The Windchime Project: Towards Gravitational Detection of Dark Matter in the Lab

arXiv:2203.07242

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Purdue University
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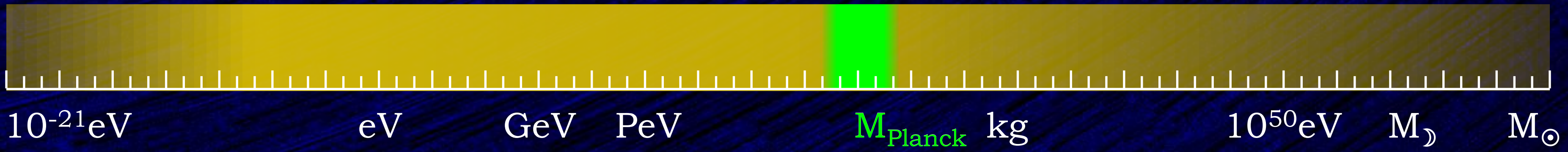
UCLA Dark Matter 2023

Where is Dark Matter Hiding?

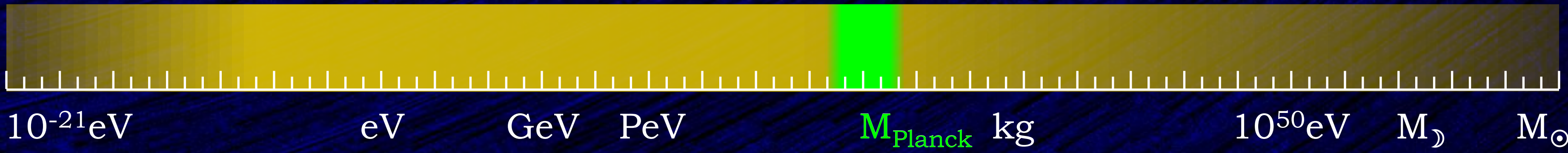
Dark Matter around the Planck Mass



✓ Uniquely motivated, e.g.

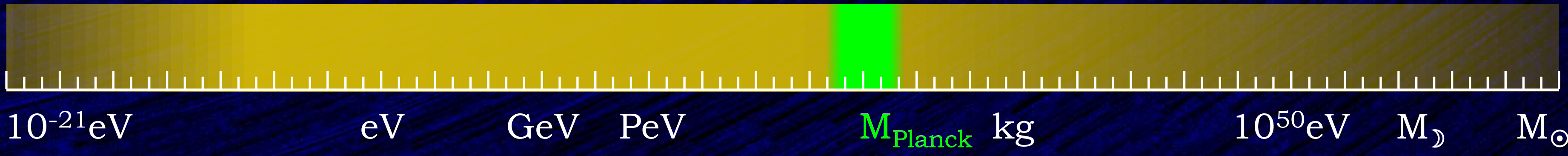
- Primordial Black Holes Hawking-evaporate and leave a quantum-gravity corpse behind MacGibbon 1987, Aharonov+ 1987
- WIMPzillas Kolb+ hep-ph/9810361, 1708.04293, Harigaya+ 1606.00923
- Composite dark matter Krnjaic+ 1406.1171, Hardy+ 1504.05419
- GUT-scale coannihilation Berlin 1704.08256
- Dark quark nuggets Detmold+ 1406.2276, Gresham+ 1707.02316
- Planckian interaction Garny+ 1511.03278
- … Bai+ 1906.04858 Blanco+ 2112.14784

Dark Matter around the Planck Mass



✓ Uniquely motivated, e.g.

Directly Probing Planck-Mass Dark Matter



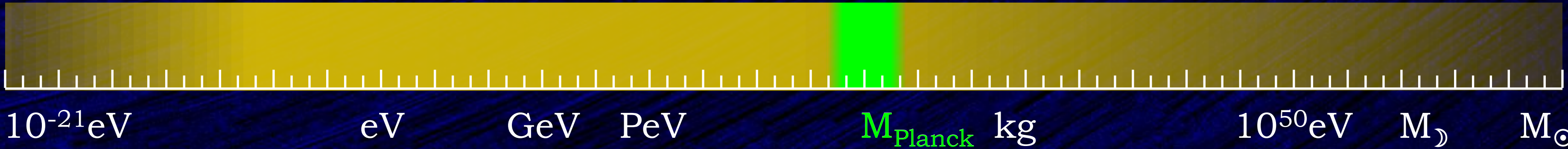
✓ Uniquely motivated

✓ Still accessible in lab

mass density fixed to ~0.3 GeV/cm^3

at $m_\chi \sim m_{Planck}$, flux ~ $1/m^2$/year

Directly Probing Planck-Mass Dark Matter



✓ Uniquely motivated

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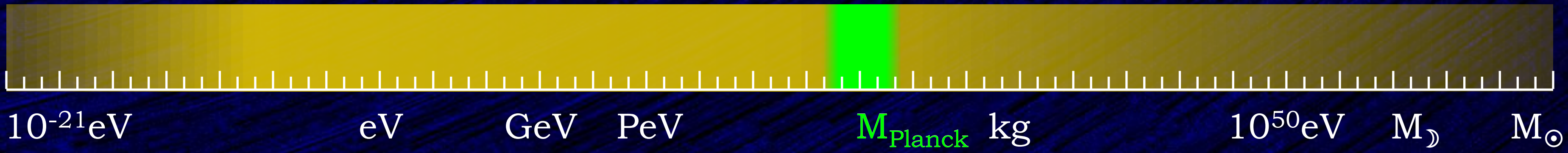
mass density fixed to ~0.3 GeV/cm^3

at m_χ~m_{Planck}, flux ~ 1/m^2/year

stablediffusional: "Rafael near cubic meter-sized detector"

Rafael Lang (Purdue): Windchime

Quantum Sensing for Dark Matter Detection



✓ Uniquely motivated

✓ Still accessible in lab

✓ Gravitational detection feasible Carney+ 1903.00492

thanks to recent advances in quantum sensing. Need

- sensitive accelerometers
- quantum-enhanced readout
- large array

The Windchime Collaboration

PURDUE UNIVERSITY

UNIVERSITY OF MARYLAND

RICE UNIVERSITY

UNIVERSITY OF MINNESOTA

CHALMERS UNIVERSITY OF TECHNOLOGY

OAK RIDGE National Laboratory

BERKELEY LAB

Fermilab

NIST National Institute of Standards and Technology U.S. Department of Commerce

IQI

Big thank you to our supporters

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QUANTUM SCIENCE CENTER

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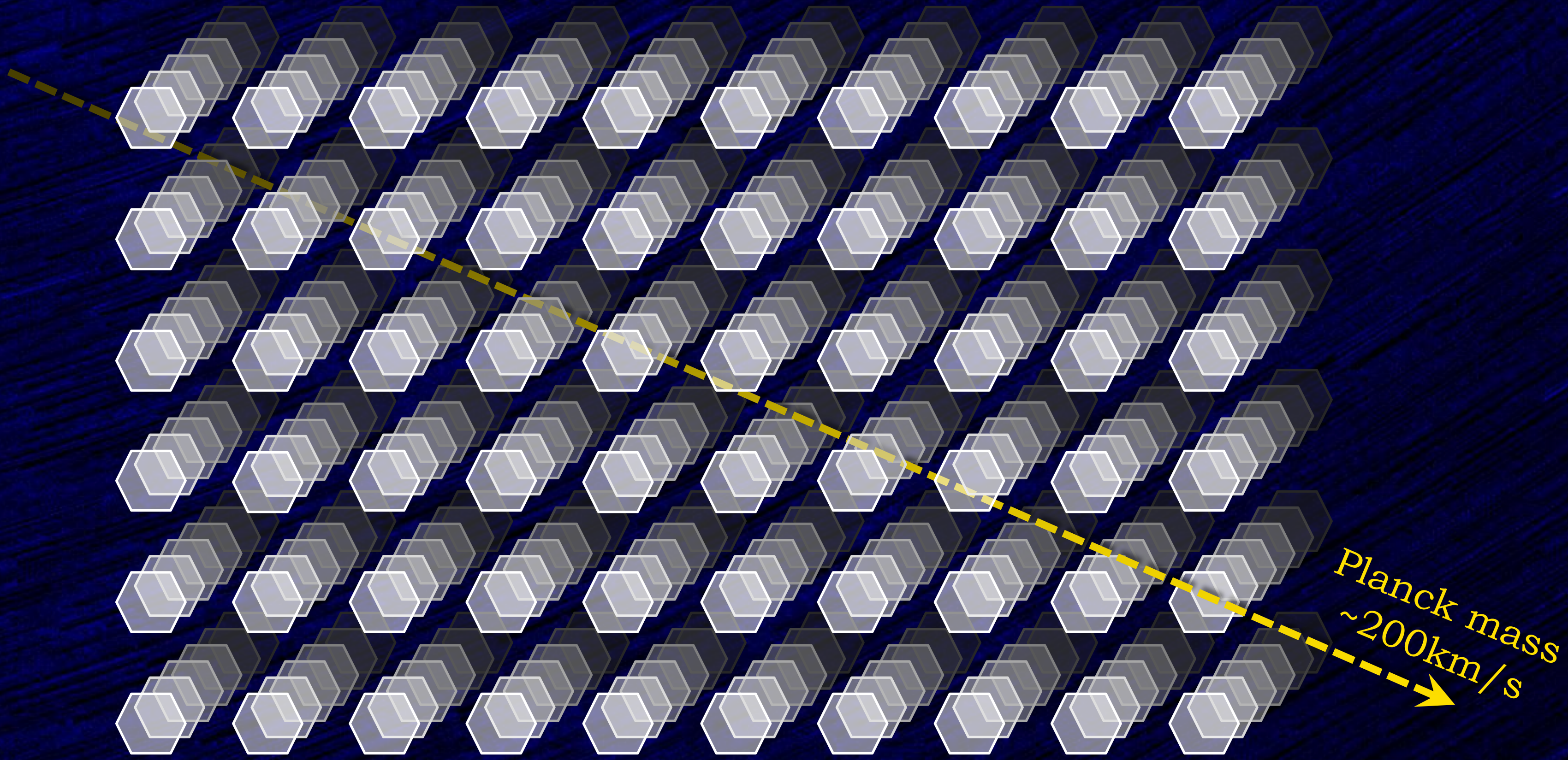
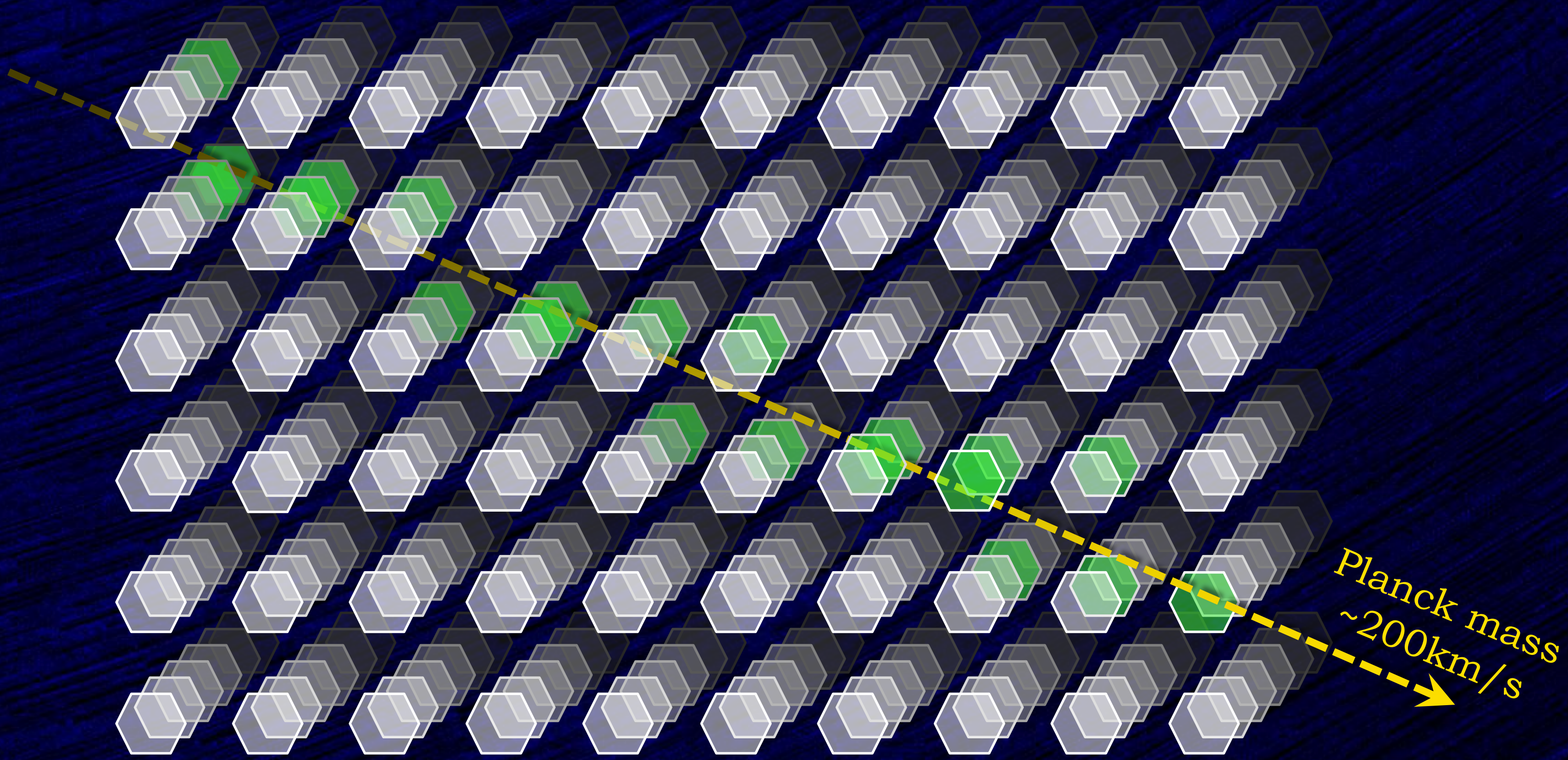
PURDUE UNIVERSITY | Purdue Quantum Science and Engineering Institute

Measure Tracks through Array of Accelerometers



Measure Tracks through Array of Accelerometers

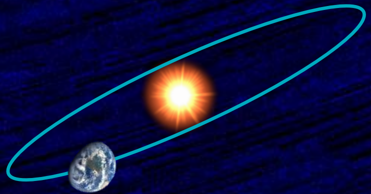


Simulating the Experiment

Dark Matter Halo
- local density
- velocity distribution

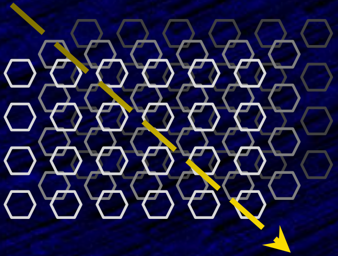
Earth orientation
- seasonal modulation
- directionality

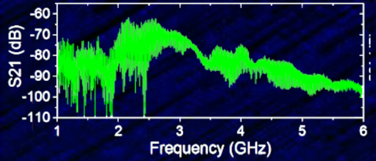
Particle properties



Particle Track

Array layout
Sensor orientation

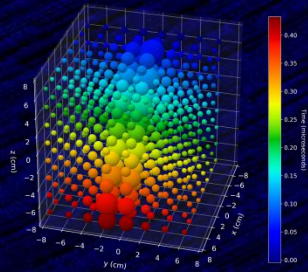




Newtonian acceleration

spectral response

noise spectra, DAQ



simulated data

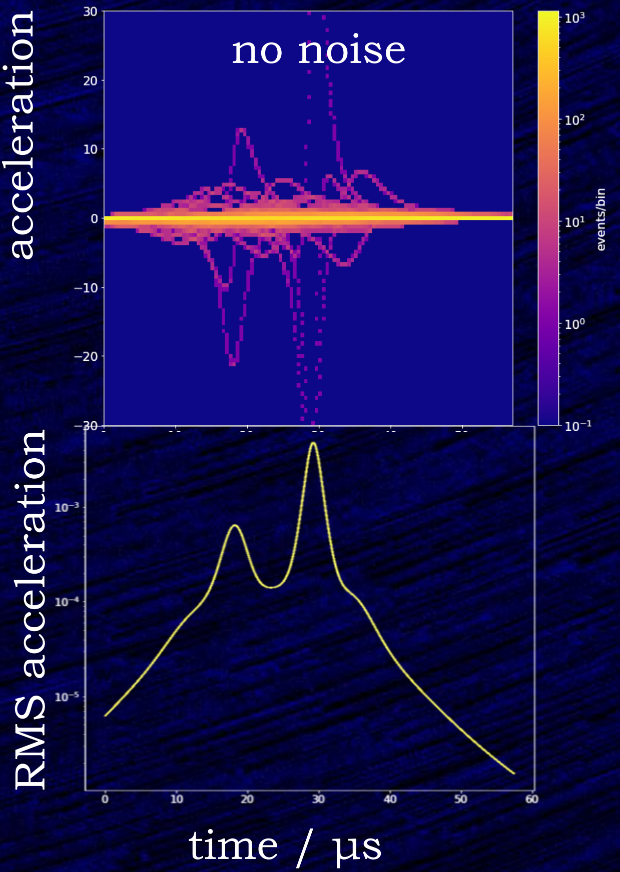
real data

template

fit or parameter scan

inference

Recovering Tracks from Noisy Data: Radon Transform



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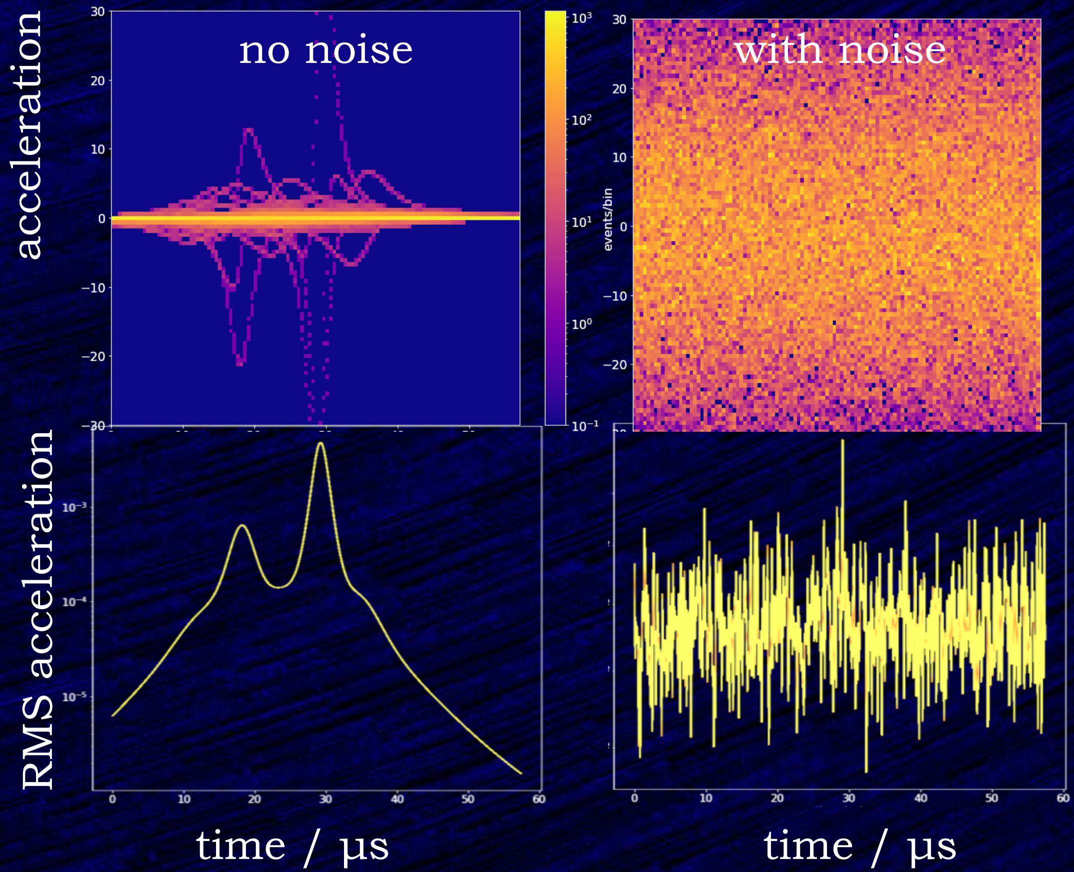

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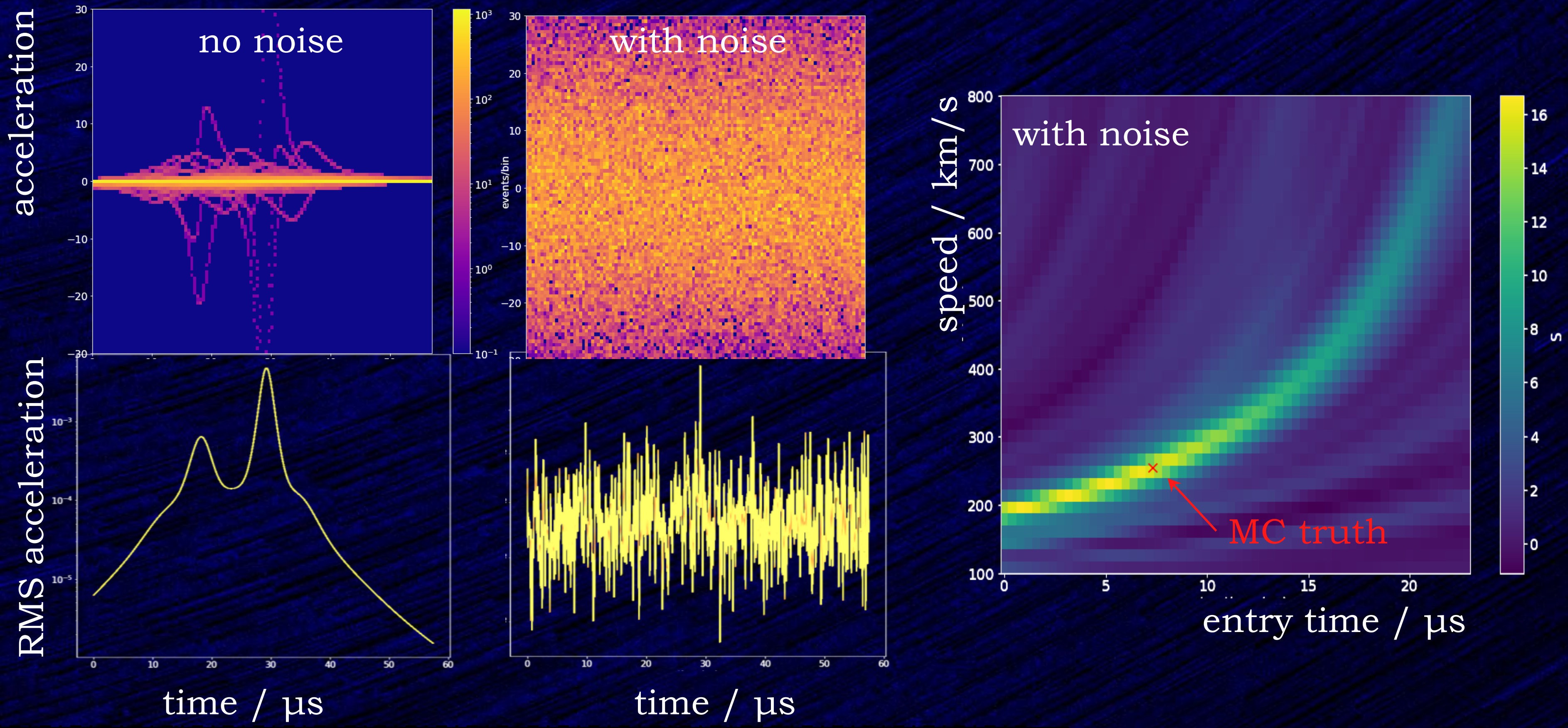
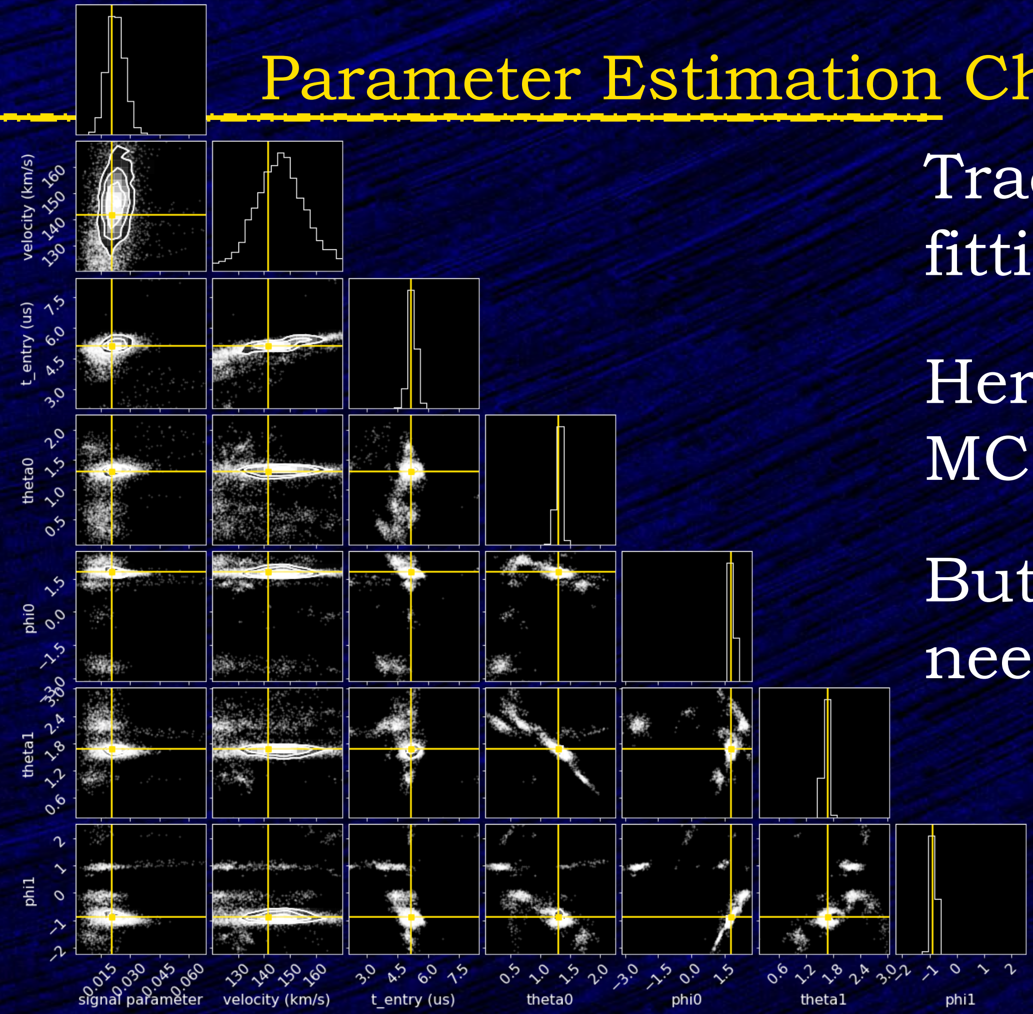


Parameter Estimation Challenge



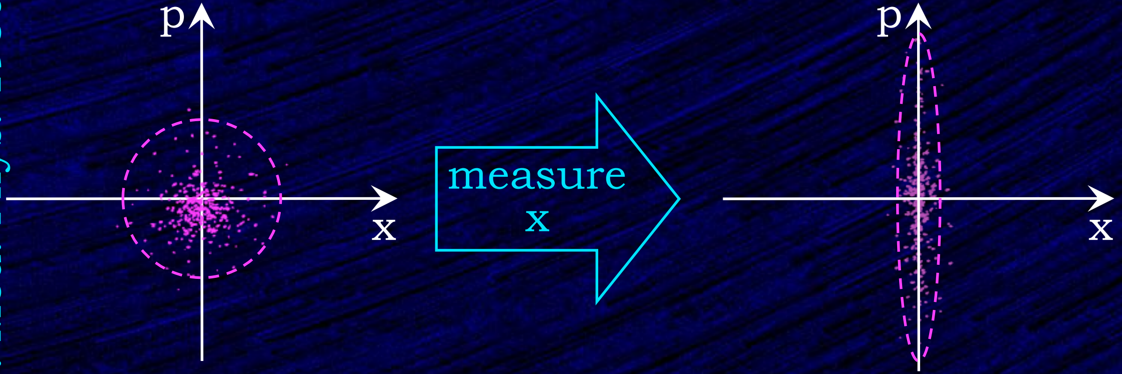
Tracks buried in noise: fitting is a challenge.

Here: Nested Sampling MCMC 64 sensors: Works.

But the trial factor is huge, need SNR~10

Quantum Back-Action Evasion through Velocity Sensing

Caves+ Rev. Mod. Phys. 1980



$\Delta x \Delta p = \hbar/2$
minimal uncertainty

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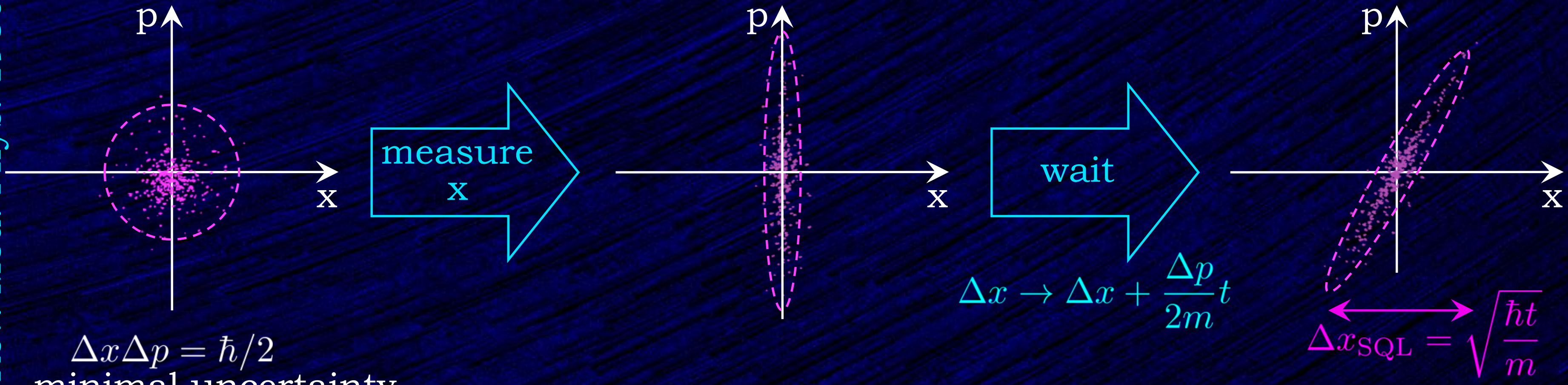

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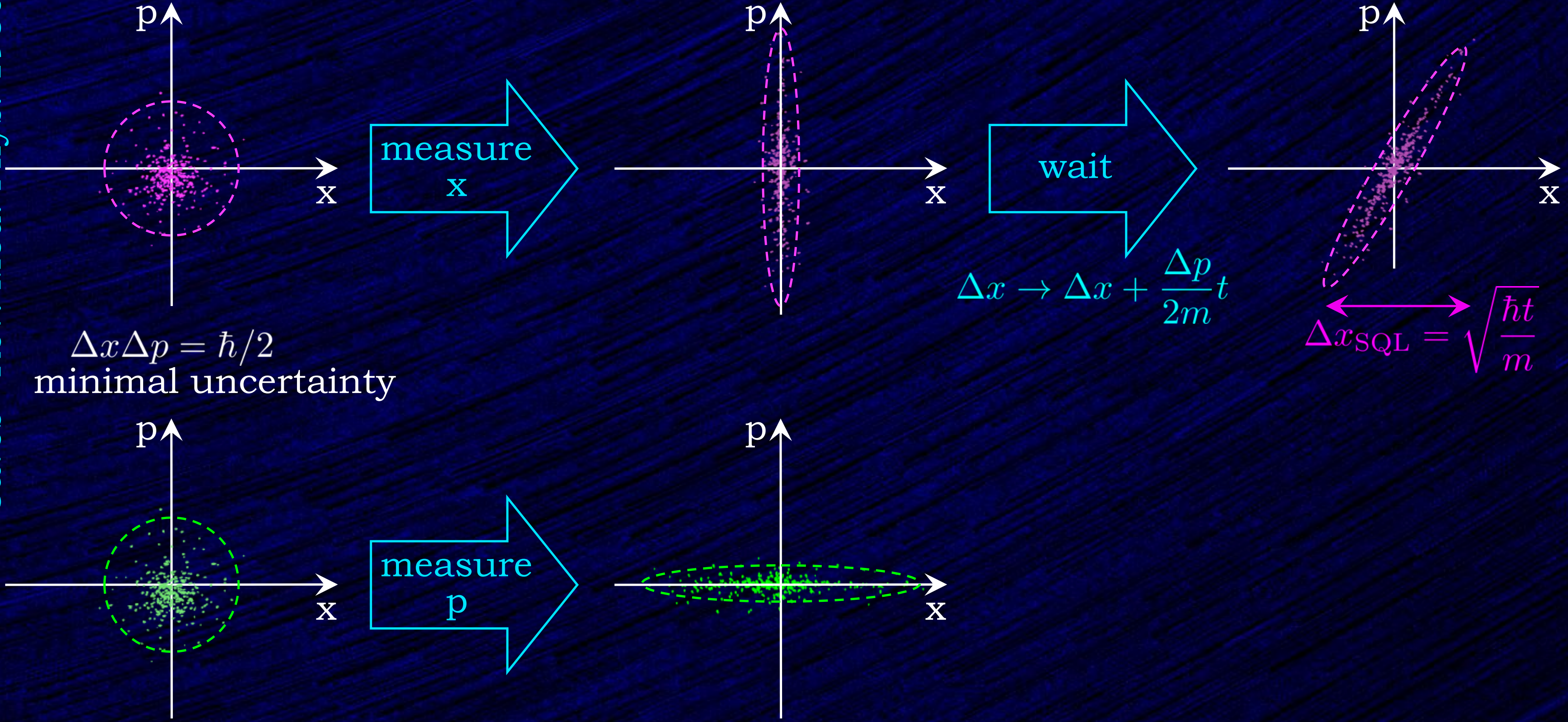

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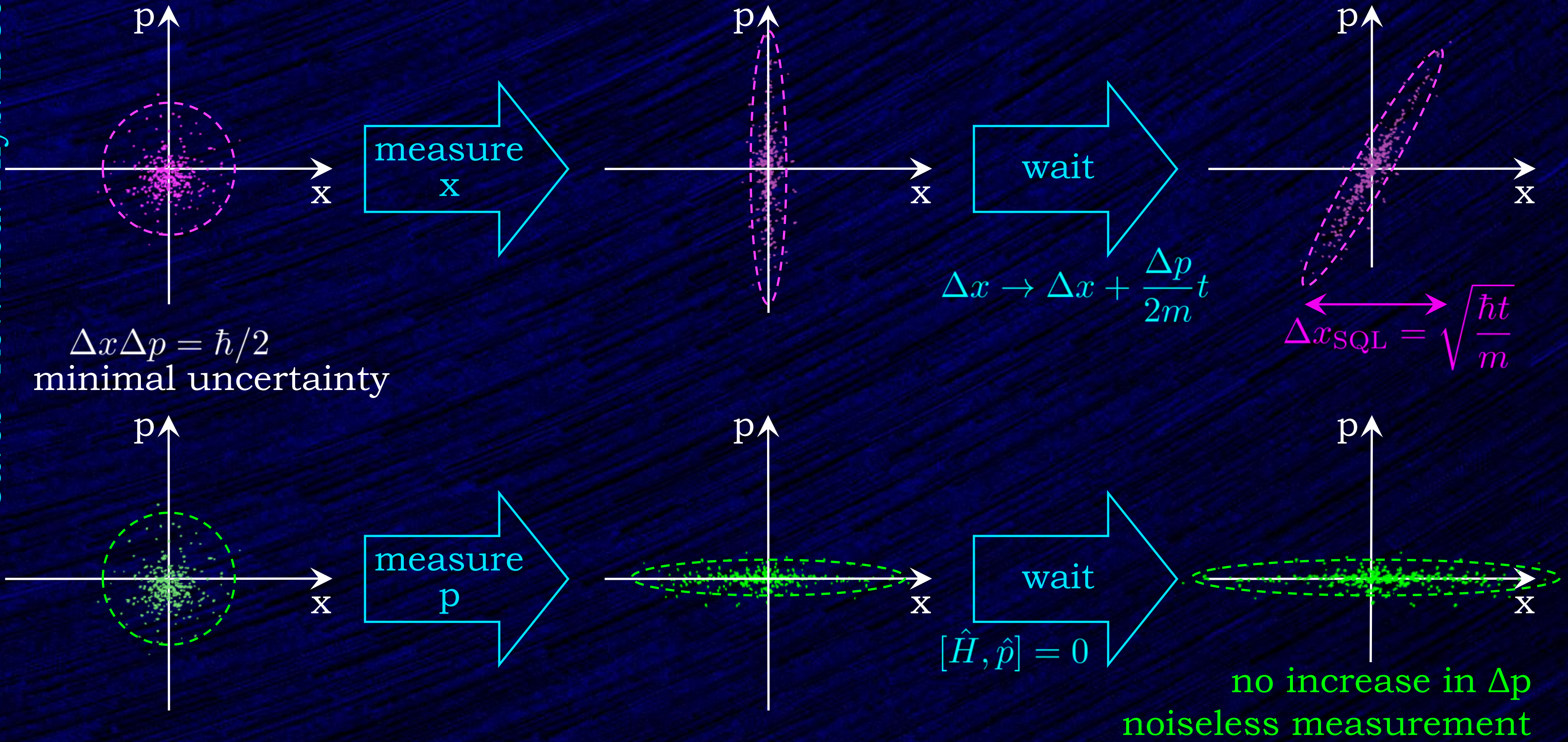
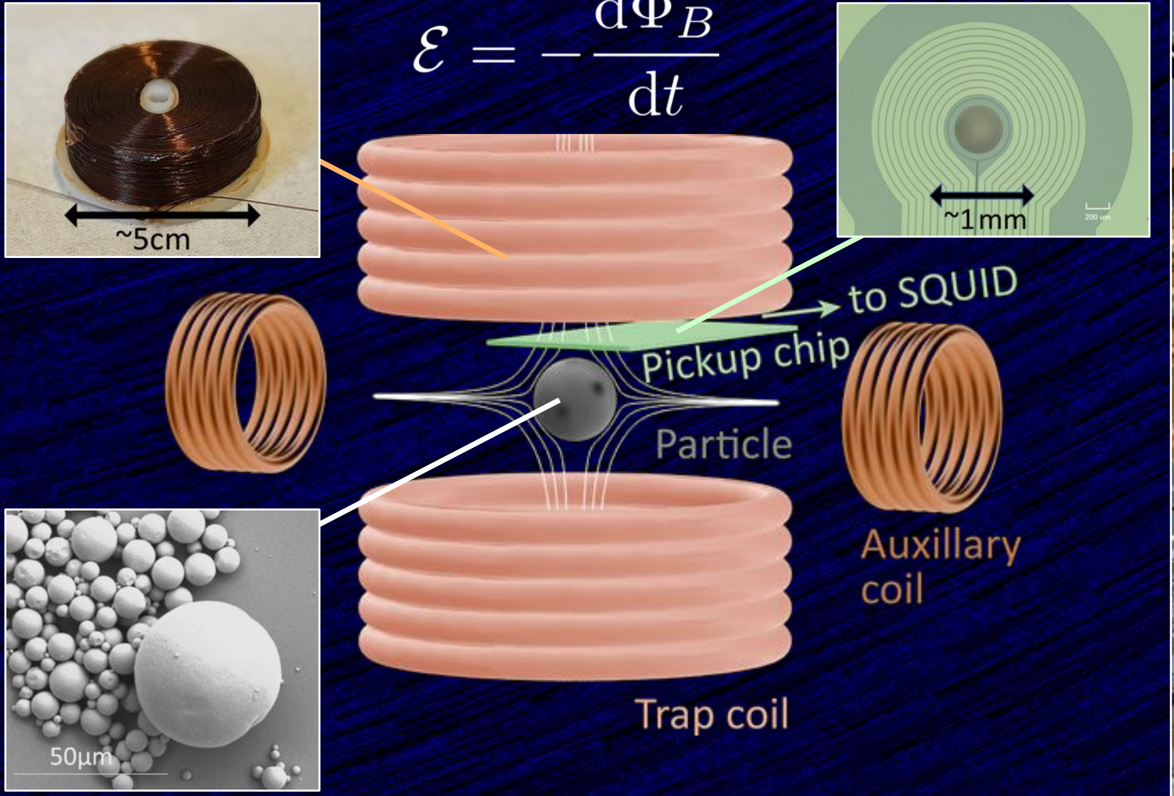


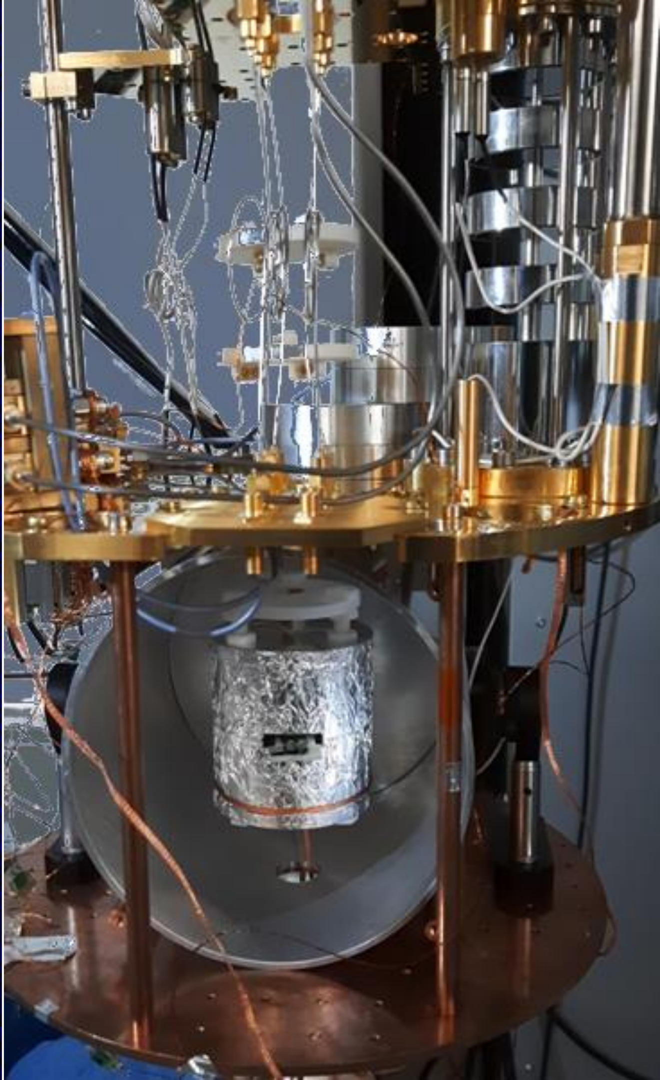
Levitated Microspheres

Hofer, Higgins+ 2211.06289

$$\mathcal{E} = -\frac{\mathrm{d}\Phi_B}{\mathrm{d}t}$$

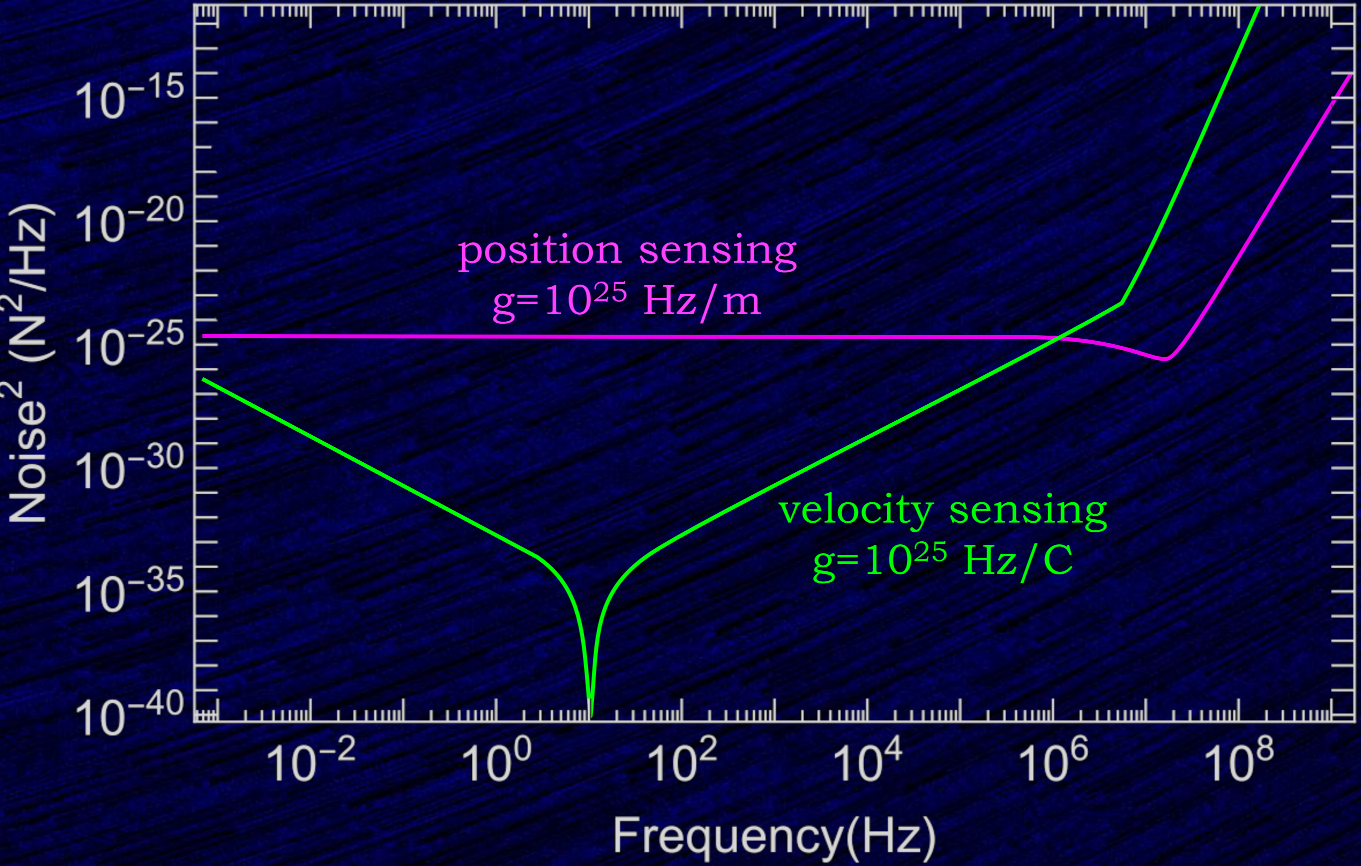


e.g. lead-tin



Broad-Band Back-Action Evasion through Velocity Sensing

Ghosh+ 1910.11892 & in prep.

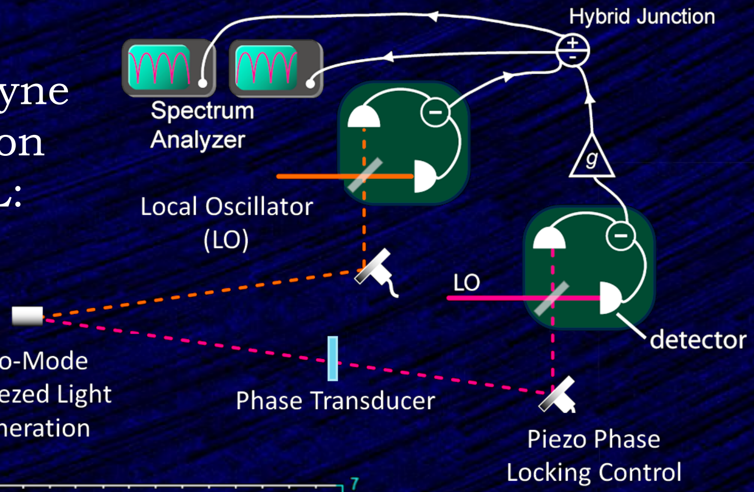


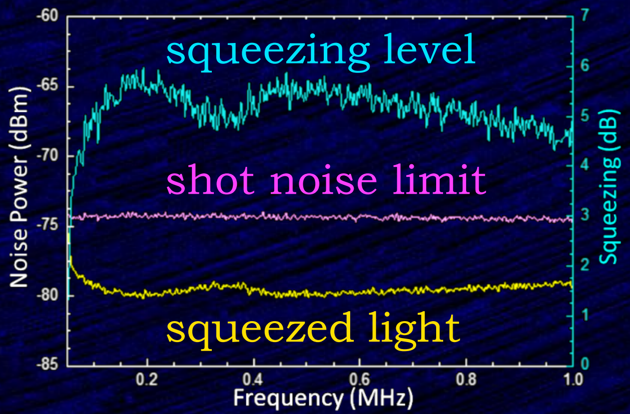
Here: Voltage measurement with electric field-dependent cavity, e.g. using a RF Single Electron Transistor

Squeezing to Go Beyond the Standard Quantum Limit™

Pooser+ 1912.10550

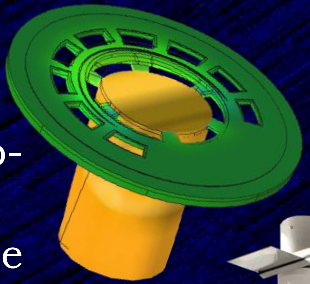
dual homodyne detection @ORNL:

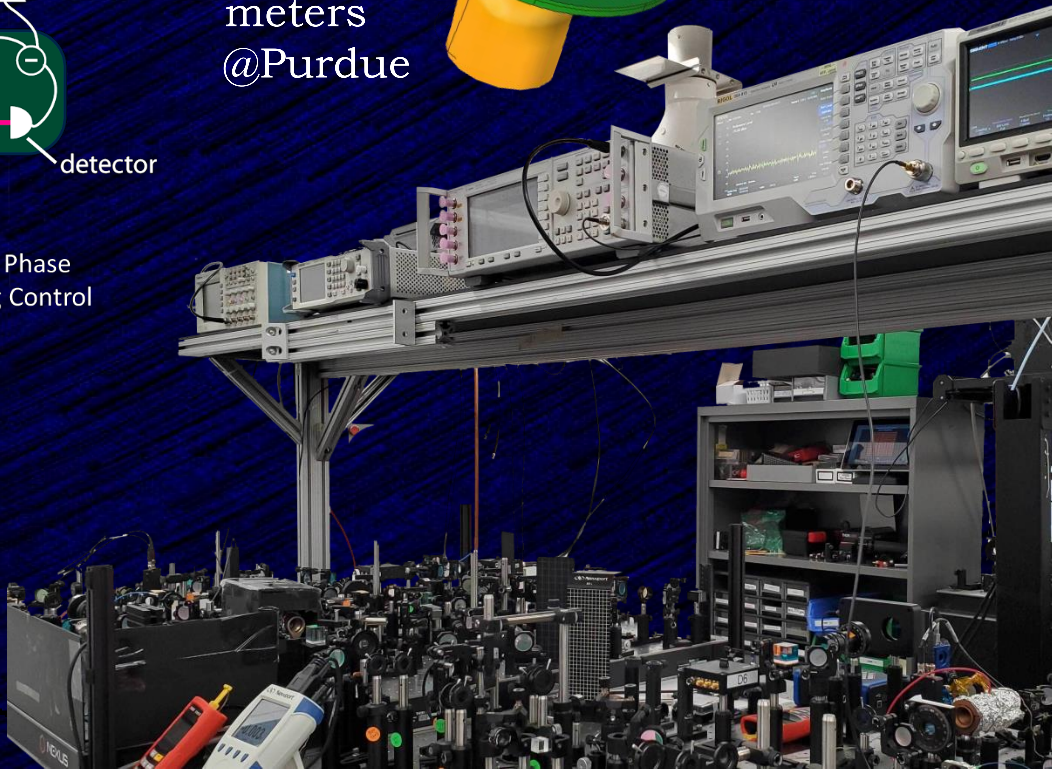




Bao+ 2018

MEMS accelero-meters @Purdue

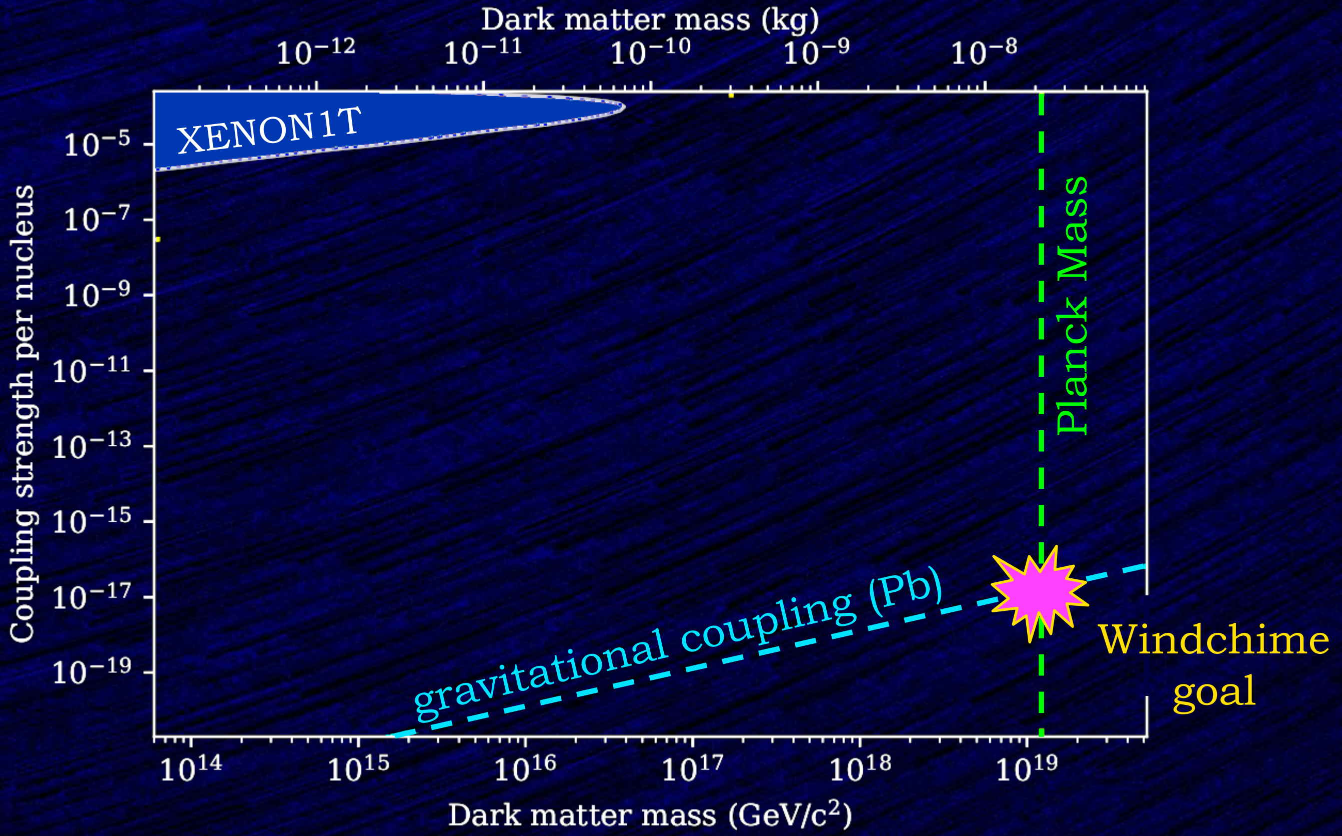




Rafael Lang (Purdue): Windchime

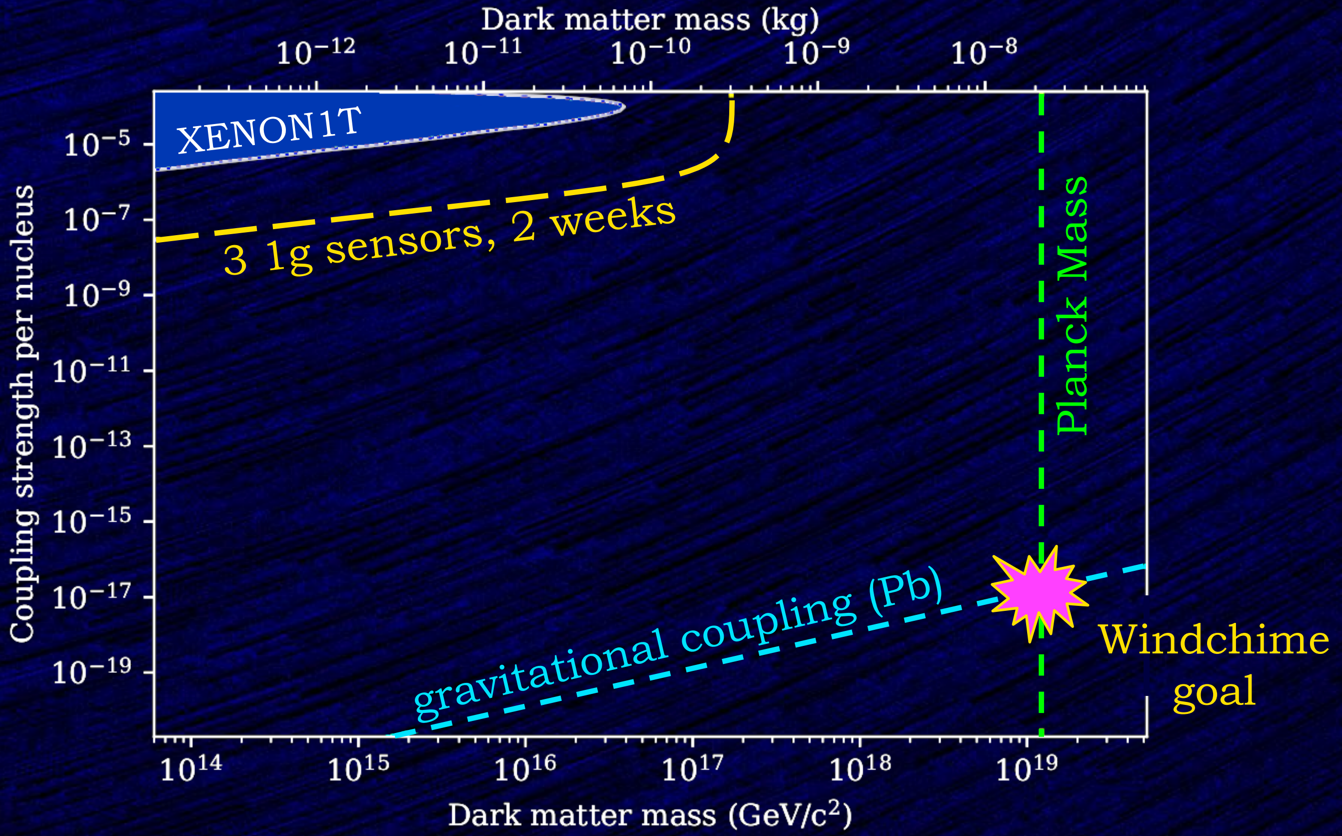
Towards Gravitational Detection

XENON1T from 2009.07909



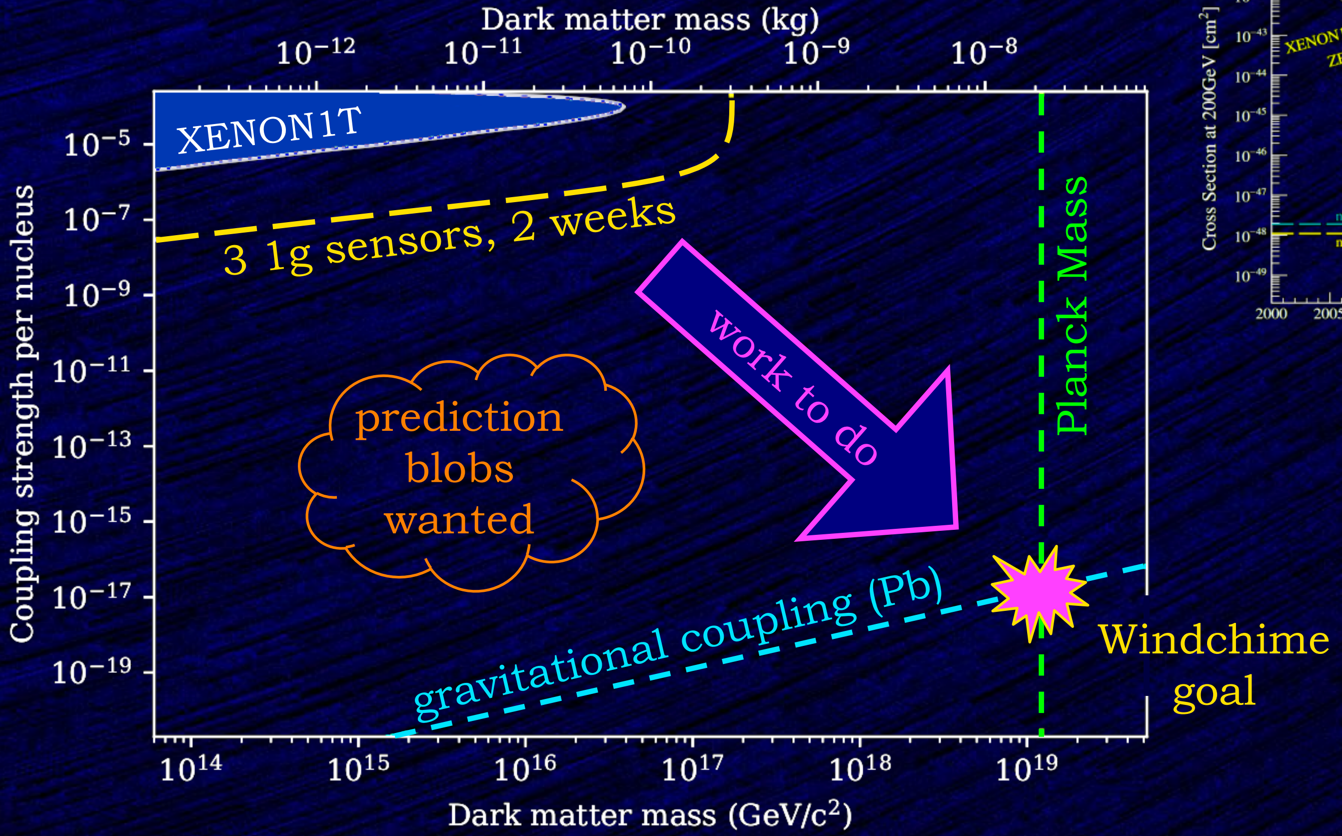
Towards Gravitational Detection

Windchime Projection and 2203.07242

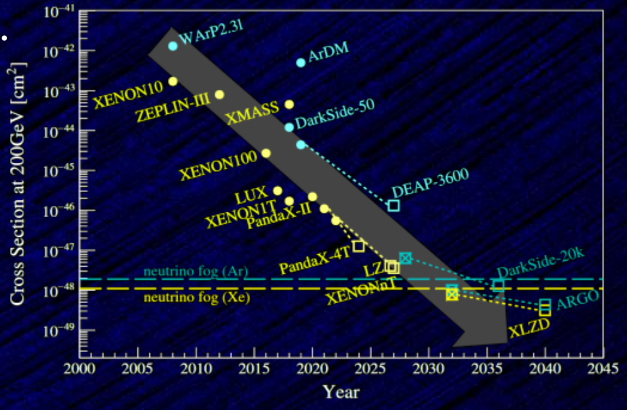


Towards Gravitational Detection

Windchime Projection and 2203.07242



cp.

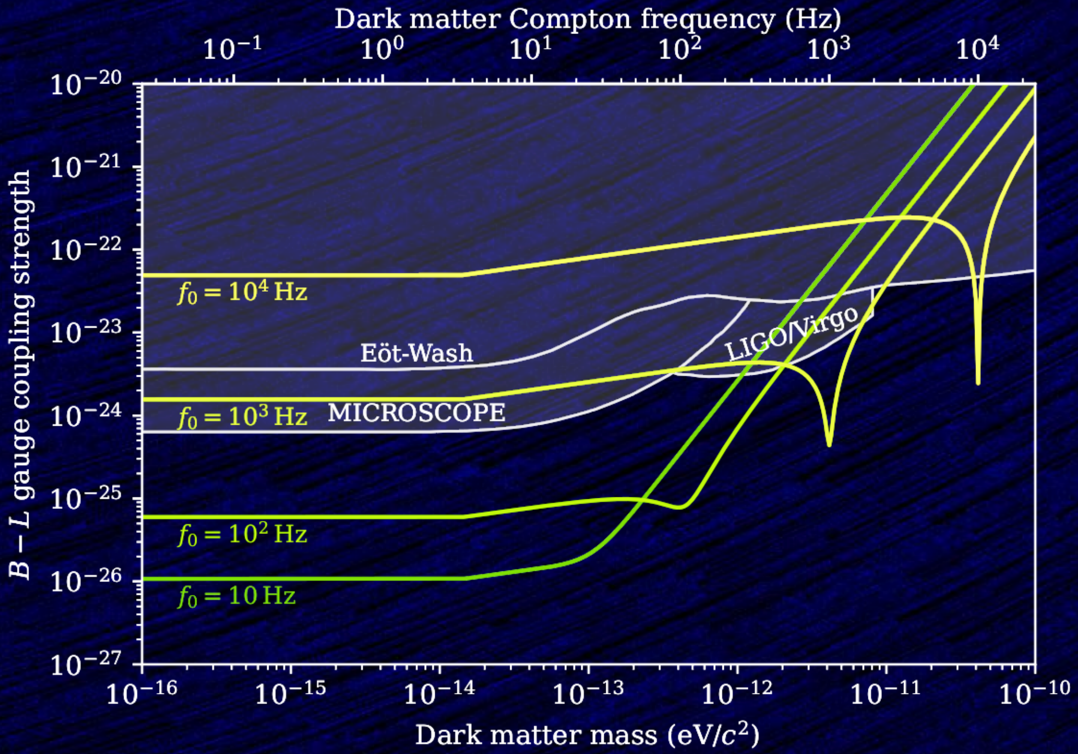


Snowmass 2209.07426

Near-Term Target: Ultralight Dark Matter

Same array also probes wave-like excitations

Graham+ 1512.06165
Carney+ 1908.04797
Manley+ 2007.04899
Carney+ 2008.06074



The Windchime Vision:
Detect dark matter in the lab through gravity alone

arXiv:2203.07242

Use array of sensitive accelerometers with quantum-enhanced readout: massive levitated superconductors

- Planck-mass dark matter
- ultralight dark matter
- impulse metrology