

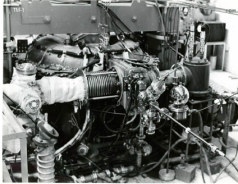
# The GOLEM tokamak

Vojtěch Svoboda  
on behalf of the GOLEM tokamak team

a General introduction

# The GOLEM tokamak for education - historical background

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



1974

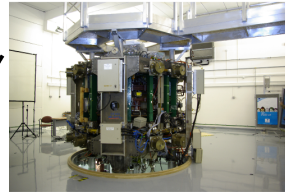


Institute of Plasma Physics  
Czech republic  
**CASTOR**      **COMPASS**

2006



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



2008



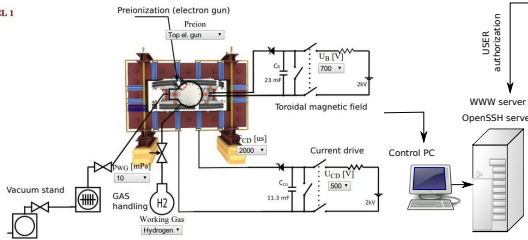
Czech Technical University Prague  
Czech republic  
**GOLEM**



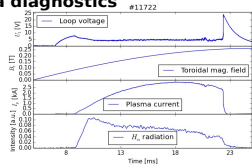
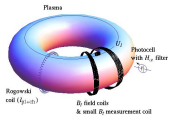
# The global schematic overview of the GOLEM experiment

LEVEL 1

## Tokamak technology setup



## Basic plasma diagnostics



internet

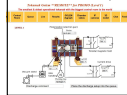
Virtual control room  
(remote participation)

WWW control interface

Data presentation

HTML & PHP scripts

HTML (www pages)



SSH control interface

WINDOWS via putty

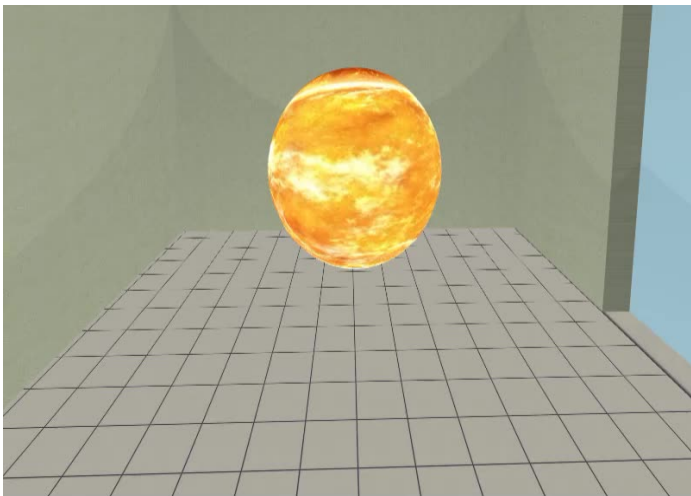
Data handling



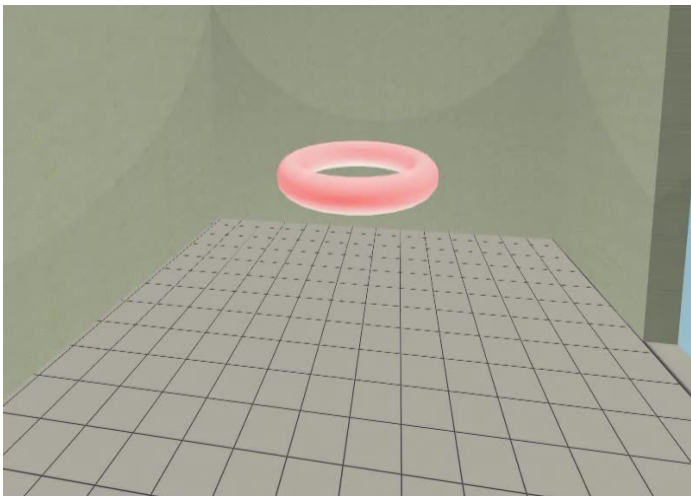
LINUX via ssh  
or ssh+X tunnel  
(advanced mode)

\*wget  
\*gnuplot  
\*idl  
\*mathematica  
\*matlab  
\*etc...

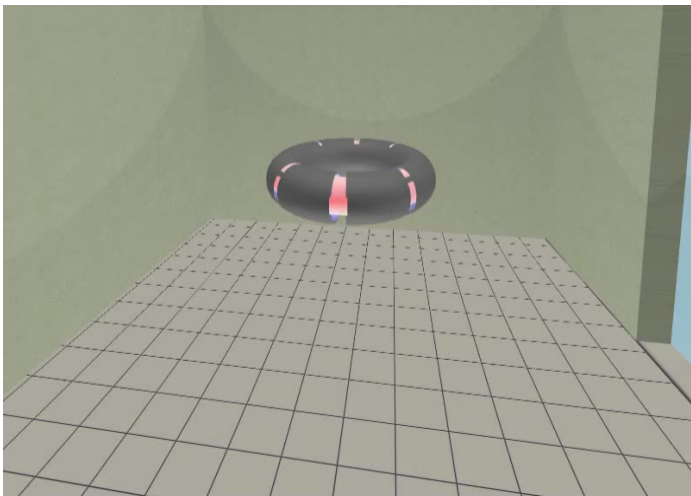
Our goal: the technology to create a  $\mu$ Sun on the Earth



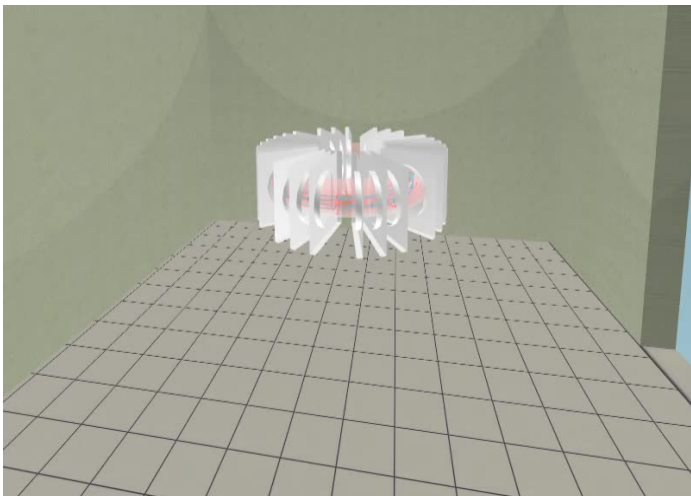
# Magnetic confinement requires toroidal geometry



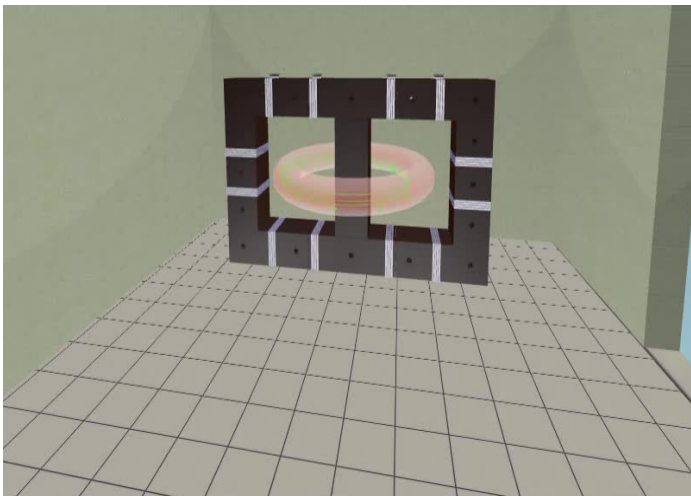
A chamber contains the thermonuclear reaction



# Toroidal magnetic field coils confine the plasma

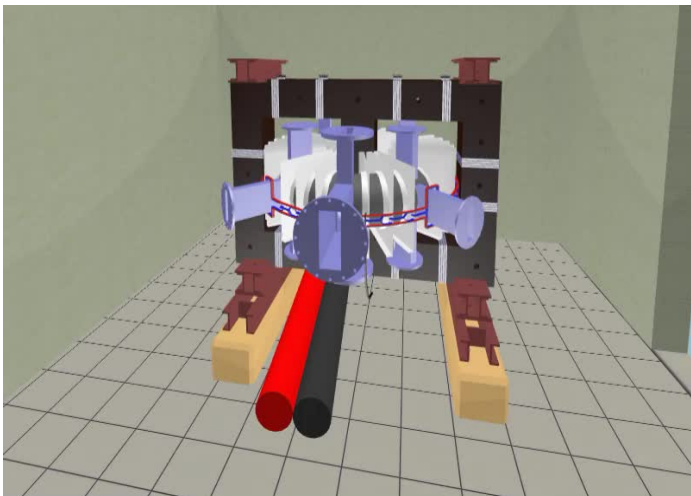


A transformer action creates and heats the plasma



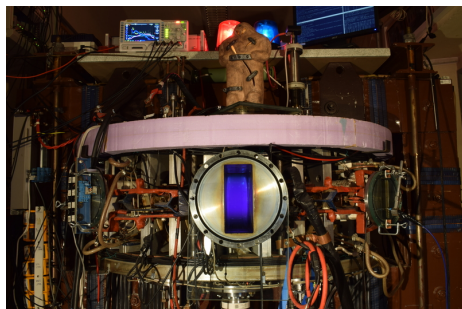


# The final technology altogether



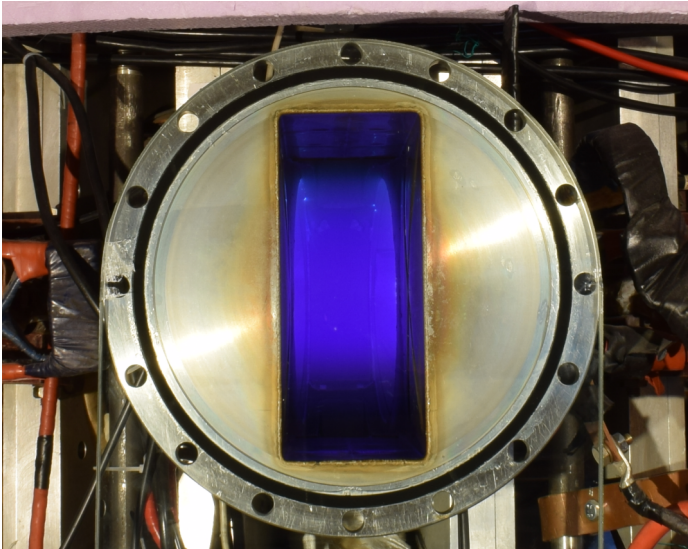
# The GOLEM tokamak basic characteristics

*The grandfather of all tokamaks (ITER newslines 06/18)*

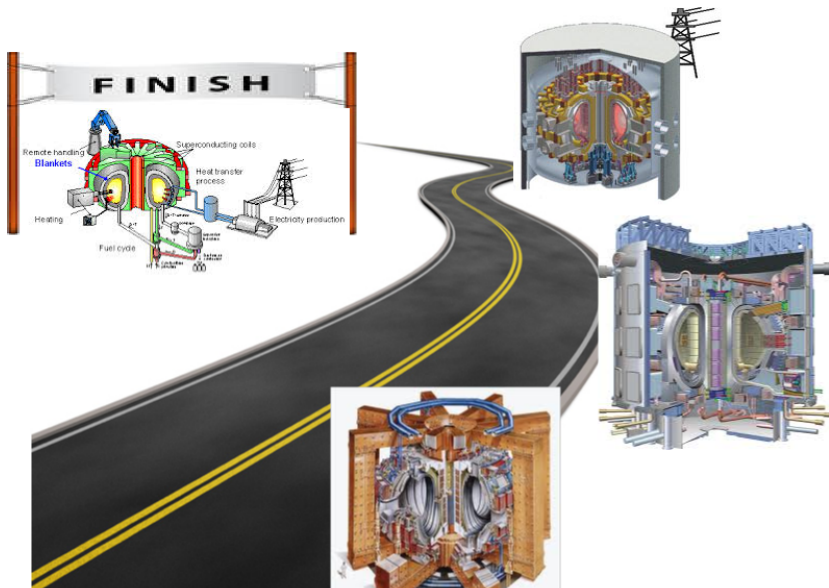


- Vessel major radius:  $R_0 = 0.4$  m
- Vessel minor radius:  $r_0 = 0.1$  m
- Maximum plasma current:  
 $I_p^{max} < 8$  kA
- Maximum toroidal magnetic field:  $B_t^{max} < 0.5$  T
- Typical electron density:  
 $\langle n_e \rangle \in (0.2, 3) \cdot 10^{19} \text{ m}^{-3}$
- Maximum electron temperature:  
 $T_e^{max} < 80$  eV
- Maximum discharge duration:  
 $\tau_p^{max} < 25$  ms

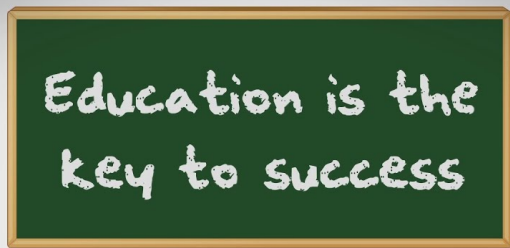
Let's make a discharge



# Milestones to Fusion Power Plant



# Education importance



# Hands on the GOLEM tokamak



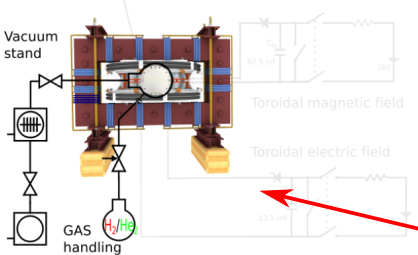
- Laboratory Practice for Basic course of Physics 2015-19 (CT University Bachelor level).
- Advanced plasma training course 2014-19 (CT University Master level).
- Week of scientists 2013-19 (Czech republic High school level).
- International Golem Training Course 2013,2019 (Master and PhD level).

# Remote control interface of the GOLEM tokamak

Introduction Working gas Preionization Magnetic field Electric field Submit

Set the pressure and type of the working gas from which the plasma is formed. Pressure must be high enough for plasma to form, but low enough for gas breakdown to occur.

Preionization (electron gun)



Vacuum stand

Toroidal magnetic field

Toroidal electric field

GAS handling

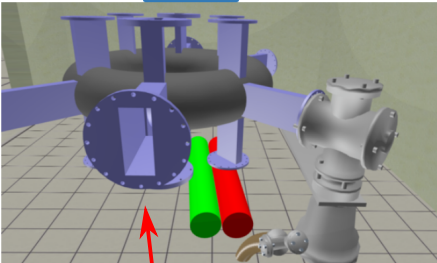
Gas type and pressure  $p_{WG} = 16 \text{ mPa}$

Hydrogen  Helium

Next Set recommended value

rendering settings

3D model rendering method: Static image (fast) Interactive X3DOM (slower)



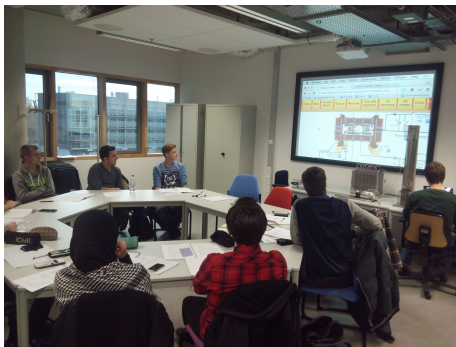
3D model rendering

engineering scheme

sliders and checkboxes

workflow buttons

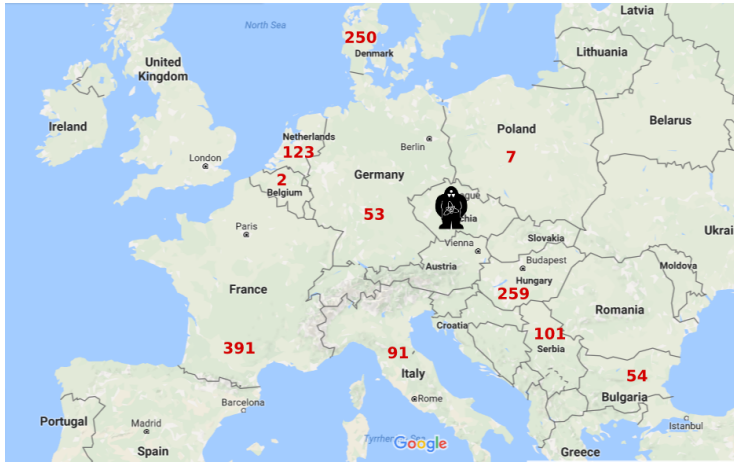
# Remote control 2009-2019 inventory



- 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 12-14,16-19; Bangkok 16-19; TU Eindhoven 11,15-19; TU Kobehaven 14,15,18; Grenoble TU 15, University of Belgrade 15-18; BUTE Budapest 10,12-18; University of Padova 14,16,18; TU Torino 16-18, St. Peterburg University 18-19. Kharkov University 19
- Workshops Kiten: 14,16,18; Observatorium Valasske Mezirici 14; Islamabad 14.



# Remote discharges over the Czech borders (up to 2017)



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

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

# Tokamak GOLEM for Fusion education

You are welcome to exploit this facility

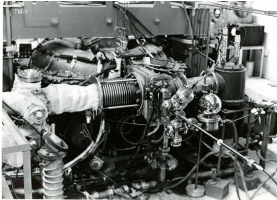
- Lectures, demonstrations at universities
- Spring/Summer/Autumn/Winter schools
- Training courses
- ... etc.
- ... even remote Bachelor and/or Diploma thesis

web:<http://golem.fjfi.cvut.cz>

mailto:[svoboda@fjfi.cvut.cz](mailto:svoboda@fjfi.cvut.cz)

# Thank you for your attention

**Tokamak TM1**  
@Kurchatov Institute near Moscow  
~1960-1977



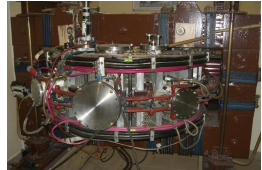
**SCIENCE**

**Tokamak CASTOR**  
@Institute of Plasma Physics, Prague  
1977-2007



**SCIENCE**  
& education

**Tokamak GOLEM**  
@Czech Technical University, Prague  
2007-



**EDUCATION**  
& science

... with the biggest  
control room  
in the world ..

**Tokamak Golem \*\*REMOTE\*\* for MASTER (Level 1)**  
The earliest & oldest operational tokamak with the biggest control room in the world

Home	WSU	Control Room	Queue	Live	Results	GOLEM diagram	Chamber status	IP camera	3D model	Chat	Feedback	Logout
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**LEVEL 1**

Preionization (electron gun)  
Preion:

Toroidal magnetic field

Current drive

Working Gas (Hydrogen)

Discharge comment

Place the discharge setup into the queue

# References I

- [1] Wikipedia contributors. Golem — Wikipedia, the free encyclopedia. <https://en.wikipedia.org/w/index.php?title=Golem>, 2020. [Online; accessed 29-March-2020].
- [2] V. Svoboda, B. Huang, J. Mlynar, G.I. Pokol, J. Stockel, and G Vondrasek. Multi-mode Remote Participation on the GOLEM Tokamak. *Fusion Engineering and Design*, 86(6-8):1310–1314, 2011.
- [3] Brotankova, J. *Study of high temperature plasma in tokamak-like experimental devices*. PhD thesis, 2009.
- [4] Tokamak GOLEM contributors. Tokamak GOLEM at the Czech Technical University in Prague. <http://golem.fjfi.cvut.cz>, 2007. [Online; accessed September 25, 2020].
- [5] J. Wesson. *Tokamaks*, volume 118 of *International Series of Monographs on Physics*. Oxford University Press Inc., New York, Third Edition, 2004.