Advances in Particle Astrophysics

Session I:
Advances and prospects in particle astrophysics, from cosmic rays to precision cosmology

Kfir Blum
Weizmann Institute

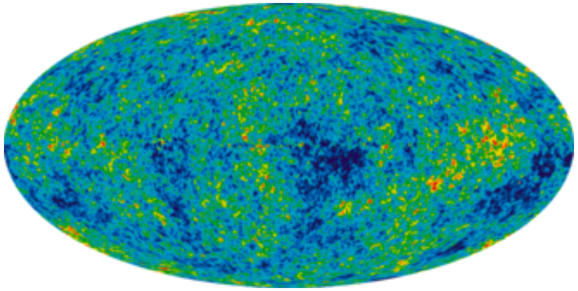
CERN academic training 11-15/04/2016

It is possible to learn something fundamental from astrophysical data.

It has happened in the past

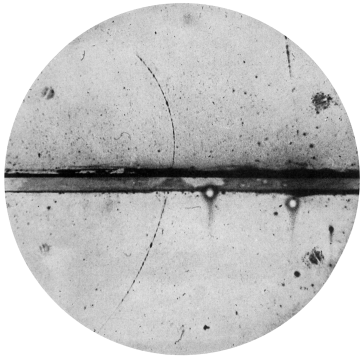
It is possible to learn something fundamental from astrophysical data.

Expansion, initial conditions



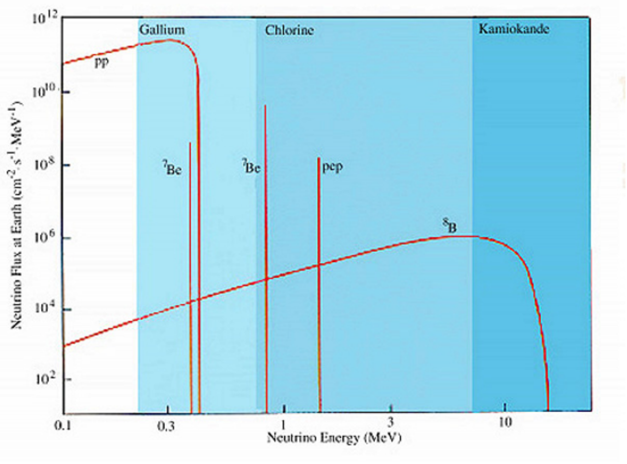
It is possible to learn something fundamental from astrophysical data.

QFT works



It is possible to learn something fundamental from astrophysical data.

The Standard Model is wrong



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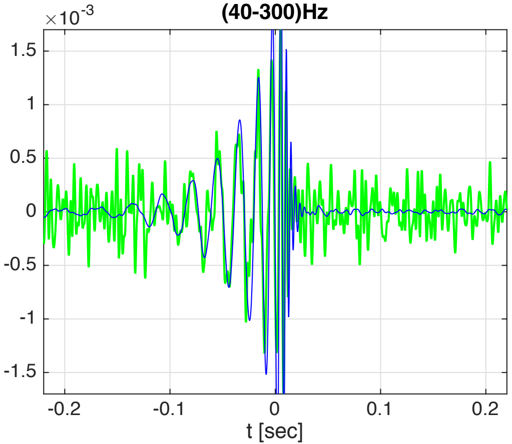
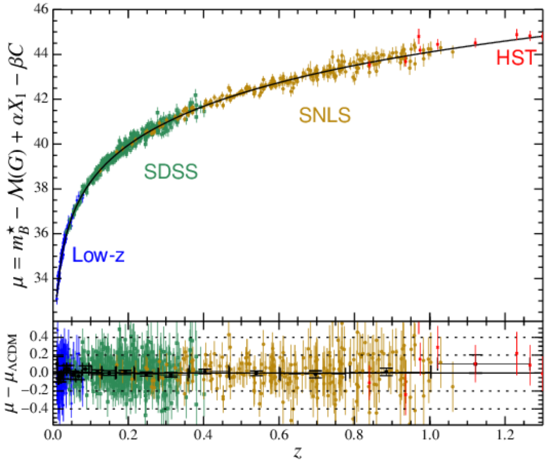
GR works



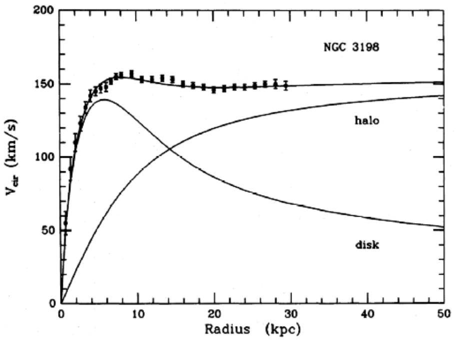
It is possible to learn something fundamental from astrophysical data.

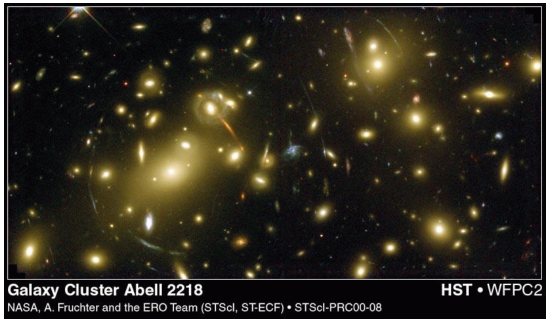
Vacuum energy



It is possible to learn something fundamental from astrophysical data.

Baryonic matter is not enough





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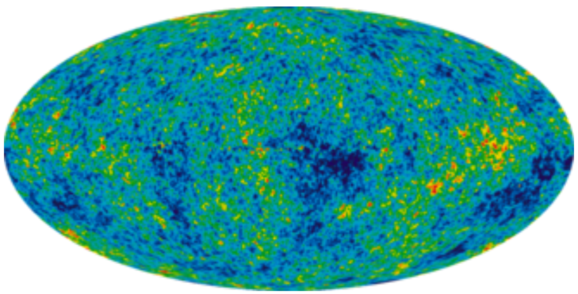
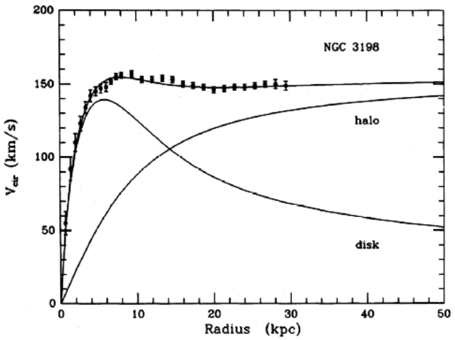
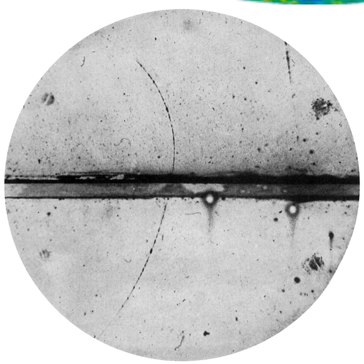
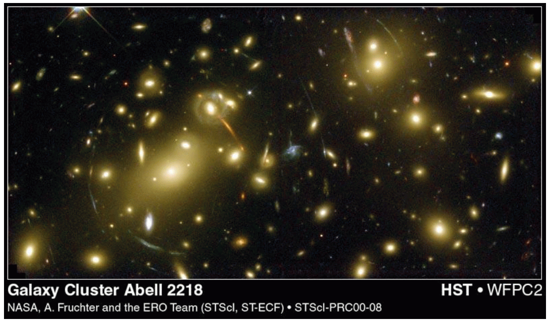
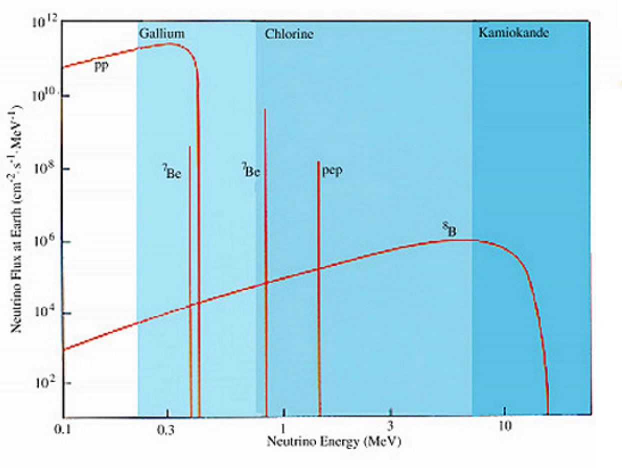
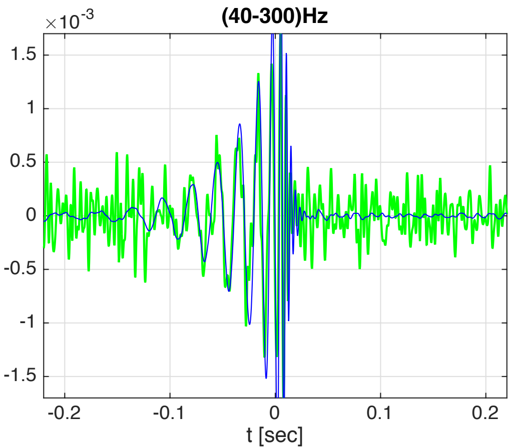


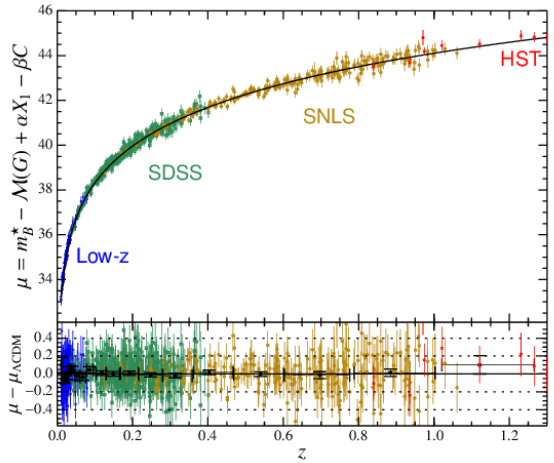












Example: The solar neutrino problem

Case was closed when astro uncertainties were addressed from first principles:

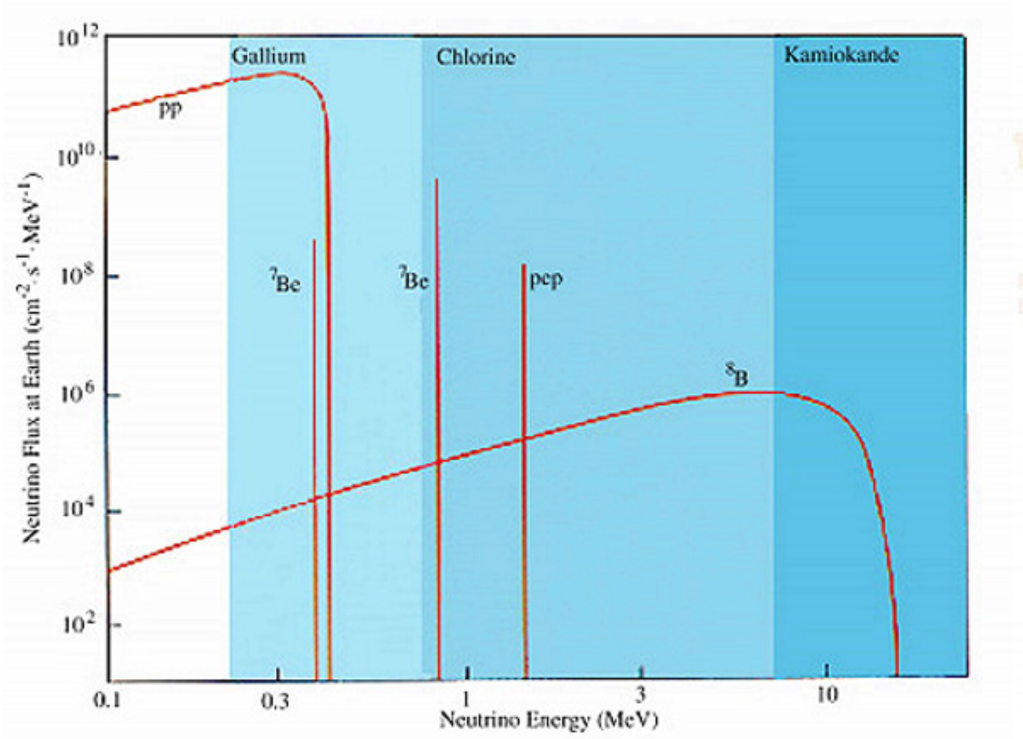
- Low energy deficit (Homestake) – T uncertainty?

- But neutrino emissivity strong function of T.

  Smaller deficit at higher energy (Kamiokande)

  ➔ ***real* anomaly**

Bahcall & Bethe, **PRD47 (1993) 1298-1301**



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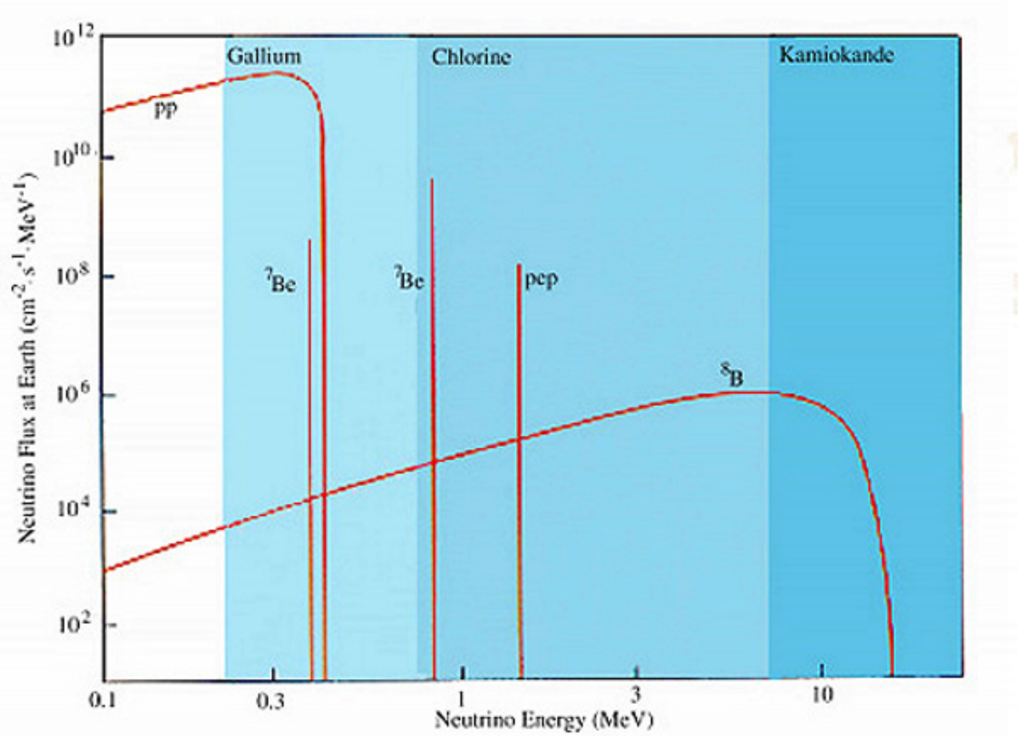


• **Lesson**:

model independent

no-go conditions

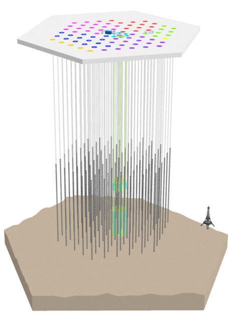
Here's the plan

Session I (today):

Some progress & prospects

Session II-III:

Cosmic rays: are 300GeV CR e+ coming from dark matter?



Session IV:

IceCube's neutrinos: what will they teach us?

Session V:

Precision cosmology: lessons for dark matter

Here's the plan

Session I (today):

Here’s the plan

Session I (today):

- Small-scale anomalies for ΛCDM? – some expected observational progress
- On the search for WIMPs – *an* ultimate target?
- Axions and the like – pure gravity; oscillating constants, redshifting chiral Lagrangian; revisiting some astrophysical arguments
- AMS02 and the positron puzzle; IceCube’s neutrinos; Cosmology (if time)

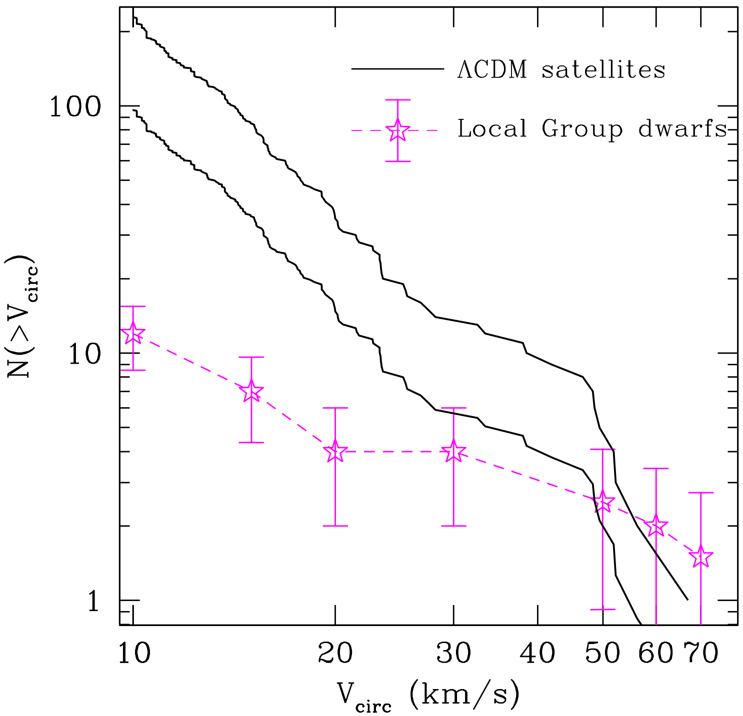
Small scale problems of collisionless cold dark matter?

Shortage of observed satellite galaxies compared

to ΛCDM? Bad slope of mass function?

e.g. Kravstov, **Adv.Astron. 2010 (2010) 281913**
Weinberg et al, 1306.0913 (PNAS, 112, 12249)

Many models suggested to extend ΛCDM



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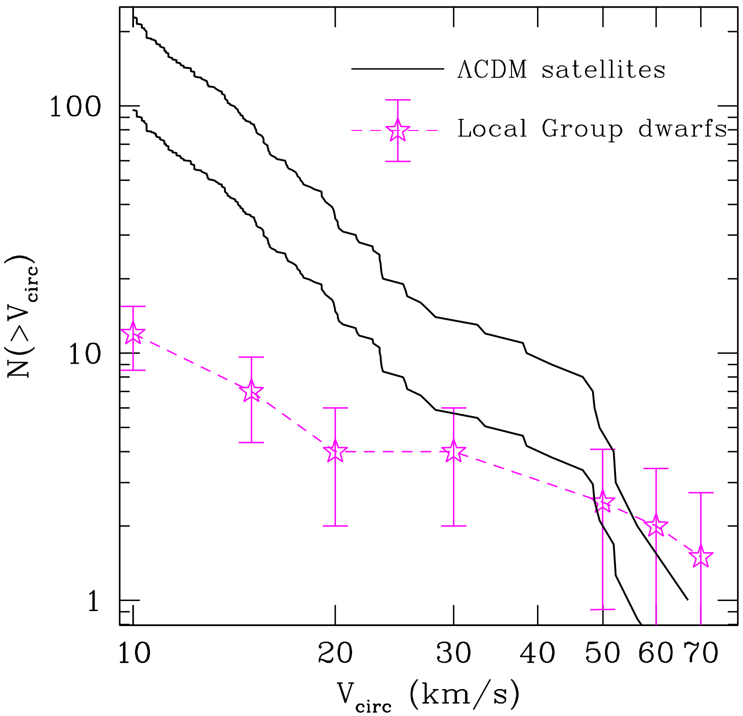


More new dwarf galaxies detected

Koposov et al, ApJ. 805 (2015) no.2, 130
Abbott et al (DES), 1601.00329

But versions of problem seem to remain.

Complicated by baryonic physics

e.g. Governato, MNRAS. 448 (2015) 792
Kravstov, Adv.Astron. 2010 (2010) 281913
Weinberg et al, 1306.0913 (PNAS, 112, 12249)

Little first-principle control (contrast to linear cosmology, session V)

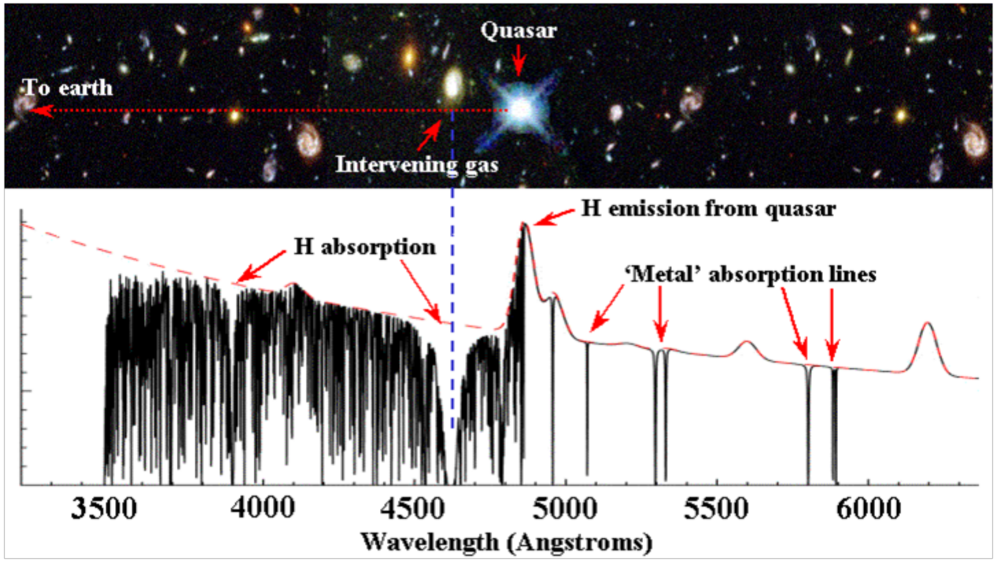
Progress in **observational methods**

Warm DM vs. Ly-alpha forest

Assuming thermal relic:

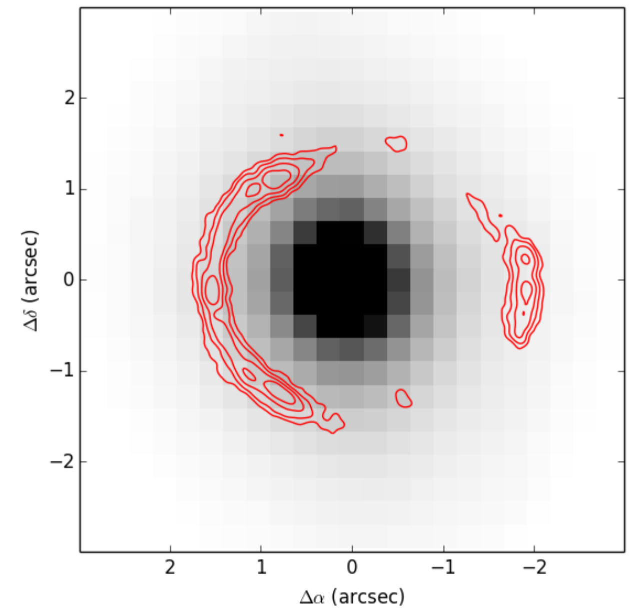
mDM > 4.35 KeV (2σ)

[31.7 KeV for DW sterile neutrino]



Baur et al, **JCAP 1502 (2015) no.02, 045**
Palanque-Delabrouille et al, JCAP 1511 (2015) no.11, 011
Viel et al, PRD88 (2013) 043502
Seljak, Makarov, McDonald, PRL 97 (2006) 191303
McDonald et al, ApJ. 635 (2005) 761-783

Strongly lensed dusty galaxies (ALMA)



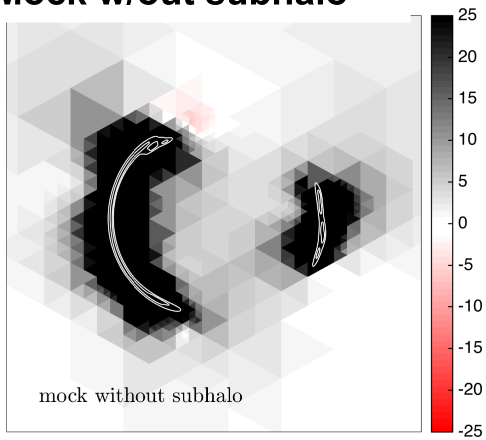
Hezaveh et al **1601.01388**

Inoue et al, MNRAS 457 (2016) 2936

Vegetti et al, MNRAS 442 (2014) no.3, 2017-2035

Dalal & Kochanek, ApJ. 572 (2002) 25-33

Mock w/out subhalo



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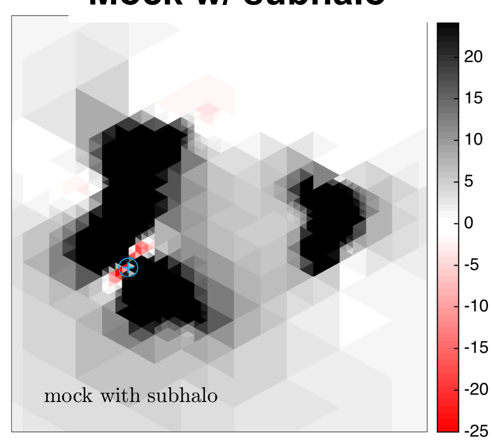
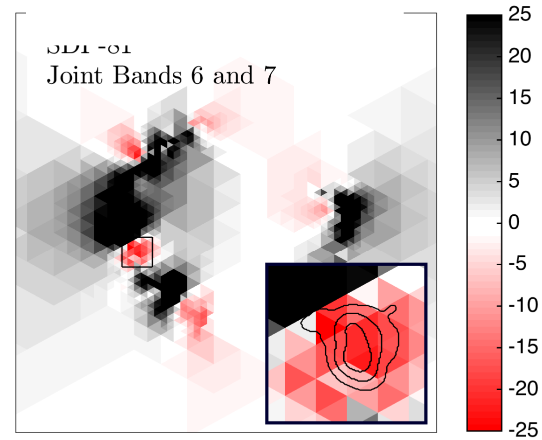
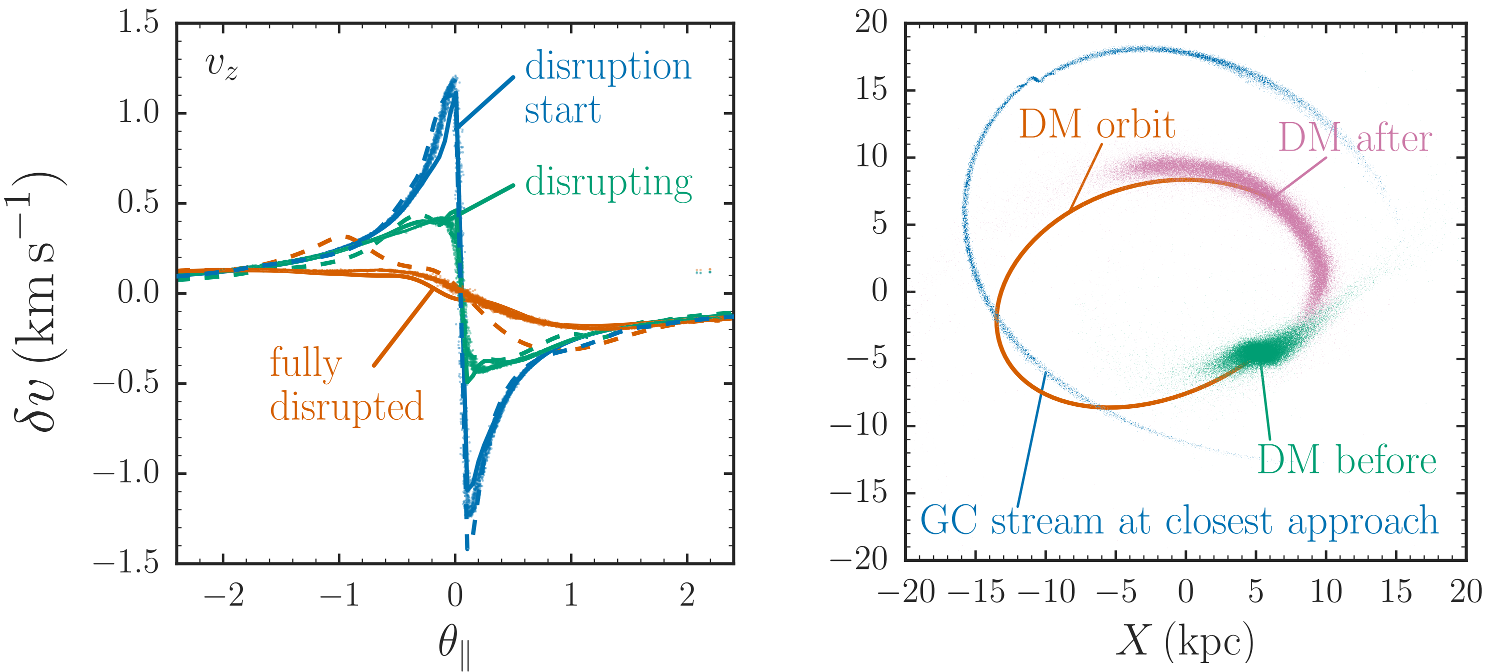


SDP-81 Bands 6-7

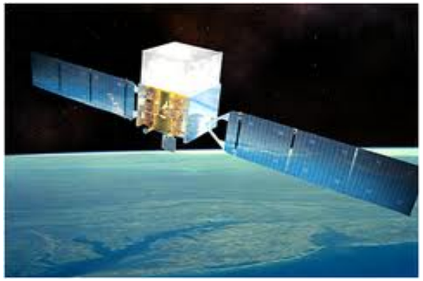


Kinematical heating of stellar streams (GAIA, LSST)

Bovy, **PRL. 116 (2016) no.12, 121301**
Erkal & Belokurov, MNRAS 454, 3542 (2015)
Johnston, Spergel, Hayden, ApJ 570, 656 (2002)
Ibata et al, MNRAS 332,915 (2002)
Carlberg, ApJ. 748, 20 (2012)



On the search for WIMPs.



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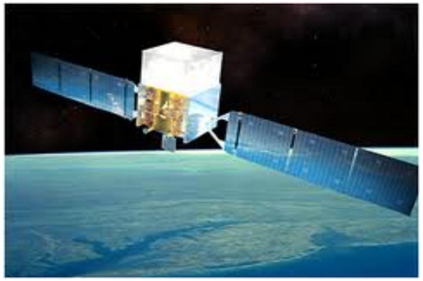


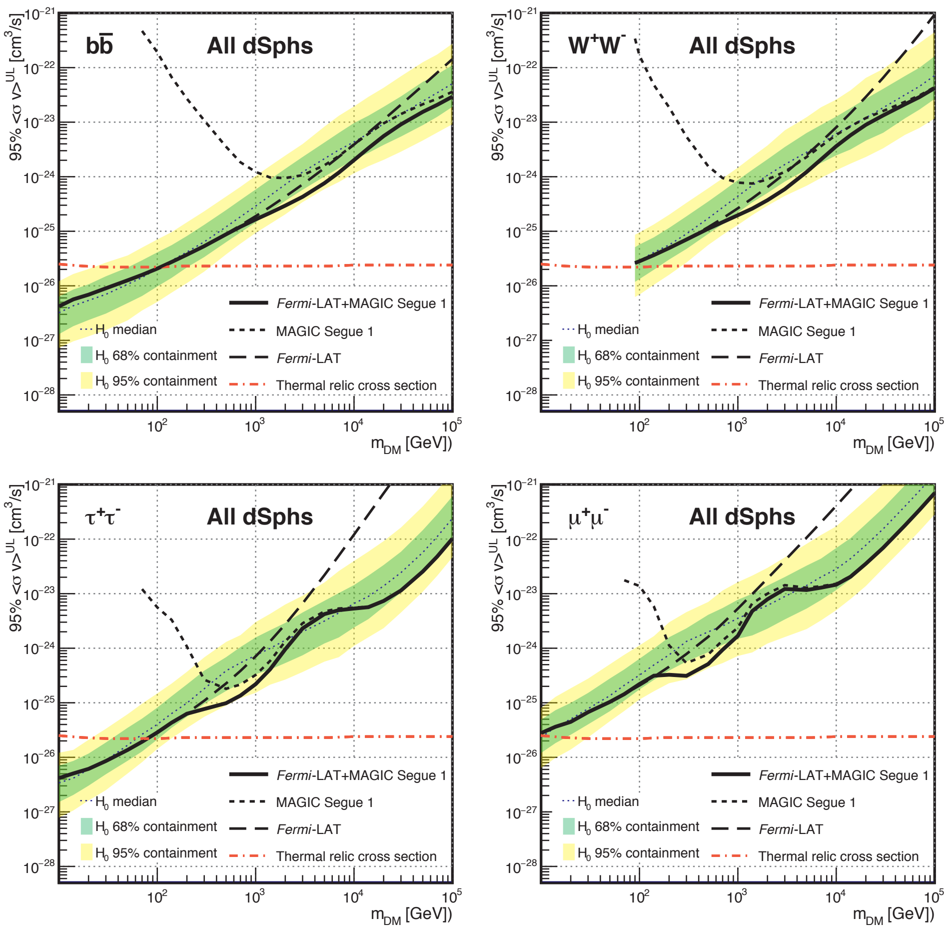
Take a slightly non-orthodox way, will allow us to glance state of the art + future

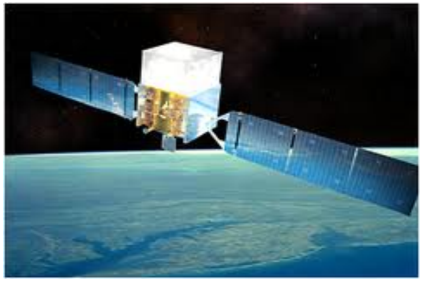
Some recent reviews:
Bringmann & Weniger, Phys.Dark Univ. 1 (2012) 194-217
Klasen, Pohl, Sigl, Prog.Part.Nucl.Phys. 85 (2015) 1-32
Baudis, J.Phys. G43 (2016) no.4, 044001
Lisanti, 1603.03797

We’ve been looking for WIMPs for a long time.

Direct and indirect searches achieve impressive sensitivity.

Ahnen et al, **JCAP 1602 (2016) no.02, 039**





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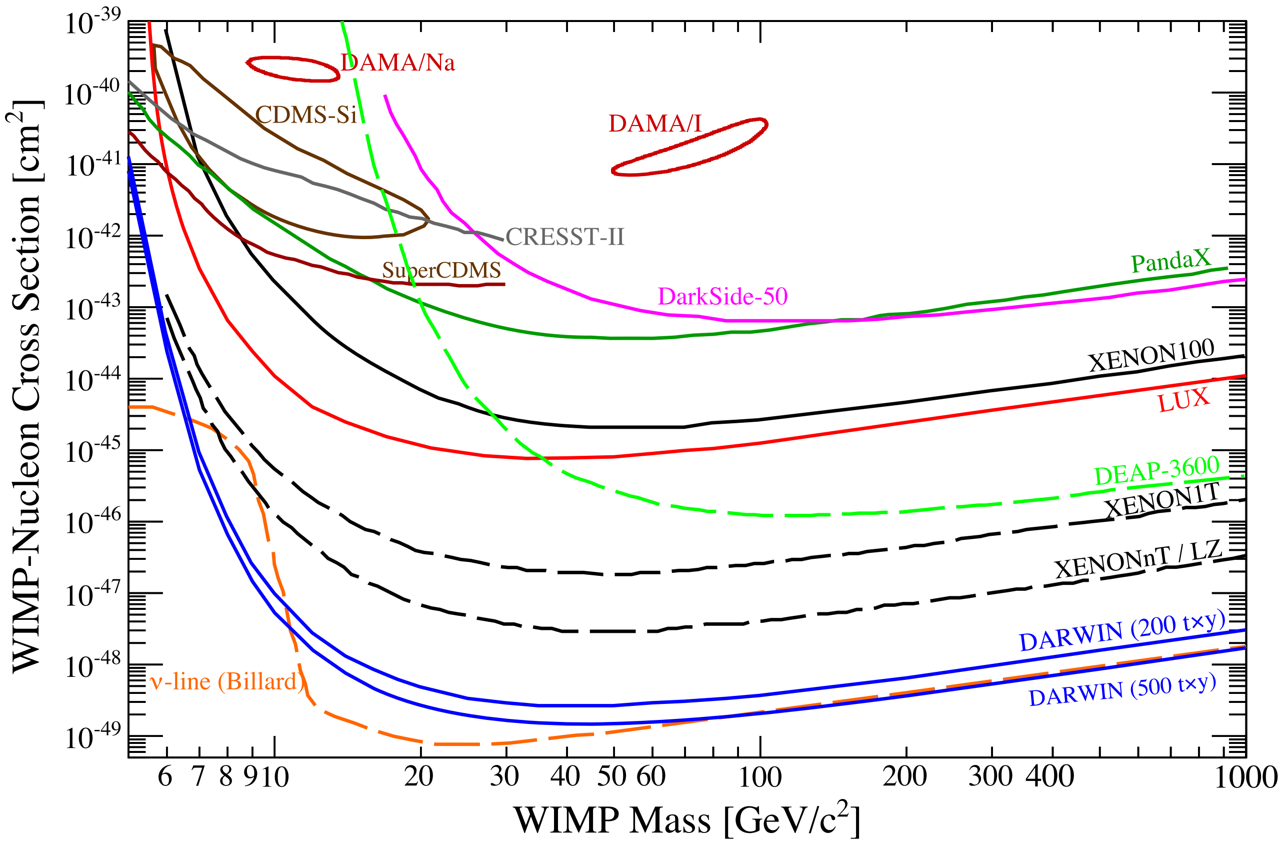

Schumann et al, **JCAP 1510 (2015) no.10, 016**
Baudis, J.Phys. **G43 (2016) no.4, 044001**

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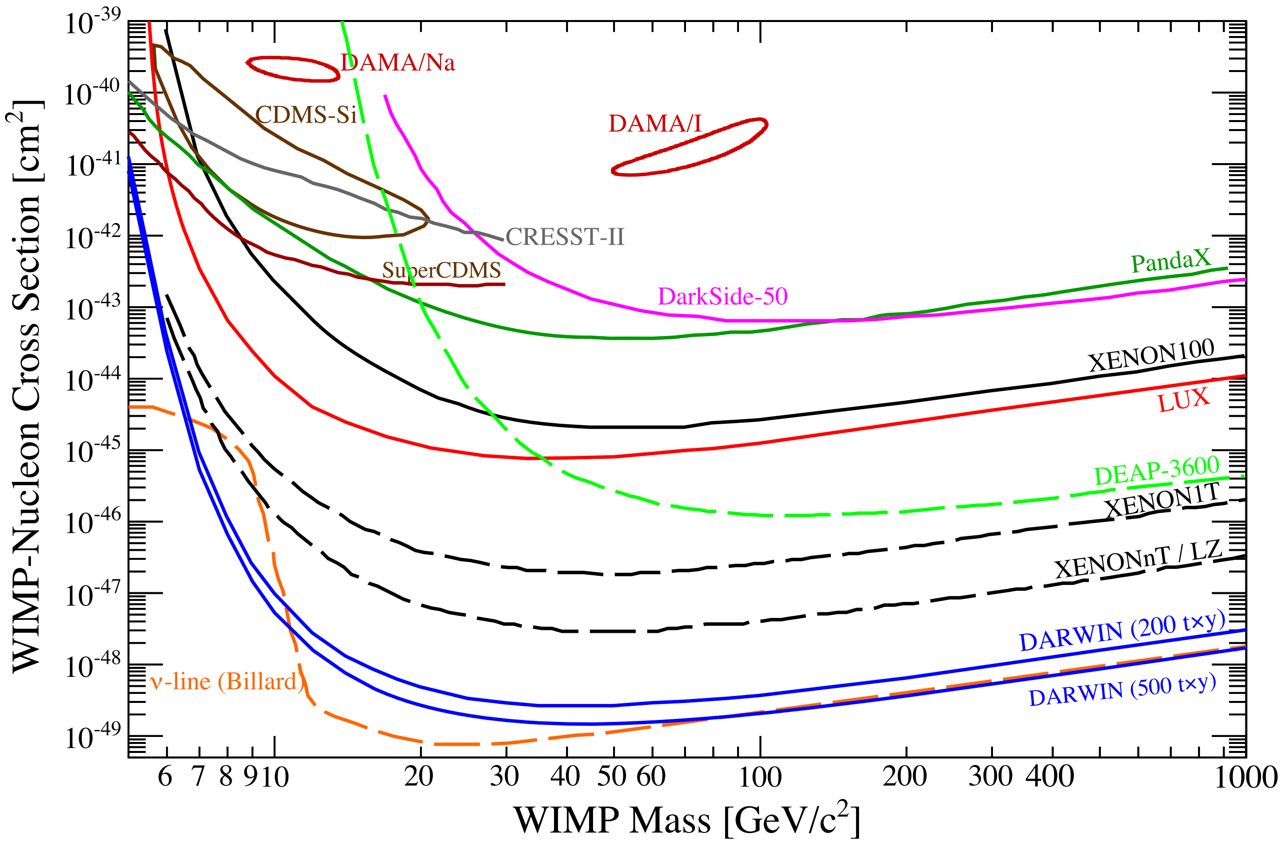
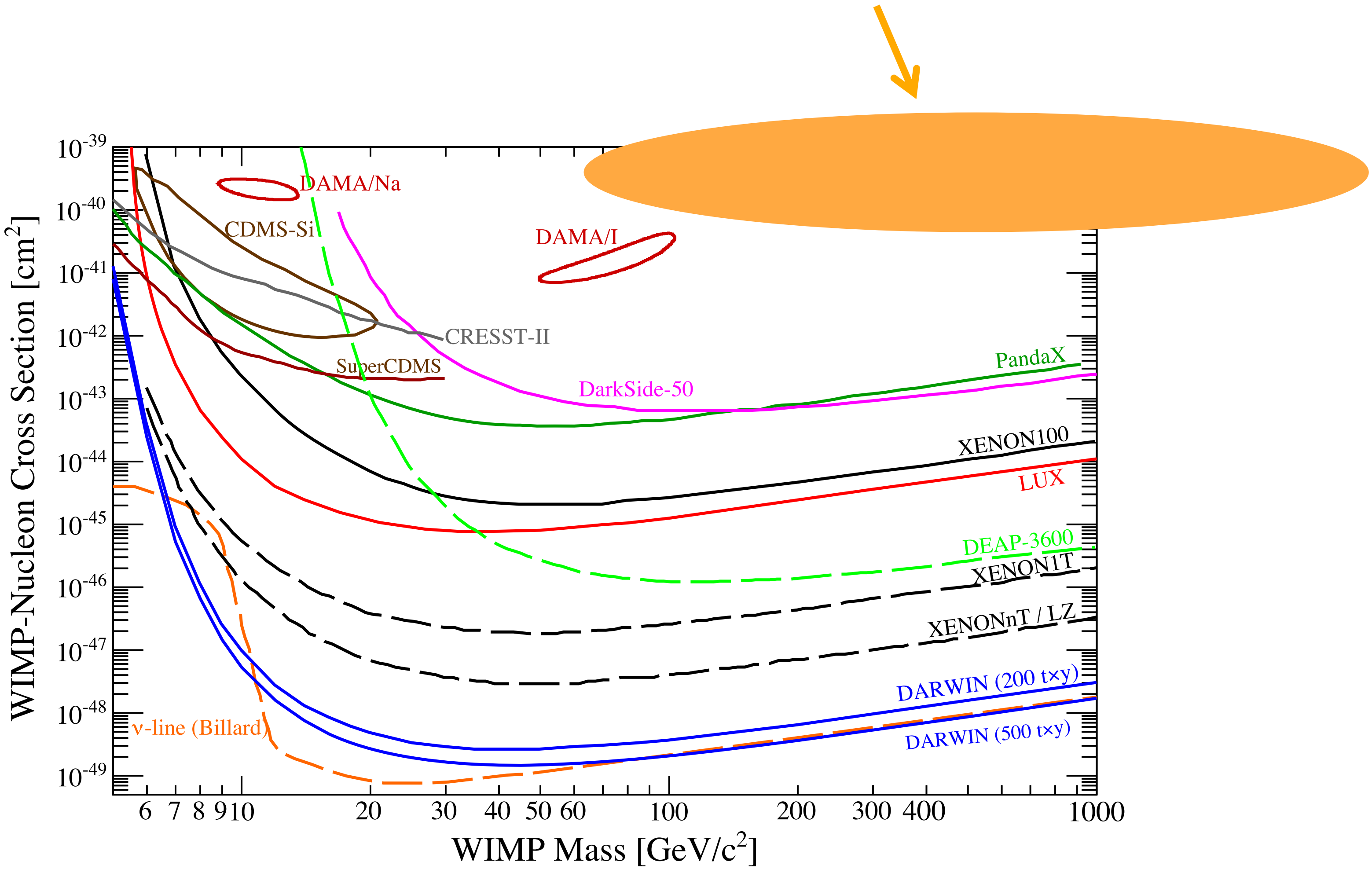
What does it mean?



Schumann et al, **JCAP 1510 (2015) no.10, 016**
Baudis, J.Phys. **G43 (2016) no.4, 044001**

Example for what it means:

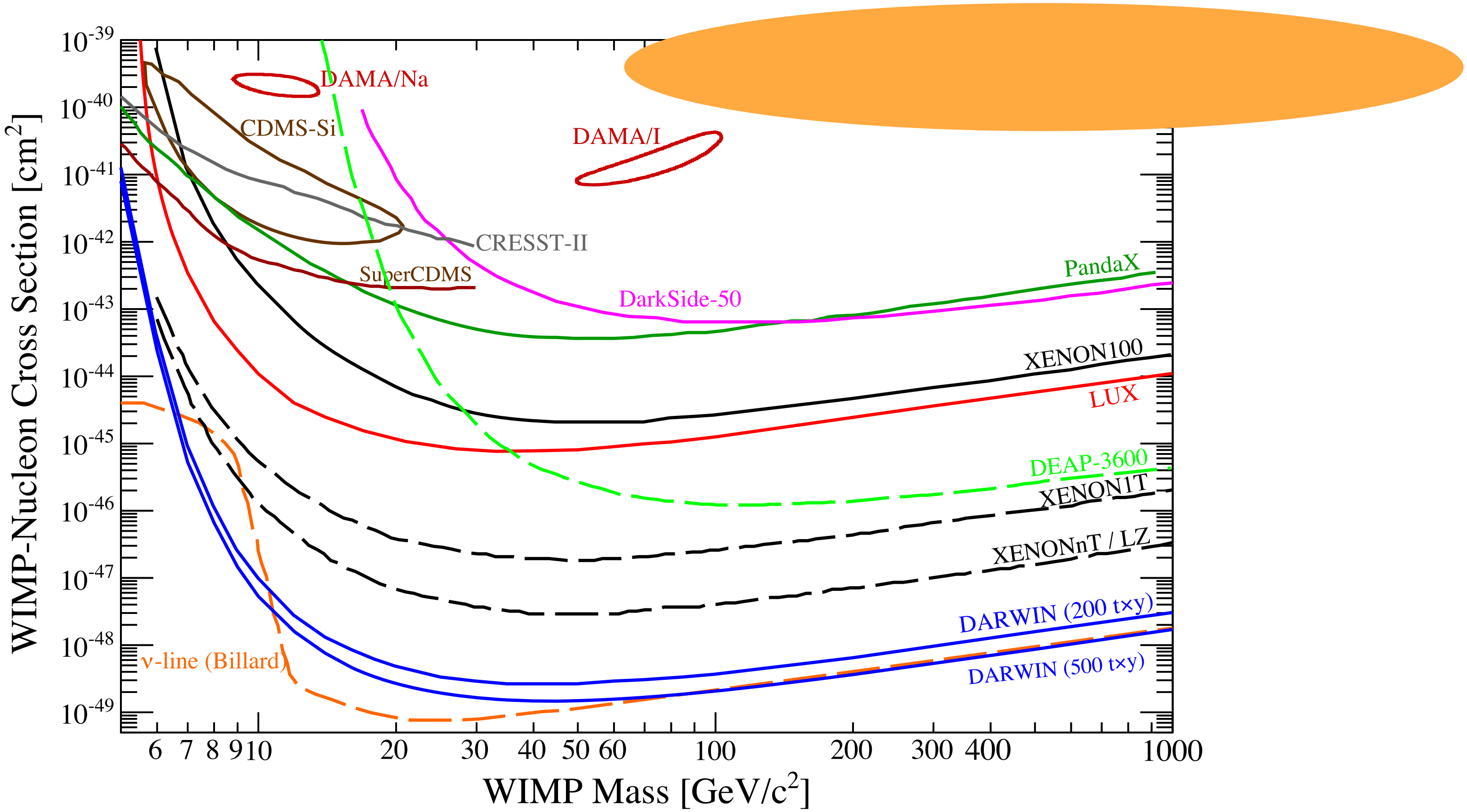
WIMP DM with tree level Z exchange would be here



Schumann et al, **JCAP 1510 (2015) no.10, 016**
Baudis, J.Phys. **G43 (2016) no.4, 044001**

As we're making these beautiful experiments, it is interesting to point out generic implications of the results.
This also helps to identify well-defined goals.

Next: point out one such generic goal



Schumann et al, **JCAP 1510 (2015) no.10, 016**
Baudis, J.Phys. **G43 (2016) no.4, 044001**

Recall the **WIMP story**, simple thermal history

$$\Gamma_{ann} = n\langle\sigma v\rangle = T^3 \left(\frac{M}{2\pi T}\right)^{\frac{3}{2}} e^{-\frac{M}{T}} \langle\sigma v\rangle$$

$$\Gamma_{ann} = H \approx \sqrt{g_*(T)} \frac{T^2}{M_{pl}} \quad \Rightarrow \quad \frac{M}{T} \approx \log\left(M_{pl} M \langle\sigma v\rangle\right) + \frac{1}{2}\log\left(\frac{M}{T}\right) \sim 20$$

$$\rho_{\chi,0} \approx M n_{\chi,fo} \frac{g_{*S}(T_0)T_0^3}{g_{*S}(T_{fo})T_{fo}^3} \approx \left(\frac{M}{T_{fo}} \frac{g_{*S}(T_0)T_0^3}{\sqrt{g_{*S}(T_{fo})}M_{pl}}\right) \frac{1}{\langle\sigma v\rangle}$$

$$\boxed{\frac{\Omega_\chi}{\Omega_{dm}} \approx \frac{\langle\sigma v\rangle_0}{\langle\sigma v\rangle}}$$

observed: $\Omega_{dm} = \frac{\rho_{dm}}{\rho_{crit}} \approx 0.2$

WIMPs and **partial-wave unitarity**

$$\sigma = \sum_L \sigma_L \,, \qquad \sigma_L = \frac{\pi(2L+1)}{\vec{p}^2}(1 - |\eta_L|^2)$$

L=0 (s-wave):

$$\sigma < \frac{4\pi}{M^2 v^2} \quad \Rightarrow \quad \langle \sigma v \rangle < \frac{4\pi}{M^2}\langle v^{-1} \rangle$$

per collision — averaged over collisions

$$\langle v^{-1} \rangle_{fo} = \sqrt{\frac{M}{\pi T_{fo}}} \sim 2.5$$

Griest & Kamionkowski, **PRL64, 615(1990):** ***upper bound on WIMP mass***

$$\frac{\Omega_\chi}{\Omega_{dm}} \approx \frac{\langle \sigma v \rangle_0}{\langle \sigma v \rangle} \quad \Rightarrow \quad \boxed{\frac{\Omega_\chi}{\Omega_{dm}} > \left(\frac{M}{110\ \mathrm{TeV}}\right)^2}$$

WIMPs and **partial-wave unitarity II**

Direct detection experiments *assume* WIMP = DM

…Assume WIMP mass density to compute event rate per unit target mass:

$$R = \frac{2}{\sqrt{\pi}} \frac{\rho_{dm} \sigma_N v_{\odot}}{M m_N}$$

$$\rho_{dm} = \rho_{dm,here} \sim 0.3 \text{ GeV/cm}^3$$

$$v_{\odot} \sim 200 \text{ km/s}$$

$$\sigma_N = \frac{A^2 \mu_{N\chi}^2}{\mu_{\chi p}^2} \sigma_{\chi p}$$

WIMPs and **partial-wave unitarity II**

Direct detection experiments *assume* WIMP = DM to plot sensitivity curves.

So, unitarity implies:

$$R_\chi = \frac{2}{\sqrt{\pi}} \frac{\rho_\chi \sigma_N v_\odot}{M m_N} > \frac{2}{\sqrt{\pi}} \frac{\rho_{dm} \sigma_N v_\odot}{M m_N} \left(\frac{M}{110 \text{ TeV}} \right)^2$$

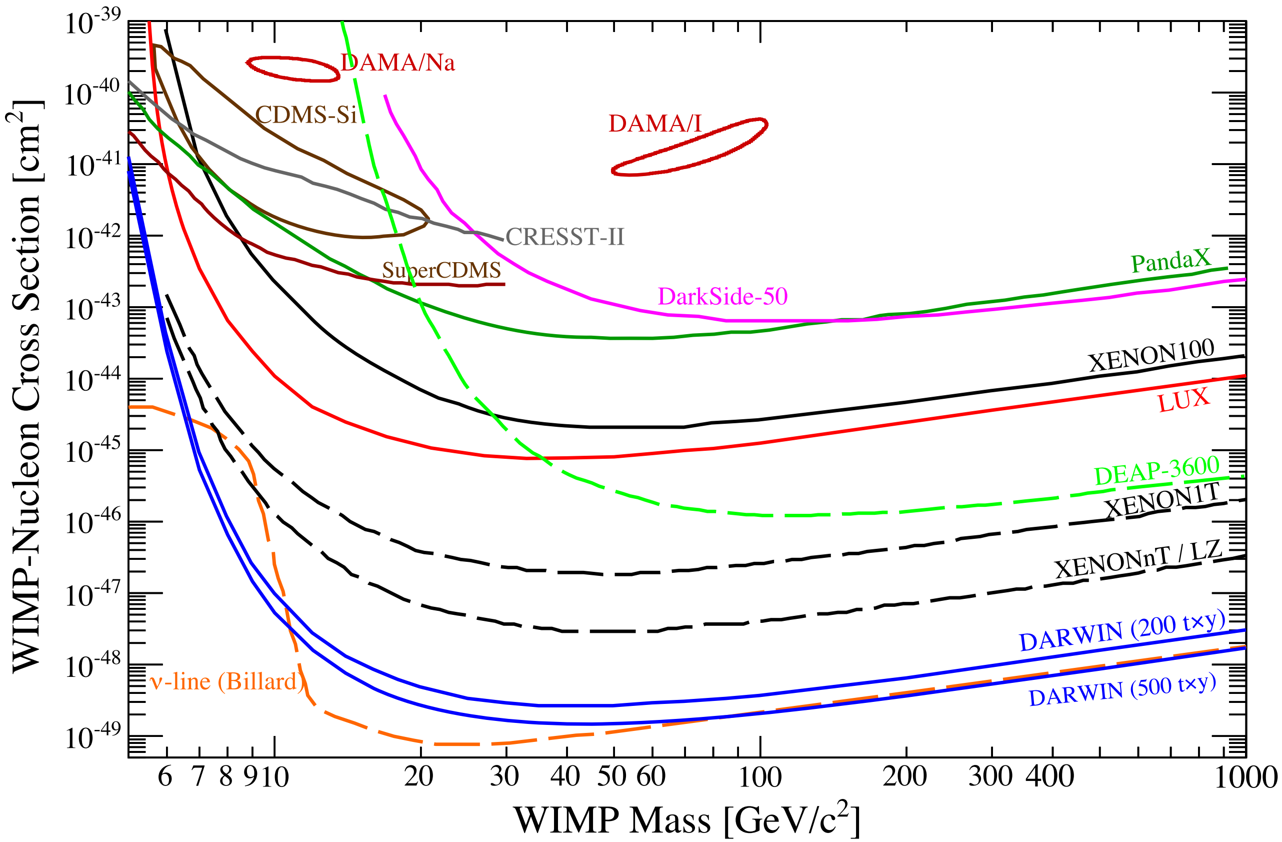
(actual bulk of DM can be something else. Could be *axions* for all we care)

➔ can put this on direct detection sensitivity plot

We've been looking for WIMPs for a long time.

What does it mean?

WIMP dark matter cannot have tree-level Z exchange



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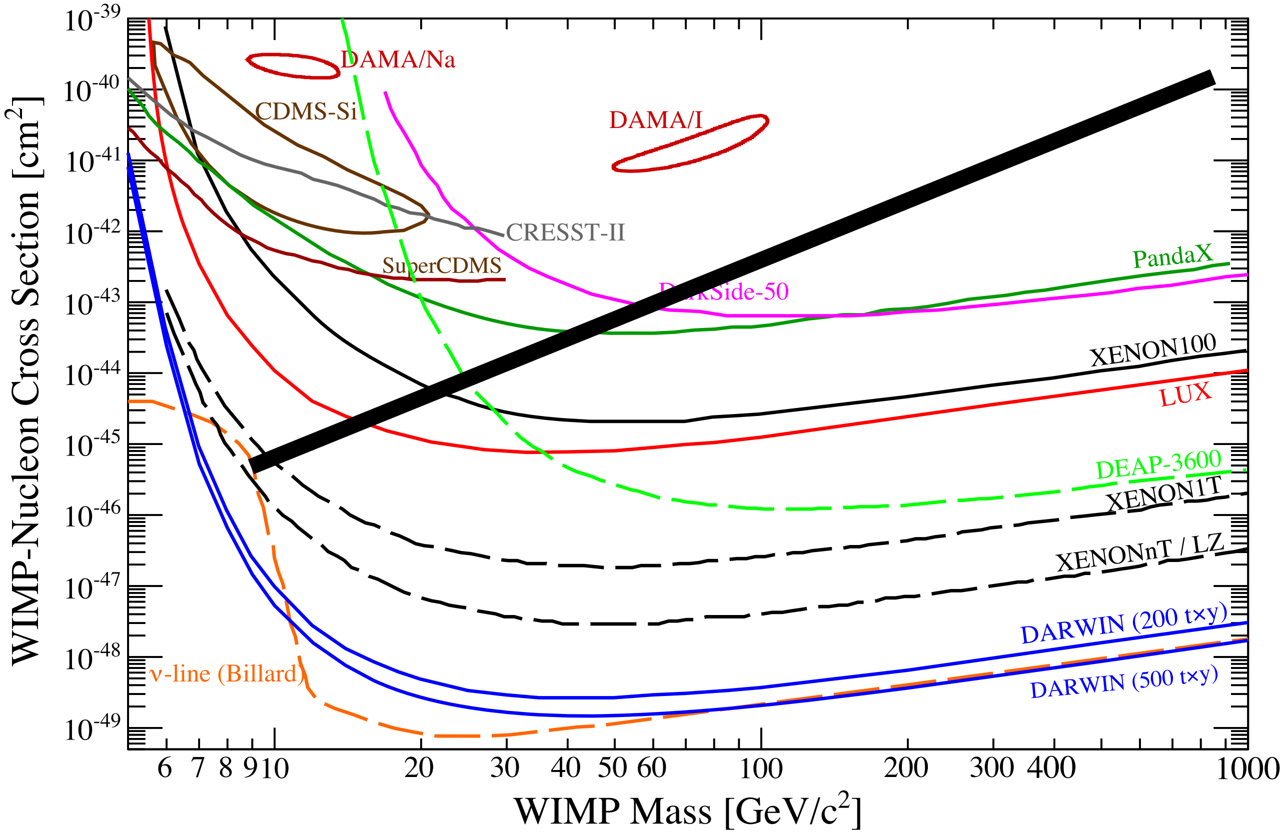
There cannot be ***any heavy thermal relic*** with tree-level Z exchange

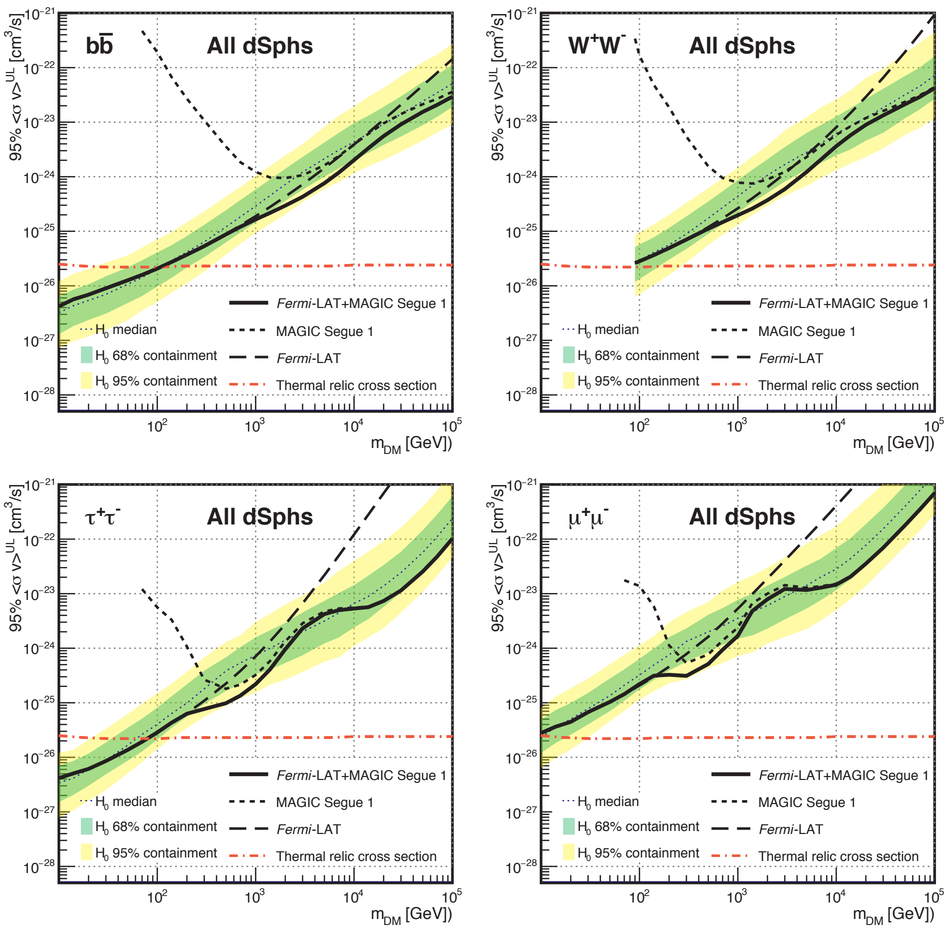


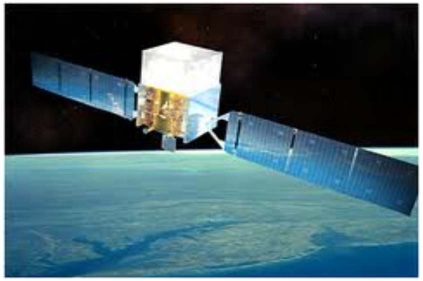
Blum, Cui, Kamionkowski, **PRD92 (2015) 2, 023528**

Application to **indirect detection** is, in some sense, more obvious:
relate annihilation to annihilation

But in other respects less general:
p-wave, Sommerfeld suppression,… would spoil it

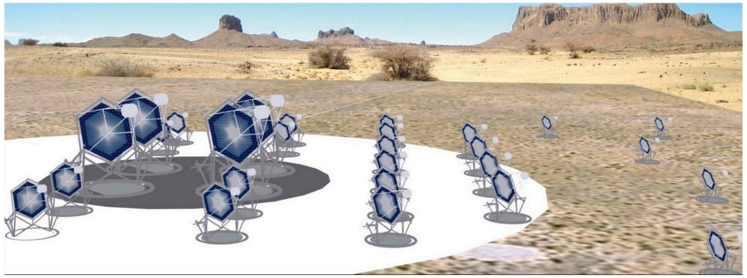
Ahnen et al, **JCAP 1602 (2016) no.02, 039**

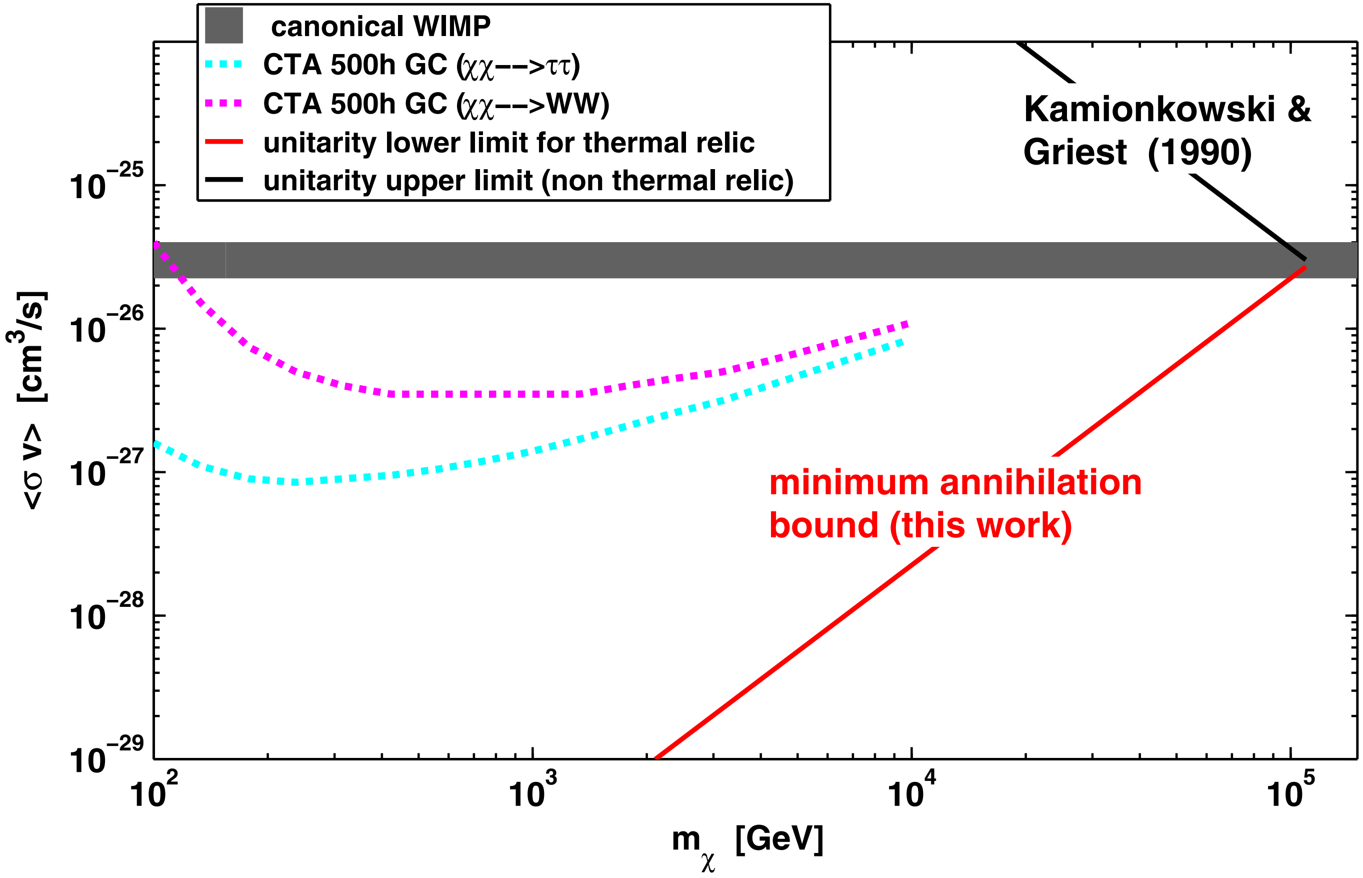




Unitarity: flux *lower* limit on sensitivity plot of CTA.

(can we figure out the backgrounds well enough?)





CTA estimate: Wood et al, 1305.0302

Axions and ultra-light fields

Axions and ultra-light fields

Strong CP?

Self-organised criticality?

Dark matter?

Graham, Kaplan, Rajendran, PRL. 115 (2015) no.22, 221801
Batell, Giudice, McCullough, JHEP 1512 (2015) 162
…

Axions and ultra-light fields

An ultra-light bosonic field could play the role of dark matter

Recently, regarding small scale issues, e.g.
Calabrese & Spergel, 1603.07321
Marsh & Pop, MNRAS. 451 (2015) no.3, 2479-2492
Schive et al, ApJ. 818 (2016) no.1, 89

Axions and ultra-light fields

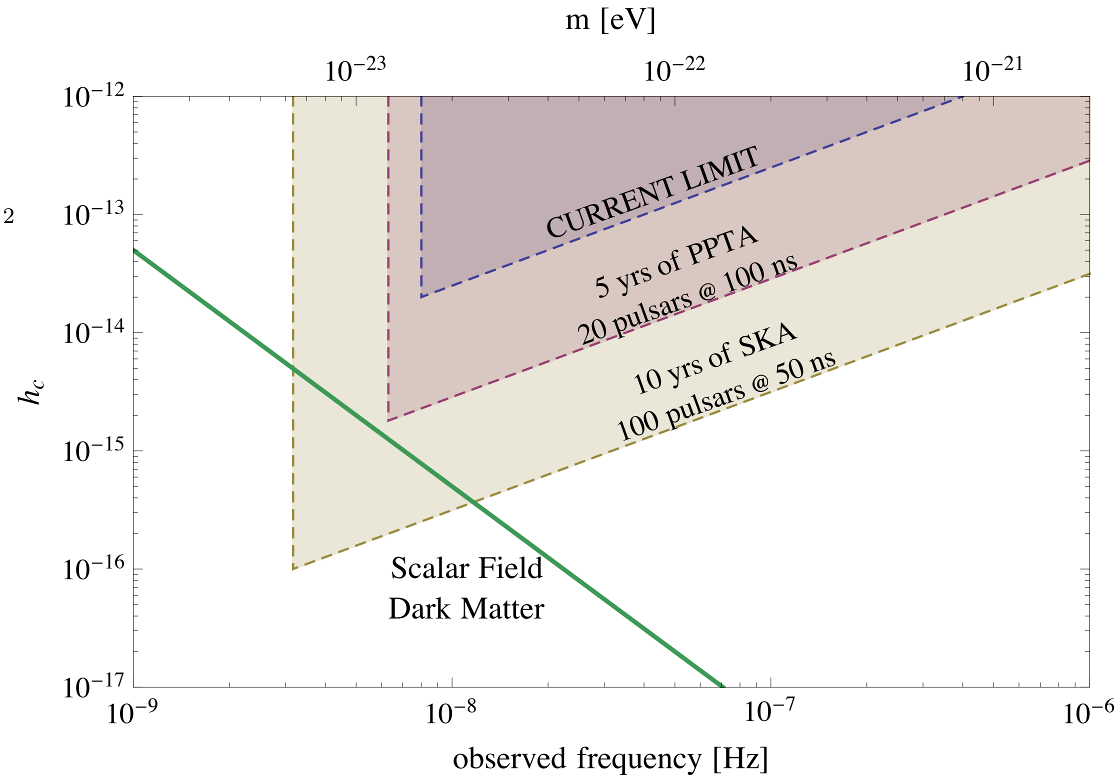
An ultra-light bosonic field could play the role of dark matter

Can we detect it w/ gravity alone?

$$h_c = 2\sqrt{3}\,\Psi_c = 2 \cdot 10^{-15} \left(\frac{\rho_{DM}}{0.3\,\mathrm{GeV/cm^3}}\right) \left(\frac{10^{-23}\,\mathrm{eV}}{m}\right)^2$$

$$f \equiv 2\pi\omega = 5 \cdot 10^{-9}\,\mathrm{Hz} \left(\frac{m}{10^{-23}\,\mathrm{eV}}\right)$$

Khmelnitsky & Rubakov, **JCAP 1402 (2014) 019**



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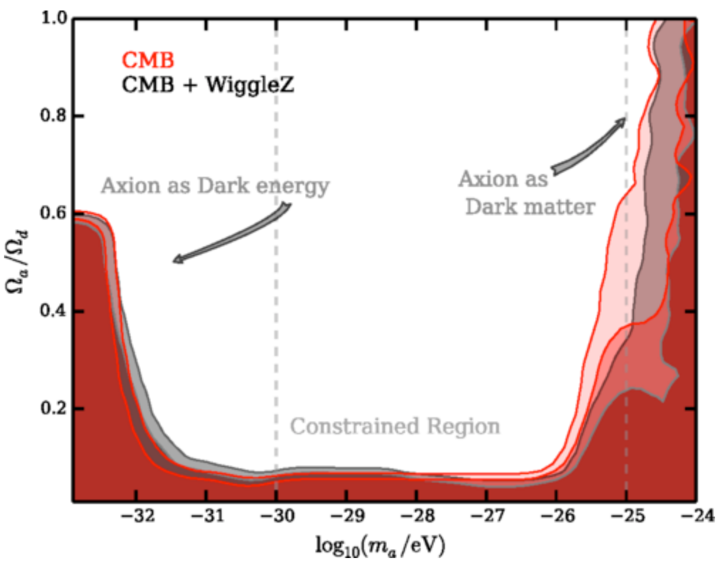

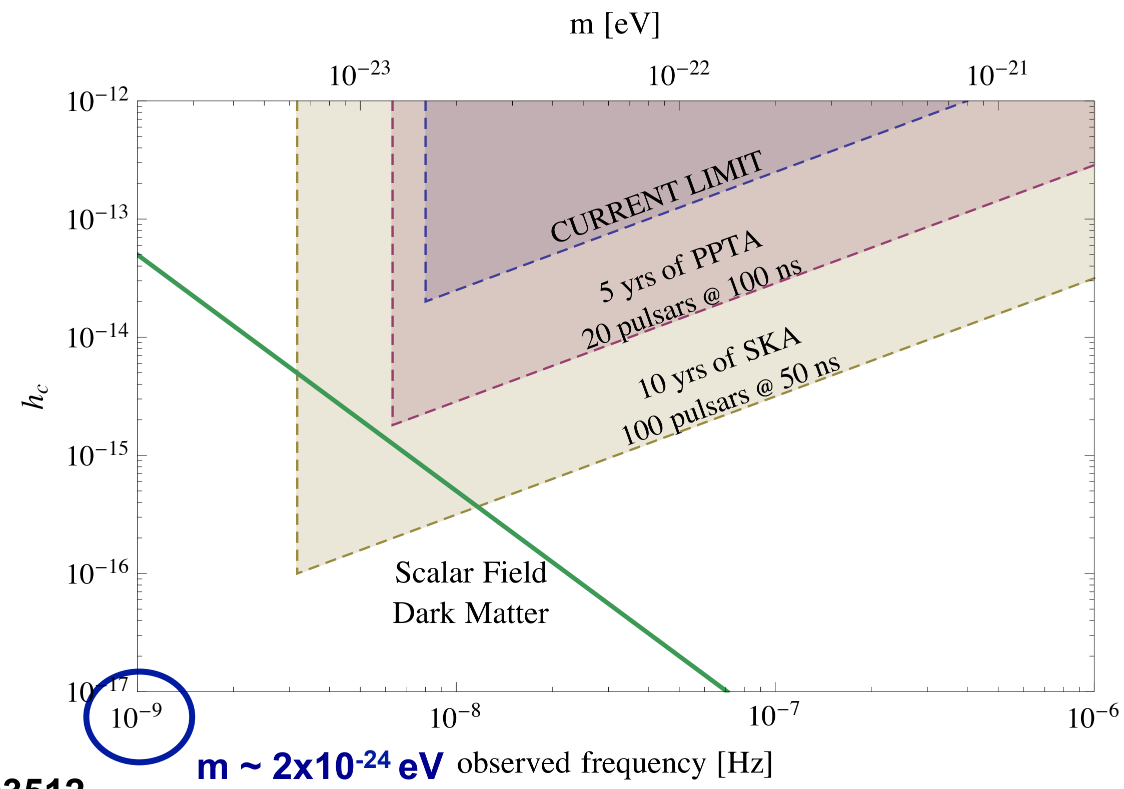

CMB: Hlozek et al, **PRD91 (2015) no.10, 103512**
Marsh, 1510.07633

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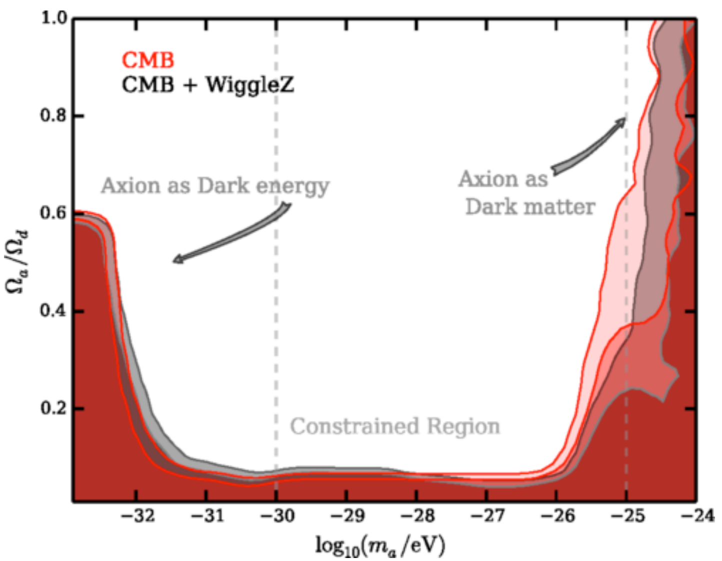
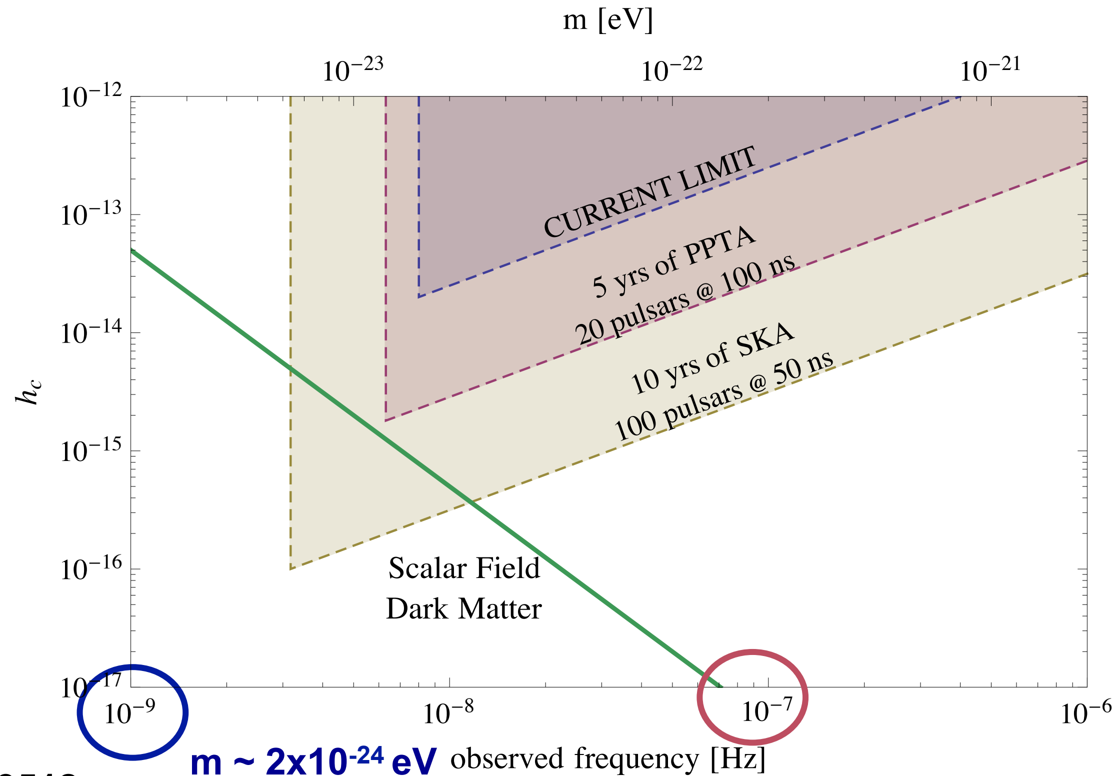
Khmelnitsky & Rubakov, **JCAP 1402 (2014) 019**



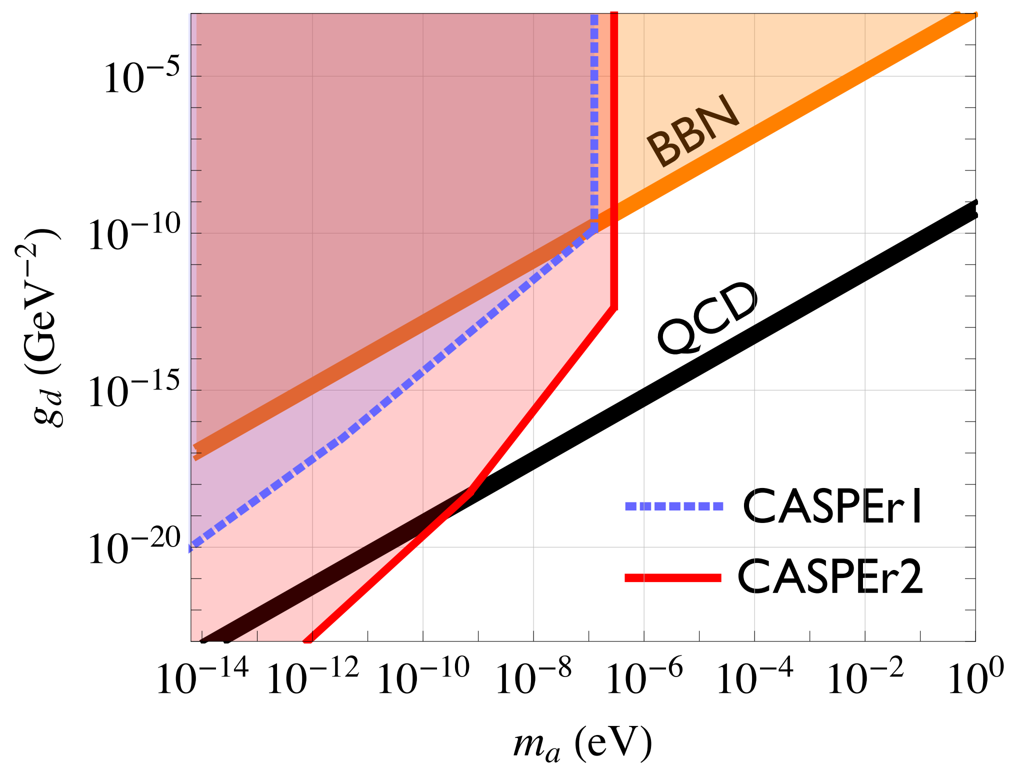


CMB: Hlozek et al, **PRD91 (2015) no.10, 103512**
Marsh, 1510.07633
but, Ly-alpha: Amendola & Barbieri, **PLB642 (2006) 192-196**

Axions and ultra-light fields

An axion coupled to QCD and playing dark matter induces oscillating nEDM

Graham & Rajendran, **PRD88 (2013) 035023**
Budker et al, **PRX4 (2014) no.2, 021030**



Axions and ultra-light fields

An axion coupled to QCD and playing dark matter induces chiral Lagrangian operators that *redshift up* in the Early Universe

$$m_n - m_p = Q_0 + \delta Q \,,$$

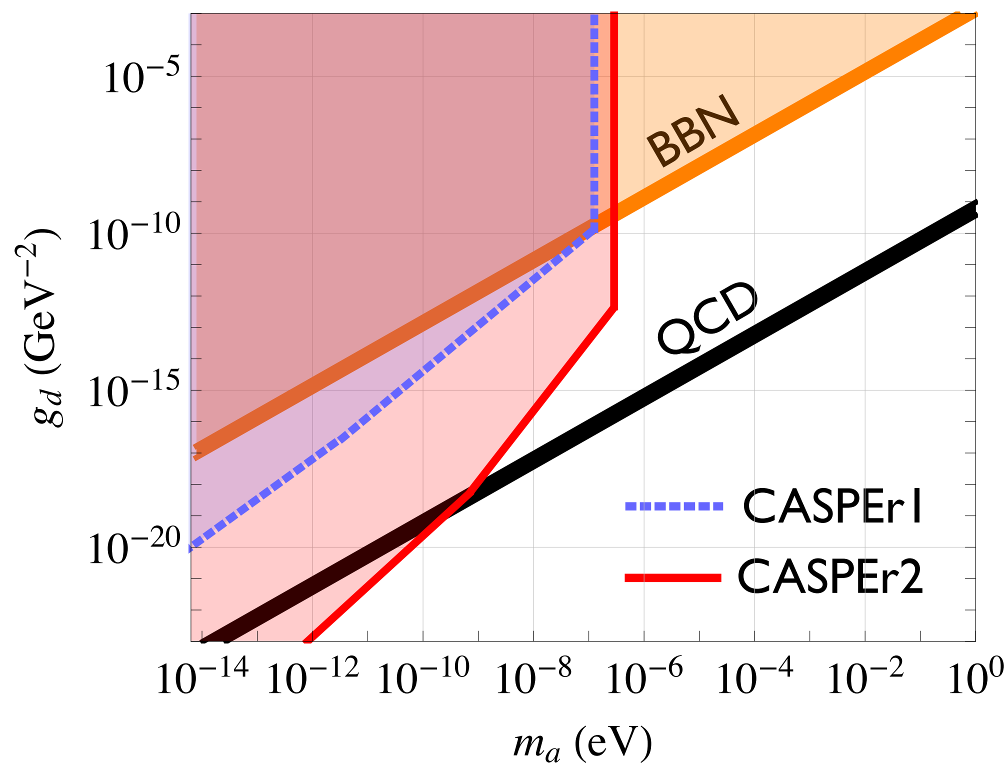
$$\delta Q \approx \frac{f_\pi \, \bar{g}_{\pi NN}}{2} \left(\frac{m_d - m_u}{m_d + m_u} \right) \left(\frac{a}{f_a} \right)^2$$

$a/f_a = \theta$

$$\theta_{\rm eff}(t) = (1+z(t))^{3/2} \frac{\sqrt{2\bar{\rho}_{\rm DM}}}{f_a \, m_a} \cos(m_a t)$$

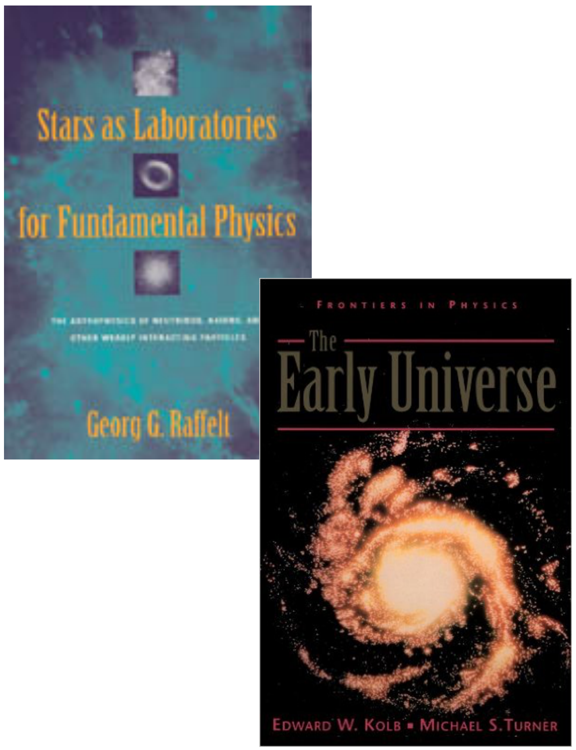
$$\approx 5 \times 10^{-9} \left(\frac{\rm GeV^2}{f_a m_a} \right) \left(\frac{1+z(t)}{10^{10}} \right)^{3/2} \cos(m_a t)$$

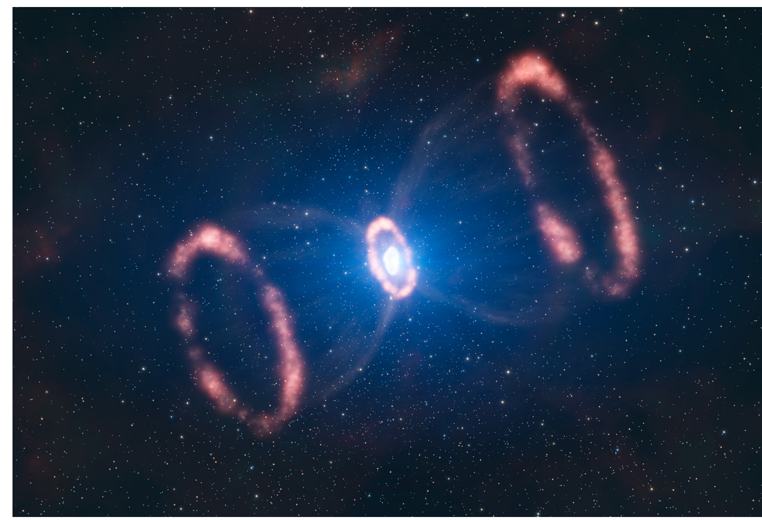
Blum et al, **PLB737 (2014) 30-33**



Axions and other light fields – **comment on some astrophysical bounds**

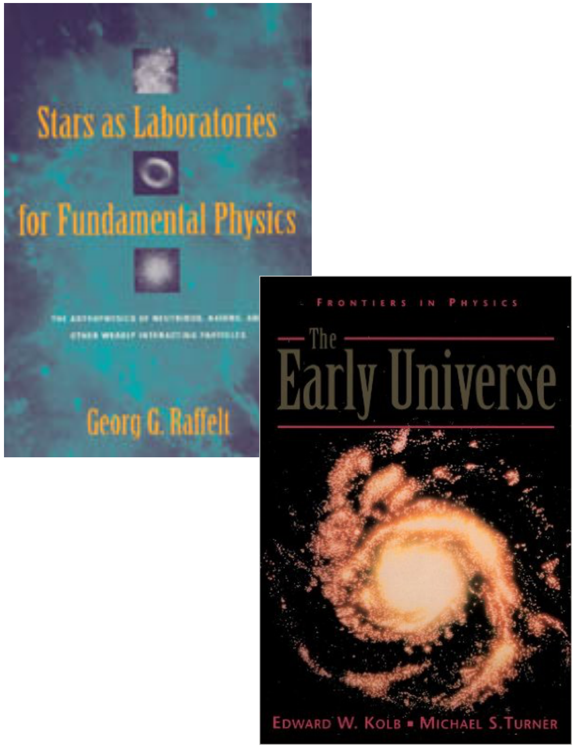
Neutrino burst of core-collapse SN1987A traditionally used to set a bound on axions

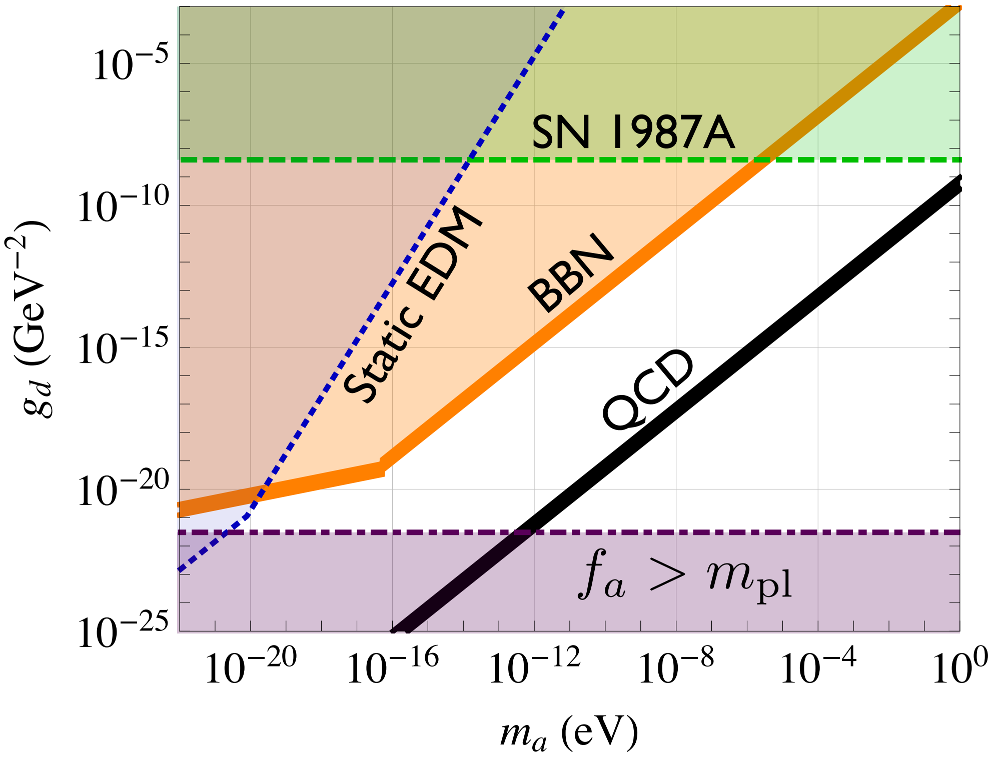




Axions and other light fields – **comment on some astrophysical bounds**

Neutrino burst of core-collapse SN1987A traditionally used to set a bound on axions

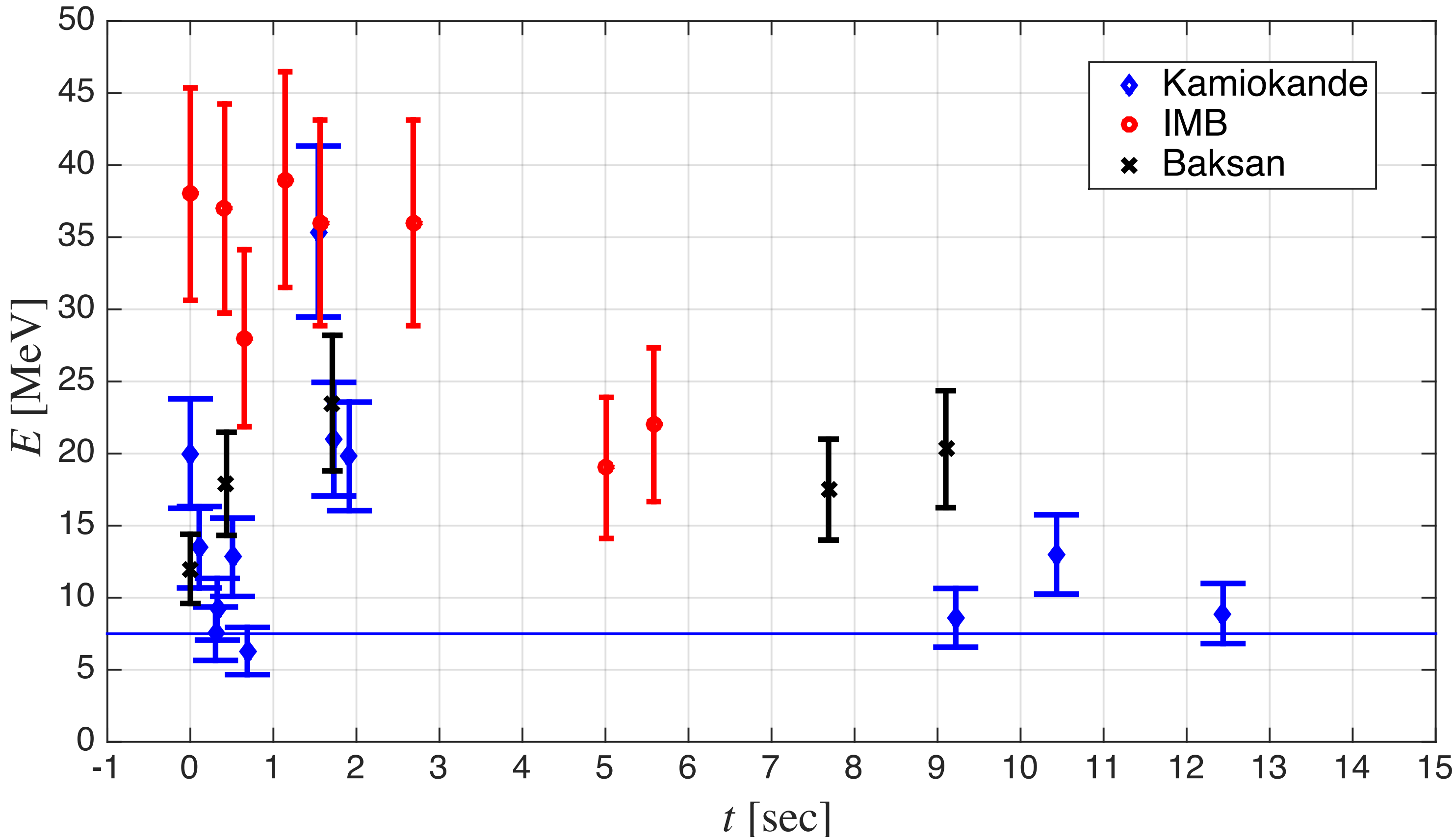




Axions and other light fields – **comment on some astrophysical bounds**

Neutrino burst of core-collapse SN1987A traditionally used to set a bound on axions

Do we understand CCSNe well enough?



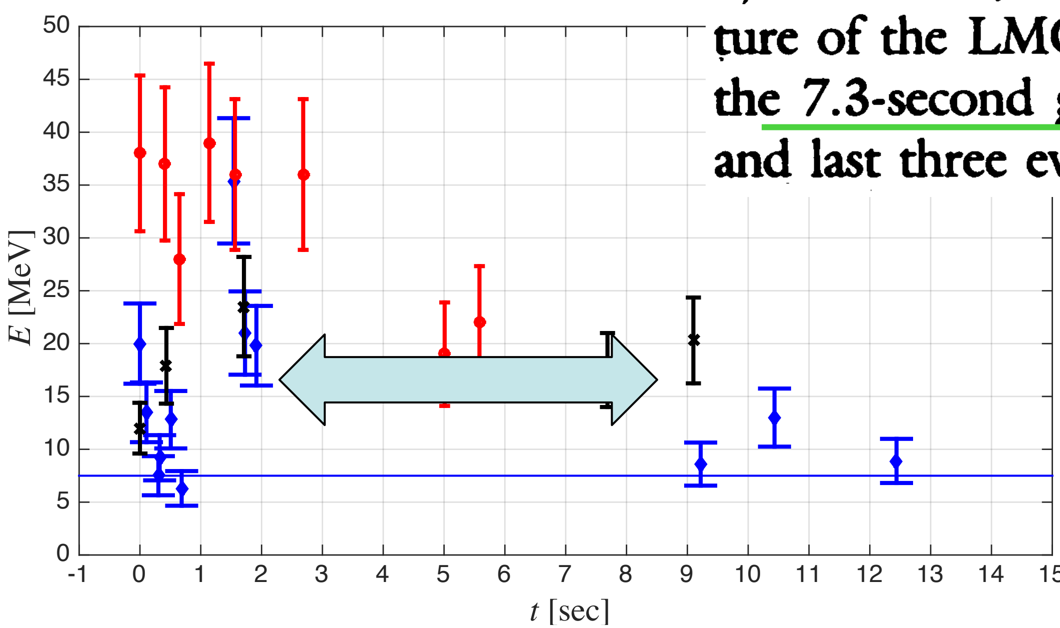
Kamiokande
IMB
Baksan
E [MeV]
t [sec]
50
45
40
35
30
25
20
15
10
5
0
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

A Simple Model for Neutrino Cooling of the Large Magellanic Cloud Supernova

D. N. Spergel, T. Piran, A. Loeb,* J. Goodman, J. N. Bahcall

A simplified analytic model of a cooling hot neutron star, motivated by detailed computer calculations, describes well the neutrinos detected from the recent supernova in the Large Magellanic Cloud. The observations do not require explanations that invoke exotic physics or complicated astrophysics. The parameters in this simple model are not severely constrained: $6.1^{+3.5}_{-3.6} \times 10^{52}$ ergs emitted in electron antineutrinos, a peak temperature of $4.2^{+1.2}_{-0.8}$ megaelectron volts, a radius of 27^{+17}_{-15} kilometers, and a cooling time of $4.5^{+1.7}_{-2.0}$ seconds.

The fluences and temperatures inferred from the neutrino observations were consistent with pre-supernova expectations (*6*, *7*). However, there is one unexpected feature of the LMC supernova neutrino data: the 7.3-second gap between the first eight and last three events in the Kamiokande II



Prog. Theor. Phys. Vol. 79, No. 4, April 1988, Progress Letters

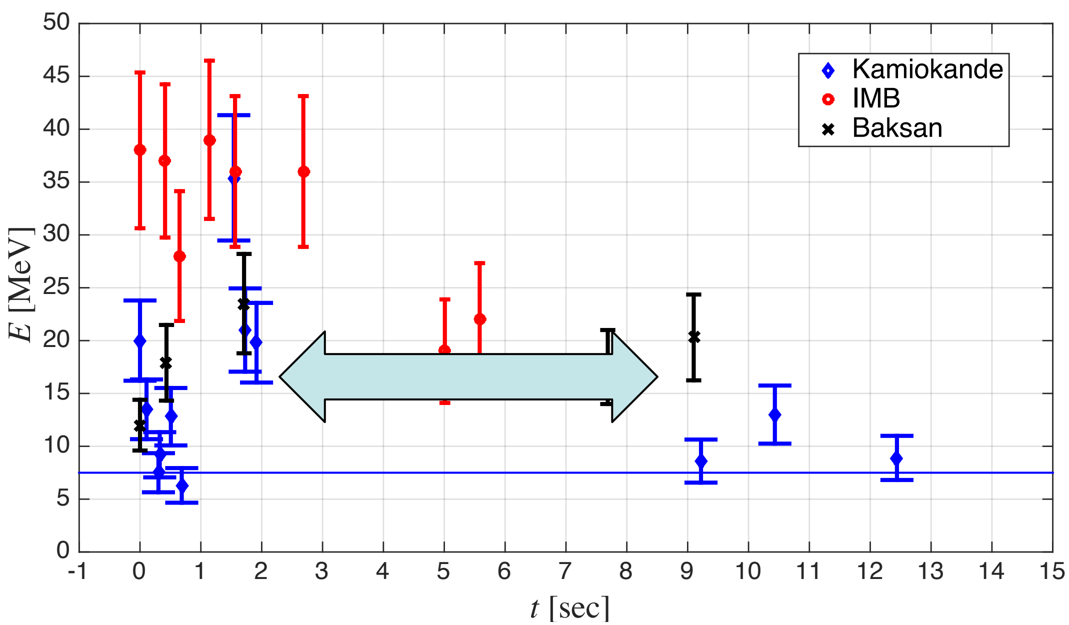
Statistical Analysis of the Neutrino Burst from SN1987A

Hideyuki SUZUKI and Katsuhiko SATO

Department of Physics, University of Tokyo, Tokyo 113

(Received January 19, 1988)

In order to clarify whether the Kamiokande data of the neutrino burst from SN1987A are explained by the "standard" cooling model of the supernova cores, we calculated the probability that the last three events are observed after a 7 second gap. It is obtained that the probability is at most 2%.

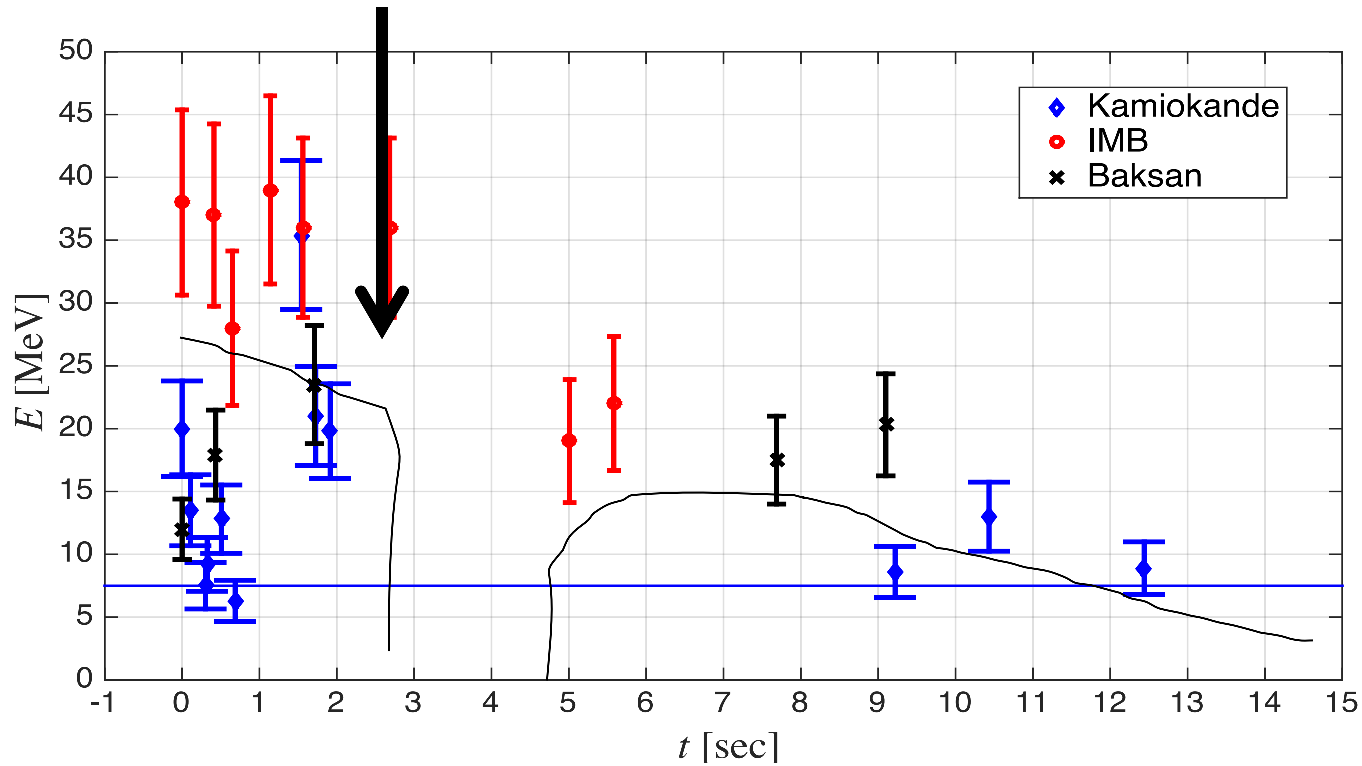


THE ASTROPHYSICAL JOURNAL, 730:70 (20pp), 2011 April 1 doi:10.1088/0004-637

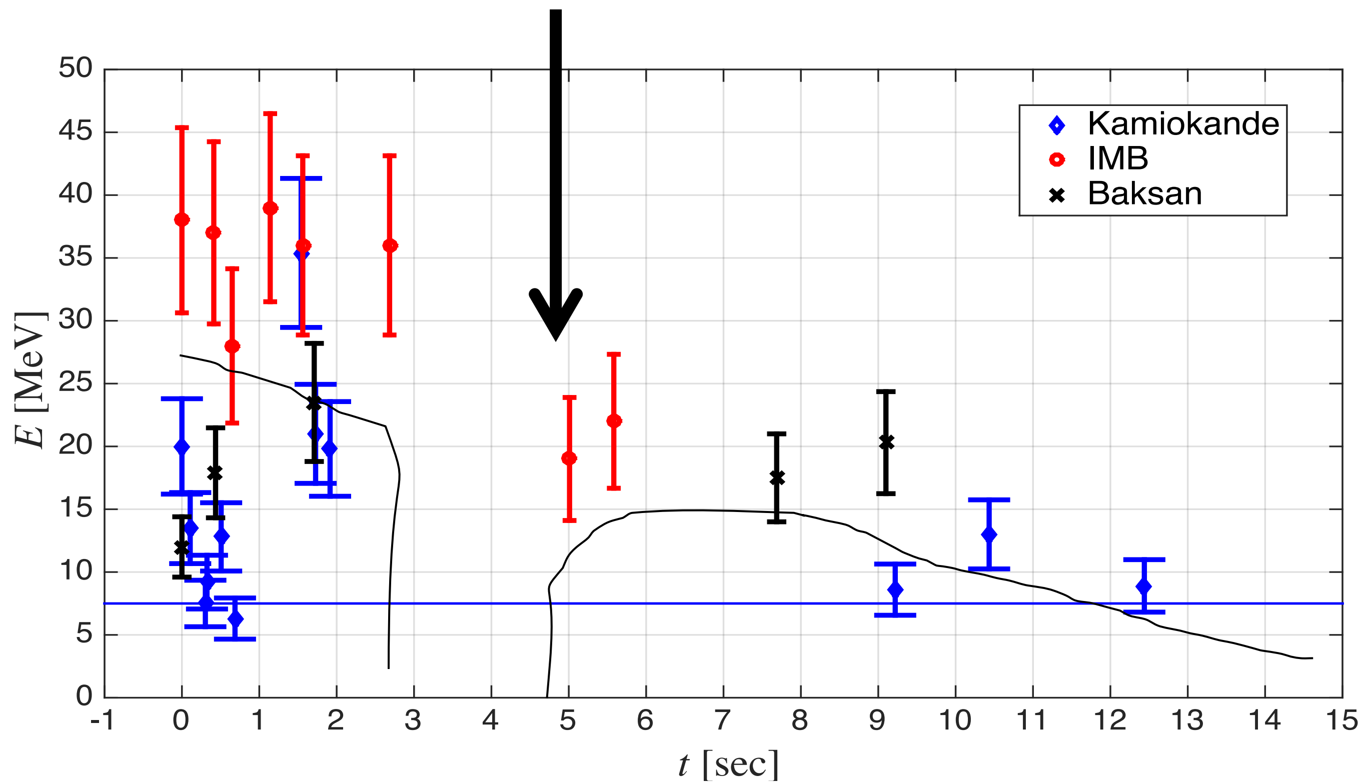
BLACK HOLE FORMATION IN FAILING CORE-COLLAPSE SUPERNOVAE

EVAN O'CONNOR AND CHRISTIAN D. OTT
TAPIR, Mailcode 350-17, California Institute of Technology, Pasadena, CA 91125, USA; evanoc@tapir.caltech.edu, cott@tapir.caltech.edu
Received 2010 October 26; accepted 2011 January 10; published 2011 March 7

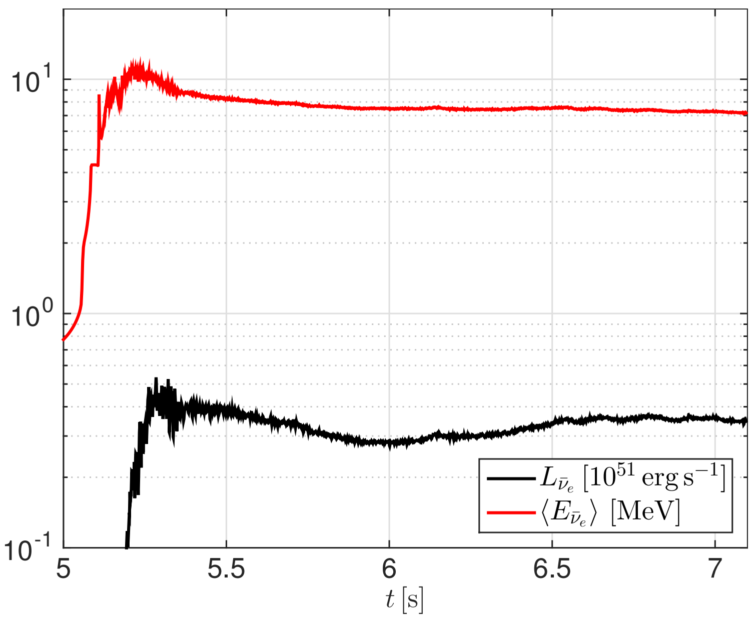
t_{BH} ~ 1-3 sec

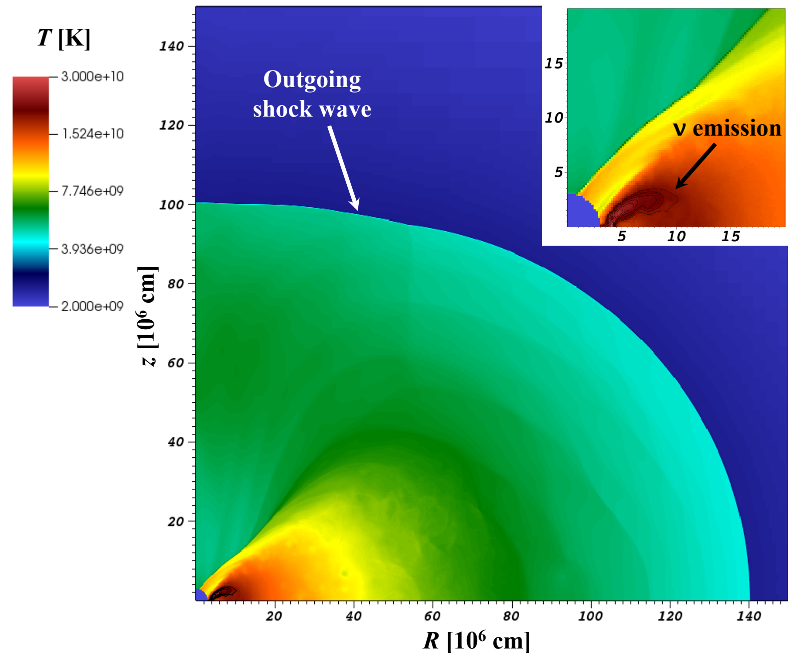


$$t_{disc} \approx 2t_{ff}(r_f) = \pi\sqrt{\frac{r_f^3}{2GM(r_f)}}.$$



Blum & **Kushnir, 1601.03422**





$$t_{disc} \approx 2t_{ff}(r_f) = \pi\sqrt{\frac{r_f^3}{2GM(r_f)}}$$

<u>Collapse-induced thermonuclear explosion **(CITE)**</u>:

Kushnir, 1506.02655

Kushnir, 1502.03111

Kushnir & Katz, ApJ. 811 (2015) no.2, 97

Burbidge et al, Rev. Mod. Phys. 29, 547 (**1957**)

Hoyle & Fowler, ApJ 132, 565 (**1960**)

Fowler & Hoyle, ApJS 9, 201 (**1964**)

Neutrino burst of core-collapse SN1987A traditionally used to set a bound on axions

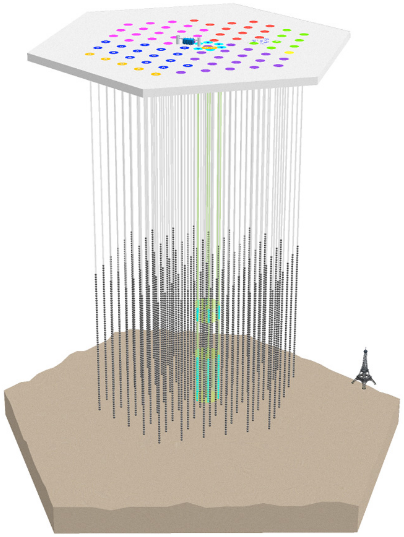
Do we understand CCSNe well enough?

Stay tuned for searches for diffuse CCSNe background.

If we're lucky a Galactic CCSNe

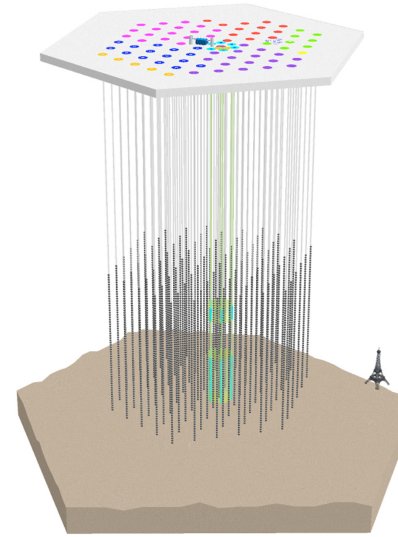
Li, et al, Int.J.Mod.Phys.Conf.Ser. 31 (2014) 1460300 (JUNO)

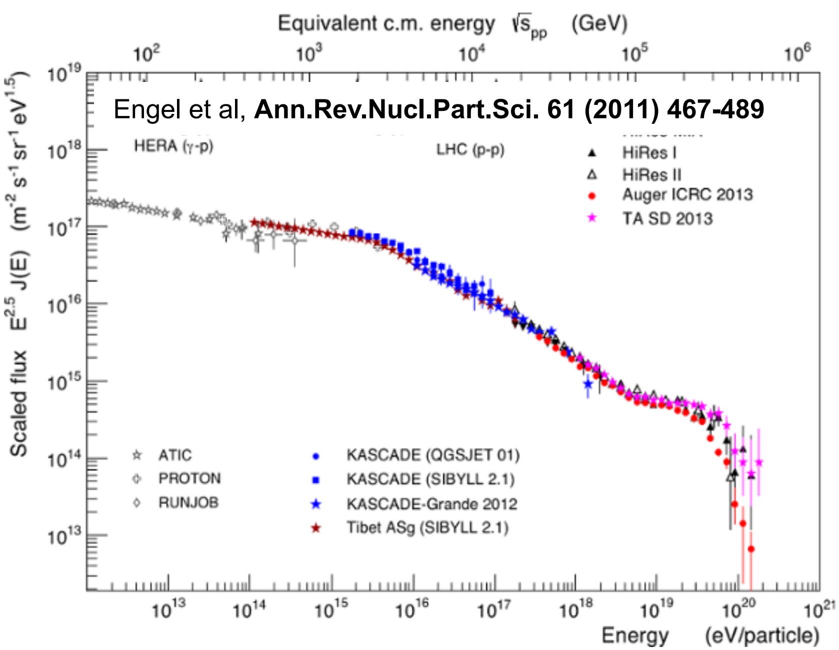
IceCube's neutrinos
(session IV)

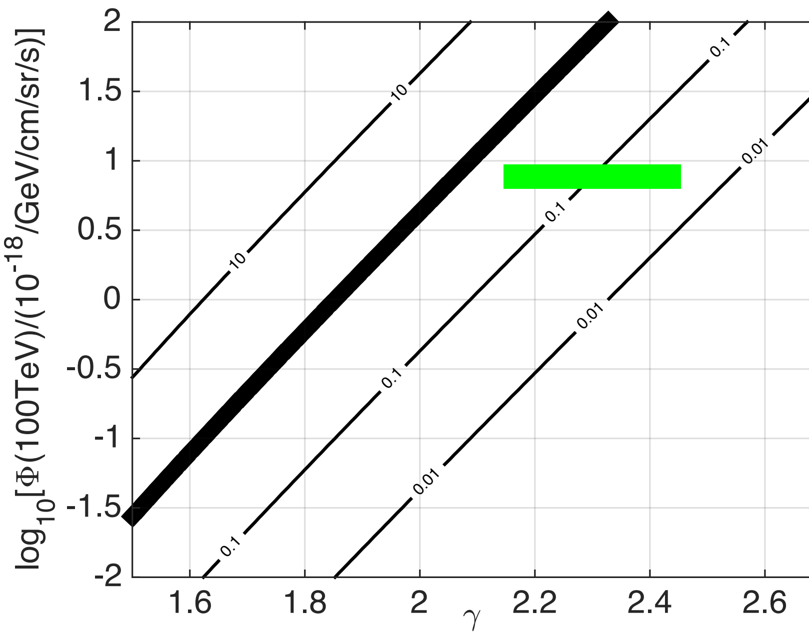


IceCube's neutrinos vs. UHECR

(session IV)



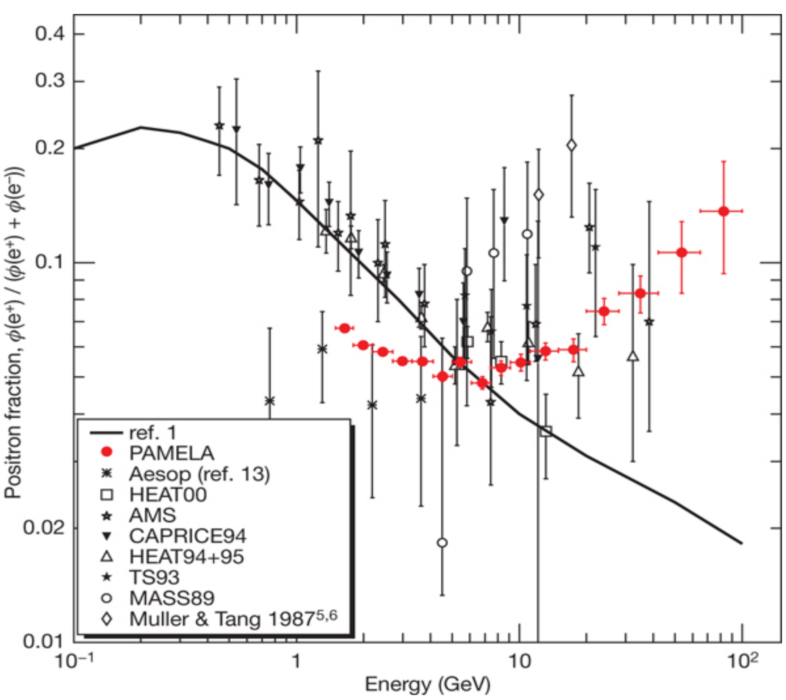


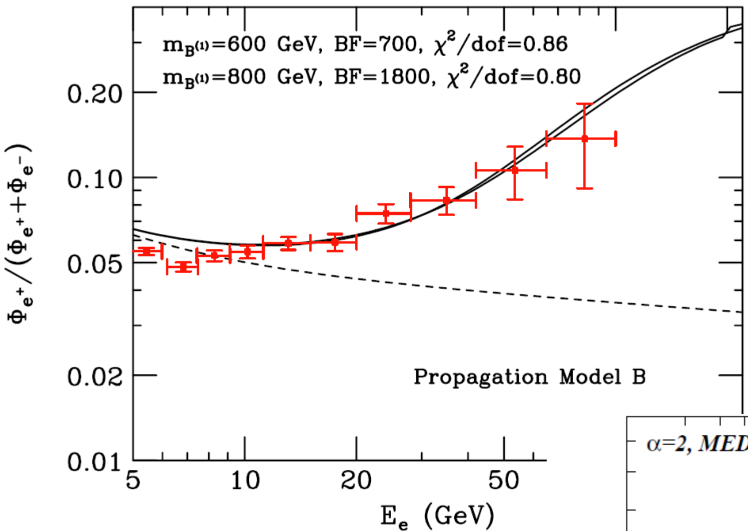


Cosmic ray antimatter

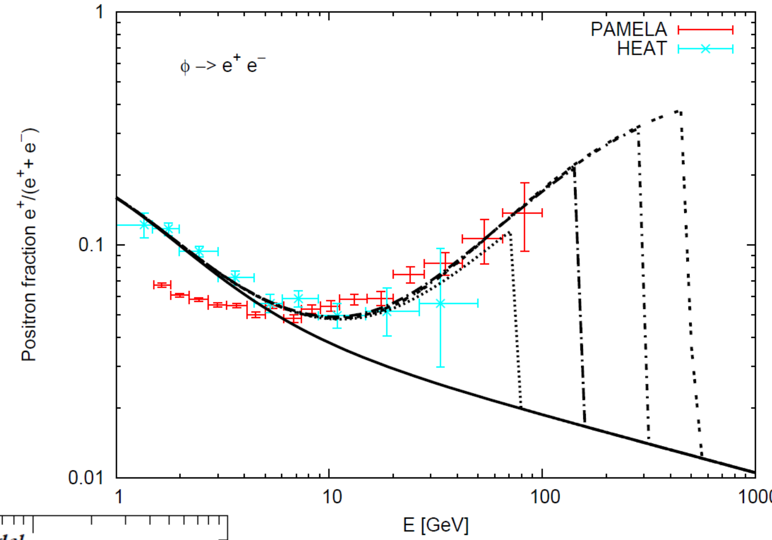
Cosmic ray antimatter

PAMELA (2009) **positron anomaly?**

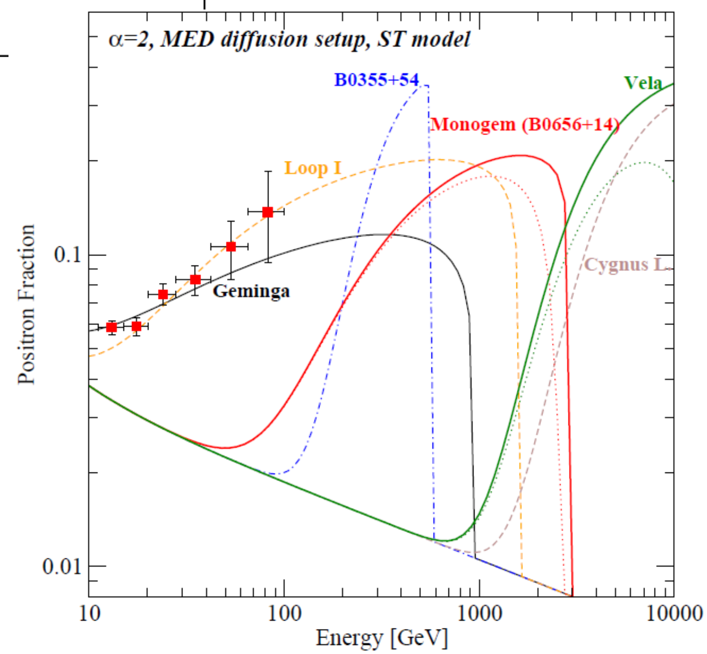




m_B(1)=600 GeV, BF=700, χ²/dof=0.86
m_B(1)=800 GeV, BF=1800, χ²/dof=0.80
Propagation Model B
0.20
0.10
0.05
0.02
0.01
5
10
20
50
E_e (GeV)
Φ_e+/(Φ_e+ + Φ_e−)



PAMELA
HEAT
φ –> e⁺ e⁻
Positron fraction e⁺/(e⁺+e⁻)
1
0.1
0.01
1
10
100
1000
E [GeV]

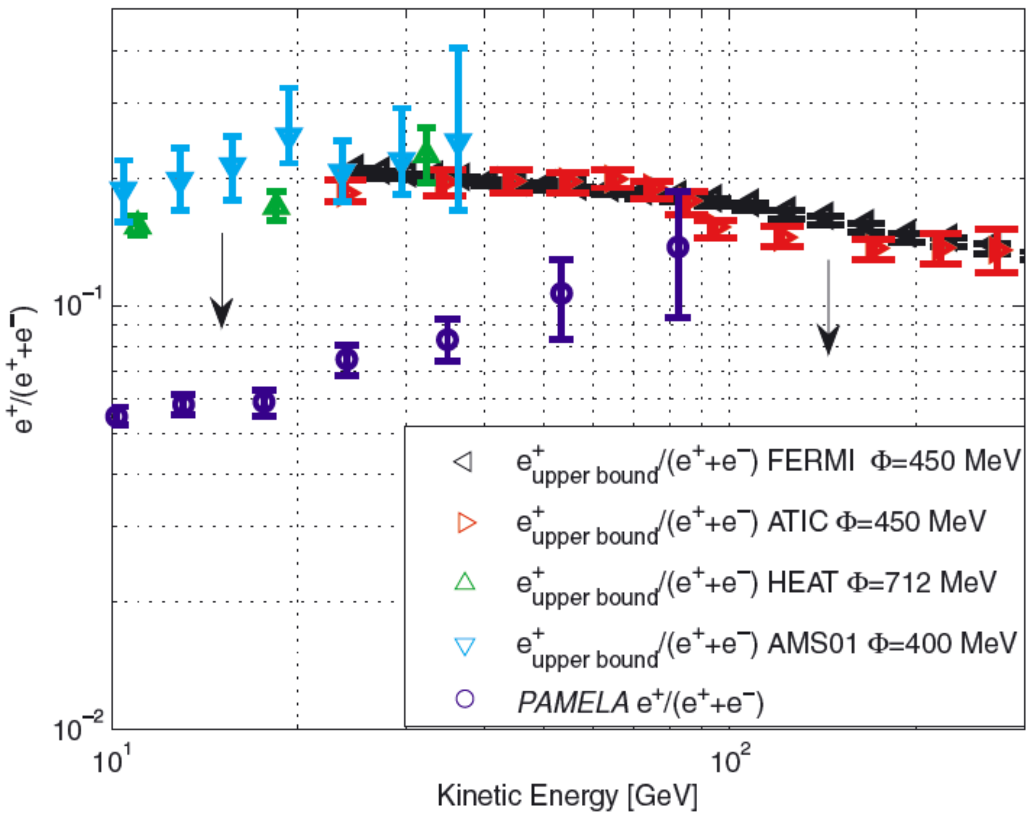


α=2, MED diffusion setup, ST model
B0355+54
Vela
Monogem (B0656+14)
Loop I
Geminga
Cygnus L
Positron Fraction
0.1
0.01
10
100
1000
10000
Energy [GeV]

PAMELA (2009)

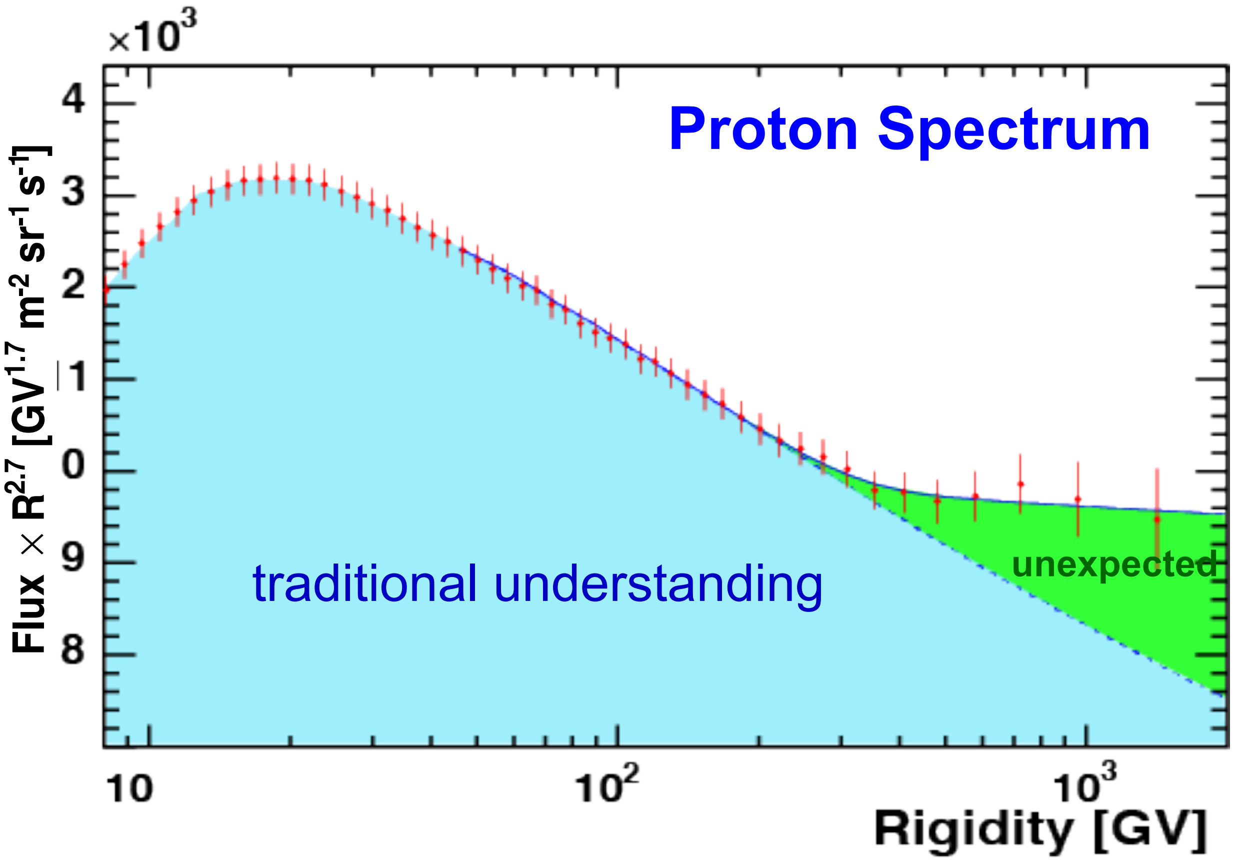
Despite many claims in the literature: consistent with known constraints.

(session II-III)



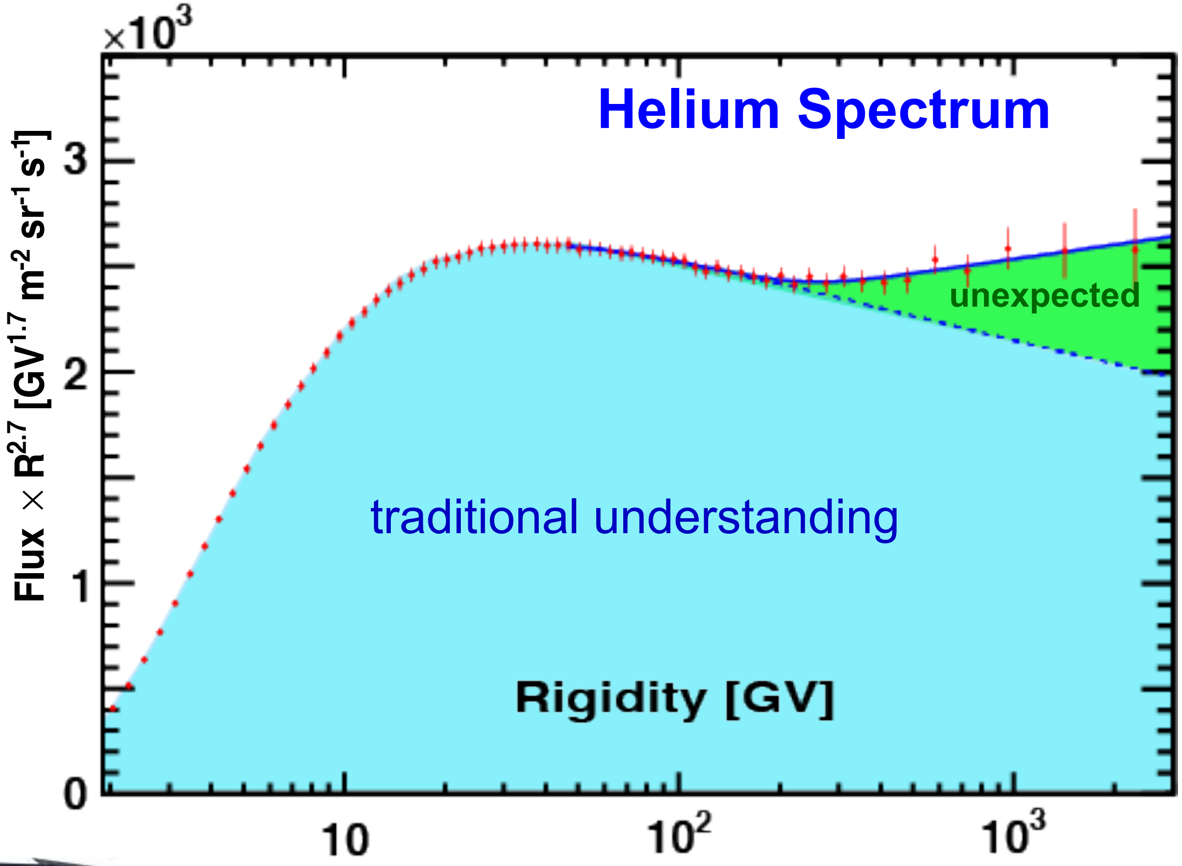
Katz, Blum, Waxman, **MNRAS 405 (2010) 1458**

Some results from AMS02:



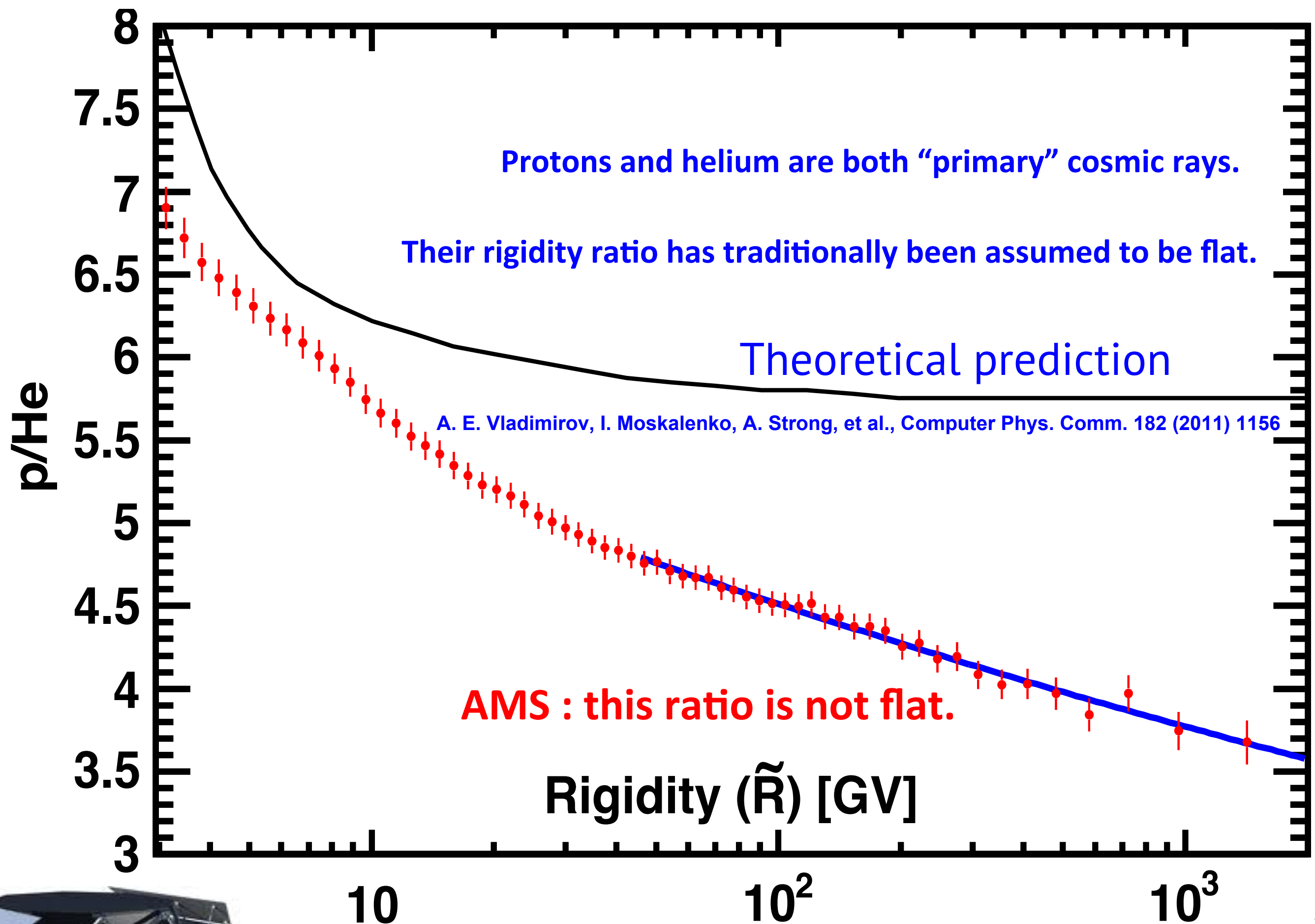
S. Schael, **Moriond 2016 for AMS02**

Some results from AMS02:



S. Schael, **Moriond 2016 for AMS02**

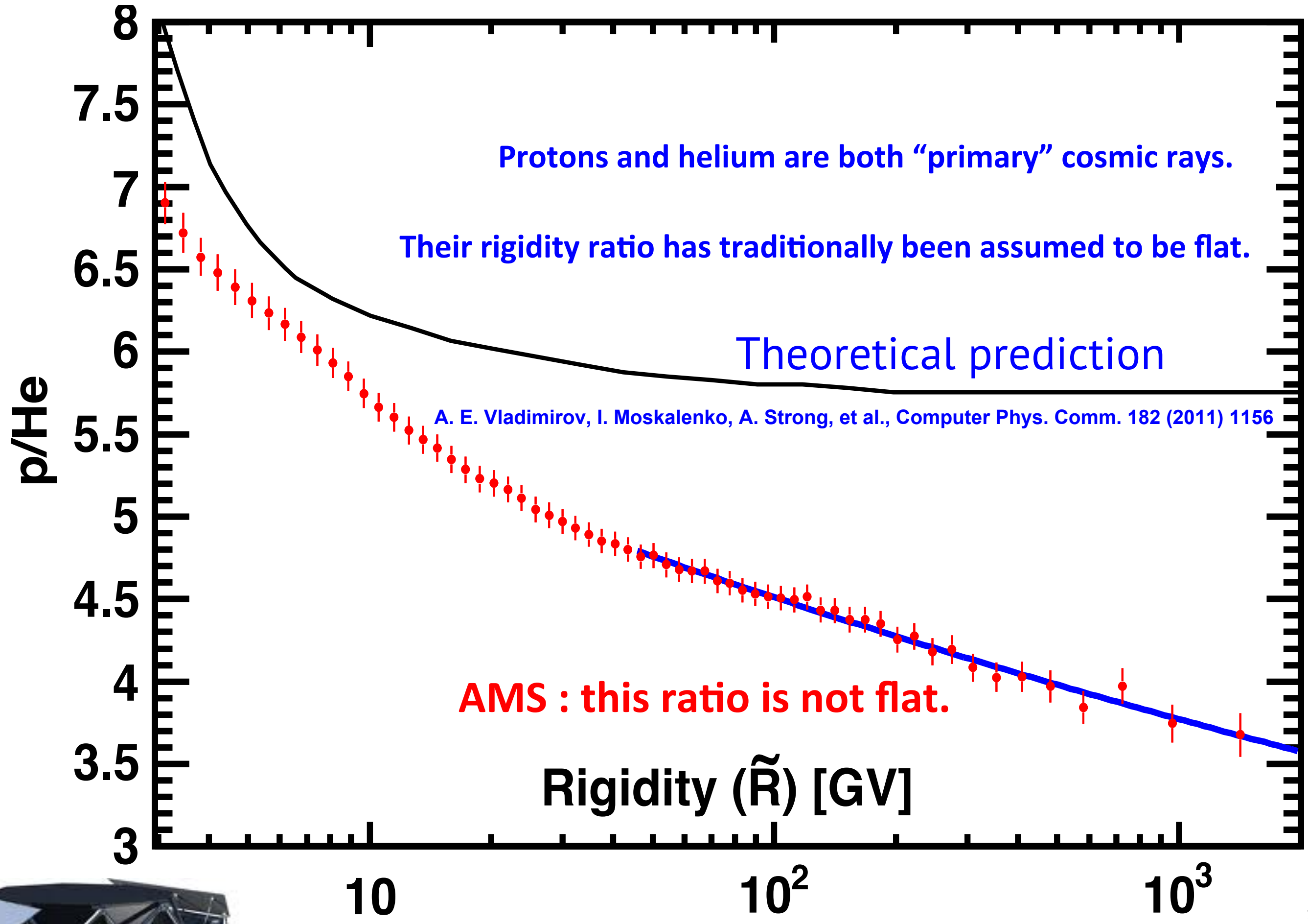
Some results from AMS02:



S. Schael, **Moriond 2016 for AMS02**

Some results from AMS02:

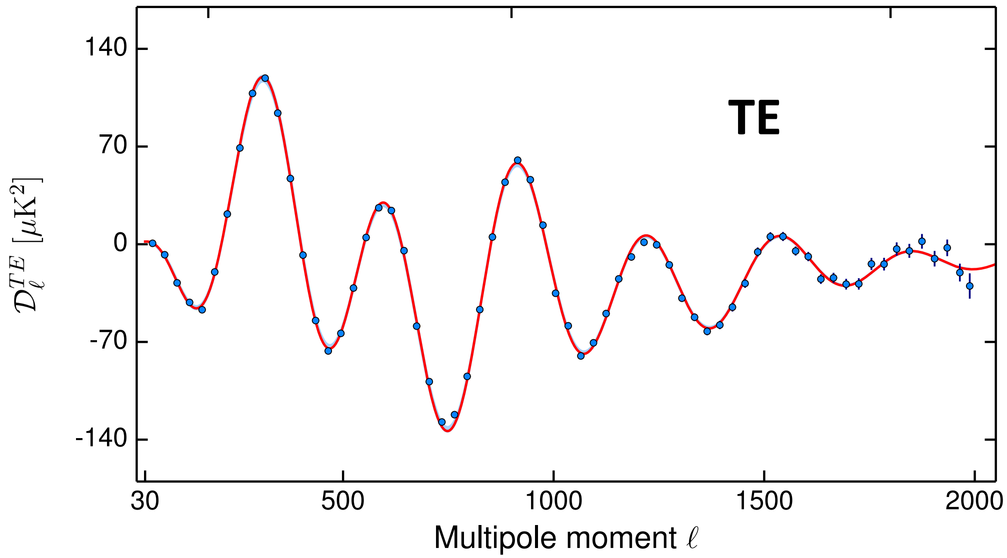
Also expect: CALET (Marrocchesi, 1512.08059), ISS-CREAM (2017?)



To be clear:
p & He are *primary* CRs: the heart of the beast.

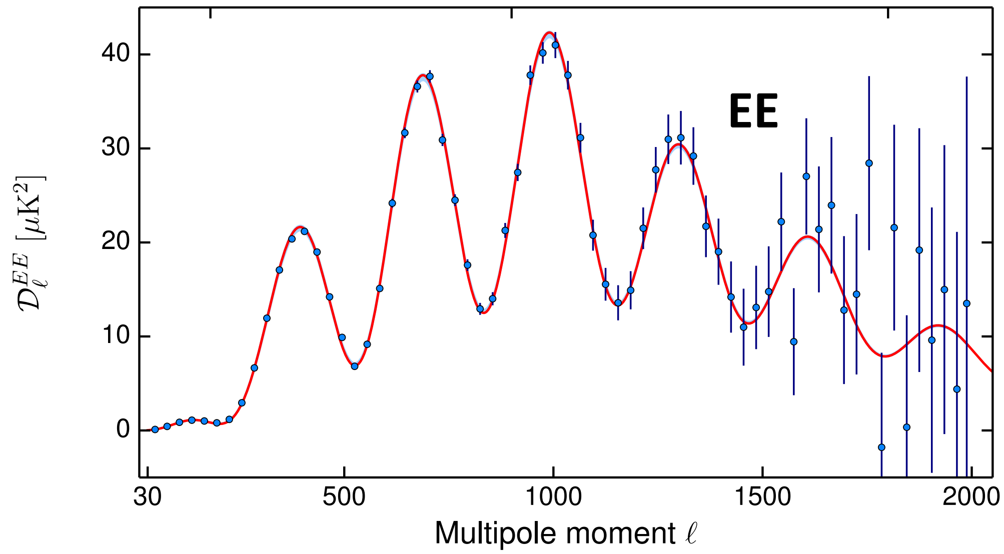
Precision cosmology

Precision cosmology



Planck 2015

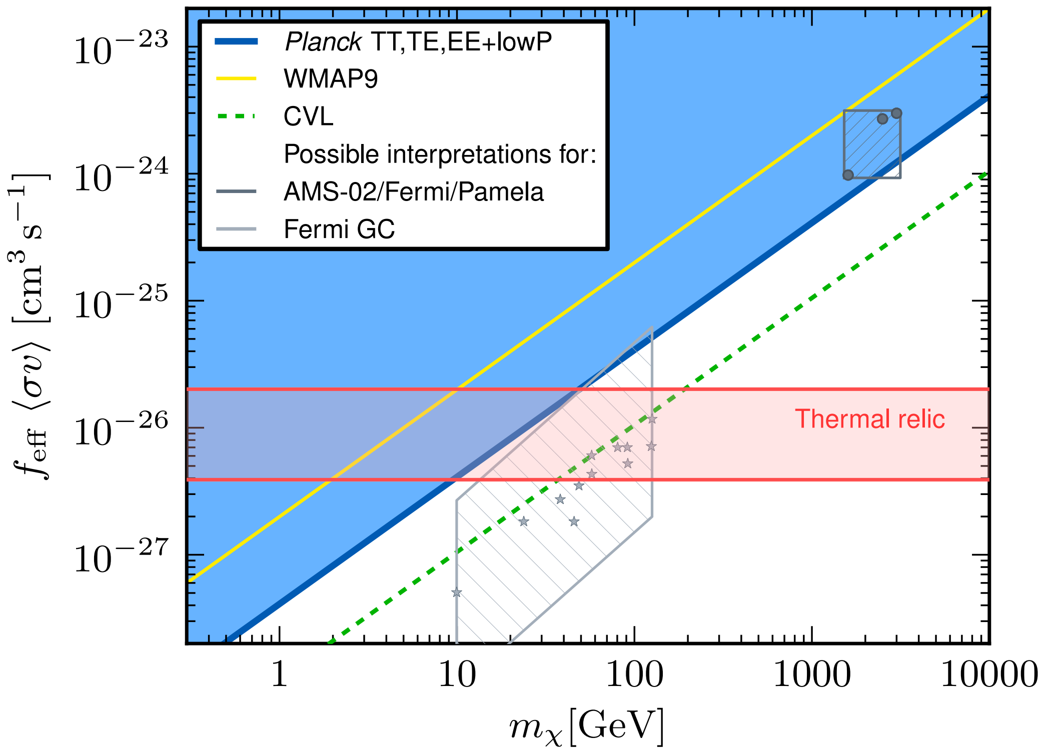
1502.01589



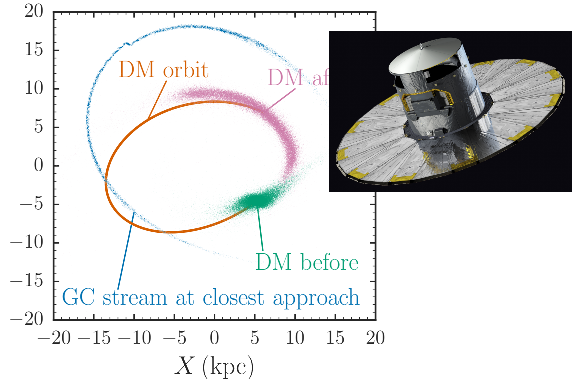
Planck 2015

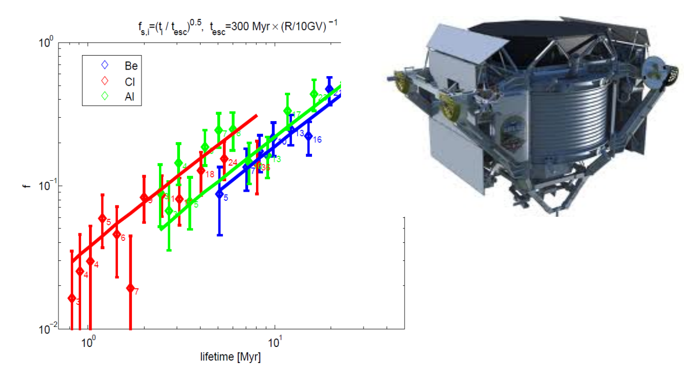
Constraints on dark matter annihilation

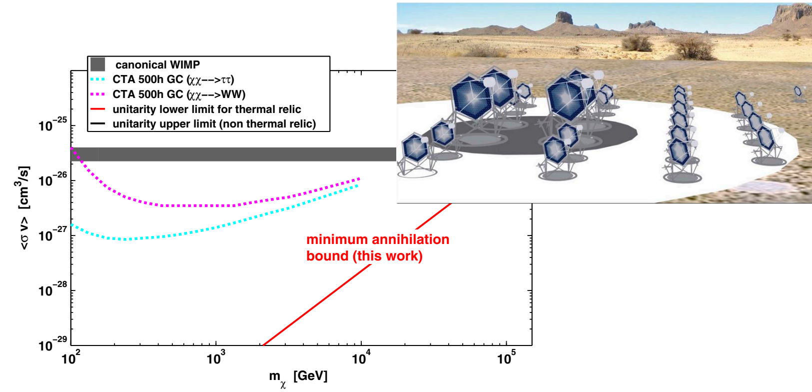
(session V)

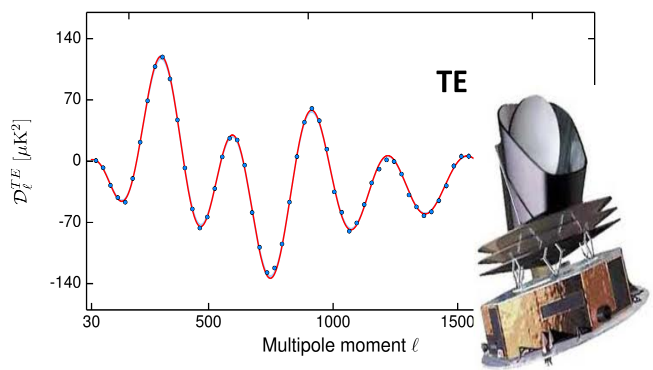


Thank you!

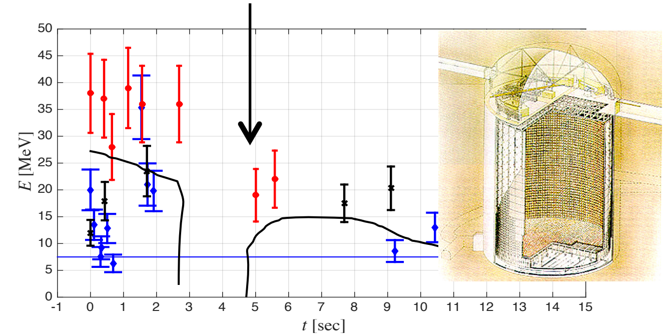








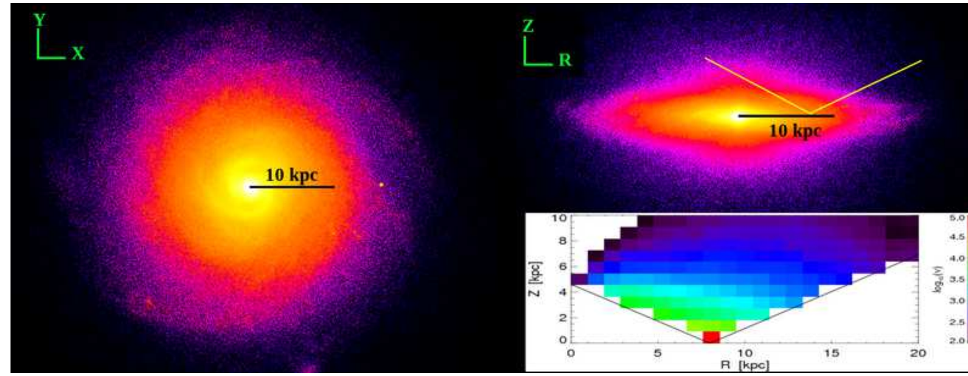
$$t_{disc} \approx 2t_{ff}(r_f) = \pi\sqrt{\frac{r_f^3}{2GM(r_f)}}.$$

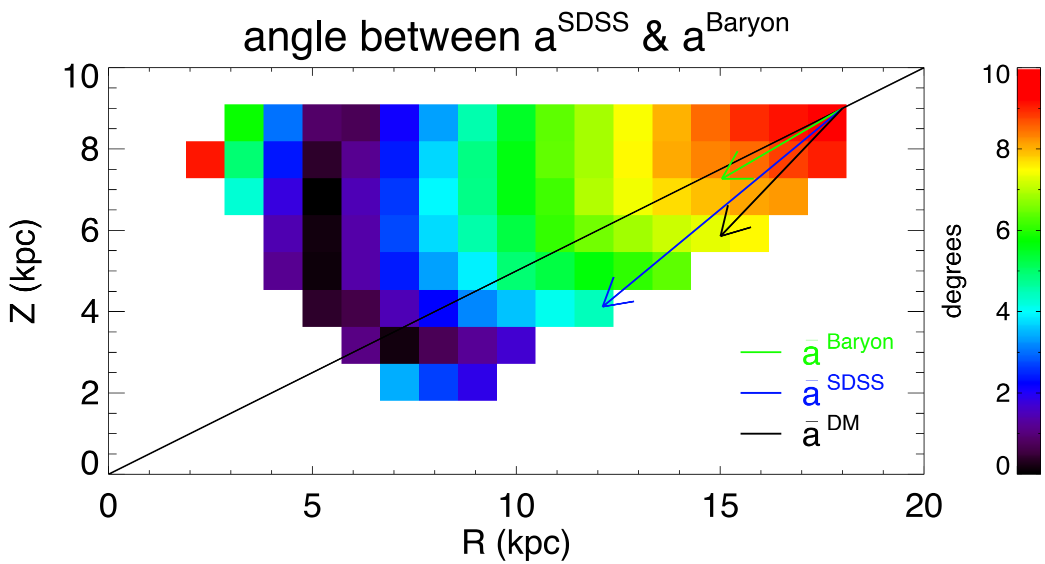


Xtras

SDSS kinematics of MW halo stars

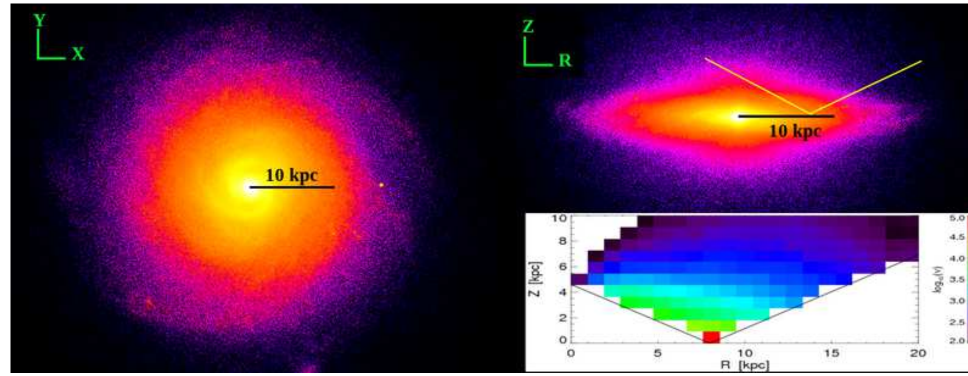
Loebman, et al, **ApJ. 794 (2014) no.2, 151**
Bovy & Rix, ApJ. 779 (2013) 115
Piffl et al, MNRAS 445 (2014) no.3, 3133-3151 (RAVE)





SDSS kinematics of MW halo stars

Loebman, et al, **ApJ. 794 (2014) no.2, 151**
Bovy & Rix, ApJ. 779 (2013) 115
Piffl et al, MNRAS 445 (2014) no.3, 3133-3151 (RAVE)

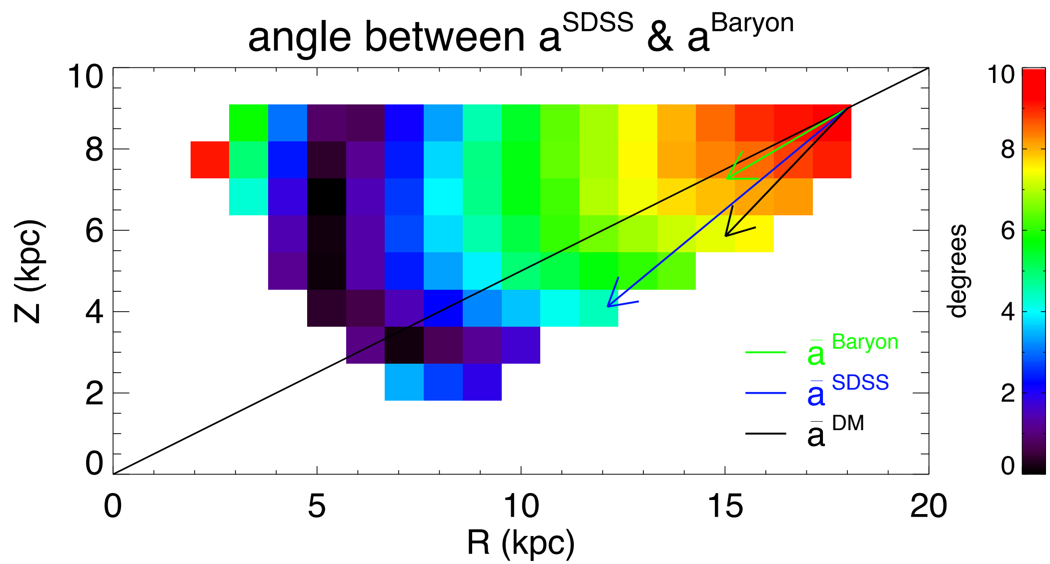


Oblate DM halo?

Testing MOND?

but note

Milgrom, PRD92 (2015) no.4, 044014



Gaia (2016)

Ivezic', Beers, Juric', ARA&A 2012. 50:251-304
http://www.cosmos.esa.int/web/gaia/release

Why Lt = NS binding energy?

Roughly speaking, this is expected in CITE just as well.

The initial phase – PNS accretion luminosity – is the same
in NM and in CITE.

CITE predicts this phase goes on longer ➔ O(1) more energy.
But then again nobody predicts any of this to better than O(1).

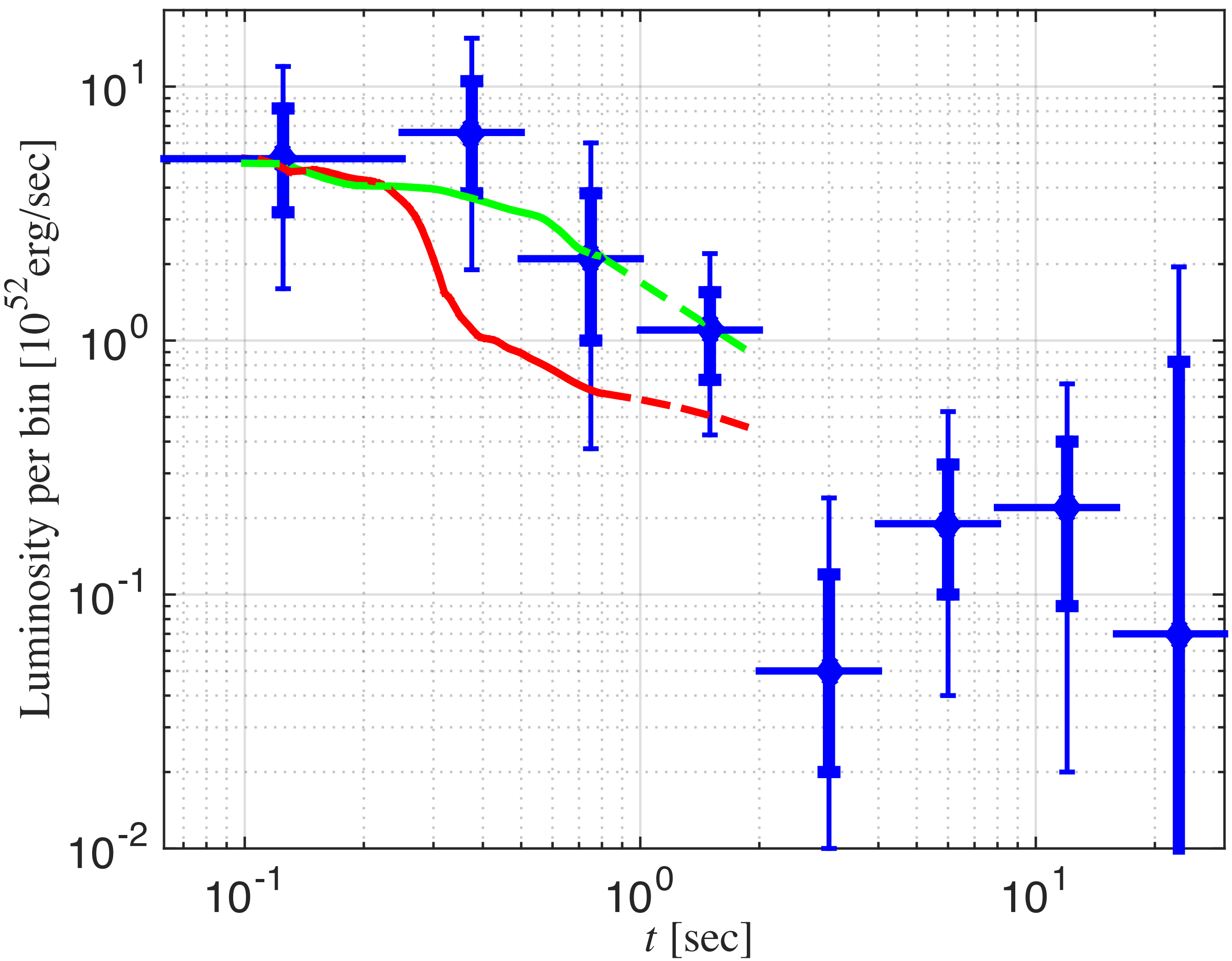
…compare simulations of the early PNS phase to the data.

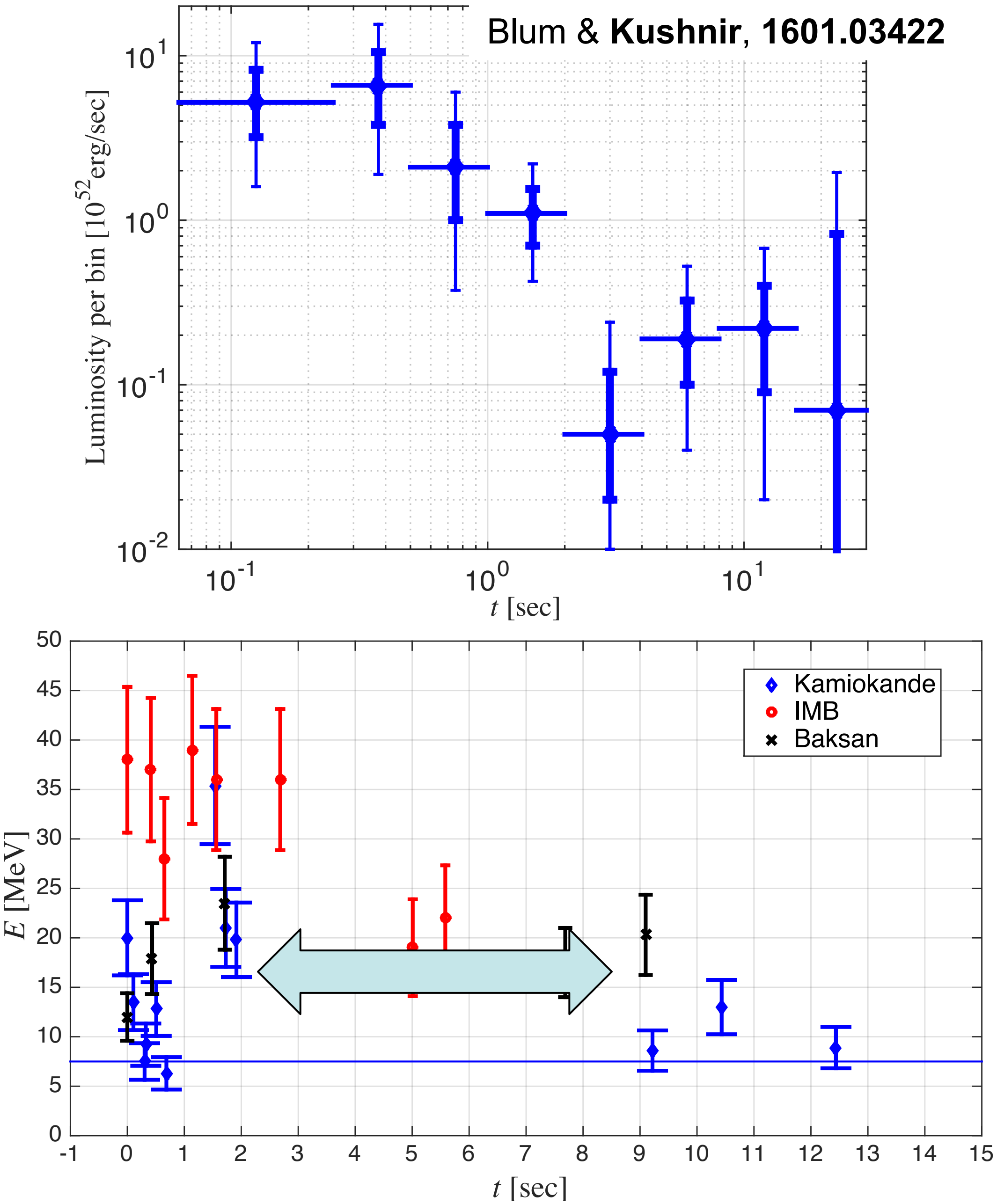
numerical simulations: e.g. Perego et al, **Astrophys.J. 806 (2015) 2, 275** (1D)

Red: "PUSH"

Green: "No PUSH"

➔ early phase <1-2 sec can't tell NM vs. CITE





Blum & Kushnir, 1601.03422
Luminosity per bin [10^52 erg/sec]
t [sec]
Kamiokande
IMB
Baksan
E [MeV]
t [sec]

A Simple Model for Neutrino Cooling of the Large Magellanic Cloud Supernova

D. N. Spergel, T. Piran, A. Loeb,* J. Goodman, J. N. Bahcall

A simplified analytic model of a cooling hot neutron star, motivated by detailed

- Not enough statistics
- Simple NS cooling works fine (but mind the gap?)

Sure. We have about ~2sigma, no more.

Thing to keep in mind:

CITE may give an alternative where a gap is natural.

Gamma rays from WIMP annihilation:

Annihilation rate density in Galactic halo $Q_\chi = \rho_\chi^2 \langle \sigma v \rangle_h / (4 m_\chi^2)$

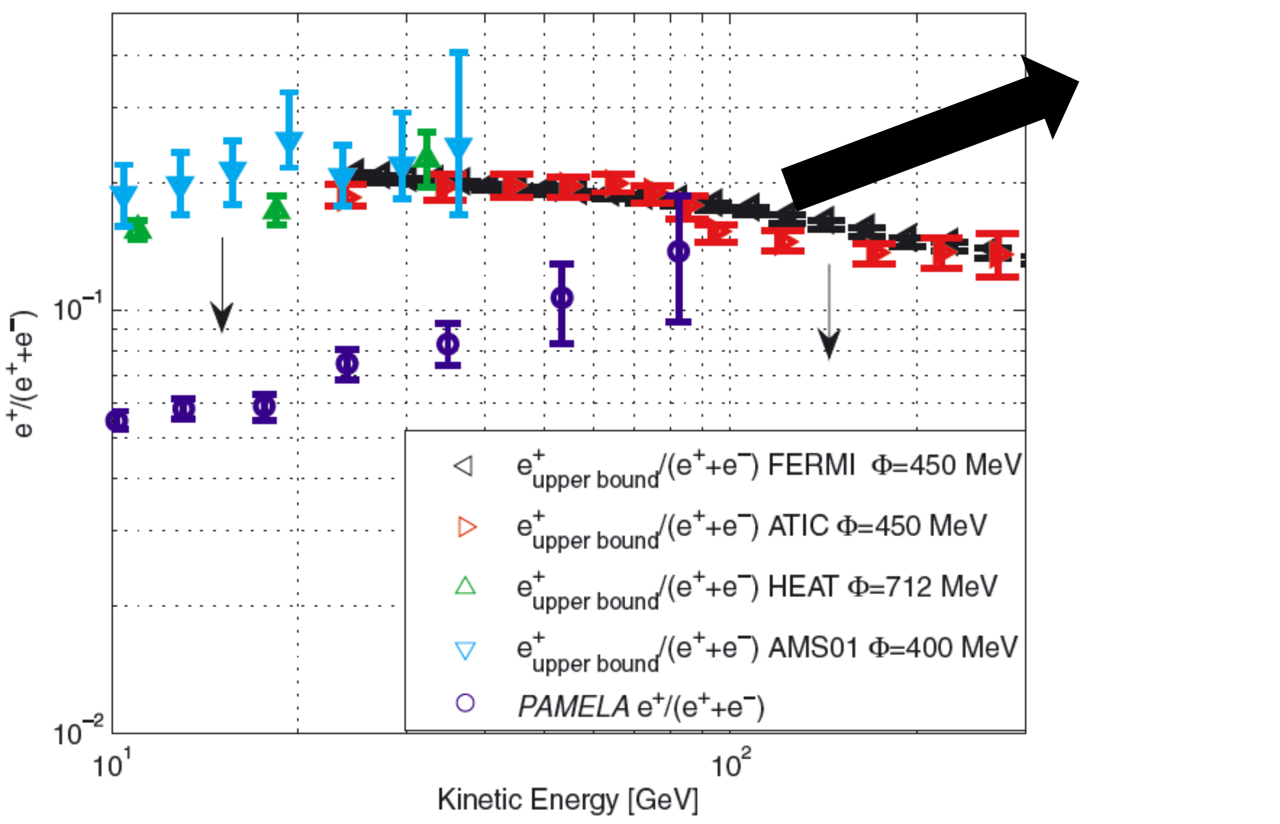
Unitarity says: $Q_\chi \geq \frac{\rho_h^2 (\langle \sigma v \rangle_0)^2}{16\pi \langle v^{-1} \rangle_{\rm fo}}$

Annihilation rate density limit is independent of M.

$$J_\gamma(E_\gamma) = \int_{\Delta\Omega} \frac{d\Omega}{4\pi} \int dr Q_\chi(r) \frac{dN}{dE_\gamma} \geq \frac{\bar{J} (\langle \sigma v \rangle_0)^2}{64\pi^2 \langle v^{-1} \rangle_{\rm fo}} \frac{dN}{dE_\gamma}$$

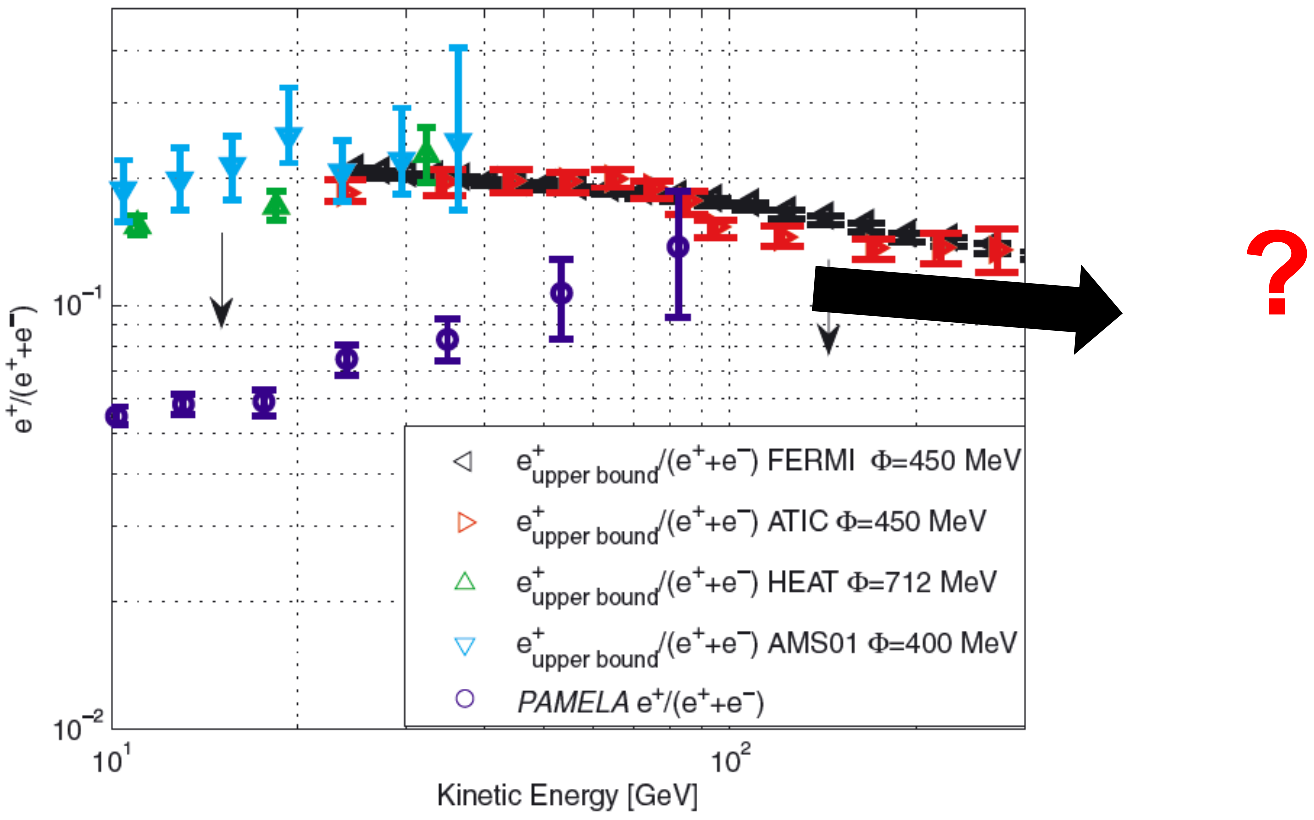
$$\bar{J} = \int_{\Delta\Omega} d\Omega \int dr \rho_h^2$$

AMS02



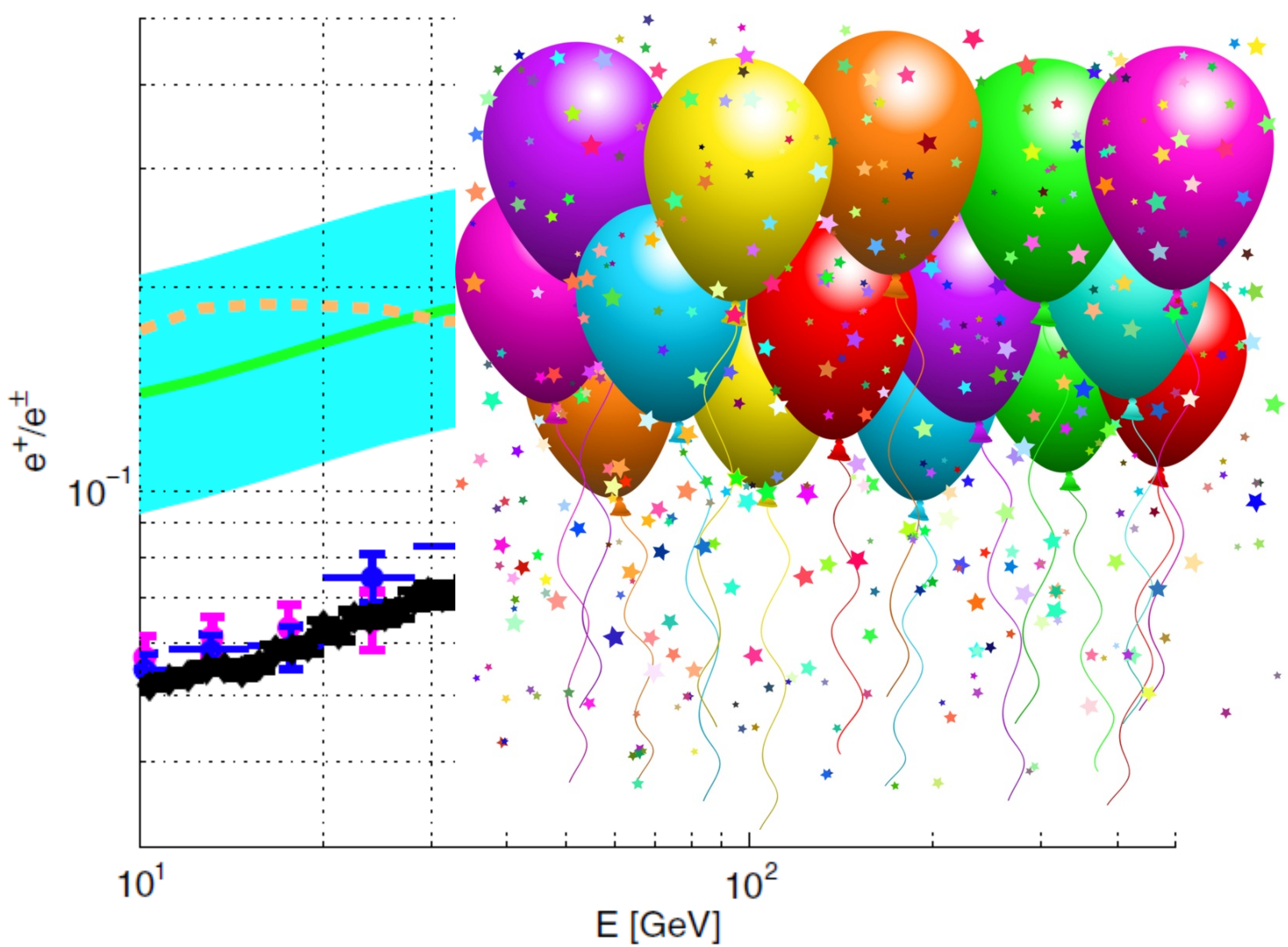
$e^+_{upper\ bound}/(e^++e^-)$ FERMI Φ=450 MeV
$e^+_{upper\ bound}/(e^++e^-)$ ATIC Φ=450 MeV
$e^+_{upper\ bound}/(e^++e^-)$ HEAT Φ=712 MeV
$e^+_{upper\ bound}/(e^++e^-)$ AMS01 Φ=400 MeV
PAMELA $e^+/(e^++e^-)$
$e^+/(e^++e^-)$
10^{-1}
10^{-2}
10^1
10^2
Kinetic Energy [GeV]
?

AMS02

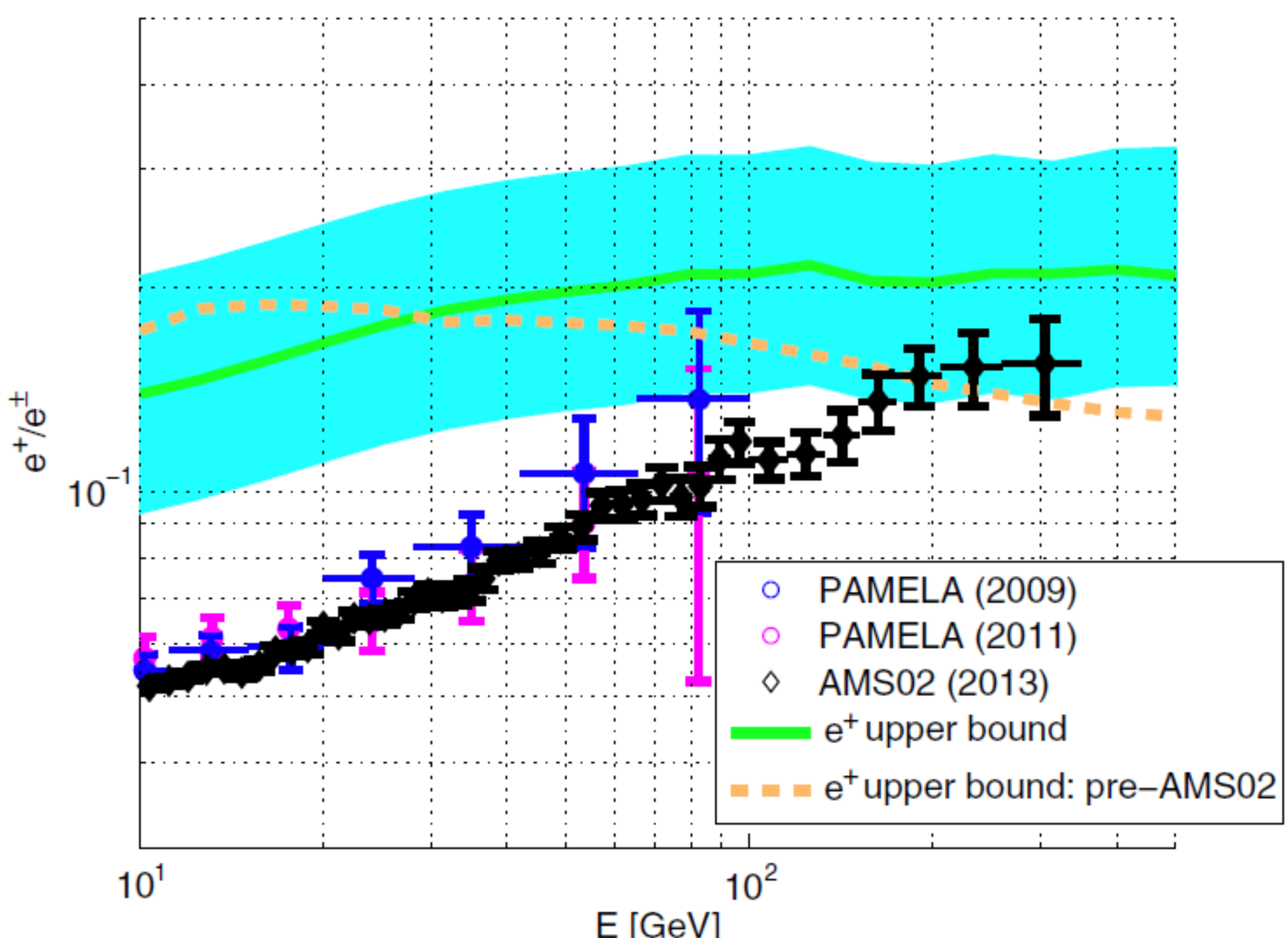


10^-1
10^-2
10^1
10^2
e+/(e++e−)
Kinetic Energy [GeV]
e+ upper bound/(e++e−) FERMI Φ=450 MeV
e+ upper bound/(e++e−) ATIC Φ=450 MeV
e+ upper bound/(e++e−) HEAT Φ=712 MeV
e+ upper bound/(e++e−) AMS01 Φ=400 MeV
PAMELA e+/(e++e−)
?

AMS02 (2013)

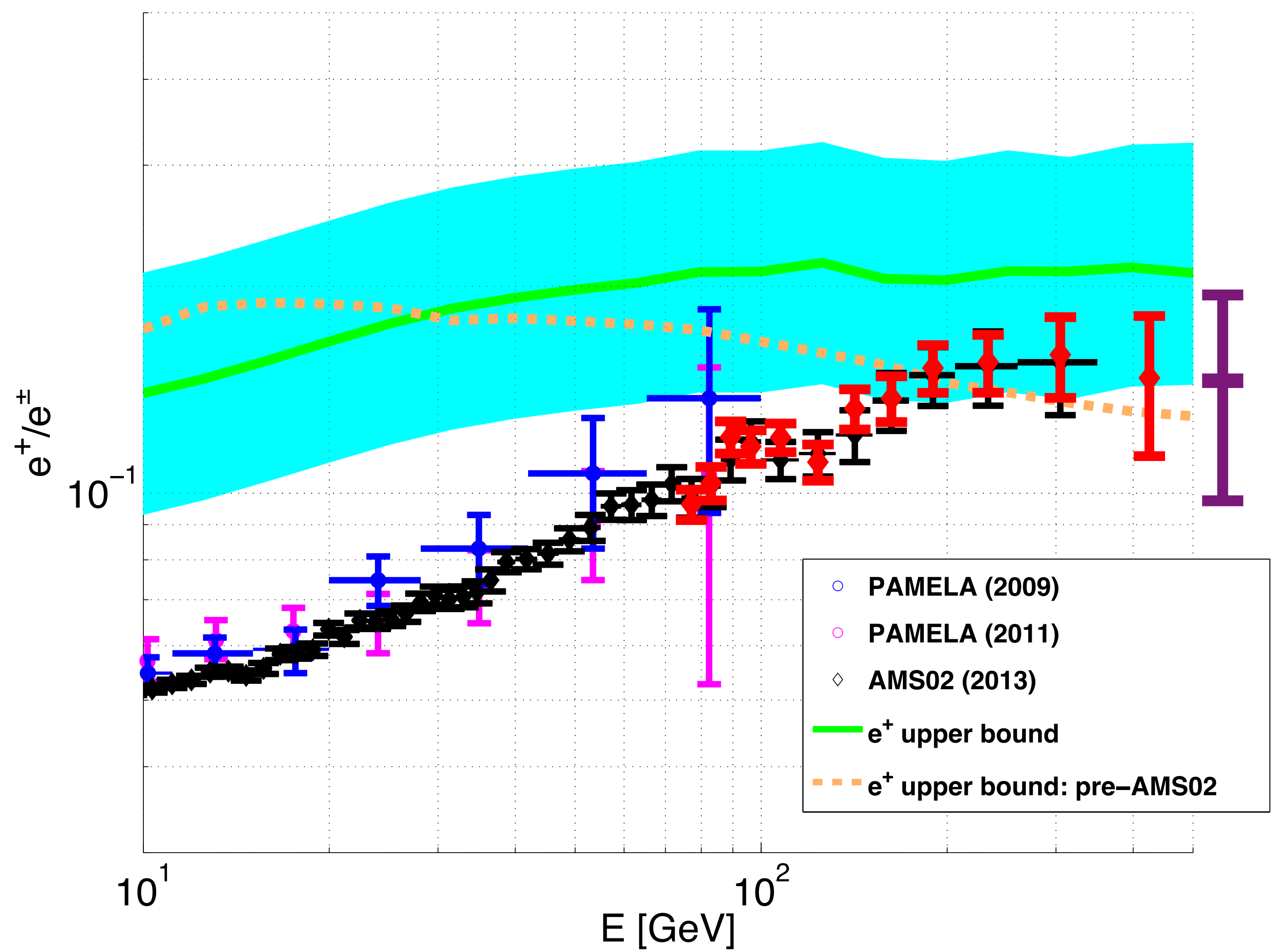


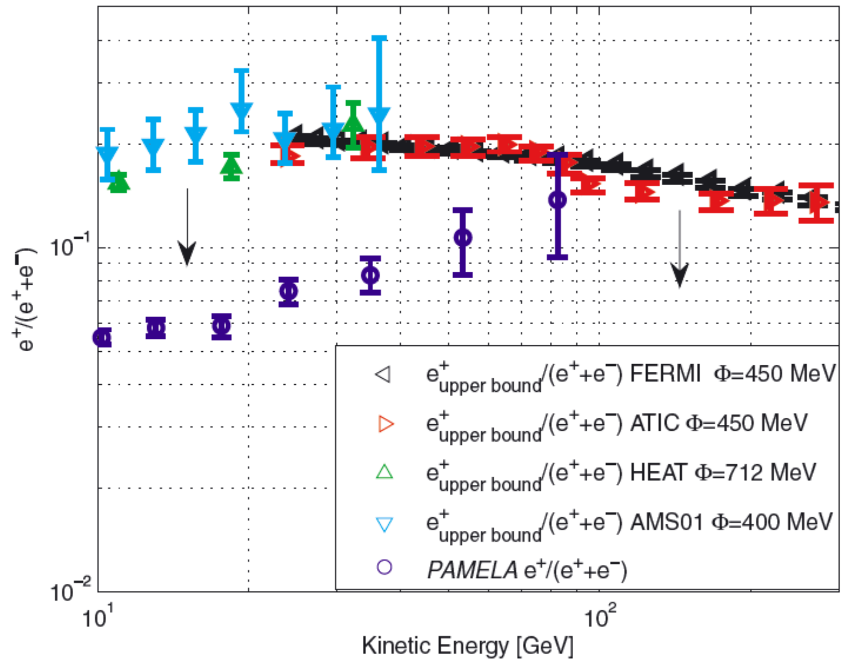
AMS02 (2013)



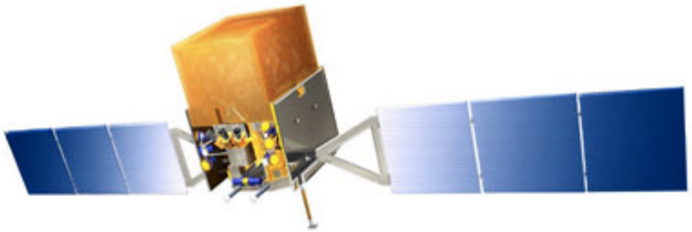
Blum, Katz, Waxman, **PRL 111, 211101 (2013)**

AMS02 (2014 I+II) (last error bar: my rough estimate)



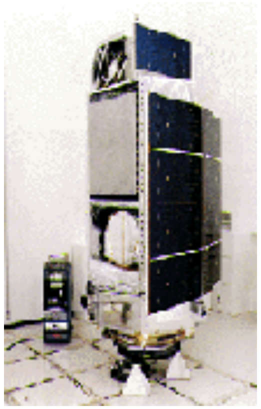


What we had to do before AMS02:



+

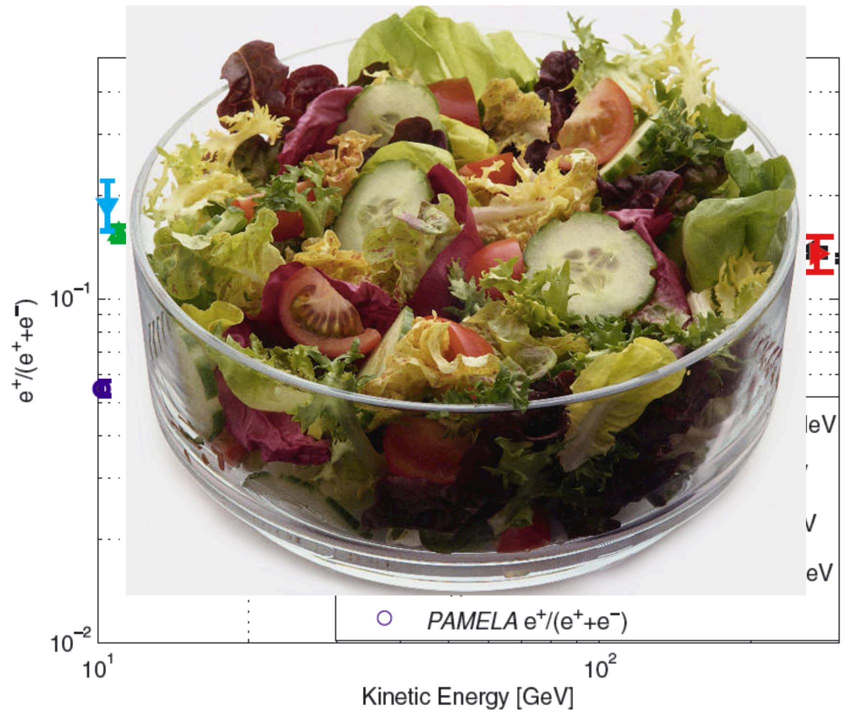
+



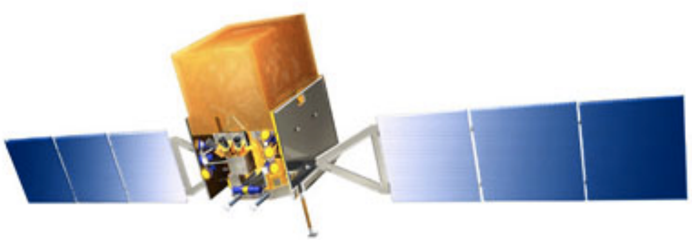
total e±

e+/e±, p, He

B/C



What we had to do before AMS02:



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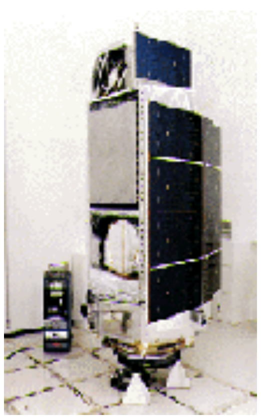


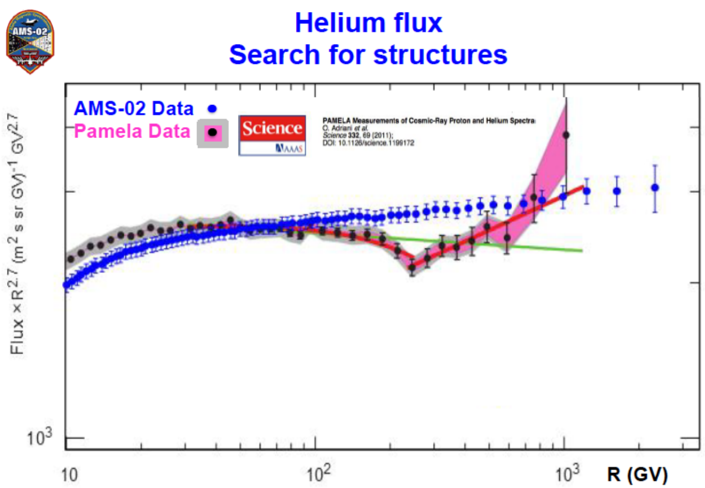
total e±

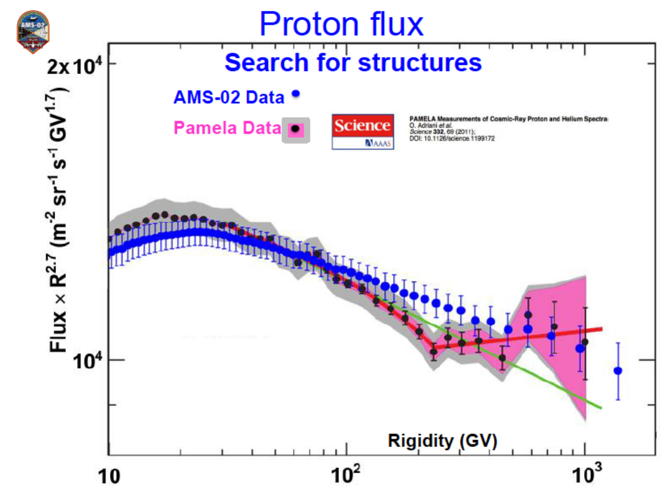
e+/e±, p, He

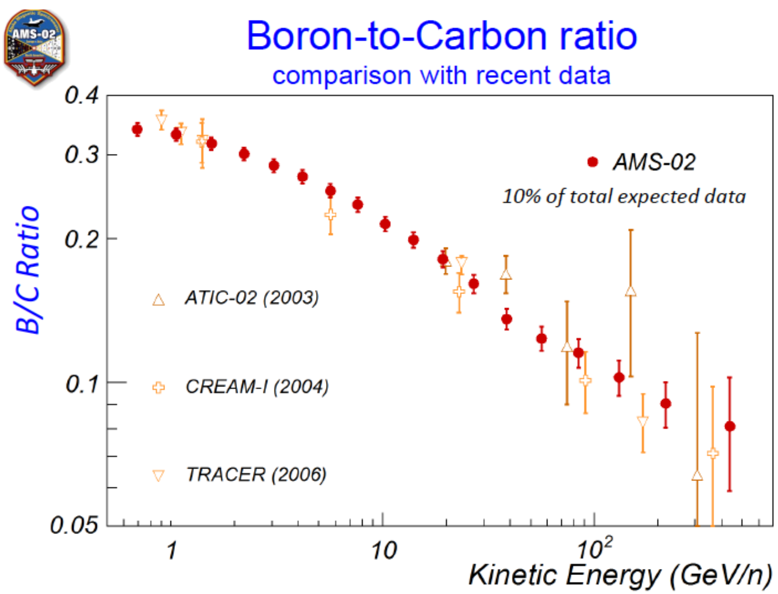
B/C

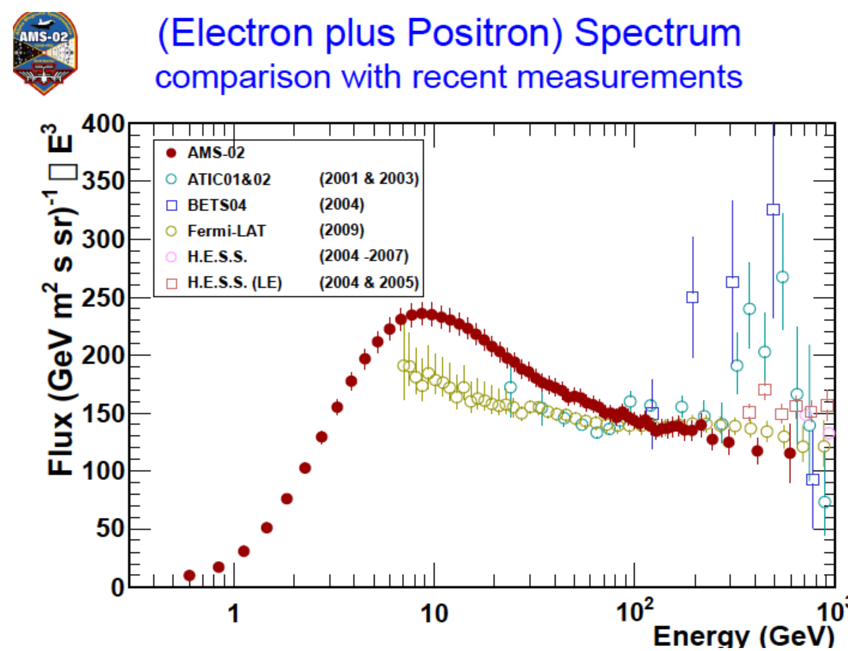
AMS02 update (2013)

For the first time, (almost!) all ingredients from same experiment

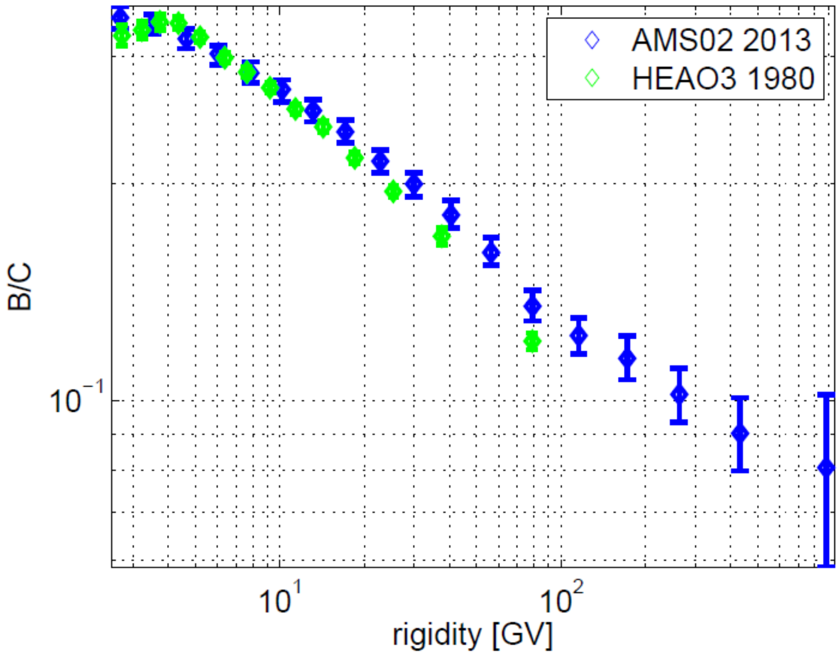


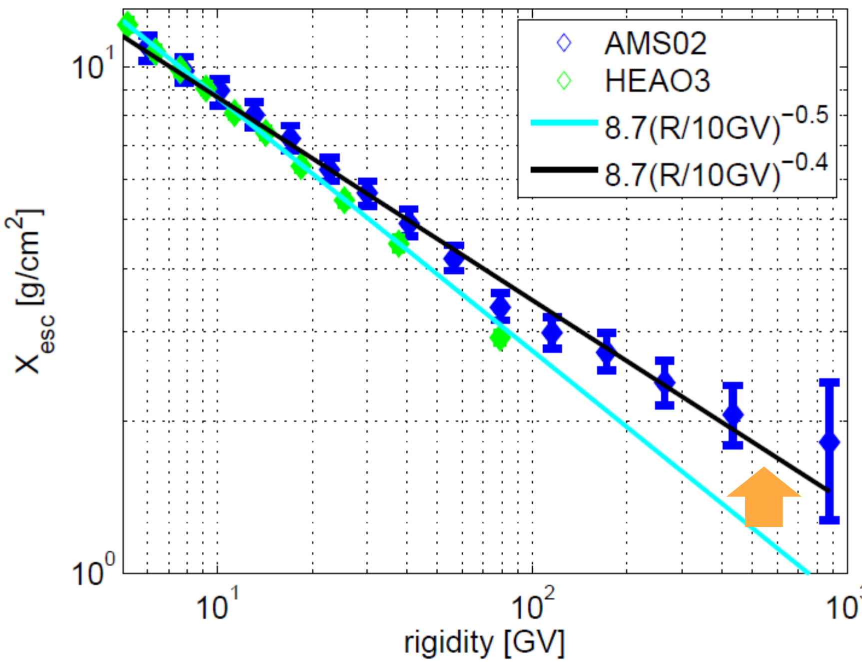




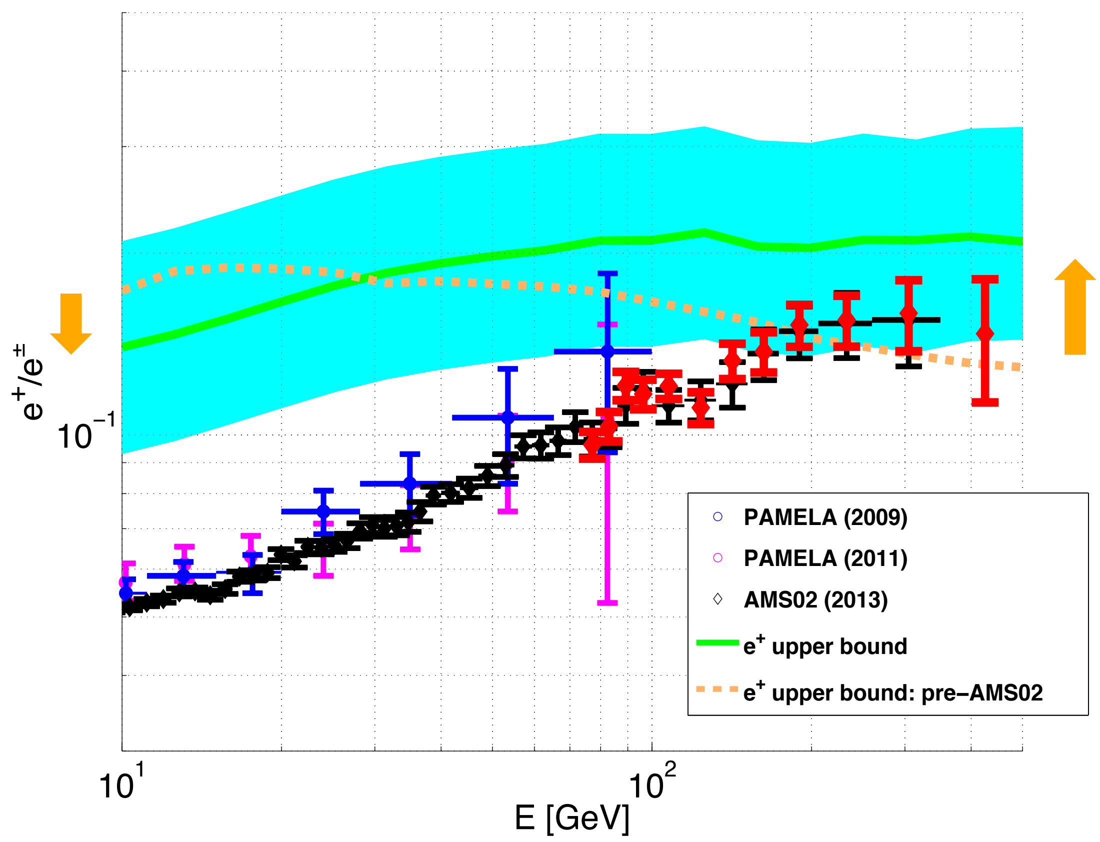


AMS02 update (2013)





Is there a hardening *feature* in the CR grammage?



e+/e±
10−1
10^1
10^2
E [GeV]
PAMELA (2009)
PAMELA (2011)
AMS02 (2013)
e+ upper bound
e+ upper bound: pre−AMS02

More unique opportunities w/ AMS02:

Relativistic radioactive nuclei: probe *high energy* CR residence time in the Galaxy

AMS-02 should do better!

Need to tell between these fits (data from 80's).