

Astroparticle Physics in the next decade

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What is astroparticle physics?

Fundamental aspects of astrophysics & cosmology, and astrophysical aspects of subatomic physics such as:

- Dark matter theory and searches (including neutrinos)
- Dark energy, CMB, SN Ia, gravitational lensing, polarization, cosmological parameters,...
- High-energy cosmic rays, acceleration mechanisms, search for Lorentz-violation,...
- Tests of GR, Gravitational waves, modified gravity,...
- ...

Outline:

- Structure of policy making and prioritization in Europe and US, and beginning globalization of astroparticle physics.
- Where were we 10 years ago? Examples from 2004-5.
- Where are we now? Subjective selection. Mostly about dark matter (i.e., more iDM than TeVPA).
- What is next, and where will we be in 10 years? Educated (?) guesses

It is difficult to make predictions, especially about the future. (Old Danish saying, often attributed to Niels Bohr)

Science policy

Main recent events in Europe:

- ✓ Particle Physics - Update of The European Strategy for Particle Physics (document approved by CERN's Council, May, 2013)
- ✓ Astroparticle Physics – New ApPEC (Astroparticle Physics European Consortium) formed 2012-13 with main European funding agencies and organizations as members (Precursors: "old" ApPEC; ASPERA & ASPERA-2). ASPERA Roadmap from 2009, new ApPEC Roadmap planned for 2015.

Main recent event in the US:

- ✓ The P5 report (summary of recommendations based on the extensive "Snowmass" exercise) submitted to HEPAP (May, 2014).
- ✓ Astrophysics "Decadal survey", 2012.



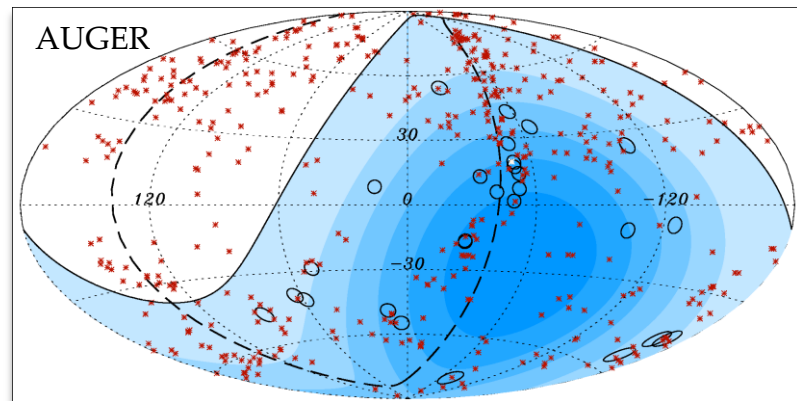
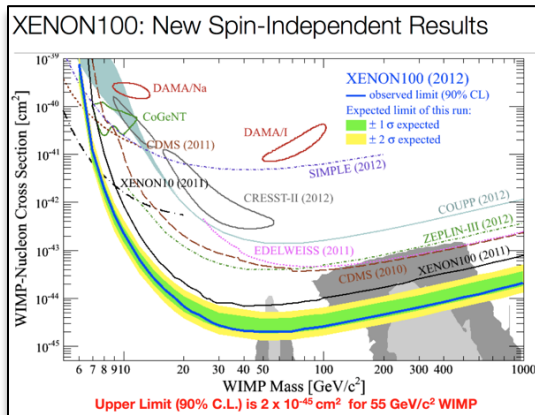
From Update of The European Strategy for Particle Physics (approved by CERN's Council, May, 2013)

Astroparticle-related (for main particle physics strategy, see talk by R. Heuer):



Theory is a strong driver of particle physics and provides essential input to experiments, witness **the major role played by theory in the recent discovery of the Higgs boson**, from the foundations of the Standard Model to detailed calculations guiding the experimental searches. *Europe should support a diverse, vibrant theoretical physics programme, ranging from abstract to applied topics, in close collaboration with experiments and extending to neighbouring fields such as **astroparticle physics and cosmology**. Such support should extend also to high-performance computing and software development.*

From Update of The European Strategy for Particle Physics, 2013



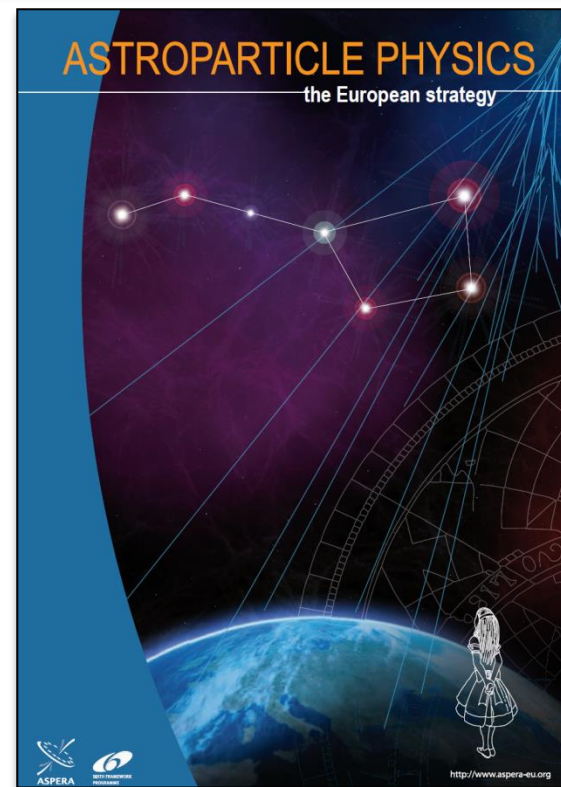
A range of important **non-accelerator experiments** take place at the **overlap of particle and astroparticle physics**, such as searches for proton decay, neutrinoless double beta decay and dark matter, and the study of high-energy cosmic-rays.

These experiments address **fundamental questions beyond the Standard Model** of particle physics. The exchange of information between CERN and ApPEC has progressed since 2006. *In the coming years, CERN should seek a **closer collaboration with ApPEC** on detector R&D with a view to maintaining the community's capability for unique projects in this field.*

Astroparticle physics European strategy, ASPERA roadmap 2009 with update 2011. Focus on scientific problems:

- 1) What is the Universe made of?
In particular: What is dark matter?
- 2) Do protons have a finite life time?
- 3) What are the properties of neutrinos?
What is their role in cosmic evolution?
- 4) What do neutrinos tell us about the interior of the Sun and the Earth, and about supernova explosions?
- 5) What is the origin of cosmic rays?
What is the view of the sky at extreme energies?
- 6) What will gravitational waves tell us about violent cosmic processes and about the nature of gravity?

ApPEC, Astroparticle Physics European **Coordination** committee, founded in 2001
→ ASPERA (2006-2012) → New ApPEC, Astroparticle Physics European **Consortium** founded in 2013





Astroparticle Physics European Consortium

[Home](#) [About](#) [Science](#) [Strategy](#) [Infrastructures](#) [Industry](#) [Computing](#) [Multidisciplinarity](#) [Theory](#) [Communication](#) [Calls](#) [Documents](#)

Objectives

History

Consortium

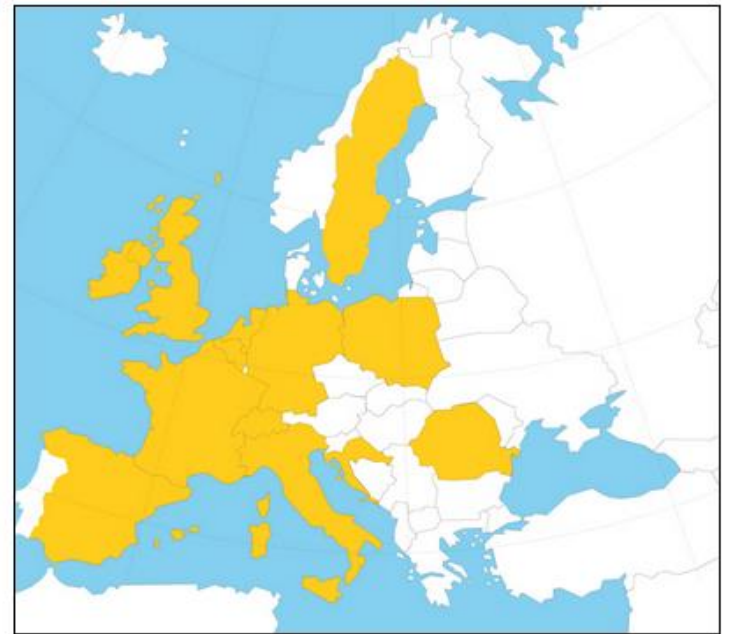
Functional centers

Management

Contacts

The APPEC consortium brings together 15 funding agencies, governmental institutions and institutes from 13 European countries:

- [CEA](#) – France
- [CNRS](#) – France
- [DESY](#) – Germany
- [FNRS](#) – Belgium
- [FOM](#) – The Netherlands
- [FWO](#) – Belgium
- [HRZZ](#) – Croatia
- [IFIN-HH](#) – Romania
- [INFN](#) – Italy
- [KIT](#) – Germany
- [LSC](#) – Spain
- [NCN](#) – Poland
- [DIAS/RIA](#) – Ireland
- [SNF](#) – Switzerland
- [STFC](#) – United Kingdom
- [VR](#) – Sweden

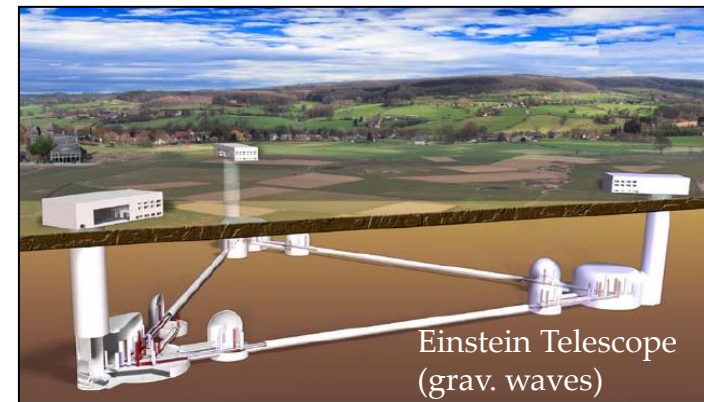
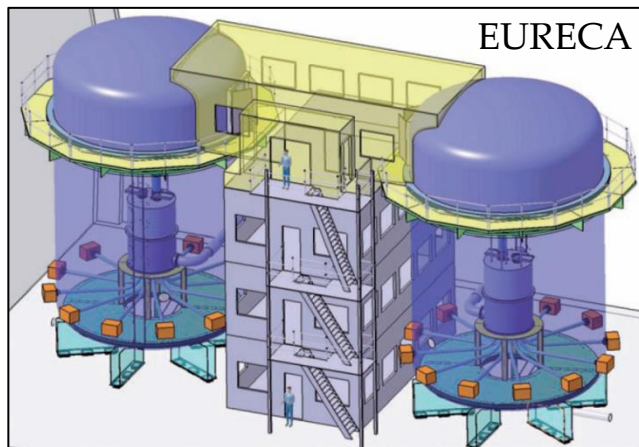
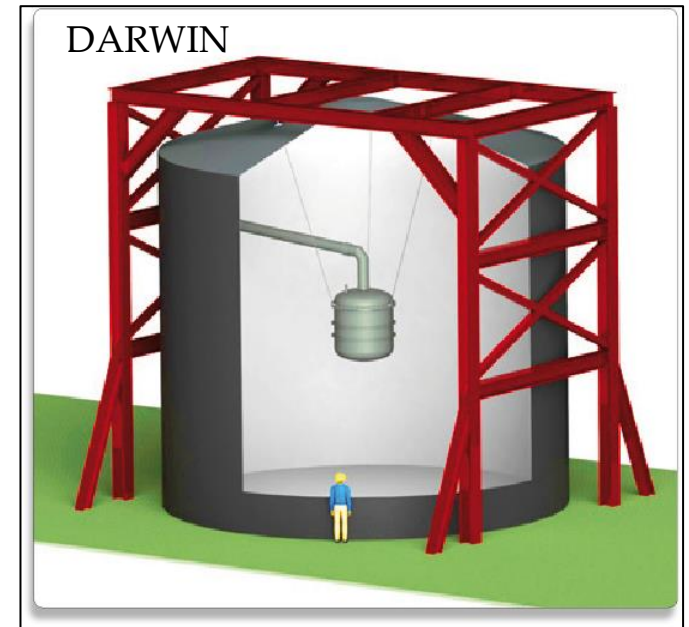
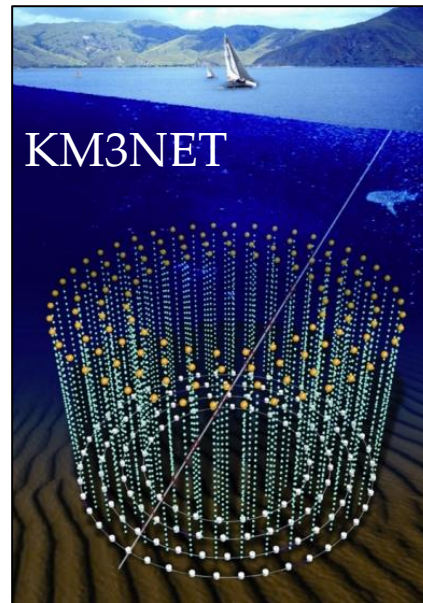


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Last update: 21st June 2014 - The APPEC website is hosted and edited by [WebMaster APPEC](#) ..



Big projects supported by the ASPERA 2011 Roadmap Update



P5 report to HEPAP (USA), May, 2014

Building for Discovery

Strategic Plan for U.S. Particle Physics in the Global Context



Scenario A) Constant funding level for 3 years, thereafter 2% increase per year based on FY 2013 budget.
B) Same as A), but increase 3% per year based on FY 2014 budget, after year 3.
C) Unconstrained.

Summary of Scenarios

Project/Activity	Scenarios			Science Drivers					Technique (Frontier)
	Scenario A	Scenario B	Senario C	Higgs	Neutrinos	Dark Matter	Cosm. Accel.	The Unknown	
Large Projects									
Muon program: Mu2e, Muon g-2	Y, <small>Mu2e small reprofile needed</small>	Y	Y					✓	I
HL-LHC	Y	Y	Y	✓		✓		✓	E
LBNF + PIP-II	Y, <small>LBNF components delayed relative to Scenario B.</small>	Y	Y, enhanced		✓			✓	I,C
ILC	R&D only	R&D, <small>possibly small hardware contributions. See text.</small>	Y	✓		✓		✓	E
NuSTORM	N	N	N		✓				I
RADAR	N	N	N		✓				I
Medium Projects									
LSST	Y	Y	Y		✓		✓		C
DM G2	Y	Y	Y			✓			C
Small Projects Portfolio	Y	Y	Y		✓	✓	✓	✓	All
Accelerator R&D and Test Facilities	Y, reduced	Y, <small>some reductions with redirection to PIP-II development</small>	Y, enhanced	✓	✓	✓		✓	E,I
CMB-S4	Y	Y	Y		✓		✓		C
DM G3	Y, reduced	Y	Y			✓			C
PINGU	Further development of concept encouraged				✓	✓			C
ORKA	N	N	N					✓	I
MAP	N	N	N	✓	✓	✓		✓	E,I
CHIPS	N	N	N		✓				I
LAr1	N	N	N		✓				I
Additional Small Projects (beyond the Small Projects Portfolio above)									
DESI	N	Y	Y		✓		✓		C
Short Baseline Neutrino Portfolio	Y	Y	Y		✓				I

TABLE 1 Summary of Scenarios A, B, and C. Each major project considered by P5 is shown, grouped by project size and listed in time order based on year of peak construction.

Building for Discovery

Strategic Plan for U.S. Particle Physics in the Global Context



LBNF: New, international neutrino long baseline facility. Will Europe participate? (In the P5 plan, the US will contribute to the LHC high luminosity upgrade.)

Figure 1 Construction and Physics Timeline



Several other planning bodies for large infrastructures:

[European Strategy Forum for Research Infrastructures \(ESFRI\)](#). “.. is a strategic instrument to develop the scientific integration of Europe and to strengthen its international outreach.”
[ESFRI's delegates are nominated by the Research Ministers of the Member and Associate Countries.](#)

More and more international cooperation and prioritization will be needed for astroparticle physics (e.g. long baseline neutrino experiments and gravitational wave detectors, and later for third generation dark matter experiments):

[OECD Astroparticle Physics International Forum of the OECD Global Science Forum – APIF](#)
(Chair: M. Turner)

[Members: Argentina, Belgium, Canada, China, European Union, France, Germany, India, Israel, Italy, Japan, Korea, Netherlands, Poland, Russian Federation, Spain, Sweden, Switzerland. United Kingdom, United States; members proposed by funding agencies.](#)

[In parallel, new group created by IUPAP, The AstroParticle Physics International Committee \(APPIC\), with scientific members:](#)

[Michel Spiro \(France\) - Chair , Pierre Binetruy \(France\), Natalie Roe \(USA\) Roger Blandford \(USA\), Sheila Rowan \(GB\), Zhen Cao \(China\), Valery Rubakov \(Russia\), Eugenio Coccia \(Italy\), Bernard Sadoulet \(USA\), Don Geesaman \(USA\), Subir Sarkar \(GB/Denmark\), Kunio Inoue \(Japan\), Christian Spiering \(Germany\), Naba Mondal \(India\), Angela Olinto \(USA\), Yoichiro Suzuki \(Japan\).](#)

European Strategy Forum on Research Infrastructures



Roadmap 2006
(initiated 2004)
and update 2011

2006
Astronomy,
Astrophysics,
Nuclear
and Particle
Physics **

ELT: The European Extremely Large Telescope	850	2018	40	
FAIR	1186	2014	120	
KM3NET	220-250	2015	NYD	
SKA: The Square Kilometre Array (GLOBAL)	1150	2014-2020	100	
SPIRAL2	137	2011	7	

2011 update

Physical Sciences
and Engineering

CTA	150	10	2019	
E-ELT	1000	30	2018	
ELI	~700****	~70	2015	
KM3NeT	220	4-6	2016	
SKA (GLOBAL)	1500	100-150	2017	

1. **Three Priority Projects for implementation**

- EPOS: European Plate Observing System
- ELIXIR: The European Life-Science Infrastructure for Biological Information
- ESS: The European Spallation Source

ESFRI update, May 2014. Projects that may start being implemented by 2015/16, after which a new roadmap update follows.

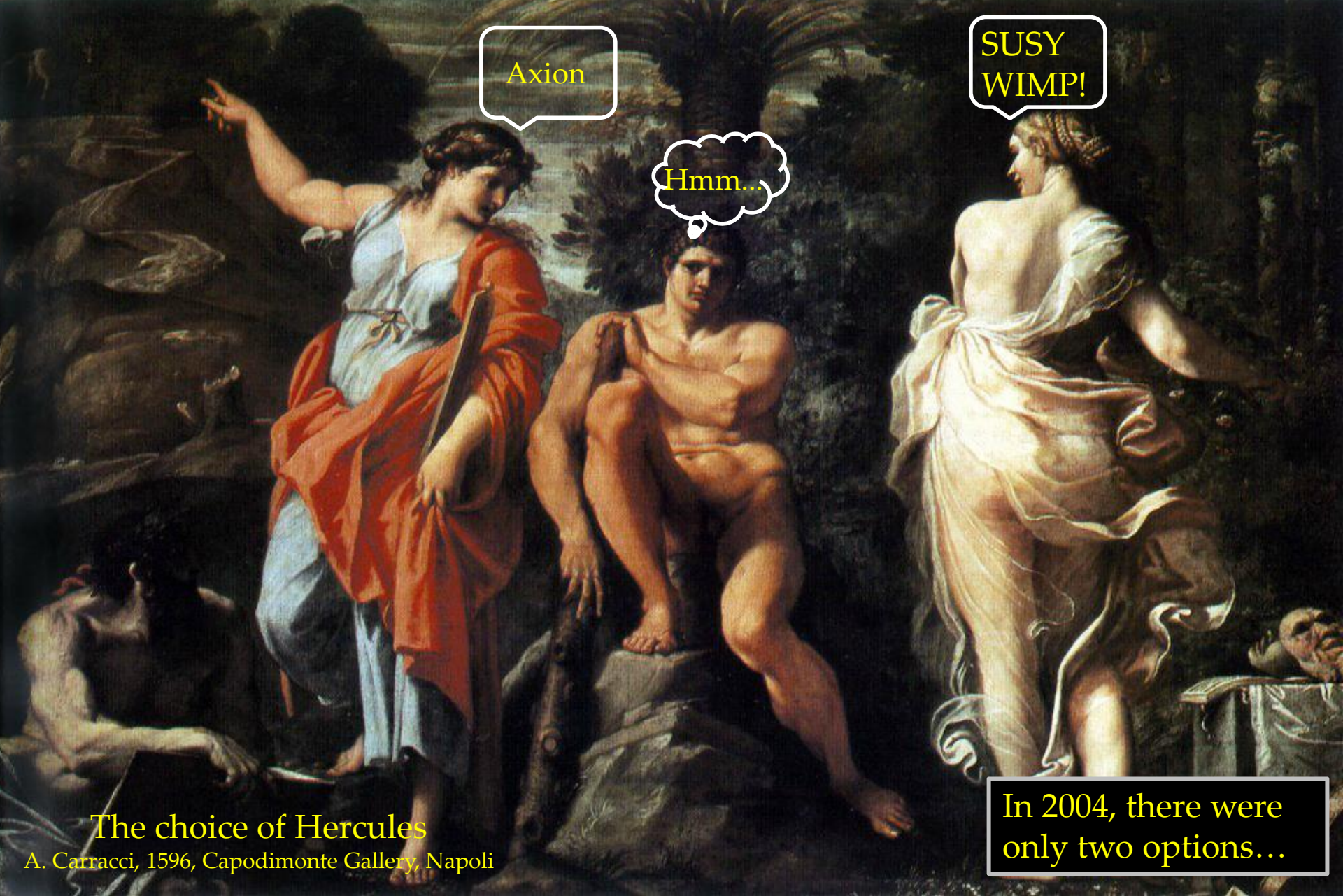
2. **Implementation Support**

- ECCSEL: European Carbon dioxide Capture and Storage Laboratory Infrastructure
- EISCAT-3D: The next generation incoherent scatter radar system
- EMSO: European Multidisciplinary Seafloor & Water column Observatory
- BBMRI: Biobanking and Biomolecular Resources Research Infrastructure
- ELI: Extreme Light Infrastructure
- CTA: Cherenkov Telescope Array
- SKA: Square Kilometre Array
- CLARIN: Common Language Resources and Technology Infrastructure
- DARIAH: Digital Research Infrastructure for the Arts and Humanities

No KM3NET yet...

Something about the
science drivers

Dark Matter



Axion

SUSY
WIMP!

Hmm...

The choice of Hercules

A. Carracci, 1596, Capodimonte Gallery, Napoli

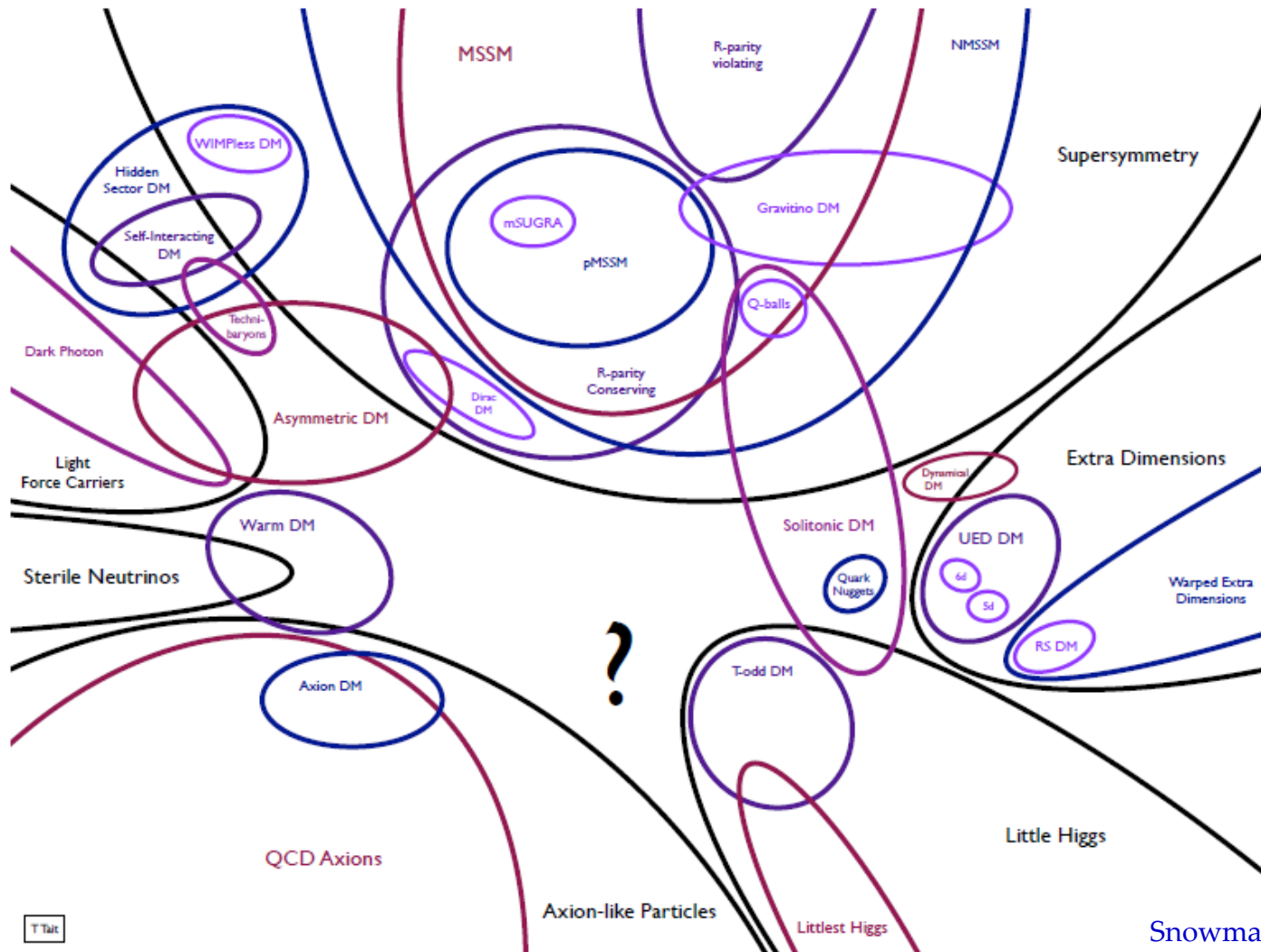
In 2004, there were
only two options...

G. Bertone, Nature 2010 (almost 5 years ago):

The future

The other possibility is of course that new physics is not found at the LHC within 5–10 years. For the reasons I have discussed above, null searches at the LHC would push the scale of new physics into more and more unnatural territory (that is, to high levels of fine-tuning). Although null searches would not rule out supersymmetry and many other new theories, they would cast doubt on the very existence of new physics at any scale, especially if the Higgs boson is found, completing the standard model.

[doi:10.1038/nature09509](https://doi.org/10.1038/nature09509)



Snowmass report, 2014

Figure 4-7. The landscape of dark matter candidates [from T. Tait].

Many experiments have the sensitivity to find DM signals in fortuitous cases \Rightarrow Risk for false alarms (*Extraordinary claims require extraordinary evidence* – C. Sagan)

None of these is (yet) generally regarded as real detections of DM (but one or more **may** still be):

A "bump" in the γ -ray spectrum at a few GeV, from a "ringlike" DM structure in the galaxy (EGRET/ W. de Boer) – in tension with antiproton data. The EGRET excess seems to have been to a large part instrumental (Fermi-LAT, 2009).

A 511 keV line from the galactic centre region (seen in the INTEGRAL satellite, J. Knödlseider & al., 2003) – difficult to model as DM (maybe "exciting DM", D. Finkbeiner & N. Weiner, 2007); not exactly spherical distribution (G. Weidenspointner & al, 2008).

The DAMA/LIBRA annual modulation (R. Bernabei & al. 1997 - 2014) – not verified by other experiments. Like indications from CoGeNT and CRESST, in tension with Xenon100, LUX and SuperCDMS limits.

An unexpected rise in the positron ratio seen in the PAMELA experiment (M. Boezio & al. 2008), verified by AMS-02 (S. Ting & al., 2013) - needs unusually large "boost factors" and/or unconventional halo model for DM interpretation.

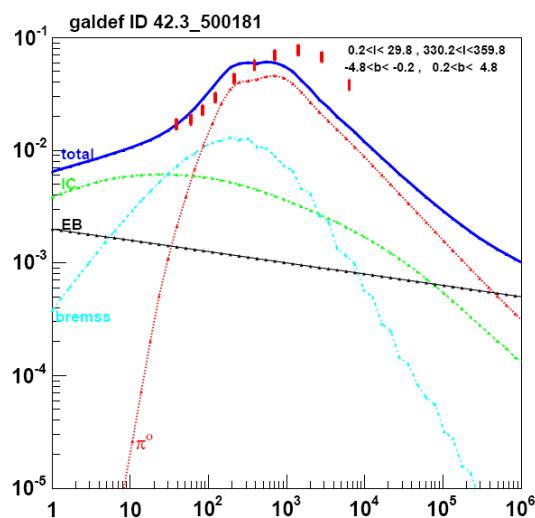
A 130 GeV γ -ray line feature seen in Fermi-LAT data (T. Bringmann & al.; C. Weniger, 2012) – seems to be partly instrumental, partly due to statistical fluke.

A GeV excess seen towards the g.c. in Fermi-LAT data (T. Daylan & al., 2014) – could be due to incomplete modelling of diffuse background (e.g., E. Carlson & S. Profumo; J. Petrovic, P. Serpico & G. Zaharijas). See special session later today.

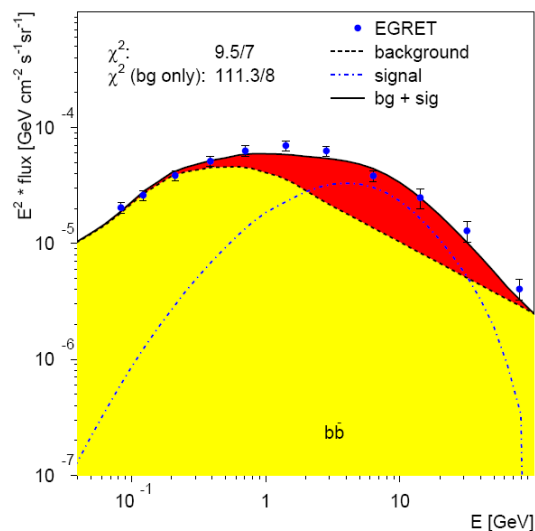
A 3.5 keV X-ray line due to decaying DM (E. Bulbul et al.; A. Boyarsky et al., 2014) – more data needed, not seen in the Milky Way (S. Riemer-Sorensen).

10-15 years ago - Interpreting the EGRET GeV excess towards the central Galaxy as due to dark matter (W. de Boer & al., 2004):

GALPROP fit

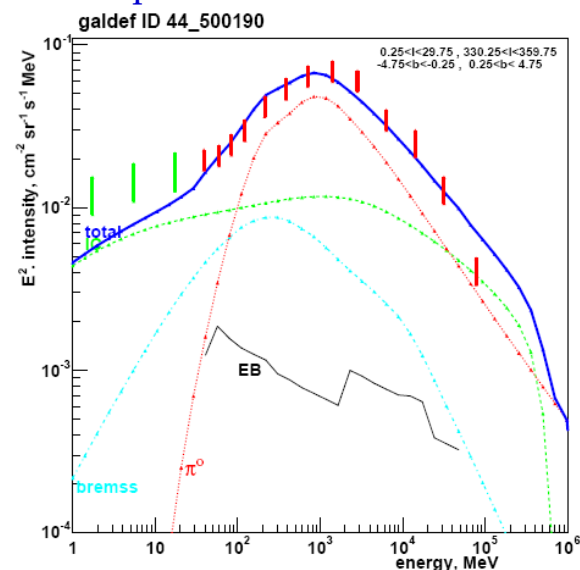


Adding 70 WIMP annihilating to bb
(DarkSUSY)



Dark matter solution

Strong, Moskalenko & Reimer, 2004
Optimized GALPROP fit

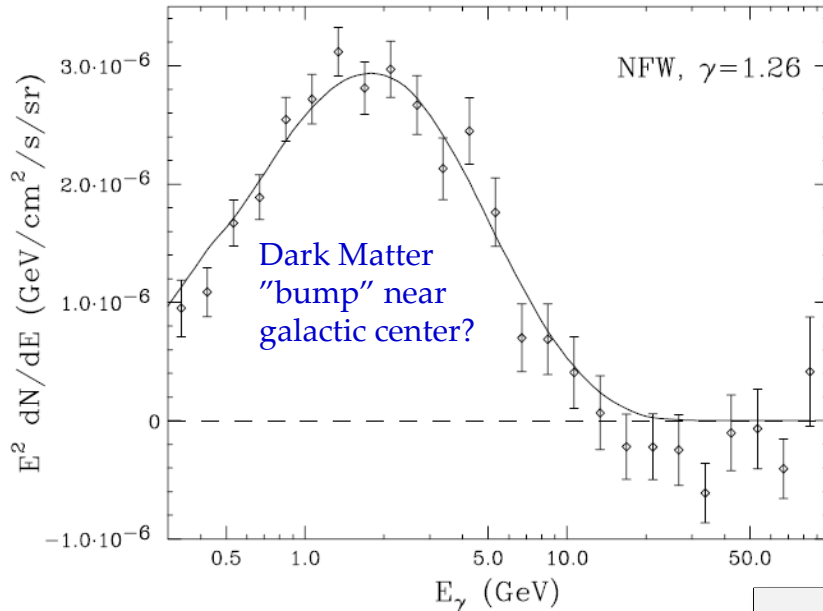


Astrophysical solution

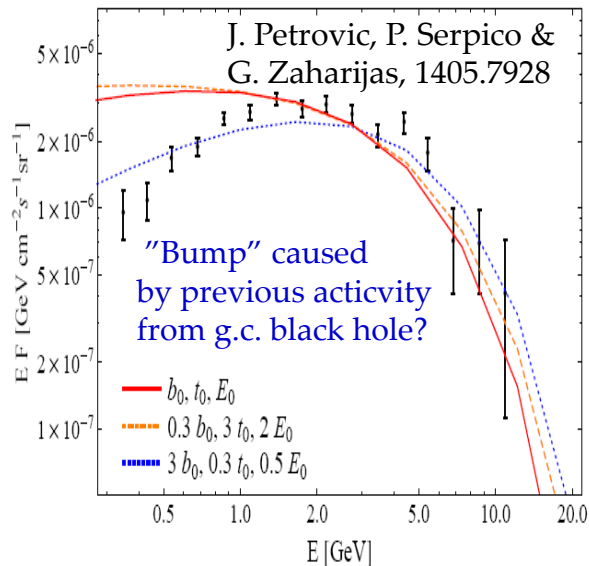
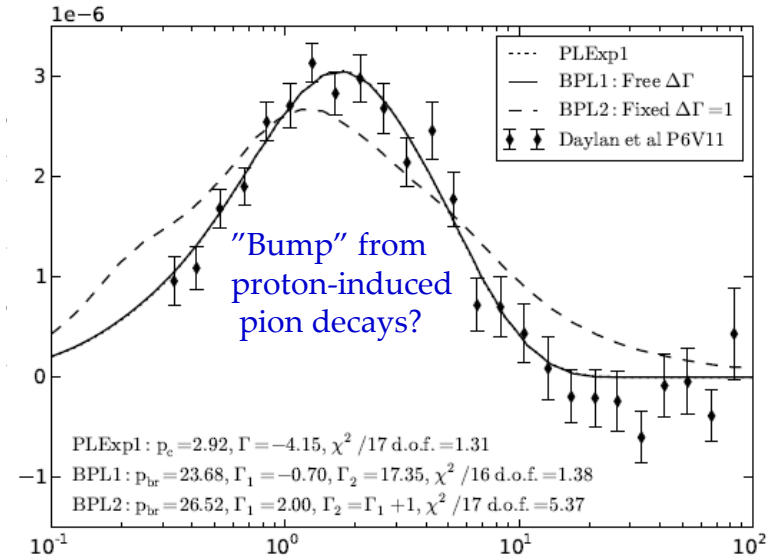
L.B., P. Ullio and J. Buckley 1998: "In fact, present EGRET observations are not inconsistent with a continuum spectrum originating from dark matter annihilations, but other explanations are possible as well"

Déjà vu, 2014:

T. Daylan & al., 1402.6703



E. Carlson & S. Profumo, 1405.7685



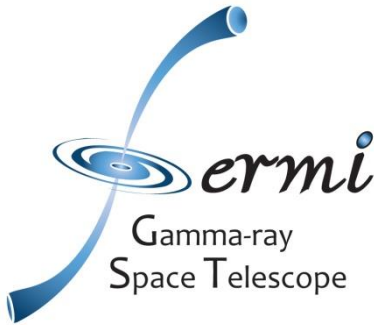
L.B., 2014: "In fact, present

Fermi observations are not inconsistent with a continuum spectrum originating from dark matter annihilations, but other explanations are possible as well"

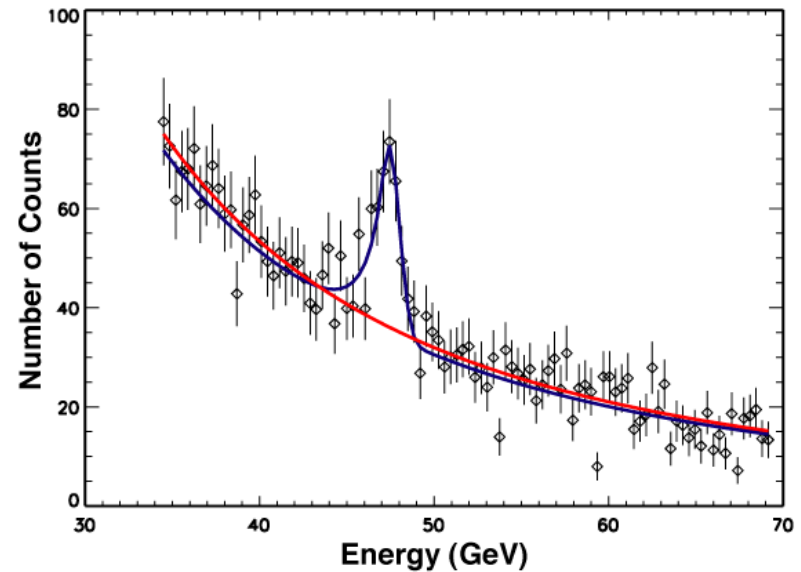
(c.f. recent strong limits from antimatter and radio emission, T. Bringmann, M. Vollman and C. Weniger, 1406.6027.)

But, see special session, including panel discussion, later today...

2004: Great hope for finding "smoking gun" for dark matter – a γ -ray line

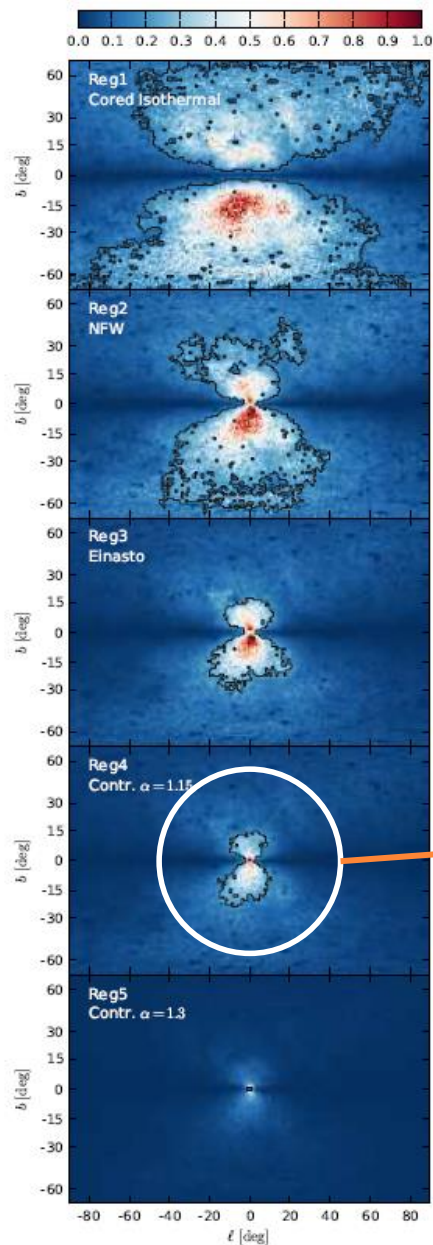


USA-France-Italy-Sweden-Japan
(-Germany) collaboration, launch
~~2006~~ 2008



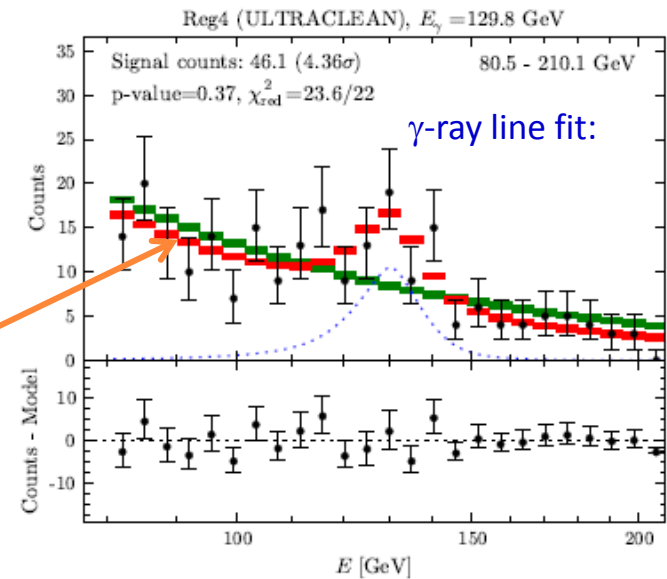
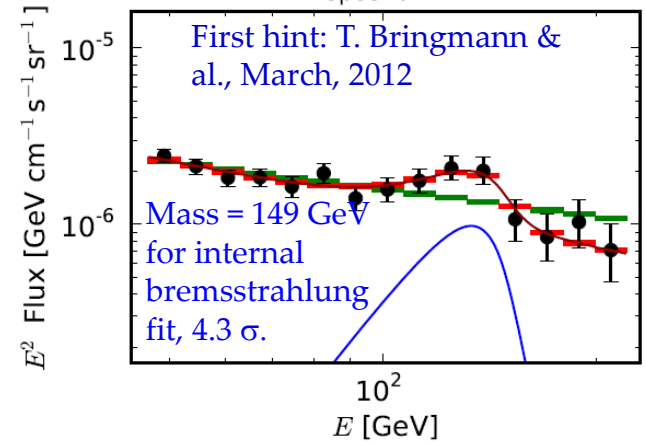
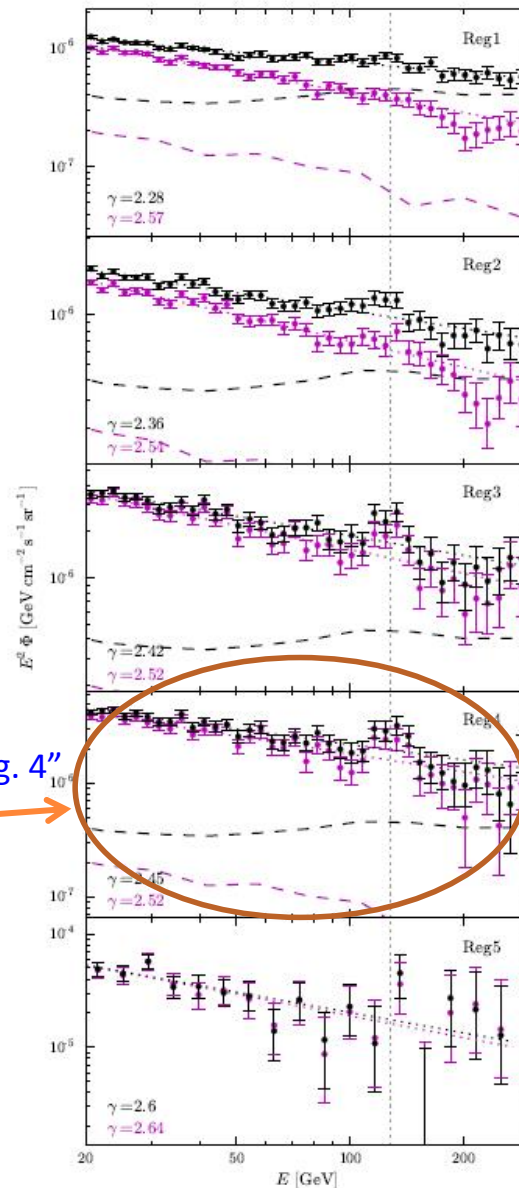
GLAST will also likely detect a few thousand new GeV blazars ...

April, 2012 – Dream come true, smoking gun found? C. Weniger:



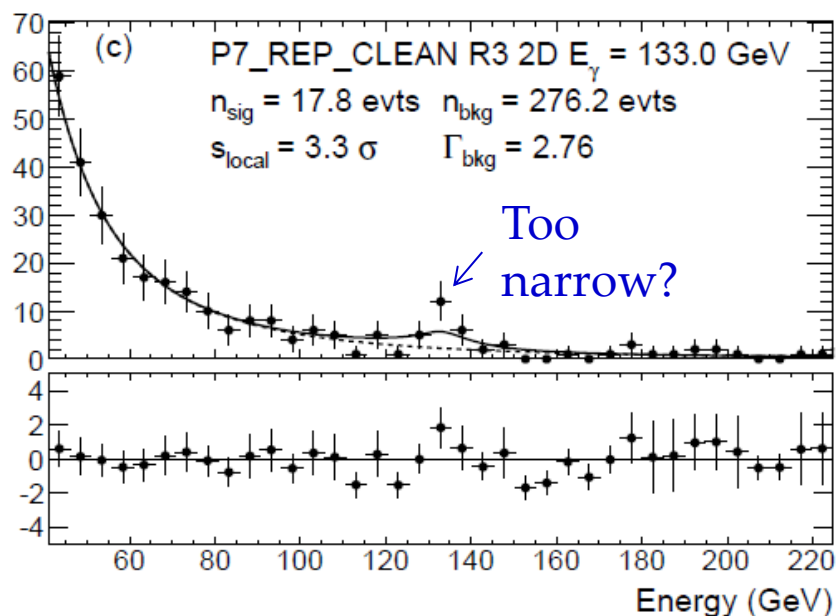
"Reg. 4"

43 months of (public) Fermi data

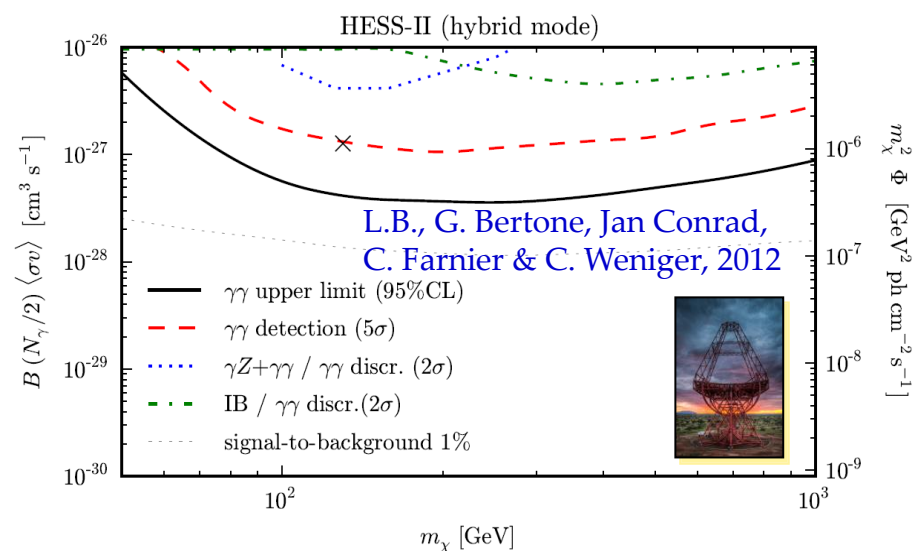


Mass = 130 GeV
Significance 4.6 σ (3.3 σ if "look elsewhere" effect included)

2013 - Back to reality: The 130 GeV line was probably due to a combination of an instrumental effect and a statistical fluke (in the last two years, the statistical significance of the effect has gone down).

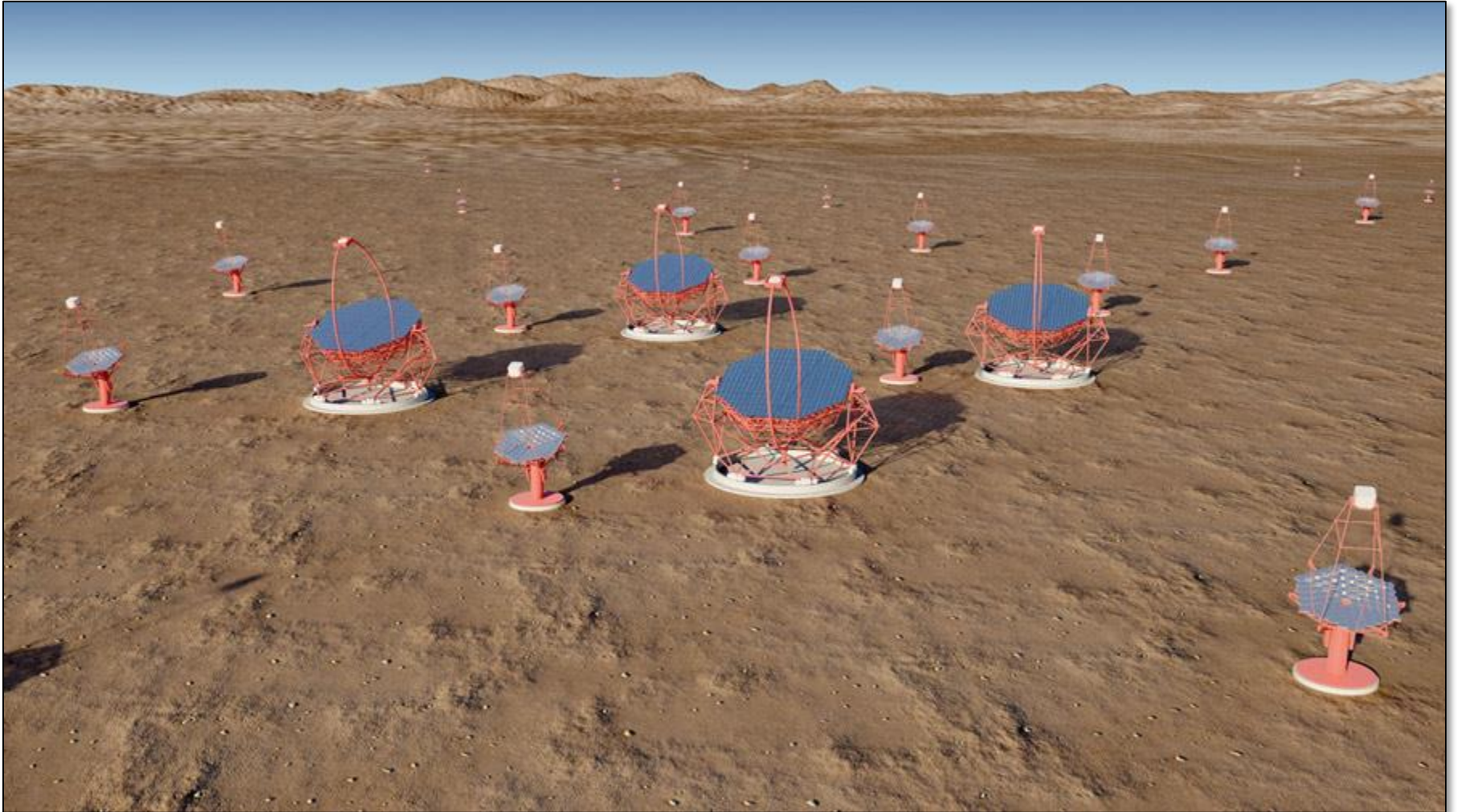


Fermi-LAT is now using a new mode of operation, with more sensitivity towards the gal. centre.

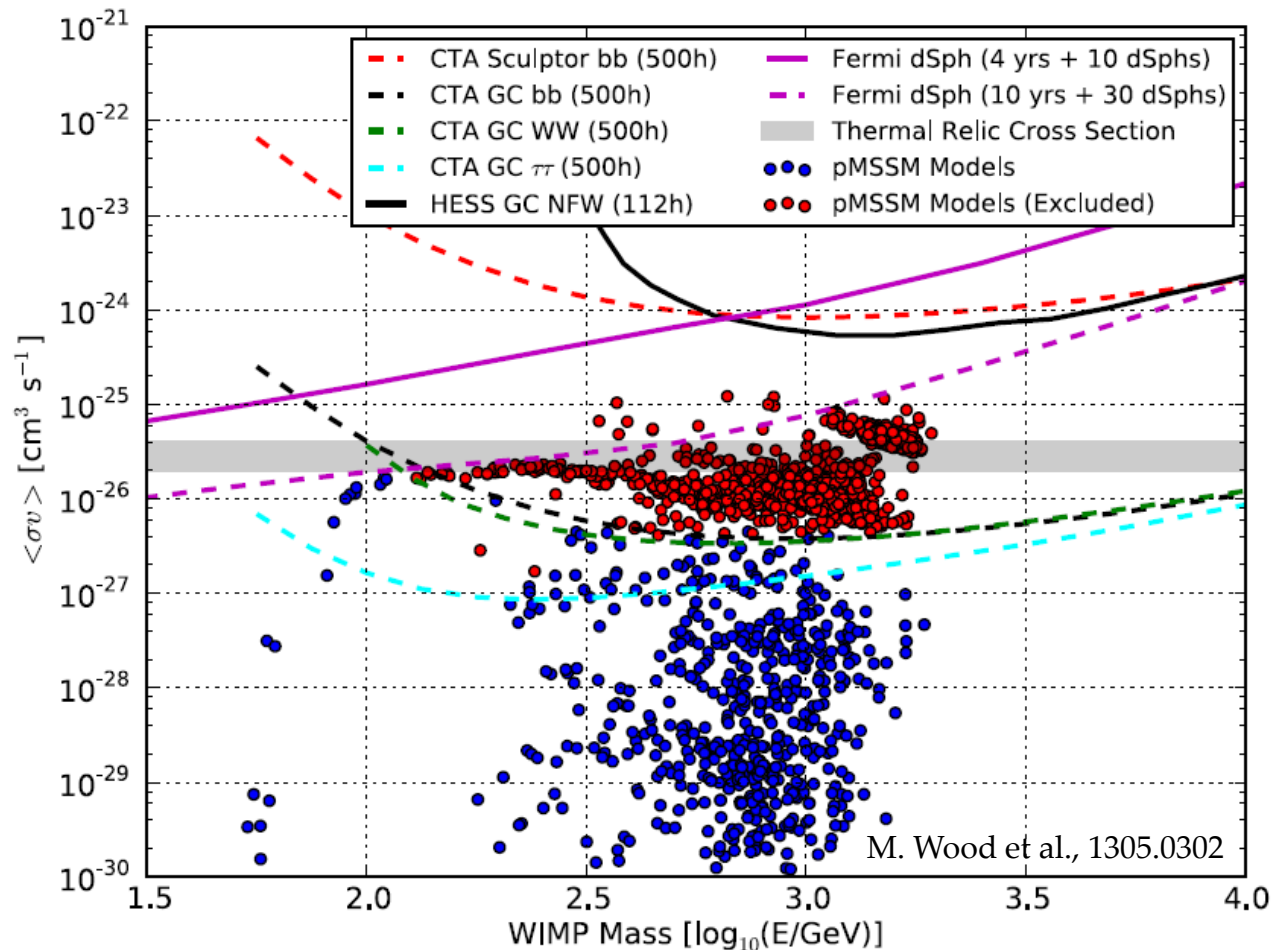


With HESS-II (currently data-taking) we should get a definite answer by October 2014.

CTA: The new window to the high-energy gamma-ray universe (c:a 2018-)



CTA (2018 -) may have good discovery potential, especially in the 100 GeV – few TeV region



Note: Systematics and diffuse emission background not included, see G. Bertone & al., in preparation. More clever methods needed!

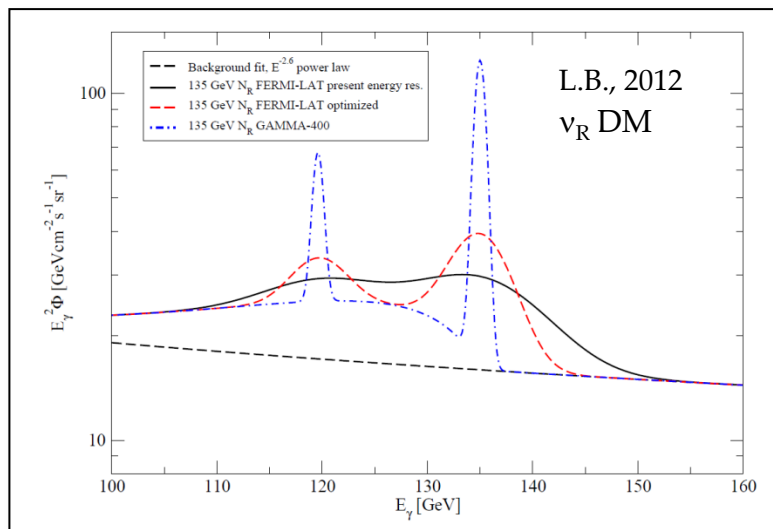
Future - No planned Fermi-LAT replacement in the US. The future seems to be in the East for gamma-ray space telescopes:

GAMMA-400, 100 MeV – 3 TeV, an approved Russian γ -ray satellite. Planned launch 2020. Energy resolution (100 GeV) $\sim 1\%$. Effective area $\sim 0.4 \text{ m}^2$. Angular resolution at 100 GeV $\sim 0.01^\circ$

Dark Matter Particle Explorer, DAMPE: Satellite of similar performance. An approved Chinese γ -ray satellite. Planned launch 2016. (Precursor to HERD.)

HERD: Instrument on Chinese Space Station. Energy resolution (100 GeV) $\sim 1\%$. Effective acceptance $\sim 4 \text{ m}^2\text{sr}$. Angular resolution (100 GeV) $\sim 0.01^\circ$. Planned launch around 2020.

All three have detection of dark matter as one key science driver

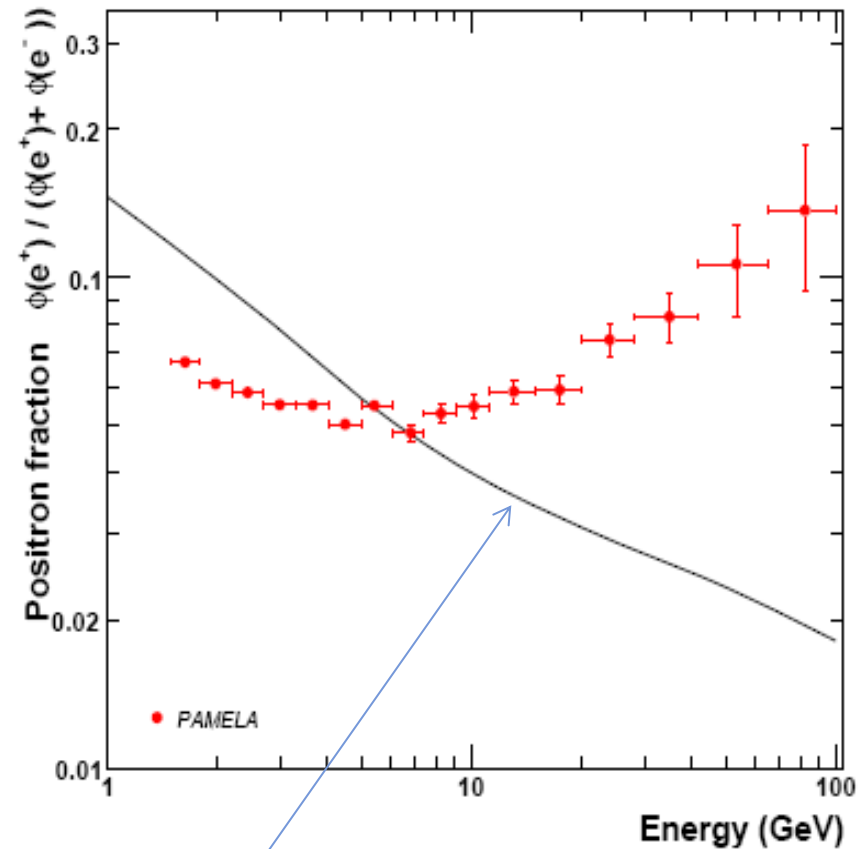
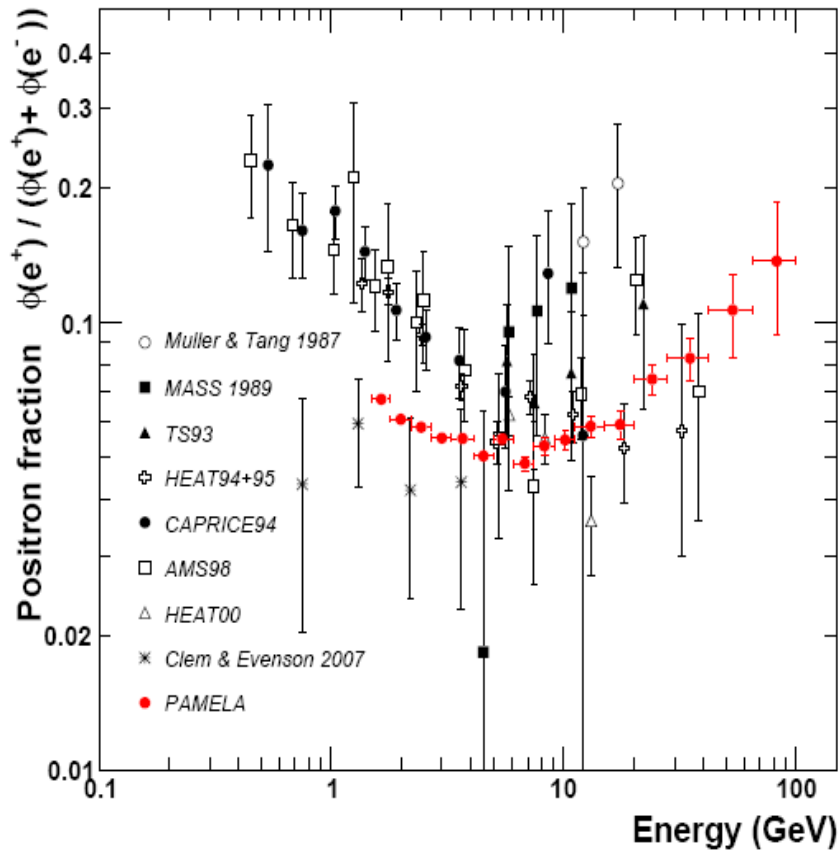


Ideal, e.g., for looking for spectral DM-induced features, like searching for γ -ray lines! Can search for γ -ray structures, with unprecedented precision.

New models with large line features and other energy structures, e.g., scalar DM: F. Giacchino & al., 2013; A. Ibarra & al., 2014.

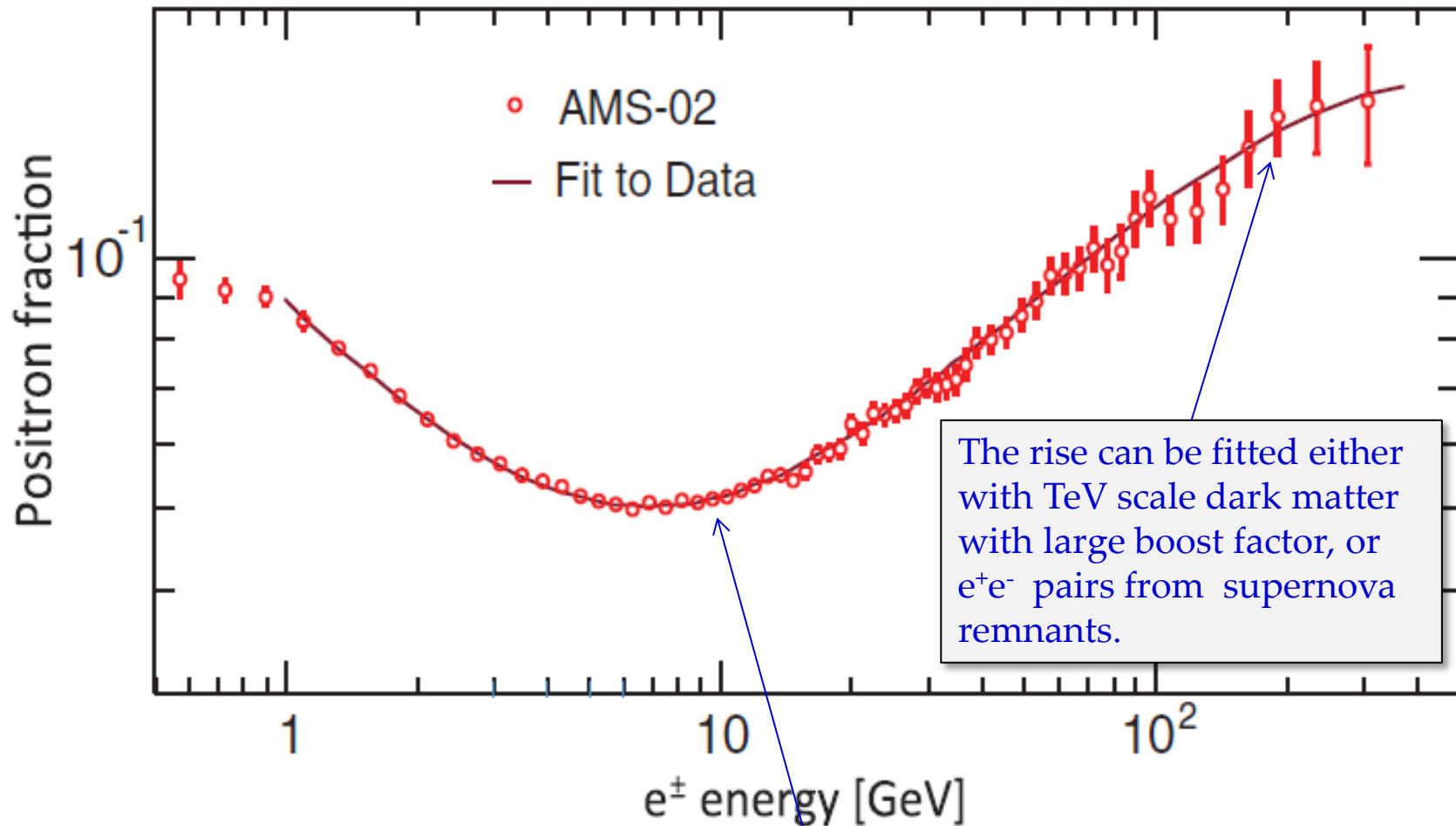
Indirect detection through **antimatter**: The surprising PAMELA data on the **positron** ratio up to 100 GeV. (O. Adriani et al., Nature 458, 607 (2009))

A very important result. An **additional, primary source** of positrons seems to be needed.

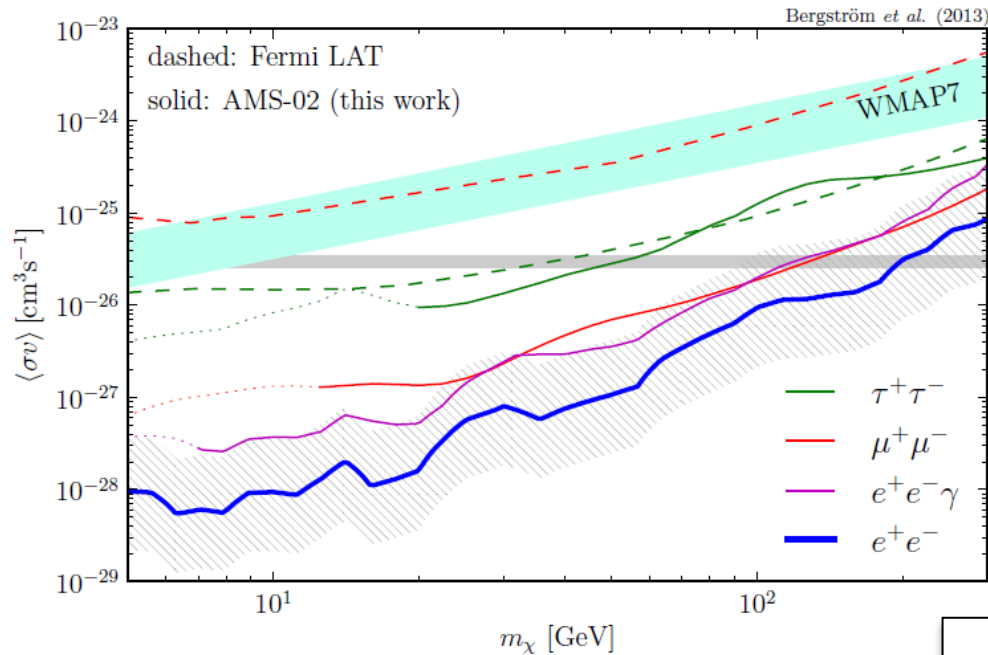


Prediction from secondary production by cosmic rays: Moskalenko & Strong, 1998

The rise was confirmed with AMS-02 on the International Space Station, 2013:



Note high precision of the very smooth AMS-02 data.
Future: The experiment will give data for at least 10 more years (new batch of data presented by S. Ting last week).



The precision of the AMS-02 data allows stringent limits on Dark Matter annihilation to positrons, muons, and taus. (L.B., T. Bringmann, I. Cholis, D. Hooper & C. Weniger, PRL 2013; A. Ibarra, A. Lamperstorfer and J. Silk, PRD 2014)

One can also search for "bumps", none found so far – wait and see...

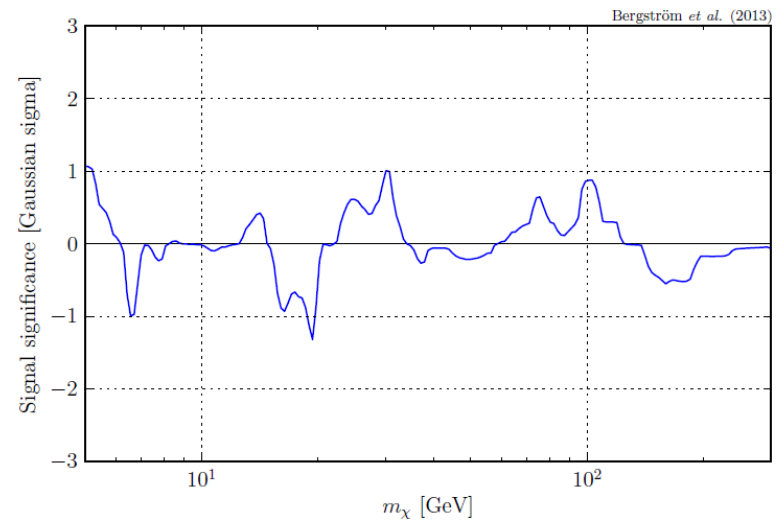


FIG. 6. Significance for a contribution from a e^+e^- DM signal to the AMS-02 positron fraction, for different DM energies, in units of Gaussian sigma. Negative values correspond to negative (but unphysical) signal normalizations.

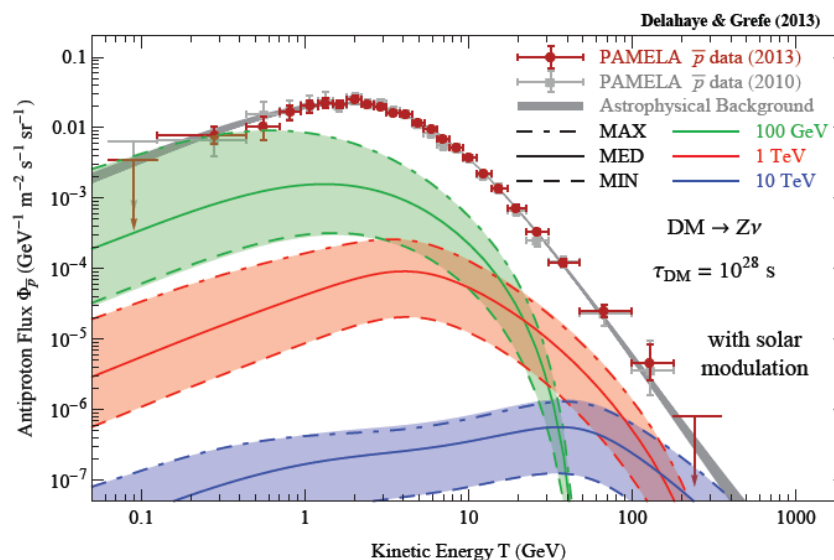
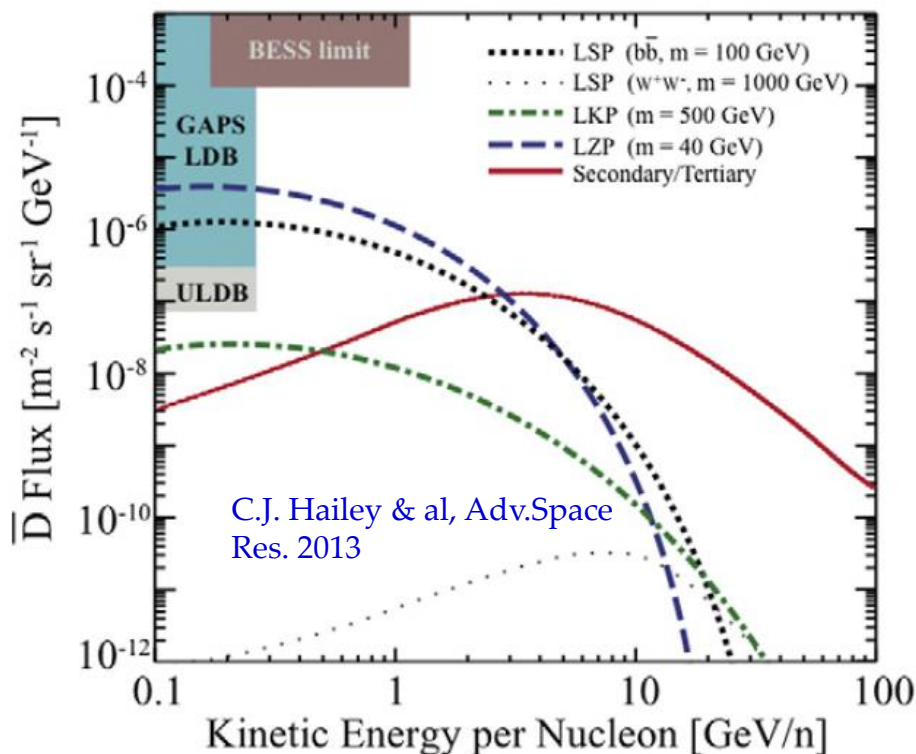
Antiprotons may be created by DM annihilation or decay. However, the signature not unique.

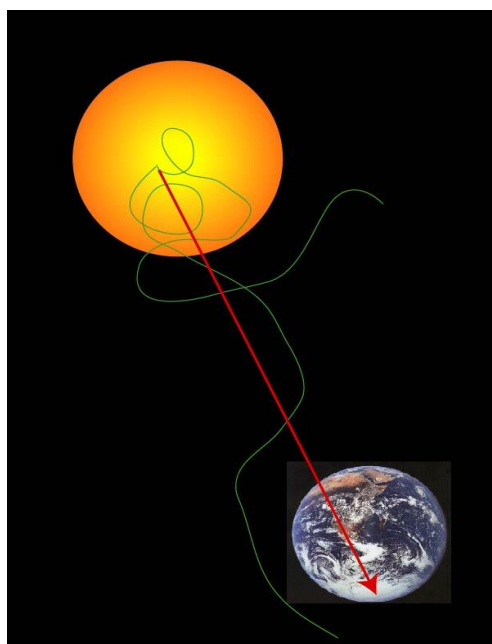
Future: Antideuterons maybe better "smoking gun" DM signal – but rare? (Donato et al., 2000). GAPS ballon experiment (2015?) will have some sensitivity.

Antiprotons still a good **check of models**.

Examples: Decaying gravitino DM (T. Delahaye and M.Grefe, 2013), limits on g.c. γ -ray excess (T. Bringmann, M. Vollman & C. Weniger, June 24, 2014)

Soon: High-quality antiproton data from AMS-02 (later this year?)

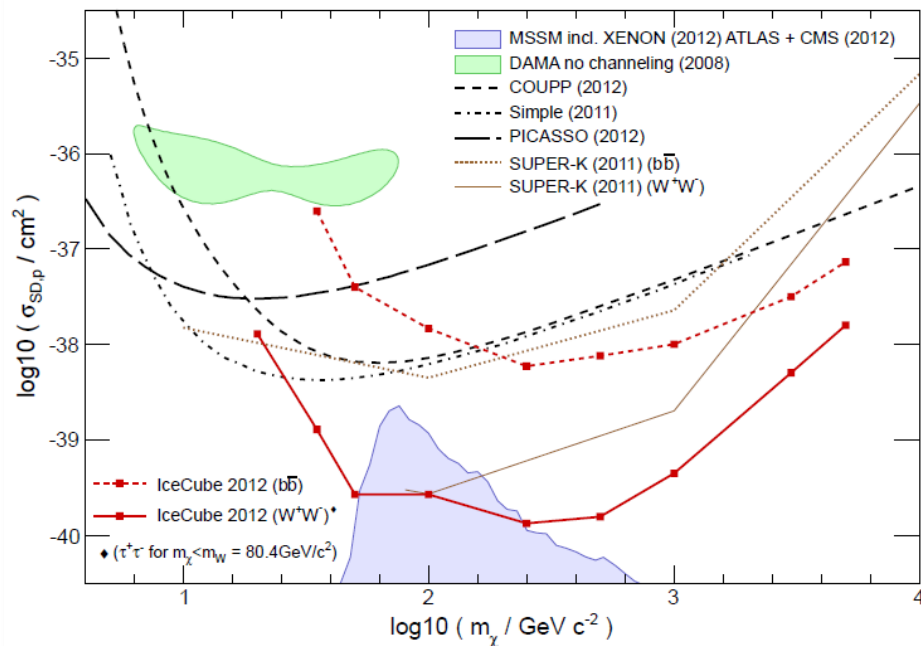




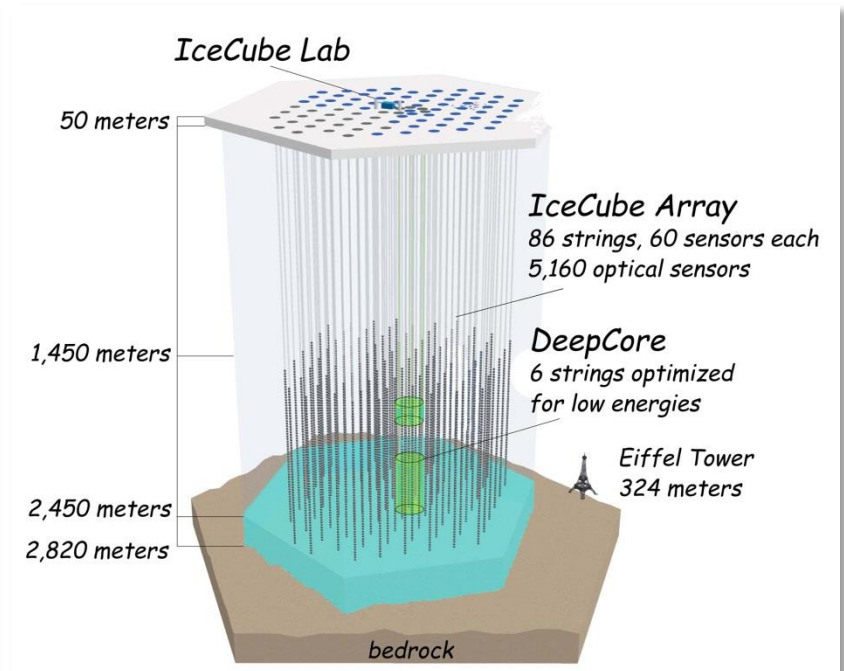
Indirect detection by neutrinos **from annihilation in the Sun:**

Present: Competitive, due to high proton content of the Sun \Rightarrow sensitive to **spin-dependent** interactions

Future: New planned addition PINGU (2020?-), will lower threshold further. May be combined with a larger area extended IceCube



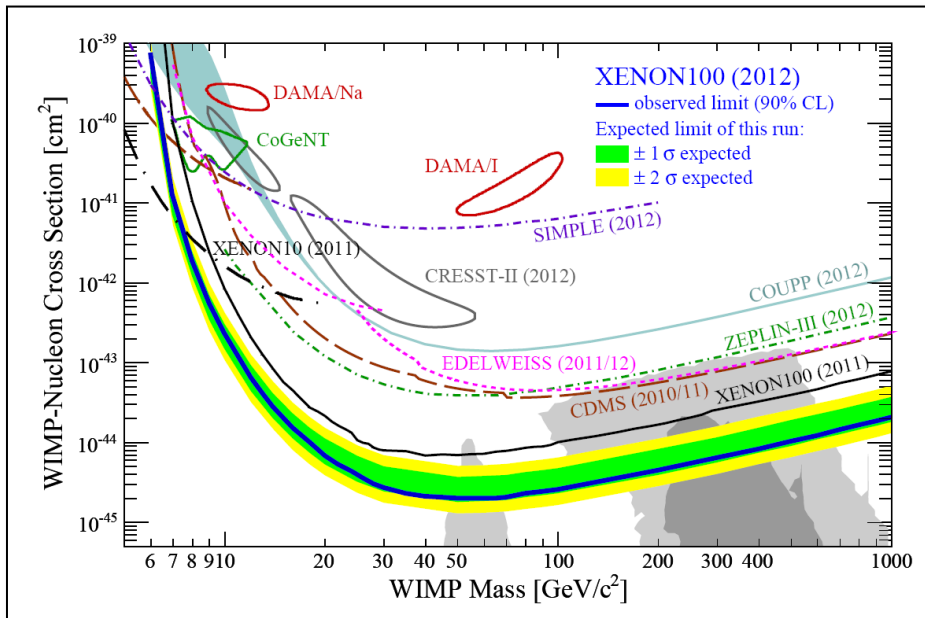
IceCube Collaboration, PRL, 2013



DM direct detection searches – a success story. Three orders of magnitude increase in sensitivity over 10 years!

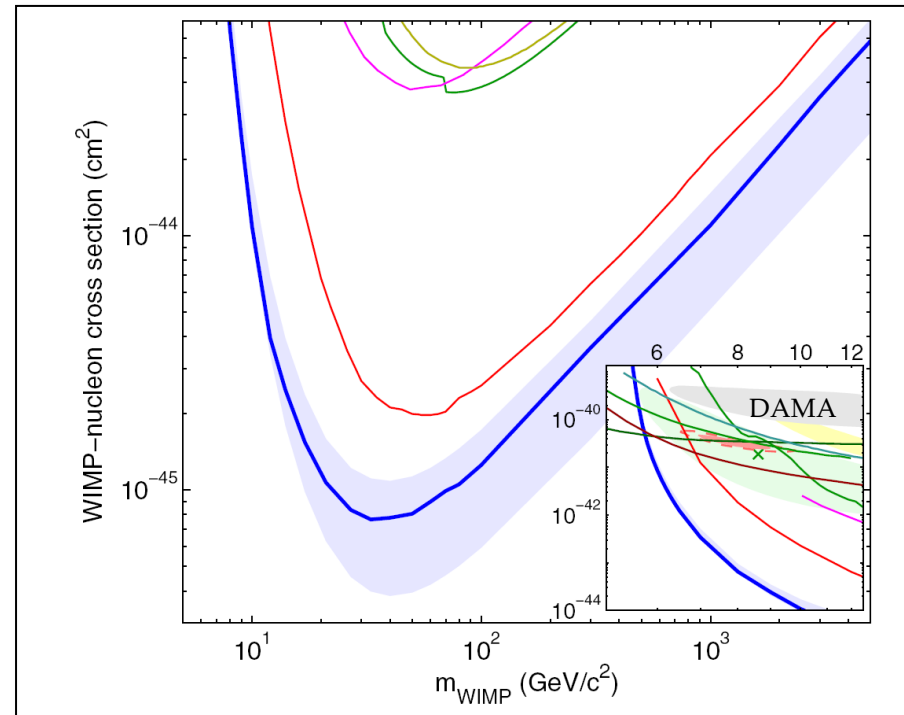
At the moment (2014), Li-Xe detectors are leading the race (and for low masses SuperCDMS), and seem to exclude scattering rates needed to explain the positive signals in DAMA/CoGeNT/CRESST:

XENON100



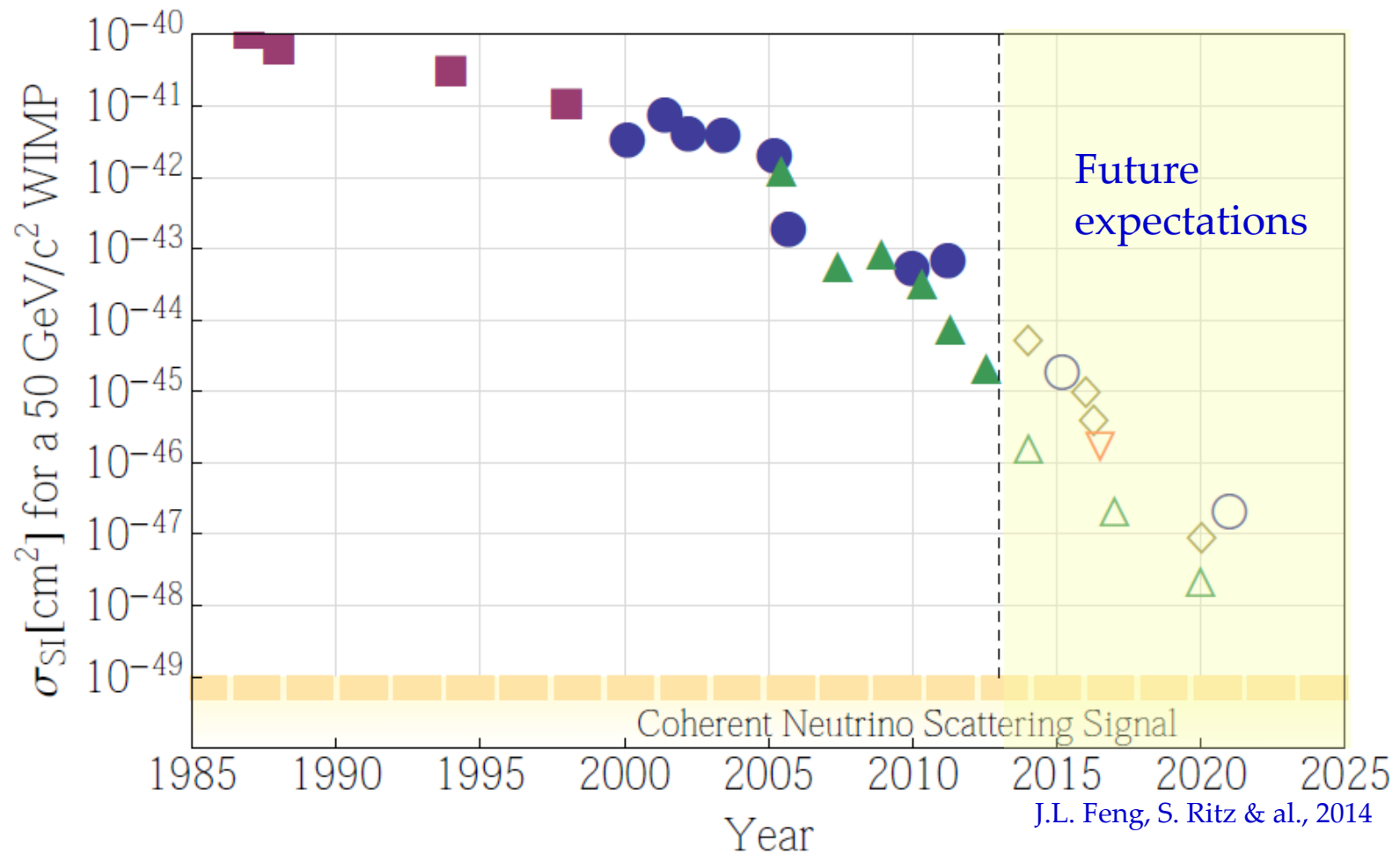
E. Aprile & al., Phys. Rev. Lett. 109 (2012) 181301

LUX



D.S. Akerib & al., Phys. Rev. Lett. 112 (2014) 091303

Evolution of the WIMP–Nucleon σ_{SI}

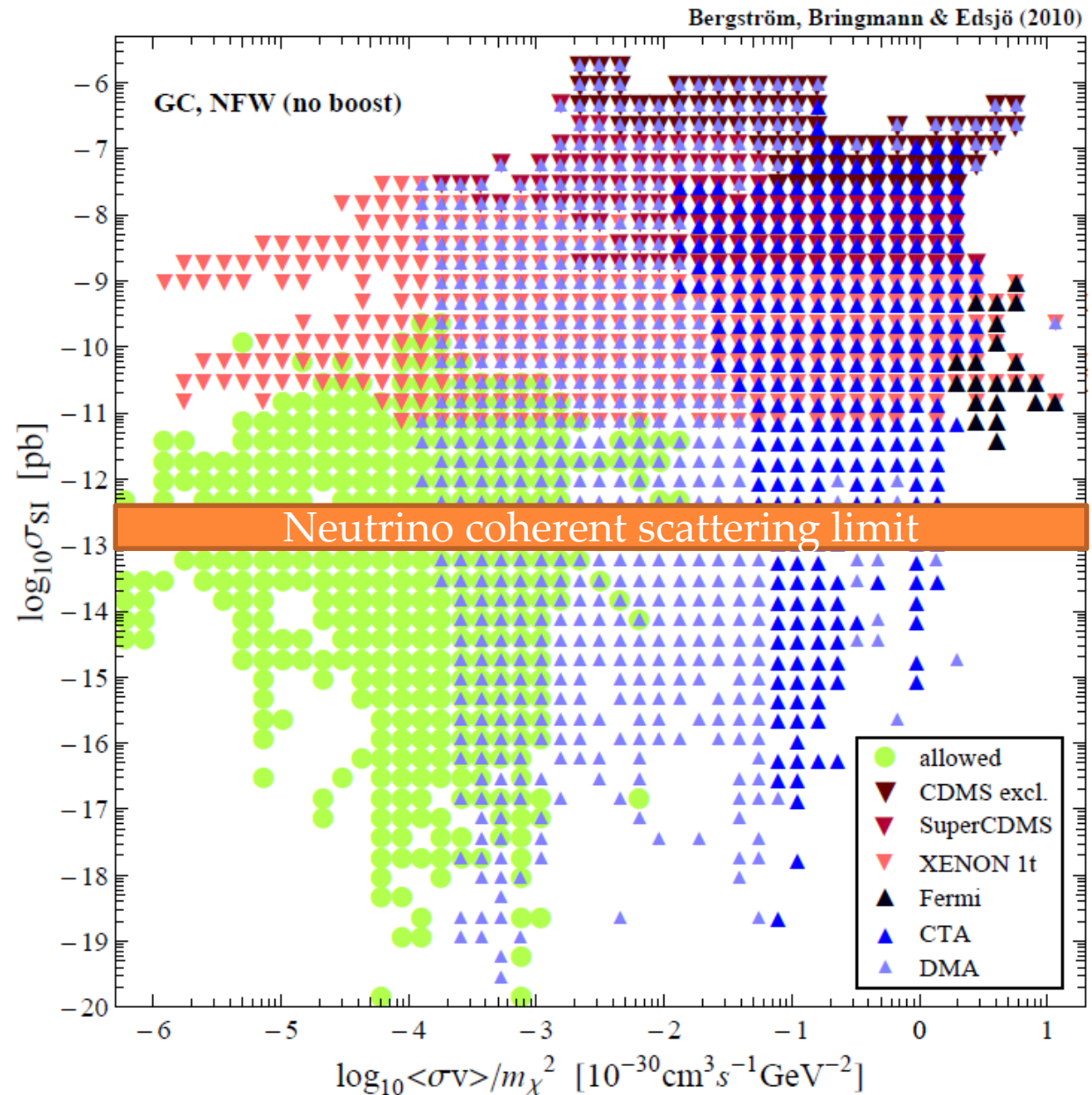


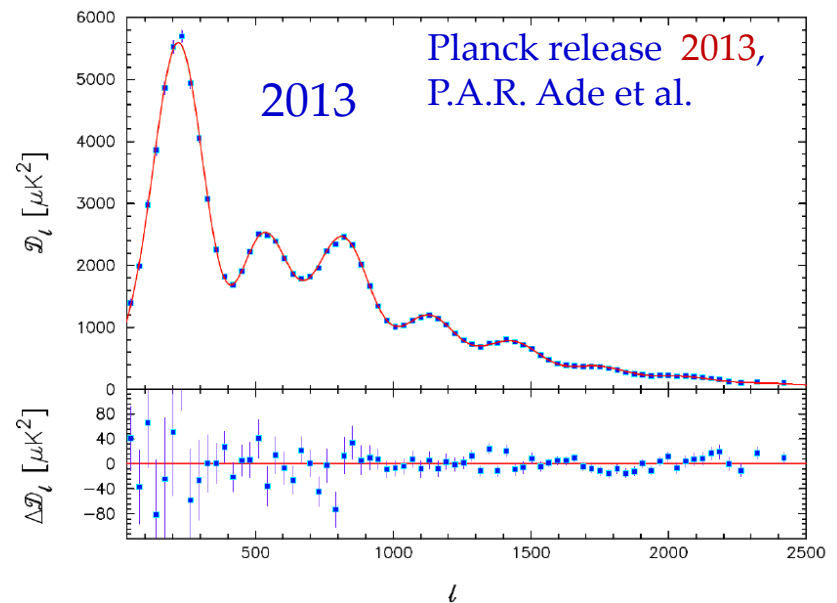
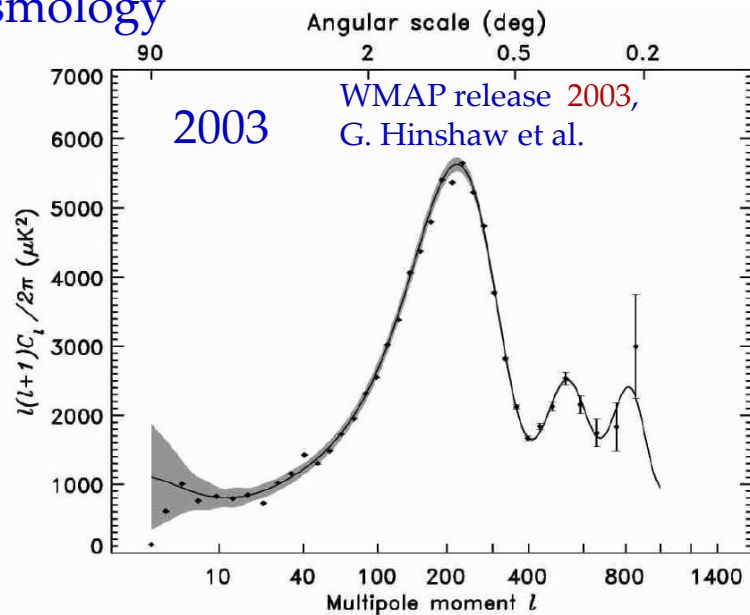
Comparison direct – indirect DM detection

pMSSM scan – but should be regarded as generic for various WIMPs

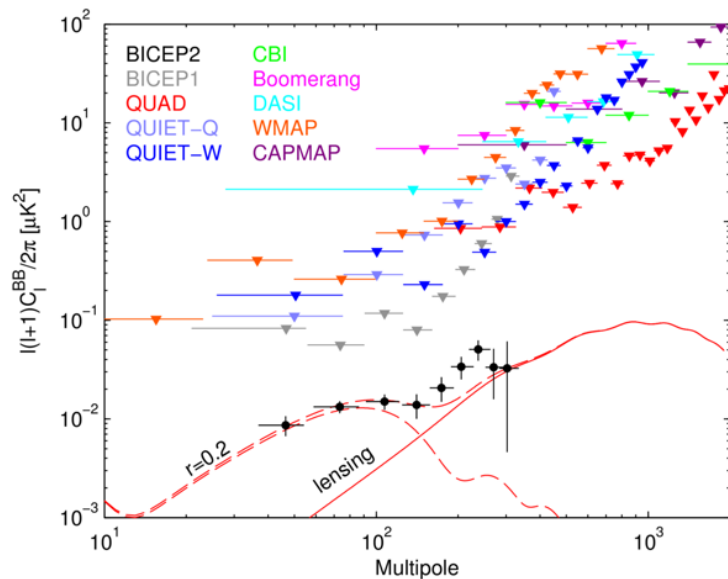
(L.B., T. Bringmann & J. Edsjö, PRD 2011)

There will always be regions beyond reach...





These amazing measurements set the framework for cosmology today:
 Λ CDM model, Ω very close to unity, adiabatic, near scale-invariant gaussian fluctuations.
 All predictions of inflation confirmed, except B-mode polarization:

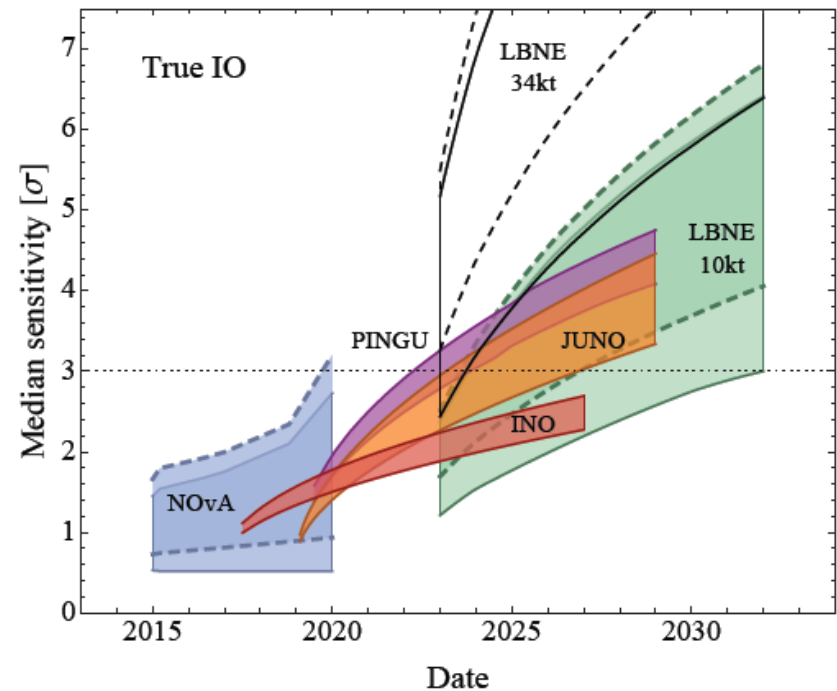
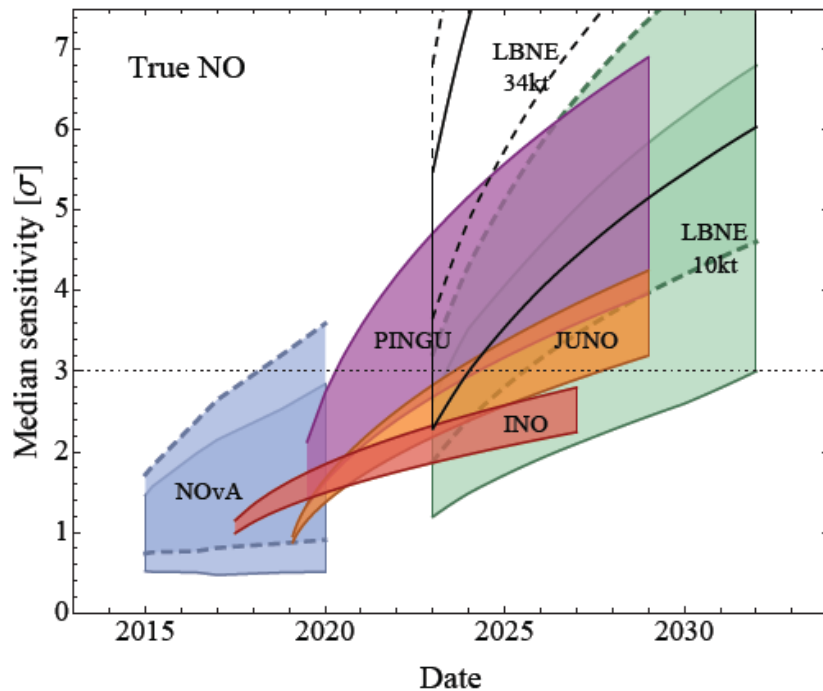


BICEP2, 2014: Tensor to scalar ratio $r = 0.2$. Seems (slightly) incompatible with Planck for standard inflation models. Will these data stand (or will they disappear in dust?)

Future - Many small-scale experiments will give further checks: CMBPol, PolarBEAR, Keck Array... P5 report singles out a "Stage 4" project, CMB-S4, which should measure r down to sub-percent level. Maybe there will also be new space missions, like PRISM (P. de Bernardis & al., 2013).

Is this the biggest hit or biggest flop of 2014?

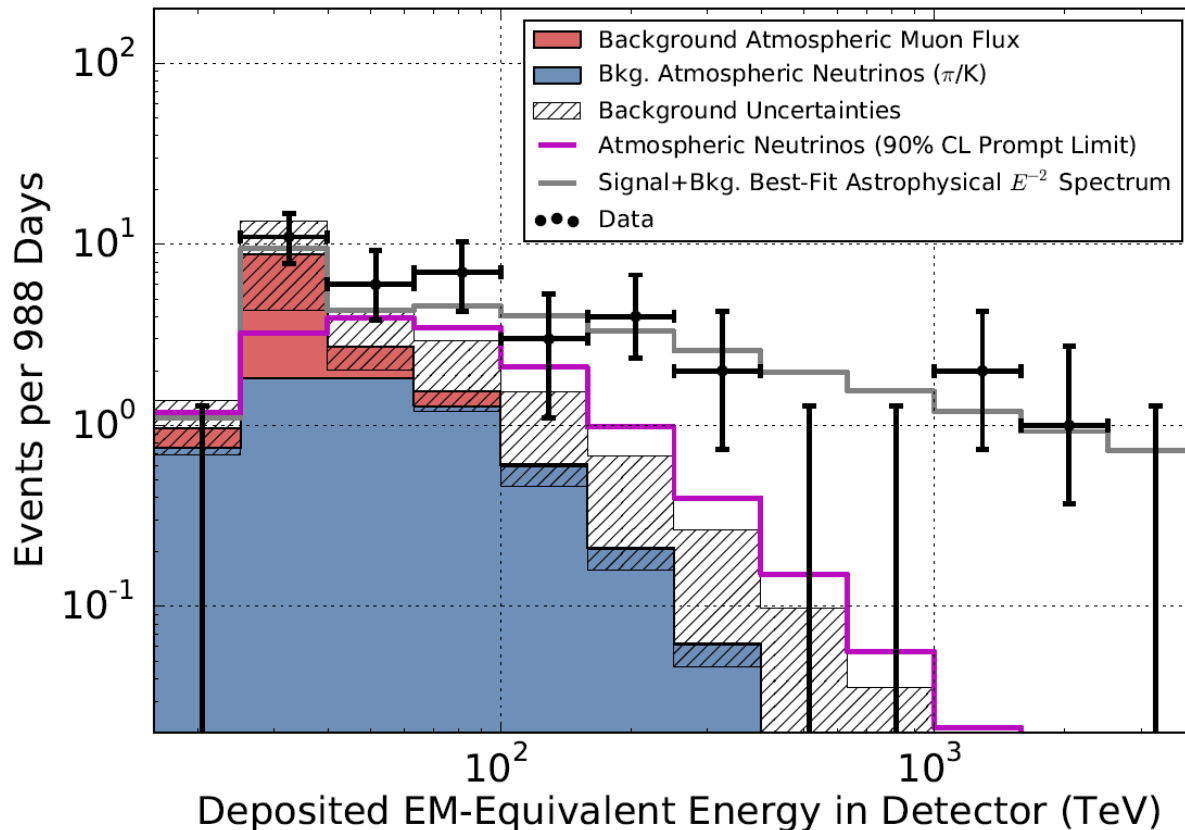
Neutrino physics, main questions: Is the hierarchy of masses normal or inverted? How strong is CP violation?



M. Blennow, P. Coloma, P. Huber & T. Schwetz, 2013.
(Also ambitious plans in Europe, LBNO/LAGUNA, A. Rubbia & al, ESSnuSB, T. Ekelöf et al.)

IceCube is finally seeing a cosmic signal!

Plans have started to increase the size by a factor of a 10 – this could be in conjunction with also building the PINGU insert. Will KM3Net follow?



The IceCube Collaboration, May 2014, 1405.5303

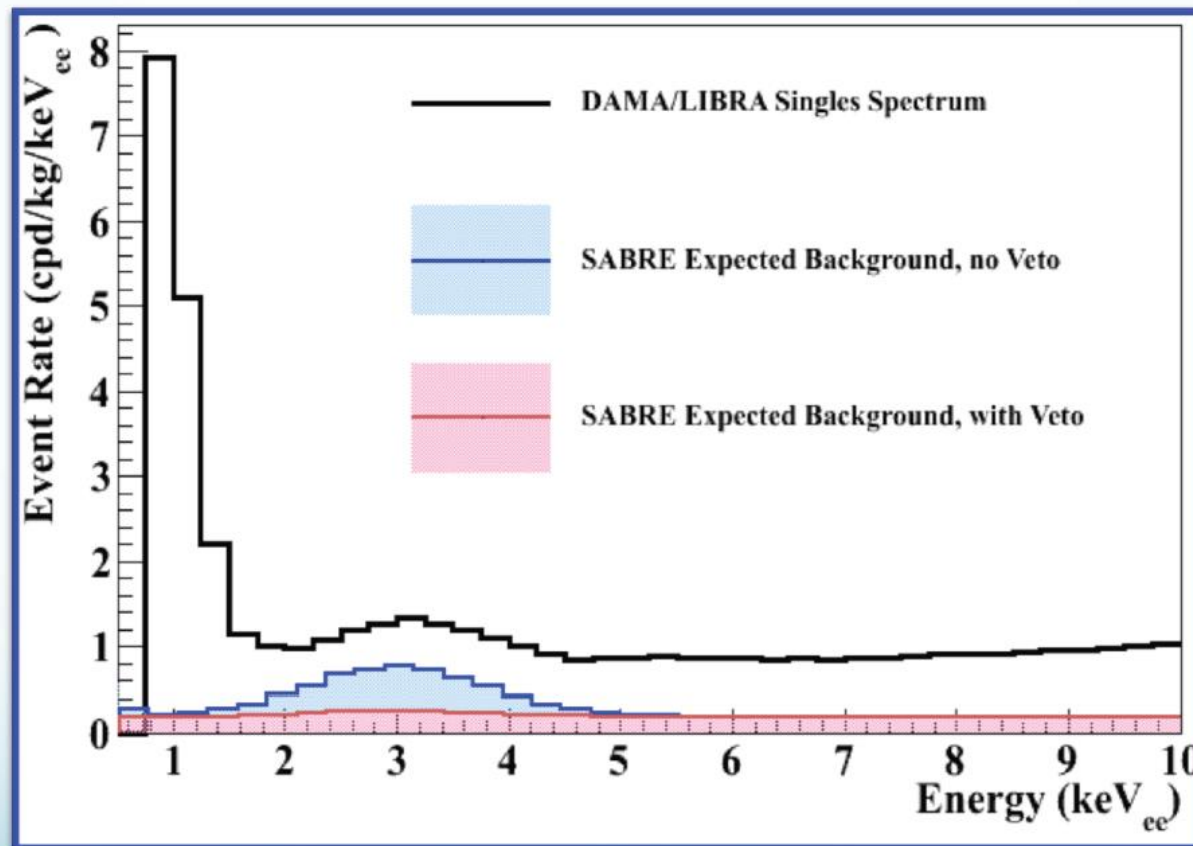
An astroparticle physicist's wishlist for the next 10 years: What we need	Will happen?	How?
New ideas on detection of non-WIMPs, like axions or axion-like particles	?	ADMX, CARRACK, CAPP, IAXO,...
CTA and space gamma-ray experiment(s) for lower energies, replacing Fermi-LAT	✓	CTA, GAMMA-400, DAMPE, HERD
Good space experiments on antimatter detection: positrons, antiprotons and antideuteron.	✓	AMS-02, Calet, GAPS?
Second- and third-generation direct detection experiments, ideally both noble gas and solid state detectors, with different target materials, and a decisive test of DAMA/LIBRA	✓	LUX, XENON-1t, SuperCDMS, XMASS, PandaX, DarkSide, ANAIS, SABRE, DM-Ice,... → G3
Indications from LHC of new physics, and a linear collider for detailed studies	?	CERN - let us hope..., ILC, FCC, ...
For neutrinos, experiments to determine hierarchy and CP phase. Also determine whether sterile neutrinos exist, perhaps being the Dark Matter	?	LBNF/LBNO?, PINGU, JUNO, ESSnuSB, X-ray line searches?
For cosmology, test of CMB B-mode polarization, and precision measurements of cosmological parameters.	✓	BICEP2-Keck Array, CMBPol, EUCLID, LSST, DESI... → CMB-S4
New direct detection experiments for gravitational waves	✓	Advanced LIGO and VIRGO, KAGRA (Japan) LISA pathfinder, Einstein Telescope, maybe LISA

DAMA has been with us, unexplained, since 1997, showing annual modulation, consistent with DM, at present with 9.2σ statistical significance.

Finally, a NaI experiment with superior sensitivity is being planned, SABRE (F. Calaprice & al., Princeton Univ.)

SABRE: Sodium-iodide with Active Background Rejection

J. Xu, UCLA DM Conference talk, 2014:



* This spectrum was made using NaI powder radioactivity; crystal can be better.

* External background is estimated to be relatively small compared to internal.

How?

ADMX, CARRACK,
CAPP, IAXO,...

CTA, GAMMA-400,
DAMPE, HERD

AMS-02, Calet, GAPS?

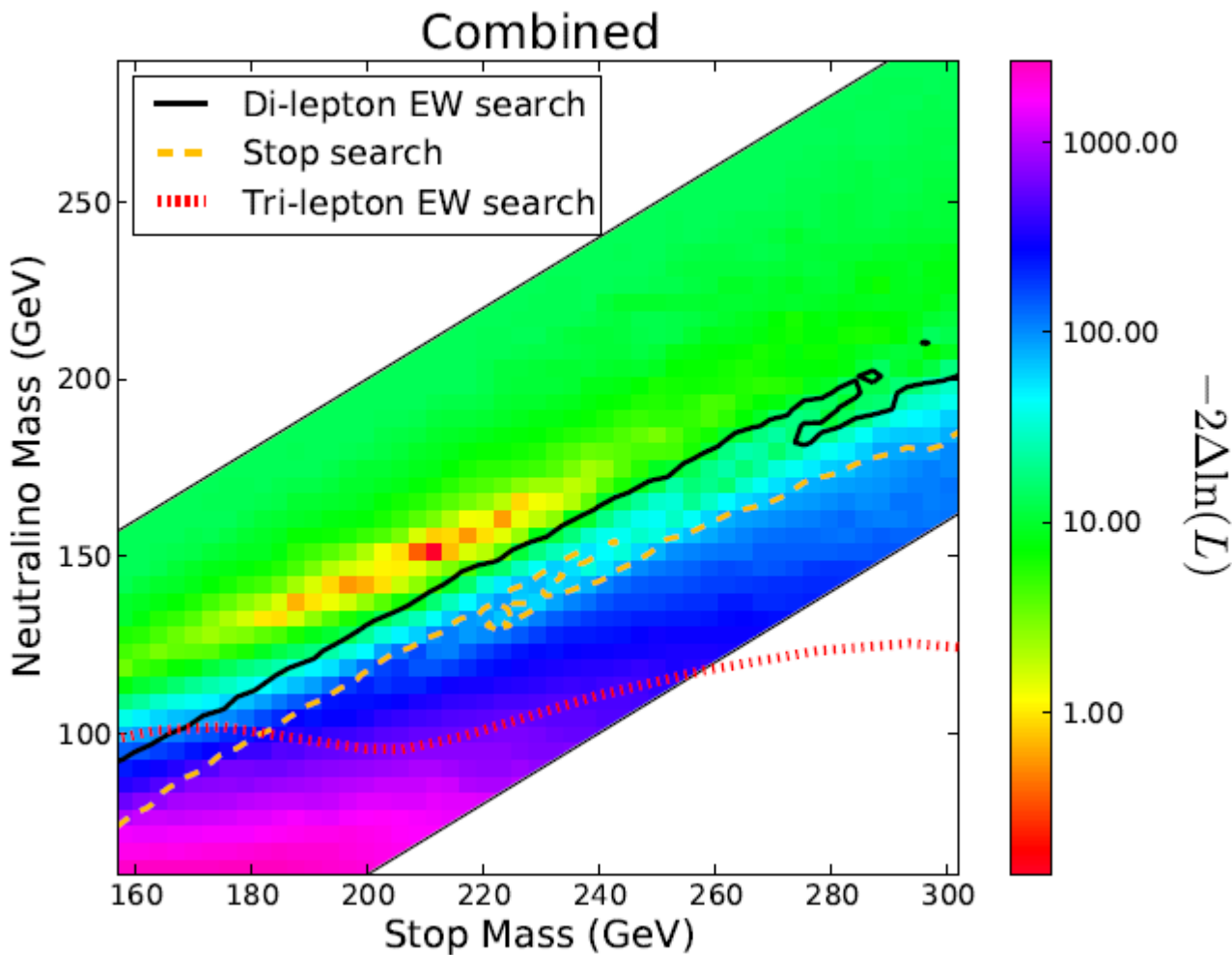
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ANAIS, SABRE, DM-
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CERN - let us hope...,
ILC, FCC, ...

LNBF/LBNO?, PINGU,
JUNO, ESSnuSB, X-ray
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BICEP2-Keck Array,
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Advanced LIGO and
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ADMX, CARRACK,
CAPT, IAXO,...

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Fit of $\sim 3\sigma$ excess in W^+W^- production seen by ATLAS and CMS
J.S. Kim, K. Rolbiecki, K. Sakurai and J. Tattersall, 1406.0858
(see also D. Curtin, P. Meade and P.-J. Tien, 1406.0848)

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Conclusions

Astroparticle physics is a thriving young field, which has had a remarkably interesting last decade, with order-of-magnitude improvements of experiments possible also in the next decade.

The main ideas and fundamental questions still stand: Dark Matter and Dark Energy rule the Universe – but what are they?

Seemingly false alarms of discovery of dark matter in recent years show that confirmation using alternative, competing methods probably will be needed to convince the physics community.

Some projects are of "big science" type and will need global coordination.

In Europe, we have ApPEC and ESFRI which will publish Roadmaps for European astroparticle physics for the coming decade. Globally, APIF and APPIC can play an important role.

Epilogue - For Dark Matter, will we be in the **nightmare scenario**,
2020? G. Bertone, Nature 2010 (almost 5 years ago):

The future

The other possibility is of course that new physics is not found at the LHC within 5–10 years. For the reasons I have discussed above, null searches at the LHC would push the scale of new physics into more and more unnatural territory (that is, to high levels of fine-tuning). Although null searches would not rule out supersymmetry and many other new theories, they would cast doubt on the very existence of new physics at any scale, especially if the Higgs boson is found, completing the standard model.

... In the absence of any signal, we would be left with the ‘nightmare’ dark matter scenario of null searches at the LHC, and no direct or indirect detections. Such circumstances would probably mark the decline of WIMPs in favour of alternative explanations, such as axions or alternative theories of gravity, provided that they can be reconciled with lensing observations.

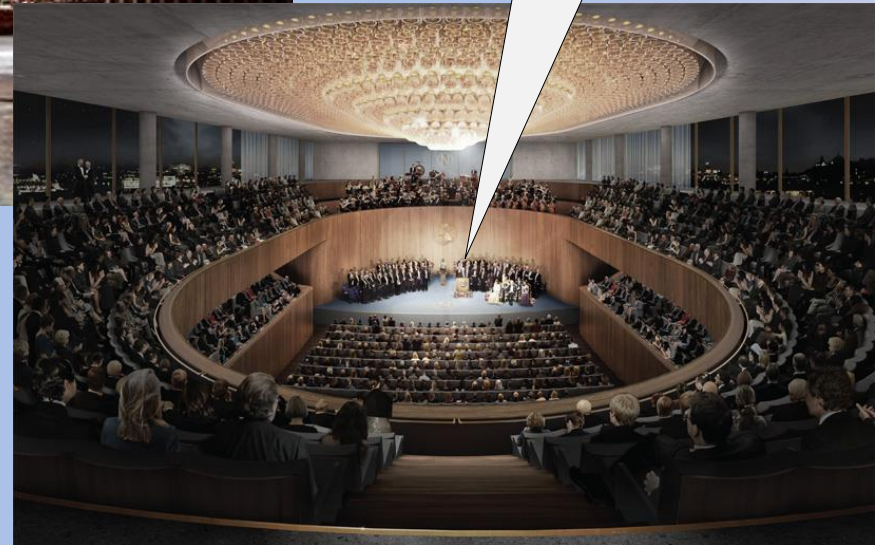
[doi:10.1038/nature09509](https://doi.org/10.1038/nature09509)

A dream scenario, taking place in the planned new Nobel Center in Stockholm (to be completed around 2020):



Architect proposal: David Chipperfield, 2013

Thank you,
Your Majesty. I got
this bright idea at
TeVPA-iDM in
Amsterdam
2014!



The End