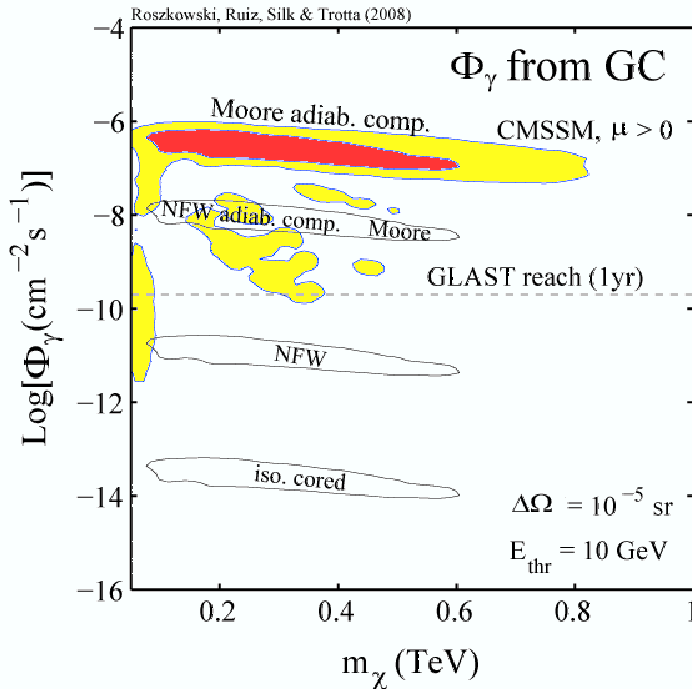
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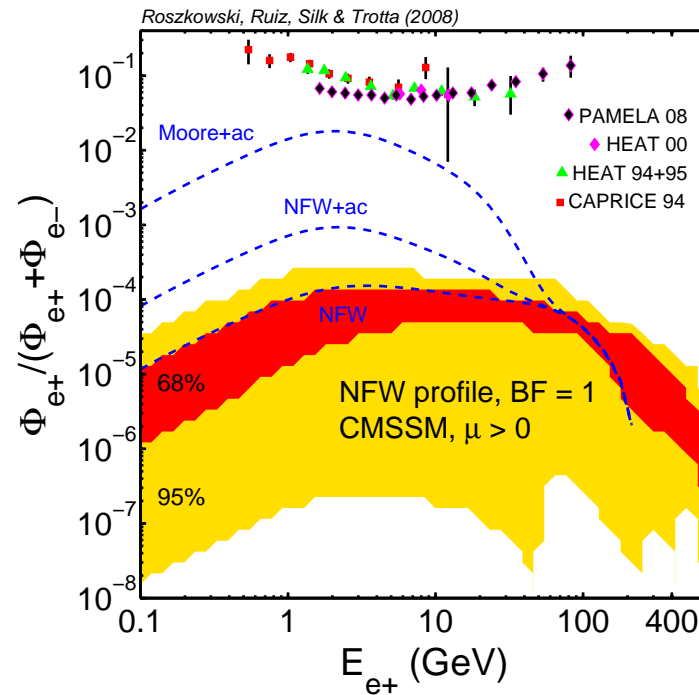
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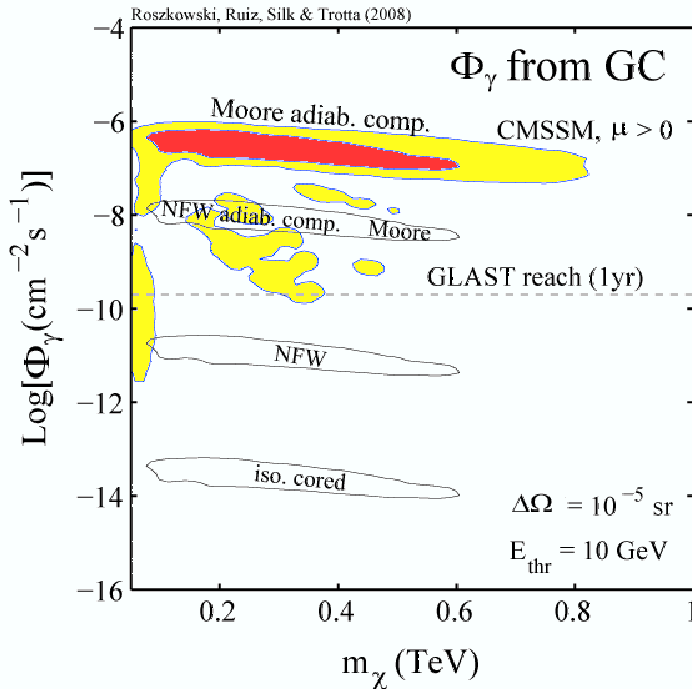
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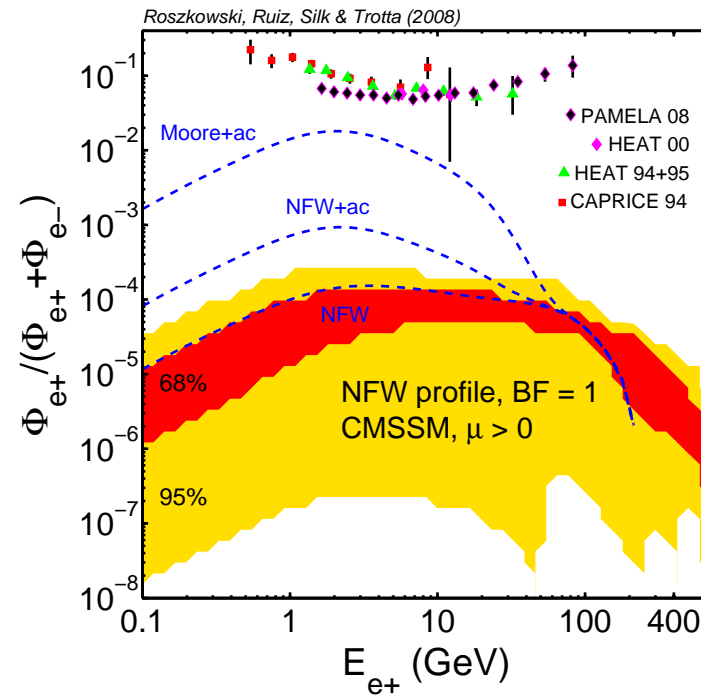
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...similar for NUHM, other unified SUSY models

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One should never believe any experiment until it
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A. Eddington

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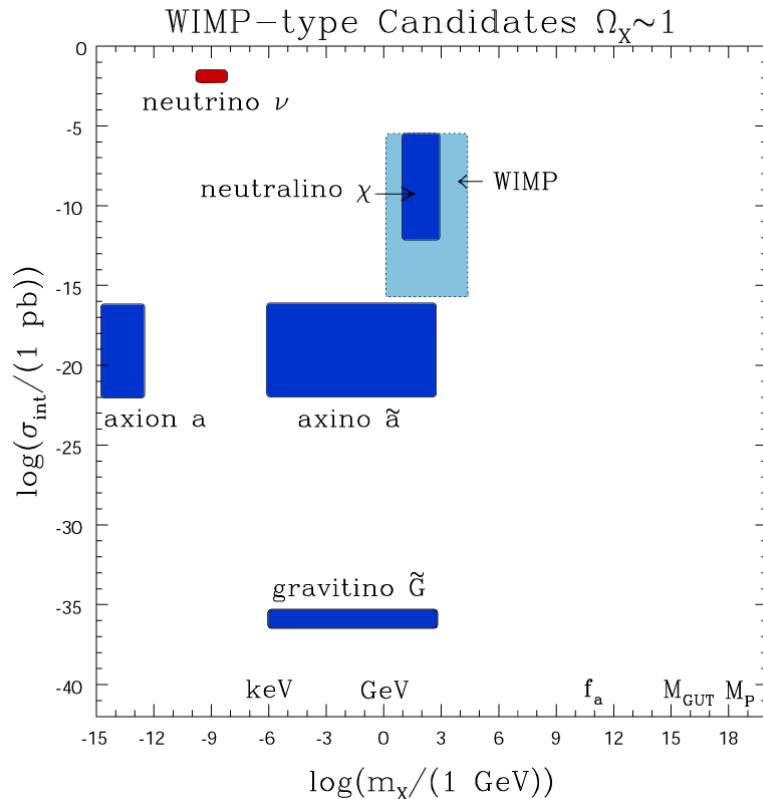
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...What if Nature has made a different choice?

The Big Picture

well-motivated particle candidates such that $\Omega \sim 0.1$



- neutrino ν – hot DM
- neutralino χ
- “generic” WIMP
- axion a
- axino \tilde{a}
- gravitino \tilde{G}

- WIMP (neutralino, weakly int'ing states, ...): discoverable now
- EWIMP/superWIMP (axino, gravitino, super-weakly int'ing states, ...): hopeless in direct detection, but hints possible at LHC

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by-product of PQ solution of strong CP
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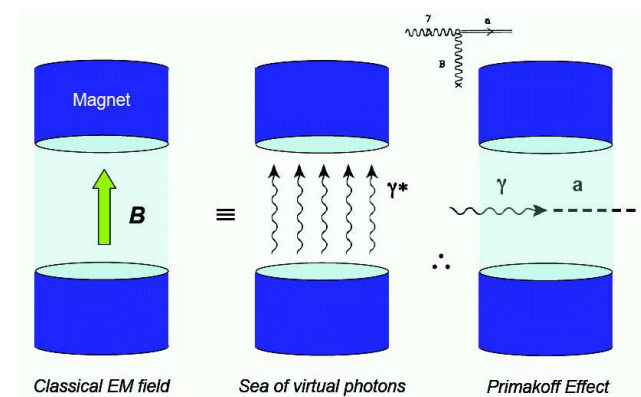
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(detection scheme)



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(ADMX, '08)

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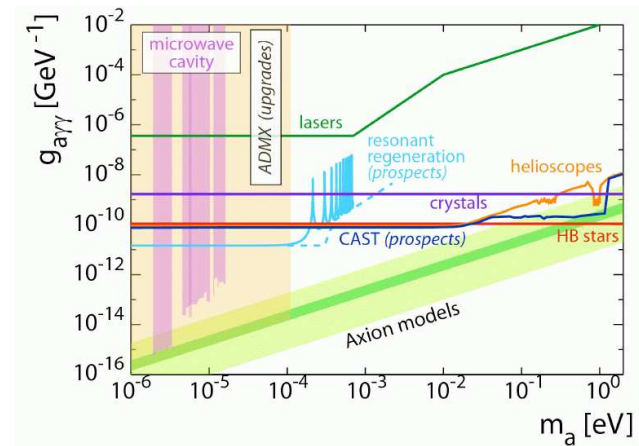
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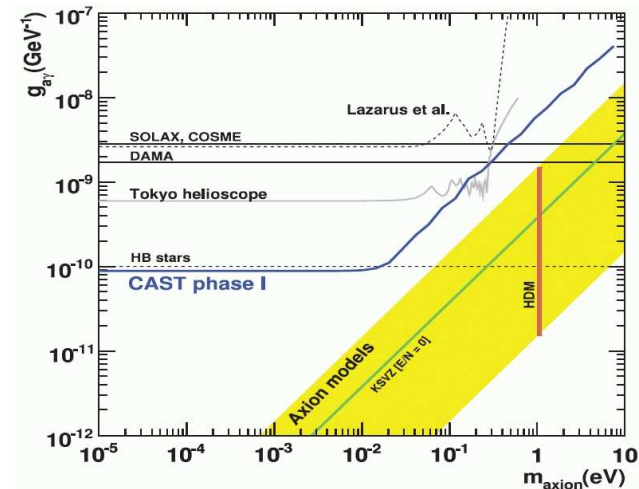
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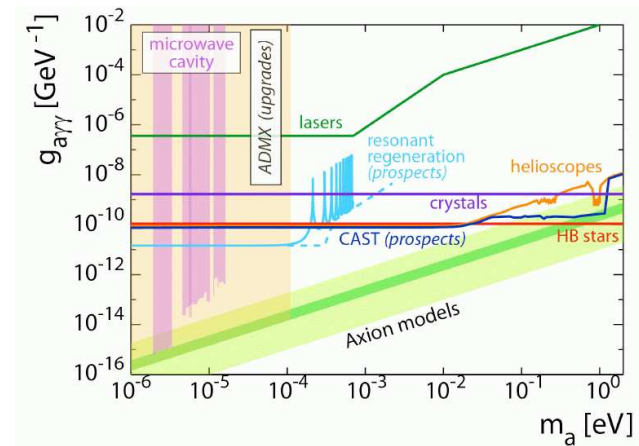
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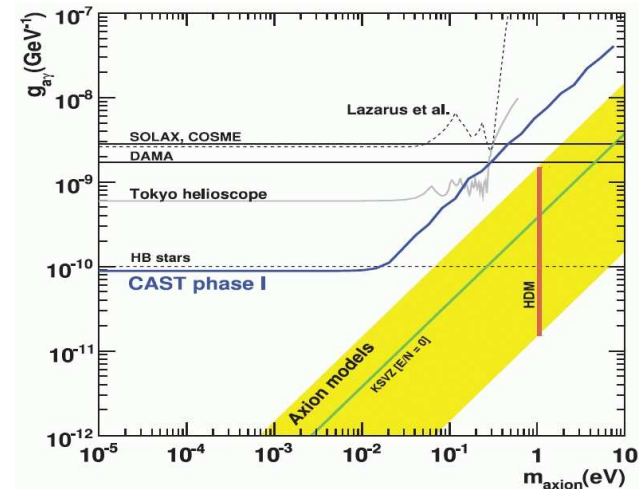
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search continues, a possibly cosmologically subdominant?

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(assume usual gravity mediated SUSY breaking)

	axino	gravitino
spin	1/2	3/2
interaction	$\sim 1/f_a^2$	$\sim 1/M_{\text{P}}^2$
mass	$\not\propto M_{\text{SUSY}}$	$\propto M_{\text{SUSY}}$

- mass model dependent

take it as free parameter

$f_a \sim 10^9 - 10^{12}$ GeV – PQ scale

$M_{\text{P}} = 2.4 \times 10^{18}$ GeV – reduced Planck mass

$M_{\text{SUSY}} \sim 100$ GeV – 1 TeV – soft SUSY mass scale

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- \Rightarrow LHC may give strong indications for EWIMP DM

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- DD: $\sigma_p^{SI} \simeq 10^{-9\pm 1}$ pb

...to be almost completely covered by planned 1-tonne detectors

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