ECRIS Related Research and Development Work at JYFL and Some Future Prospects

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1. Metal ion beam production
2. Beam formation and transport
3. Plasma studies: breakdown process, plasma coupling and instabilities
4. Photoelectric effect and ion sources
5. Charge exchange
6. Future plans

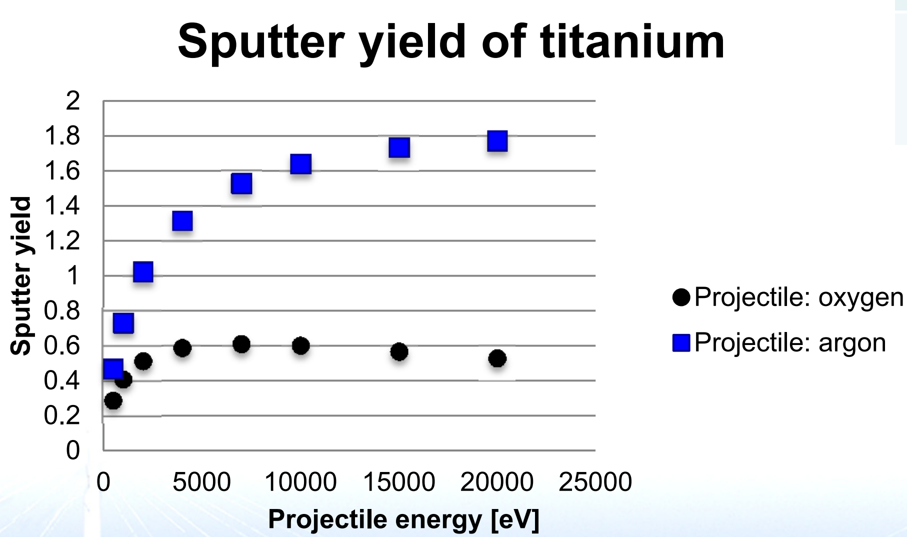
1. Metal ion beam development

Requested ion beams: ^{50}Ti, Zr, Mo,…(i.e. mainly refractory elements)

- **Sputtering**
- **MIVOC method**
- **(Induction oven: development work with minor improvements)**

Sputter development

- Sputter yield is typically low for refractory elements
- Depends strongly on the energy and projectile
- Still: can give some beam!

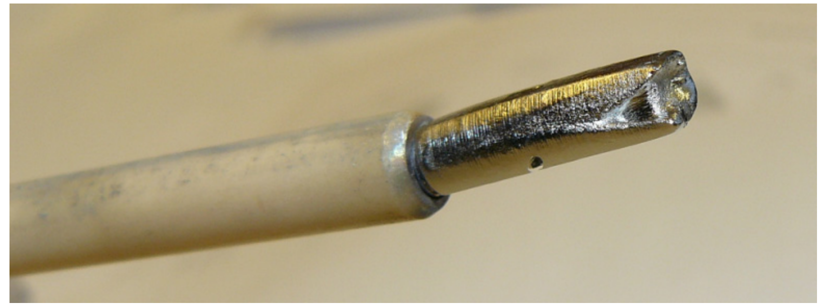


Element	Sputter yield @ 1000 eV, Oxygen as a projectile
Ag	1.8
Ti	0.4
Ni	0.9
Zr	0.4
Mo	0.4
Pb Zn	2.3 3.5

Sputtering of Zr and Ti

- Radial sputter technique has successfully been used for Zr ion beams (≈ 10 μA of Zr^{19+})

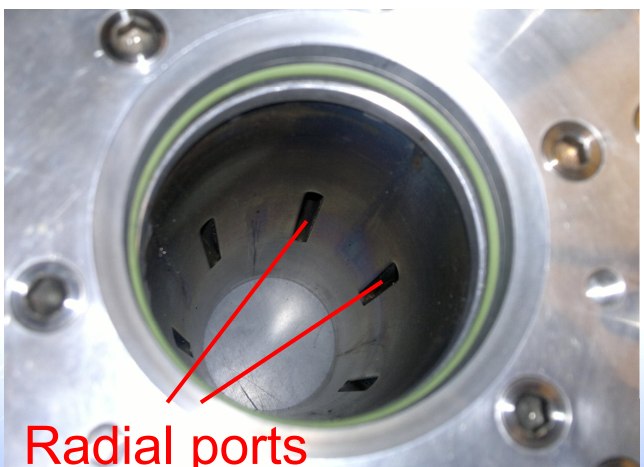
Zr sample after a successful run



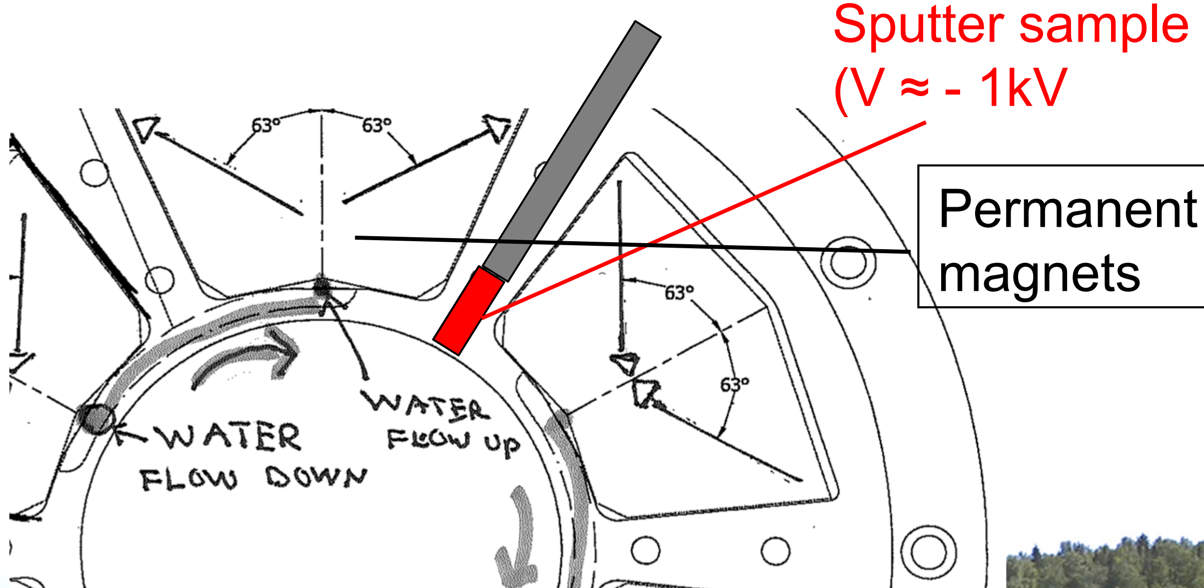
During the Ti tests up to 20 μA of $^{48}Ti^{10+}$ was produced! However, after the test we noticed that the beam didn't disappear when sputter voltage was turned OFF!

It was further confirmed that the microwave power was (directly or via plasma) coupled to the sputter sample (sensitive to positioning)

Efficient way to produce metal ion beams!



Unfortunately the PM hexapole was damaged due to insufficient heat shielding. Improved design under work.



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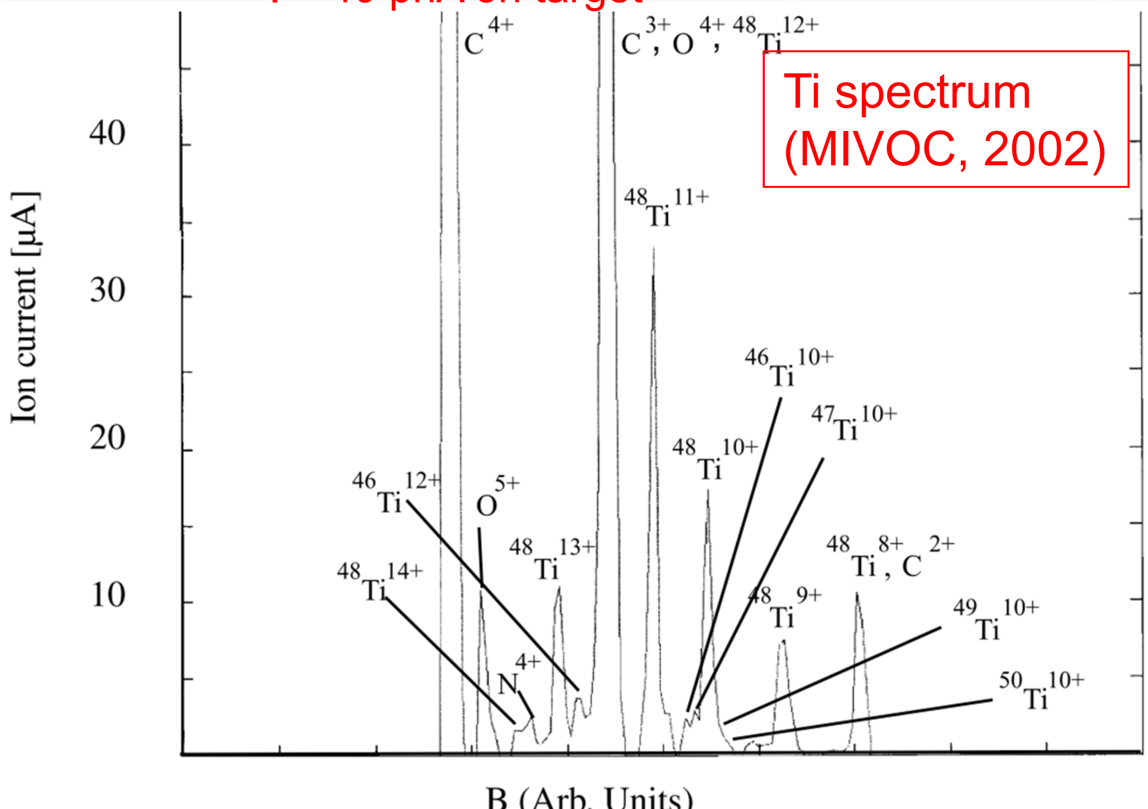
MIVOC development

- The first Ti ion beams using MIVOC were produced using commercial compound ((trimethyl)pentamethylcyclopentadienyltitanium)

Isotope/charge	8+	9+	10+	11+
^{46}Ti 7.9%	3.6*	4.7*	4.8*	4.8*
^{47}Ti 7.3%	3.3*	4.3*	4.4*	4.4*
^{48}Ti 73.9%	33	43	44	45
^{49}Ti 5.5%	2.5*	3.2*	3.3*	3.3*
^{50}Ti 5.3%	2.5*	3.2*	3.3*	3.3*

Requested,
I > 40 pnA on target



Ti spectrum
(MIVOC, 2002)

- Intensity of ^{50}Ti ion beam too low using commercial compound (enriched compound needed)!
- We were not able to synthesize the compound!

BUT….

The Strasbourg group succeeded in synthesizing the Ti compound used for MIVOC runs →

The $^{50}Ti^{11+}$ ion beam intensity of up to 500 nA (45 pnA) was accelerated to the experimental target (close to 20 μA from the ECRIS2)

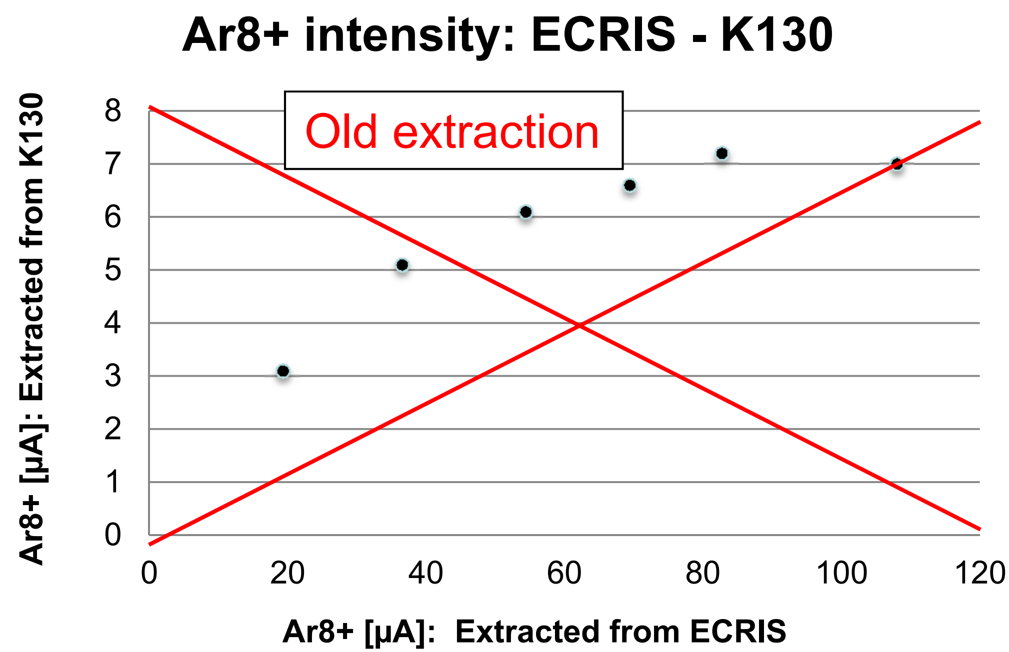
Strasbourg group:
Benoit Gall, Jerome Rubert, Zouhair Asfari (chemist, synthesis),
Julien Piot,
Ali Ouadi (chemist)
See: J. Rubert et. al., Nucl. Instrum. and Meth. in Phys. Res. B 276 (2012), p. 33.

New request:
> 200 pnA on target

How to go there?
Better tuning (20 - > 40 μA)
i.e. factor of two more….

2. Beam transport research and development

Beam transport efficiency problem at JYFL: the efficiency decrease when the total beam intensity from the ECRIS increases!



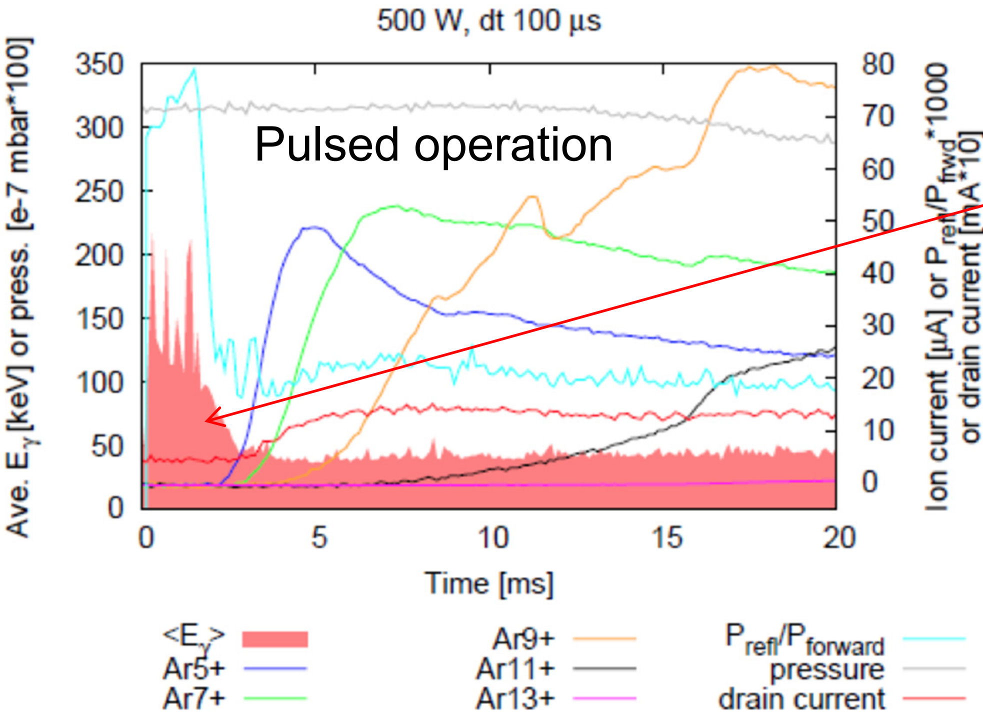
Beam transport upgrade program:

- The first successful step has been taken: improved extraction/beam formation ≈ two times more beam can be transported to the target (presented by V. Toivanen)

Almost there!!

3. Plasma studies

3.1. Plasma breakdown (collaboration with IAP-RAS, LBNL, NSCL)



<u>Bremsstrahlung experiments</u>:
Indication of high average electron energy (possibly Superadiabatic EEDF) at the beginning of plasma breakdown. Cannot be maintained when the plasma density exceeds the threshold value.

More information from:
T. Ropponen, et.al, Plasma Sources Sci. Technol. 20 (2011), 055007.

3.2. Plasma - wave coupling

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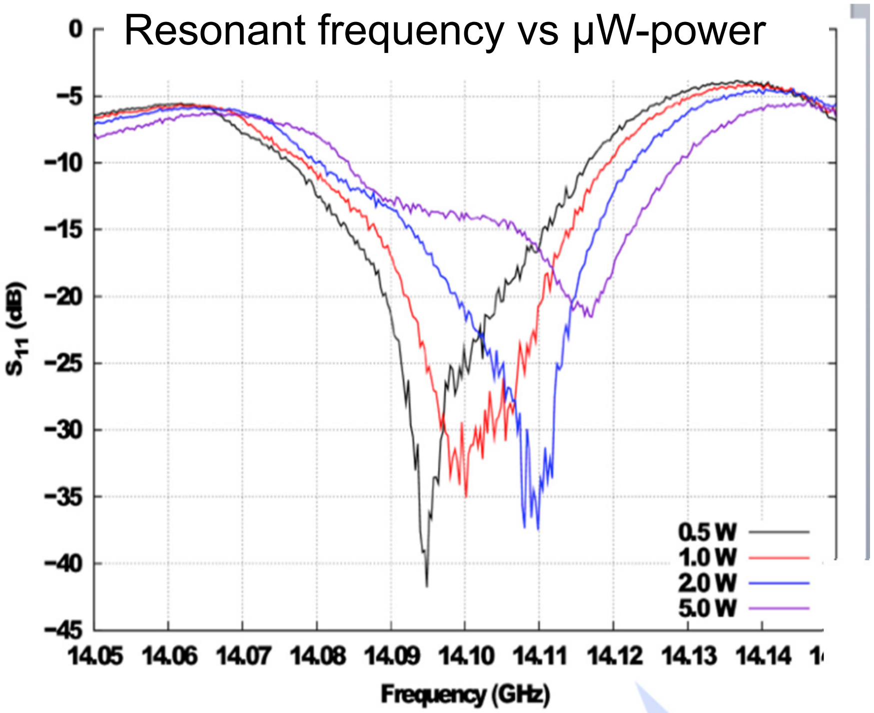
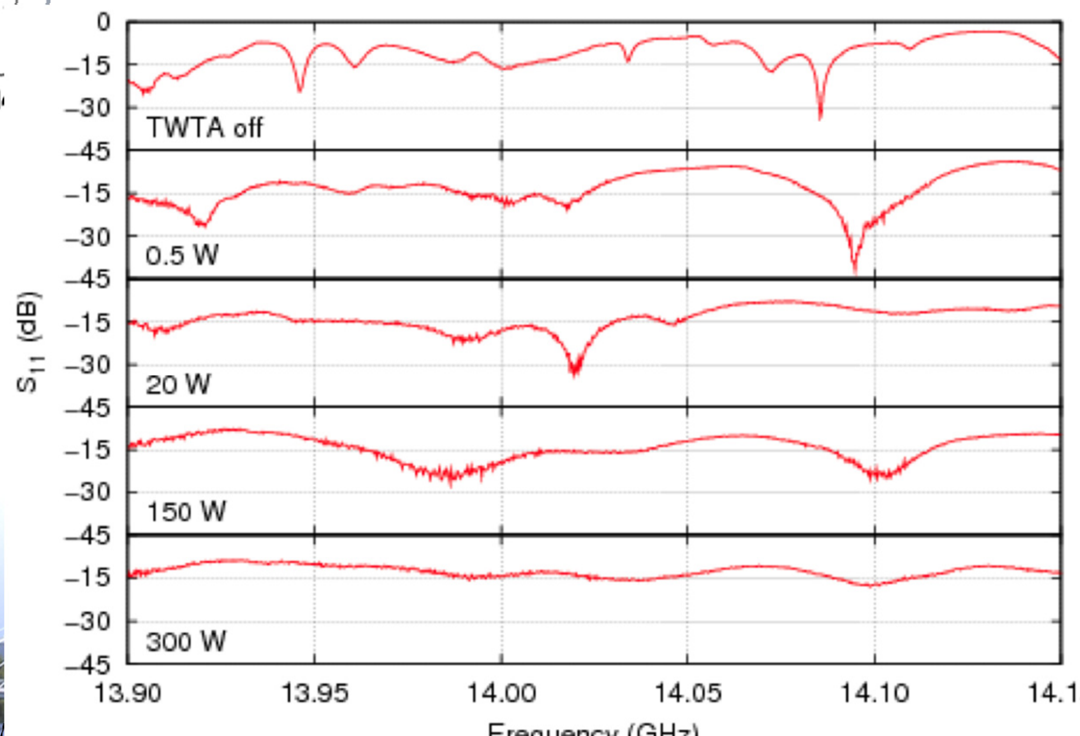
Resonant frequency vs μW-power



- plasma was maintained with TWTA frequency ≈ 11 GHz
- behavior of S_{11} was studied with R&S
- clear mode structure when weak plasma
- dimishes/vanishes with higher densities



3.3. Fast ion beam measurement vs stability of ion beams

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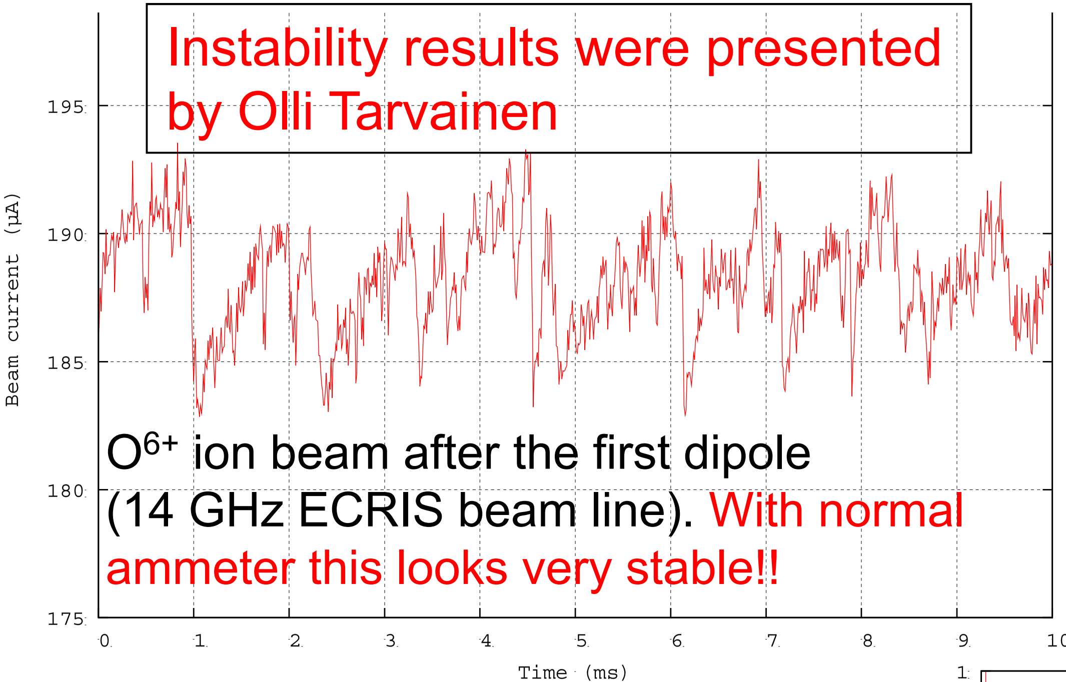
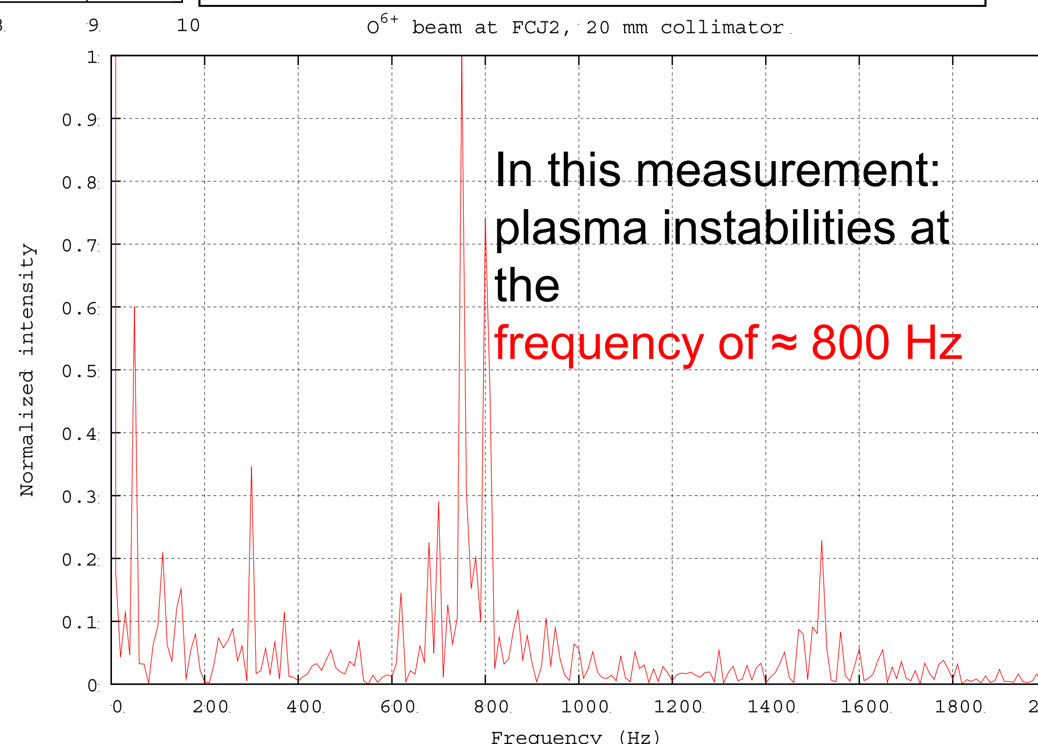
Instability results were presented by Olli Tarvainen



O^{6+} ion beam after the first dipole (14 GHz ECRIS beam line). With normal ammeter this looks very stable!!

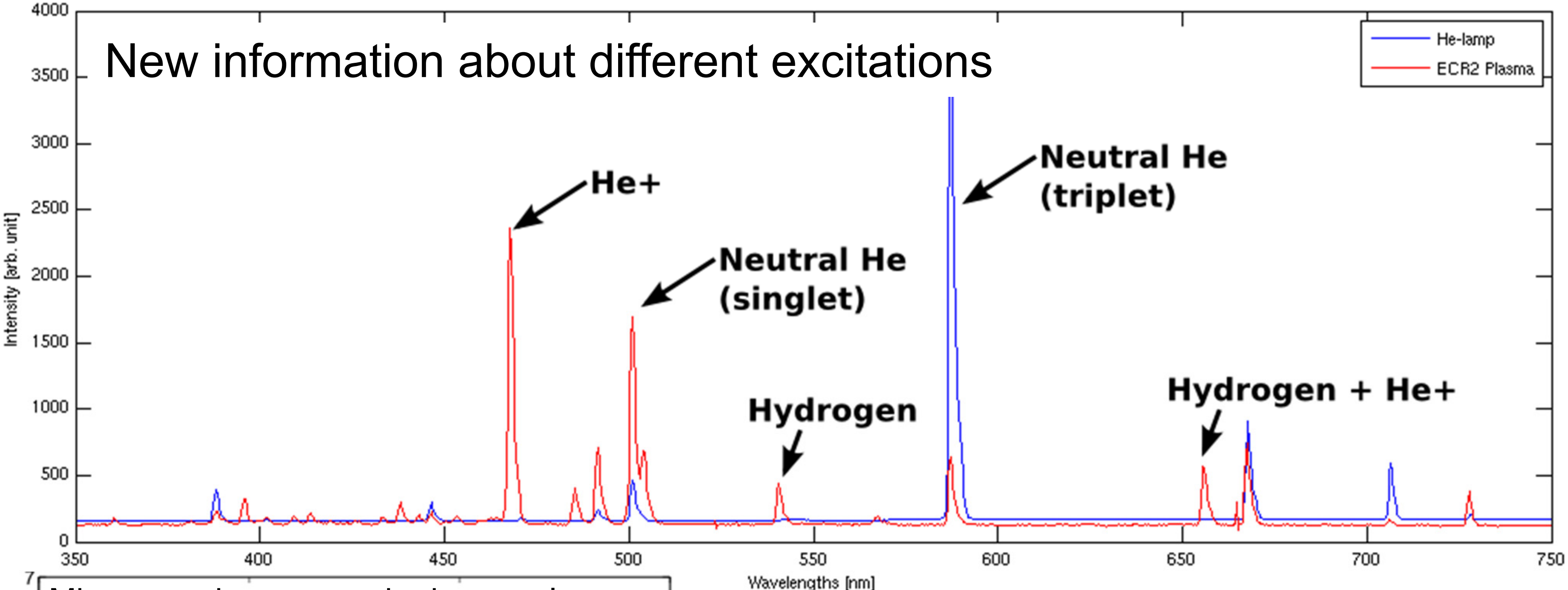
Motivation 1: DO we have instabilities and what is the amplitude? In some applications the unstable beam can cause problems

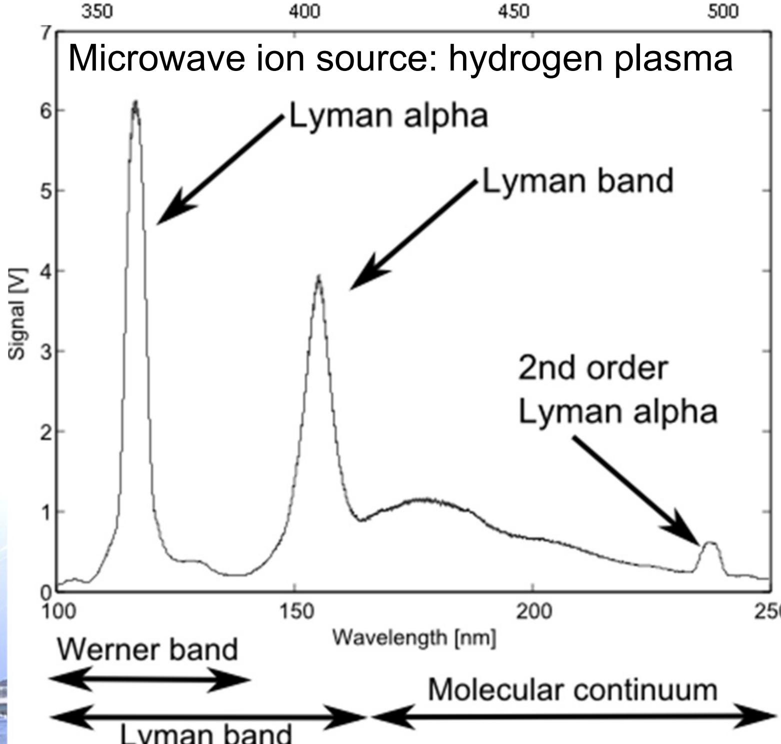
Motivation 2: What parameters affect the instabilities?



In this measurement: plasma instabilities at the frequency of ≈ 800 Hz

3.4. VUV/visible light spectroscopy of ion source plasmas





Motivation 1: Photoelectric effect versus ion source?
Master thesis work: Janne Laulainen

Motivation 2: Can we use this as a fault-finding tool?

Motivation 3: Power of visible light/VUV emission?
Thesis work: Jani Komppula

According to the first results and analysis: 20 – 30 % of heating power dissipates via visible light/VUV emission (2.45 GHz μw-ion source)

To be published: J. Komppula et. al.

ey, Australia

5. Photoelectric effect and ion sources: master thesis project

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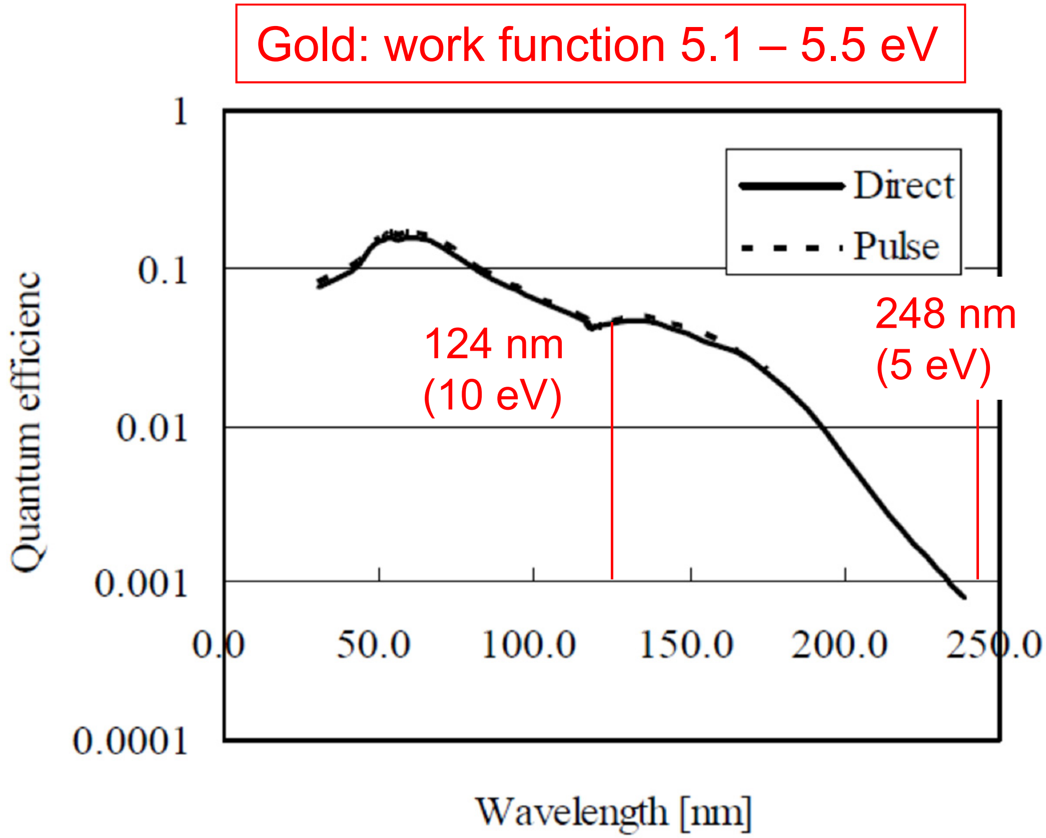
Secondary electron emission is well accepted method to increase the electron density of ECRIS plasma resulting in improved performance

Motivation/question: Effect of photoelectric emission?

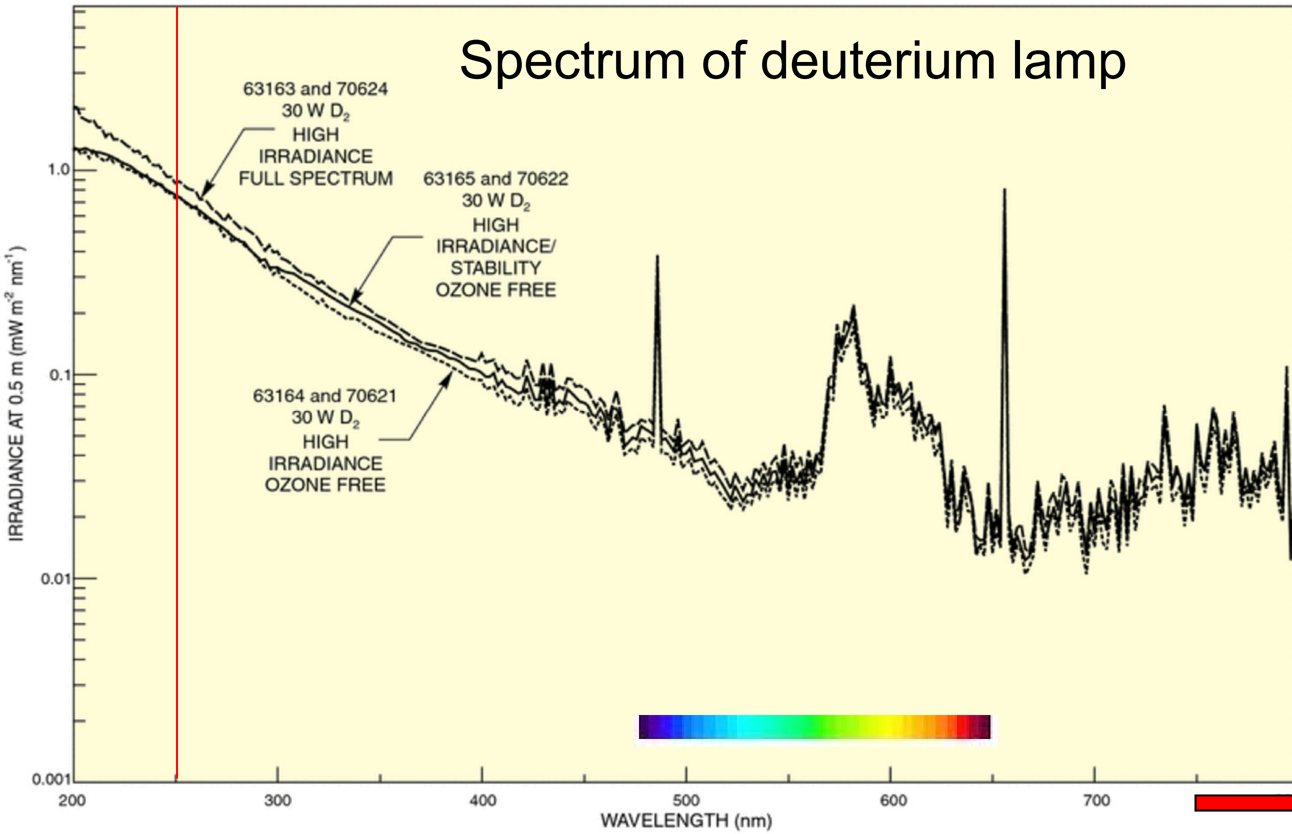
Parameters: Work function and especially quantum efficiency

Quantum efficiency vs. photon energy: Example for gold



K. Nitta et al., Int. Symp. on Discharges and Electrical Insulation in Vacuum, 2010

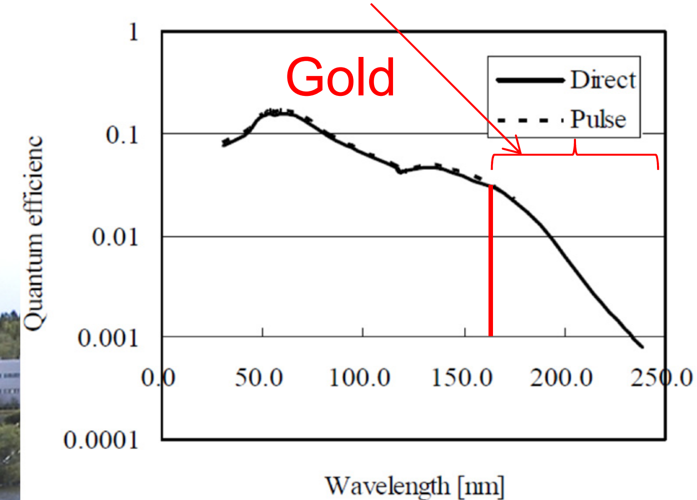
First experiments were carried out using deuterium lamp



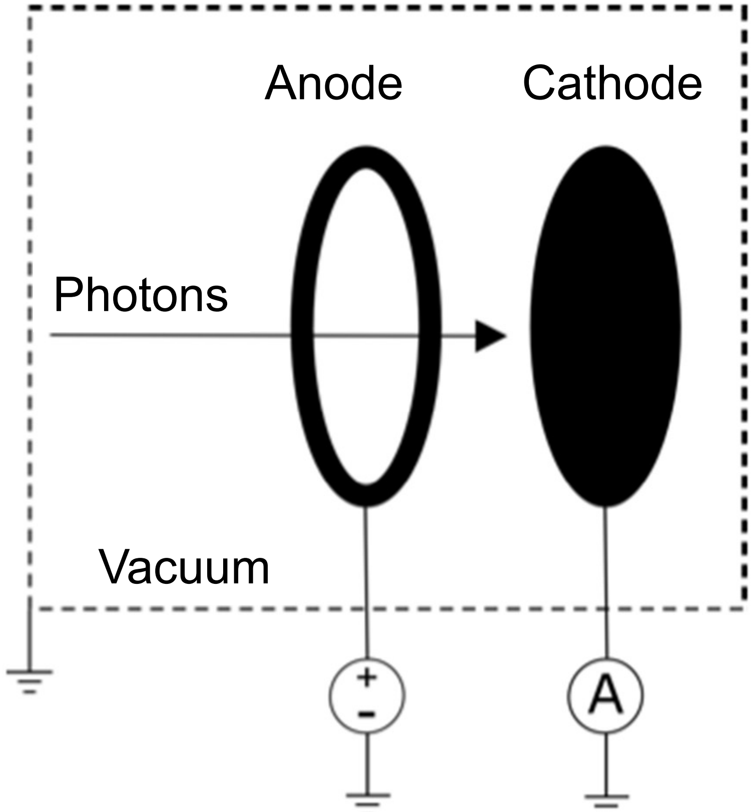
5 eV

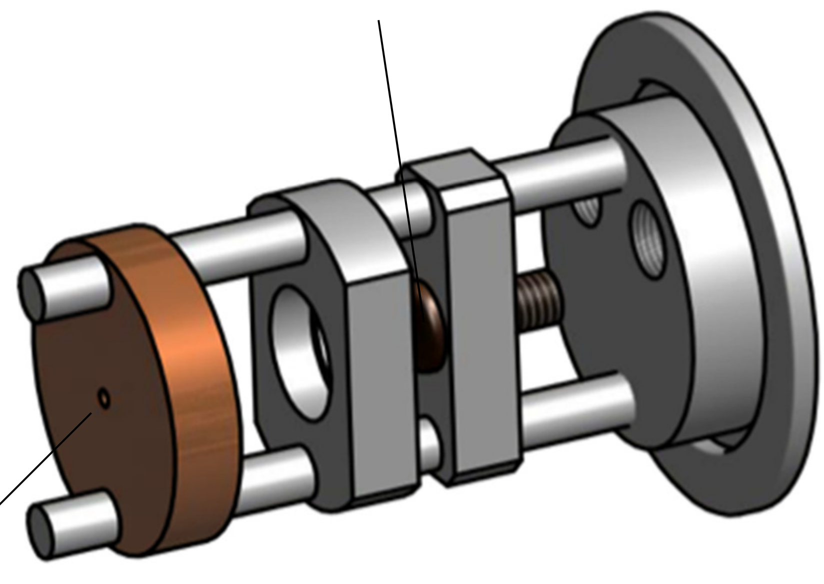
Note: the quartz window of the lamp stops the photons having wavelengths below 160 nm.

Only this part is available



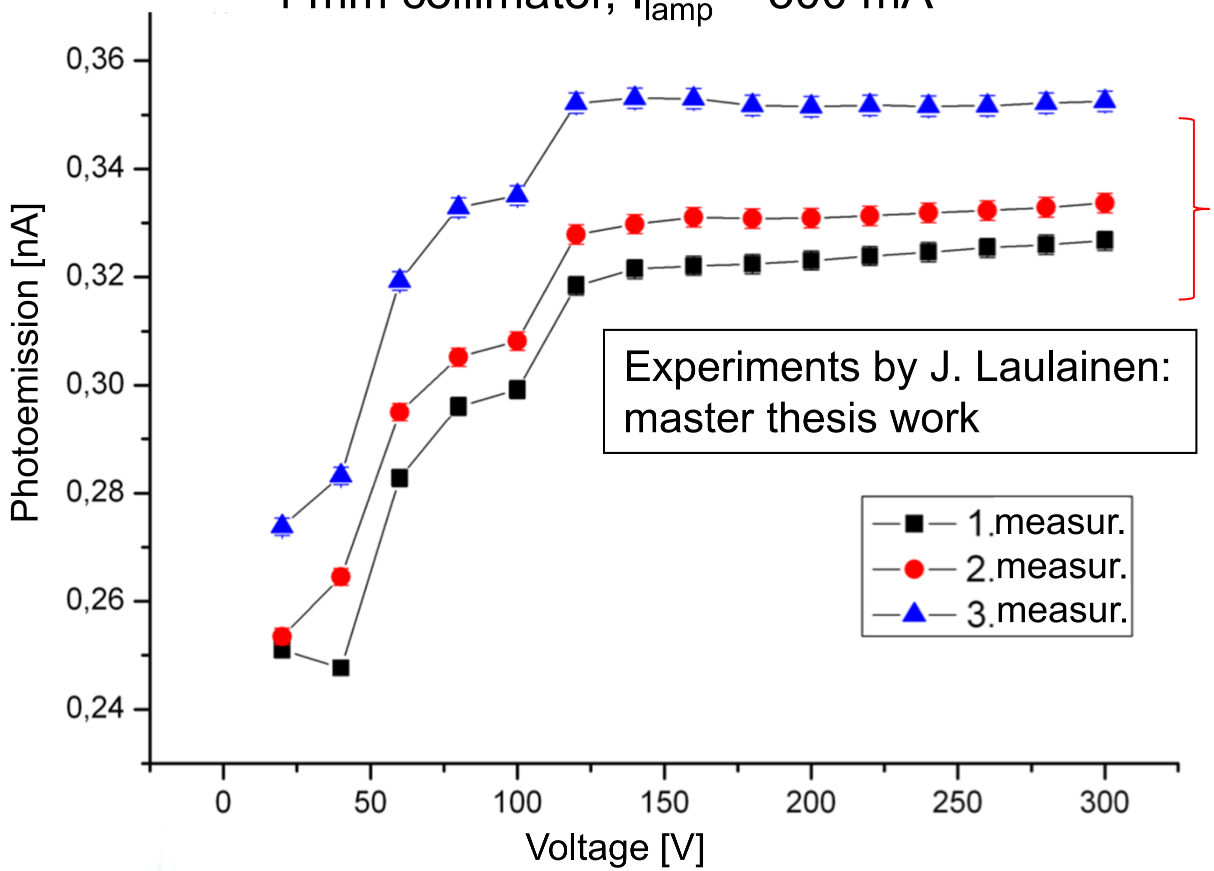
Experimental setup for photoelectric emission





Some results with the deuterium lamp

4 mm collimator, I_{lamp} = 300 mA

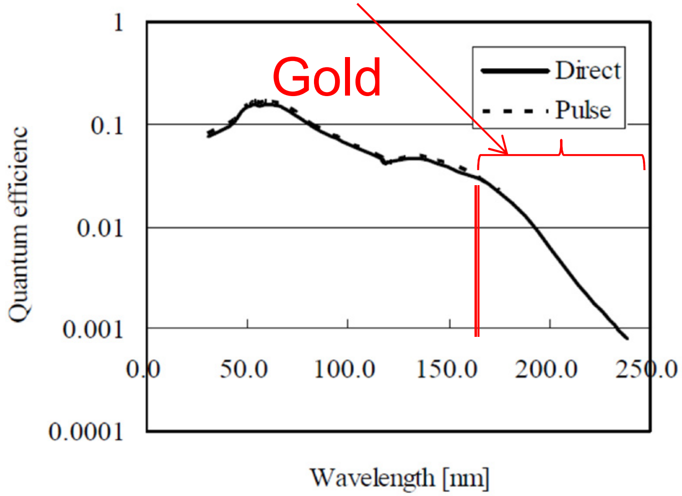


This corresponds to about 0.7 μW (measured light power)

Photon induced emission current of about 0.5 mA/W

How about in the case of ECRIS?

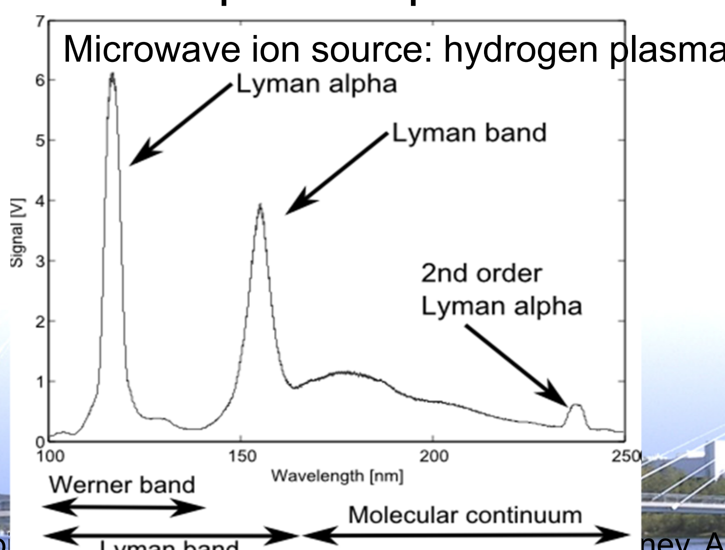
With deuterium lamp only these wavelengths were available



Can we have more optimum spectrum (factor of 10 more? Would give 5 mA/W)

Unknown parameters (ECRIS):
- VUV-spectrum
- VUV-power
- B-field limits

As a next step the experiments will be carried out with μw-ion source -> ECRIS!



4. Charge exchange: master thesis project

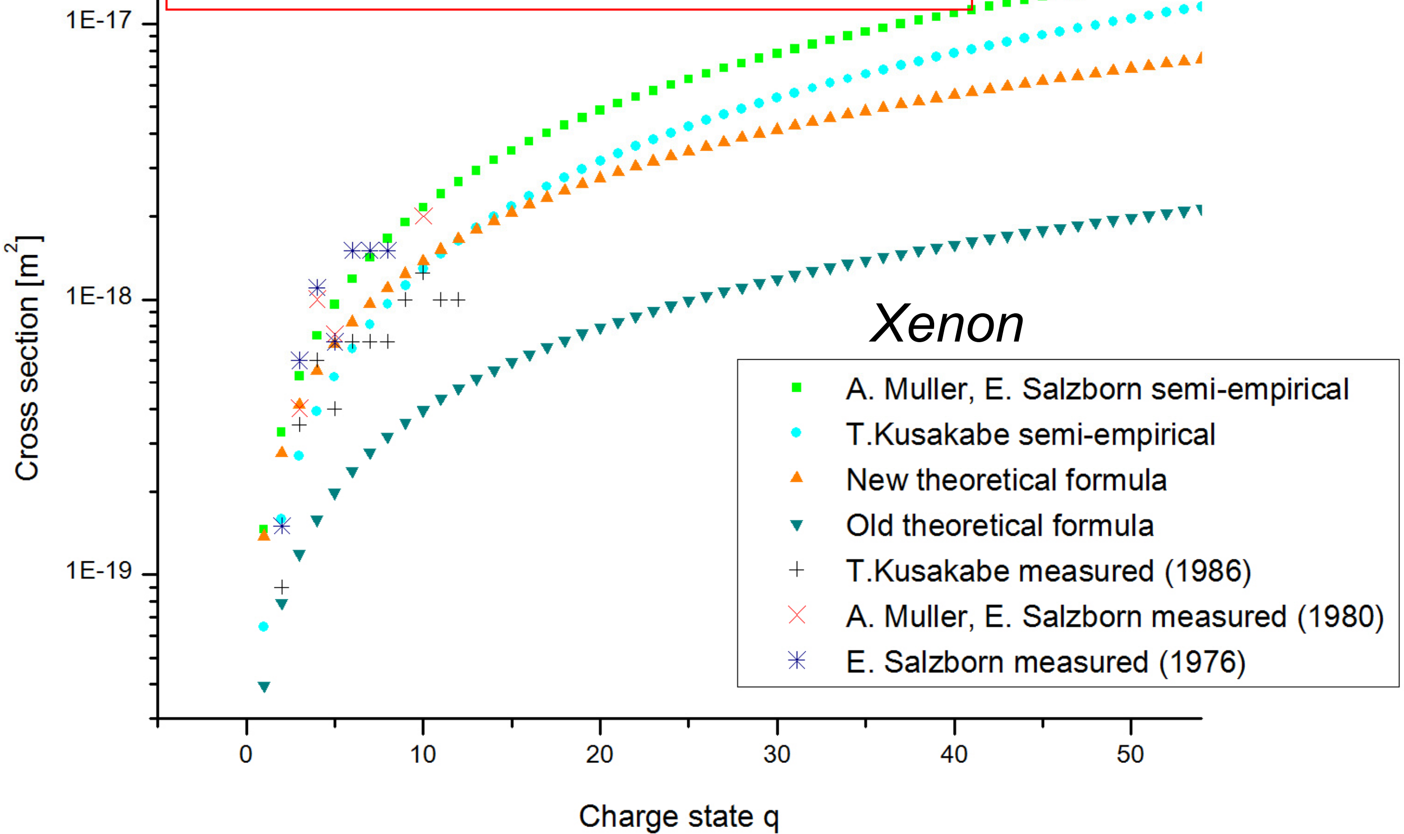
Motivation: we want have better picture about different reaction cross sections ➡ values for balance equation

Losses via charge exchange

$$\frac{dn_q}{dt} = n_e \left\langle \sigma_{q-1,q} v_e \right\rangle n_{q-1} + n_0 \left\langle \sigma_{q+1,q} v_i \right\rangle n_{q+1} - n_0 \left\langle \sigma_{q,q-1} v_i \right\rangle n_q - n_e \left\langle \sigma_{q,q+1} v_e \right\rangle n_q - \frac{n_q}{\tau}$$

Charge exchange: maximum life time of high q/maximum neutral pressure?

R. Kronholm et. al., To be published



Future plans:

-Beam transport upgrade, step 2: ECRIS closer to dipole magnet (step 3?: new central region for K130 – higher injection voltage)
-Design study of Radhard helix source (quadrupole extraction will be studied?)
-Afore mentioned can give valuable information for ARC-ECRIS (ARC-ECRIS: interesting option for beam merging and highly charged ion beams: real minimum-B structure)
-MMPS-pole structure for JYFL 14 GHz ECRIS…
-New 18 GHz ECRIS…
-This all in addition to plasma studies, metal beam development, etc…