

# Evaluation of mirror scattering component for solar observation satellite Hinode/XRT using partial solar eclipse and limb events

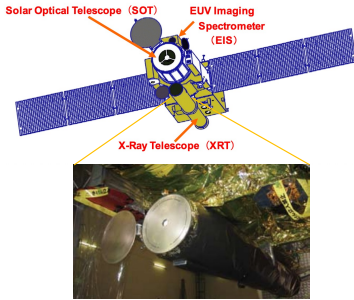
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## outline

We studied mirror scattering components using partial solar eclipse data and limb flare data taken with XRT onboard Hinode. We conducted comprehensive investigations for both partial solar eclipses and limb flares by analyzing data from 2010 to 2023. With partial solar eclipse data, we can investigate pure scattered components by utilizing the portion where the Moon obscures the Sun. In particular, by utilizing events where active regions are partially obscured by the Moon, we can study the scattered components in the vicinity (approximately a few tens of arcseconds) of bright regions on the solar surface. We also investigated the scattered components using limb flare data. In limb flare data, coronal structures of the Sun are overlaid with the scattered components, making evaluation in that region challenging. On the other hand, it is possible to determine the scattered component in regions far away from the flare core. We evaluated the mirror scattering over a wide off-axis angular range by analyzing these two types of data.

## Hinode / XRT



☐ Satellite is designed to study the behavior of dynamic space plasma and its effects on the Earth by observing explosions and heating phenomena that occur on the Sun.

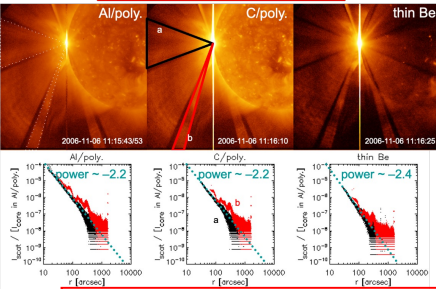
Outline of XRT	
Optics	Grazing incidence optics(Wolter type-I)/diameter 34cm /focal length 270cm
Wavelength	4~300Å
Filter	9 X-ray analysis filters
Detector	Back illuminated CCD(2048 x 2048 pixel)
Spatial resolution	1arcsec/pixel
Field of view	35' x 35' (apparent diameter of the Sun ~32')

Sun shield attached to the entrance of the XRT telescope. The narrow arc-shaped gap around the perimeter is the soft X-ray aperture.

## Research Background

### Pattern of Scattered X-ray

R.Kano(NAOJ)



☐ Scattering intensity decreases with power law  
 ➢ Power:  $\sim -2$   
 ➢ Relative intensity:  $10^{-4} \sim 10^{-8}$  @  $10'' \sim 1000''$   
 ☐ Azimuthal direction patterns are made by the sun shield aperture

No study has ever statistically investigated the scattering performance of XRT mirrors.

- ☐ Trend of scattering components
- ☐ Comparison with estimated mirror performance

This study

## Analysis Event

Scattered components (SCs) were analyzed for two types of events

Event	No.	Date	Exposure[s]	Filter	Binning
Eclipse event	1	2011/11/04	4.0	Thin Al/poly/open	2
	2	2011/11/04	4.0	#	2
	3	2012/11/13	1.0	#	2
	4	2014/04/29	1.0	#	2
	5	2017/08/21	0.707	#	1
	6	2019/01/06	11.3	#	4
Limb flare event	7	2019/01/06	11.3	#	4
	8	2019/12/26	16.0	#	4
	9	2021/06/20	2.83	#	4
	1	2011/04/17	4.0	#	2
	2	2017/01/11	8.0	#	2
	3	2017/09/20	4.0	#	4
4	2022/06/08	1.0	#	4	
5	2023/06/01	1.0	#	4	
6	2023/06/20	1.0	#	4	

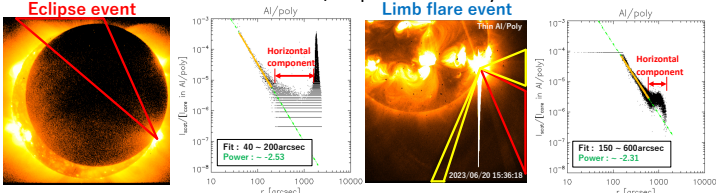
☐ Only SCs can be observed by taking advantage of the shadowed area where the moon obscures the sun.

☐ SCs in the vicinity can be determined from the bright region on the solar surface.

☐ SCs + corona structure overlap near the solar disk, difficult to evaluate.

☐ It is useful to know the SCs in the region with a large separation angle from the flare core.

### Method of limb/eclipse events analysis

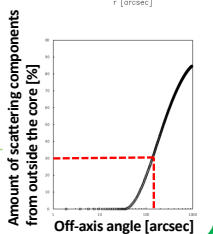


The scattering profile is a power law, only the linear part is needed for fitting. However, as the intensity decreases, the plot becomes more uneven(not linear).

The cause was found to be the mixing of scattering from other areas.

- Investigate the amount of mixing ratio from outside
- ☐ As the off-axis angle increases, the amount of scattering components from outside the core becomes more significant.
- ☐ Horizontal component is not significant and linear at mixing rate of 30% or less.

Make a limit of fitting range

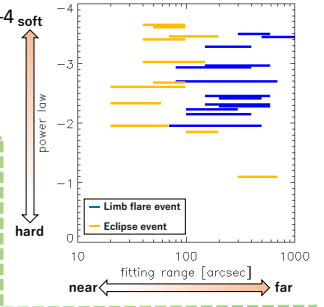


## Analysis & Results

### ① Relation between fitting range and power law

☐ Wide range of power law from -1 to nearly -4  
 ➢ We found that there is no correlation between fitting range and power law.

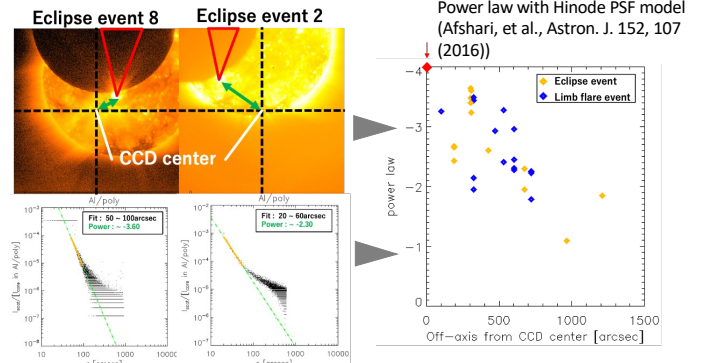
➢ What makes the power law different?



### ② Investigate the cause of the difference in power law

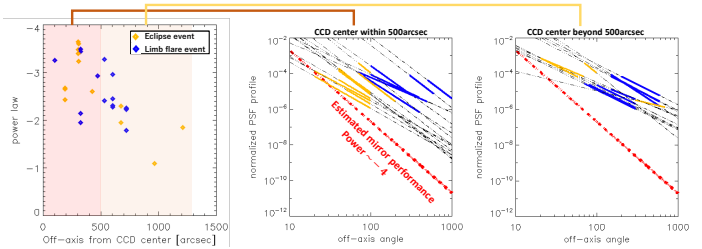
For events with scattering components taken in the same direction but different distances from the active region to the mirror optical axis:

The power law was very different between the two events, so we looked for trends for the other events as well.



Scattering components created by bright regions located away from the mirror optical axis tend to make power law hard.

### ③ Comparison of estimated and actual mirror performance



☐ The PSF wing of the mirror performed from shape data has a power law slope of  $-4$ , whereas those from XRT observations show harder slopes (less than  $-4$ ) for all events.

☐ Larger amount of scatter than expected; More pronounced for off-axis events.

☐ Although we could not evaluate the area around the PSF core, the scattering wing area showed more scattering than expected compared to the estimated mirror performance, and power law was hard.

## Summary and Future Prospects

☐ Power law tends to become harder as the core moves away from the center of the mirror optical axis.

☐ The PSF core could not be evaluated, but the scattering wing portion had more scatter and a harder power law than the estimated mirror performance.

☐ Investigated how much the deviation of power law affects the determination of physical quantities.

☐ Establish a method to accurately evaluate/eliminate the amount of scattered X-rays mixed in from the bright region.