Marco Taoso
IFIC, Valencia

News on indirect and direct Dark Matter searches

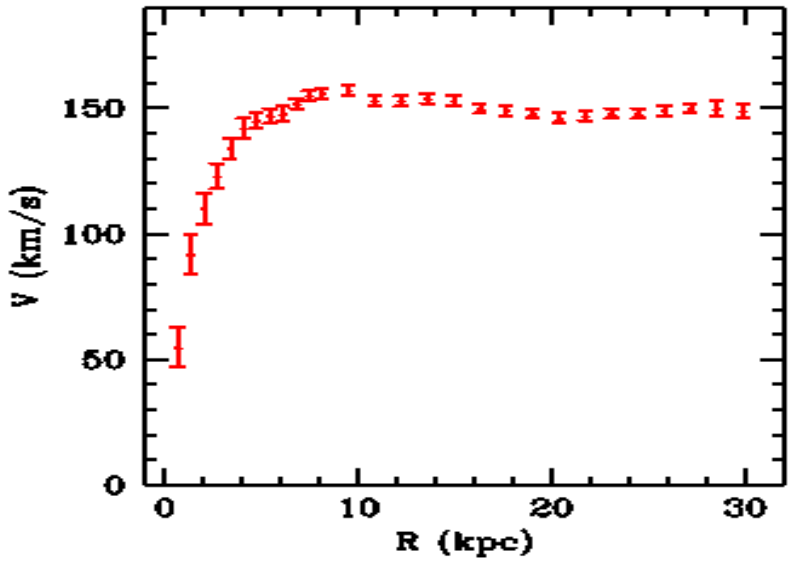
Flasy 2011
Valencia

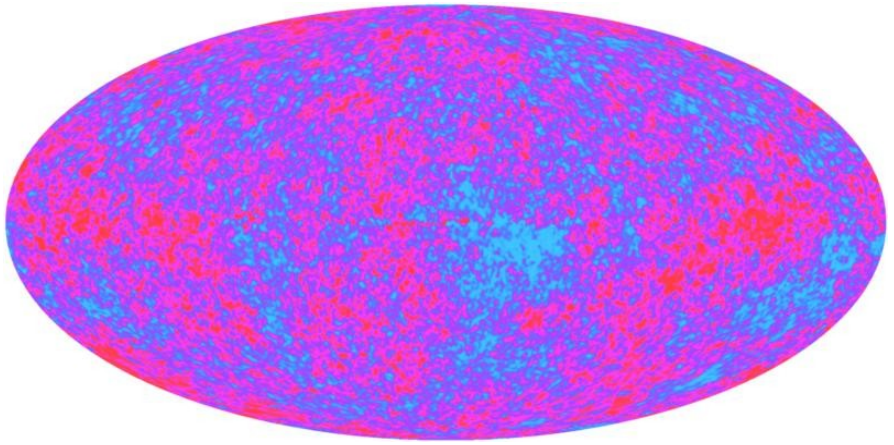
Plan of the talk

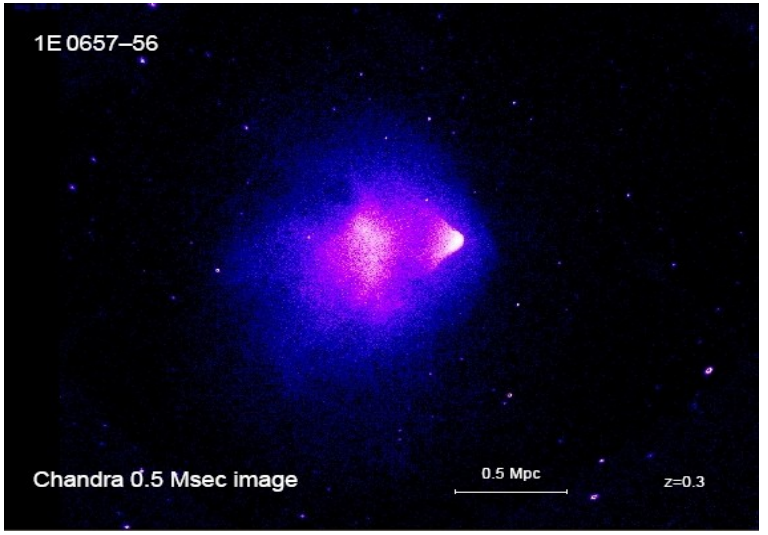
- Evidences for Dark Matter
- DM stability
- WIMPs Miracle
- Hunting DM: the status of
  - Indirect detection searches
  - Direct detection searches
- Prospects for upcoming experiments

Evidences for DM

- Rotational curves
- Clusters of galaxies
- CMB anisotropies
- Big Bang Nucleosynthesis
- ...

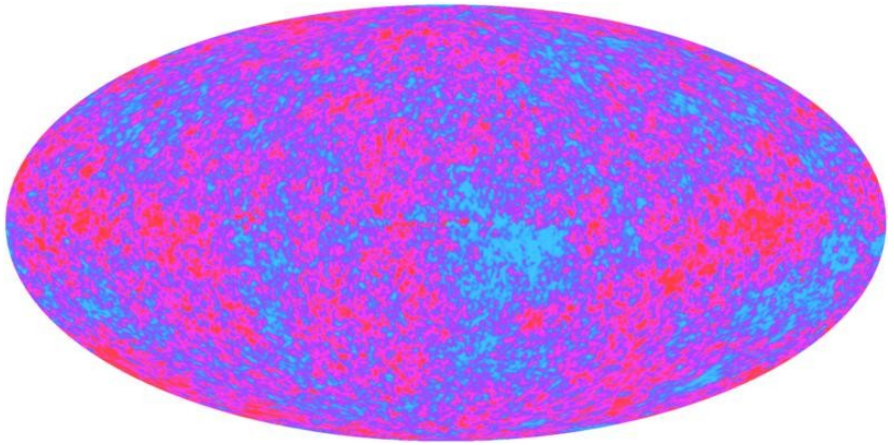


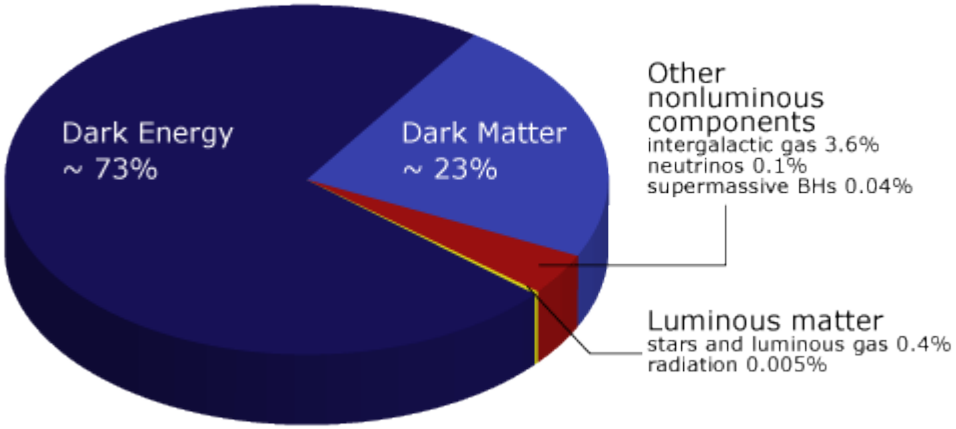




Evidences for DM

- Many independent evidences for DM at different scales
- Observations constraints the properties of DM
- We still lack evidences for DM other than through gravitational interactions





What we know about DM

- Long lived and massive
- DM cosmological abundance extracted by observations
- DM is cold (or warm...?)
- DM is electrically neutral
- DM-DM and DM-Standard Model interactions constrained by observations

For a review Taoso, Bertone, Masiero 07

DM Stability

- Stable over cosmological times $\tau_{DM} > \tau_U \simeq 10^{18} s$
- Stronger (model dependent) constraints from astrophysics

  e.g. for GeV-TeV DM decaying into $e^{\pm}, \gamma, \bar{p}$

$$\tau_{DM} \gtrsim 10^{26} s$$

What is the reason for this large lifetime?

DM Stability

- Z_2 <--- origin from more fundamental models

  $U(1)_{B-L}$ embedded in GUT models (Mohapatra 86, Martin 92)

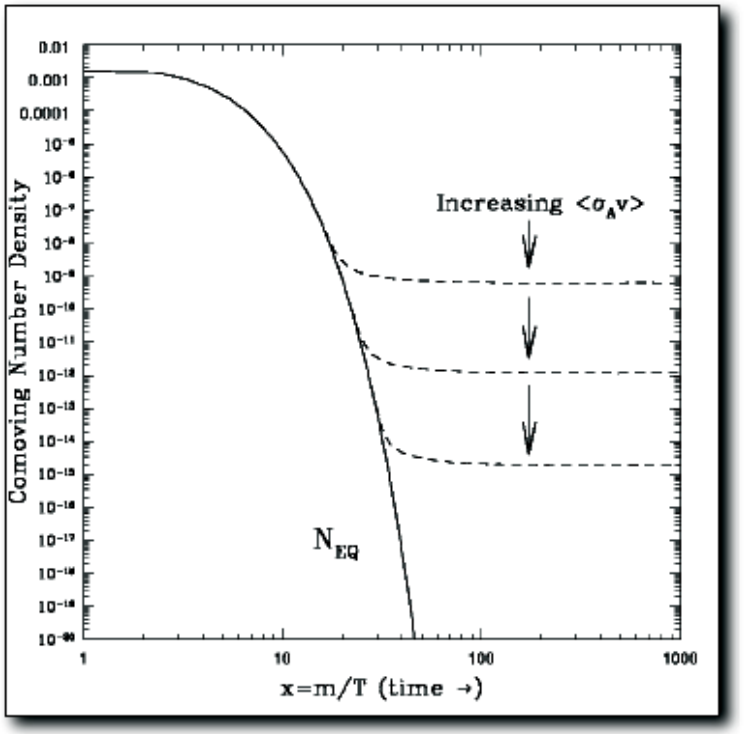
  from flavour symmetries (Hirsh, Morisi, Peinado, Valle 10)
- Accidental symmetries. Minimal DM (Cirelli, Fornengo, Strumia 06)

  Hidden vector DM (Hambye 08) Technibaryons (Gudnason, Kouvaris, Sannino 06)
- Gauged symmetry (Pospelov, Ritz, Vloloshin 07, Mambrini 10)
- Decay suppressed by small coupling

  axion, majoron, gravitino, KeV right handed neutrinos

See e.g. 1012.4587 for a recent review

Weakly Interacting Massive Particles



- WIMPs decouple from thermal bath when they are NR
- Correct relic density for

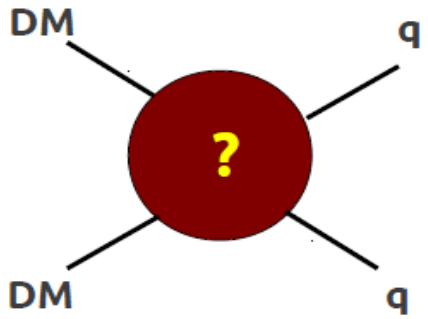
$$\langle \sigma v \rangle_{ann} \simeq 3 \cdot 10^{-26} \ \mathrm{cm}^3 \mathrm{s}^{-1}$$

(unless coannihilations)

- $\langle \sigma v \rangle_{ann} \sim \alpha^2/(100 \ \mathrm{GeV})^2 \sim 10^{-26} \ \mathrm{cm}^3 \mathrm{s}^{-1}$
- DM related with New Physics at the EW scale?

Hunting WIMPs

- Indirect detection



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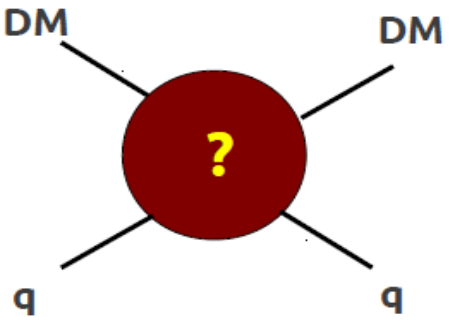
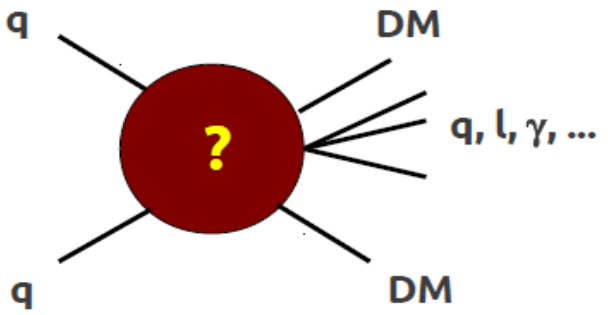
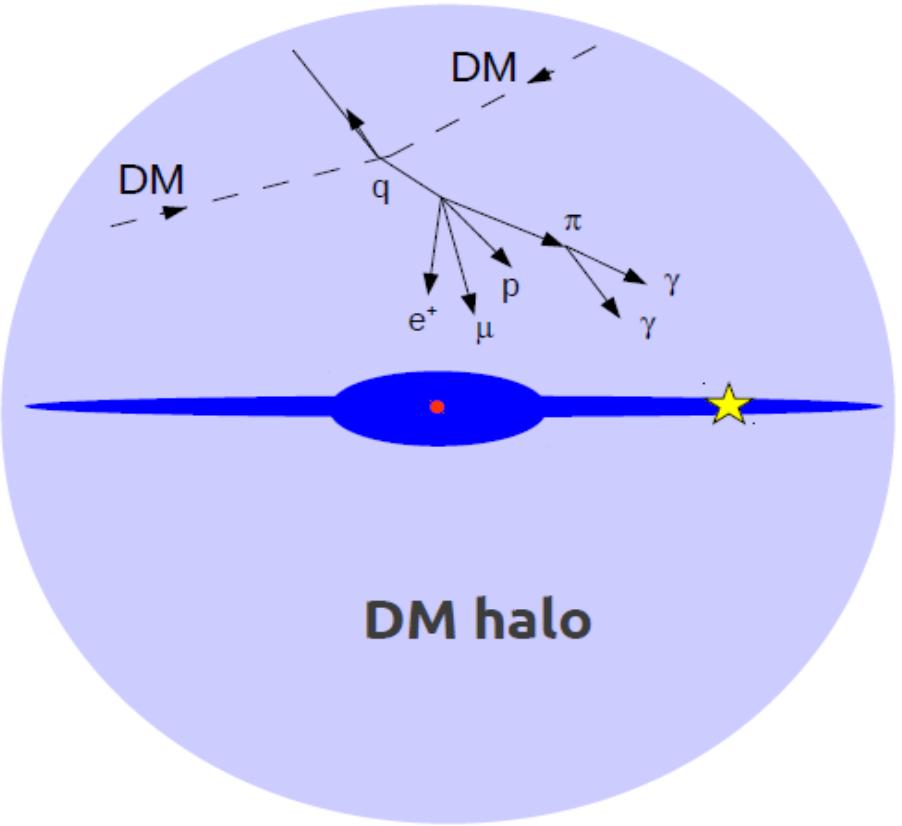


- Colliders

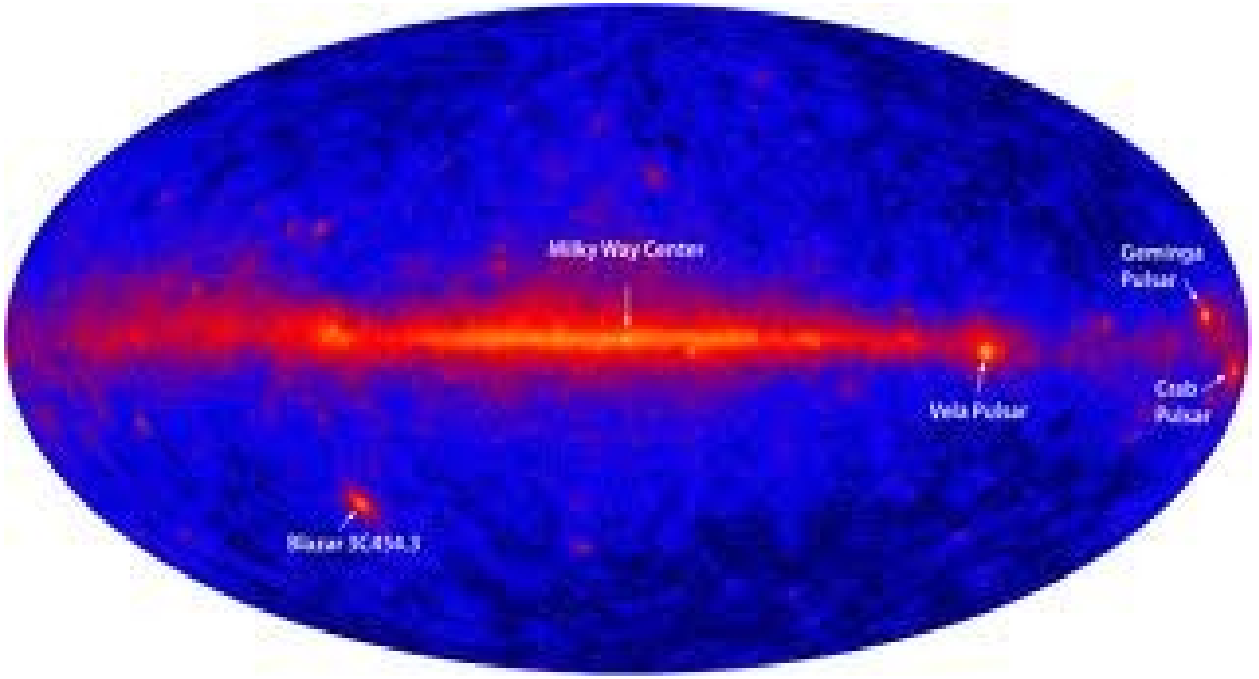


Hunting WIMPs

- Indirect detection
- Direct detection
- Colliders



Gamma-rays. Where to look for DM



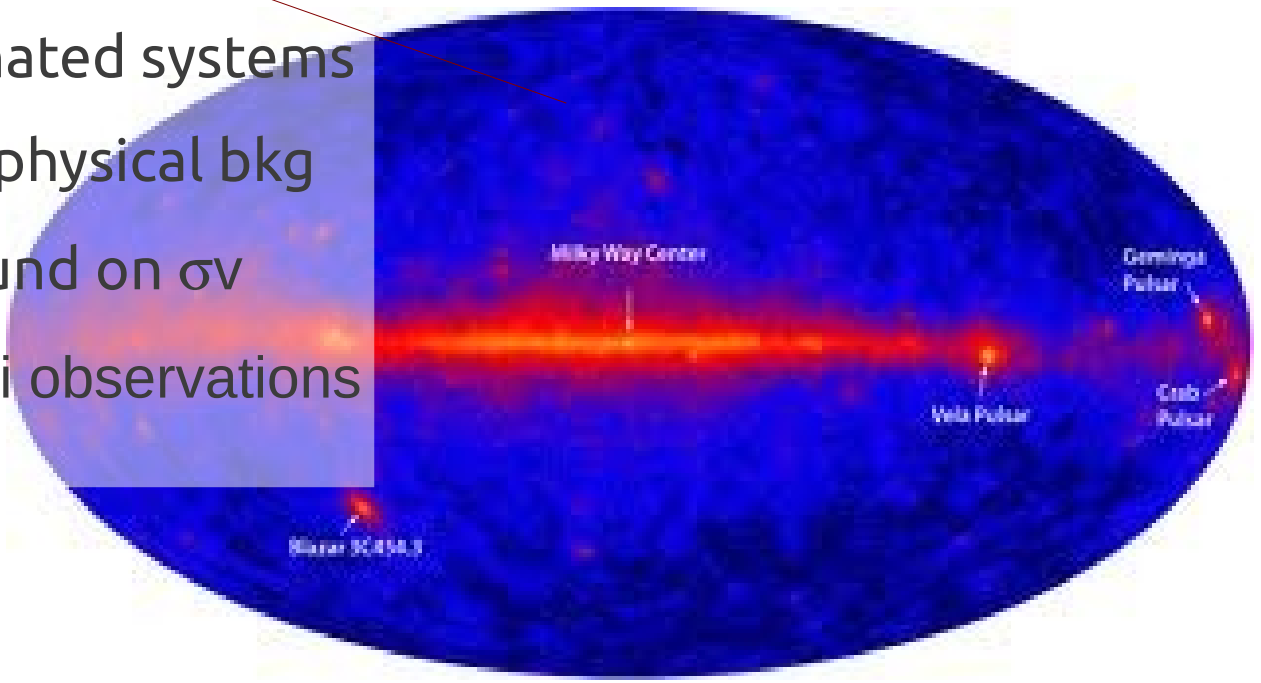
Fermi-LAT gamma-ray sky

Gamma-rays. Where to look for DM

Dwarf galaxies

- DM dominated systems
- Low astrophysical bkg
- Upper bound on σv

  from Fermi observations



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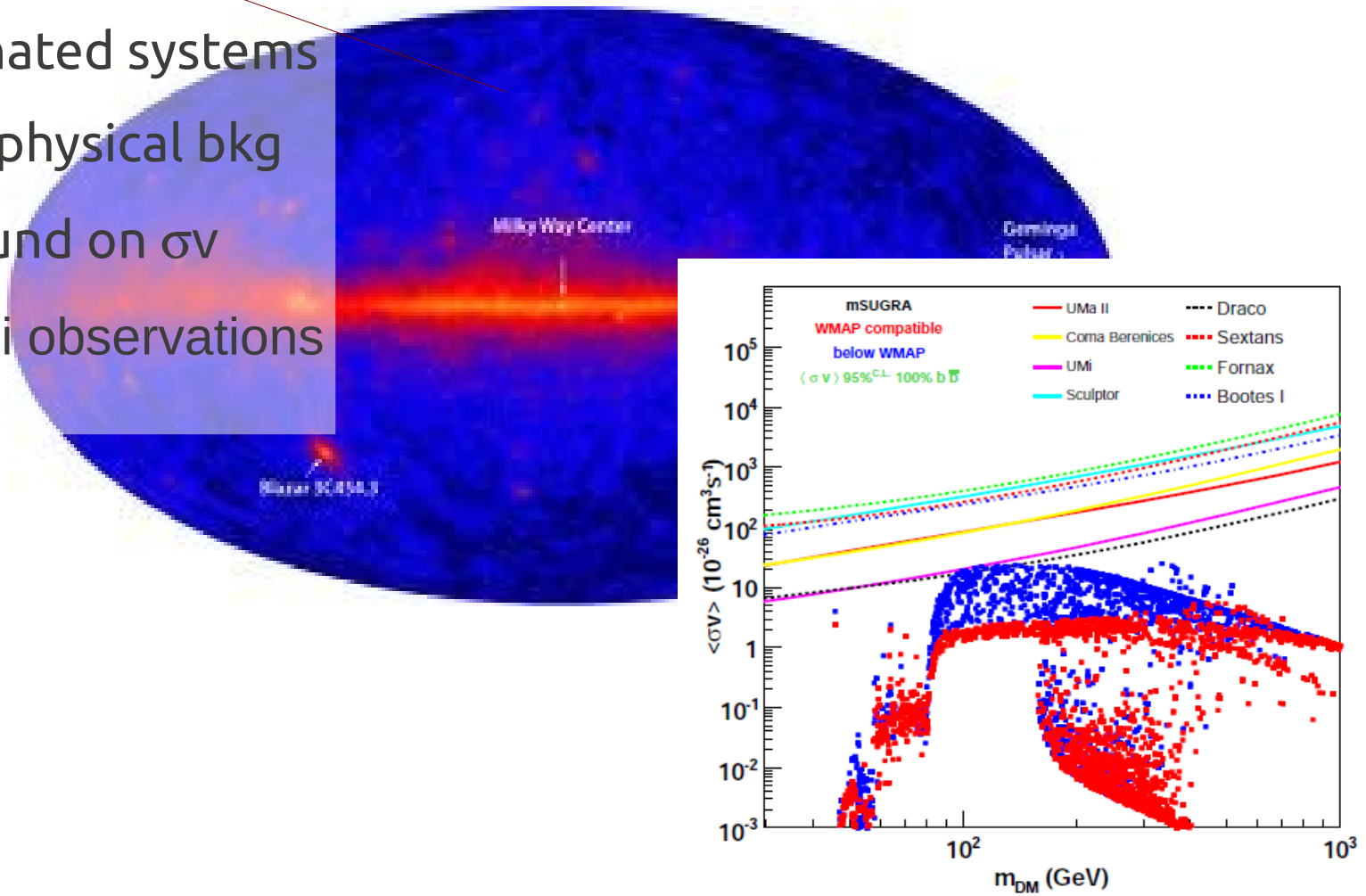

Fermi collaboration APJ (2010), arXiv 1001.4531

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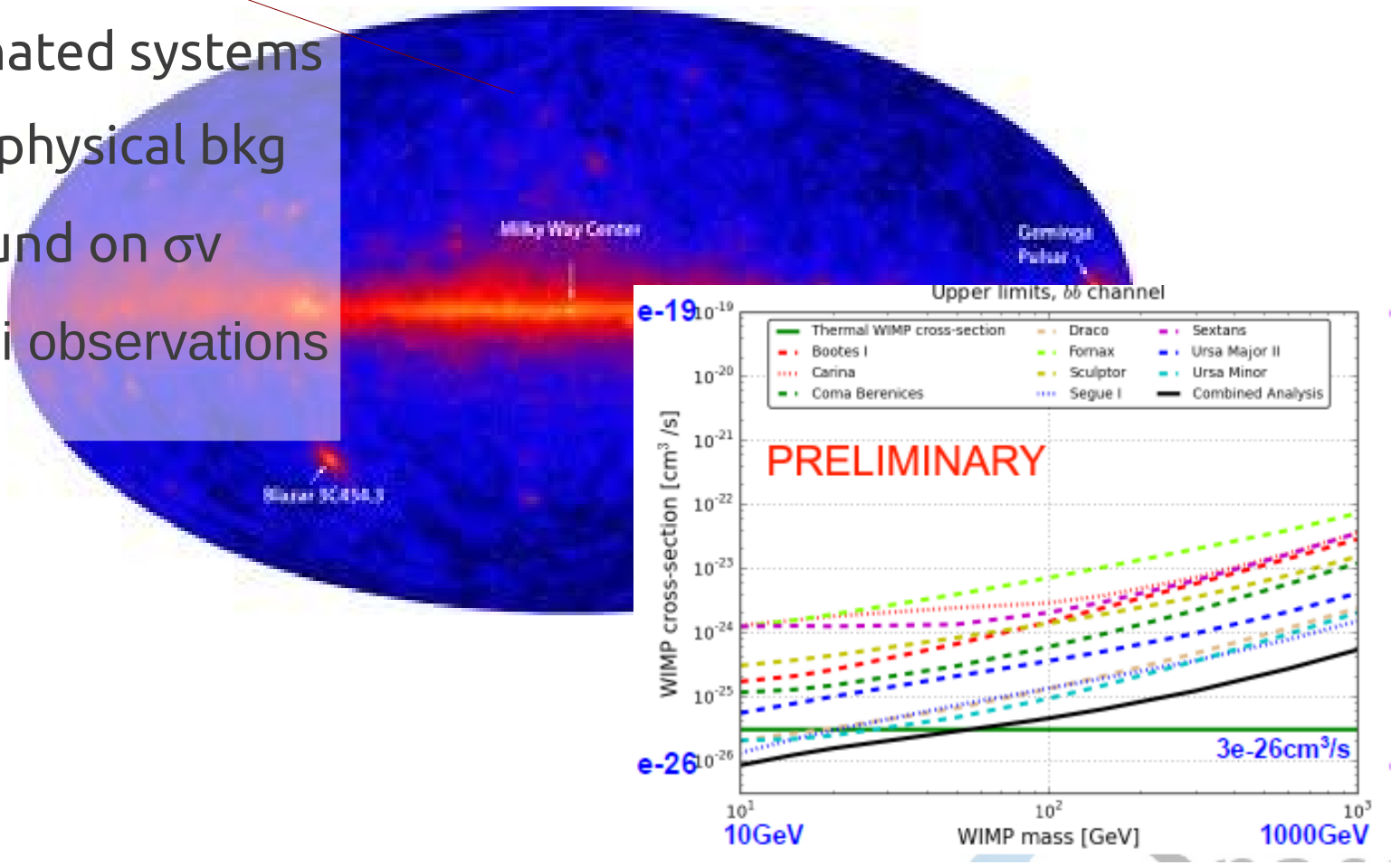


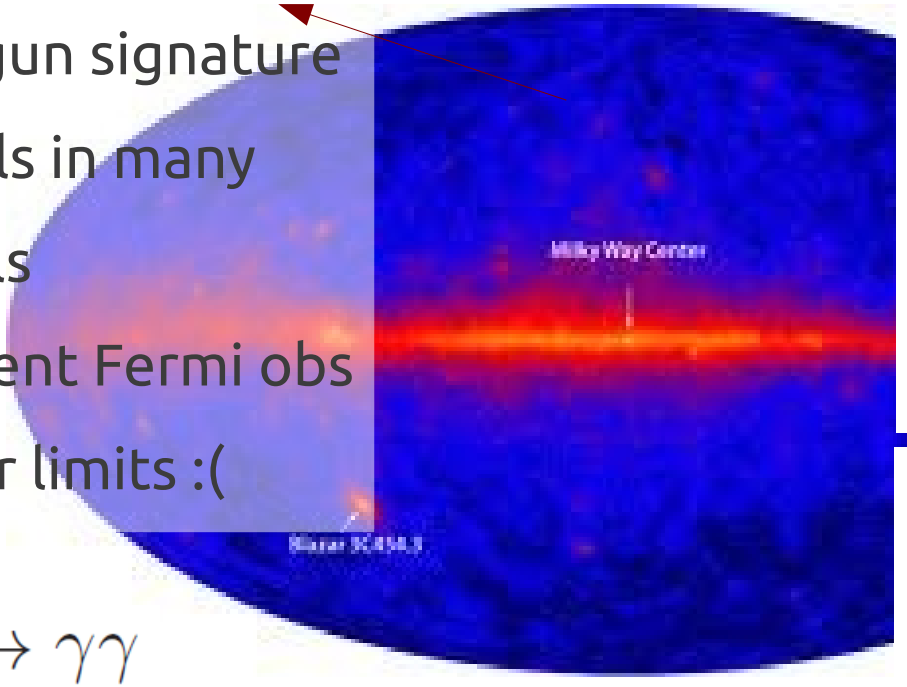
From Fermi Symposyum 2011, Maja Llena Garde

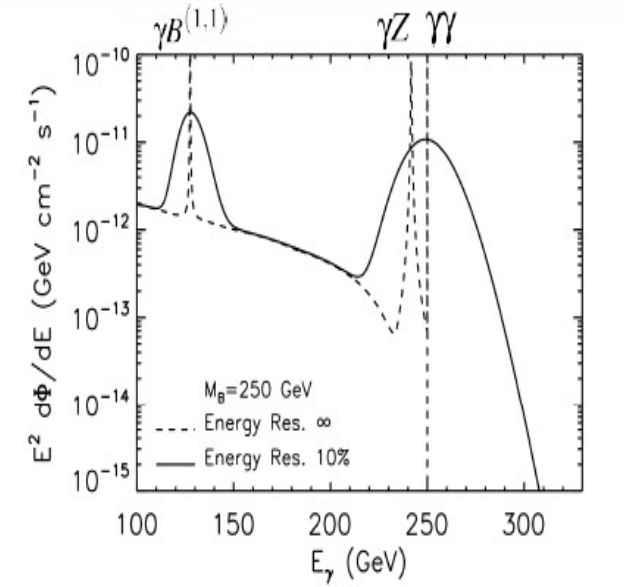
Gamma-rays. Where to look for DM

Bertone, Jackson, Shaughnessy, Tait, Vallinotto 09

Gamma-lines (monochromatic emission)

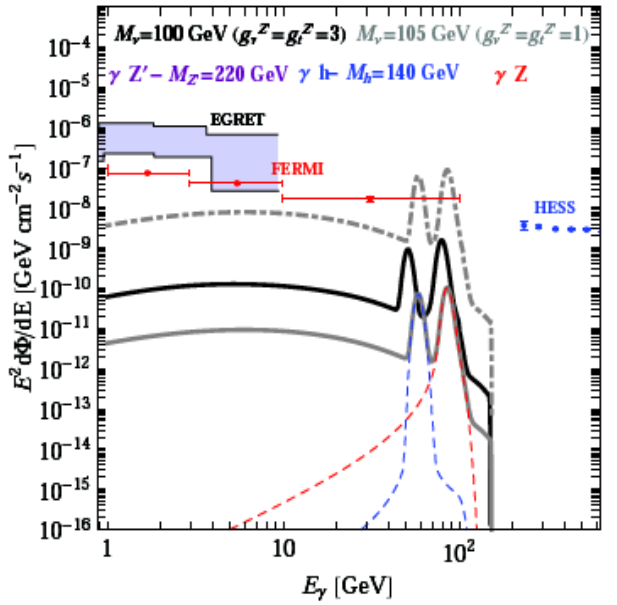
- Smoking gun signature
- Low signals in many DM models
- From current Fermi obs only upper limits :(





$$DMDM \to \gamma\gamma$$

$$DMDM \to \gamma X$$



Jackson, Servant, Shaughnessy, Tait, Taoso 10

Gamma-rays. Where to look for DM

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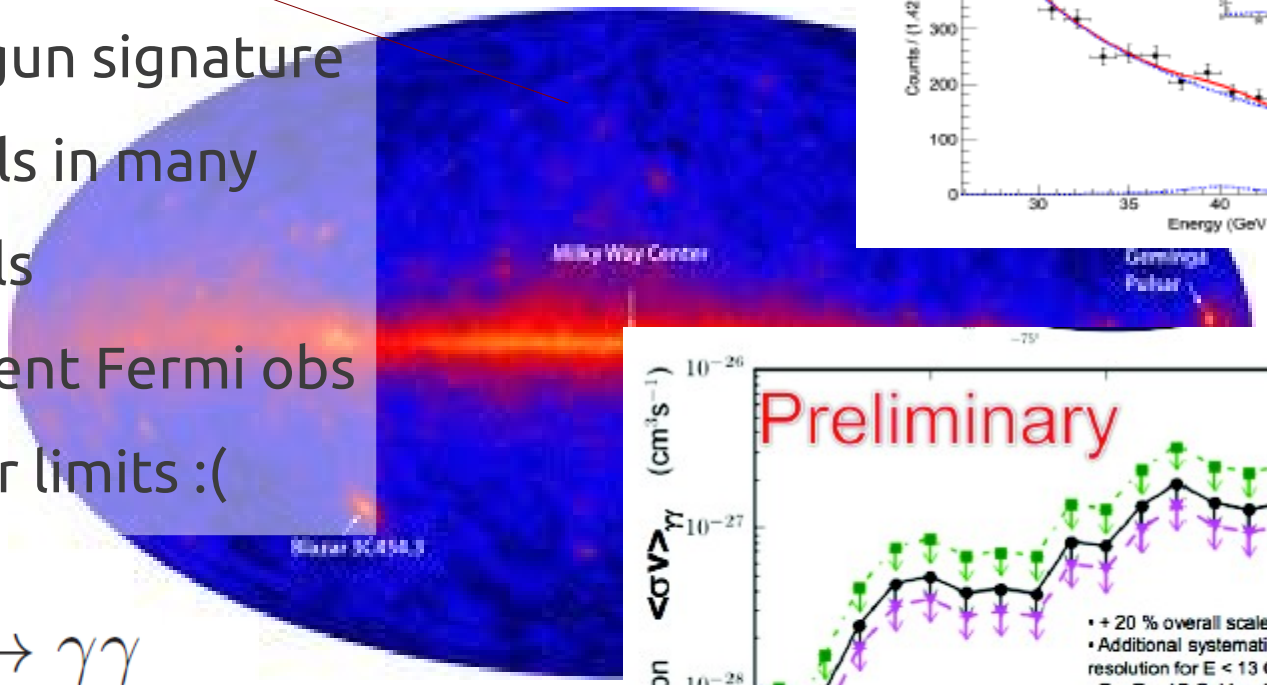
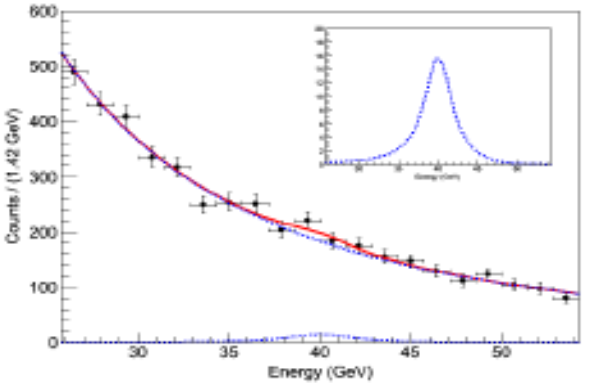
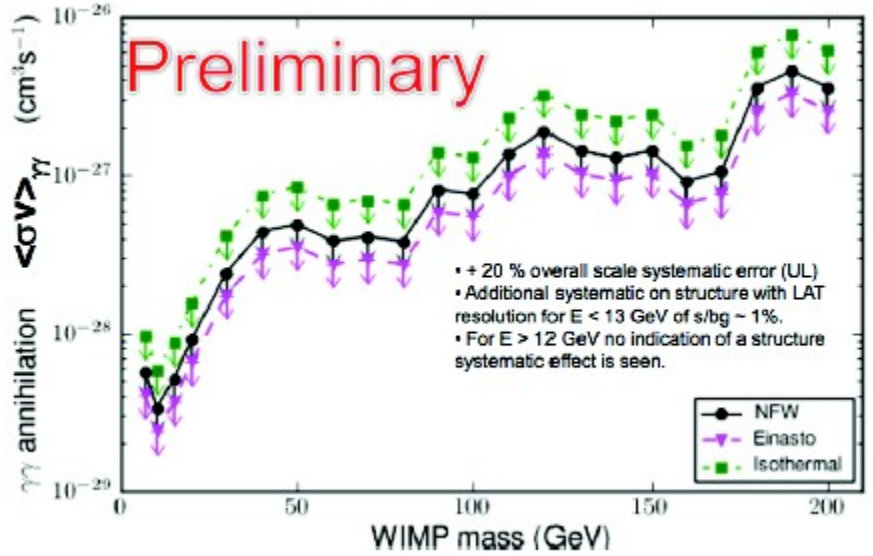






From Fermi Symposyum 2011

Update to Fermi collaboration PRL (2010), arXiv 1001.4836

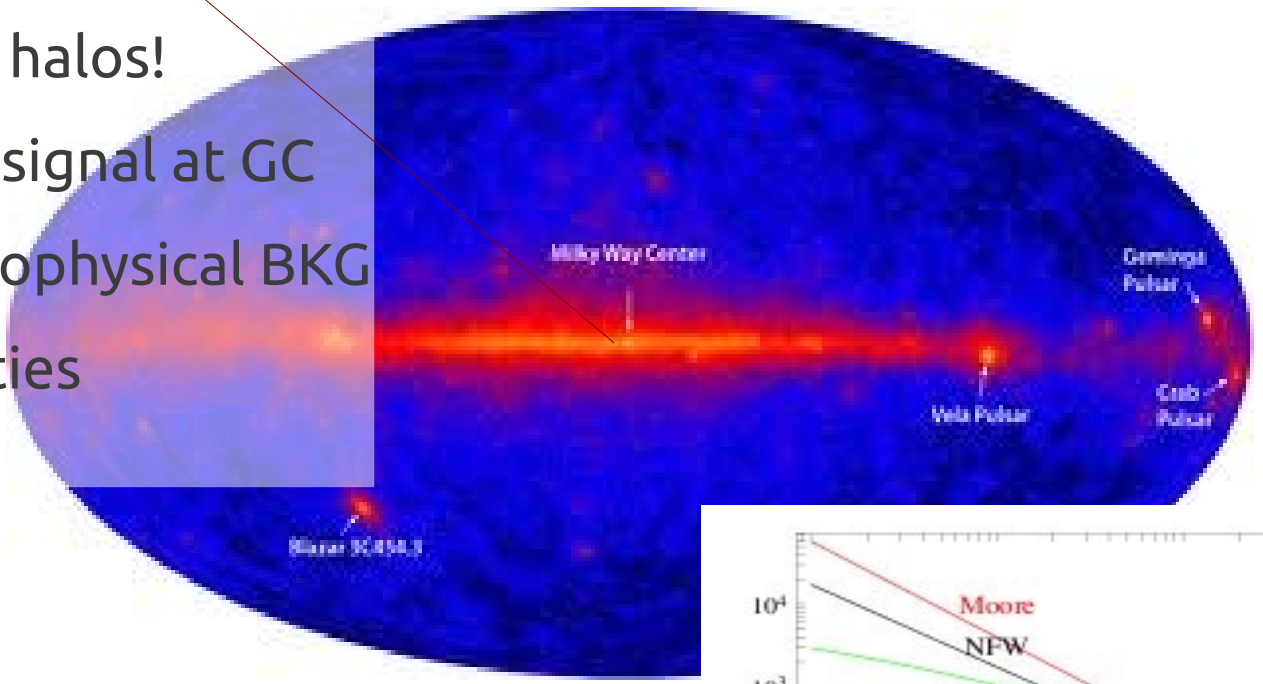
Gamma-rays. Where to look for DM

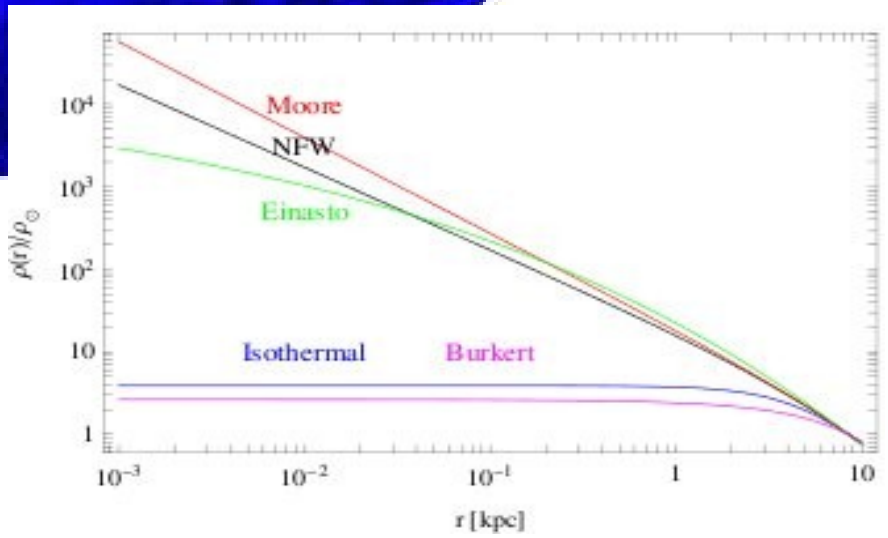
Galactic center

- Cuspy DM halos!

  Increased signal at GC
- Large astrophysical BKG

  uncertainties

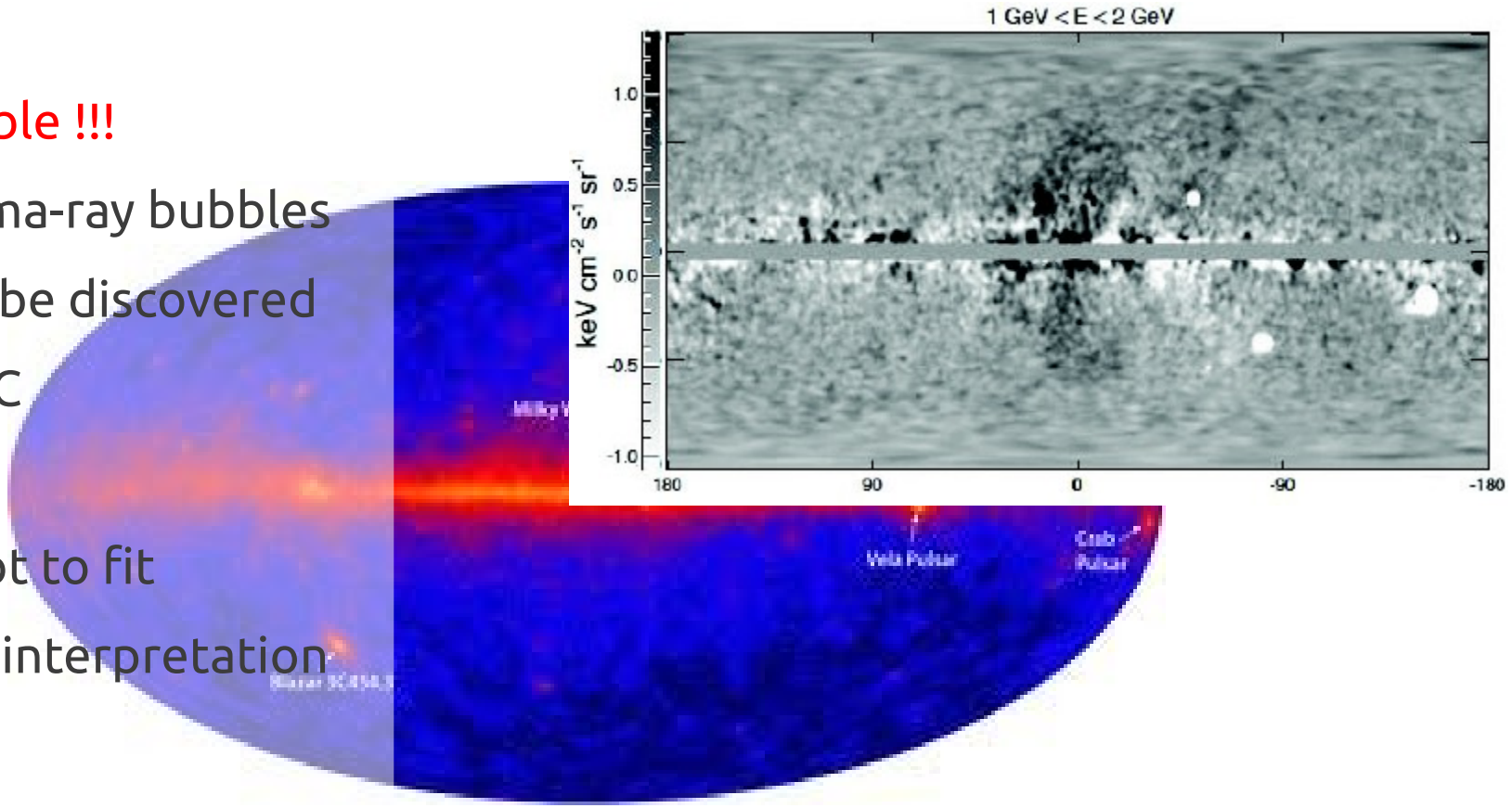




Gamma-rays. Where to look for DM

Fermi bubble !!!

- Giant gamma-ray bubbles claimed to be discovered towards GC



- It seems not to fit with a DM interpretation

- Possibly produced by IC of electrons produced by central BH or starbust activity. Correlated with WMAP haze (the synchrotron counterpart?) and X-ray observations (ROSAT)

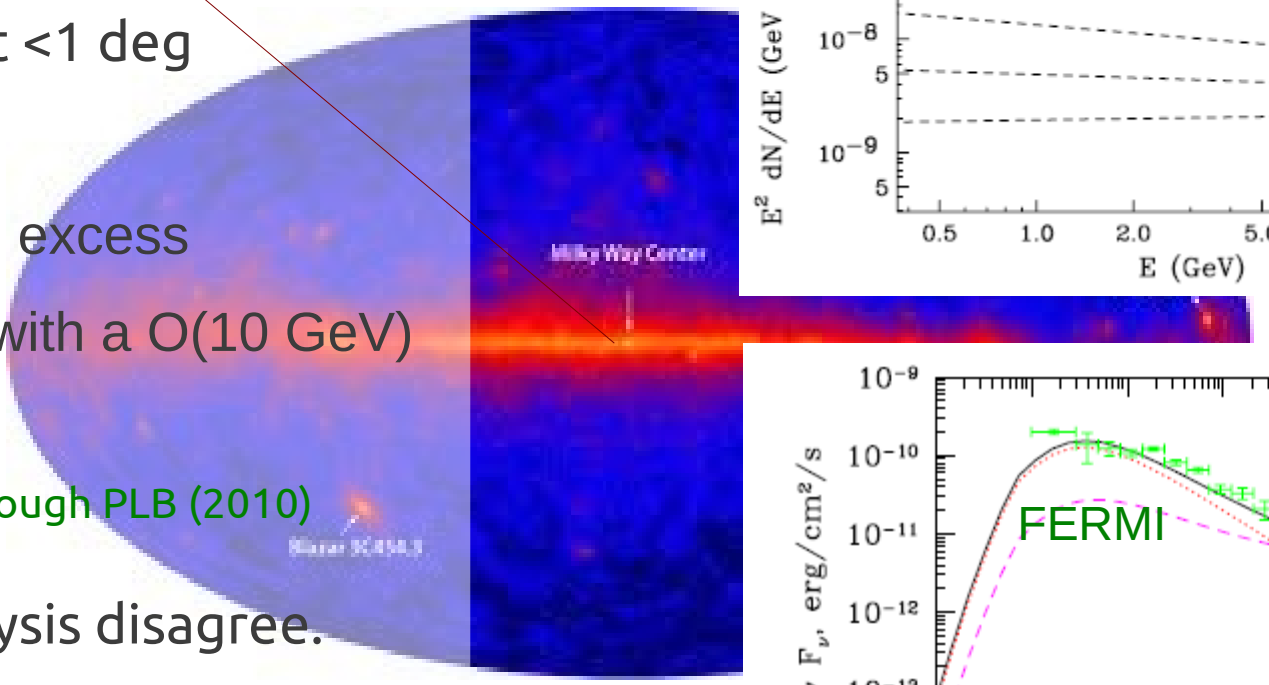
Su, Slatyer, Finkbeiner ApJ (2010), arXiv 1005.5480

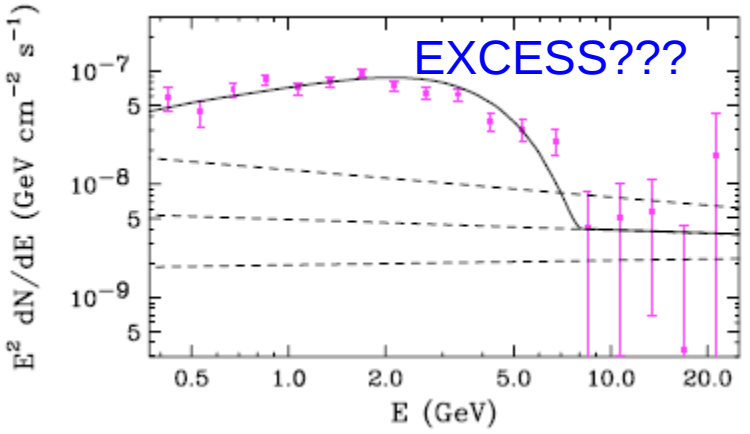
Gamma-rays. Where to look for DM

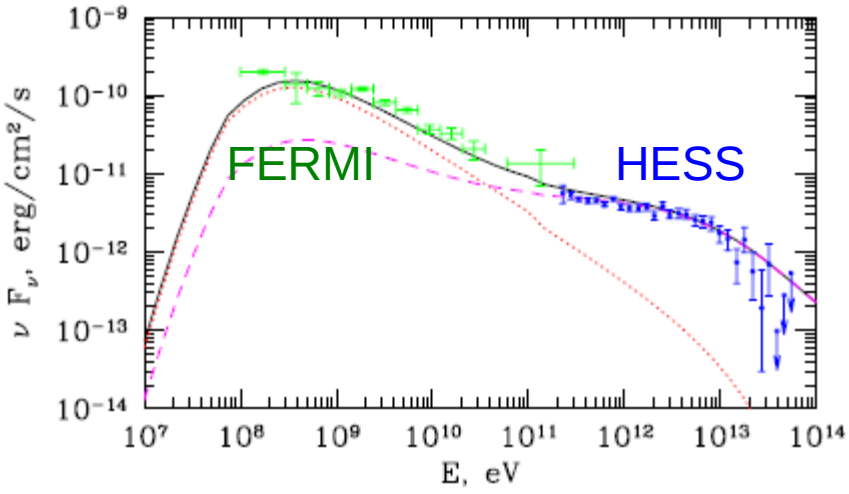
Galactic center

- Emission at <1 deg from GC.
- Claim of an excess consistent with a O(10 GeV) WIMP

Hooper, Goodenough PLB (2010)







- Other analysis disagree.

The Fermi data are consistent with an emission from known sources.

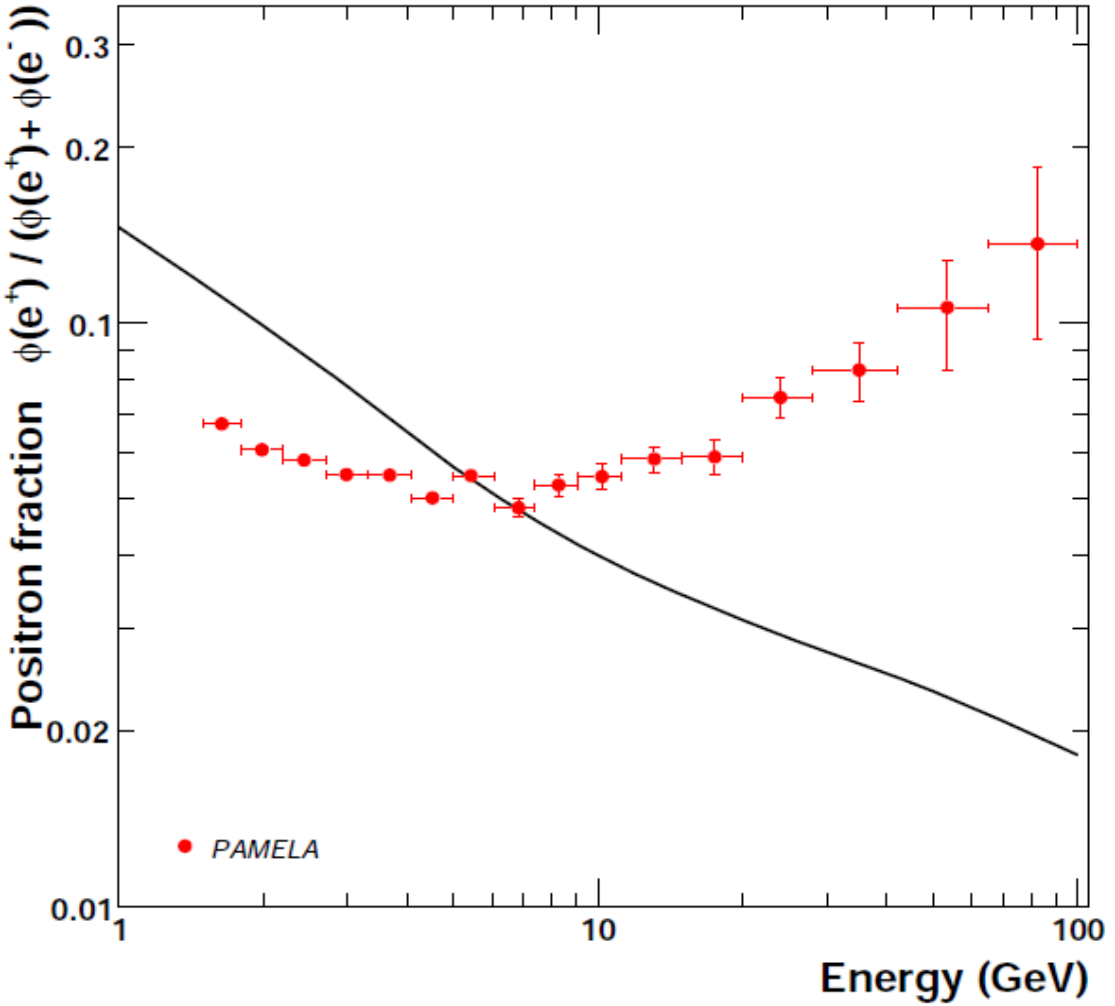
FERMI measurements of GC point source consistent with HESS data

Boyarsky, Malyshev, Ruchayskiy (2010)

Cosmic-rays positron excess. Present status

- Excess of cosmic-ray positrons with respect to "expectations"

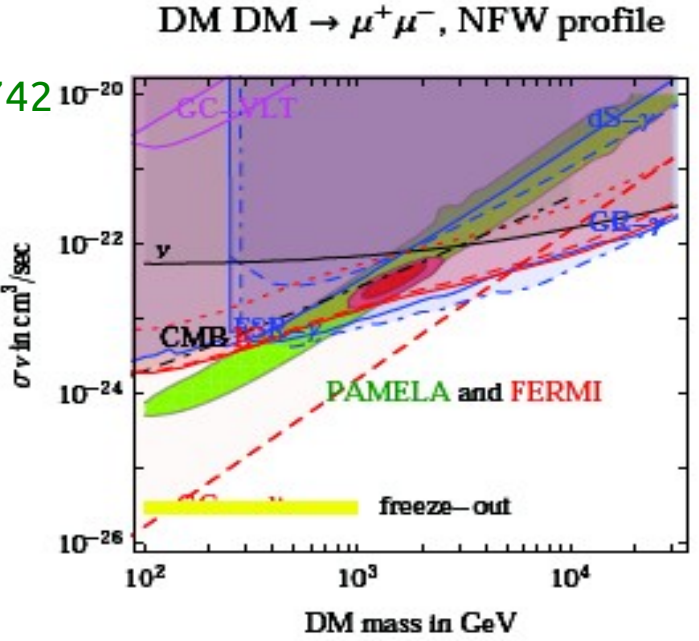
  Many papers to interpret the "anomaly "



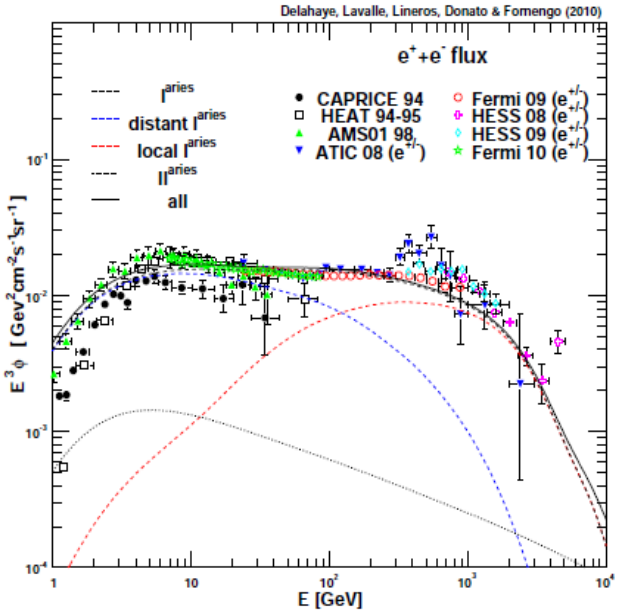
PAMELA Collaboration, Nature (2009), arXiv 0810.4995

Cosmic-rays positron excess. Present status

Papucci, Strumia JCAP (2010) arXiv: 0912.0742



- DM explanation is disfavored by multi-wavelenght observations but DM Hypothesis is not excluded.
- Special DM modeling is necessary: leptophilic DM, Sommerfeld-enchanced annihilations...
- Known astro sources can “naturally” explain all the data.



Delahaye, Lavalle, Lineros, Donato, Fornengo A&A (2010)

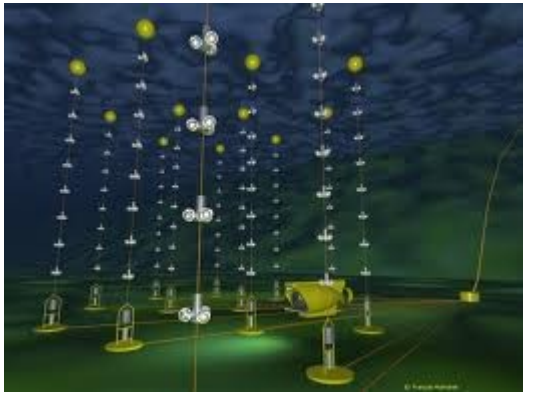
Further observations

- AMS-2 is taking data.

  Anisotropies analysis

  Searches for antideuterons from DM

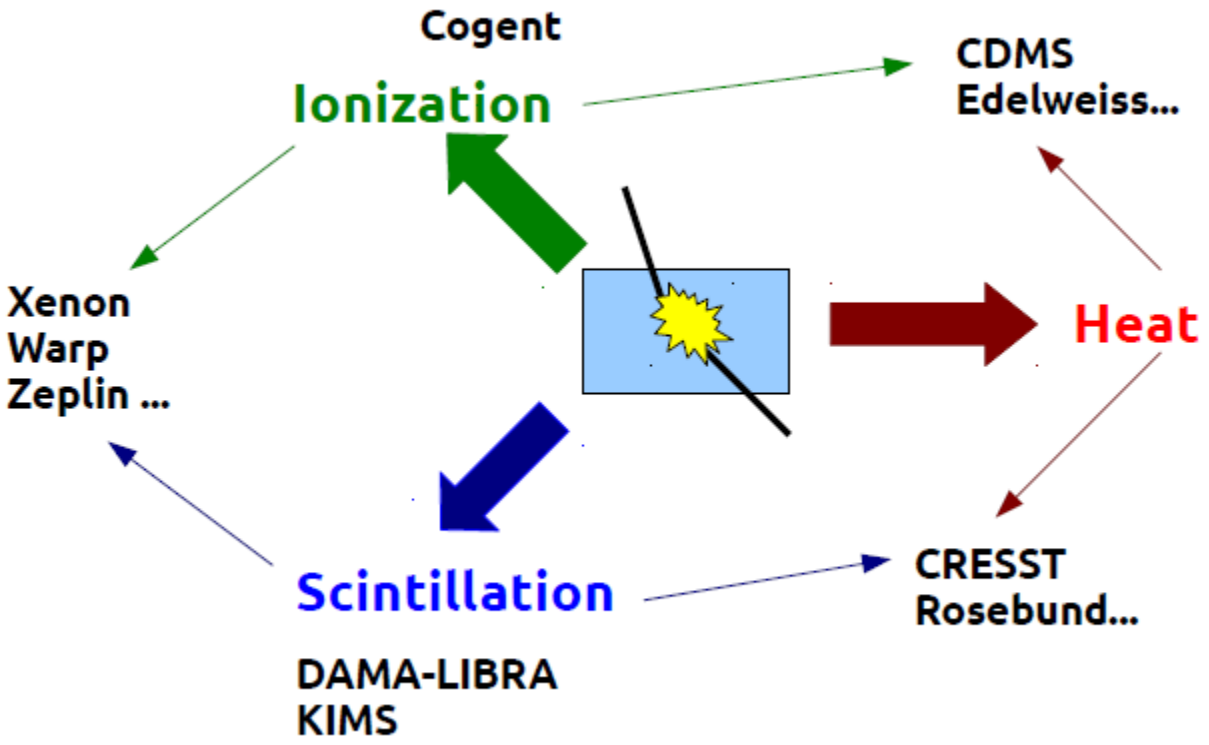
- Planck
- Further data and analysis from Fermi. (GC, anisotropies...?)
- HE neutrinos ! Ice-Cube, Antares



Direct detection principles

- To reduce background:

  underground experiments + shielding



Direct detection principles

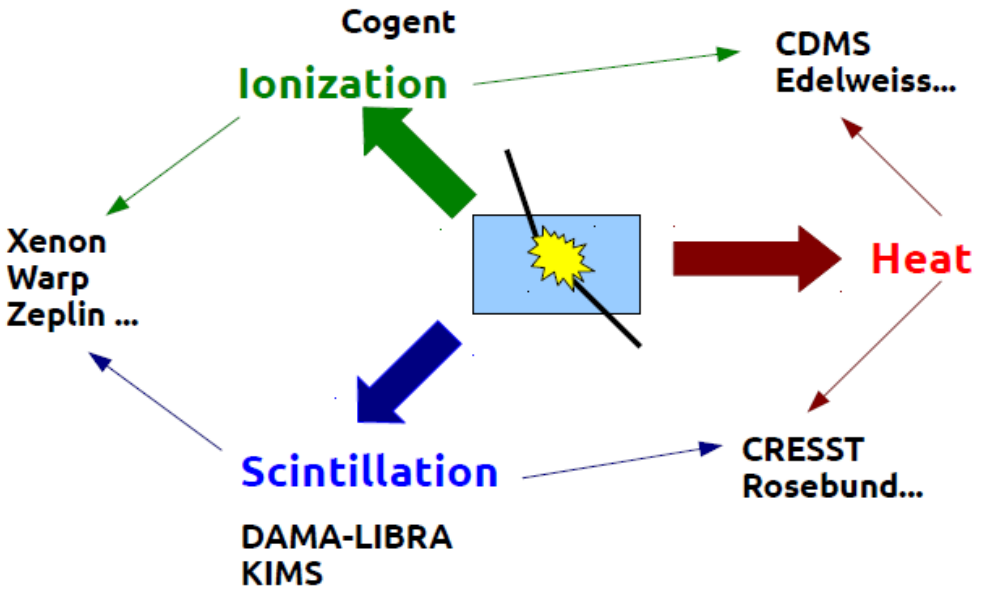
- To reduce background:

  underground experiments + shielding

- Discrimination bkg-signal

  using different variables

- DM feature (modulation)



Direct detection theory

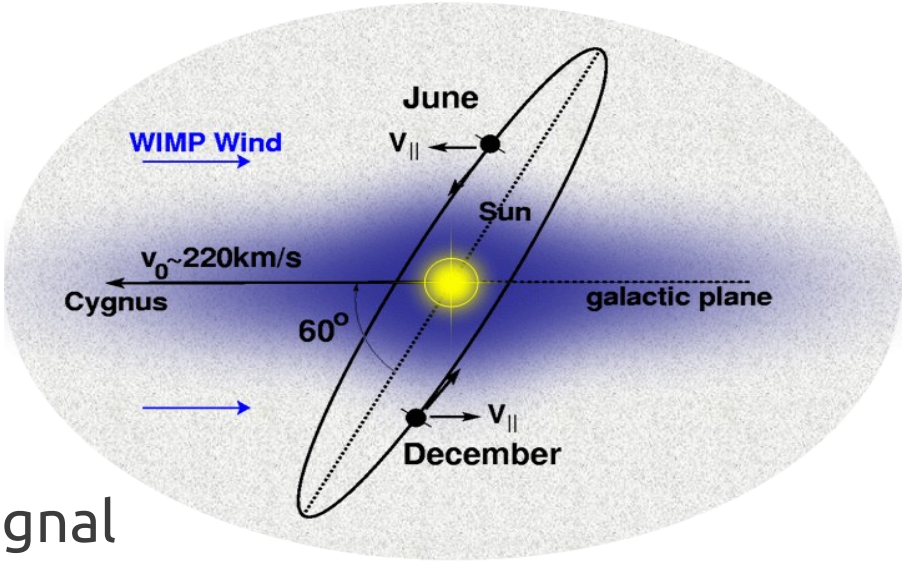
$$\frac{dR}{dE_R} = N_T \frac{\rho_\odot}{M_{DM}} \int_{|\vec{v}|>v_{min}} d^3v \; v f(v) \; \frac{d\sigma}{dE_R}$$

- Astrophysical uncertainties: local DM density and DM velocity distribution
- Particle physics DM input: how DM interacts with the detector
- Nuclear uncertainties

DM elastic scattering in the non-relativistic limit reduces to

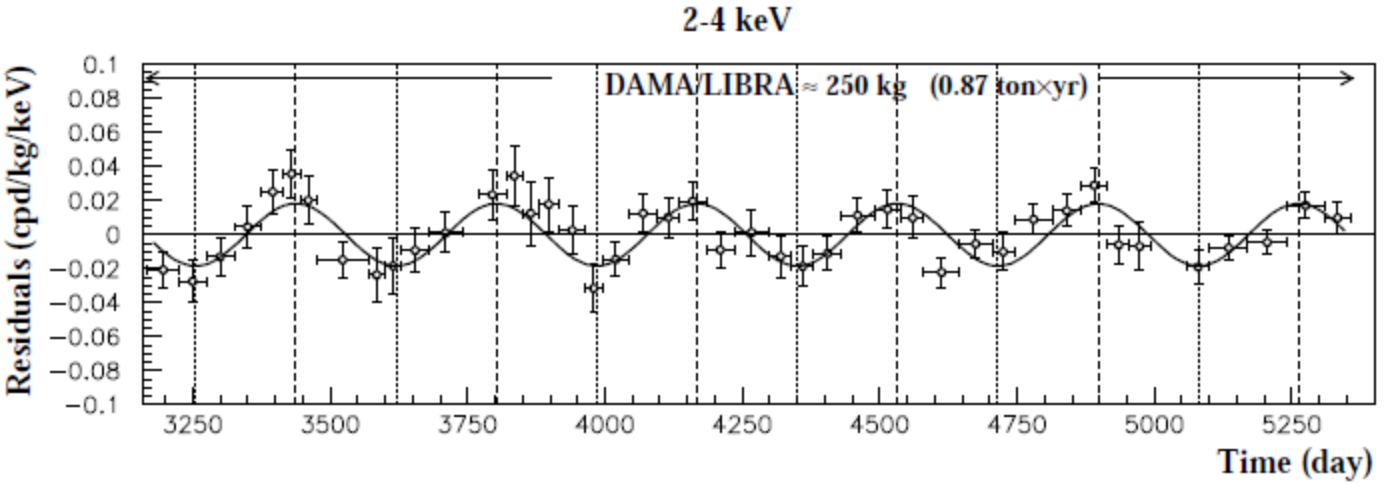
- Spin Independent: cross section ~ (mass number of nucleus)^2
- Spin dependent: cross section depends on the spin of the nucleus

Direct detection claims



- DAMA (Na I detector, @ Gran Sasso) evidence for annual modulation of the signal at 8.9 σ

  Phase, period and amplitude of the signal compatible with DM scattering off nuclei or electrons.



DAMA-LIBRA Collaboration, Eur. Phys. J. C. (2010) arXiv 1002.1028

Direct detection claims

- DAMA
- Cogent

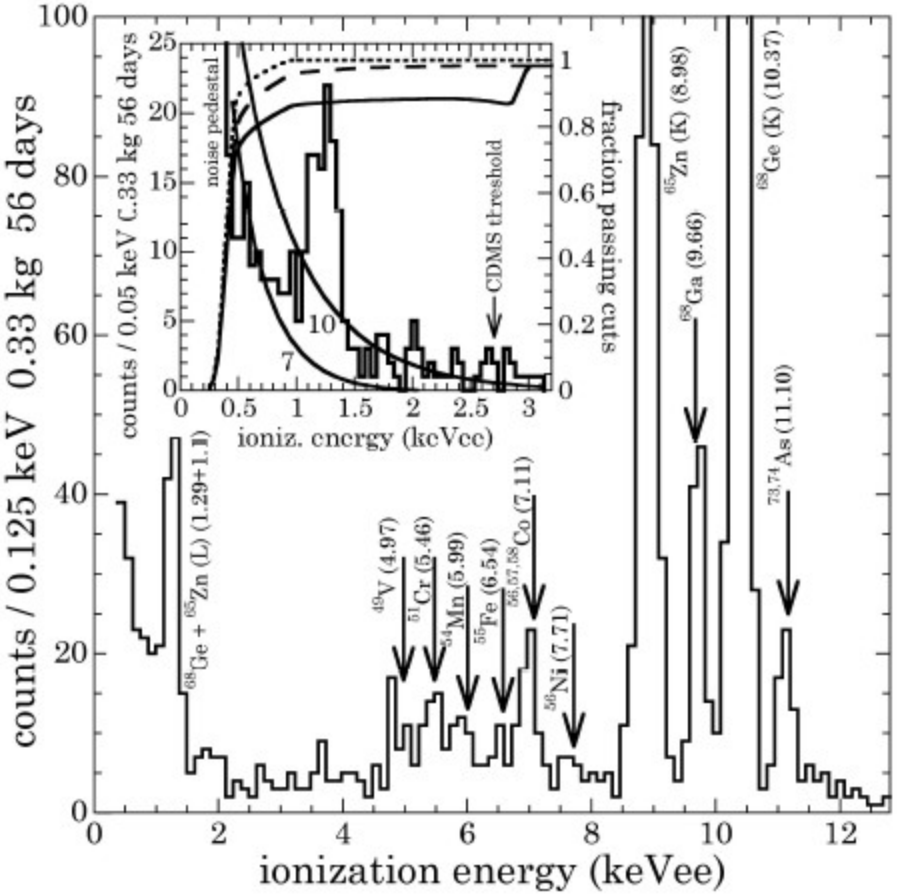
  Ge detector. @ Sudan UL

  Low E threshold:

  good for light DM searches

  Excess of bulk-like events

  below 3 KeVee

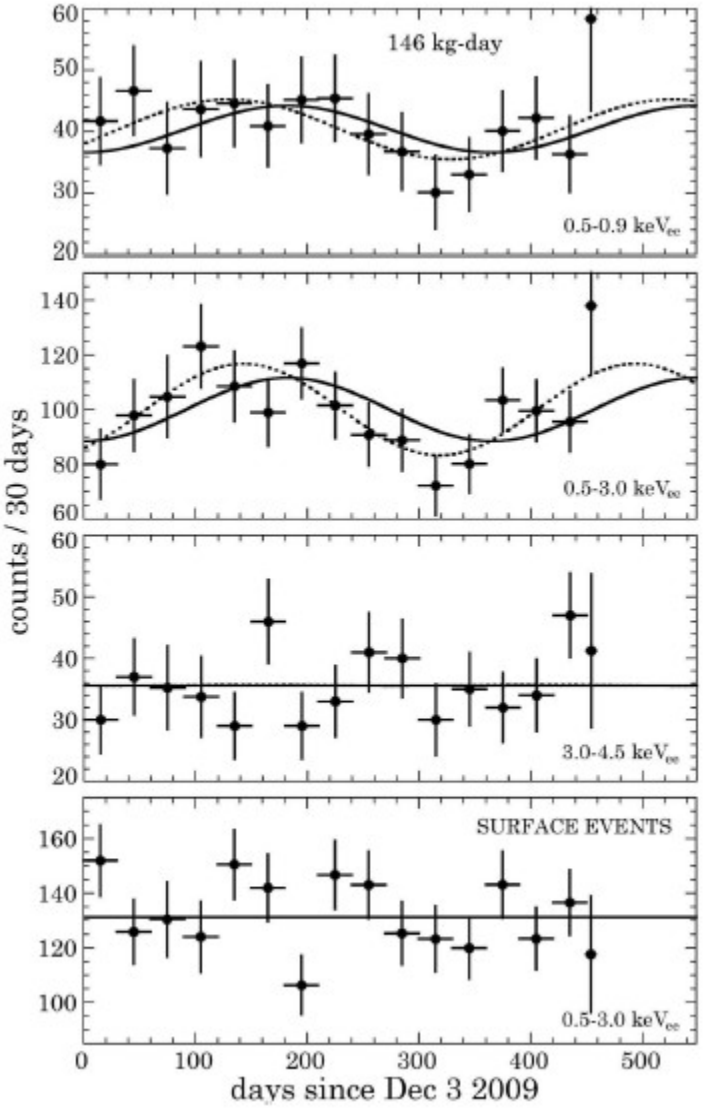


Cogent Collaboration PRL (2011) 1002.4703

Direct detection claims

- DAMA
- Cogent
- Cogent modulation

Hint of a modulation of the signal at 2.8 σ



Cogent Collaboration (2011) 1106.0650

Direct detection claims

- DAMA
- Cogent
- Cogent modulation
- CRESST II

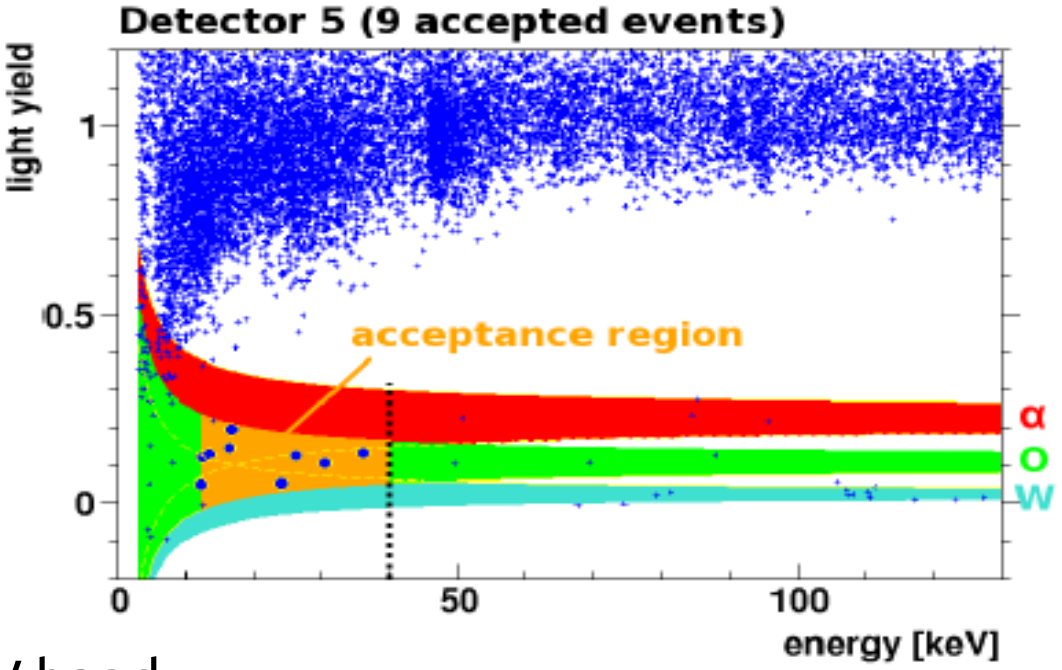
  $CaOW_4$ detector. (@ Gran Sasso)

  Phonon+ scintillation

  Excess of events in the 10-40 keV band

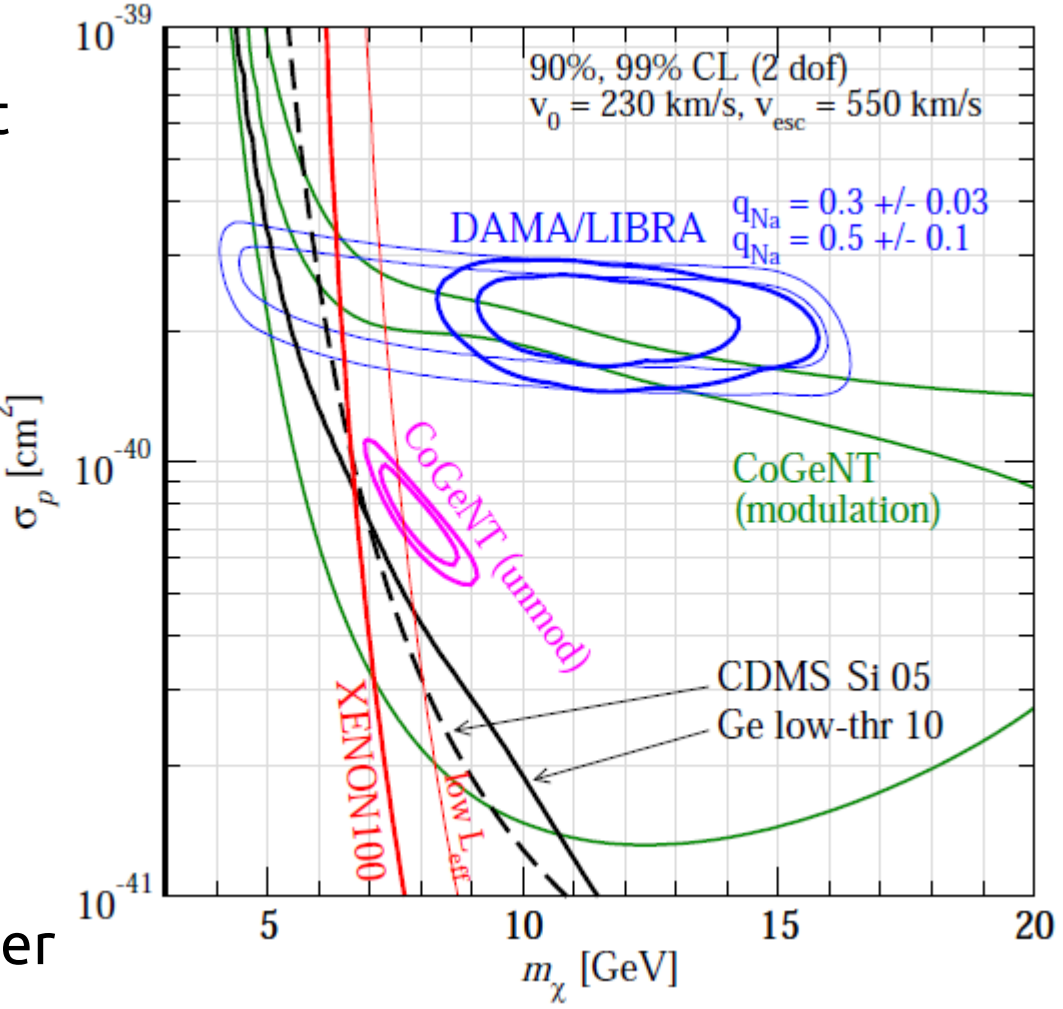
  with respect to bkg expectations

  Preliminary results shown at conferences, not yet published



Interpretations

- Elastic Spin Independent DM scatter off protons and neutrons
- Fix the astro setup
- Difficult to reconcile all the signals and the null results from the other experiments.



Schwetz, Zupan (2011) 1107.0623

Interpretations

- Change the DM interaction.

  -spin-dependent coupling

  -inelastic DM $\chi N \rightarrow \chi' N$

$$\delta = M'_{DM} - M_{DM} \sim 1 - 100 \text{ keV} << M_{DM}$$

DM can scatter only if it has enough energy to overcome the inelastic threshold

Tucker-smith, Weiner PRD (2001)

Interpretations

- Change the DM interaction.

  -spin-dependent coupling

  -inelastic

  -isospin violation (DM couples differently with proton and neutron)

  -momentum dependent scattering

  …. and combinations of the possibilities above
- Change the astrophysical assumptions
- Consider experimental uncertainties

  (channelling effects, uncert. in the Xenon scintillation response...)

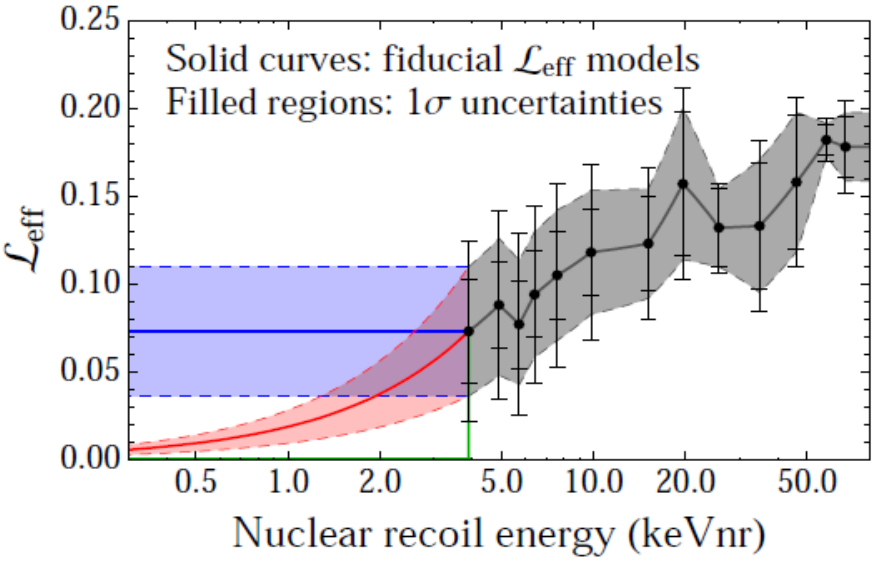
See e.g. Schwetz, Zupan (2011), Farina et al. (2011), Fox et al. (2011), McCabe(2011), Frandsen et al. (2011), Savage et al. (2010), Arina et al. (2011)

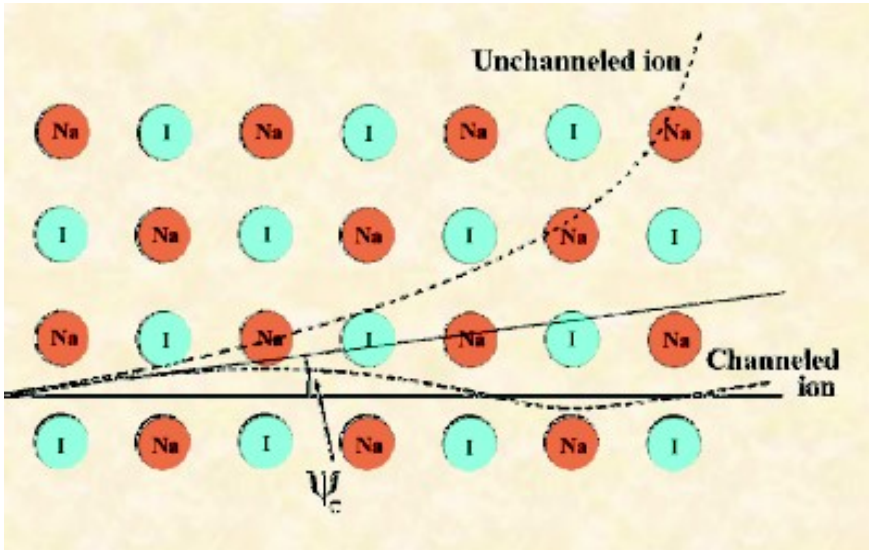
Interpretations

- Scintillation efficiency factor crucial for XENON bounds
- Quenching factor and Ion channeling in the DAMA cristal
- The controversy see

Collar arXiv 1106.3559, 1106.0653, 1103.3481

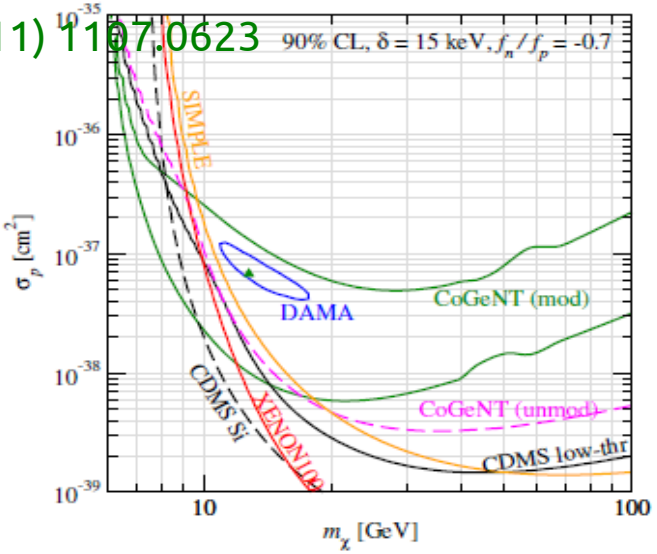
From Savage, Gelmini, Gondolo, Freese PRD (2011)

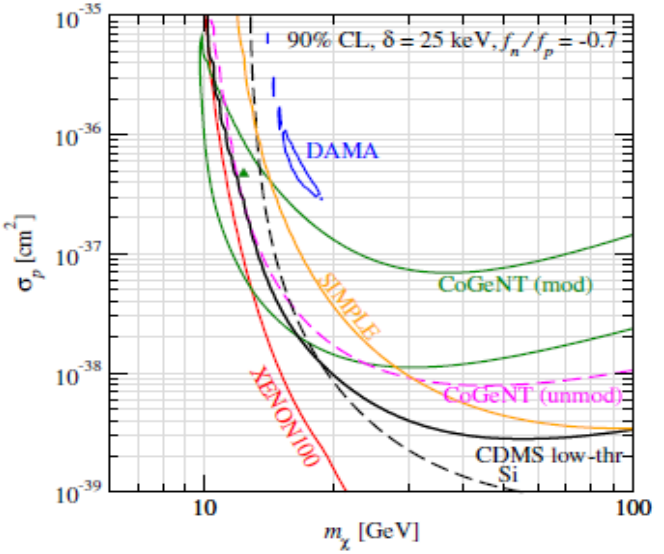


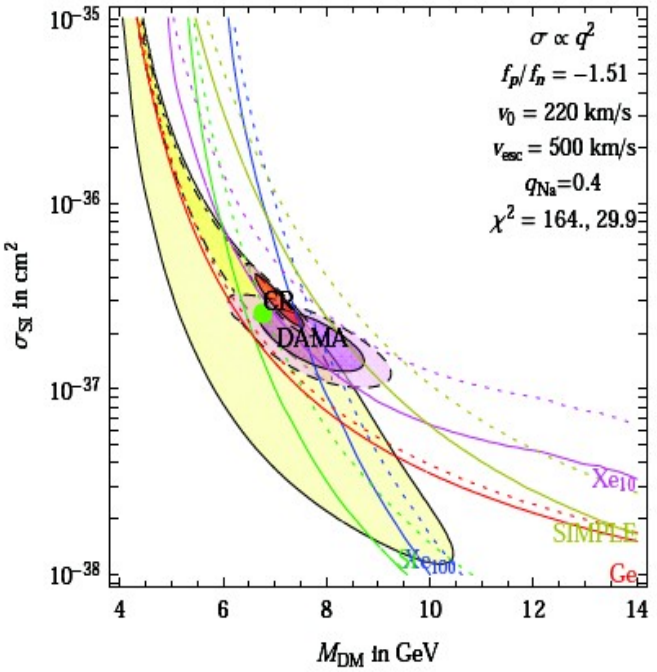


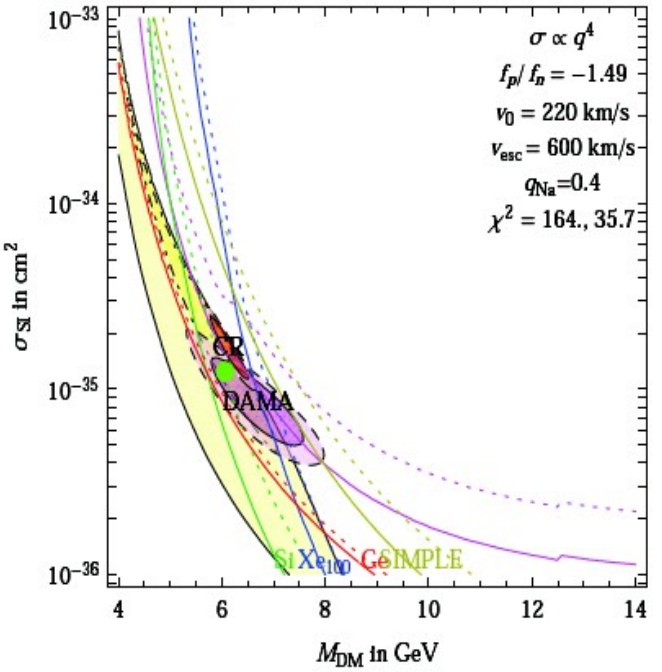
Interpretations

Schwetz, Zupan (2011) 1107.0623



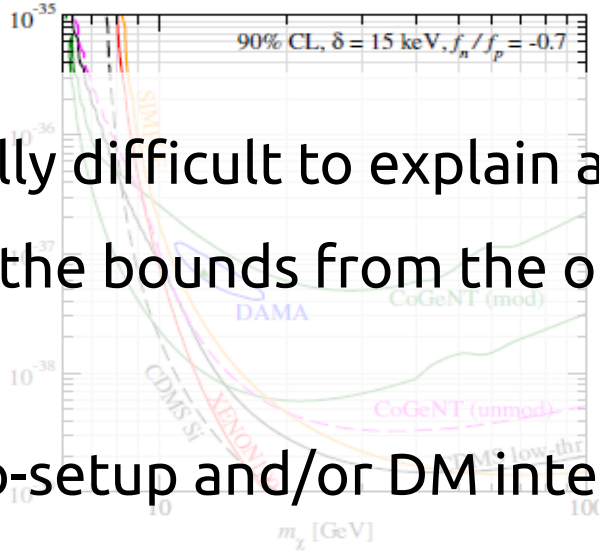


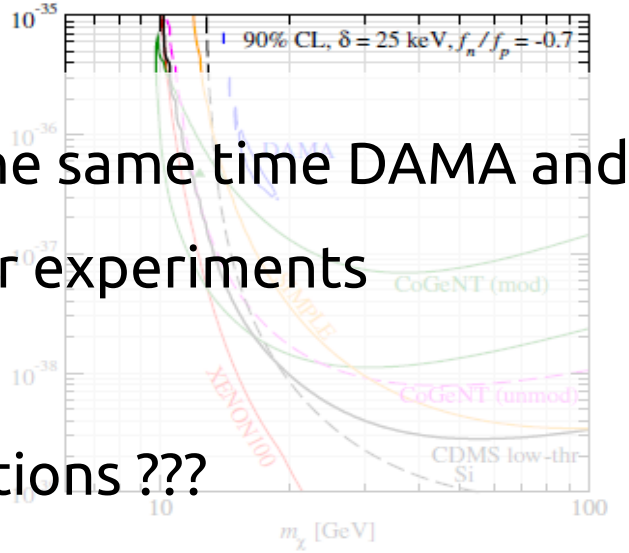




Farina, Pappadopulo, Strumia, Volansky (2011) 1107.0715

Interpretations



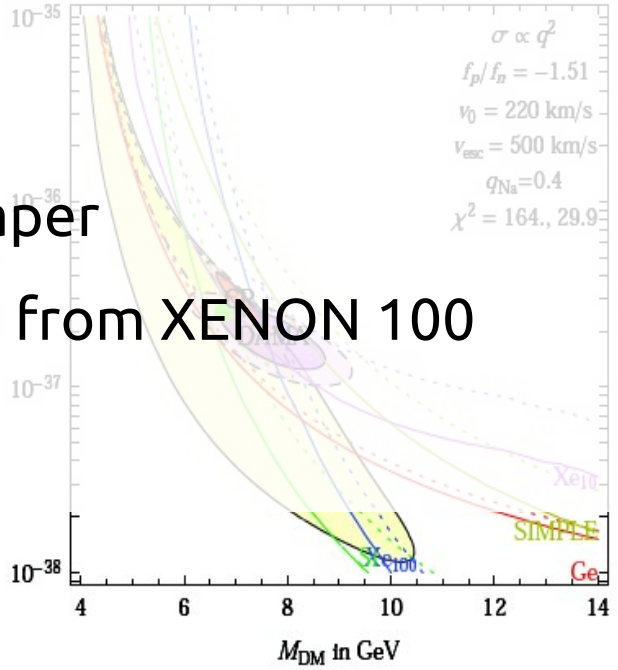


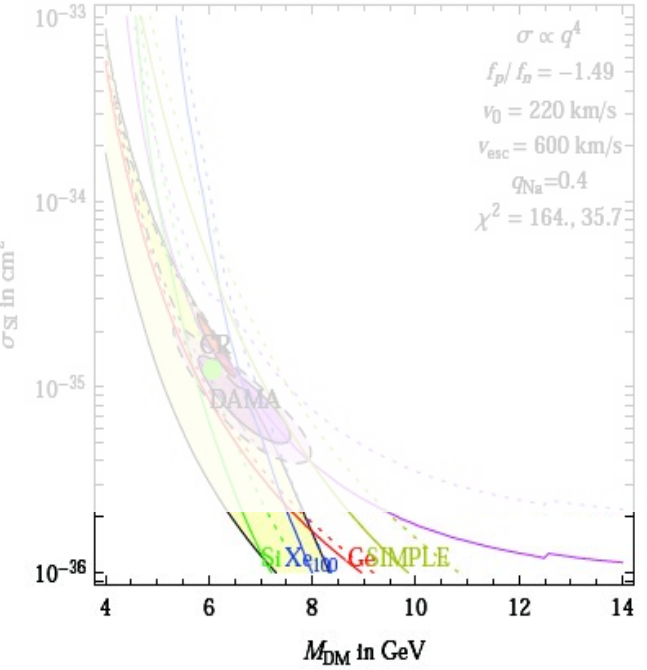
- It is generally difficult to explain at the same time DAMA and Cogent respecting the bounds from the other experiments
- Other astro-setup and/or DM interactions ???
- Soon:

  CRESST paper

  more data from XENON 100

  Cogent-4





Interpretations

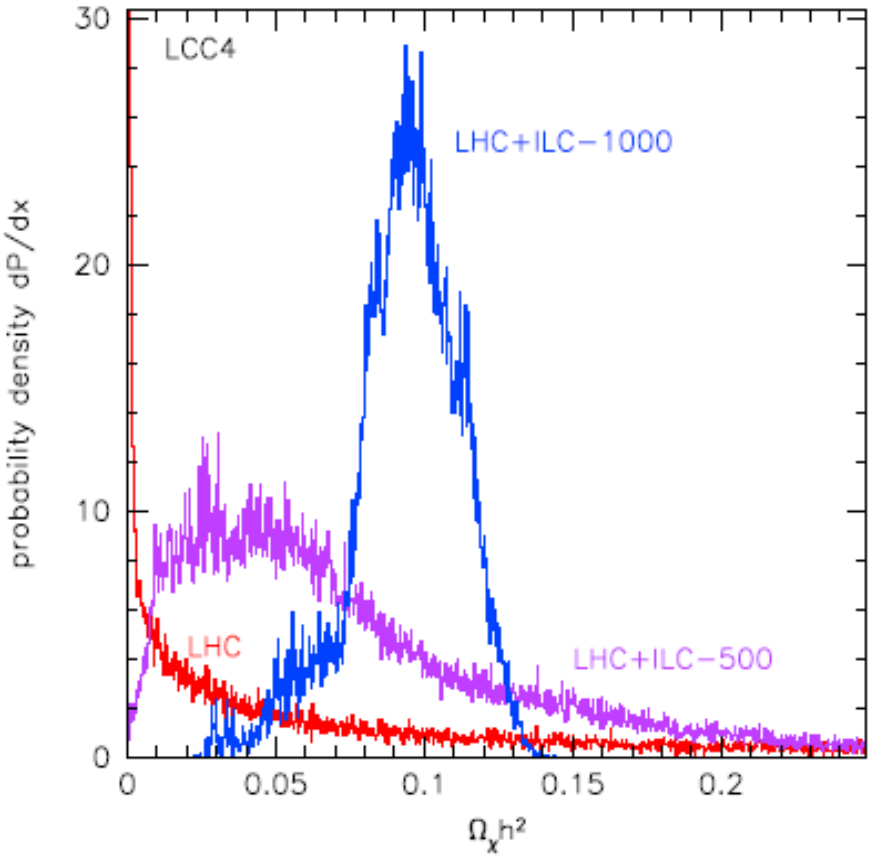
Further model dependent constraints comes from other searches:

- Antiprotons measurements Lavalle (2010), Delahaye, Cerdeño, Lavalle (2011)
- radio emission at galactic center and galaxy clusters Bohem, Ensslin, Silk (2010)
- LEP and Tevatron bounds

Fox, Harnik, Kopp, Tsai (2010), Mambrini (2010), Vasquez, Belanger, Boehm (2010), Bai, Fox, Harnik, (2010), Goodman, Ibe, Rajaraman, Shepherd, Tait, Yu (2010)...

DM & LHC

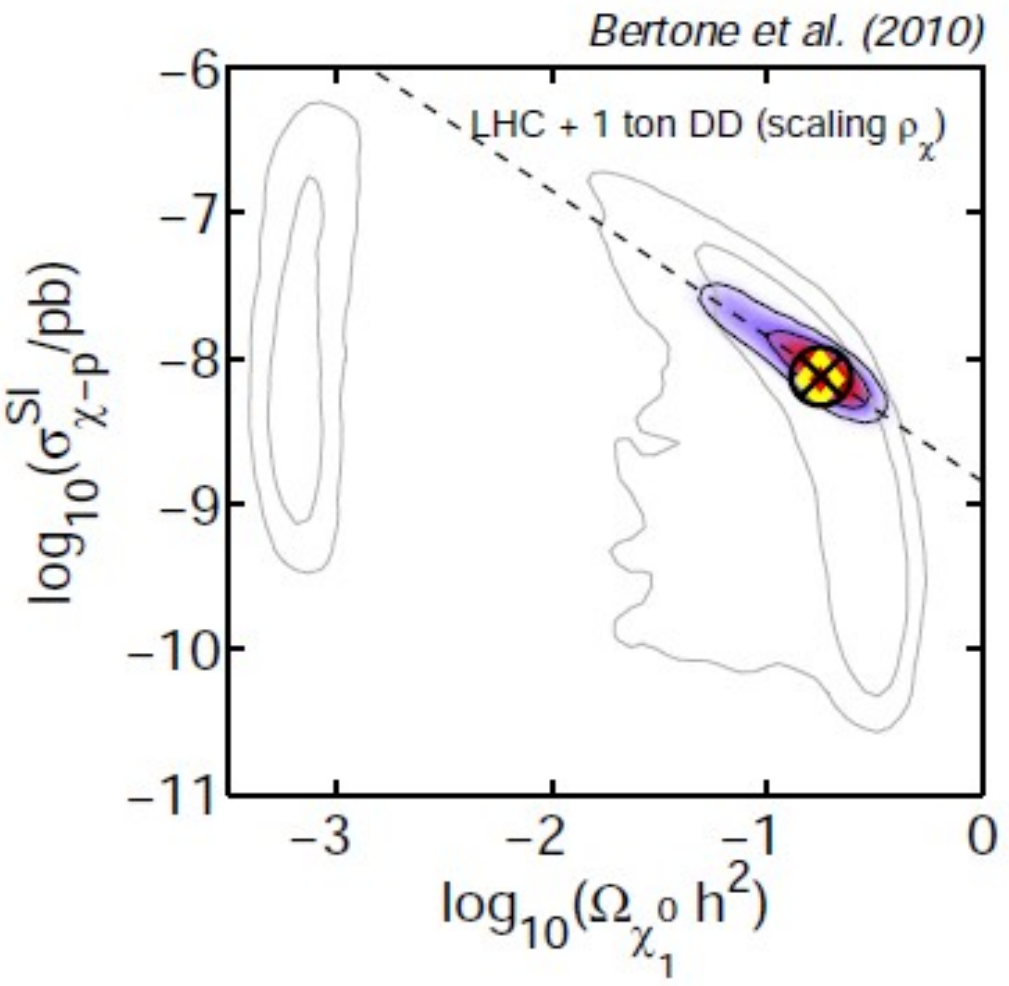
- Reconstructing DM properties at LHC
- Difficult to infer the relic abundance from collider measurements
- Need particle astrophysics to probe that a new particle is DM



Baltz, Battaglia, Peskin, Wizansky PRD (2006)

Complementarity LHC & DD

- Combining info from different experiments will be crucial to break degeneracies in DM parameter space and reconstruct the DM properties



Bertone, Cerdeño, Fornasa, Ruiz de Austri, Trotta PRD (2010)

Conclusions

- Many data for DM: direct and indirect searches
- Some anomalies both in direct and indirect exp.
- Difficult to explain the signal with “standard” WIMPs
- Much more with LHC to test the WIMPs paradigma
- Don't forget alternatives (sterile neutrinos, axions, majoron, ...) :

  maybe the searches discussed in these slides are in the wrong direction!!!

THANKS

Next generation DM searches

- Towards ton scale direct detection detectors

  XENON 1 T

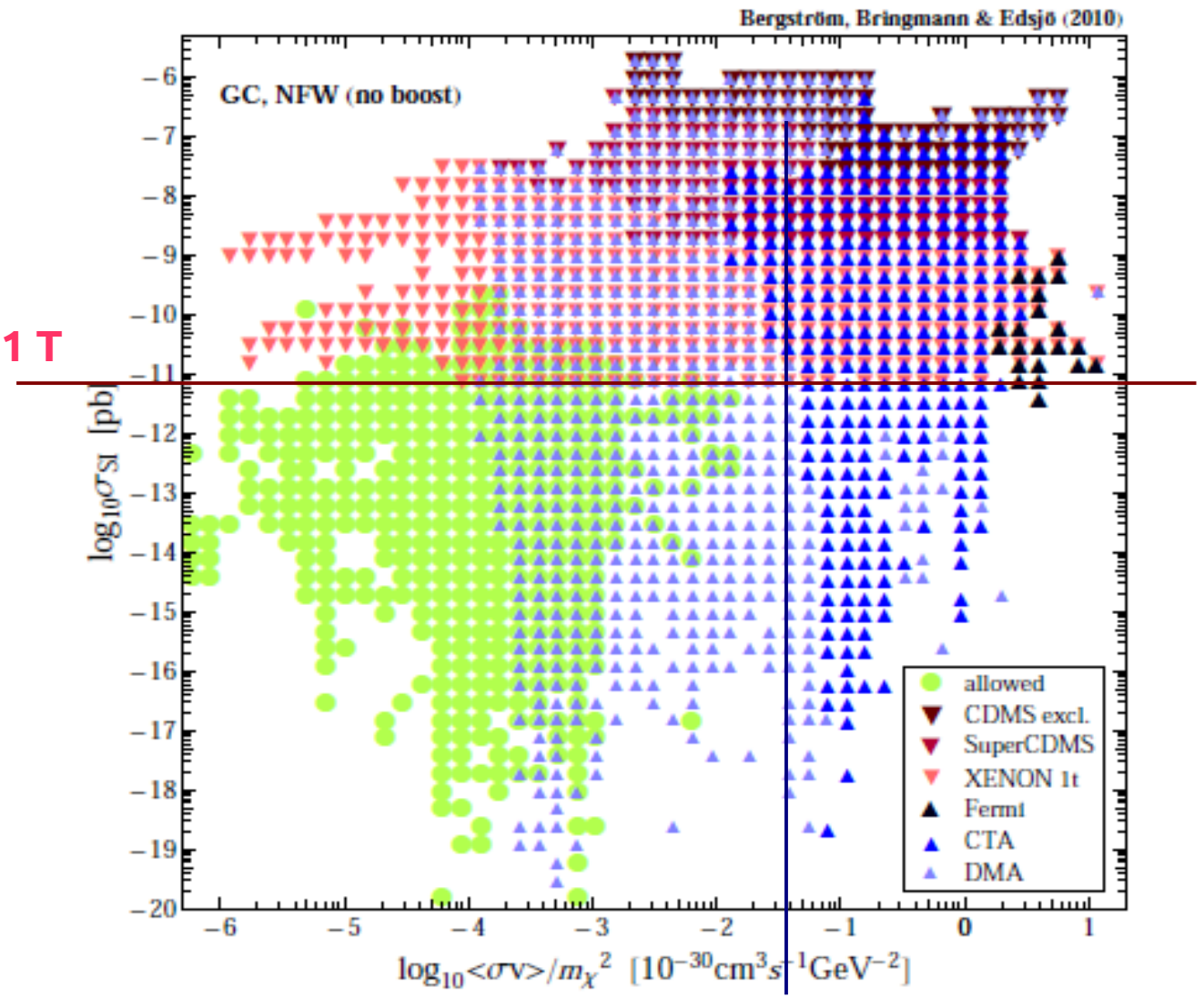
  SuperCDMS, Eureca, DARWIN, XMASS (timescale: 5-10 years????)

- Large arrays of gamma-rays detectors

  Air Cherenkov Telescope (CTA)

  Dark Matter Array (DMA) dedicated dark matter experiment

Next generation DM searches



XENON 1 T

DMA **CTA**

Bergstrom, Bringman, Edsjo PRD (2010)