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Measuring Vacuum with Cold Atoms

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26 June 2025

Measuring Vacuum with Cold Atoms

Introduction

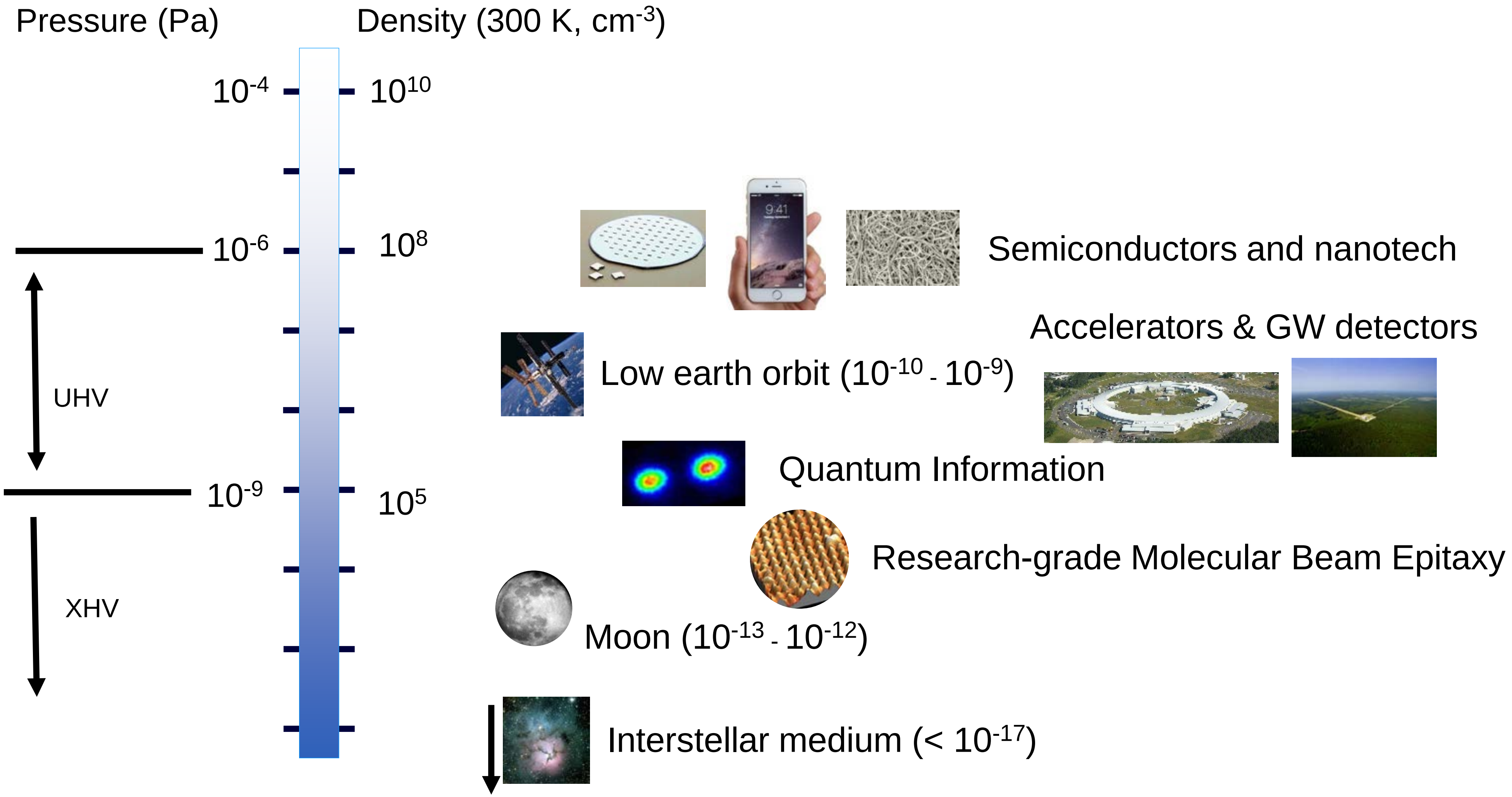
Basis of the technique

Does it work?

How to make it practical to the community

Conclusions/outlook

Introduction - vacuum scale and who cares?



Introduction

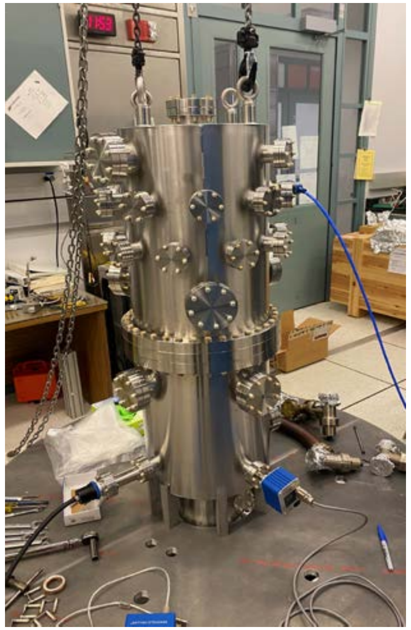
Drawbacks of traditional method: long traceability chain, generally poor accuracy, deepest vacuum not accessible

Primary standard

Sensor, high range

Standard (flow)

Standard (vacuum)



Sensor, low range

Introduction

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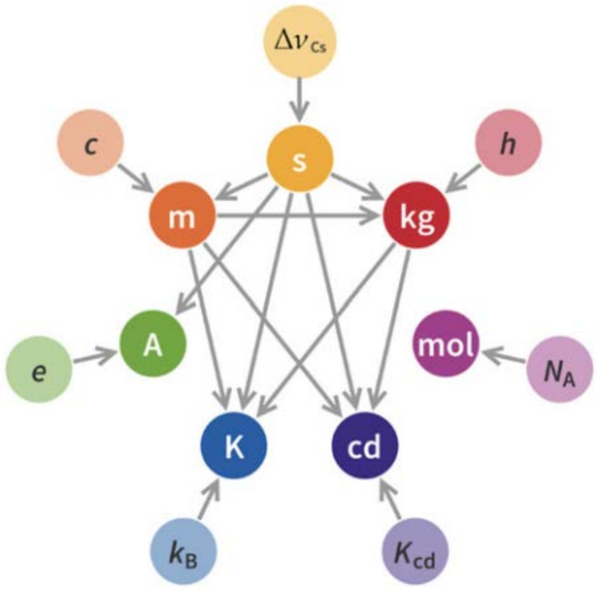
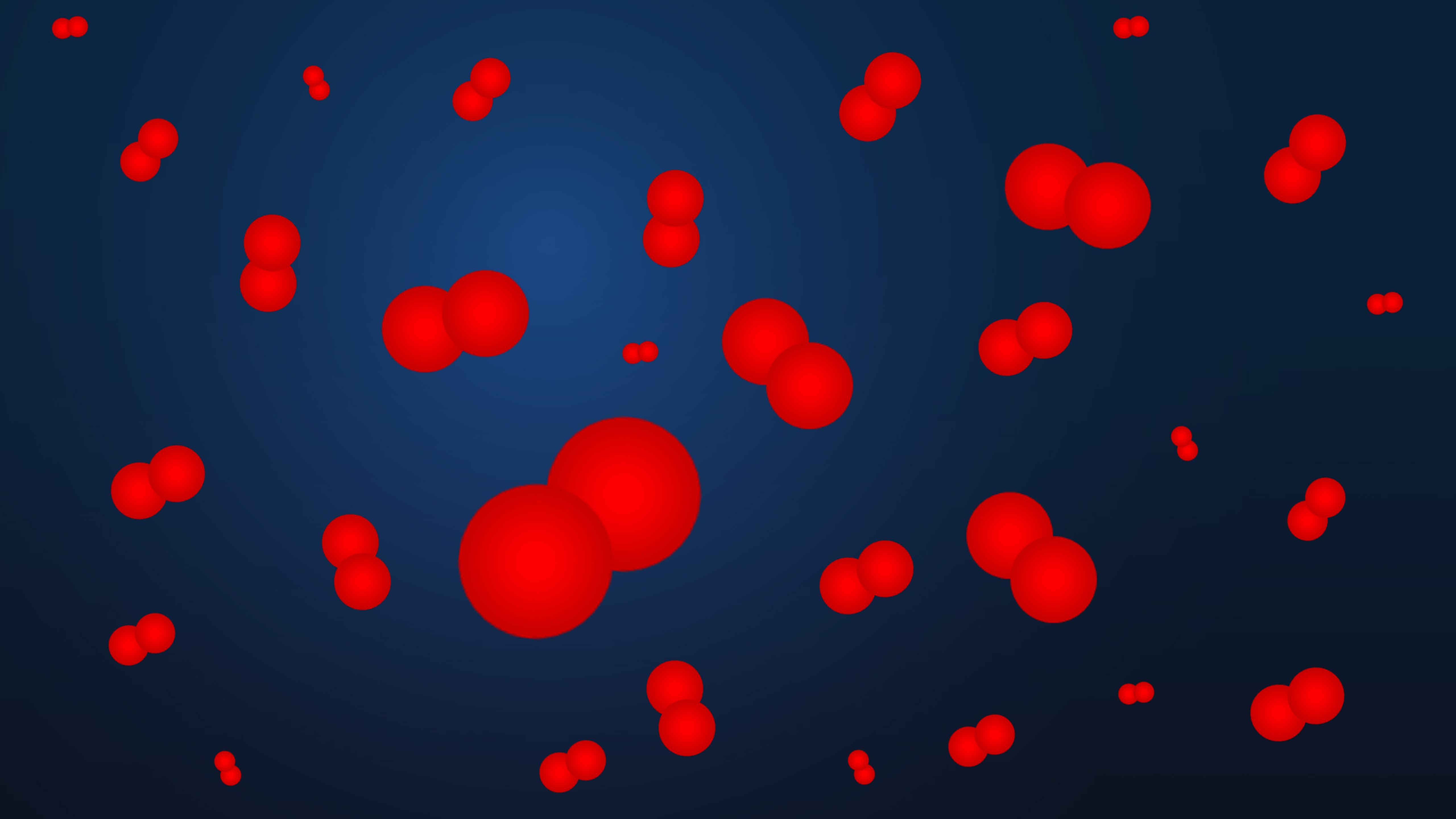
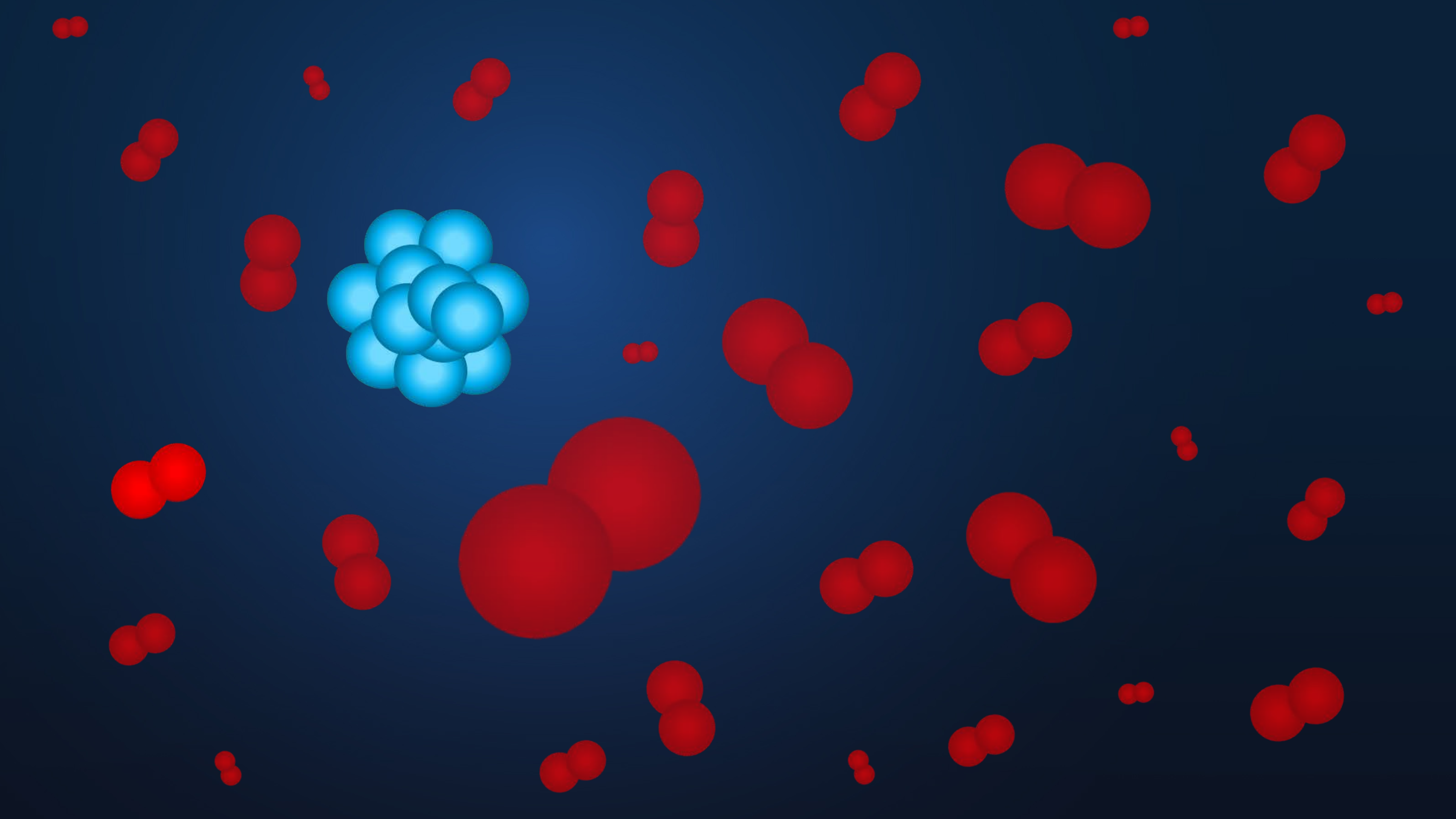
The redefinition of the SI provides an opportunity to develop new ways to realize the pascal

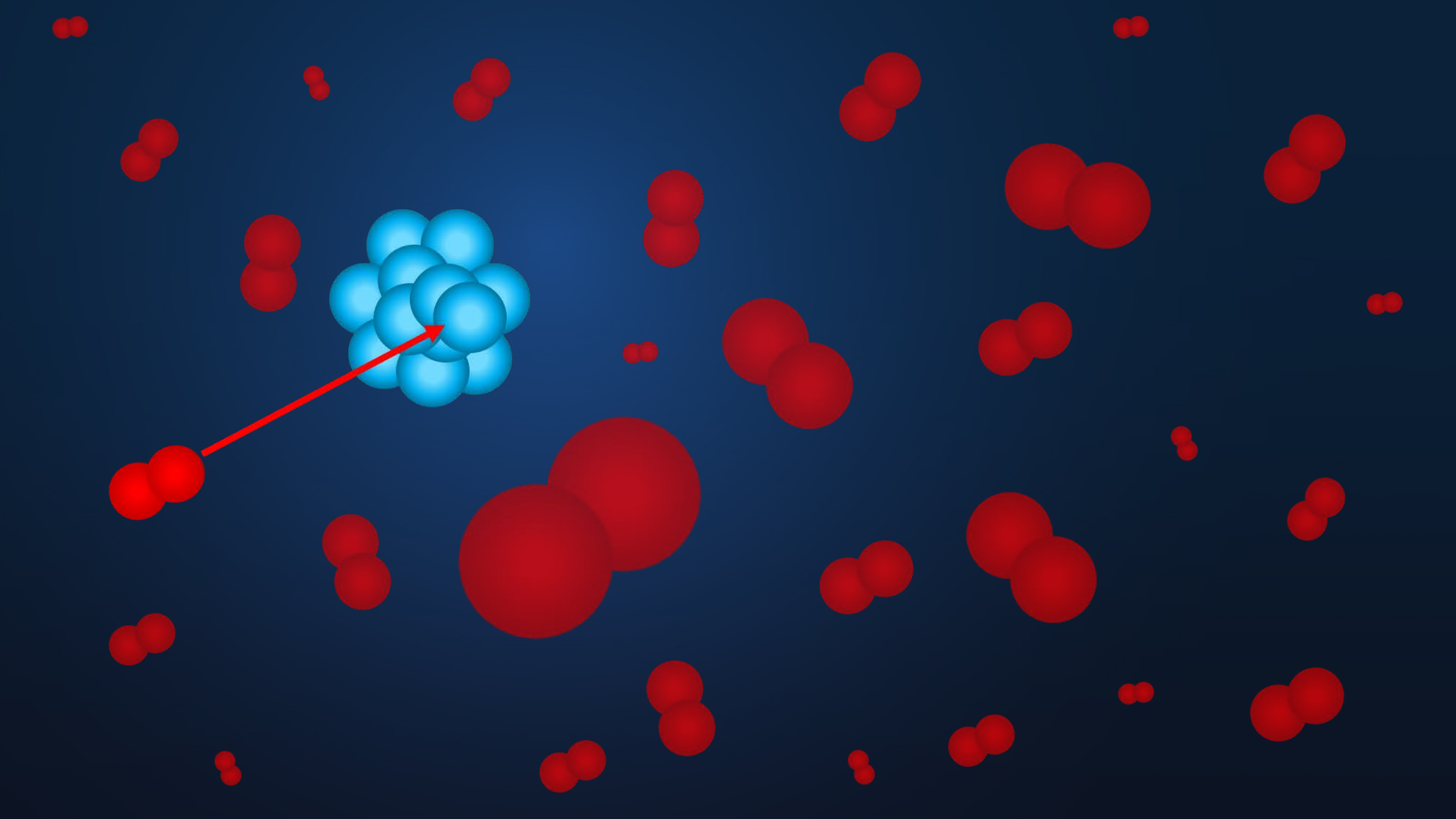


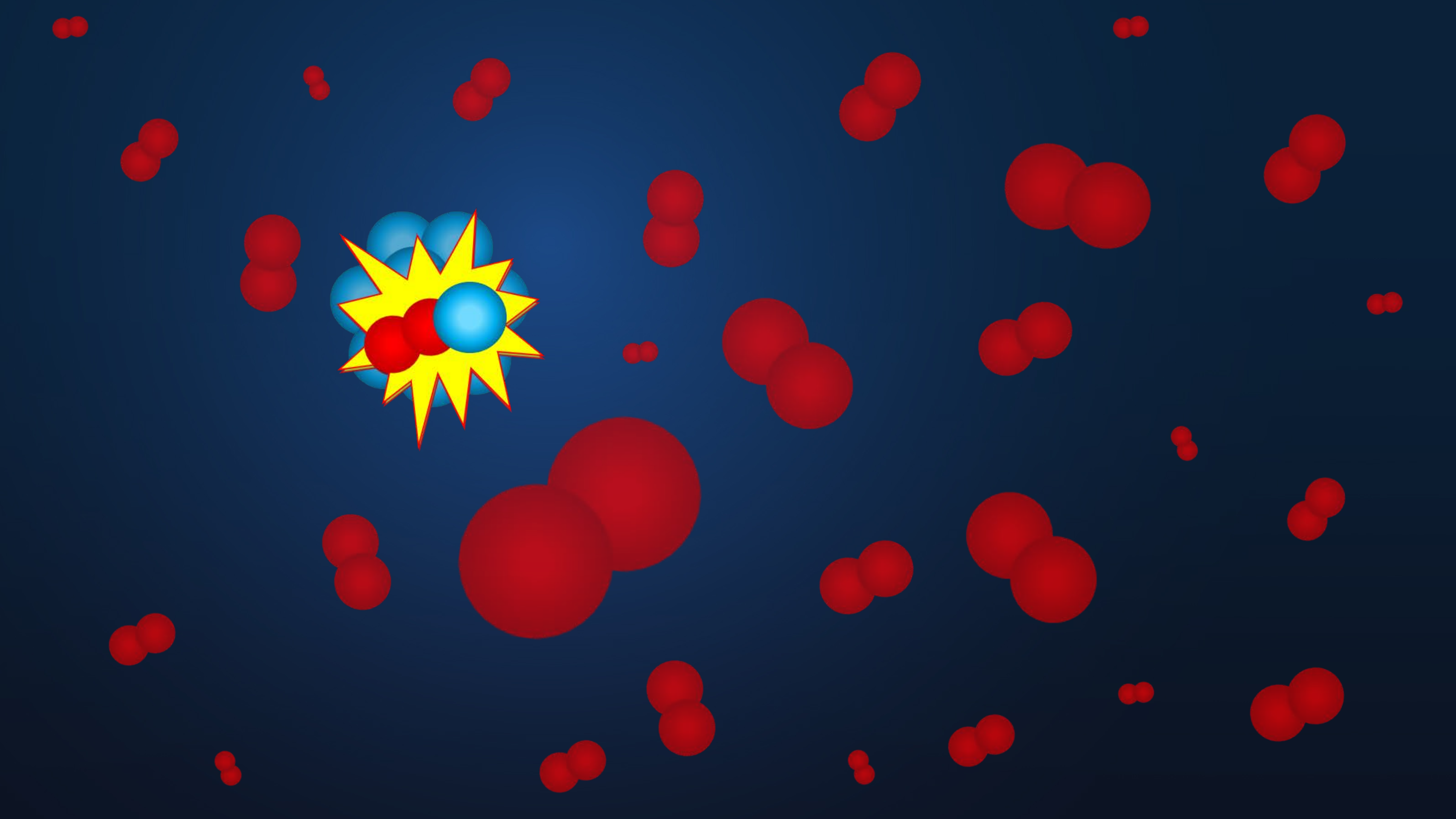
Can we make a better standard that's ALSO a gauge?

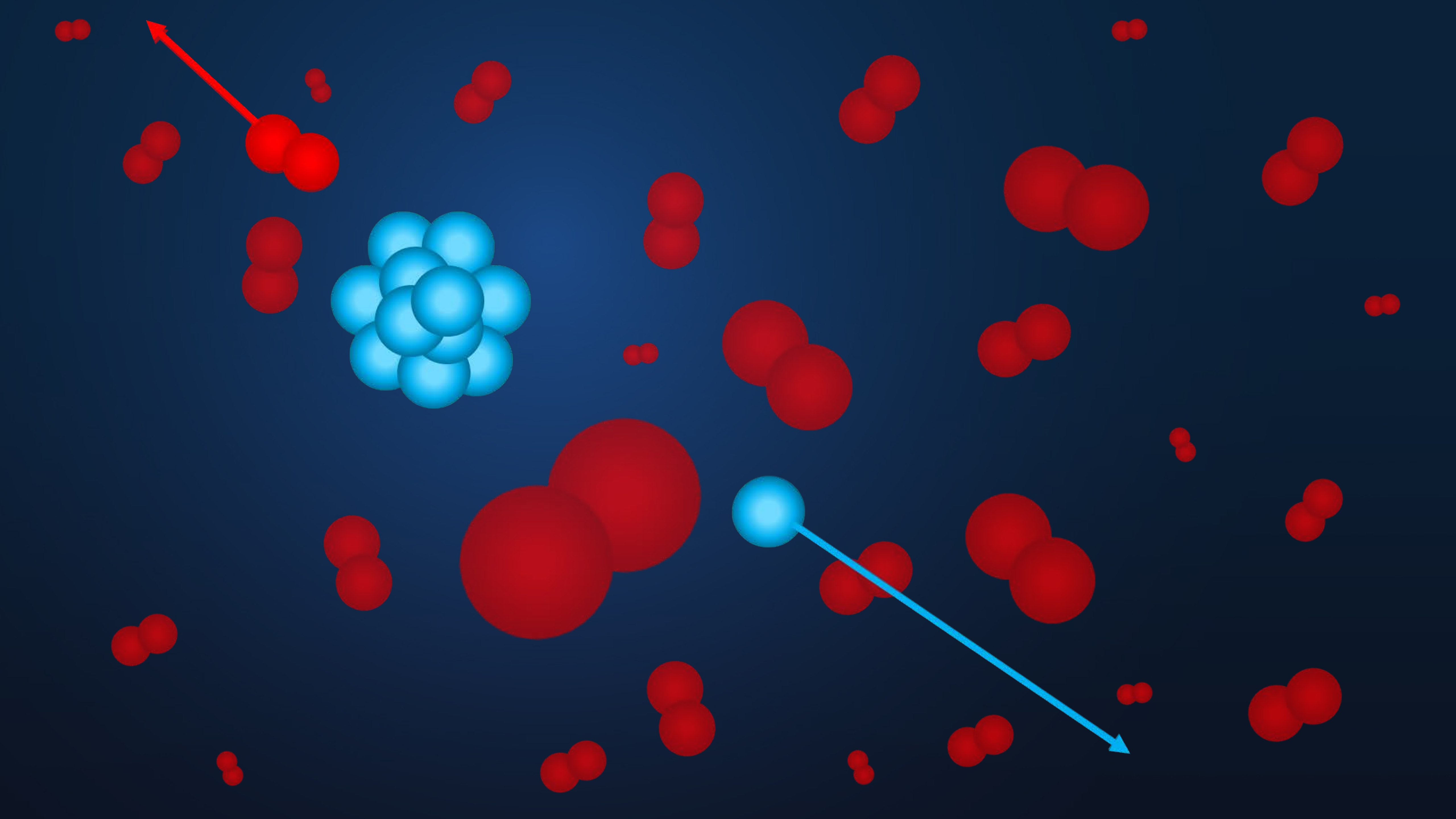
Basis of the technique

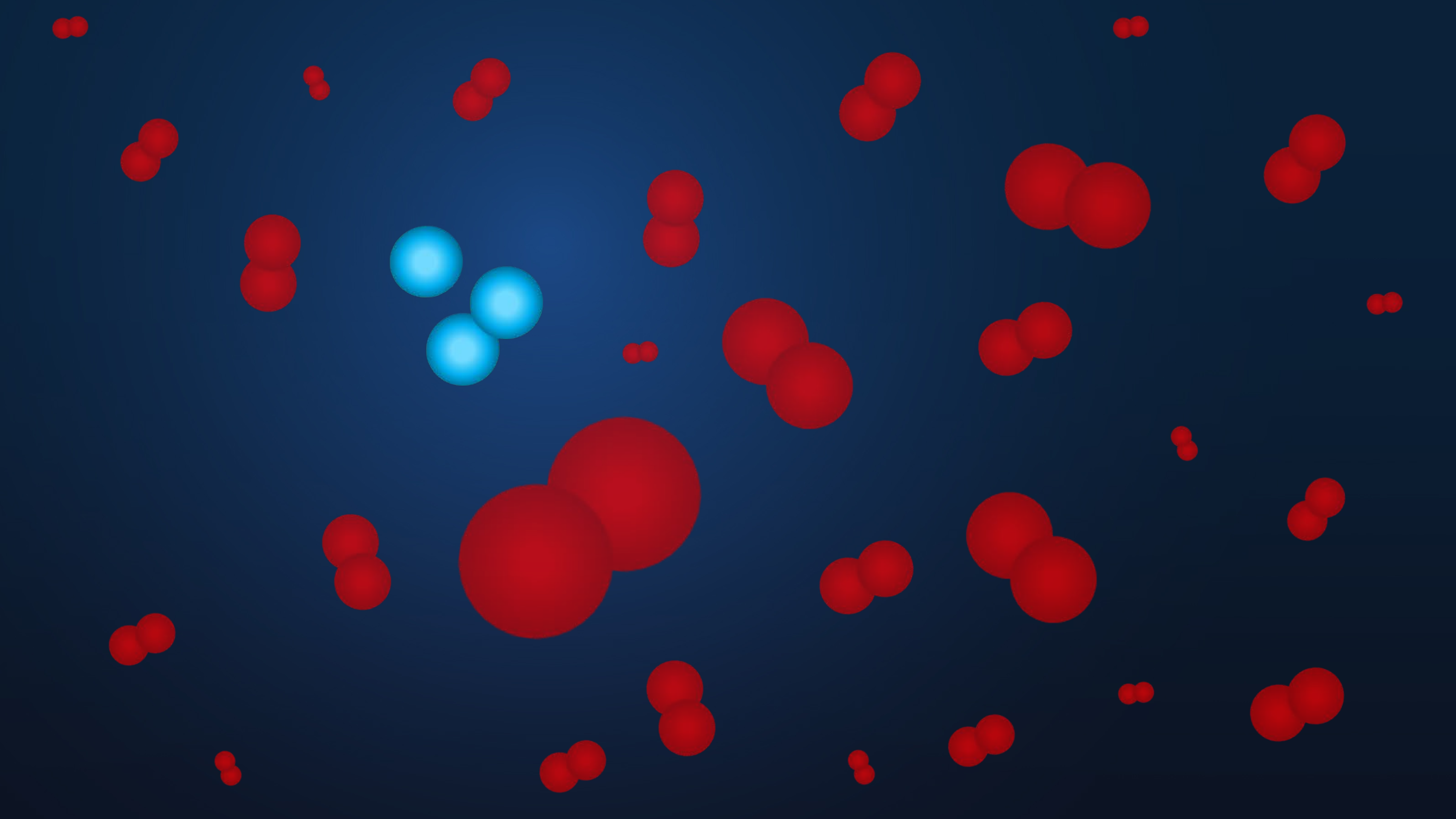






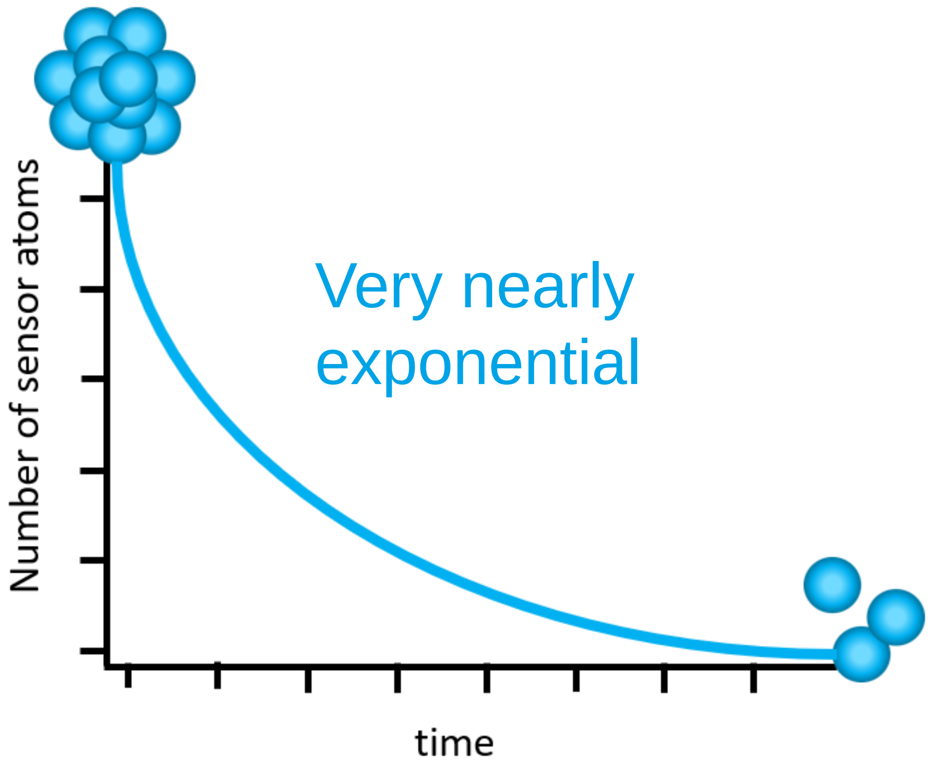






This is the Cold Atom Vacuum Standard, or CAVS

Basis of the technique



Counting collisions

How collisional loss rate gives us pressure

$$\frac{dN_s}{dt} = -\Gamma N_S + O(N_S^2) \rightarrow N_s(t) \approx N_0 e^{-\Gamma t}$$

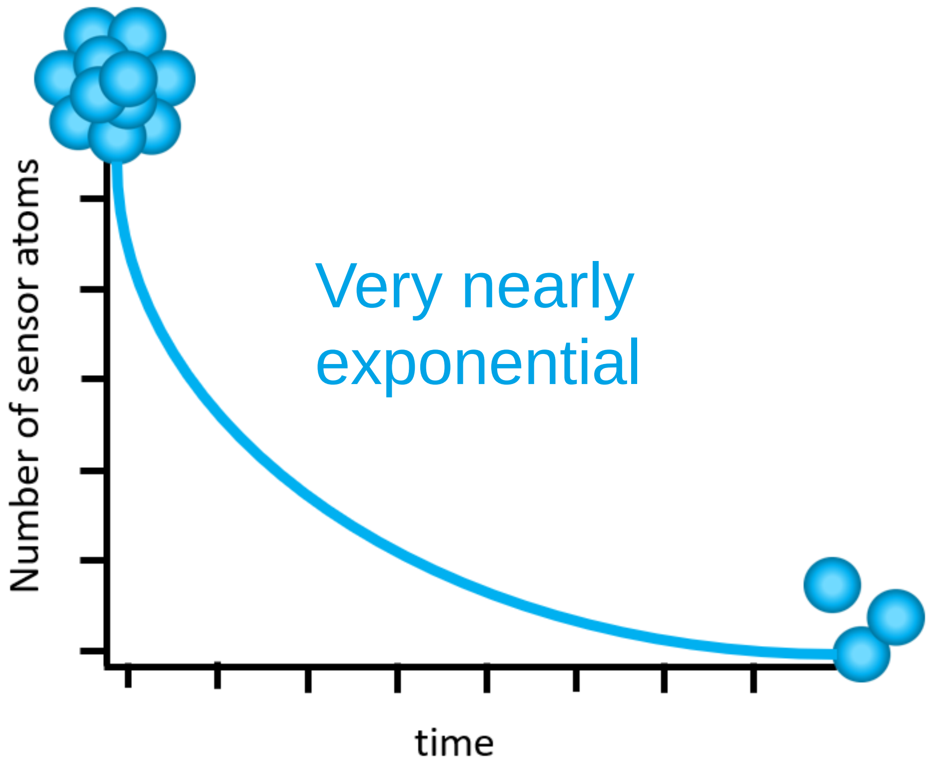
$$\Gamma = nK_{loss}$$

$$K_{loss} = <\sigma v>$$

$$p = n k_B T$$

$$p = nkBT = {}^{\Gamma}/_{K_{loss}}\, k_B T$$

Basis of the technique



Counting collisions

<u>Contributions to Uncertainty</u>

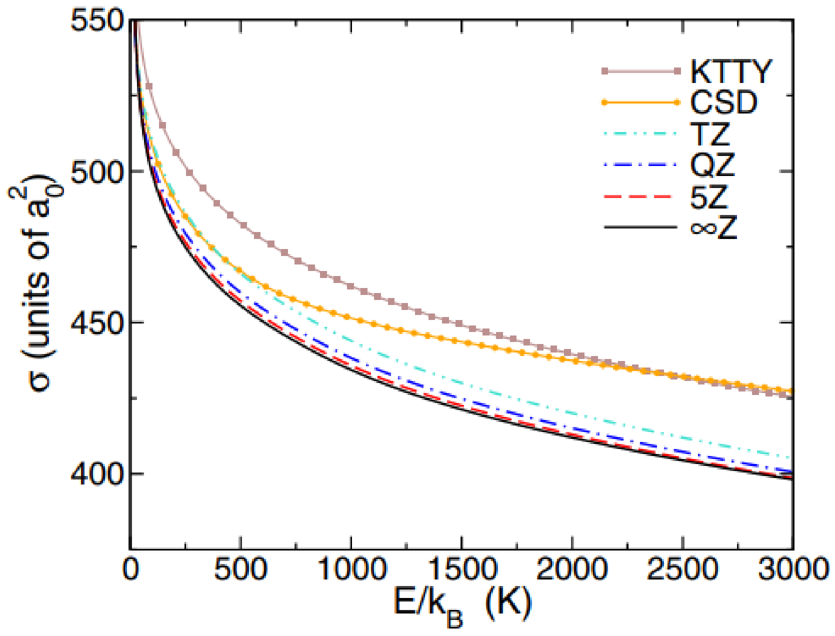
1. Glancing collision angle
2. Trap too shallow/deep
3. Multiple collisions
4. Non-adiabatic Spin Flips
5. Two- and three-body loss
6. Accuracy of imaging

Basis of the technique - theory

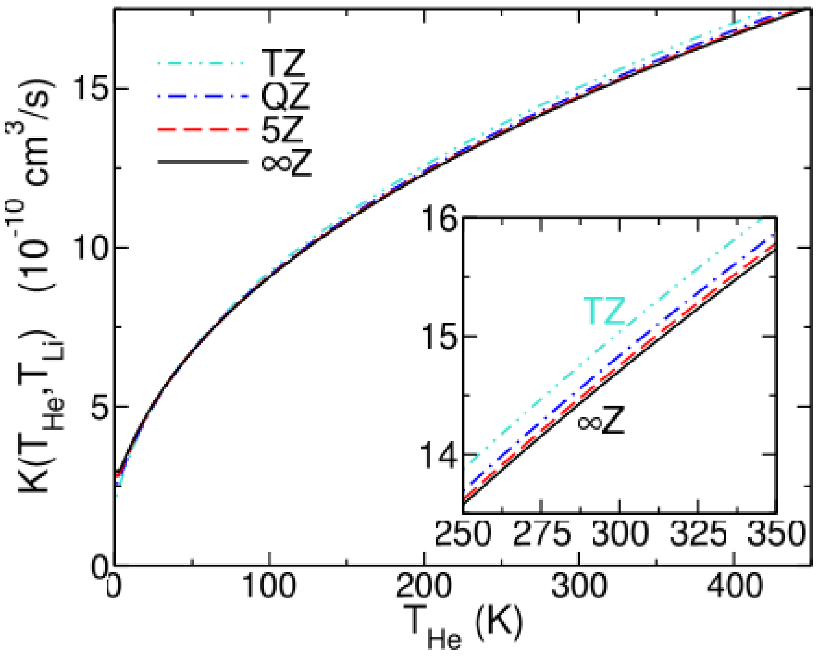
$$K = \langle v\sigma \rangle$$

Or, more precisely according to our theorist colleagues,

Cross sections are determined from numerical scattering state solutions of the single-channel Schrödinger equation.

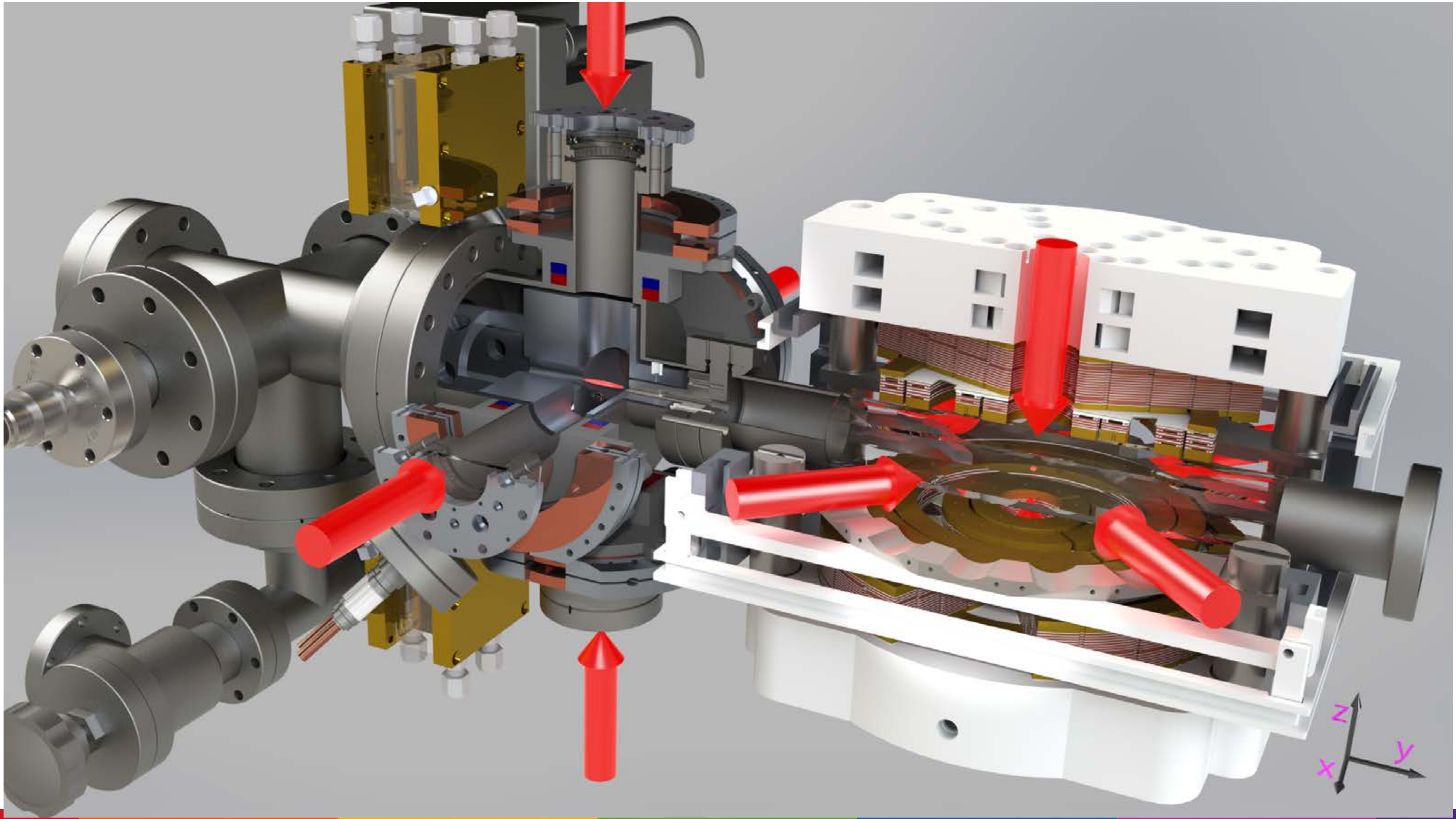


Then rate coefficients are found by integrating over Maxwell-Boltzmann distributions. (KTTY, CSD, TZ, etc are different potentials, T_{Li} = 1



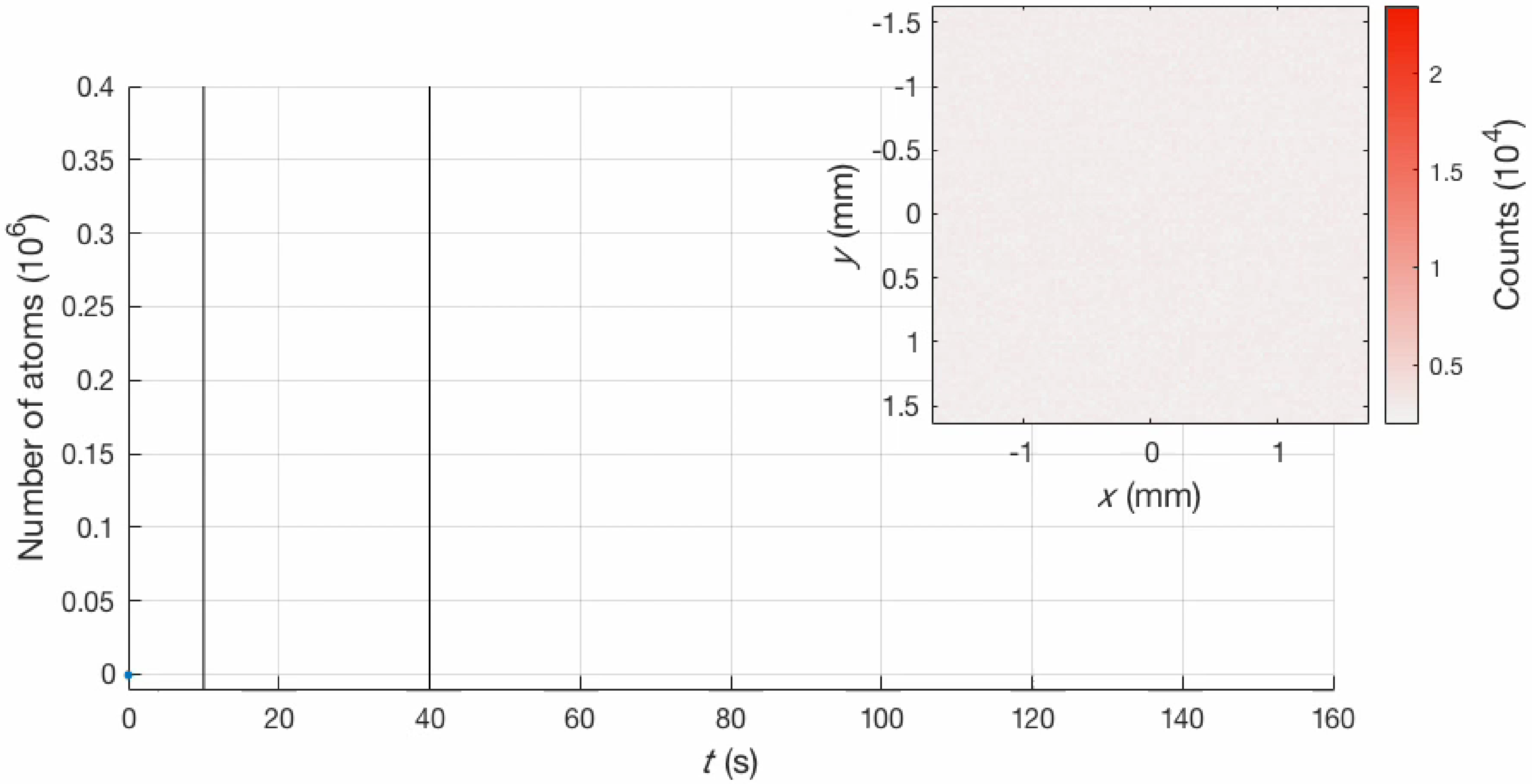
Markides et. al., Phys Rev A **101**, 012702 https://doi.org/10.1103/PhysRevA.101.012702

Basis of the technique – the atom apparatus

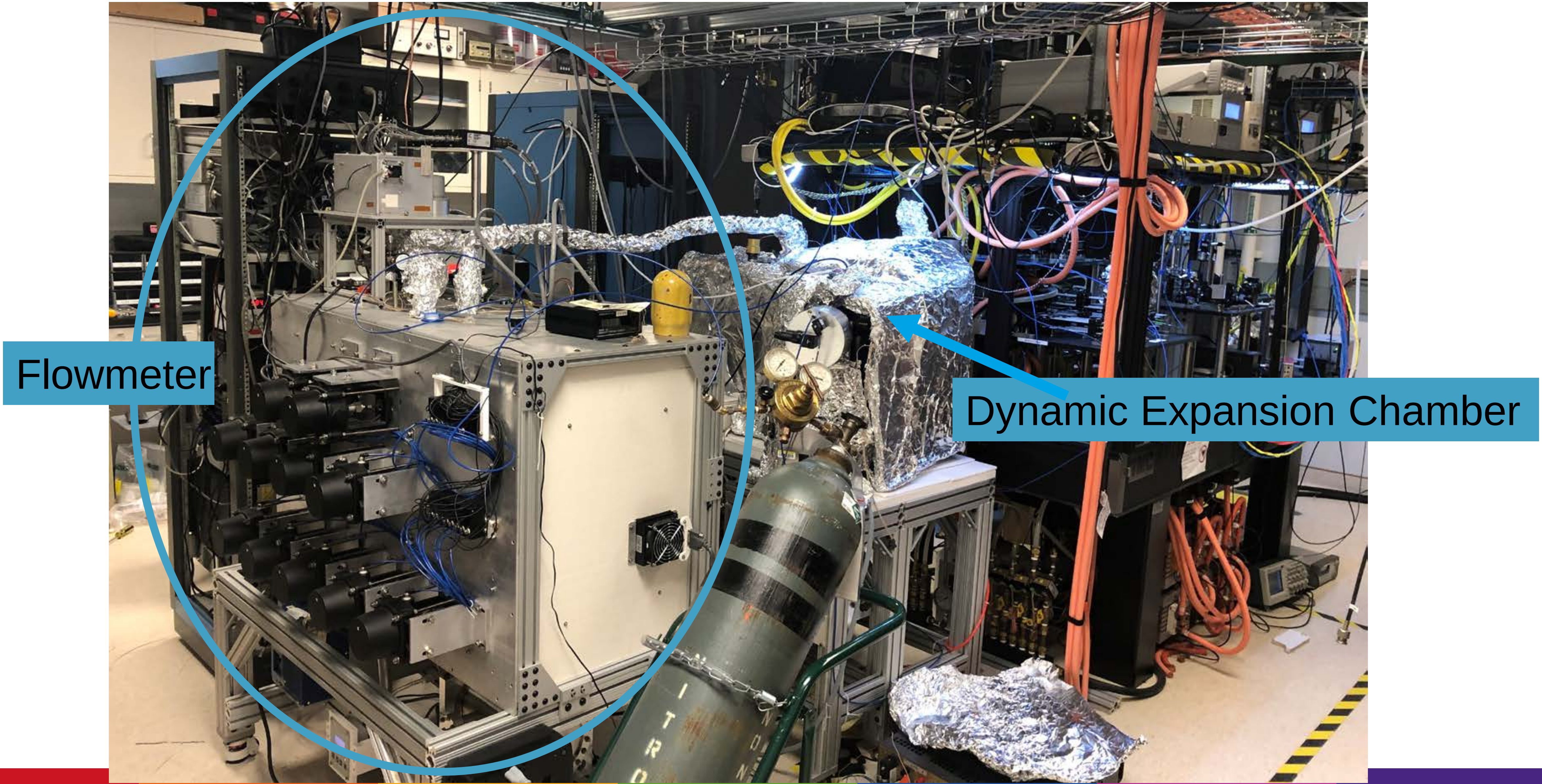


Basis of the technique – the atom apparatus

Basis of the technique



Basis of the technique – the vacuum apparatus



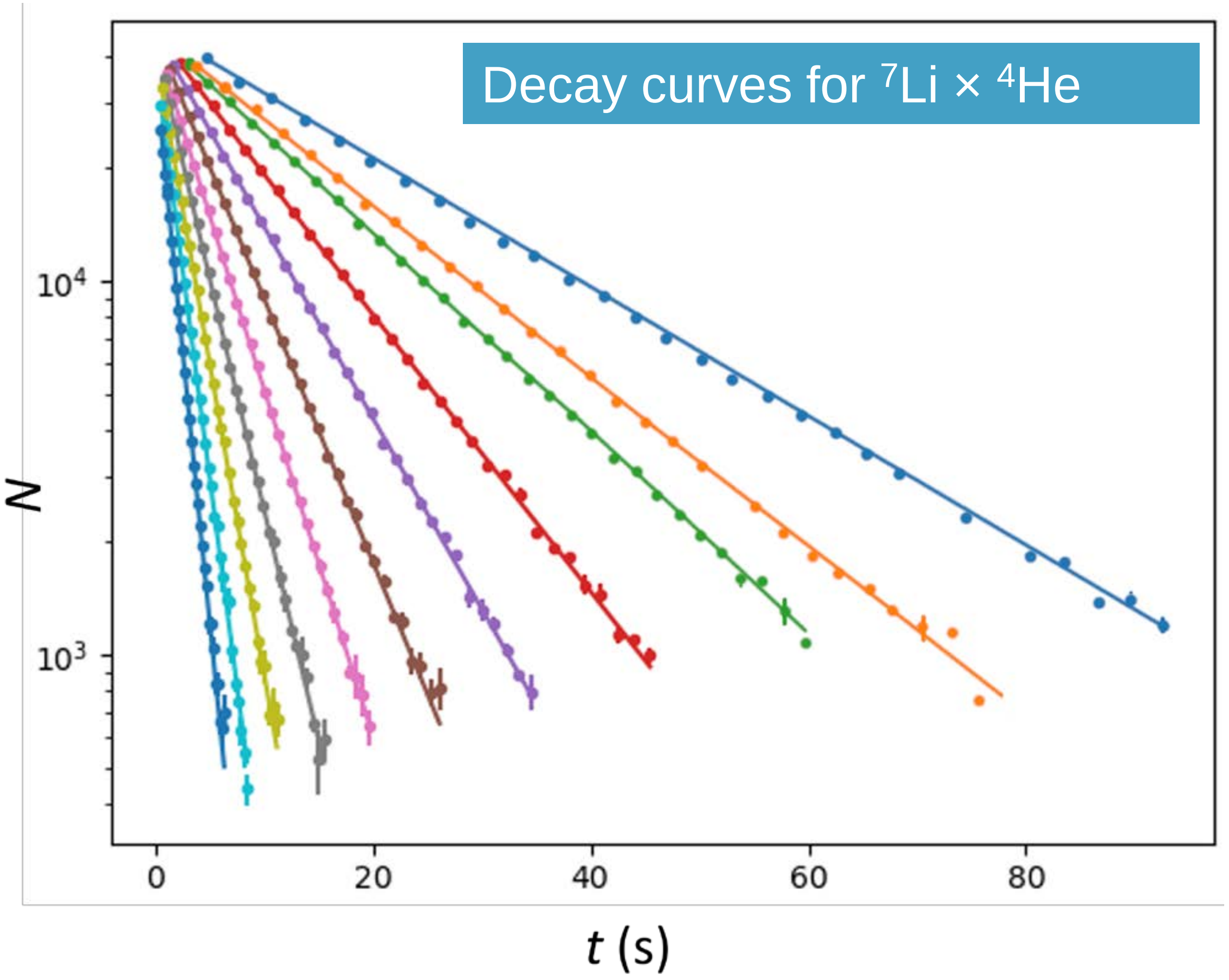
Does it work?

Theoretically predicted values for He × Li:

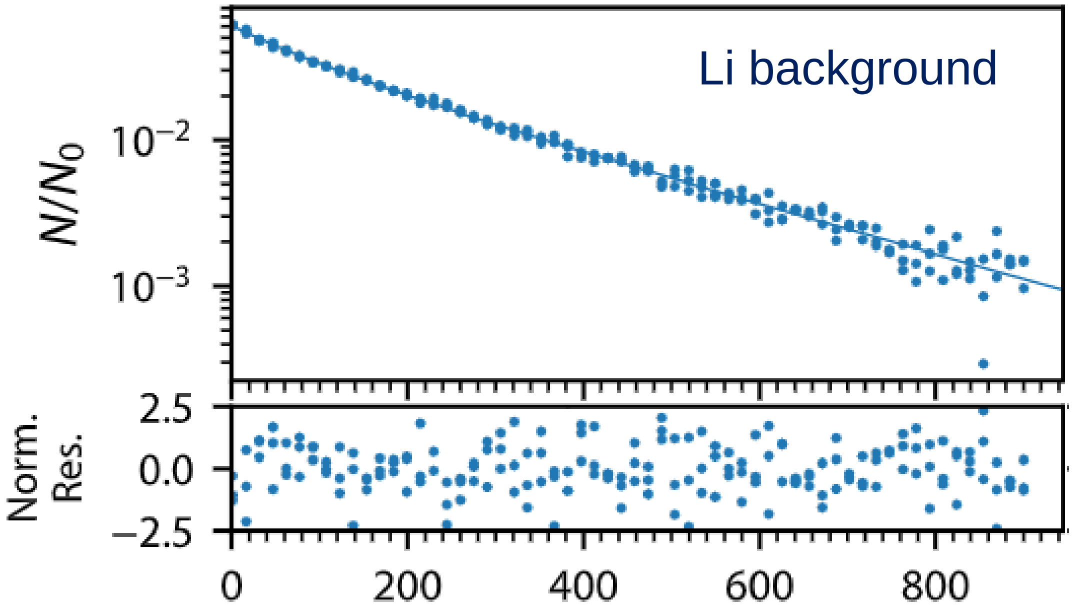
species	K_{loss} (cm^3/s)
^{4}He and ^{6}Li	$1.655(15) \times 10^{-9}$
^{4}He and ^{7}Li	$1.659(15) \times 10^{-9}$

Markides et. al., Phys Rev A **105**, 029902(E) https://doi.org/10.1103/PhysRevA.105.029902

Does it work?



$$\dot{n} = -\left(K_{gas} + \Gamma_0\right)n + K_2 n^2 + K_3 n^3$$



Does it work?

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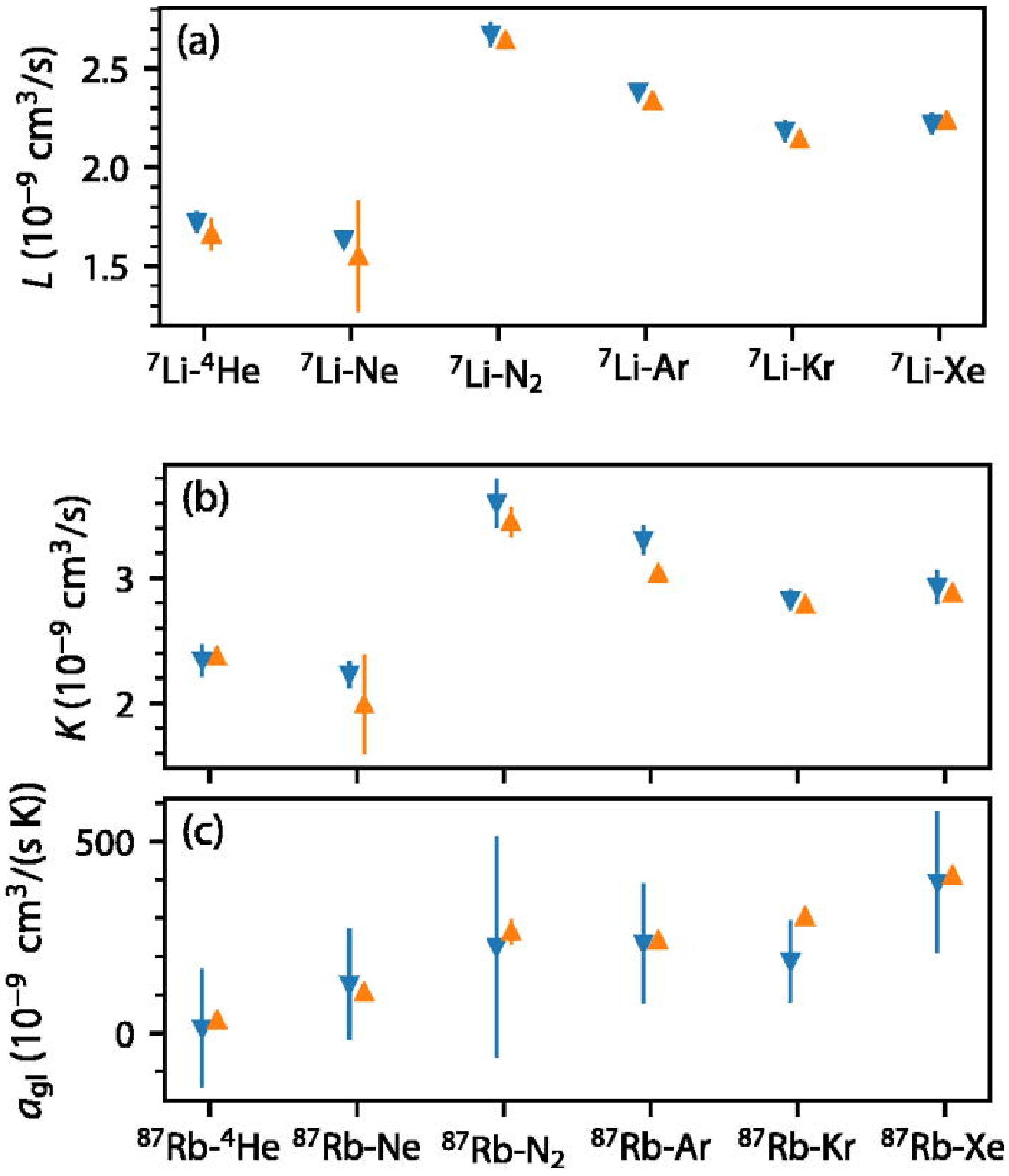
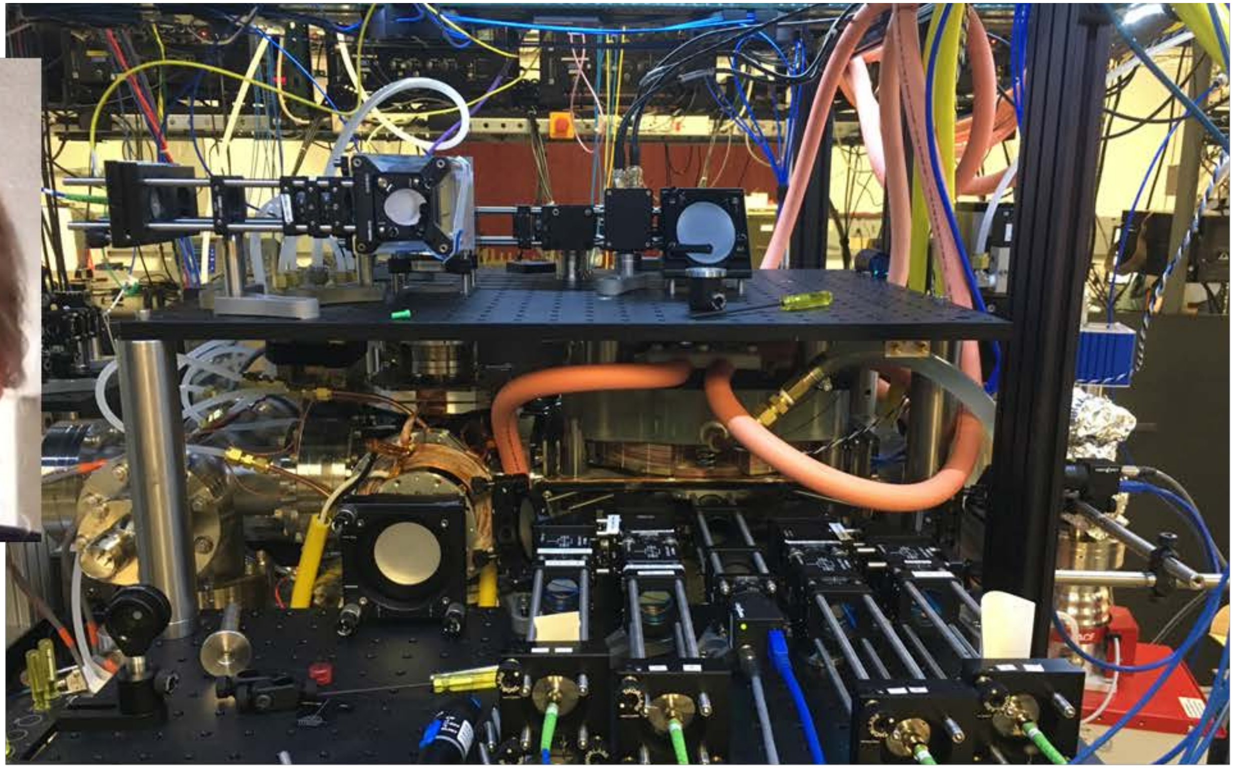
Setting a known pressure using traditional methods allows a test of the method in which

Experimental (blue downward triangles) & **Theoretical** (orange upward triangles)

values of the rate coefficient of various collisions are be compared.



How to make it practical



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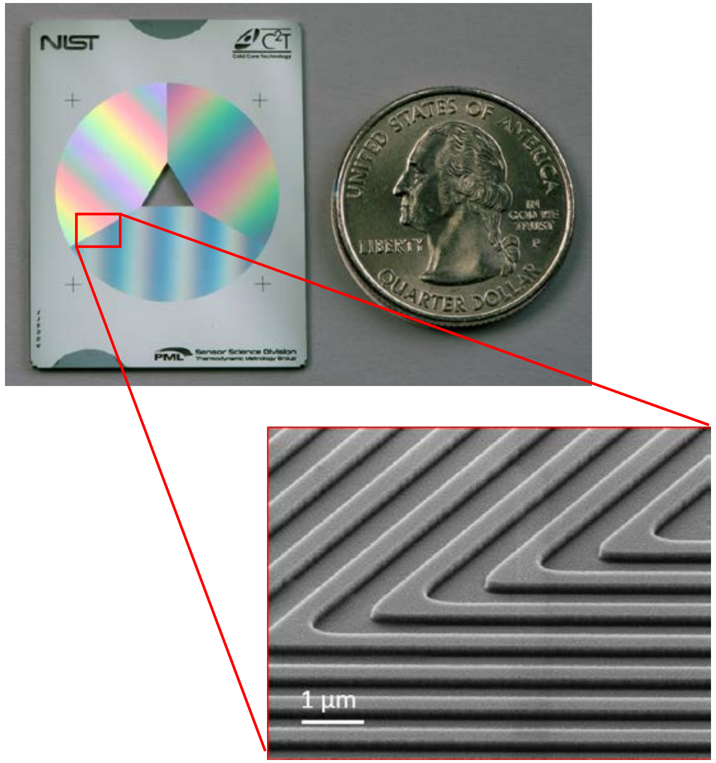

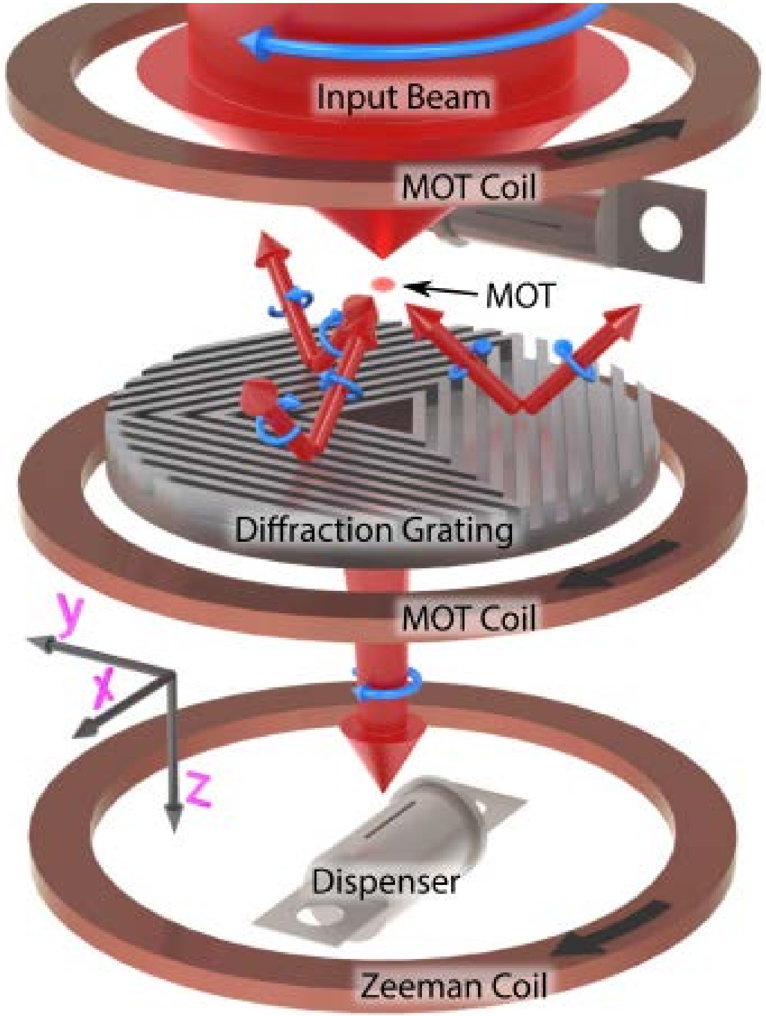

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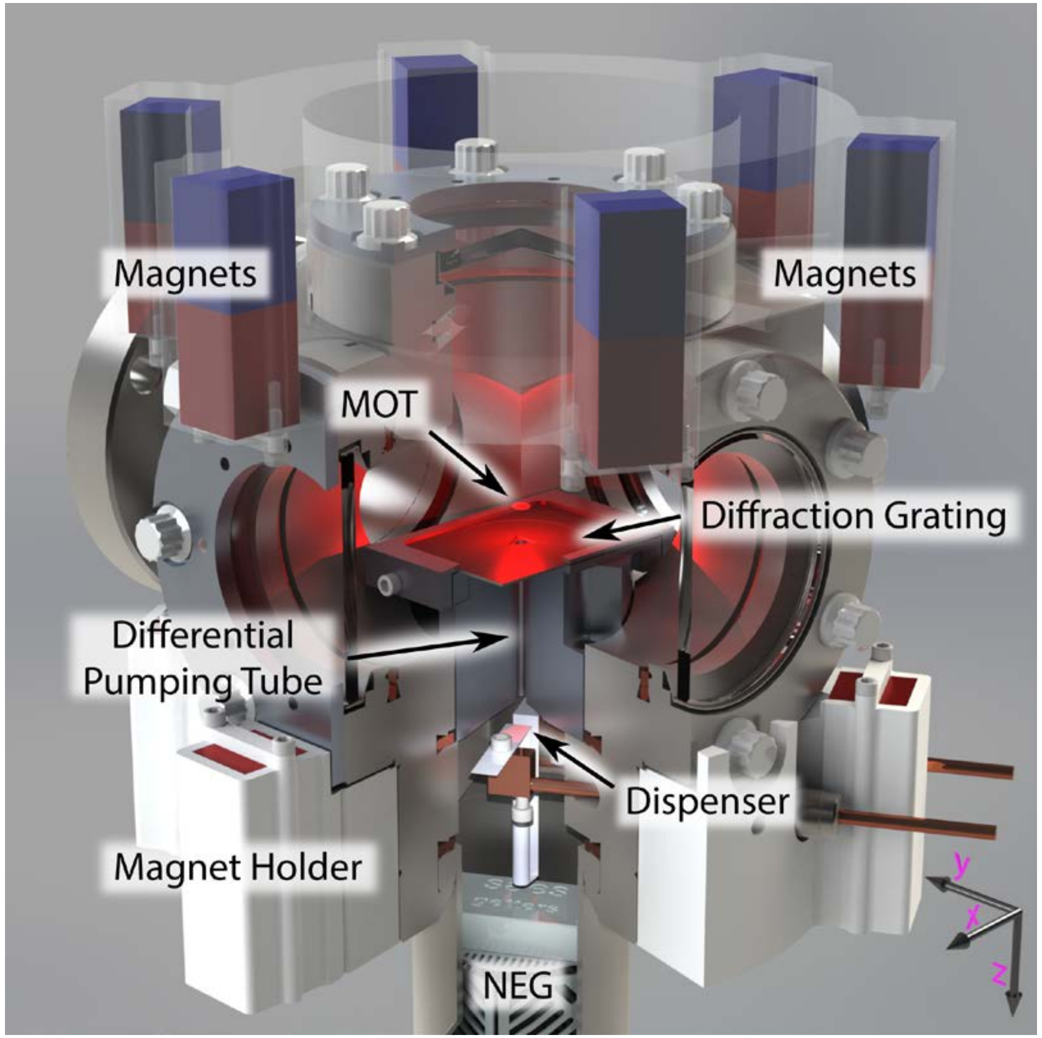

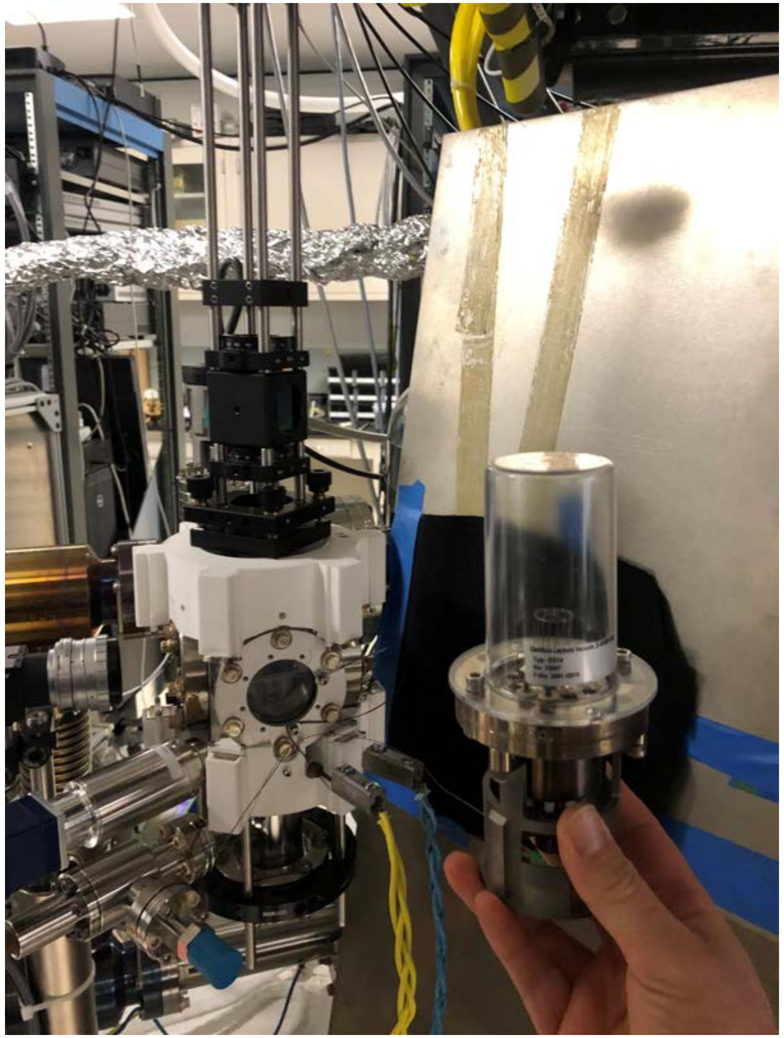

How to make it practical

Uncertainty budget (k = 1) for the pCAVS compact device in the range 10^{-6} Pa to 10^{-9} Pa

Contribution/source	Pressure independent	Pressure dependent
Rate coefficient, K_{H_2}		$0.019p$
Temperature, T		$0.005p$
Glancing fraction, f_{gl}		$1.7 \times 10^{-3}p$
Majorana losses, Γ_{other}	0.33 nPa	
Statistical, Γ	0.39 nPa	
Total variance	$(0.51\ \text{nPa})^2 + (0.020p)^2$	

Conclusions/Outlook

It works to about 1%, it's practical, but it's expensive. Market will be limited.

Outlook depends on laser technology, if the lasers get less expensive then this may become a viable product.

Next steps are to verify hydrogen cross-sections, and perform comparisons.

Thank you.

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