Detecting dark matter through gamma-rays - some recent developments

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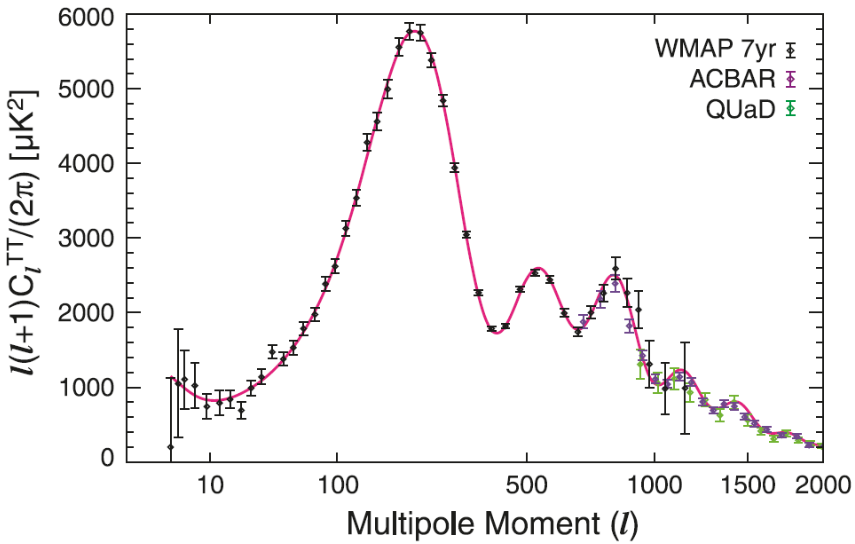
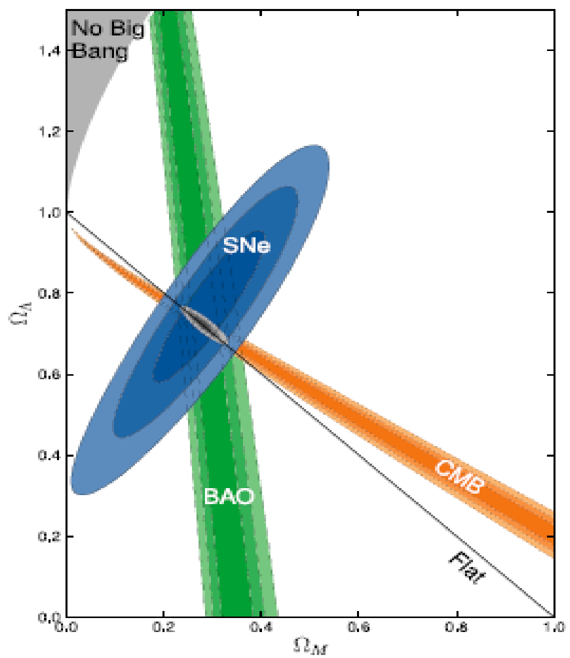
Fritz Zwicky, 1933: *"If this over-density is confirmed we would arrive at the astonishing conclusion that dark matter is present with a much greater density than luminous matter."*

(Coma galaxy cluster)



E. Komatsu et al. (WMAP team) , 2010



R. Amanullah et al. (SCP Collaboration), 2010

WMAP 2010:

$$\Omega_{tot} \equiv \frac{\rho_{tot}}{\rho_{crit}} \approx 1.003 \pm 0.01$$

$\Omega_\Lambda = 0.727 \pm 0.030$ $\boxed{\Omega_{CDM} h^2 = 0.1120 \pm 0.0056}$

$\Omega_B = 0.0455 \pm 0.0028$ $h = 0.704 \pm 0.025$

The ΛCDM Model:

Cold Dark Matter model meaning electrically neutral particles moving non-relativistically, i.e., slowly, when structure formed. In addition, the cosmological constant Λ being the dark energy, gives an accelerating expansion of the universe (Nobel Prize 2011).

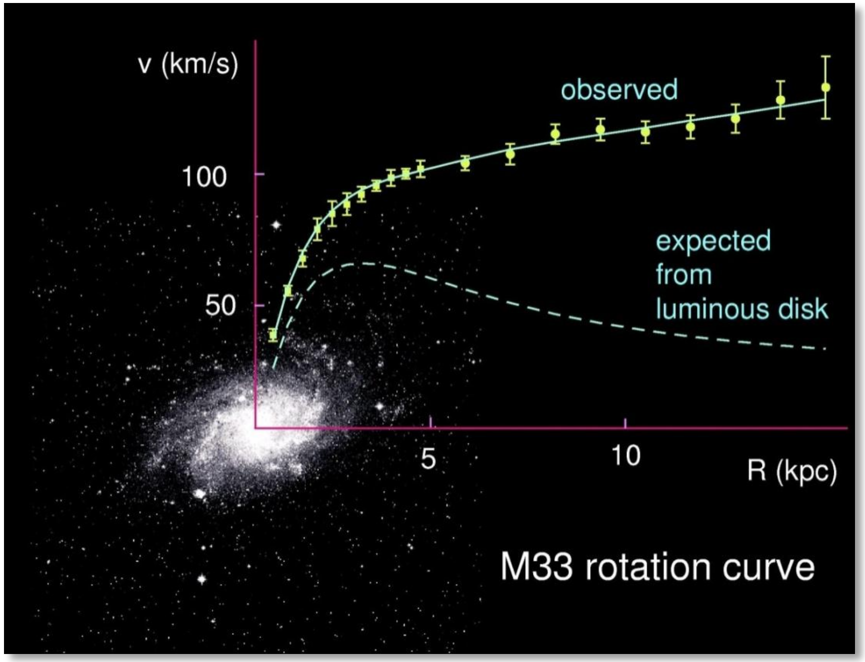
Ω_{CDM} h^2 = 0.11

Seems to fit all cosmological data!

Note: "Dark Matter" was coined by Zwicky; maybe "Invisible Matter" would have been a better name…

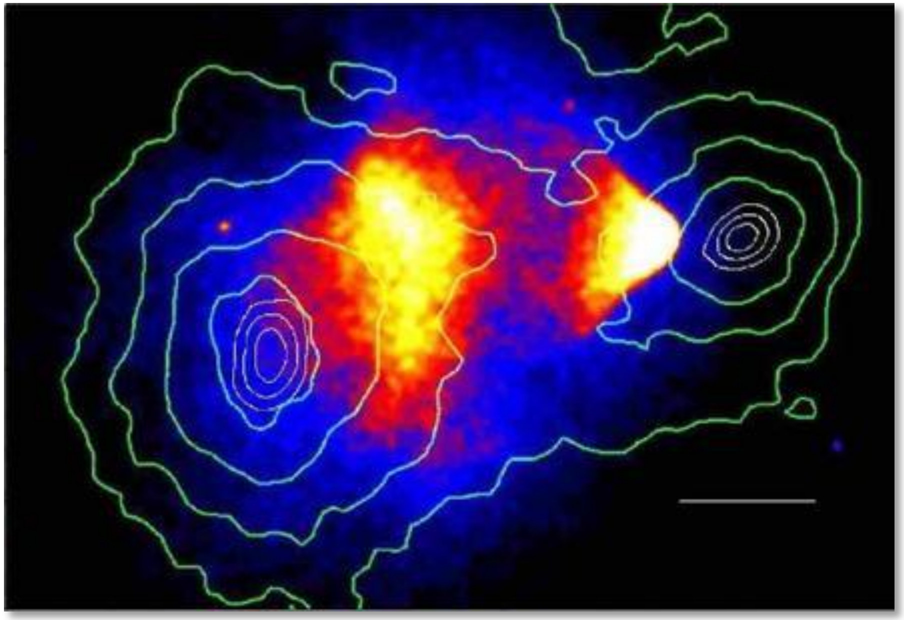
Dark matter needed on all scales!
$\Rightarrow$ Modified Newtonian Dynamics (MOND) and other *ad hoc* attemps to modify Einstein's or Newton's theory of gravitation do not seem plausible

Galaxy rotation curves



L.B., Rep. Prog. Phys. 2000

Colliding galaxy clusters

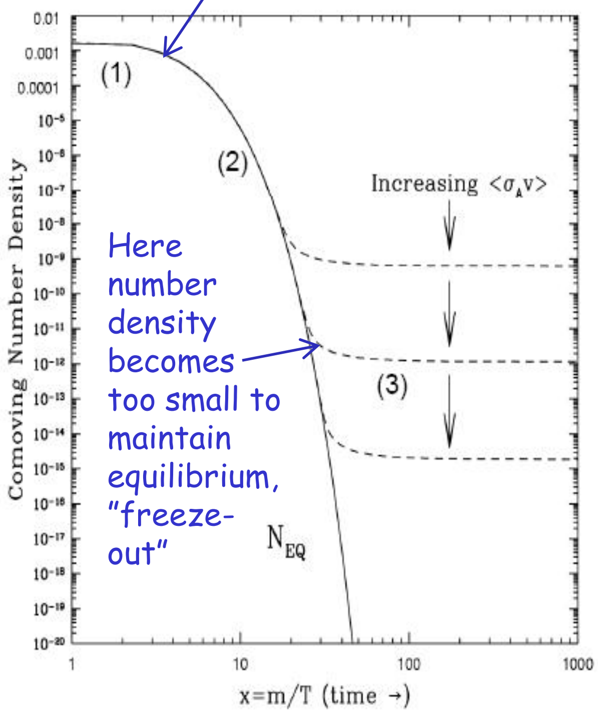


The bullet cluster, D. Clowe et al., 2006

(*cf.* new colliding cluster,Abell 2744, J. Merten et al., 2011)

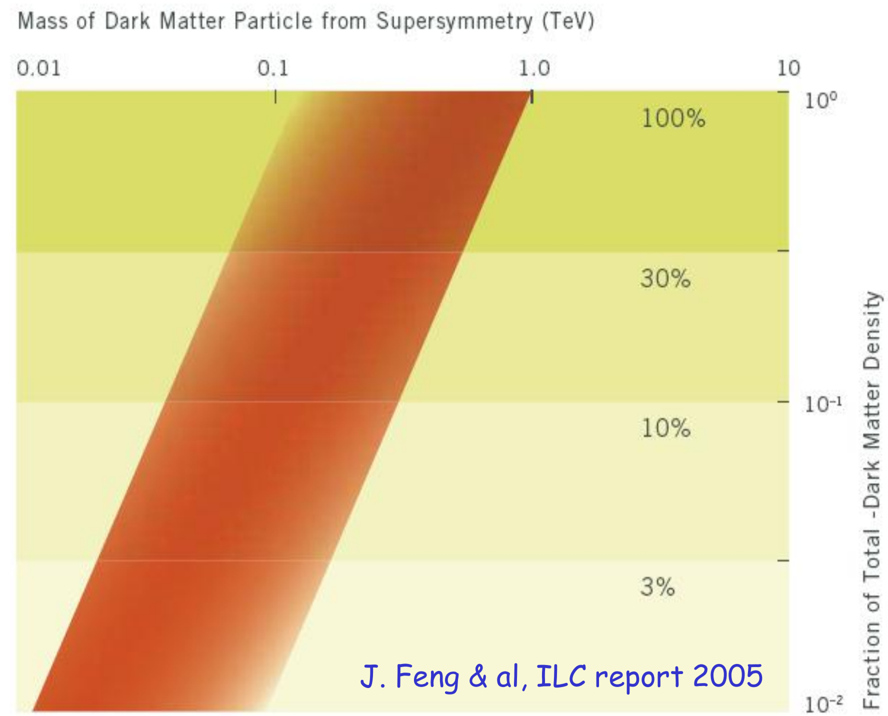
The particle physics connection: The "Weakly Interacting Massive Particle (WIMP) miracle". Is the CDM particle a WIMP?

Equilibirium curve for thermal production in the early universe. Here temperature was >> $2Mc^2$, so the particles were in thermal (chemical) equilibrium.



For thermal production, $\frac{\Omega_{WIMP} h^2}{0.11} \cong \frac{3 \cdot 10^{-26}\, cm^3 s^{-1}}{\langle \sigma v \rangle}$

With typical gauge couplings, and the weak interaction mass scale, 50 – 1000 GeV, for the DM particle, the observed relic density appears without fine-tuning. Example, supersymmetry:



Other interesting WIMPs: Lightest Kaluza-Klein particle – mass scale 600 – 1000 GeV, Inert Higgs doublet – mass scale < 90 GeV,… Non-WIMP: Axion.

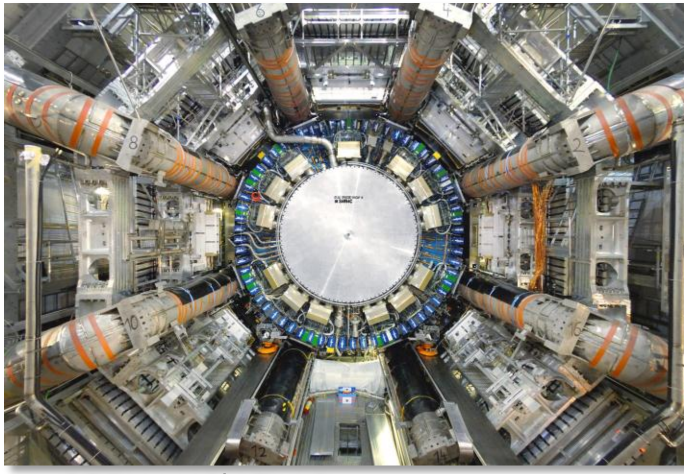
Methods of WIMP Dark Matter detection:

• Discovery at accelerators (Fermilab, LHC, ILC…), if kinematically allowed. Can give mass scale, but no proof of required long lifetime.

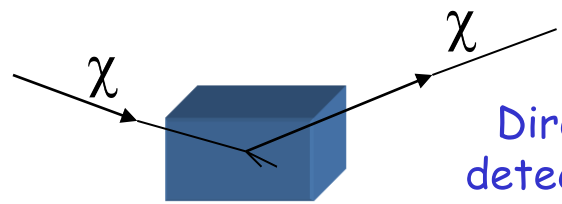
• Direct detection of halo dark matter particles in terrestrial detectors.

• Indirect detection of particles produced in dark matter annihilation: neutrinos, gamma rays & other e.m. waves, antiprotons, antideuterons, positrons in ground- or space-based experiments.

•For a convincing determination of the identity of dark matter, plausibly need detection by at least two different methods. For most methods, the background problem is very serious.



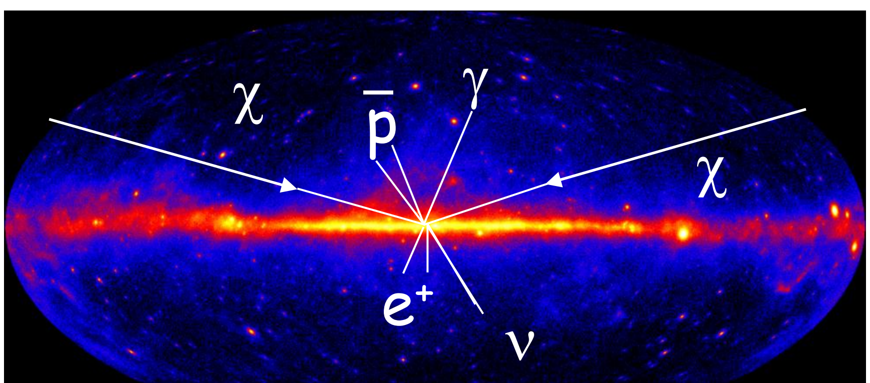
CERN LHC/ATLAS



Direct detection

$$\frac{d\sigma_{si}}{dq} = \frac{1}{\pi v^2}\left(Zf_p + (A-Z)f_n\right)^2 F_A(q) \propto A^2$$

Indirect detection



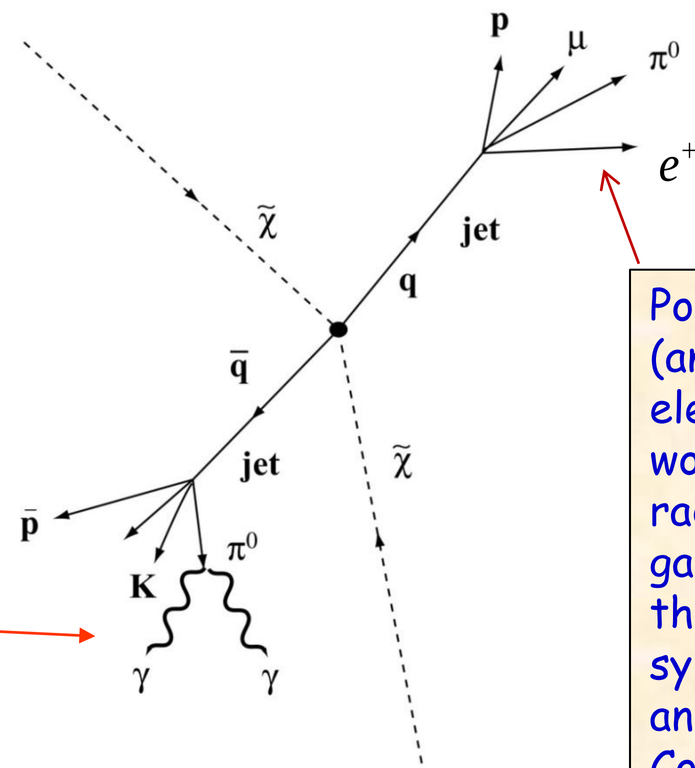
The Milky Way in gamma-rays as measured by FERMI

$$\Gamma_{ann} \propto n_\chi^2 \sigma v$$

Annihilation rate enhanced for clumpy halo; near galactic centre and in subhalos, also for larger systems like galaxy clusters, cosmological structure (as seen in N-body simulations).

Indirect detection: How dark matter shines - annihilation of WIMPs in the galactic halo

Note: equal amounts of matter and antimatter are created in annihilations - this may be a good signature! (Positrons, antiprotons, anti-deuterons.)



Positrons (and electrons) would also radiate gamma rays through synchrotron and inverse Compton radiation

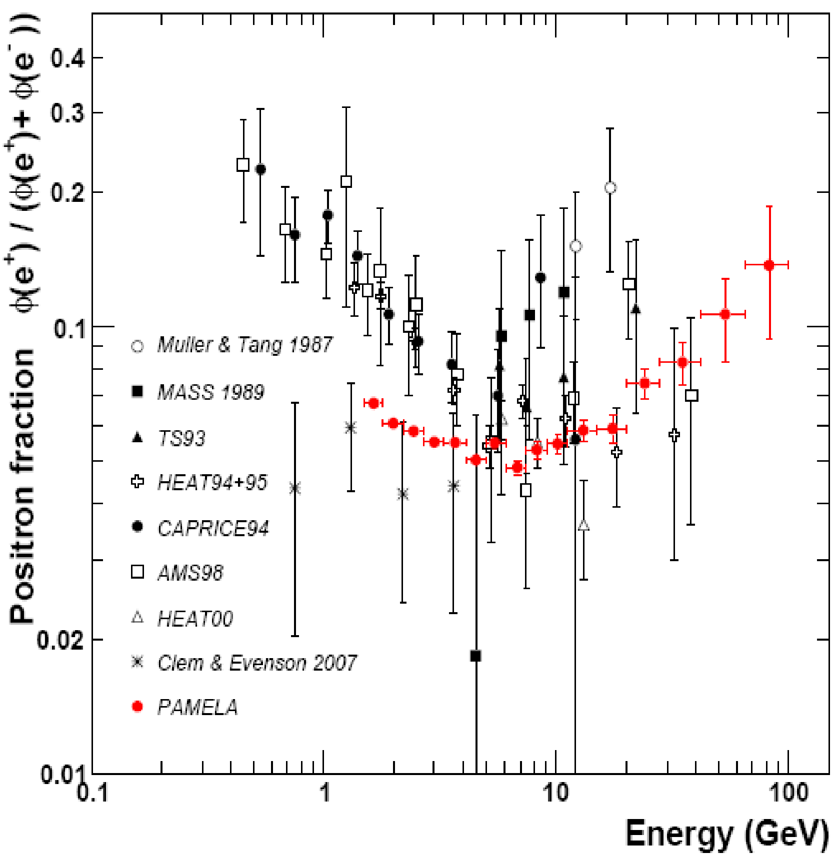
Photons (gamma-rays, i.e. very energetic light) come from decays of particles like neutral pions. Also direct annihilation to 2 gamma-rays is possible: would give a "smoking gun" gamma-ray line at the energy $M_\chi c^2$.

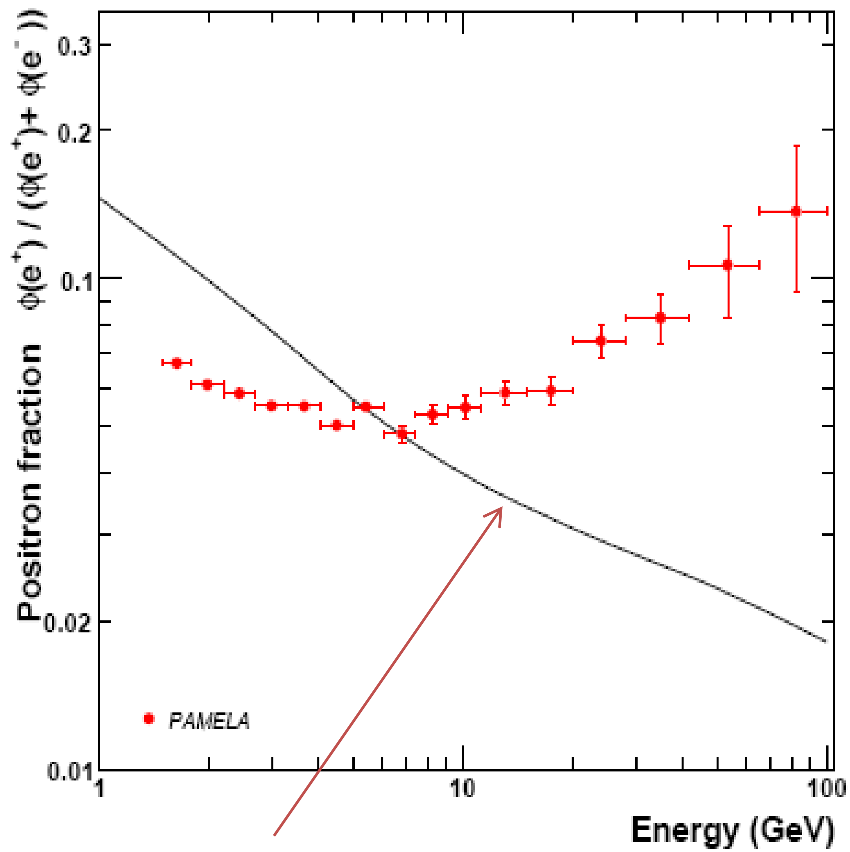
Direct and indirect detection of DM:
There have been many (false?) alarms during the last decade. Many of these phenomena would need contrived (non-WIMP) models for a dark matter explanation:

Indication	Status
DAMA annual modulation	Unexplained at the moment – in tension with other experiments
CoGeNT and CRESST excess events	Tension with other experiments (CDMS-II, XENON100)
EGRET excess of GeV photons	Due to instrument error (?) - not confirmed by FERMI
INTEGRAL 511 keV γ-line from galactic centre	Does not seem to have spherical symmetry - shows an asymmetry following the disk (?)
PAMELA: Anomalous ratio e^+/e^-	May be due to DM, or pulsars - energy signature not unique for DM
FERMI positrons + electrons	May be due to DM, or pulsars - energy signature not unique for DM
FERMI few GeV γ-ray excess towards g.c.	Unexplained at the moment – very messy astrophysics
γ-ray excess from galaxy clusters	Very weak indications, may be CR emission?
New: FERMI 130 GeV line (C. Weniger)	3.3σ – 4.6σ effect, unexplained at the moment

Oct 2008: The surprising PAMELA data on the positron ratio up to 100 GeV. (O. Adriani et al., Nature 458, 607 (2009))

A very important result (~ 1000 citations). An additional, primary source of positrons seems to be needed. Maybe dark matter – but an astrophysical source (pulsars?) may seem at least as likely.

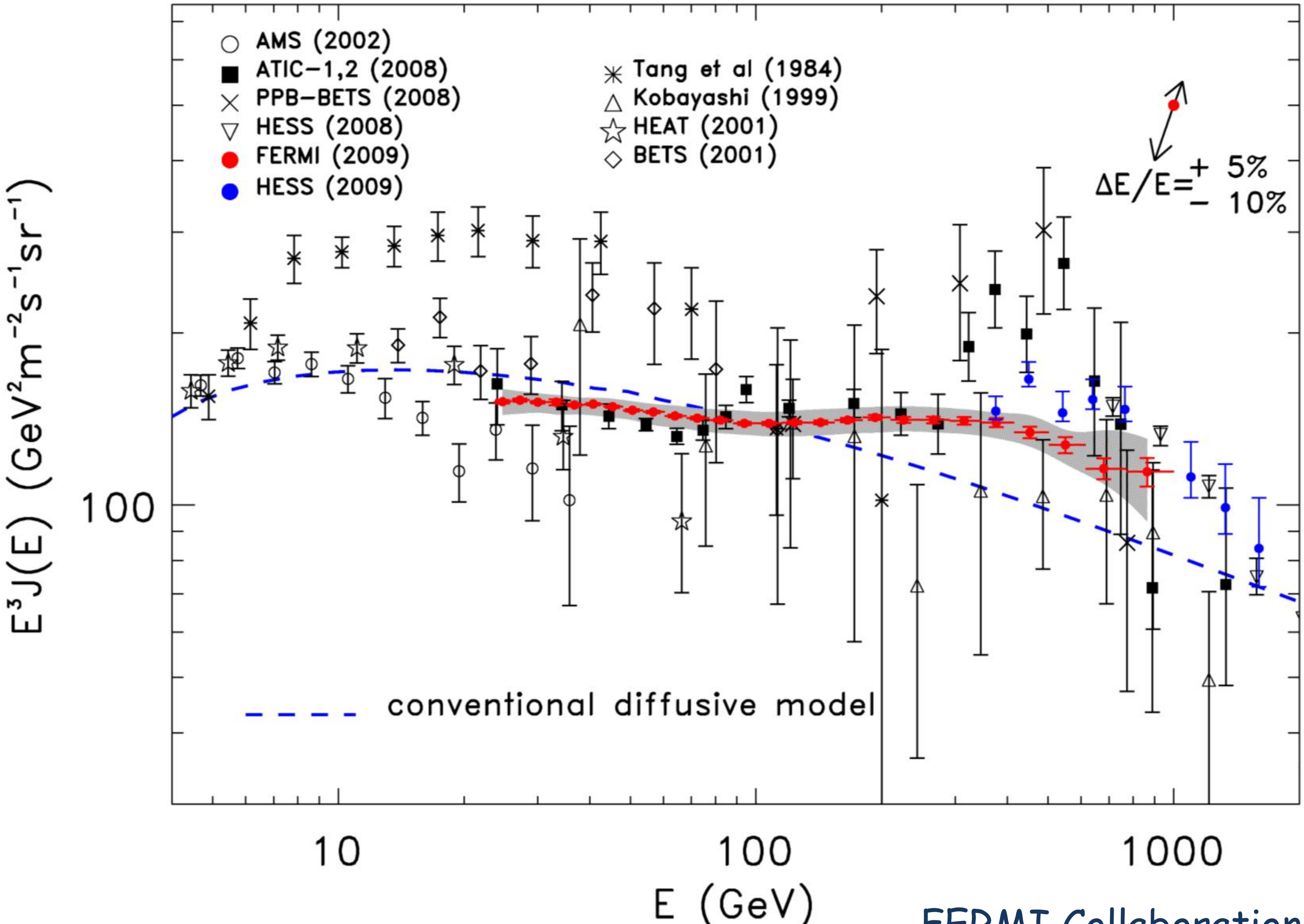




Prediction from secondary production by cosmic rays: Moskalenko & Strong, 1998

A surprise also from FERMI

Sum of electron and positron flux versus energy:



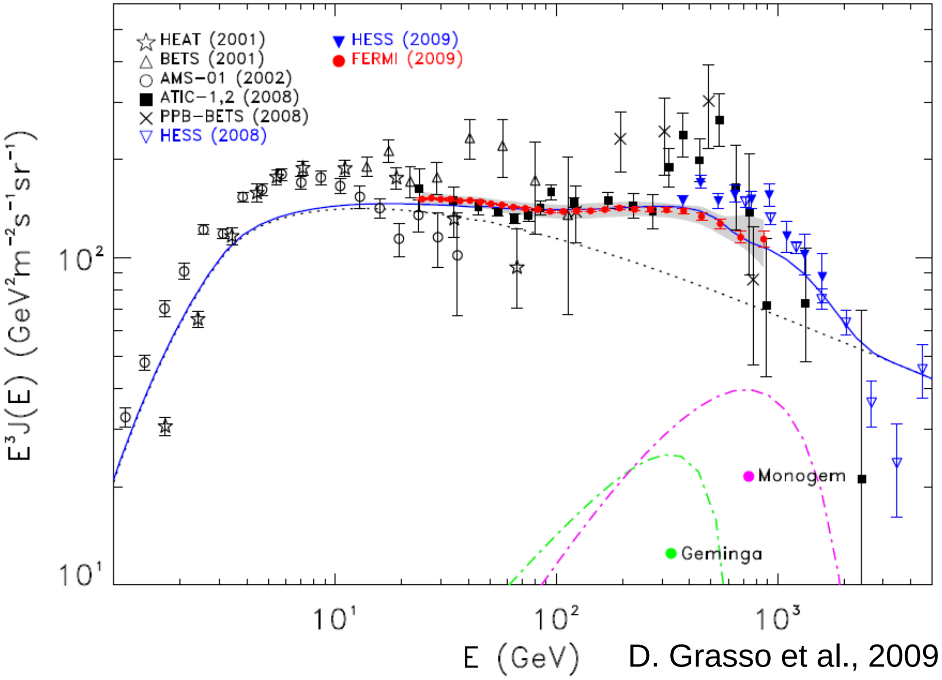
FERMI Collaboration, A.A. Abdo & al, PRL 2009.

The rising positron ratio and the "bump" in the electron plus positron spectrum are impossible to explain using only secondary production in cosmic rays. A new primary source of positrons is needed. Two main possibilities have been explored:

1. Pulsars (or other supernova remnants)
2. Dark Matter

For both scenarios, the absence of an excesss of antiprotons (PAMELA, 2009) places stringent bounds ("leptophilic" processes must dominate for dark matter)

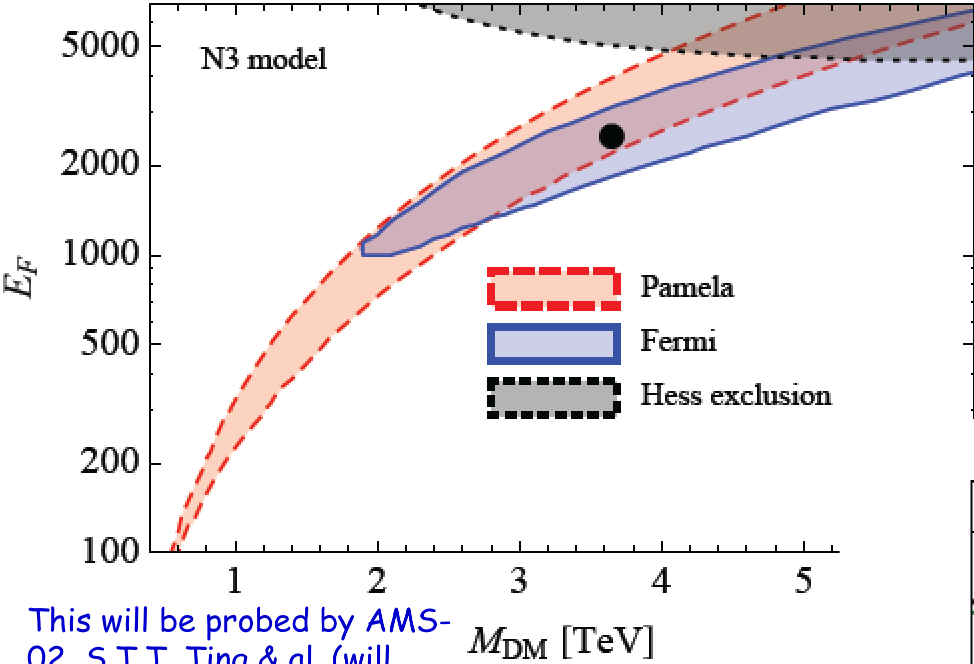
1. Positrons generated by a class of extreme objects: supernova remnants (pulsars):



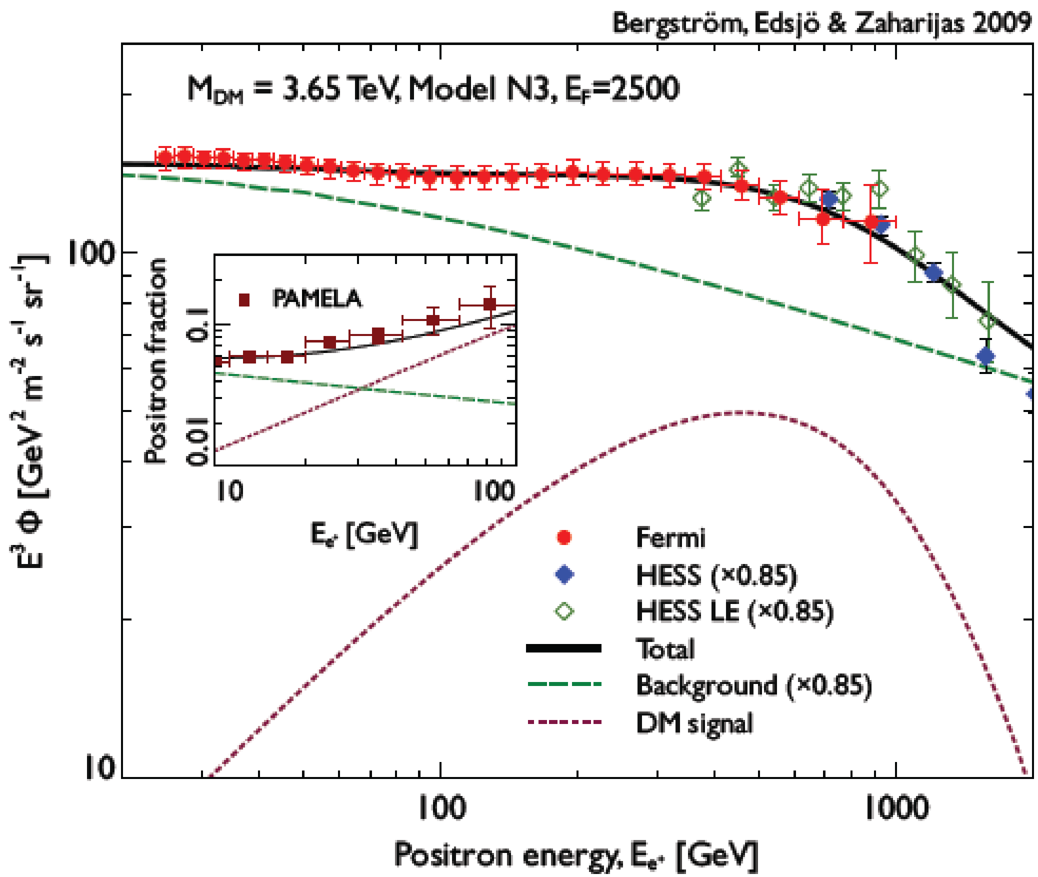
D. Grasso et al., 2009

For pulsars, the fluxes are essentially unconstrained and can be adjusted to fit. Anisotropy expected, but below a percent ⇒ undetectable at present.

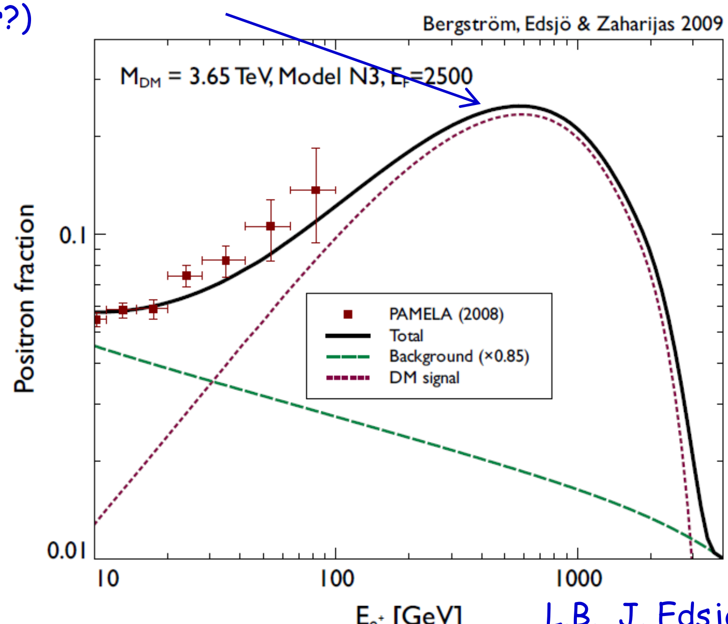
2. Dark matter example:



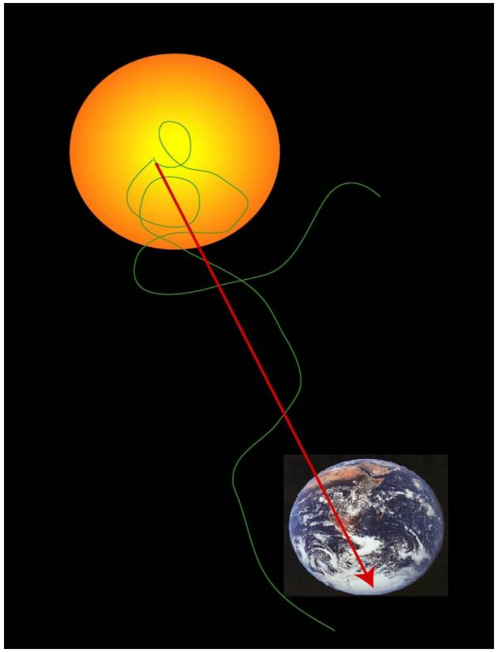
Model of Nomura and Thaler, annihilation into a+σ, with a → $\mu^+\mu^-$, axion-like, and σ scalar (maybe supersymmetric). Sommerfeld enhancement is natural in these models . Fit to spectrum is remarkably good, but huge "boost factor" needed → constraints from other data.



This will be probed by AMS-02, S.T.T. Ting & al. (will present data later this year?)

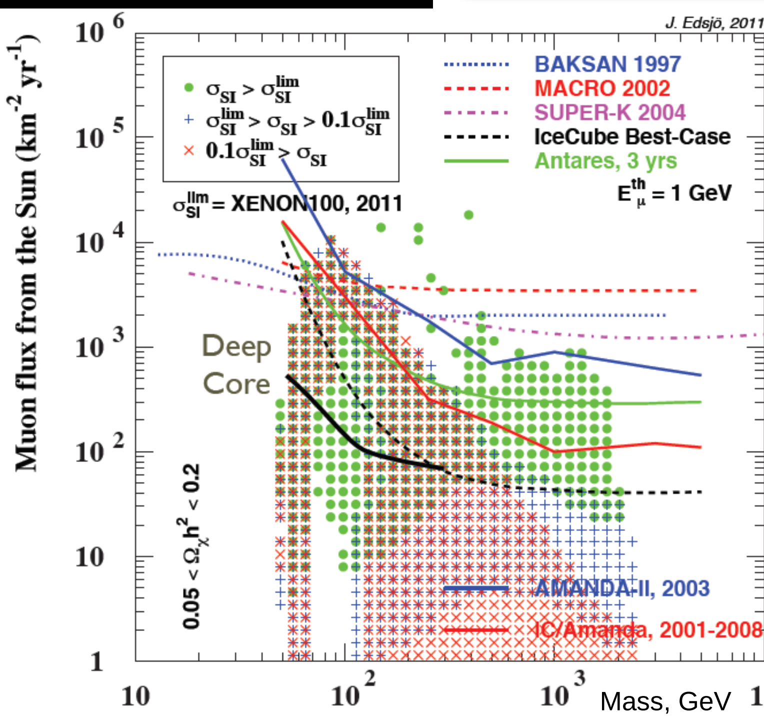


L.B., J. Edsjö and G. Zaharijas, PRL 2009.

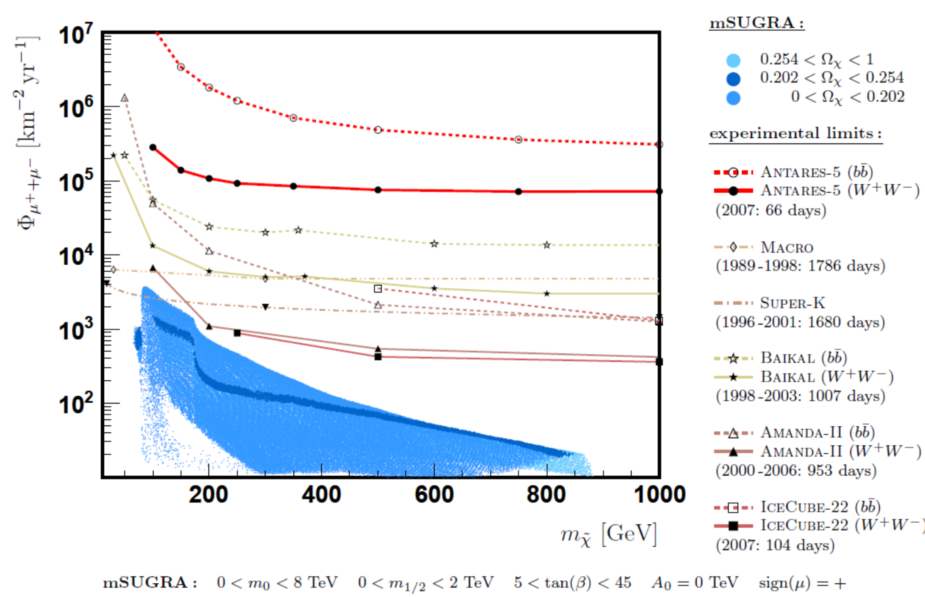


Neutrinos from annihilation in the Sun: Excellent signature, competitive, due to high proton content of the Sun ⇒ sensitive to spin-dependent interactions. With full IceCube-80 and DeepCore-6 inset operational now, a large new parameter region will be probed. The Mediterranean detector ANTARES has just started to produce limits. (Might be expanded to a km^3 array – KM3NET?)

(Neutrinos from the Earth: Not competitive with spin-independent direct detection searches due to only spin-0 elements in the Earth).



J. Edsjö, Workshop on Indirect DM Searches, Hamburg, June, 2011



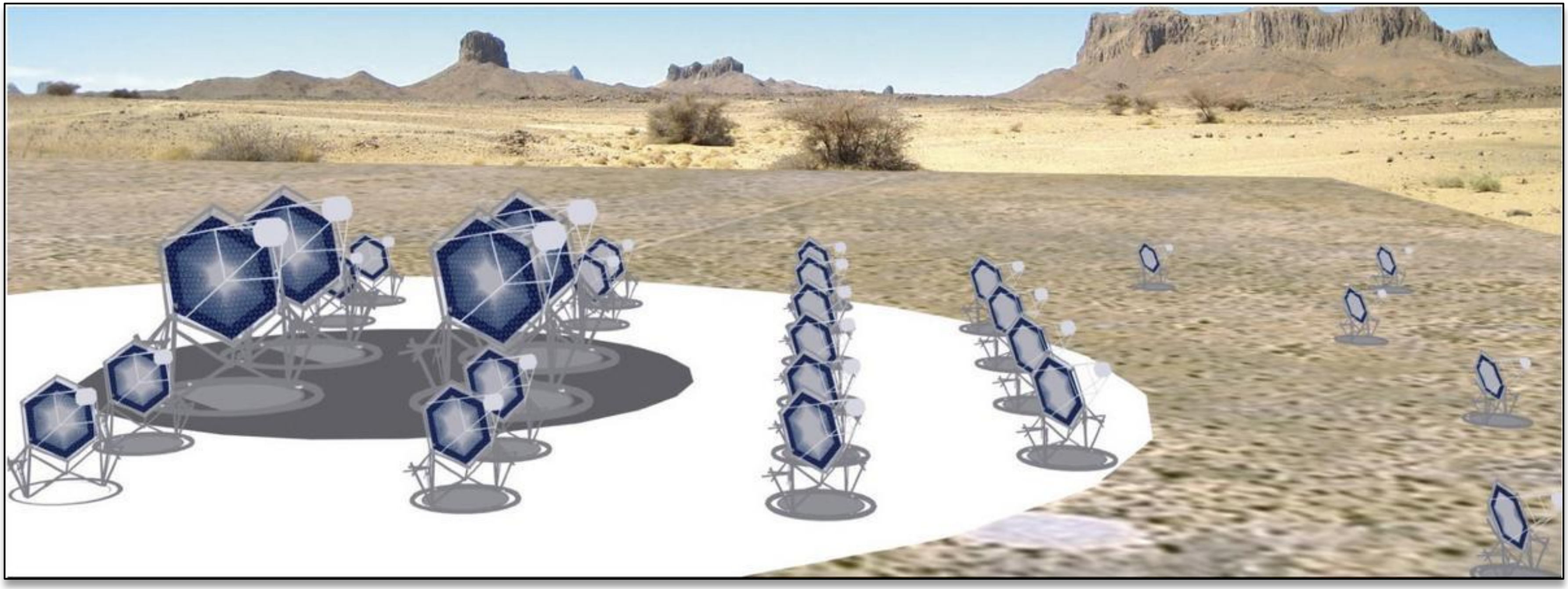
G. Lim (ANTARES), PhD thesis, NIKHEF, 2011

Indirect detection through γ-rays from DM annihilation (or decay)

Fermi-LAT (Fermi Large Area Telescope)

H.E.S.S. & H.E.S.S.-2

VERITAS



CTA (Cherenkov Telescope Array)

One major uncertainty for indirect detection, especially of γ-rays: The halo dark matter density distribution at small scales is virtually unknown. Gamma-ray rates towards the Galactic Center may vary by factor of 1000 or more. Adiabatic contraction of DM may give a more cuspy profile.

Fits to N-body simulations

$$\rho_{\mathrm{Einasto}}(r) = \rho_s e^{\left(-\frac{2}{\alpha}\left[\left(\frac{r}{a}\right)^{\alpha} - 1\right]\right)}, \quad \alpha \approx 0.17$$

$$\rho_{\mathrm{NFW}}(r) = \frac{c}{r(a+r)^2};$$

Fits to rotation curves

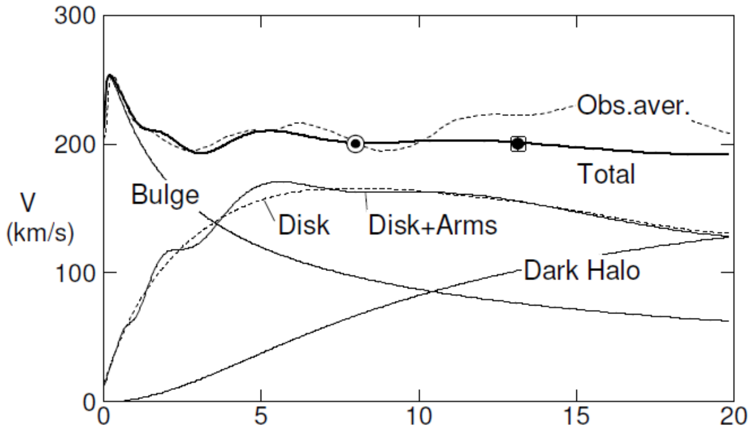
$$\rho_{\mathrm{Burkert}}(r) = \frac{c}{(r+a)(a^2+r^2)};$$

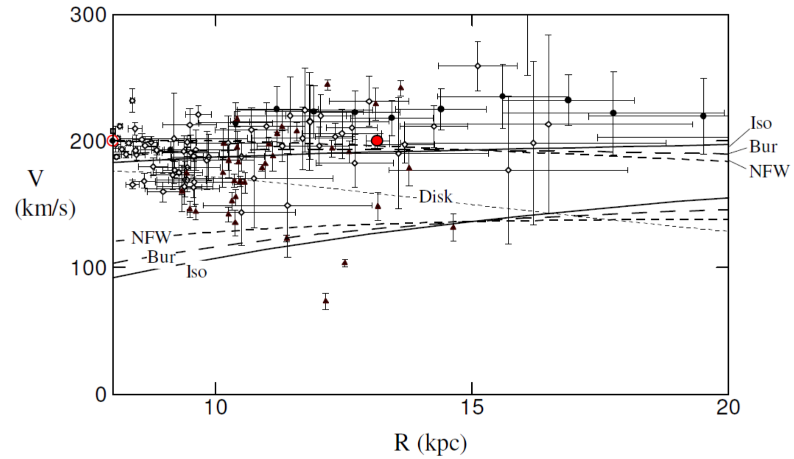
$$\rho_{\mathrm{Isothermal}}(r) = \frac{c}{a^2+r^2};$$

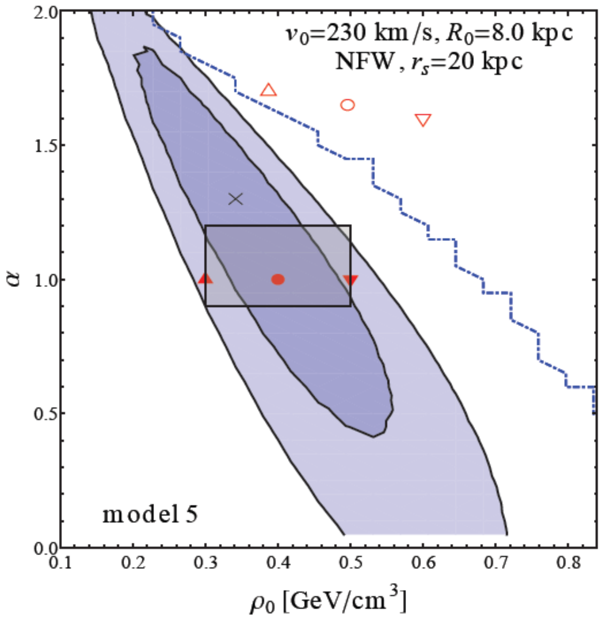
At the solar position, the local density for spherical symmetry is 0.39 ± 0.03 GeV/cm^3 (R. Catena & P. Ullio, 2010)

Can't we determine right halo model from the Milky Way rotation curve?

No, unfortunately not: Y. Sofue, M. Honma & T. Omodaka, 2008







$$\rho_{DM}(r) = \bar{\rho}_s (r/r_s)^{-\alpha}(1 + r/r_s)^{-3+\alpha} \quad \text{(NFW)}$$

Using also microlensing data, F. Iocco, M. Pato, G. Bertone and P. Jetzer, 2011

Science NOW UP TO THE MINUTE NEWS FROM SCIENCE

Has Dark Matter Gone Missing?

by Adrian Cho on 19 April 2012, 5:41 PM | 14 Comments

FLAWED!

Kinematical and chemical vertical structure of the Galactic thick disk[1,2] II. A lack of dark matter in the solar neighborhood

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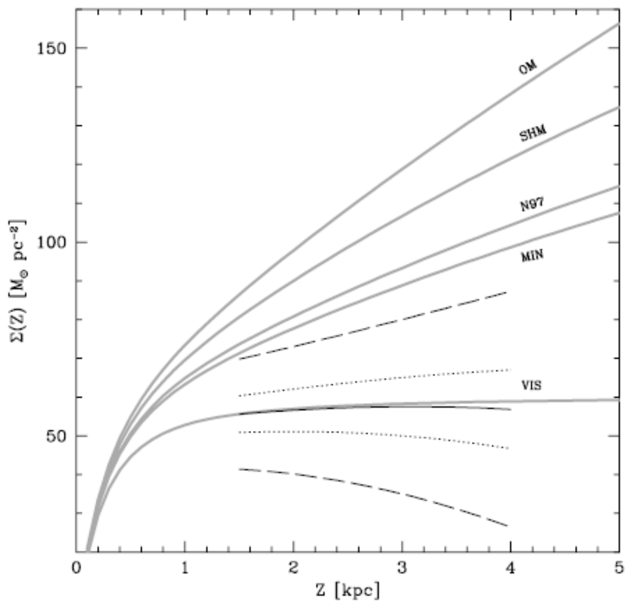
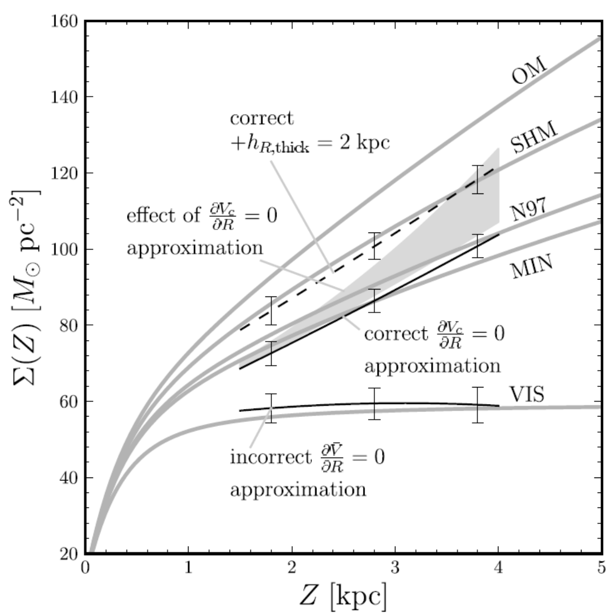
ABSTRACT

We estimated the dynamical surface mass density Σ at the solar position between Z=1.5 and 4 kpc from the Galactic plane, as inferred from the kinematics of thick disk stars. The formulation is exact within the limit of validity of a few basic assumptions. The resulting trend of $\Sigma(Z)$ matches the expectations of visible mass alone, and no dark component is required to account for the observations. We extrapolate a dark matter (DM) density in the solar neighborhood of 0 ± 1 m$M_\odot$ pc^{-3}, and all the current models



C. Moni Bidin & al.



J. Bovy & S. Tremaine.

On the local dark matter density

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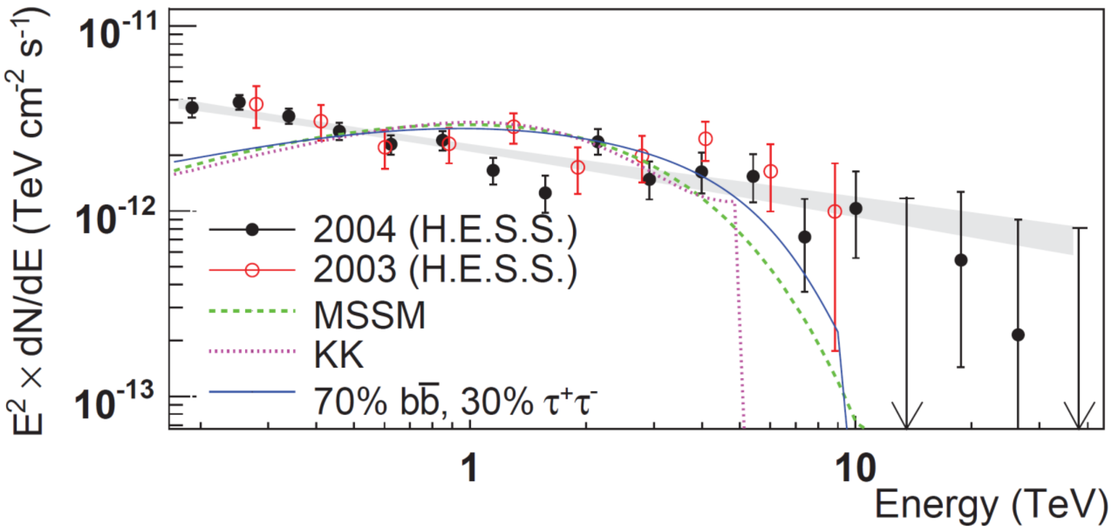
ABSTRACT

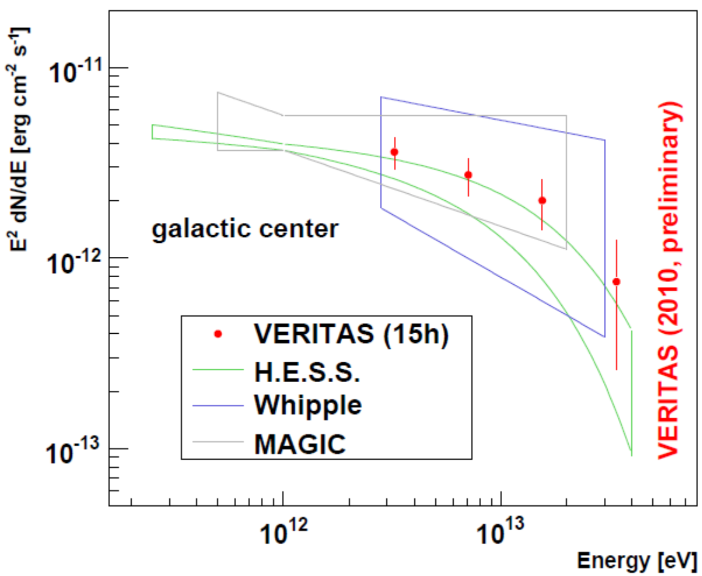
An analysis of the kinematics of 412 stars at 1–4 kpc from the Galactic mid-plane by Moni Bidin et al. (2012) has claimed to derive a local density of dark matter that is an order of magnitude below standard expectations. We show that this result is incorrect and that it arises from the invalid assumption that the mean azimuthal velocity of the stellar tracers is independent of Galactocentric radius at all heights; the correct assumption—that is, the one supported by data—is that the circular speed is independent of radius in the mid-plane. We demonstrate that the assumption of constant mean azimuthal velocity is physically implausible by showing that it requires the circular velocity to drop more steeply than allowed by any plausible mass model, with or without dark matter, at large heights above the mid-plane. Using the correct approximation that the circular velocity curve is flat in the mid-plane, we find that the data imply a local dark-matter density of $0.008 \pm 0.002\, M_\odot\,\mathrm{pc}^{-3} = 0.3 \pm 0.1\,\mathrm{Gev\ cm}^{-3}$, fully consistent with standard estimates of this quantity. This is the most robust direct measurement of the local dark-matter density to date.

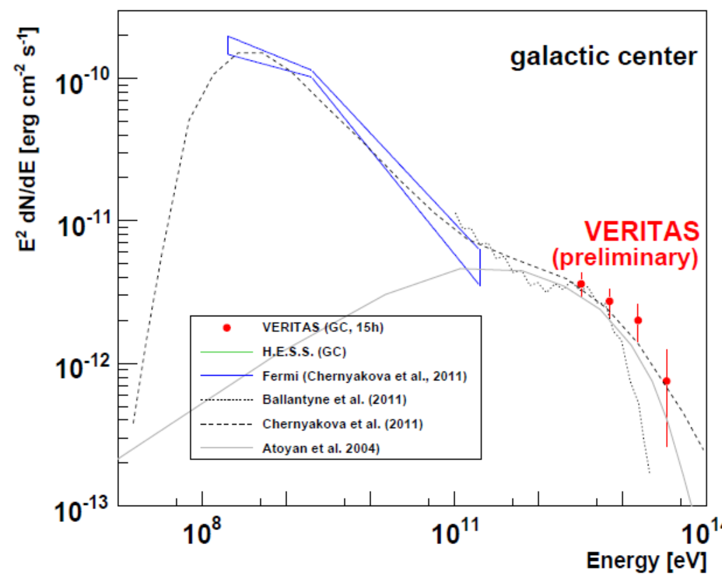
Subject headings: Galaxy: disk — Galaxy: fundamental parameters — Galaxy: kinematics and dynamics — Galaxy: halo — Galaxy: solar neighborhood — Galaxy: structure

The galactic center should have the highest density of dark matter – however also other sources of γ-rays:



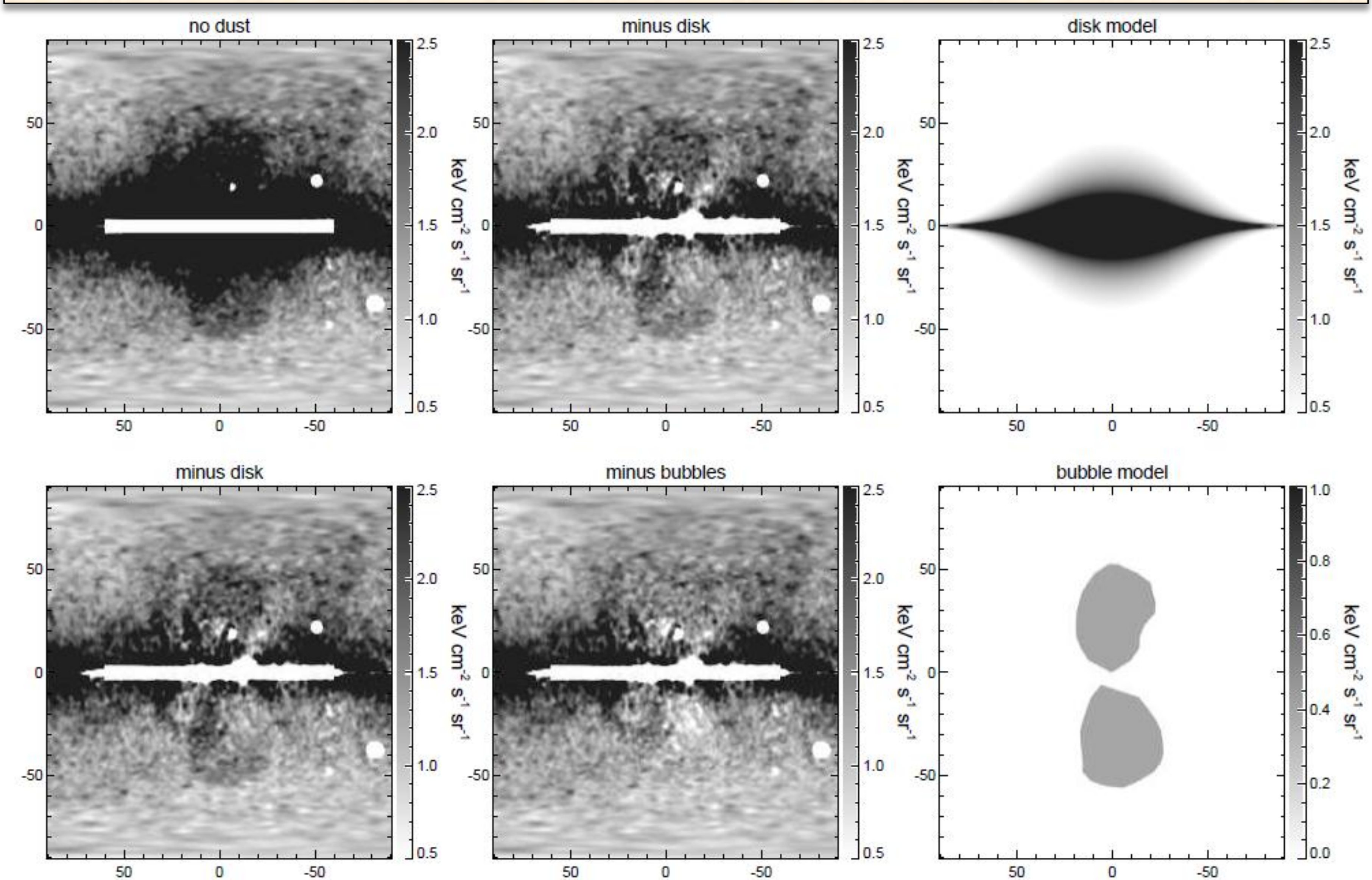
H.E.S.S. data from g.c. (treated as a point source), F. Aharonian et al., 2006





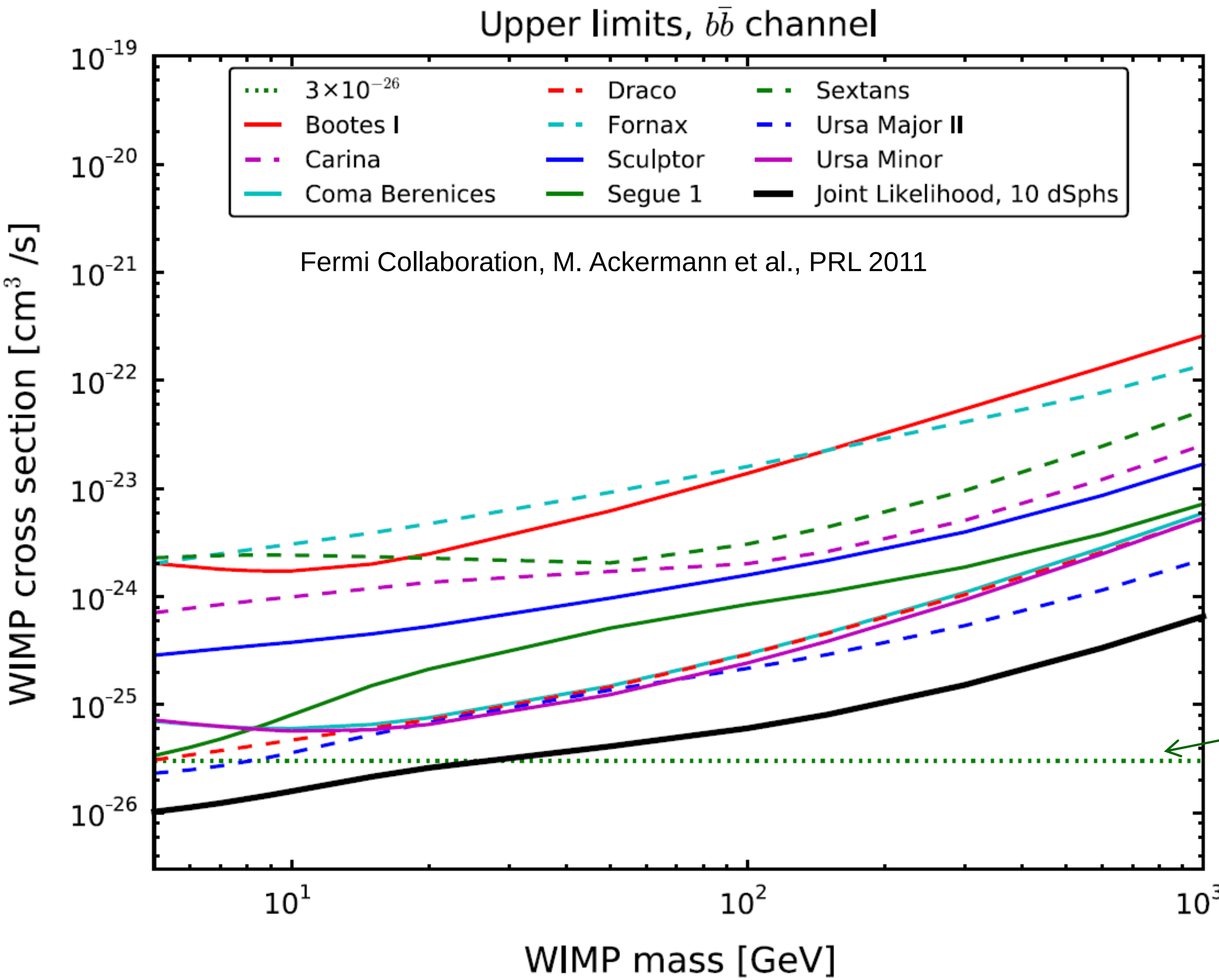
VERITAS, M. Beilicke et al., 2011

Discovery by M. Su, T. Slatyer & D. Finkbeiner, using public Fermi data: Fermi "bubbles" (2010)



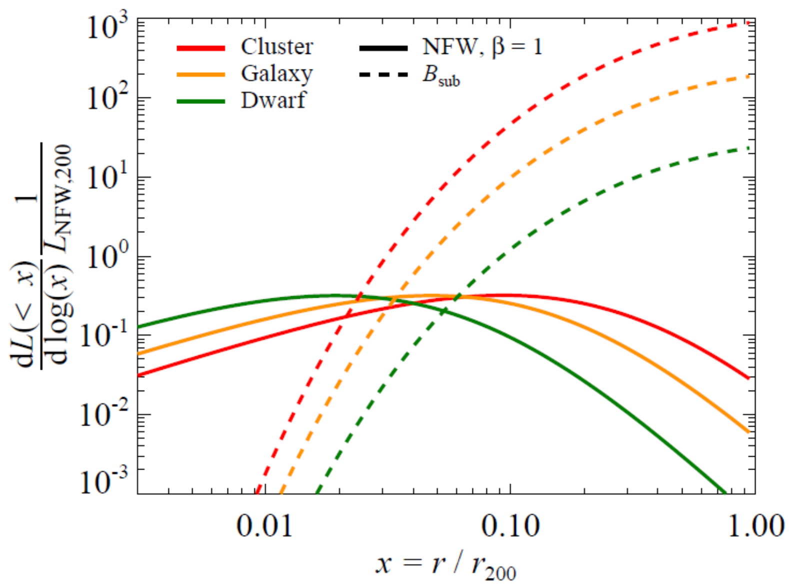
Flat γ–ray intensity from the bubbles, $E^2 dN/dE = 3{\cdot}10^{-7}$ GeV s^{-1}sr^{-1}cm^{-2}

Galactic center is not the only place to look: New promising experimental method, stacking data from many dwarf galaxies, FERMI Collaboration, esp. Maja Garde & Jan Conrad, (Phys. Rev. Letters, December, 2011)

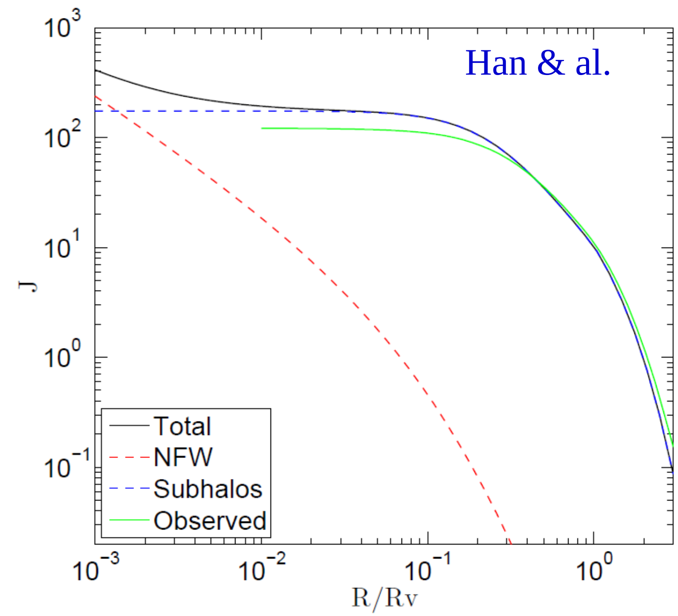


By stacking the data, sensitivity to the density profile can be minimized

Recent development: Galaxy clusters - Fritz Zwicky would be pleased…



A. Pinzke, C. Pfrommer and L.B., Phys. Rev. D, 2011 (arXiv:1105.3240).

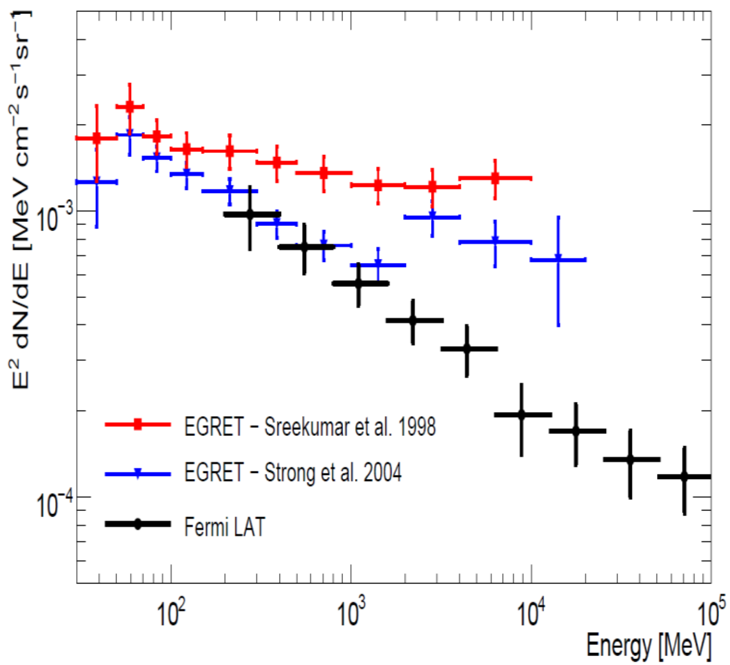


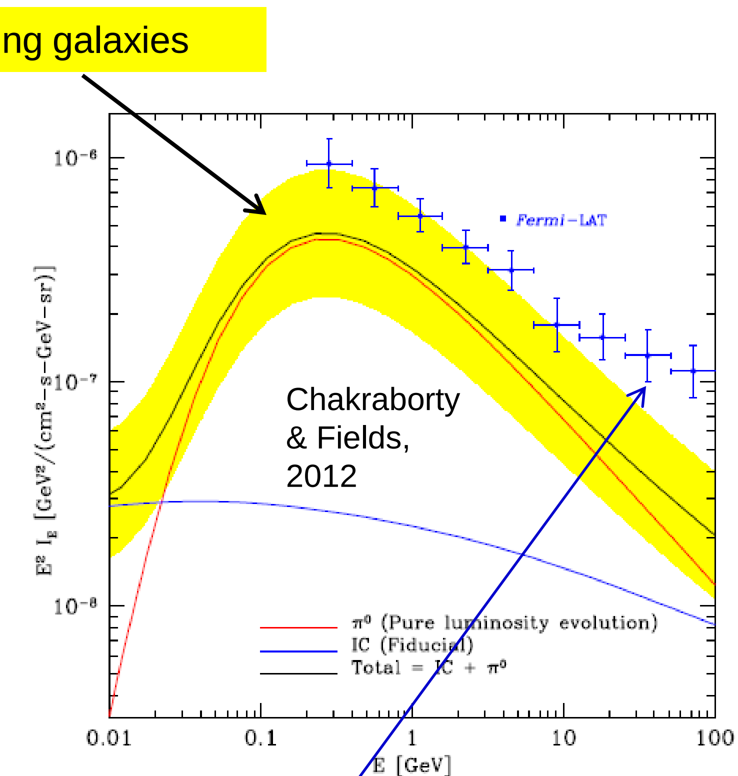
J. Han, C.S. Frenk, V.R. Eke, L. Gao and S.D.M. White, arXiv:1201.1003.

Tidal effects are smaller for clusters ⇒ boost factor of the order of 1000 possible (without Sommerfeld enhancement!). Predicted signal/noise is roughly a factor of 10 better for clusters than for dwarf galaxies! (See also L. Gao, C.S. Frenk, A. Jenkins, V. Springel and S.D.M. White arXiv:1107.1916.)

Clusters may also be suitable for stacking of FERMI data (J. Conrad, S. Zimmer & al).

Signal from the largest scales? The cosmological diffuse γ-ray background





The measured flux above a few GeV is difficult to explain with added SNRs, AGN, starforming galaxies,… Maybe still a need for dark matter (L.B., J. Edsjö, P.Ullio and C. Lacey, 2002):

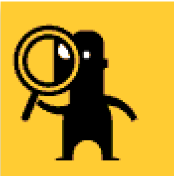
$$\frac{d\phi_\gamma}{dE_0} = \frac{\langle\sigma v\rangle}{8\pi}\frac{c}{H_0}\frac{\bar{\rho}_0^2}{m_{DM}^2}\int dz(1+z)^3\frac{\Delta^2(z)}{h(z)}\frac{dN_\gamma(E_0(1+z))}{dE}e^{-\tau(z,E_0)}$$

Wait and see…

Conclusion so far:

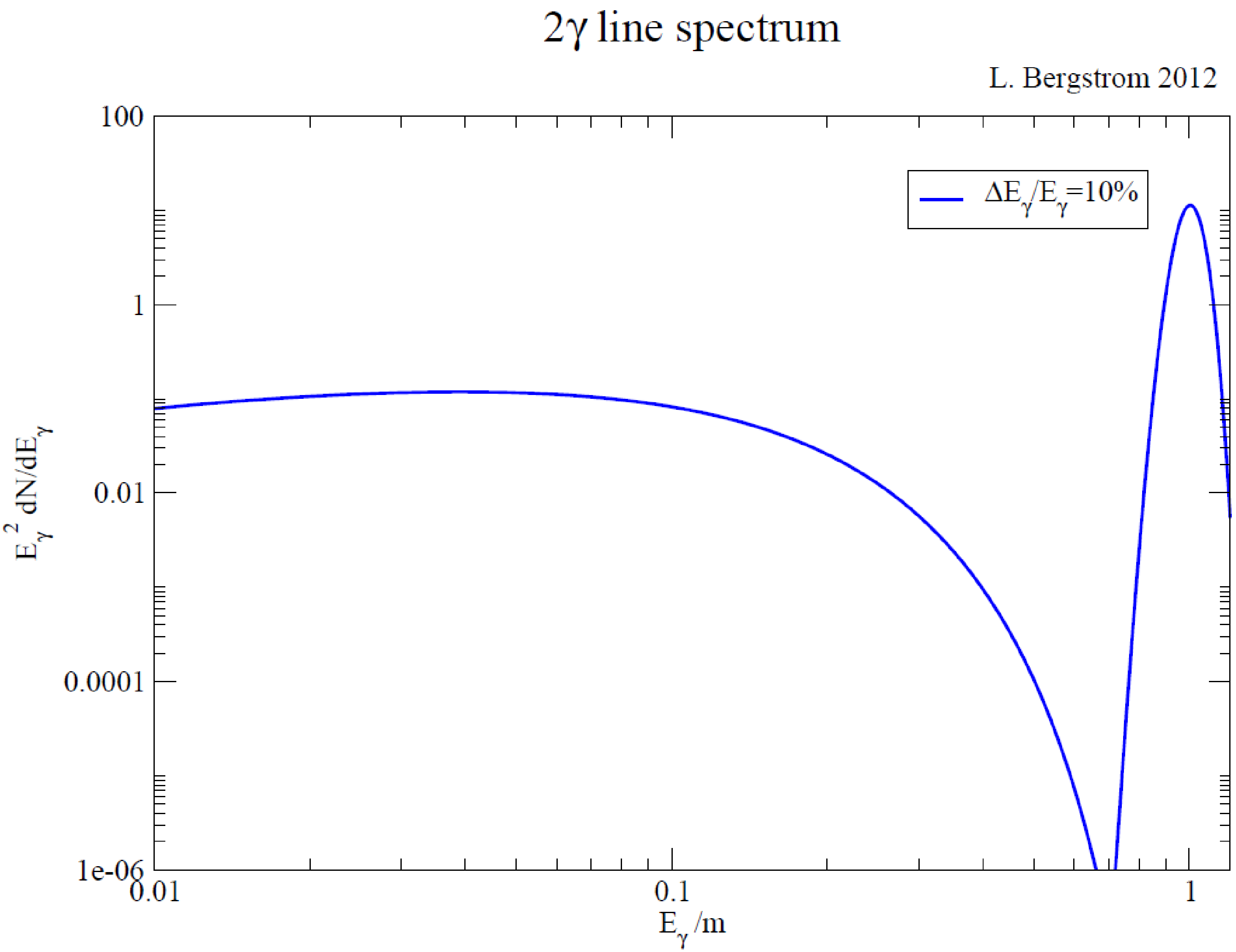
Despite candidates for DM signals existing it is difficult to prove the existence of a dark matter-induced signature in antimatter and diffuse gamma spectra.

There are well-motivated, other astrophysical processes that may give essentially identical distributions.



How do we find the DM suspect?

The “smoking gun” signal



Computing the gamma-ray line (L.B. & H. Snellman, 1988; L.B. & P. Ullio, 1997):

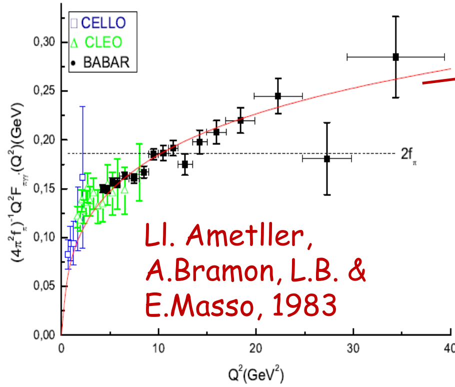
My road to this:

I had around 1982-83 computed, in view of the CELSIUS-WASA detector to be built in Uppsala,
$\pi^0 \to e^+e^-\gamma$ and
$\pi^0 \to e^+e^-$

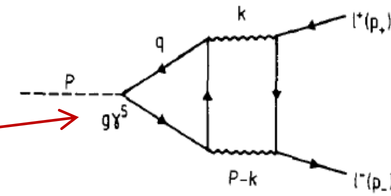
WASA was never functional, it was moved to Jülich and is now WASA-at-COSY.

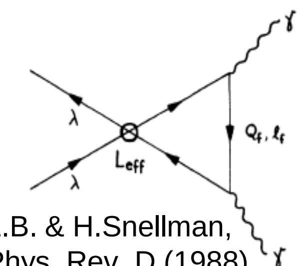
There is still an anomaly of ~ 3.3σ compared to the Standard Model prediction for $\pi^0 \to e^+e^-$ ...

I also computed in 1985 (with G. Hulth) the Higgs decays
$H^0 \to \gamma\gamma$ and
$H^0 \to Z\gamma$
(which are currently very "hot" at CERN).



A.E. Dorokhov, 2009

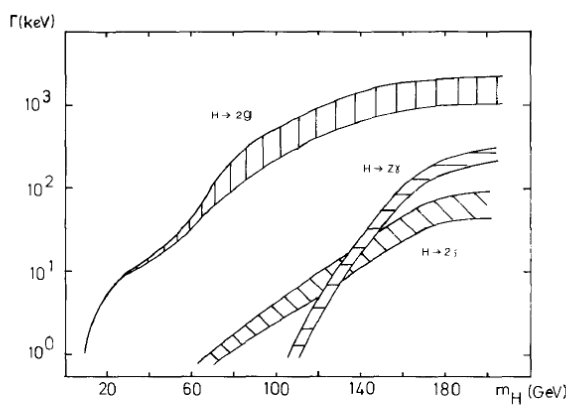


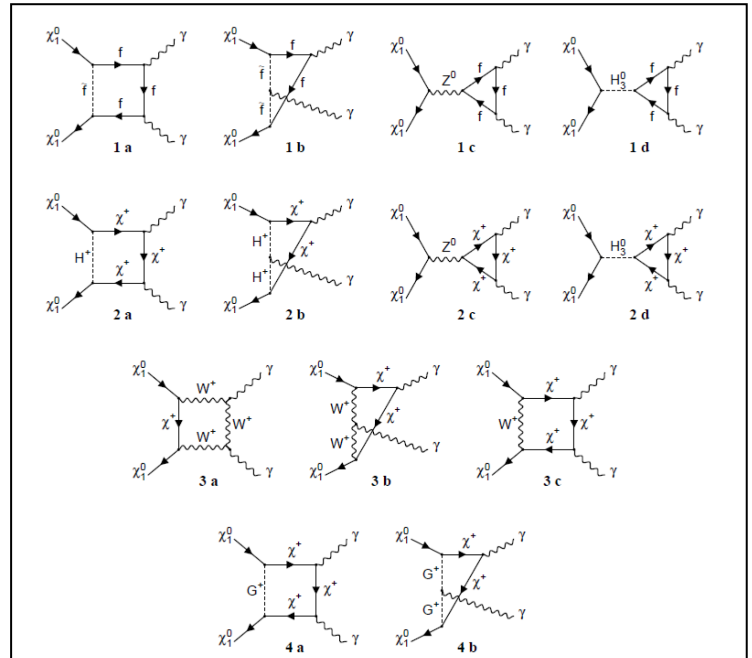


L.B. & H.Snellman, Phys. Rev. D (1988)

FIG. 3. Effective loop diagrams that contribute to the process $\lambda\bar{\lambda}\to\gamma\gamma$.

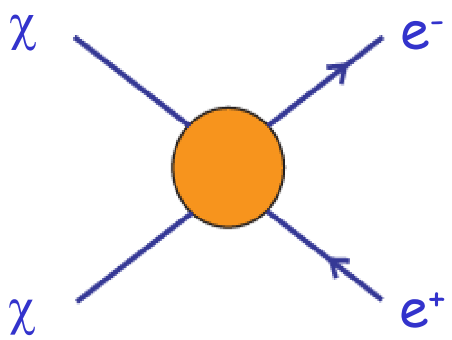
L. Bergström, G. Hulth / Higgs couplings to neutral bosons





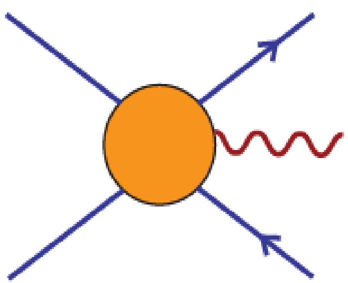
MSSM calculation,
L.B. & P. Ullio, Nucl. Phys. B (1997)
→ "Sommerfeld enhancement"
(J.Hisano et al. 2004)

The surprising size of QED "corrections" for slowly annihilating Majorana particles. Example: e^+e^- channel



Annihilation rate $(\sigma v)_0 \sim 3{\cdot}10^{-26}$ $cm^{-3}s^{-1}$ at freeze-out, due to p-wave at $(v/c)^2 \sim 0.3$. $\Omega_{CDM}h^2 = 0.1$ for mass ~ 100 - 500 GeV.

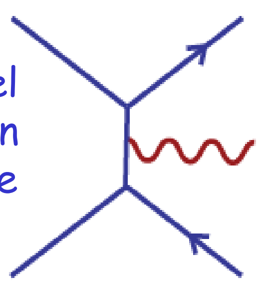
Annihilation rate today (S-wave)
$\sigma v \sim 10^{-25}\,(m_e/m_\chi)^2\ cm^3s^{-1} \sim 10^{-37}\ cm^3s^{-1}$ for $v/c \sim 10^{-3}$.
Impossible to detect! Even adding P-wave, it is too small, by orders of magnitude.



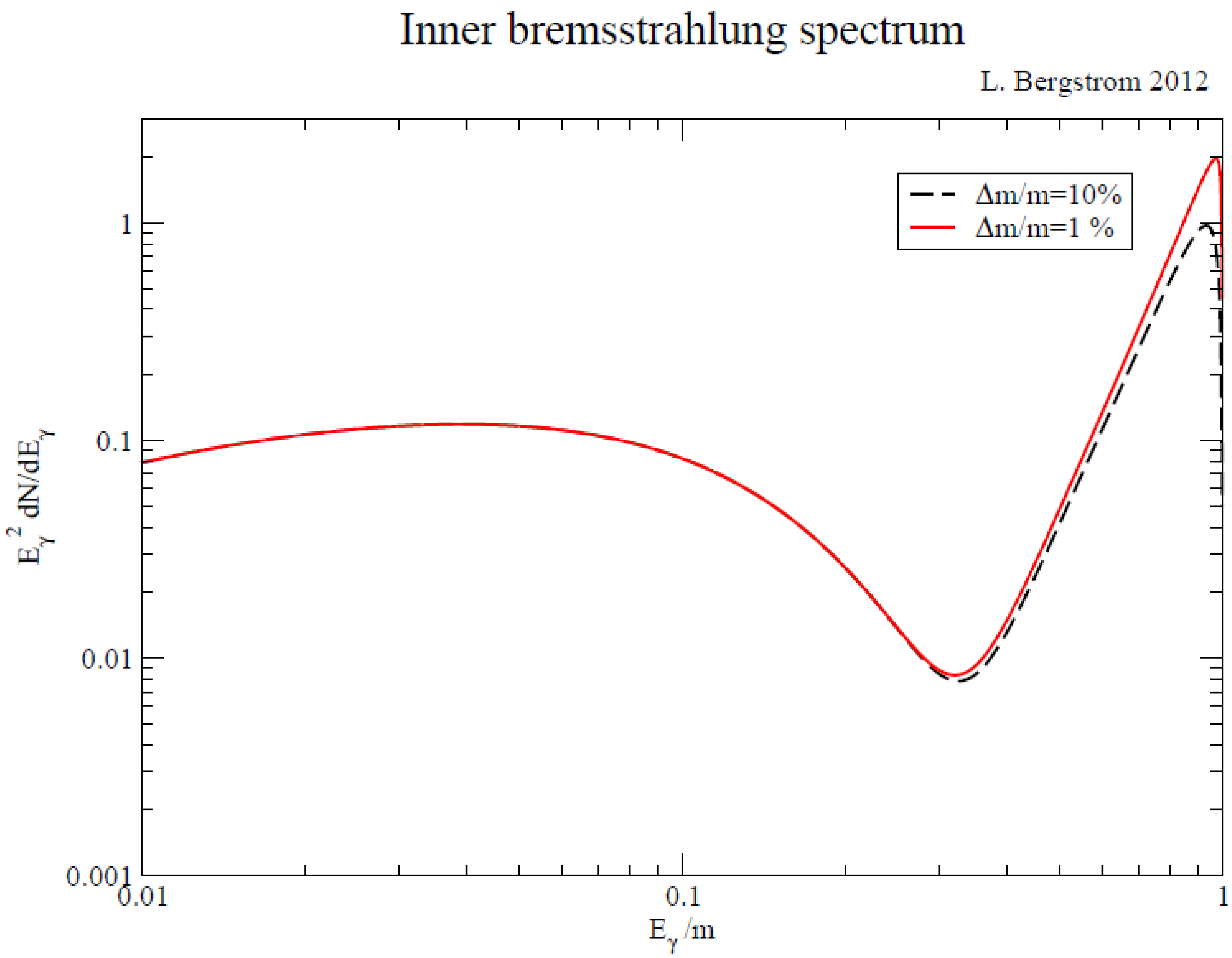
Direct emission (inner bremsstrahlung) QED "correction":
$(\sigma v)_{QED}/\,(\sigma v)_0 \sim (\alpha/\pi)\,(m_\chi/m_e)^2 \sim 10^9 \Rightarrow 10^{-28}\ cm^3s^{-1}$

The "expected" QED correction of a few per cent is here a factor of 10^9 instead! May give detectable gamma-ray rates – with good signature!

t-channel selectron exchange



(L.B. 1989; E.A. Baltz & L.B. 2003, T. Bringmann, L.B. & J. Edsjö, 2008; M. Ciafalone, M. Cirelli, D. Comelli, A. De Simone, A. Riotto & A. Urbano, 2011; N. F. Bell, J.B. Dent, A.J. Galea,T.D. Jacques, L.M. Krauss and T.J.Weiler, 2011)



Another "smoking gun" signal (may even be difficult to distinguish from the 2γ signal)

Predictions for the standard WIMP template, SUSY:

Indirect detection of SUSY DM through γ-rays. Three types of signal:

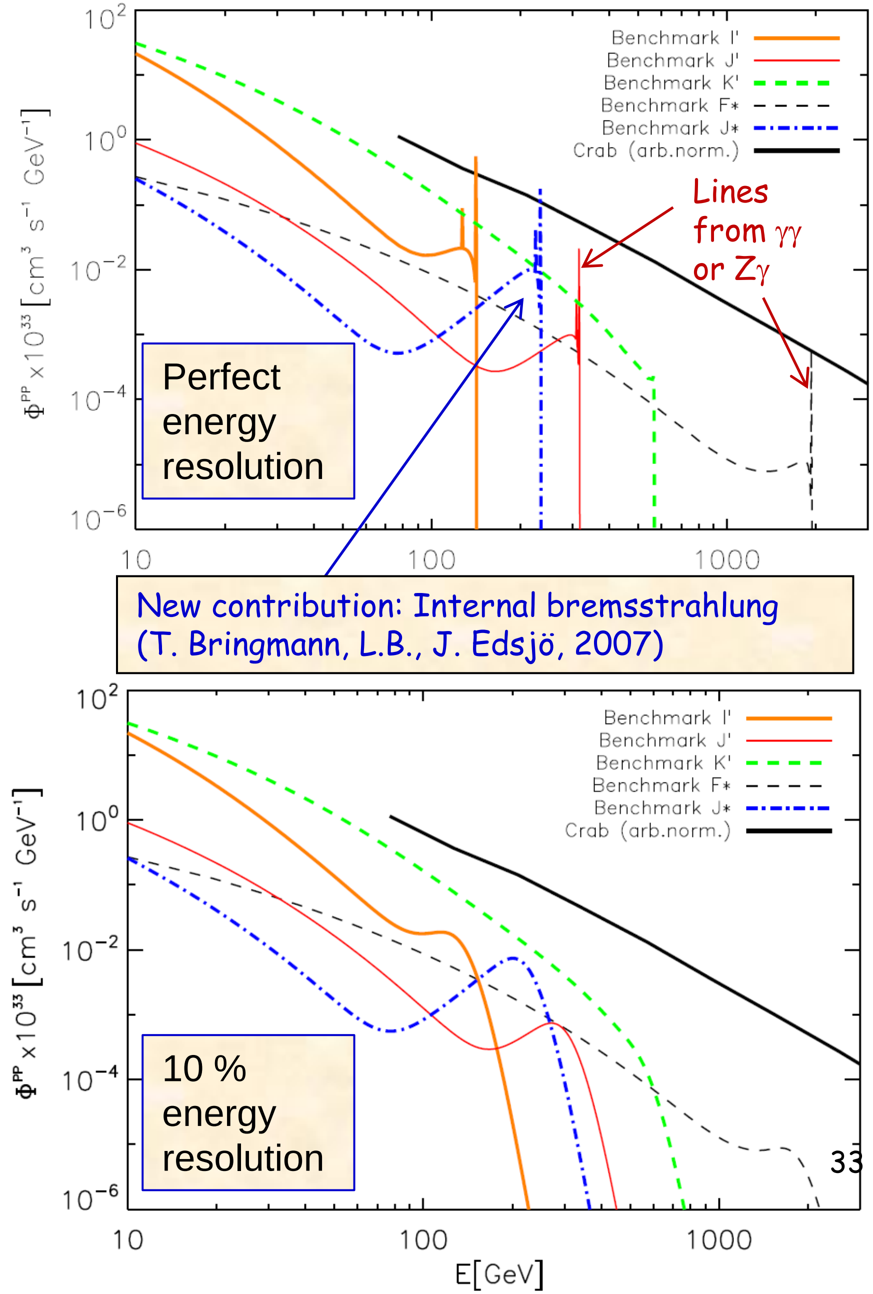
- Continuous from π^0, K^0, … decays.

- Monoenergetic line from quantum loop effects, $\chi\chi \rightarrow \gamma\gamma$ and $Z\gamma$.

- Internal bremsstrahlung from QED process.

Enhanced flux possible thanks to halo density profile and substructure (as predicted by N-body simulations of CDM).

Good spectral and angular signatures! But uncertainties in the predictions of absolute rates, due e.g. to poorly known DM density profile.



T. Bringmann, M. Doro & M. Fornasa, 2008; cf. L.B., P.Ullio & J. Buckley 1998.

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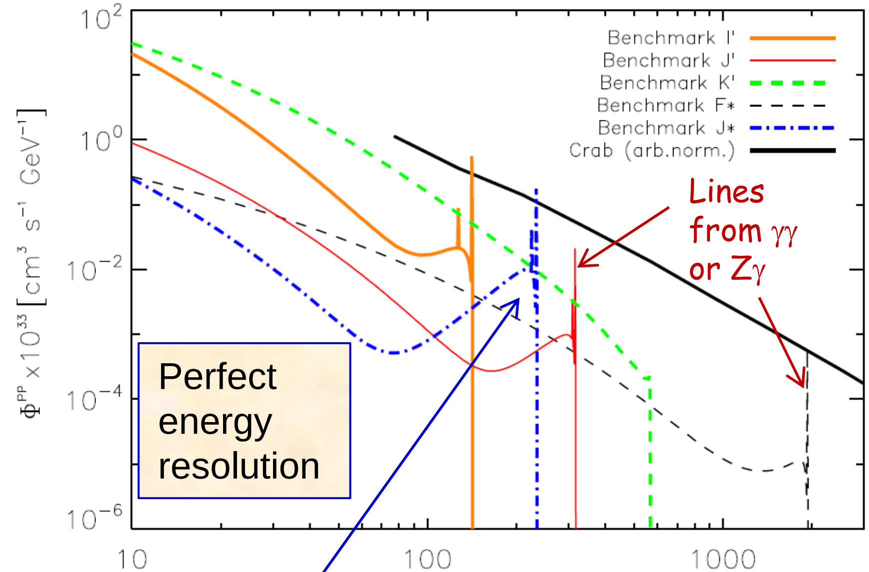
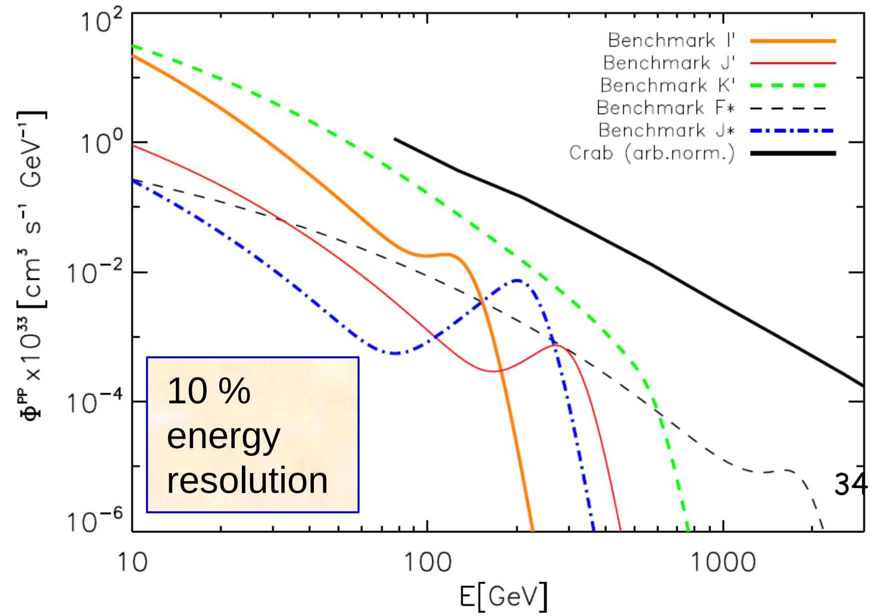
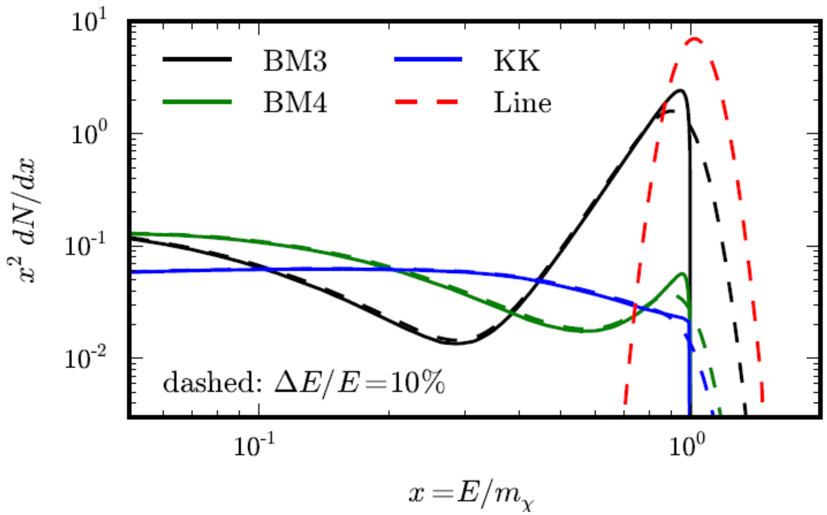


New contribution: Internal bremsstrahlung (T. Bringmann, L.B., J. Edsjö, 2007)

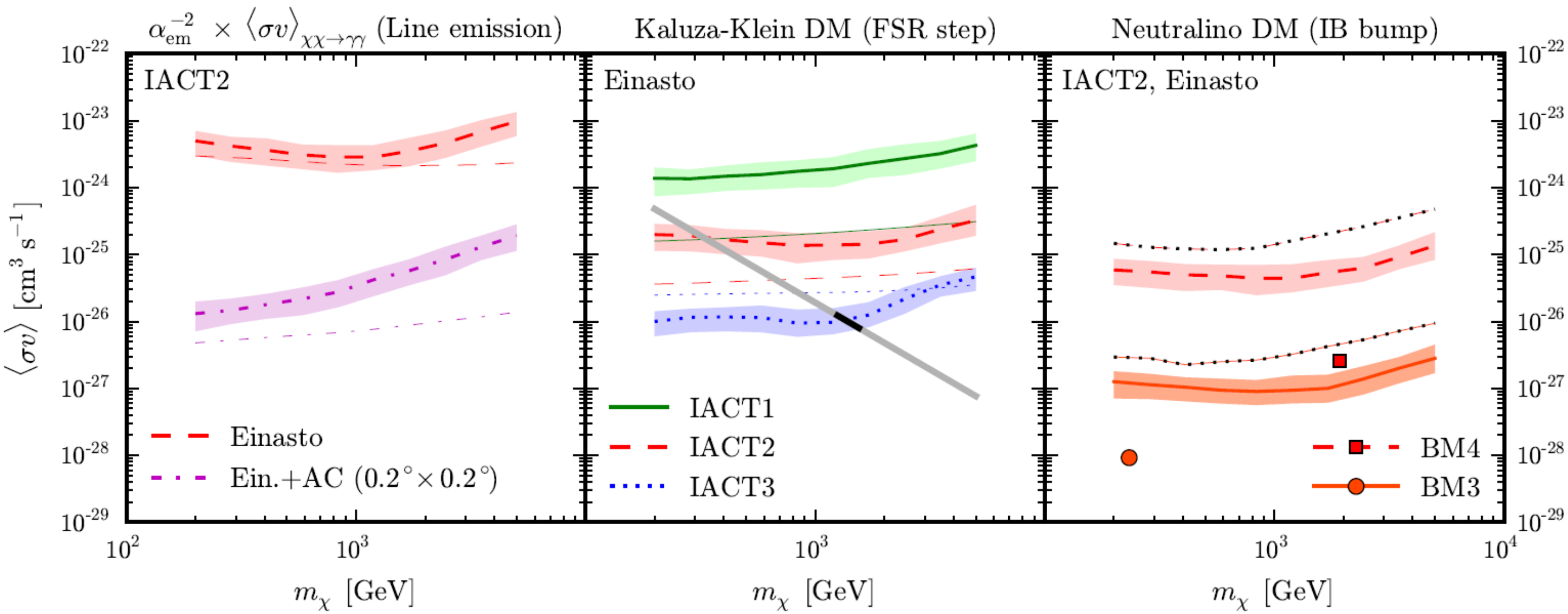


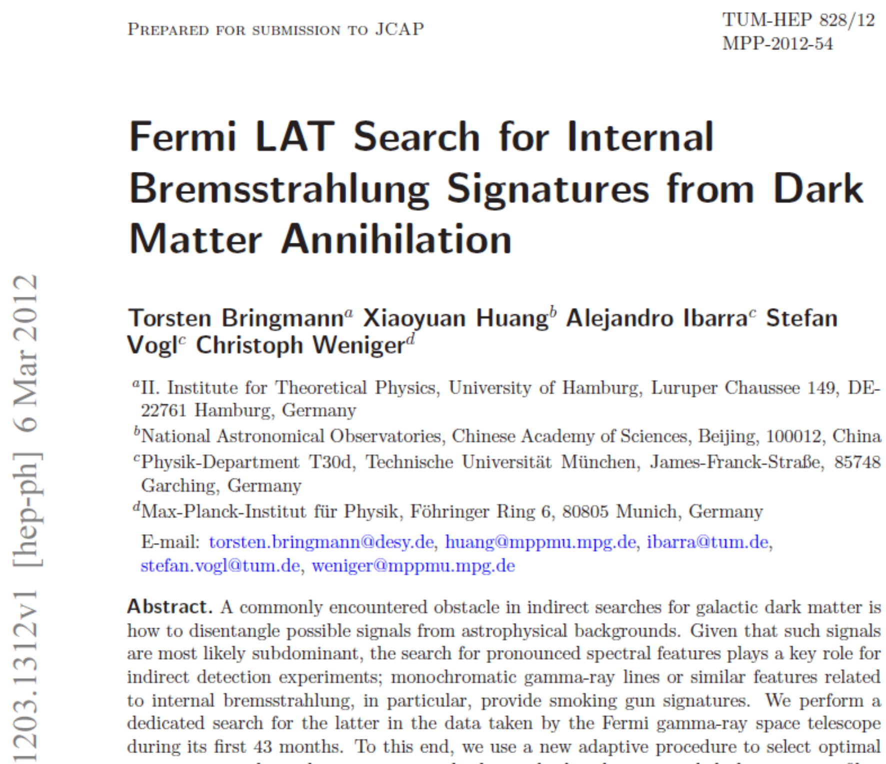
T. Bringmann, M. Doro & M. Fornasa, 2008; cf. L.B., P.Ullio & J. Buckley 1998.

T. Bringmann, F. Calore, G. Vertongen & C. Weniger Phys. Rev. D, 2011



Can one make use of the peculiar spectral features?




1203.1312v1 [hep-ph] 6 Mar 2012

Prepared for submission to JCAP

TUM-HEP 828/12
MPP-2012-54

Fermi LAT Search for Internal Bremsstrahlung Signatures from Dark Matter Annihilation

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[a]II. Institute for Theoretical Physics, University of Hamburg, Luruper Chaussee 149, DE-22761 Hamburg, Germany
[b]National Astronomical Observatories, Chinese Academy of Sciences, Beijing, 100012, China
[c]Physik-Department T30d, Technische Universität München, James-Franck-Straße, 85748 Garching, Germany
[d]Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 Munich, Germany

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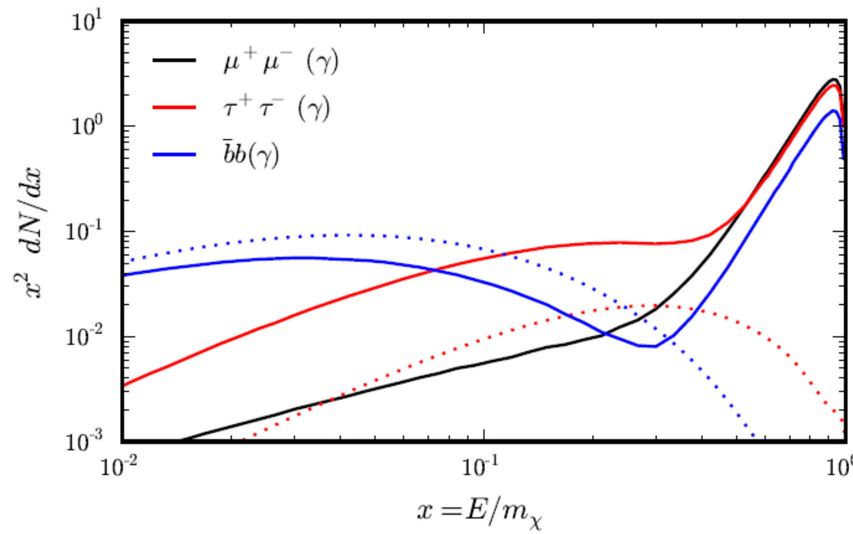
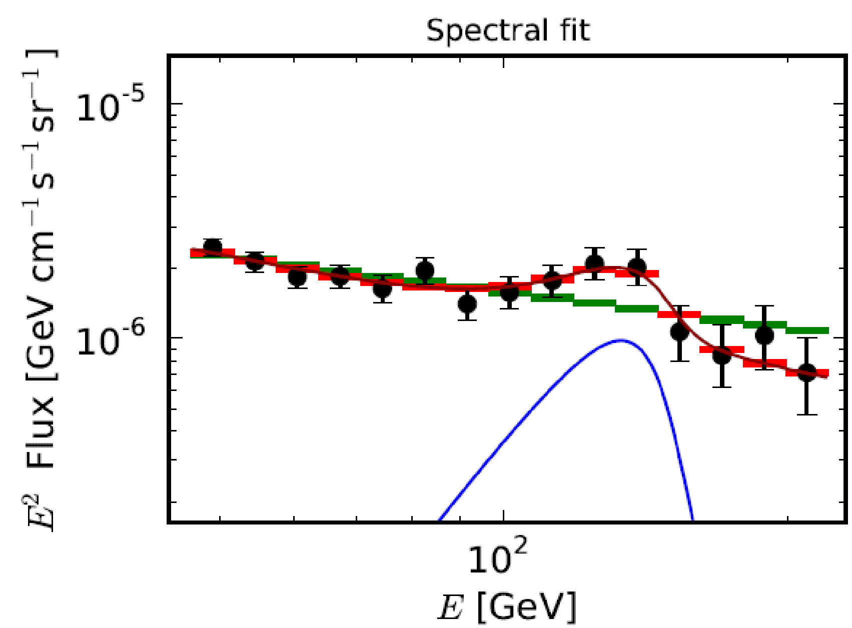
Abstract. A commonly encountered obstacle in indirect searches for galactic dark matter is how to disentangle possible signals from astrophysical backgrounds. Given that such signals are most likely subdominant, the search for pronounced spectral features plays a key role for indirect detection experiments; monochromatic gamma-ray lines or similar features related to internal bremsstrahlung, in particular, provide smoking gun signatures. We perform a dedicated search for the latter in the data taken by the Fermi gamma-ray space telescope during its first 43 months. To this end, we use a new adaptive procedure to select optimal



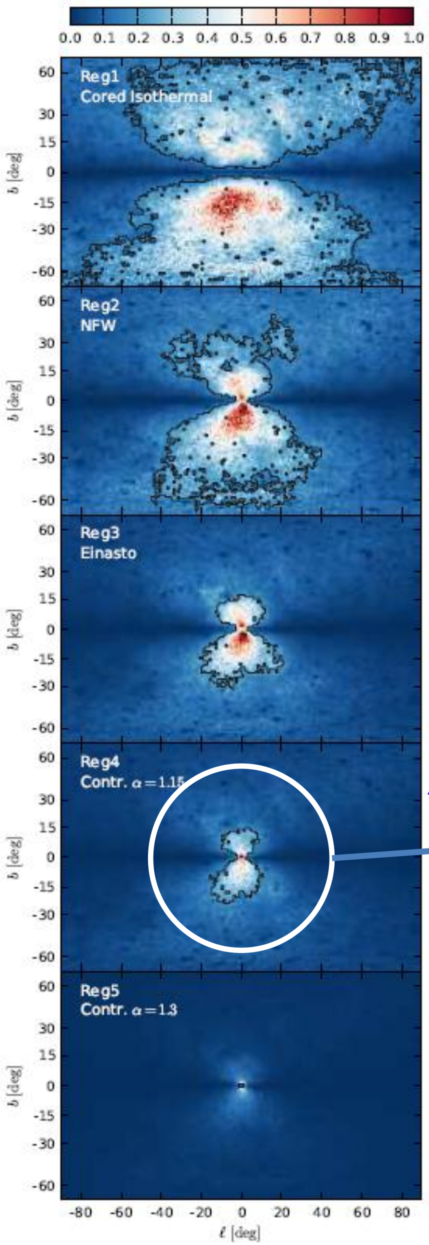
43 months of (public) Fermi data

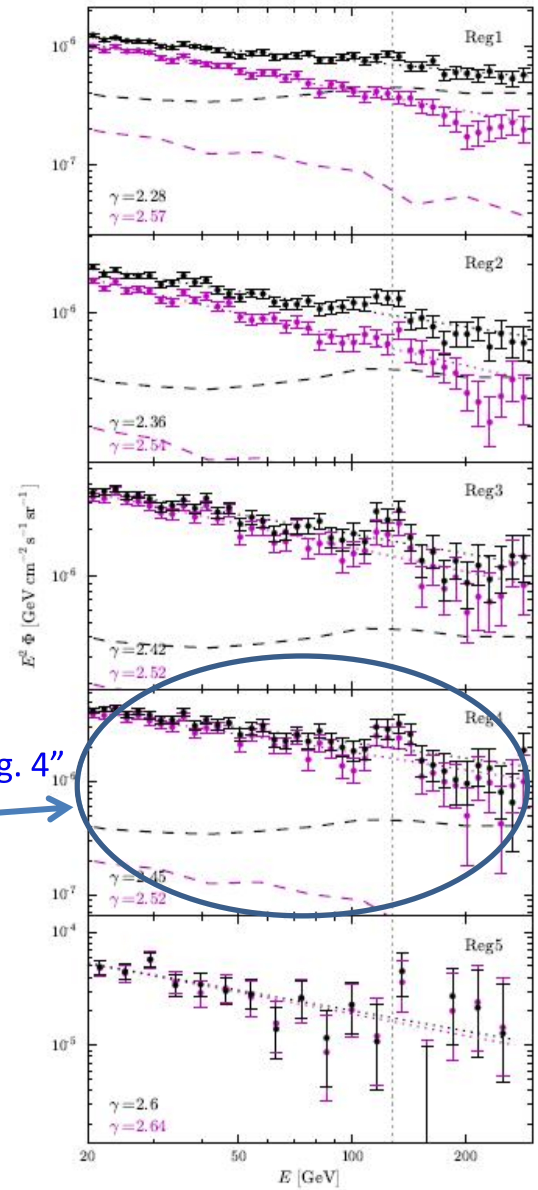


Mass = 149 GeV
Significance 4.3σ (3.1σ if ”look elsewhere” effect included)

C. Weniger, arXiv:1204.2797

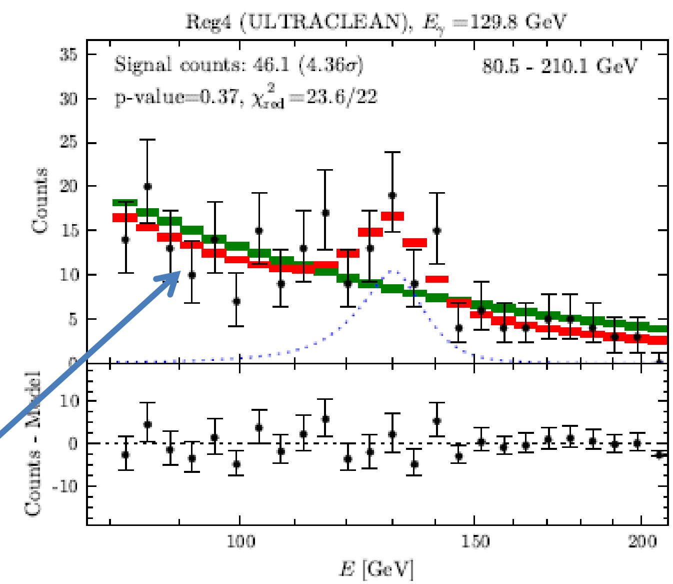
43 months of (public) Fermi data





"Reg. 4"

γ-ray line fit:



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

May 10:

Independent confirmation of the existence of the excess, and that it is not correlated with Fermi bubbles (as had been conjectured by S. Profumo and T. Linden , arXiv:1204.6047).

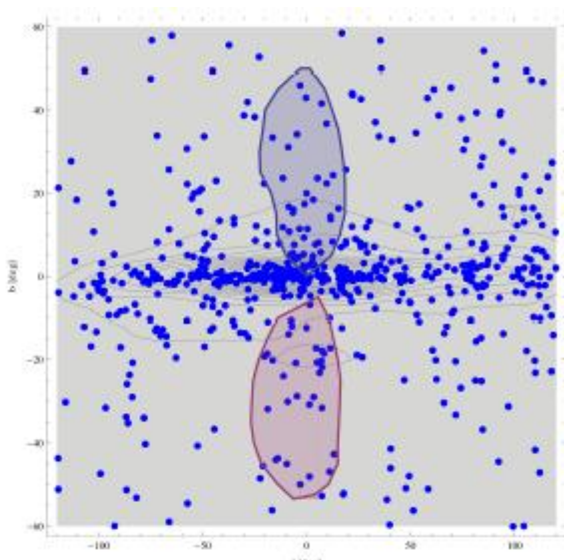
Fermi 130 GeV gamma-ray excess and dark matter annihilation in sub-haloes and in the Galactic centre

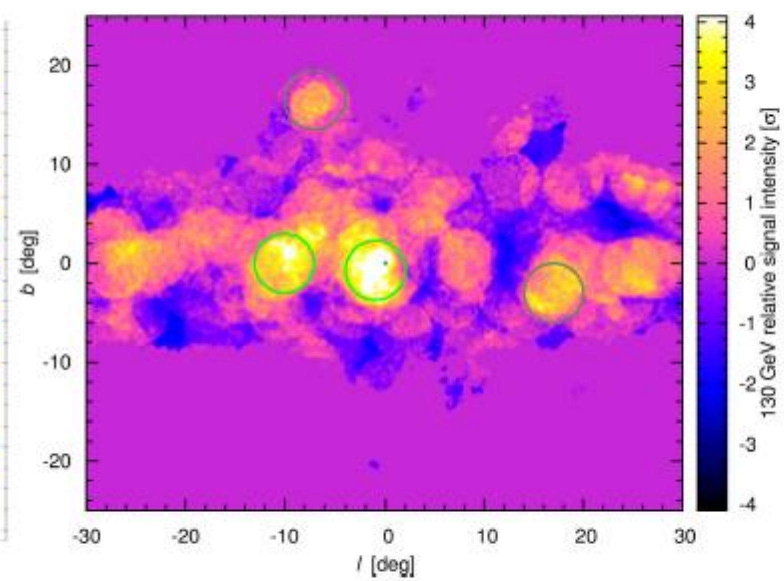
Elmo Tempel,[a,b] Andi Hektor[a] and Martti Raidal[a,c,d]

[a]NICPB, Ravala 10, Tallinn 10143, Estonia
[b]Tartu Observatory, Observatooriumi 1, Tõravere 61602, Estonia
[c]Institute of Physics, University of Tartu, Estonia
[c]CERN, Theory Division, CH-1211 Geneva 23, Switzerland

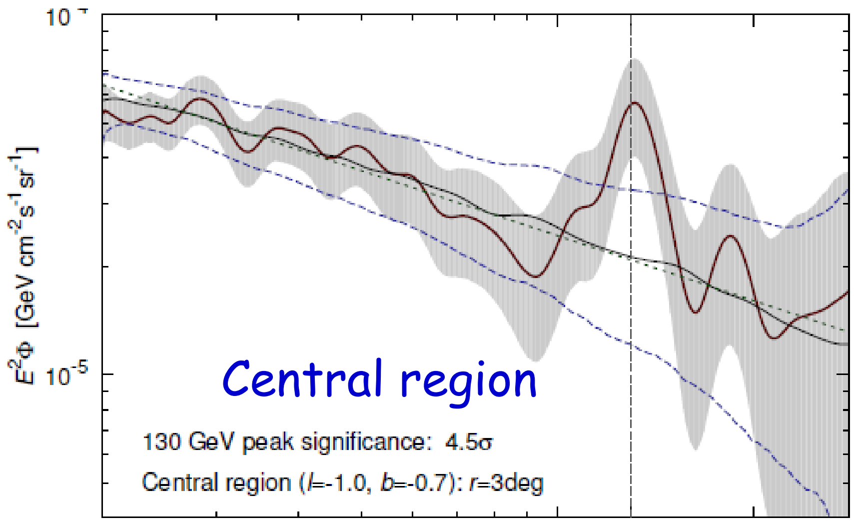
E-mail: elmo@aai.ee, andi.hektor@cern.ch, martti.raidal@cern.ch

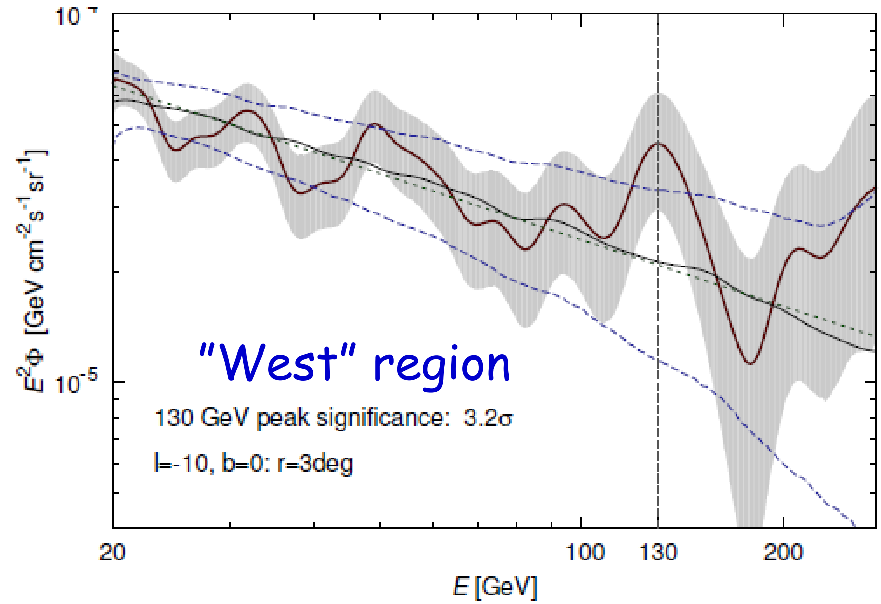
Abstract. We analyze publicly available Fermi-LAT high-energy gamma-ray data and confirm the existence of clear spectral feature peaked at E_γ = 130 GeV. Scanning over the Galaxy we identify several disconnected regions where the observed excess originates from. Our best optimized fit is obtained for the central region of Galaxy with a clear peak at 130 GeV with statistical significance 4.5σ. The observed excess is not correlated with Fermi bubbles. We compute the photon spectra induced by dark matter annihilations into two and four standard model particles, the latter via two light intermediate states, and fit the spectra

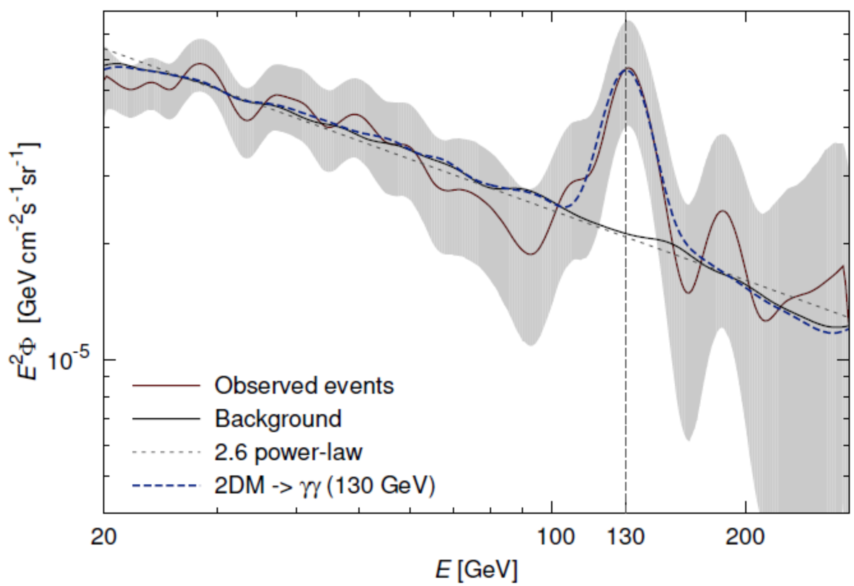




E. Tempel, A. Hektor and M. Raidal, May 10, 2012:







Best fit: $\gamma\gamma$ line, mass m_χ = 130 GeV

New, June 11, 2012: The γ-ray line also seen in the USA! (Using the same public Fermi-LAT data…)

arXiv:1206.1616v1

STRONG EVIDENCE FOR GAMMA-RAY LINES FROM THE INNER GALAXY

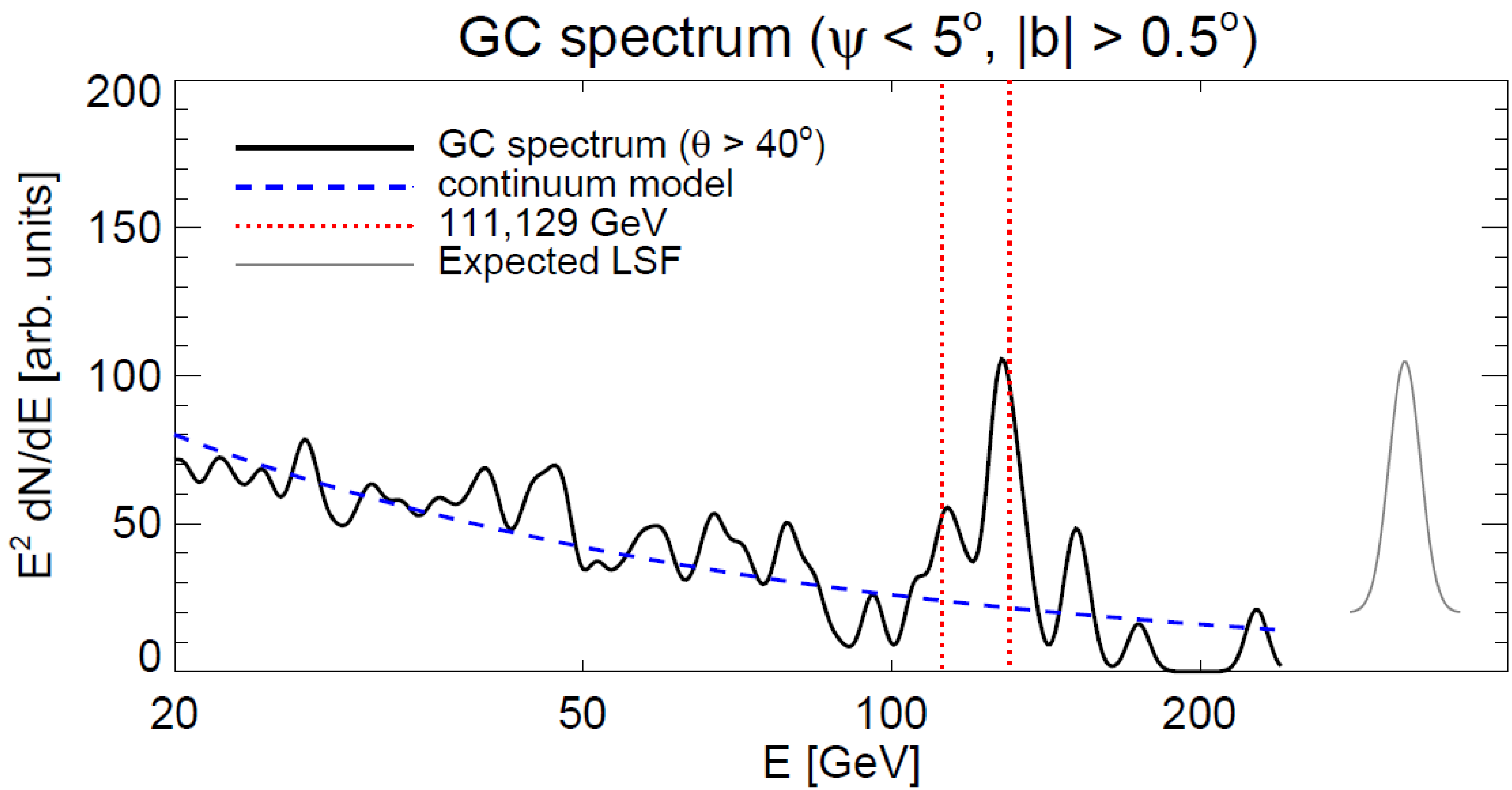
MENG SU[1,3], DOUGLAS P. FINKBEINER[1,2]

Draft version June 11, 2012

ABSTRACT

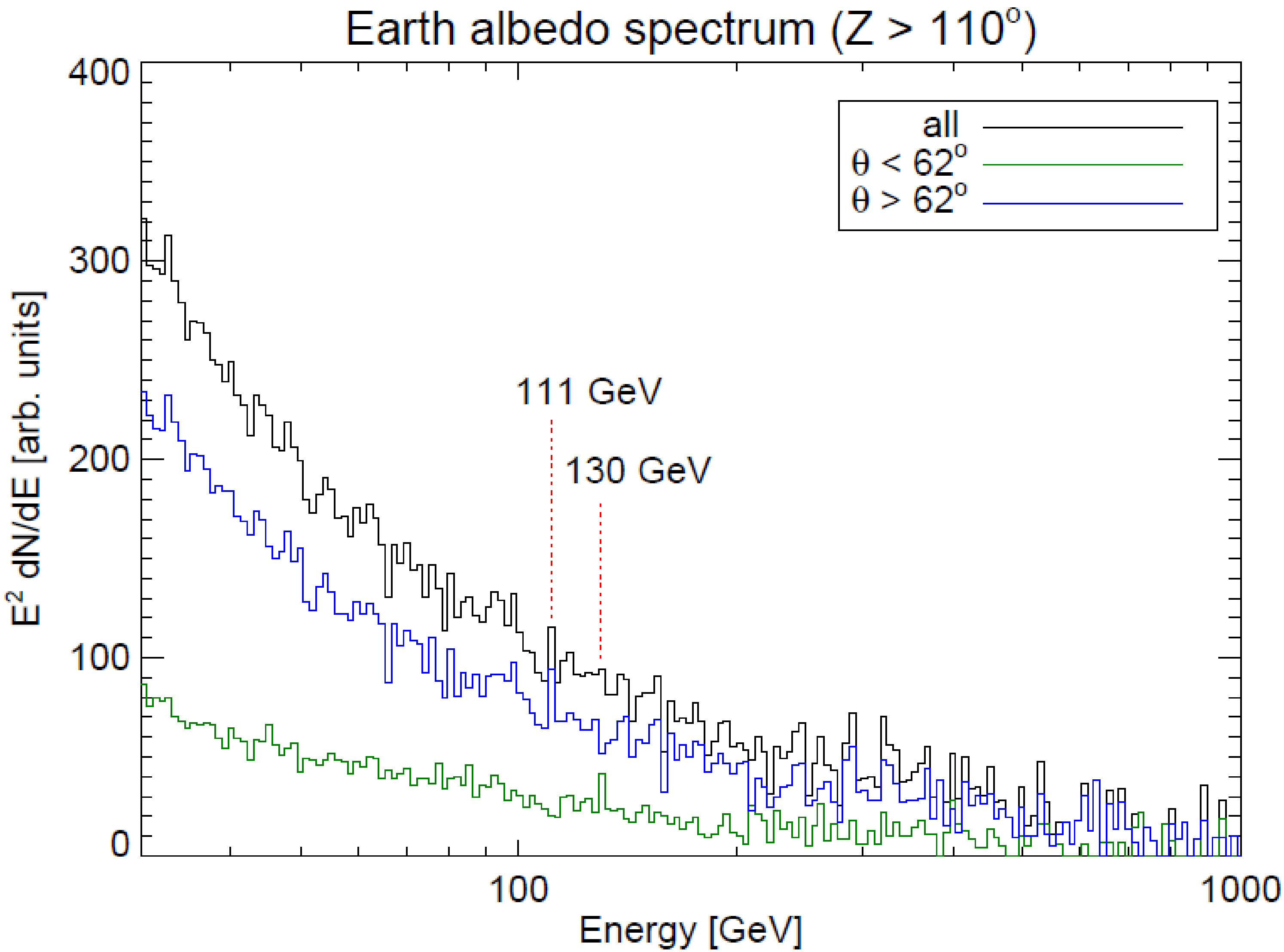
Using 3.7 years of *Fermi*-LAT data, we examine the diffuse gamma-ray emission in the inner Galaxy in the energy range 80 GeV $< E <$ 200 GeV. We find a diffuse gamma-ray feature at ~ 110 GeV to ~ 140 GeV which can be modeled by a $\lesssim 4°$ FWHM Gaussian in the Galactic center. The morphology is not correlated with the recently discovered *Fermi* bubbles. The null hypothesis of zero intensity is ruled out by 5.0σ (3.7σ with trials factor). The energy spectrum of this structure is consistent with a single spectral line (at energy 127.0 ± 2.0 GeV with $\chi^2 = 4.48$ for 4 d.o.f.). A pair of lines at 110.8 ± 4.4 GeV and 128.8 ± 2.7 GeV provides a marginally better fit (with $\chi^2 = 1.25$ for 2 d.o.f.). The total luminosity of the structure is $(3.2 \pm 0.6) \times 10^{35}$ erg/s, or $(1.7 \pm 0.4) \times 10^{36}$ photons/sec. The observation is compatible with a 142 GeV WIMP annihilating through γZ and γh for $m_h \sim 130$ GeV, as in the "Higgs in Space" scenario.

Subject headings: gamma rays — diffuse emission — milky way — dark matter



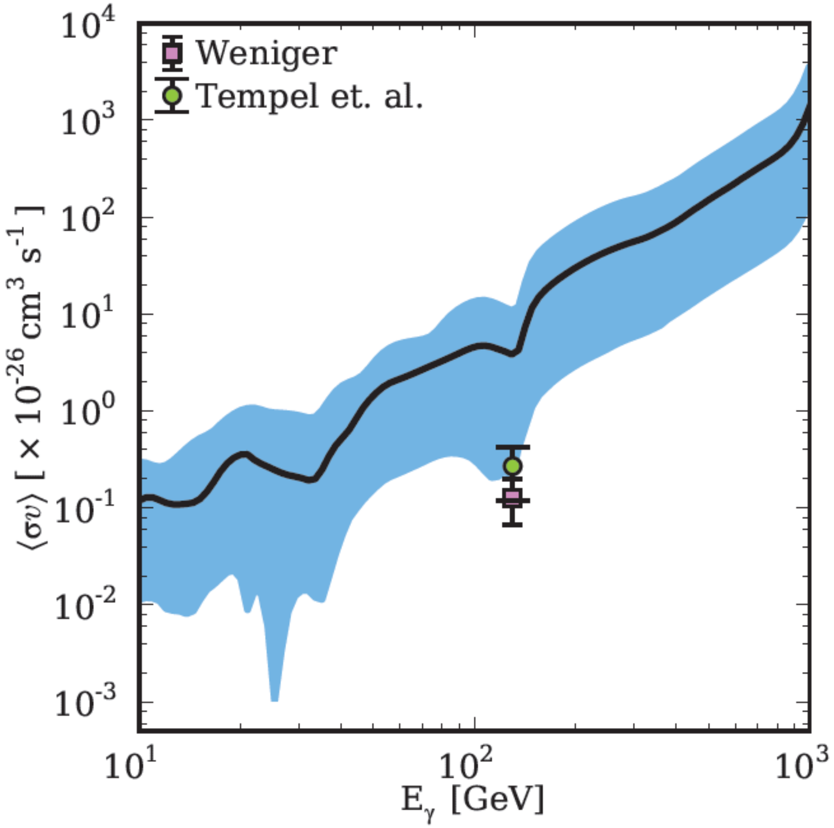
GC spectrum (ψ < 5°, |b| > 0.5°)
GC spectrum (θ > 40°)
continuum model
111,129 GeV
Expected LSF
E² dN/dE [arb. units]
E [GeV]
0
50
100
150
200
20
50
100
200

Null test, distribution of "albedo events" (γ-rays generated by cosmic rays hitting the atmosphere):



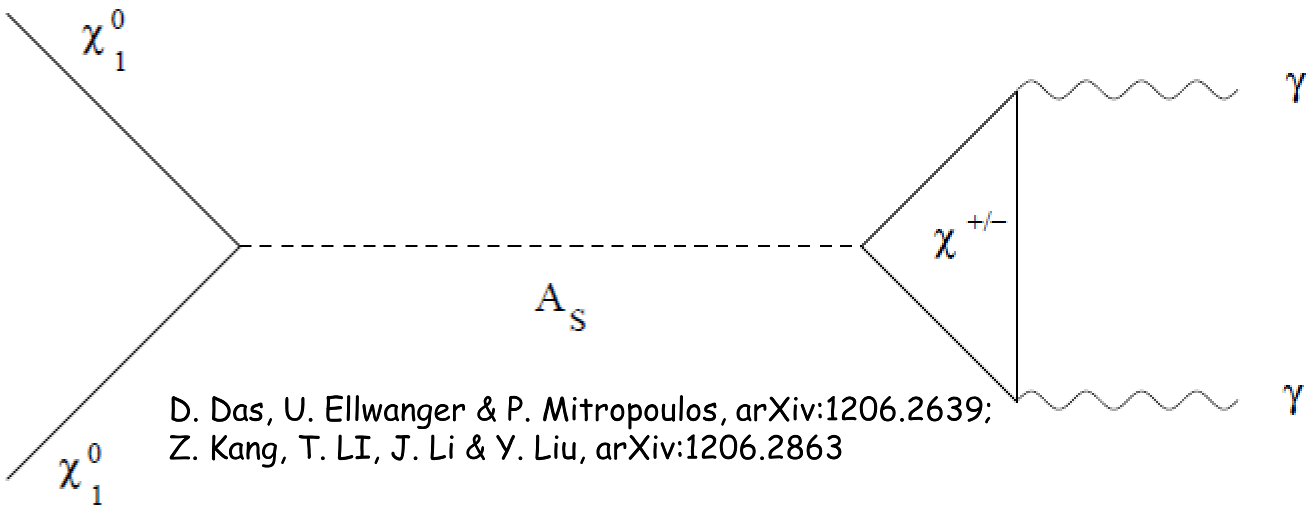
Looks OK? Maybe best to wait for statement from the FERMI-LAT Collaboration…

Search in dwarf galaxies (A. Geringer-Sameth and S.M. Koushiappas, arXiv:1206.0796)

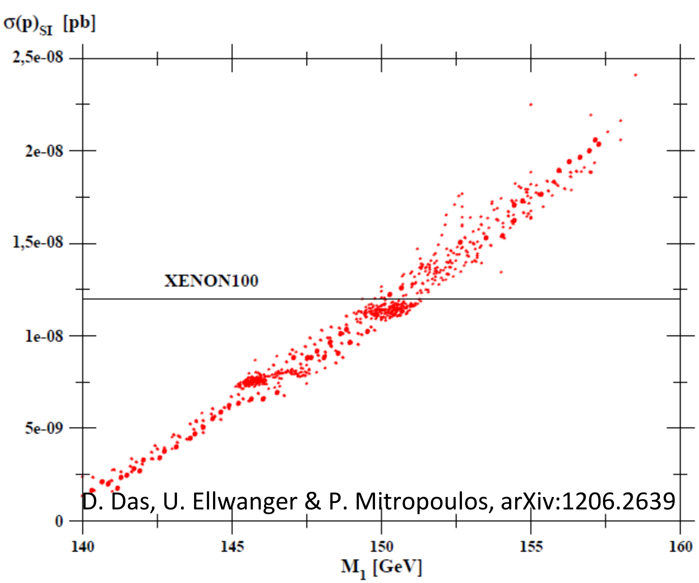


Not yet sensitive enough.

Model building? Probably too early, but on the arXiv today (June 14) there are three suggestions, two have an NMSSM proof of existence of a model that is consistent with all data:



D. Das, U. Ellwanger & P. Mitropoulos, arXiv:1206.2639;
Z. Kang, T. LI, J. Li & Y. Liu, arXiv:1206.2863



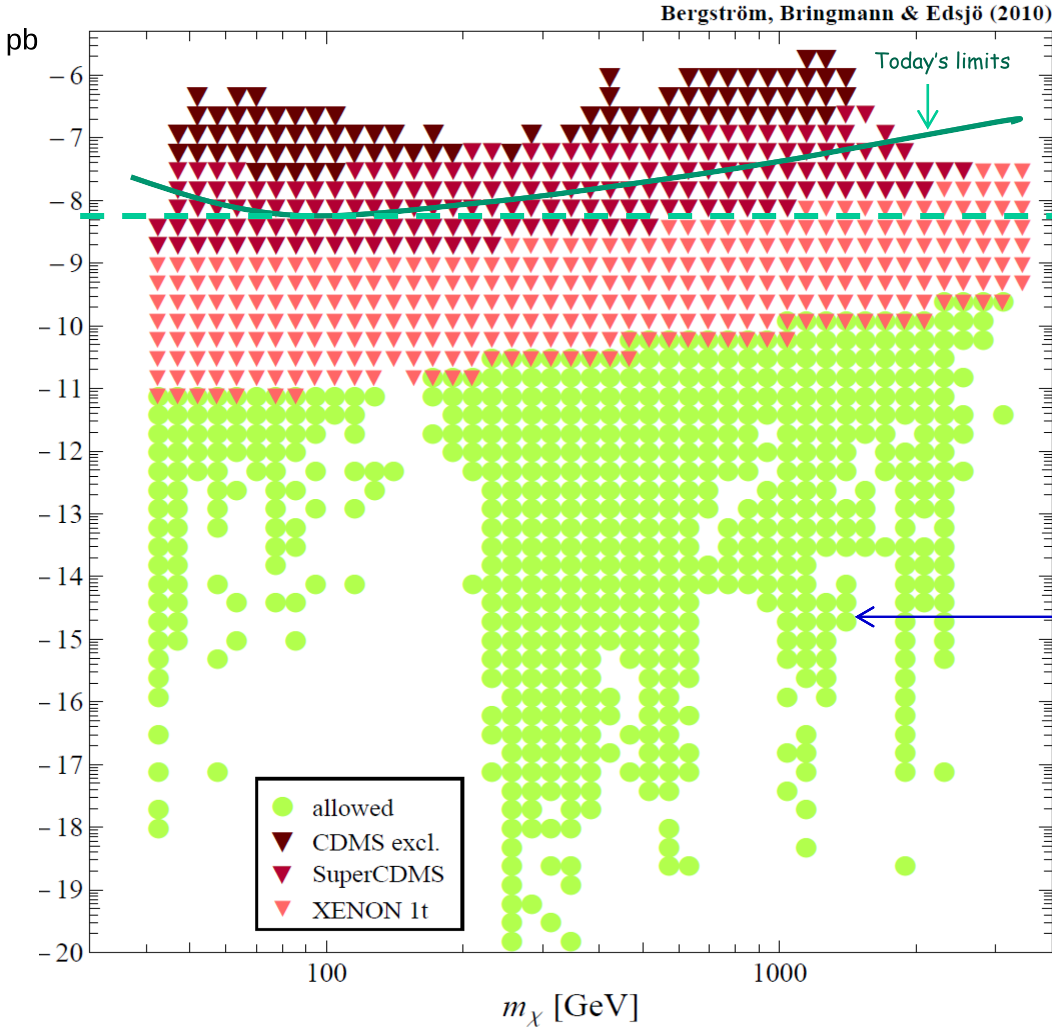
However, one piece of "fine/tuning" of order 10^{-2} is needed: Mass of A_S should be within a GeV from $2m_\chi$.

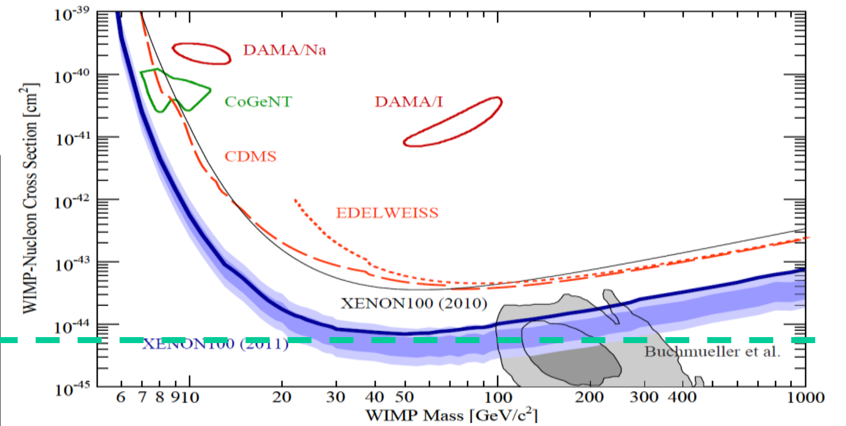
Other proposal: "Magnetic inelastic Dark Matter" (N. Weiner & I. Yavin, arXiv:1206.2910). Need nearly degenerate charged state.

Stay tuned…

The Dark Matter Array (DMA) – a dedicated DM experiment?

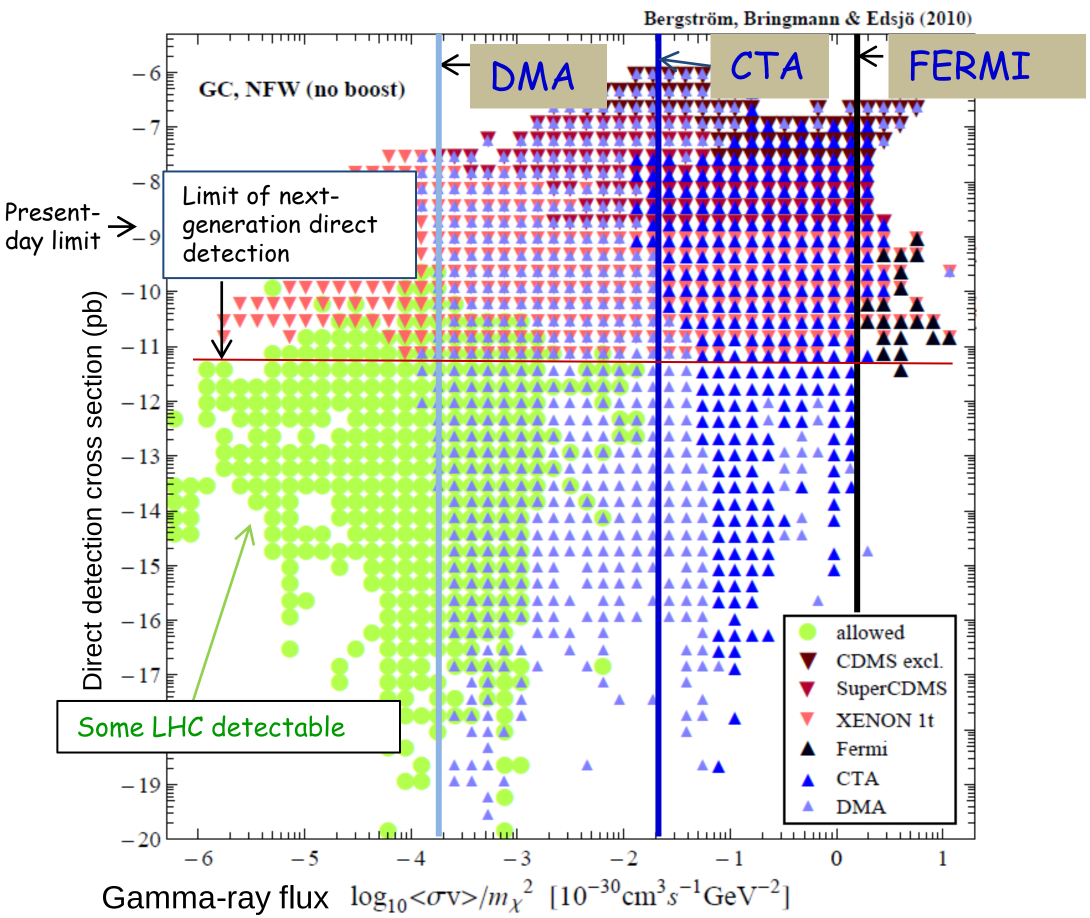
WMAP-compatible
models in pMSSM





The parameter space continues, 10 more orders of magnitude in direct detection cross section!

Complementarity between LHC, direct & indirect detection. DM search in γ-rays may be a window for particle physics beyond the Standard Model!



DMA: Dark Matter Array - a dedicated gamma-ray detector for dark matter?
(T. Bringmann, L.B., J. Edsjö, 2011)

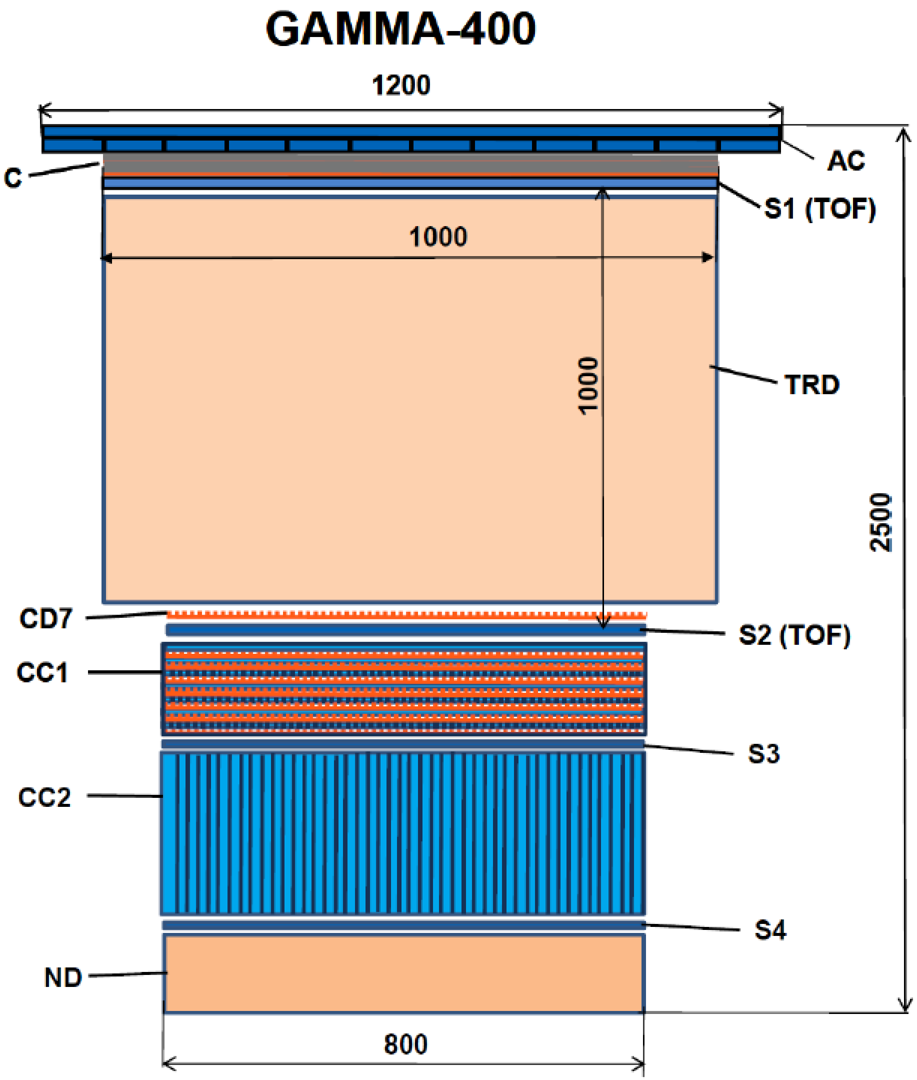
General pMSSM scan, WMAP-compatible relic density.
Check if $S/(S+B)^{0.5} > 5$ in the "best" bin (and demand $S > 5$)

DMA would be a particle physics experiment, cost ~ 1 GEUR. Challenging hard- and software development needed.

Construction time ~ 10 years, with principle tested in 5@5-type detector at 5 km in a few years…

The more immediate future?
GAMMA-400, 100 MeV – 3 TeV space telescope

A. M. Galper



An approved Russian γ-ray satellite (with Italian and Swedish-OKC?) participation (cf. PAMELA), with superior energy and angular resolution – about the size of FERMI-LAT.
Planned launch 2017-18.

Table 1. The GAMMA-400 expected performances.

GAMMA-400 gamma-ray telescope	
Gamma-ray energy range	0.1–3000 GeV
Converter (area and thickness)	$100 \times 100\,\mathrm{cm}^2$, 0.84 r.l.
Calorimeter (area and thickness)	$80 \times 80\,\mathrm{cm}^2$, ~ 30 r.l.
Field of view	$\pm 50°$
Angular resolution ($E_\gamma > 100$ GeV)	$\sim 0.01°$
Energy resolution ($E_\gamma > 10$ GeV)	$\sim 1\%$
Proton rejection factor	10^6
Point source sensitivity, ph/cm^2 s ($E_\gamma > 100$ MeV)	$\sim 2 \times 10^{-9}$
Telemetry downlink	100 GB/day
Power consumption	2000 W
Maximum dimensions	$2 \times 2 \times 3.0\,\mathrm{m}^3$
Total mass	~ 2600 kg
Lifetime	> 7 years
KONUS-FG gamma-ray burst monitor	
Energy range	10 keV – 10 MeV

Ideal, e.g., for looking for spectral DM-induced features, like searching for γ-ray lines! If Weniger is right, the 130 GeV line should be seen with about 10σ significance (L.B., G. Bertone, J. Conrad, C. Farnier & C. Weniger, in preparation).

NEWS & ANALYSIS

SPACE SCIENCE

Chinese Academy Takes Space Under Its Wing

LOFTY AMBITIONS

Mission	Chief scientist	Goals	Estimated launch
HXMT	Li Tipei, CAS Institute of High Energy Physics and Tsinghua University	Survey of x-ray sources; detailed observations of known objects	2014
Shijian-10	Hu Wenrui, CAS Institute of Mechanics	Study physical and biological systems in microgravity and strong radiation environment	Early 2015
KuaFu Project	William Liu, Canadian Space Agency and CAS Center for Space Science and Applied Research	Study solar influence on space weather	Mid-2015
Dark Matter Satellite	Chang Jin, CAS Purple Mountain Observatory	Search for dark matter; study cosmic ray acceleration	Late 2015
Quantum Science Satellite	Pan Jianwei, University of Science and Technology of China	Quantum key distribution for secure communication; long-distance quantum entanglement	2016

The Chinese initiative: The Dark Matter Satellite (DAMPE)

SCIENCE, May 20, 2011

Cosmic-ray

Gamma-ray Astronomy

Dark matter

Observation Requirements:

Particles: e; gamma-ray; p, He, and Heavy ions

Energy range： GeV-10TeV (e and ɣ)

100s TeV (p, He…)

Energy resolution： 1.5%@1TeV

space resolution： >0.5°@100 GeV

Background： <1.5%@TeV

Geo. Factor： > 0.5m^2.sr

J. Chang, Dark Side of the Universe, Beijing, 2011

Conclusions

- Most of the experimental DM indications are not particularly convincing at the present time.
- Fermi-LAT already has competitive limits for low masses, but interesting indications of a line at 130 GeV
- IceCube has a window of opportunity for spin-dependent DM scattering, and may test DAMA with DM-ICE.
- The field is entering a very interesting period: CERN LHC is running at 8 TeV at full luminosity, and in a couple of years at 14 TeV; XENON 1t is being installed; IceCube and DeepCore are operational; Fermi-LAT will collect at least 4 more years of data; DAMPE is planned for launch 2015 (?), CTA and Gamma-400 may operate by 2017-18, and perhaps even a dedicated DM array, DMA, some years later.
- However, as many experiments now enter regions of parameter space where a DM signal *could* be found, we also have to be prepared for false alarms – seeing dark matter *"Here, there and everywhere"!*

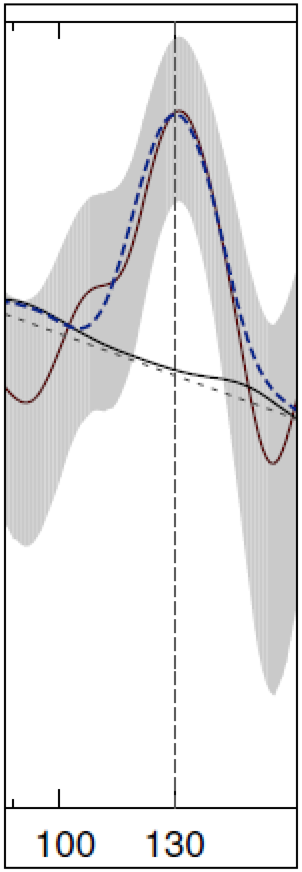
Here, there and everywhere (J. Lennon & P. McCartney):

Here, there and everywhere (J. Lennon & P. McCartney):

"… Nobody can deny that there's something there…"

Here, there and everywhere (J. Lennon & P. McCartney):

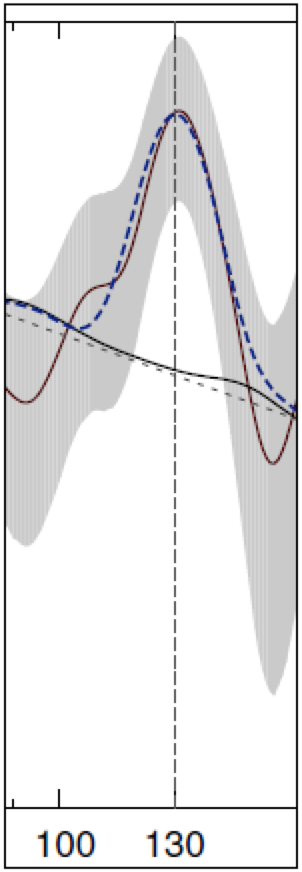
"... Nobody can deny that there's something there..."



Here, there and everywhere (J. Lennon & P. McCartney):

"… Nobody can deny that there's something there…"

But what is it???



Here, there and everywhere (J. Lennon & P. McCartney):

"… Nobody can deny that there's something there…"

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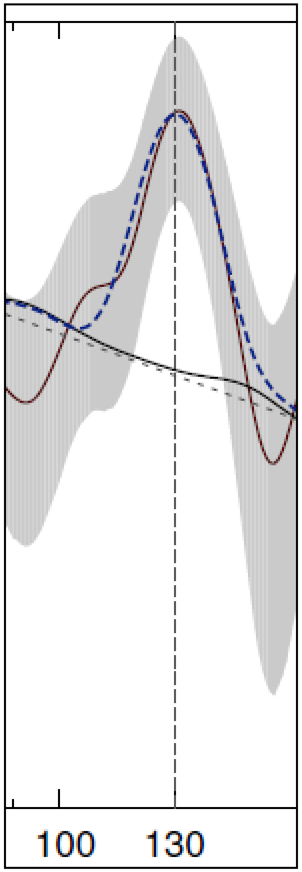

The End