NB— I will focus on particles heavier than ~ MeV
this excludes a beautiful dark matter candidate particle, the axion
cf. talk by R Khatiwada, later today
"physicists confirmed dark matter in 1998"

Physicists can’t agree on what science even means anymore

radiation. And the hypotheses predict that these traits will conform to certain numerical measurements. Some of these criteria have been met; for instance, in 1998 physicists found proof of dark energy⁴, which accounted for 70 percent of the missing matter that inflation had predicted. Confirming other criteria has been more elusive.

⁴ UPDATE 05/16/17 3:40pm ET — Previously this sentence said physicists confirmed dark matter in 1998.
• Gravitationally…
  but this is not what we mean by “direct detection”
  we mean detection in the particle physics sense
• DAMA/LIBRA
• CoGeNT, CDMS, CRESST…
  blobs drawn
  (then tacitly, inexorably, withdrawn)

"No systematic or side reactions able to mimic the
exploited DM signature have been found or suggested by
anyone over more than a decade."

safe to say: NO. Not yet, not convincingly
Background or signal?


"It is tempting to consider a cosmological origin. Past experience prompts us to exhaust less exotic possibilities."

Fig. 2. 1000 h of data from the Ge spectrometer are shown. The width of each channel is 0.2 keV. The identified peaks result from the decay products of radioactivity in the exposed solder.

1987

1 cts/keV/kg/day

~100 GeV WIMP

2011

1 cts/keV/kg/day

counts / 0.126 keV 0.33 kg 56 days

ionization energy (keVee)
Three slopes on this plot tell you that:

- walls are bad, need (x,y,z) vertex reconstruction
- discrimination is good
- liquids scale faster than solids (so far)

Snowmass CFI summary
arXiv:1310.8327
The lay of the land

2012

2017

Future: LZ, XENONnT, DARWIN, Darkside-20k

Cross Roads!
Constraints on WIMP cross section

arXiv:1310.8327
The WIMP miracle


Increasing $<\sigma_A v>$

WIMPs

Hierarchy Problem

Thermal Relics

Nobel Prize

http://xkcd.com/74/

P. Sorensen, dark matter direct detection: experimental update
But, where is SUSY?

Elephant in the room…
Or rather, absence of elephant!

No sign of weak scale BSM physics

The “WIMP Miracle” is looking less obvious/natural
Leaving “the era of strong priors”
My simple criteria for appraising BSM models

Category 1: Well motivated. New particles and interactions that are introduced for a solid reason, and among other things satisfy stringent criteria of technical naturalness (QCD axions, SUSY partners, RH neutrinos participating in mass generation…).

Category 2: Technically natural “why not” physics: New particles and interactions that are stable under quantum corrections without “black magic”. Dark photons in certain mass ranges, ALPs, sterile neutrinos beyond those that give neutrino masses.

Category 3: Perhaps not natural, but addressing a specific observational anomaly. (DM anomalies, particle physics anomalies etc).

Category 4: Technically unnatural, but I and/or my friends work on them. (E.g. models of changing couplings; chameleons; ALPs with non-derivative couplings). Justification: coolness factor

Category 5: Technically unnatural models that other people work on….
Dark sector dark matter?

plots from Essig, Volansky, Yu

standard model

$\epsilon$

dark sector

e.g. a new $U(1)$

New boson

New Experiments

Thermal Relics

http://xkcd.com/74/

“why not?”

P. Sorensen, dark matter direct detection: experimental update

PPC 2017, Corpus Christi, TX
Outline

• Recent results from WIMP searches
  • LUX
  • XENON1T
  • superCDMS
  • PICO
• R&D efforts toward future WIMP search
  • NEWS-G
  • Liquid helium (un-named)
  • Darkside-20k
  • Scintillating bubble chamber
  • CYGNUS-HD10
• R&D toward dark sector dark matter searches
  • SENSEI
  • GaAs (un-named)
  • $U_{A'}(1)$
• 350 kg xenon mass, dual phase liquid/gas TPC
• World-leading sensitivity until last week :)
• Rich, on-going physics program:


"Low-energy (0.7-74 keV) nuclear recoil calibration of the LUX dark matter experiment using D-D neutron scattering kinematics" (2016), submitted to PRC, arXiv:1608.05381


LUX: present state of the art

- 350 kg xenon mass, dual phase liquid/gas TPC
- World-leading sensitivity until last week :) 
- Rich, on-going physics program:


"Low-energy (0.7-74 keV) nuclear recoil calibration of the LUX dark matter experiment using D-D neutron scattering kinematics" (2016), submitted to PRC, arXiv:1608.05381


cf. talk by R Webb, later today

UN-salted data post-unsalting cut

• Great work in spite of earthquakes
• no evidence for vanilla WIMPs
• one event consistent with inelastic dark matter, cf. arXiv:1608.02662
Two modes of operation:
- iZIP — “normal” operation with ER/NR discrimination
- HV — probably give up discrimination, obtain lower energy threshold
• phenomenal ER/NR discrimination $\sim 10^{-10}$, + vertex reconstruction
• world-leading sensitivity to spin-dependent WIMP-quark scattering

Phys Rev D 93 052014 (2016)
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NEWS-G

- Projection for 140 cm NEWS-G at 10 bar
- Gas (Ne) target! Competitive low-mass WIMP search!
- see arXiv:1401.7902 and Gerbier talk at U.S. Cosmic Visions Workshop
Liquid helium

- a target material with massive potential due to multiple signal channels
- Leveraging HERON solar neutrino detector R&D, so watch for rapid prototyping
- cf. Hertel, McKinsey talks at Cosmic Visions Workshop
Darkside-20k

- Dual-phase 20 tonne liquid argon TPC
  - 3D vertex reconstruction
  - excellent ER/NR pulse shape discrimination
    \( \sim 10^{-7} \)
  - requires underground argon to avoid \(^{39}\text{Ar}\)
    (demonstrated at \( \sim 100 \) kg scale)
- Projected sensitivity \( 3 \times 10^{-48} \) cm\(^2\) at 100 GeV
  (comparable to LZ baseline projection)

Results from DS-50 kg with underground argon

[Engineering drawing of DS-20k installation]

[Image of energy distribution and WIMP search region]

*Phys Rev D* 93 081101 (2016)
Dahl (Northwestern) and Szydagis (U. Albany)

- Take the success of PICO
  - vertex reconstruction
  - acoustic parameter discrimination
  - bubble nucleation discrimination
- And add scintillation!
  - extra handle on incident particle type
  - expected to improve bubble nucleation discrimination
- Xenon is an obvious target choice
- Prototype operational since last June

Glaser et al, Phys Rev 102 586 (1956)
CYGNUS-HD10

- 3D directional (with head-tail !) 10 m³ target at 1 atm
- amplification via micromegas, readout via xy strips on 200 um pitch
- cf. Vahsen talk at Cosmic Visions Workshop
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  • SENSEI
  • GaAs (un-named)
  • $U_A'(I)$
• a DAMIC progeny
• dark sector dark matter search with Skipper CCDs (LBL-FNAL collaboration), arXiv: 1106.1839
• expected signal is 1-2 e-
• cf. Tiffenberg talk at Cosmic Visions Workshop
GaAs scintillator

- another dark sector dark matter search concept
- expected signal is 1-2 photons
- GaAs crystal scintillates with no long-lived excitations, i.e. a zero dark count target, arXiv:1607.01009
- **needs an IR scintillation photon detector that also has no dark counts!**
- evolve CDMS athermal phonon detector into a thin photon detector
- cf. Pyle talk at Cosmic Visions Workshop

\[ \sigma \sim 1 \text{ eV} \]

\[ \sigma \sim 50 \text{ eV} \]
The only limits on dark sector dark matter are from XENON10/100.

The problem is un-extracted electrons at the xenon liquid/gas interface, which dribble out on $O(10)$ ms time scales.

The proposal is to build a 10 kg scale liquid xenon TPC (like XENON10), having suppressed the electron train backgrounds.

Expected signal is again 1-2 e-.

cf. Sorensen talk at Cosmic Visions Workshop.
Summary

• Excellent progress on not finding WIMPs
• Widespread, on-going R&D and planning of new experiments for WIMP search, despite massive head start enjoyed by xenon TPCs
• Directional detection continues to tantalize
• Active inquiry into many new directions (not WIMPs) in direct detection
• Dark photon searches represent a particular coalescence of focus, look for first results in the next ~year

Thanks