Brazilian Tunable Filter Imager (BTFI)
Conceptual Design Review (CoDR)

Performance Modeling
Version 0.1

USP-IAG Universidade de São Paulo

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Performance Modeling

- Double-pass VPHGs
  - Limits of the modeling
  - Transmission Mode
  - Reflection Mode
- SNR
  - Emission line / Surface Brightness
  - Continuum / Point source

Double-Pass VHPGs

- Bragg's Condition
- Kogelnik Efficiency
  - Polarization S
  - "Thick" gratings
  - Weak gratings
  - Unslanted gratings

$$m\lambda = 2\Lambda \sin\theta_{air}$$

$$\eta_B = \sin^2\left(\frac{\pi \Delta n D}{\lambda_B \cos\theta_n}\right)$$

$$Q = \frac{2\pi\lambda D}{n_0 \Lambda^2} \gg 1$$

$$\Delta n < \frac{\lambda_B \cos\theta_n}{2D}$$

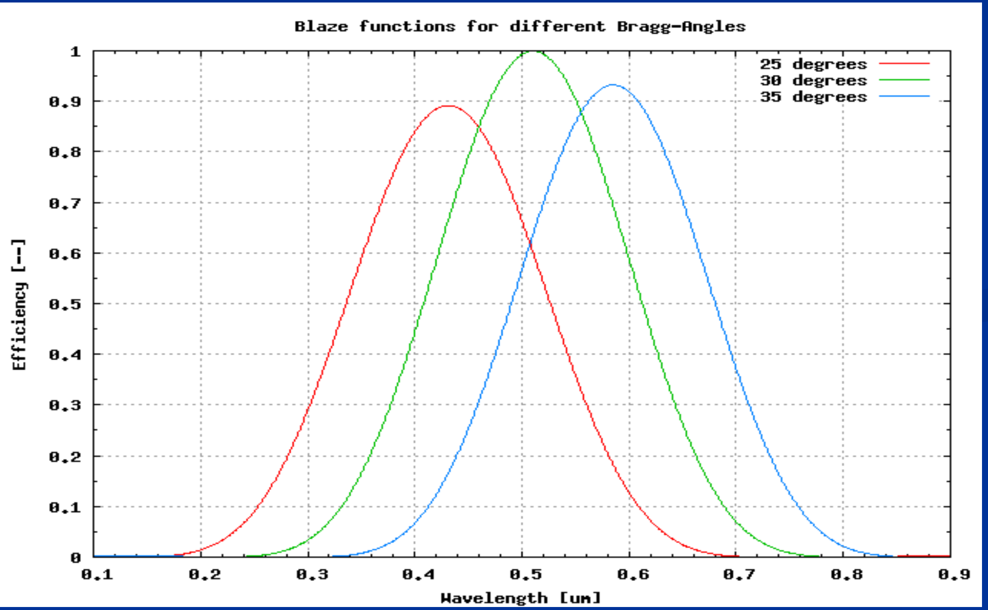
$$\eta_\lambda = \eta_B\, sinc^2\left(\frac{\lambda_B - \lambda}{\Delta\lambda}\right)$$

Double-Pass VHPGs

- Grating in transmission mode

Grating thickness = 7.22 μm
Refractive Index = 1.50
Grating strength = 0.033
Line frequency = 1960 lines/mm
Bragg angle = 30°
Bragg wavelength = 510 nm
Efficiency = 0.9995

$\Delta\lambda$ = 101.95 nm
$\Delta\theta$ = 9.11°
Q = 62
Δn_{REF} = 0.042



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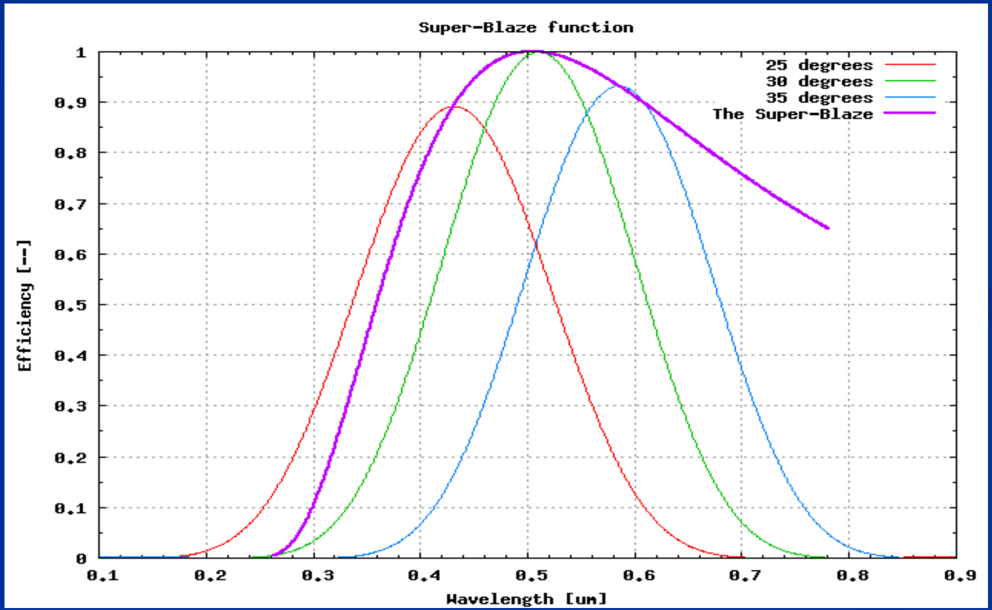

$\Delta\lambda$ = 101.95 nm
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$\Delta\theta$ = 9.11º
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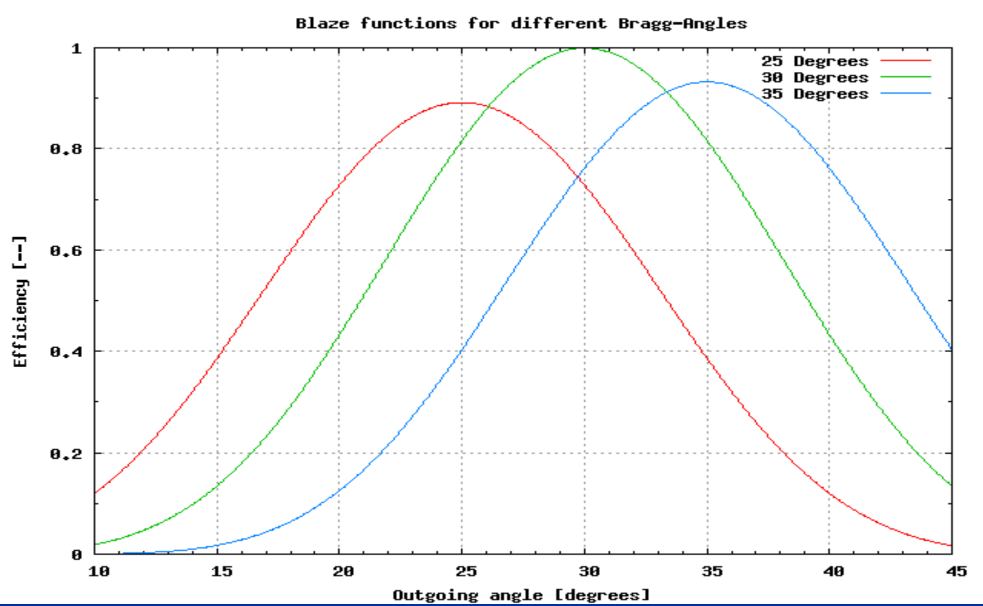
Δn_{REF} = 0.0005



Signal-to-Noise Ratio

- L3CCD x CCD

Classic CCD

$$\sigma^2_{CCD} = \sigma^2_{SKY} + \sigma^2_{Dark} + R^2_{ON}\, n_{Sweep}$$

$$SNR = \frac{\Sigma}{\sqrt{\Sigma + F_{SS}\,\sigma^2}}$$

L3CCD

$$\sigma^2_{L3} = F^2\sigma^2_{Sky} + F^2\sigma^2_{Dark} + n_{Sweep}\frac{R^2_{ON}}{G^2} + n_{Sweep}F^2\,CIC$$

SNR calcs.

Emission-line / Surface Brightness

S_B	Object Surface Brightness [erg.s^{-1}.cm^{-2}.arcsec^{-2}]	2,00E-015	cgs	Σ	Object Flux in z-frame [e-/binned-pixel]	23,30		
					Object Flux in single exposure [e-/binned-pixel]	1,16		
T_{3D}	Total observing time [hours]	2	hrs	T_{Exp}	Exposure time per z-frame	205,00	s	
n_Z	Number of z-frames in a sweep [---]	32		T_{Int}	Integration time	10,25	s	
n_{Sweep}	Number of integrations per z-frame [---]	20		T_{Read} / T_{exp}	Duty cycle loss (%)	9,76	%	
T_{Read}	Readout time [s]	1	s					
λ	Emission wavelength [Å]	5500	A					
$Ø_{Telescope}$	Telescope's primary mirror diameter [m]	4,1	m	$A_{Telescope}$	Telescope's primary mirror area [cm^2]	132025	cm^2	
$S_{ampling}$	Sampling per pixel [arcsec]	0,120	"	S_{Area}	Sky area per binned-pixel [arcsec^2]	0,0144	"^{2}	
bp_X	Number of binned pixels in x-direction [---]	1						
bp_Y	Number of binned pixels in y-direction [---]	1						
Q_{CCD}	Detector quantum efficiency [e$^-$/photon]	0,90						
Q_{IT}	Instrument throughput [---]	0,12						
Q_{Atm}	Atmosphere throughput [---]	1,00						
S_{Sky}	Sky surface brightness [erg.s^{-1}.cm^{-2}.arcsec^{-2}]	0	cgs	σ_{Sky}^2	Sky flux [photons/binned-pixel]	0,0		
F_{SS}	Sky subtraction factor [---]	1,2						
D	Dark-noise [e$^-$.s^{-1}.pixel^{-1}]	0,003		σ_{Dark}^2	Dark count [e-/binned-pixel]	0,62		
RON(slow)	Read-noise (rms) [e$^-$.binned pixel^{-1}]	3	rms	$\sigma_{Read\,CCD}^2$	Read-noise squared [(e-/binned-pixel)^2]	180,00		
RON(fast)	Read-noise (rms) [e$^-$.binned pixel^{-1}]	20	rms	$\sigma_{Read\,L3}^2$	Read-noise squared [(e-/binned-pixel)^2]	8000,00		
G	L3CCD gain [---]	3000		$\sigma_{Read\,L3}^2$		0,0009		
CIC	Clock induced charges [e$^-$.binned pixel^{-1}]	0,02	rms	σ_{CIC}^2		0,4000		
				α		1,16		
SNR_{CCD}		1,50		g		0,5907		
SNR_{L3}		4,71		N		1,4043		
SNR_{L3}/SNR_{CCD}		3,13		F^2		0,0070		1

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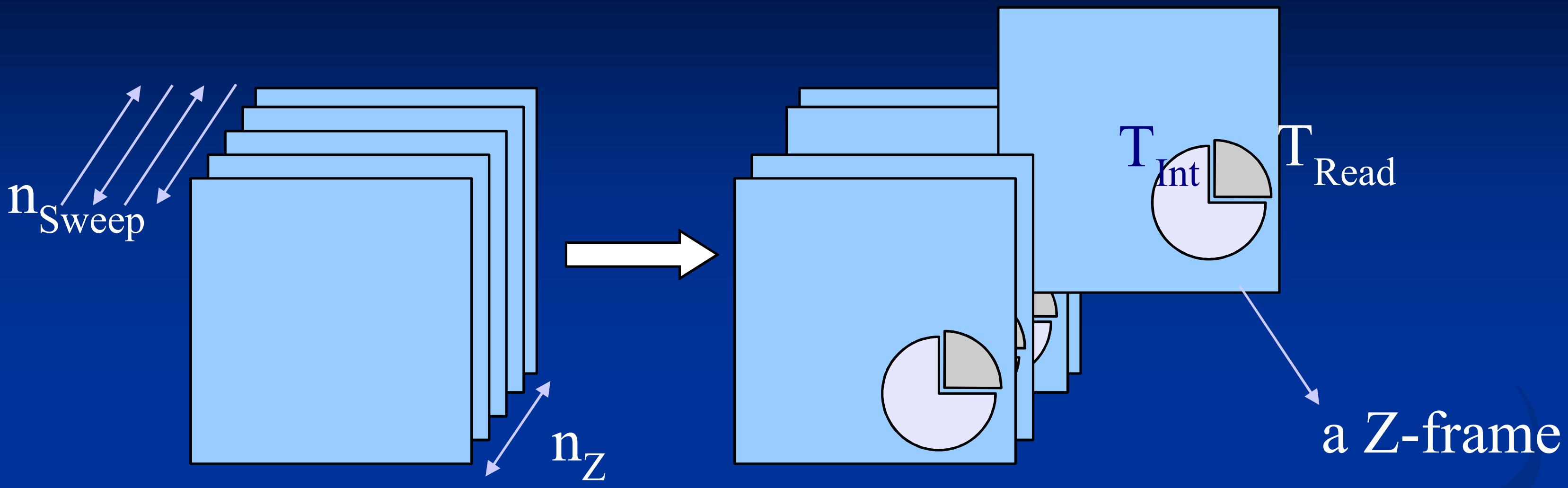
SNR calcs.

Continuum / Point Source (Mags)

m	Object's magnitude [---]	21		S_{point}	Point-source brightness [photons.s^{-1}.nm^{-1}.m^{-2}]	0,39	
S_0[photon]	Zero-point for the waveband [photons.s^{-1}.nm^{-1}.m^{-2}]	9,71E+007	V-band	Σ	Signal [e^-.binned $pixel^{-1}$]	67,704388	
					Object Flux in single exposure [e-/binned-pixel]	1,35	
T_{3D}	Total observing time [hours]	8	Hrs	T_{Exp}	Exposure time per z-frame [s]	670	s
n_z	Number of frames in a sweep [---]	40		T_{Read} / T_{exp}	Duty cicle loss [%]	7,463	%
n_{Sweep}	Number of integrations per z-frame [---]	50		n_{Exp}	Number of exposures [---]	2000	
T_{Read}	Readout time [s]	1	s				
λ	Emission wavelength [Å]	5500					
R	Spectral resolution [---]	10000					
Fwhm	Seeing [arcsec]	1,2	"				
$Ø_{Telescope}$	Telescope's primary mirror's diameter [m]	4,1	m	$A_{Telescope}$	Telescope's primary mirror's area [m^2]	13,20	
$S_{ampling}$	Sampling per pixel [arcsec]	0,120	"	S_{Area}	Sky area per binned-pixel [$arcsec^2$]	0,0144	m^2
bp_X	Number of binned pixels in x-direction [---]	1					"2
bp_Y	Number of binned pixels in y-direction [---]	1					
Q_{CCD}	Detector quantum efficiency [e^-.$photon^{-1}$]	0,90					
Q_{IT}	Instrument throughput [---]	0,20					
Q_{Atm}	Atmosphere throughput [---]	1,00					
m_{Sky}	Sky surface brightness [---]	40		S_{Sky}	Sky surface brightness flux [photons.s^{-1}.nm^{-1}.m^{-2}]	0	
F_{SS}	Sky subtraction factor [---]	1,2		σ_{Sky}^2	Sky noise [e^-.binned $pixel^{-1}$]	0,0000	
D	Dark-noise charges [e^-.s^{-1}.binned $pixel^{-1}$]	0,003		σ_{Dark}^2	Dark-noise [(e^-.binned $pixels^{-1}$)²]	100,50	
RON(slow)	Readout charges [e^-.binned $pixel^{-1}$]	3		$\sigma_{Read\ CCD}^2$	Expected number of events [e-.binned pixel-1.frame-1]	450	
RON(fast)	Read-noise (rms) [e^-.binned $pixel^{-1}$]	20		$\sigma_{Read\ L3}^2$	Read-noise squared [(e-/binned-pixel)^2]	20000	
G	L3CCD gain [---]	3000		$\sigma_{Read\ L3}^2$	Readout noise for L3CCD [(e^-.binned $pixel^{-1}$)²]	0,0022	
CIC	Clock induced charges [e^-.binned $pixel^{-1}$]	0,024		σ_{CIC}^2	CIC noise [e^-.binned $pixels^{-1}$]	1,2000	
				α	Expected number of events [e^-.binned $pixel^{-1}$.$frame^{-1}$]	1,3541	
SNR_{CCD}	Classic CCD Signal-to-Noise Ratio [---]	2,51		g	Proportion of counted events [(e^-.binned $pixel^{-1}$.$frame^{-1}$)	0,5478	
SNR_{L3}	L3CCD Signal-to-Noise Ratio [---]	4,92		N	Non-linear noise [---]	1,5722	
SLR_{L3}/SNR_{CCD}		1,96		F^2	Noise factor [---]	0,0126	

Sheet1

Modelled Observational Scenario



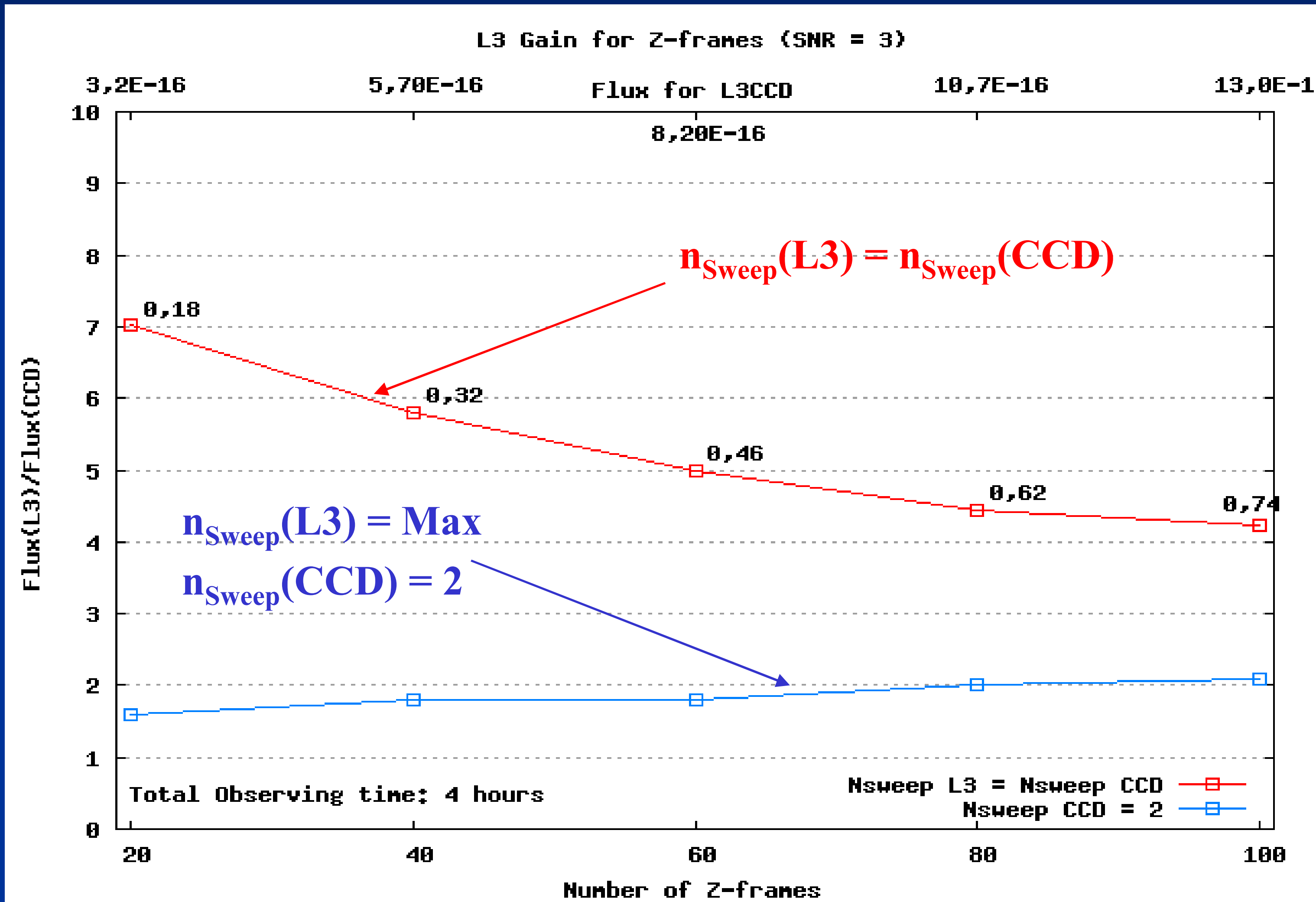
$T_{exp} = T_{Int} \cdot n_{Sweep}$ $T_{obs} = (T_{Int} + T_{read}).(n_{Sweep} \cdot n_Z)$

Note:

- $T_{Int} \sim 10 * T_{read}$ to reduce duty cycle losses to acceptable level
- For PC: Saturation for flux rate > 0.1 cnts/T_{Int}

⇨ Minimize T_{int} & T_{read} ⇨ Maximize n_{Sweep}

SNR as f(n_Z)



L3 Gain for Z-frames (SNR = 3)
Flux for L3CCD
3,2E-16
5,70E-16
8,20E-16
10,7E-16
13,0E-1
Flux(L3)/Flux(CCD)
0,18
0,32
0,46
0,62
0,74
nSweep(L3) = nSweep(CCD)
nSweep(L3) = Max
nSweep(CCD) = 2
Total Observing time: 4 hours
Nsweep L3 = Nsweep CCD
Nsweep CCD = 2
Number of Z-frames

SNR as f(n_Z) for:

n_{Sweep}(L3) = Max & n_{Sweep}(CCD) = 2