Dark Matter Indirect Detection (theoretical aspects)

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LAPTh
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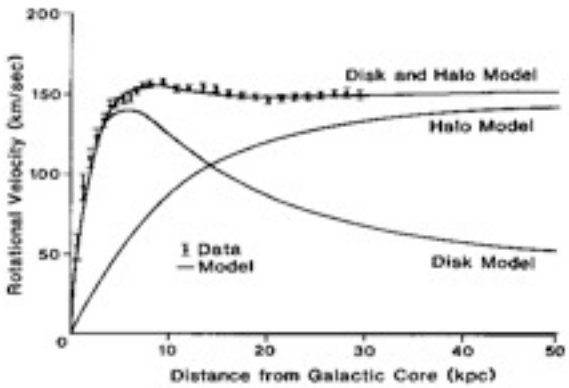
Outline of the talk

- Some generalities on DM and detection strategies to put recent activity in context
- “Summary” of the latest years of research in indirect detection and some new claims
- Some links with proposals inspired by Direct Detections or theoretical ideas [depending on time...]
- Conclusions: what have we learned? Perspectives

DM already detected indirectly: gravity!

Rotation curves of Galaxies



Galaxy Clusters

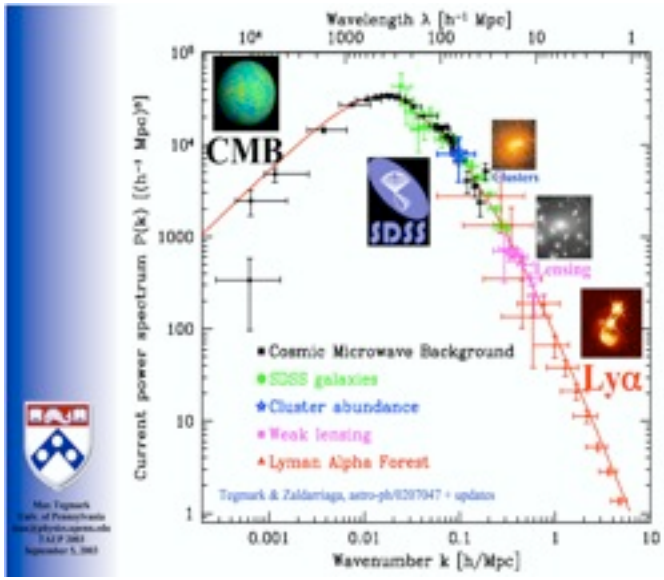
Lensing

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

Something people forget about (sometimes)

There is no astrophysical or cosmological evidence whatsoever for the electroweak scale being the right one for explaining the DM problem.

The logic has always been the opposite: since the EW scale can be motivated by particle physics, then it might offer "natural" candidates for the DM problem while being accessible to a multi-disciplinary strategy.
The WIMP paradigm only makes sense from a "top-down" perspective.

If one gives away particle physics/BSM motivation there is no special motivation in looking for signatures of DM in HE astrophysics @ GeV-TeV.
"Anomalies" exist in astro data also in radio, visible, X-ray, MeV bands...
DM is clearly not the answer to any astrophysical puzzle.

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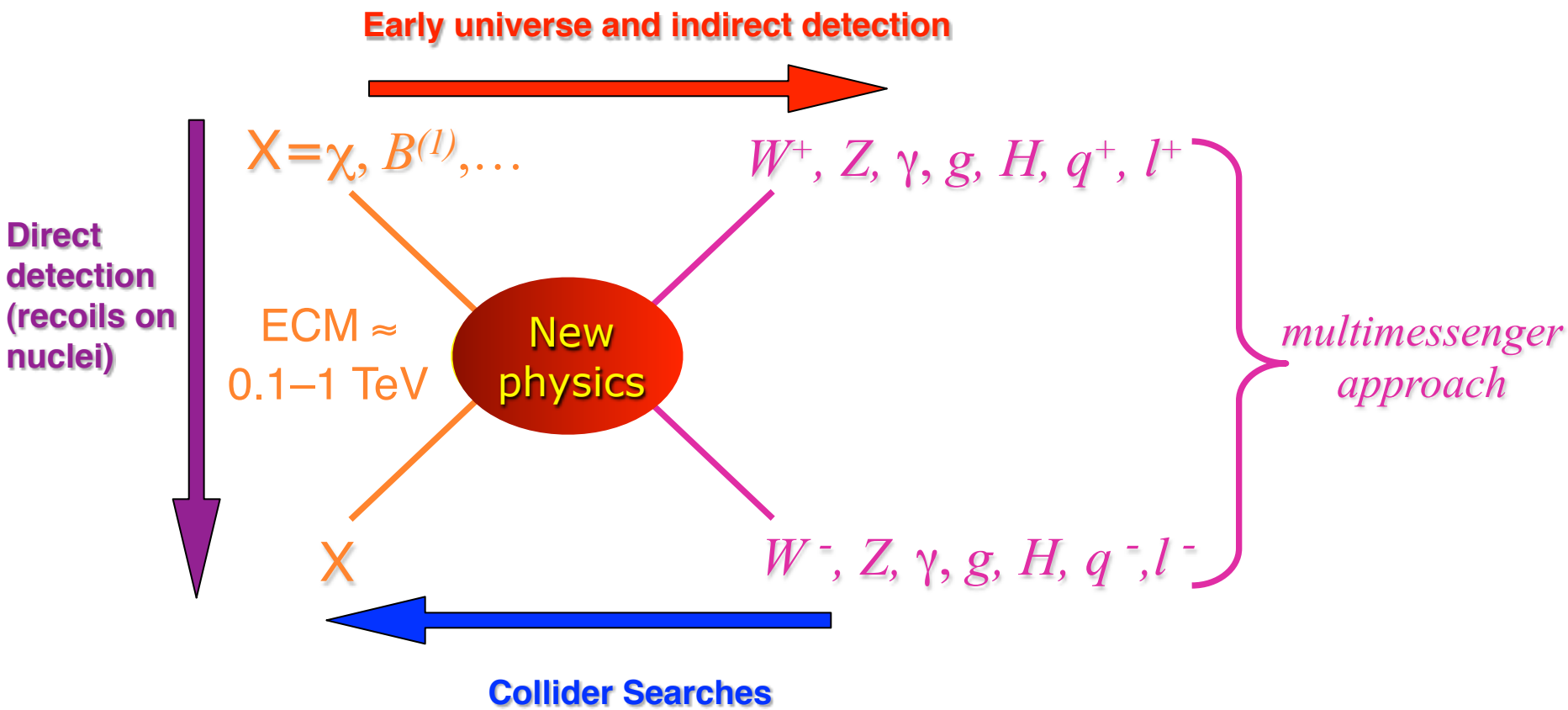
If one is willing to play within these "rules", here's what follows:

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

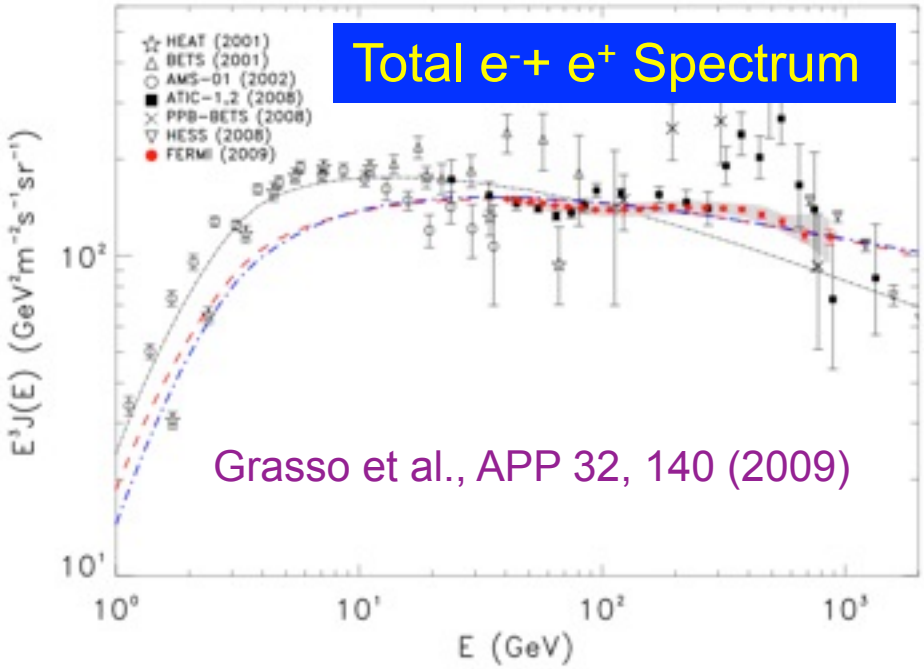
Data → **Assume** DM explanation → *Creative* Model building to fit the data.

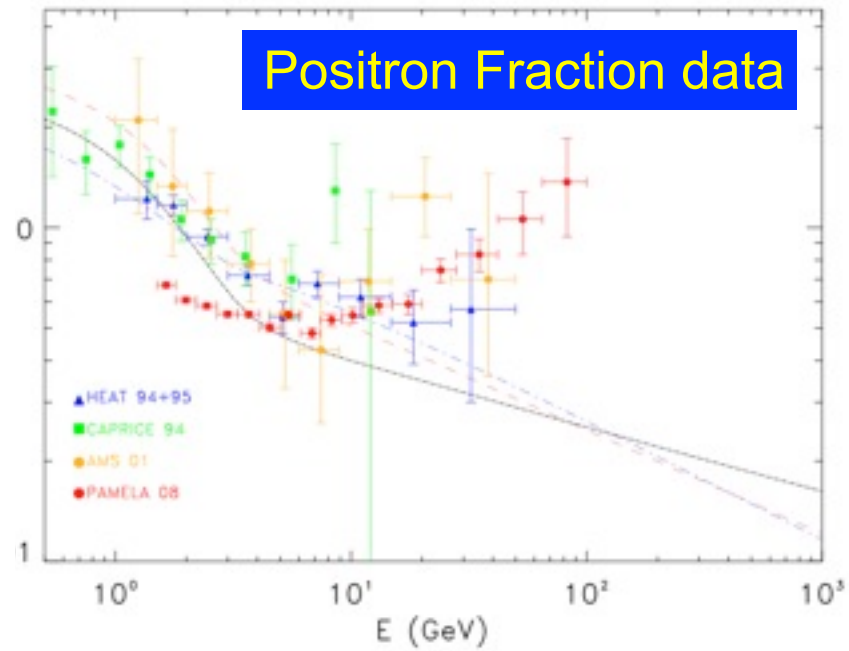
- "Beyond the WIMP paradigm", relax one or more assumptions and explore consequences for DD, ID, Colliders.

- 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?

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

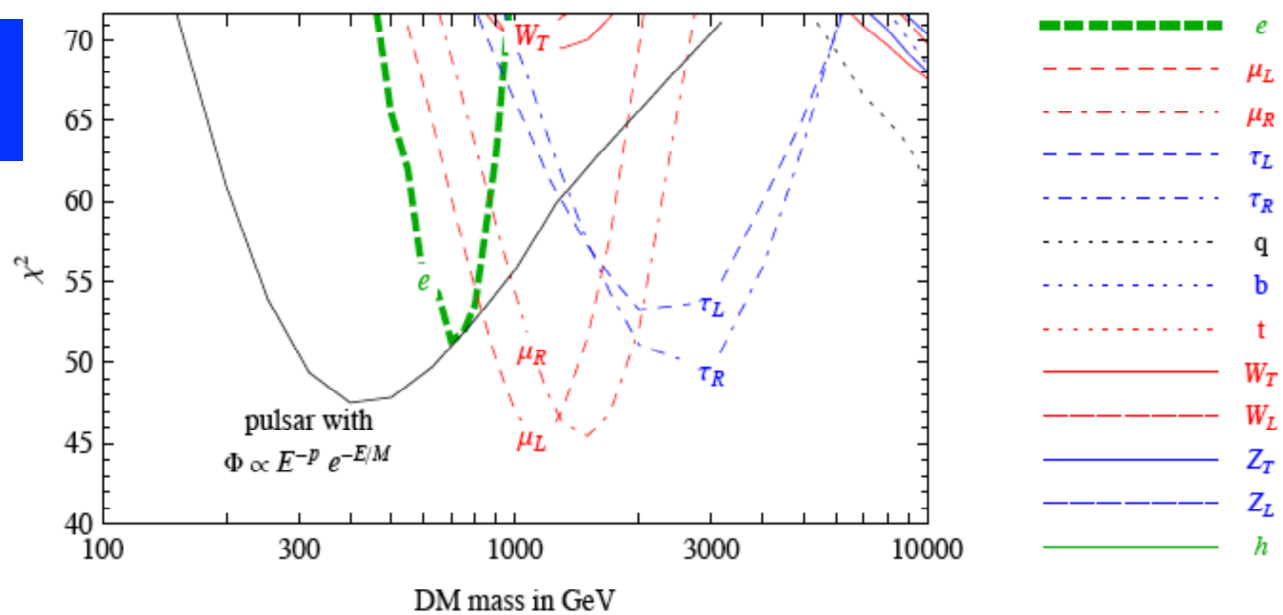
No need to recall you the data excitement...





Fit to different Dark Matter models

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



... nor the burst of Creative (Dark Matter) Writing

Double-action
Axion-portal
Secluded
Lorentz-violating
scalar
Gaugino
Leptophilic
Sneutrino
Cascade
R-PARITY
Sommerfeld
HIGGSINOS
Singlinos
Unparticle
Nonabelian
singlet
split-UED
split-SUSY
Minimal
EXTENDED MSSM
Hidden
Annihilation
Inert
Kinetic-Mixing
Effective
Kaluza-Klein
Higgs-Portal
Decaying

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 generic 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)
- Non-thermal relic and/or decaying relics (more parameters)

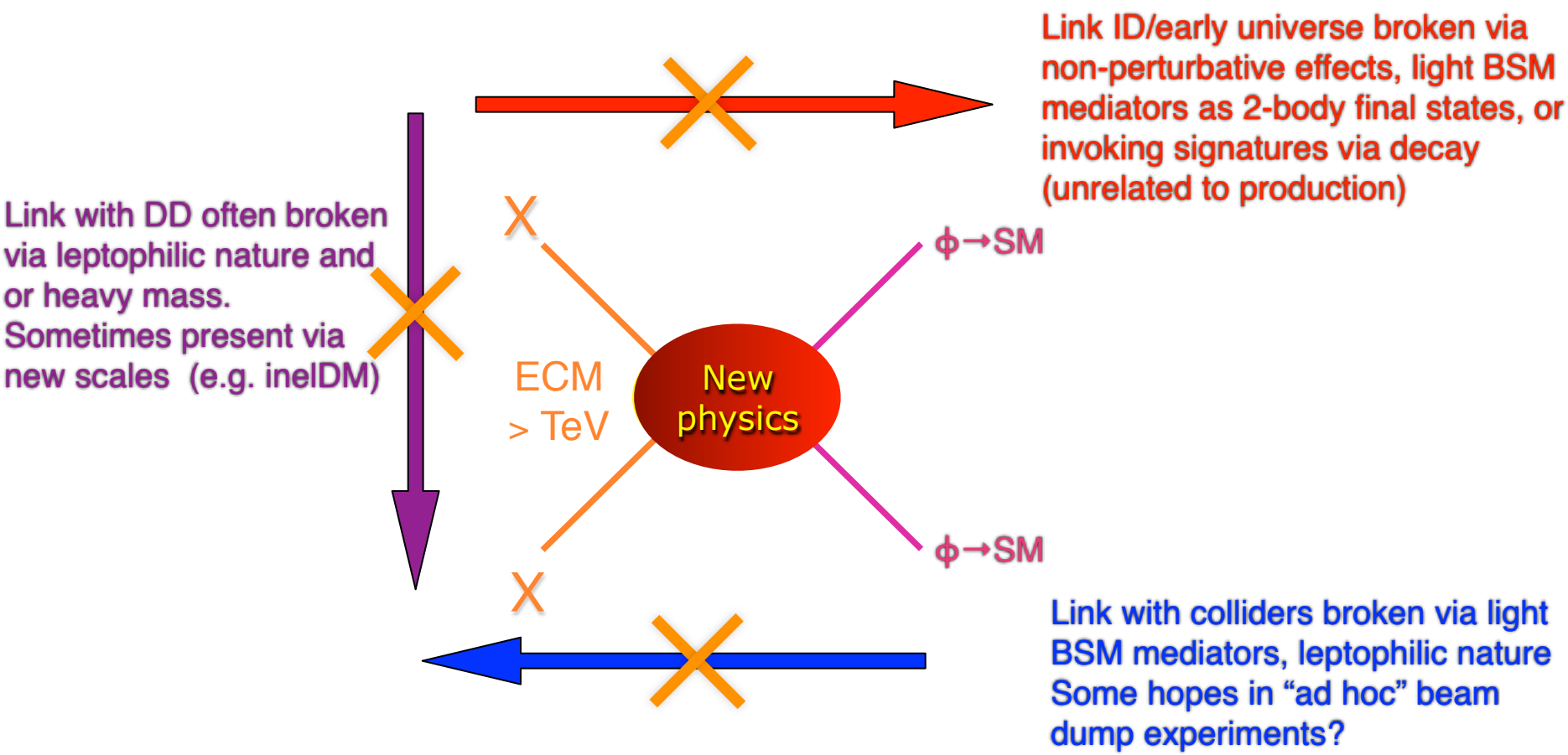
Requires a dominant b.r. in leptonic final states

(common to decaying dark matter models, too)

Common features

Significant levels of "model-engineering" and fine-tunings are required and usually stringent bounds/exclusions from gamma rays, from radio-signals, from cosmology, etc.

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



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

Are “standard” calculations of IDM signatures reliable?

Heavy, leptophilic DM candidates imply that most indirect signatures in CRs are at $E \ll m$.
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 (W,Z-strahlung, 3-body from sub-threshold virtual states...)

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

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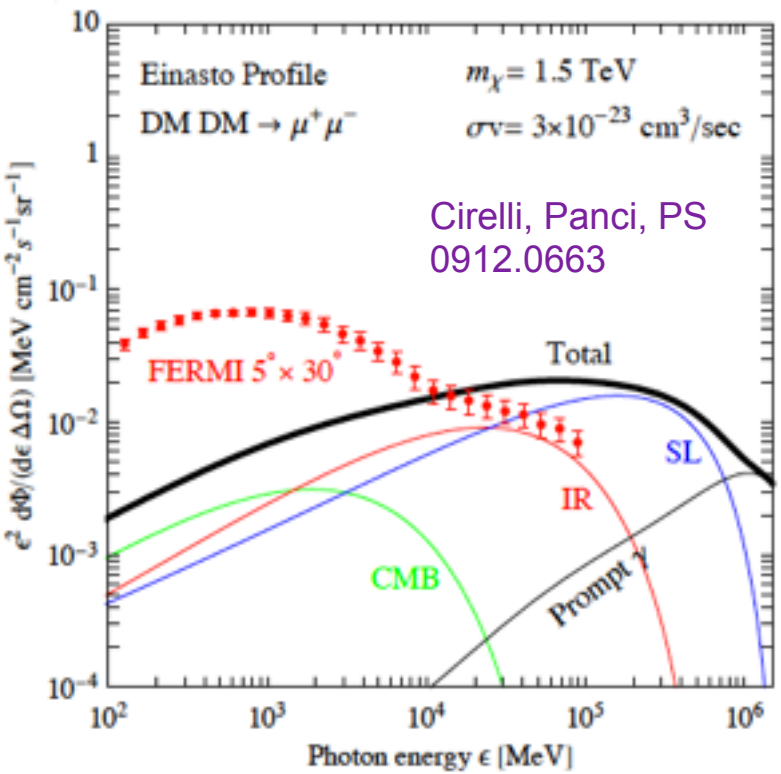
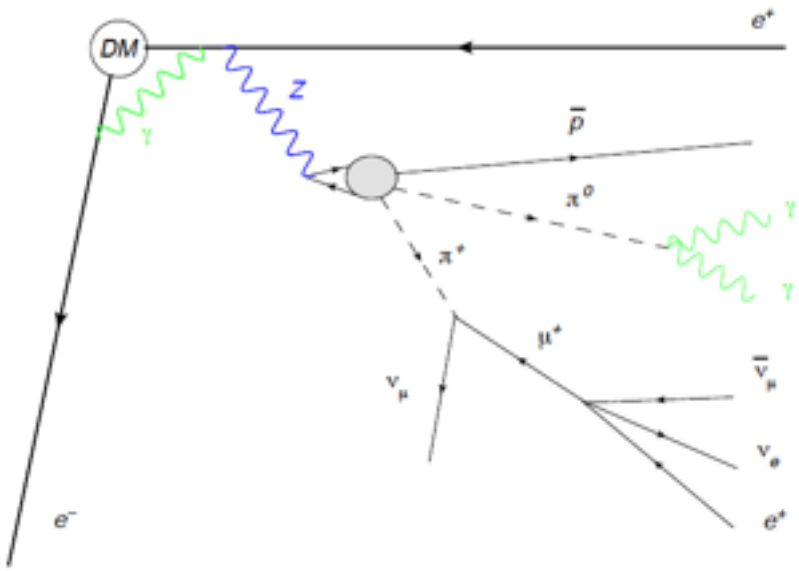
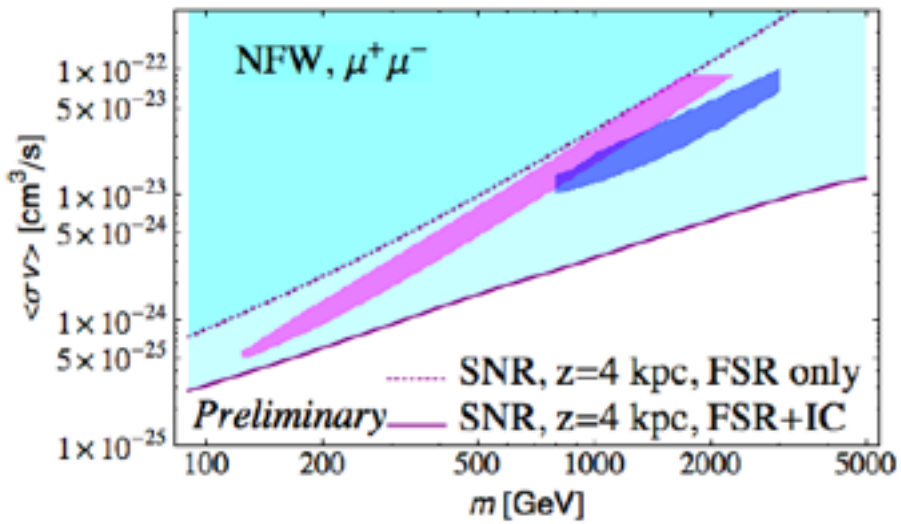
- ✓ γ signatures are present at high latitudes.
- ✓ Leptophilic models do have b.r. in other channels
- ✓ e± spectra are softer and fits typically worsen

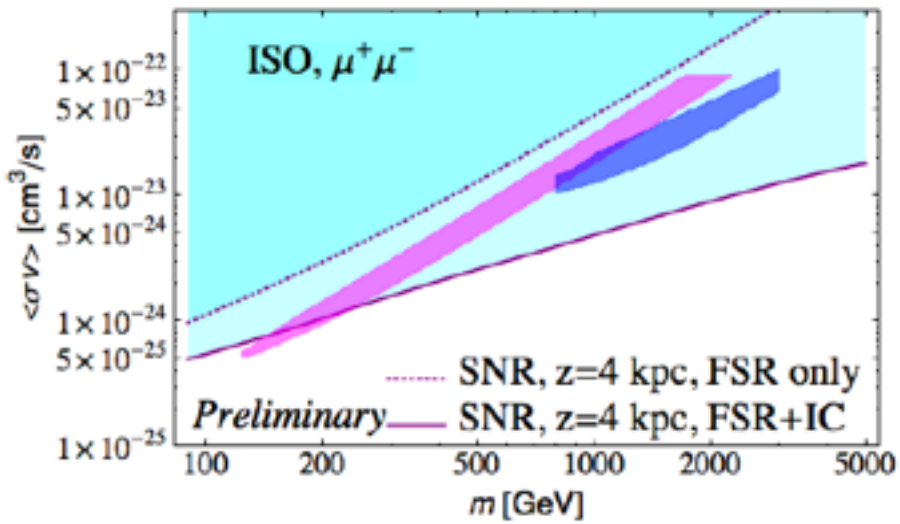
Kachelriess, PS 0707.0209
Bell, Jacques, Dent, Weiler '08-'11
Kachelriess, PS, Solberg 0911.0001
Yaguna,1003.2730
Ciafaloni et al. 1009.0224, 1104.2996
...





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

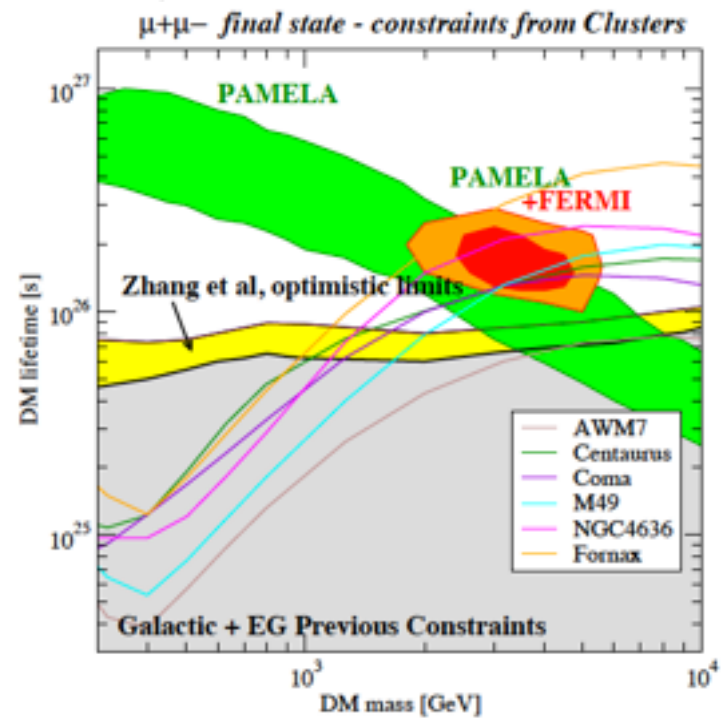




Zaharijas et al. [Fermi-LAT], 1012.0588 (diffuse galactic emission)

- ⋆ *Constraints from: antiprotons, γ's (some examples shown), radio, cosmology...*
- ⋆ *At the moment, most scenarios are ruled out and a few "contrived" ones barely survive.*

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



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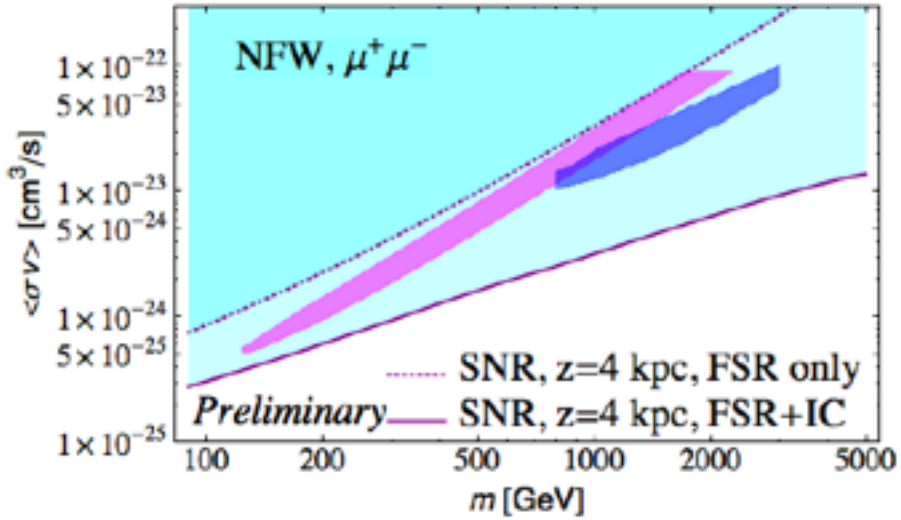

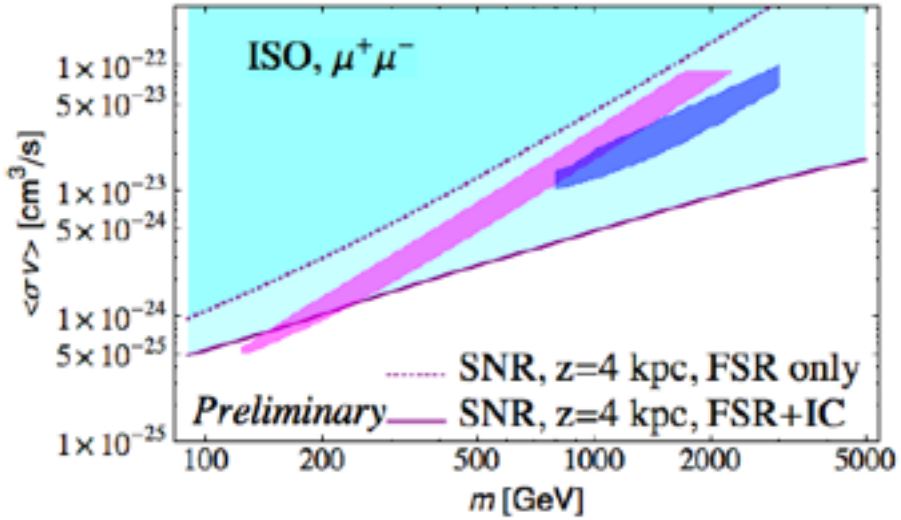

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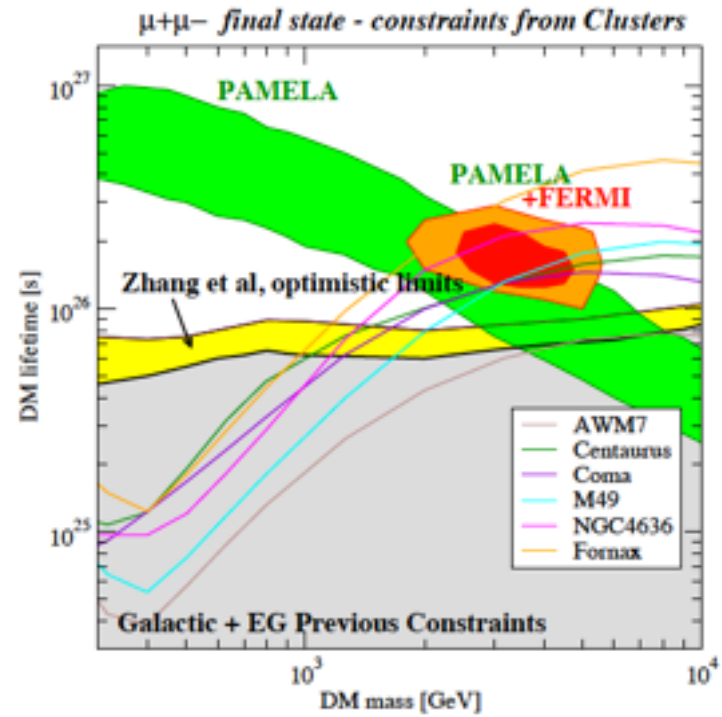

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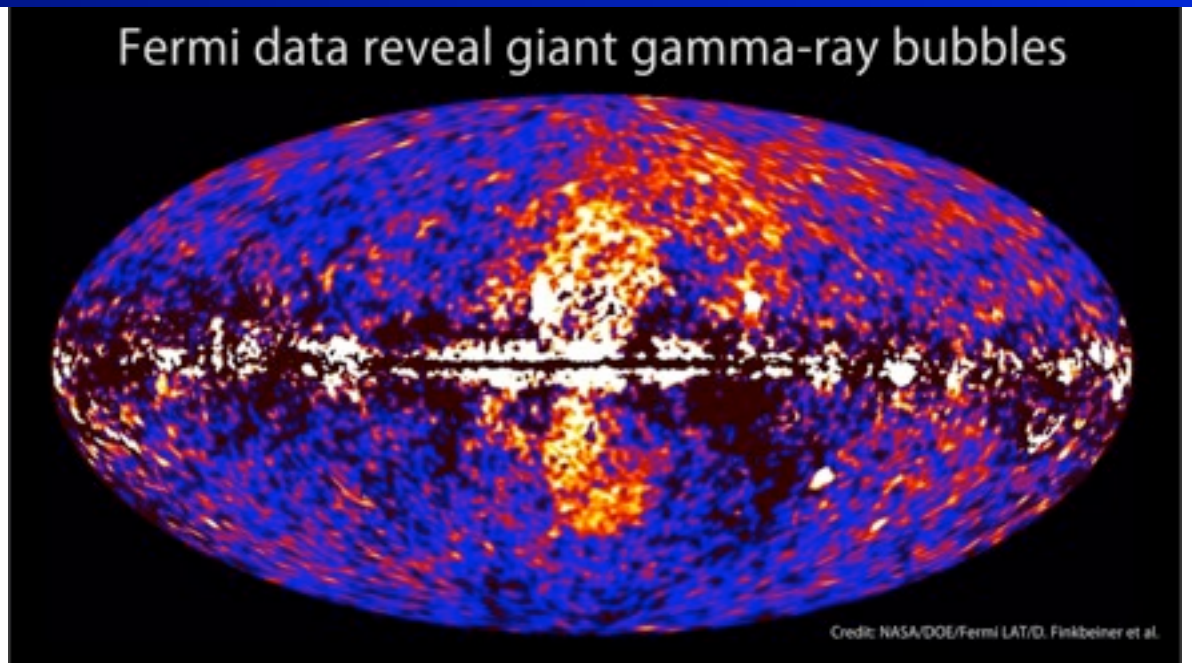
So, what causes the rise? Plenty of astrophysical candidates...

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”

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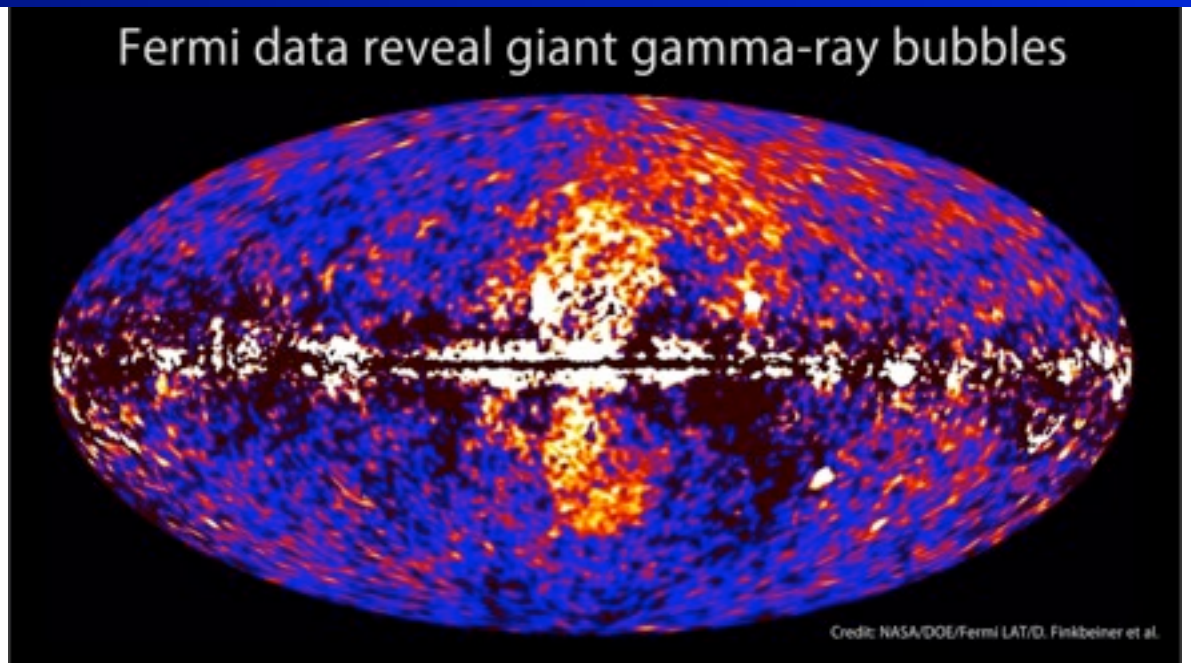

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Interpretation: "it is the inverse Compton emission generated by the same electrons which generate the microwave synchrotron haze at WMAP wavelengths[...] *a model of Galactic cosmic-ray diffusion* that incorporates *both an ordered and turbulent* 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:

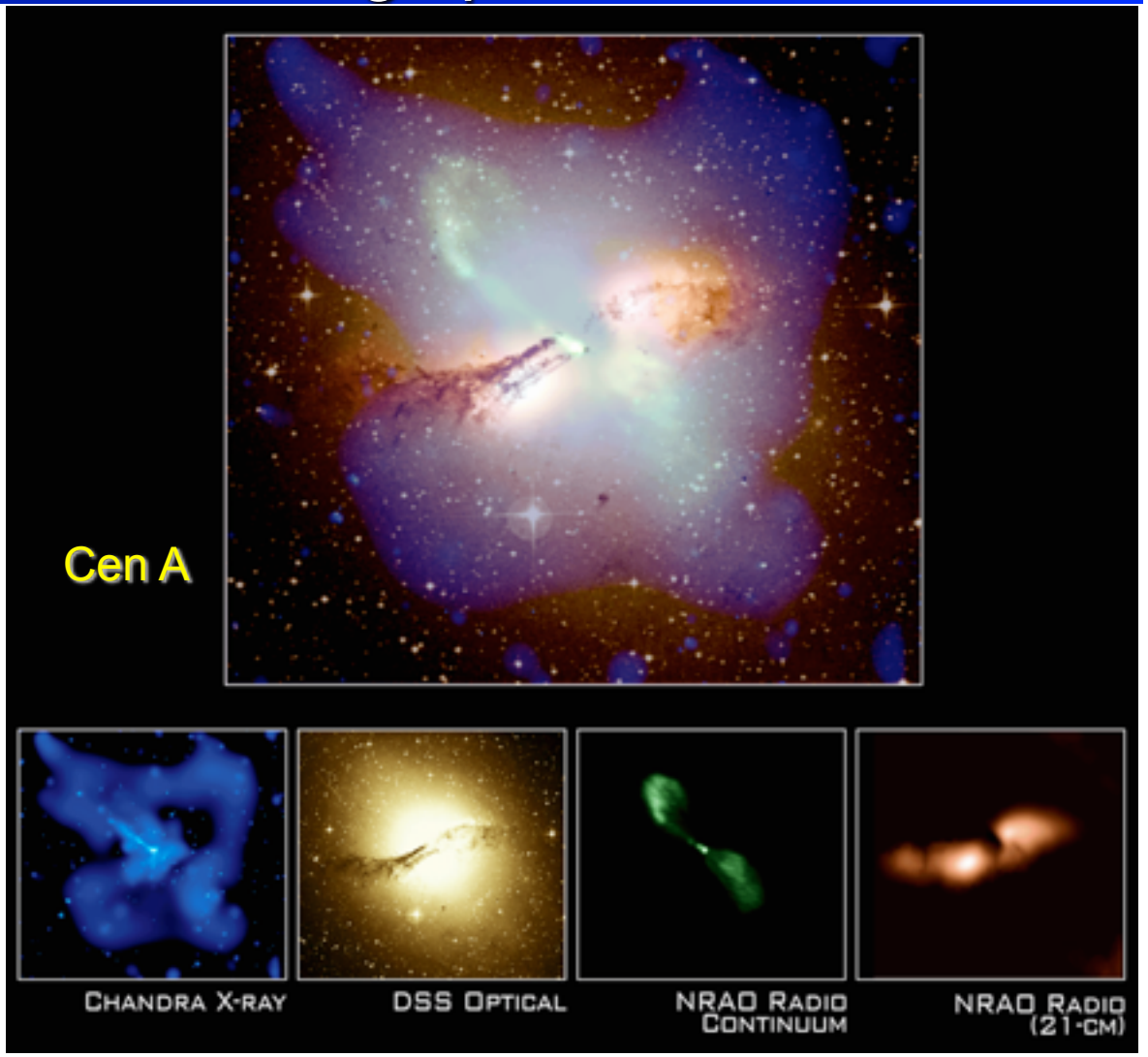
"In other galaxies, we see that starbursts can drive enormous gas outflows.[...]Whatever the energy source behind these huge bubbles may be, it is connected to many deep questions in ***astrophysics.****"*

David Spergel

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.

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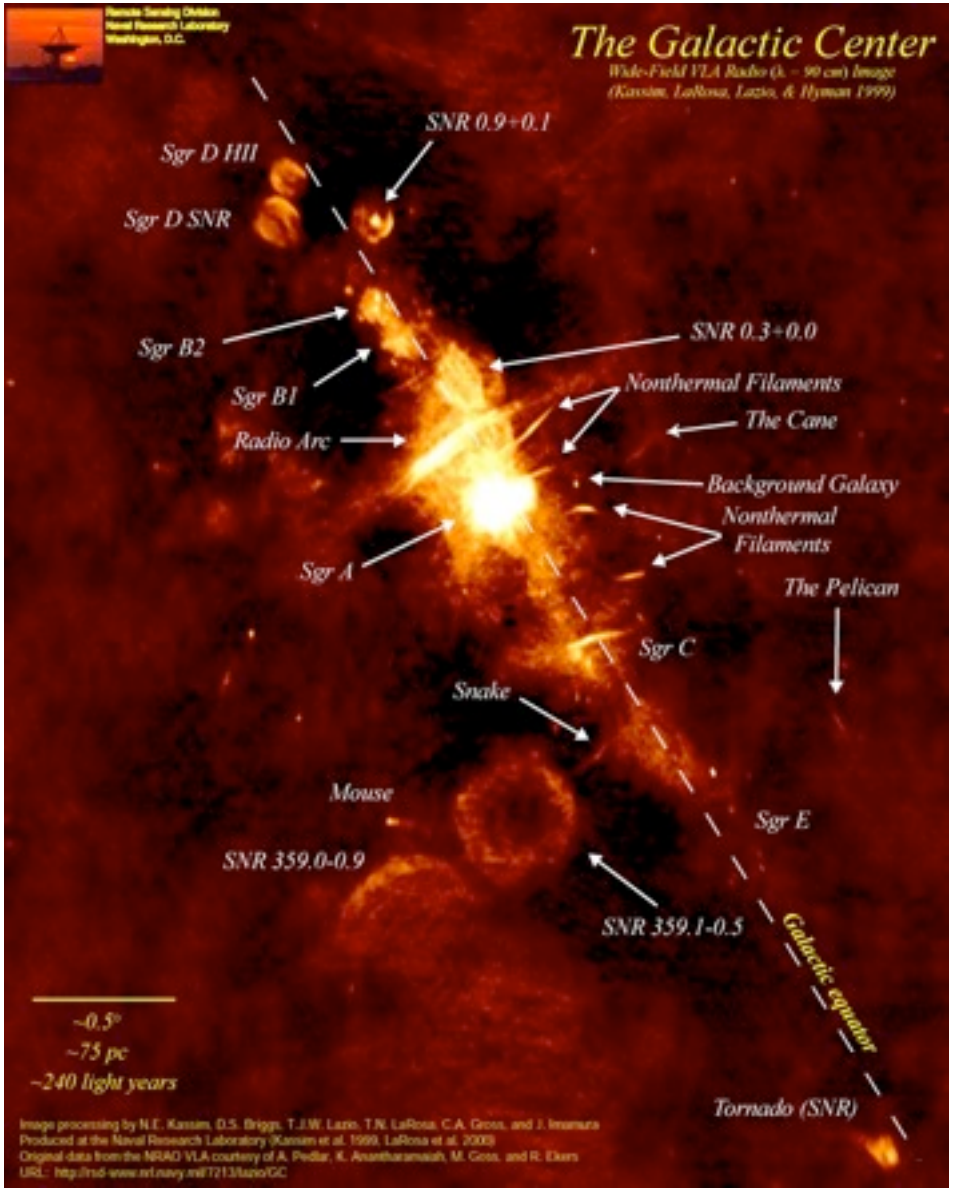
Great... If were not for the fact that the GC is the most crowded environment for non-thermal sources!



Alternative explanations

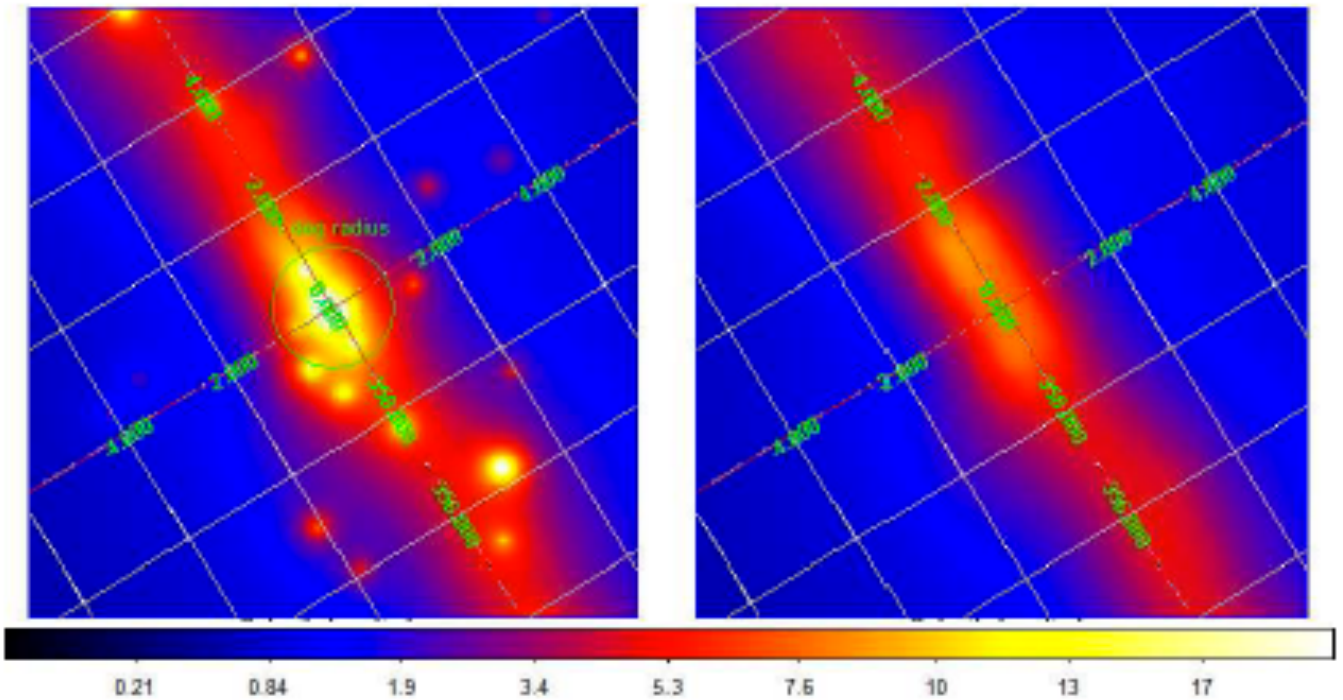
★ PSF/resolution effects (unlikely...)

★ 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,"

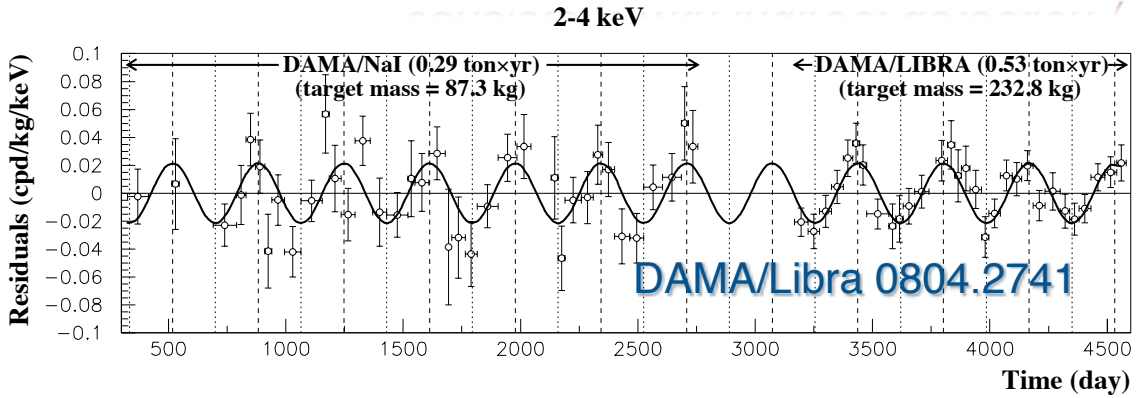


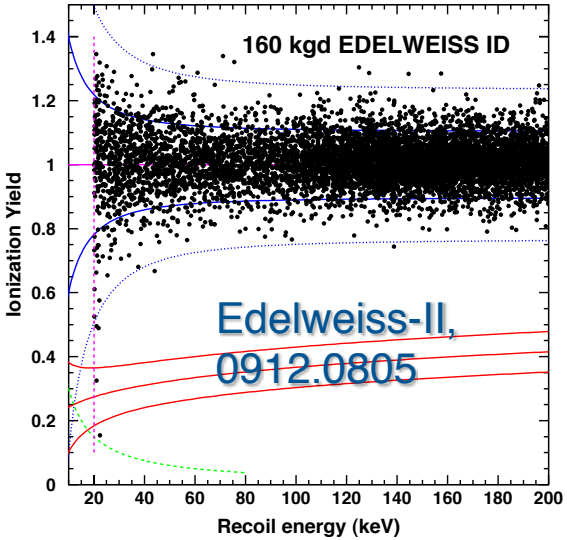
What has the Fermi collaboration to say on this subject?

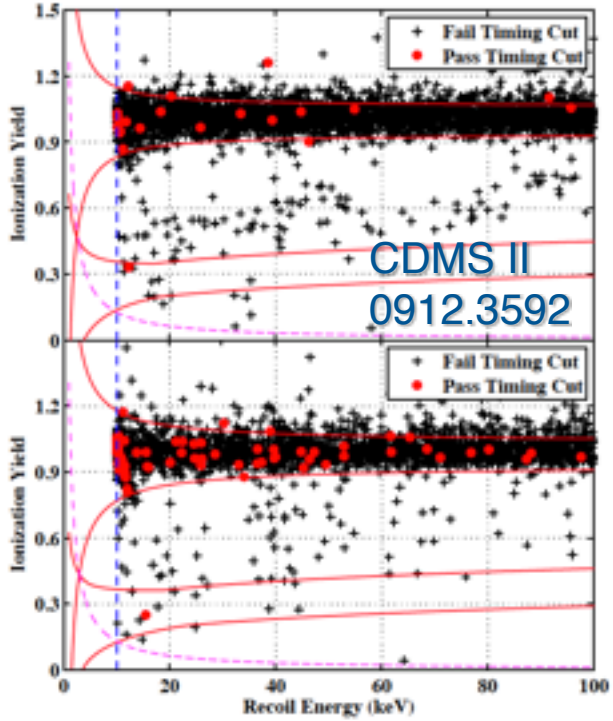
Links with DD

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?)

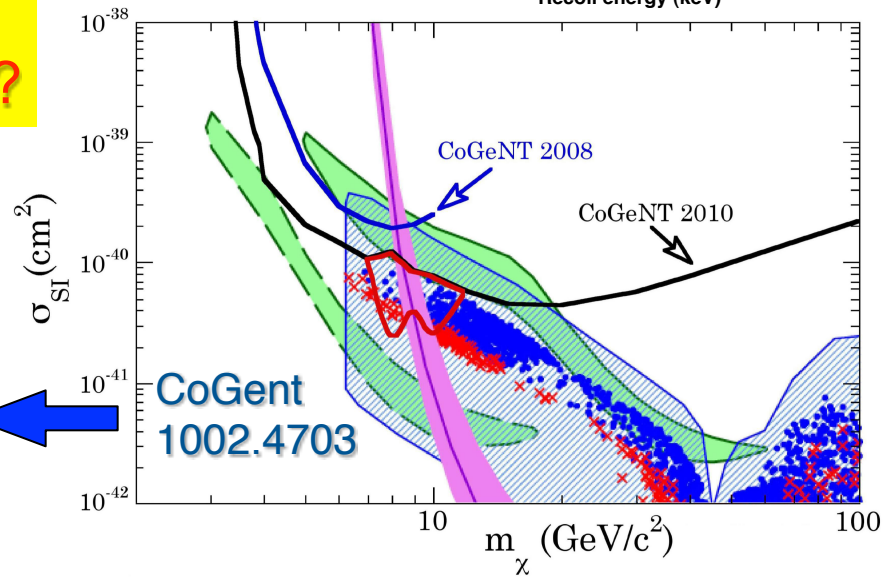






Are they DM events?

"Modulation" in 1106.0650

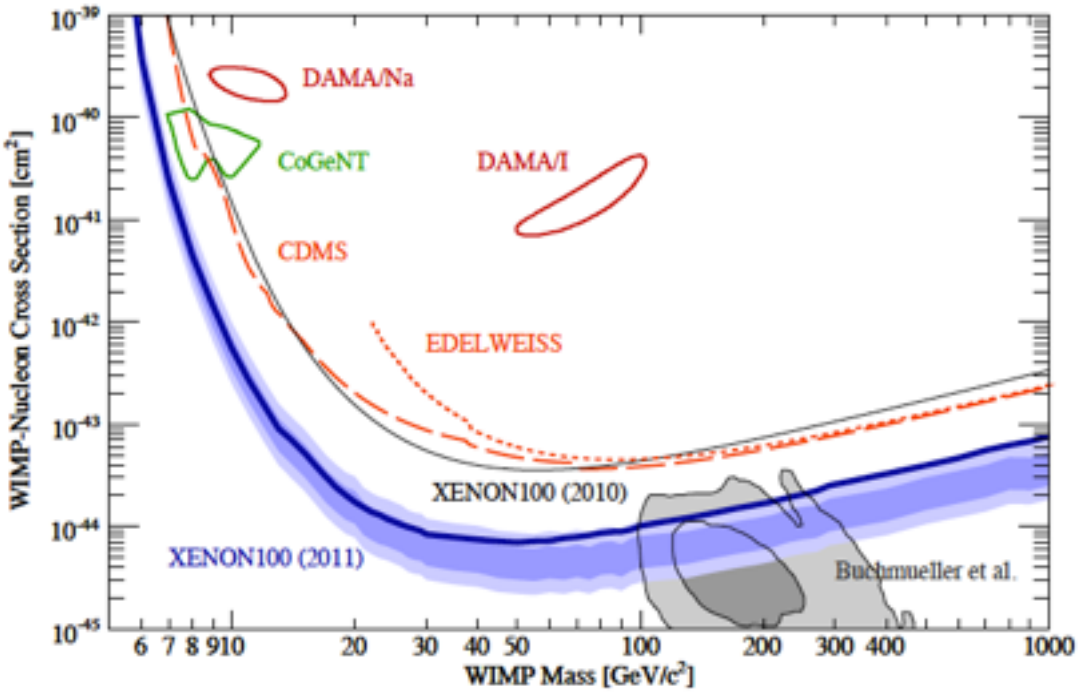


Recent Results

The new results published by Xenon100 (100 live days, 1104.2549) taken at face value exclude the "DAMA-CoGeNT region" in a SI-standard halo & light-WIMP interpretation

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

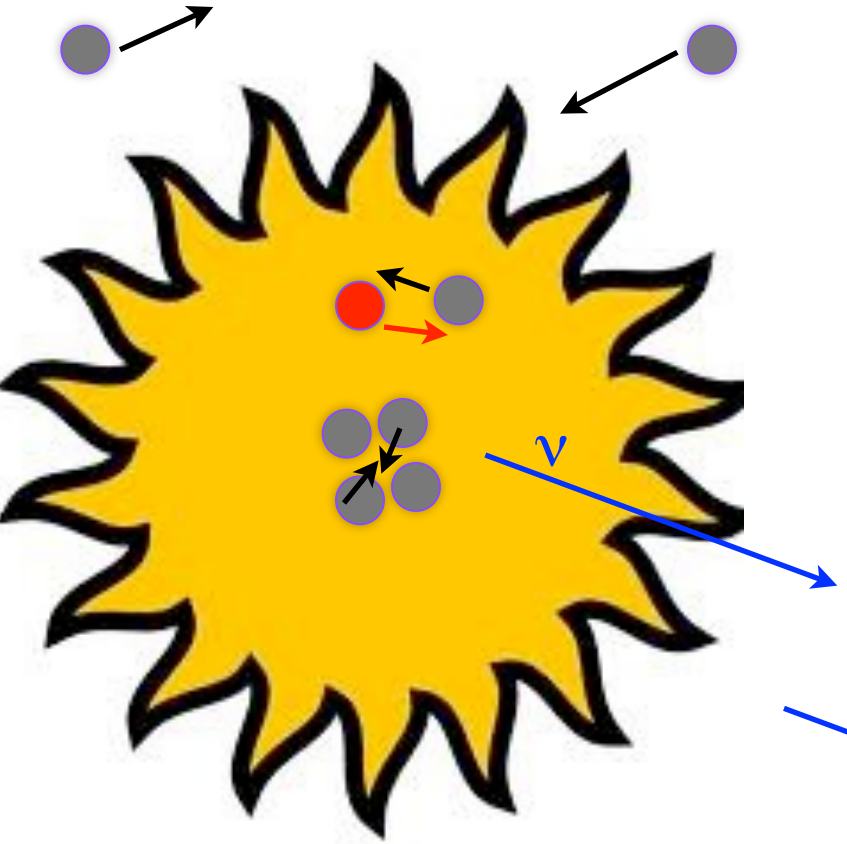
The robustness of this conclusion has been challenged by J. Collar in 1106.0653



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,"

Here we want to discuss some "caveats" when combining these direct detection data with indirect signatures, taking the neutrino signal as a benchmark case

A possible indirect handle: neutrinos from the Sun



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

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

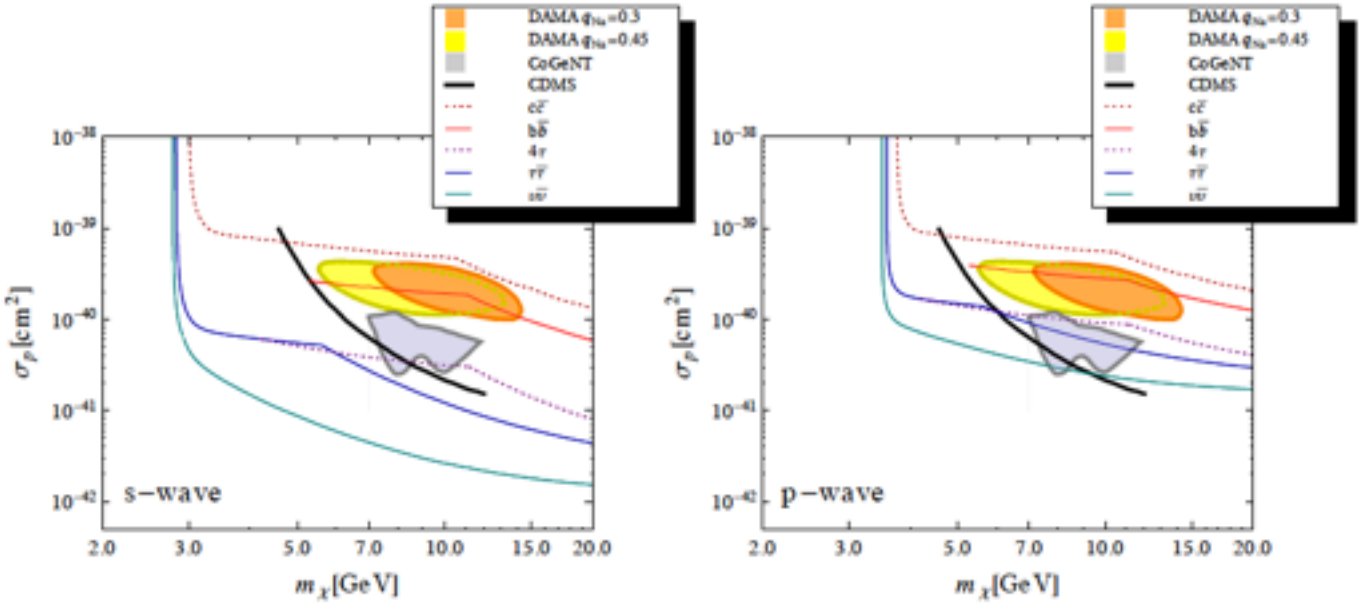
$$\Gamma_A = \frac{C_A}{2} {N_{\rm eq}}^2 = \frac{C}{2}$$

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

"just like" (although not exactly) DD experiments!

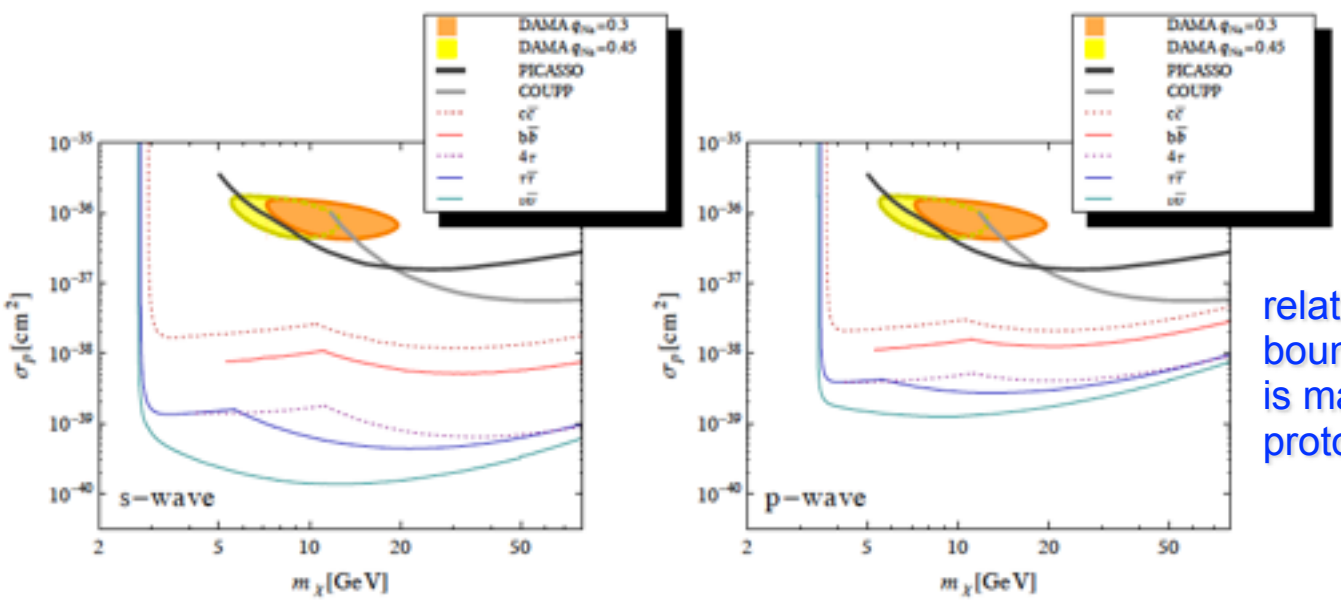
Recent neutrino bounds (from SK data)

SI



Kappl & Winkler 1104.0679

SD



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

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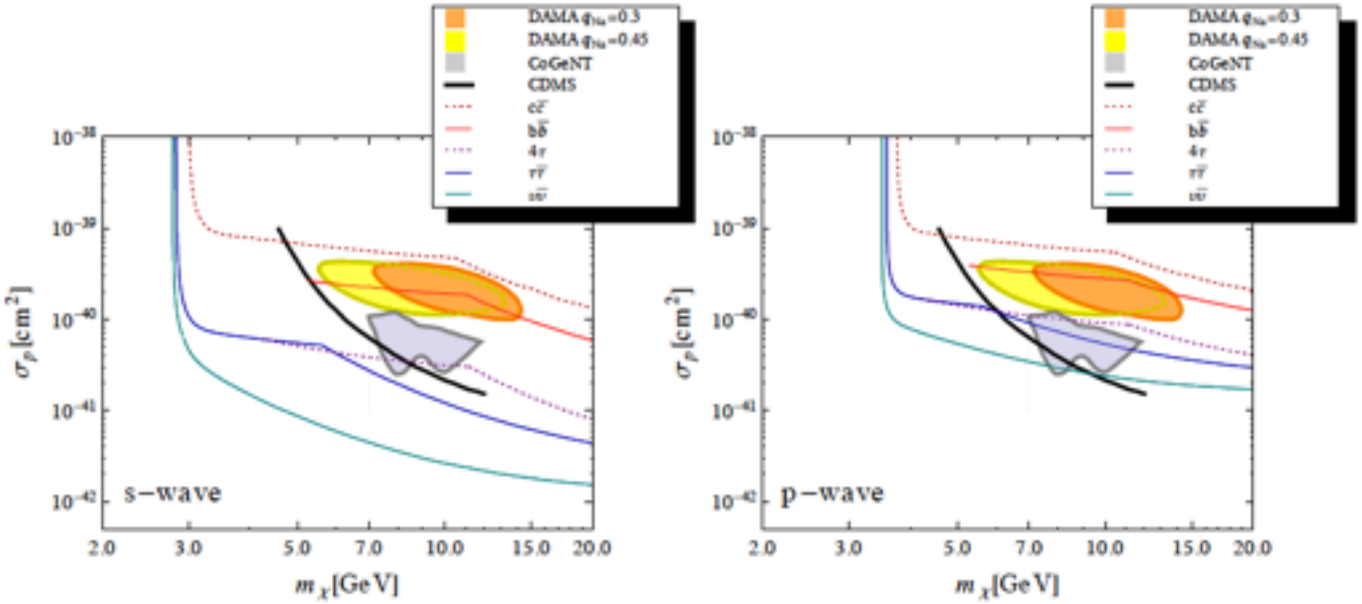
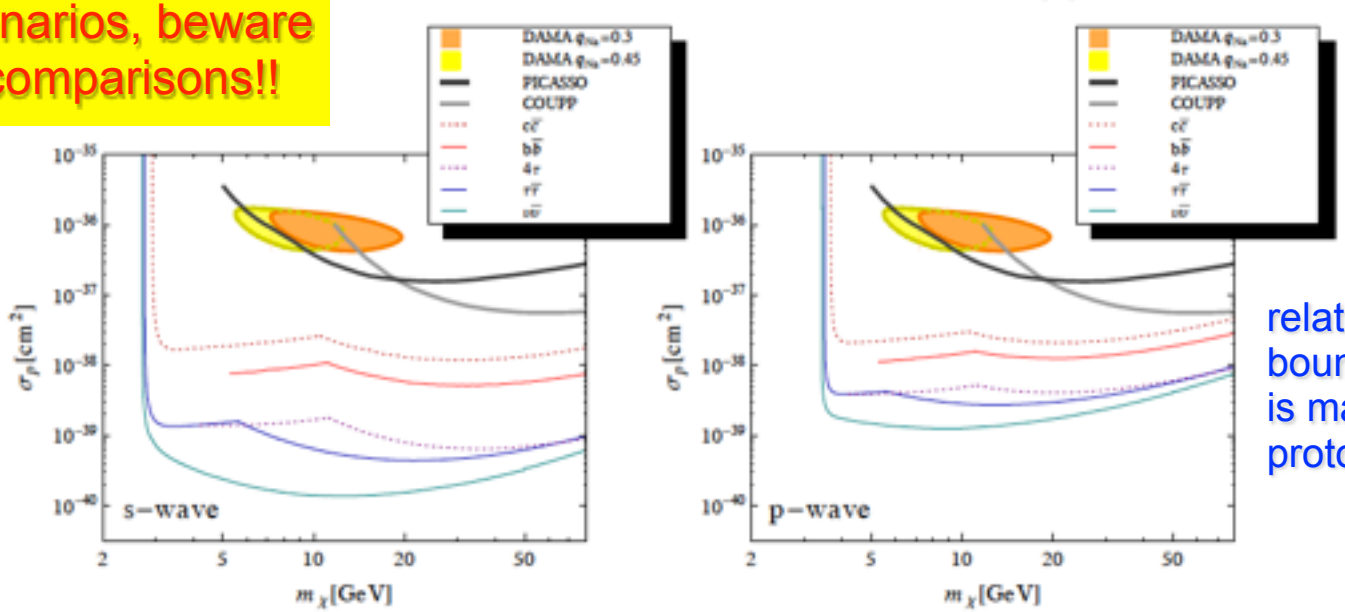


When going beyond simplest scenarios, beware of "naive" comparisons!!

Kappl & Winkler 1104.0679



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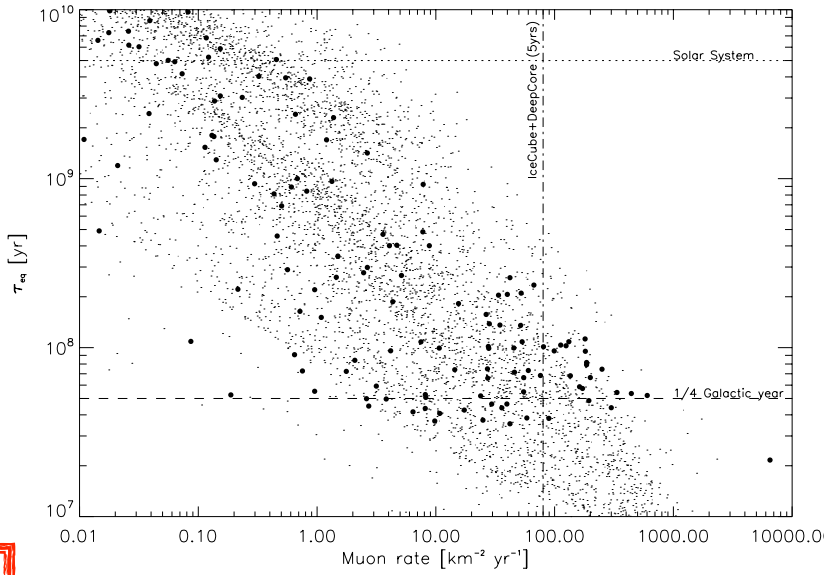
SD

Example

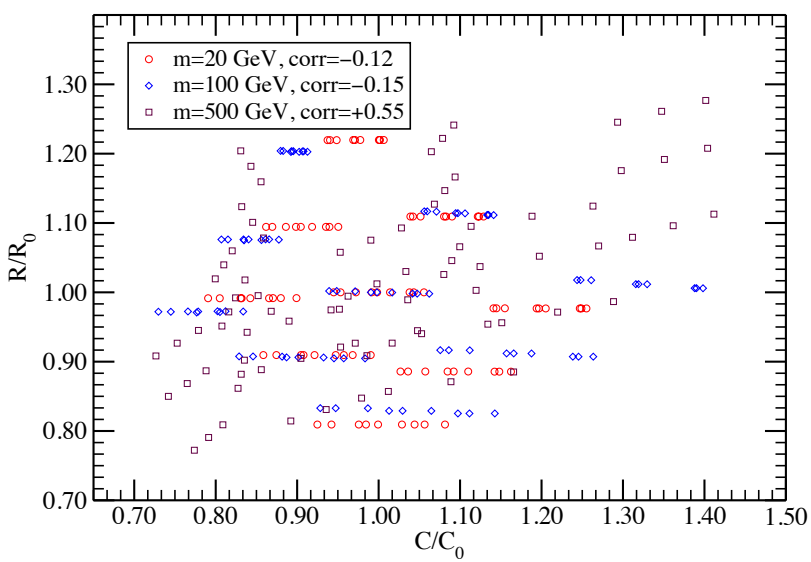
Most models yielding appreciable ν's from the Sun require an equilibration time comparable with the orbiting time of the Sun in the Milky Way

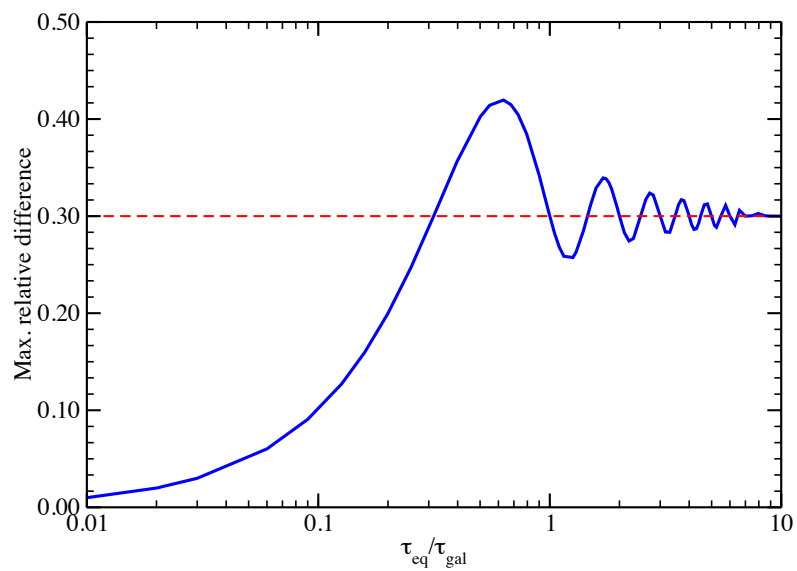
✤ The effective halo probed by the ν's and DD is different (in general it's triaxial)!
✤ There is a different sensitivity from underlying astro parameters!



Bounds can shift one wrt the other easily by a factor 2!

PS & Bertone 1006.3268





Asymmetric DM, no or asymmetric SM final states

- if they carry some new additively conserved quantum number, there's (almost?) no indirect annihilation signal, like for baryons.

- For multiplicatively conserved numbers or decays asymmetric final states are produced (e.g. S. Chang and L. Goodenough, 1105.3976): but that's what astrophysics does as well, either through isospin violation (e.g. more "leading" π^+ than π^- in pp collisions) or via plasma dynamics!

Asymmetric DM, no or asymmetric SM final states

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It looks hard to distinguish from astro backgrounds or ordinary WIMP candidates via ID

Alternative effects (for non-annihilating DM candidates)

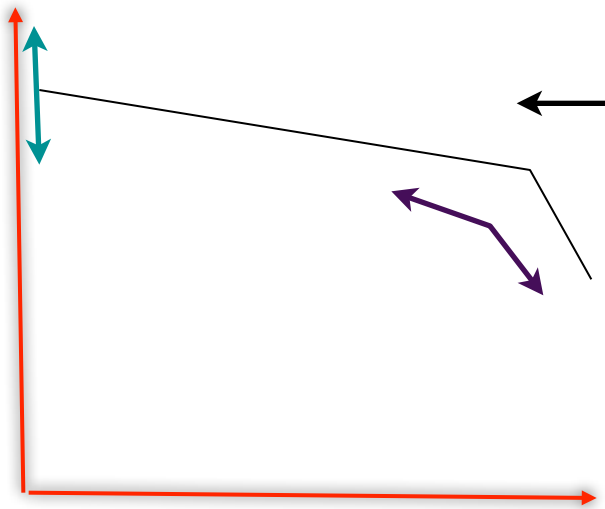
Energy transport in stars, after being captured and accumulating at the core (recycling old "cosmion" solution to solar neutrino problem). However, only relevant for light particles and large x-sections (e.g. M. Taoso et al. 1005.5711 & refs.), or perhaps for popIII stars

Outlook and conclusions

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

It' a trivial question. The generic answer is "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 and/or
propagation parameters

The real issues for "detection" are:
can one find an explanation of many phenomena with PP motivated models?
Can one explain unexplained features in a predictive way which
cannot be understood by known astrophysics?

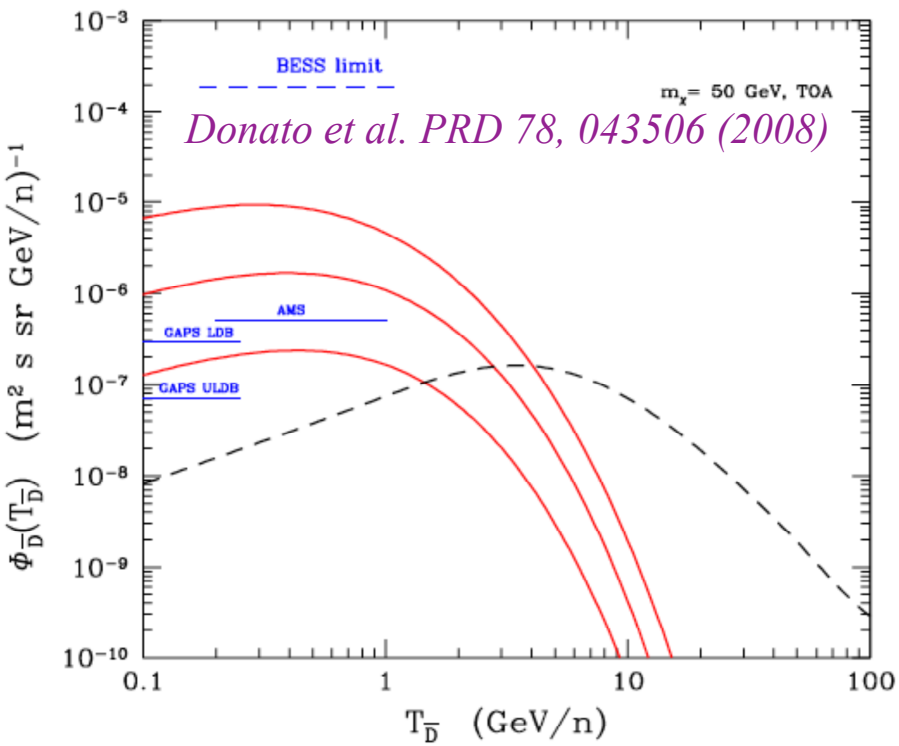
My birthday present: a new friend in space...

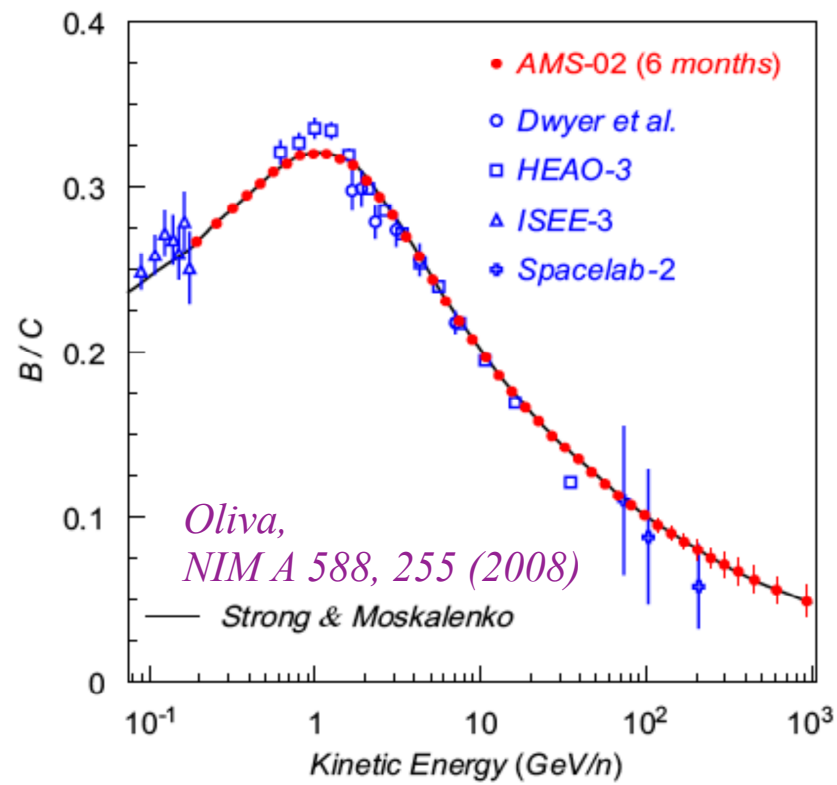
AMS-02 lauched on May 16th
attached to the ISS arm and
collecting data since May 19th

ID, what have we learned?

With a few "hints" still debated, most indirect signatures told us that DM signals are not dominant, rather at or below the level of "astrophysical systematics". 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 detailed knowledge of the sources

After PAMELA, 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.





Outlook

Indirect probes (astrophysics & Cosmology) tell us a lot: BSM physics is there!
However, they do not tell us its scale, and blind searches are more and more challenging, facing to little known 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 good 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 as well as better understanding of astrophysical sources & propagation parameters