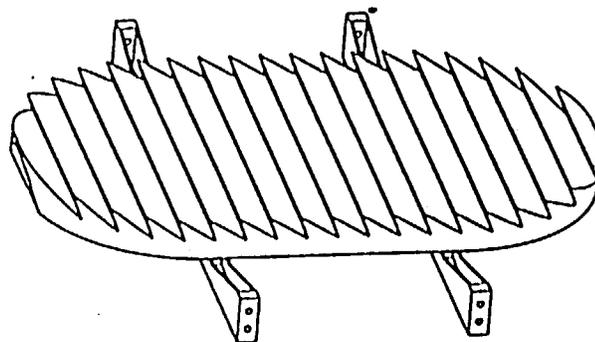


# *The MODIS On-Board Blackbody*

## **Calibration Overview**



**Dan Knowles Jr.**

*MODIS Algorithm Team Meeting  
9 Mar, 1994*

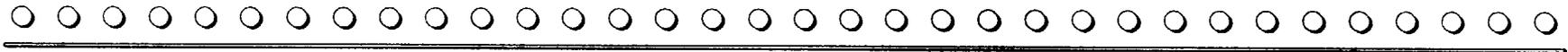
# Blackbody Design

## GSFC Top System Requirements



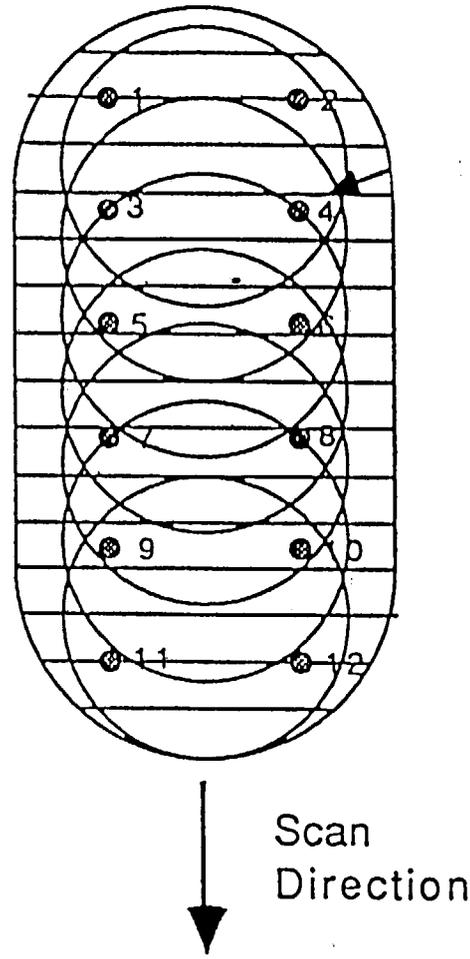
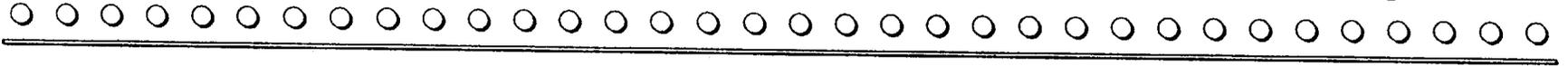
- Absolute 1% (1 sigma) radiometric calibration of MWIR and LWIR bands (0.75% for band 20; 0.5% for bands 31, 32)
- DC restoration view for all bands

# *SBRC Derived Requirements (Spec 151790)*

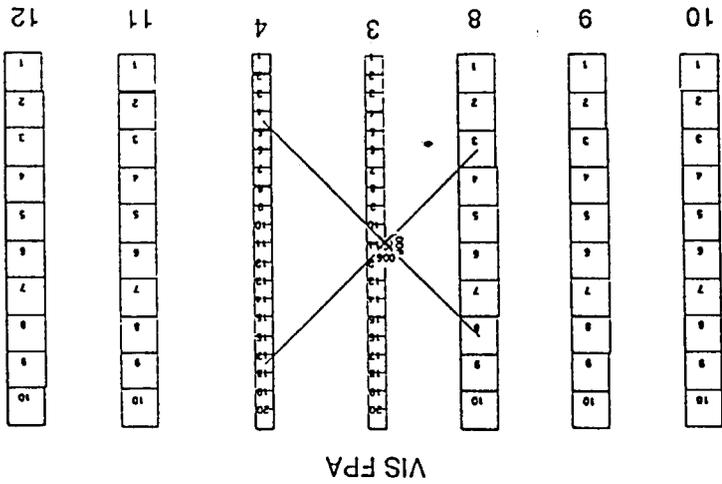


- Full aperture illumination filling 46 IFOVS along-scan
- Emittance  $\geq 0.992$  known to within 0.004 for 3.5 - 14.4 $\mu\text{m}$
- Temperature knowledge  $\leq 0.1\text{K}$  for 280K to 320K
- Ambient and 315K temperature control modes
- Temperature sensors' calibration traceable to NIST
- No direct or indirect solar radiance; minimize earth shine on blackbody
- Power consumption:  $\leq 30\text{W}$  average;  $\leq 40\text{W}$  peak.

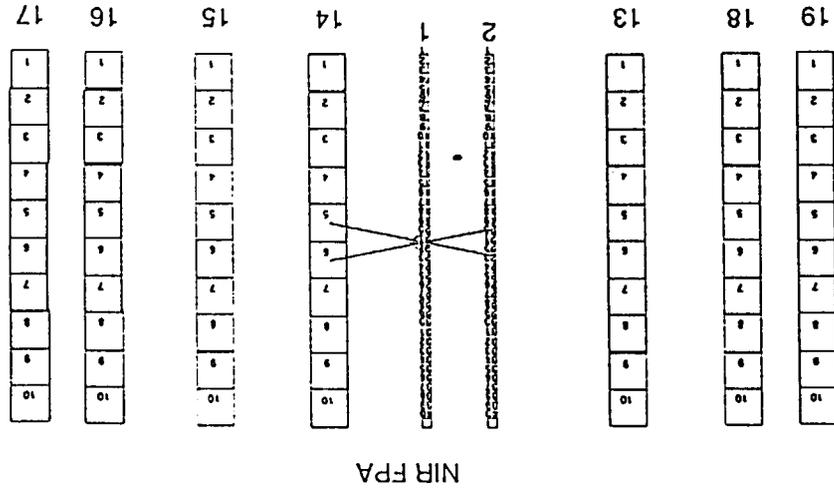
# Focal Plane Scan of Blackbody

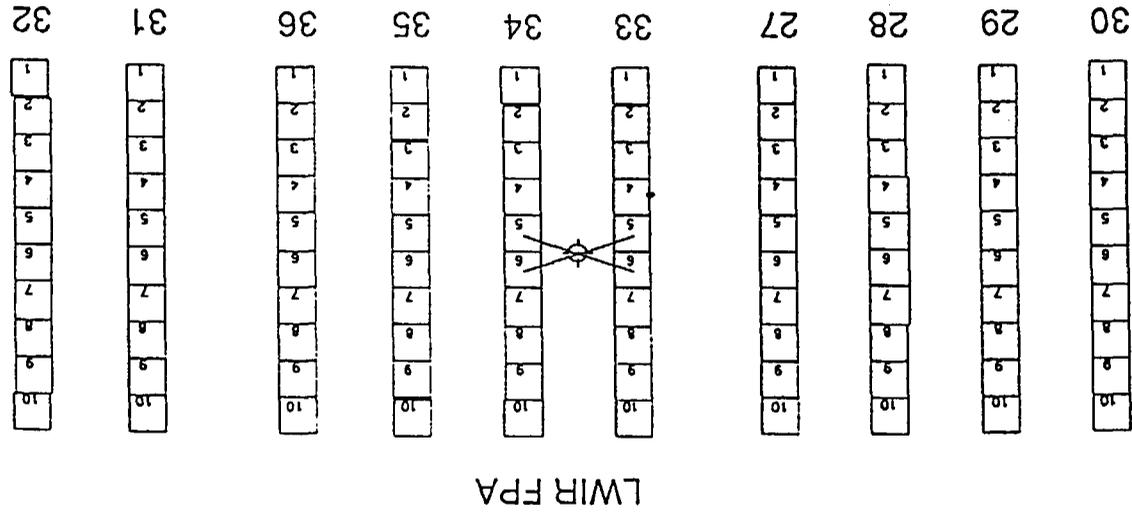


Scan ---->

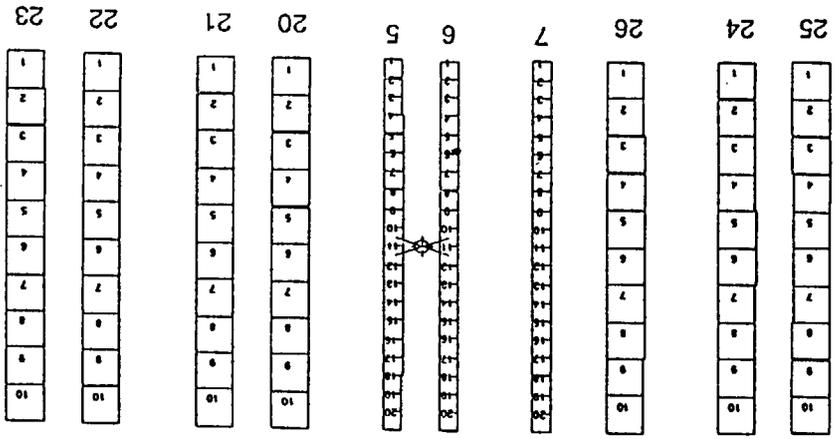


Scan ---->





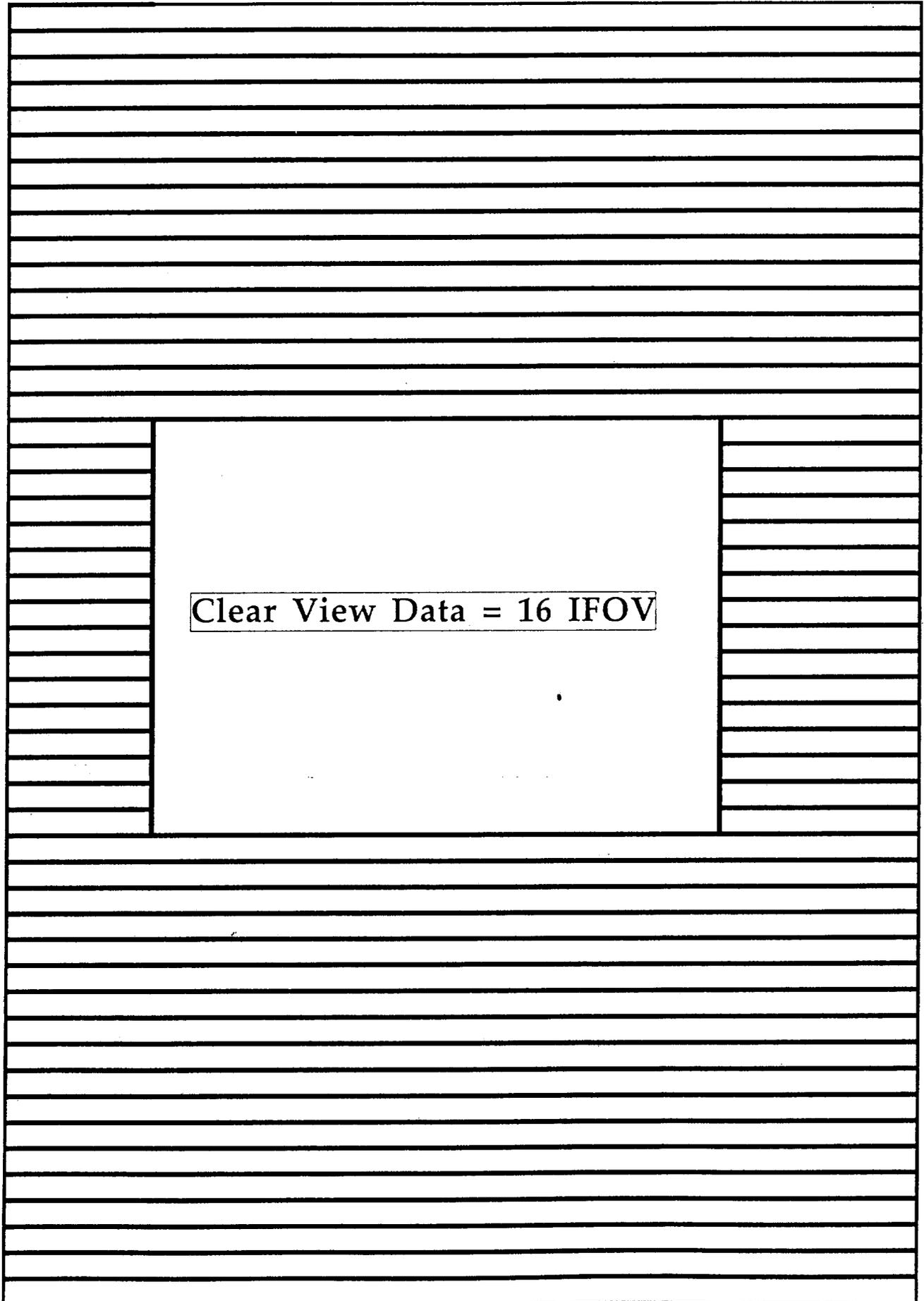
Scan ---->



SMWIR FPA

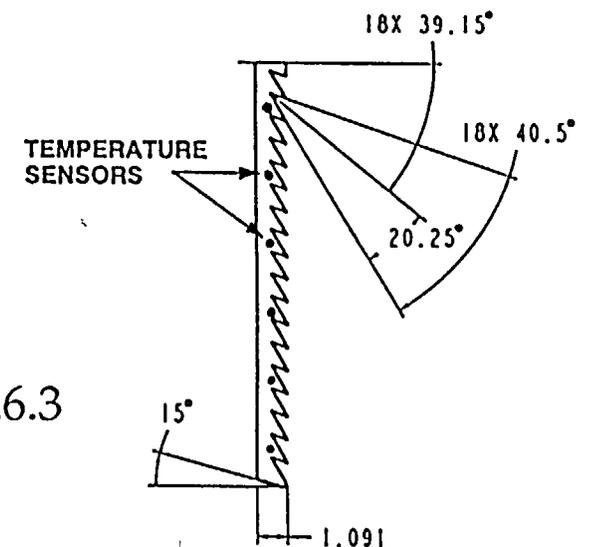
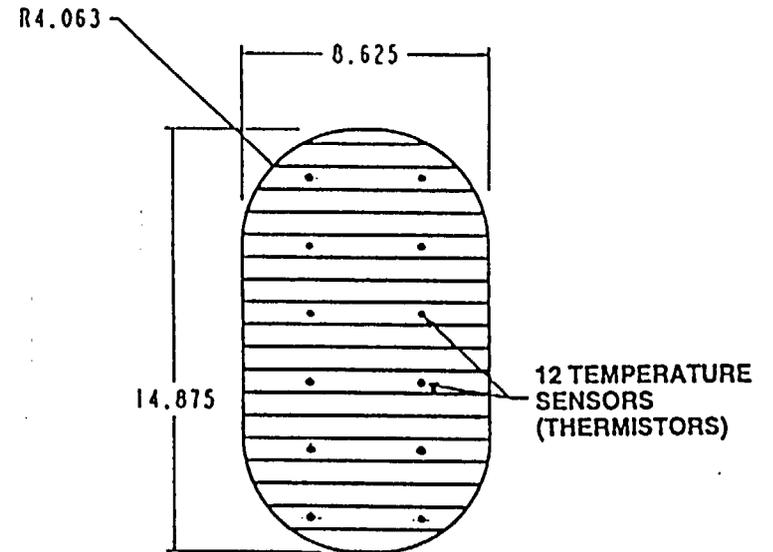


# Scan Of MODIS Focal Planes Across Blackbody



# Blackbody Parameter Summary

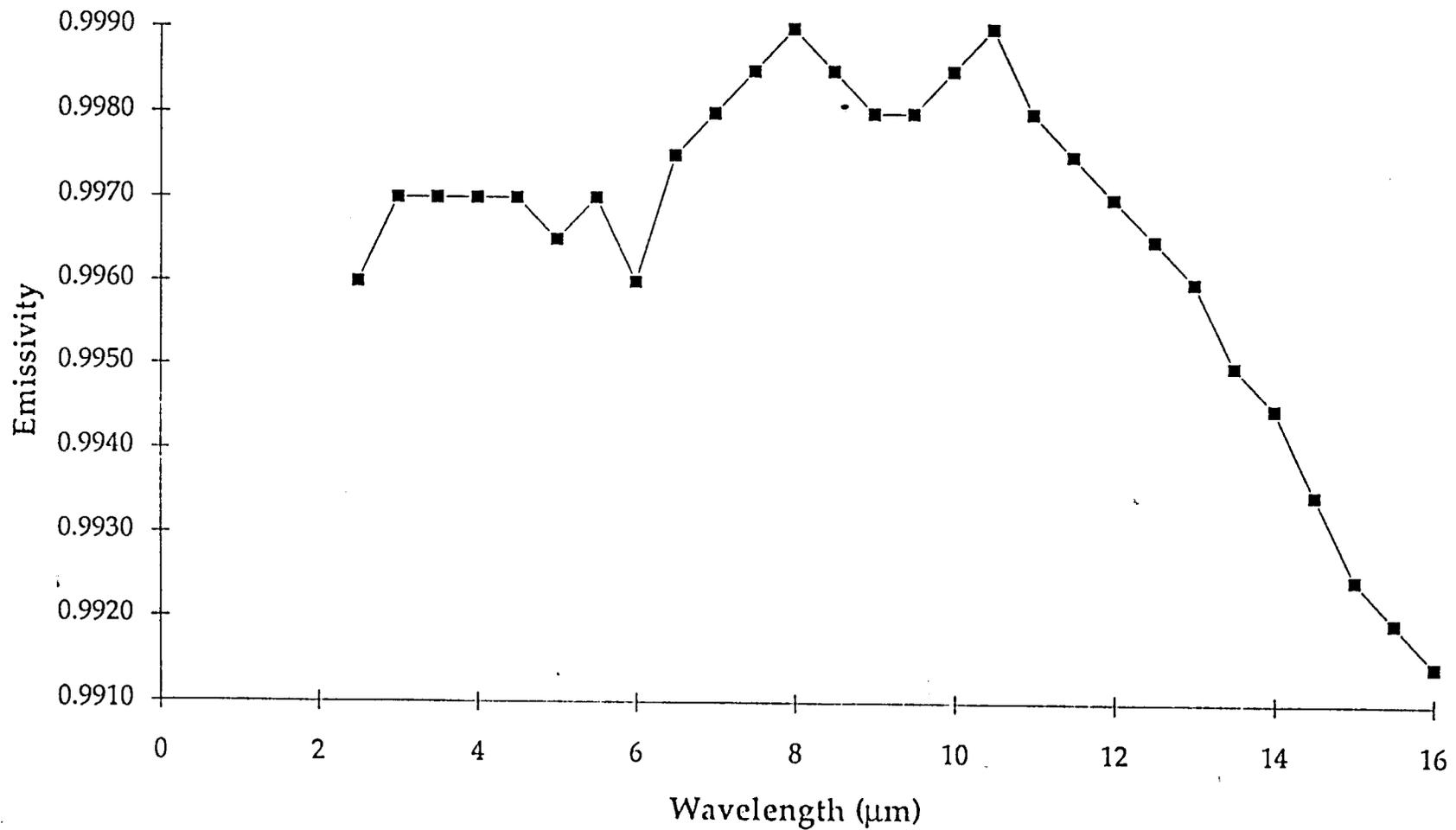
Material - anodized aluminum  
Height - 14.875"  
Width - 8.625"  
Thickness - 1.091"  
Weight - 8.3 lbs  
Heaters - 4  
Thermistors - 12 "bead in glass" thermistors  
Blackbody "heat up" (285 - 315) - 130 minutes  
Blackbody "cool down" (315 - 285) - 100 minutes  
View Angle Range "clear view" - (230.750 - 232.050)  
Number of Frames of "clear view" Data - 15  
Included Groove Angle - 40.5  
Index View Angle - 284  
Nominal Blackbody View angle - 231.4  
Angle of Incidence on Scan Mirror for Nominal View - 26.3



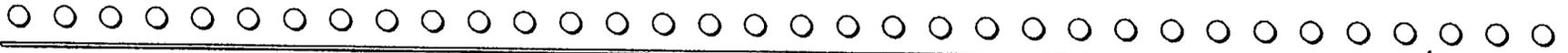
# MODIS Blackbody Emissivity vs Wavelength



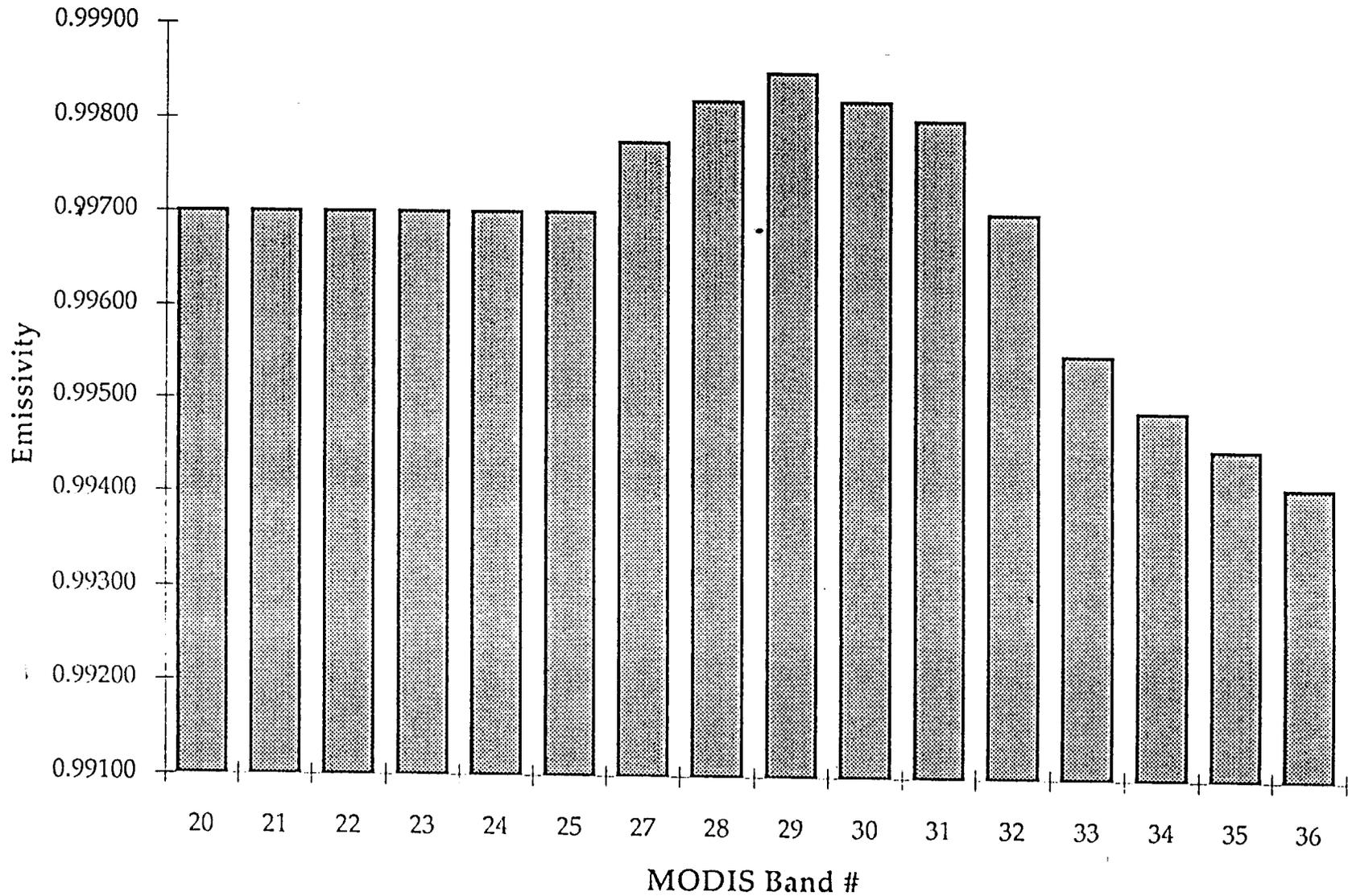
• Calculation based on type II anodized aluminum data applied to the SBRC emissivity equation



# Emissivity vs MODIS Band #



• Calculation based on type II anodized aluminum data applied to the SBRC emissivity equation



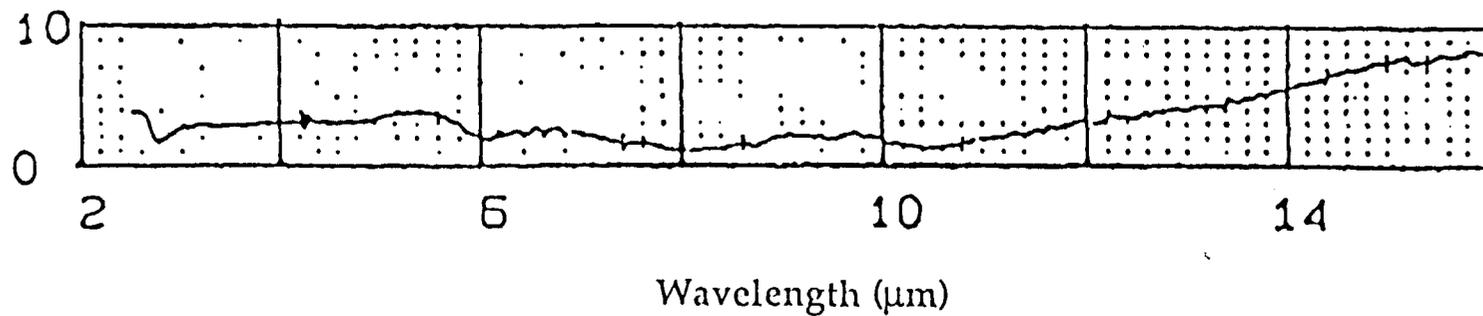
# Reflectance of Black Anodized Aluminum



Candidate Anodized Aluminum Material for MODIS Blackbody:

- 6101-T6
- 1100-H18
- 1100-annealed

*%Reflectance Plot of Type II Black Anodized Aluminum*



# Derivation of V-Groove Blackbody Emissivity Equation

$$\varepsilon(\lambda) = 1 - P(\lambda)$$

where;  $P(\lambda)$  = reflectance of blackbody

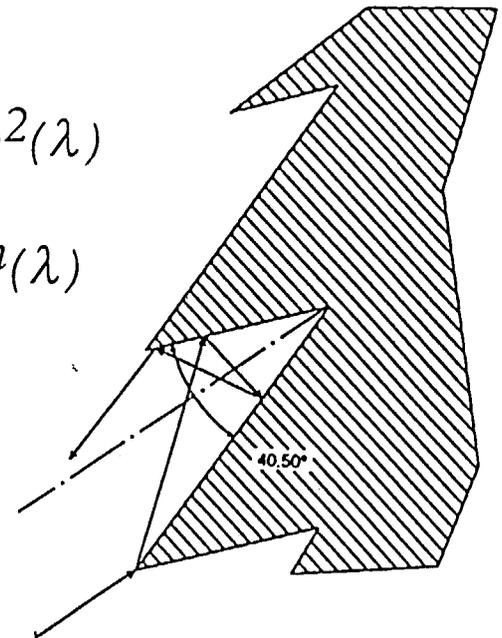
if light undergoes one specular reflection then  $P_1(\lambda) = \rho(\lambda)$

if light undergoes two specular reflections then  $P_2(\lambda) = \rho(\lambda)P_1(\lambda) = \rho^2(\lambda)$

if light undergoes n specular reflections then  $P_n(\lambda) = \rho(\lambda)P_{n-1}(\lambda) = \rho^n(\lambda)$

if light undergoes a variety of reflections with k as its maximum then

$$\varepsilon(\lambda) = 1 - \sum_{n=1}^k w_n \rho^n(\lambda)$$



# Calculated Emissivity of the MODIS Blackbody

$$\varepsilon(\lambda) = 1 - \sum_{n=1}^k w_n \rho^n(\lambda)$$

k = # of spectral reflections

$\rho(\lambda)$  = reflectance of black anodized aluminum

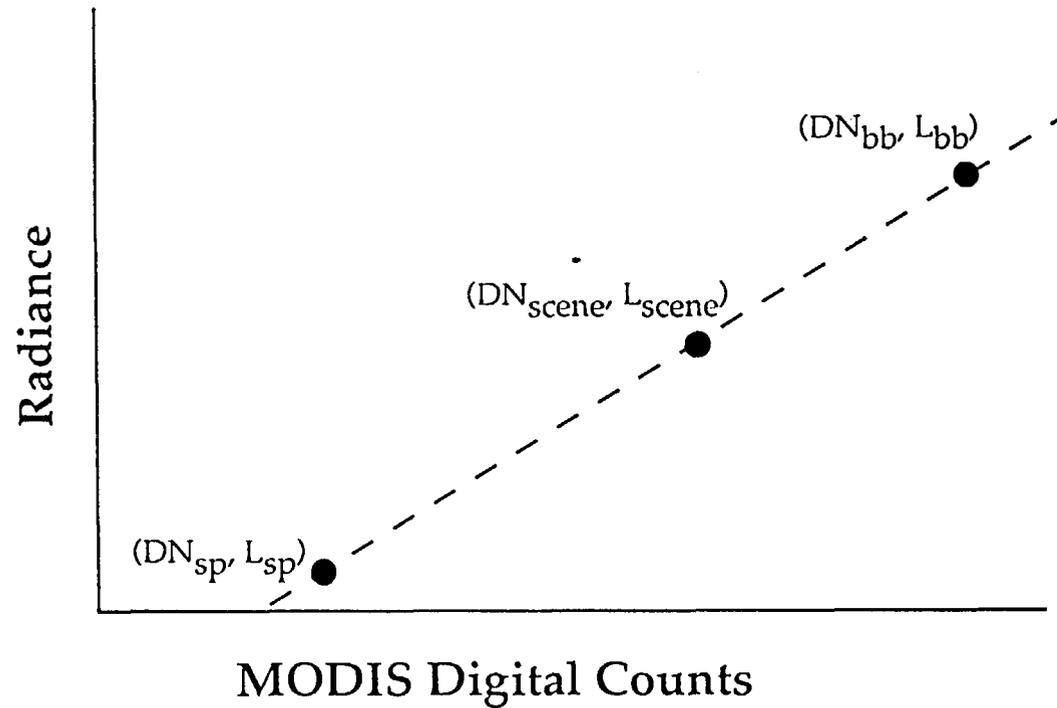
$w_1$  = 0.1 (10% weight for one specular reflection)

$w_4$  = 0.9 (90% weight for four specular reflections)

The MODIS V-groove blackbody is designed such that 90% of the reflected light undergoes at least four specular reflections. The remaining 10% undergoes at least one specular reflection. Therefore, emissivity can be calculated as follows:

$$\varepsilon(\lambda) \geq 1 - (w_4 \rho^4(\lambda) + w_1 \rho(\lambda))$$

# SBRC's Algorithm Assumes Linear Calibration



$$L_{scene} = L_{sp} + m(DN_{scene} - DN_{sp})$$

$$m = \frac{L_{bb} - L_{sp}}{DN_{bb} - DN_{sp}}$$

# Equation for Determining the In-Flight Radiance of the MODIS Blackbody



$$\begin{aligned}
 L_{bb/eff}(fd\#,b\#,ch\#) &= \sum_{\lambda_{lower}(b\#)}^{\lambda_{upper}(b\#)} B_{\lambda}(\lambda, T_{bb}(ch\#,fd\#)) \epsilon_{bb}(\lambda) R(\lambda,b\#,ch\#) \Delta\lambda \\
 &+ \frac{\Omega_{cav(bb)}}{\pi} \sum_{\lambda_{lower}(b\#)}^{\lambda_{upper}(b\#)} B_{\lambda}(\lambda, T_{cav}(fd\#)) \rho_{bb}(\lambda) \epsilon_{cav}(\lambda) R(\lambda,b\#,ch\#) \Delta\lambda \\
 &+ \frac{\Omega_{cav(bb)} \Omega_{Earth(ev)}}{\pi^2} \sum_{\lambda_{lower}(b\#)}^{\lambda_{upper}(b\#)} L_{Earth/eff}(\lambda,fd\#) \rho_{bb}(\lambda) \rho_{cav}(\lambda) R(\lambda,b\#,ch\#) \Delta\lambda \\
 &+ \frac{\Omega_{cav(bb)} \Omega_{Moon(sv)}}{\pi^2} \sum_{\lambda_{lower}(b\#)}^{\lambda_{upper}(b\#)} L_{Moon/eff}(\lambda,fd\#) \rho_{bb}(\lambda) \rho_{cav}(\lambda) R(\lambda,b\#,ch\#) \Delta\lambda \\
 &+ \frac{\Omega_{Earth(bb)}}{\pi} \sum_{\lambda_{lower}(b\#)}^{\lambda_{upper}(b\#)} L_{Earth/eff}(\lambda,fd\#) \rho_{bb}(\lambda) R(\lambda,b\#,ch\#) \Delta\lambda
 \end{aligned}$$

$L_{\text{Earth/eff}}$  = Effective radiance of the Earth

$L_{\text{Moon/eff}}$  = Effective radiance of the Moon

$L_{\text{bb/eff}}$  = Effective radiance of the MODIS blackbody

$T_{\text{bb}}$  = Temperature of a spatial area of the MODIS blackbody

$T_{\text{cav}}$  = Temperature of the MODIS cavity

$\Omega_{\text{cav(bb)}}$  = solid angle segmented by the cavity and the blackbody

$\Omega_{\text{Moon(sv)}}$  = solid angle segmented by the Moon and the space view

$\Omega_{\text{Earth(bb)}}$  = solid angle segmented by the Earth and the blackbody

$\Omega_{\text{Earth(ev)}}$  = solid angle segmented by the Earth and the Earth view

$\rho_{\text{bb}}$  = reflectance of the MODIS blackbody

$\rho_{\text{cav}}$  = reflectance of the MODIS cavity

$R$  = spectral responsivity of the MODIS band

$\text{fd\#}$  = spatially coincident frame of data

$\text{b\#}$  = MODIS band number

$\text{ch\#}$  = MODIS channel number

$\Delta\lambda$  = wavelength resolution

$\lambda_{\text{upper}}$  = center wavelength minus twice the bandwidth

$\lambda_{\text{lower}}$  = center wavelength plus twice the bandwidth

$$B_{\lambda} = \left[ \frac{2hc^2}{\lambda^5 (e^{(ch/\lambda kT)} - 1)} \right]$$