# ELM induced divertor heat loads on TCV

ECOLE POLYTECNIQUE FEDERALE DE LAUSANNE

*J. Marki*[a], R. A. Pitts[a], J. Horacek[b], D. Tskhakaya[c] and the TCV Team*

*a) Centre de Recherches en Physique des Plasmas (CRPP), École Polytechnique Fédérale de Lausanne (EPFL), Association Euratom – Confédération Suisse, 1015 Lausanne, Switzerland b) Institute of Plasma Physics, Association EUROATOM-IPP.CR c) Association EURATOM-ÖAW, Institut für Theoretische Physik, A-6020 Innsbruck, Austria*

## Motivation:

- Several aspects of **ELM dynamics** remain **unexplained**

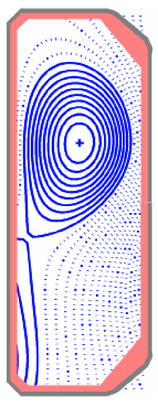
- **fast IR cameras** are ideal tools for analysing **ELM heat deposition**

- Main goals: **Characterisation** by collecting databases of **ELM profile width**, **pulse rise time**, **deposited power** and investigating **deposited layer** and **filament** behaviour

## IR analysis procedure:

- IR photon flux ⇒ **digital signal** ⇒ blackbody calibration ⇒ **apparent temperature +** assuming ε (0.85) ⇒ **real surface temperature** T ⇒ mapping to real space ⇒ averaging along toroidal band ⇒ **radial T profile**
- Spatio-temporal evolution of T + simple model of deposited surface layer ⇒ **power flux $P_{IR}$** (THEODOR 2D code = inverse solution of heat conduction eqn.)

## Power deposition characteristics:



- Camera response ~ photon flux ⇒ problem for simultaneous resolution of ELM- and inter-ELM profiles
- *3 dedicated discharges:* TCV shots #35033, 35036-7
- Ohmic ELMy H-modes $I_p$=380 kA, $B_T$ = 1.43 T, W ~ 15 kJ, $f_{ELM}$ = 90-120 Hz and $\Delta W_{ELM}/W$ ~ 5-10%
- 35033: Full frame, 880 Hz, $\tau_{int}$ = 101.1 μs: inter-ELM profiles (saturated for ELMs)
- 35036: Sub-array, 40x16 (yellow), 18kHz, $\tau_{int}$ = 15.3 μs ELM profiles from "clean" tile
- 35037: Sub-array, 40x16 (cyan), 18 kHz, $\tau_{int}$ = 4.8 μs ELM profiles from tile covered by thick layers

*General thermal response*

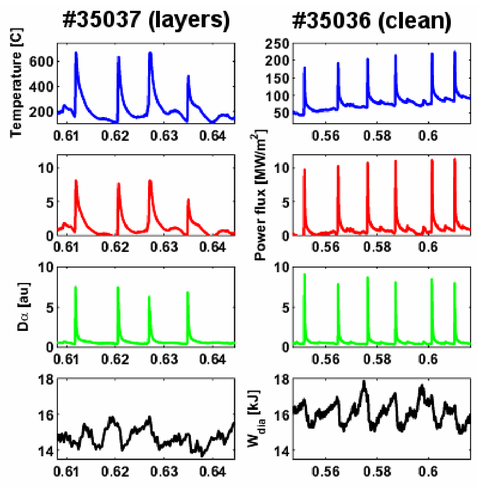
•ELM energies slightly larger for #35036 (~30%)

•Temperature maxima on "untreated" tile reach ~3x higher values ~ measured during X3 ECRH heated discharges 1 year earlier (~3x $W_{ELM}$)

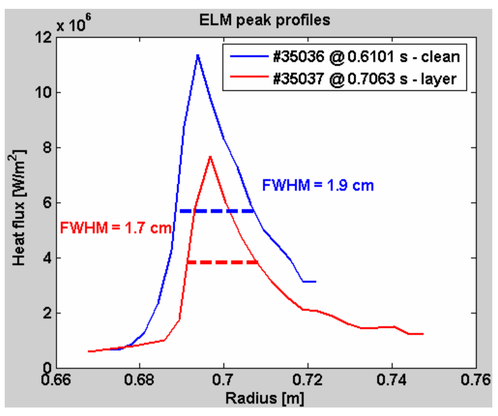
•Consequence of thick, co-deposited layers

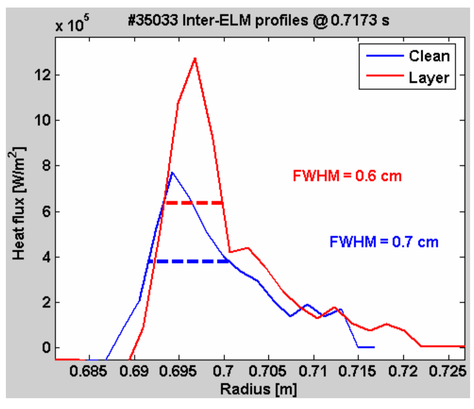
•Based on a photograph, the freshly deposited layers ("clean" tile) are already ~60-200 nm thick (1st or 2nd order interference)

•For THEODOR heat flux calculations, $\alpha_{layer}$ = 15.000 W/m²K, $\alpha_{clean}$ = 85.000 W/m²K were found reasonable




*Profile broadening*




Averaging for a handful (6 vs. 4) of ELMs and 3 pairs of inter-ELM profiles yielded:

| | $q_{max}$ [MW/m²] | FWHM [cm] |
|---|---|---|
| ELM (clean) | 10.8 | 2.1 |
| Inter-ELM (clean) | 0.8 | 0.9 |
| ELM (layers) | 8 | 1.8 |
| Inter-ELM (layers) | 1.2 | 0.7 |

• Difference in max. fluxes – tile inclination, layer model, spatial resolution or camera resolution

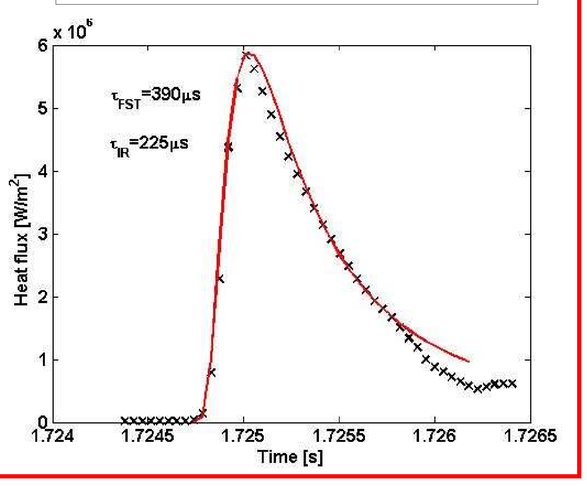
• **Average ELM profile width = x2 inter-ELM profile width**

## Comparison with kinetic model

$$q_{ELM}(t) = \frac{E_{ped}}{\sqrt{\pi}\tau_{FSP}} \cdot \exp\left(-\left(\frac{\tau_{FSP}}{t}\right)^2\right) \times \frac{\tau_{FSP}^2}{t^2} \times (1+\tau_{FSP}^2)$$

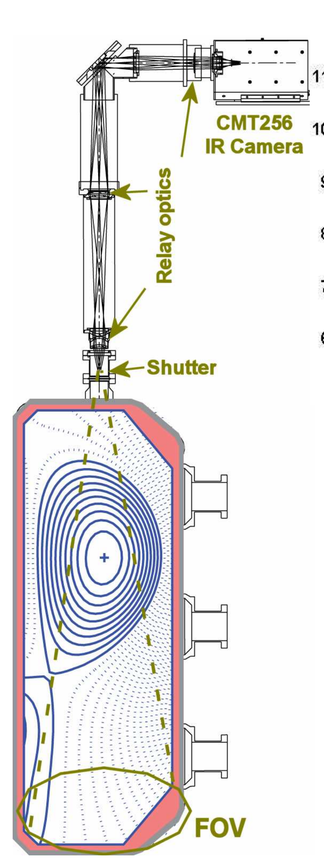
•Using the expression derived in **W.Fundamenski, PPCF46, p.109 (2006)**, we check whether experimental observations are in agreement with the free streaming particle model

•This seems to be the case, with the free streaming time being approximately twice the heat pulse rise time

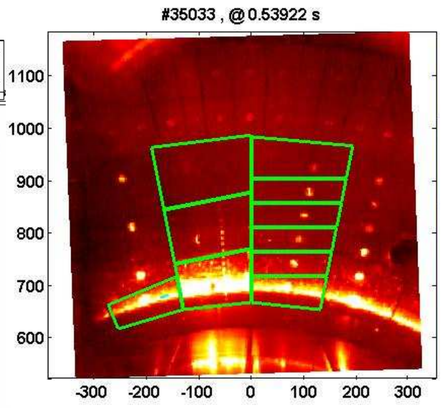



## Experimental setup:

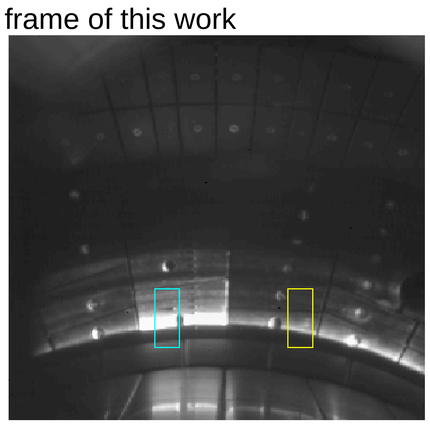
*Diagnostic:* Thermosensorik CMT256 HS **IR camera** (1.5 – 5.1 μm), 256x256 FPA @ 880 Hz, free sub-array configuration in 8x8 pixel units @ >20 kHz, integration times down to $\tau_{integration}$ = 1 μs, **imaging outer divertor region**

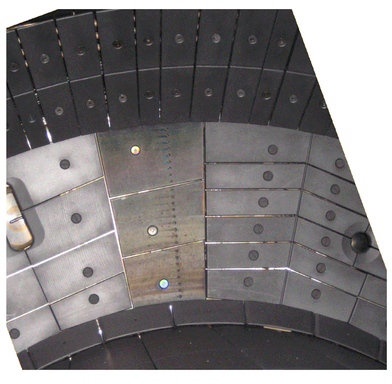



Above: Experimental setup

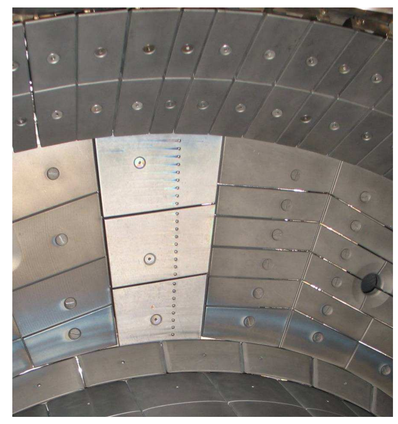



*Top:* Mapping to physical objects
*Bottom:* sub-arrays used in the frame of this work





*Top:* TCV tiles after shutdown
*Bottom:* tiles after 1 month



•ALL (except 3 LP tiles) TCV tiles have been Grit-blasted with $B_4C$ over recent TCV shutdown

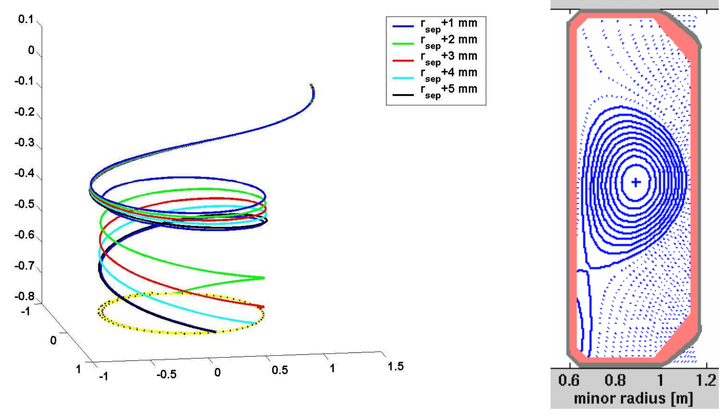
• Observation of fresh layer growth possible both visually and through IR: THEODOR α-parameter

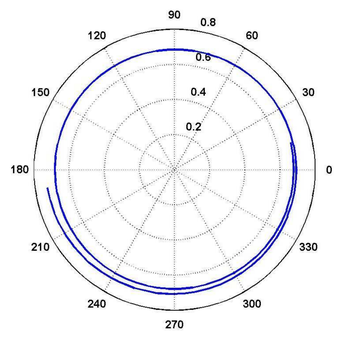
## Investigations of ELM filament characteristics:

*Divertor floor pattern:*

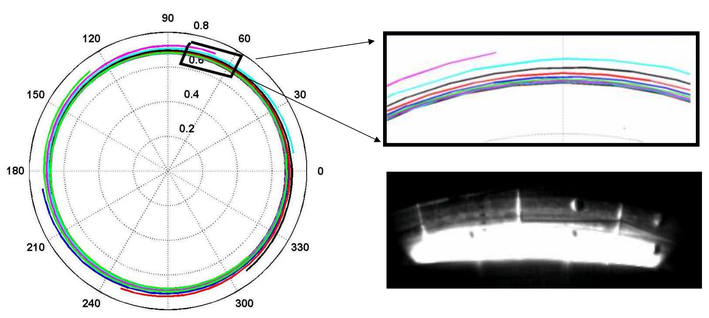
**•Field line tracing**

**exercise**: placing several points to the **same toroidal** location and **different radii** at the outer midplane, then following field lines to the divertor targets



Pattern on the floor from following points from 1 single toroidal location across 99% of the LCFS-Wall shadow in radius



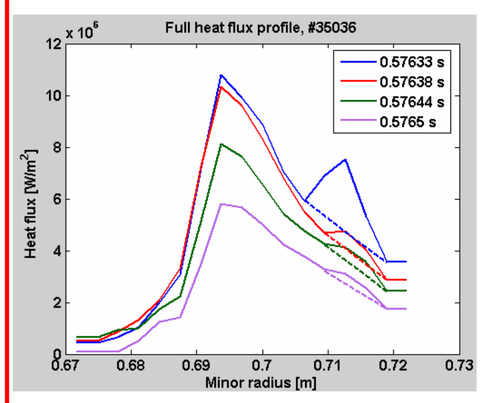
Pattern on the floor from following points from 6 separate toroidal locations like the one to the left

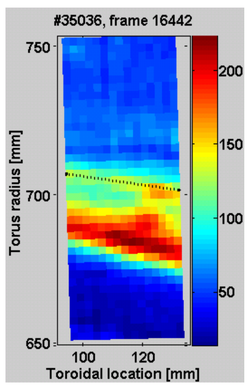
*Top:* Deposition pattern at a slice of the torus similar in size to IR FOV

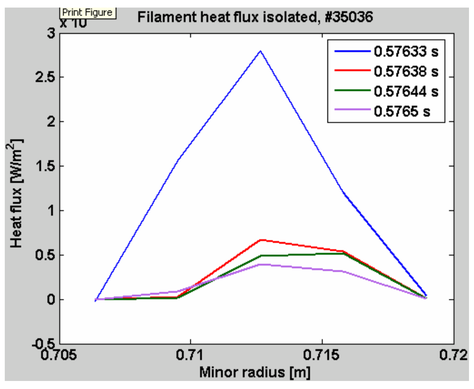
*Bottom:* IR image from #34948

Nearly all **filamentary patterns** on IR **toroidal or near-toroidal** ⇒ the **free streaming particle** model seems valid for TCV

*Individual filament energy content:*




•**Isolation** of the filamentary component of the heat flux profile via **linear interpolation**
•Integration of resulting profile for a symmetric circle (aproximation for the pattern visible above)
•Total energy found to be **~10J, i.e. <1% of $W_{ELM}$**

## Interesting videos: *Please ask presenting author for a demonstration!*

**•movement of dust particles**

**•strike point jumps during ELMs**

**•Langmuir probe periodic heating due to voltage sweeping**

## Conclusions:

• Filament deposition in agreement with free streaming particle model for ELM pulse rise phase, energy content of individual filaments: ~1% ELM energy

• ~x2 Profile broadening observed during ohmically heated type III ELMs

• Heat pulse waveform shows reasonable agreement with analytic kinetic expression