
CERN

First observation of the LHC beam halo using a Synchrotron Coronagraph

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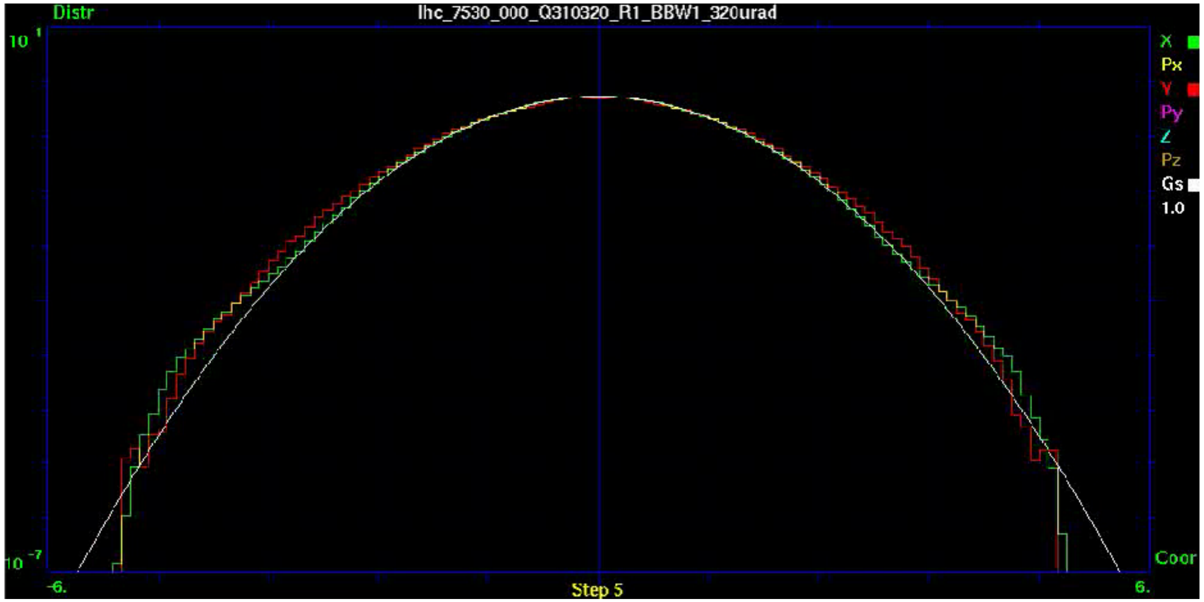
CERN , *KEK

Agenda

1. Halo formation in HL-LHC
2. Working principle of the coronagraph
3. Coronagraph at LHC
4. Artificail beam halo formation with beam exciter
5. Observation of beam halo at 450 GeV
6. Design of dedicated coronagraph for HL LHC

1. Understanding Beam Halo Formation in the HL LHC

Simulation of halo formation from long-range beam-beam interactions



Halo is expected between 2σ (10^{-1}) to 5σ (10^{-5})

Halo control essential to limit beam loss

- Best done by tuning the machine to avoid populating the tails in the first place

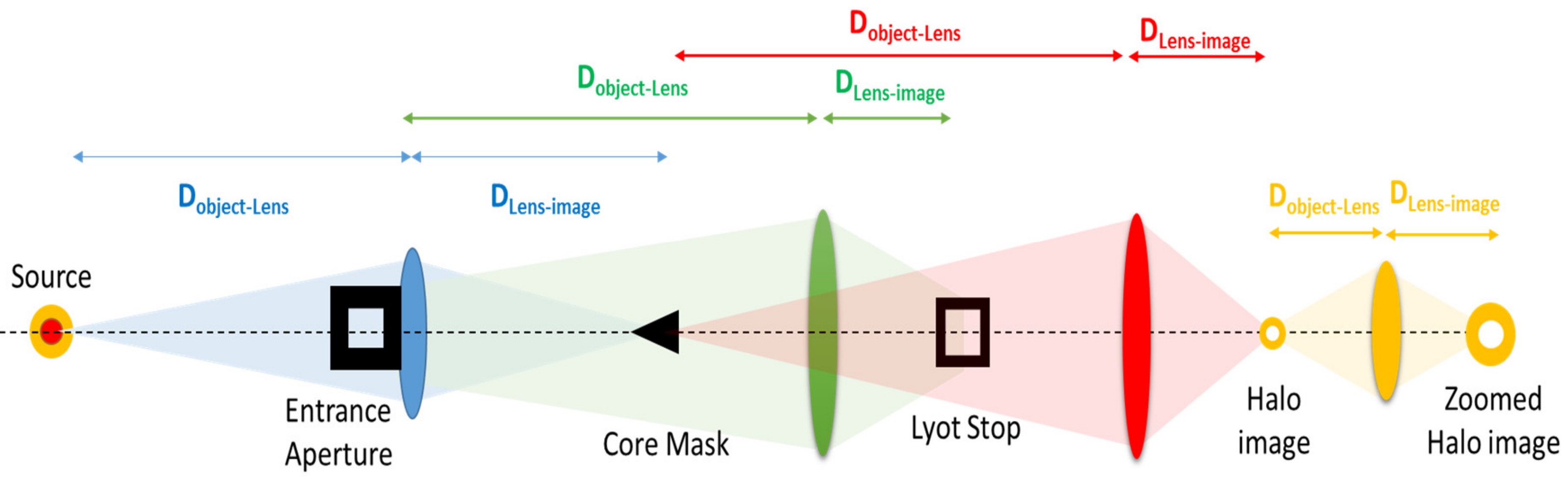
- For high energy or high power machines too much beam in the halo can lead to damage of accelerator components
  Due to instantaneous losses or long term irradiation

2. Coronagraph

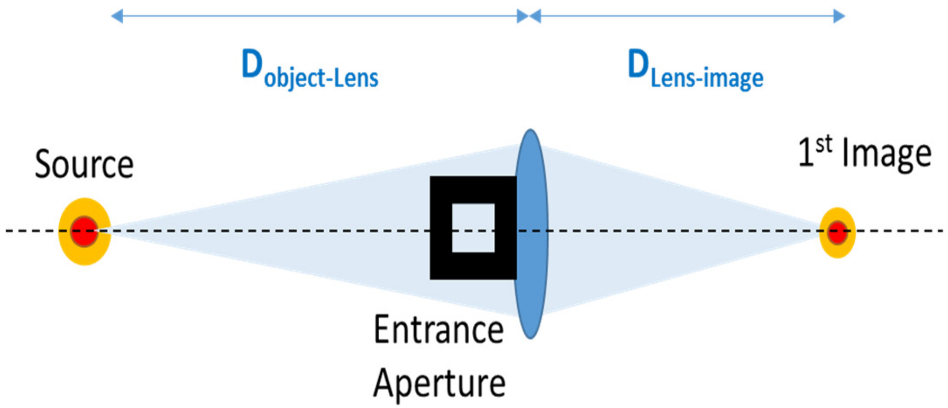
WHAT? **Spatial telescope used to observe the sun corona by creating an artificial eclipse.**

⇒ blocking the glare of the bright core image to allow the observation of a fade corona.

Already used for the observation of halo, tails of an electron beam core at the PF, KEK.

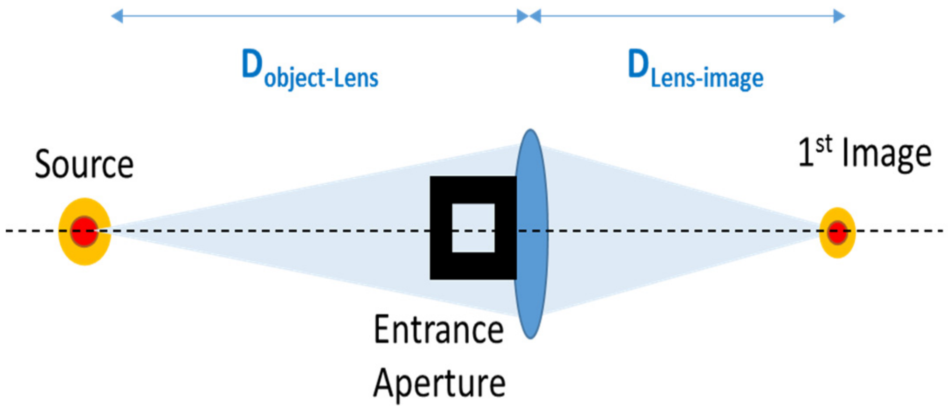


Sketch of the coronagraph optical system showing the three stages and the final zooming stage. the mask used to block the beam core image and the Lyot stop to block the diffraction fringes



A first image of the beam is created at the 1st stage of the coronagraph by the objective lens.

The “Halo” information is hidden in this image plane by aperture diffraction.



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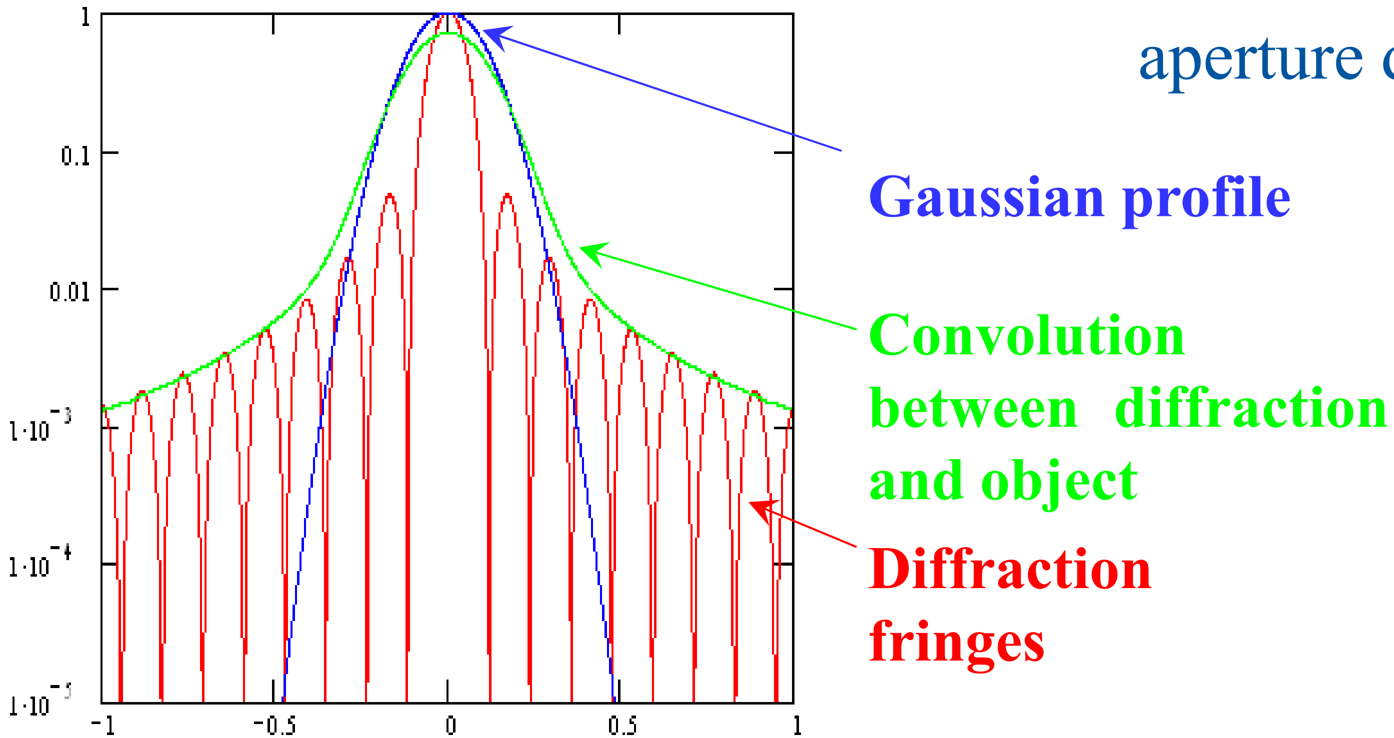

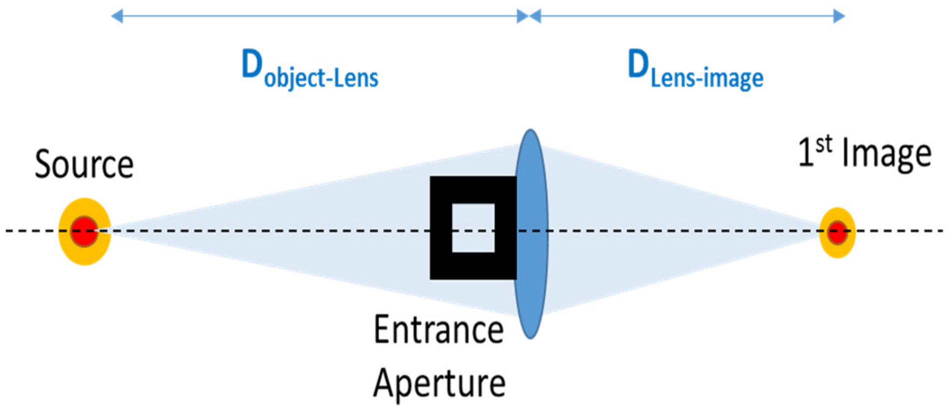

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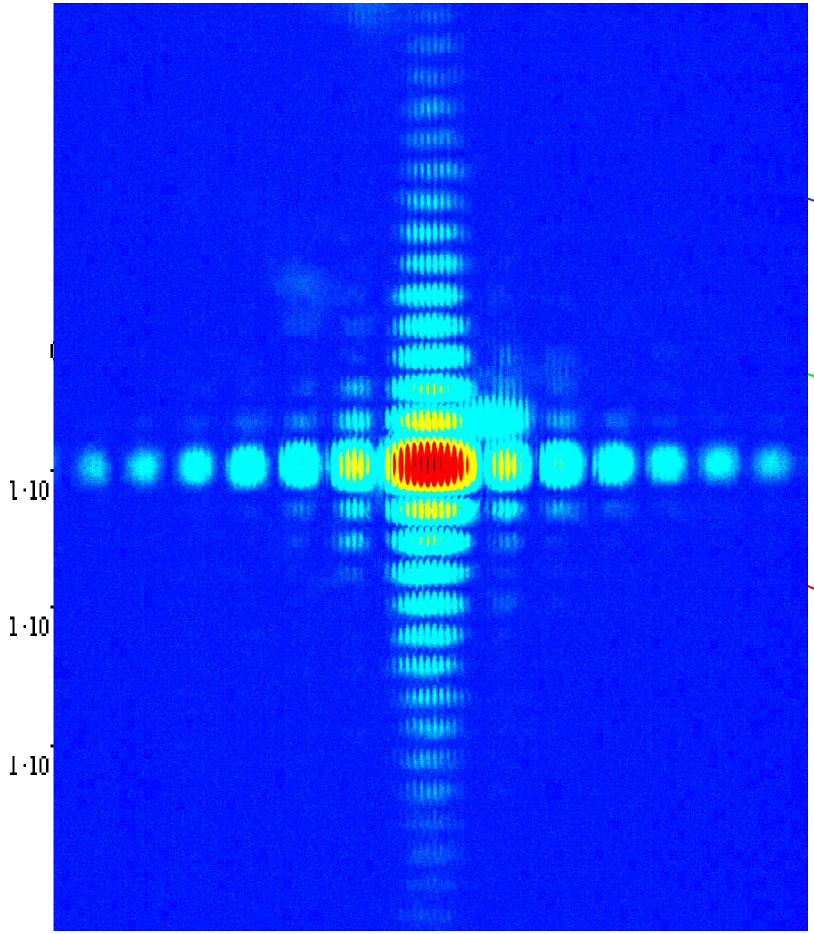
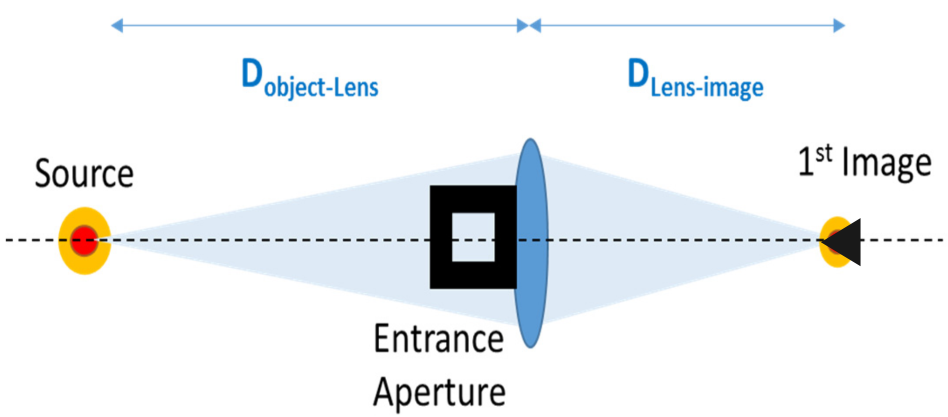


Gaussian profile

Convolution between diffraction and object

Diffraction fringes



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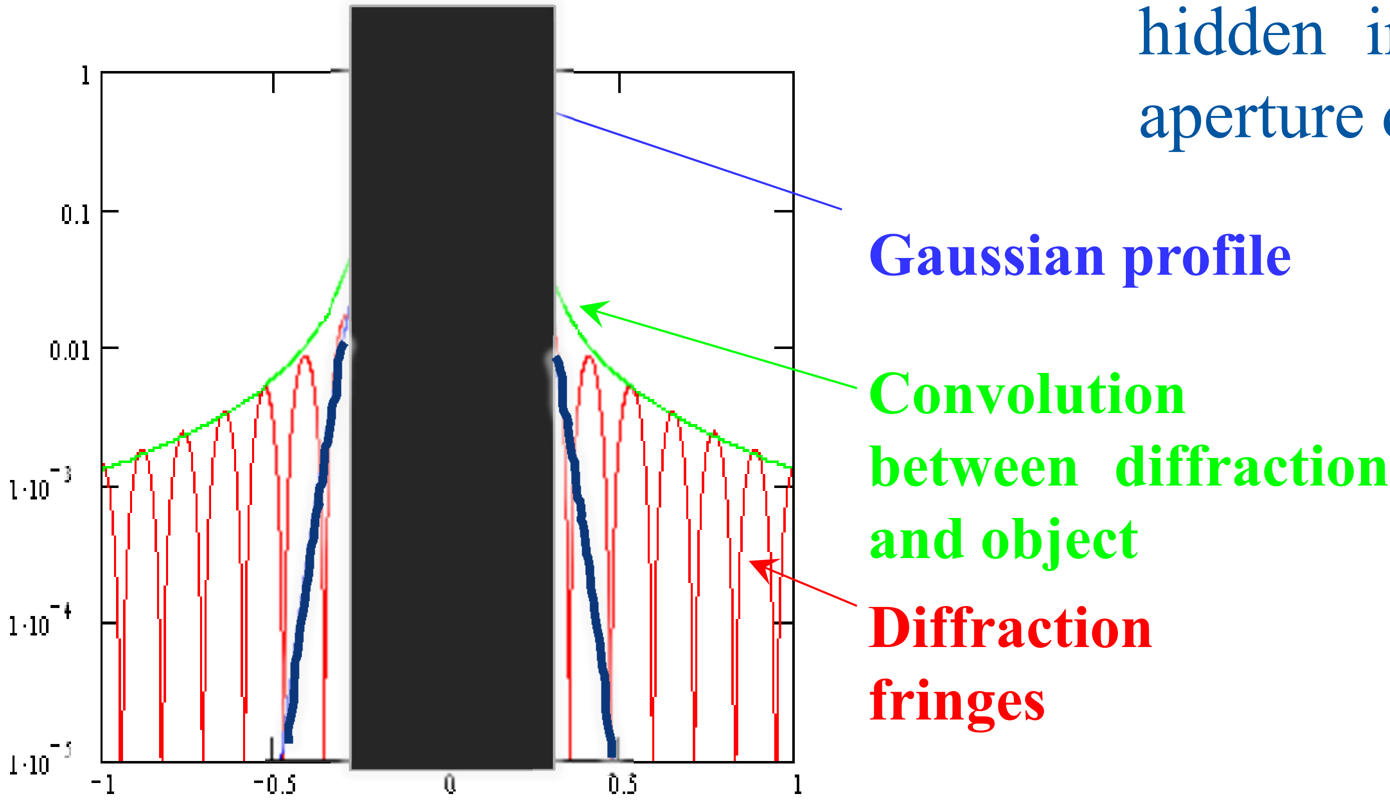
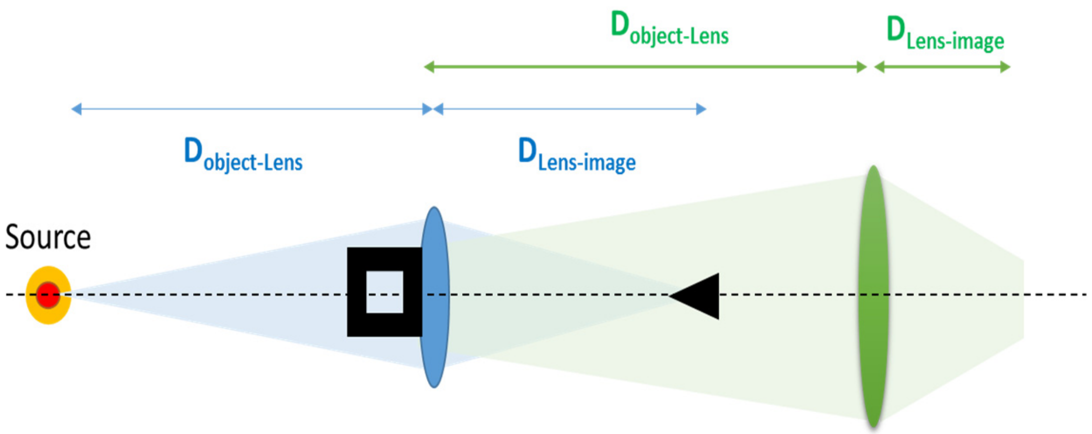


A “Mask” blocks the image of beam core.



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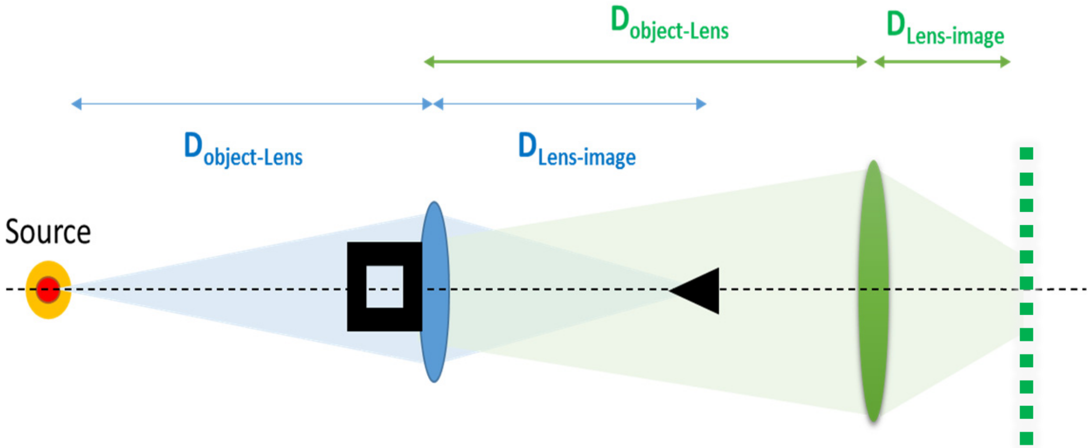

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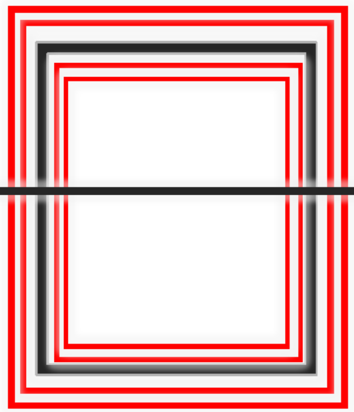
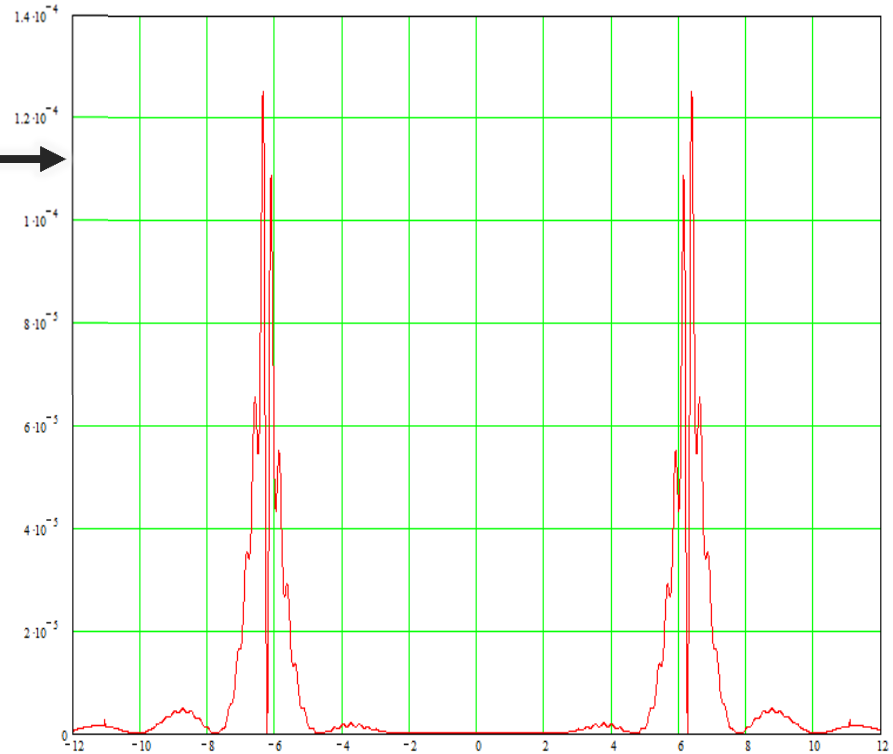


Cross section



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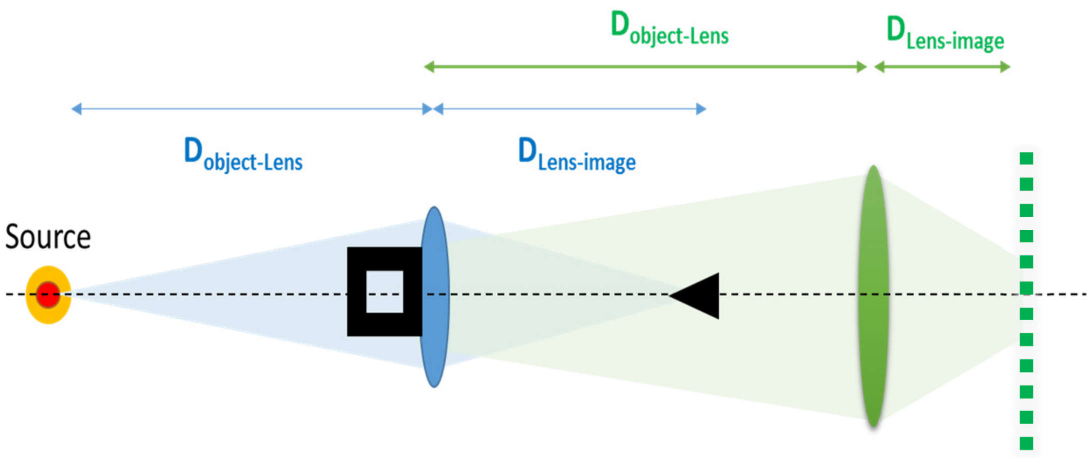

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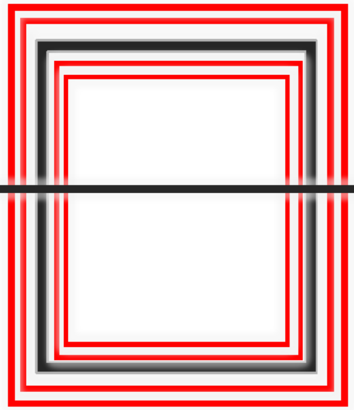

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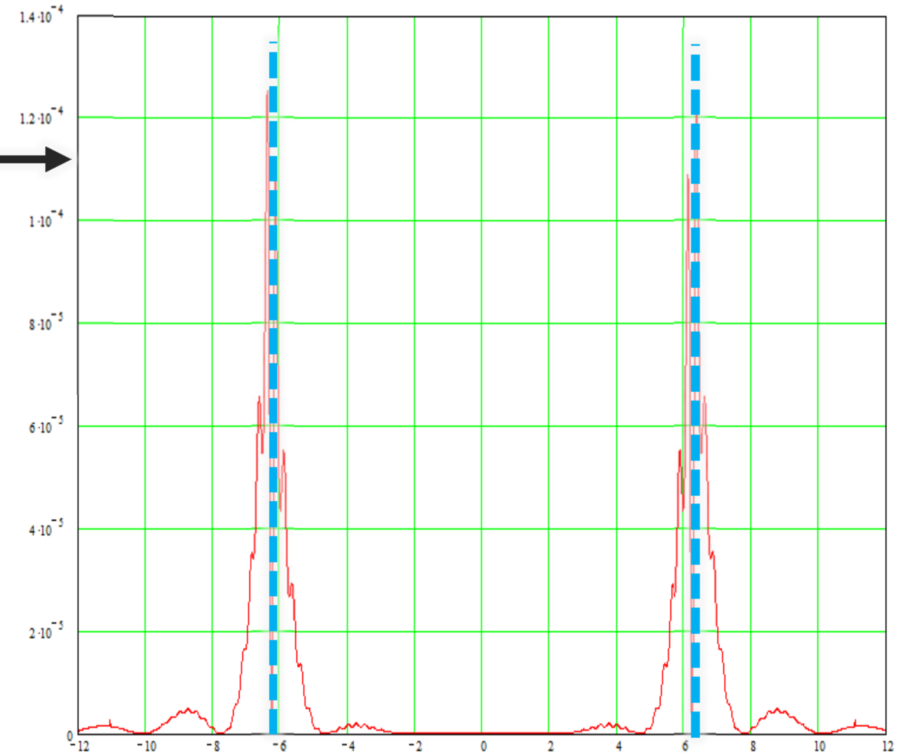

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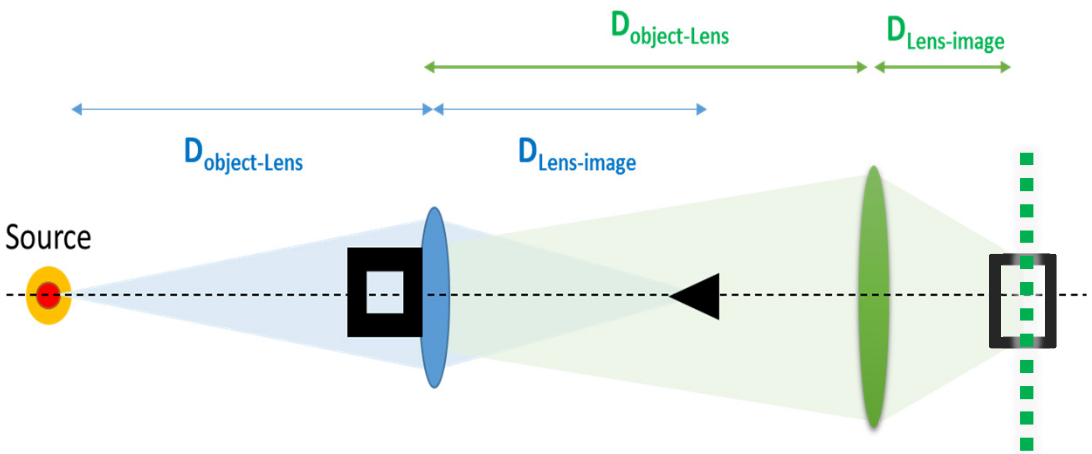
=> The diffraction fringes of objective lens aperture are re-diffracted , and produce fringes surrounding of objective aperture image



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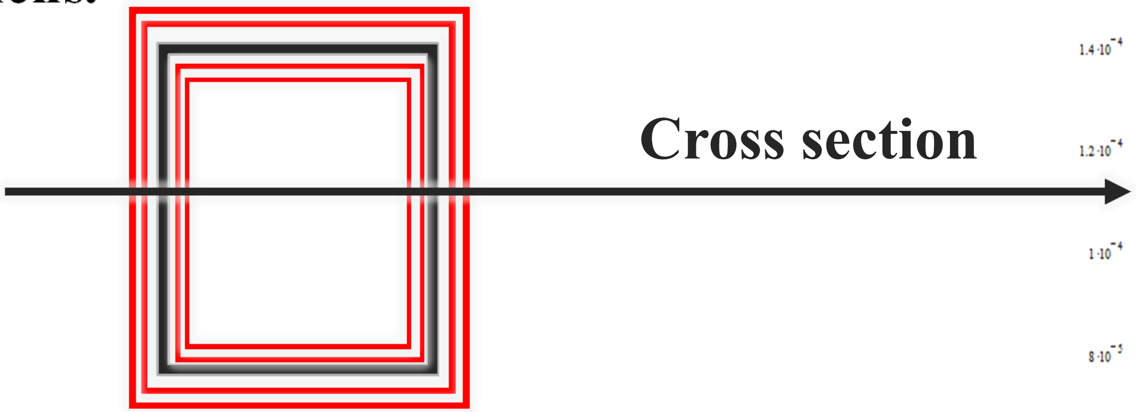

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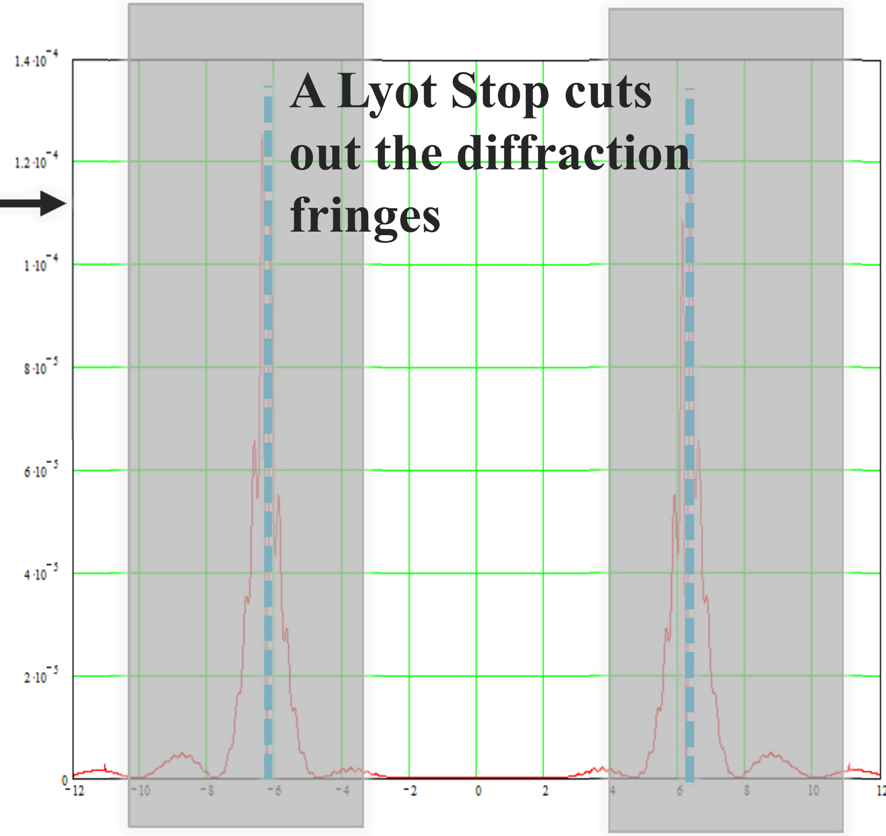

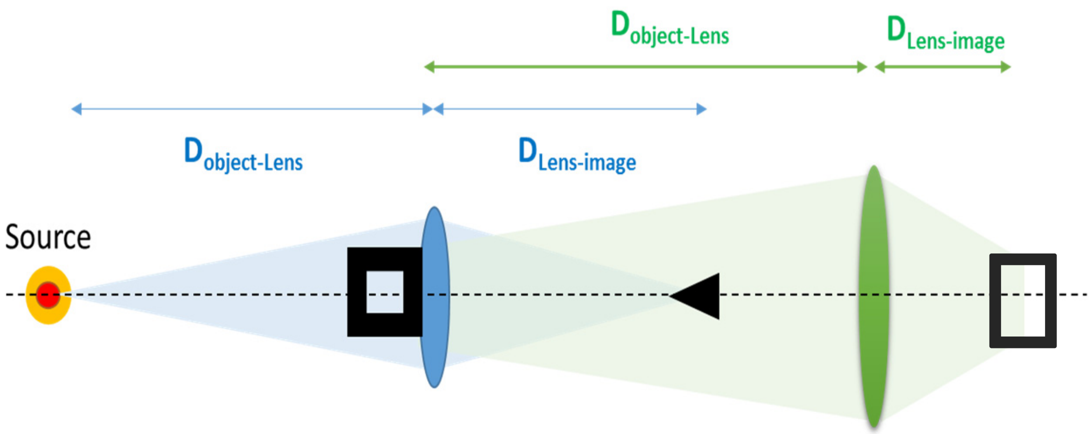

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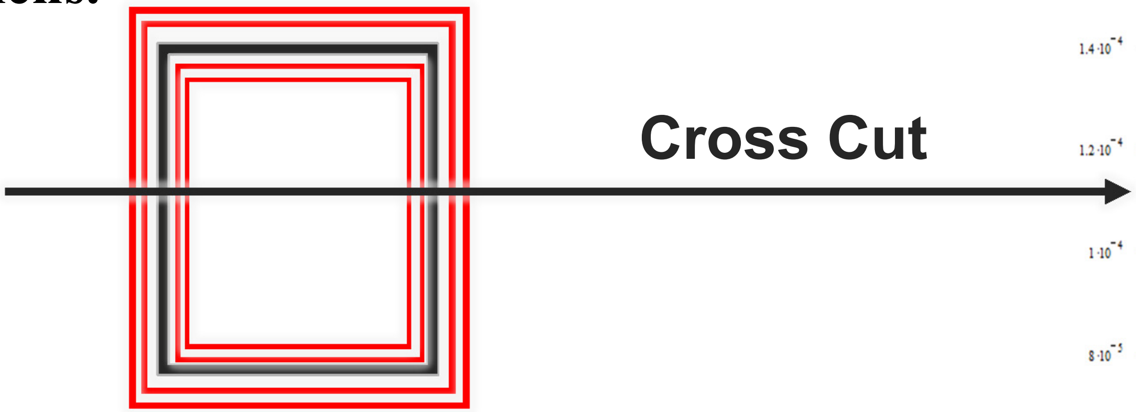
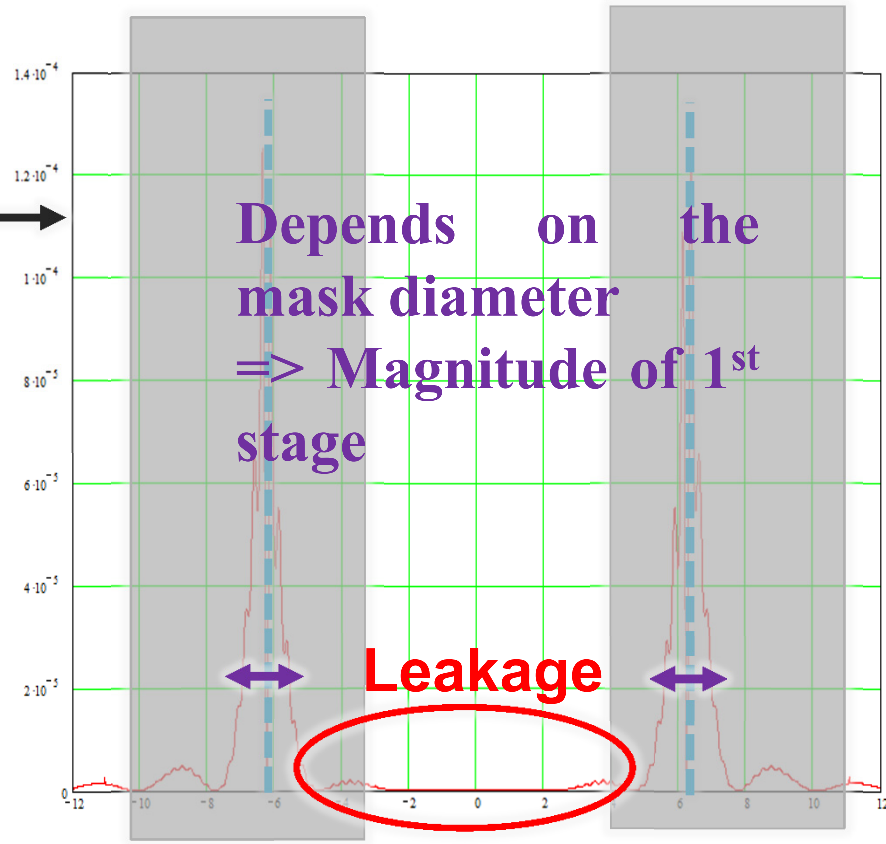
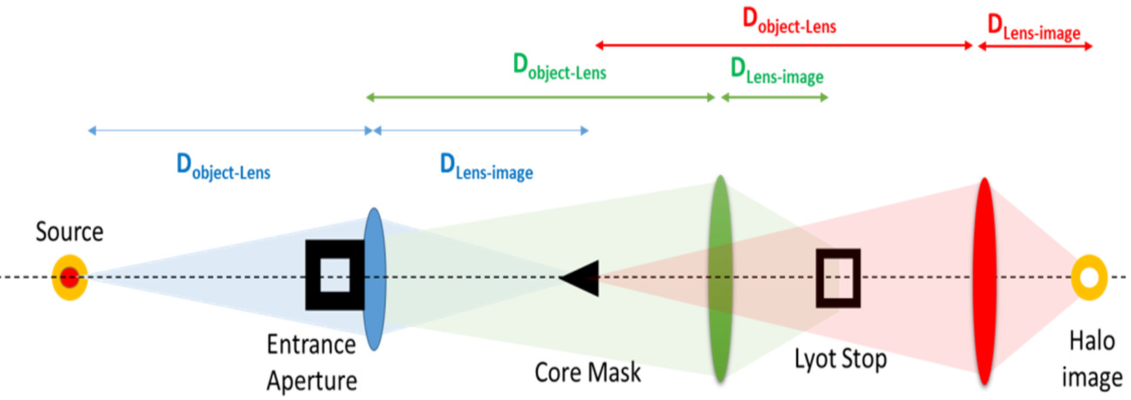




=> The diffraction fringes of objective lens aperture are re-diffracted , and produce fringes surrounding of objective aperture image



A first image of the beam is created at the 1st stage of the coronagraph by the objective lens.

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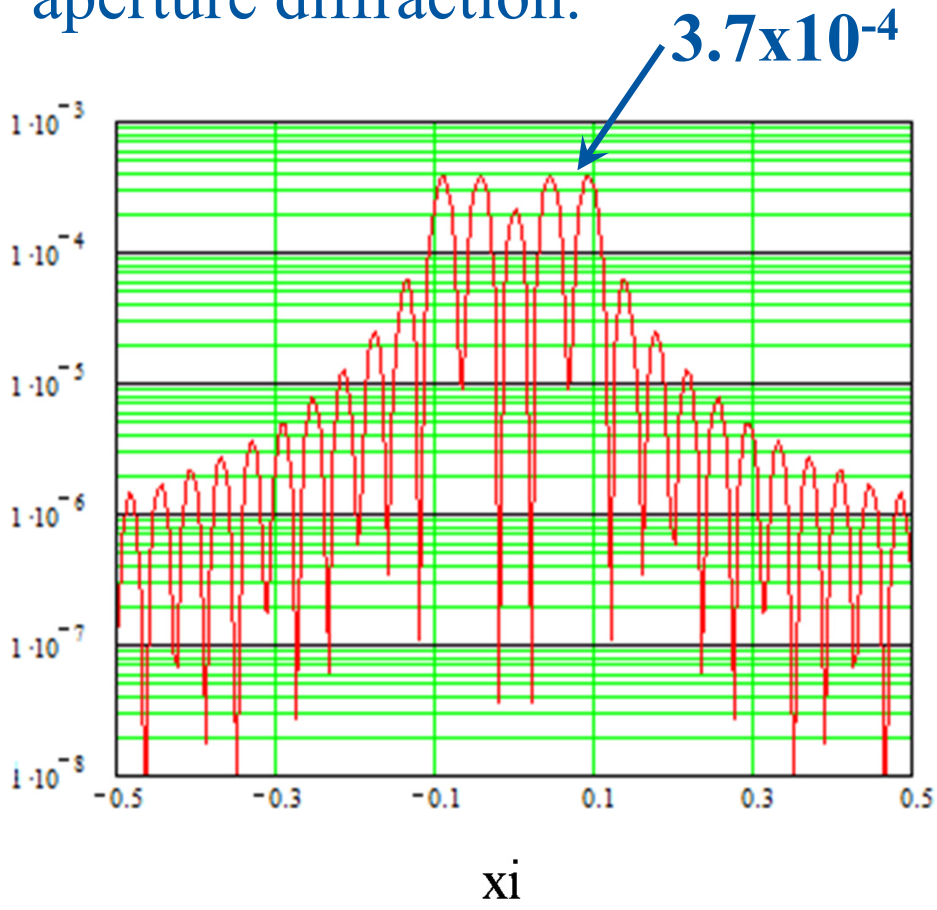
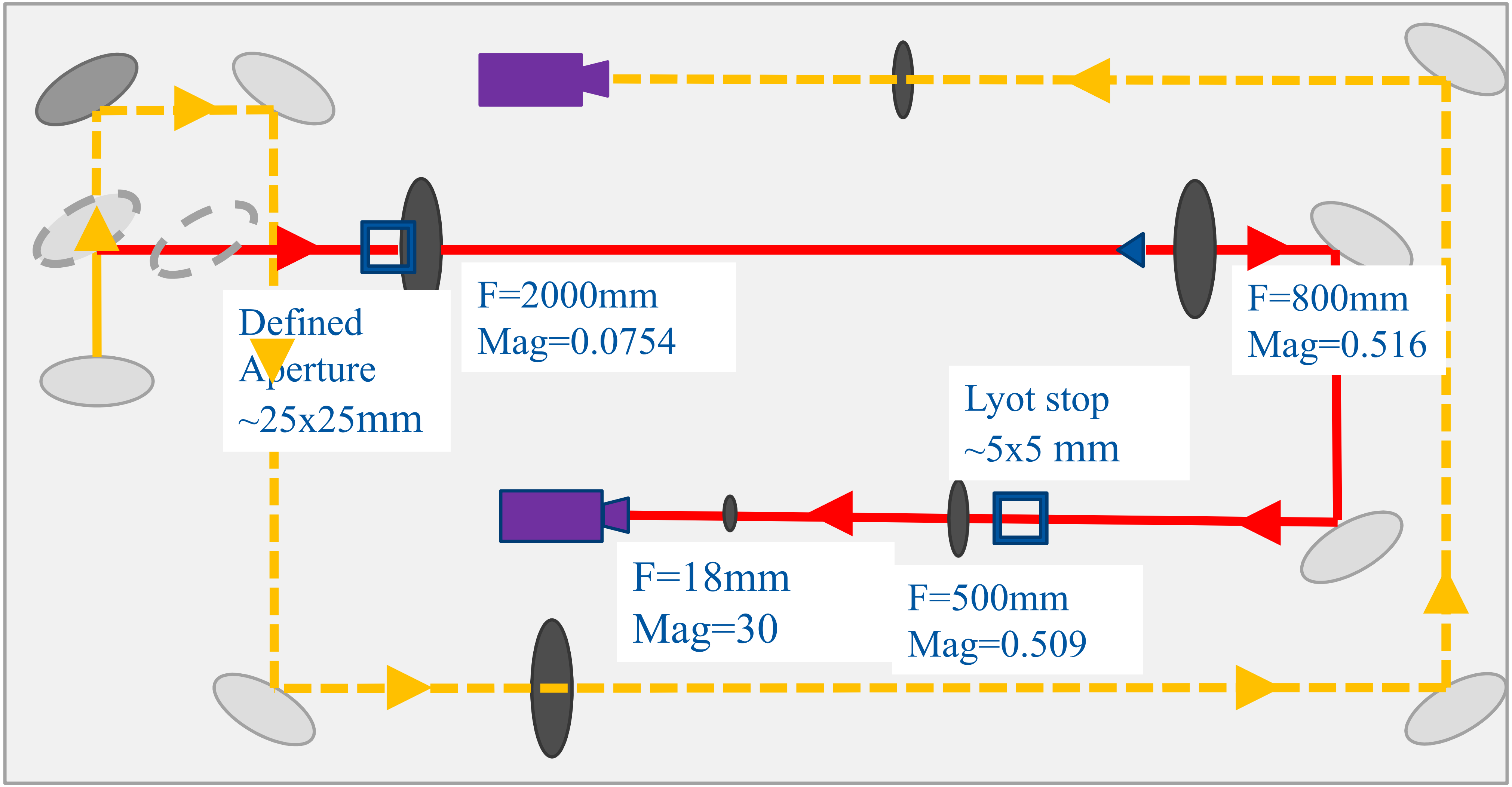
- The Field lens images entrance aperture of the 1st stage.
- **A Lyot Stop cuts the diffraction fringes in 1st stage.**
- **Relay Lens transfer halo image onto its focal point.**



3. LHC Coronagraph

Phase 1

- Mostly using optics inherited from KEK PF coronagraph
- Demonstrator for proton beams
- Max. achievable contrast: 10^{-3}-10^{-4}
- Limited by 1st stage magnification

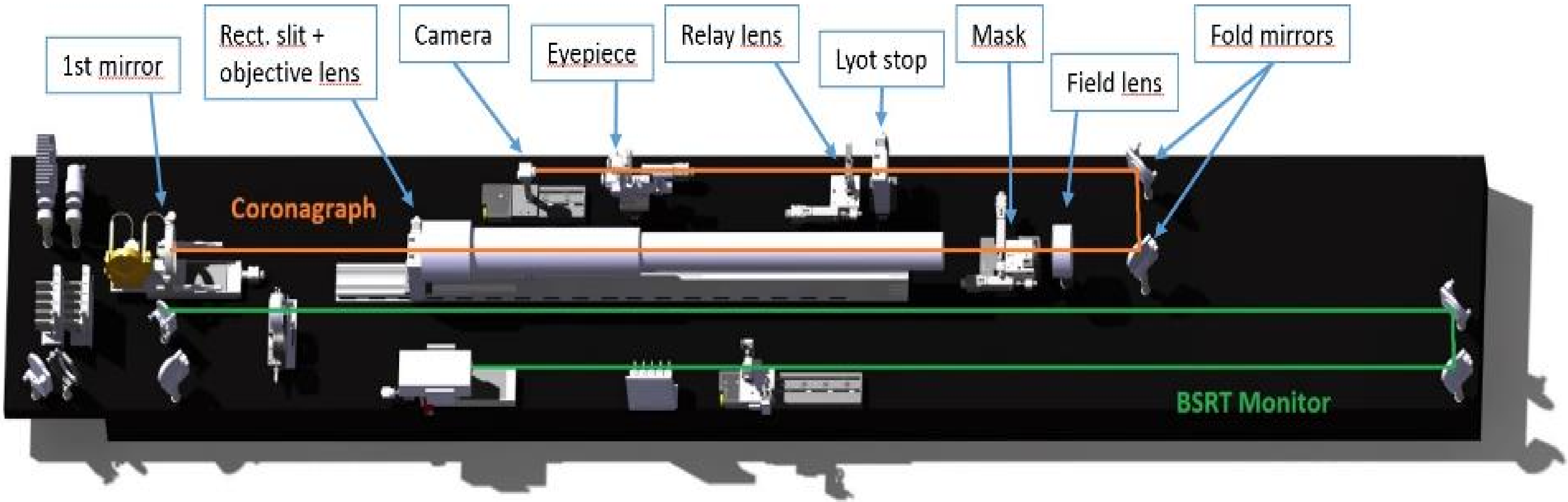


Total Size needed is 5.2 m
Achieving 2.26 final Mag fitting on camera measurable halo +/-10 sigma (after the not wanted 5 sigma)

Tunnel Installation

- Installed on B2
- Commissioning in parallel to LHC operation
- Dedicated MD November 2016

Tunnel Installation

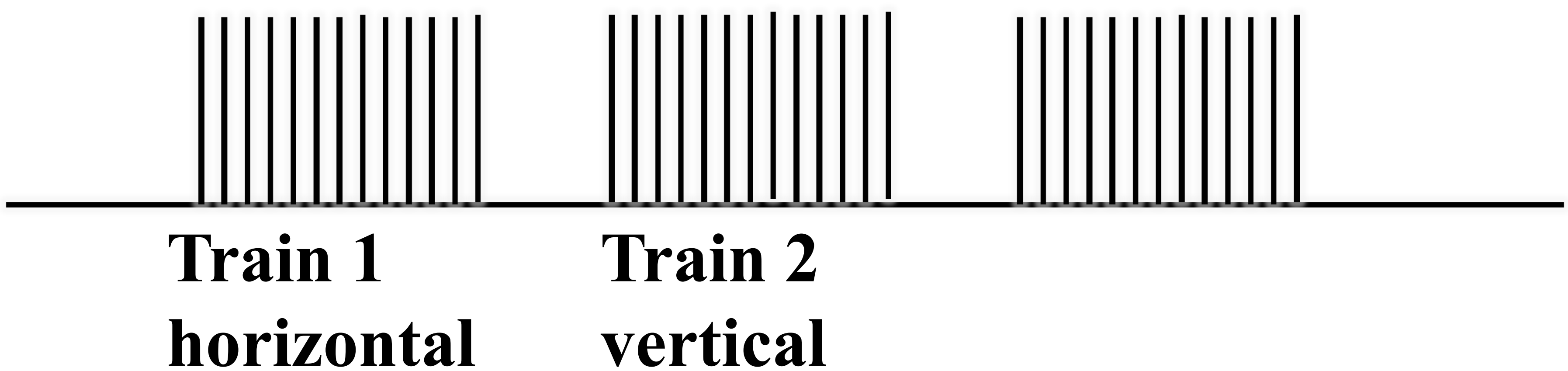


Test at injection Energy 450 GeV

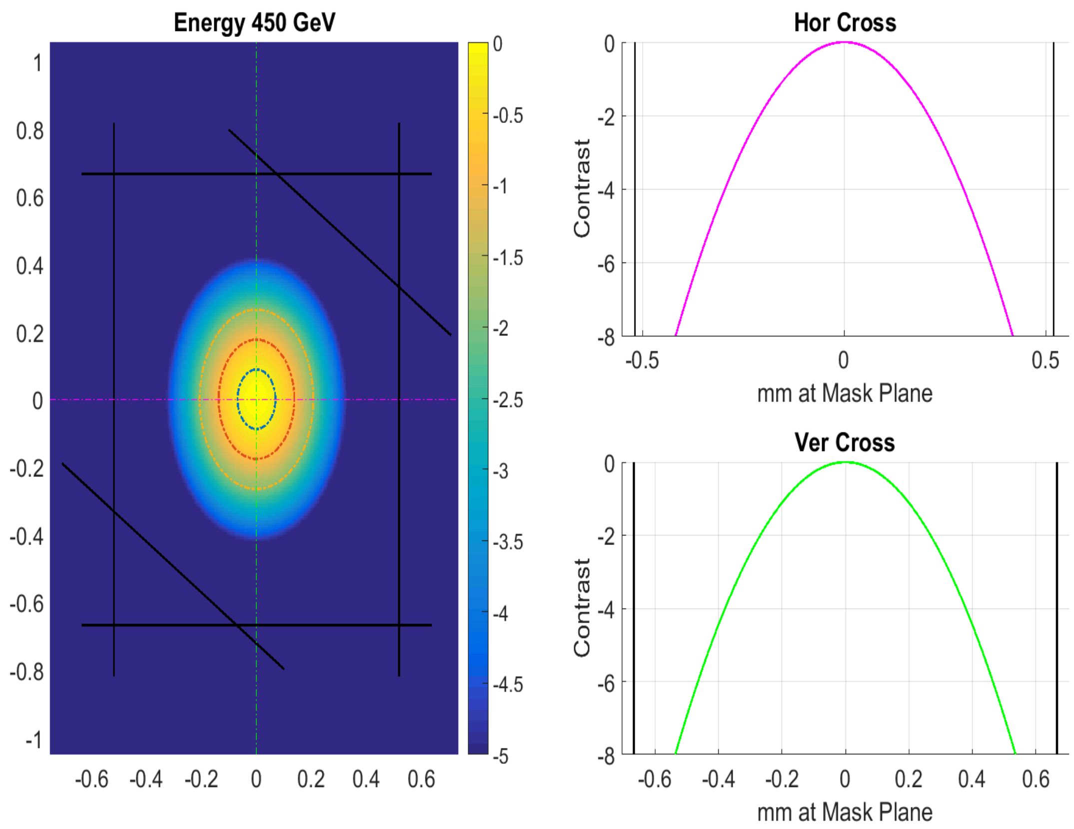
4. Artificial halo formation

The ADT(transverse damper) is used as exciter for one of beam train.

12bunches 3 trains



Injection of 3
12 bunches trains
Average bunch Intensity:
~10^{11} protons/bunch
Average Normalized Emittance (H&V):
~1.8 µm



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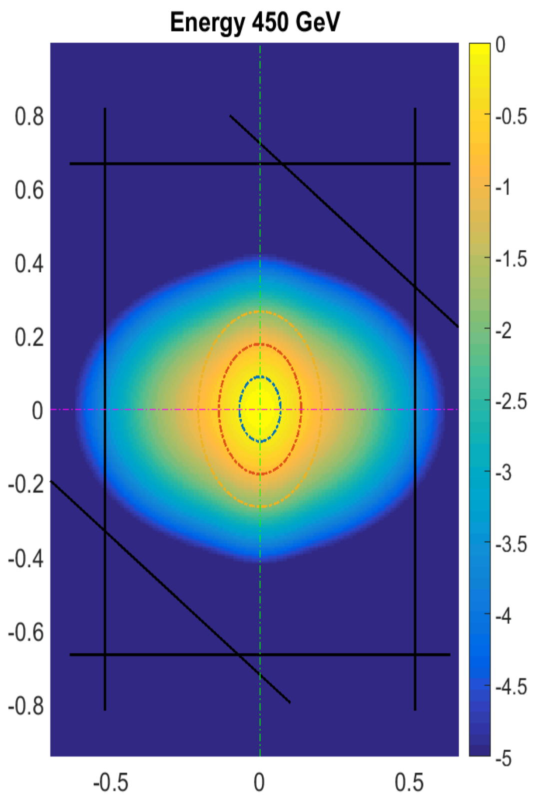

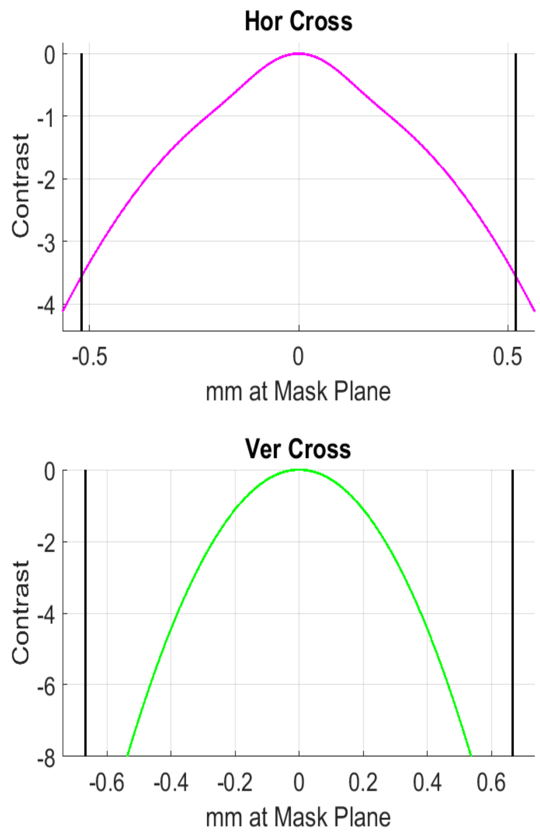

Experiment A

Horizontal Blow Up of **Train 1** to 8 microns

Close H scraper down to 2.9 sigma (nominal)

Open back to 5.7 sig (nominal)

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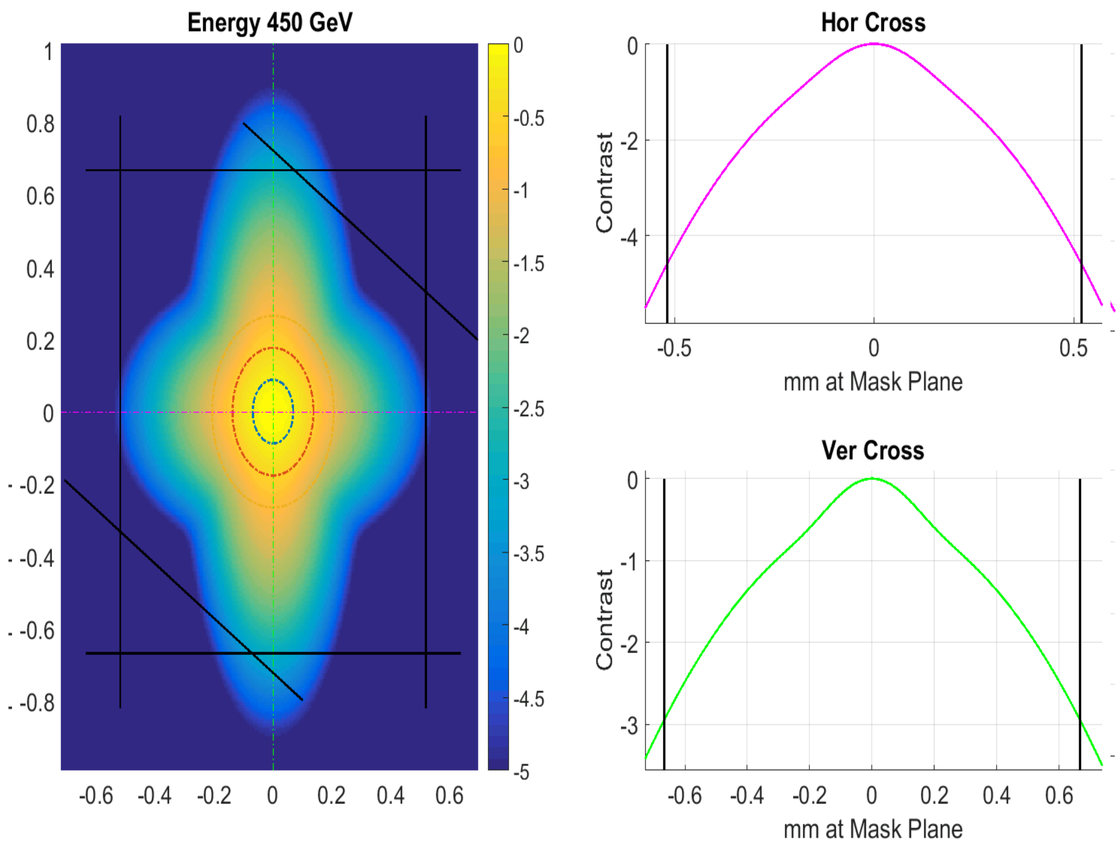


Experiment A

Horizontal Blow Up of **Train 1** to 8 microns

Close H scraper down to 2.9 sigma (nominal)

Open back to 5.7 sig (nominal)

Experiment B

Vertical Blow Up of **Train 2** to 10 microns

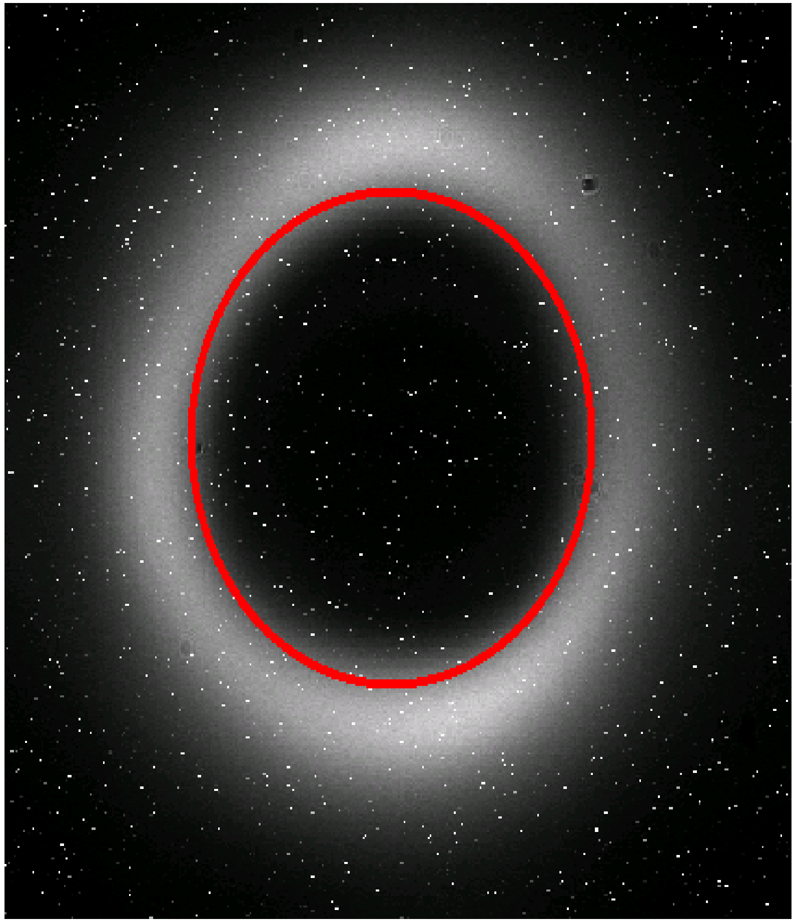
Close V scraper down to 2.6 sigma (nominal)

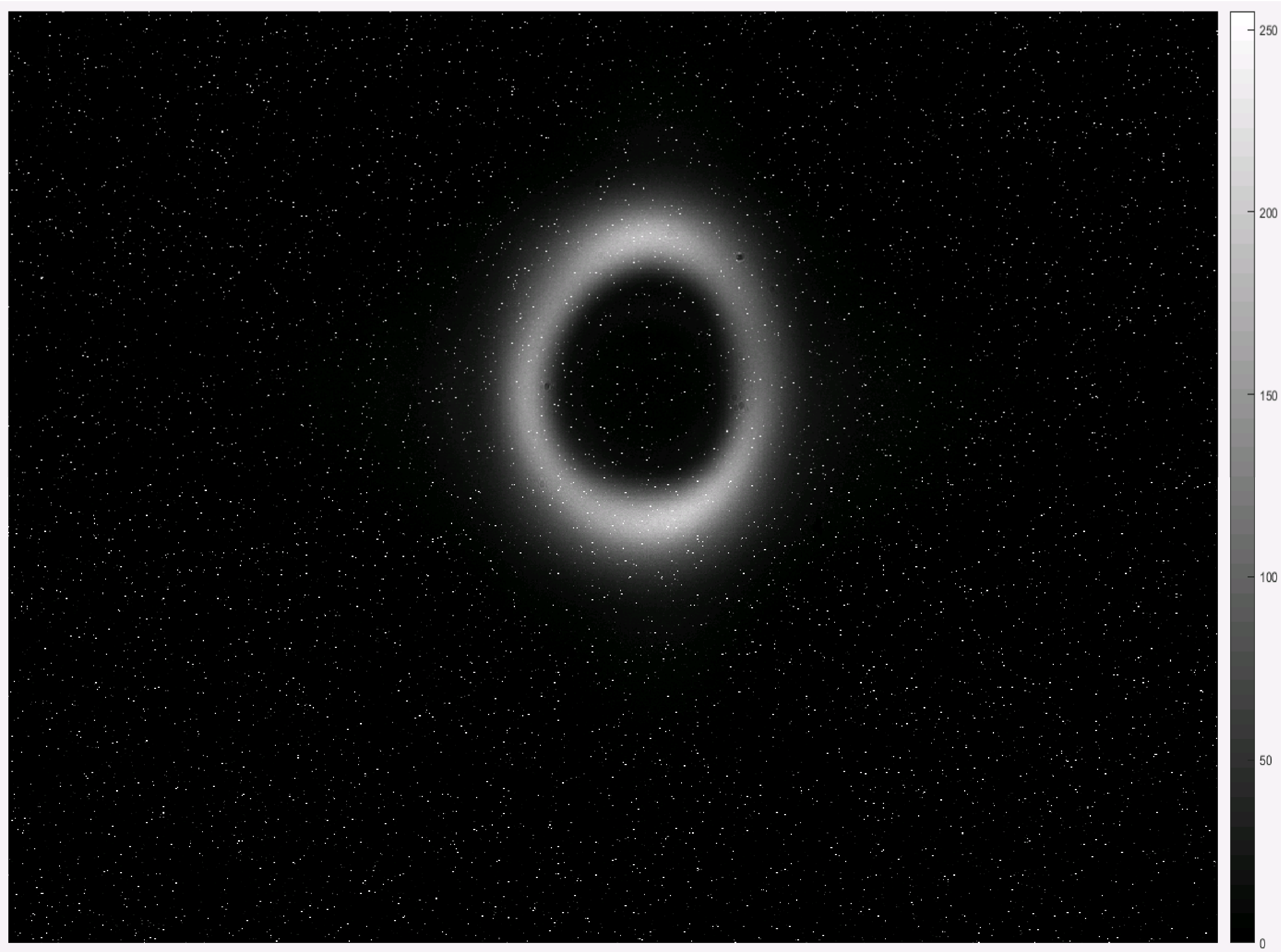
Open back to 5.7 sig (nominal)

5. Halo observation
at
injection Energy 450 GeV

Coronagraph Configuration

	horizontal	vertical
Entrance pupil	19.9mm	19.7mm
Objective lens focal length	2000mm	
Opaque mask diameter	350µm	350µm
Field lens focal length	800mm	
	horizontal	vertical
Lyot stop aperture	5.2mm	3.8mm
Relay lens focal length	500mm	





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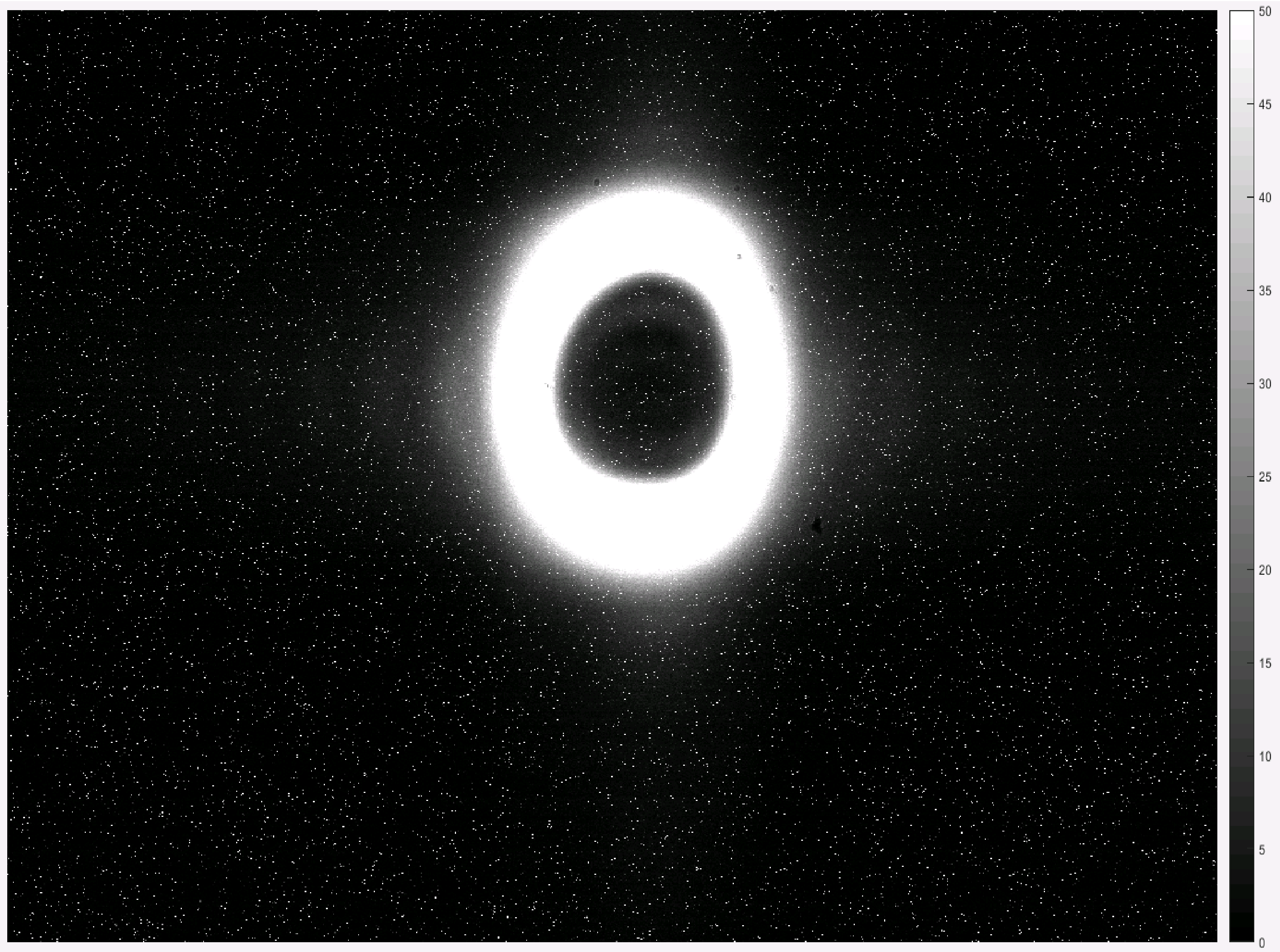

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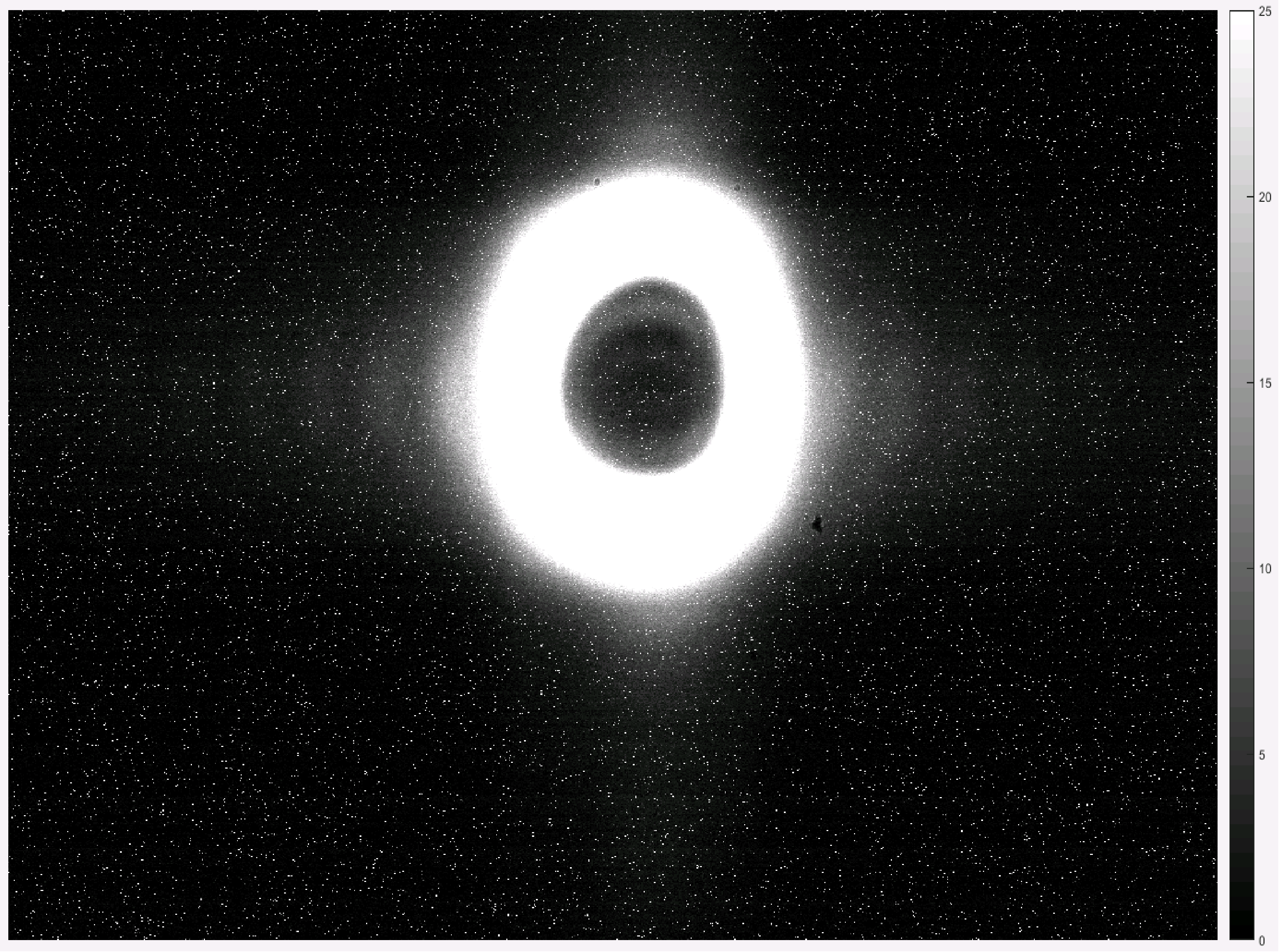

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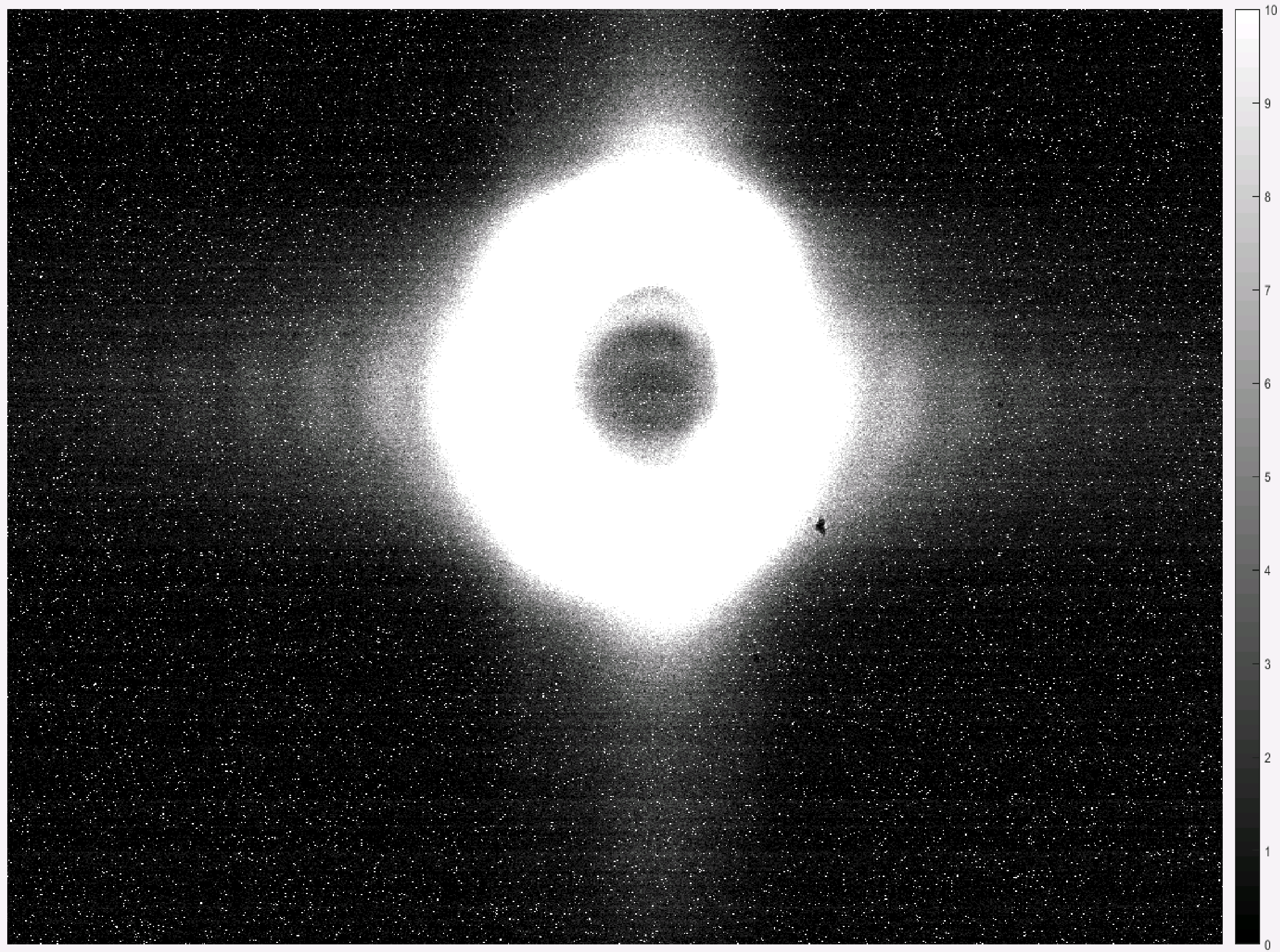

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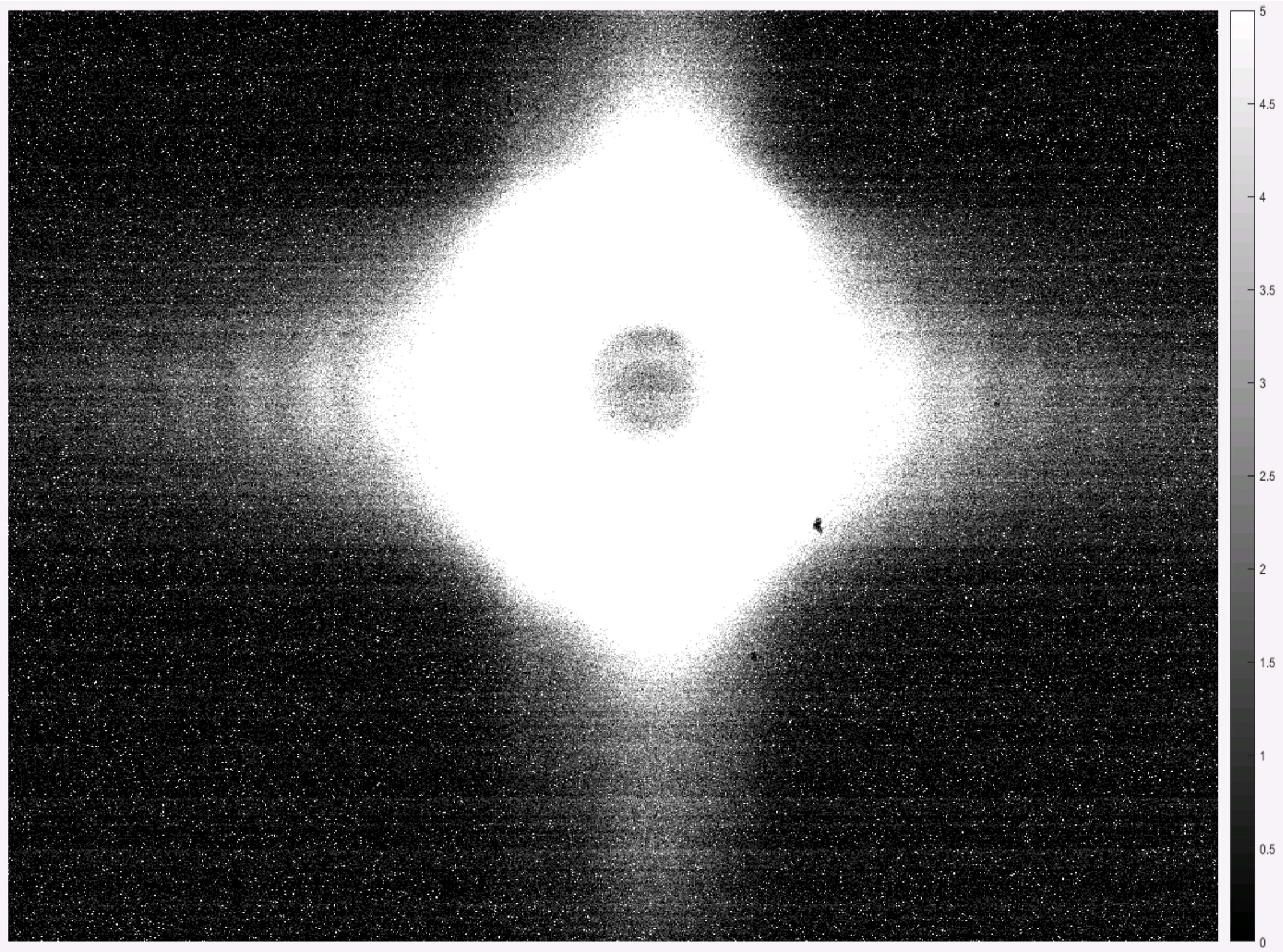

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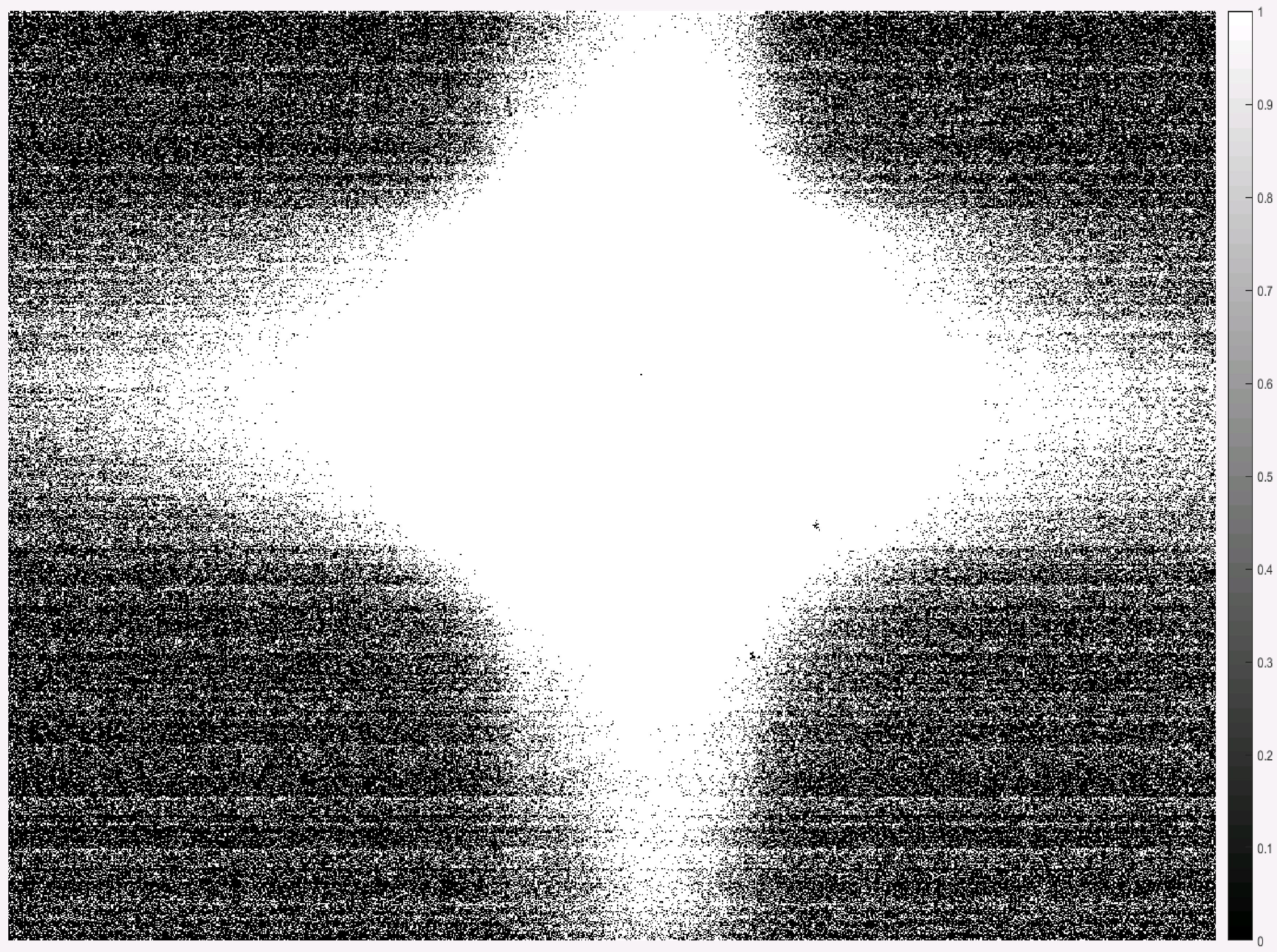
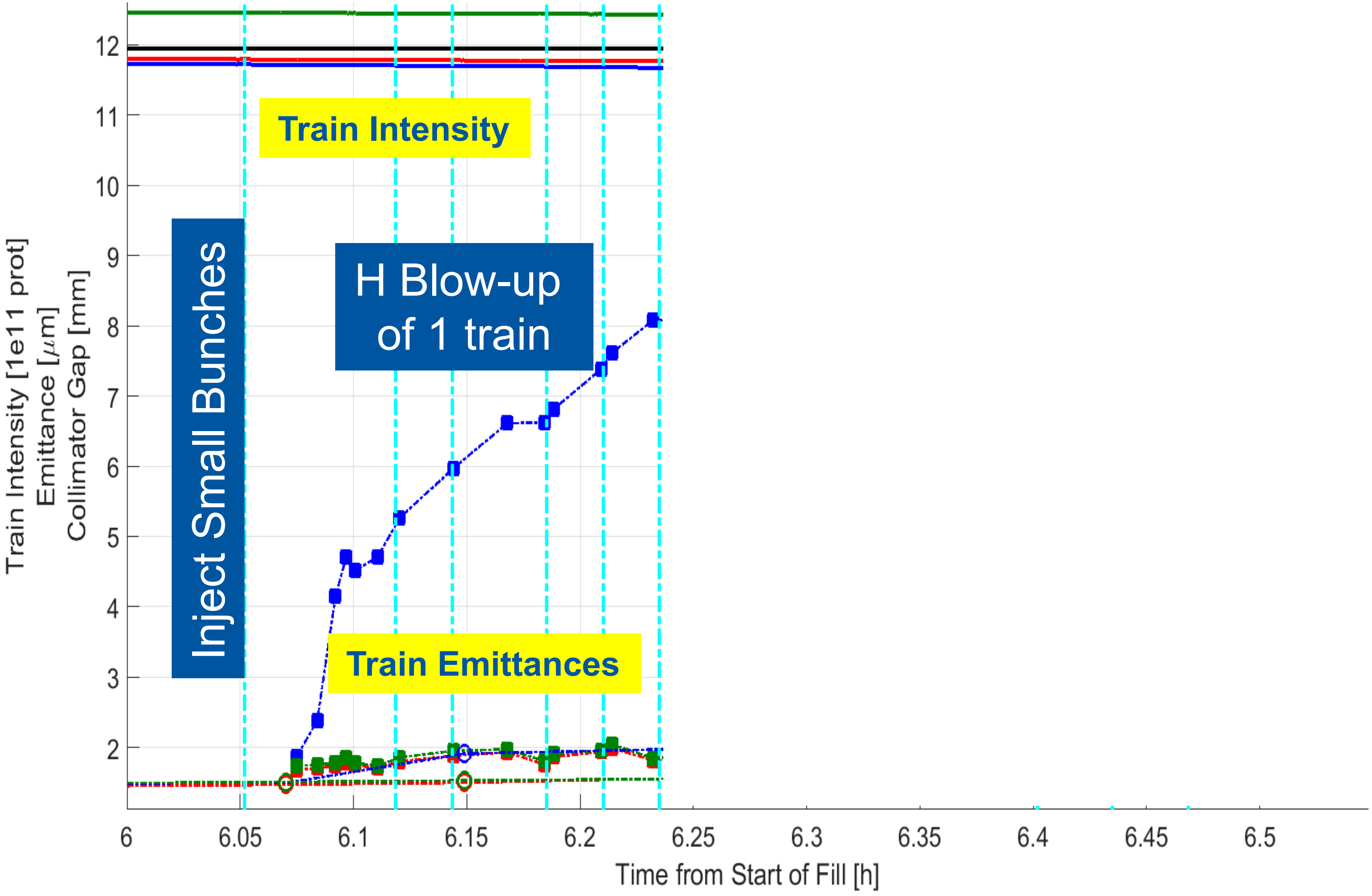


1

Experiment A



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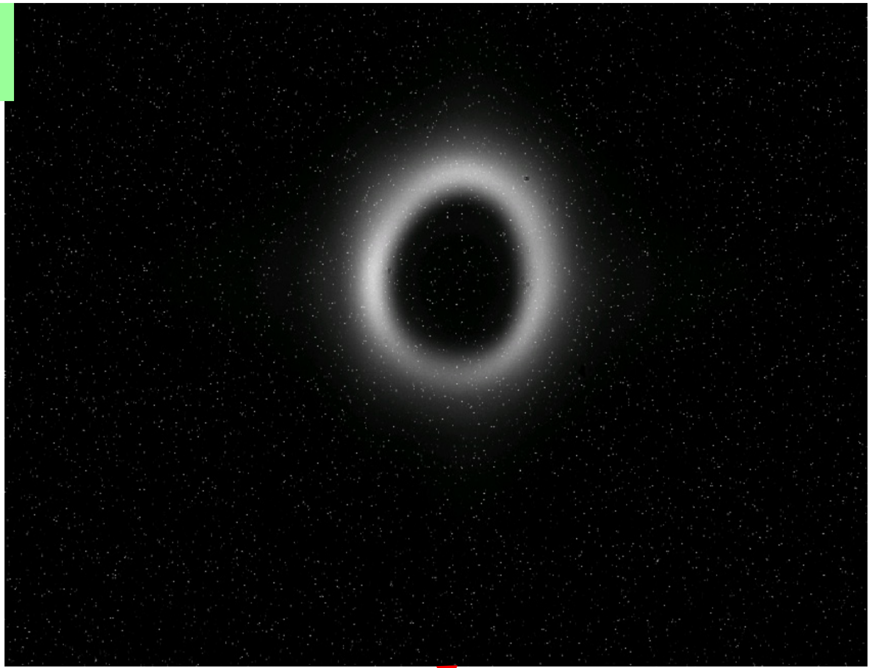
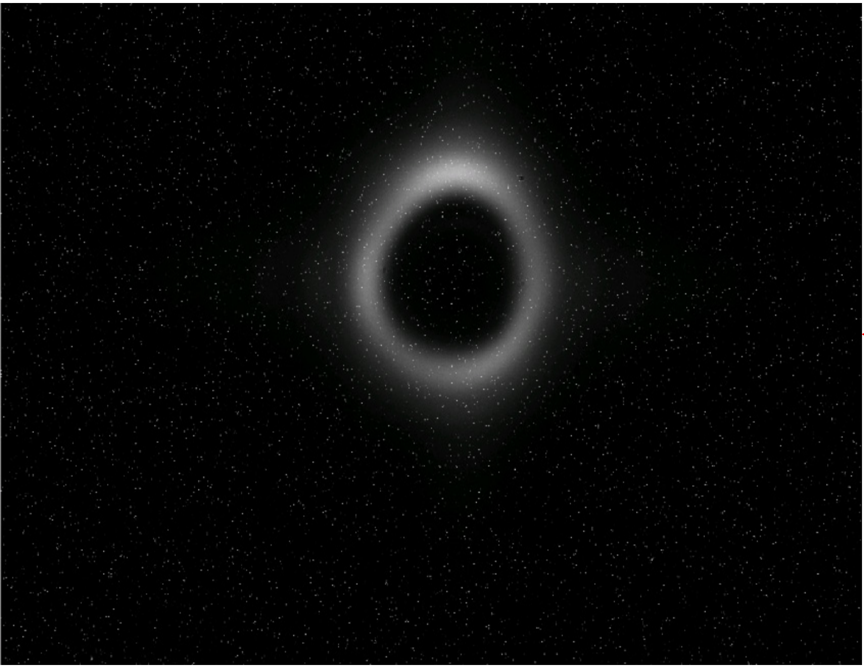
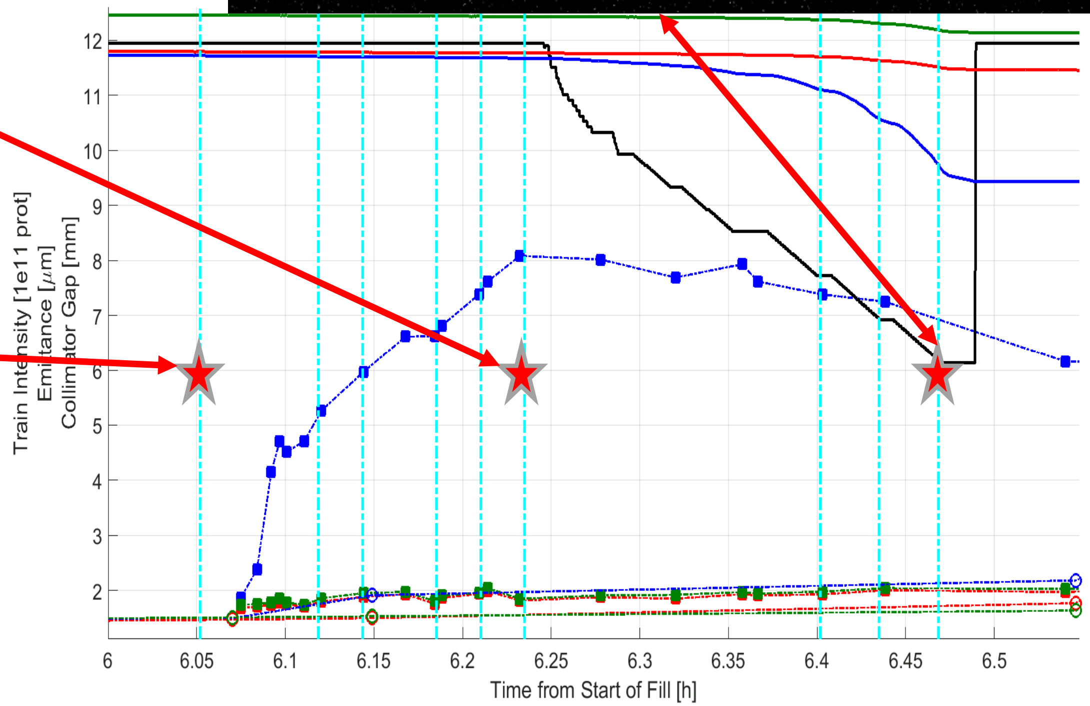


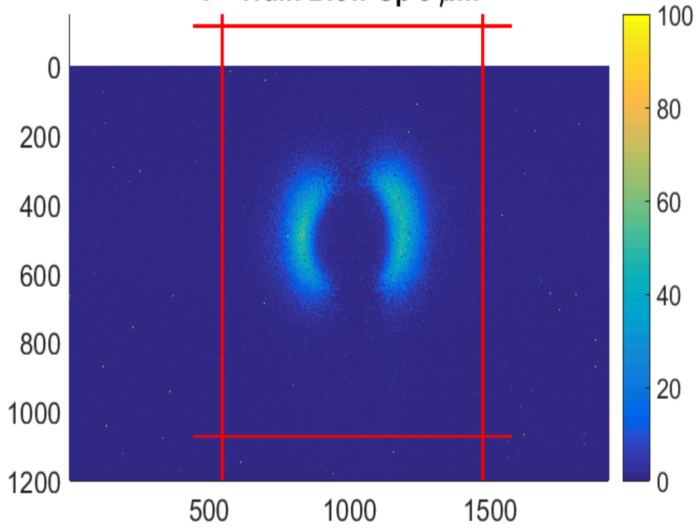




Experiment A

During transverse emittance blow-up (H)

1st Train Blow Up 5 μm

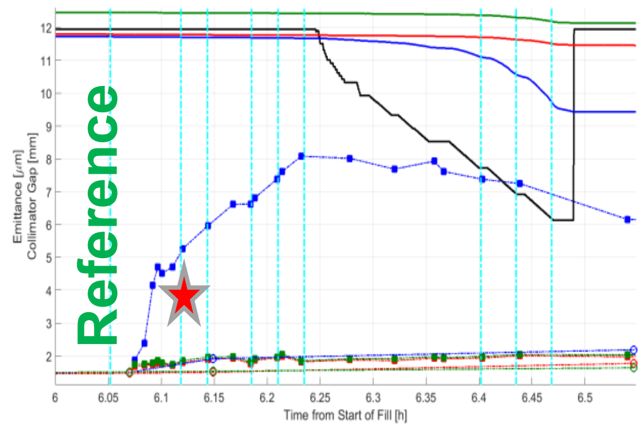


1st Train Blow Up 6 μm

Light Variation against to initial conditions (i.e. small bunches before the blow up)

1st Train Blow Up 7 μm

1st Train Blow Up 8 μm



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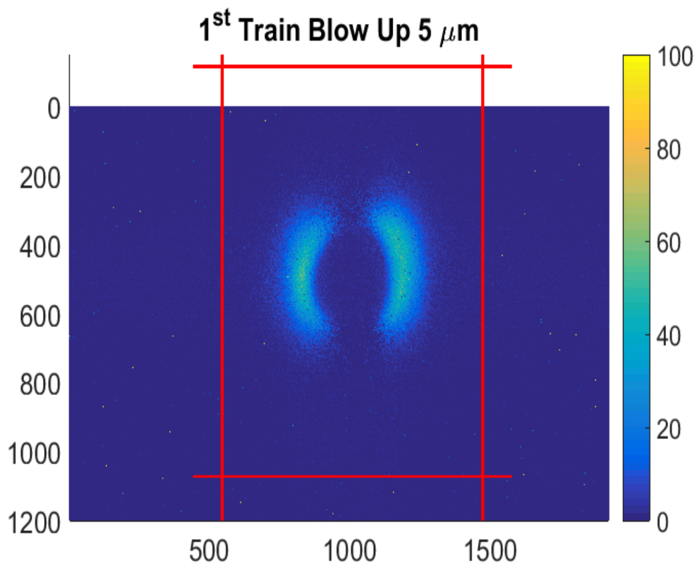

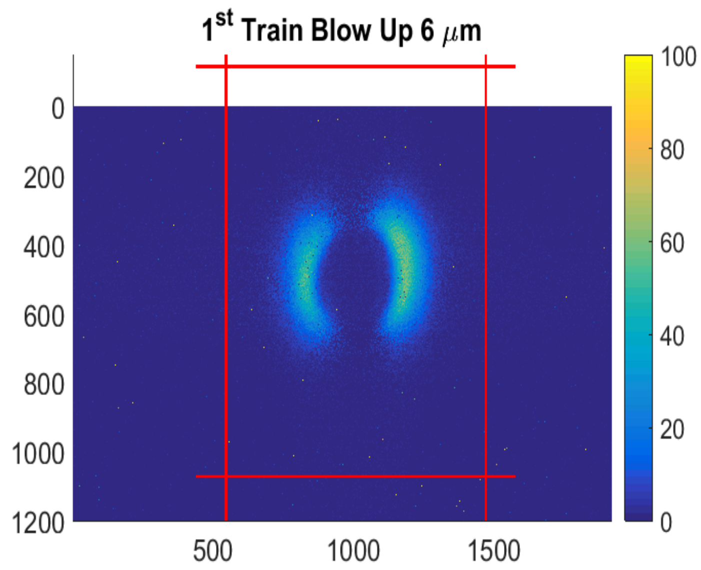

1st Train Blow Up 7 μm

1st Train Blow Up 8 μm

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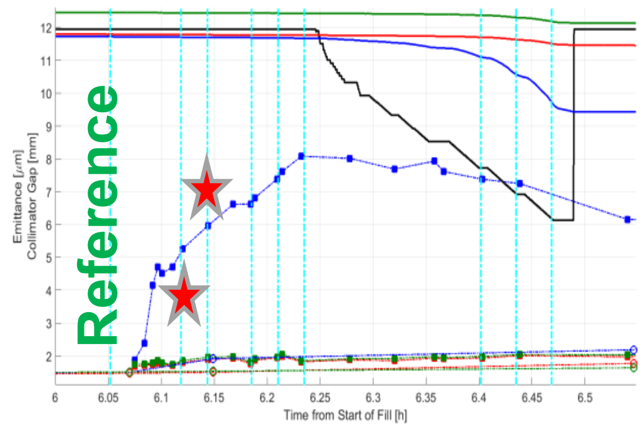

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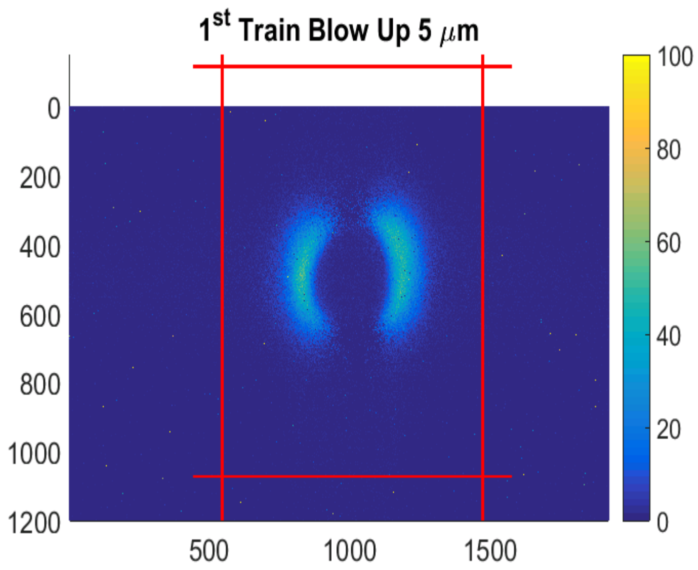

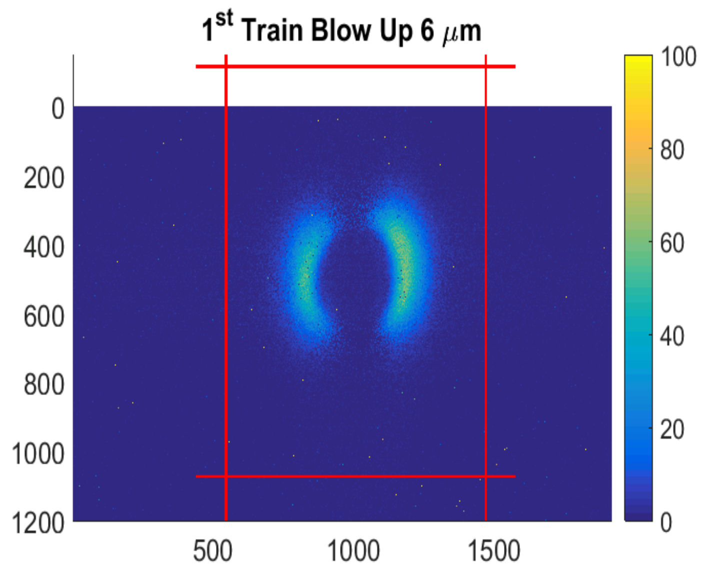

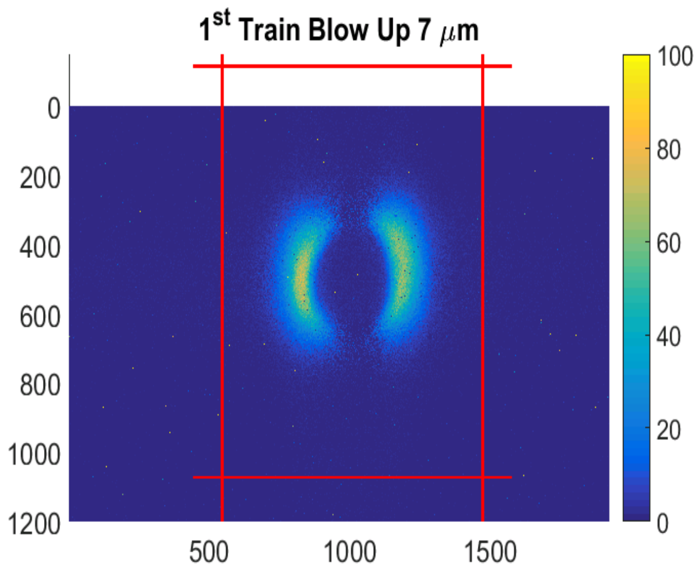

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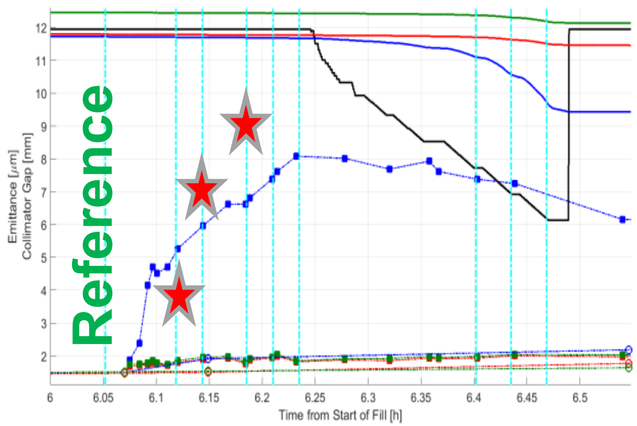

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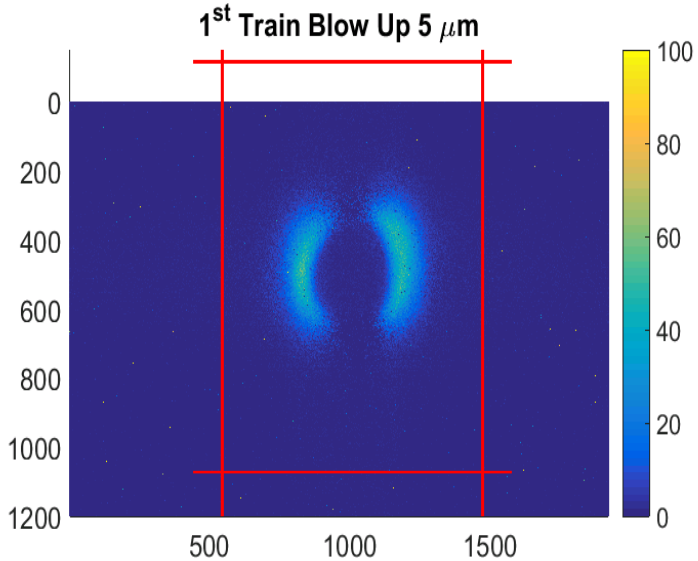
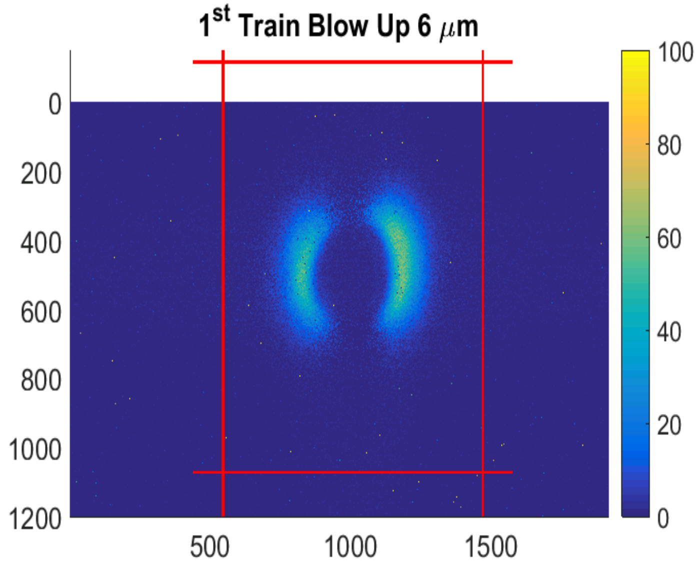
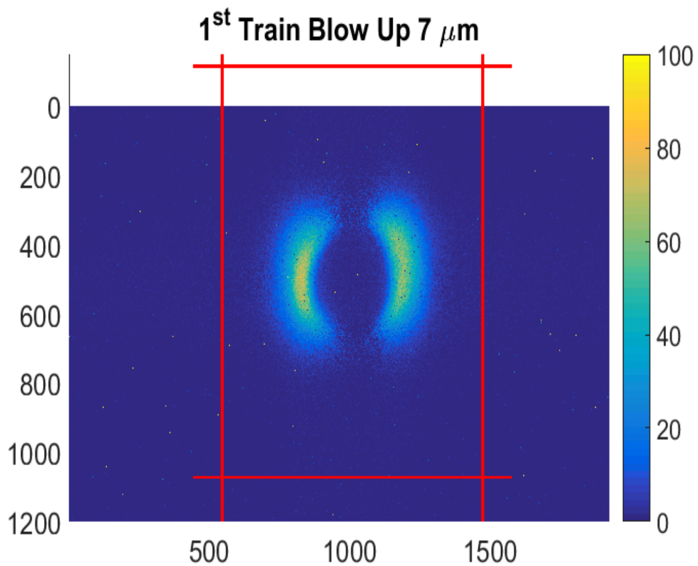
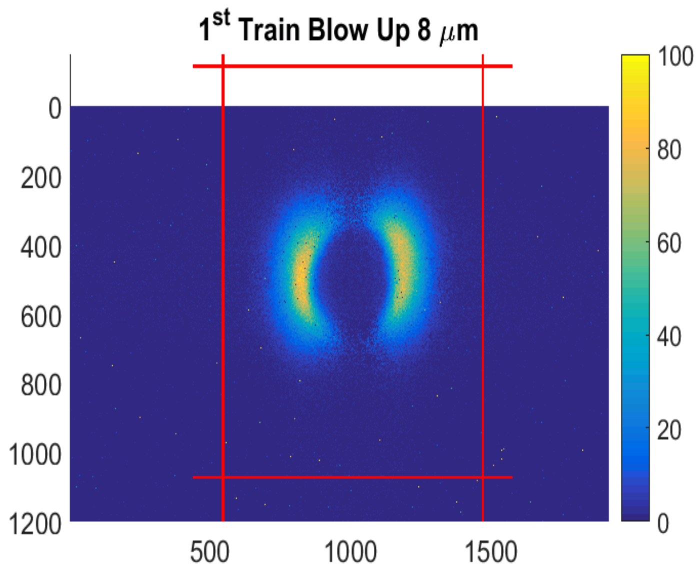
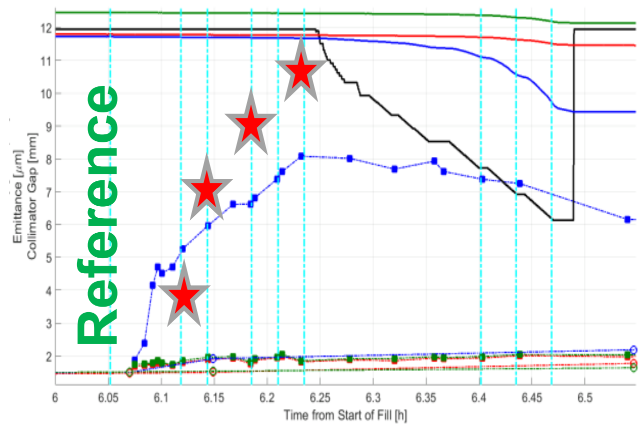








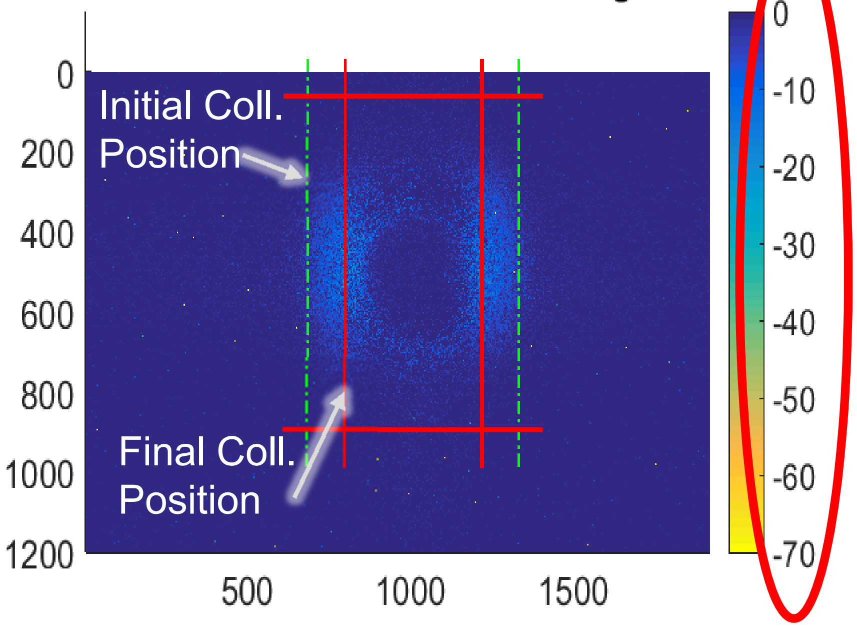
Light Variation against to initial conditions (i.e. small bunches before the blow up)



Experiment A

During transverse emittance scraping (H)

H Collimator to 3.7 Nominal Sigma

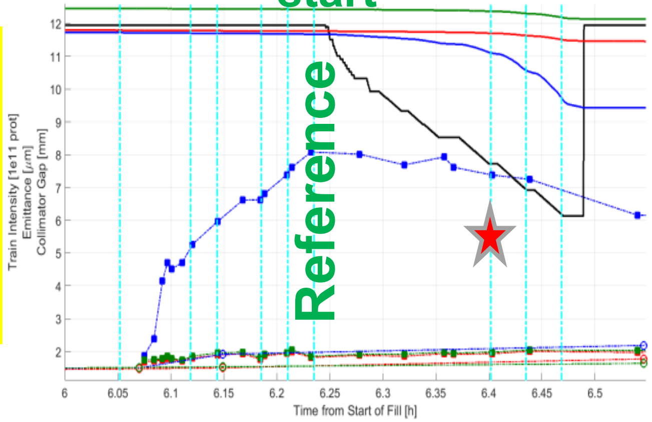


H Collimator to 3.3 Nominal Sigma

H Collimator to 2.9 Nominal Sigma

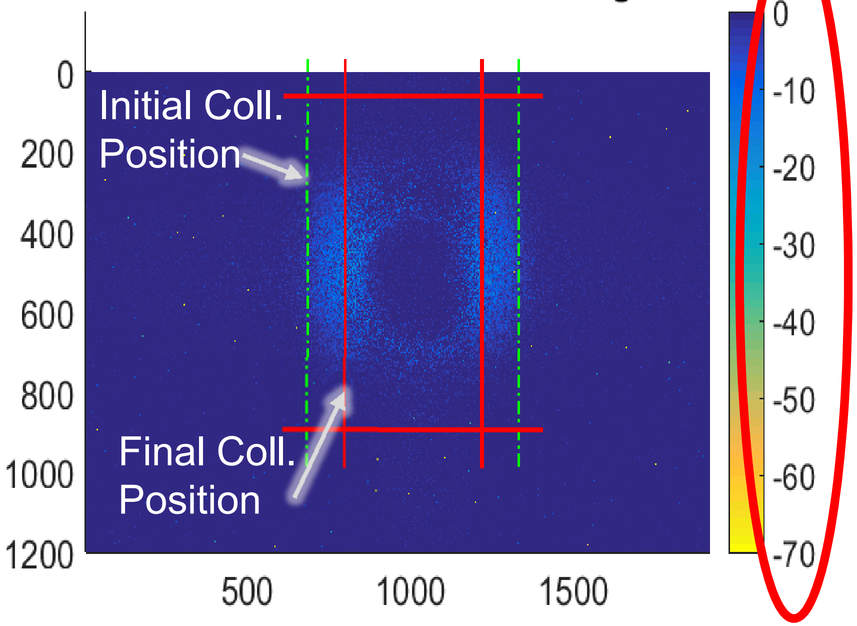
Light Variation against to initial conditions (i.e. intense bunches before the scraping)

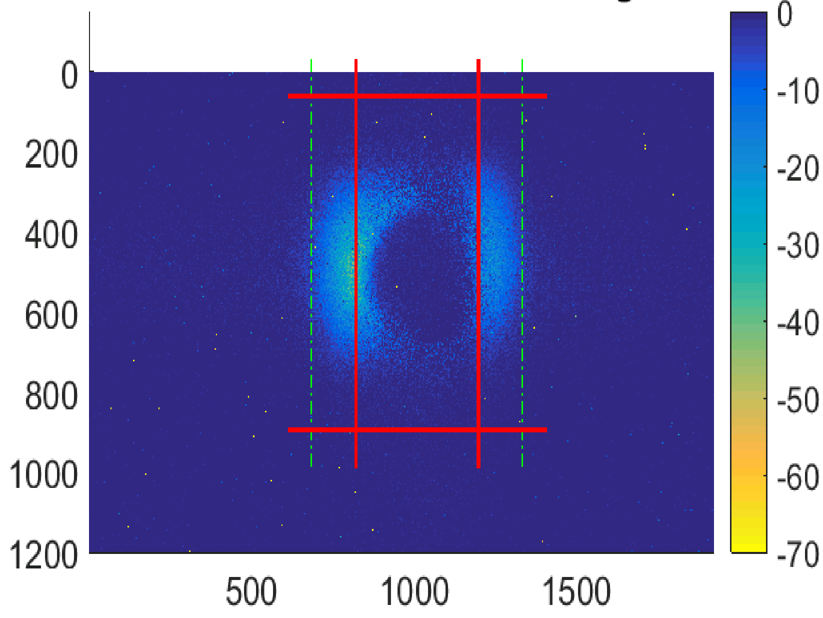
Reference image is before scraping start



Experiment A

During transverse emittance scraping (H)

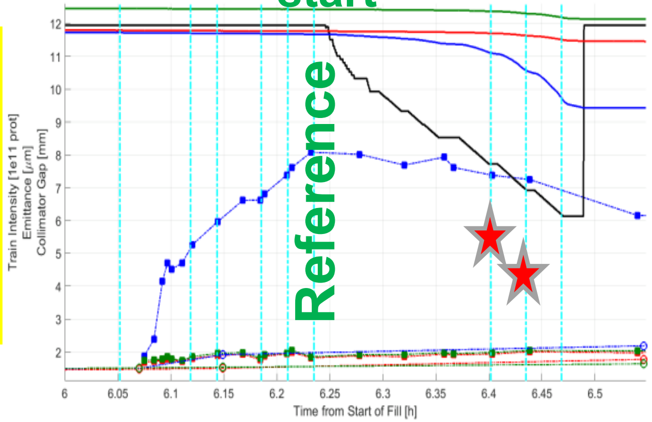




H Collimator to 2.9 Nominal Sigma

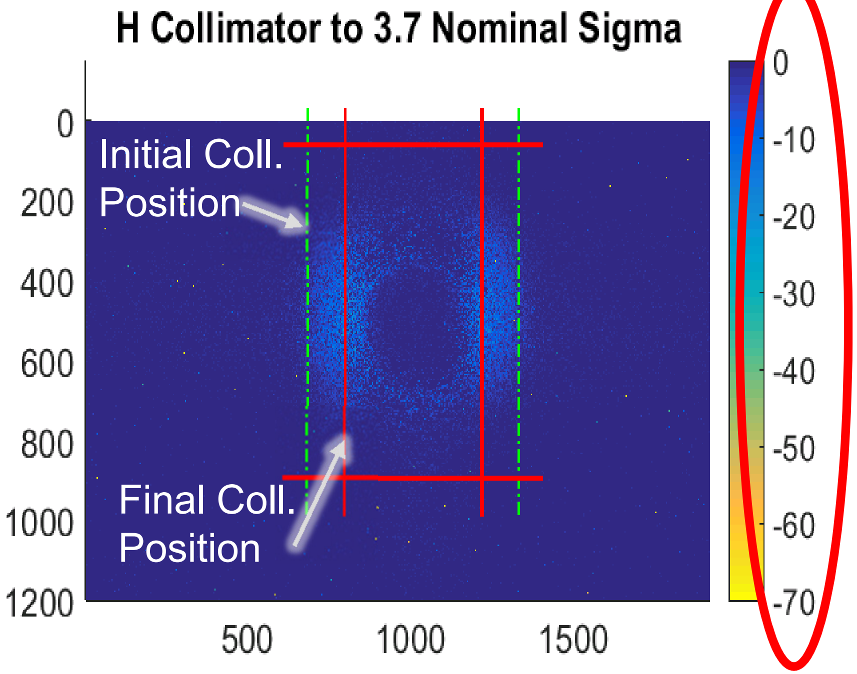
Reference image is before scraping start

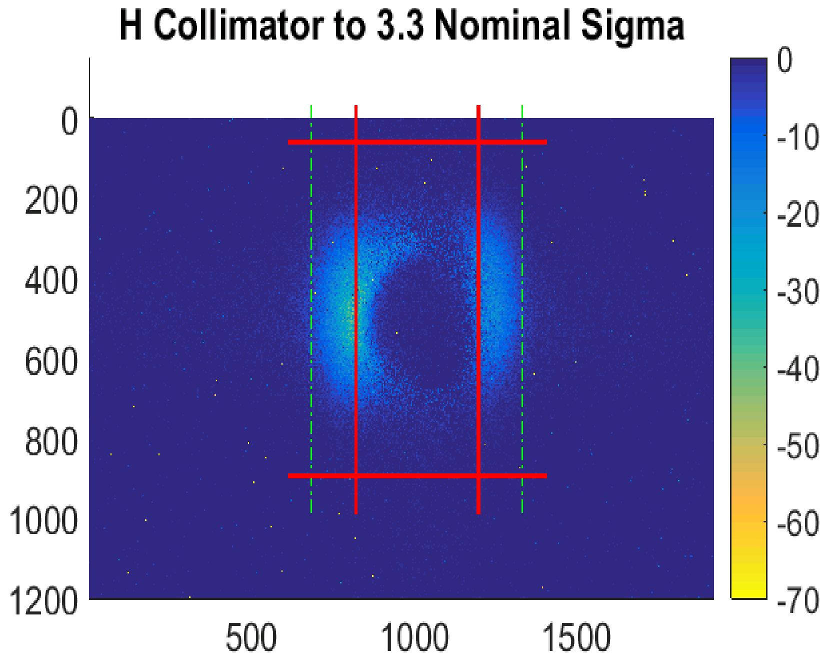
Light Variation against to initial conditions (i.e. intense bunches before the scraping)

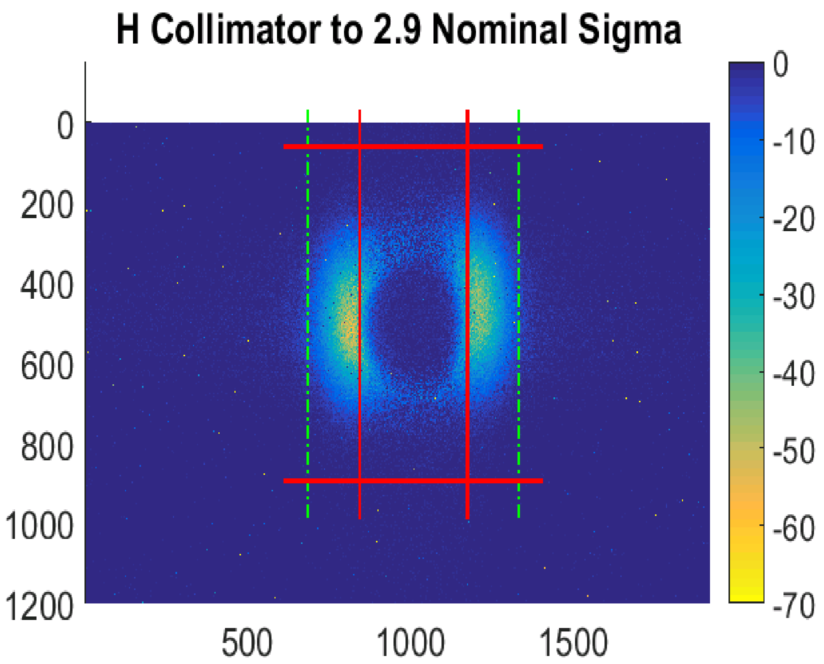


Experiment A

During transverse emittance scraping (H)

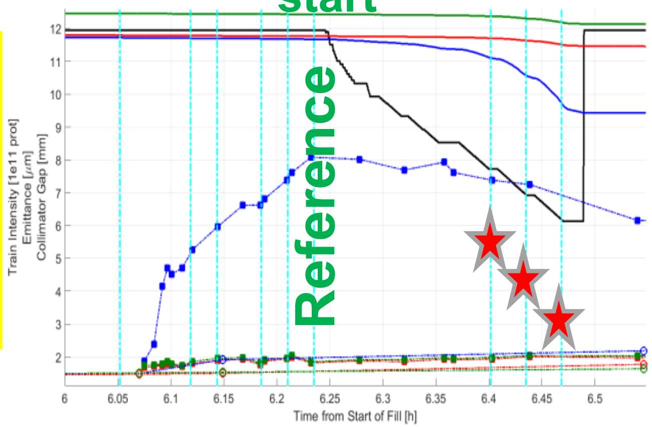




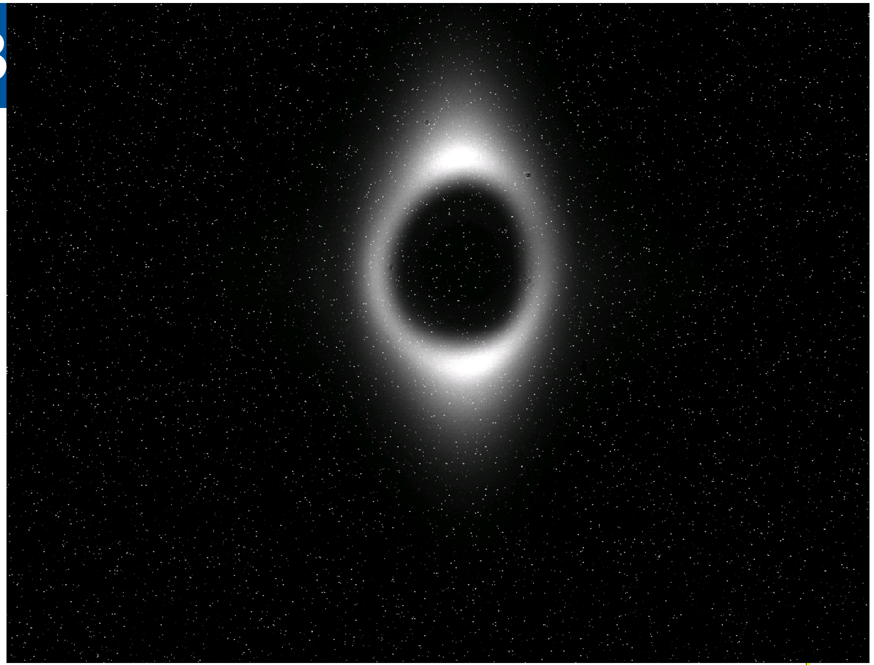


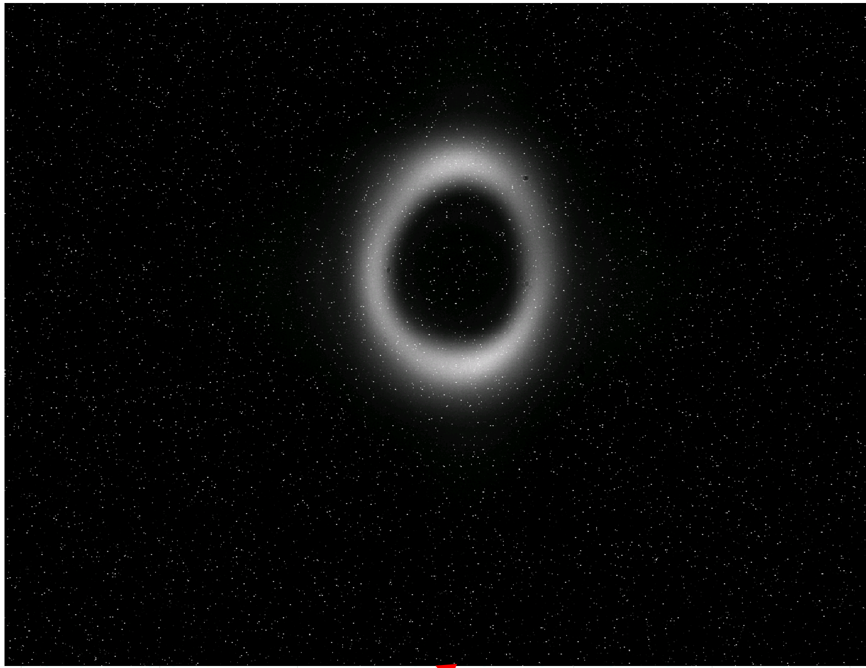
Light Variation against to initial conditions (i.e. intense bunches before the scraping)

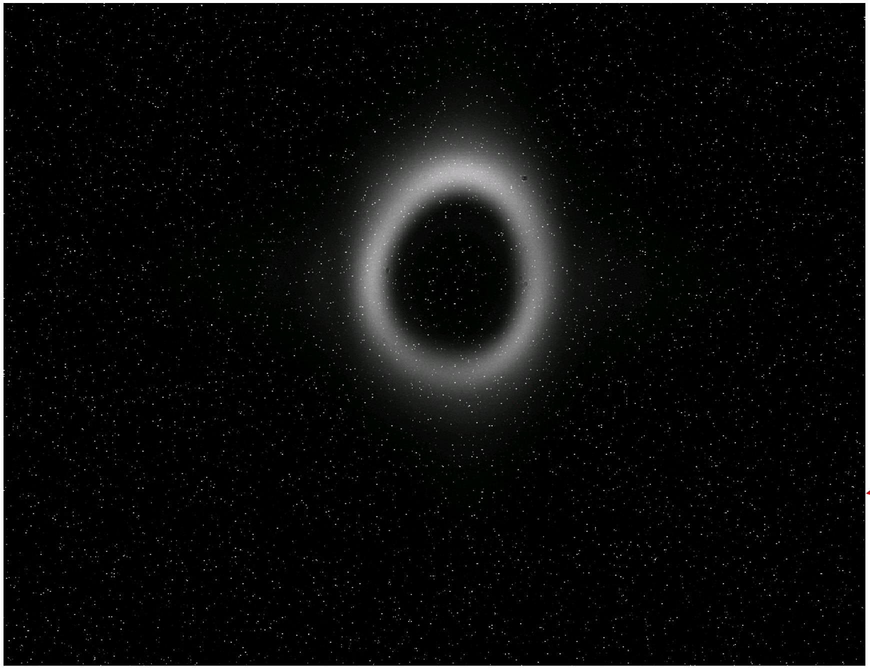
Reference image is before scraping start

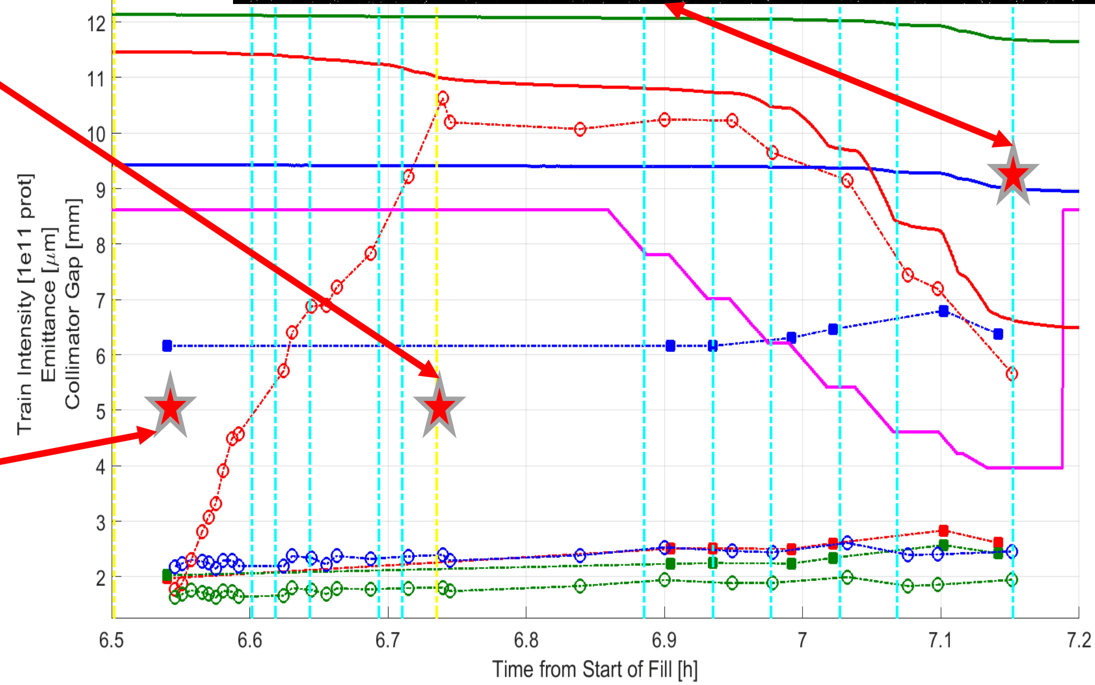


Experiment B

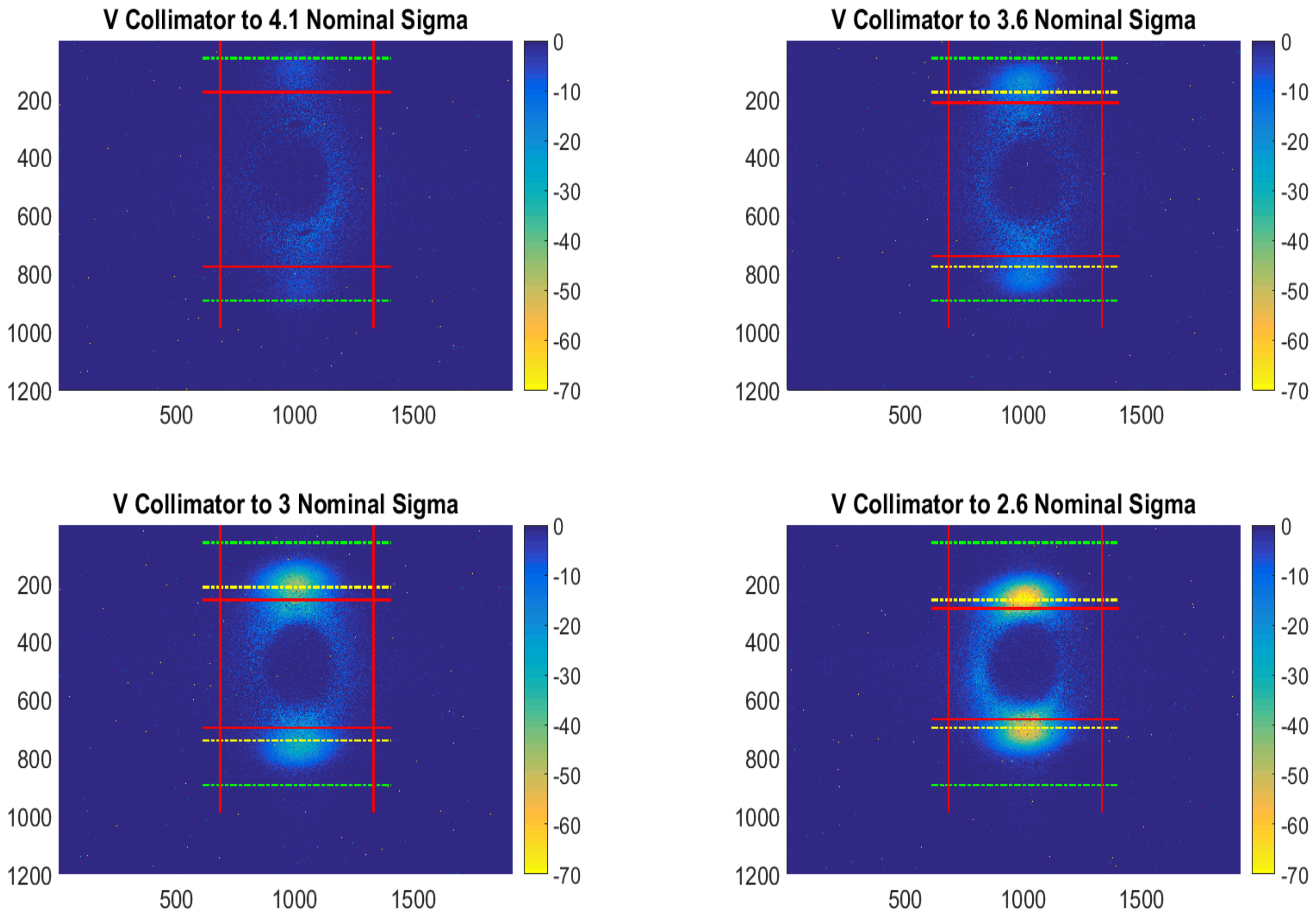






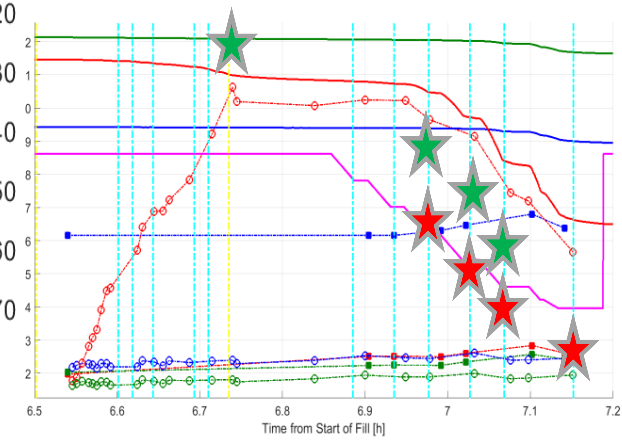


Experiment B



Light Variation agianst to initial conditions (i.e. intense bunches before the scraping)

Reference image is reset at each step of scraping

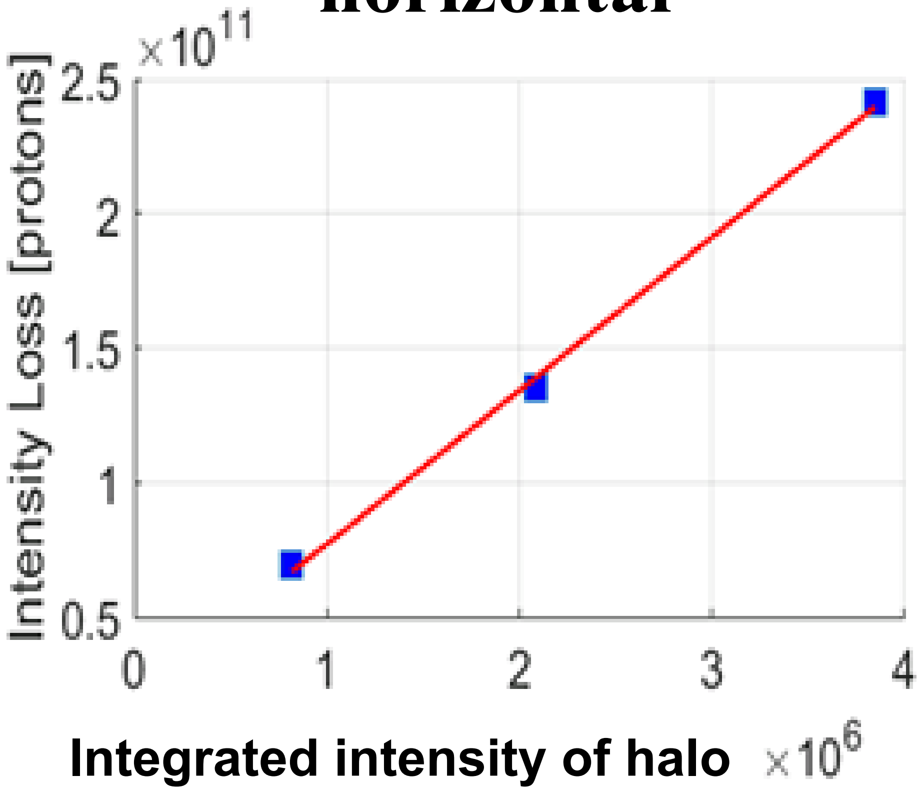


Correlation plot for the integrated intensity of halo and proton intensity

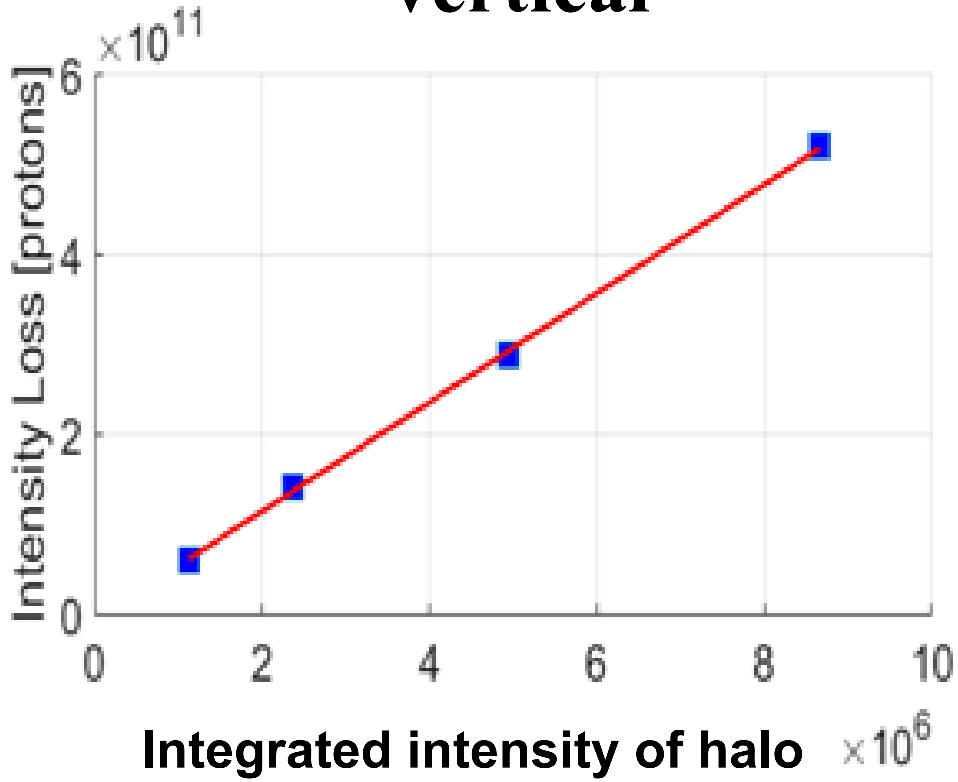
Experiment A

Experiment B

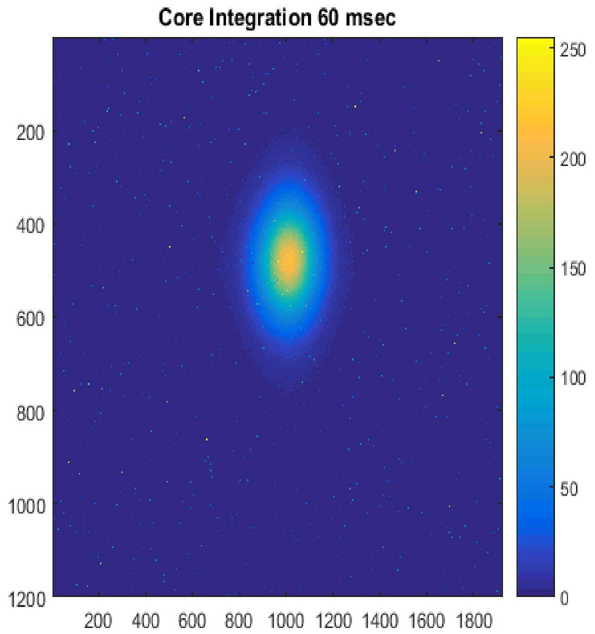
horizontal

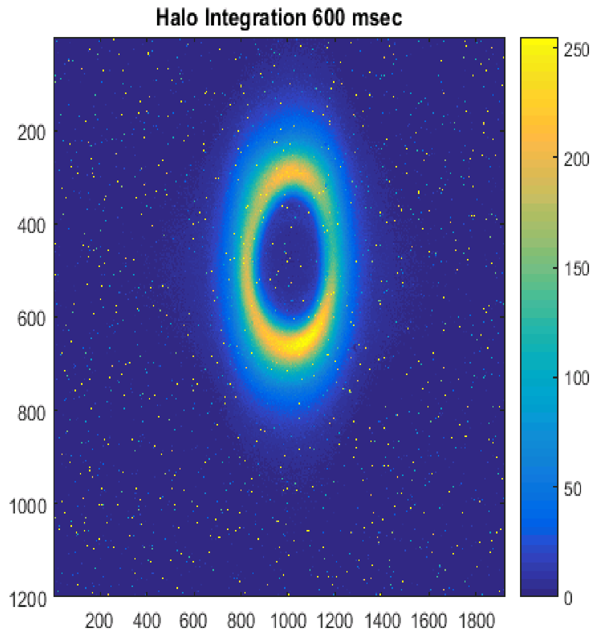


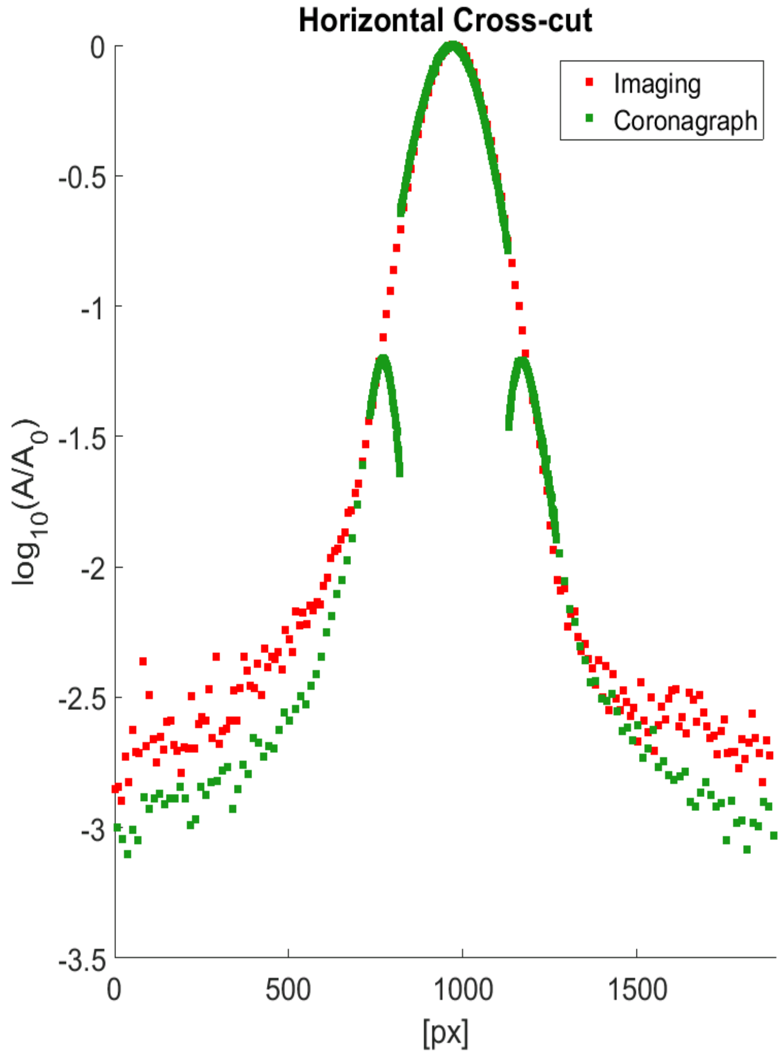
vertical



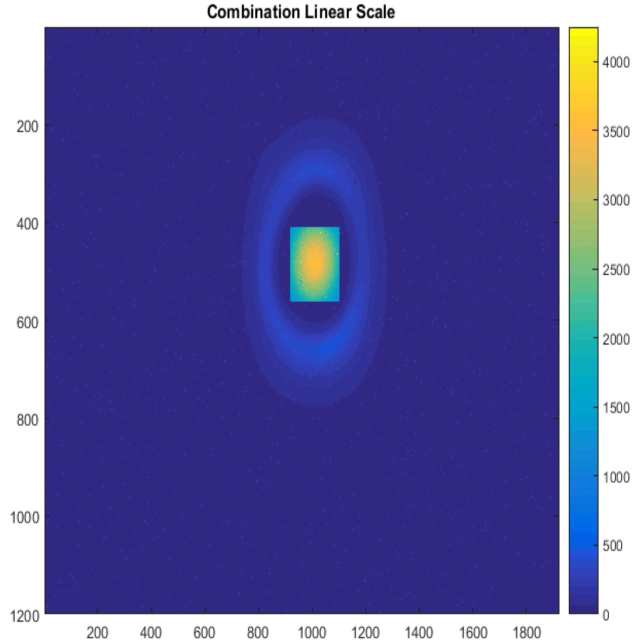
In Terms of Contrast

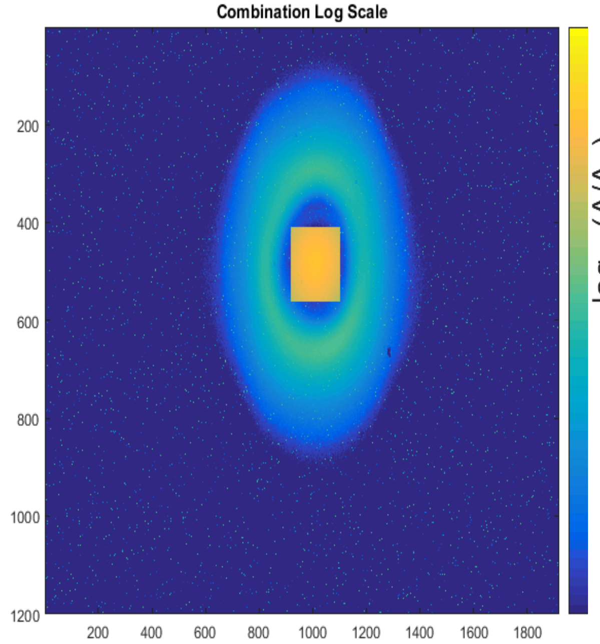


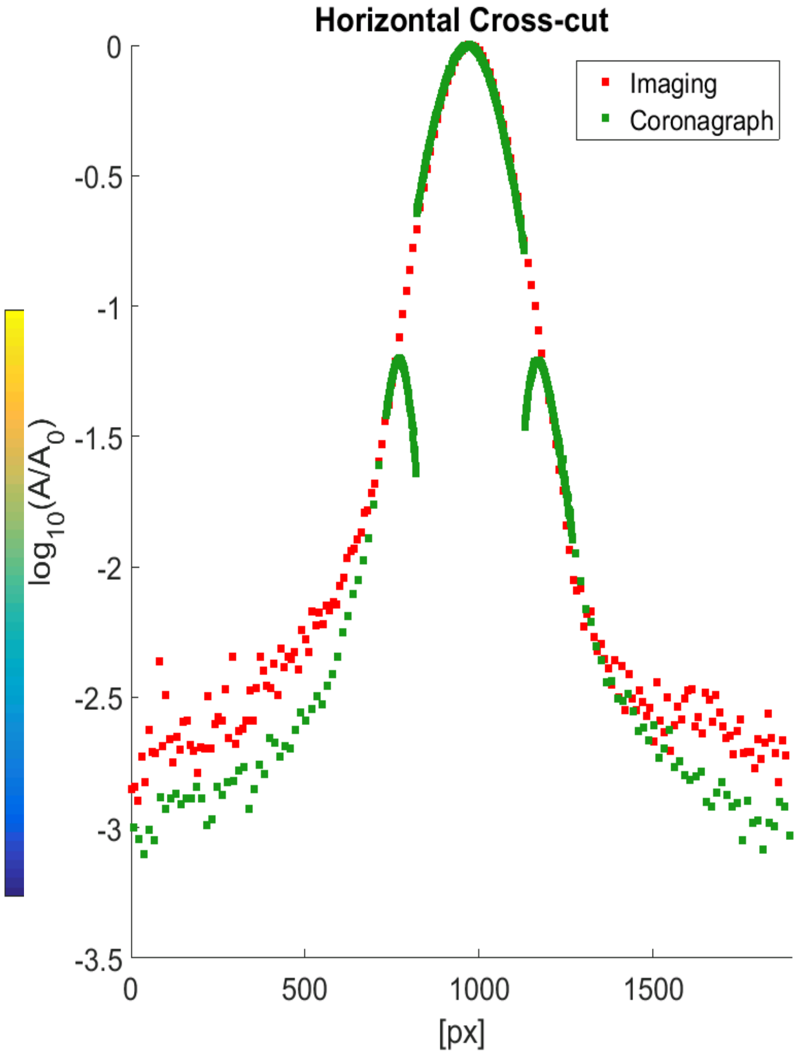




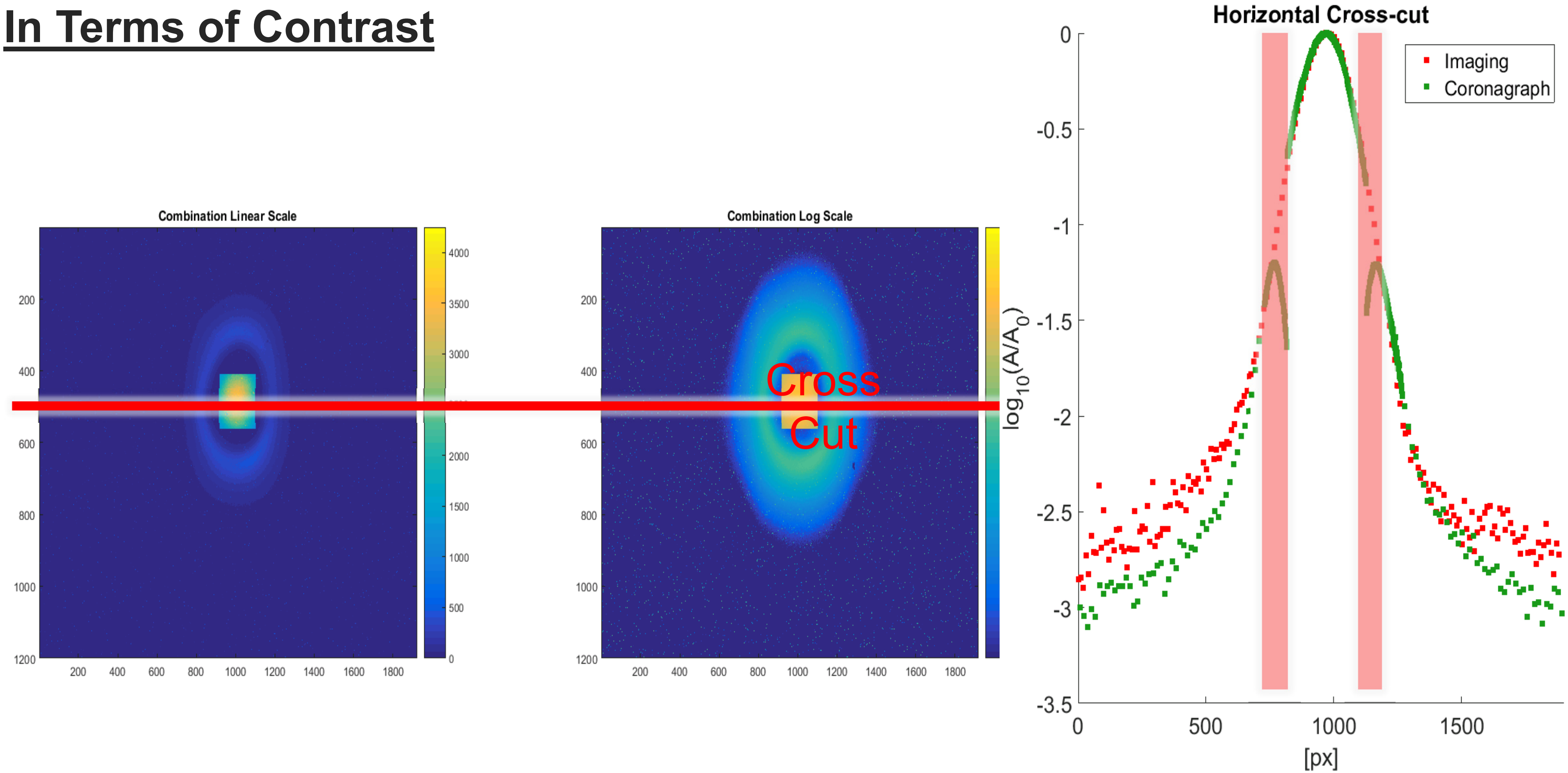
In Terms of Contrast



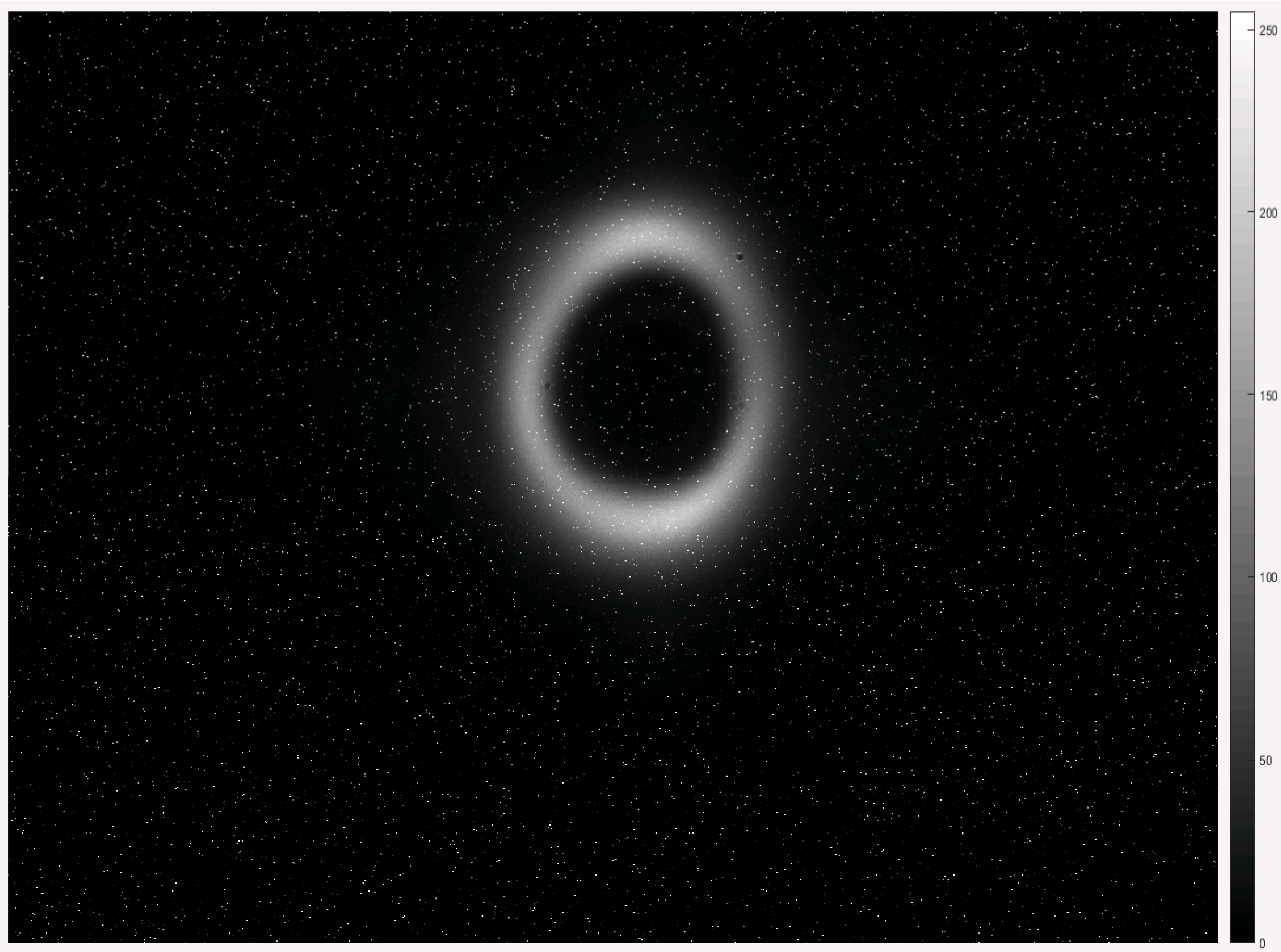




In Terms of Contrast

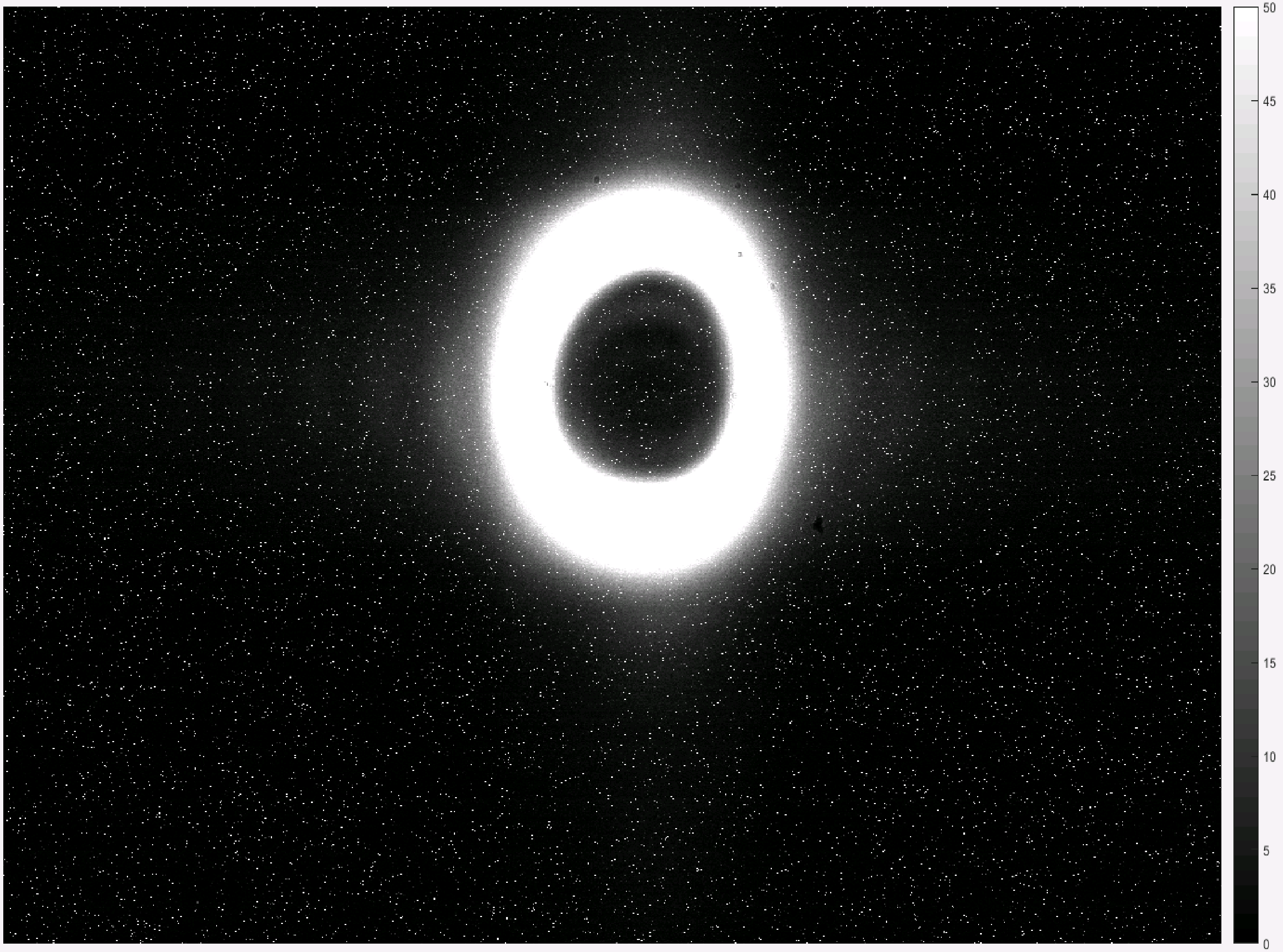


Contrast of 2.10^{-3} demonstrated



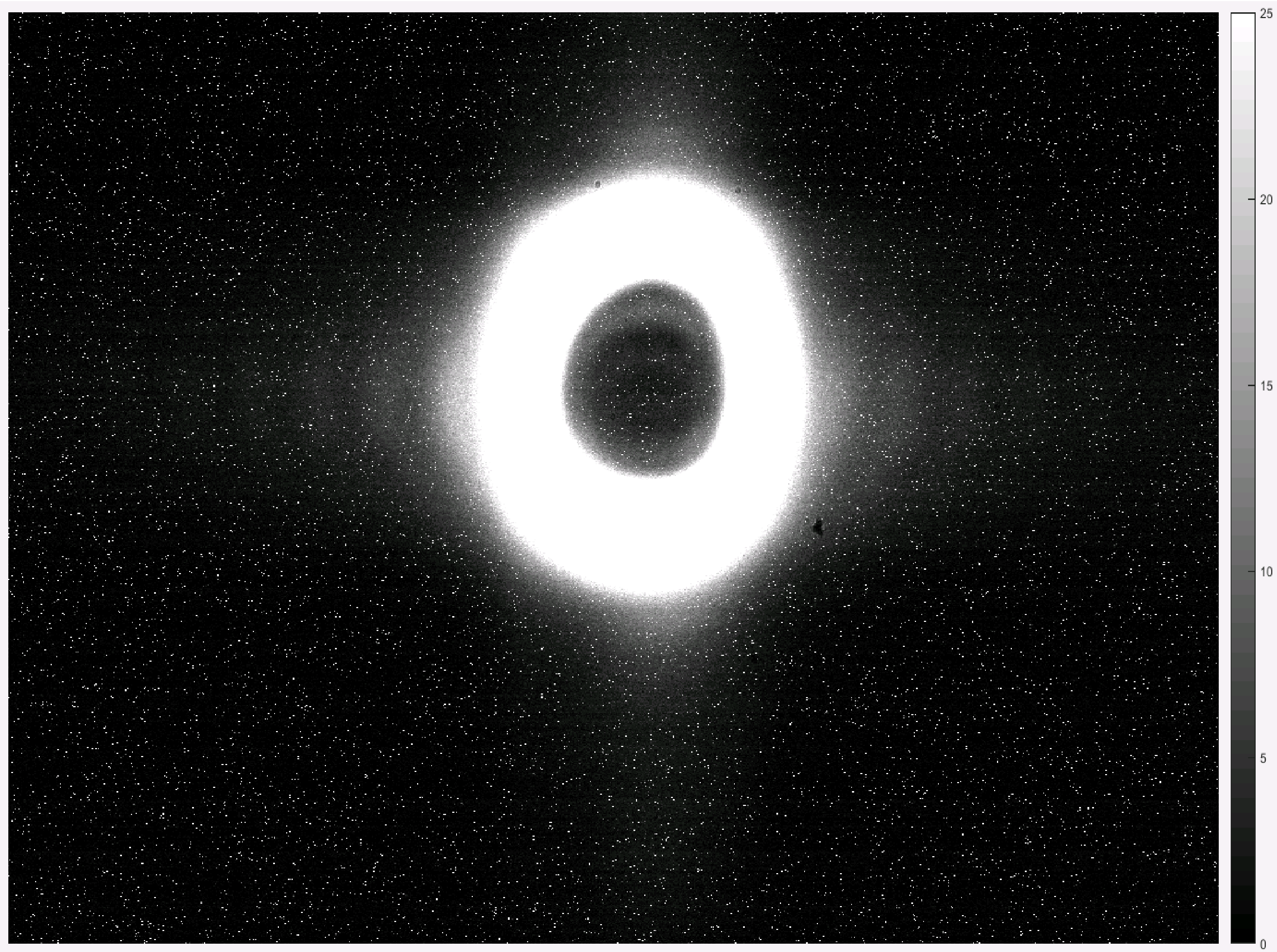
250

Phase 1 coronagraph has still large amount of diffraction fringe leakage!

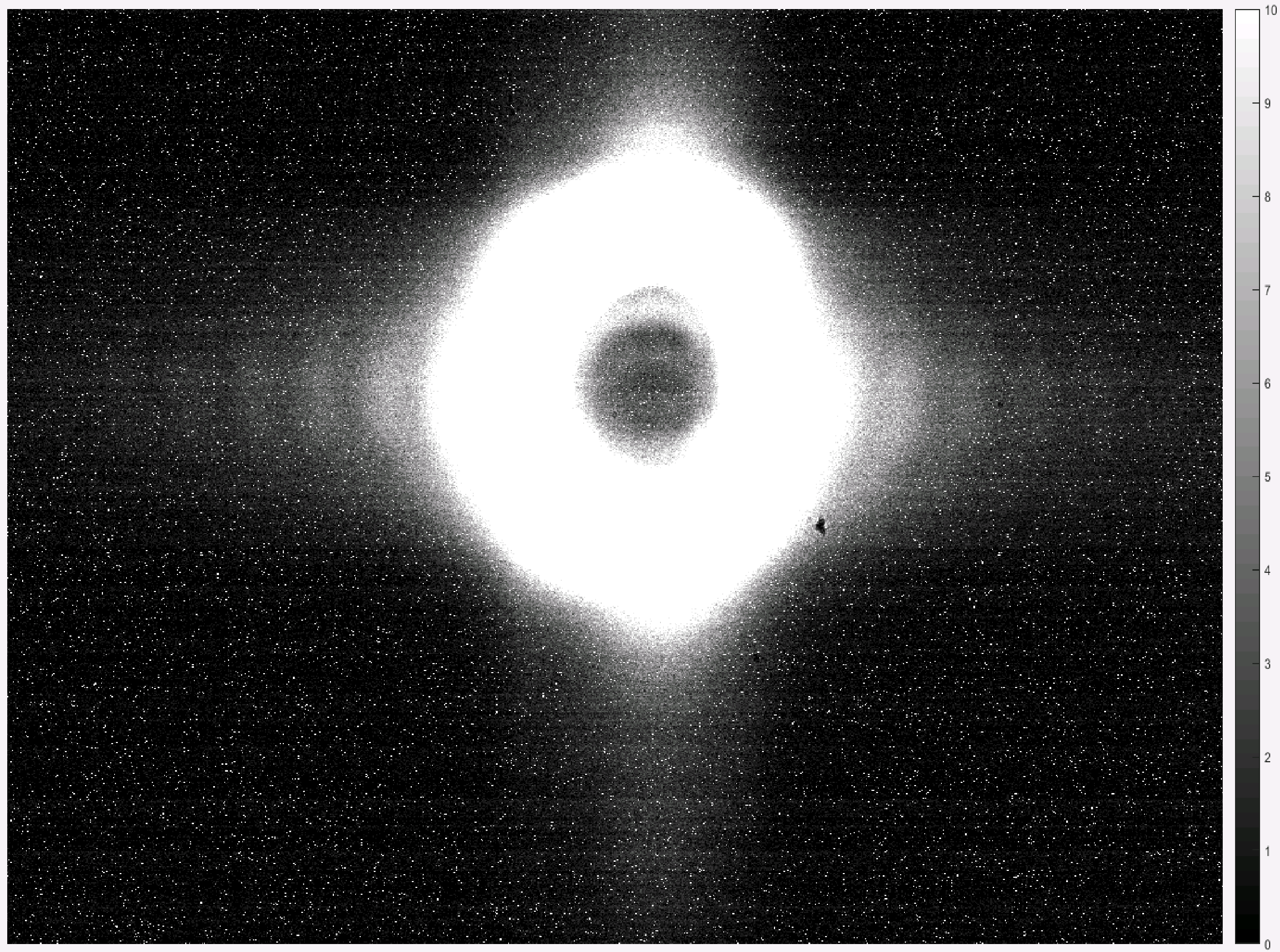


50

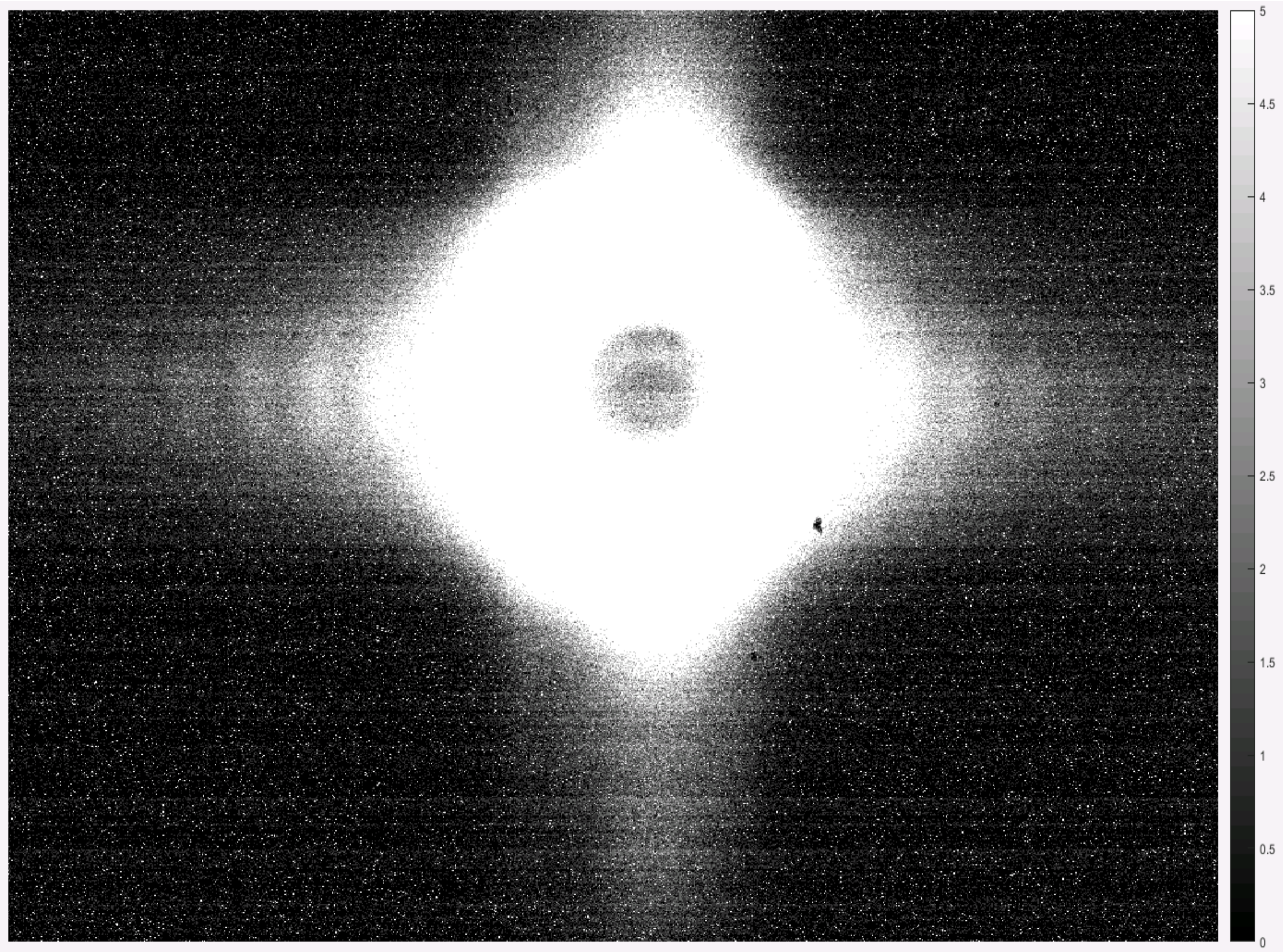
Phase 1 coronagraph has still large amount of diffraction fringe leakage!



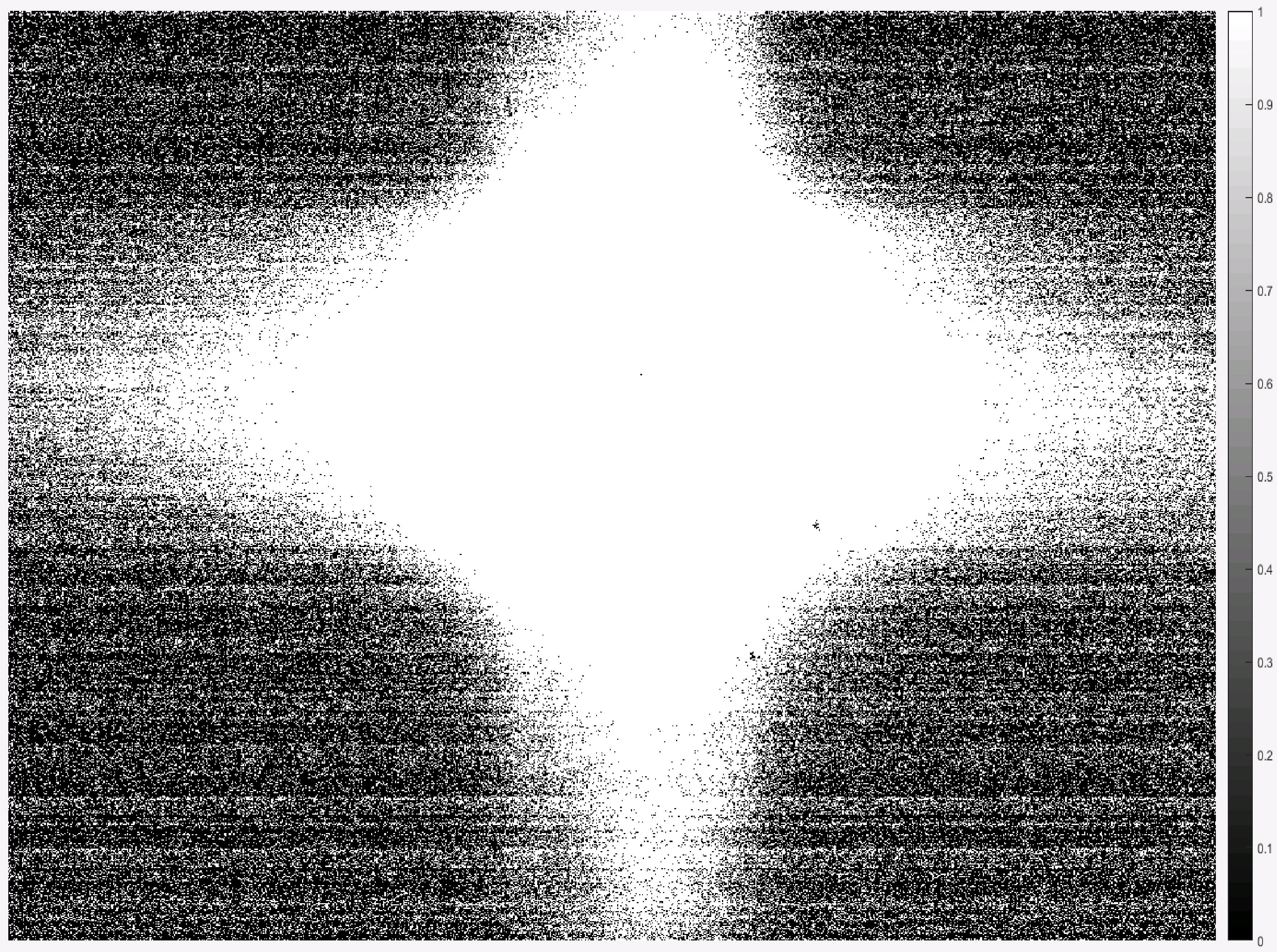
Phase 1 coronagraph has still large amount of diffraction fringe leakage!



Phase 1 coronagraph has still large amount of diffraction fringe leakage!



Phase 1 coronagraph has still large amount of diffraction fringe leakage!



1

Phase 1 coronagraph has still large amount of diffraction fringe leakage!

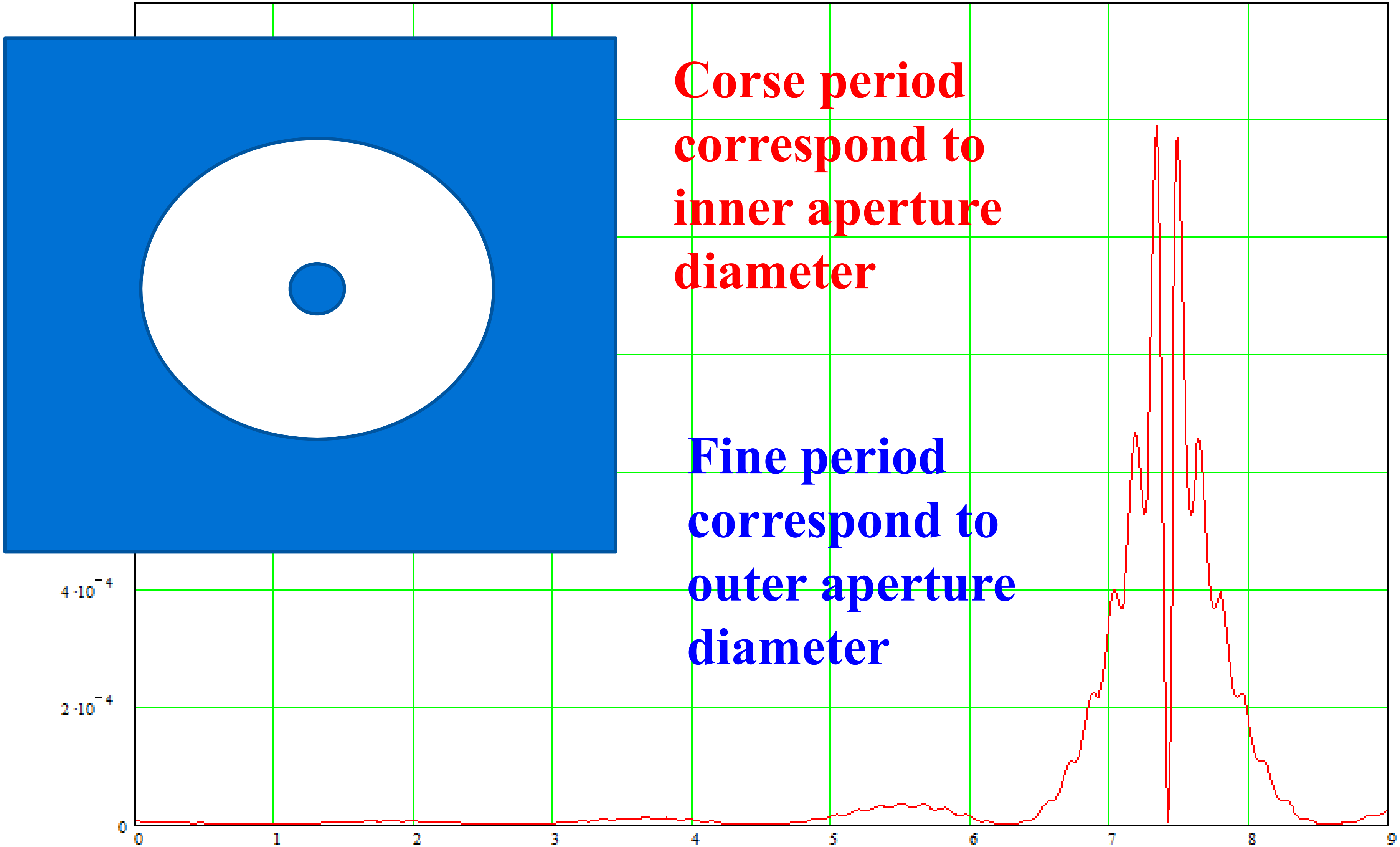
Conclusions for first observation of beam halo using an artificial halo

- **Phase 1 Coronagraph was installed at B2 (SR monitor line) .**
- **Test for Observation started with 450GeV beam last summer using artificial halo which is formed by beam exciter**
- **Decrease of beam halo intensity with beam scraper is observed.**
  10^{-3} contrast is achieved.
- **Phase 2 (dedicated coronagraph for HL LHC) design is started.**

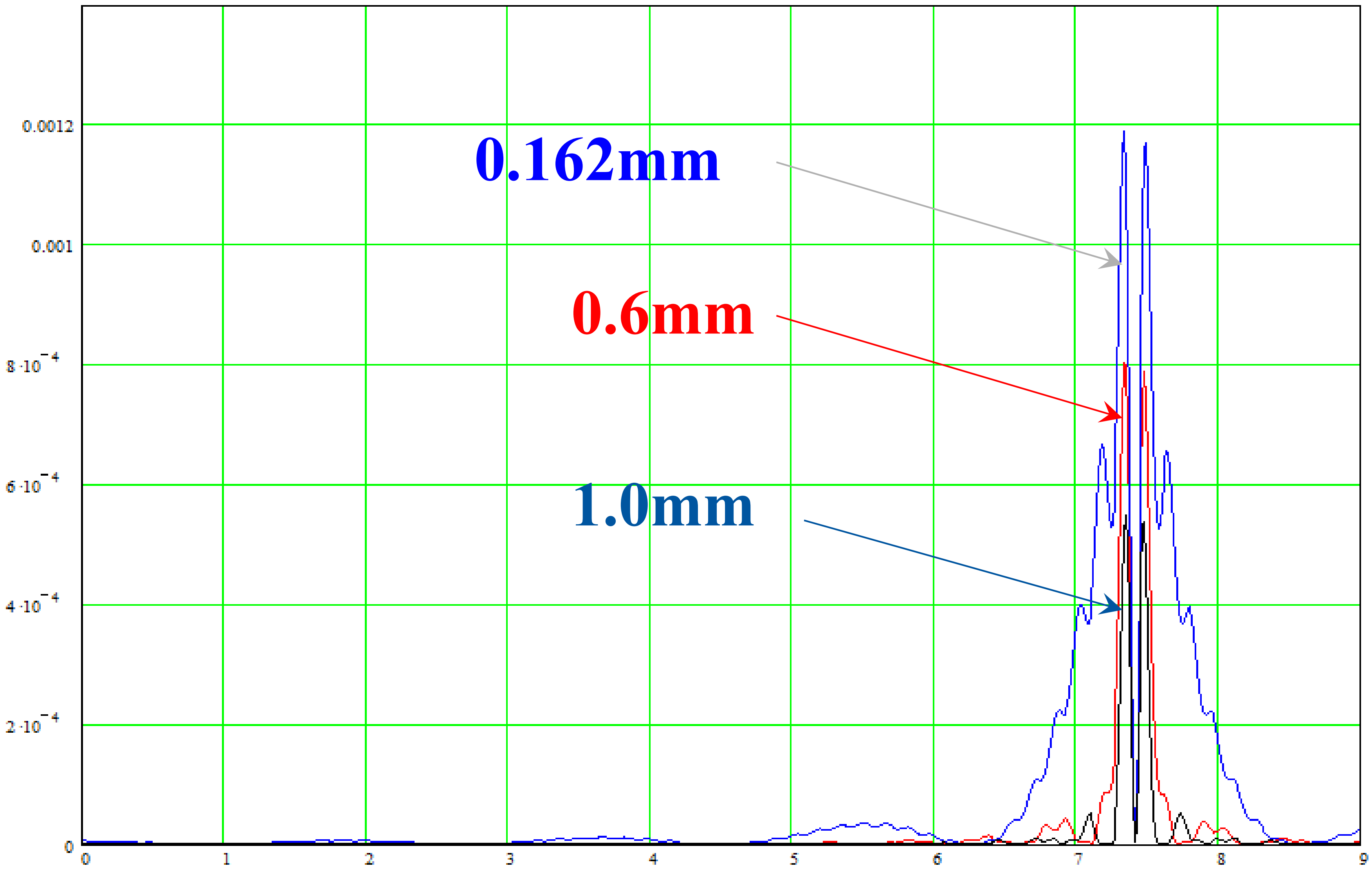
6. Phase 2 coronagraph

The performance of coronagraph is limited by which reason?

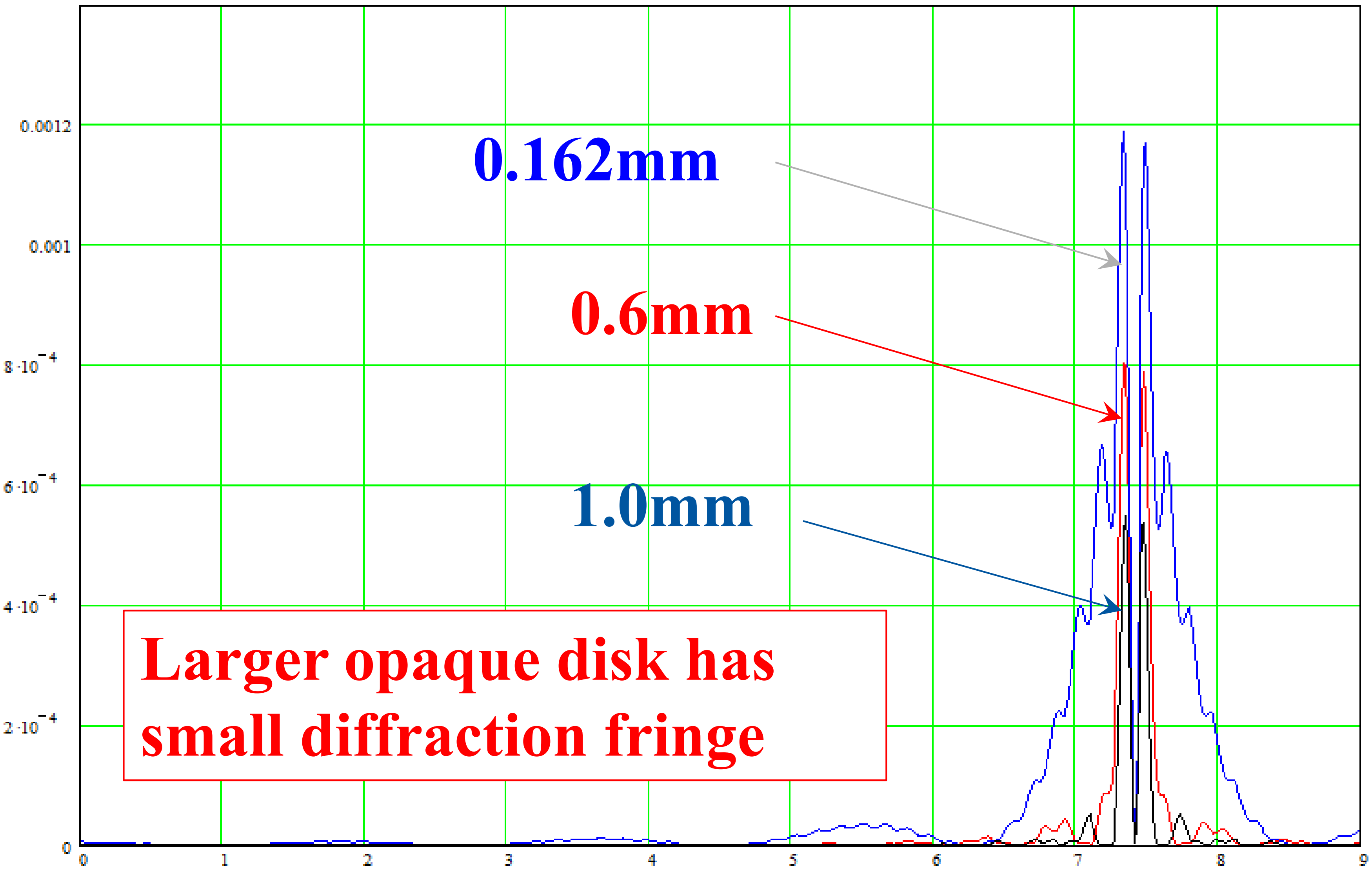
Back to diffraction fringe on Lyot stop



Back to diffraction fringe on Lyot stop



Back to diffraction fringe on Lyot stop

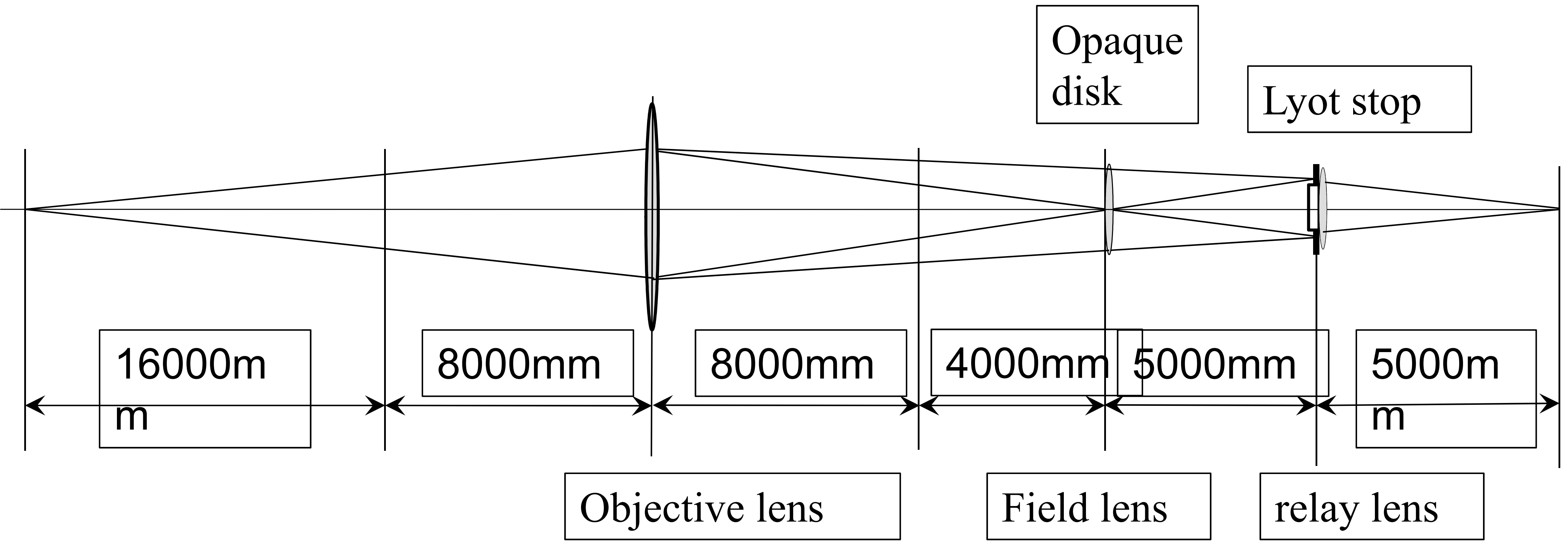


Key point to reduce leakage of diffraction fringe (increse contrast)

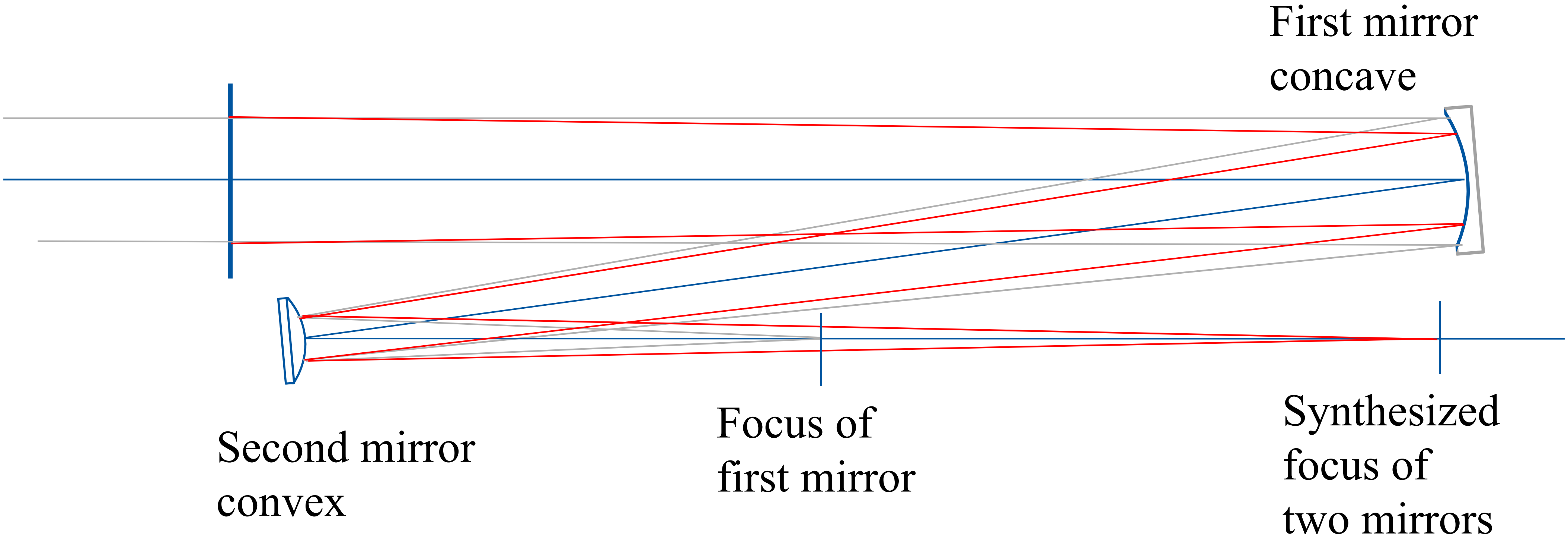
Apply a larger opaque mask!

Make transverse magnification of first objective lens larger.

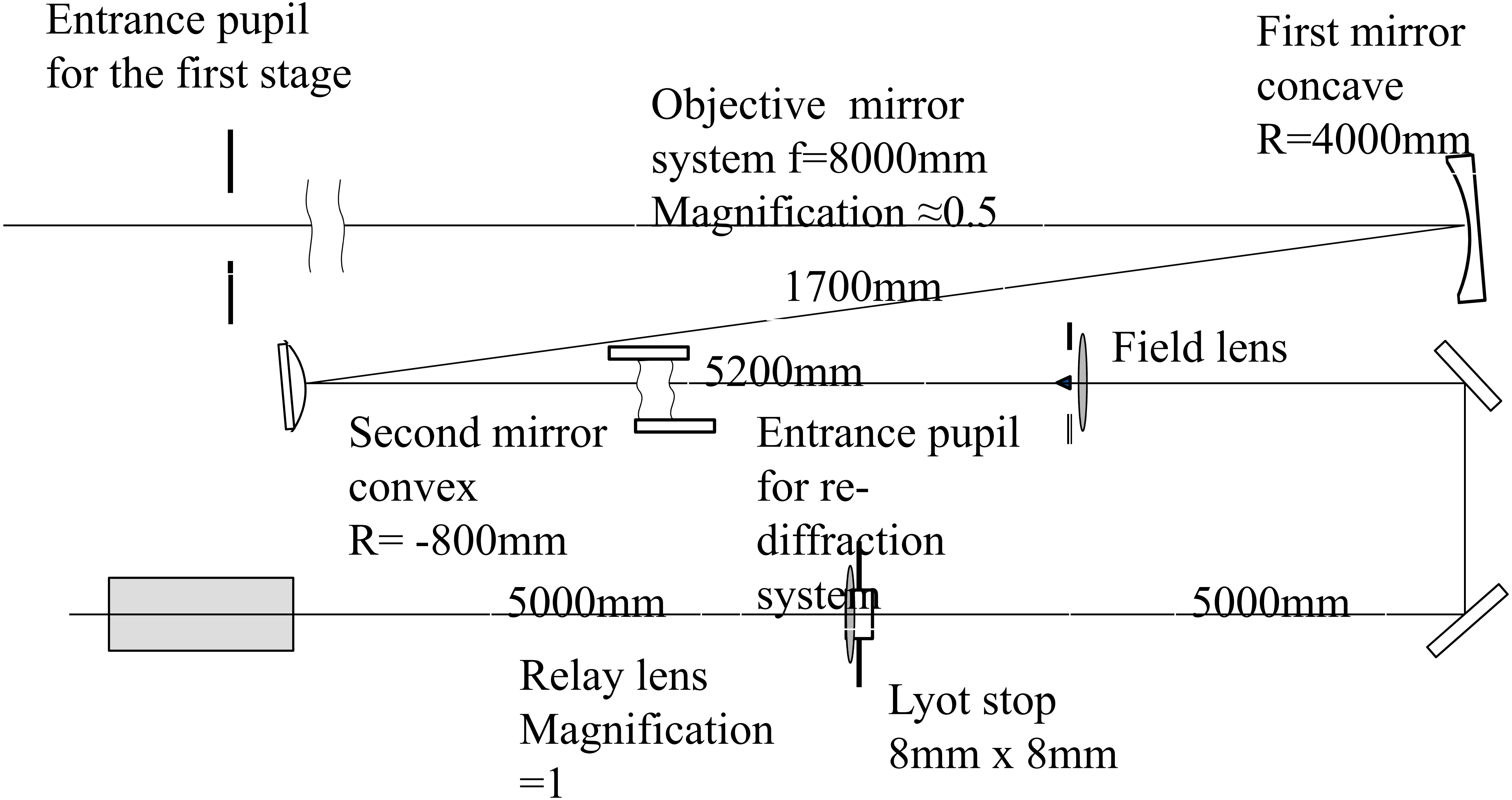
Coronagraph having a magnification of 0.5 (about 7 times larger transverse magnification)



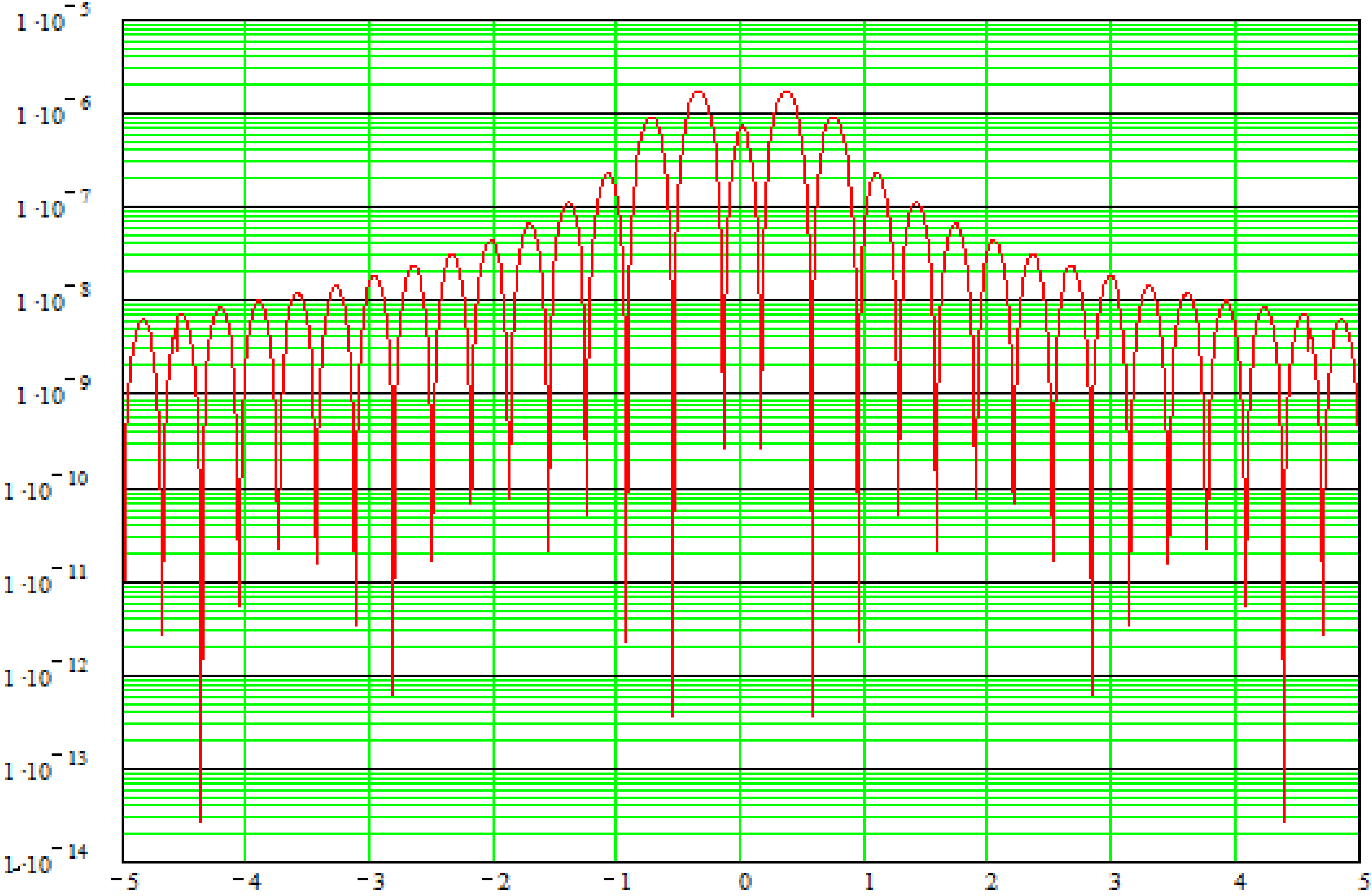
Telephoto type with reflectors



Optical design



Diffraction background at 3ed stage
In Log scale 2x10^{-6} to 10^{-7}



Thank you for your attention!