



UNIVERSITY OF  
GOTHENBURG



UNIVERSITY OF  
GOTHENBURG

# Dag Hanstorp

# Laser Spectroscopy of radioactive and stable negative ions

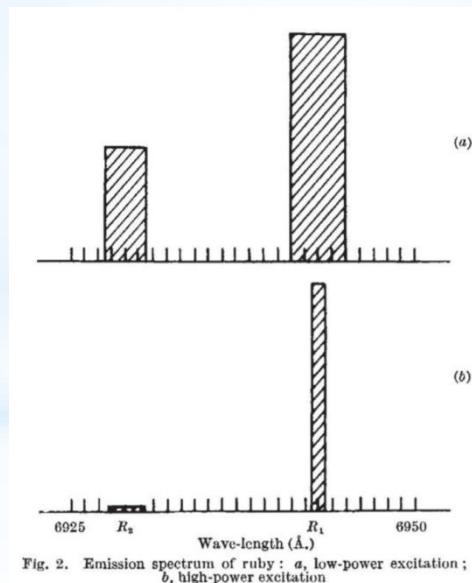
Solvay Workshop in honour of Michel Godefroid  
‘New Frontiers in Atomic, Nuclear, Plasma and Astrophysics’

Brussels, November <sup>1</sup> 25 - 27, 2019

# Charlotte Froese Fischer - Opening Remarks: *In the beginning*

"It all began in the 60ies"

16<sup>th</sup> of May 1960



T. H. Maiman Nature **187**, 493–494(1960)

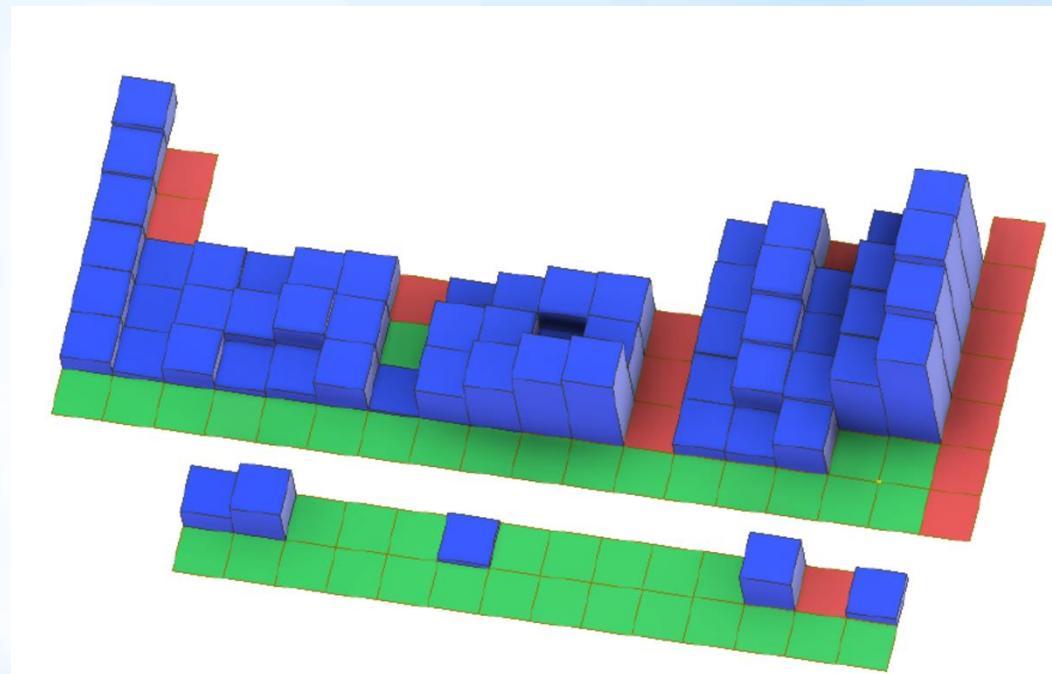
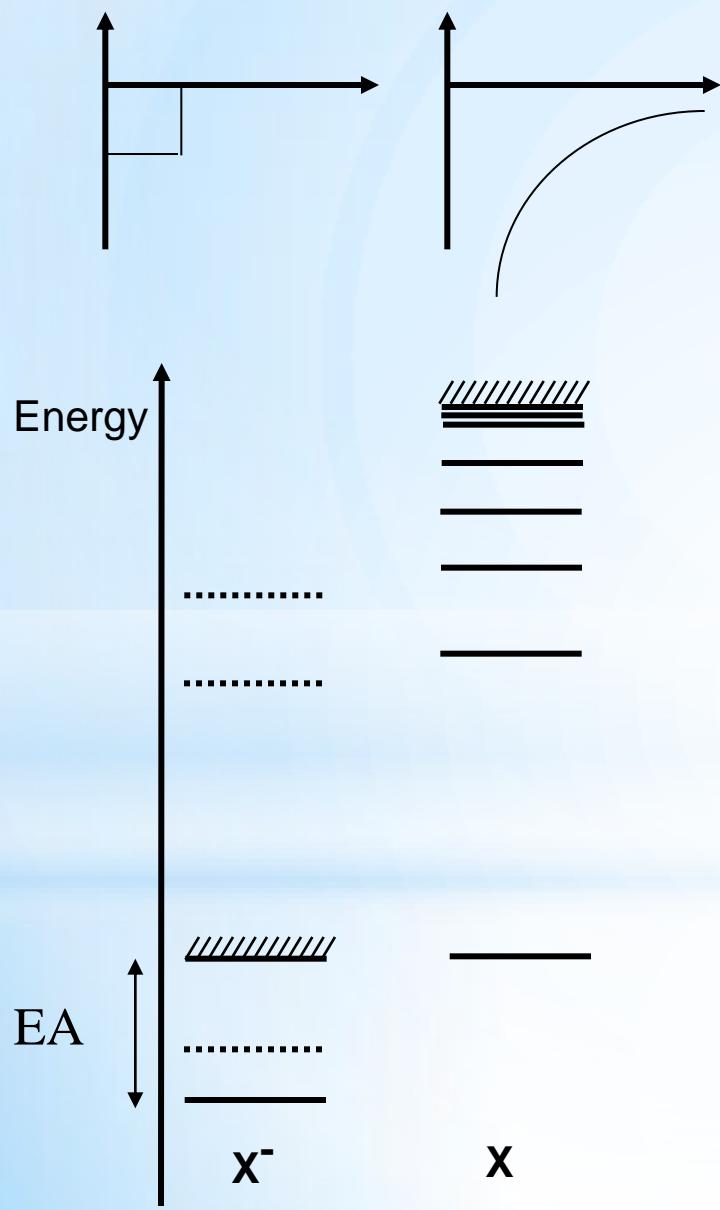
## **The negative ion of hydrogen: H<sup>-</sup>**

Hatree Fock predict H<sup>-</sup> to be unstable

EA of H<sup>-</sup> experimentally determined to be 0,75 eV

Can be predicted only by properly including electron correlation

# Properties of Negative Ions



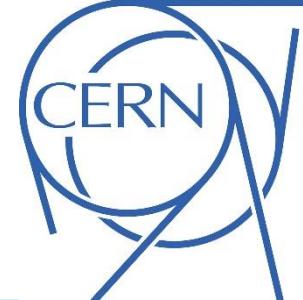
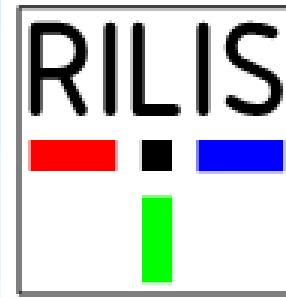
# Why study negative ions?

- Benchmark for electron correlation theory
- Single state system
- Efficient method to produce ground-state atoms
- Heating of thermonuclear reactors
- Accelerator Mass Spectrometry
- Sympathetic cooling of antiprotons

Cerchiari, *et al.* PRL **123**, 103201 (2019), Tang *et al.* PRL **123**, 203002



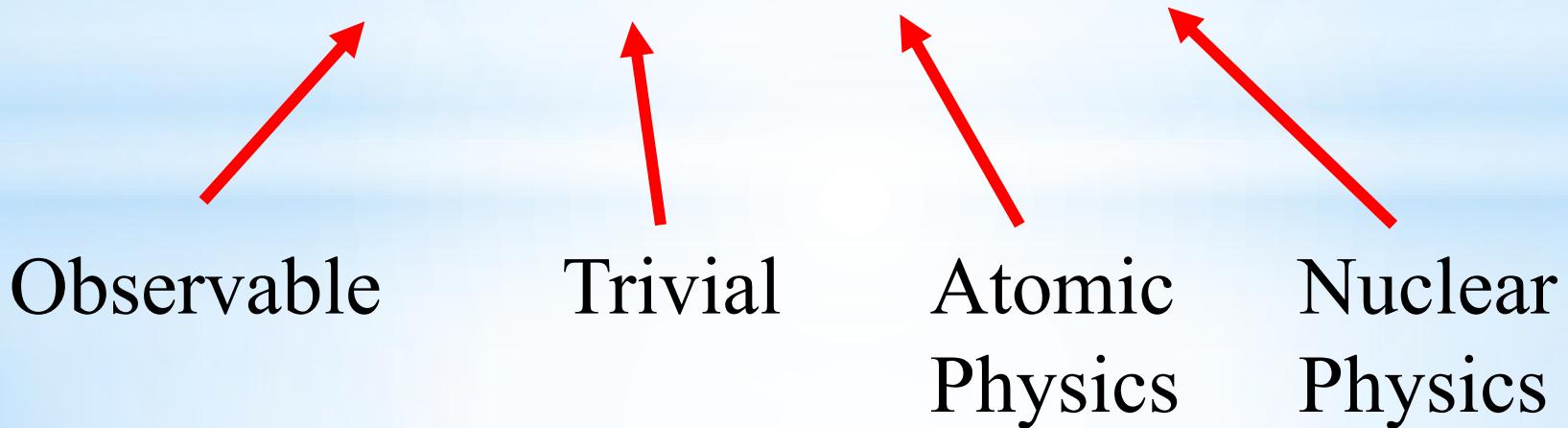
UNIVERSITY OF  
GOTHENBURG



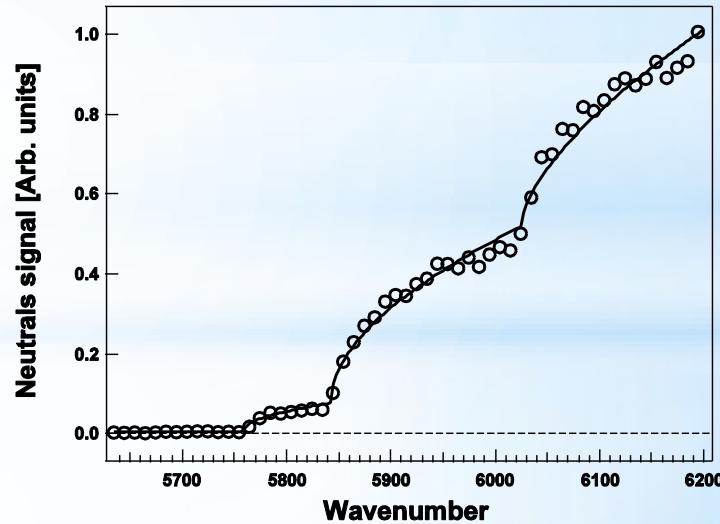
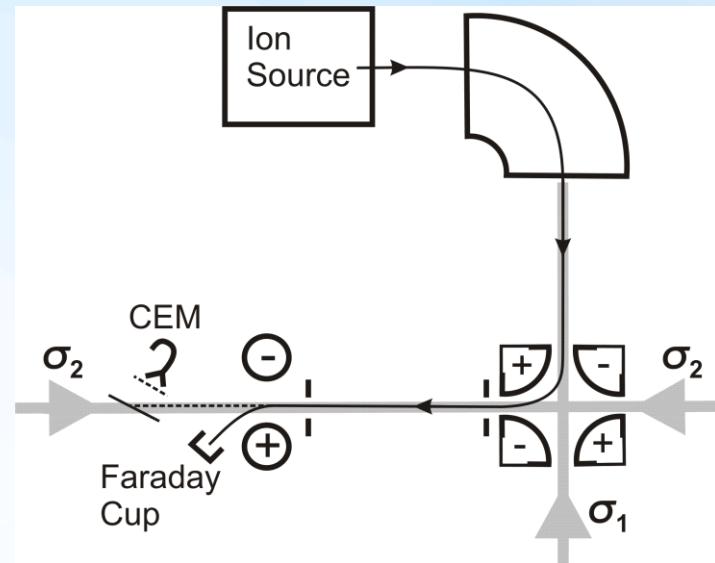
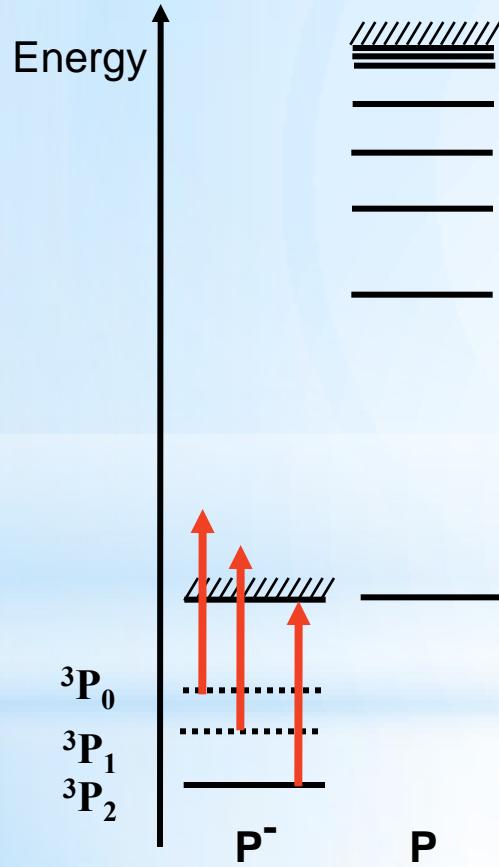
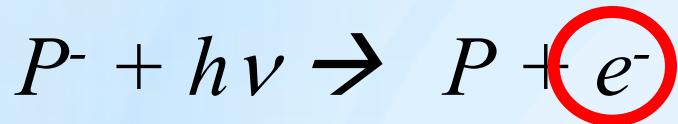
# Isotope shifts in the Electron affinity

# Isotope shift

$$\mathbf{IS} = \mathbf{NMS} + \mathbf{SMS} + \mathbf{VS}$$



# Laser photodetachment Threshold Spectroscopy

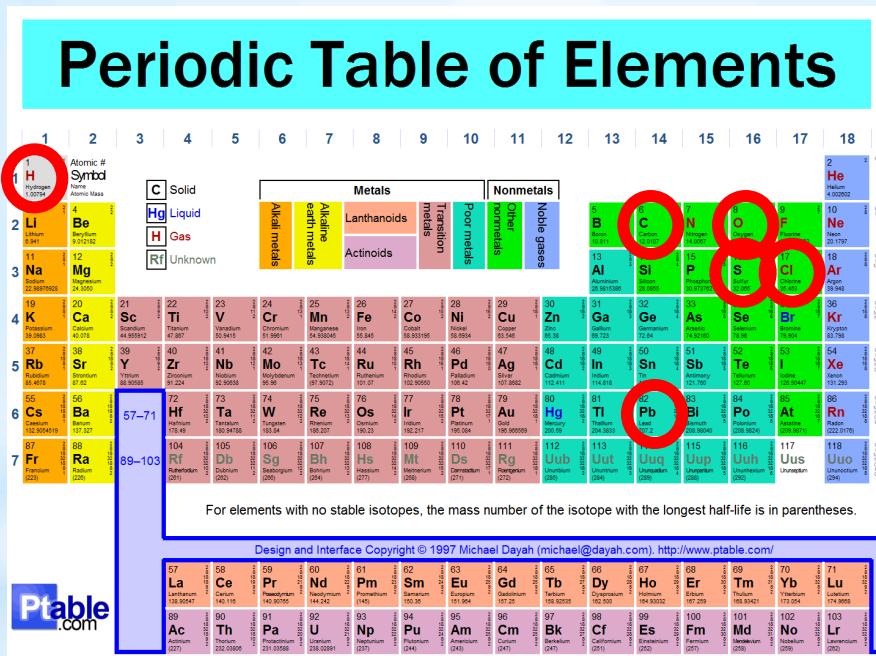


Andersson *et al.*  
J. Phys. B **40** (2007) 4097.

The Wigner law: 
$$\sigma = k (E - E_{EA})^{l+1/2}$$

# Isotope shift in electron affinity

## Ideal test case for electron correlation



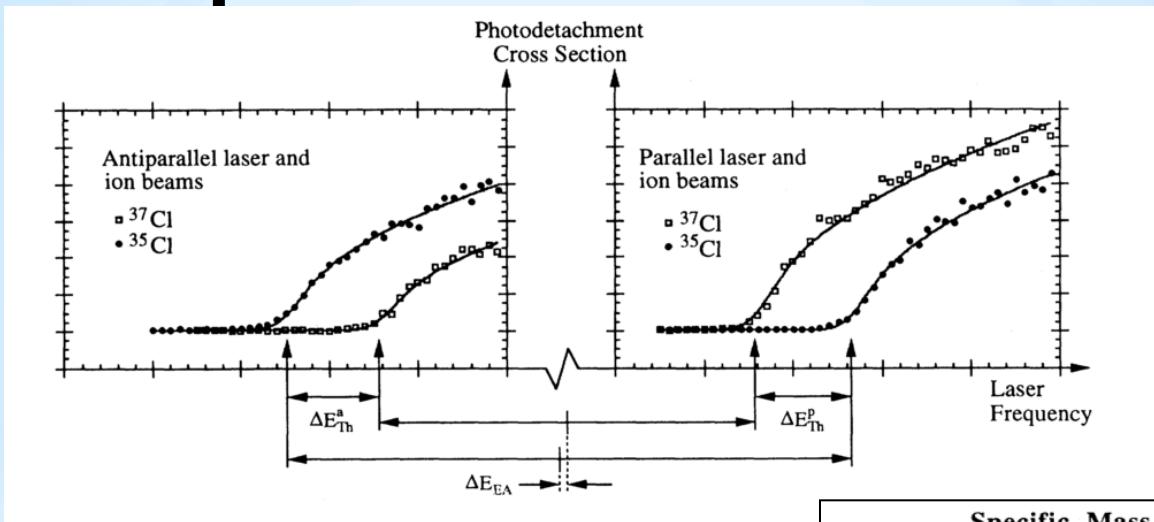
$^1\text{H}/^2\text{H}$   
 $^{35}\text{Cl}/^{37}\text{Cl}$   
 $^{16}\text{O}/^{17}\text{O}/^{18}\text{O}$   
 $^{32}\text{S}/^{34}\text{S}$   
 $^{12}\text{C}/^{13}\text{C}$   
 $^{206}\text{Pb}/^{208}\text{Pb}$

- Lykke, Murray and Lineberger, *Phys. Rev. A* **43** (1991) 6104  
Berzinsh et al. *Phys. Rev. A* **51**, (1995) 231  
Blondel et al. *Phys. Rev. A* **64** (2001) 052504  
Carette, et al. *Phys. Rev. A* **81** (2010) 042522  
Bresteau, Drag and Blondel, *Phys. Rev. A* **93** (2016) 013414  
Chen and Ning, *J. Chem. Phys.* **145** (2016) 084303

9

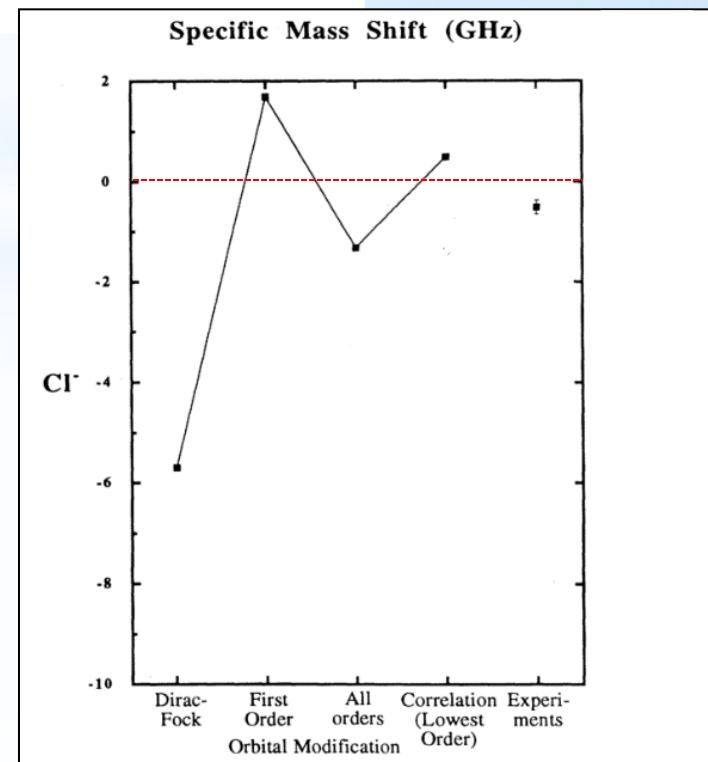
**Only stable isotopes investigated**

# Isotope shift in EA of $^{35}/^{37}\text{Cl}$



$$\text{SMS} = -0.51(14) \text{ GHz}$$

Berzinsh et al. *Phys. Rev. A* **51**, (1995) 231



# Isotope shift in EA of $^{35}/^{37}\text{Cl}$

IOP PUBLISHING

JOURNAL OF PHYSICS B: ATOMIC, MOLECULAR AND OPTICAL PHYSICS

J. Phys. B: At. Mol. Opt. Phys. 46 (2013) 095003 (10pp)

doi:10.1088/0953-4075/46/9/095003

## Isotope shift on the chlorine electron affinity revisited by an MCHF/CI approach

T Carette<sup>1,2</sup> and M R Godefroid<sup>2</sup>

	SMS	MS	FS	RIS	IS
				This work	
HF	-1.348	-0.607	-0.003(22)	-1.351(22)	-0.610(22)
val. FC-MCHF	-0.674	+0.067	-0.002(20)	-0.676(20)	+0.065(20)
val. MCHF	-0.495	+0.246	-0.003(21)	-0.497(21)	+0.244(21)
final results	-0.535(51)	+0.206(51)	-0.003(22)	-0.538(72)	+0.203(72)
			Berzinsh <i>et al</i> [7]		
Exp.				-0.51(14)	+0.22(14)
DF	-1.3	-0.6	+0.014(14)	-1.3	-0.6
MB low corr.	+0.50	+1.24	+0.014(14)	+0.51(2)	+1.26(2)

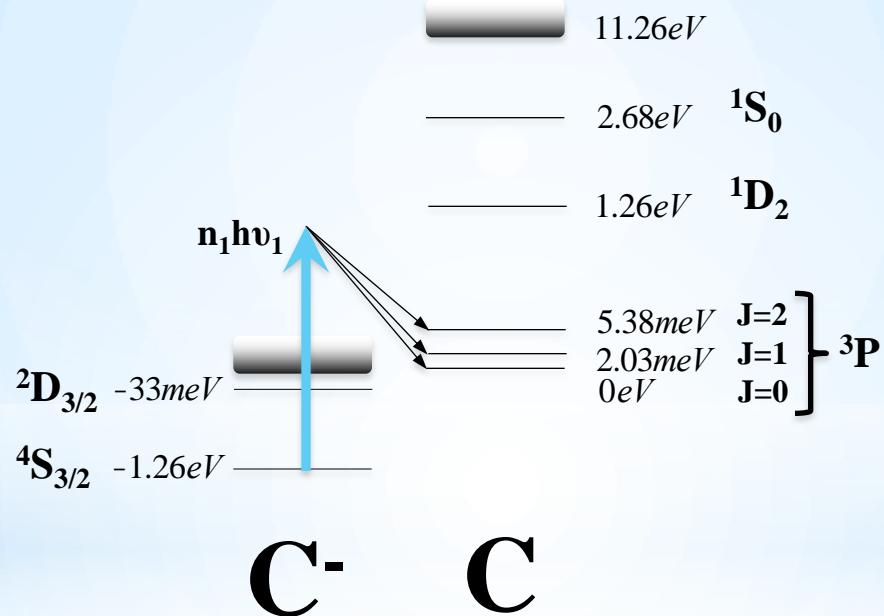


UNIVERSITY OF  
GOTHENBURG

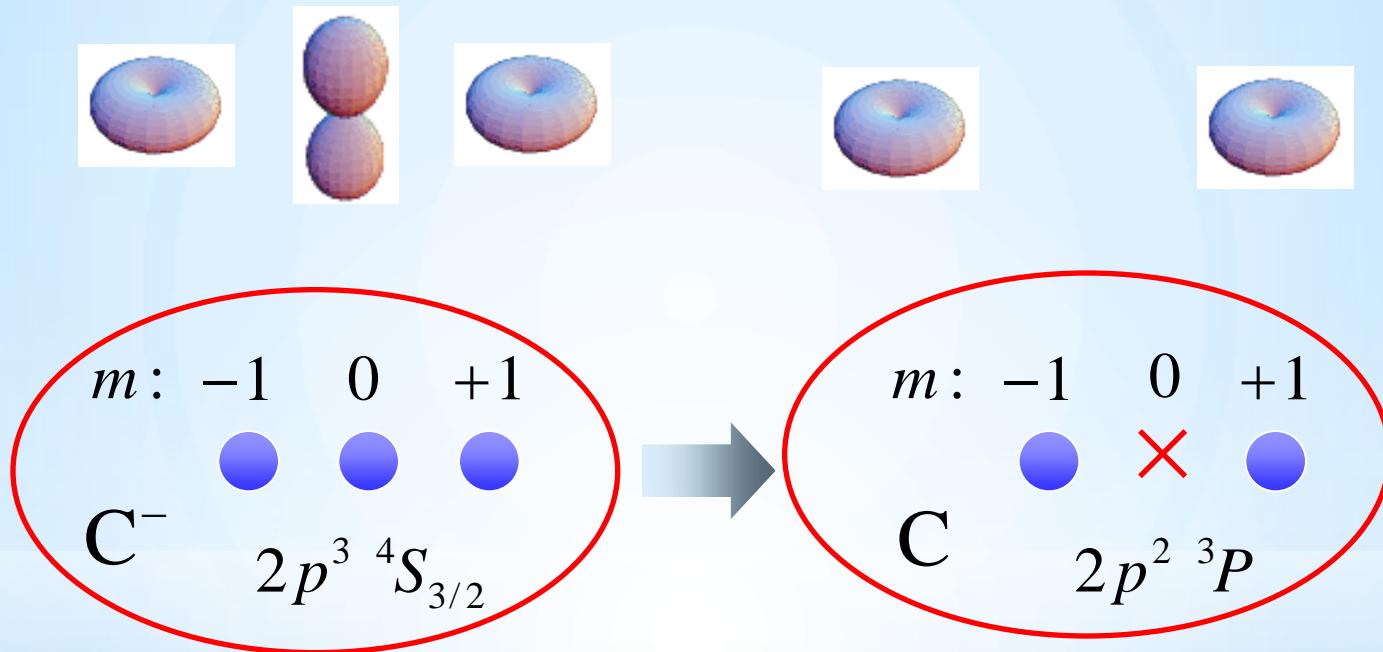


# Visualization of electronic motion in an atomic ground state

# Energy levels of C<sup>-</sup> and C

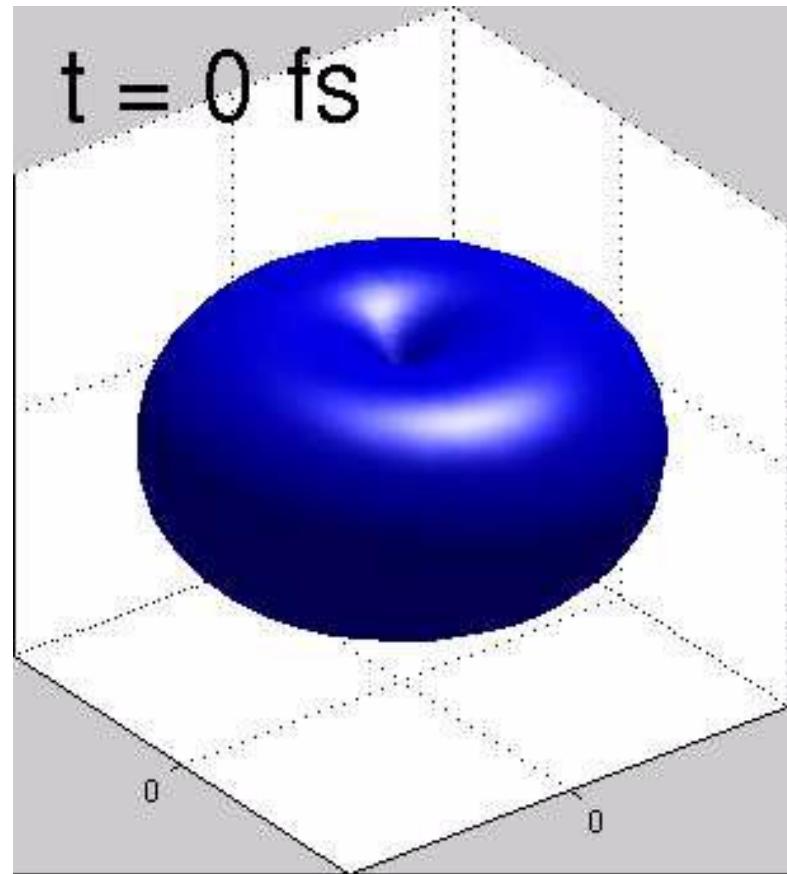
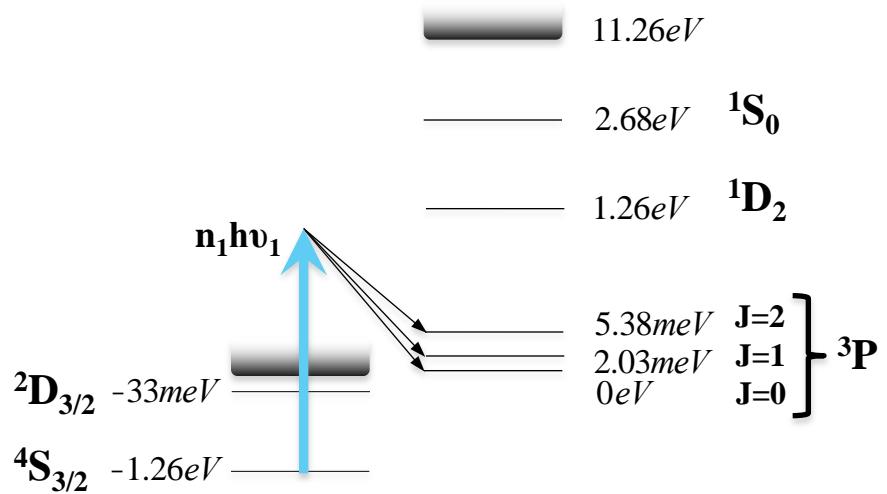


# Photodetachment in a strong field:

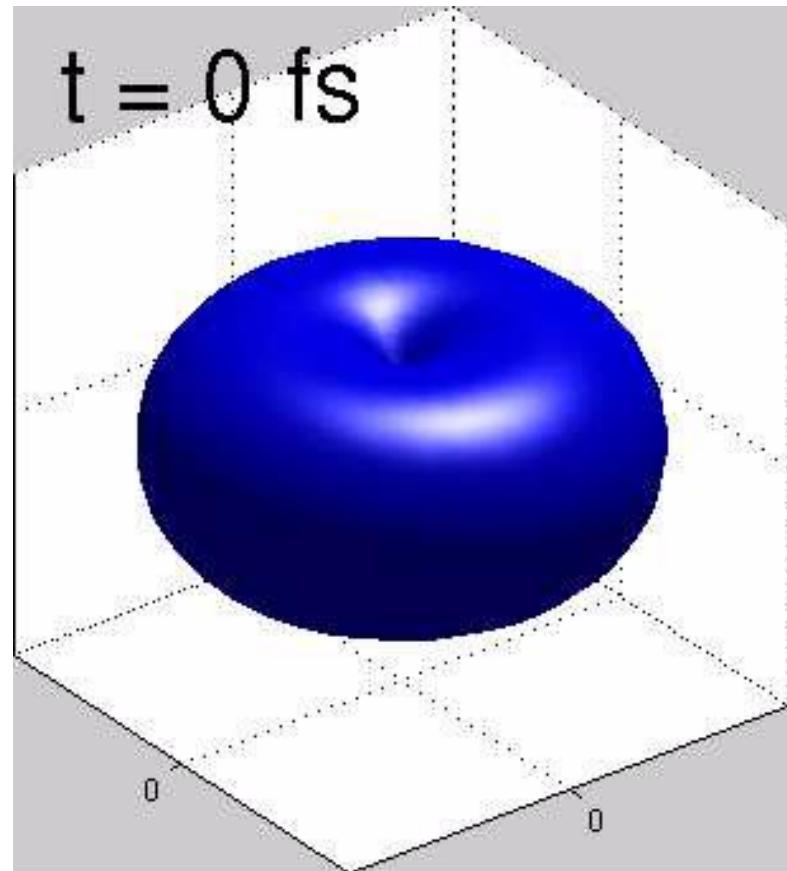
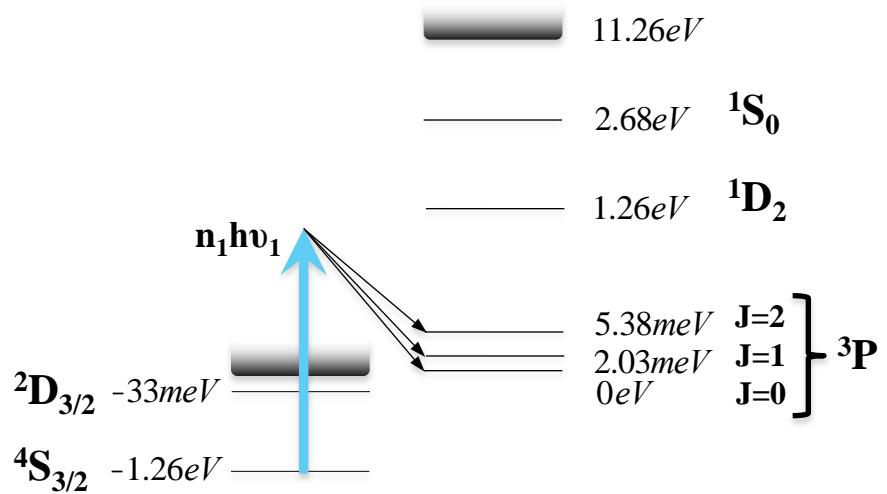


$$w_{m=0} \gg w_{m=\pm 1}$$

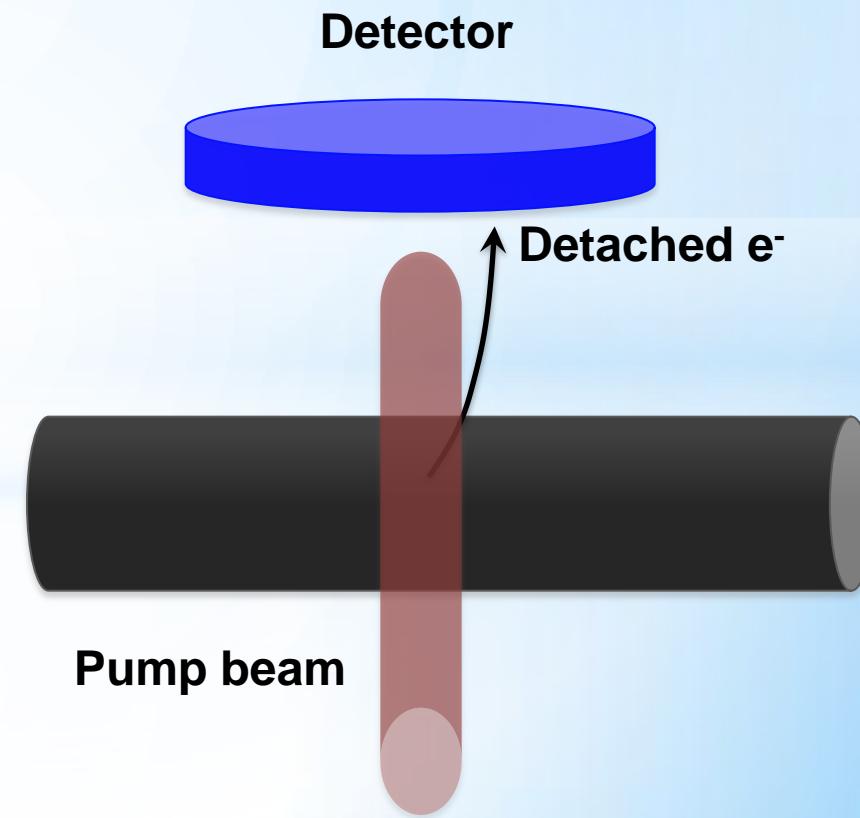
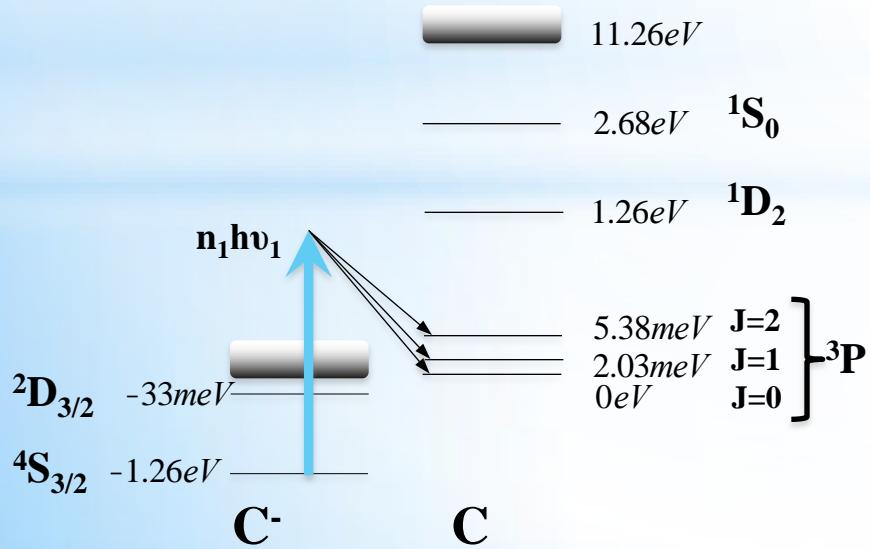
N. Rohringer and R. Santra, Phys. Rev. A **79**, 053402 (2009)

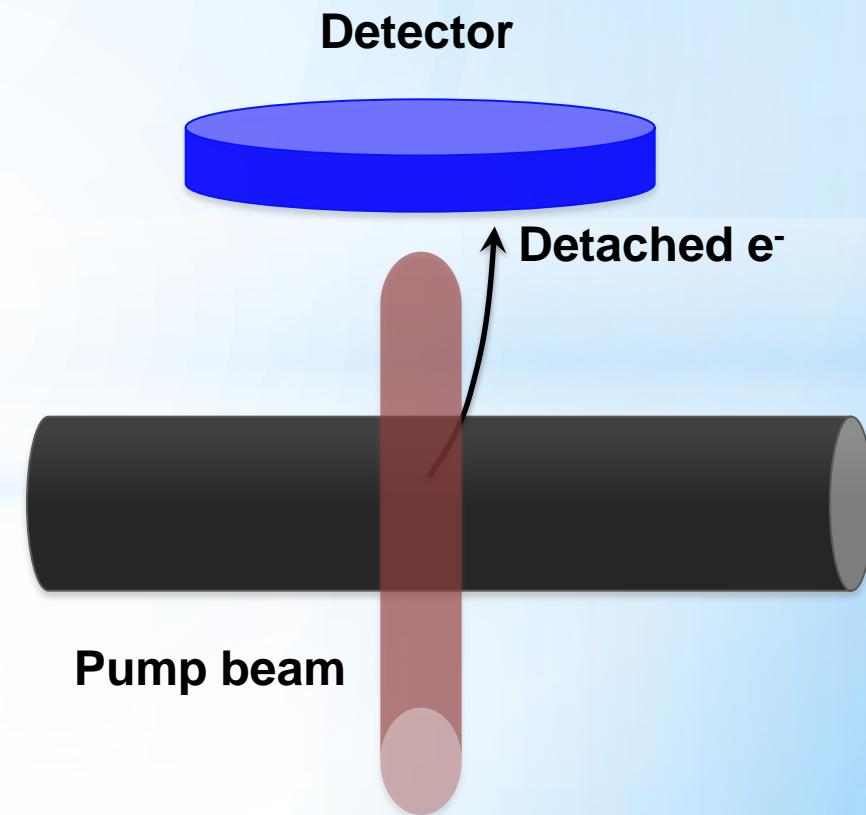
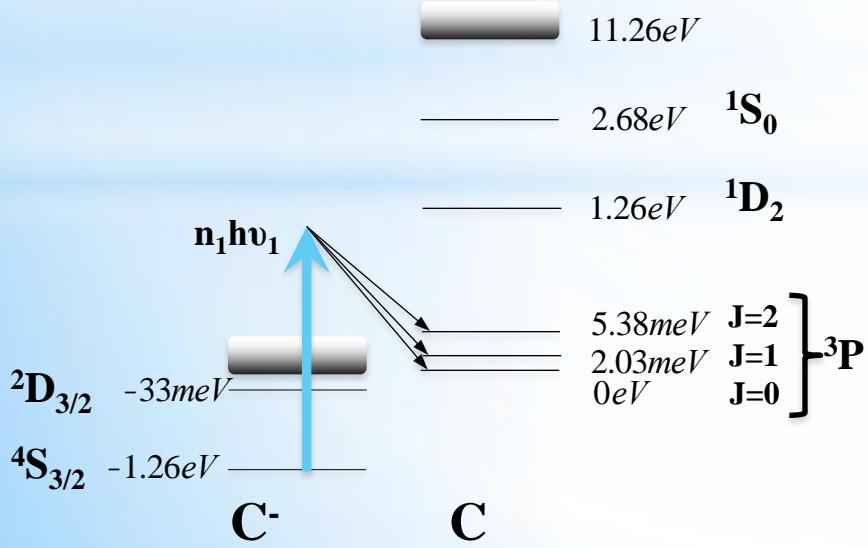
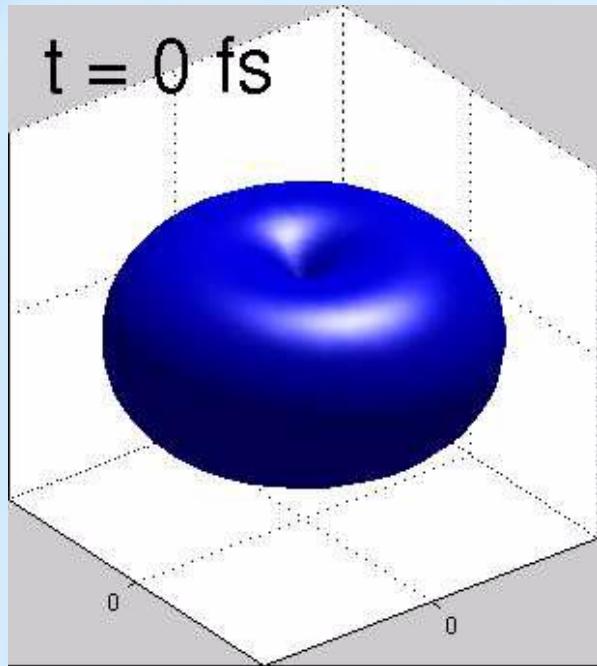


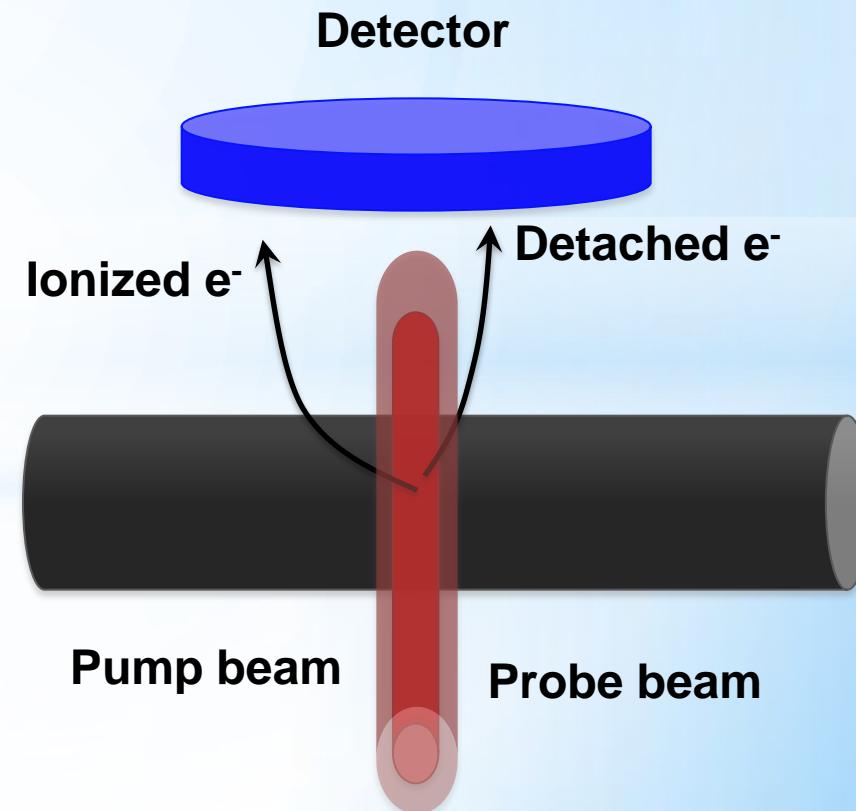
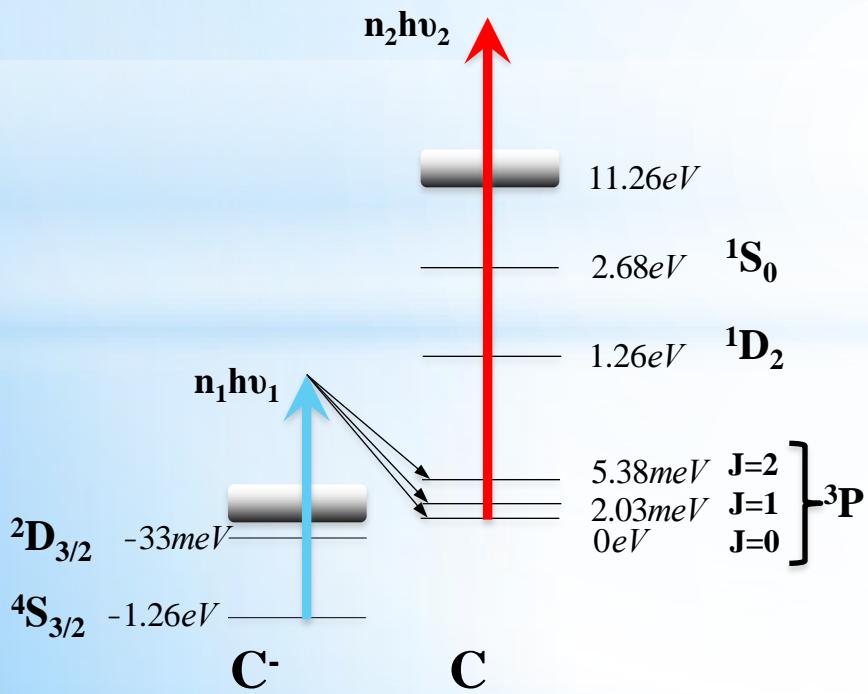
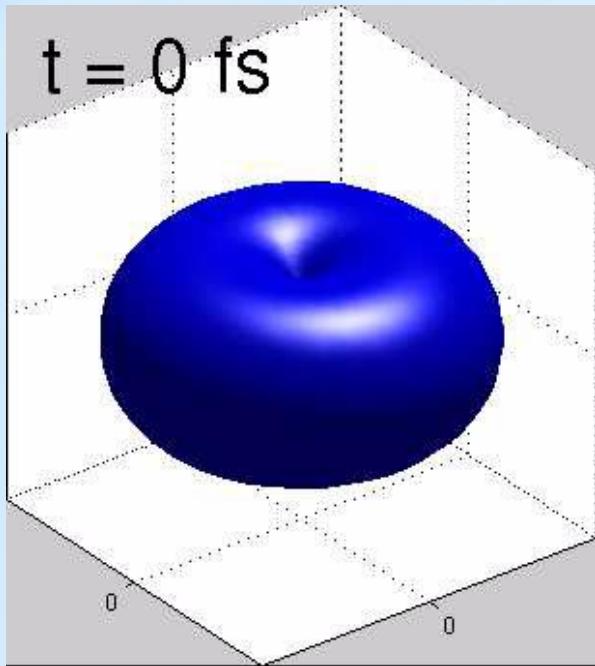
Bandwidth of laser > Fine structure splitting of C  $\rightarrow$   
Coherently populated states

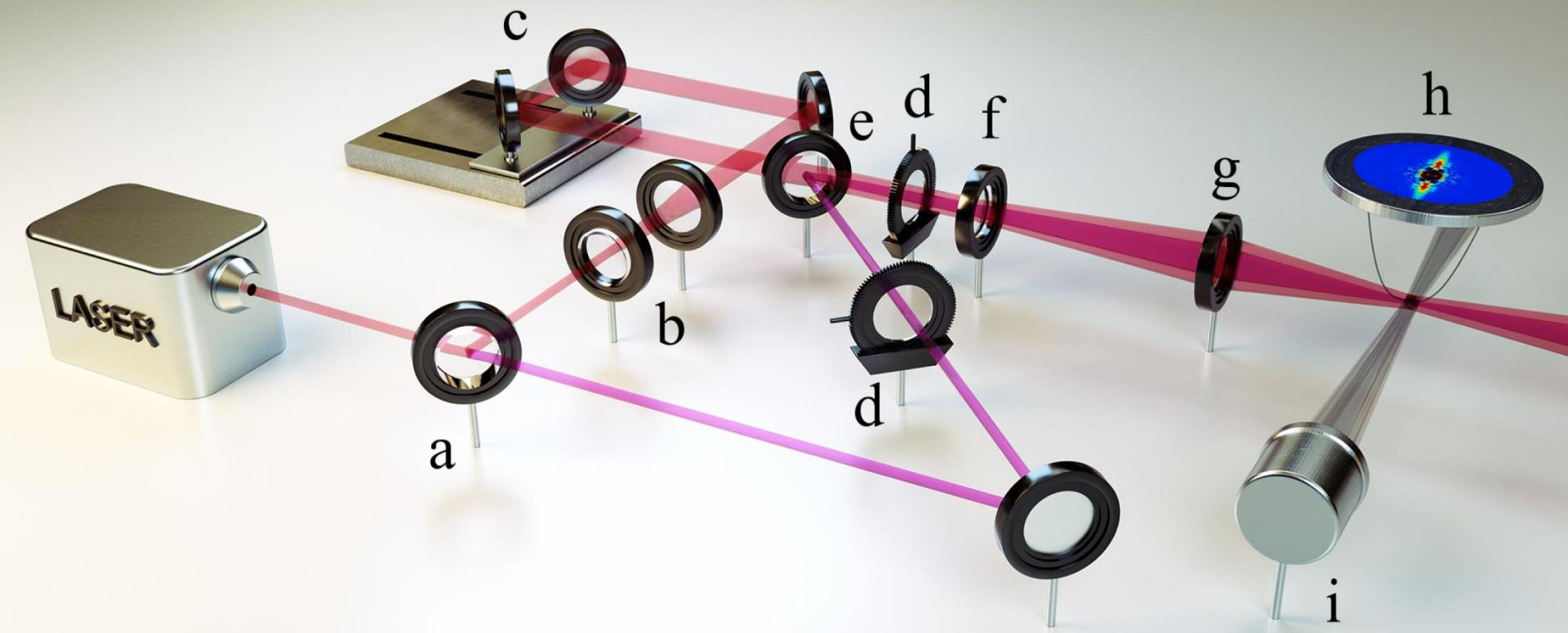


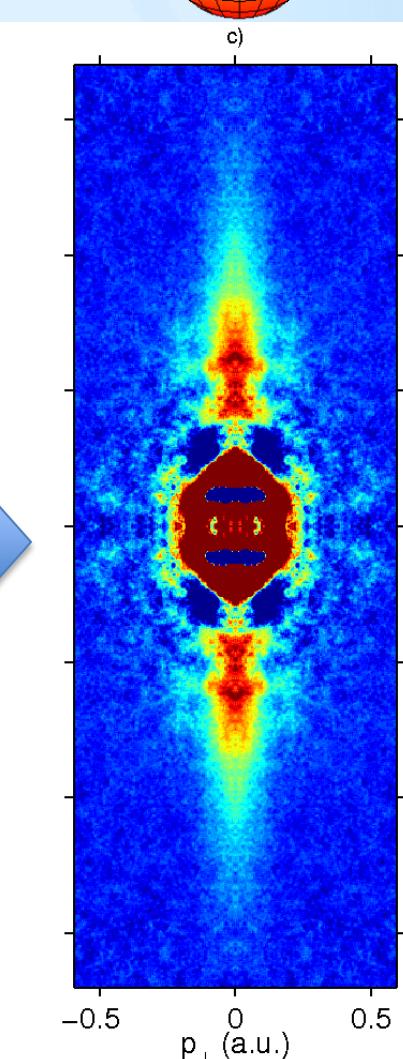
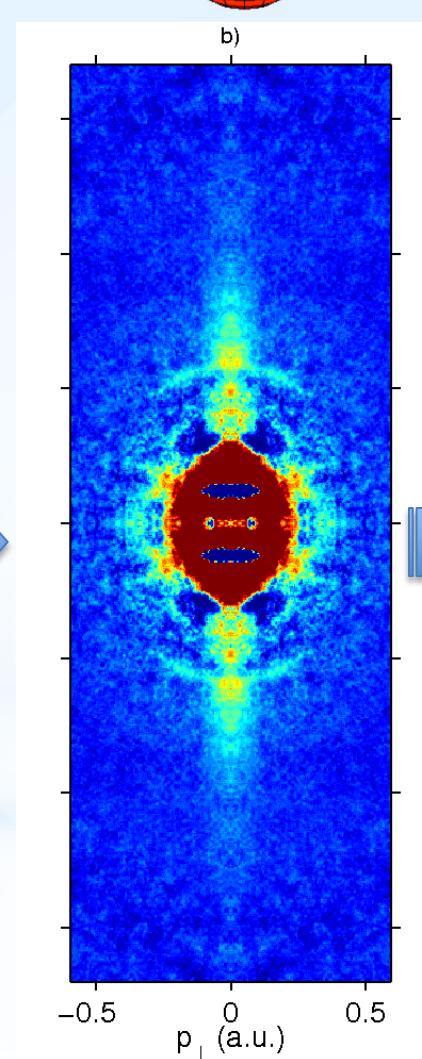
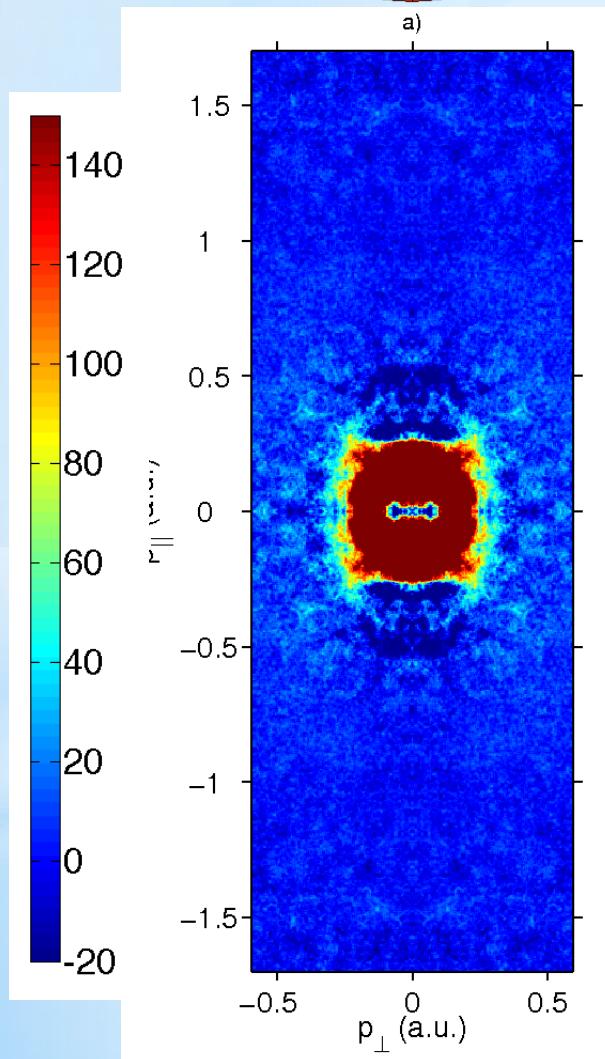
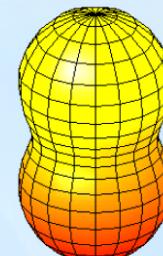
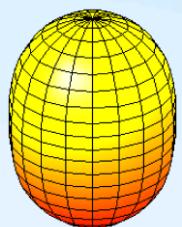
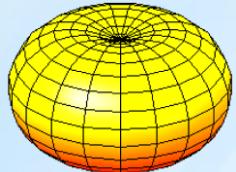
Bandwidth of laser > Fine structure splitting of C →  
Coherently populated states

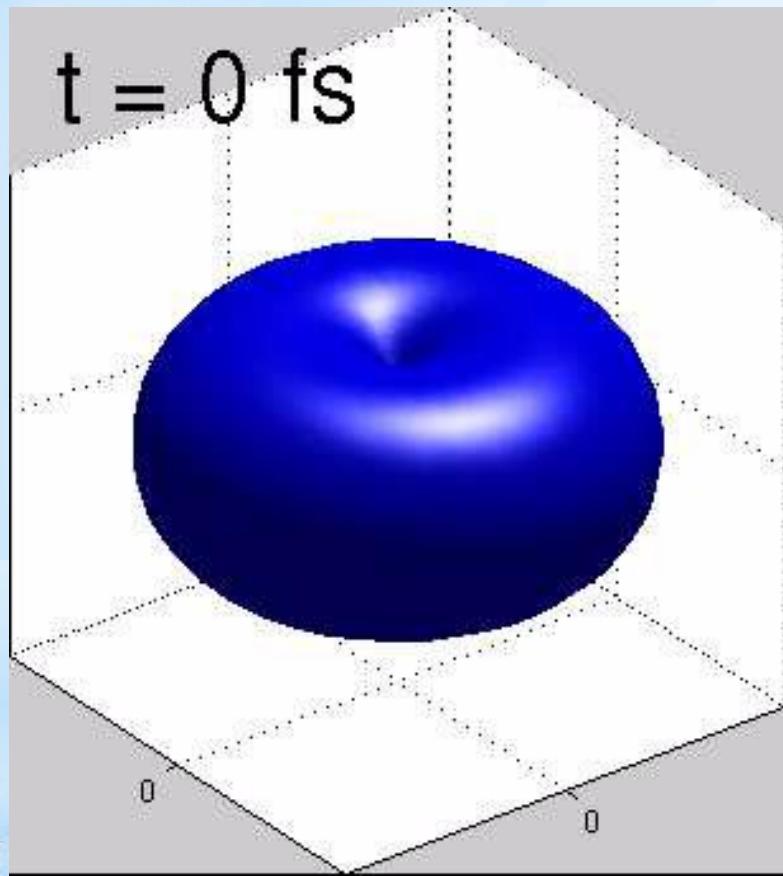






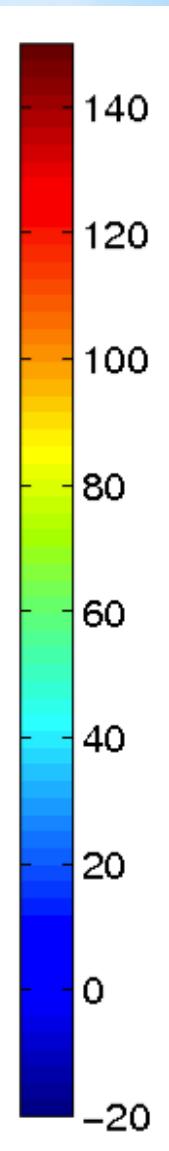
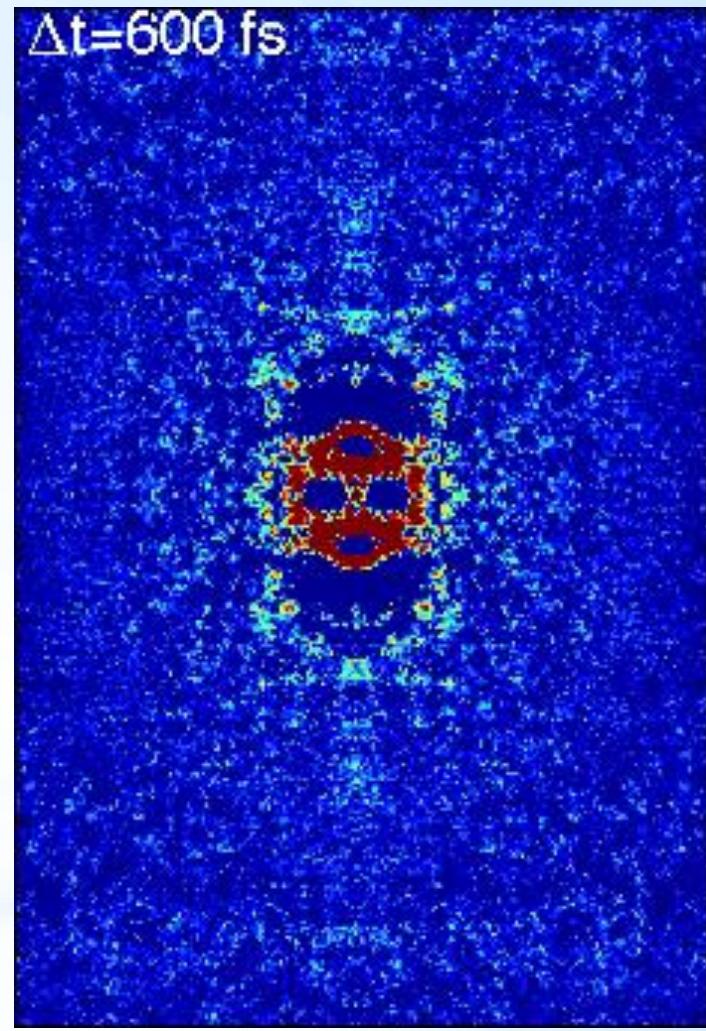




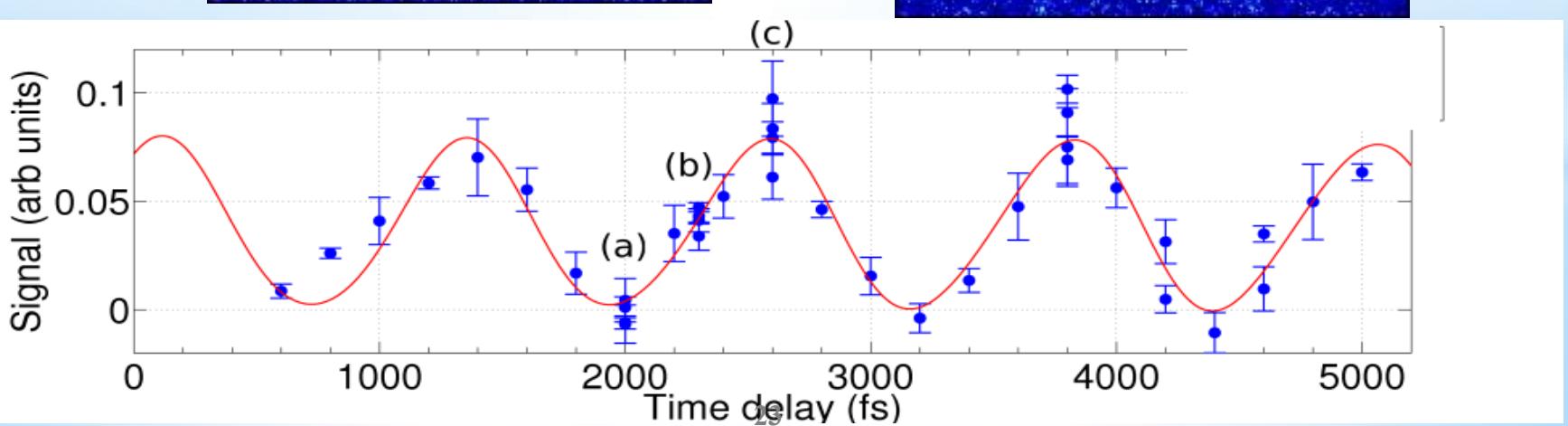
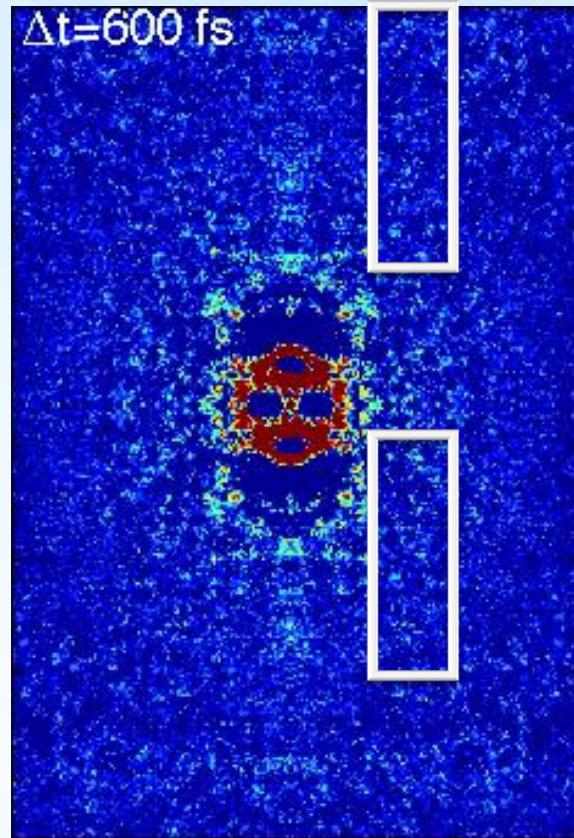
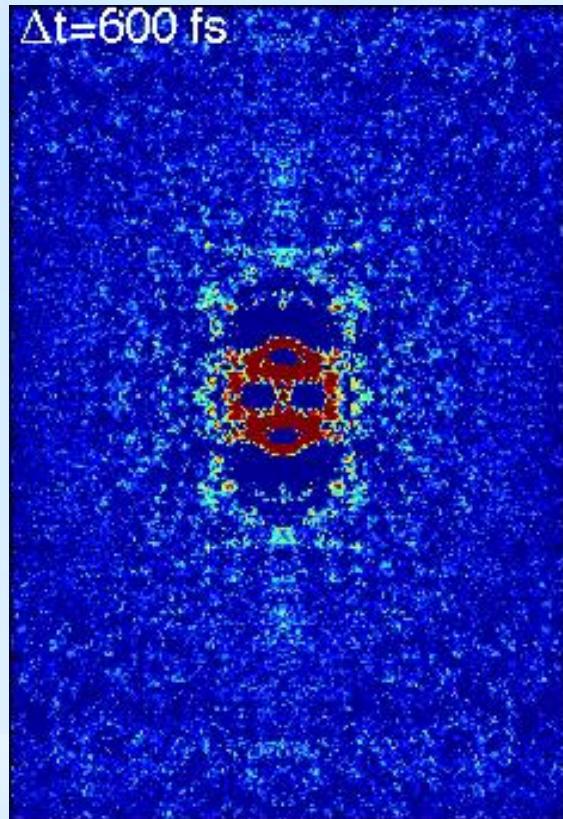


Laser Polarization

A large red double-headed arrow pointing vertically, labeled "Laser Polarization" in black text, indicating the direction of polarization.

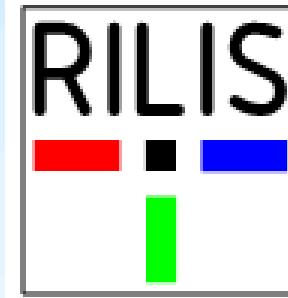


Laser Polarization





UNIVERSITY OF  
GOTHENBURG



# The electron affinity of Astatine

# Astatine

ASTATINE 70mg



1 x per Planet  
(Apply to crust)



- Least abundant element on earth
- 70 mg in the crust of the earth (1 atom per 100 kg mass)
- Decays through  $\alpha$ -decay
- Small knowledge about its chemical and physical properties
- Used in cancer treatment  
Targeted Alfa Therapy (TAT)  
(suitable lifetime and energy,  
non-toxic, non-radioactive daughters)

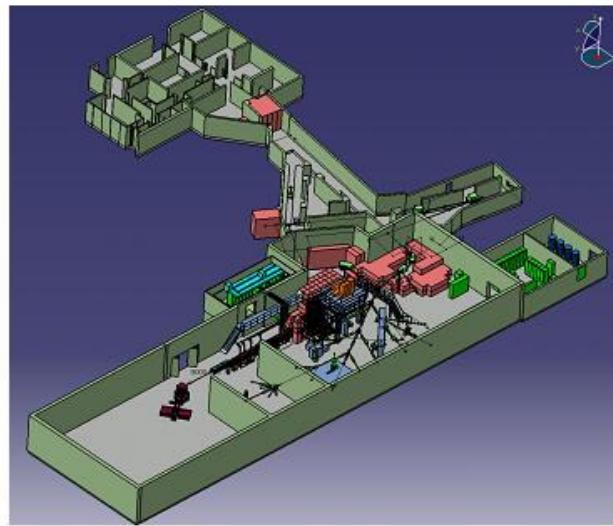
Periodic Table of Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen Atomic Mass 1.00794	2 He Helium Atomic Mass 4.002602	3 Li Lithium Atomic Mass 6.941	4 Be Beryllium Atomic Mass 9.012182	5 B Boron Atomic Mass 10.81	6 C Carbon Atomic Mass 12.011	7 N Nitrogen Atomic Mass 14.011	8 O Oxygen Atomic Mass 15.999	9 F Fluorine Atomic Mass 18.9984	10 Ne Neon Atomic Mass 20.1797	11 Na Sodium Atomic Mass 22.989769	12 Mg Magnesium Atomic Mass 24.365	13 Al Aluminum Atomic Mass 26.981538	14 Si Silicon Atomic Mass 28.0855	15 P Phosphorus Atomic Mass 30.911622	16 S Sulfur Atomic Mass 32.065	17 Cl Chlorine Atomic Mass 35.453	18 Ar Argon Atomic Mass 39.949
<b>C Solid</b> Hg Liquid H Gas Rf Unknown	<b>Metals</b> <b>Alkali metals</b> Li Na K Rb Cs Fr	<b>Lanthanoids</b> Sc Y La Ce Pr Nd Pm Sm Eu Gd Dy Tb Bk	<b>Actinoids</b> Be Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te At	<b>Transition metals</b> V Cr Mn Fe Co Ni Cu Zn Ga Ge As Sb Te I	<b>Poor metals</b> Ti Cr Mn Fe Co Ni Cu Zn Ga Ge As Sb Te I	<b>Nonmetals</b> B C N O F Ne S P Cl Ar Se As Sb Te Br Te Po At	<b>Noble gases</b> He Ne Ar Kr Xe Rn Uuo Uup Uun Uuh Uub Uut Uus Uuo Lu Lr										
21 Sc Scandium Atomic Mass 44.955792	22 Ti Titanium Atomic Mass 47.9468	23 V Vanadium Atomic Mass 50.9442	24 Cr Chromium Atomic Mass 51.9961	25 Mn Manganese Atomic Mass 54.9389	26 Fe Iron Atomic Mass 55.845	27 Co Cobalt Atomic Mass 58.9354	28 Ni Nickel Atomic Mass 58.9332	29 Cu Copper Atomic Mass 63.546	30 Zn Zinc Atomic Mass 65.402	31 Ga Gallium Atomic Mass 69.723	32 Ge Germanium Atomic Mass 72.611	33 As Arsenic Atomic Mass 75.00	34 Se Selenium Atomic Mass 78.96	35 Br Bromine Atomic Mass 79.904	36 Kr Krypton Atomic Mass 83.798	37 Xe Xenon Atomic Mass 131.906	38 Po Polonium Atomic Mass 161.973
39 Y Yttrium Atomic Mass 88.90588	40 Zr Zirconium Atomic Mass 91.224	41 Nb Niobium Atomic Mass 92.90638	42 Mo Molybdenum Atomic Mass 95.98	43 Ru Ruthenium Atomic Mass 101.07	44 Rh Rhodium Atomic Mass 102.90560	45 Pd Palladium Atomic Mass 106.42	46 Ag Silver Atomic Mass 107.885	47 Cd Cadmium Atomic Mass 112.411	48 In Indium Atomic Mass 114.818	49 Sn Tin Atomic Mass 118.718	50 Sb Antimony Atomic Mass 121.765	51 Te Tellurium Atomic Mass 127.00	52 Po Polonium Atomic Mass 139.906	53 At Astatine Atomic Mass 177.807	54 Iodine Atomic Mass 126.9045	55 Cs Cesium Atomic Mass 132.9054519	
56 Ba Barium Atomic Mass 137.327	57 La Lanthanum Atomic Mass 140.90767	58 Ce Cerium Atomic Mass 140.90767	59 Pr Praseodymium Atomic Mass 141.90767	60 Nd Neodymium Atomic Mass 144.242	61 Pm Promethium Atomic Mass 145.921	62 Sm Samarium Atomic Mass 150.947	63 Eu Europium Atomic Mass 151.964	64 Gd Gadolinium Atomic Mass 158.925	65 Tb Terbium Atomic Mass 160.933	66 Dy Dysprosium Atomic Mass 162.933	67 Ho Holmium Atomic Mass 164.933	68 Er Erbium Atomic Mass 167.939	69 Tm Thulium Atomic Mass 169.934	70 Yb Ytterbium Atomic Mass 173.934	71 Lu Lutetium Atomic Mass 174.938		
72 Tc Technetium Atomic Mass 98.90549	73 Ta Tantalum Atomic Mass 180.94788	74 W Tungsten Atomic Mass 183.94	75 Re Rhenium Atomic Mass 186.207	76 Os Osmium Atomic Mass 187.923	77 Ir Iridium Atomic Mass 190.954	78 Pt Platinum Atomic Mass 191.954	79 Au Gold Atomic Mass 196.96909	80 Hg Mercury Atomic Mass 200.59	81 Tl Thallium Atomic Mass 204.333	82 Pb Lead Atomic Mass 208.994	83 Bi Bismuth Atomic Mass 209.998	84 Po Polonium Atomic Mass 210.975	85 At Astatine Atomic Mass 217.807	86 Iodine Atomic Mass 214.9045	87 Fr Francium Atomic Mass 220	88 Ra Radium Atomic Mass 226	
89 Ac Actinium Atomic Mass 227	90 Th Thorium Atomic Mass 232.03898	91 Pa Protactinium Atomic Mass 231.03898	92 U Uranium Atomic Mass 238.02891	93 Np Neptunium Atomic Mass 237	94 Pu Plutonium Atomic Mass 244	95 Am Americium Atomic Mass 243	96 Cm Curium Atomic Mass 247	97 Bk Berkelium Atomic Mass 247	98 Cf Californium Atomic Mass 251	99 Es Einsteinium Atomic Mass 252	100 Fm Fermium Atomic Mass 257	101 Md Mendelevium Atomic Mass 259	102 No Nobelium Atomic Mass 259	103 Lr Lawerence Atomic Mass 258	104 Hf Hafnium Atomic Mass 264		
105 Db Dubnium Atomic Mass 262	106 Sg Seaborgium Atomic Mass 260	107 Bh Bohrium Atomic Mass 261	108 Hs Hassium Atomic Mass 267	109 Mt Meitnerium Atomic Mass 268	110 Ds Darmstadtium Atomic Mass 270	111 Rg Rutherfordium Atomic Mass 272	112 Ub Unnilumber Atomic Mass 270	113 Ut Unnilactinium Atomic Mass 270	114 Un Unnilium Atomic Mass 270	115 Uu Unnilpentium Atomic Mass 270	116 Uuh Unnilhexium Atomic Mass 270	117 Uuo Unnilseptium Atomic Mass 270	118 Uup Unniloctium Atomic Mass 270	119 Uuu Unnilnonium Atomic Mass 270	120 Uuh Unnildecium Atomic Mass 270		
101-103	104-106	107-109	110-112	113-115	116-118	119-121	122-124	125-127	128-130	131-133	134-136	137-139	140-142	143-145	146-148	149-151	

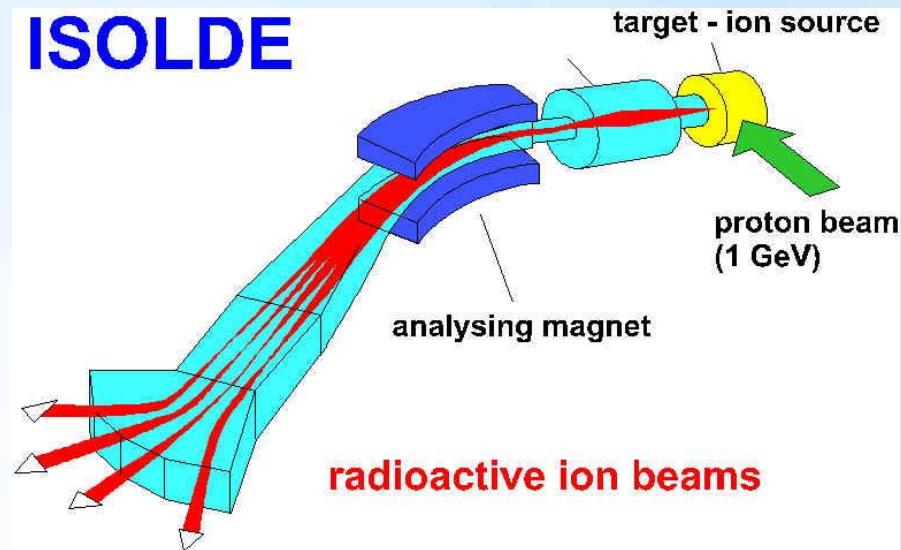
Ptable.com

Design and Interface Copyright © 1997 Michael Dayah (michael@dayah.com). <http://www.ptable.com/>

# Experimental program at ISOLDE

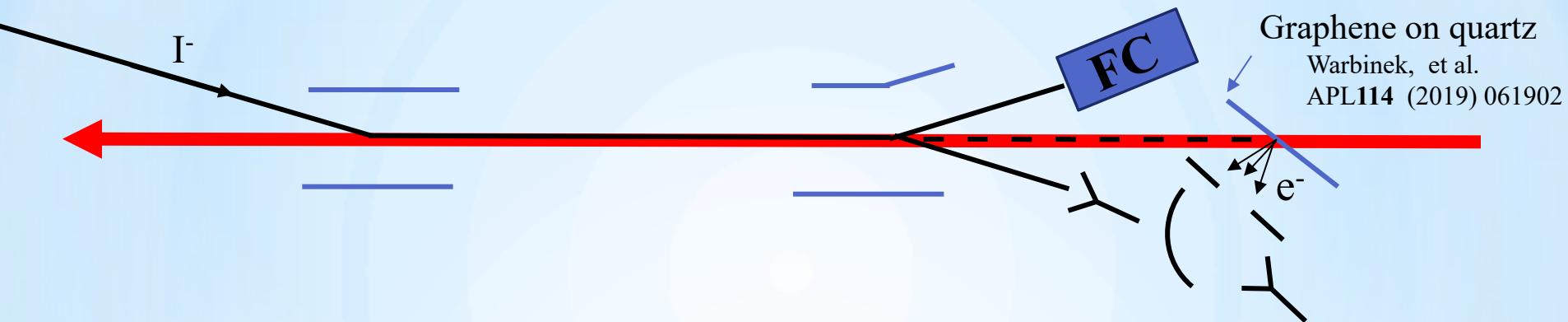


**ISOLDE**



# GANDALPH

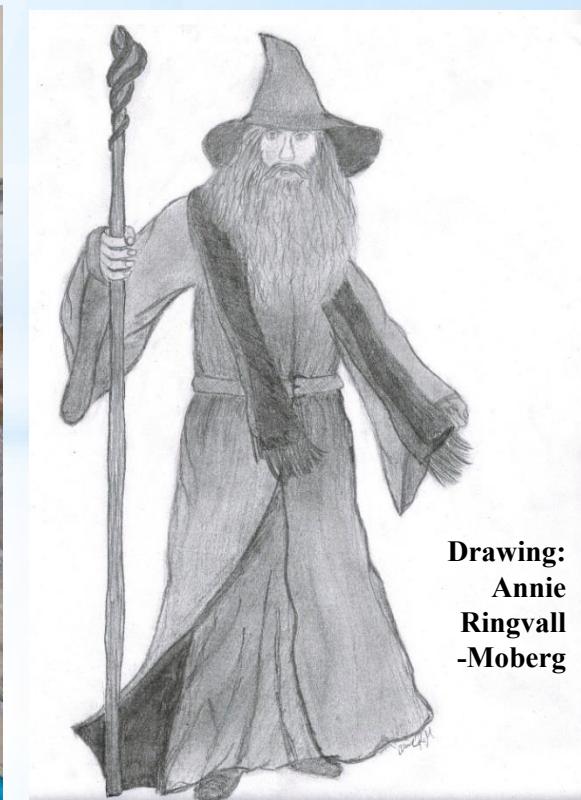
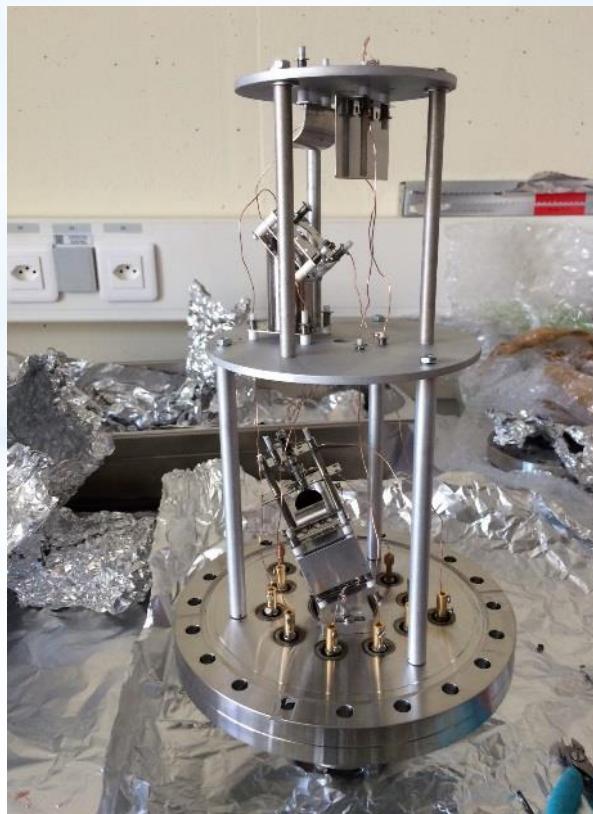
Gothenburg ANion Detector for Affinity measurements by Laser PHotodetachment

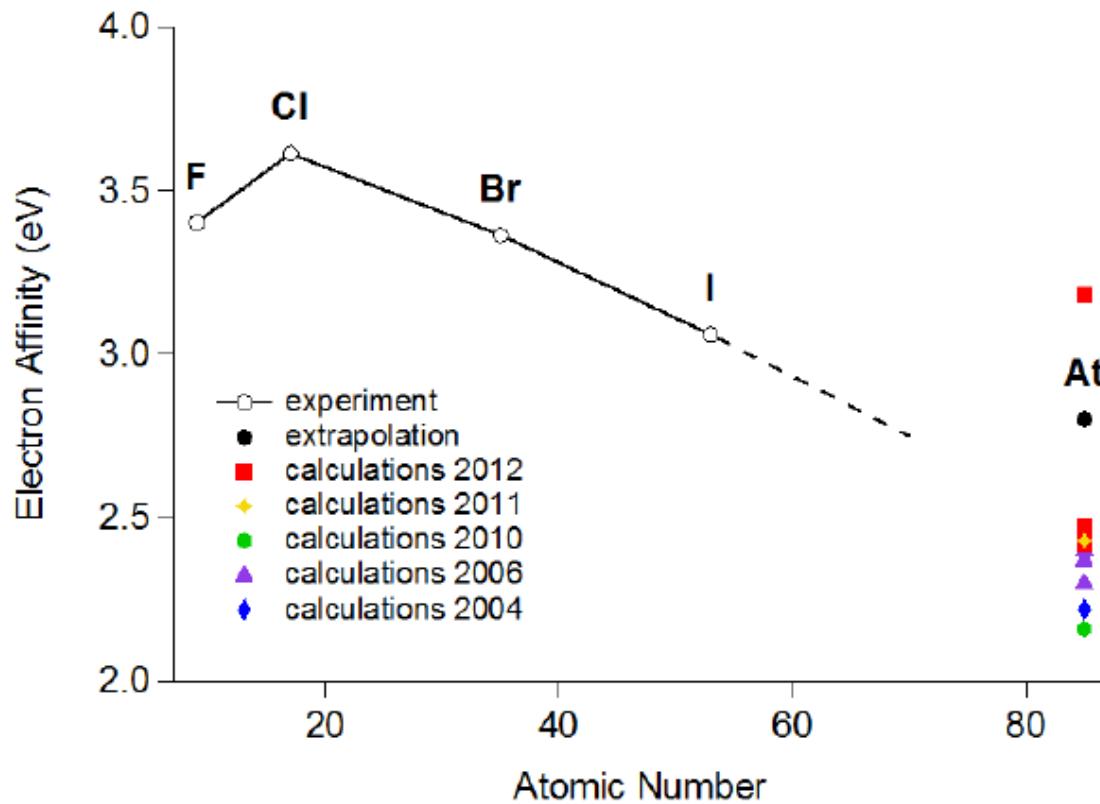


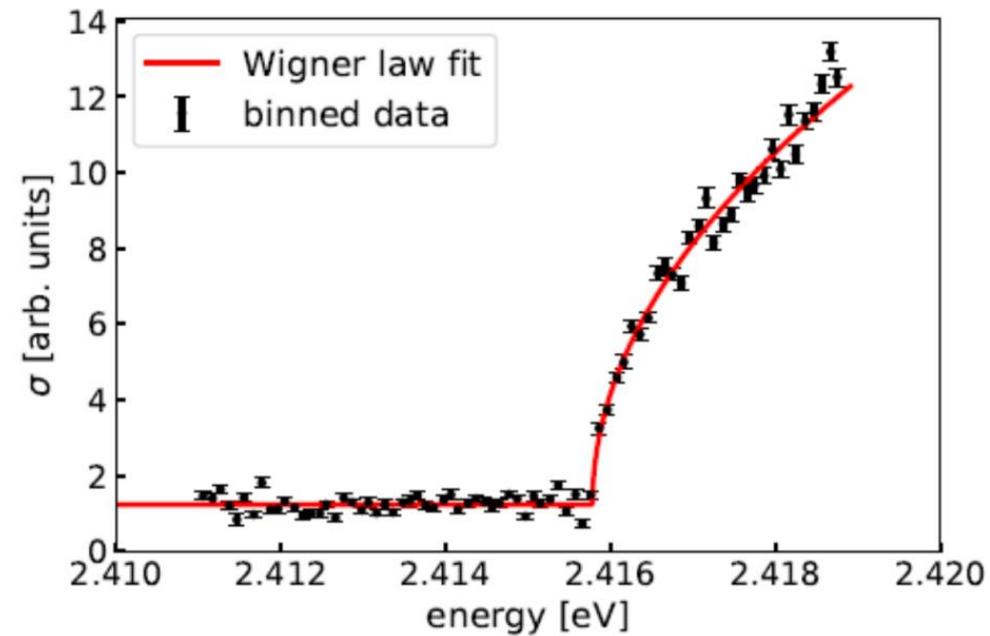
For each laserpuls:

Signal:  
0.01 atom

Background:  
 $10^{14}$  photons







## The electron affinity of astatine

David Leimbach<sup>1,2,3</sup>, Julia Sundberg<sup>2</sup>, Yangyang Guo<sup>4</sup>, Rizwan Ahmed<sup>5</sup>, Jochen Ballot<sup>1,6</sup>, Lars Bengtsson<sup>2</sup>, Ferran Boix Pamies<sup>1</sup>, Anastasia Borschevsky<sup>4</sup>, Katerina Chrysalidis<sup>1,3</sup>, Ephraim Elias<sup>11</sup>, Dmitry Fedorov<sup>7</sup>, Valentin Fedosseev<sup>1</sup>, Oliver Forstner<sup>8,9</sup>, Nicolas Galland<sup>10</sup>, Ronald Fernando Garcia Ruiz<sup>1</sup>, Camilo Granados<sup>1</sup>, Reinhard Heinke<sup>3</sup>, Karl Johnston<sup>1</sup>, Agota Koszorus<sup>1</sup>, Ulli Köster<sup>13</sup>, Moa K. Kristiansson<sup>14</sup>, Yuan Liu<sup>15</sup>, Bruce Marsh<sup>1</sup>, Pavel Molkhanov<sup>7</sup>, Lukáš F. Paštěka<sup>12</sup>, Joao Pedro Ramos<sup>1</sup>, Eric Renault<sup>10</sup>, Mikael Reponen<sup>16</sup>, Annie Ringqvall-Moberg<sup>1,2</sup>, Ralf Erik Rosseel<sup>1</sup>, Dominik Studer<sup>9</sup>, Adam Vernon<sup>17</sup>, Jessica Warbinek<sup>2,3</sup>, Jakob Welander<sup>5</sup>, Klaus Wendt<sup>3</sup>, Shane Wilkins<sup>1</sup>, Dag Hanstorp<sup>2</sup> and Sebastian Rothe<sup>1</sup>

<sup>1</sup>CERN, Geneva, Switzerland

<sup>2</sup>Department of Physics, University of Gothenburg, Gothenburg, Sweden

<sup>3</sup>Institut für Physik, Johannes Gutenberg-Universität, Mainz, Germany

<sup>4</sup>Van Swinderen Institute for Particle Physics and Gravity, University of Groningen, Groningen, The Netherlands

<sup>5</sup>National Centre for Physics (NCP), Islamabad, Pakistan

<sup>6</sup>Institut für Kemchemie, Johannes Gutenberg-Universität, Mainz, Germany

<sup>7</sup>Petersburg Nuclear Physics Institute - NRC KI, Gatchina, Russia

<sup>8</sup>Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität Jena, Germany

<sup>9</sup>Heinrich Heine Universität Düsseldorf, Düsseldorf, Germany

<sup>10</sup>CEISAM, Université de Nantes, CNRS, Nantes, France

<sup>11</sup>School of Chemistry, Tel Aviv University, Tel Aviv, Israel

<sup>12</sup>Department of Physical and Theoretical Chemistry & Laboratory for Advanced Materials, Faculty of Natural Sciences, Comenius University, Bratislava, Slovakia

<sup>13</sup>Institut Laue-Langevin, Grenoble, France

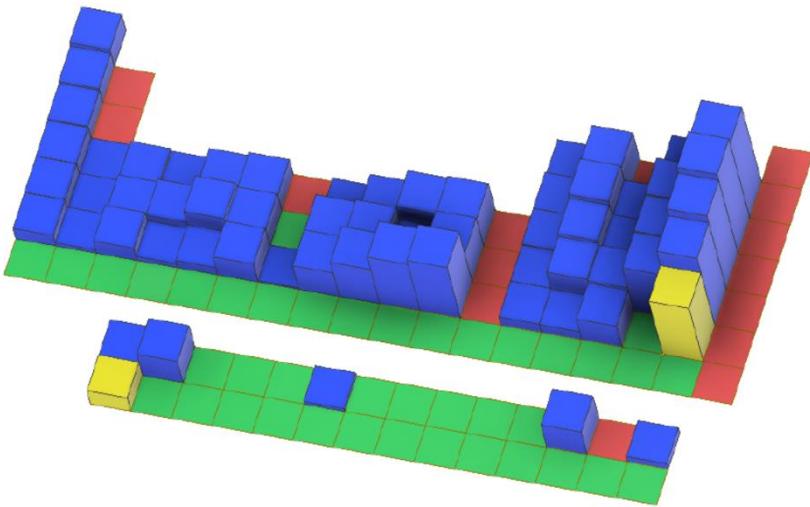
<sup>14</sup>Department of Physics, Stockholm University, Stockholm, Sweden

<sup>15</sup>Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA

<sup>16</sup>Department of Physics, University of Jyväskylä, Jyväskylä, Finland

<sup>17</sup>School of Physics and Astronomy, The University of Manchester, Manchester, UK

Method	Author	Year	EA
Experiment			2.41578(5)
CBS-DC-CCSDT(Q)+Breit+QED			2.414(16)
MCDHF+SE corr.	Chang et al	2010	2.38(2)
MCDHF	Zhao et al	2012	2.416
DC-CCSD(T)+Breit+QED	Broschevsky et al	2015	2.412
MCDHF+Extrap.+Breit+QED	Si and Fischer	2018	2.3729(46)
CBS-DC-CCSD(T)+Gaunt+QED	Finney and Peterson	2019	2.423(13)



Property	Definition	Value
Electron affinity	$EA$	2.415 78(5) eV
Ionization energy	$IE$	9.317 51(8) eV <sup>20</sup>
Electronegativity	$\chi_M = \frac{IP+EA}{2}$	5.866 65 eV
Hardness	$\eta = IE - EA$	6.901 72(13) eV
Softness	$S = \frac{1}{\eta}$	0.144 89(2) eV <sup>-1</sup>
Electrophilicity	$\omega = \frac{\chi^2}{2\eta}$	2.493 41(8) eV

The At-H molecule should be called **astatine hydride**  
(not hydrogen astatide)



UNIVERSITY OF  
GOTHENBURG

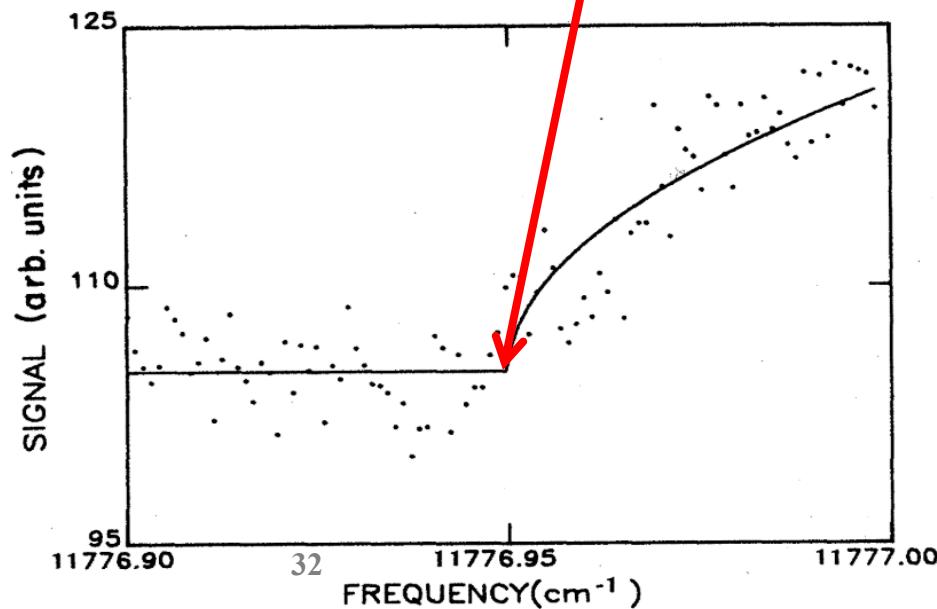
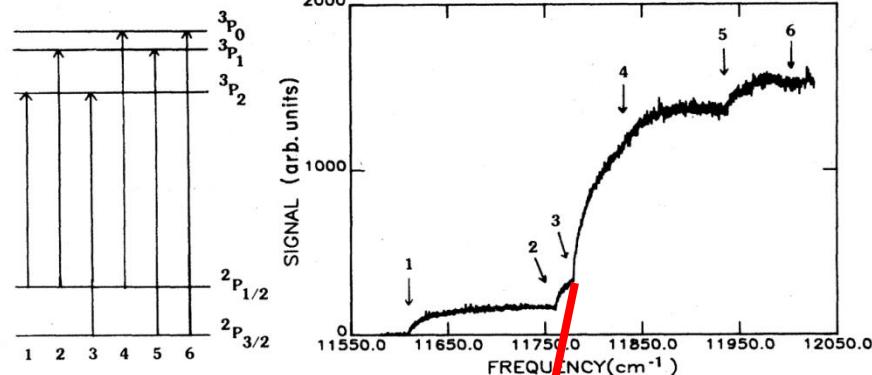


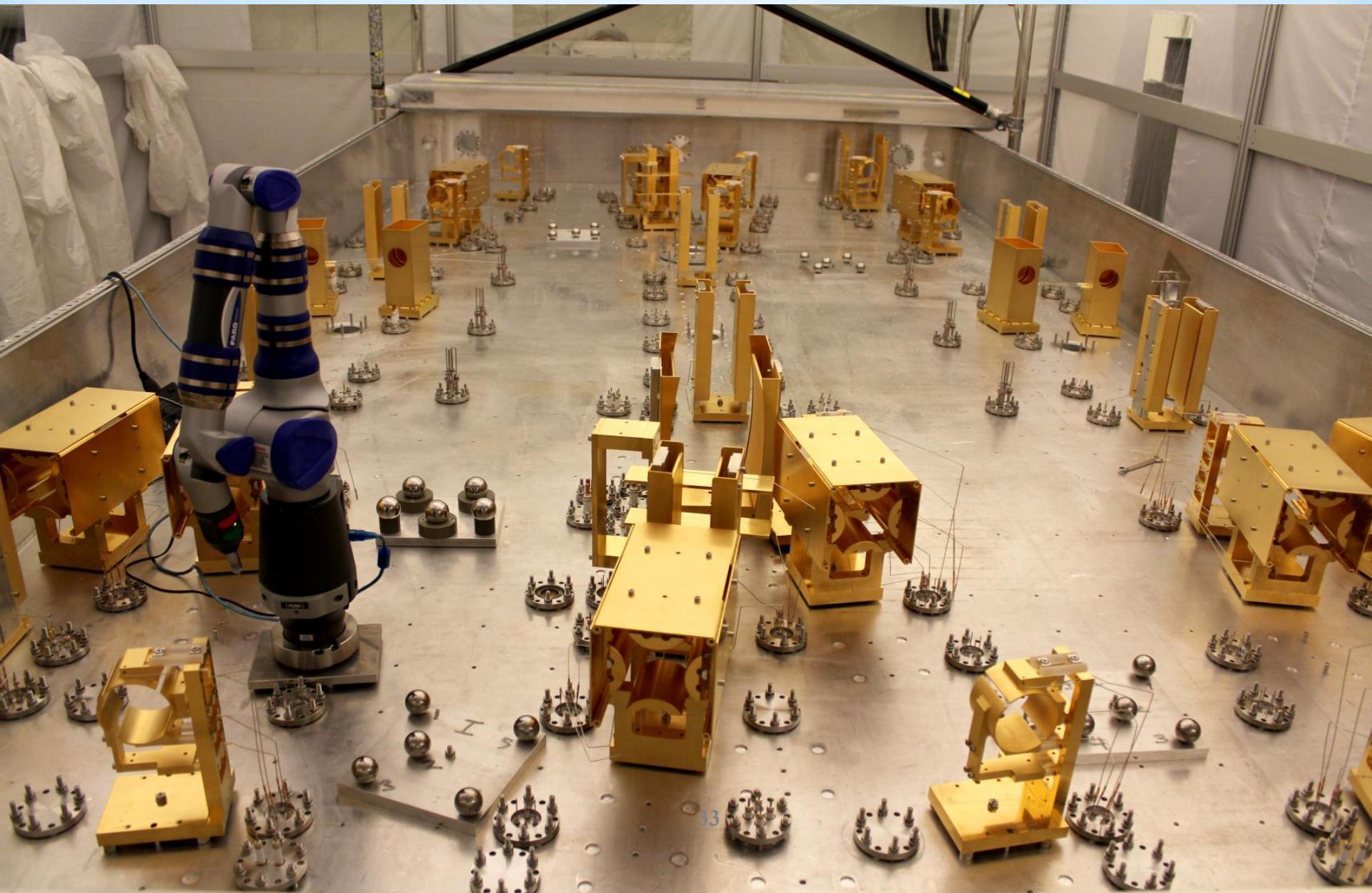
Stockholm  
University

# Photodetachment using an electrostatic storage ring

## Laser photodetachment measurement of the electron affinity of atomic oxygen

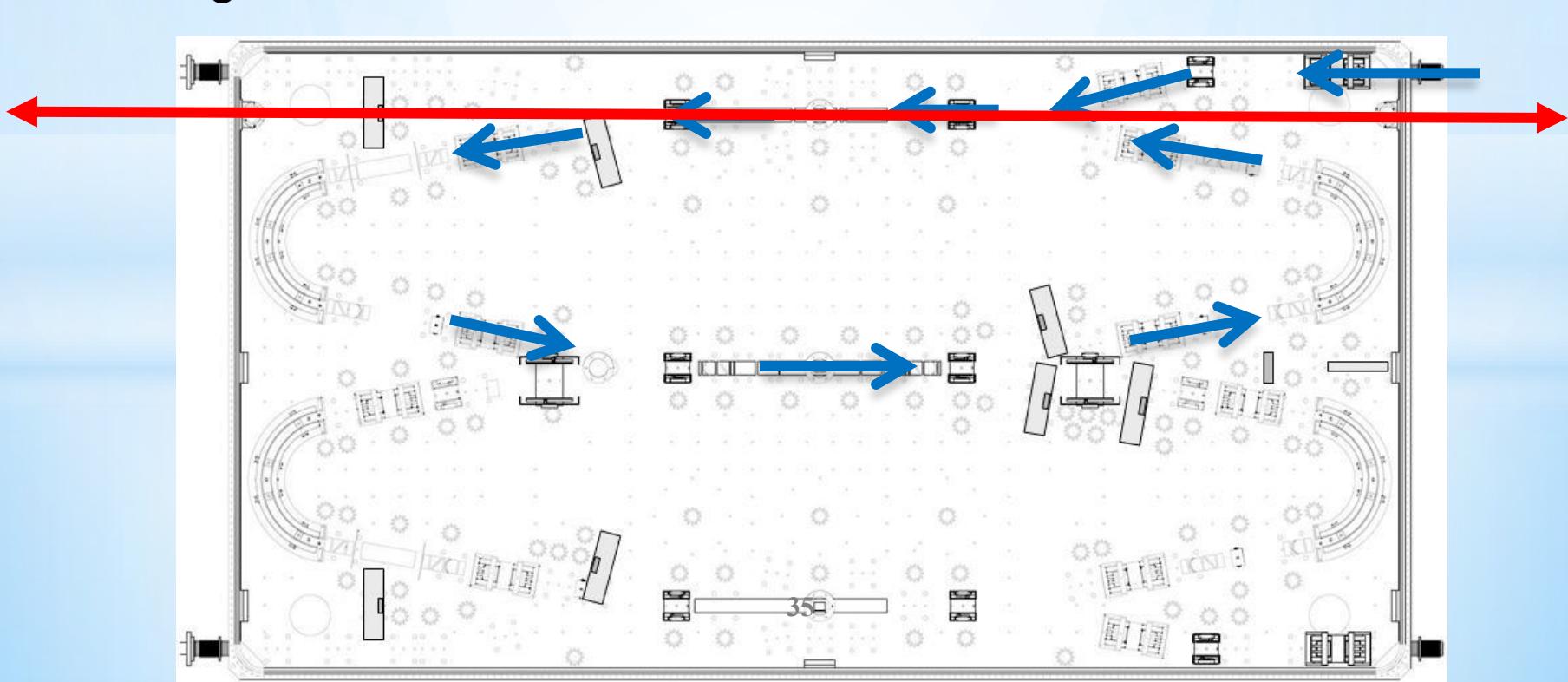
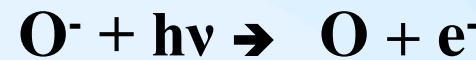
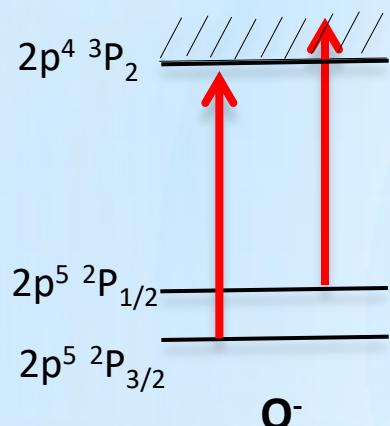
D. M. Neumark, K. R. Lykke, T. Andersen,\* and W. C. Lineberger

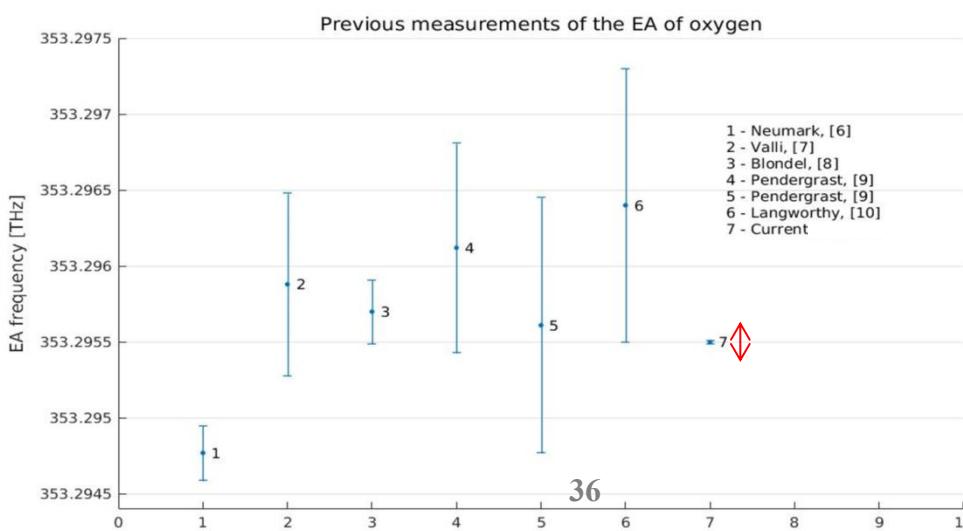






# Measuring the EA of O<sup>-</sup>





# ACKNOWLEDGEMENT

## University of Gothenburg

Anton Lindahl  
Pontus Andersson  
Johan Rohlén  
Jakob Welander  
Julia Sundberg  
Annie Moberg-Ringqvist  
Moa Kristiansson

## Stockholm University



## University of Freiburg, Freiburg, Germany

Igor Kiyan  
Hannes Hultgren  
Mikael Eklund  
Hanspeter Helm

## CERN

Sebastian Rothe  
David Leimbach

Charlotte Froese Fischer - Opening Remarks:  
*In the beginning*

"It all began in the 60ies"

"2019 is not the end, but the beginning of the future!"

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Measurement of shifts in the electron affinities of chlorine isotopes

Dag Hanstorp<sup>1</sup>, Jakob Welander<sup>1</sup>, David Leimbach<sup>1</sup>, Annie Ringvall-Moberg<sup>1,2</sup>, Michel Godefroid<sup>3</sup>,

Per Jönsson<sup>4</sup>, Jörgen Ekman<sup>4</sup>, Tomas Brage<sup>5</sup>, Klaus Wendt<sup>6</sup>, Reinhard Heinke<sup>6</sup>, Oliver Forstner<sup>7</sup>,  
Yuan Liu<sup>8</sup>, Ronald Garcia Ruiz<sup>9</sup>, Shane Wilkins<sup>9</sup>, Adam Vernon<sup>9</sup>, Cory Binnersley<sup>9</sup>, Kieran Flanagan<sup>9</sup>,  
Gerda Neyens<sup>10</sup>, Agi Koszorus<sup>10</sup>, Kara Lynch<sup>2</sup>, Sebastian Rothe<sup>2</sup>, Tim Giles<sup>2</sup>, Katerina Chrysalidis<sup>2,6</sup>,  
Pierre Larmonier<sup>2</sup>, Valentin Fedosseev<sup>2</sup> and Bruce Marsh<sup>2</sup>.

<sup>1</sup> Department of Physics, University of Gothenburg, SE 412 96 Gothenburg, Sweden

<sup>2</sup> CERN, CH-1211 Geneva 23, Switzerland

<sup>3</sup> Université libre de Bruxelles, B 1050 Brussels, Belgium

<sup>4</sup> Materials Science and Applied Mathematics, Malmö University, 205 06 Malmö, Sweden

<sup>5</sup> Division of Mathematical Physics, Department of Physics, Lund University, Box 118, SE-221 00 Lund,

<sup>6</sup> Institut für Physik, Johannes-Gutenberg Universität, Mainz, Germany

<sup>7</sup> Friedrich Schiller Universität, Jena, Germany

<sup>8</sup> Physics Division, Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee, USA

<sup>9</sup> School of Physics and Astronomy, University of Manchester, Manchester, M13 9PL, United Kingdom

<sup>10</sup> Institute for Nuclear and Radiation Physics, Celestijnenlaan 200d - box 2418, 3001 Leuven, Belgium

Spokesperson: D. Hanstorp ([dag.hanstorp@gu.se](mailto:dag.hanstorp@gu.se))

Co-spokesperson: J. Welander ([jakob.welander@gu.se](mailto:jakob.welander@gu.se))

Contact persons: S. Rothe ([sebastian.rothe@cern.ch](mailto:sebastian.rothe@cern.ch))

ABSTRACT

We propose to conduct measurements of the isotope shift in the electron affinity (EA) for chlorine isotopes. The specific mass shift is sensitive to electron correlation that is particularly pronounced in negative ions and neutral atoms. Hence, a study of isotope shifts in electron affinities is an excellent method to obtain benchmark data for theoretical models that go beyond the independent-particle model. The treatment and interpretation of the experimental data will be supported by multiconfiguration Dirac-Hartree-Fock (MCDHF) calculations performed by leading specialists in the field of theoretical atomic physics. The collinear laser photodetachment spectroscopy will be conducted using the GANDALPH experimental beam line at GLM using the RILIS laser system in narrow linewidth configuration.

This proposal is based on the letter of intent I-177

Requested shifts: 8 shifts



Solvay Workshop in honour of  
Michel Godefroid

# NEW FRONTIERS IN ATOMIC, NUCLEAR, PLASMA AND ASTROPHYSICS

BRUSSELS, 25 - 27 NOVEMBER 2019

ULB - Campus Plaine | Solvay Room

## INVITED SPEAKERS

- Marc Arnould (ULB, Brussels, Belgium)
- Martin Asplund (Australian National U., Canberra, Australia)
- Peter Behnkefoner (LLNL, Livermore, CA, USA)
- Julian C. Berengut (U. Of New South Wales, Sydney, Australia)
- Michael Block (GSI, Darmstadt, Germany)
- Tomas Brage (Lund U., Sweden)
- Charlotte Froehn Fischer (UBC, Vancouver, Canada)
- Dag Hänsch (U. of Gothenburg, Sweden)
- Hans-Thoma Jau (MPA, Garching, Germany)

- Per Jonsson (Malmö U., Sweden)
- Michel Kocher (Trikkeburg Nuclear Physics I, Garching, Russia)
- James M. Lattimer (One U. Of New York, Stony Brook, USA)
- Iain Moon (U. of Ayrshire, Scotland)
- Whitold Majewicz (Michigan State U., East Lansing, MI, USA)
- Winfried Knechtshauser (Technische U. Darmstadt, Germany)
- Gerard O'Sullivan (U. College Dublin, Ireland)
- Bertrand Priez (U. Montpellier, France)
- Achim Schwenk (Technische U. Darmstadt, Germany)
- Chris Sudan (U. of Texas, Austin, USA)
- Eliel Ten Kate (U. of Groningen, The Netherlands)

## SCIENTIFIC AND ORGANISING COMMITTEE

- Thierry Bastin (ULB, Liege, Belgium)
- Pierre Coeur (ULB, Bruxelles, Belgium)
- Charlotte Froehn Fischer (UBC, Vancouver, Canada)
- Michel Godefroid (ULB, Brussels, Belgium)
- Stephan Gorlitz (ULB, Brussels, Belgium)
- Alain Jorissen (ULB, Brussels, Belgium)
- Per Jonsson (Malmö U., Sweden)
- Patrick Lehner (UMONS, Mons, Belgium)
- Bertrand Priez (U. Montpellier, France)
- Pieter Van Duppen (KU Leuven, Belgium)
- Nathalie Vancle (ULB, Brussels, Belgium)
- Sophie Van Eck (ULB, Brussels, Belgium)



**Thanks to**

**the organizers for an  
excellent conference**

**Michel for a career where  
you have combine scientific  
excellence with friendship**

**you for your attention**

