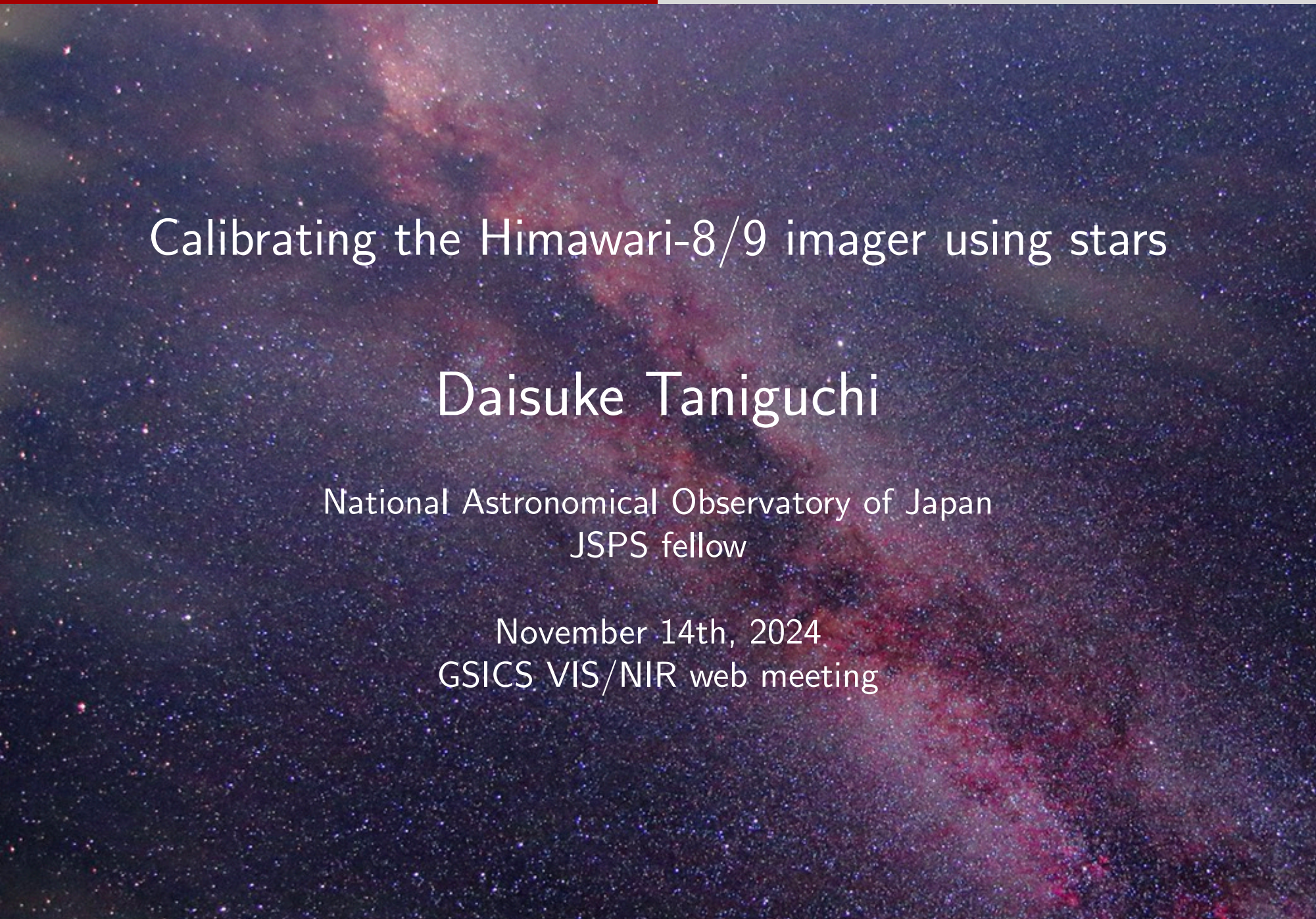


Calibrating the Himawari-8/9 imager using stars

Daisuke Taniguchi

National Astronomical Observatory of Japan
JSPS fellow

November 14th, 2024
GSICS VIS/NIR web meeting

Interdisciplinary study!

- I (astronomer) worked together with Kazuya Yamazaki (Univ. Tokyo; meteorologist) to publish a paper.

LETTERS
https://doi.org/10.1038/s41550-022-01680-5

nature astronomy

Check for updates

OPEN

The Great Dimming of Betelgeuse seen by the Himawari-8 meteorological satellite

Daisuke Taniguchi[1]✉, Kazuya Yamazaki[2] and Shinsuke Uno[3]

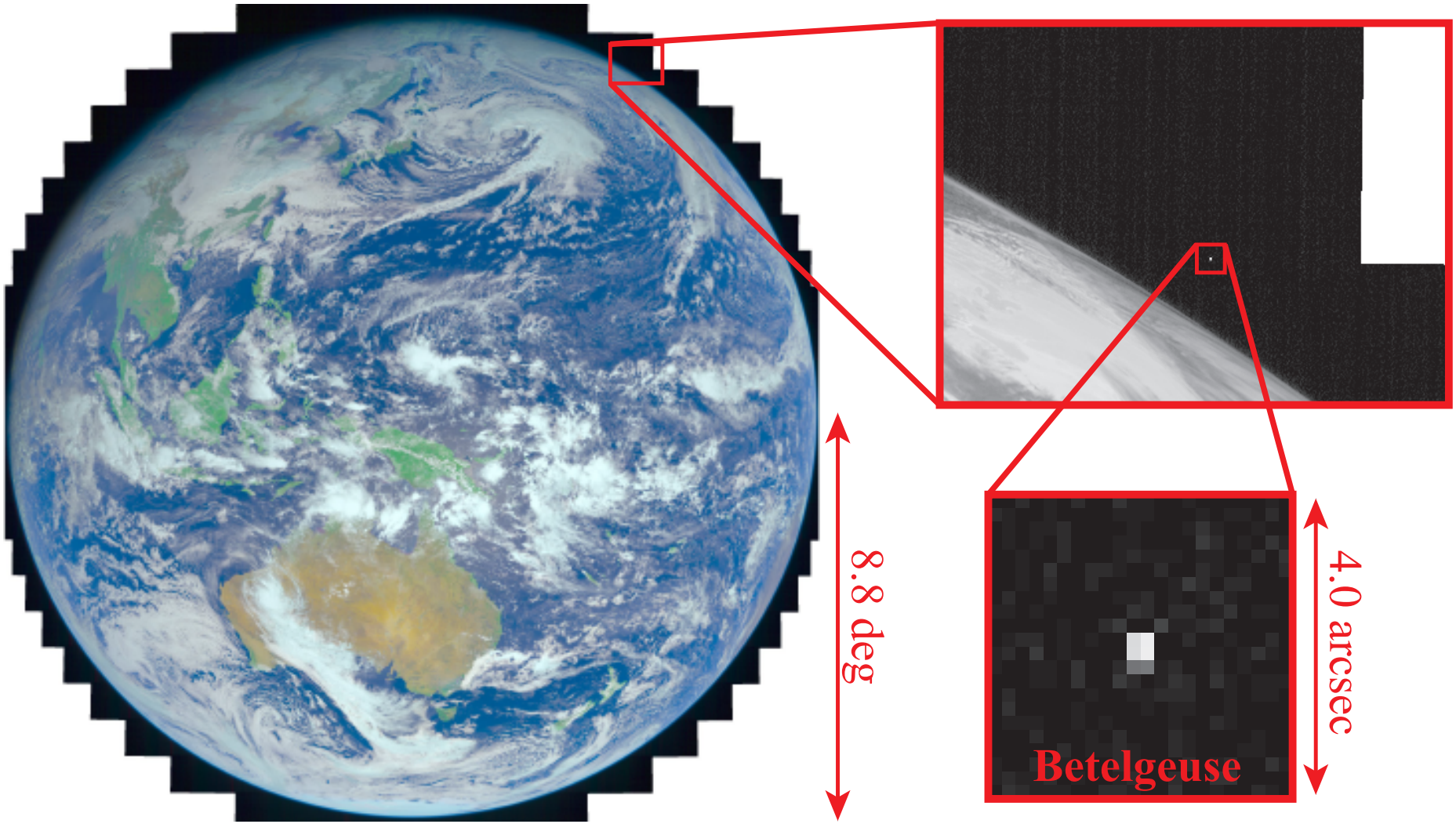
https://www.nature.com/articles/s41550-022-01680-5

1. Observation of stars with Himawari: case study with Betelgeuse (Taniguchi et al. 2022, Nature Astronomy, 6, 930)

2. Using Rigel and Procyon to calibrate Himawari-8/9

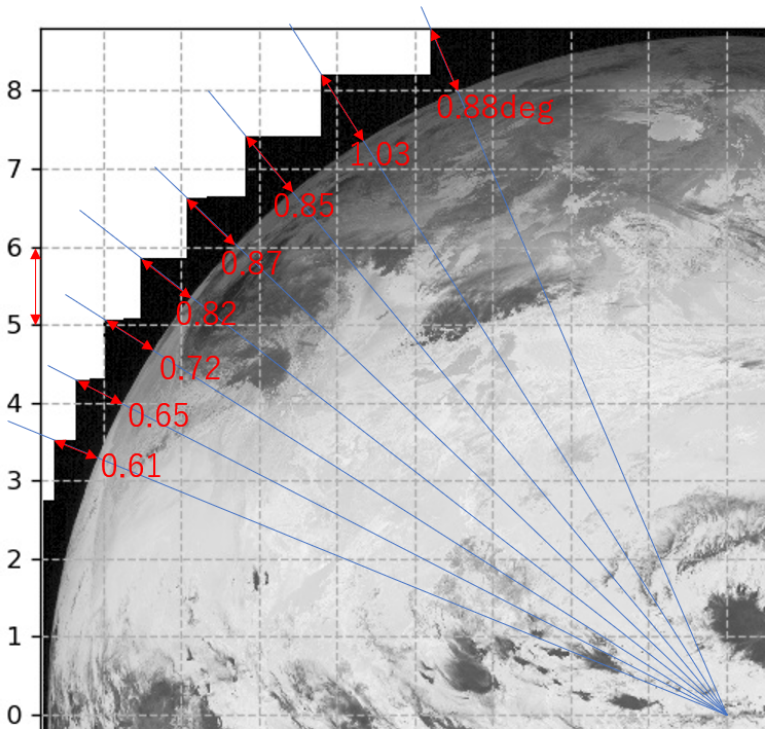
Pale red dot: a star in Himawari's image

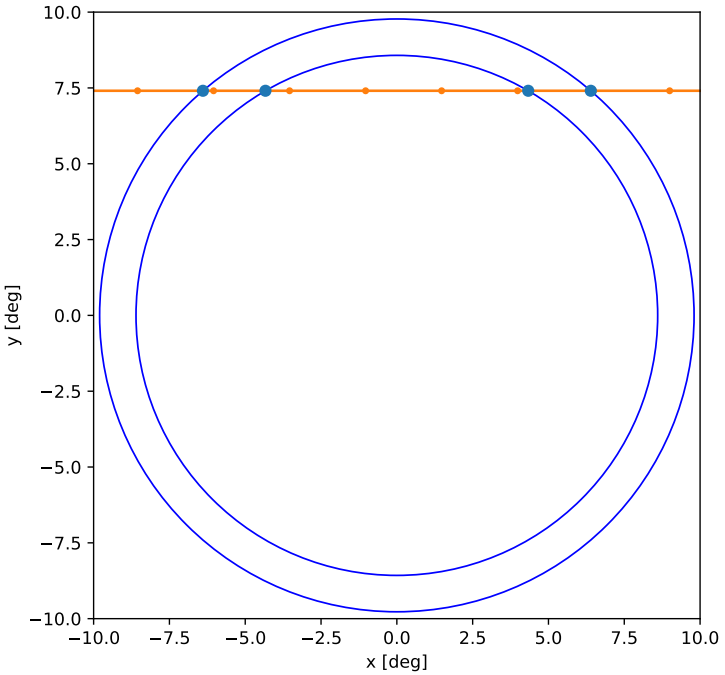
Betelgeuse: a variable, interesting star in the Orion constellation.



When stars photobombs in Himawari

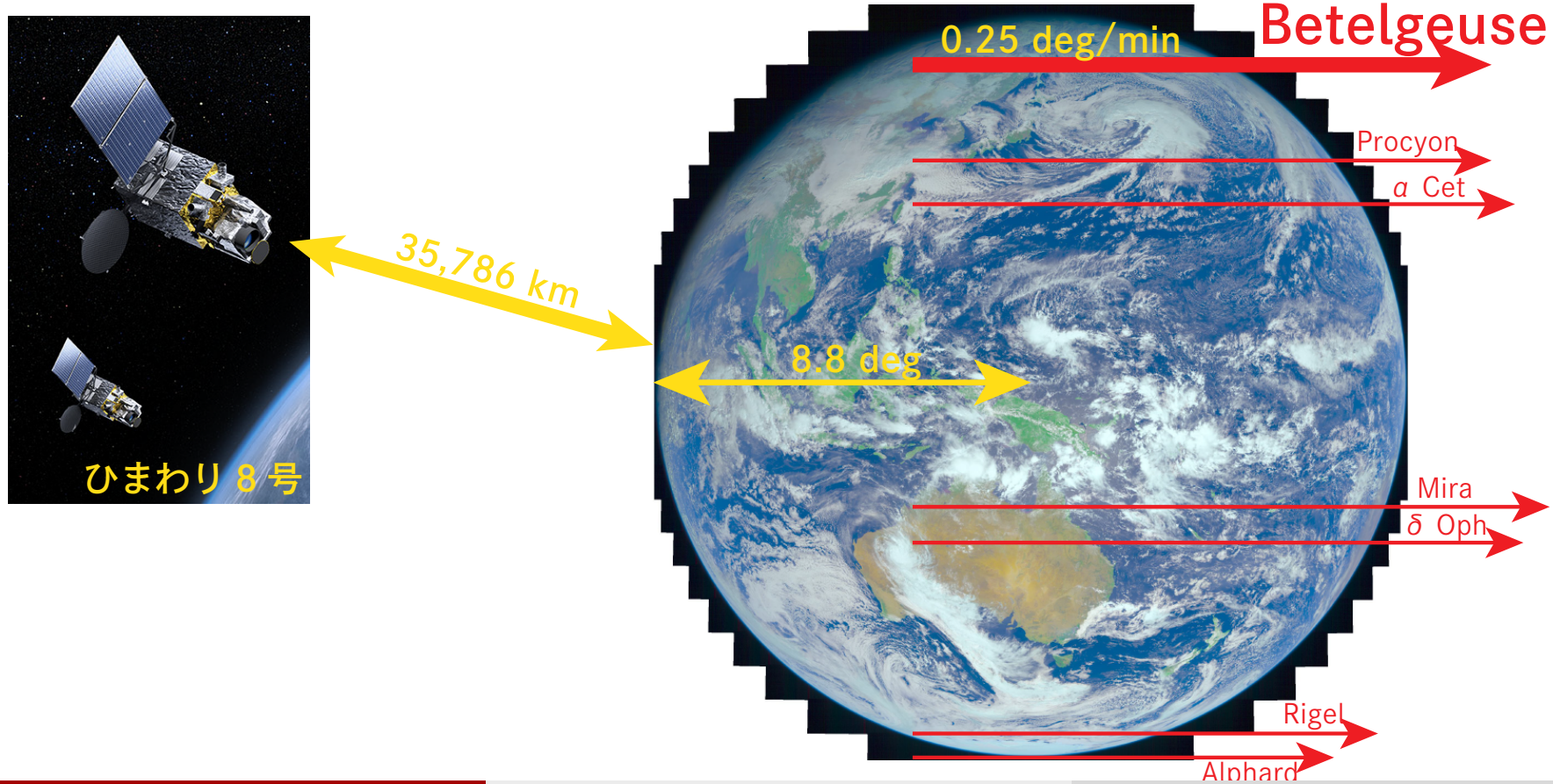
- Stars cross the Earth every day.
- Himawari observes and publishes (in L2b) the Earth (8.8 deg in radius) and maximum of 1.0 deg space.
- For example, Betelgeuse appears in the images of Himawari once per 1.8 days on average.





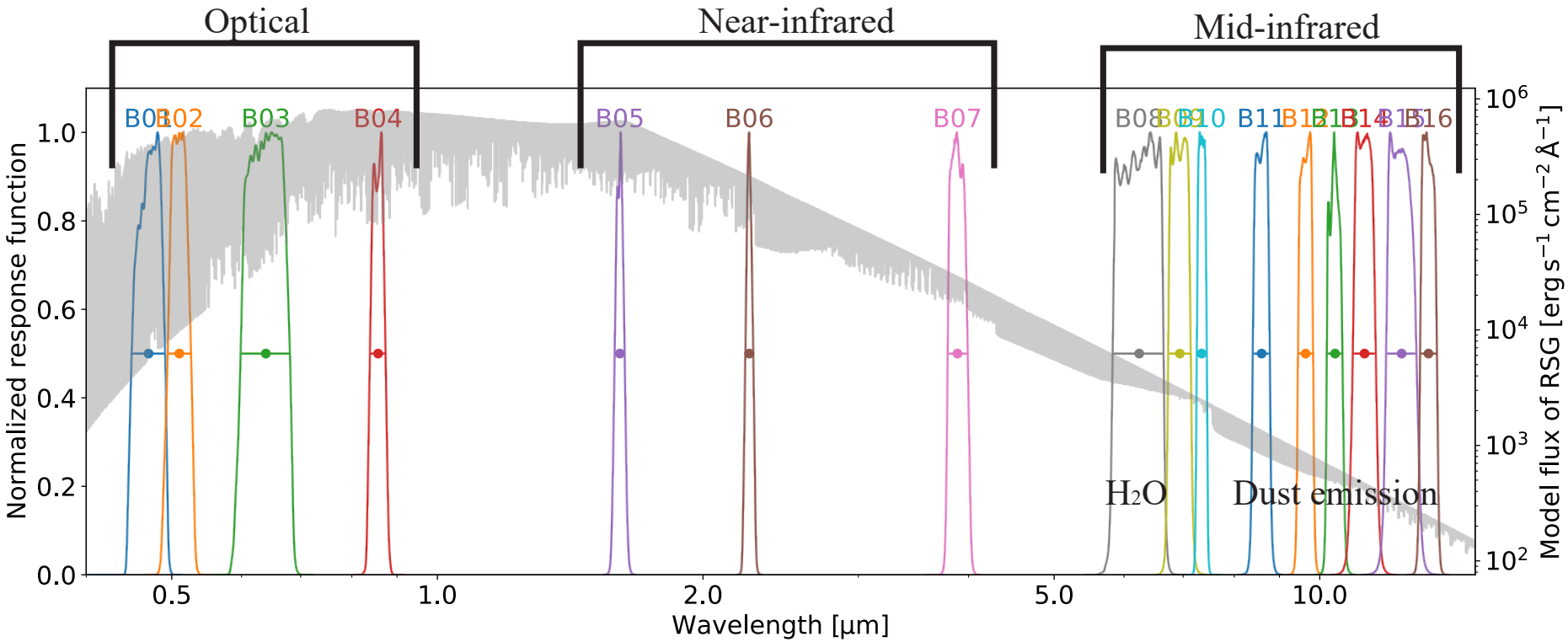
Himawari's field-of-view

- Extremely bright stars with $-8.8 < \mathrm{Dec} < +8.8$, every day.
  - Early-type stars: Rigel (B supergiant), Procyon (F dwarf)
  - Late-type stars: alf Cet, del Oph (KM giant),
    Betelgeuse (red supergiant), omi Cet (Mira)



Himawari's wavelength coverage

- 16 bands between optical and mid infrared.
- Advantage to observation in the mid infrared for dust and H_2O.
  →Useful for infrared astronomy! (observation of dust)



Himawari's limiting magnitude

Conditions of detectable stars:

- $|\mathrm{Dec}|$ between $\sim$ 1–8.8 deg
- One of the following:
  - Brighter than 3σ limiting magnitudes in two bands.
  - Extremely bright in one band.

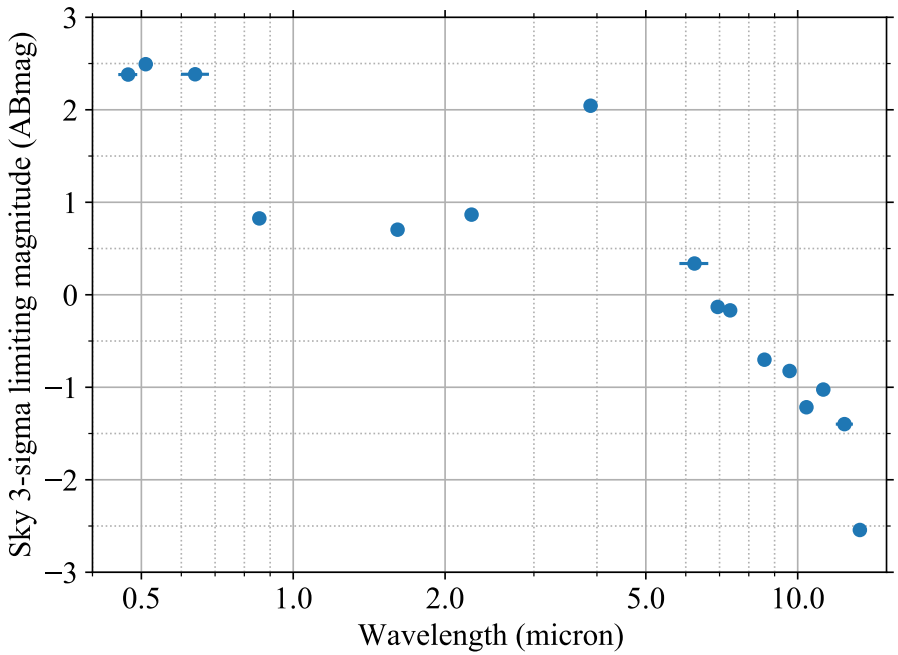


Table 1. Basic property of Himawari-8 AHI's image.

Band No.	λ_0 [a] (μm)	$\Delta\lambda$ [a] (μm)	Pixel scale (km) [b]	Pixel scale (arcsec)	m_{AB} [c] (mag)	F_{max} [d] (nW m^{-2} μm^{-1})
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	0.471	0.041	1.0	5.76	2.4	597
2	0.510	0.031	1.0	5.76	2.5	560
3	0.639	0.082	0.5	2.88	2.4	121
4	0.857	0.034	1.0	5.76	0.8	288
5	1.610	0.041	2.0	11.53	0.7	287
6	2.257	0.044	2.0	11.53	0.9	89.1
7	3.89	0.20	2.0	11.53	2.0	40.2
8	6.24	0.82	2.0	11.53	0.3	29.9
9	6.94	0.40	2.0	11.53	−0.1	36.4
10	7.35	0.19	2.0	11.53	−0.3	38.8
11	8.59	0.37	2.0	11.53	−0.7	50.6
12	9.64	0.38	2.0	11.53	−0.8	49.7
13	10.41	0.42	2.0	11.53	−1.2	47.5
14	11.24	0.67	2.0	11.53	−1.0	44.3
15	12.38	0.97	2.0	11.53	−1.4	39.4
16	13.28	0.56	2.0	11.53	−2.5	36.0

[a] Each band is centered on λ_0 with the FWHM of $\Delta\lambda$; see the response function via https://www.data.jma.go.jp/mscweb/en/himawari89/space_segment/spsg_ahi.html.

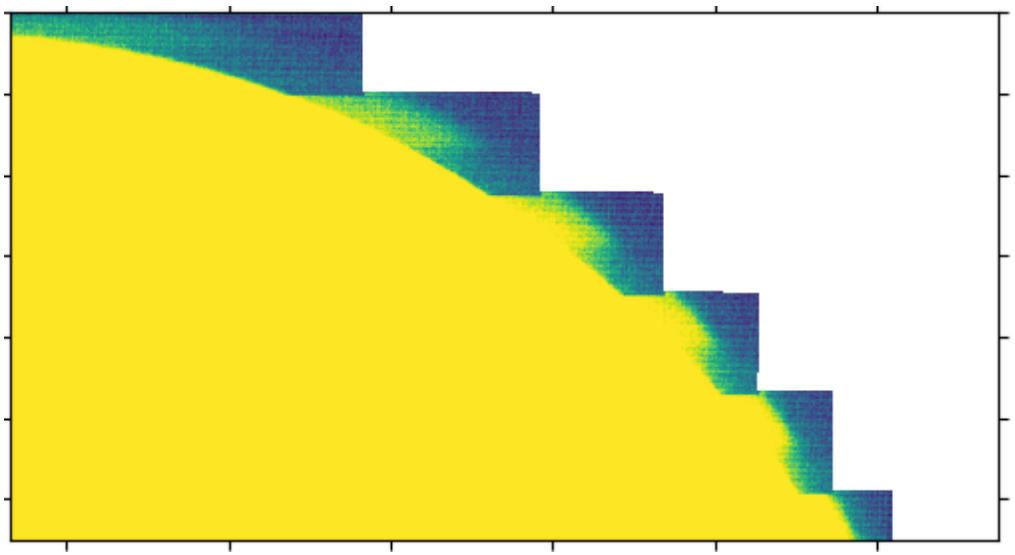
[b] Spatial resolution at the sub-satellite point, namely 35,786 km from the satellite.

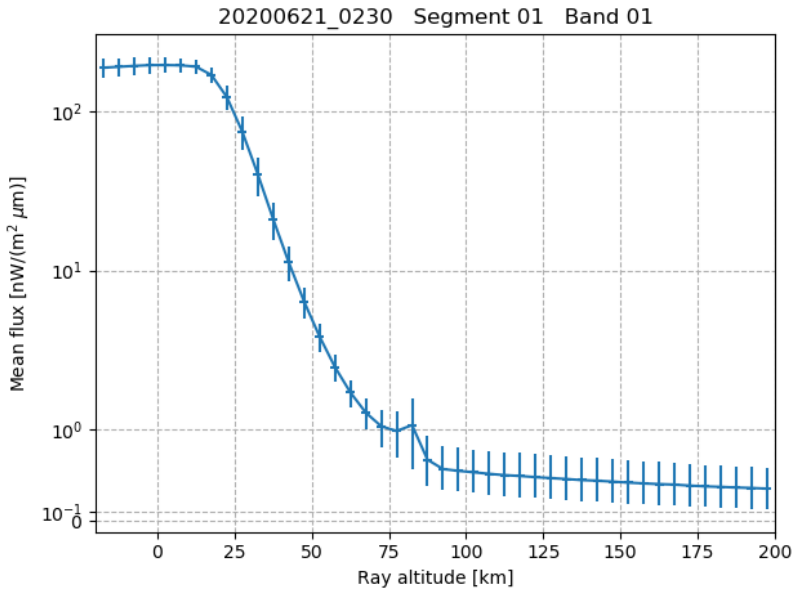
[c] Sky-3σ limiting AB magnitude of each band.

[d] Maximum valid flux per pixel in the calibrated L1B dataset.

Problem in photometry of stars

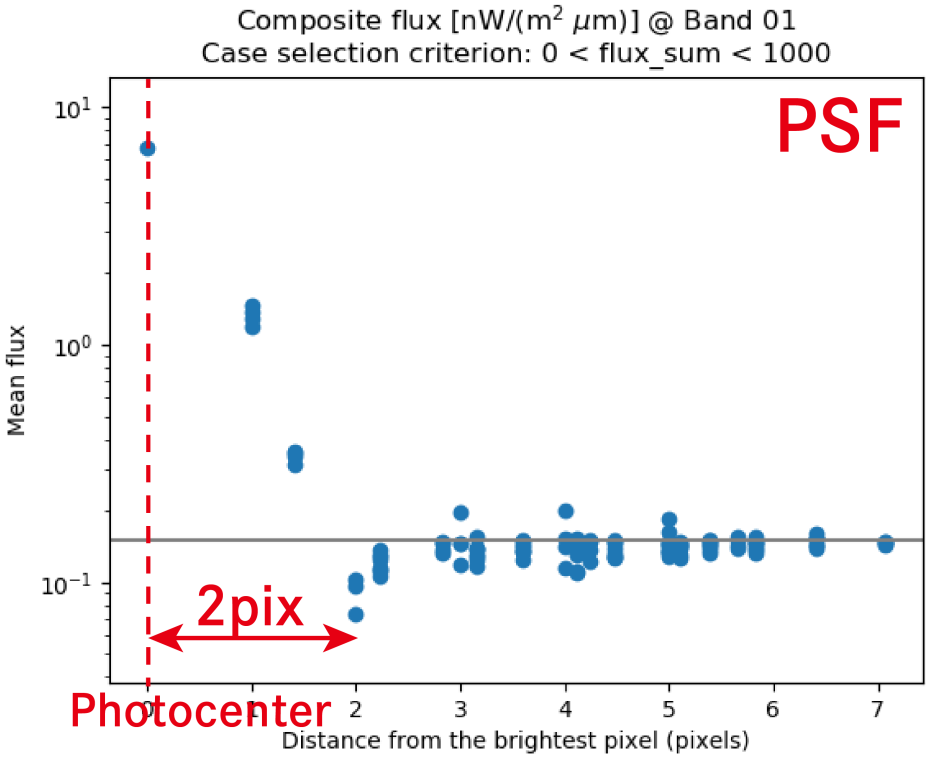
- There is very strong light around the Earth (maybe stray light?), which contaminates star observation.
- We subtracted the "sky background" by fitting the surface brightness with 2nd–4th order polynomials (next page).





Photometry of Himawari-8's 16-bands images

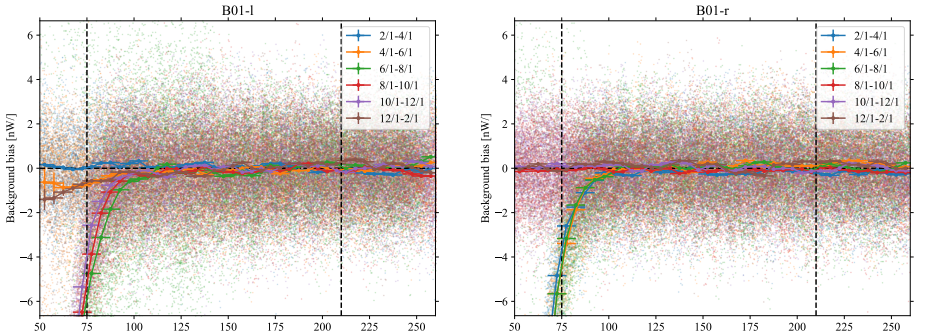
- Reduced data is distributed by Japan Meteorological Agency.
  - Flux-calibrated
  - Geometrically transformed (11.5 arcsec/pix @ infrared)
- PSF $\sim 2\,\mathrm{pix} \rightarrow 7 \times 7\,\mathrm{pix}^2$ aperture photometry



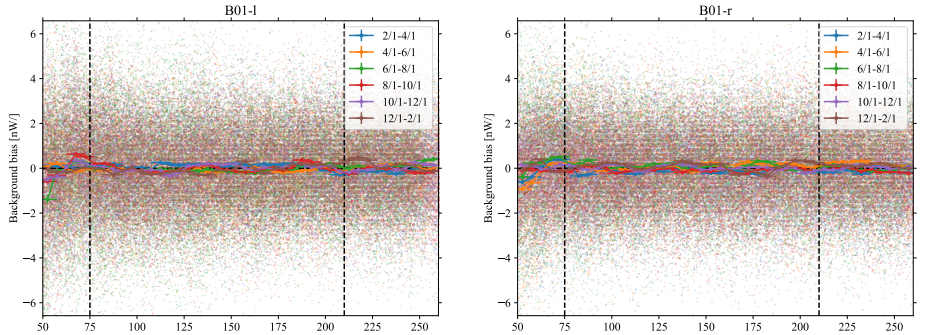
Result of background subtraction

- We "observed" a blank sky region with or without background subtraction.
- Left (w/o background subtraction): there is a strong bias in the measured flux depending on season (i.e., which direction the satellite sees).
- Right (with background subtraction): the bias is reduced significantly.

without

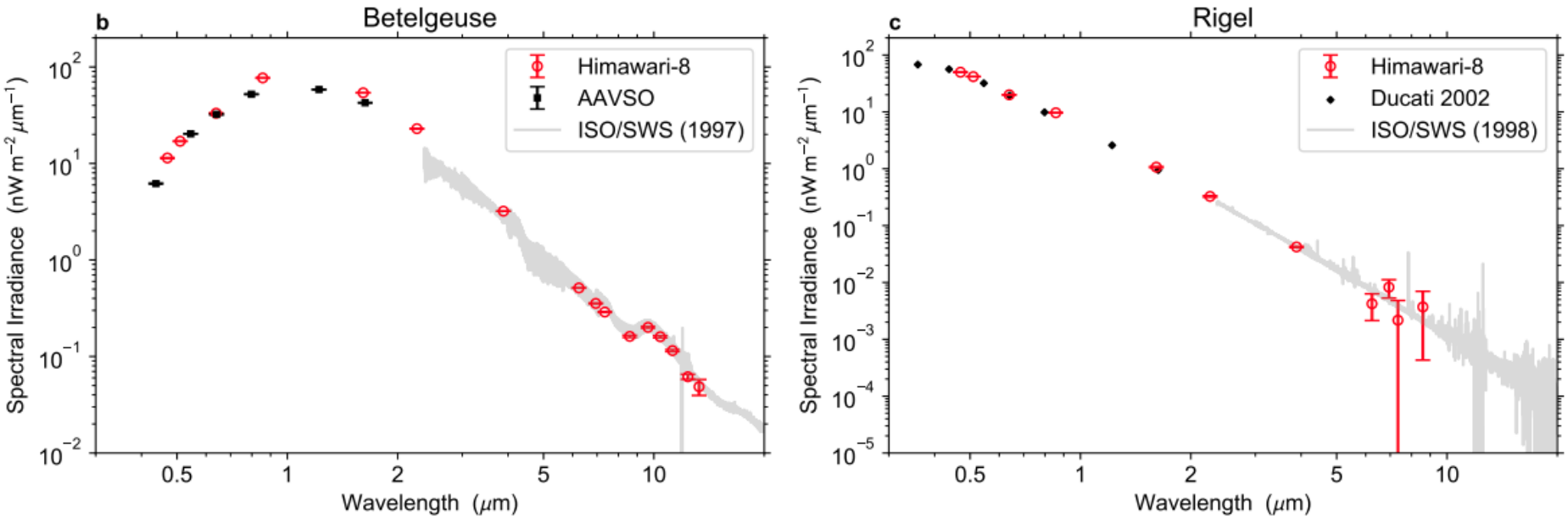


with



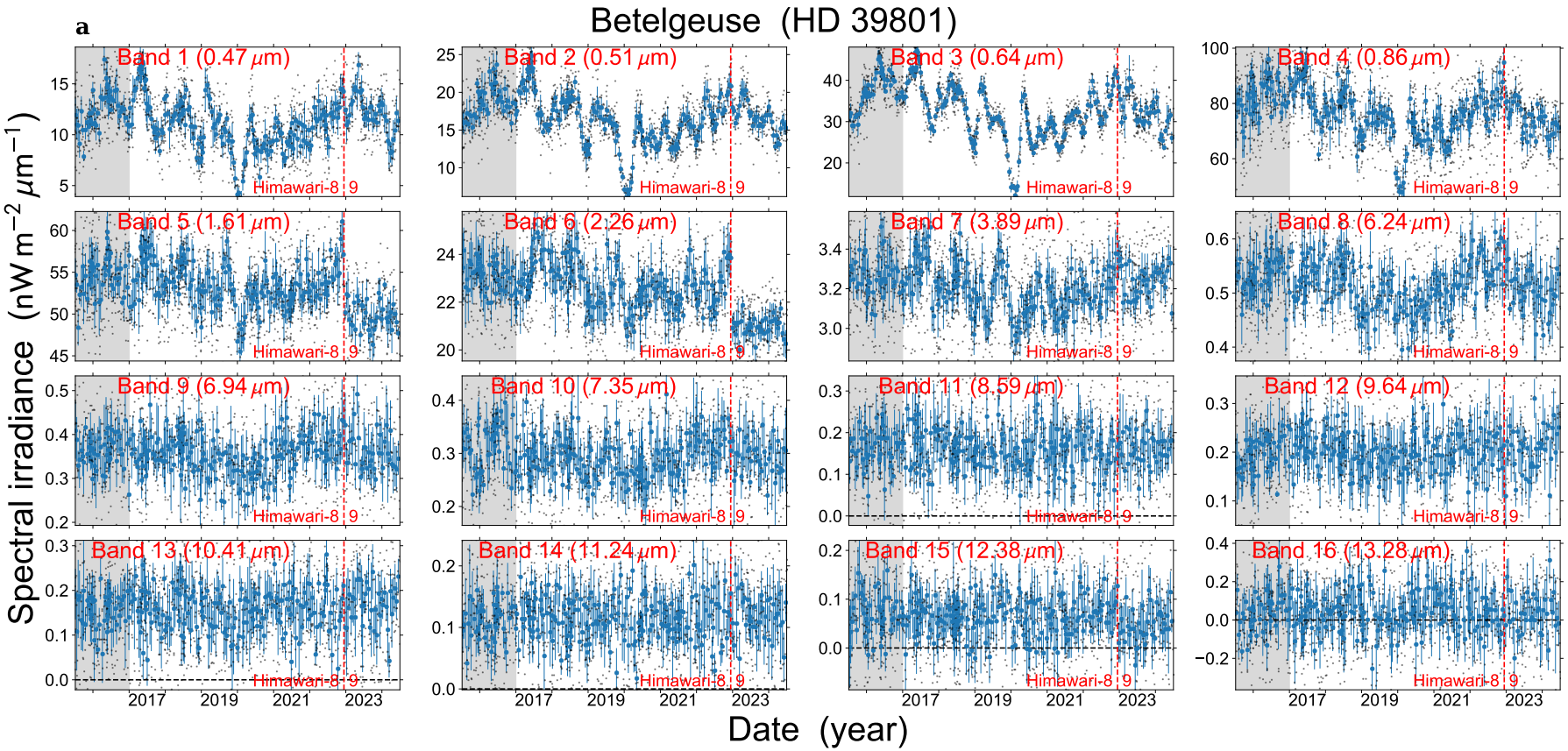
Result: spectrum of Betelgeuse and Rigel

- We obtained spectral-energy distribution (more-or-less; 10% level) consistent with astronomical observations.
- This supports the reliability of the Himawari photometry.



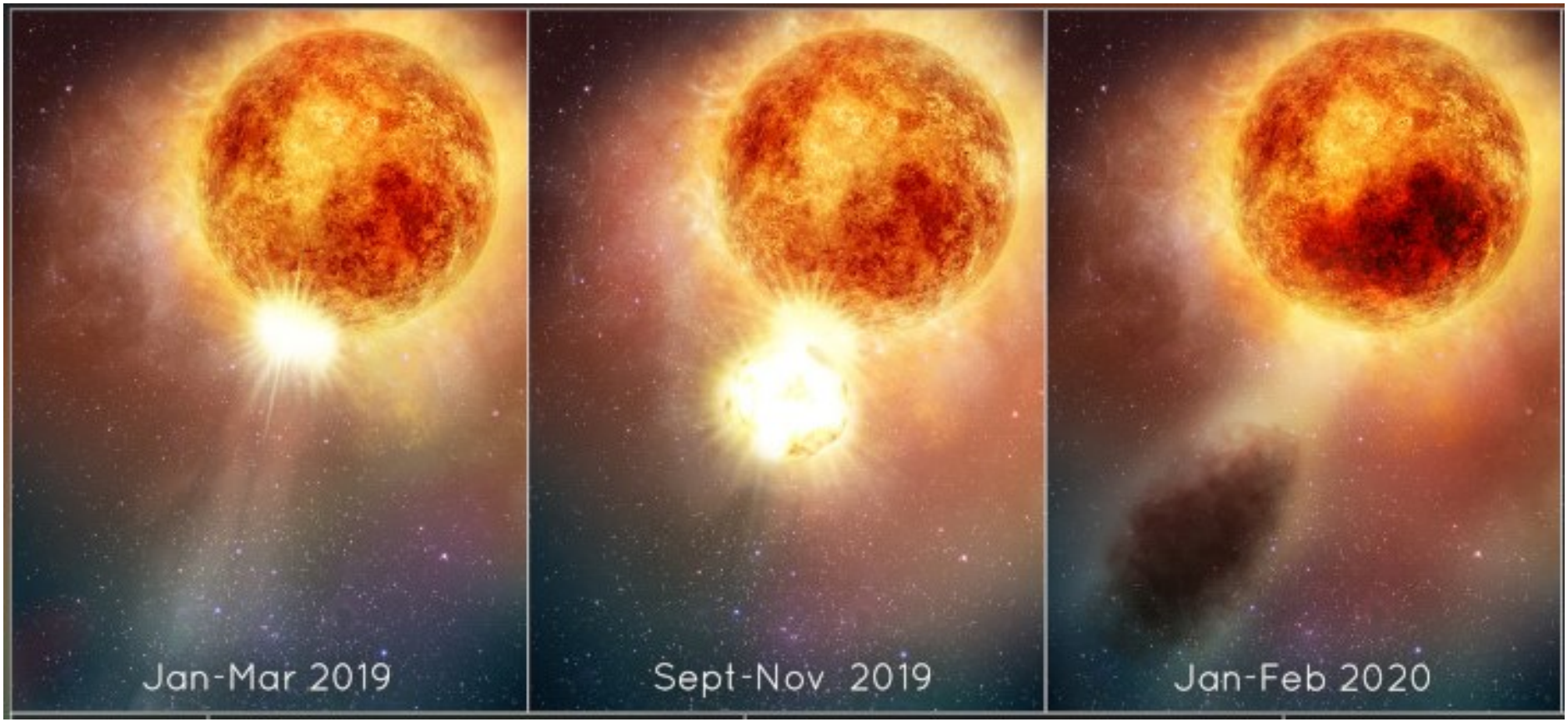
Result: 7.5-year light curve of Betelgeuse

- Typically, once per 1.8 days, un-interrupted by the Sun!
- Optical, near infrared, and even mid infrared!



Main astronomical result: Great Dimming

We confirmed that a circumstellar dust cloud shaded Betelgeuse in 2020 (Great Dimming).

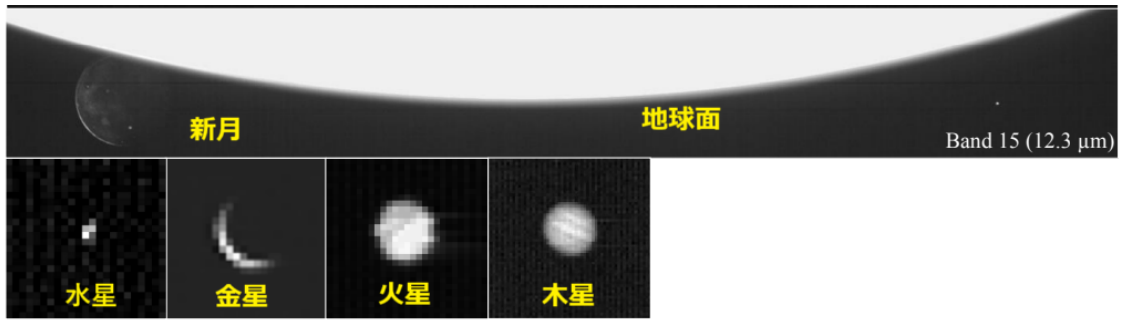


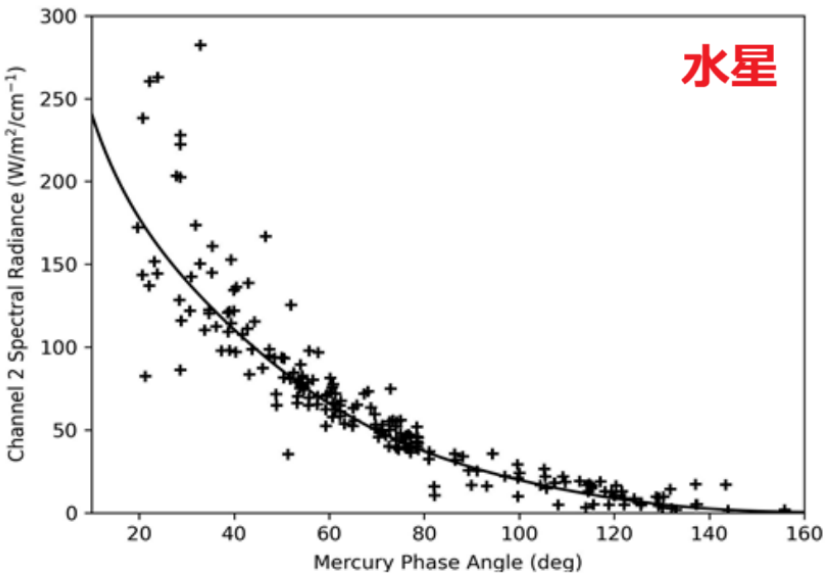
1. Observation of stars with Himawari: case study with Betelgeuse (Taniguchi et al. 2022, Nature Astronomy, 6, 930)

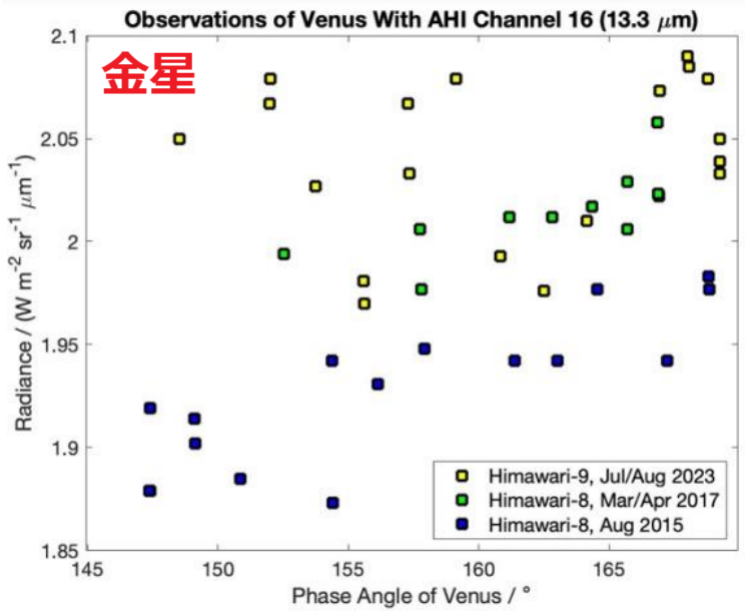
2. Using Rigel and Procyon to calibrate Himawari-8/9

Previous works: using planets

- Moon and planets have been used for cross calibration.
- There are a few percent level scatter/bias in planet observation?



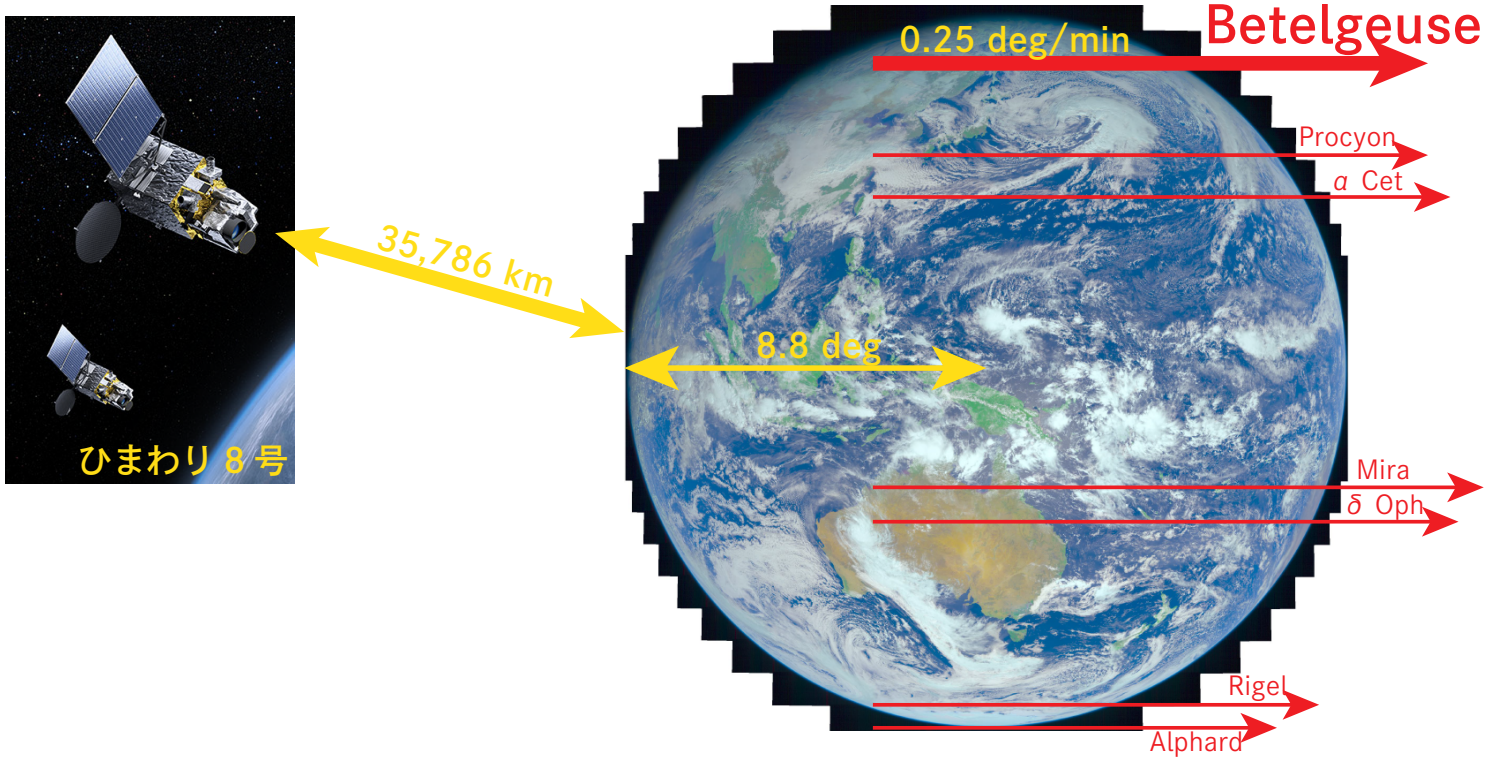




(Fulbright et al. 2023; Burgdorf & **DT** 2024)

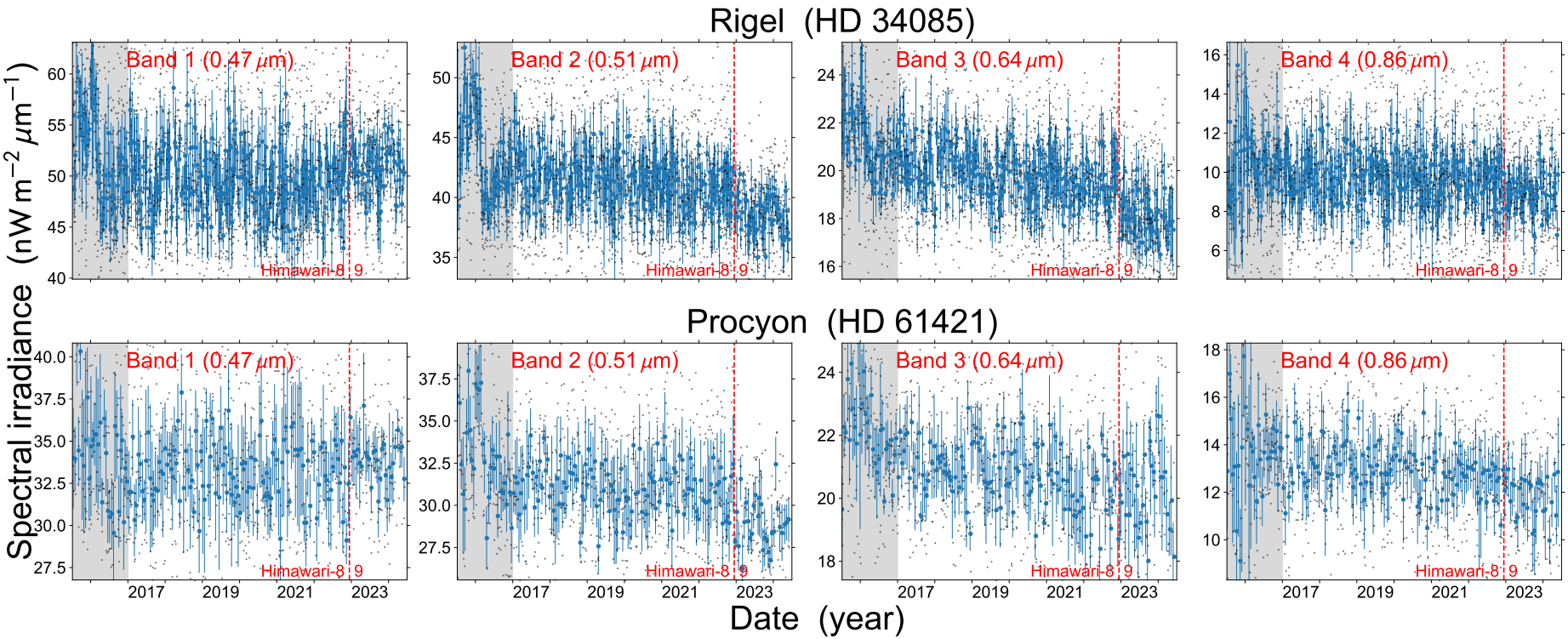
This talk: Is Himawari star observation reliable?

- Himawari has been extensively checked against surfaces (e.g., Earth and Moon), but not for point sources (e.g., planets and stars).
- We use Rigel and Procyon (non-variable stars) for check the consistency between Himawari-8/9 optical bands.



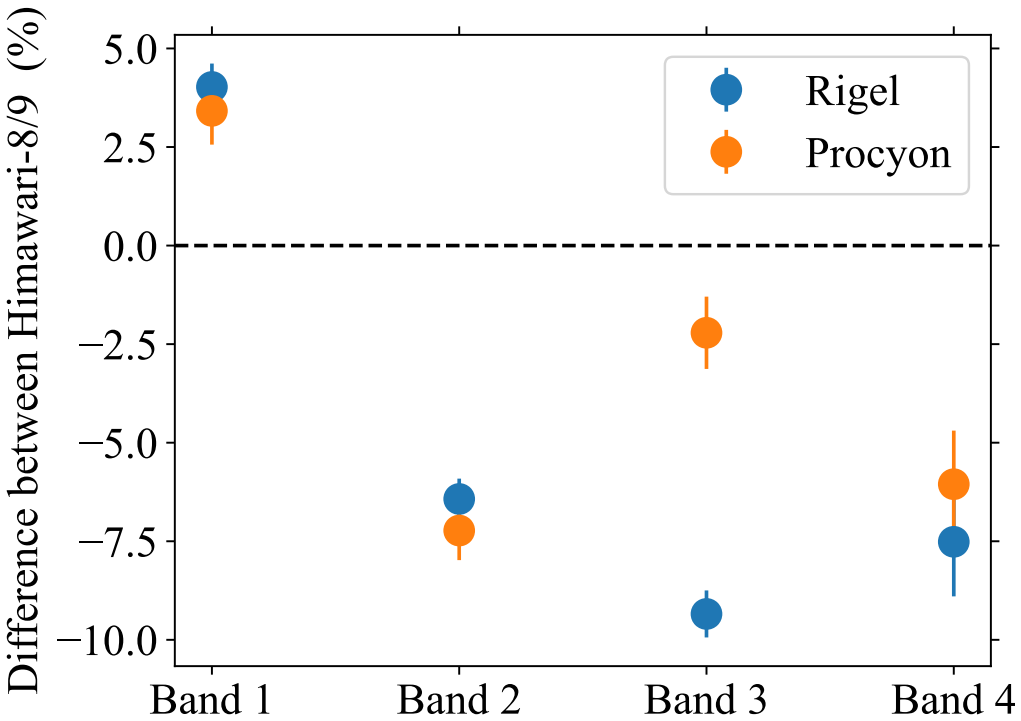
Optical light curve of Rigel and Procyon

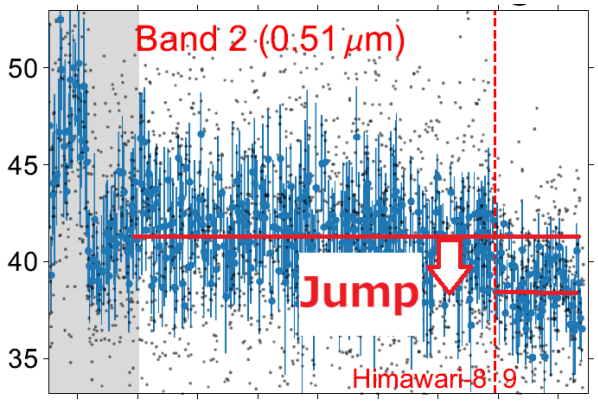
- Within Himawari-8 (or 9) observations, fluxes of Rigel and Procyon are constant (within $\lesssim$5%), which is expected.
- However, there is a difference between Himawari-8 and 9 up to $\sim$10%?

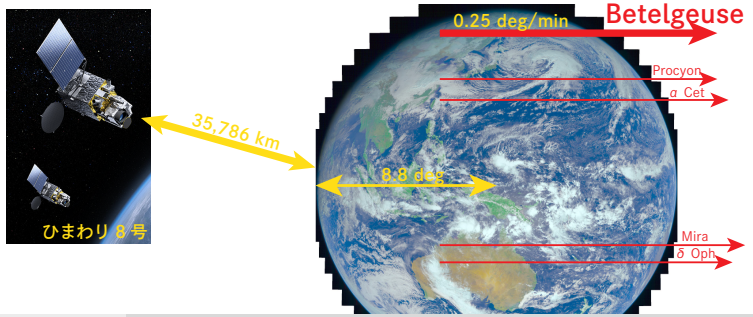


Flux difference between Himawari-8 and 9

- Bands 1, 2, and 4:
  - There are difference in flux between Himawari-8/9 by 3–8%.
  - The amount of difference is similar between Rigel and Procyon.
    →Difference in calibration for point source for Himawari-8/9?
- Band 3:
  - Himawari-8/9 difference is different between the two! Why?

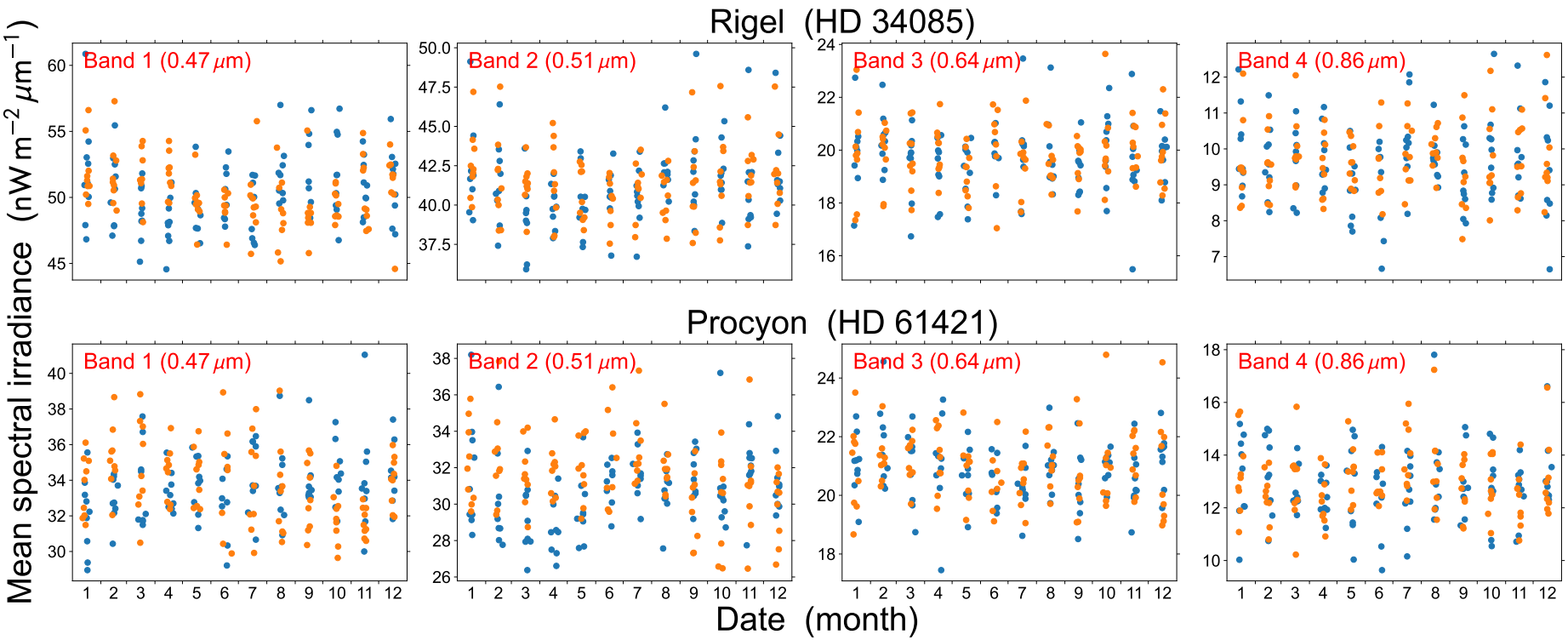






Mean flux for each month

- Midnight observation (i.e., the satellite faces towards the Sun) could be affected by the Sun.
  - Rigel: mid January
  - Procyon: late February–early March
- There seems no (detectable) month-dependent behavior?



Summary

- We use Rigel and Procyon (non-variable stars) to compare Himawari-8/9 optical fluxes.
- There are difference between Himawari-8/9 by up to ∼10%. This should be corrected for Betelgeuse observation.