Consequences of a New Force in the Dark Sector

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Based on work with

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A new framework for WIMP models

Arkani-Hamed et al, 0810.0713; Pospelov and Ritz, 0810.1502

- The past few years have been a very exciting time in dark matter searches, with rapid progress in setting constraints, and several potential signals.

- Strategy: take observed anomalies seriously and consider the implications if they are attributed to dark matter physics.

- Questions: can the observed anomalies be generated by our favorite generic WIMP model, a thermal relic SUSY neutralino? If not, what sort of dark matter models do we need? <u>In what ways do the predictions of these models differ from the generic case?</u>

- Our framework: a new gauge interaction in the dark sector with ~GeV gauge bosons. Dark U(1) factor mixes with SM hypercharge.

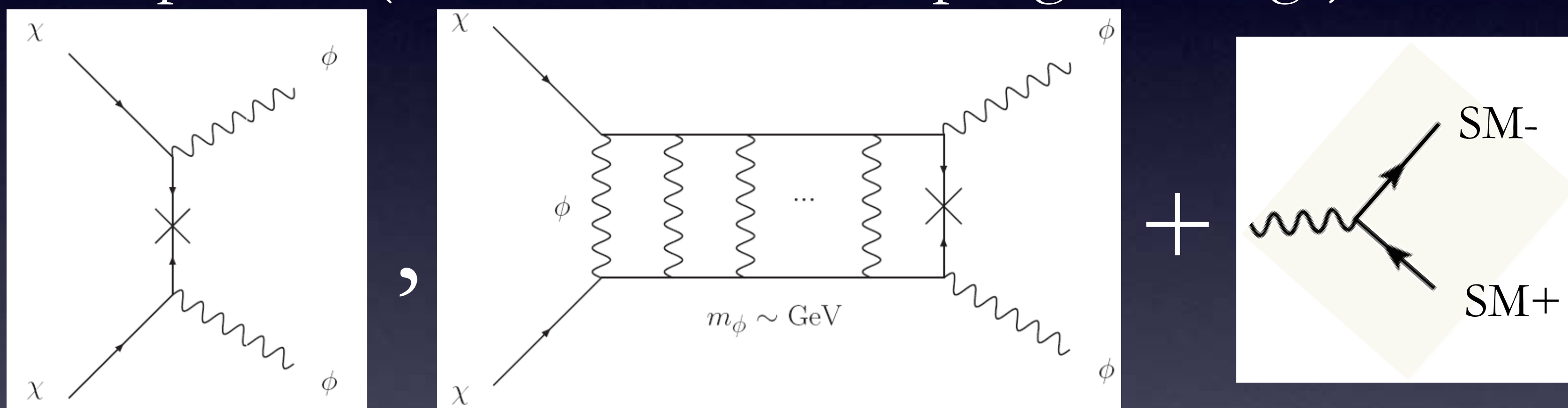
Consequences for DM searches

This simple idea has a wide range of phenomenological consequences, for indirect, direct and collider-based WIMP searches:

- New annihilation channels
- Enhanced annihilation at low velocities
- Excited states and inelastic scattering
- New decay channels for more massive particles
- New light states accessible in colliders

New annihilation channels

- Two WIMPs can now annihilate to a pair of the new dark gauge bosons – highly boosted, as their mass (~GeV) is much less than the WIMP mass. The gauge bosons then decay to pairs of charged SM particles with masses less than $m_A/2$, via their mixing with the photon (which induces a coupling to charge).



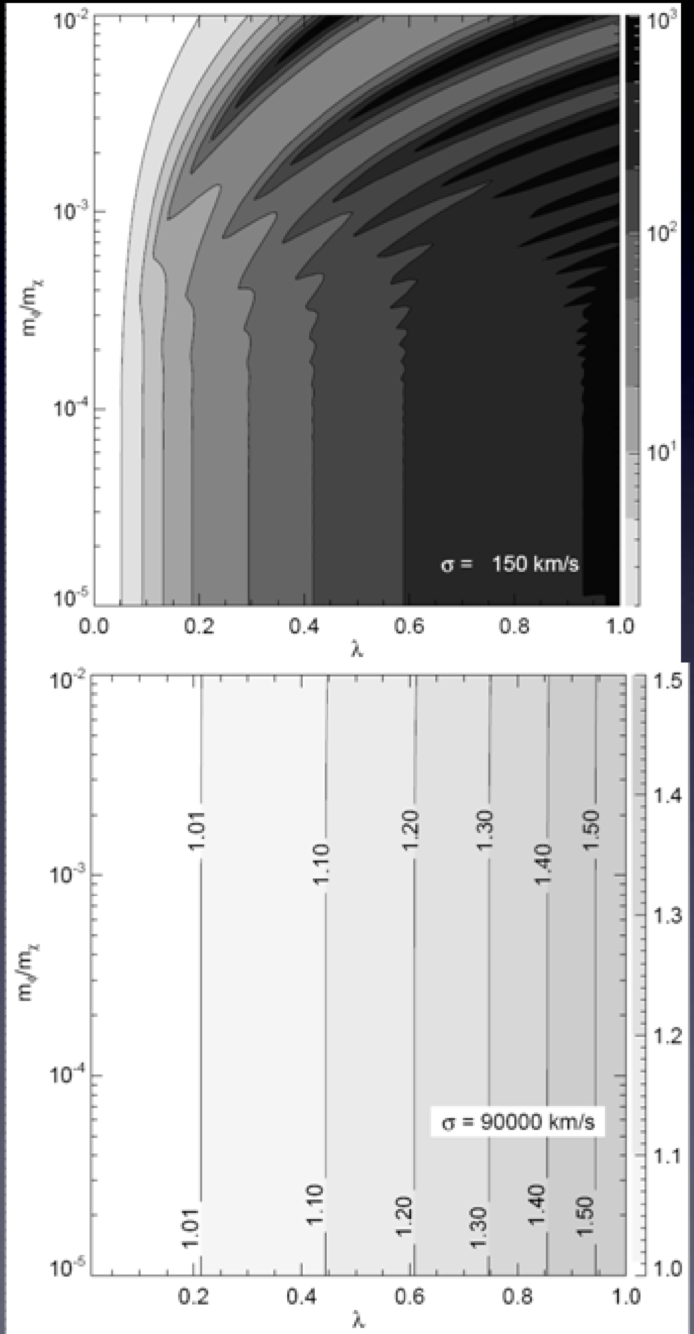
- Result: annihilations give hard spectra of highly boosted, light, charged SM states (e.g. e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^-$).

- If $m_A < 2\ m_p \sim 2$ GeV, no antiprotons produced. Branching ratio to neutral pions is typically very small, so few γ's from π^0 decay.

Sommerfeld enhanced annihilation

- Exchange of light force carriers gives nonperturbative enhancement S to annihilation xsec.
- In non-resonant case, S scales as 1/v for $v/c < \alpha$, until saturation when $m_\phi / M \sim v/c$.
- In resonant regions (dependent on α, m_ϕ / M), S can scale as $1/v^2$.
- $S \sim 1$ at DM freeze-out ($\beta \sim 0.3$), but can be 2-3 orders of magnitude in local halo ($\beta \sim 10^{-4}$-10^{-3}).

(see e.g. Hisano et al, hep-ph/0412403)

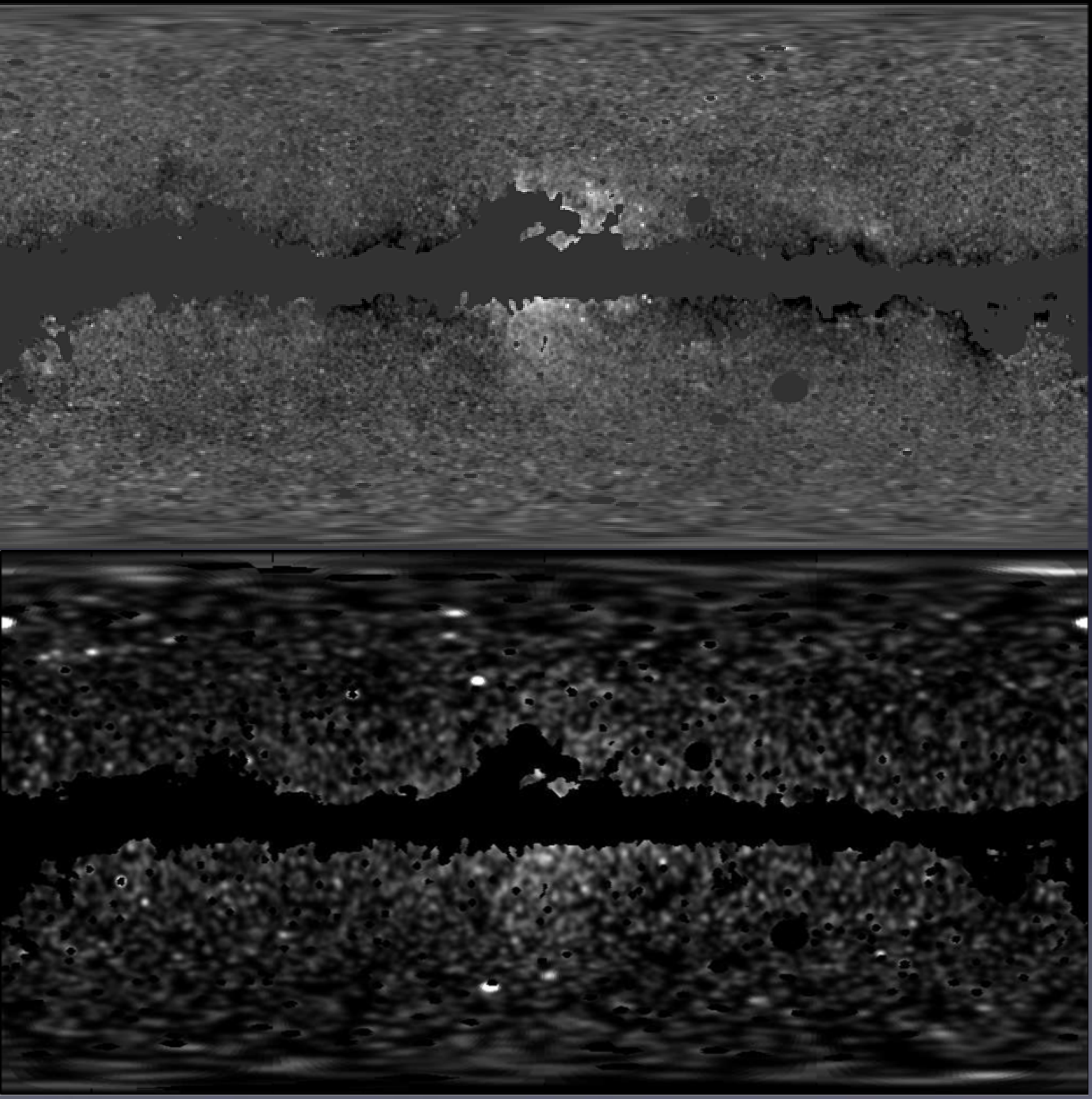


Consequences of modified annihilation in indirect detection

- Generic prediction for $m_A < 1$ GeV: annihilations produce hard e^+e^-, no antiprotons and few or no π^0 γ's. The direct photon signature from annihilation is small, but inverse Compton scattering and synchrotron radiation from the high energy e^+e^- can produce large diffuse photon signals.

- Annihilation cross section is boosted above thermal relic xsec in present day, possibly boosted further in DM substructure and/or early universe before structure formation. Possible large effects on cosmic microwave background, reionization, etc (see talks by Hektor, Iocco later this afternoon, also Galli et al 09; TRS, Padmanabhan & Finkbeiner 09; Belikov & Hooper 09, Cirelli, Iocco & Panci 09, Huetsi, Hektor & Raidal 09). Planck can explore these effects.

The inner galaxy: synchrotron and ICS



The WMAP Haze

Residual emission in WMAP 23-94 GHz maps – synchrotron?

Hooper, Finkbeiner and Dobler, 0705.3655

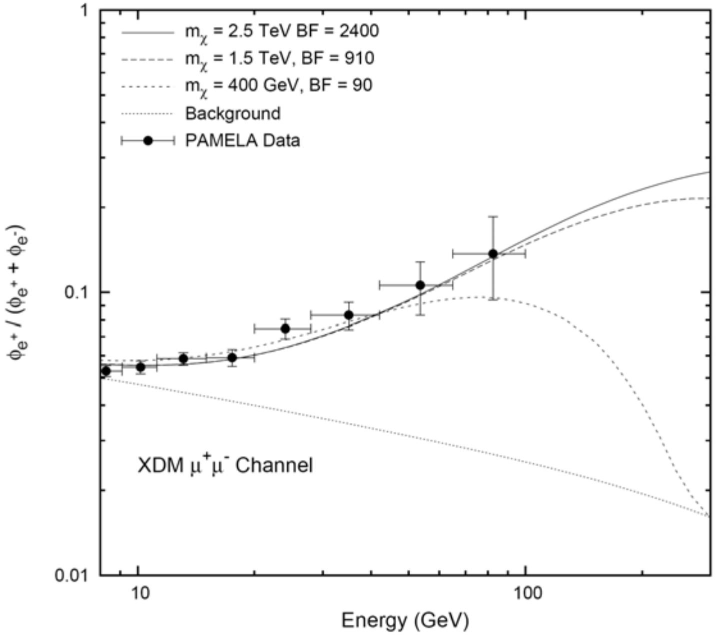
PRELIMINARY:

The Fermi Haze?

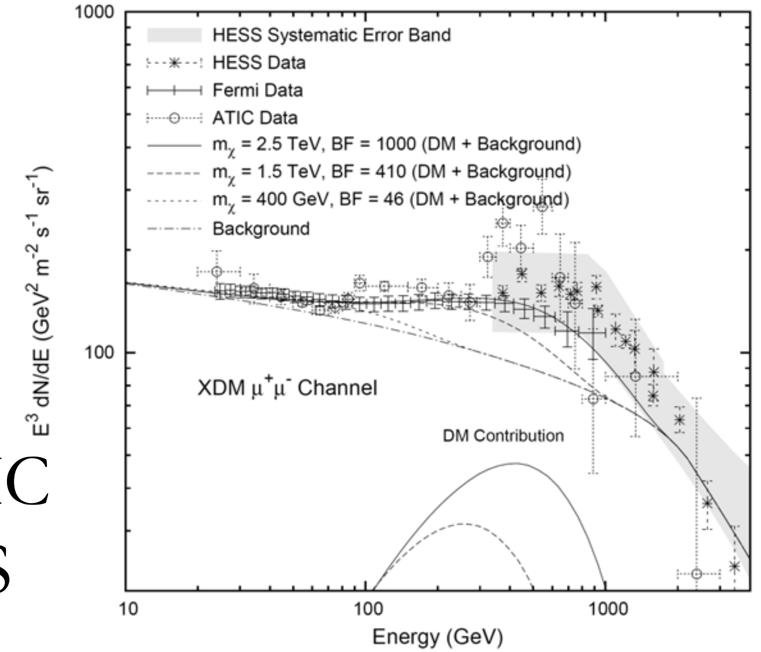
Class 3 Fermi LAT data, 20-50 GeV – ICS?

Spectral fits for sample channels

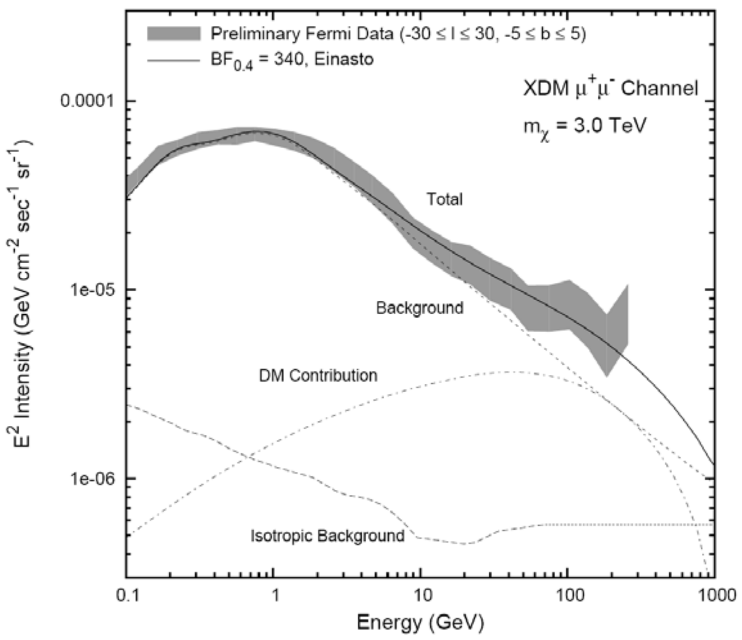
Cholis et al 08; Cholis, Dobler, Finkbeiner, Goodenough, TRS and Weiner, 0907.3953



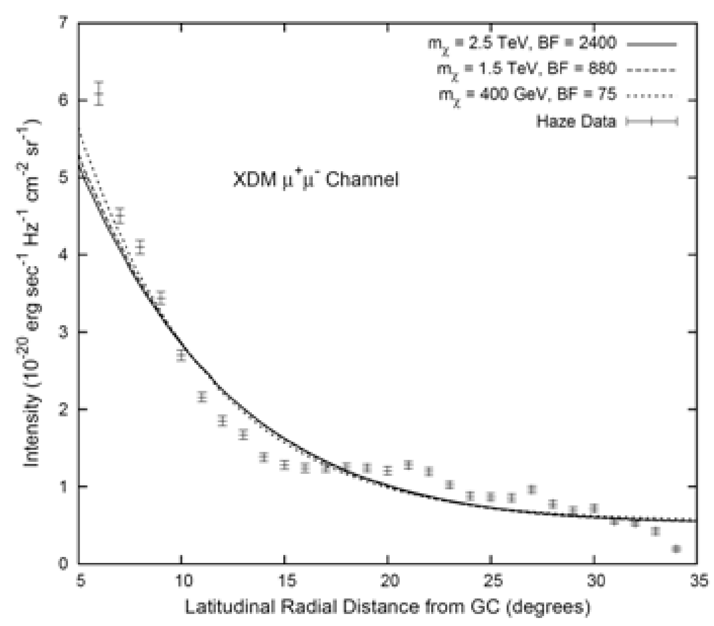
PAMELA



Fermi, ATIC and HESS

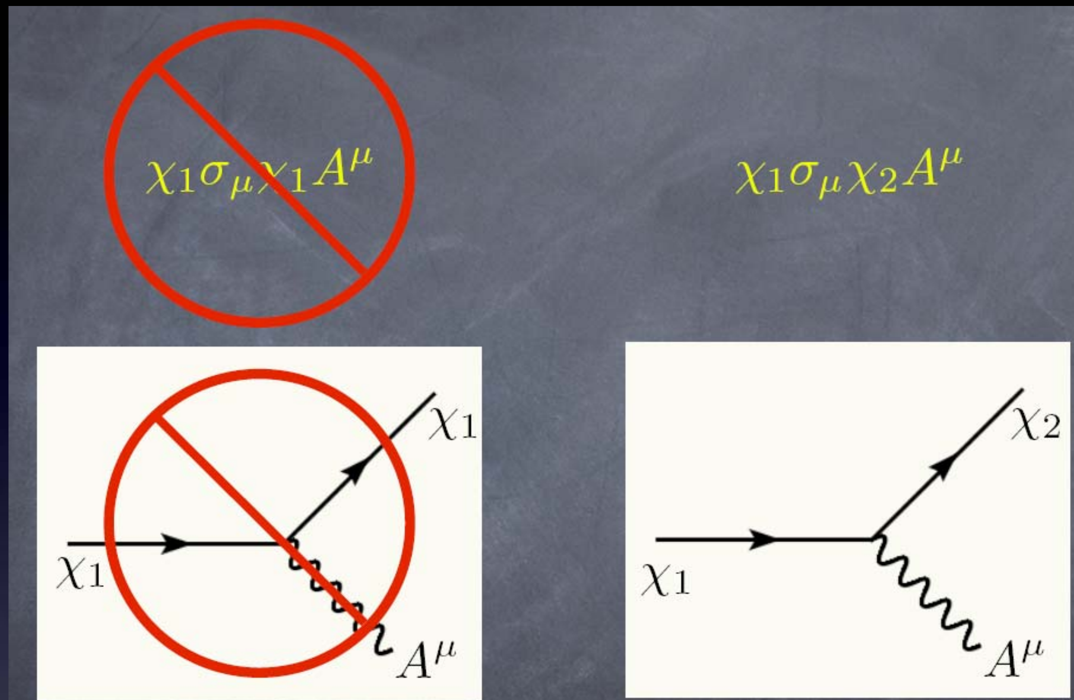


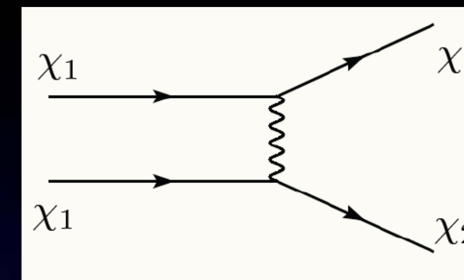
Fermi LAT (inner galaxy)

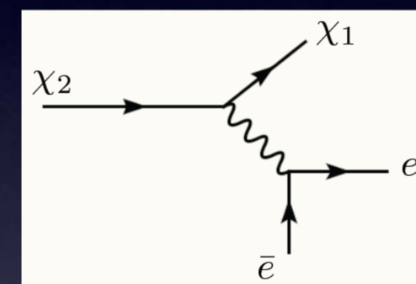


Haze (angular distribution)

Inelastic scattering







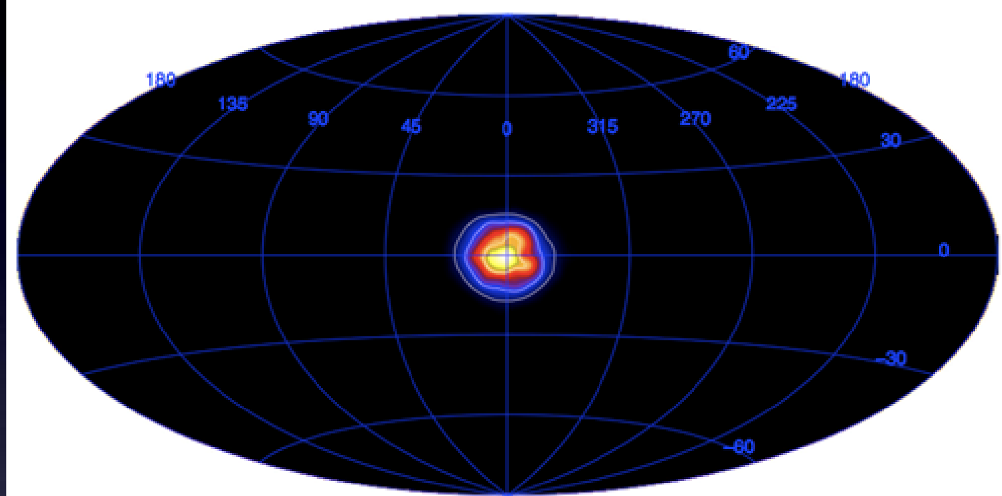
- Vector interactions for $m_{WIMP} >> m_A$ require multiple states (for Majorana fermion DM). Radiative corrections from new gauge bosons determine mass splittings (~ MeV).
- Interaction is off-diagonal – elastic WIMP-nucleus scattering suppressed.
- WIMP-WIMP collisions can excite the higher-mass states; decay back to the ground state can produce SM particles (depending on mass splitting).

Inelastic scattering and indirect detection: the INTEGRAL 511 keV line

- INTEGRAL spectrometer observes excess 511 keV emission from Galactic center.
- To give narrow line shape, positrons must be injected with low energy – not from WIMP annihilation.
- Signal can be explained if ~TeV dark matter has ~MeV excited state, and DM scatters off itself into excited state, then decays emitting e^+e^-.

Finkbeiner and Weiner, astro-ph/0702587

Weidenspointner et al 06



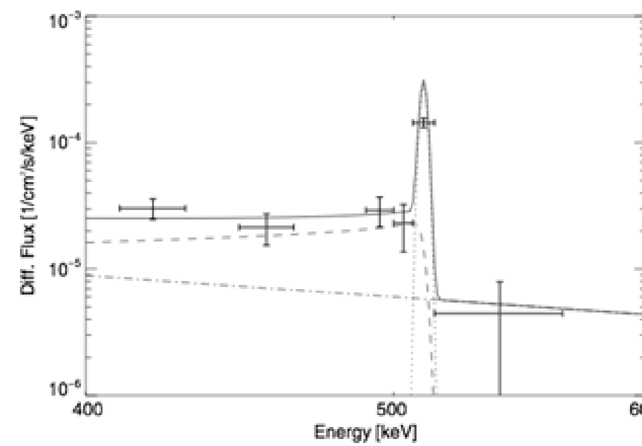


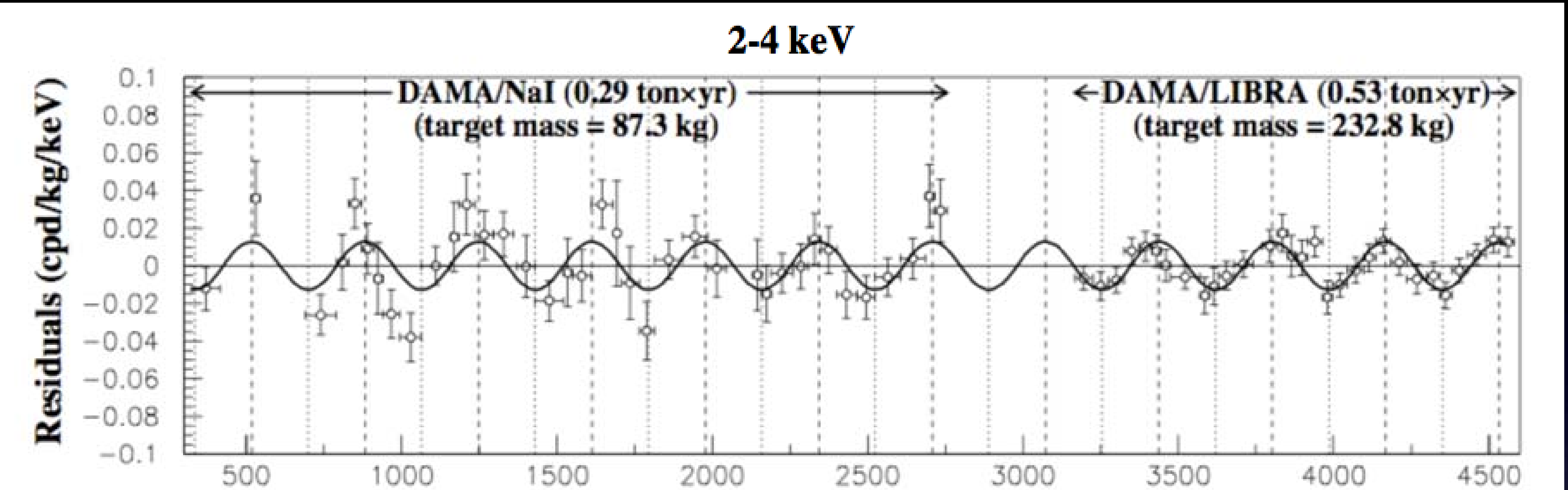
Fig. 2. A fit of the SPI result for the diffuse emission from the GC region ($|l|, |b| \leq 16°$) obtained with a spatial model consisting of an 8° *FWHM* Gaussian bulge and a CO disk. In the fit a diagonal response was assumed. The spectral components are: 511 keV line (dotted), Ps continuum (dashes), and power-law continuum (dash-dots). The summed models are indicated by the solid line. Details of the fitting procedure are given in the text.

Inelastic scattering and direct detection

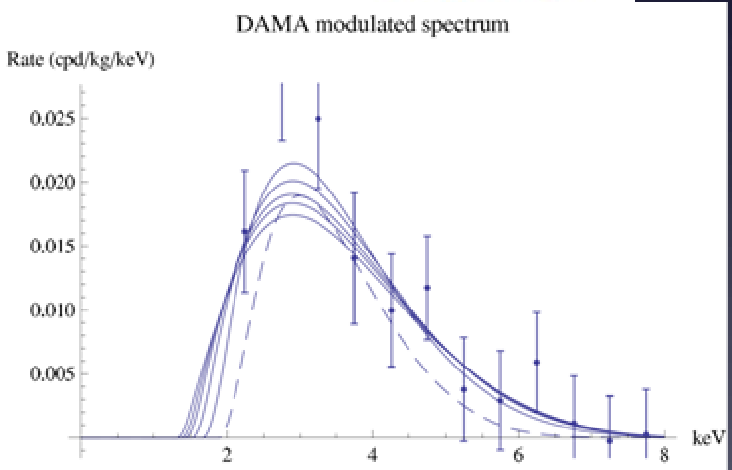
In these models, elastic scattering of WIMPs on nuclei is suppressed: at tree level, WIMPs scatter only into excited states. Consequently:

- Energy threshold – new kinematics modify spectrum of nuclear recoils, and NO recoil events below a specific energy.
- Only (exponentially falling) tail of velocity distribution participates in scattering:
  - Heavier nuclei (more KE in COM frame) sample more of the tail. Too light nuclei may not scatter WIMPs at all (if required WIMP velocity exceeds escape velocity).
  - Event rate is more sensitive to the velocity of Earth relative to WIMPs = annual modulation of flux is enhanced.

Inelastic scattering and DAMA/LIBRA



Bernabei et al., DAMA/LIBRA, 0804.2741

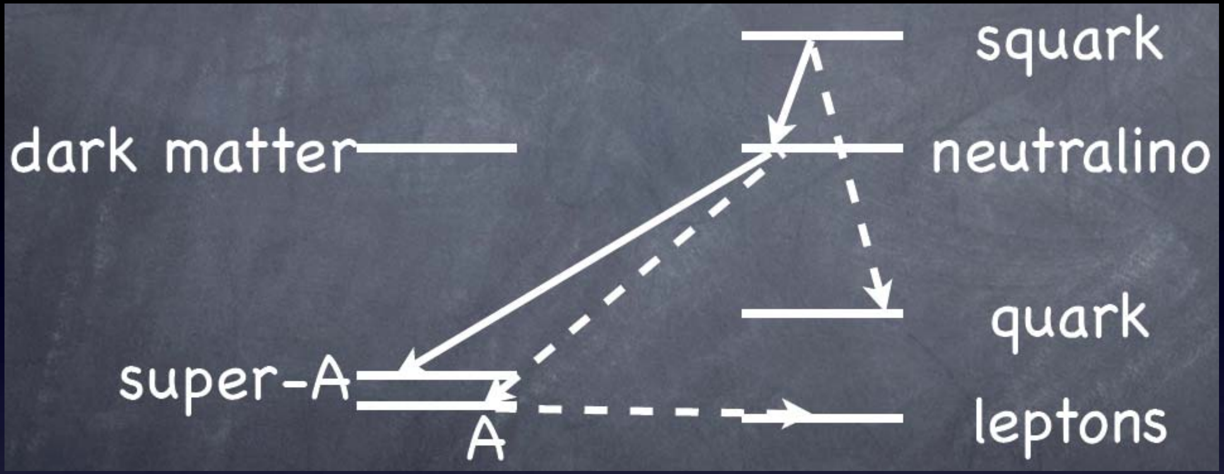


DAMA/LIBRA experiment detects annual modulation in nuclear recoils in NaI detector, with period and phase matching expected modulation of WIMP flux (due to motion of Earth around Sun).

Generally considered inconsistent with limits from other DM searches: however, in the case of inelastic scattering with a ~100 keV mass splitting, no inconsistency (Smith & Weiner, hep-ph/0101138; Chang et al, 0807.2250). Upcoming xenon (high nuclear mass) experiments – XENON100, LUX – will test this possibility.

New decay modes and LHC signatures

(see Cheung et al 0909.0290 for a detailed analysis)



Arkani-Hamed, NW, '08; Baumgart, Cheung, Ruderman, Wang, Yavin, ' 09; Bai, Han '09

- In SUSY realizations of these models, normal LSP is weakly mixed with (and can decay to) LSP_{dark}, via kinetic mixing.

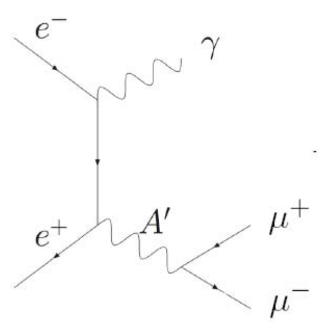
- Decay of electroweak-inos into the dark sector, followed by dark sector cascades, leads to showers of dark gauge bosons, which in turn decay to highly collimated leptons with invariant mass ~GeV.

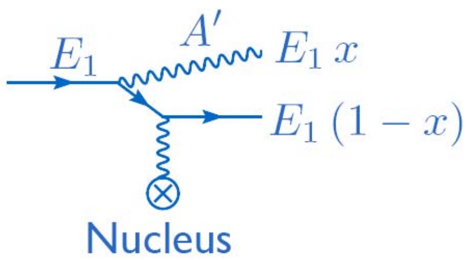
- Rare Z^0 decays can also produce these "lepton jets".

Searches for the new gauge boson

- New GeV-scale gauge boson mixes with photon: can be produced in e^+e^- collider experiments, or as bremsstrahlung from e^- beams in fixed target experiments.

Collider vs. Fixed-Target



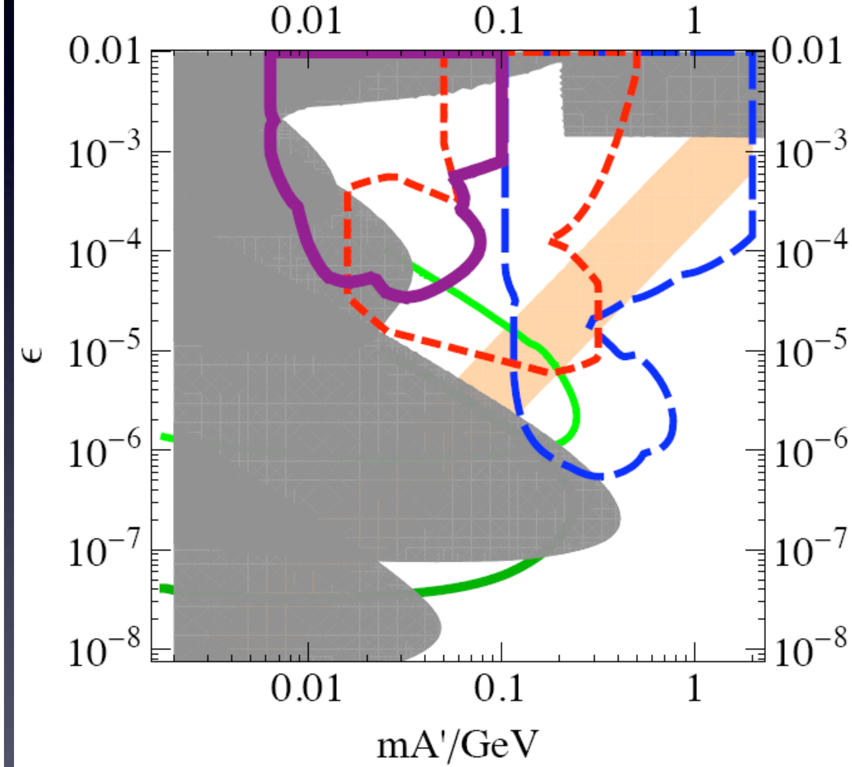


$$\sigma \sim \frac{\alpha^2\epsilon^2}{E^2} \sim O(10\ fb)$$

$$\sigma \sim \frac{\alpha^3 Z^2\epsilon^2}{m^2} \sim O(10\ pb)$$

O(few) ab^{-1} per decade

O(few) ab^{-1} per day



Bjorken et al, 0906.0580

- Existing beams have significant discovery potential (see e.g. Essig, Schuster & Toro 09, Bjorken et al 09, Batell, Pospelov & Ritz 09, Reece & Wang 09).

Upcoming probes

LHC lepton jets
(2010+)

Dark force
searches
(2009+)

Colliders

LUX
(2010-11)

Test IDM
explanation
for DAMA

Direct

PAMELA
e+, e-,
antiprotons

Dark
Matter?

XENON100
(2010)

Indirect,
local
(near
Earth)

Planck CMB
measurements
(2012-13)

Indirect,
cosmological

Planck Haze
measurements
(2012-13)

Fermi LAT
All-sky ICS
(2009)

Indirect, Galactic

Summary

- We have proposed a new framework for WIMP models containing a new gauge interaction at the GeV scale, interacting with the SM through a kinetic mixing term.

- Such models provide a unified explanation for several currently unexplained anomalies, and have a wide range of interesting potential consequences in direct and indirect detection experiments, and collider searches. Regardless of whether these ideas are right or not, it is interesting to explore how different DM models can lead to very different experimental signatures than the "generic" case.

- Current and upcoming experiments can test predictions of these models in the near future.