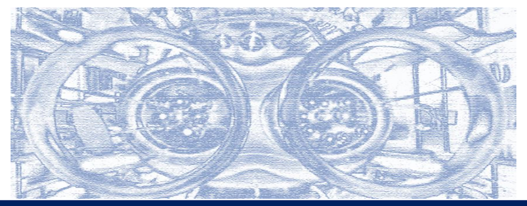

Continuous pulse advances in the negative ion source NIO1

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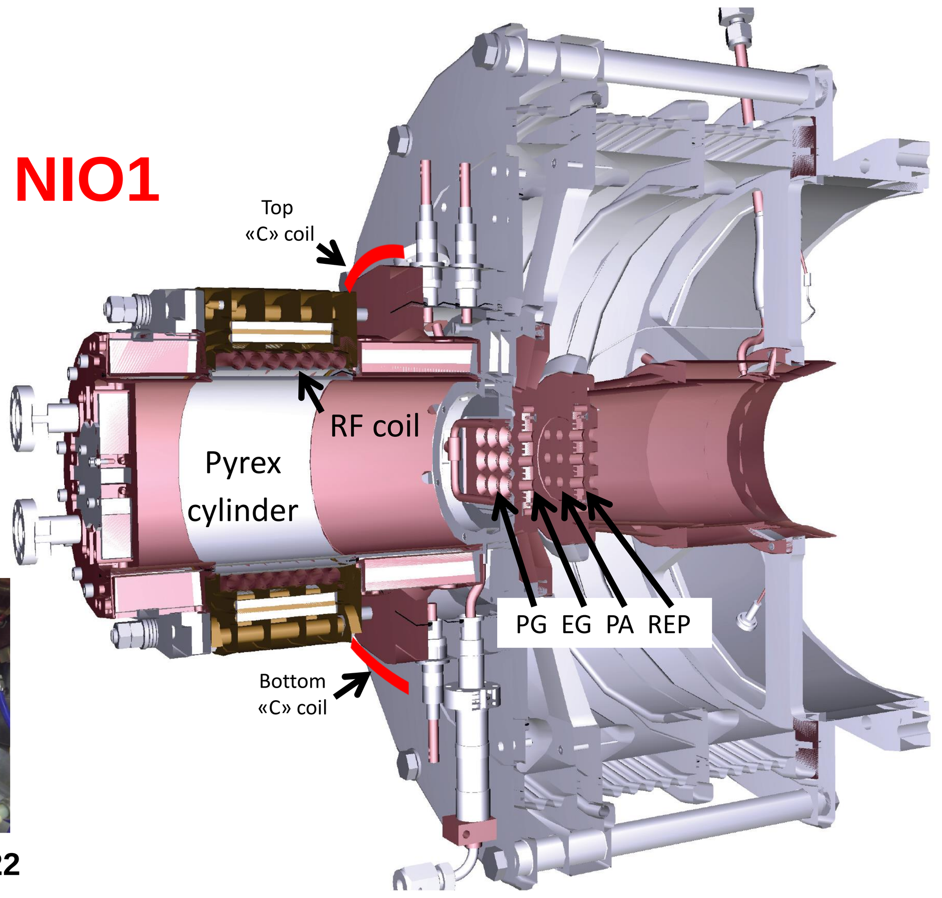
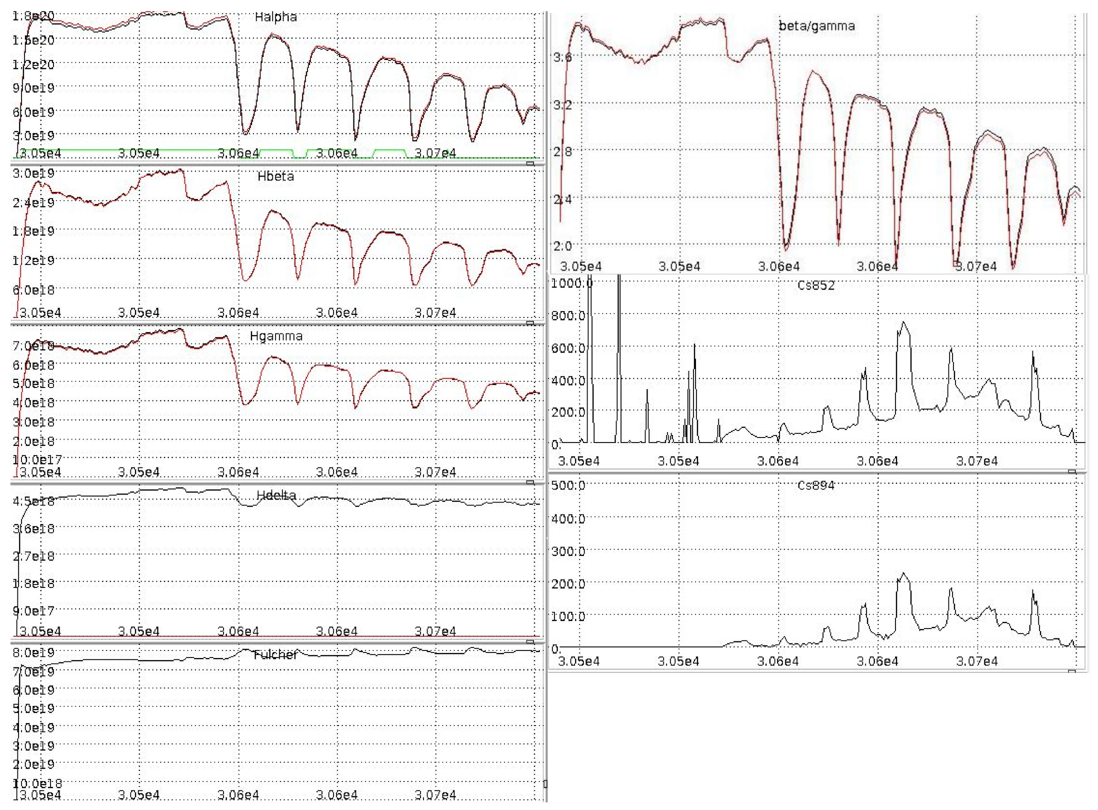
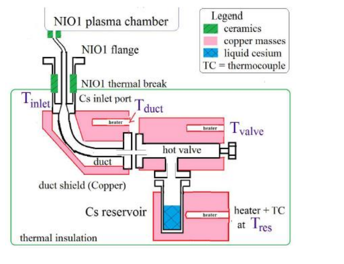
Introduction

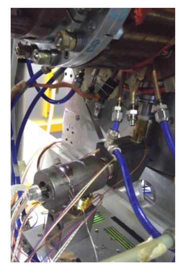
- Consorzio RFX and INFN-LNL have designed, built and operated the compact radiofrequency negative ion source NIO1 (Negative Ion Optimization phase 1) with the aim of studying the production and acceleration of H- ions. In particular, NIO1 was designed to keep plasma generation and beam extraction continuously active for several hours.
- Since 2020 the production of negative ions at the plasma grid (the first grid of the acceleration system) is enhanced by a Cs layer, deposited on its surface by means of active Cs evaporation in the source volume. For the negative ion sources applied to neutral beam injectors for fusion, keeping the beam current and the fraction of co-extracted electrons stable for times of at least 1 h is essential. Optimal conditions must also take into account the redistribution of caesium among the plasma box surfaces due to the action of the plasma.
- The latest results of the NIO1 source, in terms of beam performances during continuous (6+7 h) plasma pulses, are presented. The information and the developments from Optical Emission Spectroscopy and Laser Absorption Spectroscopy are also presented.

NIO1

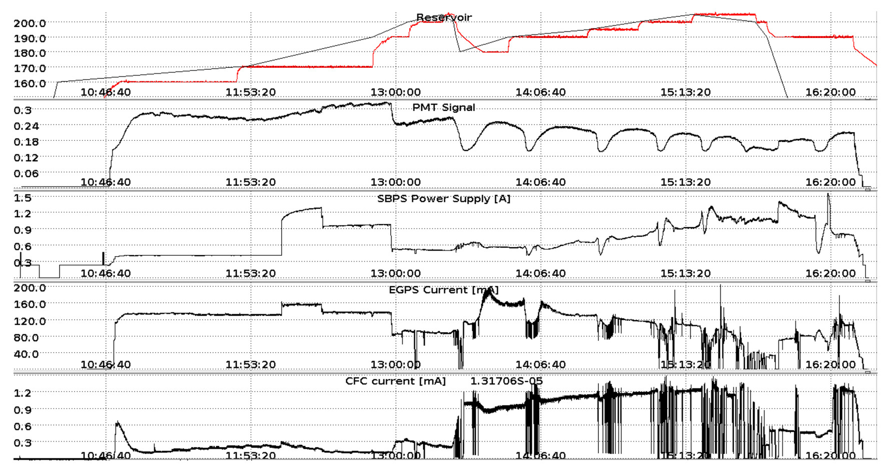




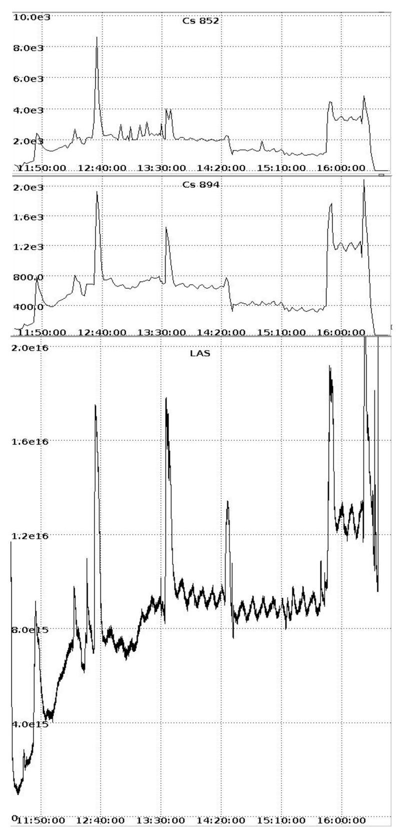




NIO1 OES& beam data – 16/03/2022



Cs density 07/04/2022
Cs emission vs LAS data

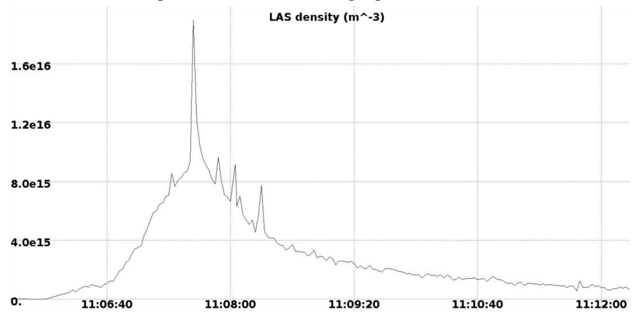


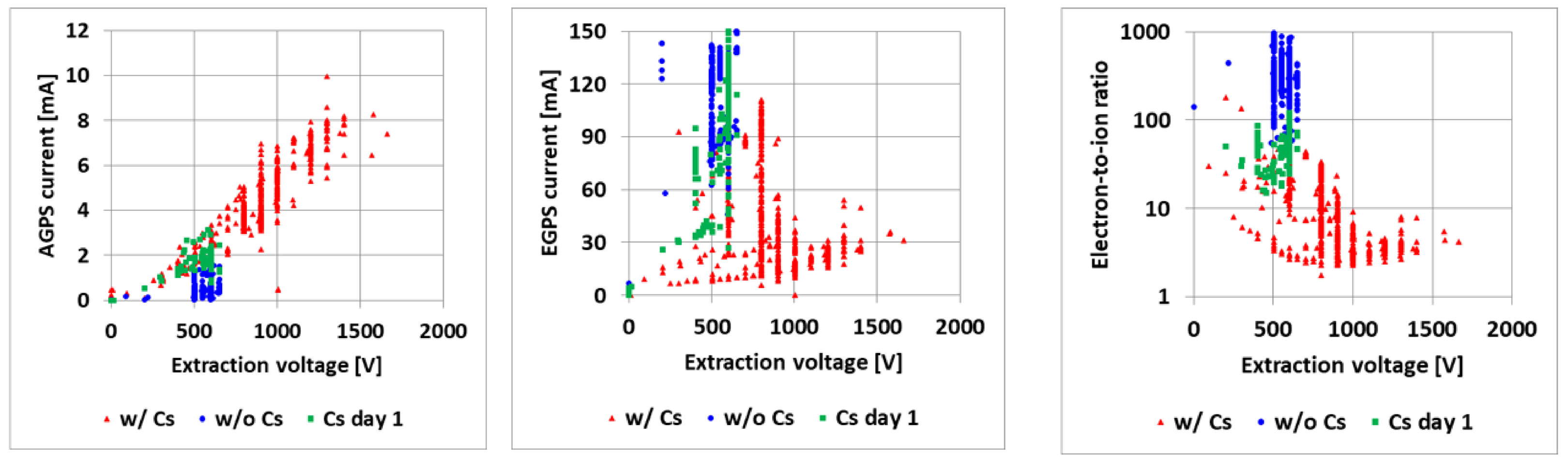
During the 2022 experimental campaign in Cs, it was possible to evaporate Cs in a controlled and reversible way in cw operation. Cs oven reservoir temperature ranged from 180°C (minimum to detect Cs) to about 215°C.

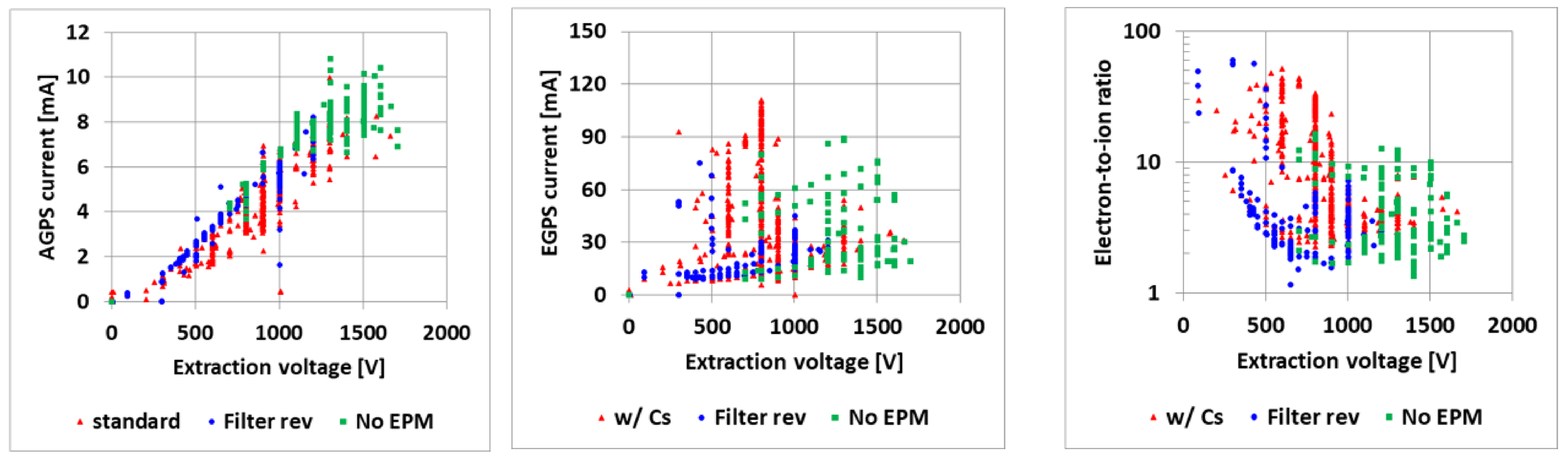
The Cs density, measured by LAS at the PG, was extremely high (10^{15}÷10^{16} m^{-3}) as in overcesiated conditions (see M. barbisan et al.,*Cs Evaporation in a Negative Ion Source and Cs Cleaning Tests by Plasma Sputtering*", in IEEE Transactions on Plasma Science, 2022). This is likely attributed to a high recycling of Cs from the walls with plasma operation, with a S/V ratio higher than in other larger sources.

The increase of Cs density is associated to a reduction of plasma luminosity and also H_β/H_γ ratio. When the Cs oven reservoir temperature is increased, a temporary peak in Cs density/emission is observed.

Cs density 06/04/2022
no evaporation, only plasma action







Beam performances

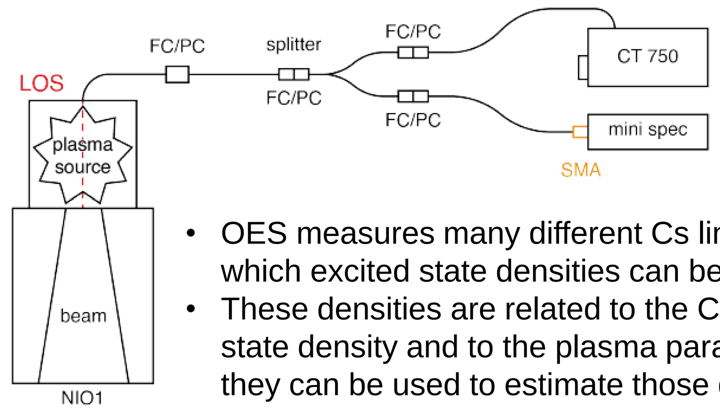
The evaporation of cesium in the source, as expected, introduced a significant increase of extracted current density in cw operation, up to 25÷30 A/m^2 and with a fraction of co-extracted electrons down to around 2. The beam current was below what obtained in 2022 (60 A/m^2), but Cs was under control. The source was operated at a max pressure of 1.5 Pa, to scale the typical mean free path of plasma particles with the source dimensions.

In NIO1, the magnetic filter field in proximity of the PG is generated by a set of external magnets and by a current flowing horizontally in the PG.

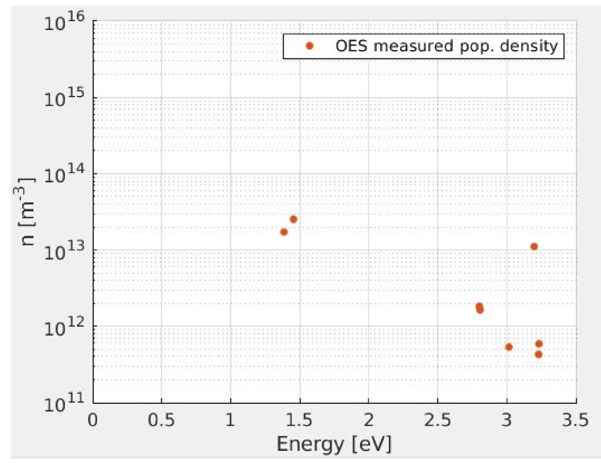
In order to increase the plasma density at the PG (and then the beam current), the current polarity was reversed, so to reduce the field of the external magnets. At last, the same magnets were removed.

The reduction of the magnetic filter field led to a noticeable but not significant improvement of beam current. The fraction of co-extracted electrons was not significantly affected.

OES studies – checking the plasma volume longitudinally



- OES measures many different Cs lines, from which excited state densities can be recovered
- These densities are related to the Cs ground state density and to the plasma parameters : they can be used to estimate those quantities



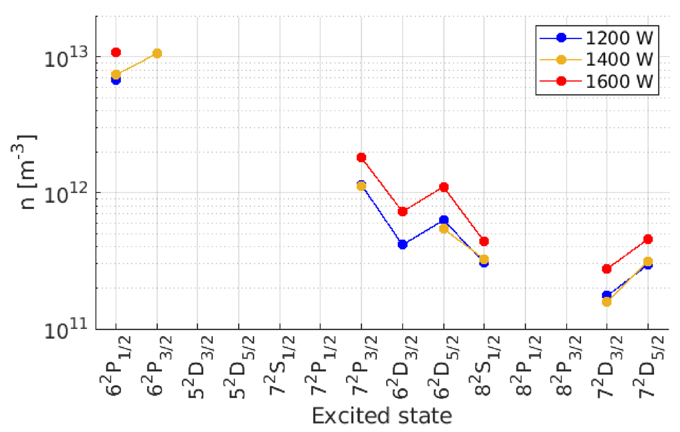
Wavelength [nm]	Transition	Photon flux [ph/m^2/s]	Einstein coefficient [s^{-1}]
672	$7^2D_{3/2} \rightarrow 6^2P_{1/2}$	3.6e+17	6.45e+06
697	$7^2D_{5/2} \rightarrow 6^2P_{3/2}$	5.5e+17	7.15e+06
764	$9^2P_{3/2} \rightarrow 5^2D_{5/2}$	7.0e+17	
794	$8^2S_{1/2} \rightarrow 6^2P_{3/2}$	3.2e+17	4.58e+06
801	$5^2F_{5/2} \rightarrow 5^2D_{3/2}$	3.2e+17	
852	$6^2P_{3/2} \rightarrow 6^2S_{1/2}$	1.1e+20	3.33e+07
876	$6^2D_{3/2} \rightarrow 6^2P_{1/2}$	1.7e+18	1.09e+07
885	$8^2P_{3/2} \rightarrow 5^2D_{3/2}$	5.6e+16	3.9e+04
894	$6^2P_{1/2} \rightarrow 6^2S_{1/2}$	6.8e+19	3.03e+07
917	$6^2D_{5/2} \rightarrow 6^2P_{3/2}$	2.8e+18	1.32e+07
920	$6^2D_{3/2} \rightarrow 6^2P_{3/2}$	5.33e+17	2.25e+06

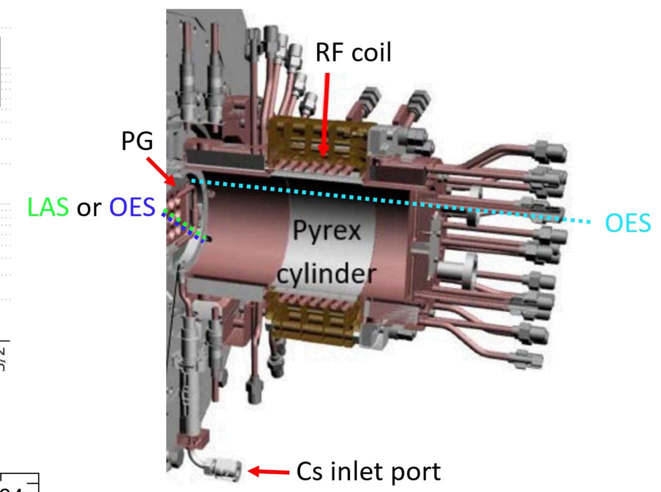
OES and LAS LOS parallel to PG

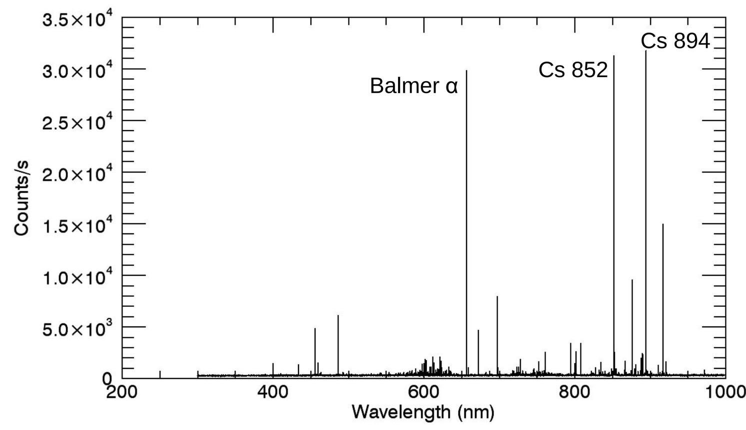
See poster #18 by B. Pouradier Duteil et al.

- During the last campaign, the line of sight in front of the PG usually reserved for LAS was used for OES → this enables an easier interpretation of the Cs emission lines thanks to the information we have on the Cs ground state density in this location
- Example with a power scan: OES measurements of Cs emission lines are used together with assumptions on ground state n_{Cs} (LAS) to extract information n_e

	Hypotheses				
Power [W]	T_e [eV]	n_{H-} [m^{-3}]	n_{Cs+}/n_{Cs0} [-]	n_{Cs0} (ground state) [m^{-3}]	n_e [m^{-3}]
1200	3.5	3 x 10^{15}	5	1.5 x 10^{16}	1.05 x 10^{17}
1400		4 x 10^{15}			1.0 x 10^{17}
1600		5 x 10^{15}			1.55 x 10^{17}



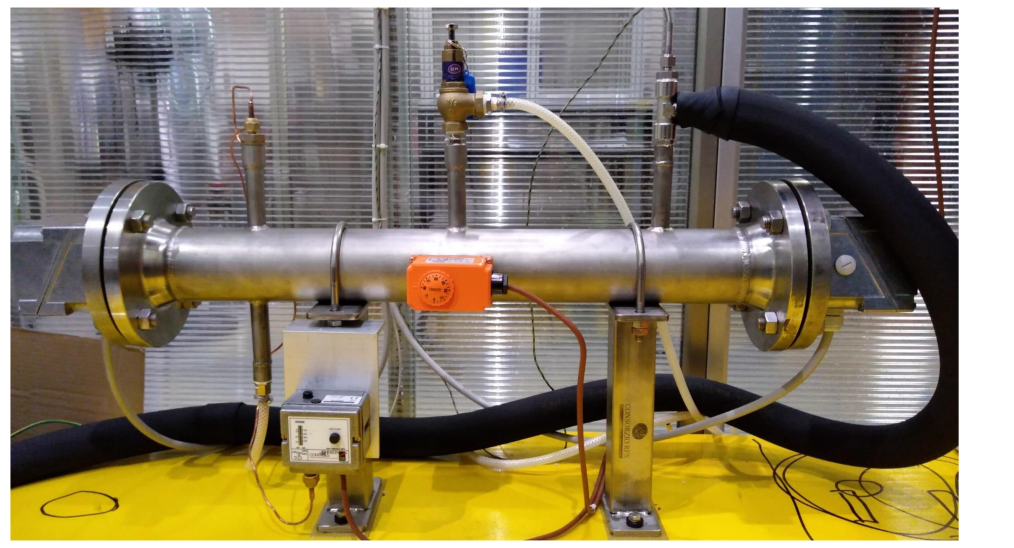




← Example spectrum acquired in parallel to the PG. The Cs 852 nm and 894 nm lines are actually saturated, they are several times higher than H_α (up to 5-10)!

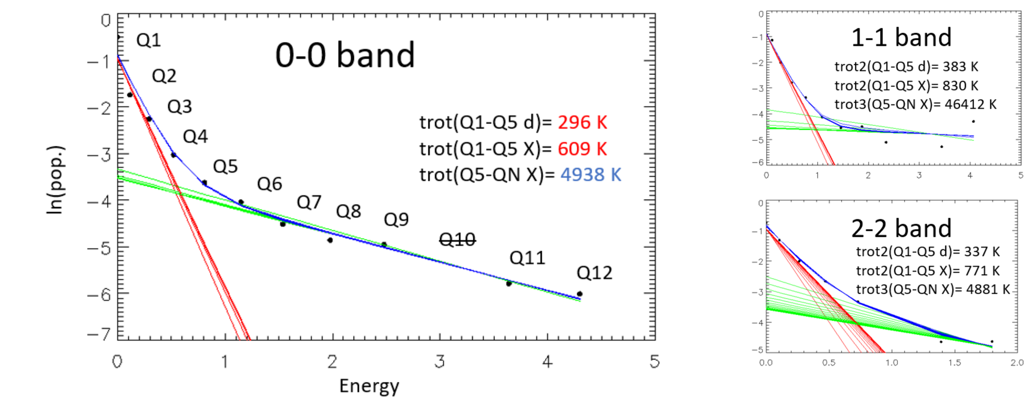
PG heater

Up to now the PG and the source body were kept at about 30°C. To improve the conditioning of the PG, its temperature will be raised progressively up to about 90°C, thanks to a water heater. The device hosts 2x4kW 3-phase resistors and is PID controlled by a thermocouple at the heater outlet. The heater is under test; plasma operation with PG heating will start in few days.

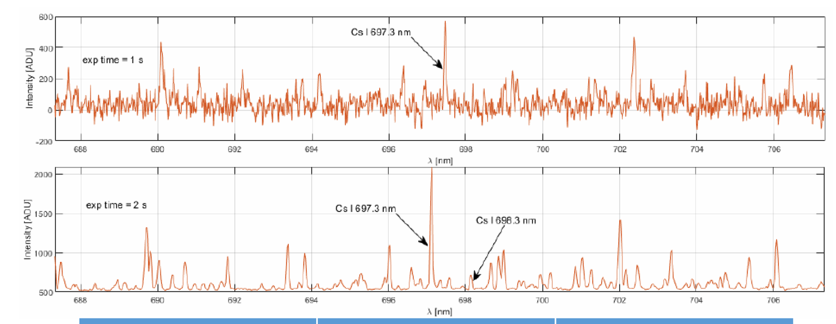


Rotational temperature from H_2 Fulcher Band

Double temperature distribution (as found by S Briefi and U Fantz Plasma Sources Sci. Technol. 29 125019 (2020))



The results were also made possible by testing a high resolution spectrometer dedicated to the MITICA experiment (ITER NBI prototype. The new device and its CCD provided much better performances in terms of sensitivity and SNR.



	P.I. HRS Spectrapro 750	ARC spectrapro 750
Focal length	750 mm	750 mm
f#	9	9
grating	900	1200
CCD pixel	20	13
CCD size	1340x400 26.8x8 mm	512x512 6.7x6.7 mm

Conclusions

- The 2022 experimental campaign in NIO1 allowed to achieve a much better control of Cs evaporation during cw operation.
- High but controllable densities of Cs are likely related to higher S/V ratio than similar larger experiments.
- OES data, thanks also to new equipment in testing, allowed further development of a Cs collisional radiative model, useful also for SPIDER and MITICA.
- Beam current density in cw conditions, even with high pressure, remains limited. The flux on the PG of particles covertible to H- may still be too limited. Further improvements are expected within 2022 by heating the PG up to 90°C.

Don't miss these posters!

- **#18: B. Pouradier Duteil et al., Characterization of plasmas in negative ion sources using a Cs-H Collisional Radiative model**
- **#30: M. Ugoletti et al., Observation of beamlet displacement and parallelism in NIO1**
- **#65: M. Cavenago, Volume and surface effects in Cs-free regimes in NIO1**
- **(Oral) M. Cavenago, Simplified fluid models of radiofrequency and plasma density for NIO1 and design**

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