The Hunt for Particle Dark Matter:

a brief overview from indirect detection to collider and direct searches

Pasquale D. Serpico

LAPTh Annecy-le-Vieux

GDR Terascale 2011 Lyon - 19 April 2011

Outline of the talk

- (Very few) generalities on DM and detection strategies
- "Summary" of the last years of research, with special emphasis on indirect detection (both because of my expertise and reflecting the interest of the community)
- Current and future perspectives in Direct and Collider searches
- Conclusions & Outlook

Dark Matter has been detected (and it's blue)

So… much ado about nothing?

Press Release 06-120

Astronomers 'See' the Invisible

First 'direct observation' sheds new light on dark matter

The separation of luminous gas appears red, and dark matter appears blue.
Credit and Larger Version

August 21, 2006

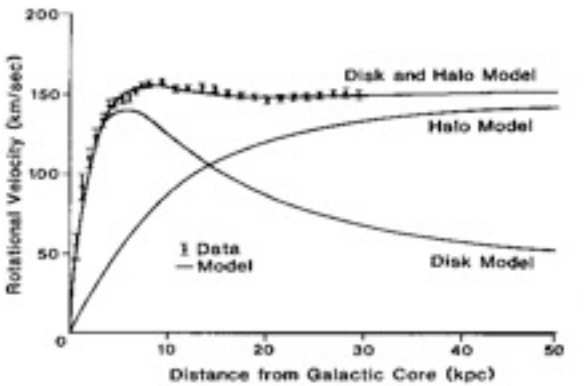
News Release Number: STScI-2007-17

May 15, 2007 *01:00 PM (EDT)*

Hubble Finds Ring of Dark Matter

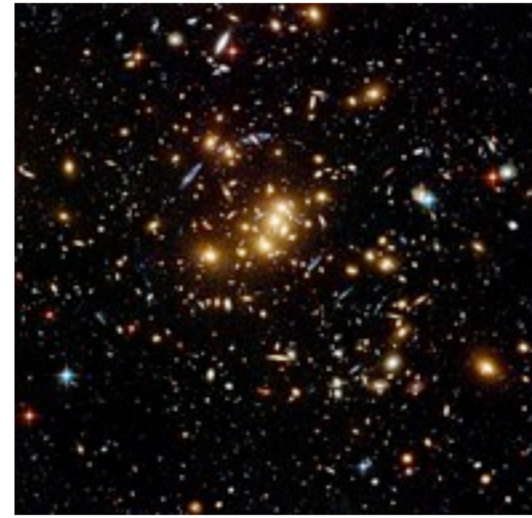
Dark Matter detected… only gravitationally!

Rotation curves of Galaxies



Galaxy Clusters

Lensing

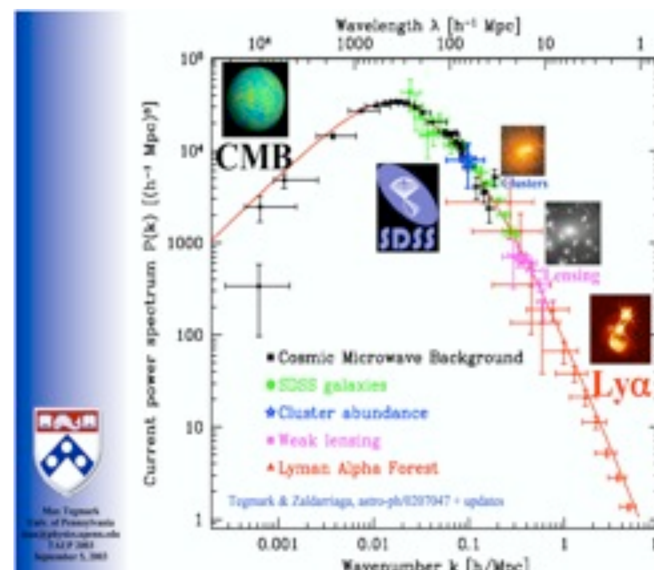


Discovery via gravity

F. Zwicky, 1933

V. Rubin, 1970

Large scale structures



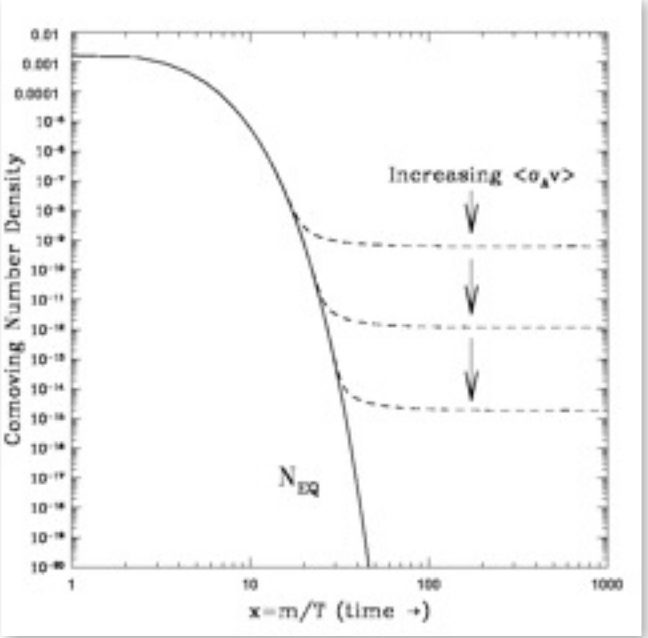
But gravity is “universal”, does not permit particle identification: a discovery via electromagnetic, strong or weak probes is needed

What is DM? WIMPs? Our most reasonable bet

- ✓ It's cold (maybe a little warm…)
- ✓ It's dark (<u>at most</u> weakly interacting with SM fields)
- ✓ It's non-baryonic (New Physics!)

What is DM? WIMPs? Our most reasonable bet

- ✓ It's cold (maybe a little warm…)
- ✓ It's dark (<u>at most</u> weakly interacting with SM fields)
- ✓ It's non-baryonic (New Physics!)



❖ The Weakly Interacting Massive Particle "miracle"

thermal relic with EW gauge couplings & $m_X \approx 0.01$– 1 TeV matches cosmological requirement, $\Omega_X \approx 0.25$

$$\Omega_{wimp} \sim 0.3/ <\sigma v> (pb)$$

❖ New EW scale physics may be related with DM!

Stability ⇔ Discrete Symmetry ⇔ Only pair production at Colliders (SUSY R-parity, K-parity in ED, T-parity in Little Higgs)

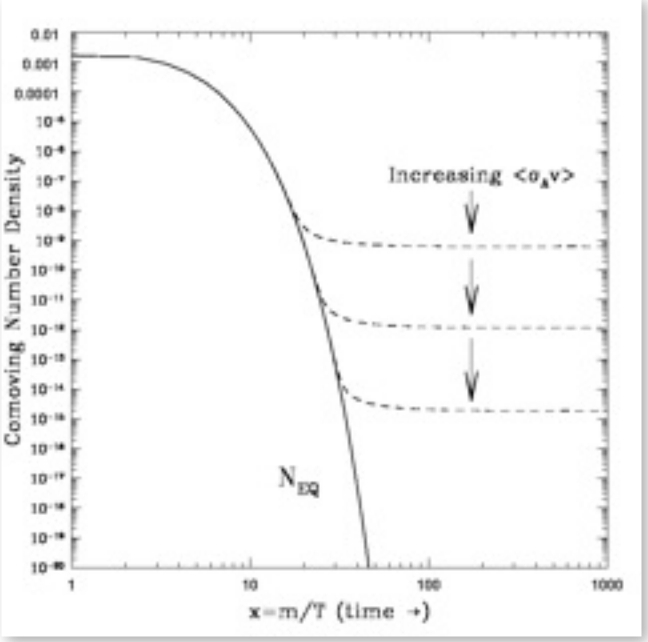
Also would ease agreement with EW observables, Proton stability…

❖ EW-related candidates have a rich phenomenology

Higher chances of detection via collider, direct, and indirect techniques

What is DM? WIMPs? Our most reasonable bet

- ✓ It's cold (maybe a little warm…)
- ✓ It's dark (<u>at most</u> weakly interacting with SM fields)
- ✓ It's non-baryonic (New Physics!)



❖ The Weakly Interacting Massive Particle "miracle"

thermal relic with EW gauge couplings & $m_X \approx 0.01 - 1$ TeV matches cosmological requirement, $\Omega_X \approx 0.25$

$$\Omega_{wimp} \sim 0.3/<\sigma v>(pb)$$

❖ New EW scale physics may be related with DM!

Stability ↔ Discrete Symmetry ↔ Only pair production at Colliders
(SUSY R-parity, K-parity in ED, T-parity in Little Higgs)
Also would ease agreement with EW observables, Proton stability…

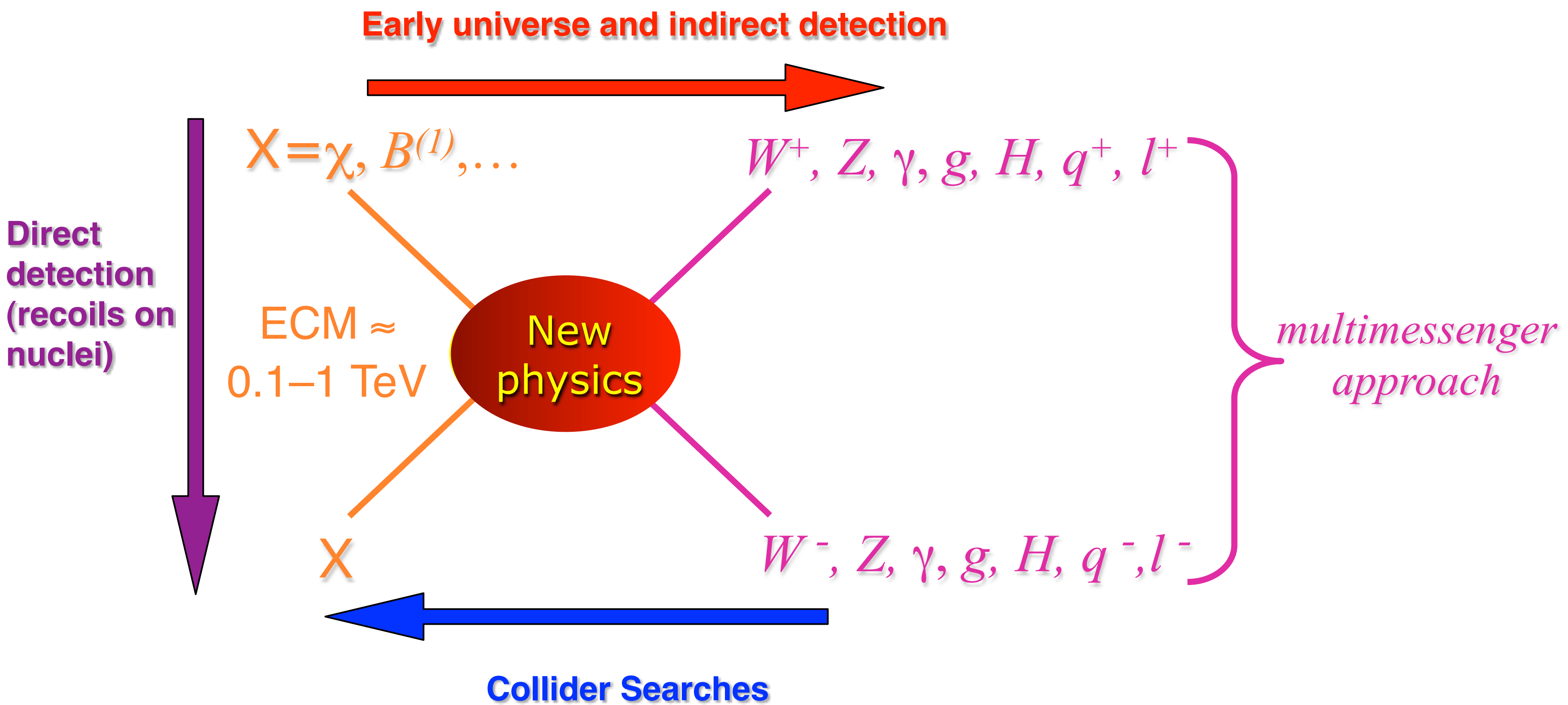
❖ EW-related candidates have a rich phenomenology

Higher chances of detection via collider, direct, and indirect techniques

➢ *Warning: keep in mind other possibilities!*

(Axions, SuperHeavy DM, SuperWIMPS, MeV DM, sterile neutrinos…)
They have peculiar signatures and require ad hoc searches

A benchmark diagram & the discovery program



- ✓ demonstrate that astrophysical DM is made of particles (locally, via DD; remotely, via ID)
- ✓ Possibly, create DM candidates in the controlled environments of accelerators
- ✓ Find a consistency between properties of the two classes of particles. Ideally, we would like to calculate abundance and DD/ID signatures → link with cosmology/test of production

Theory/Phenomenology directions in the last 3 yrs

AKA
Le Bon, la Brute et le Truand
or
The Good, the Bad and the Ugly
or
El Bueno, el Feo y el Malo
...

Theory/Phenomenology directions in the last 3 yrs

- A period of bursting activity in DM theory, mostly inspired by new cosmic ray data. We can summarize the pipeline as

Data → **Assume** DM explanation → *Creative* Model building to fit the data.

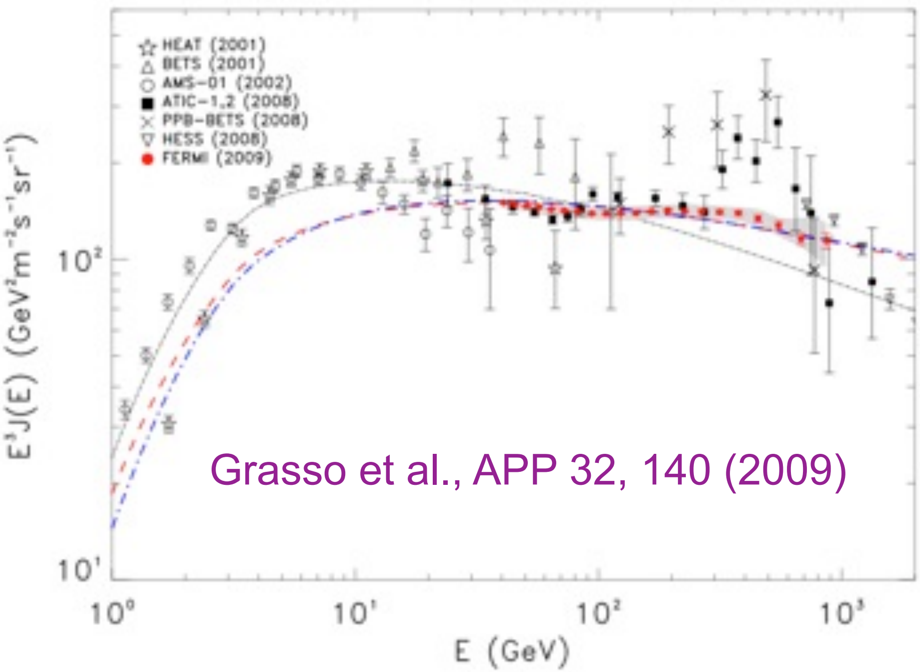
- "Beyond the WIMP paradigm", relax one or more assumptions and explore consequences for DD, ID, Colliders.

- Strategies to **identify** DM vs. background:
  - ★ Do we really know what we are looking for in ID ("the signal")?
  - ★ Do we know astrophysical "backgrounds" (actually NEW signals)?
  - ★ How well we control backgrounds in underground detectors?

★ How well we control backgrounds in underground detectors?
★ Do we know astrophysical "backgrounds" (actually NEW signals)?
★ Do we really know what we are looking for in ID ("the signal")?

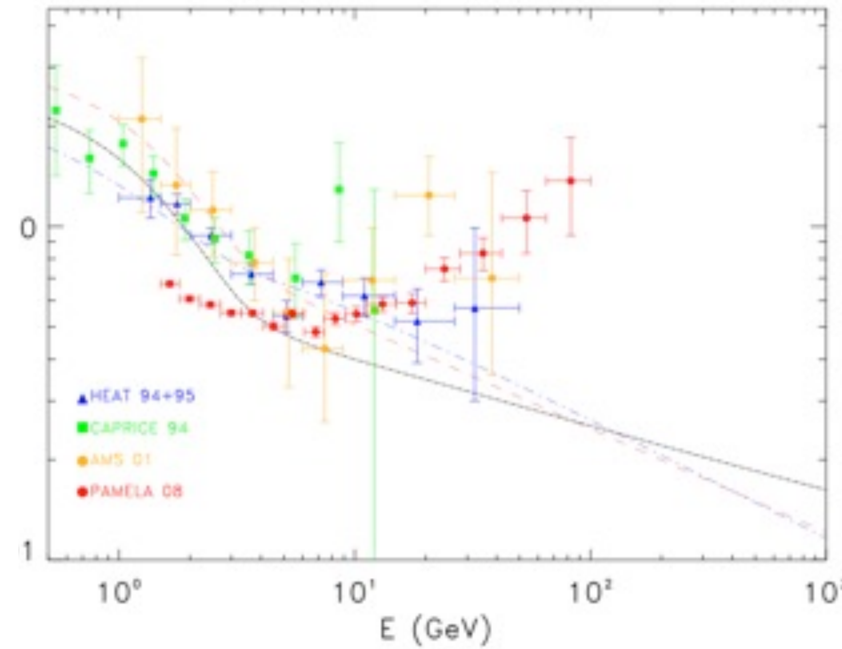
The identification with the above-mentioned movie characters is straightforward but clearly subjective and is left as an exercise to the audience.

Overall $e^- + e^+$ Spectrum



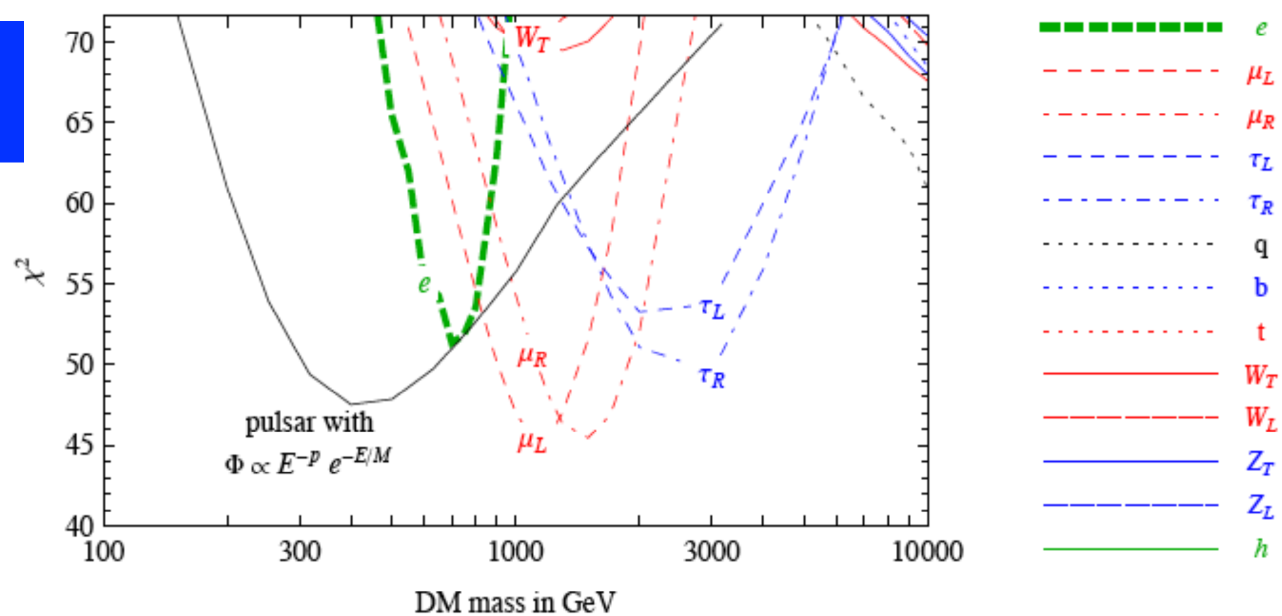
Grasso et al., APP 32, 140 (2009)

Positron Fraction data

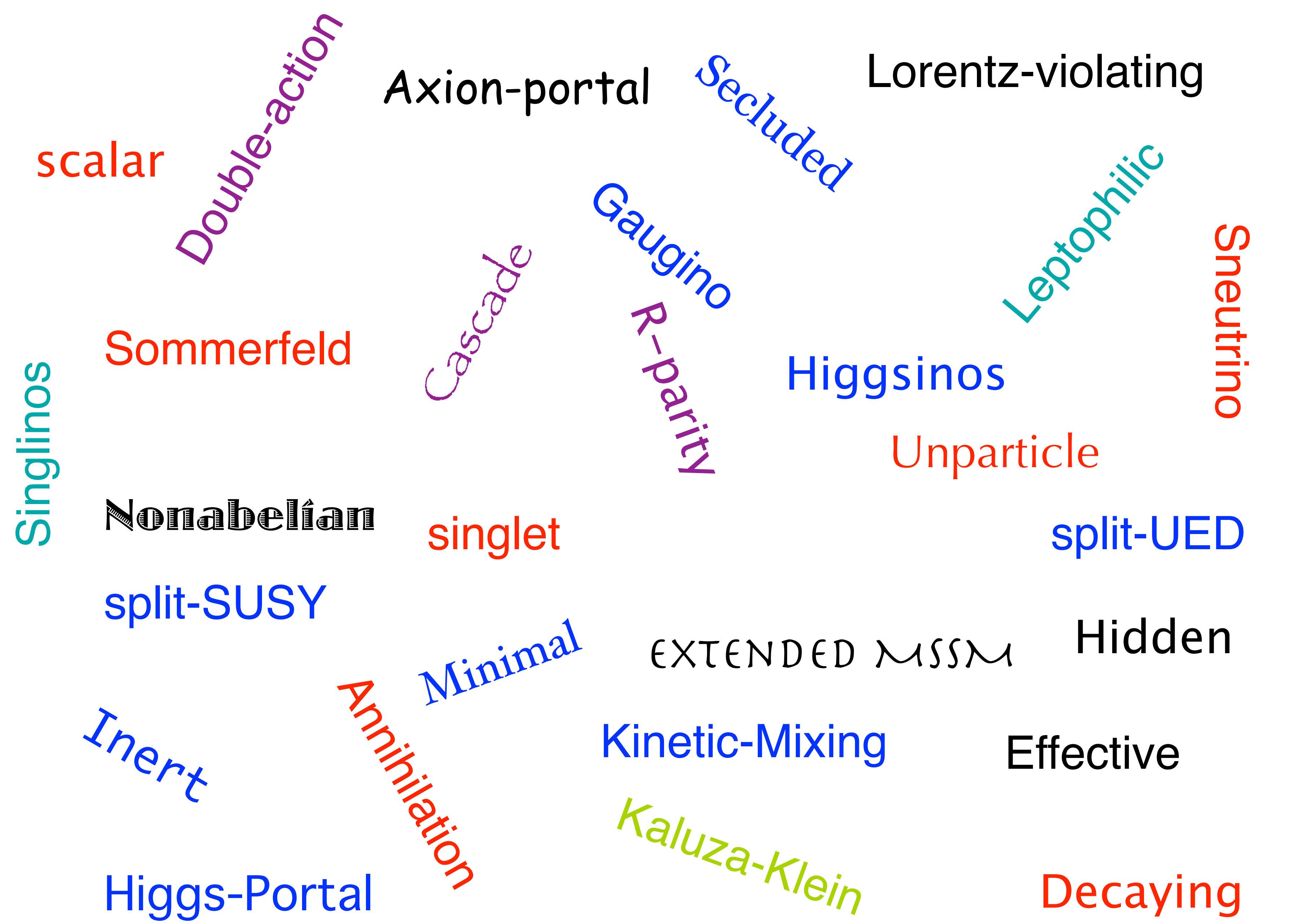


Fit to different Dark Matter models

e.g.: Cirelli et al.
NPB 813, 1 (2009)



Burst of Creative (Dark Matter) Writing



Issues with DM interpretations

Large "enhancement" with respect to S-wave thermal relic <σv> is required

$$B \sim 10 \left(\frac{m_X}{100\,\mathrm{GeV}} \right)^{1.7}$$

Might be due to astrophysics?
As far as we know, the answer is no.
Requires fine tuning & γ-rays should have been seen (Bringmann, Lavalle, Salati 0902.3665)

Might be due to "Particle Physics"?

- Sommerfeld enhancement (large m & light mediator of long-range forces, fine-tuning?!)
- Non-thermal relic? Add another parameter and gives up WIMP miracle!!!
- Decaying? Possible, again gives up the "WIMP miracle" link to signatures

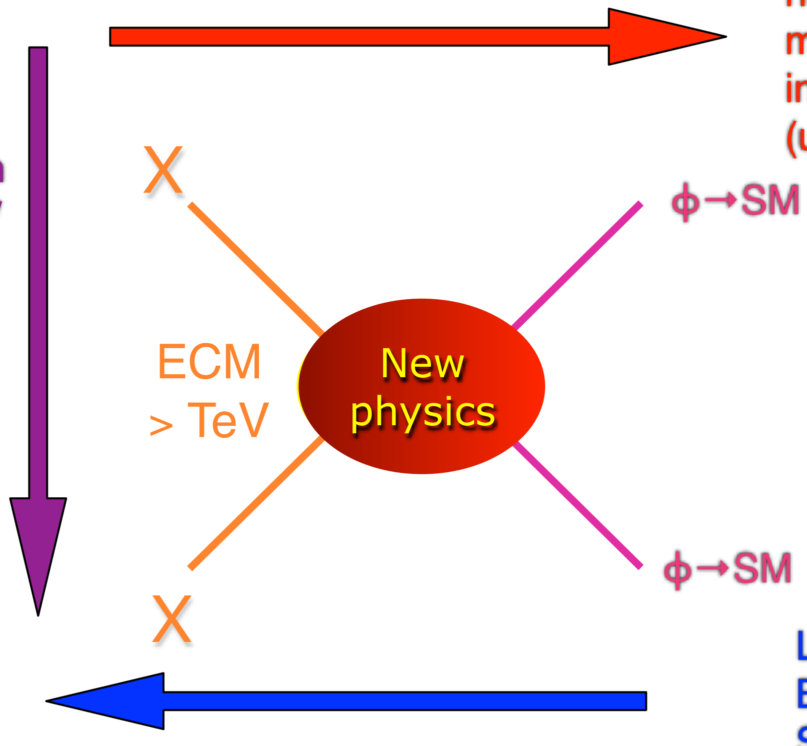
Requires a dominant b.r. in leptonic final states
(common to decaying dark matter models, too)

- Requires some level of "model-engineering", usually violates bounds from gamma rays, from radio, from cosmology, etc. unless one advocates some (unappealing?) way outs, e.g. that the DM responsible for the signal is not most of the DM out there, see for example Cirelli & Cline 1005.1779, that the DM profile is different than what found in simulations, etc.

“Losing my religion”, or a tale of broken arrows

Link ID/early universe broken via non-perturbative effects, light BSM mediators as 2-body final states, or invoking signatures via decay (unrelated to production)

Link with DD often broken via leptophilic nature and/or heavy mass.
Sometimes present via “epicycles” (inelastic? New scales?)



Link with colliders broken via light BSM mediators, leptophilic nature
Some hopes in “ad hoc” beam dump experiments?

A generic consequence of the “new creative models” is that the original search program for WIMP DM is untenable, LHC is useless to the purpose and the link astro/cosmo is broken.
The TeV is justified “observationally”, rather than from first principles/links to new physics

Are “standard” calculations of signatures reliable?

Heavy, leptophilic DM candidates imply that most indirect signatures in CRs are at ***$E << m$***.
It’s important to consider “tertiary” signatures (e.g. Inverse Compton γ’s from $e^{\pm}$ originating from DM) and/or multi-body final states.

Need to go beyond mere “one step production” (need propagation!) and 2-body final states

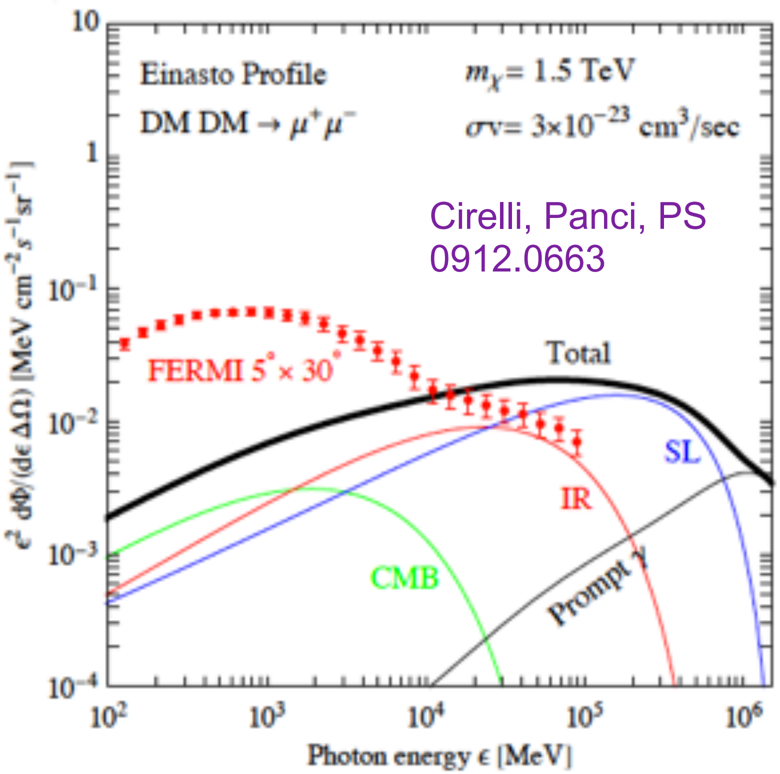
Are "standard" calculations of signatures reliable?

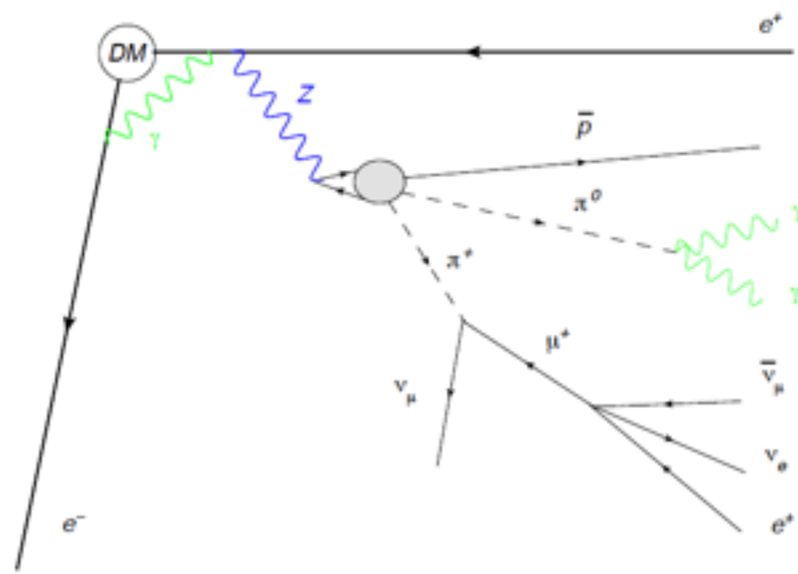
Heavy, leptophilic DM candidates imply that most indirect signatures in CRs are at ***E << m***.
It's important to consider "tertiary" signatures (e.g. Inverse Compton γ's from $e^{\pm}$ originating from DM) and/or multi-body final states.

Need to go beyond mere "one step production" (need propagation!) and 2-body final states

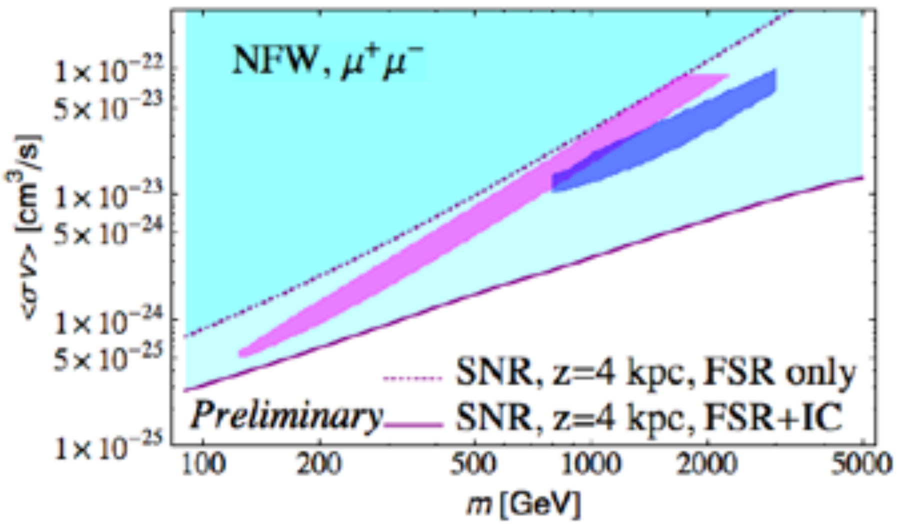
- ✓ γ signatures are present at high latitudes.
- ✓ Leptophilic models do have b.r. in other channels
- ✓ $e^{\pm}$ spectra are softer and fits typically worsen

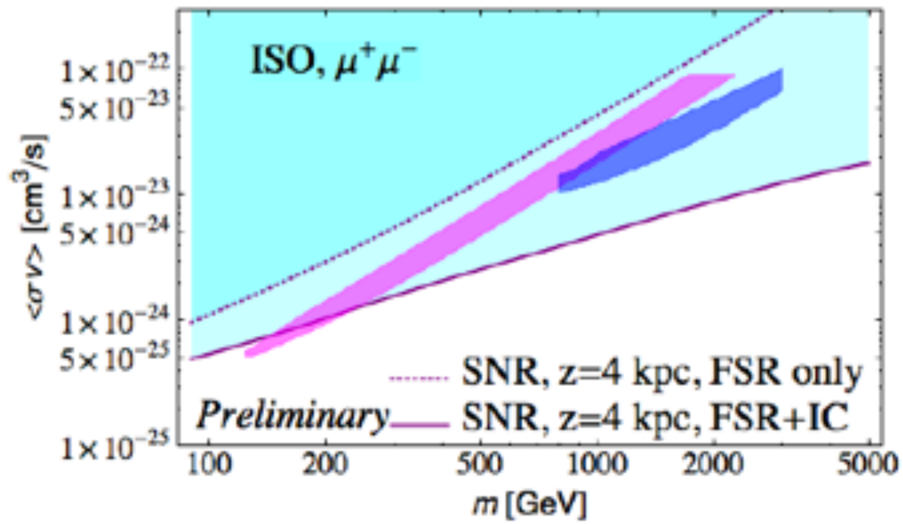
Kachelriess, PS 0707.0209
Bell, Jacques, Dent, Weiler '08-'11
Kachelriess, PS, Solberg 0911.0001
Yaguna,1003.2730
Ciafaloni et al. 1009.0224, 1104.2996
...





At the end of the day...does it work? Not really well



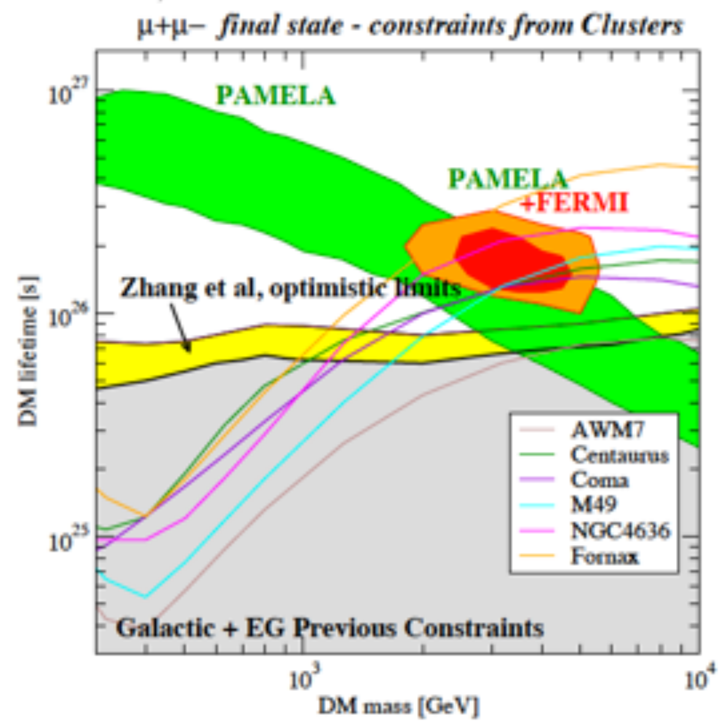


Zaharijas et al. [Fermi-LAT], 1012.0588 (diffuse galactic emission)

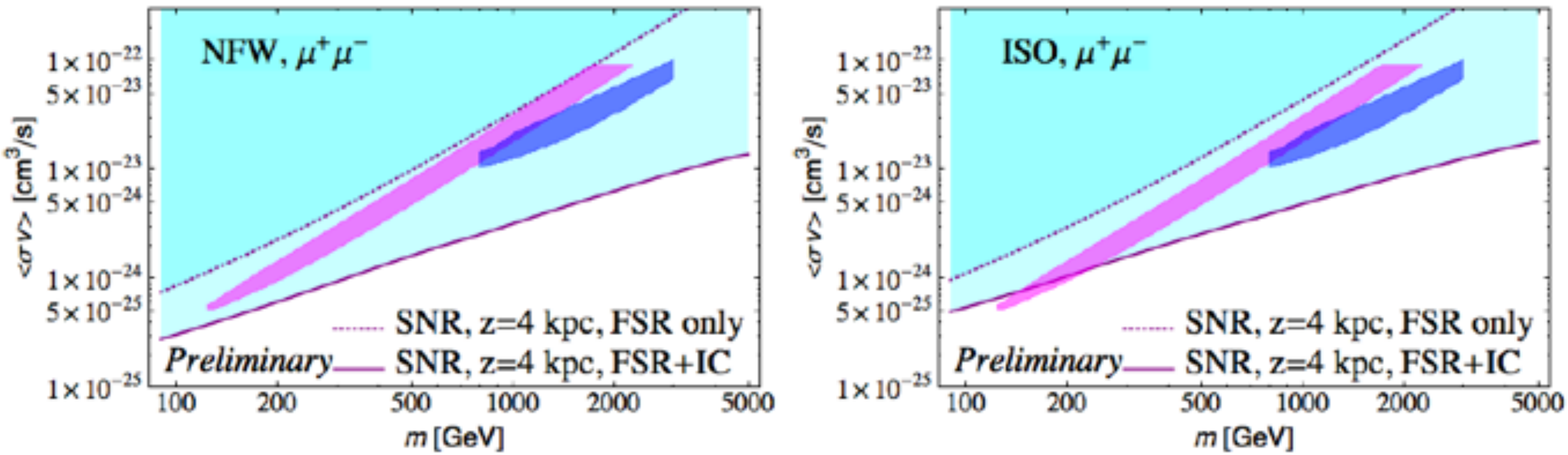
★ *Constraints from: antiprotons, γ's (some examples shown), radio, cosmology...*

★ *At the moment, most scenarios are ruled out and a few "contrived" one barely survive.*

Dugger, Jeltema, Profumo, 1009.5988
(e.g. from clusters, for decaying DM)



At the end of the day...does it work? Not really well



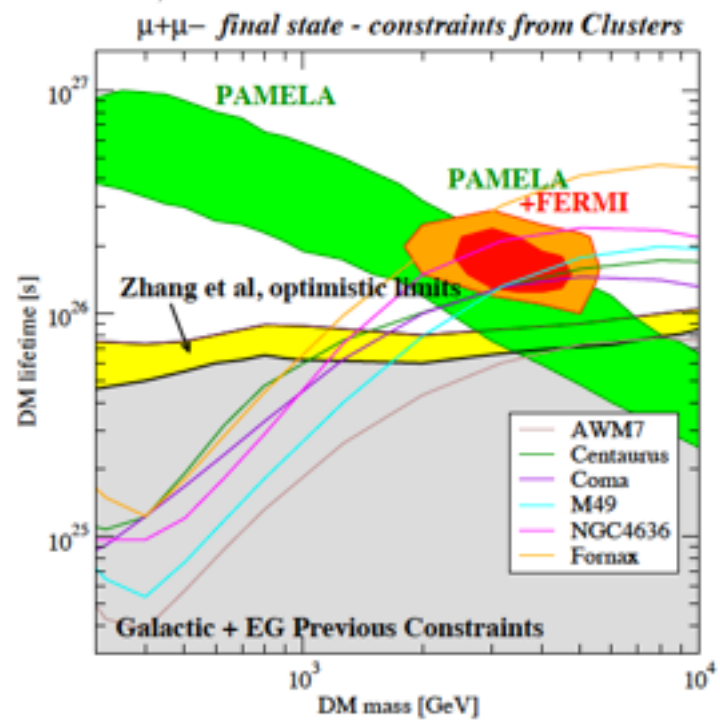
Zaharijas et al. [Fermi-LAT], 1012.0588 (diffuse galactic emission)

⋆*Constraints from: antiprotons, γ's (some examples shown), radio, cosmology...*

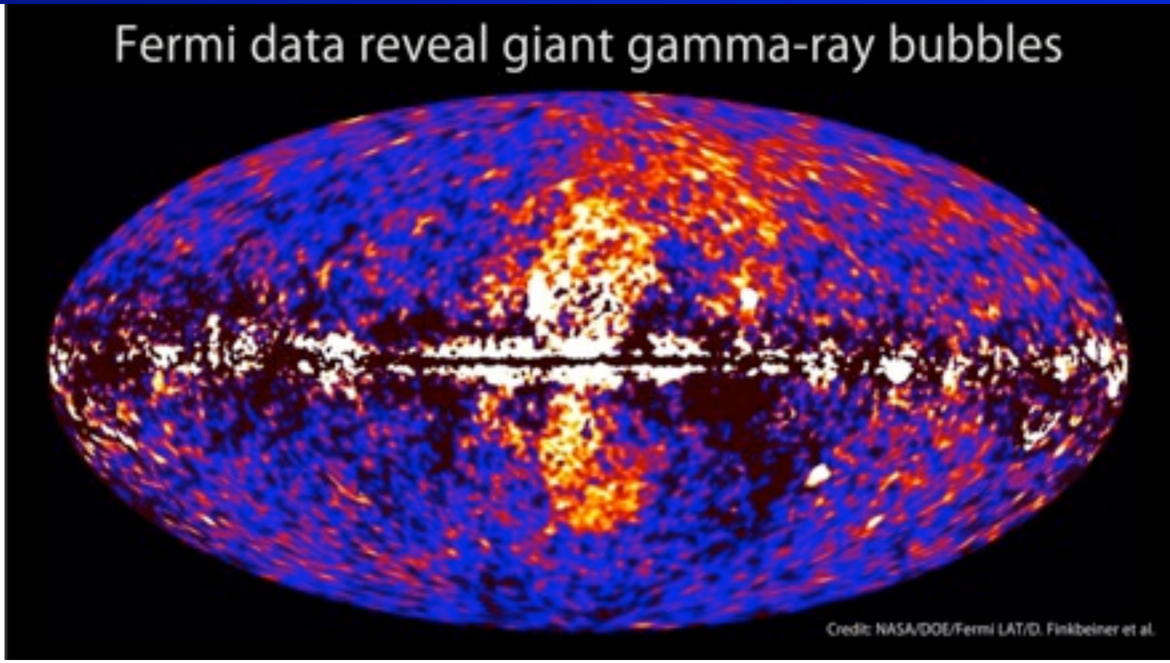
⋆ *At the moment, most scenarios are ruled out and a few "contrived" one barely survive.*

Dugger, Jeltema, Profumo, 1009.5988
(e.g. from clusters, for decaying DM)

So, what causes the rise? If you're curious, please ask me in the question time!



Recent claims of Indirect DM “hints”. I



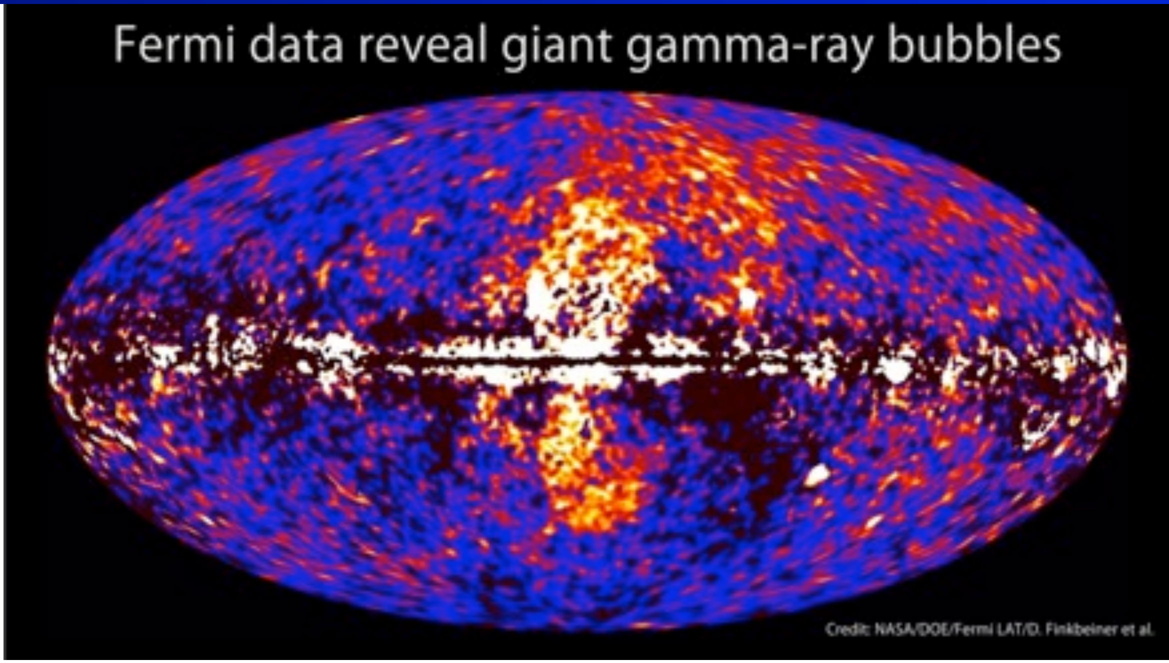
Finkbeiner et al.’s “lobes” in Fermi data

(artist’s view below)

G. Dobler, I. Cholis and N. Weiner [1102.5095]
“The Fermi Gamma-Ray Haze from Dark Matter Annihilations and Anisotropic Diffusion”

“emission towards the GC and extending up to roughly ±50º in latitude[...] has two distinct characteristics: the spectrum is significantly harder than emission elsewhere in the Galaxy and the morphology is elongated in latitude with respect to longitude with an axis ratio ≈2”

Recent claims of Indirect DM "hints". I



Finkbeiner et al.'s "lobes" in Fermi data

(artist's view below)

G. Dobler, I. Cholis and N. Weiner [1102.5095]
"The Fermi Gamma-Ray Haze from Dark Matter Annihilations and Anisotropic Diffusion"

"emission towards the GC and extending up to roughly ±50° in latitude[...] has two distinct characteristics: the spectrum is significantly harder than emission elsewhere in the Galaxy and the morphology is elongated in latitude with respect to longitude with an axis ratio ≈2"

Interpretation: "it is the inverse Compton emission generated by the same electrons which generate the microwave synchrotron haze at WMAP wavelengths[...] *a model of Galactic cosmic-ray diffusion* that incorporates *both an ordered and turbulent* B-field component. *The ordered component results in anisotropic diffusion of cosmic-ray electrons* along field lines. Combining this model of diffusion with DM annihilations in a *prolate DM halo* produces an inverse Compton γ-ray signal that matches the morphology and spectrum of the observed Fermi γ-ray haze"

I share the following opinion:

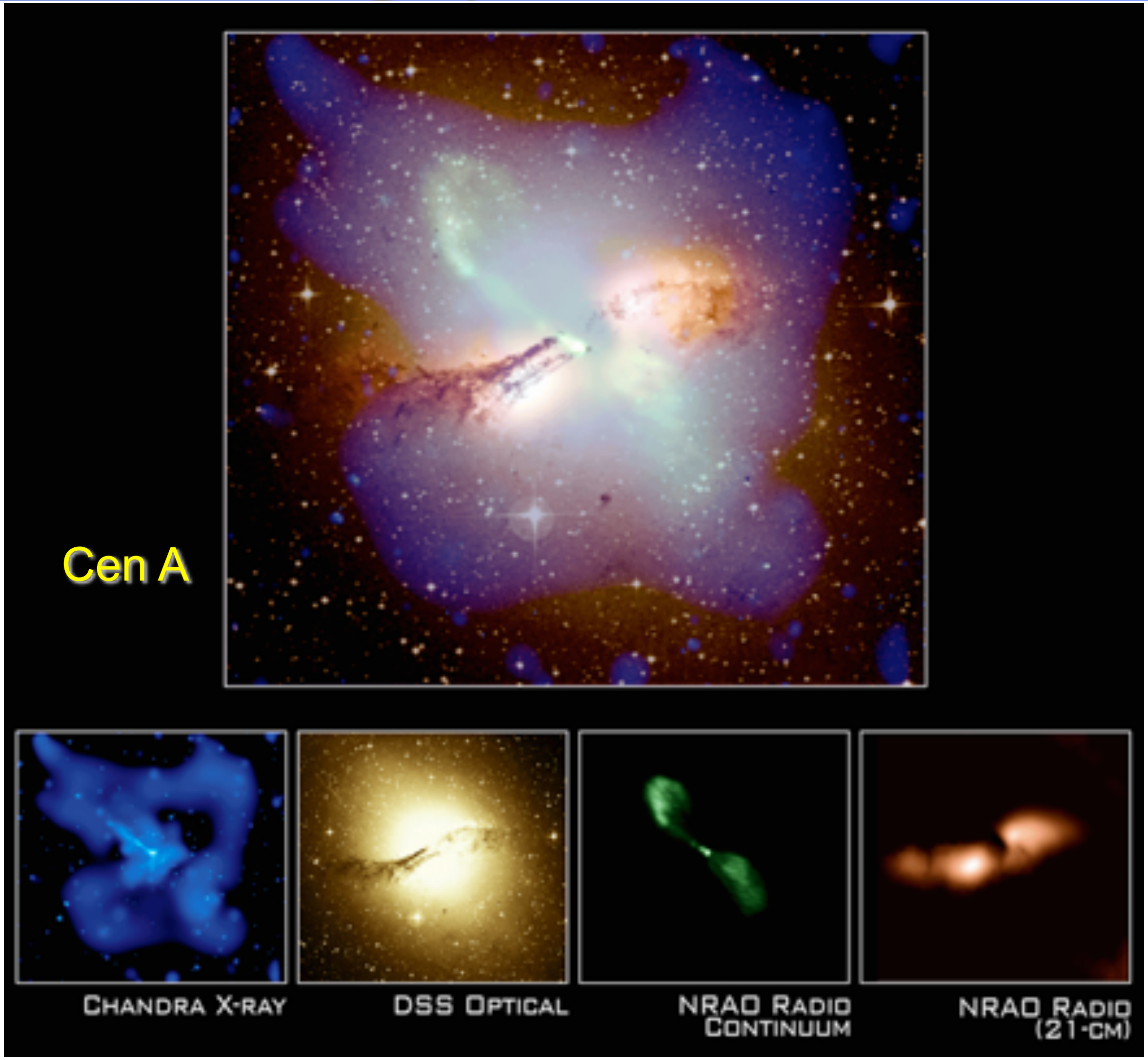
"In other galaxies, we see that starbursts can drive enormous gas outflows.[...]Whatever the energy source behind these huge bubbles may be, it is connected to many deep questions in ***astrophysics.****"*

David Spergel, Princeton

AGN activity or strong bipolar winds have been observed elsewhere, models exist for our Galaxy:

✦ Su, Slatyer & Finkbeiner, "Giant Gamma-ray Bubbles from Fermi-LAT: AGN Activity or Bipolar Galactic Wind?," 1005.5480

✦ Crocker, Jones, Aharonian, Law, Melia, Oka & Ott, "Wild at Heart: The Particle Astrophysics of the Galactic Centre," 1011.0206



- What powers them? The Black Hole?
- Is it a stationary phenomenon or rather a "cocoon" of past activity? HE universe is t-dependent!
- Purely leptonic or p/nuclei play a role?

Recent claims of Indirect DM "hints". II

D. Hooper and L. Goodenough [1010.2752]
"Dark Matter Annihilation in The Galactic Center As Seen by the Fermi Gamma Ray Space Telescope"

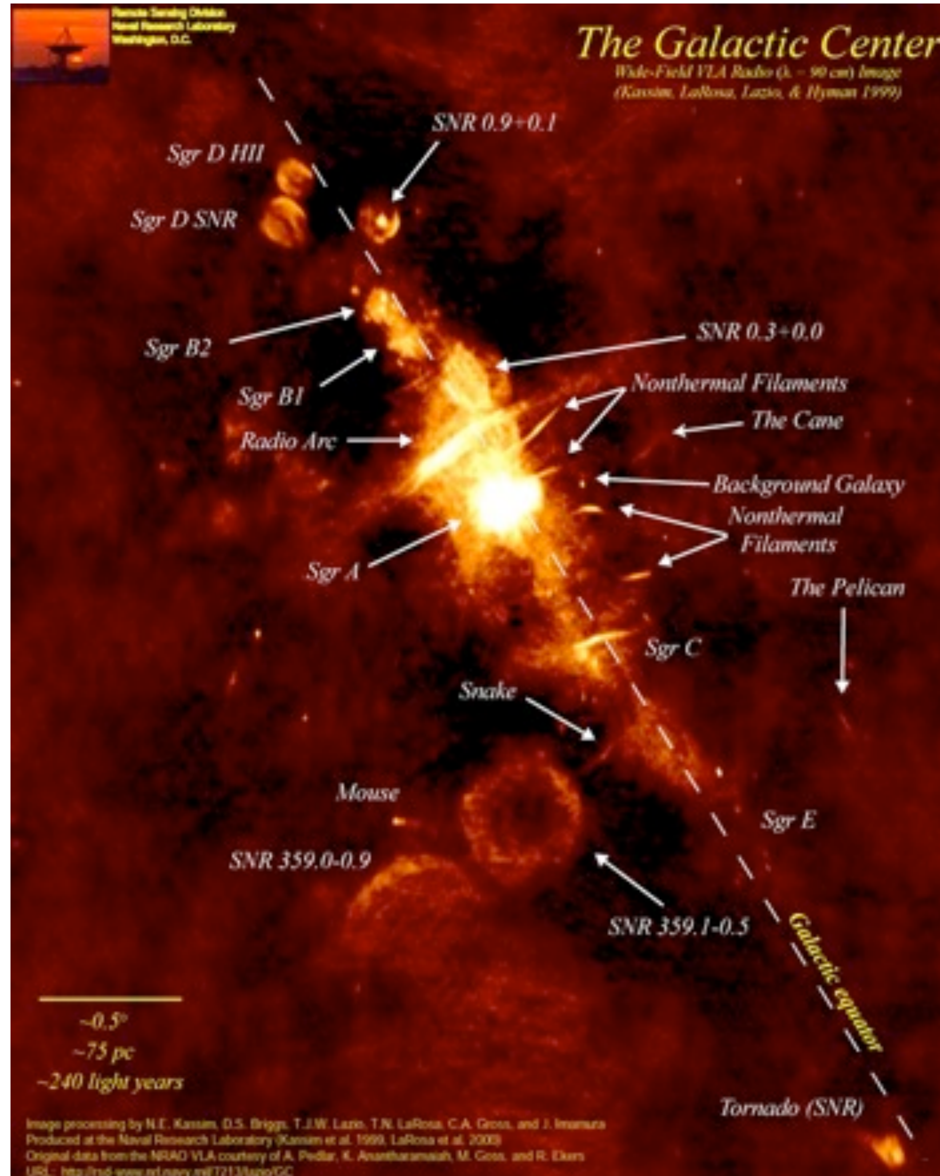
The observed spectrum and morphology of the emission within approximately 1.25^o (~175 pc) of the GC [...] is consistent with that predicted from annihilating DM with a cusped [...] halo distribution (density proportional to $r^{-\Upsilon}$, with Υ=1.18 to 1.33. The observed spectrum of this component, which peaks at energies between 1-4 GeV (in E^2 units), can be well fit by a 7-10 GeV DM particle annihilating primarily to τ's with a σ in the range of 4.6×10^{-27} to 5.3×10^{-26} cm^3/s depending on how the DM distribution is normalized.

Recent claims of Indirect DM "hints". II

D. Hooper and L. Goodenough [1010.2752]
"Dark Matter Annihilation in The Galactic Center As Seen by the Fermi Gamma Ray Space Telescope"

The observed spectrum and morphology of the emission within approximately 1.25° (~175 pc) of the GC [...] is consistent with that predicted from annihilating DM with a cusped [...] halo distribution (density proportional to $r^{-\Upsilon}$, with Υ=1.18 to 1.33. The observed spectrum of this component, which peaks at energies between 1-4 GeV (in E^2 units), can be well fit by a 7-10 GeV DM particle annihilating primarily to τ's with a σv in the range of 4.6×10^{-27} to 5.3×10^{-26} cm^3/s depending on how the DM distribution is normalized.

Great... If were not for the fact that the GC is the most crowded environment for non-thermal sources!



Alternative explanations

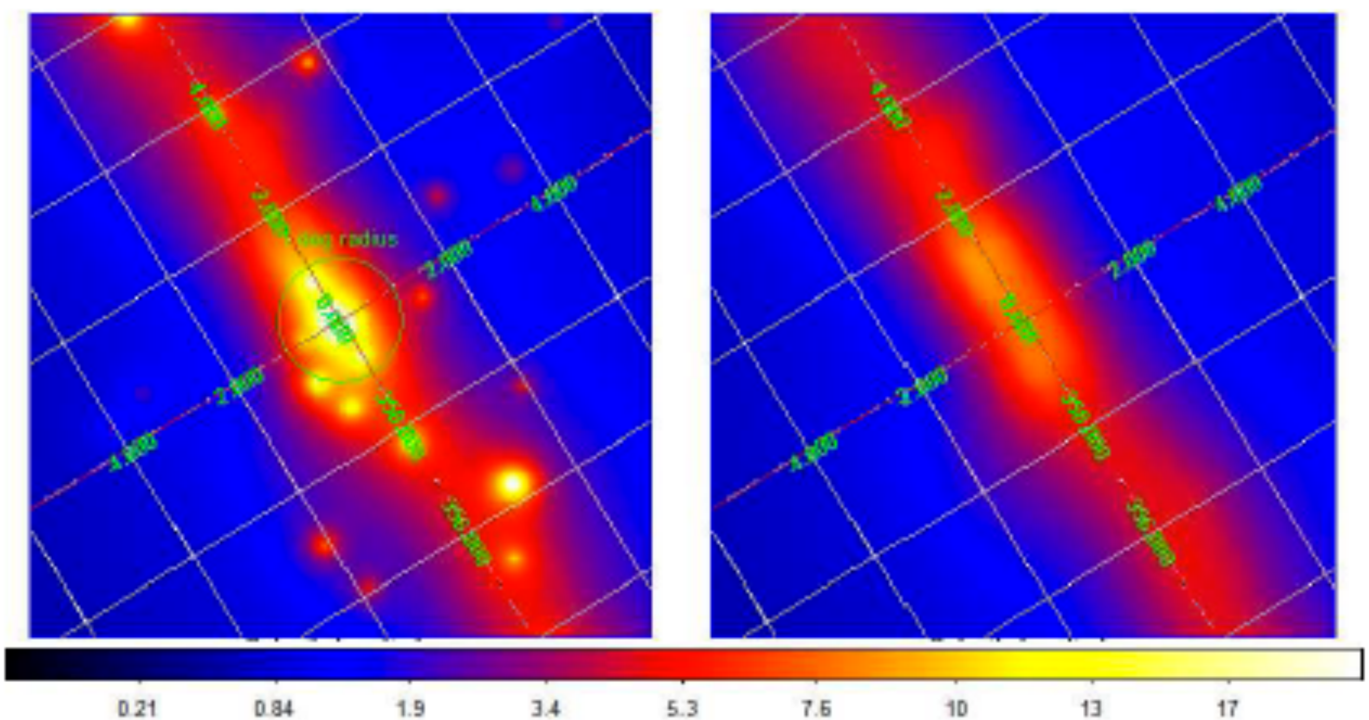
- ★ PSF/resolution effects (unlikely?)

- ★ Pulsar population in a star cluster close to the GC

K.N. Abazajian [1011.4275]
“The Consistency of Fermi-LAT Observations of the Galactic Center with a Millisecond Pulsar Population in the Central Stellar Cluster,"

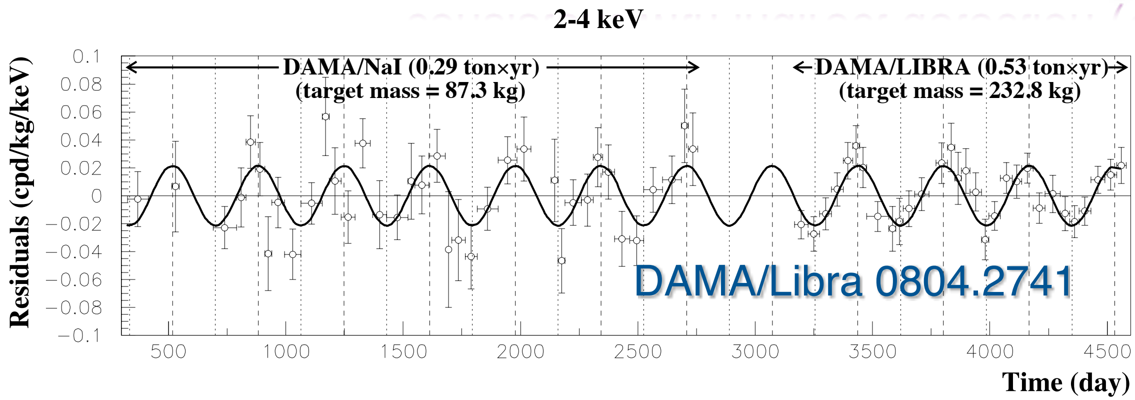
- ★ Central black hole (see results of the MC below...)

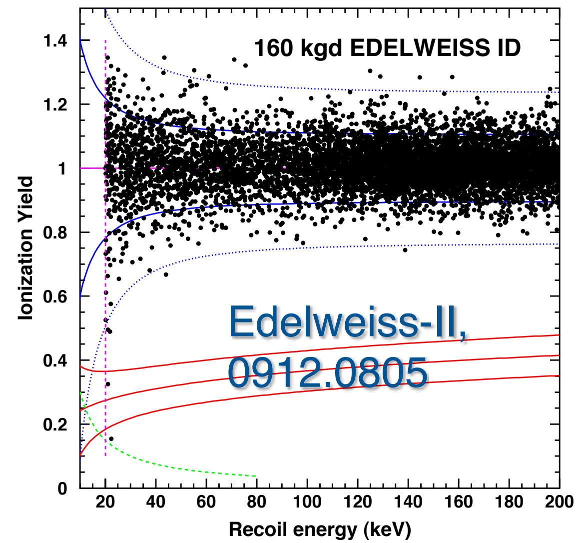
A. Boyarsky, D. Malyshev, O. Ruchayskiy, [1012.5839]
“A comment on the emission from the Galactic Center as seen by the Fermi telescope,”

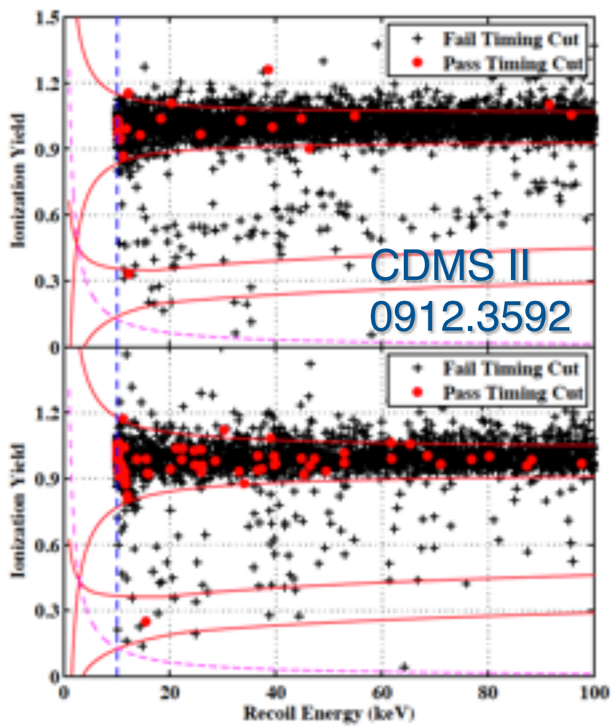


The “Direct Detection Excitement”

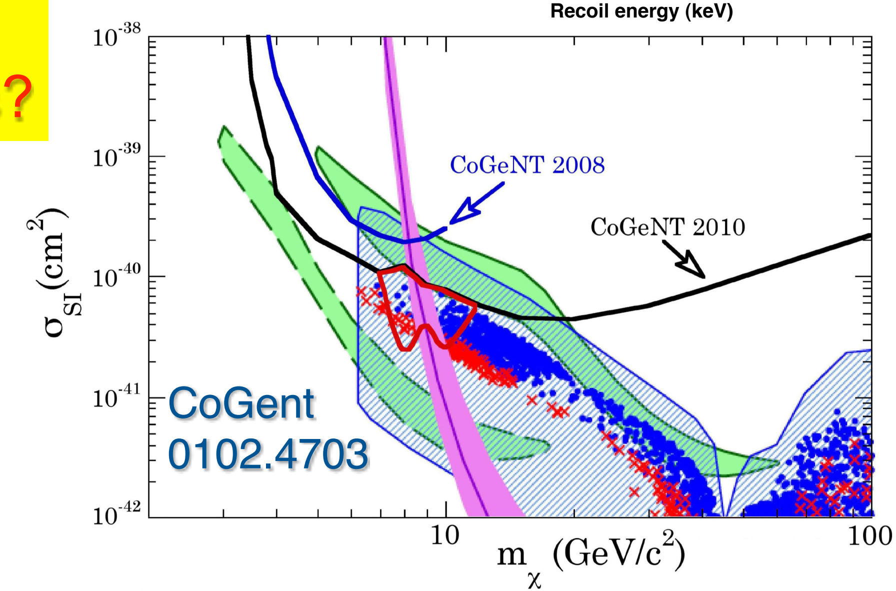
Several anomalies or event detections at the ~2-8 sigma level in direct detection (DAMA, CoGent...), possibly indicating low-scale models consistent with indirect detection (Galactic Center?)





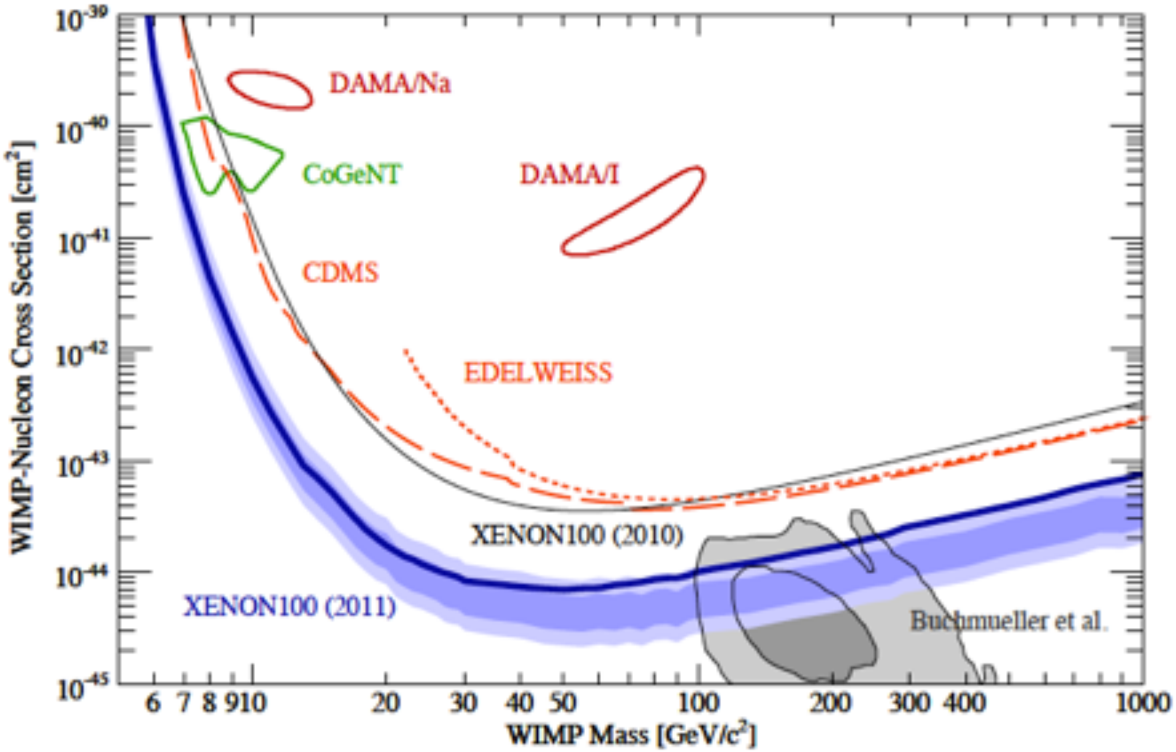


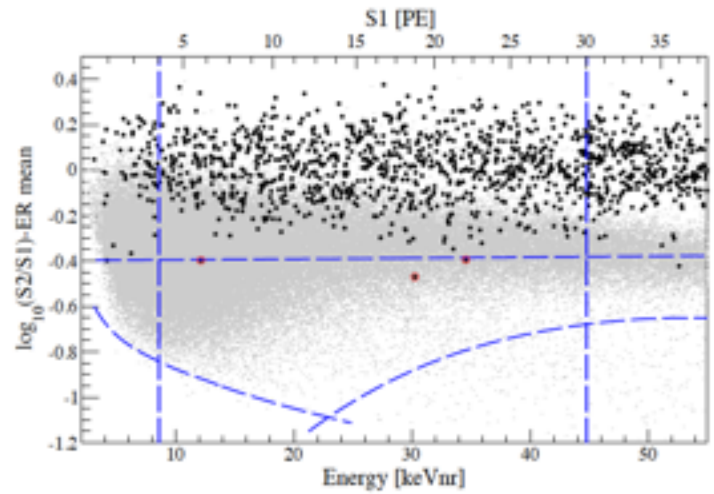
Are they DM events?



Very Recent Results (SI)

The newest published results are the final ones by Edelweiss-II (1103.4070, will hear news later on by Alexandre Juillard) and the 100 Xenon100-100 live days (1104.2549). The latter has now the highest sensitivity over all the range.





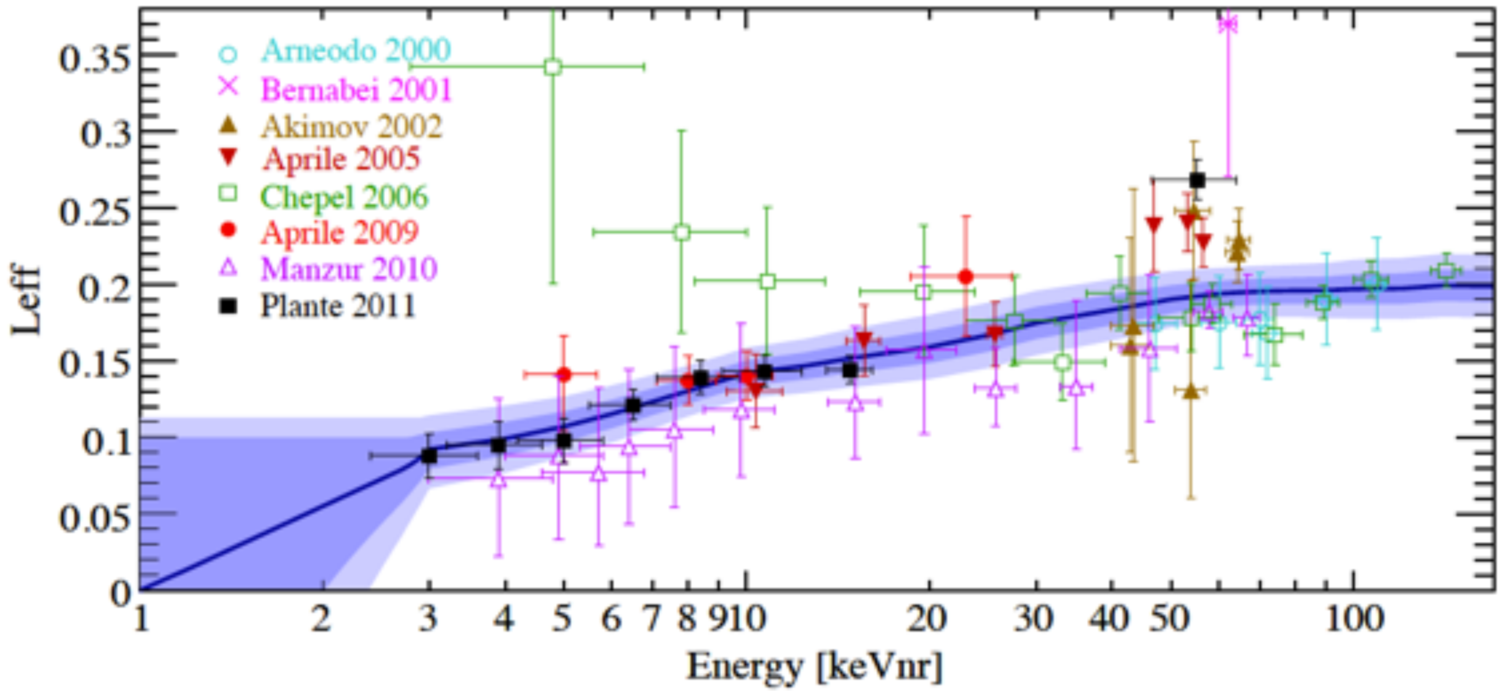
3 events vs 1.8±0.6 expected
(28% Poisson probability ≥3)

"DAMA-CoGeNT region" in a SI-standard halo & light-WIMP interpretation excluded

see also 1104.3088 for a similar conclusion based on Xenon10 data (single-e trigger, E_{th}=1.4 keV)

"The debate" on systematics

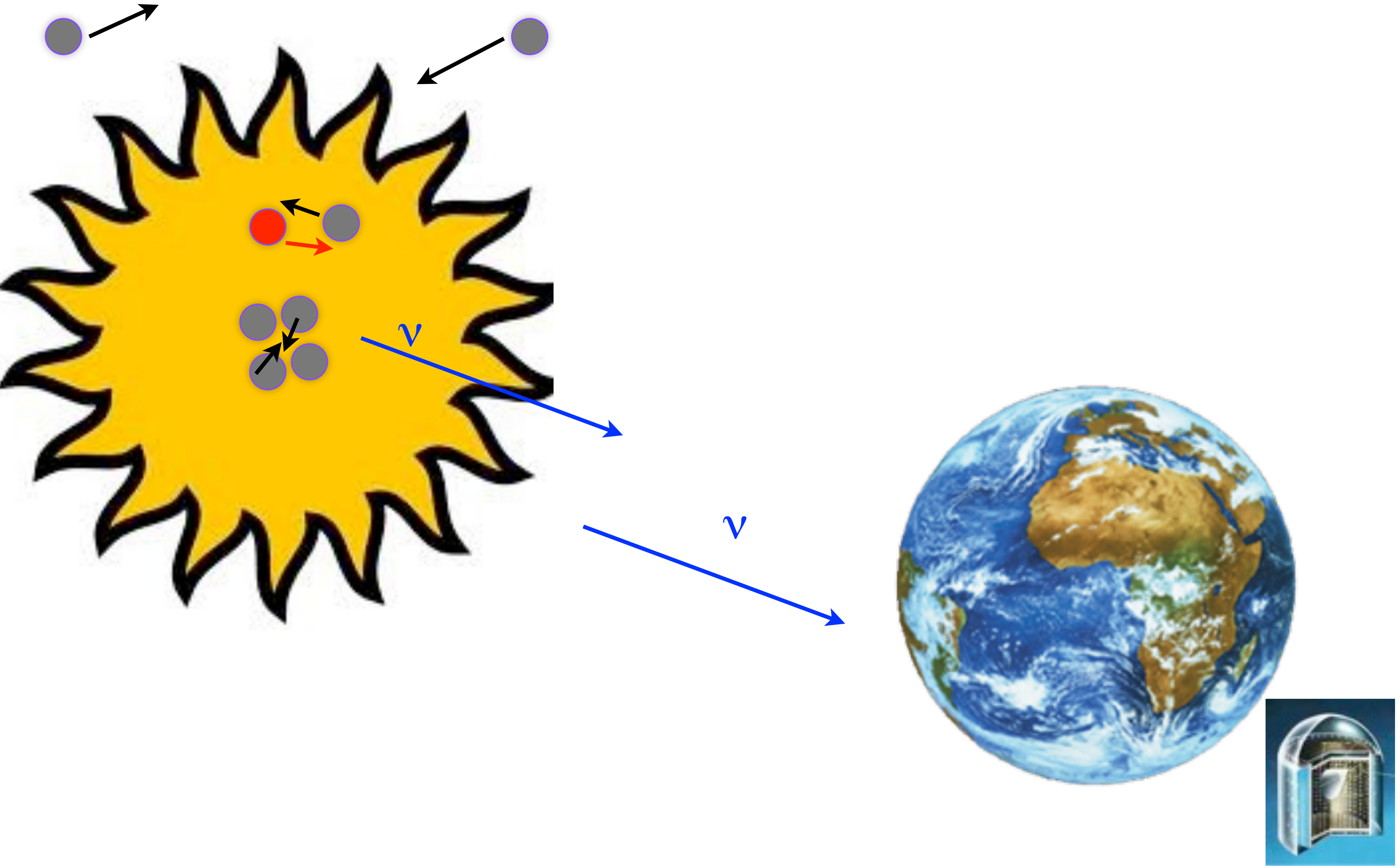
The low-m bound in Xenon100 depends on how the low recoil scintillation energy efficiency is treated: new measurement in Plante et al., 1104.2549 !



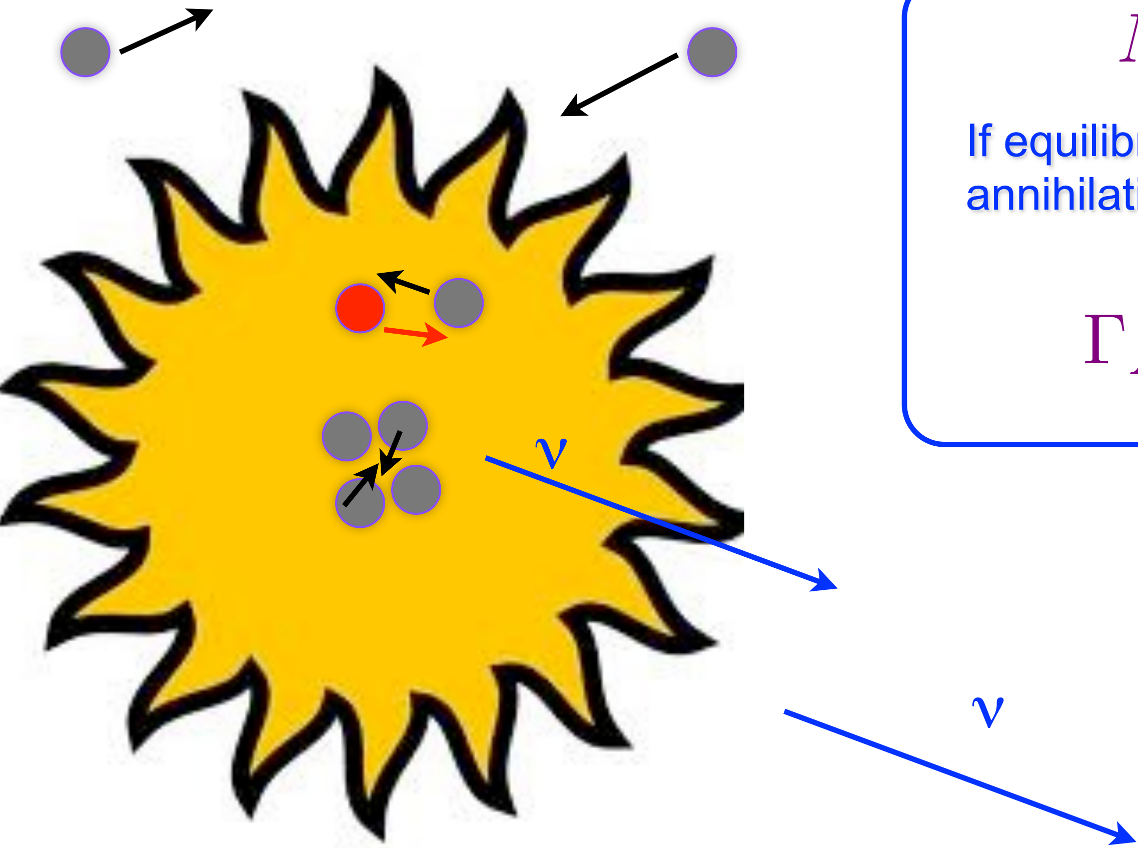
Caveat: in some cases a consistent interpretation of "detections" & exclusions can be obtained by departing significantly from the vanilla WIMP and/or simplest halo scenario, see e.g.

T. Schwetz [1011.5432] "Direct detection data and possible hints for low-mass WIMPs,"

Other possible issue: neutrinos from the Sun



Other possible issue: neutrinos from the Sun



$$\dot{N} = C - C_A N^2$$

If equilibrium is reached btw the two, the annihilation signal rate writes:

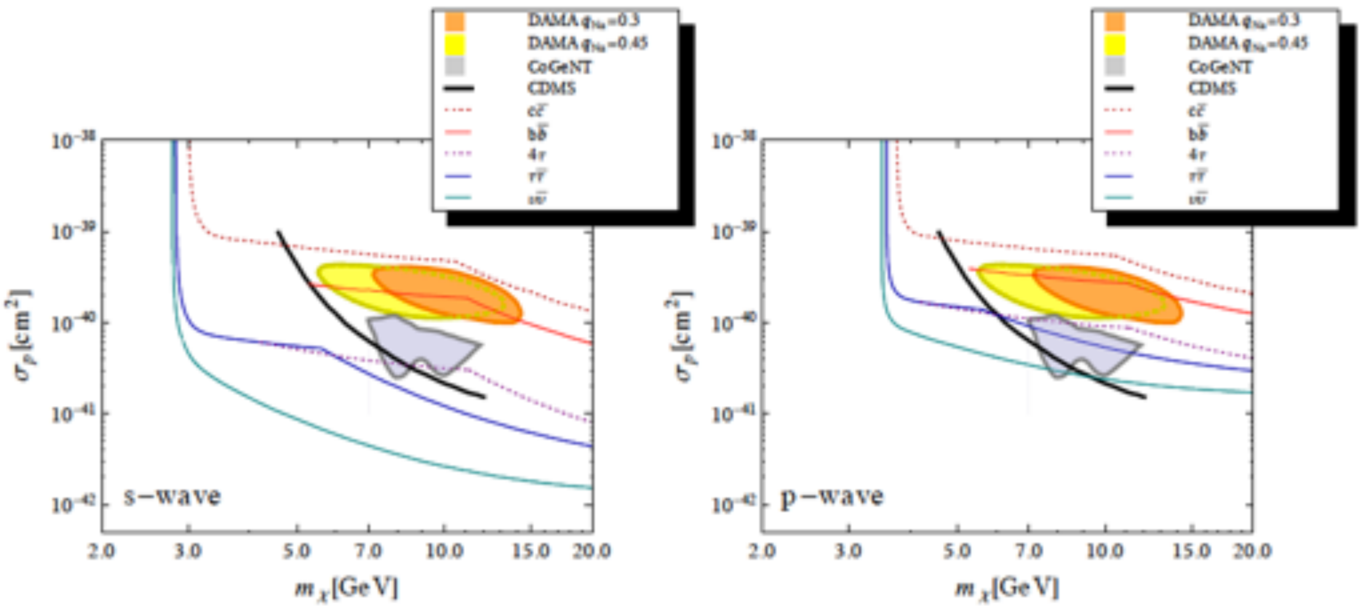
$$\Gamma_A = \frac{C_A}{2} {N_{\rm eq}}^2 = \frac{C}{2}$$

$$C \propto \sigma \, \rho_{\rm DM}$$

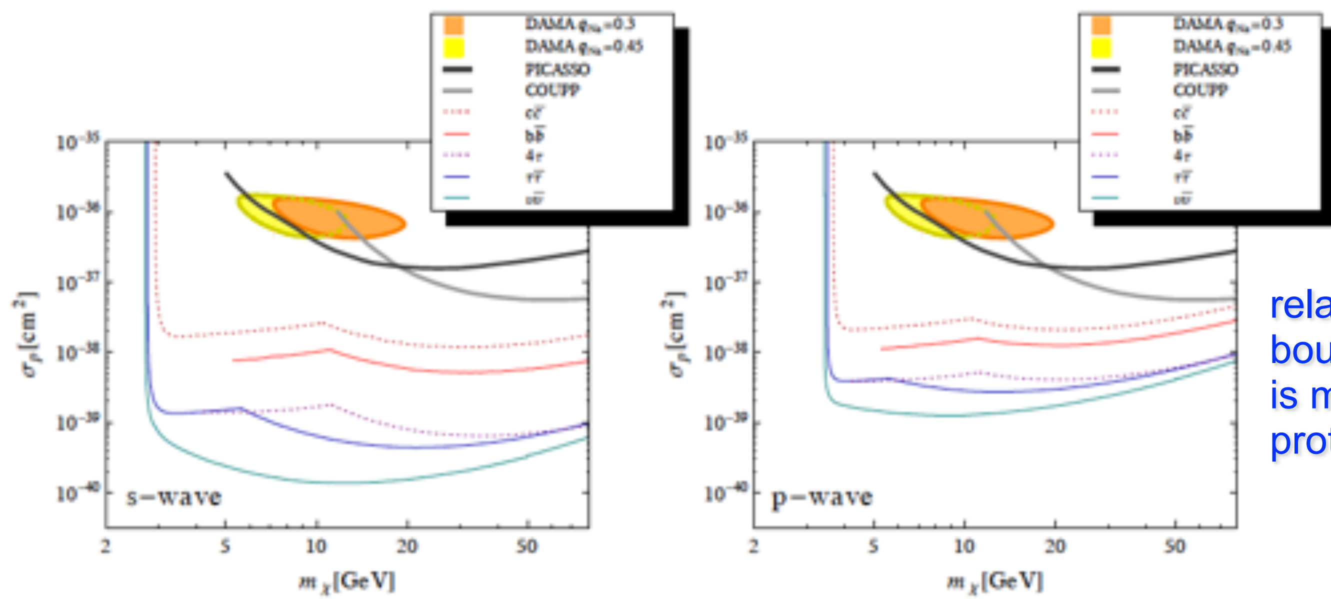
“just like” (although not exactly) DD experiments!

Recent neutrino bounds (from SK data)

SI



Kappl & Winkler 1104.0679

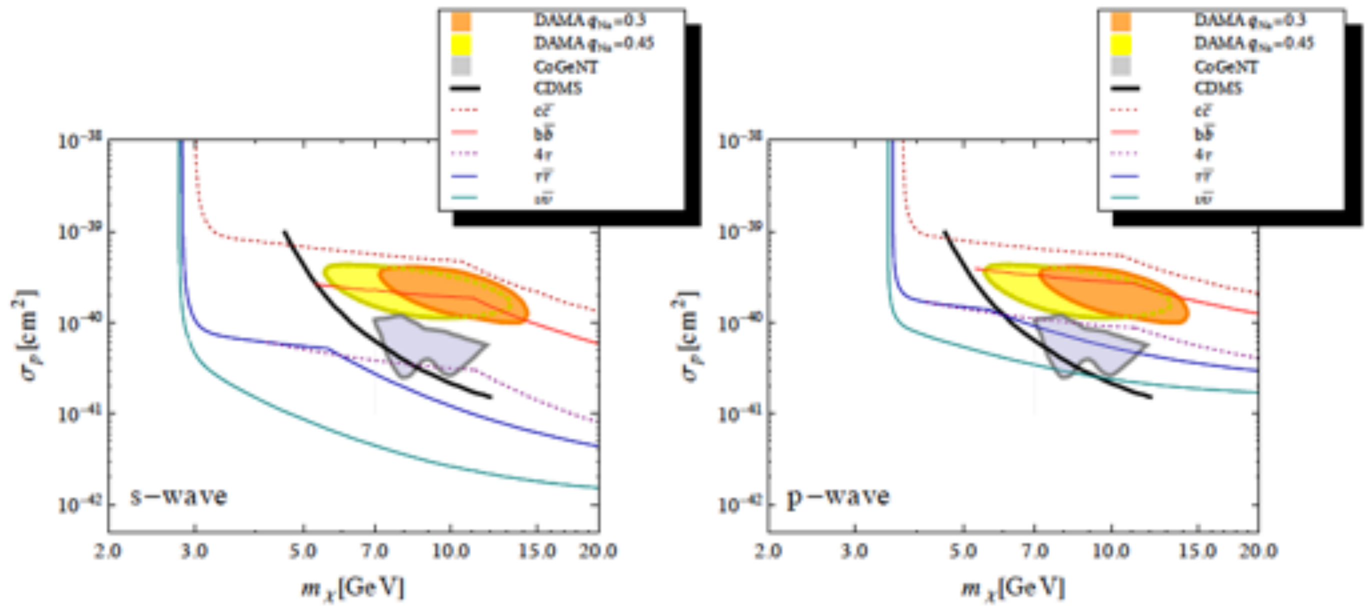


relatively stronger bounds, the Sun is made mostly of protons!

SD

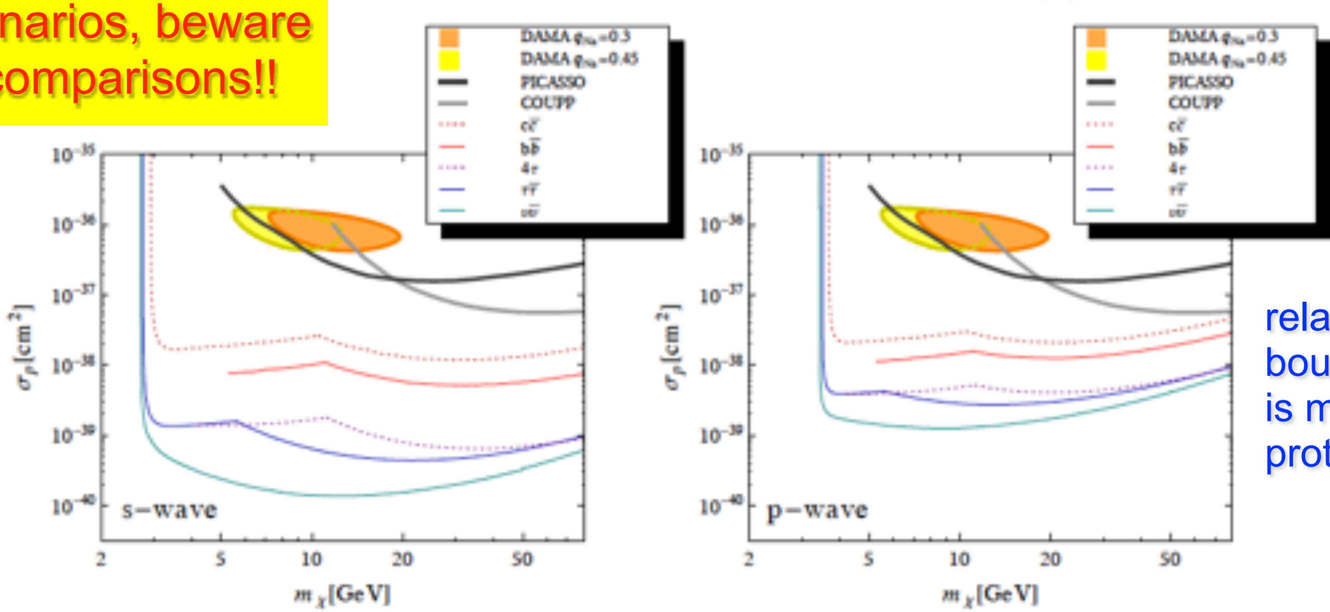
Recent neutrino bounds (from SK data)

SI



When going beyond simplest scenarios, beware of "naive" comparisons!!

Kappl & Winkler 1104.0679



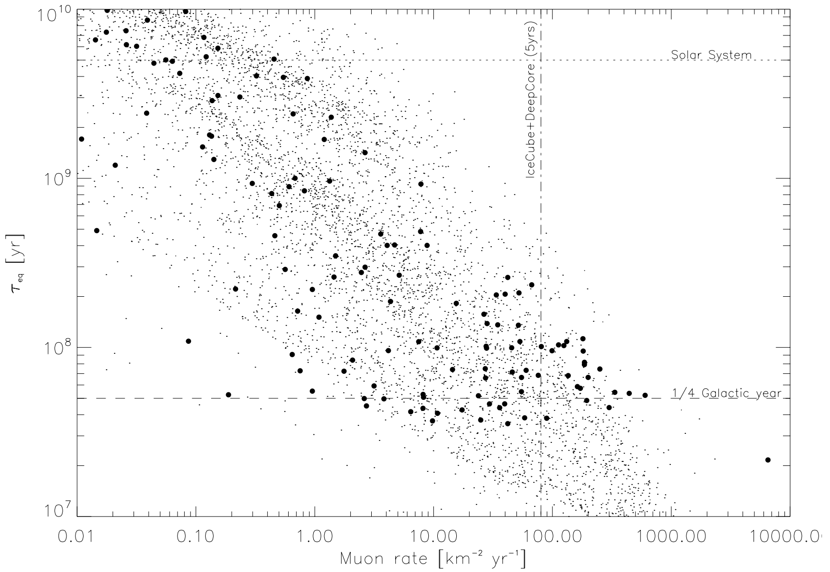
SD

relatively stronger bounds, the Sun is made mostly of protons!

Example

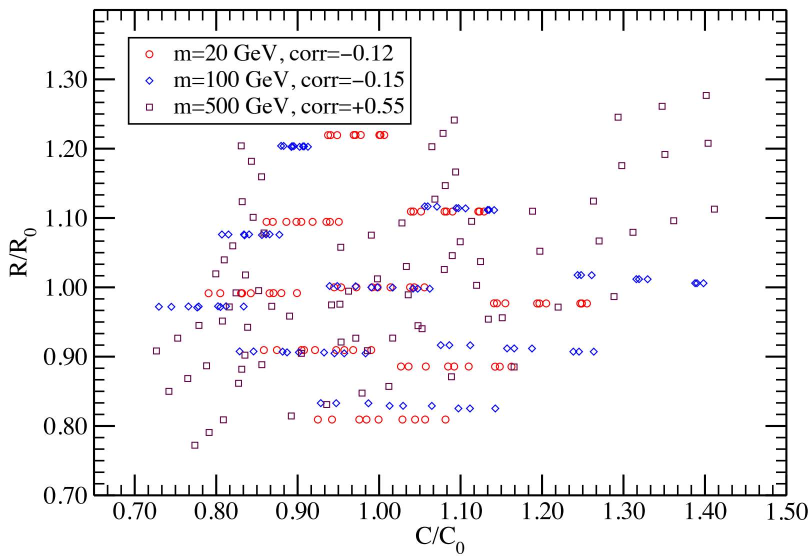
Most models yielding appreciable ν's from the Sun require an equilibration time comparable with the orbiting time of the Sun in the Milky Way

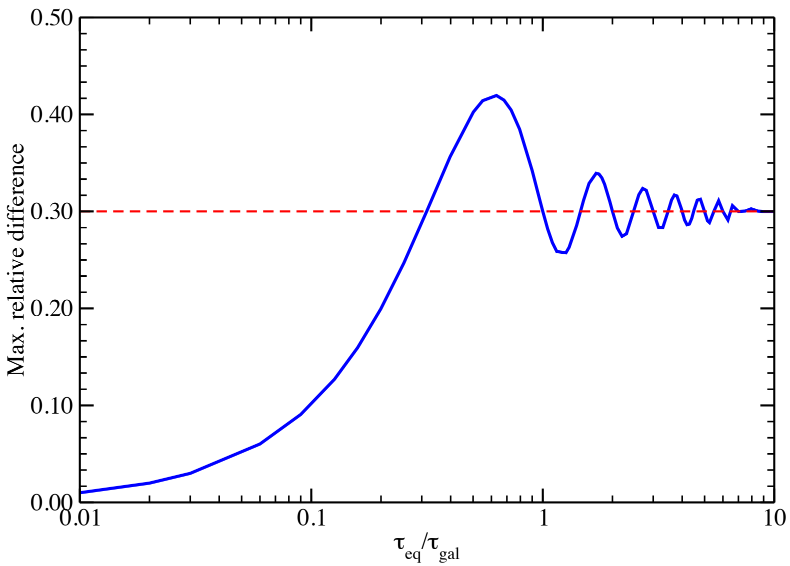
✤ The effective halo probed by the ν's and DD is different (in general it's triaxial)!
✤ There is a different sensitivity from underlying astro parameters!



Bounds can shift one wrt easily by a factor 2!

PS & Bertone 1006.3268



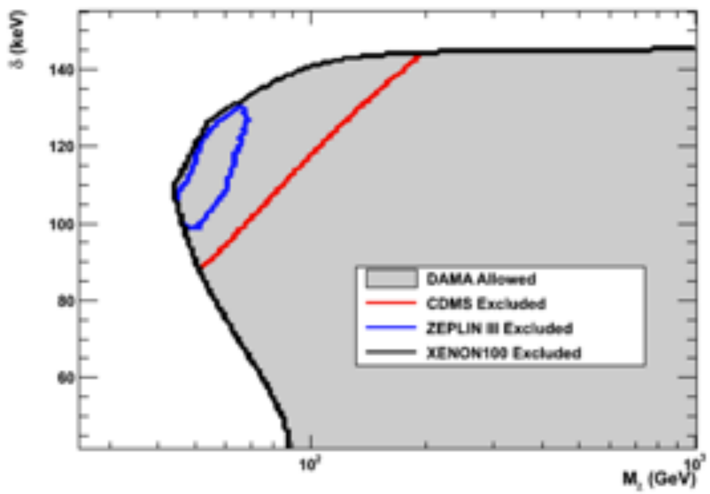


Some “exotic” models proposed...

- asymmetric models (from “technicolor”?) e.g. M. T. Frandsen, S. Sarkar, K. Schmidt-Hoberg, 1103.4350

- spin independent couplings to protons and neutrons, spin dependent couplings, momentum dependent scattering, and inelastic interactions
S. Chang, J. Liu, A. Pierce, N. Weiner, I. Yavin,1004.0697

just yesterday, the IDM interpretation seems to have been excluded by Xenon100!
E. Aprile et al. 1104.3121
(quite insensitive to astro details, like escape velocity...)

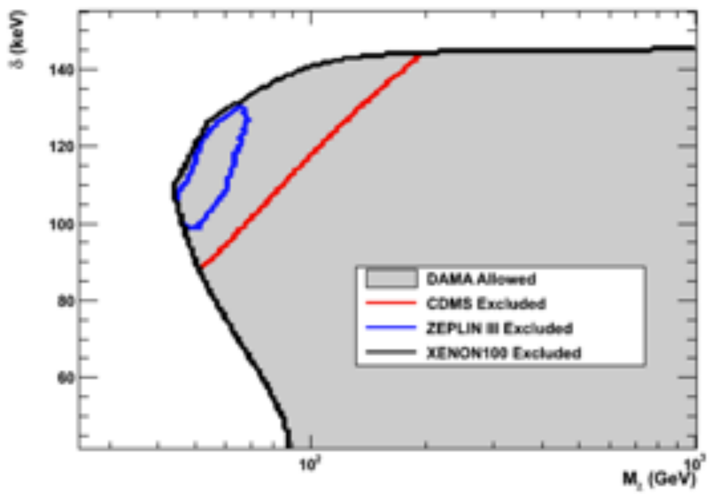


Some “exotic” models proposed...

- asymmetric models (from “technicolor”?) e.g. M. T. Frandsen, S. Sarkar, K. Schmidt-Hoberg, 1103.4350

- spin independent couplings to protons and neutrons, spin dependent couplings, momentum dependent scattering, and inelastic interactions
S. Chang, J. Liu, A. Pierce, N. Weiner, I. Yavin,1004.0697

just yesterday, the IDM interpretation seems to have been excluded by Xenon100!
E. Aprile et al. 1104.3121
(quite insensitive to astro details, like escape velocity...)



Although they often have some “predictions” for Colliders and/or DD, generically suffer of the same problem of the ID “solutions” previously discussed: unless they can be strongly motivated from particle physics, they require “breaking” some handle in the Dark Matter search program, hence lose predictivity

DM @ Colliders?

If the "WIMP paradigm" is correct, one can produce DM "as in the early universe", via

$$(SM)(SM) \rightarrow XX$$

- ✤ Main problem: the dominating channel (SM)(SM) → XX is obviously invisible.
- ✤ One may consider the "large $\not{E}$" channel (SM)(SM) → XXY with Y= γ, jet(s) unavoidably produced at least by initial state leptons/quarks.

DM @ Colliders?

If the "WIMP paradigm" is correct, one can produce DM "as in the early universe", via

$$(SM)(SM) \to XX$$

✤ Main problem: the dominating channel (SM)(SM) → XX is obviously invisible.
✤ One may consider the "large $\not{E}$" channel (SM)(SM) → XXY with Y= γ, jet(s) unavoidably produced at least by initial state leptons/quarks.

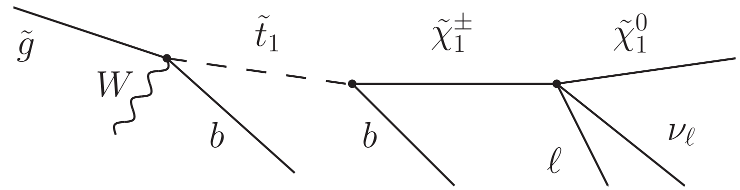
- At a future linear collider, such a "model-independent" approach should permit an intriguing check of WIMP cosmology paradigm (especially if some polarized beams are available)
Birkedal, Matchev and Perelstein [hep-ph/0403004], see also 0902.2000

- For typical candidates, the analogous signal with jet(s) at LHC is much smaller than background, and suffers in S/B optimization from the probabilistic distribution of energy in the parton-parton system (e.g. no hard cut on jet energy is possible)
E.g. Feng, Su, Takayama hep-ph/0503117

The model-dependent way

<u>Dark Matter studies at LHC are model-dependent.</u>

Either one can limit oneself to processes involving "chains" ending with large $\not{E}$, which allow at most to check if a "stable" particle (on detector scale!) has been produced, and in some cases to constrain its mass (scale).



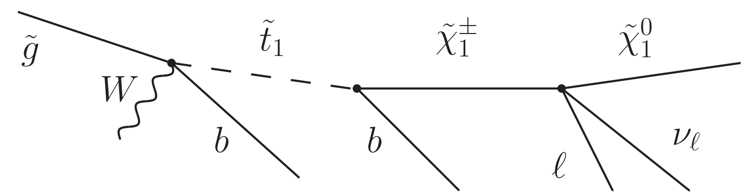
$$M_{\rm eff} = \sum_i p_T^{{\rm jet},i} + \sum_i p_T^{{\rm lep},i} + E_T^{\rm miss}$$

For a review, Barr & Lester 1004.2732

The model-dependent way

Dark Matter studies at LHC are model-dependent.

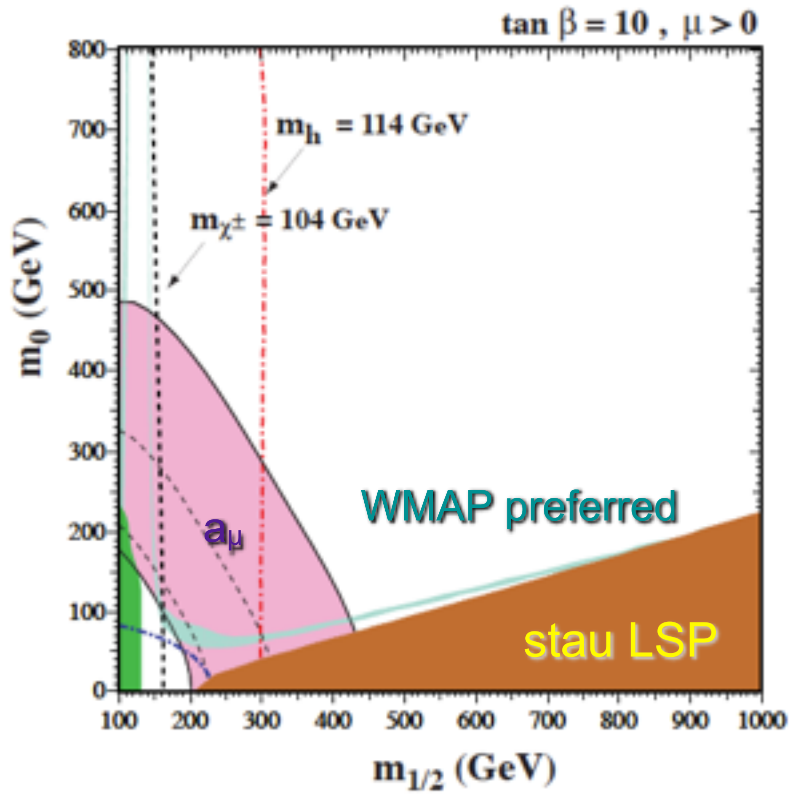
Either one can limit oneself to processes involving "chains" ending with large $\not{E}$, which allow at most to check if a "stable" particle (on detector scale!) has been produced, and in some cases to constrain its mass (scale).



$$M_{\rm eff} = \sum_i p_T^{{\rm jet},i} + \sum_i p_T^{{\rm lep},i} + E_T^{\rm miss}$$

For a review, Barr & Lester 1004.2732

Alternative Strategy: Pick "benchmark" models (e.g. in CMSSM), derive bounds on DM from bounds on "observable" object and theoretical relations, with plots e.g. in m_0-$m_{1/2}$ for different tan β... hope to learn "generic lessons"



For a review, Ellis & Olive 1001.3651

P.S.: if you wonder about color choice, be aware that K. Olive is color-blind...

The EFT approach

The major drawback of previous study is their lack of generality. More recently, people have been considering EFT where DM-SM interactions are described by higher-order, non-renormalizable effective operators, which allow however to compare parametrically the reach of "widely different" search strategies. E.g., for a Dirac fermion:

$$\mathcal{L} = \mathcal{L}_{SM} + i\bar{X}\gamma^{\mu}\partial_{\mu}X - M_X \bar{X}X + \sum_q \sum_{i,j} \frac{G_{qij}}{\sqrt{2}} \; [\bar{X}\Gamma_i^X X] \, [\bar{q}\Gamma_q^j q]$$

Beltran, Hooper, Kolb, Krusberg, Tait, 1002.4137
Goodman et al, 1005.1286 (majorana)
Goodman et al, 1008.1783 (dirac, scalar)
M. Buckley, 1104.1429 (EFT for asymmetric DM)

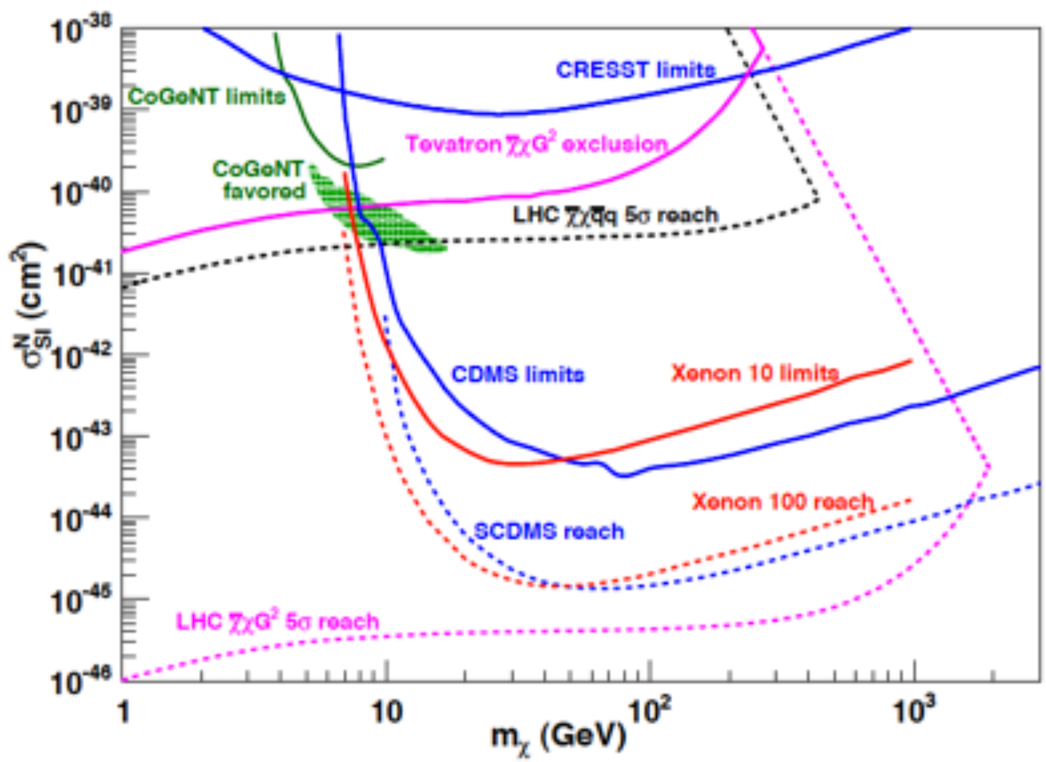
The EFT approach

The major drawback of previous study is their lack of generality. More recently, people have been considering EFT where DM-SM interactions are described by higher-order, non-renormalizable effective operators, which allow however to compare parametrically the reach of “widely different” search strategies. E.g., for a Dirac fermion:

$$\mathcal{L} = \mathcal{L}_{SM} + i\bar{X}\gamma^\mu\partial_\mu X - M_X\bar{X}X + \sum_q \sum_{i,j} \frac{G_{qij}}{\sqrt{2}} \; [\bar{X}\Gamma_i^X X]\,[\bar{q}\Gamma_q^j q]$$

Map the effective operators into signatures of missing energy+jet(s) as well as DD cross sections.
Remarkable bounds already now!

Of course breaks down when/if BSM physics at low scale is present, hence it is complementary to explicit models



Beltran, Hooper, Kolb, Krusberg, Tait, 1002.4137
Goodman et al, 1005.1286 (majorana)
Goodman et al, 1008.1783 (dirac, scalar)
M. Buckley, 1104.1429 (EFT for asymmetric DM)

The moment of truth for χ detection? It's Higgs time!

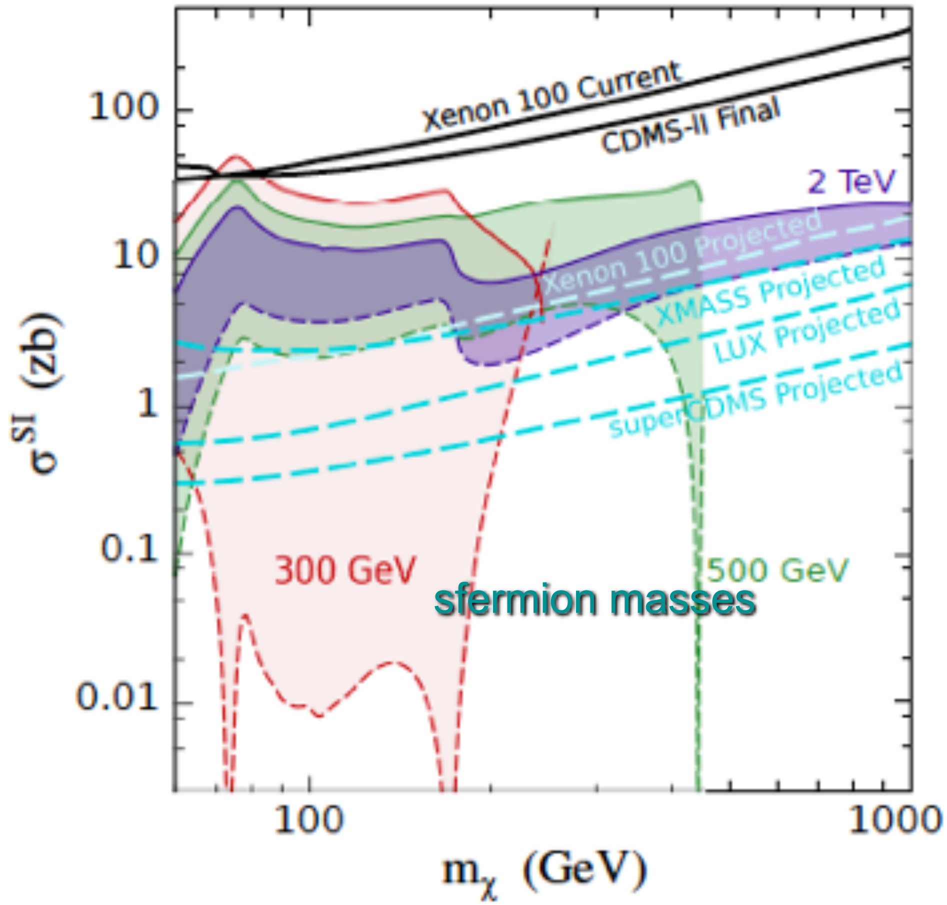
Past efforts in DD already excluded "large" scatterings via Z-exchange (e.g. sneutrino DM candidates)

Generically (barring cancellations, resonances, etc.) we expect for neutralinos that the (lightest) higgs exchange channel dominates scattering

$$\sigma^{\rm SI} \propto \frac{a_{\tilde{H}}^4}{m_h^2} \approx 1 - 40\,{\rm zb}$$

Higgsino content typically fixed within factor 2 by relic abundance; while the denominator by lightest higgs bounds. Generic prediction usually relaxed only for "light" sfermions (hence "easier" discovery at LHC!)

Feng & Sanford 1009.3934



The moment of truth for χ detection? It's Higgs time!

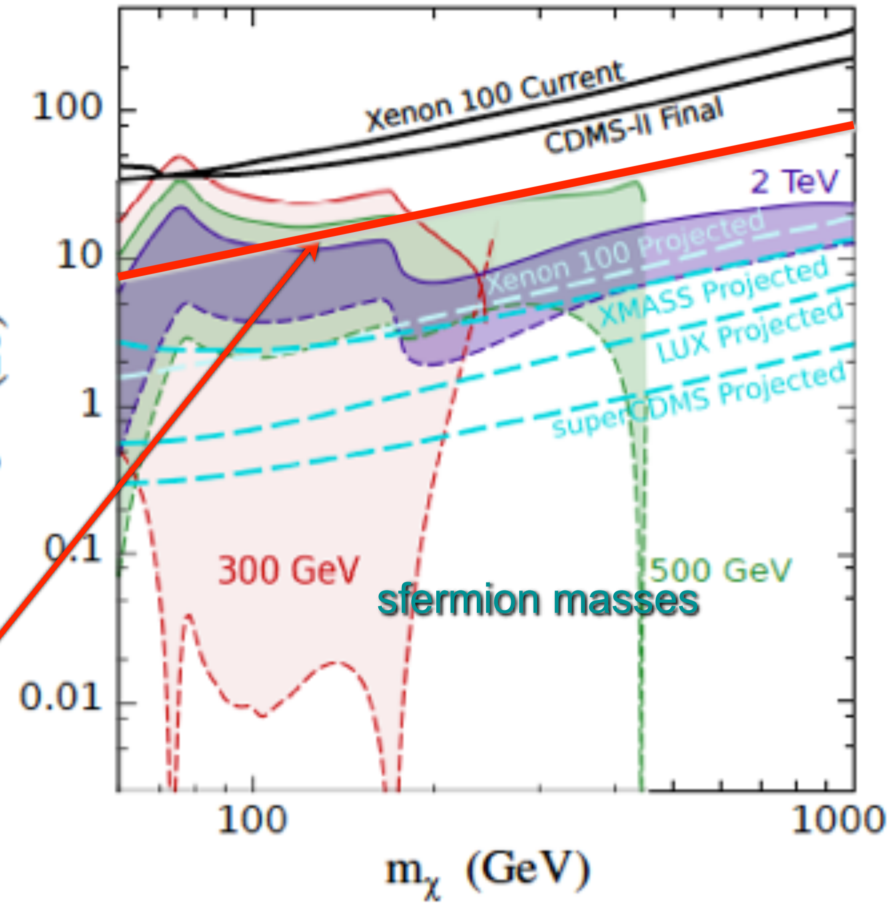
Past efforts in DD already excluded "large" scatterings via Z-exchange (e.g. sneutrino DM candidates)

Generically (barring cancellations, resonances, etc.) we expect for neutralinos that the (lightest) higgs exchange channel dominates scattering

$$\sigma^{SI} \propto \frac{a^4_{\tilde{H}}}{m^2_h} \approx 1 - 40\,\mathrm{zb}$$

Higgsino content typically fixed within factor 2 by relic abundance; while the denominator by lightest higgs bounds. Generic prediction usually relaxed only for "light" sfermions (hence "easier" discovery at LHC!)

Feng & Sanford 1009.3934

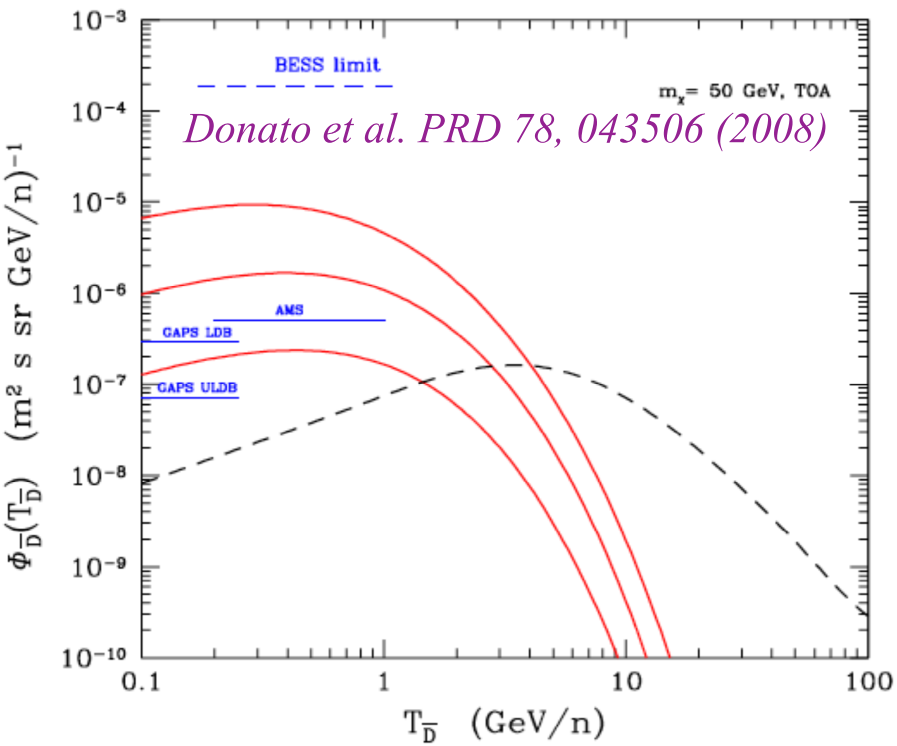


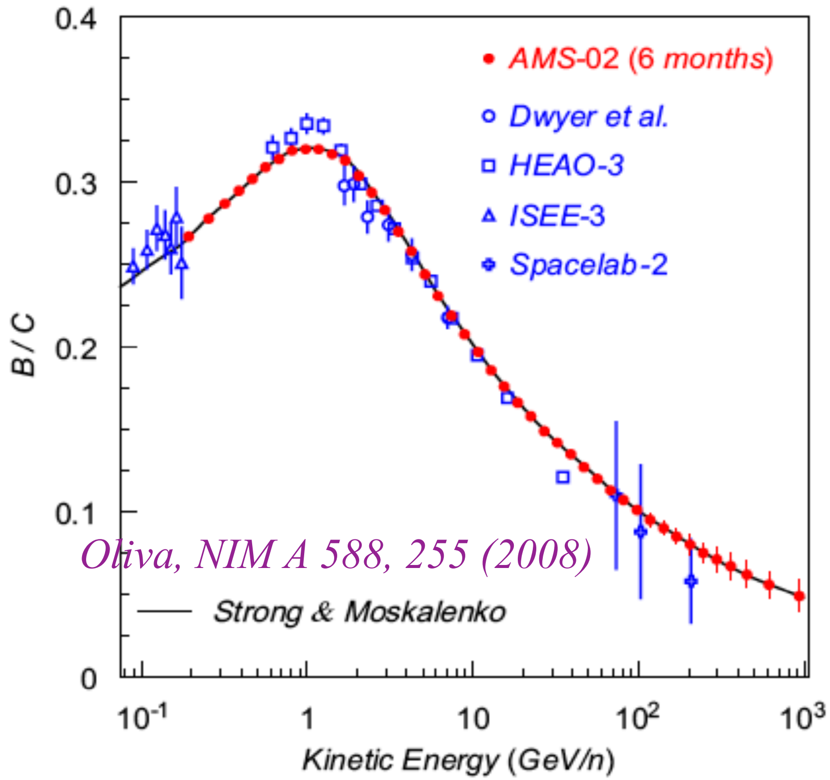
current Xenon100: discovery or significant test within 1 order of magnitude!

ID, what have we learned?

With a few “hints” still debated, most indirect signatures told us that DM signals are not dominant. New “backgrounds” have been discovered/discussed. Before PAMELA, the attitude was that the major uncertainties in antimatter background searches were due to propagation parameters. A large(r) community now appreciates that a greater limitation comes from lack of knowledge of the sources

Shortly AMS-02 (and gamma-ray experiments) should provide further checks of the internal consistency of a simple model of CRs without primary sources of antimatter. The field is being re-defined by high-quality data, extending over a larger dynamical range.

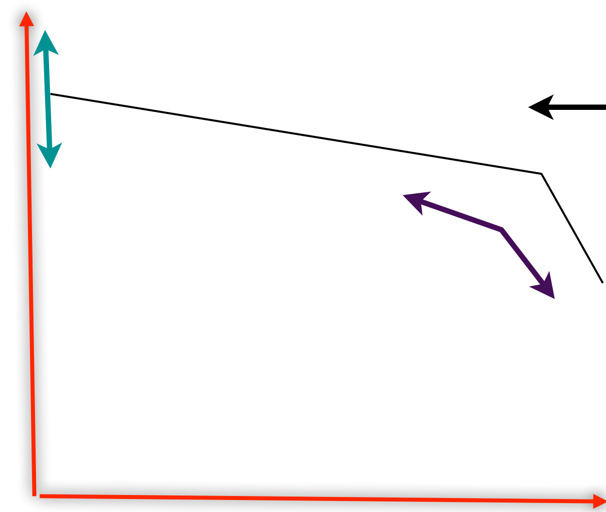




Can a CR dataset be fitted in terms of a DM model?

It’ an ill-posed question. The generic answer is in fact “Yes”, rather than “No”!
In fact, one has enough handles to control:
a) spectral shape b) endpoint/Energy scale c) normalization...

adjust σ or Γ,
or DM profile
(also controls
ang. shape!)



adjust mass

for the shape,
adjust final state &/or
propagation parameters

The real issue for detection is:
can one give a consistent explanation of many phenomena?
Can one explain unexplained features in a predicted way which
cannot be understood by known astrophysics? Perhaps in a
few cases, like γ lines, low-energy anti-D, high-energy ν‘s from the Sun

Outlook

Astrophysics and Cosmology tell us a lot: that new physics is there!
However, they do not tell us its scale, and blind searches are more and more challenging, facing to unknown astrophysics.

This is the "golden age" for direct searches and colliders!
It's advisable to go back to the "standard practice": experiments must guide us to BSM physics, following the new (old!) pipeline:
Particle Physics progress → Theory Framework → Prediction for indirect, allowing a priori searches

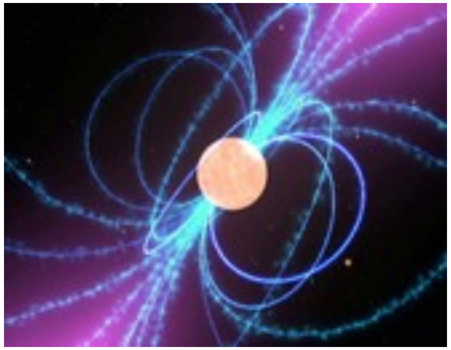
If a signal is found in other channels (collider/DD) We still *need* ID:

- To confirm that whatever we find in the Lab is the same "dark stuff" responsible for astrophysical and cosmological observations.
- To access particle information not otherwise available in the Lab (annihilation cross section or decay time, b.r.'s)
- to infer cosmological properties of DM (e.g. power spectrum of DM at very small scales) not accessible otherwise.

Consistency Checks/constrained searches way more promising than blind ones
ongoing/near future ID experiments will help with more sensitivity and precision

ongoing/near future ID experiments will help with more sensitivity and precision

So, finally, what causes "the rise"?

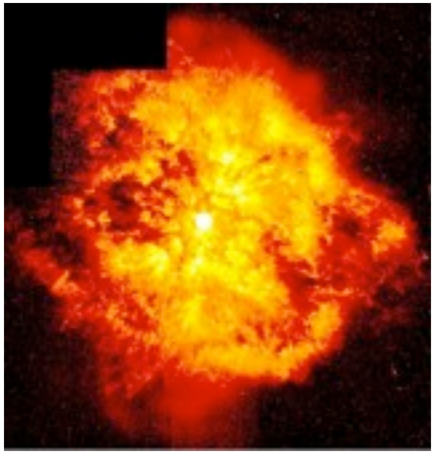


Pulsar Wind Nebulae

- Complex astrophysics, no "robust predictions"
- "Natural" normalization; shape of the signal consistent
- Purely e.m. cascade, explains why no anti-p & no ν
- No consensus on how to produce hard spectra with O(10%) efficiency, but: 1. they are observed! 2. some models do exist.

Mature SNRs *(standard source of CRs!!!)*

- In situ production is certain at some level. Naively, hard spectra ($\sim E^{-2}$) are expected, hard enough to hamper DM searches at TeV scale, not enough to explain the raise.
- Blasi conjectured that e.g. by non-linear effects still harder spectra can be achieved (*injection in the acceleration region, which grows in size with E*). Hard to calculate reliably a priori, can be answered observationally.
- Prediction of high-energy feature in anti-p, S/P nuclei

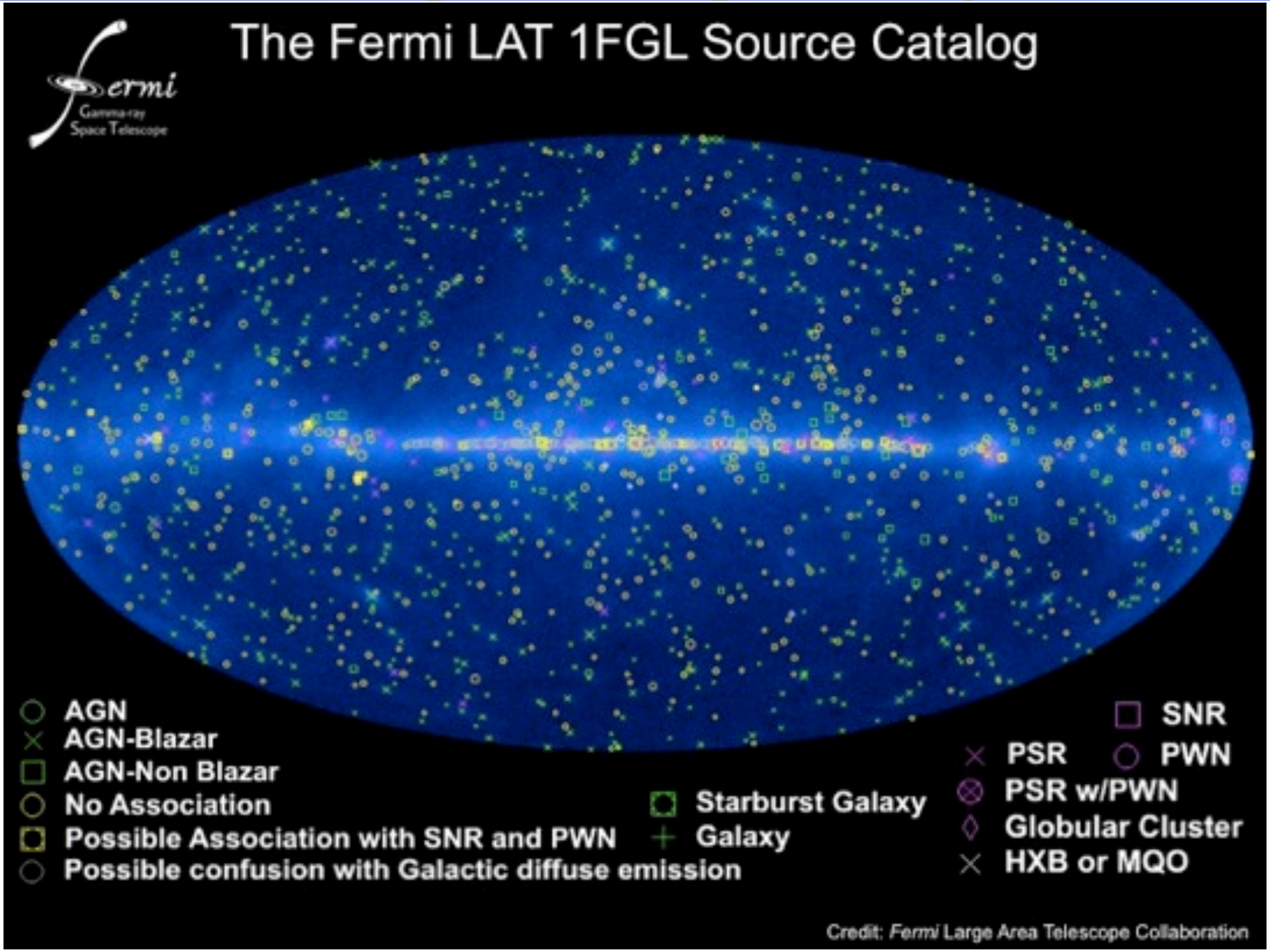


"Special" objects?

- Local "monster", GRBs, μ-QSO,contribution from WR stars... The latter linked with recently observed hardening in CRs?

Should ring a bell: apart for propagation uncertainties, how well do we know the astrophysical backgrounds (i.e. sources)?

Note: there is a big advantage for any astro model...



All invoked sources are know to exist. The particle physics nature of DM remains to be proven: We are still in the discovery phase, rather than in the property-fitting stage!

The “excitement” explained: BSM physicists psychology

Everything we see hides another thing, we always want to see what is hidden by what we see.

R. Magritte

The Promenades of Euclid