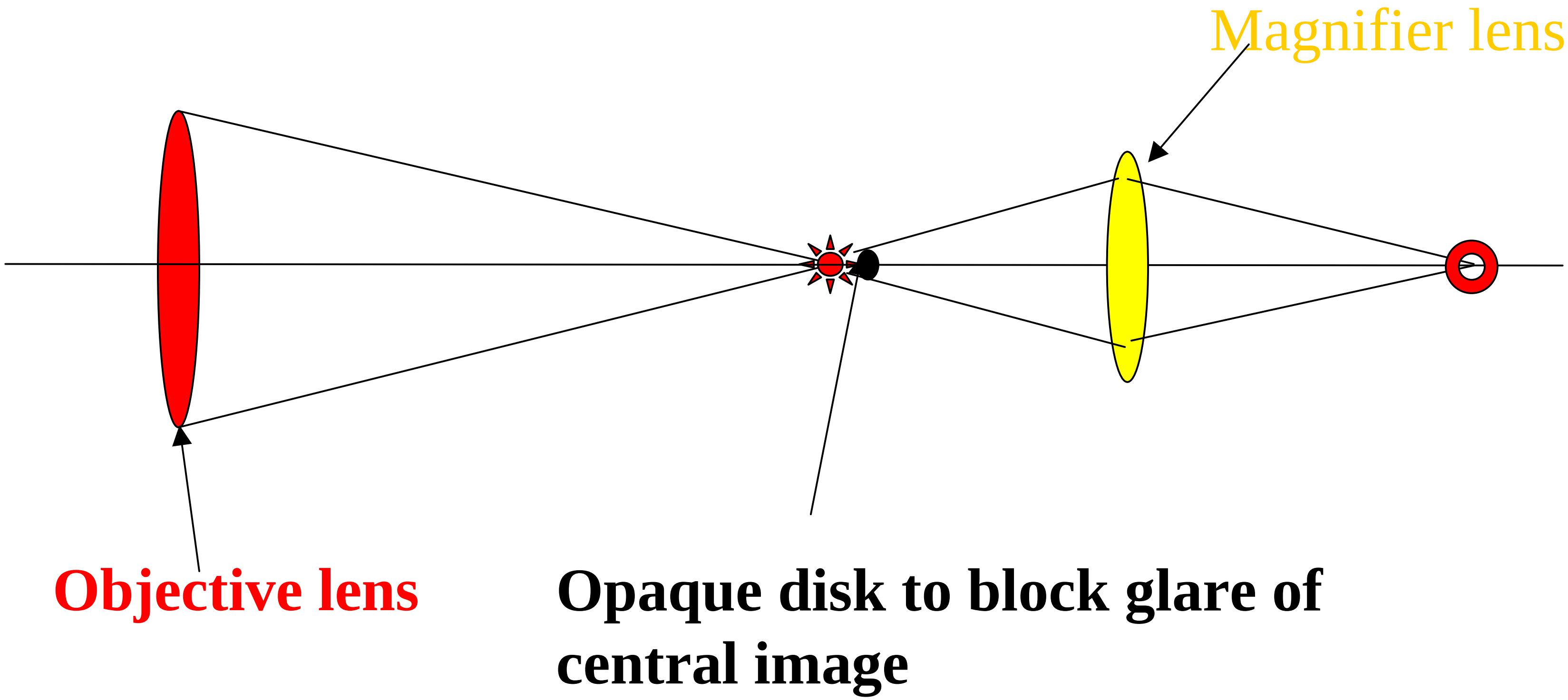
Observation of beam halo with coronagraph

1. Diffraction fringes vs. beam tail (halo)

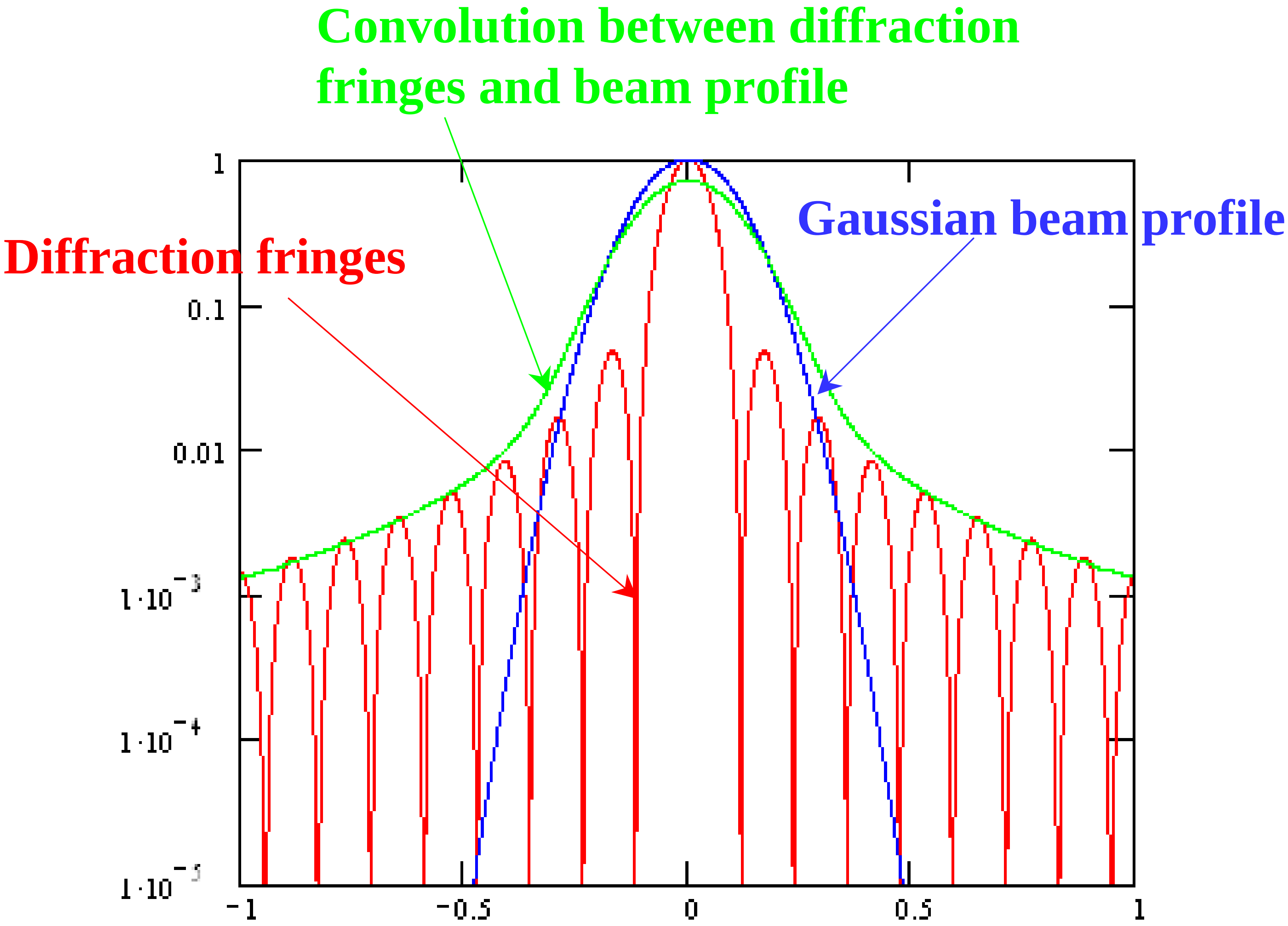
Observation with normal telescope



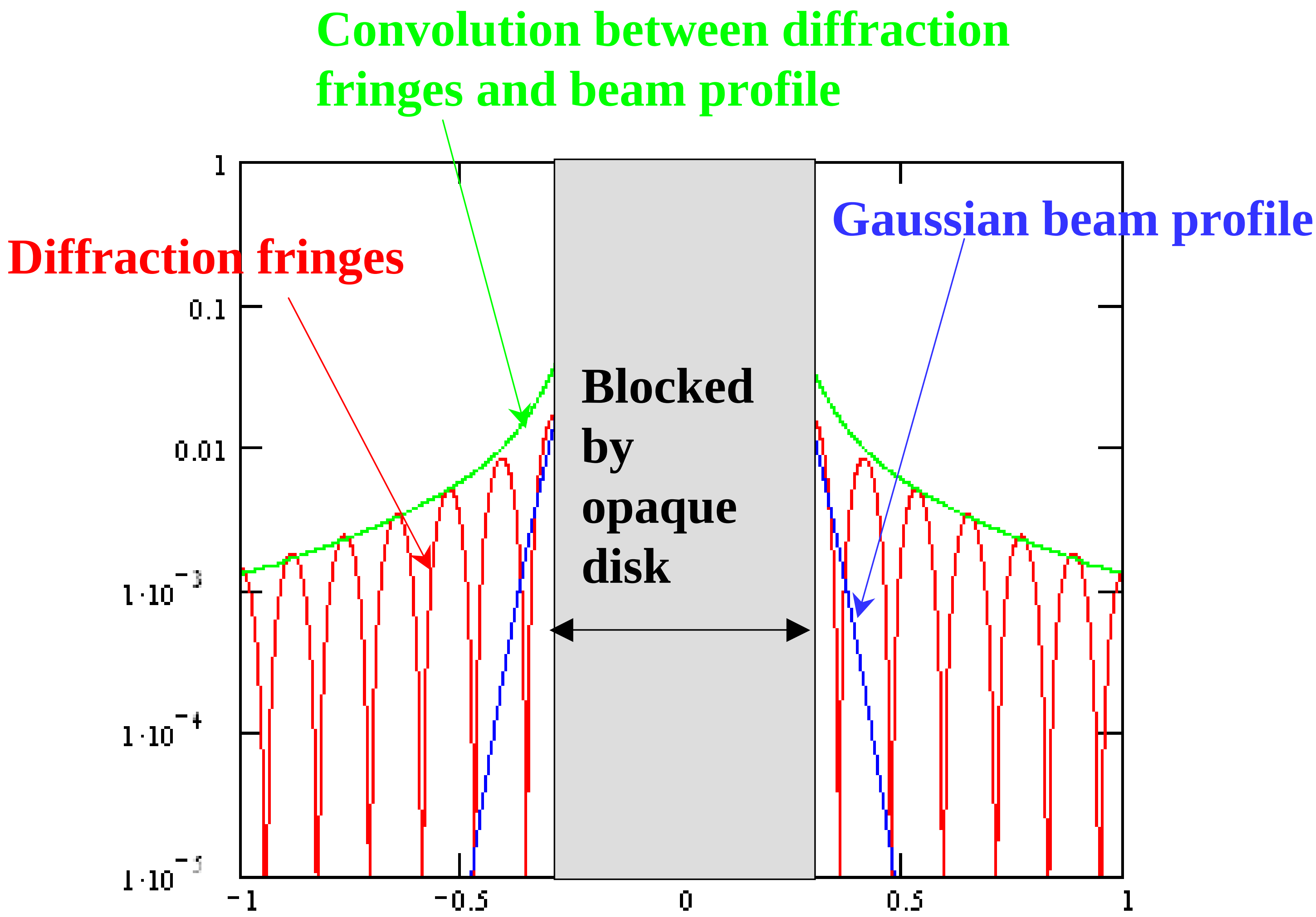
Diffraction fringes makes tail surrounding from the central beam image.

Intensity of diffraction tail is in the range of 10^{-2} -10^{-3} of the peak intensity.

The diffraction tail disturb an observation of week object surrounding from bright central beam



Convolution between diffraction fringes and beam profile
Gaussian beam profile
Diffraction fringes
1
0.1
0.01
1·10⁻³
1·10⁻⁴
1·10⁻⁵
−1
−0.5
0
0.5
1



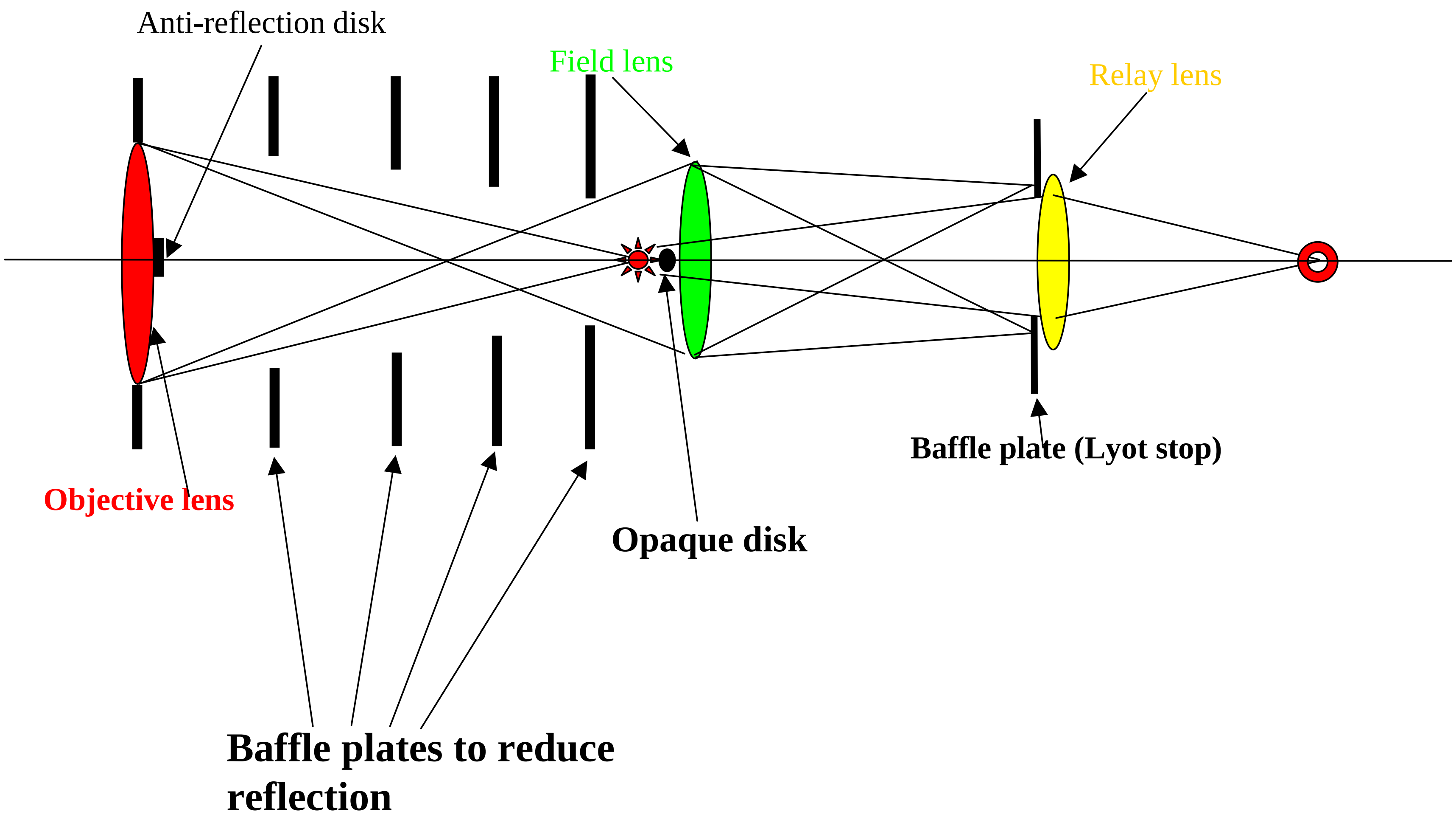
Convolution between diffraction fringes and beam profile
Diffraction fringes
Gaussian beam profile
Blocked by opaque disk
1
0.1
0.01
1·10⁻³
1·10⁻⁴
1·10⁻⁵
−1
−0.5
0
0.5
1

2. The coronagraph to observe sun corona

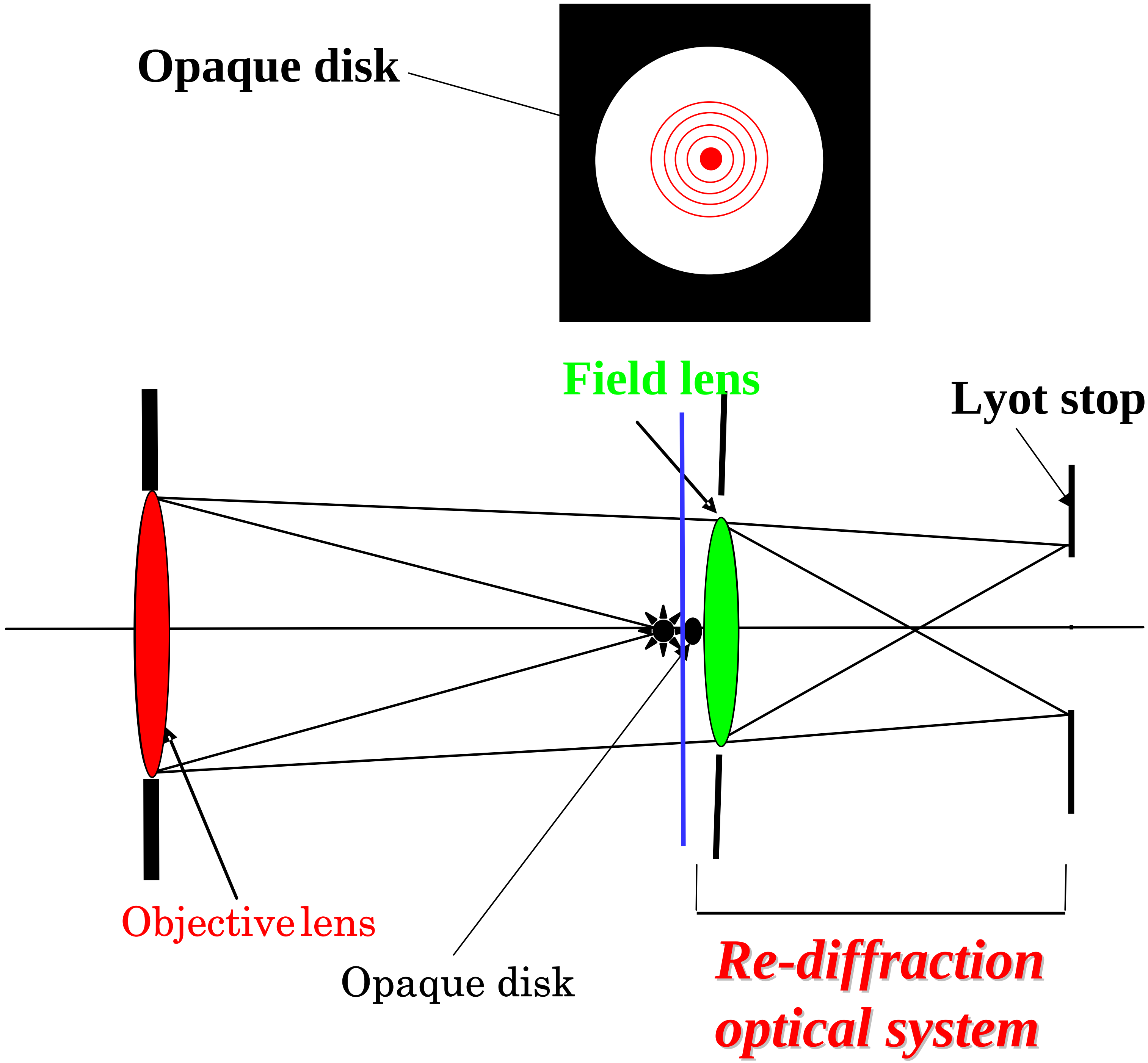
Developed by B.F.Lyot in 1934 for a observation of sun corona by artificial eclipse.

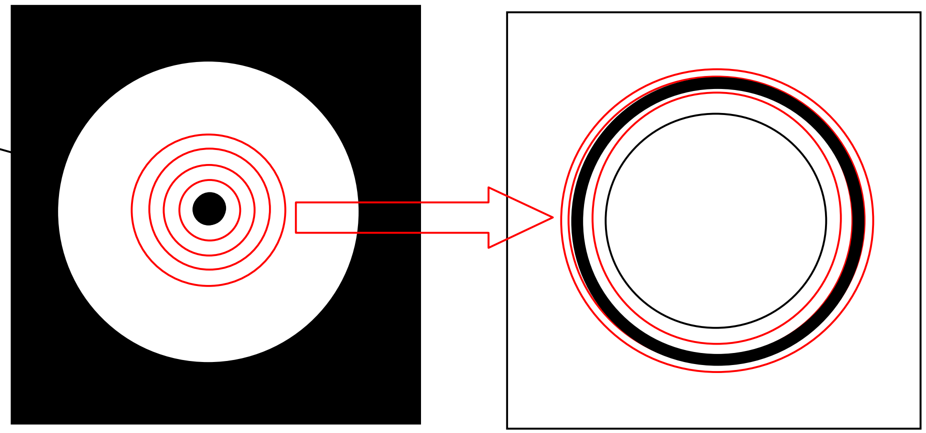
Special telescope having a re-diffraction system to eliminate a diffraction fringe.

Optical system of Lyot's corona graph

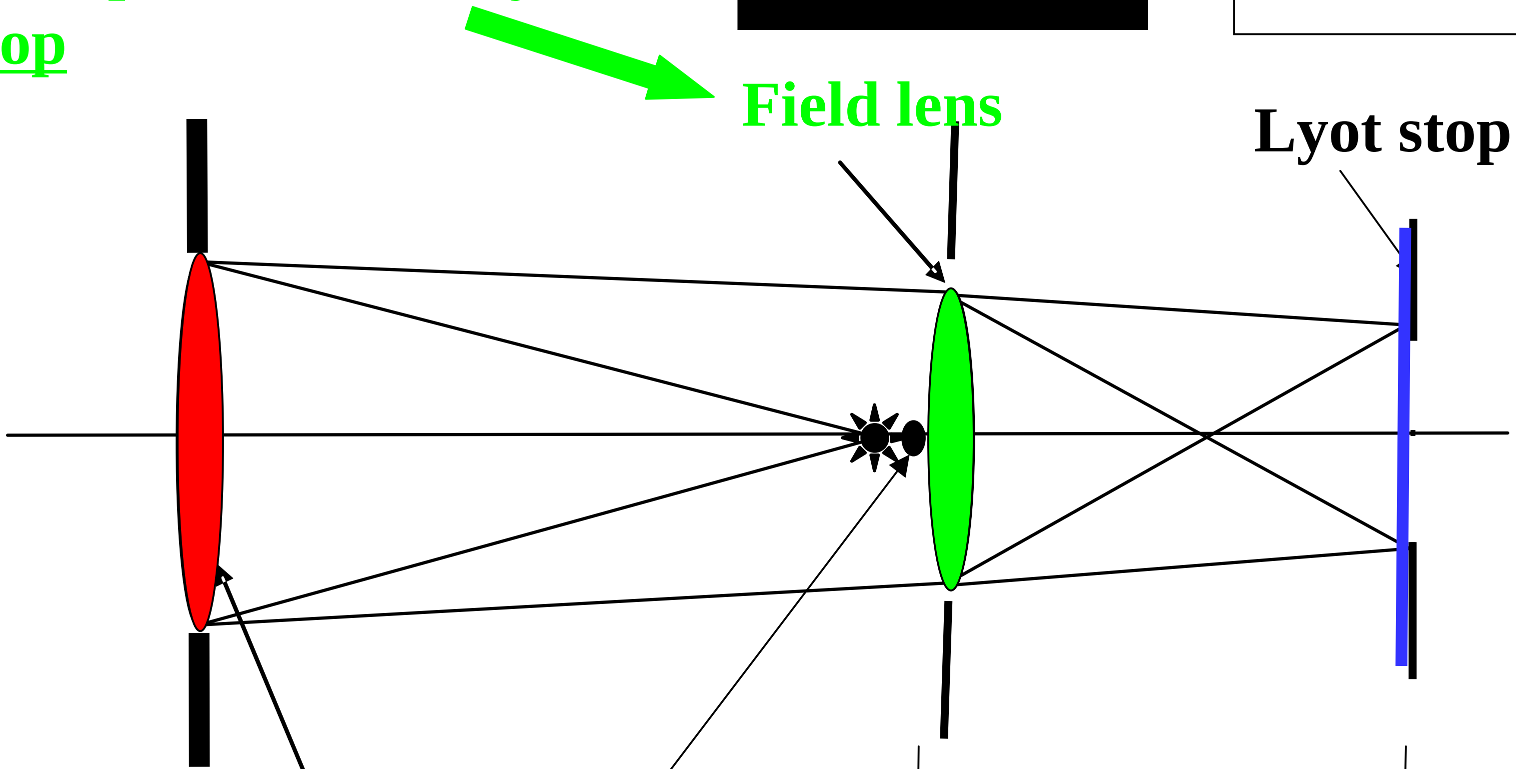


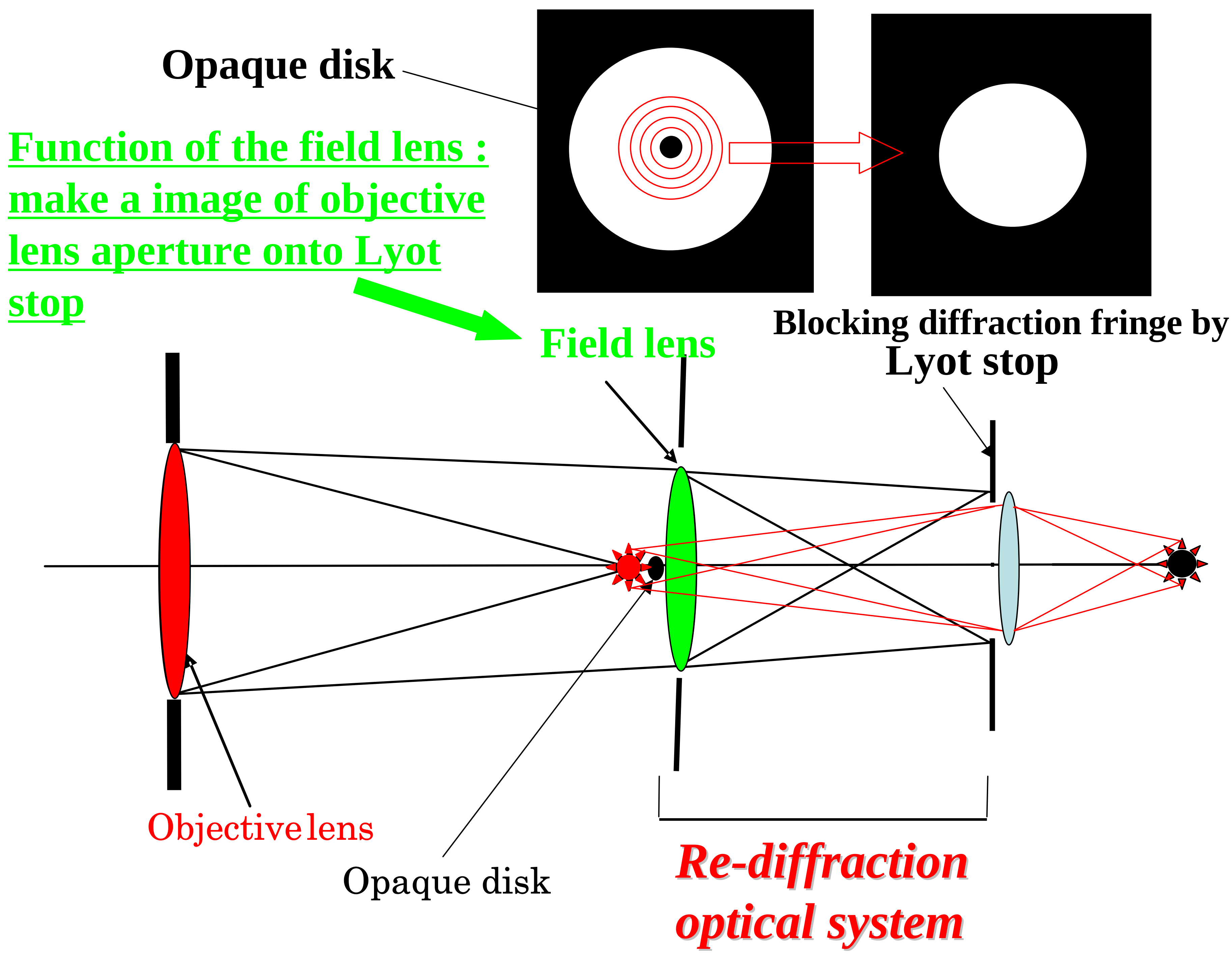
3. Re-diffraction optics system to eliminate the diffraction fringe


Opaque disk
Field lens
Lyot stop
Objective lens
Opaque disk
Re-diffraction
optical system



Function of the field lens : make a image of objective lens aperture onto Lyot stop



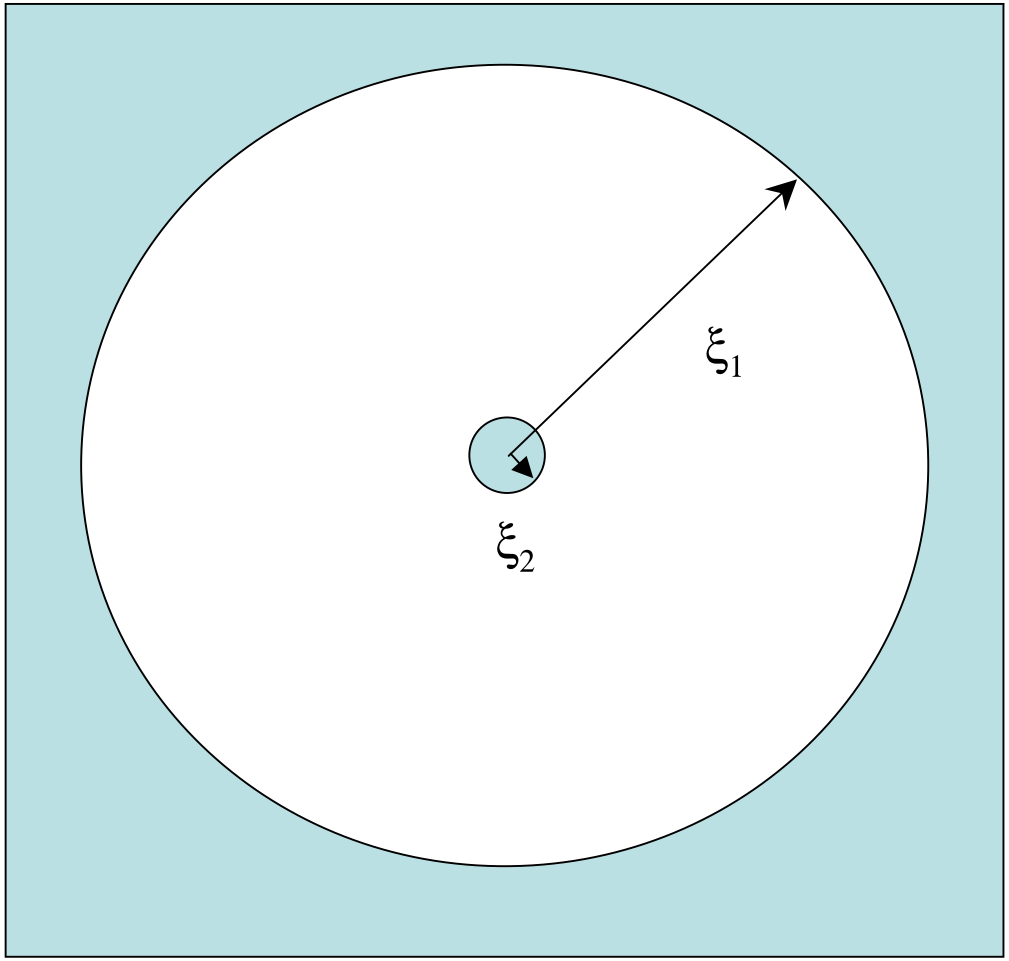

Opaque disk
Function of the field lens :
make a image of objective
lens aperture onto Lyot
stop
Field lens
Blocking diffraction fringe by
Lyot stop
Objective lens
Opaque disk
Re-diffraction
optical system

Intensity distribution on Lyot's stop by re-diffraction system is given by;

$$u(x) = \frac{1}{i \cdot \lambda \cdot f} \int_{\xi 1}^{\xi 2} F(\xi) \exp\left\{ -\frac{i \cdot 2 \cdot \pi \cdot x \cdot \xi}{\lambda \cdot f} \right\} d\xi$$

In here, F(ξ) is disturvance of the light on field lens

The integration performs ξ_1 and ξ_1

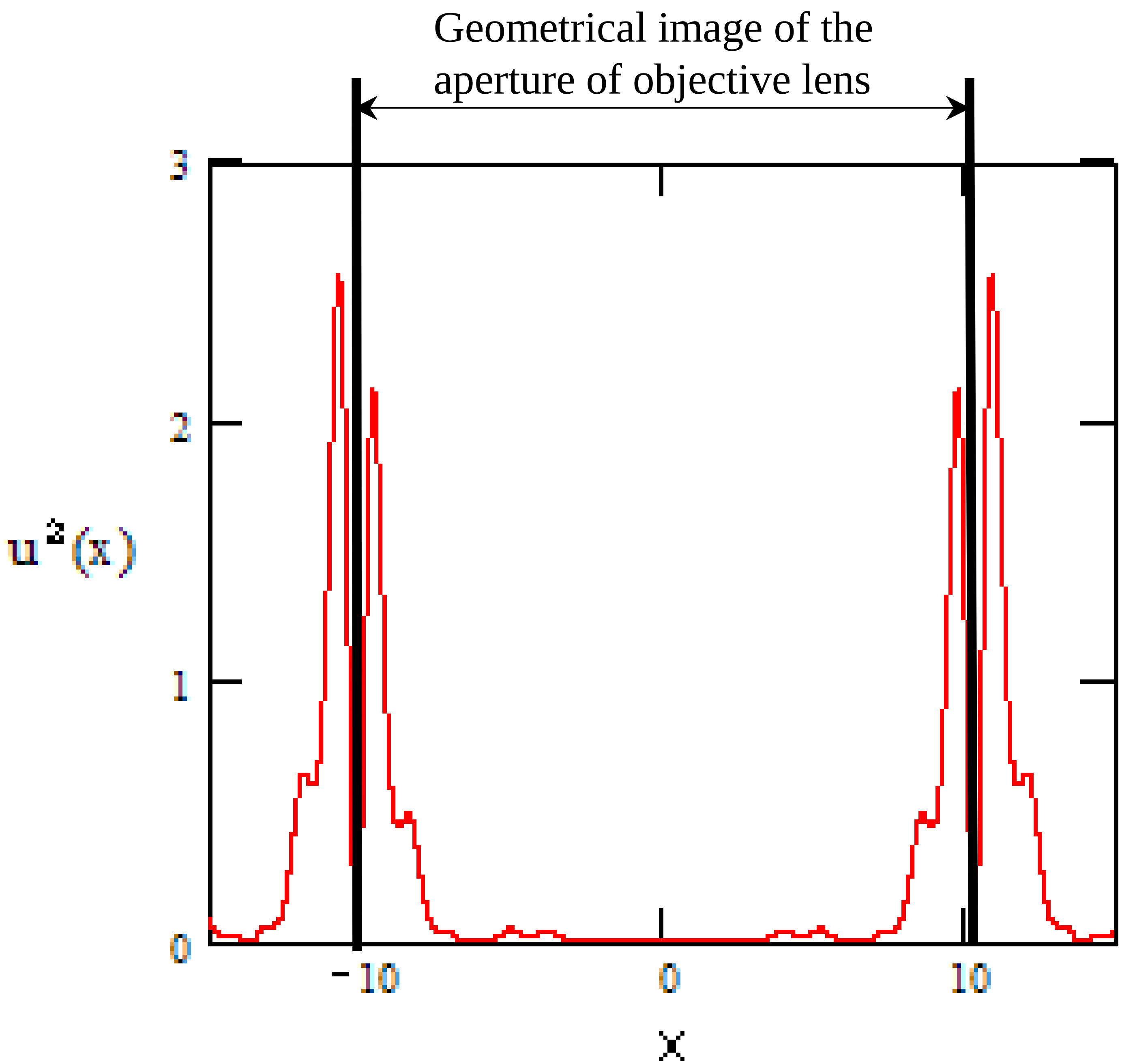


ξ_1: radius of

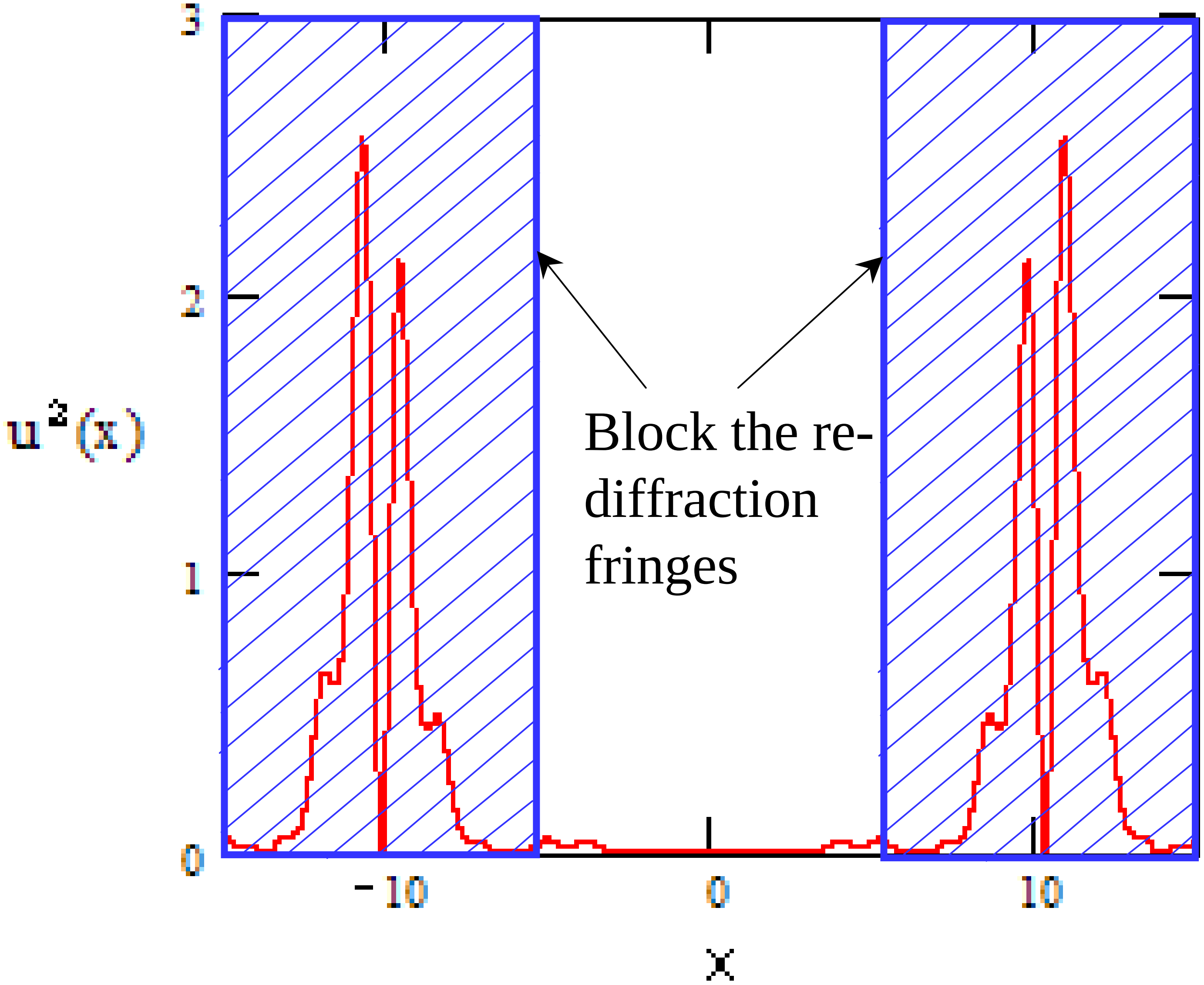
field lens

ξ_2: radius of

opaque disk



Geometrical image of the
aperture of objective lens
3
2
1
0
u²(x)
− 10
0
10
x

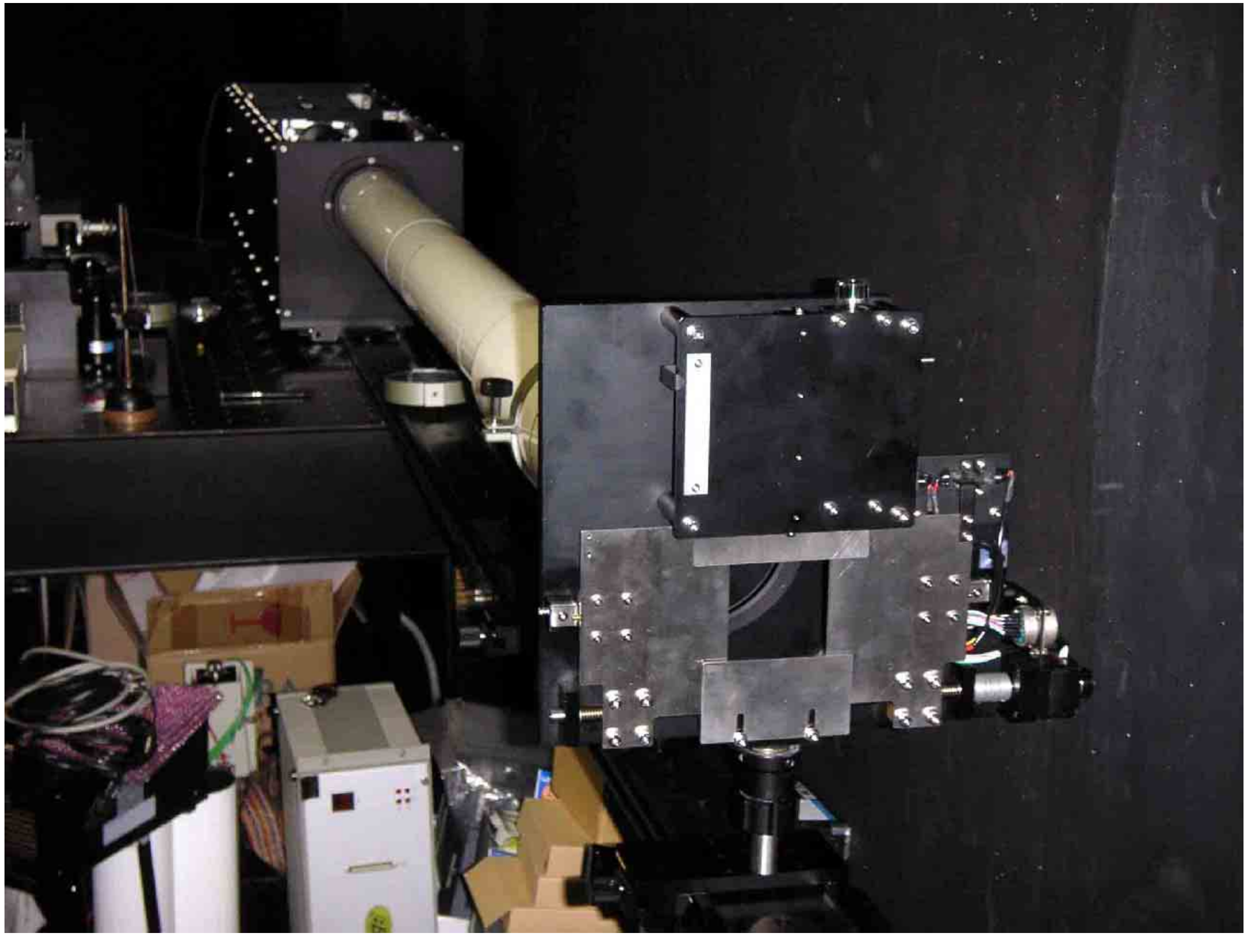


3
2
1
0
$u^2(x)$
Block the re-diffraction fringes
−10
0
10
x

Observation of the sun corona by coronagraph

4. Photographs of coronagraph

Front view of the coronagraph

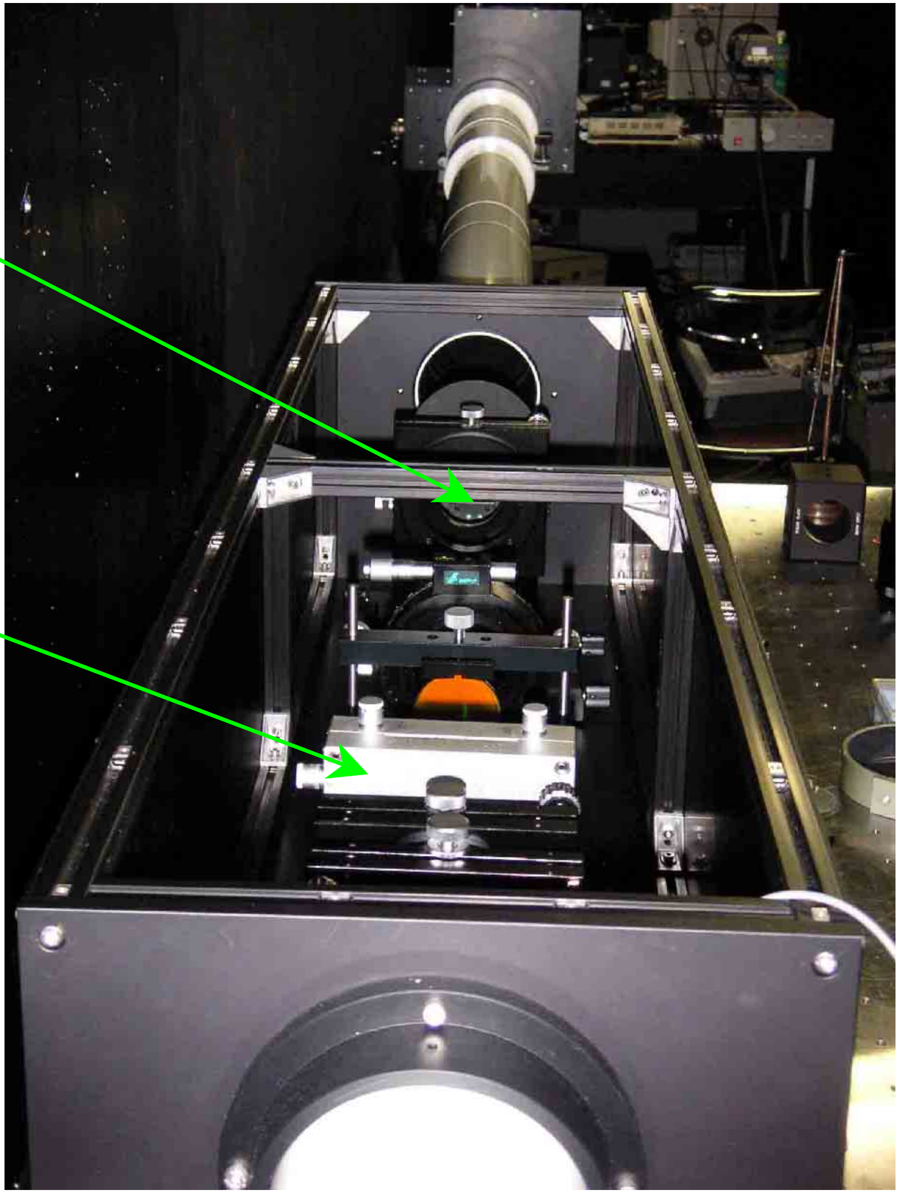


Objective lens with anti-reflection disk to block reflected light from opaque disk

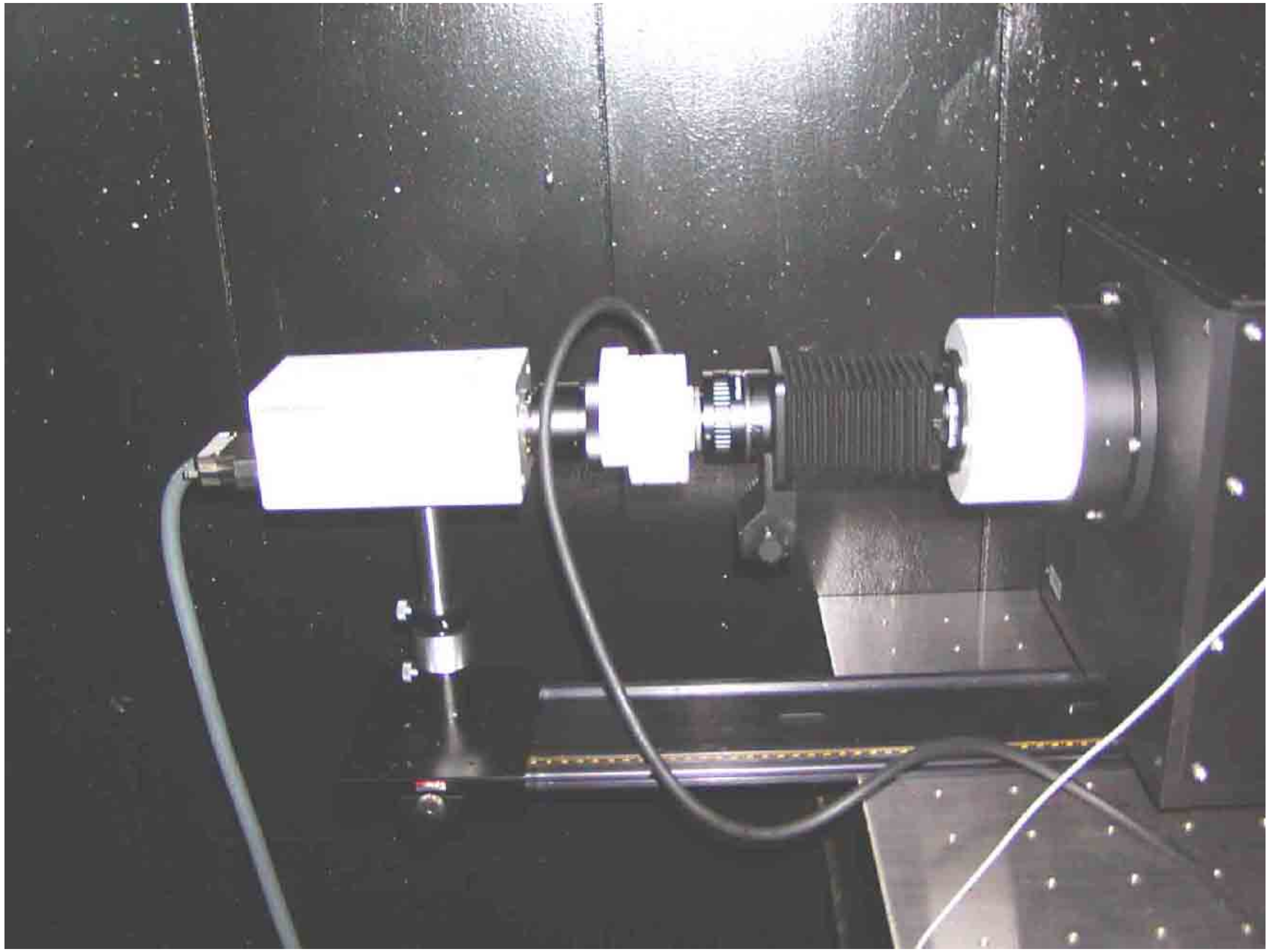
View from the back side

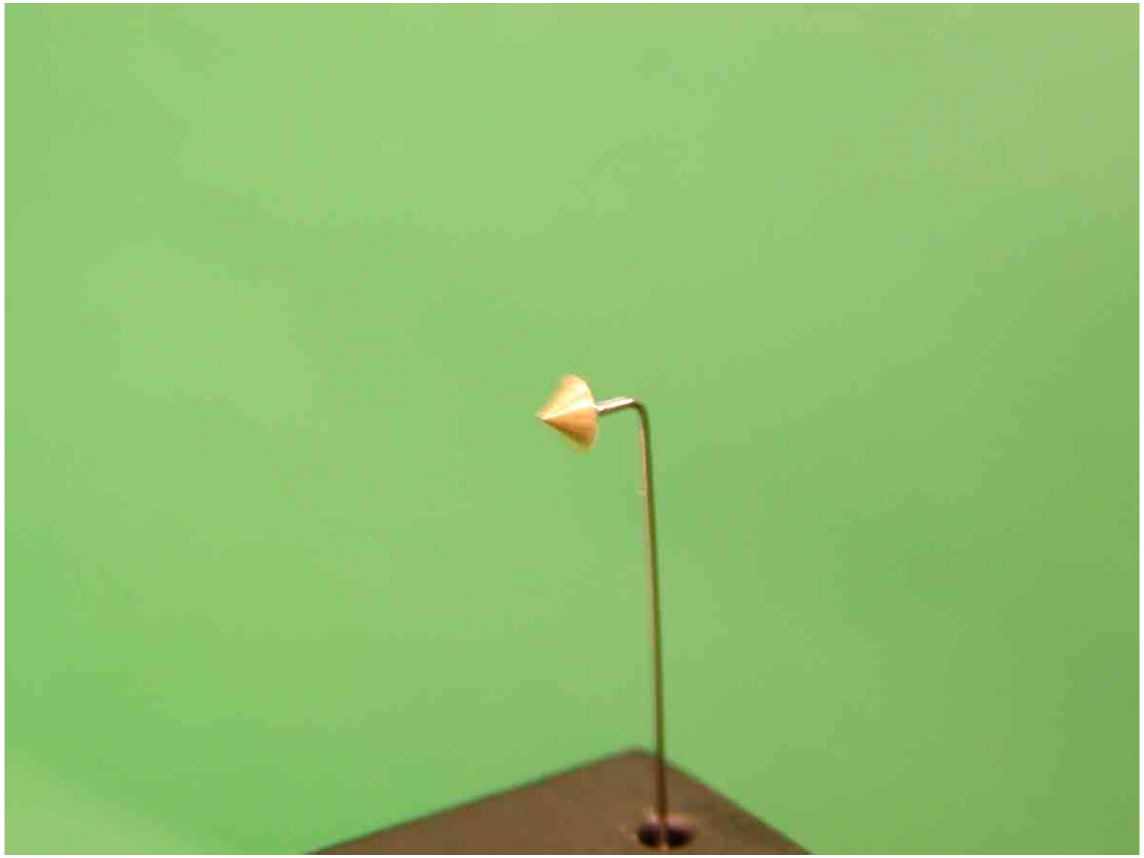
Field lens

Lyot's stop



Fast gated camera set on the final focusing point

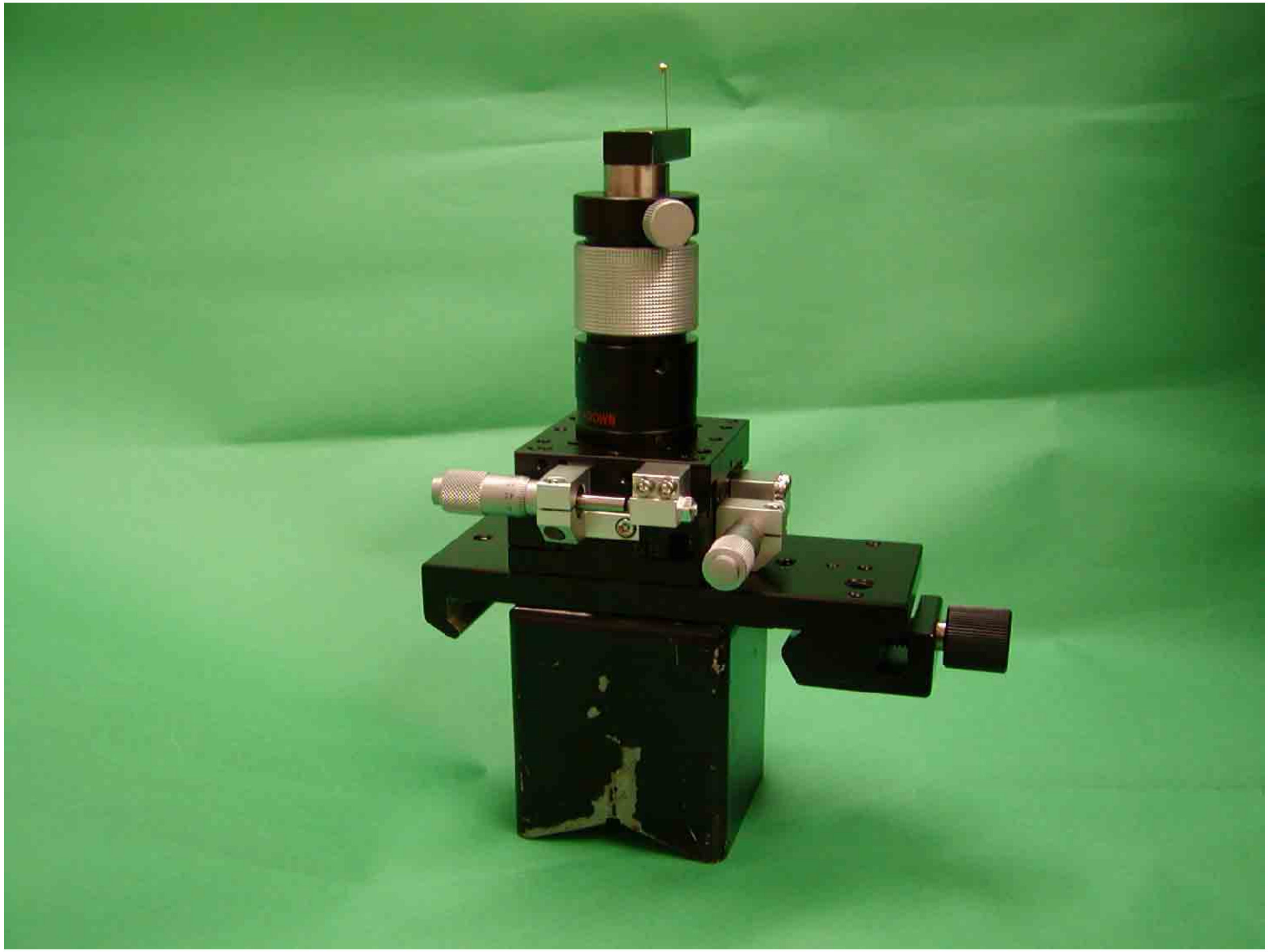




Zoom up of opaque disk.

Shape is cone and top-angle is 45°

Opaque disk assembly



5. Background sources

1. Scattering by defects on the lens surface (inside) such as scratches and digs.

2. Scattering from the optical components (mirrors) near by coronagraph.

3. Reflections in inside wall of the coronagraph. → Cover the inside wall with a flock paper (light trapping material).

4. Scattering from dust in air. → Use the coronagraph in clean room.

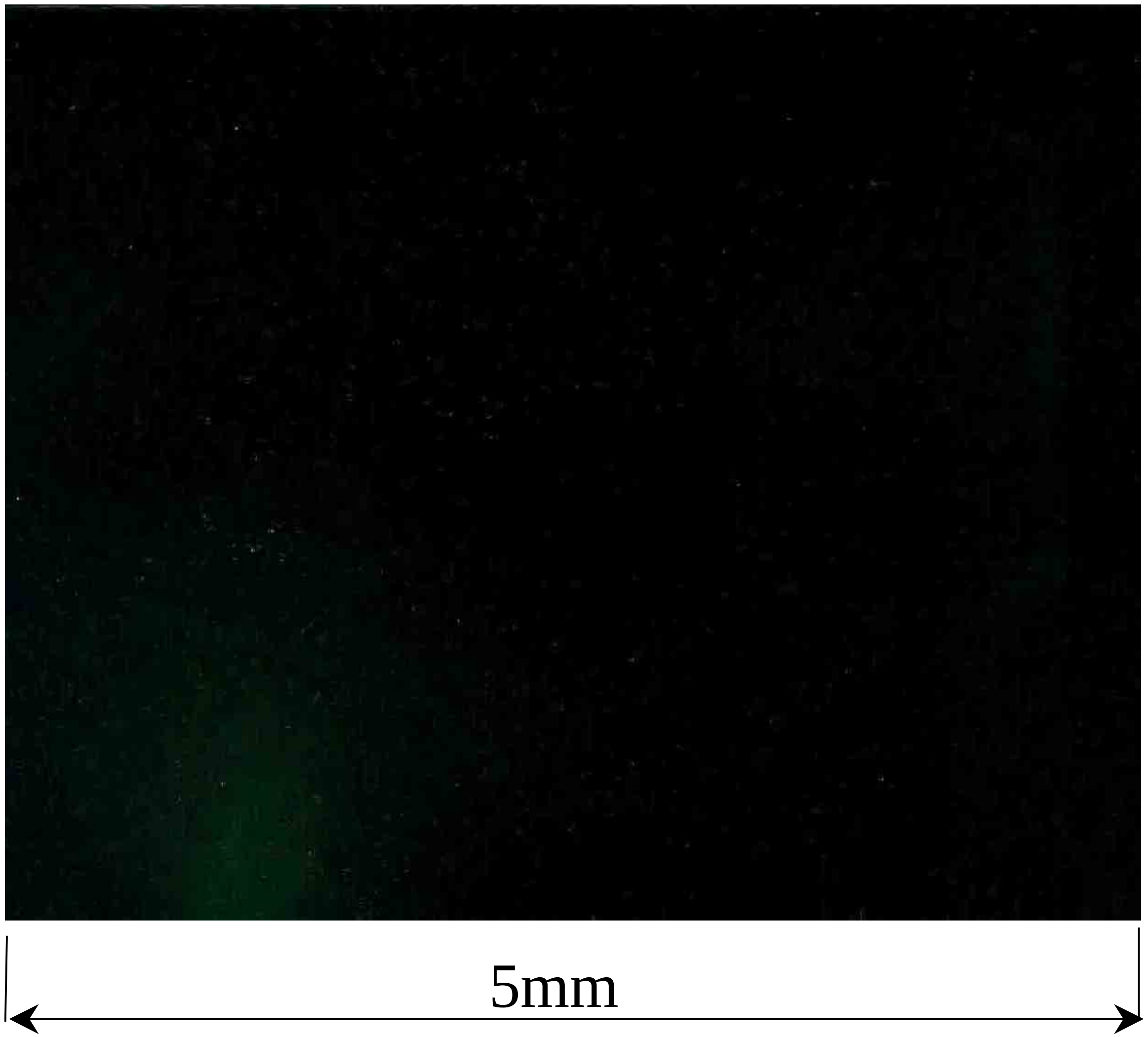
5-1. Scattering by defects on the lens surface such as scratches and digs.

With normal optical polishing, for example S&D 60/40 → scattered light intensity : about 10^{-3} times of input light intensity.

S&D 60/40 surface of the glass

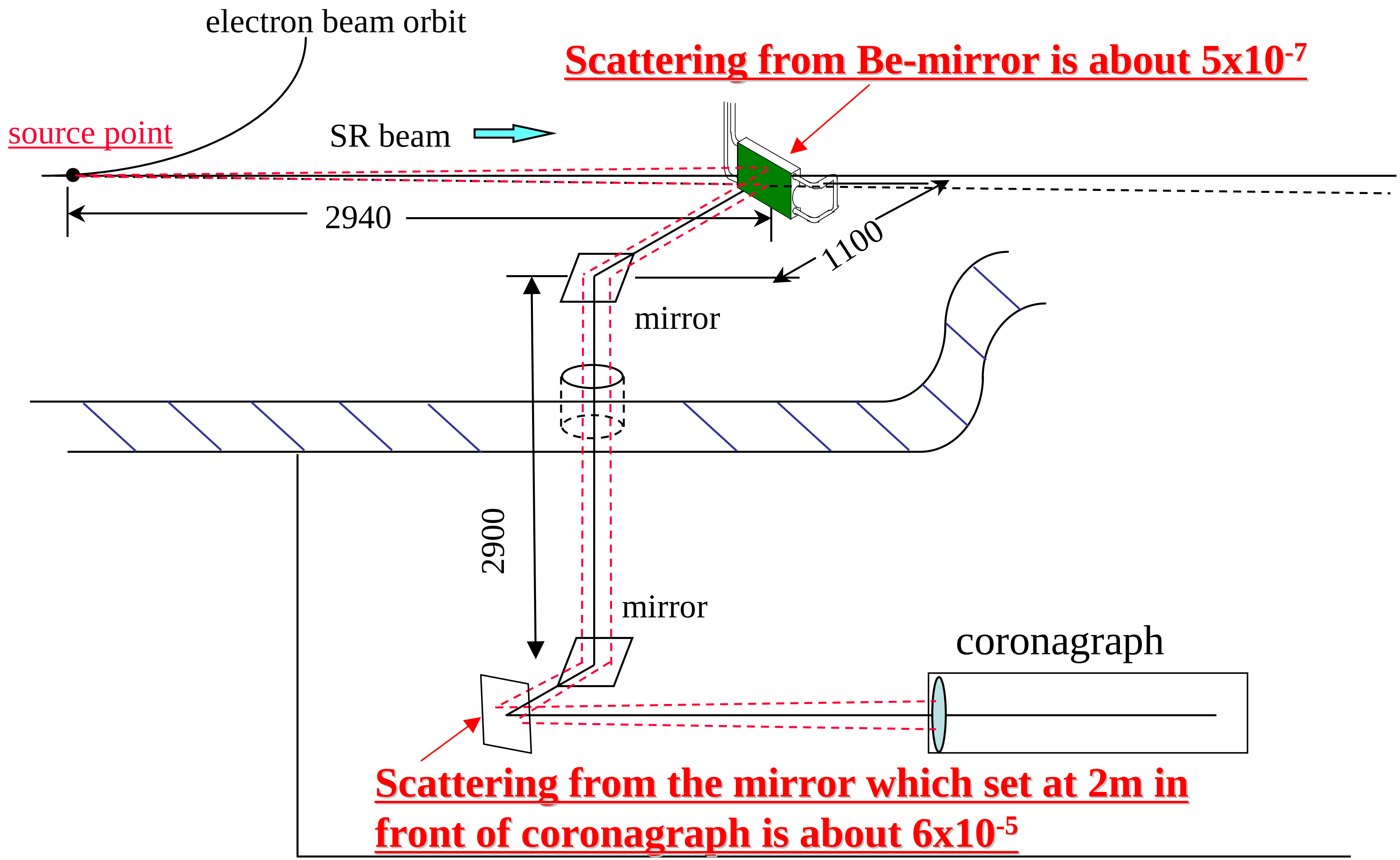
5mm

Result of careful optical polishing for the objective lens



5-2. Scattering from the optical components (mirrors) near by coronagraph

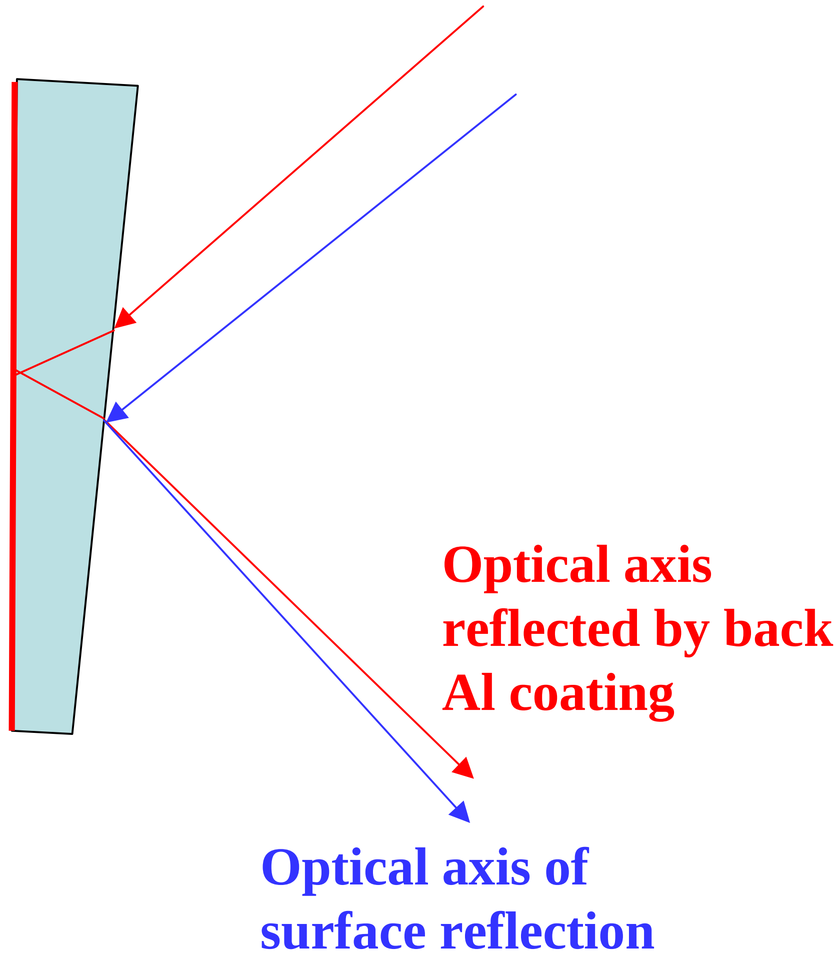
Set up of SR monitor at the Photon factory



Low scattering noise mirror for optical path

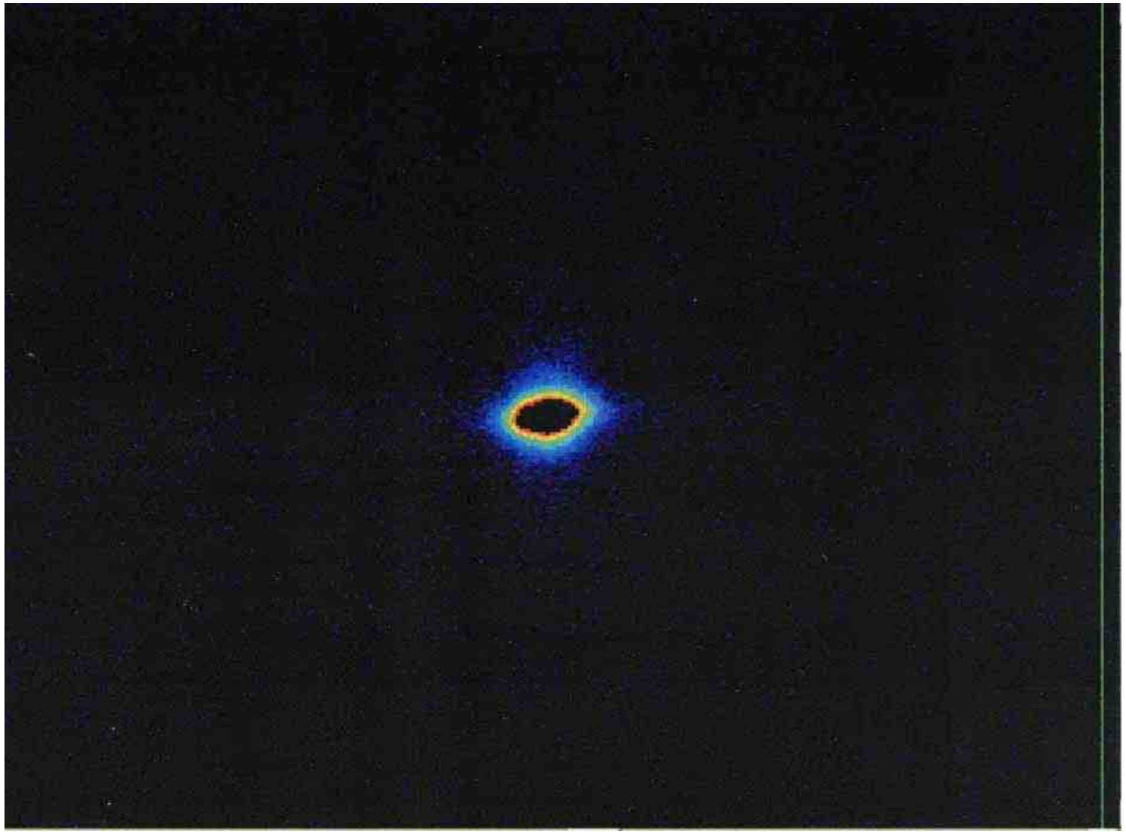
To escape from scattering noise from mirrors in the optical path, we used back-coated mirror with well polished optical flat having a small wedge angle.

The wedge angle is necessary to separate surface reflection

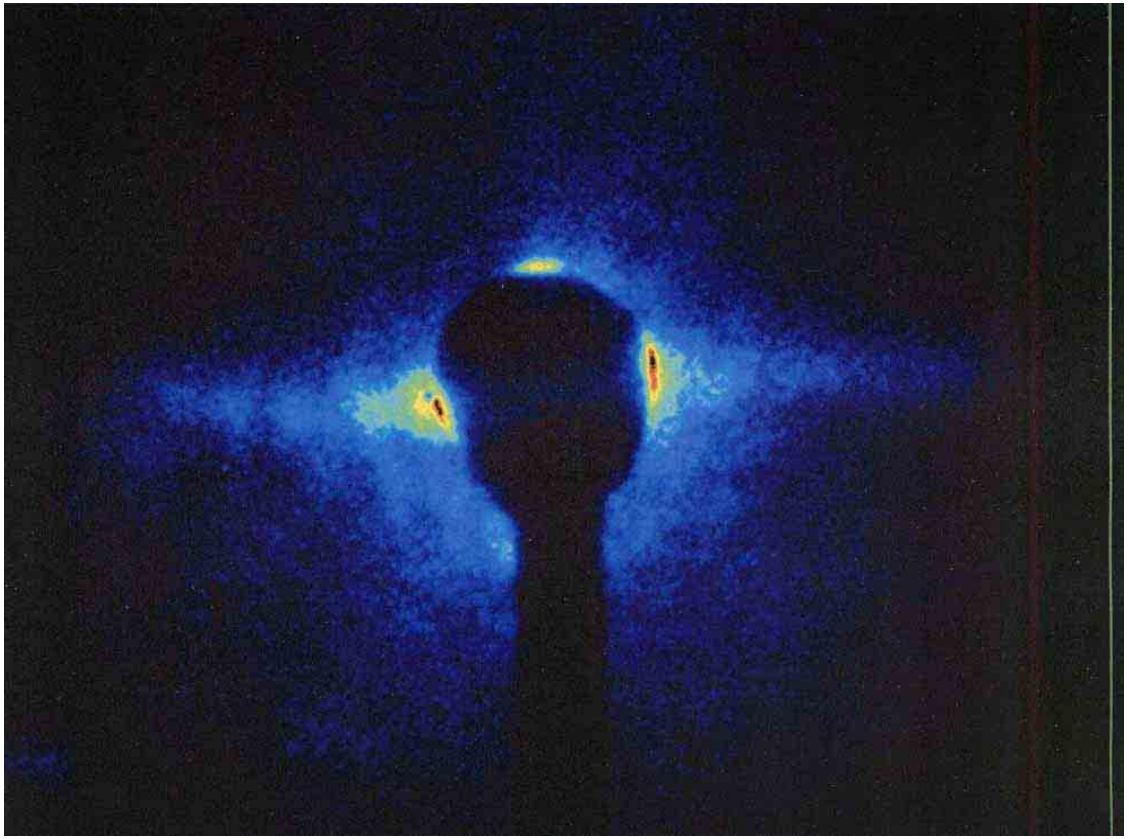


6. Observation of beam tail (halo) at the Photon Factory, KEK

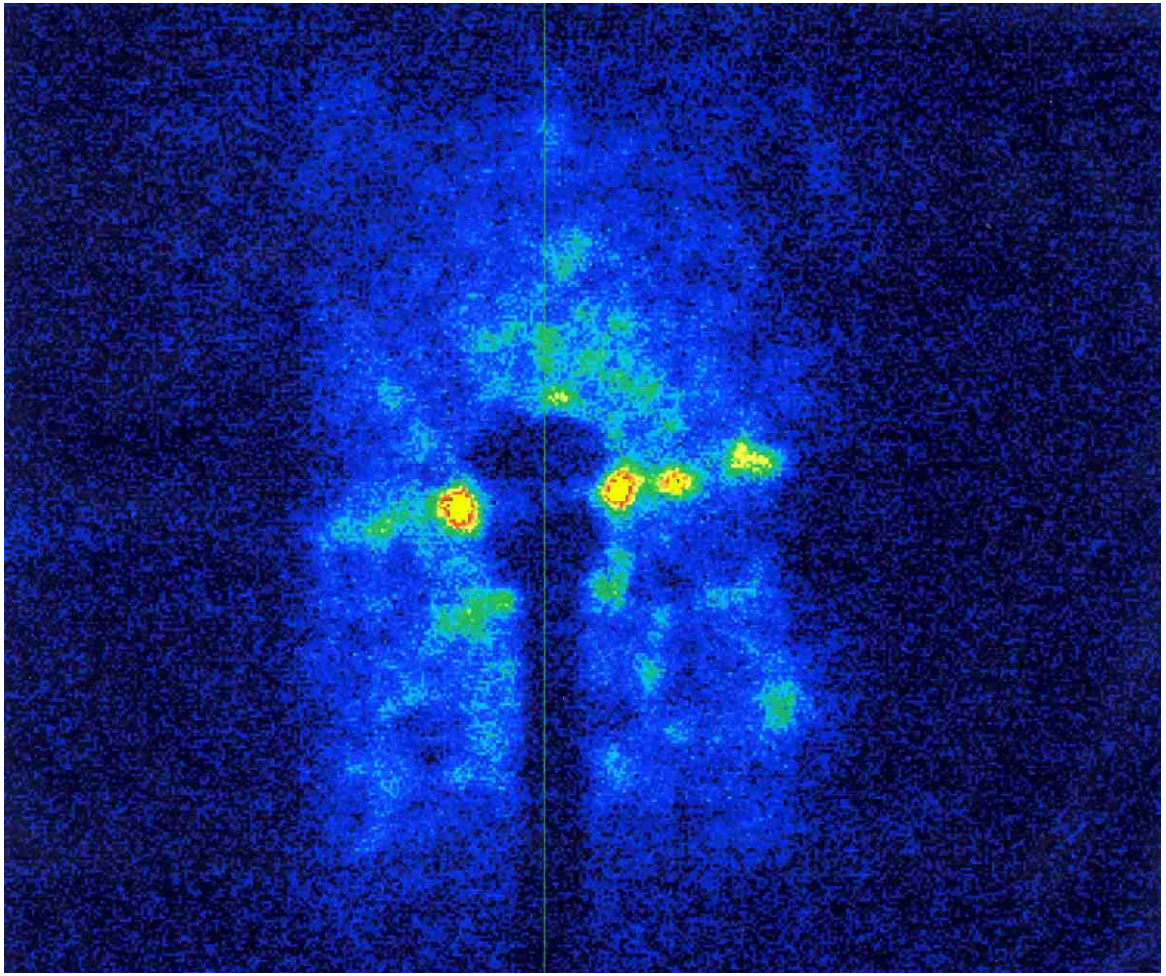
Beam profile



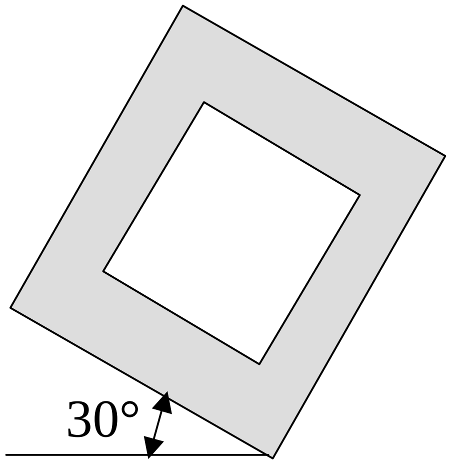
Beam tail



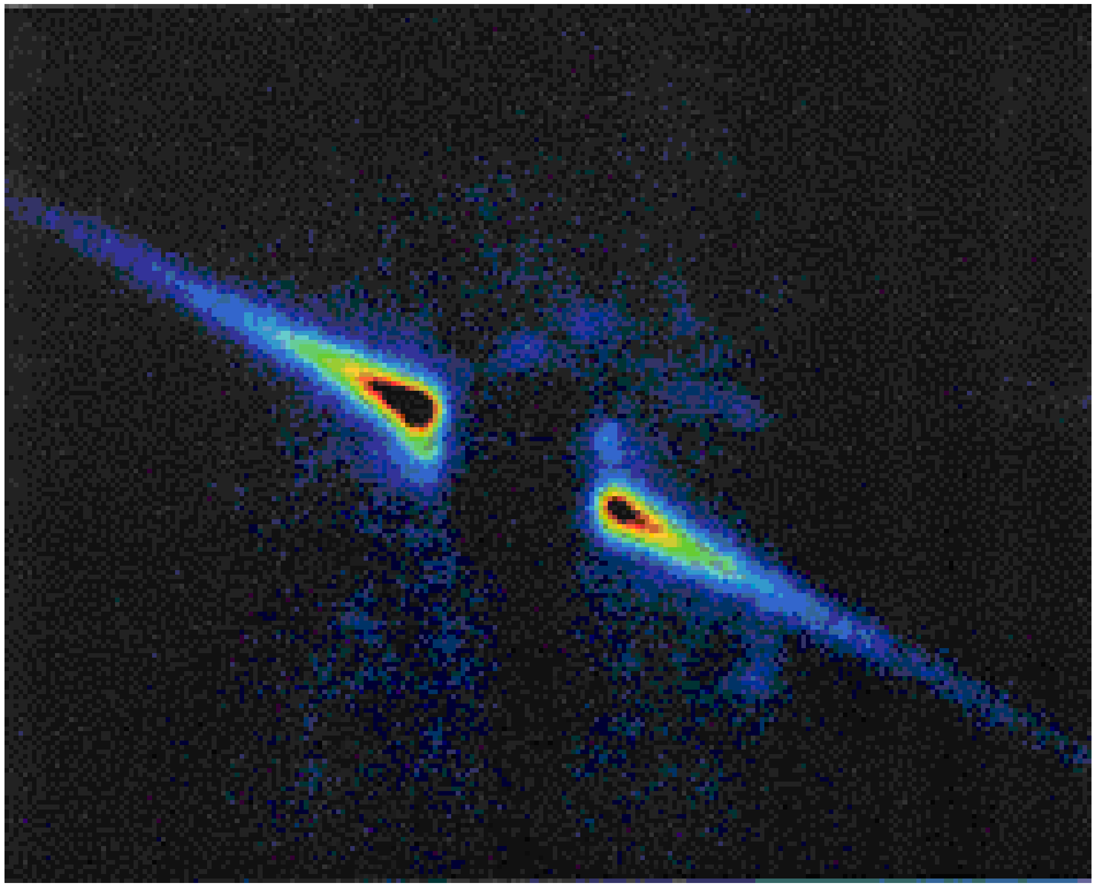
Intentionally spread some dust on the mirror in 2m front of the coronagraph



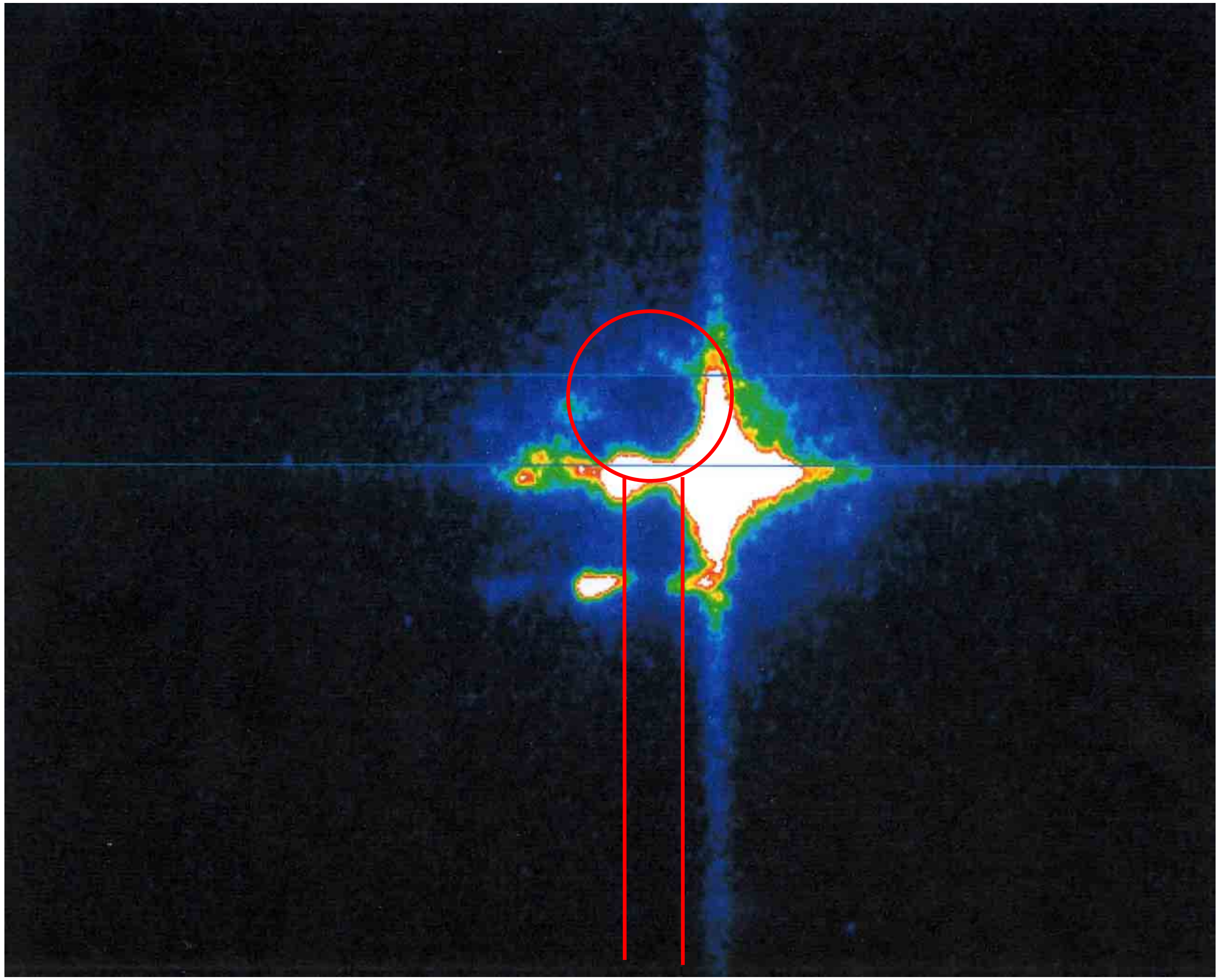
Diffraction tail observed without Lyot's stop



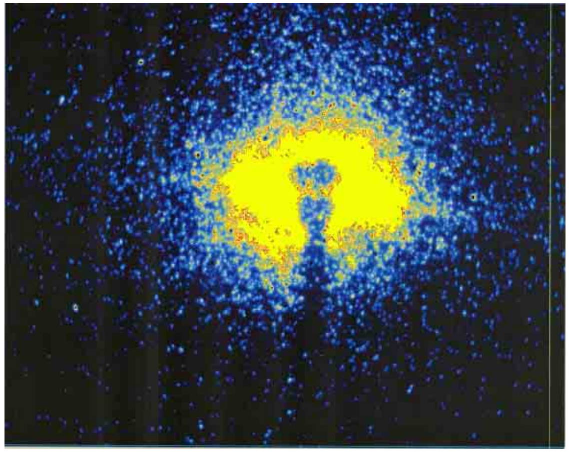
Entrance pupil is intentionally rotated by 30º to recognize diffraction tail easily.



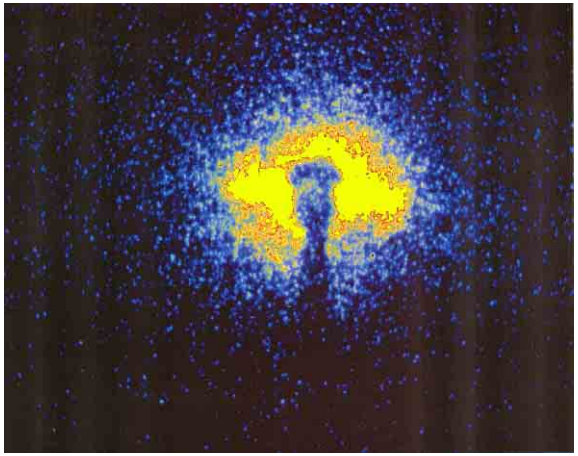
Move the opaque disk slightly to show the edge of central beam image (diamond ring!)



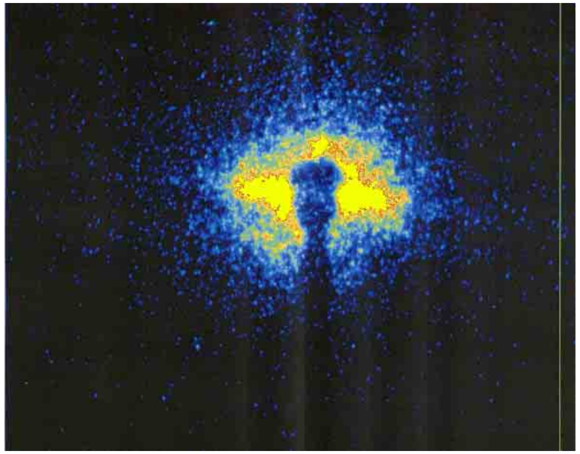
Beam tail images in the single bunch operation at the KEK PF measured at different current



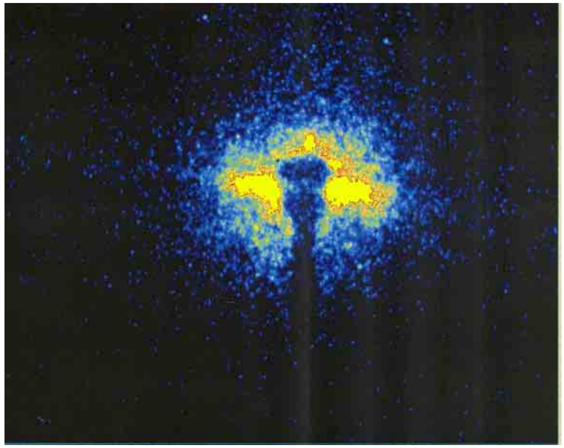
65.8mA



61.4mA

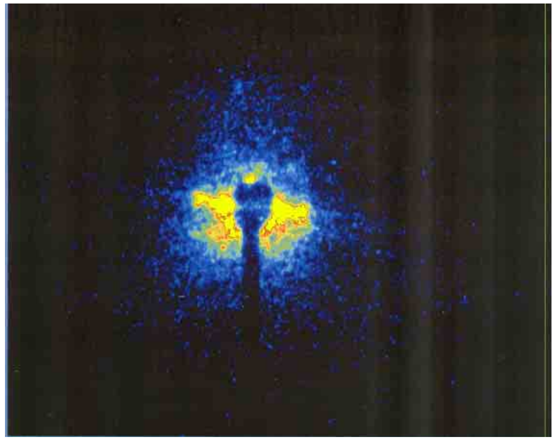


54.3mA



45.5mA

35.5mA

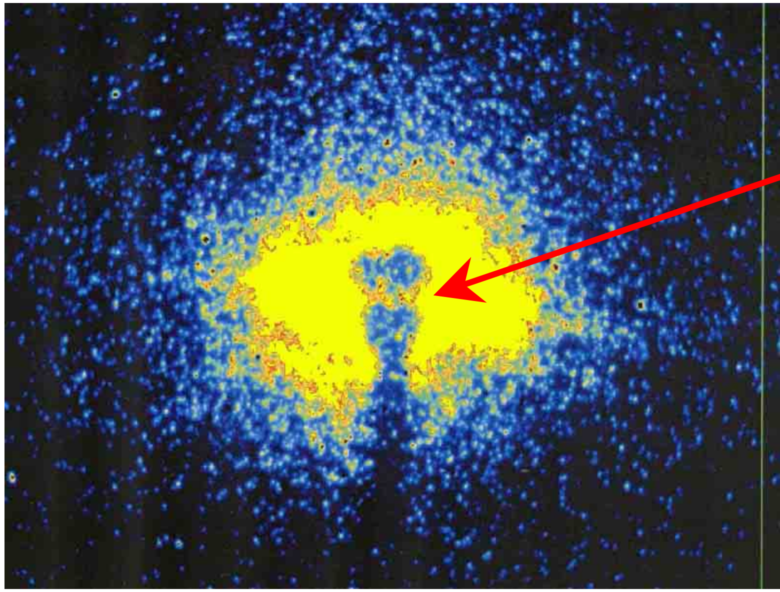


396.8mA
Multi-bunch
bunch current 1.42mA

Observation for the more out side

Single bunch 65.8mA

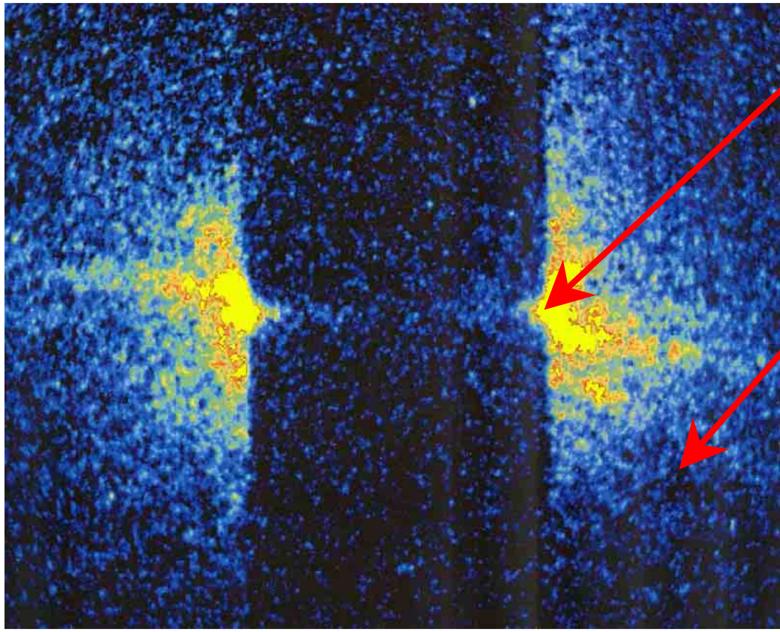
Exposure time of CCD : 3msec



Intensity in here : $2.05x10^{-4}$ of peak intensity

Far tail

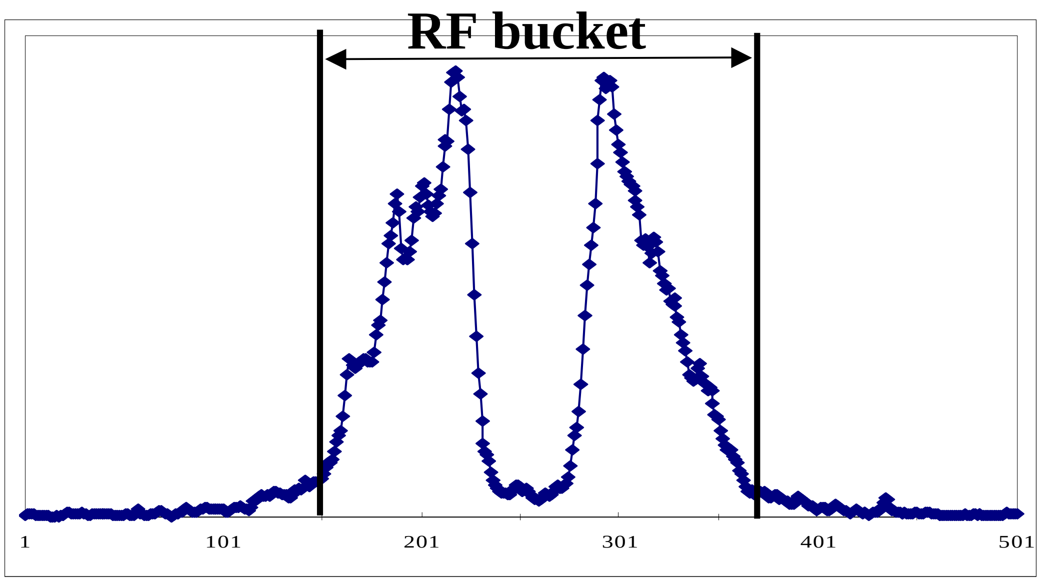
Exposure time of CCD : 100msec



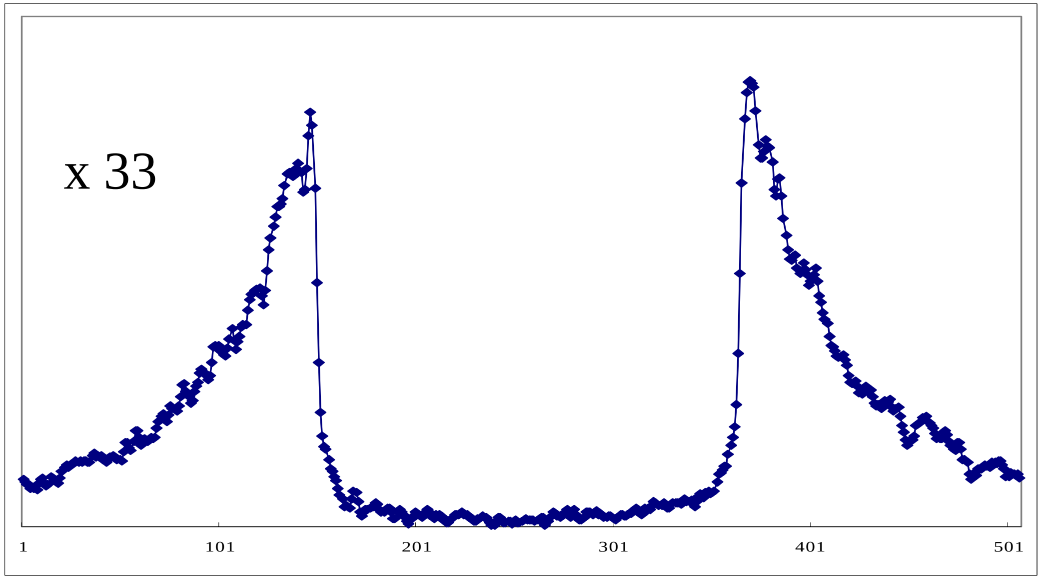
$2.55x10^{-6}$

Background leavel : about $6x10^{-7}$

Strong tail in RF bucket



Weak tail in outside of RF bucket



7. Conclusions

- The coronagraph was designed and constructed for the observation of weak object (such as tail and halo) surrounding from central glare of the beam.
- Optical polish of the objective lens is key point to realize good S/N ratio, and we reached ratio of background to peak intensity 6×10^{-7}.
- Spatial resolution is about 50μm
- By using the coronagraph, we observe beam tail at the photon factory storage ring. As results;

  1. a strong beam tail was observed in inside of RF bucket
  2. a weak, and wide-spread tail is observed in outside of RF bucket.