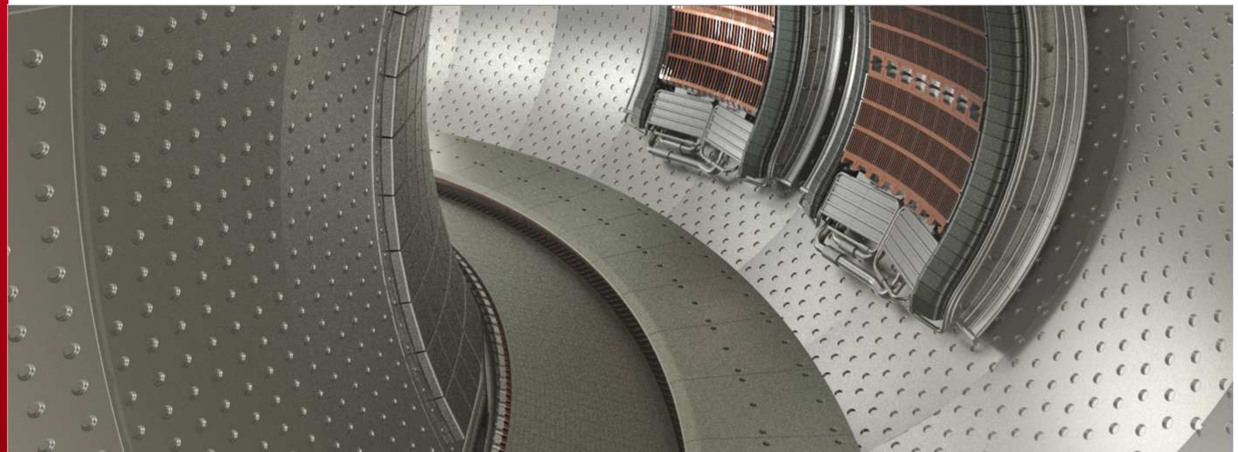
DE LA RECHERCHE À L'INDUSTRIE

SURFACE TEMPERATURE MEASUREMENT ON PLASMA FACING COMPONENTS IN FUSION DEVICES



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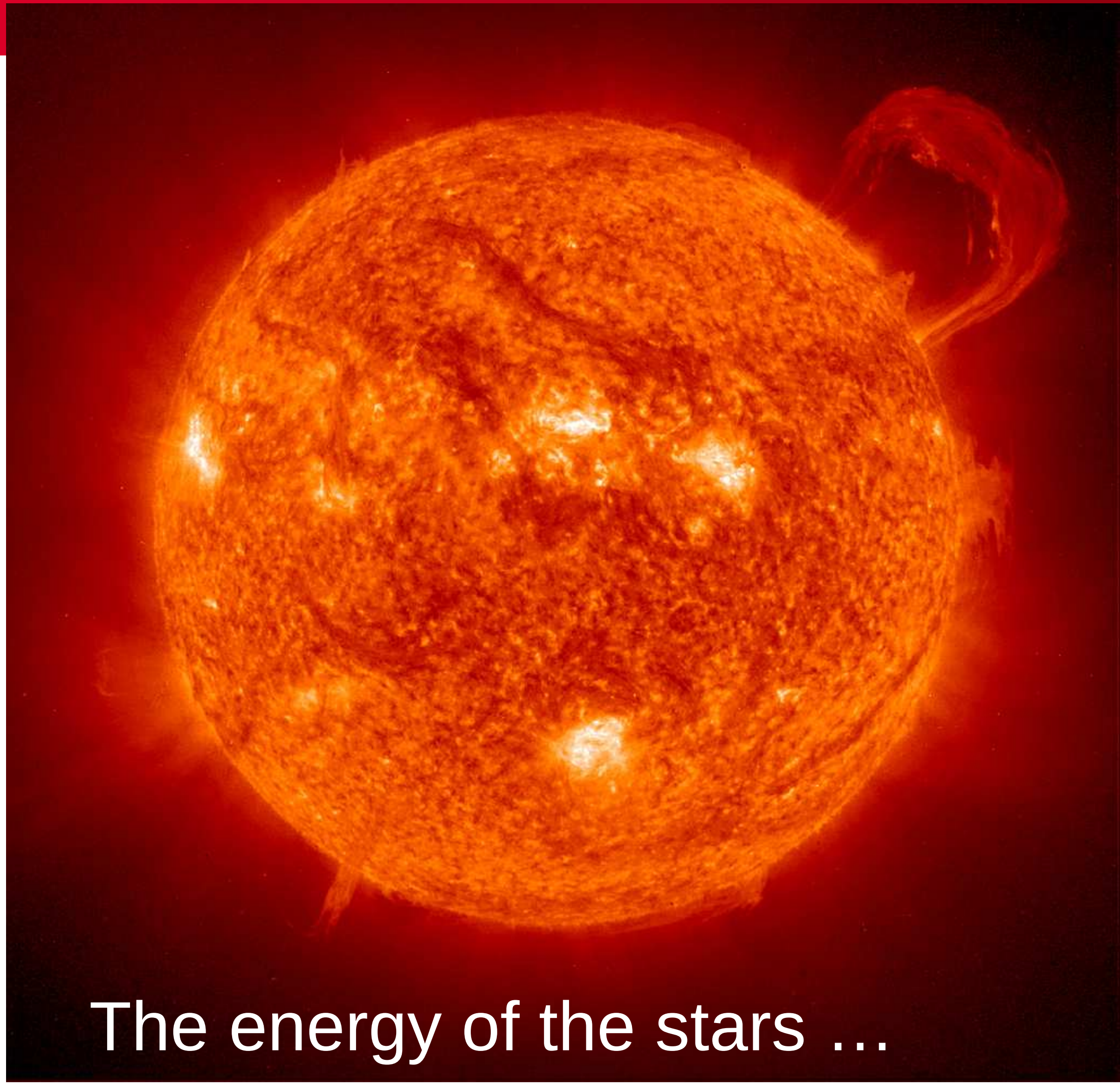
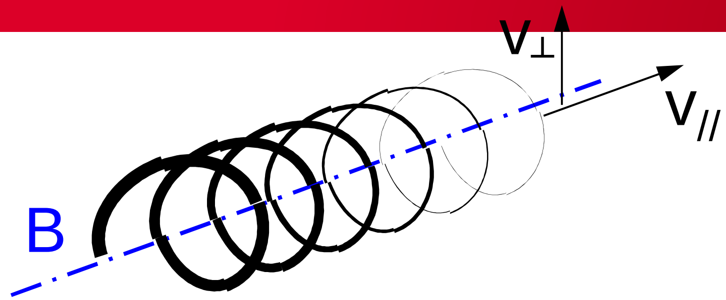
OUTLINE

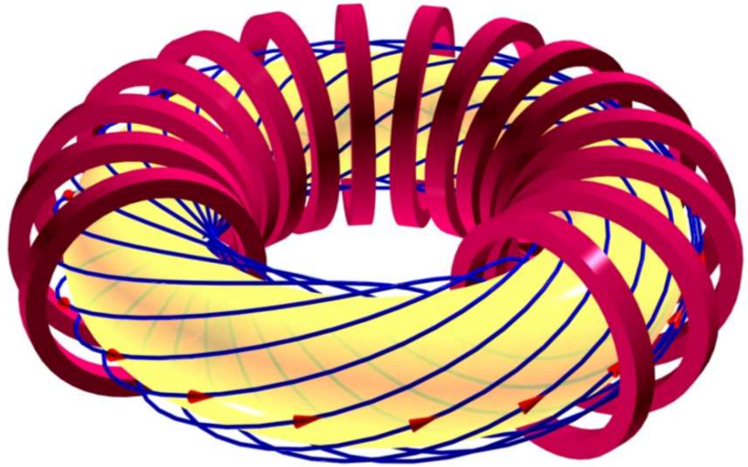
- Introduction
- Monitoring surface temperature in tokamak
  - ➢ Carbon on Tore Supra
  - ➢ Be and W on JET
- Challenge of PFC control in ITER
- WEST project
- Lab development on metalic PFC Ts monitoring
  - Bicolor camera
  - Active IR thermography
- Conclusion

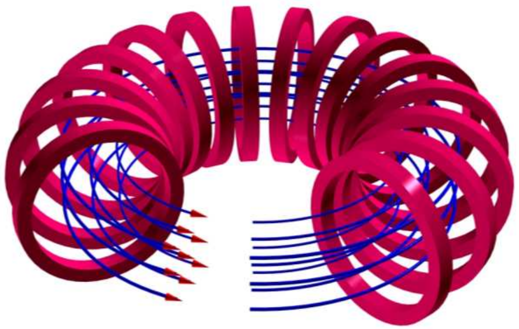
What is fusion ?

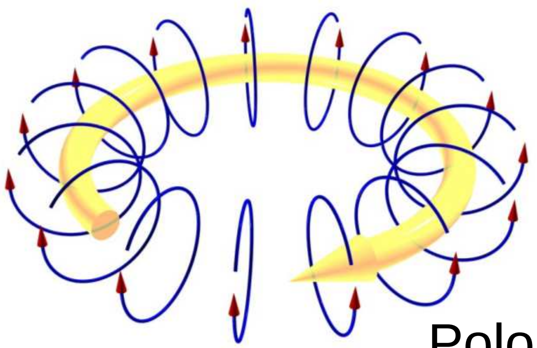


Fusion on earth : the magnetic trap



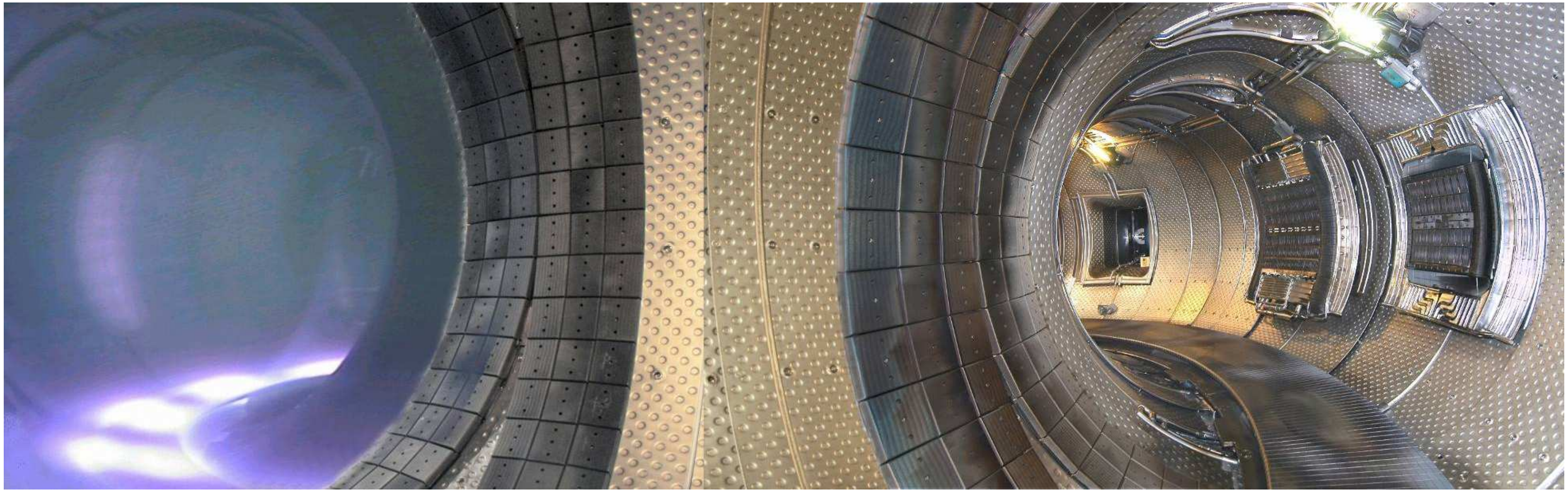


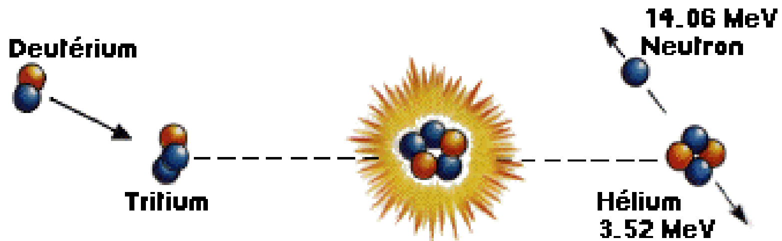




- Tokamak :
- external coils ➔ toroidal field
- plasma current Ip ➔ poloidal field

Edge plasma : extracting heat and particles

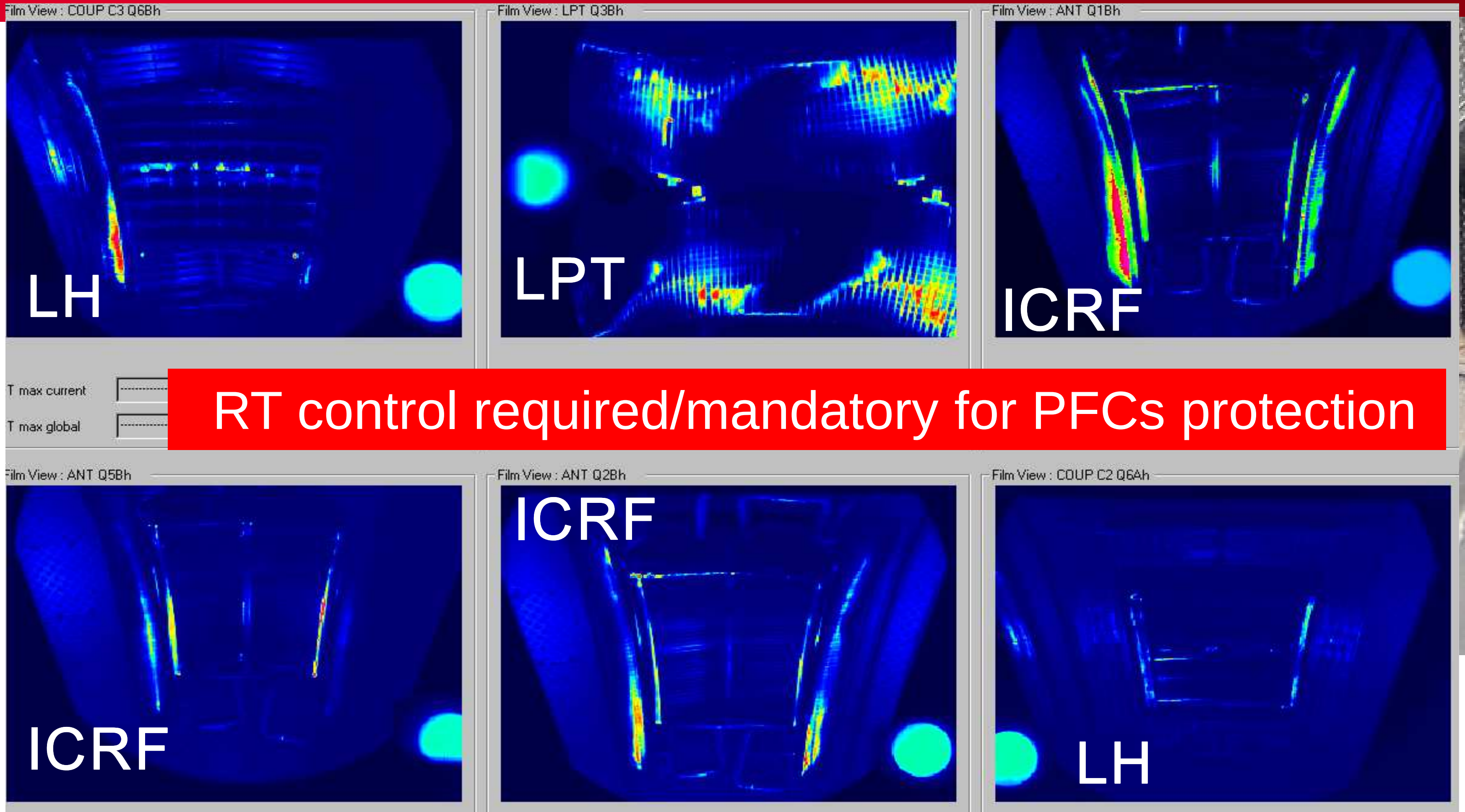




Edge plasma :

- exhaust heat fluxes (~ 10 MW/m^2
- exhaust the reaction ashes (He)
- without perturbing core plasma performance (impurities)

PFCs MONITORING on TORE SUPRA

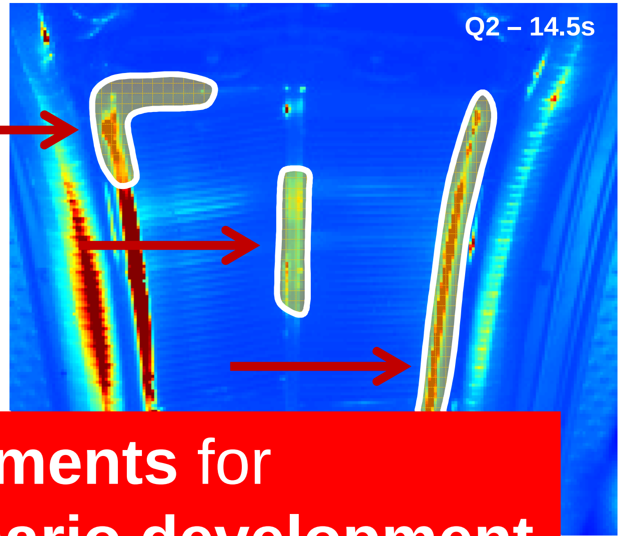


RT control required/mandatory for PFCs protection

Endoscopes and IR cameras
(3-5µm – τ=20ms – 10mm)

- Actively cooled Toroidal Pumped Limiter
- 3 ICRH antennae
- 2 LHCD launchers

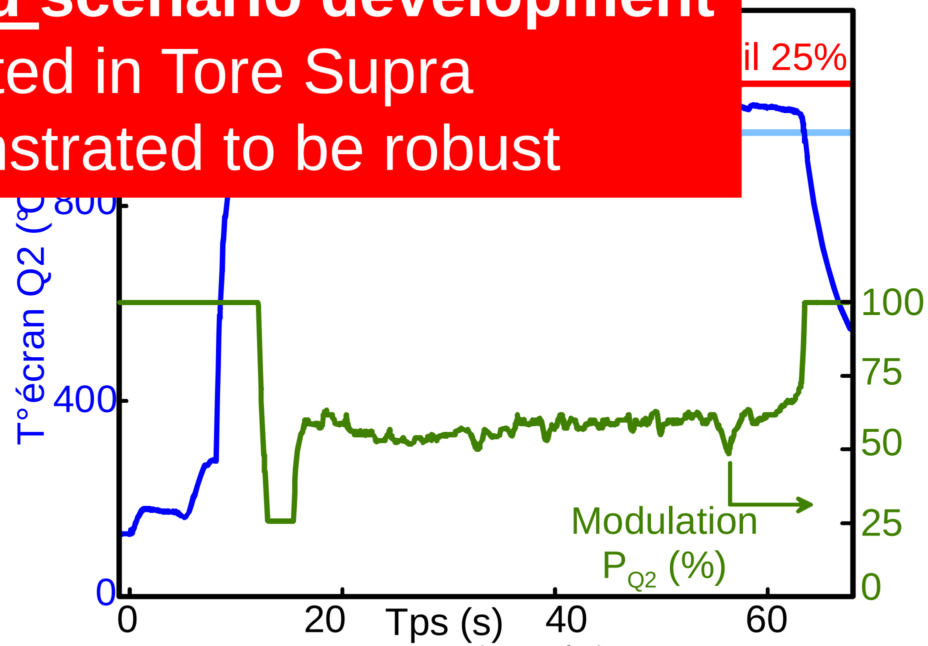
REAL TIME CONTROL ON ICRH POWER



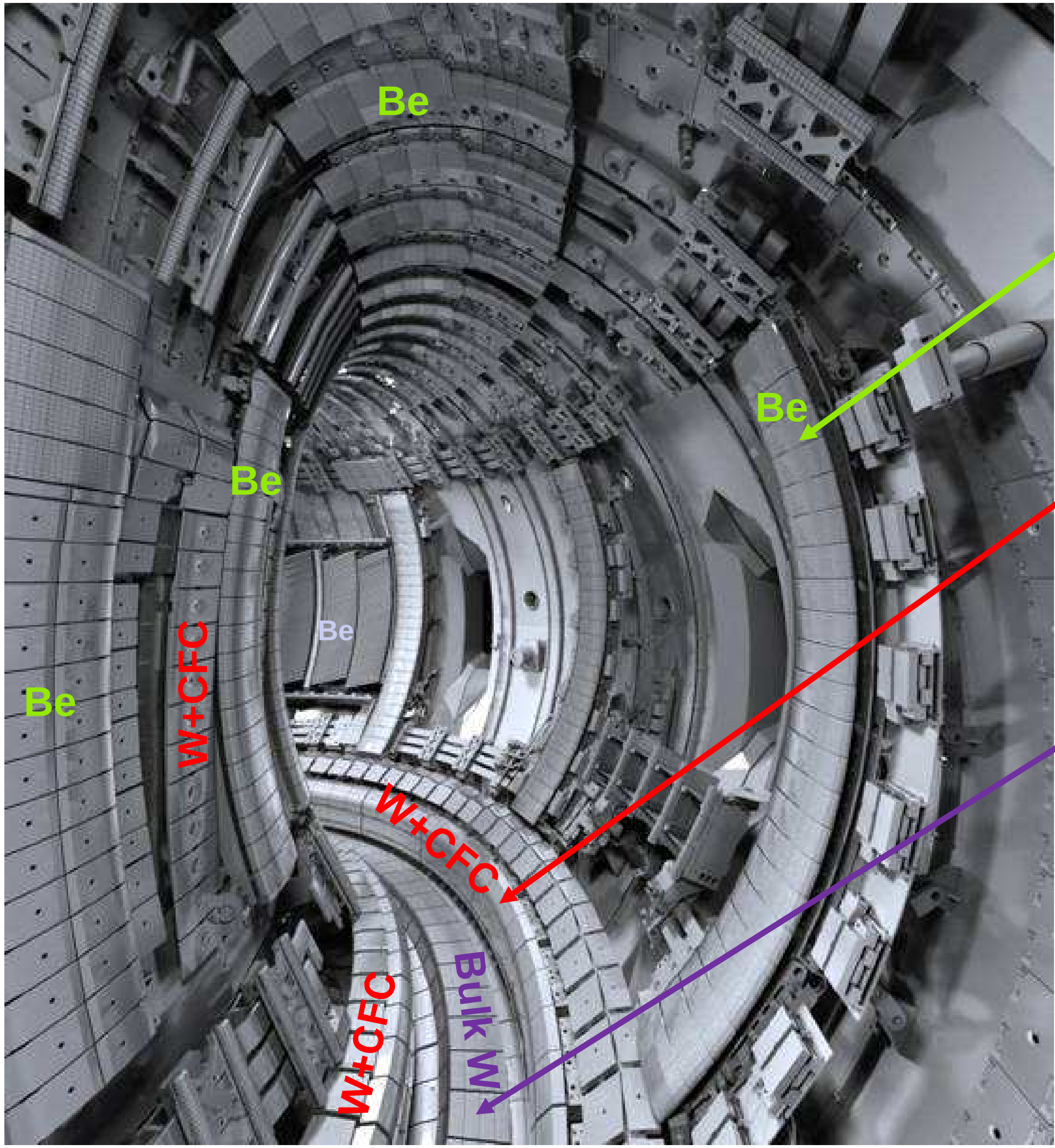
Accurate T measurements for
Protection of PFCs <u>and</u> scenario development
Routinely operated in Tore Supra
IR cameras demonstrated to be robust

1. Before plas
- Defin
- Temp

2. Real Time
- Extraction of T_{max} in each ROI
- If Tmax>Tthrshold → Warning to RTC system



JET : ITER Like Wall



First wall:
Be
Surface temperature < 900ºC

Divertor:
W coating on CFC
Surface temperature < 1200ºC

Bulk W
Surface temperature < 3400ºC

Iniertial PFCs.

RT protection required for avoiding damages

ITER Like Wall protection

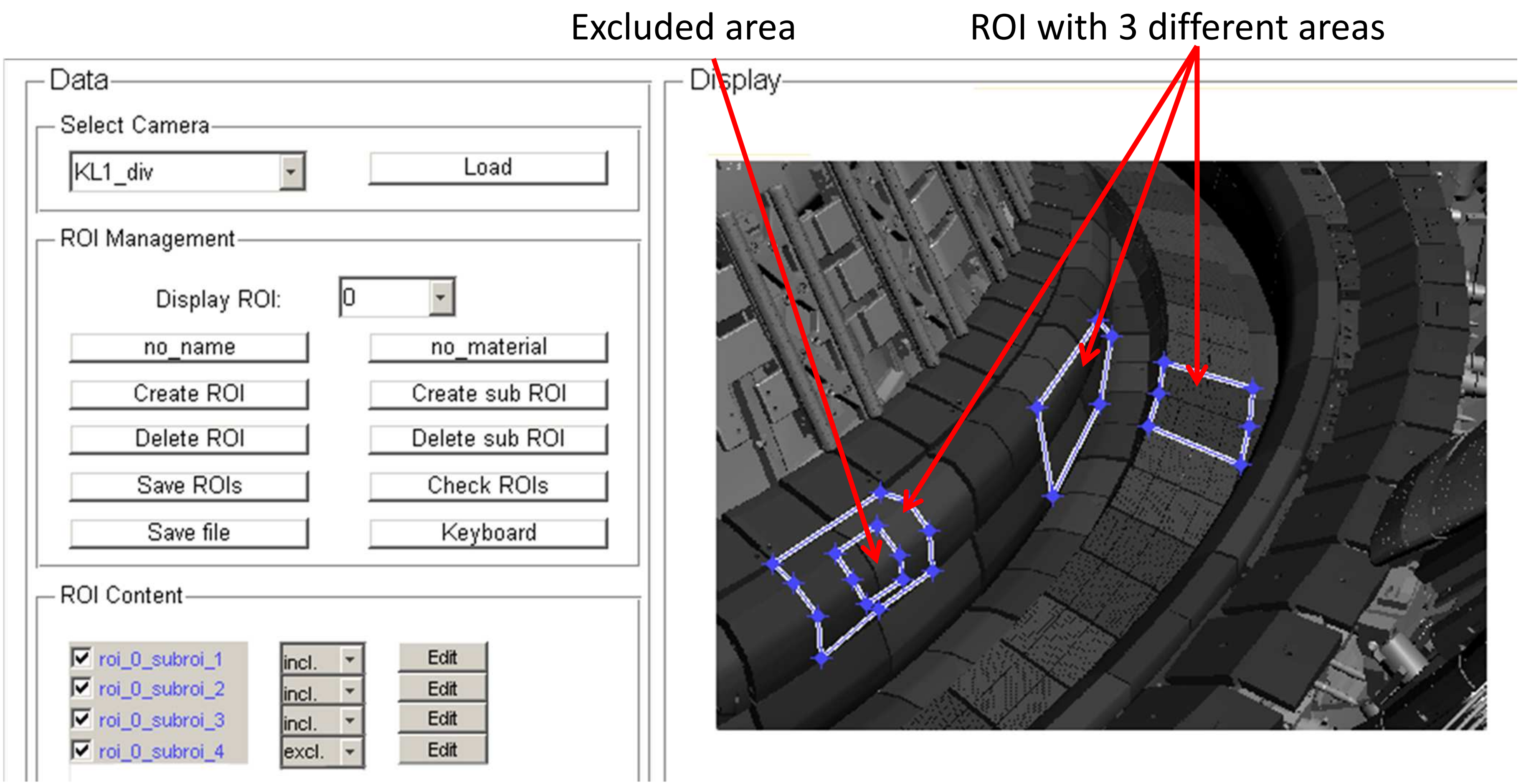
Safety system based on 3 systems

- Thermocouples

- 8 bicolor pyrometers (IMPAC: IGAR 12-LO)
  1.52 and 1.64 µm
  Temperature range 400ºC - 1277ºC

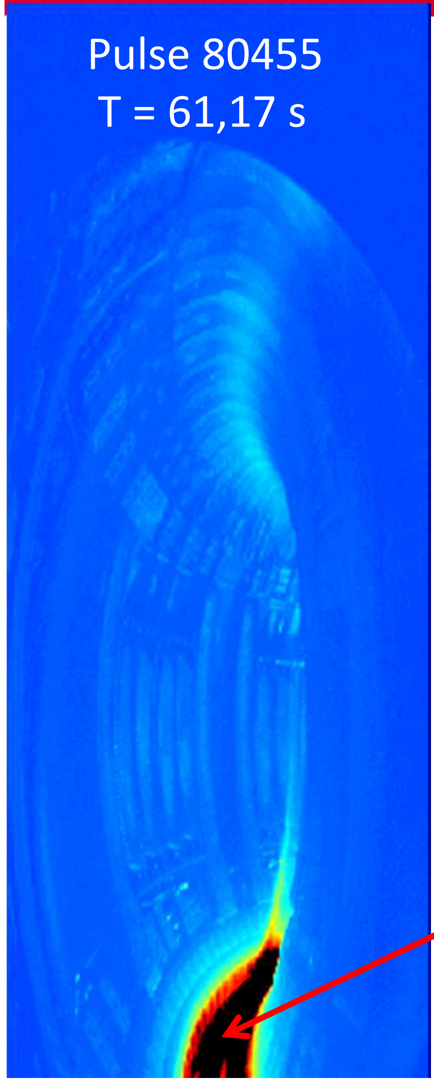
- 13 CCD Cameras equipped with filters
  λ= 981nm ; $\Delta\lambda$ = 10nm
  λ=1016nm ; $\Delta\lambda$ = 80nm

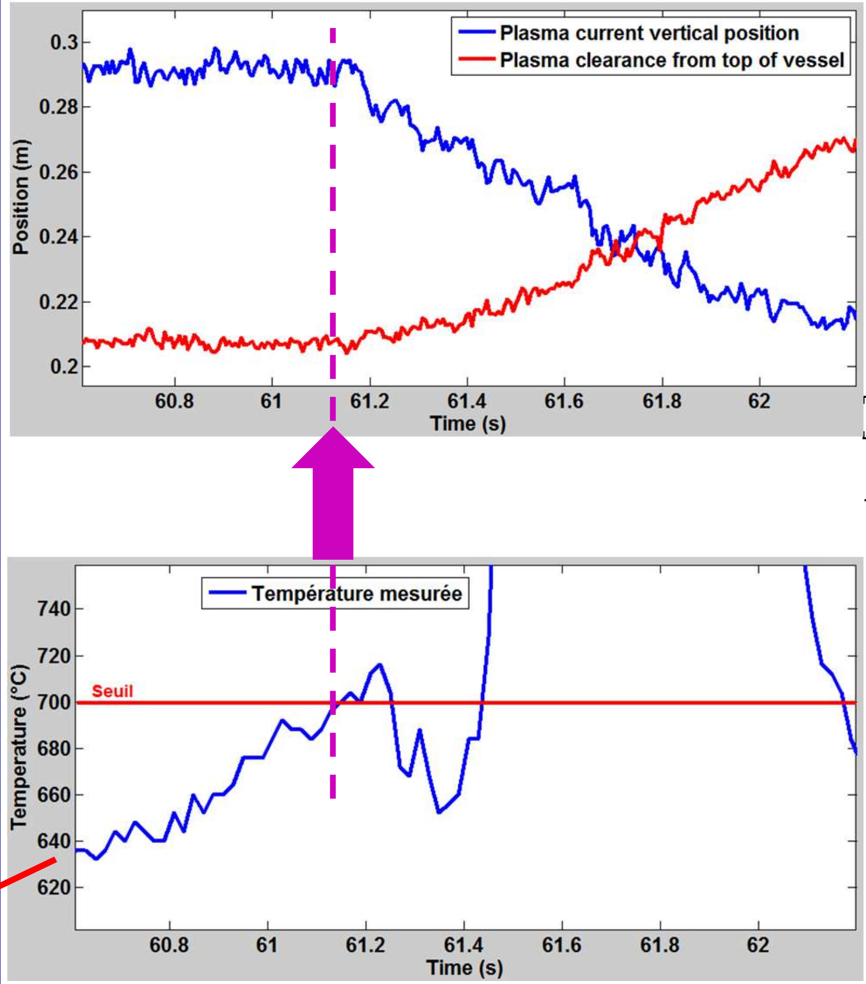
Defining ROI

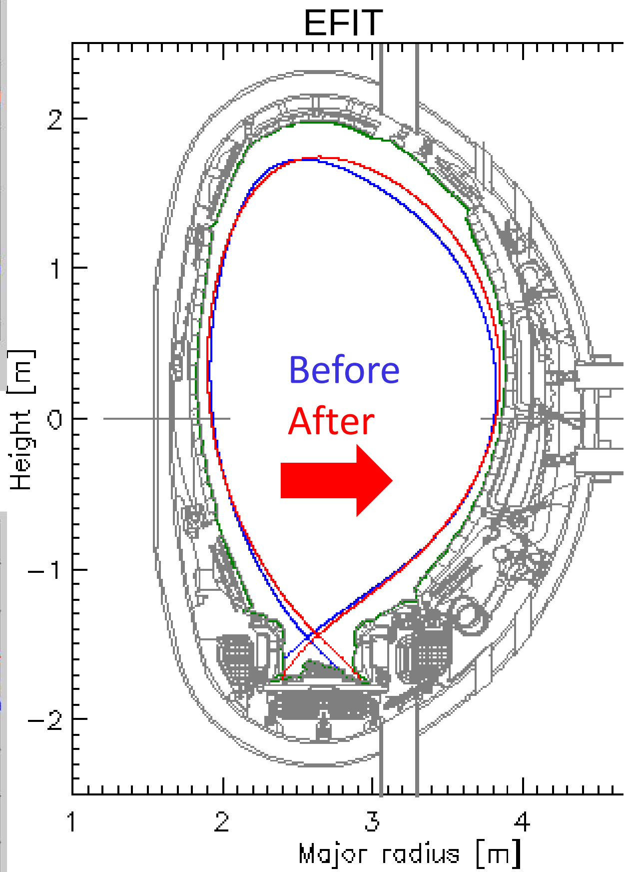


Ex: View of the divertor KL1

Commissioning





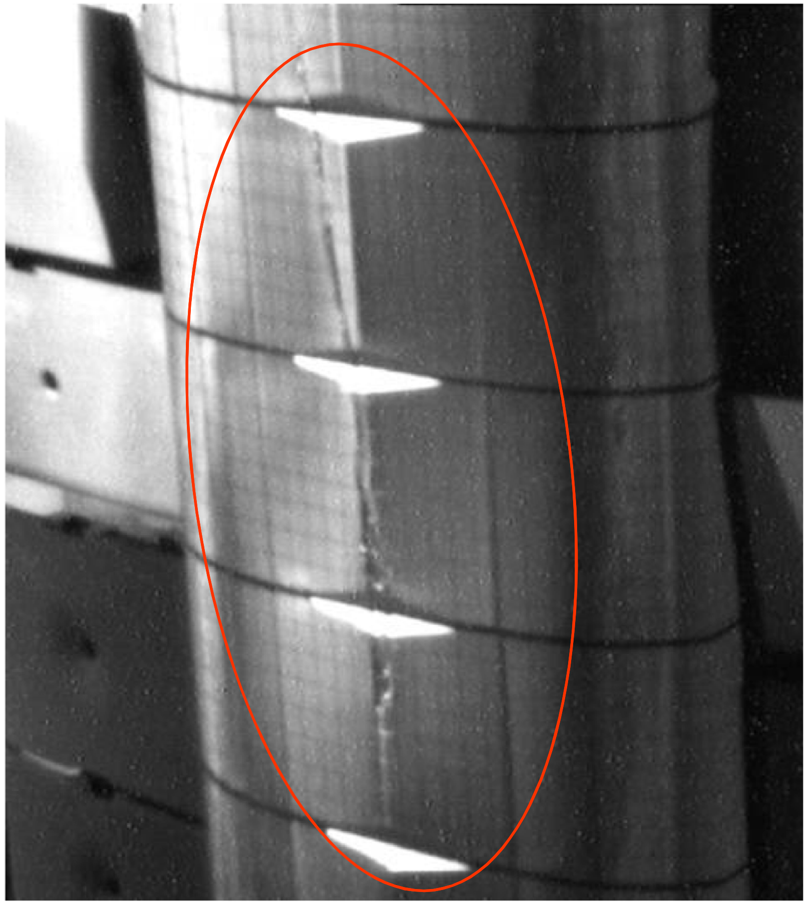


From Camera (DL) ➔ Real Time treatment ➔ Warning VTM ➔ Actuator (Plasma moved)

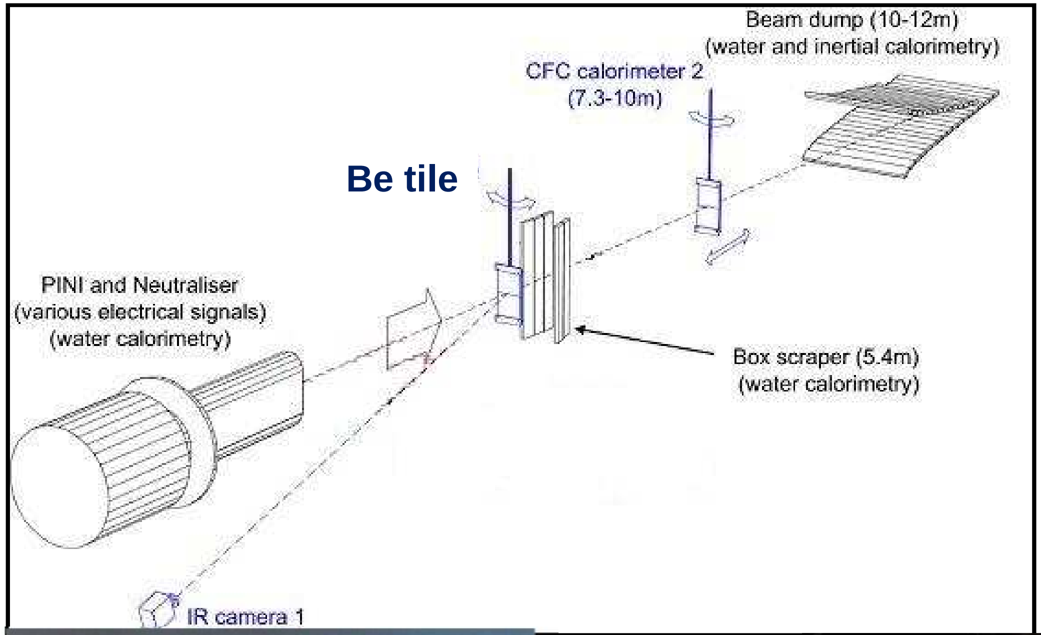
OPERATION NEAR LIMITS

- However…limits/thresholds not always detected

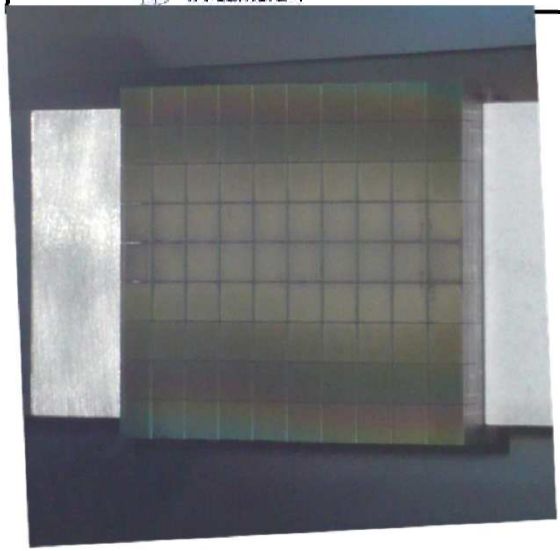
- Local melting due to off-normal events and prolonged heated limiter tests (high elongation limiter plasmas at low q_{95} with P_{IN}=5MW for 7.5s)

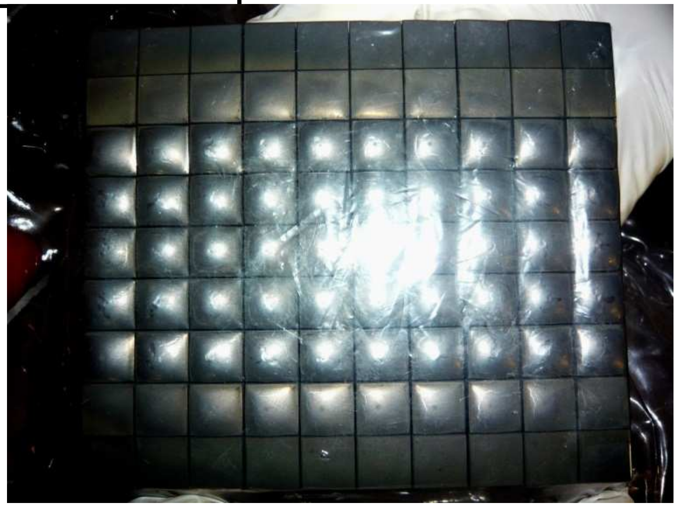


I Nunes et al., IAEA 2012

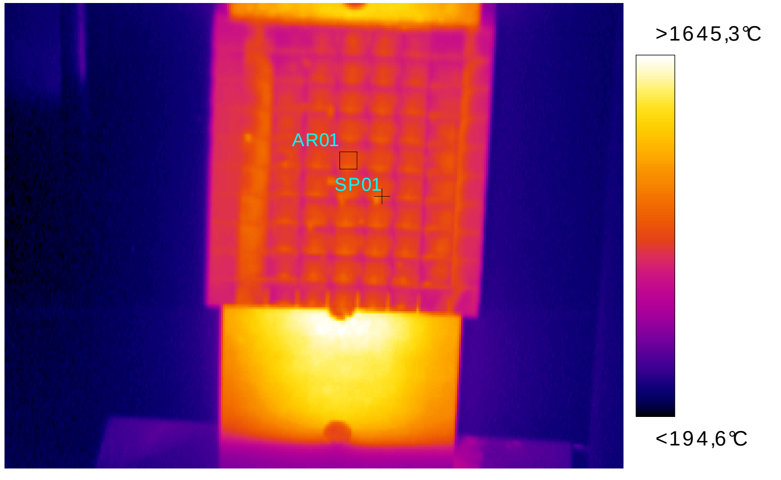


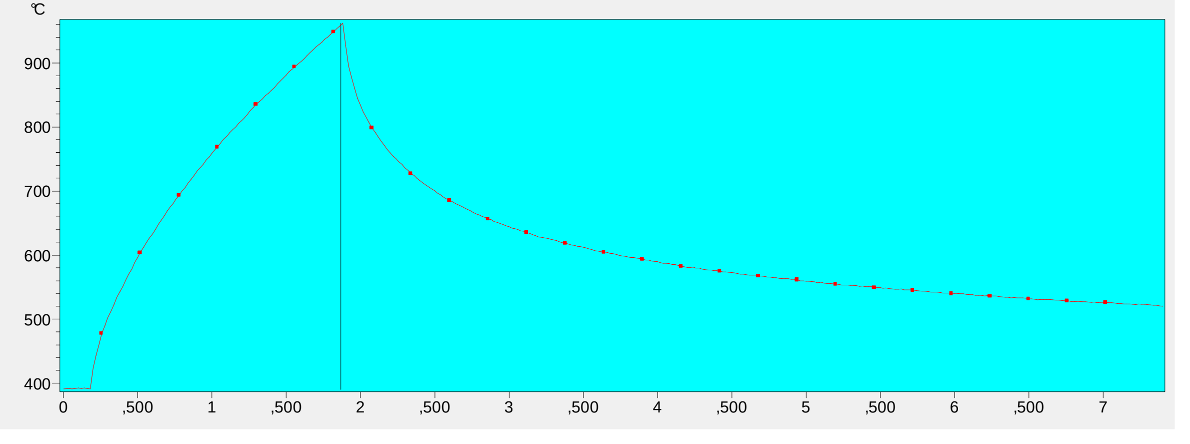
P : 2 - 7 MW/m²
t : 0-5s
To :20 - 400℃





IR IMAGE ON BE TILE





#207071

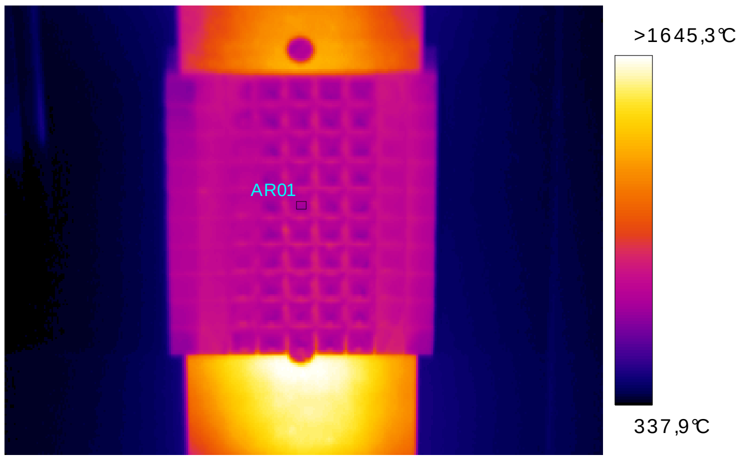
ε = 0,25

To = 370℃

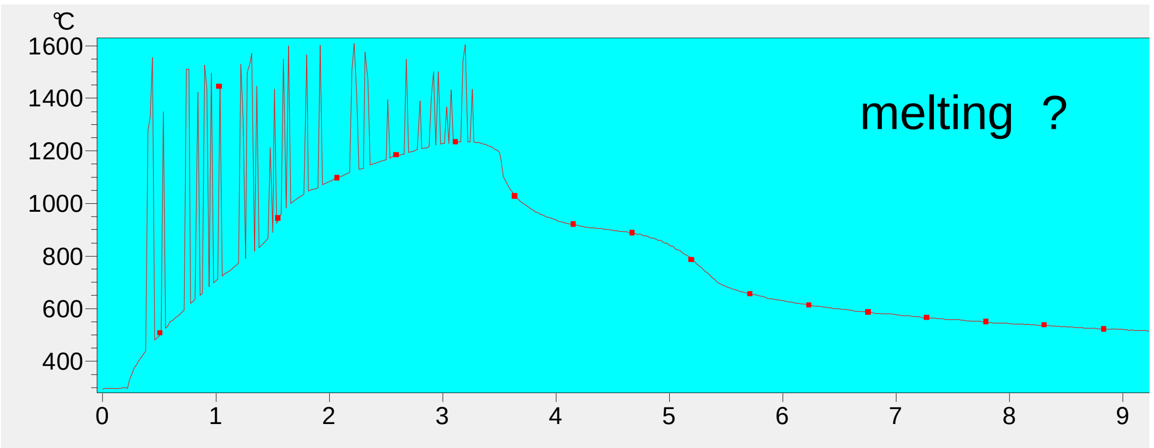
P = 5.2MW/m²

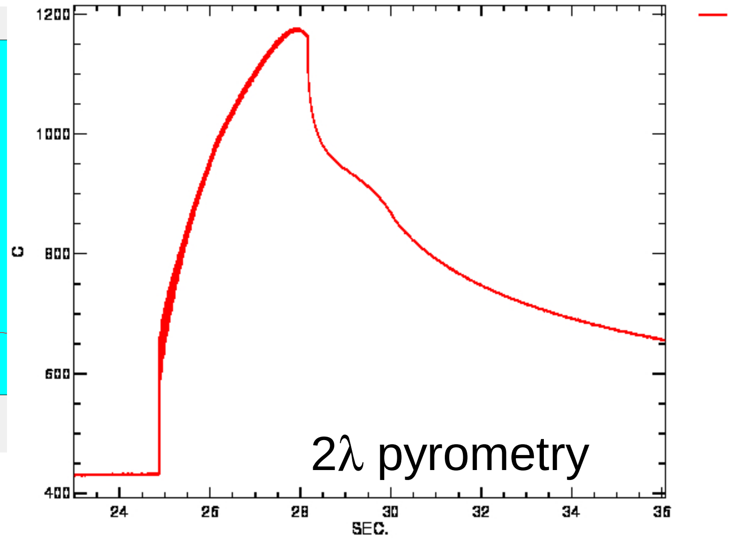
Δt = 1.7s

IR IMAGE ON BE TILE

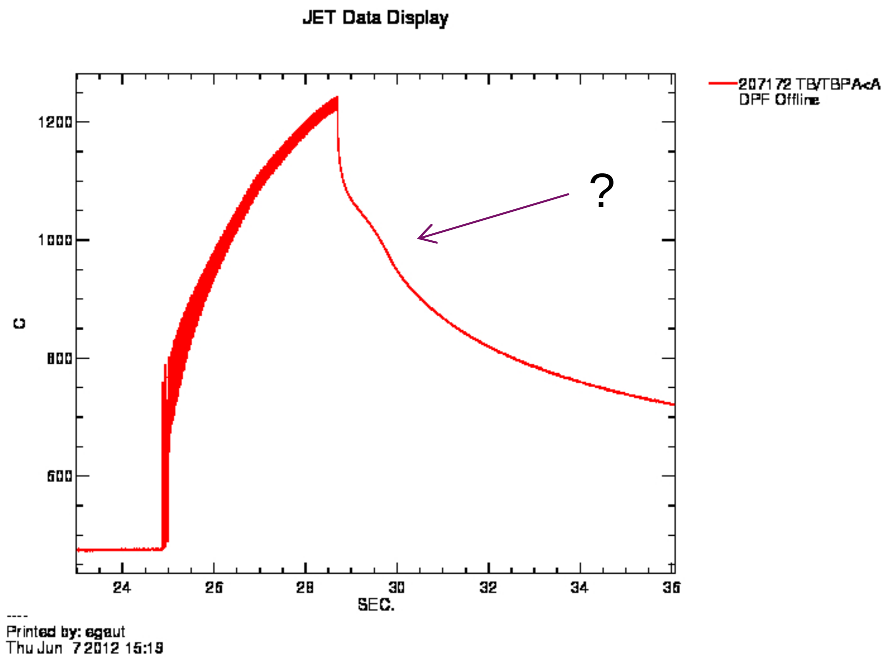


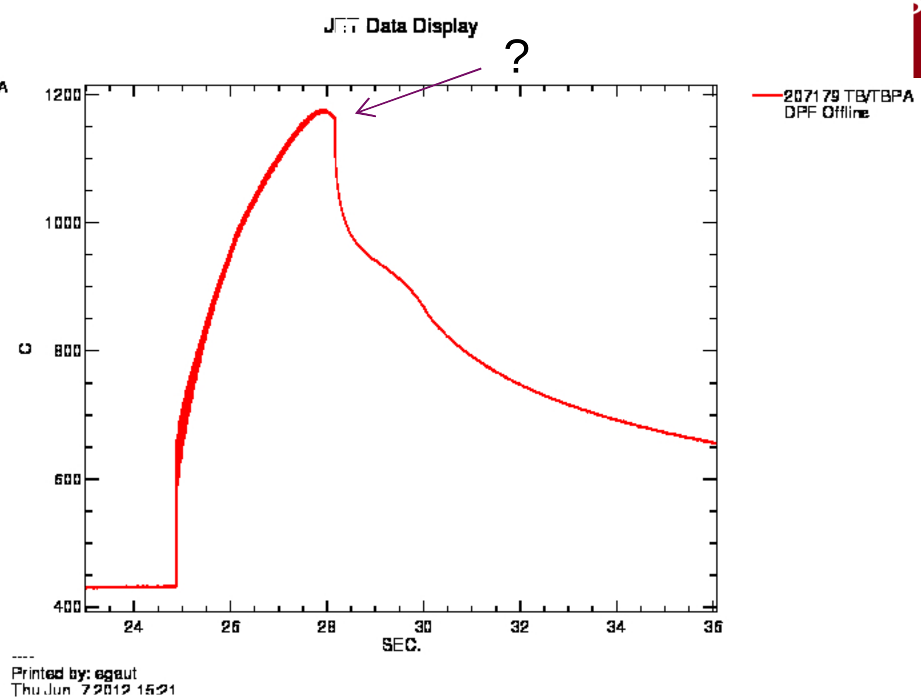
#207179
ε = 0,25
To = 470℃
P = 7.5 MW/m²
Δt = 3.3s

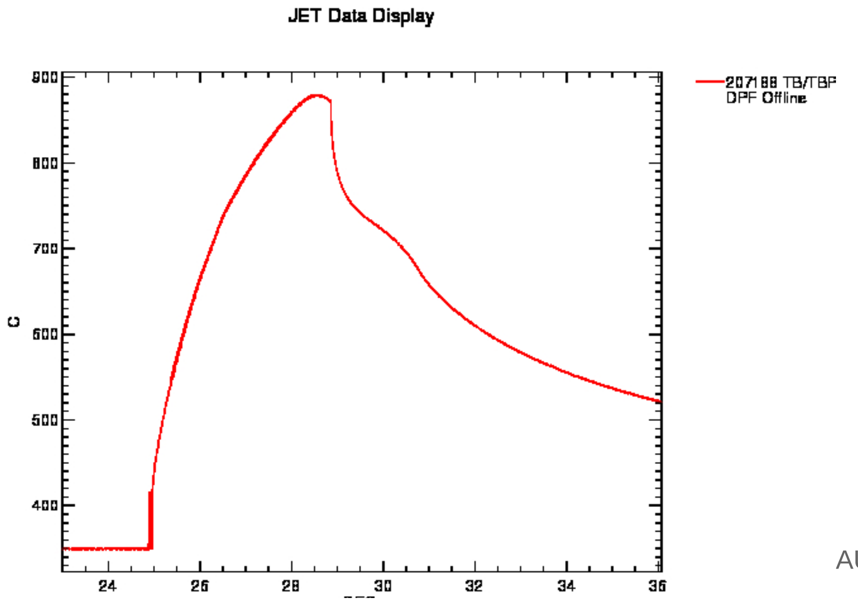


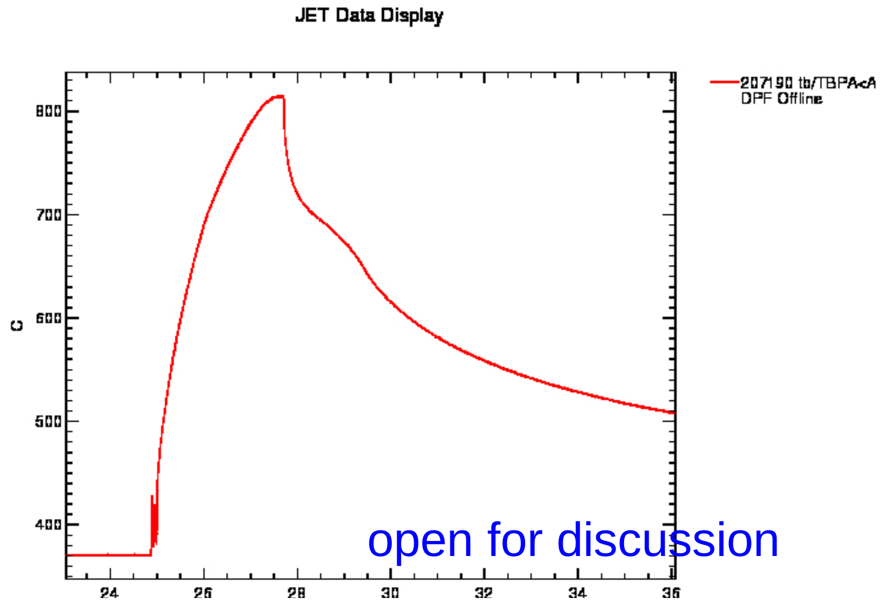


E. GAUTHIER



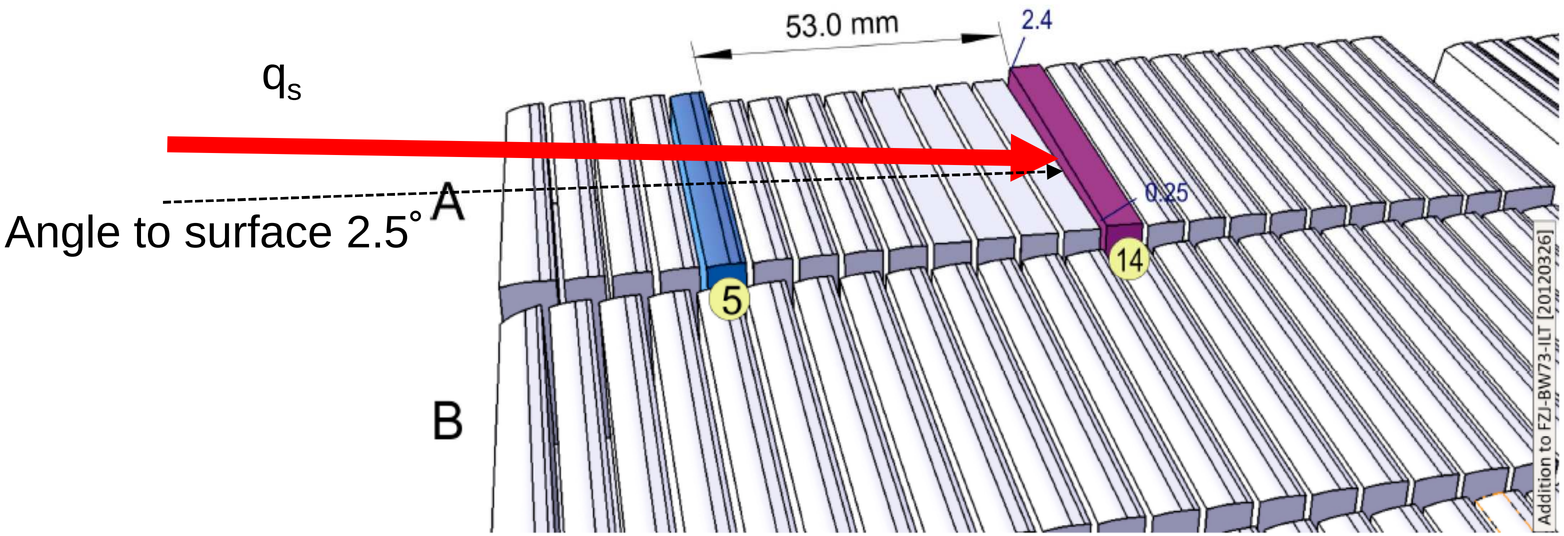


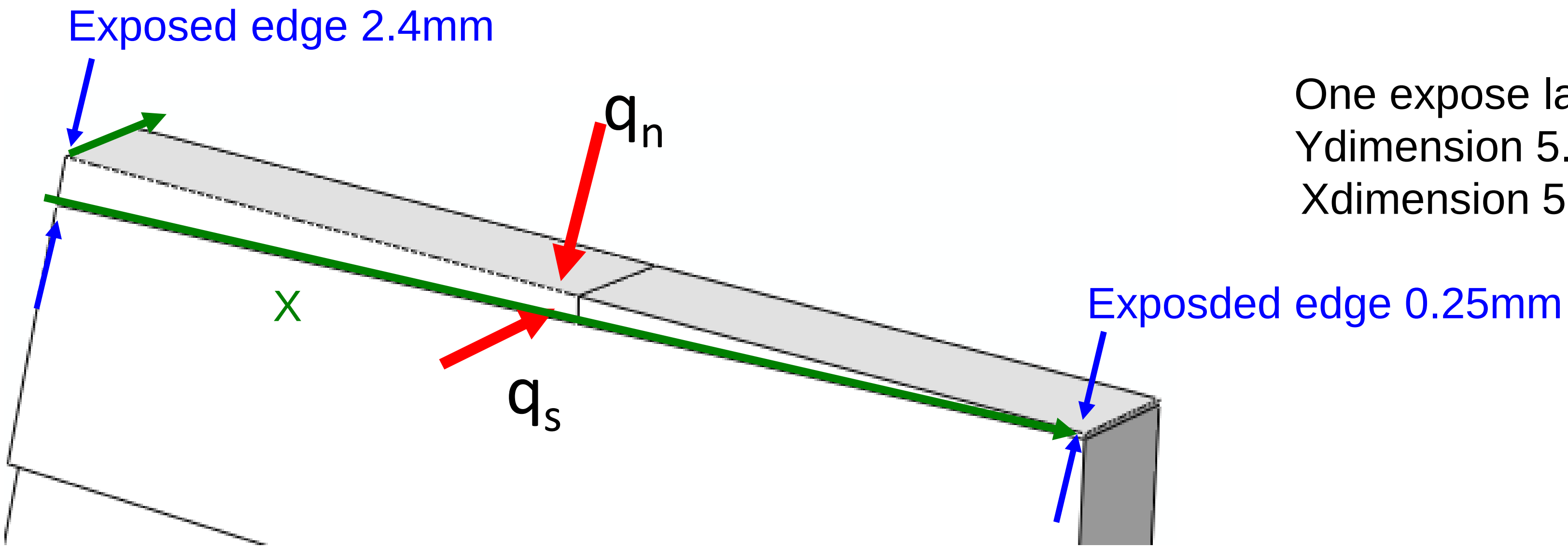




open for discussion

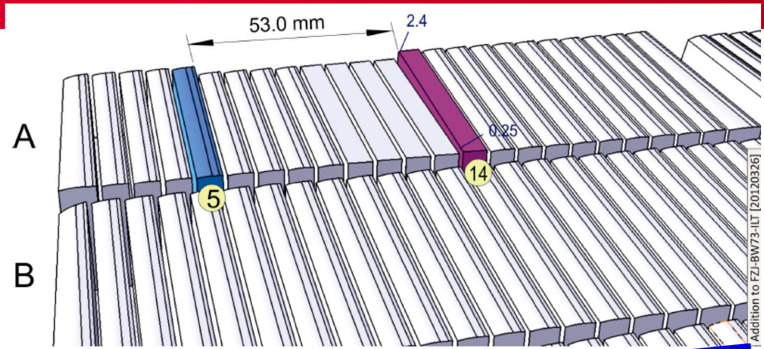
DEDICATED W MELTING EXPERIMENT



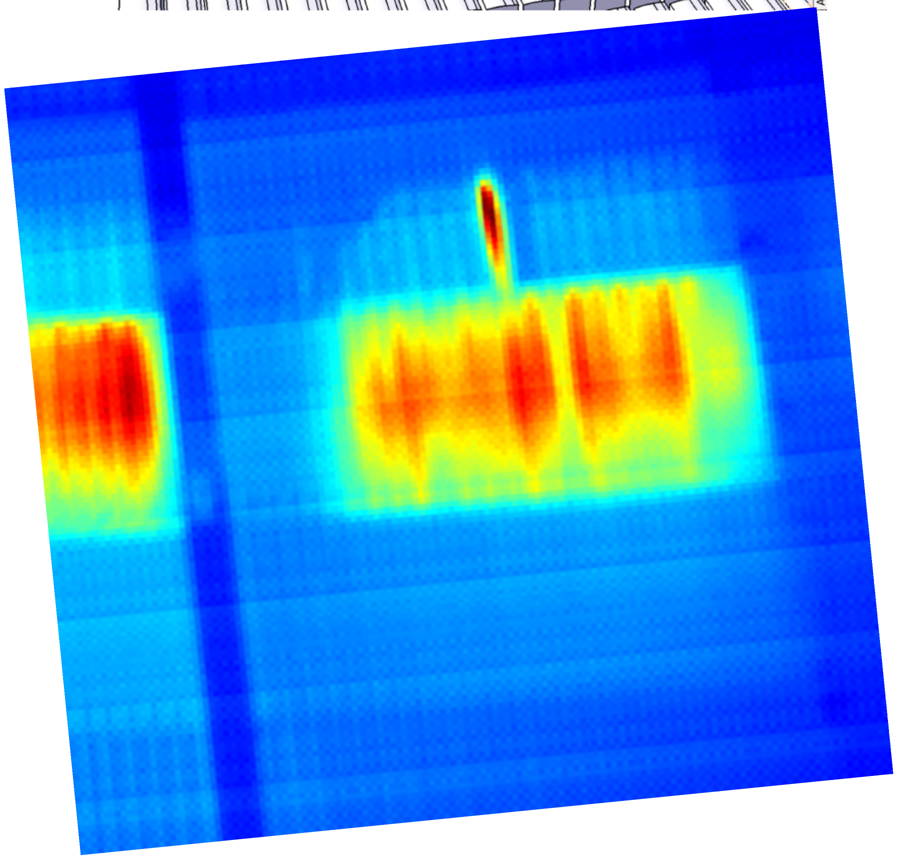


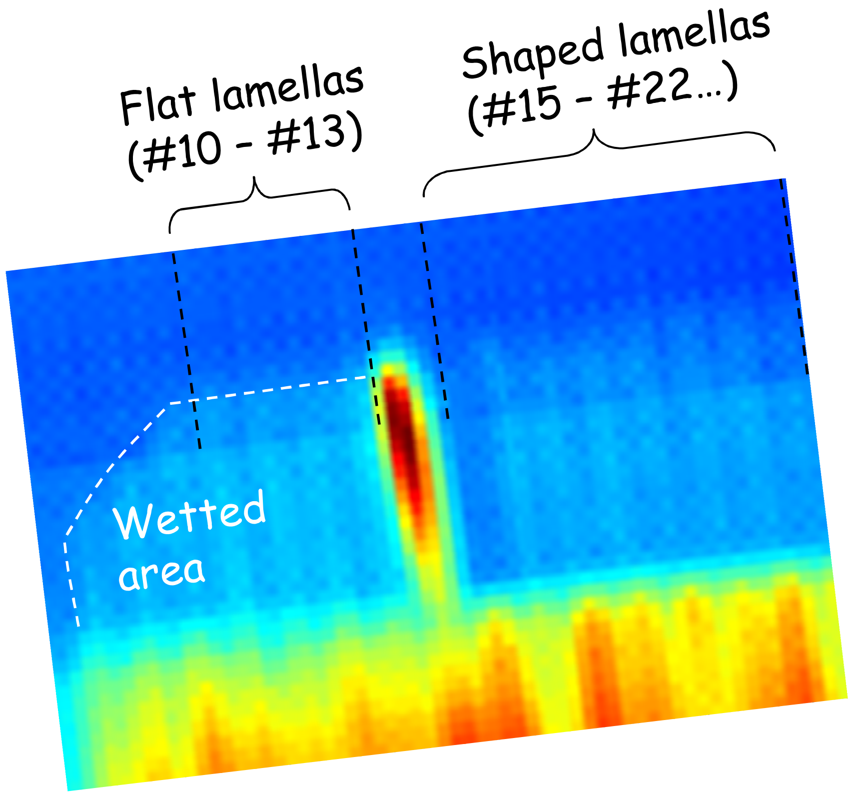
One expose lamella
Ydimension 5.9 mm
Xdimension 58 mm

DATA PROCESSING ON THE REFERENCE LAMELLAS

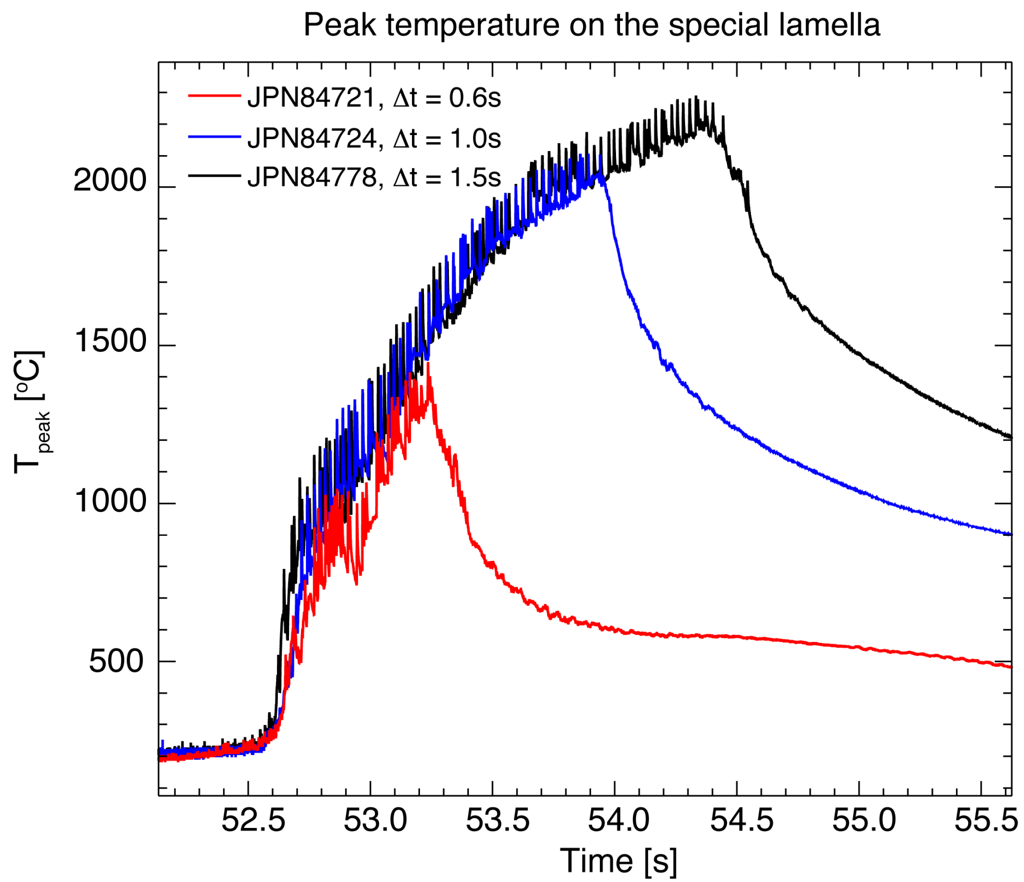


Field of view of KL9A
(L-mode, JPN 84514)





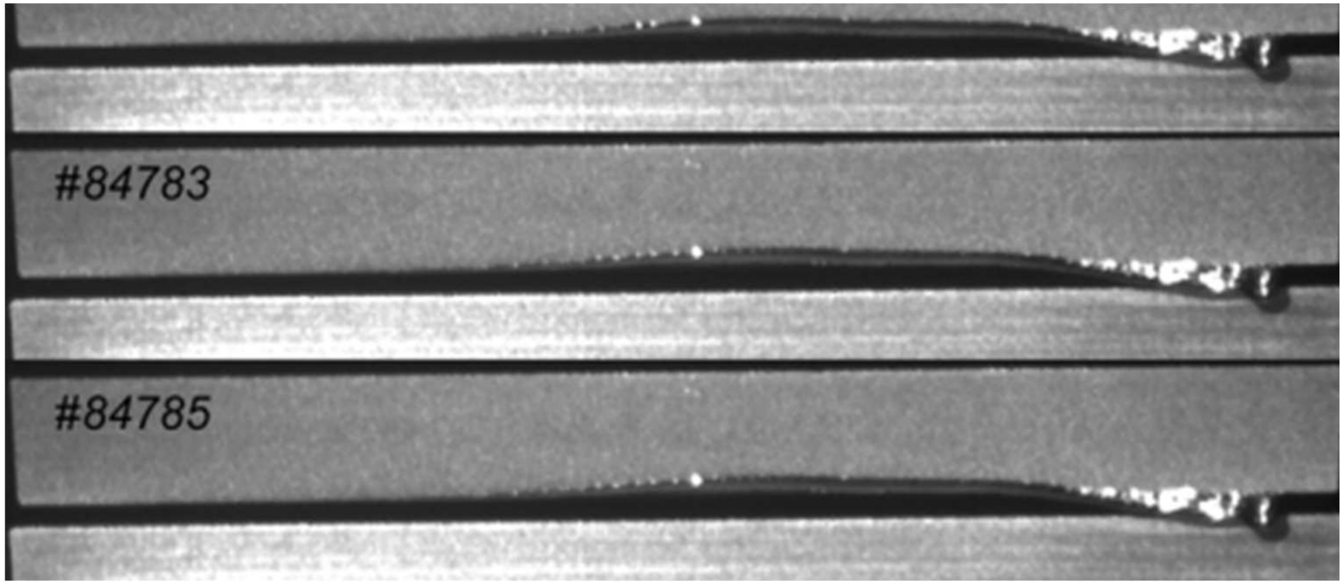
TEMPERATURE RISES



Temperature evolution on the special Lamella for three different durations. The two longest exposures showed signs of melting

JET M13-01 and M13-02 experiment

Melting experiment successful… BUT



2D sensor
(r=1.7mm, σ=0.85m)

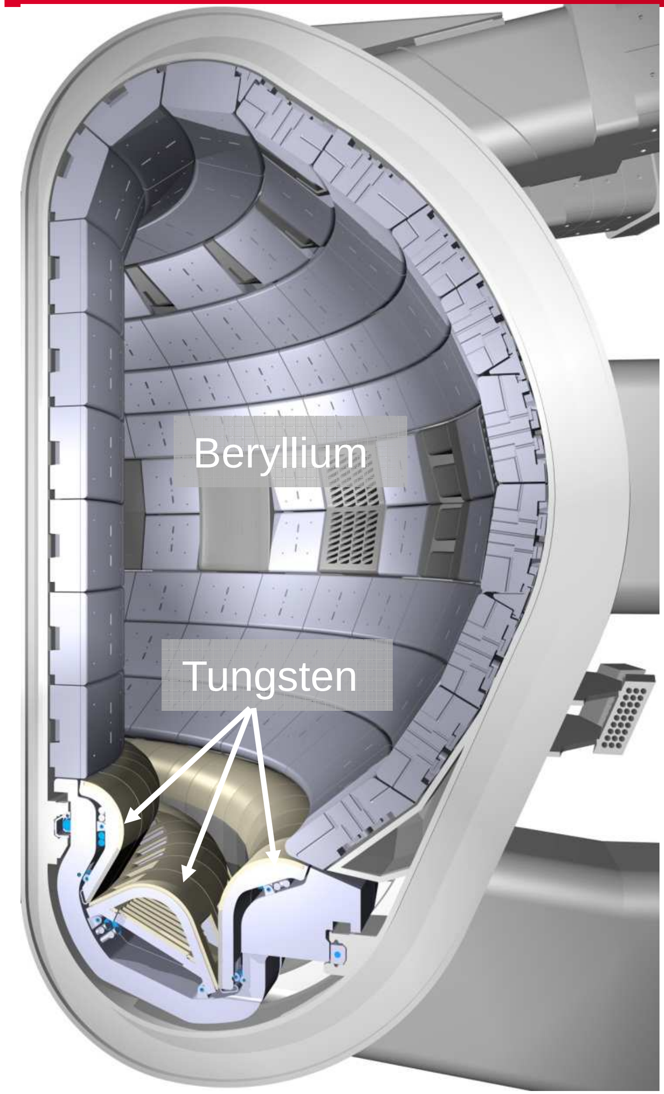
#84781 H-mode
melting W

T° measured by IR ~2300°C

T° corner ~3250°C (inter-ELM, close to melting point)

T° ~3400°C (reached during ELM and melting point reached)

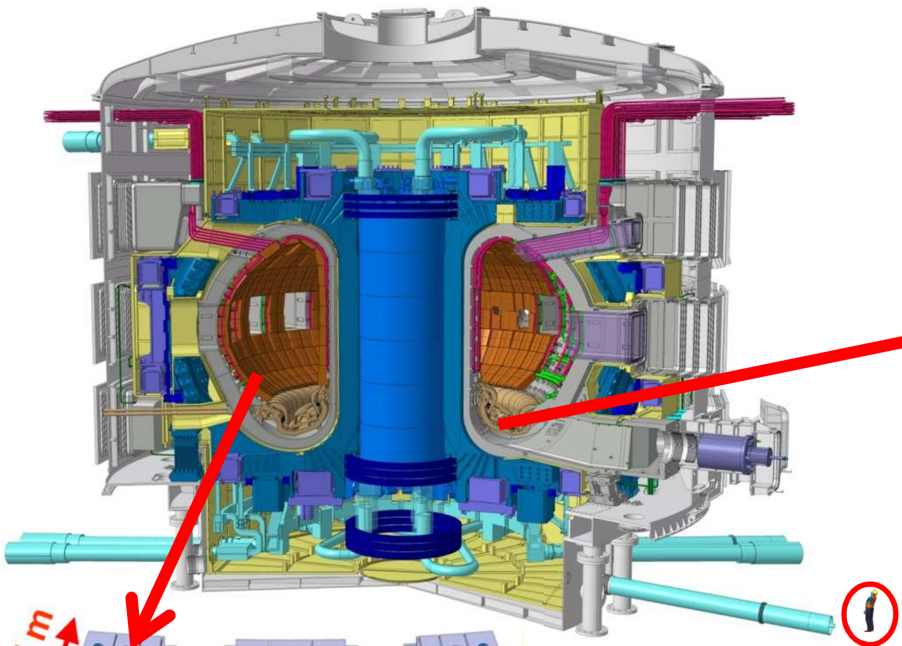
Materials for ITER

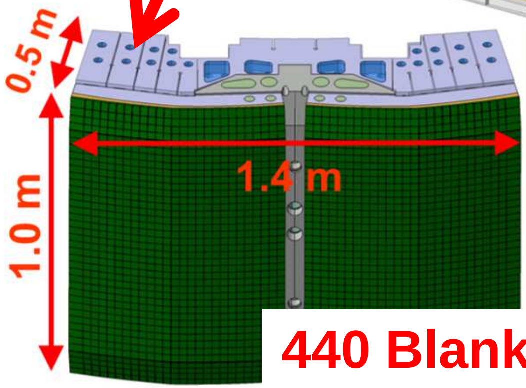


First wall : Be (700 m^2)
moderate heat flux
low Z, oxygen getter : control of impurity content
⇒ plasma performance

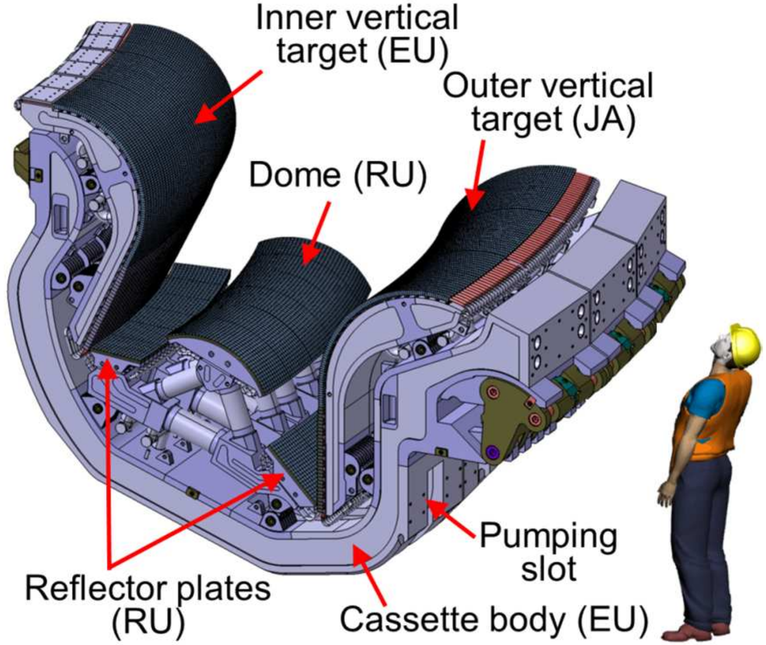
Divertor : W (150 m^2)
high heat flux
high erosion threshold
⇒ life time + T retention

ITER PFCs : changing scale





440 Blanket modules



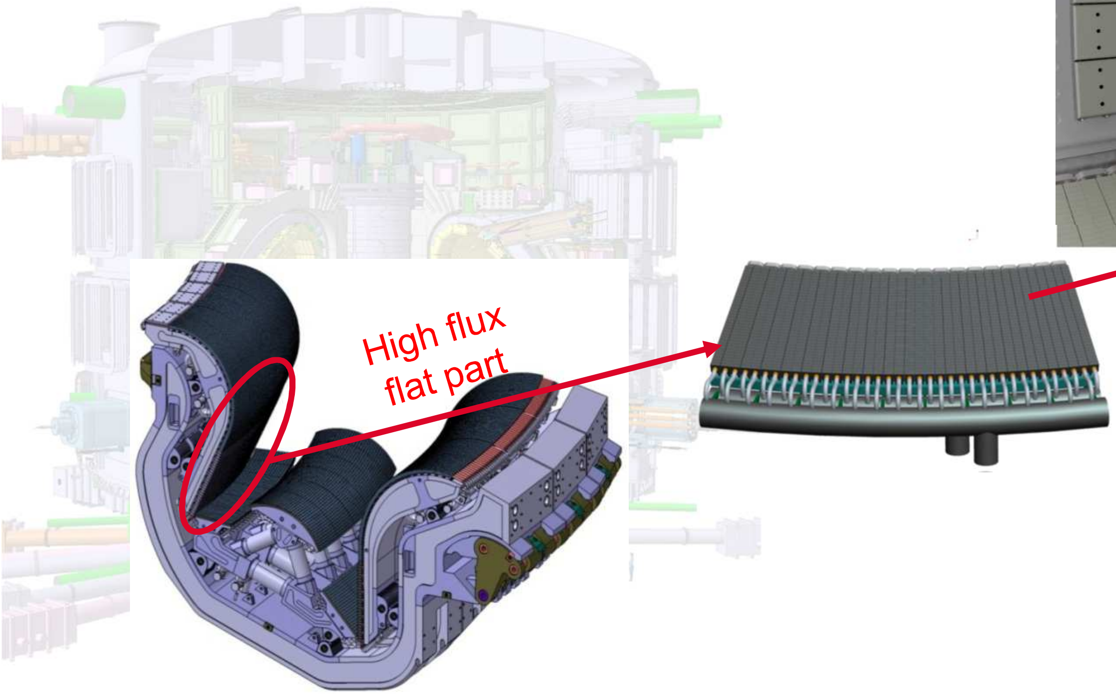
Keys figures for ITER divertor risk analysis
- *Cost > 100 M€*
- *Manufacturing: ~ 6 to 8 years*
- *Installation and commissioning*
- *ar environment : ~1 year*

Pitts, SWIP CFS, March 2013]

- **WEST : risk minimisation in support of ITER divertor strategy**

WEST : in support to the ITER divertor strategy

- WEST : scale 1 of high heat flux flat part of ITER divertor target
- >15 000 W monoblocks (~14 % ITER)

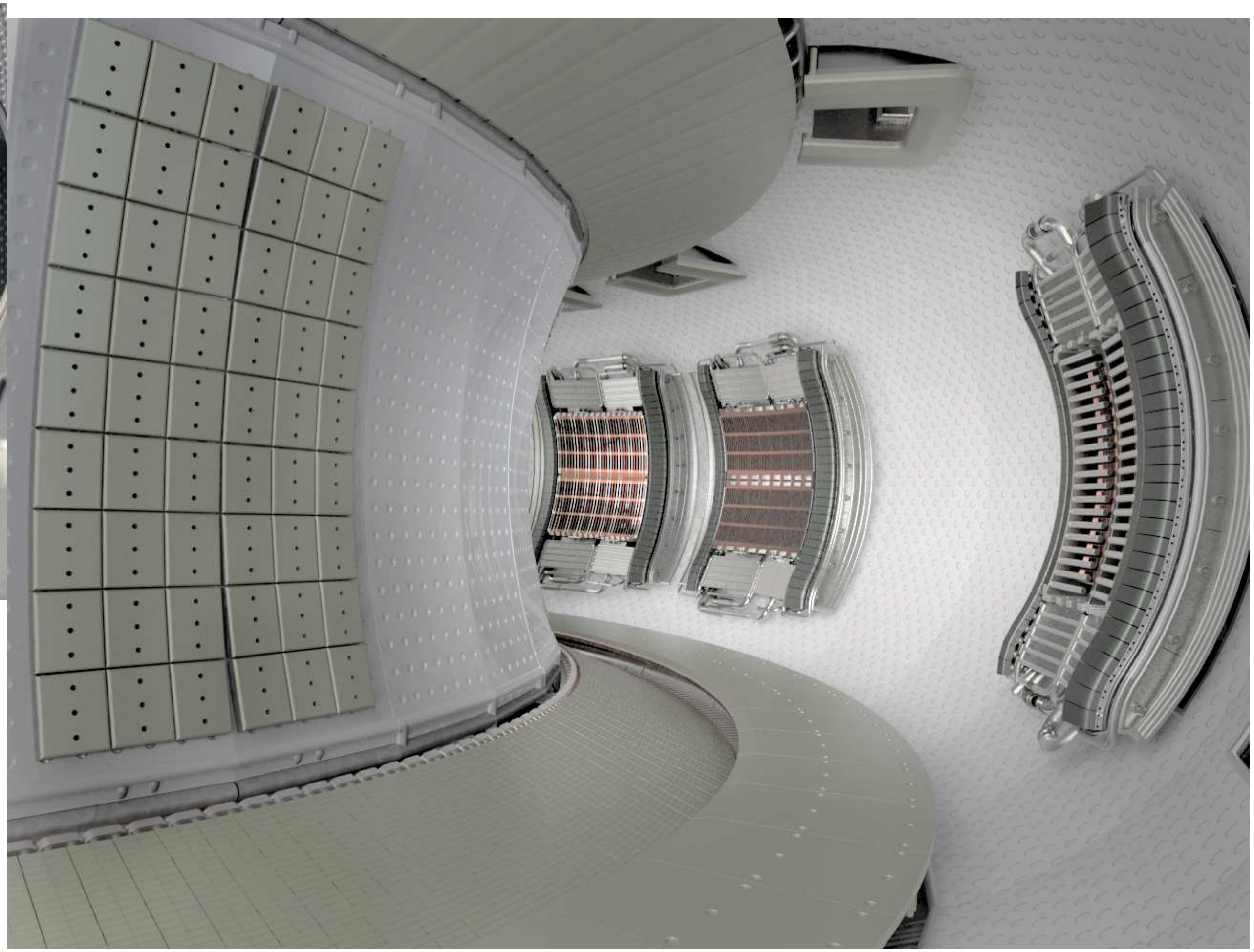


	WEST vs ITER
Monoblock geometry and shape	Identical
Assembling technology	Identical
Thermal hydraulic conditions	Identical

First integrated test in tokamak environment

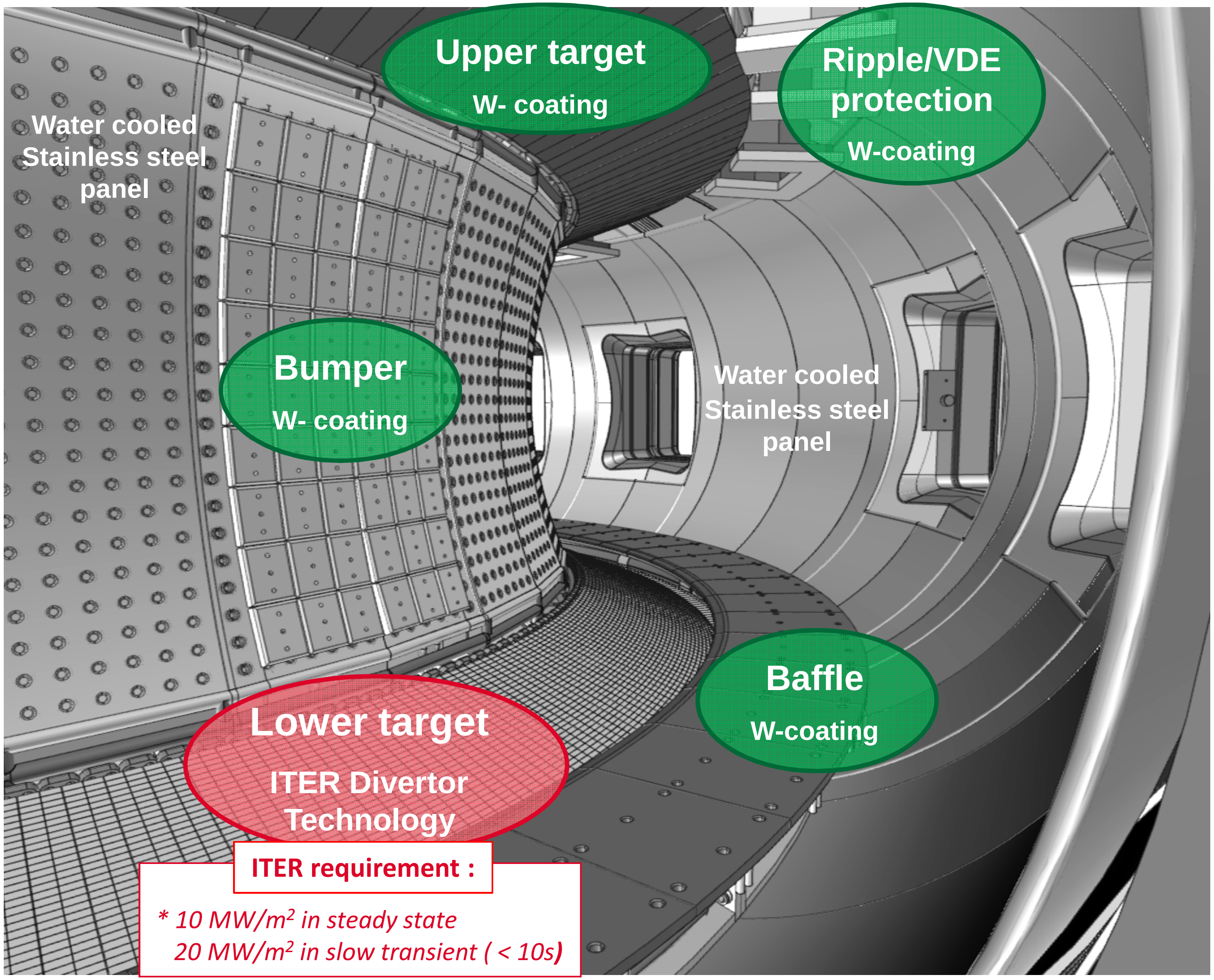
TORE SUPRA going WEST

CIEL configuration



WEST configuration

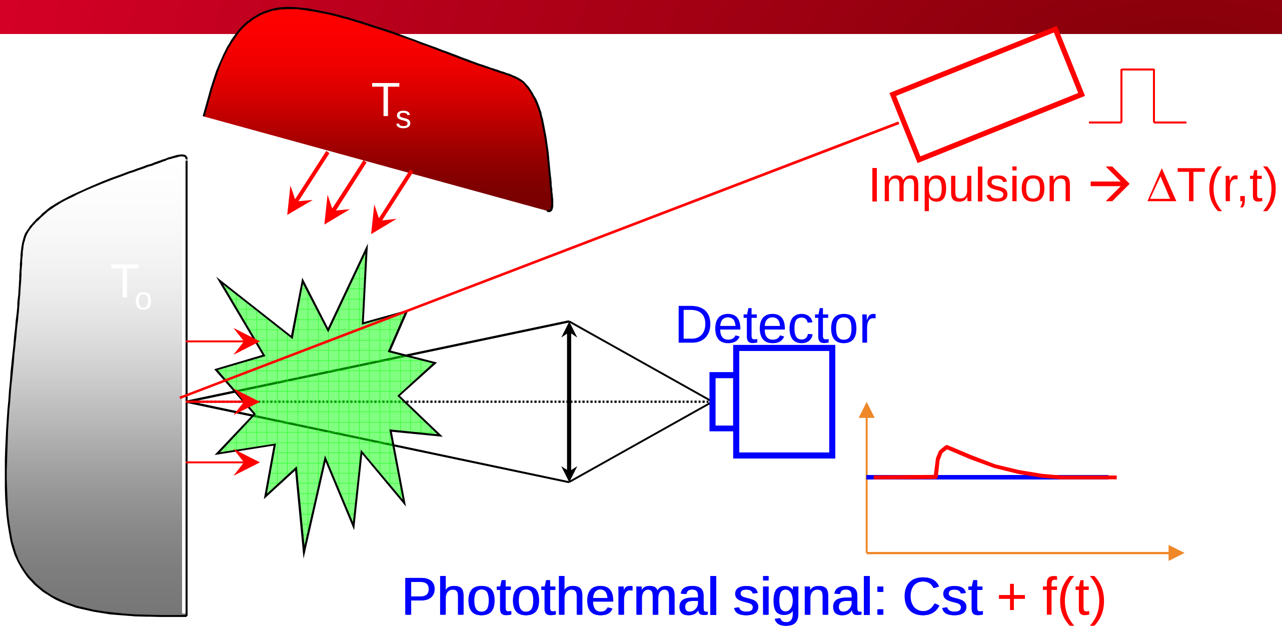
WEST Plasma Facing Components : full metallic actively cooled environment



ITER requirement :

* *10 MW/m² in steady state*
  20 MW/m² in slow transient (< 10s)

Active Pyrometry



Photothermal signal: Cst + f(t)

$$S_\lambda \;\alpha\; \underbrace{\overbrace{\varepsilon'_\lambda L^o_\lambda(T_o)}^{\text{Emission}} + \overbrace{(1-\varepsilon'_\lambda)\varepsilon_\lambda L^o_\lambda(T_s)}^{\text{Reflexions}} \; \overbrace{+ Brem_\lambda(Plasma)}^{\text{Parasitic}}}_{\text{Cst}} \; \underbrace{+\, \varepsilon'_\lambda \frac{\partial L^o_\lambda}{\partial T}(T_o)\,\Delta T(t)}_{\text{f(t)}}$$

Filtering the electrical signal

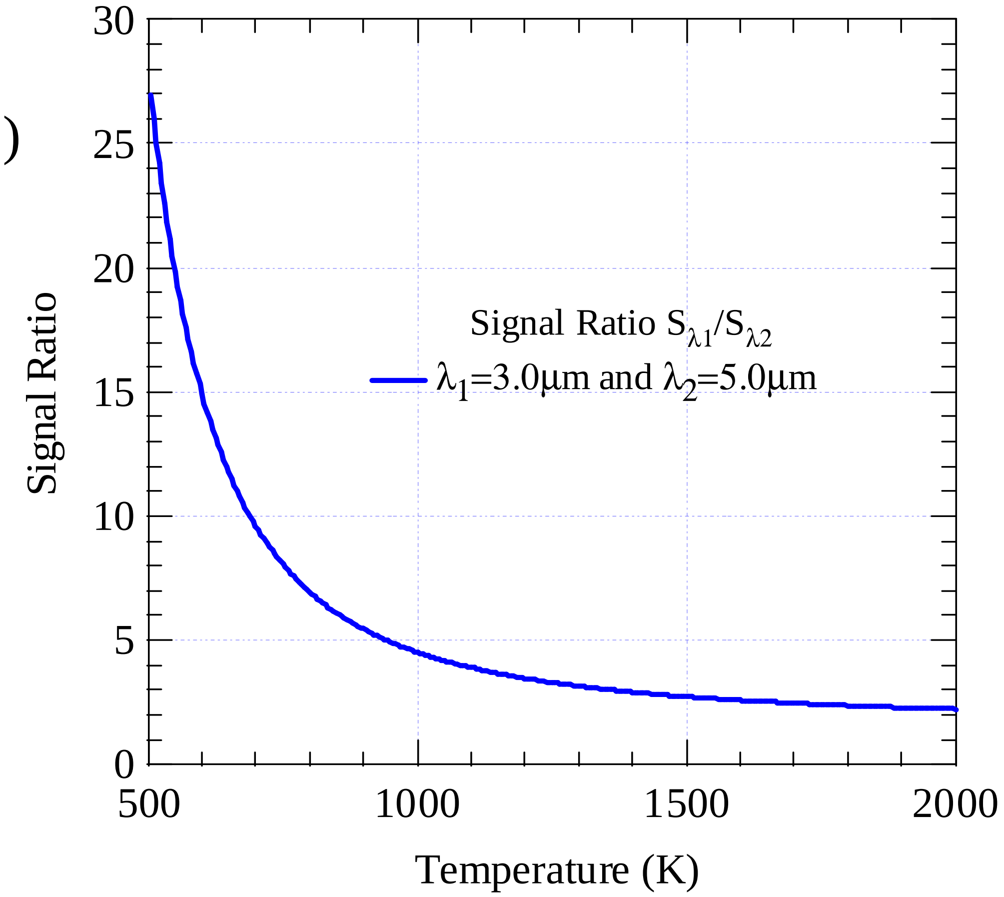
→ Separation of emission f(t) reflexion (Cst)

How to deduce T_o ?

$$S_\lambda(t) = D_\lambda \varepsilon_\lambda \Delta\Omega \tau_\lambda \Delta\lambda \frac{\partial L^o_\lambda}{\partial T}(T_o)\Delta T(t)$$

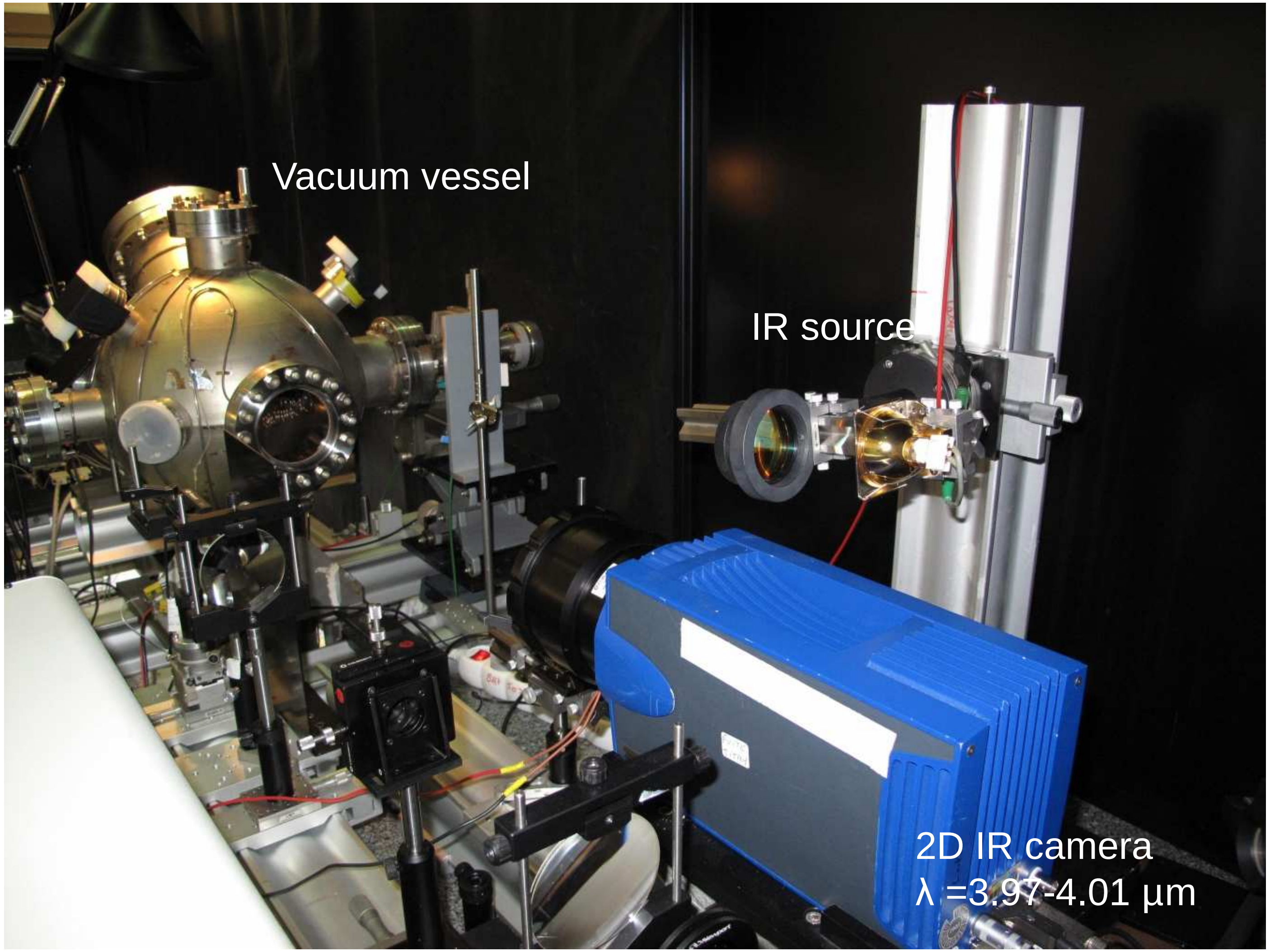
Measurement at two λ and ratio :
→ ΔT "disappears"
→ $\varepsilon_{\lambda 1}/\varepsilon_{\lambda 2}$ known

$$\frac{S_{\lambda_1}}{S_{\lambda_2}} = \frac{D_{\lambda_1}\tau_{\lambda_1}\Delta\lambda_1}{D_{\lambda_2}\tau_{\lambda_2}\Delta\lambda_2}\frac{\varepsilon_{\lambda_1}}{\varepsilon_{\lambda_2}}\frac{\frac{\partial L^o_{\lambda_1}}{\partial T}(T_o)}{\frac{\partial L^o_{\lambda_2}}{\partial T}(T_o)}$$

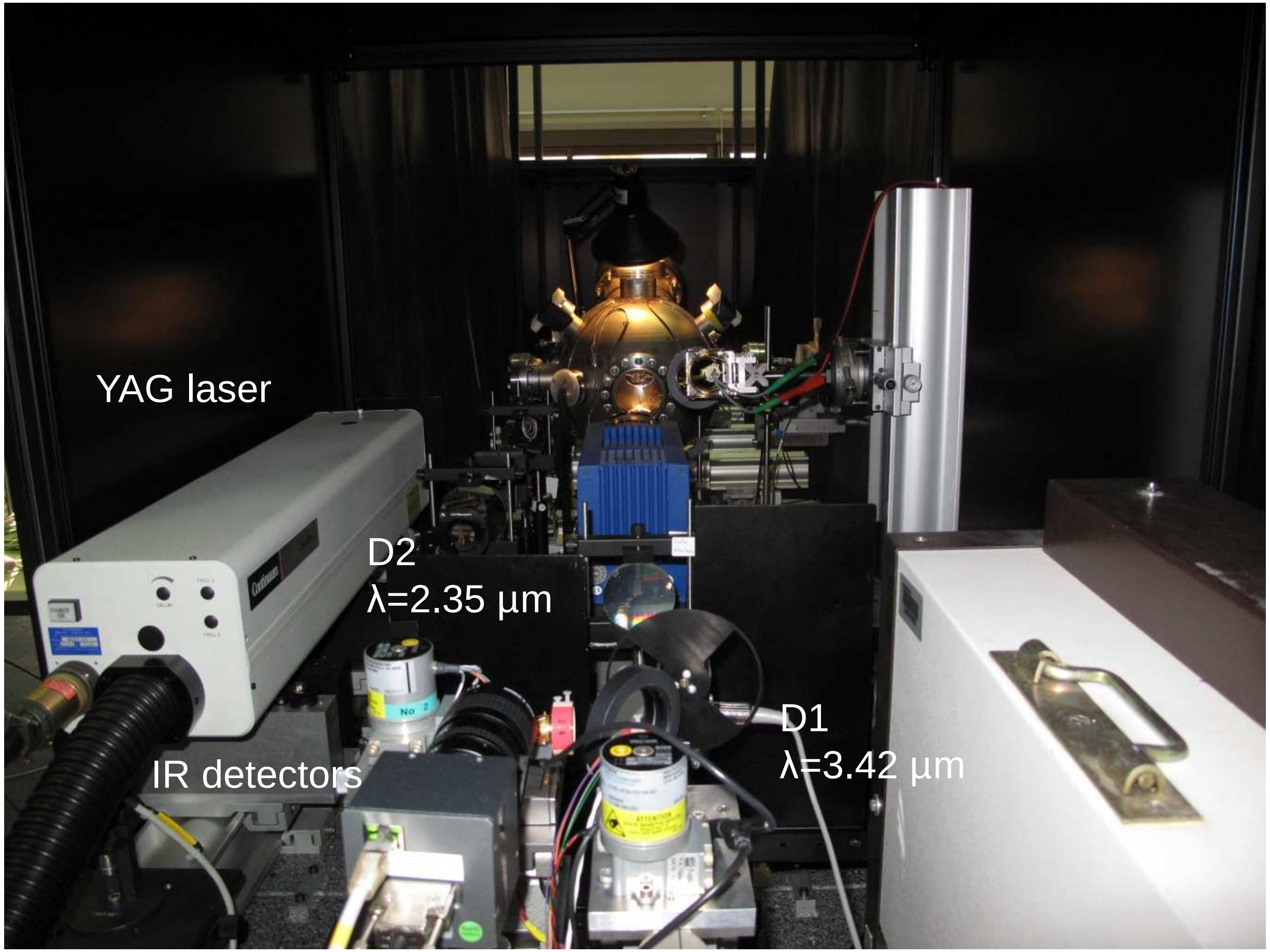


- Constant value ⇒ R = f(T_o) λ_1, λ_2 ⇒ T detection range

IR ACTIVE PYROMETRY BENCH



IR ACTIVE PYROMETRY BENCH

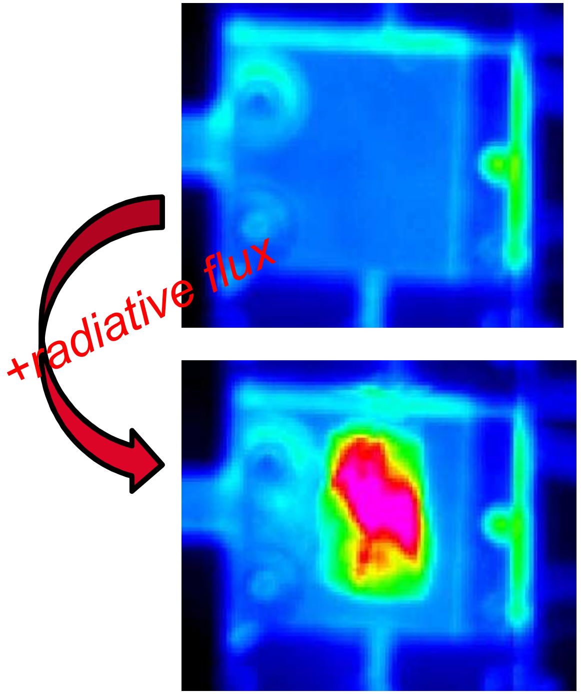


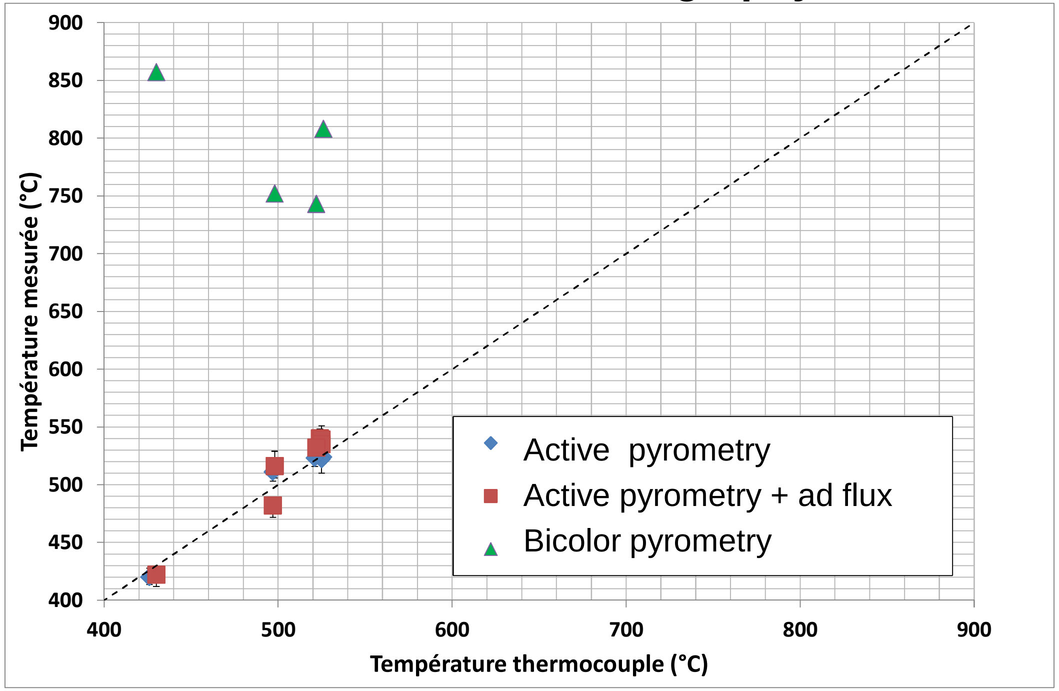
ACTIVE THERMOGRAPHY ON ALUMINIUM WITH PARASITIC FLUX

Objectif : Demonstrate active thermography unaffected by reflected flux

Material : **Aluminium** (polished)

Standard thermography IR camera, **bicolor measurements** and **active thermography measurements**





Active 2-wavelength thermography **unaffected** by reflected flux

Conclusion

- So far, Real Time control of PFC in tokamaks performed by standard IR thermography, but
- Occasional melting of Be
- Large uncertainties on surface temperature on W
- Control of PFC in ITER is very challenging
- R&D needs on accurate temperature measurement on W & Be in tokamak environment