# Pointing control of extreme ultraviolet spectroscope onboard the SPRINT-A satellite

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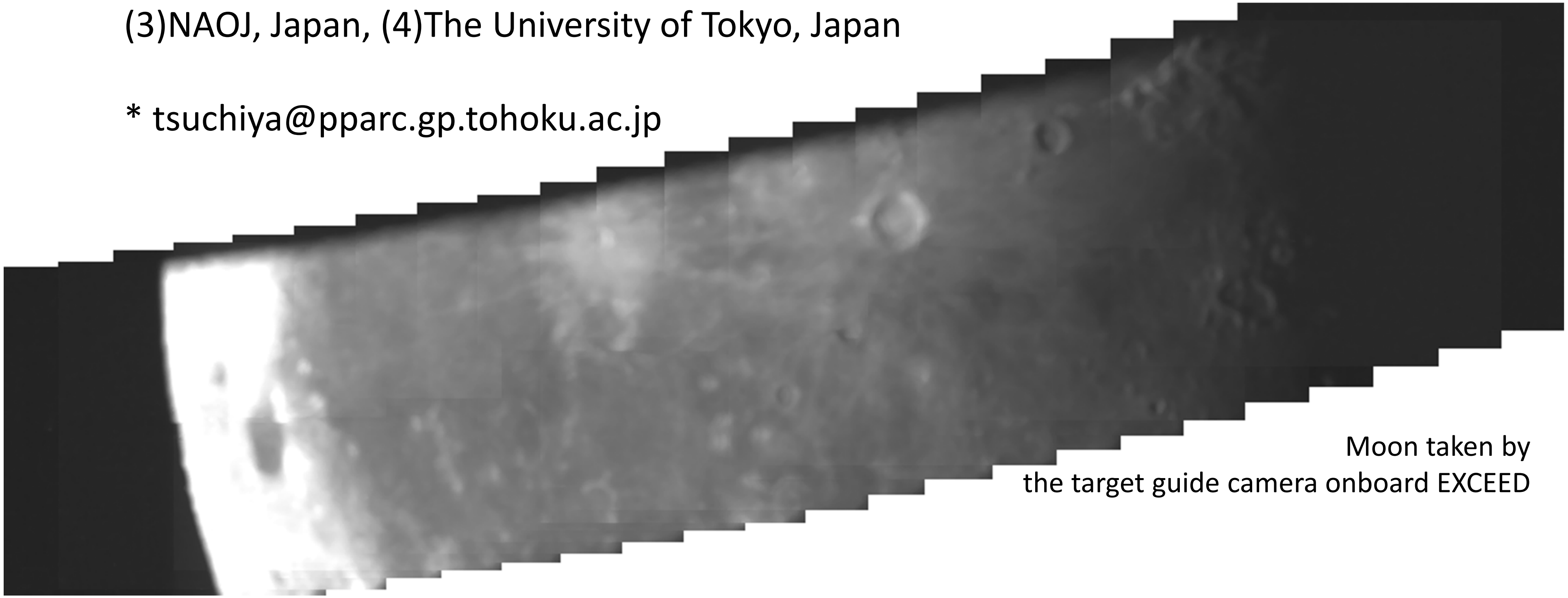


Moon taken by
the target guide camera onboard EXCEED

# Abstract

HISAKI (SPRINT-A) satellite is an earth-orbiting EUV spectroscopic mission and launched on 14 Sep. 2013. Extreme ultraviolet spectroscope (EXCEED) onboard the satellite will investigate plasma dynamics in Jupiter's inner magnetosphere and atmospheric escape from Venus and Mars. EUV spectroscopy is useful to measure electron density and temperature and ion composition in hot plasma environment. EXCEED also has an advantage to measure spatial distribution of plasmas around the planets. To measure radial plasma distribution in the Jovian inner magnetosphere and plasma emissions from ionosphere, exosphere and tail separately (for Venus and Mars), the pointing displacement of the telescope should be smaller than spatial structures of interest. The displacement is caused by change of alignment between the satellite bus and the telescope due to the changing thermal inputs from the Sun and Earth. The satellite is designed to compensate the displacement by tracking the target with using a target guide camera . Initial checkout of the attitude control for the EXCEED observation (bright stars, Jupiter and Venus) shows that **pointing accuracy kept within 2-arcsec in a case of "track mode"** which is used for Jupiter observation. For observations of Mercury, Venus, Mars, and Saturn, the entire disk will be guided inside slit to observe plasma around the planets. Since the guide camera does not capture the disk in this case, the satellite uses a star tracker (STT) to hold the attitude ("hold mode"). **Pointing accuracy during the "hold mode" has been 20-25 arcsec**. It has been confirmed that the attitude control works well as designed. EXCEED started regular observation of Jupiter at middle of Dec. 2013.

# Overview of the EXCEED instrument

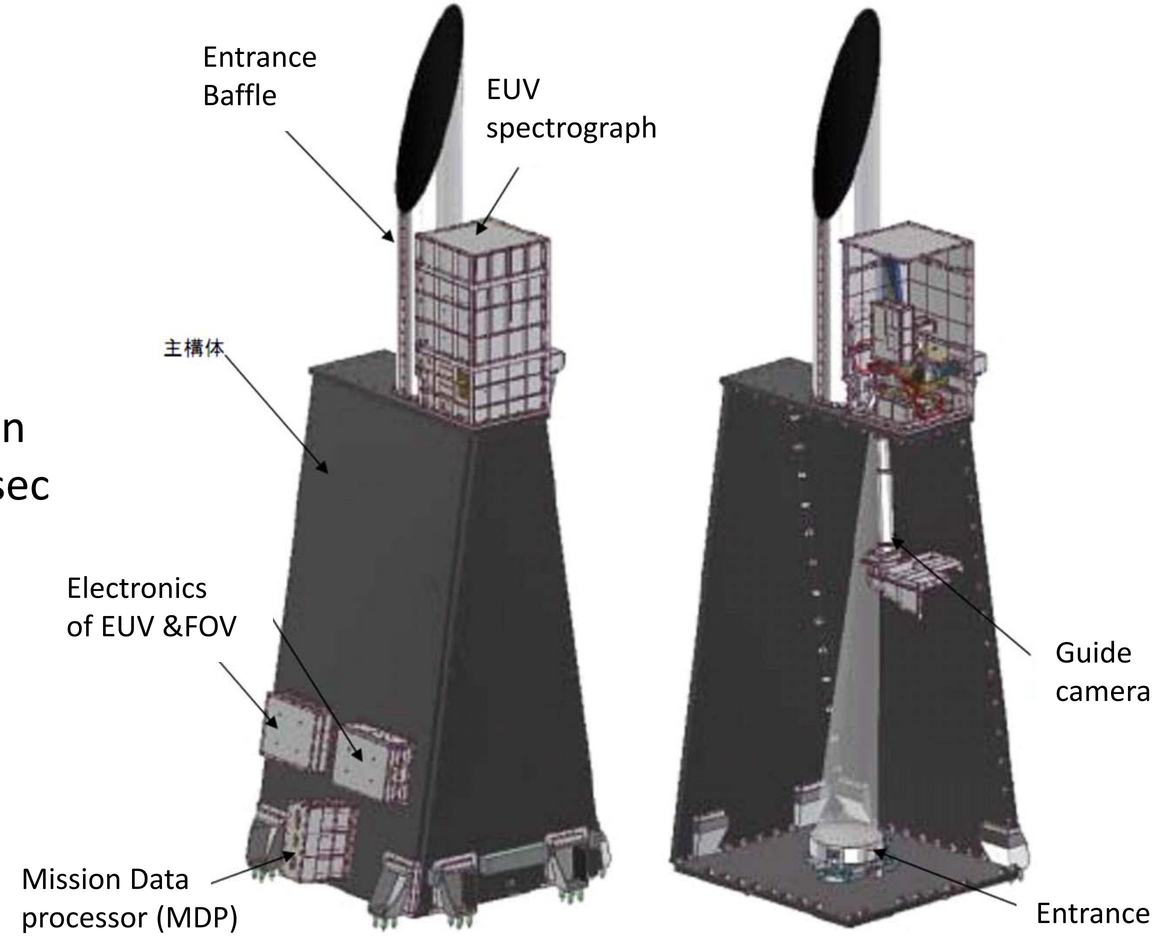
## (EXtreme ultraviolet spectrosCope for ExosphEric Dynamics)

- An earth-orbiting Extreme Ultraviolet (EUV) spectroscopic mission
- EUV emissions from tenuous gases and plasmas around the planets
- Observation targets : Mercury, Venus, Mars, Jupiter, Saturn, and EUV stars

Major specifications

- Launch : Sep 14, 2013
- Size：1m × 1m × 4m
- Orbit：950km × 1150km (LEO)
- Inclination: 31 deg
- Mission life ：>1 year
- Pointing accuracy : ±2 arc-min
  (designed to improve ±5arc-sec
  by using a guide camera)

- Wavelength range:
  55-145nm
- Spectral resolution:
  0.4-1.0nm
- Spatial coverage (slit length):
  400 arc-sec



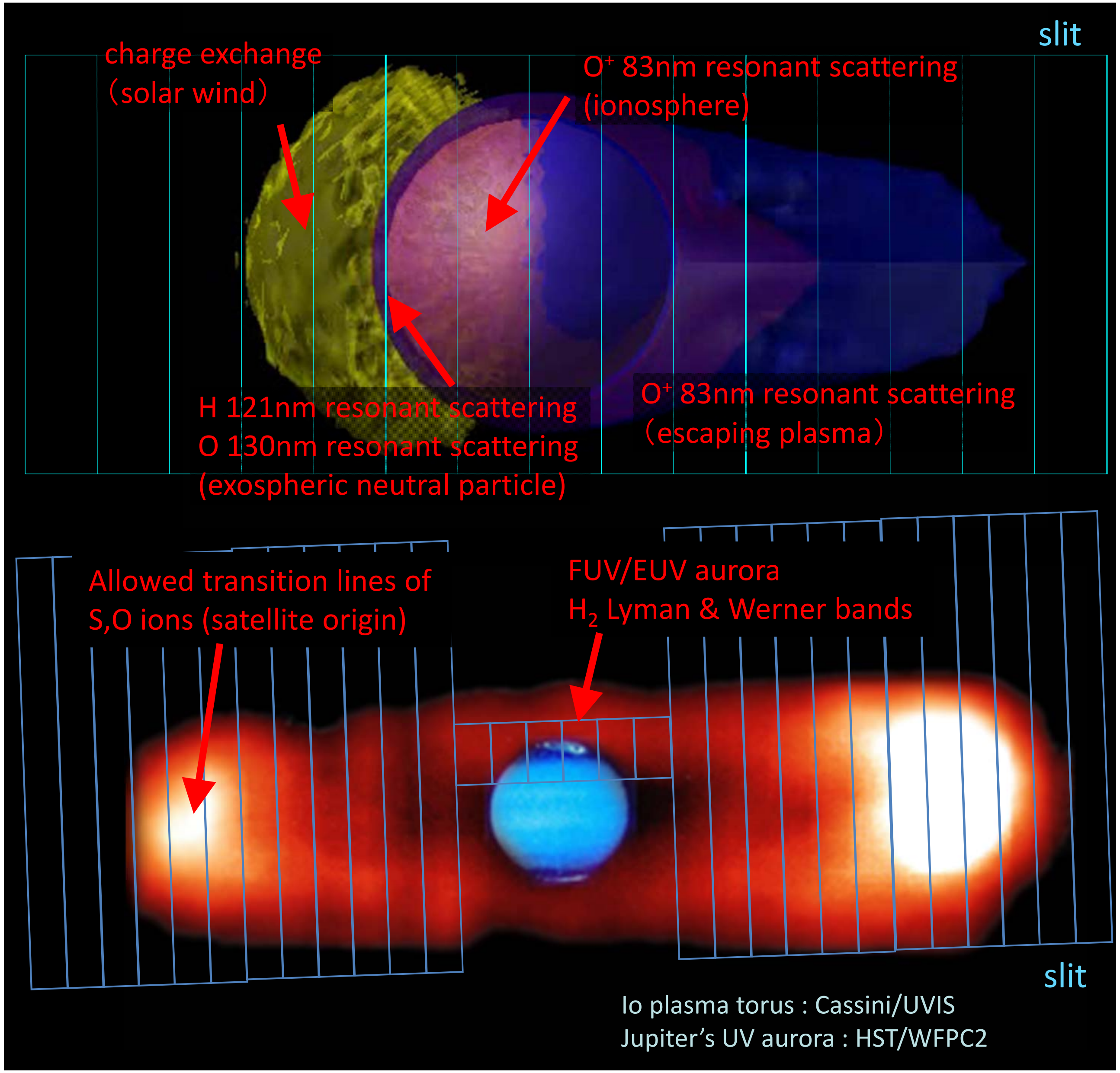

SPRINT-A/EXCEED

# Two main targets of EXCEED

(1) Simultaneous observation of exosphere, ionosphere, and escaping plasma down the tail (Venus, Mars, and Mercury)

(2) Aurora and gas torus (Jupiter and Saturn)

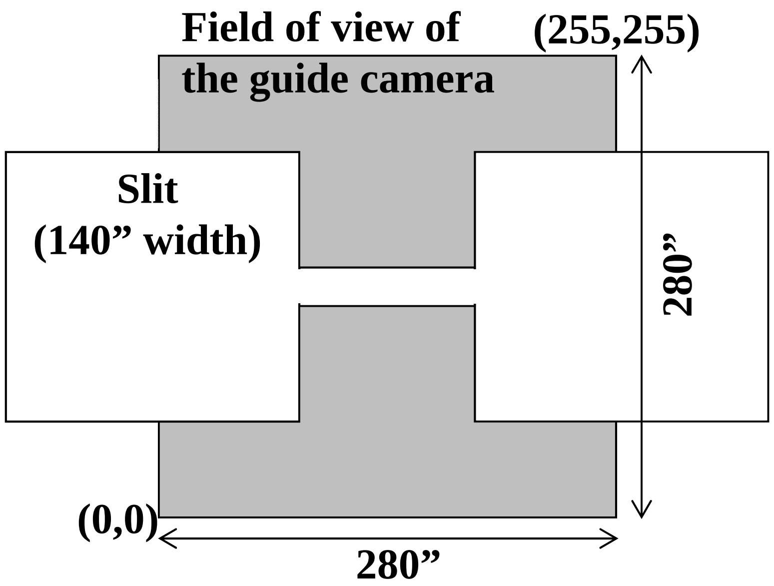
Spatial resolution of 10 arc-sec is needed to measure radial plasma distribution in the Jovian inner magnetosphere and detect plasma emissions from ionosphere, exosphere and tail separately .



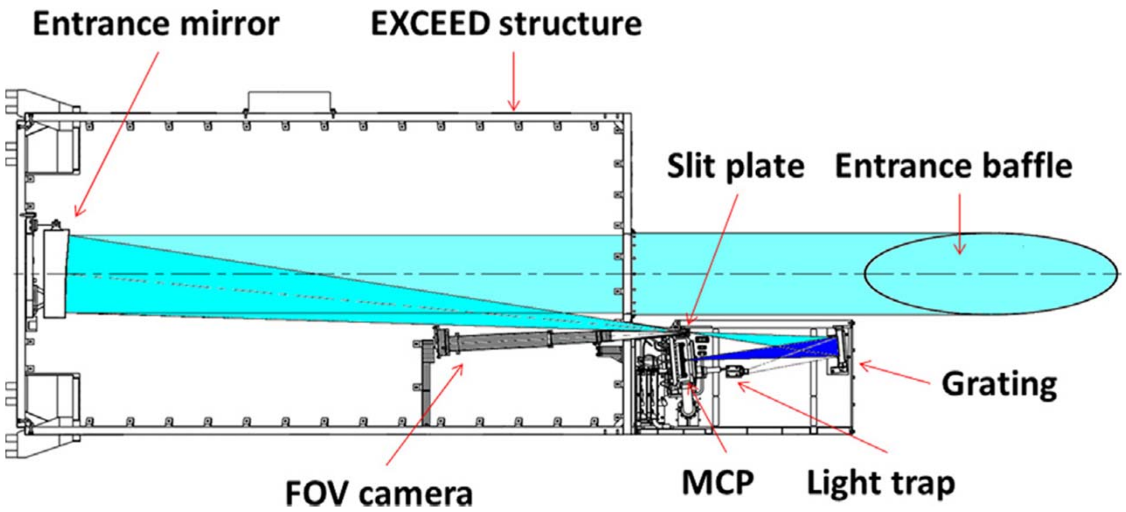
# Target guide camera

## Specification of the guide camera

| | |
|---|---|
| Field of view | 280 arcsec x 280 arcsec |
| Exposure time | 1sec (nominal) |
| Pixel number | 256 pixel x 256 pixel |
| Plate scale | 1.1 arcsec/pixel |
| Wavelength | 550nm(width～20nm) |

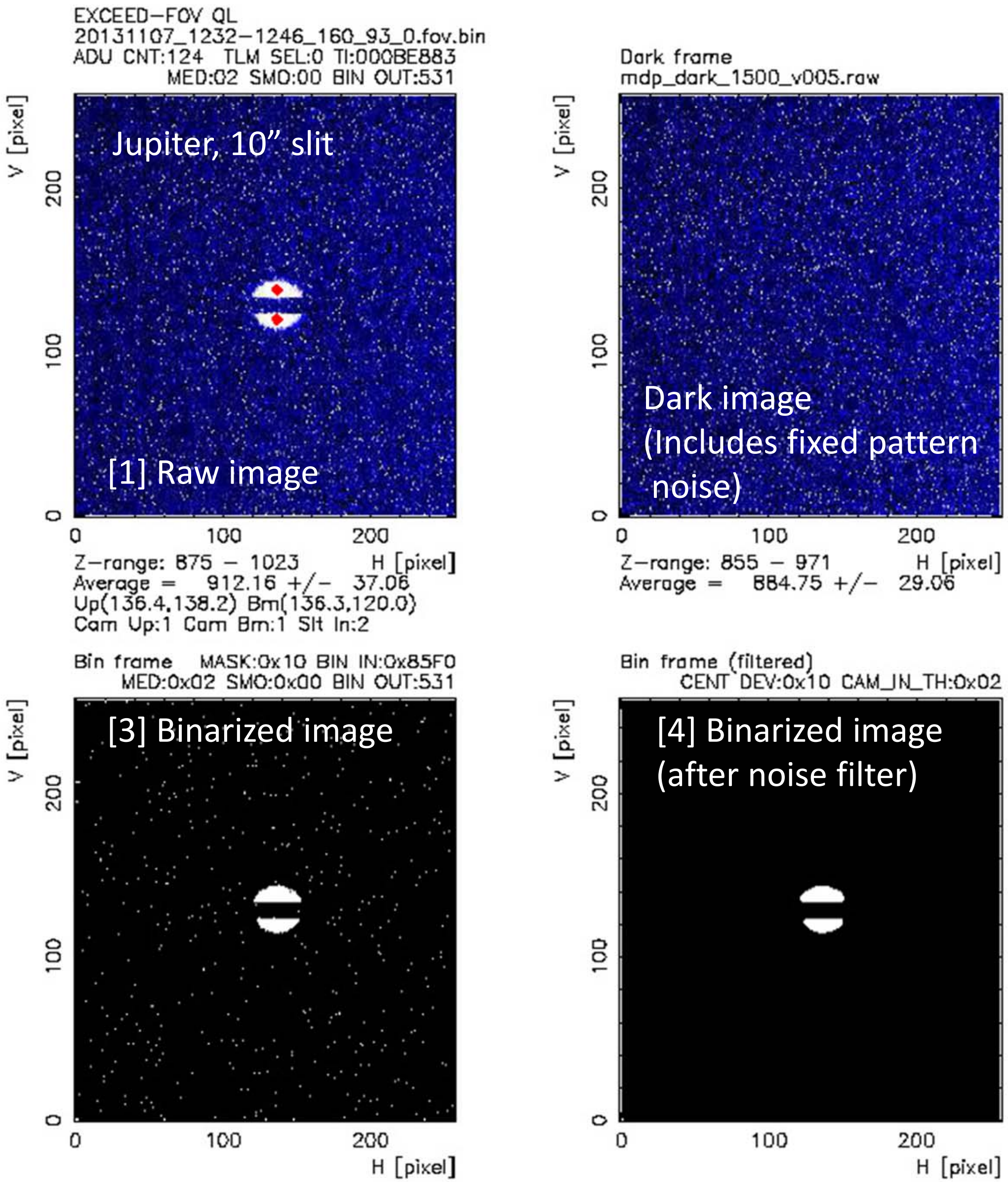



Schematic picture of field of views of EUV spectrometer (white) and the target guide camera (gray).




Schematic picture of the EXCEED optics. The light that reflects in front of the slit is guided to the camera. (Yoshioka et al. 2013)

# Onboard image processing




## Typical procedure

- Acquisition of a camera image [1]
- Image processing
  - Dark image subtraction [2]
  - Binarization [3]
  - Noise filter [4]
- Centroid calculation
  (red marks on the raw image)
- Send the centroid to the attitude control system

# Attitude control designed for EXCEED

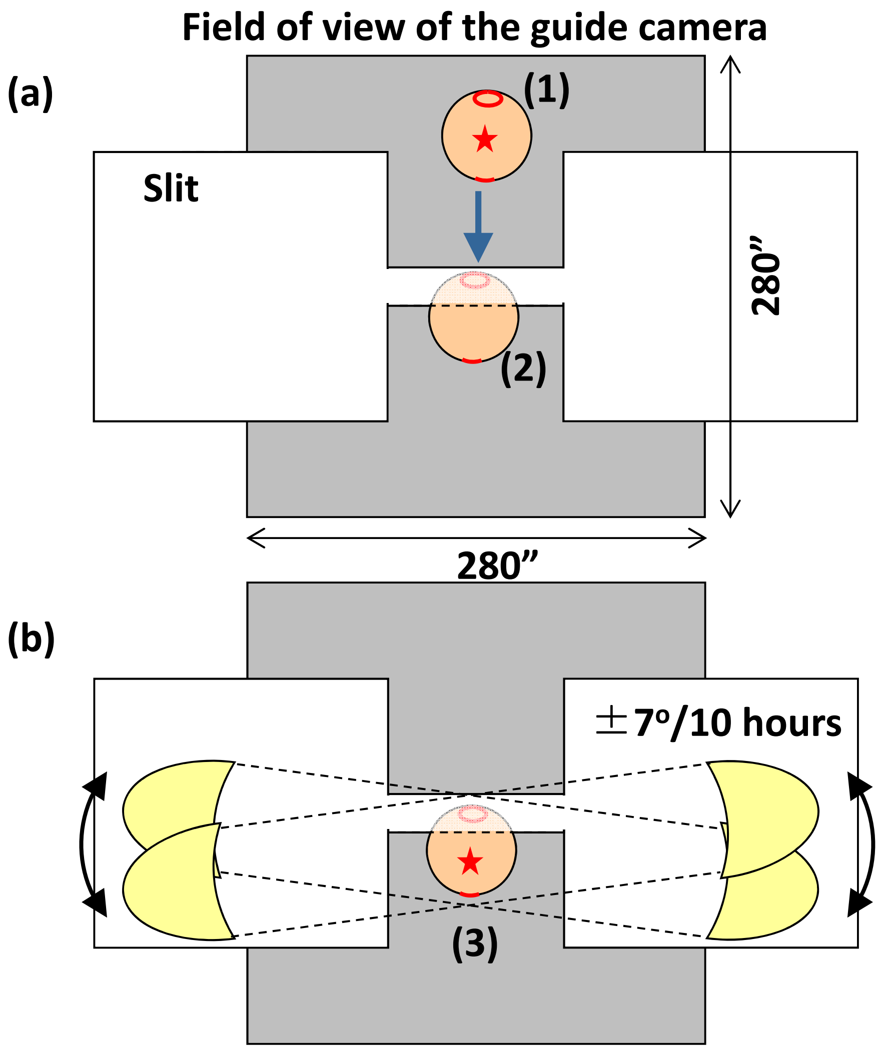
- Pointing accuracy (bus system)
  ±2 arc-min
- Scientific requirement
  ±5 arc-sec
  The FOV camera is used to achieve the spatial resolution required.

## Designed sequence to find and track observation targets

(1) Mission data processor (MDP) acquires the image taken by the guide camera and calculates a centroid of the bright planet disk. MDP sends it to the attitude control system every 3-sec.

(2) Using the centroid, the satellite attitude control system carries out attitude maneuver to capture a target into a slit.

(3) Attitude control system keeps the centroid position at the uplinked position within an accuracy of +/- 5 arc-sec.




(a) Schematic picture which shows sequence to find and guide observation target.
(b) Typical observation mode for Jupiter's aurora and Io plasma torus.

# Three attitude control modes

Track mode : Part of target planet disk is captured by the guide camera
Hold mode (1)(2): Entire bright area of target is within a slit (can not use guide camera)

[1] Guide a target star/planet inside FOV of the guide camera

[2] Find the target position by the guide camera and set it on the slit.

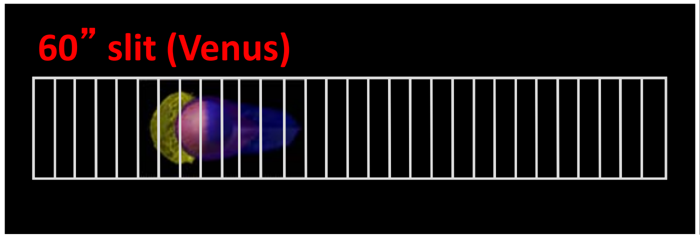
[3] Track the target position by using the centroids calculated from the camera image

**Hold mode(1)**
The satellite holds the attitude with STT (without the centroid position)

For Dark stars (<4mag)
(The centroid can not be identified by the guide camera & MDP)

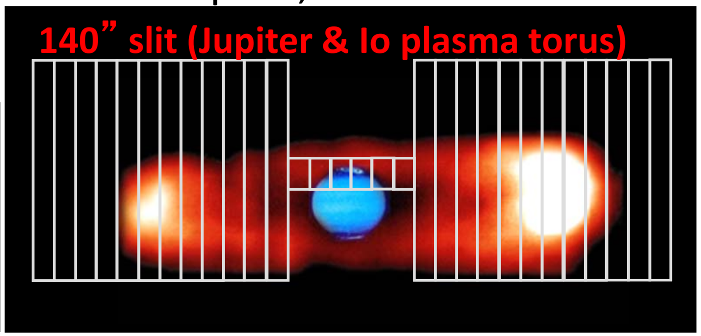
**Hold mode(2)**
Same as hold mode(1) but the target position is routinely checked by the guide camera.

For Mercury, Venus, Mars, Saturn & bright stars

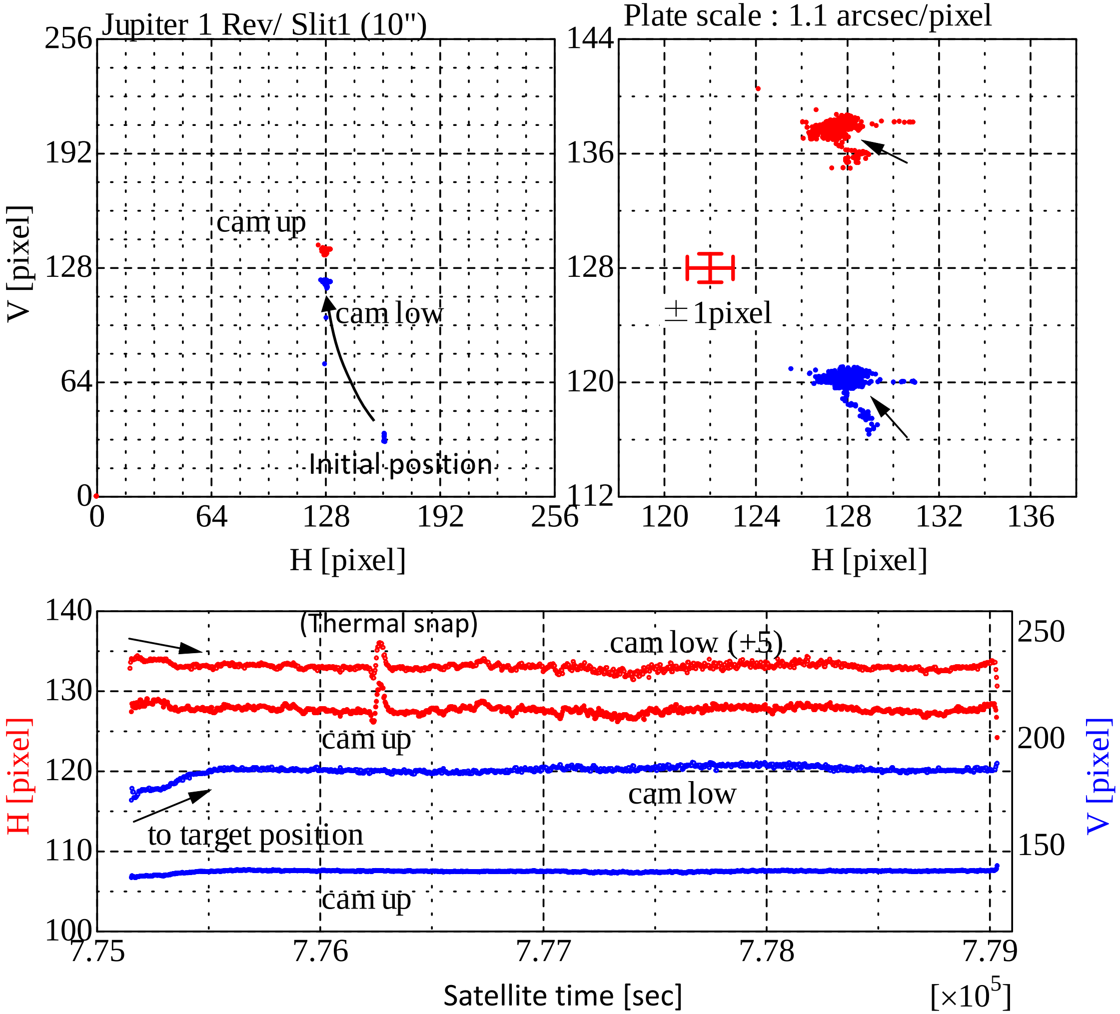


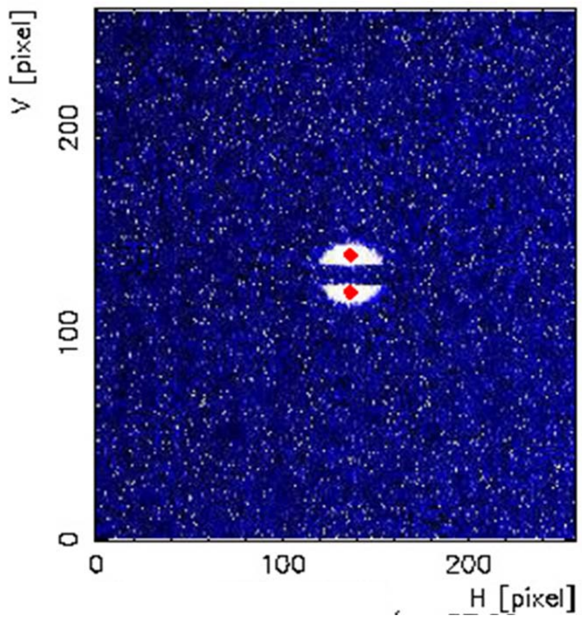

**Track mode**
The satellite keeps the attitude by using the information of target position from the guide camera.

For Jupiter, Venus & Saturn



# "Track mode" with Jupiter



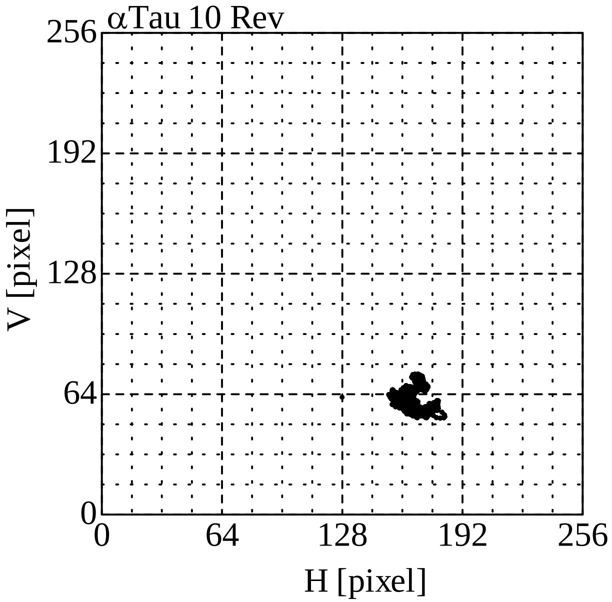

An example of Jupiter's image taken by the guide camera. Red points indicate the centroids calculated by MDP.

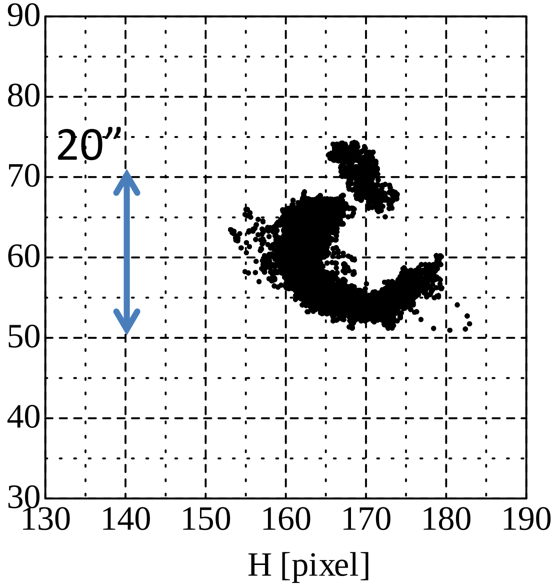
Pointing accuracy during the track mode is about 2 arc-seconds.

Centroid positions of Jupiter's disk taken by the guide camera during one satellite revolution. Jupiter was located on the center of the 10" slit and two centroids were separately found in the upper and lower areas of the camera. Data was taken on 7 Nov. 2013 and angular diameter of Jupiter was 42".

# “Hold mode” with αTau

αTau: Aldebaran, 0.8mag



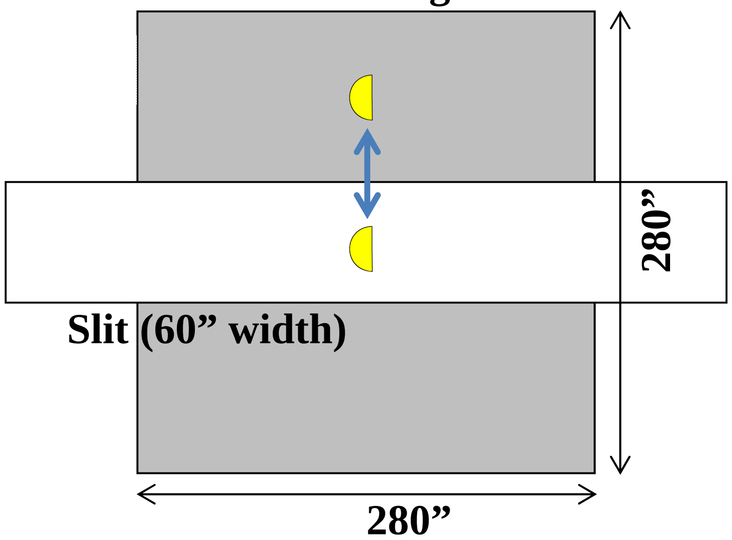




Pointing accuracy during the hold mode is 20-25 arc-seconds.

Centroid positions of αTau taken by the guide camera during 10 satellite revolutions. The attitude control was in “hold mode”. To evaluate the pointing stability in the hold mode, the star was captured on the guide camera. Data was taken on 31 Oct. 2013.

During planet observations, the satellite sometimes maneuvers the attitude to capture the disk by the guide camera and confirm its position (right figure).

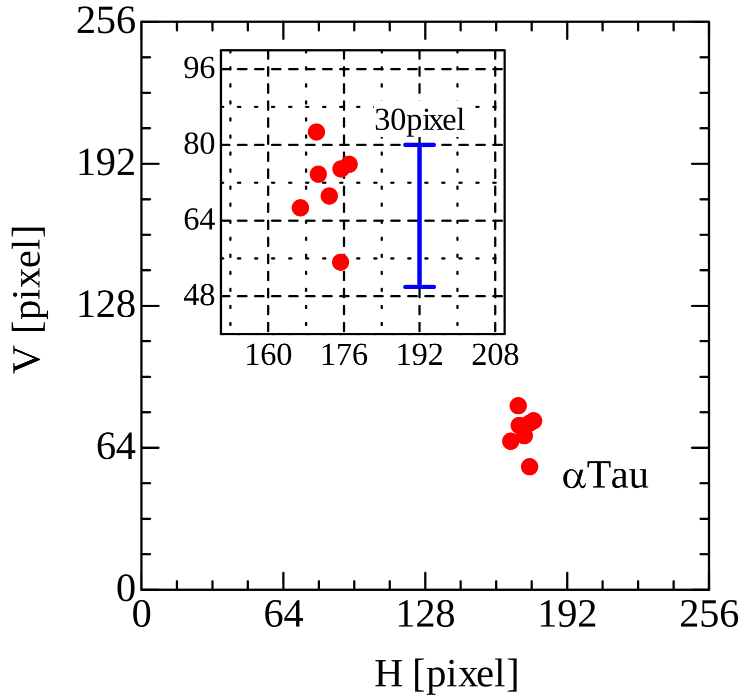
**Field of view of the guide camera**



# Absolute pointing accuracy

For target sources which are darker than 4 mag, onboard identification of their position on the guide camera is difficult. The guide of the dark sources into a slit depends on absolute pointing accuracy of the attitude control system.

Actual performance of the star tracker (STT) is expected to be better than 2 arc-min. To evaluate the absolute accuracy, positions of αTau on the camera guided at the first contact are examined (right figure).




Positions of αTau on FOV of the guide camera.

The absolute accuracy is currently evaluated to be **about 30 arc-seconds**, which means that the satellite could guide a dark star inside the 60”-width slit without use of the guide camera.