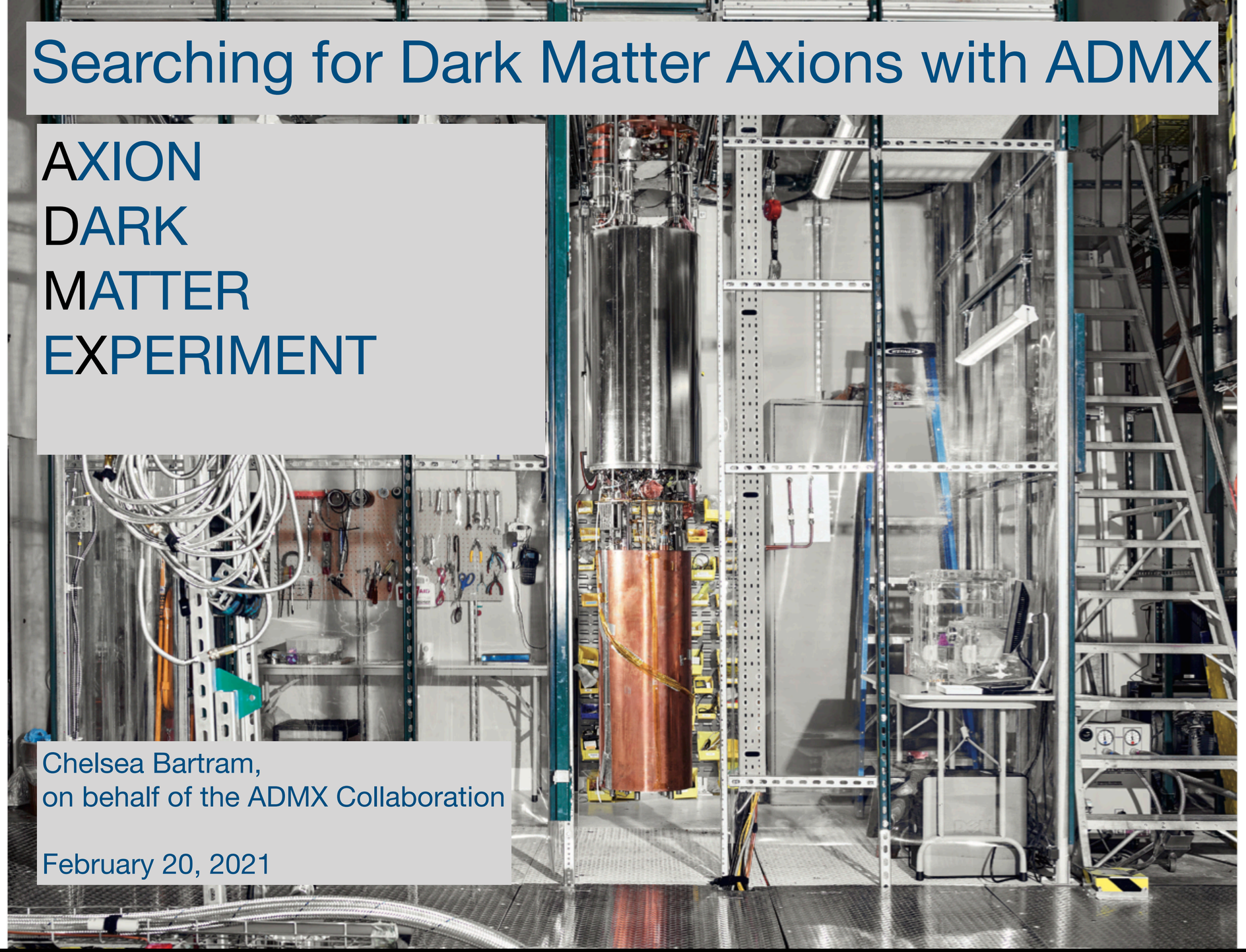
Searching for Dark Matter Axions with ADMX

AXION
DARK
MATTER
EXPERIMENT



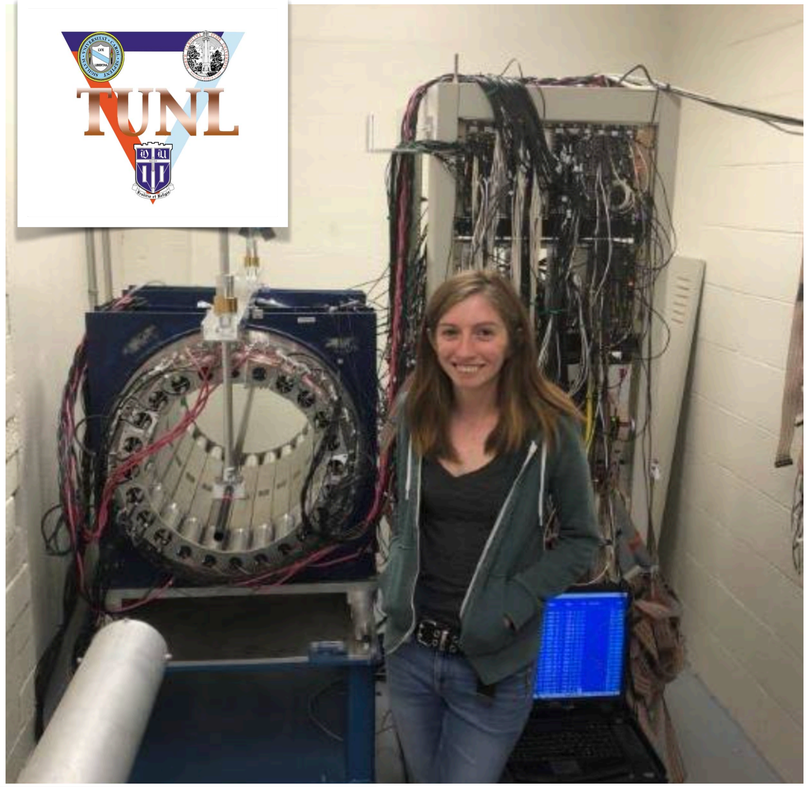
Chelsea Bartram,
on behalf of the ADMX Collaboration

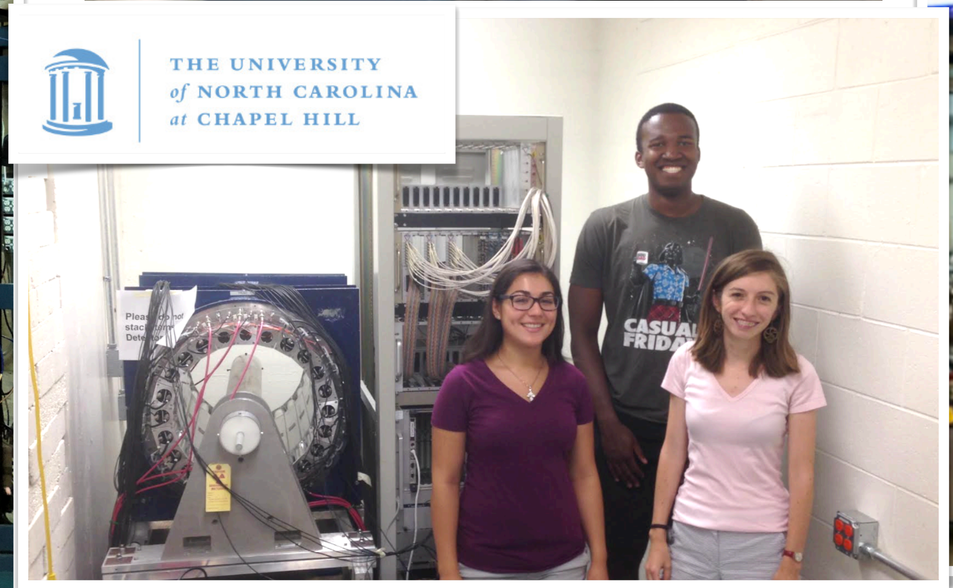
February 20, 2021

Who am I?

Chelsea Bartram

I am a nuclear/particle physicist!

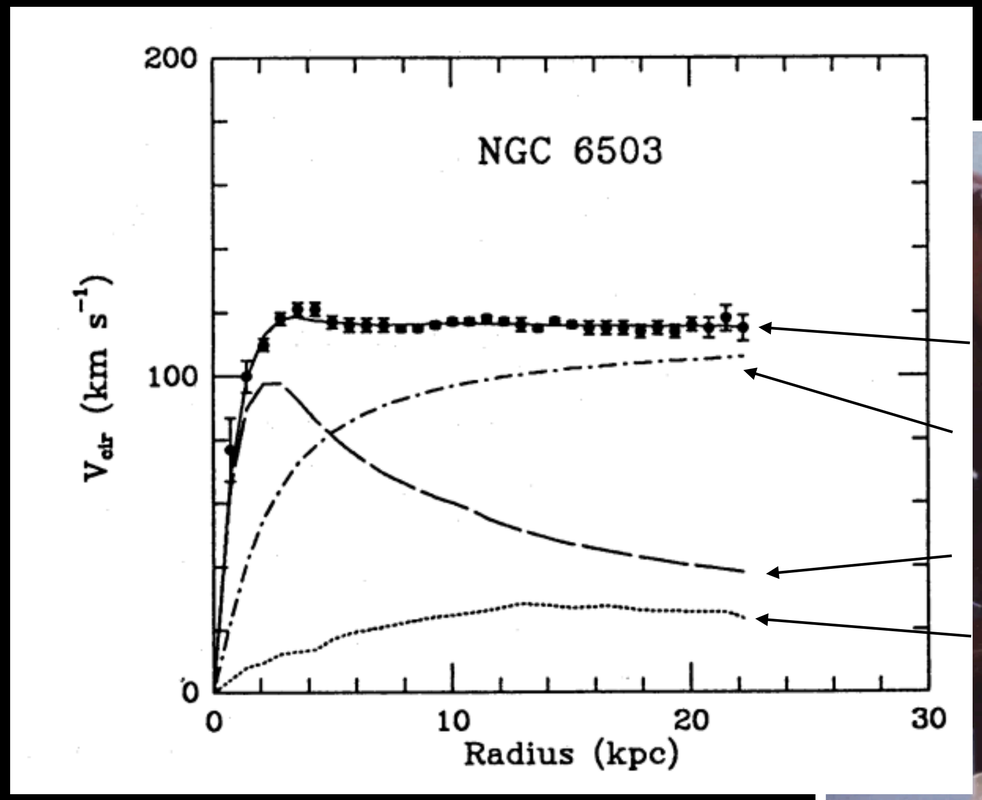




85% of the matter content in the universe is unknown!

Ok, but how do we know it exists?

Galactic Rotation Curves



Vera Rubin working at her observatory

Bullet Clusters

Bullet Cluster
Composite: NASA, Markevitch etal., Clowe et al

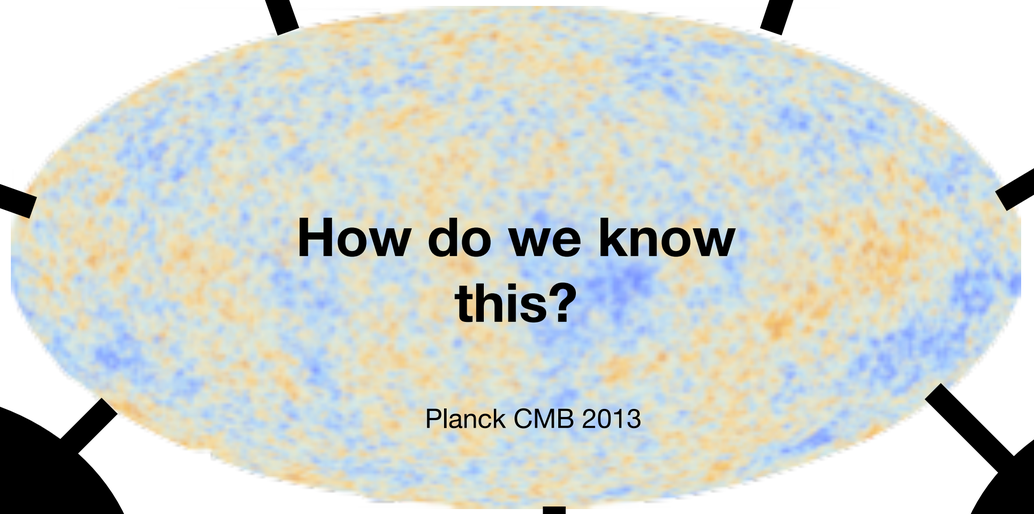
Baryonic (“Ordinary”) matter is slowed by the collision due to interactions.

Dark matter (detected by gravitational lensing) is not.

Matter Radiation Fluctuations

Cosmic Microwave Background

Galaxy Cluster Collisions



How do we know this?

Planck CMB 2013

Rotational Curves of Galaxies

Primordial Nucleosynthesis

Baryon Acoustic Oscillations

Gravitational Lensing

Ok, but where is the dark matter?

Ok, but where is the dark matter?

Your local coffee shop?

Ok, but where is the dark matter?

Your local coffee shop?

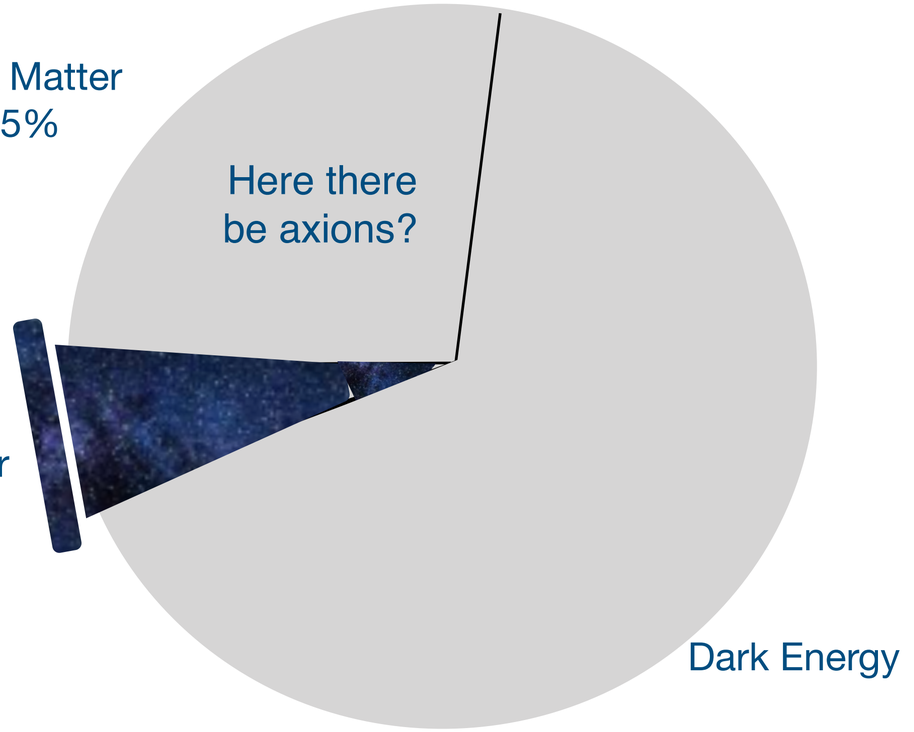
Actually, yes!

Because dark matter is everywhere around us!

In Summary

85% of the matter content of the universe is unknown!

- Indirect observations tell us:
  - Dark matter concentrated near galaxies
  - Interacts via gravity, unclear if other interactions
  - Cold (non-relativistic)
  - Feebly interacting
  - Very stable
  - Non-baryonic



Vera Rubin working in her lab

Rubin, Vera C. "Rotation curves of high-luminosity spiral galaxies and the rotation curve of our galaxy." *Symposium-International Astronomical Union*. Vol. 84. Cambridge University Press, 1979.

Axion Dark Matter eXperiment (ADMX)

- Experiment to search for dark matter called ‘axions’.
- ADMX is the most sensitive axion dark matter search!
- ADMX is currently a global collaboration of 11 institutions.

Sponsors

Primary Sponsor

Axions are “wave-like”

What does this mean?

$$a(\vec{x},t) = \frac{\sqrt{(2\rho_{DM})}}{m_a}\cos\left(m_a t + \mathcal{O}(\nu_{DM})\vec{x}\right)$$

ρ_{DM}: dark matter density
m_a: axion mass

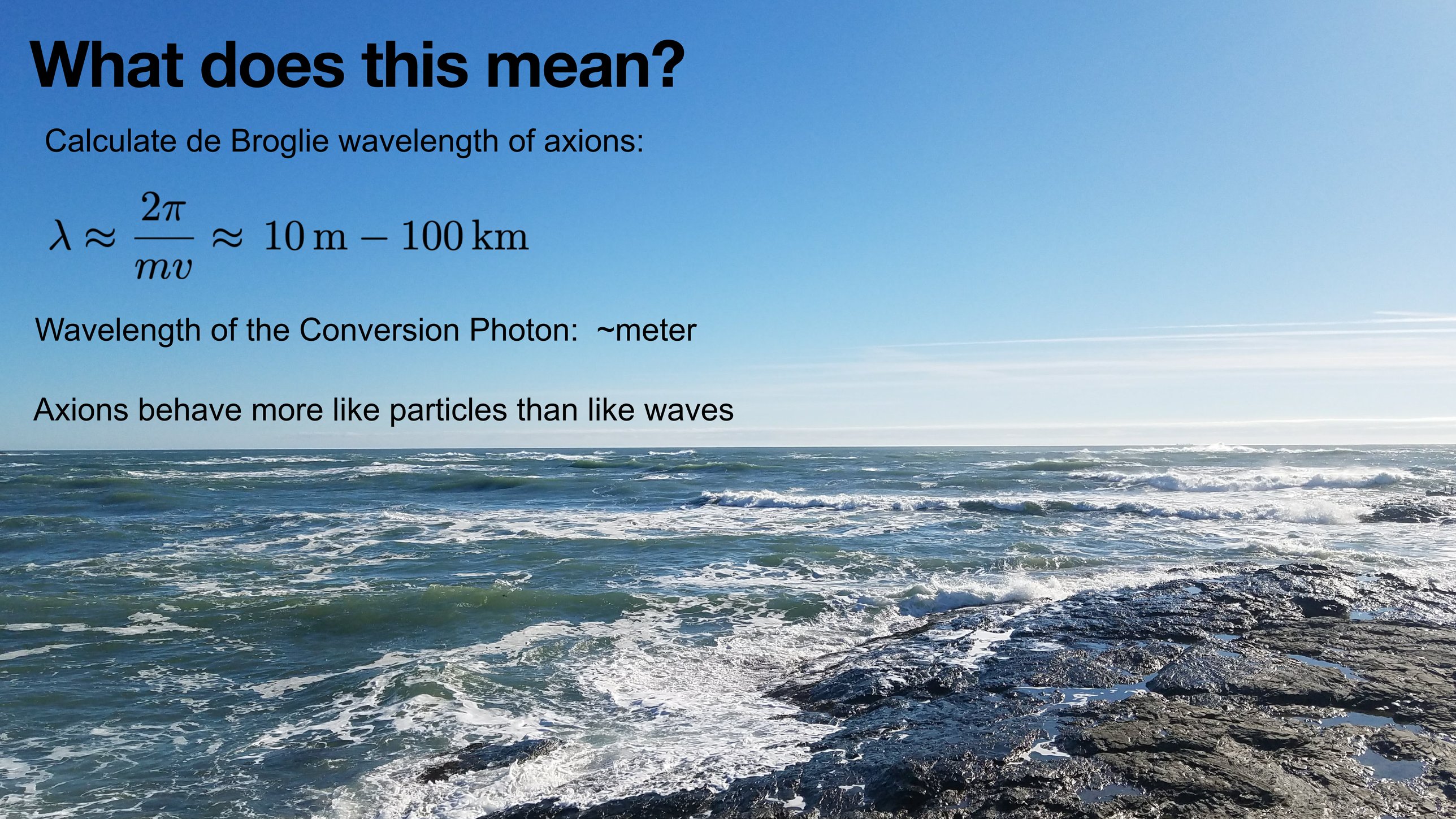
What does this mean?

Calculate de Broglie wavelength of axions:

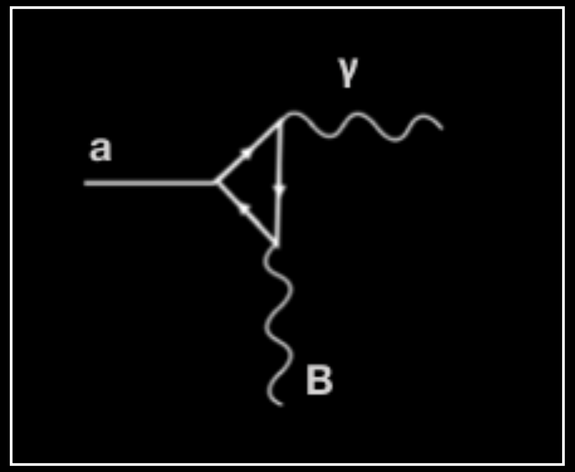
$$\lambda \approx \frac{2\pi}{mv} \approx 10\,\mathrm{m} - 100\,\mathrm{km}$$

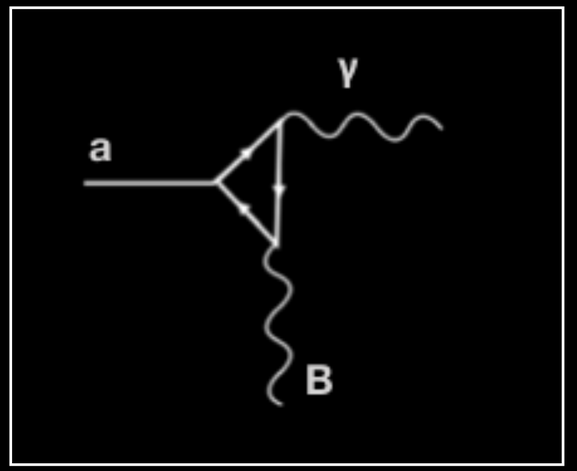
Wavelength of the Conversion Photon: ~meter

Axions behave more like particles than like waves



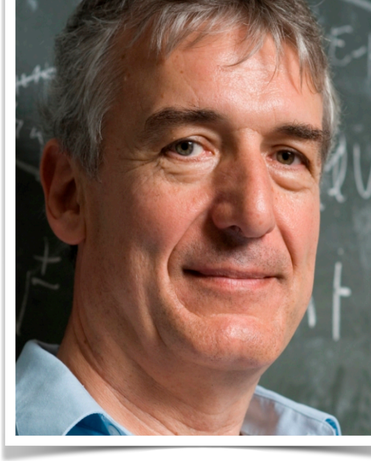
How do we detect axions?
Axion Haloscope

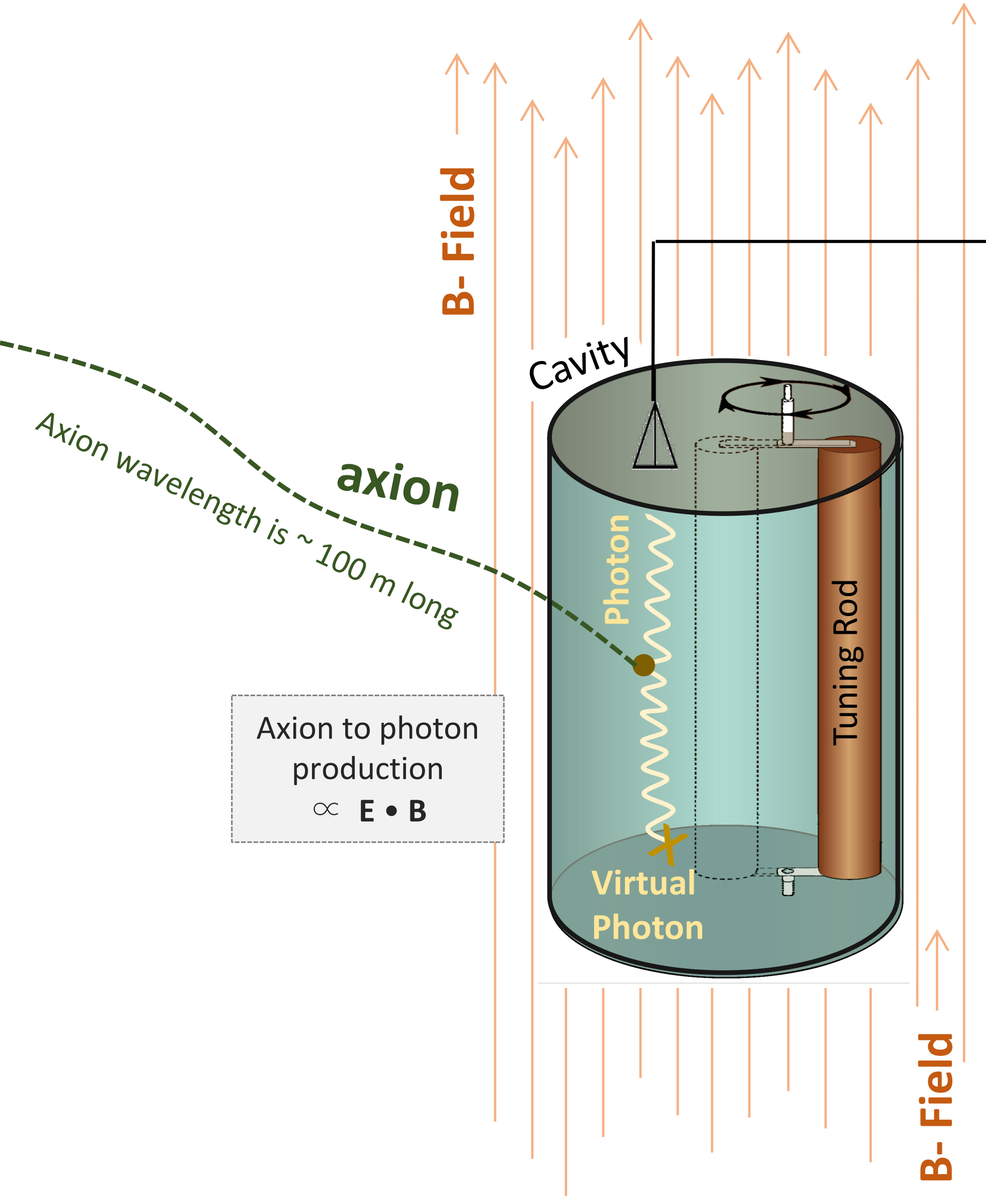




What's a haloscope?
A big metal cavity in a magnetic field, connected to a radio.

The Axion Haloscope



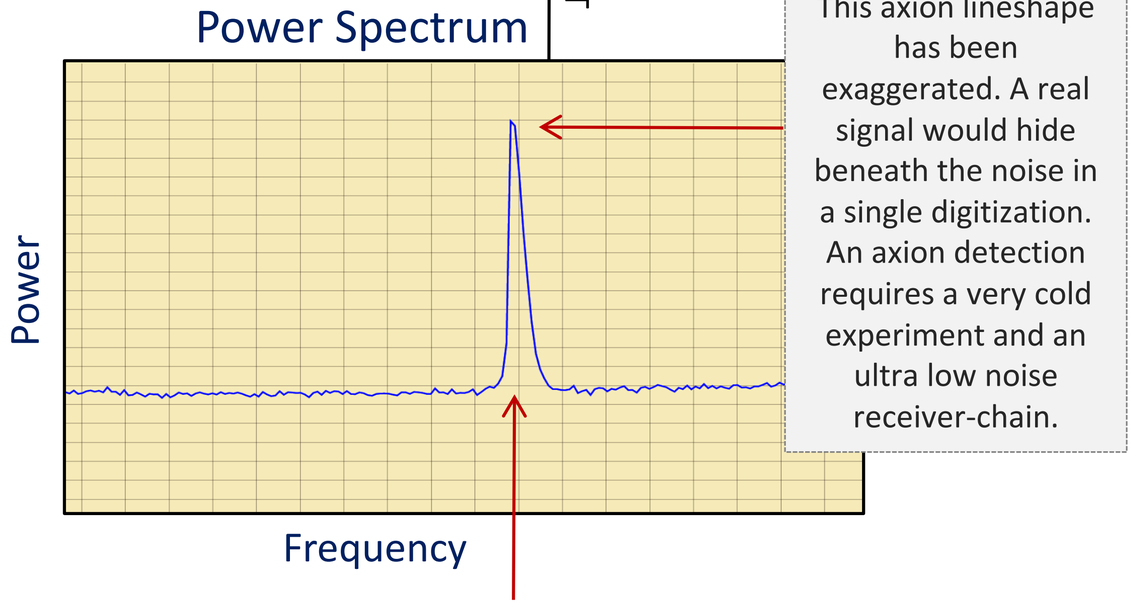


Axion to photon production
$\propto$ **E • B**

Amplify

Digitize

FFT

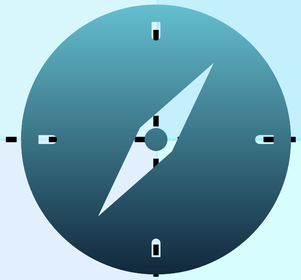


This axion lineshape has been exaggerated. A real signal would hide beneath the noise in a single digitization. An axion detection requires a very cold experiment and an ultra low noise receiver-chain.

Unknown axion mass requires a tunable resonator

SINGLE PHOTONS
(LIGHT PACKETS)

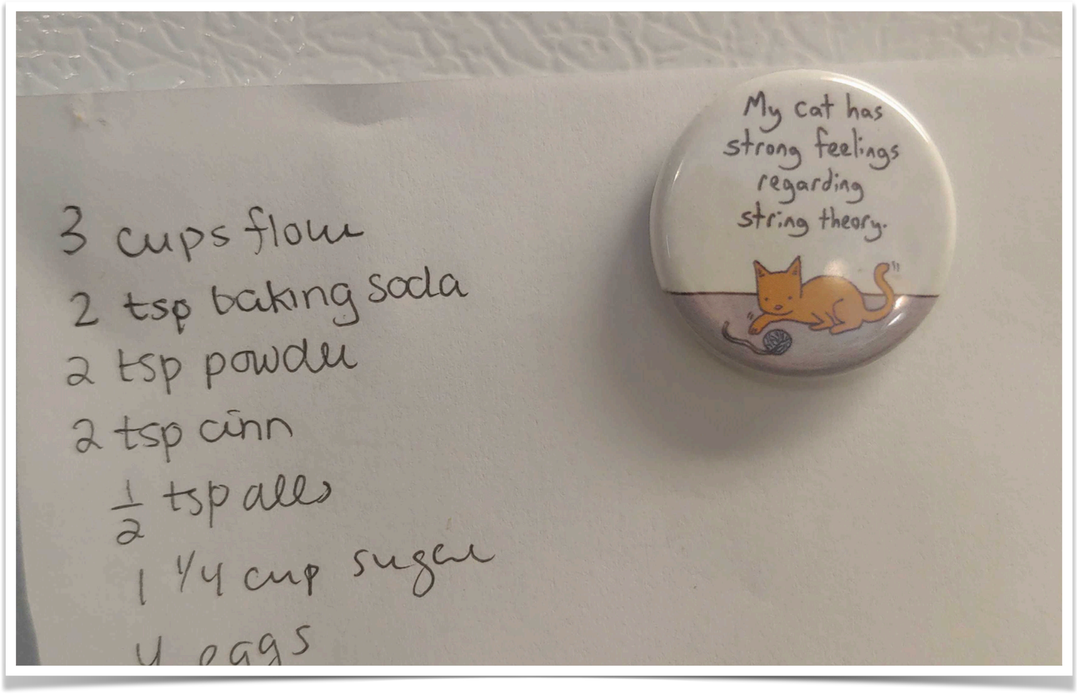
COLD TEMPERATURES



FANCY AM RADIOS

HIGH MAGNETIC FIELDS

How strong are these magnetic fields?



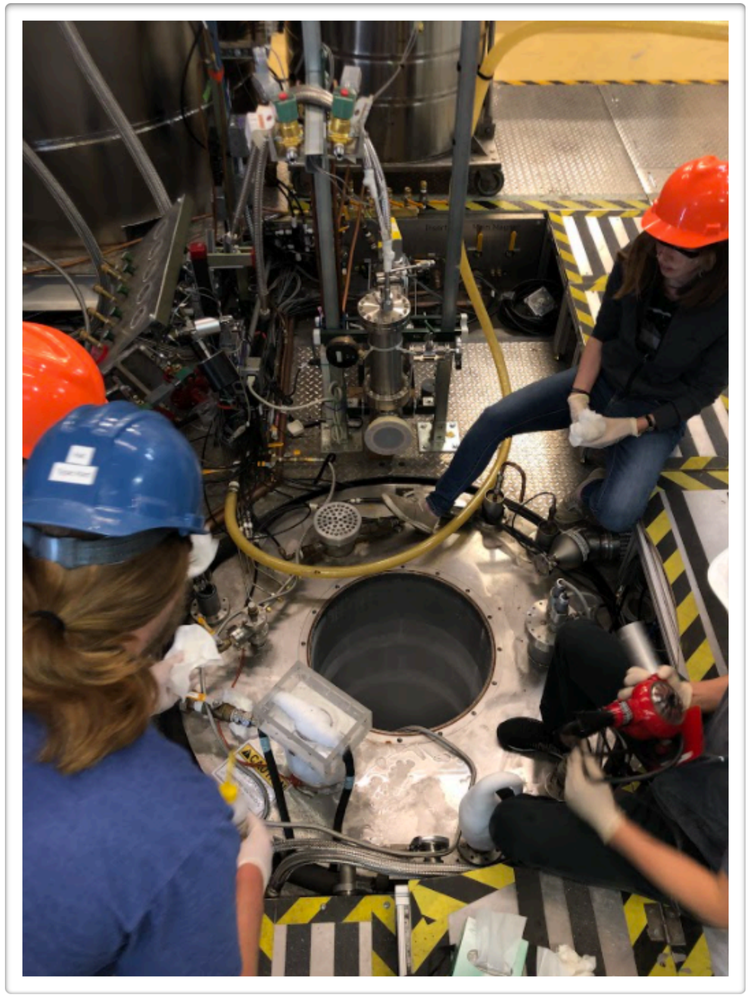
Typical refrigerator magnet: 100 Gauss

Typical MRI magnet at a hospital: 30,000 Gauss

How strong is our magnetic field?

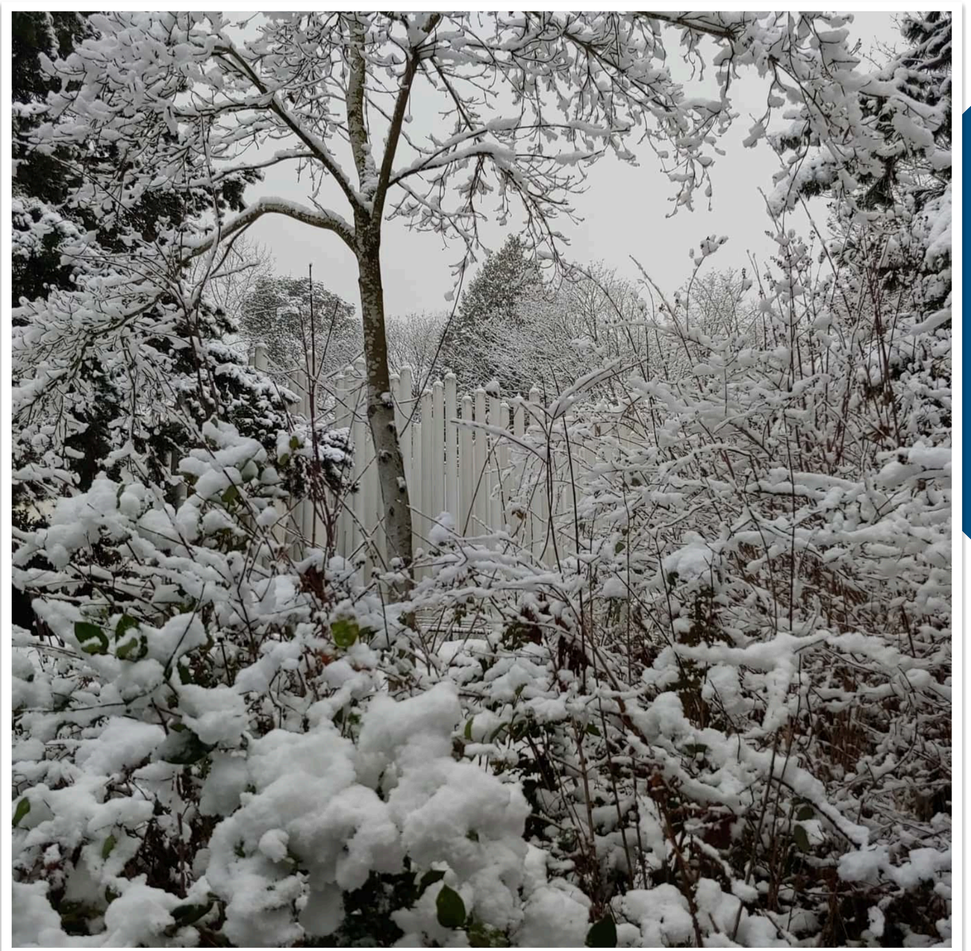
ADMX Magnet

70,000 Gauss!



ADMX Magnet Bore

How cold is ADMX?



Is it colder than our snow last week?

Is it colder than icicles?

How cold is ADMX?

Is it colder than our snow last week?

Is it colder than icicles?

YES!

How cold is ADMX?

Is it colder than Antarctica?

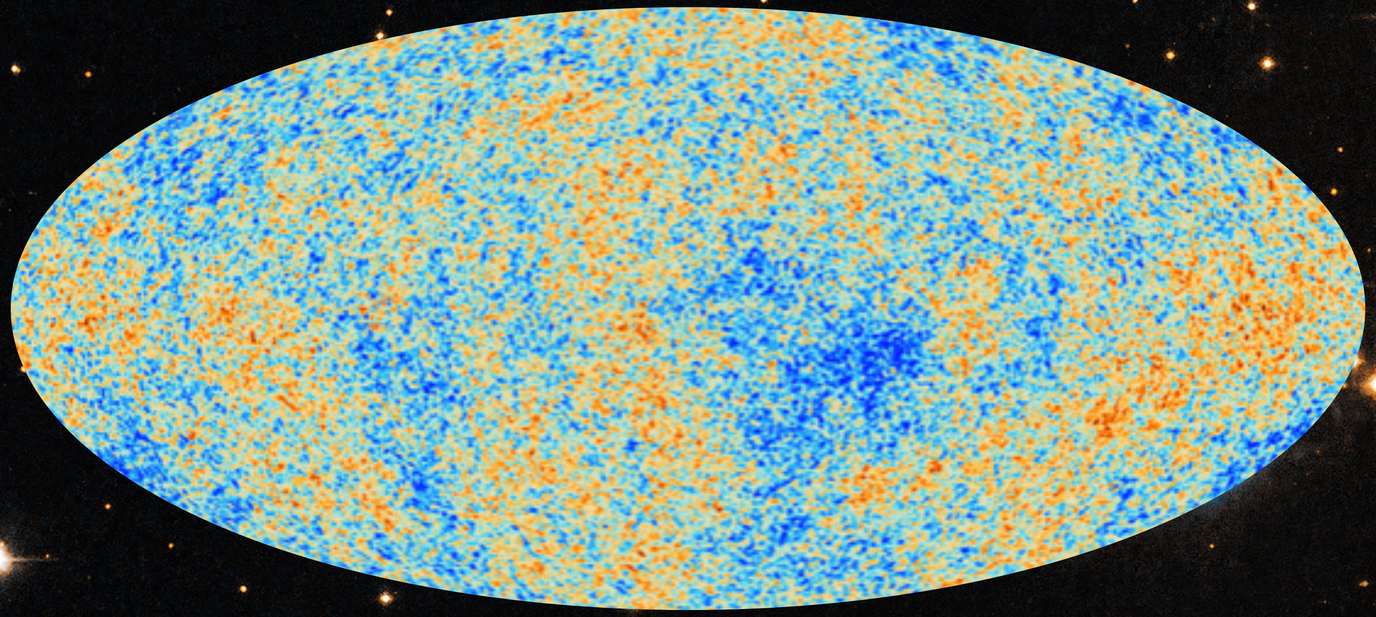
How cold is ADMX?

Is it colder than Antarctica?

YES!

How cold is interstellar space?

Determined by the Cosmic Microwave Background



Originated from the Big Bang

Planck Results

Planck Experiment

How cold is interstellar space?

2.7 K

-454.81 F

Is ADMX colder than interstellar space?

YES!

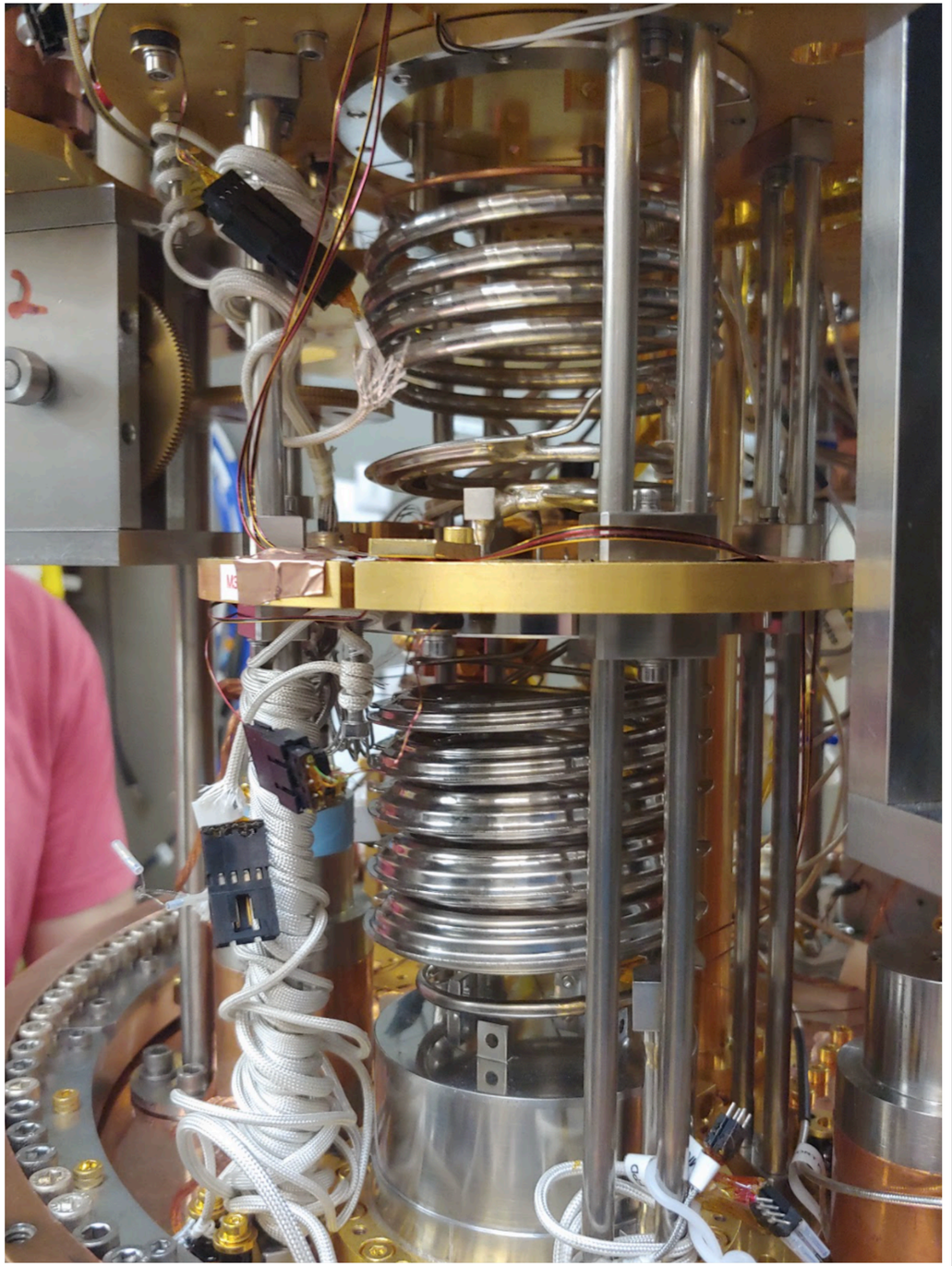
Planck Experiment

How cold is ADMX?

100 mK

-459.49 F

Dilution Refrigerator
Uses Liquid Helium



Removing the insert from the magnet bore

Can see from the from that it is very cold!

How small is the signal from axions?

10^{-24} Watts!

~0.000000000000000000000002 Watts!

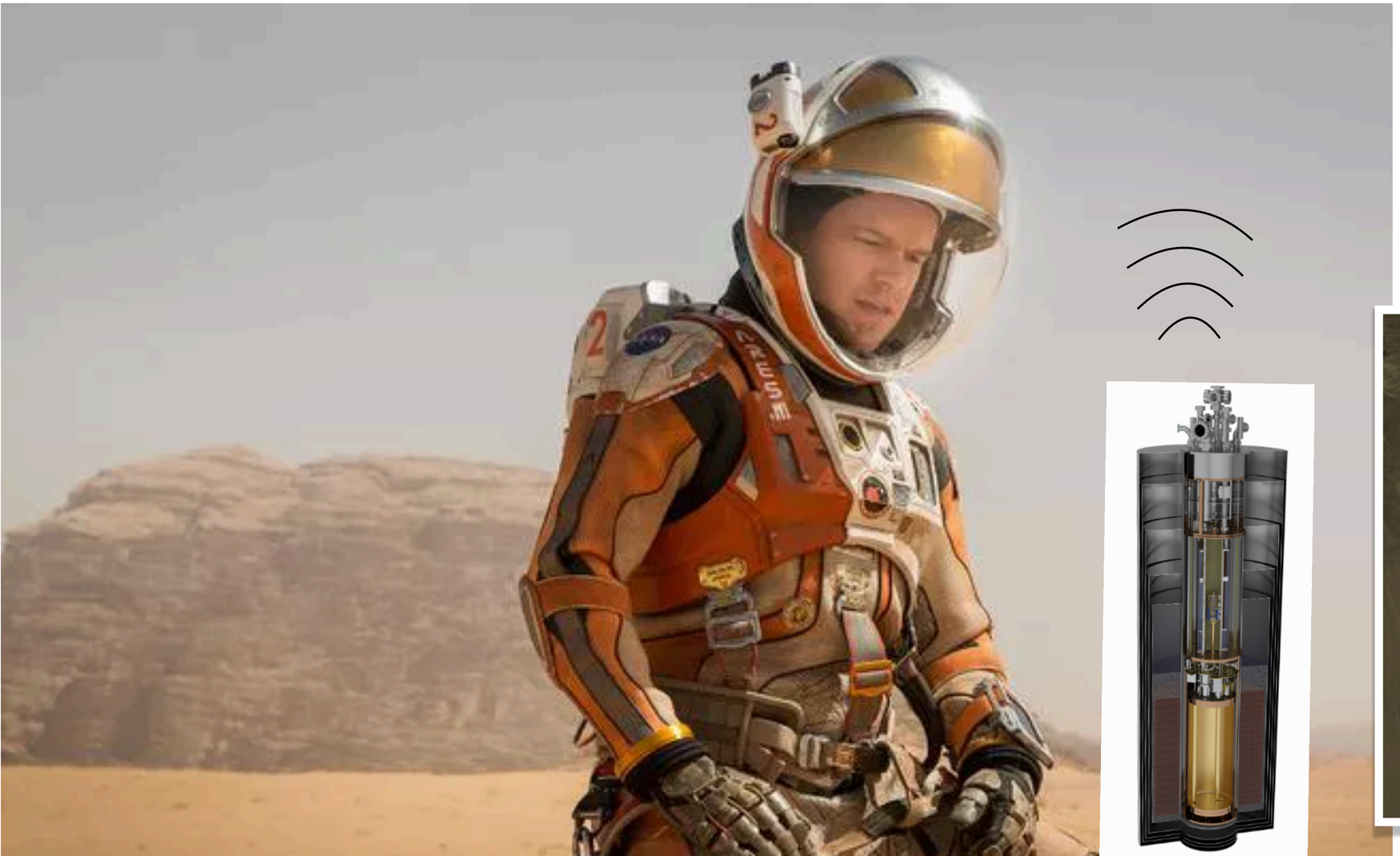
How small is the signal from axions?

10^{-24} Watts!

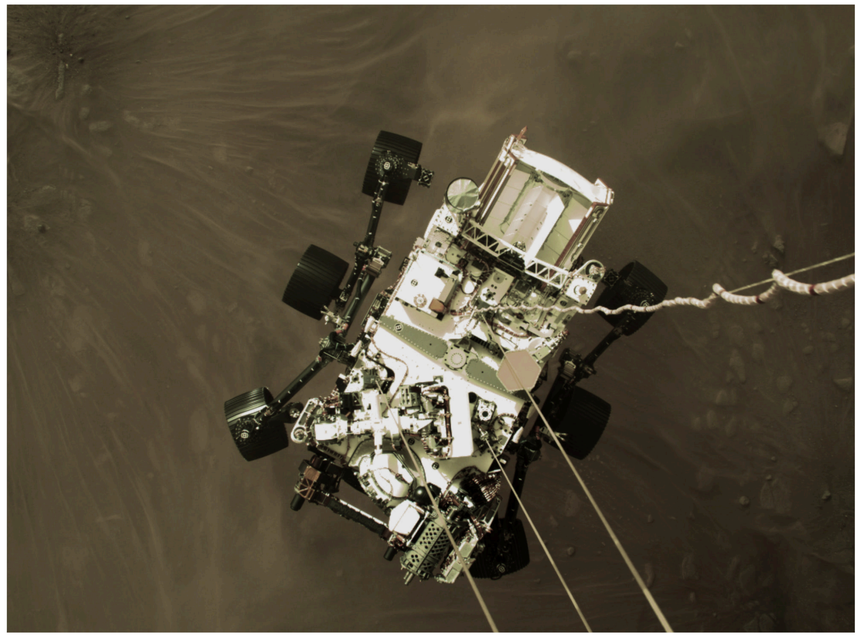
We call this a “yoctowatt”.
We haven’t named any numbers small than this.

4 Bars on Mars

So if you are Mark Watney and you happen to be stuck on Mars, maybe try building an ADMX style cell phone?



Shout out to NASA and Perseverance!



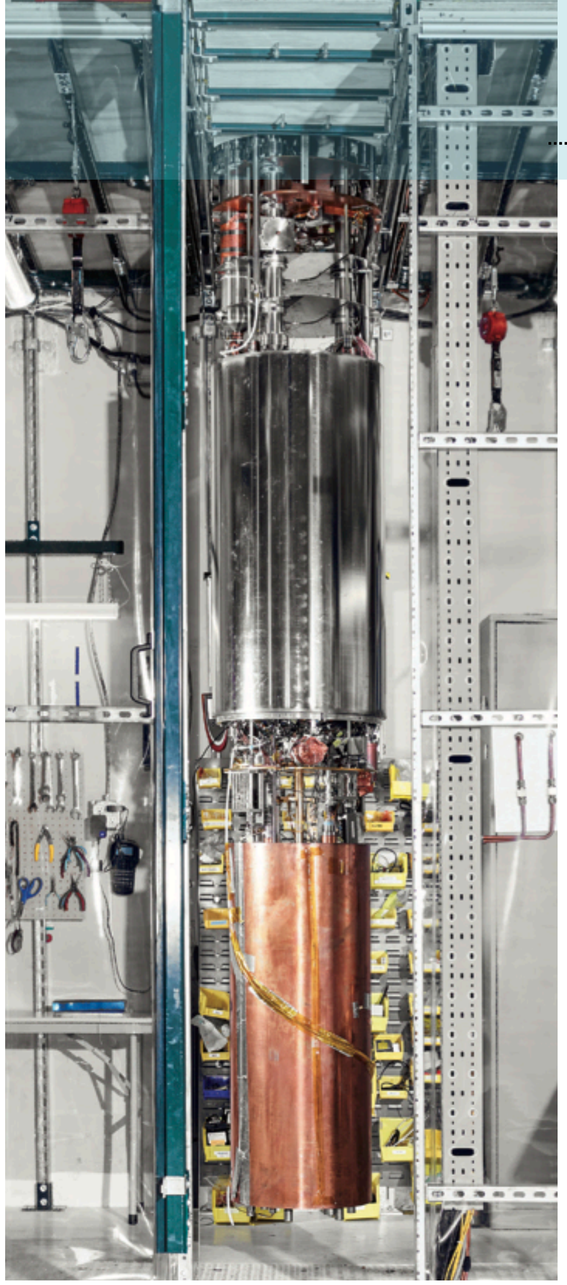
Resonant Cavities

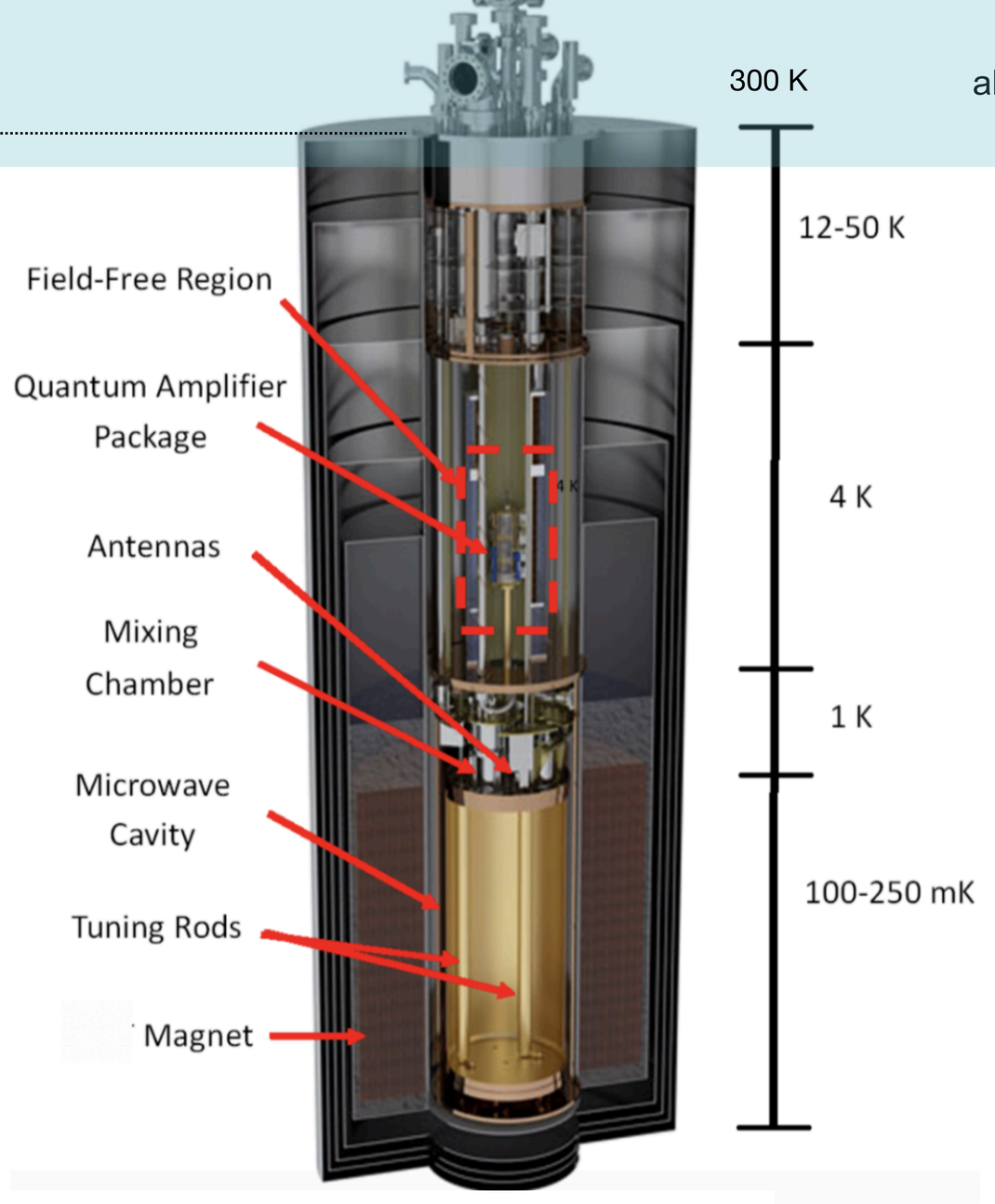
Many musical instruments are resonant cavities that support standing waves

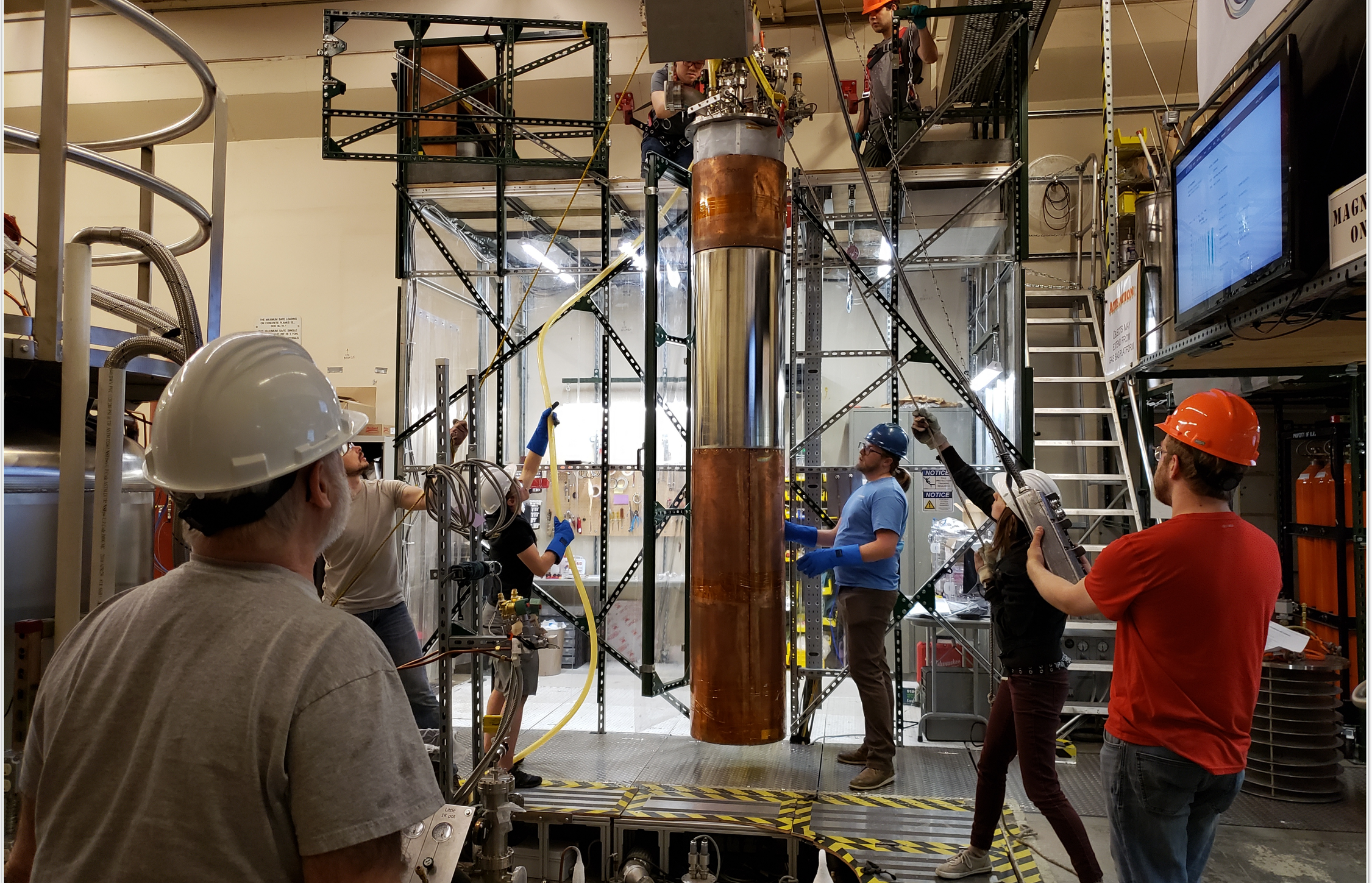
Our resonant cavity is electromagnetic in nature
Idea is still the same!
Can tune by changing the “boundary conditions”

ADMX

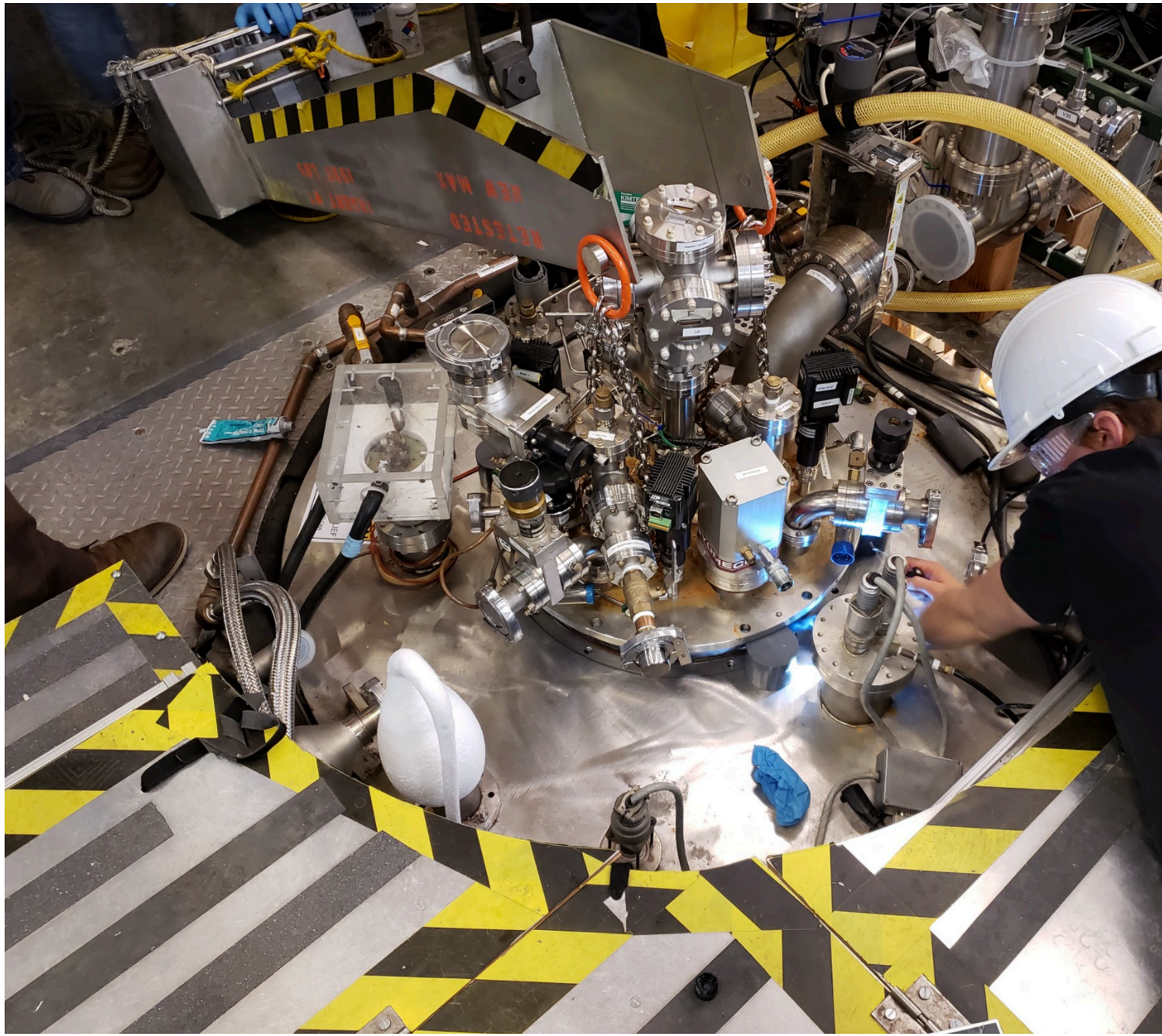
- Dil Fridge: Reaches ~100 mK
- Superconducting magnet:
  ~can reach up to 8 T
- Quantum electronics: Josephson Parametric Amplifier (JPA)
- Field cancellation coil
- Microwave cavity and electronics

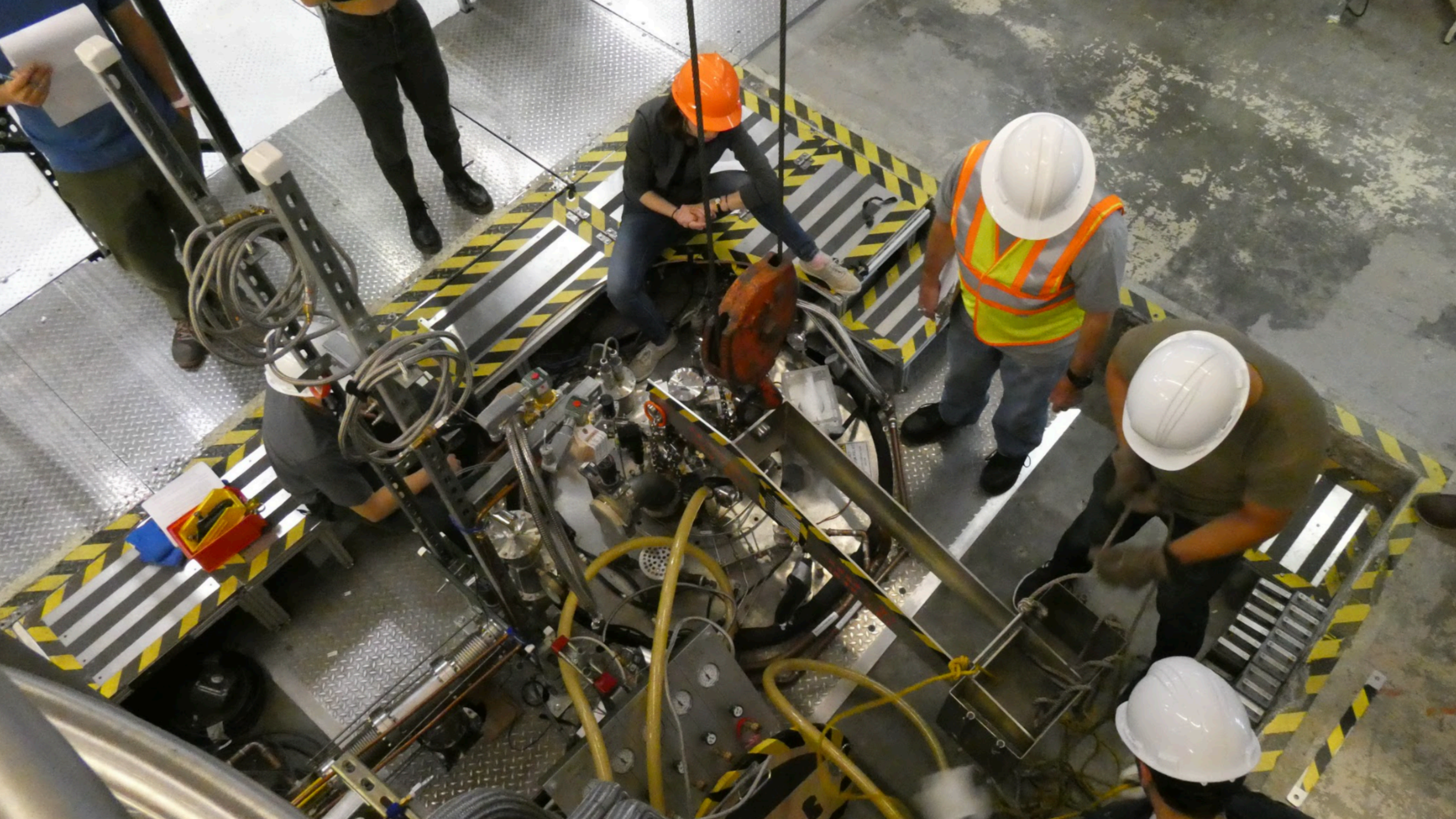





NOTICE
NOTICE
Little
1K pot

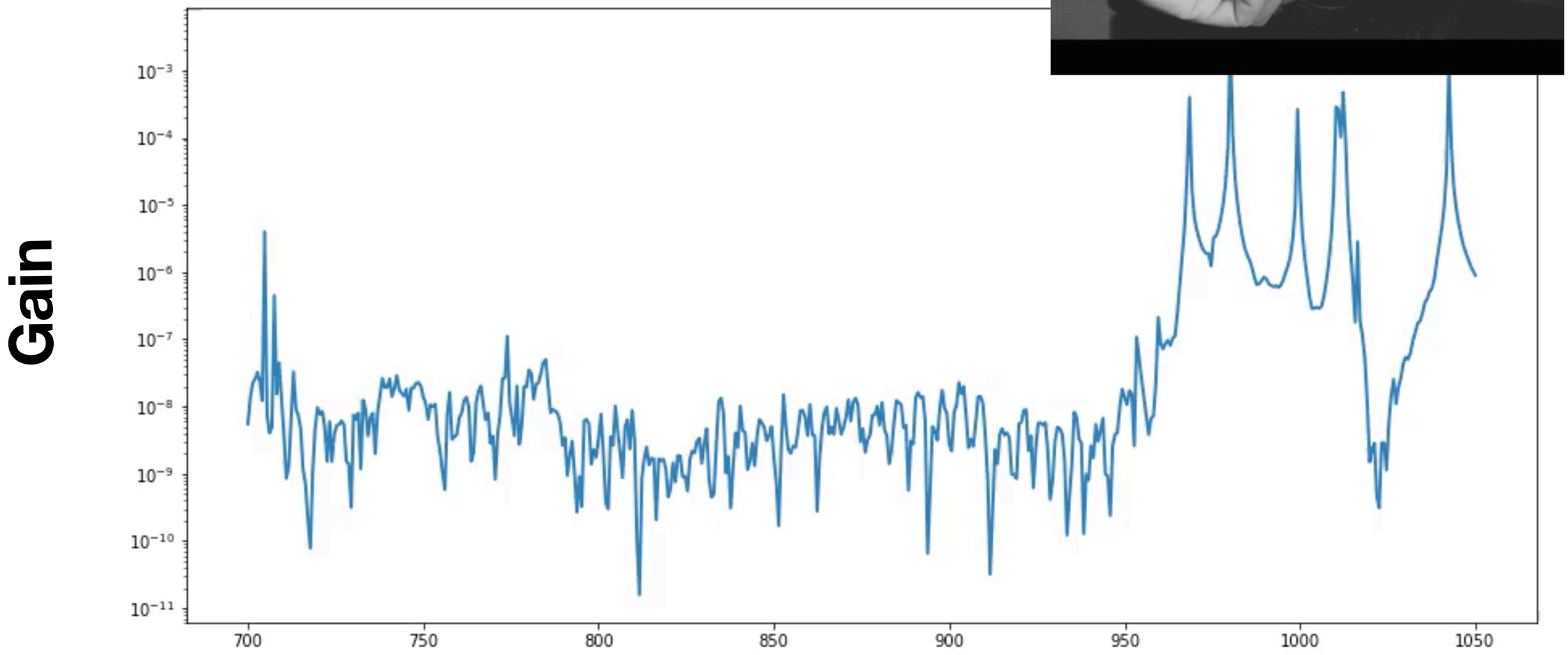
Working on top of the experiment





Tuning an AM Radio

Peaks = greater axion sensitivity



One day, we will know what this one is….

https://www.particlezoo.net/

Dark Matter Plushie
I think it *should* be the axion!

Thank you!

May the dark matter be with you!

This work was supported by the U.S. Department of Energy through Grants No DE-SC0009800, No. DE-SC0009723, No. DE-SC0010296, No. DE-SC0010280, No. DE-SC0011665, No. DEFG02-97ER41029, No. DE-FG02-96ER40956, No. DEAC52-07NA27344, No. DE-C03-76SF00098 and No. DE-SC0017987. Fermilab is a U.S. Department of Energy, Office of Science, HEP User Facility. Fermilab is managed by Fermi Research Alliance, LLC (FRA), acting under Contract No. DE-AC02-07CH11359. Additional support was provided by the Heising-Simons Foundation and by the Lawrence Livermore National Laboratory and Pacific Northwest National Laboratory LDRD offices.

ADMX Collaboration Fermilab Collaboration Meeting in 2018