TECHNISCHE UNIVERSITÄT WIEN

VCQ

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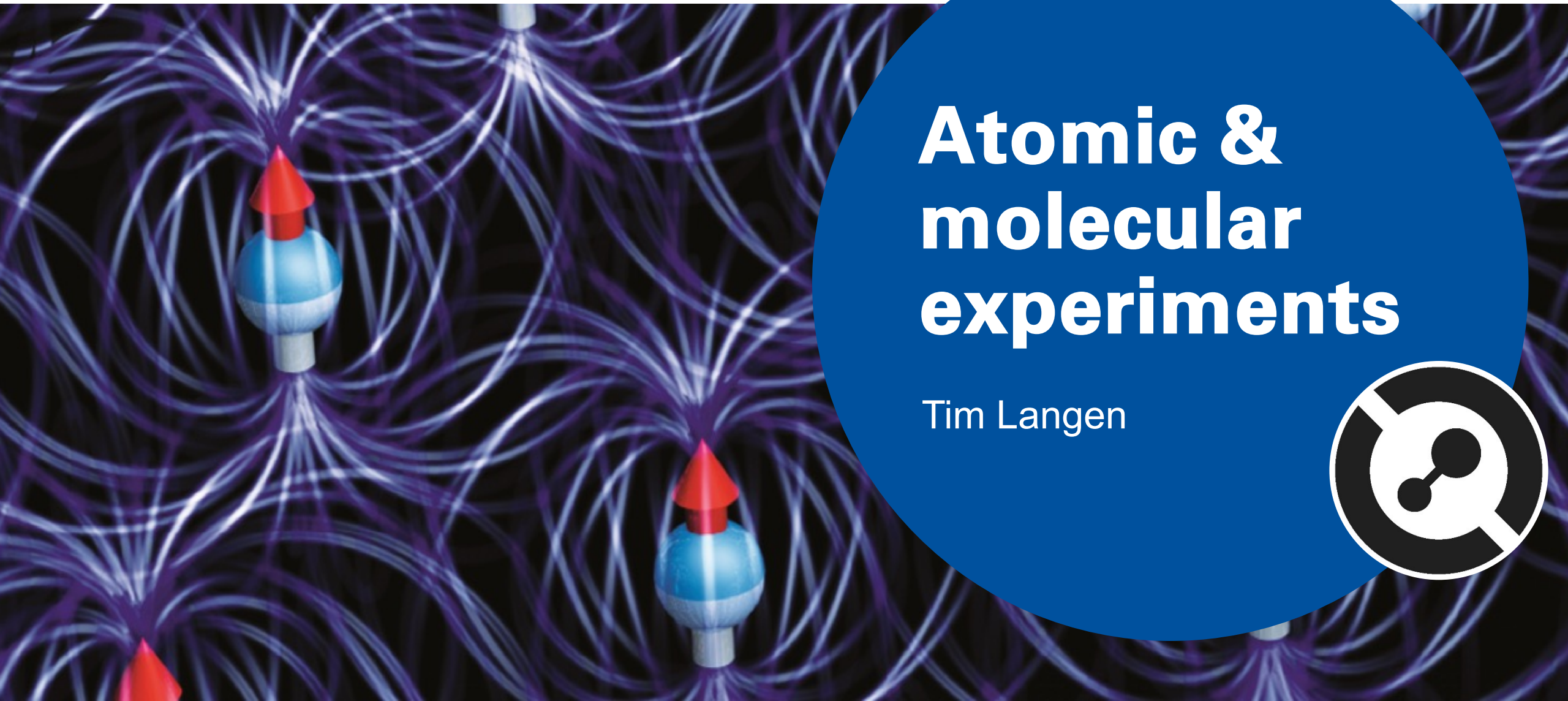


Atomic & molecular experiments

Tim Langen

Motivation

There are some problems with the Standard Model

(Baryon asymmetry, strong CP problem, dark matter/energy, quantum gravity, …)

There is no consensus at which energy or length scales new physics will appear!

So, let's look anywhere we can!

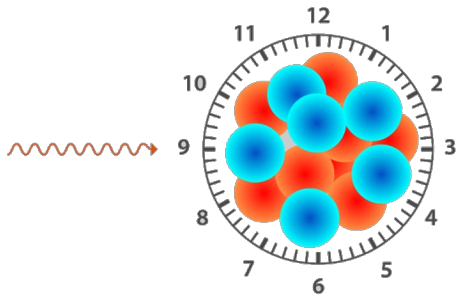
Colliders, Neutrinos, Dark Matter Searches, Gravitational Waves …

… but also: AMO Systems (Atoms, Molecules)!

AMO physics is quantum physics

Strong expertise quantum science and quantum "tools" in Austria

An emerging focus at the **Atominstitut Wien**:
Nuclear, particle and high-energy physics using low energy *quantum* tools

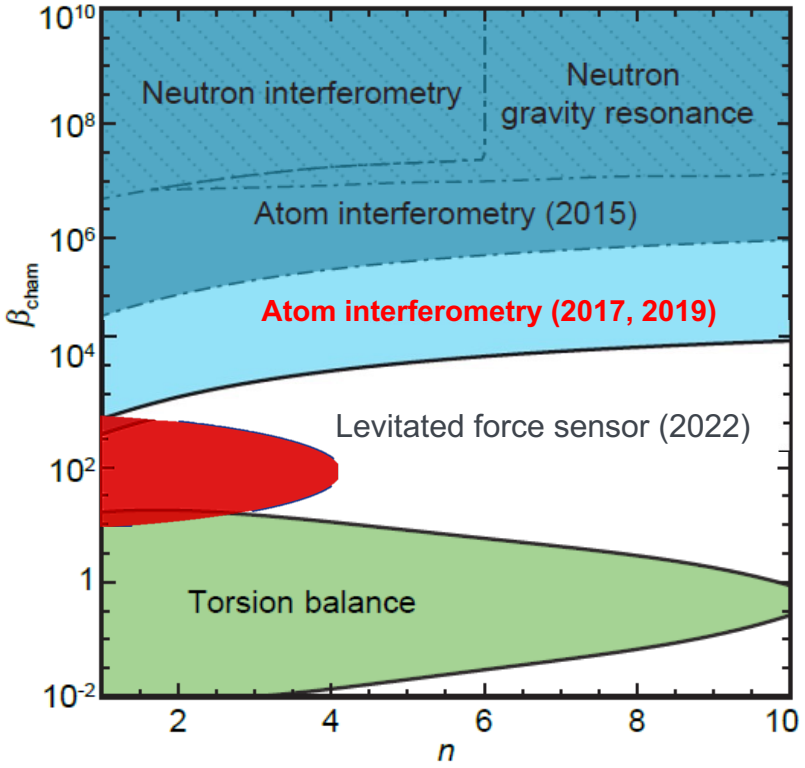


- Thorsten Schumm: Nuclear laser spectroscopy
- Hartmut Abele: Neutron physics
- Philipp Haslinger: Dark energy searches via atom interferometry
- Tim Langen: Cold molecules for electron EDM searches & weak parity violation

Also: Close connections to HEPHY (Florian Reindl, Jochen Schieck)

Example 1: Atom interferometry for dark energy searches

- What if scalar dark energy effects are there, but shielded in normal matter?
- Way out: Use the a small and very light sensor: atoms (or neutron)



- H. Lemmel et al. Phys. Lett. B 743 (2015)
- T. Jenke et al. PRL 112, 151105 (2014)

- P. Hamilton, M. Jaffe, P. Haslinger, *et al.*, Science 349, 849 (2015)
- M. Jaffe, P. Haslinger, *et al.*, Nature Physics 13, 938 (2017)

$$V_{\text{eff}} = \Lambda^4 + \frac{\Lambda^{4+n}}{\phi^n} + \frac{\phi}{M}\rho$$

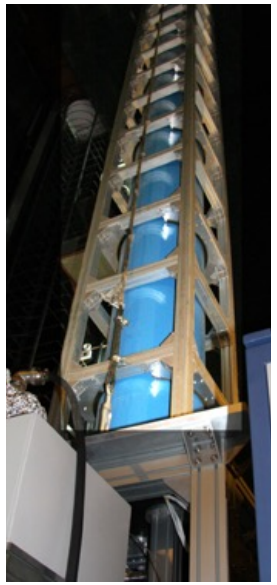
Limits at $\Lambda = 2.4\ \text{meV}$ versus power law exponent *n*, of the chameleon potential

Pushing the frontier: Haslinger group

- Longer interrogation times increase interferometer performance

Larger

(CN, US, DE, UK, FR, ...)



Zhou et al. PRL (2015)

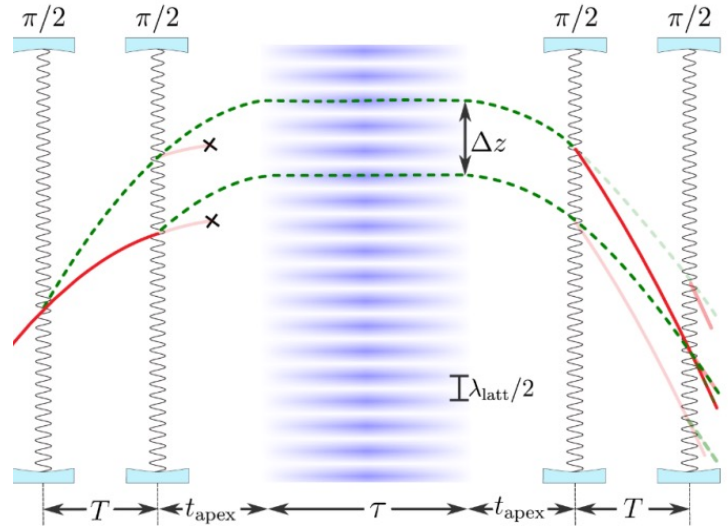
Turn off gravity

ISS or rockets

Carollo et al. Nature 606, 281 (2022)

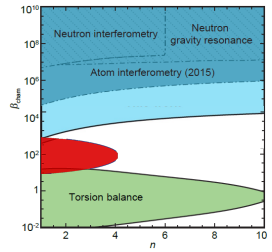
Levitate using AMO toolbox

Haslinger group



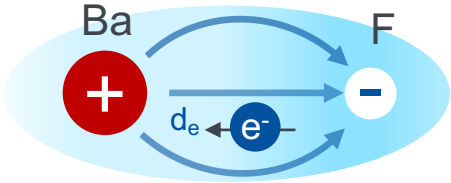
Ultralong interaction times with probe mass (minutes!)

- Closing the gap for viable chameleon theories!



Example 2: Exploring the energy frontier with molecules

- An electron EDM violates time-reversal symmetry, and thus CP symmetry
- Molecules provide exceptional sensitivity



E_{eff} ~ 10-100 GV/cm

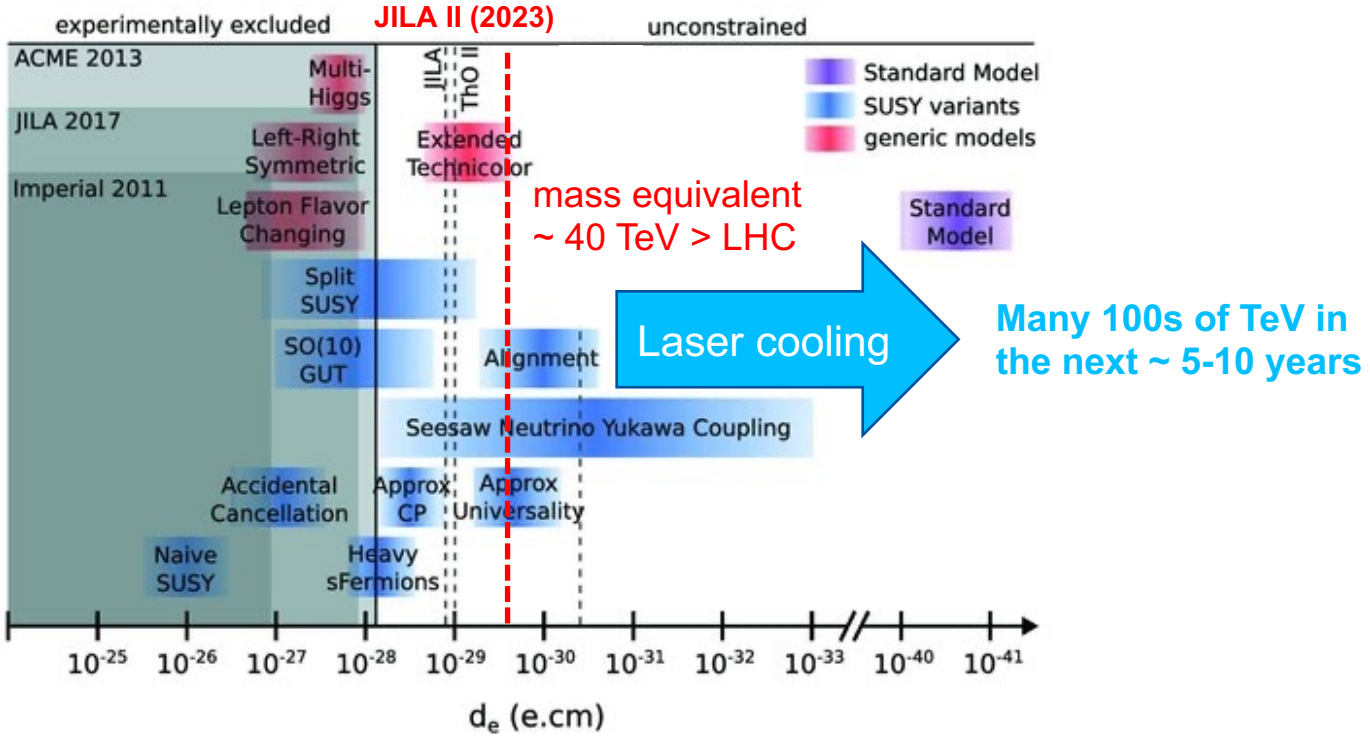
(given 10 V/cm in lab frame)

- Status of the field:

Beam:
ACME (Harvard/Chicago)
NL:eEDM (Groningen)
YbF (Imperial College)

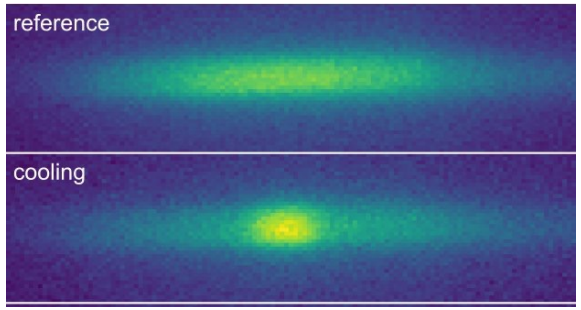
Trapped Ions:
JILA

Matrix:
EDM^3 (Toronto/York)
Guarise (Ferrara)



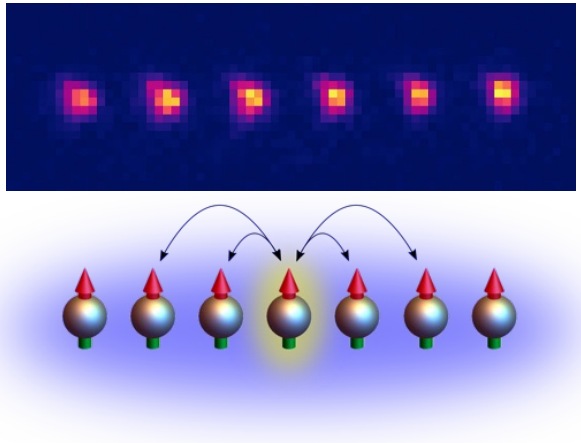
Pushing the frontier: Langen group

- Better: more molecules for longer times: Cooling and trapping!
- In contrast to atoms: molecules are extremely hard to cool, but exceptional progress ~ 10 years! Langen *et al.*, Nature Physics 20, 702 (2024)



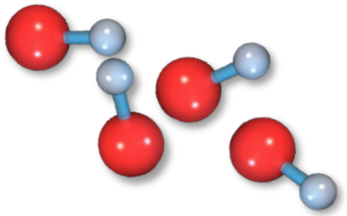
Rockenhäuser, Kogel, *et al.* arxiv:2405.09427 (2024)
Kogel, Garg, *et al.* arxiv: 2406.01569 (2024)

- My group: More complex molecules with high sensitivity - first laser cooling of BaF
- Long term: trapped samples, polyatomics, radioactive molecules, quantum metrology …
- Besides eEDM: Rotational state boost for neutral current weak parity violation (anapole moments, Z boson exchange etc.)



Doyle group: Nature 628, 282–286 (2024)

Conclusion & future prospects



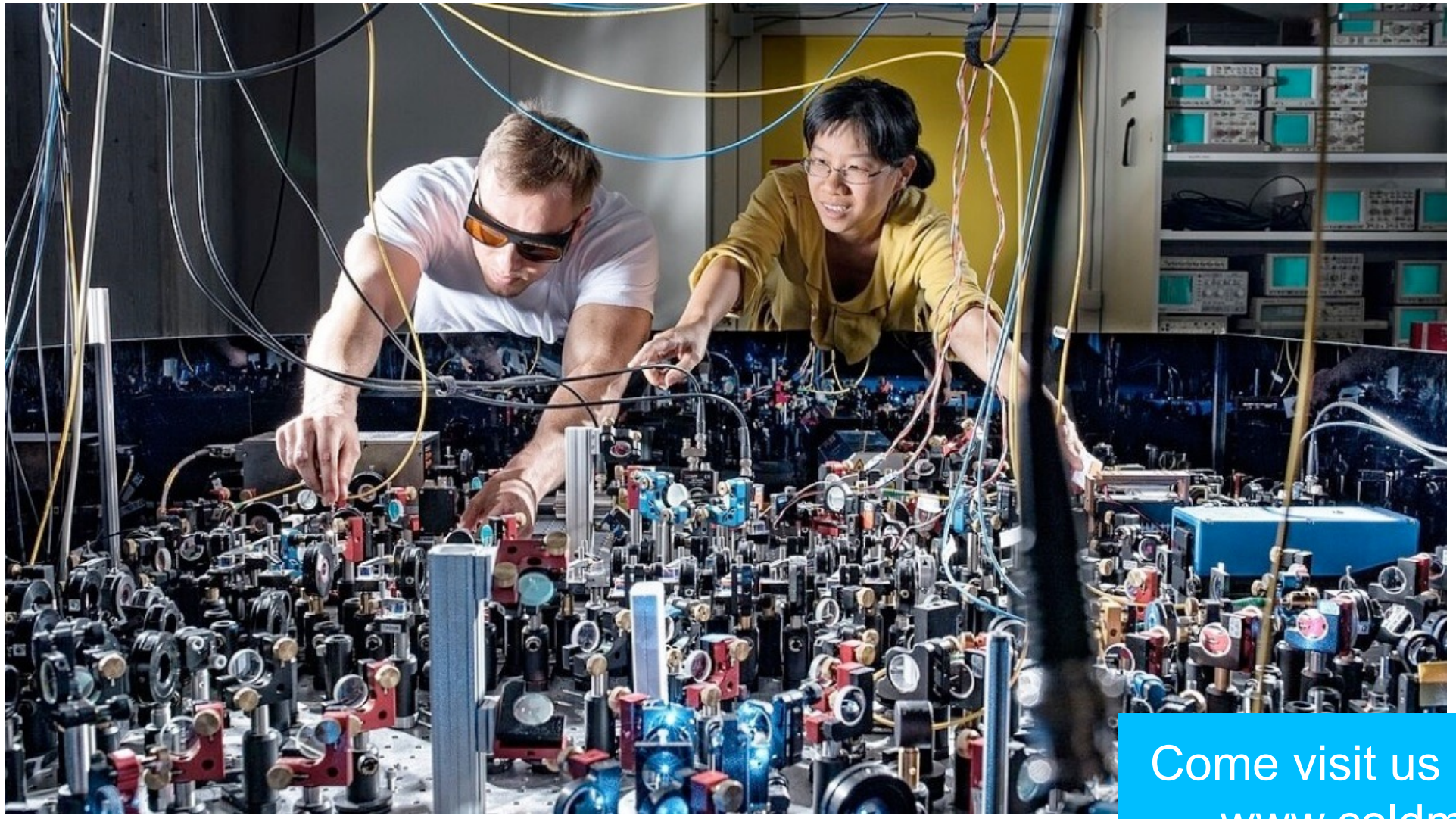
- AMO: Complementary to the other efforts presented here.
  Ability to probe interesting regimes that are inaccessible by other means!

- Will not replace colliders *et al.*, but can provide powerful methods to pinpoint
  e.g. at which scales (energy, mass, etc.) things go wrong!

- Required facilities: A priori - it's table-top! e.g. RaF collaboration, Nature **581**, 396 (2020)
  But community uses e.g. TRIGA reactor @ ATI, ISOLDE @ CERN, …
  To connect to standard model parameters: extensive theory input & computational power

- **A lot of relevant AMO & quantum expertise in Austria!**
  Always happy to learn & collaborate!

Thank you!



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www.coldmolecules.at