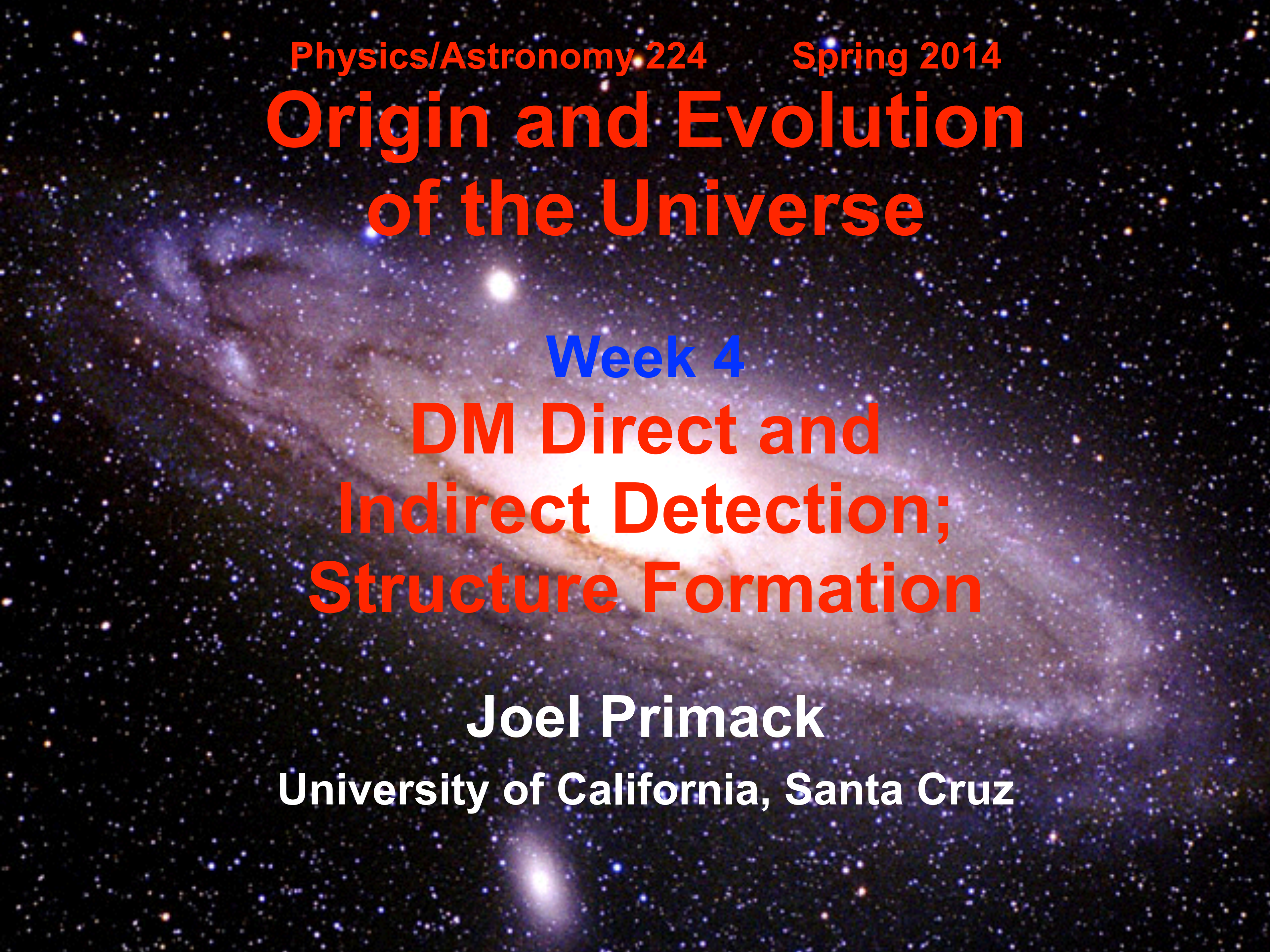


Physics/Astronomy 224 Spring 2014

Origin and Evolution of the Universe

Week 4

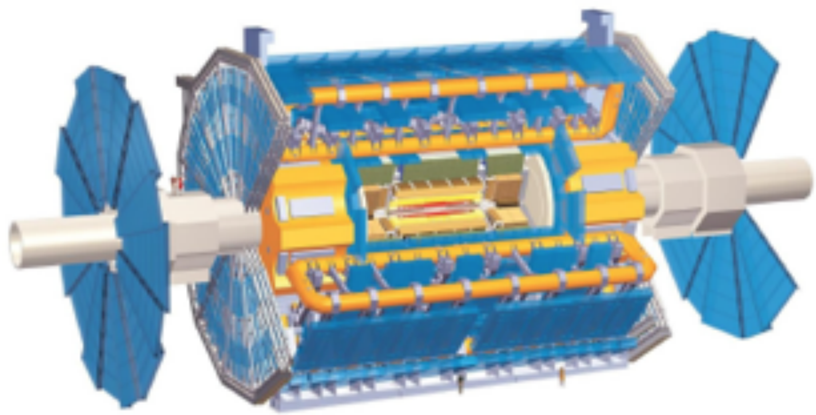
DM Direct and Indirect Detection; Structure Formation

Joel Primack

University of California, Santa Cruz

The LHC – an essential component of the DM story

- If DM is made of WIMPs, they will be produced at LHC in abundance
- Indirect DM detection using principally missing E_T signatures
- Unique role of LHC: multiple measurements allow understanding of underlying theory, determination of identity of DM



ATLAS Detector

multiple measurements of WIMP observables → Optimisation of parameters within a canididate theory, eg SUSY → DarkSUSY/ MicroMEGAS software → $\Omega_\chi h^2$

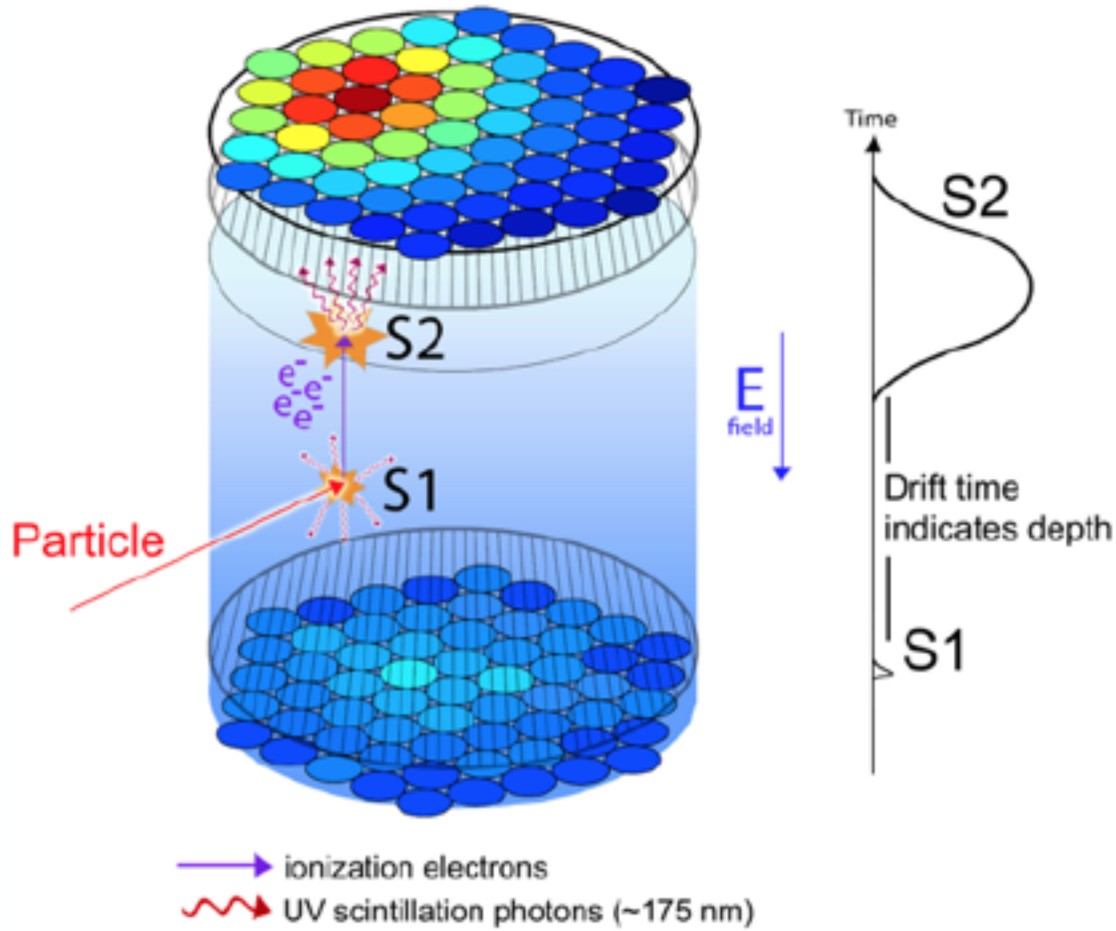
Note that a detection of missing mass, energy, and momentum at the LHC is not proof that the invisible particle is the dark matter. The particle needs only to have a lifetime of $\sim 10^{-9}$ s to escape the Atlas and CMS detectors.

It will be the dark matter particle if direct and/or indirect detection experiments see the same mass and interaction pattern.

Thus all three approaches must be pursued: production, direct detection and indirect detection.

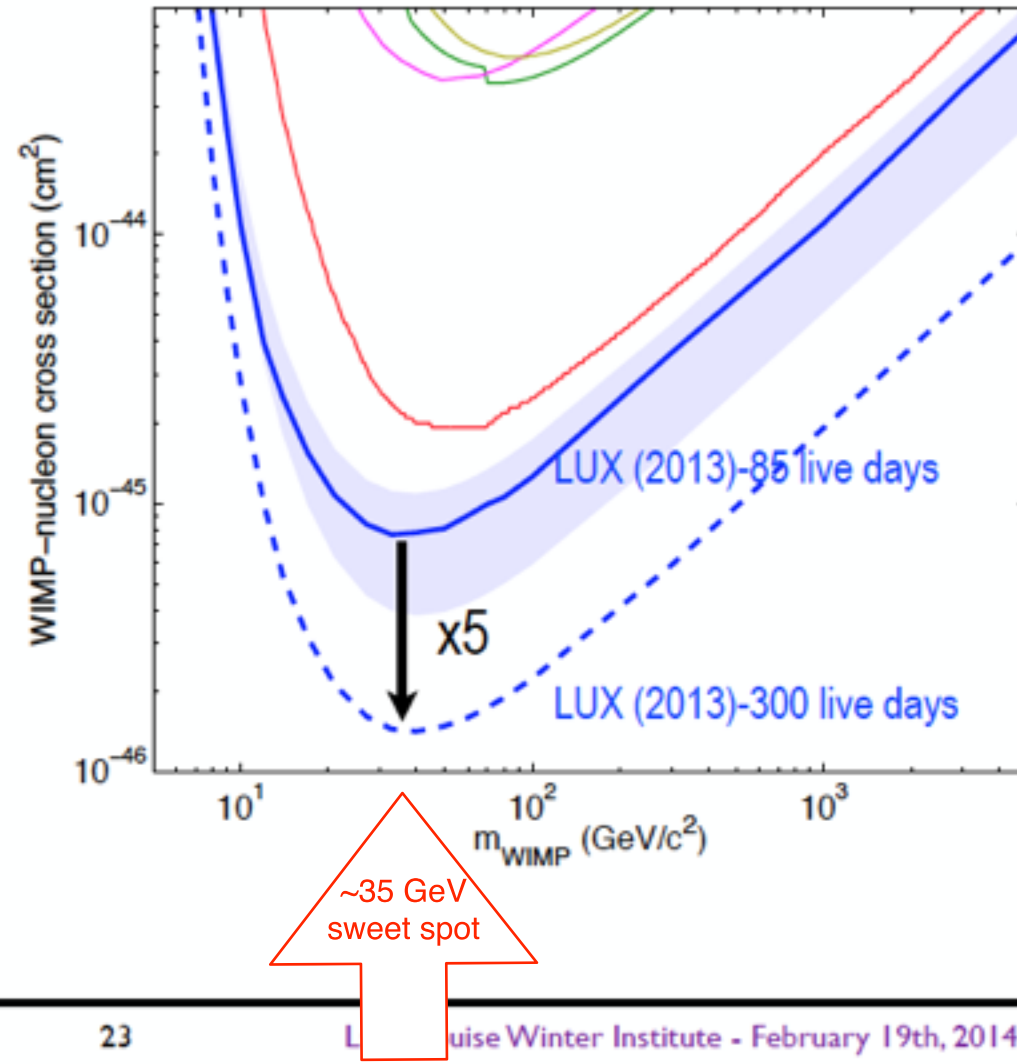
The LUX Dark Matter Detector

- What is LUX?
  - a particle detector
  - a monolithic wallless fiducial region within 370 kg Xe TPC
  - viewed by 122 Photomultiplier Tubes
  - able to reconstruct (x,y,z) for each event
  - exceptional self-shielding from outer xenon layer
  - discrimination between electronic and nuclear recoils (99.6%)
- How would LUX see dark matter?
  - it detects scintillation photons and ionized electrons created by particle interactions
  - if dark matter interacted with a xenon atom, energy transferred to that atom would be visible to LUX
  - $\alpha_1 \sim O(0.10)$ and $\alpha_2 \sim O(10)$ are the amplification factors for each quanta
  - n_γ and n_e are the fundamental measured quantities



Projected LUX 300 day WIMP Search Run

- We intend to run LUX for a new run of 300 days in 2014/15
  - Extending sensitivity by another factor 5
  - Even though LUX sees no WIMP-like events in the current run, it is still quite possible to discover a signal when extending the reach
  - LUX does not exclude LUX
- WIMPs remain our favored quarry
- LZ 20x increase in target mass
  - If approved plans to be deployed in Davis Lab in 2016+



past
(2005 - 2007)

XENON10

Achieved (2007) $\sigma_{SI}=8.8 \times 10^{-44}$ cm^2

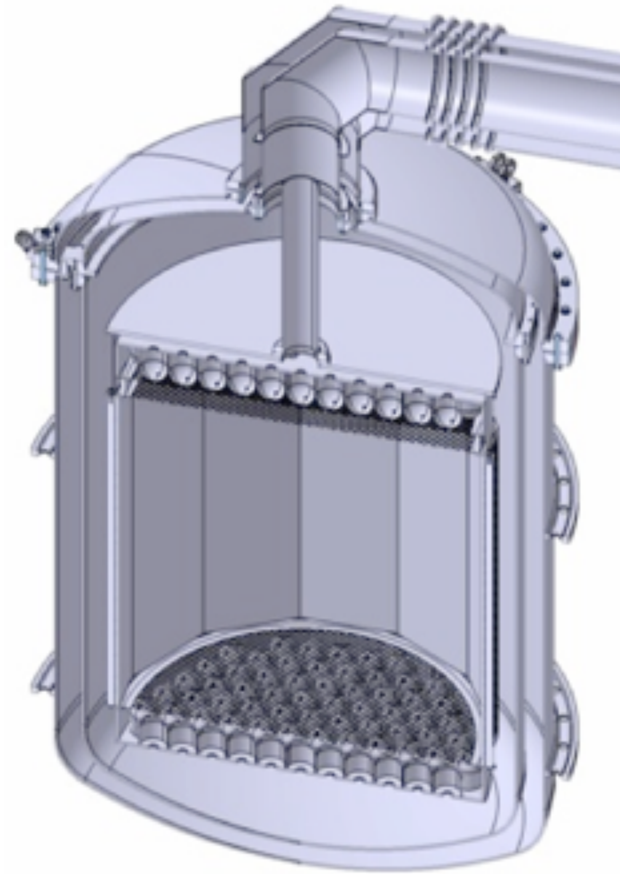
Phys. Rev. Lett. **100**, 021303 (2008)
Phys. Rev. Lett. **101**, 091301 (2008

current
(2007-2012)

XENON100

Achieved (2011) $\sigma_{SI}=7.0 \times 10^{-45}$ cm^2
Projected (2012) $\sigma_{SI} \sim 2\times10^{-45}$ cm^2

future
(2012-2017)



XENON1T

Projected (2017) $\sigma_{SI} \sim 10^{-47}$ cm^2

XENON100 is a collaboration including Columbia and Rice universities, University of Zurich, University of Coimbra, Gran Sasso National Laboratory, and UCLA.

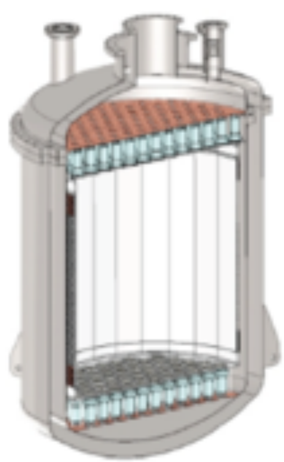
XENON1T: OVERVIEW

- Detector: 1m drift TPC with 2.2 ton LXe target
- Shield: ~10 m x 10 m Water Cherenkov Muon Veto
- Background: 0.01 mdru (100 lower than XENON100
- Location: approved by INFN for LNGS Hall B
- Capital Cost: ~11 M$ (50% US and 50% non-US)
- Status: Construction start in Fall 2012
- Science Run: projected to start in 2015
- Sensitivity: 2 x 10^{-47} cm^2 at 50 GeV with 2.2 ton-years

COLUMBIA RICE UCLA PURDUE ZURICH COIMBRA

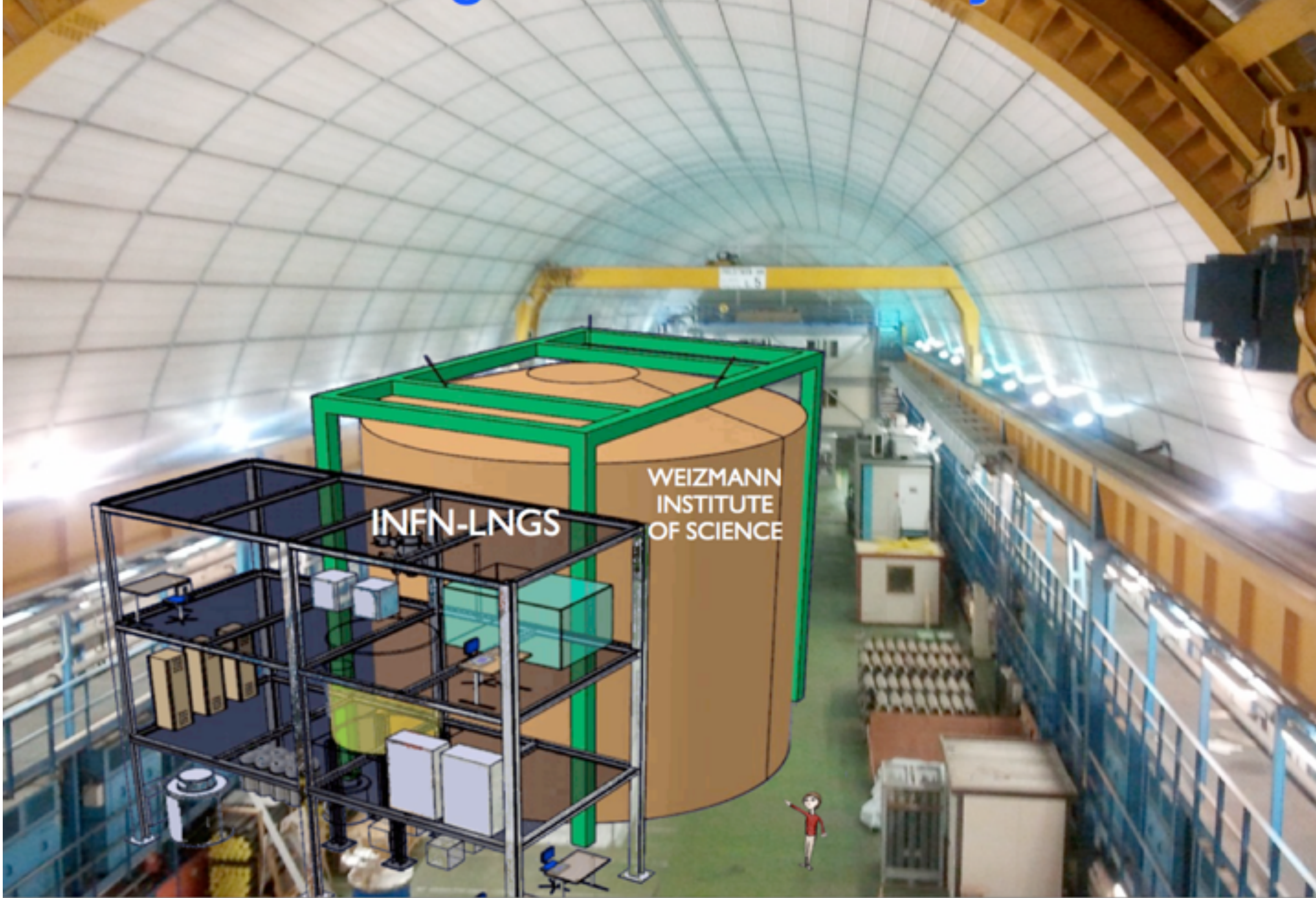
LNGS INFN MPIK BOLOGNA SJTU

MUENSTER SUBATECH NIKHEF WEIZMANN

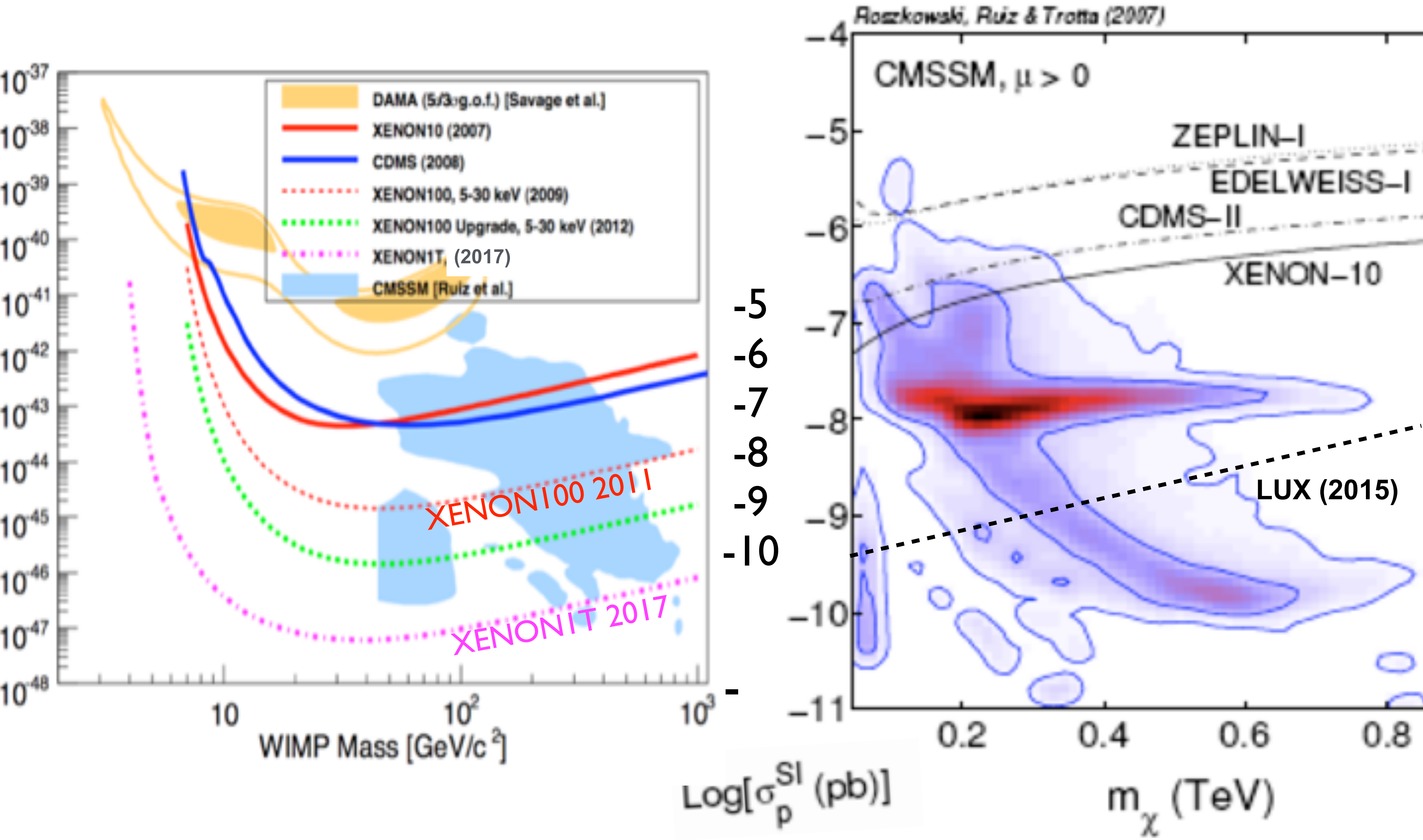


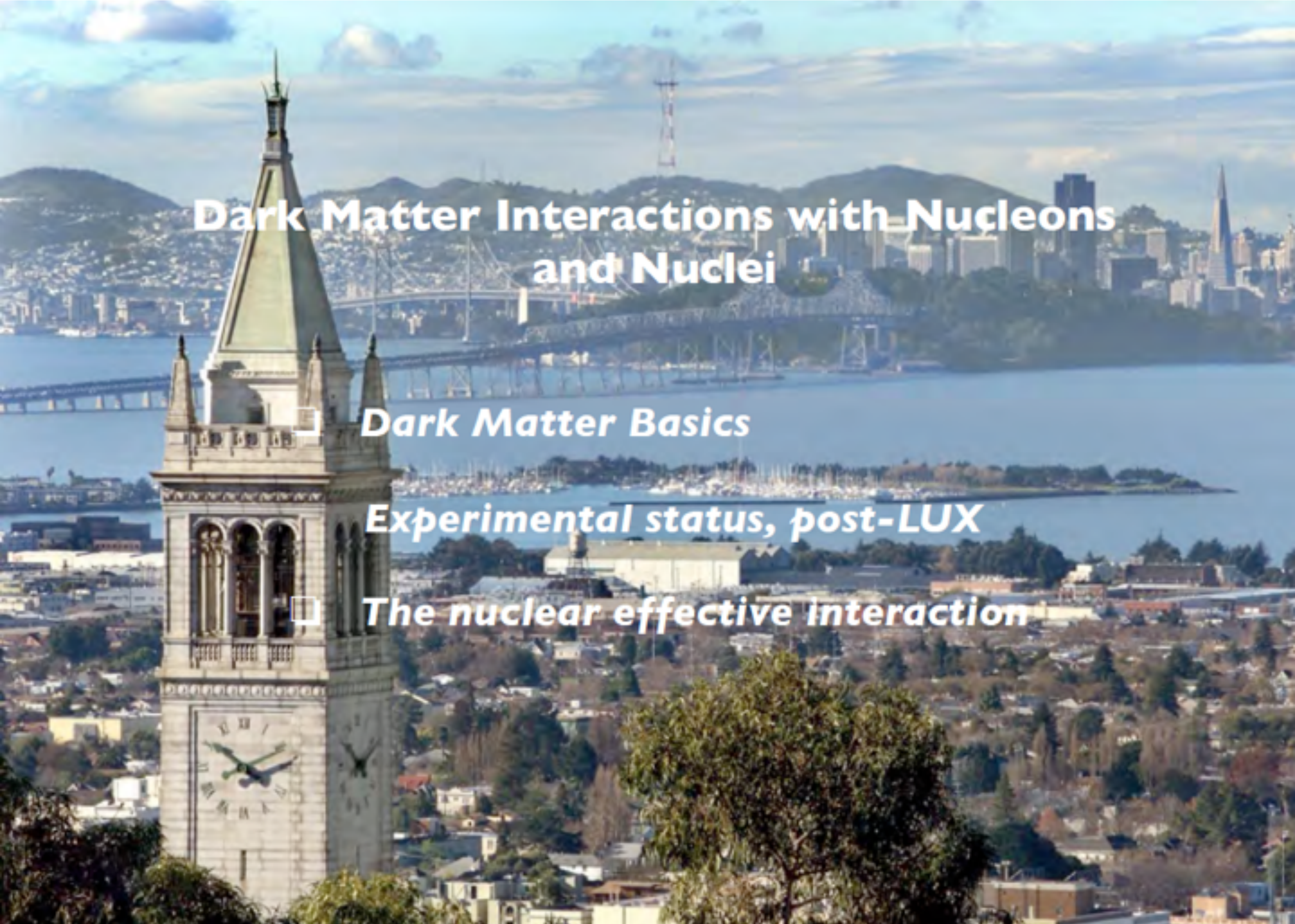
LNGS Underground Laboratory – Hall B

LNGS Underground Laboratory – Hall B



By ~2017 Direct Detection could probe most of the CMSSM (constrained minimal supersymmetric standard model) and mSUGRA (minimal supergravity) WIMP parameter space!

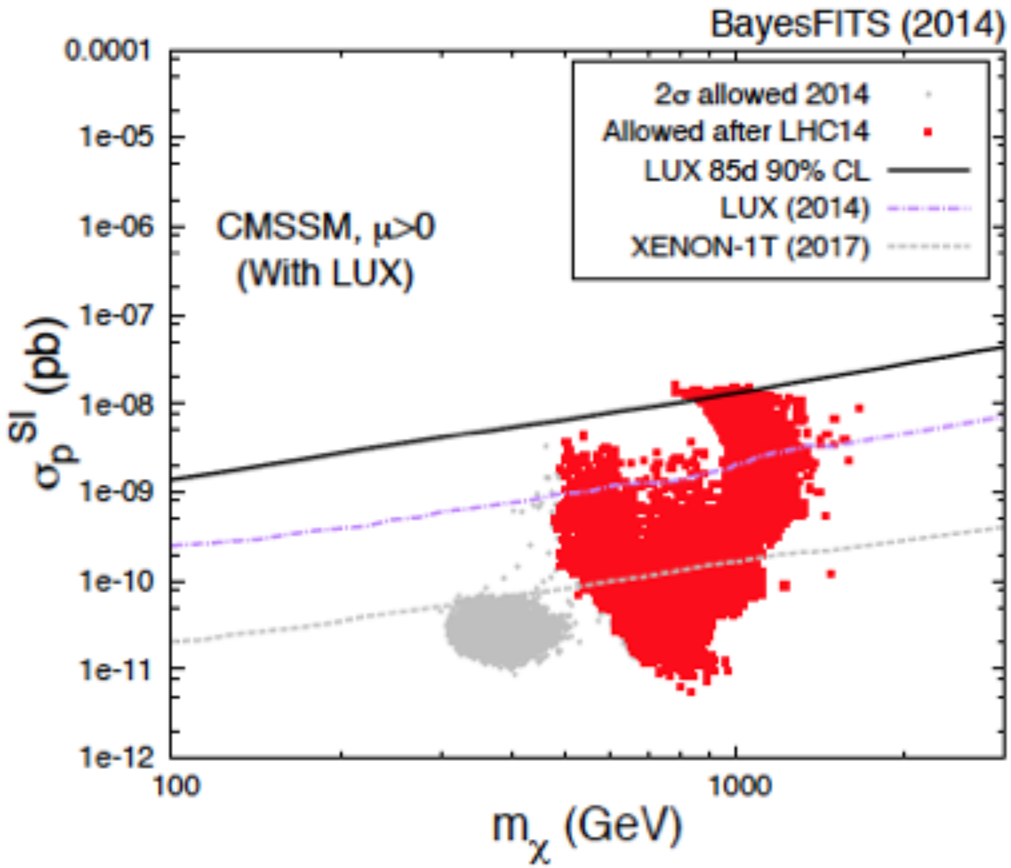




Dark Matter Interactions with Nucleons and Nuclei

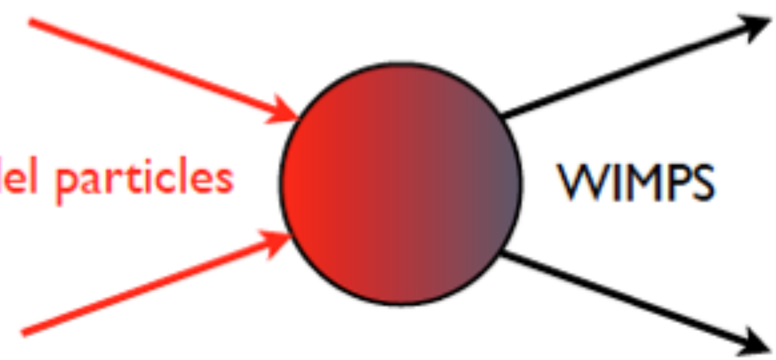
- *Dark Matter Basics*
- *Experimental status, post-LUX*
- *The nuclear effective interaction*

Wick Haxton UCSC April 18, 2014



LHC second run starting in 2015 will extend collision energies to 14 TeV

Note: σ^{SI} means spin independent elastic scattering cross section



From L. Roszkowski, DM@UCLA 2014

- Experiments are frequently analyzed and compared in a formalism in which the nucleus is treated as a point particle

$$\text{S.I.} \quad \Rightarrow \quad \langle g.s.| \sum_{i=1}^{A} (a_0^F + a_1^F \tau_3(i)) \; |g.s.\rangle$$

$$\text{S.D.} \quad \Rightarrow \quad \langle g.s.| \sum_{i=1}^{A} \vec{\sigma}(i) \; (a_0^{GT} + a_1^{GT} \tau_3(i)) \; |g.s.\rangle$$

- Is this treatment sufficiently general, to ensure a discovery strategy that will lead to the right result?

(SI/SD is in fact the starting point of Fermi and Gamow&Teller...)

Observations:

SM = Standard Model

- The set of operators found here map on to the ones necessary in describing *known* SM electroweak interactions

ES = Elastic Scattering

- ES can in principle give us 8 constraints on DM interactions

- This argues for a variety of detectors - or at least, continued development of a variety of detector technologies

- There are a significant number of relativistic operators that reduce in leading order to the new operators

- Power counting -- e.g., 1 vs q/m_N -- does not always work as the associated dimensionless operator matrix elements differ widely
    - examples can be given

Summary

- Reminds one of the early days of the weak interaction, SPVAT $\leftrightarrow$ V-A (a simpler problem that was not easily sorted out)

- Pairwise exclusion of experiments in general difficult

- But the bottom line is a favorable one: there is a lot more that can be learned from elastic scattering experiments than is apparent in conventional analysis

- This suggests we should do more experiments, not fewer

- When the first signals are seen, things will get very interesting: those nuclei that do not show a signal may be as important as those that do

Thanks to my collaborators: Liam Fitzpatrick, Nikhil Anand, Ami Katz

Axion Physics in a Nutshell

Why axions? QCD with $m_{quarks} \neq 0$ violates **CP** and therefore **T** due to instantons, unless an undetermined parameter θ is very small – or the axion field absorbs the **CP**-violating phase. If this **CP** violation isn't avoided, the neutron gets an electric dipole moment 10^{10} times larger than the experimental upper bound!

$\Omega_m > 1$

$m_a < 10^{-6}$ eV

window

SN87A **RED GIANTS** **ACCEL. EXPTS**

10^{-2} eV 100 keV

$m_\pi f_\pi \approx m_a f_a$ implies that $f_a = 10^9 – 10^{12}$ GeV

When the temperature T drops to $T \sim f_a$, the axion field gets a vacuum expectation value $f_a e^{i\theta}$, and then when T drops to $\Lambda_{QCD} \sim 100$ MeV QCD causes the axion to get mass m_a and density $\rho_a \propto 1/m_a$.

What? Axions are never relativistic, so there is no free streaming to erase fluctuations in their density. So they behave like Cold Dark Matter.

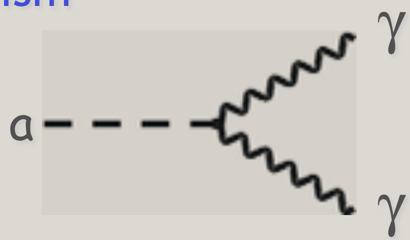
Axion Physics in a Nutshell

Particle-Physics Motivation

CP conservation in QCD by Peccei-Quinn mechanism

→ Axions $a \sim \pi^0$

$m_\pi f_\pi \approx m_a f_a$



For $f_a >> f_\pi$ axions are "invisible" and very light

Solar and Stellar Axions

Axions thermally produced in stars, e.g. by Primakoff production

- No excessive energy drain:

  $m_a < 10$ meV

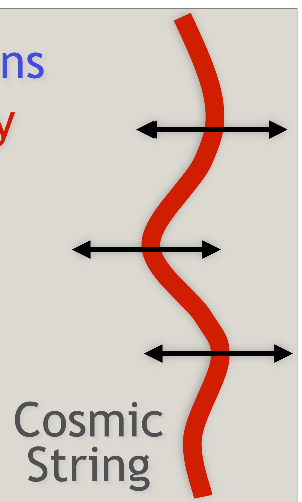
- Search for solar axions (CAST)

Cosmology

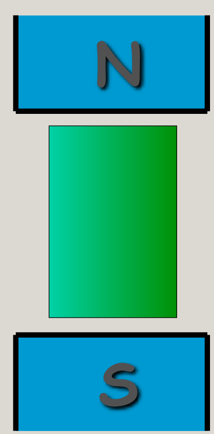
In spite of small mass, axions are born non-relativistically ("non-thermal relics")

→ "Cold dark matter" candidate

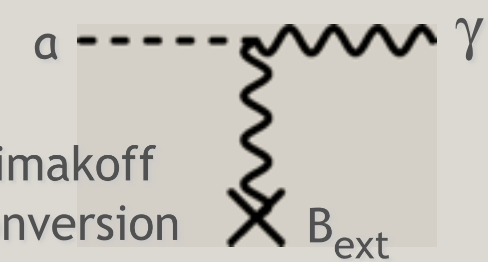
$m_a \sim 1\text{-}1000\ \mu$eV



Search for Axion Dark Matter



Microwave resonator (1 GHz = 4 μeV)



Primakoff conversion

Experimental Search for Axions

DM axions
Velocities in galaxy
Energies therefore

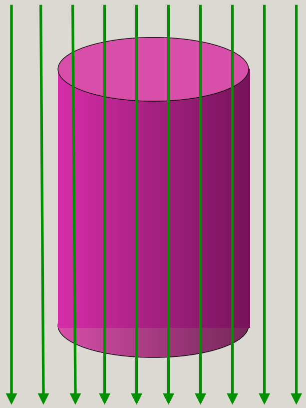
m_a = 10-3000 μeV

$v_a \approx 10^{-3}$ c

$E_a \approx (1 \pm 10^{-6})\ m_a$

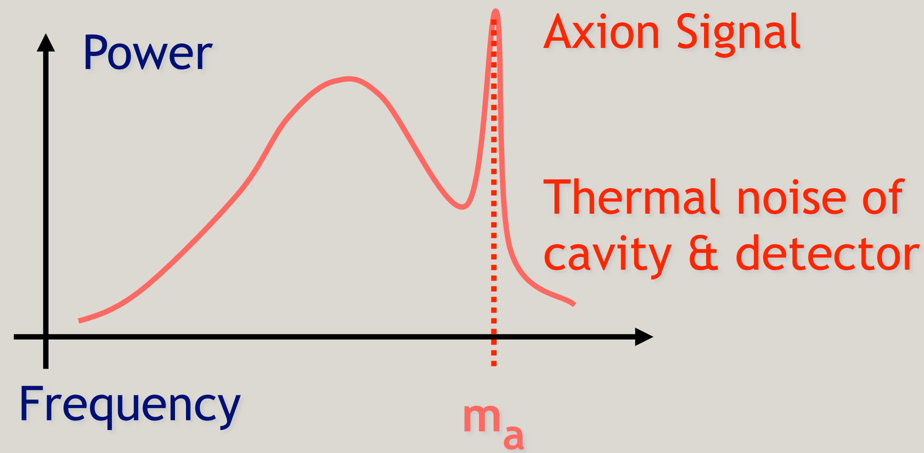
Microwave Energies
(1 GHz ≈ 4 μeV)

Axion Haloscope (Sikivie 1983)

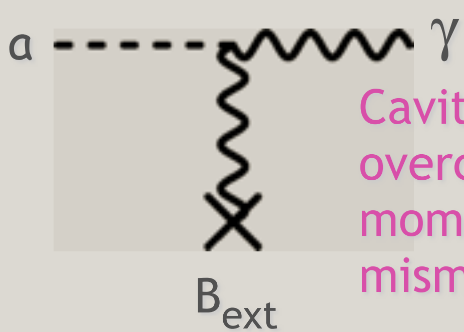


$B_{ext} \approx 8$ Tesla

Microwave Resonator
$Q \approx 10^5$



Primakoff Conversion



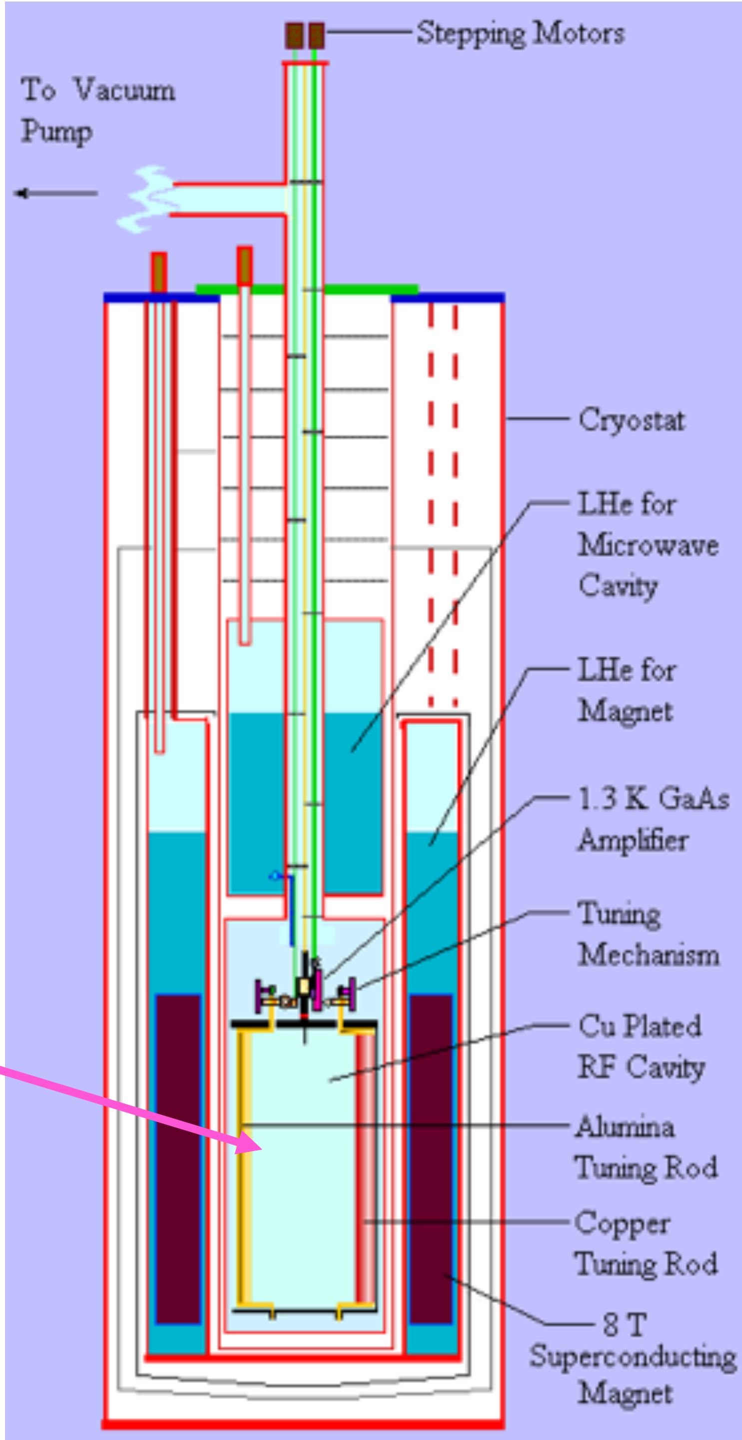
Cavity overcomes momentum mismatch

2 Experiments in Operation

- Axion Dark Matter Experiment (ADMX), Livermore, US
- CARRACK II, Kyoto, Japan

AXION search

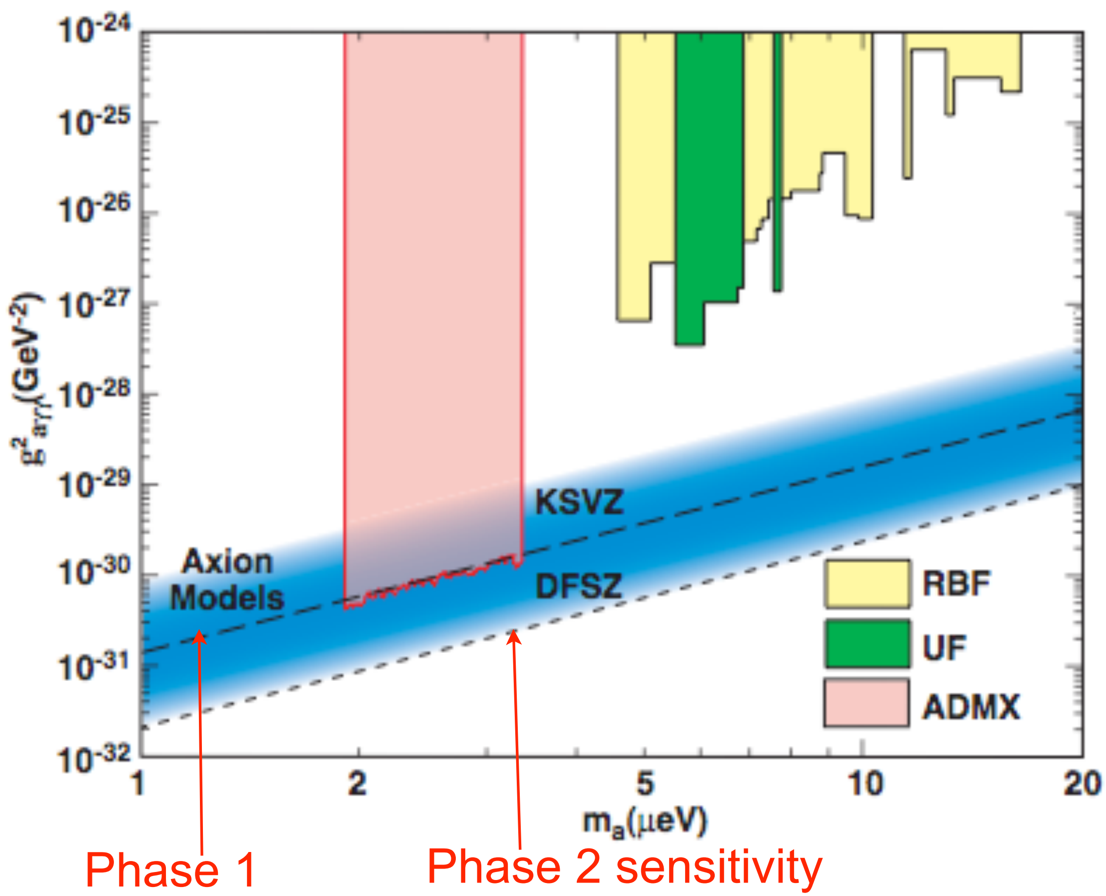
The diagram at right shows the layout of the axion search experiment now underway at the University of Washington. Axions would be detected as extra photons in the Microwave Cavity.



AXION search

The Strong CP Problem. The standard SU(3) theory of the Strong force violates CP conservation, for example predicting that the neutron has an electric dipole moment 10^8 times bigger than the current upper limit, unless an uncalculable parameter is very small. The only elegant solution to this "Strong CP Problem" involves a new particle that interacts so weakly that it has never been detected before. This particle is the Axion. Fortunately this particle would interact with other particles just enough that if you went looking for it very carefully, you might be able to find it.

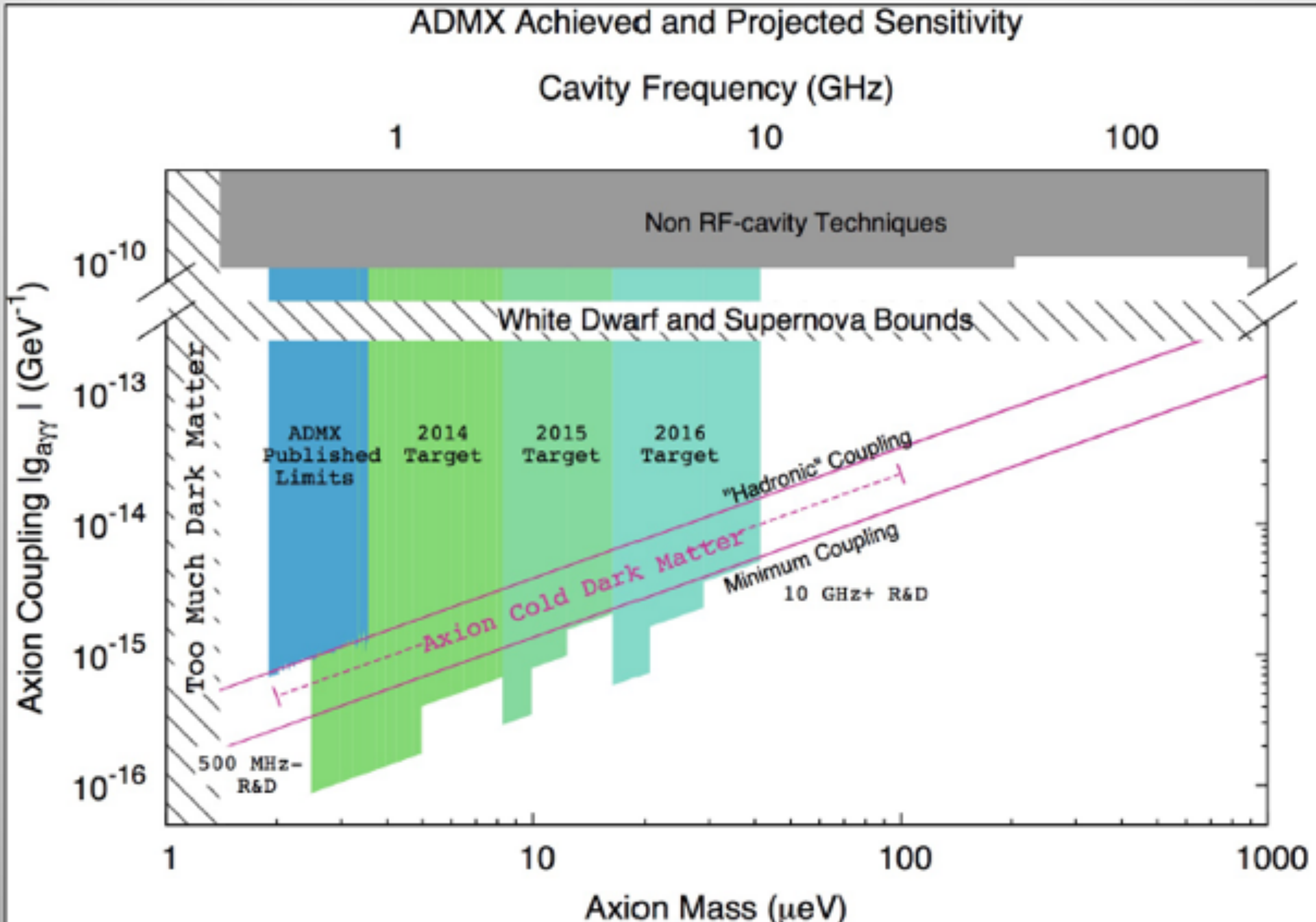
The **Axion DM Experiment (ADMX)** is designed to look into only a slice of the allowed mass range. The reason it's only a slice and not the whole range is simply due to the equipment. The frequency that is scanned by ADMX depends on the tuning rods and the resonant cavity. Making the apparatus able to scan a larger frequency range would have cost more and made the apparatus bigger, which makes cooling and transportation harder, among other things. As to why it is that particular slice, it's because it's the most convenient one to look in. There's no significant reason to believe that the Axion would be more likely to be in any particular range, so this one was chosen based on it being easiest to scan with current technology.



ADMX Upgrade

Gianpaolo Carosi

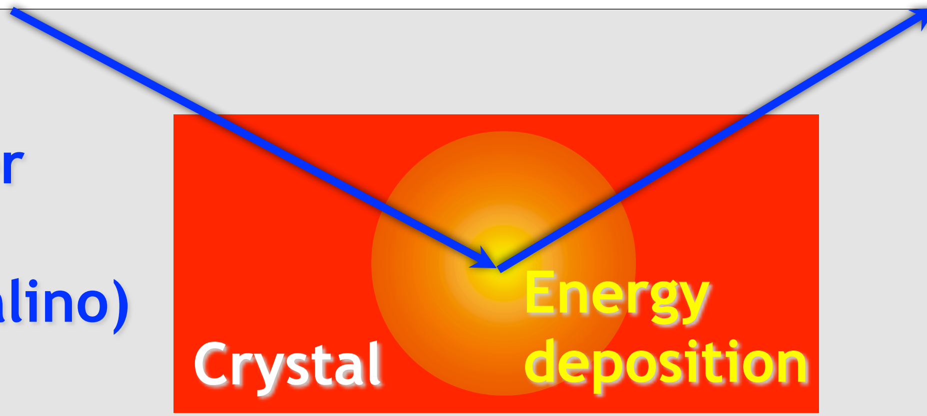
UCLA Dark Matter Symposium 2014



Search for Neutralino Dark Matter

Direct Method (Laboratory Experiments)

Galactic dark matter particle (e.g.neutralino)

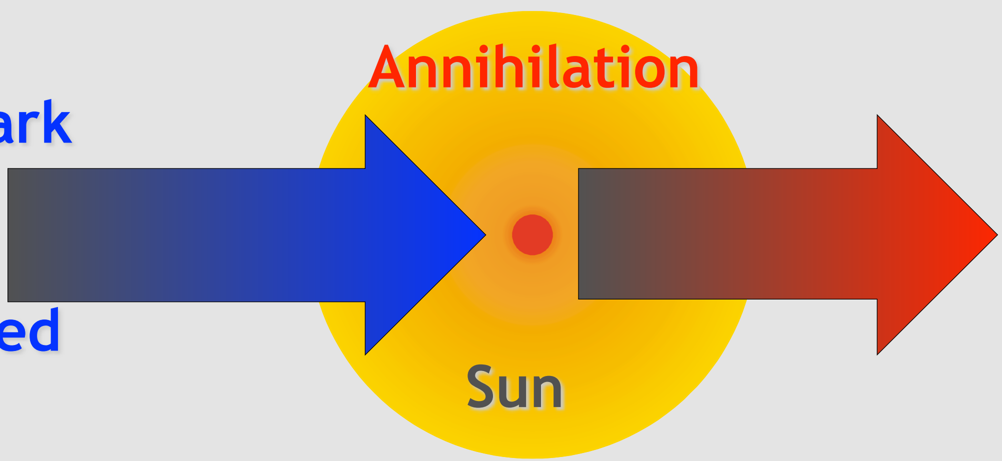


Recoil energy (few keV) is measured by

- Ionisation
- Scintillation
- Cryogenic

Indirect Method (Neutrino Telescopes)

Galactic dark matter particles are accreted



High-energy neutrinos (GeV-TeV) can be measured

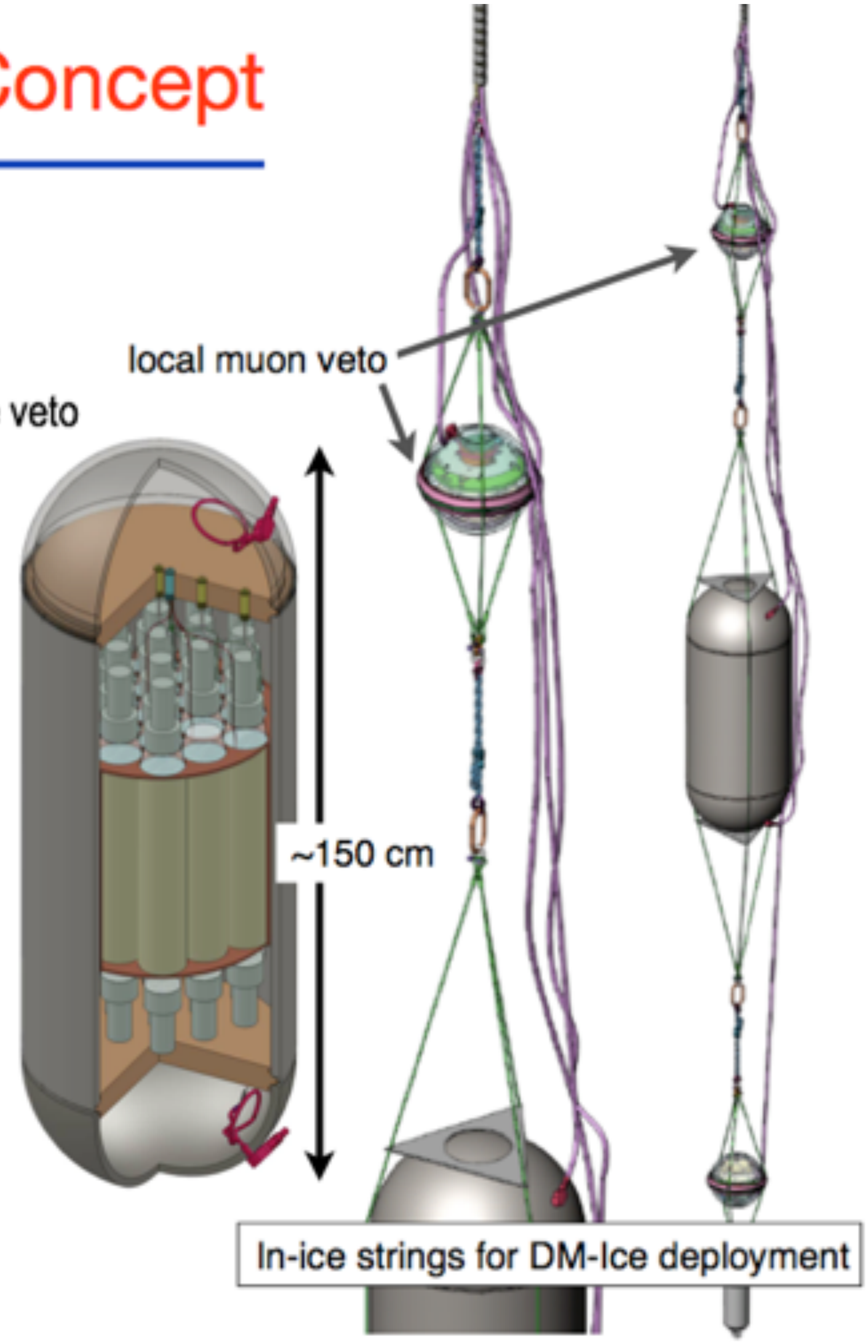
DM-Ice Concept

Detector
- 250–500 kg NaI(Tl)
- Closely-packed inside pressure vessel for coincidence veto
- Two PMTs/Crystal

Location
- South Pole, ~ 2500 m deep in the ice
- Near the center of IceCube for additional veto

Pressure vessel
- Withstand > 7000 psi of freeze-back pressure
- Low-background stainless steel
- Low background copper shielding where needed

Electronics
- Pulse digitization inside the vessel
- Power from SP Station or IceCube Counting Lab
- Remotely controllable

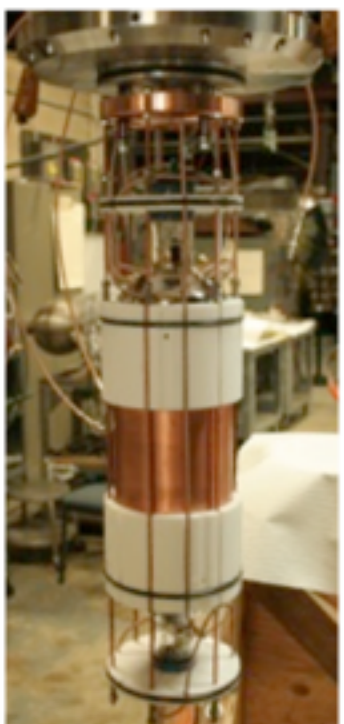


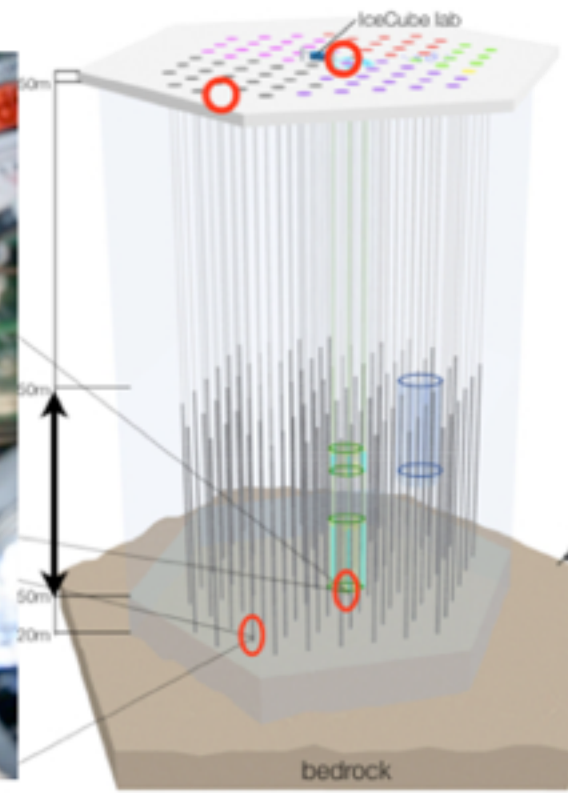
Slide from Reina Maruyma,
DM2012

DM-Ice-17 (kg)

Slide reformatted from Reina Maruyma, DM2012

- 17 kg of NaI(Tl) (formerly part of NaIAD) deployed as a feasibility study at the South Pole Dec. 2010
- Continuous operation since Jan. 2011
- Data transmitted via satellite
- Analysis underway





First Data from DM-Ice17

J. Cherwinka[a], D. Grant[b], F. Halzen[c], K. M. Heeger[c,f], L. Hsu[d], A. J. F. Hubbard[c], A. Karle[c], M. Kauer[c], V. A. Kudryavtsev[e], R. H. Maruyama[c,f,*], C. MacDonald[e], S. Paling[h], W. C. Pettus[c], Z. P. Pierpoint[c], B. N. Reilly[c], M. Robinson[e], P. Sandstrom[c], N. J. C. Spooner[e], S. Telfer[e], L. Yang[g]

(The DM–Ice Collaboration)

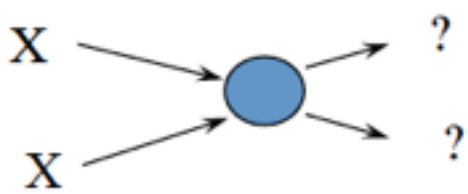
[a]*Physical Sciences Laboratory, University of Wisconsin, Stoughton WI, USA*
[b]*Department of Physics, University of Alberta, Edmonton, Alberta, Canada*
[c]*Department of Physics and Wisconsin IceCube Particle Astrophysics Center, University of Wisconsin-Madison, Madison, WI, USA*
[d]*Fermi National Accelerator Laboratory, Batavia, IL, USA*
[e]*Department of Physics and Astronomy, University of Sheffield, Sheffield, UK*
[f]*Department of Physics, Yale University, New Haven, CT, USA*
[g]*Department of Physics, University of Illinois at Urbana-Champaign, Urbana, IL, USA*
[h]*STFC Boulby Underground Science Facility, Boulby mine, Cleveland, TS13 4UZ, UK*

Abstract

We report the first analysis of background data from DM-Ice17, a direct-detection dark matter experiment consisting of 17 kg of NaI(Tl) target material. It was successfully deployed 2457 m deep in South Pole glacial ice at the bottom of two IceCube strings in December 2010 and is the first such detector to be operating in the Southern Hemisphere. Data from the first two years of operation after commissioning, July 2011 – June 2013, are presented here. The background rate in the 6.5 – 8.0 keV_{ee} region is measured to be 7.9 ± 0.4 counts/day/keV/kg. This is in agreement with the expected background from the crystal assemblies and is consistent with simulation. Background contributions from the surrounding ice were demonstrated to be negligible. The successful deployment and operation of DM-Ice17 establishes the South Pole ice as a location for future underground, low-background experiments in the Southern Hemisphere. The detector assembly, deployment, and analysis of the DM-Ice17 backgrounds are described.

Indirect Detection of Dark Matter

Some important models in particle physics could also solve the dark matter problem in astrophysics. If correct, these new particle interactions could produce an anomalous flux of cosmic particles ("indirect detection").



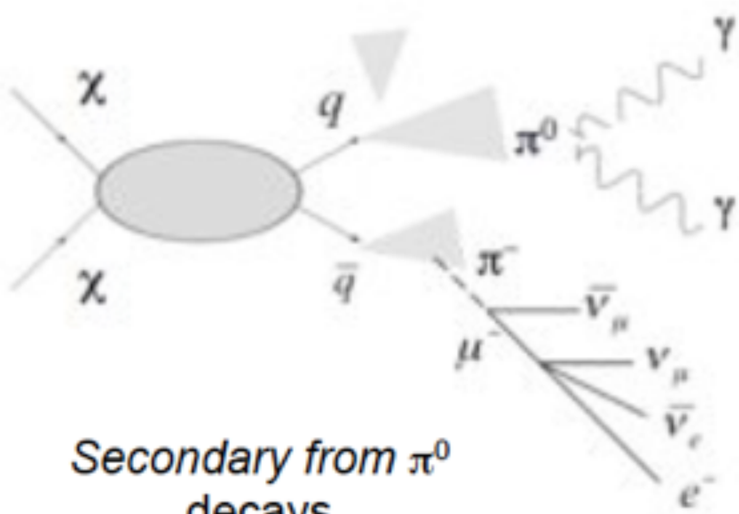
Anomalous gamma ray spectra and/or $\gamma\gamma$ or $Z\gamma$ "lines" and/or anomalous charged cosmic rays and/or neutrinos?

- If particles are stable: rate ~ (DM density)^2
- If particles unstable: rate ~ (DM density)

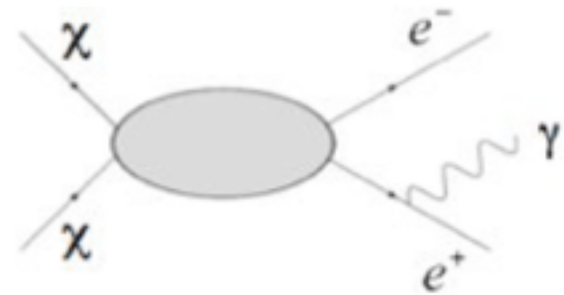
- Key interplay of techniques:
  - colliders (TeVatron, LHC)
  - direct detection experiments underground
  - indirect detection (most straightforward: gamma rays and neutrinos)
    - Full sky coverage look for clumping throughout galactic halo, including off the galactic plane (if found, point the way for ground-based facilities)
    - Intensity highly model-dependent
    - **Challenge is to separate signals from astrophysical backgrounds**

Steve Ritz

Gamma rays from Dark Matter annihilation



Secondary from π^0 decays



Prompt lepton pair production

+ "lines" from 2-body final states

$$\Phi_{WIMP}(E,\Psi)=J(\Psi)\times\Phi^{PP}(E)$$

Astrophysical factor

$$J(\Psi)=\int_{l.o.s} dl(\Psi)\,\rho^2(l)$$

Particle physics factor

$$\Phi^{PP}(E)=\frac{1}{2}\frac{\langle\sigma v\rangle}{m^2_{WIMP}}\sum_f \frac{dN_f}{dE}B_f$$

Steve Ritz

Dark Matter: Many Places to Look!

Galactic Center

Good Statistics but source confusion/diffuse background

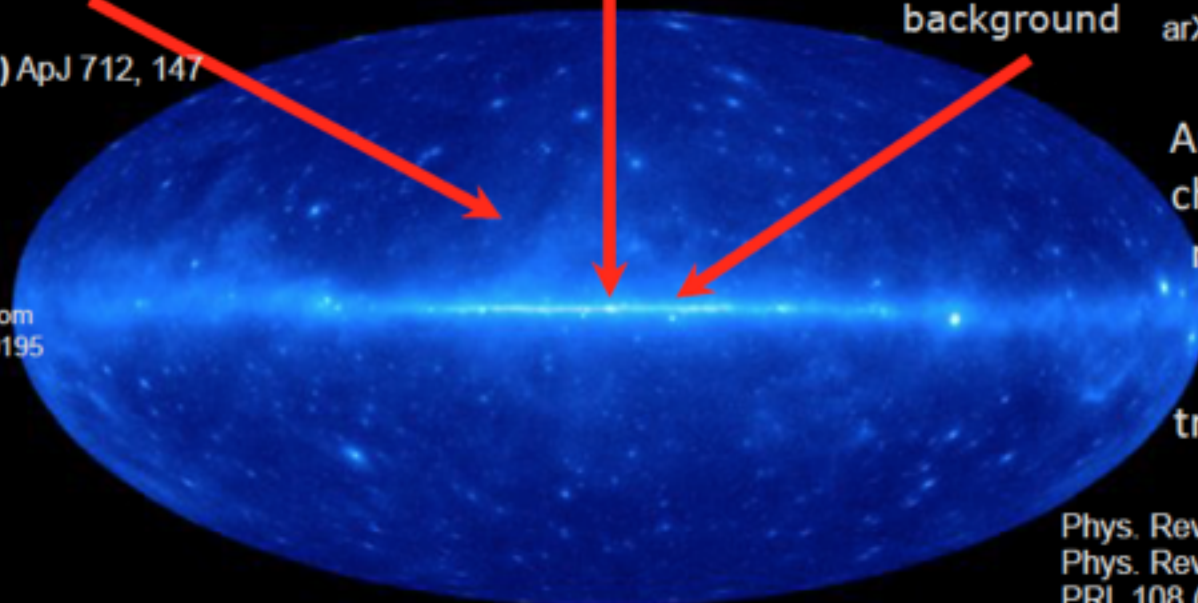
Satellites

Low background and good source id, but low statistics, in some cases astrophysical background

JCAP 1204 (2012) 016
ApJ 747, 121 (2012)
PRL 107, 241302 (2011) ApJ 712, 147 (2010)
JCAP 01 (2010) 031
ApJ 718, 899 (2010)

Milky Way Halo

Large statistics but diffuse background arXiv:1205.6474



All-sky map of gamma rays from DM annihilation arXiv:0908.0195 (based on Via Lactea II simulation)

And anomalous charged cosmic rays (little/no directional information, trapping times, etc.)

Phys. Rev. D84, 032007 (2011
Phys. Rev. D82, 092003 (2010
PRL 108 (2012)

Spectral Lines

No astrophysical uncertainties, good source id, but low sensitivity because of expected small BR

Phys. Rev. D, In press (2012)
Phys. Rev. Lett. 104, 091302 (2010)

Galaxy Clusters

Low background, but low statistics
JCAP 05 (2010) 025

Extragalactic

Large statistics, but astrophysics, galactic diffuse background JCAP 04 (2010) 014

Steve Ritz

Gamma-Ray Searches with Fermi

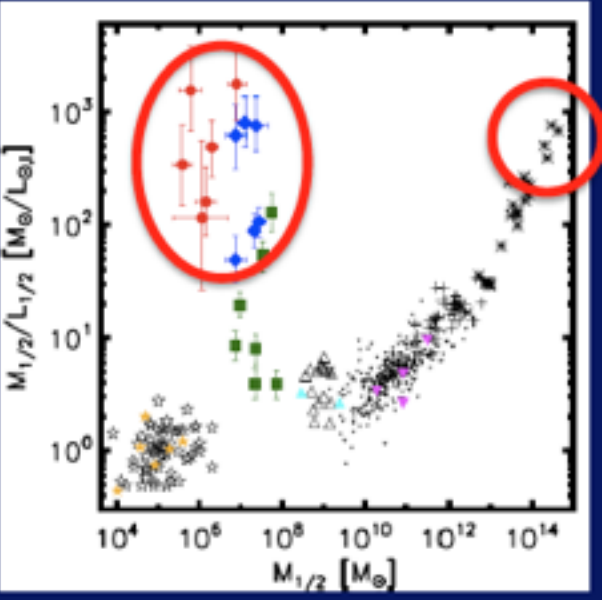
Dwarf spheroidal galaxies give strong constraints on dark matter annihilation.

Clusters of galaxies constrain:

- dark matter decay
- leptophilic dark matter when IC emission dominate (models fitting the PAMELA positron excess)

(Abdo et al. 2010; Ackermann et al. 2010; Dugger, Jeltema, & Profumo 2010; Ackermann et al. 2011)

dwarfs clusters

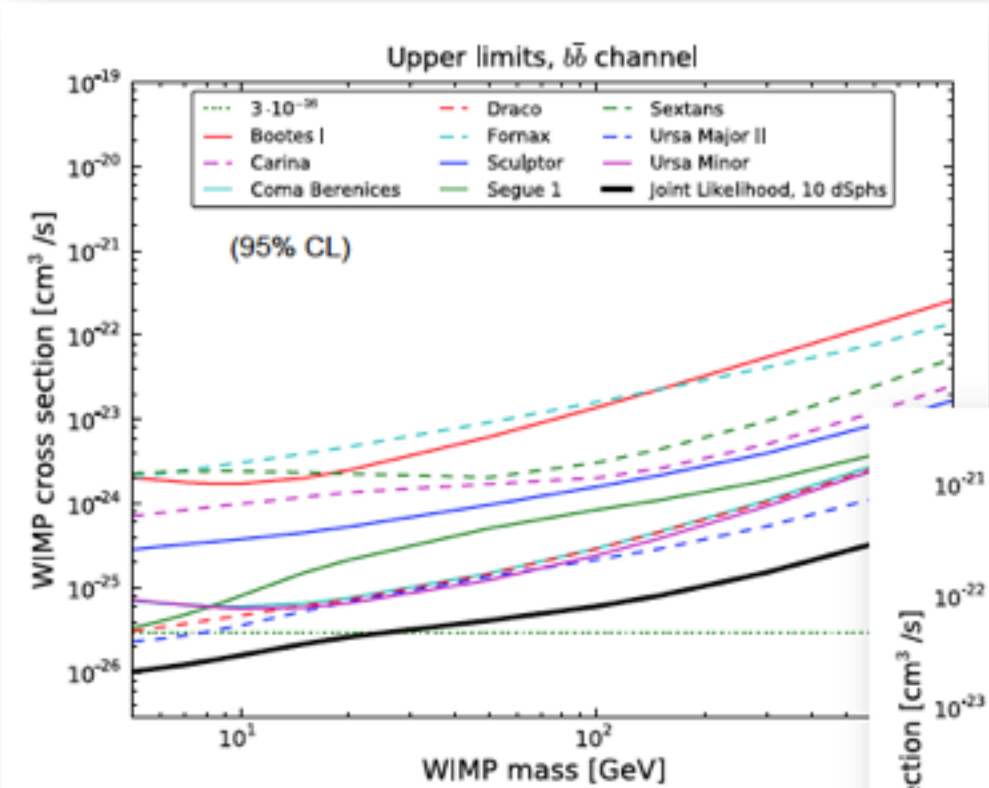


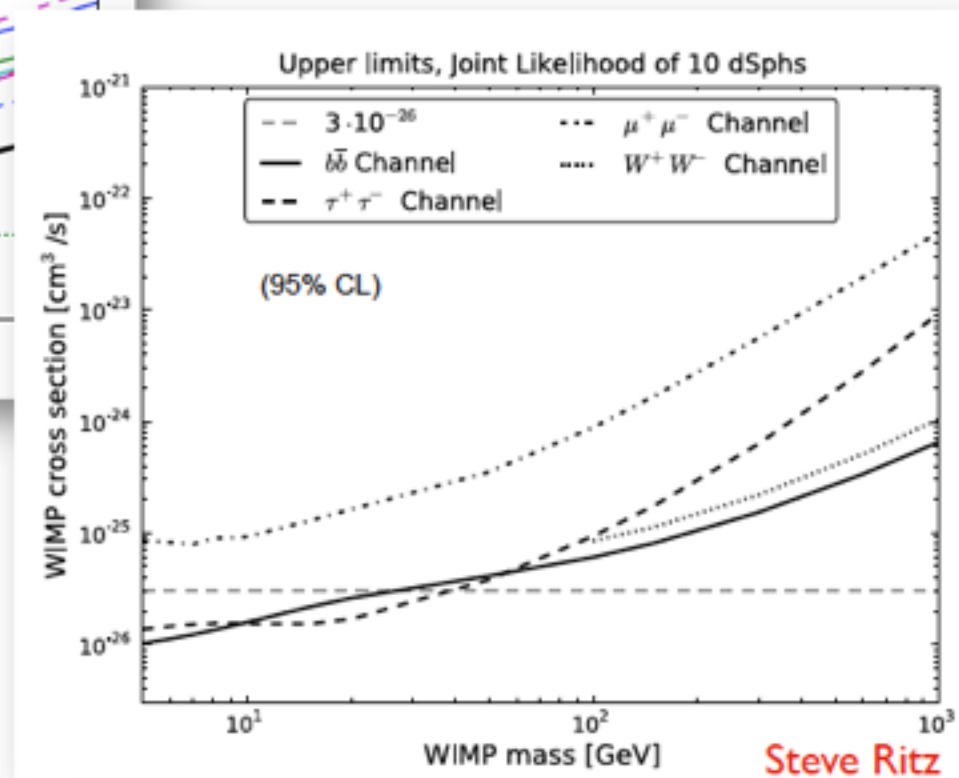
Wolf et al. 2009

Tesla Jeltema

Combining dSph Limits

PRL 107(2011)
arXiv:1108.3546v2



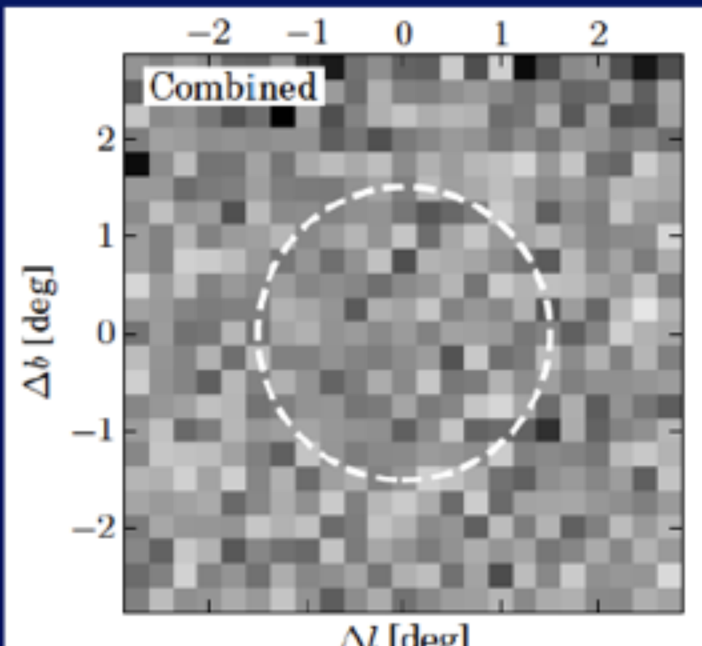


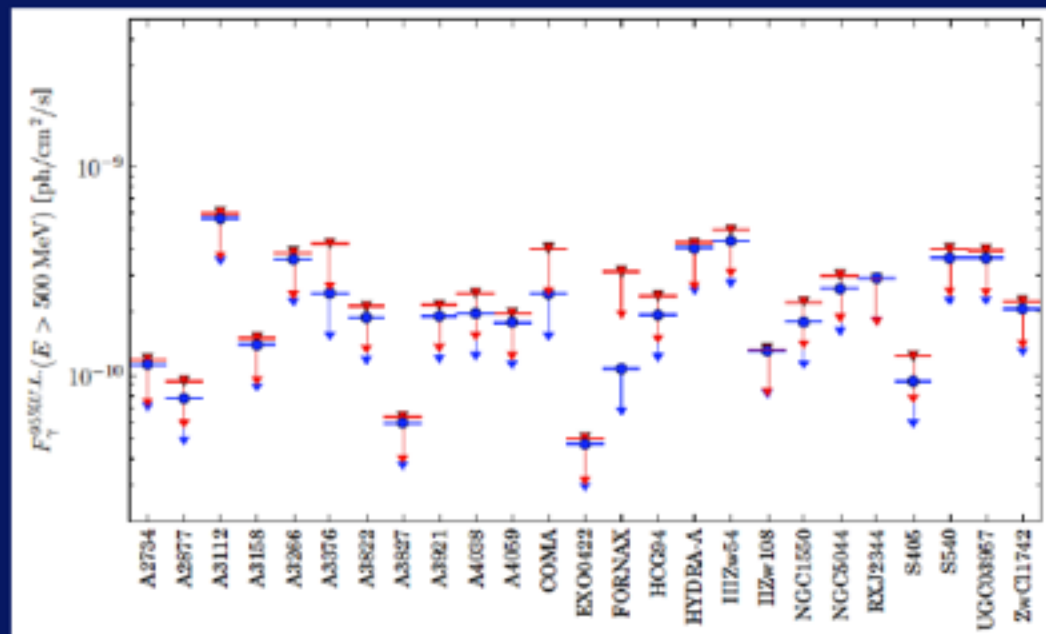
Now getting to very interesting sensitivity ranges!

Steve Ritz

Upcoming from Fermi: Cluster Stacking

- Fermi does not detect gamma-ray emission from clusters even for a joint fit of 50 clusters with 4 years of data.



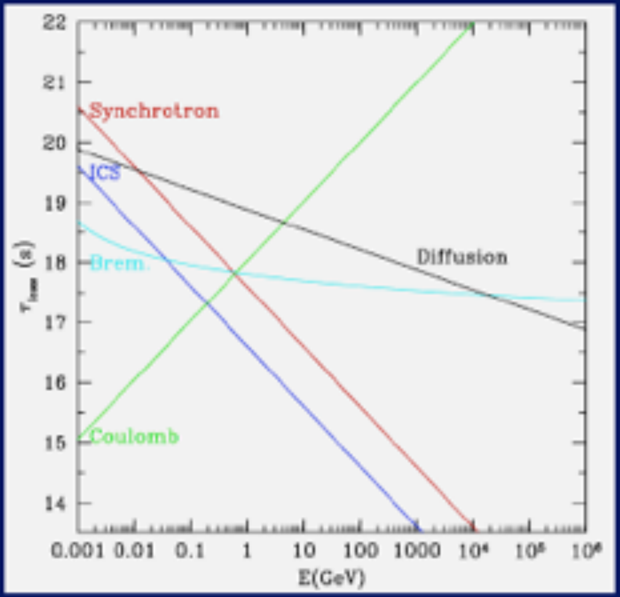


Ackermann et al. 2013, arXiv:1308.5654

Tesla Jeltema

Multiwavelength Dark Matter Searches

- Clusters are excellent targets for searches for secondary synchrotron and IC radiation:
  1. The energy loss timescale is much shorter than the diffusion time
  2. They have large-scale magnetic fields



Colafrancesco et al. 2006

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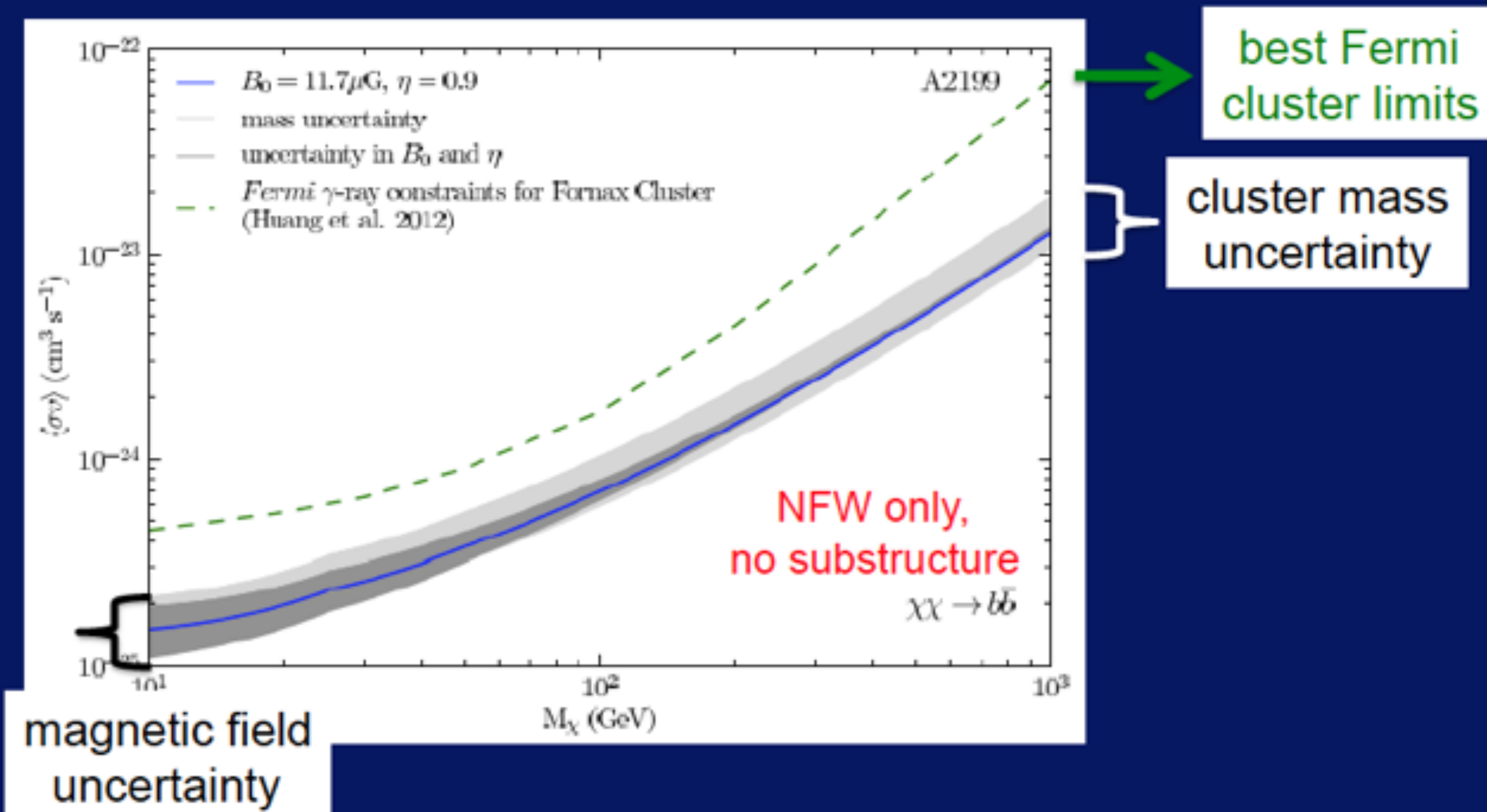
Dark Matter Annihilation Limits



Storm, Jeltema, Profumo, & Rudnick 2013

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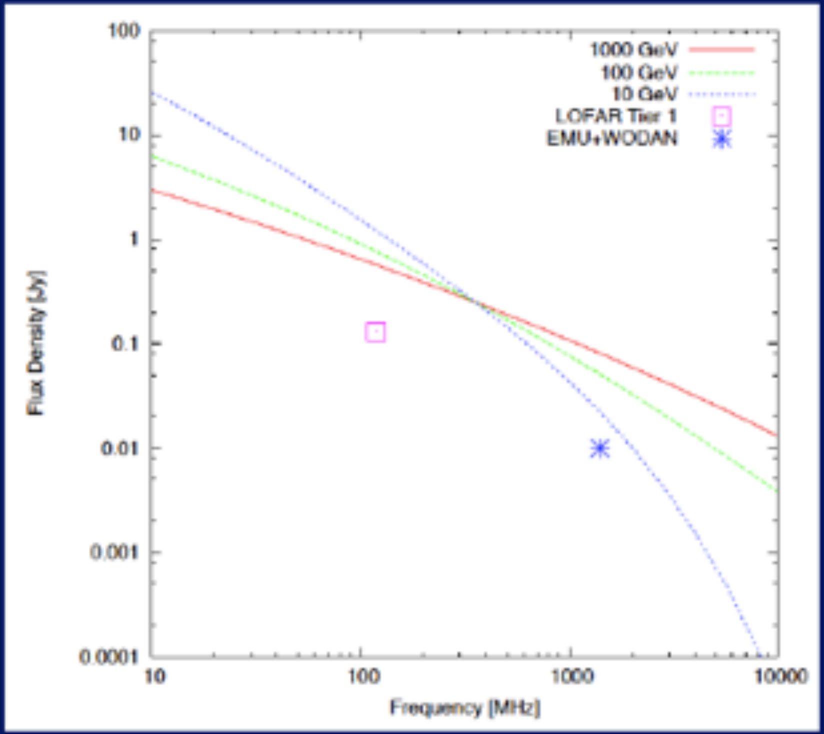
Future Radio Observations

Large near term gains from:

- New low frequency capabilities (LOFAR, LWA)
- Increased sensitivity at GHz frequencies (ASKAP, APERTIF, MeerKAT)



Order of magnitude gains from planned surveys alone!

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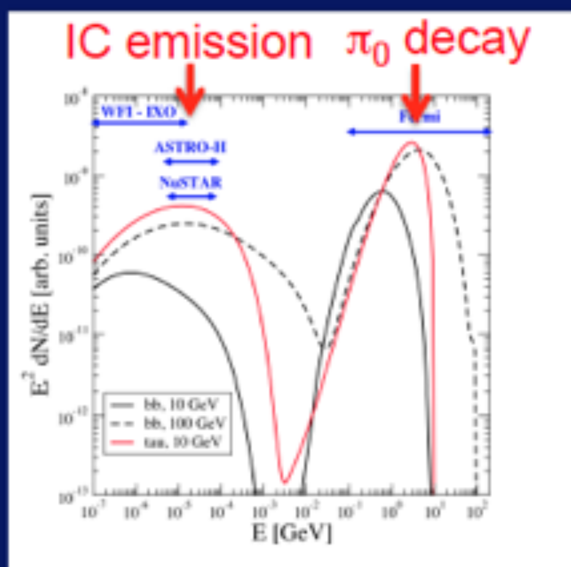
X-ray Emission from Dark Matter

- For a range of DM models, IC emission from the scattering of the CMB by the e^+ e^- produced peaks in the hard X-ray band.
- Again clusters are a good target – diffusion negligible, thermal X-ray emission drops off steeply at high energy



Jeltema & Profumo 2012

- Planned X-ray telescopes will have (at best) similar sensitivity to Fermi.

Dark Matter Summary

- Observations of clusters across the electromagnetic spectrum can probe dark matter models

- Gamma-ray: Strong constraints on decay and leptophilic models, upcoming gains from stacking

- Radio: Current constraints are competitive with gamma-ray in some cases, and new facilities are imminent

- X-ray: limits are not currently competitive, but could be with an appropriately planned telescope.

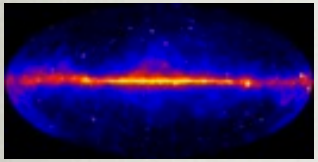
- A multiwavelength approach is highly complementary to future high energy gamma-ray searches

Tesla Jeltema

Understanding the Gamma-ray Sky

Simona Murgia
University of California, Irvine

UCLA Dark matter
26-28 February 2014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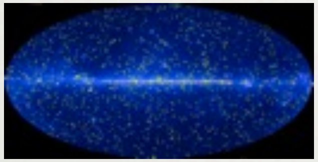
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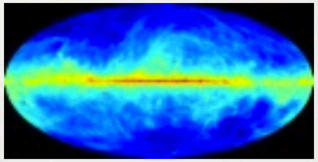
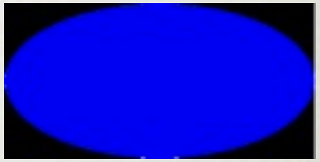

galactic diffuse

+


isotropic

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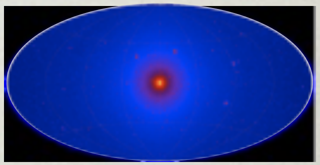
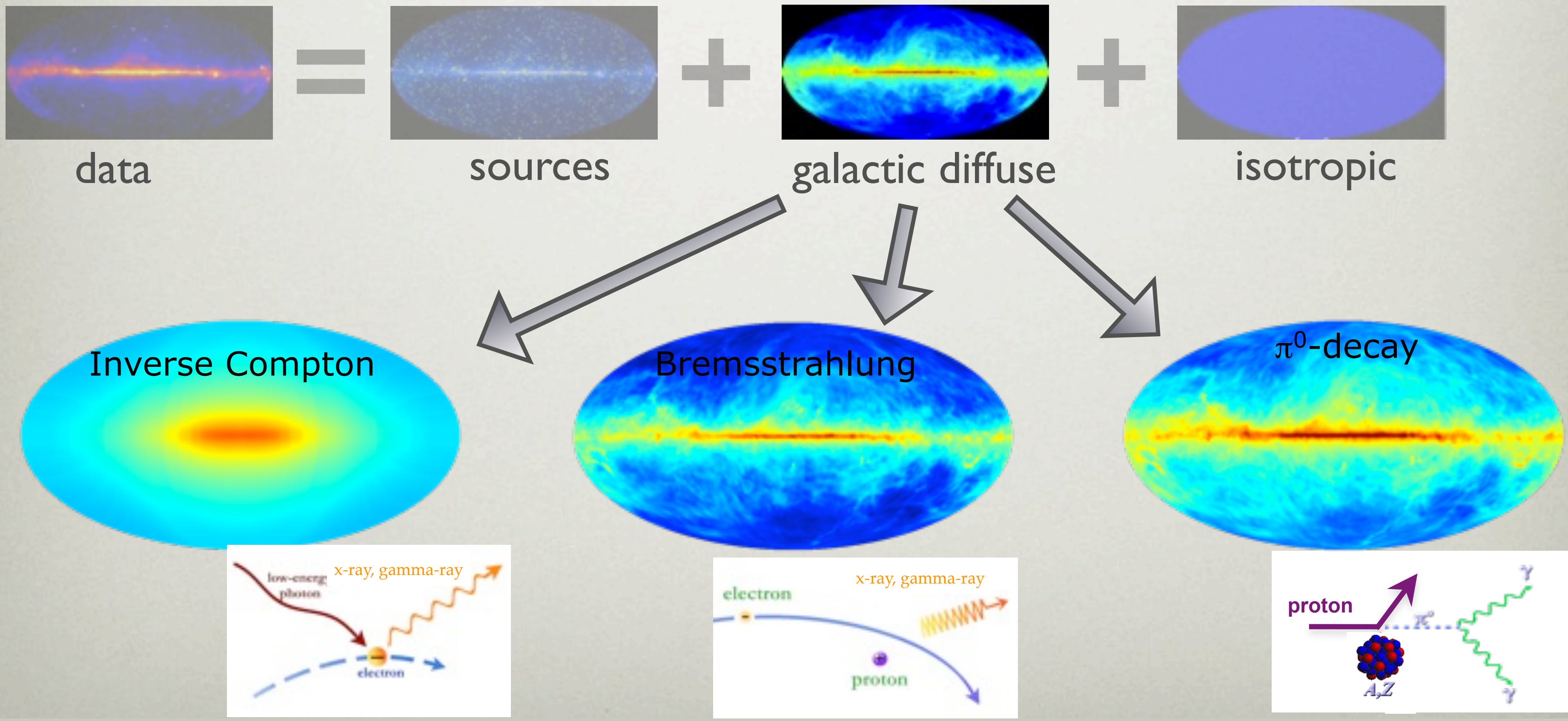

dark matter??

Galactic Diffuse Emission

- The diffuse gamma-ray emission from the Milky Way is produced by cosmic rays interacting with the interstellar gas and radiation field and carries important information on the acceleration, distribution, and propagation of cosmic rays.



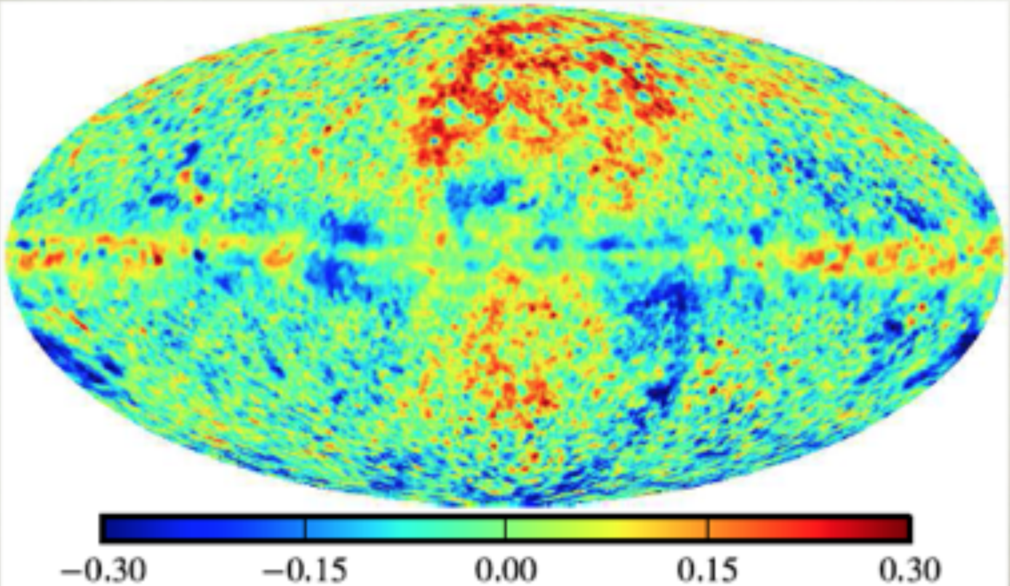
All Sky Modeling

- Cosmic ray origin, propagation, and properties of the interstellar medium can be constrained by comparing the data to predictions.
- Generate models (in agreement with CR data) varying CR source distribution, CR halo size, gas distribution (GALPROP, http://galprop.stanford.edu) and compare with Fermi LAT data (21 months, 200 MeV to 100 GeV, P6 DATACLEAN)

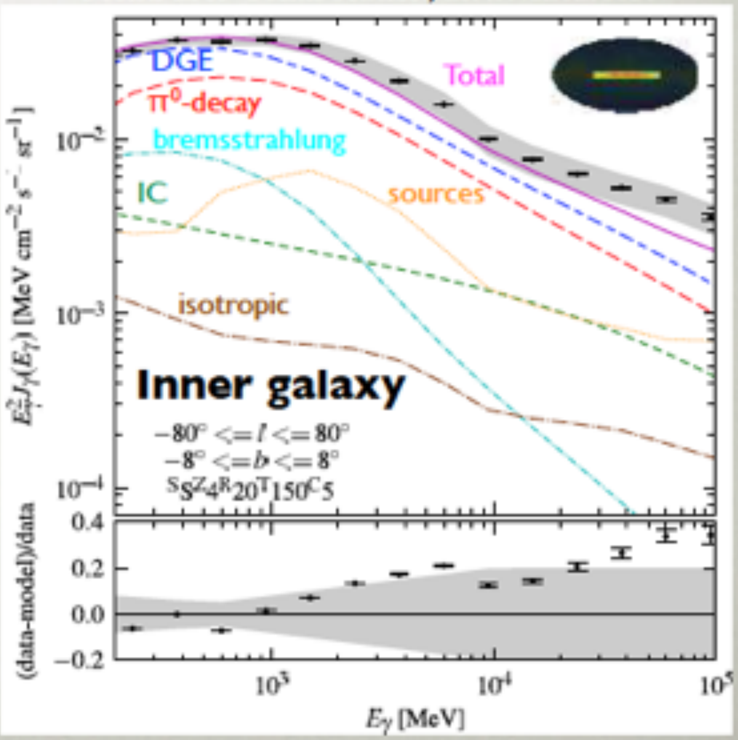
On a large scale the agreement between data and prediction is overall good, however some extended excesses stand out.

(data - prediction)/prediction) for example model

Fermi LAT Collaboration, arXiv:1202.4039

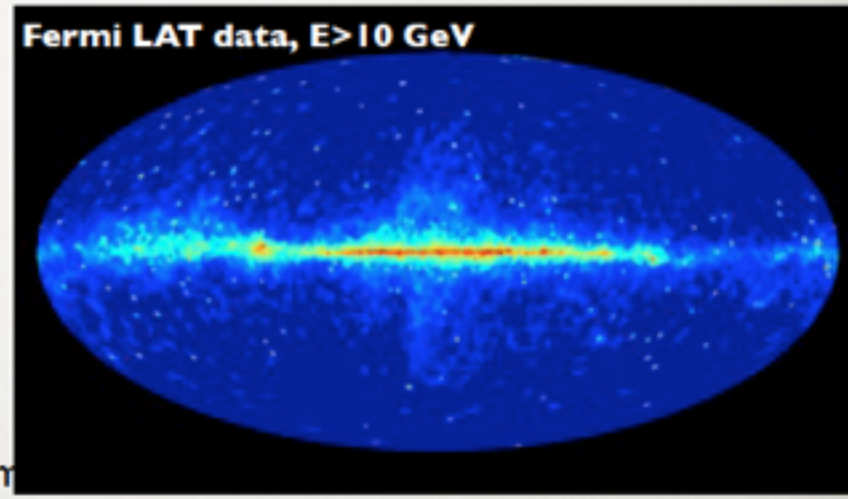


Fermi LAT Collaboration, arXiv:1202.4039



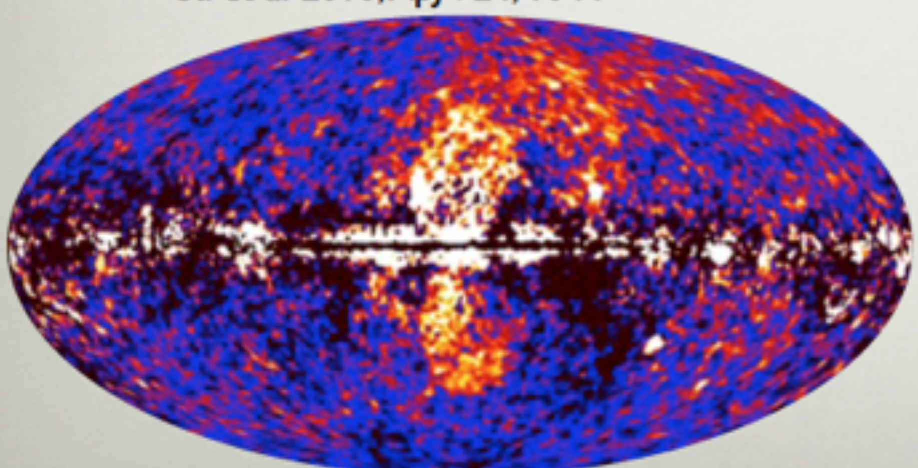
Extended Lobe-like Features in the Fermi Sky

- Gamma-ray bubbles (Su et al 2010, ApJ 724, 1044):
  - very extended (~ 50° from plane)
  - hard spectrum (~E^{-2}, 1-100 GeV)
  - sharp edges
  - possible counterparts in other wavelengths (ROSAT, WMAP, and Planck)

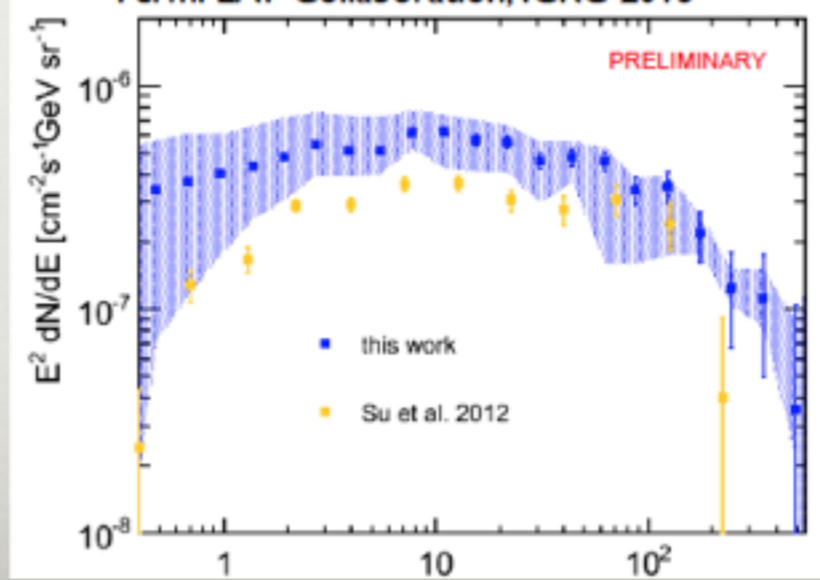


- Outflow from the center of the Milky Way: jets from the supermassive black hole? starburst?

Su et al 2010, ApJ 724, 1044



Fermi LAT Collaboration, ICRC 2013



Galactic Center Region

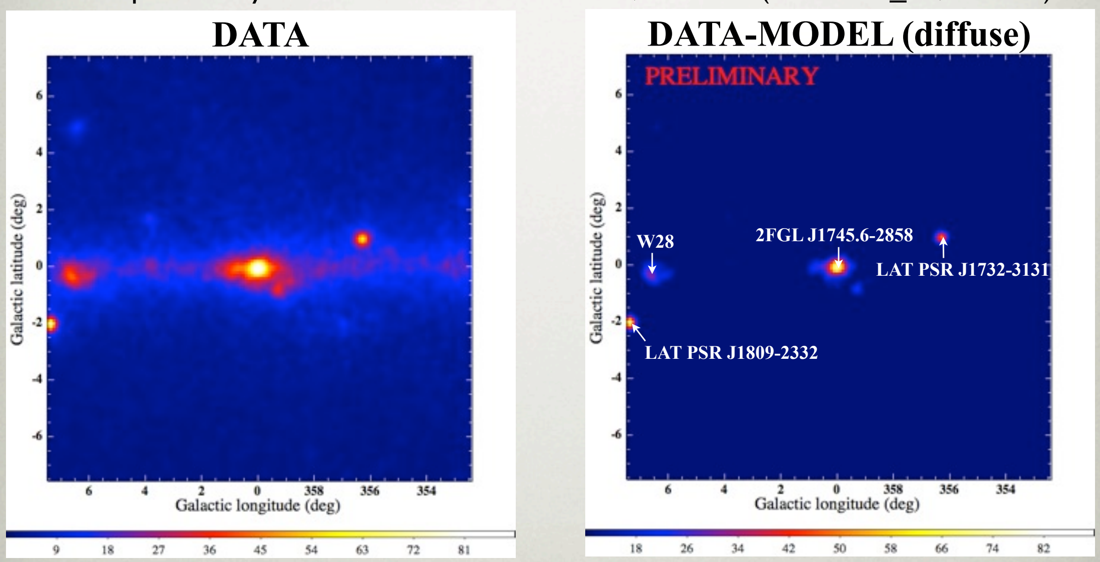
☺ Steep DM profiles predicted by CDM ⇒ Large DM annihilation/decay signal from GC!

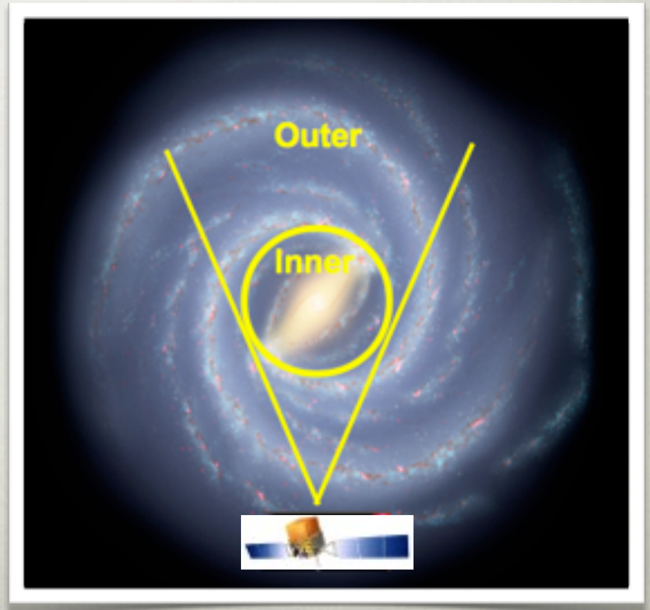
☹ Good understanding of the conventional astrophysical background is crucial to extract a potential DM signal from this complex region of the sky:

- source confusion: many energetic sources near to or in the line of sight of the GC
- diffuse emission modeling: large uncertainties due to the overlap of structures along the line of sight, difficult to model

Fermi's View of the Inner Galaxy (15°x15° region)

Fermi LAT preliminary results with 32 months of data, E>1 GeV (P7CLEAN_V6, FRONT):



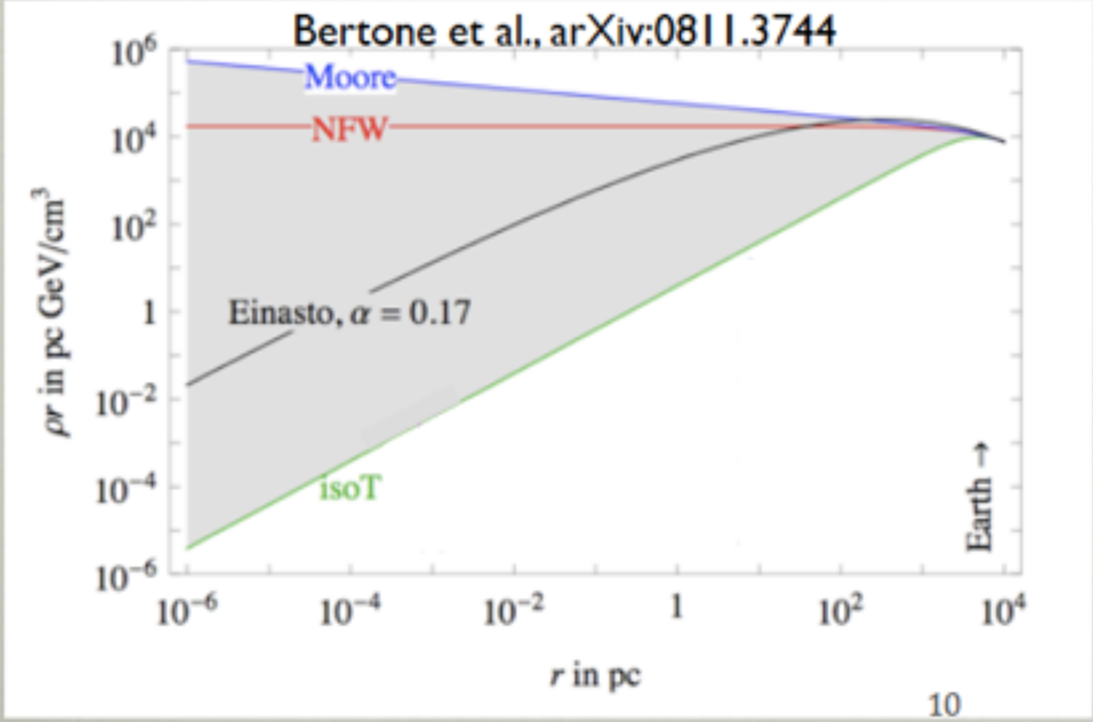


- Galactic diffuse emission model: all sky GALPROP model tuned to the inner galaxy

➡ Bright excesses after subtracting diffuse emission model are consistent with known sources.

Dark Matter Distribution

- The dark matter annihilation (or decay) signal strongly depends on the dark matter distribution.
- Cuspier profiles can provide large boost factors



10

NFW profile

Navarro, Frenk, and White 1997

$$\rho(r) = \rho_0 \frac{r_0}{r} \frac{(1 + r_0/a_0)^2}{(1 + r/a_0)^2}$$

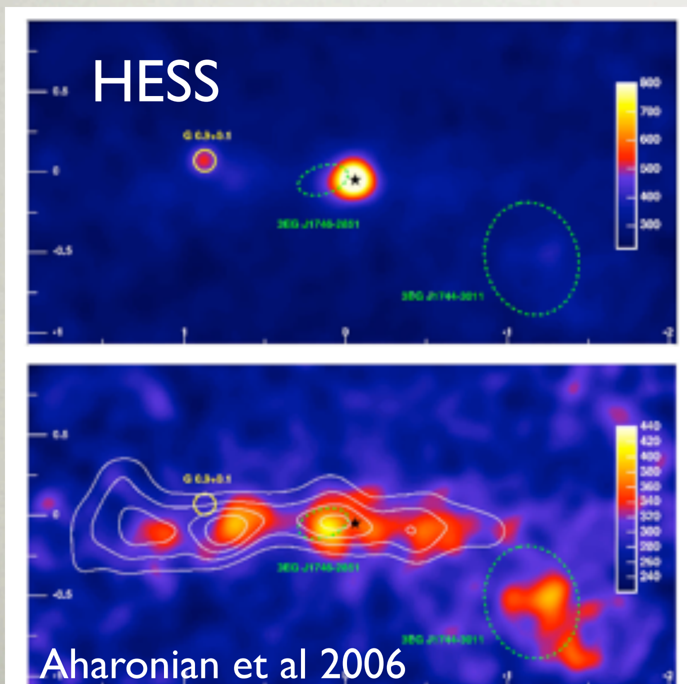
$$\rho_0 = 0.3 \text{ GeV/cm}^3$$
$$a_0 = 20 \text{ kpc}, \; r_0 = 8.5 \text{ kpc}$$

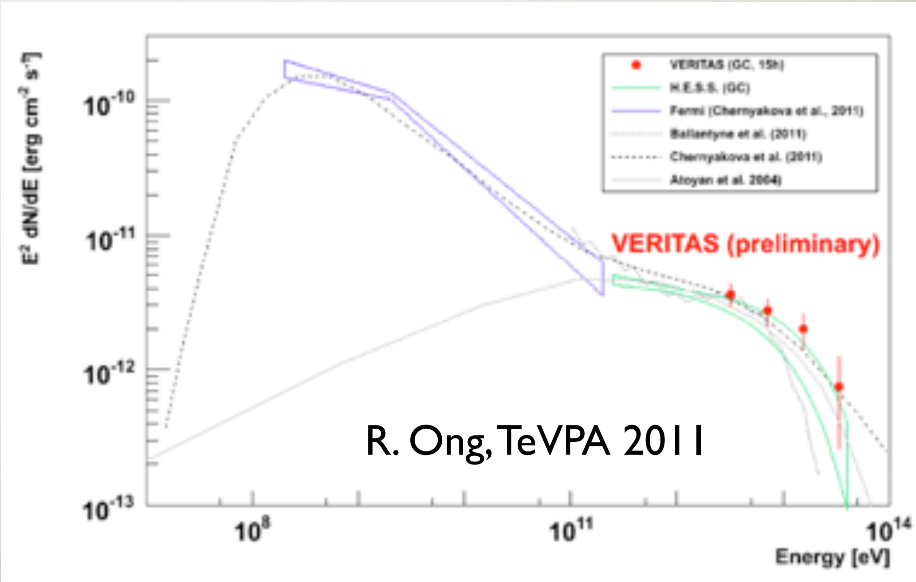
✓ Via Lactea II (Diemand et al 2008) predicts a cuspier profile, $\rho(r) \propto r^{-1.2}$

✓ Aquarius (Springel et al 2008) predicts a shallower than r^{-1} innermost profile

Galactic Center Source: GeV/TeV

- GeV/TeV spectrum compatible with gamma-ray production from protons accelerated in Sgr A* and diffusing in the interstellar medium
- No time variability

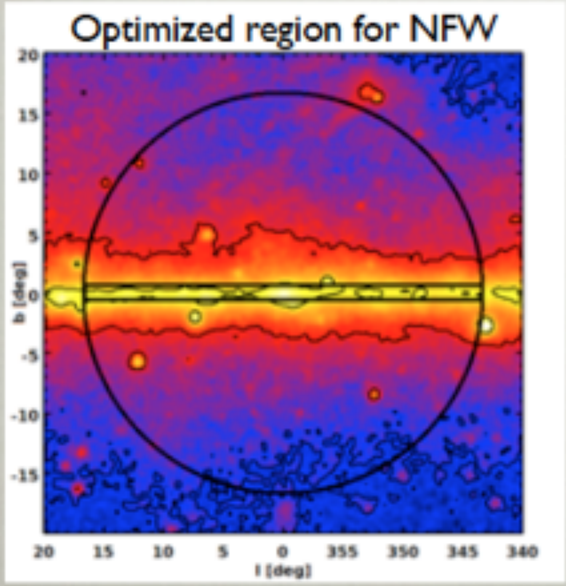


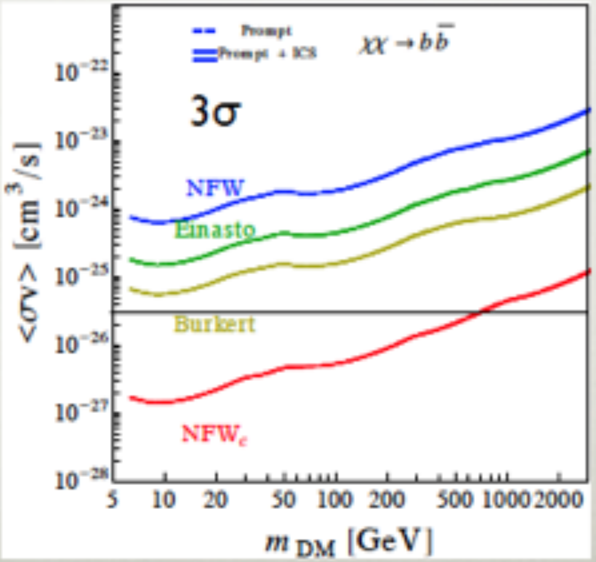


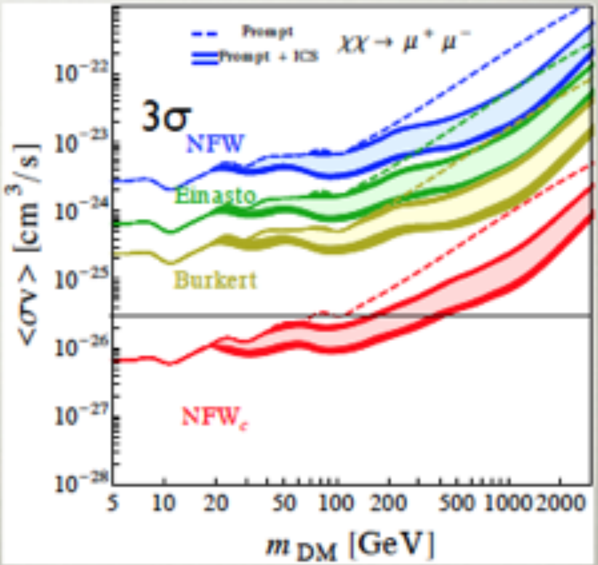
Inner Galaxy - DM Constraints

Fermi LAT Collaboration, arXiv:1308.3515

- Use LAT data from the inner Galaxy to constrain DM by requiring that the DM contribution doesn't exceed observed data
- Data: 46 months, 1-100 GeV, P7ULTRACLEAN_V6:: FRONT
- Competitive limits only for a contracted NFW profile

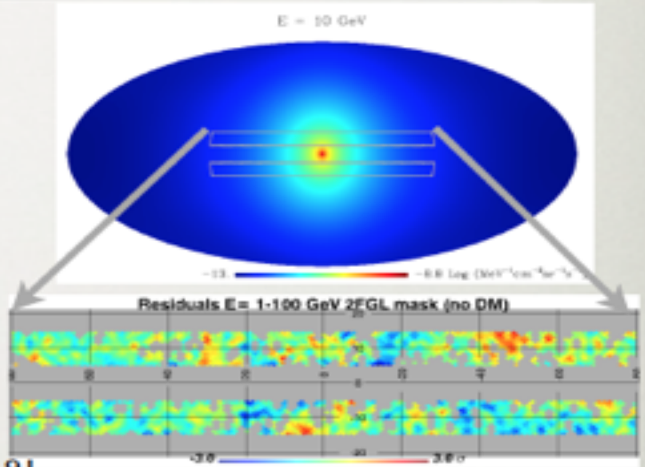




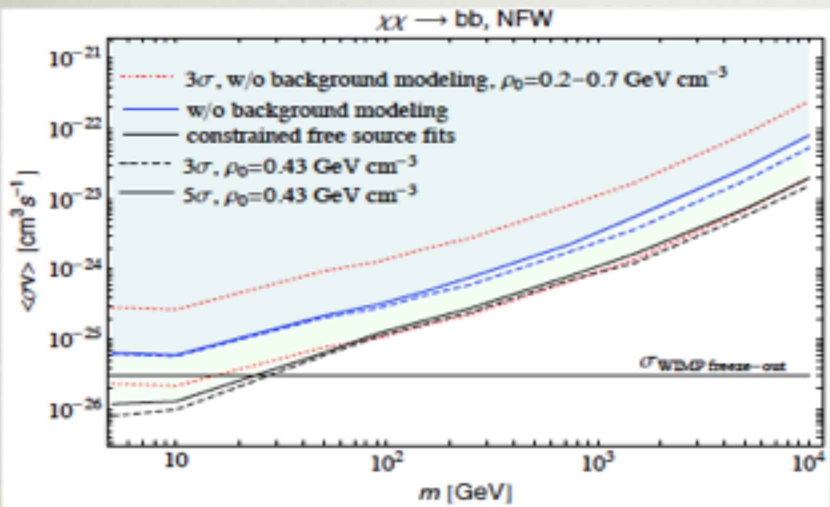


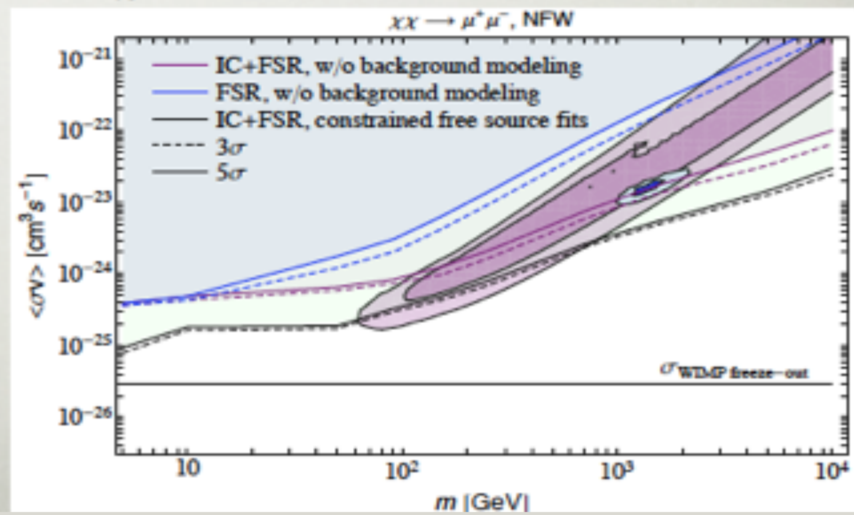
Galactic Halo

- Limit the analysis to regions of the galactic halo better described by the model.
- Robust limits can be determined by requiring that a DM contribution does not over-predict the data in these regions
- Data: 2 years, 1-100 GeV (w/ background modeling), 1-400 GeV (w/o background modeling)
- Constrains DM interpretation of Fermi/PAMELA electron and positron measurements. Significant improvements foreseen as modeling of the diffuse background improves



Fermi LAT Collaboration, 2012, ApJ, 761, 91





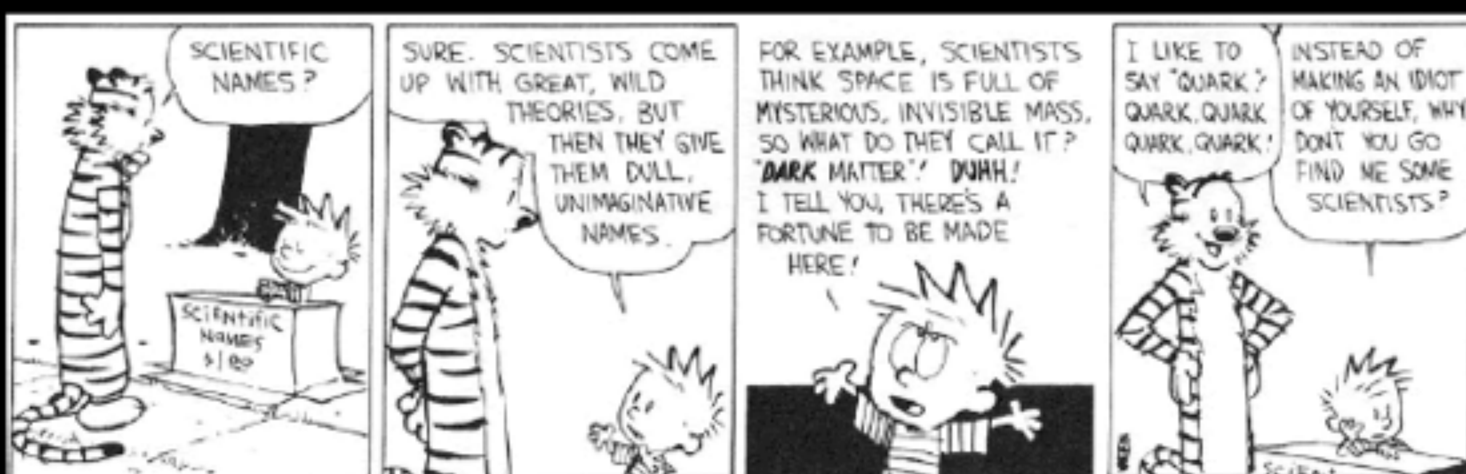
Conclusions

- Our knowledge of the conventional astrophysical background is uncertain. This is currently a big limitation for the search of dark matter in the Galactic center with gamma rays, which otherwise has huge potential for discovery or for setting constraints.
- In addition, better understanding of the dark matter density distribution in the Galactic center is essential in interpreting observations.

"Cold Dark Matter: An Exploded View" by Cornelia Parker

A few of my favorite slides from the DM2014 Conference at UCLA, Feb 2014

Slides at https://hepconf.physics.ucla.edu/dm14/agenda.html



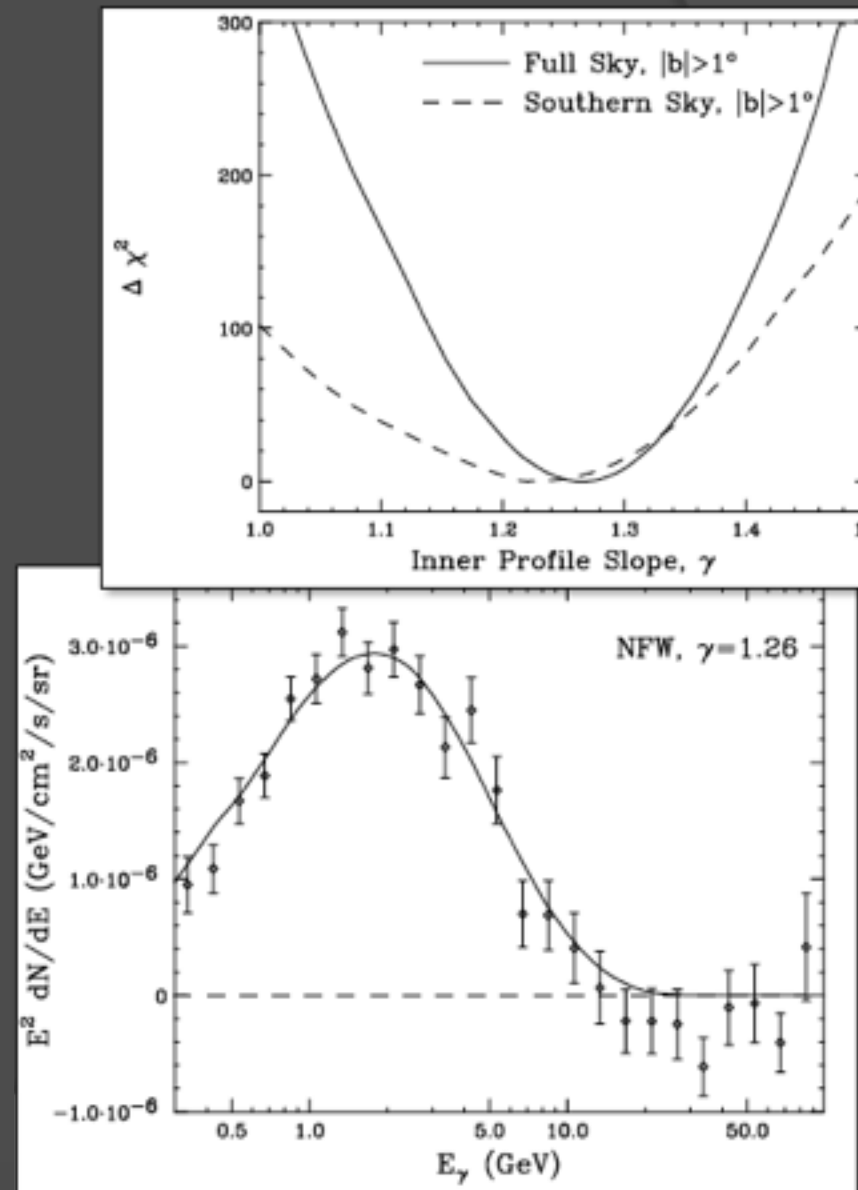
Basic Features of the GeV Excess

Dan Hooper's talk

The excess is distributed around the Galactic Center with a flux that falls off approximately as $r^{-2.4}$ (if interpreted as dark matter annihilation products, this implies $\rho_{DM} \sim r^{-1.2}$)

The spectrum of this excess peaks at ~1-3 GeV, and is in very good agreement with that predicted from a 30-40 GeV WIMP (annihilating to b quarks)

To normalize the observed signal with annihilating dark matter, a cross section of $\sigma v \sim (1\text{-}2) \times 10^{-26}$ cm^3/s is required (for $\rho_{local} = 0.3$ GeV/cm^3)



What's new?

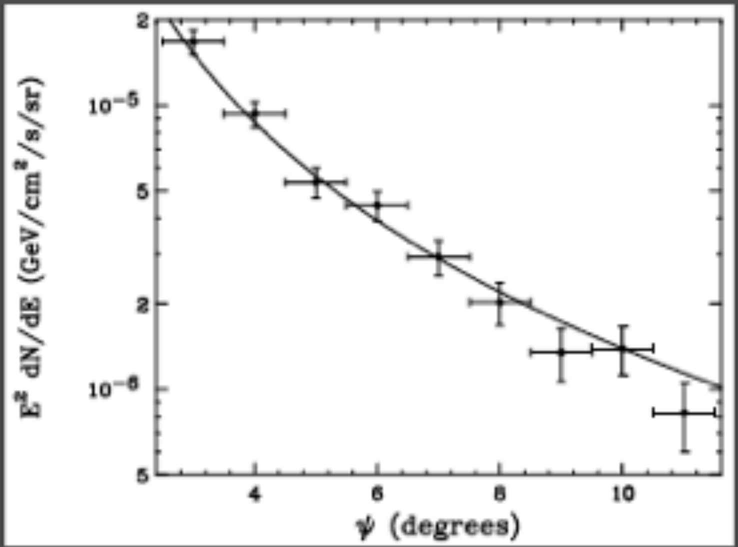
Why should we take this seriously?

Reason 1: Overwhelming Statistical Significance and Detailed Information

- This excess consists of ~10^4 photons per square meter, per year (>1 GeV, within 10° of the Galactic Center)
- In our Inner Galaxy analysis, the quality of the best-fit found with a dark matter component improves over the best-fit without a dark matter component by over 40 σ (the Galactic Center analysis "only" prefers a dark matter component at the level of 17 σ)
- This huge data set allows us to really scrutinize the signal, extracting its characteristics in some detail

Reason 2: The Signal is Well-Fit by Simple, Predictive Dark Matter Models

On the other hand, the Milky Way's gamma-ray excess is fit by very simple and predictive dark matter models. We tune only 1) the halo profile's slope, 2) the dark matter's mass, and 3) the dark matter's annihilation cross section and final state



Reason 3: The Lack of a Plausible Alternative Interpretation

This signal does not correlate with the distribution of gas, dust, magnetic fields, cosmic rays, star formation, or radiation

(It does, however, trace quite well the square of the dark matter density, for a profile slightly steeper than NFW)

No known diffuse emission mechanisms can account for this excess

Dan Hooper's talk

Summary

- We have revisited and scrutinized the gamma-ray emission from the Central Milky Way, as observed by Fermi
- The previously reported GeV excess persists, and is highly statistically significant and robust
- The spectrum and angular distribution of this signal is very well fit by a 31-40 GeV WIMP (annihilating to b quarks), distributed as $\rho \sim r^{-1.2}$
- The normalization of this signal requires a dark matter annihilation cross section of $\sigma v \sim (1.4\text{-}2.0) \times 10^{-26}$ cm^3/s (for $\rho_{local} = 0.3$ GeV/cm^3); this is in remarkable agreement with the value predicted for a simple thermal relic
- The excess is distributed with approximate spherical symmetry and extends out to at least 10° from the Galactic Center
- Although a population of several thousand millisecond pulsars might have been able to account for much of the excess observed within 1-2° of the Galactic Center, the very extended nature of this signal strongly disfavors pulsars as the primary sources of this emission

But see arXiv:1404.2318

The Characterization of the Gamma-Ray Signal from the Central Milky Way: A Compelling Case for Annihilating Dark Matter

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Past studies have identified a spatially extended excess of ∼1-3 GeV gamma rays from the region surrounding the Galactic Center, consistent with the emission expected from annihilating dark matter. We revisit and scrutinize this signal with the intention of further constraining its characteristics and origin. By applying cuts to the *Fermi* event parameter CTBCORE, we suppress the tails of the point spread function and generate high resolution gamma-ray maps, enabling us to more easily separate the various gamma-ray components. Within these maps, we find the GeV excess to be robust and highly statistically significant, with a spectrum, angular distribution, and overall normalization that is in good agreement with that predicted by simple annihilating dark matter models. For example, the signal is very well fit by a 31-40 GeV dark matter particle annihilating to $b\bar{b}$ with an annihilation cross section of $\sigma v = (1.4 - 2.0) \times 10^{-26}$ cm^3/s (normalized to a local dark matter density of 0.3 GeV/cm^3). Furthermore, we confirm that the angular distribution of the excess is approximately spherically symmetric and centered around the dynamical center of the Milky Way (within ∼0.05° of Sgr A*), showing no sign of elongation along or perpendicular to the Galactic Plane. The signal is observed to extend to at least ≃ 10° from the Galactic Center, disfavoring the possibility that this emission originates from millisecond pulsars.