

Scientific and education activities on the GOLEM
tokamak in the framework of the IAEA CRP

Vojtěch Svoboda

Czech Technical University in Prague
October 1, 2018

Outline

- 1 Introduction
- 2 The GOLEM tokamak research (recent issues)
 - Runaway studies
 - Edge plasma studies using probes
- 3 The GOLEM tokamak education activities
 - Hands on experiments
 - Remote experiments
- 4 The GOLEM tokamak for IAEA CRP

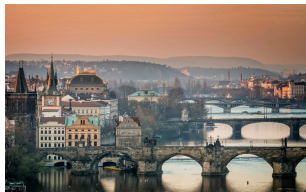
Czech Technical University in Prague



CTU Campus



CTU insignia



Prague

- Founded in 1707 by the emperor Joseph I.
- In more than 300 years long history CT university has developed into the full scale technical university educating students in technical and natural sciences.
- Approximately 2200 staff members, 15000 undergraduate students, 9000 graduate and PhD students. Out of the total of 24000 students there are 2500 foreign students.

Faculty of Nuclear Sciences and Physical Engineering CTU



FNSPE main building



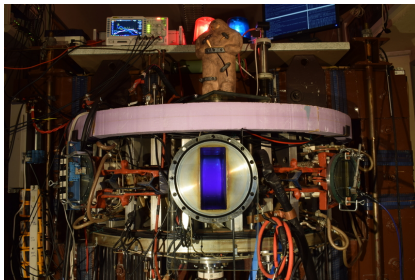
FNSPE insignia



CTU ceremony hall

- Established in 1955 with the mission to train new experts for the emerging Czechoslovak nuclear programme.
- Currently a centre of education and research specialised in boundary fields between modern science and their applications in technologies, medicine, economy, biology, ecology, and other fields.
- Departments: Mathematics, Physics, Humanities and Languages, Solid State Engineering, Physical Electronics, Materials, Nuclear Chemistry, Dosimetry and Application of Ionizing Radiation, Nuclear Reactors, Software Engineering

The GOLEM tokamak basic characteristics



- Vessel major radius: $R_0 = 0.4$ m
- Vessel minor radius: $r_0 = 0.1$ m
- Plasma minor radius: $a \approx 0.06$ m
- Toroidal magnetic field: $B_t < 0.5$ T
- Plasma current: $I_p < 8$ kA
- Electron density:
 $n_e \approx 0.2 - 3 \times 10^{19} \text{ m}^{-3}$
- Effective ion charge: $Z_{\text{eff}} \approx 2.5$
- Electron temperature: $T_e < 100$ eV
- Ion temperature: $T_i < 50$ eV
- Discharge duration: $\tau_p < 25$ ms

The GOLEM tokamak for education - historical background

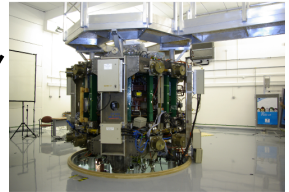
Kurchatov Institute near Moscow,
Soviet Union
1960: **TM1-MH**



1974



Culham Centre for Fusion Energy
Great Britain
1989: **COMPASS-D**



2006



Institute of Plasma Physics
Czech republic
CASTOR **COMPASS**



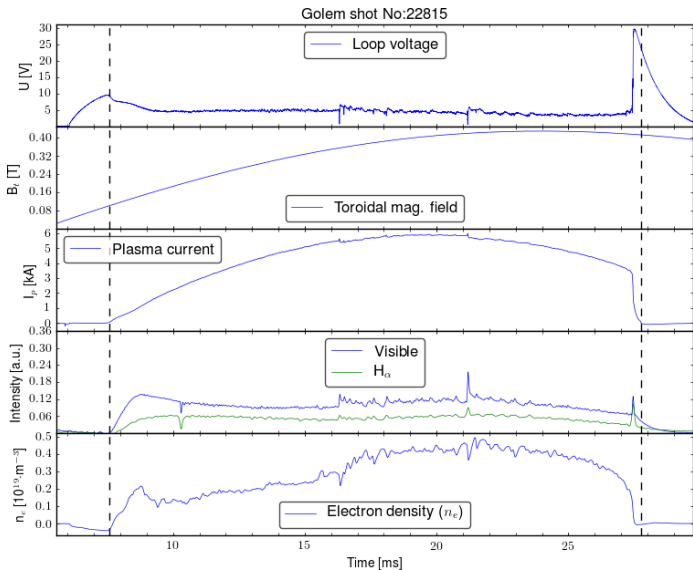
2008



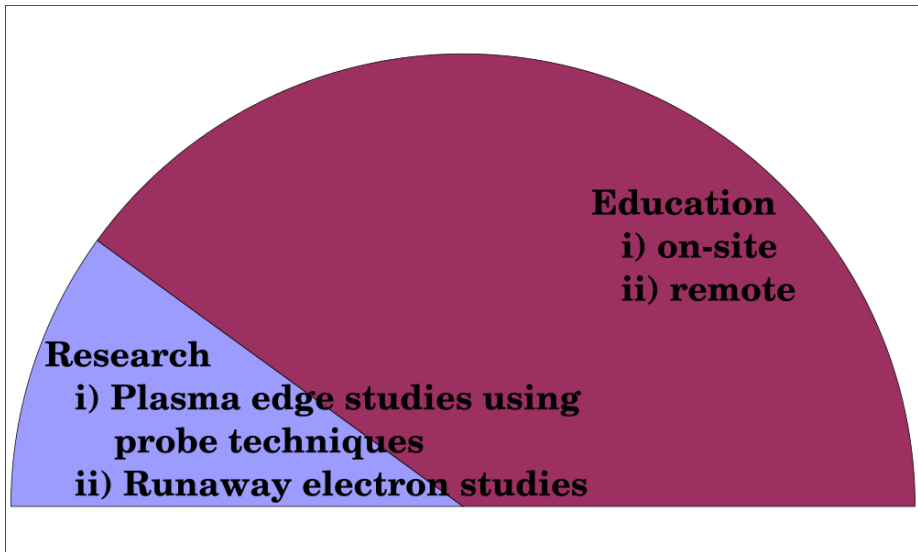
Czech Technical University Prague
Czech republic
GOLEM



"Typical", well executed discharge @ GOLEM



The GOLEM tokamak mission



Research

- i) Plasma edge studies using probe techniques**
- ii) Runaway electron studies**

Education

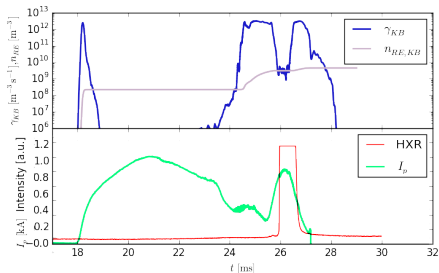
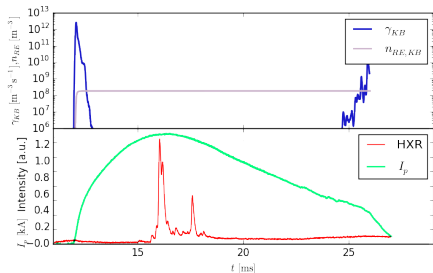
- i) on-site**
- ii) remote**

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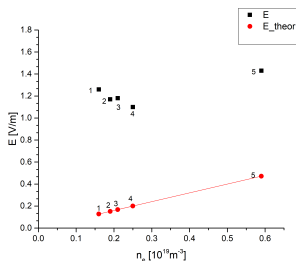
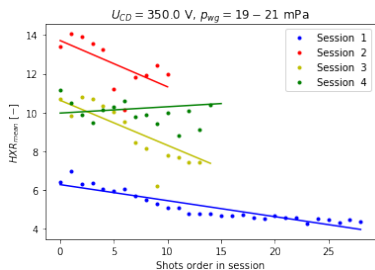
REs@GOLEM: A basic observation

- A new NaI(Tl) scintillation detector with a photomultiplier tube was installed
- Kruskal-Bernstein criterion used for estimating the RE generation rate
- RE generation observed during the breakdown phase as well as during position instabilities
- Plasma recreation observed after the loss of RE (probably due to secondary electrons)



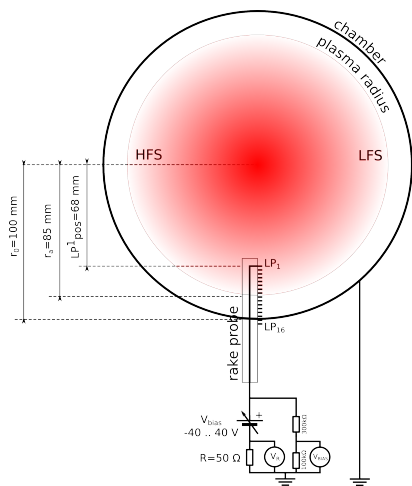
REs@GOLEM: Critical value of the electric field E_{theor}

- Low electron density ($4 - 6 \cdot 10^{18} \text{ m}^{-3}$) and relatively high loop voltage (4-6 V) \rightarrow RE generation
- Improving plasma performance with the session progress.
- Underestimation of the E_{theor} critical value by 3-10 times.



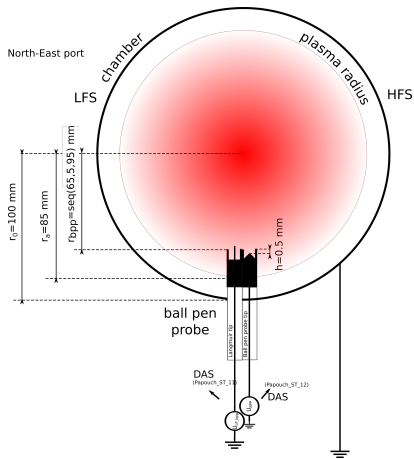
Left Evolution of the mean HXR intensity during the chosen sequence of discharges. Right - Comparison of theoretical and experimentally measured values of the critical electric field; 1: #25292, 2: #25508, 3: #25506, 4: #25507, 5: #25505.

Probes@GOLEM: Double rake probe @ South-East-Down port



- Radial array of 16 Langmuir tips is immersed in the plasma from the bottom of the tokamak vessel, movable on the shot to shot basis.
- The DC voltage (from -40 to $+40\ \text{V}$) is applied to a probe (No 1) on the shot to shot basis and the temporal evolution of the probe current is recorded with sampling frequency $1\ \text{MHz}$ i.e. with temporal resolution $1\ \mu\text{s}$.

Probes@GOLEM: Combined Ball-pen probe and Langmuir probe @ North-East-Down port

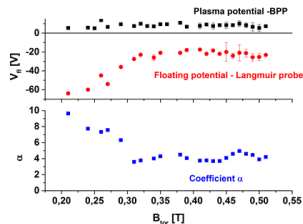
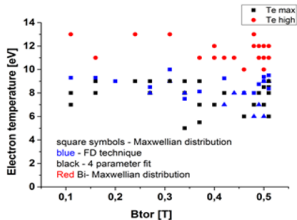
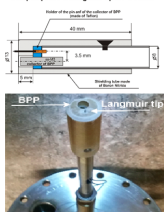


- Combined probe head composed of the Ball Pen Probe and the single Langmuire probe.
- Direct measurements of plasma potential Φ and the electron temperature T_e .
- The DC voltage (from -140 to +140 V) is applied to a probe on the shot to shot basis and the temporal evolution of the probe current is recorded with temporal resolution 1 us.

Ball pen probe measurements

- EEDF is bi-maxwellian in some cases, with tail characterized by higher T_e .
- The average electron temperature T_e and coefficient α is independent for $B_{TOR} > 0.3$.

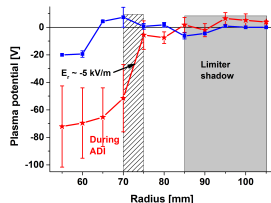
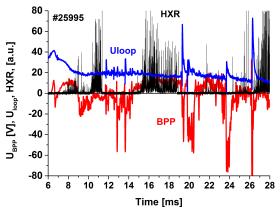
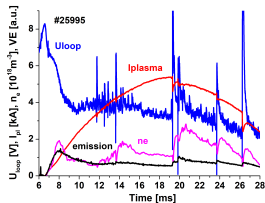
Ball pen probe & Langmuir tip for GOLEM



Left - Electron temperature versus the toroidal magnetic field in discharges # 23447, 23449, 23450, 23451. Right - Plasma and floating potential and the resulting coefficient α versus B_{TOR} .

Anomalous Doppler Instability observation by the Ball-Pen Probe

- Low density discharges ($n_e \sim 10^{18} \text{ m}^{-3}$) in GOLEM exhibit an ADI, which is: i) manifested by 3 spikes of the U_{loop} ii) accompanied by an increase of HXR followed by an increase of the line average density \rightarrow signature of an enhanced plasma-wall interaction
- Edge plasma analysis by a nearly exact direct measurement of the plasma potential with BPP.

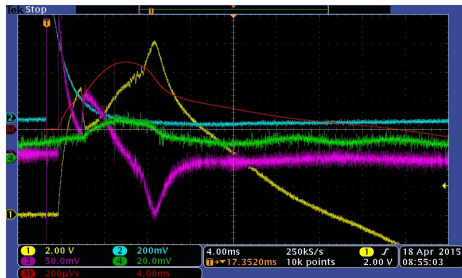


Temporal evolution of: left - a low density H discharge, mid - plasma potential at $r = 70$ mm and the HXR emission. Right - Radial profiles of the plasma potential during the appearance of the ADI.

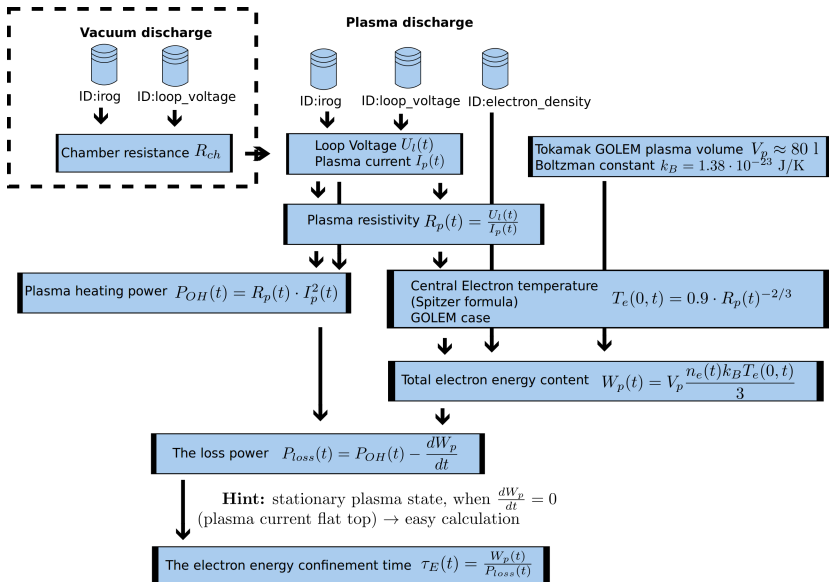
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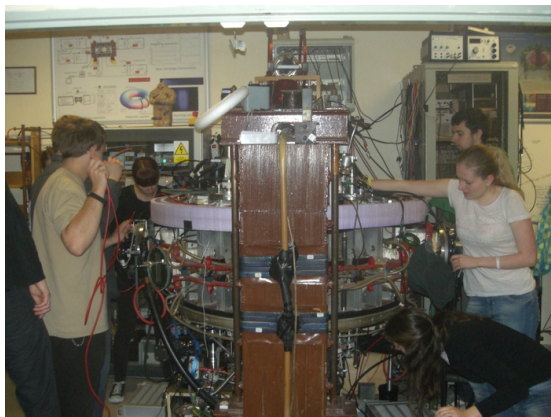
Hands on the GOLEM tokamak



Towards Electron energy confinement time τ_E



Hands on the GOLEM tokamak



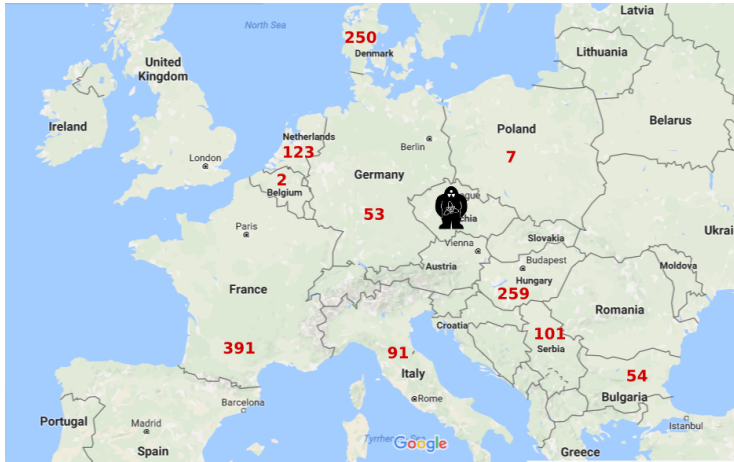
- Laboratory Practice for Basic course of Physics 15-18 (CT University Bachelor level).
- Advanced plasma training course 14-18 (CT University Master level).
- Week of scientists 13-18 (Czech republic High school level).
- Golem Training course 13 (Master and PhD level).

Remote control



- Demonstrations: Ghent University 09; Bochum University 13; Garching 13; Lemvig High School 14; Instituto Tecnologico Costa Rica 10; Armidale University 17.
- Training courses: French Training Course & EM 12-14,16-18; Bangkok 16-18; TU Eindhoven 11,15-18; TU Kobehaven 14,15; University of Belgrade 15-17; BUTE Budapest 10,12-18; University of Padova 14,16; TU Torino 16-18.
- Workshops Kiten: 14,16,18; Observatorium Valasske Mezirici 14; Islamabad 14.
- Miscellaneous: Global Tokamak Experiment 10.

Remote discharges over the Czech borders



+ IN ~ 10, + PK ~ 70, + OTHERS ~ 100

$\Sigma(09/12-02/17) \sim 1500$

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Research

	Tasks	Deliverables	Inputs needed / Remarks
Research	Edge plasma studies	Characterization of the influence of plasma species mass and edge biasing on edge plasma parameters and turbulence	* Remote/on site participation * Particular diagnostics share and development. 2 nd year: Joint event @ the GOLEM tokamak ?
	Runaway studies	Experimental test of various runaway detection techniques	

Education

	Tasks	Deliverables	Inputs needed / Remarks
Education	GOLEM on-site: GOLEM training course GOMTRAIC	On-site Training of graduate (and post-graduate students) for ~ 15 students. Feb-Apr.	The event advertisement
	GOLEM remote	Remote Training courses of graduate (and post-graduate students)	Experienced tutor on the remote side.

Acknowledgement

Financial:

FUSENET, MSM 6840770039, MSM 6840770014 and A1581, SGS SGS11/131/OHK4/2T/14.

Students, teachers, technicians (random order):

Vladimír Fuchs, Ondřej Grover, Jindřich Kocman, Tomáš Markovič, Michal Odstrčil, Tomáš Odstrčil, Gergo Pokol, Gabriel Vondrášek, František Žáček, Lukáš Matěna, Honza Stockel, Jan Mlynář, DG ITER BB, Sabina Griffith, Jára Krbec, Tatiana Okonechnikova, Radan Salomonovič, Tomáš Peltán, Vladimír Linhart, Martin Matušů, Katka Jiráková, Dáša Hodková, Jiří Žára, Ondra Ficker,