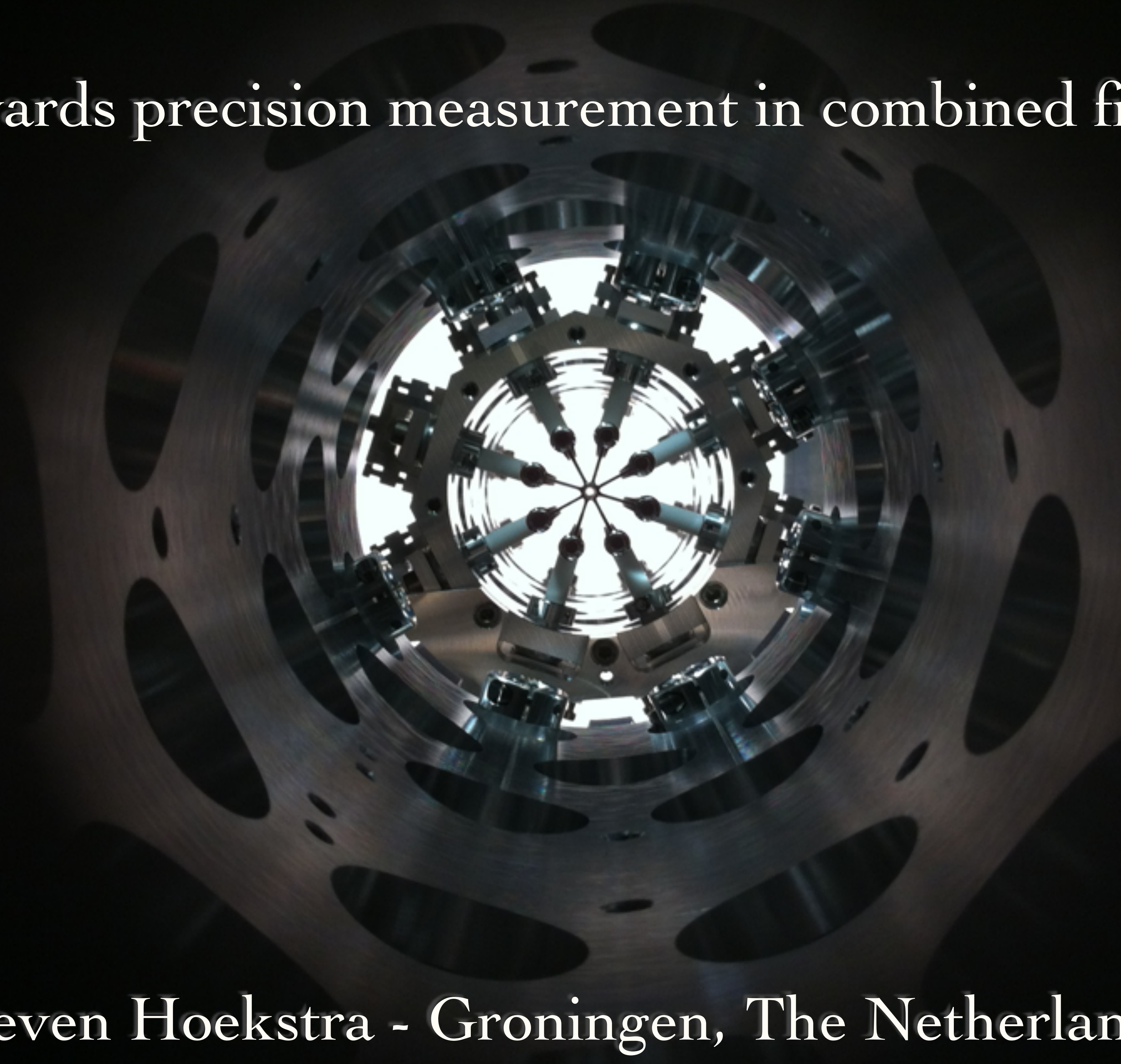
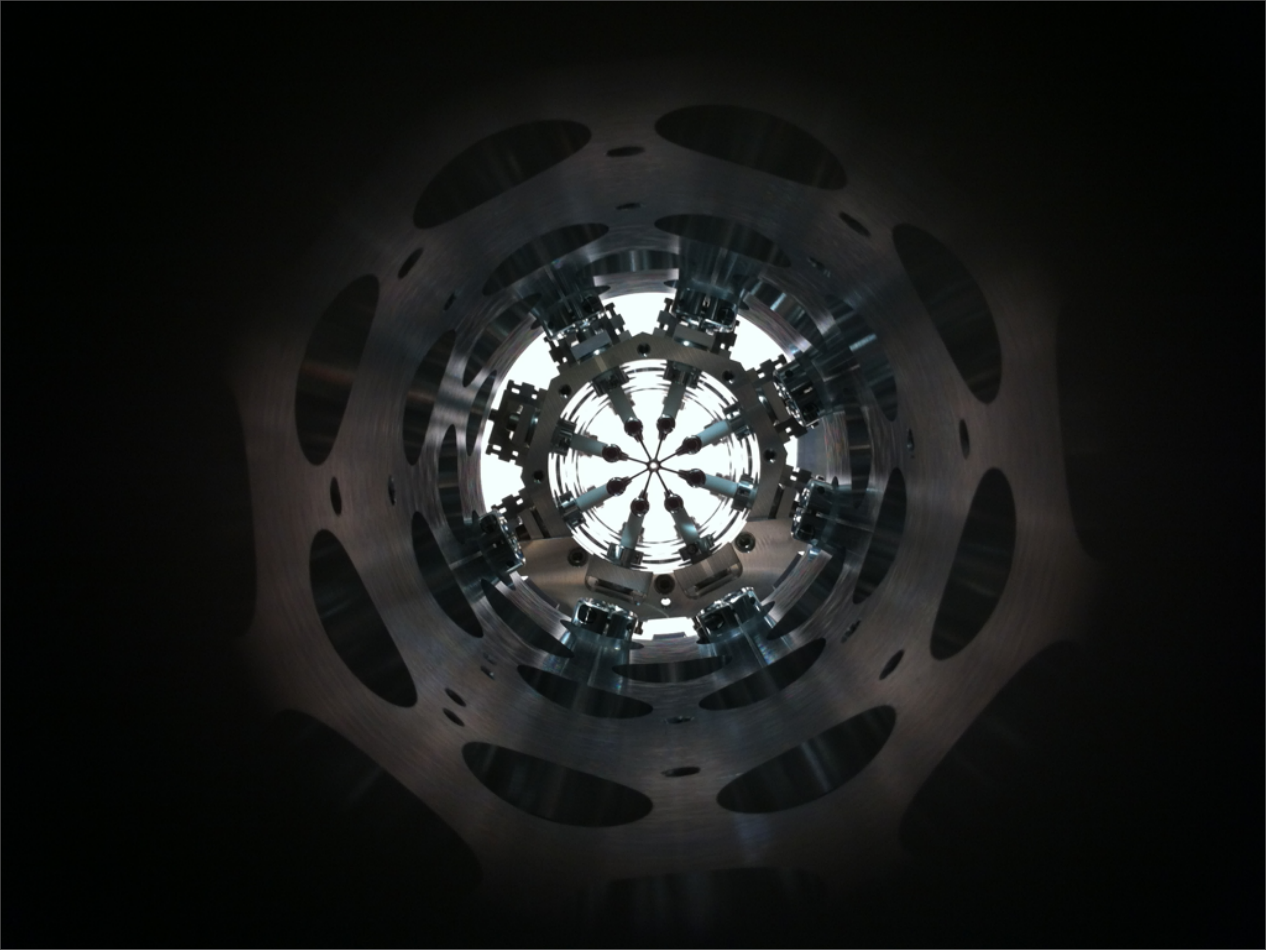
Deceleration and trapping of SrF

towards precision measurement in combined fields



Steven Hoekstra - Groningen, The Netherlands



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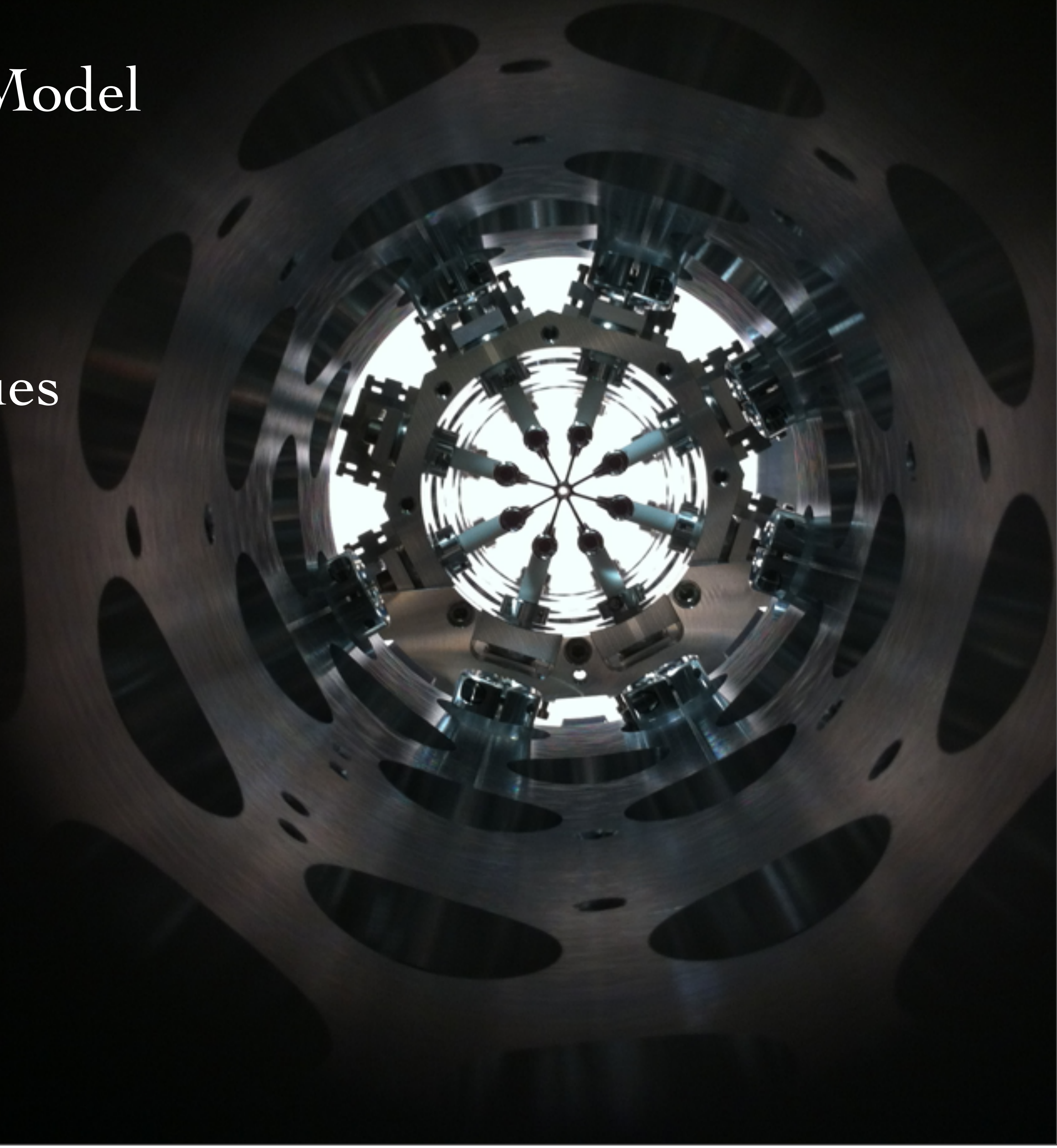
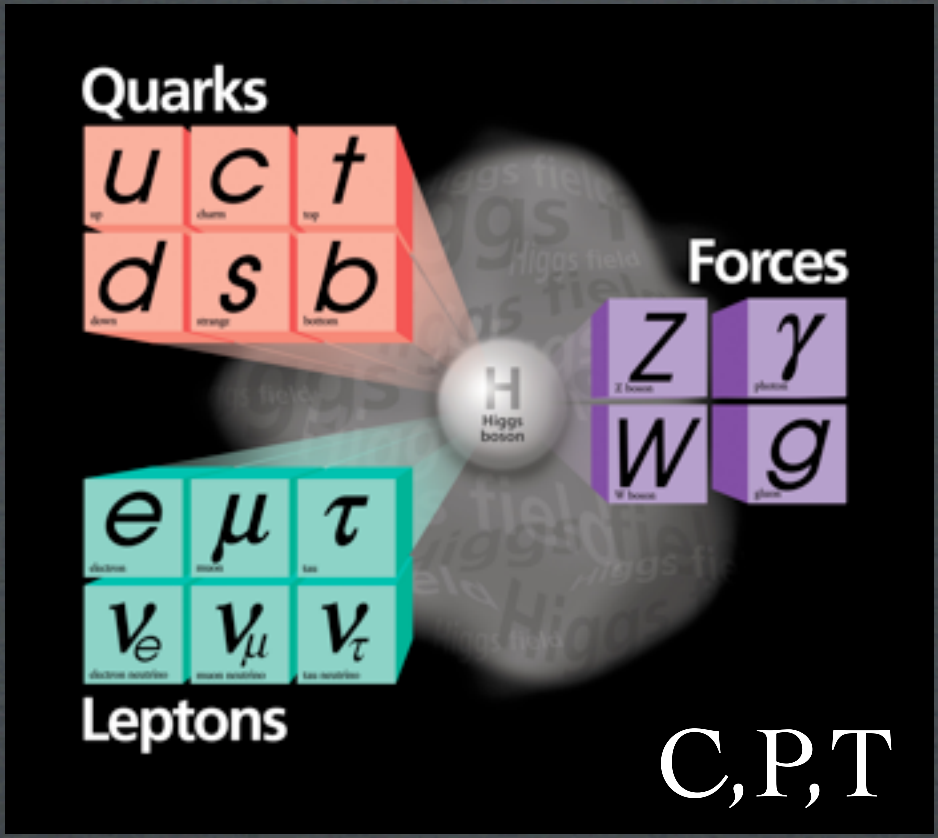


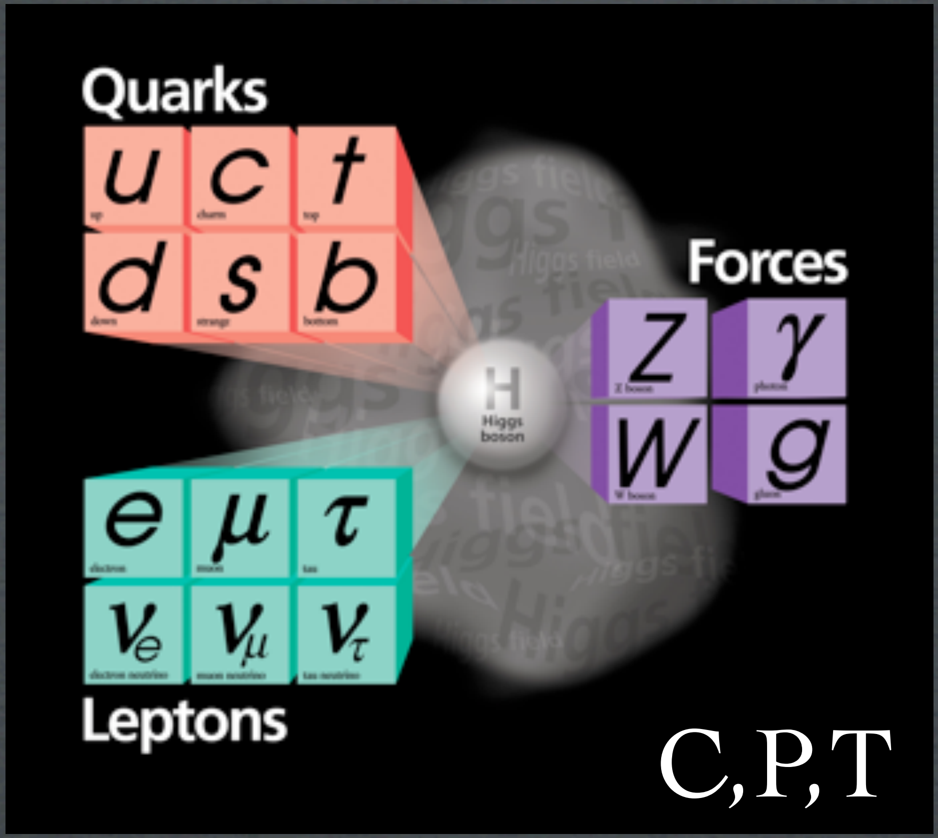
- Testing the Standard Model
- Using cold molecules
- Experimental techniques
- Status
- Open questions

Testing the Standard Model



C,P,T

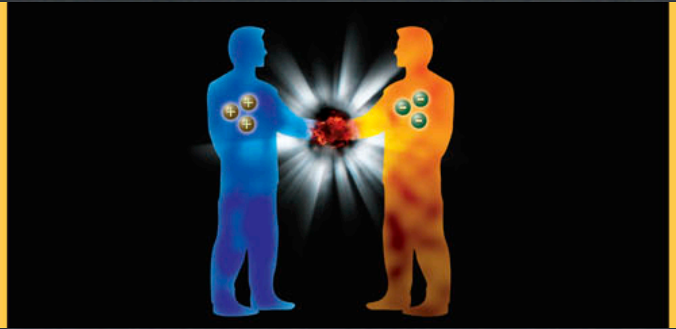
Testing the Standard Model



Unsolved mysteries

Expansion of the universe?

Where is the anti-matter?



Dark matter?

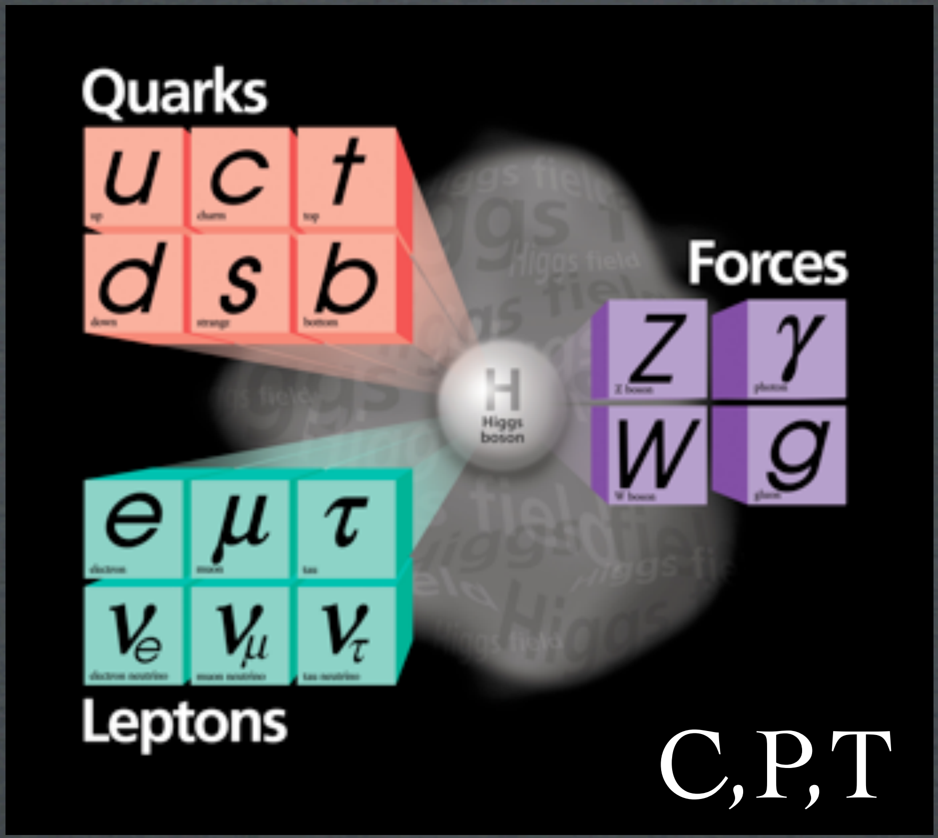
Origin of mass?

Can we explain the values of the physical constants, and are they constant at all?

Testing the Standard Model

LHC @ CERN

Direct observation of new particles at TeV scale



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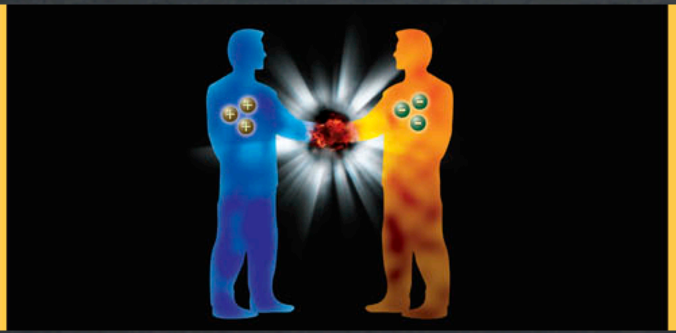

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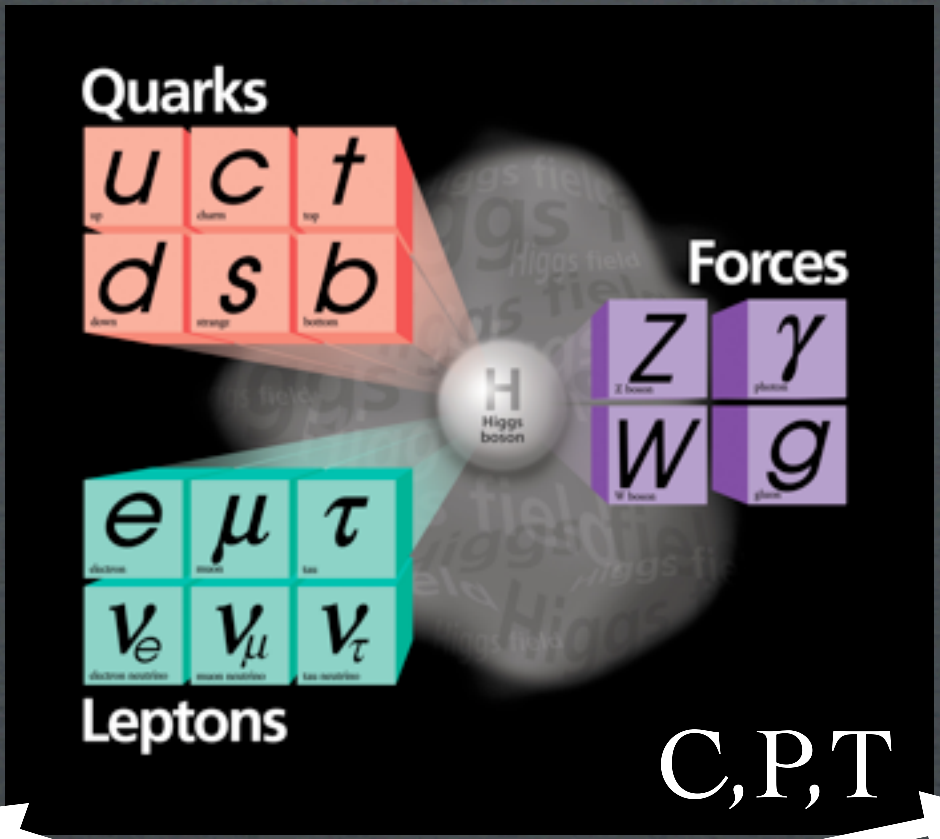

C,P,T

Ca atom trapping @ Groningen

Direct observation of new particles at TeV scale

Precision measurements on the molecular scale

Complementary:
Constraining parameter space for SM extensions

Unsolved mysteries

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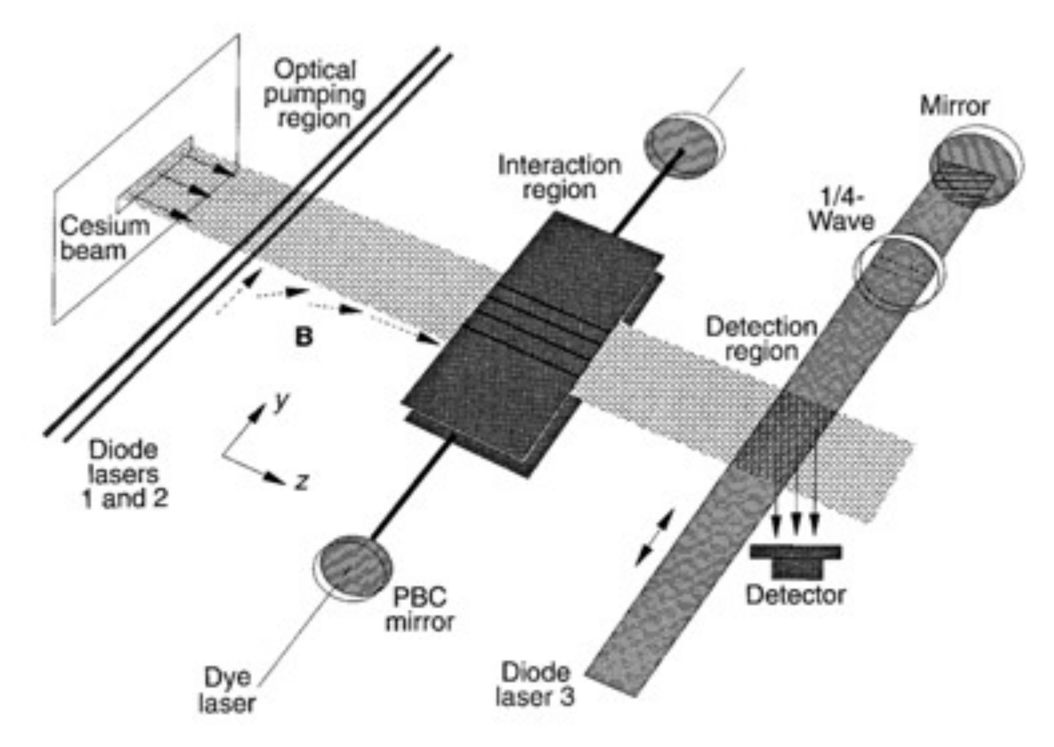
Example 1: Parity violation



Cs experiment

Measurement of Parity Nonconservation and an Anapole Moment in Cesium
C Wood, S Bennett, D Cho, B Masterson, J Roberts, C Tanner, and C Wieman.
Science, 1997 vol. 275 (5307) p. 1759.

First observation of anapole moment.

Need atomic structure calculation to get the amount of Stark mixing and the relevant PNC electronic matrix elements. 1997 result:

$$Q_w = -72.06(28)_{\text{expt}}(34)_{\text{theor}}$$

which is 2.5 sigma from SM prediction...

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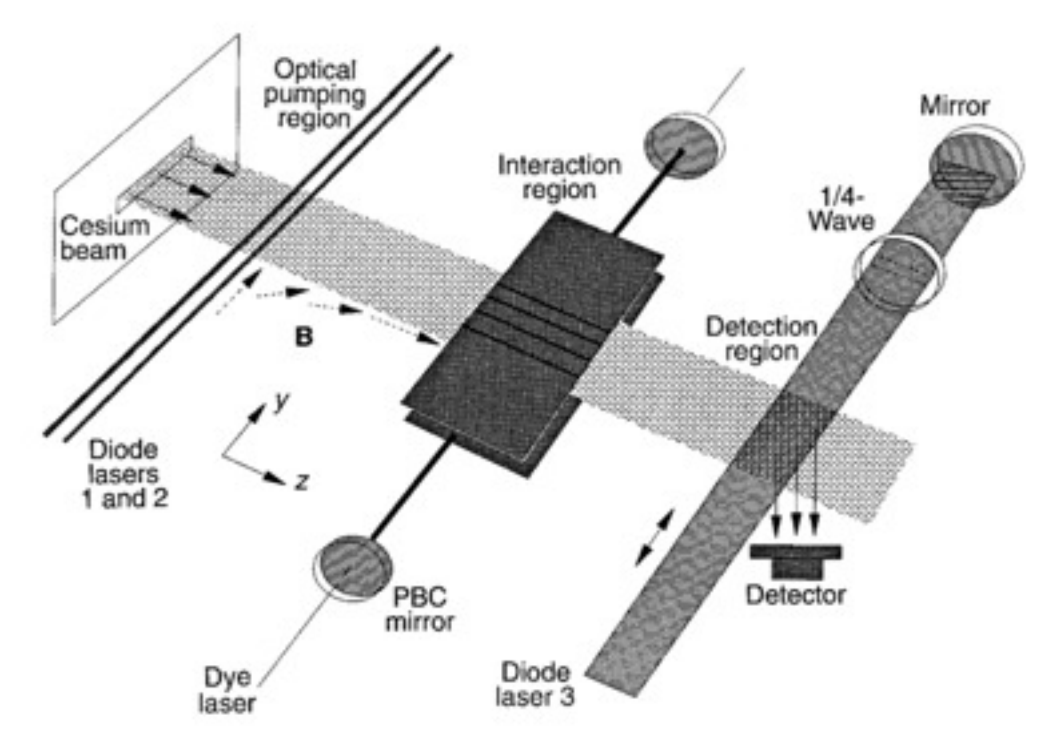

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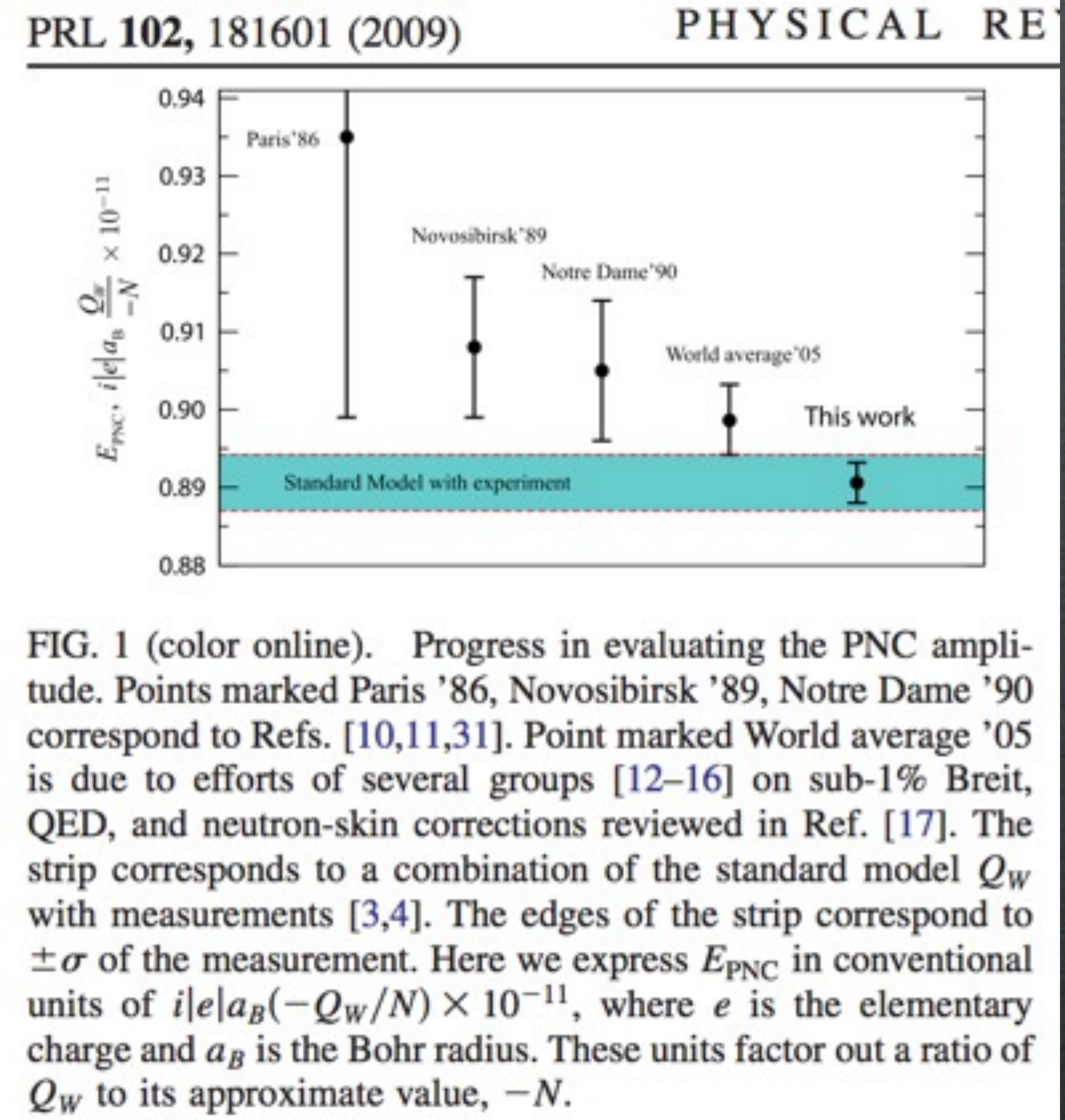


PRL **102,** 181601 (2009) PHYSICAL RE

FIG. 1 (color online). Progress in evaluating the PNC amplitude. Points marked Paris '86, Novosibirsk '89, Notre Dame '90 correspond to Refs. [10,11,31]. Point marked World average '05 is due to efforts of several groups [12–16] on sub-1% Breit, QED, and neutron-skin corrections reviewed in Ref. [17]. The strip corresponds to a combination of the standard model Q_W with measurements [3,4]. The edges of the strip correspond to $\pm\sigma$ of the measurement. Here we express $E_{\rm PNC}$ in conventional units of $i|e|a_B(-Q_W/N) \times 10^{-11}$, where e is the elementary charge and a_B is the Bohr radius. These units factor out a ratio of Q_W to its approximate value, $-N$.

Cs theory

Precision Determination of Electroweak Coupling from Atomic Parity Violation and Implications for Particle Physics.

S G Porsev, K Beloy, and A Derevianko.

Phys Rev Lett, 2009 vol. 102 (18) p. 181601.

$$Q_w = -73.16(29)_{\mathrm{expt}}(20)_{\mathrm{theor}}$$

Example 2: The dipole moment of the electron

An electron-EDM would violate time-inversion symmetry: the standard model essentially rules out an e-EDM.

So finding a non-zero e-EDM is direct proof of physics beyond the standard model.

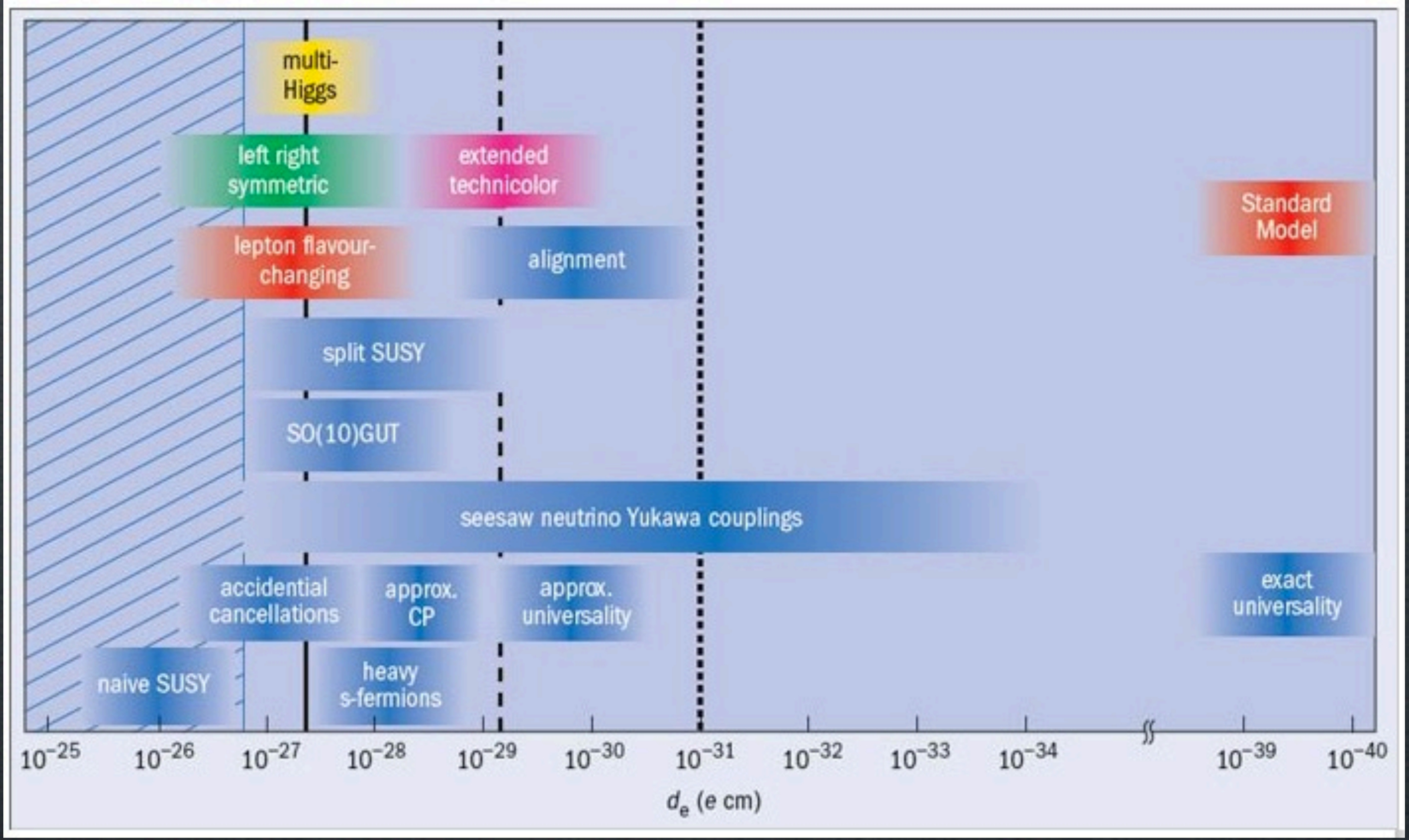
Many models beyond the standard model allow for a higher e-EDM: these models are tested in e-EDM experiments.

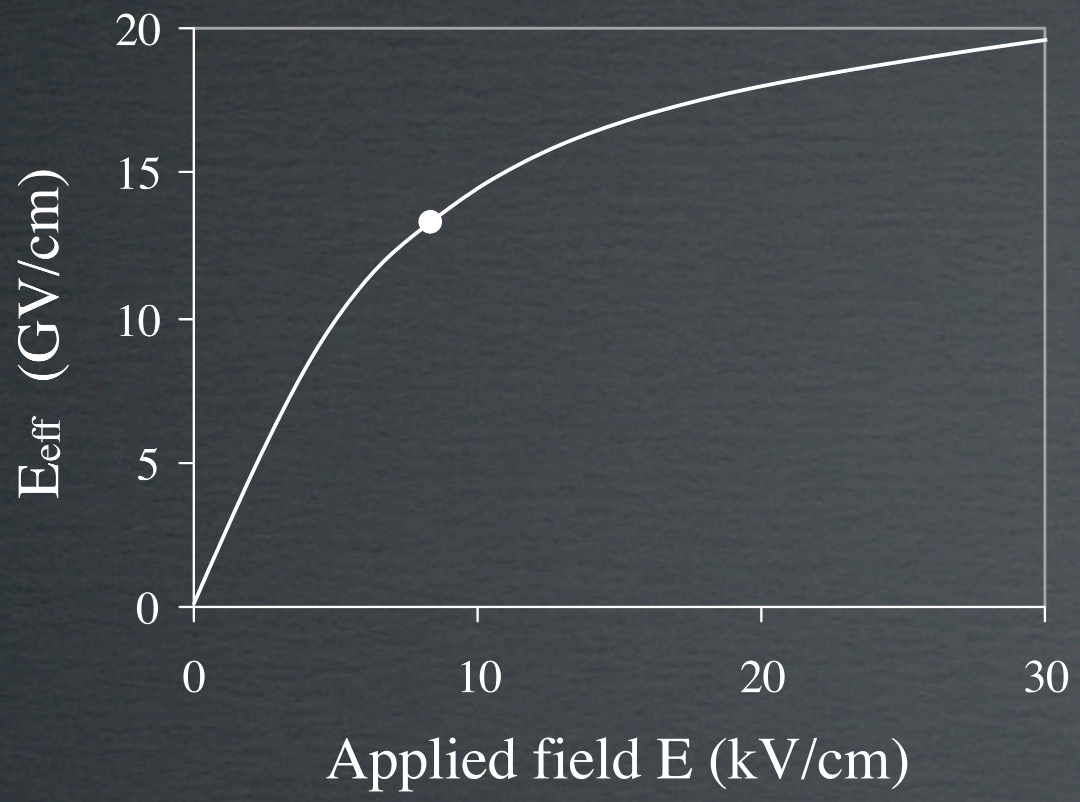
Cold molecules are nowadays the most promising for e-EDM experiments

current molecule experiments

next generation cold molecule experiments

current experimental limit (2002) using atoms



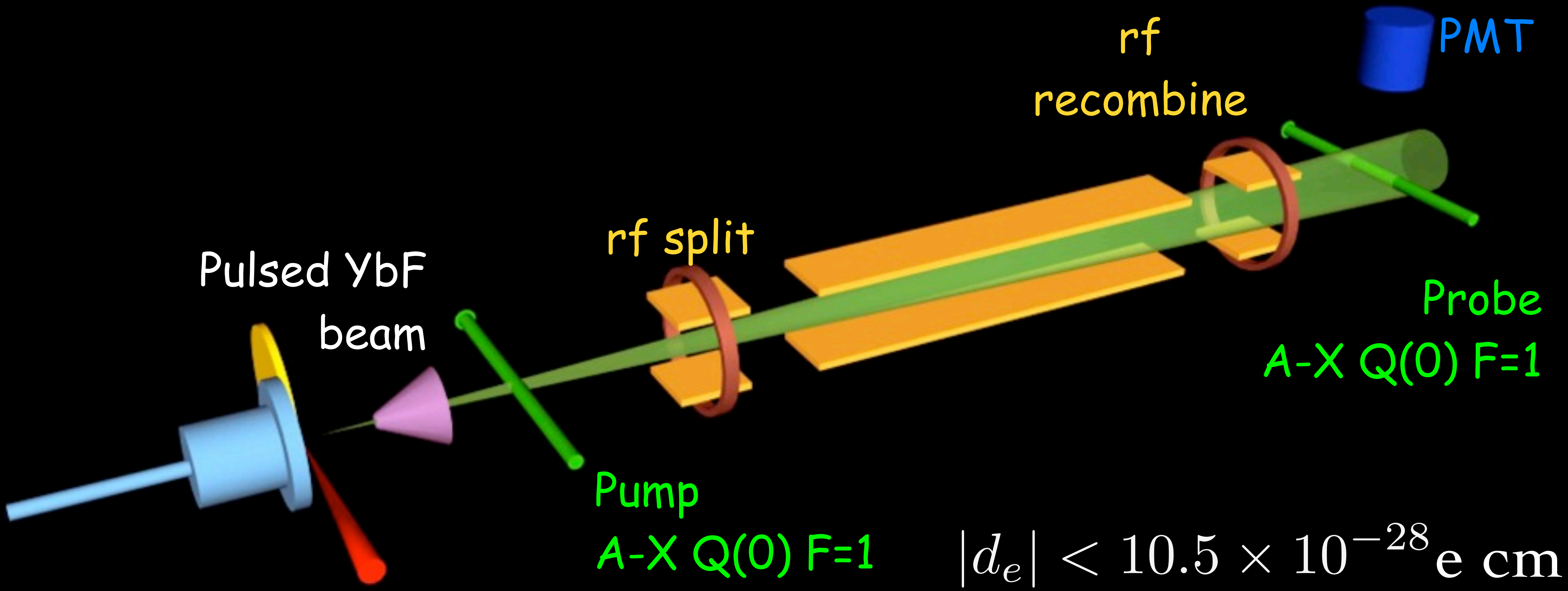


electron-EDM

Measured using a molecular beam: enhancement due to internal electric field

Molecules oriented using dipole moment, measure electron spin precession

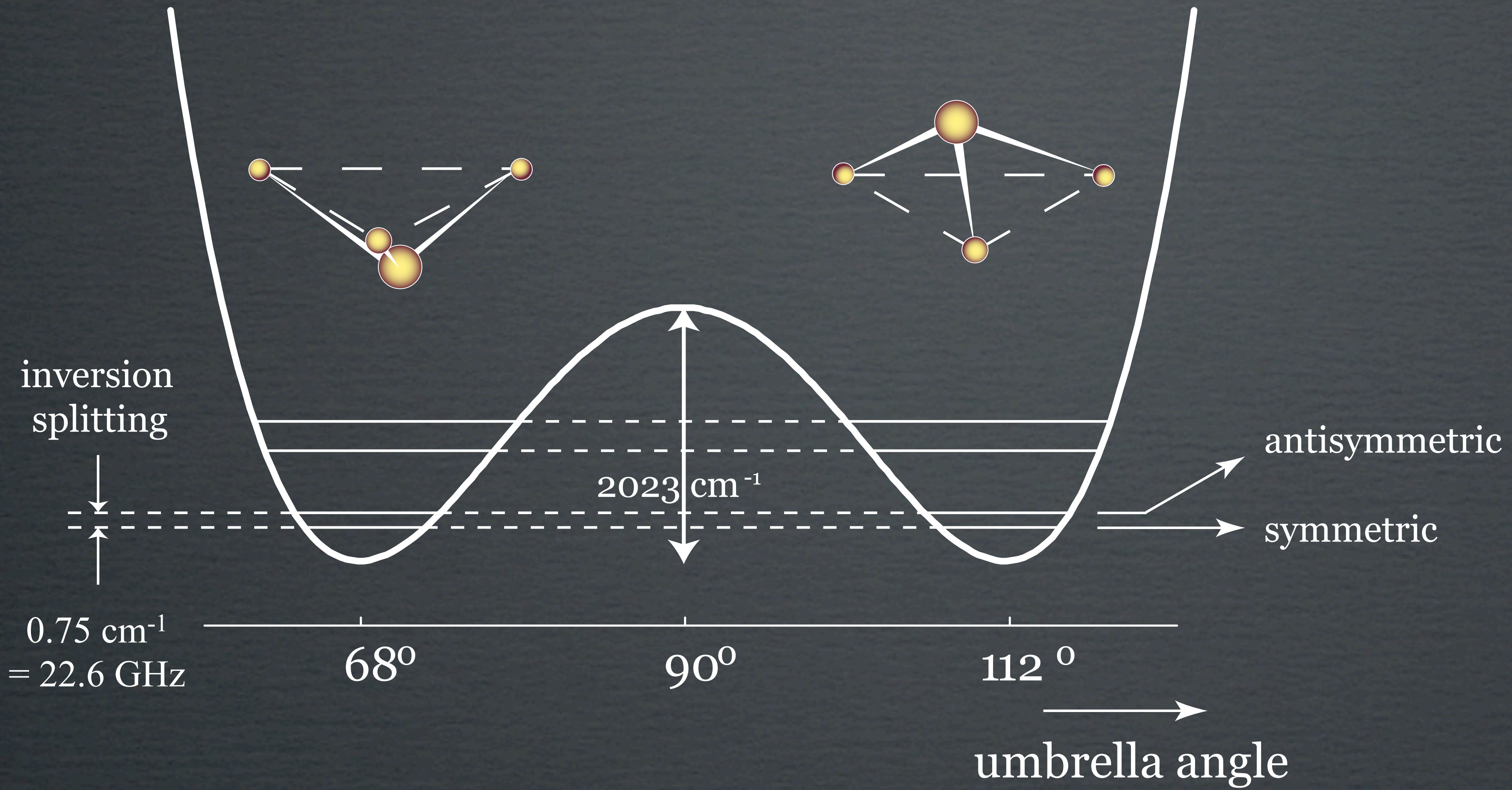
By flipping external magnetic field and electric field an electron-EDM is probed



$$|d_e| < 10.5 \times 10^{-28} \text{e cm}$$

J. J. Hudson, D. M. Kara, I. J. Smallman, B. E. Sauer, M. R. Tarbutt, and E. A. Hinds, Nature **473**, 493 (2011).

Example 3: Time-variation of constants



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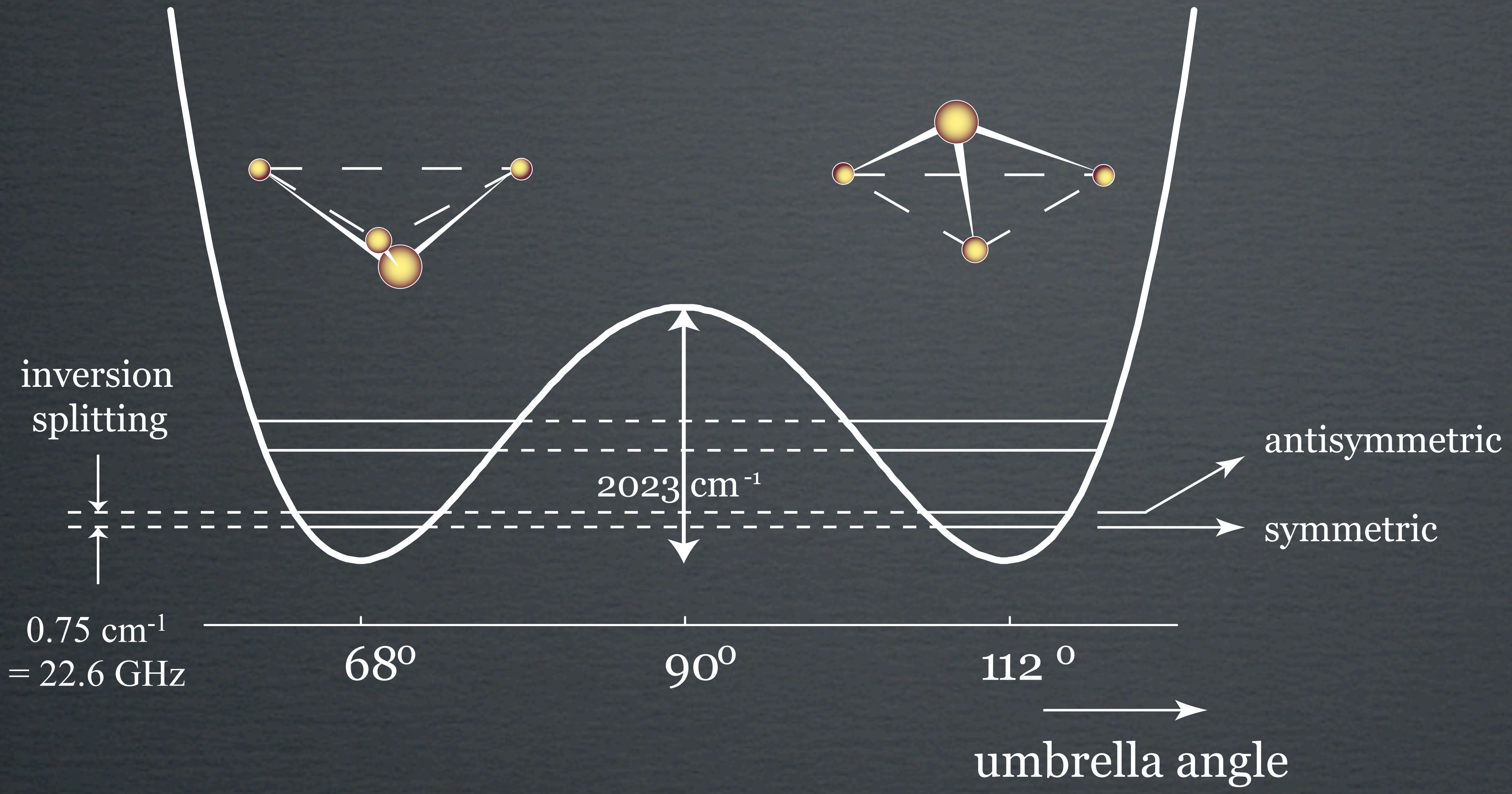


inversion splitting

$0.75\ \mathrm{cm}^{-1}$ = 22.6 GHz

$2023\ \mathrm{cm}^{-1}$

antisymmetric

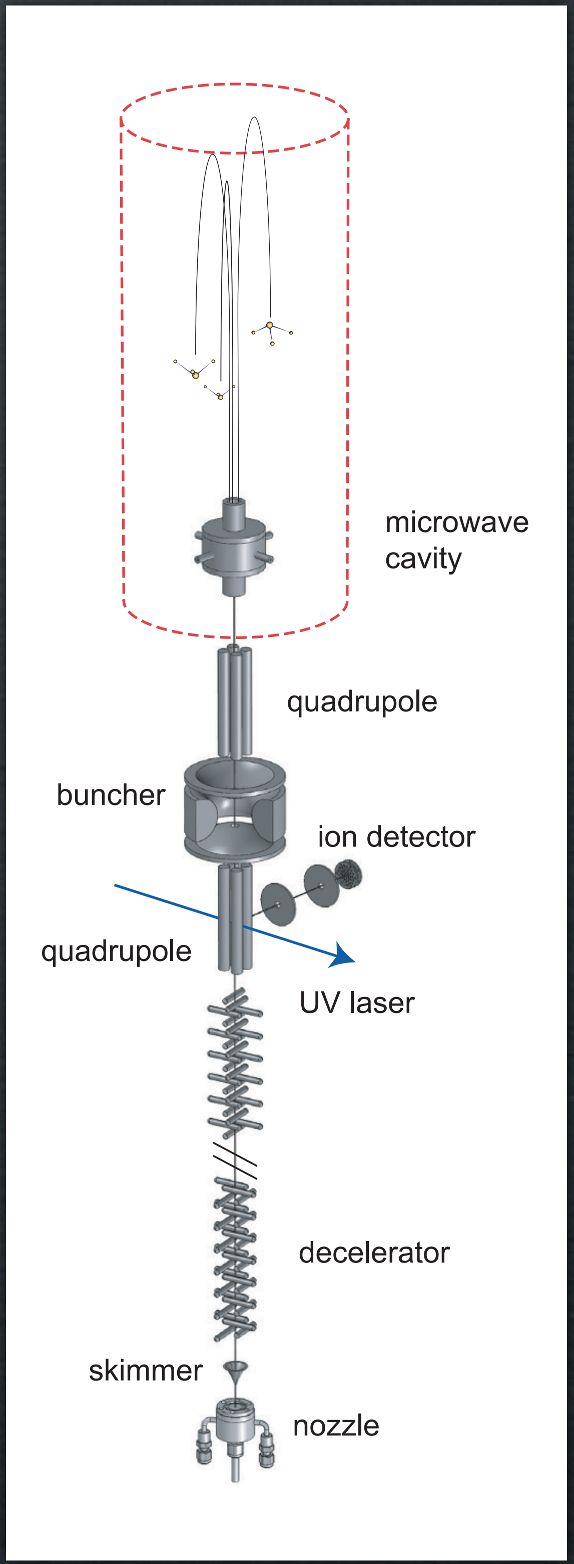
symmetric

68^0

90^0

$112\ ^0$

umbrella angle



The inversion splitting frequency is extremely sensitive to the proton mass, and can therefore be used to probe a change of m_p/m_e

In an experiment in Amsterdam, a molecular fountain for decelerated molecules is being set up for this purpose.

Bethlem et al, The European Physical Journal 163, 55 (2008)

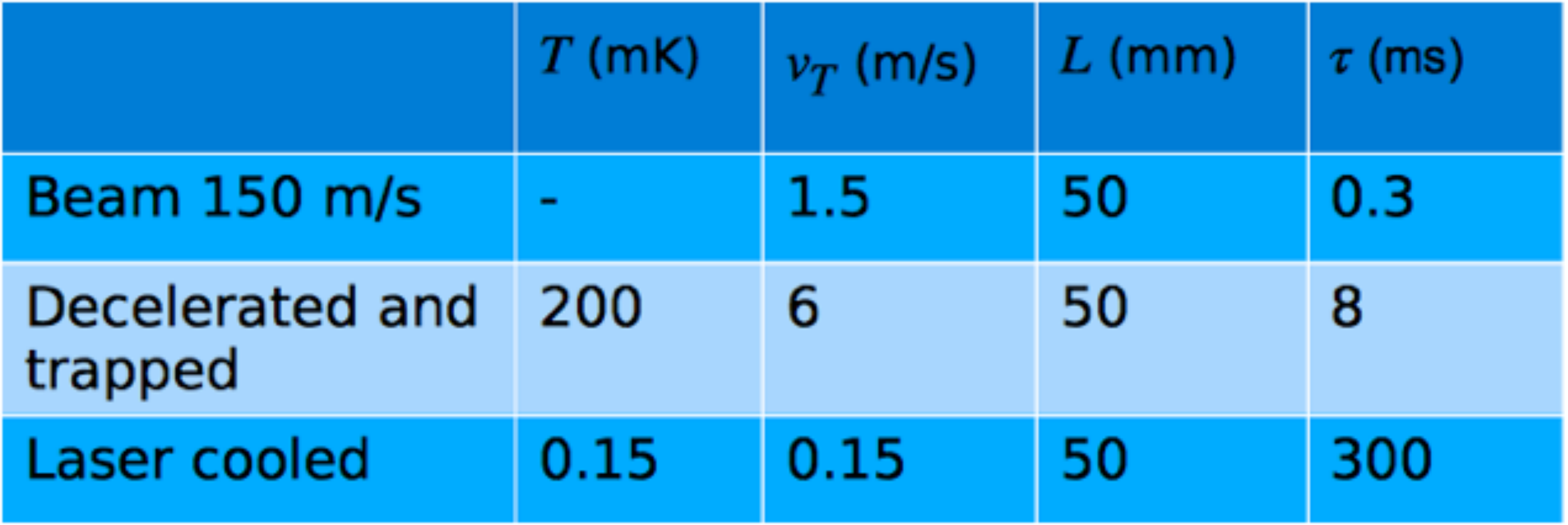
Precision measurements using molecules

- **Molecules** are interesting for precision measurements, because:
  - coexisting frequency domains probe different interactions, and offer (almost) degenerate states
  - polar molecules are very sensitive to electric fields
- **Cold Molecules** promise increased sensitivity and precision:
  - at low temperatures, fewer states are populated
  - low velocity -> reduced doppler shifts
  - precision of measurements limited by interaction time: slow beams
- **Trapped cold molecules** offer additional advantages:
  - even longer coherence times
  - molecules confined spatially: easier to control environment stability

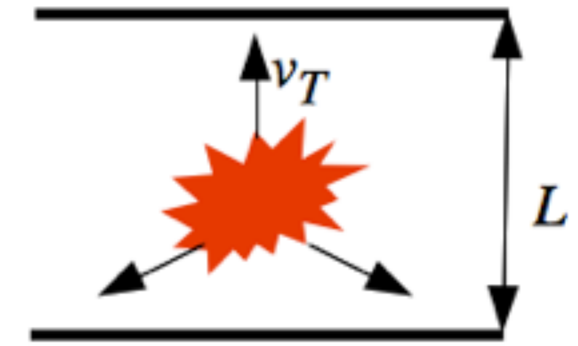
Precision reached with atoms is (still) better, but enhancement effects in molecules can compensate

Ultracold offers higher precision:

Measurement sensitivity: $\propto \sqrt{N\tau}$

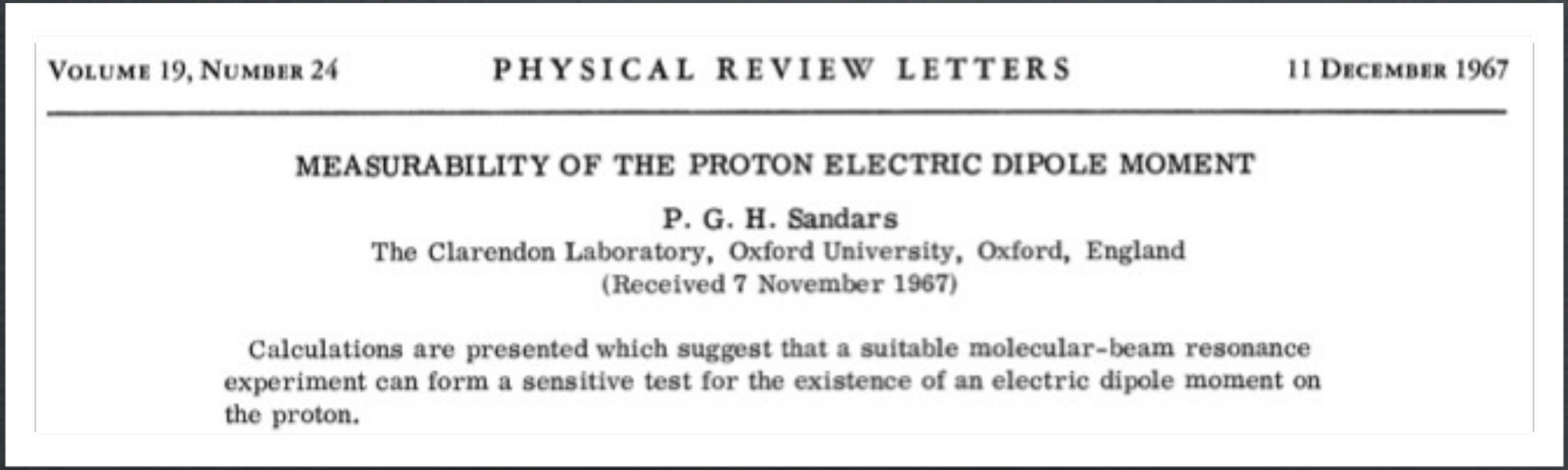


	T (mK)	v_T (m/s)	L (mm)	τ (ms)
Beam 150 m/s	-	1.5	50	0.3
Decelerated and trapped	200	6	50	8
Laser cooled	0.15	0.15	50	300



Expanding cloud of molecules inside measurement region

The idea to use molecules is not new....



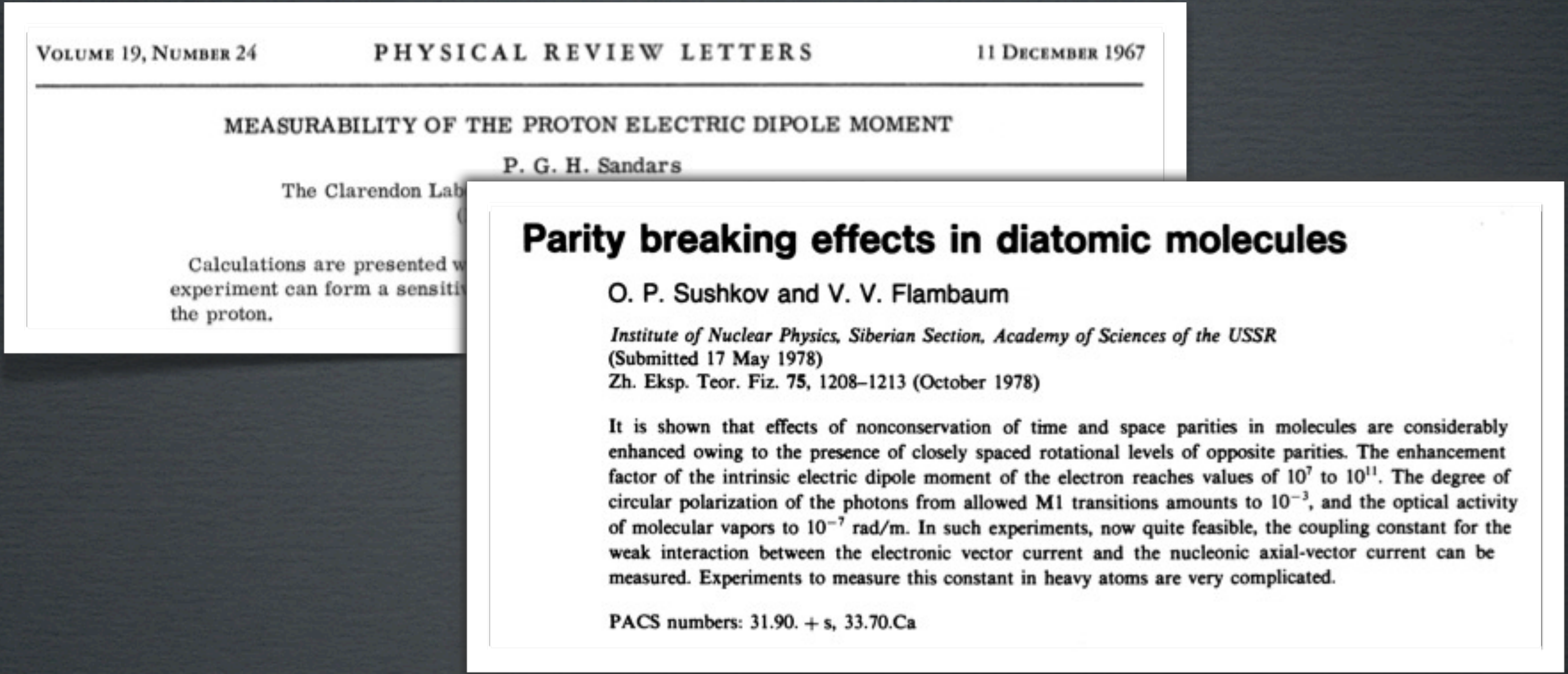
VOLUME 19, NUMBER 24 PHYSICAL REVIEW LETTERS 11 DECEMBER 1967

MEASURABILITY OF THE PROTON ELECTRIC DIPOLE MOMENT

P. G. H. Sandars
The Clarendon Laboratory, Oxford University, Oxford, England
(Received 7 November 1967)

Calculations are presented which suggest that a suitable molecular-beam resonance experiment can form a sensitive test for the existence of an electric dipole moment on the proton.

The idea to use molecules is not new....



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Parity breaking effects in diatomic molecules

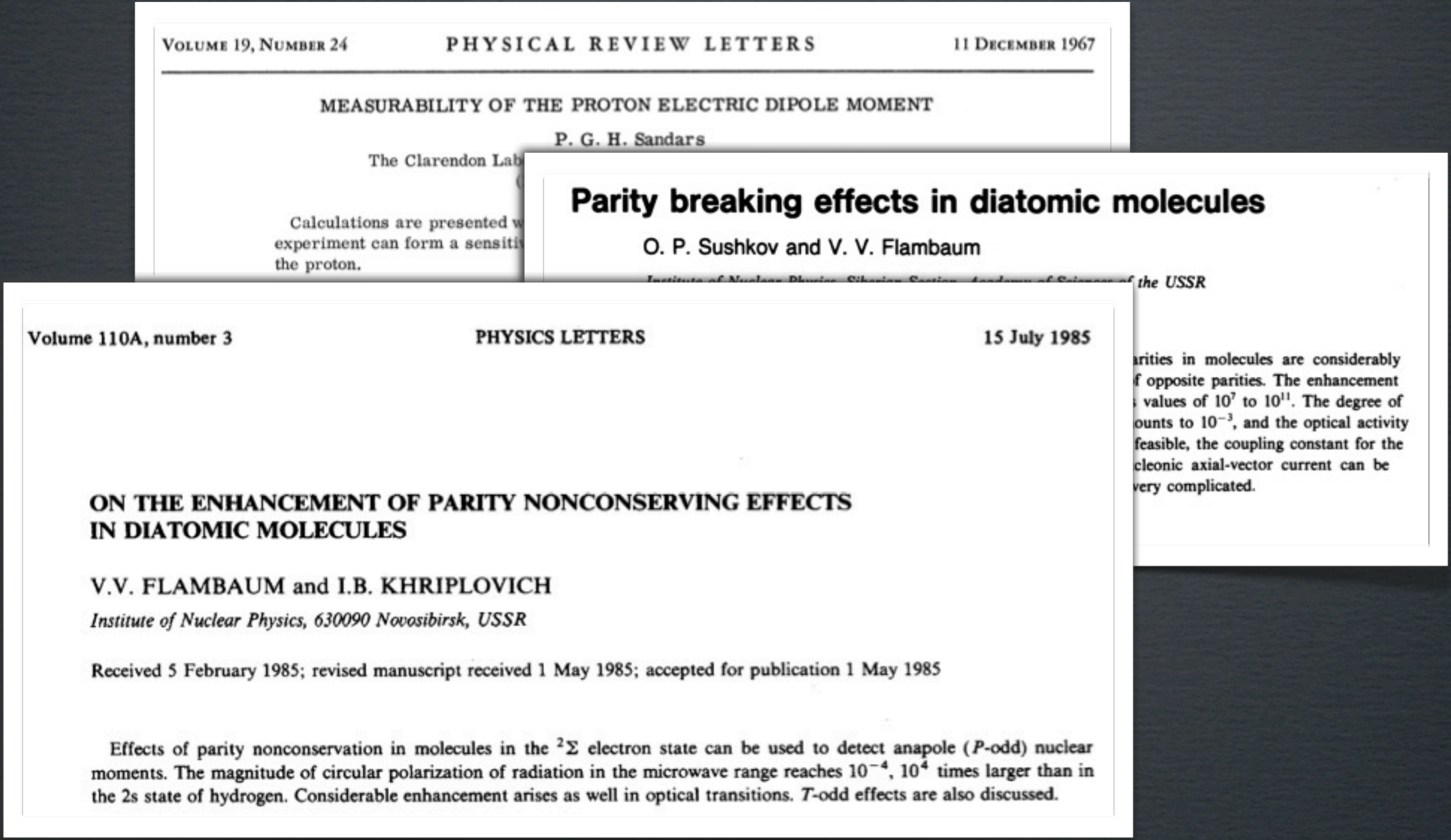
O. P. Sushkov and V. V. Flambaum

Institute of Nuclear Physics, Siberian Section, Academy of Sciences of the USSR
(Submitted 17 May 1978)
Zh. Eksp. Teor. Fiz. **75**, 1208–1213 (October 1978)

It is shown that effects of nonconservation of time and space parities in molecules are considerably enhanced owing to the presence of closely spaced rotational levels of opposite parities. The enhancement factor of the intrinsic electric dipole moment of the electron reaches values of 10^7 to 10^{11}. The degree of circular polarization of the photons from allowed M1 transitions amounts to 10^{-3}, and the optical activity of molecular vapors to 10^{-7} rad/m. In such experiments, now quite feasible, the coupling constant for the weak interaction between the electronic vector current and the nucleonic axial-vector current can be measured. Experiments to measure this constant in heavy atoms are very complicated.

PACS numbers: 31.90. + s, 33.70.Ca

The idea to use molecules is not new....



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Volume 110A, number 3 PHYSICS LETTERS 15 July 1985

ON THE ENHANCEMENT OF PARITY NONCONSERVING EFFECTS IN DIATOMIC MOLECULES

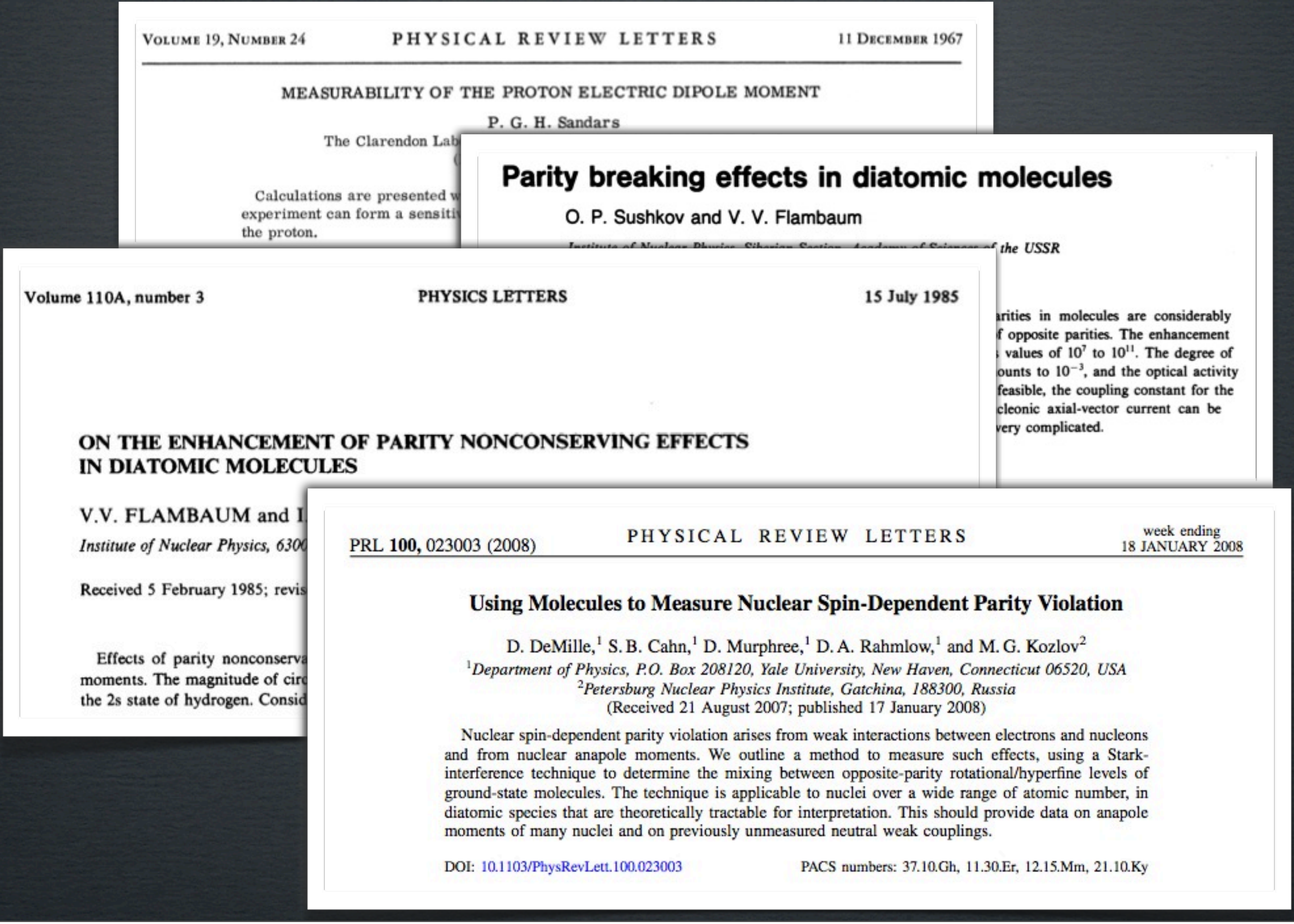
V.V. FLAMBAUM and I.B. KHRIPLOVICH

Institute of Nuclear Physics, 630090 Novosibirsk, USSR

Received 5 February 1985; revised manuscript received 1 May 1985; accepted for publication 1 May 1985

Effects of parity nonconservation in molecules in the $^2\Sigma$ electron state can be used to detect anapole (*P*-odd) nuclear moments. The magnitude of circular polarization of radiation in the microwave range reaches 10^{-4}, 10^4 times larger than in the 2s state of hydrogen. Considerable enhancement arises as well in optical transitions. *T*-odd effects are also discussed.

The idea to use molecules is not new….



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Received 5 February 1985; revis

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the 2s state of hydrogen. Consid

PRL **100,** 023003 (2008) PHYSICAL REVIEW LETTERS week ending 18 JANUARY 2008

Using Molecules to Measure Nuclear Spin-Dependent Parity Violation

D. DeMille,[1] S. B. Cahn,[1] D. Murphree,[1] D. A. Rahmlow,[1] and M. G. Kozlov[2]

[1]*Department of Physics, P.O. Box 208120, Yale University, New Haven, Connecticut 06520, USA*

[2]*Petersburg Nuclear Physics Institute, Gatchina, 188300, Russia*

(Received 21 August 2007; published 17 January 2008)

Nuclear spin-dependent parity violation arises from weak interactions between electrons and nucleons and from nuclear anapole moments. We outline a method to measure such effects, using a Stark-interference technique to determine the mixing between opposite-parity rotational/hyperfine levels of ground-state molecules. The technique is applicable to nuclei over a wide range of atomic number, in diatomic species that are theoretically tractable for interpretation. This should provide data on anapole moments of many nuclei and on previously unmeasured neutral weak couplings.

DOI: 10.1103/PhysRevLett.100.023003 PACS numbers: 37.10.Gh, 11.30.Er, 12.15.Mm, 21.10.Ky

... but the experimental control to make them cold is!

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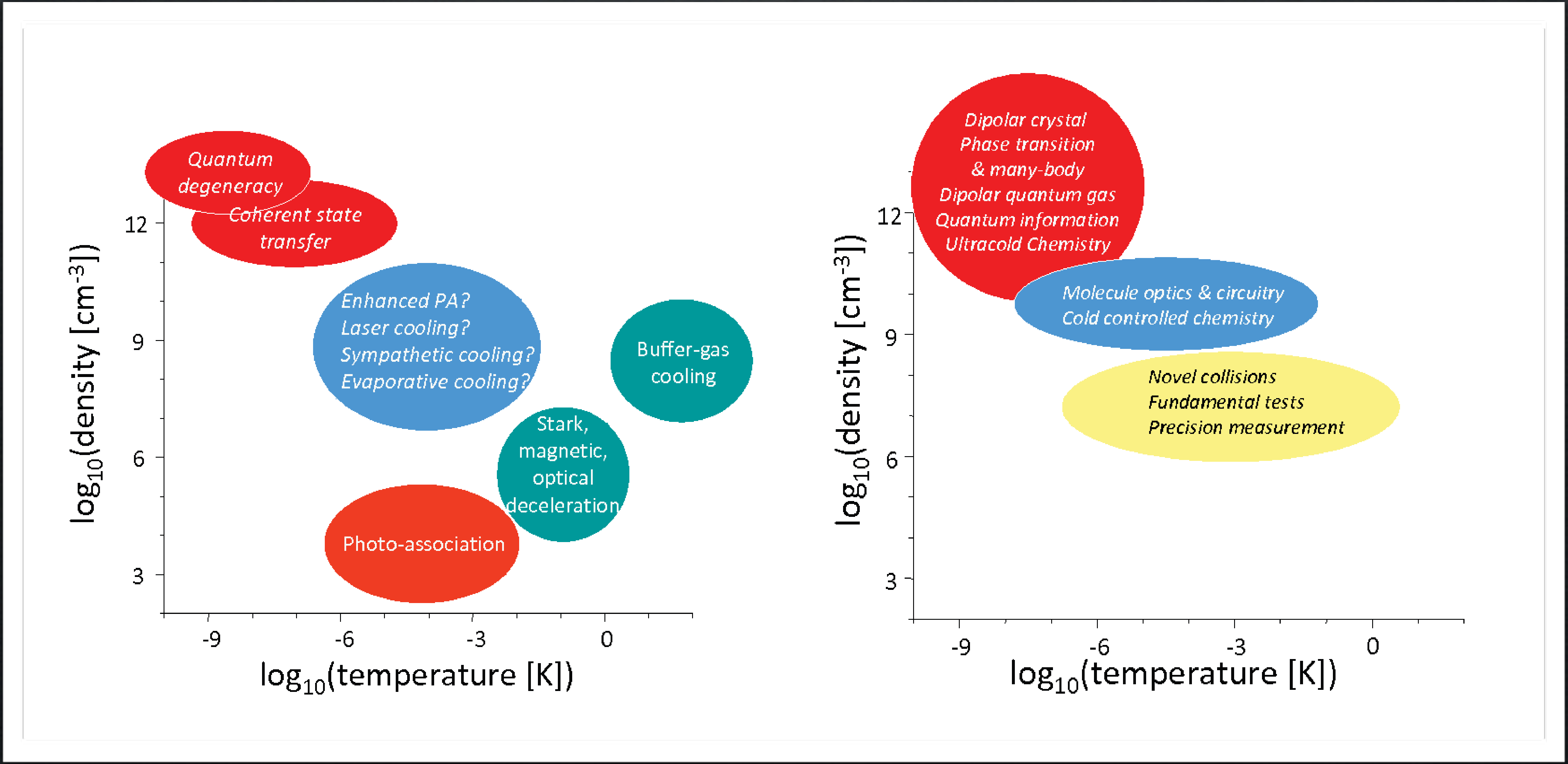
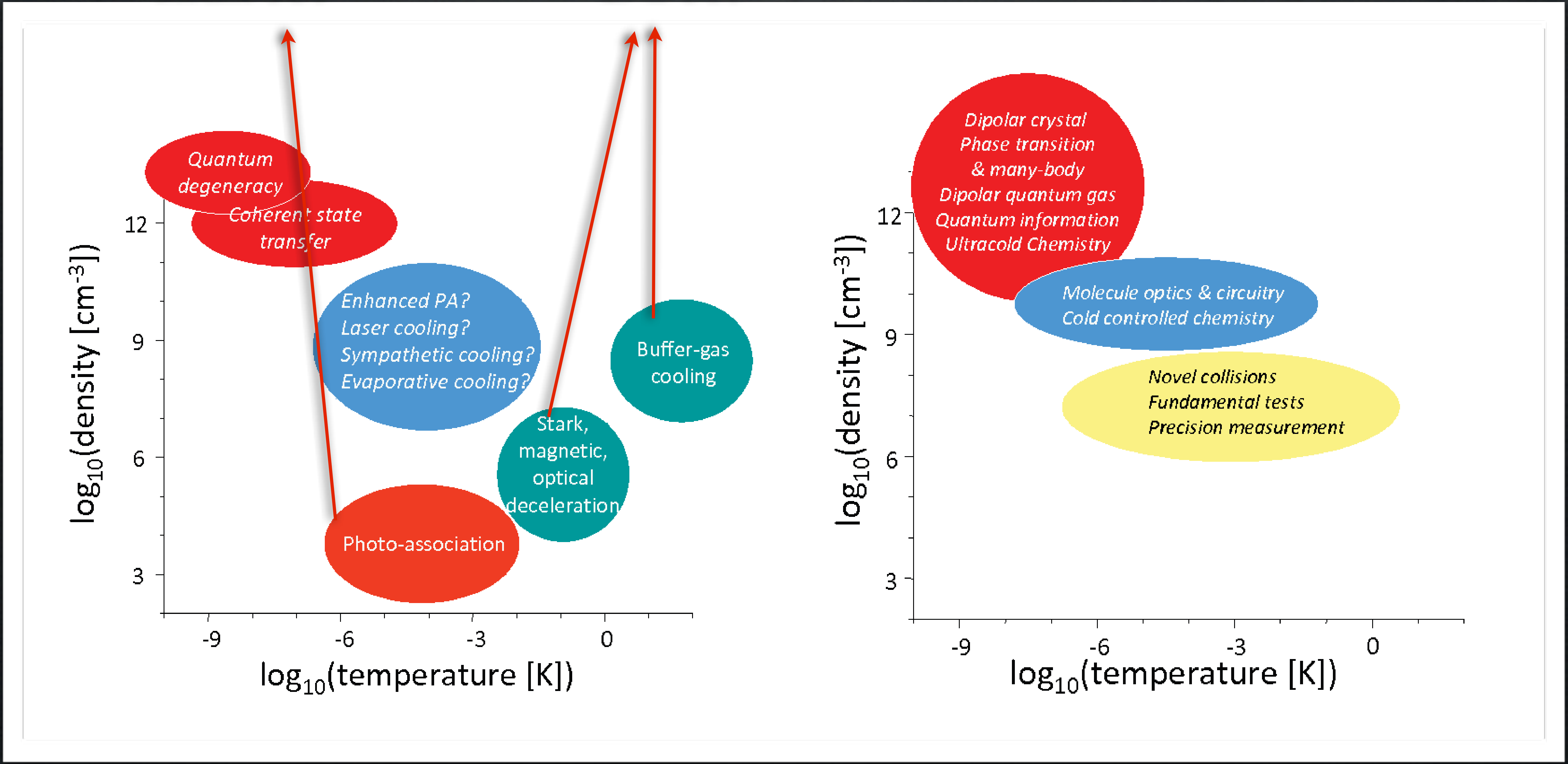


Carr, Demille, Krems, Ye: special issue on cold molecules, New Journal of Physics 11 055049 (2009)

… but the experimental control to make them cold is!

Indirect

Direct



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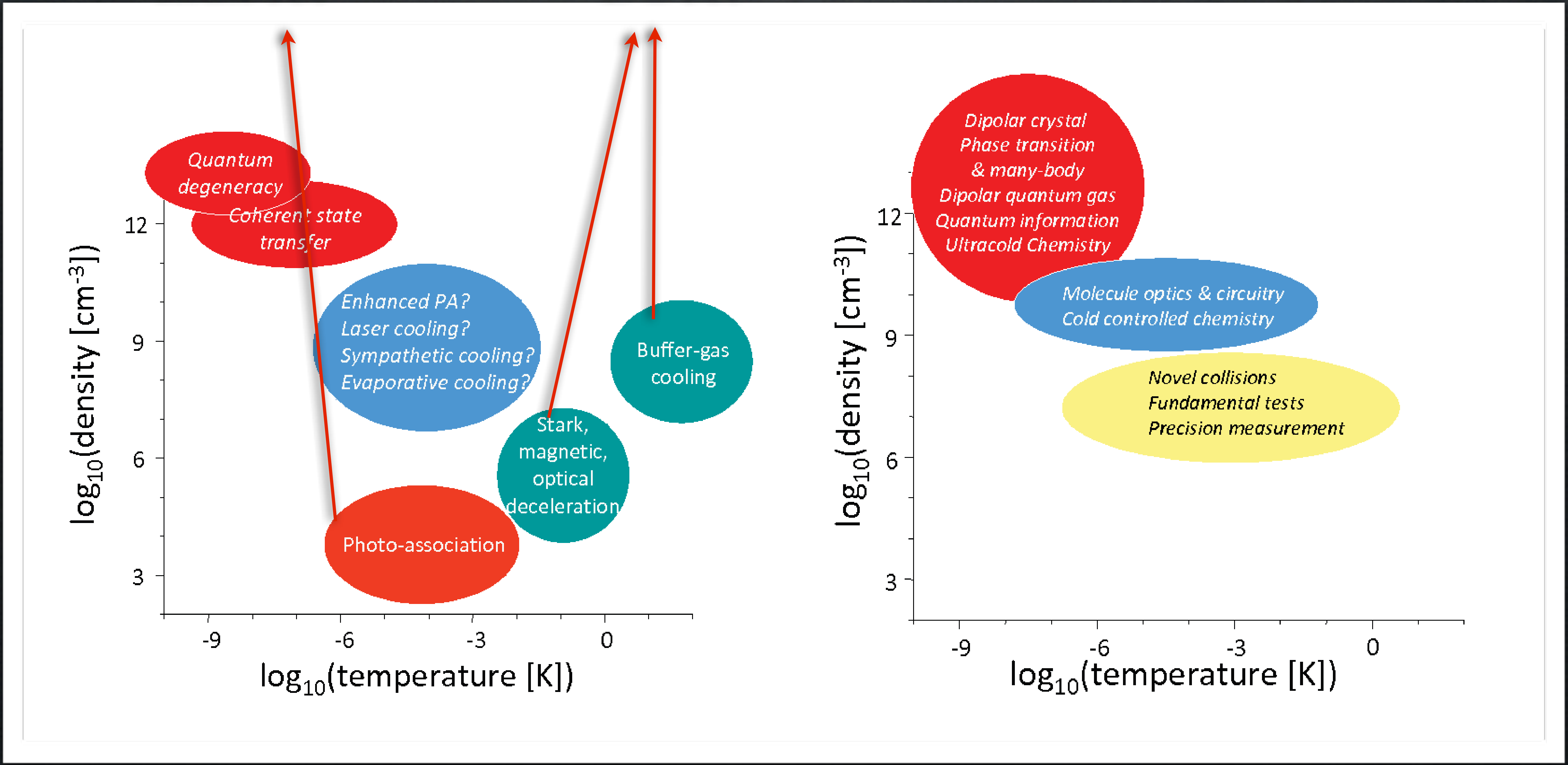
… but the experimental control to make them cold is!

The ultimate precision experiment is performed on a sample of ultracold, trapped molecules, prepared in a single quantum state.

Indirect Direct



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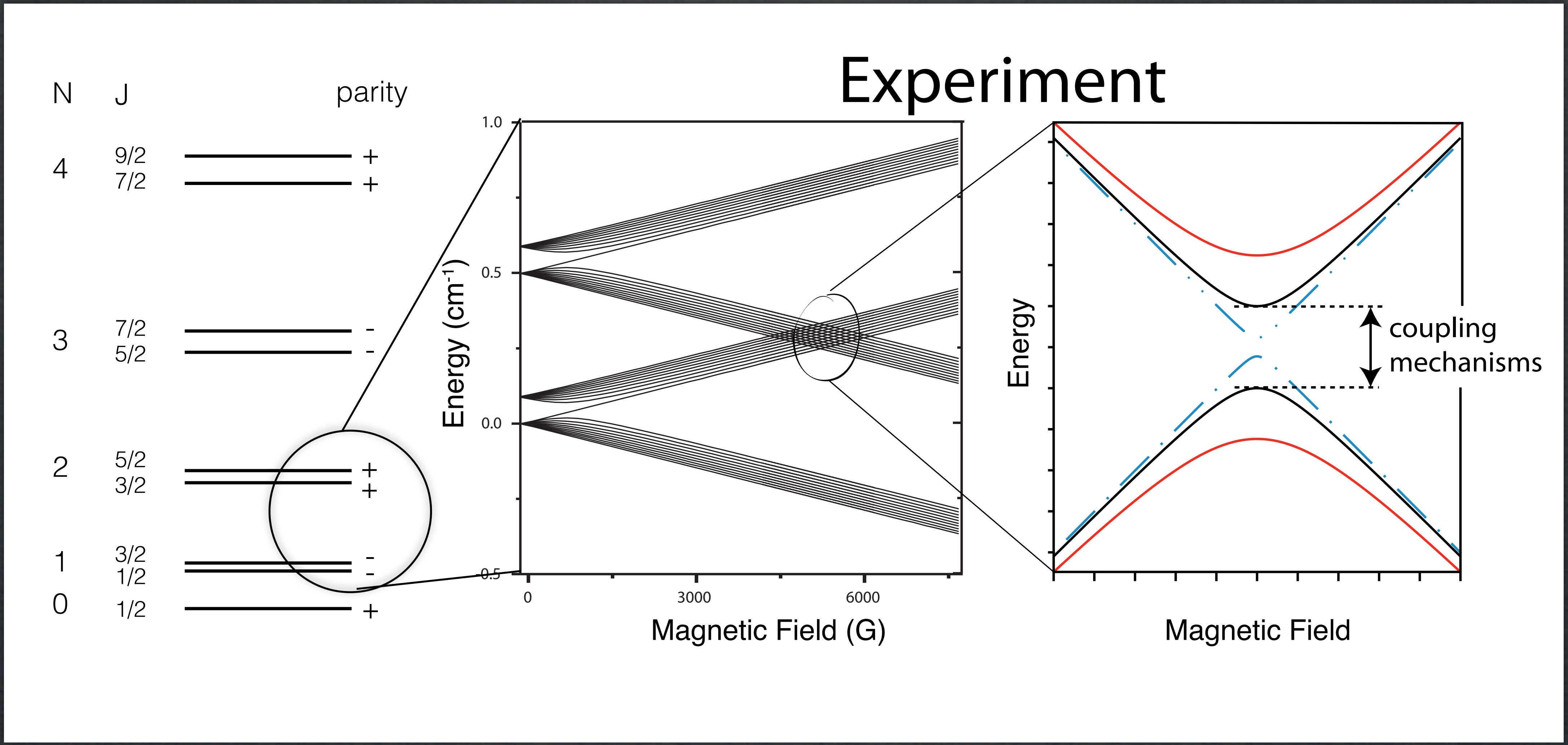
Goal: use cold trapped gasses of these molecules as extremely sensitive antenna's for new physics

Measure parity-violating coupling in SrF:



Potential enhancement compared to atoms: 10^4-10^5

Stability needed: ~ 1 kHz

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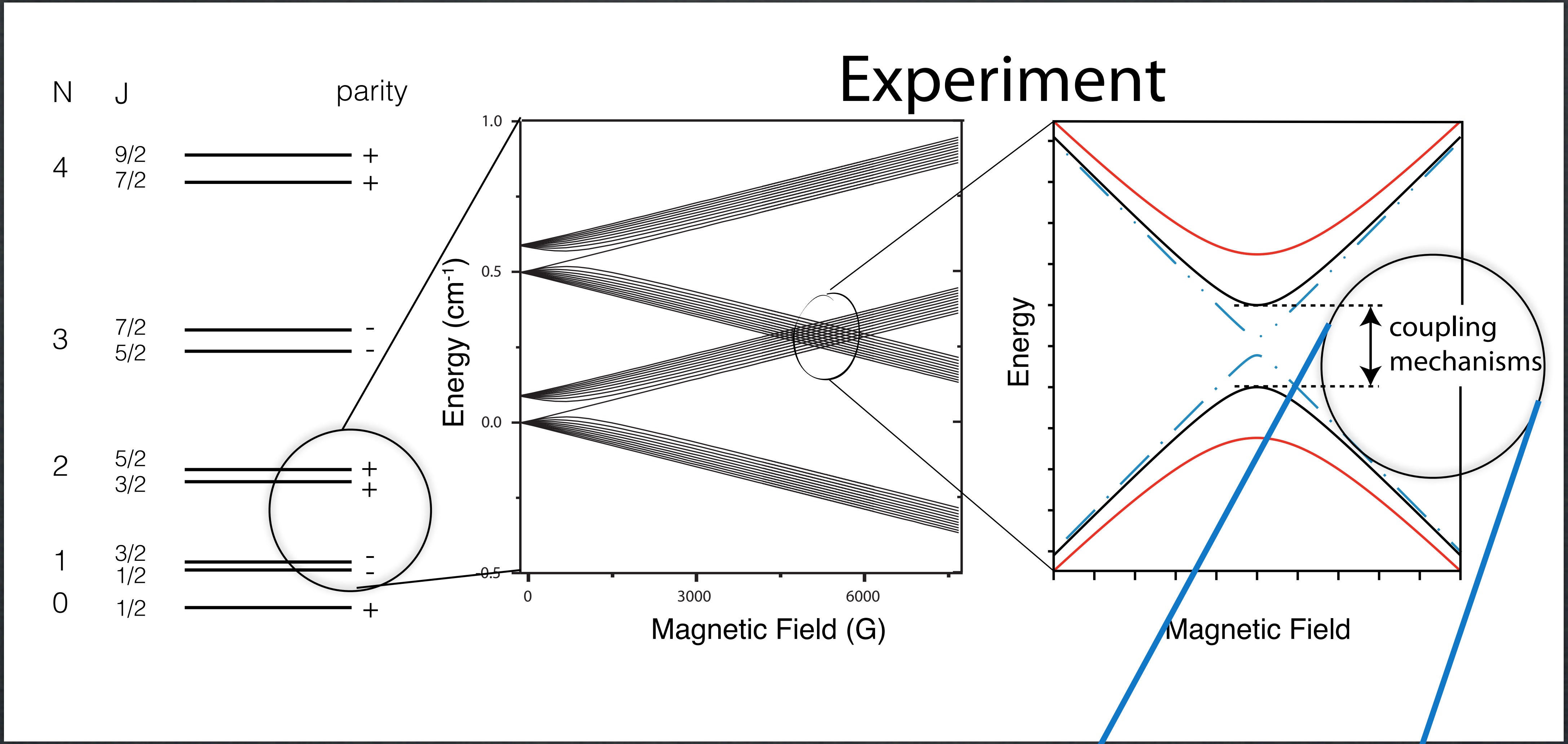

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Theory

Theory input: P,T violating physics within - and outside of - the Standard Model

- Selection of best candidate atoms & molecules
- Translate observable to Standard Model parameter

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Testing the Standard Model of particle physics:

Electroweak interaction (Flambaum, Kozlov, Derevianko, DeMille)

- Anapole moment (nucleon-nucleon)
- Weak charge (quark-electron)
- Spin-dependent weak interaction (quark-electron)

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Looking beyond the Standard Model:

Coupling of Z^0 to a dark Z_d boson? (Marciano)

- Parity violation experiments might provide[1] 'a window to the dark side'

Existence of an electron-EDM?

- Current best measurement of the shape of the electron provided[2] by a measurement using YbF
- Additional sources of CP violation are needed to explain antimatter

[1] H. Davoudiasl, H.-S. Lee, and W. J. Marciano, Phys Rev D **85**, 115019 (2012).

[2] J. J. Hudson, D. M. Kara, I. J. Smallman, B. E. Sauer, M. R. Tarbutt, and E. A. Hinds, Nature **473**, 493 (2011).

So what molecules are good candidates?
Open shell, enhancements for heavy nucleus

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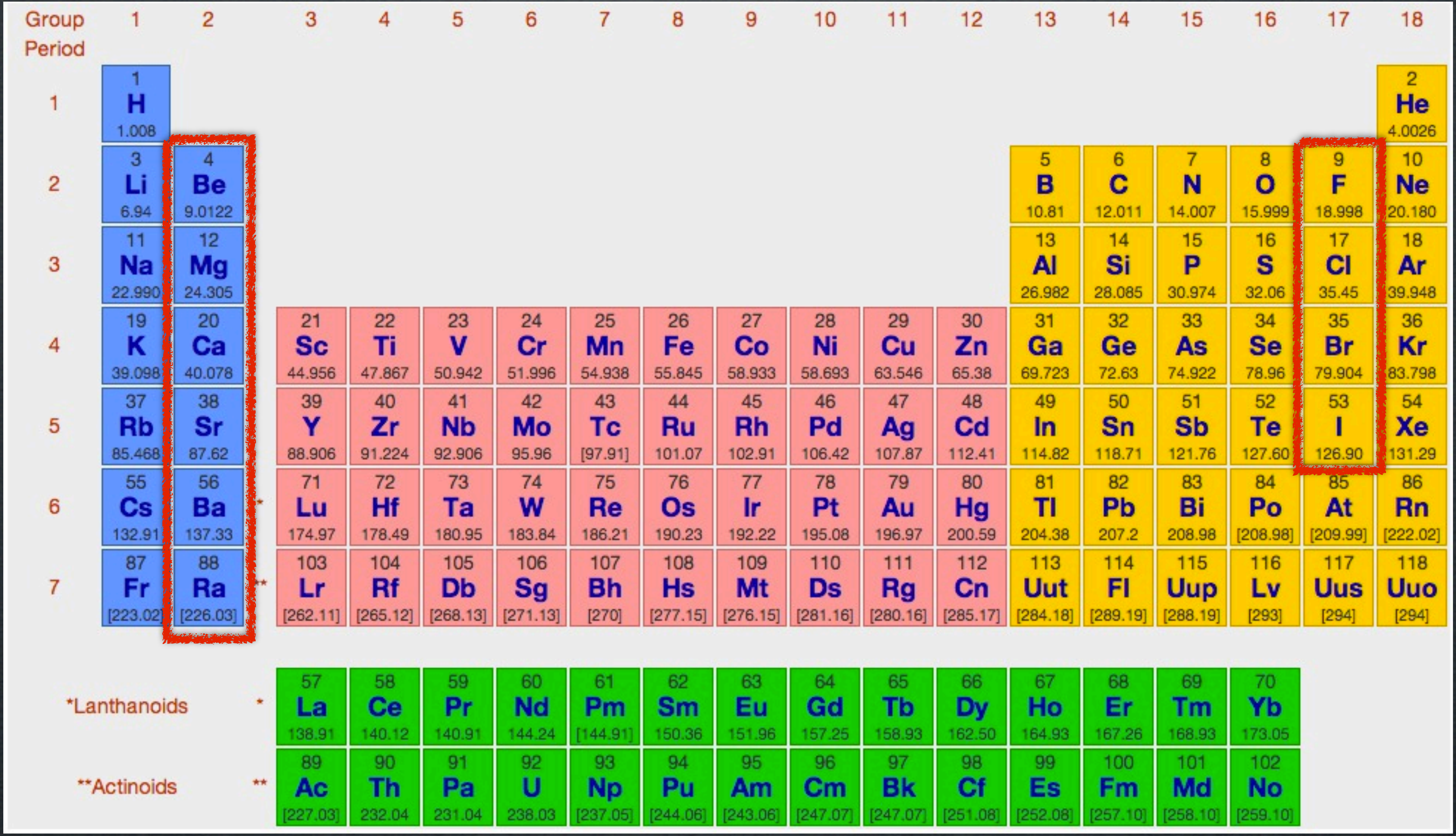
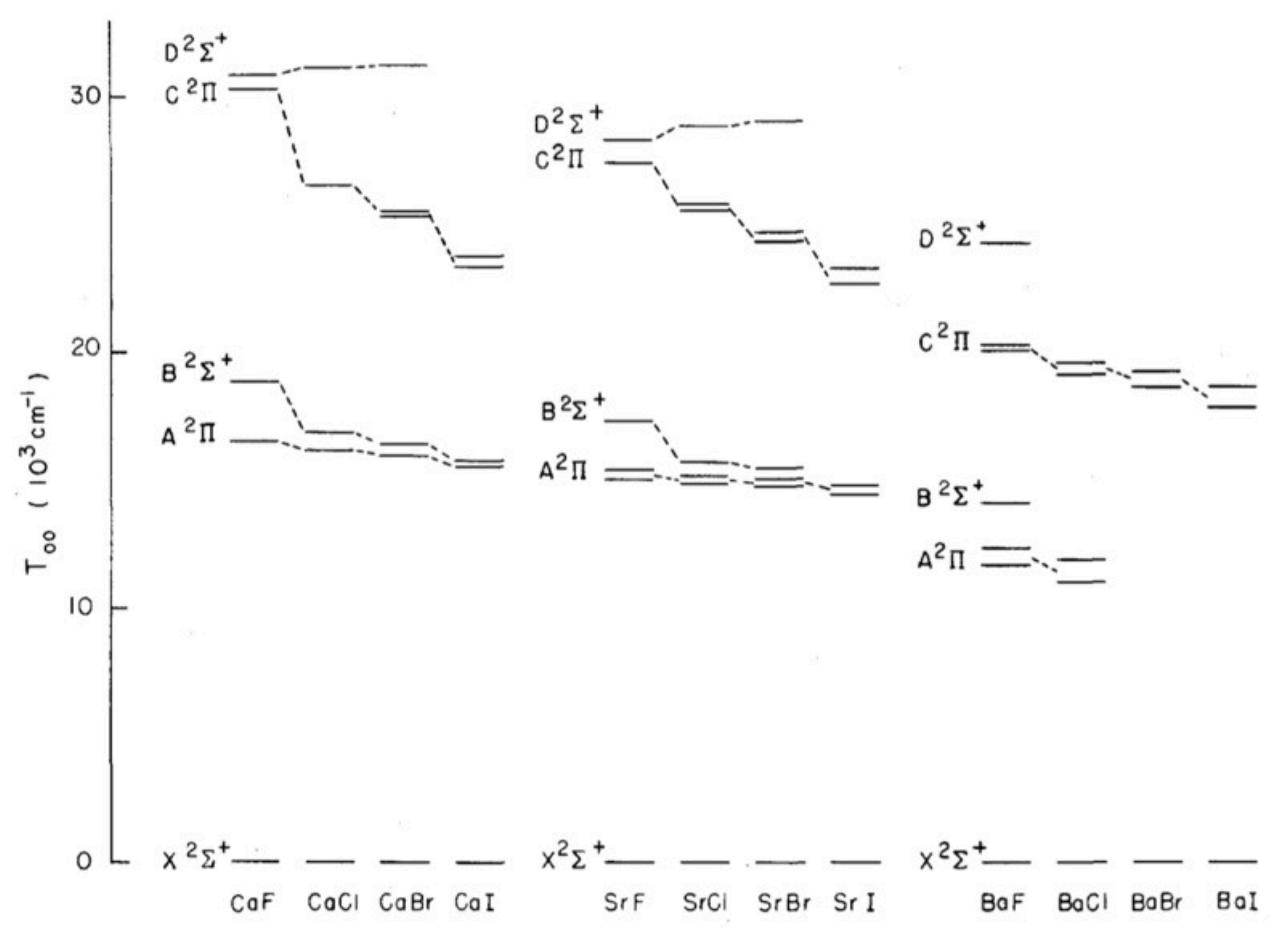


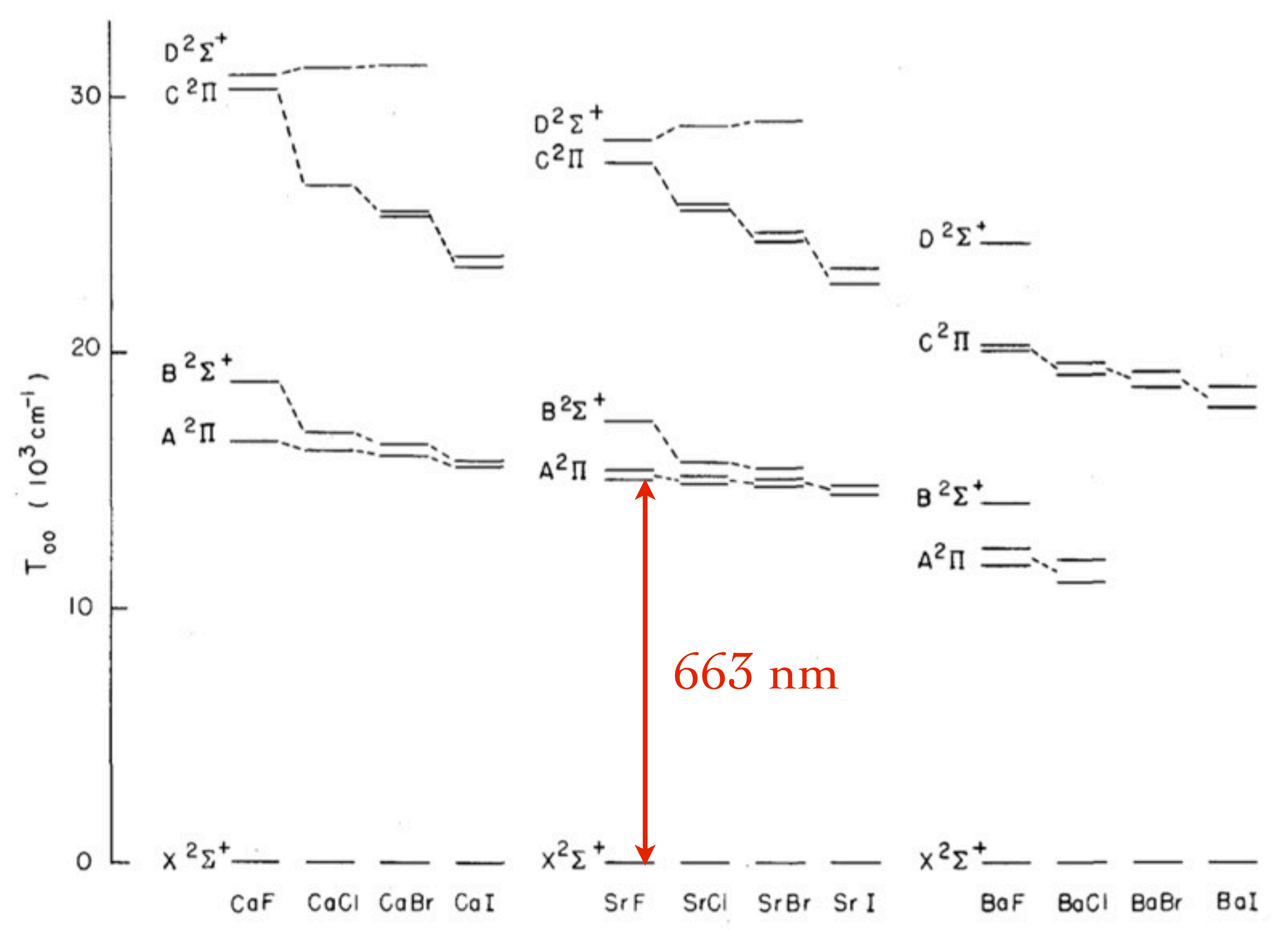
Group Period	1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 **H** 1.008																		2 **He** 4.0026
2	3 **Li** 6.94	4 **Be** 9.0122												5 **B** 10.81	6 **C** 12.011	7 **N** 14.007	8 **O** 15.999	9 **F** 18.998	10 **Ne** 20.180
3	11 **Na** 22.990	12 **Mg** 24.305												13 **Al** 26.982	14 **Si** 28.085	15 **P** 30.974	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.948
4	19 **K** 39.098	20 **Ca** 40.078		21 **Sc** 44.956	22 **Ti** 47.867	23 **V** 50.942	24 **Cr** 51.996	25 **Mn** 54.938	26 **Fe** 55.845	27 **Co** 58.933	28 **Ni** 58.693	29 **Cu** 63.546	30 **Zn** 65.38	31 **Ga** 69.723	32 **Ge** 72.63	33 **As** 74.922	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.798
5	37 **Rb** 85.468	38 **Sr** 87.62		39 **Y** 88.906	40 **Zr** 91.224	41 **Nb** 92.906	42 **Mo** 95.96	43 **Tc** [97.91]	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
6	55 **Cs** 132.91	56 **Ba** 137.33	*	71 **Lu** 174.97	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** [208.98]	85 **At** [209.99]	86 **Rn** [222.02]
7	87 **Fr** [223.02]	88 **Ra** [226.03]	**	103 **Lr** [262.11]	104 **Rf** [265.12]	105 **Db** [268.13]	106 **Sg** [271.13]	107 **Bh** [270]	108 **Hs** [277.15]	109 **Mt** [276.15]	110 **Ds** [281.16]	111 **Rg** [280.16]	112 **Cn** [285.17]	113 **Uut** [284.18]	114 **Fl** [289.19]	115 **Uup** [288.19]	116 **Lv** [293]	117 **Uus** [294]	118 **Uuo** [294]
*Lanthanoids			*	57 **La** 138.91	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** [144.91]	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05		
**Actinoids			**	89 **Ac** [227.03]	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** [237.05]	94 **Pu** [244.06]	95 **Am** [243.06]	96 **Cm** [247.07]	97 **Bk** [247.07]	98 **Cf** [251.08]	99 **Es** [252.08]	100 **Fm** [257.10]	101 **Md** [258.10]	102 **No** [259.10]		

Electronic structure



[1] P. J. Dagdigian, H. Cruse, and R. Zare, J. Chem. Phys. **60**, 2330 (1974).

Electronic structure



[1] P. J. Dagdigian, H. Cruse, and R. Zare, J. Chem. Phys. **60**, 2330 (1974).

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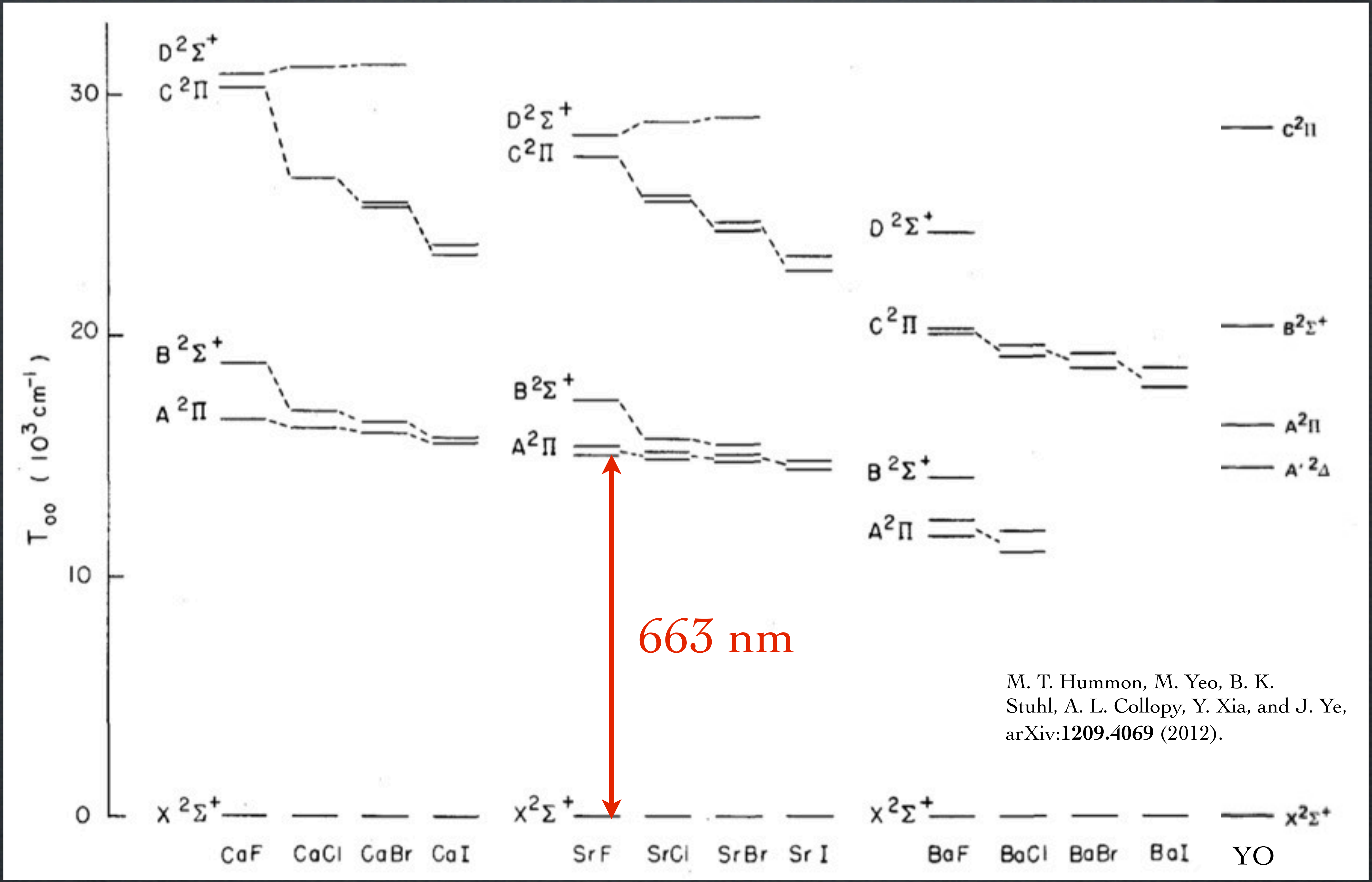


M. T. Hummon, M. Yeo, B. K. Stuhl, A. L. Collopy, Y. Xia, and J. Ye, arXiv:**1209.4069** (2012).

[1] P. J. Dagdigian, H. Cruse, and R. Zare, J. Chem. Phys. **60**, 2330 (1974).

[2] S. R. Langhoff and C. W. Bauschlicher, J. Chem. Phys. **89**, 2160 (1988).

Properties:

- Electronic lifetimes ~ 25 ns
  - large scattering rate possible
- Large Franck-Condon overlap
  - vibrationally almost closed: potential for cycling transitions
- Electronic transitions in the visible
  - diode and dye lasers

Properties:

- Electronic lifetimes ~ 25 ns
  - large scattering rate possible
- Large Franck-Condon overlap
  - vibrationally almost closed: potential for cycling transitions
- Electronic transitions in the visible
  - diode and dye lasers
- Paramagnetic
  - can be manipulated using magnetic fields and trapped
- Alternating parity in rotational structure
  - rotationally closed transition possible
  - long-lived opposite parity levels nearby
- Rotational constants ~0.25 cm^{-1}
  - rotational states can even be tuned to degeneracy
- Strongly polar ~ 3-5 Debye
  - long range anisotropic interaction
  - huge internal fields
  - can be manipulated using electric fields
- Beams can be made
  - laser ablation

All very good properties!

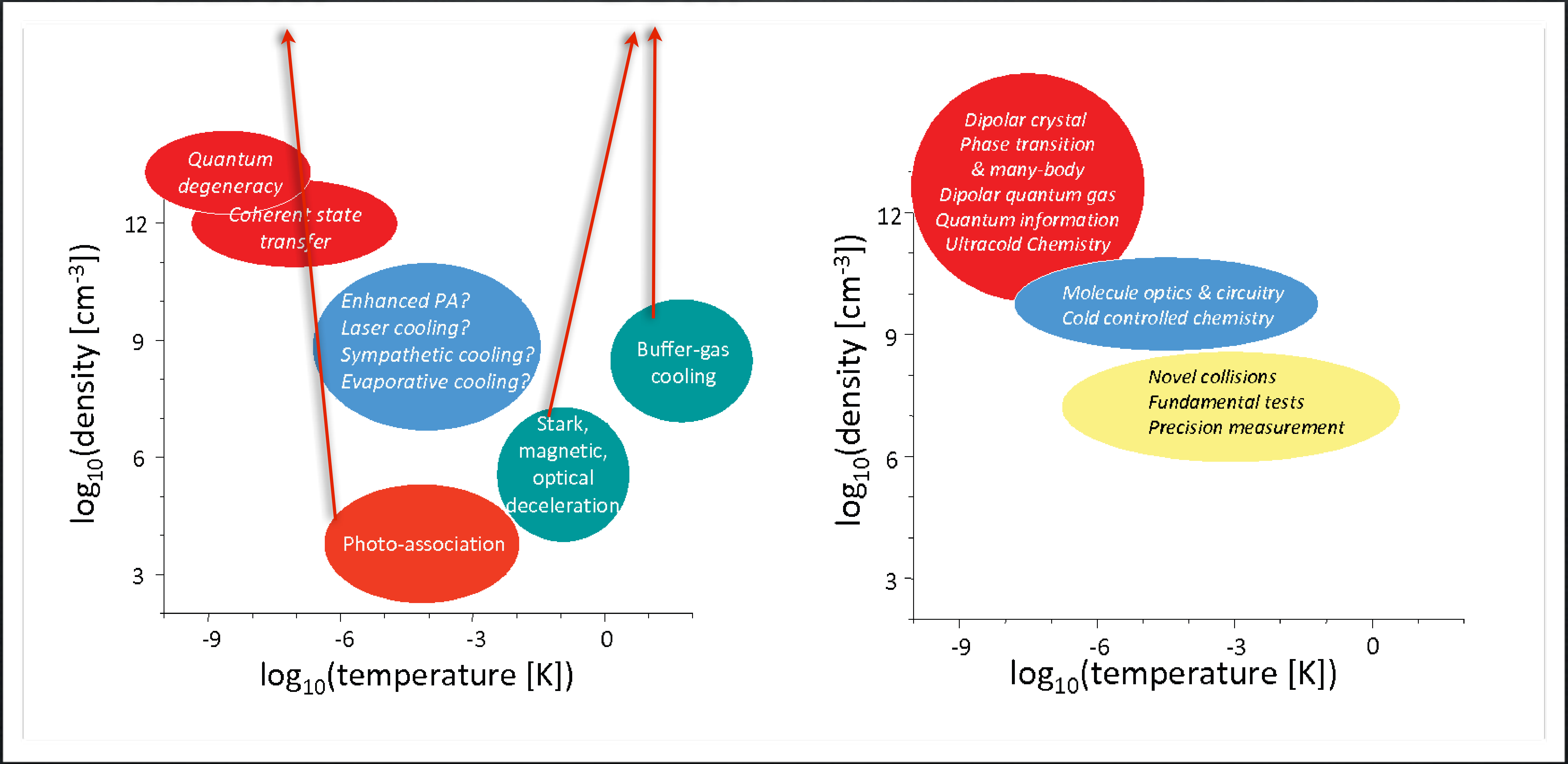
All very good properties!

But these molecules can not be formed from lasercooled atoms...

All very good properties!

But these molecules can not be formed from lasercooled atoms...

Indirect Direct



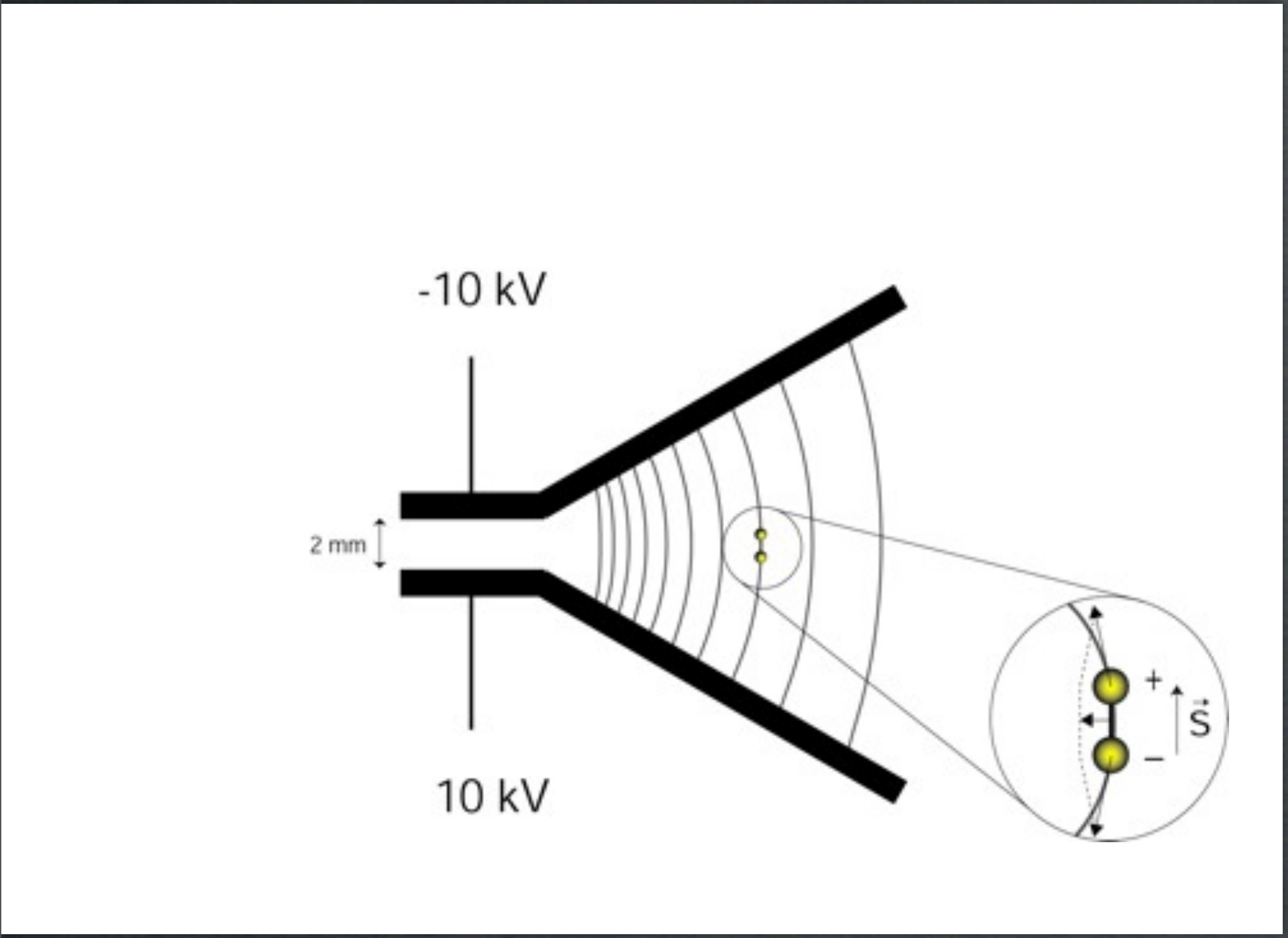
Carr, Demille, Krems, Ye: special issue on cold molecules, New Journal of Physics 11 055049 (2009)

FHI Berlin
Meijer / Haak / vd Meerakker

Stark deceleration
Overview of technique, what has been achieved

Stark decelerator:

Interaction of polar molecules with electric fields



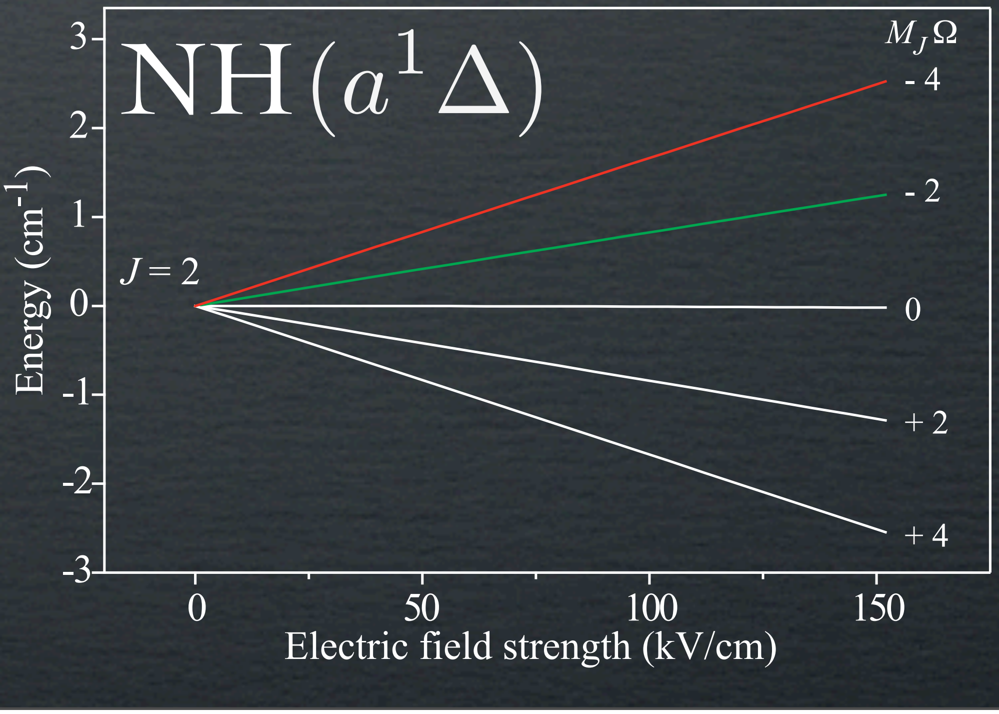
The electric field mixes close-lying states of opposite parity.

Typical Stark shifts: 1 cm^{-1} per 100 kV/cm

$$U_{pot} = W_{Stark}$$

$$W_{Stark} = -\vec{\mu} \cdot E$$

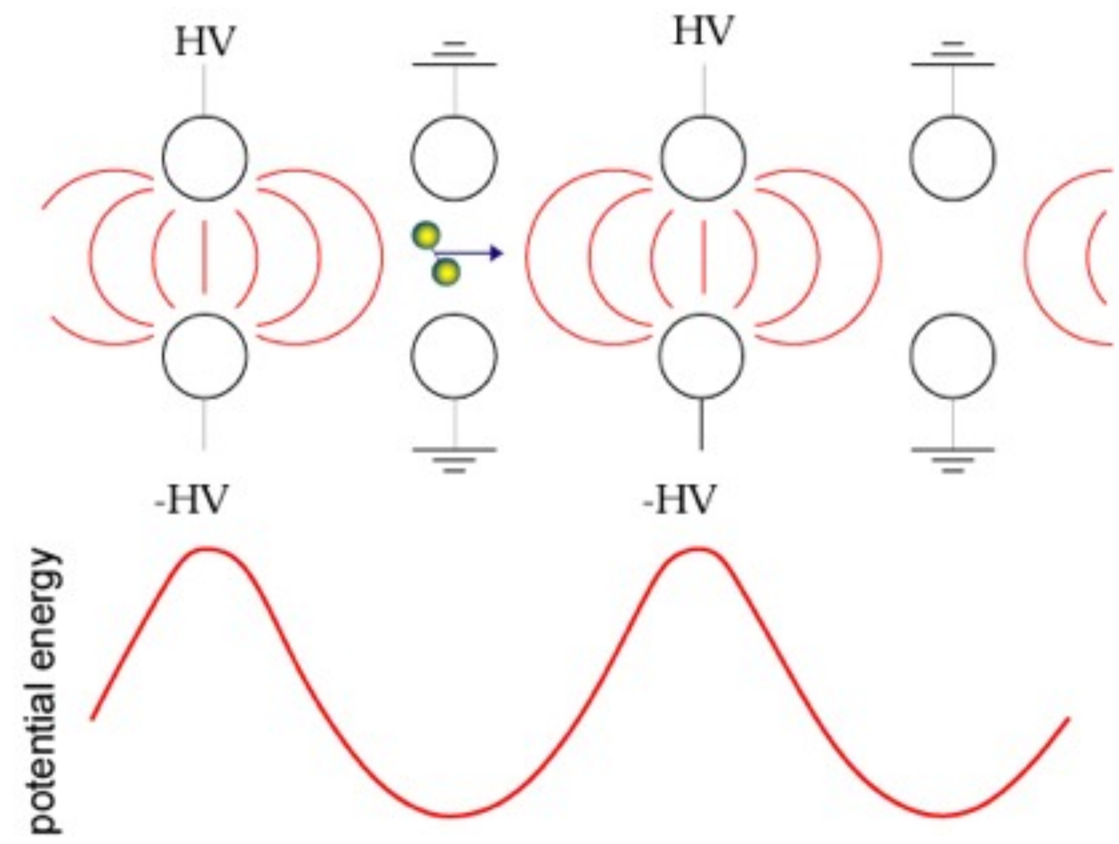
$$\vec{F}_{Stark} = -\vec{\nabla} W_{Stark}$$



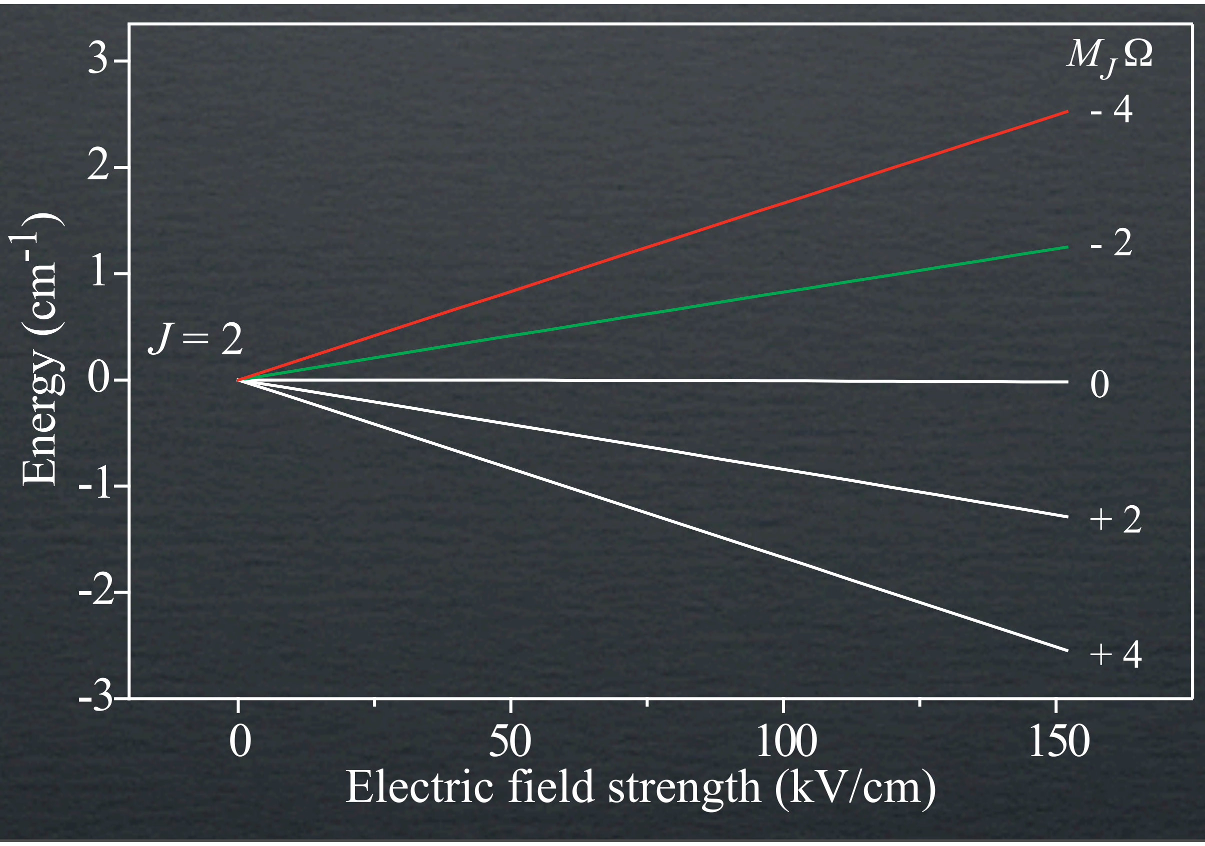
Electrostatic trapping of NH molecules

S. Hoekstra, M. Metsälä, P. Zieger, L. Scharfenberg, J. Gilijamse, G. Meijer, and S. van de Meerakker, Phys. Rev. A 76, 063408 (2007).

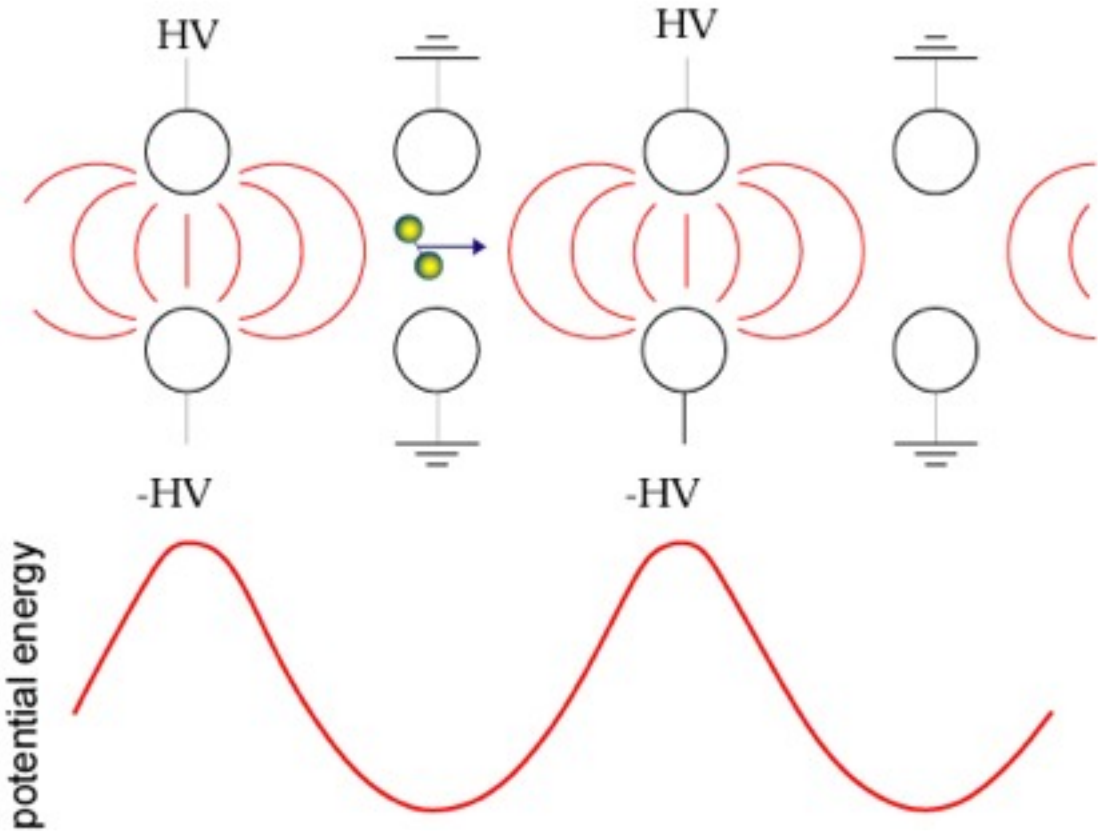
Stark decelerator: principle of operation



Molecules in low-field seeking states gain Stark energy at the expense of kinetic energy



Stark decelerator: principle of operation



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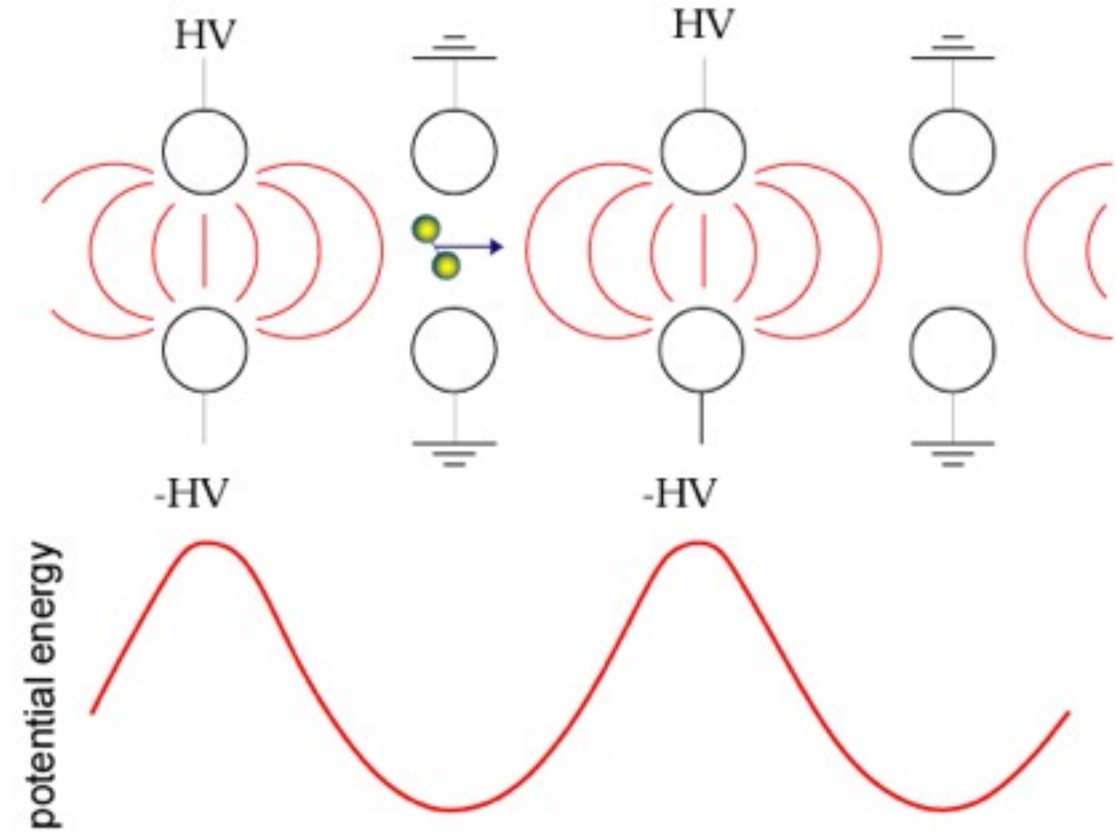

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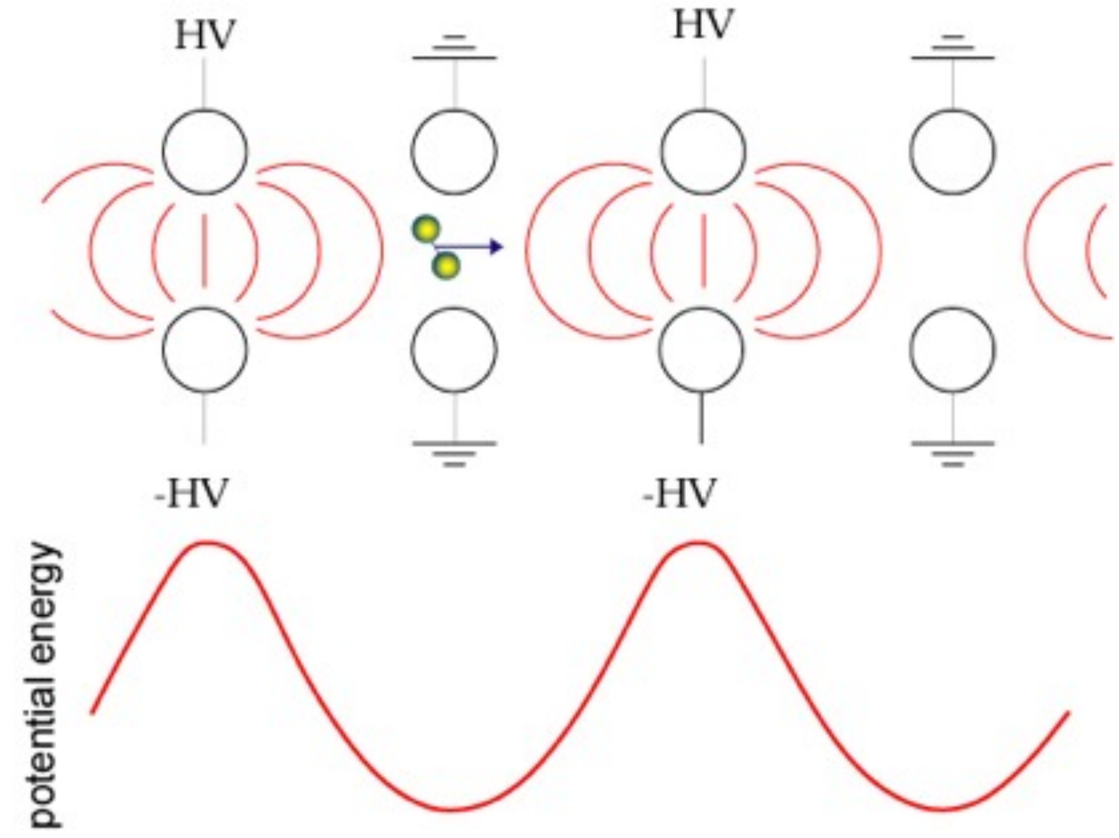

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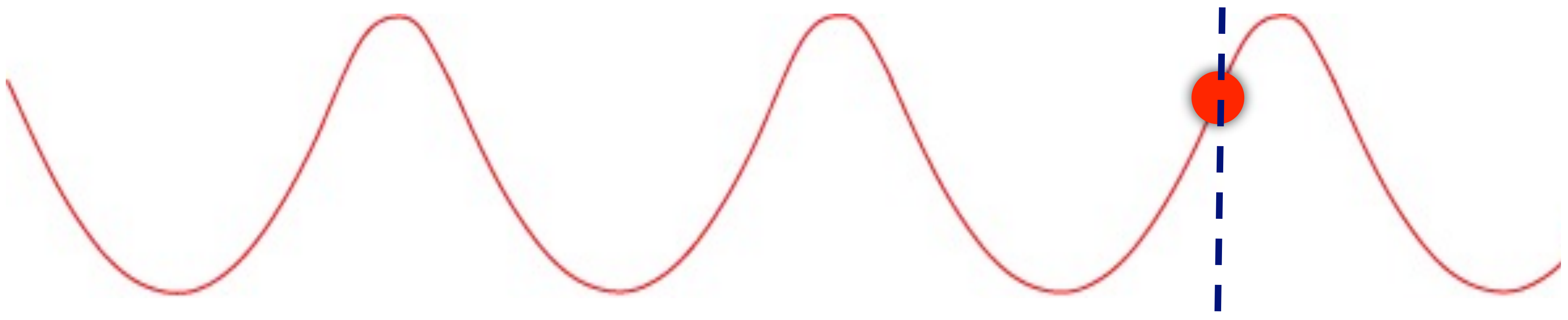
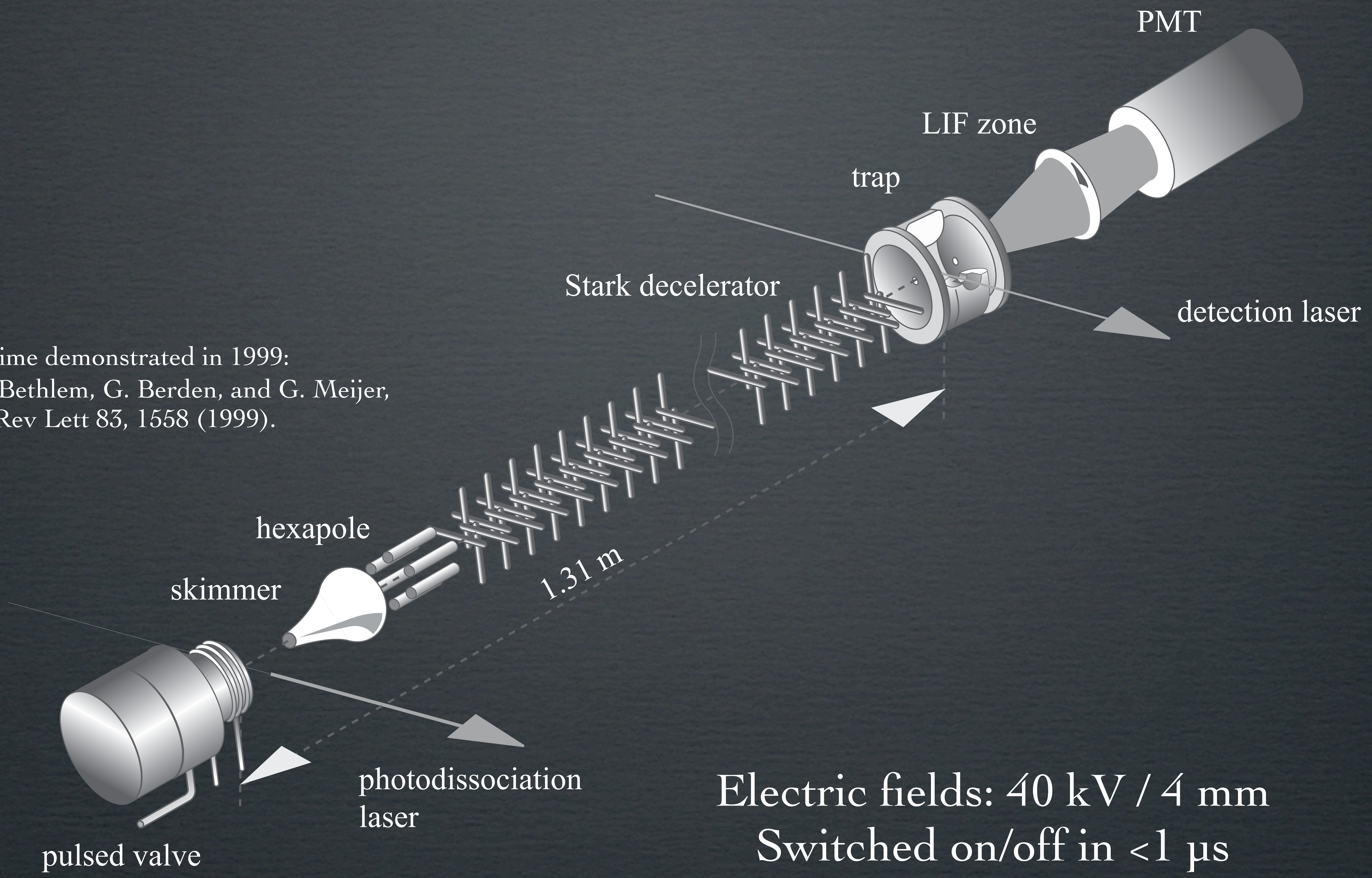


Final velocity of the beam depends on the settings of the decelerator

Stark decelerator: schematic overview

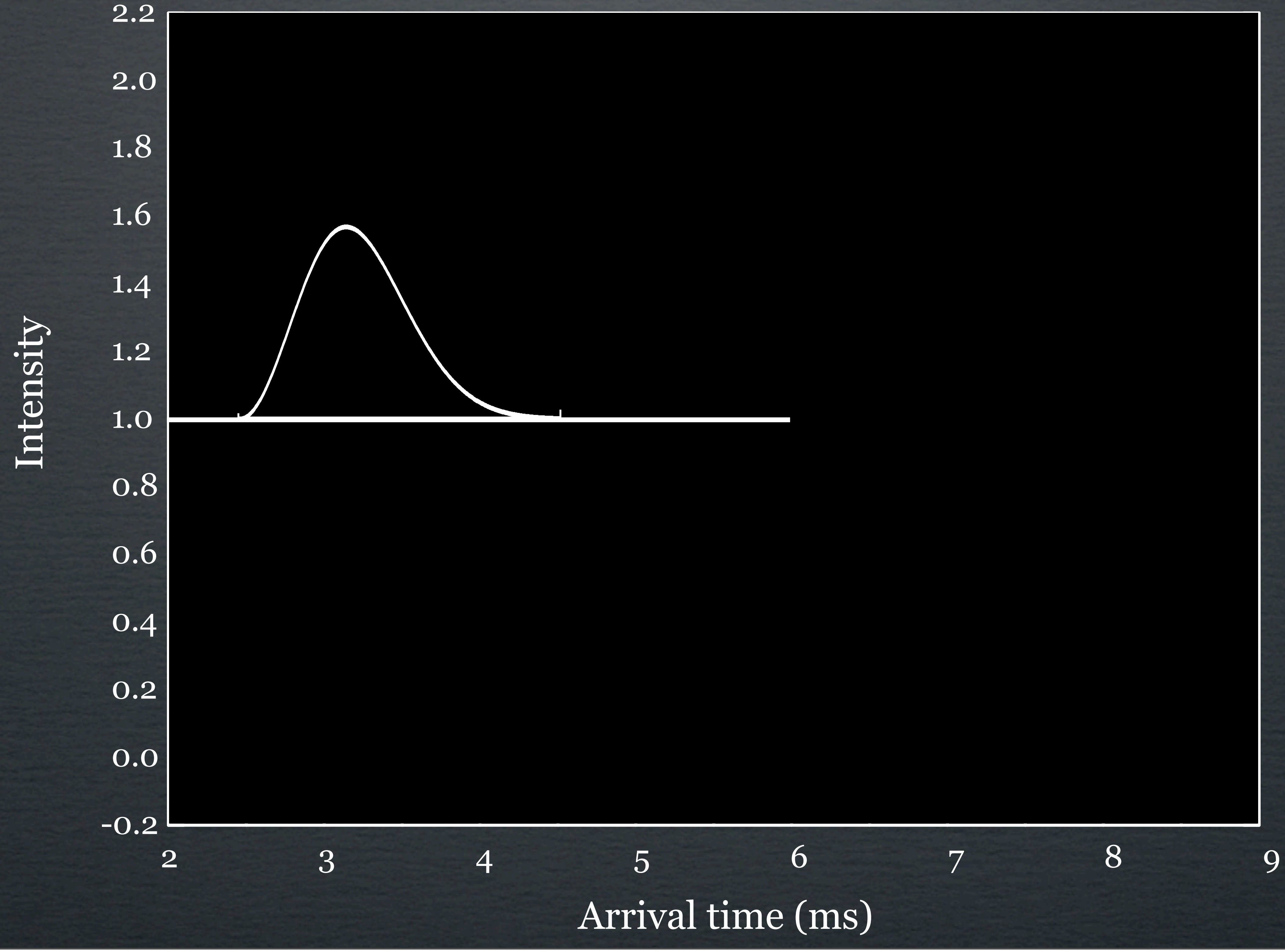


First time demonstrated in 1999:
H. L. Bethlem, G. Berden, and G. Meijer,
Phys Rev Lett 83, 1558 (1999).

Electric fields: 40 kV / 4 mm
Switched on/off in <1 µs
Number of deceleration stages: ~100

Example measurements: deceleration of OH molecules

Arrival time spectra, 100 m/s and 30 m/s deceleration
Measured with CW laser, F=2 component only



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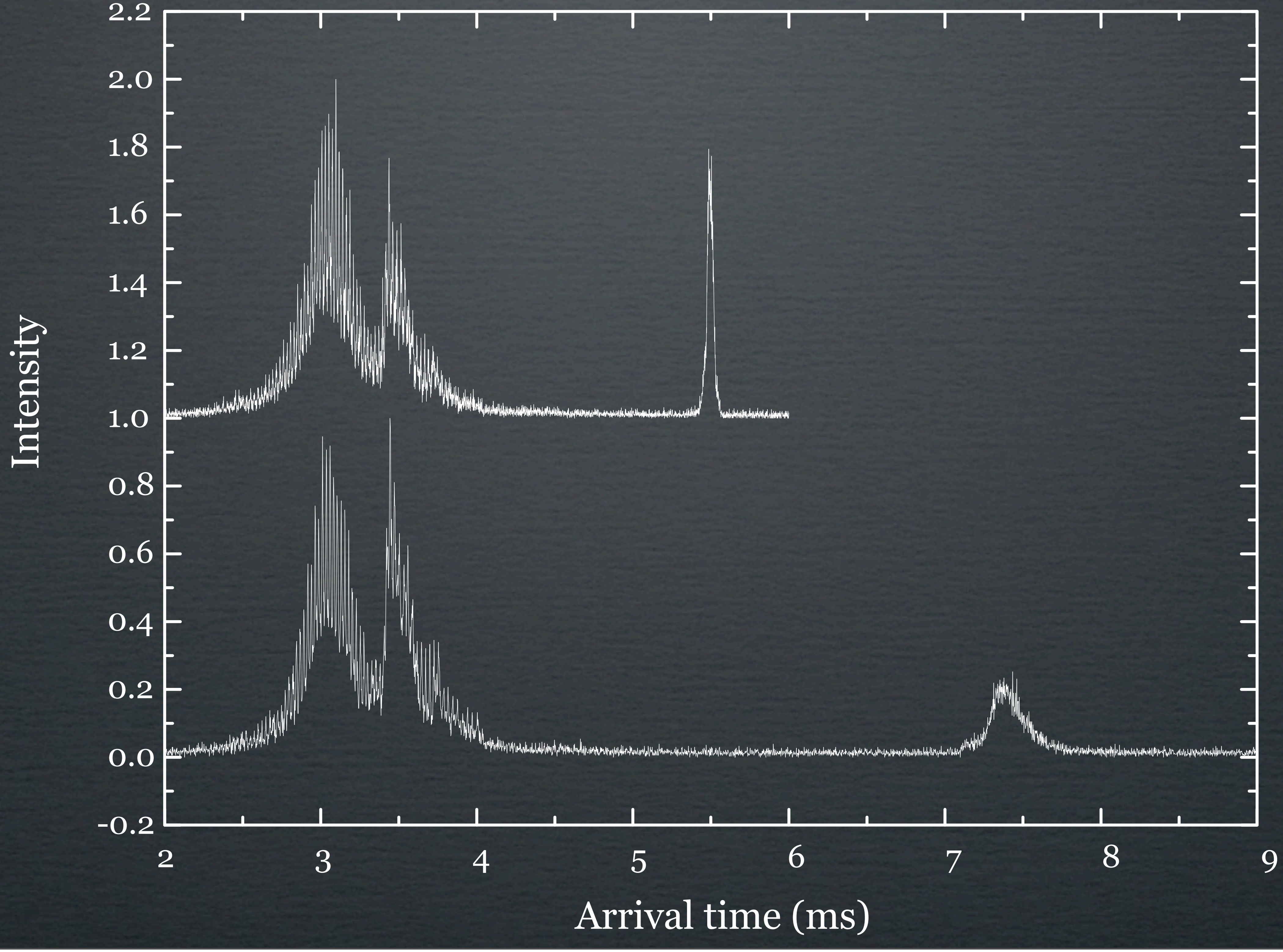
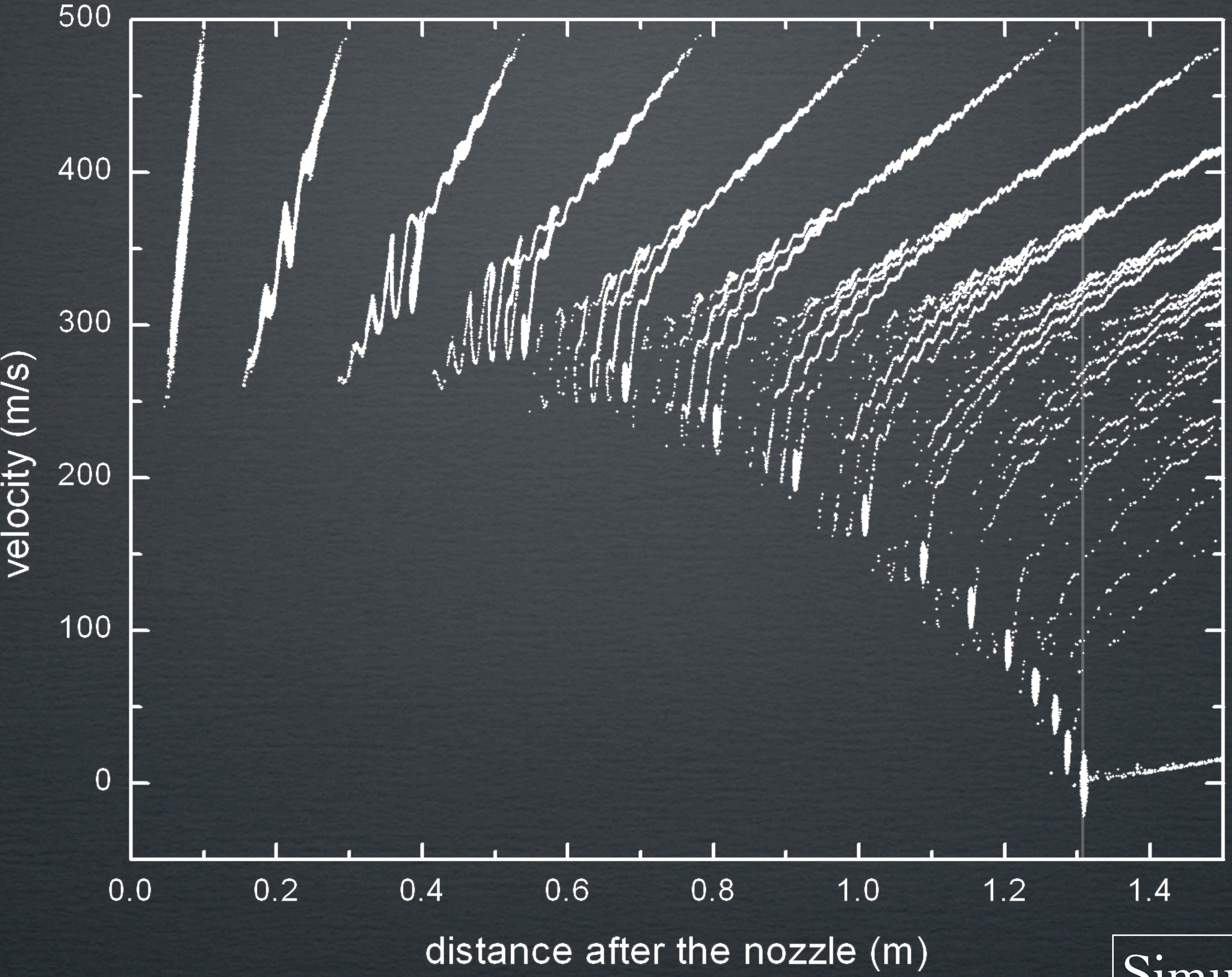
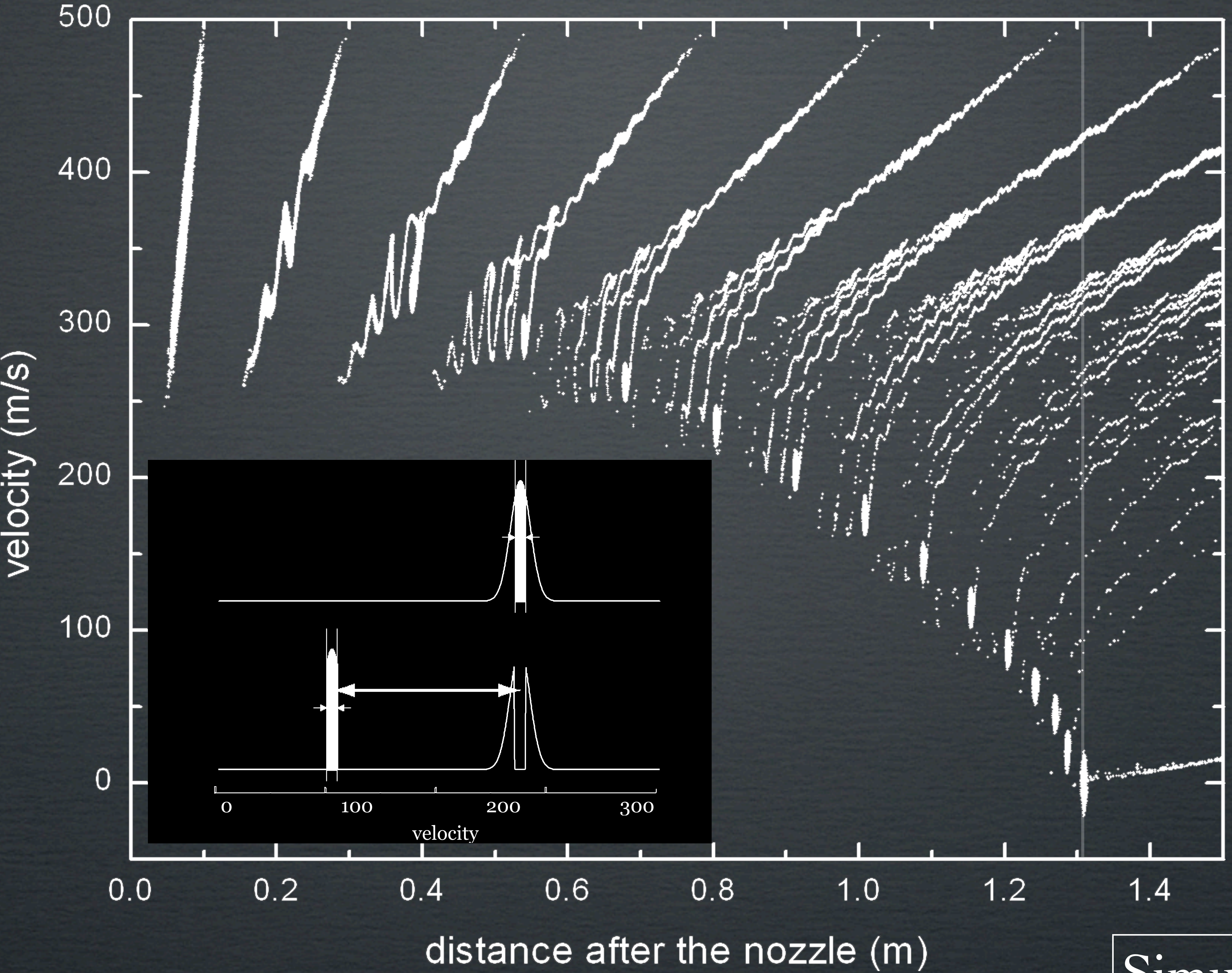


Snap-shots of the distribution of OH in (longitudinal) phase space



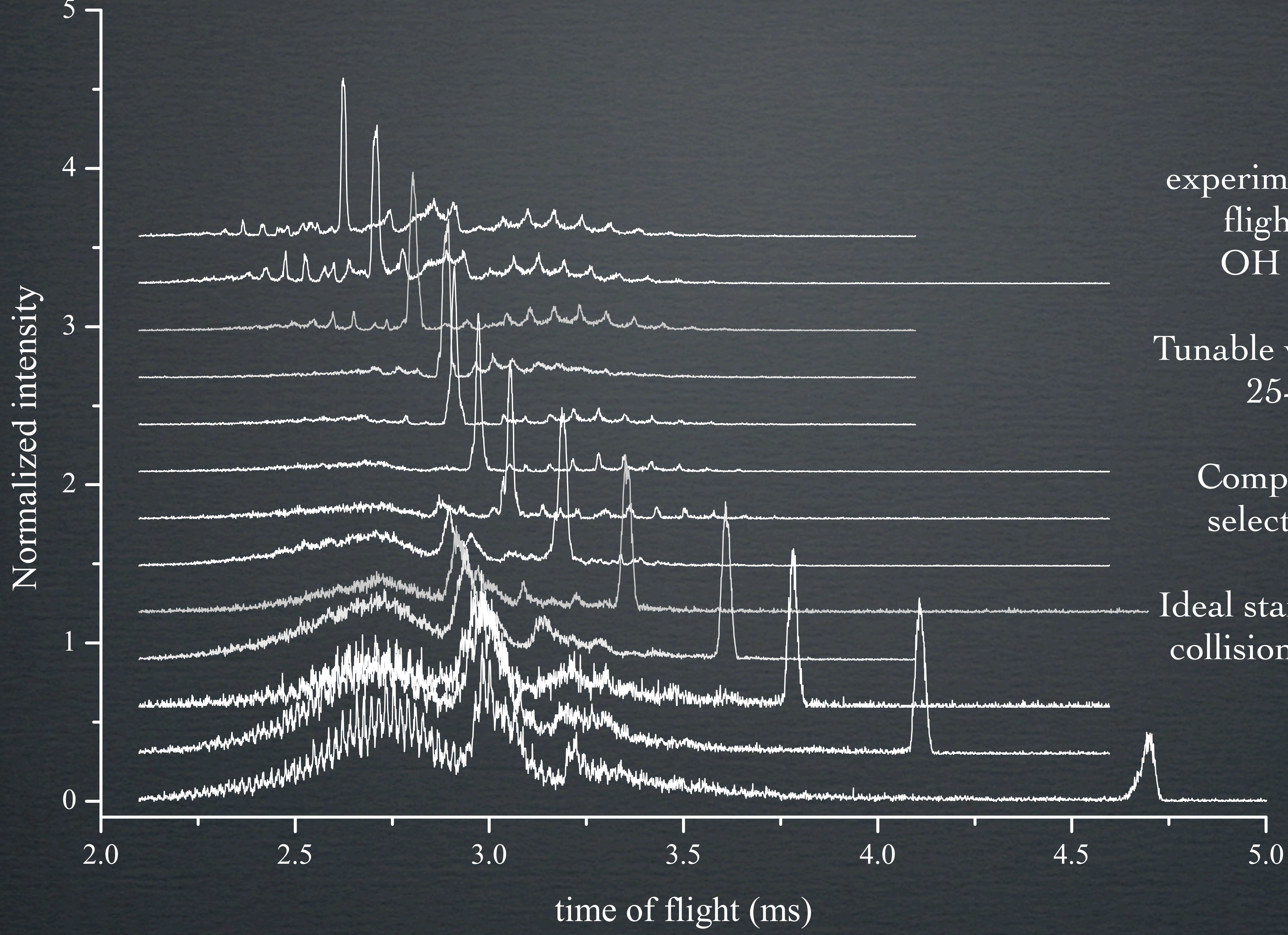
Simulation

Snap-shots of the distribution of OH in (longitudinal) phase space



Simulation

Velocity tunable packets of molecules



experimental time-of-flight profiles: OH molecules

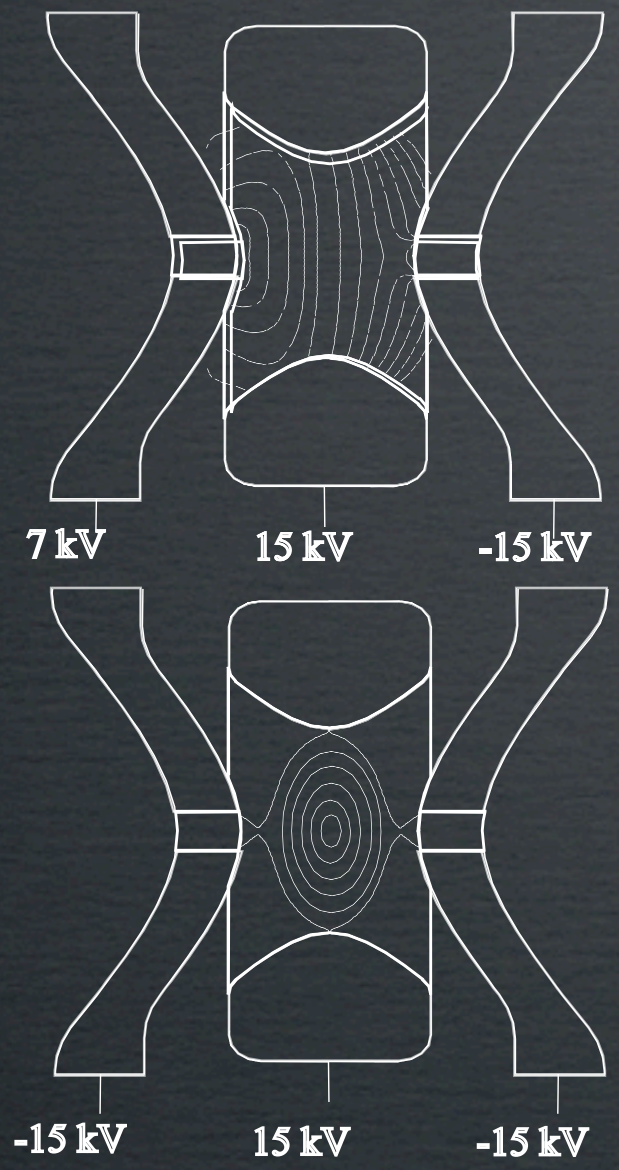
Tunable velocity range: 25-650 m/s

Completely state-selected packets

Ideal starting point for collision experiments

J. J. Gilijamse, S. Hoekstra, S. Y. T. van de Meerakker, G. C. Groenenboom, and G. Meijer, Science 313, 1617 (2006).

Example measurements:
electric trapping up to a few seconds



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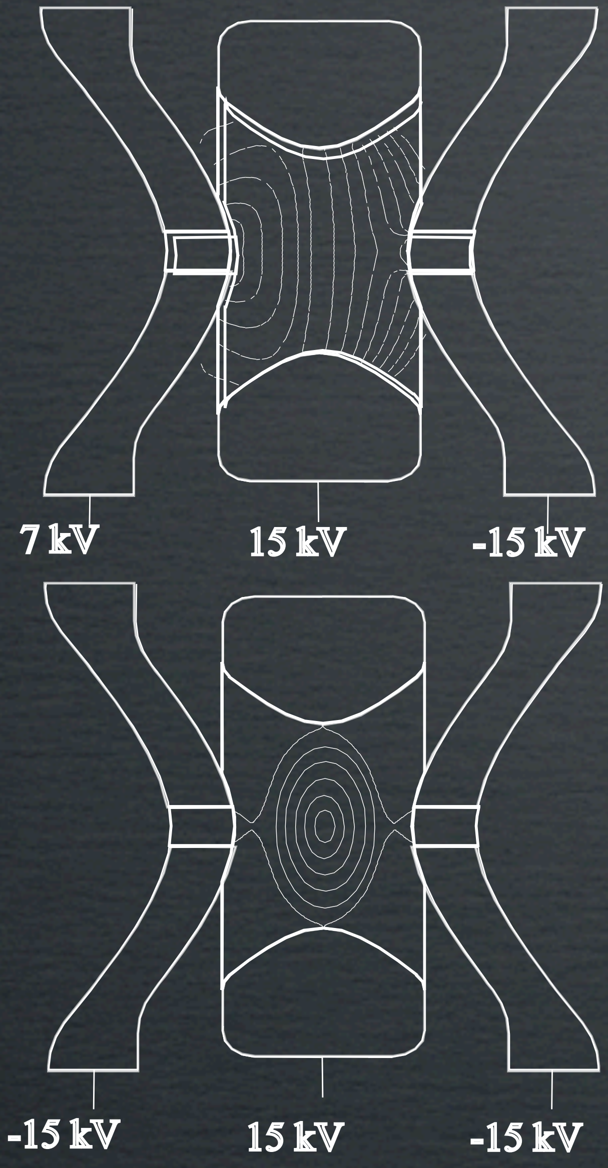
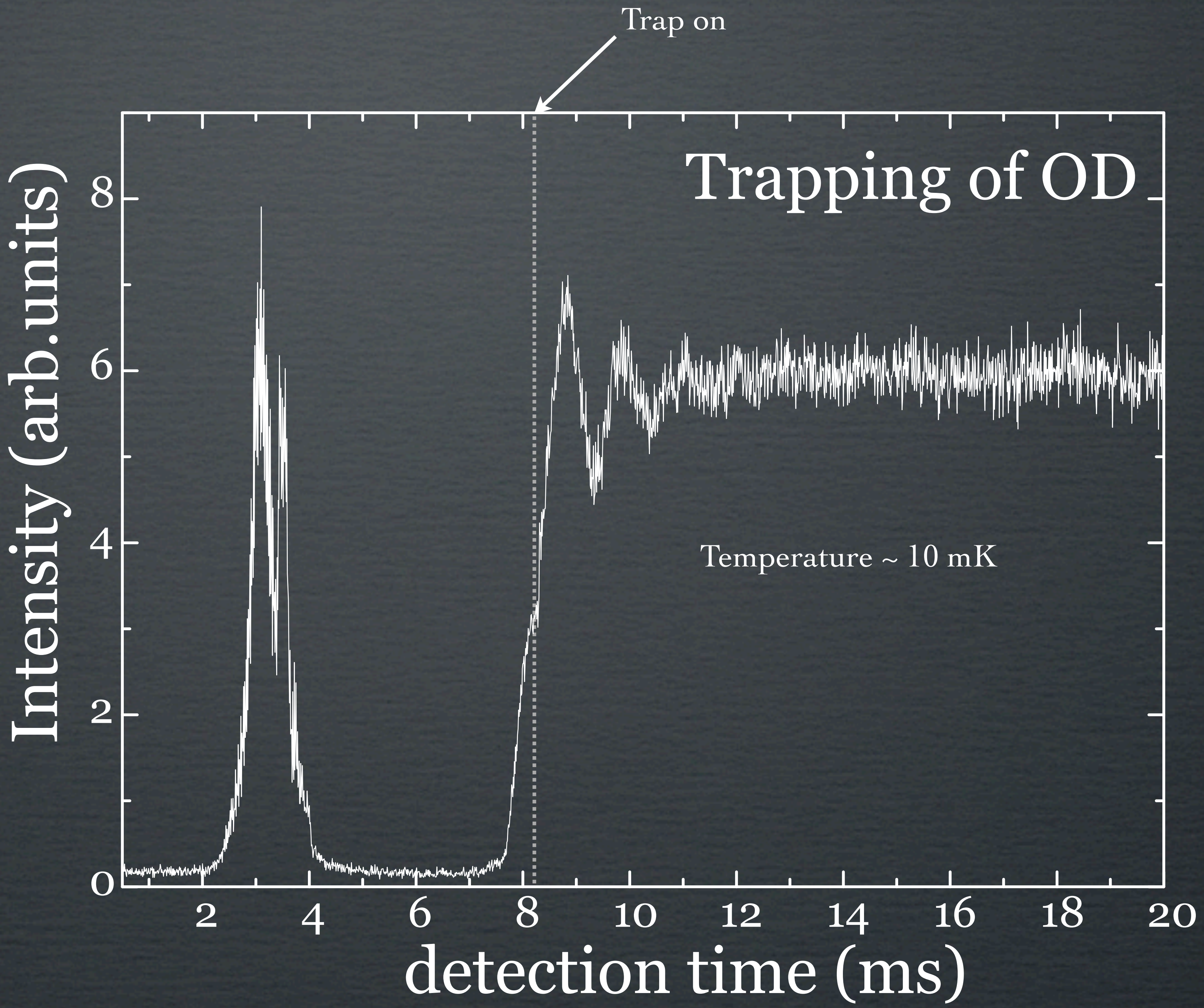




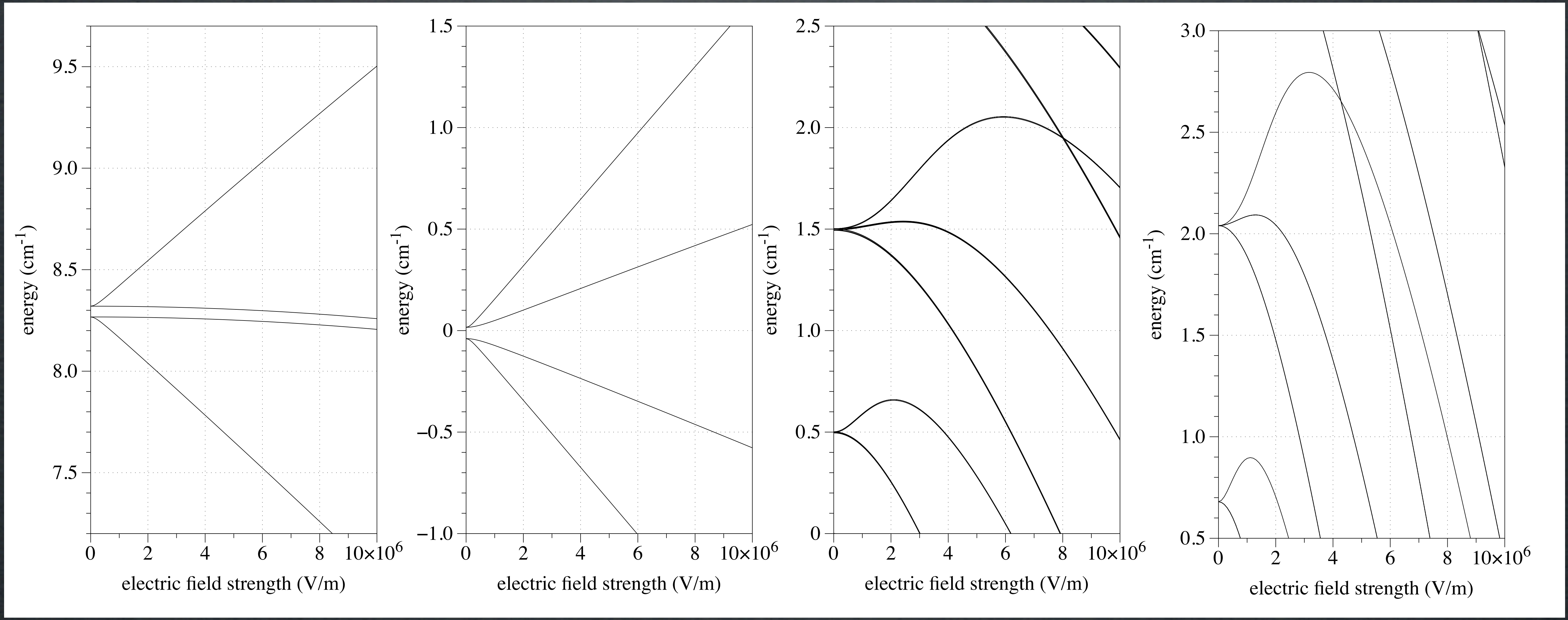
Optical pumping of trapped neutral molecules by blackbody radiation.
Steven Hoekstra, Joop J Gilijamse, Boris Sartakov, Nicolas Vanhaecke, Ludwig Scharfenberg, Sebastiaan Y T van de Meerakker, and Gerard Meijer.
Phys Rev Lett, 2007 vol. 98 (13) p. 133001.

so.... just do it!

Challenge 1: Stark curves

Limited force, because only low fields can be used.

At higher fields, the trajectories in the decelerator become unstable.



ND_3 $\quad$ OH $^2\Pi_{3/2}$ $\quad$ SrF $^2\Sigma$ $\quad$ SrO $^1\Sigma$

3.5 Debye

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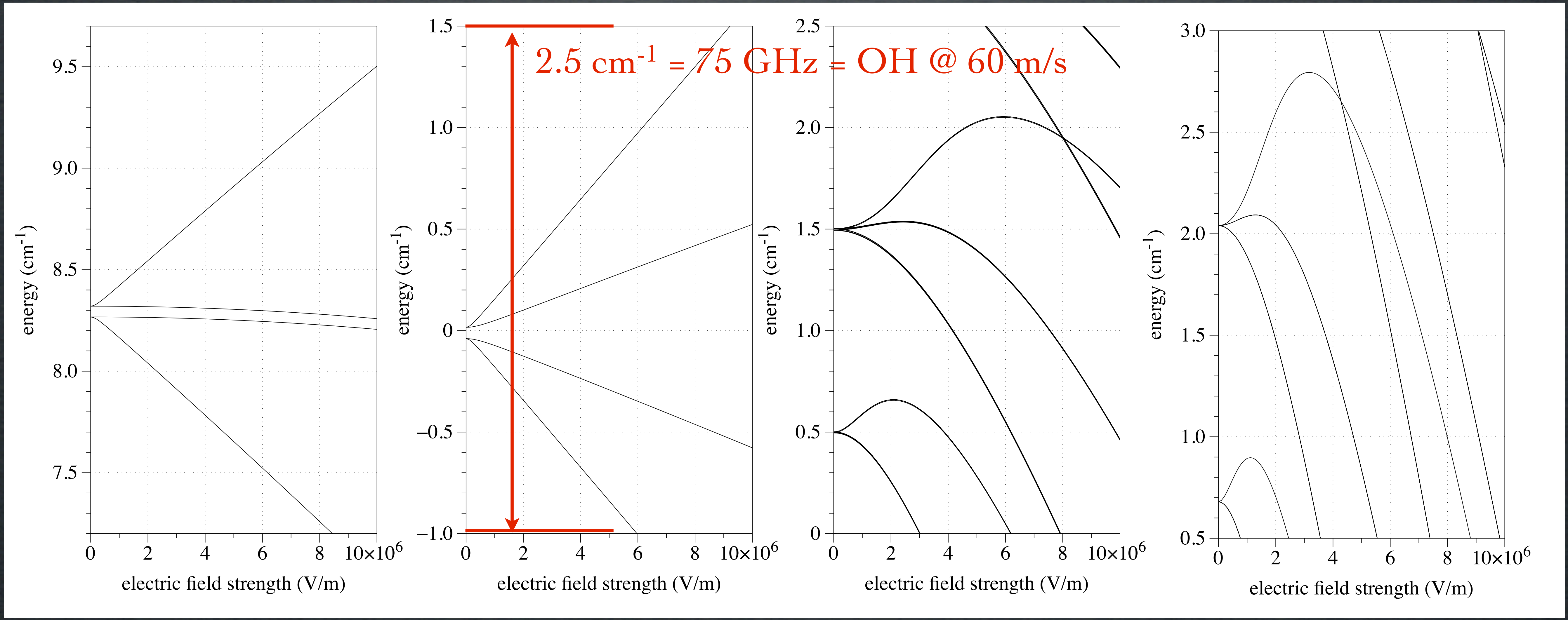

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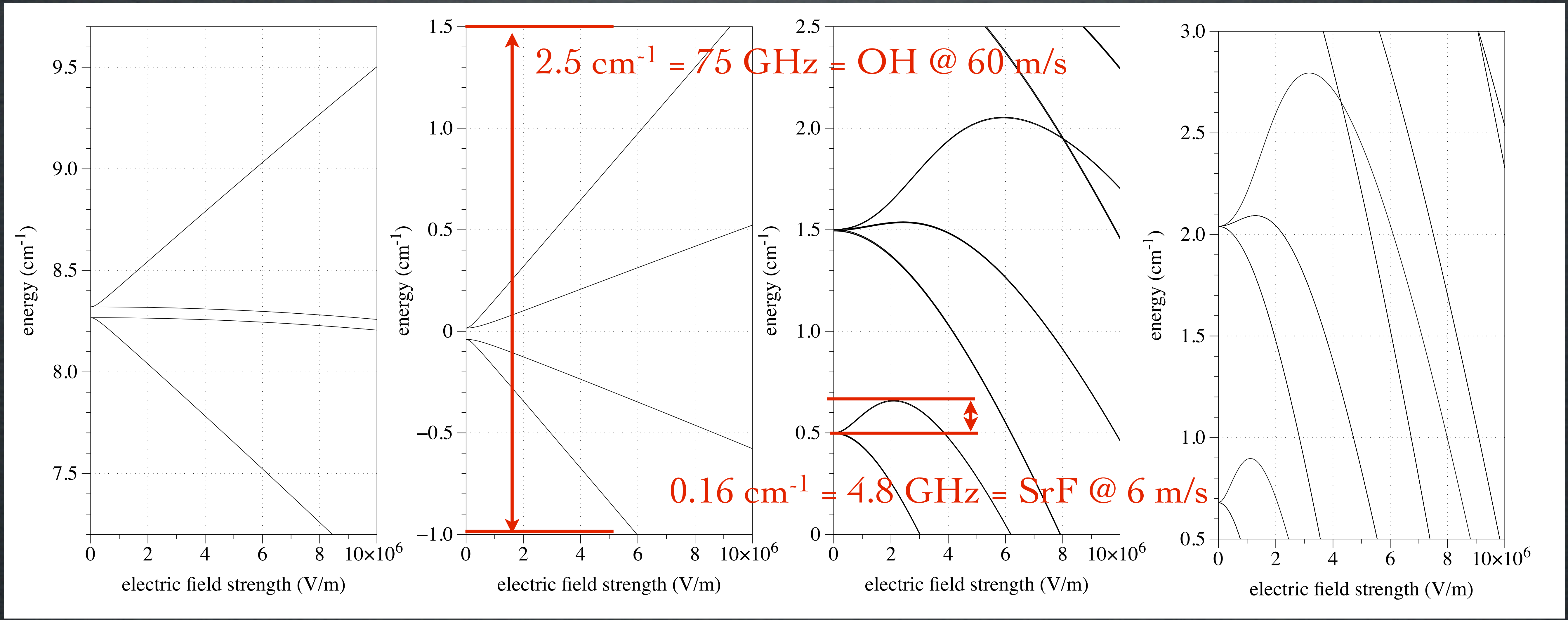


$2.5\ \mathrm{cm^{-1}}$ = 75 GHz = OH @ 60 m/s

$0.16\ \mathrm{cm^{-1}}$ = 4.8 GHz = SrF @ 6 m/s

ND_3

OH $^2\Pi_{3/2}$

SrF $^2\Sigma$

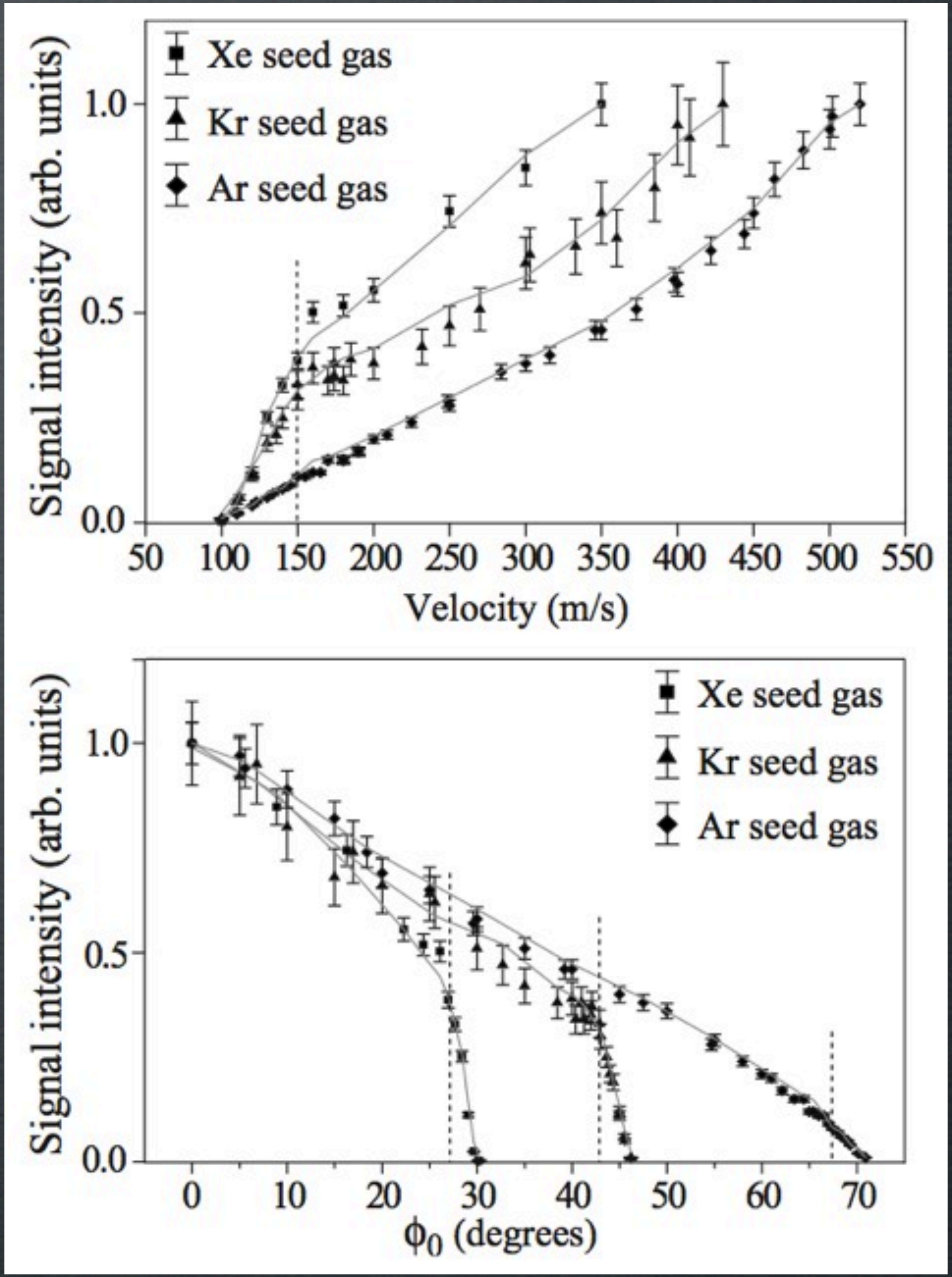
3.5 Debye

SrO $^1\Sigma$

Challenge 2: Instabilities

Where traditional decelerators fail:
coupling of longitudinal and transverse motion

SrF, due to its mass and Stark curves, needs a long decelerator :-(



L. Scharfenberg, H. Haak, G. Meijer, and S. Y. T. van de Meerakker, PRA **79**, 023410 (2009)

Solution: Ring deceleration (travellling wave)

Distribute the voltage over 8 rings: $V_n(t) = V_0 Cos(2\pi f t + 2\pi n/8)$

Oscillating voltage on rings creates a moving potential well -> co-moving traps
Stable -> now it is possible (if needed) to build a long decelerator
Molecules stay in low electric field region

mm

kV/cm

[1] A. Osterwalder, S. A. Meek, G. Hammer, H. Haak, and G. Meijer, Phys. Rev. A **81**, 051401 (2010).
metastable CO decelerated from 288 m/s to 144 m/s, using 0.5 meter decelerator

[2] N. E. Bulleid, R. J. Hendricks, E. A. Hinds, S. A. Meek, G. Meijer, A. Osterwalder, and M. R. Tarbutt, Phys. Rev. A 86, 21404 (2012).
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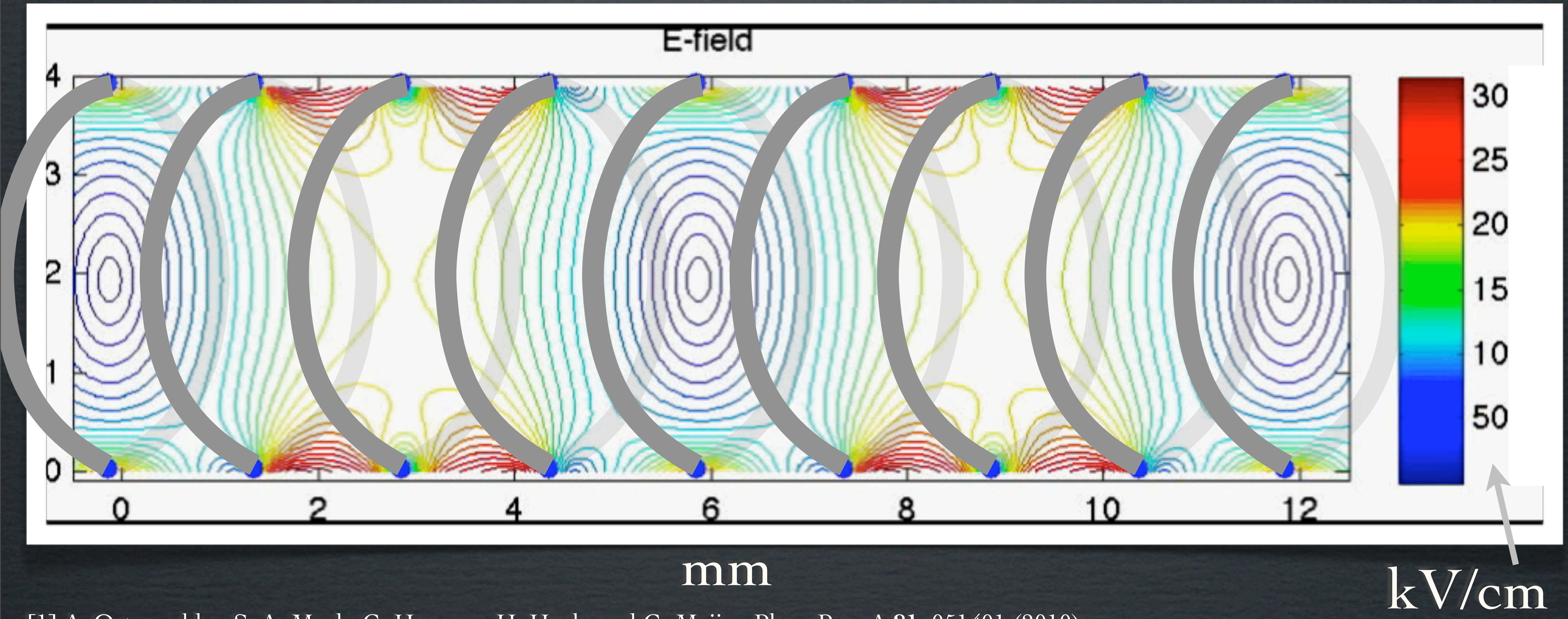

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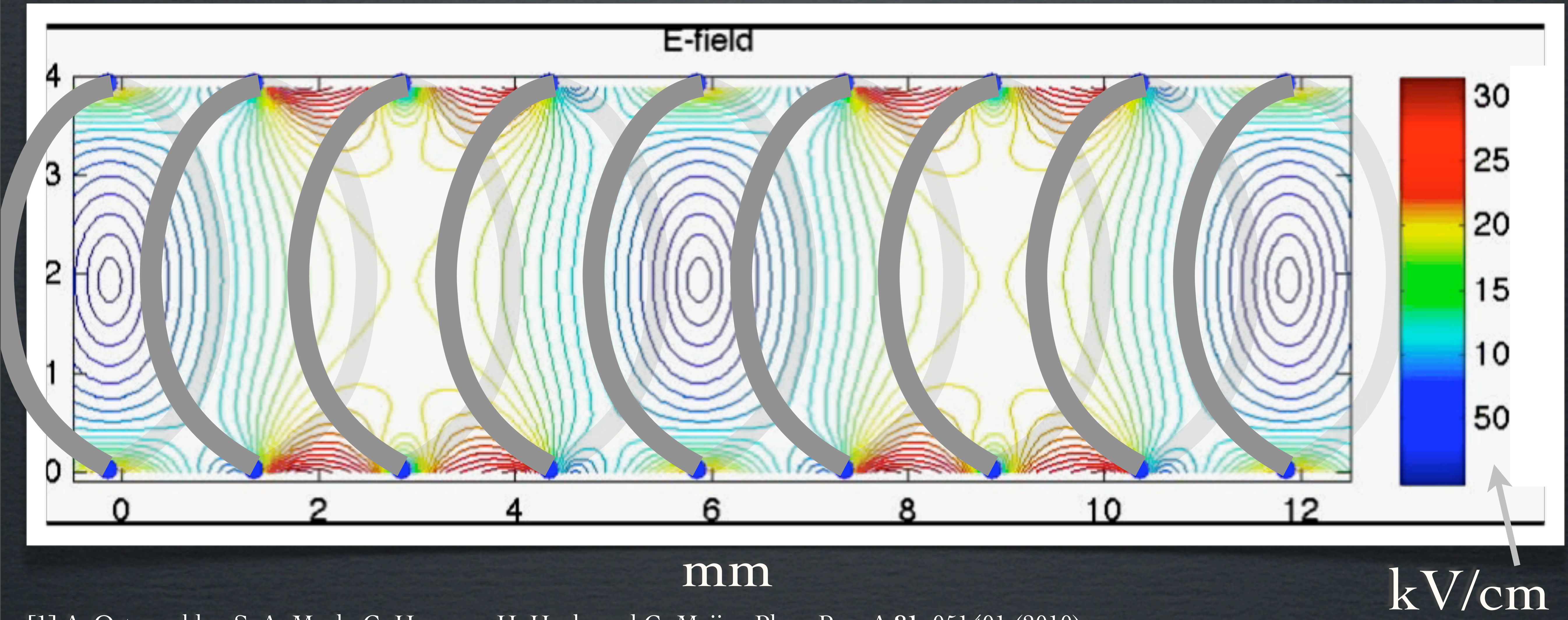

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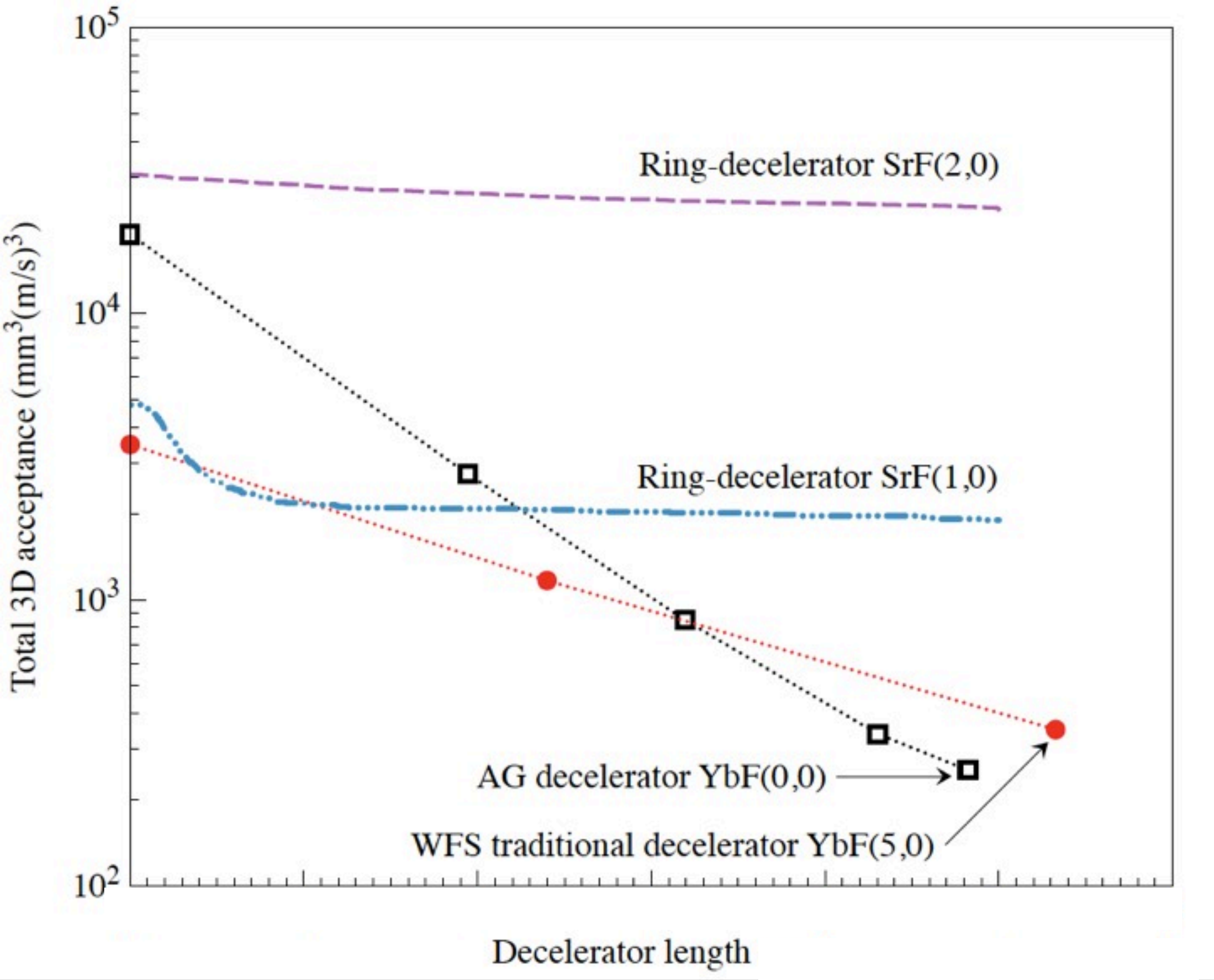
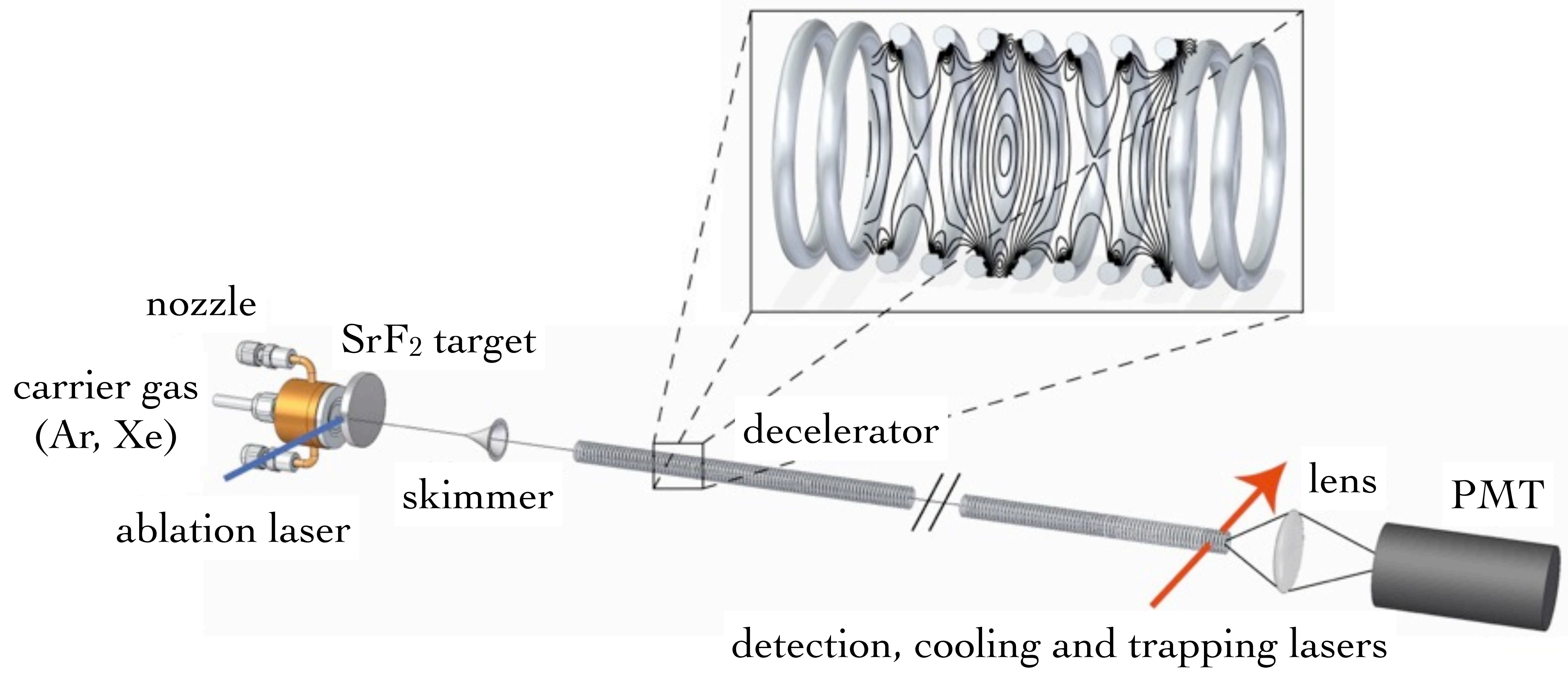
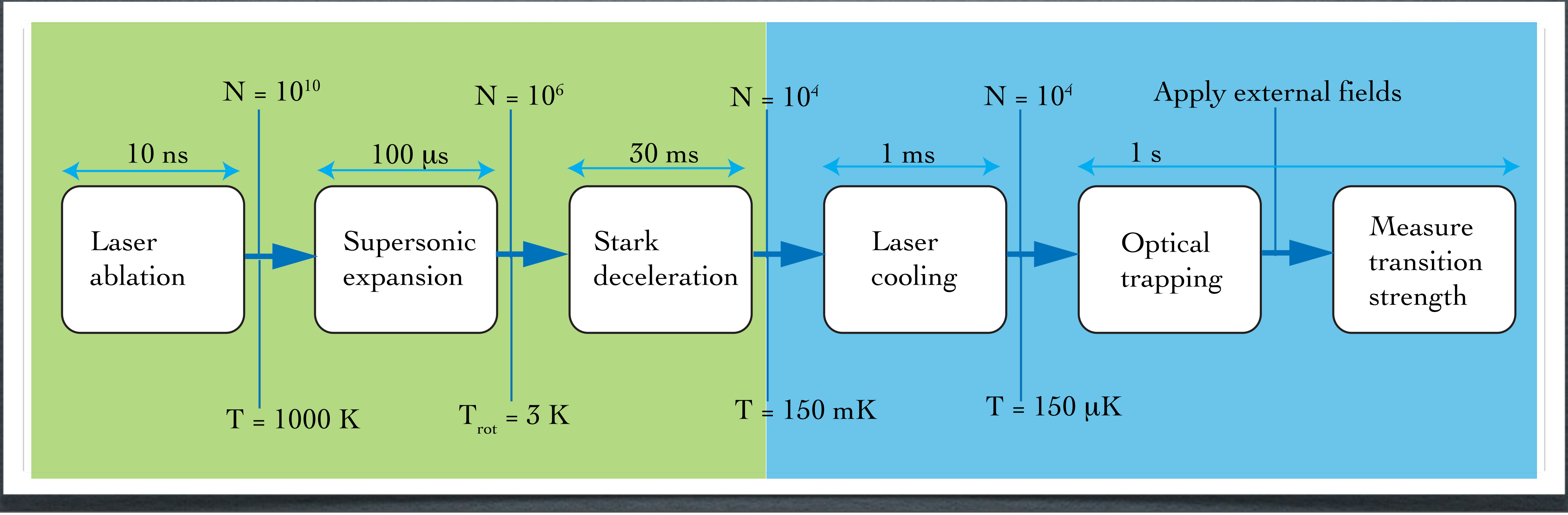
Ring-decelerator: stability



J. E. Berg, S. H. Turkesteen, E. B. Prinsen, and S. Hoekstra, Eur. Phys. J. D **66**, 235 (2012).

stark deceleration + laser cooling + optical trapping





Laser ablation — 10 ns

N = 10^{10}, T = 1000 K

Supersonic expansion — 100 μs

N = 10^6, T_{rot} = 3 K

Stark deceleration — 30 ms

N = 10^4, T = 150 mK

Laser cooling — 1 ms

N = 10^4, T = 150 μK

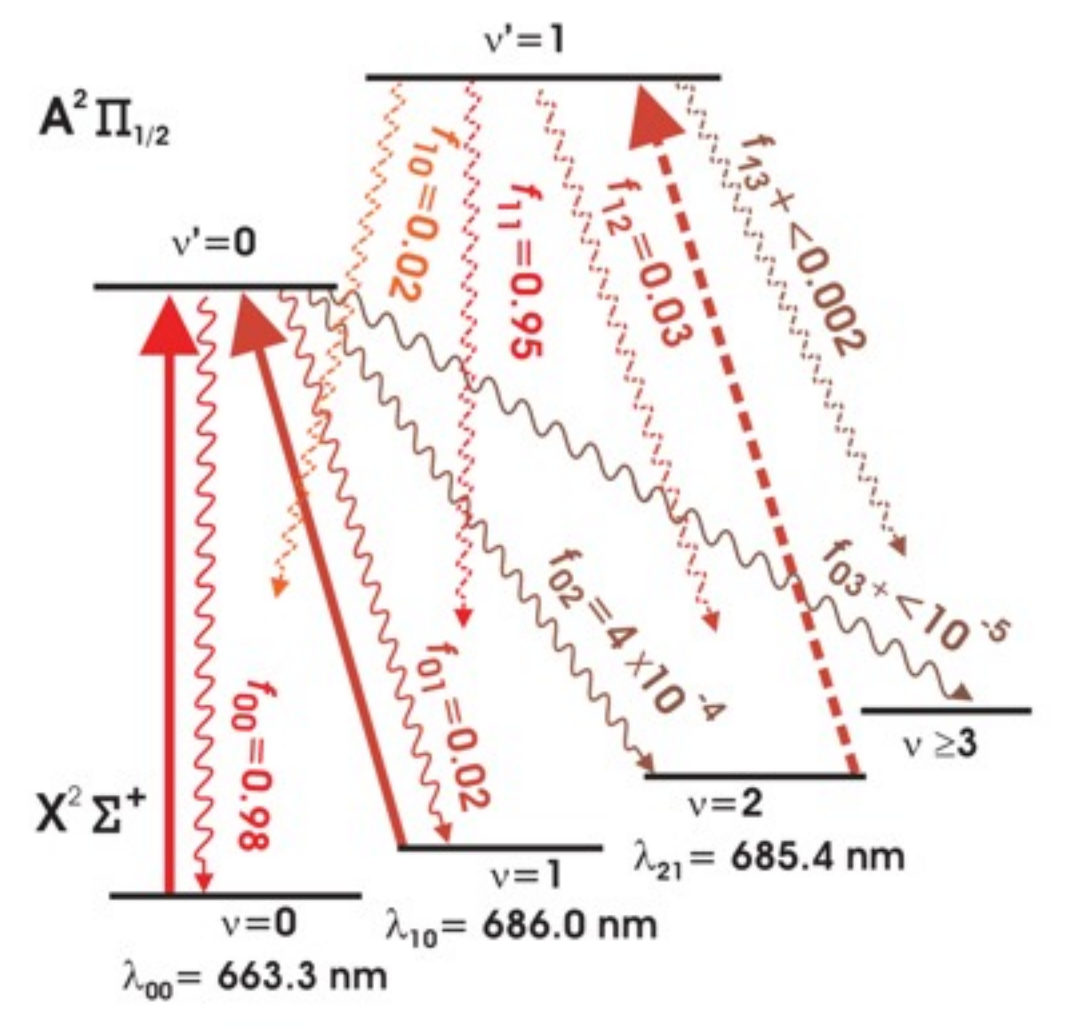
Optical trapping — 1 s

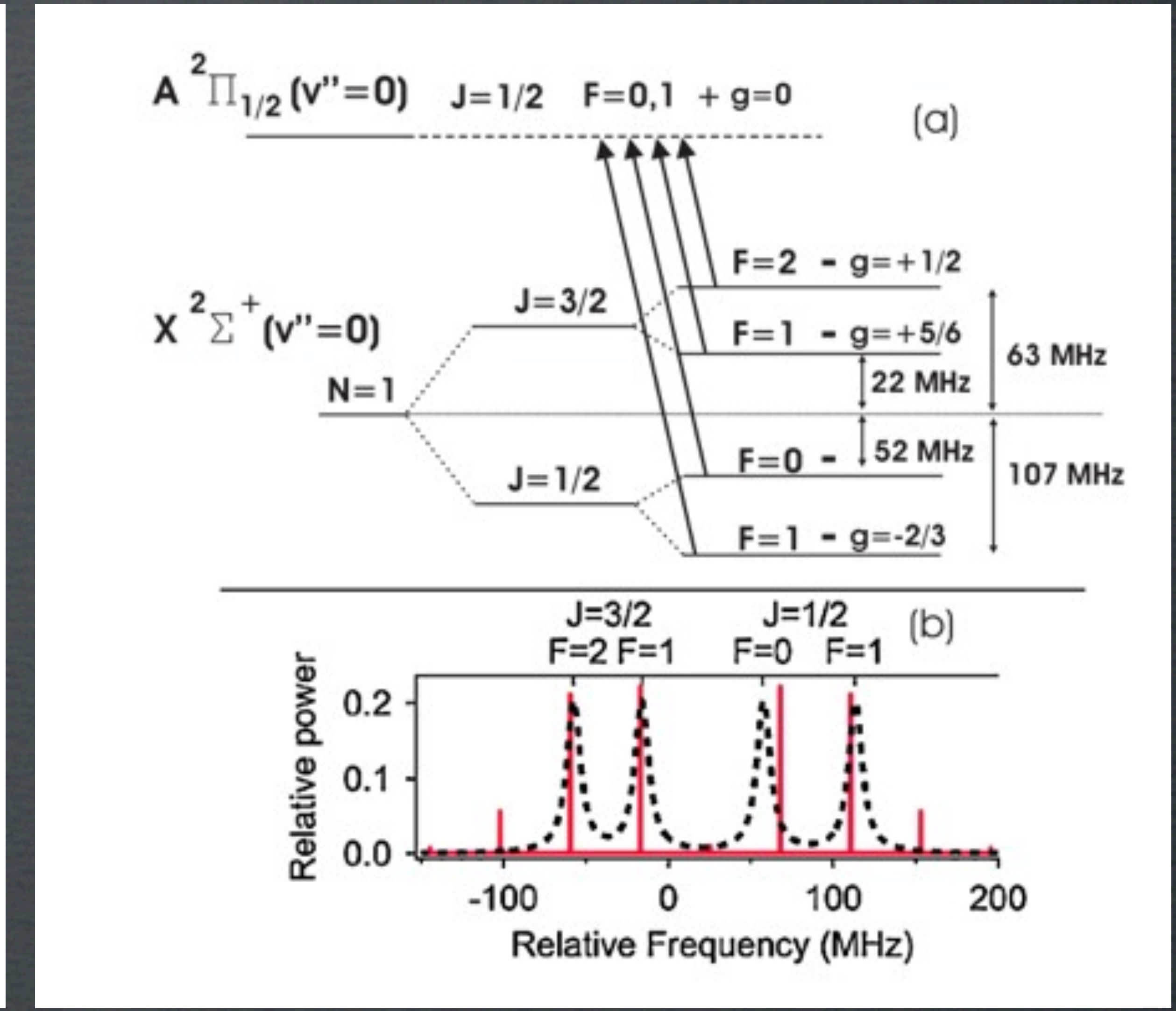
Apply external fields

Measure transition strength

Lasercooling of molecules

Lasercooling of molecules





vibrationally closed

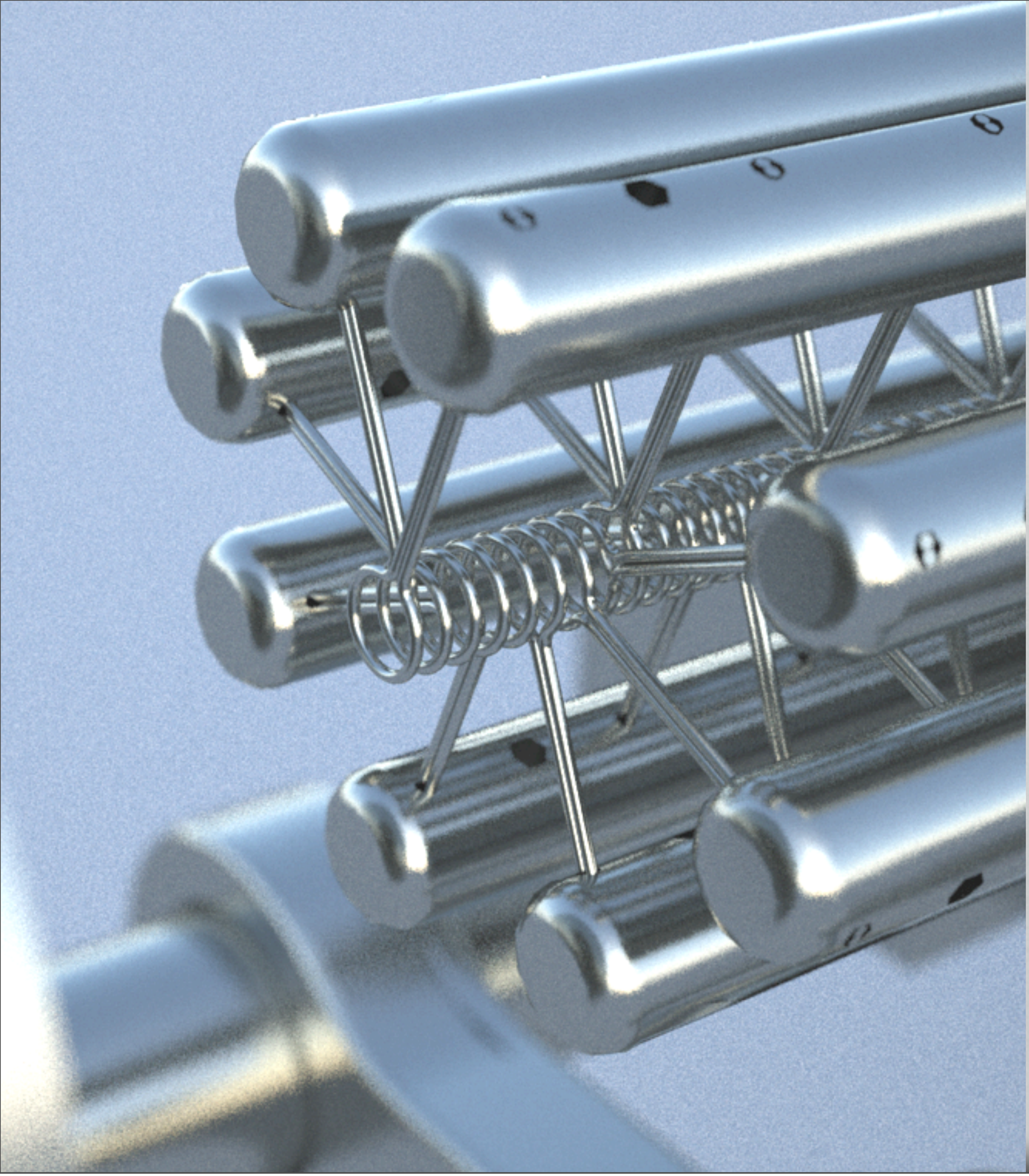
Rotational and hyperfine

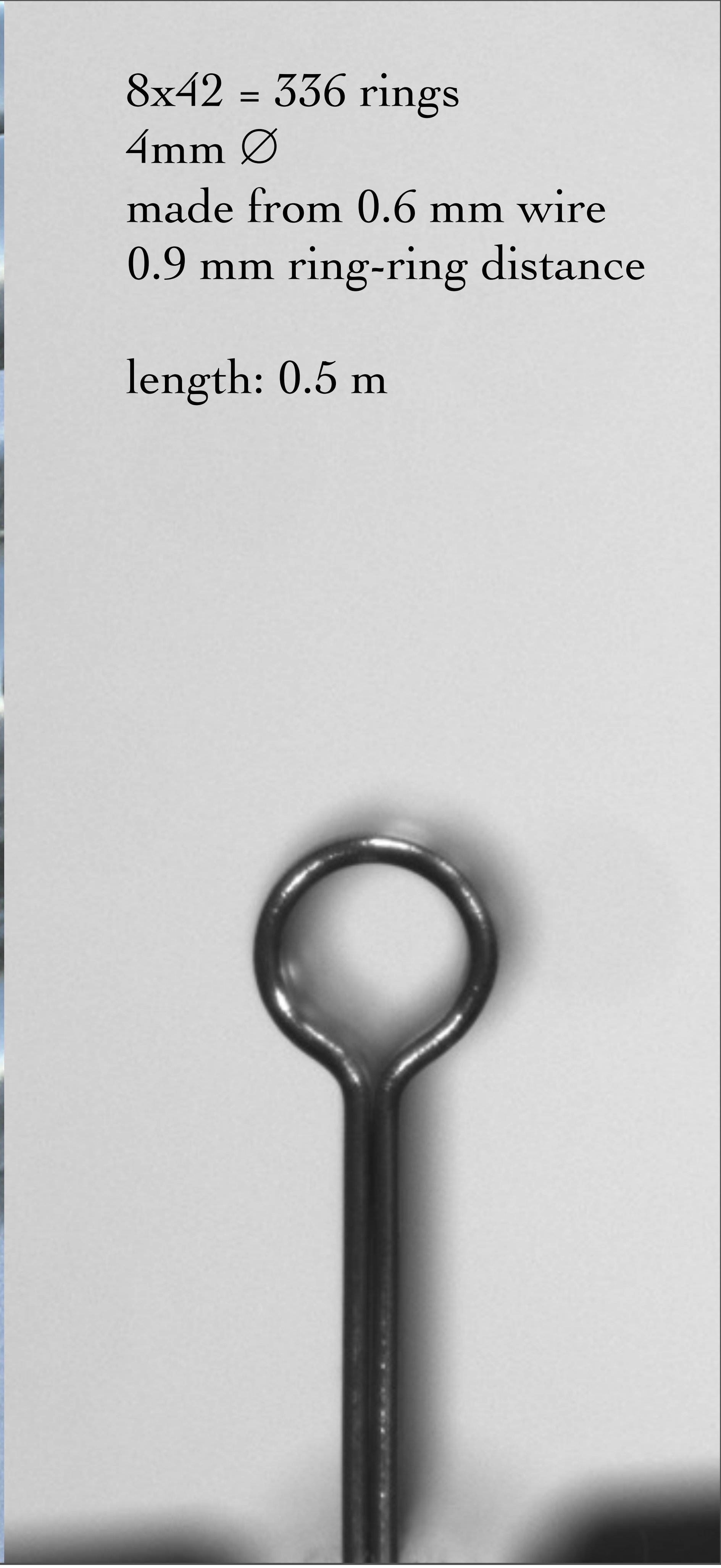
Dave DeMille (SrF), Jun Ye (YO)
- perhaps possible but still very challenging -

By pre-cooling the molecules, n_{photons} required is reduced (by factor 20) to 3,000

[1] E. S. Shuman, J. Barry, D. R. Glenn, and D. Demille, Phys Rev Lett **103**, 223001 (2009).
[2] E. S. Shuman, J. Barry, and D. Demille, Nature **467**, 820 (2010).
[3] J. F. Barry, E. S. Shuman, E. B. Norrgard, and D. DeMille, Phys Rev Lett **108**, 103002 (2012).
[4] M. T. Hummon, M. Yeo, B. K. Stuhl, A. L. Collopy, Y. Xia, and J. Ye, arXiv:**1209.4069** (2012).

From theory to experiment...

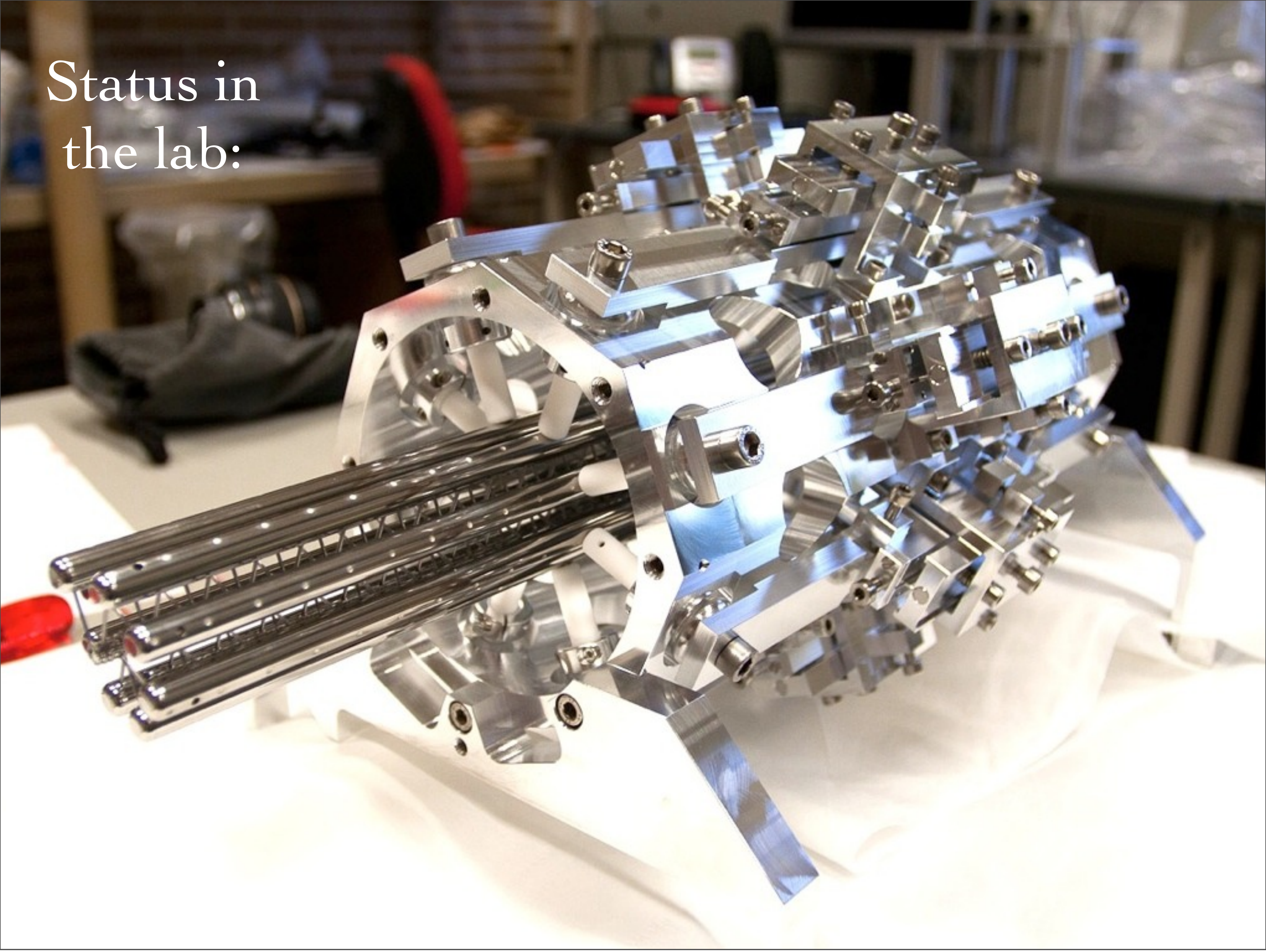




8x42 = 336 rings
4mm ∅
made from 0.6 mm wire
0.9 mm ring-ring distance

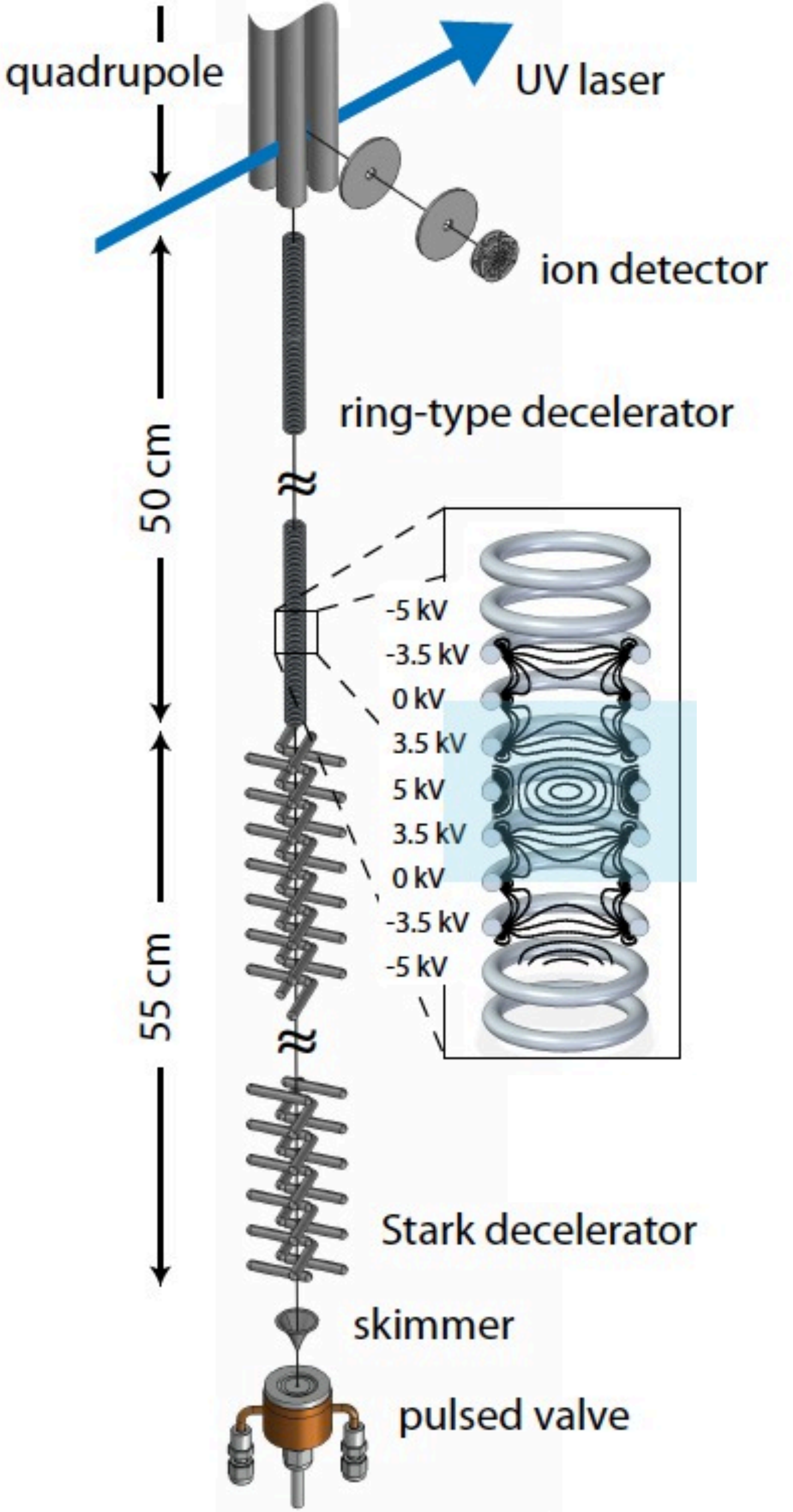
length: 0.5 m

Status in the lab:



First thing we have done: Put on top of NH_3 fountain!

Joint project with Rick Bethlem, A'dam



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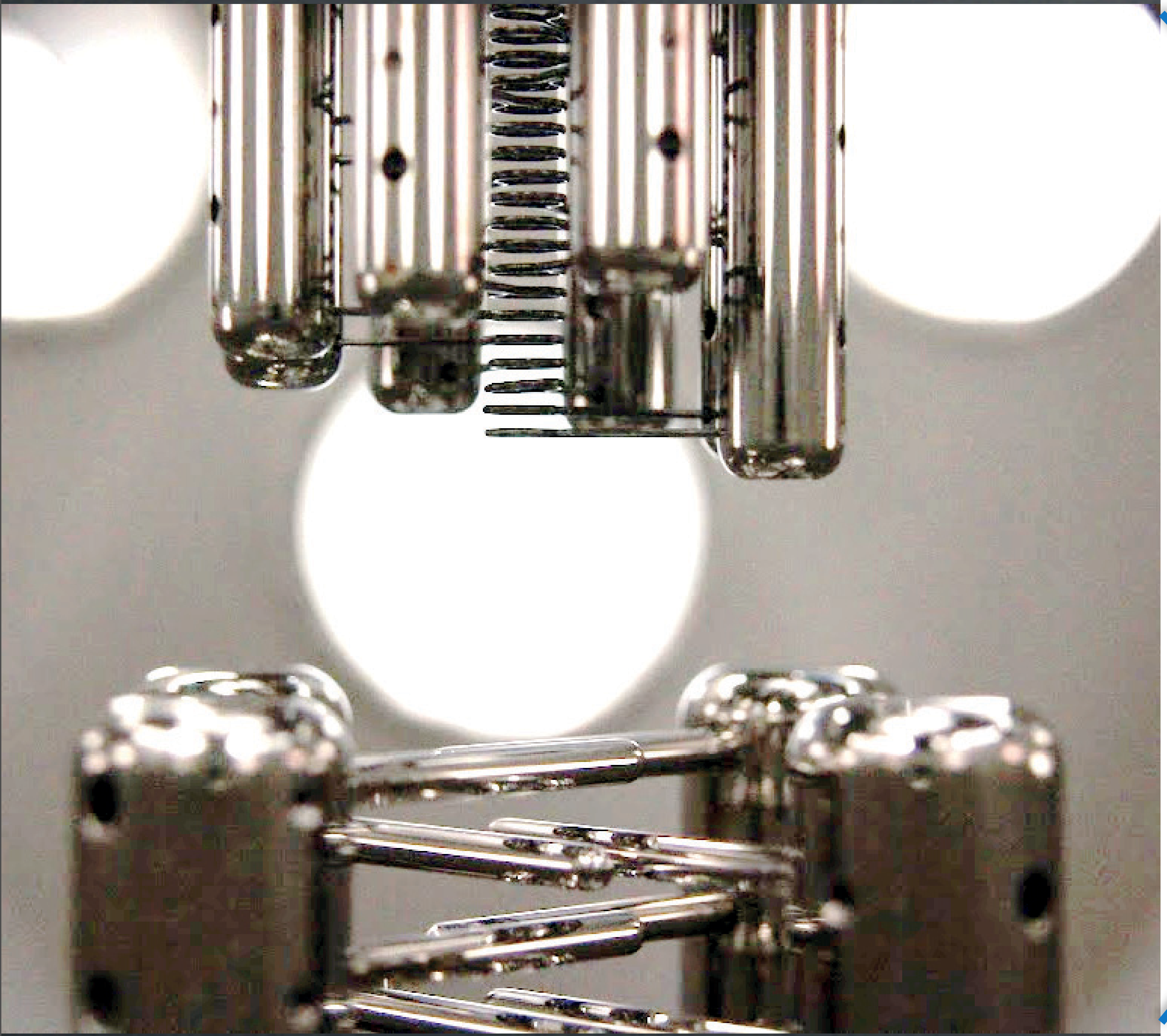

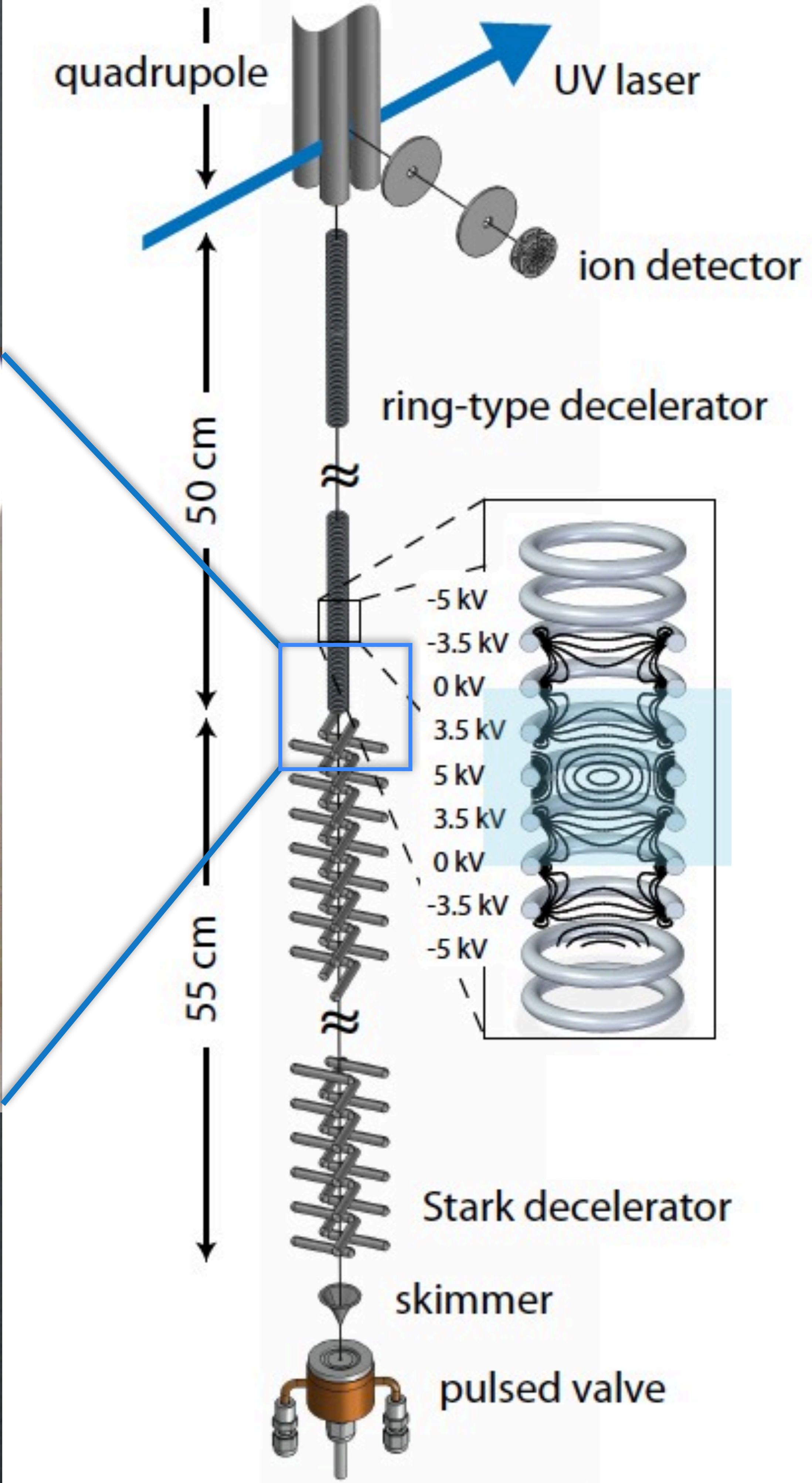

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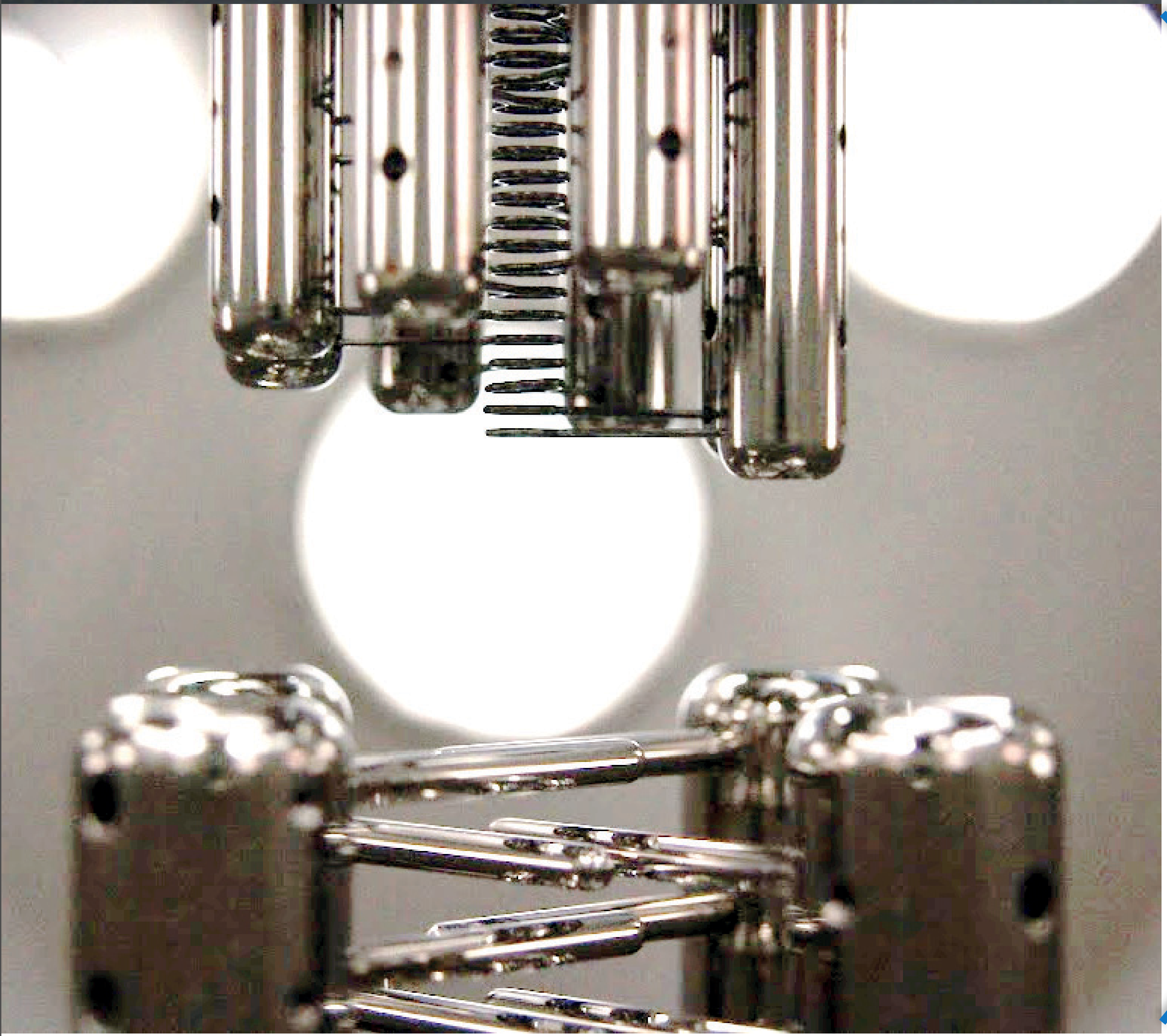
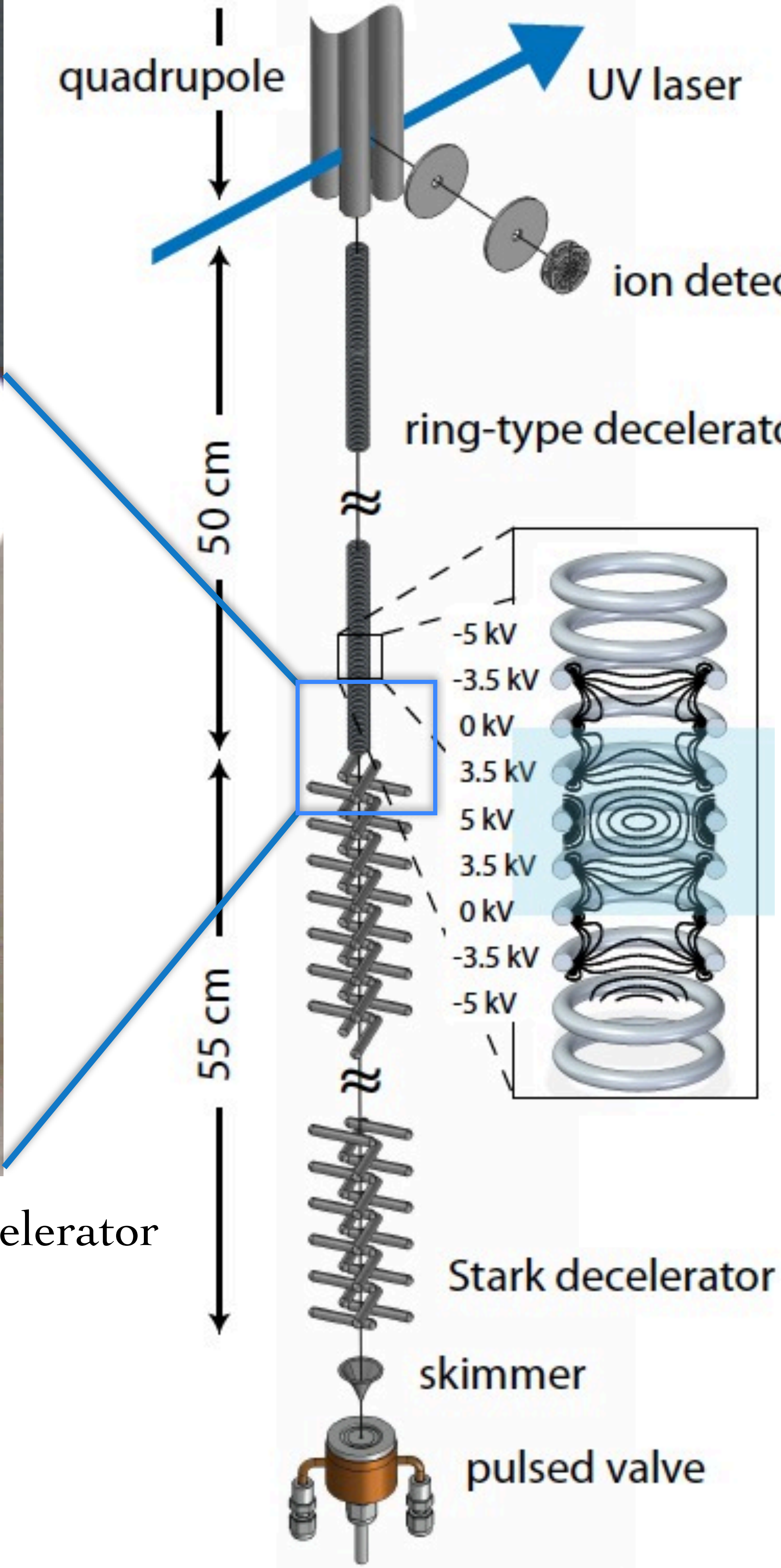
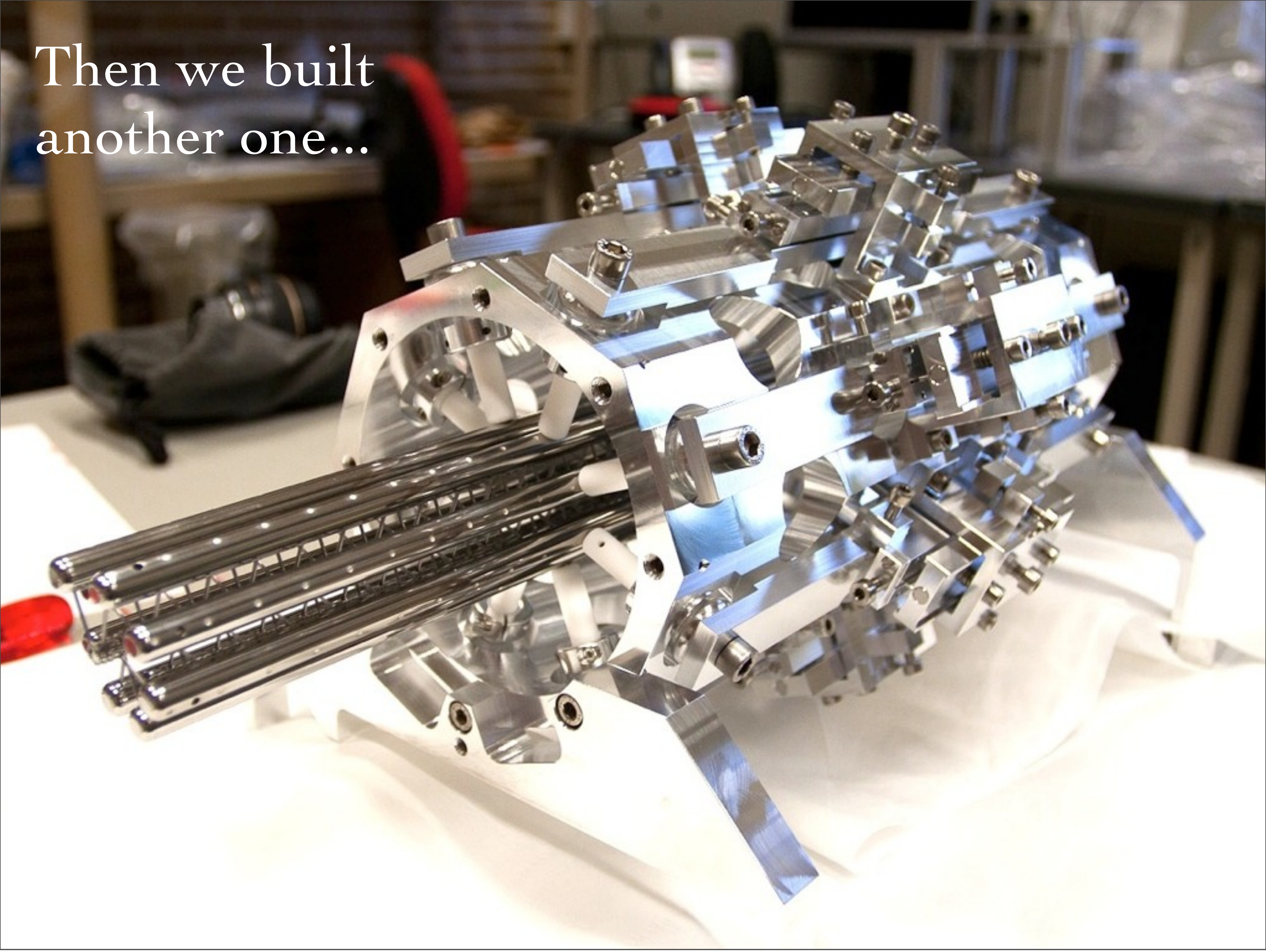
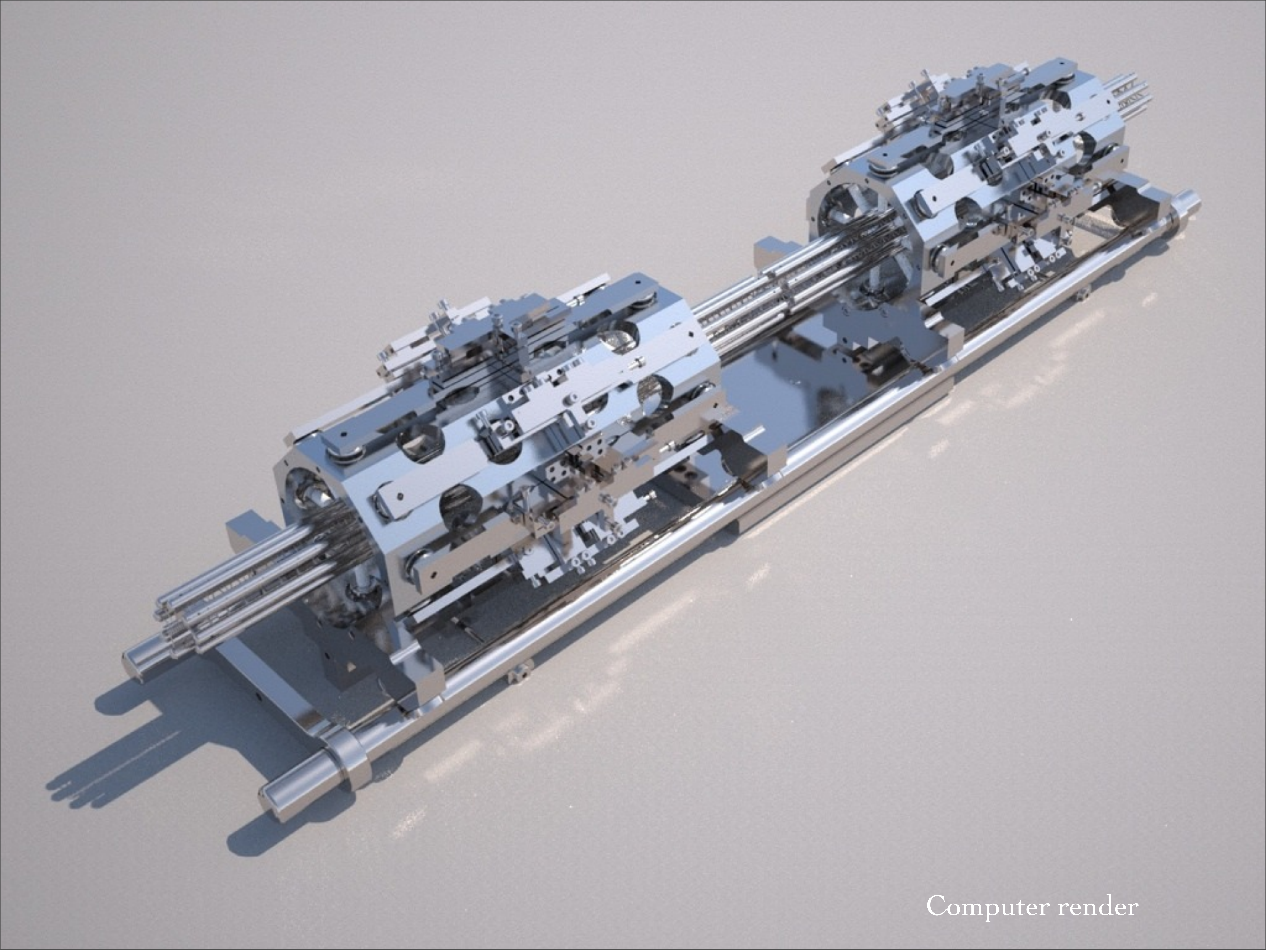




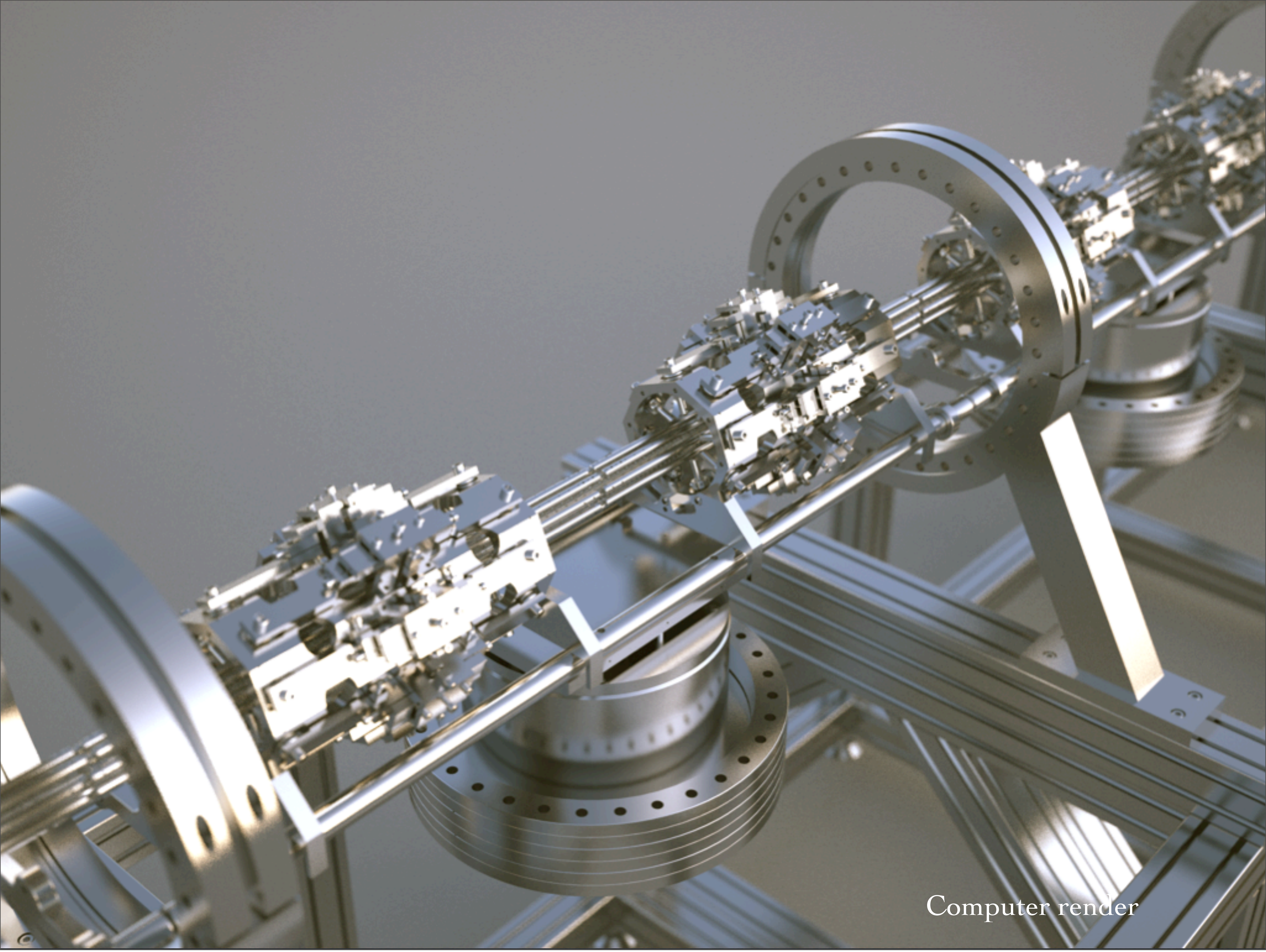
- We have trapped NH_3 inside the ring decelerator
- Novel phase-space manipulation
- Crucial step towards molecular fountain
- arXiv:1301.2113 (2013)

Then we built another one...





Computer render



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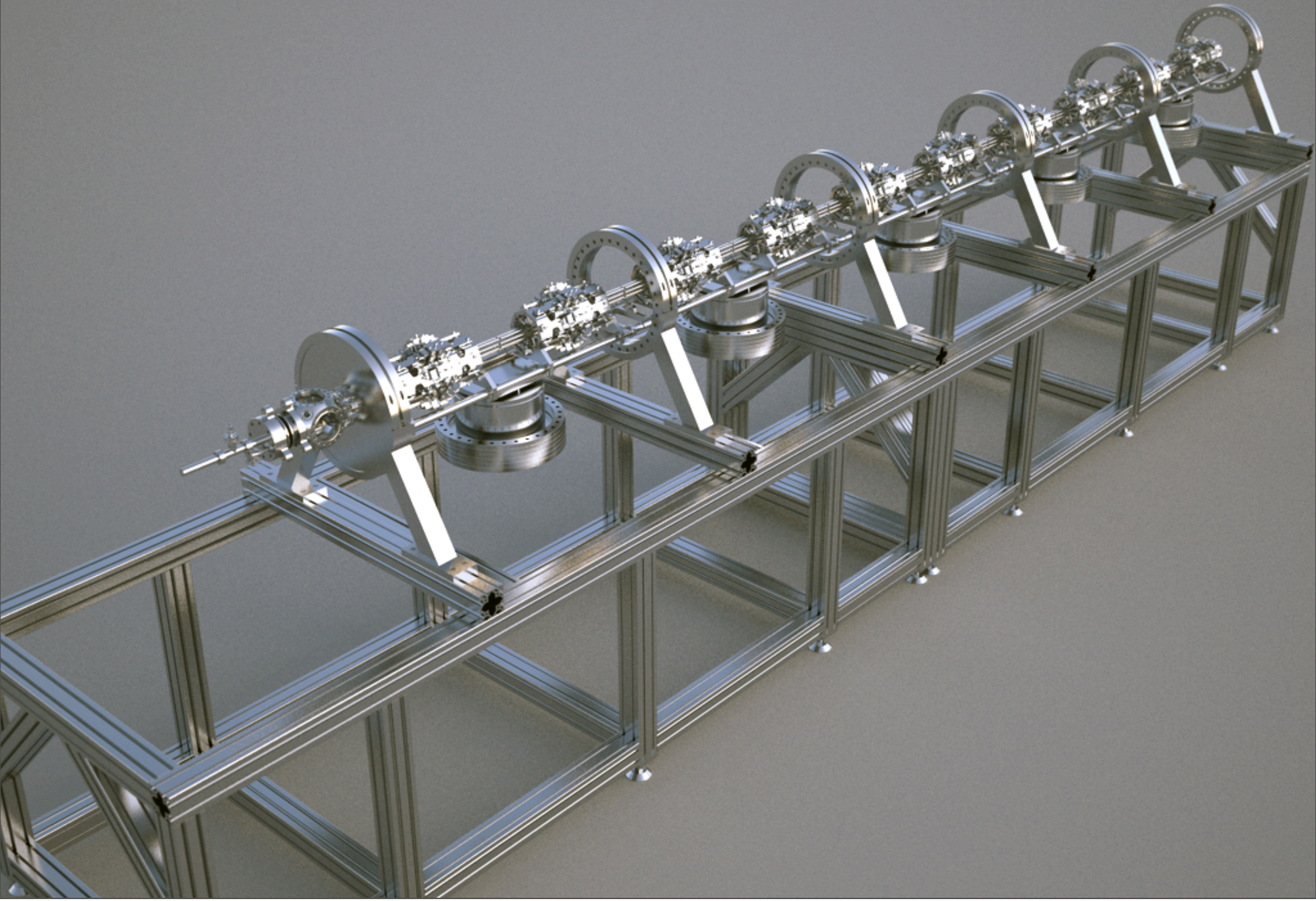
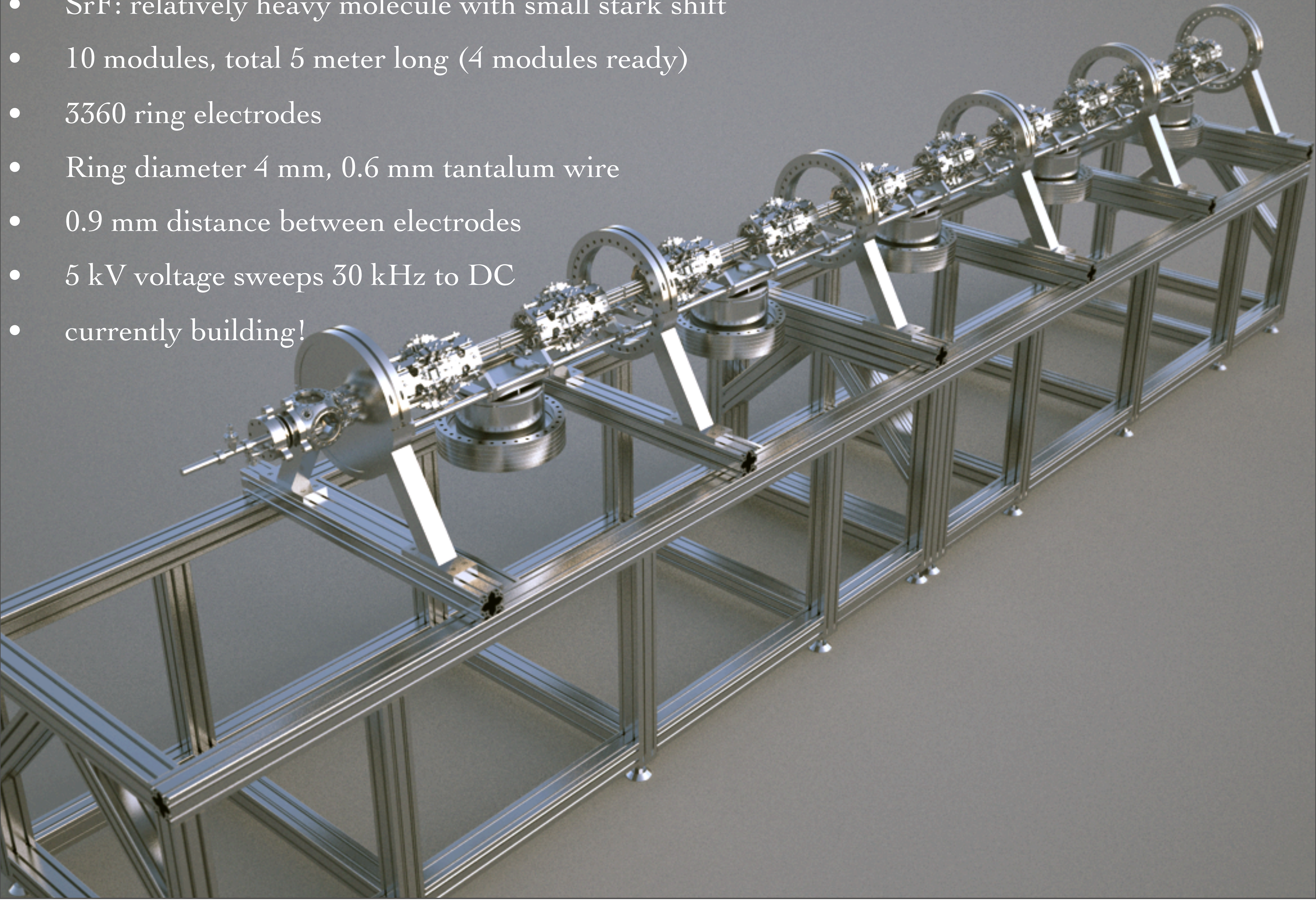
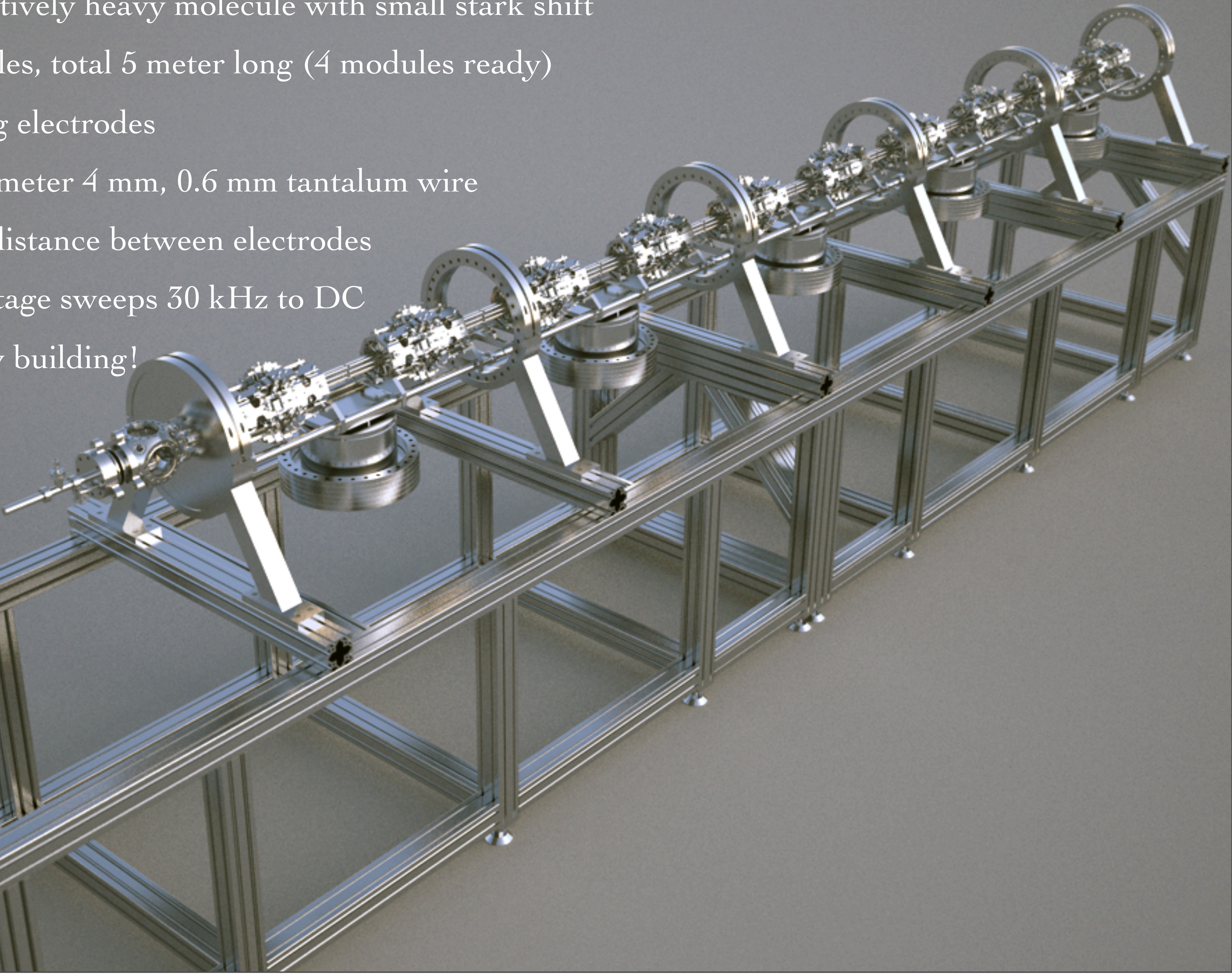




- SrF: relatively heavy molecule with small stark shift
- 10 modules, total 5 meter long (4 modules ready)
- 3360 ring electrodes
- Ring diameter 4 mm, 0.6 mm tantalum wire
- 0.9 mm distance between electrodes
- 5 kV voltage sweeps 30 kHz to DC
- currently building!

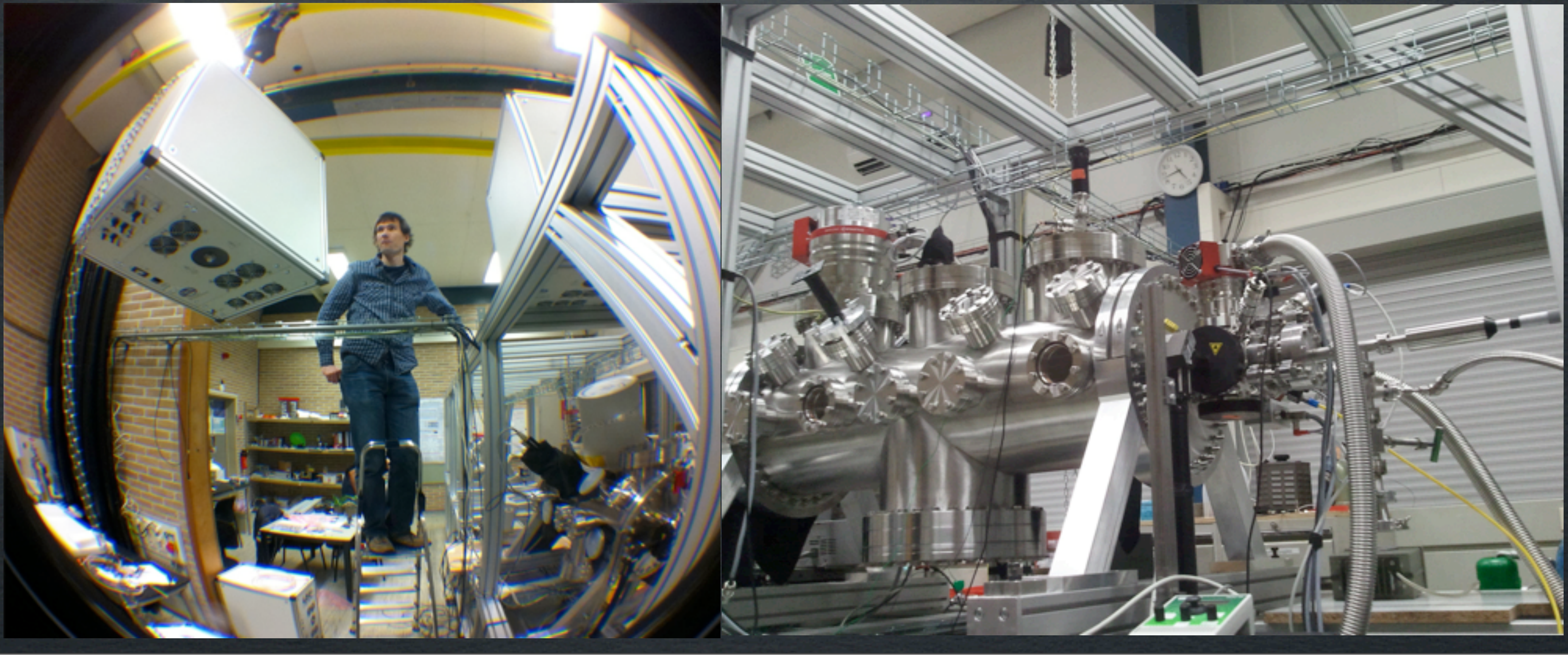
General tool to decelerate and trap a new class of molecules



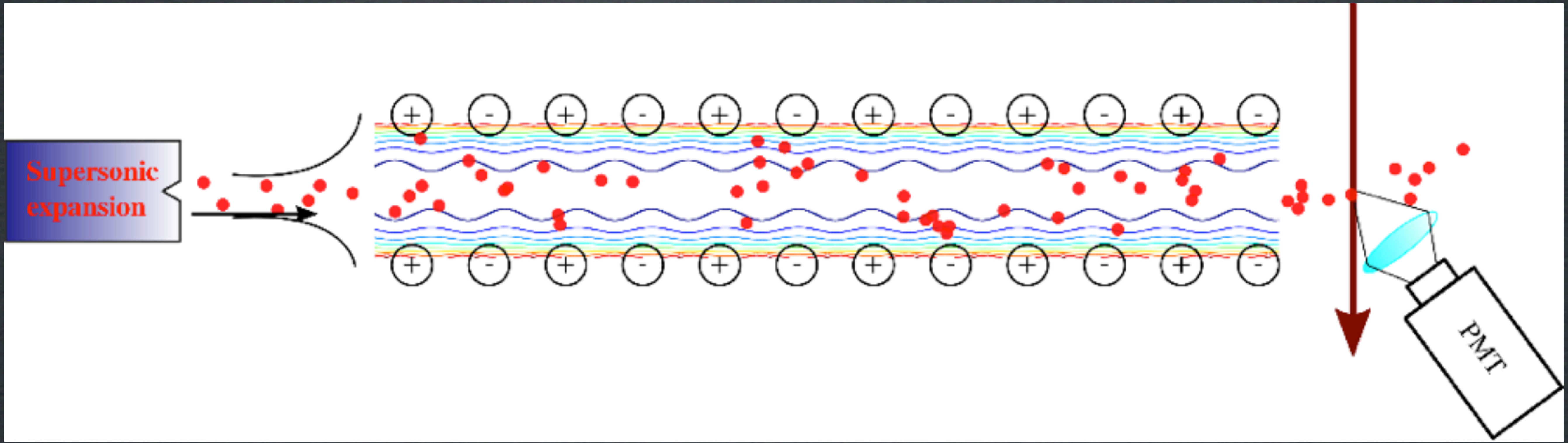
- SrF: relatively heavy molecule with small stark shift
- 10 modules, total 5 meter long (4 modules ready)
- 3360 ring electrodes
- Ring diameter 4 mm, 0.6 mm tantalum wire
- 0.9 mm distance between electrodes
- 5 kV voltage sweeps 30 kHz to DC
- currently building!

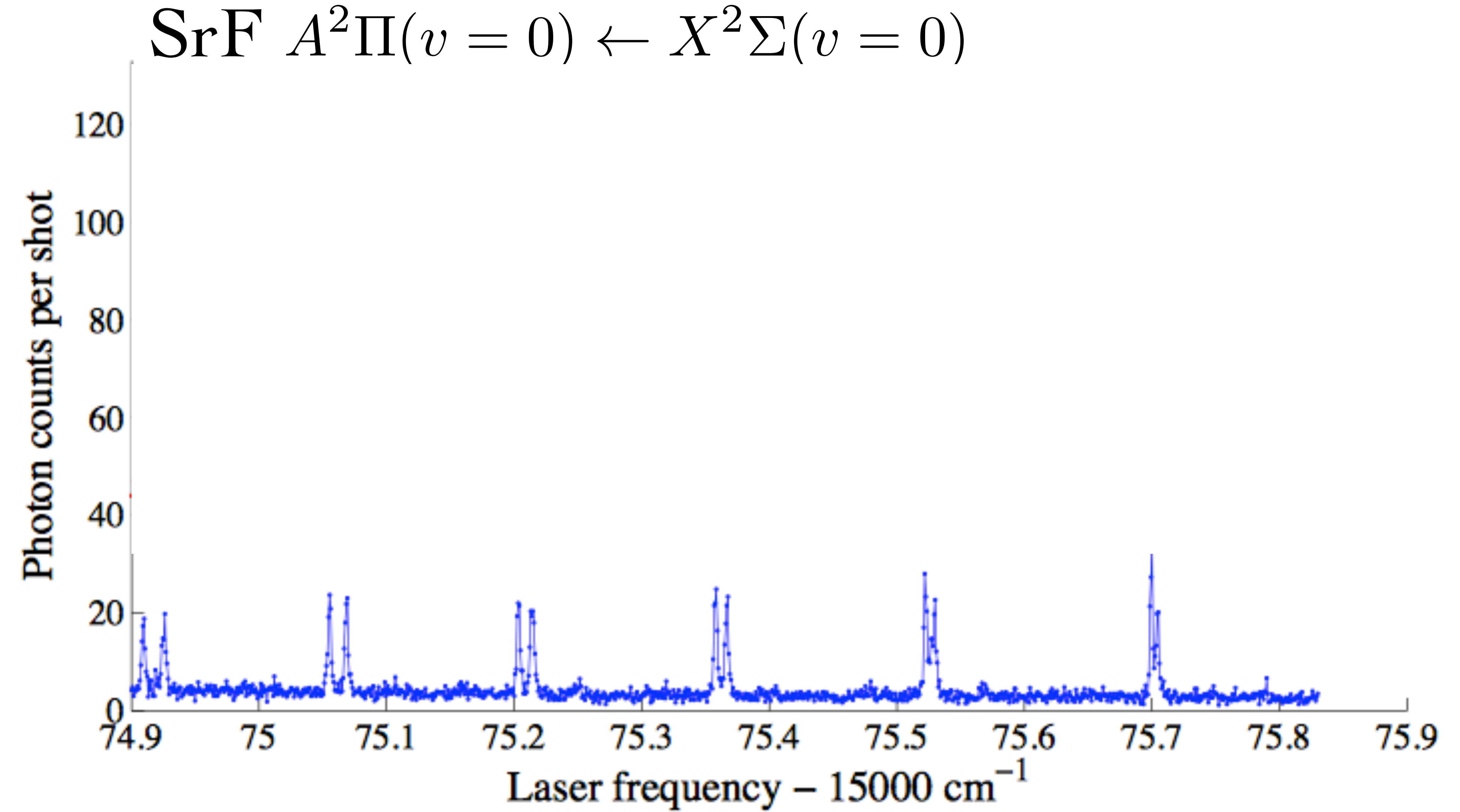
Status of the experiment

- Molecular beam operational
- 4 modules of 0.5 m each ready
- Alignment procedure developed & tested
- Electronics challenge solved, installed jan 2013
- Detection (and cooling) lasers setup, tested



Recent test measurements:





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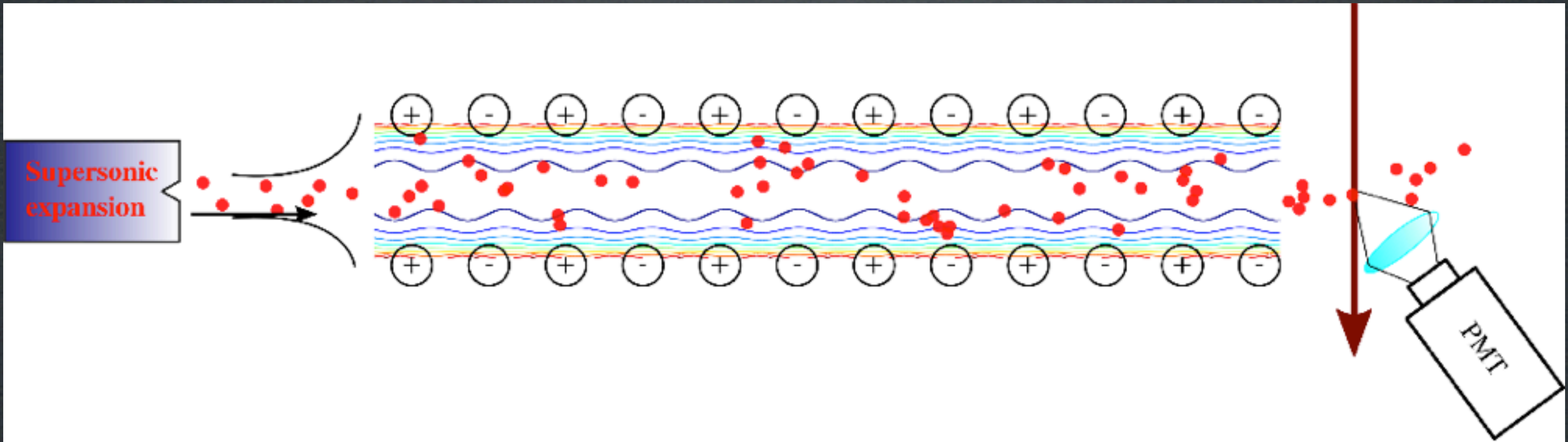

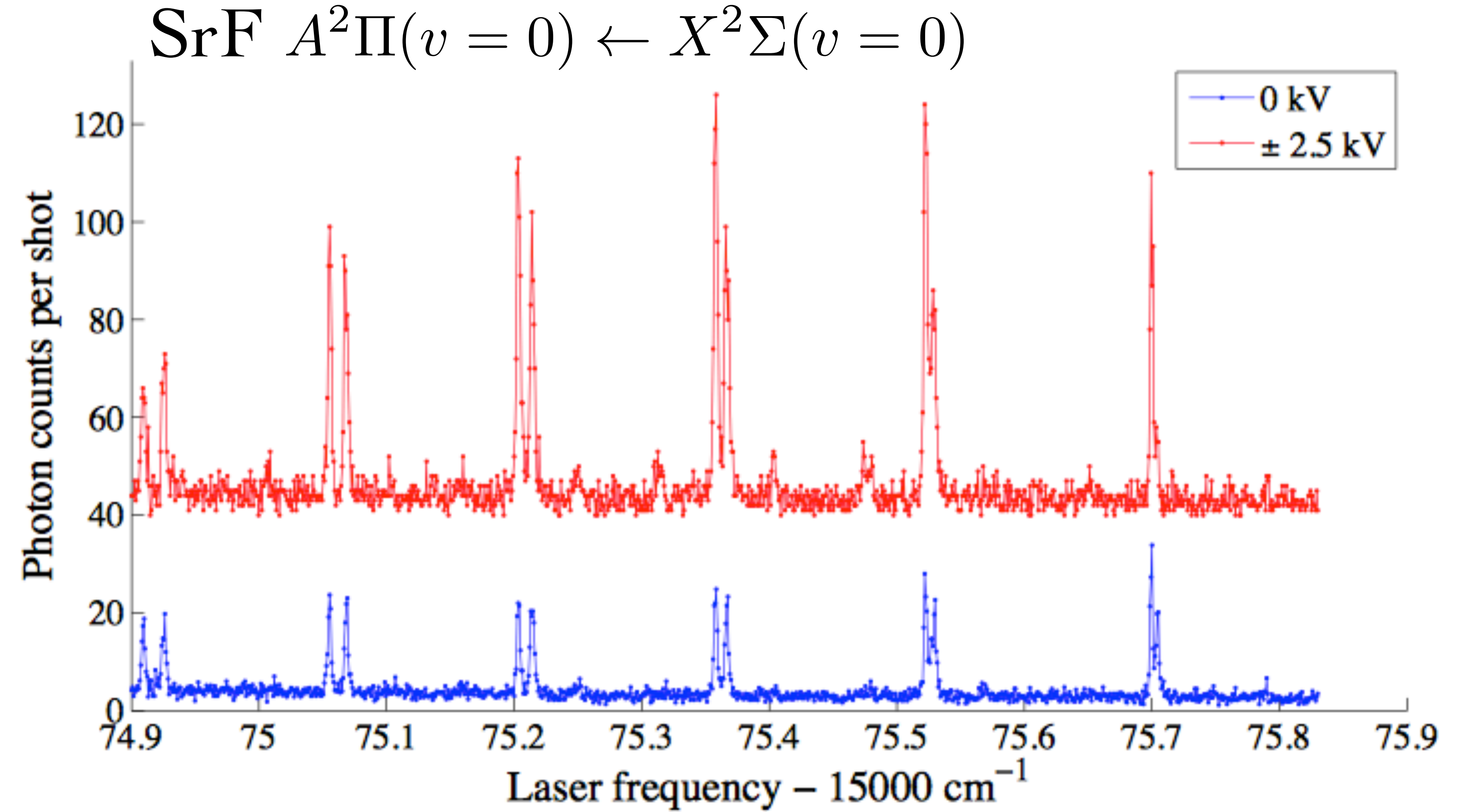
$$\mathrm{SrF}\ A^2\Pi(v=0) \leftarrow X^2\Sigma(v=0)$$

Conclusions & outlook:

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-Selected molecules are ideal probes for ‘new physics’

-Have to develop direct cooling methods. Our approach:
Stark deceleration + laser cooling + optical trapping

-Looking forward to deceleration & trapping of SrF in 2013!

-Deceleration of a range of new molecules is possible

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Open questions / issues

At what temperature and density will we be influenced by the interactions between the molecules?

How to achieve 'magic' conditions ?

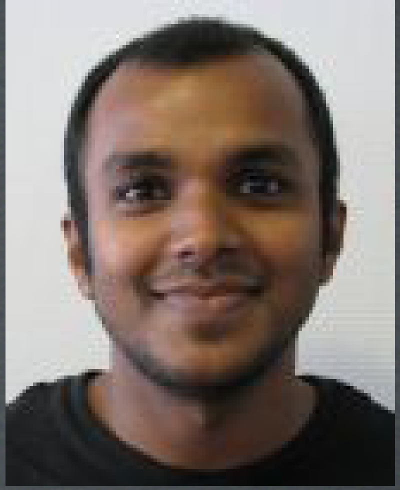
Stability needed: ~ 1 kHz

People involved

Team


Joost van den Berg


Corine Meinema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