2024/07/19

TRISEP-2024 Close Out

Dr. Erica Caden
Chair


SNOLAB | July 8-19 2024
PI · SNOLAB · TRIUMF
TRISEP
STANDARD MODEL PHYSICS AND BEYOND
STATISTICS & COMPUTING FOR PARTICLE PHYSICS
DARK MATTER CANDIDATES AND DETECTION
NEUTRINOS PHYSICS
LONG BASELINE NEUTRINO MEASUREMENTS
NEUTRINOLESS DOUBLE BETA DECAY
FOCUSED LECTURES ON UNDERGROUND TOPICS
$\frac{\Delta m^2_{ij} L}{4E} \approx 1.267 \frac{\Delta m^2_{ij}[eV^2] \times L[km]}{E[GeV]}$.


Capstone Exercise I: Make The Universe
$\rho(T) = \frac{\pi^2}{30} g_* T^4,$
$s(T) = \frac{4}{3}\frac{\pi^2}{30} g_{*s} T^3$
$g_* = \sum_{i=bosons} g_i \left(\frac{T_i}{T_\gamma}\right)^4 + \frac{7}{8} \sum_{i=fermions} g_i \left(\frac{T_i}{T_\gamma}\right)^4$
$3m_{pl}^2 H^2 = \rho$
$\ddot{\phi} + 3H\dot{\phi} + \frac{dV}{d\phi} = 0$
$\rho = \rho_0 a^{-3}$ matter
$\rho = \rho_0 a^{-4}$ radiation
$\rho = \rho_0$ vacuum energy
Quick tip: to relate a decay width to a time during expansion, use the Hubble time
$t_H^{-1} \equiv H = \Gamma_{decay}$
Key temperatures
matter-radiation equality T_r=0.8 eV
baryon asymmetry for BBN T~10^{-1} GeV
max temp from inf? T=10^{16} GeV
Hint for setting dark matter abundance: work backwards from m-r equality T universe where
$3m_{pl}^2 H^2 = \rho = \frac{\pi^2}{30} g_*^{SM} T^4$
DM density required at T:
(rad. dom. universe)
$\rho_{dm}(T) = \frac{\pi^2 g_*}{30} T^3 T_r$
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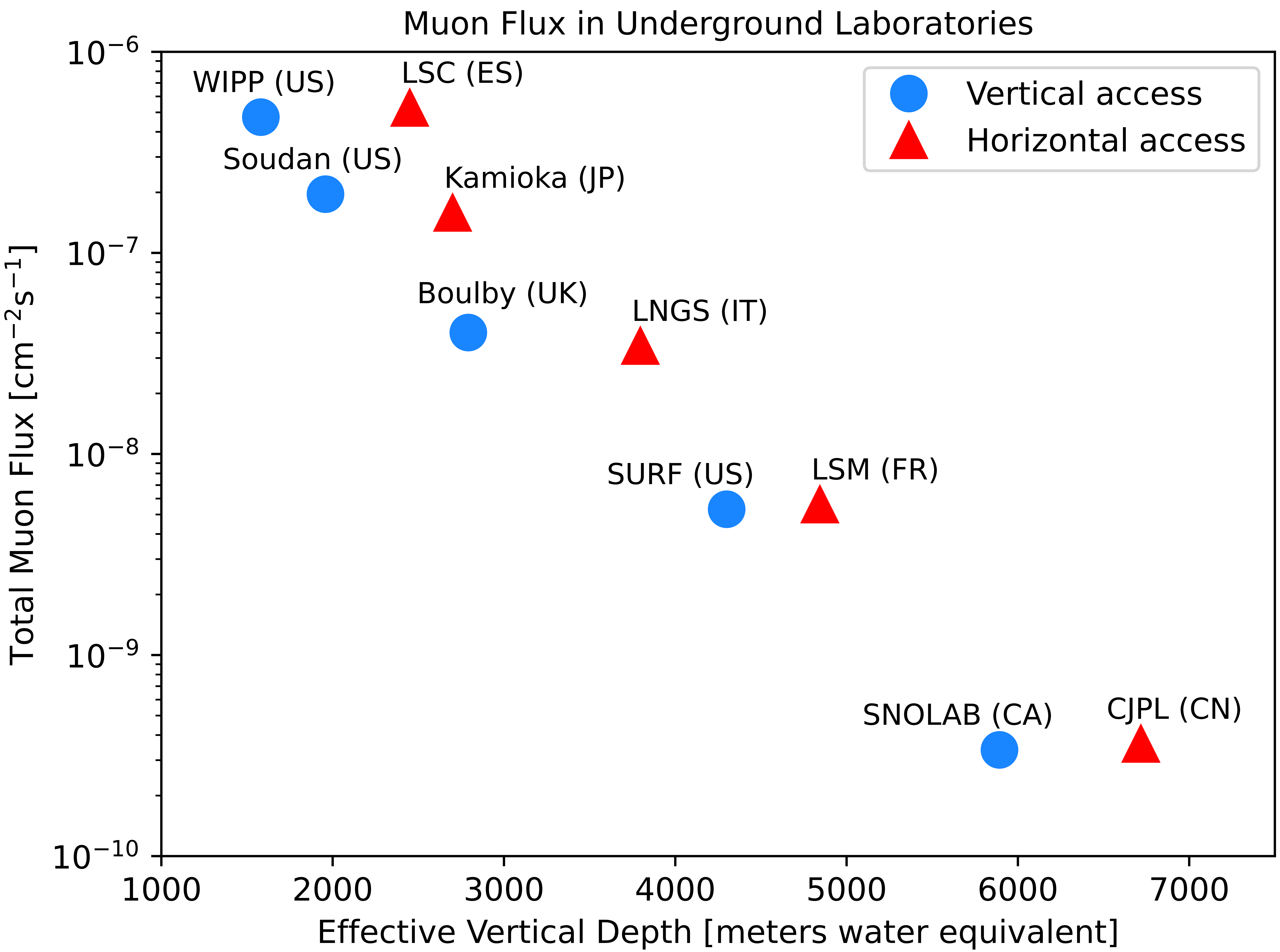

Adapted from Chin. Phys. C 45 (2021) 2, 025001

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MI-HQPAC

McDonald Institute **Highly Qualified Personnel** Advisory Committee

- Meets monthly to develop ideas and initiatives
- Hosts monthly virtual community open discussions to talk about areas of improvement for the HQP Community
- Has a ~$10k budget to make things happen
- Advises the McDonald Institute on improvements for the HQP Community
- Is a great way to connect and practice community leadership!

The Committee welcomes you to their next open discussion!

Are you HQP? Probably! All Graduate, PhD Students, Postdocs, PDFs, and early career researchers working or studying astroparticle and related physics, or in cross/interdisciplinary research involving astroparticle and related physics.

mcdonaldinstitute.ca/hqpac


The Higgs Particle
SNOLAB
m_H = 125.11 GeV (± 0.08%)
ATLAS Preliminary
√s=13 TeV, 140 fb⁻¹
H → γγ
All categories
Data
Background
Signal + Background
CMS
35.9 fb⁻¹ (13 TeV)
H→γγ
All categories
S/(S+B) weighted
S+B fit
B component
±1 σ
±2 σ
B component subtracted
Sum of Weights / 1 GeV
$m_{\gamma\gamma}$ [GeV]
Consistent with the spin-0 parity-even boson predicted by SM.

What is Next?
There is only one free
parameter of the original
Standard Model left: λ
=0.129
"Di-Higgs Production" is a major experimental target of the LHC program for the next 10+ years. Talk to Michael Kagan to learn more – he's an expert!
The Higgs particle's "self interaction" manifests in a particle collider as the production of a pair of Higgs particles. These events should be exceedingly rare (1000 times rarer than the single-Higgs production processes that led to the 2012 discovery)
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What do we know about dark matter?
mass in GeV
wide binaries
smallest galaxies
10^{-30} 10^{-20} 10^{-10} 10^{0} 10^{10} 10^{20} 10^{30} 10^{40} 10^{50} 10^{60}
fermi pressure
vs small scale
fermion
de Broglie
vs small scale
Planck
mass
boson
composite: boson star nuclearite q ball dark nucleus black holes
Its mass falls along a wide range, for fermions, bosons, or composite dark matter the allowed masses are different.


Bosonic dark matter (axion, alp, any ultralight)
"the misalignment mechanism"
$w_\phi \equiv \frac{p_\phi}{\rho_\phi} = \frac{\frac{1}{2}\dot{\phi}^2 - V}{\frac{1}{2}\dot{\phi}^2 + V}$
$\ddot{\phi} + 3H\dot{\phi} + \frac{dV}{d\phi} = 0$
V(ϕ)
ϕ
Θ̄=0
from Raffelt
Consider an inflaton or another scalar field in an FRW background with
$V = \frac{1}{2}m^2\phi^2$
With H > m, this field will act like an overdamped harmonic oscillator, however once H << m, the field will have a simpler EOM.
1. Find the time-average EOS for this field. Assume the field starts at $\phi = \phi_0 \neq 0$.
2. What is the average energy density of this scalar field at the time it starts oscillating?
w=0, $\rho \sim m^2\phi_0^2$


Measuring Neutrino Masses
Direct measurement
Indirect measurements
Kinematic measurement
Effective ββ mass
Observational Cosmology
virtual ν exchange
Majorana nature
Upper limit: ~0.05 – 0.2 eV
GERDA, KamLAND-ZEN, MAJORANA, LEGEND, nEXO, CUORE, CUPID, NEXT, ...
Multi-parameter cosmological model
Upper limit: ~0.11 – 0.54 eV*
Planck satellite


Final thoughts in neutrinos
It's a Marathon not a Sprint.
FINISH... NOT QUITE THERE YET...
FINISH... HMM, NO, STILL NOT RIGHT...
FINISH... WAIT, ONE MORE THING.
THE ARTIST 10K
TRISEP 2024 - Neutrinos
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Adding non-linearity
What if we want a non-linear decision boundary?
– Choose basis functions, e.g.: φ(x) ~ {x², sin(x), log(x), ...}
ear decision boundary?
φ(x) ~ {x², sin(x), log(x), ...}
Adding non-linearity
What if we want a non-linear decision boundary?
– Choose basis functions, e.g.: φ(x) ~ {x², sin(x), log(x), ...}


Principle Components Analysis
• Given data $\{\mathbf{x}_i\}_{i=1\ldots N}$ can we find a directions in features space that explain most variation of data?
• Data covariance: $\mathbf{S} = \frac{1}{N}\sum_{i=1}^{N}(\mathbf{x}_i - \bar{\mathbf{x}})^2$
SLAC

SuperCDMS
HVeV Run 2
This Work
HVeV R1
DAMIC
SENSEI
XENON10
XENON1T
$F_{DM} = 1$
$\bar{\sigma}_e\,[\mathrm{cm}^2]$
$m_\chi\,[\mathrm{MeV}/c^2]$
https://arxiv.org/abs/2005.14067
Ultralight
Mediator
SNOLAB
Change is long
overdue
COVID-19
VACCINE


WIMPing out?
“Weakly Interacting Massive Particles” (WIMP) candidates:
Supersymmetric partners
Additional Higgs bosons
“Mirror universe” / “Hidden Valley” particles
Kaluza-Klein particles
Sterile neutrinos
... etc
But... searches where we most expected to find WIMPs haven't found them!
Dark Matter Mass [GeV/c²]
1
10
100
1000
proton mass


US Cosmic Visions: New Ideas in Dark Matter 2017
Community Report
zeV aeV feV peV neV μeV meV eV keV MeV GeV TeV PeV 30M⊙
QCD Axion
WIMPs
Ultralight Dark Matter
Hidden Sector Dark Matter
Black Holes
Pre-Inflationary Axion
Hidden Thermal Relics / WIMPless DM
Post-Inflationary Axion
Asymmetric DM
Freeze-In DM
SIMPs / ELDERS
Beryllium-8
Muon g-2
Small-Scale Structure
https://arxiv.org/pdf/1707.04591
Small Experiments: Coherent Field Searches, Direct Detection, Nuclear and Atomic Physics, Accelerators
Microlensing


The Evidence for Dark Matter
Gravitational Lensing
Galactic Rotation Curves
smithsonianmag.com
~5 times as much dark matter in the

Example of the extended maximum likelihood
in action: SNO flux fits
CC
ES
NC
Energy
Radius
Angle
Isotropy
P(E,R,Θ,β) =
CC P_CC(E,R,Θ,β)
+ ES P_ES(E,R,Θ,β)
+ NC P_NC(E,R,Θ,β)
for the numbers of
and NC
either CC, ES, or
the three event totals
are anti-correlated
with each other.
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Problem to work in groups:
A neutrinoless double-beta decay experiment counts the number of events in a signal region. The expected background is 2 events. For an effective neutrino mass of $m_{\beta\beta}$ = 50 meV the experiment expects 4 signal events. The experiment is done, and no events are seen in the signal region.
• What is the Feldman-Cousins 90% CL upper limit on $m_{\beta\beta}$?
• Assuming a flat prior, what is the Bayesian upper limit on $m_{\beta\beta}$?
• Suppose a second experiment has the same expected signal rate but an expected background of 5. It also observes zero events. What Feldman-Cousins limit do you get now? Compare to your result from Part A. Do these results make sense?
https://arxiv.org/abs/physics/9711021
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Solar neutrinos
The Sun's fusion reactions produce copious quantities of electron neutrinos!
We know how bright the Sun is and how the fusion reactions work ...
We calculate that 60 billion neutrinos from the Sun pass through your thumbnail every second!


Systematic Uncertainties in HK Era
HK Sensitivity for δcp=-π/2 (maximal CP viol.)
$\sqrt{\Delta\chi^2}$ to exclude $\sin\delta_{cp}=0$
5σ C.L. if δcp=-π/4
5σ C.L.
w/ eff. 2016 sys. errors
w/ eff. sys. improvements
w/o syst. errors
Running Time [years]
Reaching 5σ C.L. for maximal CP will require improved systematic uncertainty estimates
Will require improved understanding of:
Hadron-production distributions
ν cross-sections
Detection efficiencies


≈ LHC (2009-2040)
Protons
ATLAS
P
= 13.6 TeV
Compute
Circumference
27 km
build LHC?
year 2000
IN1608: Input 7
No Signal


SPIN AND PARITY MEASUREMENT
Golden channel decay to 4 leptons.
h
Z
Z
Each event described by 5 variables in Higgs rest frame.
July 16-18, 2024
TRISEP


TRISEP 2024
0νββ
Jeanne Wilson


A Little History
• Maria Goeppert-Mayer
• Proposed double beta decay in 1935
• Nobel prize 1963 (shell model)
• Ettore Majorana
• Proposed 2 component neutrino in 1937
• 'Majorana neutrino'
• Wendell Furry
• If neutrinos are majorana, double beta decay could proceed without the emission of any neutrinos (1939)
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0νββ
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Rare event searches:
WIMP dark matter cross section on the order of the weak scale.
$R_{\chi N} \propto N_N \cdot \Phi_\chi \cdot \sigma_{\chi N} \propto M_T$
High detector mass increases number of targets
Recoils spectrum approximately exponential
Energy range from sub-keV to a few 10 keV
Assume elastic scattering of WIMP on target
$E_{R,max} = 30$ keV
$(m_\chi = m_N = 100$ GeV,
V=220 km/s)
How many events do I
expect per tonne material
and year of measurement?
Recoil energy on target Nucleus
Low backgrounds for rare event searches
5


Detector materials
Calibration of active veto efficiency via an AmBe
about 50 % of all cases an
Low backgrounds for rare event searches
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Natural background
Location
Annual dose (mSv)
World Average
3
Guarapari, Brazil
Up to 175
Ramsar, Iran
Up to 100
Kerala, India
Up to 35
Yangjian, China
Up to 25
U.S. Rocky Mountain States
6–12
U.S. Gulf States
0.8–1.2
Evacuated land near Chernobyl
1–10
Evacuated land near Fukushima
<10
REPAIR
REPAIR


One example of how it works to wander through this space...
WMAP data ~2004: very detailed view of CMB
Can we test BSM models of inflation? String theory?
Non-Gaussianity as a probe of particle interactions
in the primordial universe
Lots of theory work
What about large-scale structure?
(Stay tuned for SPHERE-X!)
Primordial Gravitational waves?
Need better experiments to measure CMB polarization
Inflation with interactions? Finite universe? Need to
understand open quantum systems
Big opportunity: LIGO data!
Nicole R. Fuller, NSF
Shandera, TRISEP 2024

Doran Planetarium presents

Cultural Parallax: Stories Under the Night Sky

ay, 2022

Featuring:

Ojibwe storyteller **Will Morin**
BFA, BA, B.Ed, MA, PhD (ABD)

Science Communicator **Hoi Cheu**
PhD

SNOLAB Scientist **Christine Kraus**
PhD

B

the Faculty of Science, Enginee
and the Faculty of Arts,

Arthur B. McDonald
Canadian Astroparticle Physics Research Institute

Through storytelling,
with a focus on
Anishinaabe culture,
this presentation introduces
the wonders of the night sky.


THE CREATIVE TEAM

UP HERE


SCIENCE NORTH
SCIENCE NORD
Dynamic Earth
Terre dynamique
Home of the Big Nickel | Site du Big Nickel


UNDER ARMOUR


Cosmology, Dark
Matter and New Physics
Katie Mack
Hawking Chair in Cosmology and Science Communication
Perimeter Institute for Theoretical Physics
Image: A. Loeb/Scientific American

Inquiry Cube!


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misalignment mechanism"
Bosonic dark matter (axion, alp, any ultralight)
"the misalignment mechanism"


IN1608: Input 7
No Signal
IN1608: Input 7
No Signal


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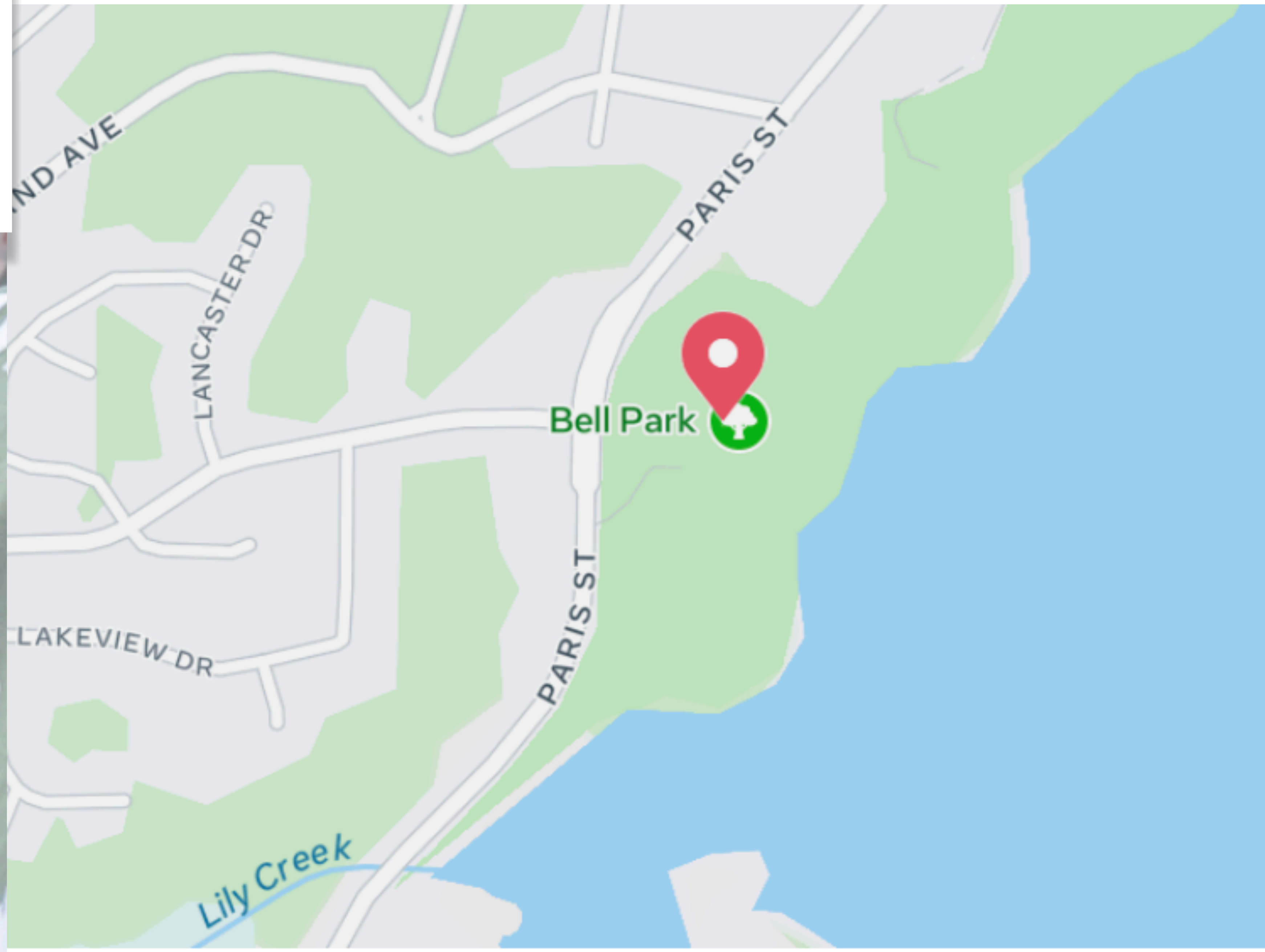
If you're still in town tomorrow...

JAPAN Festival Sudbury



Grace Hartman Amphitheatre

900 Paris Street, Sudbury

TRISEP-2024 Follow Up


THANK YOU!!!