Theory Program

Nicole Bell

Theory Chief Investigators

9 Theory Chief Investigators

Nicole Bell, Celine Boehm, Matthew Dolan, Alan Duffy, Cedric Simenel, Anthony Thomas, Ray Volkas, Martin White, Anthony Williams.

Large team, spanning 5 nodes, with a diverse skill set.

→ We will cover a lot of ground on particle, nuclear and astro aspects of dark matter theory.

Theory Partner Investigators

Amsterdam, Caltech, MIT

Theory Postdocs

Adelaide

Wei Su

BSM phenomenology, GAMBIT.

Xuan-Gong Wang

Nuclear physics, DM-nucleon scattering cross sections, dark matter capture in stars

ANU

Giorgio Busoni:

Direct detection; dark matter capture in stars; collider and BSM pheno. (To start in 2021.)

Swinburne

To appoint in the area of cosmological simulations

Melbourne

Jayden Newstead

Direct detection and DM phenomenology, at theory-experiment interface.

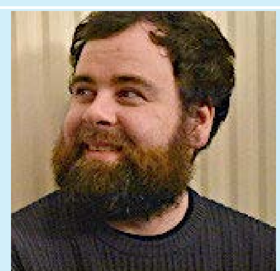
Michael Baker

General BSM and DM phenomenology expertise.

Sandra Robles

Particle pheno & astrophysics. Including dark matter capture in stars & indirect detection.

Sydney



Ciaran O'Hare

Dark mater particle physics and astrophysics, including direct detection & cosmology

Theory Program Overview

- Dark matter model building and phenomenological constraints, using all available experimental data (Adelaide, Melbourne, Sydney).
- Sensitivity of direct detection experiments to dark matter candidates & novel experimental signatures (Adelaide, ANU, Melbourne, Sydney).
- Refinement of cross section calculations for nuclear recoil experiments (Adelaide, ANU).
- Particle astrophysics, as complementary probe of dark matter interactions, e.g. indirect detection, the capture of dark matter in neutron stars (Adelaide, Melbourne, Sydney).
- Cosmological simulations, e.g., local dark matter density and velocity profiles, which determine direct detection event rates; ability to distinguish between different classes of dark matter candidates (Swinburne, Sydney).

Theory-experiment interactions

- Theory is critical for making connections across the Centre's Research Programs. Aim is to embed theory within the experimental programs whenever that makes sense.
- Direct Detection – lots of natural theory-exp links. Postdocs Giorgio Busoni, Jayden Newstead and Ciaran O'Hare, in particular, will help facilitate dialogue with the experimental direct detection programs.
- LHC – established theory-exp dialogue in Melbourne and Adelaide via CoEPP that we should maintain.

Cross-node theory plans

- Multiple nodes are involved in all key research topics.
- Theory journal club started in July. It runs fortnightly and is well attended. Have had interesting and pedagogical talks spanning a good spectrum of topics, which have generated a healthy amount of discussion.
- Cross-node collaboration on projects has started.
- Postdoc hiring coordinated across nodes. Cross-node representation on selection panels.

Theory Program Outputs

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An IOP and SISSA journal

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PHYSICAL REVIEW LETTERS 125, 161803 (2020)
Editors' Suggestion | Featured in Physics

Explaining the XENON1T Excess with Luminous Dark Matter

Nicole F. Bell,[1,*] James B. Dent,[2,†] Bhaskar Dutta,[3,‡] Sumit Ghosh,[3,§] Jason Kumar,[4,‖] and Jayden L. Newstead[1,¶]
...10, Australia

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Media Coverage

Jayden Newstead, Physics World podcast

IOP Publishing

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Room-temperature superconductor arrives at last, a dark-matter detector mystery

22 Oct 2020 Hamish Johnston

Nicole Bell & Jayden Newstead

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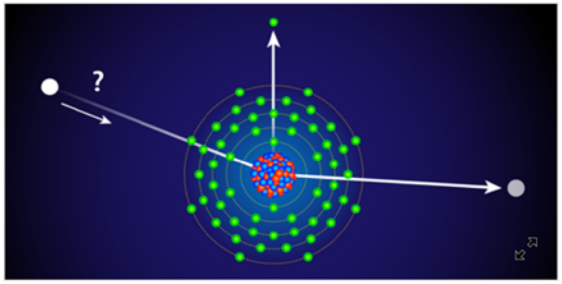
SYNOPSIS

Theorists React to Potential Signal in Dark Matter Detector

October 12, 2020 • *Physics* 13, s132

A tantalizing signal reported by the XENON1T dark matter experiment has sparked theorists to investigate explanations involving new physics.



APS/Alan Stonebraker

Michael Baker

scitechdaily.com/new-theory-for-the-origin-of-dark-matter/

New Theory for the Origin of Dark Matter

TOPICS: Astrophysics Dark Matter Particle Physics Popular University Of Melbourne

By UNIVERSITY OF MELBOURNE OCTOBER 19, 2020

Peter Cox

THE HON DAN TEHAN MP
Minister for Education
MEDIA RELEASE

6 November 2020

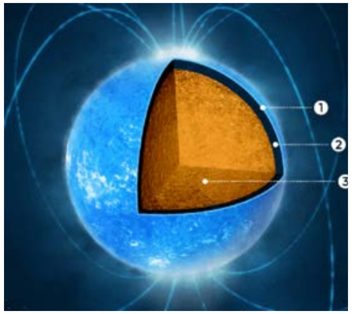
Research to better understand properties of dark matter

A world-leading Australian physicist has been awarded a research grant to investigate new models of dark matter.

The Morrison Government is providing $445,688 to fund research conducted by Dr Peter Cox from the University of Melbourne into dark matter.

Cross-node theory highlight: **Dark Matter Capture in Neutron Stars**

Melbourne: Nicole Bell, Sandra Robles, Michael Virgato
Adelaide: Anthony Thomas, Theo Motta
ANU: Giorgio Busoni



Dark Matter Capture in Stars

→ complementary approach to DM-nucleon recoil experiments

- Due to their extreme density, ***neutron stars*** capture dark matter very efficiently.
- ***Capture probability is of order unity*** when $\sigma_{n\chi} > \sigma_{th} \sim 10^{-45}\mathrm{cm}^2$

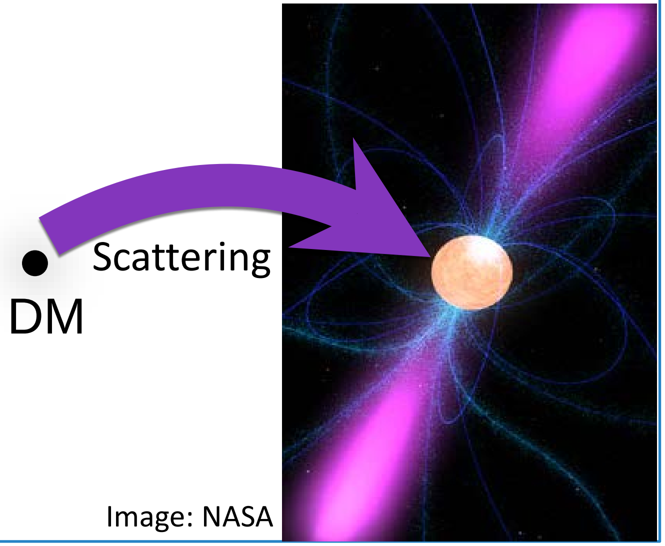


Image: NASA

Consequences of dark matter capture in neutron stars

- DM kinetic energy heats neutron star by ~ 1700 K
- DM annihilation would cause addition heating of ~ 700 K
  → Potentially observable in next generation telescopes

- If DM density becomes too high
  → In some cases the neutron star can collapse to a black hole

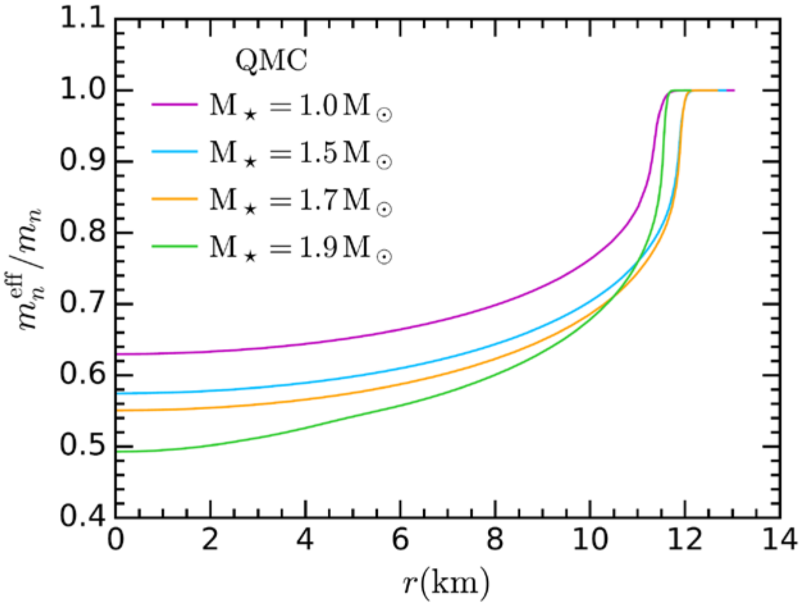
Direct detection vs neutron star scattering

	Direct Detection	Neutron stars
DM velocity	Non-rel $v \ll c$	Quasi-rel. $v \sim 0.5\,c$
Cross-sections	Can be suppressed by velocity/momentum	Unsuppressed
Momentum transfer	$< \mathcal{O}(100\ \mathrm{MeV})$	$\mathcal{O}(10\ \mathrm{GeV})$
Density	Normal matter	Extremely high density

Two important physical effects are typically neglected:

Direct detection – Hadronic matrix elements calculated at zero momentum transfer
Neutron star scattering – momentum transfer $\sim 10\ \mathrm{GeV}$ → couplings suppressed

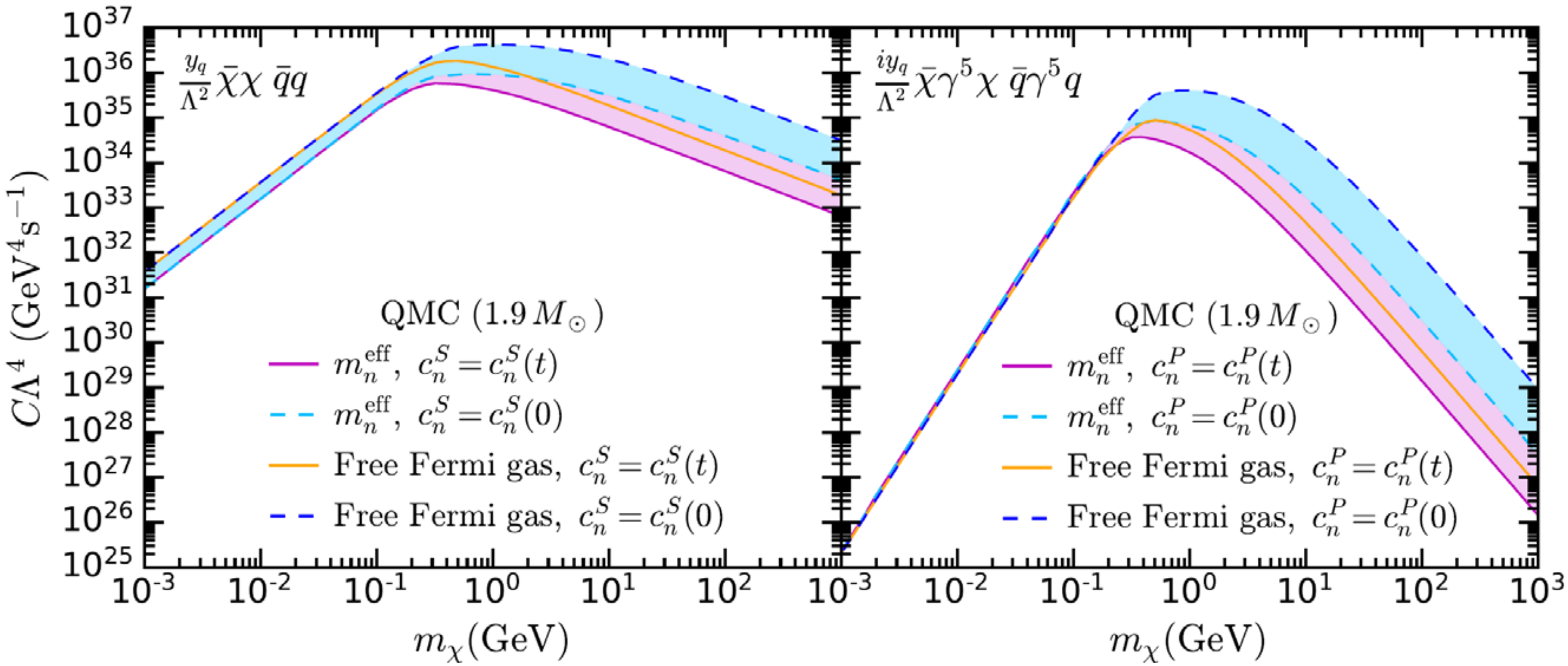
High density neutron star environment
→ define an effective nucleon mass to express energy spectrum of interacting nucleons



NFB, Busoni, Motta, Robles, Thomas & Virgato, *in preparation*

Correctly including nucleon structure and strong interactions:

→ capture rate altered by up to 3 orders of magnitude



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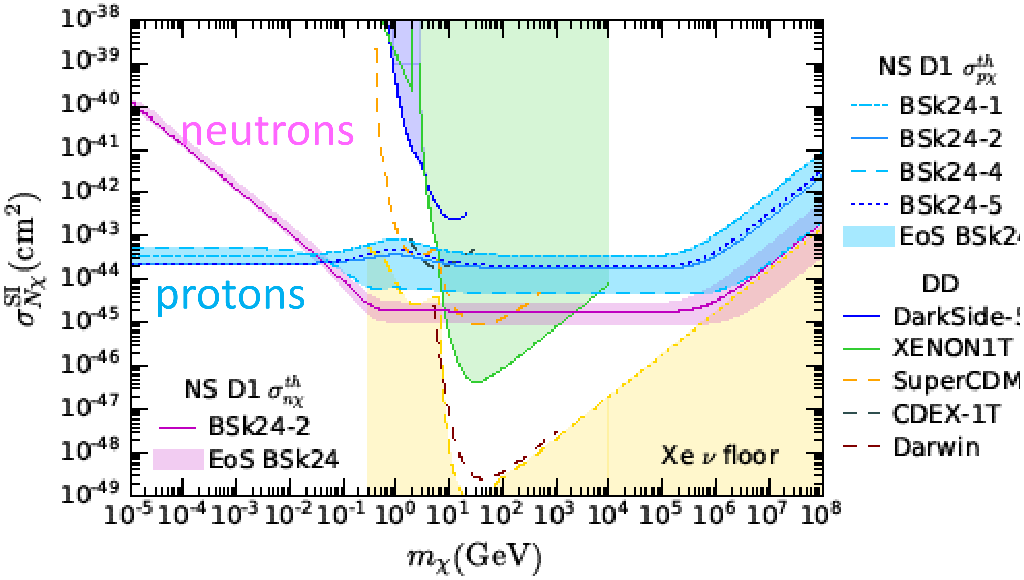
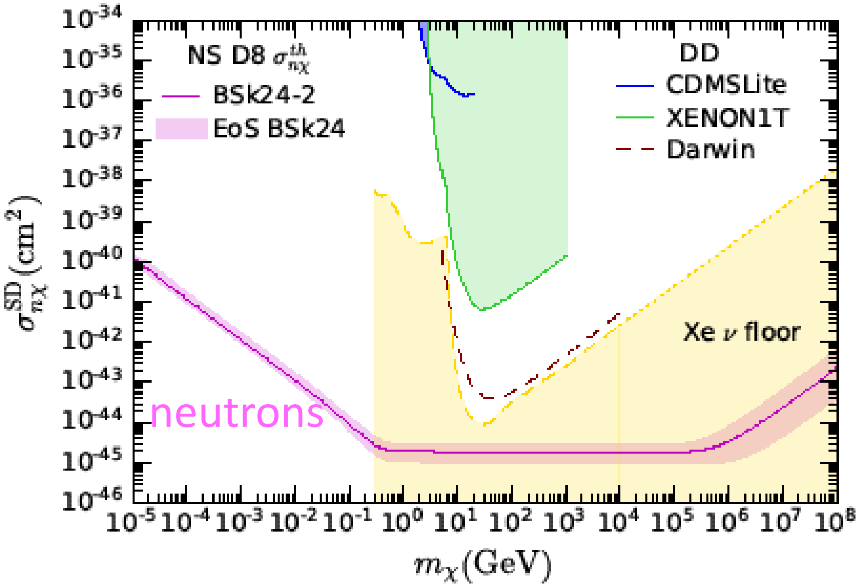
DM-Nucleon scattering in neutron stars

→Potential sensitivity below neutrino floor

SI scattering



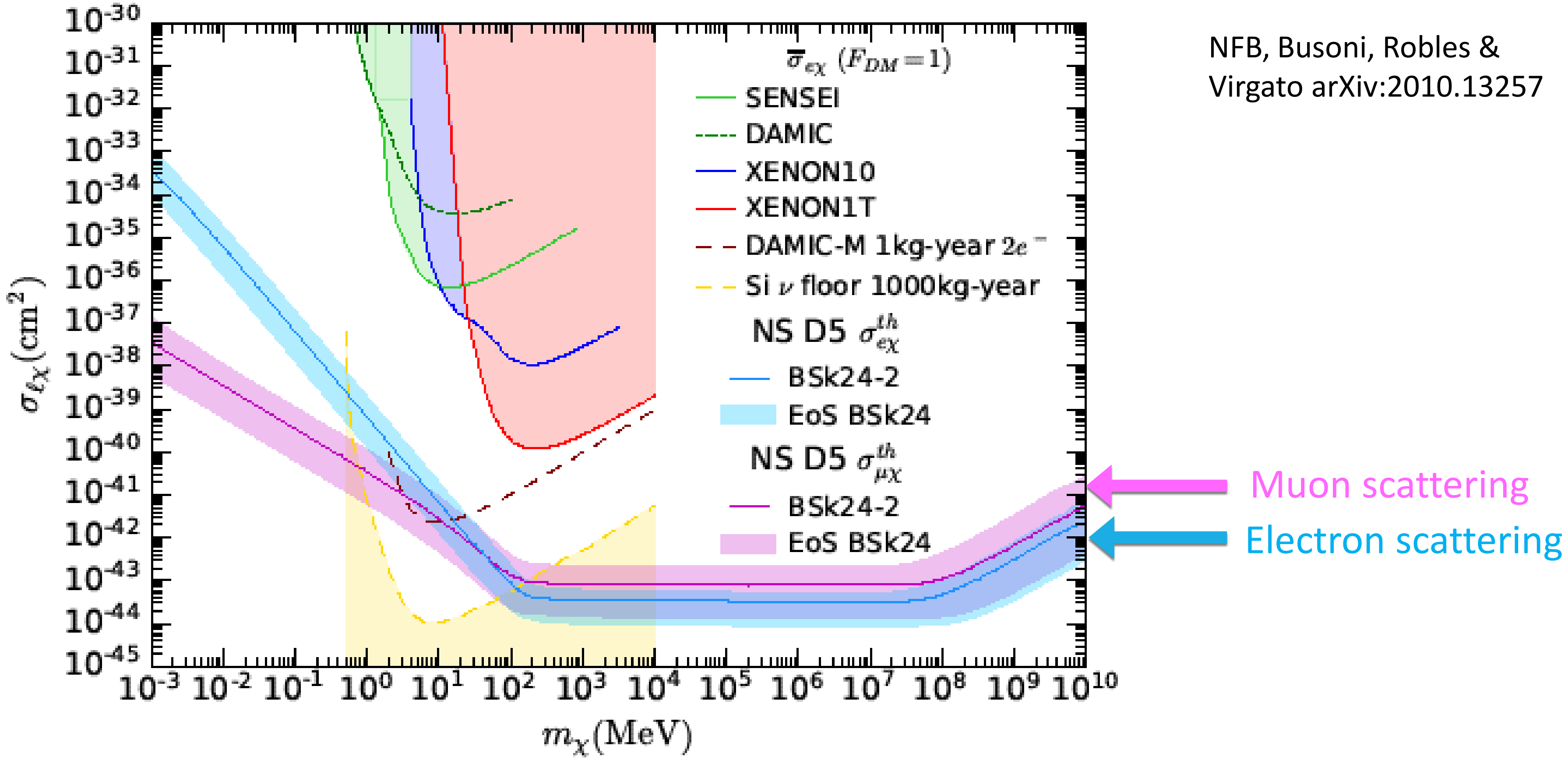
SD scattering



NFB, Busoni, Robles, Thomas & Virgato, *in preparation*

DM-Lepton scattering in neutron stars

→Potentially much more sensitive than electron-recoil direct detection



NFB, Busoni, Robles & Virgato arXiv:2010.13257

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