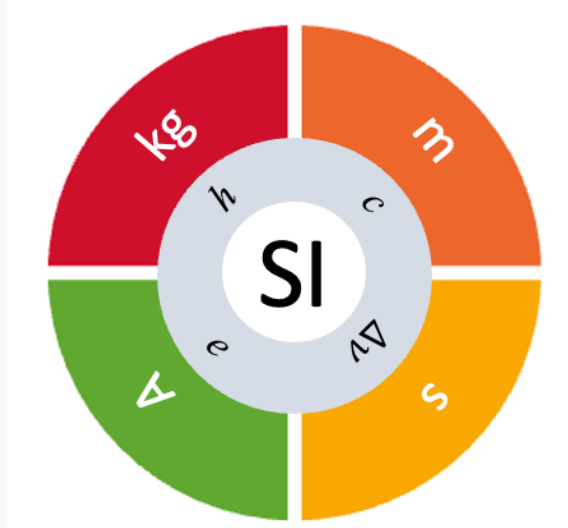




The Kibble (Planck) Balance and the Future of the Optical Watt

John Lehman, Brian Simonds, Kyle Rogers, Gordon Shaw, David Newell, Paul Williams
National Institute of Standards and Technology, USA



Practical realization of the optical watt was liberated by the 2019 Redefinition of the International System of Units and the kilogram. At least four orthogonal routes are possible. Since the 1980's, the dominant realization was by electrical substitution and thermal detectors [1]. Langley demonstrated this as early as 1881 and Kurlbaum shortly after [2,3]. One can also realize a watt through Boltzmann constant and temperature measurement of a blackbody source [4]. Of the four, the ultimate quantum realization is arguably by counting photons, the hyperfine frequency of cesium being the required fundamental constant [5]. But if the redefinition of the kilogram and the Kibble balance was a catalyst of change for mass, we think it has a great future in optical power and radiation pressure. It is possible to achieve 0.01 % uncertainty of 100 mg[6]. This implies, therefore, one should be able to achieve the lowest uncertainty optical power measurements with equivalent force at approximately 100 kW (1 μm wavelength) without knowledge of the gravitational constant. 100 kW may seem impractical for any sensible realization, but multiplying reflections from a laser beam is intuitive and practical. We have realized an optical watt by means of an electrostatic force balance and ‘amplification’ of optical force, putting optical power on the same footing as the kilogram and the Kibble balance. As commercial lasers generating 10's of kilowatts become commonplace, we see a path forward to optical power realization, high-energy measurements for fusion experiments, and measurement of force without a gravitational reference. Furthermore, traditional optical power measurements (below one watt), can help us achieve the lowest uncertainty of small mass and force measurements.[7]

How to Realize Optical Power

Kibble Balance ca. 2019
Best in the world uncertainty
0.01 % at 100 mg

Force = Power/c
Implies 100 kW can be measured at 0.01 %

Force

"Electrical Substitution"
Best in the world uncertainty < 0.01 %

Optical Power
Heater Absorber Thermistor
Weak Thermal Link
Reference Temperature

Optical Power Traceable to the SI by Electrical Measurements
resistance, current, voltage

Energy

Time

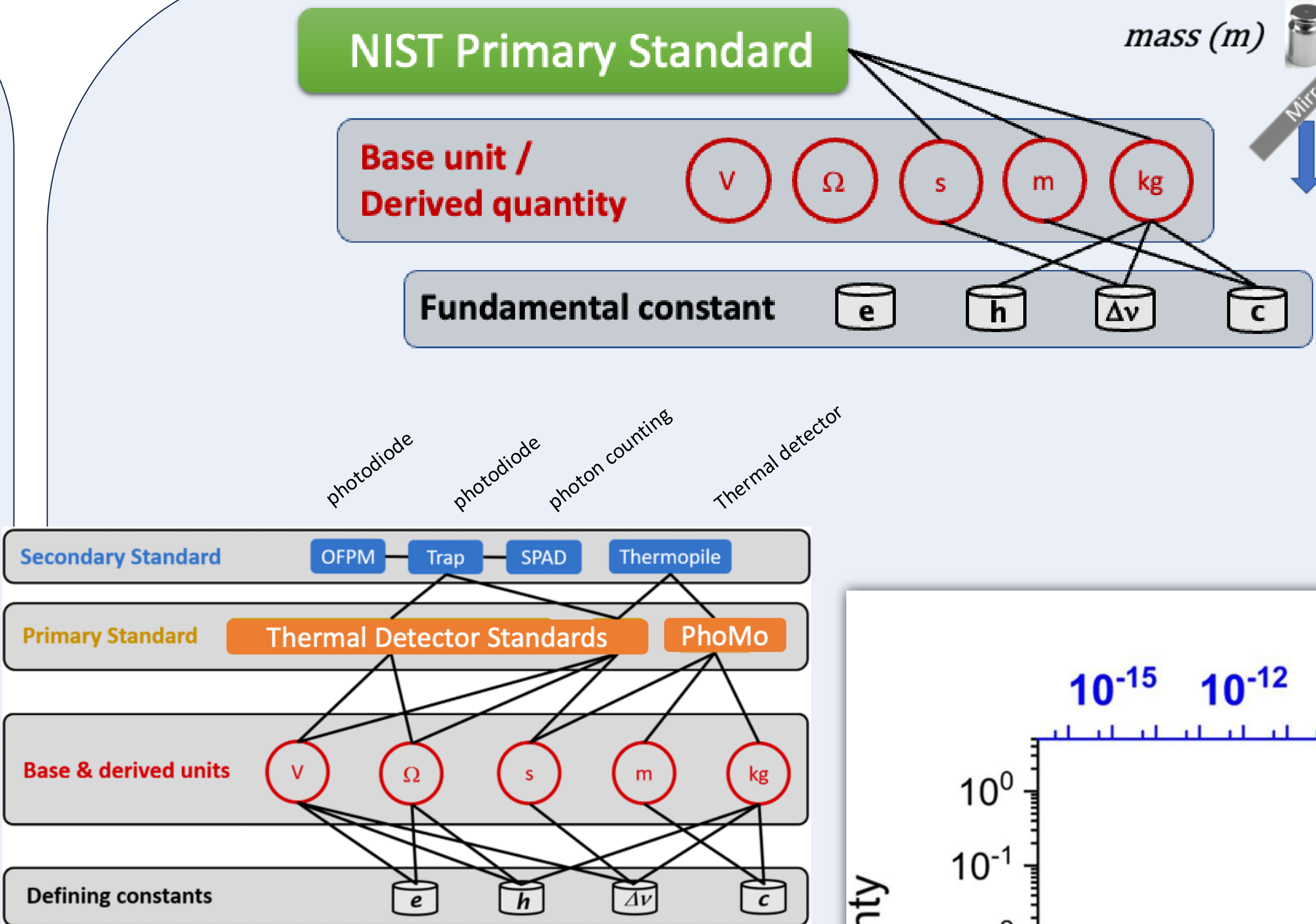
Counting
Light is Quantized

$I = \sigma T^4$

Temperature

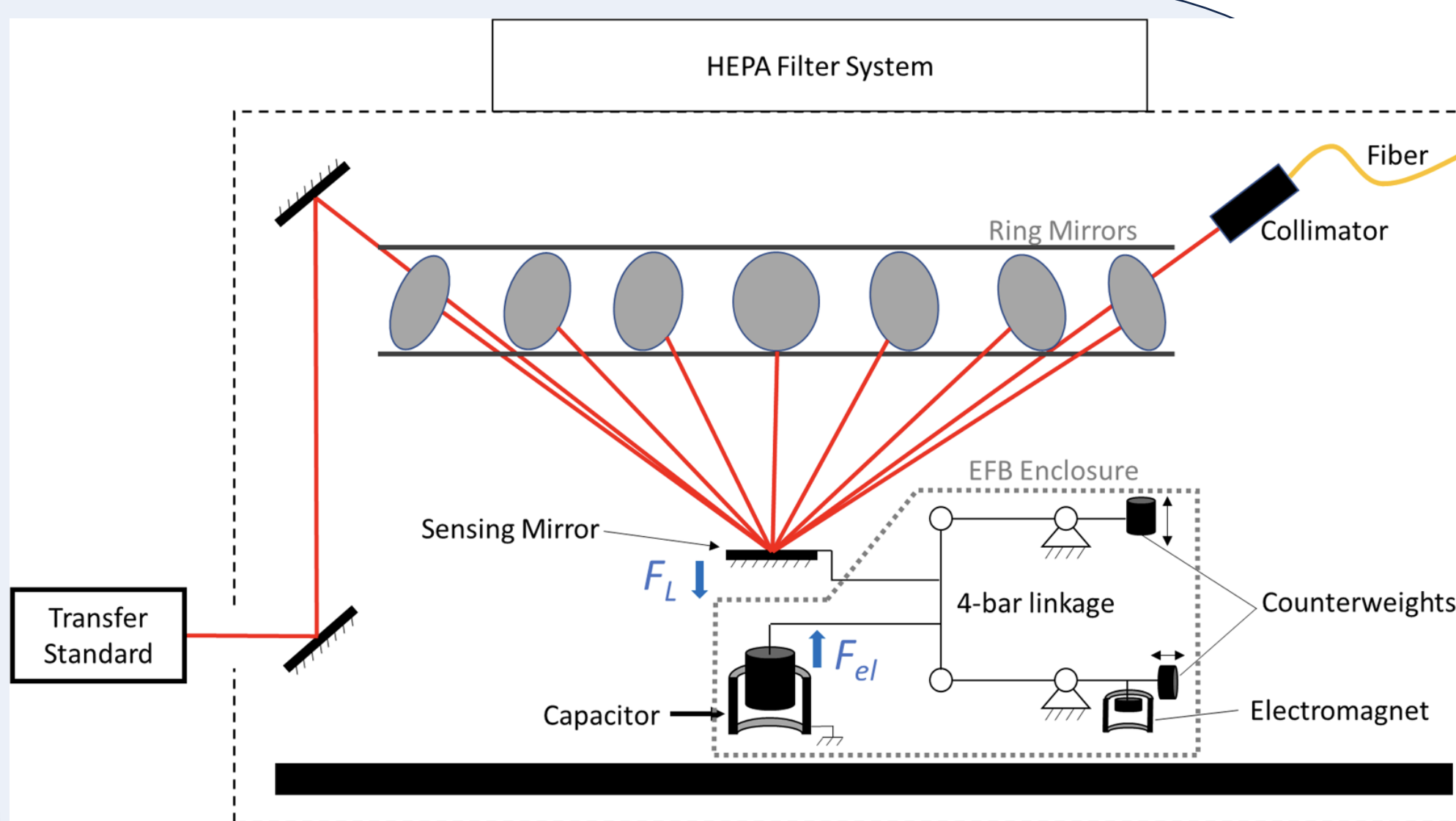
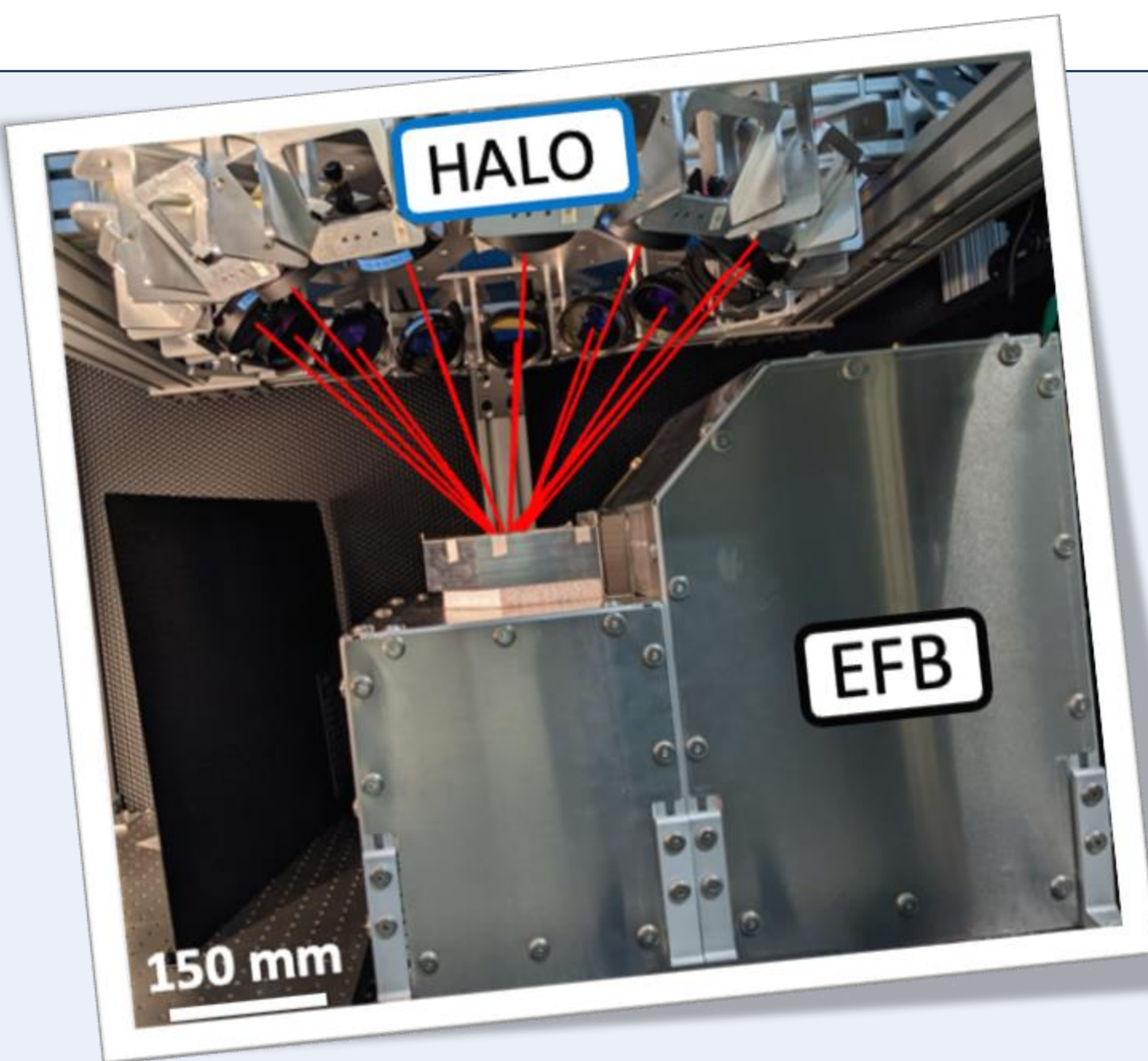
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NIST Primary Standard

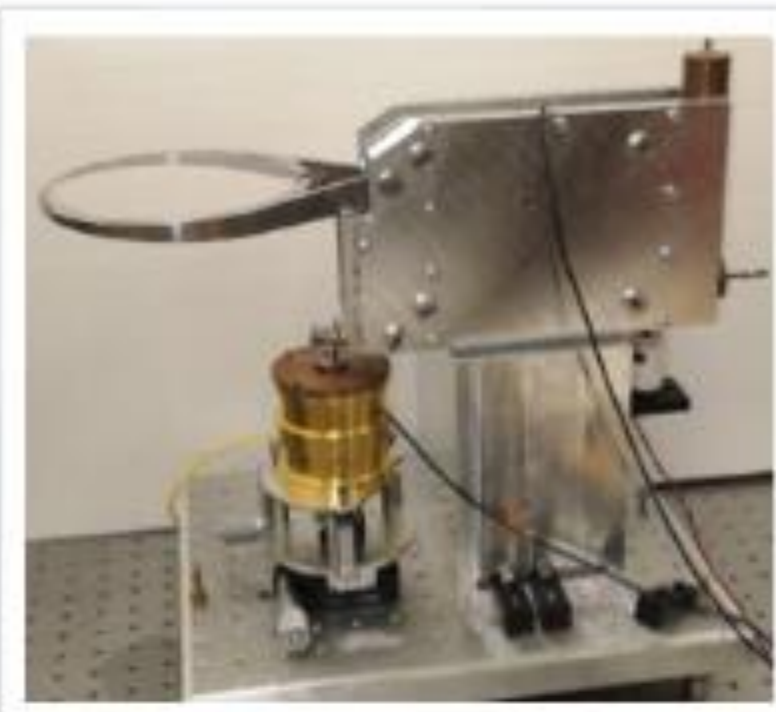


HALO and EFB

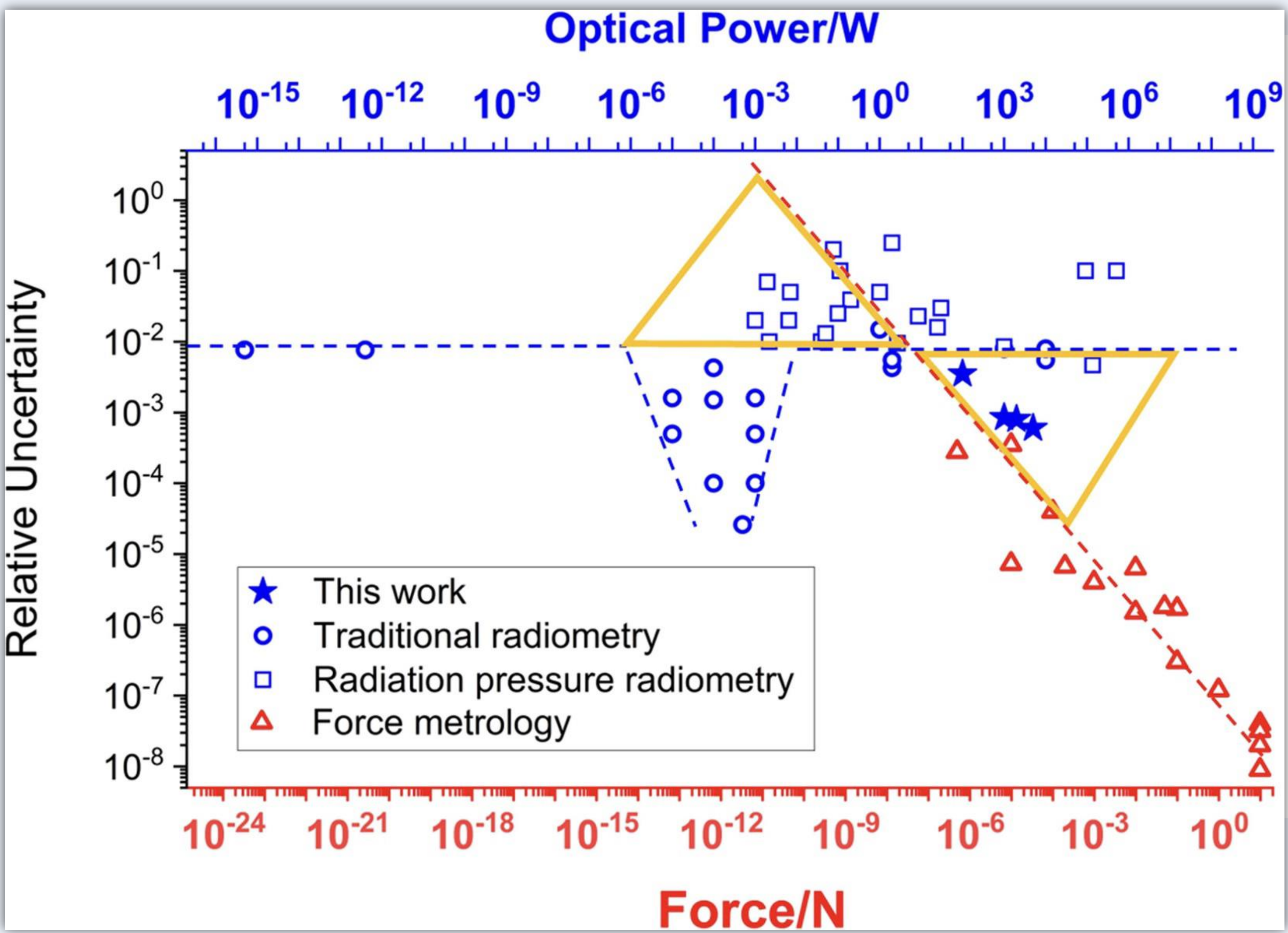
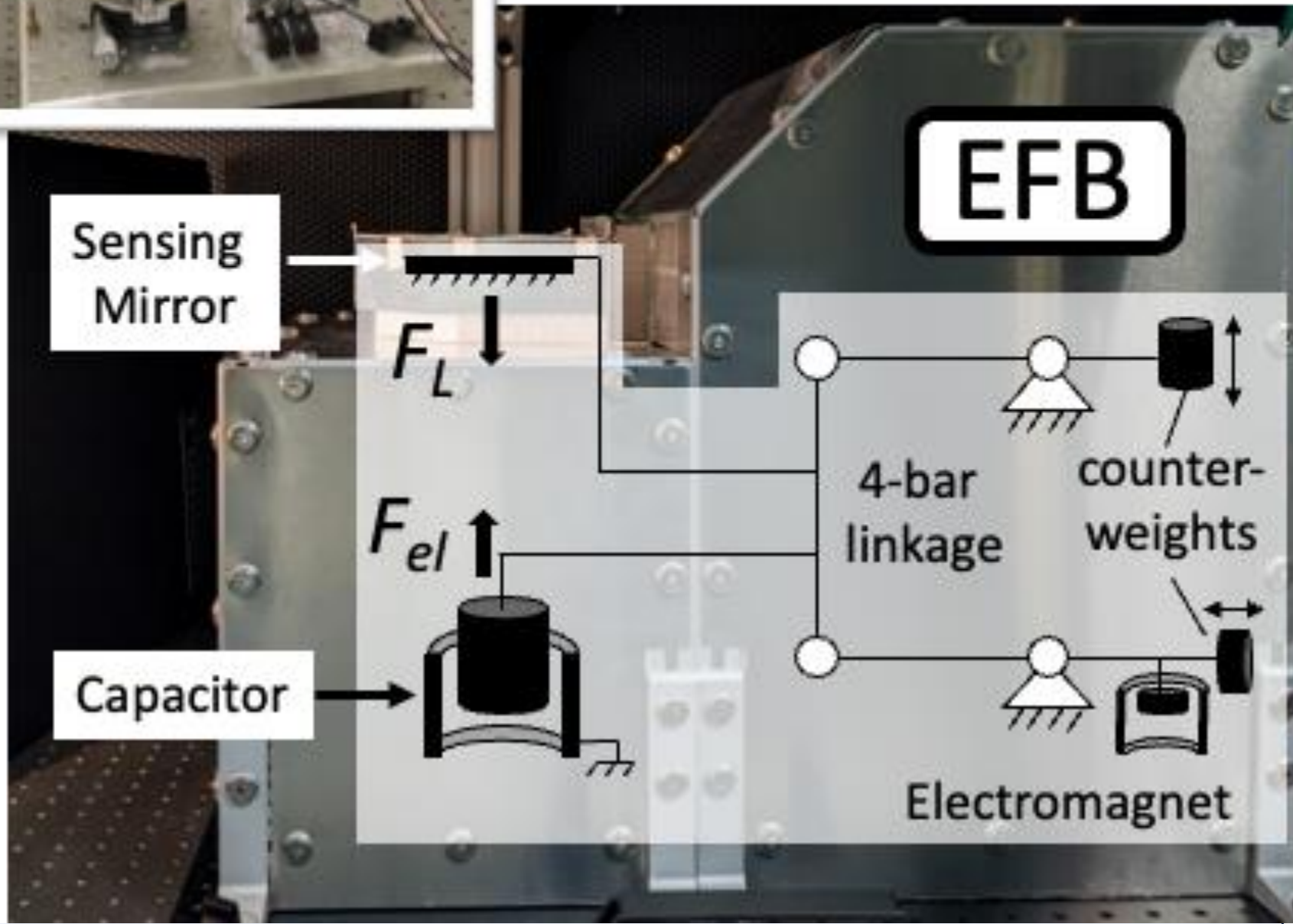
1. Lowest uncertainty multi-kW optical power measurement
2. Lowest uncertainty radiation pressure measurement
3. Validation at 2kW against thermal primary standard



Electronic Force Balance (EFB)



$$F = -\frac{1}{2}V^2 \left(\frac{dC}{dz} \right)$$



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4.V I Sapritsky, et al., "High temperature fixed-point blackbodies based on metal-carbon eutectics for precision measurements in radiometry, photometry and radiation thermometry," AIP Conf. Proc. 684 273-8 (2003).
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