

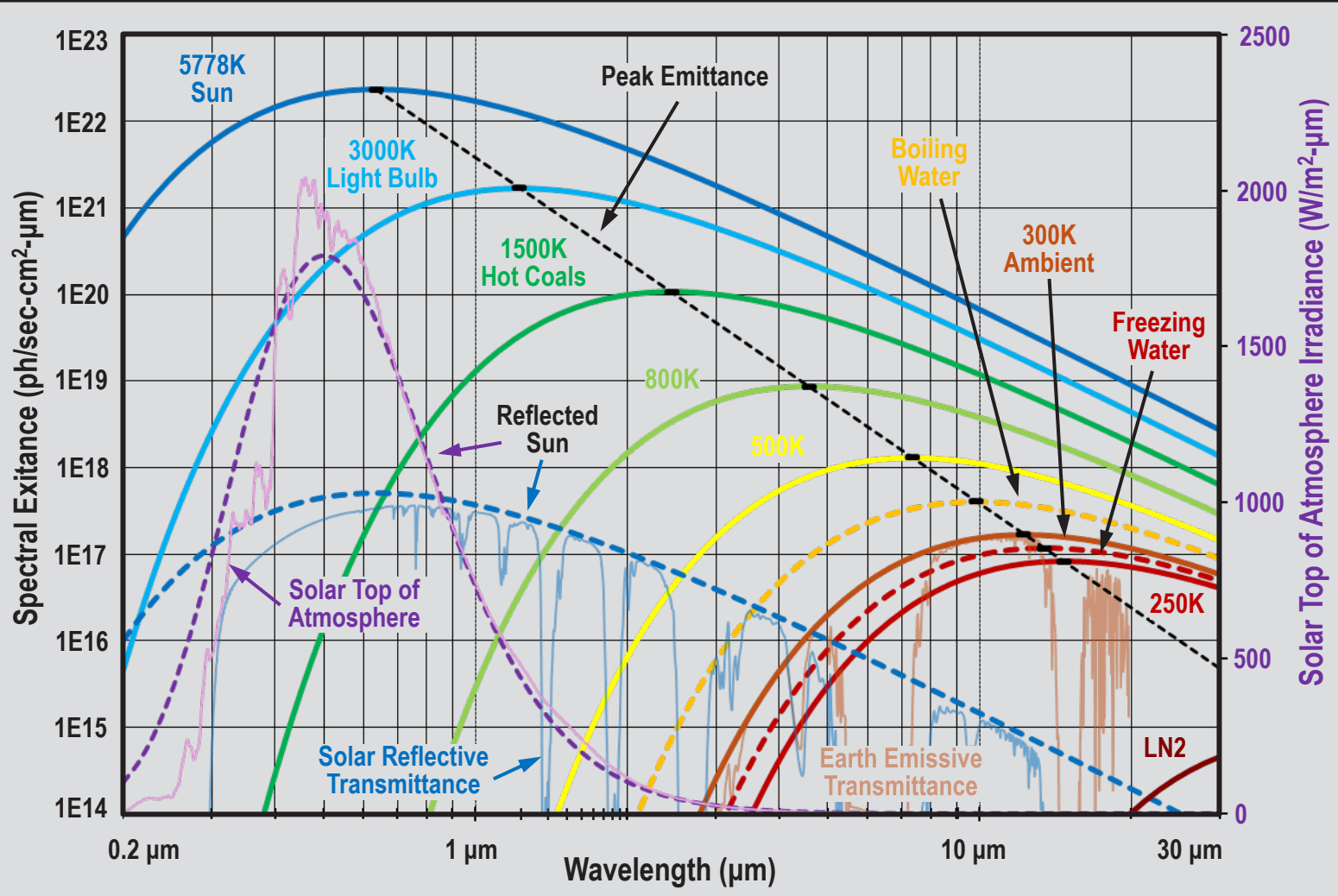
The Raytheon Infrared Wall Chart

TRANSMITTER/RECEIVER TERMINOLOGY

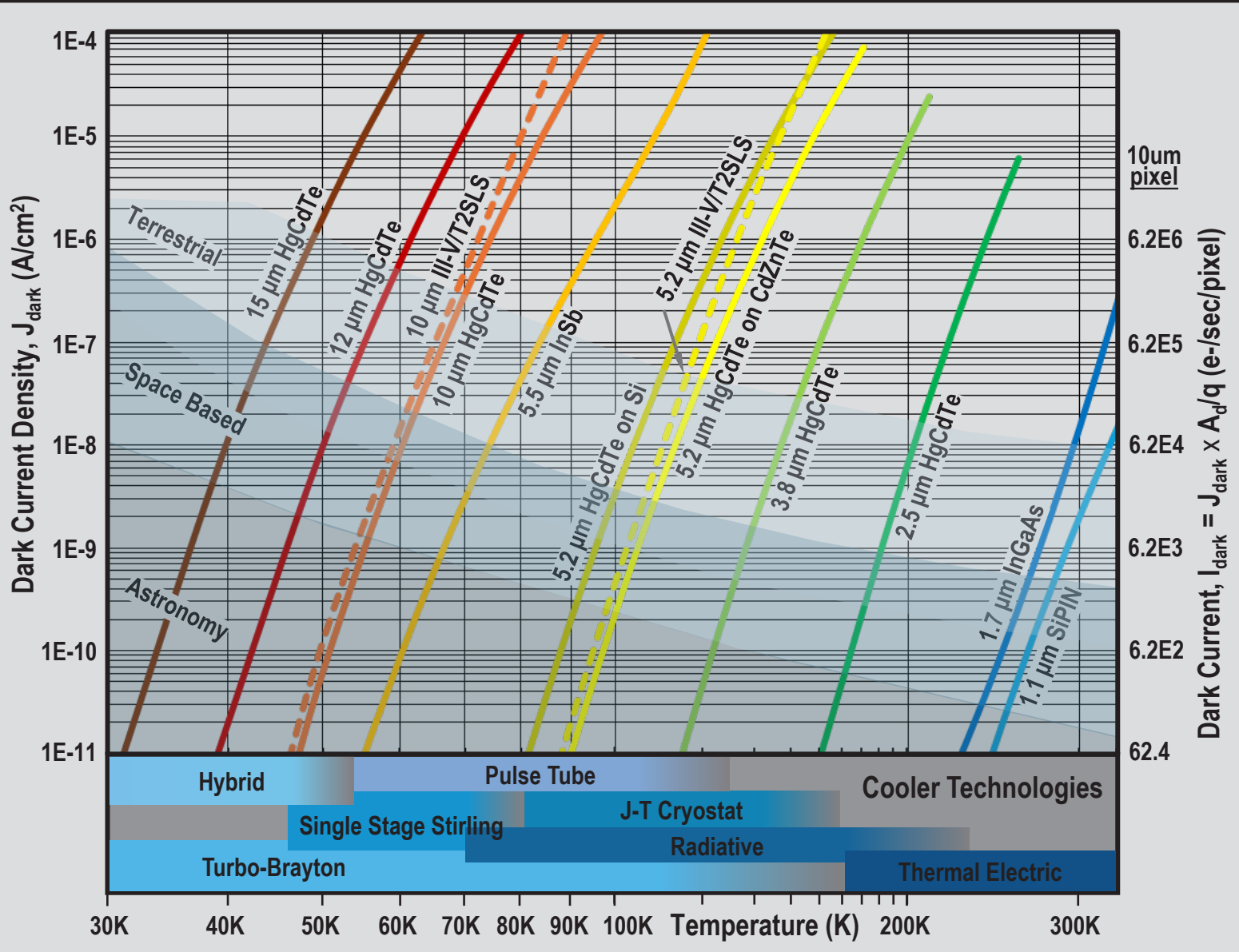
Term	Symbol	Energy Units	Quantum units	Definition
Energy	$Q_{e,q}$	J	ph	Basic unit of energy
Power (flux)	$\Phi_{e,q}$	W	ph/sec	Rate of energy transfer
Intensity	$I_{e,q}$	W/sr	ph/sec-sr	Point source transmitter (pointance)
Exitance	$M_{e,q}$	W/m ²	ph/sec-cm ²	Area transmitter (areance)
Radiance	$L_{e,q}$	W/m ² -sr	ph/sec-cm ² -sr	Area/angular transmitter (sterance)
Spectral radiance	$L_{\lambda,q}$	W/cm ² -sr-um	ph/sec-cm ² -sr-um	Generalized transmitter (flick)
Irradiance	$E_{e,q}$ (or Q)	W/m ²	ph/sec-cm ²	Incident flux surface receiver

Subscripts e denotes energy, q denotes quantum, λ denotes over spectral bandpass

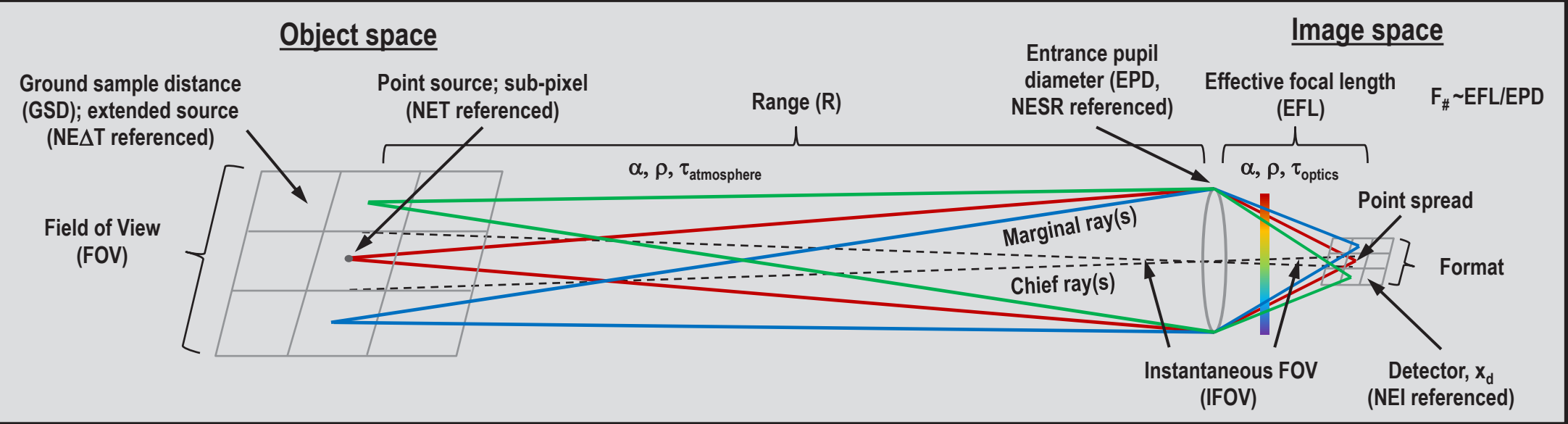
PHOTON SPECTRAL EXITANCE



DETECTOR DARK CURRENT DENSITY



GENERALIZED EOIR SYSTEM GEOMETRY



SELECTED BLACKBODY FORMULAS

Planck's Law for photon spectral exitance
 $M_{\lambda}(\lambda, T) = \frac{2\pi \cdot c}{\lambda^4} \left(\exp\left(\frac{hc}{\lambda k T}\right) - 1 \right)^{-1}$ ph/sec-cm²-μm

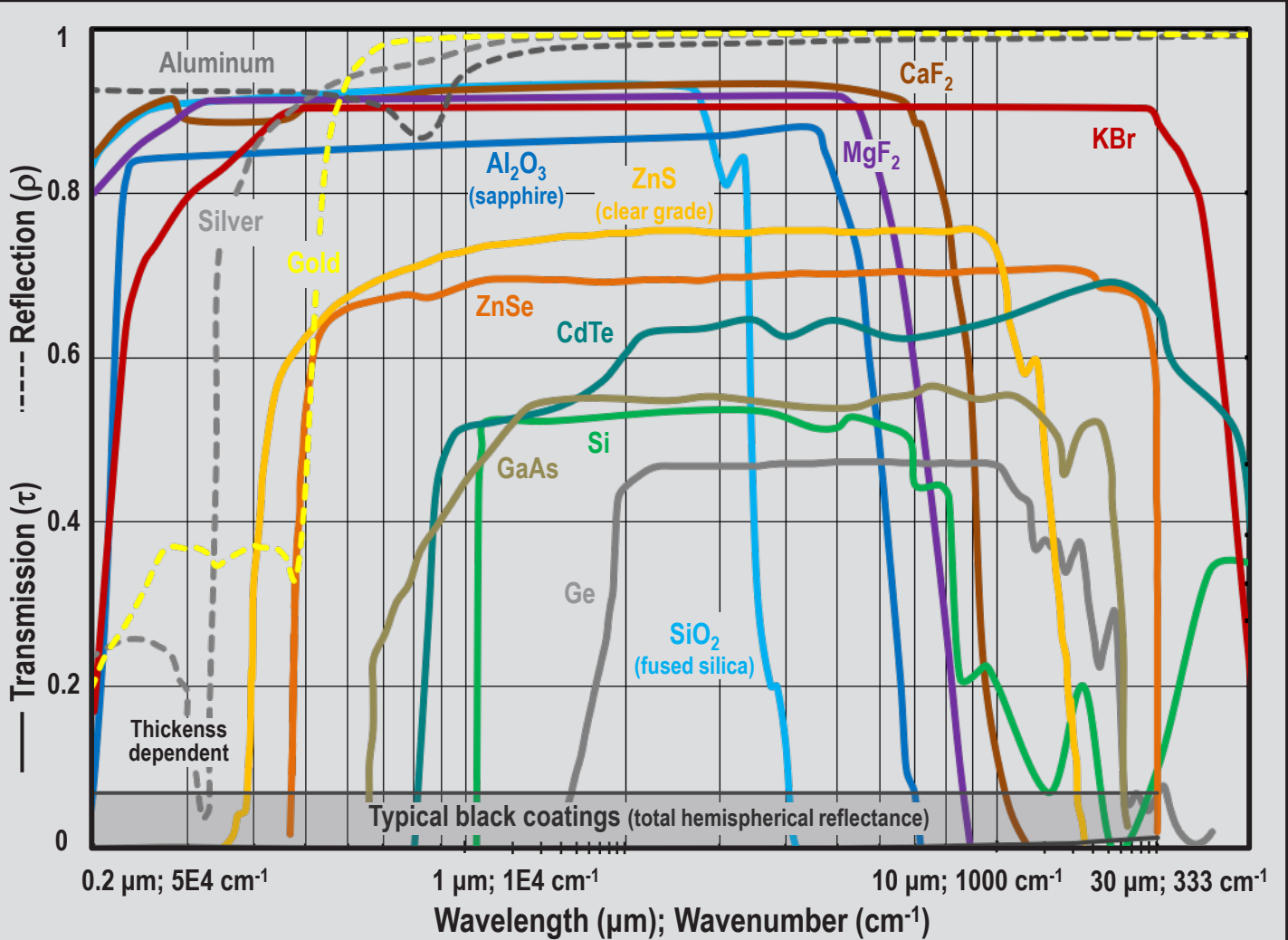
Spectral exitance
 $M_{\lambda}(\lambda, T) = M_{\lambda}(\lambda, T) \frac{h \cdot c}{\lambda} = \frac{2\pi \cdot h \cdot c^2}{\lambda^5 \left(\exp\left(\frac{hc}{\lambda k T}\right) - 1 \right)}$ W/cm²-μm

Photon irradiance (at image plane for a Lambertian source with a narrow, uniform spectral bandpass)
 $Q(\Delta\lambda, T) = \frac{Q_d \cdot \Delta\lambda}{\pi} M_{\lambda}(\lambda, T)$ ph/sec-cm²

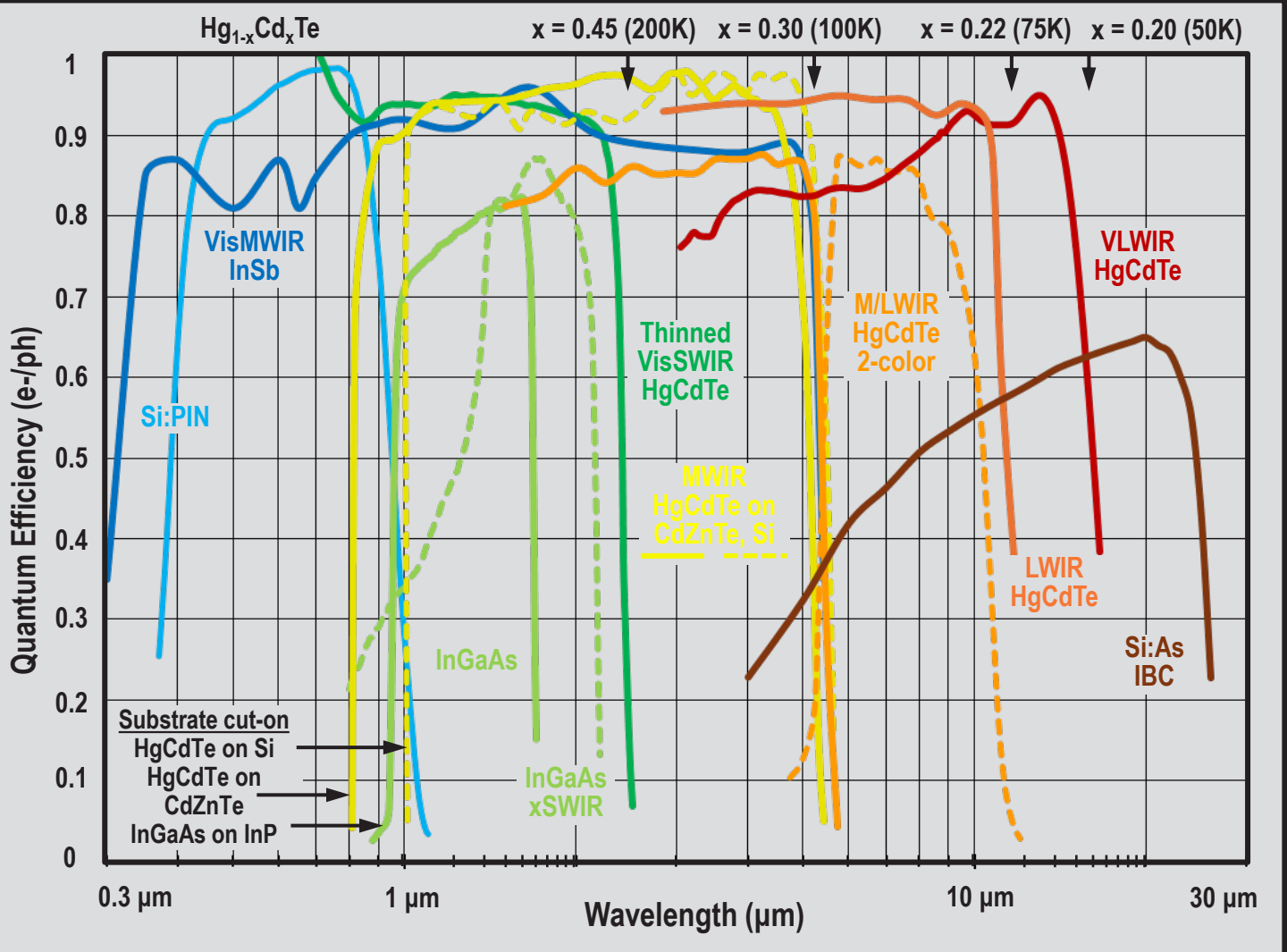
Total blackbody exitance (Stefan-Boltzmann Law)
 $M_{\text{total}} = \int_0^{\infty} M_{\lambda}(\lambda, T) d\lambda = \sigma_b T^4$ W/cm²
 $\sigma_b = 5.6705 \times 10^{-12}$ W/cm²-K⁴ for spectral radiance
 $\sigma_b = 1.5205 \times 10^{11}$ ph/sec-cm²-K⁴ for ph. spectral radiance
 $\sigma_b = 36679$ W/cm²-K⁴ for photon spectral radiance

Wien's Displacement Law
 $\lambda_m T = \lambda_{b,q}$
 $\lambda_{b,q}$ = wavelength of maximum spectral radiance
 $\lambda_{b,q} = 2891.8$ μm-K for spectral radiance
 $\lambda_{b,q} = 3669.7$ μm-K for photon spectral radiance

COMMON OPTICAL MATERIAL PROPERTIES



RESPONSE OF VARIOUS DETECTOR MATERIALS



FIRST ORDER OPTICAL MEDIA PARAMETERS

For single surface, normal incidence in vacuum (n = 1) without absorption

Reflection $\rho = \frac{(n-1)^2}{(n+1)^2}$

Transmission $\tau = \frac{4n}{(n+1)^2}$

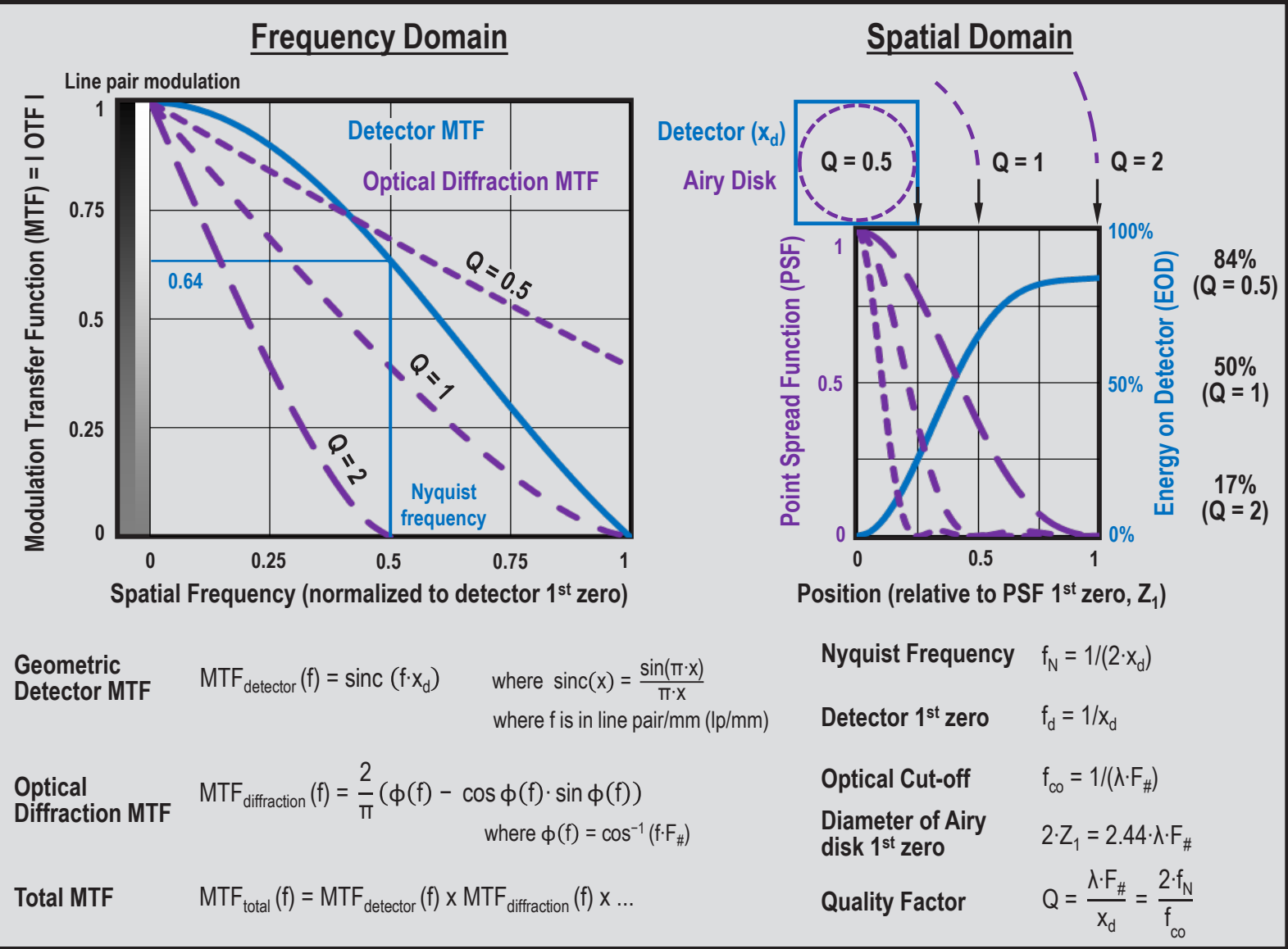
Critical angle $\theta_c = \sin^{-1}\left(\frac{1}{n}\right)$

Brewster's angle $\theta_B = \tan^{-1}(n)$

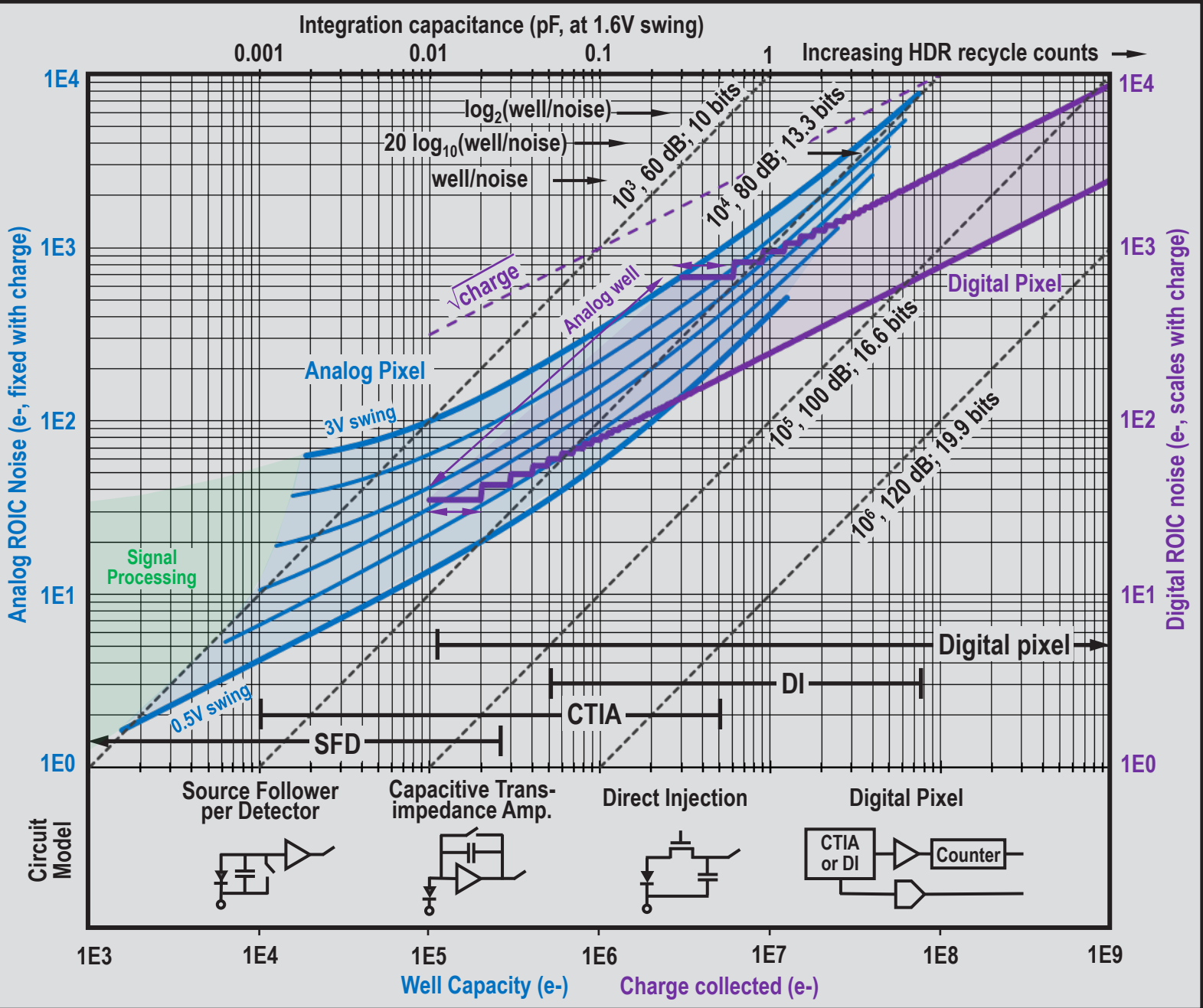
Total power $1 = \alpha + \rho + \tau$

Emissivity $\epsilon = 1 - \rho$

SPATIAL PERFORMANCE FIGURES OF MERIT



READOUT NOISE AND CHARGE CAPACITY



RADIOMETRIC SENSITIVITY FIGURES OF MERIT

Figure of Merit	Equation	Units
Instantaneous Field of View (IFOV)	$IFOV = \frac{GSD}{R} = \frac{x_d}{EFL}$	Radians (rad)
Projected Solid Angle	$\Omega_d = \pi \sin^{-1}\left(\tan^{-1} \frac{EPD}{2 \cdot EFL}\right) \approx \frac{\pi}{4 F_\#^2}$ $\Omega_{\text{object}} = \frac{\pi EPD^2}{4 R^2}$ $\Omega_{\text{optics}} = IFOV^2$	Steradian (sr)
Etendue invariant (area x solid angle)	$A_{\text{object}} \Omega_{\text{object}} = A_{\text{optics}} \Omega_{\text{optics}} = A_d \Omega_d$	cm ² -sr
Source Signal	$S_{\text{source}}(\lambda) = \int L_{\lambda} \frac{\lambda}{h \cdot c} A \cdot \Omega \cdot \tau(\lambda) \eta(\lambda) t_{\text{int}} \eta_{\text{TDI}} d\lambda$	Electrons
Responsivity	$R = \eta A_d t_{\text{int}}$	e-/ph/sec-cm ²
Background Limited Performance	$BLIP = \sqrt{Q_{\text{source}} \eta A_d t_{\text{int}}}$	Electrons
Photon Noise	$\sigma_{\text{photon}} = \sqrt{Q_{\text{source}} + Q_{\text{dark}}} \eta A_d t_{\text{int}}$	Electrons
Detector Noise	$\sigma_{\text{dark}} = \frac{J_{\text{dark}} A_d t_{\text{int}}}{q}$ $\sigma_{\text{1/f,d}} = \alpha_d \sigma_{\text{dark}}^2 \ln\left(\frac{T_{\text{cal}}}{2 t_{\text{int}}}\right)$	Electrons
ROIC Noise	$\sigma_{\text{ROIC}} = \sqrt{N_{\text{count}} \sigma_{\text{digital}}^2 + \sigma_{\text{analog}}^2 + \sigma_{\text{1/f,R}}^2}$	Electrons
FPA Noise (NEC or NEQ)	$\sigma_{\text{total}} = \sqrt{\sigma_{\text{photon}}^2 + \sigma_{\text{dark}}^2 + \sigma_{\text{1/f,dark}}^2 + \sigma_{\text{ROIC}}^2}$	Electrons
Noise Equivalent Irradiance	$NEI = \frac{\sigma_{\text{total}}}{\eta A_d t_{\text{int}}} \left(\text{SNR} = \frac{Q_{\text{source}}}{NEI \text{ (at } Q_{\text{source}})} \right)$	ph/sec-cm ²
Noise Equivalent Spectral Radiance (for small bandwidths)	$NESR = \frac{NEI}{\Omega_d \tau_o \Delta\lambda} \frac{\lambda}{h \cdot c}$	W/cm ² -sr-μm
Noise Equivalent Temp. Difference	$NE\Delta T = \frac{NEI}{\Omega_d \tau_o \Delta\lambda} \frac{\partial \lambda}{\partial T} \left(T, \lambda \right) \frac{\lambda}{h \cdot c}$	mK
Noise Equivalent Target	$NET = \frac{A_d NEI}{\Omega_{\text{object}} \tau_o T_r} \frac{\lambda}{h \cdot c}$	W/sr

A_d = Detector area, cm² (x_d^2)
 A_{object} = Object area, cm² (GSD^2)
 A_{optics} = Optics area, cm² ($\pi/4 EPD^2$ (1-obs²))
 $\sigma_{\text{1/f,d}} =$ Detector 1/f noise, e-
 $\sigma_{\text{1/f,R}} =$ ROIC 1/f noise, e-
 $\sigma_{\text{obs}} =$ Optical obscuration (if any)
 $\sigma_{\text{1/f,dark}} =$ Native ROIC noise, e-
 $\sigma_{\text{analog}} =$ Digital ROIC noise, e-
 $\tau_o =$ Throughput of atmosphere, optics
 $\eta =$ Quantum efficiency, e-/ph
 $t_{\text{int}} =$ Integration time, sec
 $n_{\text{TDI}} =$ number in TDI (co-adds, from 1 to n)
 $TDI =$ Time delay integration (scanner/starer)
 $Q_{\text{source}} =$ Source signal, ph/sec-cm²
 $Q_{\text{dark}} =$ Extrinsic signal, ph/sec-cm²
 $\alpha_d =$ 1/f noise (Tobin) co-efficient (unitless)
 $T_{\text{cal}} =$ Calibration interval, sec
 $N_{\text{count}} =$ Digital pixel counts (unitless)
 $\sigma_{\text{1/f,d}} =$ Detector 1/f noise, e-
 $\sigma_{\text{1/f,R}} =$ ROIC 1/f noise, e-
 $\sigma_{\text{analog}} =$ Native ROIC noise, e-
 $\sigma_{\text{digital}} =$ Digital ROIC noise, e-
 $\tau_o =$ Temperature (K)
 $\Delta U/\Delta T =$ Thm. derivative, W/cm²-sr-um-K
 $\Delta\lambda =$ Spectral band, um (for small values)
 $\lambda =$ Avg. wavelength, um (in band)
 $T_r =$ Target response (<EOD across FOV)

SELECTED CONSTANTS AND CONVERSIONS

Speed of light in vacuum	c	2.998 x 10 ⁸ m/sec
Astronomical unit	AU	1.496 x 10 ¹¹ m
Elementary charge (e-)	q	1.602 x 10 ⁻¹⁹ C
Electron rest mass	m	9.109 x 10 ⁻³¹ kg
Planck's constant	h	6.626 x 10 ⁻³⁴ J-sec
Boltzmann constant	k	1.381 x 10 ⁻²³ J/K
Boltzmann constant (k/q)	k	8.617 x 10 ⁻⁵ eV/K
Photon energy (hc/q)	E _{ph}	1.24 eV-um
Photometric power	lm	Lumen (eye weighted)
Photometric /area	lx	lux (lm/m ²)
Photometric /Ω	cd	candela (lm/sr)
Photometric /area-Ω	nit	nit (lm/m ² -sr = cd/m ²)

THE ELECTROMAGNETIC SPECTRUM

