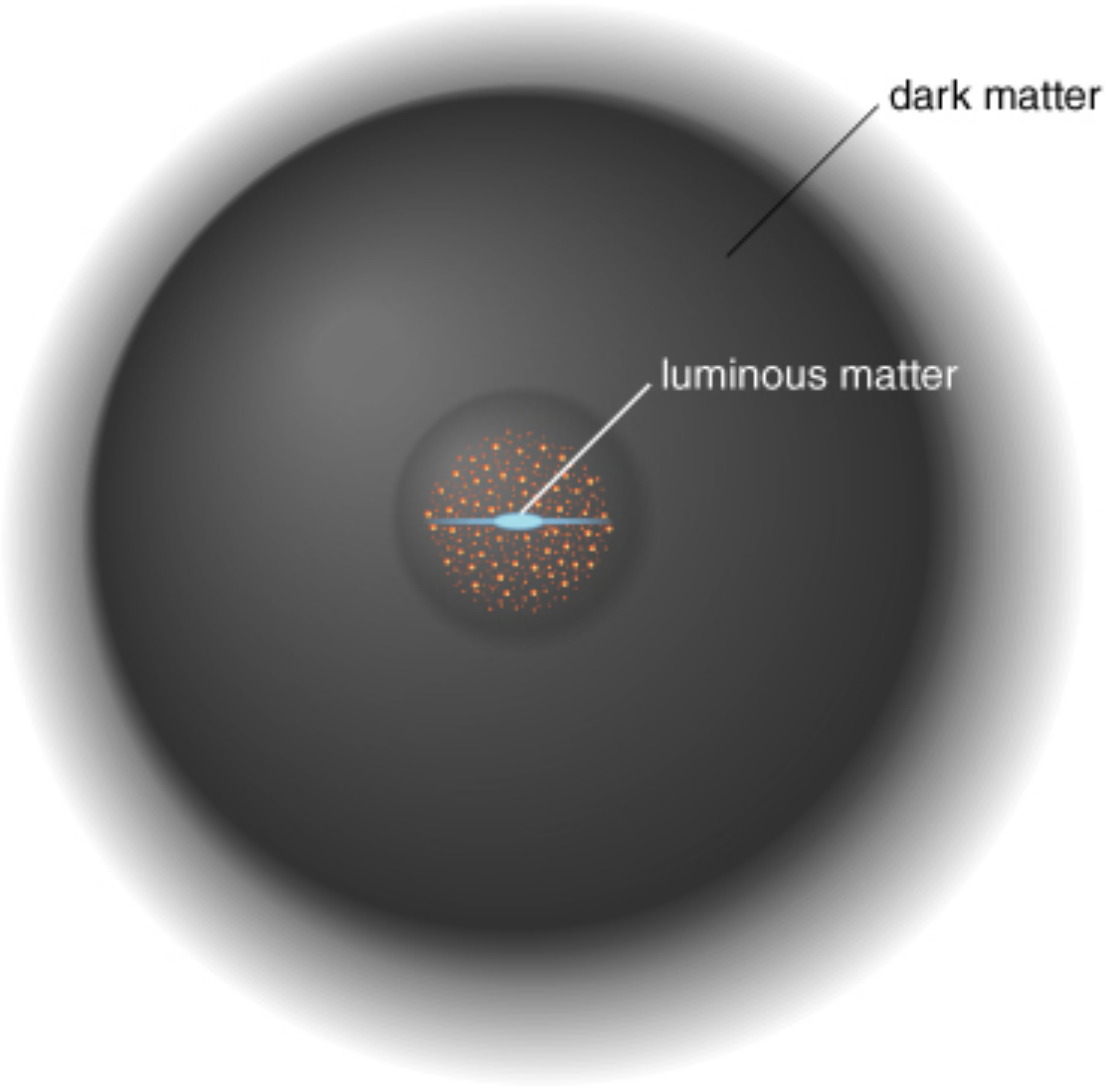
Stefano Profumo

Santa Cruz Institute for Particle Physics
University of California, Santa Cruz

New Physics and Indirect Dark Matter Detection

Fermilab Center for Astrophysics

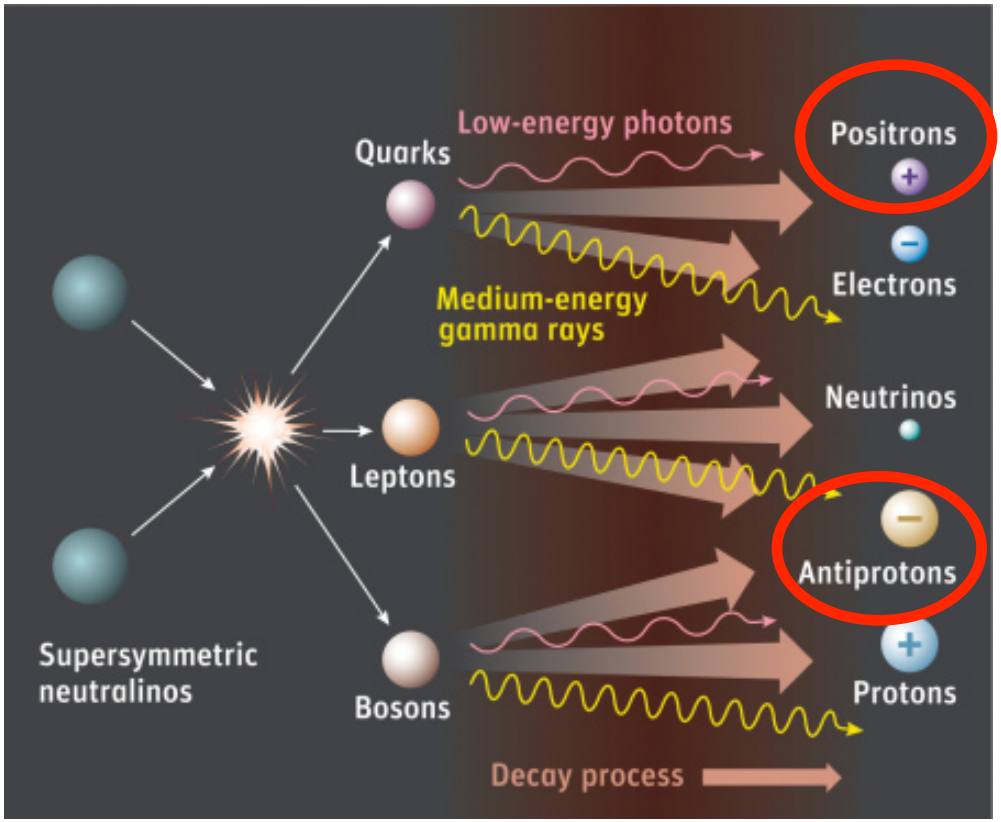
September 15, 2014, Fermilab, Batavia, IL

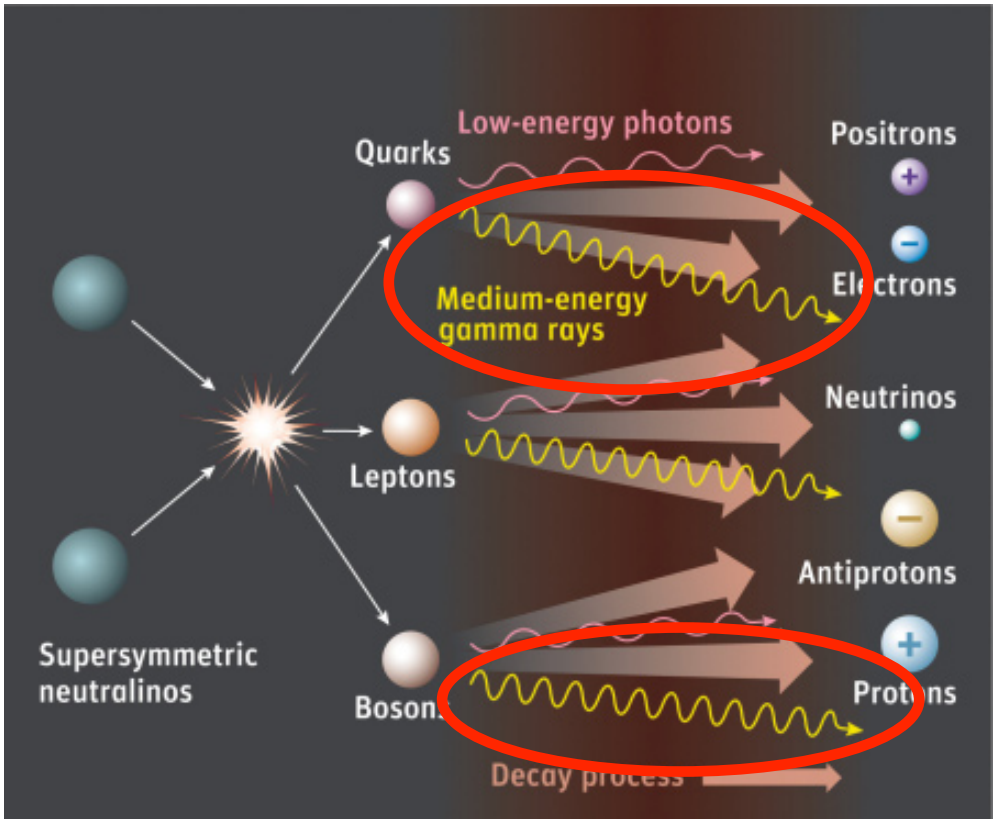


© Addison-Wesley Longman

Antimatter

- ✓ Rare
- x Propagation



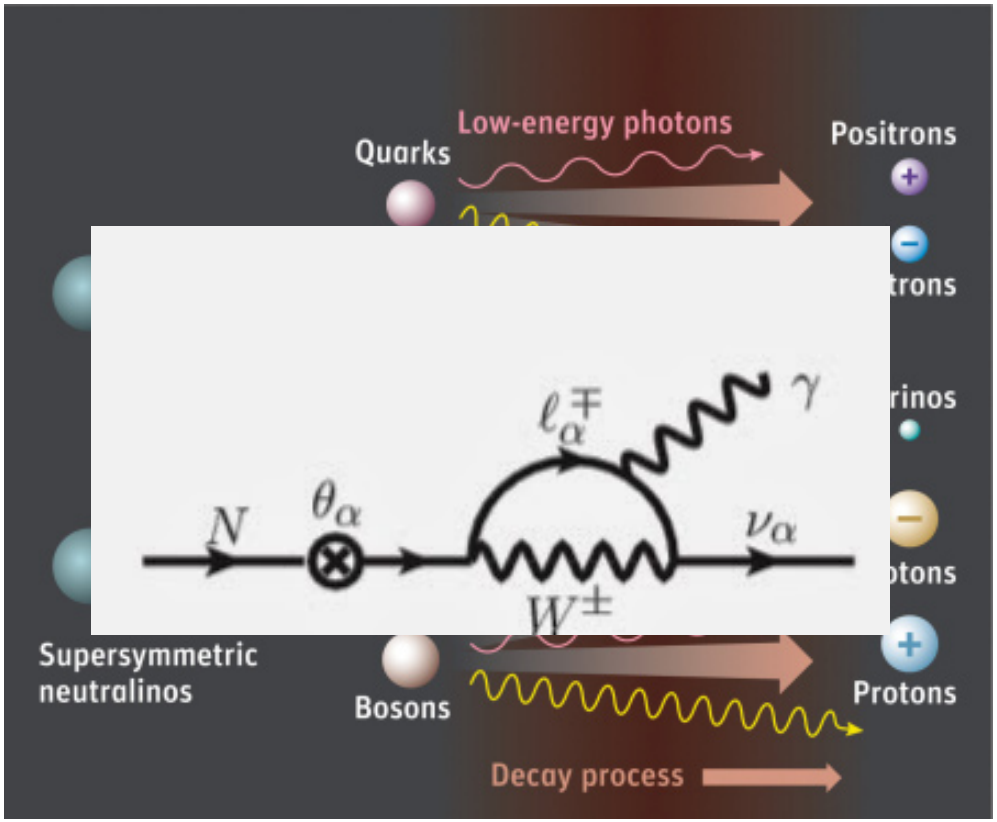


Antimatter

- ✓ Rare
- x Propagation

Gamma Rays

- ✓ Travel Straight
- ✓ Don't lose Energy
- x Background



Antimatter

- ✓ Rare
- x Propagation

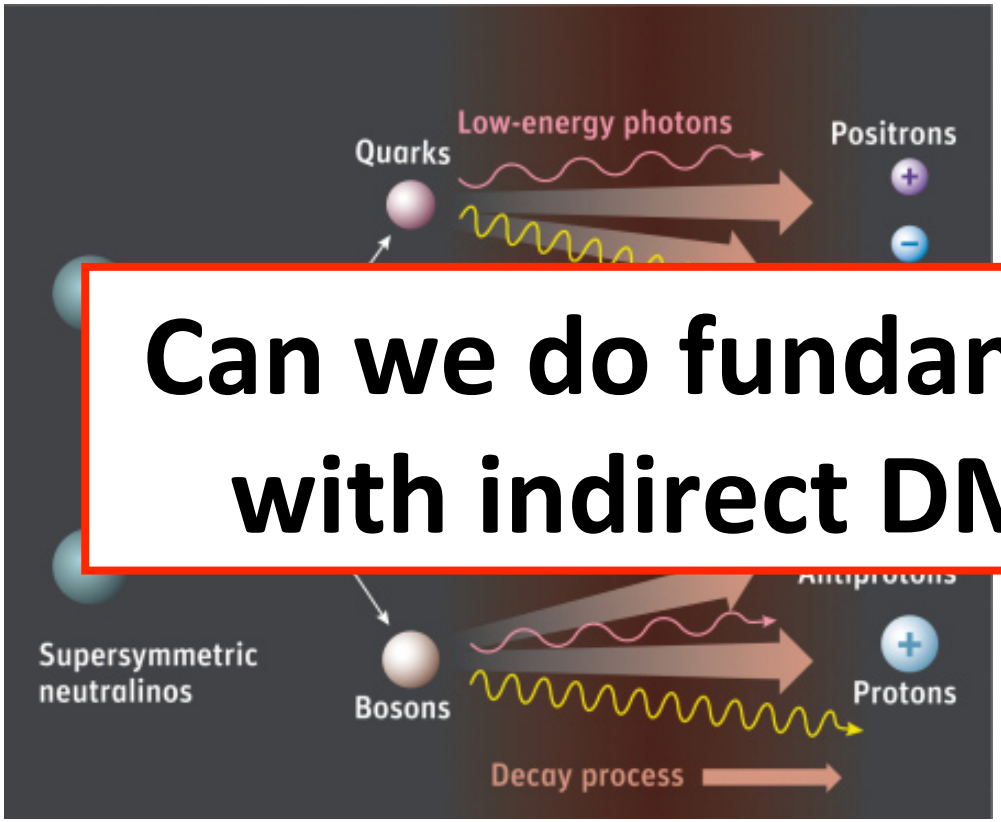
Gamma Rays

- ✓ Travel Straight
- ✓ Don't lose Energy
- x Background

Decays

- ✓ Across EM spectrum…
- x Background

“Indirect” Dark Matter Detection



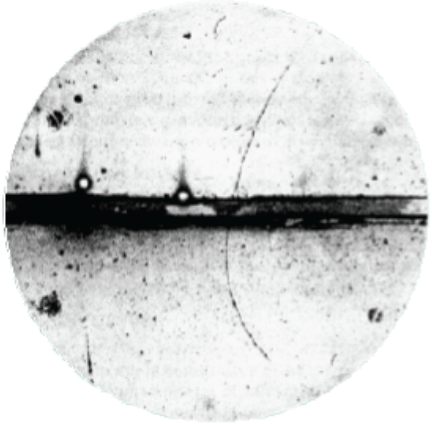
Can we do fundamental physics with indirect DM detection?

“Indirect” Dark Matter Detection

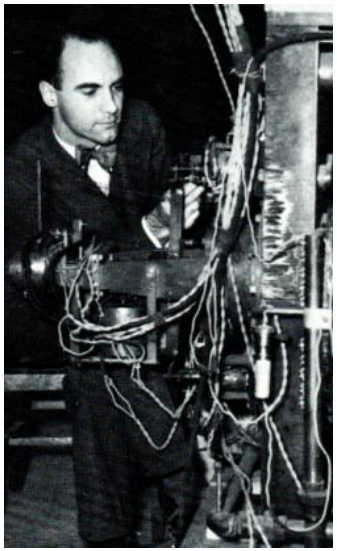
Can we do fundamental physics with indirect DM detection?

“Indirect” Dark Matter Detection

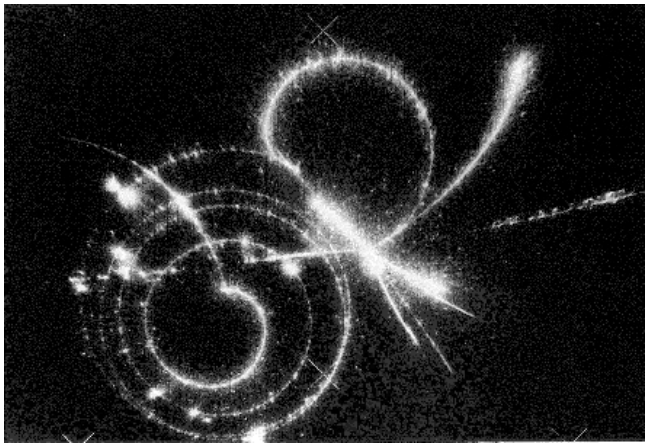
Can we do fundamental physics with astroparticle/astronomical data?



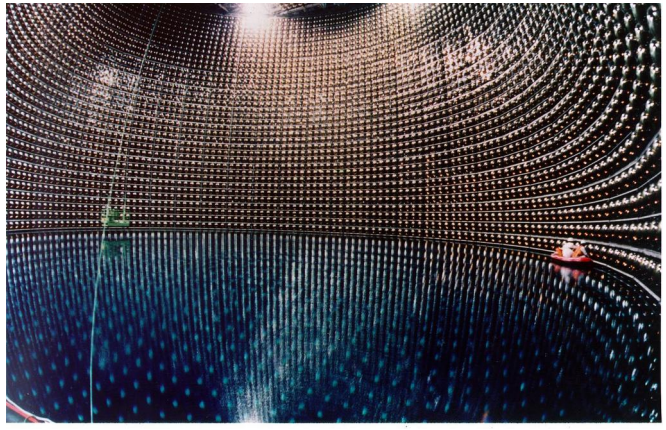
Antimatter
(positron, Anderson, 1932)



Second Generation
(muon, Anderson, 1936)



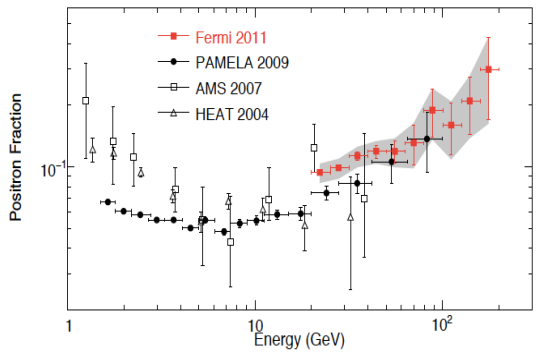
Pions (“Yukawa” particles)
(Lattes, Powell and
“Beppo” Occhialini)



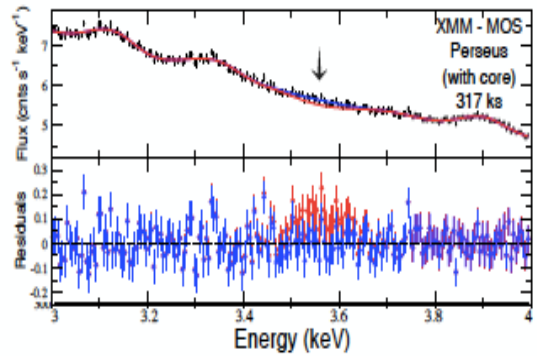
Neutrino Masses

4 tantalizing results might start delivering fundamental, New Physics from the sky

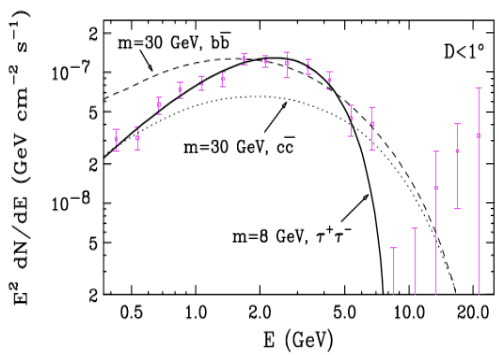
Cosmic-Ray Positron Excess



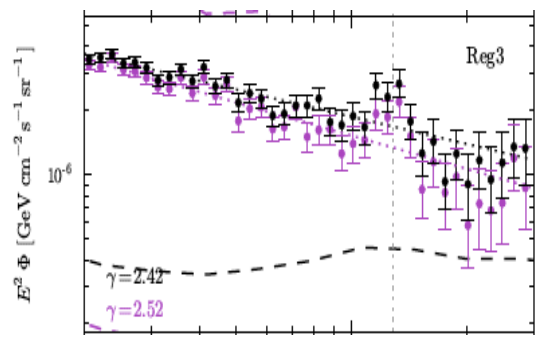
3.5 keV line



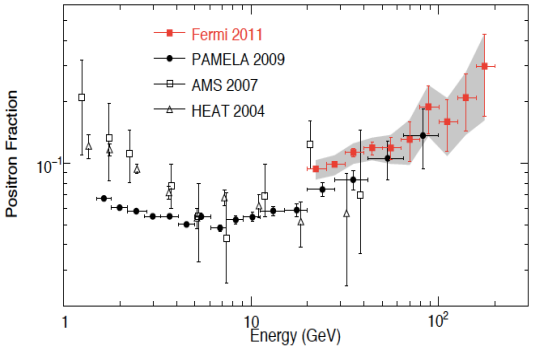
Gamma-ray excess in the Galactic Center



A 130 GeV line

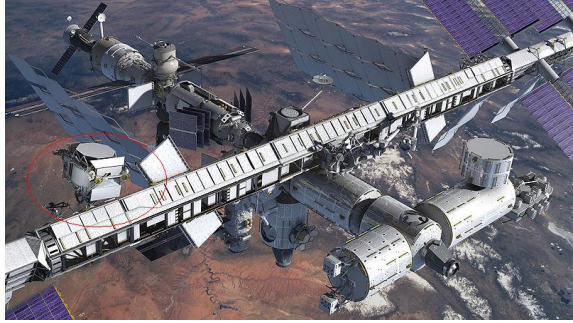


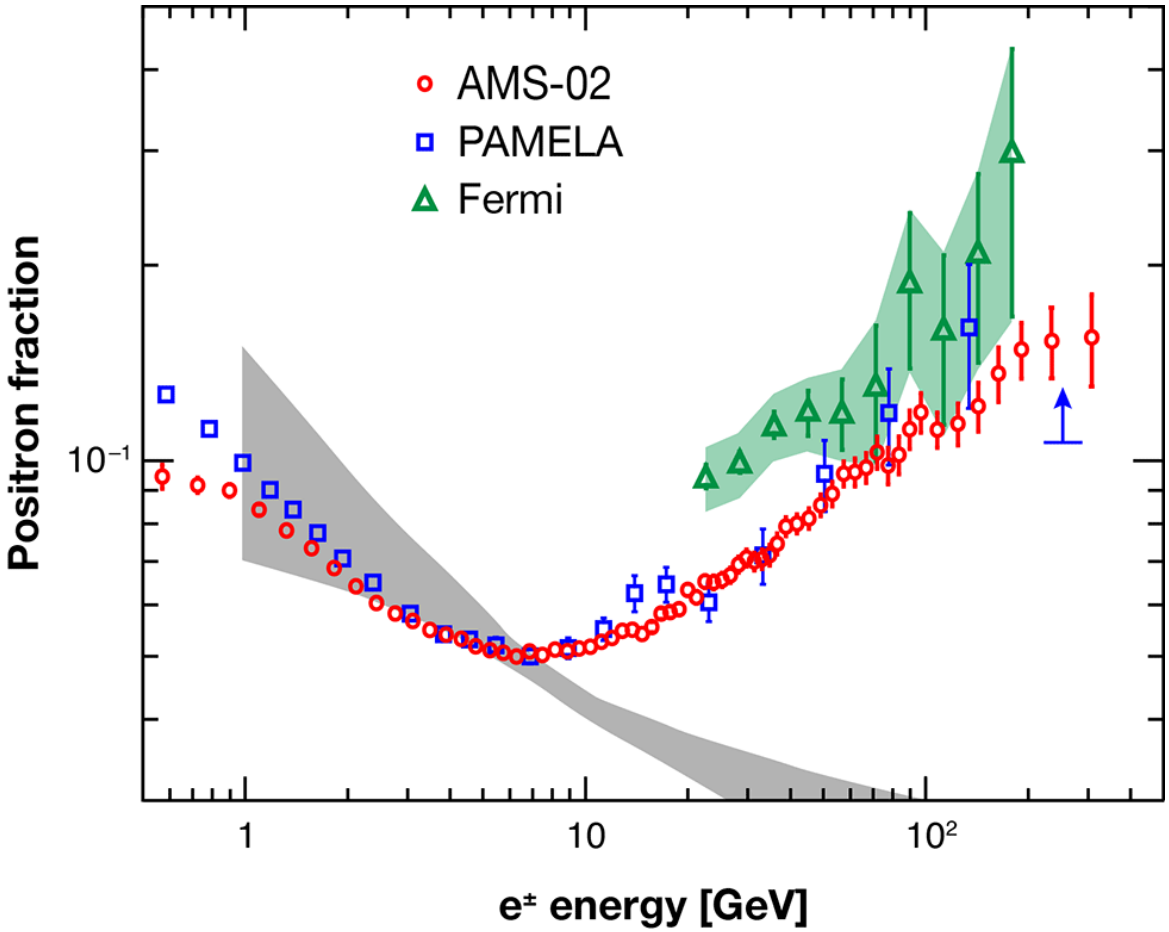
Cosmic-Ray Positron Excess



signal is **genuine**: established by Pamela, confirmed by Fermi, high-statistics with **AMS-02**

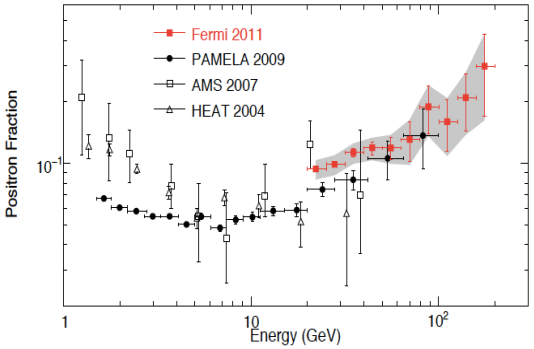
April 2013





PRL, **110** (2013) 14

Cosmic-Ray Positron Excess



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within any reasonable/predictive cosmic-ray model, the **rising e^+ fraction** constitutes an "**anomaly**"

Cosmic Ray **Secondary-to-Primary** ratio

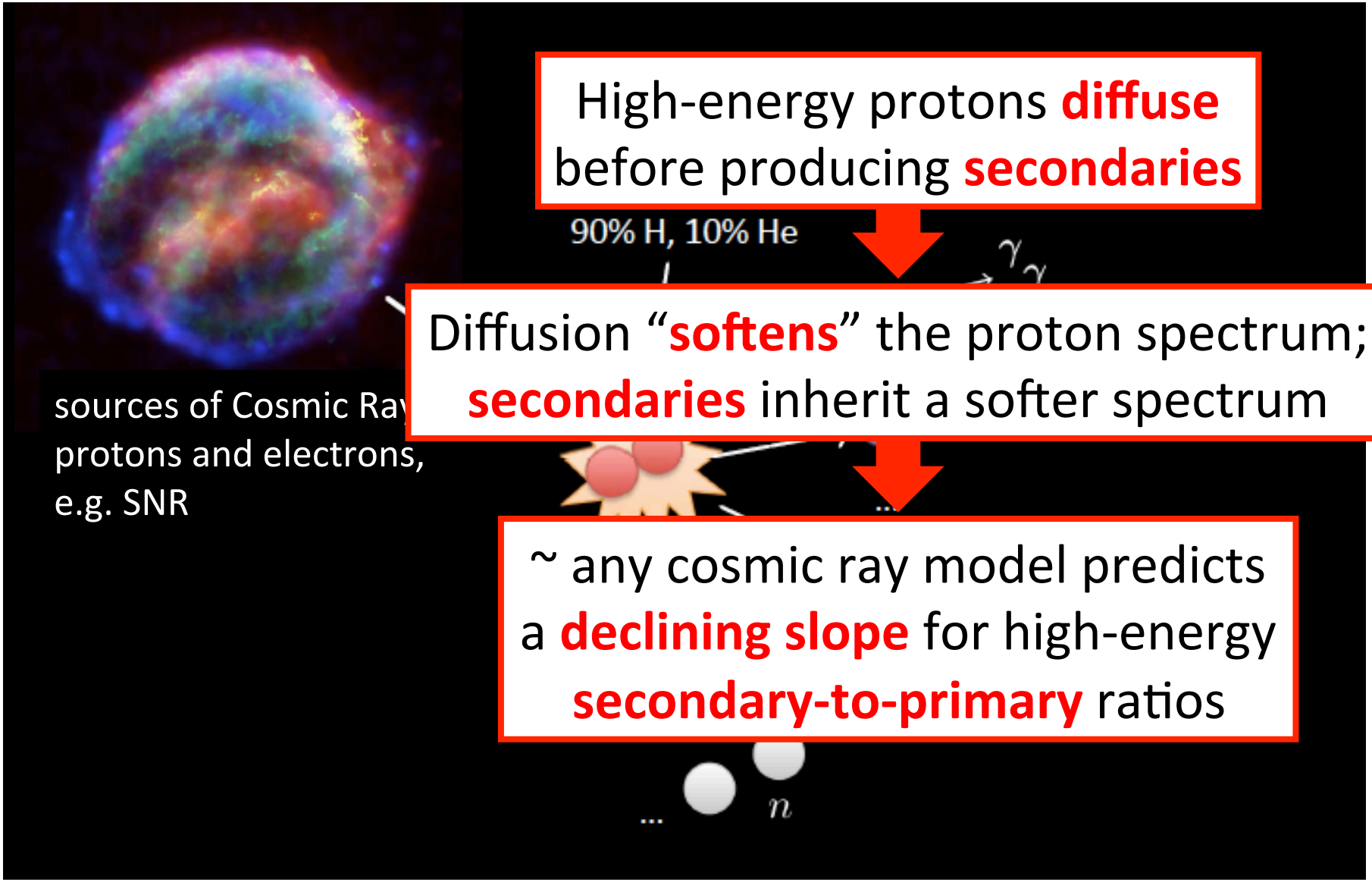
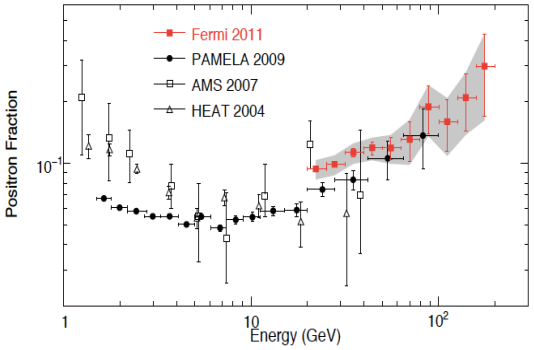


image credit: Philip Mertsch

Cosmic-Ray Positron Excess



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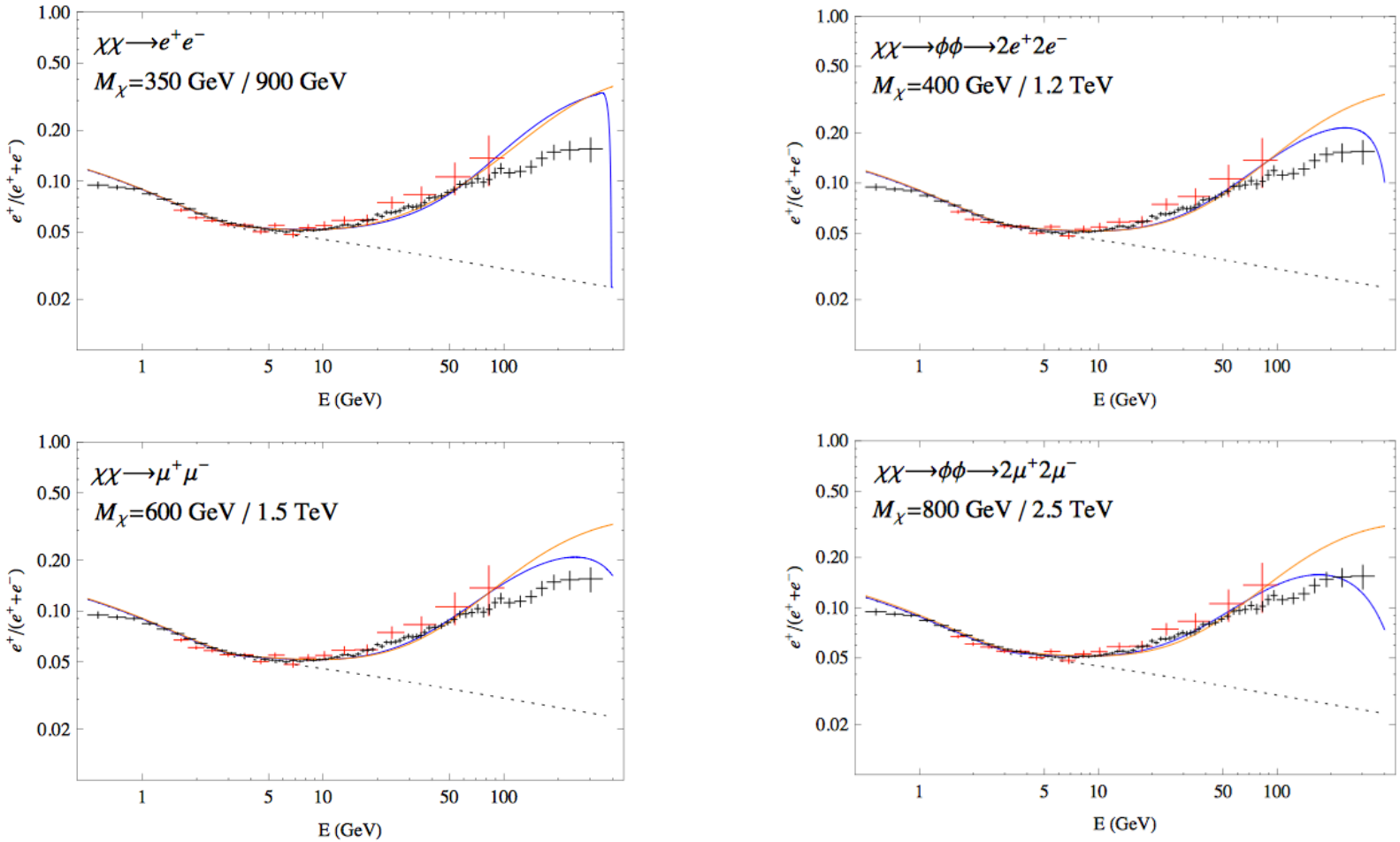
AMS spectral data, and **indirect** constraints strongly **disfavor** a DM annihilation interpretation



AMS data now **exclude** "**leptophilic**" DM
...even in **non-trivial incarnations**

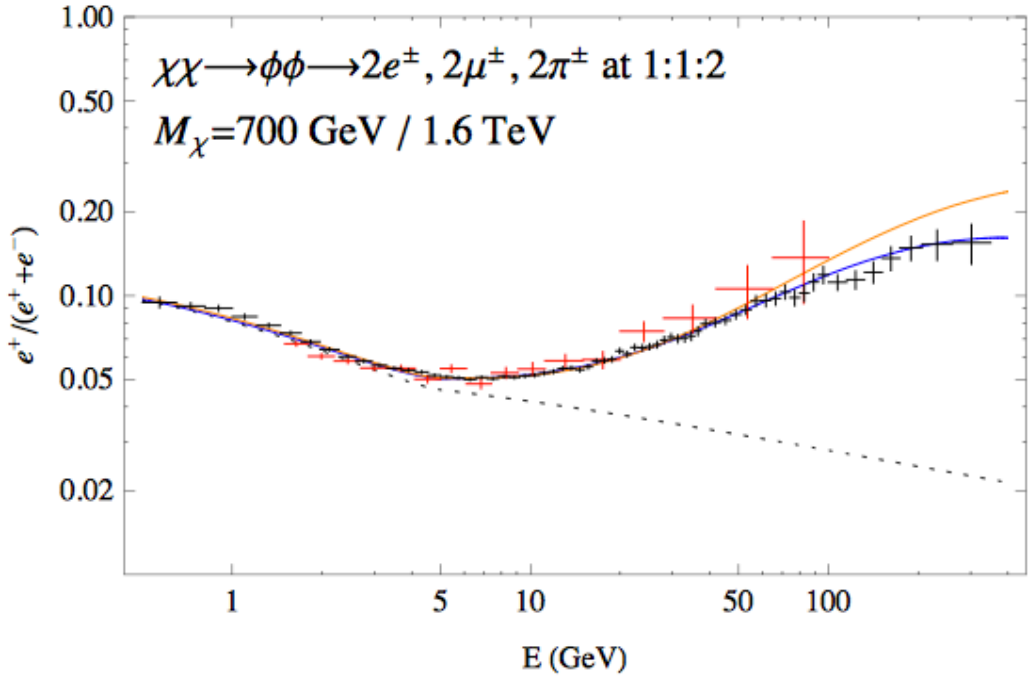
Cholis and Hooper, 1304.1840, **Phys. Rev. D88 (2013) 023013**

Redman's Theorem

"Any competent theoretician can fit any given theory to any given set of facts" (*)

Roderick O. Redman
(b. 1905, d. 1975)
Professor of Astronomy
at Cambridge University

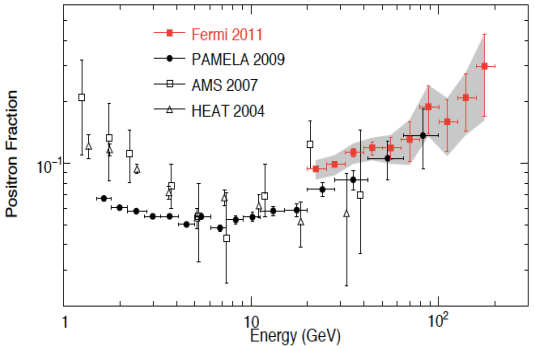
(*) Quoted in M. Longair's "High Energy Astrophysics", sec 2.5.1 "The psychology of astronomers and astrophysicists"



Redman's theorem **verified**,
but **good luck** on **model building**!

Cholis and Hooper, 1304.1840, **Phys. Rev. D88 (2013) 023013**

Cosmic-Ray Positron Excess



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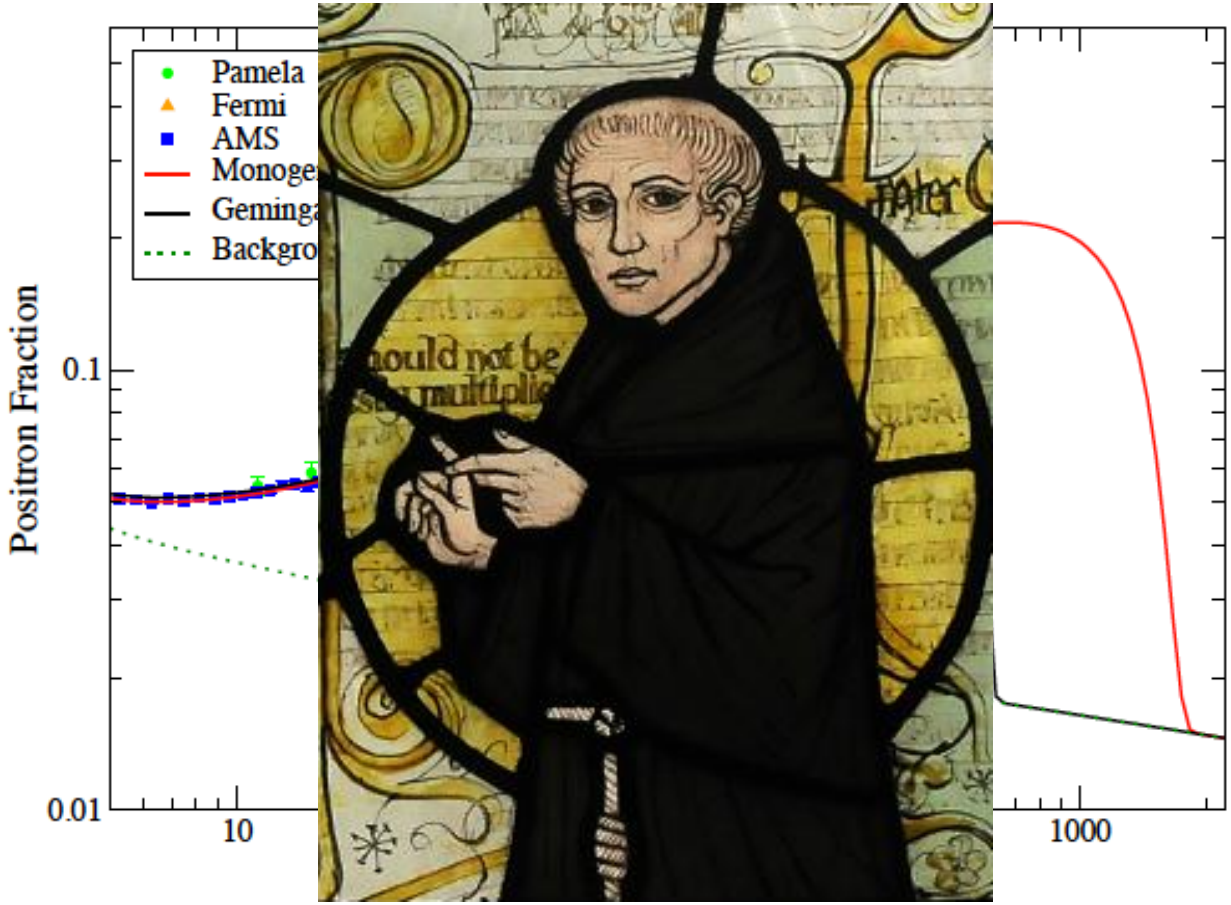
AMS spectral data, and **indirect** constraints strongly **disfavor** a DM annihilation interpretation

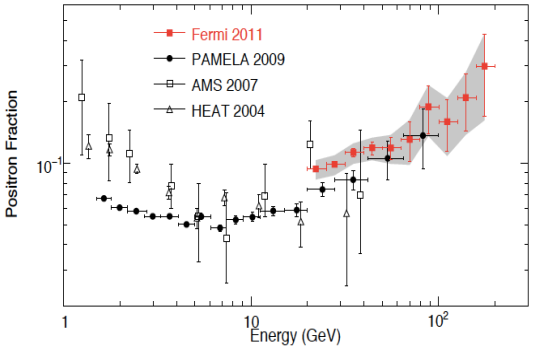
One or more young (~10^5 yrs), nearby (~kpc) **pulsar(s)** naturally fit the bill



- **Distance** and **Age** from observation (set the cutoff)
- **Normalization**: 1-10% spin-down luminosity
- Injection **Spectrum**: ~ E^{-2} (Fermi 1st order)

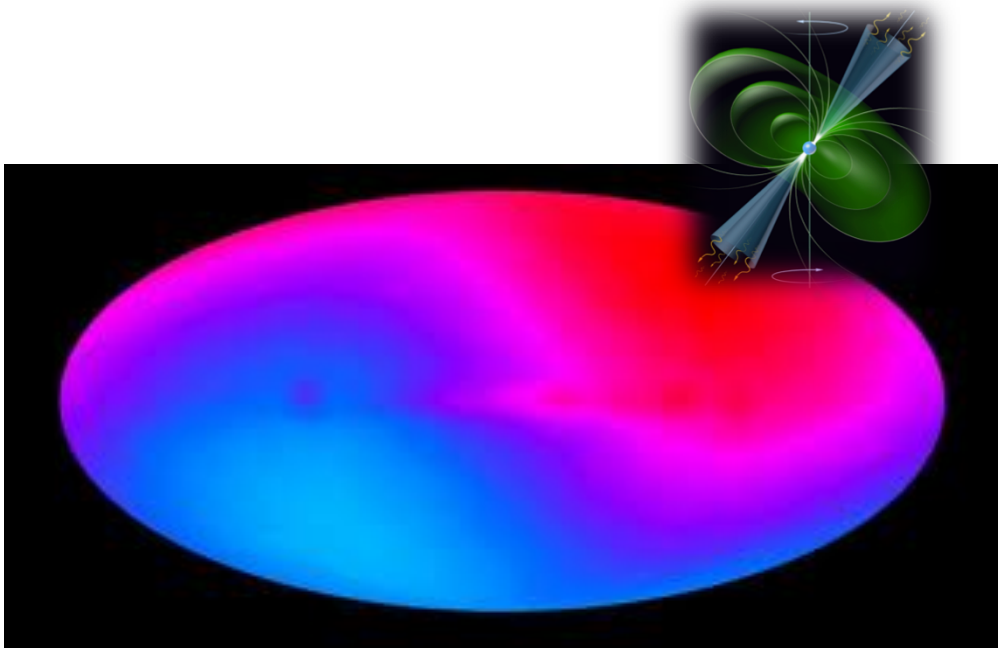
Linden and Profumo, 1304.1791, **Astrophys.J. 772 (2013) 18**

Cosmic-Ray Positron Excess



Is there a **conclusive test** of the origin of the anomalous positrons?

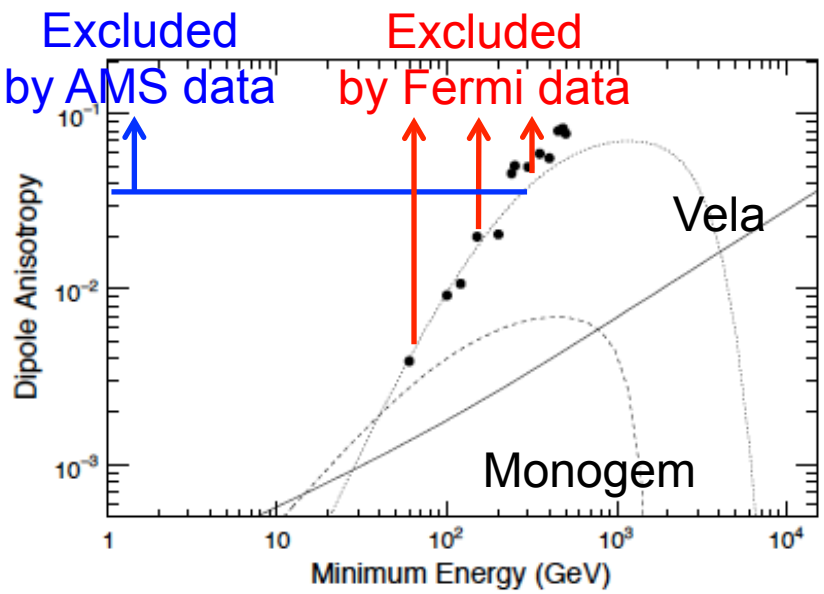
Detection of an **anisotropy** in the arrival direction of $e^+ e^-$



The detection of a cosmic-ray electron-positron anisotropy is a sufficient (but not necessary) condition to discard a Dark Matter origin for the anomalous positron fraction

Stefano Profumo*
Department of Physics and Santa Cruz Institute for Particle Physics, University of California, Santa Cruz, CA 95064, USA
(Dated: May 21, 2014)

I demonstrate that if an anisotropy in the arrival direction of high-energy cosmic-ray electrons and positrons is observed, then dark matter annihilation is ruled out as an explanation to the positron excess. For an observable anisotropy to originate from dark matter annihilation, the high-energy electrons and positrons must be produced in a nearby clump. I consider the annihilation pathway producing the smallest flux of gamma rays versus



No Anisotropy observed in the **Fermi** e^+e^- data, or in the **AMS** data

Pulsar interpretation entirely **consistent** with **all data**!

Fermi-LAT Collaboration, PRD, 1008.5119
AMS-02 Collaboration, PRL, 110, 141102

DM annihilation only produces a **detectable anisotropy** if there most e^+e^- come from a **nearby clump**

If such clump exists, and produces a detectable anisotropy, it should have been **seen in gamma rays**

(i) consider DM final state with **smallest γ-ray** yield

(ii) **solve** (**analytically**) diffusion and energy-loss propagation equation

(iii) calculate **minimal emission** (from internal brems)

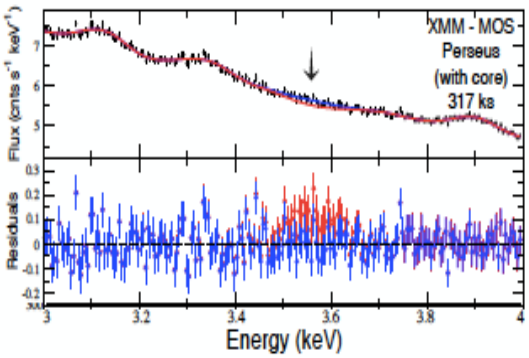
$$\phi_{\gamma,\mathrm{TOT}} > \left(\frac{10^{-2}}{\Delta}\right)\frac{4\times 10^{-8}}{\mathrm{cm}^2\,\mathrm{s}} \gg \phi_{\gamma,\mathrm{TOT}}^{\mathrm{Fermi},5\sigma} \simeq \frac{\mathrm{few}\times 10^{-9}}{\mathrm{cm}^2\,\mathrm{s}}$$

- we are **closing in** on the **dark matter** interpretation

- **AMS-02** positron fraction **data "favor" PSR's** over dark matter

- Conclusive argument against dark matter: **anisotropy**

3.5 keV line

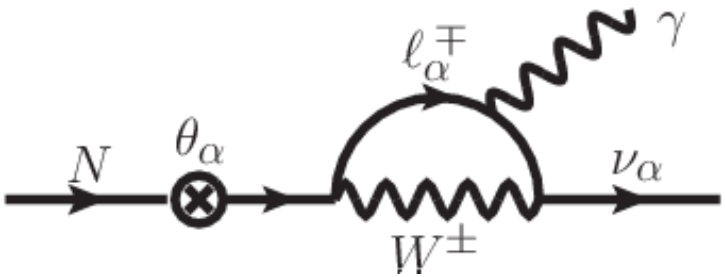


Detected, with **mild significance** (<~4σ) mostly with **XMM**, but also with Chandra observations, of **Perseus**, M31, stacked collection of clusters

(Balbul+ '14, Boyarsky+ '14)

if not astrophysical, likely related to **DM decay**

(many other more complicate scenarios also possible)



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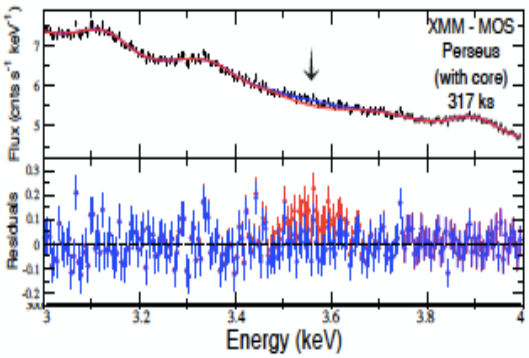
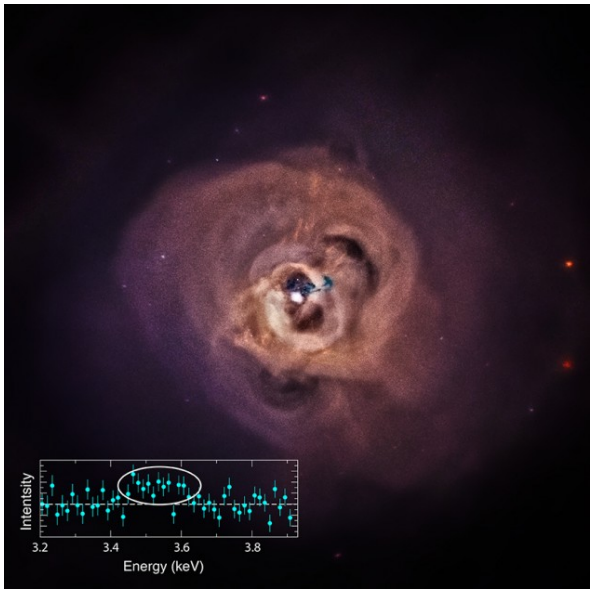
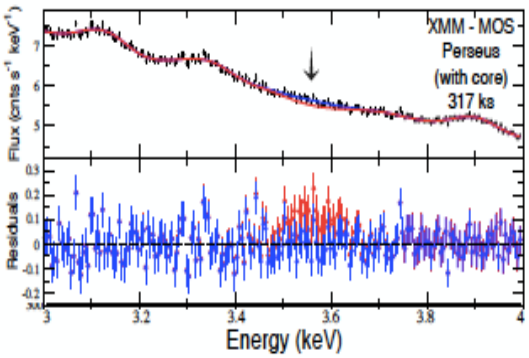




easy to calculate and **compare** rates for different objects…

3.5 keV line



Hierarchy of signals makes little sense…

Strength of signal ($\sin^2 2\theta/10^{-11}$):

- **Perseus**: 20-60
- Coma+Oph.+Perseus: 18
- Full **cluster sample**: 6
- **M31**: 2-20

Preliminary **Chandra GC** (<2.5, Riemer-Sorensen '14), **Virgo** (<10, Bulbul+ '14) observations put **tension**

Some **theoretical constructions** could explain some of the **discrepant predictions** (e.g. DM -> ALP -> photon)*

*Conlon et al 2014

Dark matter searches going bananas:
the contribution of Potassium (and Chlorine) to the 3.5 keV line

Tesla Jeltema[1]* and Stefano Profumo[1]†
[1]*Department of Physics and Santa Cruz Institute for Particle Physics University of California, Santa Cruz, CA 95064, USA*

1. New analysis of XMM **Galactic Center** data
2. Re-analysis of XMM **M31** data
3. Assess **systematics of lines strengths** for Galactic Center, M31, and, especially **clusters**

Dark matter searches going bananas: the contribution of Potassium (and Chlorine) to the 3.5 keV line

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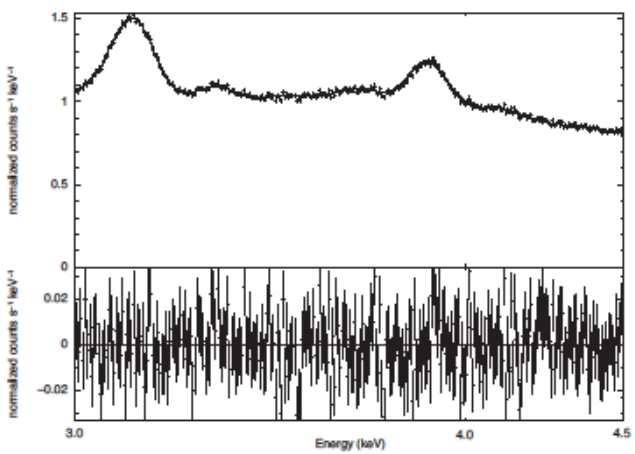
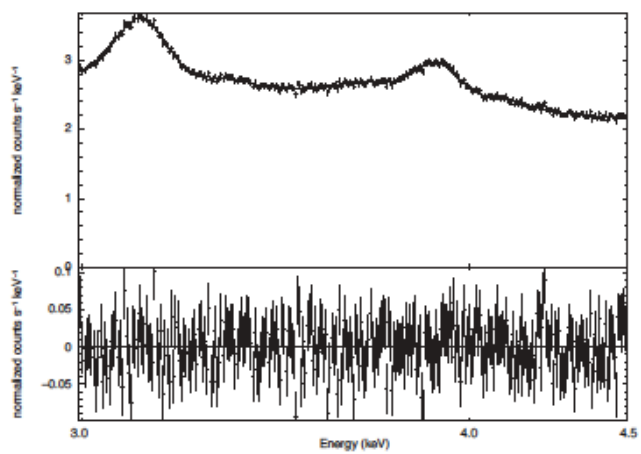
1. New analysis of XMM Galactic Center data

=> There is a **line at 3.5 keV**; Line is compatible with an **atomic emission line from K XVIII** ($1s^1\ 2p^1$ -> $1s^2$) at **3.51 keV**





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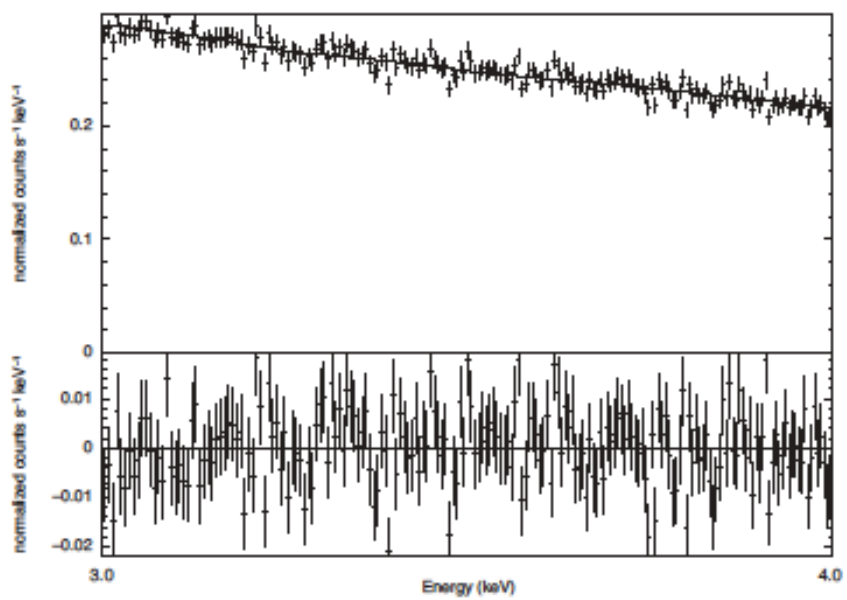
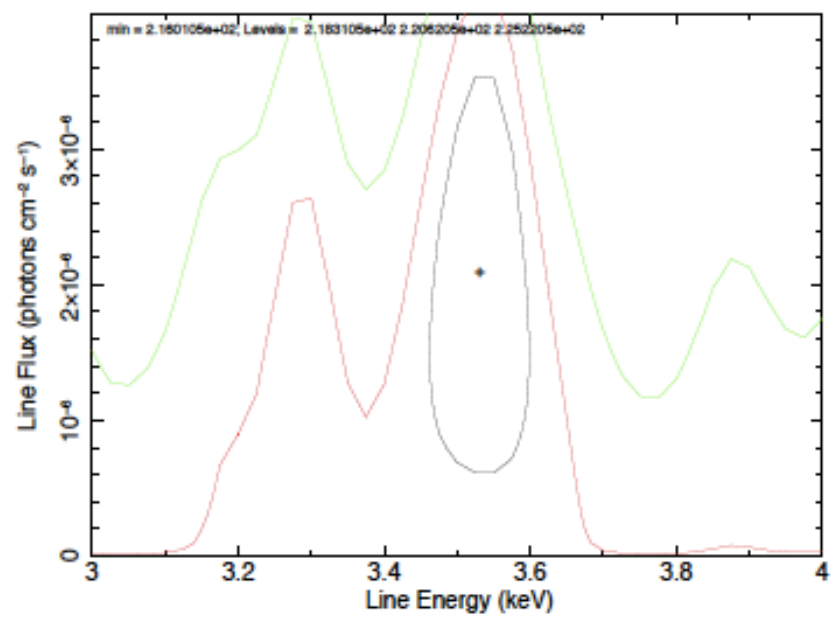
2. Re-analysis of XMM M31 data

We find no evidence for any line between 3 and 4 keV





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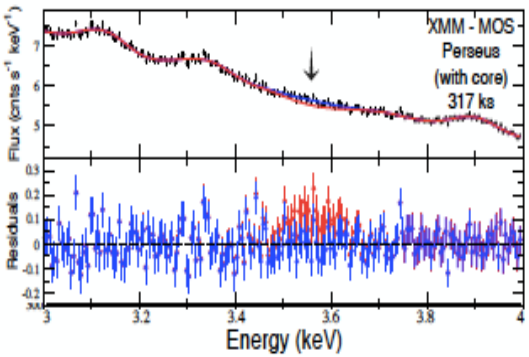
3. **Assess systematics of lines strengths for clusters**

We find that the **K XVIII line** (with the possible, albeit not necessary contribution from a Cl XVII line) might, within systematics, **explain the clusters 3.57 keV line**

3.5 keV line



The pattern of emission lines depends on **two key unknowns**:

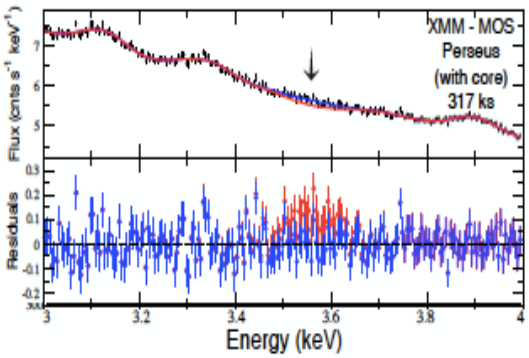
(i) plasma temperature

(ii) relative "metal" abundances

(i) is affected by the fact that there are pockets of thermalized ISM, so a **multi-temperature** pattern is very often observed, both in Galaxies and in **clusters**

the best guess at (ii) is the pattern of **solar abundances**, but the Sun is not a robust benchmark, esp. for **massive** stars, and for the turbulent, star forming environment of the **GC** or e.g. of cool-core **clusters**!

3.5 keV line



Relative strength of lines appears reasonable for GC and for clusters (where other lines are detected), **well within systematics**.

Potassium lines **could explain** all of the X-ray **3.5 keV** line features.

After our paper, **two new analyses**, and **one comment** on our work from **Boyarsky et al** (plus one **coming soon** from **Balbul et al**)

Constraints on 3.55 keV line emission from stacked observations of dwarf spheroidal galaxies

D. Malyshev, A. Neronov, and D. Eckert
Department of Astronomy, University of Geneva, ch. d'Ecogia 16, CH-1290 Versoix, Switzerland

Obs Id	Name	Duration, ksec	Clean exposure, ksec
0200500201	Carina	41.9	19.2+16.7+8.4
0603190101	Draco	19.0	17.5+17.9+14.3
0603190201	Draco	19.9	18.5+18.2+14.7
0603190301	Draco	17.7	12.2+12.6+6.3
0603190501	Draco	19.9	18.6+18.5+14.9
0302500101	Fornax	103.9	65.1+65.9+53.0
0555870201	Leo	94.0	75.4+77.1+0
0652210101	NGC 185	123.5	91.4+96.2+66.7
0650180201	UMa II	34.3	11.7+12.5+7.4
0301690401	UMi	11.8	10.8+10.9+7.9
0652810101	Willman	29.3	15.0+19.0+9.5
0652810301	Willman	36.0	21.9+23.2+15.5
0652810401	Willman	36.2	27.5+28.5+16.2
TOTAL		602.3	404.8+417.2+232.8

Malyshev et al, 1408.3531

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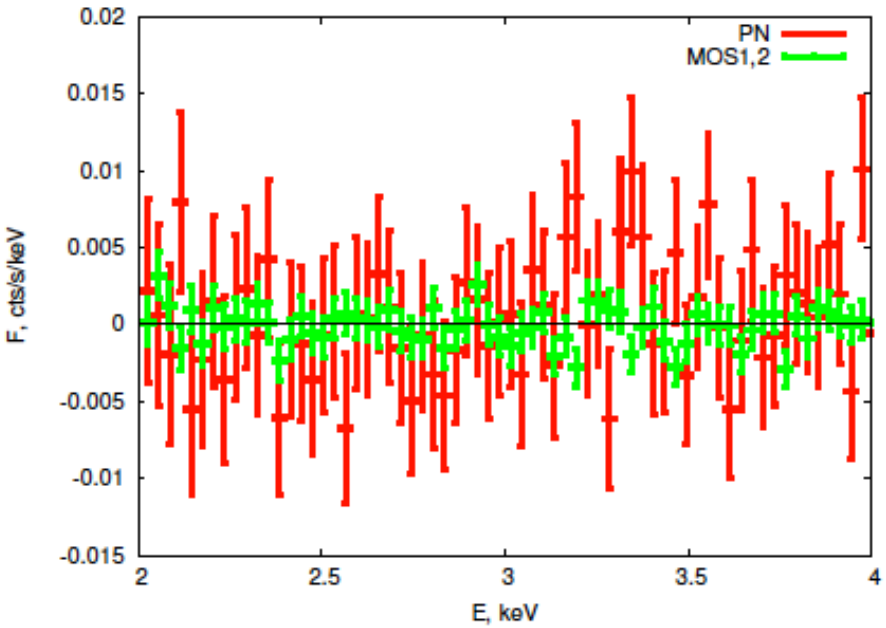

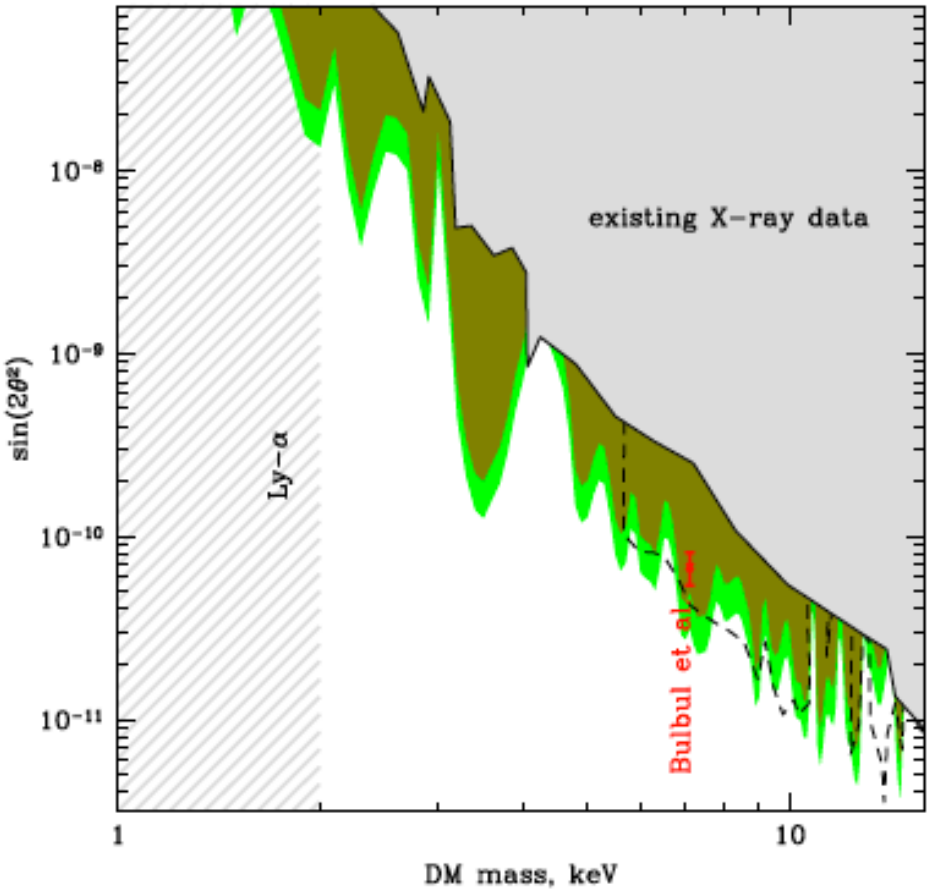

Malyshev et al, 1408.3531

Non-Detection of X-Ray Emission From Sterile Neutrinos in Stacked Galaxy Spectra

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v1 [astro-ph.HE] 18 Aug 2014

20 August 2014

ABSTRACT
We conduct a comprehensive search for X-ray emission lines from sterile neutrino dark matter, motivated by recent claims of unidentified emission lines in the stacked X-ray spectra of galaxy clusters and the centers of the Milky Way and M31. Since the claimed emission lines lie around 3.5 keV, we focus on galaxies and galaxy groups (masking the central regions), since these objects emit very little radiation above ~ 2 keV and offer a clean background against which to detect emission lines. We develop a formalism for maximizing the signal-to-noise of sterile neutrino emission lines by weighing each X-ray event according to the expected dark matter profile. In total, we examine 81 and 89 galaxies with Chandra and XMM-Newton respectively, totaling 15.0 and 14.6 Ms of integration time. We find no significant evidence of any emission lines, placing strong constraints on the mixing angle of sterile neutrinos with masses between 4.8-12.4 keV. In particular, if the 3.57 keV feature from Bulbul et al. (2014) were due to 7.1 keV sterile neutrino emission, we would have detected it at 4.4σ and 11.8σ in our two samples. Unlike previous constraints, our measurements do not depend on the model of the X-ray background or on the assumed logarithmic slope of the center of the dark matter profile.

Boyarsky et al on "Dark Matter searches going bananas"

Comment on the paper "Dark matter searches going bananas: the contribution of Potassium (and Chlorine) to the 3.5 keV line" by T. Jeltema and S. Profumo

A. Boyarsky[1], J. Franse[1,2], D. Iakubovskyi[3], and O. Ruchayskiy[4]

key point: the line strikes back if one **broadens** the **energy range** from 3-4 keV to 2-8 keV

In the 3-4 keV range, **easy** to model **background** (simple power law); things a lot **murkier** in a broader energy range!

Bulbul et al on "Dark Matter searches going bananas"

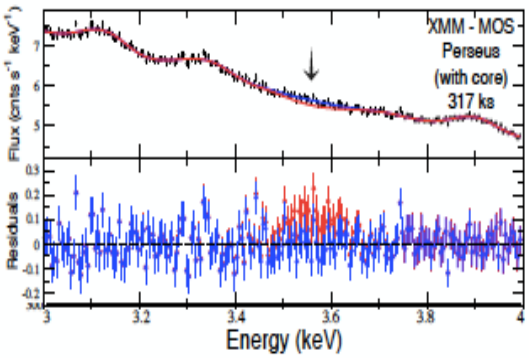
(to appear presumably soon)

key points:

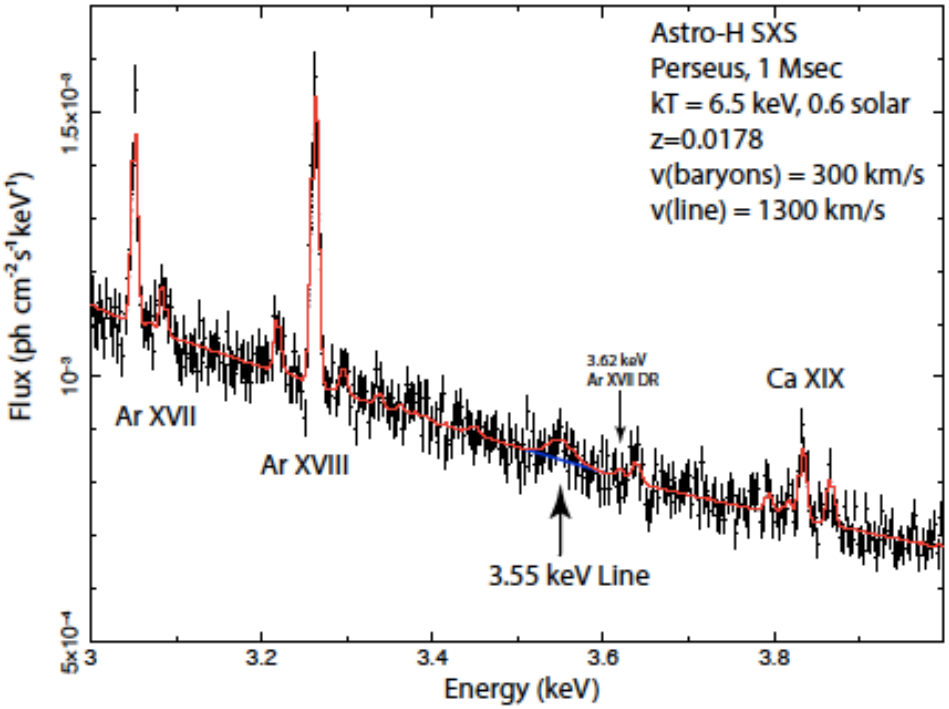
1. We used an approximate version of the AtomDB predictions (WebGuide, also used in their original paper)
2. A brighter Cl line at lower energy (outside original range reported upon) is not detected, therefore Cl does not contribute to the 3.57 keV line

1. Moot point: **line ratios are accurate** to within few percent with the WebGuide tool
2. We could not use this cross check; still Cl was invoked as **minor contributor** to explain the line

3.5 keV line

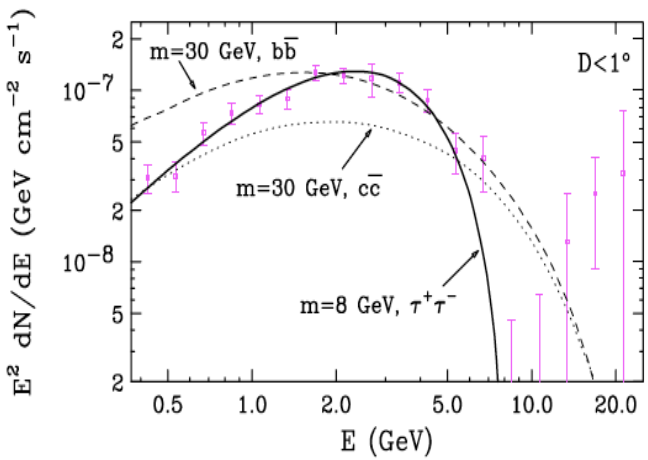


What next?



1. Wait for **Astro-H**
2. Use data in **different** ways from **spectral analysis**

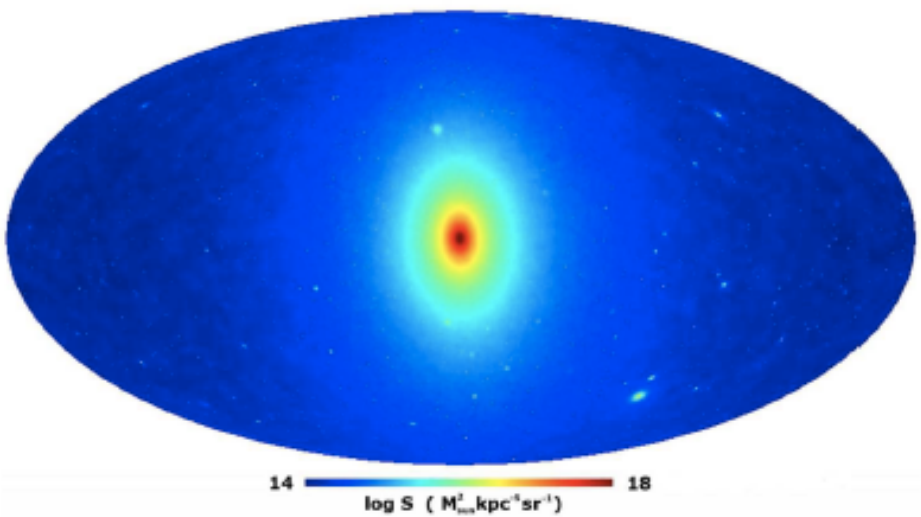
Dark Matter annihilation in the Galactic Center?



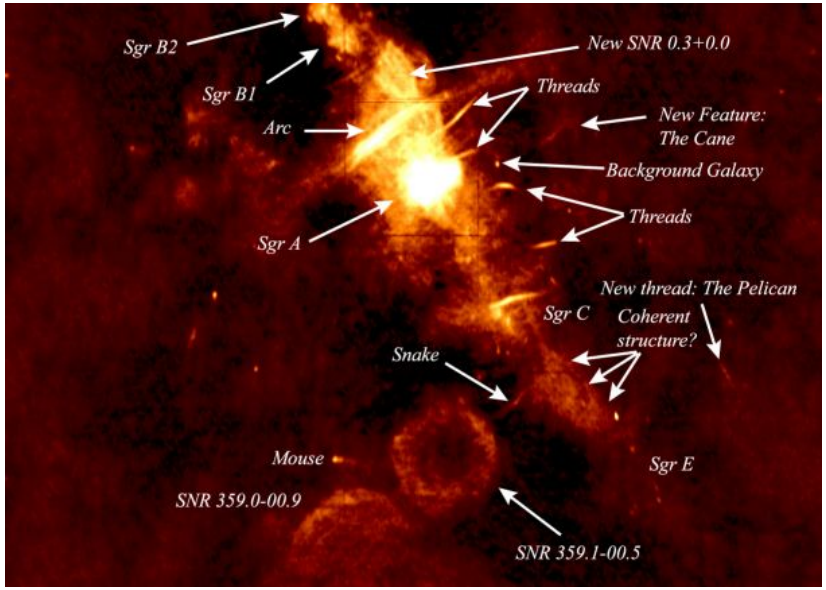
The **Galactic Center** Region: a Holy Grail or a Hornet's Nest?

- Largest (known) Galactic **Dark Matter** Density
- There appears to be an **excess** of soft gamma rays

- Largest **Cosmic Ray** Density
- Largest **Gas** and **Radiation** Densities
- Largest concentration of Galactic **Gamma Ray sources**

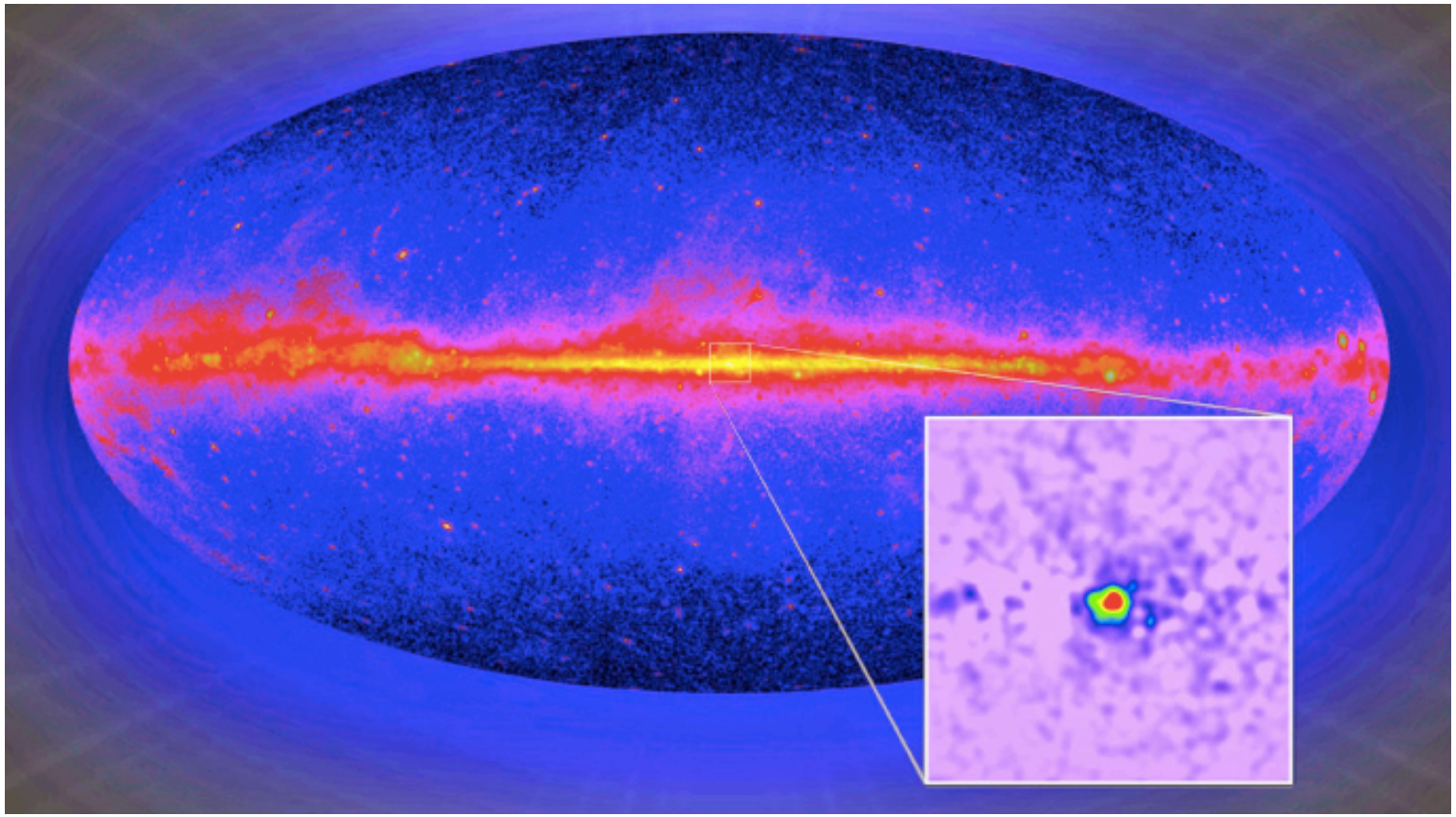


Springel et al, 2009



Kassim et al, 1999

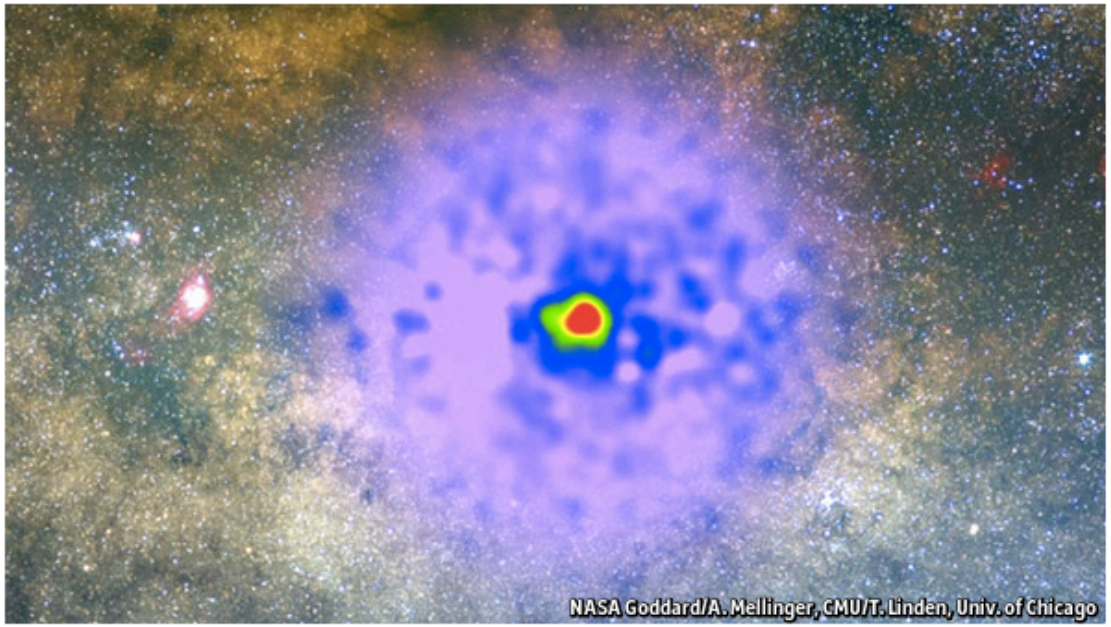
After early reports (primarily by Hooper et al) **Galactic Center Excess** reported independently, and with a variety of different assumptions for background etc, by Daylan et al (Harvard+MIT+Fermilab); Abazijian et al (UCI); Macias and Gordon (NZ)



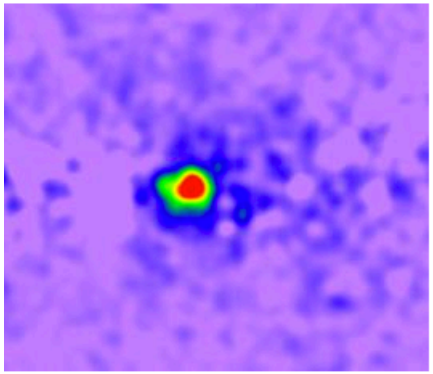
Fundamental physics

Casting light on dark matter

Apr 12th 2014 | From the print edition Timekeeper Like 26 Tweet 3
283 Tweet 604 g+1 69
512



This picture, physicists think, shows telltales of dark matter: mysterious stuff which makes up five times as much of the universe as the more familiar matter of atoms. The image, based on data from Fermi, an American satellite, and created by Dan Hooper, an astrophysicist at Fermilab, in Illinois, superimposes onto a picture of the visible substance of the Milky Way's centre a map of part of its gamma-ray production—the part in excess of



false-colour image of the centre of the
taken by the Fermi space telescope, all
gamma-ray sources have been removed,
ing excess emissions that may arise from
matter annihilations *(Image: T. Linden,*
rsity of Chicago)

Dark Matter
in Milky Wa

Excess gamma-ray light at the g

Apr 8, 2014 | By Clara Moskowitz

SAVANNAH, Ga.—Gamma r
from the center of the Milky
the result of dark matter par
scientists say. If so, the signa
NASA's Fermi space telesco
the first-ever indirect detect
particles that make dark ma
stealthy and elusive substan
contributes most of the mat
universe.

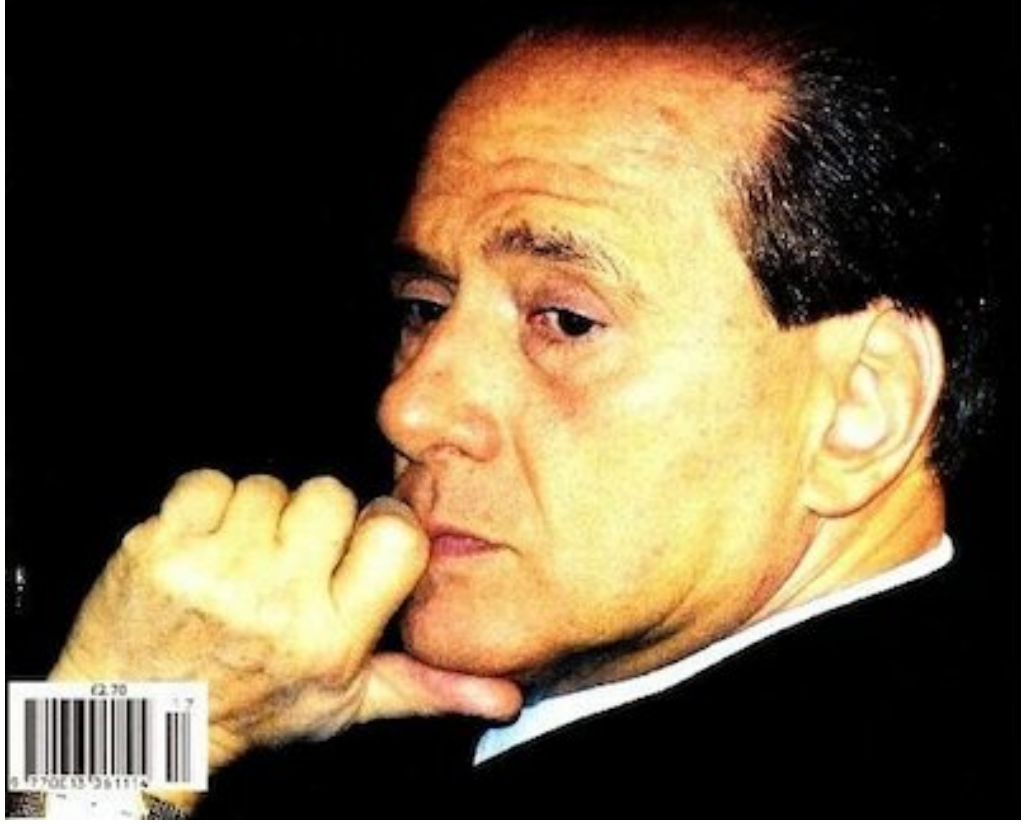
The **Economist** has the tendency to get **things right**

The Economist
APRIL 28TH - MAY 4TH 2001

IS INEQUALITY GROWING?
pages 95-97 and 136

TARGET-CRAZY LABOUR
pages 22 and 31

Why Silvio Berlusconi is unfit to lead Italy



Best background model yet, but with a **key weakness**:

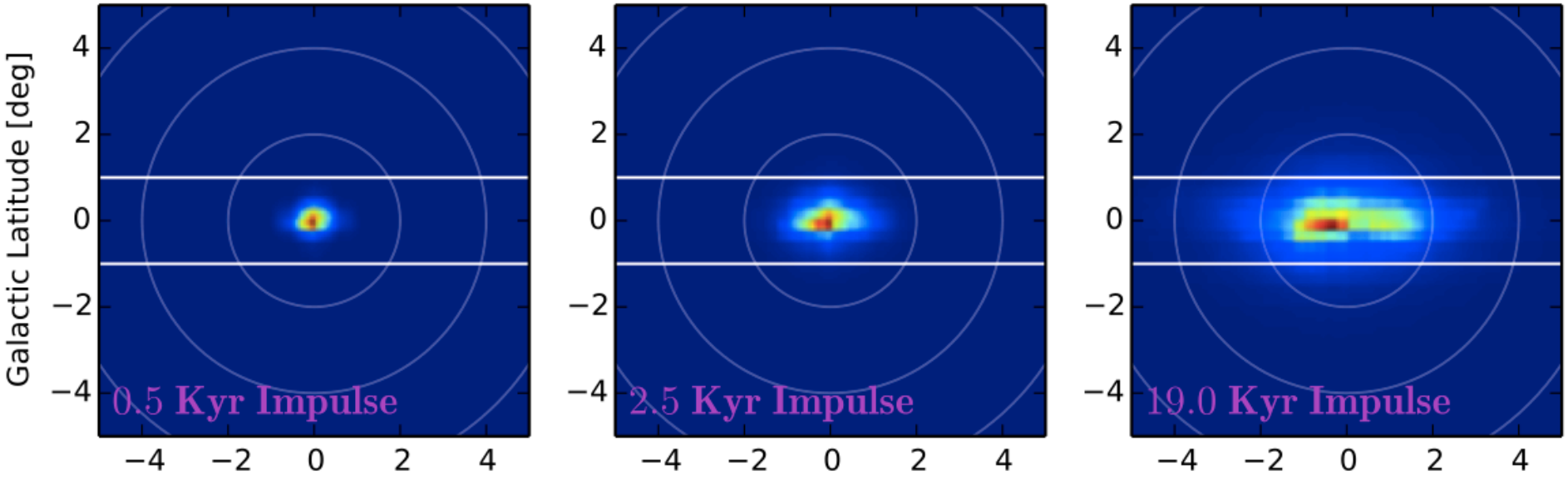
Output flux = (**target** density) x (**incident** flux)

GC excess studies: **Output** flux = (target density)

Recent studies addressed the possible role of **cosmic ray bursts** injected in the GC, which potentially alter the diffuse background dramatically*

* Eric Carlson and Stefano Profumo, 1405.7685, PRD in press; Petrovic et al, 1405.7928

For example, an **additional Cosmic-Ray Proton source** in the Galactic Center region fits the bill! *



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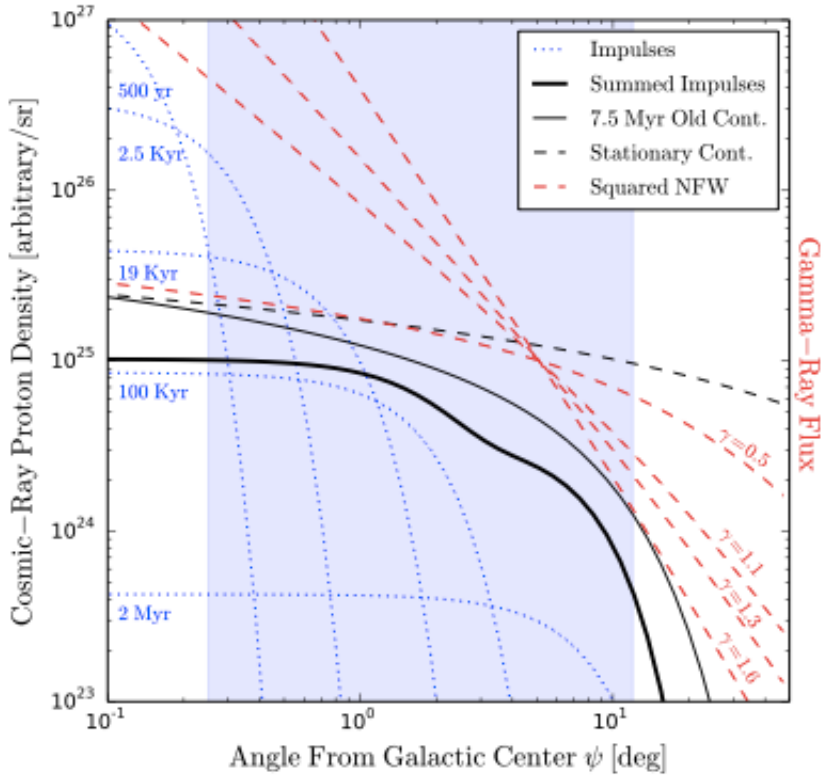

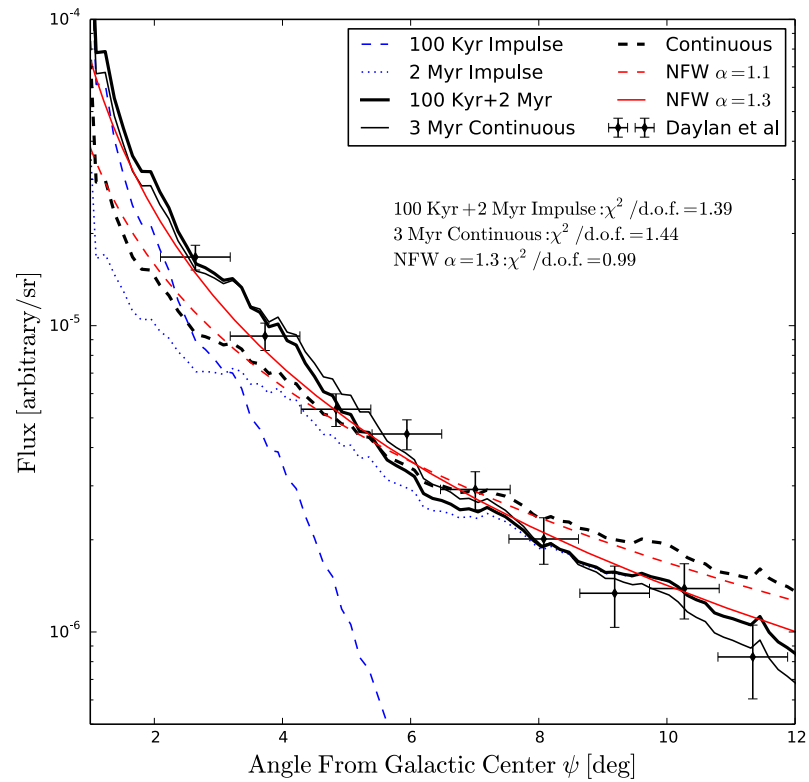

* Eric Carlson and Stefano Profumo, 1405.7685, PRD in press

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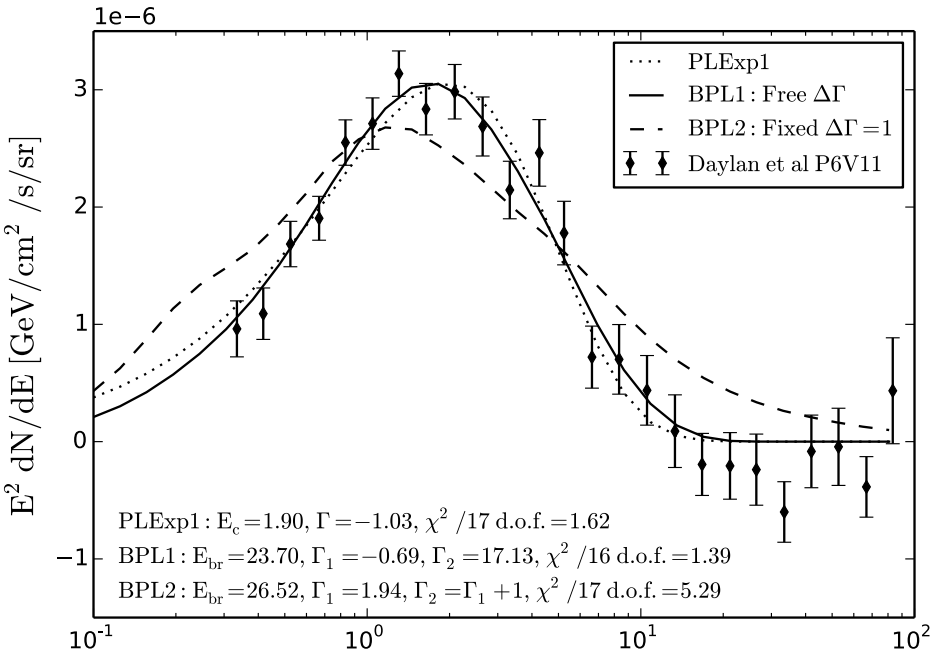

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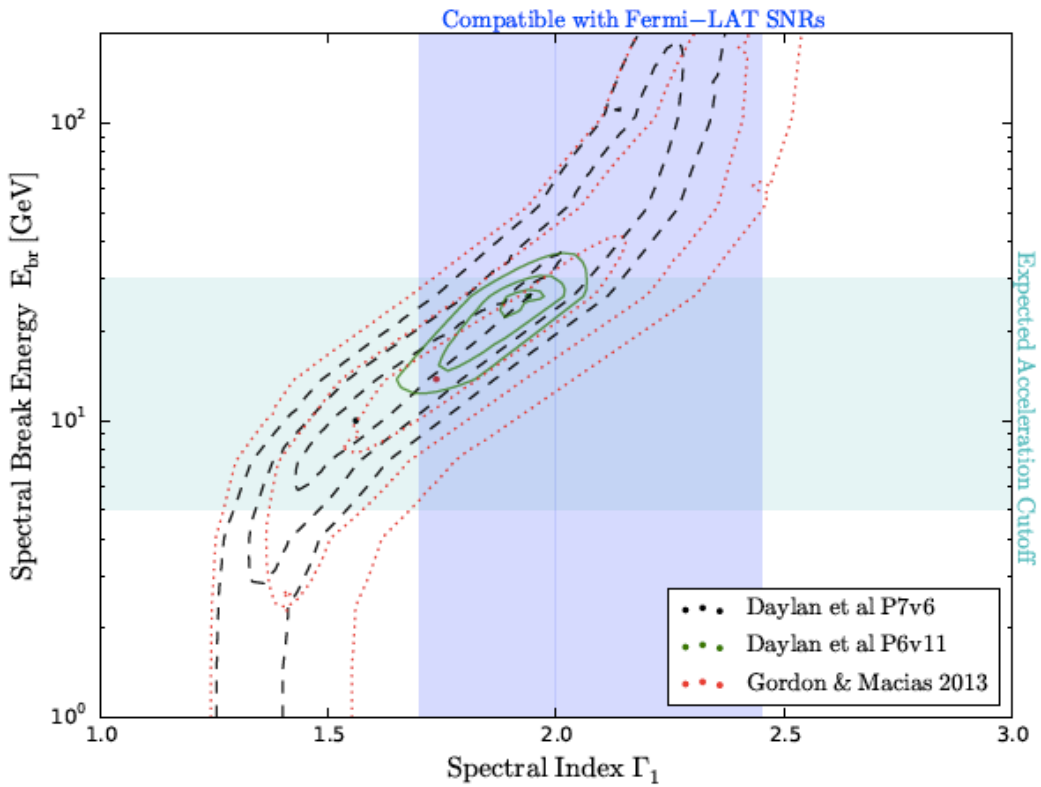

* Eric Carlson and Stefano Profumo, 1405.7685, PRD in press

New constraints from dSph + BH

Systematic **detection** of **Black Holes** in a large sample of **dwarf galaxies**

THE ASTROPHYSICAL JOURNAL, 775:116 (24pp), 2013 October 1 doi:10.1088/0004-637X/7
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DWARF GALAXIES WITH OPTICAL SIGNATURES OF ACTIVE MASSIVE BLACK HOLES

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Received 2013 May 27; accepted 2013 August 12; published 2013 September 13

ABSTRACT

We present a sample of 151 dwarf galaxies ($10^{8.5} \lesssim M_\star \lesssim 10^{9.5}\ M_\odot$) that exhibit optical spectroscopic signatures of accreting massive black holes (BHs), increasing the number of known active galaxies in this stellar-mass range by more than an order of magnitude. Utilizing data from the Sloan Digital Sky Survey Data Release 8 and stellar masses from the NASA-Sloan Atlas, we have systematically searched for active BHs in ~25,000 emission-line galaxies

Gonzalez, Profumo and Queiroz, 1406.2424, PRD sub.

New constraints from dSph + BH

Tentative detections also in **local dSph** (M31 and MW)

Hint for a faint intermediate mass black hole in the Ursa Minor dwarf galaxy

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INFN, Sez. di Lecce, via Per Arnesano, CP 193, I-73100 Lecce, Italy

HIGHLIGHTS

- Analysis of a Chandra observation of the Ursa Minor galaxy.
- Possible identification of an X-ray source (possibly a BH) associated to a radio object.
- Using several fundamental planes, a possible range of the BH mass is found.
- The BH seems to radiate at a very tiny fraction of the associated Eddington luminosity.

ARTICLE INFO

Article history:
Received 16 November 2012

ABSTRACT

We report the results of the analysis of an archive *Chandra* observation of the Ursa Minor spheroidal g
axv. one of the closest Milkv

The Astrophysical Journal, 628:137–152, 2005 July 20
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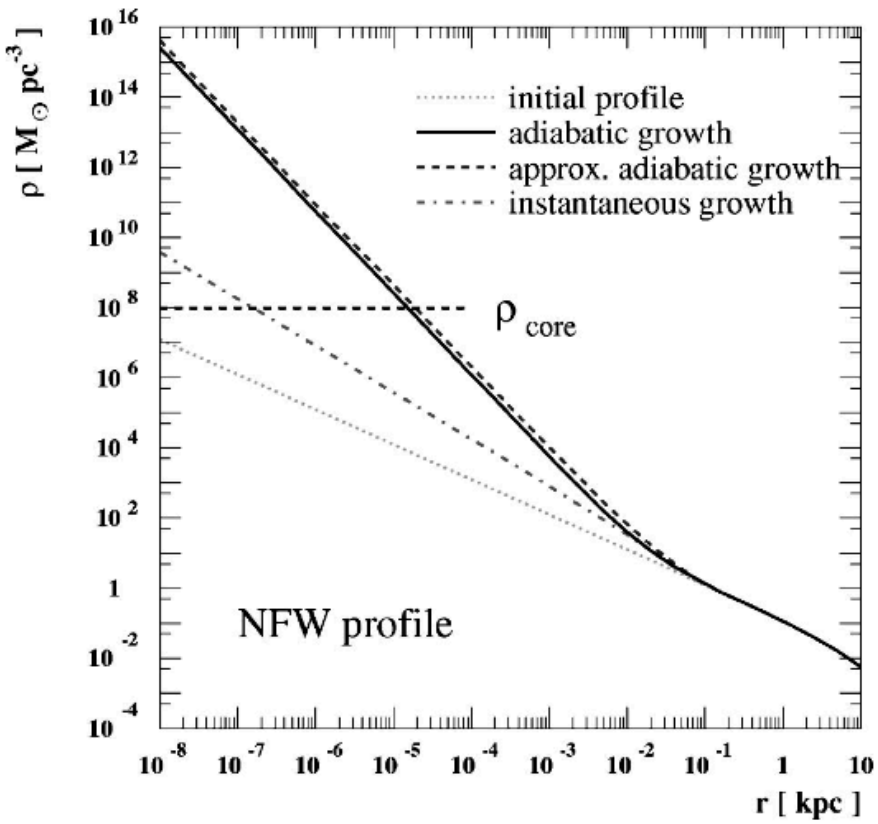
THE LOW END OF THE SUPERMASSIVE BLACK HOLE MASS FUNCTION: CONSTRAINING THE MASS OF A NUCLEAR BLACK HOLE IN NGC 205 VIA STELLAR KINEMATICS

Monica Valluri,[1] Laura Ferrarese,[2,3] David Merritt,[4] and Charles L. Joseph[2]
Received 2004 July 19; accepted 2005 March 30

ABSTRACT

Hubble Space Telescope (*HST*) images and spectra of the nucleated dwarf elliptical galaxy NGC 205 are combined with three-integral axisymmetric dynamical models to constrain the mass M_{BH} of a putative nuclear black

Given an initial DM density profile, and an **adiabatically** accreting **Black Hole**, the DM profile adiabatically **steepens** around the central BH



Adiabatic **invariants**, with spherical symmetry

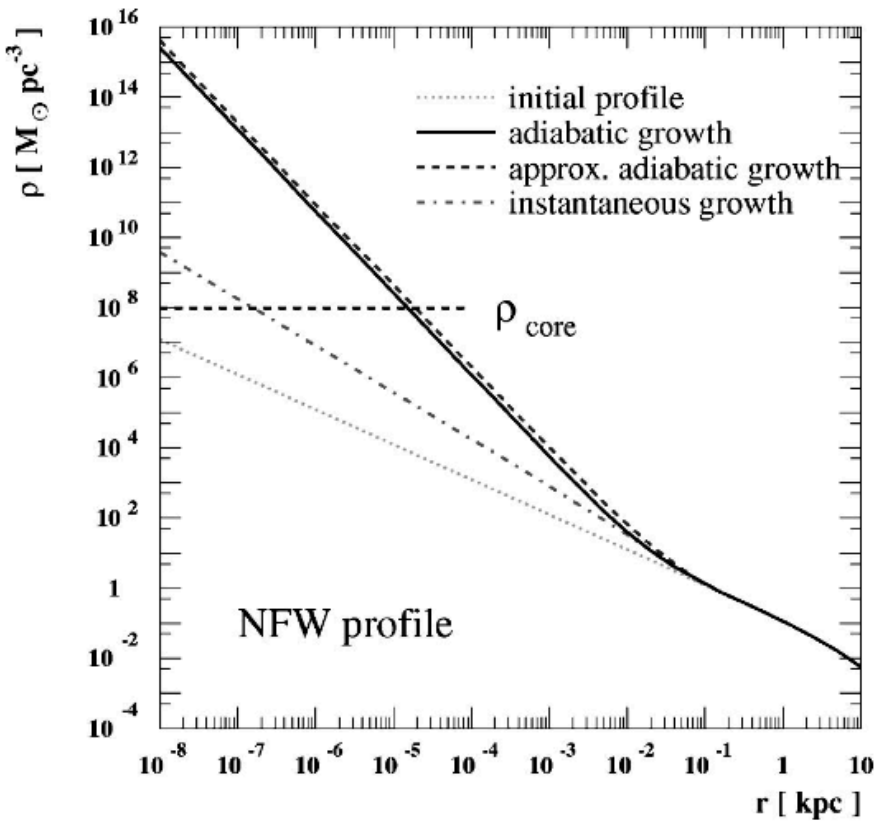
$$L_f = L_i \equiv L$$

$$J_{r,f}(E_f, L) = J_{r,i}(E_i, L)$$

$$J_r(E,L) = \frac{1}{\pi}\int_{r_{\min}}^{r_{\max}} dr\, v_r$$

Ullio, Zhao, Kamionkowski, 2001

Given an initial DM density profile, and an **adiabatically** accreting **Black Hole**, the DM profile adiabatically **steepens** around the central BH



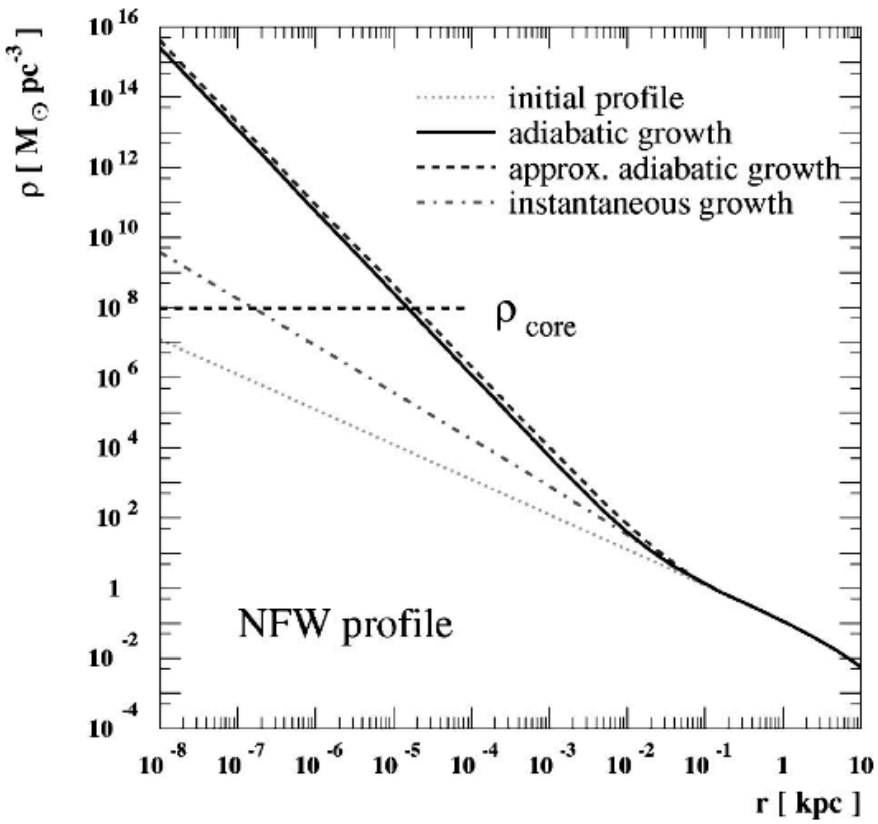
Maximal density is **cut off** by **annihilation** processes (dep. on mass and annihilation cross sec.)

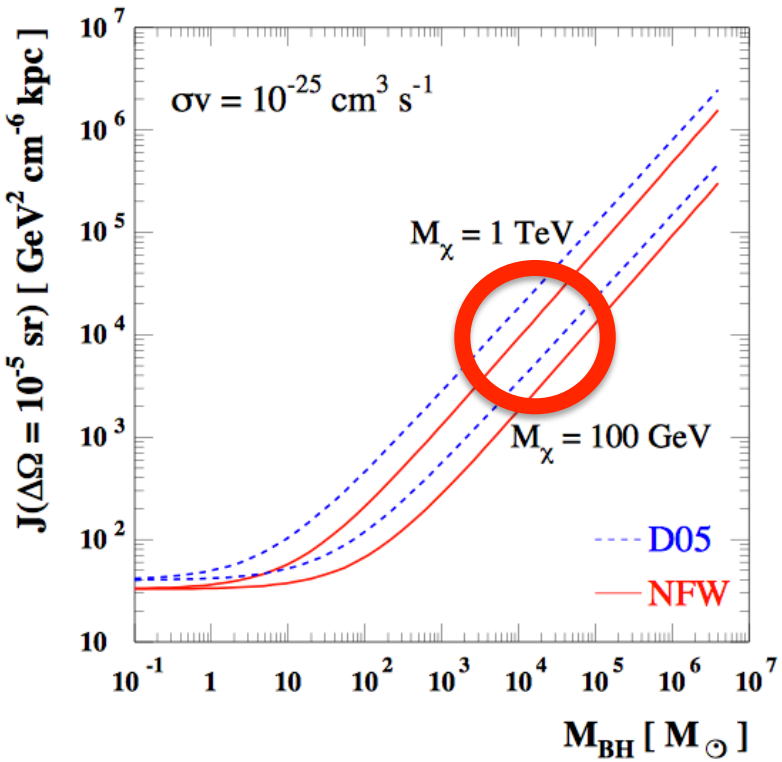
$$\rho_{\rm core} = m/\sigma v t_{\rm bh}$$

$$\rho_{\rm max} = 3 \times 10^{18} \left(\frac{m_\chi}{100{\rm GeV}}\right) \left(\frac{10^{-26}{\rm cm}^3{\rm s}^{-1}}{\langle \sigma v \rangle}\right) {\rm M}_\odot {\rm kpc}^{-3}.$$

Ullio, Zhao, Kamionkowski, 2001

Resulting number of **DM particle pairs** along line of sight is **dramatically increased**





Colafrancesco, Profumo, Ullio, 2006

Three bracketing choices for M_{bh} attribution

(i) Magorrian '98

$$M_{\rm bh} = 0.0013 L_* \qquad M_*/L_* = 1$$

(ii) Tremaine '02

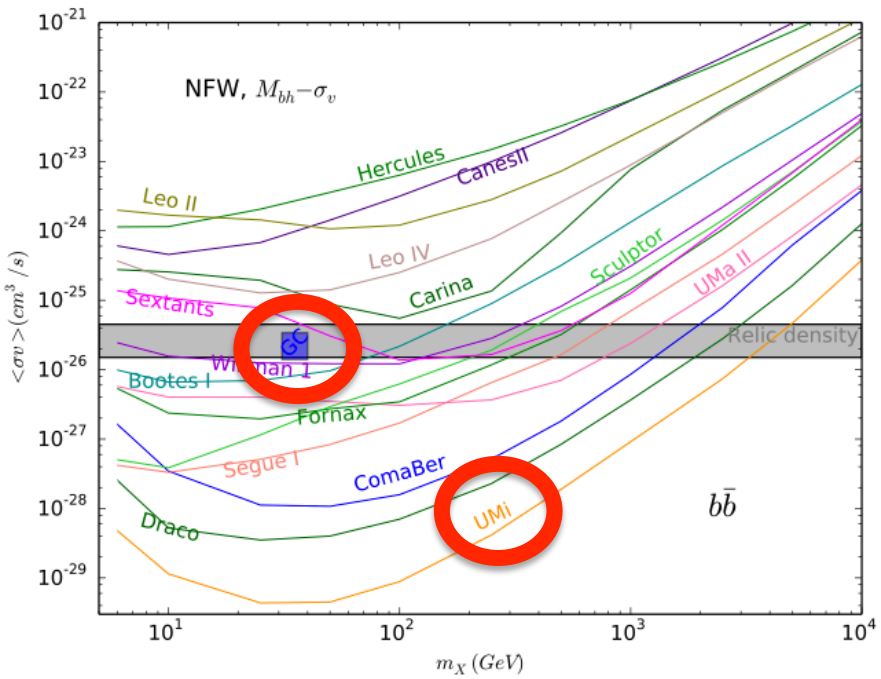
$$\frac{M_{\rm bh}}{\rm M_\odot} = \begin{cases} 10^{6.91}\left(\frac{\sigma_*}{100\,{\rm km/s}}\right)^4 & (\sigma_* \geq 6\,{\rm kms}) \\ 100 & (\sigma_* < 6\,{\rm km/s}). \end{cases}$$

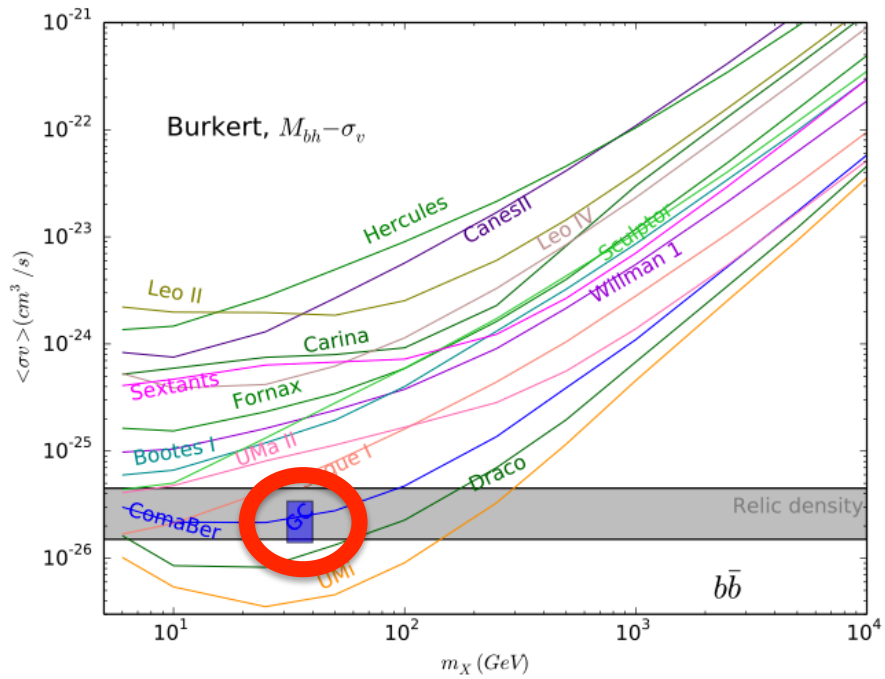
(iii) McConell & Ma '13

$$\frac{M_{\rm bh}}{\rm M_\odot} = \begin{cases} 10^{8.32}\left(\frac{\sigma_*}{200\,{\rm kms^{-1}}}\right)^{5.64} & (\sigma_* \geq 15\,{\rm kms}) \\ 100 & (\sigma_* < 15\,{\rm km/s}) \end{cases}$$

Constraints from **Individual** dSph

bb final state, Tremaine rel, NFW (left) vs Burkert (right)

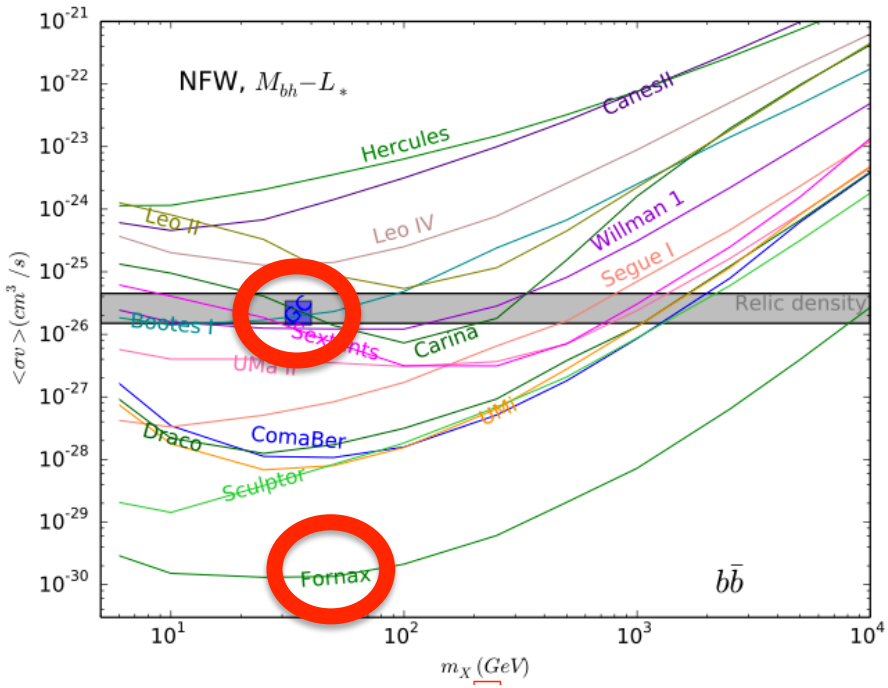


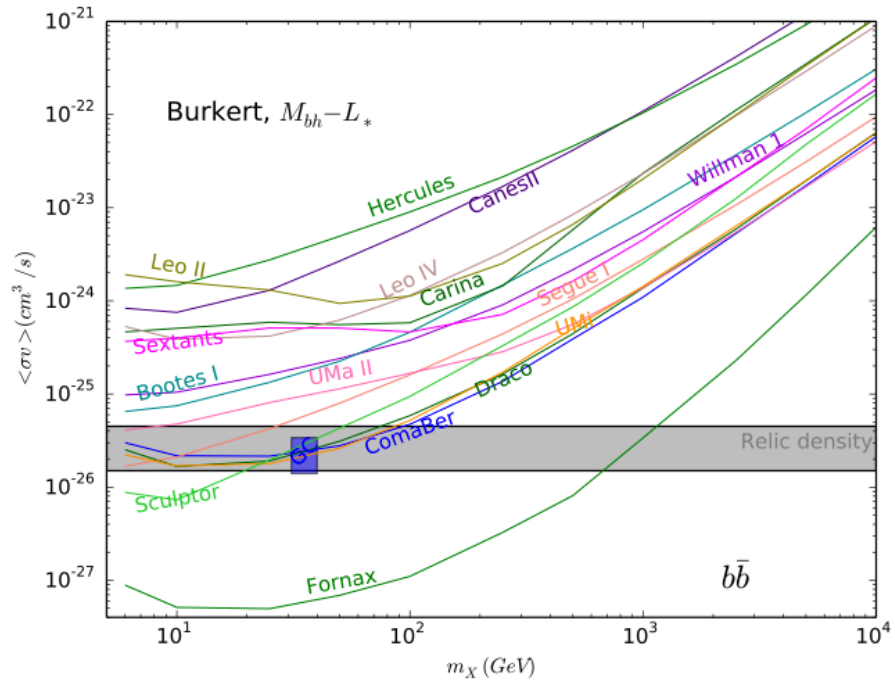


Gonzalez, Profumo and Queiroz, 1406.2424, PRD sub.

Constraints from **Individual** dSph

*bb final state, **Magorrian** rel, NFW (left) vs Burkert (right)*

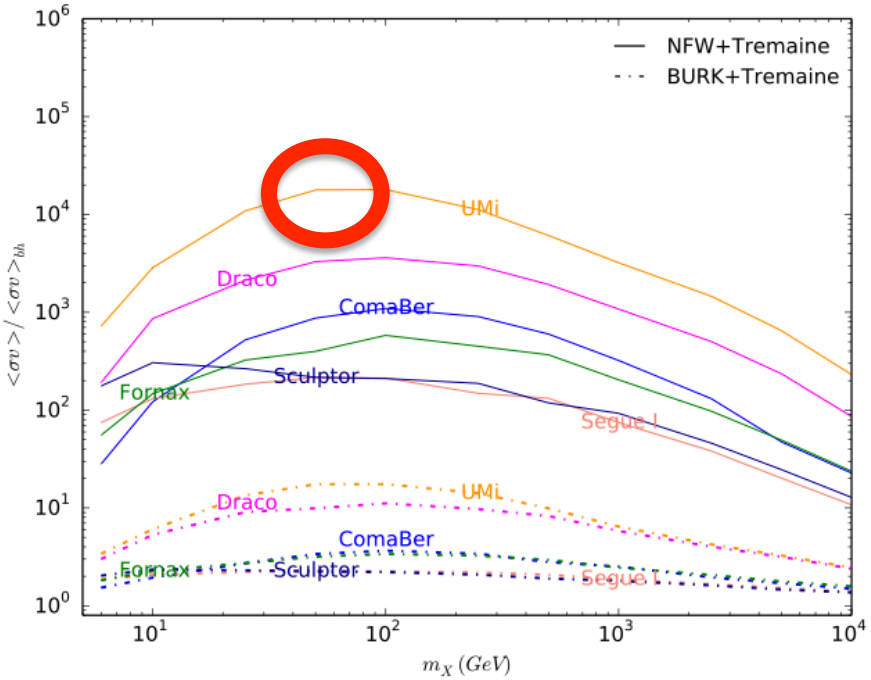


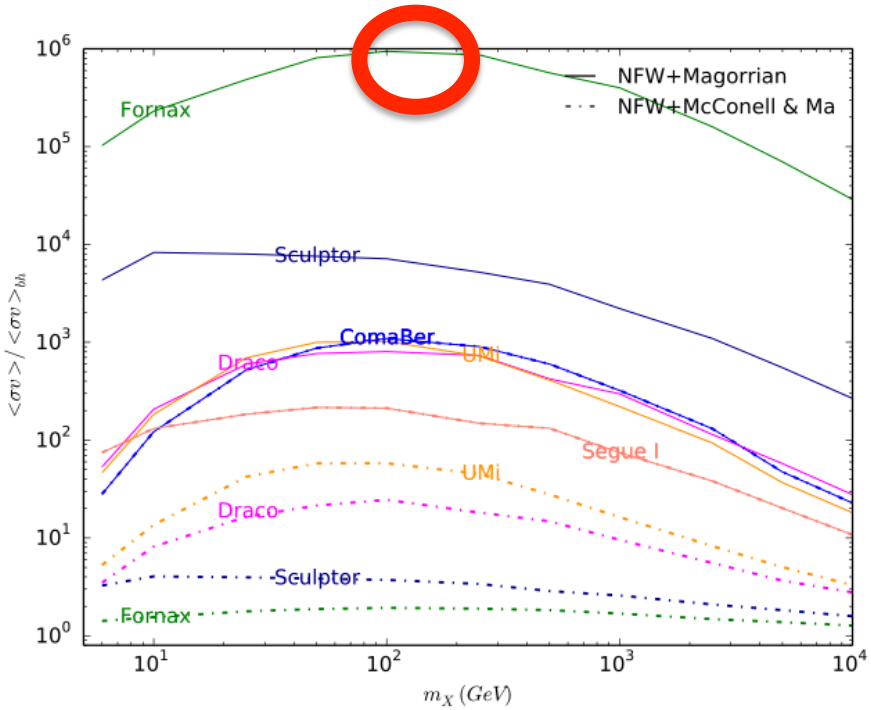


Gonzalez, Profumo and Queiroz, 1406.2424, PRD sub.

Relative Constraints from **Individual** dSph

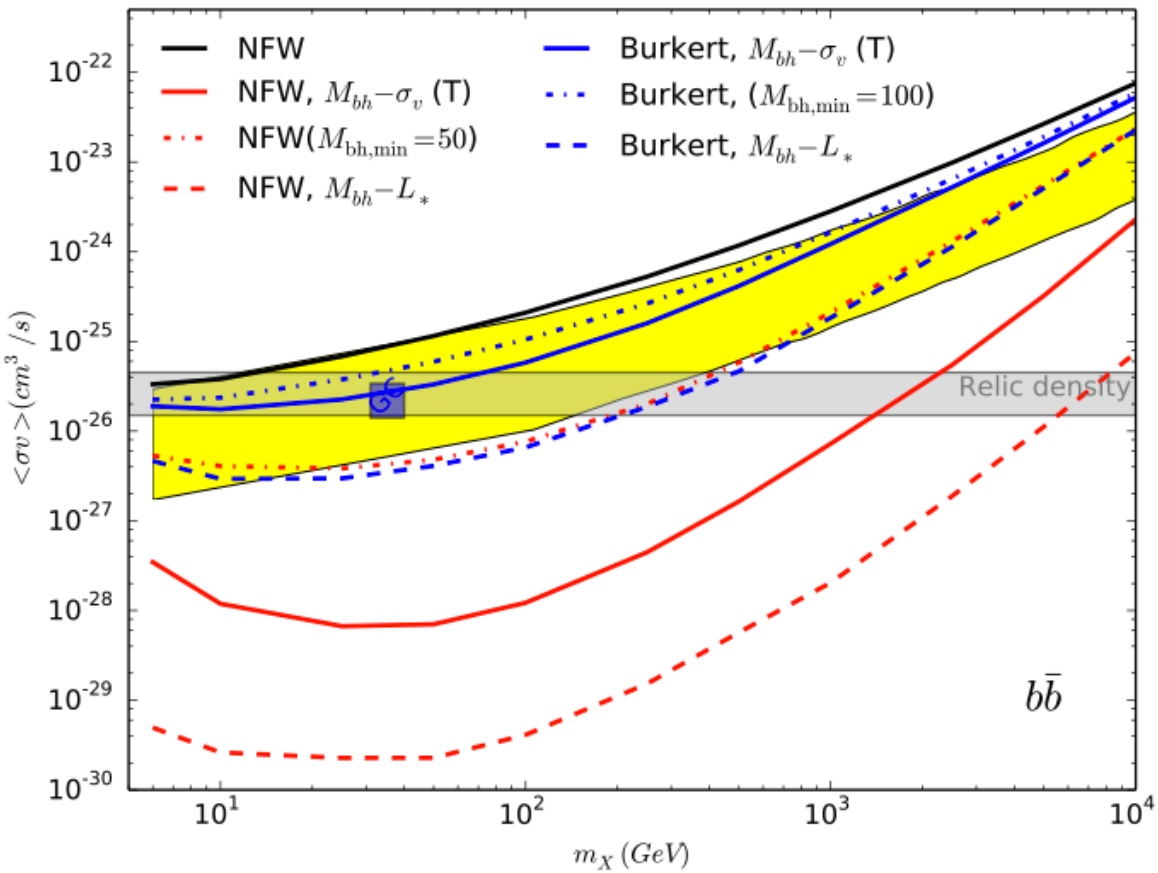
bb final state, NFW + Burkert (left), Magorrian vs McC&Ma (right)





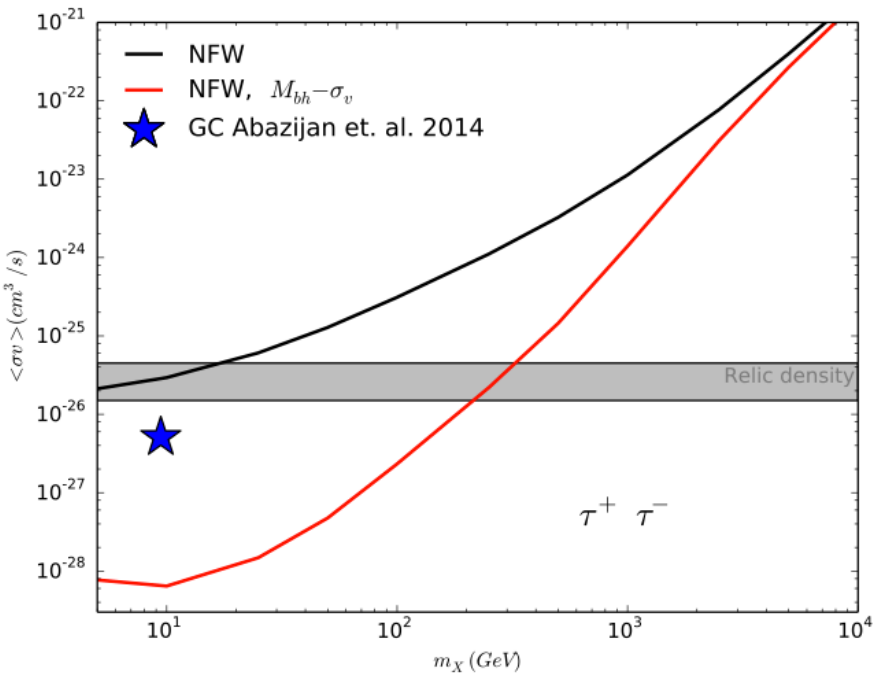
Gonzalez, Profumo and Queiroz, 1406.2424, PRD sub.

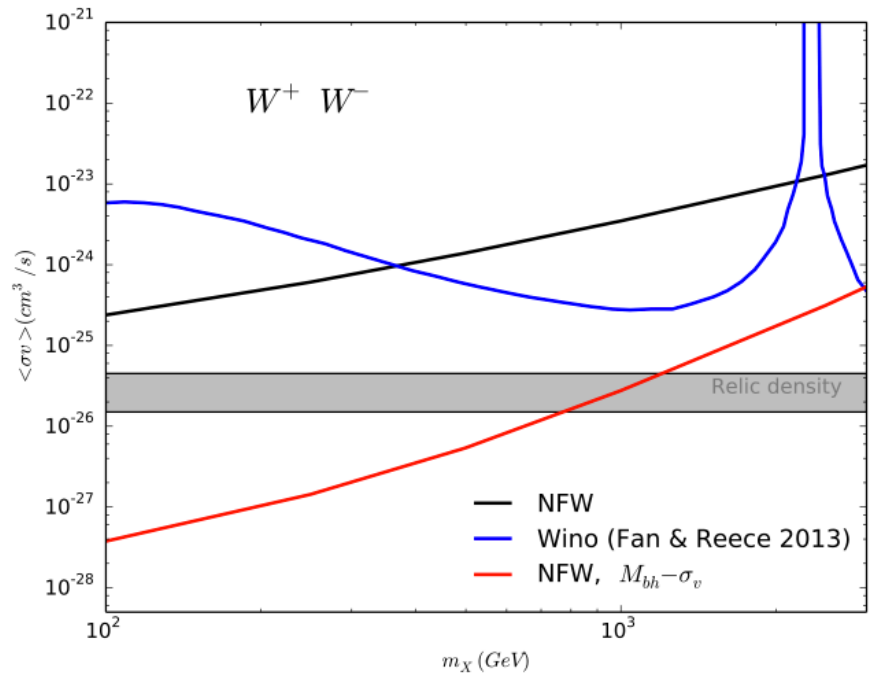
Combined constraints from 15 dSph



Gonzalez, Profumo and Queiroz, 1406.2424, PRD sub.

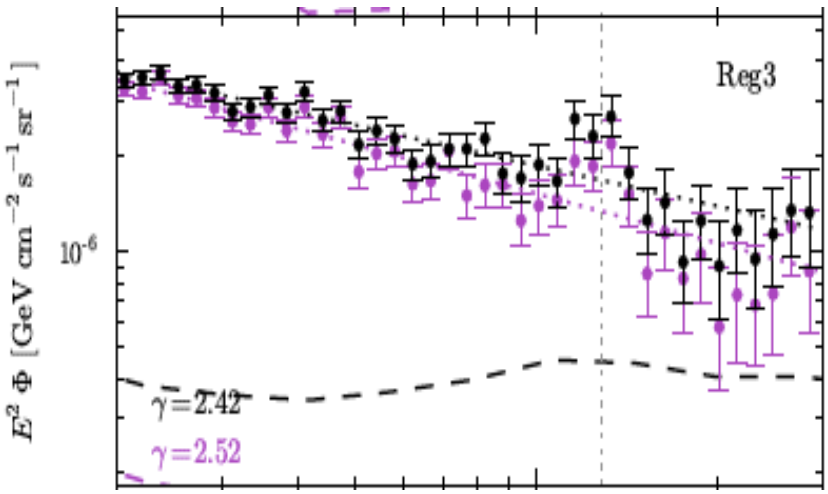
Combined constraints from 15 dSph
implications for specific particle physics models



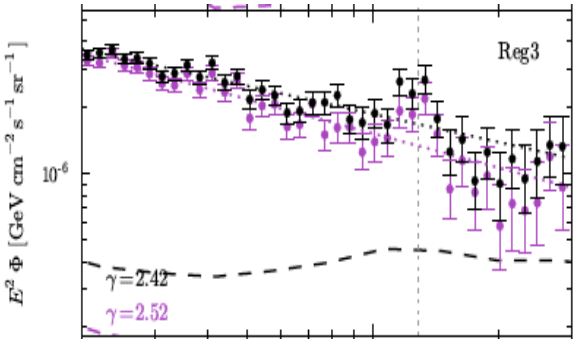


Gonzalez, Profumo and Queiroz, 1406.2424, PRD sub.

The Gamma-Ray Line



“Troubling and Inconclusive”

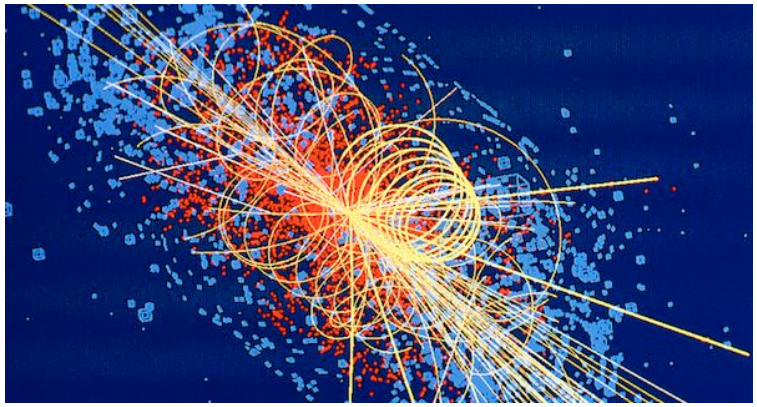


Steve Ritz (UCSC)
former Fermi-LAT Deputy PI

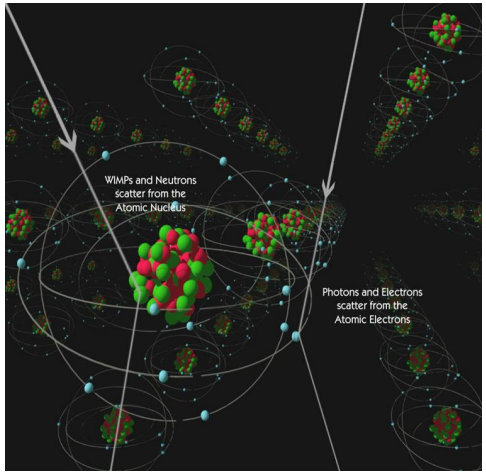
If confirmed, huge **impact** on **particle physics**!

DM particle at rest, so $\chi\chi \rightarrow \gamma\gamma$ implies $\mathbf{E_\gamma = m_\chi}$!

m_χ sets the **missing energy** scale for **collider** studies

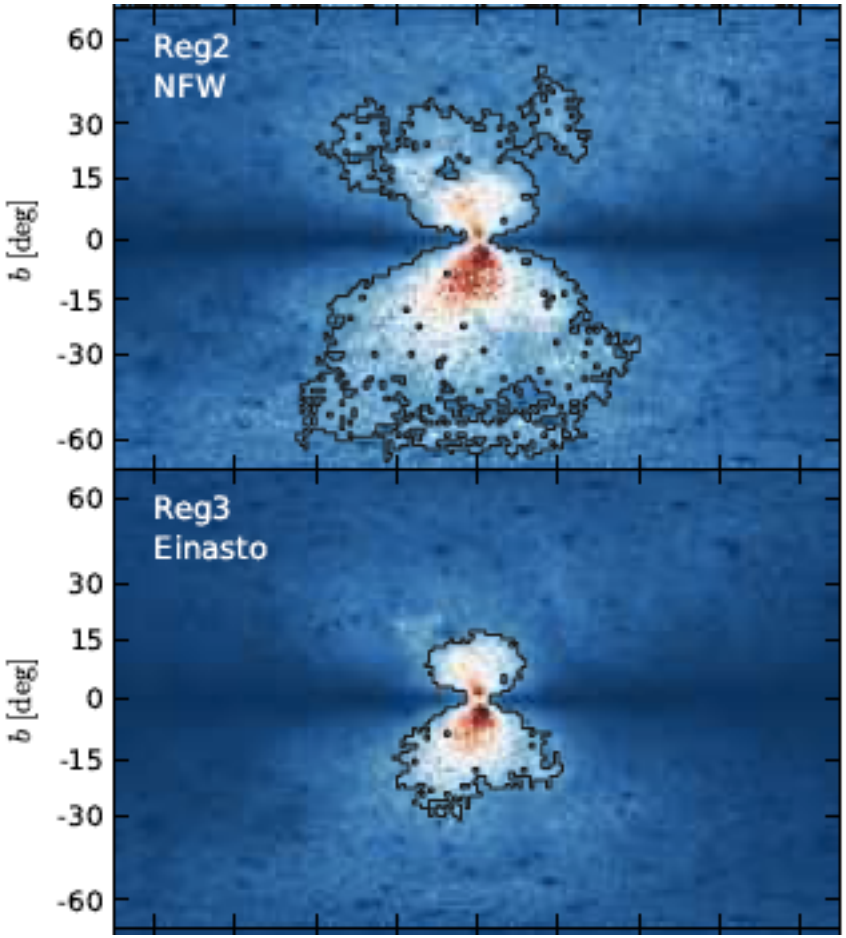


...and the target mass for **direct detection** experiments!



Weniger (1204.2797)

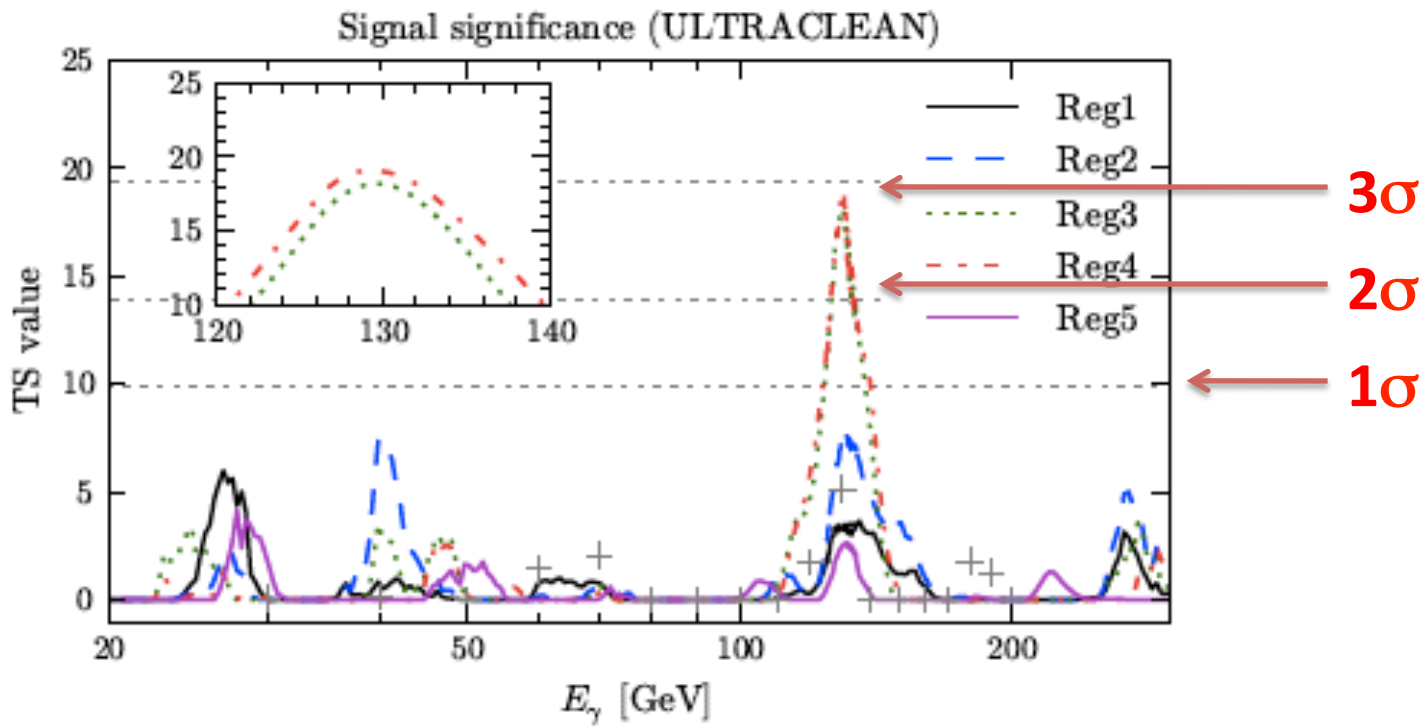
Key novelty: **optimized** Regions of Interest



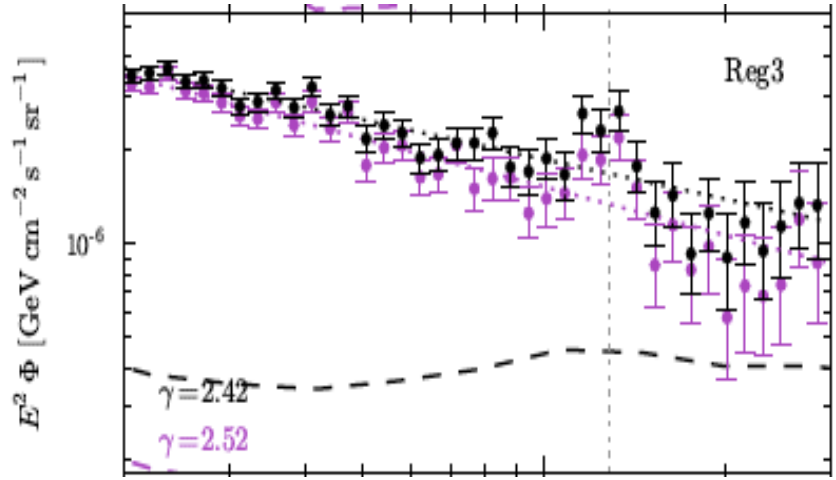
Signal: $\sim(\rho_{DM})^2$

Noise: $(1\text{-}20\ \text{GeV sky})^{1/2}$

(almost) **3σ effect**, E_γ=**130 GeV**
look-elsewhere effect accounted for



could it be an
instrumental effect?



One culprit could be **energy reconstruction**:
E>130 GeV mis-read as E=130 GeV event!

Instr. effects under investigation by Fermi Collaboration,
including troubling **Earth's Limb** feature!
[**Pass 8**: currently being tested internally/public soon]

If not instrumental, potentially **very interesting**
wait for **more statistics** (so far ~50 photons)!

can we hope for more statistics with **other** existing/near future **telescopes**?

Fermi: $A_{eff} x T_{obs} = (1\ m^2) \times 4\pi x 10^7 \times (1/6)\ s \sim$ **$2x10^7\ m^2\ s$**

ACT, with 100h: $(10^5\ m^2) \times 100x60x60\ s \sim$ **$3x10^{10}\ m^2\ s$**

e.g., HESS: promising,
but **A_{eff}** rapidly **declining**
in energy region of interest

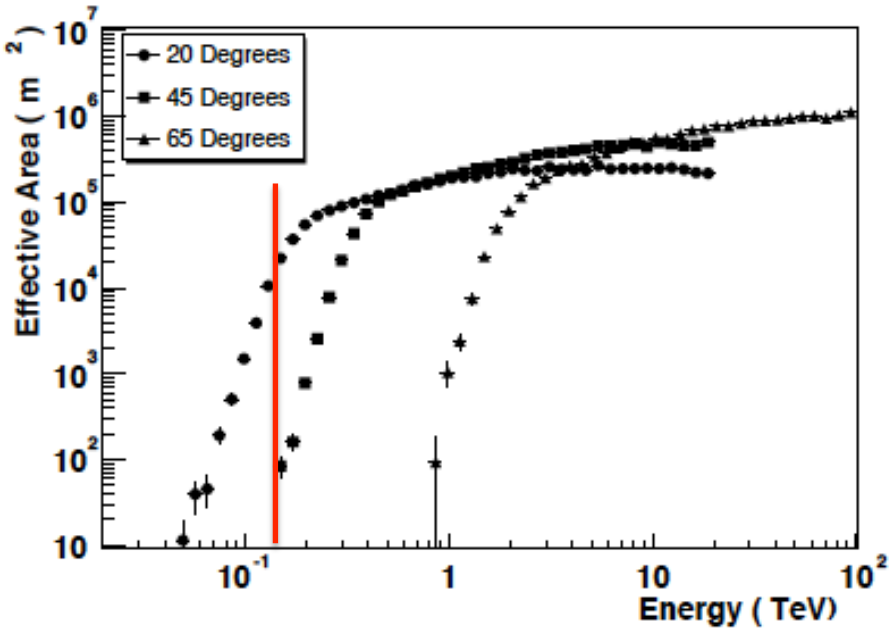
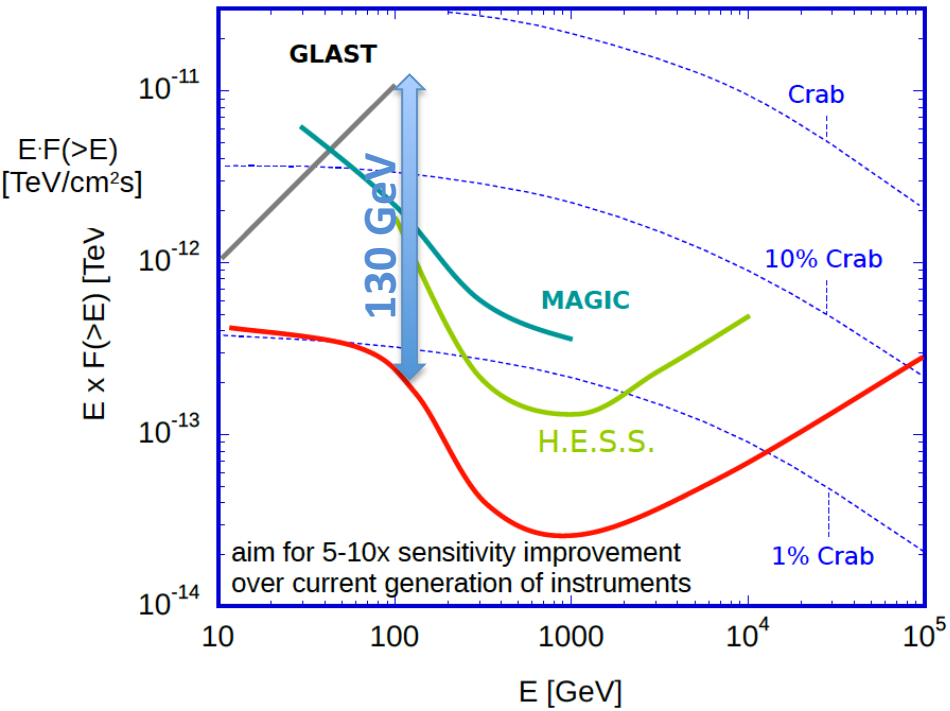
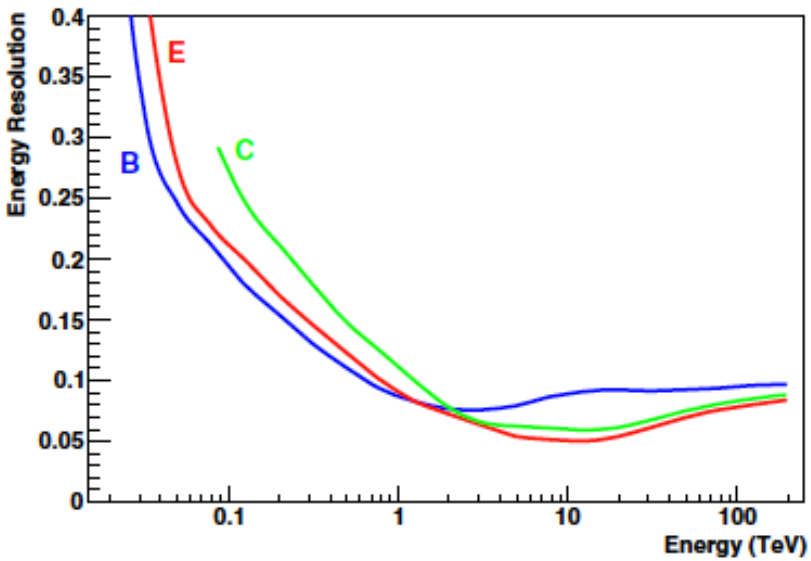


Figure credit: Benow, for HESS collaboration

CTA: superior energy resolution, angular resolution, energy threshold and effective area





Cherenkov Telescopes will be **key** for further studies of the **line**

Astrophysical backgrounds?

Always keep **Occam** in mind!

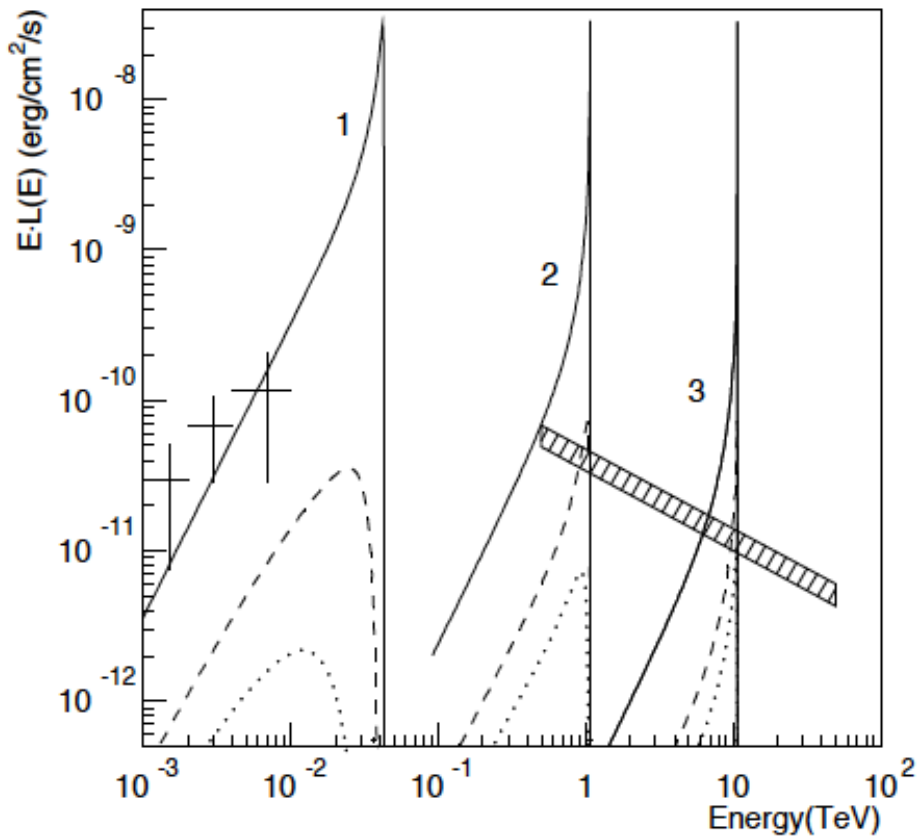
Klein-Nishina regime: almost all energy transferred from e to γ → $\mathbf{E_e \sim 130\ GeV}$

Need~ mono-chromatic electrons and target photons with $\omega_0 >> m_e^2/E_e \sim$ **2 eV**

Both OK with **electron pulsar wind**

Aharonian et al, 2012; image credit: NASA

This is **not** a **POST-diction**!



Bogovalov and Aharonian, **2000**

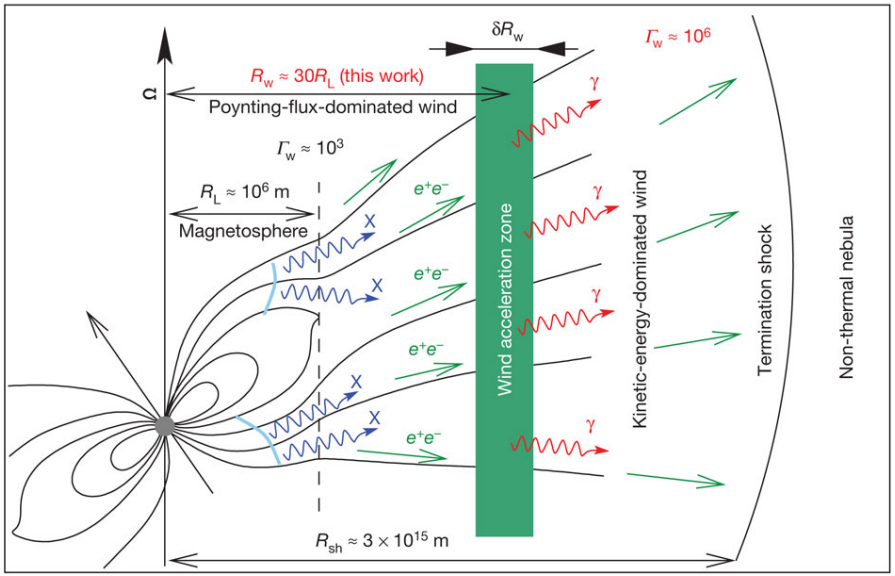
Energetics works out fine!

130 GeV line luminosity ~ **3×10^{35} erg/s**

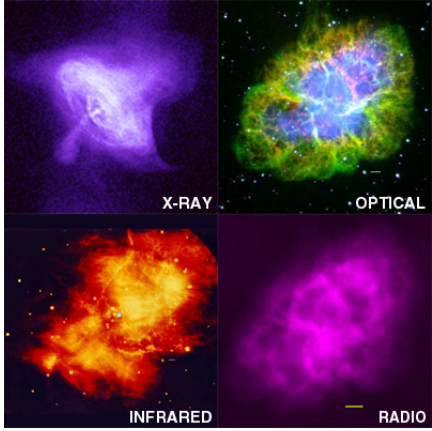
Crab luminosity in shock-acc. e^+e^- ~ **3×10^{38} erg/s**

[spin-down luminosity~ 5×10^{38} erg/s]

efficiency to produce gamma rays??



Aharonian et al, Nature 2012

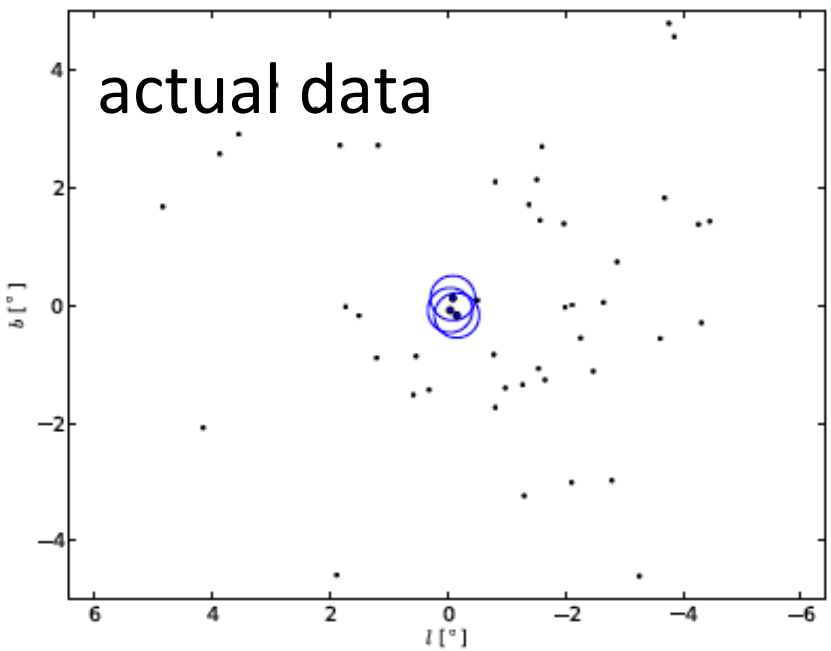


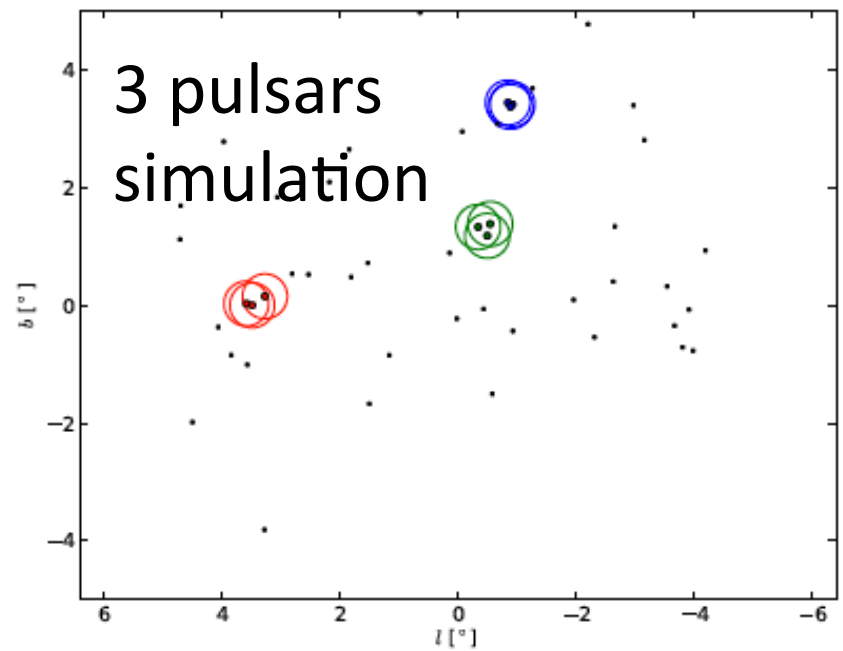
Many open questions…

- **how many** point sources are needed?

- if more than one astrophysical source is needed, do we expect **130 GeV** to be a **special** universal **value**?

Applied a **clustering algorithm** (DBSCAN) and demonstrated one needs at least **5 pulsars** (@90%CL)





Astrophysical backgrounds are **unlikely**, given current data!

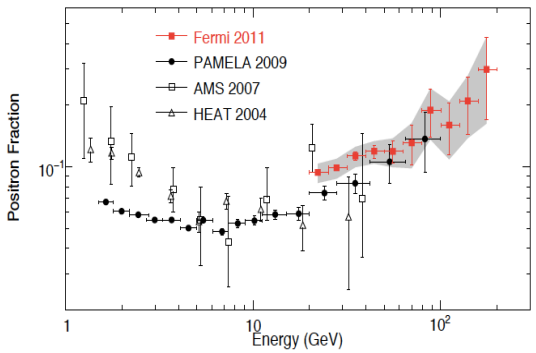
Carlson, Linden, Profumo and Weniger, 1304.5524, **Phys.Rev. D88 (2013) 043006**

Unfortunately, the **accumulated significance** is not fueling enthusiasm…

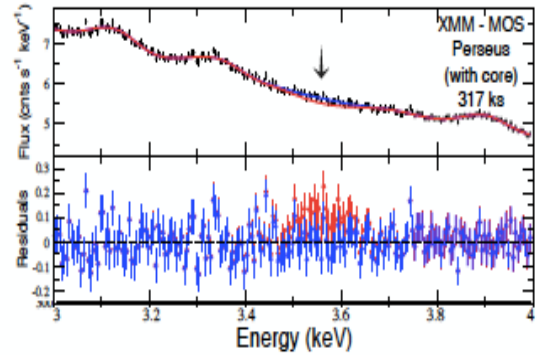
Still I think this is the **only** potentially "**robust**" signal (if only there were a signal!)

Weniger, 2014

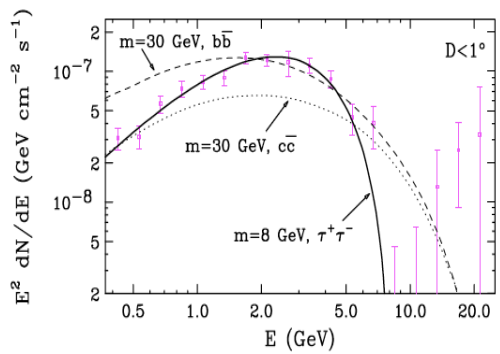
Cosmic-Ray Positron Excess



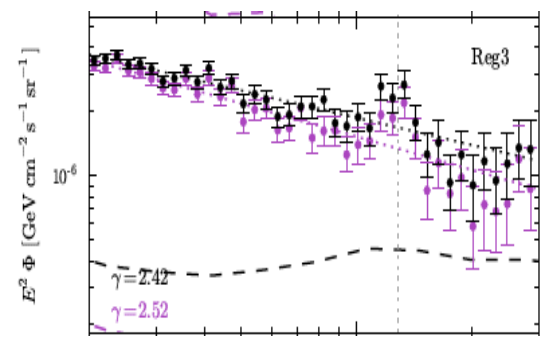
3.5 keV line



Gamma-ray excess in the Galactic Center



A 130 GeV line



The promenades of Euclid

…an appropriate adage for indirect dark matter detection :

"Everything we see hides another thing,

we always want to see what is hidden by what we see"

R. Magritte

[slide concept: Pasquale Serpico]

Sample text here

Sample text here

$$\frac{\partial f}{\partial t} - D(E)\Delta f + \frac{\partial}{\partial E}\left(b(E)f\right) = Q(\vec{r}, E, t)$$

$$Q(E) \sim \delta(\vec{r} - \vec{r}_0)\delta(t - t_0)\delta(E - m_\chi), \quad \text{with} \quad |\vec{r} - \vec{r}_0| = d,$$

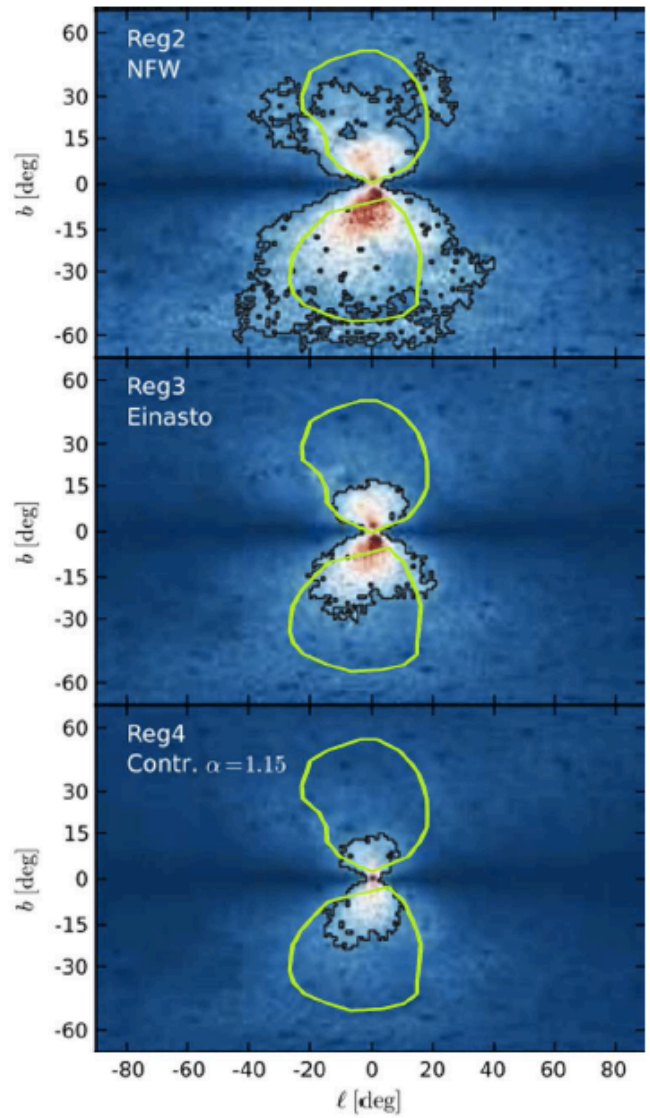
$$\mathcal{L} \equiv \frac{\langle \sigma v \rangle}{2m_\chi^2} L_{\text{clump}} \qquad L_{\text{clump}} \equiv \int_{\text{clump}} \rho_{\text{DM}}^2 \, \mathrm{d}^3 x,$$

$$\phi_\gamma > \left(\frac{10^{-2}}{\Delta}\right) \frac{5 \times 10^{-10}}{\text{GeV cm}^2 \text{ s}} \gg \phi_\gamma^{\text{Fermi},5\sigma} \simeq \frac{\text{few} \times 10^{-11}}{\text{GeV cm}^2 \text{ s}}$$

$$I_{\text{max}} + I_{\text{min}}$$

Two remarks*

(1) ROI's overlap with **Fermi bubbles**: photons from bubbles are important **background**

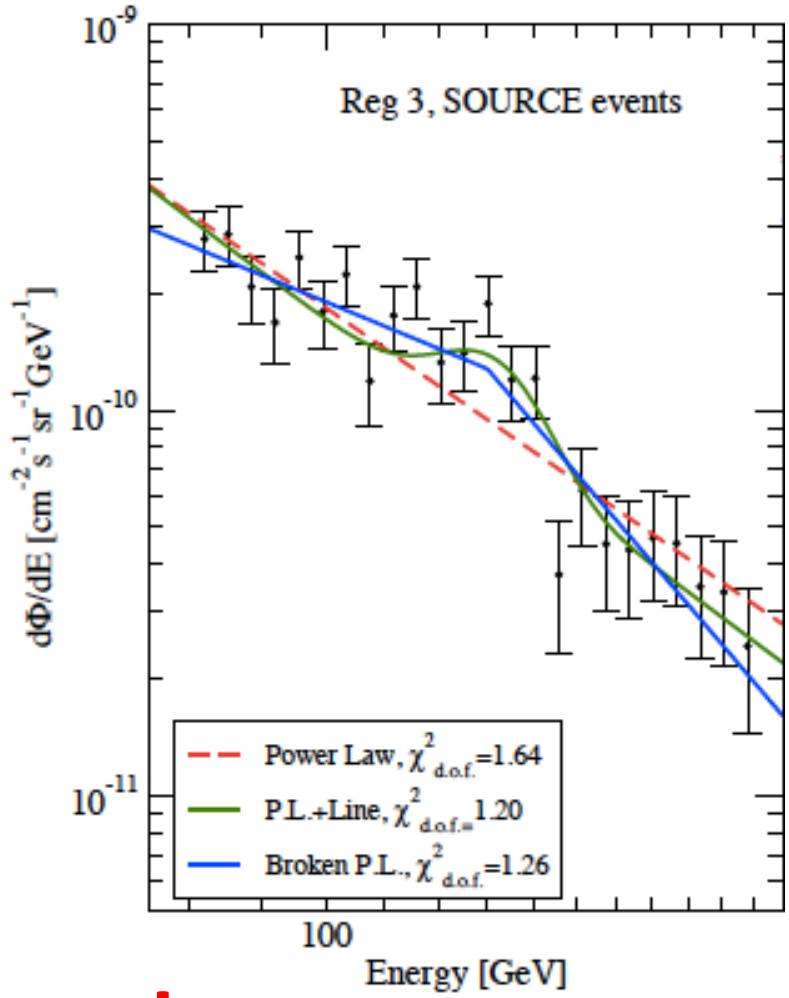


* Profumo and Linden, "Gamma-Ray Line in the Fermi Data: is it a Bubble?", JCAP 2012

Two remarks*

(1) ROI's overlap with **Fermi bubbles**: photons from bubbles are important **background**

(2) broken power-law could be **mistaken** for a **line** - Fermi bubbles have **broken power-law spectrum**



* Profumo and Linden, "Gamma-Ray Line in the Fermi Data: is it a Bubble?", JCAP 2012

A quick history of the discovery of **Dark Matter** in the **Galactic Center**

Oct. 2009

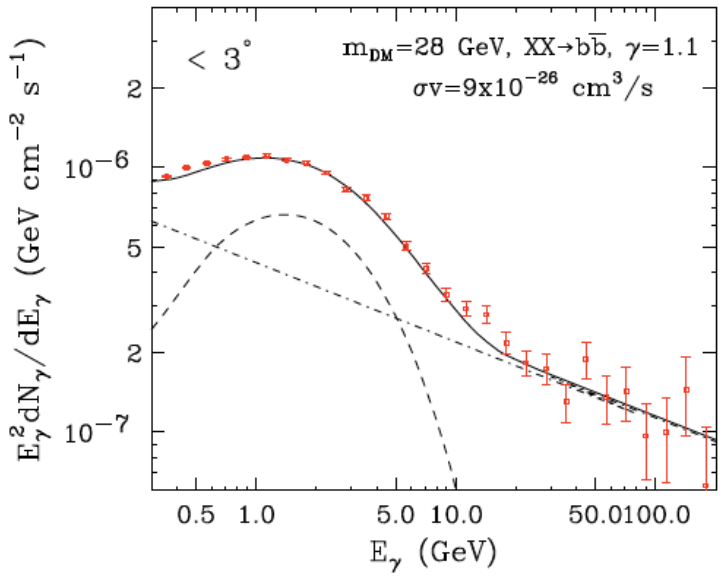
Goodenough, Hooper

Background

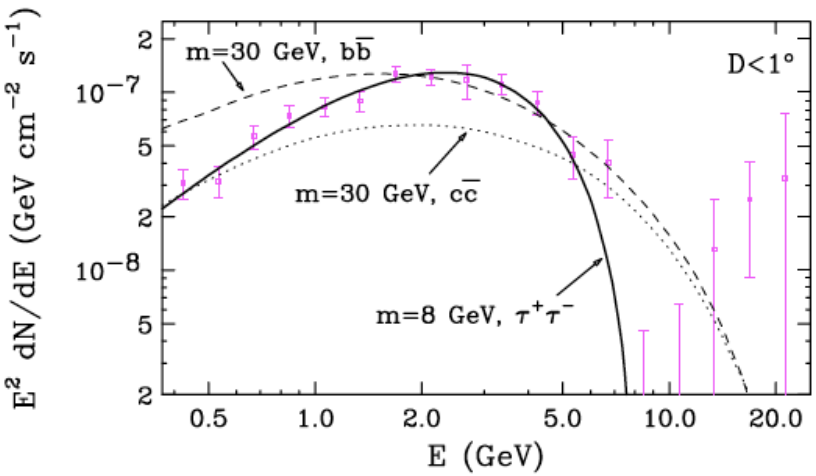
Exponential angular fall-off
Power-law spectrum

Dark Matter particle

28 GeV, bb quark



	Background	Dark Matter particle
Oct. 2009 Goodenough, Hooper	*Exponential angular fall-off* *Power-law spectrum*	*28 GeV, bb quark*
Oct. 2010 Hooper, Goodenough	*$r^{-1.55}$ fall-off* Spectrum: extracted from >2deg region	*8 GeV, $\tau^+\tau^-$*



How shall the new Dark Matter particle be called?

"Goodenough Hooperon"

The Effective Hooperon

Alexandre Alves,[1] Stefano Profumo,[2] Farinaldo S. Queiroz,[2] and William Shepherd[2]

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Universidade Federal de São Paulo, Diadema-SP, 09972-270, Brasil

[2]*Santa Cruz Institute for Particle Physics and Department of Physics,*

University of California Santa Cruz, Santa Cruz CA, USA

(Dated: March 21, 2014)

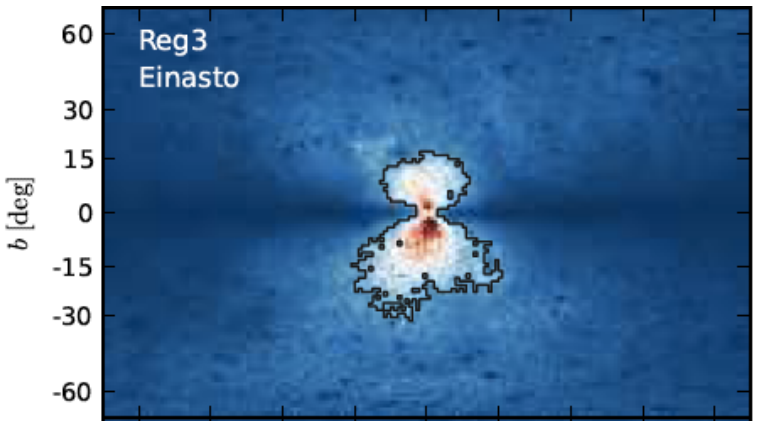
20 Mar 2014

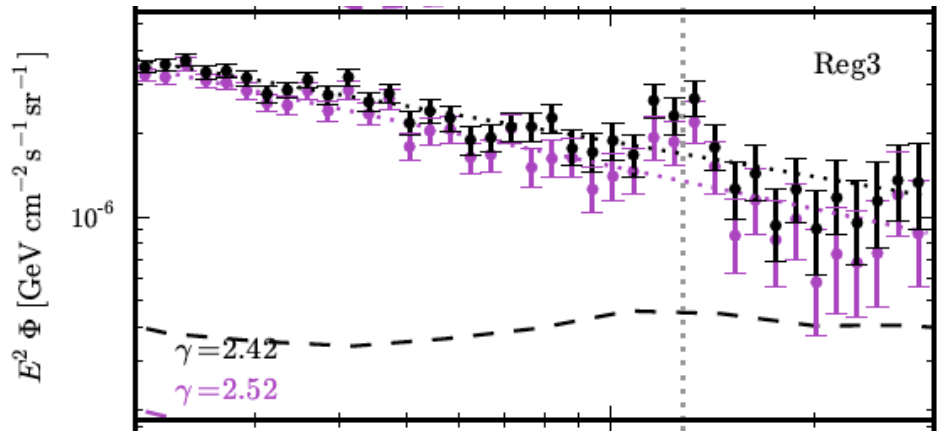
Abstract

We explore the possibility of explaining a gamma-ray excess in the Galactic center, originally pointed out by Hooper, collaborators, and other groups, in an effective field theory framework. We assume that dark matter annihilation is mediated by particles heavy enough to be integrated

	Background	Dark Matter particle
Oct. 2009 Goodenough, Hooper	*Exponential angular fall-off* *Power-law spectrum*	*28 GeV, bb quark*
Oct. 2010 Hooper, Goodenough	*$r^{-1.55}$ fall-off* *Spectrum: extracted from >2deg region*	*8 GeV, $\tau^+\tau^-$*
Oct. 2011 **Linden (UCSC)**, Hooper	*Angular distrib: gas maps* *Spectrum from: π^0 decay plus point-source*	***~10 GeV,*** *$\tau^+\tau^-$ or bb,* *or generic* ***diffuse excess***

A model that does everything





- **Line** with right cross section
- Suppressed GR **continuum**
- Right **Higgs** mass
- Right Thermal **Relic Density**

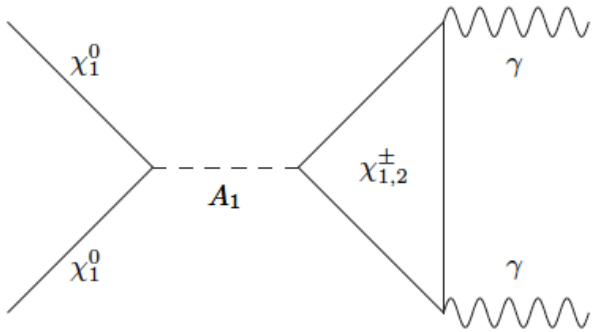
- Successful **EW Baryogenesis**
- Strongly first order **EWPT**
- OK with direct detection
- OK with SUSY searches
- OK with EDM searches

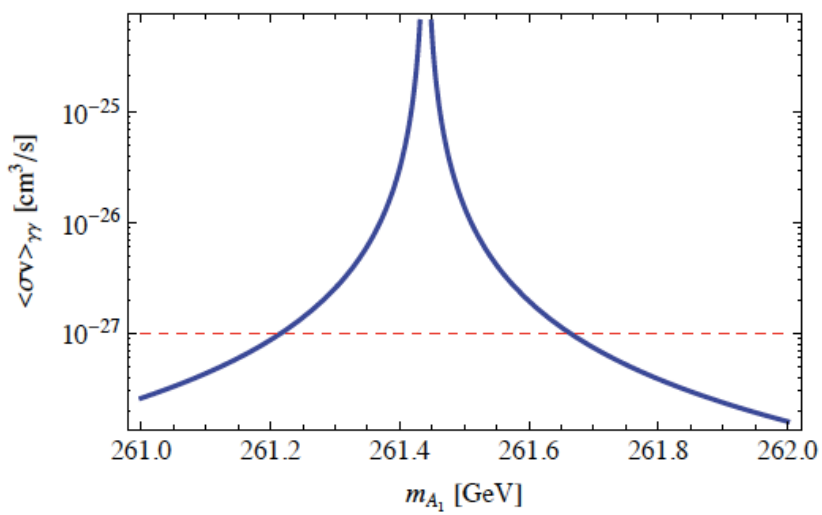
Weniger, 2012; Kozaczuk, Profumo and Wainwright 2013

A model that does everything

$$W = W_{\rm MSSM}|_{\mu=0} + \lambda \widehat{S}\widehat{H}_u\widehat{H}_d + \frac{\kappa}{3}\widehat{S}^3,$$

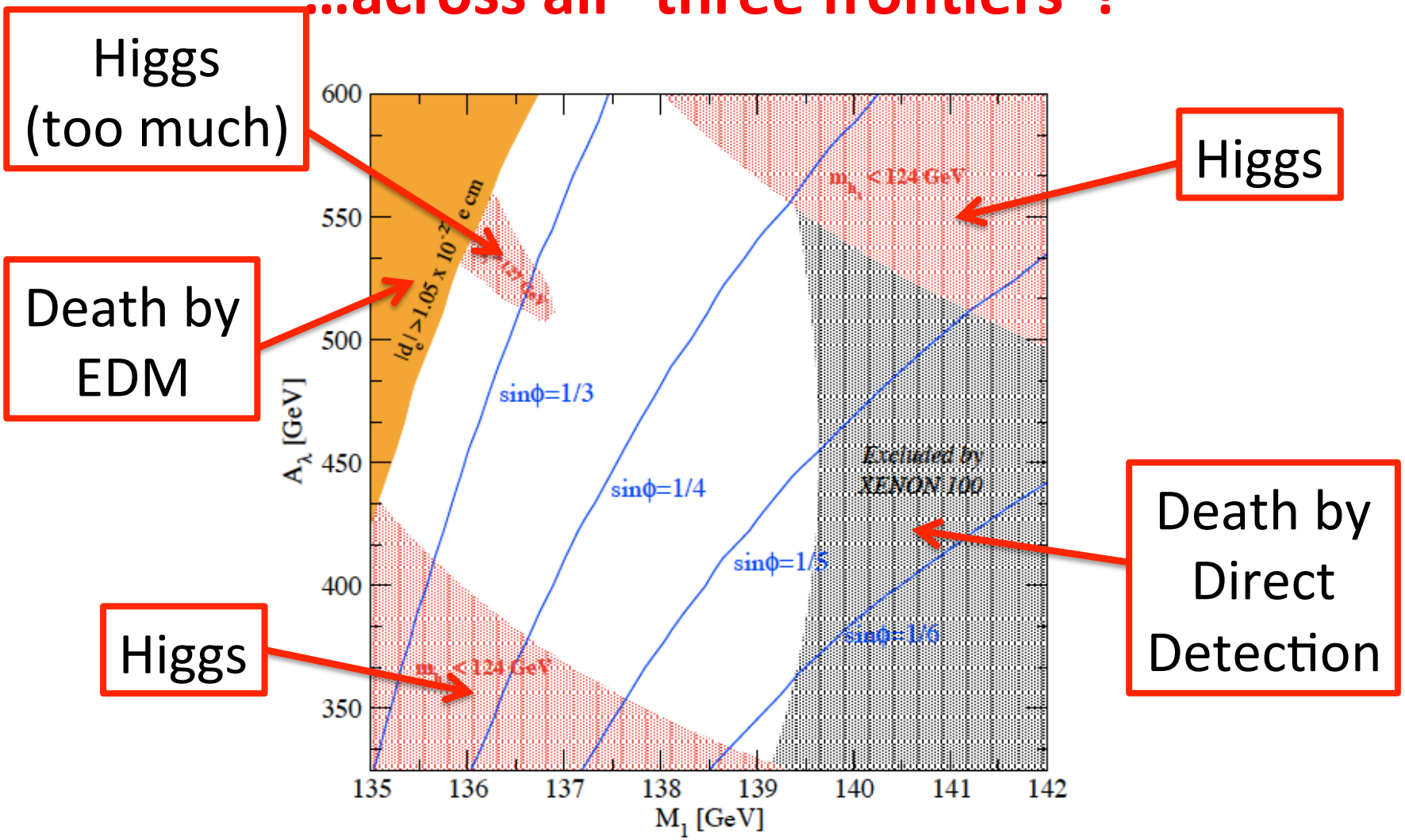
$$-\mathcal{L}^{soft} = -\mathcal{L}^{soft}_{\rm MSSM} + m_S^2\,|S|^2 + \left(\lambda A_\lambda S H_u H_d + \frac{1}{3}\kappa A_\kappa S^3\right) + \text{h.c.}$$





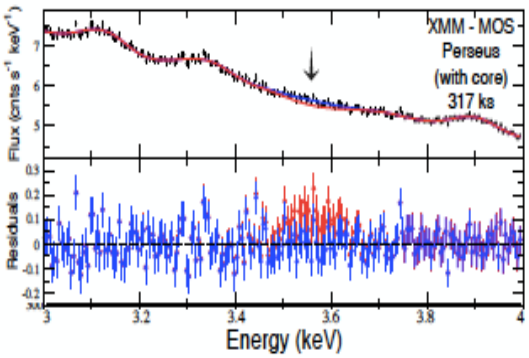
Kozaczuk, Profumo and Wainwright, 2013

A model that does everything…
…across all "three frontiers"!

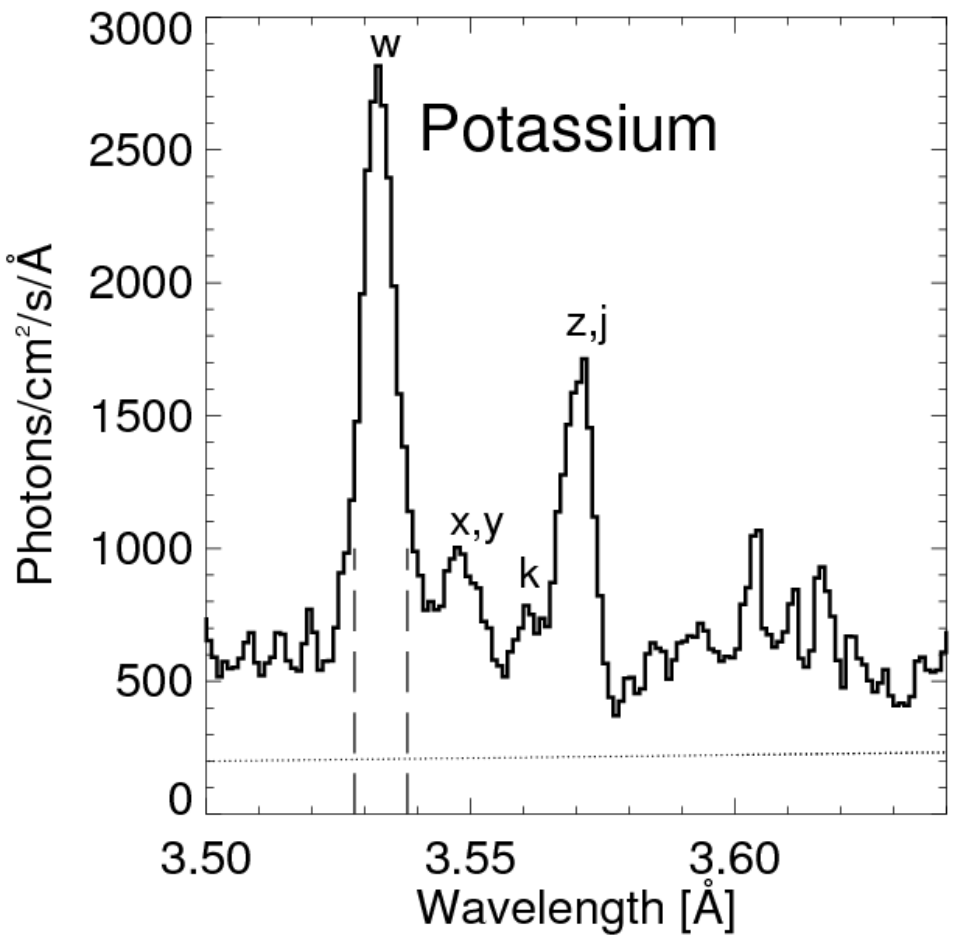


Kozaczuk, Profumo and Wainwright, 2013

3.5 keV line



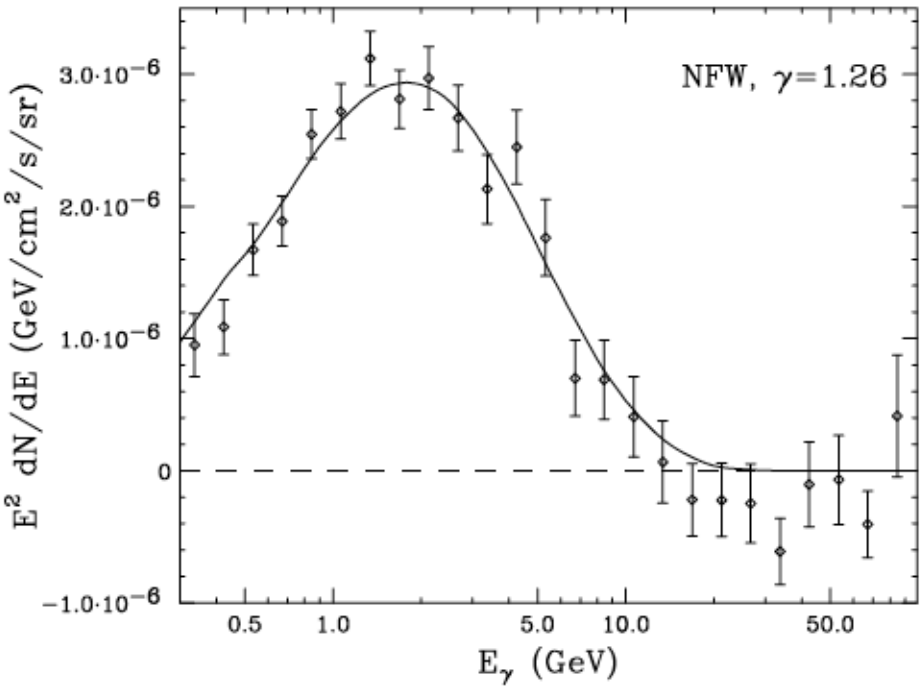
Key line(s) associated with Potassium

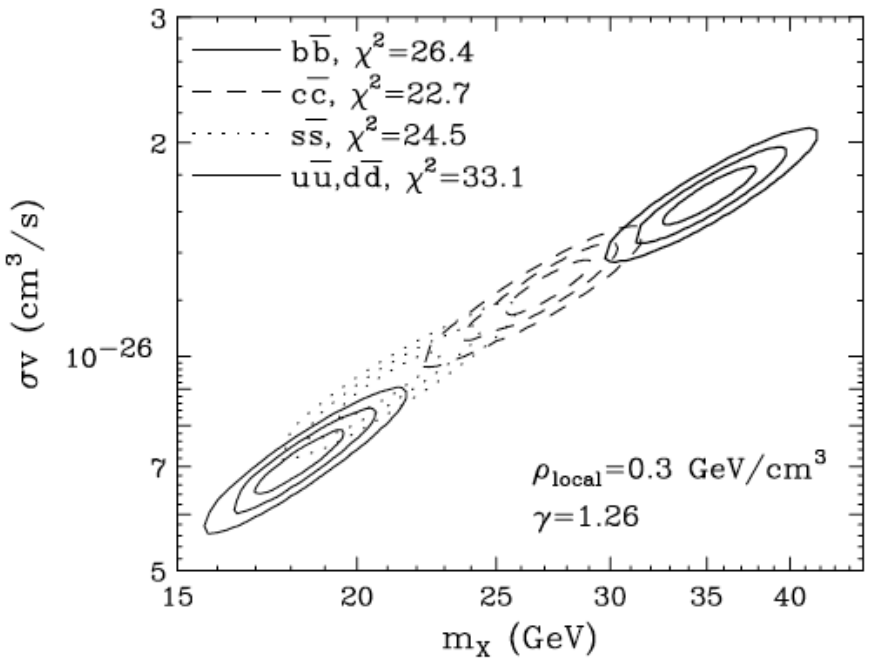


Fun fact (I):
A x keV ~12

Fun fact (II):
energy res.~ 0.1 keV

Jeltema and Profumo, in preparation


NFW, γ=1.26
E^2 dN/dE (GeV/cm^2/s/sr)
E_γ (GeV)
3.0·10^{-6}
2.0·10^{-6}
1.0·10^{-6}
0
−1.0·10^{-6}
0.5
1.0
5.0
10.0
50.0


$b\bar{b}$, χ^2=26.4
$c\bar{c}$, χ^2=22.7
$s\bar{s}$, χ^2=24.5
$u\bar{u}$,$d\bar{d}$, χ^2=33.1
ρ_{local}=0.3 GeV/cm^3
γ=1.26
σv (cm^3/s)
m_X (GeV)
3
2
10^{-26}
7
5
15
20
25
30
35
40

More here on the Calore et al

* Calore et al, 2014, 1409.0042