PROMES (Odeillo) Main Goals in Temperature Measurements (Optical Pyrometry)

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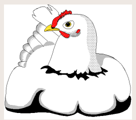
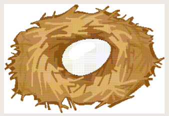
1 Solar Blind Pyrometry

2 Determination of the true temperature

$$S(\lambda,T) = K\,[(1-P)\,[\varepsilon'(\lambda,T)\,L^{\circ}(\lambda,T) + \Sigma_i\,\rho^{i,'}(\lambda,T)\,L^{i}(\lambda) + \Sigma_j\,\tau^{j,'}(\lambda,T)\,L^{j}(\lambda)]]$$

Losses **Emission** **Reflection** **Transmission**

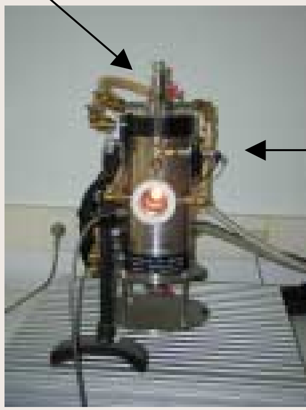




CALIBRATION DEVICES

$$S(\lambda,T) = L°(\lambda,T)$$

Comparizon with a certified pyrometer on industrial 'black body'



Graphite
Tmax = 2700°C
Inerte atmosphere

Diaphragm equipped
Tmax = 1200°C

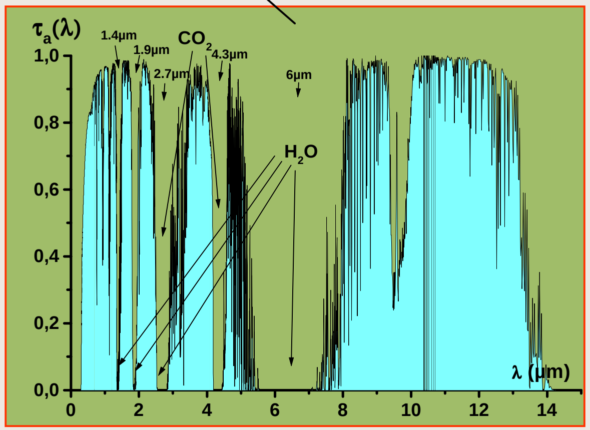
$LaCr_2O_3$
Tmax=1700°C

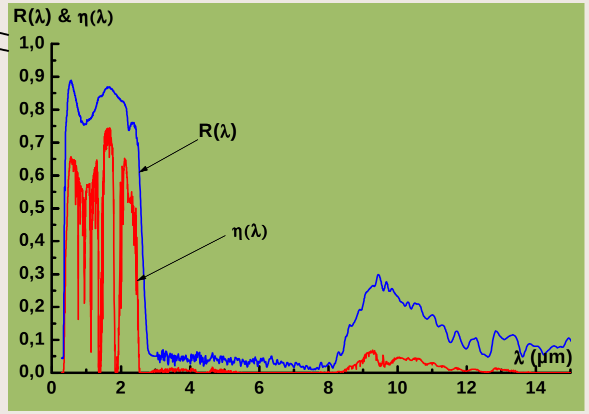
$\Delta T = 10°$

SOLAR BLIND PYROMETRY

$$L^{O}(T,\lambda)=\varepsilon^{O}(T,\lambda)L_{o}(T,\lambda)+\int_{\Omega_p}\rho^{\theta,0}(T,\lambda,\theta)L_p(\lambda,\theta,\varphi)\cos(\theta)d\Omega_p$$

$$G_p\tau_a(\lambda)R^2(\lambda)C_p(\lambda)Ls(\lambda)\Omega_s\int_{\Omega_p}\rho^{\theta,0}(T,\lambda,\theta)\cos(\theta)d\Omega_p$$

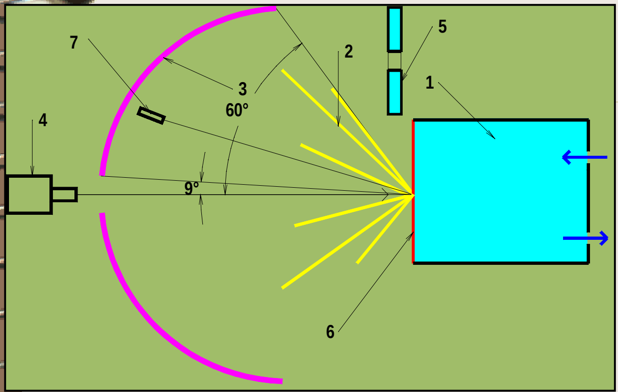




SMART & MODTRAN CODES → $\tau_a(\lambda)$

Performance Factor → $\eta(\lambda) = \tau_a(\lambda)\, R^2(\lambda)$

Experimental Measurements



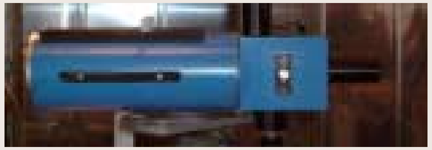
Blasted copper

λ (µm)	1.38	1.4	1.4	1.6	1.86	2.7	3.9	4.3	5.2	9
Δλ nm	10	45	10	20	40	60	150	50	200	2000
$\tau_a(\Delta\lambda)$ %	2	8	5	96	2	0	89	0	22	67
η(Δλ) %	1.7	7.4	2.6	72	2	0	1	0	0	3
T °C	1182	1560	1205	2586	800	15	425	15	15	236
η(Δλ) %	2	8.6	2.3	78	1.1	0	2.5	0	0	5.1

Solar Blind Apparatus

Impac InGaS 1.4µm , t=0.01s
Lenses Optical fiber, f=0.6cm, Spot 3mm

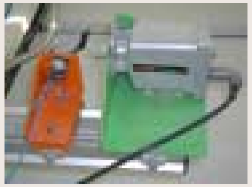
Heiman Bolometer, selectable filter, t=0.1s
Cassegrain, Radiance Signal, f:1.3m, spot: 7mm



Heitronic Pyroelectric Selectable Filter
Lenses, f=1m , spot: 6mm , t=0.1s

Heitronic Pyroelectric 5.2µm ,t=0.1s
Lenses -Spot size 2mm f=0.5m

Ircon Pyroelectric 5.2µm, t=0.1s
Lenses- size 6mm f 1.2m



Solher: InGAs 1.8µm & InAs:2.7µm
Lenses f=0.65mm spot:0.5mm

Infrared Camera 5µm
Lenses

TEMPERATURE DETERMINATION

MEASUREMENTS FOR IN SITU AND ROUGHT CONDITIONS ON OPAQUE MATERIAL

$$S(\lambda,T_R) = L°(\lambda,T_R) = \varepsilon'(\lambda,T)\, L°(\lambda,T) = (1-\rho'^{,\Omega})\, L°(\lambda,T)$$

THE WAYS

ORIGINAL RADIOMETERS : Radiometer equipped with optical fibres

NEW METHODS: Two and three colours pyroreflectometry

Pyroreflectometry Bases

$$\frac{1}{T}=\frac{1}{T_{R\lambda}}+\frac{\lambda}{C_2}\ln(1-\rho^{O,\Omega}(T,\lambda))$$

$$\rho^{O,\Omega}(T,\lambda)=\int_\Omega \rho^{0,\theta}(T,\lambda)\cos(\theta)d\Omega=\rho^{0,0}(T,\lambda)\int_\Omega f(\theta,T)\cos(\theta)d\Omega$$

Diffuse factor independent of λ → $\eta(T)=\int_\Omega f(\theta,T)\cos(\theta)d\Omega$

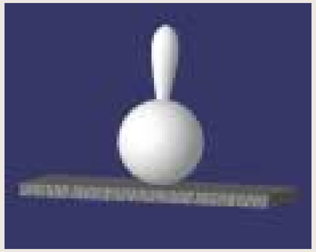
$$\frac{1}{T}=\frac{1}{T_{R\lambda}}+\frac{\lambda}{C_2}\ln(1-\eta(T)\rho^{O,O}(T,\lambda))$$

Solvable System

Physical Limits

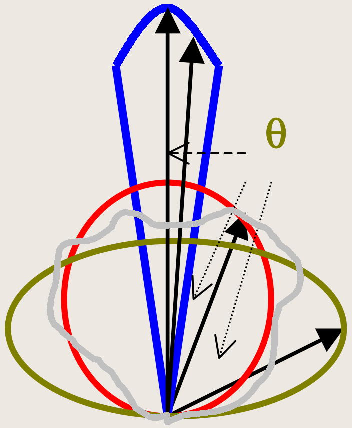
Lambertian

$0 \leq \eta \leq \pi$



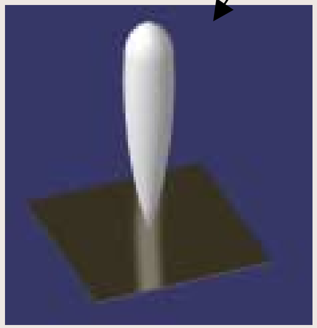
Diffuse & specular

$\rho^{o,o} \times \eta \leq 1$



B.R.D.F. → η

Specular

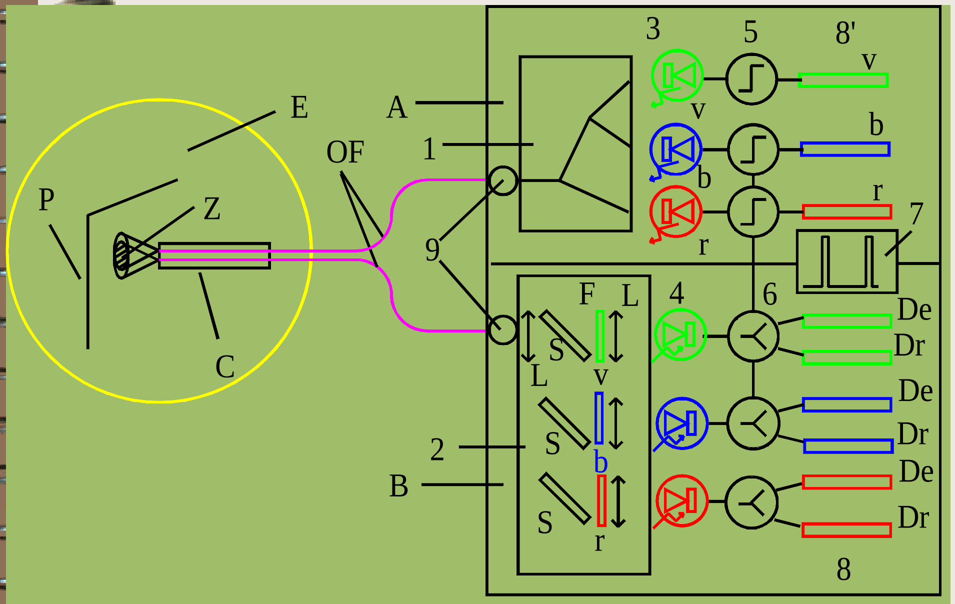


$\rho^{o,o} \rightarrow \infty \, et \, \eta \rightarrow 0$

Oriented

$\eta > \pi$

The tri or bi color pyroreflectometer



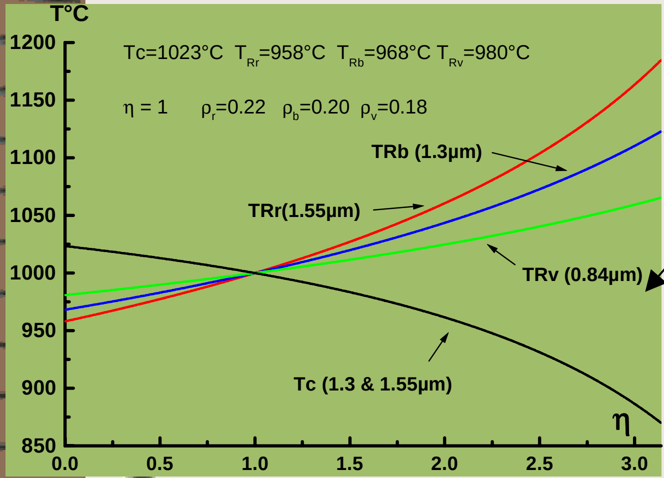
A: Emission B: Detection F: Optical fibres
3: Diode laser 4: Detector 7: Delay generator

Mesured Parameters

$Tl(\lambda_r)$, $Tl(\lambda_b)$, $Tl(\lambda_v)$, $Tc(\lambda_r, \lambda_b)$

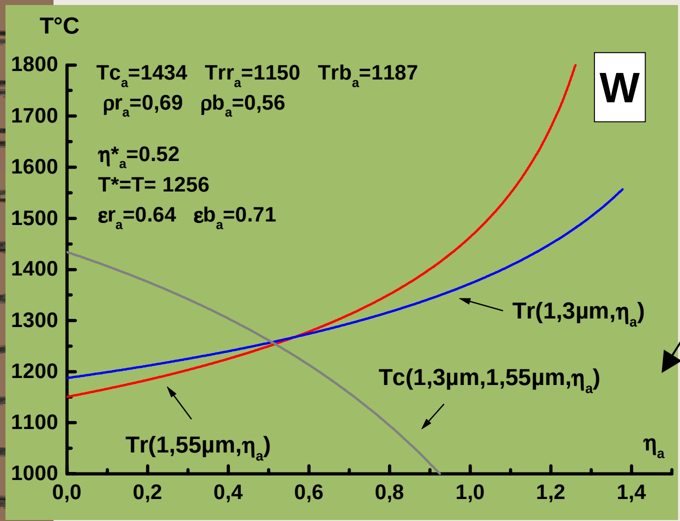
$\rho^{0,0}(\lambda_r,T)$, $\rho^{0,0}(\lambda_b,T)$, $\rho^{0,0}(\lambda_v,T)$

Pyoreflectometry Examples

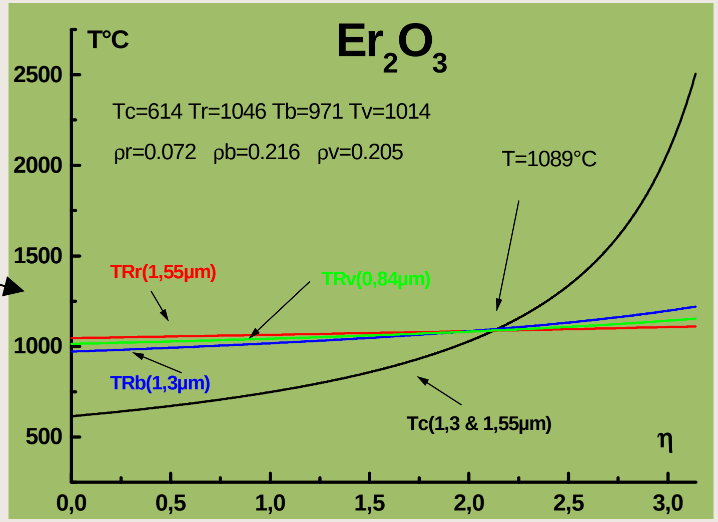


Simulation T=1000°C

ρr=ρb : T= Tc, T >Tr T>Tb ⇨ Bicolor pyrometry
ρr>ρb : T< Tc, T >Tr T>Tb ⇨ Bi-color pyroreflectometry
ρr<ρb : T>Tc, T >Tr T>Tb ⇨Tri-color pyroreflectometry



Experimental Results



Measurement of directional Reflectivity

$$\rho^{O,\Omega}(T,\lambda)=\int_{\Omega}\rho^{0,\theta}(T,\lambda)\cos(\theta)d\Omega=\rho^{0,0}(T,\lambda)\int_{\Omega}f(\theta)\cos(\theta)d\Omega$$