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Implementation of a temperature and density monitoring diagnostic for the LANSCE negative ion source

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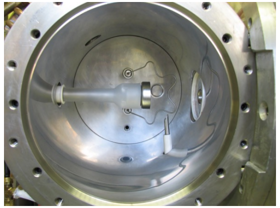
Outline

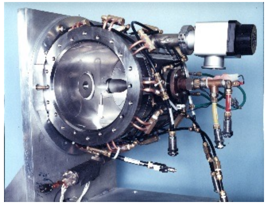
- Overview of LANSCE
- Motivation for noninvasive source diagnostics
- H- Laser Diagnostics Stand (LDS) overview
- Doppler broadening, absorption and emission measurements
- Diagnostic setup
- Measurement results with Dual wavelength TLDS System
- Future developments

The Los Alamos Neutron Science Center (LANSCE)

- Dual beam (H+ & H-) delivery to 5 experimental Areas
  - H+ : 100 MeV
  - H- : 800 MeV
- 50th Anniversary of Operation in 2022
  - Challenging environment to implement new equipment/methods
- User requirements are pushing for more beam current and more uptime

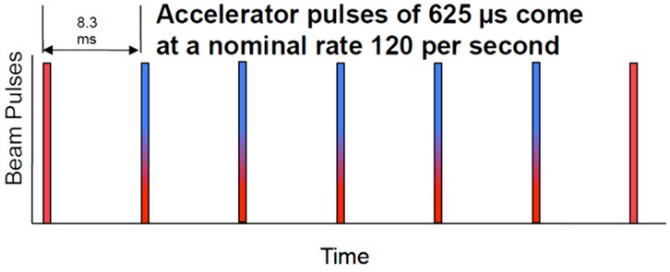
The LANSCE Negative Ion Source



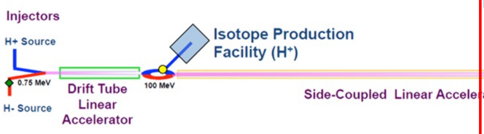


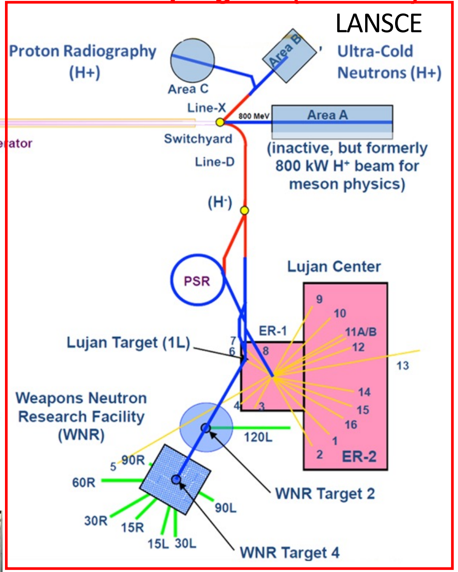
H- ion source

- LANSCE Dual H+ and H- beam programs
  - H+ beam one program
    - Isotope Production Facility
  - H- beam multiple programs
    - (Proton Radiography, Lujan Center, WNR, Ultra-Cold Neutrons)
- The LANSCE H- Ion Source
  - H- ion source parameters
    - 120 Hz, 10% (**833μs pulse**)
    - 14-16 mA of H- current
    - Ion Source recycle every 4-5 weeks

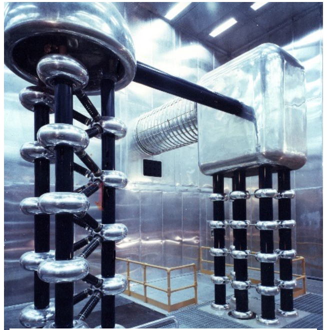


H- beam program (800 MeV)

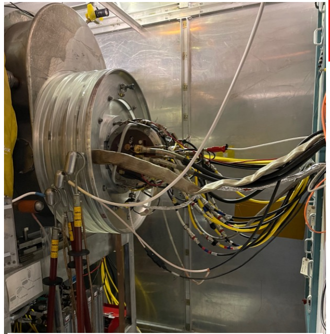




https://lansce.lanl.gov



Cockroft-Walton Injector (670 kV)



Source & 80 kV extraction column

Motivation

Question to be answered

- Can nonintrusive optical diagnostics of the H- source improve
  - Reliability
  - Beam current / brightness
  - Source recycle times
  - Predictability of failure, or premature failure

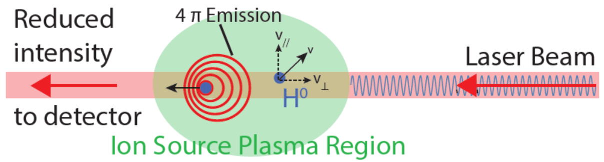
Goal

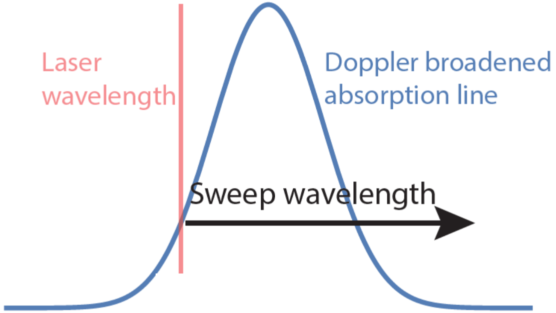
- Implement a new diagnostics in a risk intolerant environment
- Establish historical trends of source internal parameters (Cs: T & ρ, H0: T)
- Correlate trends with source performance
- Experiment with run parameters on test platform to look for improvements

Constraints

- Current H- production source is well established
  - New methods should not impact performance
- High Voltage CW environment
  - Limit new diagnostics to maintain current working conditions (no new conductors)
  - Fiber optic transport in/out of CW dome minimally impacts operations
  - Runing fiber requires no large delays or facility changes

Dual Wavelength TLDS

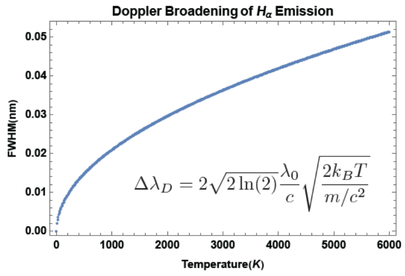


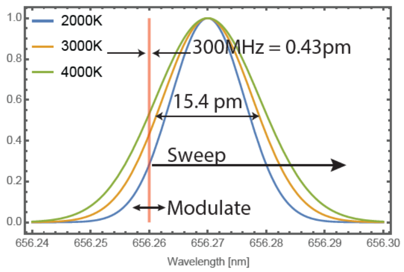


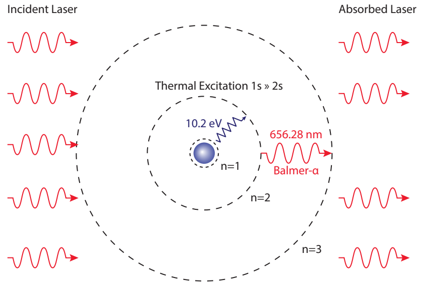
- TLDS is the use of a narrow linewidth laser source to scan over an atomic absorption line.
- Widely tunable laser diodes (LD) centered at 656.3nm (Eblana Photonics) and 852.1nm (Thorlabs)
  - Simultaneous characterization of atomic Cs and H
  - Cs time resolved inside and outside plasma
- Useful physical parameters can be calculated from line shape:

$$T = \frac{m_p c^2}{8\ln(2) k_B}\left(\frac{\Delta\lambda_D}{\lambda_0}\right)^2$$

$$n = \frac{8\pi c}{\lambda^4}\frac{g_k}{g_i}\frac{1}{A_{ik}L}\int -\ln\left(\frac{I(\lambda,L)}{I(\lambda,0)}\right)d\lambda$$

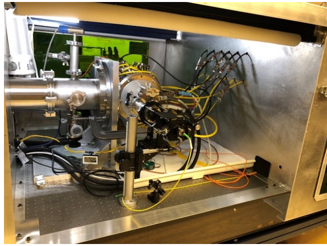






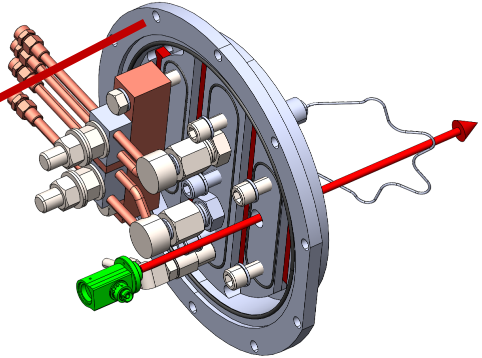
Side plate modifications on LDS

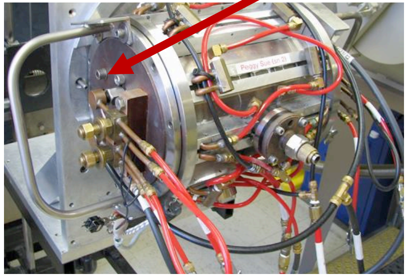
Laser Diagnostics Stand (LDS) with Source



Minimal side plate modifications

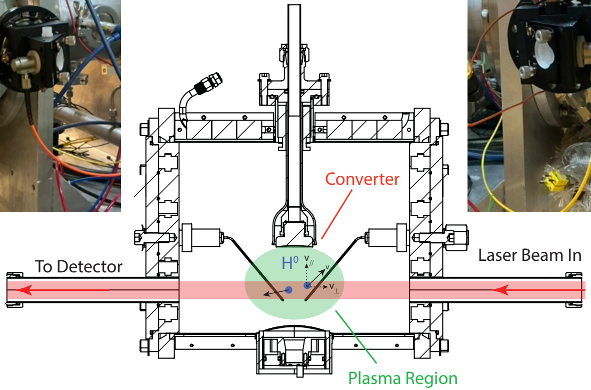
- Modified the source side plates
  - matched optical inspection ports
  - supporting TLDS and optical emission spectroscopy (OES).

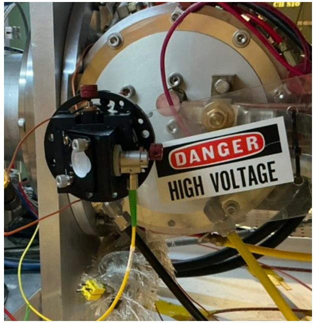




Optical coupling of TLDS Probe Lasers

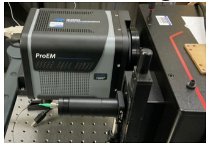
- Optical fiber input/output ports installed.
  - Achromatic reflective fiber collimators for multiple wavelengths.
  - MMF output also enables OES collection

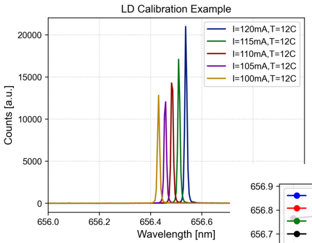


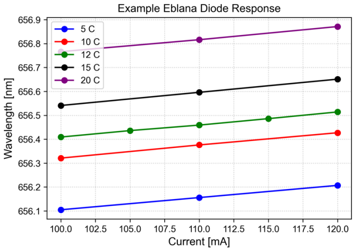


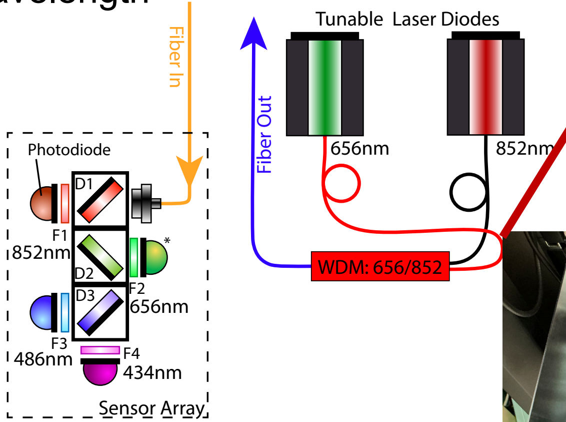
Dual Wavelength and OES Detector Design

- Initial Source / Detector Setup
- 852 nm : stock item from Thorlabs
- 656 nm : custom DFB-like Laser Diode from Eblana Photonics
  - change emission wavelength based on operating temperature and drive current.
  - The output wavelength was calibrated using a high-resolution spectrometer.
- Peak detection used to estimate emission wavelength
- 20m single mode optical fiber delivery
- Custom-built fiber WDM (combiner)
- 400 micron-core MMF used for return



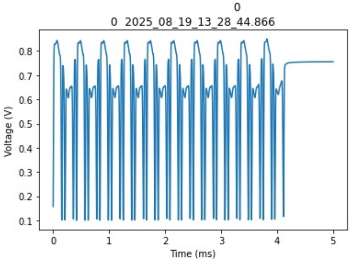


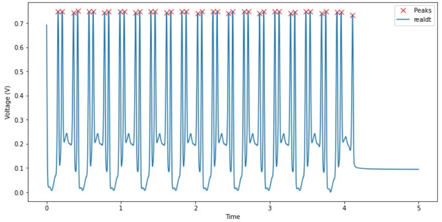


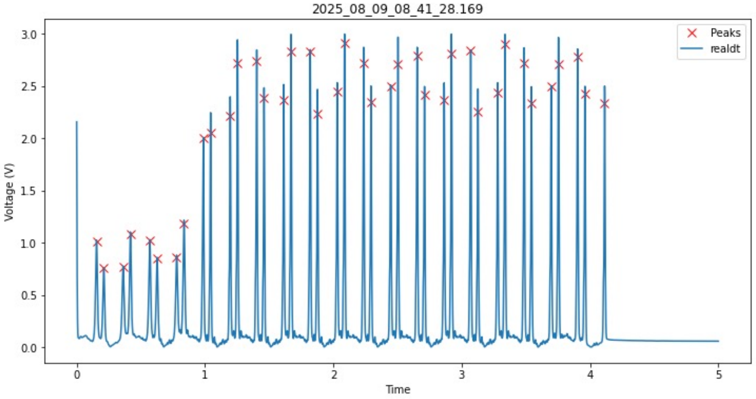


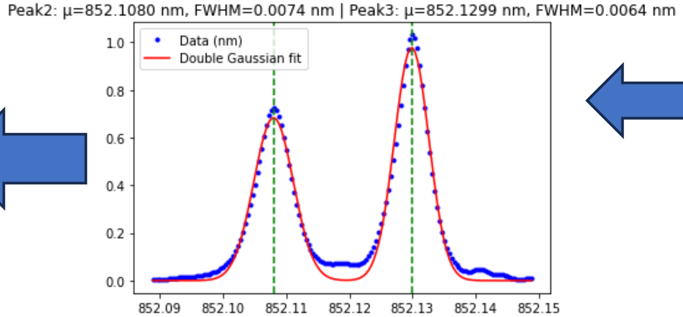
Cesium TLDS Collection

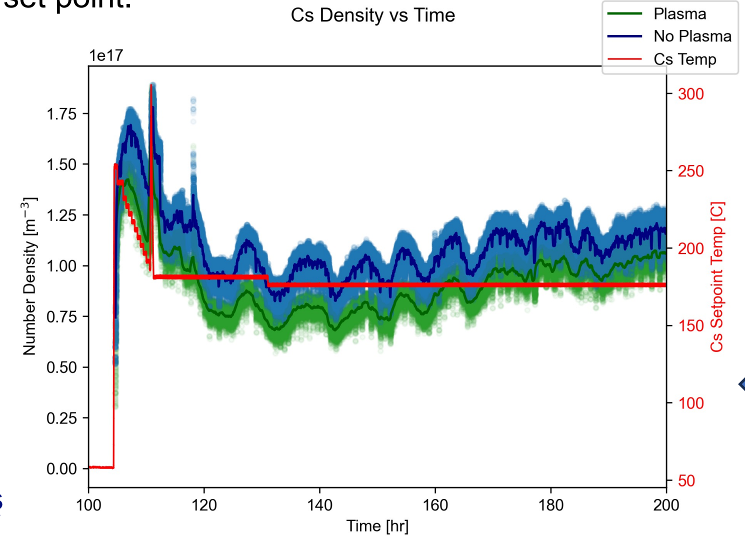
- Cs TLDS signals are based on measuring the absorption of the Cs ground state ($6^2S_{1/2} \rightarrow 6^2P_{3/2}$) transition.
  - Ground state absorption measurement results in a strong, self calibrating signal.
- Cs conditioning
  - Three weeks Cs operation.
  - TLDS Cs density measurement overlaid on Cs oven temperature set point.





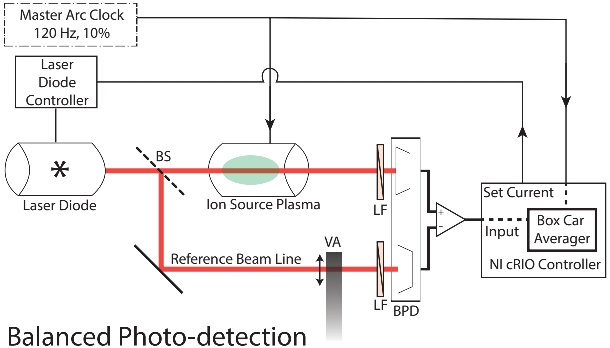




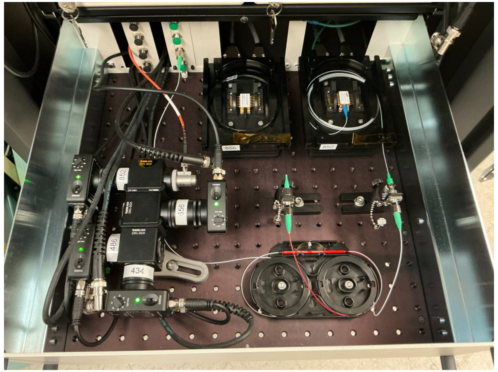


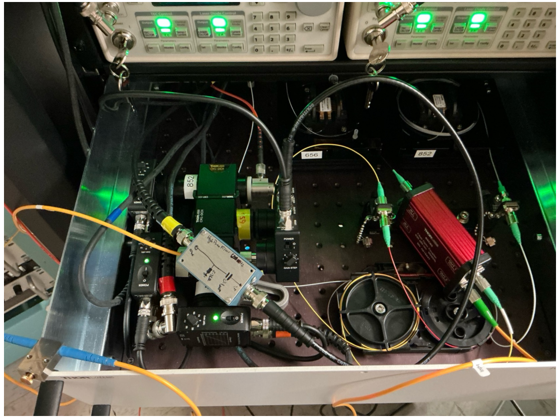
Hα TLDS Measurement Challenges

- Attempts to wavelength scan with Hα laser by current modulation resulted in a signal with too much noise in the data
- Additional, noise canceling methods were deemed necessary.
- Battling noise with a small Hα signal
  - BPD
  - Aggressive filtering
  - Long averaging times



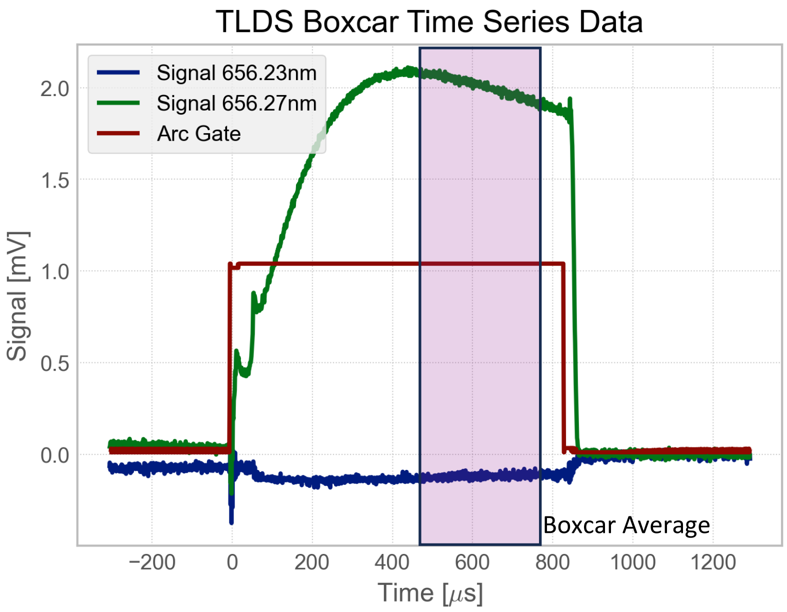
Balanced Photo-detection

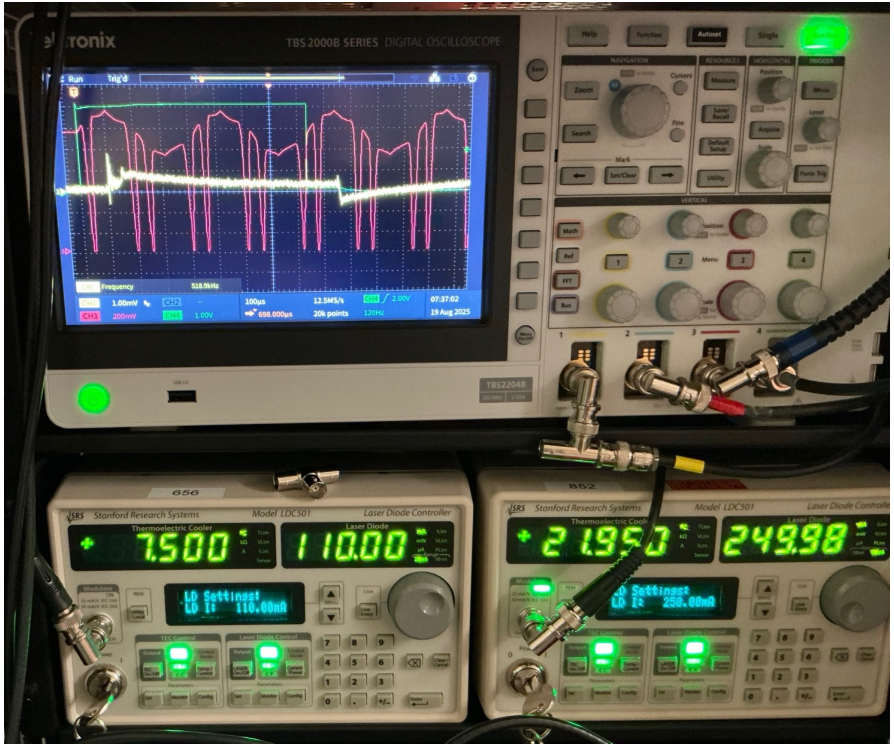




Hα TLDS Measurement

- Balanced photodetection is working, but is slow (20 min per acquisition).
  - Large number of single wavelength data sets averaged together ~ 1 min / λ

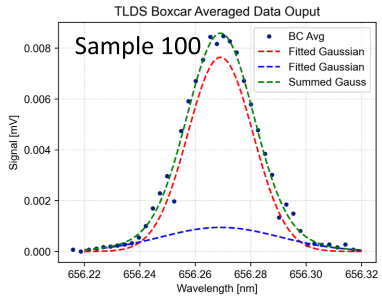


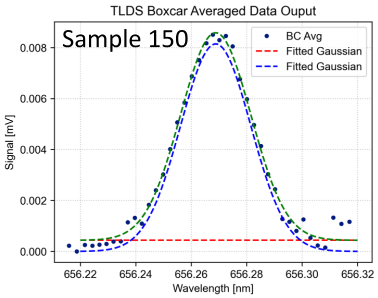


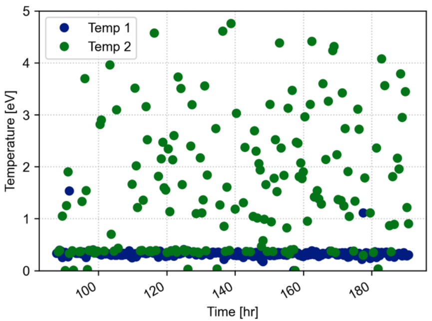
Hα TLDS Measurement

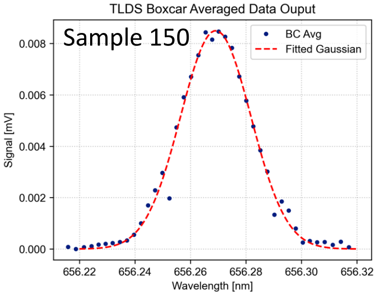
Examining Collected Hα Line Shapes

- Some Hα TLDS scans fitted a two-temperature model, most did not

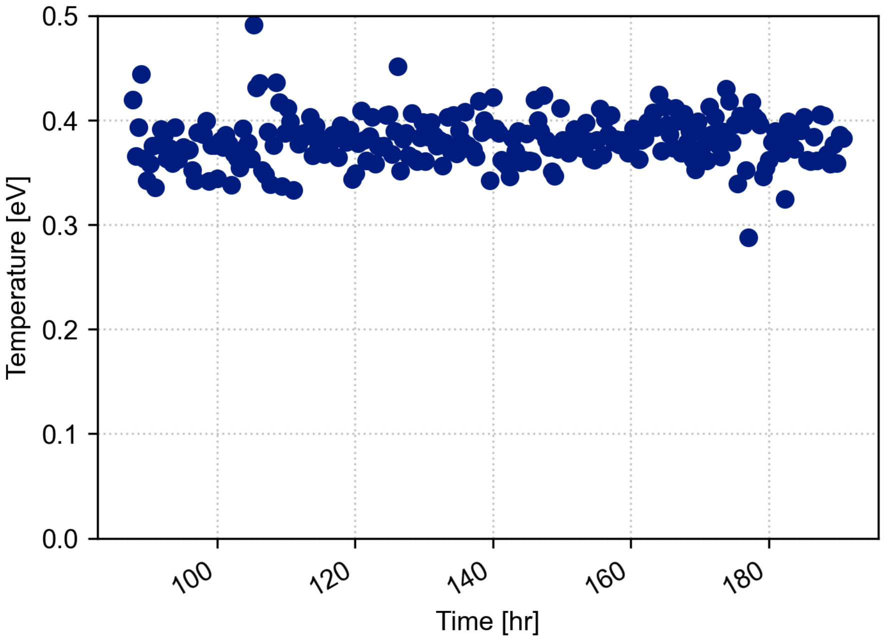






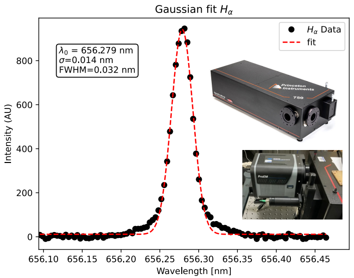


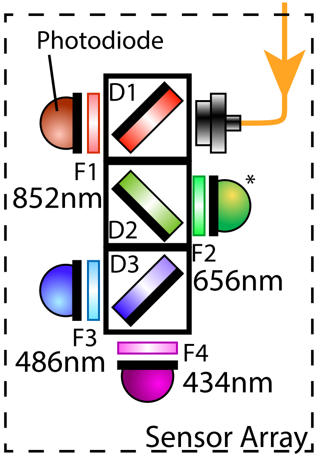
Single Temperature Model vs Time

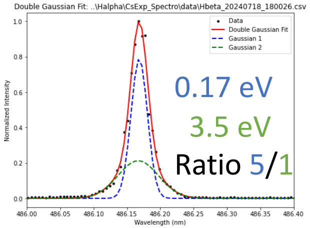


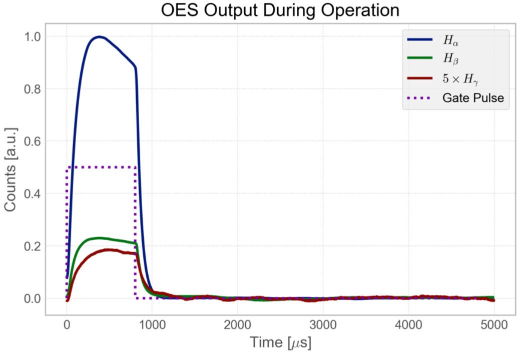
Optical Emission Spectroscopy

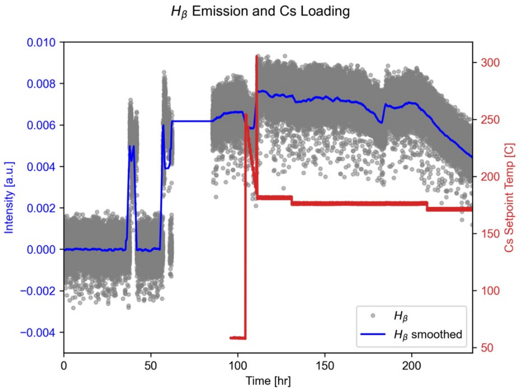
- OES has been collected at three wavelengths
  - High resolution spectrometer with gated, high efficiency EMCCD (FY24 run) indicates little thermal background.
  - Current setup contains a dichroic cascade and narrow bandpass filters
    - D1: T: > 805nm
    - D2: T: < 550nm / F2: 1 nm @ 656.3 nm→ Hα
    - D3: R: > 450nm / BPF:, 10 nm & 488 nm → Hβ
    - D3: T: < 450nm / BPF: 1 nm @ 437 nm → Hγ

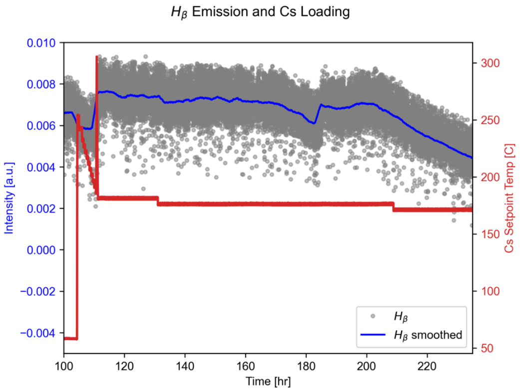












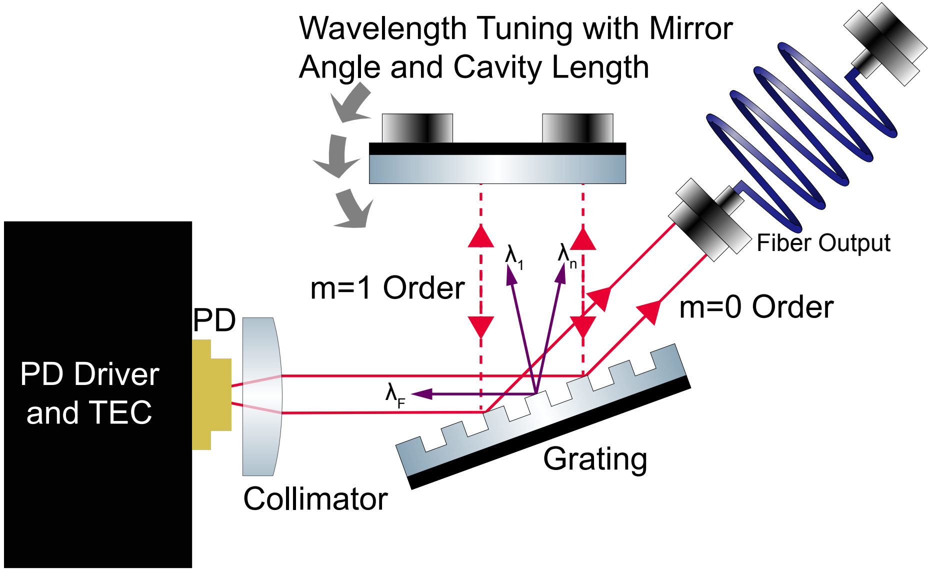
Summary & Future Directions

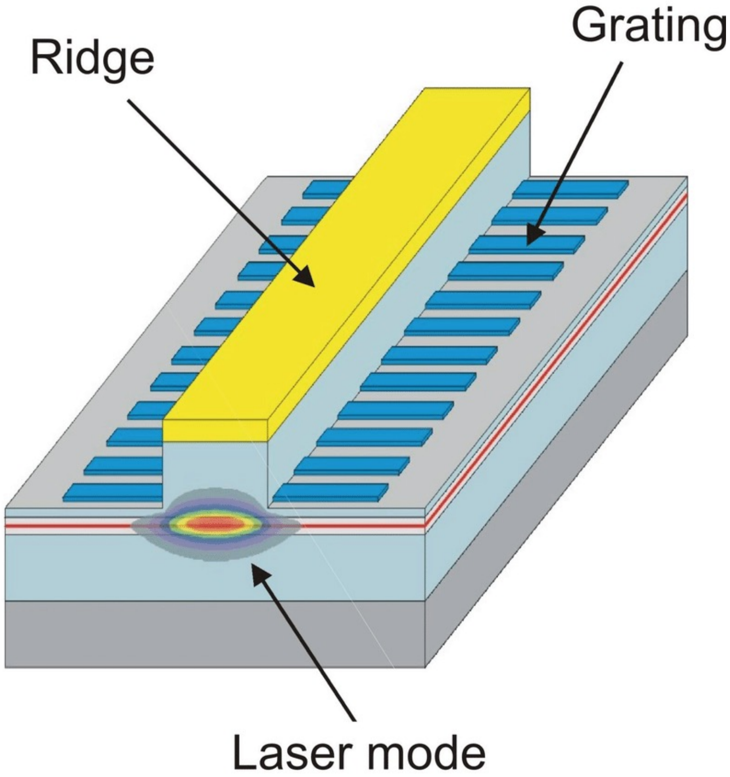
- Demonstrated Dual wavelength TLDS diagnostic at 656.3 nm (Hα) and 852.1 nm (Cs)
- OES capability retained at *656.3 nm*, 487 nm, & 437 nm
- Fiber transport to/from source body over 40 m.
- kHZ modulation rates estimates Cs density inside & outside plasma pulse (limited by DAQ)
- Box car averaging for estimating hydrogen line shape.
- We are working towards implementing these measurements into real-time diagnostics on LANSCE production sources and improving Hα speed.

Thank you for your attention

BACKUP SLIDES

Two Types of Wavelength Tunable Laesr





DFB LD Wavelength Control

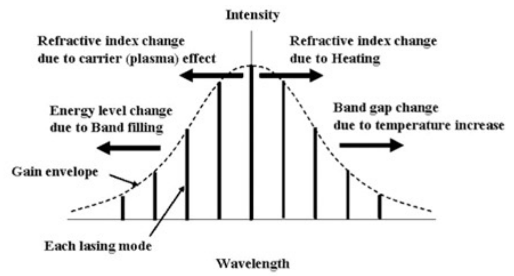
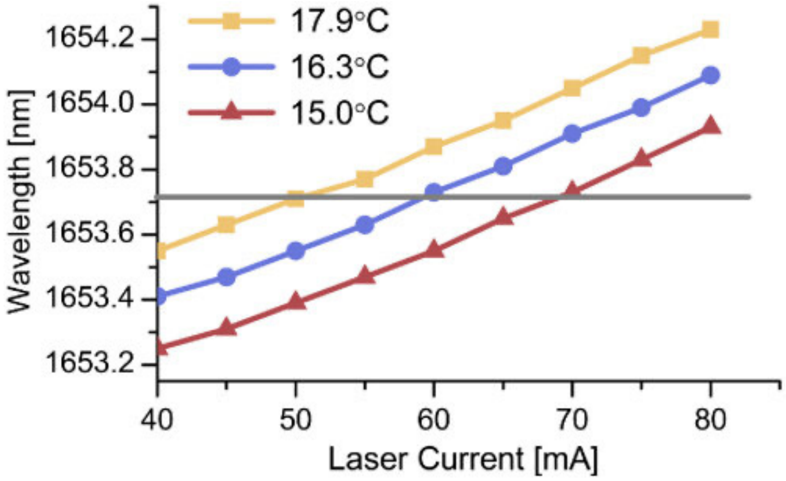
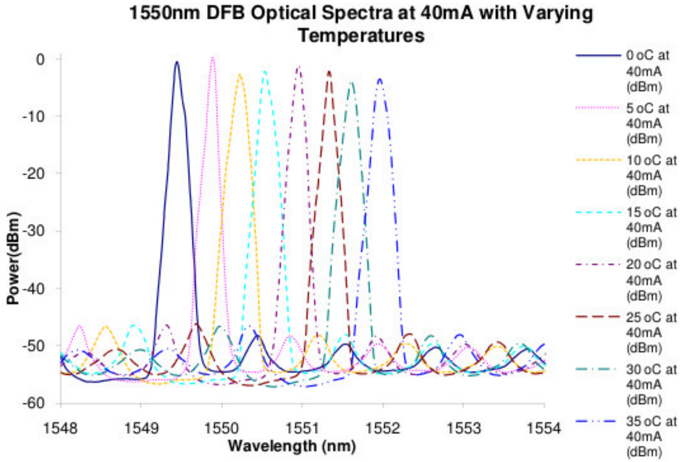
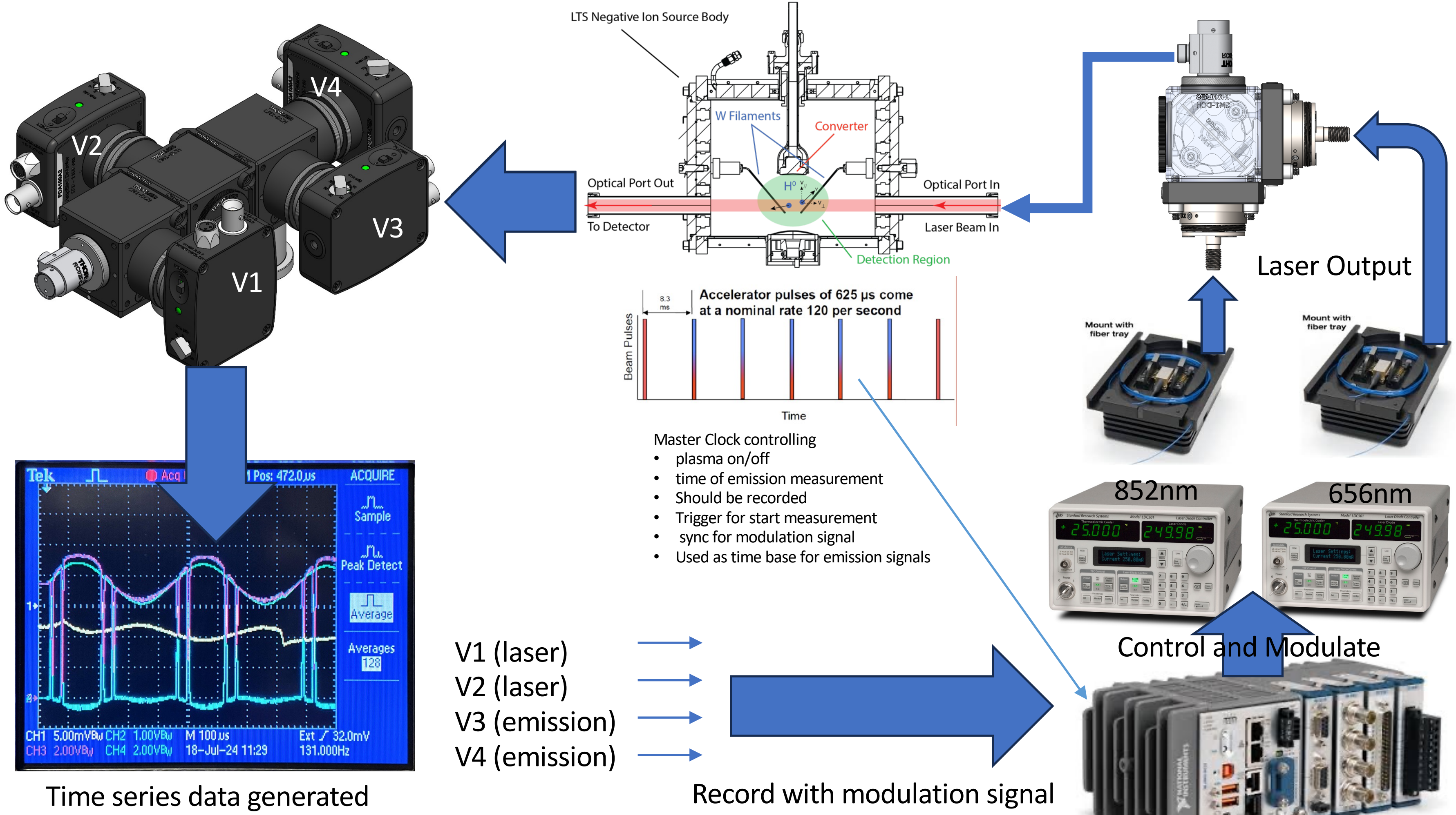


Figure 1: It is the rate of change of physical properties that determines the conventionally used temperature and tuning coefficients.





- Bandgap energy changes due to changes in temperature, and a band-filling effect induced by drive current injected into the active layer of the semiconductor.
- A change to the refractive index in the active layer, which is induced by changes in ambient temperature and temperature changes resulting from the Joule heating associated with injected drive current density.



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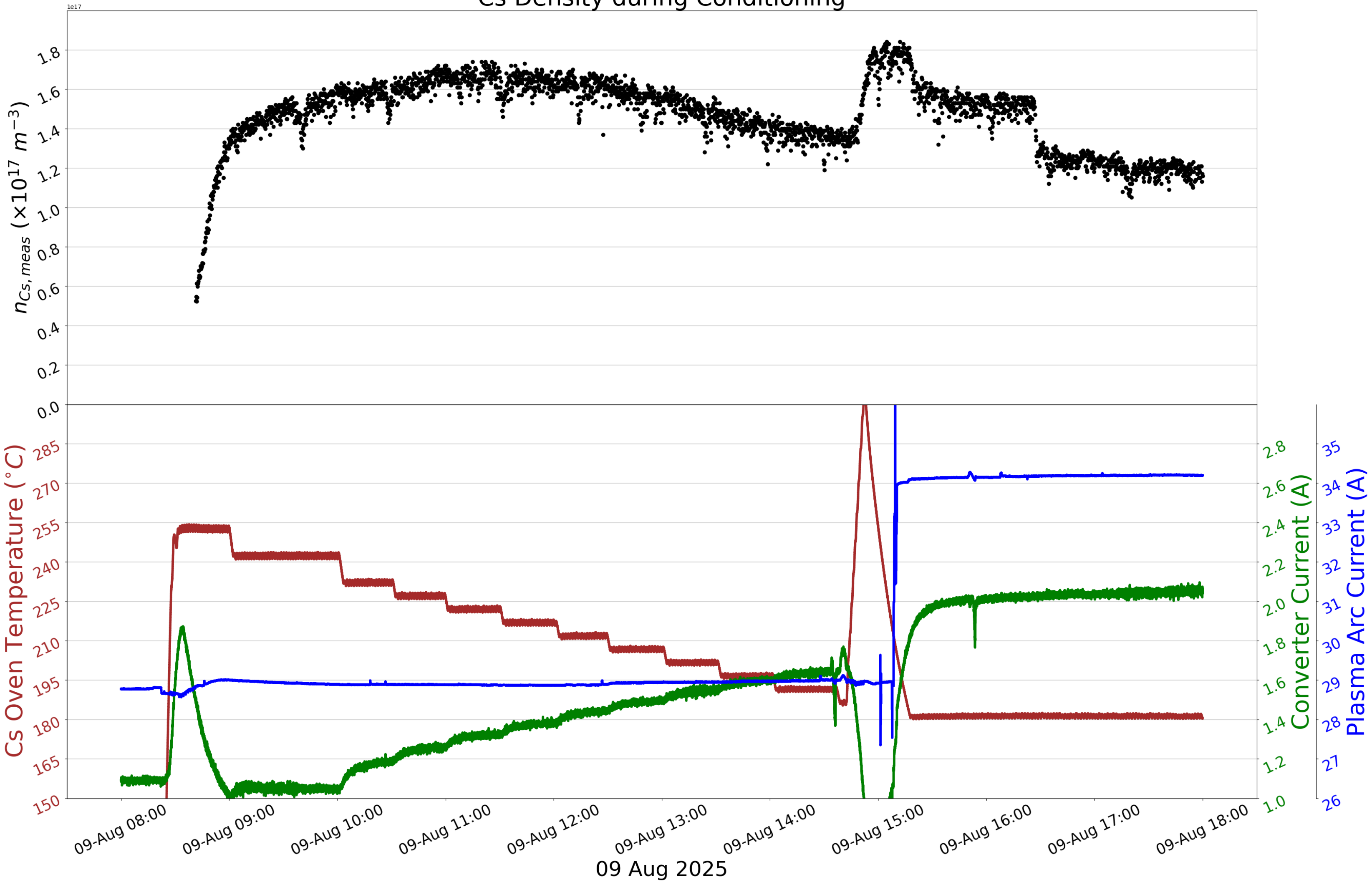
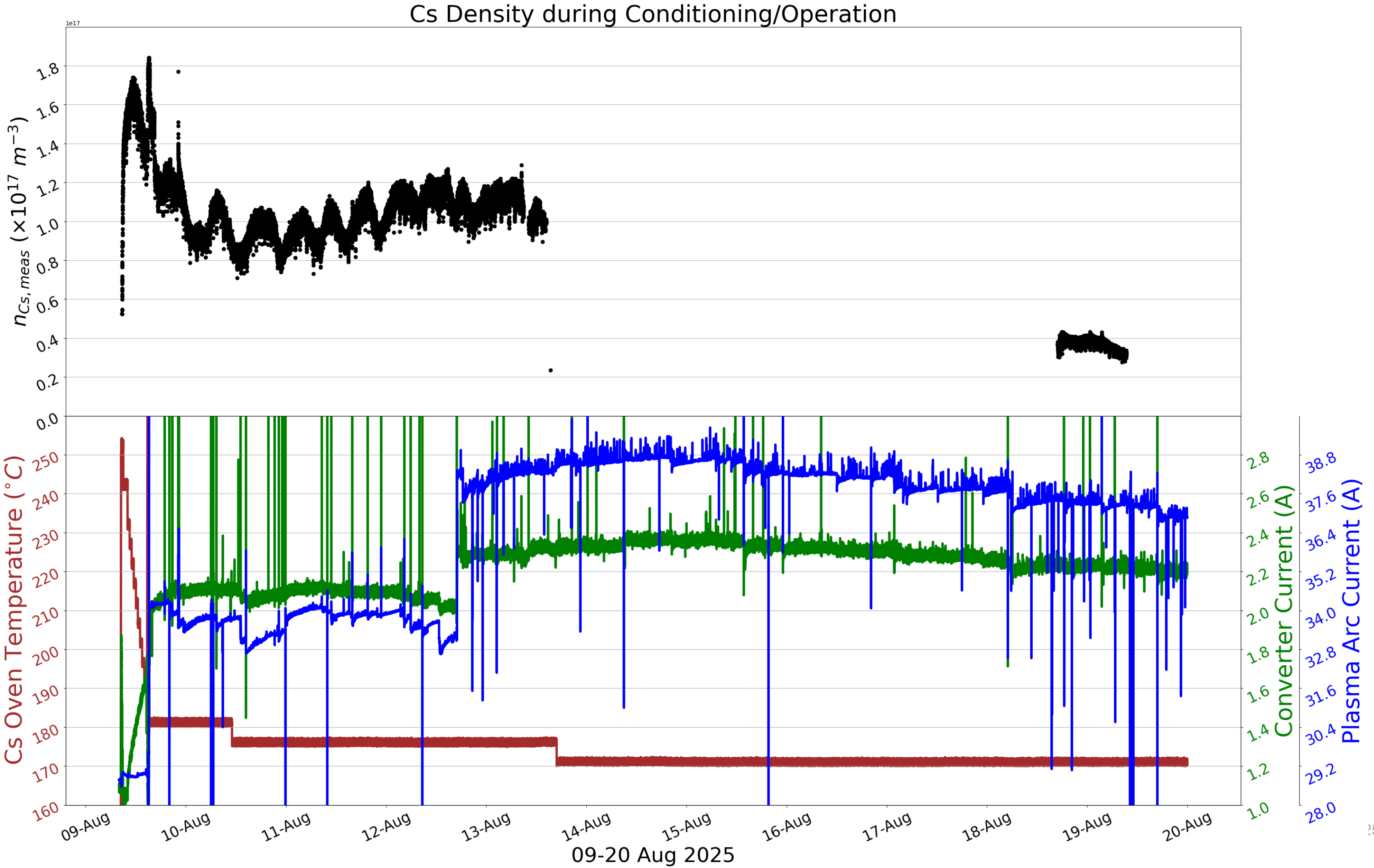
Cs Density during Conditioning





Cs Density during Conditioning/Operation
1e17
$n_{Cs,meas}$ ($\times10^{17}$ m^{-3})
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Cs Oven Temperature (°C)
160
170
180
190
200
210
220
230
240
250
Converter Current (A)
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
Plasma Arc Current (A)
28.0
29.2
30.4
31.6
32.8
34.0
35.2
36.4
37.6
38.8
09-Aug
10-Aug
11-Aug
12-Aug
13-Aug
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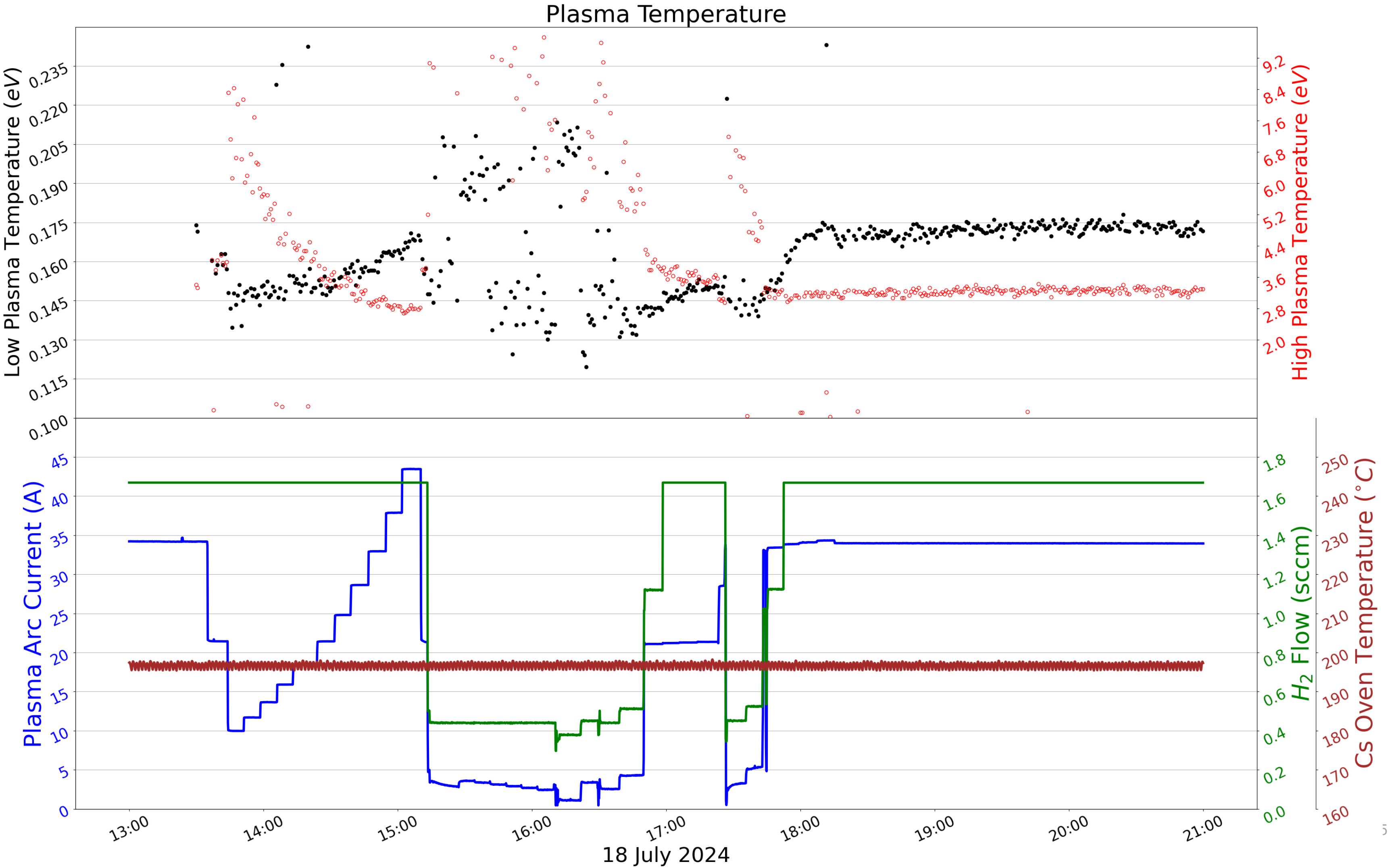
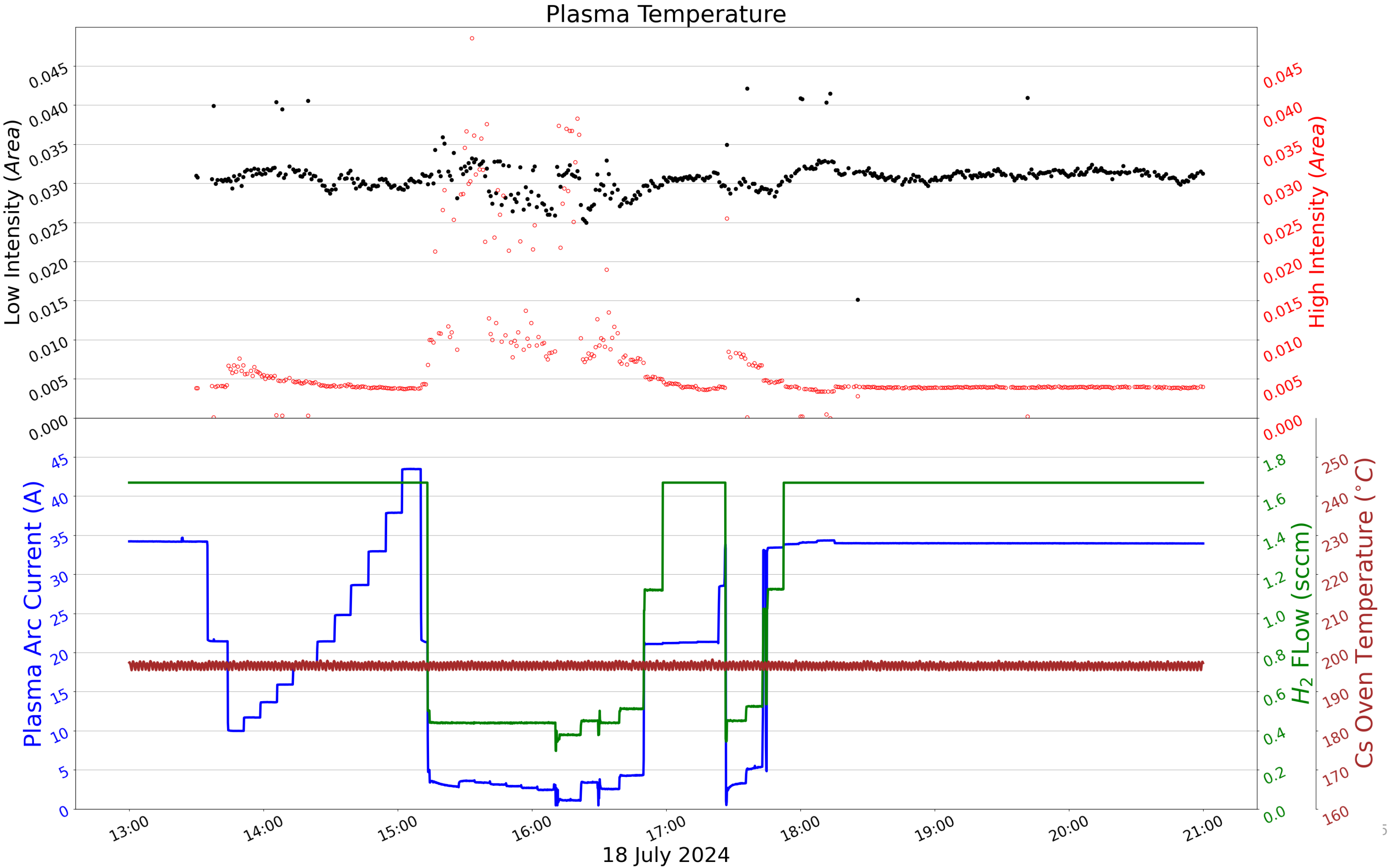
20-Aug
09-20 Aug 2025


Plasma Temperature
Low Plasma Temperature (eV)
0.100
0.115
0.130
0.145
0.160
0.175
0.190
0.205
0.220
0.235
High Plasma Temperature (eV)
2.0
2.8
3.6
4.4
5.2
6.0
6.8
7.6
8.4
9.2
Plasma Arc Current (A)
0
5
10
15
20
25
30
35
40
45
H_2 Flow (sccm)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Cs Oven Temperature (°C)
160
170
180
190
200
210
220
230
240
250
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
18 July 2024



Plasma Temperature
Low Intensity (Area)
High Intensity (Area)
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
0.045
Plasma Arc Current (A)
0
5
10
15
20
25
30
35
40
45
H_2 FLow (sccm)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Cs Oven Temperature (°C)
160
170
180
190
200
210
220
230
240
250
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
18 July 2024