Innovative Compact Coronagraph Approach for Balloon-borne Investigation of Temperature and Speed of Electrons in the corona (BITSE)

Qian Gong, Natchimuthuk Gopalswamy, Jeffrey Newmark
NASA Goddard Space Flight Center, 8800 Greenbelt Road, Greenbelt, MD 20771 USA

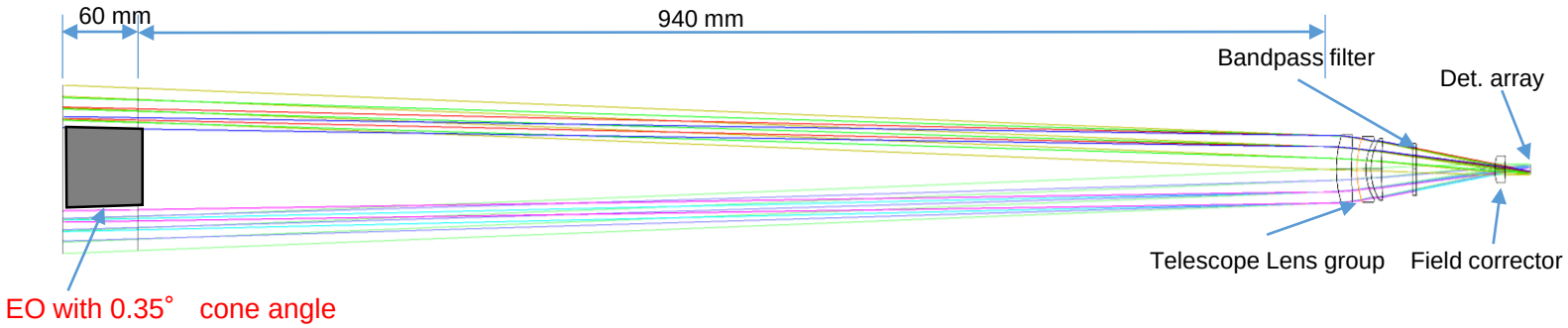
Overview

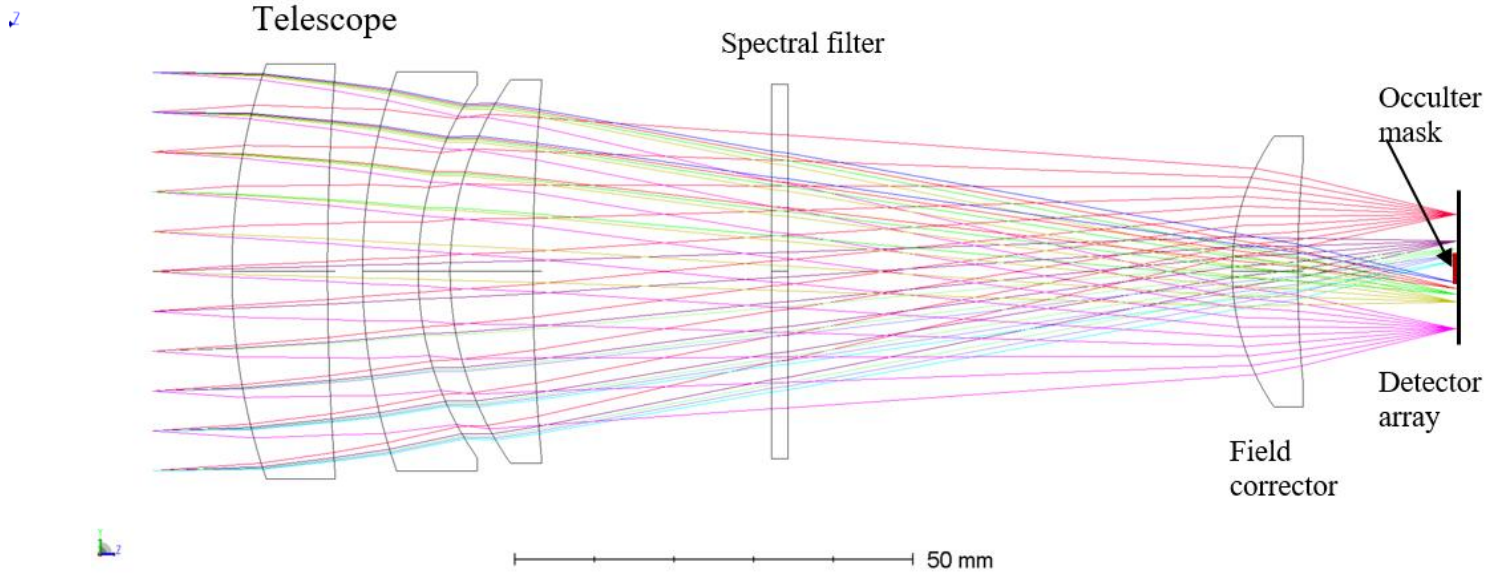
- BITSE is a compact coronagraph for studying the physical conditions in the solar wind acceleration region (~3-9 solar radii $R_{\odot}$).
- The proposed compact coronagraph is a one stage externally occulted coronagraph without internal occulter or Lyot stop mask.
- The key of this new idea is to set the inner field cutoff at External Occulter (EO) much smaller than the specified Inner Field of View Cutoff (IFoVC) angle.
- With this change, we obtain 2 significant improvements:
  - Data can be used right at the specified IFoVC.
  - Much higher Signal to Noise Ratio (SNR).
- Another new feature is the use of polarization camera, which can capture the 4 different polarized image simultaneously.
- It is a pathfinder for future orbit missions.

BITSE Optical System Requirement

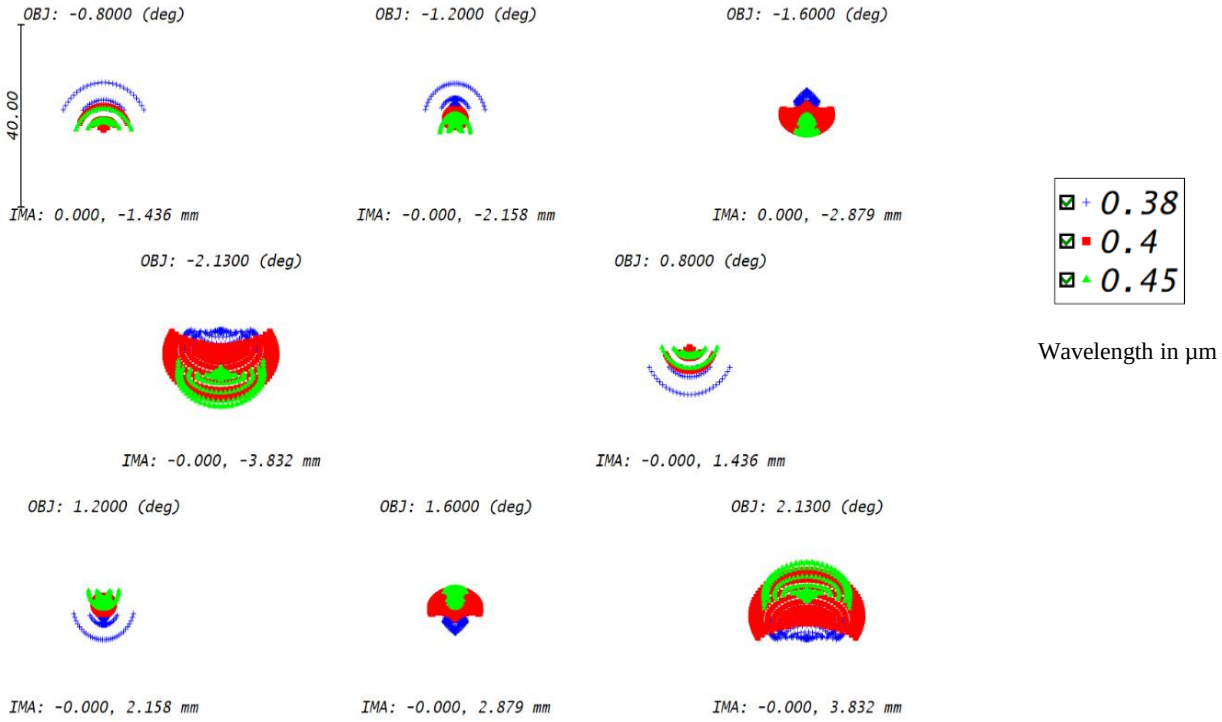
Parameter	Range
FOV (R_0)	15*
Inner FOV cutoff (R_0)	3
Wavelength range (nm)	380 – 430, including broadband
Effective Focal Length (mm)	103
Entrance pupil diameter (mm)	50
Detector array	CCD, 1950x1950, 7.4µm pixel
Diffraction and vignetting	S/N ratio meets requirement based on science model
Optics Throughput (average over λ & FOV)	> 85%

Coronagraph Overlay





Coronagraph Spot Diagram



Wavelength in µm

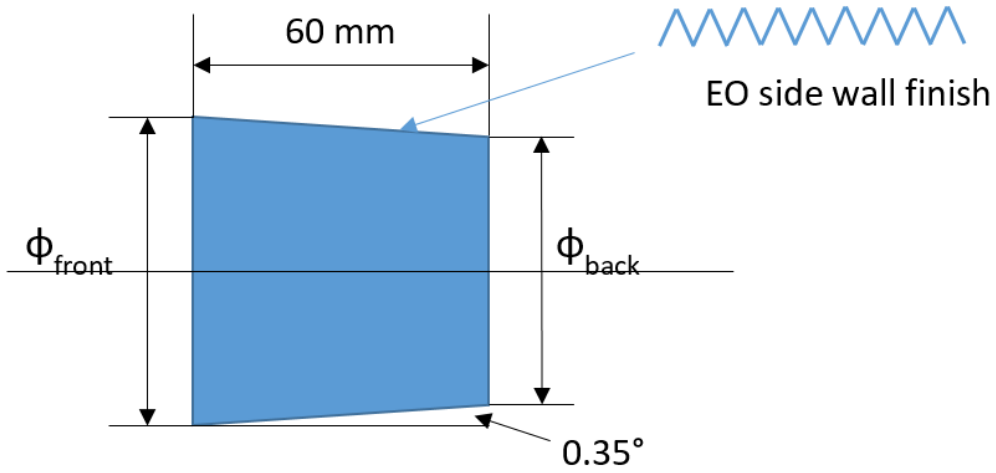
The peak wavelengths of the 4 narrowband filters are 393.5nm, 398.7nm, 405.0nm, and 423.3nm. The broadband filter has a wavelength range from 380nm to 450nm. Most of the time in the mission, the 4 narrowband filters are used.
The spot size is better than needed. For our polarization camera,

Coronagraph Diffraction Compression

- The diffraction design is aimed to increase the SNR without compromising the diffraction compression.
- The method is to make the EO cutoff much smaller than the specified IFoVC : 1.5 R⊙ to 3.0 R⊙. Place an occulter disk on detector array to block the light inside 3.0R⊙.
- EO cutoff at 1.5R⊙ reduce the vignetting for the FoV that is not completely unvignetted. It is shift the fully unvignetted FoV towards the Sun. The less vignetting increases SNR.
- The diffraction analysis shows that the diffraction distribution does not change with the EO cutoff in the range after the cutoff.
- **Result: SNR increases without compromising diffraction compression.**

Diffraction Modelling Parameters

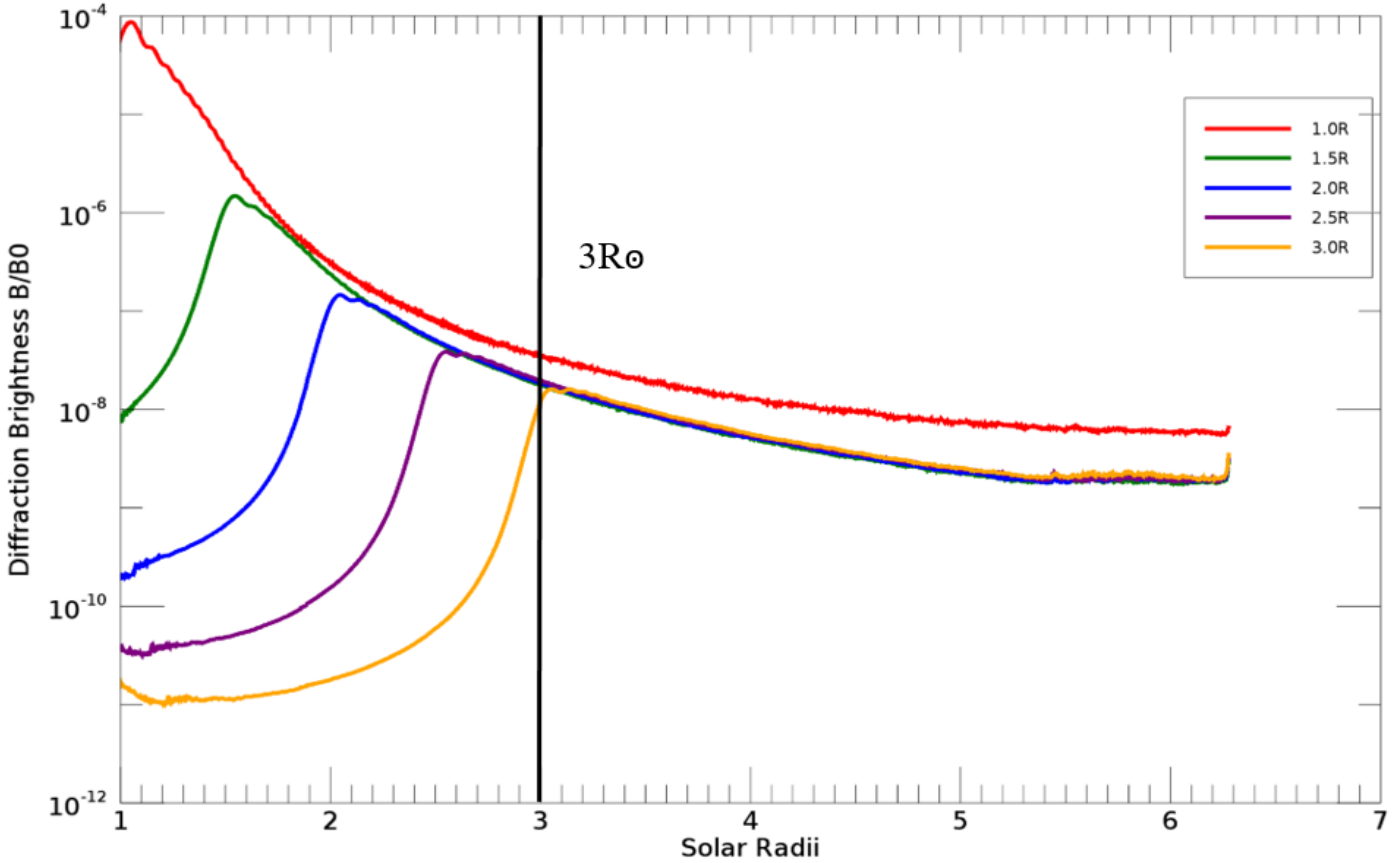
- The diffraction model is based on the BITSE coronagraph design on page 3.
- In the diffraction model, EO with 5 different cutoff angles are used for simulating the diffraction distribution.



IFoVC (Rʘ)	1	1.5	2	2.5	3
Front dia. (mm)	59.49	63.87	68.26	72.64	77.02
Back dia. (mm)	58.76	63.14	67.52	71.90	76.28

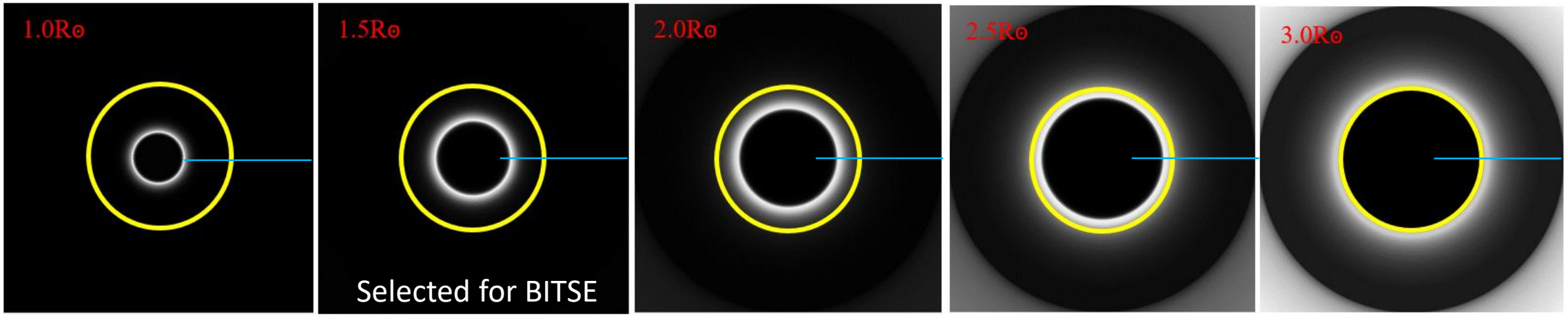
Occulter disk on the detector array has a diameter of 3.0 Rʘ.

Diffraction Intensity Distribution on Detector Array



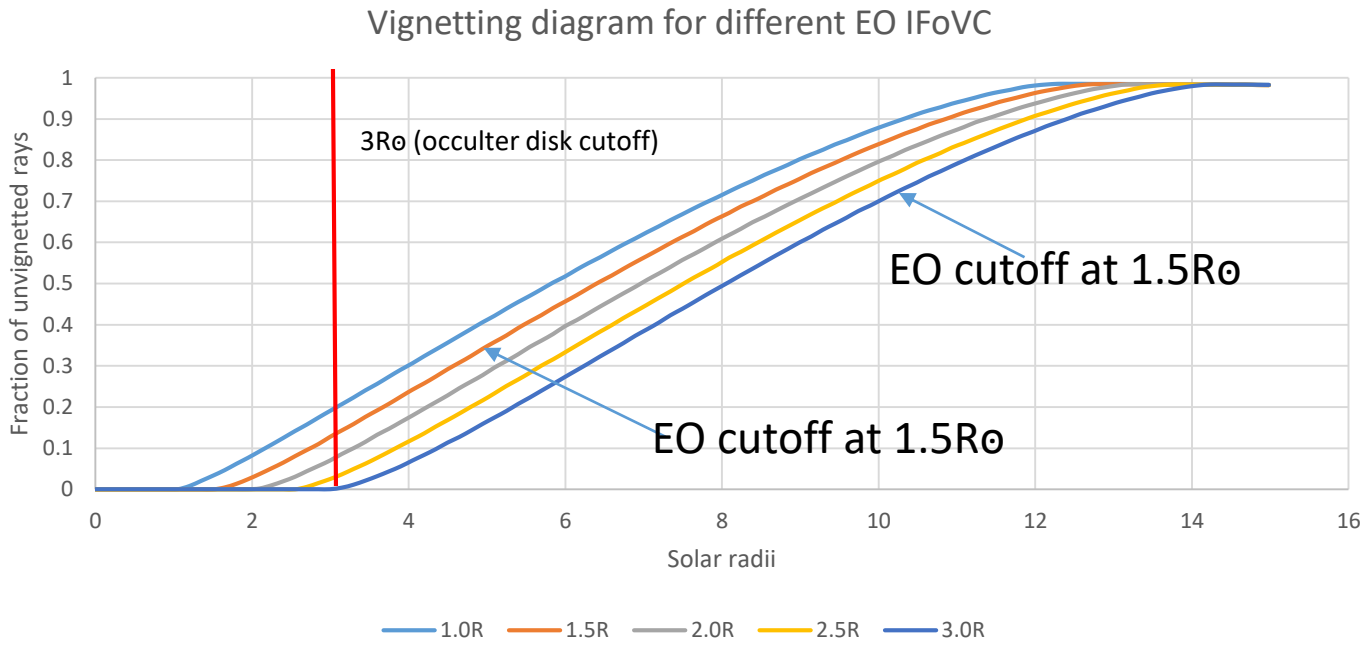
This is the most important plot of this presentation. It tells us that the diffraction intensity distribution after 3.0Rʘ is independent of EO cutoff except EO cutoff at 1.0Rʘ. As long as the central area within the 3.0Rʘ can be masked out, there is no difference whether EO cutoff is at 1.5, 2.0, 2.5, or 3.0 Rʘ.

Diffraction Intensity distribution on Detector Array



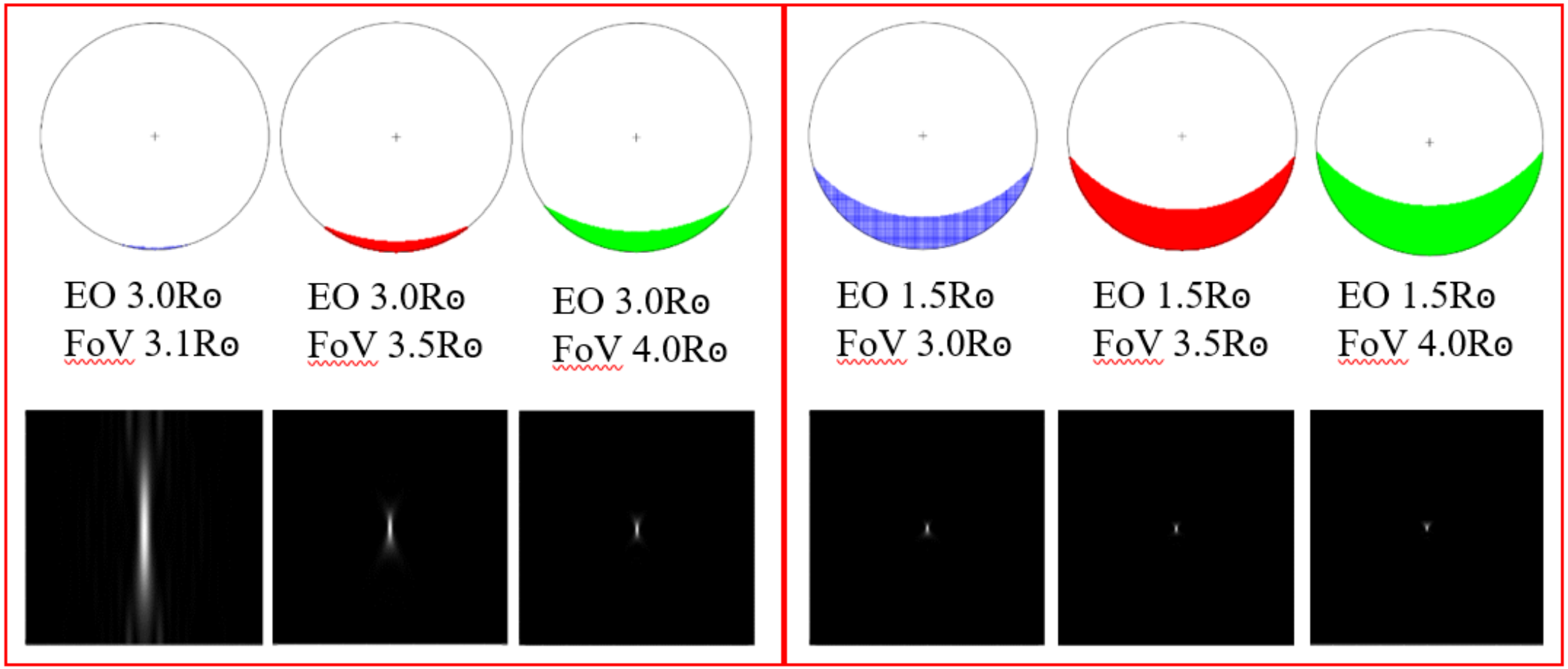
- This is the 2D image of the diffraction distribution. Each image is normalized to its own maximum.
- The yellow circles are the diameter of occulter disk.
- The diffraction intensity distribution on the last page is along the blue line of each picture.

Fraction of Unvignetted Rays vs. Solar Radii



- EO cutoff does not change the distribution on detector, but it change the vignetting significantly.
- The occulter disk on the detector does not cause any additional vignetting, because it is an image plane.

Vignetting and corresponding PSF



Definition of SNR Improvement ratio

- The SNR improvement ratio just compare the signal improvement ratio for different EO cutoff at FoV nearby IFoVC.
- The noise in the improvement ratio considers diffraction introduced noise, F-corona and sky brightness are not included.
- Define ξ = the fraction of unvignetted rays divided by the PSF size as the signal strength measure.
- The case being evaluated is the comparison of EO cutoffs 1.5 and 3.0 $R_\odot$. Both of them has an IFoVC of 3.0$R_\odot$.
- Three field points in the image planes are used: 3.1, 3.5, and 4.0 $R_\odot$.

Improvement Ratio versus FoV Near Cutoff

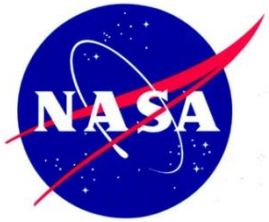
Fraction of unvignetted rays at different FoV near IFoVC for 2 EO cutoffs

	Fraction of unvignetted rays			Relative PSF size		
	3.1Rʘ	3.5Rʘ	4.0Rʘ	3.1Rʘ	3.5Rʘ	4.0Rʘ
EO cutoff 1.5Rʘ	0.138	0.18	0.235	0.0183	0.0108	0.0085
EO cutoff 3.0Rʘ	0.0015	0.023	0.065	1.0000	0.0740	0.0303

$\xi_{EO1.5}$, $\xi_{EO3.0}$ and improvement ratio at 3 FoV

	3.1Rʘ	3.5Rʘ	4.0Rʘ
ξ (EO 1.5Rʘ)	7.554	16.714	27.773
ξ (EO 3,0Rʘ)	0.002	0.311	2.146
Improvement ratio	5035.789	53.804	12.941

Conclusion and Path Forward



- We have introduced a novel compact solar coronagraph design that increases the SNR without compromising the diffraction compression.
- The key of this novel design is to make the EO smaller than specified IFoVC and place an occulter disk on the detector array.
- Besides reducing the vignetting, the design also makes the data useable right at the IFoVC, instead of throwing the data that is 0.5 – 1.0$R_\odot$ from the IFoVC.
- BITSE is a pathfinder for future orbital mission
- A mission to measure corona temperature and velocity onboard of International space station has been proposed and completed phase A study.