# PERFORMANCE OF PYROREFLECTOMETRY IN REFLECTIVE ENVIRONMENT NUMERICAL ASSESSMENT

E. Delchambre, D. Hernandez*, MH. Aumeunier, E. Gauthier,
T. Loarer, C. Pocheau, H. Roche, S. Constans**

*a  CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France*
*b PROMES CNRS 8521, Centre Felix Trombe, BP5, Odeillo, F-66125 Font Romeu, France*

- **Context**
- **Principle of the method**
- **Limitation and Performance**
- **Conclusions & Perspectives**

# PYROMETRY
# CONTEXT

$T_{surf}$ required for: PFC survey, power heat load, energy balance…

In pyrometry, the major obstacles in determining the true temperature with in-situ conditions: the emissivity variation ε and the reflected flux (low emissivity).

Unknown emissivity issue:
☹ optical monochromatic pyrometry (ε=1).
😐 bicolor pyrometry: $T_{COLOR}$ hypothesis: $\varepsilon_{\lambda 1} / \varepsilon_{\lambda 2}$ known or = 1.

☺ Pyroreflectometry 2λ → Measures online $T_{TRUE}$ and ε on metallic surface *(via thermo-optical properties linked to surface state)* never been tested in high reflective environment.

Reflected flux issue:
☺ Active pyrometry → Emitted flux de-correlated from reflected one by modulating Ts with pulsed laser → $T_{COLOR}$ (hypothesis on $\varepsilon_1/\varepsilon_2$) → but $\varepsilon_1/\varepsilon_2$ required !

ITER → unknown emissivity + reflected flux

complementarity of Active Pyrometry and Pyroreflectometry.

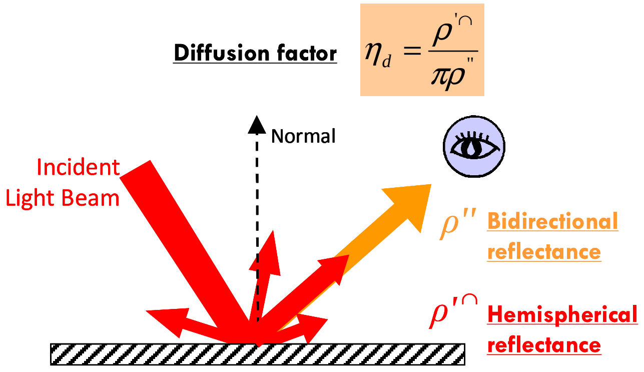
Final objective: Coupling Active Pyrometry & Pyroreflectometry for a 2D surface temperature measurement without hypothesis on emissivity and reflected fluxes

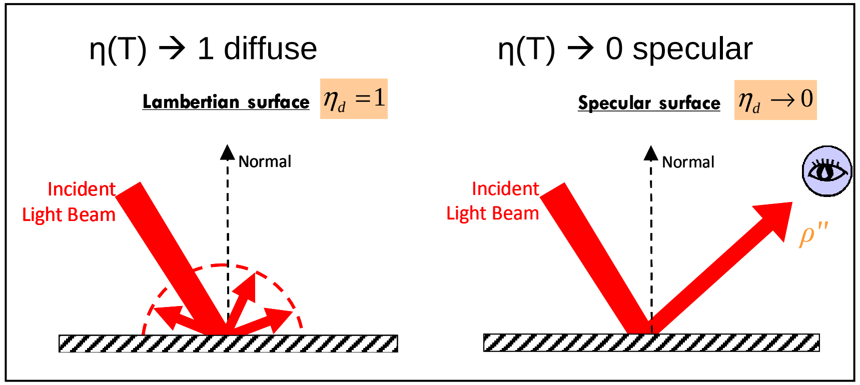
AIMS of this study: asses limitation of the pyroreflectometry method and errors in reflective environement → Numerical evaluation + experimental test ongoing

# PYROREFLECTOMETRY
## PRINCIPLE

! Introduction of η (diffusion factor)
key parameter $\eta_\lambda = \rho^{\cap\prime}_\lambda / \pi.\rho''_{\lambda\,(BRDF)}$

0< η(T) <1 : related to surface roughness





**Assumption of invariance diffusion factor with λ** : $\eta(\lambda 1) = \eta(\lambda 2) = \rho^{\cap\prime}_\lambda / \pi.\rho''_\lambda$

→ verified experimentaly on W, copper, Al, ceramics, Inconel, coating Er2O3 *[D. Hernandez et al., Measurement 42 (2009) 836-843]*

$\varepsilon_{T,\lambda} = 1 - \boldsymbol{\rho}^{\cap\prime}_\lambda = 1 - \pi.\ \eta.\ \rho''_\lambda$

$L(T_\lambda) = (1 - \pi.\eta.\ \rho''_\lambda)\ L(T_{TRUE},\lambda_\lambda)$ Planck law

Wien approximation

$1/\ \mathbf{T_{TRUE}} = 1/T_1 + \lambda_1/Cte\ .\ \ln[1 - \pi\ \boldsymbol{\eta(T)}.\ \rho''(T,\lambda_1)$
$1/\ \mathbf{T_{TRUE}} = 1/T_2 + \lambda_2/Cte\ .\ \ln[1 - \pi\ \boldsymbol{\eta(T)}.\ \rho''(T,\lambda_2)$

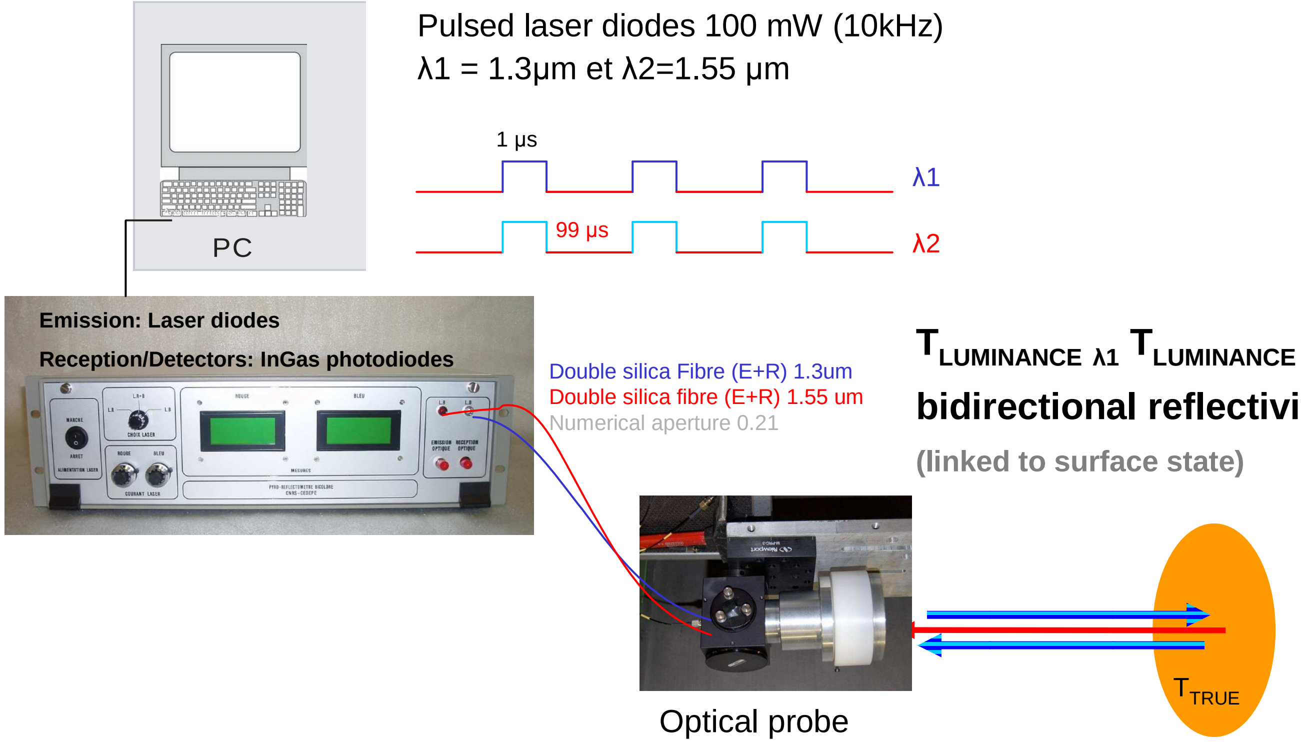
→ solvable system of 2 equations (2 unknown parameters: $T_{TRUE}$, η). Iterative calculations on η until T* is the same for both equations.

# PYROREFLECTOMETRY MEASUREMENT

$$1/\ T_{vraie} = 1/T_1 \ + \ \lambda_1/Cte\ .\ \ln[1-\pi\ \eta(T).\ \rho''(T,\lambda_1)$$

$$1/\ T_{vraie} = 1/T_2 \ + \ \lambda_2/Cte\ .\ \ln[1-\pi\ \eta(T).\ \rho''(T,\lambda_2)$$

Pyroreflectometer = 1 reflectometer + 2 monochromatic pyrometers



Pulsed laser diodes 100 mW (10kHz)

λ1 = 1.3µm et λ2=1.55 µm

**Emission: Laser diodes**

**Reception/Detectors: InGas photodiodes**

Double silica Fibre (E+R) 1.3um

Double silica fibre (E+R) 1.55 um

Numerical aperture 0.21

$T_{LUMINANCE\ \lambda 1}$ $T_{LUMINANCE\ \lambda 2}$ **(Planck ε = 1)**

**bidirectional reflectivities $\rho''_{\lambda 1}$ and $\rho''_{\lambda 2}$**

**(linked to surface state)**

**Solvable system of 2 equations 2 unknown parameters ($T_{TRUE}$ and η).**

## PYROREFLECTOMETRY

***D. Hernandez** Laboratoire Procédés Matériaux et Energie Solaire **PROMES-CNRS,** Odeillo*

❑ developped for "in-situ" measurement (metallurgy) at solar furnace (Font Romeu) by PROMES-CNRS → 500℃<Ts <3000℃ when ε is unknown.

❑ semi-industrial prototype « on shalves ». Spot measurement.

❑ method verified with solar thermal source 10 MW/m² with thermo-couple data for T, with multi-directional reflectometer for diffusion factor η invariance.

❑ tested on ASDEX for validation in tokamak environment (remote probe, laser alignment with CCD…) on W target introduced during plasma discharge → pyroreflectometry well adapted but higher laser power needed to improve ρ'' measurement.

→Following numerical assessments of limitation and performance in reflective environemenr are based on ASDEX tungsten data for simulation validation:

$\rho''(T,\lambda 2) = 0.278$ sr-1
$\rho''(T,\lambda 1) = 0.256$ sr-1
$\underline{T_{TRUE} = 938\ ℃}$
$\eta = 0.877$

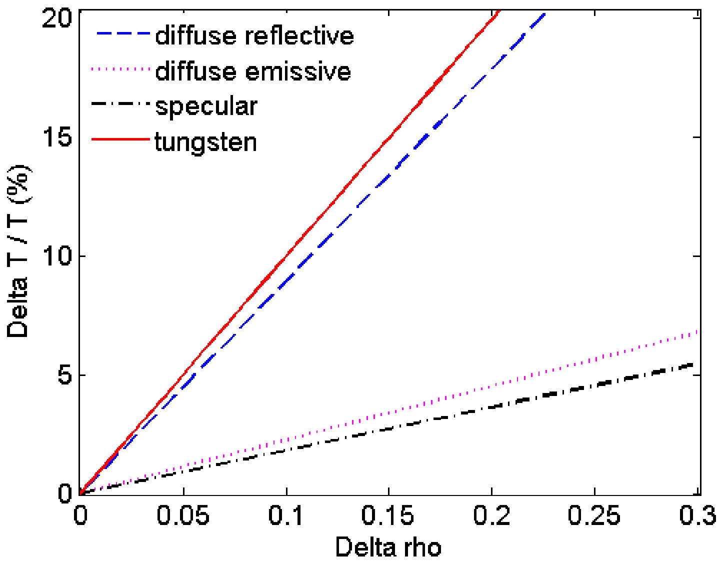
# LIMITATION

**Limitations:** 2 limiting cases for ρ measurements: low ρ (monochromatic pyrometry), grey surface → bicolor pyrometry. pyroreflectometry can verify hypothesis !

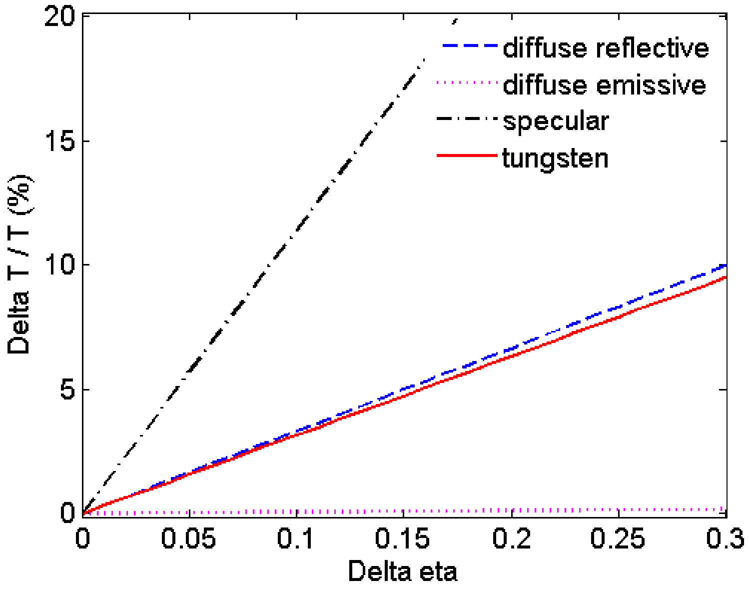
**Errors:** Sensitivity on Δρ and Δη ?

$$\frac{\Delta T^*}{T^*} = \frac{T^* \Delta T_{R,\lambda}}{T^2_{R,\lambda}} + \frac{\pi\lambda T^*}{C_2 \varepsilon^0}[\eta.\Delta\rho + \rho^{0,0}.\Delta\eta]$$

**Sensitivity on Δρ (Δη=0):**



**Sensitivity on Δη (Δρ=0):**



relative low sensitivity on Δη for W. higher sensitivity on Δρ which has to be < 0.1 to keep ΔT/T < 10 % → reliable bidirectional reflectivity measurement needed.

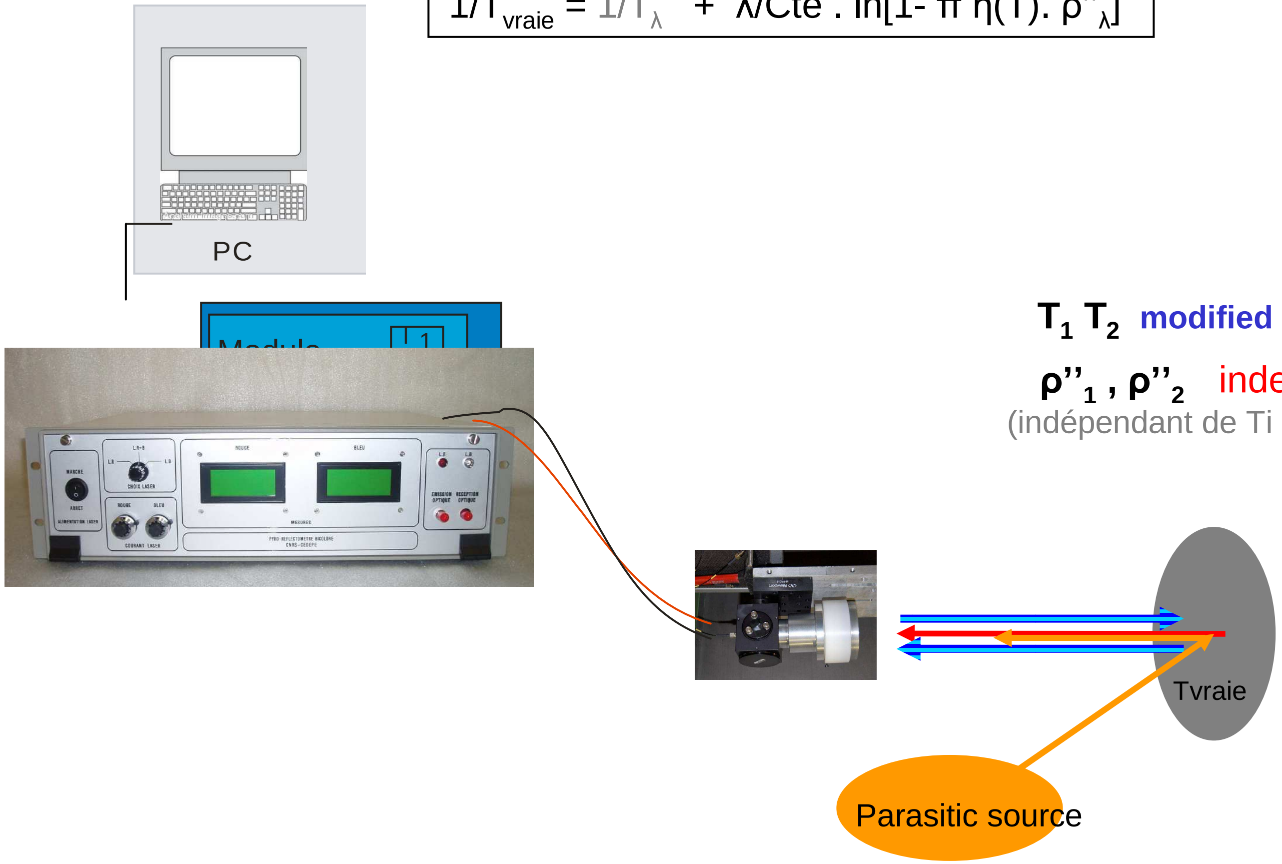
# PERFORMANCE WITH PARASITIC SOURCE – EFFECT OF REFLEXION ON T

PRINCIPLE : implement a “global temperature environment” Ti = weighted sum of parasitic sources

$$L(T_\lambda, \lambda_1) = (1- \pi.\eta(T). \rho''_\lambda) . L(T_{vraie},\lambda) + \pi. \eta . \rho''_\lambda. L(Ti, \lambda_1)$$

Reflective part

$$\boxed{1/T_{vraie} = 1/T_\lambda + \lambda/Cte . \ln[1- \pi\, \eta(T). \rho''_\lambda]}$$



**$T_1$ $T_2$** **modified by Ti**

**$\rho''_1$ , $\rho''_2$** independant from Ti

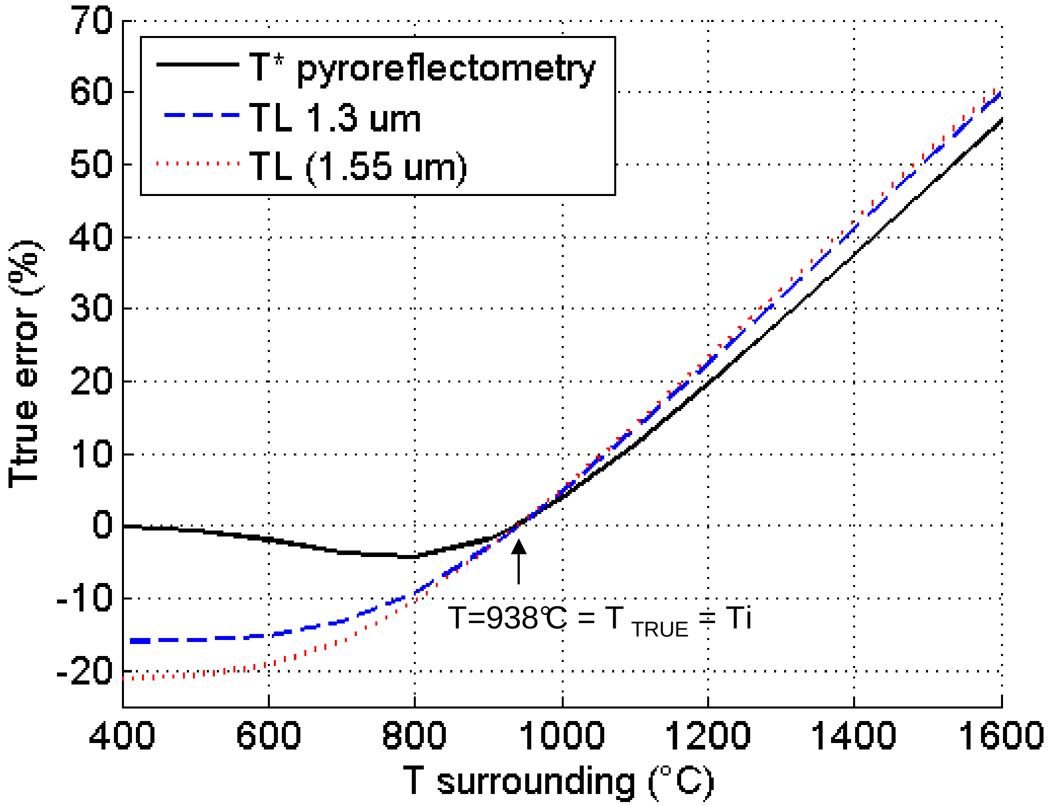
(indépendant de Ti $\rho = [S^{E+R} – S^E/S_0]\ \rho_0$)

Reflectivity reference

Effect of parasitic source 400℃<Ti<1600℃ on Ts ?

# PERFORMANCE WITH PARASITIC SOURCE

Effect of parasitic source 400℃<Ti<1600℃  on W Ts :



Other case: when observing hottest surface $T_{TRUE}$ = 1600 ℃ and $T_i$ = 800℃ et 1100℃. In the case Ti < $T_{TRUE}$:  T recovered is under-estimated respectively at  ~ 1 % and ~ 2 %

→ Pyroreflectometry could be adapted for Ti < Ts (for highest T compared with environment)

## CONCLUSIONS

### Pyroreflectometry in current state:

❑ Allows to measure on line, the evolution of the reflectivity (→ surface state & ε) and to determine the $T_{TRUE}$ even when ε is unknown.

❑ For W: higher sensitivity on Δρ than Δη (→ needs reliable ρ measurement)

### Performance in reflective environment:

❑ over-estimation when $T_{surrounding} > T_{TRUE}$.

❑ method seems well adapted when $T_{TRUE} > T_{SURROUNDING}$. Relative low under-estimation $T_{vraie}$ < 5%. adapted for hotest surface.

❑ ρ'' independent with Ti → can be used in Active Pyrometry.

### Perspectives:

❑ Introduction of a global T environment $T_i$ and of a third λ but simplification of surrounding radiation by single Planck emission needs to be verified.