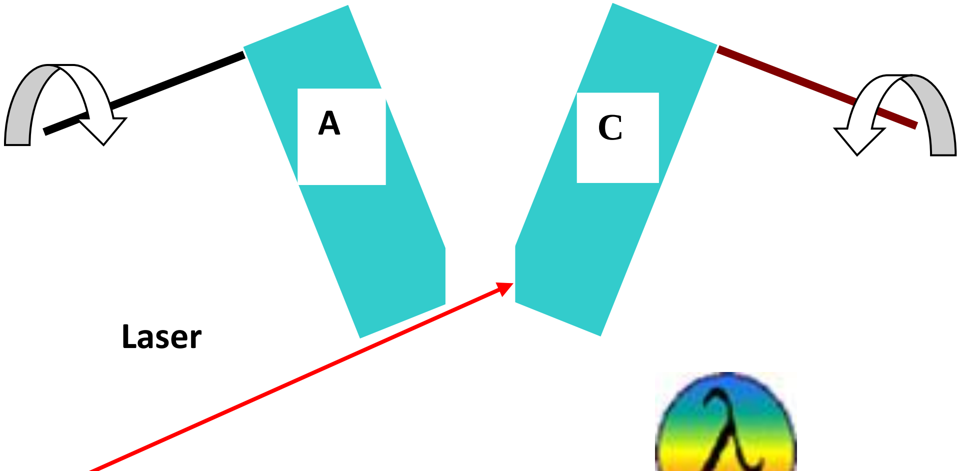
Investigation and optimisation of spatial and spectral characteristics of EUV emission from Laser Assisted Vacuum Arc

Larissa Juschkin, Isaac Tobin, Yuri Sidelnikov, Fergal O'Reilly, Imam Kambali, Emilien Foiret, Paul Sheridan, Emma Sokel, James G. Lunney

Laser Assisted Vacuum Arc (LAVA-lamp)



ISAN, Troitsk

High-current discharge between two rotating electrodes covered with a thin liquid Tin or Galinstan film is triggered by local laser ablation of electrode material.

Discharge

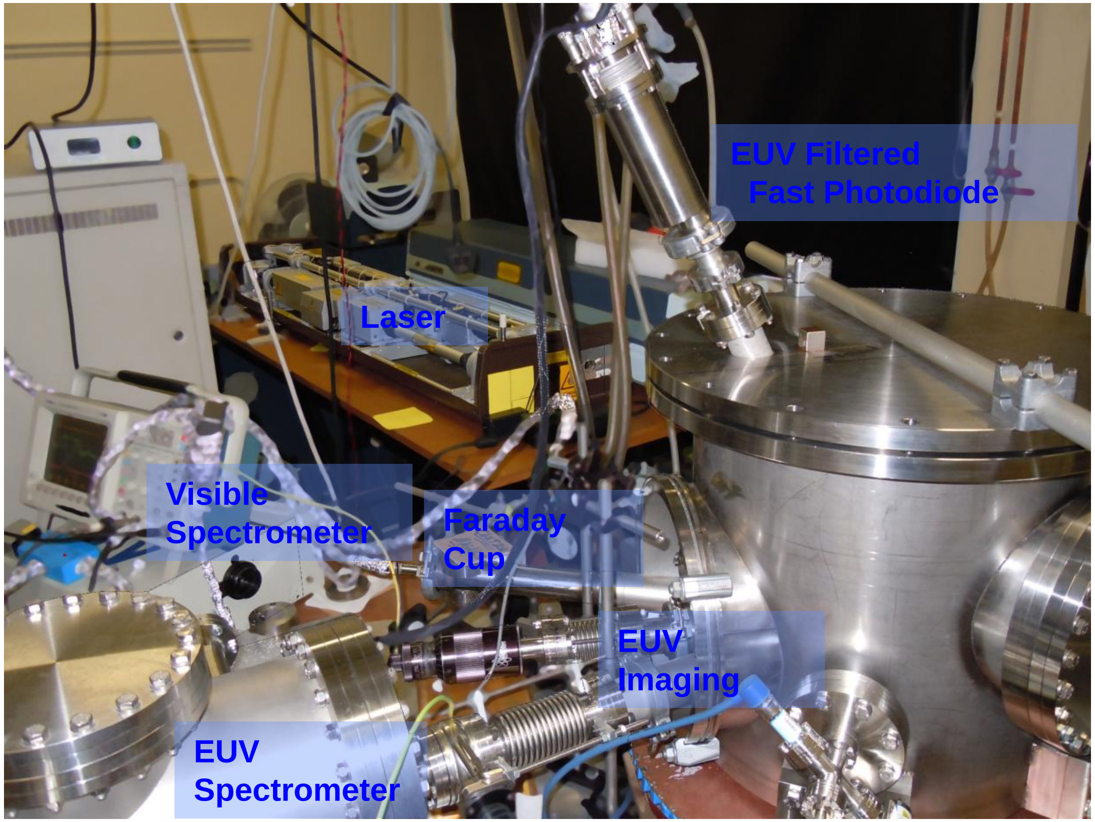
capacitance	0.4 μF
inductance	19 nH
voltages	3 – 6 kV
energies	1.8 – 7.2 J
current	20 kA at 4.5 kV

Trigger laser:

wavelength	1064 nm
beam diameter	3 mm
focal lens	30 cm
energy	5 – 50 mJ

(varied by means of rotatable half-wave plate and polarizing beam splitter)

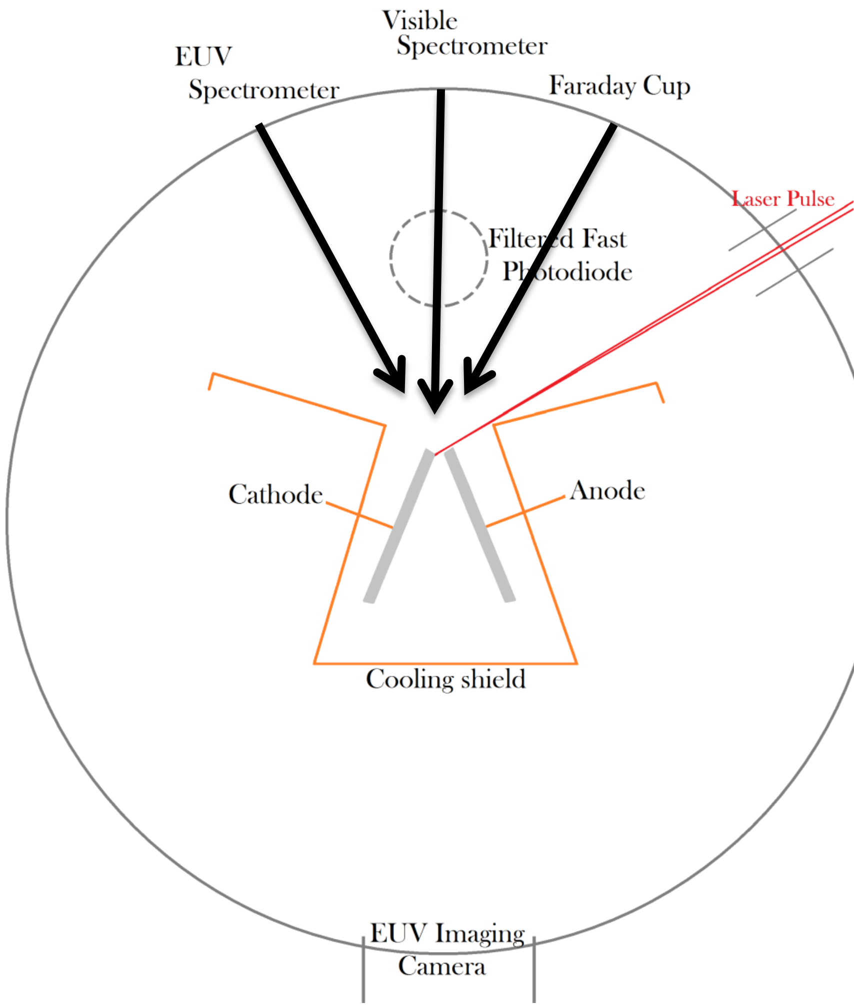
Experimental Setup



Diagnostic techniques

- absolutely calibrated time integrated EUV spectroscopy
- 2 µm spatially resolved time integrated in-band EUV imaging
- time resolved in-band filtered fast EUV photodiode
- time- and spatially-resolved fast gated visible emission spectroscopy
- time of flight diagnostic of ions with a Faraday cup
- Rogowski coil characterisation of discharge current

Experimental Setup



Diagnostic techniques

- **absolutely calibrated time integrated EUV spectroscopy**
- **2 µm spatially resolved time integrated in-band EUV imaging**
- **time resolved in-band filtered fast EUV photodiode**
- **time- and spatially-resolved fast gated visible emission spectroscopy**
- **time of flight diagnostic of ions with a Faraday cup**
- **Rogowski coil characterisation of discharge current**

EUV imaging layout

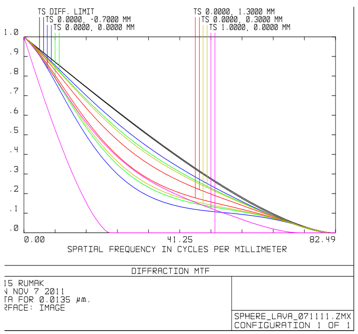
EUV CCD Zr filter, 1 µm

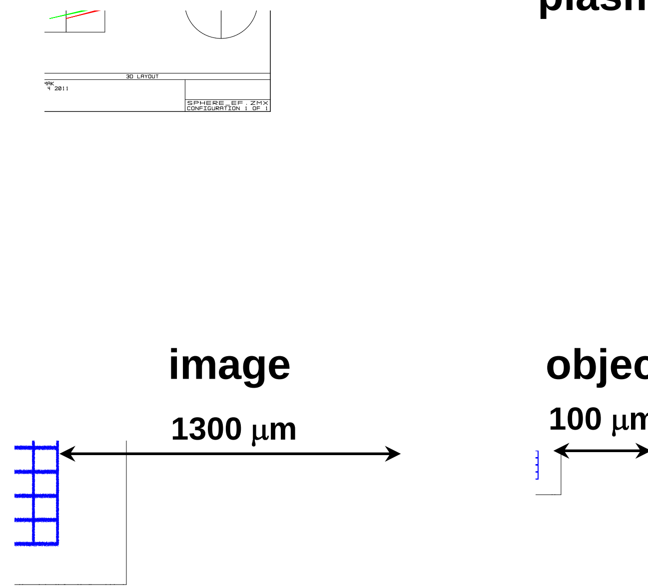
distance detector - plasma 1600 mm

apertures & spherical ML-mirror

plasma

MTF on detector





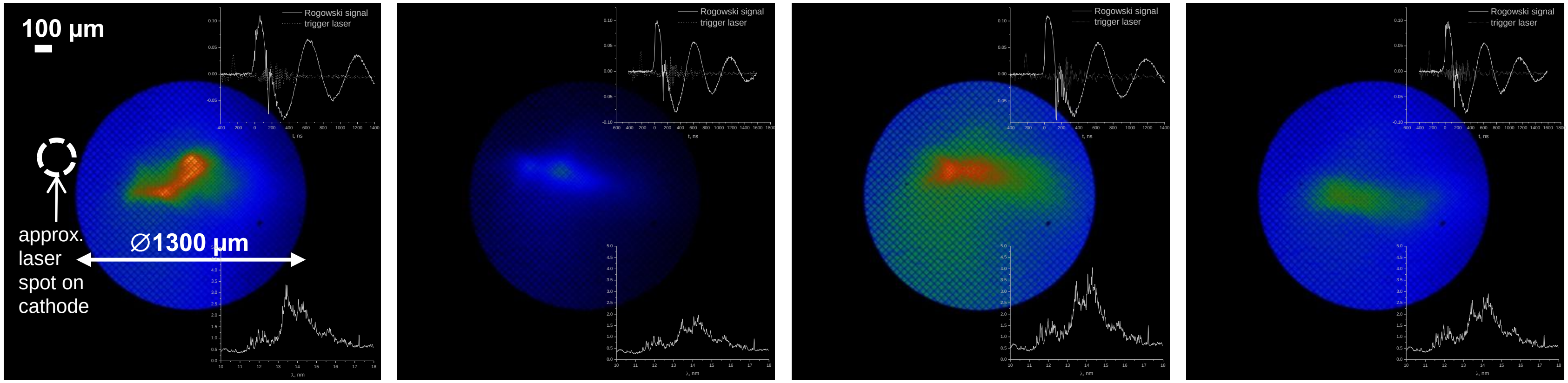
M=13

1 CCD pixel – ~1 µm

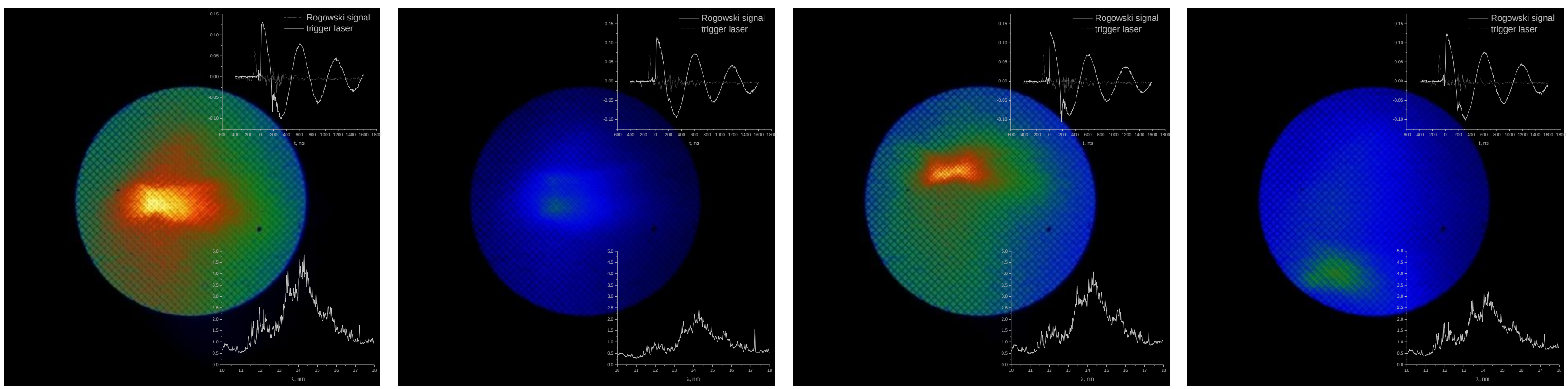
Resolution ~ 5 µm (focusing limited)

EUV imaging of plasma pinch for 2 different laser energies

4 J (4.5 kV), trigger laser 5 mJ, color scale (min – max): 5000 - 35000 counts



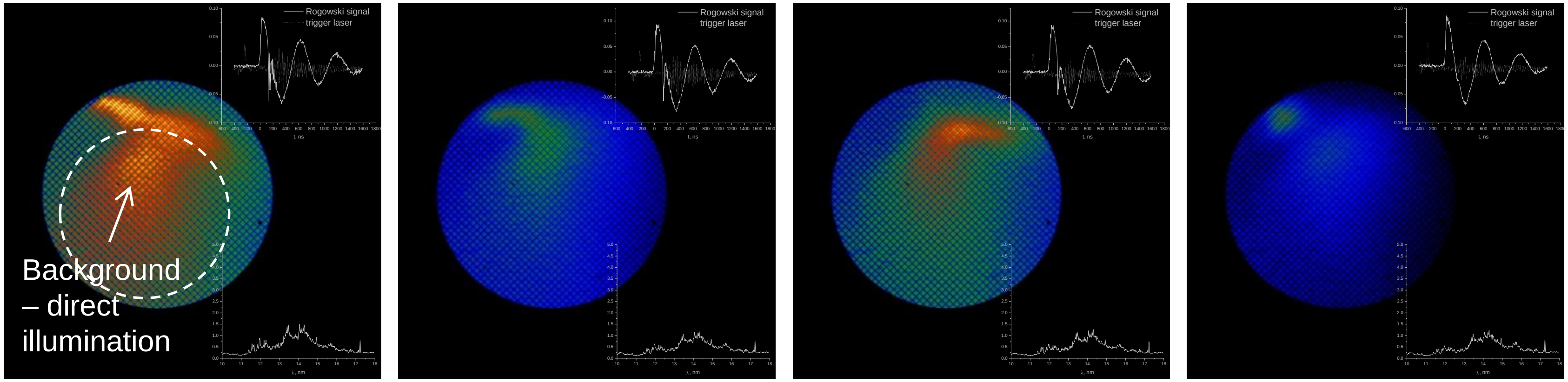
4 J (4.5 kV), trigger laser 40 mJ, color scale (min – max): 5000 - 35000 counts



EUV imaging of plasma pinch for a range of discharge energies

Laser energy = 5 mJ

3.2 J (4 kV), color scale (min – max): 2500 - 10000 counts

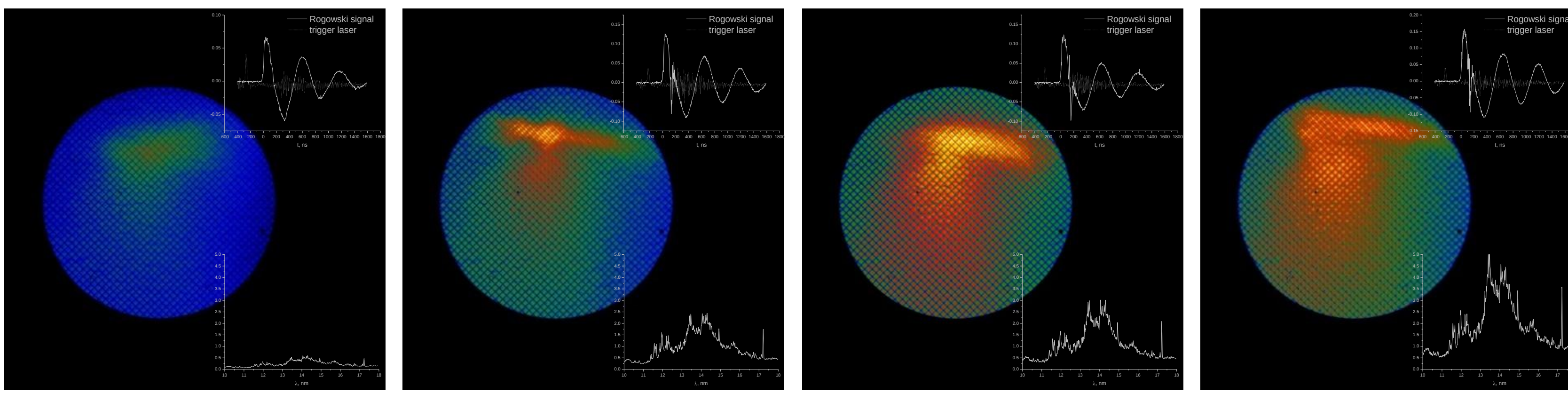


1.8 J (3 kV)
1250 - 5000 cts

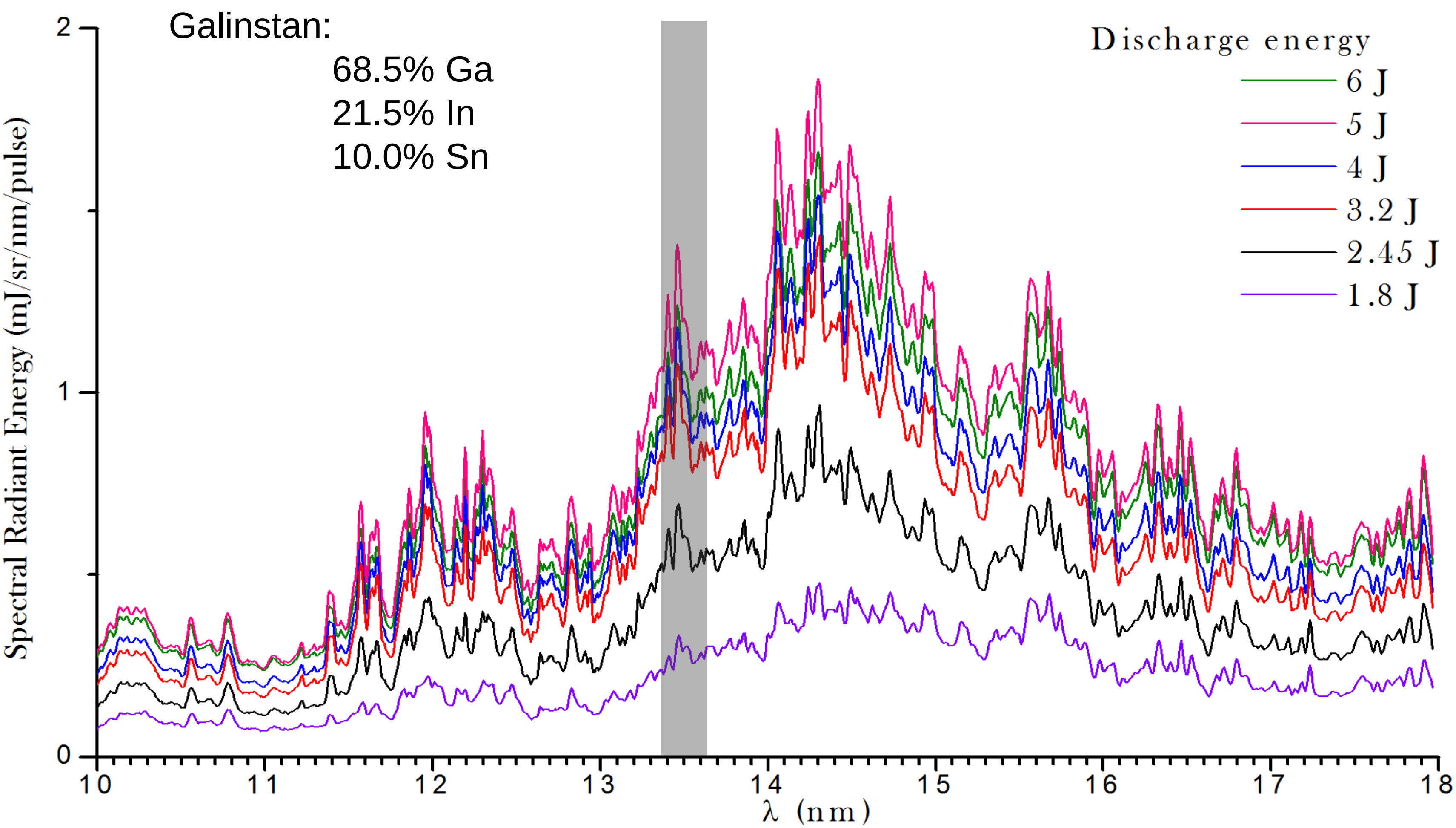
5 J (5 kV)
5000 - 20000 cts

6 J (5.5 kV)
5000 - 20000 cts

7,2 J (6 kV)
7500 - 30000 cts

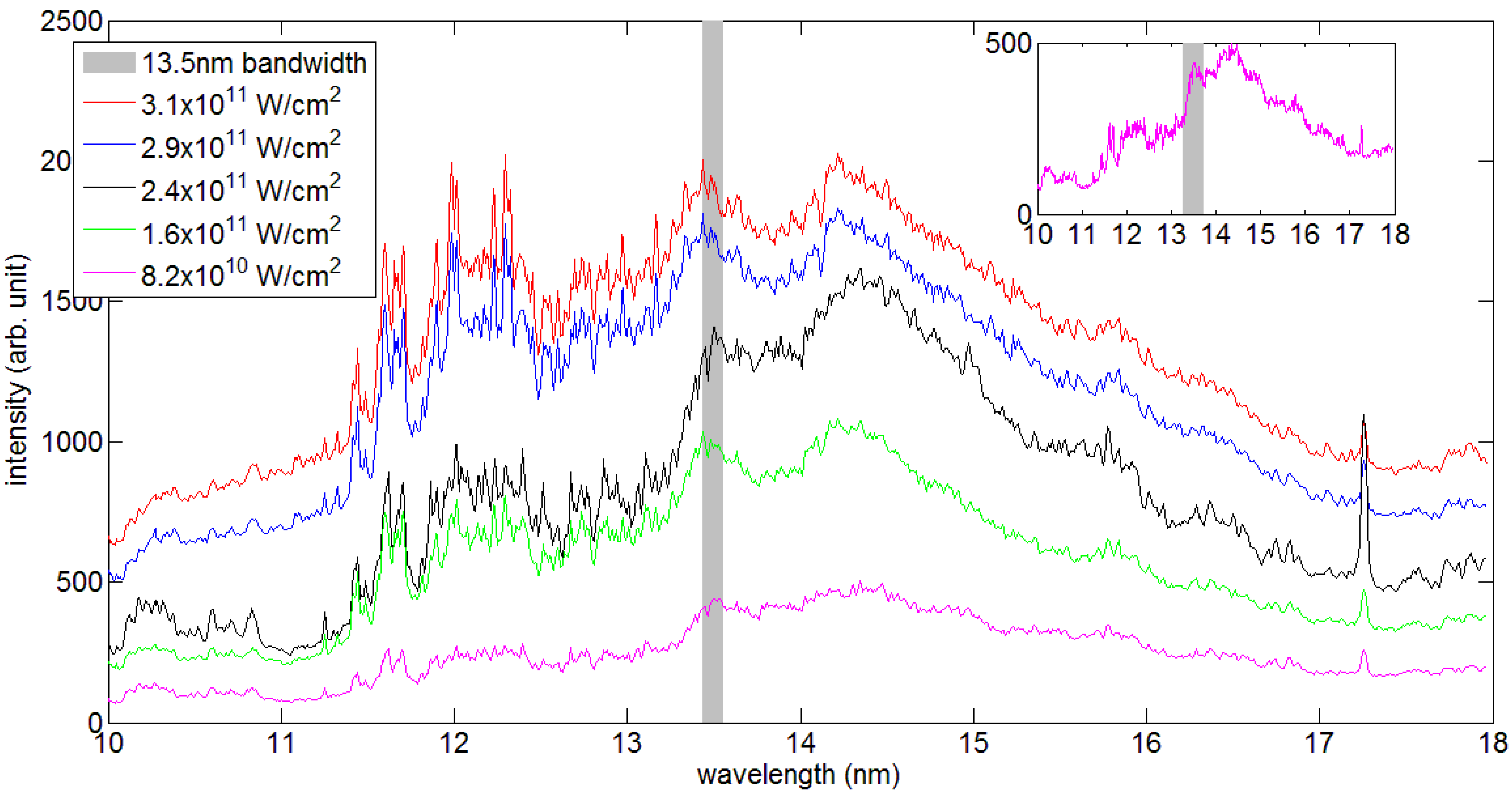


EUV spectra for various discharge energies: Galinstan



Comparison to LPP spectra

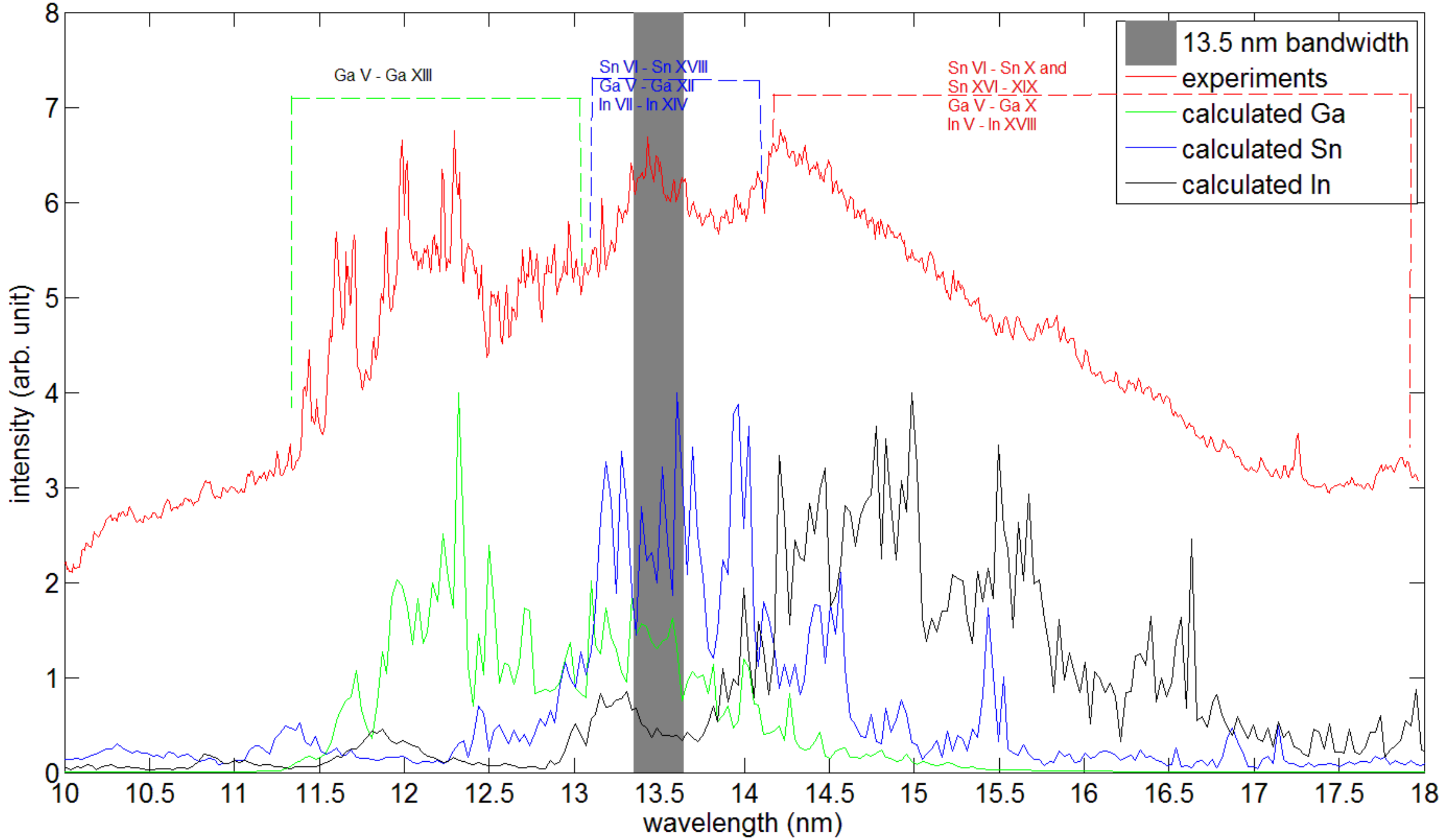
Courtesy of Imam Kambali, UCD



Dr. Larissa Juschkin
COST MP0601 Workshop
Paris, November 16 – 18, 2011

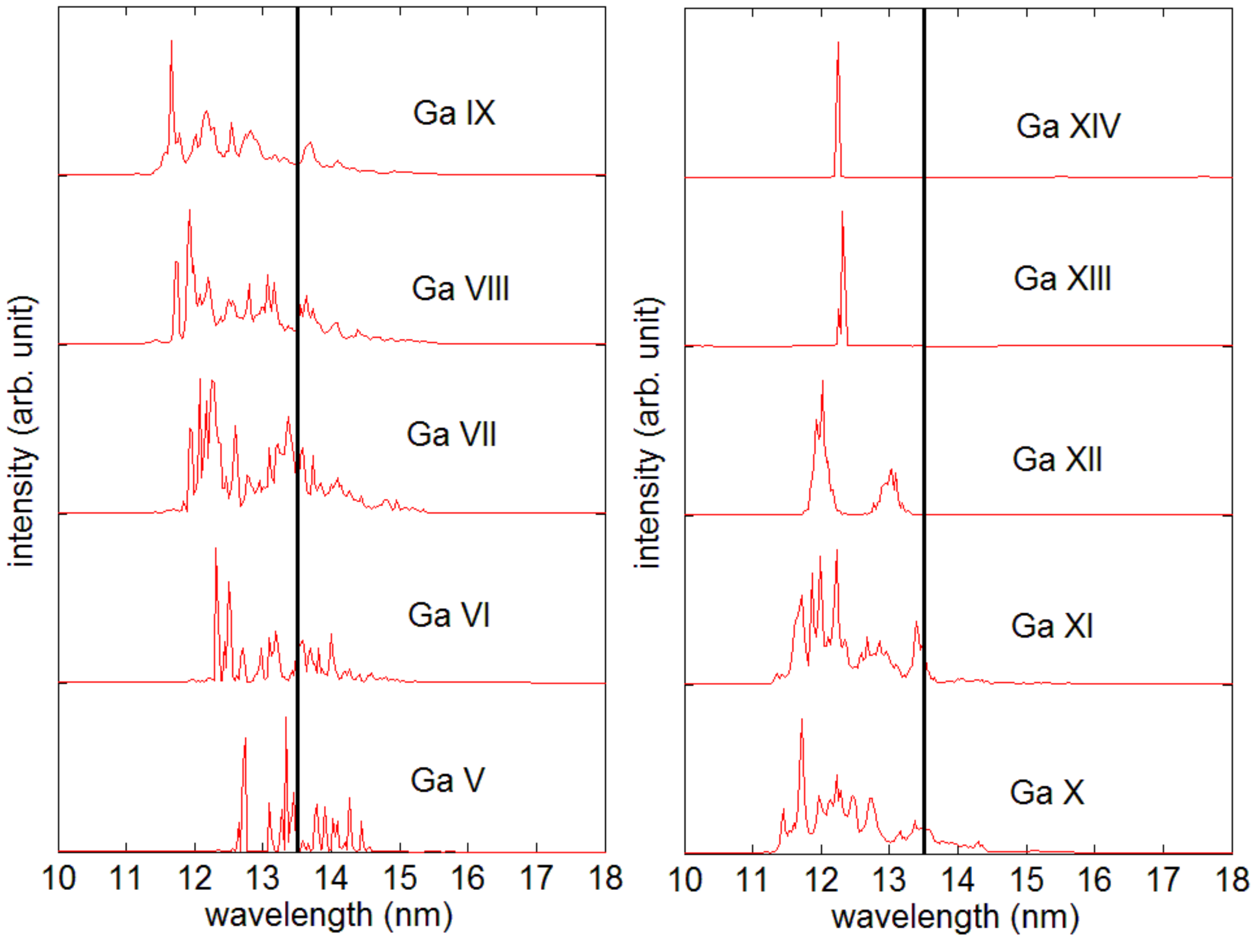
Comparison to LPP spectra and calculations

Courtesy of Imam Kambali, UCD



Calculated Ga spectra, Cowan code

Courtesy of Imam Kambali, UCD

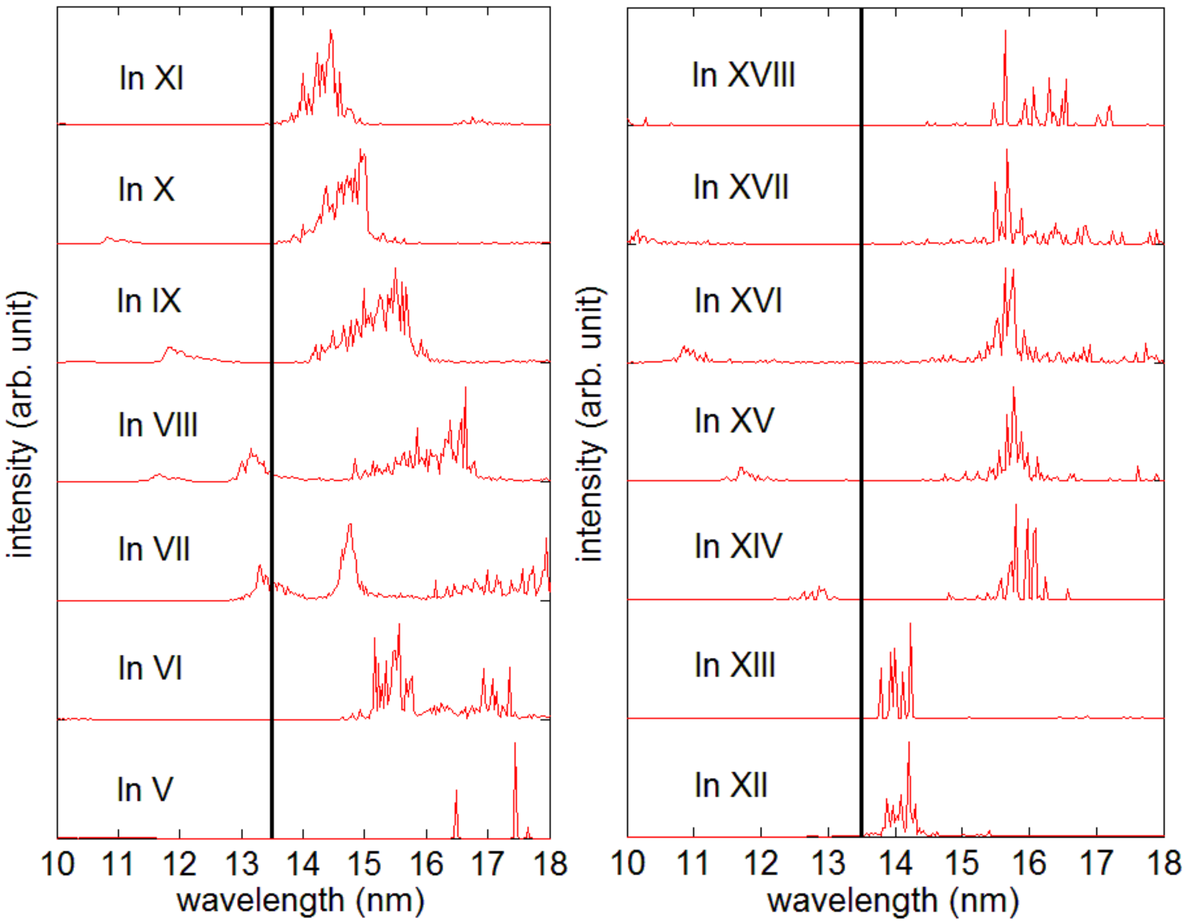


Oscillator strengths convolved with Gaussian broadening of 0.01 nm (spectrograph's resolution)

Investigated transitions:
resonance
$3p^6 3d^N - 3p^5 3d^{N+1}$
$+ 3p^6 3d^{N-1} 4p$
$+ 3p^6 3d^{N-1} 4f$
$+ 3p^6 3d^{N-1} 5p$
$+ 3p^6 3d^{N-1} 5f$

Calculated In spectra, Cowan code

Courtesy of Imam Kambali, UCD

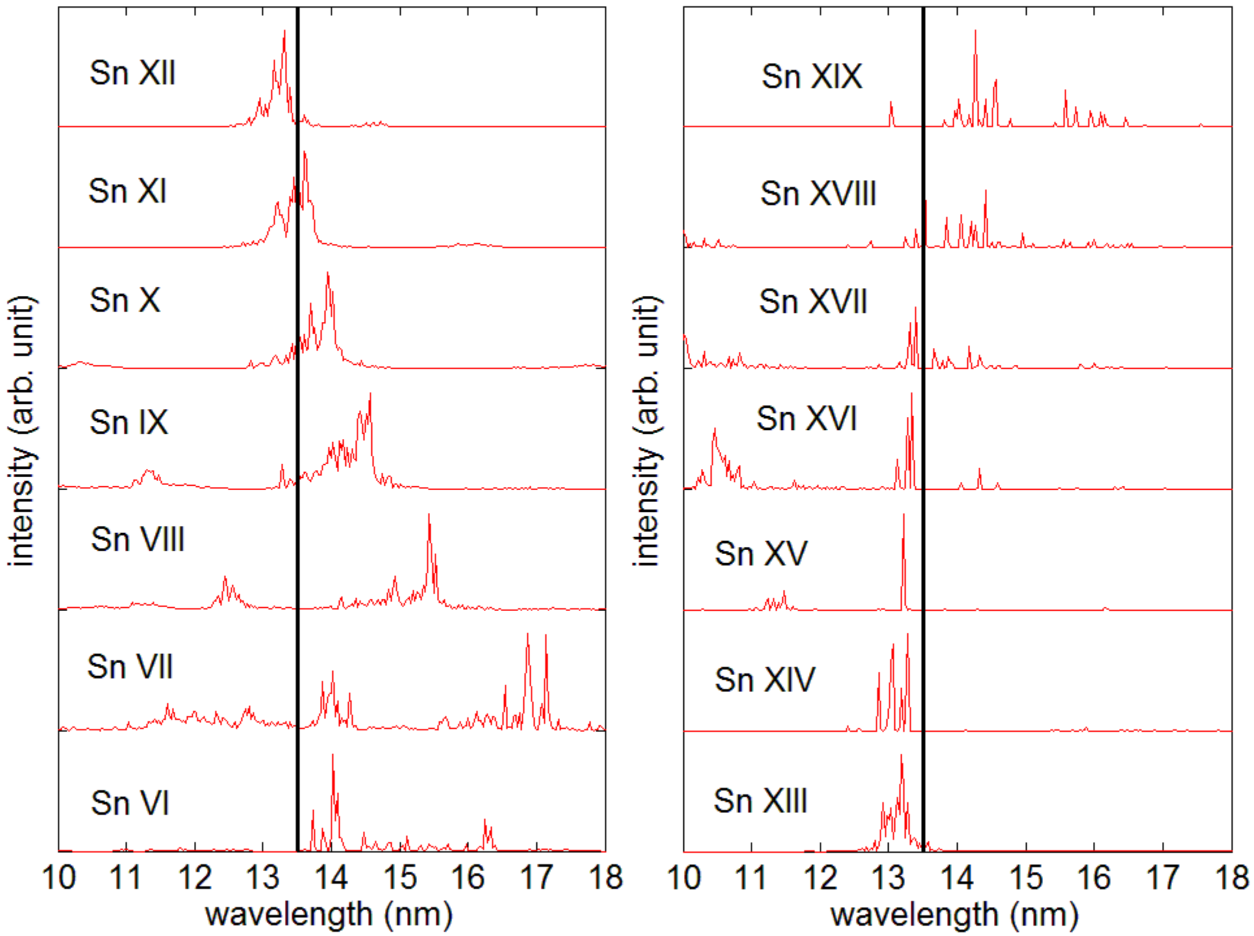


Oscillator strengths convolved with Gaussian broadening of 0.01 nm (spectrograph's resolution)

Investigated transitions:
resonance
$4p^64d^N - 4p^54d^{N+1}$
$+ 4p^64d^{N-1}4f$
$+ 4p^64d^{N-1}5p$
$+ 4p^64d^{N-1}5f$
$+ 4p^64d^{N-1}6p$

Calculated Sn spectra, Cowan code

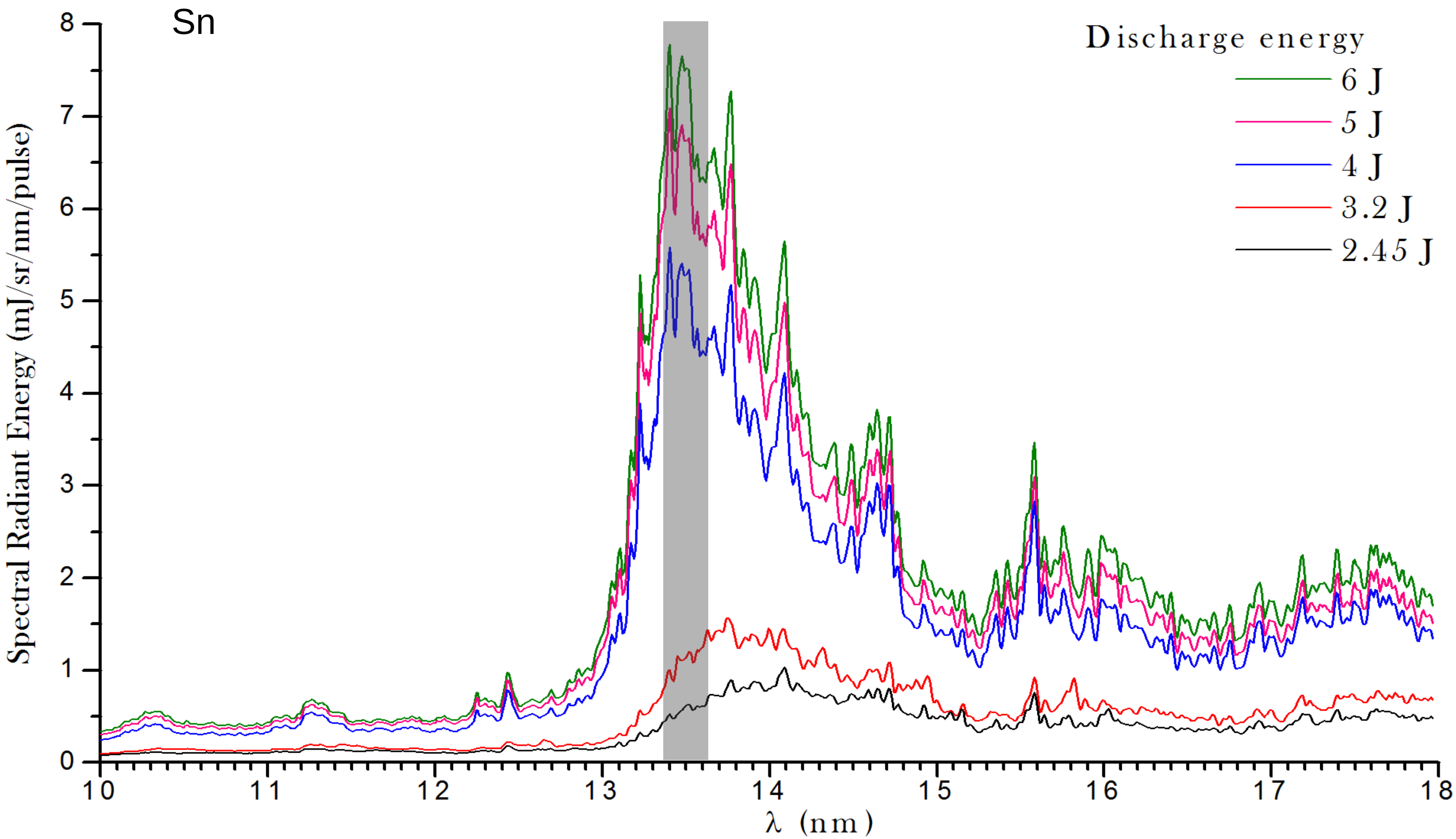
Courtesy of Imam Kambali, UCD



Oscillator strengths convolved with Gaussian broadening of 0.01 nm (spectrograph's resolution)

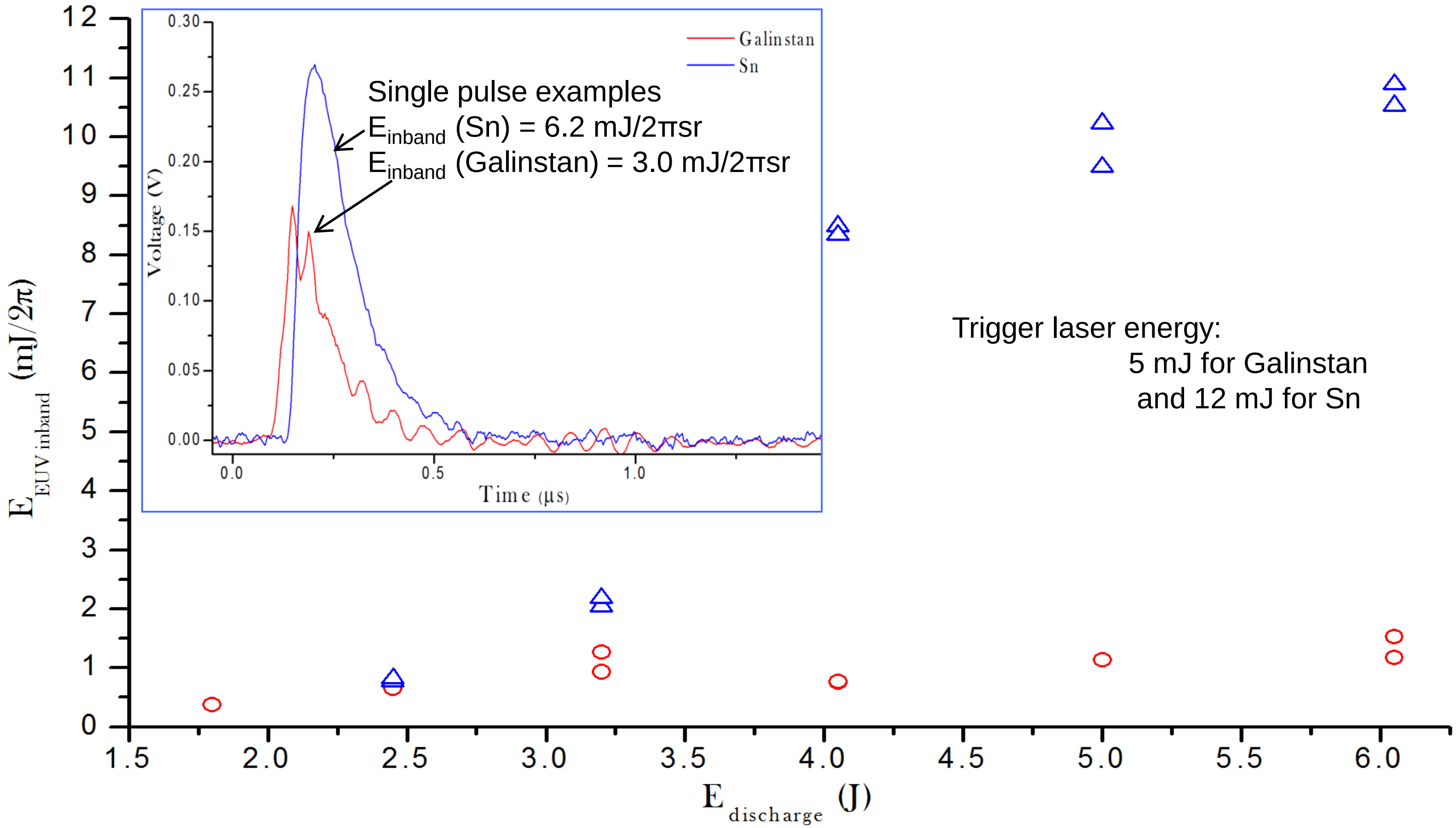
Investigated transitions: 4p-4d, 4d-4f and 4d-5p (similar to In resonance)

EUV spectra for various discharge energies: Tin



Inband EUV output in 2πsr for Galinstan and Tin

Average of 32 signals for in-band EUV energy depending on discharge energy

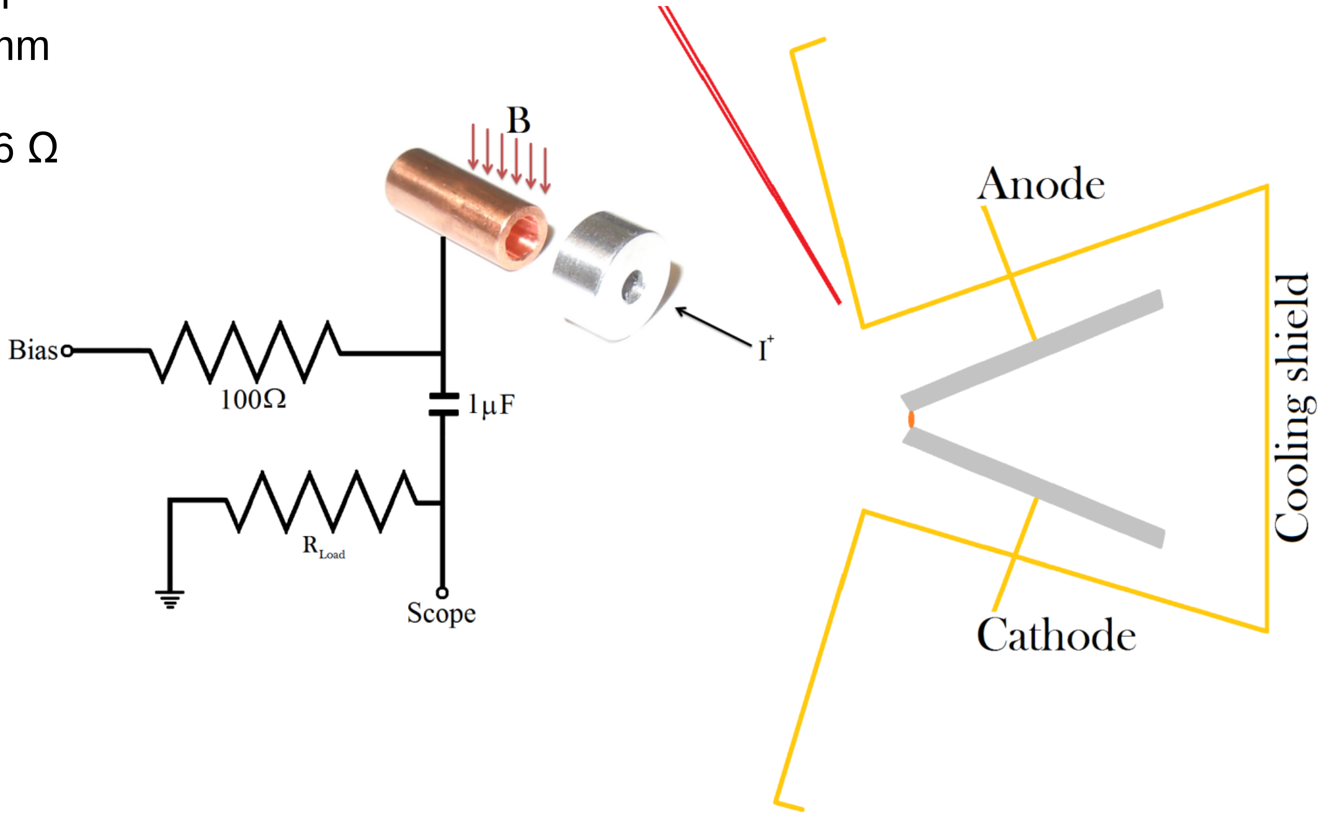


Dr. Larissa Juschkin
COST MP0601 Workshop
Paris, November 16 – 18, 2011

Speclab

Faraday cup

distance to mouth of cup = 45 cm
magnetic field across cup ~ 75 mT
aperture = 2.7 mm
cup mouth = 3.9 mm
bias = - 25 V
R_{load} = 296 Ω / 996 Ω

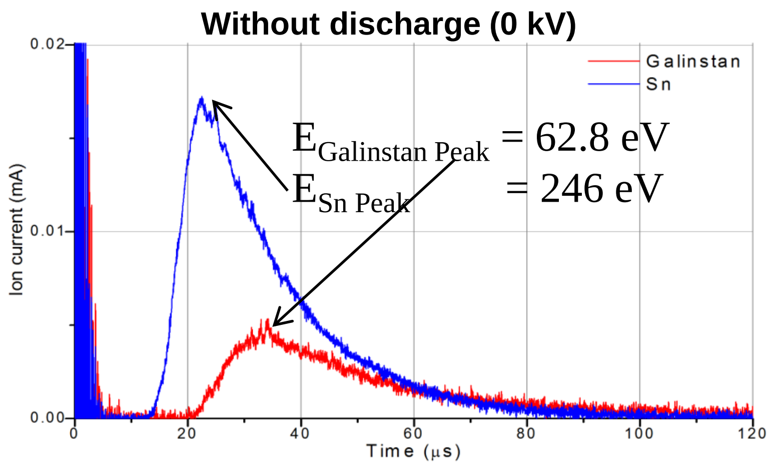


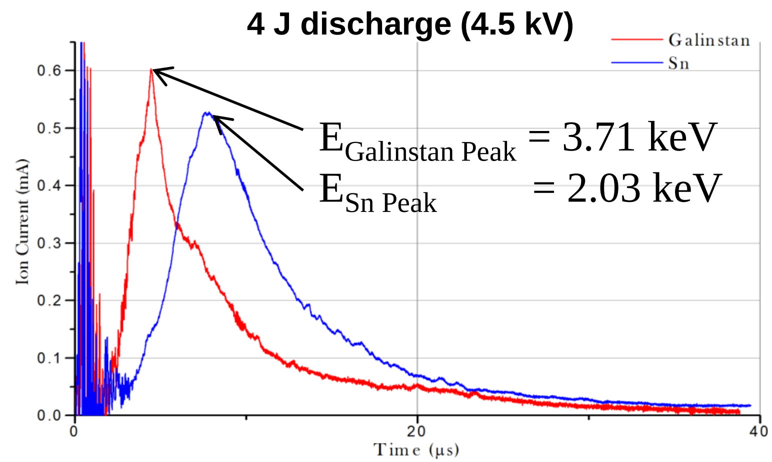
Dr. Larissa Juschkin
COST MP0601 Workshop
Paris, November 16 – 18, 2011

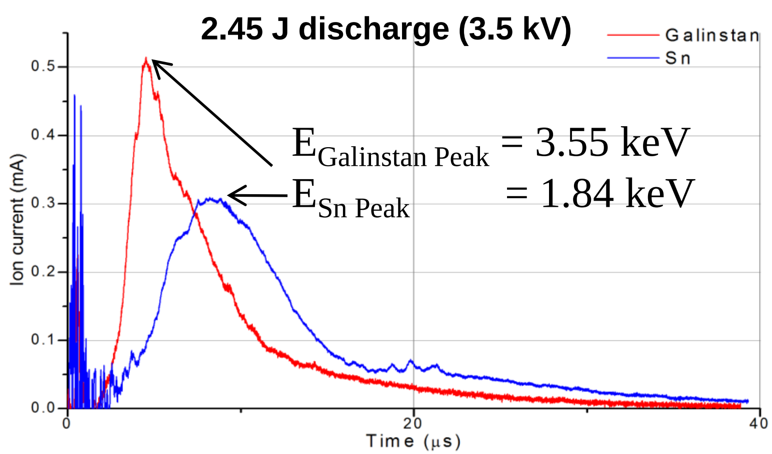
Speclab

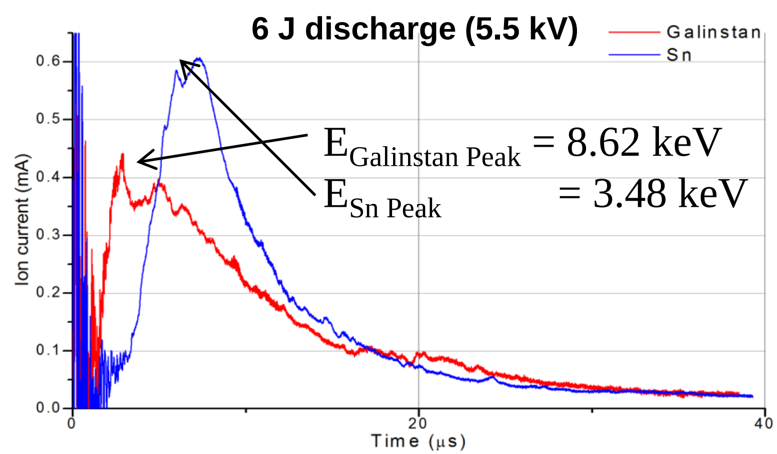
Ion current

Average of 32 signals for ion currents (laser energy of 5 mJ for Galinstan and 12 mJ for Sn)





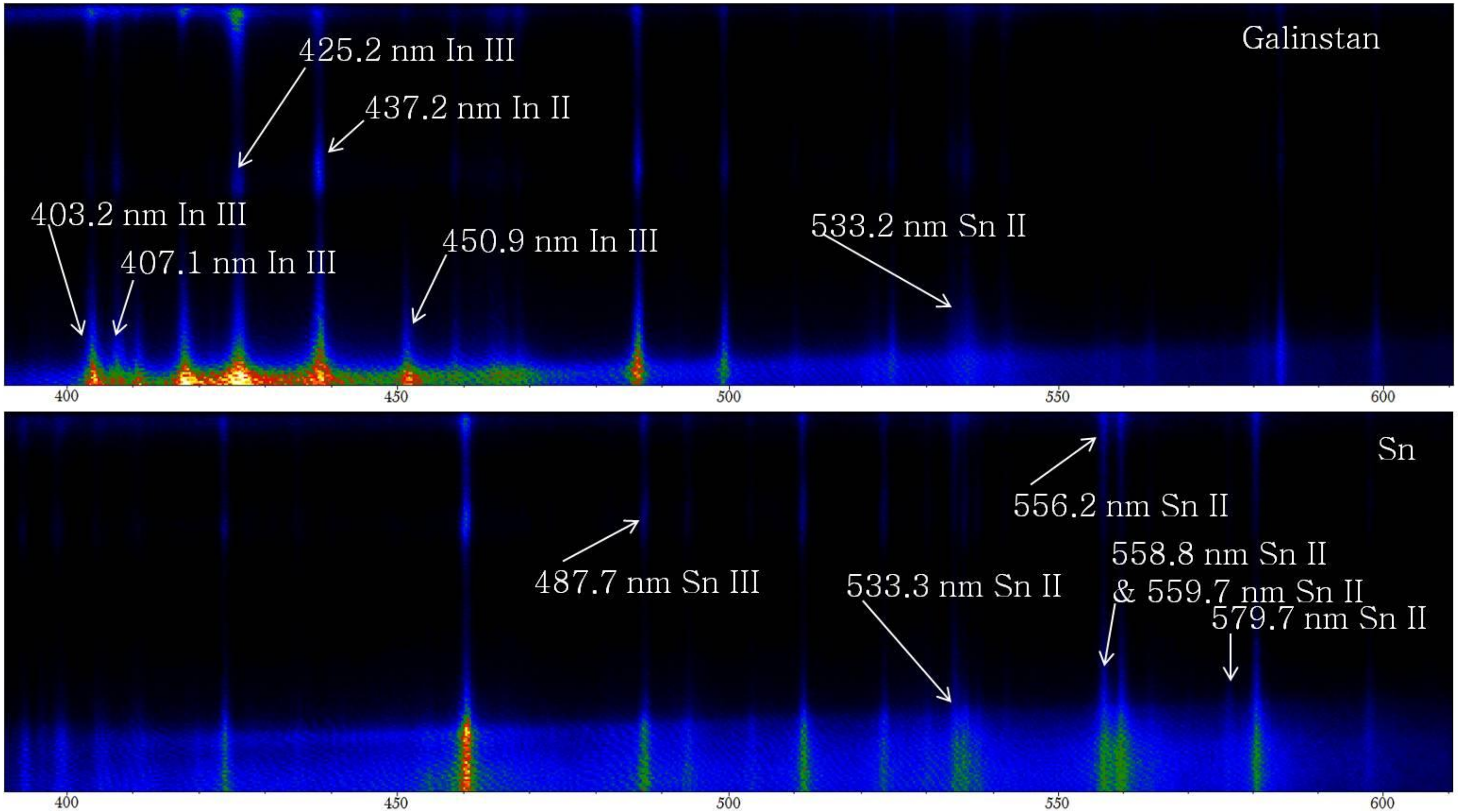




Speclab

Visible spectroscopy

Visible spectra captured 0 ns after laser pulse with 1 μs gate time, 4 J, 5 mJ (Galinstan) and 12 mJ (Tin) & gain 1 and 2 respectively



Conclusions

- EUV emission from Laser Assisted Vacuum Arc (LAVA-lamp) discharge in Galinstan and Tin vapor is investigated and compared.

- EUV imaging – pinch is ~100 μm (or even smaller) in diameter and ~0.5 – 1 mm in length.
- Tin in-band emission is more efficient (by a factor of 2x to 10x, partially because of spectral efficiency) and more reproducible, however the discharge was not optimised for Galinstan.
- Pinching time matching to the current maximum is essential for high EUV output and is sensitive to trigger laser energy.
- Discharge plasma is characterised by means of time- and spatially-resolved fast gated visible emission spectroscopy to determine dynamic evolution of plasma densities and temperatures.
- Comparison with calculated spectra for Galinstan is ongoing. Gallium ions are mainly responsible for EUV emission below 13 nm whereas Indium ions emission dominates the spectra above 14 nm.

Acknowledgements

University College Dublin - School of Physics

Fergal O’Reilly, Gerry O’Sullivan, Imam Kambali, Emilien Foiret, Emma Sokel, Padraig Dunne, Tony Donnelly, Niksa Krstulovic, Colm O' Gorman, Thomas Cummins, Enda Scally, Robert Stefanuik, Colm Harte, Bowen Li, Tom McCormack, Rebekah D'Arcy

Trinity College Dublin - School of Physics

Isaac Tobin, James Lunney

New Lambda, Dublin

Paul Sheridan, Kanneth Fahy

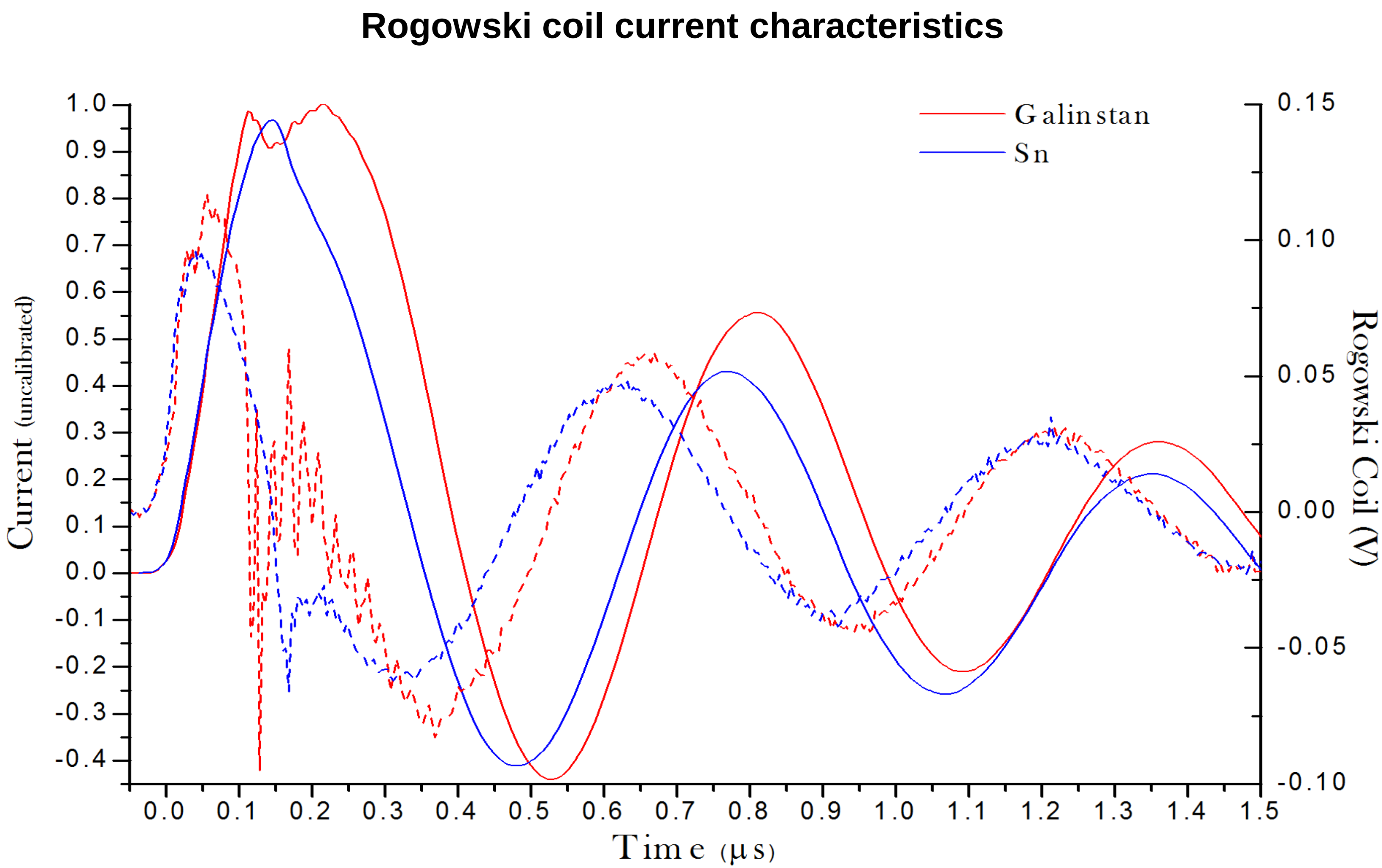
ISAN, Troitsk

Yuri Sidelnikov, Konstantin Koshelev

We acknowledge the support of Science Foundation Ireland under grants 7/RFP/PHYF143 and 07/IN.1/I1771

Thank you very much for your attention!

Time of pinching



-

Dr. Larissa Juschkin
COST MP0601 Workshop
Paris, November 16 – 18, 2011

Stark widths

Sn II	$6d\ {}^2D_{3/2} \longrightarrow 6p\ {}^2P^o_{1/2}$	533.39 nm
Sn III	$6p\ {}^3P^o_1 \longrightarrow 5d\ {}^3D_1$	529.3 nm
	$6p\ {}^3P^o_1 \longrightarrow 5d\ {}^3D_2$	535.1 nm
	$6p\ {}^3P^o_0 \longrightarrow 5d\ {}^3D_1$	537.1 nm
	$6p\ {}^1P^o_1 \longrightarrow 6s\ {}^1S_0$	522.6 nm