INTRODUCTION OF AMICA
- Specification and DATA Handling-

COSPAR

Capacity Building Workshop on Planetary Science

July 23 - Aug. 3, 2007

Montevideo, Uruguay

Masateru Ishiguro

(Hayabusa AMICA Team)

1. What is AMICA?

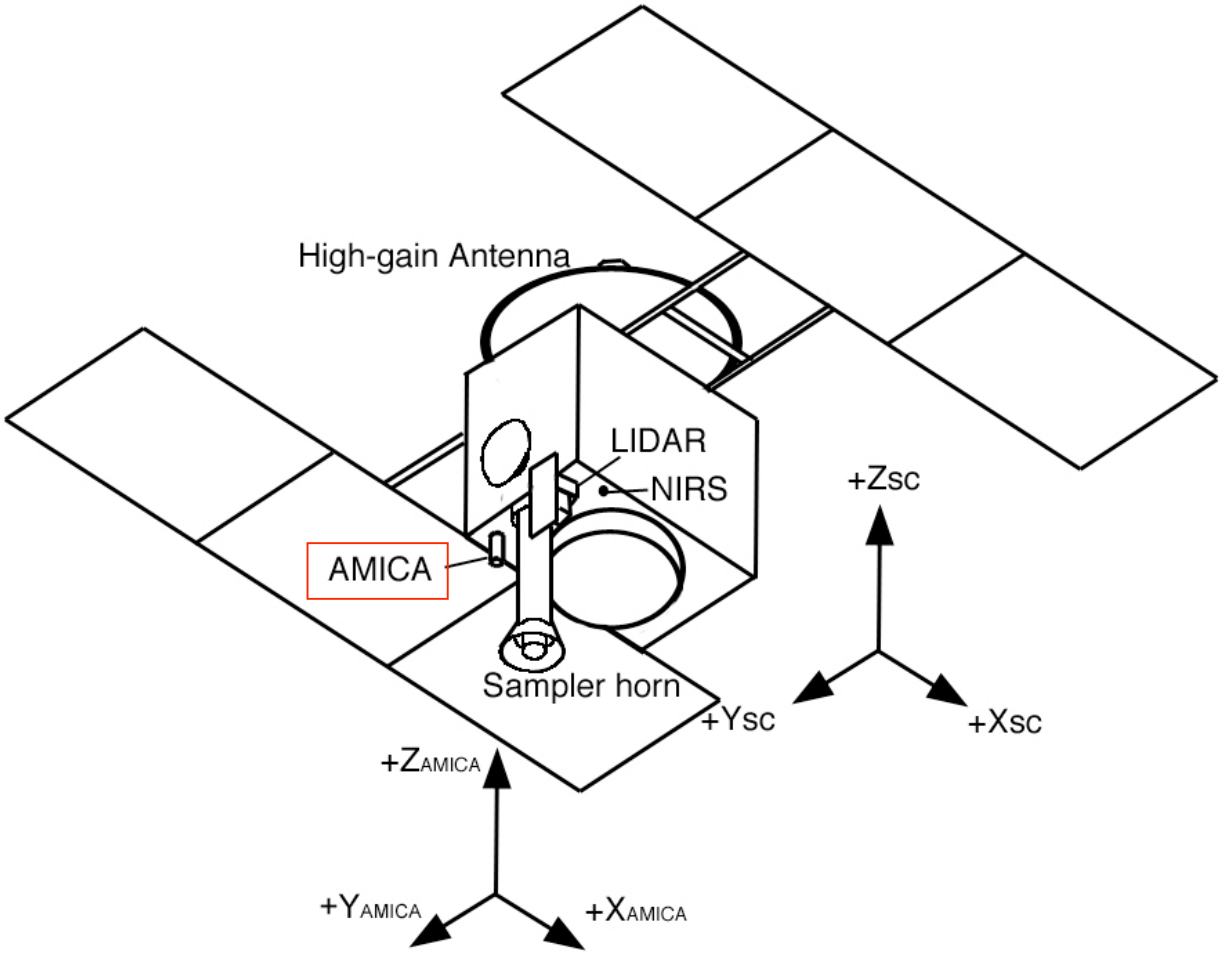
- One of the optical navigation cameras onboard Hayabusa spacecraft is referred to as the AMICA (Asteroid Multiband Imaging CAmera) when used for the scientific observations.

- It has a filter system close to that of ECAS (the Eight Color Asteroid Survey), the standard for ground based asteroid taxonomy (Zellner et al., 1985), as well as the wide-band filter for the optical navigation.

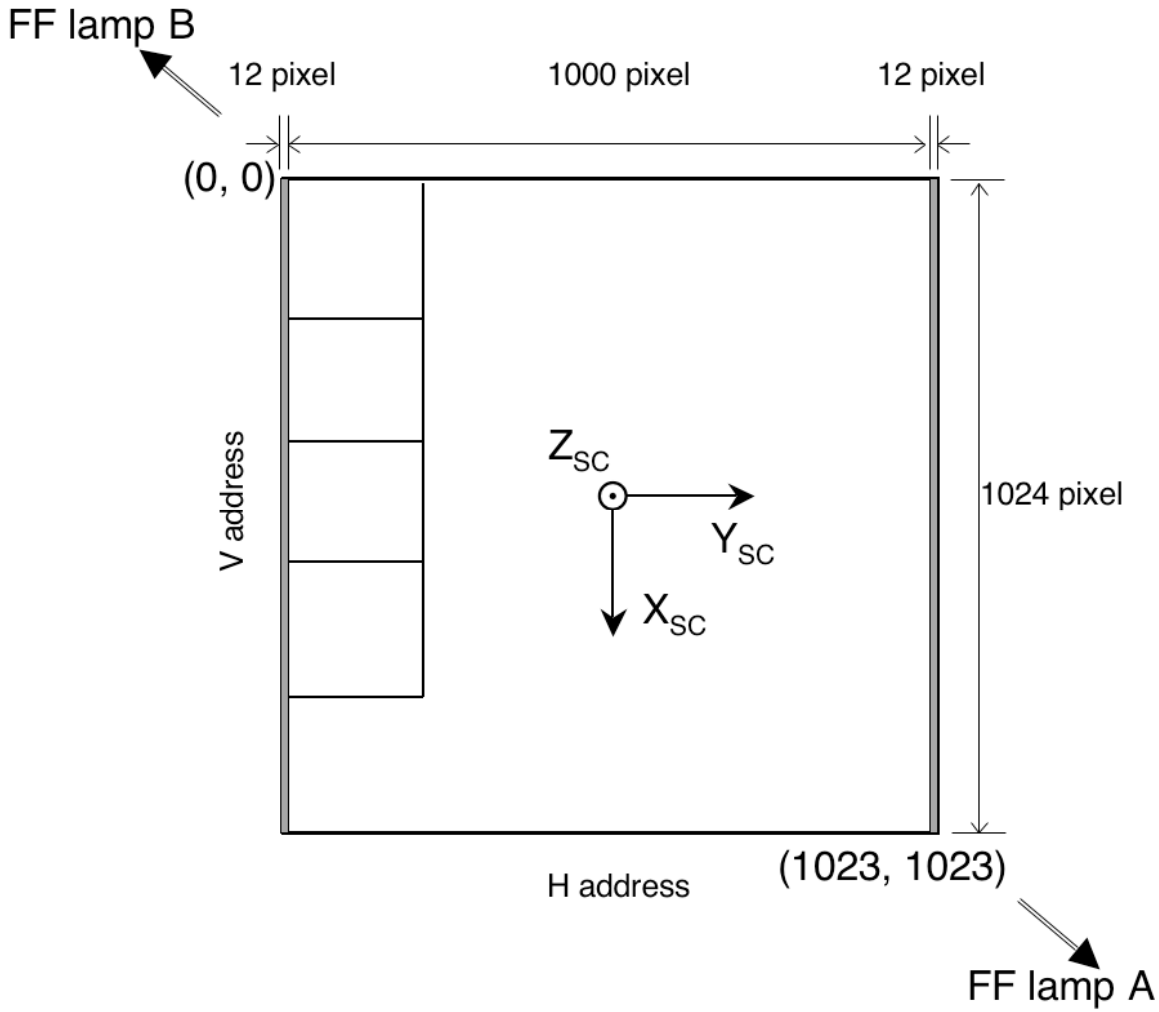
- The effective field of view is 5.83°×5.69° square, which is covered by 1024 ×1000 pixels, so that one pixel length is corresponding to 20.49″. The pixel resolution is corresponding to ~70 cm at home position (nominal distance of 7 km from Itokawa surface).

- The obtained data are stored in 1024×1024 pixels format. There are two 12-columns masked areas on the right and left edge of images to monitor the zero signal level.

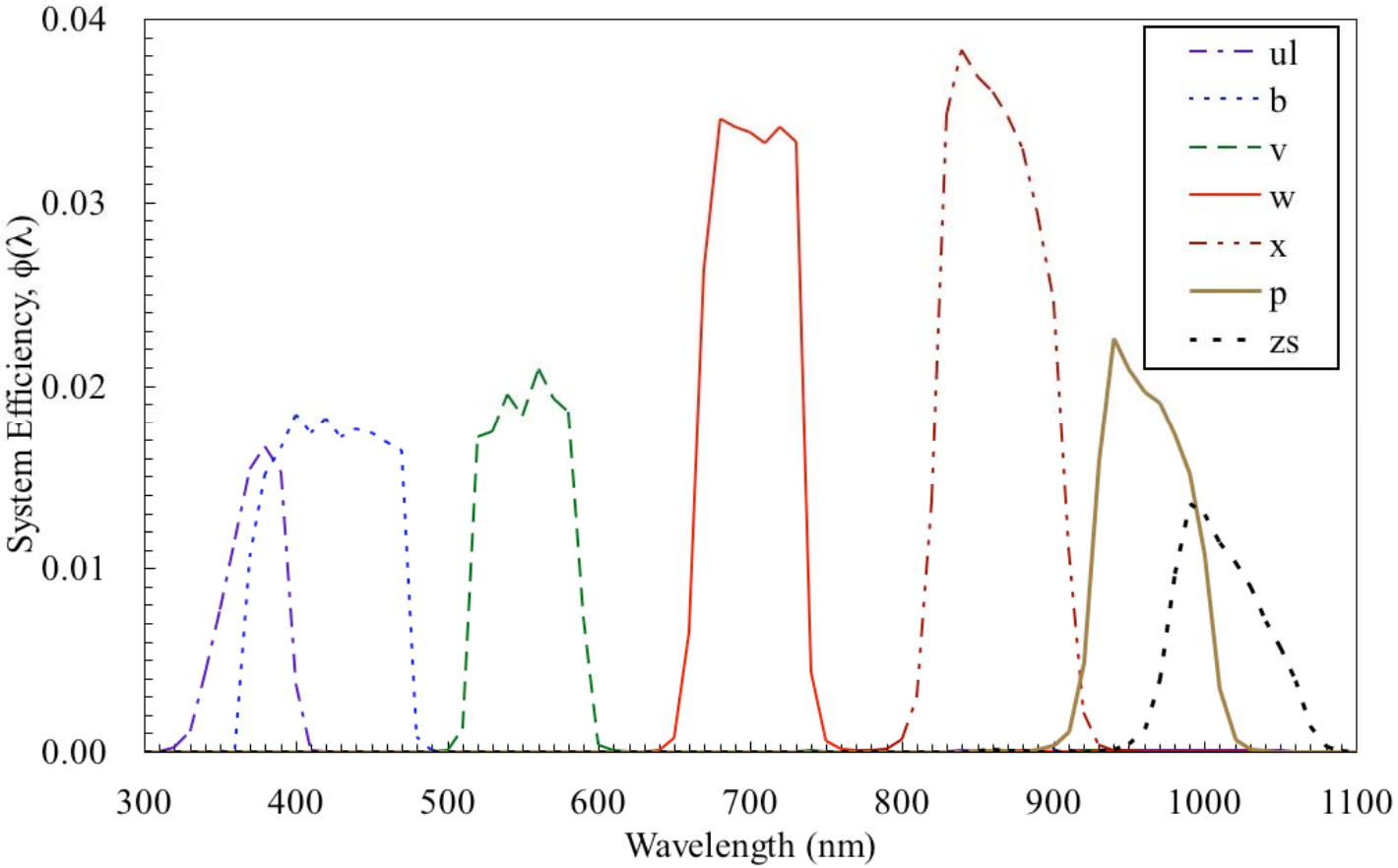
AMICA Camera Head	Effective Lens Aperture	15 mm
	Focal Length	120.80 mm (measurement value)
	Field of View	5.83°×5.69° (measurement value)
	CCD Format	1024×1000 pixels
	CCD pixel size	12 μm square
	Pixel Resolution	20″.490 (measurement value)
	Filters (Turnover Rate)	7 narrow band and 1 wide band (4.69 sec./filter)
	Polarizer	4 position angle glass polarizers
	Pixel sampling rate	3MHz
	Gain factor	~17 DN/e^-
	Readout noise	~60 e^- (measurement value)
ONC-AE/E for AMICA control	A/D conversion	12 bit
	Image memory storage	16 frames
	Exposure time	5.44ms, 8.20ms, 10.9ms, 16.4ms, 21.8ms, 32.8ms, 43.5ms, 65.6ms, 87.0ms, 131ms, 174ms, 262ms, 348ms, 525ms, 696ms, 1.05s, 1.39s, 2.10s, 2.79s, 4.20s, 5.57s, 8.40s, 11.1s, 16.8s, 22.3s, 33.6s, 44.6s, 67.2s, 89.1s, 134s, 178s, <1μs (for smear)
	Software pixel binning	None, 2×2, 4×4, 8×8
	Arithmetic operation between 16 image storage	Average Median Mode Sum
	Output mode	Lossless image Lossy image (indicated by *Q* factor) Histogram Average value
	The other option	12 bit 1 bit (for shape model)



The bottom view of Hayabusa spacecraft. AMICA is installed on the bottom ($-Z_{SC}$) plane. In the normal attitude, the Sun and the Earth are located in the $+Z_{SC}$ direction, and Itokawa in the Z_{SC}.



Design of AMICA imaging section. There are two masked areas on the right and left edge. AMICA has four position angle polarizers, which are composed of 200 x 200 pixels each and located in on left edge of the imaging section.



The system efficiency (bottom) of AMICA seven band filter.

- AMICA has no mechanical shutter, but the exposure time is controlled electronically. We can specify any of 30 different exposure times, ranging from 5.44 msec to 178 sec including 0 sec exposure (precisely, less than 1 μsec).

- The finite duration of frame transfer produces the streak (readout smear) parallel to the direction of frame transfer (along V-direction).

- In a nominal imaging sequence, we took a pair of images at a short time interval (typically 15 sec) and then subtract the latter frame (smear frame), which was taken with a 0 sec exposure, from the former frame (>5.44 msec exposure).

- After the second breakdown of a reaction wheel, most of data were obtained without correcting the smear. However, it is found that the smear is essentially corrected by the method proposed by Ishiguro et al. (show later).

2. Inflight Operation

- First Itokawa images by AMICA were acquired in late August of 2005.

- On September 1, we got the deepest images of Itokawa with the long exposure time in order to detect satellites.
  - No detection! (Fuse et al. in review)

- First resolved images were taken in early September.

- The regular observation was started on 12 September. We initially observed the asteroid's surface from a distance of ~20 km in the "gate position (GP)", a region roughly on a line connecting the Earth with the asteroid on the sunward side. The global color mapping (Ishiguro et al., 2007) and the shape modeling (Demura et al., 2006) were carried out in the term.

- The higher-resolution imaging was done from a distance of about 7 km (home position, hereafter HP). AMICA could cover the whole surface of Itokawa from both GP and HP.

- On 3 October 2005 Hayabusa lost the use of the Y_{SC}-axis reaction wheel and used one reaction wheel and two chemical thrusters to maintain the attitude control. The trouble made change the data acquisition strategy.

- In early October, we made tour to various attitude and solar phase angle (Sun-Itokawa-AMICA angle, <35°) in order to access the polar region and make high-resolution topographic images under differing lighting conditions (Fujiwara et al., 2006).

- The spacecraft moved close to the surface in November 4 and 12 for rehearsals of touchdown. First and second touchdown were made on November 19 and 25. During the descending and ascending terms, we got close-up images of Itokawa (Yano et al., 2006; Miyamoto et al. 2007;

3. Data Format

- AMICA raw data are archived on the Internet server in ISAS as Level 1. These images are provided in units of raw data number as received from the spacecraft after data were uncompressed. All inflight data and preflight flatfield are included there. All of these files are in FITS format with a header 2880 bytes long.

- The calibrated data archive is in preparation. It will be released around March 2008.

```
SIMPLE  =                    T / DATA IS IN FITS FORMAT
BITPIX  =                   16 / 16 BIT SIGNED TWOS COMPLEMENT INTEGER
NAXIS   =                    2 / NUMBER OF AXIS
NAXIS1  =                  384 / PIXELS ON 1st MOST VARYING AXIS
NAXIS2  =                 1024 / PIXELS ON 2nd MOST VARYING AXIS
DAT_TYPE= 'SCIENCE           ' / DATA TYPE: SCIENCE NAVDUMP_DIFF,MAIN,SUB
OUT_MODE= 'LOSS-LESS         ' / OUTPUT MODE: HISTOGRAM MEAN LOSS-LESS LOSSY RAW
IMG_OPE = 'MEAN              ' / OPERATION TYPE: MEAN MEDIAN MODE MULTIPLE
LUT_NO  =                    0 / LUT No FOR LOSS-LESS ENCODING
BINNING =                    1 / BINNING PIXEL: 1 (NON BINNING) 2 4 8
START_H =                  320 / IMAGE CROPPING AREA
START_V =                    0 /
LAST_H  =                  703 /
LAST_V  =                 1023 /
NSUBIMG =                    1 / NUMBER OF SUBIMAGES
COMMENT   ***************** info of Subimage No.0 (0-F) **********************
IMG_NO_0= '6                 ' / Total image number processed in ONC-E
SUMDIF_0= 'SUM               ' / OPERATION TYPE ON THIS SUBIMAGE: SUM DIFF
CAMERA_0= 'T                 ' /
TI_0    =           2559940276 / SPACECRAFT CLOCK COUNT [1/32sec]
EXP_0   =             4.35e-02 / EXPOSURE TIME [sec]
FILTER_0= 'v                 ' / FILTER NAME
FLASH_0 = 'OFF               ' / FLASH LIGHT STATUS
FF_A_0  = 'OFF               ' / FLATFIELD LAMP A STATUS
FF_B_0  = 'OFF               ' / FLATFIELD LAMP B STATUS
TEMP_0  =                -20.84 / CCD TEMPERATURE IN DEGREES CELSIUS
UTC_0   = '2005-11-19T20:26:36.' / UTC converted from TI_0
COMMENT  OPERATED BY T.HASHIMOTO, T.KUBOTA, M.ISHIGURO, Y.YOKOTA and J.SAITO
COMMENT  ARCHIVED BY M.ISHIGURO and Y.HIGUCHI
QF      =                    0 / 0-GOOD 1-TRANSFER ERROR 2-COMMAND ERROR
END
```

Example of FITS header in Level 1 data.

Important FITS Keywords

DAT-TYPE: Data type. Scientific data (SCIENCE), navigation dump data (NAVDUMP_DIFF). *<< I recommend to use only 'SCIENCE'.*

OUT_MODE: Histogram, mean, median or mode value within the area of interest, or lossless compressed (LOSS-LESS), lossy compressed (LOSSY) or uncompressed (RAW) image. *<< Use 'LOSS-LESS' for the photometry or colorimetry.*

BINNING: Binning factor. without binning (1), 2x2 (2), 4x4 (4), and 8x8 (8).
<< Use '1' for the topographic studies.

START_i, LAST_i: Range of cropping area along i-axis.

NSUB: Number of subimage used on ONC-E.
<< 2 after the onboard smear correction, and 1 without smear correction.
The data of NSUB=1 should be corrected by the smear model.

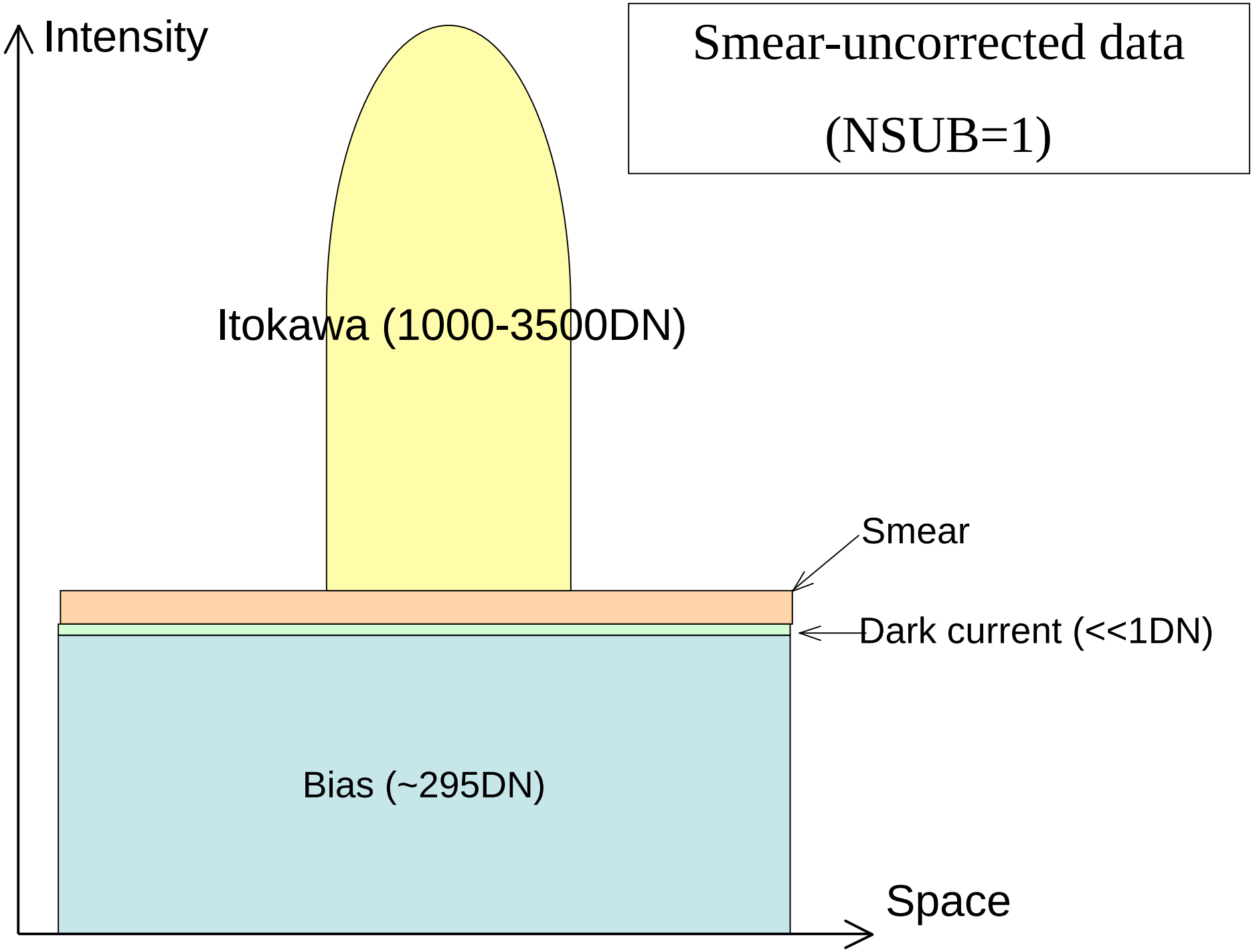
EXP_j: Commanded exposure time for image j [sec].

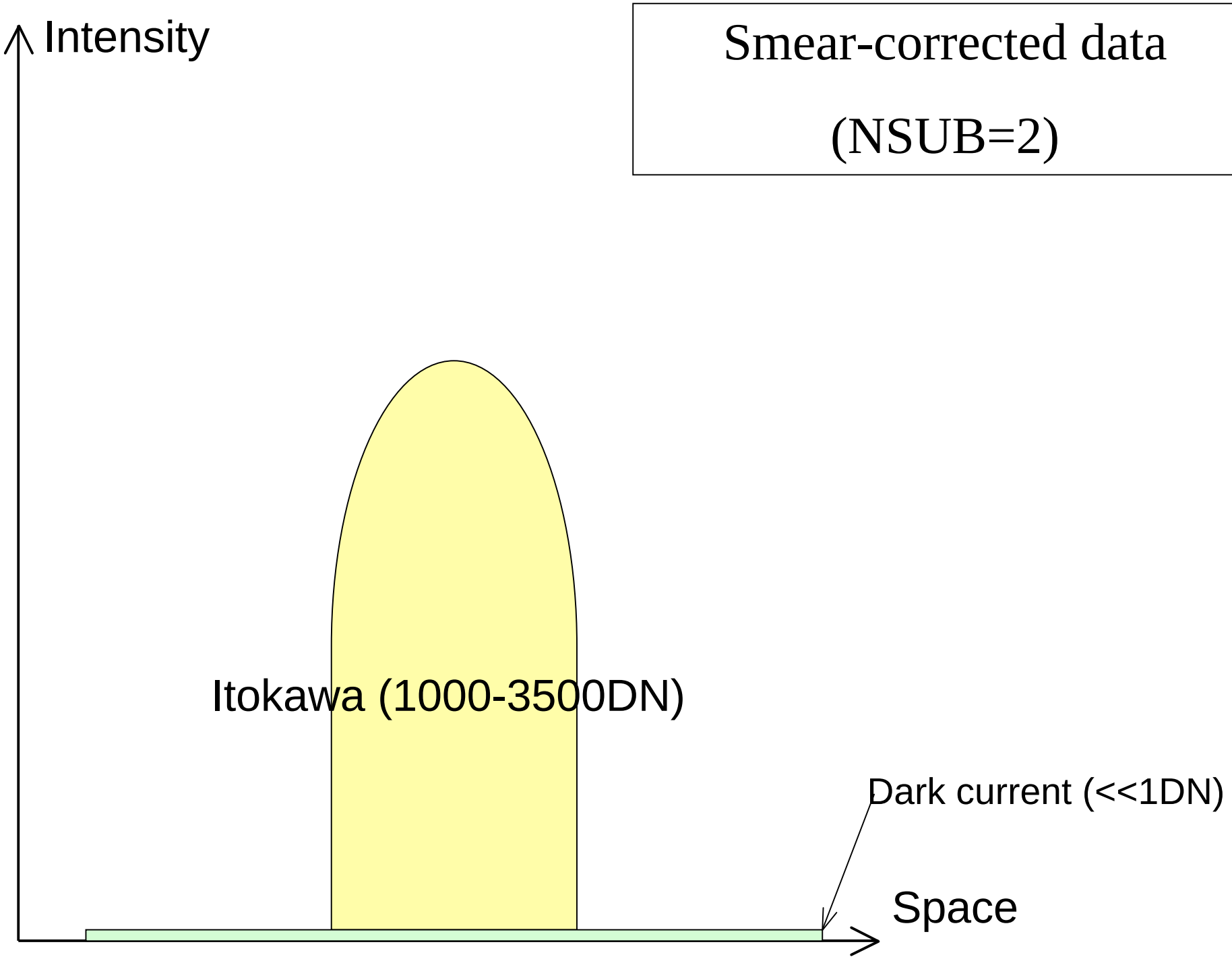
FILTER_j: Filter applied. ul, b, v, w, x, p, zs and wide.

UTC_j: UTC for image j. This was converted from TI_j.

4. Tutorial of simplified data reduction

① Subtract ‘smear’ and ‘bias’ when NSUB=1


Intensity
Smear-uncorrected data
(NSUB=1)
Itokawa (1000-3500DN)
Smear
Dark current (<<1DN)
Bias (~295DN)
Space


Intensity
Smear-corrected data
(NSUB=2)
Itokawa (1000-3500DN)
Dark current (<<1DN)
Space

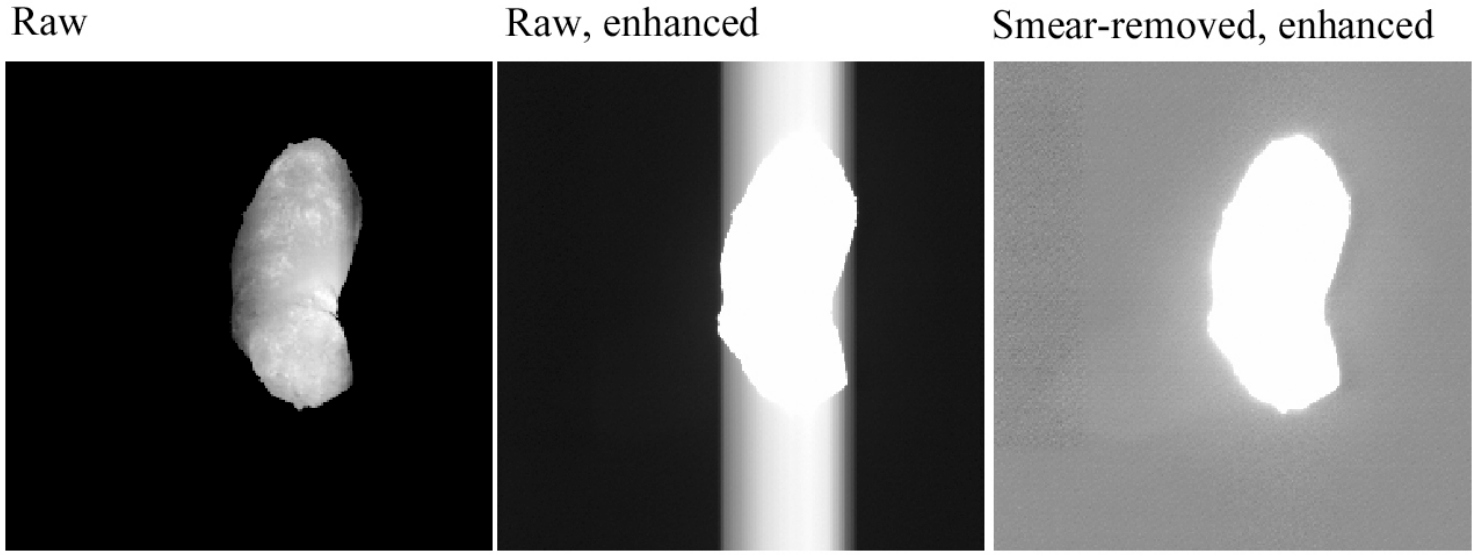
Smear Model

Since AMICA has no mechanical shutter, the observed images are exposed not only in the commanded exposure time but also during the vertical charge-transferred period (t_{VCT}=12μsec×1024=12.288 msec). The finite duration of frame transfer produces the streak (readout smear) parallel to the direction of frame transfer (along V-direction). The brightness of readout smear $I_{SMEAR}(H)$ can be estimated from the observed images,

$$I_{\mathrm{SMEAR}}(H) = \sum_{H=0}^{N_{\mathrm{V}}-1} \frac{t_{\mathrm{VCT}}}{t_{\mathrm{VCT}} + t_{\mathrm{EXP}}} \frac{I_{\mathrm{RAW}}(H,V) - I_{\mathrm{SKY}}(H,V)}{N_{\mathrm{V}}}$$

where $I_{\mathrm{RAW}}(H,V)$ is the intensity in raw data taken with the commanded exposure time t_{EXP}. N_{V}=1024 is the pixel number along V-direction. $I_{\mathrm{SKY}}(H,V)$~295 DN is the sum of bias and dark current (mainly in store section of the CCD).

The technique worked on images taken in descending and ascending period when the subsequence smear exposures were hard to duplicate the streaks on the observed images.



The effects of readout smear removal in w-band image. (Left) Raw image. (Center) Raw image with the contrast enhanced to bring out the smear. (Right) Enhanced image after smear removal. The residuals are below 1 DN.

Tutorial of very simplified data reduction

① Subtract ‘smear’ and ‘bias’ when NSUB=1

② Correct the ununiformity in the sensitivity of each pixel using the flatfield data. The data can simply divided by the published flatfield data.

Tutorial of very simplified data reduction

① Subtract ‘smear’ and ‘bias’ when NSUB=1

② Correct the ununiformity in the sensitivity of each pixel using the published flatfield data. The data (1) can simply divided by the published flatfield data.

③ The DN can be converted into the reflectance by multiplying a factor in the table below.

Conversion factor from DN into Radiance or Reflectivity

Filter	λ_{eff} (μm)	Conversion into Radiance (W m^{-2} μm^{-1} sr^{-1}) / (DN sec-1)	Scale factor (error)
ul	381	—	6.259 (0.063) [*2]
b	429	—	1.254 (0.008)
v	553	3.42×10^{-3}	1
w	700	—	0.645 (0.005)
x	861	—	0.600 (0.006)
p	960	(1.89×10^{-3}) [*1]	1.514 (0.014)
zs	1008	—	—[*3]

Ishiguro et al. (submitted to Icarus)

Example on IRAF

```
cl> imarith level1_w.fits - 295 tmp1.fits
cl> imarith tmp1.fits - smear_w.fits tmp2.fits
cl> imarith tmp2.fits / flat_w.fits tmp3.fits
cl> imarith tmp3.fits * 0.645 results_w.fits
```

```
cl> imarith level1_b.fits - 295 TMP1.fits
cl> imarith TMP1.fits - smear_b.fits TMP2.fits
cl> imarith TMP2.fits / flat_b.fits TMP3.fits
cl> imarith TMP3.fits * 1.254 results_b.fits
```

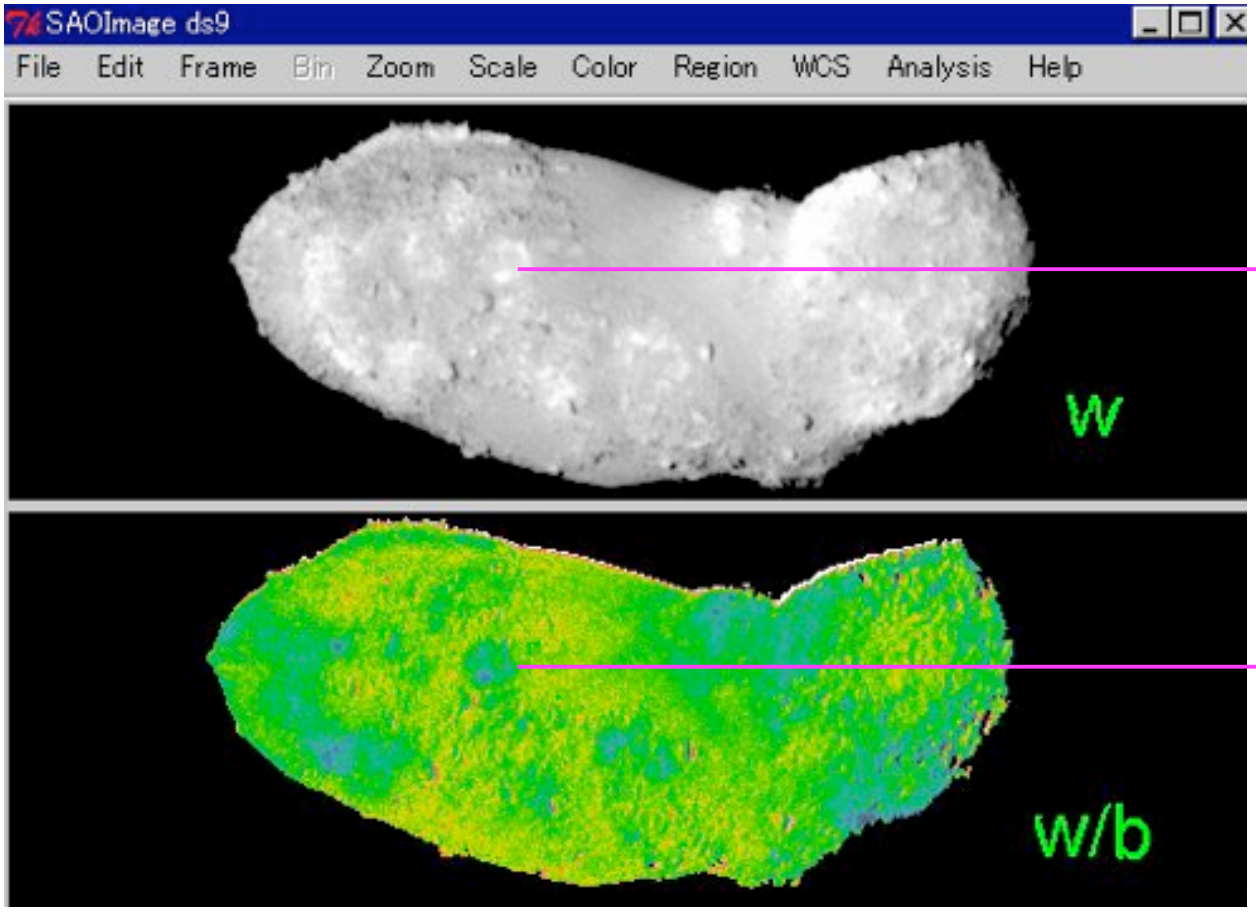
```
cl> imshift results_b.fits 2 3 results_b_shift.fits
```

Image registration

```
cl> imarith results_w.fits / results_b_shift.fits w_b_ratio.fits
```

Color ratio

Example



Blue and bright
on crater limb