WPPW (SP X) LIBS analysis of relevant samples in view of the LIBS application at JET during the last experimental campaigns at VTT

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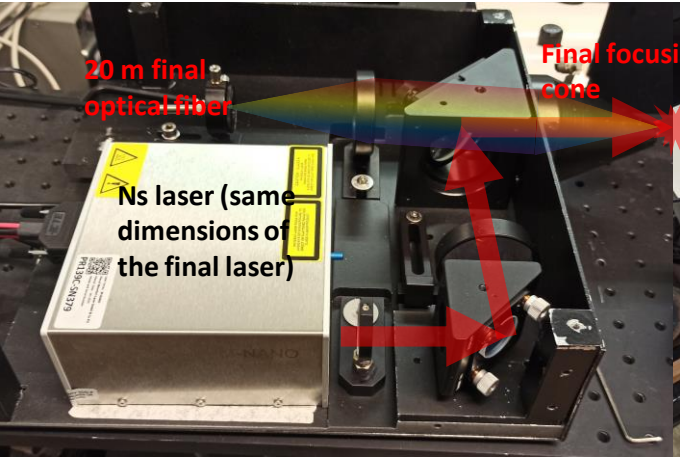
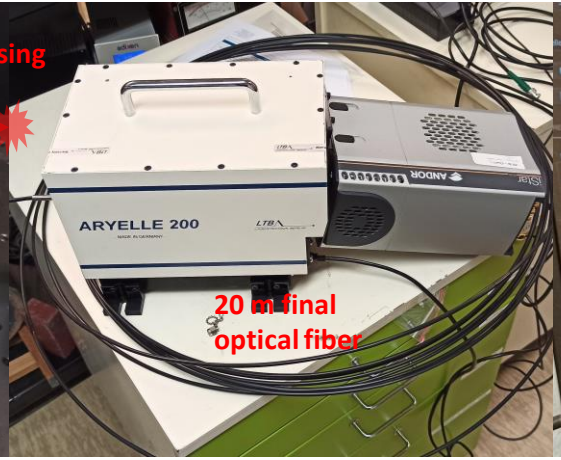
Outline

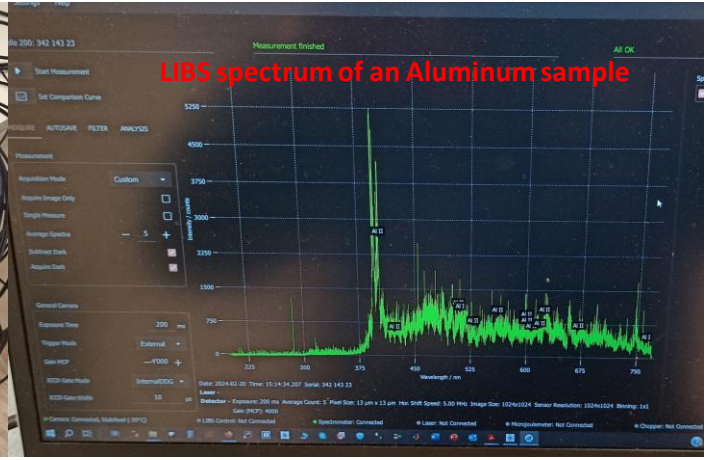
- LIBS campaigns at VTT in view of application of LIBS at JET
  - Set-up of the JET-relevant LIBS system
  - Prototypal LIBS measurements on different samples:
    - Samples from the WEST machine
    - Bulk Mo (with implanted D), W, samples
    - Be coating with implanted D
    - Real samples from JET from the previous experimental campaigns
  - Study of the WEST samples with optical profilometer measuring the crater depth and estimate the ablation rate
  - Depth profiling of the samples from LIBS data

Set-up of the JET-relevant LIBS system

The preliminary setup of the LIBS system relevant for JET took place in the first experimental campaign at VTT (19-23 February 2024) using the already-available prototype tool. On this tool the optics equivalent to those of the final tool and the compact ns laser (as a replacement of the final sub-ns laser) were mounted and aligned. In this campaign, the functionality of the optical alignment, the management of the software of the laser, the 20 m optical fiber and the data acquisition of the "Aryelle 200" full-range spectrometer were verified.

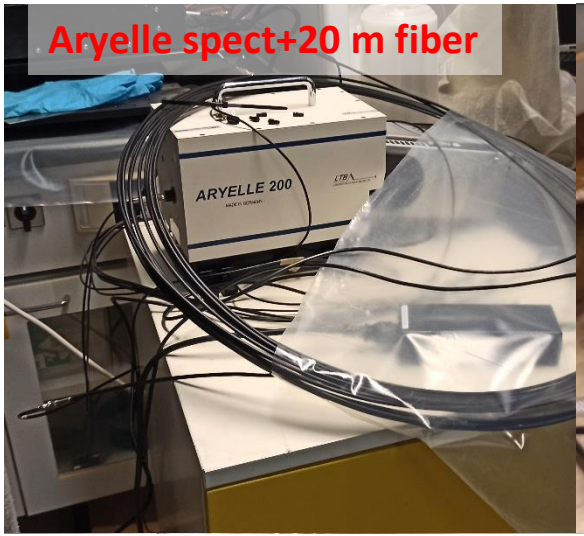


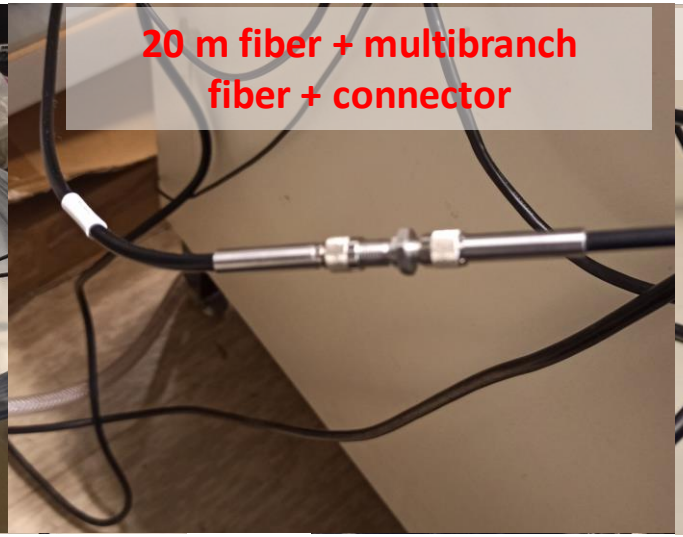


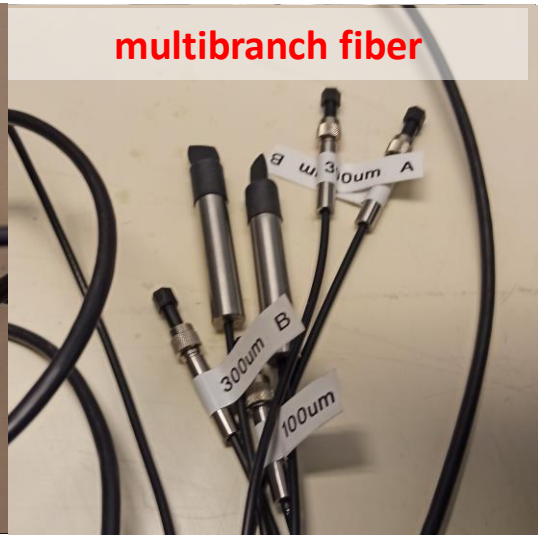


Be campaign at VTT in support of RH LIBS at JET

The prototypal setup of the LIBS system relevant for JET was set in the second experimental campaign at VTT (11-22 March 2024) by completing the alignment of the previous campaign with a new semi-transparent mirror (beamsplitter), the final compact sub-ns laser and the final fiber. In this campaign, setup and data acquisition of the “Aryelle 200” full-range spectrometer were verified in the final configuration. The two WEST samples measured in the previous campaign, two “Full Mo” samples with D, a “Full W” sample, Be-based samples and real JET samples were measured.

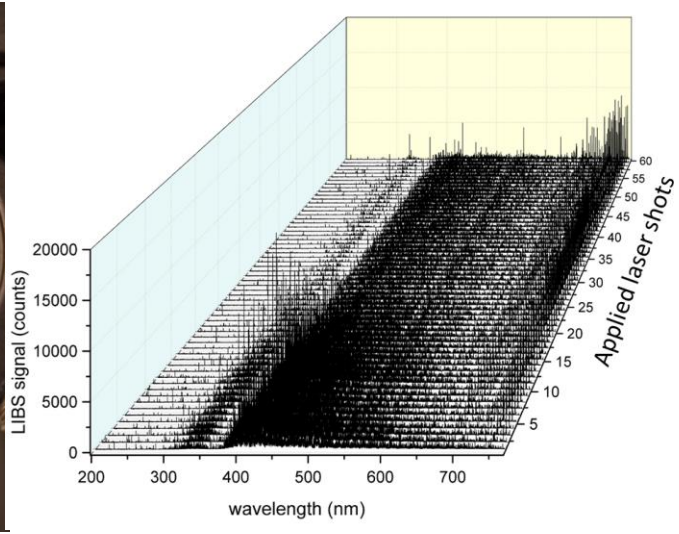


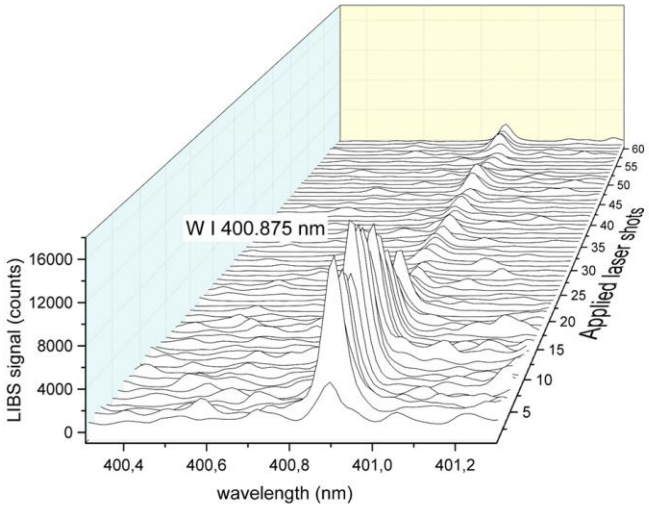




LIBS measurements of WEST samples

After completing the alignment and setting the laser to a pulse energy of 10 mJ, LIBS measurements were carried out on samples of the WEST tokamak (being authorized by interested colleagues):
Example: WEST sample C3-34-iK. **LIBS spot 5**, laser energy ≈ 10 mJ delay 1μs, 9 μs width # 60 laser shot applied





Depht profiling data analysis

A MATLAB procedure has been developed to perform multiple depht profiling analyses of the acquired spectra looking at intense and free of interference emission lines of the elements.

```
tic;
clear all
d=dir('C:\Users\Almaviva-ENEA\Desktop\file_matlab_aggiornati_funzionanti'); % path to your files
l = length (d);
ind_PCA = 0;
for i =1:l
    namefile = d(i).name
    k = strfind(namefile, '.txt');
    if k >= 0
       ind_PCA = ind_PCA +1; #spectra counter
       read_Aryelle_files; peak analysis function
    end
end
delete file_appoggio.txt;
figure(3)
x_axis = linspace(1,ind_PCA,ind_PCA);
plot(x_axis,Be_I_332_11nm,'-b',x_axis,Be_I_457_27nm,'-b',x_axis,W_I_400_87nm,'-k',x_axis,W_I_407_45nm,'-k',x_axis,T_D_H_656nm,'-ro'
legend("Be I 332.11nm","Be I 457.27nm","W I 400.87nm","W I 407.45nm","T-D-H alpha 656nm","Mo I 550.65nm","Mo I 553.3nm","Mo I 557.0
xlabel('number of laser shots')
ylabel('Integral intensity (a.u.)')
figure(4)
x_axis = linspace(1,ind_PCA,ind_PCA);
semilogy(x_axis,Be_I_332_11nm,'-b',x_axis,Be_I_457_27nm,'-b',x_axis,W_I_400_87nm,'-k',x_axis,W_I_407_45nm,'-k',x_axis,T_D_H_656nm,'
legend("Be I 332.11nm","Be I 457.27nm","W I 400.87nm","W I 407.45nm","T-D-H alpha 656nm","Mo I 550.65nm","Mo I 553.3nm","Mo I 557.0
xlabel('number of laser shots')
ylabel('Integral intensity (a.u.)')
fclose all;
toc;
elapsedTime = toc;
```

‘for’ cycle to look for ‘.txt’ files in the folder

Depht profiling data analysis

A MATLAB procedure has been developed to perform multiple depht profiling analyses of the acquired spectra looking at intense and free of interference emission lines of the elements.

```
fin = fopen(namefile);   % apre il file di input
fout = fopen('file_appoggio.txt', 'wt');              % apre il file di output di servizio non servirà alla fine
tline = fgetl(fin);                                   % mette in tline la riga del file di input con fgetl
count = 0;                                            %imposta a zero il contatore
while ischar(tline)                                   % mentre il file non è finito
    tline = fgetl(fin);                               % metti in tline la riga del file di input con fgetl
    if tline ~= -1                                    % questa istruzione perchè alla fine di ogni file mette un "-1"
       fprintf(fout, '%s\n', tline);                     %scrivi come riga sul file di output
       count = count + 1;
    end
end
fclose(fout);                                         % chiudi l'output
load file_appoggio.txt                                %ricarica il file di servizio
x = file_appoggio(:,1);                               %colonna delle lunghezze d'onda
y = file_appoggio(:,2);

indices = find( x > 341.38 & x <= 341.58);
Ni_I_341_48nm(ind_PCA,1) = sum(y(min(indices): max(indices)));
indices = find( x > 345.75 & x <= 345.95);
Ni_I_345_85nm(ind_PCA,1) = sum(y(min(indices): max(indices)));
indices = find( x > 346.065 & x <= 346.265);
Ni_I_346_165nm(ind_PCA,1) = sum(y(min(indices): max(indices)));
indices = find( x > 400.83 & x <= 400.94);
W_I_400_87nm(ind_PCA,1) = sum(y(min(indices): max(indices)));
indices = find( x > 407.35 & x <= 407.55);
W_I_407_45nm(ind_PCA,1) = sum(y(min(indices): max(indices)));
indices = find( x > 425.34 & x <= 425.54);
Cr_I_425_44nm(ind_PCA,1) = sum(y(min(indices): max(indices)));
indices = find( x > 427.38 & x <= 427.58);
Cr_I_427_48nm(ind_PCA,1) = sum(y(min(indices): max(indices)));
indices = find( x > 428.9 & x <= 429.1);
Cr_I_429_00nm(ind_PCA,1) = sum(y(min(indices): max(indices)));
indices = find( x > 332 & x <= 332.35);
figure(1)
plot(file_appoggio(min(indices):max(indices),1),file_appoggio(min(indices):max(indices),2))
hold on
Be_I_332_11nm(ind_PCA,1) = sum(y(min(indices): max(indices)));
indices = find( x > 457.24 & x <= 457.43);
Be_I_457_27nm(ind_PCA,1) = sum(y(min(indices): max(indices)));
indices = find( x > 550.55 & x <= 550.75);
Mo_I_550_65nm(ind_PCA,1) = sum(y(min(indices): max(indices)));
indices = find( x > 553.2 & x <= 553.4);
Mo_I_553_3nm(ind_PCA,1) = sum(y(min(indices): max(indices)));
indices = find( x > 556.94 & x <= 557.14);
Mo_I_557_04nm(ind_PCA,1) = sum(y(min(indices): max(indices)));
indices = find( x > 587.49 & x <= 587.69);
```

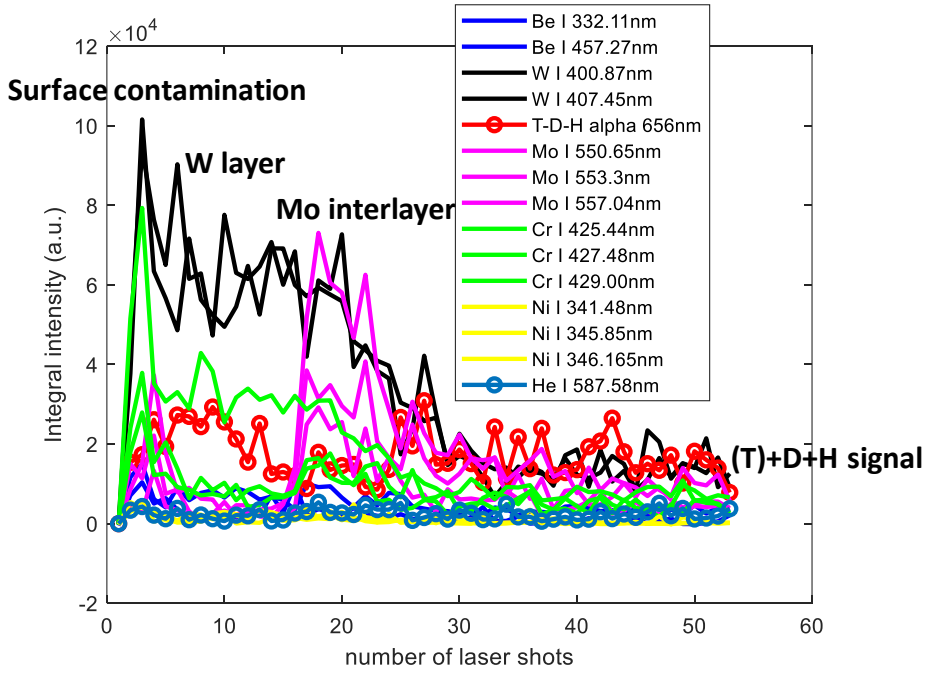
Look for Ni I @ 341.48 nm…

Look for W I @ 400.87 nm…

Look for Be I @ 332.11 nm…

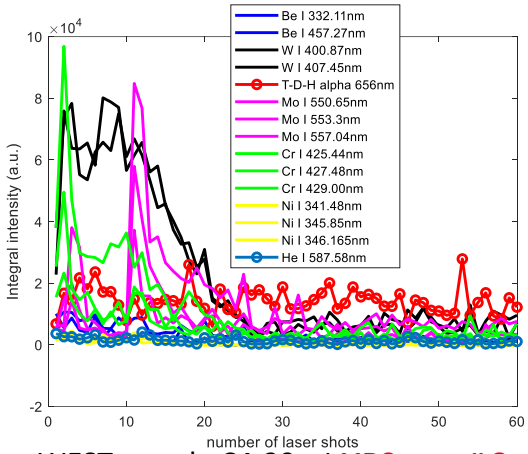
Look for Mo I @ 550.65 nm…

Ex. WEST sample C3-34-iK **LIBS spot # 5**

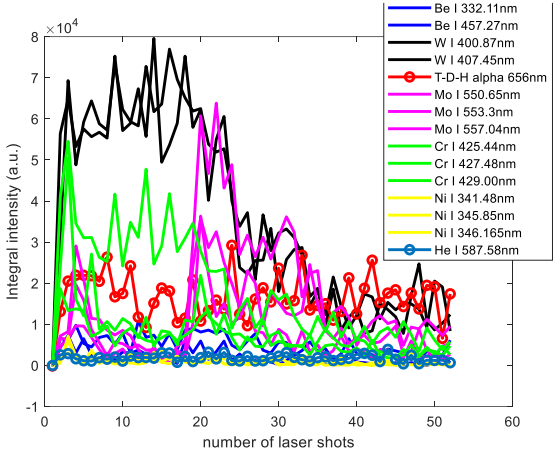


Depht profiling data analysis

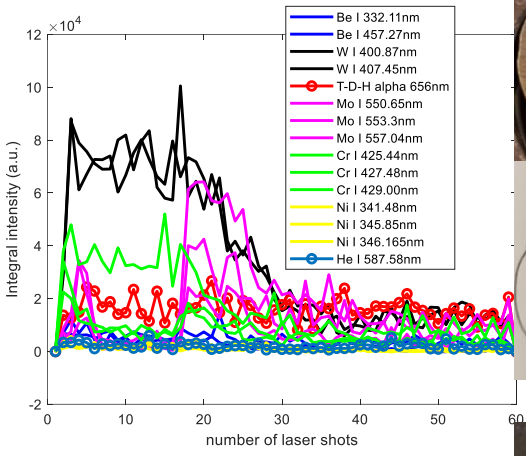
WEST sample C3-34-iK **LIBS spot # 2**

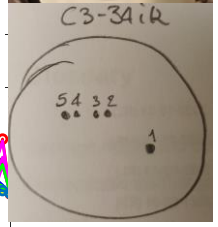


LIBS spot # 3

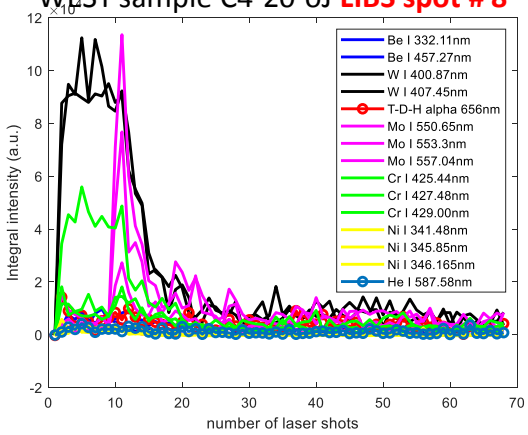


LIBS spot # 4

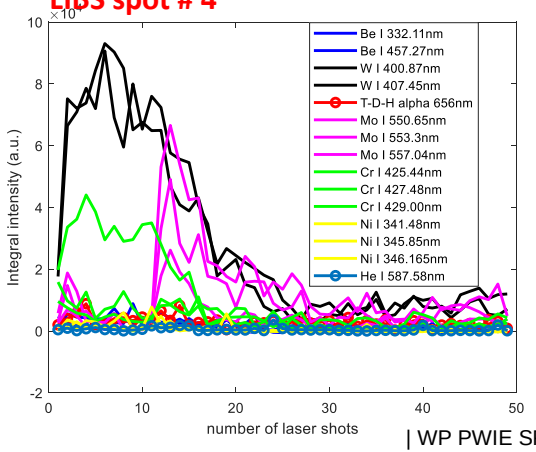




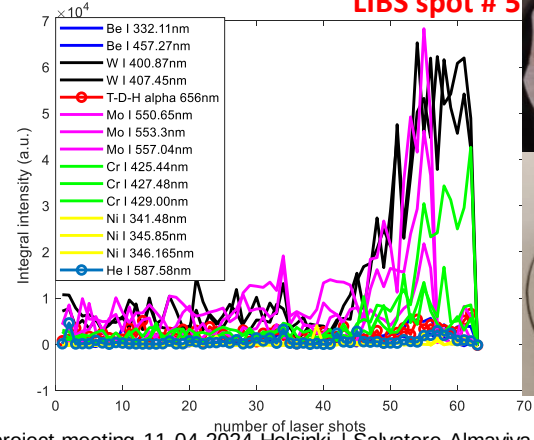
WEST sample C4-20-oJ **LIBS spot # 8**

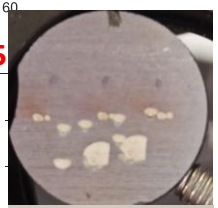


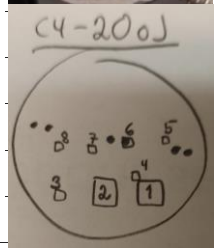
LIBS spot # 4



LIBS spot # 5







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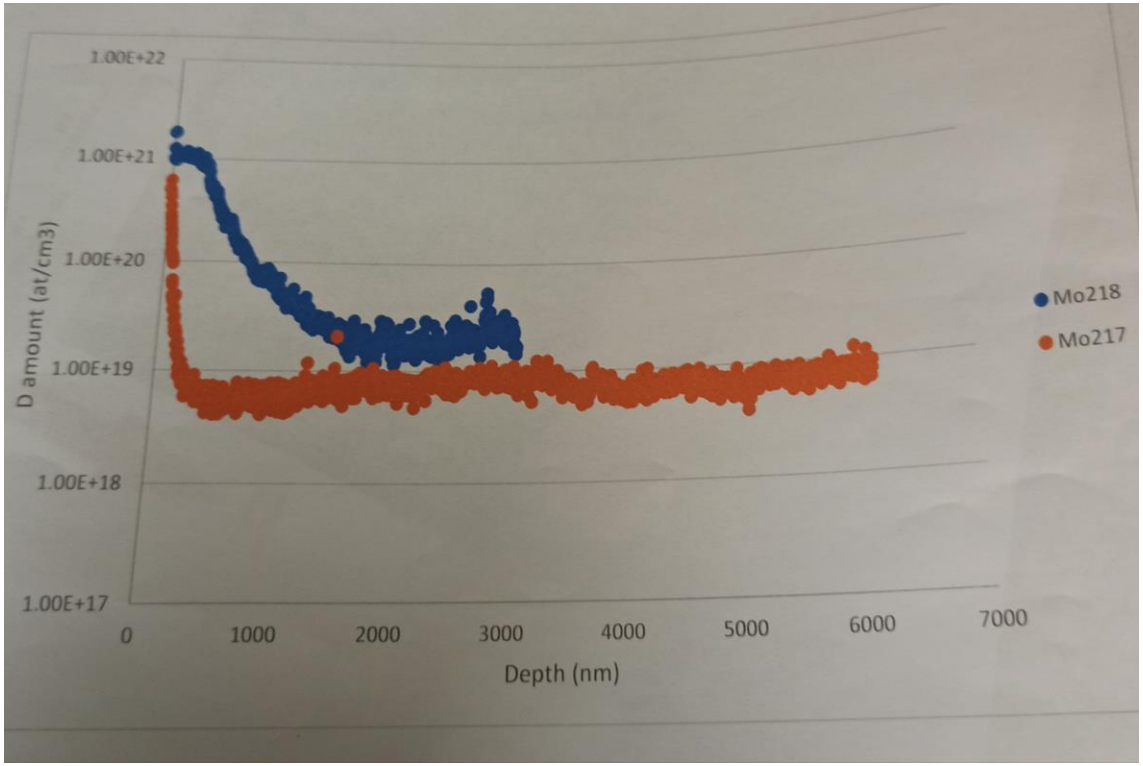
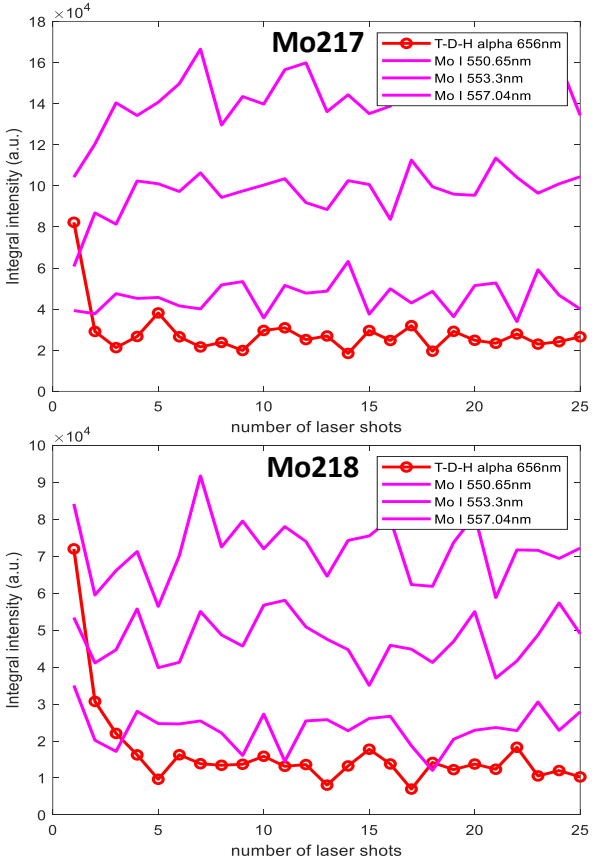
Full Mo samples with D (Mo217 and Mo218)





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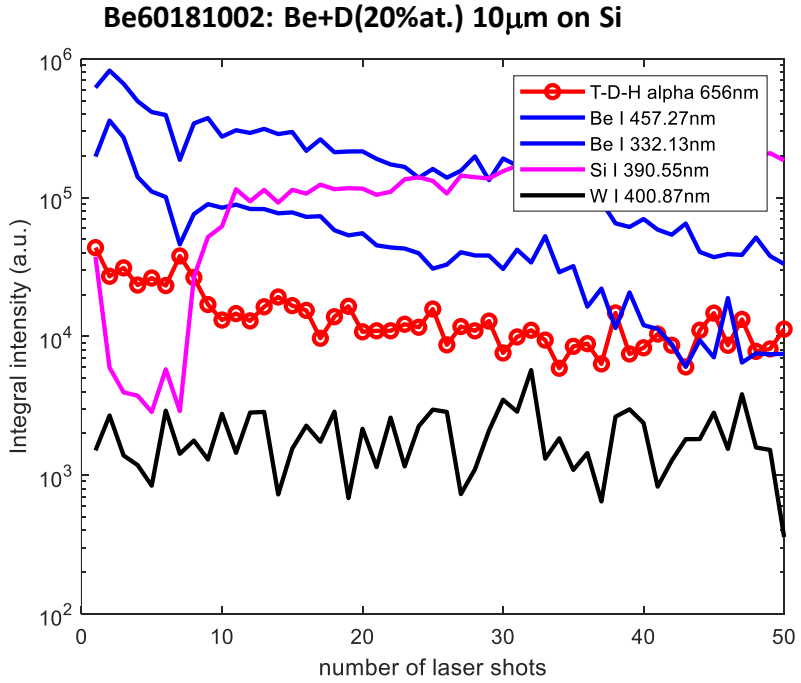
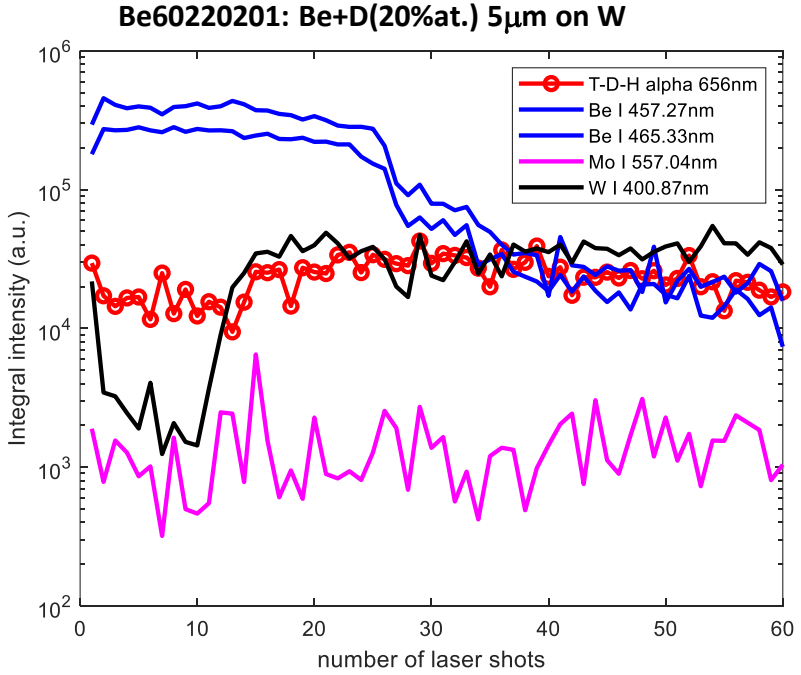
Be samples with D (**Be60181002** and **Be60220201**)





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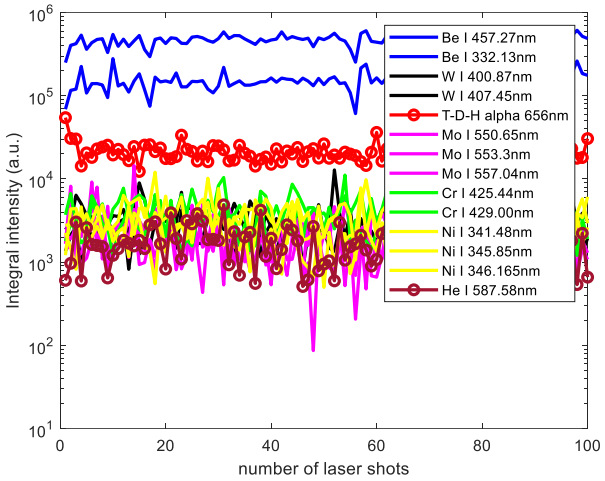
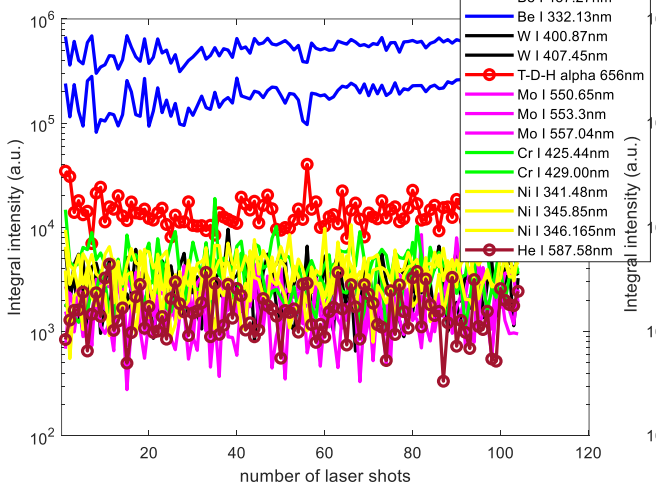
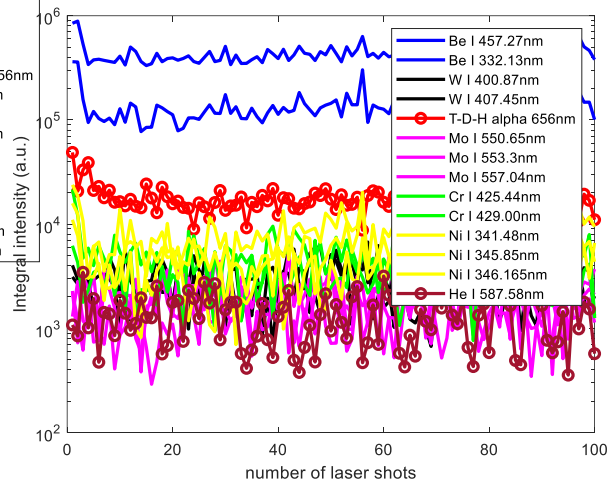
JET sample 2XR11-623

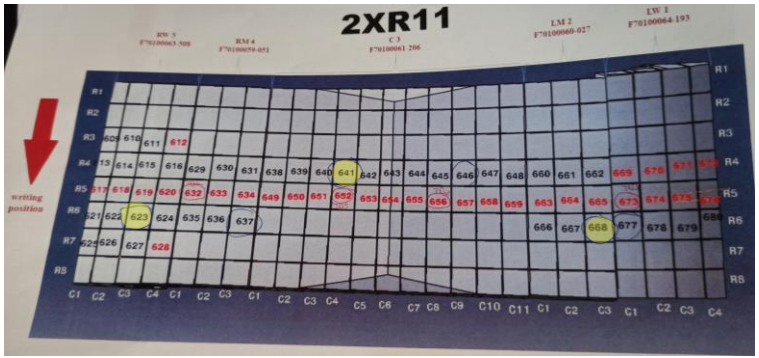


JET sample 2XR11-641



JET sample 2XR11-668





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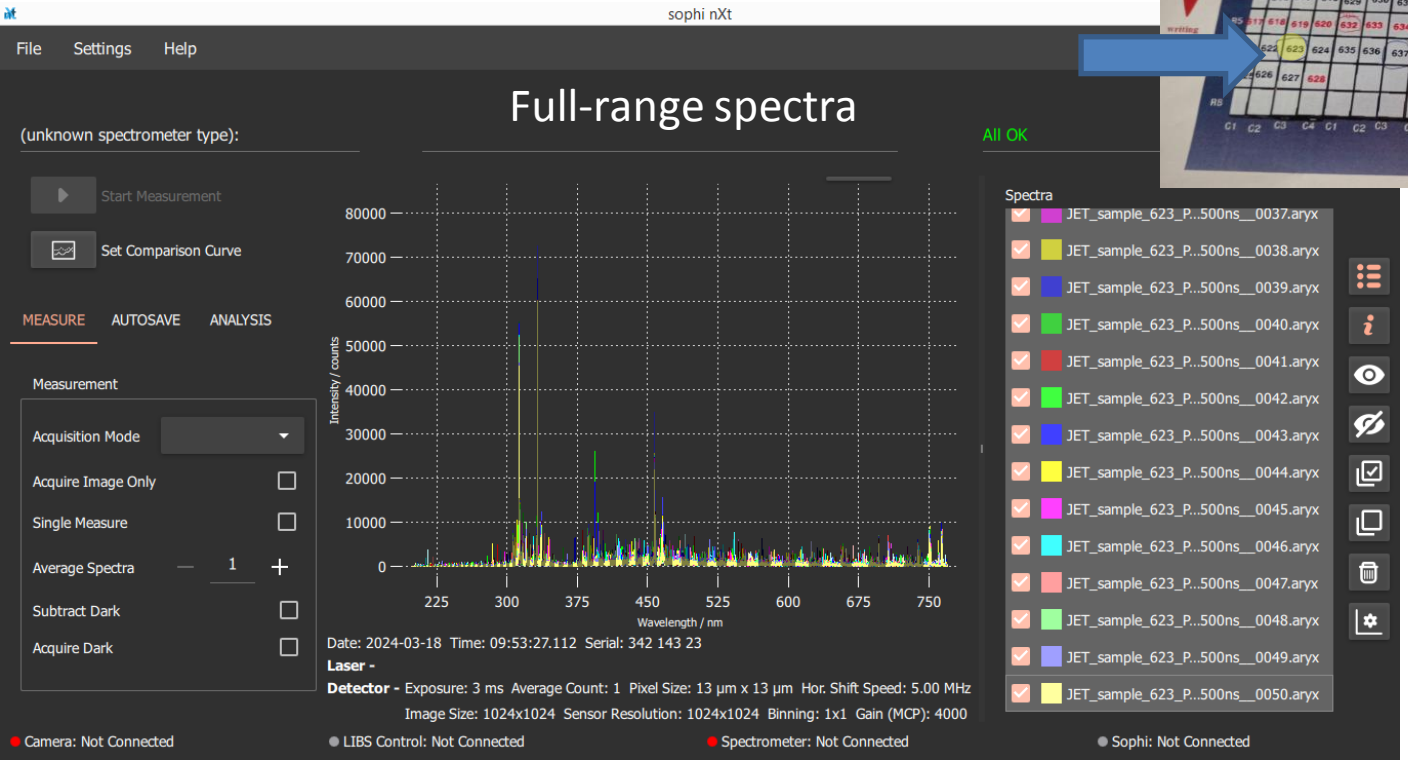
JET sample 2XR11-623



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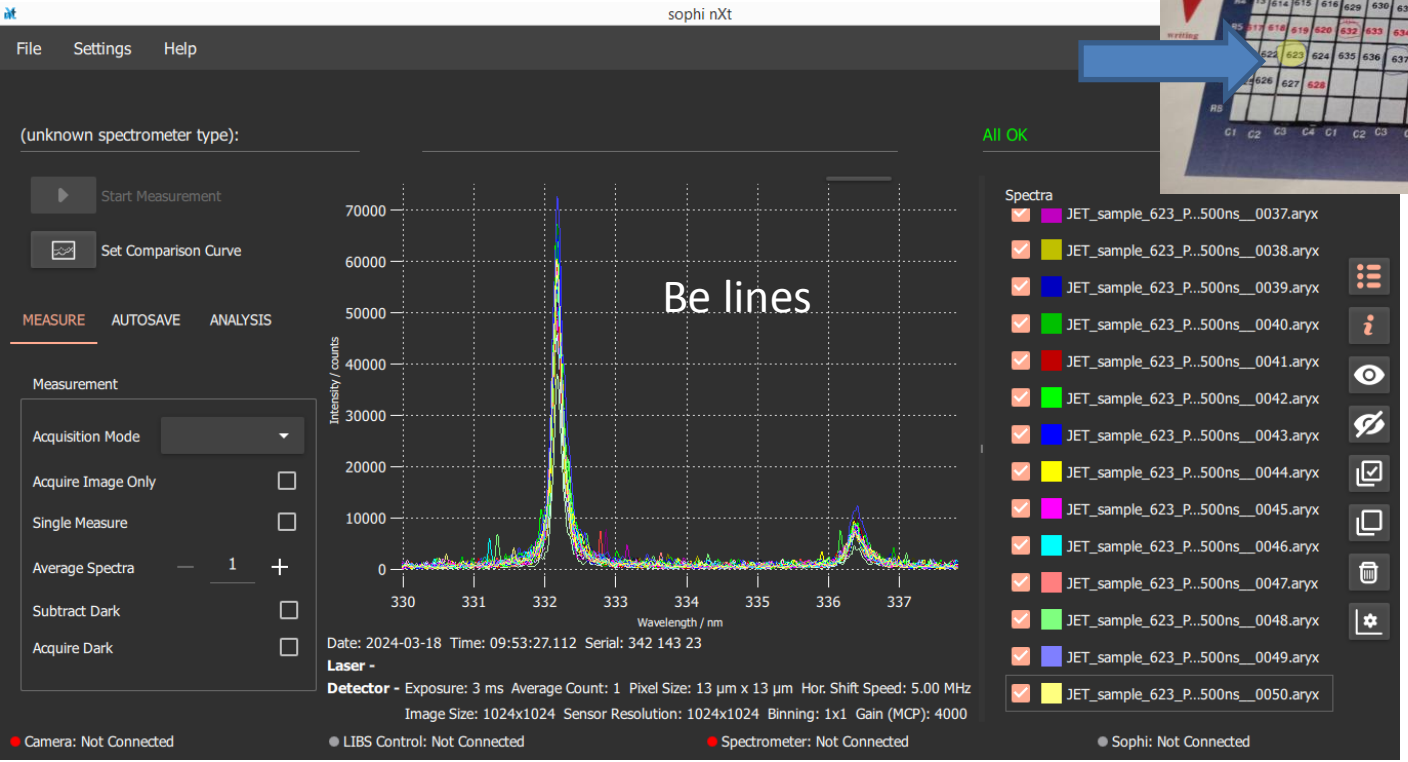
JET sample 2XR11-623



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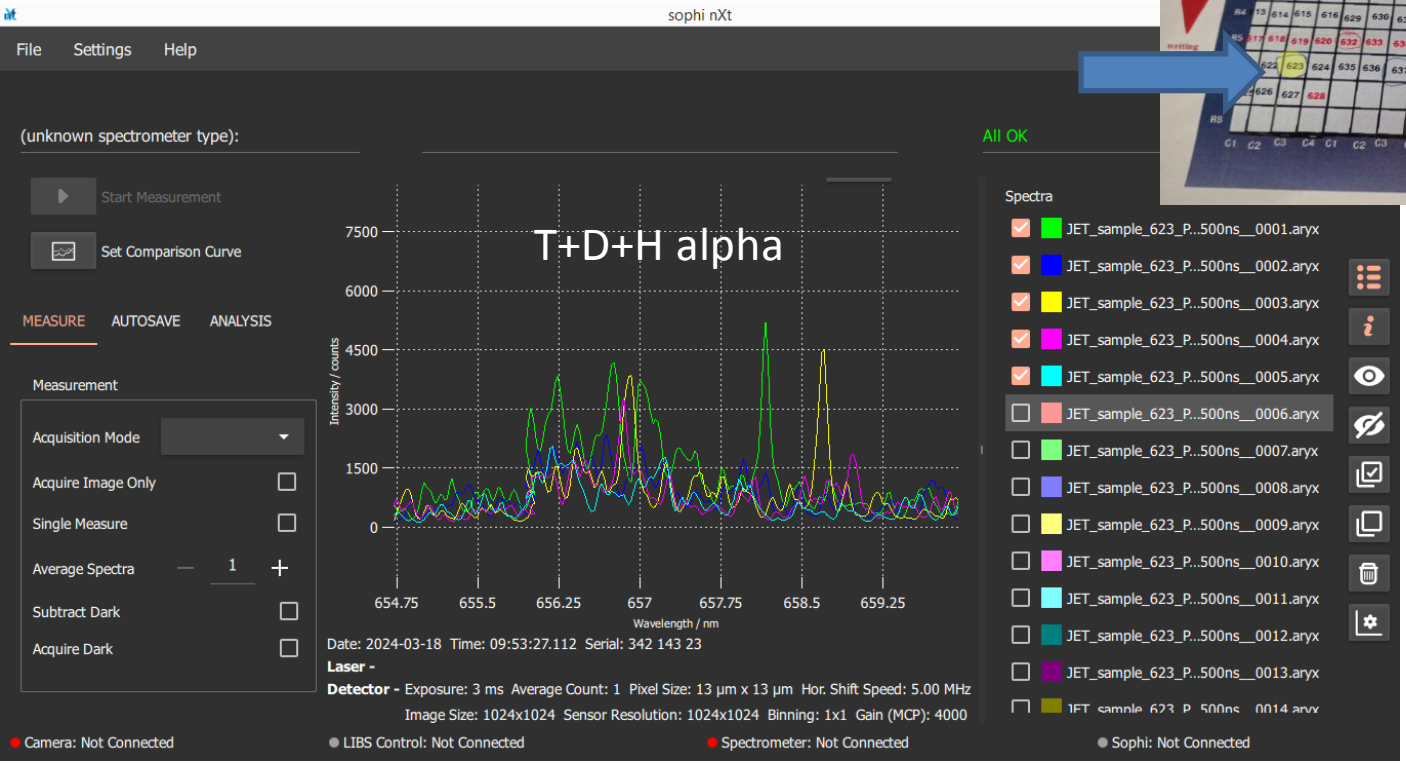
JET sample 2XR11-623



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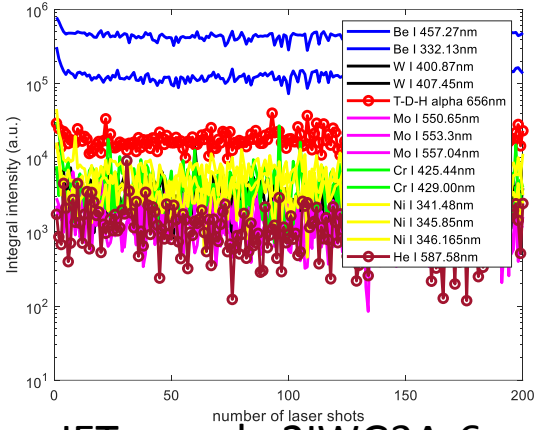
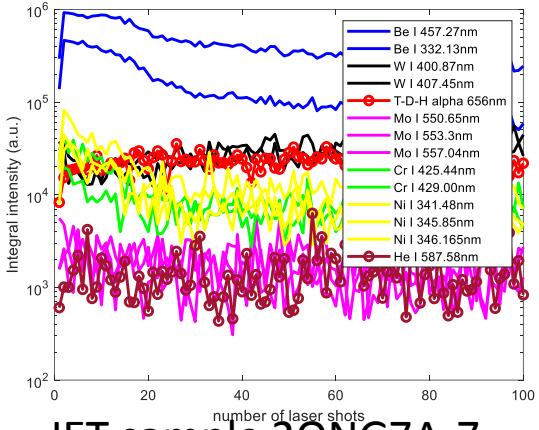
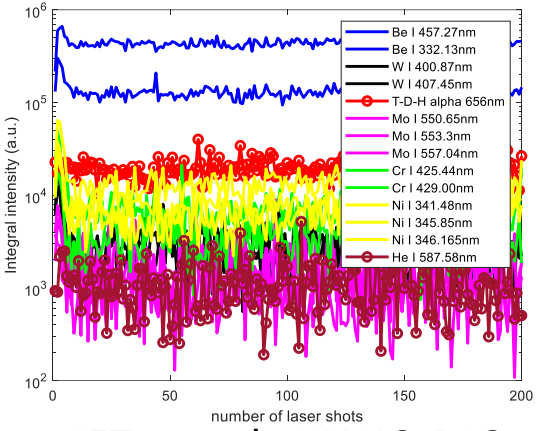
JET sample 4D15-703



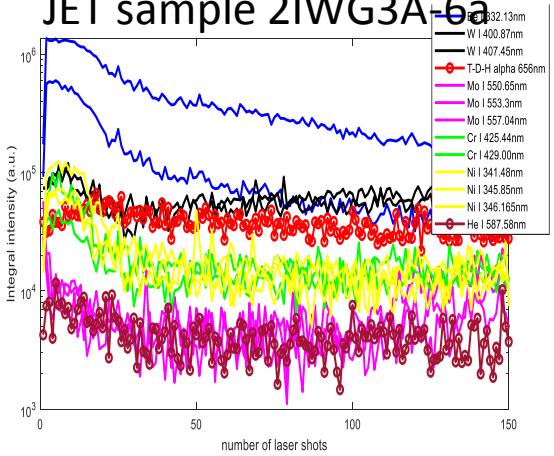
JET sample 14IWG1-A



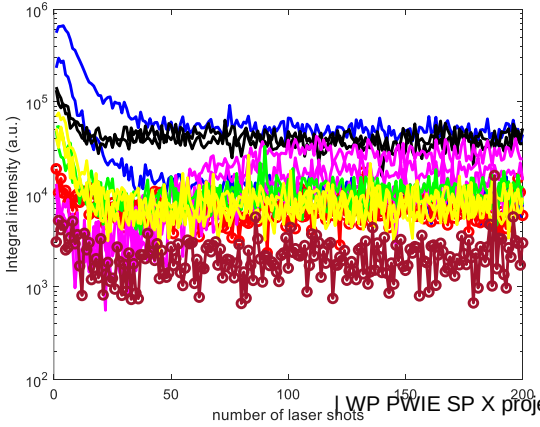
JET sample HFGC-1c



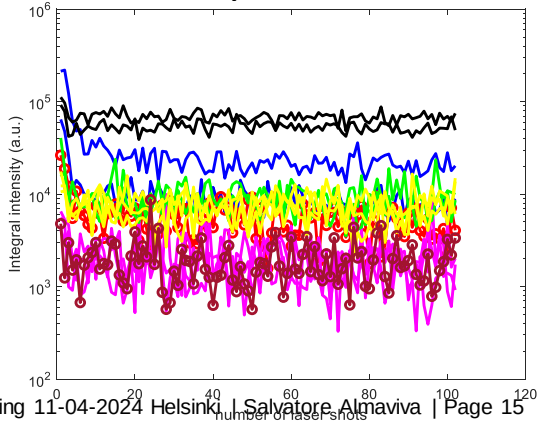
JET sample 2IWG3A-6a



JET sample 2ONG7A-7



JET sample ILW13-B12



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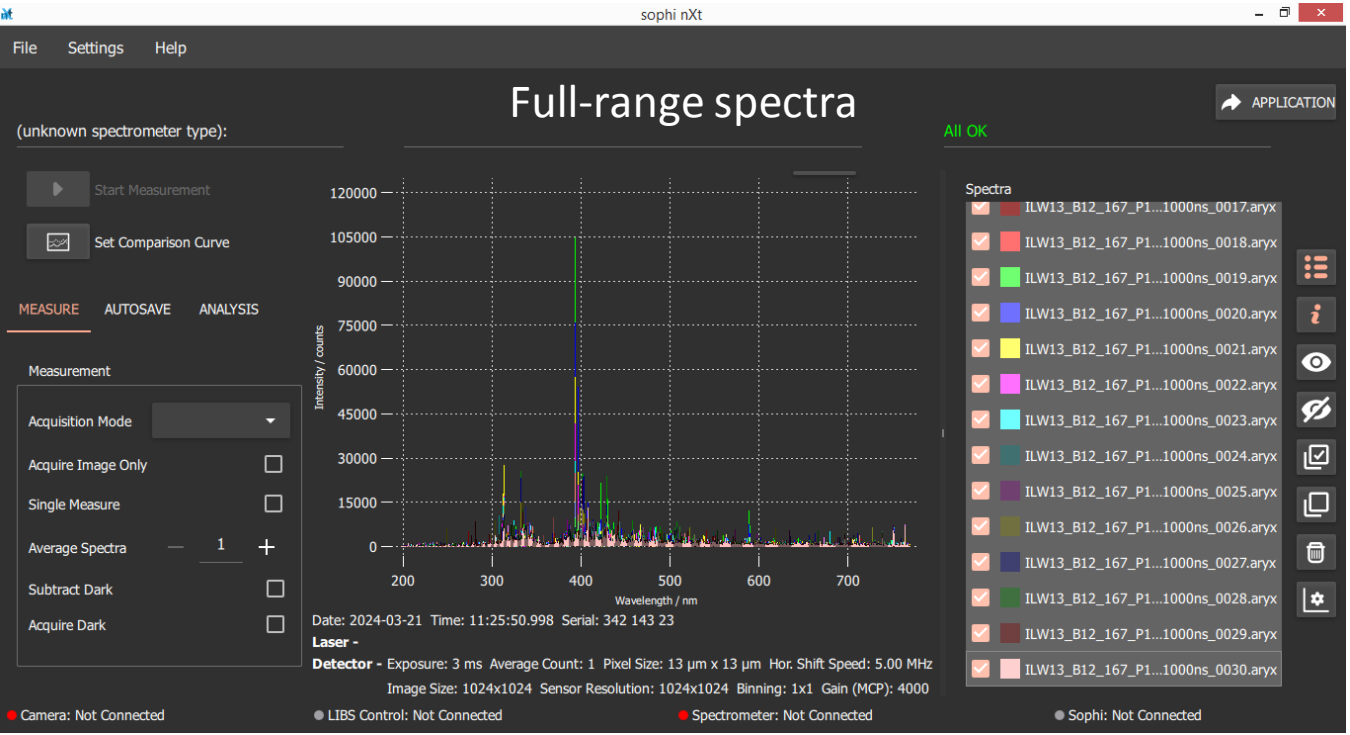
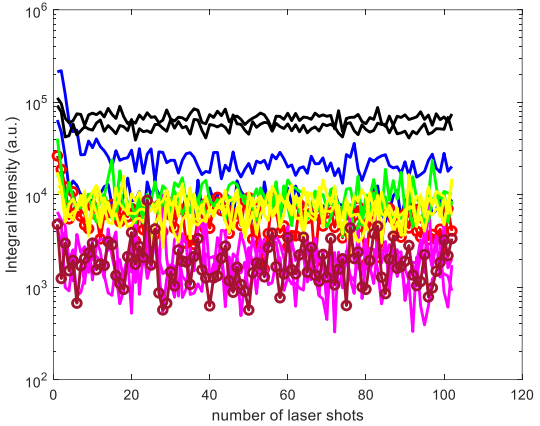


JET sample ILW13-B12



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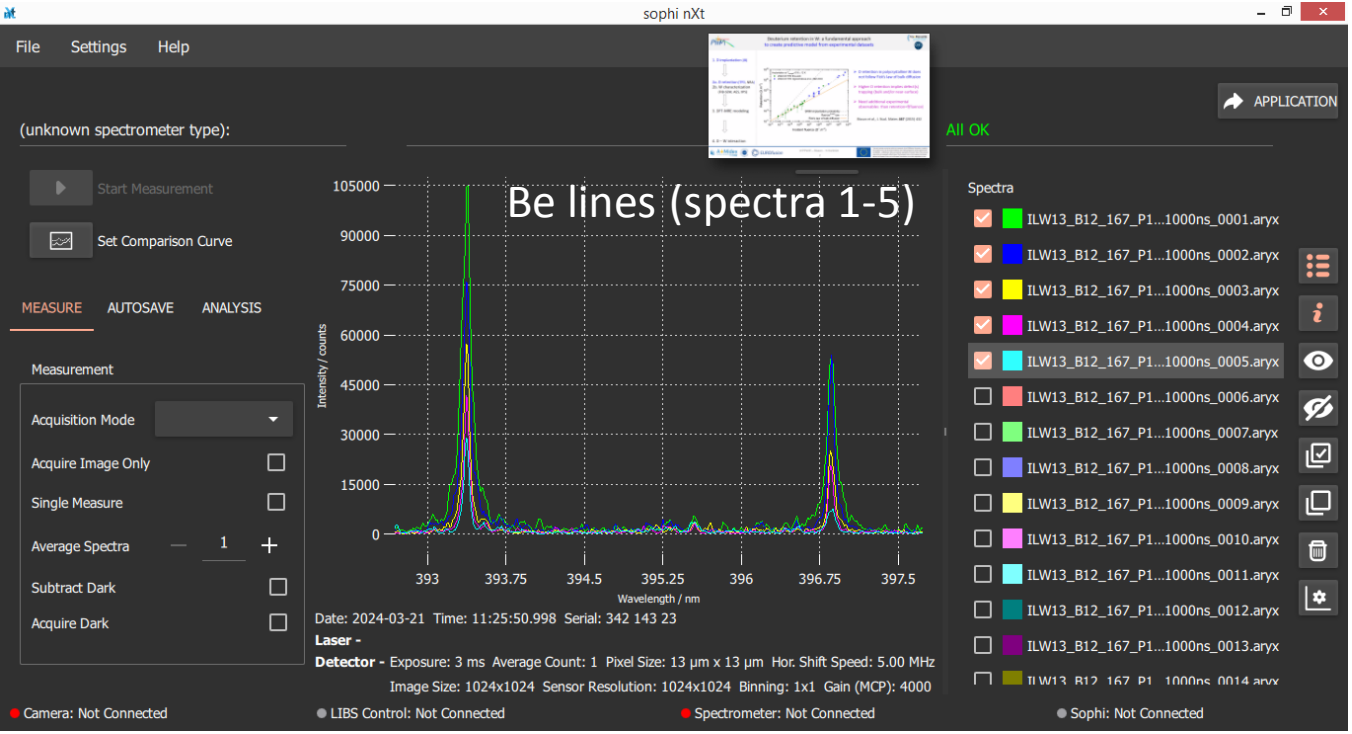
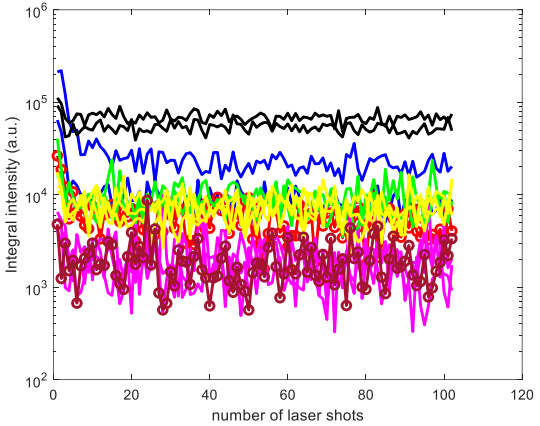
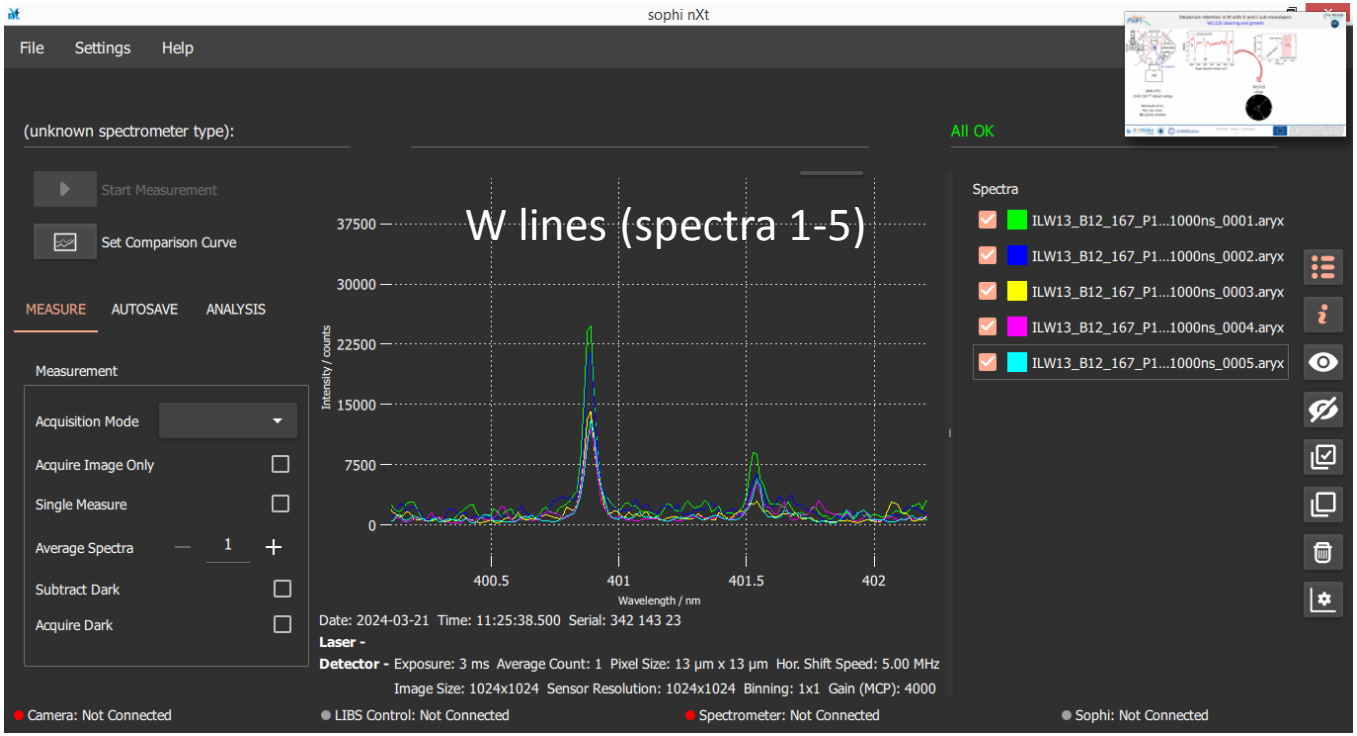


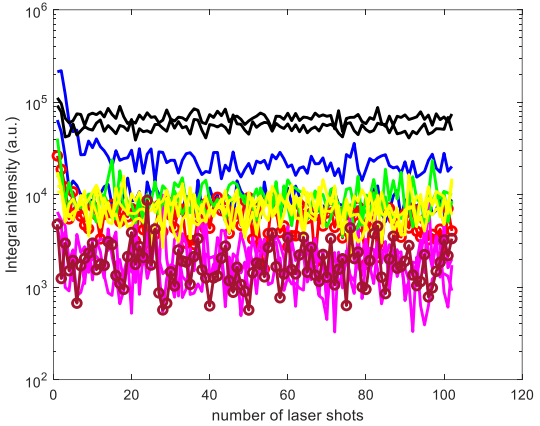
JET sample ILW13-B12



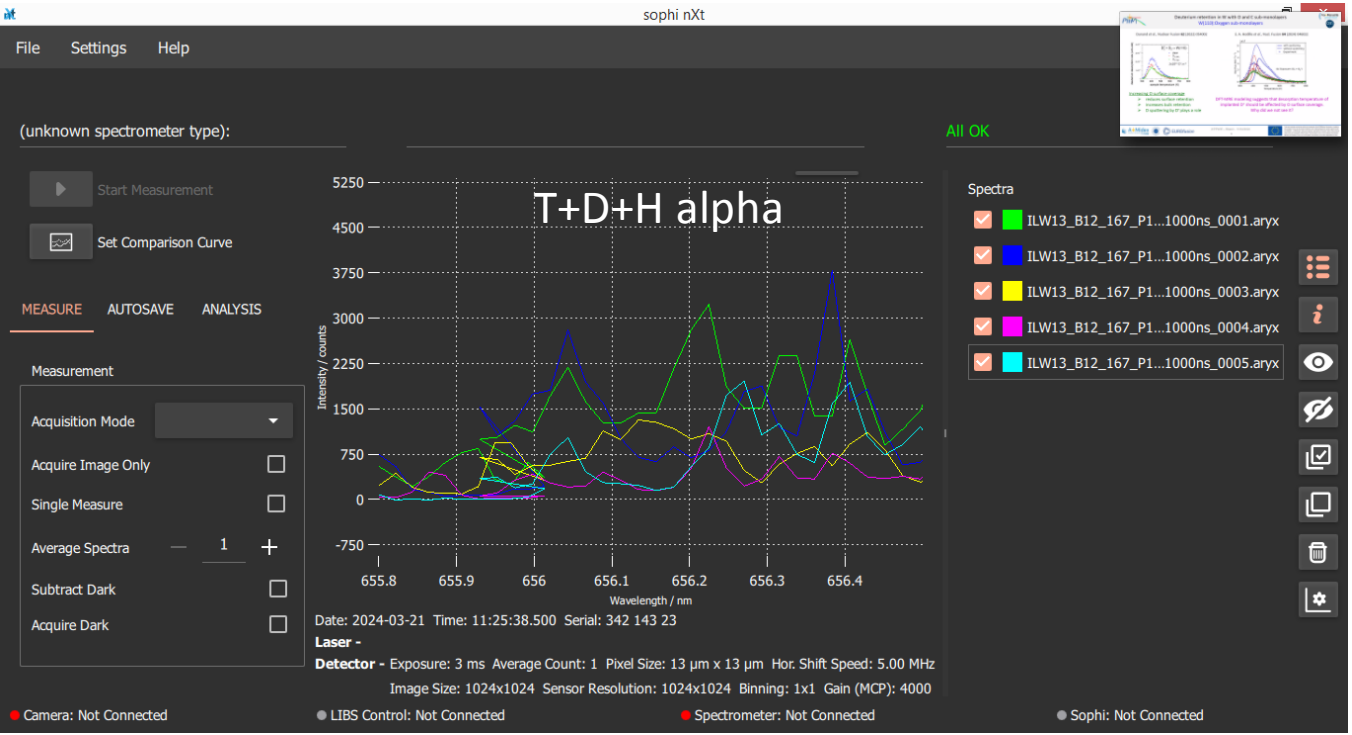
Be campaign at VTT in support of RH LIBS at JET



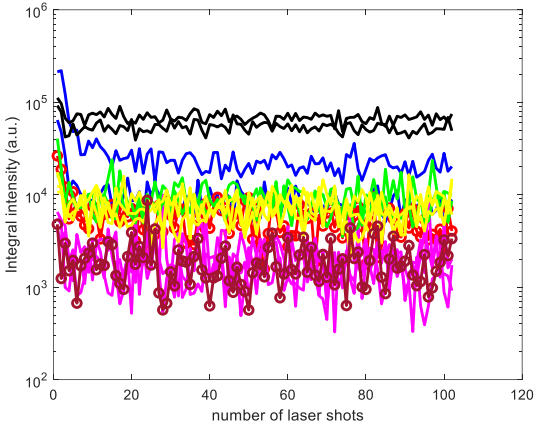
JET sample ILW13-B12



Be campaign at VTT in support of RH LIBS at JET



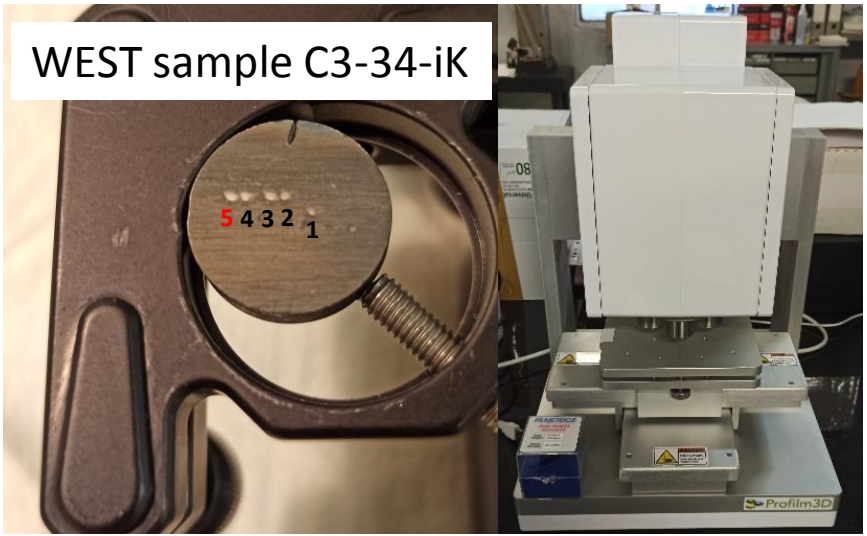
JET sample ILW13-B12



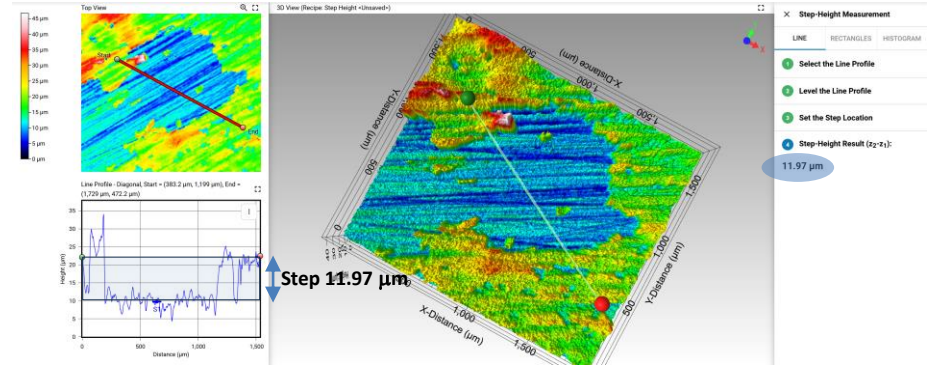
Analysis of samples with optical profilometer for depth profiling and ablation rate

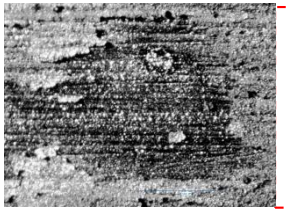
The sample has been characterized by the optical profilometer «Profilm 3d», to estimate the total depth of the LIBS spot (after 60 shots) and the average ablation rate

LIBS spot # 5



Optical profilometer image





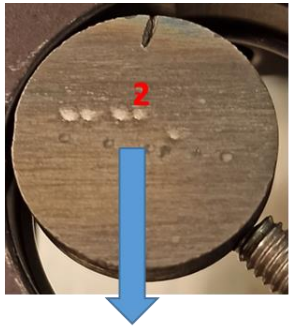
Step height ≈ 12 µm
 # LIBS shots : 53
Estimated ablation rate ≈ 225 nm x shot
Spot diameter ≈ 1 mm

Optical microscope image

LIBS measurements of WEST samples

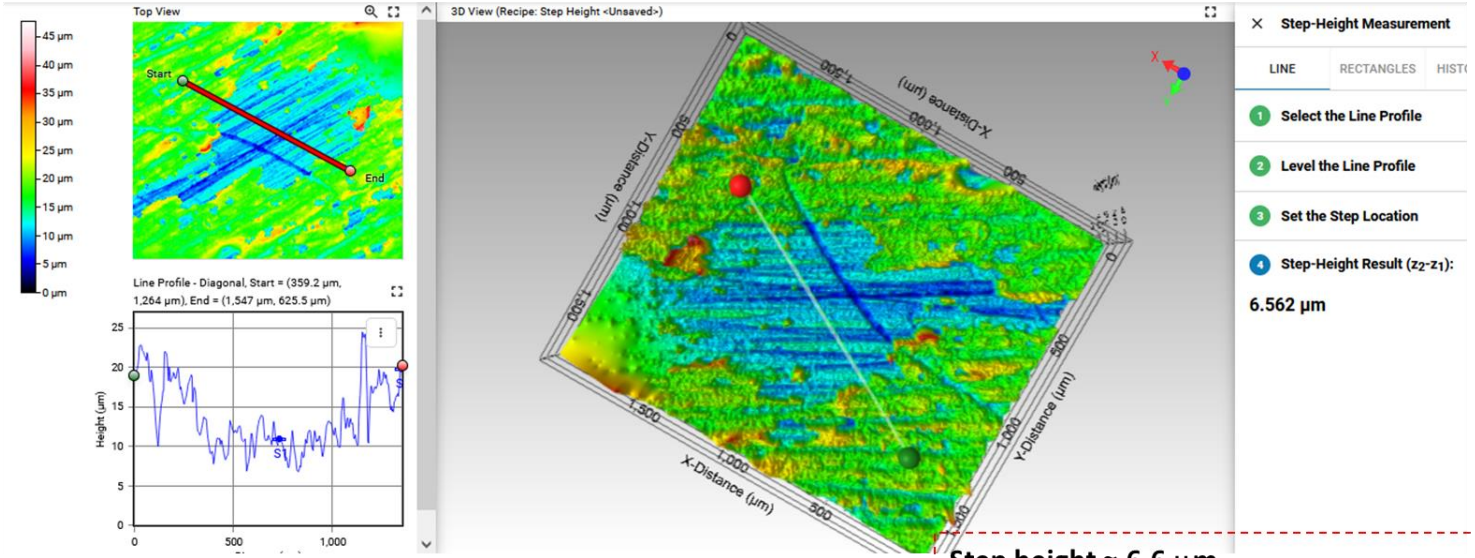
The sample has been characterized by the optical profilometer «Profilm 3d», to estimate the total depth of the LIBS spots and the average ablation rate

WEST sample C3-34-iK **LIBS spot # 2**



Optical microscope image

Optical profilometer image

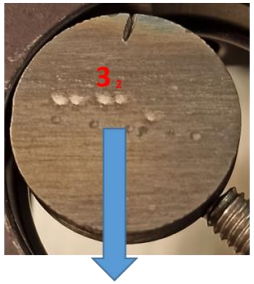


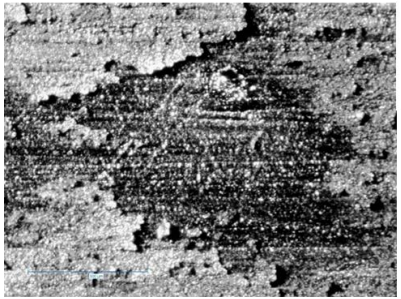
Step height ≈ 6.6 µm
 # LIBS shots : 60
Estimated ablation rate ≈ 110 nm x shot
Spot diameter ≈ 1 mm

LIBS measurements of WEST samples

The sample has been characterized by the optical profilometer «Profilm 3d», to estimate the total depth of the LIBS spots and the average ablation rate

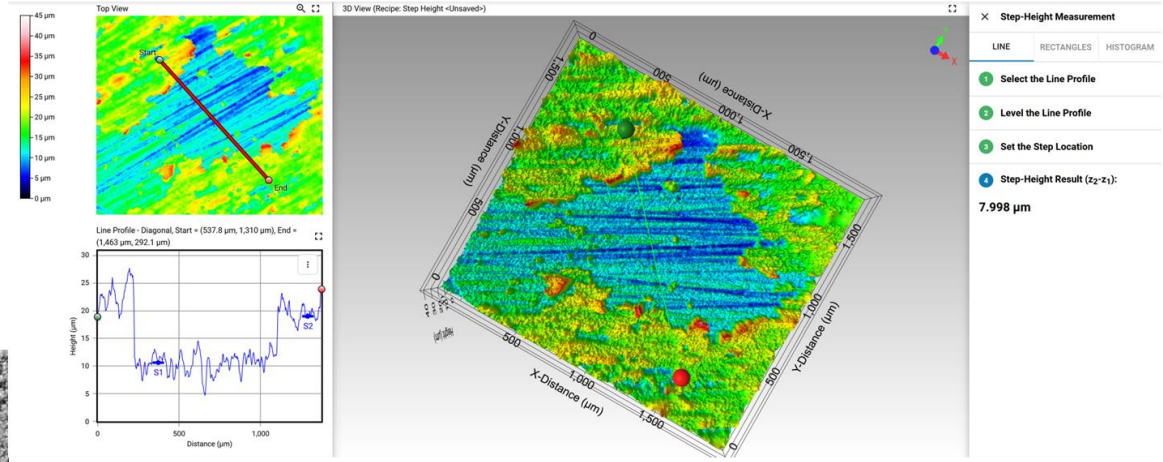
WEST sample C3-34-iK **LIBS spot # 3**





Optical microscope image

Optical profilometer image

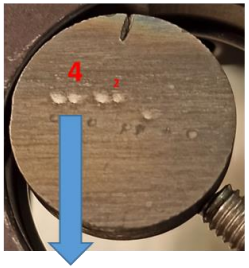


Step height ≈ 8 µm
 # LIBS shots : 52
Estimated ablation rate ≈ 154 nm x shot
Spot diameter ≈ 1 mm

LIBS measurements of WEST samples

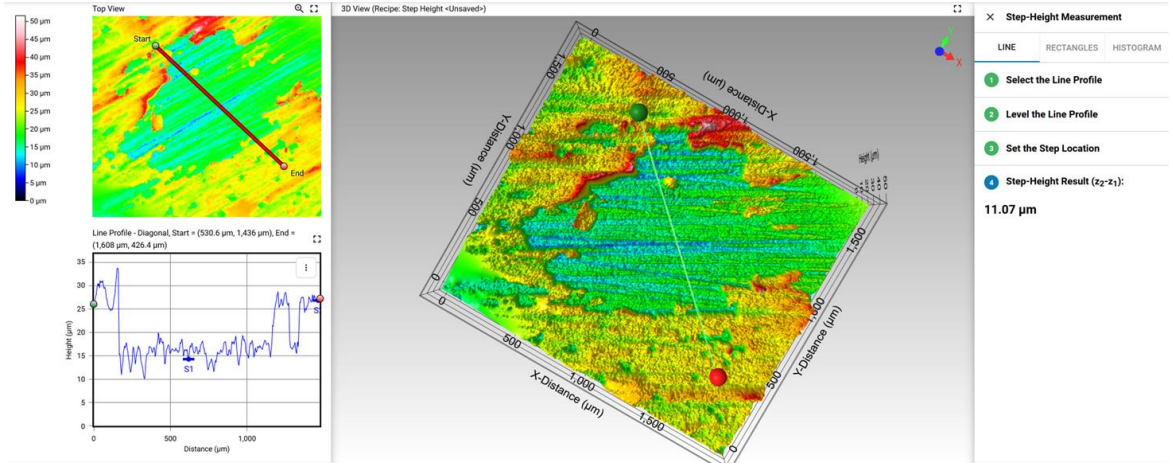
The sample has been characterized by the optical profilometer «Profilm 3d», to estimate the total depth of the LIBS spots and the average ablation rate

WEST sample C3-34-iK **LIBS spot # 4**



Optical microscope image

Optical profilometer image



Step height ≈ 11 µm
 # LIBS shots : 62
Estimated ablation rate ≈ 177 nm x shot
Spot diameter ≈ 1 mm

Conclusions

- LIBS campaigns at VTT in view of application at JET
  - The prototype set-up of the JET LIBS system was completed and tested at VTT with the full-range spectrometer foreseen for the final campaign
  - LIBS measurements of WEST, pure Mo, W, Be samples has been completed showing the peculiar emission lines of the elements with high SNR
  - We studied samples from the WEST with an optical profilometer for depth profiling and ablation ate
  - Other samples (bulk Mo, W and thin layer of BE and samples from JET) have been measured showing the emission lines of Be, W, and other elements expected to be found in the next LIBS campaign at JET with high SNR
  - We also detected the signal of the implanted or residual D(H) Hydrogen isotopes on the samples, although with a reduced SNR
  - A depth profiling data analysis of these samples is currently ongoing showing the intensity of the emission lines as a function of the applied laser shots per point