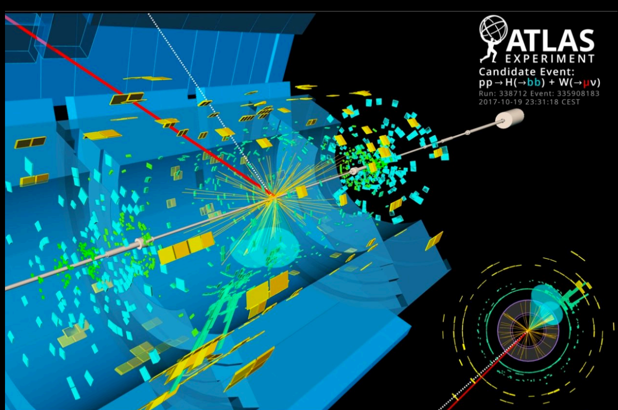
Perspectives on Hidden Sector Searches

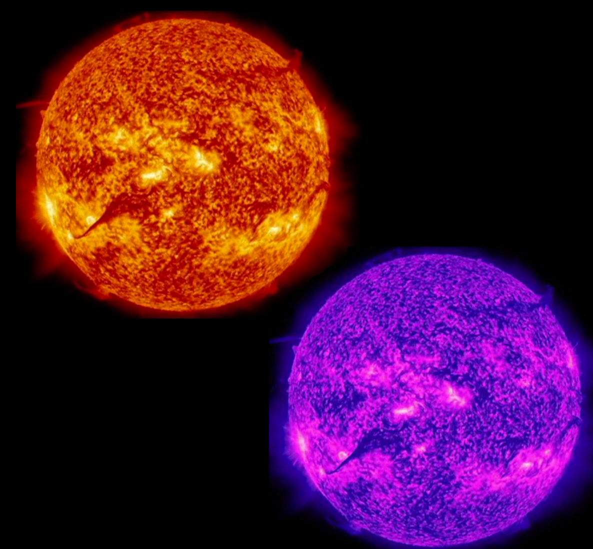
From Colliders to Astrophysics



IPP
Virtual Town Hall July 2020
Canada

21 July 2020

David Curtin
University of Toronto



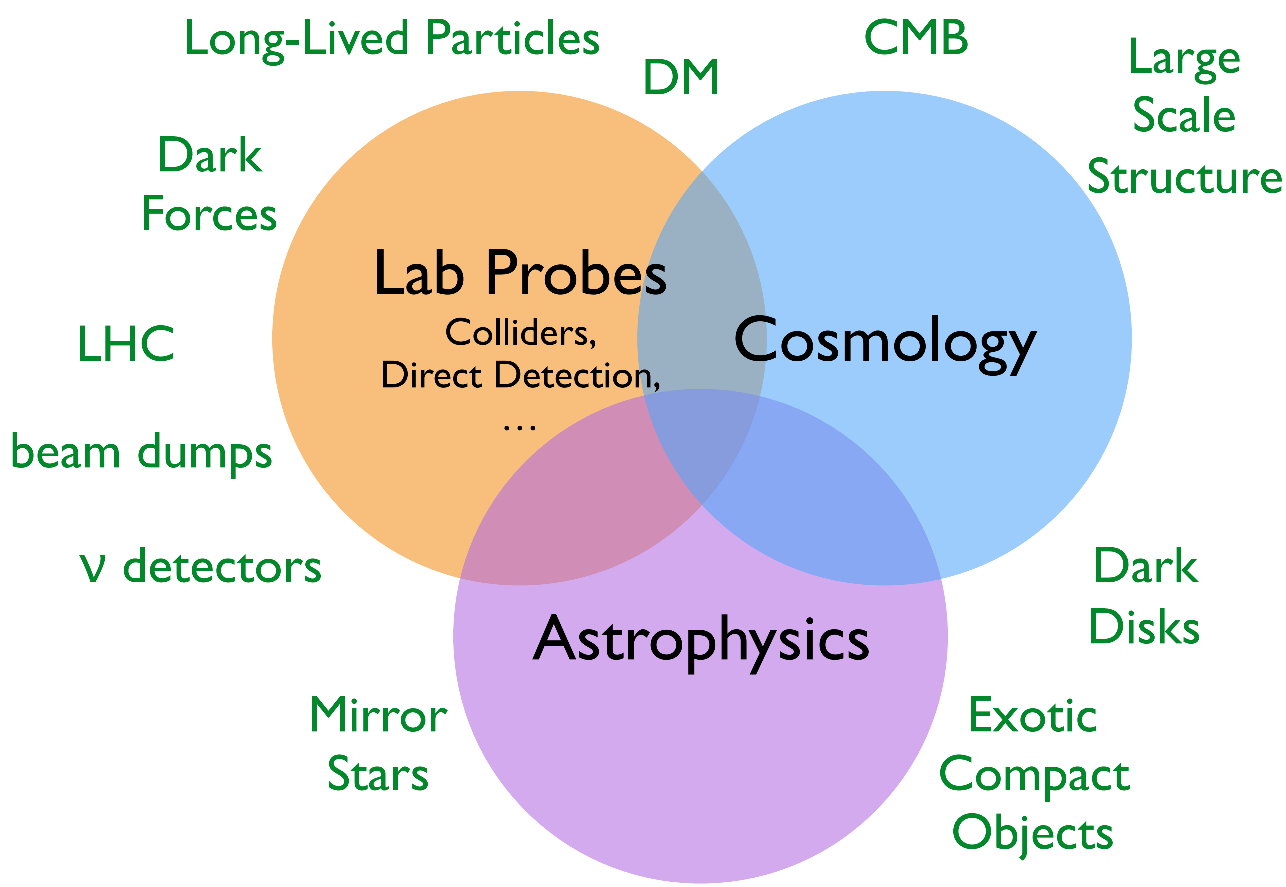
UNIVERSITY OF
TORONTO

Hidden Sectors Upshot

Hidden Sectors are hypothetical new particles and forces, hidden from us through their weak coupling to SM particles.

Commonly associated with Dark Matter direct detection & intensity frontier, but **much broader than that!**

Hidden sectors are an incredibly rich and unifying theme for a particle physics program that brings together **all corners** of **theory & experiment** with many **new frontiers and challenges!**



Motivation

Broad Motivation for Hidden Sectors

Pragmatism: SM has interesting IR physics, QCD shows how this can arise from simple theory ingredients: perhaps the same happens in new physics sector!? (Hidden Valleys, Dark Photons, LLPs, etc…).

Strong CP problem: axions?

Muon (g-2)! latest consensus: 2006.04822

Dark matter exists. Hints of BSM in cosmology? (H0 anomaly, DM halo shapes?)

Top-Down: theoretical solution to many fundamental mysteries like Hierarchy Problem, DM, Neutrino Masses, Baryogenesis *relies* on **hidden sectors** and/or **Long-Lived Particles** (LLPs)

Long-Lived Particles at the Energy Frontier: The MATHUSLA Physics Case 1806.07396

Naturalness begs for new physics at TeV, but LHC constraints push us to look for hidden sector solutions (e.g. Neutral Naturalness)

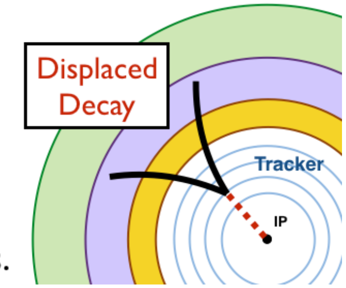
Twin Higgs Model

hep-ph/0506256
1611.07975, 1611.07977
1501.05310
1506.06141
1803.03263

A useful **benchmark** for a ***rich* hidden sector**.
Little Hierarchy Problem is solved by introducing **hidden sector that is ~ copy of SM with a few times higher EWSB scale.**

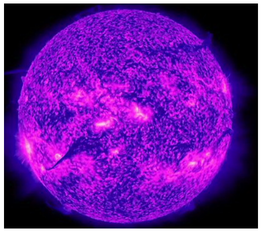
Depending on extent of symmetry between SM & hidden sector, predicts either

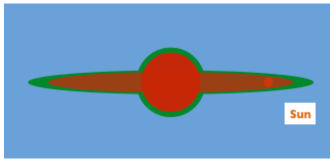
Long-Lived Particles at colliders



or

stable relics (mirror baryons) that form part of DM and have rich self-interactions.





The phenomenology of the Twin Higgs intersects with all the experimental and theoretical themes of hidden sector physics.

Probing Hidden Sectors

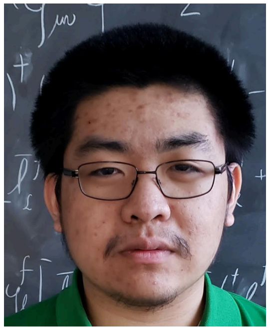
Probing Hidden Sectors

Large Hadron Collider

Canadian Collaborators:

Jared Barron
U of T PHD student

Lillian Luo
U of T undergrad



Wentao Cui
U of T undergrad

Canadian MATHUSLA collaboration:

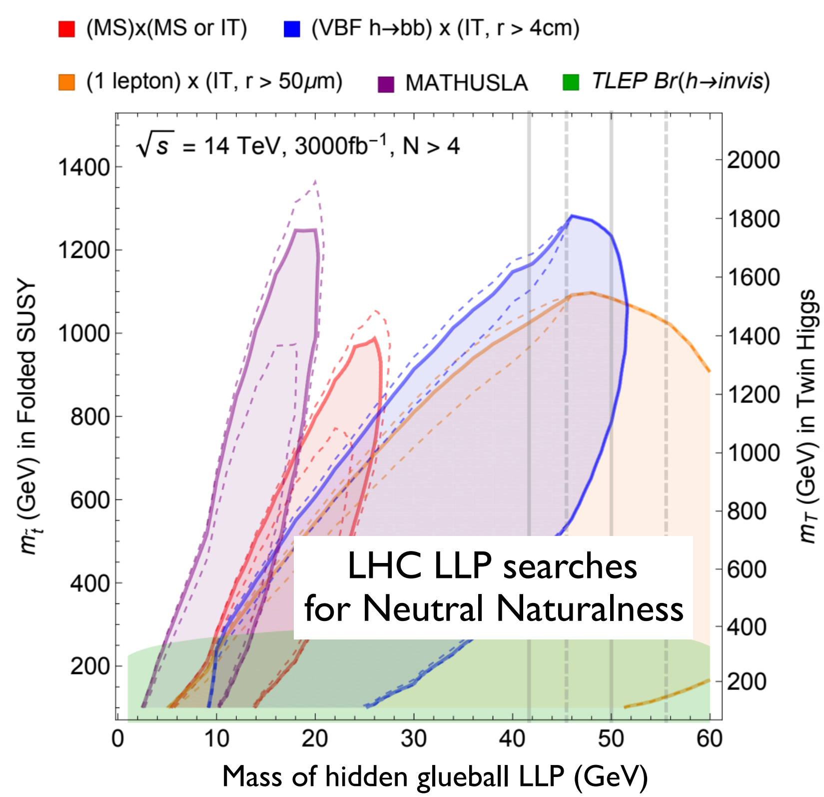
Miriam Diamond
Steve Robertson
David McKeen
David Morrissey
Daniel Stolarski

Hidden Sectors at the Energy Frontier

Hidden sectors don't have to have < GeV mass, and LHC is the only game in town for probing the TeV scale directly.

Hallmark signatures include **heavy** new states that **mediate** feeble forces in the IR and **long-lived particles (LLPs)**.

Long Lived Particle searches at the LHC are **difficult** but are being developed and could probe TeV-scale hidden sectors solving the hierarchy problem!



LHC LLP Community

CERN LLP WG:
lpcc.web.cern.ch/lhc-llp-wg

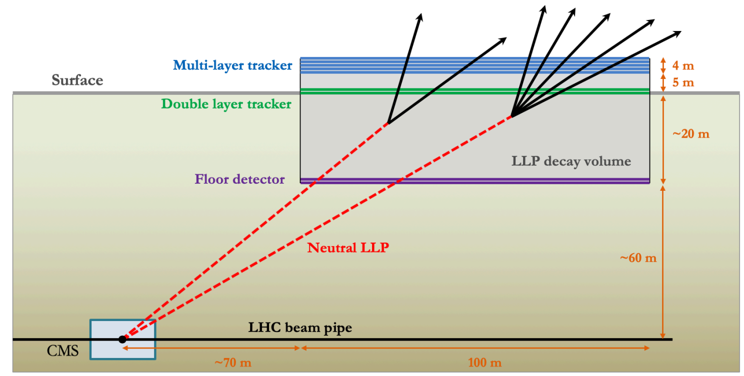
1506.06141, 1806.07396

See talk by
Miriam Diamond

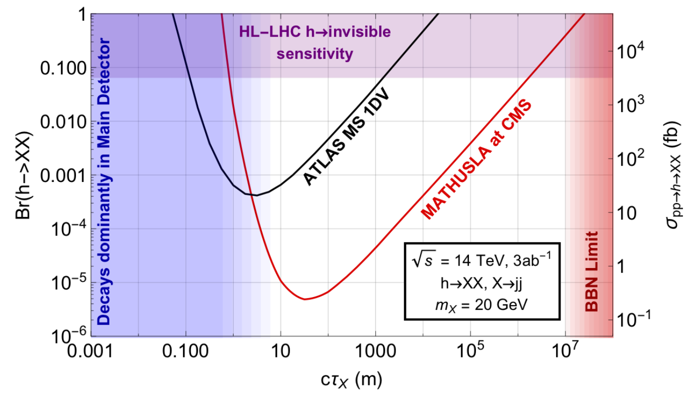
MATHUSLA

Chou, DC, Lubatti 1606.06298
LOI: 1811.00927
physics case whitepaper: 1806.07396
mathusla-experiment.web.cern.ch

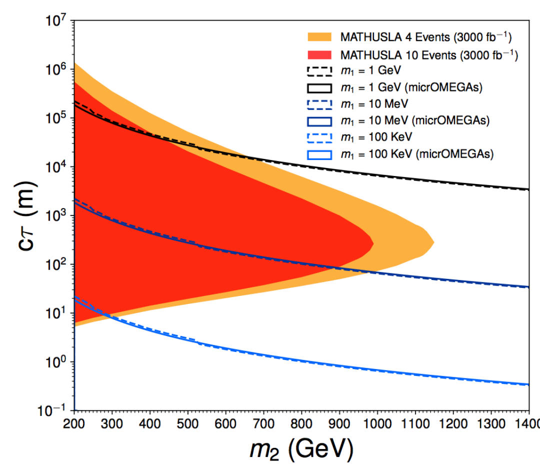
Proposal for ~100m size LLP detector near CMS.
Significant Canadian involvement & opportunity for leadership.



Probes heavy and light LLPs using full energy of LHC.
Can improve ATLAS/CMS sensitivity by orders of magnitude!



DM and LLPs are closely connected.
LLP → DM + SM could be only way to produce/observe DM!
MATHUSLA reach for Freeze-in DM:



Probing Hidden Sectors

Future High Energy Colliders

Canadian Collaborators:

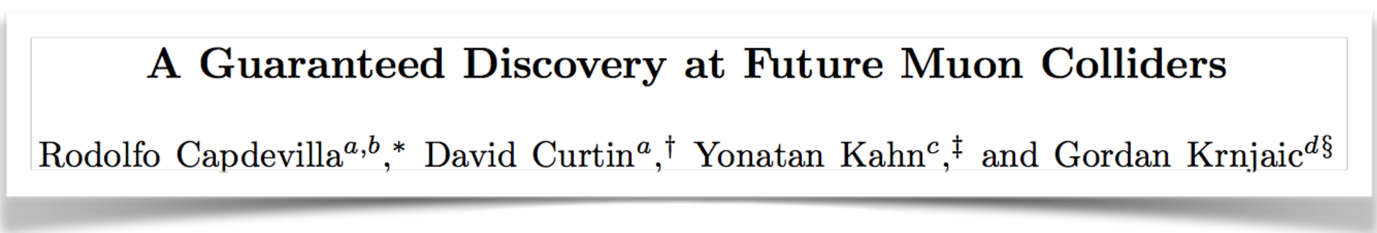
Rodolfo Capdevila
U of T / Perimeter postdoc

Muon Colliders

shameless plug

In general, future ee, pp colliders provide precision & energy reach to deeply probe hidden sector scenarios.

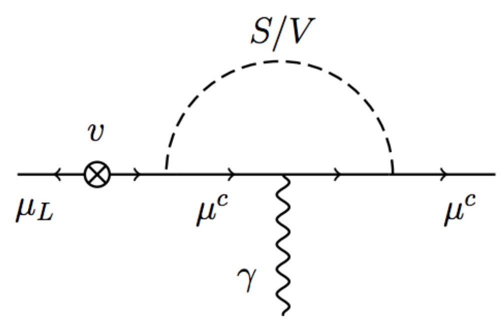
However, only a **TeV-scale Muon Collider** is guaranteed to probe *all* explanations of g-2 involving only SM singlets, due to guaranteed muon coupling of new states!



A Guaranteed Discovery at Future Muon Colliders

Rodolfo Capdevilla[a,b,*] David Curtin[a,†] Yonatan Kahn[c,‡] and Gordan Krnjaic[d§]

2006.16277



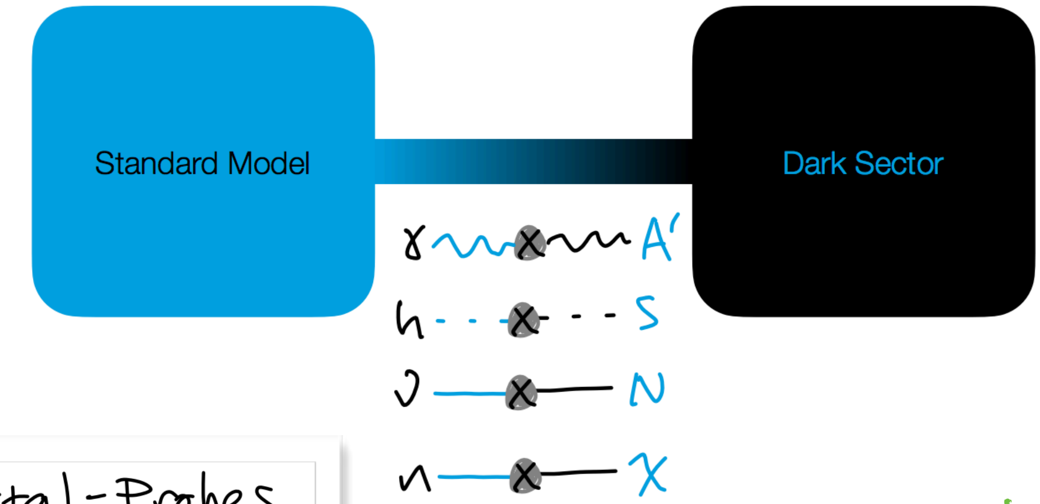
If g-2 is real, and < TeV solutions are excluded, a few-10-TeV muon collider should find high-scale scenarios with EW states!

Probing Hidden Sectors

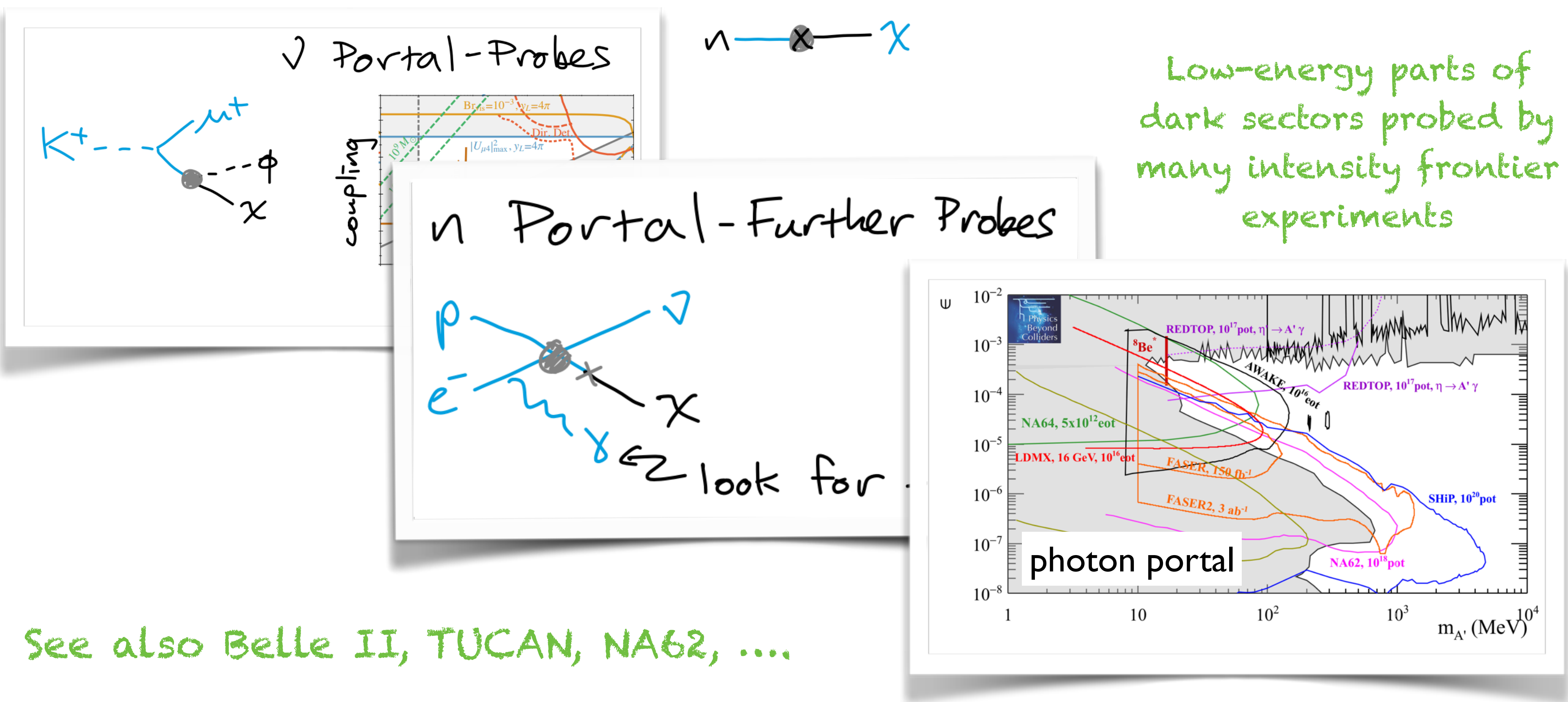
High Intensity & Precision

Low Energy Probes of Dark Sector

From talk by David McKeen



Low-energy parts of dark sectors probed by many intensity frontier experiments



See also Belle II, TUCAN, NA62, ...

Probing Hidden Sectors

DM Direct Detection

DM Direct Detection

Rich Canadian Program @ SNOLAB (DEAP, PICO, SuperCDMS…)

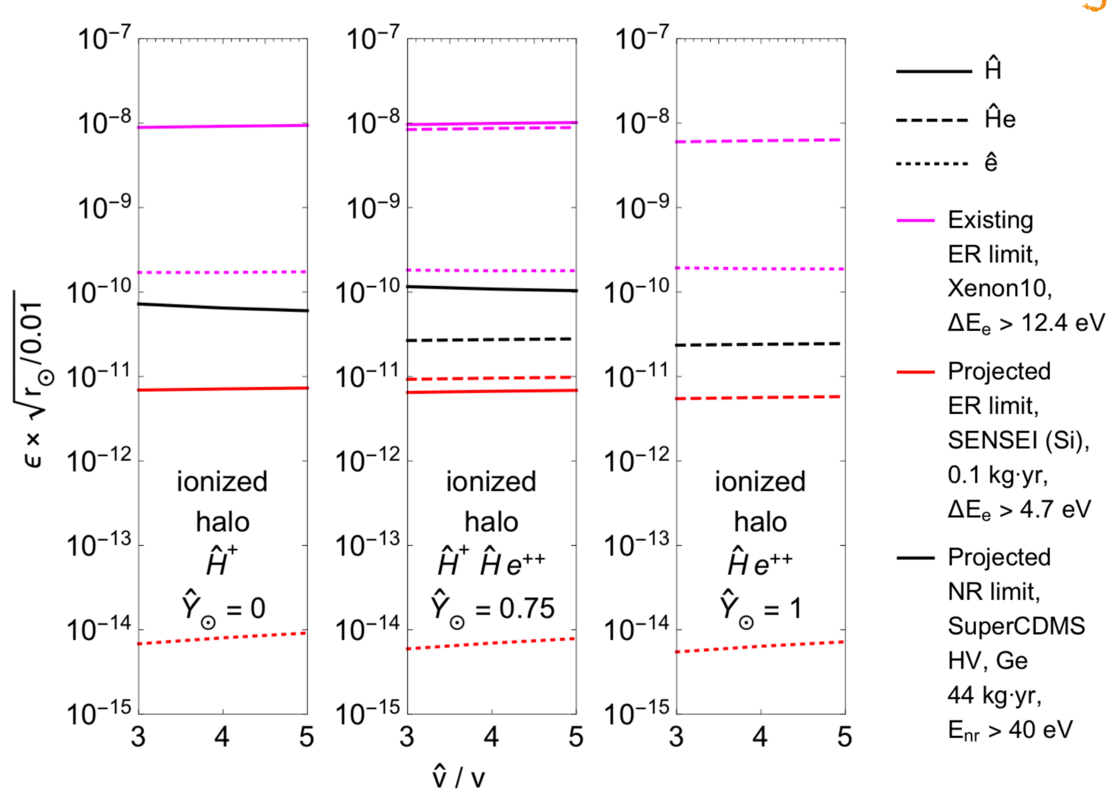
see talk by Joe Bramante

The WIMP ain't dead but expanded sensitivities for low-energy electron and nuclear recoil are particularly important for hidden sectors, since they can give rise to rich multi-state dark sectors with non-standard distributions.

see also talk by Yue Zhang

Example:

In **Mirror Twin Higgs, Mirror electrons** and **mirror H, He nuclei** form a subcomponent of DM. *Fast mirror e give distinctive ER signal.*



Chacko, DC, Geller, Tsai (on arXiv soon)

Probing Hidden Sectors

Cosmology

Canadian Collaborators:

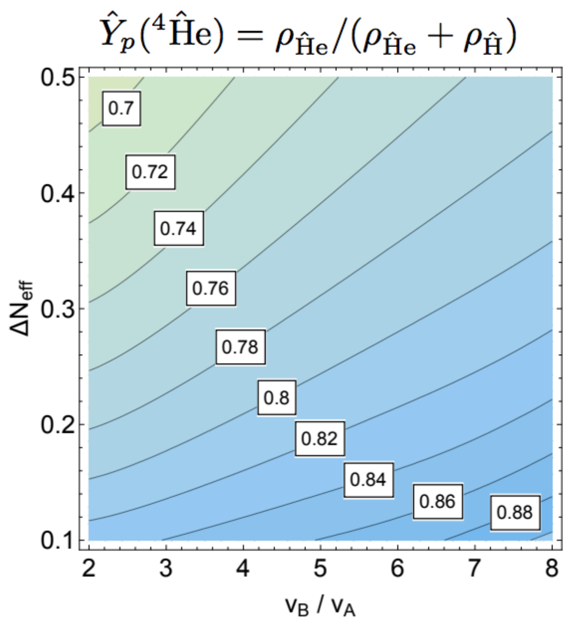
Shayne Gryba
U of T PHD student

Weirdo Relics = fun Cosmology

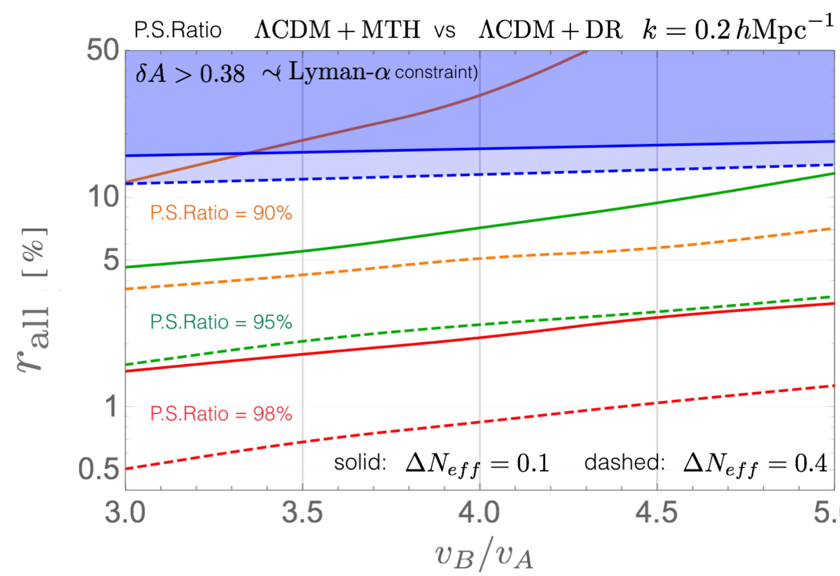
Once again, the Mirror Twin Higgs demonstrates how a highly theoretically motivated hidden sector gives rich cosmological signals.

ΔNeff ~ 0.few from mirror neutrinos/photons

DM subcomponent made up of mirror baryons. Mirror-BBN gives mirror-H/He prediction different from SM H/He



Acoustic Oscillations of mirror baryon DM subcomponent affect Large Scale Structure

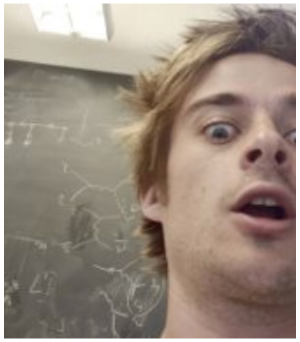


1611.07975, 1611.07977, 1803.03263

Probing Hidden Sectors

Weirdo Astrophysics!

Canadian Collaborators:

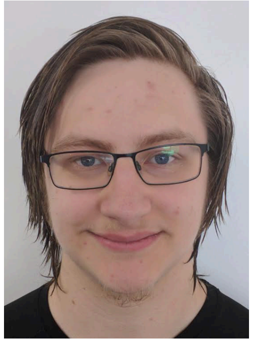


Jack Setford
U of T postdoc
(THEP)

Harrison Winch
U of T PHD
(Astro)

Jo Bovy
U of T
(Astro)

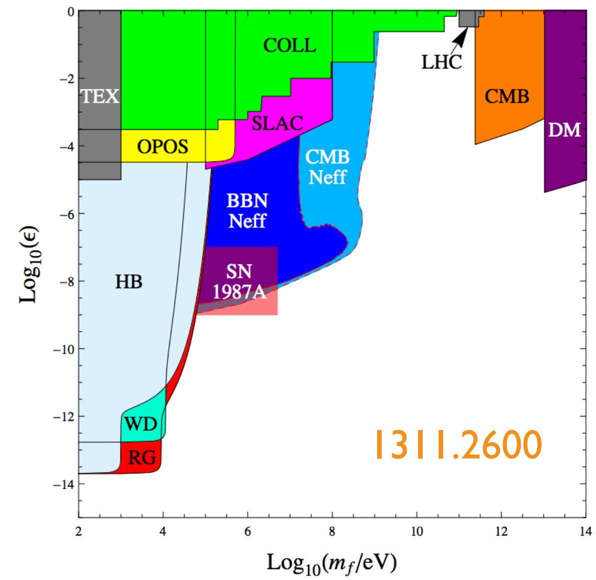
Chris Matzner
U of T
(Astro)



Aaron Howe
U of T undergrad

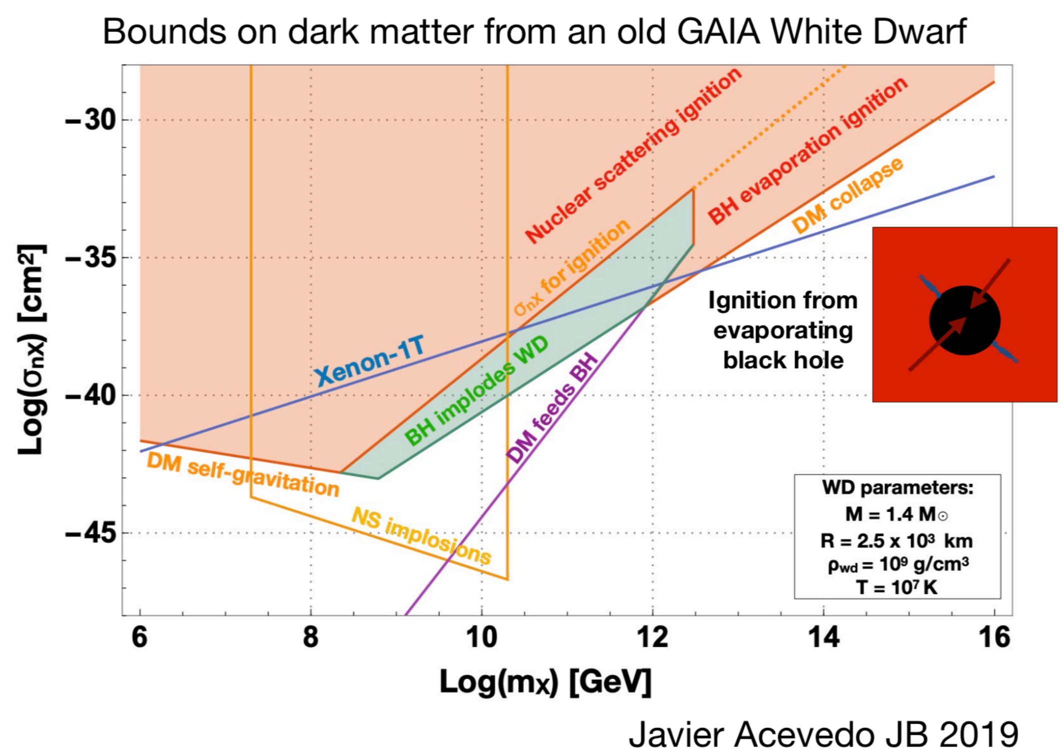
Stars as Hidden Sector Laboratories

It is well-known you can constrain e.g. dark photons, dark fermions, axions via stellar cooling, since stars can **produce** these light d.o.f. with masses ≲ 10s MeV



Stars can also act as "direct-detection experiments", getting disrupted/perturbed if they **interact** with ambient DM too much.

Slide from Joe Bramante:



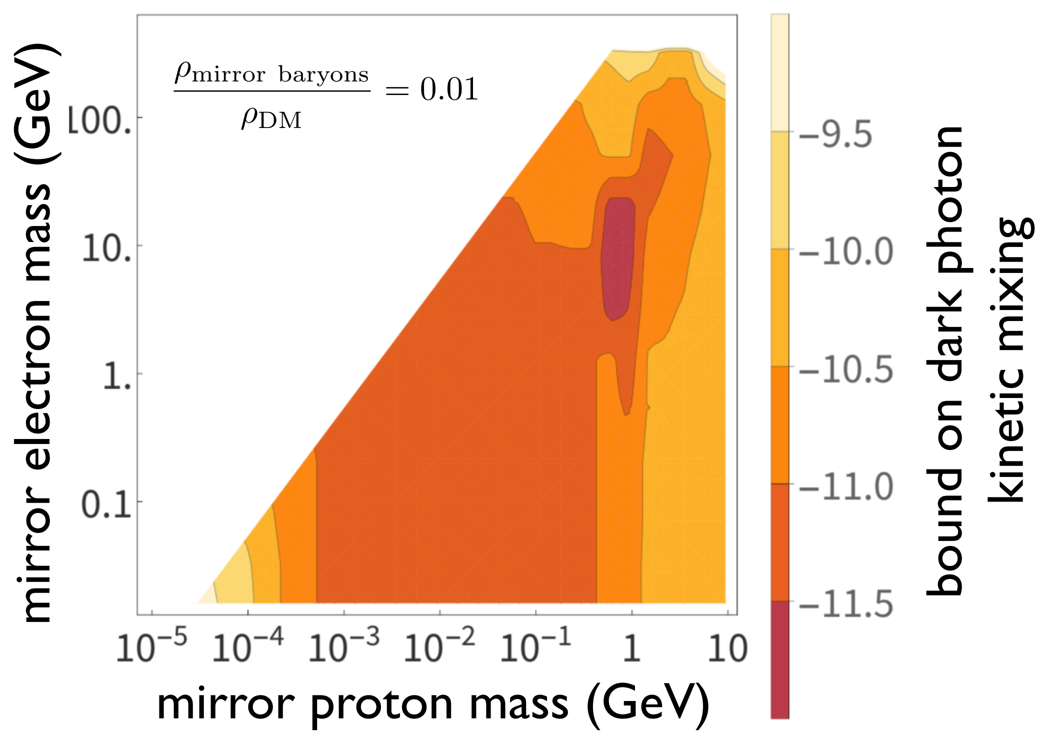
Rich Dark Sectors & Stellar Cooling

Asymmetric, dissipative DM arises in rich dark sectors with multi-state DM subcomponents and dark photons, e.g. **Mirror Baryons in Twin Higgs**.

They get trapped in stars, get heated up via small dark photon kinetic mixing, and **radiate away dark light**.

DC, Jack Setford (on arxiv soon)

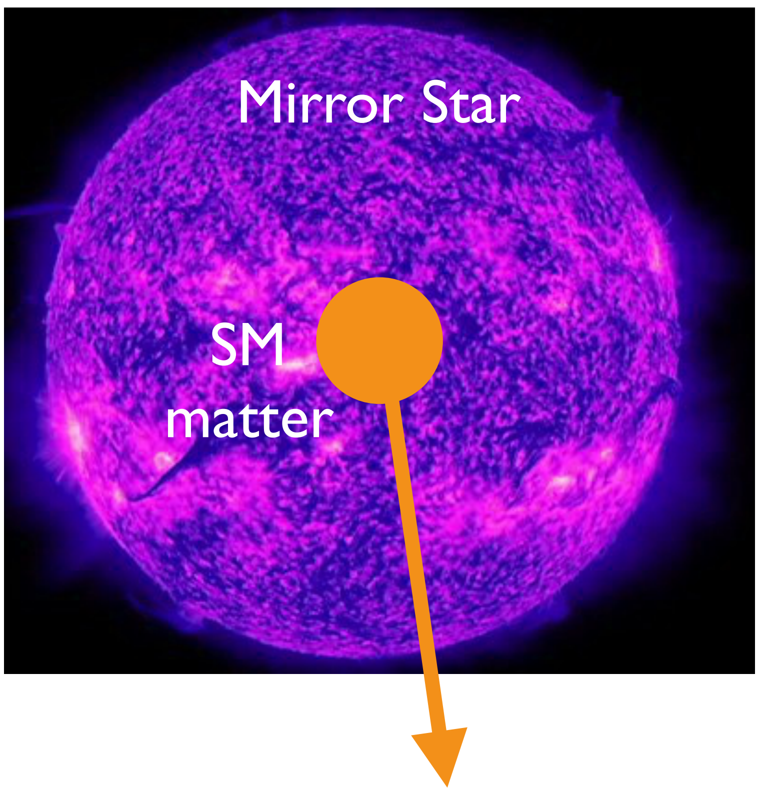
White Dwarf cooling provides strongest known bounds on dark baryons, especially in distributions (dark atomic disk) that are difficult to probe with direct detection. **Important Complementarity!**



Mirror Stars

DC, Setford
1909.04072, 1909.04071

In the Mirror Twin Higgs or other rich dark sectors, mirror baryon DM subcomponent can **clump** and form **Mirror Stars** that fuse **Dark Nuclei** and shine in **Dark Light**.



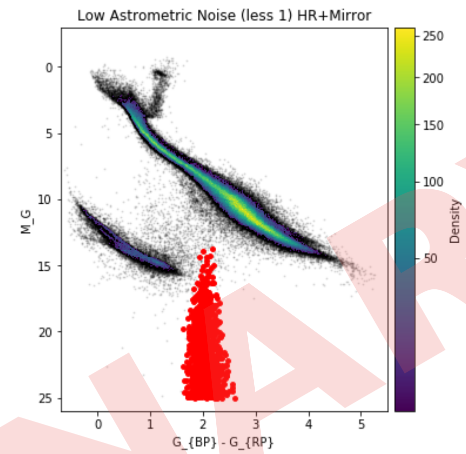
For expected range of dark photon kinetic mixings $\epsilon \sim 10^{-13}$ - 10^{-10}, mirror stars **capture SM matter**, which is **heated** and also **converts mirror-X-rays to SM-X-rays.**

→ Discover signatures of DM in in optical/X-ray telescopes!

Distinctive Thermal (~ 7000 K) + X-ray signals

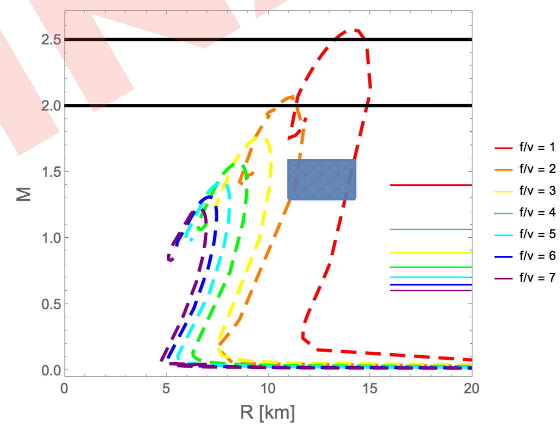
A new astronomical DM frontier

Search for Mirror Stars in GAIA data. Signal region of optical emission is ~ independent of hidden sector physics!



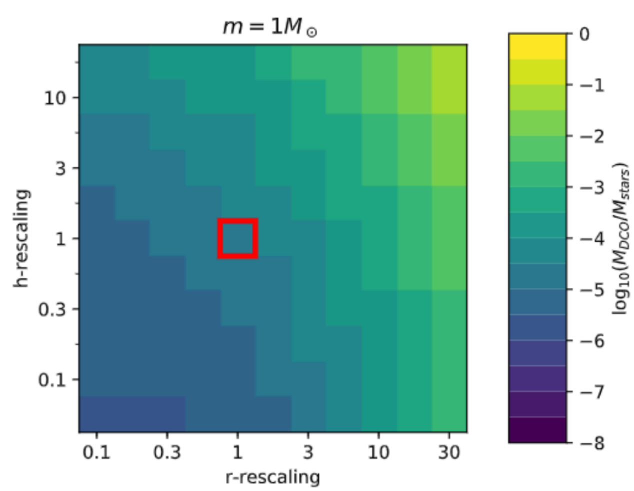
GAIA HR diagram with Mirror Star signal region in red. DC, Chris Matzner, Jack **Setford**, Aaron Howe (ugrad)

LIGO could observe **gravitational waves** from **Mirror Neutron Star mergers** below 1 solar mass



Mirror neutron star mass-radius relationship. DC, Hippert, Noronha-Hostler, **Setford**, Tan, Yunes

LSST microlensing surveys can probe mirror star distributions down to ~% of SM stellar number densities



Sensitivity projections for disk of dark stars in milky way. Harrison Winch, Jo Bovy, DC, Jack **Setford**

Theoretical Challenges

Unique Theoretical Challenges

Rich hidden sectors can come in staggering varieties.
What are the universal signatures of such complexity in astrophysics, cosmology, colliders?
What is the minimal set of simplified models that covers signature space?

Detailed phenomenology is by definition challenging for these models:

- rich dark sector DM subcomponent in MHD N-Body Simulations to understand effect on galaxy formation?
- confining dark sectors: mass spectra, dark showers at colliders, DM indirect detection signatures?
- …

Many leaders in this field here in Canada!

Conclusions

Conclusions

Hidden Sectors could be connected to our most fundamental questions about the universe: Dark Matter, the Hierarchy Problem, neutrino masses, Baryogenesis, ….

Probing hidden sectors must draw upon a uniquely wide array of tools from the LHC and new LLP detectors, underground particle detectors, laboratory precision experiments, astrophysics and astronomical observations, precision cosmology…

The theoretical and experimental challenges to deal with this complexity are daunting but exciting, and enormous progress is being made here in Canada and the rest of the world.