Integrated Design Capability / Instrument Design Laboratory

Ocean Color Experiment Ver. 2 (OCE2)

~ Concept Presentation ~

Radiometry

Jay Smith / 550

Qian Gong / 551, Peter Hill / 551, Carl Kotecki / 553

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from the Scientific Point of Contact Jay Smith (James.C.Smith@nasa.gov)
or the Programmatic Point of Contact Angela Mason (Angela.J.Mason@nasa.gov)
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EDT Instrument Requirement Options

- **Case 1**
  - Open ocean science measurement bands at 1km ±10% spatial resolution

- **Case 2**
  - Case 1 + additional atmosphere science bands (3-4) at 1km ±10% spatial resolution

- **Case 3**
  - Case 2 + 250m (±10% - ?) spatial resolution option to address atmosphere and coastal oceans science

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Analysis Constants and Definitions

$mr \equiv 10^{-3}\,rad$

$fA := 1 \times 10^{-15}\,A$

$BPS := 1\,Hz$

$pm := 10^{-12}\,m$

$k := 10^{3}$

$M := 10^{6}$

$G_Bits := 10^{9}$

$k_B := 1.3806505 \times 10^{-23} \times \frac{joule}{K}$

$h := 6.6260693 \times 10^{-34} \times joule \times sec$

$c = 2.998 \times 10^{8} \times \frac{m}{s}$

$Gm := 6.67259 \times 10^{-11} \frac{m^3}{kg \times sec^2}$

Gravitational Constant

$pe := 1.60217653 \times 10^{-19} \times coul$

$E(\lambda) := \frac{h \times c}{\lambda}$

Photon unit definition

$qe := pe$

$q := pe$

$ph := 1$

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Instrument Parameters

Orbit_alt := 700km

Ap_dia := 180mm

GSD := 1km

Alongtrack at 20deg. tilt

Tilt_ang := 20deg

Alongtrk_sampling := 1.1km

Crosstrk_sampling := 1.1km

AD_bits := 14

Fiber_dia := 800μm

Crosstrk_scan := 102deg

Lat_coverage := 140deg

$Det_dia_{dir} := 2mm$

2 day global repeat with +/- 51 deg

Lat_coverage = +/- 70 deg. latitude

$$iFOV := 2\,atan\left(\frac{0.5\,GSD}{Orbit_alt}\right) = 1.429 \times mr$$

$$Ap_area := \pi \times \left(\frac{Ap_dia}{2}\right)^2 = 0.025 \times m^2$$

Initial est. w/o Tilt Angle adjustment

iFOV = 1.233mr with Tilt Angle (see backup)

$$Obs_area := \pi(38mm \times 42mm) = 5.014 \times 10^{-3} \times m^2$$

Secondary shadow

Area of Elipse = π a b
a = 1/2 major diameter
b = 1/2 minor diameter

$$Rx_area := (Ap_area) - (Obs_area) = 2.0433 \times 10^{-2} \times m^2$$

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Channel Specific Parameters

$n := 0 .. 2250$ $a := 360 .. 710$ $b := 748 .. 865$ $d := 350 .. 820$ **Predefined subscript ranges**

Fixed instrument parameters = GREEN (Subscripts denote channel ID in 'nm')

$Opt_Tx_n := 75\%$ $BPF_Tx_n := 75\%$ $QE_n := 80\%$ $BPFs_n := 5nm$ $BPF_n := 5nm$ $\lambda_n := n \times nm$

Ocean science = BLUE and Atmosphere science = YELLOW

$SNR_req_a := 1000$ $SNR_req_b := 600$ $Lt_n := 0.0001$ $\lambda_0 := 0.1 \times nm$

$SNR_req_{350} := 300$ $SNR_req_{678} := 1400$ $SNR_req_{1245} := 250$ $SNR_req_{1640} := 180$ $SNR_req_{2135} := 100$

$SNR_req_{763} := 100$ $SNR_req_{940} := 150$ $SNR_req_{1378} := 100$ $SNR_req_{2250} := 150$

$BPF_{350} := 15nm$ $BPF_{360} := 15nm$ $BPF_{385} := 15nm$ $BPF_{412} := 15nm$ $BPF_{425} := 15nm$

$BPF_{443} := 15nm$ $BPF_{460} := 15nm$ $BPF_{475} := 15nm$ $BPF_{490} := 15nm$ $BPF_{510} := 15nm$

$BPF_{532} := 15nm$ $BPF_{555} := 15nm$ $BPF_{583} := 15nm$ $BPF_{617} := 15nm$ $BPF_{640} := 10nm$

$BPF_{655} := 15nm$ $BPF_{665} := 10nm$ $BPF_{678} := 10nm$ $BPF_{710} := 15nm$ $BPF_{748} := 10nm$

$BPF_{763} := 5nm$ $BPF_{765} := 40nm$ $BPF_{820} := 15nm$ $BPF_{865} := 40nm$ $BPF_{940} := 15nm$

$BPF_{1245} := 20nm$ $BPF_{1378} := 10nm$ $BPF_{1640} := 40nm$ $BPF_{2135} := 50nm$ $BPF_{2250} := 50nm$

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Channel Specific Parameters - cont'd

Ltyp and Lmax radiance definitions

$Lt_{350} := 7.46$	$Lm_{350} := 35.6$	$Lt_{555} := 3.39$	$Lm_{555} := 64.3$	$Lt_{865} := 0.45$	$Lm_{865} := 33.3$
$Lt_{360} := 7.22$	$Lm_{360} := 37.6$	$Lt_{583} := 2.81$	$Lm_{583} := 62.4$	$Lt_{1245} := 0.088$	$Lm_{1245} := 15.8$
$Lt_{385} := 6.11$	$Lm_{385} := 38.1$	$Lt_{617} := 2.19$	$Lm_{617} := 58.2$	$Lt_{1640} := 0.029$	$Lm_{1640} := 8.2$
$Lt_{412} := 7.86$	$Lm_{412} := 60.2$	$Lt_{640} := 1.90$	$Lm_{640} := 56.4$	$Lt_{2135} := 0.008$	$Lm_{2135} := 2.2$
$Lt_{425} := 6.95$	$Lm_{425} := 58.5$	$Lt_{655} := 1.67$	$Lm_{655} := 53.5$		
$Lt_{443} := 7.02$	$Lm_{443} := 66.4$	$Lt_{665} := 1.60$	$Lm_{665} := 53.6$		
$Lt_{460} := 6.83$	$Lm_{460} := 72.4$	$Lt_{678} := 1.45$	$Lm_{678} := 51.9$		
$Lt_{475} := 6.19$	$Lm_{475} := 72.2$	$Lt_{710} := 1.19$	$Lm_{710} := 48.9$		
$Lt_{490} := 5.31$	$Lm_{490} := 68.6$	$Lt_{748} := 0.93$	$Lm_{748} := 44.7$		
$Lt_{510} := 4.58$	$Lm_{510} := 66.3$	$Lt_{765} := 0.83$	$Lm_{765} := 43.0$		
$Lt_{532} := 3.92$	$Lm_{532} := 65.1$	$Lt_{820} := 0.59$	$Lm_{820} := 39.3$		

Atmosphere science

$Lt_{763} := 0.83$	$Lm_{763} := 43.0$
$Lt_{940} := 0.78$	$Lm_{940} := 21.0$
$Lt_{1378} := 0.35$	$Lm_{1378} := 9.5$
$Lt_{2250} := 0.07$	$Lm_{2250} := 2.1$

$$Lw_typ := Lt \times \frac{mW}{cm^2 \times \mu m \times sr}$$

$$Lw_max := Lm \times \frac{mW}{cm^2 \times \mu m \times sr}$$

$$Dyn_range := \frac{Lw_max}{Lw_typ}$$

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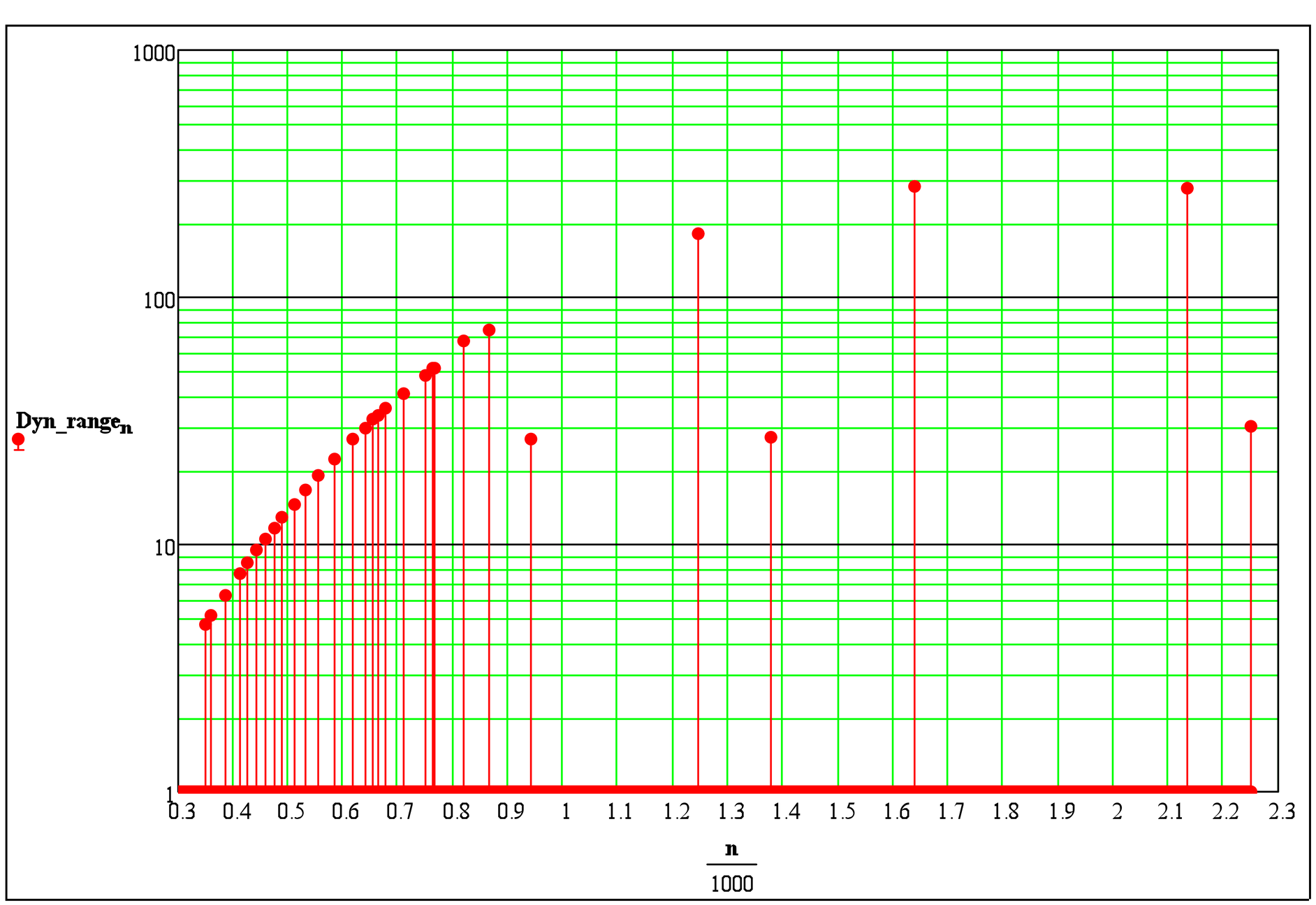
Ltyp => Lmax Dynamic Range - $f(\lambda_{\mu m})$



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Instrument timing parameters

$$Gnd_\nu(700km) = 6.7624 \times \frac{km}{sec}$$

$$Alongtrk_sampling = 1.1 \times km$$

Driven by fiber core + cladding diameter = 1.1km (800um + 80um)

$$\tau_Alongtrk_sampling = 0.163\,s$$

$$Scan_rate := \frac{1}{\tau_Alongtrk_sampling} = 6.148 \times Hz$$

Telescope rotation rate

$$\tau_iFOV := \frac{iFOV}{2 \times \pi \times Scan_rate} = 31.917 \times \mu s$$

Cross-track iFOV period (integration)

$$\tau_iFOV_space := 10\% \times \tau_iFOV = 3.192 \times \mu s$$

Fiber cladding diameter = 10% fiber core => 100m

Cross-track iFOV space => timing for CDS A/D's, etc.

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A*Ω throughput product (1km and 250m)

$GSD = 1 \times km$

Area of Elipse = π a b
a = 1/2 major diameter
b = 1/2 minor diameter

$\frac{Rx_area}{Ap_area} = 0.803$

Telescope obscuration losses

$GSA_{1k} := \pi\left[\frac{GSD}{2} \times \left(\frac{iFOV \times Slant_rng}{2}\right)\right] \times \cos(Tilt_surface_ang) = 0.672 \times km^2$

$\Omega A_{1k} := \frac{Rx_area}{(Slant_rng)^2} \times (GSA_{1k}) = 2.439 \times 10^{-8}\, m^2$

$\frac{GSA_{1k}}{16} = 0.042 \times km^2$

$GSA_{250} := \pi\left[\frac{GSD}{8} \times \left(\frac{iFOV \times Slant_rng}{8}\right)\right] \times \cos(Tilt_surface_ang) = 0.042 \times km^2$

$\Omega A_{250} := \frac{Rx_area}{(Slant_rng)^2} \times (GSA_{250}) = 1.525 \times 10^{-9}\, m^2$

$\frac{\Omega A_{1k}}{16} = 1.525 \times 10^{-9} \times m^2$

See backup charts for iFOV, Slant_rng and Tilt_surface_ang derivations

$iFOV = 1.233 \times mr$

$Slant_rng = 750.422 \times km$

$Tilt_surface_ang = 22.306\, deg$

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Photons => Photo-current

$$AW_n := \frac{QE_n \times qe}{E(\lambda_n)}$$

$$Ityp_n := Lw_typ_n \times \Omega A_{1k} \times Opt_Tx_n \times BPF_Tx_n \times BPFs_n \times AW_n$$

$$Imax_n := Lw_max_n \times \Omega A_{1k} \times Opt_Tx_n \times BPF_Tx_n \times BPFs_n \times AW_n$$

$$It_n := Lw_typ_n \times \Omega A_{250} \times Opt_Tx_n \times BPF_Tx_n \times BPFs_n \times AW_n$$

$$Im_n := Lw_max_n \times \Omega A_{250} \times Opt_Tx_n \times BPF_Tx_n \times BPFs_n \times AW_n$$

$QE_0 = 0.8$

$Opt_Tx_0 = 0.75$

$BPF_Tx_0 = 0.75$

$BPFs_0 = 5 \times nm$

$BPF_0 = 5 \times nm$

System throughput losses

$QE_0 \times Opt_Tx_0 \times BPF_Tx_0 = 0.45$

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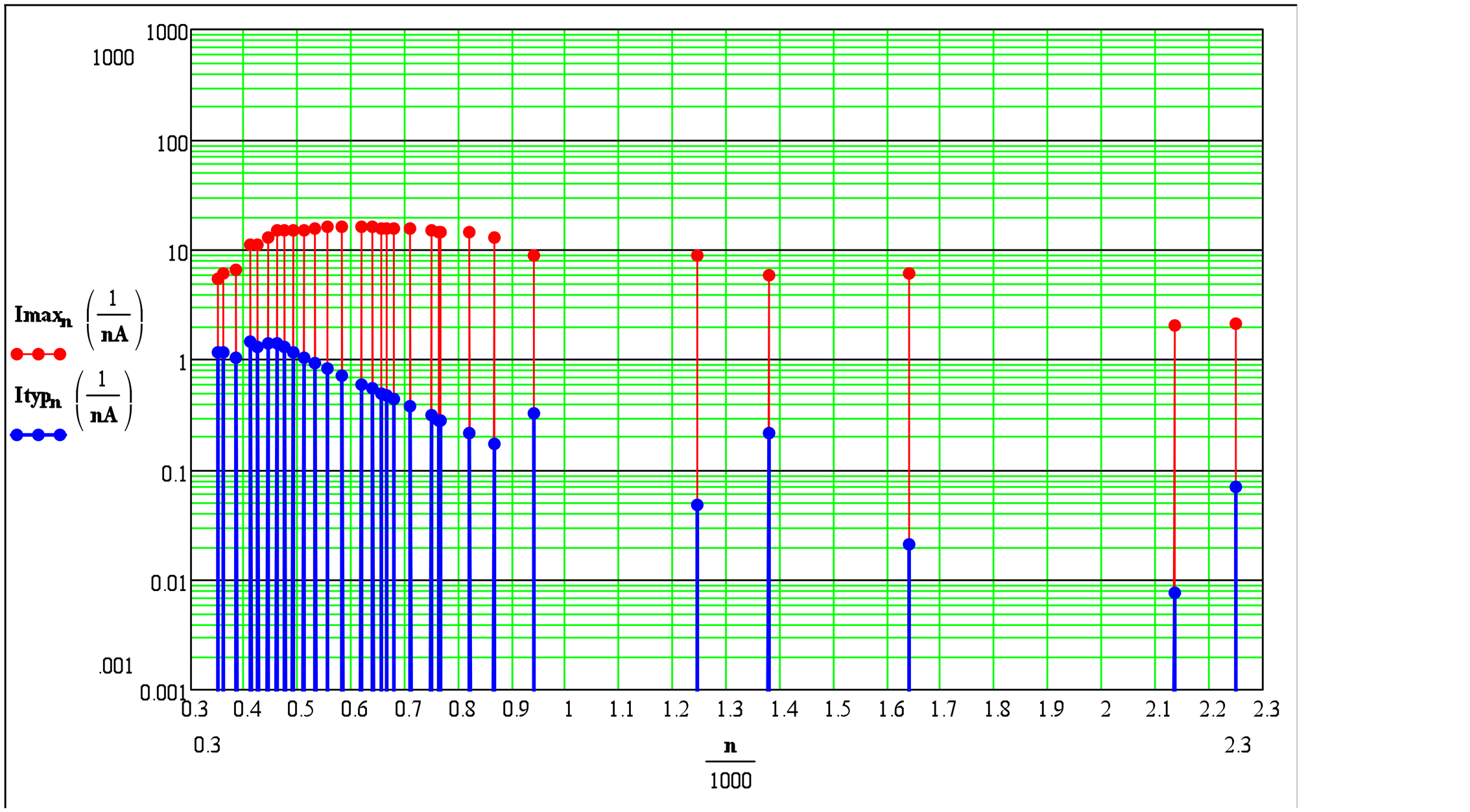
Ltyp & Lmax Photo-Current (1km)



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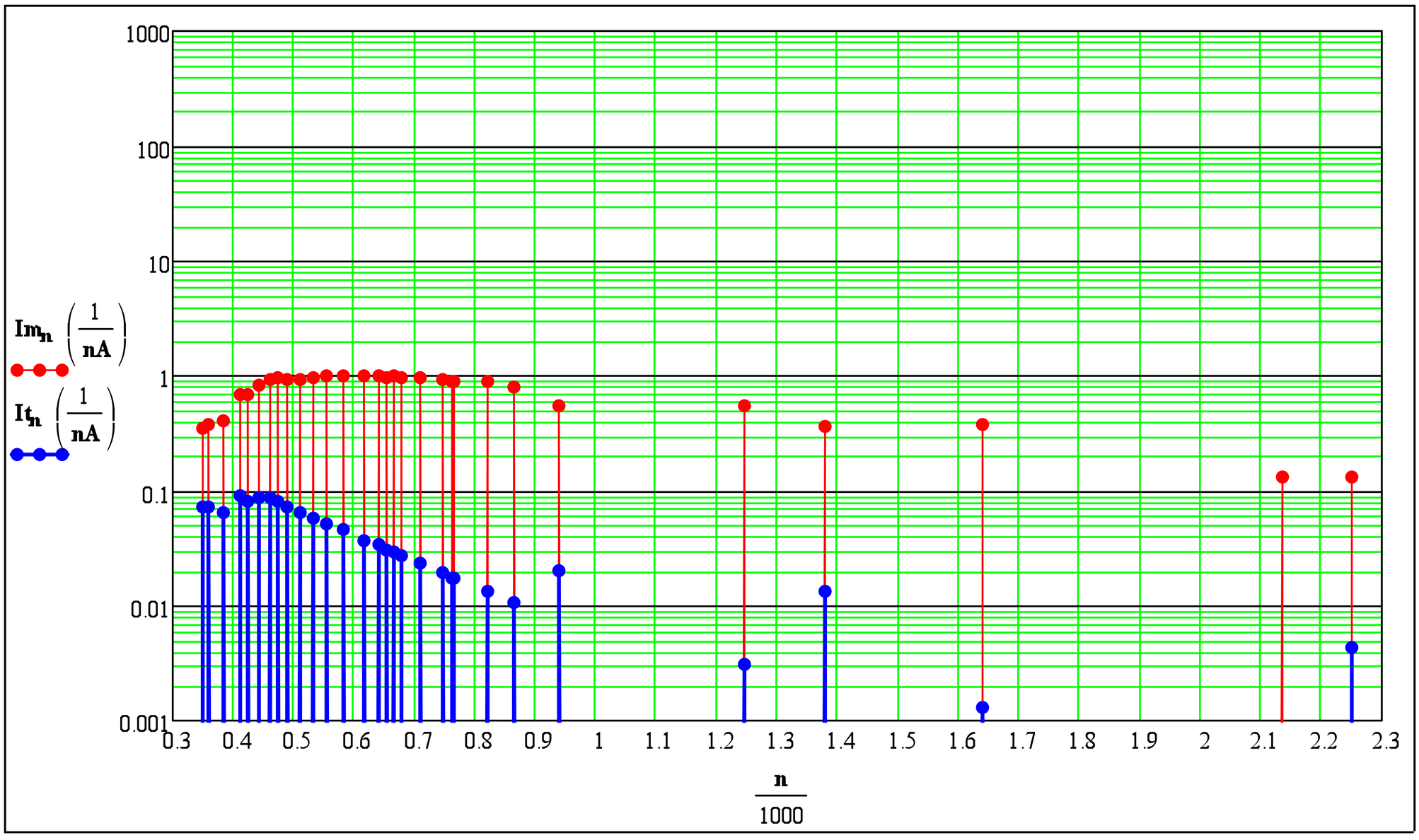
Ltyp & Lmax Photo-Current (250m)



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SNR Input Parameters

$Cx := 0.1\,pF$ $Ib := 0\,A$ $Id := 0\,A$ $\tau_iFOV = 31.917 \times \mu s$ $T_{rf} = 300\,K$

q = C x V

$$Vc(I, \tau, Cx) := \frac{I \times \tau}{Cx} \qquad Xc(\tau, Cx) := \frac{\tau}{Cx}$$

$Vmax := Vc(max(Imax), \tau_iFOV, Cx) = 5.14\,V$

$$bw(\tau) := \frac{1}{2\tau}$$

bw to τ conversion

$$In(\tau) := 0.13 \frac{fA}{\sqrt{Hz}} \times \left(\sqrt{bw(\tau)}\right) \qquad Vn(\tau) := 22 \frac{nV}{\sqrt{Hz}} \times \left(\sqrt{bw(\tau)}\right)$$

Pre-Amp Spec's - National LMC 6001

$$Well_max(Cx) := \frac{Vmax \times Cx}{pe} \qquad Vnq := \frac{Vmax}{2^{AD_bits} \times \sqrt{12}} = 0.091 \times mV$$

$Well_max(Cx) = 3.208\,M$

$$Vsn(I, \tau, Cx) := \sqrt{2q \times (I + Id + Ib)\, bw(\tau) \times Xc(\tau, Cx)^2} \qquad kTC(C) := \sqrt{\frac{k_B \times T_{rf}}{C}}$$

$$SNR_Cv(I, \tau, Cx) := \frac{Vc(I, \tau, Cx)}{\sqrt{Vsn(I, \tau, Cx)^2 + Vn(\tau)^2 + (In(\tau) \times Xc(\tau, Cx))^2 + (kTC(Cx))^2 + Vnq^2}}$$

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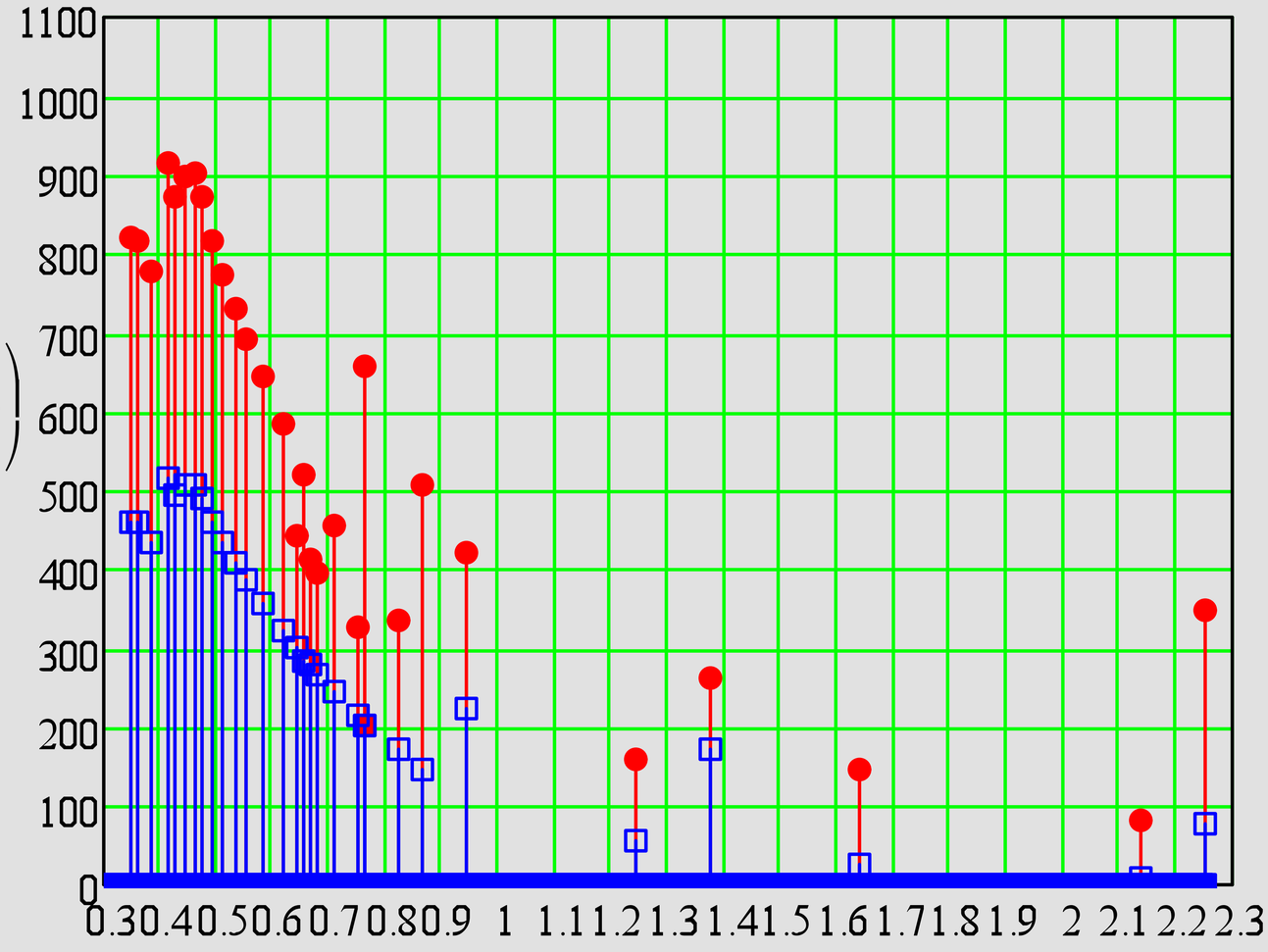
SNR's - Aggregated and 5nm bands (1km)

RED = Aggregated Science Bands
BLUE = 5nm Science Bands

$SNR_Cv\left(Ityp_n \frac{BPF_n}{BPFs_n} _iFOV\ Cx\right)$

$SNR_Cv(Ityp_n _iFOV\ Cx)$

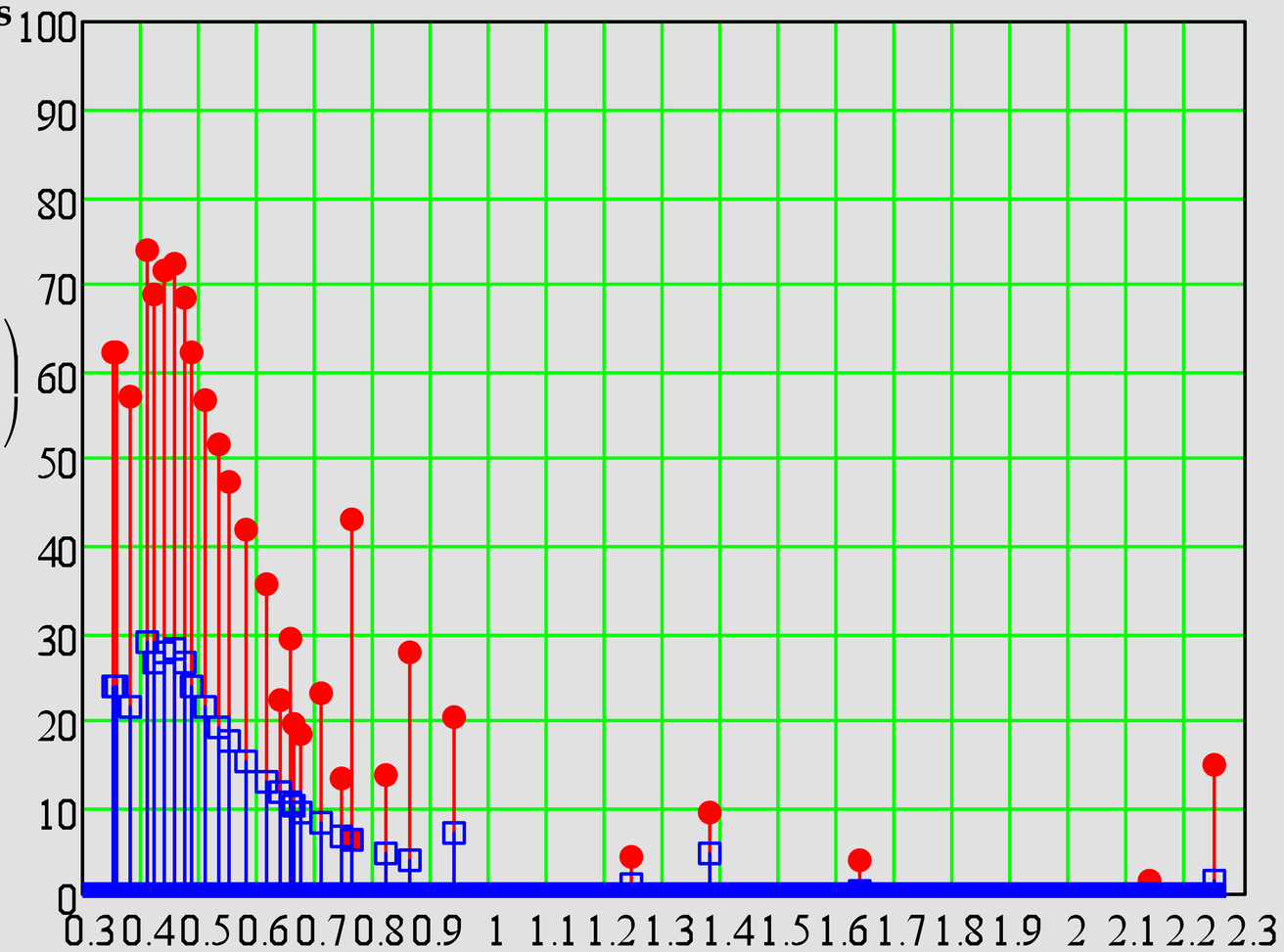


SNR's - Aggregated and 5nm bands (250m)

RED = Aggregated Science Bands
BLUE = 5nm Science Bands

$$SNR_Cv\left(It_n \quad \frac{BPF_n}{BPFs_n} \quad \frac{_iFOV}{4} \quad Cx\right)$$

$$SNR_Cv\left(It_n \quad \frac{_iFOV}{4} \quad Cx\right)$$



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Aggregated SNR Predicts (1km)

$$SNR_n := SNR_Cv\left(Ityp_n \times \frac{BPF_n}{BPFs_n}, \tau_iFOV, Cx\right)$$

This requires (77 + 4) fiber channels (144 - 81 = 63 avail.)

$SNR_{350} \times \sqrt{1} = 820$	$SNR_{510} \times \sqrt{2} = 1095$	$SNR_{710} \times \sqrt{5} = 1014$	$SNR_{1245} \times \sqrt{3} = 278$
$SNR_{360} \times \sqrt{2} = 1157$	$SNR_{532} \times \sqrt{2} = 1032$	$SNR_{748} \times \sqrt{4} = 651$	$SNR_{1378} \times \sqrt{1} = 263$
$SNR_{385} \times \sqrt{2} = 1099$	$SNR_{555} \times \sqrt{3} = 1199$	$SNR_{763} \times \sqrt{1} = 204$	$SNR_{1640} \times \sqrt{2} = 206$
$SNR_{412} \times \sqrt{2} = 1294$	$SNR_{583} \times \sqrt{3} = 1116$	$SNR_{765} \times \sqrt{1} = 655$	$SNR_{2135} \times \sqrt{2} = 115$
$SNR_{425} \times \sqrt{2} = 1235$	$SNR_{617} \times \sqrt{3} = 1009$	$SNR_{820} \times \sqrt{4} = 667$	$SNR_{2250} \times \sqrt{1} = 349$
$SNR_{443} \times \sqrt{2} = 1268$	$SNR_{640} \times \sqrt{6} = 1086$	$SNR_{865} \times \sqrt{2} = 716$	
$SNR_{460} \times \sqrt{2} = 1275$	$SNR_{655} \times \sqrt{4} = 1042$	$SNR_{940} \times \sqrt{1} = 420$	
$SNR_{475} \times \sqrt{2} = 1232$	$SNR_{665} \times \sqrt{7} = 1091$		
$SNR_{490} \times \sqrt{2} = 1157$	$SNR_{678} \times \sqrt{7} \times \sqrt{4} = 2090$		

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Summary

- **The GOOD:**
  - Little, if any,
    - spatial crosstalk
    - spectral crosstalk
    - spectral ‘drift’
    - striping
  - Serves atmosphere and oceans applications
  - Do not need spectral diffuser plate (internal target)
  - Calibration target door incorporated
  - Simple and high TRL components with production assembly advantages
  - Graceful failure degradation
  - Dynamic pre-amp integration control (available) to accommodate $L_{max's}$ (saturation).
- **The BAD**
  - Individual channel accessibility during I&T
  - Unknown fiber coating - selectivity and application
  - SNR performance at 5nm resolution is not as ‘plentiful’ as requested

The UGLY

- (144 + 32) channels seems a bit ‘excessive’

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Backup Material

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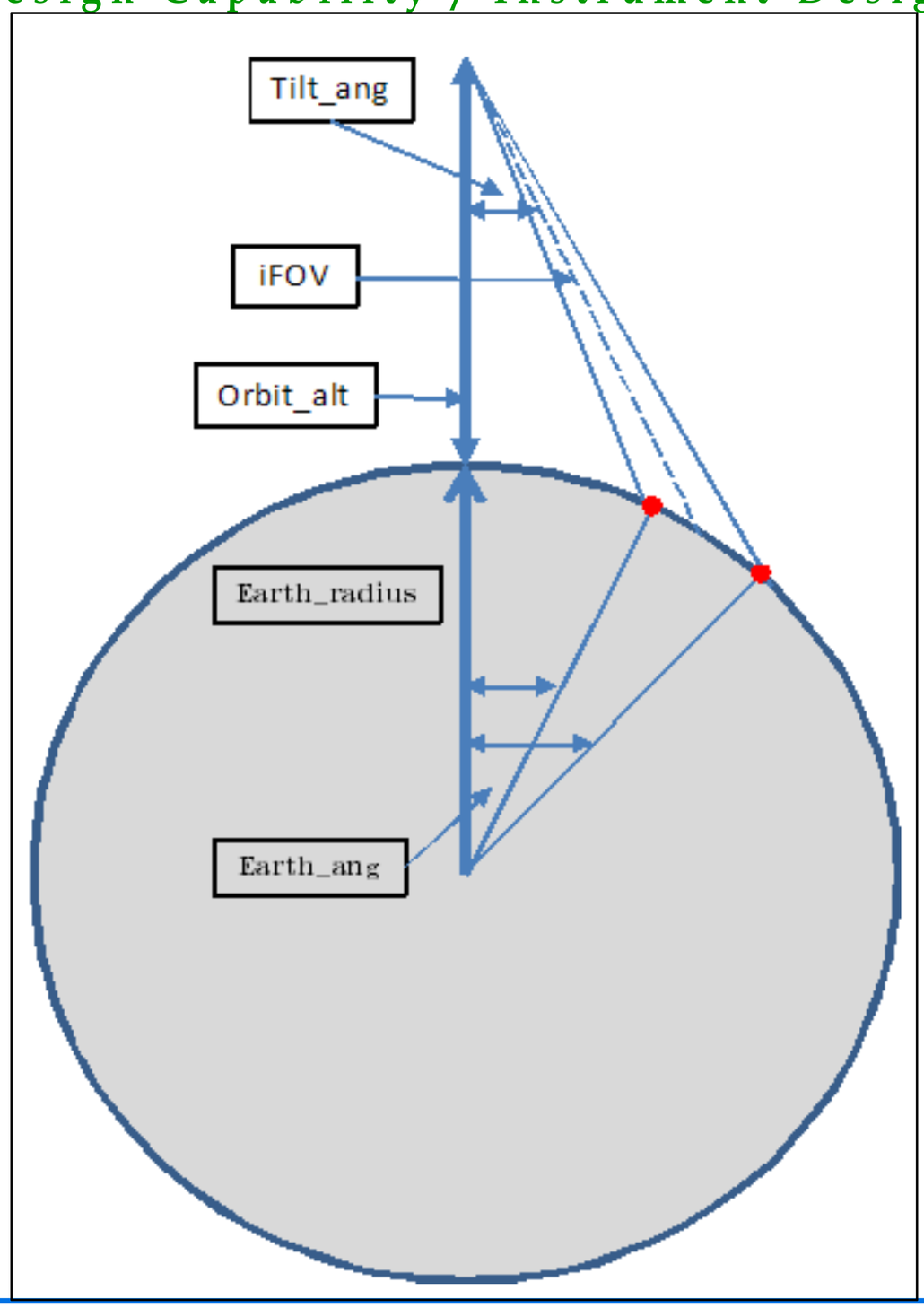
Geometry model for look-ahead angle



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iFOV corrections due to ±20° look-ahead tilt angle, orbit alt. and curved Earth

$Tilt_ang = 20 \times deg$

Nadir iFOV footprint for 1km

$iFOV = 1.429 \times mr$

Law of Sines - Must use complementary for the obtuse angles in this case

$$Earth_ang_lo := \pi - \operatorname{asin}\left[\frac{\sin\left(Tilt_ang - \frac{iFOV}{2}\right) \times (Earth_radius + Orbit_alt)}{Earth_radius}\right] = 157.74 \times deg$$

$$Earth_ang_hi := \pi - \operatorname{asin}\left[\frac{\sin\left(Tilt_ang + \frac{iFOV}{2}\right) \times (Earth_radius + Orbit_alt)}{Earth_radius}\right] = 157.648 \times deg$$

$$Earth_ang_lo := \left[\pi - Earth_ang_lo - \left(Tilt_ang - \frac{iFOV}{2}\right)\right] = 2.301 \times deg$$

$$Earth_ang_hi := \left[\pi - Earth_ang_hi - \left(Tilt_ang + \frac{iFOV}{2}\right)\right] = 2.311 \times deg$$

$Earth_angle := Earth_ang_hi - Earth_ang_lo = 0.010409 \times deg$

Along-track footprint at 20 deg. tilt angle

$gsd := Earth_radius \times Earth_angle = 1.158742269769 \times km$

iFOV required for 1km along-track footprint at 20 deg. tilt angle

$iFOV := 1.23286371 mr$

$$Surface_ang := \pi - \operatorname{asin}\left[\frac{\sin(Tilt_ang) \times (Earth_radius + Orbit_alt)}{Earth_radius}\right] = 157.694 \times deg$$

$Earth_ang := (\pi - Surface_ang - Tilt_ang) = 2.306 \times deg$

$Tilt_surface_ang := \pi - Surface_ang = 22.306\, deg$

$$Slant_rng := \frac{\sin(Earth_ang) \times Earth_radius}{\sin(Tilt_ang)} = 750.422\, km$$