Dark Matter Related Research and Activities

Anthony G Williams, University of Adelaide

SPECIAL RESEARCH CENTRE FOR THE SUBATOMIC STRUCTURE OF MATTER

THE UNIVERSITY of ADELAIDE

SUB CRUCE LUMEN

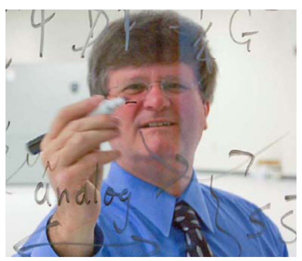
STAWELL UNDERGROUND PHYSICS LAB

SABRE

Centre staff at the Adelaide Node:

A/Prof Gary Hill (CI)

A/Prof Paul Jackson (CI)



Prof Anthony Thomas (CI)

A/Prof Martin White (CI)

Prof Anthony Williams
(CI, Deputy Director,
Adelaide Node manager)

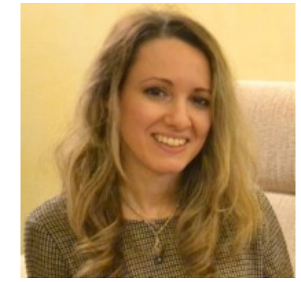
Dr Wei Su
(Res Assoc - theory)

Dr Xuan-gong Wang
(Res Assoc - theory)

Dr Padric McGee
(IT & Research Support
Specialist)

Ms Sharon Johnson
(PA to Node Manager)

Ms Silvana Santucci
(Admin Assistant)



Dr Irene Bolognino
(Res Assoc - direct
detection, waiting
on her visa)

Dr Harish Potti
(Res Assoc - ATLAS,
waiting on his visa)

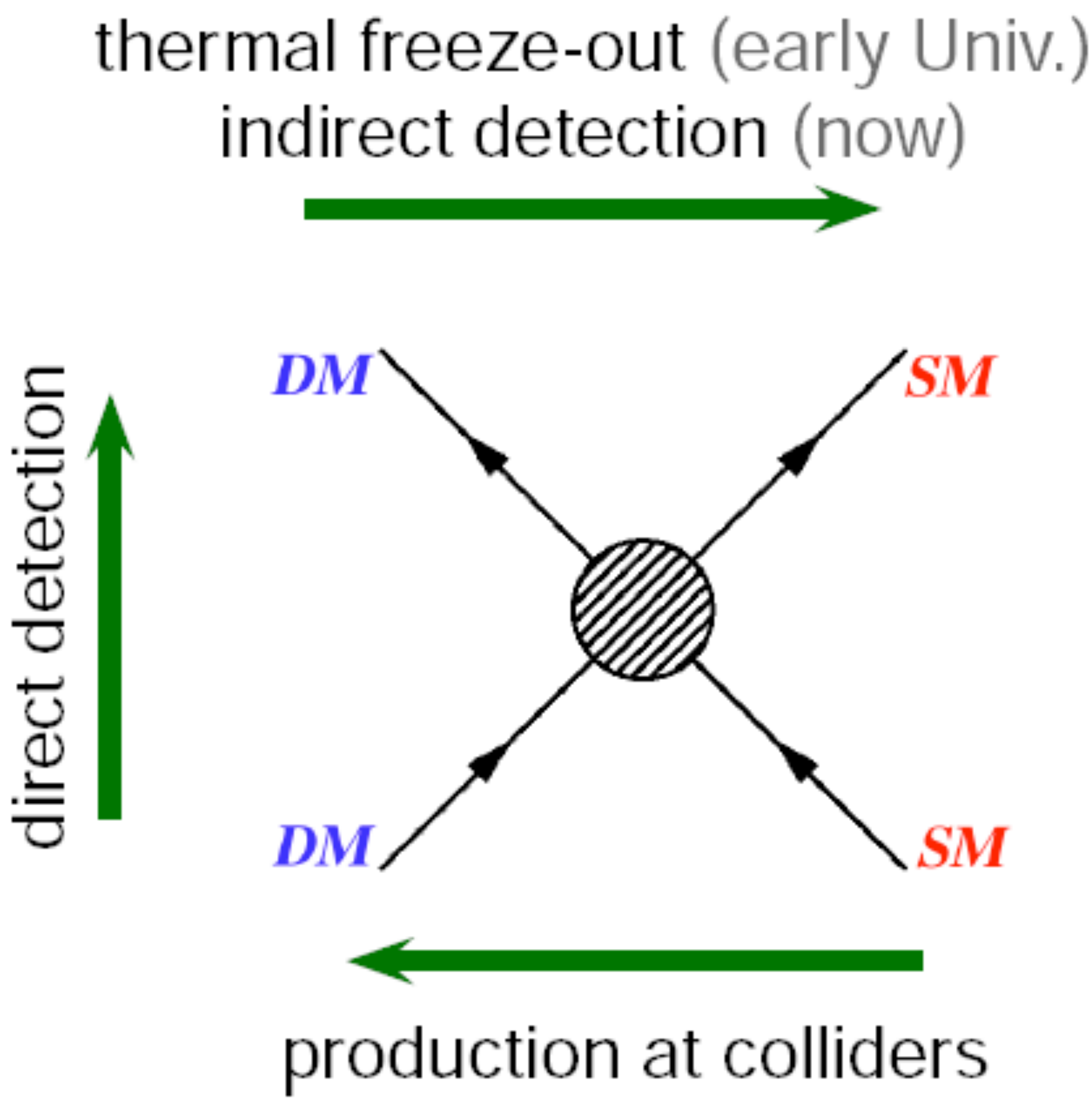
?

Level B appointment
(direct detection
WIMP+Axion+
ATLAS, detector R&D;
target female)

A/Prof Martin White (CI)

Searches for Dark Matter

Direct detection of Dark Matter is often done deep underground to minimize the cosmic ray background

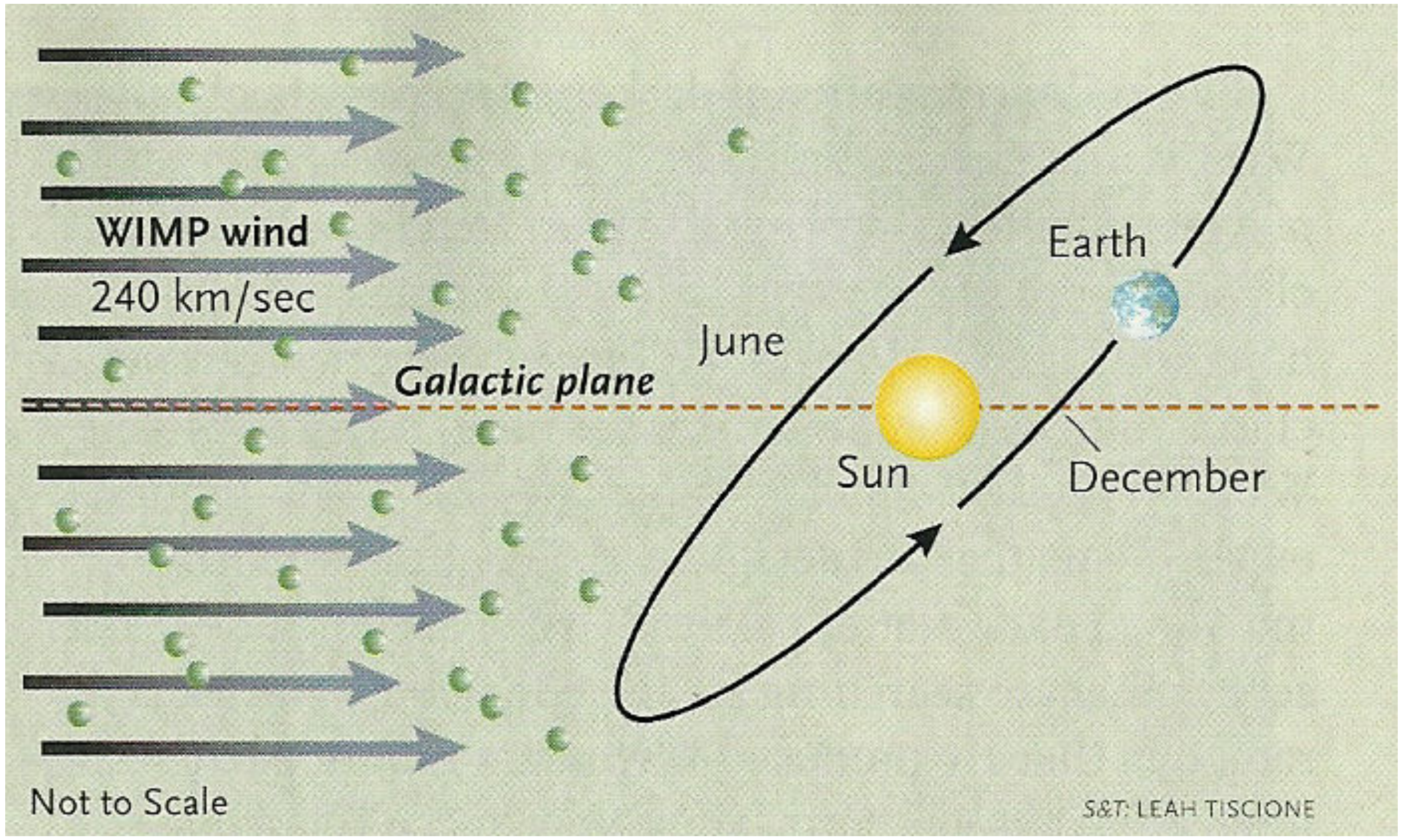


SUPL Excavation Complete -(SUPL Partners are U Melbourne, U Adelaide, ANU, Swinburne and ANSTO)

- Serving as University of Adelaide representative on SUPL Steering Committee since inception (circa 2015);
- Refer to talk by Amanda Western describing SUPL.

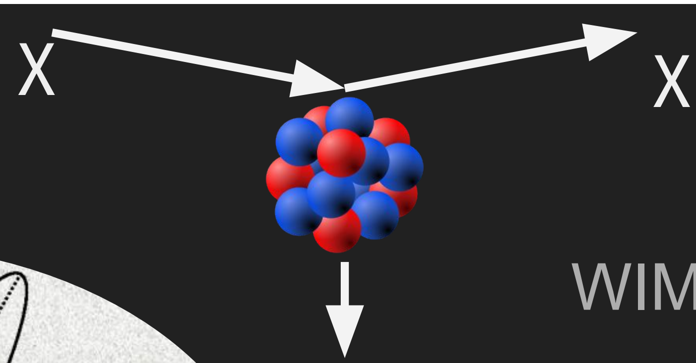
- SUPL = Stawell Underground Physics Laboratory
- SUPL is 1km beneath the surface in the Stawell Gold Mine;
- Looking into Main Hall (right) from loading bay;
- SABRE and other experiments at the back of Main Hall (10m high);
- 15km main road/tunnel to the surface (left) left, runs past SUPL;
- At back of Main Hall (behind tractor) to the left is the Annex that runs until it rejoins the road;
- Lab construction to be completed in 2021

Dark Matter Wind

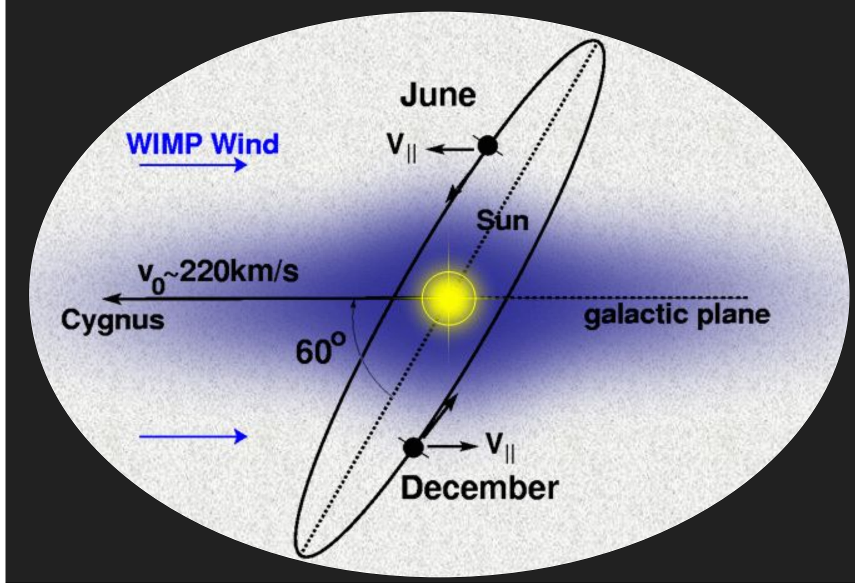


- Dark Matter (e.g., Weakly Interacting Massive Particles - WIMPs) are expected to form an approximately static halo around the galaxy (shown in blue); Is there small scale structure, turbulence?
- As the spiral galaxy rotates, the Sun experiences a wind of DM particles (appoximate direction is from the direction of Cygnus);
- As the earth rotates around the sun, the velocity of the Dark Matter wind passing through the earth changes accordingly.

DAMA/LIBRA enigma



Annual Modulation

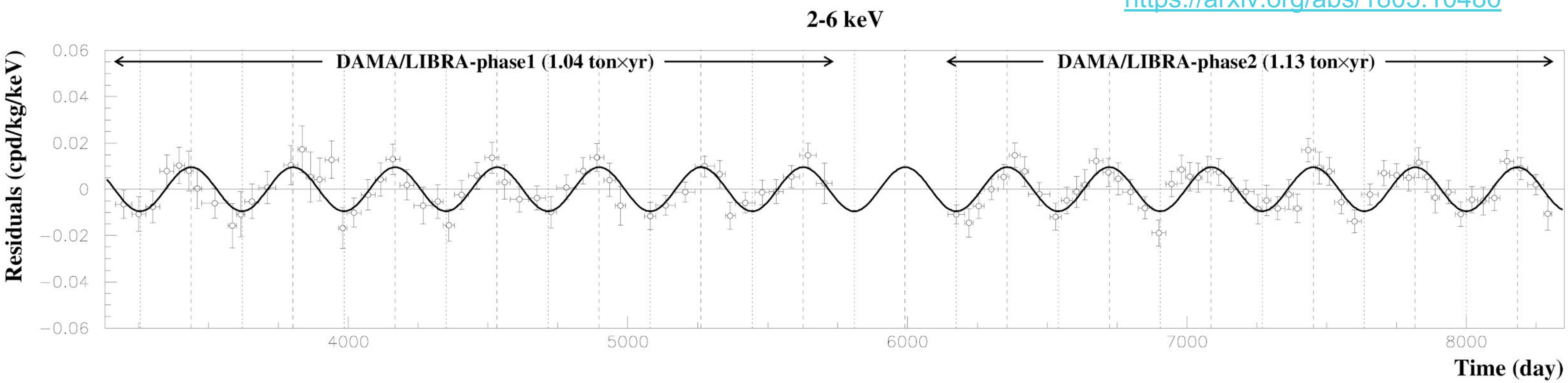


WIMP dark matter detection: elastic scattering.

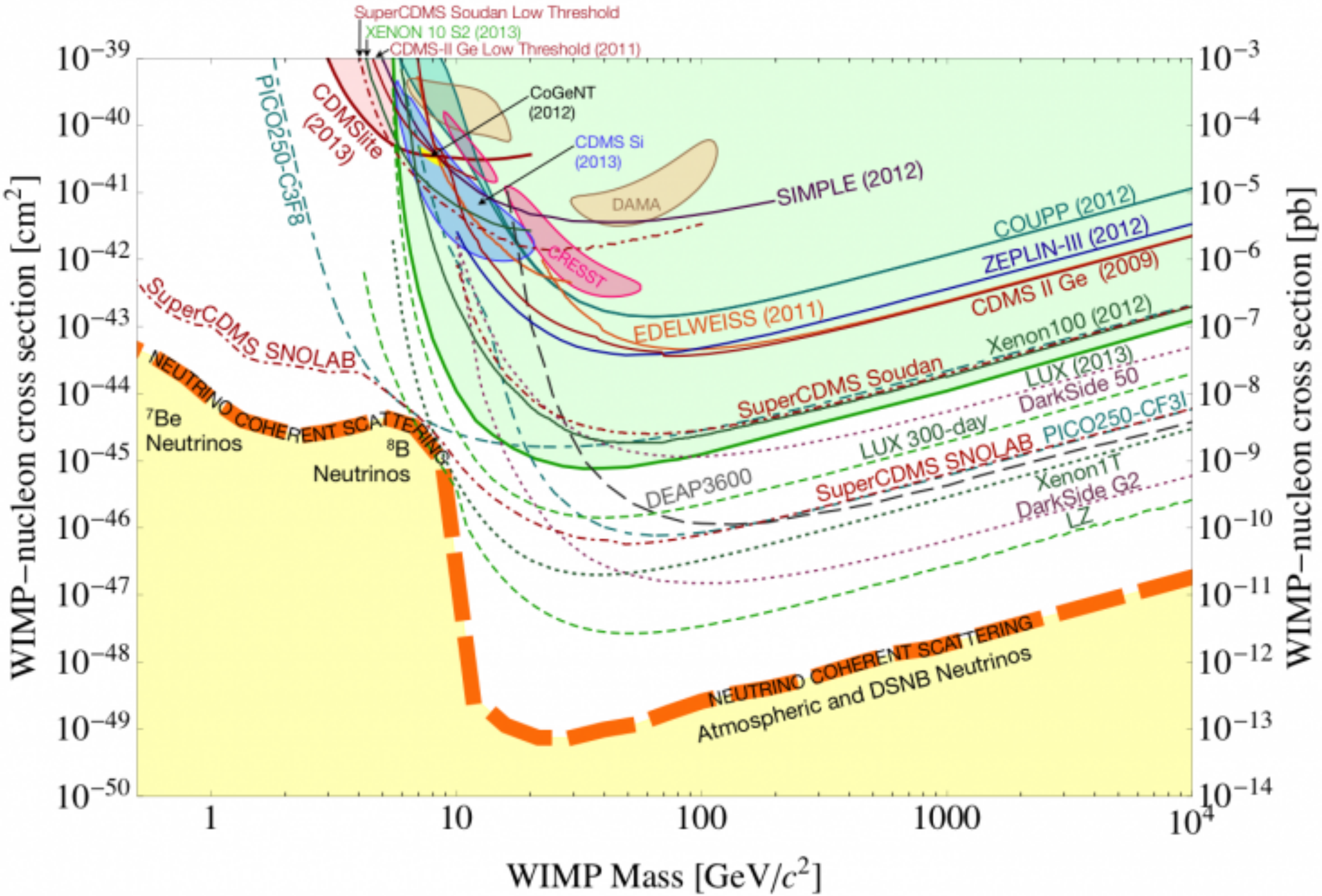
Flux (scatter rate) of dark matter modulates through the year

DAMA: reports a highly significant (11.9 σ) modulation signal consistent with dark matter.

https://arxiv.org/abs/1805.10486

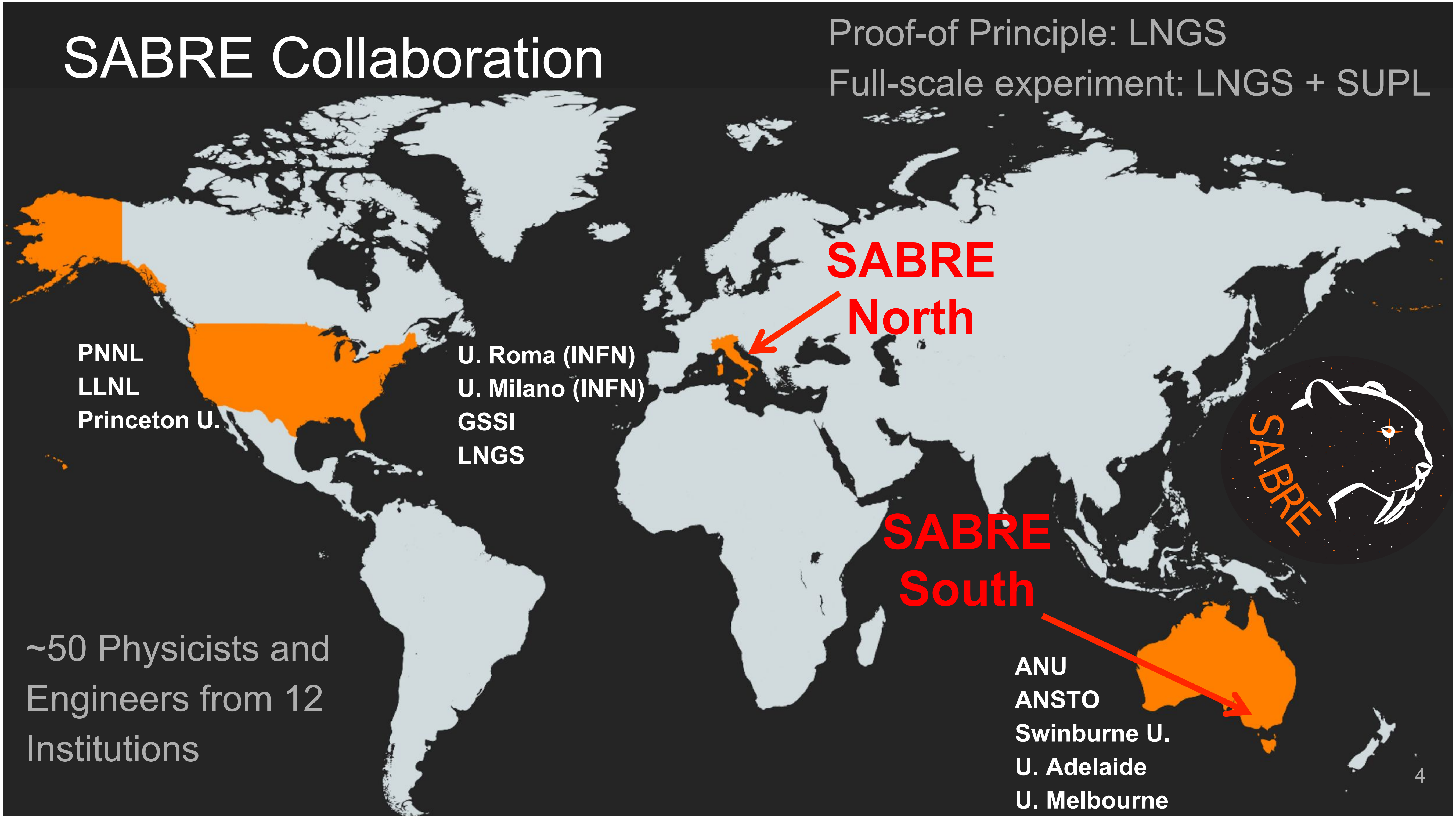


Simplest assumptions are inconsistent with all other experiments; No known backgrounds appear to be able to explain it.



(Note: DSNB = Diffuse Supernova Neutrino Background)

SABRE Collaboration



Direct detection experimental involvement

- First two SABRE publications, another in preparation

Eur. Phys. J. C (2019) 79:363
https://doi.org/10.1140/epjc/s10052-019-6860-y

THE EUROPEAN PHYSICAL JOURNAL C

Check for updates

Regular Article - Experimental Physics

The SABRE project and the SABRE Proof-of-Principle

M. Antonello[1], E. Barberio[2], T. Baroncelli[2], J. Benziger[3], L. J. Bignell[4], I. Bolognino[1,5], F. Calaprice[6], S. Copello[7,8], D. D'Angelo[1,5], G. D'Imperio[9,a], I. Dafinei[9], G. Di Carlo[7], M. Diemoz[9], A. Di Ludovico[6], W. Dix[2], A. R. Duffy[10,11], F. Froborg[12], G. K. Giovanetti[6], E. Hoppe[13], A. Ianni[7], L. Ioannucci[7], S. Krishnan[11], G. J. Lane[4], I. Mahmood[2], A. Mariani[8], M. Mastrodicasa[9,14], P. Montini[9,14,17], J. Mould[10,11], F. Nuti[2], D. Orlandi[7], M. Paris[7], V. Pettinacci[9], L. Pietrofaccia[6], D. Prokopovic[16], S. Rahatlou[9,14], N. Rossi[9], A. Sarbutt[16], E. Shields[6], M. J. Souza[6], A. E. Stuchbery[4], B. Suerfu[6], C. Tomei[9], V. Toso[1,5], P. Urquijo[2], C. Vignoli[7], M. Wada[6], A. Wallner[4], A. G. Williams[15], J. Xu[6]

Astroparticle Physics 106 (2019) 1–9

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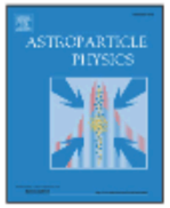
Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropartphys



Monte Carlo simulation of the SABRE PoP background

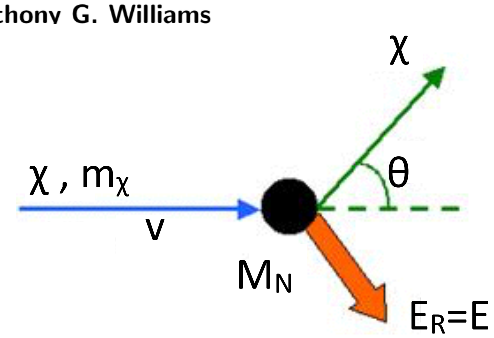
M. Antonello[a], E. Barberio[b], T. Baroncelli[b], J. Benziger[c], L.J. Bignell[d], I. Bolognino[a,e], F. Calaprice[f], S. Copello[g,h], D. D'Angelo[a,e], G. D'Imperio[i,*], I. Dafinei[i], G. Di Carlo[g], M. Diemoz[i], A. Di Ludovico[f], A.R. Duffy[j,k], F. Froborg[l], G.K. Giovanetti[f], E. Hoppe[m], A. Ianni[g], L. Ioannucci[g], S. Krishnan[k], G.J. Lane[d], I. Mahmood[b], A. Mariani[h], P. McGee[n], P. Montini[i,o,1], J. Mould[j,k], F. Nuti[b], D. Orlandi[g], M. Paris[b,g], V. Pettinacci[i], L. Pietrofaccia[f], D. Prokopovich[p], S. Rahatlou[i,o], N. Rossi[i], A. Sarbutt[p], E. Shields[f], M.J. Souza[f], A.E. Stuchbery[d], B. Suerfu[f], C. Tomei[i], P. Urquijo[b], C. Vignoli[g], M. Wada[f], A. Wallner[d], A.G. Williams[n], J. Xu[f], M. Zurowski[b], The SABRE Collaboration

Direct detection theory publications

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal
JCAP11(2017)021

On the direct detection of multi-component dark matter: sensitivity studies and parameter estimation

Juan Herrero-Garcia, Andre Scaffidi, Martin White and Anthony G. Williams



- In nuclear recoil experiments we could detect two components of dark matter if masses are sufficiently different;
- Most sensitivity when “kink” is pronounced, which occurs when lighter DM particle mass is < 20 MeV or so.

$$r_\rho = r_\sigma = 1$$

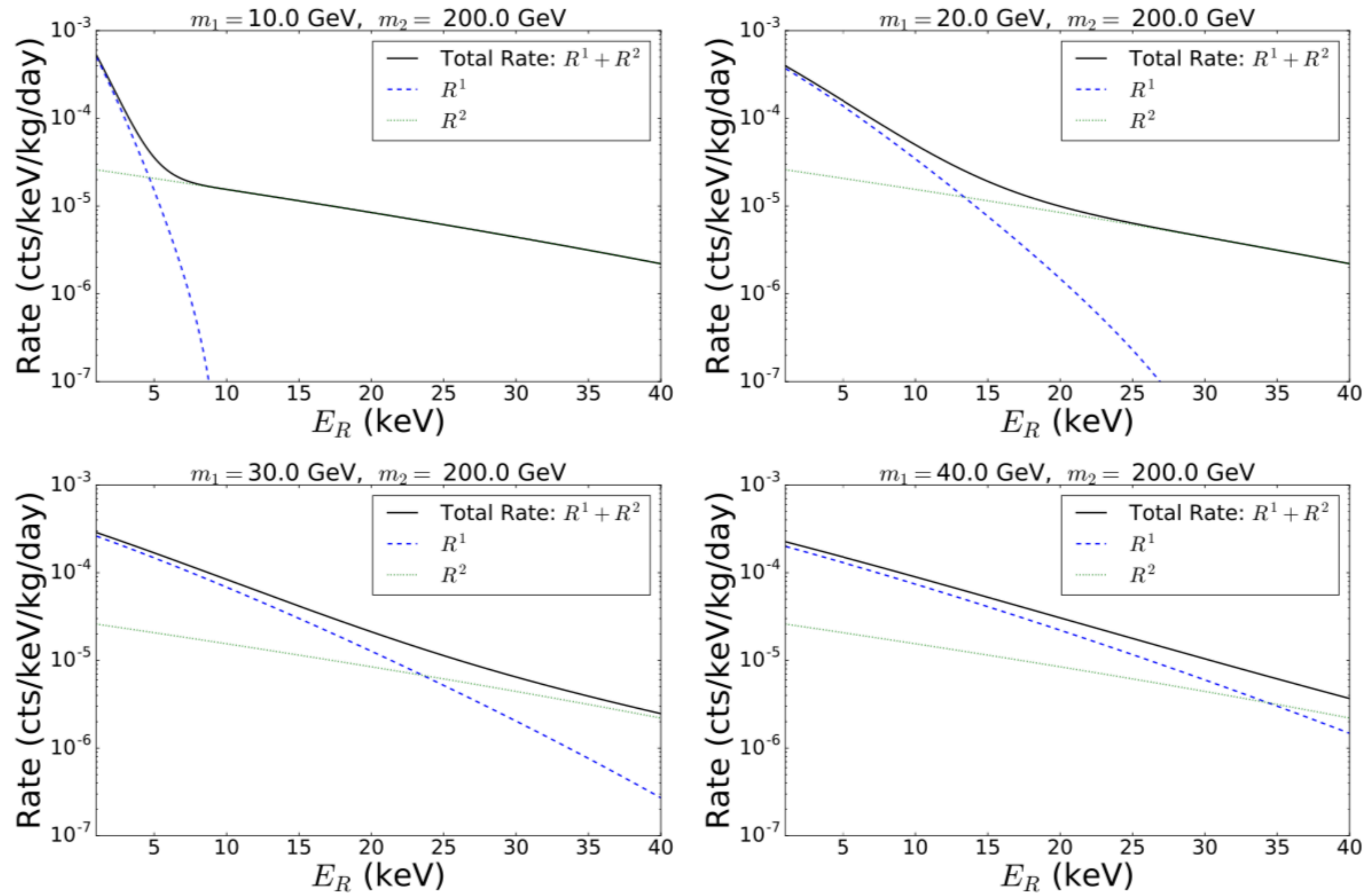


Figure 2. Total differential event rate for 2 DM particles (solid black), as well as their individual contributions (1 dashed blue, 2 dotted green) for a variety of DM mass splittings on the energy range [2, 30] keV. One should notice that the *kink* feature in the combined spectrum rapidly vanishes with smaller mass splittings.

$$\rho_1 + \rho_2 = \rho_{\rm loc} = \text{local DM mass density}$$

$$r_\sigma \equiv \frac{\sigma_1^p}{\sigma_2^p} \equiv \text{ratio of DM-proton cross-sections}$$

$$r_\rho \equiv \frac{\rho_1}{\rho_2} \equiv \text{ratio of mass densities}$$

Direct detection theory publications (continued)

PHYSICAL REVIEW D **98,** 123007 (2018)

Time-dependent rate of multicomponent dark matter: Reproducing the DAMA/LIBRA phase-2 results

Juan Herrero-Garcia,* Andre Scaffidi,† Martin White,‡ and Anthony G. Williams§

ARC Centre of Excellence for Particle Physics at the Terascale, Department of Physics, University of Adelaide, Adelaide, South Australia 5005, Australia

(Received 25 September 2018; published 11 December 2018)

Journal of Cosmology and Astroparticle Physics

An IOP and SISSA journal

On the direct detection of multi-component dark matter: implications of the relic abundance

Juan Herrero-Garcia,[1] Andre Scaffidi,[2] Martin White and Anthony G. Williams[3]

ARC Centre of Excellence for Particle Physics at the Terascale, Department of Physics, University of Adelaide, Adelaide, South Australia 5005, Australia

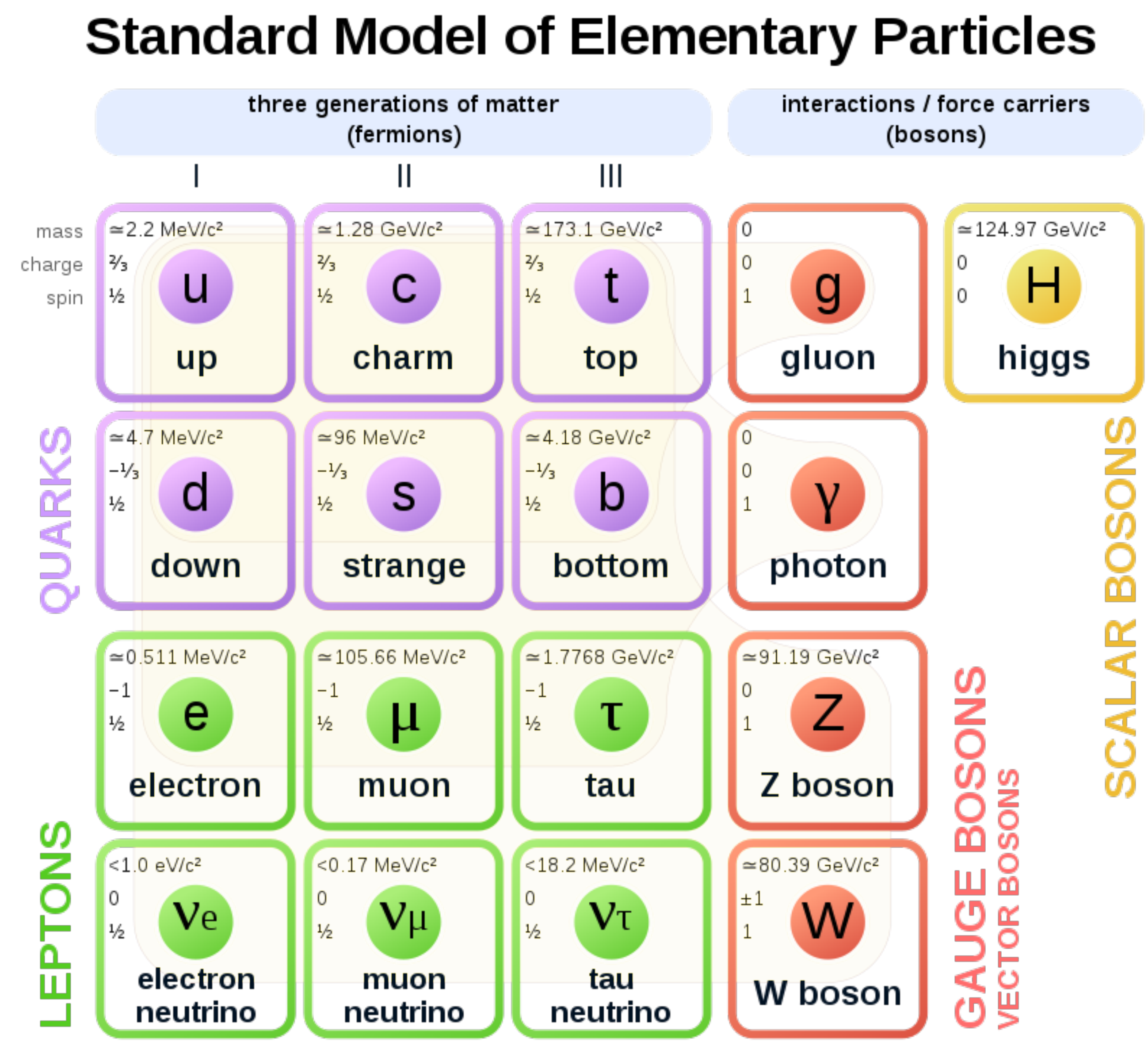
E-mail: juan.herrero-garcia@coepp.org.au, andre.scaffidi@adelaide.edu.au, martin.white@adelaide.edu.au, anthony.williams@adelaide.edu.au

Received October 12, 2018
Accepted December 4, 2018
Published January 3, 2019

- The issue with DAMA/LIBRA being in tension with other searches remains - hence the motivation for the SABRE North and South experiments;
- In addition, after DAMA-LIBRA Phase-2 results were published it was argued that isospin conserving single component DM was ruled out *assuming* that DAMA-LIBRA had seen DM;
- We showed in the top left paper that with two DM components the DAMA-LIBRA phase 2 results could be consistent with isospin conservation;
- In the second paper (bottom left) we investigate two dark matter genesis scenarios: (a) asymmetric DM and (b) thermal freeze out. Both models constrain parameter space and tend to slightly smooth out kink behavior;
- However, regions of parameter space with a pronounced kink remain. So detection of two component DM remains possible in some regions of parameter space.

Beyond the Standard Model (BSM)

- Dark matter theory program:
  - dark matter candidates - what are the possible particle properties of dark matter consistent with observations?;
  - model building - extend the SM to various BSM theories to include DM;
  - dark matter phenomenology - experimental signatures for given models; and
  - dark matter & astroparticle physics and cosmology



Challenges for the SM and BSM theories:

- There are phenomena not explained by the Standard Model (SM):
  - Gravity and Dark Energy - A Theory of Everything includes gravity and remains a bridge too far;
  - Dark matter - the big challenge for our Centre. What is the particle nature of DM?;
  - Neutrino masses and neutrino oscillations - a simple extension of the SM that only needs the PMNS matrix for leptons to be included (analog of quark CKM matrix) - origin of mass?;
  - Matter-antimatter asymmetry - we need additional sources of CP violation;
  - Why is the Higgs so light at ~125 GeV? - Naturalness/fine-tuning problem;
  - Strong CP problem - QCD can be extended to have a large CP violating term that would lead to a neutron dipole moment etc. Not seen at precision of ~ 10^{-9}. Why is this so tiny? Another naturalness/ fine-tuning problem. Theoretical attempt to explain this leads to the Peccei-Quinn axion prediction;
  - The SM vacuum seems to become unstable/metastable at energies below the GUT scale of ~10^{16} GeV. Note that GUT = Grand Unified Theory such as $\text{SM} = SU(3) \times SU(2) \times U(1) \subset SU(5)$
  - This suggests that the SM is an effective low-energy theory of some BSM/GUT theory.
- Examples of BSM theories:
  - Supersymmetry (SUSY) - symmetry between fermions and bosons and then softly break it;
  - Composite Higgs models - Higgs is a composite particle that is a pseudo-Goldstone boson if some BSM theory, which explains why the Higgs is light;
  - Two-Higgs doublet models (2HDM) - one of the simplest extensions of the SM. 2HDM models are one of the natural choices for BSM theories and contain two Higgs doublets instead of just one;
  - Scotogenic models - an economical setup that induces Majorana neutrino masses at the 1-loop level and includes a dark matter candidate.

Some recent BSM-related theory papers

Strong first order electroweak phase transition in 2HDM confronting future Z & Higgs factories

November 9, 2020

Wei Su[*], Anthony G. Williams[*], Mengchao Zhang[†]
[†]*Department of Physics and Siyuan Laboratory, Jinan University, Guangzhou 510632, P.R. China*
[*]*ARC Centre of Excellence for Dark Matter Particle Physics, Department of Physics, University of Adelaide, South Australia 5005, Australia*

The ScotoSinglet Model: A Scalar Singlet Extension of the Scotogenic Model

October 20, 2020

Ankit Beniwal,[a] Juan Herrero-García,[b] Nicholas Leerdam,[c] Martin White[c] and Anthony G. Williams[c]

Model-independent approach for incorporating interference effects in collider searches for new resonances

August 18, 2020

Stefano Frixione[1], Lydia Roos[2], Edmund Ting[3], Eleni Vryonidou[4], Martin White[3], and Anthony G. Williams[3]

JHEP
Published for SISSA by Springer
Received: October 4, 2019
Revised: December 2, 2019
Accepted: December 20, 2019
Published: February 25, 2020

Higgs quark flavor violation: simplified models and status of general Two-Higgs-Doublet Model

Juan Herrero-Garcia,[a] Miguel Nebot,[c] Filip Rajec,[b] Martin White[b] and Anthony G. Williams[b]

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Higgs quark flavor violation: simplified models and status of general Two-Higgs-Doublet Model

Juan Herrero-Garcia,[a] Miguel Nebot,[c] Filip Rajec,[b] Martin White[b] and Anthony G. Williams[b]

JHEP
Published for SISSA by Springer
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Accepted: February 15, 2019
Published: February 27, 2019

Gravitational waves and electroweak baryogenesis in a global study of the extended scalar singlet model

Ankit Beniwal,[a,b,1] Marek Lewicki,[b,c,d,2] Martin White[b] and Anthony G. Williams[b,3]

Eur. Phys. J. C (2019) 79:38
https://doi.org/10.1140/epjc/s10052-018-6513-6
The European Physical Journal C
CrossMark
Regular Article - Theoretical Physics

Global analyses of Higgs portal singlet dark matter models using GAMBIT

The GAMBIT Collaboration: Peter Athron[1,2], Csaba Balázs[1,2], Ankit Beniwal[2,3,4,5,a], Sanjay Bloor[6,b], José Eliel Camargo-Molina[6], Jonathan M. Cornell[7], Ben Farmer[6], Andrew Fowlie[1,2,8], Tomás E. Gonzalo[9], Felix Kahlhoefer[10,c], Anders Kvellestad[6,9], Gregory D. Martinez[11], Pat Scott[6], Aaron C. Vincent[12], Sebastian Wild[13,d], Martin White[2,3], Anthony G. Williams[2,3]

JHEP
Published for SISSA by Springer
Received: December 10, 2018
Revised: March 8, 2019
Accepted: March 26, 2019
Published: April 9, 2019

Exploring fine-tuning of the Next-to-Minimal Composite Higgs Model

Daniel Murnane,[1] Martin White and Anthony G. Williams[2]

PHYSICAL REVIEW D **98**, 035042 (2018)

Effect of a light sterile neutrino at NOνA and DUNE

Shivani Gupta,[*] Zachary M. Matthews,[†] Pankaj Sharma,[‡] and Anthony G. Williams[§]
Center of Excellence for Particle Physics at the Terascale (CoEPP), University of Adelaide, Adelaide, South Australia 5005, Australia

(Received 10 April 2018; published 29 August 2018)

Physics Letters B 780 (2018) 603–607
Contents lists available at ScienceDirect
Physics Letters B
www.elsevier.com/locate/physletb
ELSEVIER

Triple top signal as a probe of charged Higgs in a 2HDM

Riley Patrick, Pankaj Sharma[*], Anthony G. Williams

JHEP
Published for SISSA by Springer
Received: April 11, 2017
Revised: July 19, 2017
Accepted: August 13, 2017
Published: September 12, 2017

Constraining fine tuning in composite Higgs models with partially composite leptons

James Barnard,[a] Daniel Murnane,[b] Martin White[b] and Anthony G. Williams[b]

JHEP
Published for SISSA by Springer
Received: April 20, 2017
Accepted: August 10, 2017
Published: August 23, 2017

Gravitational wave, collider and dark matter signals from a scalar singlet electroweak baryogenesis

Ankit Beniwal,[a,1] Marek Lewicki,[a,b,2] James D. Wells,[c,d,3] Martin White[a] and Anthony G. Williams[a,4]

Conclusions

- I am still a theorist 95% of the time, but felt that it was important to contribute to helping to get SABRE and SUPL happening Australia;
- Our new Centre lead by Elisabetta is a game-changing addition to this effort. It will strengthen dark matter research in Australia for the next 7 years and, through its legacy, well beyond;
- Whatever SABRE (North + South) finds will be interesting;
- The theory challenge: Construct BSM/GUT theories with a suitable Dark Matter candidate that are consistent with all known observations and hopefully explain other puzzles along the way.