Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Convergence or Disruption?

Particle View

Joe Lykken

Fermilab

8 October 2019

The Early-Late Hubble constant tension: Convergence or Disruption?

My prediction:

The Early-Late Hubble constant tension: Convergence or Disruption?

My prediction:

Convergence

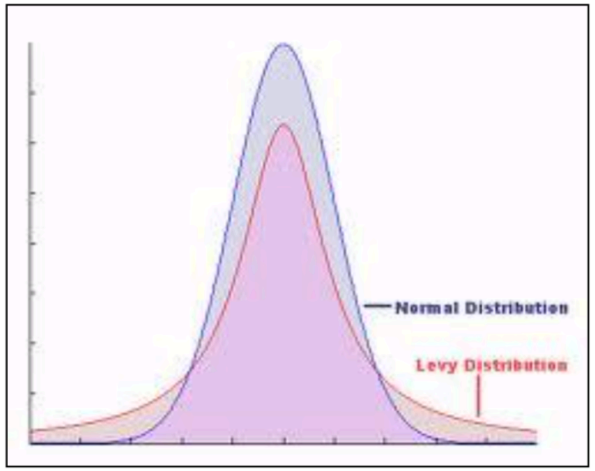
The Early-Late Hubble constant tension: Convergence or Disruption?

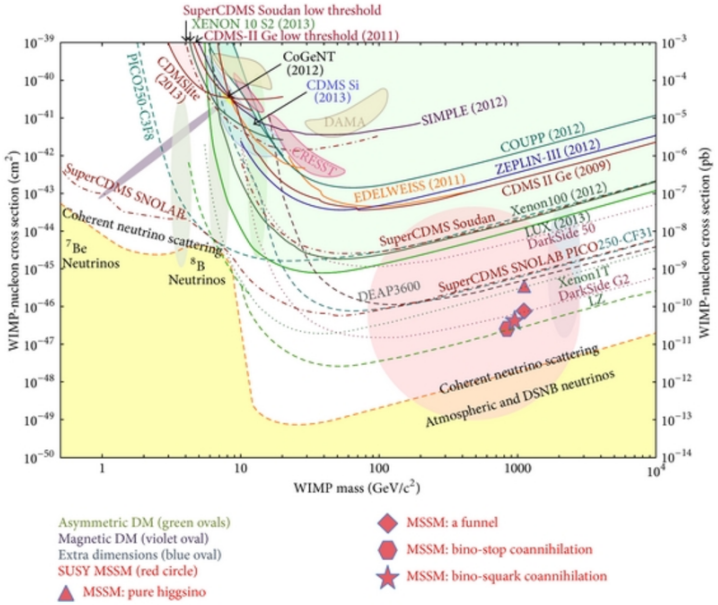
My prediction: Convergence

- It is a triumph of precision astronomy to see the kind of mature data analysis presented [and argued about] at this conference
- As Roger Blandford said, tensions are normal
- In the world of particle physics we have learned to be very patient about such tensions – they can take a decade or more to resolve
- Based on historical precedent [not any expertise], I would agree with Roger that the current tension is more likely to be caused by some combination of systematics, measurement issues, and astrophysics issues, rather than new fundamental ingredients

Caveats on the 5 sigma “gold standard’

- In particle physics a 5 sigma deviation is considered a necessary ***but not sufficient*** condition, to claim a discovery
- One reason is that in the real world there is no such thing as a 5-sigma Gaussian deviation, because in the real world distributions have non-Gaussian flat tails
- Thus even after you work really hard to estimate your total 1 sigma uncertainty, the probability of an excursion 5 times this value is usually ***much higher*** than the p-value for Gaussian 5 sigma
- Thus for example in the CMS experiment we fit nominally Gaussian distributions with a “Cruijff function”, that has flat tails built in
- Furthermore some 5 sigma discrepancies are resolved by (eventual) community consensus to discount a particular experiment or set of measurements, even though the flaw in those measurements is never clearly identified. [e.g. DAMA]





Explanation of Cosmic Acceleration: Convergence or Disruption?

My prediction:

Explanation of Cosmic Acceleration: Convergence or Disruption?

My prediction:

Disruption

Explanation of Cosmic Acceleration: Convergence or Disruption?

My prediction: Disruption

- I am surprised at the varying reactions to what Joe Silk called “the worst prediction in physics”, i.e. the 120 order of magnitude discrepancy in the vacuum energy as measured by cosmic expansion
- To me this embarrassment shows one thing**: that we don’t know how to do the calculation**
- This is not too surprising since the LHC seems to be telling us that we don’t know how to do the similar calculation for the Higgs mass and the electroweak scale in naïve extensions of the Standard Model
- The latter is related to **issues of naturalness in extensions of the Standard Model**
- Note that the Standard Model itself does not have a naturalness problem, since the Higgs mass and the electroweak scale are not predicted: they are empirical parameters
- Note however that in the SM the QCD scale ~ 300 MeV **is predicted** [in terms of log running of a dimensionless parameter], and this scale is intermediate between the electroweak scale and the scale of dark energy

Explanation of Cosmic Acceleration: Convergence or Disruption?

My prediction: Disruption

- We have been using naturalness arguments to motivate experimental searches for at least 35 years now, with zero success
- My personal belief is that these arguments are fundamentally wrong when applied to extensions of the SM, and that eventually some smart young person will articulate why, creating a disruption
- In any event it is clear that this approach is not working very well, so it is time to strongly encourage alternative approaches
- For example I was happy to see Justin Khoury suggesting that the near-criticality of the Higgs should be a focus of our attention

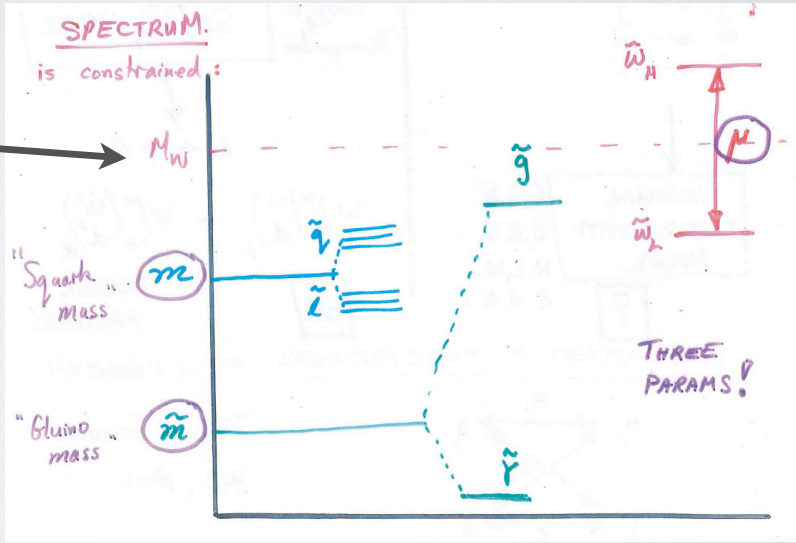
NATURAL SUSY, 1984

From Lawrence Hall's talk at SavasFest

W boson near the top of the spectrum....

1984 was a utopian year for SUSY.

Times have changed!



slide stolen from Matt Reece

Explanation of Cosmic Acceleration: Convergence or Disruption?

My prediction: Disruption

- We have been using naturalness arguments to motivate experimental searches for at least 35 years now, with zero success
- My personal belief is that these arguments are fundamentally wrong when applied to extensions of the SM, and that eventually some smart young person will articulate why, creating a disruption
- In any event it is clear that this approach is not working very well, so it is time to strongly encourage alternative approaches
- For example I was happy to see Justin Khoury suggesting that the near-criticality of the Higgs should be a focus of our attention

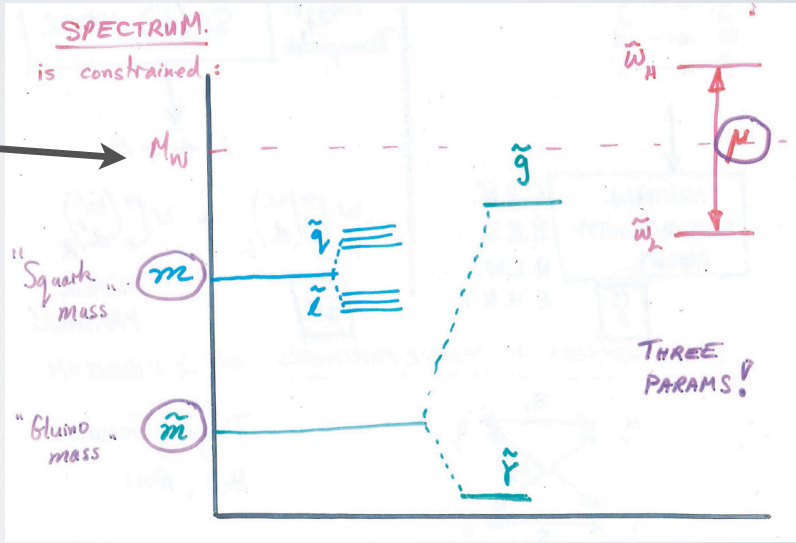
NATURAL SUSY, 1984

From Lawrence Hall's talk at SavasFest

W boson near the top of the spectrum....

1984 was a utopian year for SUSY.

Times have changed!



slide stolen from Matt Reece

I therefore propose a voluntary 10-year moratorium on the use of the word "naturalness" in scientific publications

Multiverse or not:
Convergence or Disruption?

My prediction:

Multiverse or not:
Convergence or Disruption?

My prediction:

Disruption

The peek-a-boo universe?

Is the hypothesis of eternal inflation as a generic mechanism creating a multiverse a "plausible scientific theory"? [Alan Guth]

My answer:

- Yes it is both plausible and scientific [and possibly wrong]
- By "plausible" I mean that there is already substantial observation evidence for primordial inflation, and that at least in the "cartoon" version of inflation it appears that eternal inflation is generic
- By "scientific" I mean that one can imagine over time gathering additional evidence that will either support [but not prove] or disfavor [but not disprove]
- Just because the rest of the putative multiverse is not observable today doesn't mean that we cannot *at some confidence level* assert that it is there
- This is not so different from the first scientific discovery that every infant makes at age 18 months: the discovery of object permanence
- Also I agree with Alan that once we develop a robust theory of universe formation we might reasonably conclude that it would be very odd if ours is the only instantiation

Anthropic Angst

“I would advocate anthropic explanations be thought of as explanations of last resort” [Alan Guth]

I strongly agree with this:

- It is pretty obvious that certain features of our existence are explained at least in part by anthropic reasoning
- So applied sparingly and with rigor, anthropic reasoning can be scientific [but beware falling into the kinds of traps that social Darwinists and evolutionary psychologists get caught in]
- My real concern is that we may be jumping to the “last resort” prematurely
- Just because we seniors were too stupid to figure a better explanation for the cc, doesn’t mean that the younger generation will not make a breakthrough
- It is our responsibility as seniors to support the possibility of radically new approaches rather than discounting it

Anthropic Angst

“I would advocate anthropic explanations be thought of as explanations of last resort” [Alan Guth]

I strongly agree with this:

- It is pretty obvious that certain features of our existence are explained at least in part by anthropic reasoning
- So applied sparingly and with rigor, anthropic reasoning can be scientific [but beware falling into the kinds of traps that social Darwinists and evolutionary psychologists get caught in]
- My real concern is that we may be jumping to the “last resort” prematurely
- Just because we seniors were too stupid to figure a better explanation for the cc, doesn’t mean that the younger generation will not make a breakthrough
- It is our responsibility as seniors to support the possibility of radically new approaches rather than discounting it

I therefore propose a voluntary 10-year moratorium on the use of the word “anthropic” in scientific publications

Don’t drain the swamp

In my view the scientific hypothesis of a multiverse is only very weakly connected to the string theory landscape or the swampland of non-string-compatible EFTs

- The argument that the only possible UV completions of the Standard Model with gravity are in string theory was mostly along the lines of “nobody has come up with any other examples”
- Instead I regard string theory more as a useful theoretical laboratory for talking about and learning about quantum gravity (especially AdS/CFT), rather than as The Theory of Our Universe
- It is certainly interesting to try to understand the Landscape and the Swampland
- But from the view of cosmology I would assert that it is much more interesting and potentially useful to use string theory to investigate cosmological singularities like the Big Bang
- However papers on the former seem to outnumber papers on the latter by log(10^500) to 1

Dark matter beyond WIMPs: Convergence or Disruption?

My prediction:

Dark matter beyond WIMPs: Convergence or Disruption?

My prediction:

Disruption

Dark matter beyond WIMPs: Convergence or Disruption?

My prediction: Disruption

- Let's be honest that the main motivation for ~100 GeV WIMPs was supersymmetry, not the WIMP Miracle
- This is not to discount the importance of the incredibly powerful direct searches currently planned or underway
- But we had better have a broader direct detection program that covers a larger fraction of the possible mass range
- And we had better think about what we are going to do if DM particles have **only** gravitational-strength interactions with ordinary matter

Dark matter beyond WIMPs: Convergence or Disruption?

The good news:

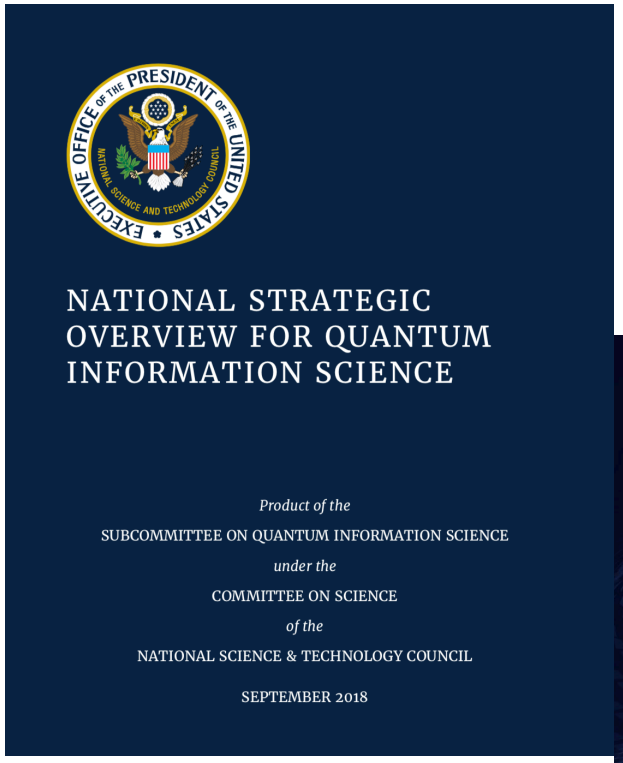
- There is overwhelming evidence that dark matter exists and consists of one or more kinds of particles [or clumps thereof]

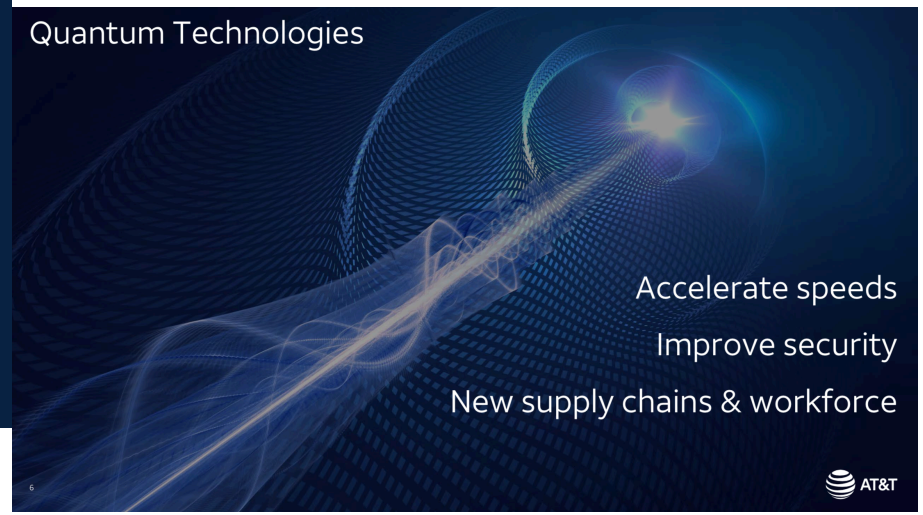
- I support the approach advocated by Kathryn Zurek with addendum from Elena Aprile:
  - Pick a target with some theory motivation and benchmarks
  - Figure out how to probe it and what you need to build to do that
  - Start small and iterate, learning about the backgrounds as you go

- It is our good luck that many relevant new detection technologies are appearing just as we have realized that we need them

Dark matter beyond WIMPs: Convergence or Disruption?

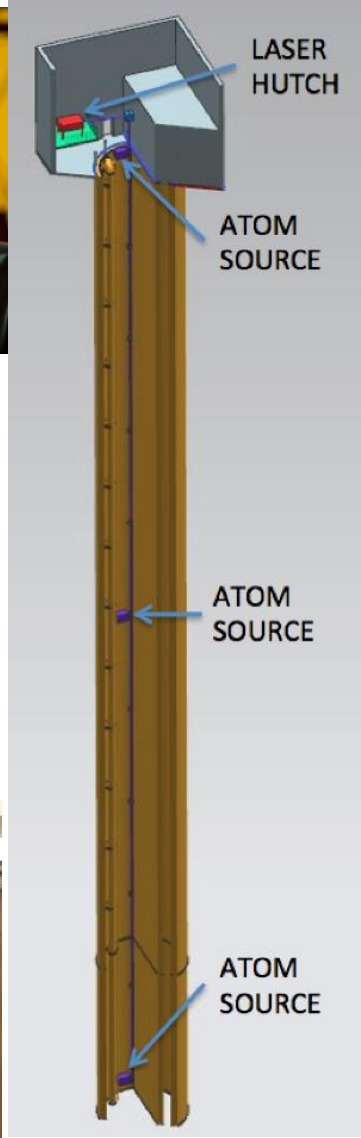
The good news: National Quantum Initiative



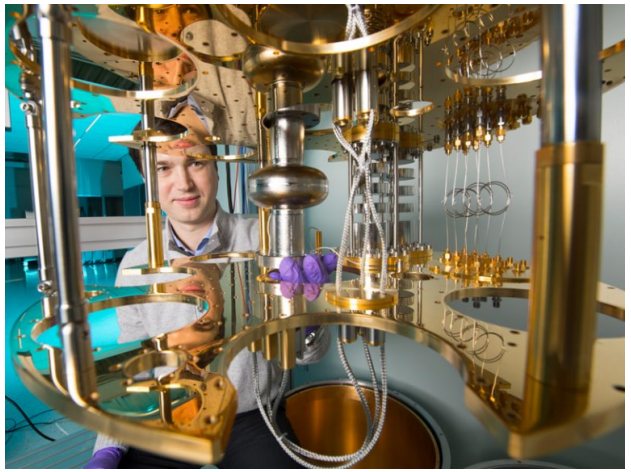


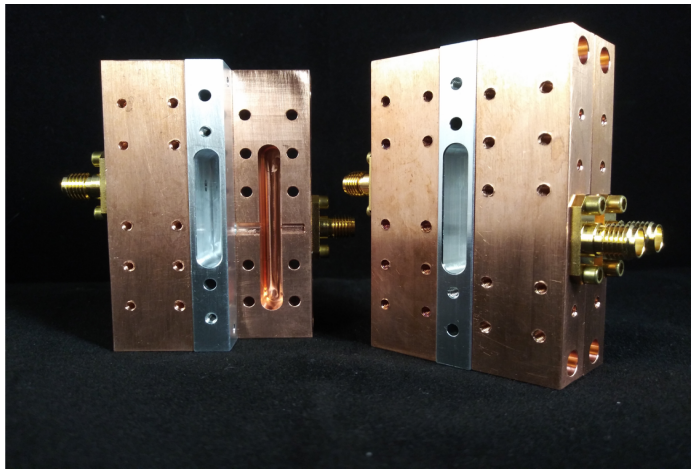
8 **SEC. 402. NATIONAL QUANTUM INFORMATION SCIENCE RE-**
9 **SEARCH CENTERS.**
10 (a) IN GENERAL.—The Secretary of Energy shall en-
11 sure that the Office of Science carries out a program, in
12 consultation with other Federal agencies, as appropriate,
13 to establish and operate up to 5 National Quantum Infor-
14 mation Science Research Centers to conduct basic re-
15 search to accelerate scientific breakthroughs in quantum

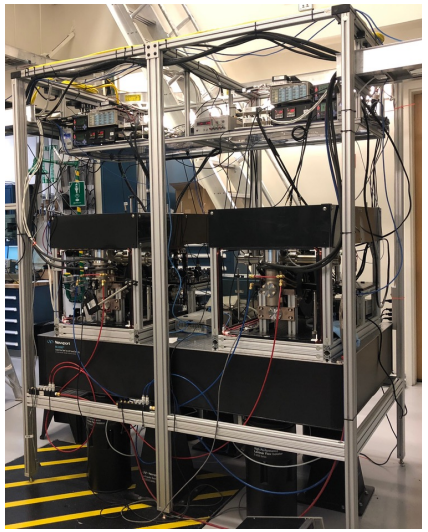
Fermilab collaborations on quantum sensors



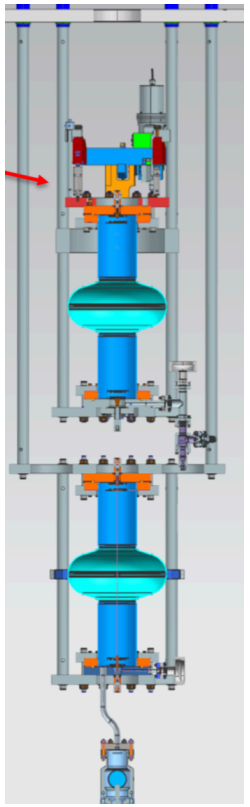
- Fermilab is collaborating with 22 universities and other labs on quantum R&D, with a large fraction related to quantum sensors
- The very challenging science goals like laboratory detection of dark matter, are now driving advances in quantum technologies; these advances will eventually have broad impact beyond particle physics



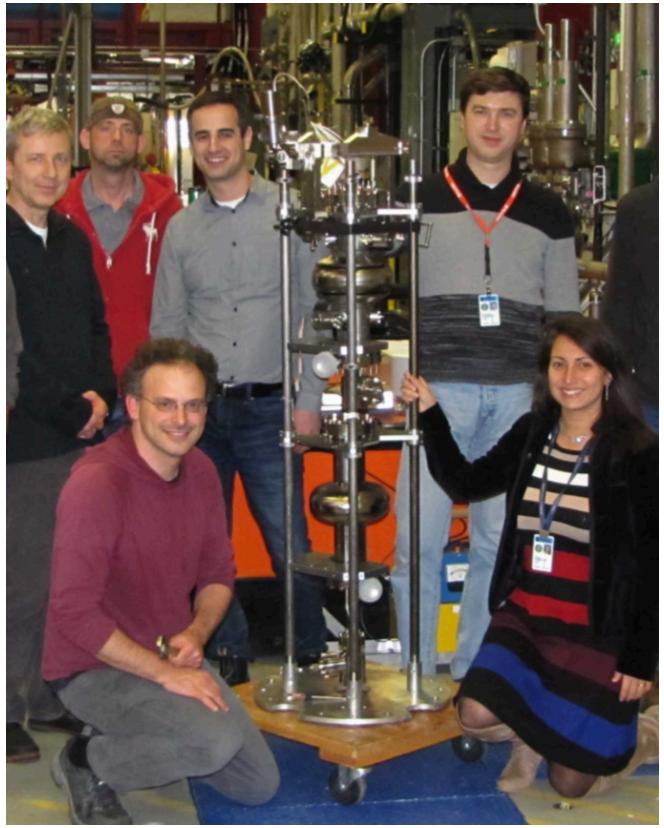




Fermilab Dark SRF Experiment: produce and detect dark photons



Tunable powered “Emitter” SRF cavity and quiet “Receiver” SRF cavity, tuned to within 1 Hz

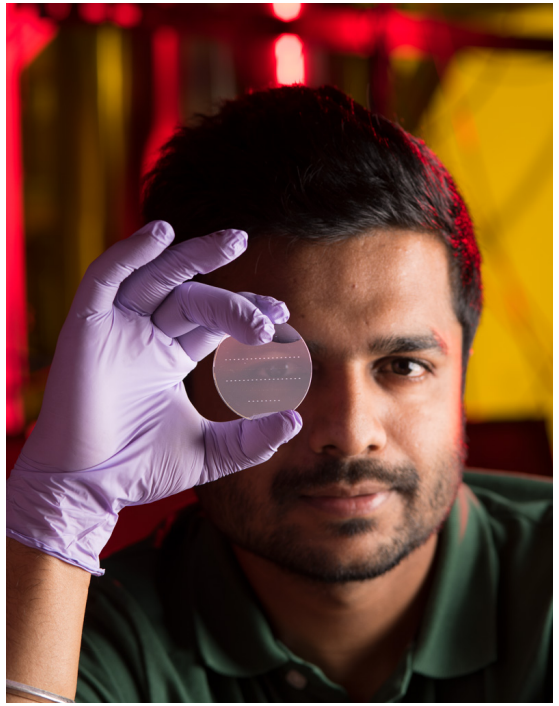


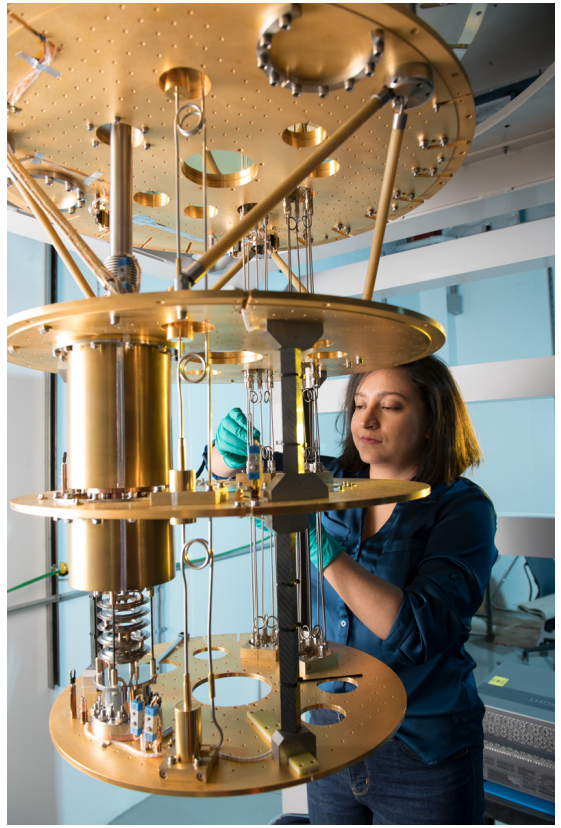
Prototype “R2D2” ready for testing: supported by the DOE QuantISED program

“Run 1” in the Fermilab Vertical Test Stand used for cryogenic tests of SRF cavities; “Run 2” in dilution fridge

Physics Today, June 2019

- axion dark matter searches are already limited by quantum noise
- new quantum sensing techniques are needed to make further progress towards higher mass axions.





Putting the squeeze ON AXIONS

Karl van Bibber, Konrad Lehnert, and Aaron Chou

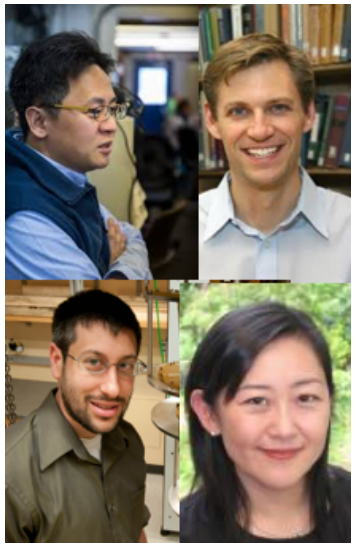
Microwave cavity experiments make a quantum leap in the search for the dark matter of the universe.

Sixty years ago Norman Ramsey and collaborators asserted that the neutron's electric dipole moment (EDM)—a measure of the separation of its positive and negative electric charge—was consistent with zero. More precisely, their experiment[1] bounded 1 part in 10 billion—just by dumb luck.

Or not? In 1977 Stanford University physicists Roberto Peccei and Helen Quinn conceived a minimal and appealing theory by which θ would be promoted to a dynamical variable. Just below some large energy scale, θ

https://physicstoday.scitation.org/doi/10.1063/PT.3.4227

Fermilab THE UNIVERSITY OF CHICAGO JILA CU-Boulder and NIST Yale HEISING-SIMONS FOUNDATION

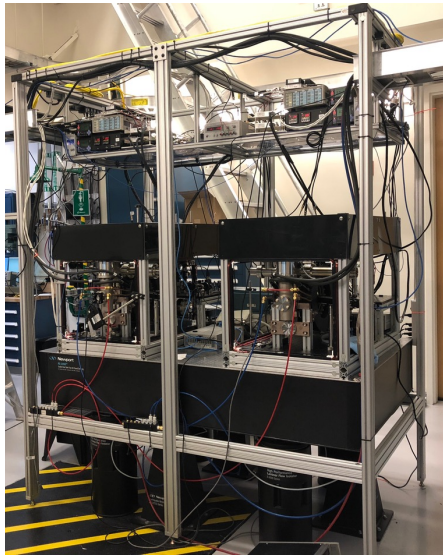


MAGIS-100 cold atom gradiometer:

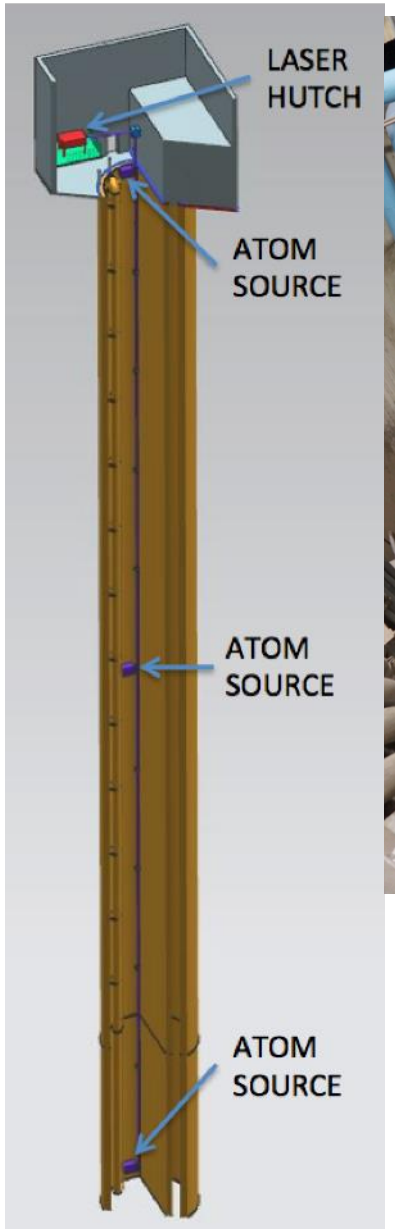
an incredibly sensitive quantum measuring device, first of its kind

- 100 meter vacuum system with 3 atom interferometers driven by a single laser system
- Use the same ultra-cold strontium atoms that are the basis of the best atomic clocks
- Proof-of-concept used the Stanford prototype
- Advancing quantum science with long-range superposition, coherence and entanglement of atoms
- Sensitivity to ultralight dark matter
- Technology pathfinder for future midband gravitational wave detectors

Jason Hogan PI
(Stanford)



Two assembled Sr atom sources



MINOS shaft at Fermilab

supported by the DOE QuantISED program

Final words of wisdom:

- **Saul Perlmutter:** “Cosmology is still a pretty young field, so I still expect major new developments on relatively short timescales”
- **Justin Khoury:** “A drunken man will find his way home, but a drunken bird is lost forever”
- **Roger Blandford:** “Discoveries are like burglars – they break in through the side window instead of walking in the front door”

Jim Peebles: What might we learn from lines of research that are off the beaten track? They check accepted ideas, always a Good Thing, and there is the chance Nature has prepared yet another surprise for us.