5 QUESTIONS FOR DARK MATTER

Neal Weiner
CCPP NYU

Unsolved problems in Astrophysics and Cosmology

2011, Feb 13 -- Feb 19

Organizers:

H. Peiris (U. College London)

R. Jiménez (ICREA, ICC, U. Barcelona)

C. Pena-Garay (IFIC, CSIC, U. Valencia)

Monday, February 14

09:00h
21 cm Cosmology
Avi Loeb

10:30h
Neutrinos
Hitoshi Murayama

12:00h
Lunch and Skiing

17:30h
Dark Matter
Neal Weiner

19:00h
Galaxy Formation
Brant Robertson

Tuesday, February 15

09:00h
String Cosmology
Daniel Baumann

10:30h
LSS Physics
Licia Verde

12:00h
Lunch and Skiing

17:30h
Gravitational Waves
Alberto Vecchio

19:00h
21 cm Observations
Jackie Hewitt

Wednesday, February 16

09:00h
Extra Dimensions
Raman Sundrum

10:30h
Theoretical Cosmology
Ruth Durrer

12:00h
Lunch and Skiing

17:30h
Cosmo Simulations
Volker Springel

19:00h
Impacts of Comprehensive Multimessenger Astronomy
Marka Szabolcs

Thursday, February 17

09:00h
String Theory
Eva Silverstein

10:30h
CMB Prospects
Anthony Lewis

12:00h
Lunch and Skiing

17:30h
First Galaxies
Zoltan Haiman

19:00h
Dark Energy
Wayne Hu

Friday, February 18

09:00h
LSS
Alan Heavens

10:30h
Non-Gaussianity Planck/Core
S. Matarrese / M. Bucher

12:00h
Lunch and Skiing

Unsolved problems in Astrophysics and Cosmology

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More questions

More answers

Mon
Februa

09:00h
21 cm Cosmology
Avi Loeb (+6 hrs)

10:30h
Neutrinos
Hitoshi Murayama (+9 hrs)

12:00h
Lunch and Skiing

17:30h
Dark Matter
Neal Weiner (+6 hrs)

19:00h
Galaxy Formation
Brant Robertson (+9 hrs)

09:00h
String Cosmology
Daniel Baumann

10:30h
LSS Physics
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L S
Alan Heavens

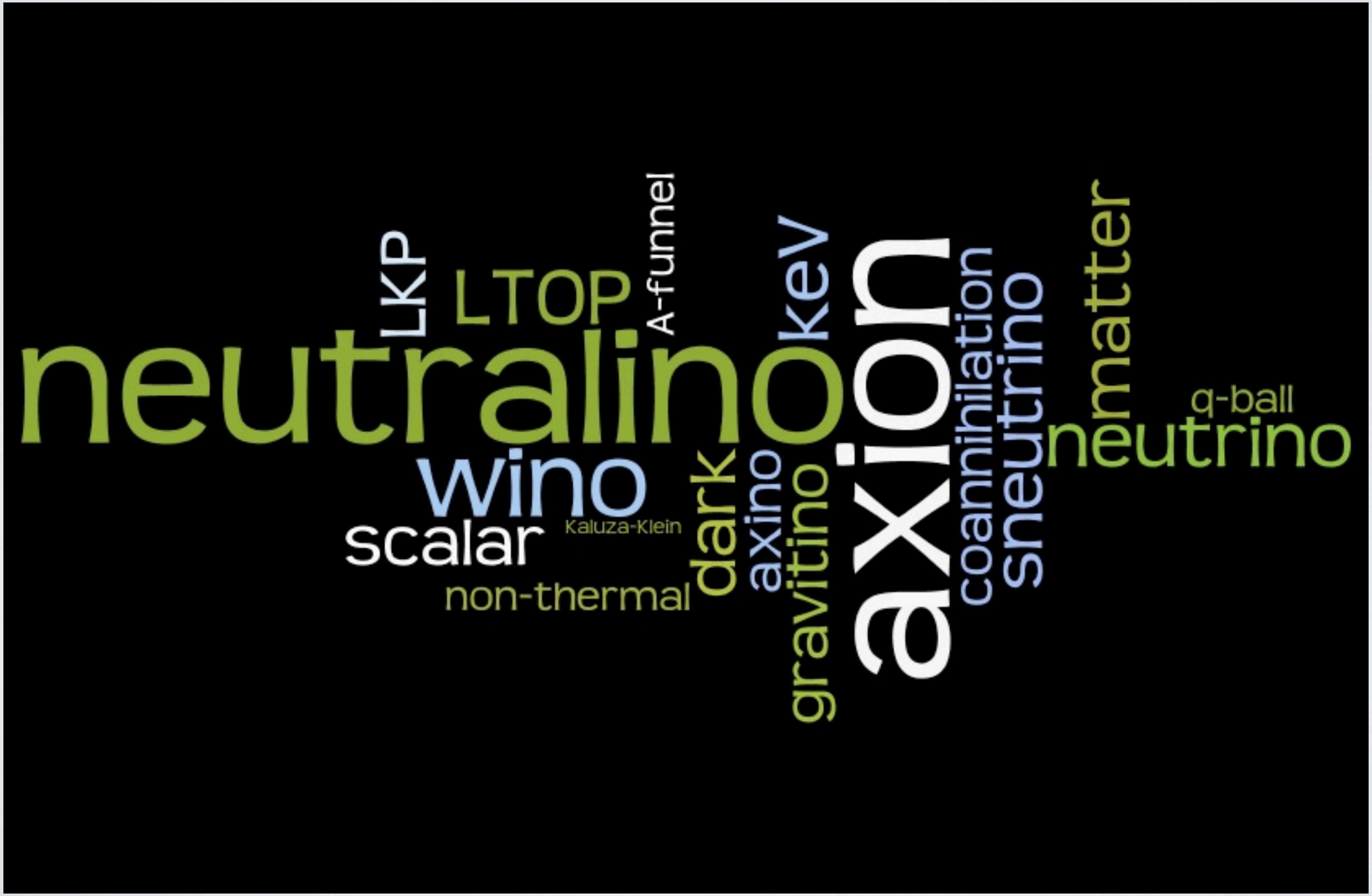
10:30h
Non-Gaussianity
Planck/Core
S. Matarrese / M. Bucher

12:00h
Lunch and Skiing

FOR THE SAKE OF ARGUMENT

- i shall attempt to raise more questions than I can hope to answer or even completely develop
- i shall not let my own ignorance prevent me from forming strong opinions

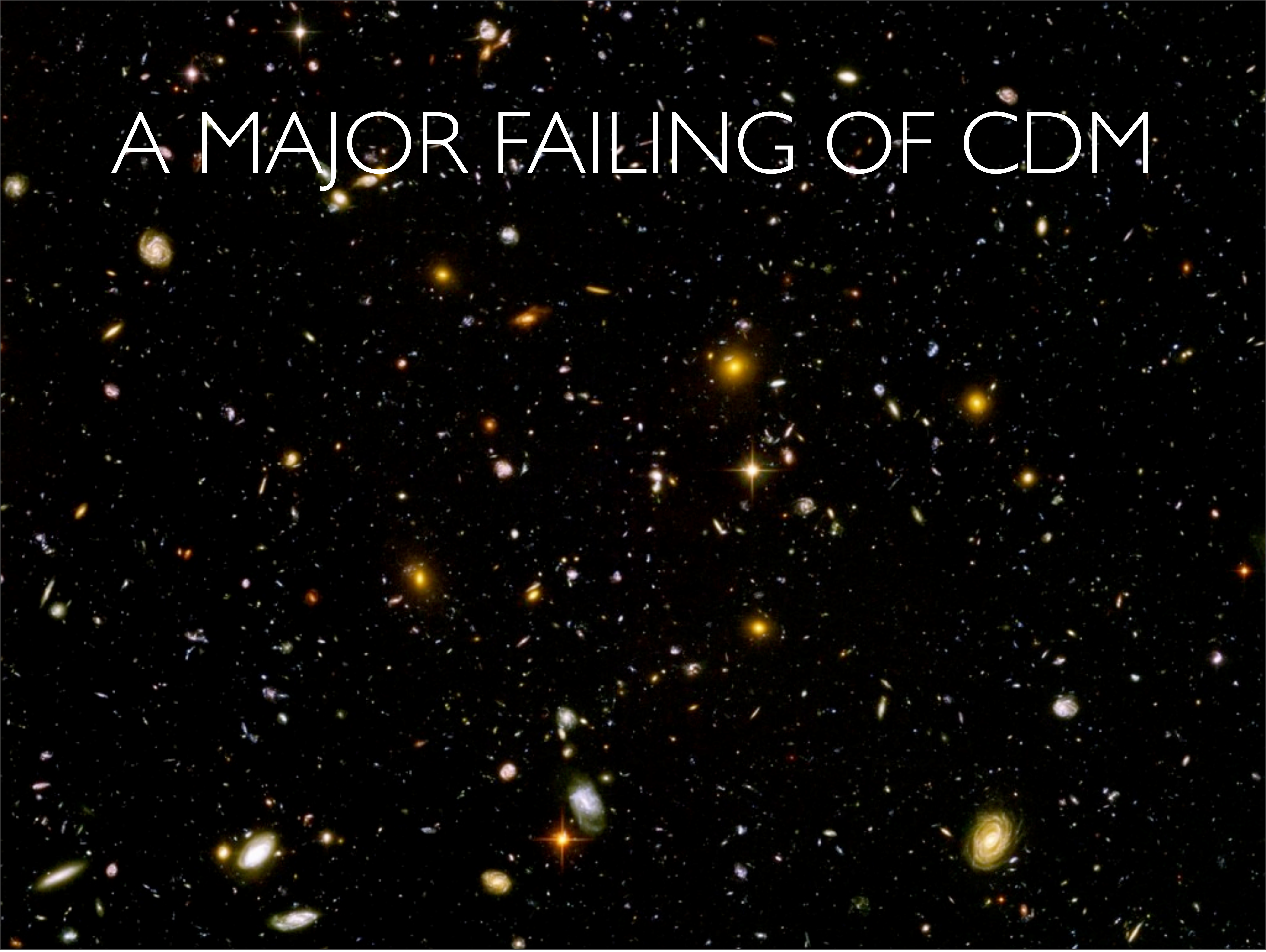
HOW A PARTICLE PHYSICIST SEES DARK MATTER

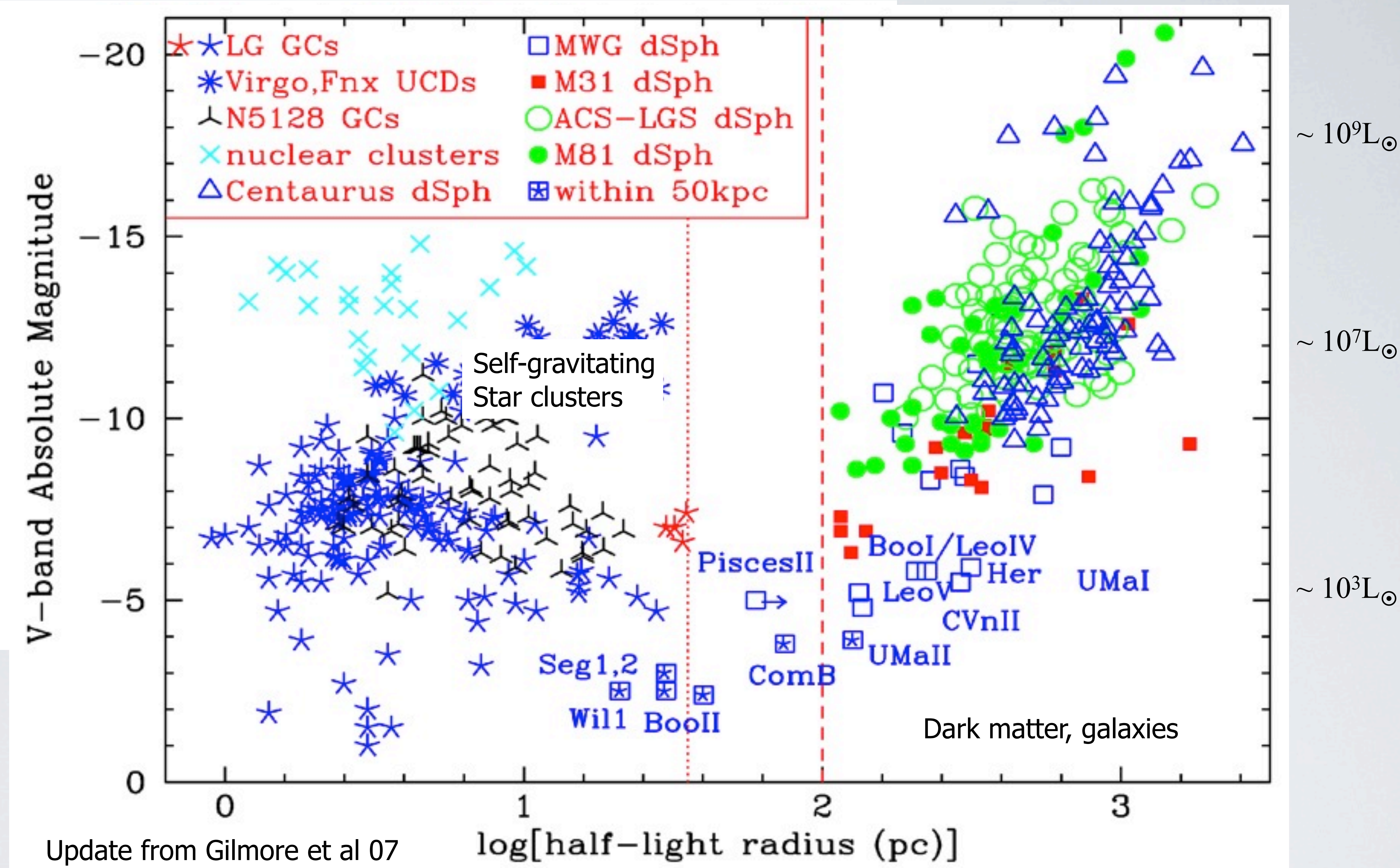


HOW AN ASTROPHYSICIST SEES DARK MATTER

IS CDM CONSISTENT WITH DATA?

A MAJOR FAILING OF CDM

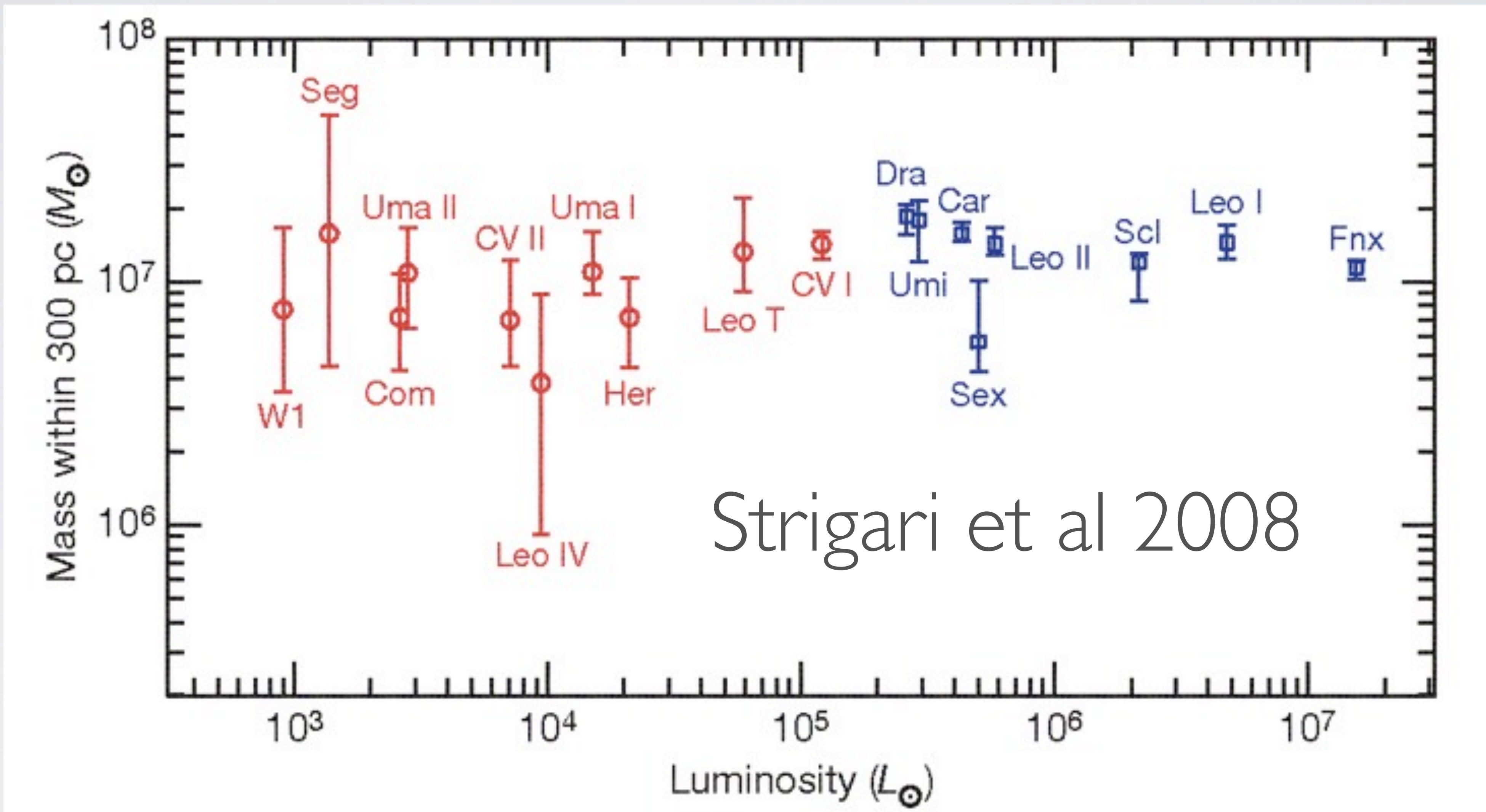




Add ~20 new satellites, galaxies and star clusters - but note low yield from Southern SEGUE/SDSS imaging : only Segue 2 and Pisces II as candidate galaxies 3/8 area (Belokurov et al 09,10)

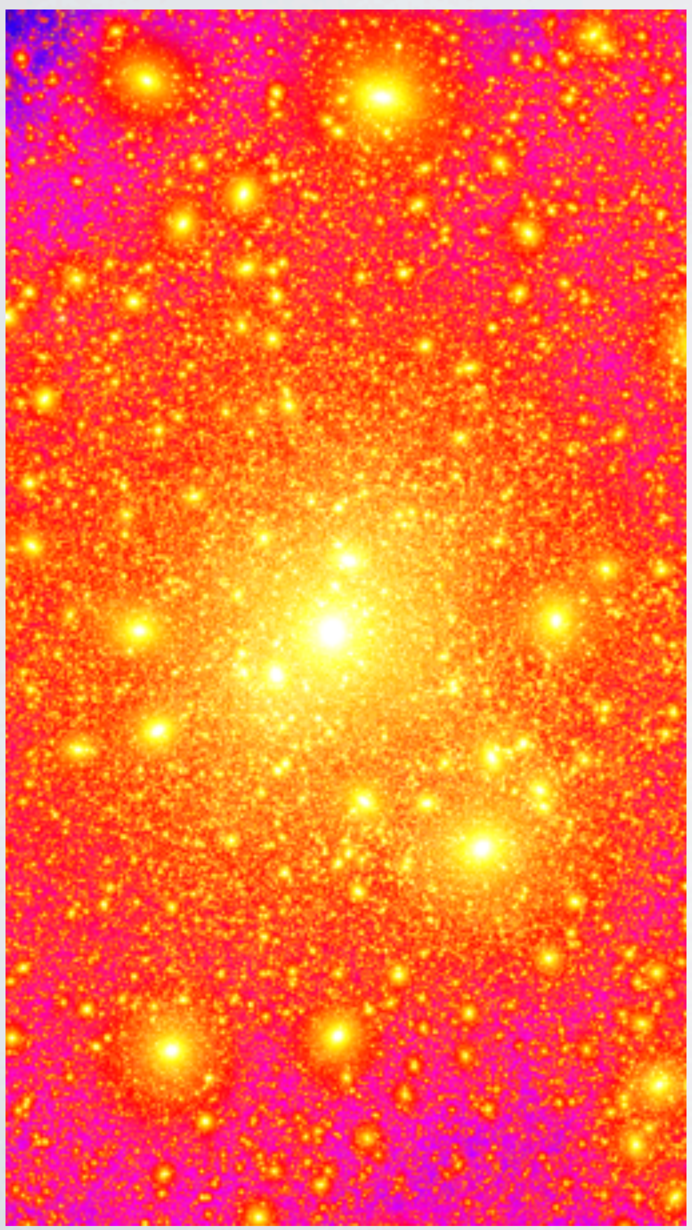
(stolen from R. Wyse)

ISSUES ON SMALL SCALES

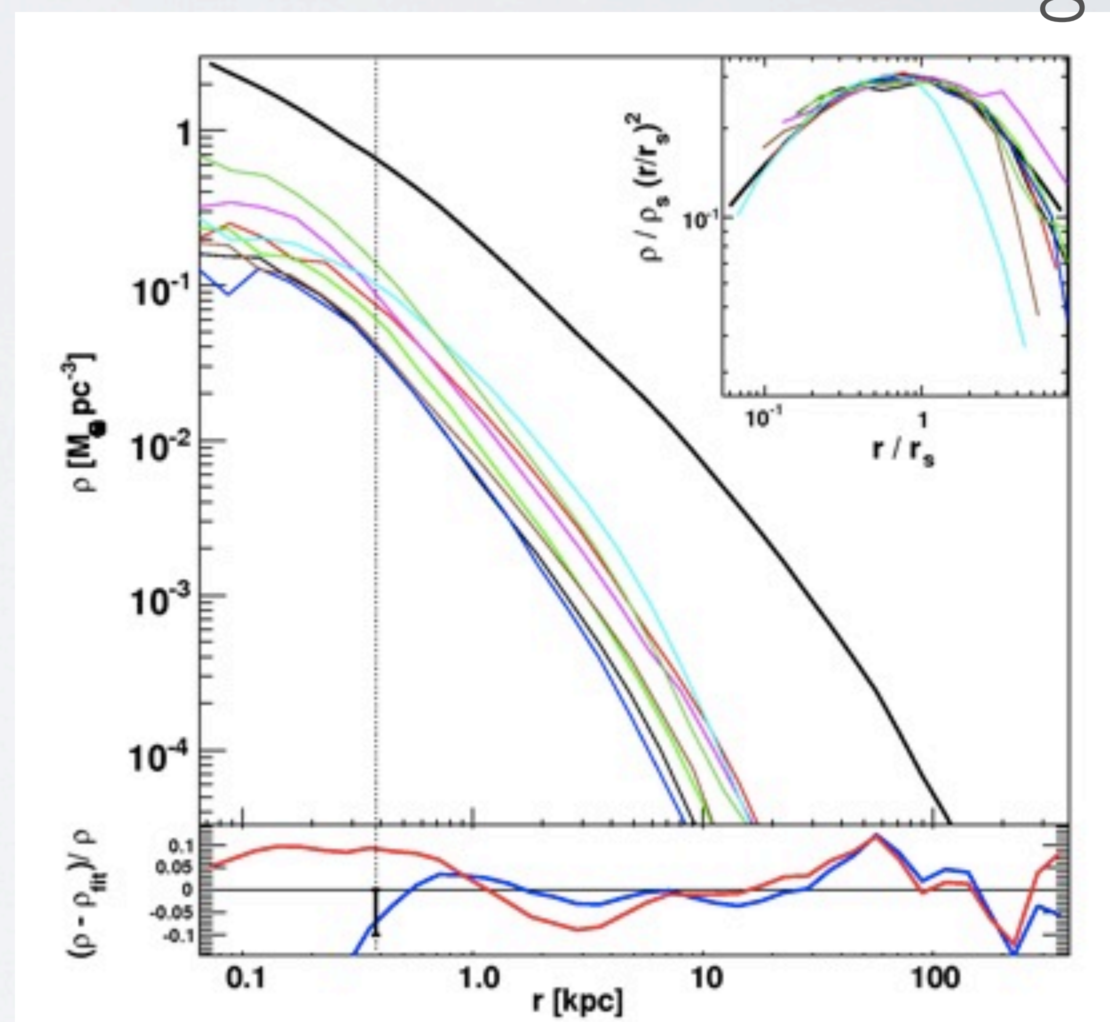


CDM PREDICTS CUSPS

GHALO (Stadel et al 09)
MW Dark Halo in ΛCDM



$\rho \propto r^{-1.2}$
in inner regions



Diemand et al 2008

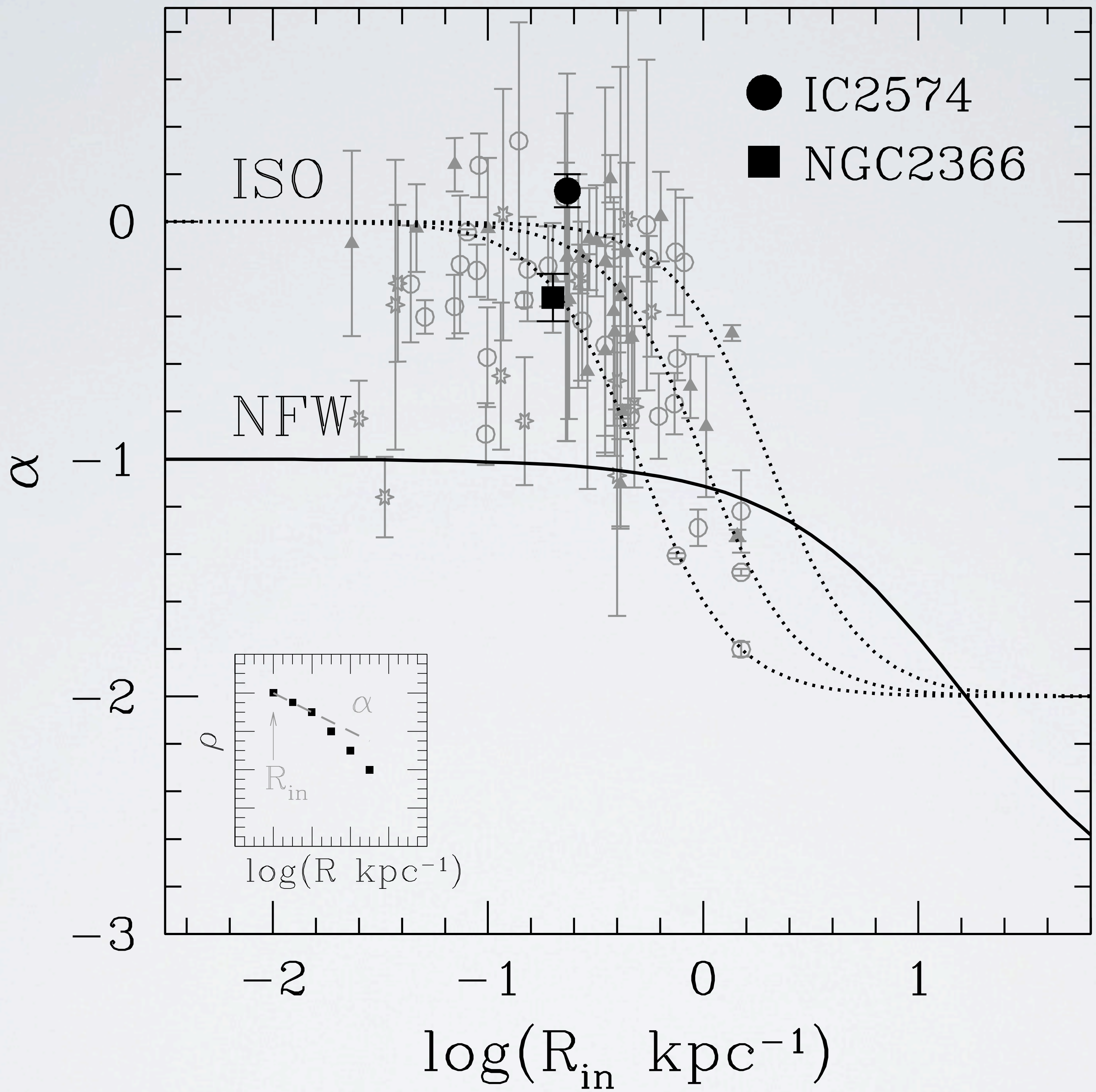
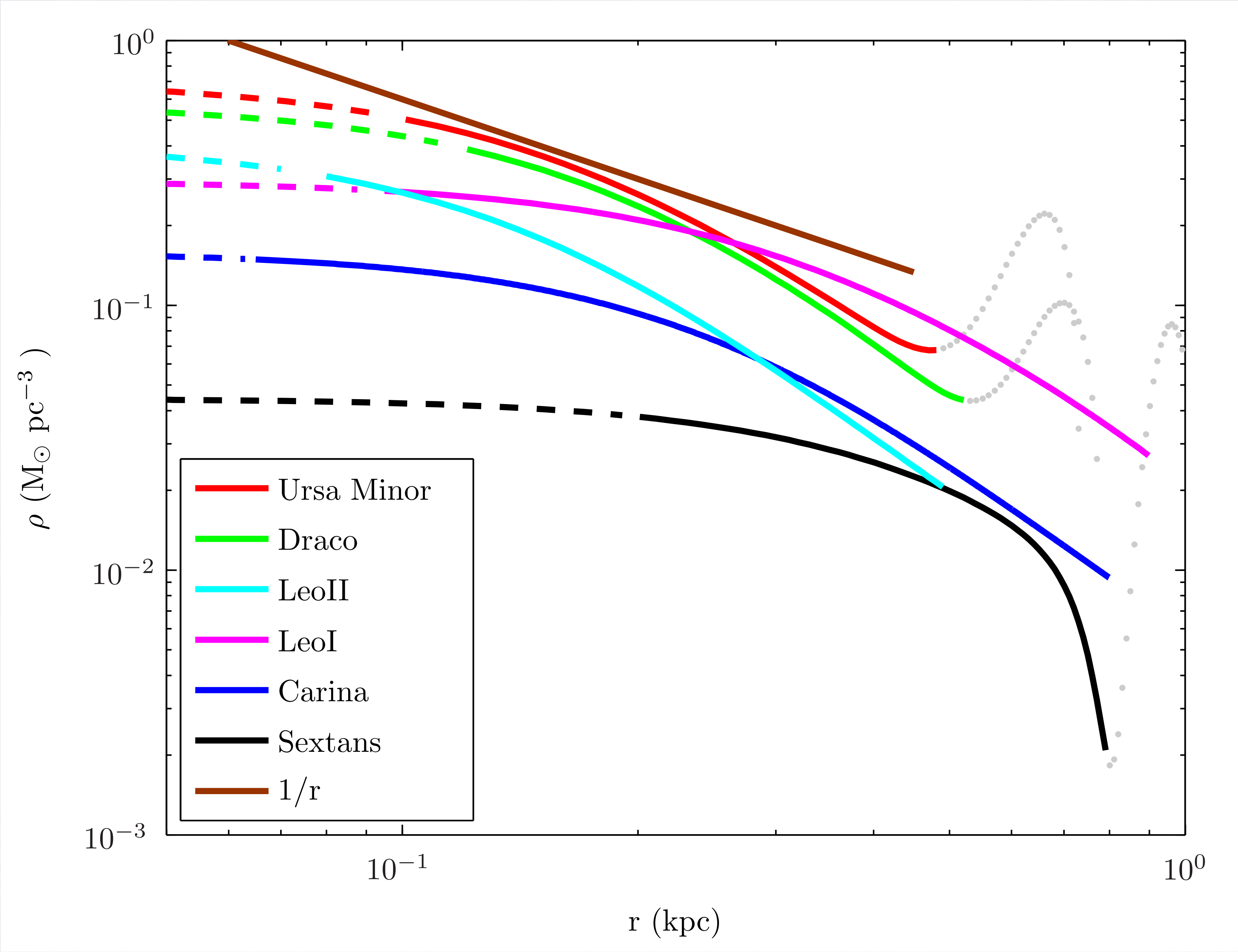


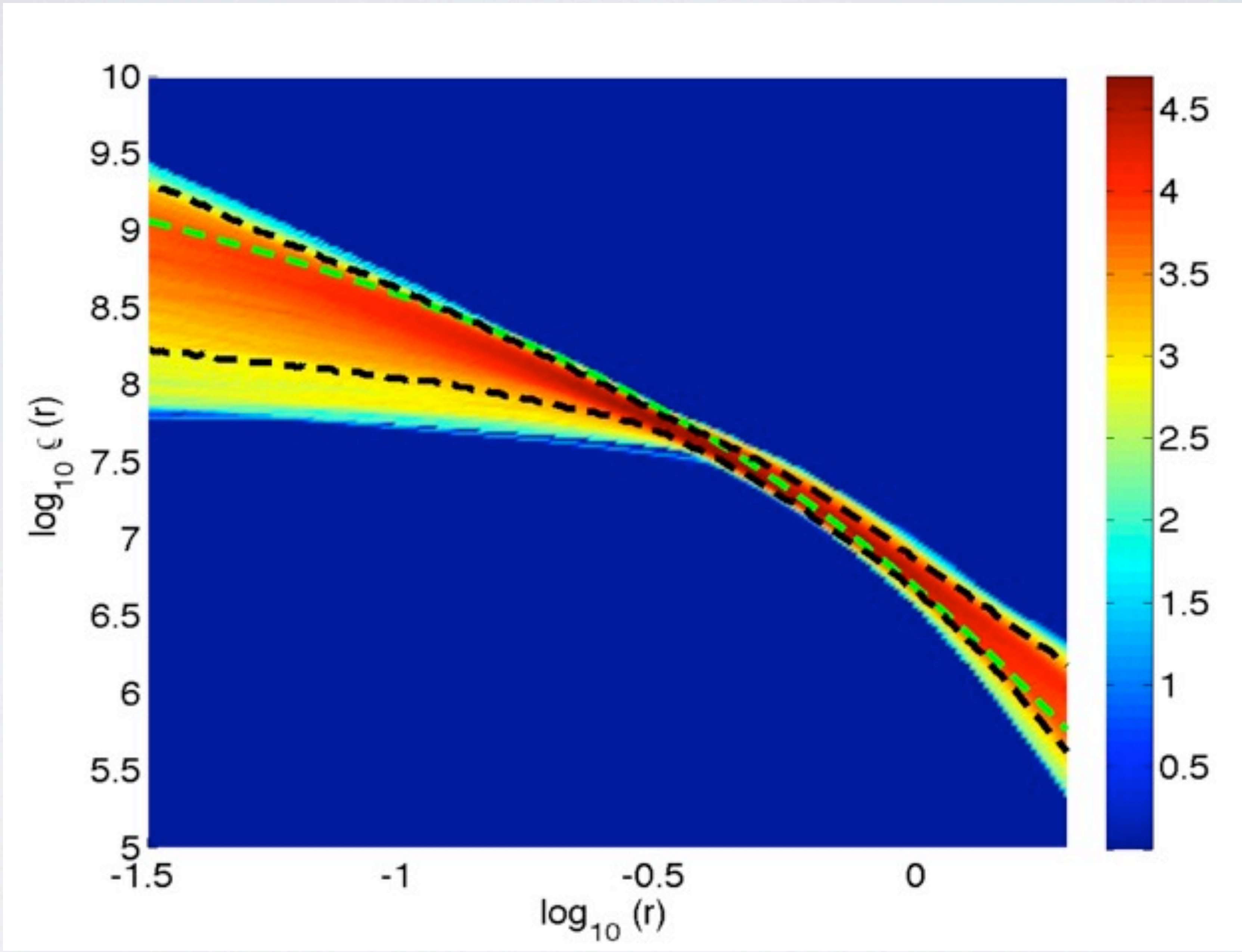
Fig. 25.— The inner slope of the dark matter density profile plotted against the radius of the innermost point. The inner-slopes of the mass density profiles of IC 2574 and NGC 2366 are overplotted with earlier work; they are consistent with previous measurements. Open circles: de Blok et al. (2001); squares: de Blok & Bosma (2002); open stars: Swaters et al. (2003). The pseudo-isothermal model is preferred over the NFW model to explain the observational data.

DWARF CORES?



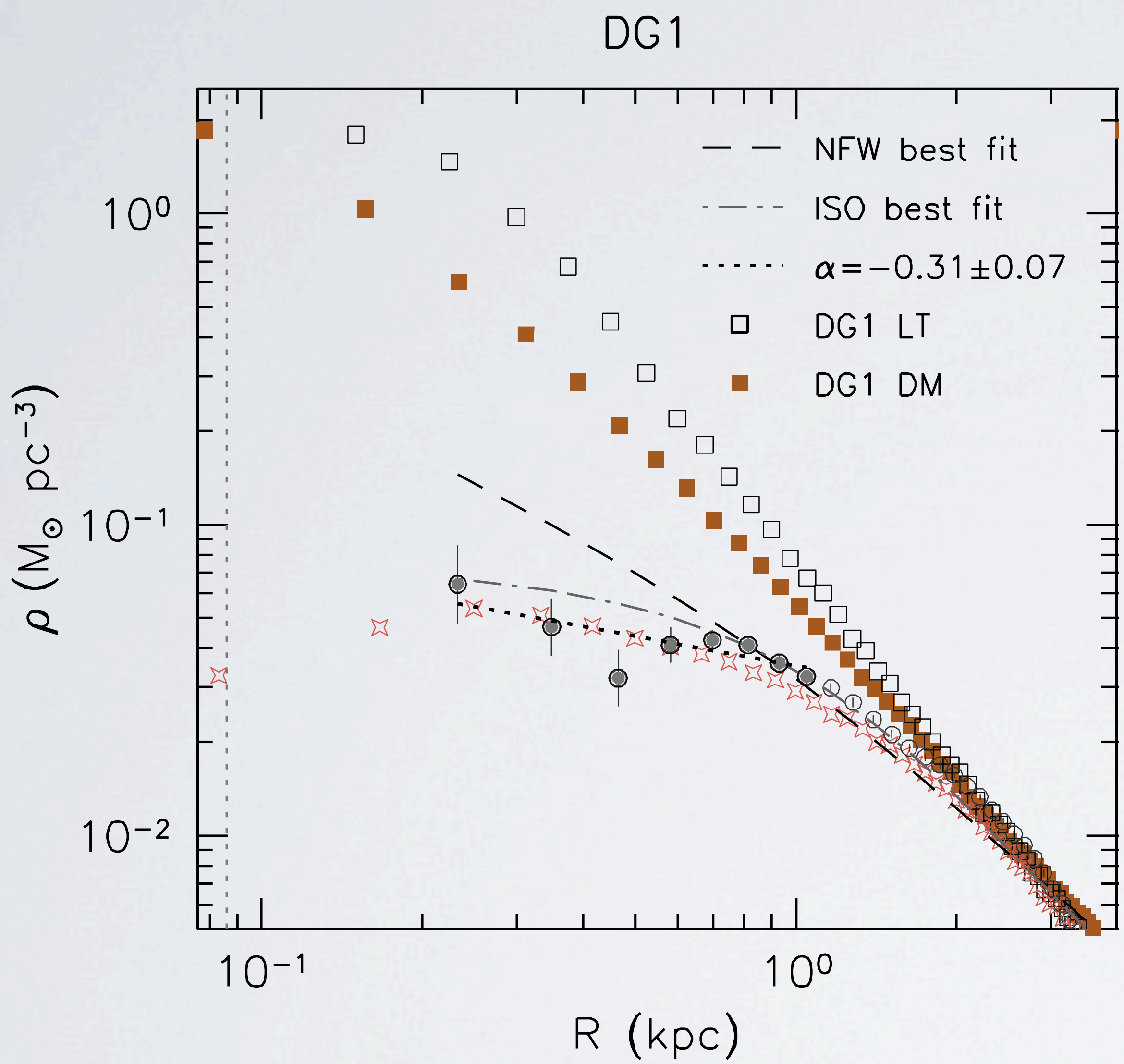
Gilmore et al, '07

Fornax: real data - PRELIMINARY density profile



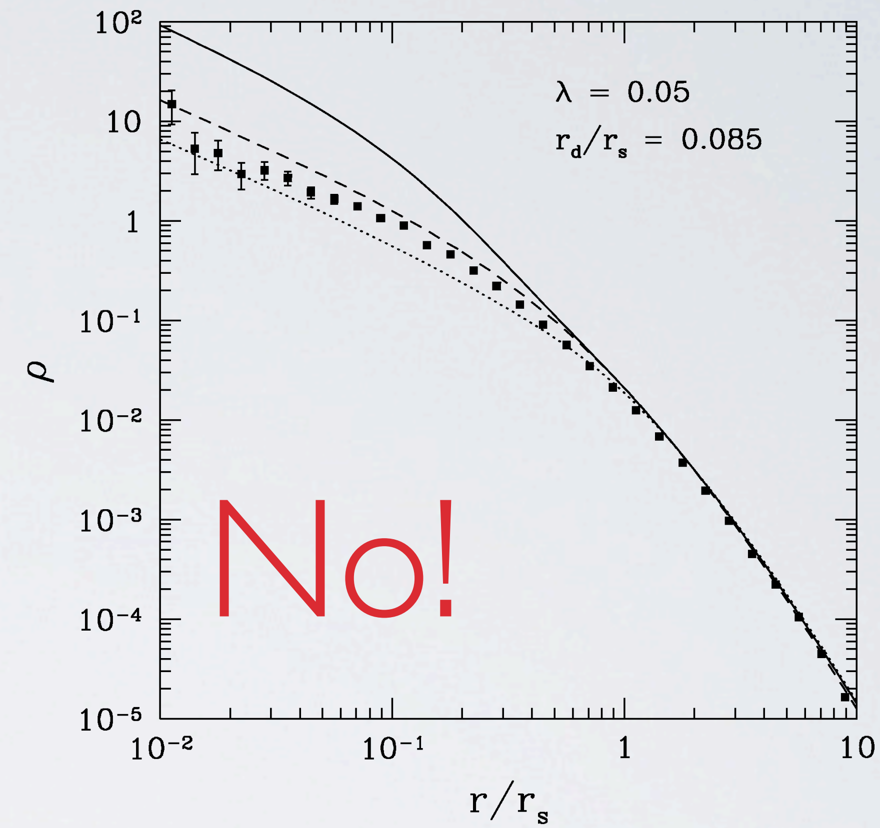
(from R. Wyse Aspen talk)

DO BARYONS MAKE CORES?



Oh et al, '10

Yes!



Gnedin +Zhao '02

Sawala, Scannapieco, Maio and White, '09

1994). Within the framework of ΛCDM, numerical simulations by Navarro et al. (1996), Read & Gilmore (2005), Mashchenko et al. (2008) and others have suggested that cores of kpc scale may form either as a result of dynamical coupling to supernova-induced bulk gas motions, or the rapid ejection of large amounts of baryonic matter. Our simulations fail to fulfil these requirements in two ways. The ejection of gas is not sufficiently rapid (which would also be difficult to reconcile with the observed age-spreads), and our dark matter haloes continue to evolve and grow after star formation and supernova rates have peaked, instead of simply settling to an equilibrium configuration. As a result, we do not observe the formation of cores in our runs with feedback. The final dark matter density distributions can be described by NFW-profiles up to the resolution limit.

CONNECTION TO DM

'It is also a good rule not to put overmuch confidence in the observational results that are put forward until they are confirmed by theory. ' -Sir Arthur Eddington

VOLUME 84, NUMBER 17 PHYSICAL REVIEW LETTERS 24 APRIL 2000

Observational Evidence for Self-Interacting Cold Dark Matter

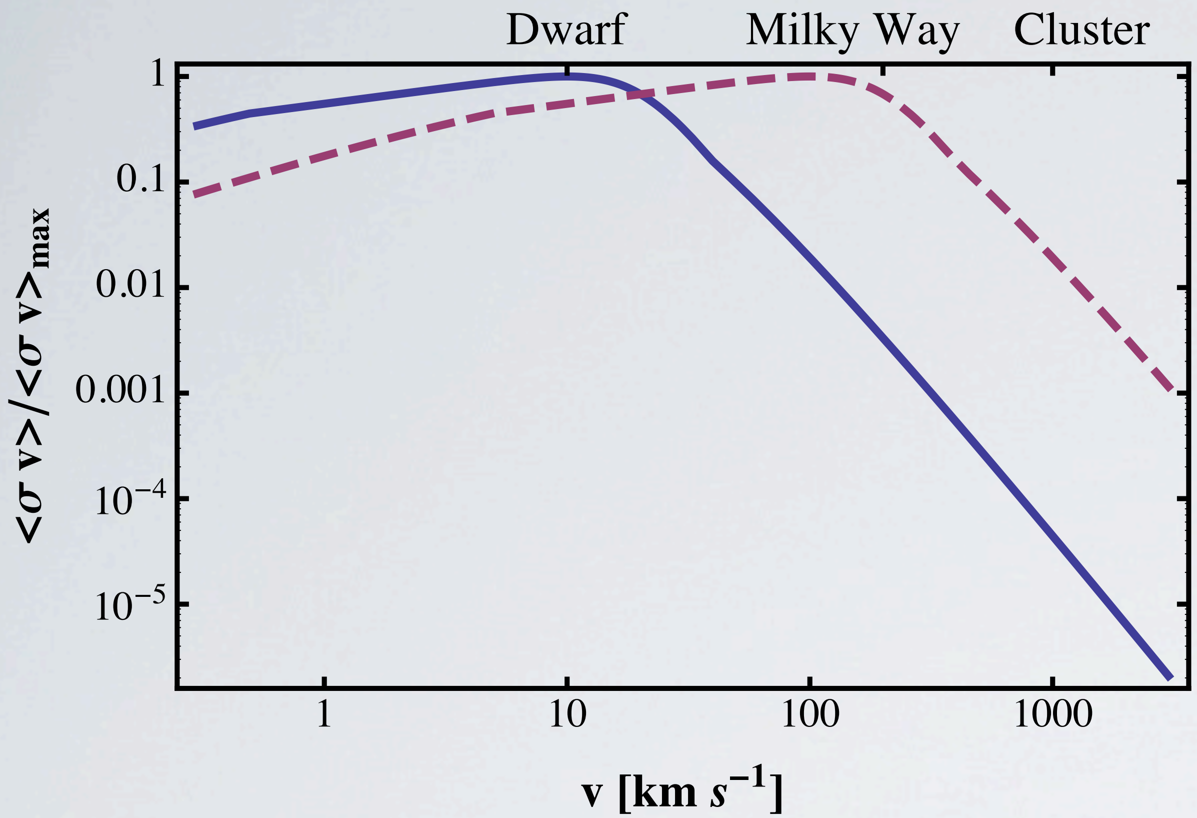
David N. Spergel and Paul J. Steinhardt
Princeton University, Princeton, New Jersey 08544
(Received 20 September 1999)

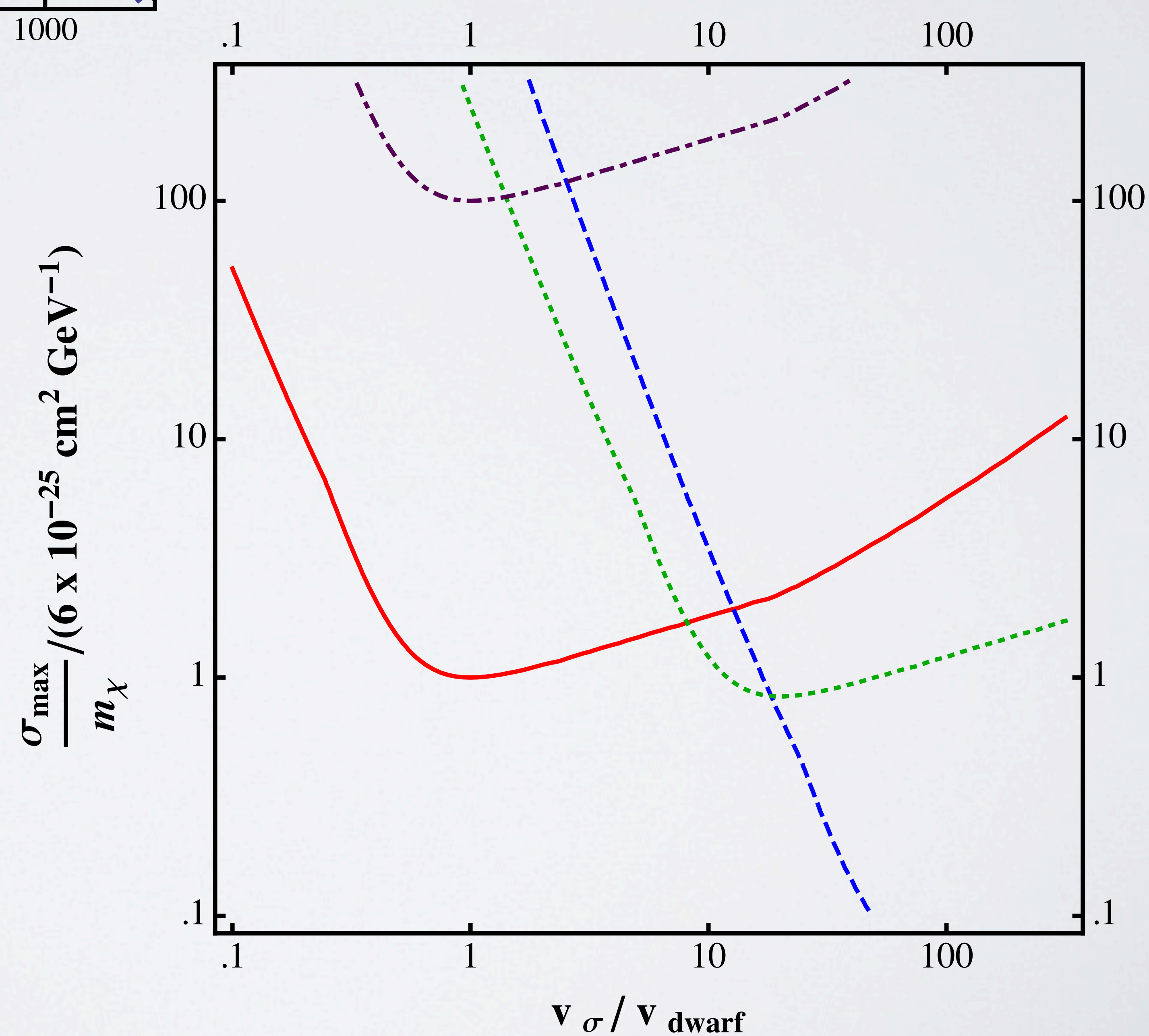
Cosmological models with cold dark matter composed of weakly interacting particles predict overly dense cores in the centers of galaxies and clusters and an overly large number of halos within the Local Group compared to actual observations. We propose that the conflict can be resolved if the cold dark matter particles are self-interacting with a large scattering cross section but negligible annihilation or dissipation. In this scenario, astronomical observations may enable us to study dark matter properties that are inaccessible in the laboratory.

PACS numbers: 95.35.+d, 98.35.Gi, 98.62.Ai, 98.62.Gq

SIDM PROBLEMS?

- Effects in cores of clusters/ellipticals => high velocity => large interaction rates
- Cores of dwarfs => gravothermal collapse/evaporation





Yukawa potential
naturally achieves

Loeb + NW '10

IS THERE A MISSING SATELLITE PROBLEM?

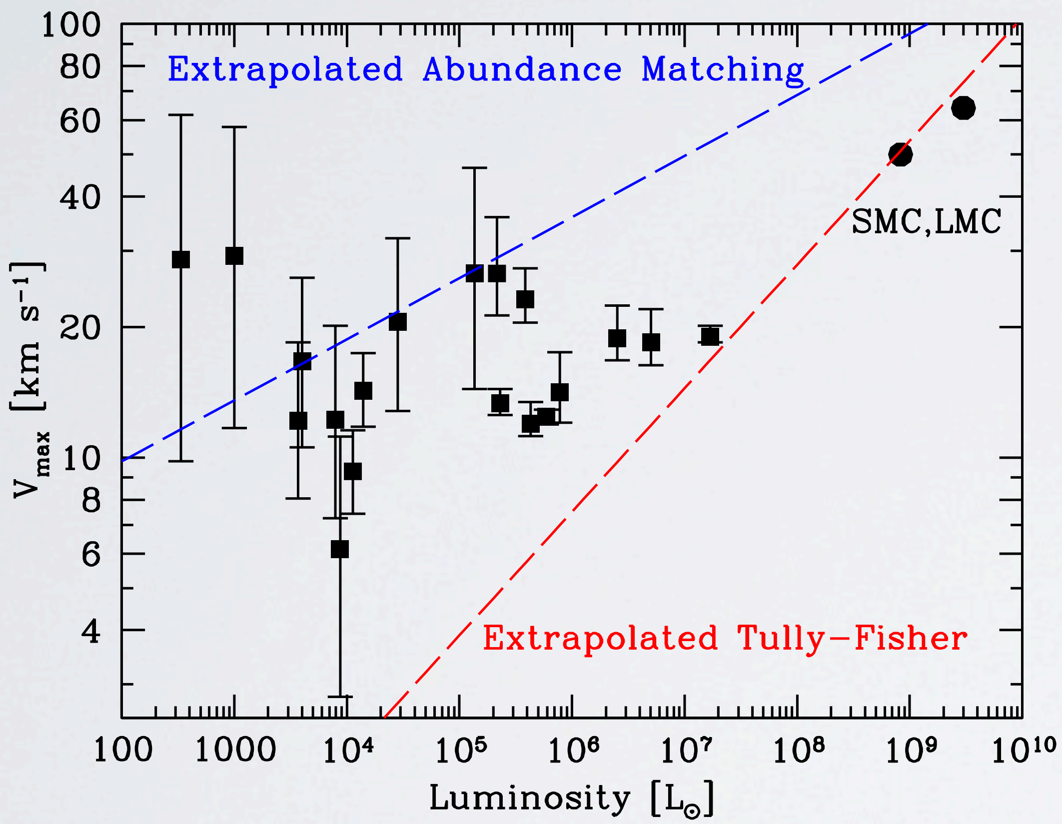


Fig. 1.9. The $V_{\rm max}$ vs. V-band luminosity relation for the Milky Way satellite population, as inferred from assuming that dSph galaxies sit within NFW dark matter halos that obey the same scaling relations as do subhalos in ΛCDM N-body simulations. The lower red dashed line is the Tully Fisher relation from Courteau et al. (2007) extrapolated to low lumnosities and the upper blue dashed line is the relation one obtains from extrapolating the abundance matching power-law from Busha et al. (2010).

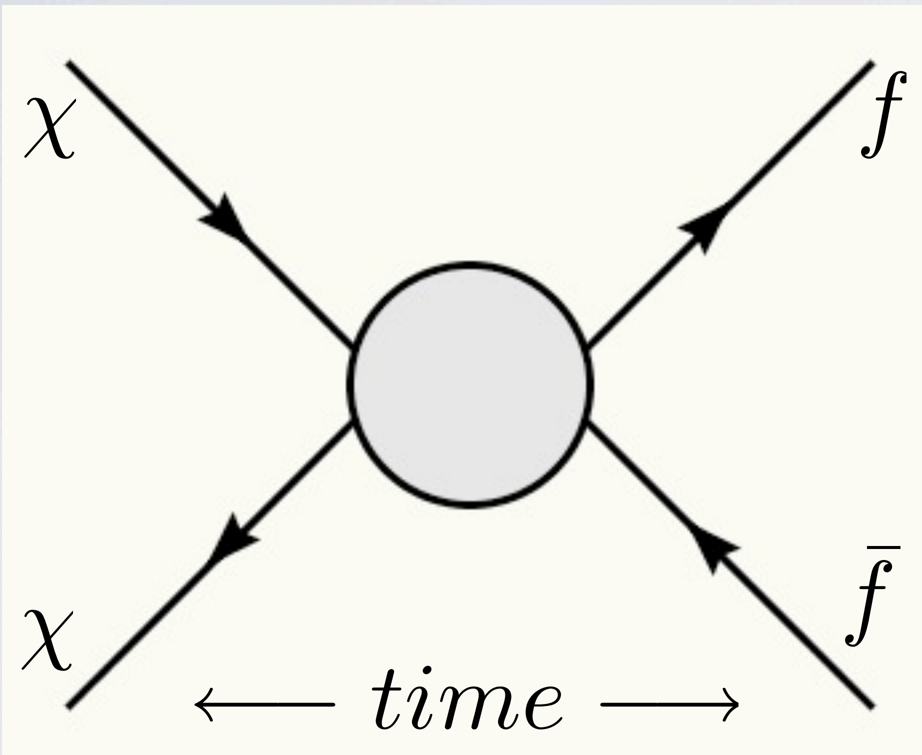
More puzzling is the overall lack of observed correlation between Milky Way satellite galaxy luminosities and their M_{300} masses or $V_{\rm max}$ values (see Figures 1.7 and 1.9). Most of the models that have been constructed to confront the mass-luminosity over-predict $V_{\rm max}$ values at for the brightest dwarfs and under-predict them for the faintest dwarfs (Li et al. 2009; Macciò et al. 2009; Okamoto et al. 2009; Busha et al. 2009; Bullock et al. 2010).

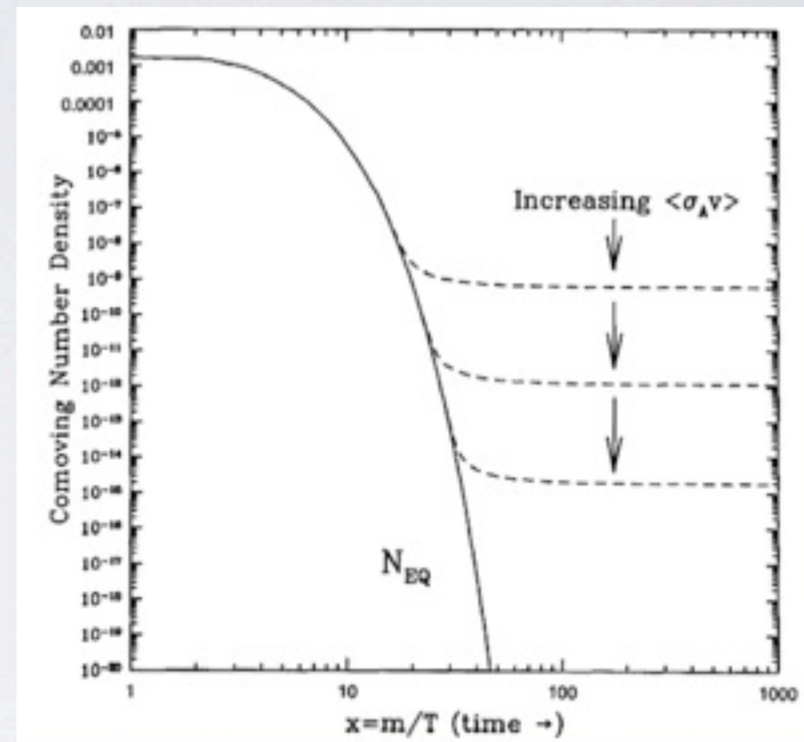
Bullock '10

ASTROPARTICLE PHYSICS QUESTIONS

ARE WE GOING TO FIND A WIMP?

THE WIMP MIRACLE



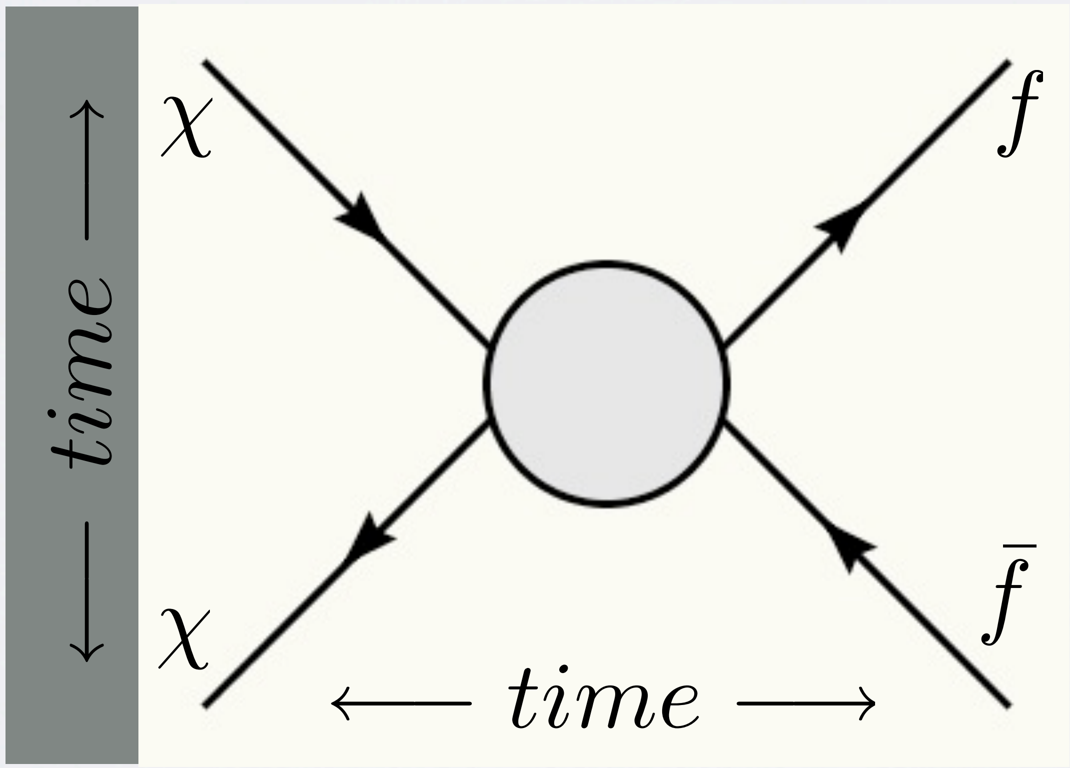


$$\Omega_\chi h^2 \approx 0.1 \times \frac{3 \times 10^{-26}\mathrm{cm}^3\mathrm{s}^{-1}}{\langle \sigma v \rangle}$$

$$\Rightarrow \langle \sigma v \rangle \approx \frac{\alpha^2}{M_W^2}$$

SIGNALS OF THERMAL DM

- Production (accelerators)
- Cosmic rays/indirect detection (PAMELA/Fermi/WMAP...)
- Direct detection (DAMA/XENON/CDMS...)



ARE WE GOING TO FIND A WIMP?

in direct detection experiments

DARK MATTER EXPERIMENTS ARE GETTING EXCITING!

Where we are

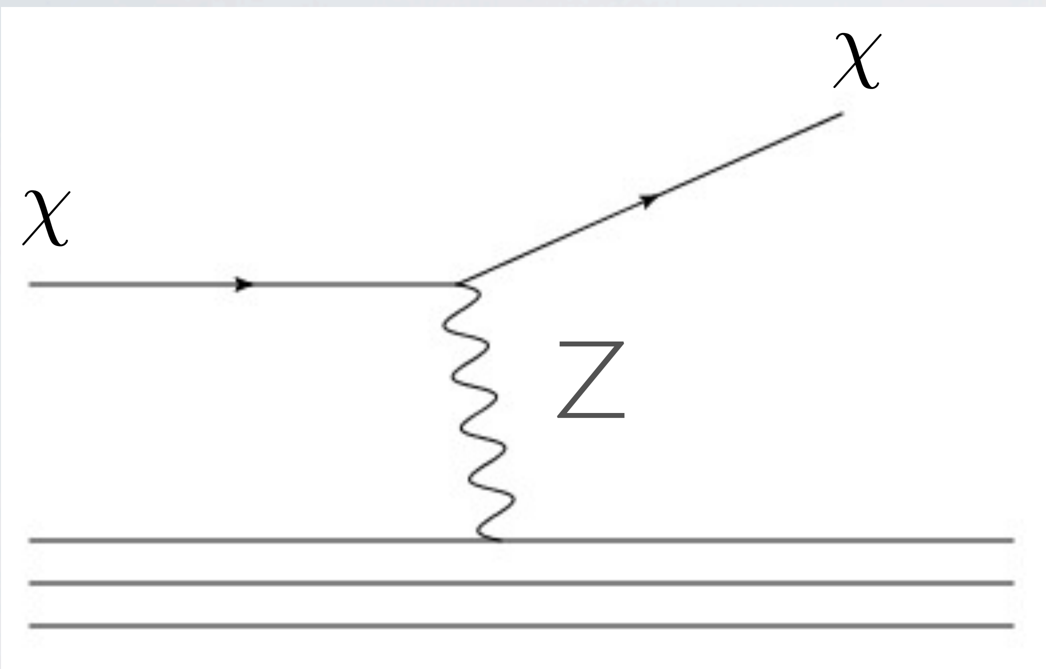
Where we'll be soon

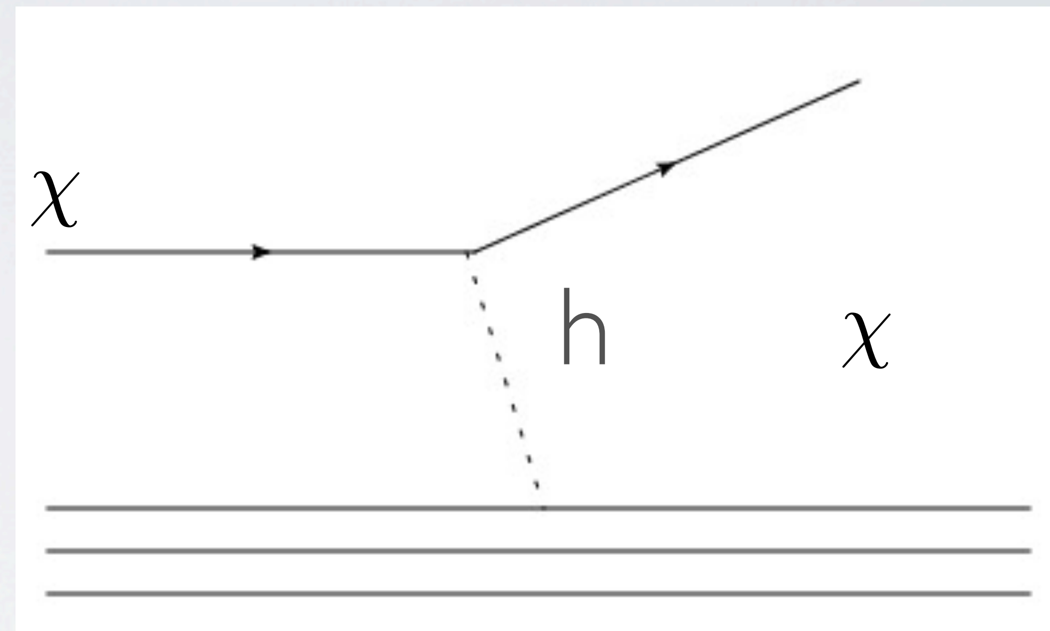
Where we'll be soonish (knock wood)

Is there any reason to think this range is special?

What is going to get us there?

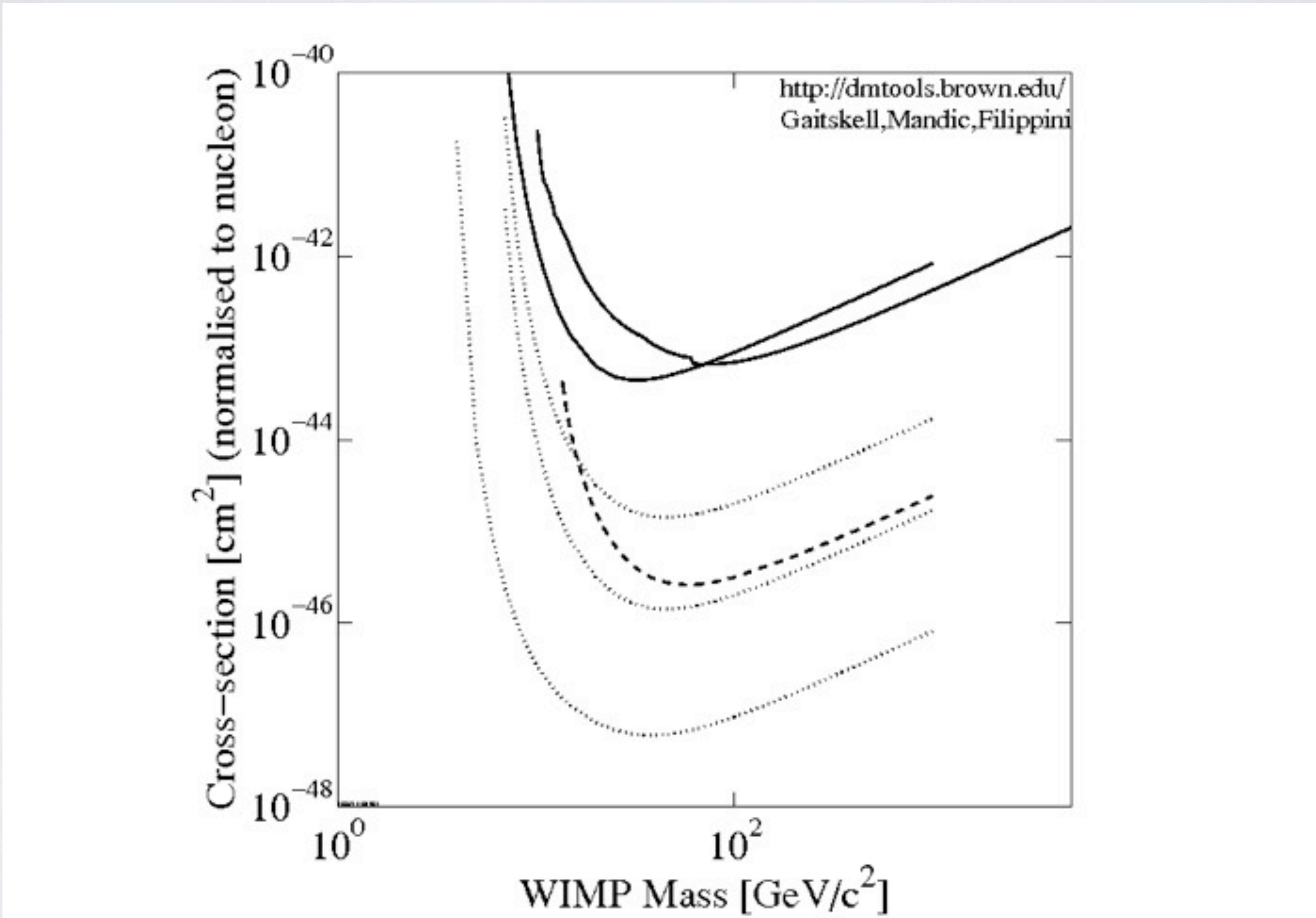
THE TWO CROSS SECTIONS TO THINK ABOUT



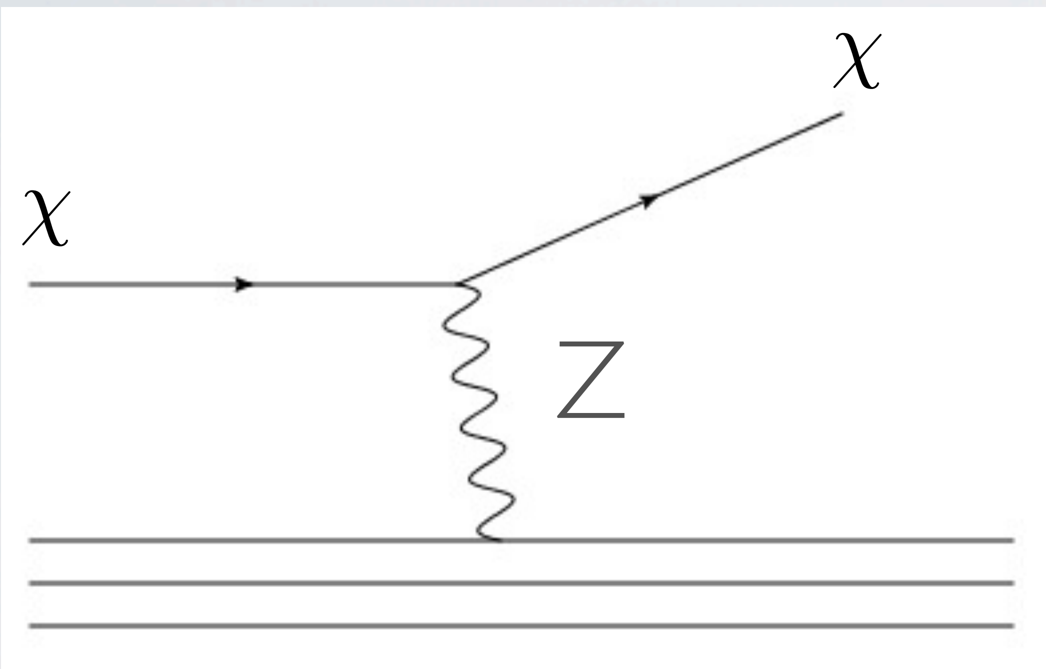


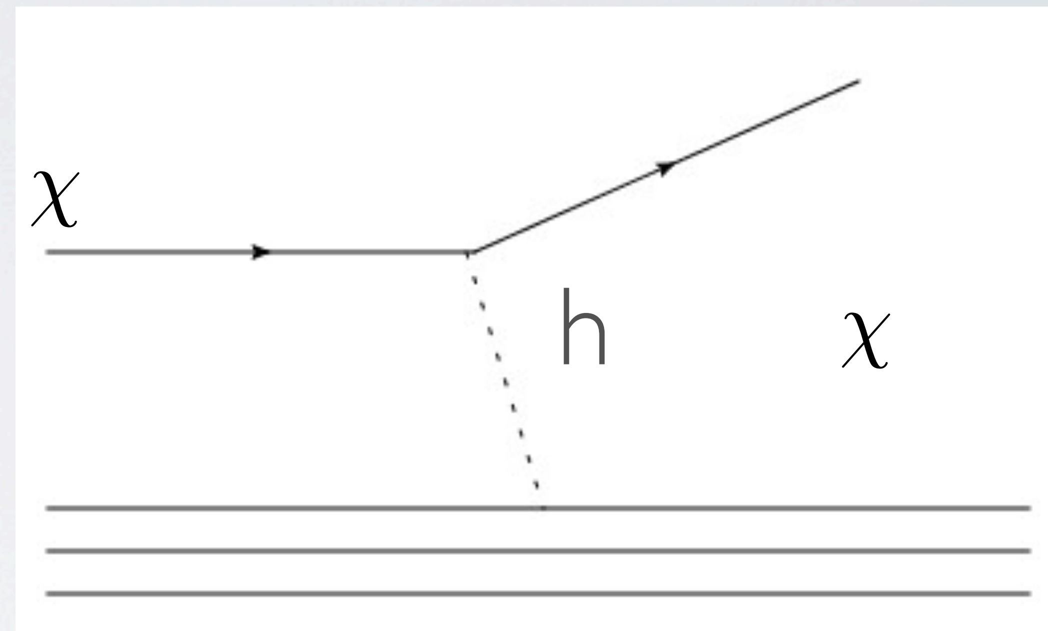
$$\sigma_0 \approx \frac{G_f^2 \mu^2}{2\pi} \sim 10^{-39}\mathrm{cm}^2$$

Ruled out
(just a little bit)



THE TWO CROSS SECTIONS TO THINK ABOUT





$$\sigma_0 \approx \frac{G_f^2 \mu^2}{2\pi} \sim 10^{-39}\mathrm{cm}^2$$

$$g \sim 1 \Rightarrow y_p \sim \frac{1}{\mathrm{few}} \frac{m_p}{v}$$

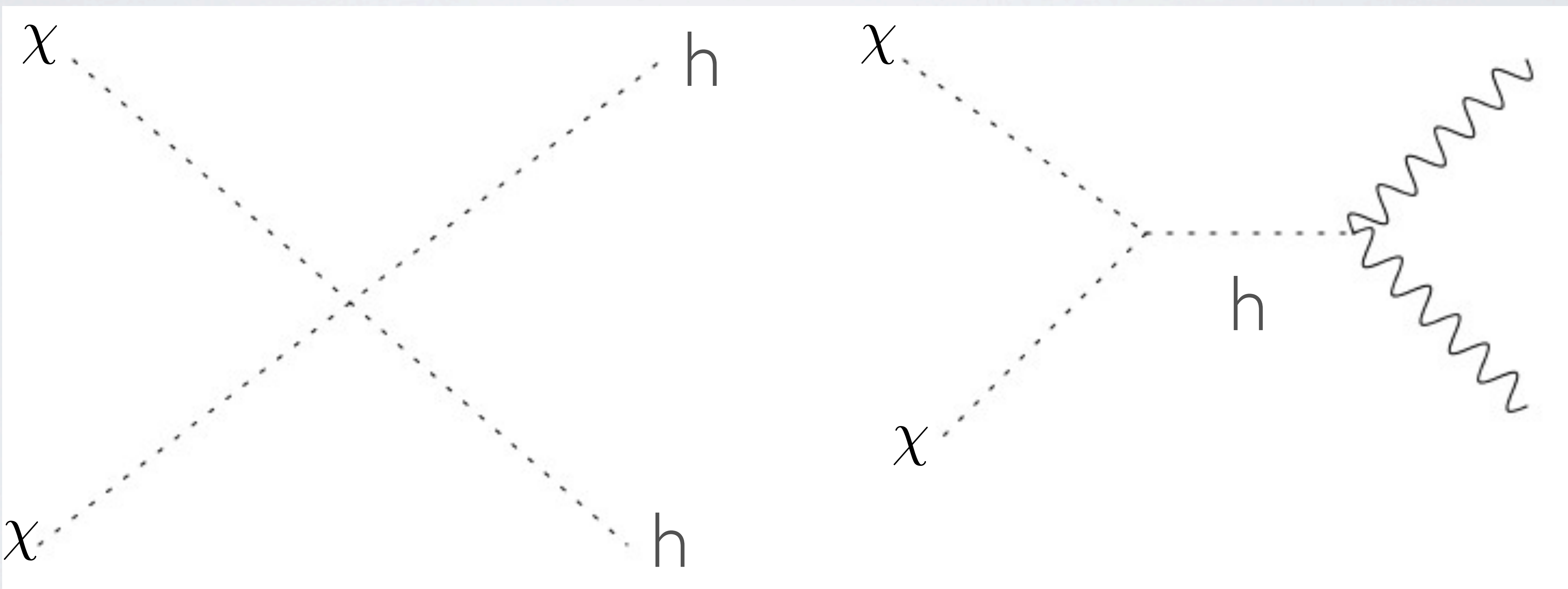
$$\sigma_0 \sim 10^{-39}\mathrm{cm}^2 \times 10^{-6}$$

$$\sim 10^{-45}\mathrm{cm}^2$$

A "MINIMAL MODEL" OF DARK MATTER

Burgess, Pospelov, ter Veldhuis, '01

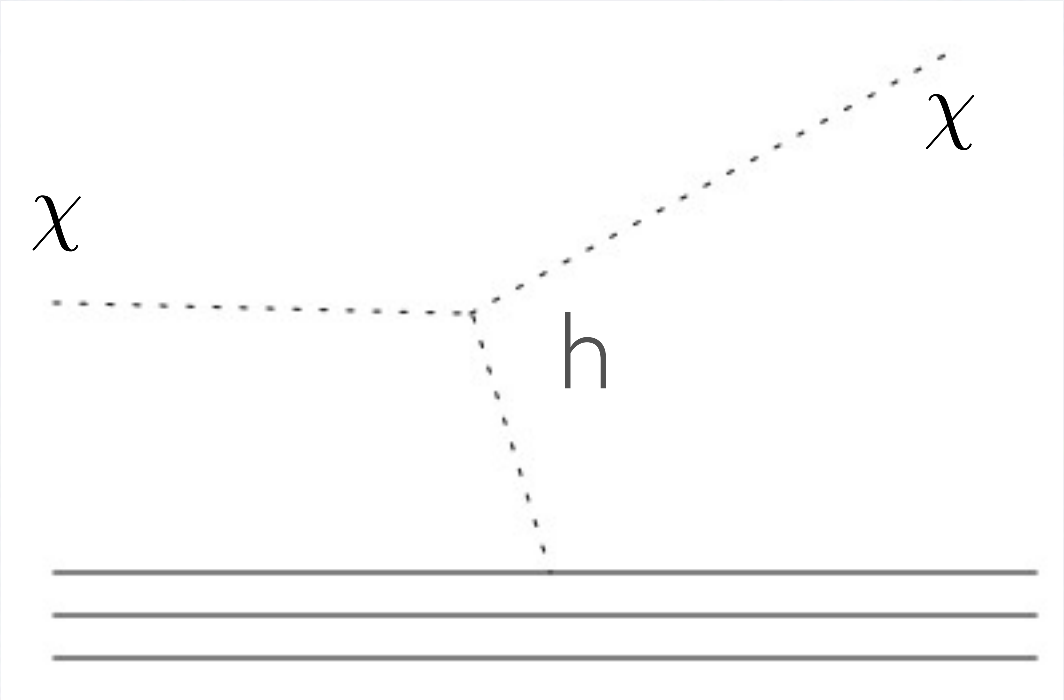
$$V = \frac{m_0^2}{2} S^2 + \frac{\lambda}{2} S^2 h^2 + \frac{\lambda_S}{4} S^4 + \frac{\lambda_h}{4}\left(h^2 - v_{EW}^2\right)^2.$$



A "MINIMAL MODEL" OF DARK MATTER

Burgess, Pospelov, ter Veldhuis, '01

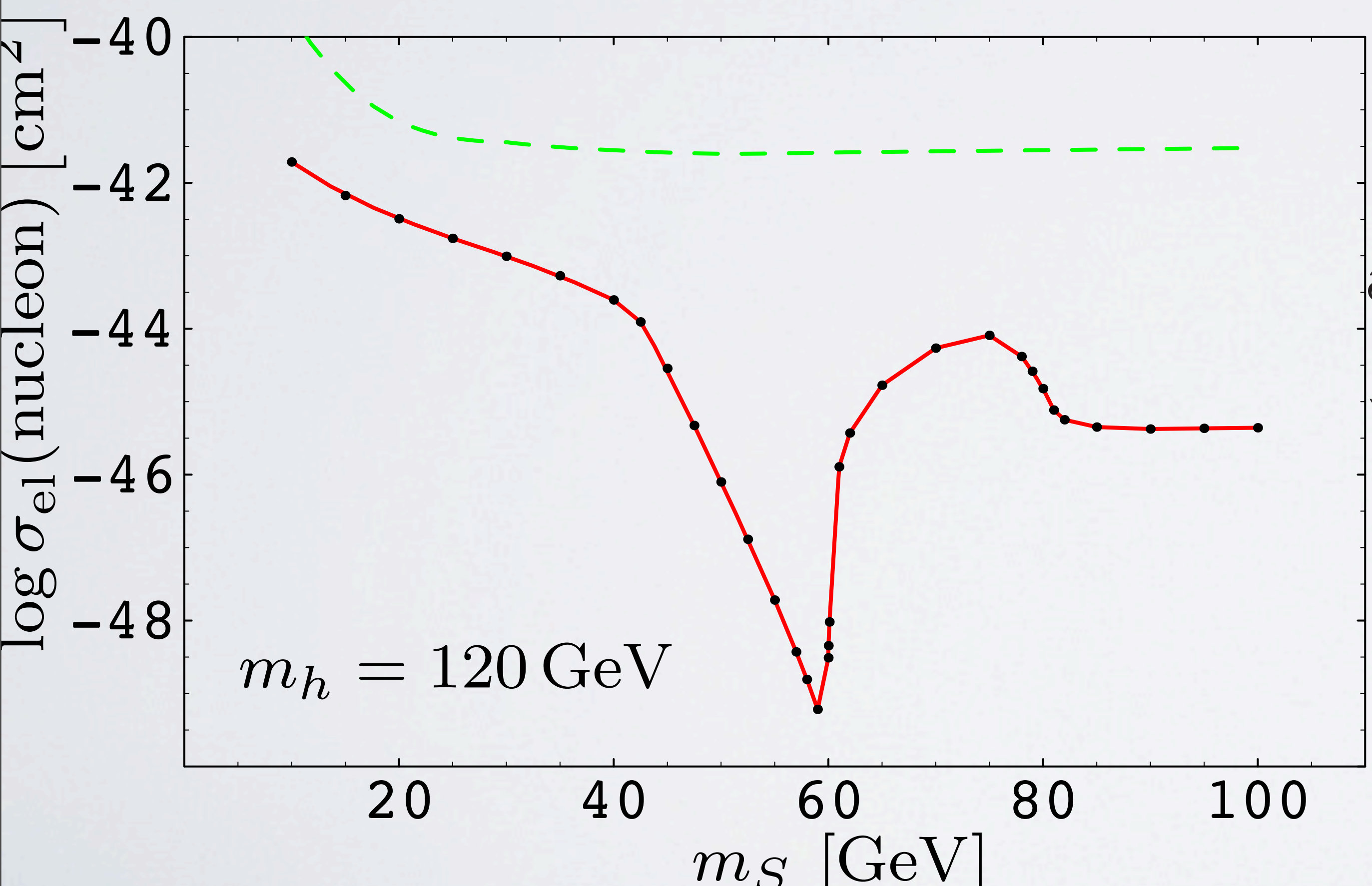
$$V = \frac{m_0^2}{2}\, S^2 + \frac{\lambda}{2}\, S^2 h^2 + \frac{\lambda_S}{4}\, S^4 + \frac{\lambda_h}{4}\Big(h^2 - v_{EW}^2\Big)^2 .$$

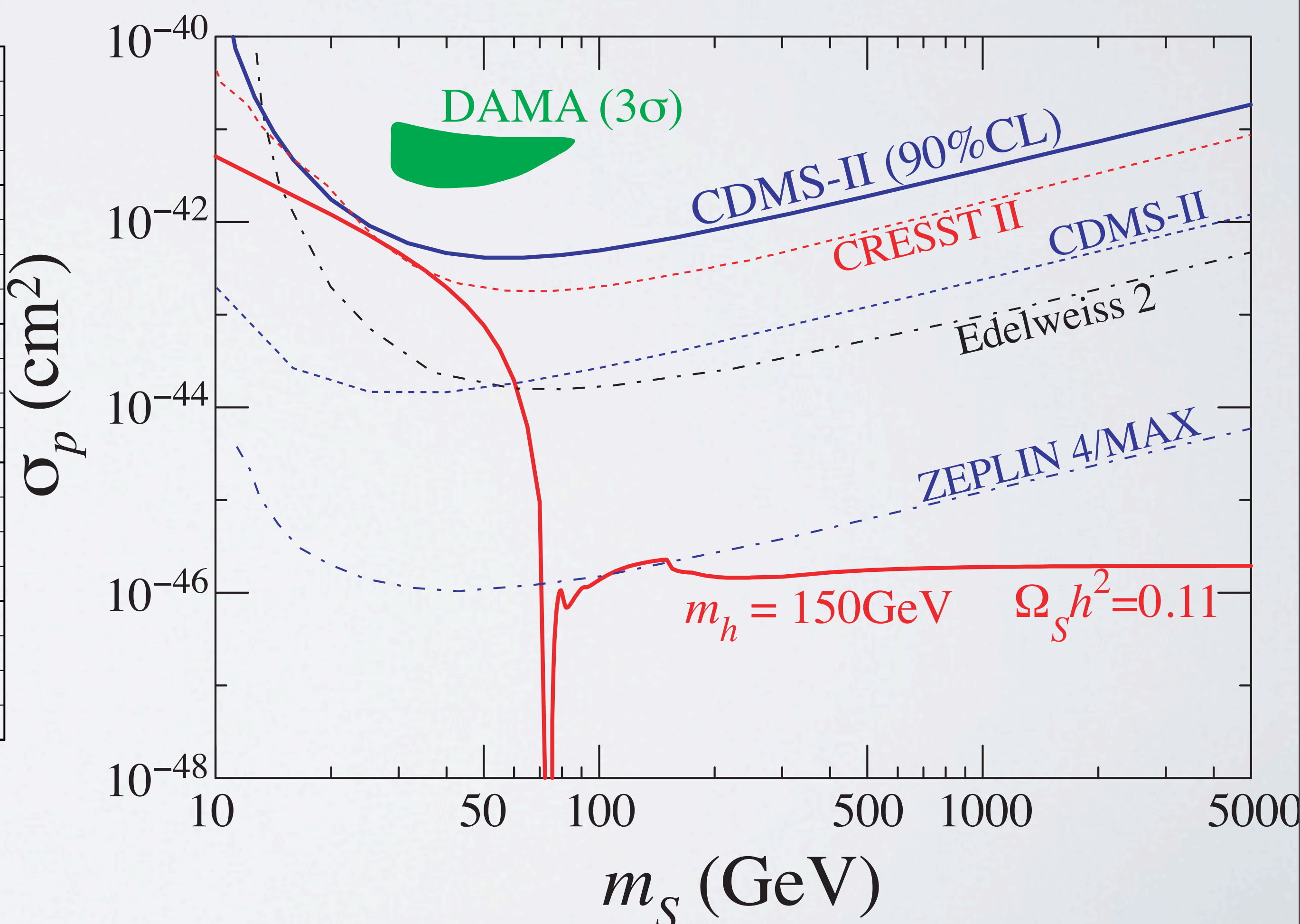


A "MINIMAL MODEL" OF DARK MATTER

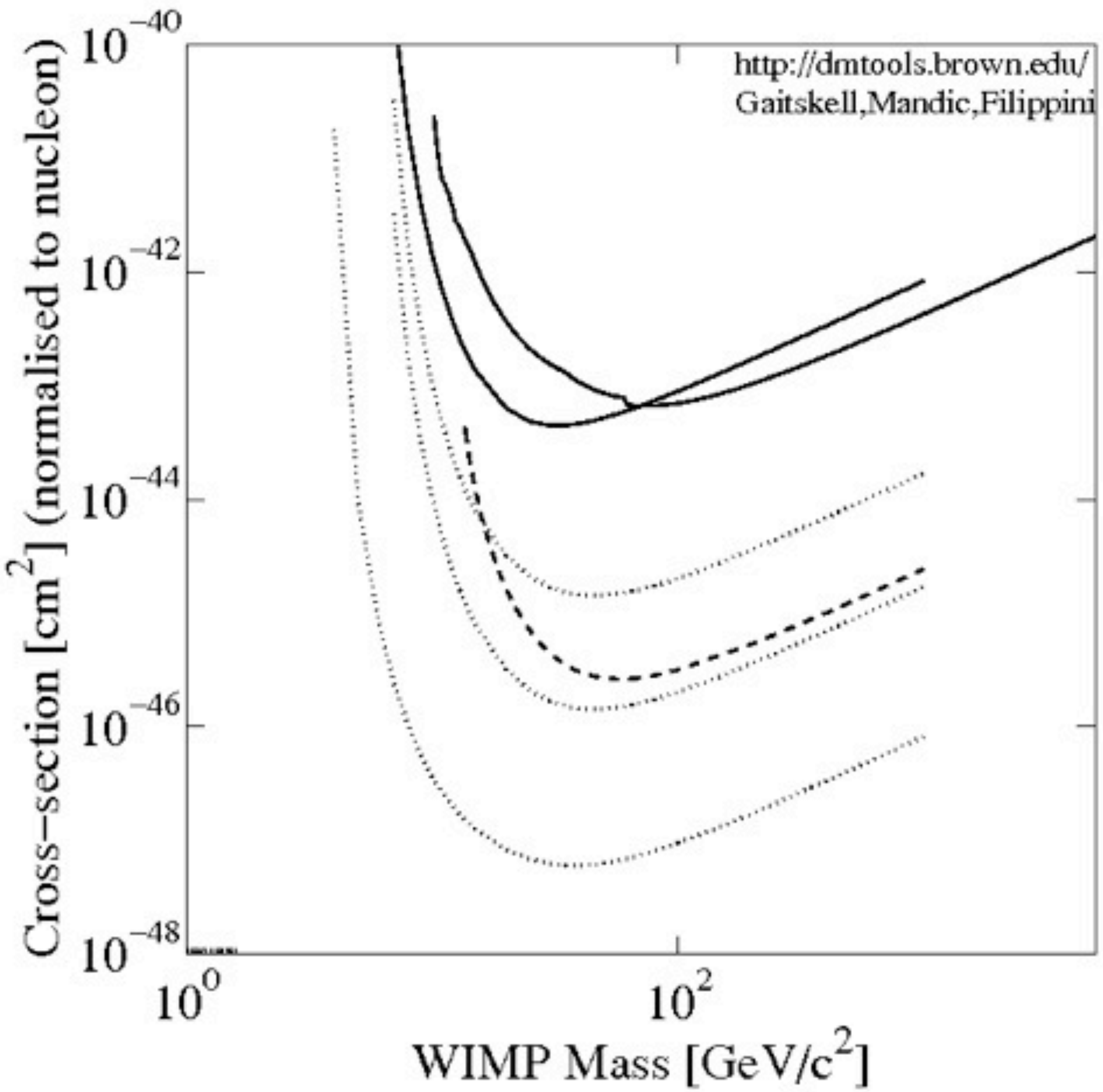
Burgess, Pospelov, ter Veldhuis, '01;
Davoudiasl, Kitano, Li, Murayama '04

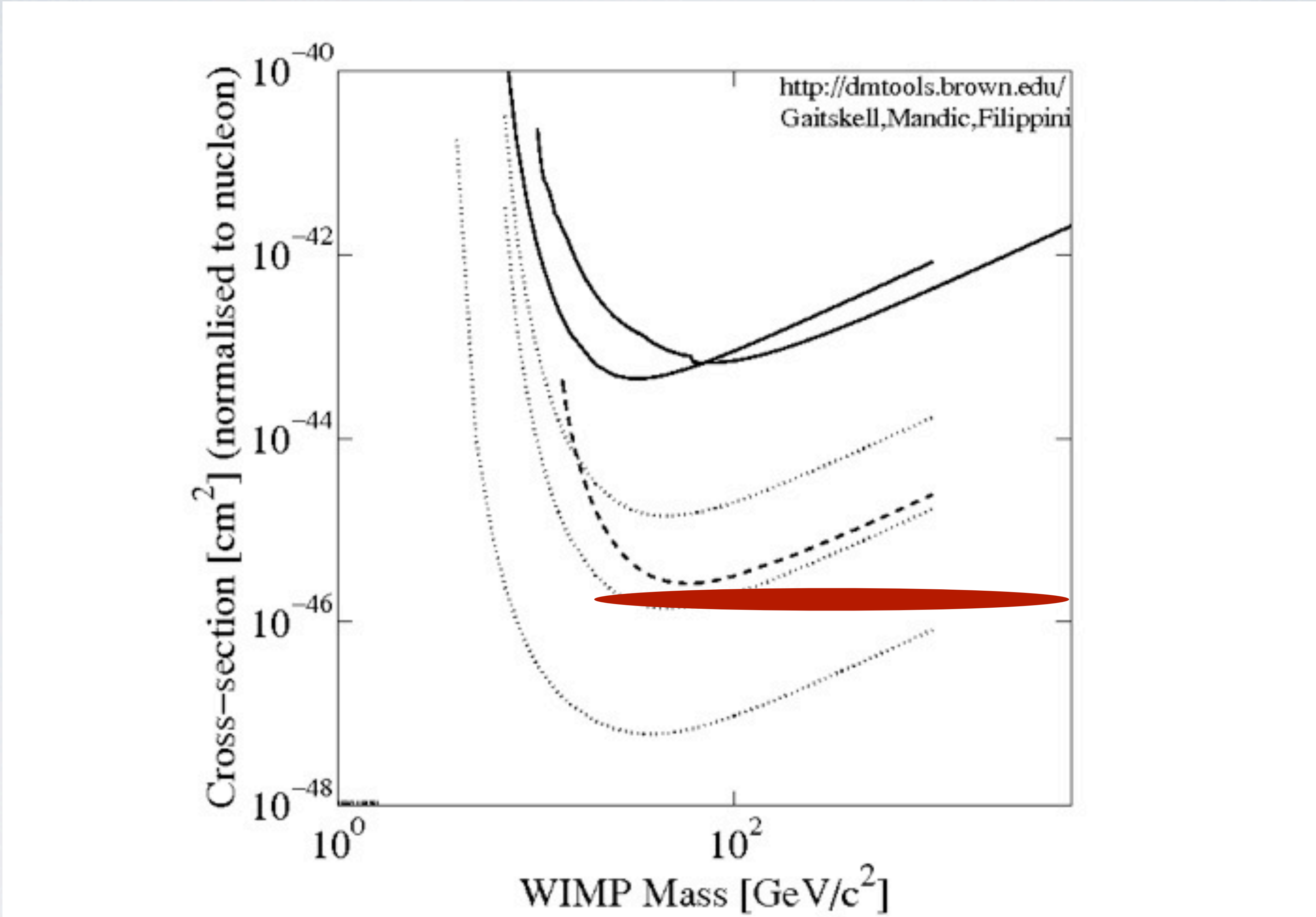
$$V = \frac{m_0^2}{2} S^2 + \frac{\lambda}{2} S^2 h^2 + \frac{\lambda_S}{4} S^4 + \frac{\lambda_h}{4}\left(h^2 - v_{EW}^2\right)^2.$$





Davoudiasl, Kitano, Li, Murayama '04


http://dmtools.brown.edu/
Gaitskell,Mandic,Filippini
Cross−section [cm^2] (normalised to nucleon)
10^{-40}
10^{-42}
10^{-44}
10^{-46}
10^{-48}
10^{0}
10^{2}
WIMP Mass [GeV/c^2]

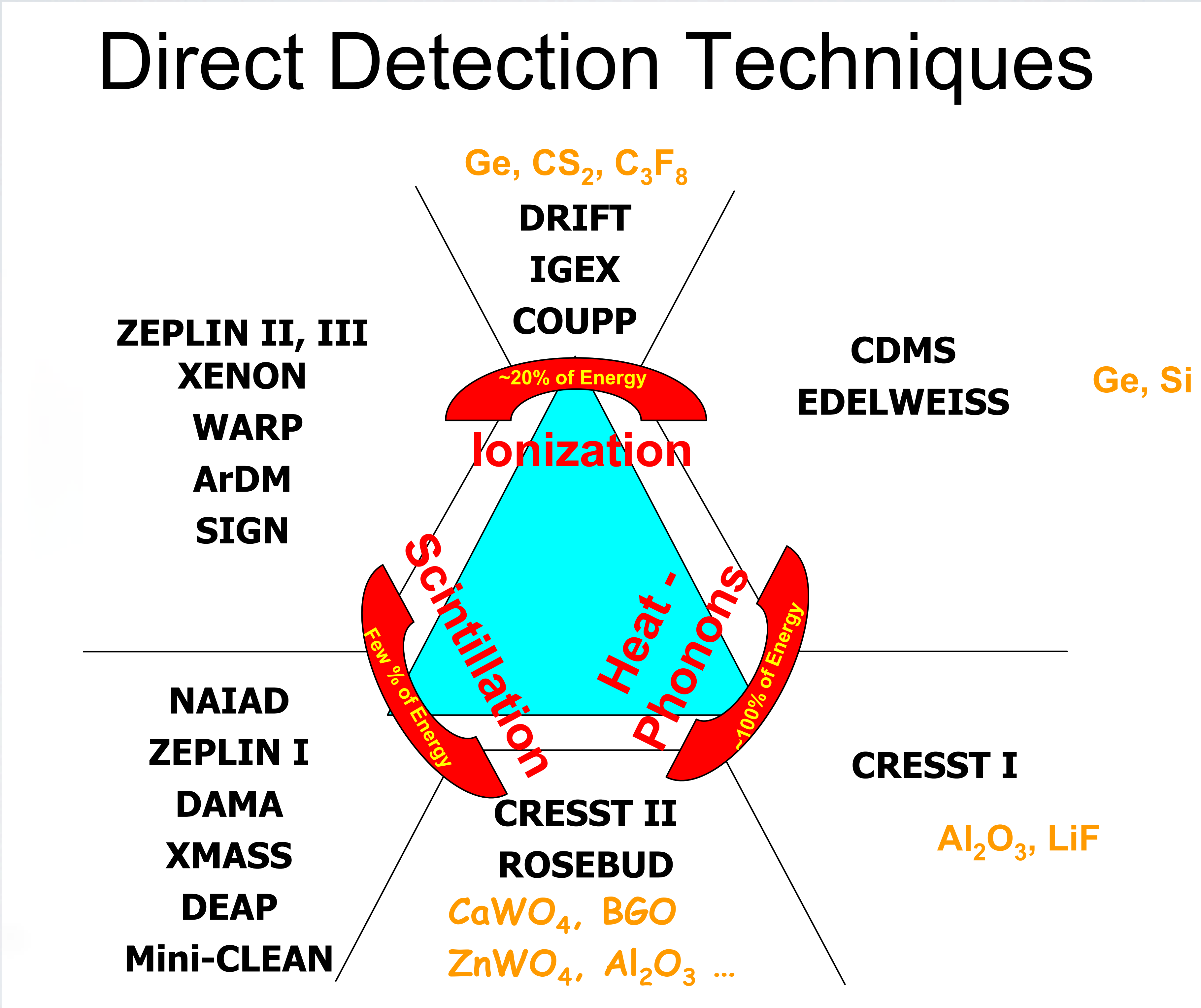


Various physics can move it up or down - but this is a natural starting point

TWO CROSS SECTIONS

- If I had to pick two numbers for the cross section that a WIMP would scatter with, they'd be 10^{-39} cm^2 and 10^{-45} cm^2.
- It's not the former.
- How will we get there?

need: low threshold (~keV) signal, eliminate bkg (shielding), discriminate bkg



(plot shamelessly stolen from B. Sadoulet)

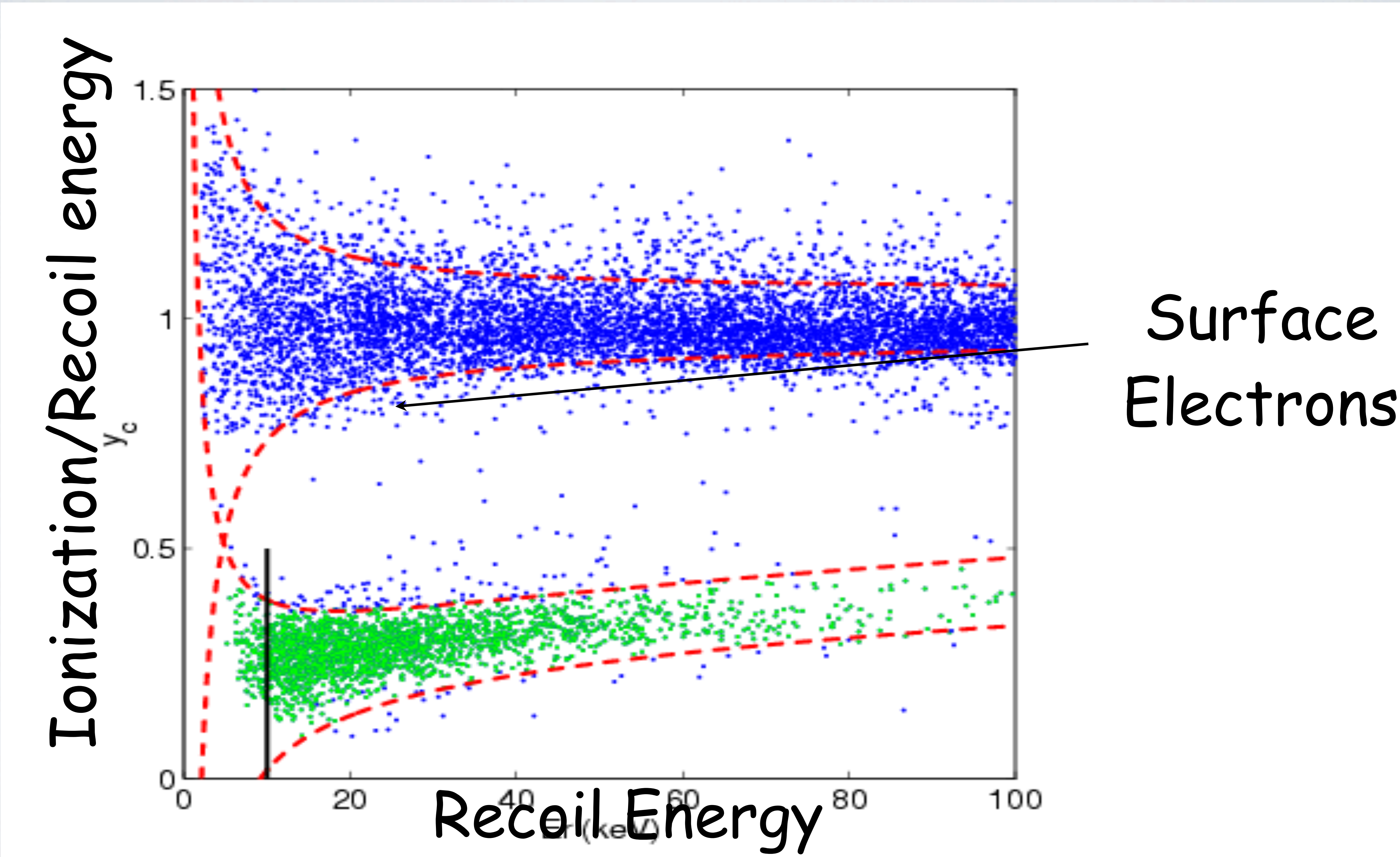
EVENT DISCRIMINATION

- Dark matter scatters off of nuclei, backgrounds scatter off of electrons
- Can you tell the two apart?

EVENT DISCRIMINATION

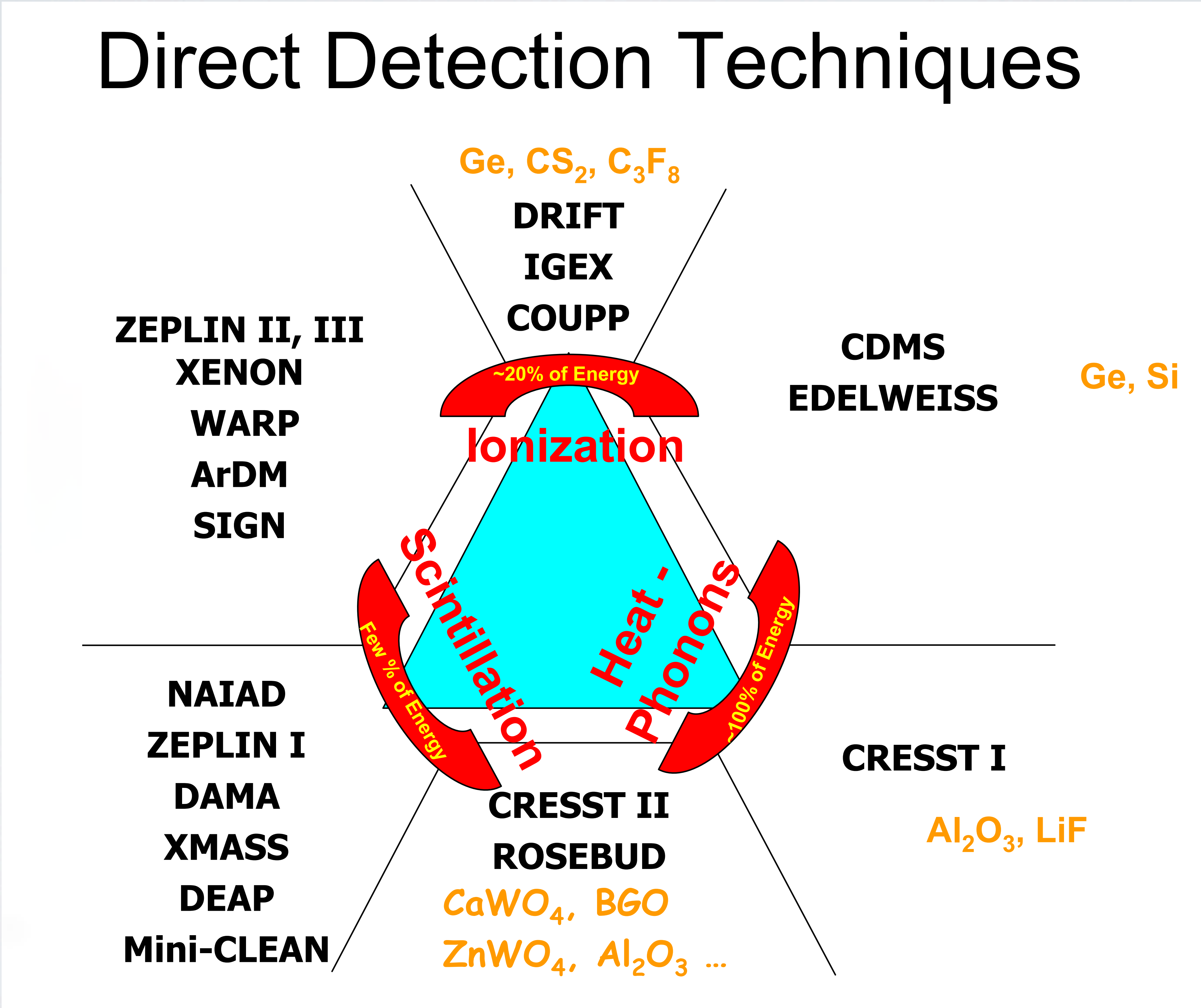
- Dark matter scatters off of nuclei, backgrounds scatter off of electrons
- Can you tell the two apart?

E.G., CDMS



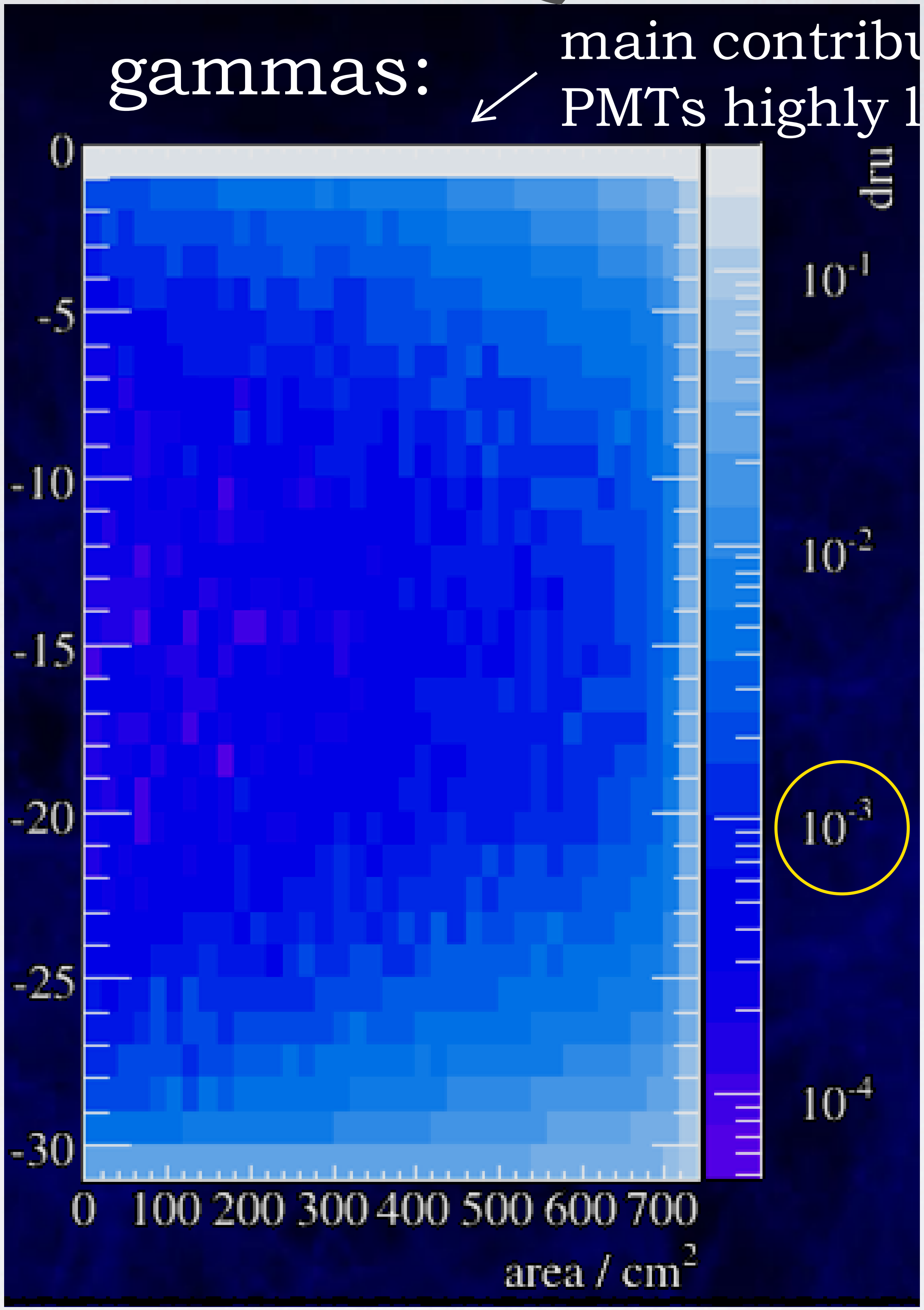
Ionization/Recoil energy
y_c
1.5
1
0.5
0
0
20
40
60
80
100
Er (keV)
Recoil Energy
Surface Electrons

need: low threshold (~keV) signal, eliminate bkg (shielding), discriminate bkg

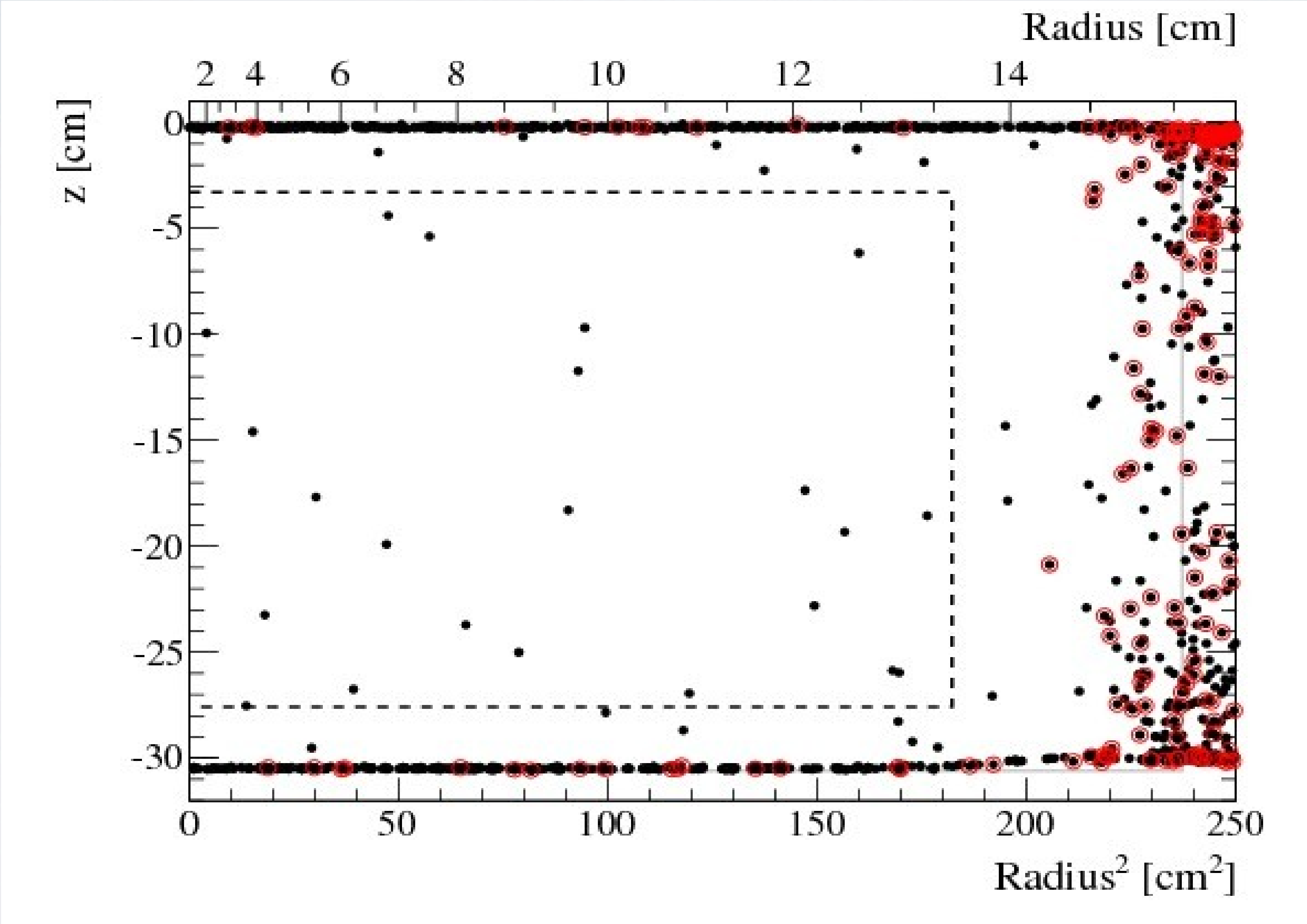


(plot shamelessly stolen from B. Sadoulet)

THE RISE OF LIQUID NOBLES



THE RISE OF LIQUID NOBLES

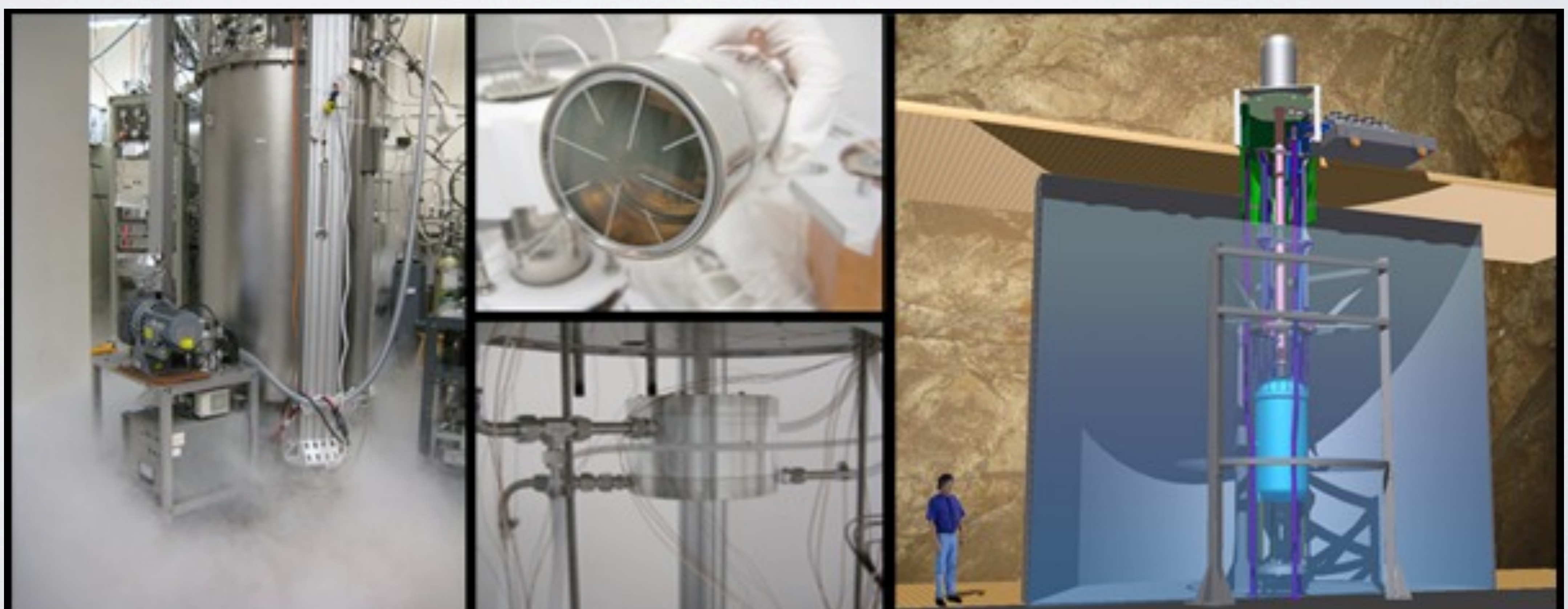


THE RISE OF LIQUID NOBLES

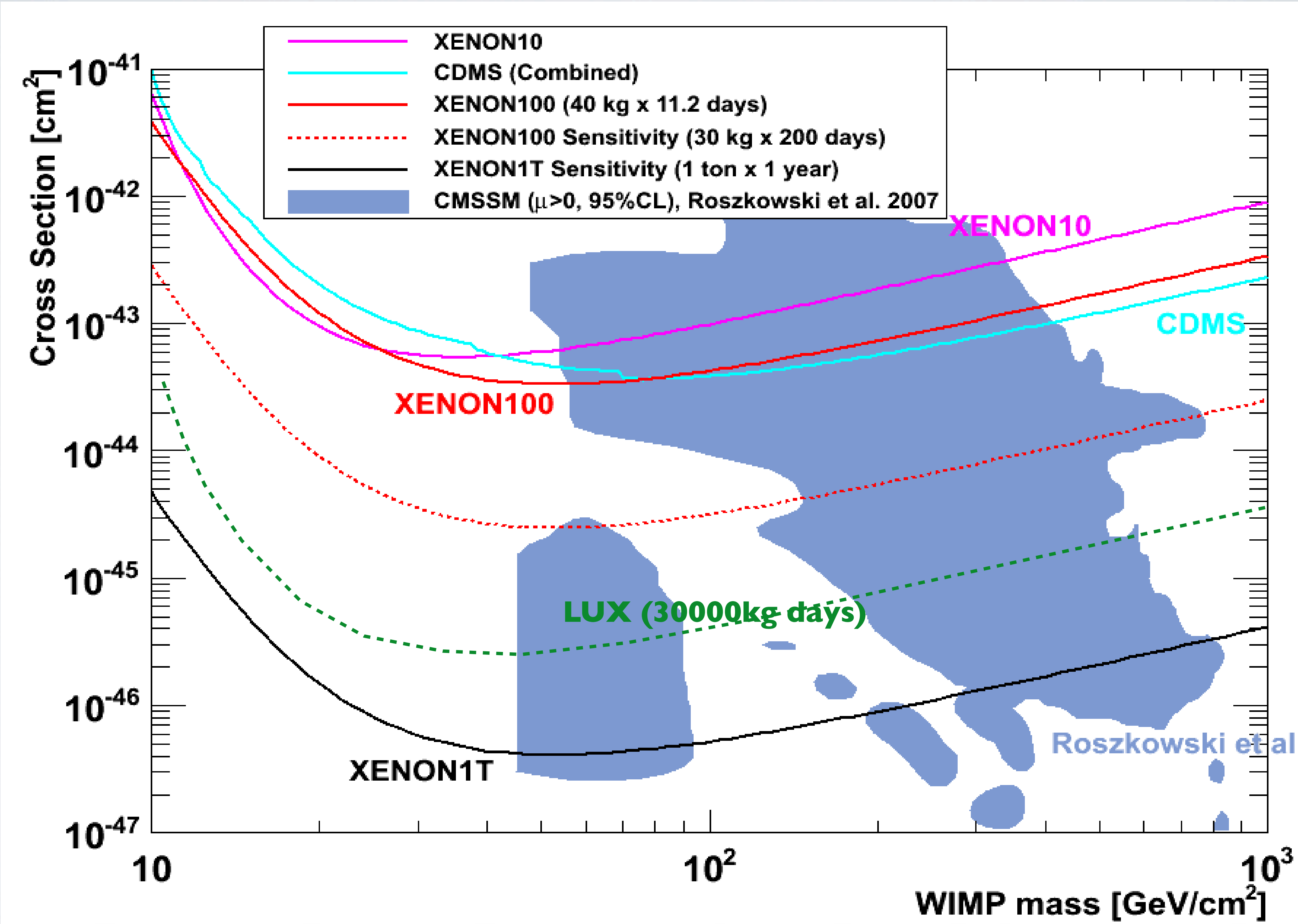
XENON100:
3000 kg days

LUX (350KG LXE 2 PHASE, ~100 KG FIDUCIAL)

(NEXT YEAR)



THE RISE OF LIQUID NOBLES



An order of magnitude this year!

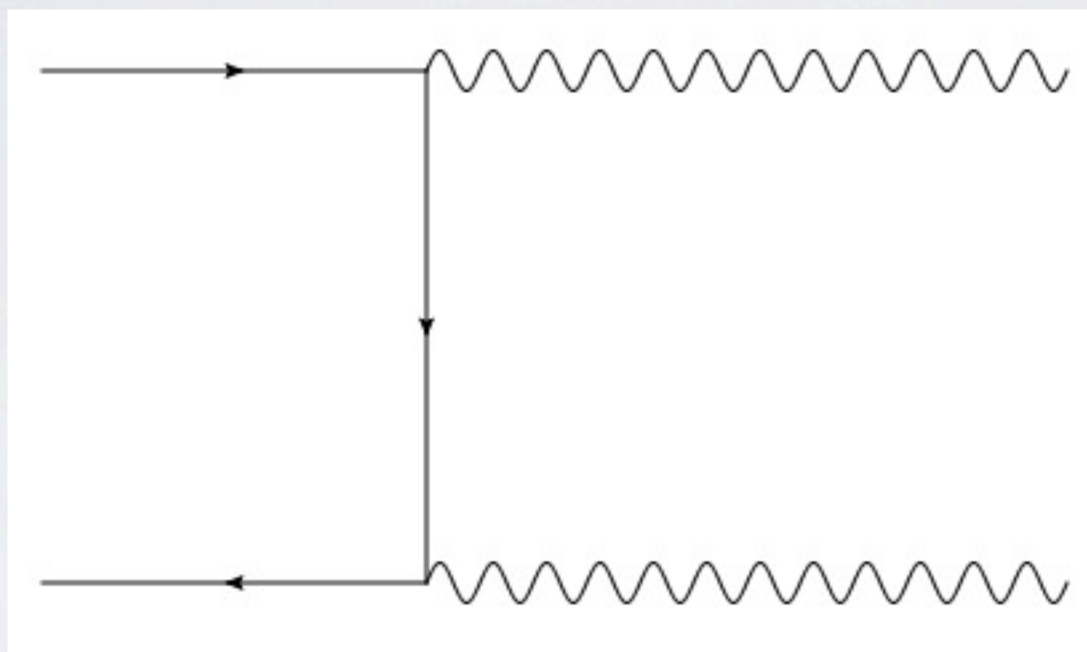
February/March first results ~ 100 days

KEY EVENTS IN 2011

- XENON100 (Unblinding and first results)
- COUPP (First results)
- KIMS (1 year results)
- COGENT (Update)
- LUX begins

PESSIMISM

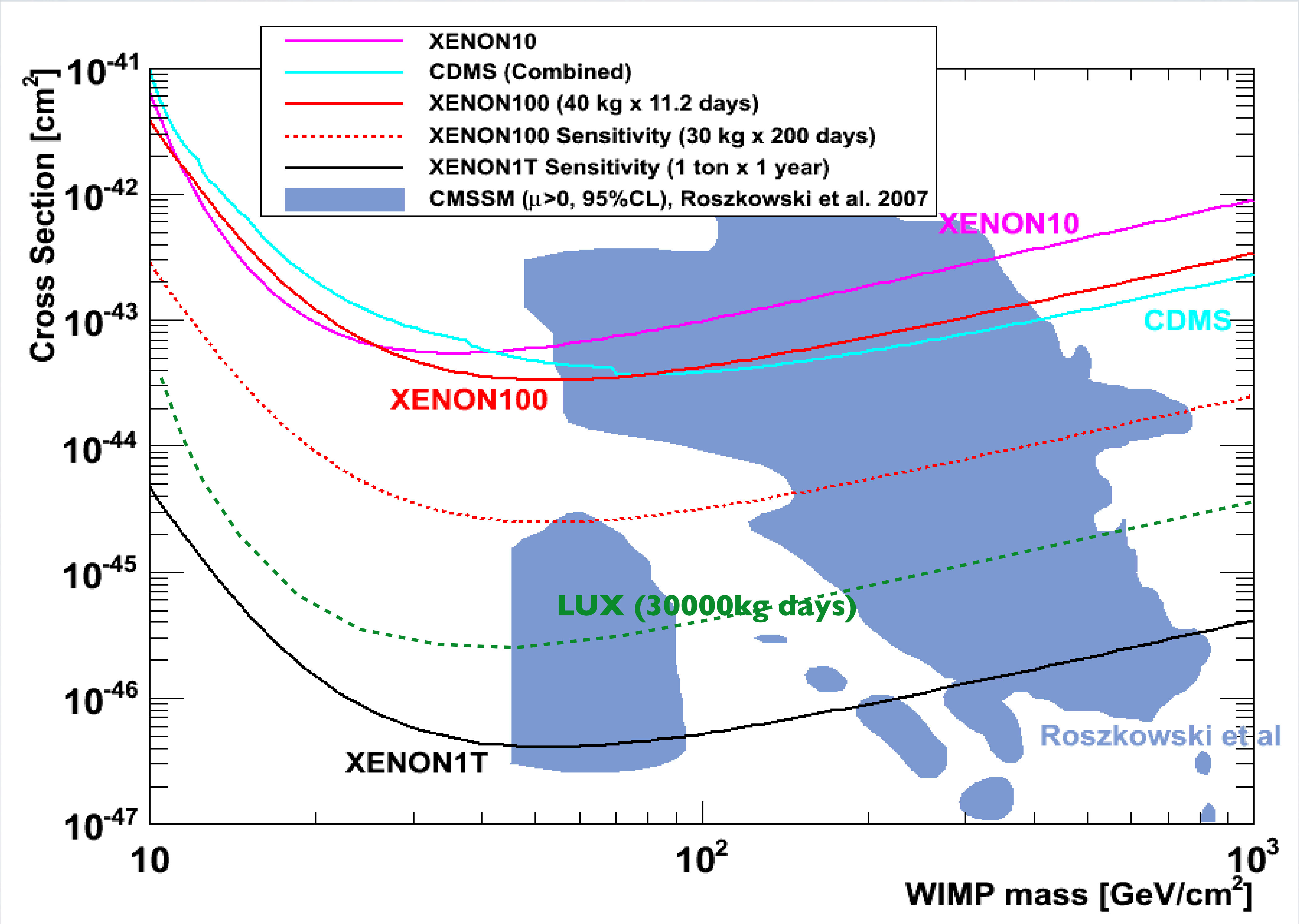
SU(2) triplet (a "Wino")



$\sim 10^{-46–47}\mathrm{cm}^2$, ~2 TeV

Hisano, Matsumoto, Nojiri, Saito '05

PESSIMISM

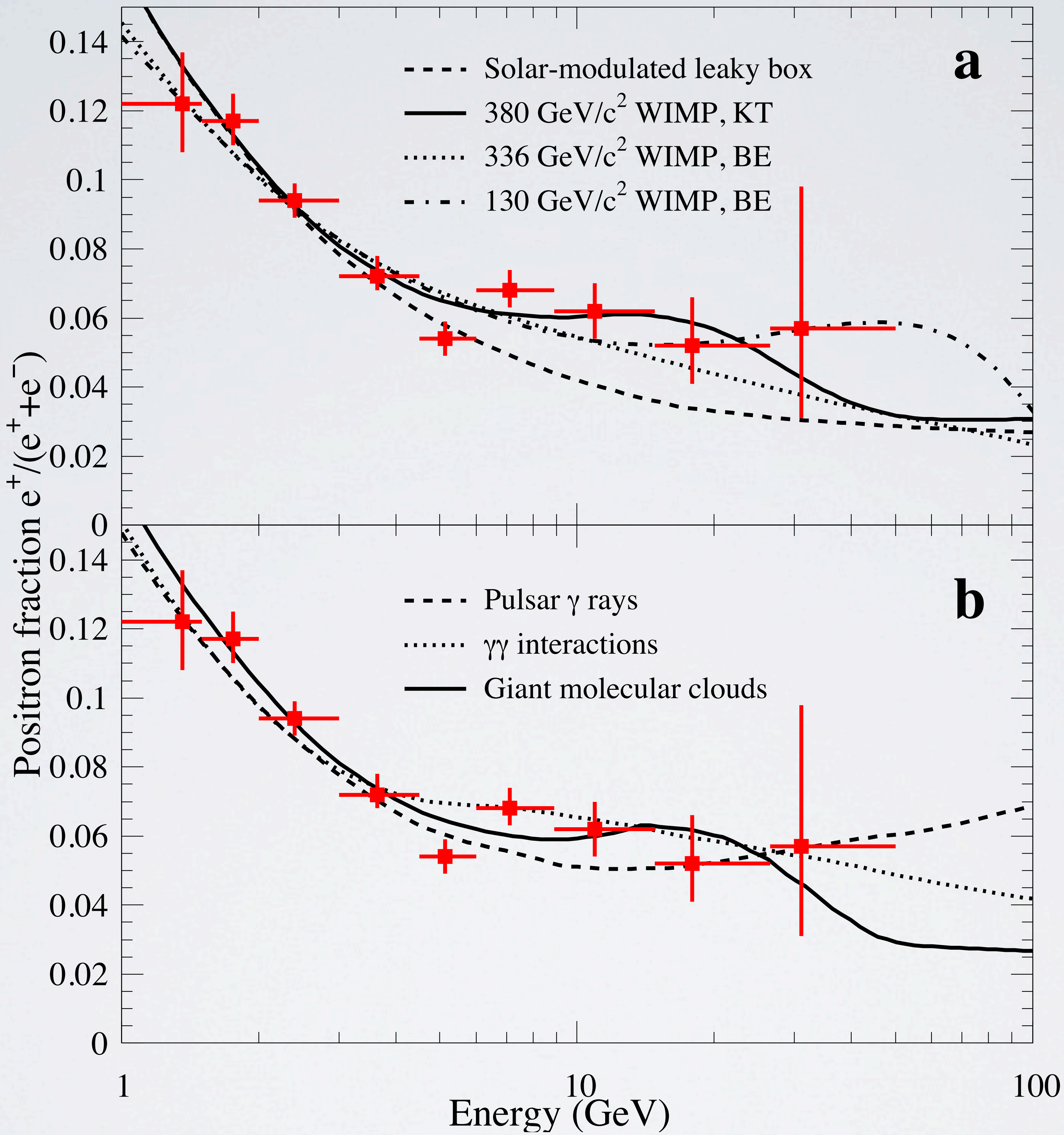


XENON10
CDMS (Combined)
XENON100 (40 kg x 11.2 days)
XENON100 Sensitivity (30 kg x 200 days)
XENON1T Sensitivity (1 ton x 1 year)
CMSSM (μ>0, 95%CL), Roszkowski et al. 2007
Cross Section [cm^2]
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10
10^2
10^3
WIMP mass [GeV/cm^2]
XENON10
CDMS
XENON100
LUX (30000kg days)
XENON1T
Roszkowski et al

WHAT IS A COMPELLING ASTROPHYSICAL (INDIRECT) SIGNAL?

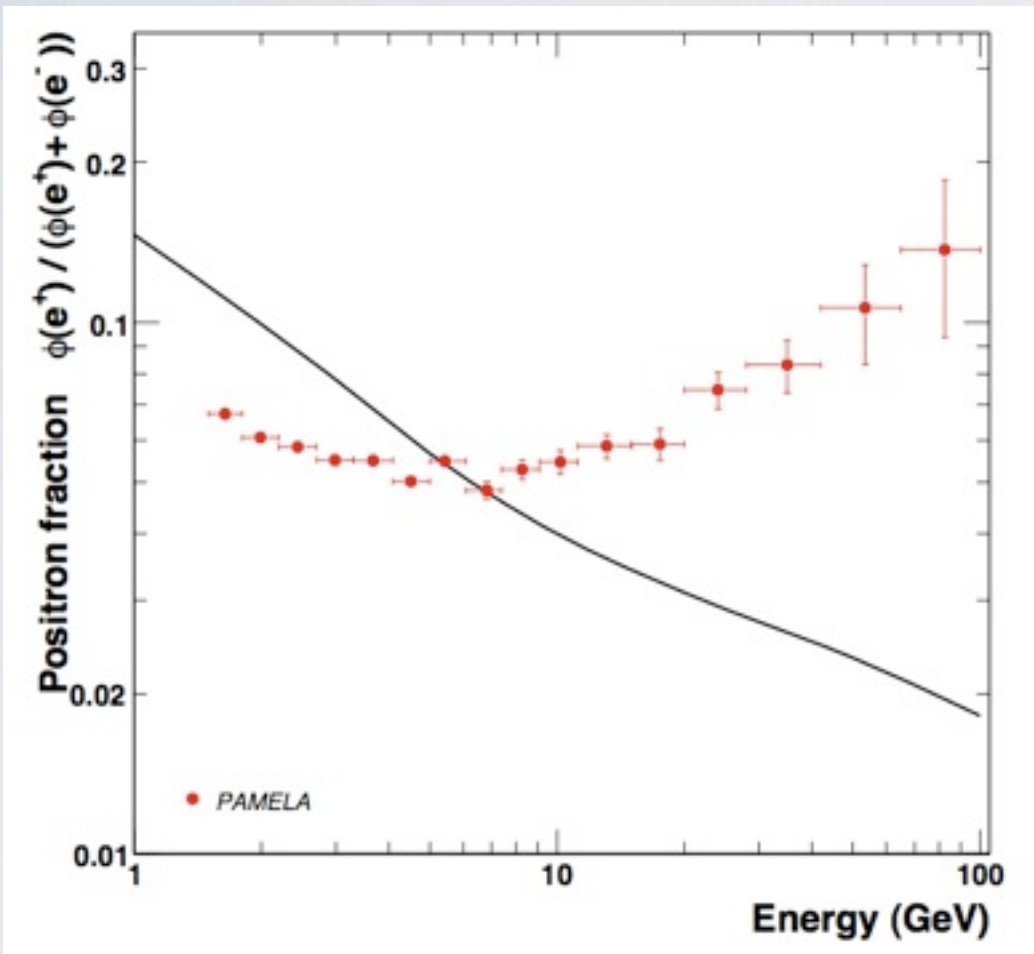
DISCOVERING A WIMP IN SPACE

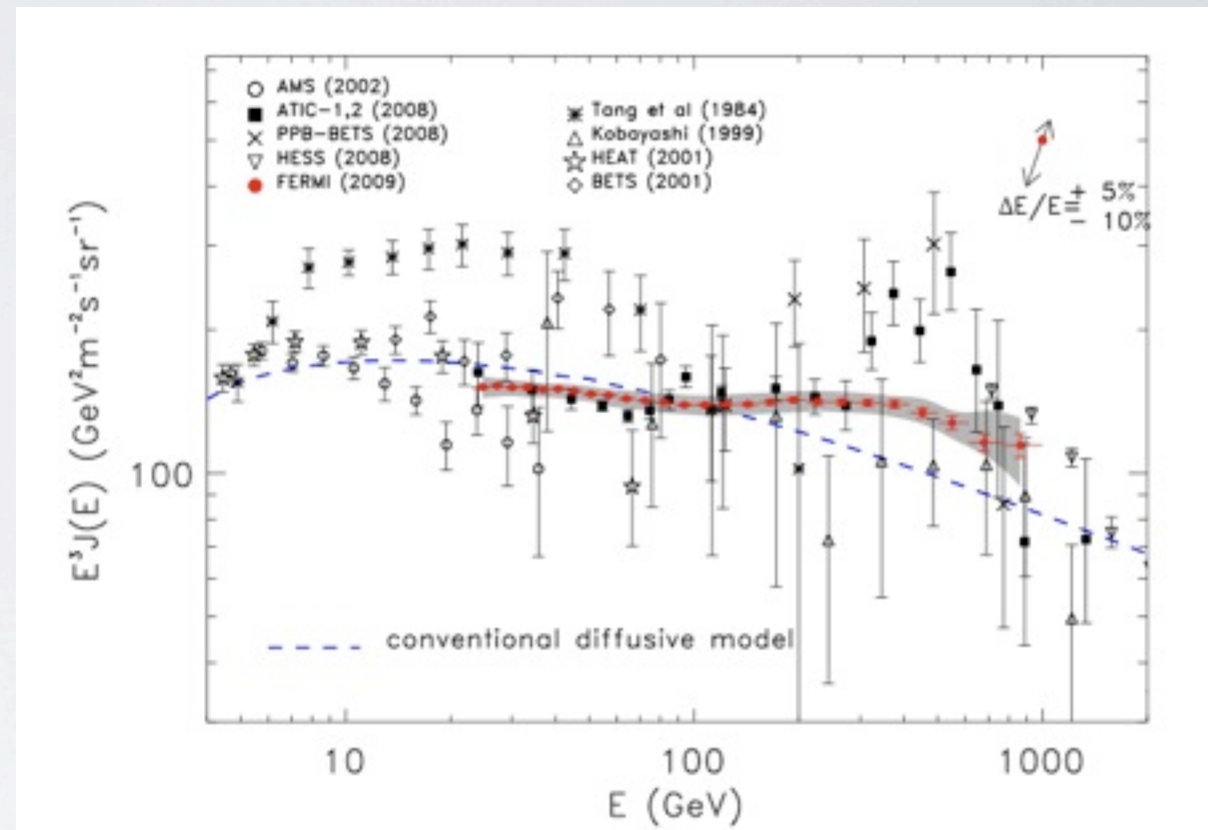
- Gamma Ray Lines
- TeV Neutrinos from dwarfs/other unexpected sources
- TeV gammas from dwarfs/other unexpected sources
- TeV antimatter cosmic rays
- sub GeV signals



a
Solar-modulated leaky box
380 GeV/c^2 WIMP, KT
336 GeV/c^2 WIMP, BE
130 GeV/c^2 WIMP, BE
b
Pulsar γ rays
γγ interactions
Giant molecular clouds
Positron fraction $e^+/(e^++e^-)$
Energy (GeV)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1
10
100

COSMIC RAYS: PAMELA/FERMI





Fermi/LAT collaboration

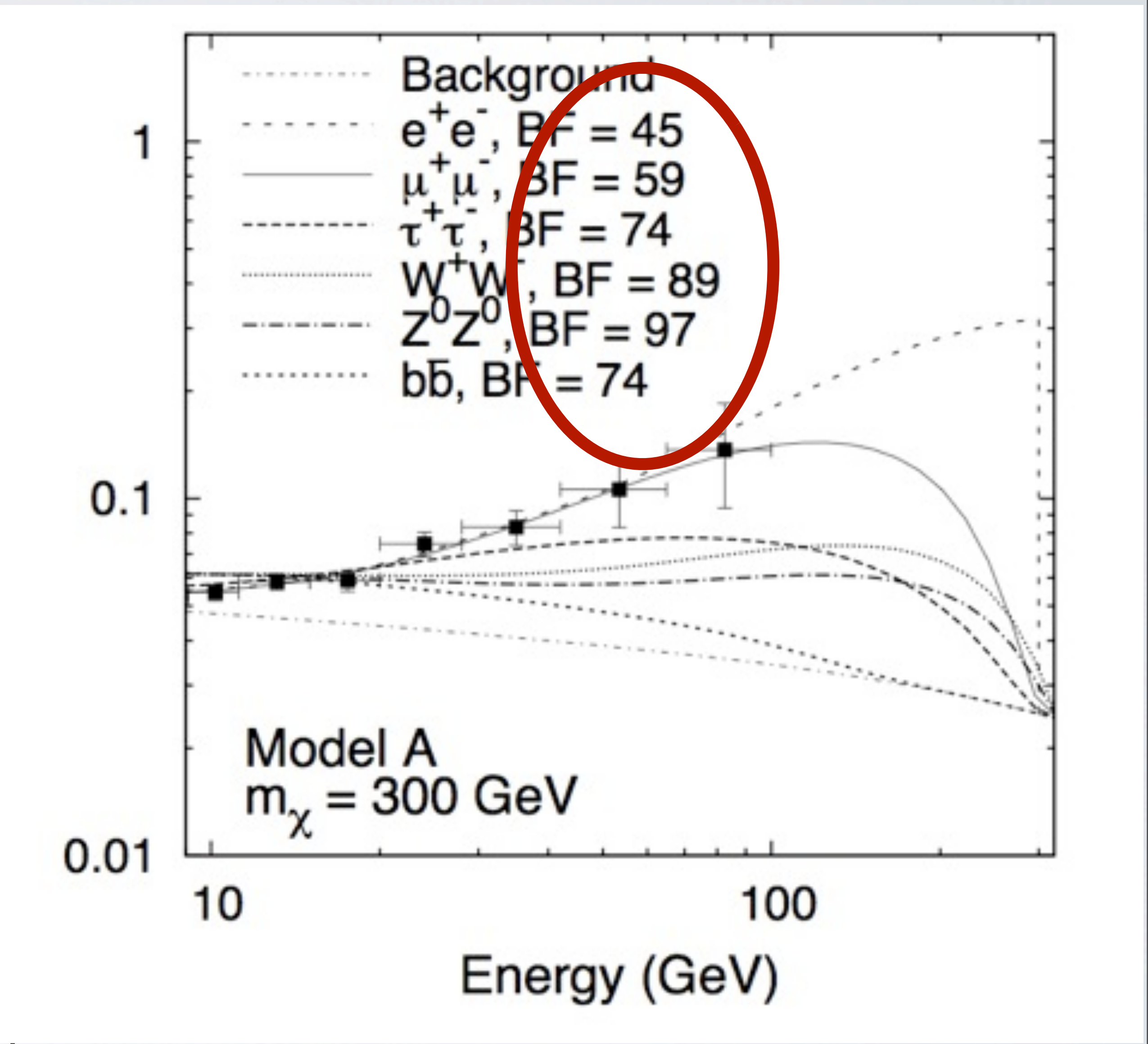
DM?

COSMIC RAYS: PAMELA/FERMI

PAMELA sees no excess in antiprotons - excludes hadronic modes by order of magnitude (Cirelli et al, '08, Donato et al, '08)

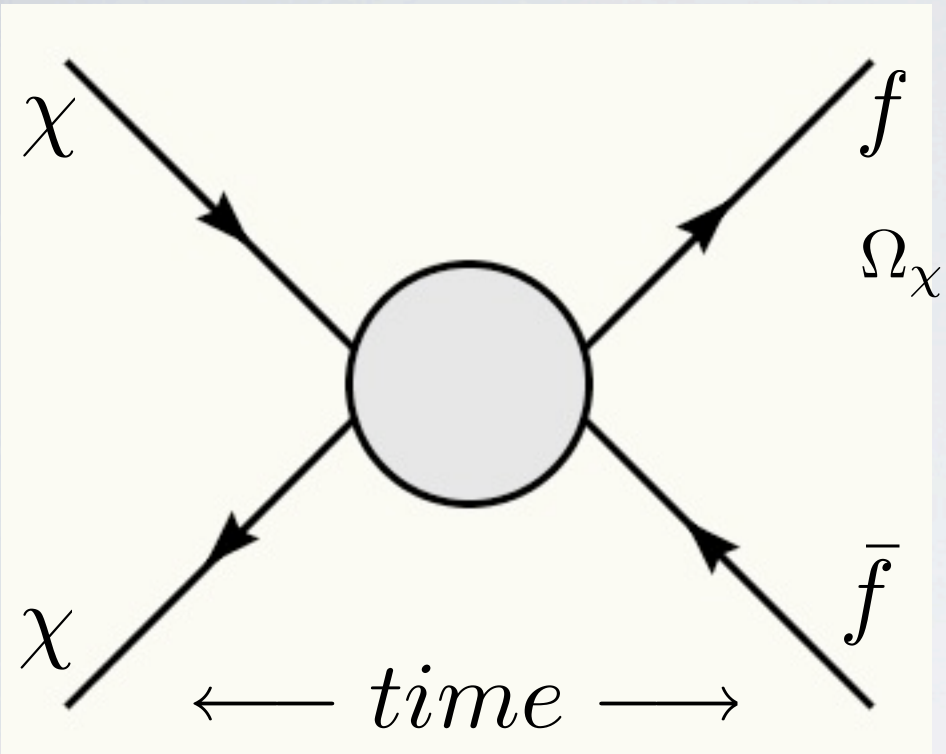
The spectrum at PAMELA is very hard - not what you would expect from e.g., W's

The cross sections needed are 10-1000x the thermal cross section



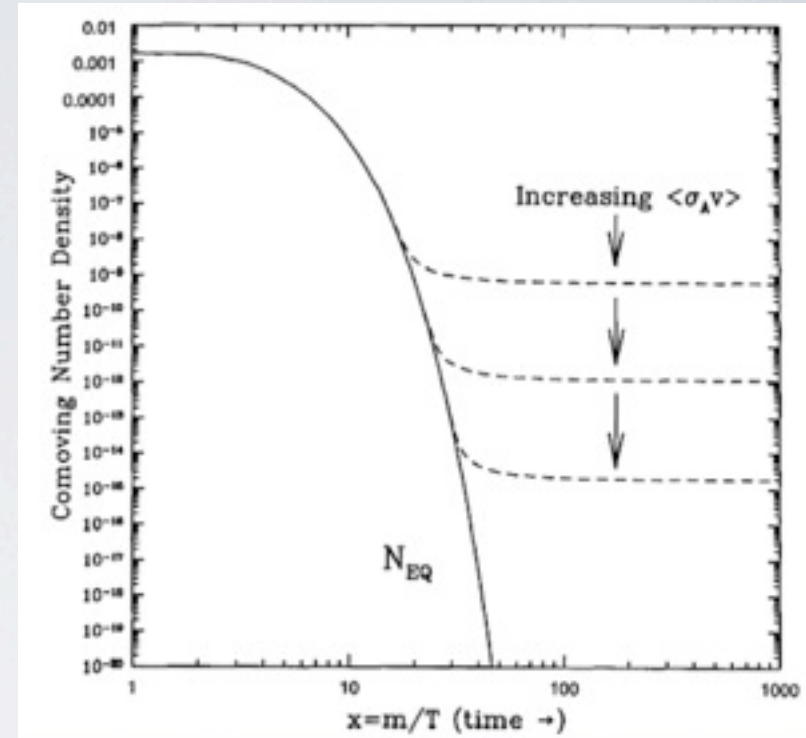
FREEZEOUT INTO A DARK PHOTON

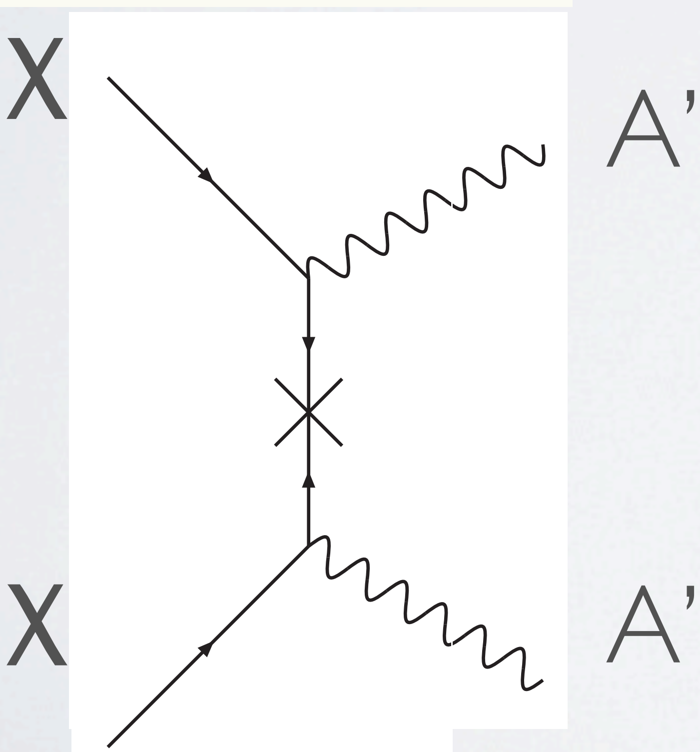
"Classic" WIMP

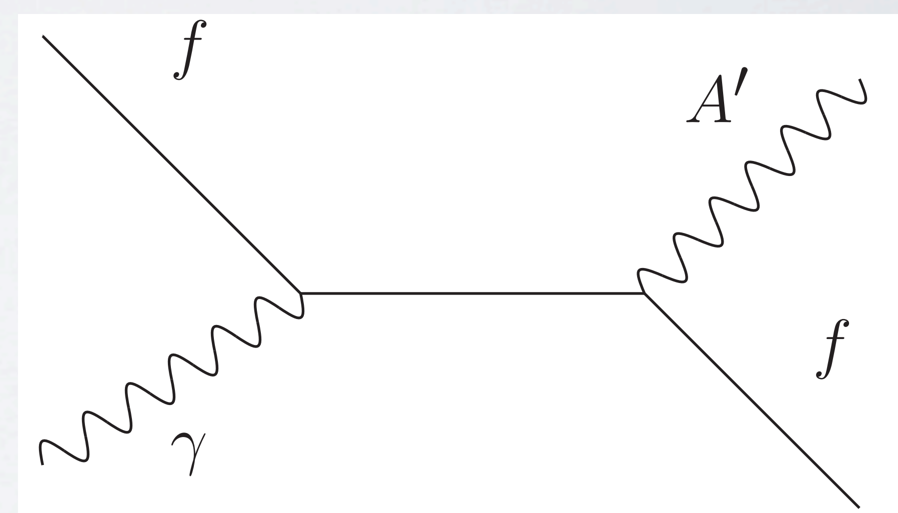


$$\Omega_\chi h^2 \approx 0.1 \times \frac{3 \times 10^{-26}\mathrm{cm}^3\mathrm{s}^{-1}}{\langle \sigma v \rangle}$$

$$\Rightarrow \langle \sigma v \rangle \approx \frac{\alpha^2}{M_W^2}$$

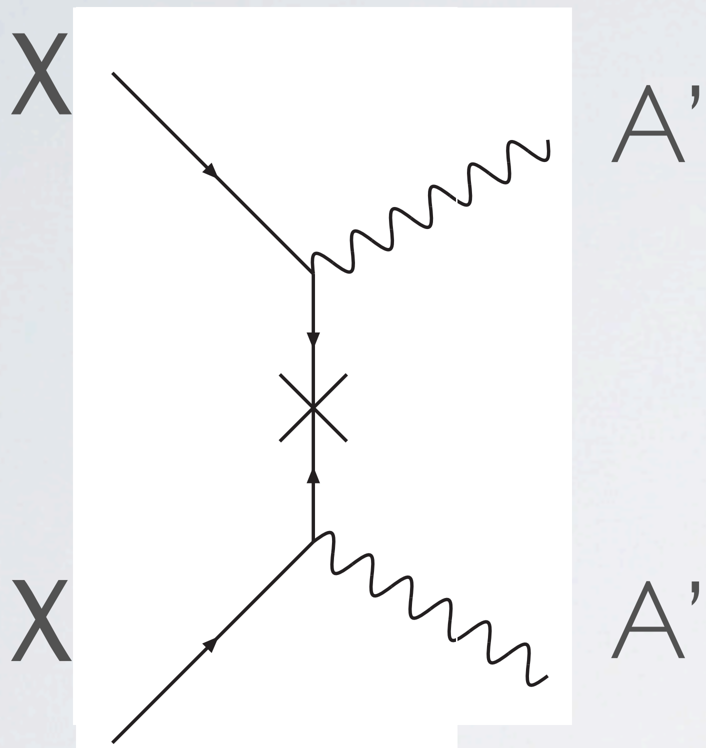


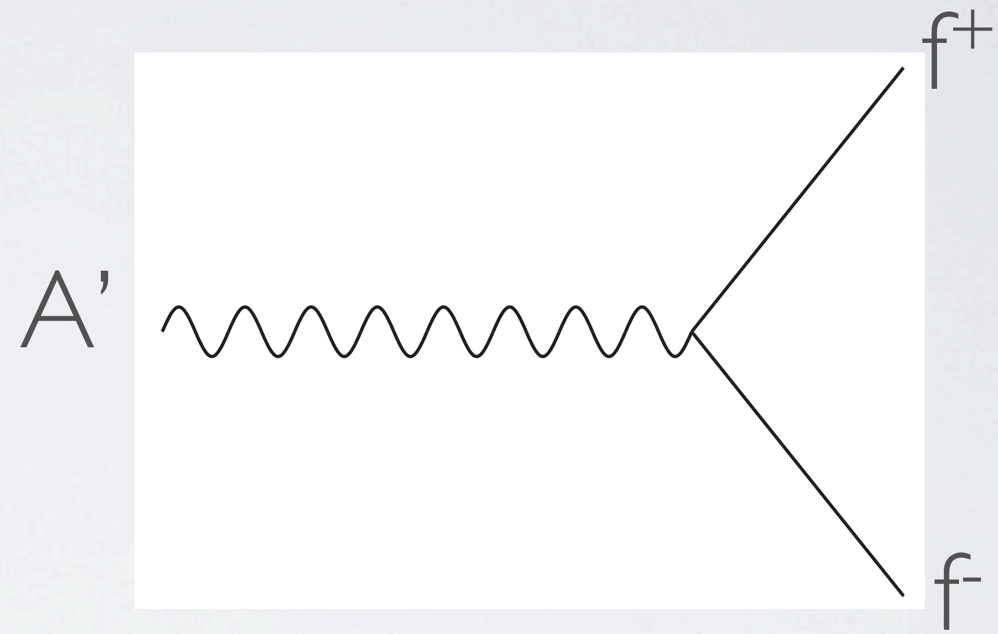




Finkbeiner, NW astro-ph 0702587v2; Pospelov,Ritz,Voloshin arxiv 0711.4866

COSMIC RAYS: PAMELA/FERMI





$m_{A'}$<GeV (no antiprotons, hard leptons)

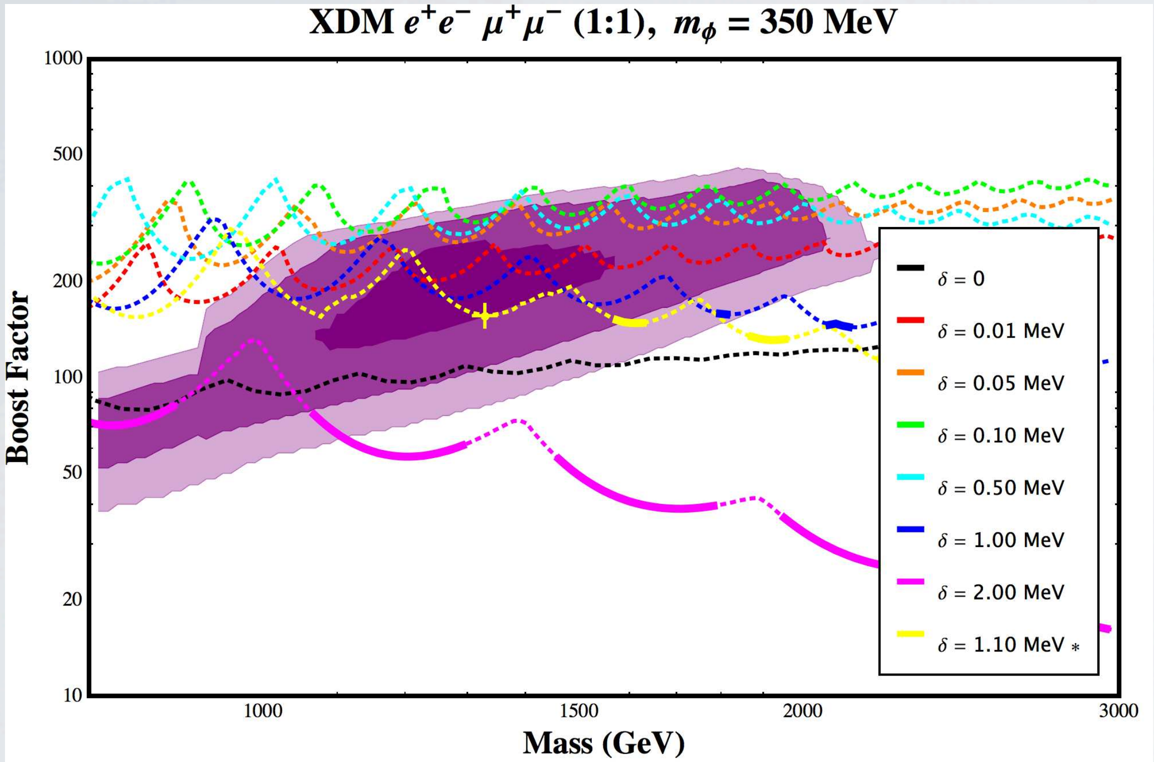
(Finkbeiner, NW, arxiv 0702587v2; Cholis, Goodenough, NW arxiv 0802.2922)

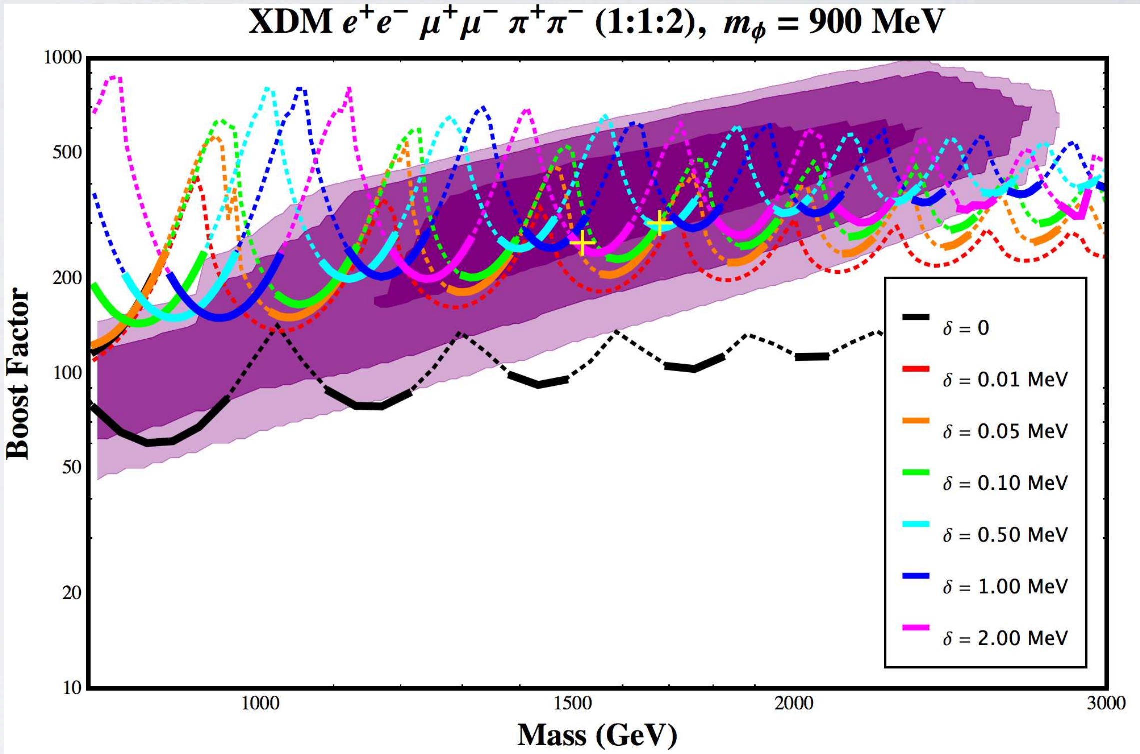
Large cross section from Sommerfeld enhancement

Hisano, Nojiri, Matsumoto ’04; Cirelli+Strumia ’08; Arkani-Hamed et al ’08; Pospelov+Ritz ’08

(also possible: Breit-Wigner enhancement Ibe, Murayama, Yanagida ’08)

COSMIC RAYS: PAMELA/FERMI

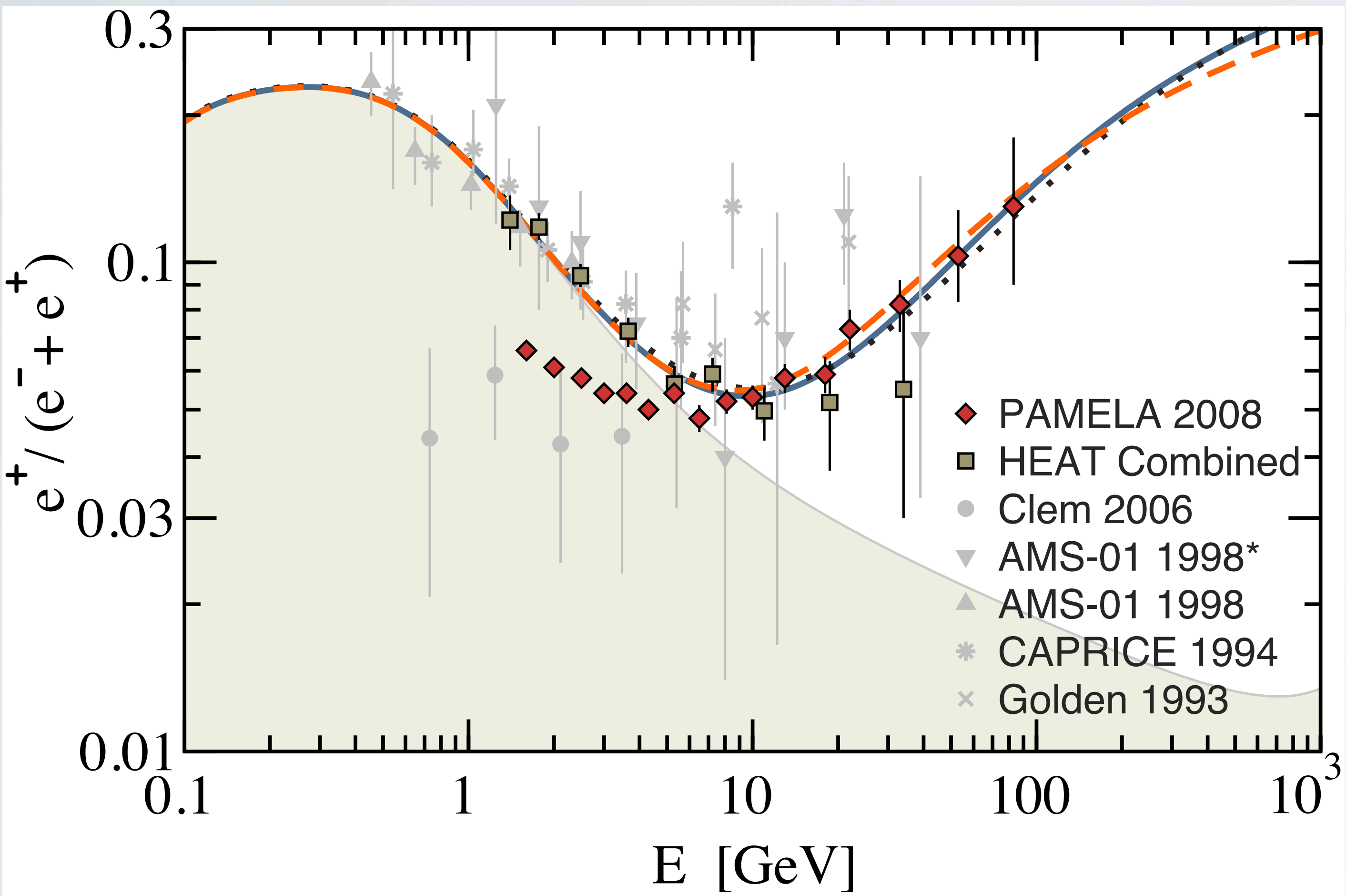




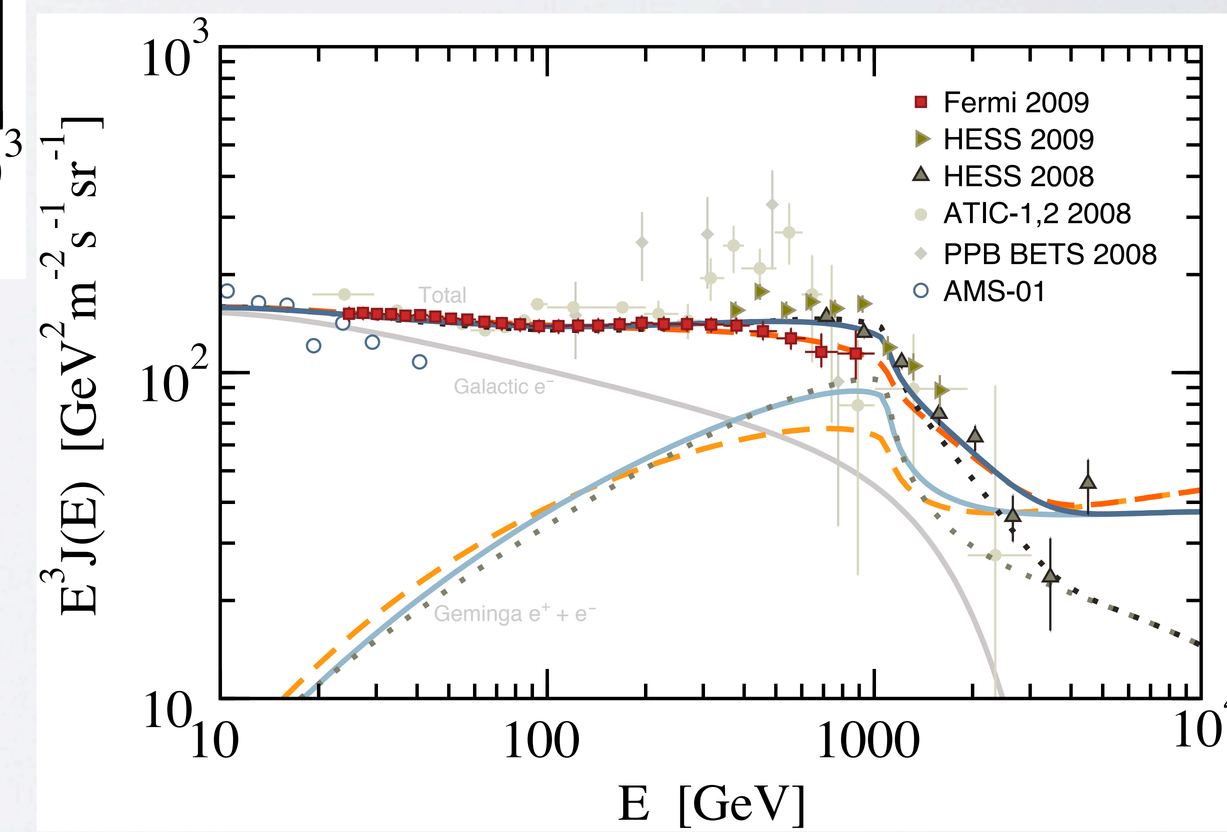
Finkbeiner et al, arxiv1011.3082

- Provides a consistent and testable DM interpretation
- But is it DM?

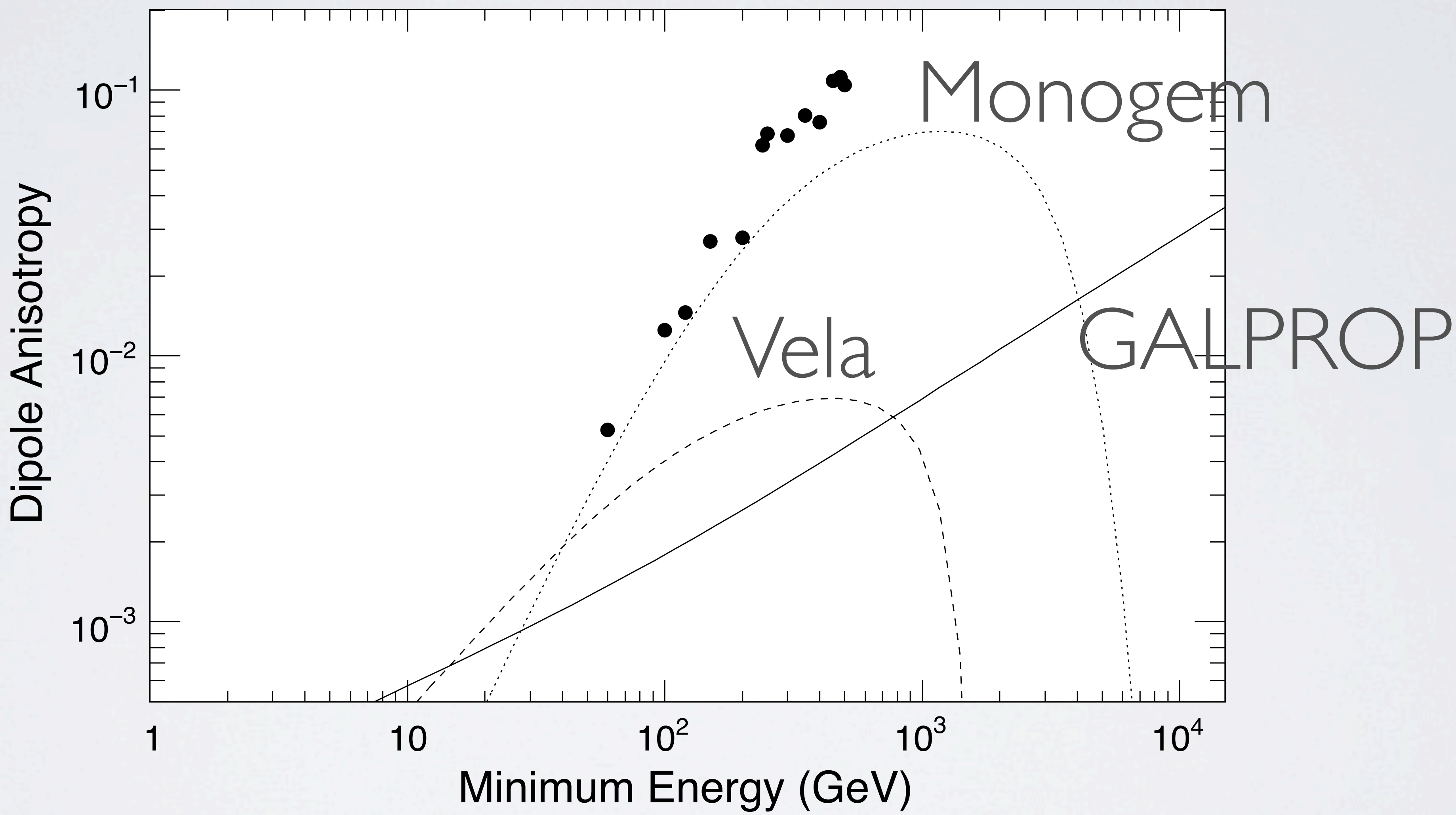
PULSARS



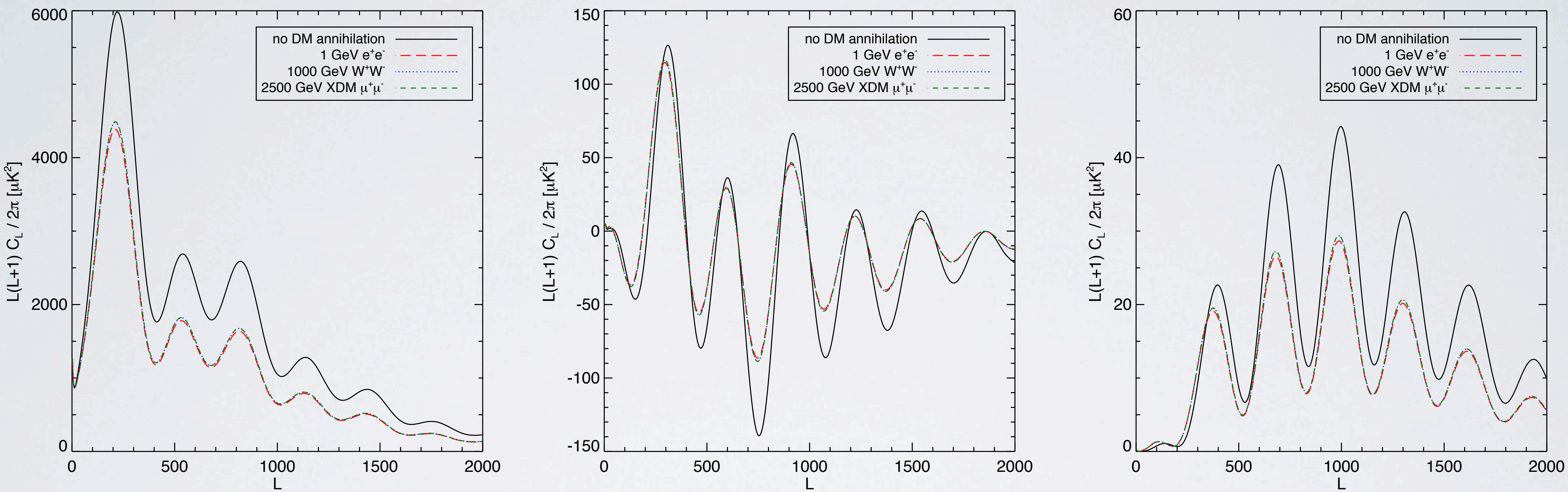
e.g. Yüksel, Kistler, Stanev '09



NO ANISOTROPY (YET)



A RESOLUTION IN 2013?

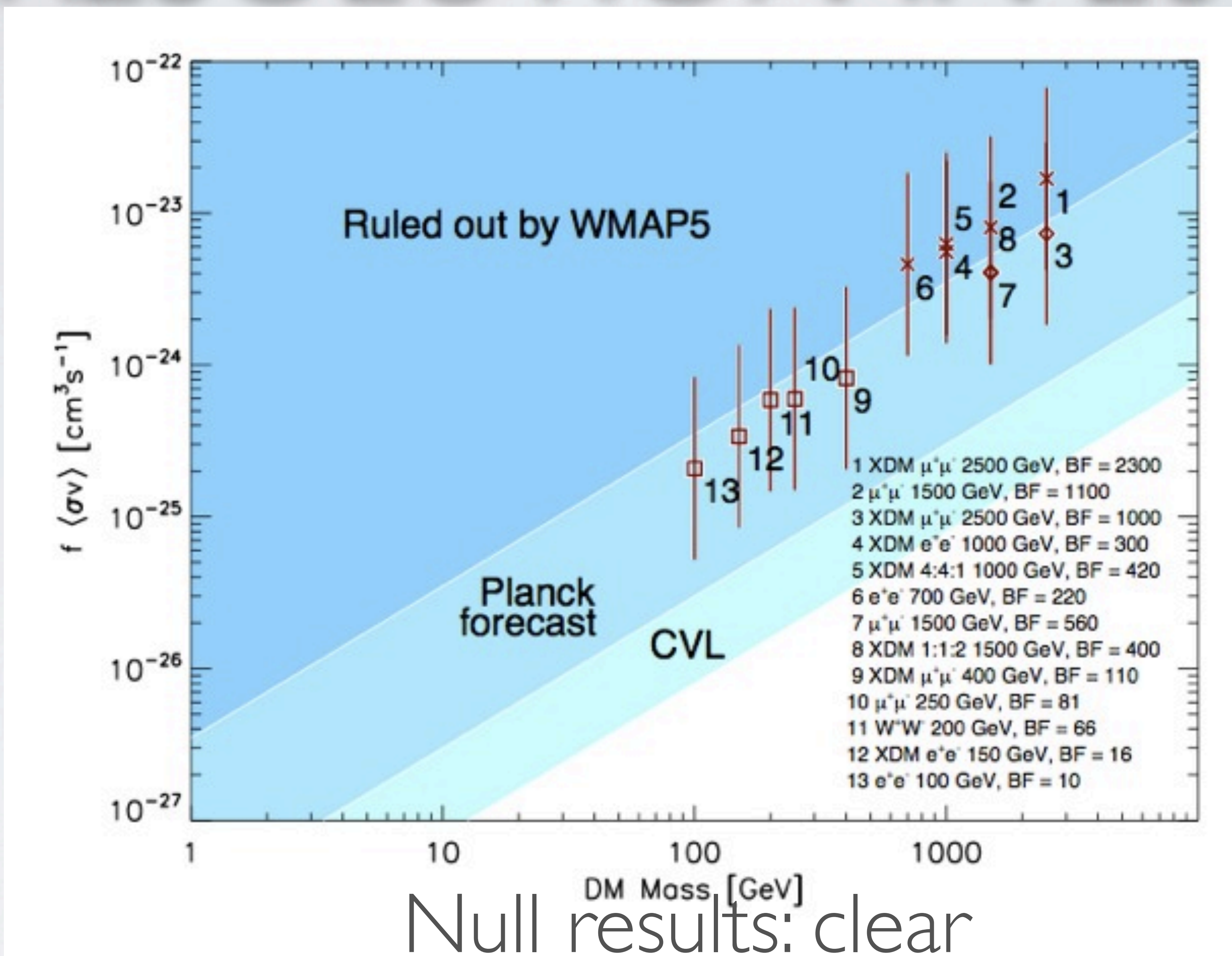


Null results: clear

Positive results?

Finkbeiner, Padmanabhan '05; Galli, Iocco, Bertone, Melchiorri '09;
Slatyer, Padmanabhan, Finkbeiner, '09

A RESOLUTION IN 2013?



Null results: clear

Positive results?

Finkbeiner, Padmanabhan '05; Galli, Iocco, Bertone, Melchiorri '09;
Slatyer, Padmanabhan, Finkbeiner, '09

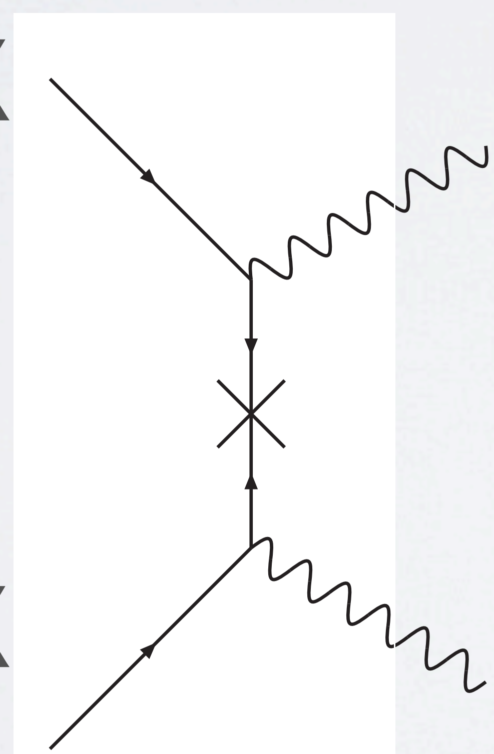
WHAT WOULD DO IT?

- Suppose the PAMELA signal *is* from dark matter
- No anisotropy detected for any pulsar away from the GC
- Polarization signal in CMB consistent w/ DM
- Is that enough?

NB: Also decaying models

COSMIC RAYS: PAMELA/FERMI

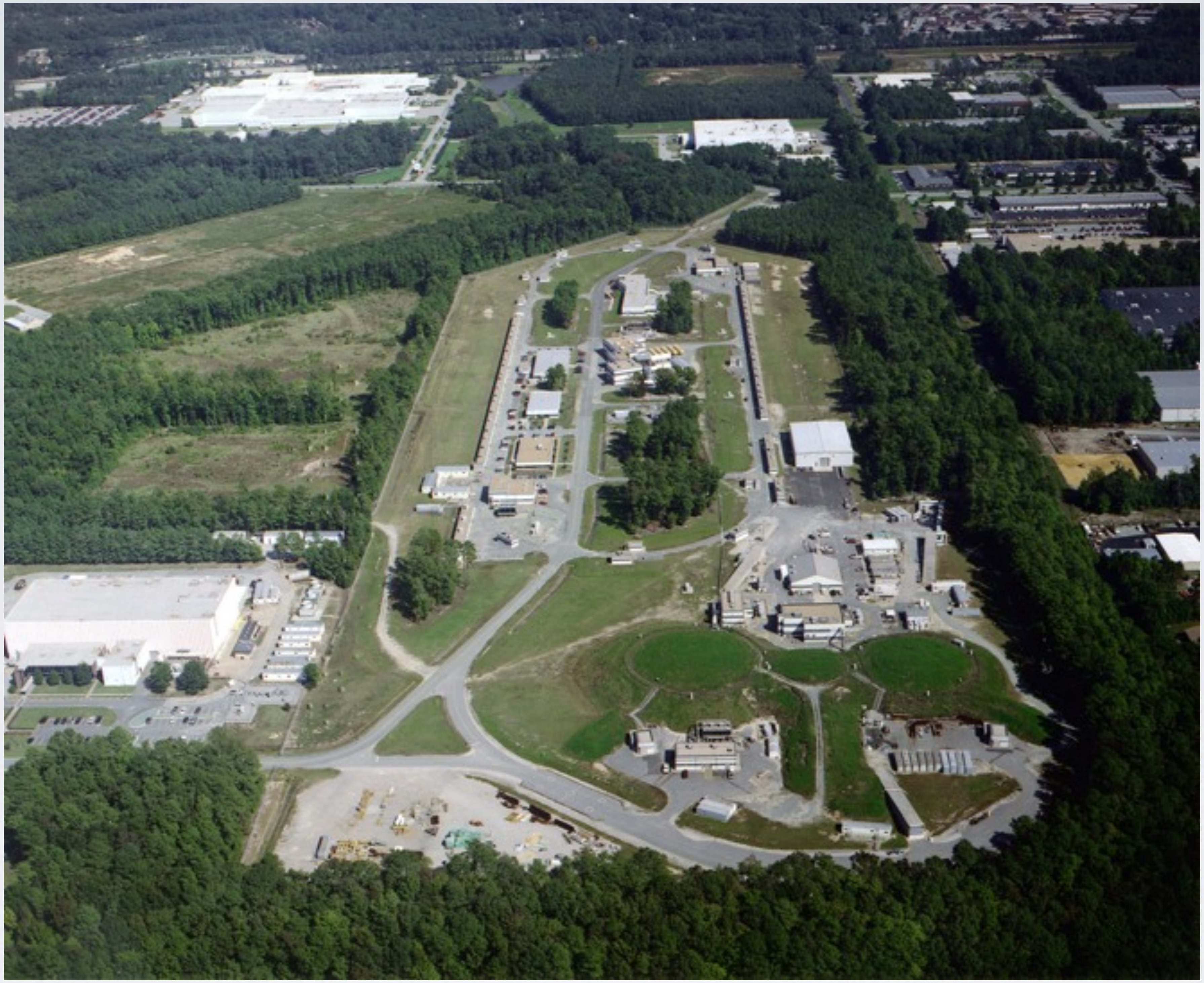
- Motivates sub-GeV dark photon (determined by spectrum of positrons); typically 10 MeV < $m_{A'}$ < ~GeV



doesn't depend on α'

SEARCHES AT LOW ENERGY

- Very weakly coupled, ~ GeV mass state
- LHC/Tevatron not the best place to make it



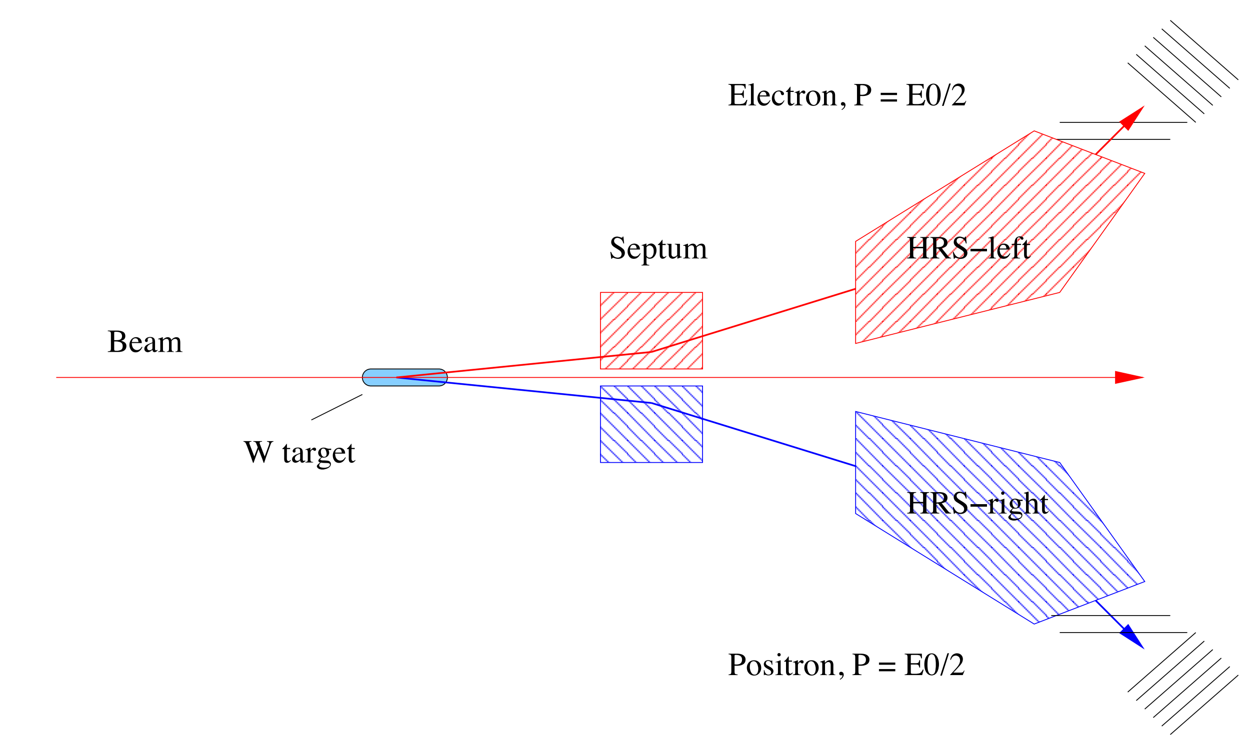
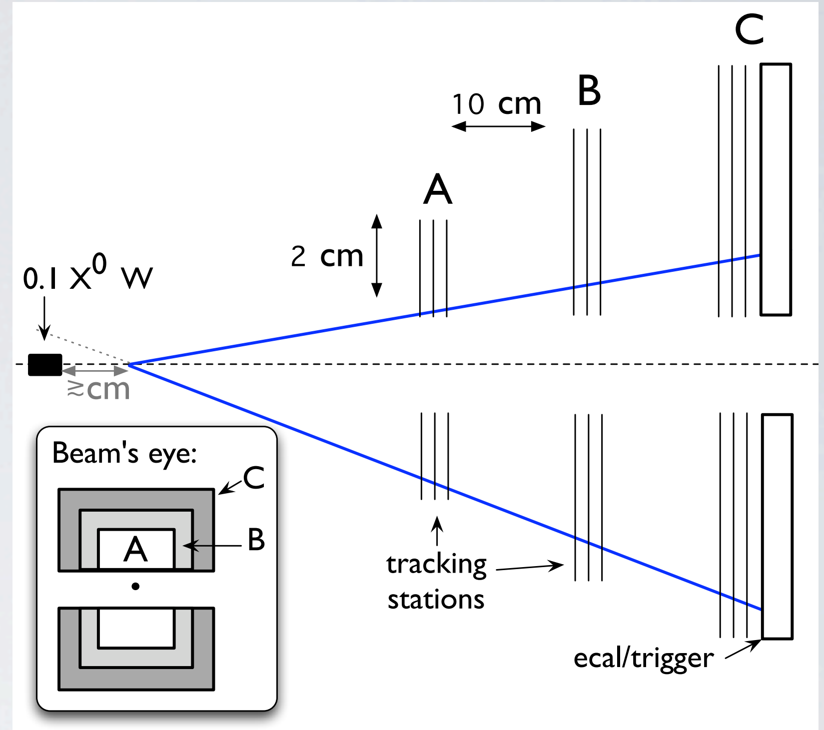
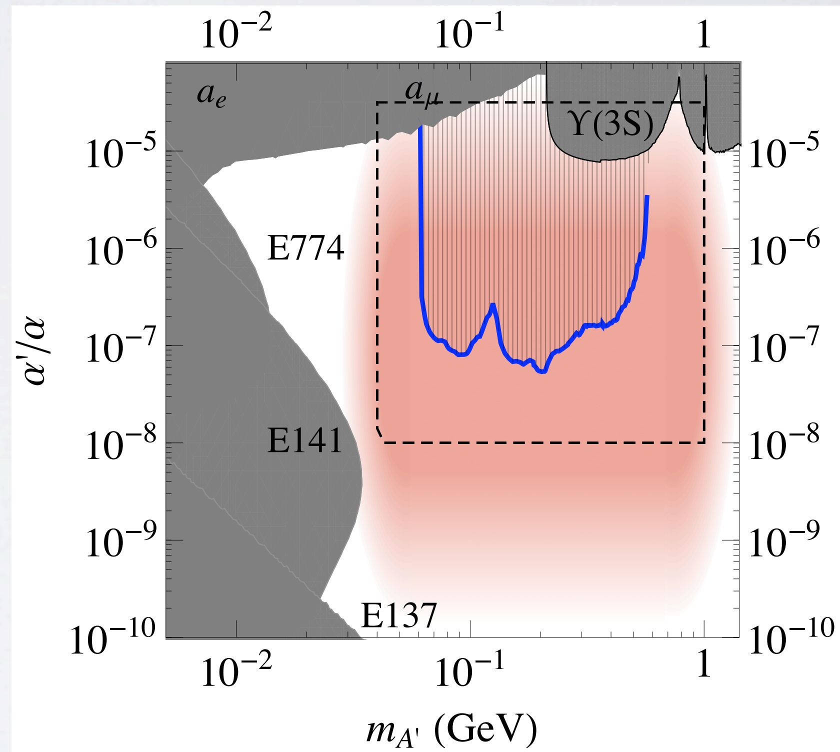


FIG. 5: The layout of the experimental setup — see text for details.

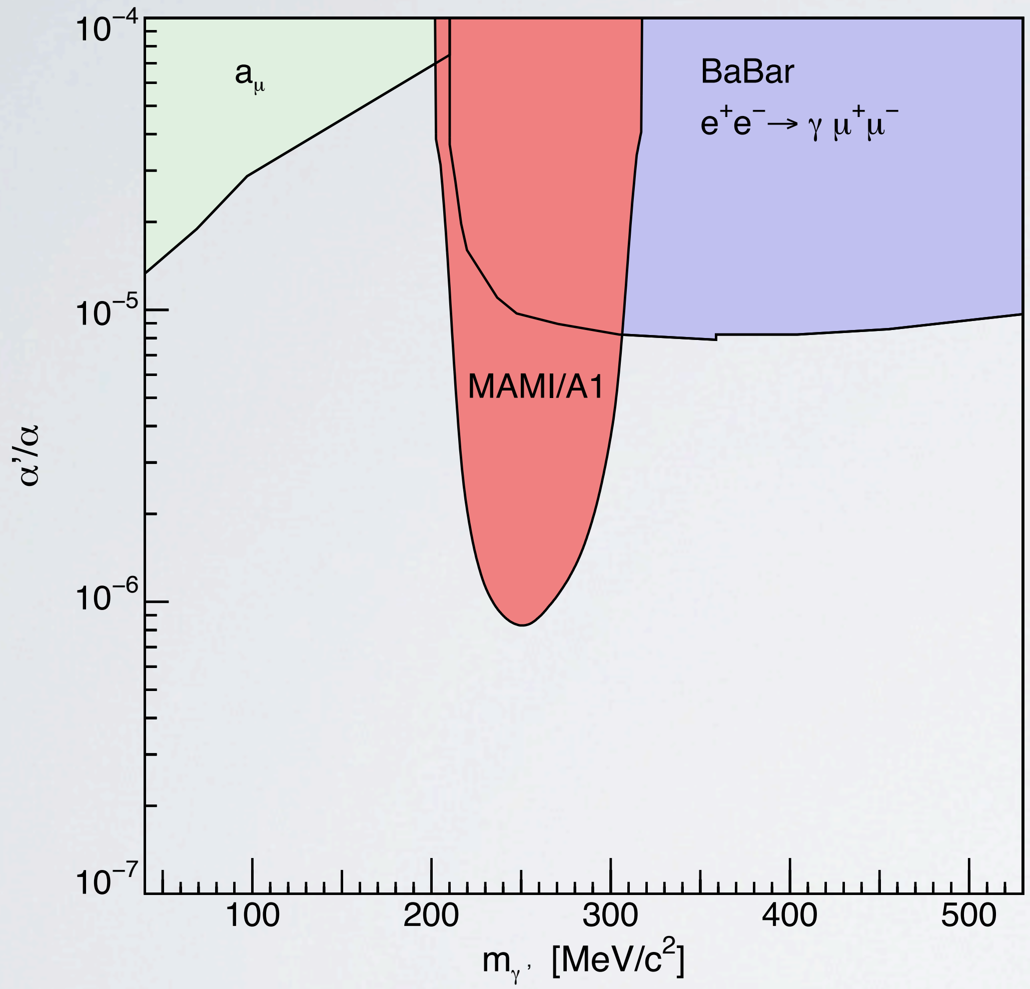


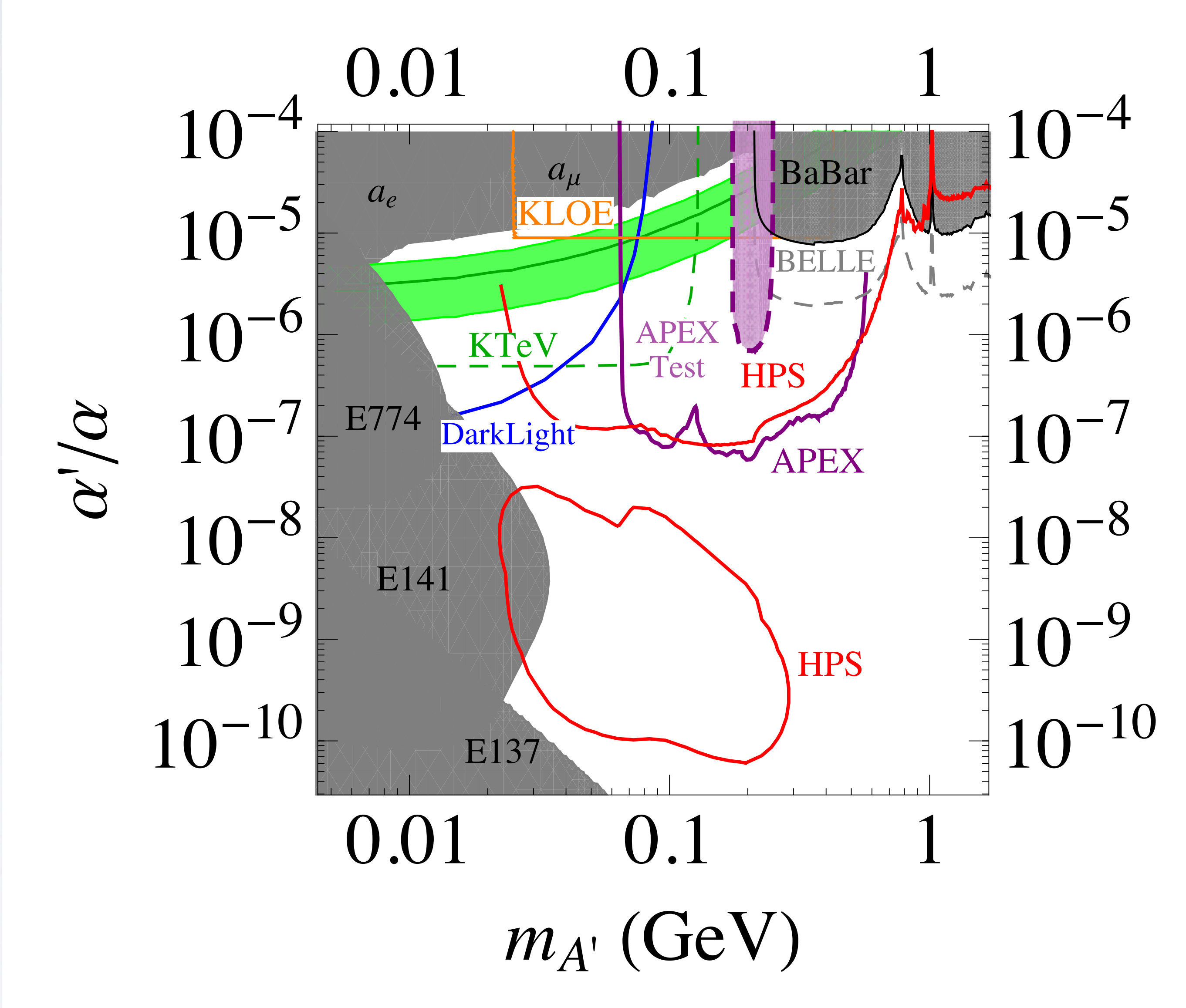


Bjorken, Essig, Schuster, Toro

APEX, HPS, Darklight... - searches for new physics at the **<GeV** scale

First results from MAMI

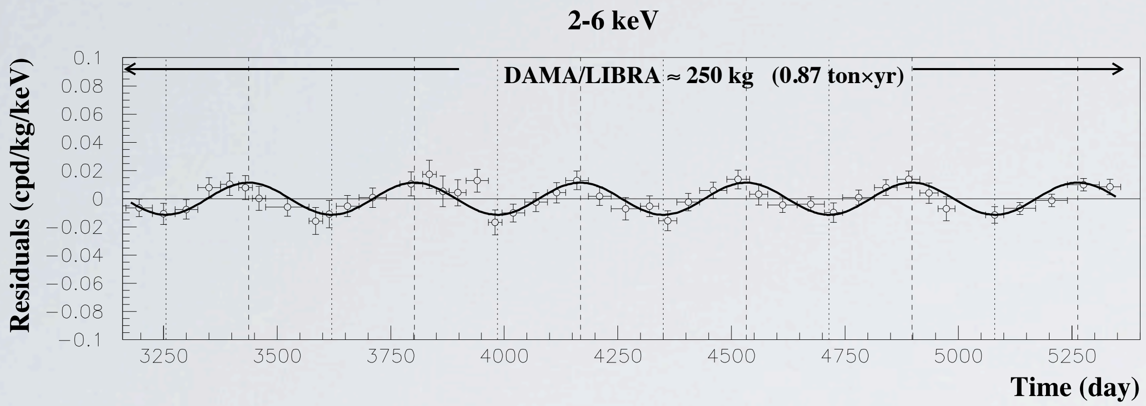




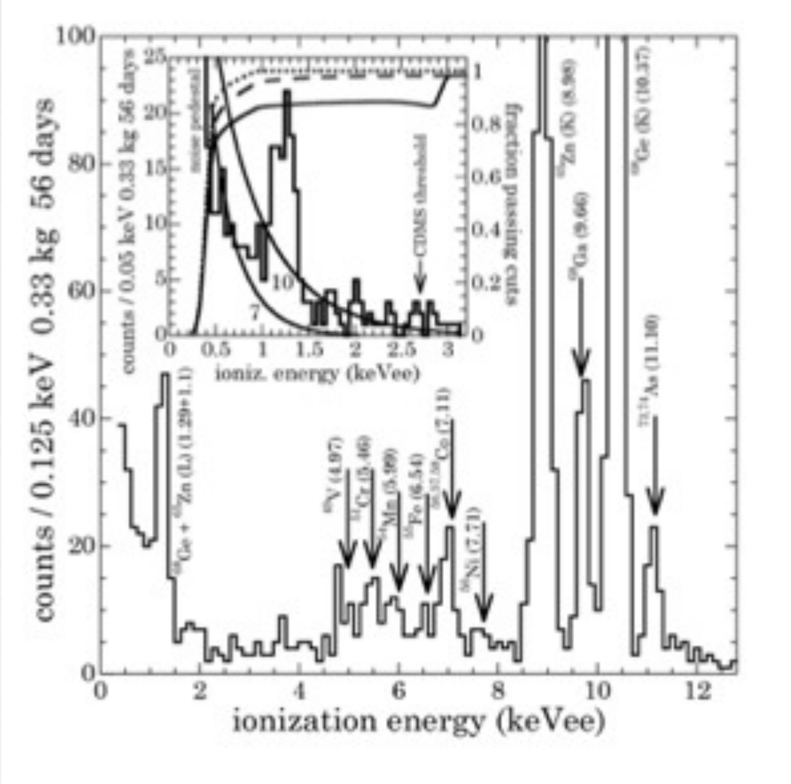
JLAB reach

ARE ANY OF THE DIRECT DETECTION "HINTS" ACTUALLY HINTS?

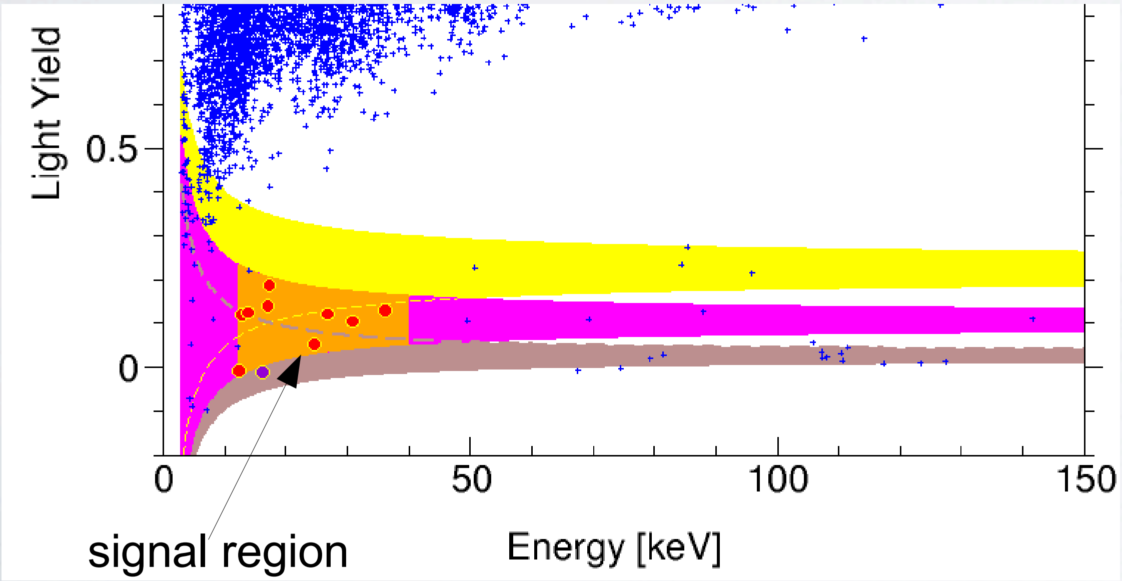
HINTS?



DAMA

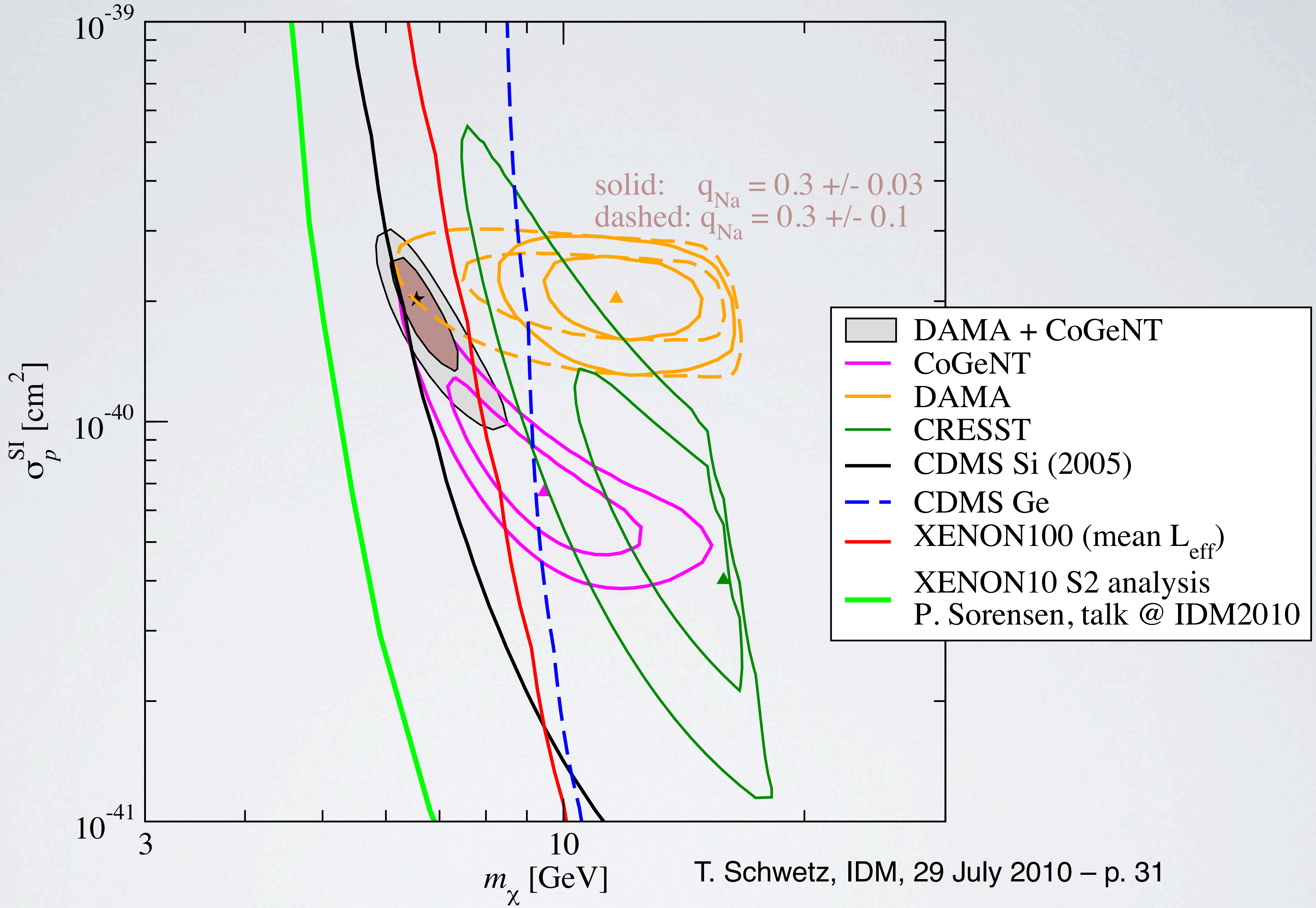


CoGeNT



CRESST

- The same beast?

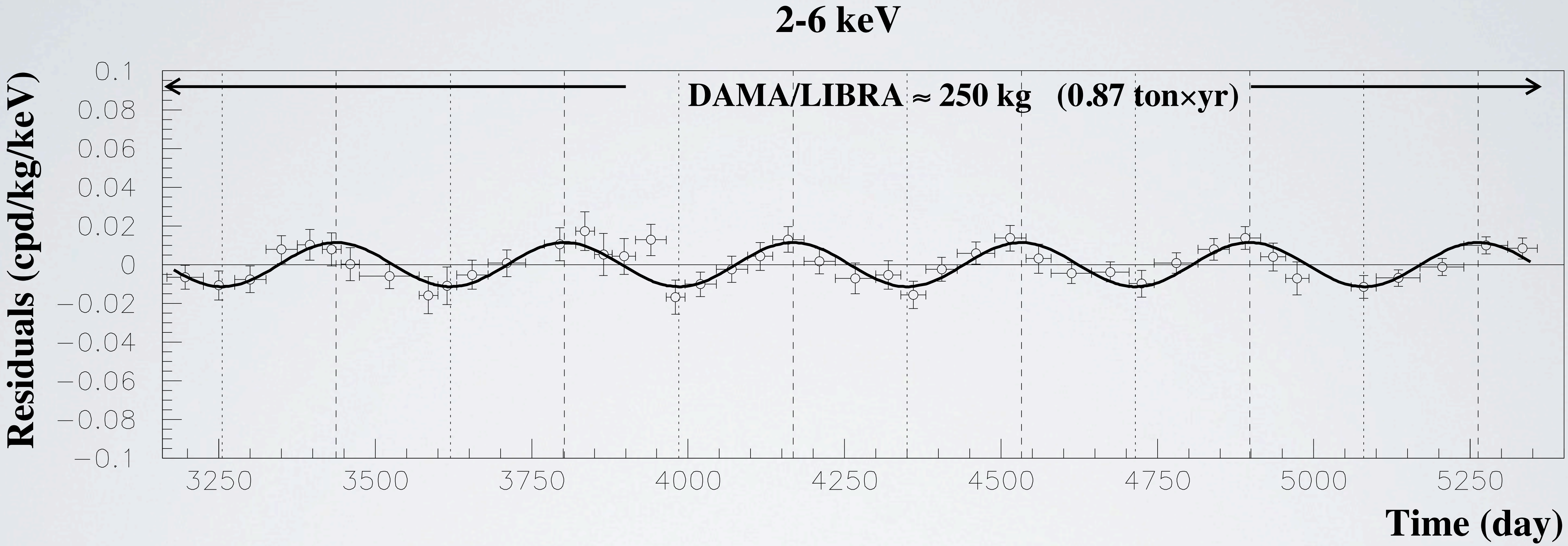


T. Schwetz, IDM, 29 July 2010 – p. 31

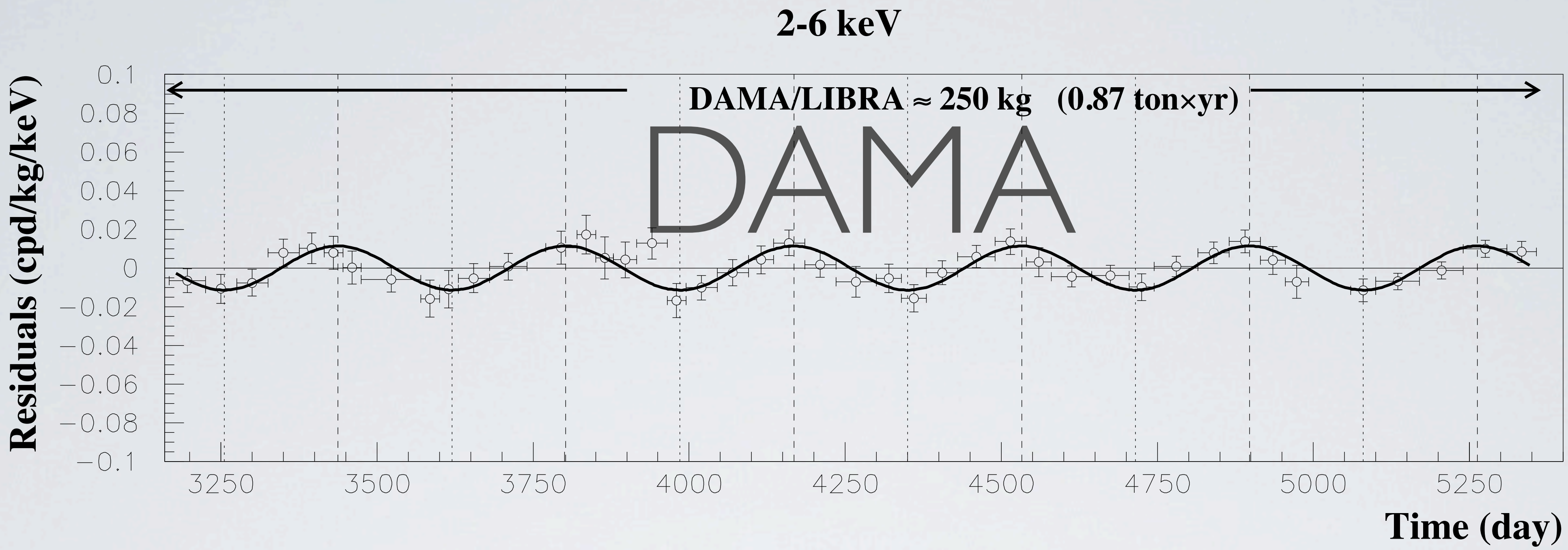
don't *really* line up, but within spitting distance

NB: *Not* MSSM (Kuflick, Pierce, Zurek '10)

DAMA

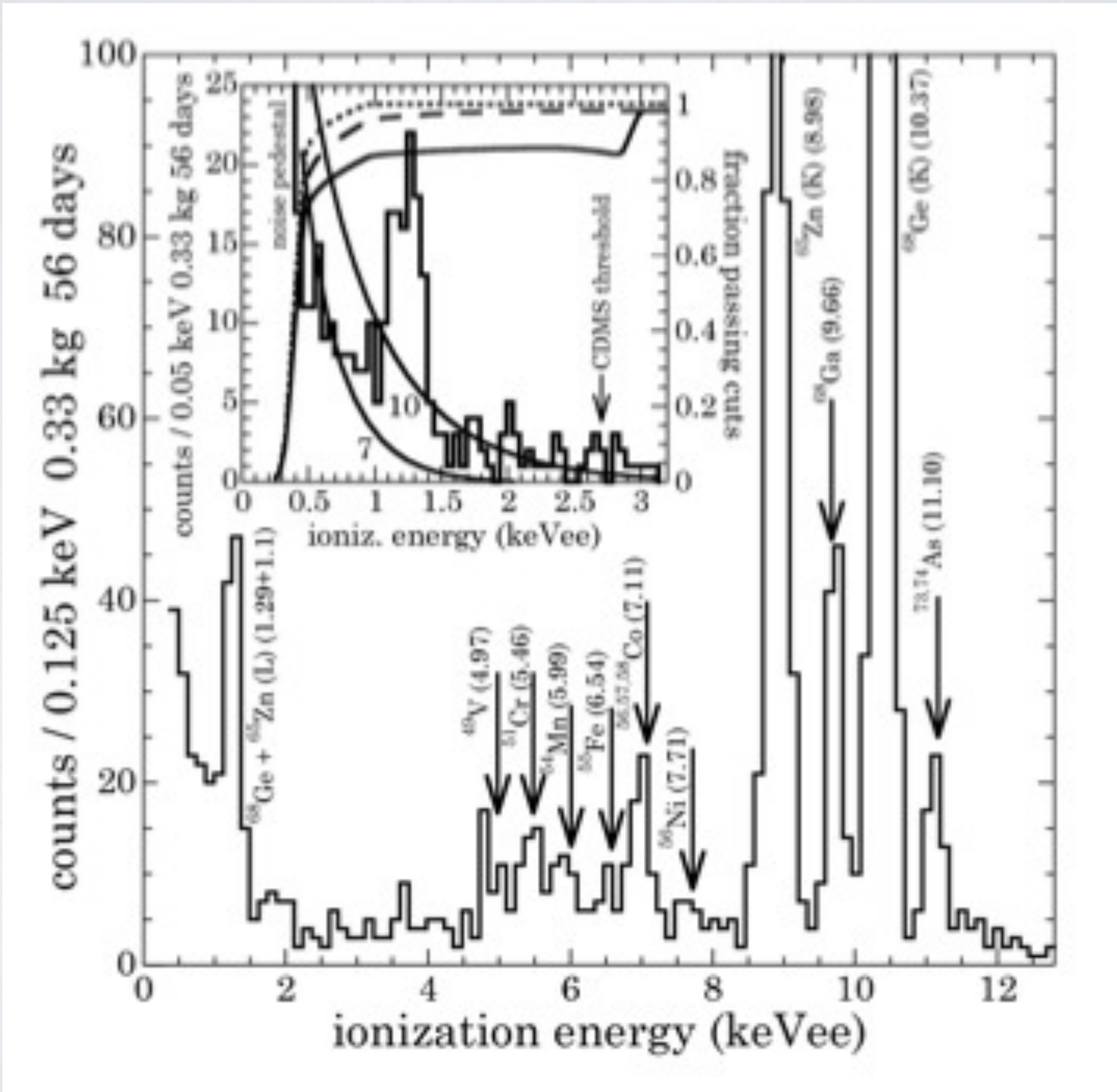

2-6 keV
DAMA/LIBRA ≈ 250 kg (0.87 ton×yr)
Residuals (cpd/kg/keV)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
3250
3500
3750
4000
4250
4500
4750
5000
5250
Time (day)

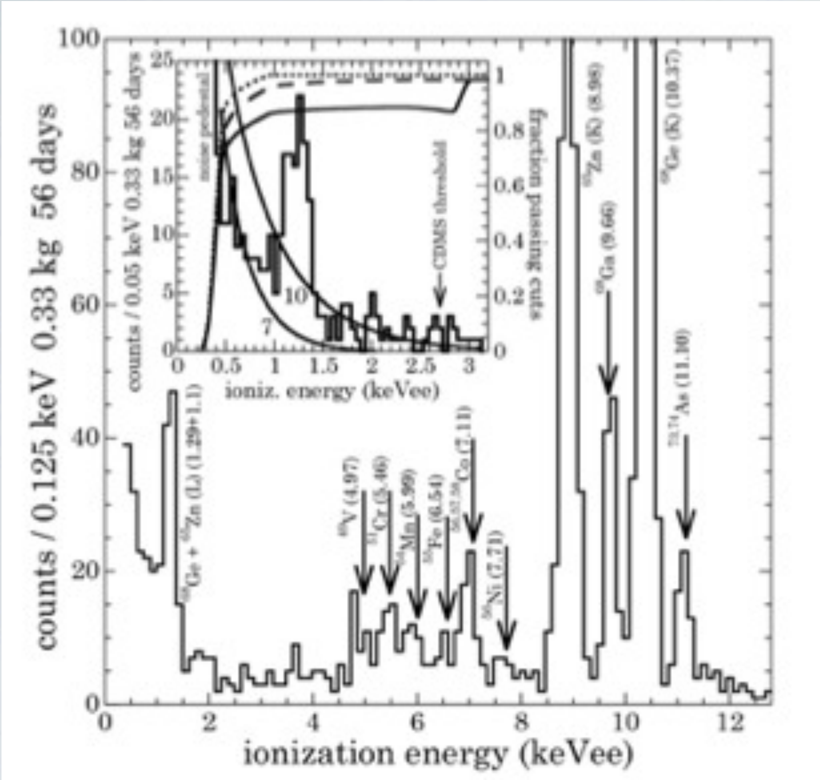
DAMA



- What is it: annual modulation in scintillation events in 100/250 kg NaI(Tl) crystal - DM?
- What's to like: single hit, stable phase, low energy, no candidate "conventional" explanations
- What's not to like: null results from other exps, data are still unavailable, no event discrimination

COGENT

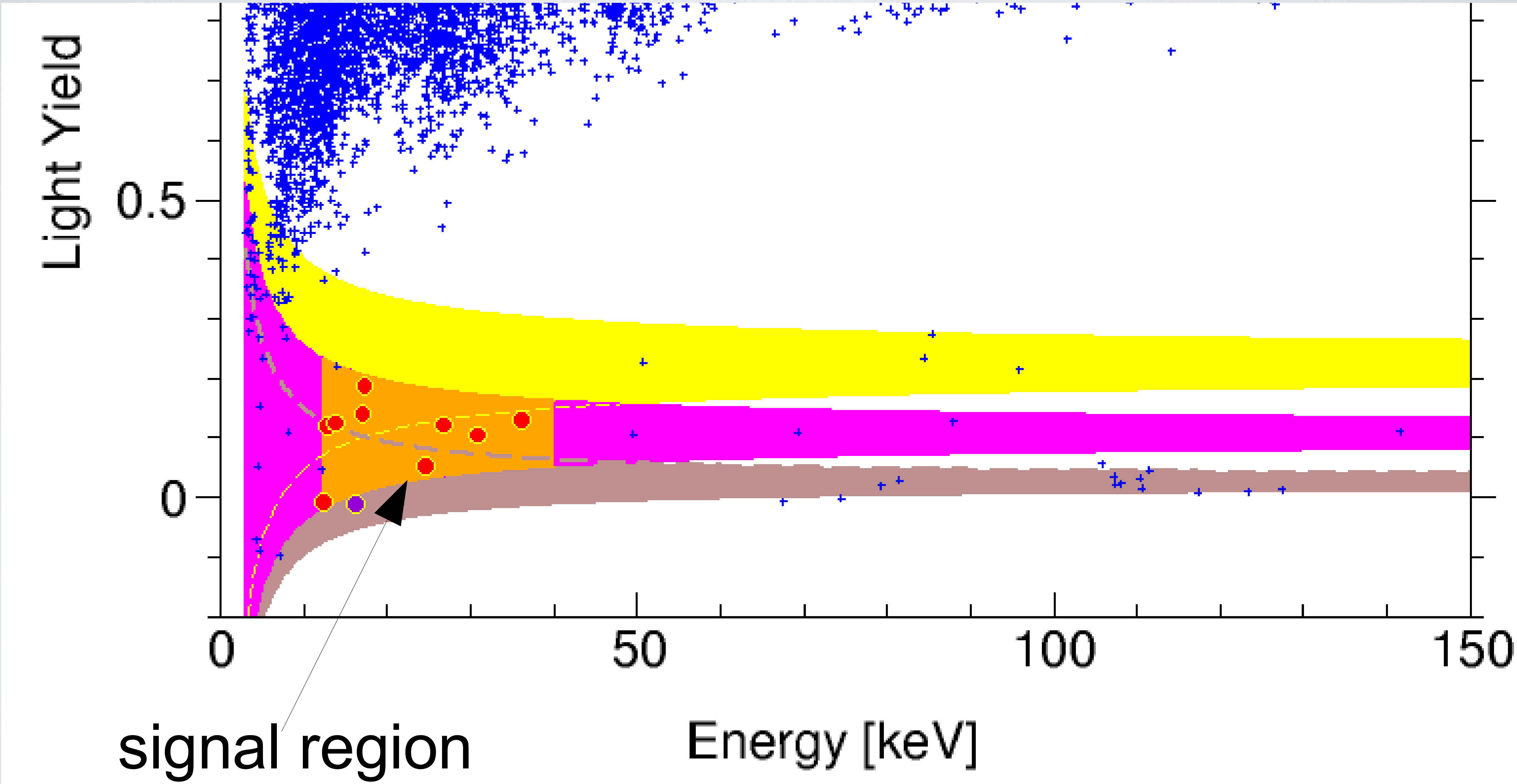

counts / 0.125 keV 0.33 kg 56 days
ionization energy (keVee)
counts / 0.05 keV 0.33 kg 56 days
fraction passing cuts
ioniz. energy (keVee)
noise pedestal
CDMS threshold
10
7
^{68}Ge + ^{65}Zn (L) (1.29+1.1)
^{49}V (4.97)
^{51}Cr (5.46)
^{54}Mn (5.99)
^{55}Fe (6.54)
^{56,57,58}Co (7.11)
^{56}Ni (7.71)
^{65}Zn (K) (8.98)
^{68}Ga (9.66)
^{68}Ge (K) (10.37)
^{73,74}As (11.10)

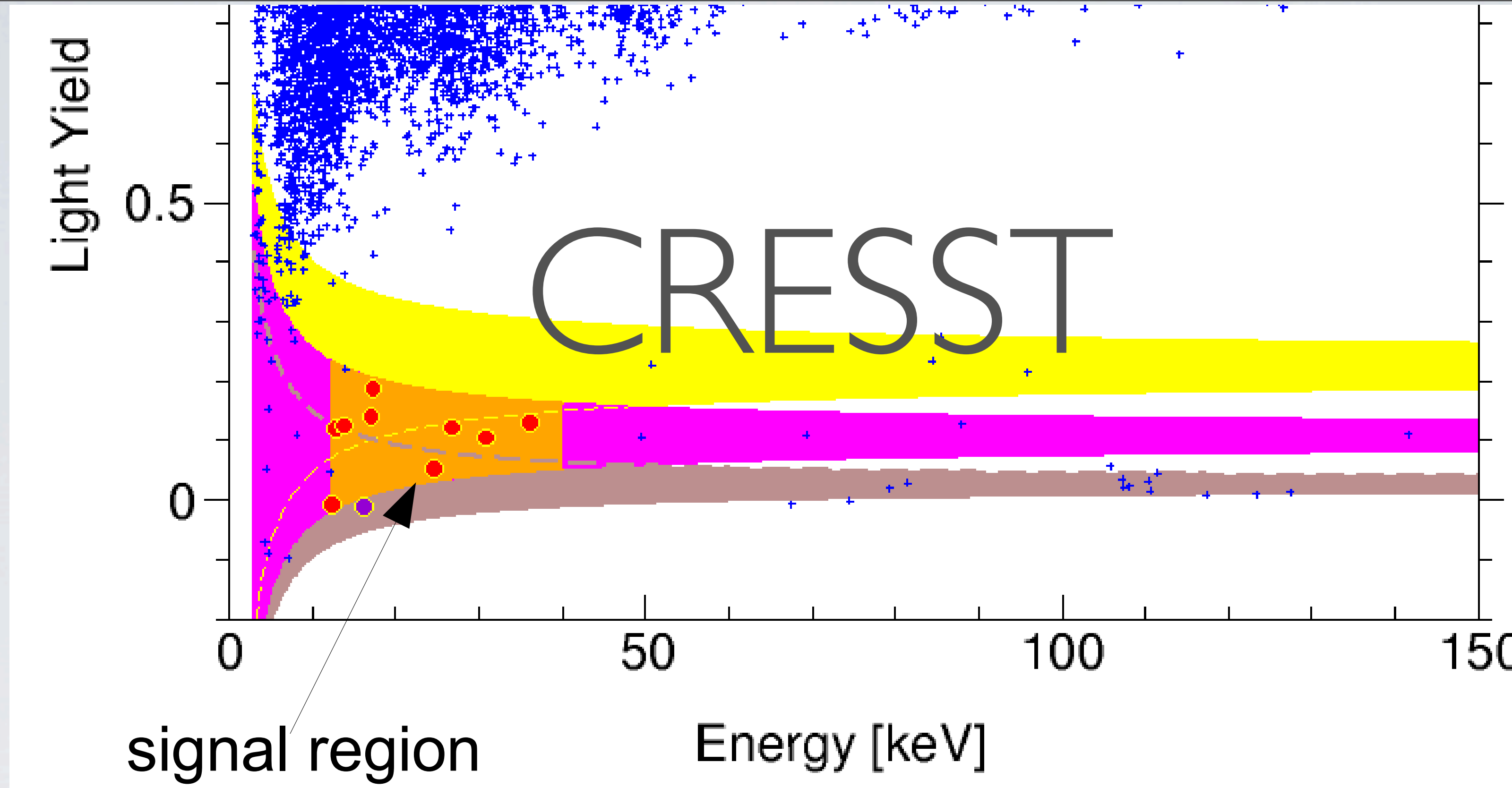


COGENT

- What is it: events in an ionization experiment, x10 larger than expected background - DM?
- What's to like: excellent energy resolution/calibration, good statistics
- What's not to like: no discrimination, hasn't been mercilessly beaten for a decade, no corroborating features [yet] (e.g. modulation), null results from other exps

CRESST





- What is it: an excess of events in a $CaWO_4$ detector, consistent with Oxygen scattering (~10-40 keV)

- What's to like: good discrimination vs electron recoil, not muon induced neutrons

- What's not to like: lots of events at high (15 keV+ energy, should have been seen elsewhere), signal lies left, right, above and below clear background sources, still have only seen 2 of 9 detectors, naively low energy looks too clean to be WIMP

THE CONTROVERSY

3) **Comments on arXiv:1006.0972 'XENON10/100 dark matter constraints in comparison with CoGeNT and DAMA: examining th**
J.I. Collar, . Jun 2010. 2pp. Temporary entry
e-Print: **arXiv:1006.2031** [astro-ph.CO]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 10 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

4) **Response to arXiv:1005.2615.**
J.I. Collar, D.N. McKinsey, . May 2010. Temporary entry
e-Print: **arXiv:1005.3723** [astro-ph.CO]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Cited 15 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

5) **Reply to the Comments on the XENON100 First Dark Matter Results.**
The XENON100 Collaboration, . May 2010. Temporary entry
e-Print: **arXiv:1005.2615** [astro-ph.CO]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 14 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

6) **Comments on 'First Dark Matter Results from the XENON100 Experiment'.**
J.I. Collar, D.N. McKinsey, . May 2010. Temporary entry
e-Print: **arXiv:1005.0838** [astro-ph.CO]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 22 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

7) **First Dark Matter Results from the XENON100 Experiment.**
By XENON100 Collaboration (E. Aprile *et al.*). May 2010. (Published Sep 24, 2010). 4pp.
Published in **Phys.Rev.Lett.105:131302,2010**.
e-Print: **arXiv:1005.0380** [astro-ph.CO]

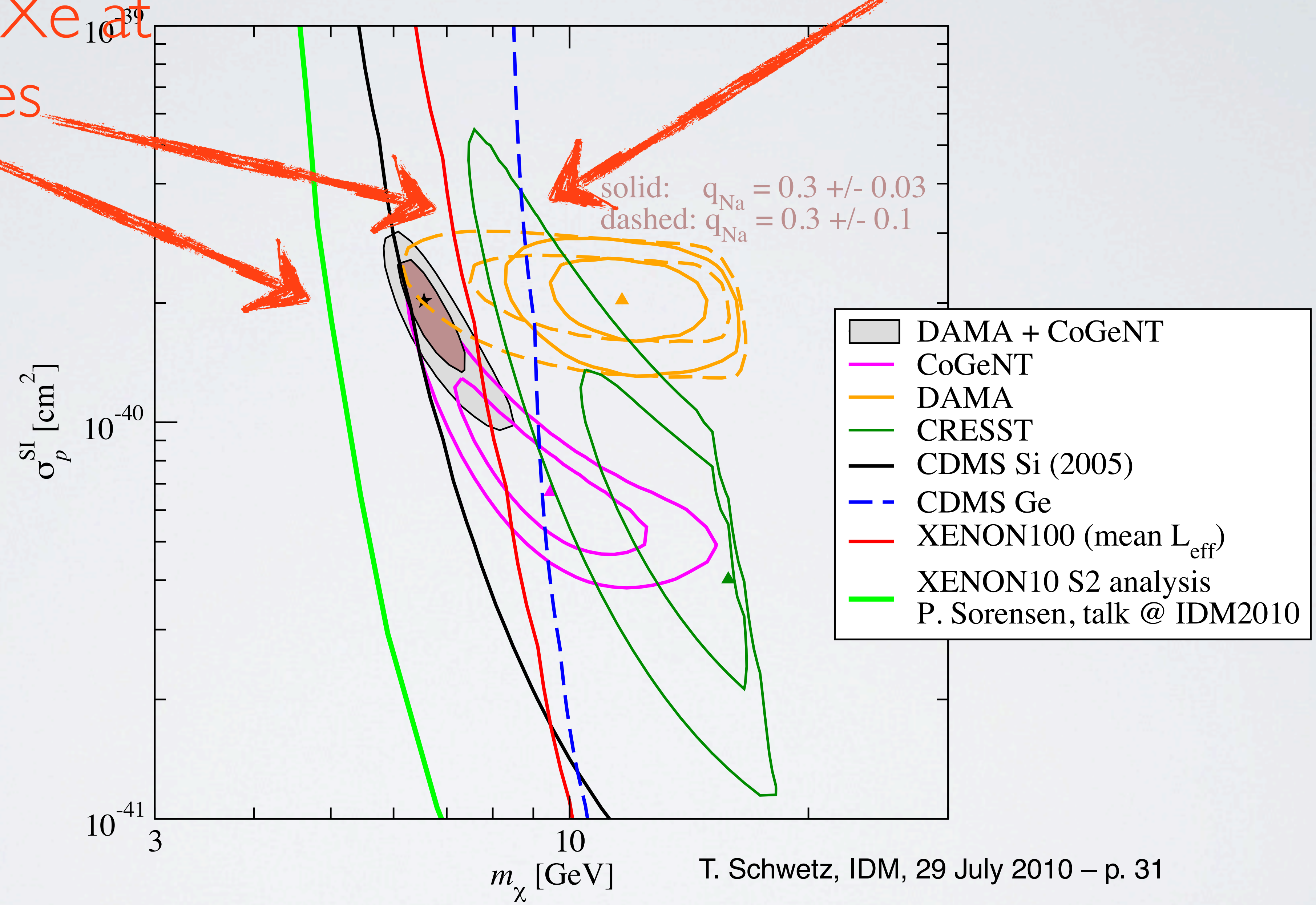
TOPCITE = 50+
References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 103 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Journal Server [doi:10.1103/PhysRevLett.105.131302]
EXP XENON
Bookmarkable link to this information

FIND KEYWORD BIG TIZZY

THE CONTROVERSY

Limits from XENON invoke unmeasured properties of LXe at low energies

DAMA/CoGeNT agreement requires generous assumptions about QNa



T. Schwetz, IDM, 29 July 2010 – p. 31

INTEGRATING OUT ASTROPHYSICS

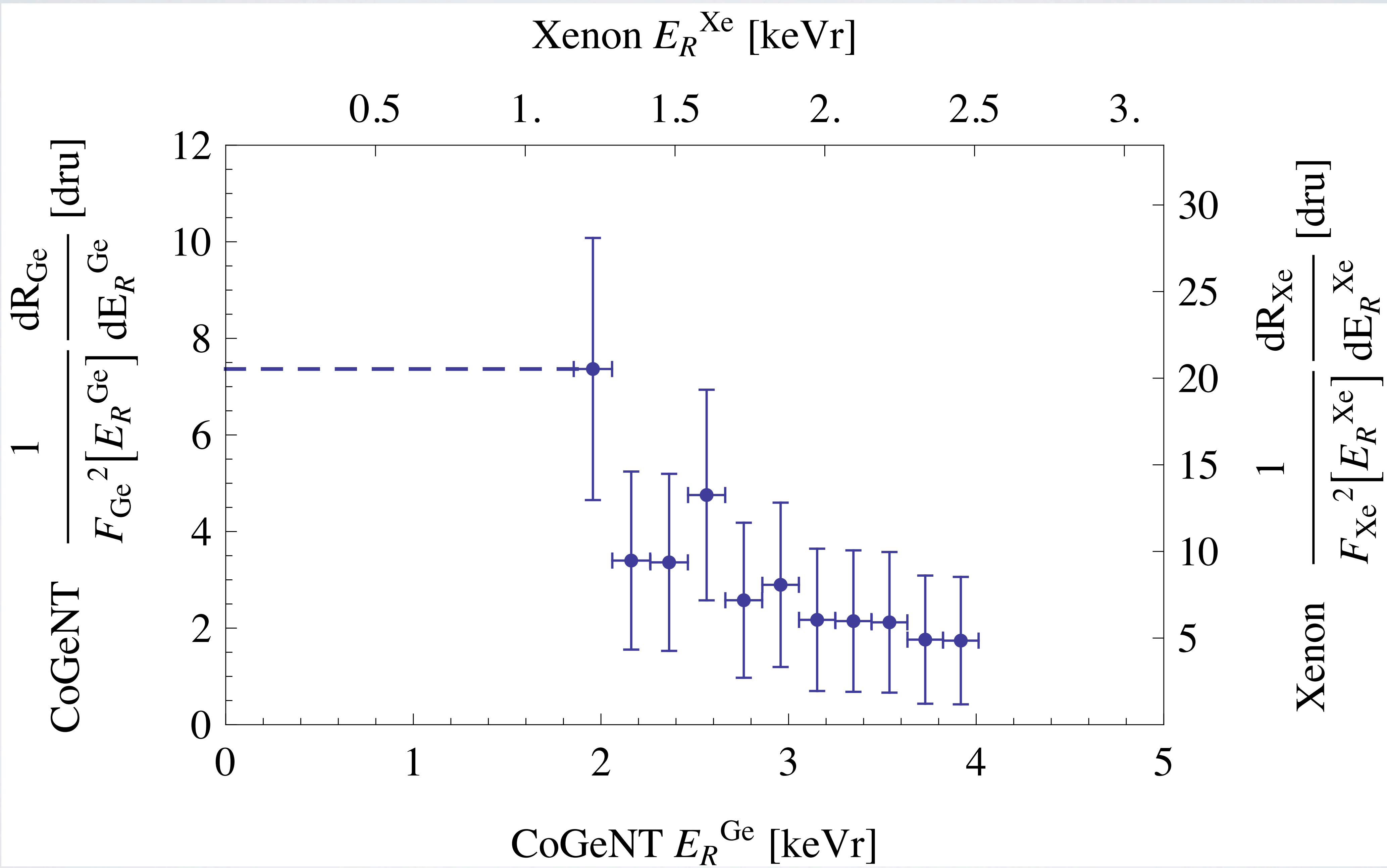
$$\frac{dR}{dE_R} = \frac{N_T M_T \rho}{2 m_\chi \mu^2} \sigma(E_R)\, g(v_{min}) \longrightarrow g(v) = \frac{2 m_\chi \mu^2}{N_T M_T \rho \sigma(E_R)} \frac{dR_1}{dE_1}$$

$$\frac{dR_2}{dE_R}(E_2) = \frac{C_T^{(2)}}{C_T^{(1)}} \frac{F_2^2(E_2)}{F_1^2\left(\frac{\mu_1^2 M_T^{(2)}}{\mu_2^2 M_T^{(1)}} E_2\right)} \frac{dR_1}{dE_R}\left(\frac{\mu_1^2\, M_T^{(2)}}{\mu_2^2\, M_T^{(1)}} E_2\right)$$

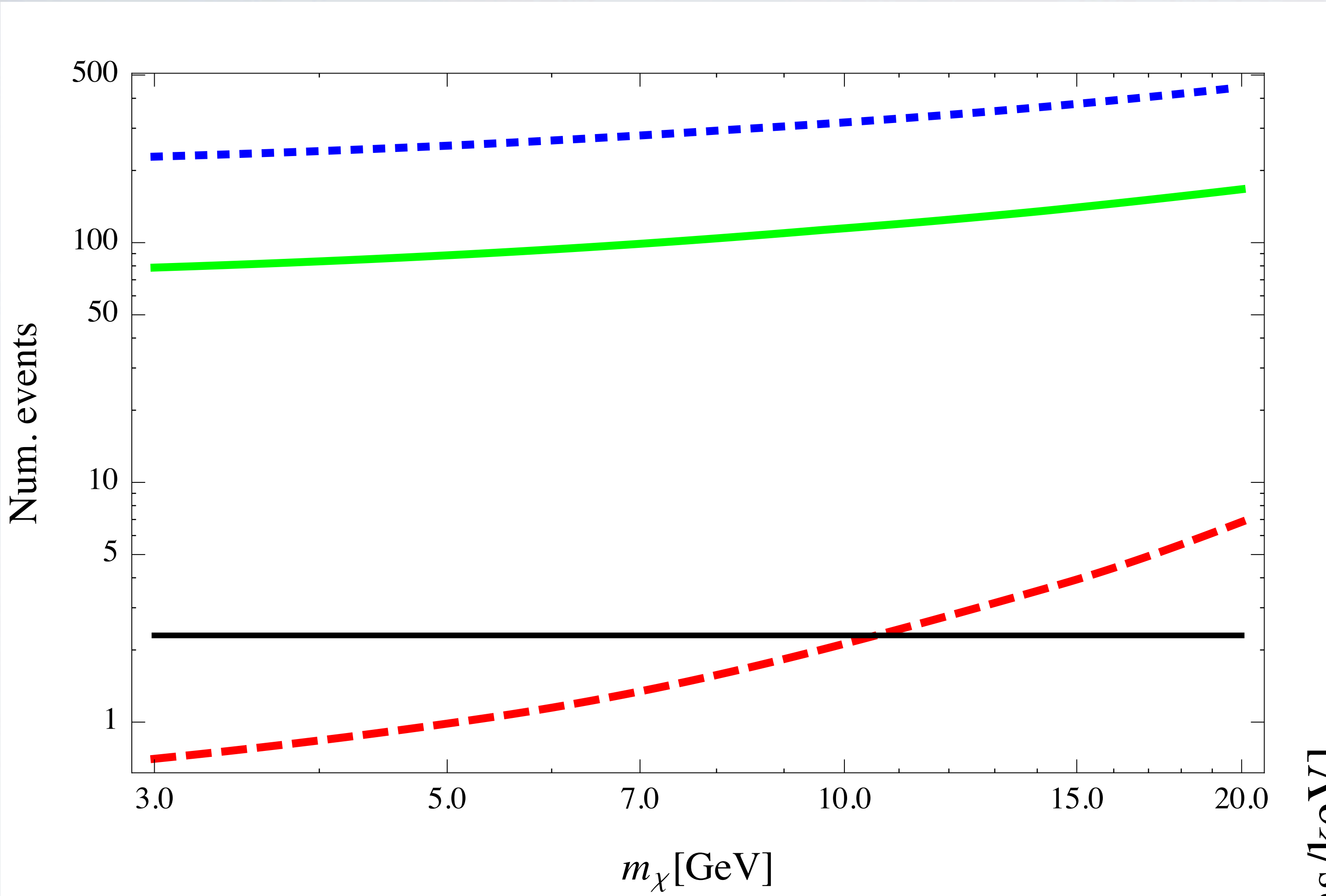
A direct prediction of the rate at experiment 2 from experiment 1

Liu, Fox, NW '10

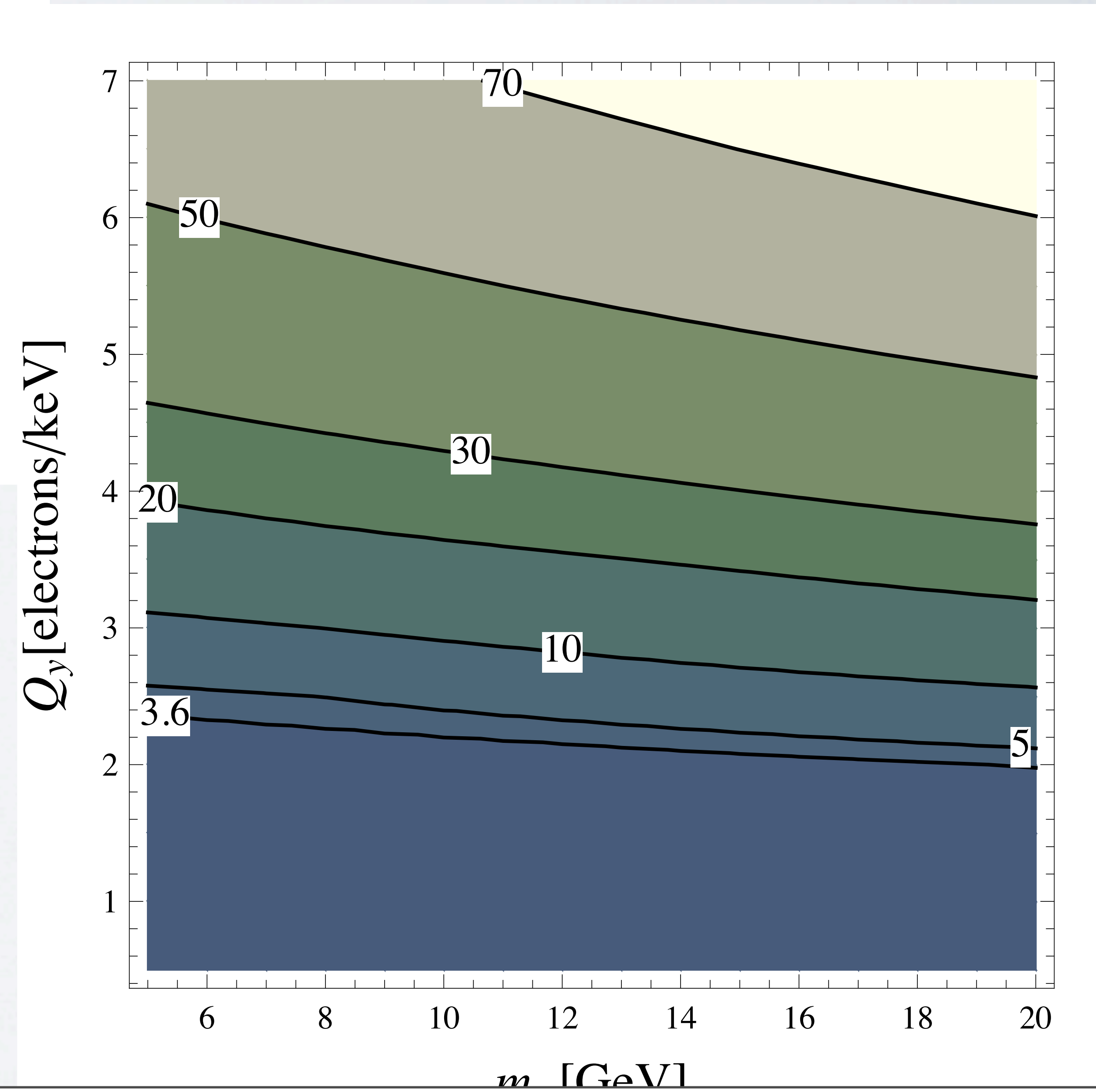
MAPPING RATES



COGENT->XENON

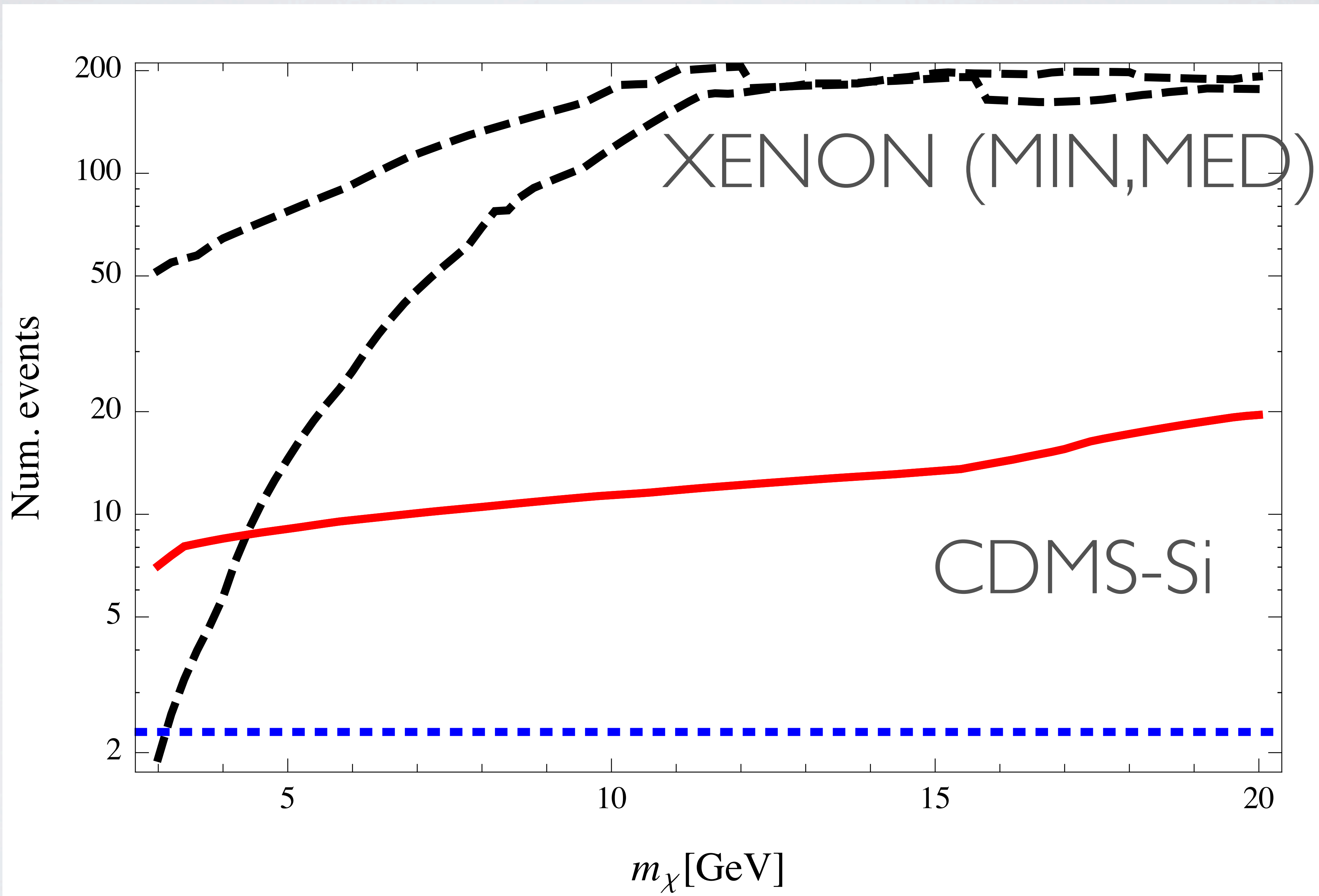


S1+S2

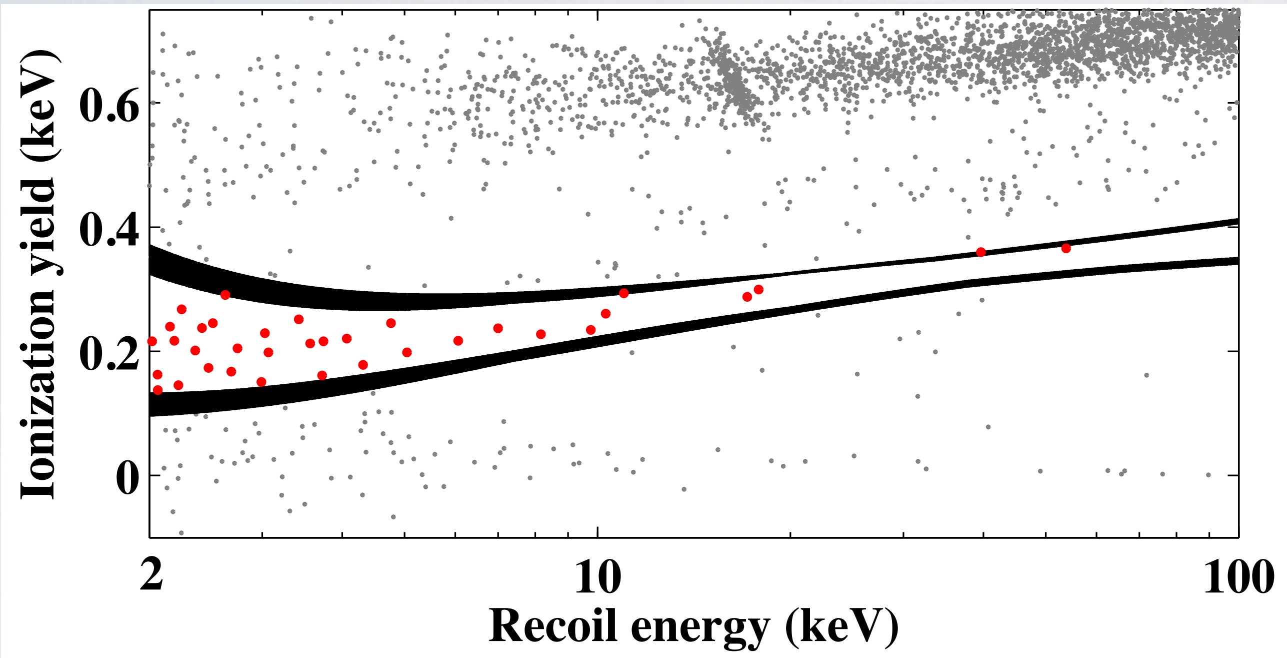


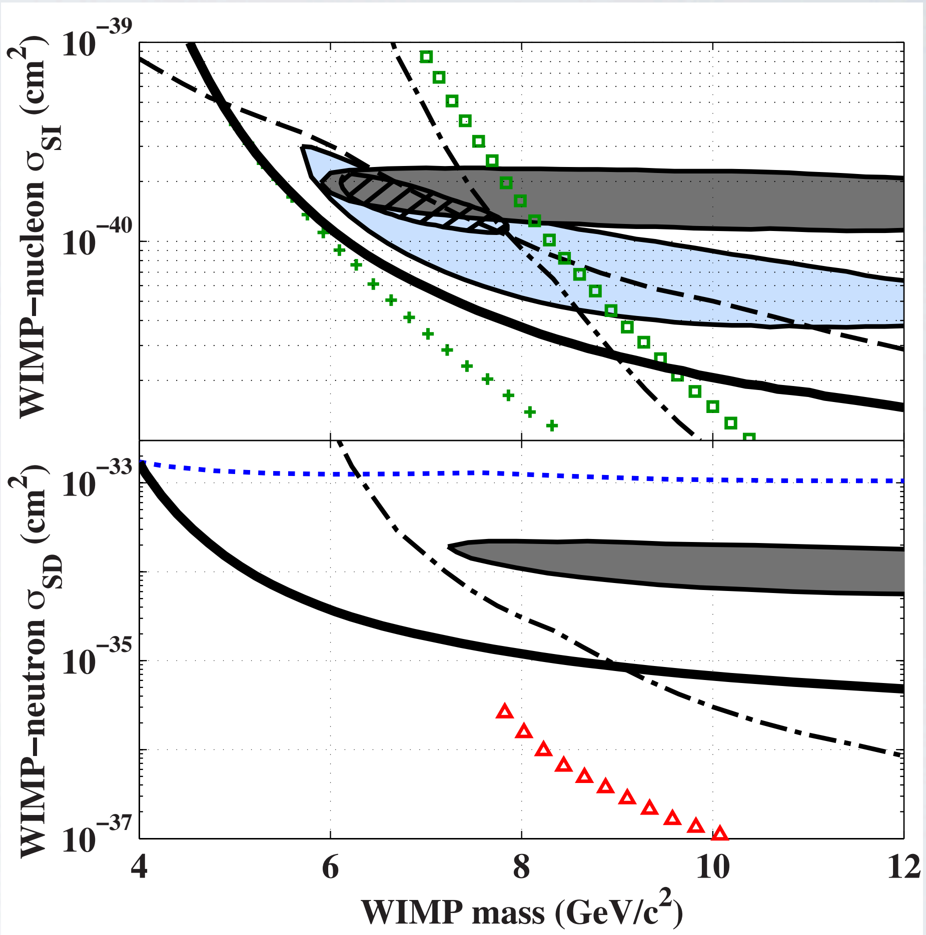
S2 only

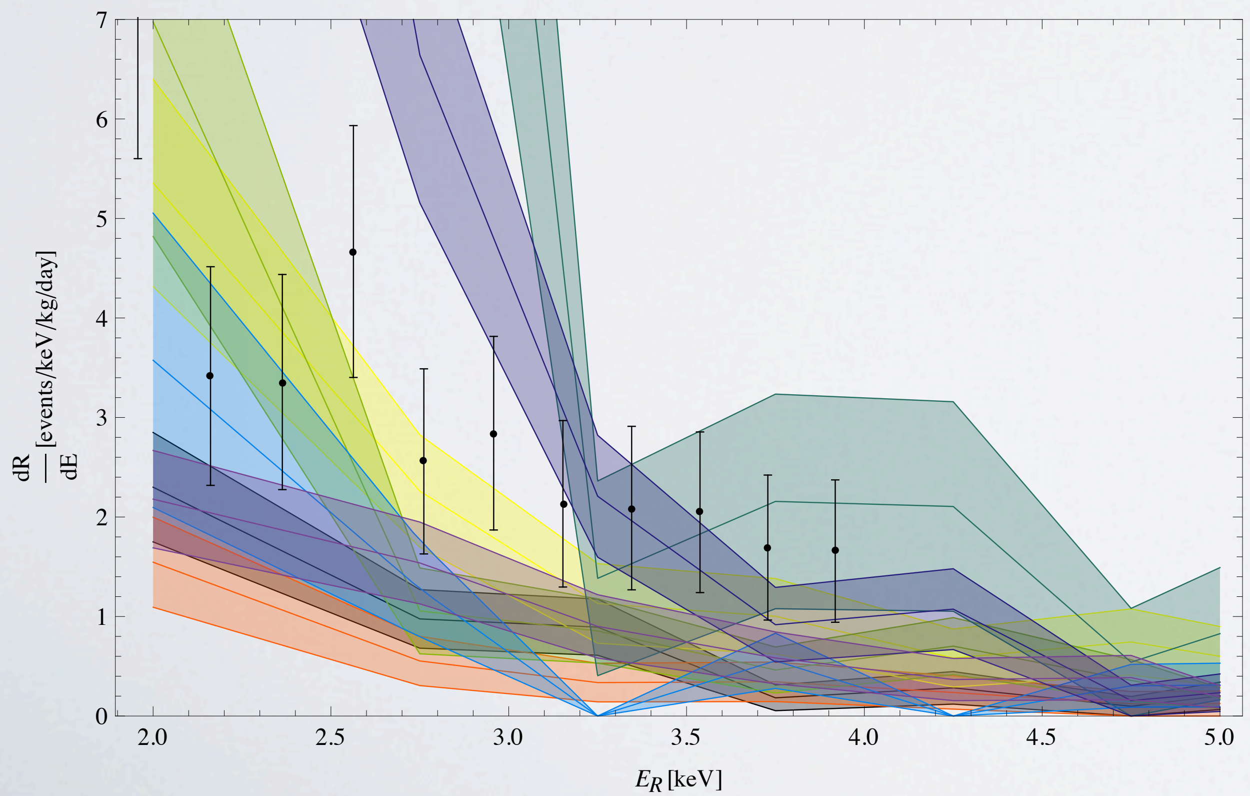
CRESST AT XENON10



CDMS LOW THRESHOLD







Same target. Appears to exclude CoGeNT...

WHERE ARE WE W/ COGENT

- Limits from CDMS, XENON (ionization+scintillation, ionization only) seem strong
- Ball is in CoGeNT court: better knowledge of shape, look for modulation, etc - new info can reinvigorate
- Status: already 120 kg day recorded (vs 18.5), expected update 2-3 months; CoGeNT-4 installation this summer. Modulation may require 18 months+

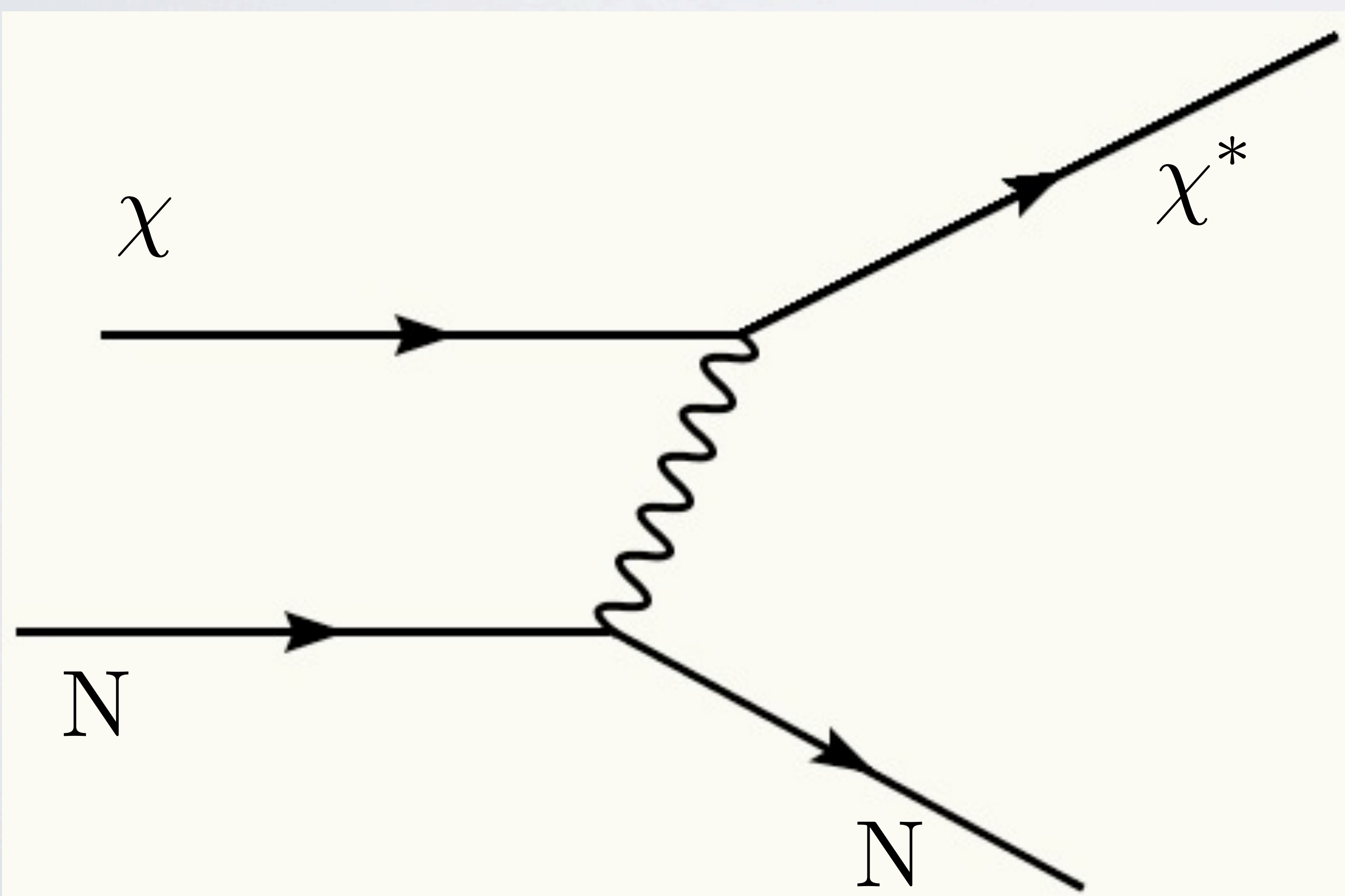
OTHER EXPLANATIONS OF DAMA

- What if it's not a light WIMP?

"INELASTIC" DARK MATTER

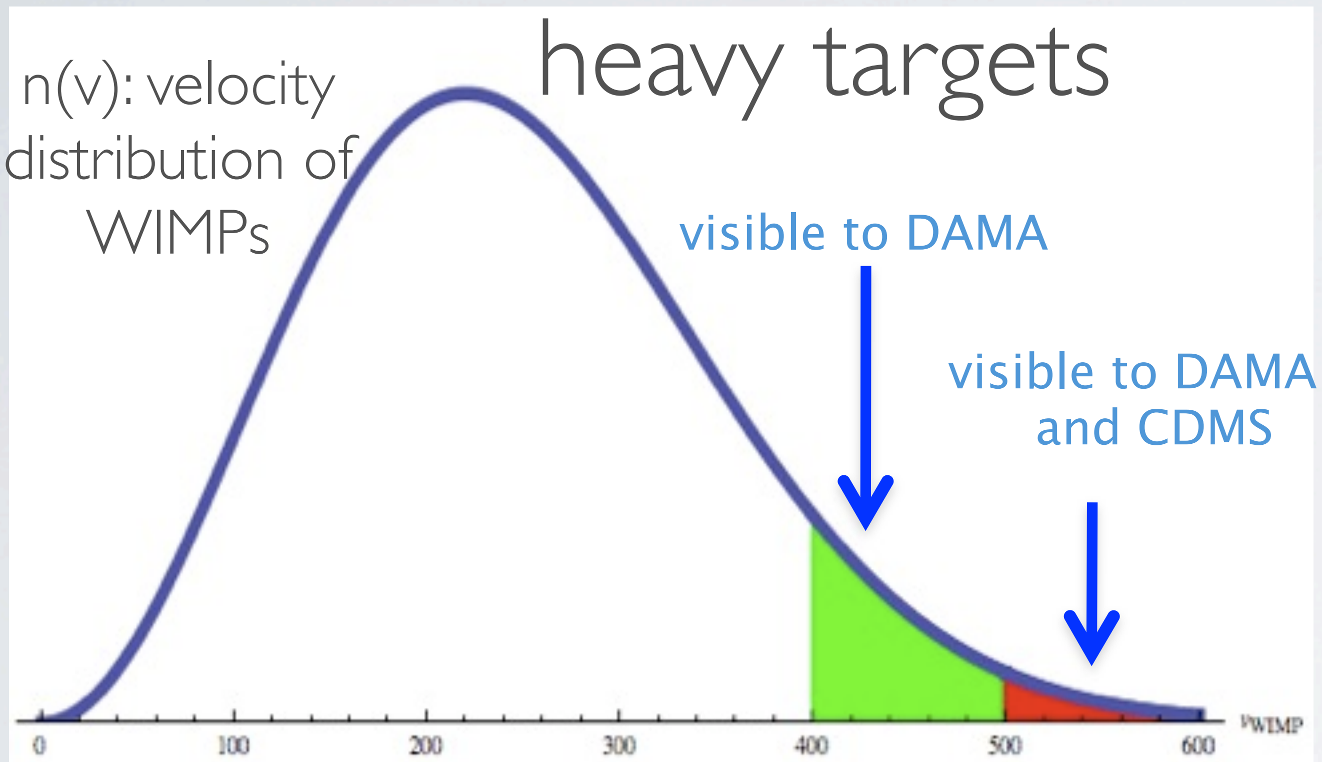
D.Tucker-Smith, NW, Phys.Rev.D64:043502,2001;Phys.Rev.D72:063509,2005

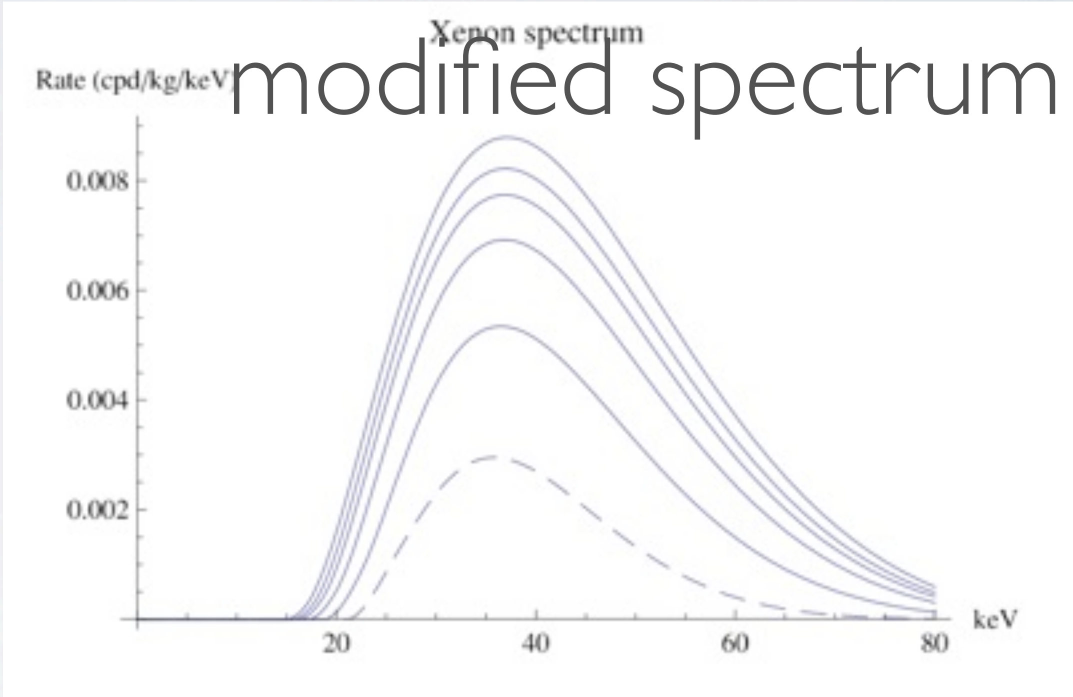
- With dark forces, DM-nucleus scattering must be inelastic
- If dark matter can only scatter off of a nucleus by transitioning to an excited state (100 keV), the kinematics are changed dramatically

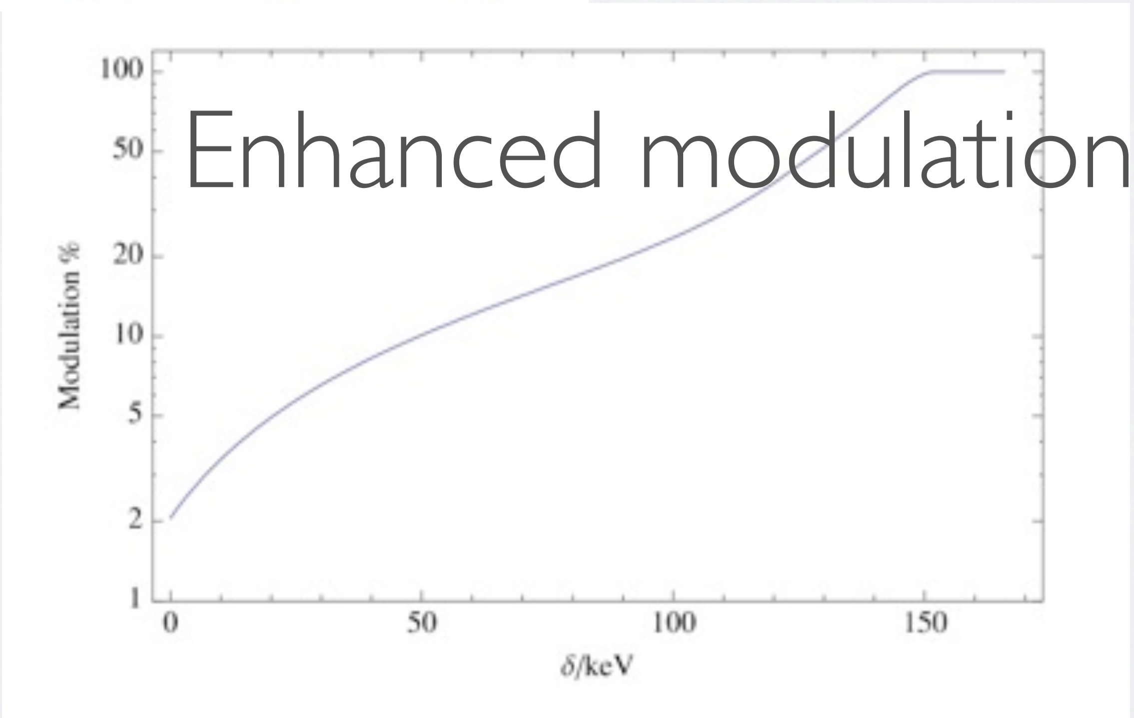


$$\frac{\mu_{\chi N} v^2}{2} > \delta$$

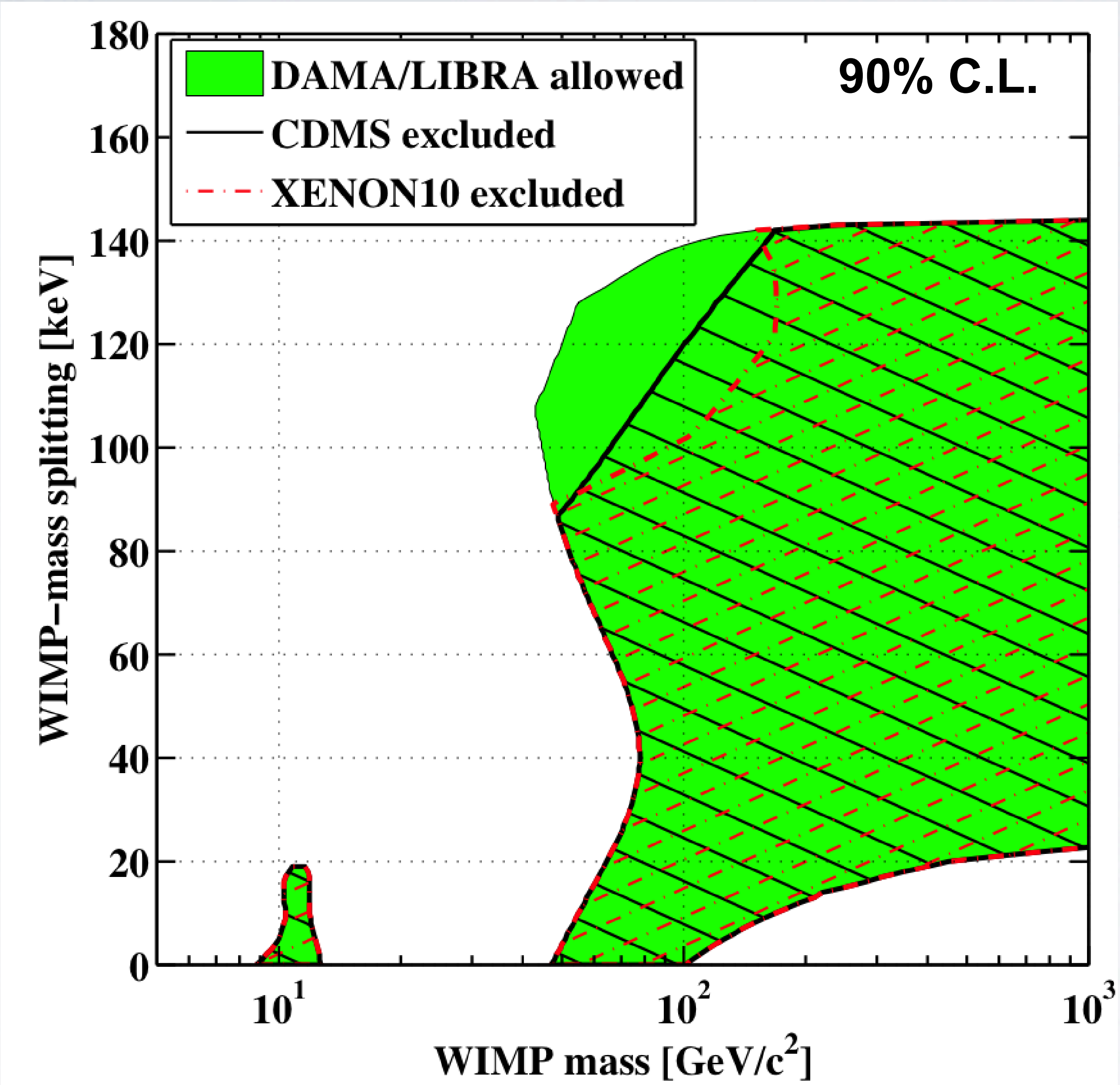
EFFECTS ON WIMP SEARCHES







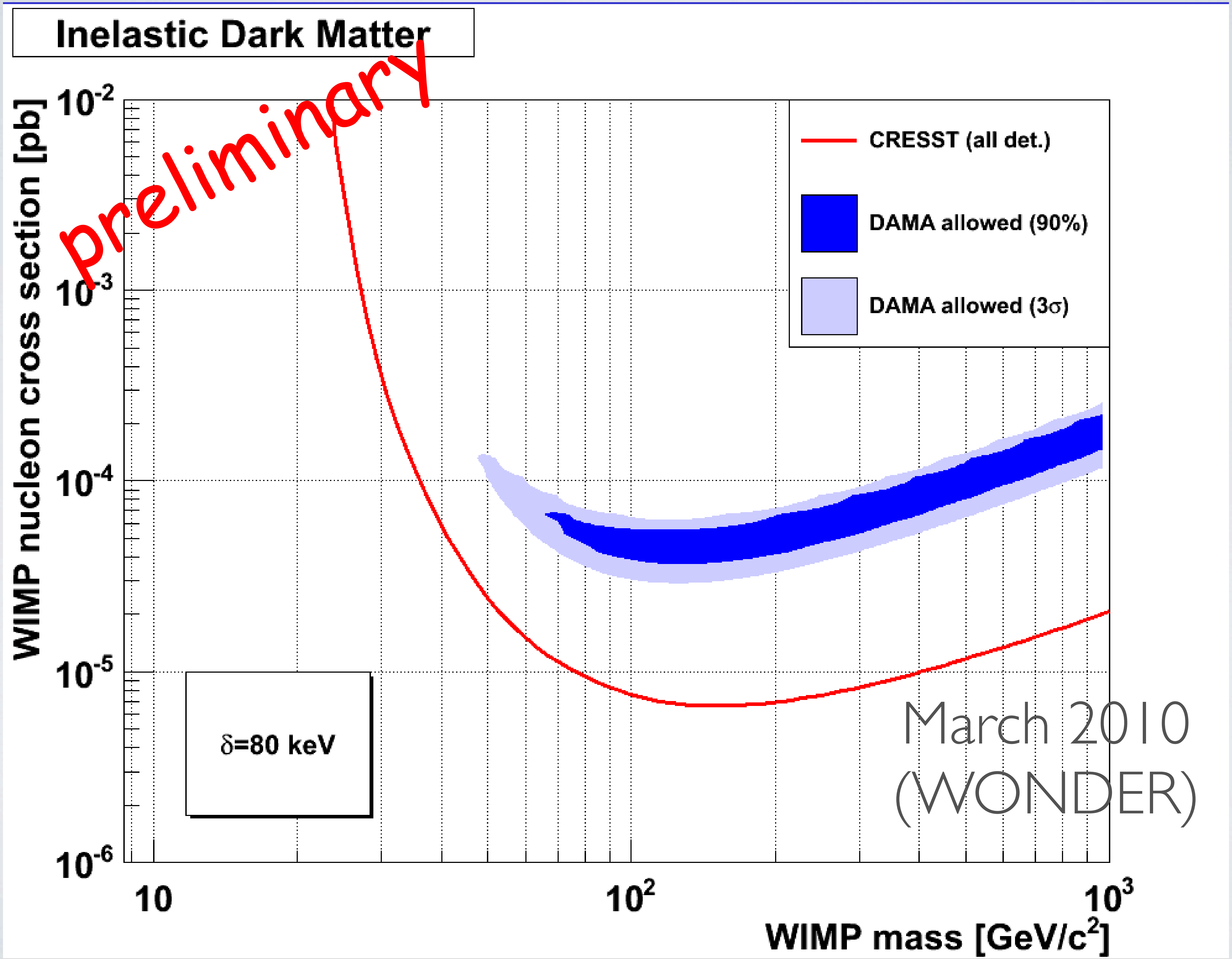
IDM CONSTRAINTS



Tight constraints from CDMS, XENON (shown), also ZEPLIN,

Assume Maxwellian - must be in the highly modulated regime

IDM IN 2010

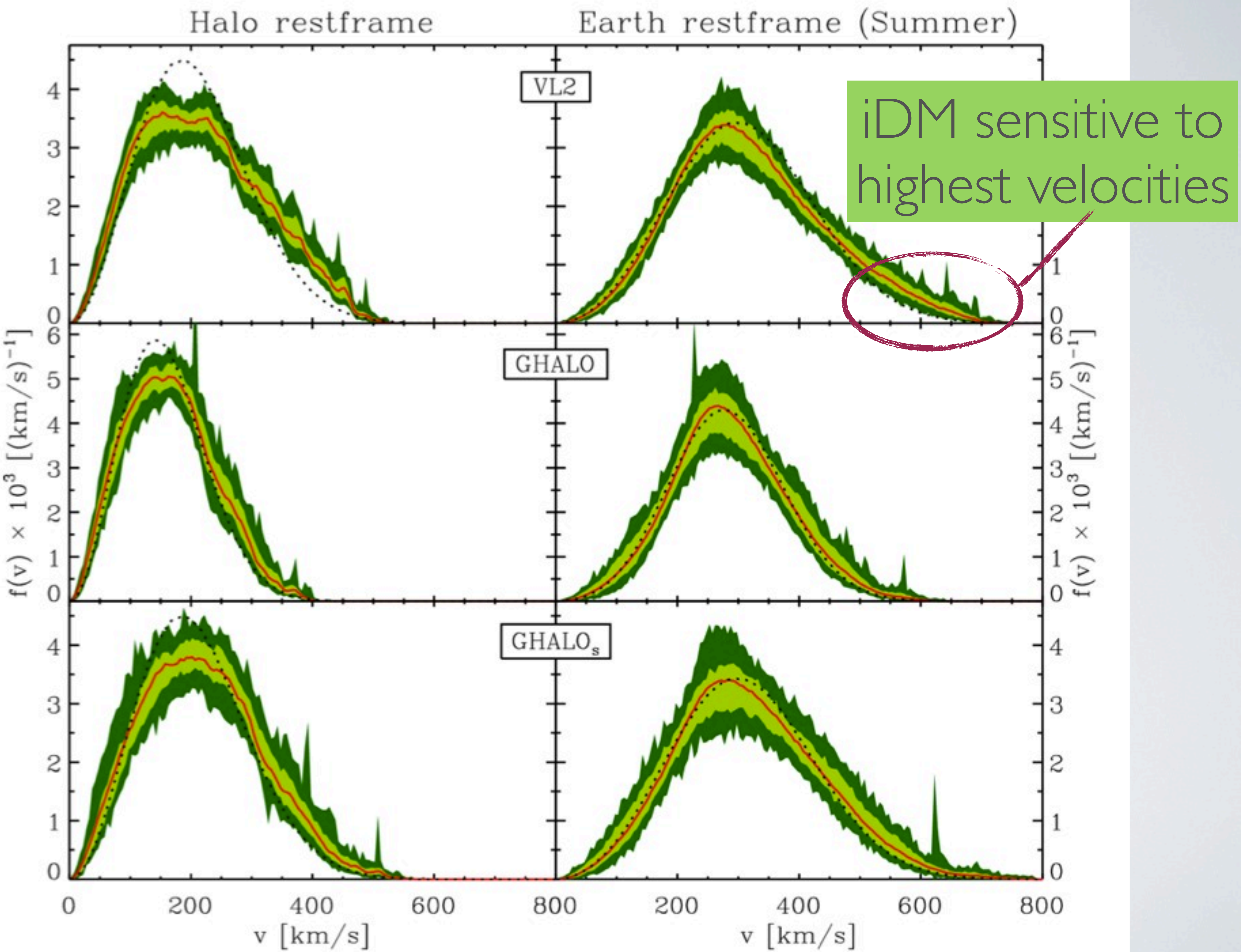


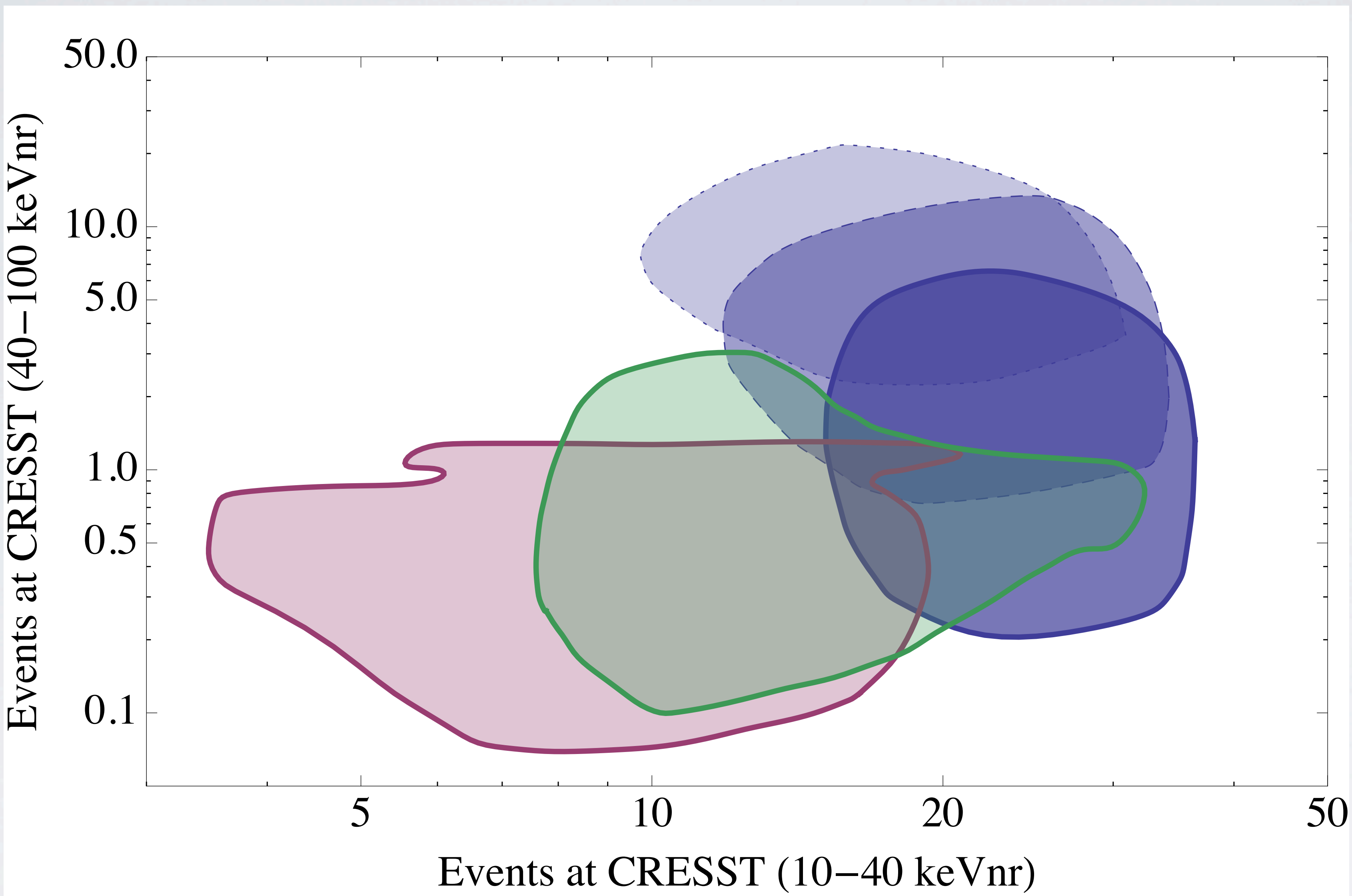
March 2010
(WONDER)

A FACTOR OF FOUR

AN OPPORTUNITY!

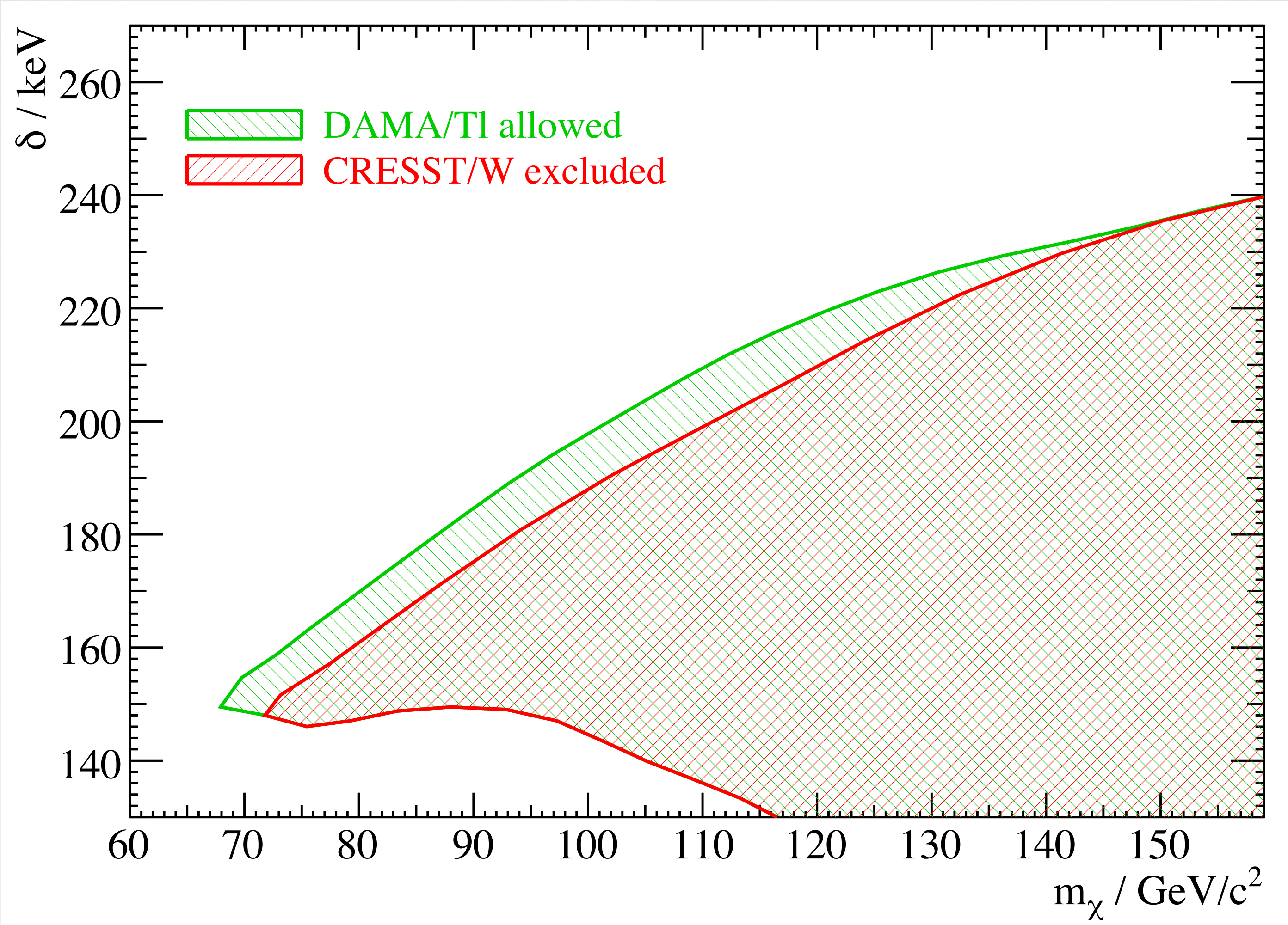
Astrophysics Detector Properties Model


Halo restframe
Earth restframe (Summer)
VL2
GHALO
GHALO$_s$
iDM sensitive to highest velocities
f(v) × 10^3 [(km/s)$^{-1}$]
v [km/s]



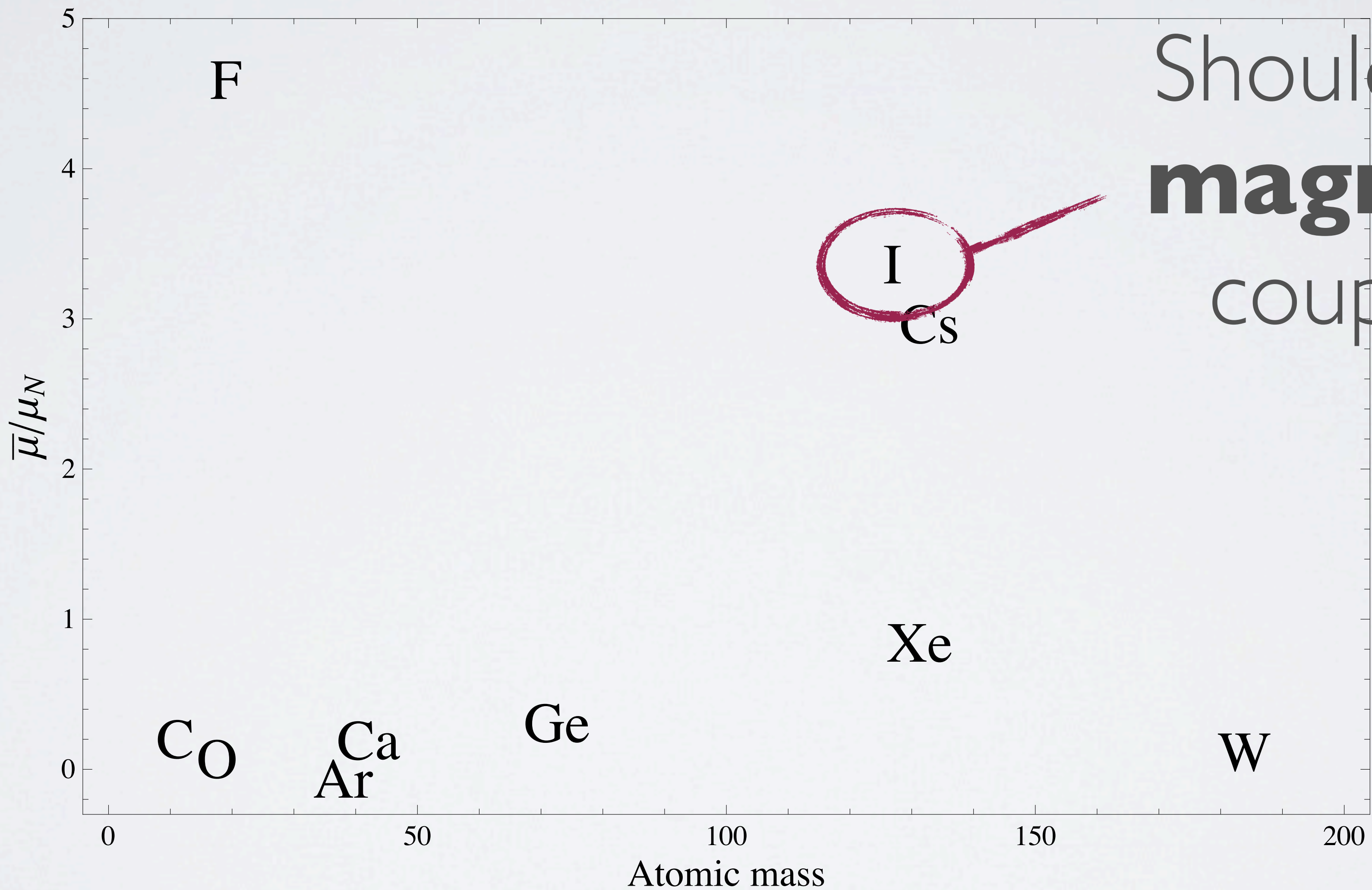
Alves, Lisanti, Wacker

DETECTOR PROPERTIES



- Tuned at 5% level
- Maybe have just been considering wrong target the whole time!

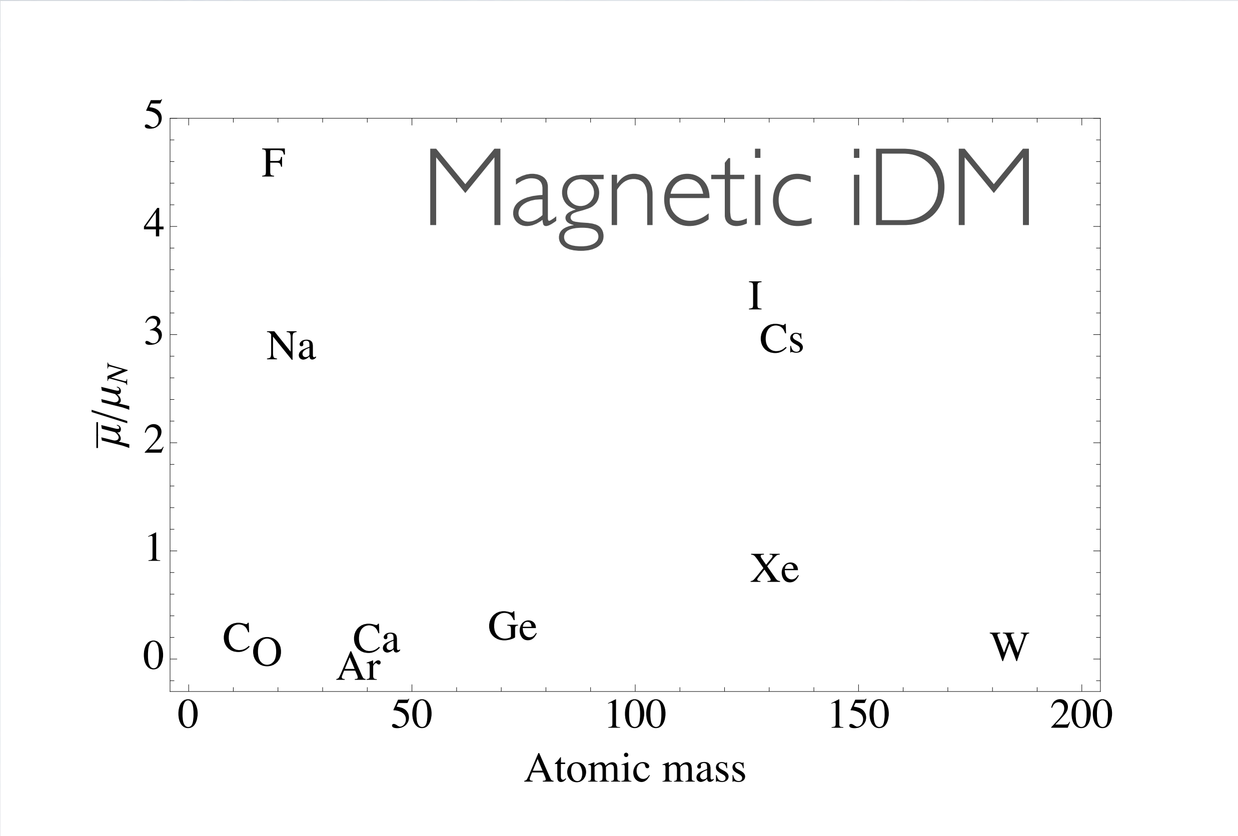
THE TARGETS OF DARK MATTER DETECTION

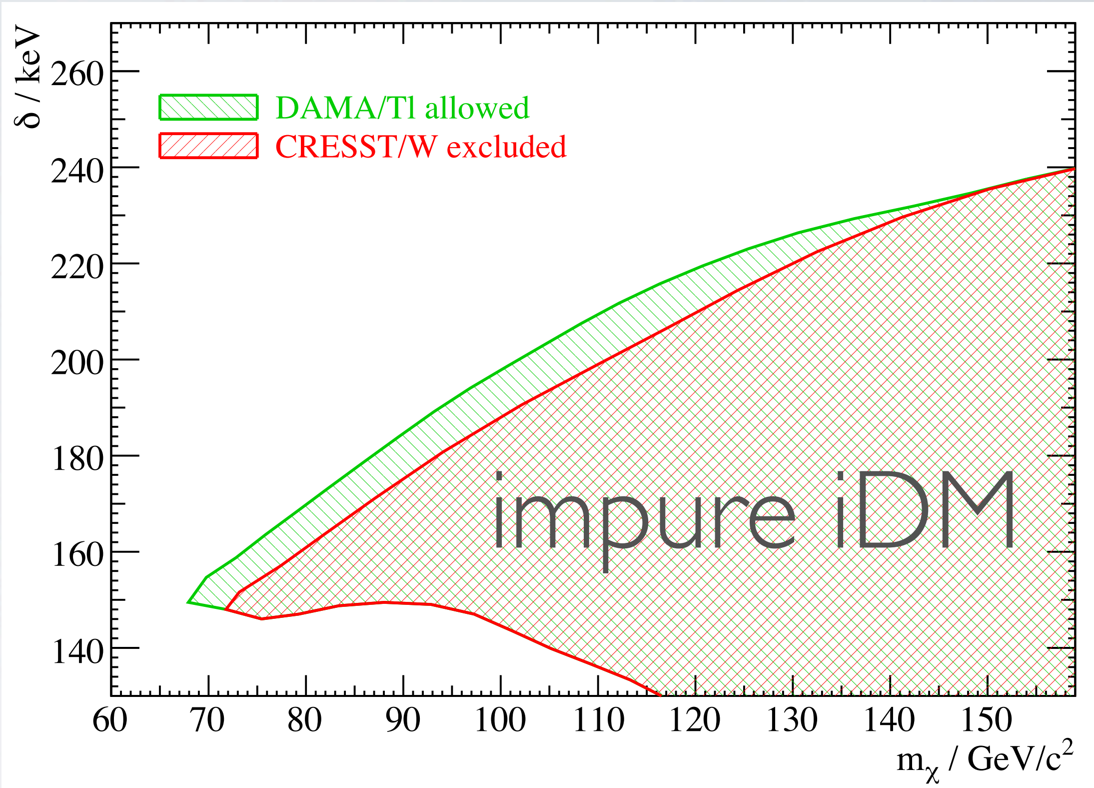


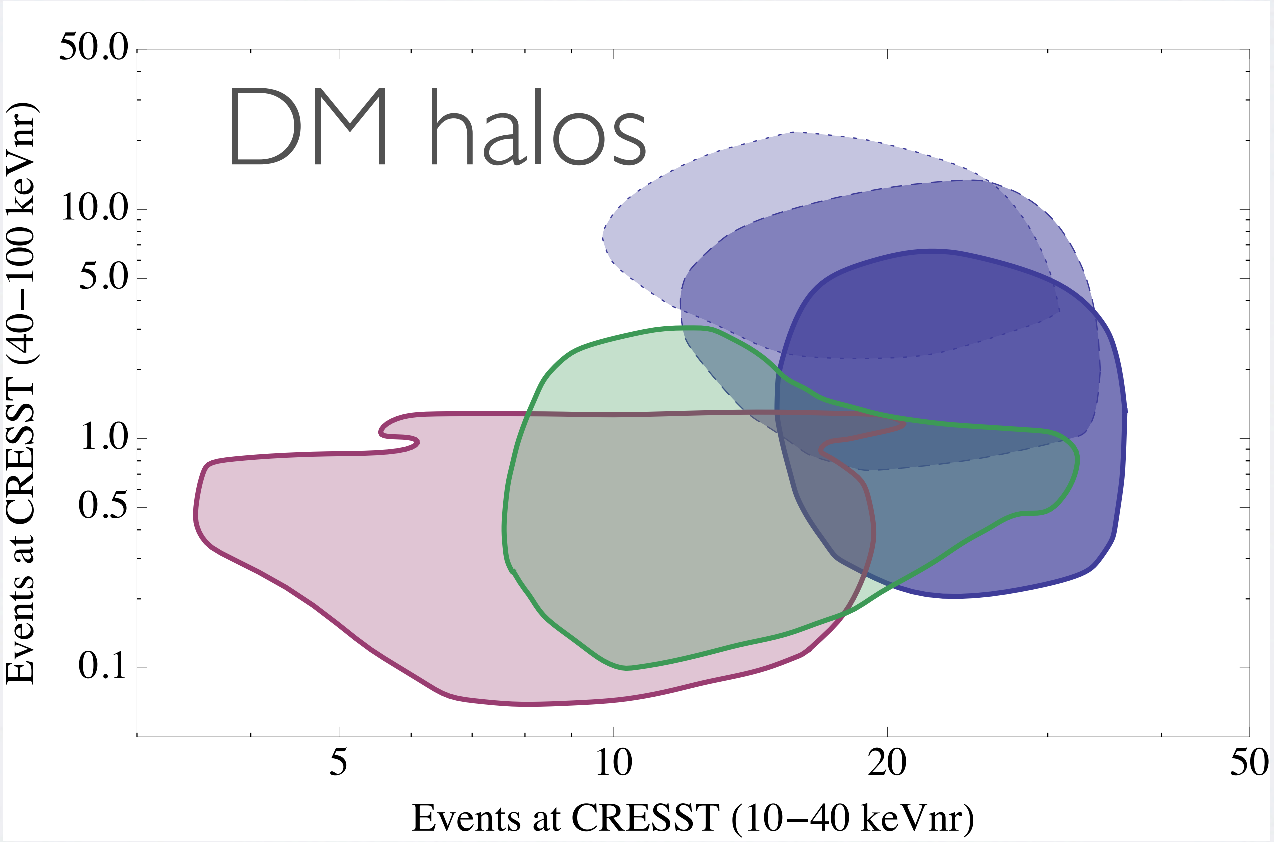
Should consider **magnetically** coupled iDM

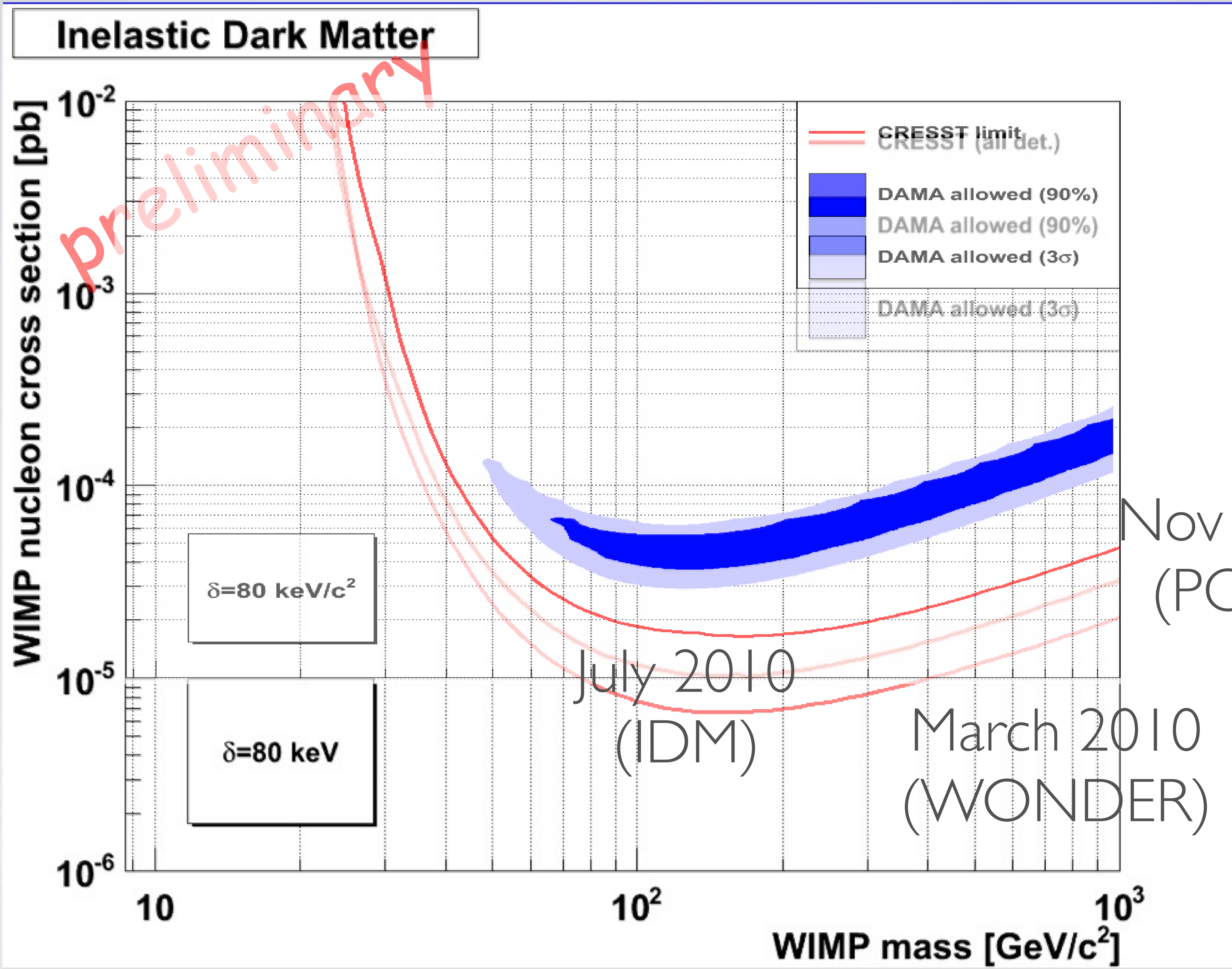
Chang, NW, Yavin '10

Also: SDiDM Kopp, Schwetz, Zupan '09


Magnetic iDM
F
Na
I
Cs
Xe
C
O
Ca
Ar
Ge
W
$\overline{\mu}/\mu_N$
Atomic mass
0
1
2
3
4
5
0
50
100
150
200


DAMA/Tl allowed
CRESST/W excluded
impure iDM
δ / keV
m_χ / GeV/c^2
140
160
180
200
220
240
260
60
70
80
90
100
110
120
130
140
150


DM halos
Events at CRESST (40−100 keVnr)
Events at CRESST (10−40 keVnr)
50.0
10.0
5.0
1.0
0.5
0.1
5
10
20
50

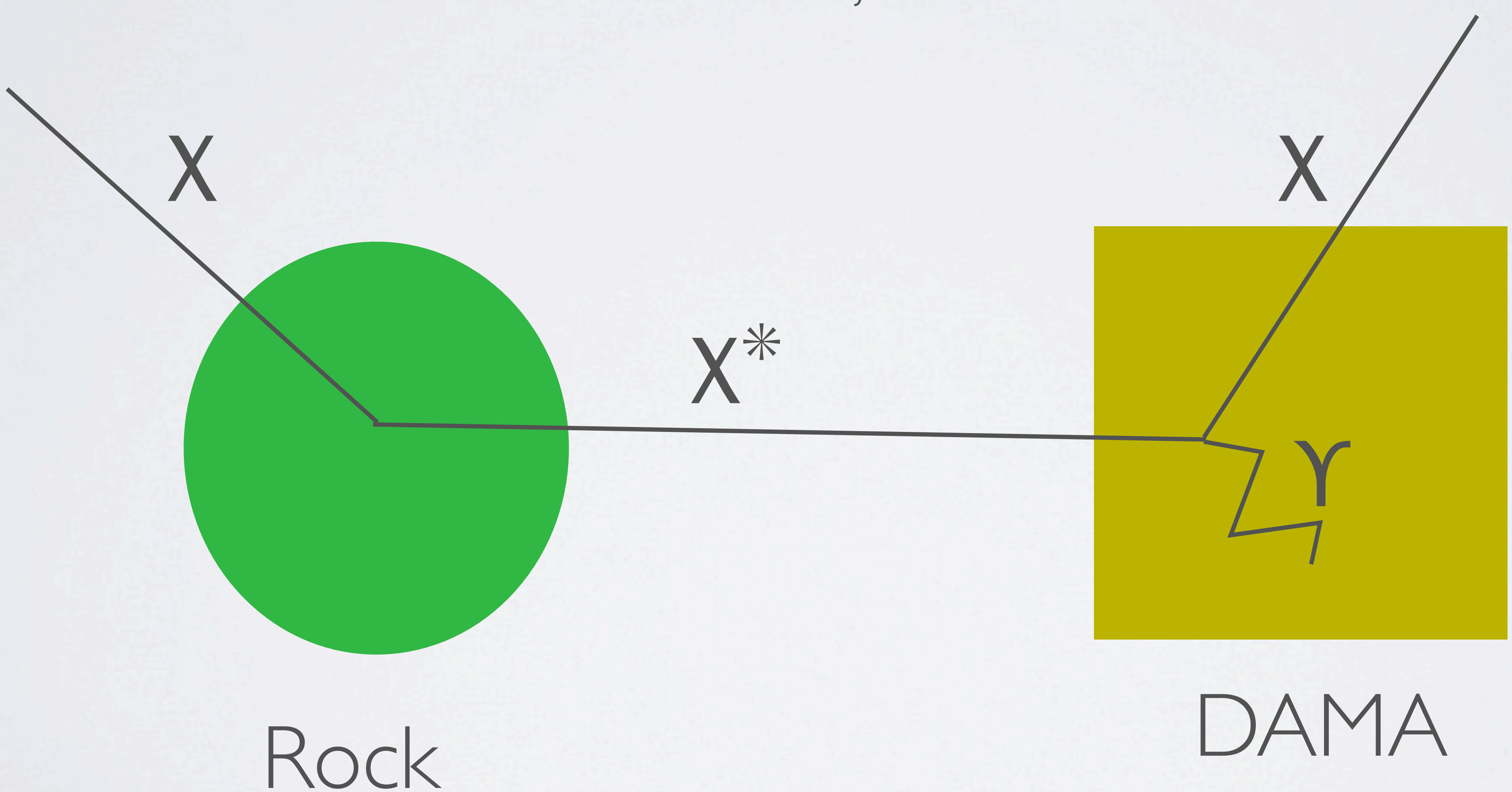


Currently excluded by ~1.5 assuming MB halo

NEW IDEAS

"Luminous" Dark Matter

Graham, Harnik, Rajendran '10



Electronic signal proportional to **volume** of detector

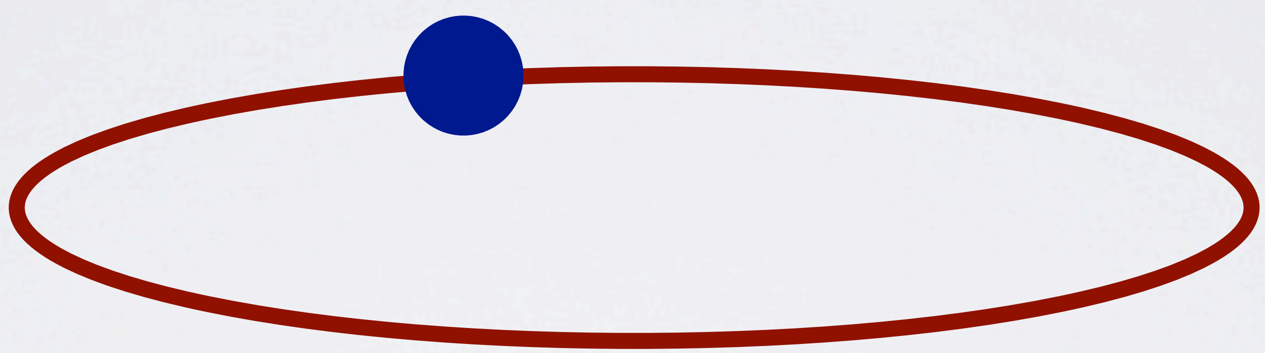
KEY EVENTS IN 2011

- XENON100 unblinding/results
- CoGeNT update
  - Removal of L-shell peaks, modulation study
- COUPP First results (CF_3I)
  - C**F₃**I ⇒ Light dark matter
  - C**F₃**I ⇔ **Na**I(Tl), CF_3**I** ⇔ Na**I**(Tl)
- KIMS (CsI(Tl)), 1 yr study
  - **CsI**(Tl) ⇔ Na**I**(Tl), CsI(**Tl**) ⇔ NaI(**Tl**)

HOW MANY TYPES OF DARK MATTER ARE THERE?
(HINT >3)

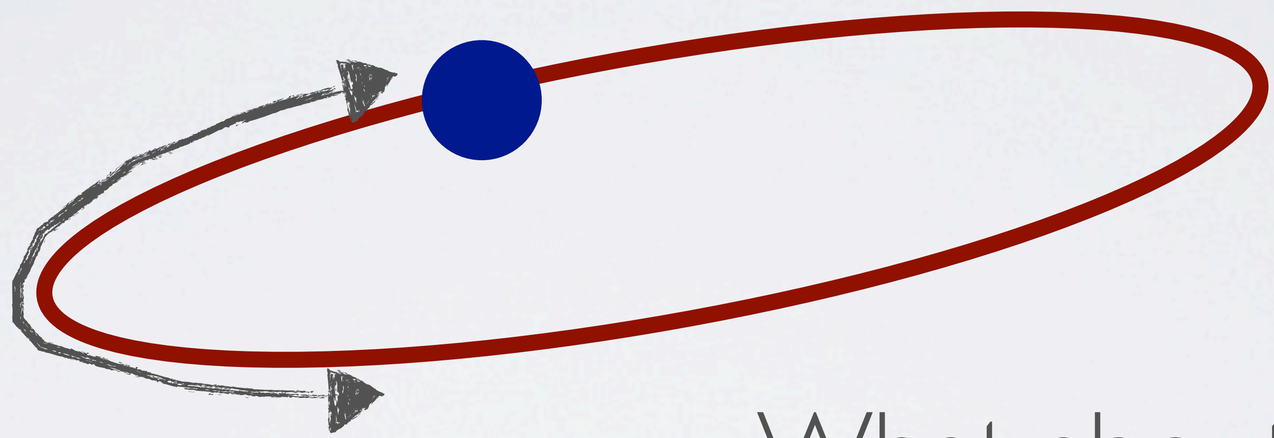
Hierarchy problem => WIMPS

Strong CP problem => axion



Hierarchy problem => WIMPS

Strong CP problem => axion



What about other axions? (aka the “axiverse” Arvanitaki et al, ’10)

Non-thermal candidates (gravino, axino - there are others)

Things we haven’t thought about...

TO SUMMARIZE

- CDM is in major trouble (or not)
- Cosmic rays are compelling signals of DM

  (or not, or yes, but only conditionally)
- DM is definitely going to be discovered soon

  (or not, or maybe just some)
- We've already directly detected DM

  (or twice, or three times, or not at all)
- There are an infinite number of DM candidates

  (but we've already thought of the good ones)
- Or maybe not