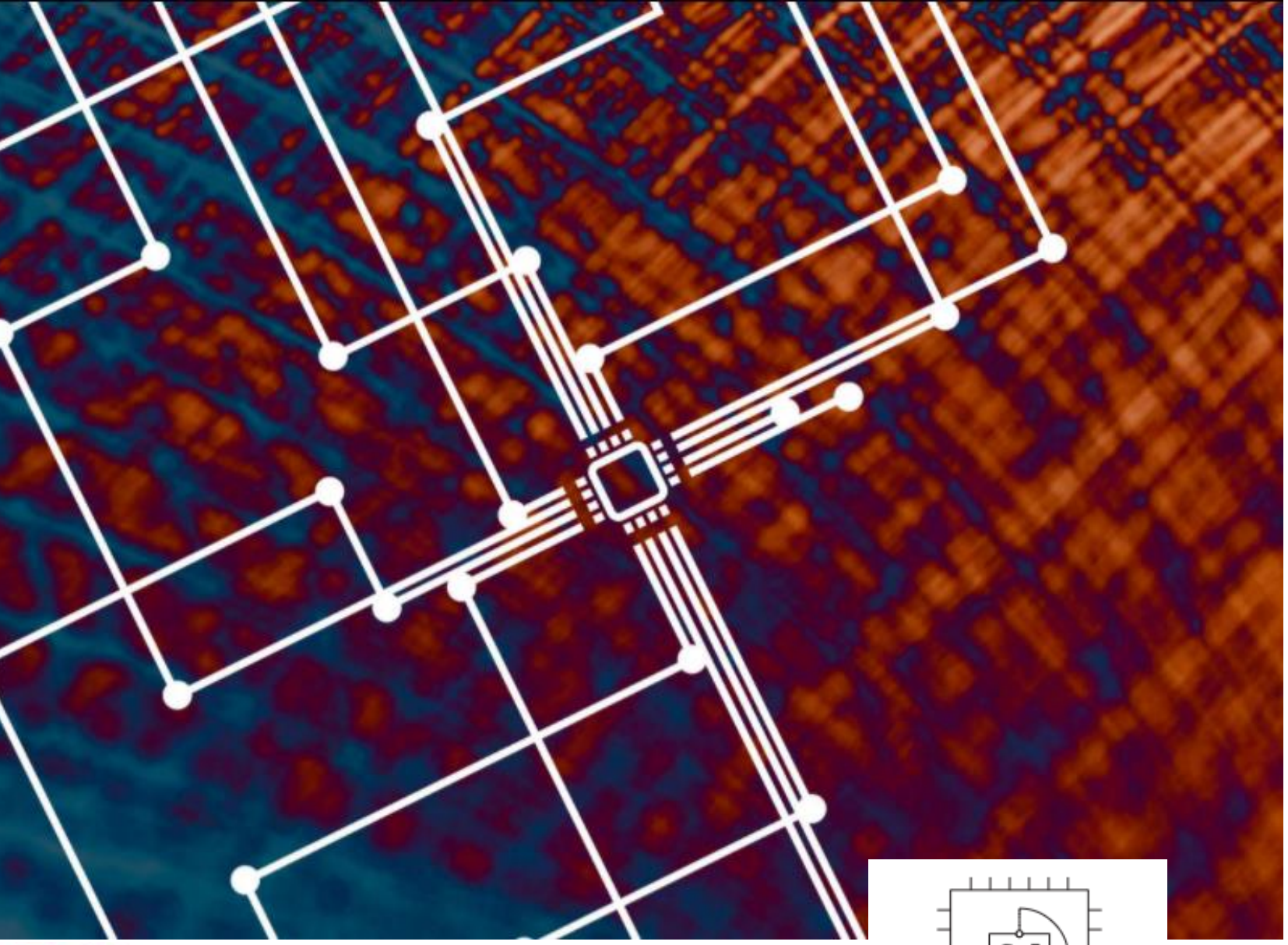

# Traceability challenges for intrinsic, deployable standards


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SISTEMA INTERAMERICANO DE METROLOGIA

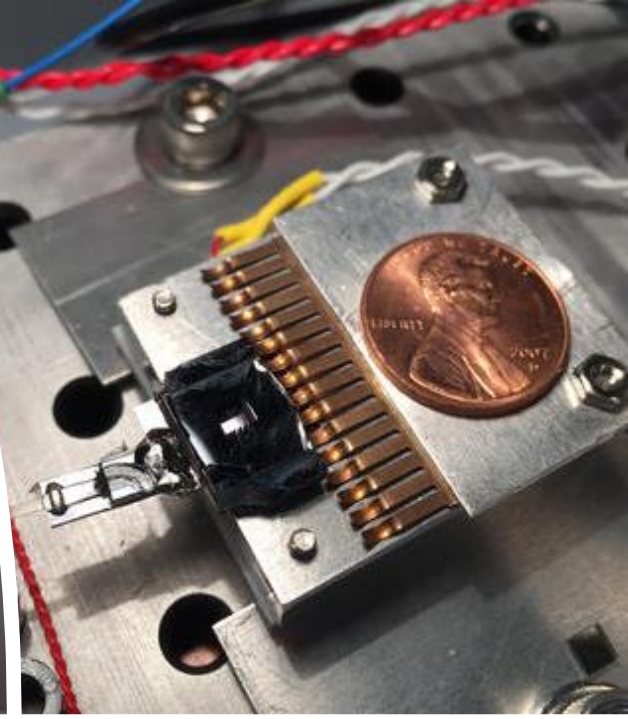
October 10, 2024

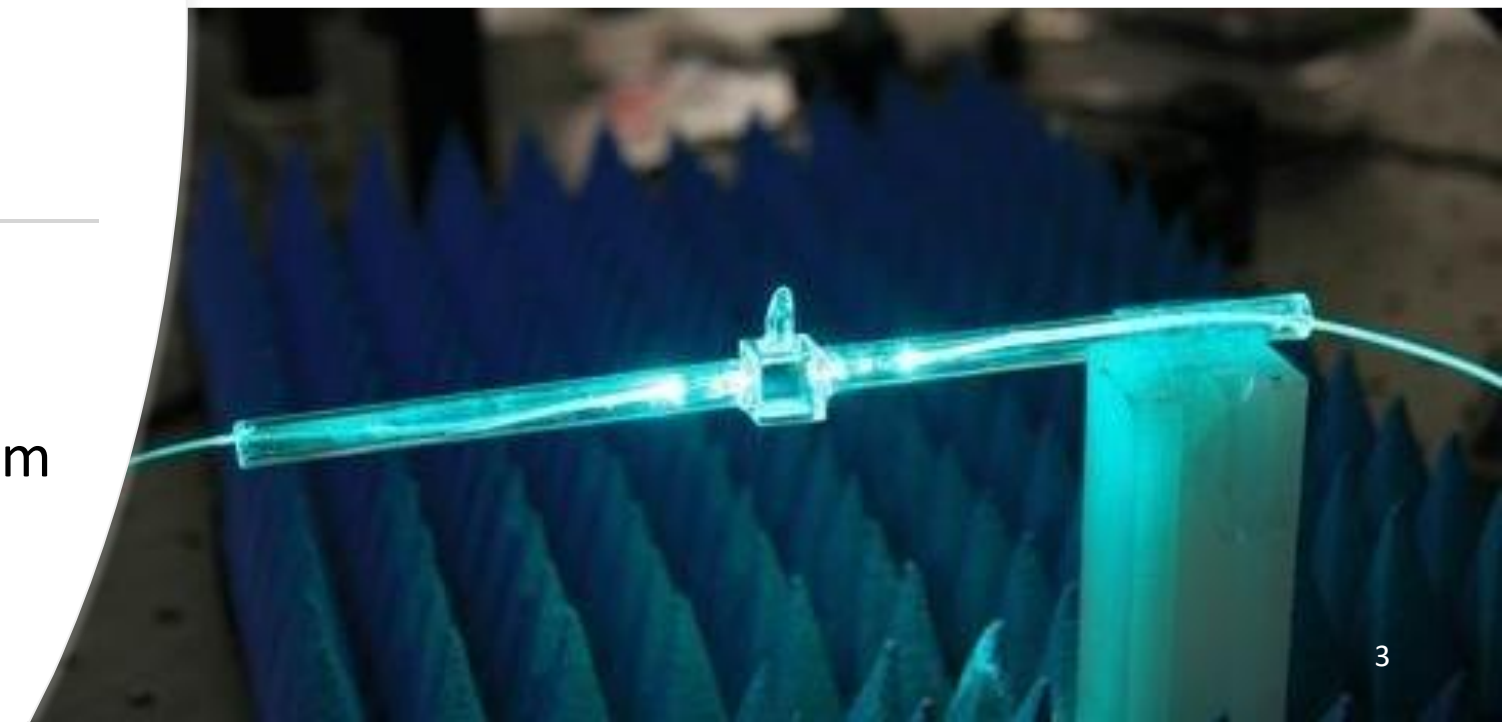
https://www.nist.gov/noac

# Innovations in Technology

# Demand innovations in metrology

- How we make measurements
- How we deliver them
- How we provide confidence in them



# Metrology takes a village…

**For every measurement you need, NIST has to:**

- Make it first
- Make it better – usually a **whole lot** better
- Have anticipated that you would need it
- Make sure there's a "bucket brigade" to deliver that measurement to where its needed

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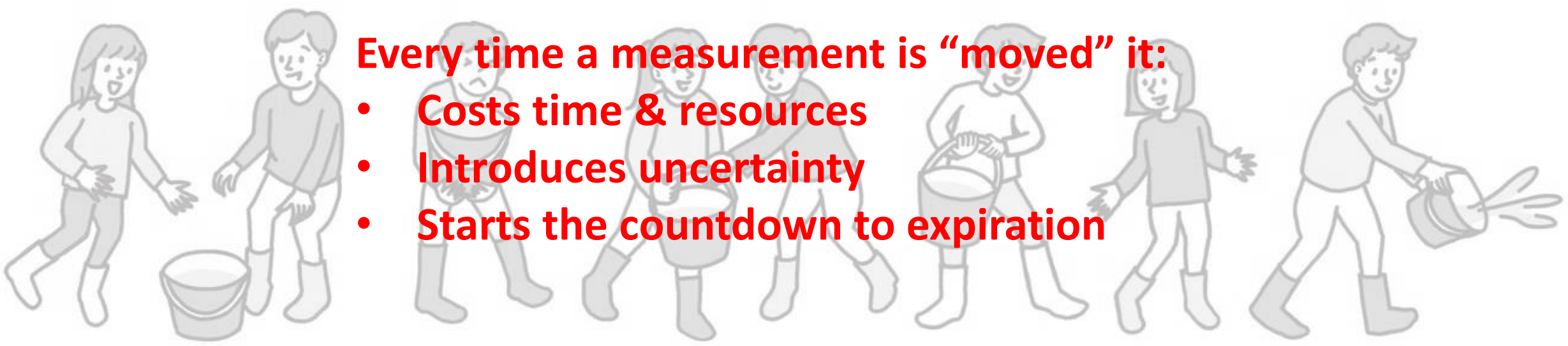
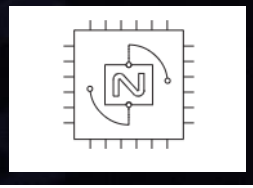


**Every time a measurement is "moved" it:**

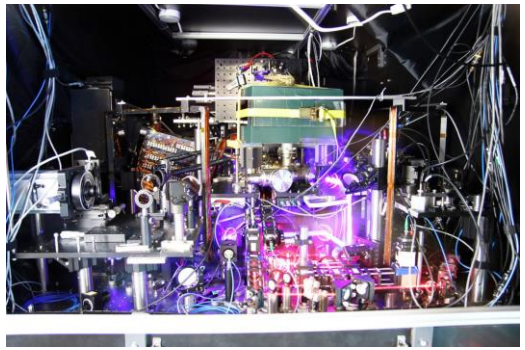
- **Costs time & resources**
- **Introduces uncertainty**
- **Starts the countdown to expiration**

# Introducing NIST on a Chip



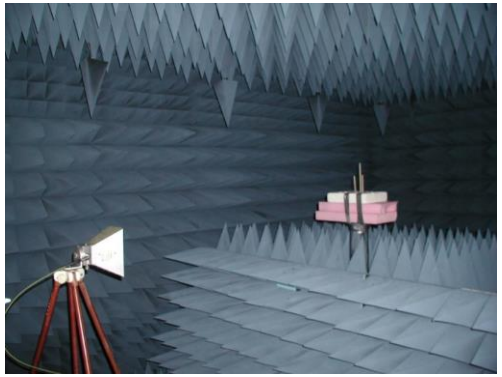
# NIST on a Chip – the vision

## To shrink measurement equipment like this…



NIST Strontium atomic clock

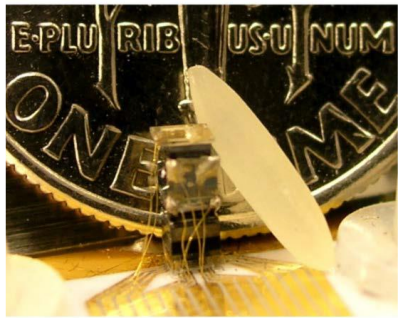
100 kW thermal power meter



Horn antenna in an anechoic chamber

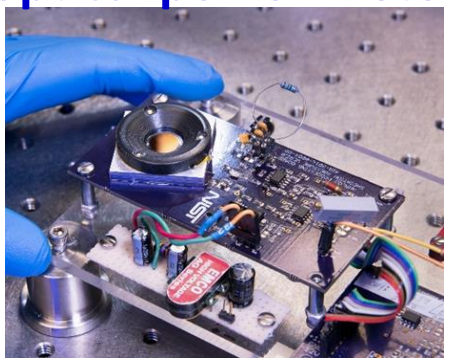
# NIST on a Chip – the vision

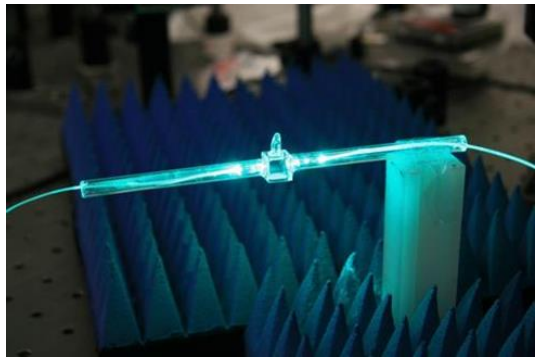
## To devices like this…



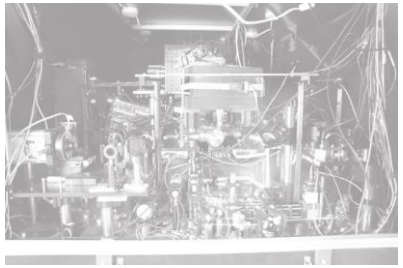

**Chip-scale atomic clock**

**Radiation pressure-based optical power meter**



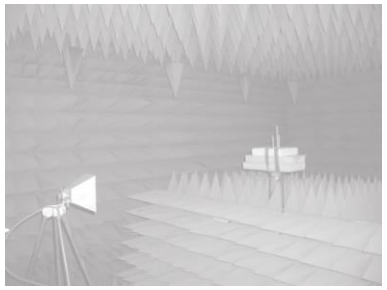


**Atoms as sensors**



NIST Strontium atomic clock

100 kW thermal power meter



Horn antenna in an anechoic chamber

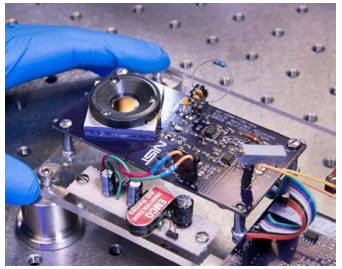
# NIST on a Chip – quantum sensing

## The vision

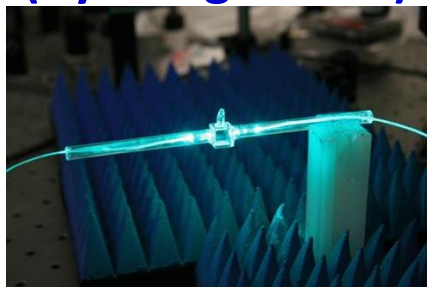
Shrinking NIST's precision metrology to a suite of chip-scale, quantum-based sensors, deployed at point-of use through commercial products

**Chip-scale Atomic Clock**

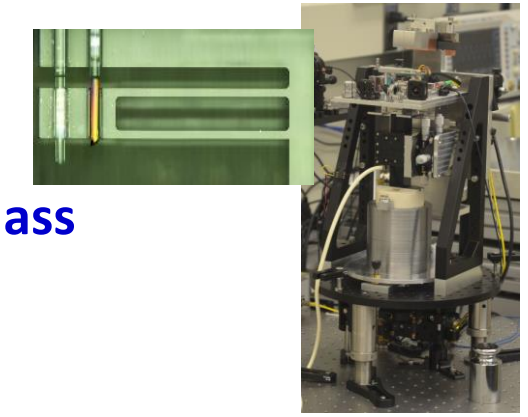
**Laser Power (Photonic Power)**

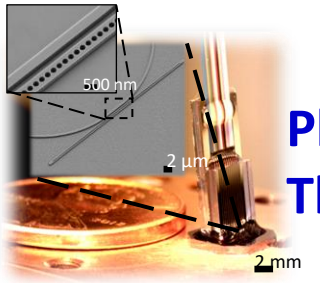


**E-Field Sensing (Rydberg Atoms)**

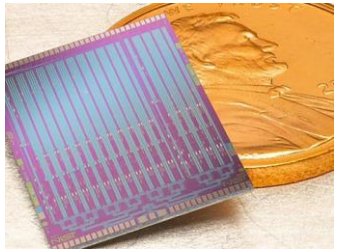


**Mass**





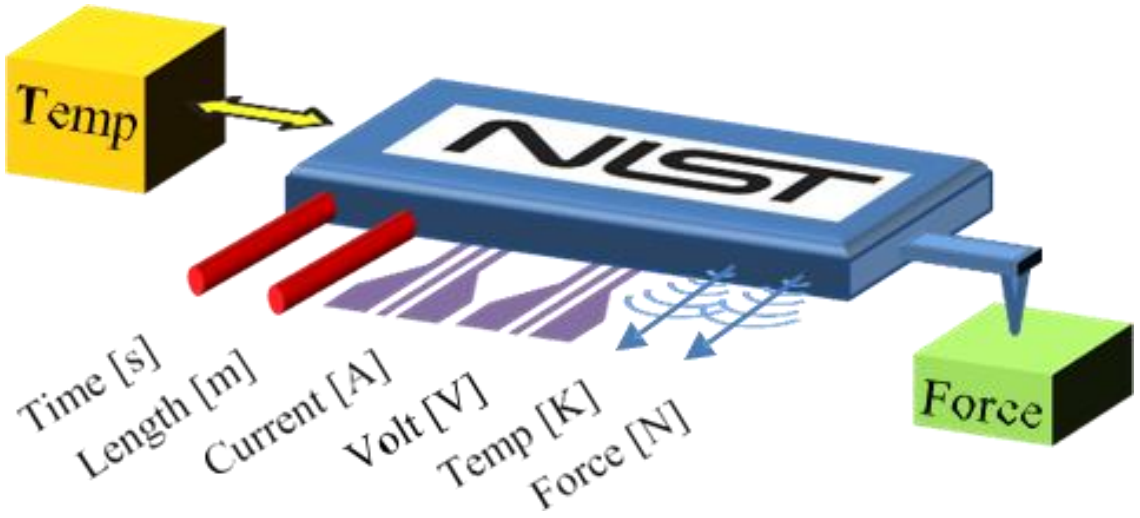

**Photonic Thermometer**



**Voltage**

https://www.nist.gov/noac

# Measurement standards in chip-scale format

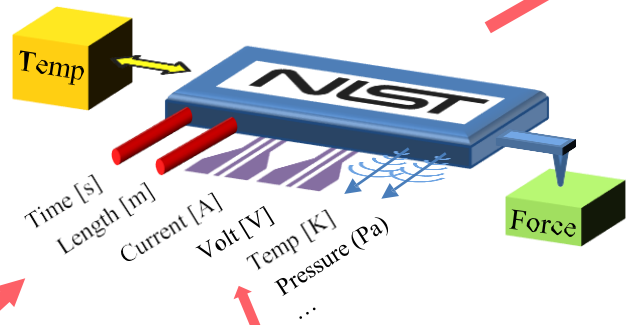


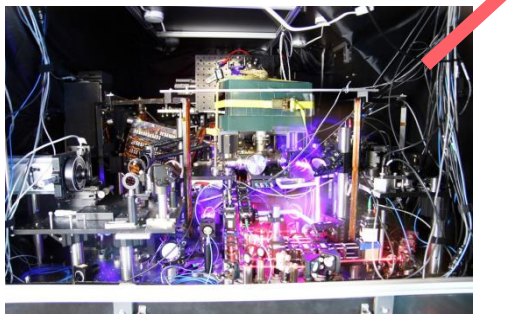

- **Embedded** directly in equipment, deploy where needed
- Flexible, useful, **manufacturable**, deployable
- **Break the calibration chain**
- Give the **right answer or no answer** at all
- Based on fundamental (**quantum**) properties of nature

# The Promise of NIST on a Chip

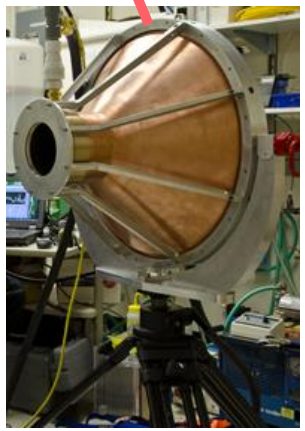
**“Zero-chain traceability”**
**- But what does this mean?**

NIST Mercury Manometer



NIST Strontium atomic clock



100 kW laser calorimeter
(ca. 2012)

# What does traceability mean…

…in a world where measurement standards are:

- Inspired by NIST but manufactured by third parties
- Not calibrated – so how can you have an unbroken chain back to a metrology institute?

What does “intrinsic” really mean?

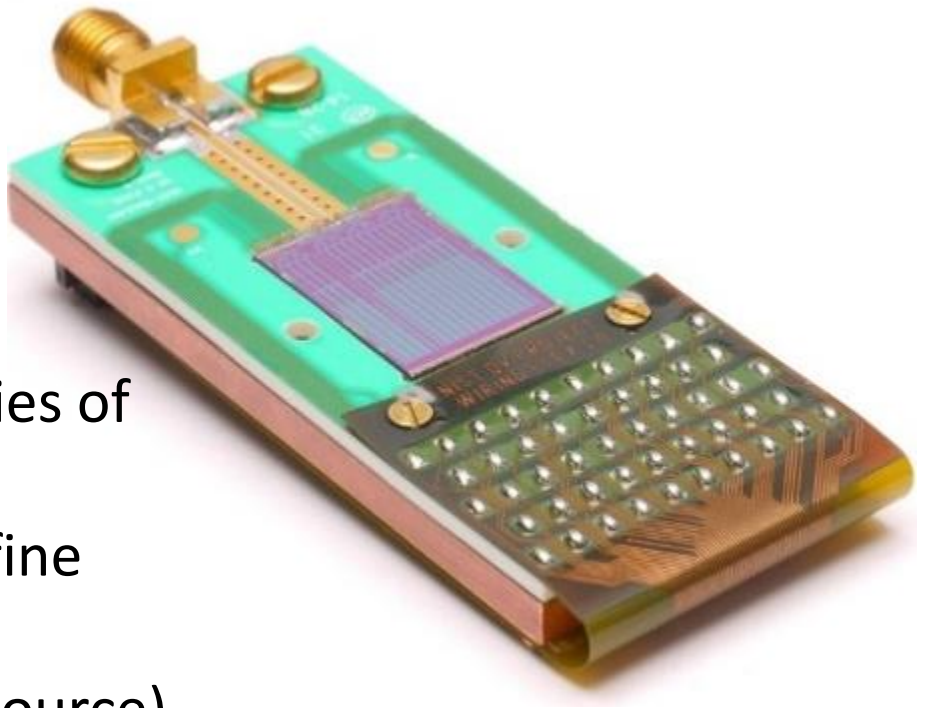
- Just because it’s quantum, is it beyond reproach?
- If you land an airplane on it, how do you know it still works?

And what is the role of the Mutual Recognition Agreement?

- How do Metrology Institutes trust each other’s “measurements” when they’re not producing the standards?

# Voltage – a case study in intrinsic standards

**VIM definition: intrinsic standard**
a measurement standard based on an inherent and reproducible property of a phenomenon or substance



The **Josephson Voltage Standard** (JVS)

- Based on fundamental constants and inherent properties of nature:
  - Planck's constant, charge of an electron, the hyperfine transition of a Cs atom
- Is a realization of the SI Volt (with a proper frequency source)
- Used as the primary standard at NIST and metrology institutes around the world
- Is not calibrated.  Its performance is *verified*.

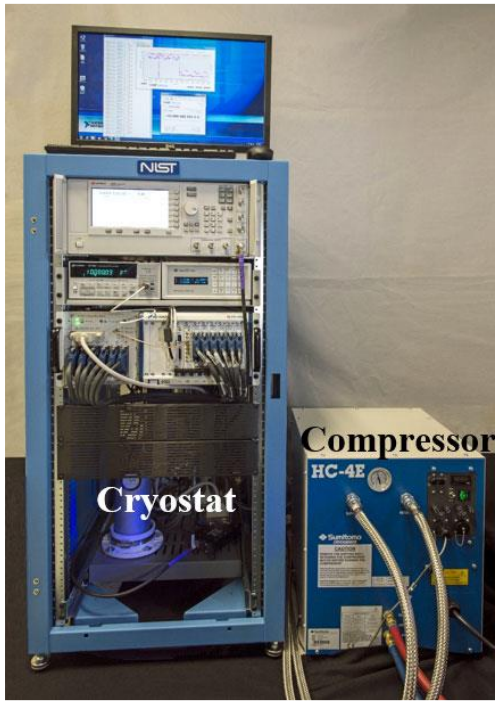
# Voltage – a case study in intrinsic standards

**How do we provide assurance in a world without traditional traceability?**

An “unbroken chain” of calibrations isn’t relevant.

The North American Josephson Voltage Interlaboratory Comparison

- Established in 1991 and conducted every 2-3 years to verify reliability and provide a link to NMIs
- Provides “scientific rigorous evidence”




NIST SRI 6000 Programmable Josephson Voltage Standard (PJVS)

**Josephson Voltage Systems are still made by NIST and maintained by NMIs**

- **But what about other NIST on a Chip standards and quantum sensors that are neither?!**

# Strategies for the brave new world

Do you impose a quality “system” on third-party manufacturers of intrinsic standards?

- Do they need to “qualify” their production process?
- Do they need to participate in regular intercomparisons?
- How do we handle innovations to the NMI-provided design?
- How can manufacturers anticipate all the environments in which their standard will be deployed?

Do you impose quality assurance measures on users?

Do you make chip-scale standards report back to a Metrology Institute?

Do you need to run traditional check-calibrations?

- Eg: calibrate masses on deployed Kibble balances

# Summary

Traceability is challenged by standards that are:

- Intrinsic – and thus not calibrated
- Inspired but not manufactured by a metrology institute

Optical temperature sensor

Atomic magnetometer

What role should – or can – a Metrology Institute play for deployed, embedded standards?

Is there a difference for intrinsic standards vs. sensors?

I clearly have more questions than answers!

# Thank you for your attention!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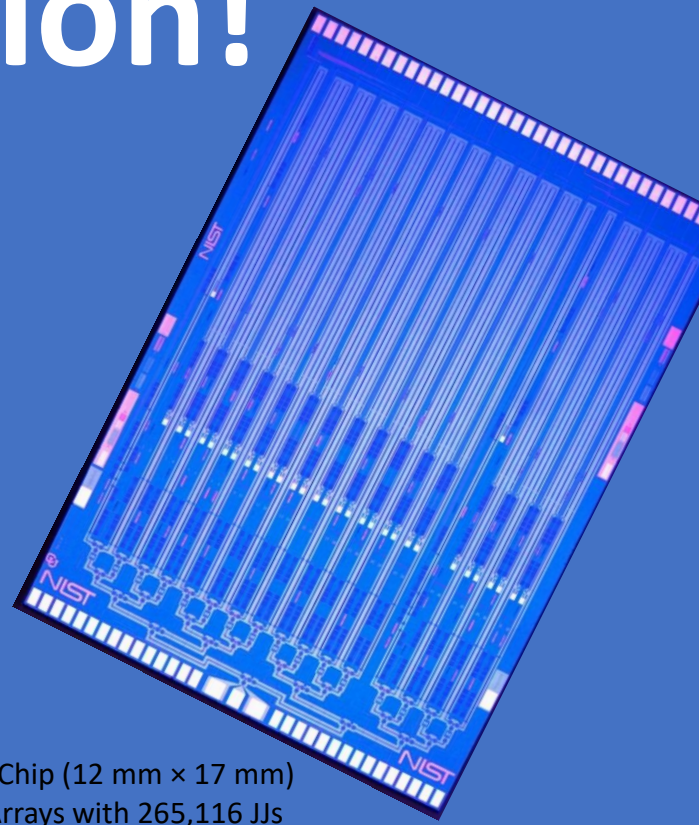


PJVS Chip (12 mm × 17 mm)
16 Arrays with 265,116 JJs

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

SIM SISTEMA INTERAMERICANO DE METROLOGIA