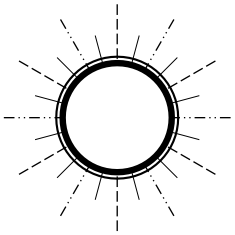
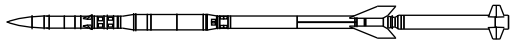
NAOJ Future Symposium : Science Roadmap of NAOJ
November 7 and 8, 2023

Poster [06]

Solar flare X-ray focusing imaging spectroscopy

state-of-the-art solar flare observations with spatial, temporal and energy resolutions in X-rays





Noriyuki Narukage (NAOJ)

FOXSI sounding rocket team members

PhoENiX WG members

Science Goal

of solar flare X-ray focusing imaging spectroscopy

- The overarching goal is
  to understand the universality of plasma acceleration to high-energies and how such phenomena on the Sun and stars can impact planetary environments and habitability.

  - Scientific Key Words

    As the Plasma Universe

    - **Magnetic Reconnection**
    - **Plasma Heating**
    - **Particle Acceleration**

    Impacts to Environments

    - **Space Weather**
    - **Habitability**

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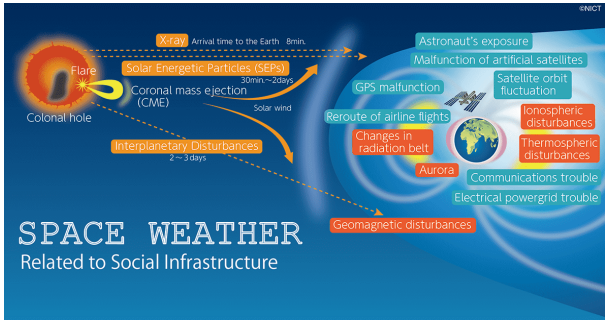

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Why Solar Flare Observation
– Significance of solar flare study –

[Plasma physics]

Natural laboratory of plasma

- **Magnetic reconnection**
- **Particle acceleration**

[Unique observation target]

The closest star

- **Solar phenomenon can be observed with wide field of view and with spatial and temporal resolutions**

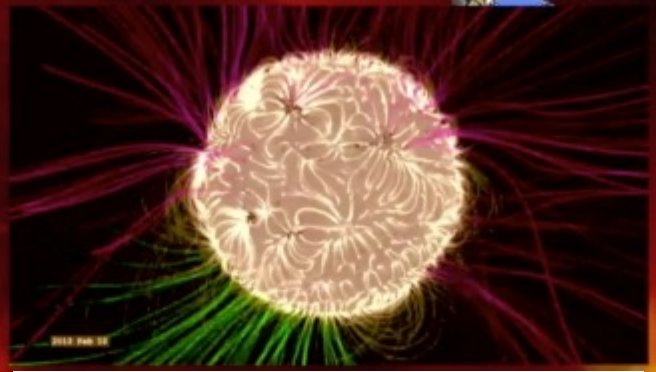
[Impacts on the Earth and social environments]

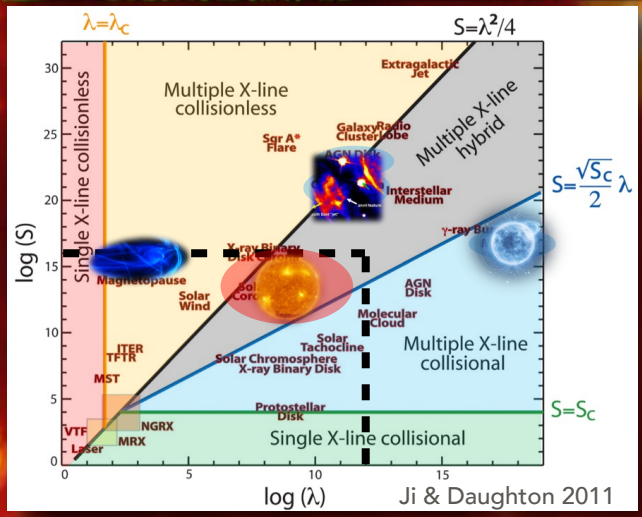
The mother of the Earth

- **Evolution of life (cosmic rays)**
- **Space weather**

[As a star]

- **Reference of other astrophysical objects**





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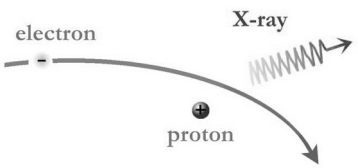
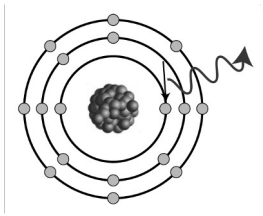
X-ray Focusing Imaging Spectroscopy

Bremsstrahlung (continuum)



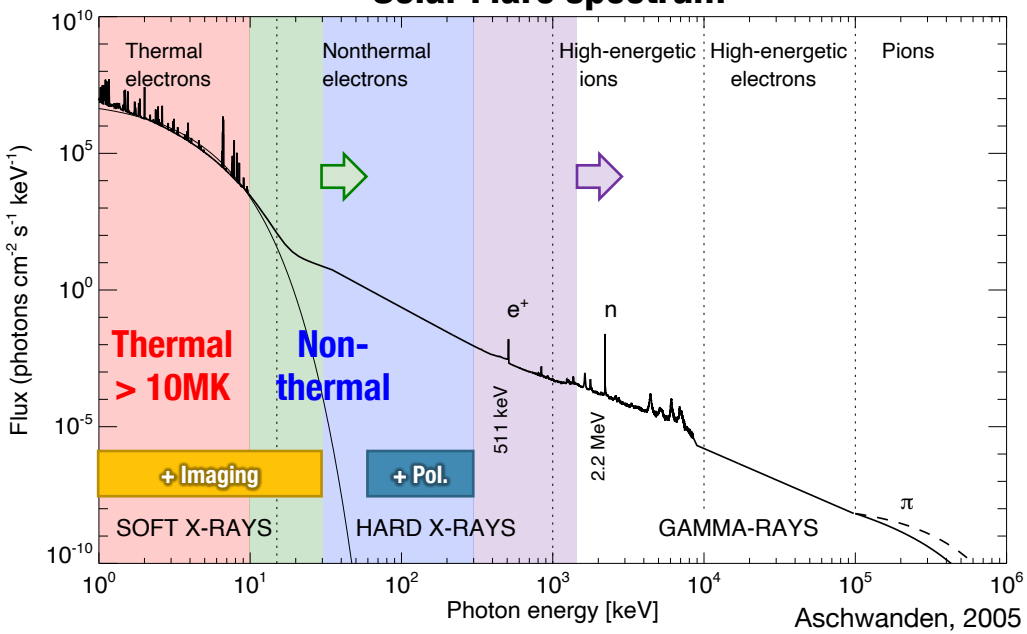
Responds to rapid temperature changes

Emission lines

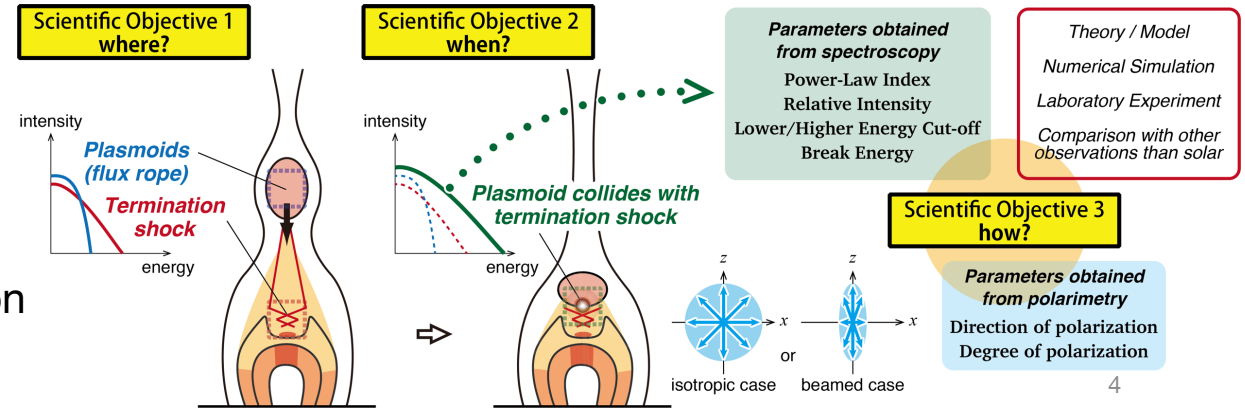


Information on abundance etc.

Solar Flare spectrum



To achieve the science goal, X-ray focusing imaging spectroscopy is the key observation, since it can **track the evolution of spatially resolved X-ray spectrum** which contains rich information on the high energy plasma generated by solar flares.



Required technologies

for solar flare X-ray focusing imaging spectroscopy

Optical blocking filter

Metal 3D printed pre-collimator

High-precision X-ray grazing incidence mirror

Soft X-ray CMOS detector

Camera electronics

Hard X-ray CdTe detector

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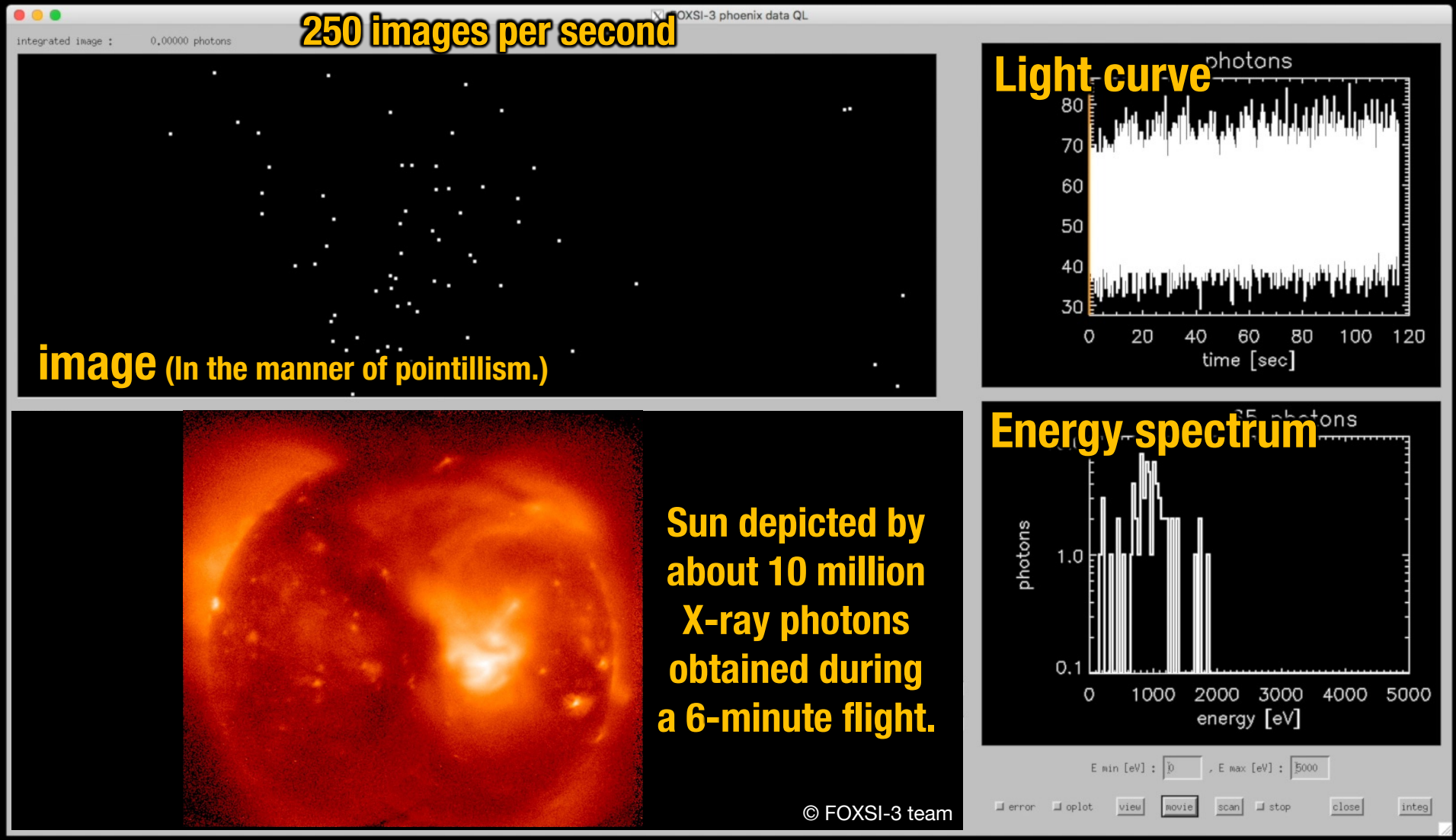
Soft X-ray data acquired by FOXSI-3 (launched in 2018)

High-speed continuous imaging at 250 images per second (4 ms exposure)

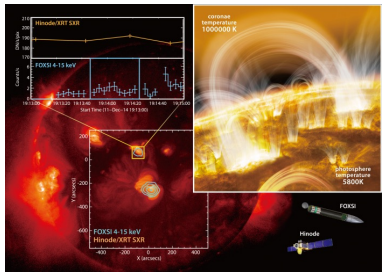


Sun depicted by about 10 million X-ray photons obtained during a 6-minute flight.

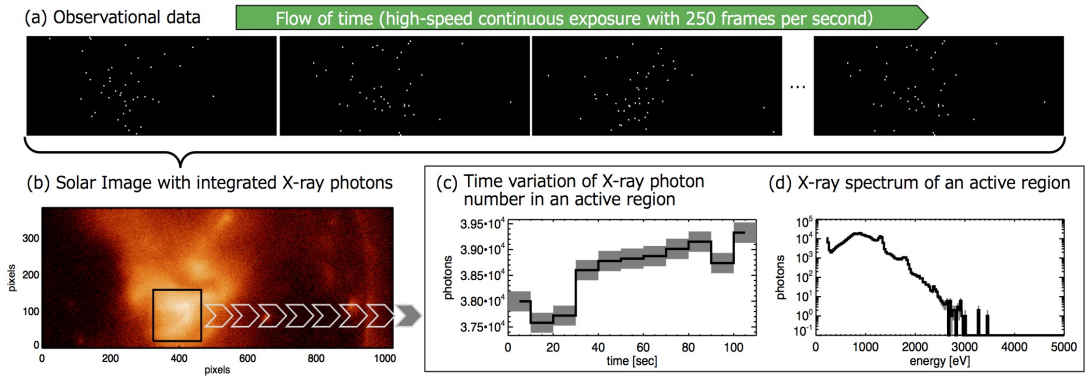
Achievements

of solar flare X-ray focusing imaging spectroscopy

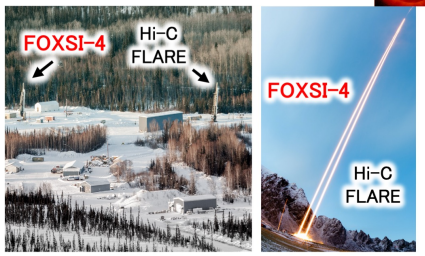
- Successful FOXSI sounding rocket series, which are the US-Japan collaborative projects using NASA rockets
  - First focusing imaging spectroscopy for the solar corona **in hard X-rays** (FOXSI-1 and -2)
  - First focusing imaging spectroscopy for the solar corona **in soft X-rays** (FOXSI-3)
  - In 2024, first focusing imaging spectroscopy for **a solar flare** in X-rays (FOXSI-4)



FOXSI-2 result
Published in nature astronomy



FOXSI-3 result
First imaging-spectroscopy in soft X-rays

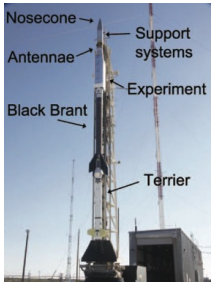


FOXSI-4
Flare campaign in 2024

Future Plans

Utilizing three types of opportunities in different scales, we will create scientific results speedily and ceaselessly.

Category	Spatial resolution	Energy range	Observable flaring phase	Mission lifetime	Cost	Preparatory period	Example	Opportunity
Sounding rocket	~ 1 arcsec sampling	0.8 – 20 keV	from the peak of a flare	~5 minutes	< 5M	2-3 years	• ***FOXSI-4*** (2024) • ***FOXSI-5*** (2025; TBD)	NASA H-LCAS (Heliophysics Low Cost Access to Space)
SmallSat (90kg class)	~ 3 arcsec sampling	0.8 – 10 keV	before the occurrence of flares	~ 2 years	~ 10M	2-3 years	Using microsatellite bus of Canon Electronics (in the 2020s)	NASA H-FORT (Heliophysics Flight Opportunities for Research and Technology)
Full size satellite	~ 0.75 arcsec sampling	0.8 – 30 keV	before the occurrence of flares	> 2 years	> ~200M	10 years	• ***PhoENiX*** (in the 2030s)	• ISAS/JAXA competitive M-class mission concept A/O • NASA MIDEX



Sounding rocket
(NASA)
- 2m long instrument
- Recoverable

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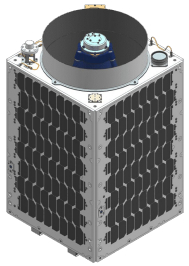

SmallSat
(Canon Electronics)
- ~0.6m long instrument
- ~90kg (total mass)

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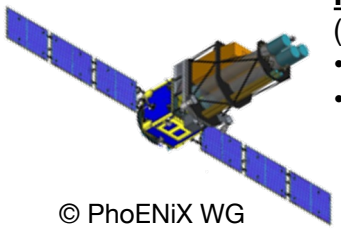

Full size satellite
(ISAS/JAXA)
- ~3m long instrument
- ~600kg (total mass)

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As the NAOJ Project

- The world's first X-ray focusing imaging spectroscopic sounding rocket experiment FOXSI series is a US-Japan collaborative project. The staffs from the NAOJ have participated in these projects as core members, and it has been implemented as one of the small-scale projects of the Solar Science Observatory in NAOJ.
  - The budget for the implementation of FOXSI project has been obtained through competitive external funding.
  - It has been used as an educational and research opportunity for graduate students from SOKENDAI and other universities.

- The upcoming projects are also planed to be implemented as a project of NAOJ. It is expected that NAOJ will make the following contributions:
  - Provides a full-time researcher to lead the solar flare X-ray focusing imaging spectroscopy.
  - Technical support from the Advanced Technology Center.

  (NOTE: The budget for the implementation of future projects is planed to be obtained through competitive external funding in the same manner as before.)