

## B11

## 光・赤外大学間連携による Starlink Visorsat の等級評価 Magnitude Estimation of Starlink's Visorsat by the OISTER Collaboration

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SpaceX は高速インターネット通信サービスの充実を目的として 2019 年 5 月に 60 機の Starlink 衛星を低軌道(550km)に打ち上げ, 将来的に 12,000 機に達する予定である. 一方で, Starlink 衛星は低軌道ゆえに太陽の反射光が明るく見えて, 地上観測に多大な影響を残すことが示唆されている. 近年, SpaceX は太陽光入射を遮り反射を抑えるため, 衛星本体に庇を装着したバイザーサット(Visorsat)を複数開発し 2020 年 6 月に打ち上げた.

我々は紫外から近赤外の領域で Visorsat と庇のない通常のスターリンク衛星の一つ(STARLINK-1113)の等級の比較を行うべく, 光・赤外大学間連携(OISTER)による連携観測を実施した. 結果として, 各波長で Visorsat(7 等程)は 1 等級程度 STARLINK-1113(6 等程)より暗くなり庇の効果を実証することができた. 一方で, 地上観測への影響は未だに無視できず, 更なる反射逓減対策が必要である.

SpaceX launched 60 Starlink satellites into low orbit (550 km) in May 2019 for the purpose of enhancing high-speed Internet communication services, reaching 12,000 satellites in the future. On the other hand, it has been suggested that sunlight reflection from the Starlink satellites strongly shows a significant impact on ground-based observations due to their low orbit. In recent years, SpaceX has developed Visorsat, which are equipped with a sun visor on the main body of the satellite to block the incoming sunlight and suppress the reflection, and its first satellite was launched in June 2020.

We conducted cooperative observations by optical and infrared synergetic telescopes for education and research (OISTER) to compare the magnitudes of Visorsat and one of the ordinary Starlink satellites without the sun visor (STARLINK-1113) in the UV to near-infrared region. As a result, Visorsat (~ 7 mag) is fainter than STARLINK-1113 (~ 6 mag) by about 1 mag at each wavelength region, demonstrating a shading effect of the sun visor. On the other hand, the effect of Visorsat on ground-based observations is still not negligible, and further measurements for dimming of reflections are needed.

2022/11/28 -30

第10回スペースデブリワークショップ

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# 光・赤外大学間連携による Starlink Visorsat の等級評価

Magnitude estimation of Starlink's Visorsat by  
the OISTER collaboration

東京大学 天文学教育研究センター

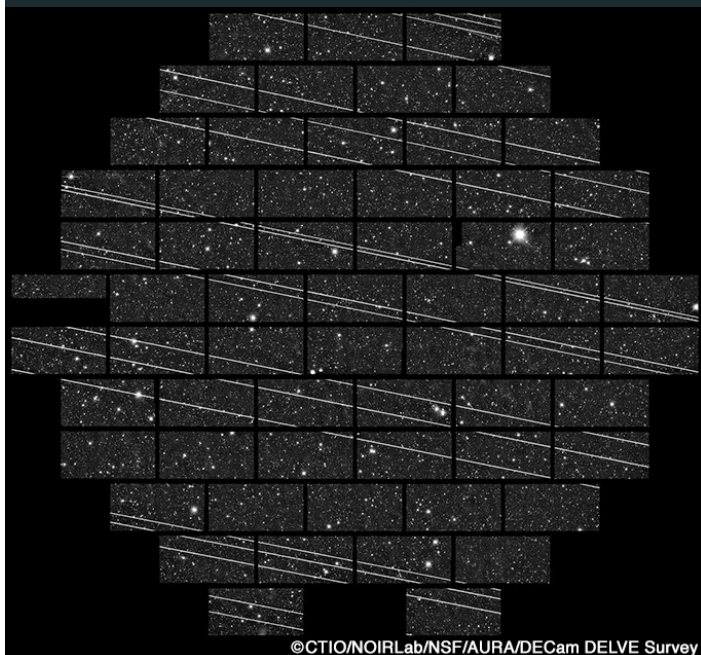
特任研究員

堀内 貴史 / Takashi Horiuchi



## Light pollution from the Starlink satellites

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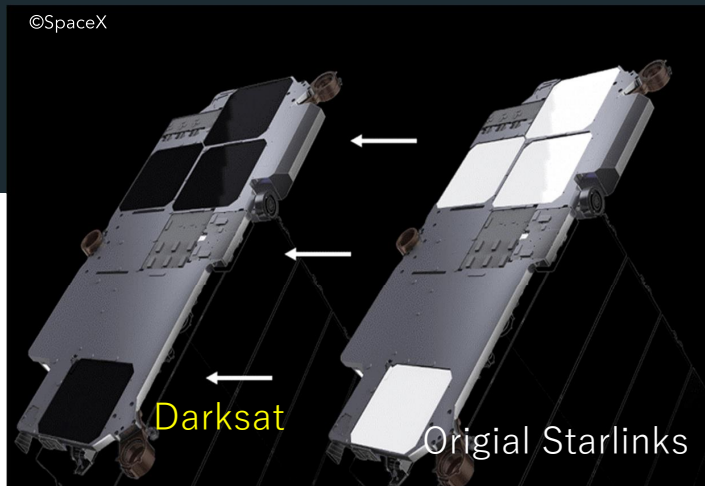


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- ☐ SpaceX launched the first 60 Starlink satellites on May 24, 2019 for high-speed internet communications.
- ☐ However, the mega-constellation including the Starlink satellites pollutes the environment of astronomical observations (orbital height: **550 km**).
  - IAU expressed the concern on that incident.
- ☐ SpaceX plans to launch 12,000 satellites until mid 2020s.

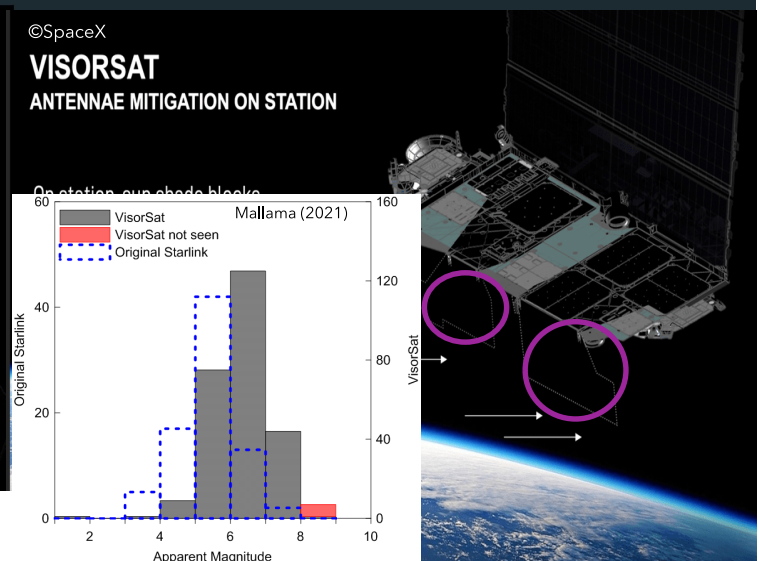
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## Light pollution countermeasures by SpaceX - Darksat and Visorsat -



Magnitude at the orbital height of 550 km  
(e.g., Horiuchi+2020; Tregloan-Reed+2020)

- Original Starlink (STARLINK-1113)  
5.33 ( $g'$ ), 5.60 ( $R_c$ ), 4.25 ( $I_c$ )
- Darksat  
6.10 ( $g'$ ), 6.00 ( $R_c$ ), 5.65 ( $I_c$ )



Multicolor magnitudes of Visorsat are not well known. →→ Our motivation !

## Observation with the OISTER collaboration

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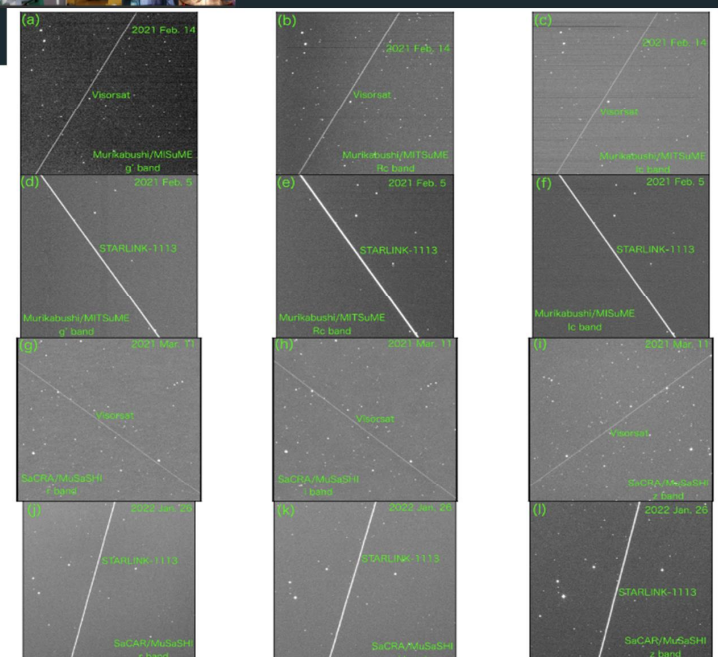
- Simultaneous multicolor observations with the Japanese OISTER collaboration

→ capture the trail of Visorsat and STARLINK-1113 (original satellite)

- Telescopes/instruments:

- Murikabushi and Akeno 50 cm/MITSuME ( $g$ ,  $R$ ,  $I$ )
- SaCRA/MuSaSHI ( $r$ ,  $i$ ,  $z$ )
- Kanata/HONIR ( $B$ ,  $V$ ,  $H$ )
- Nayuta/NIC ( $J$ ,  $H$ ,  $K$ )
- Kyoto 40cm ( $B$ )
- Prika/MSI ( $U$ )
- PROMPT6@CTIO ( $V$ ; other than OISTER)

12 bands



# Typical magnitudes of Visorsat

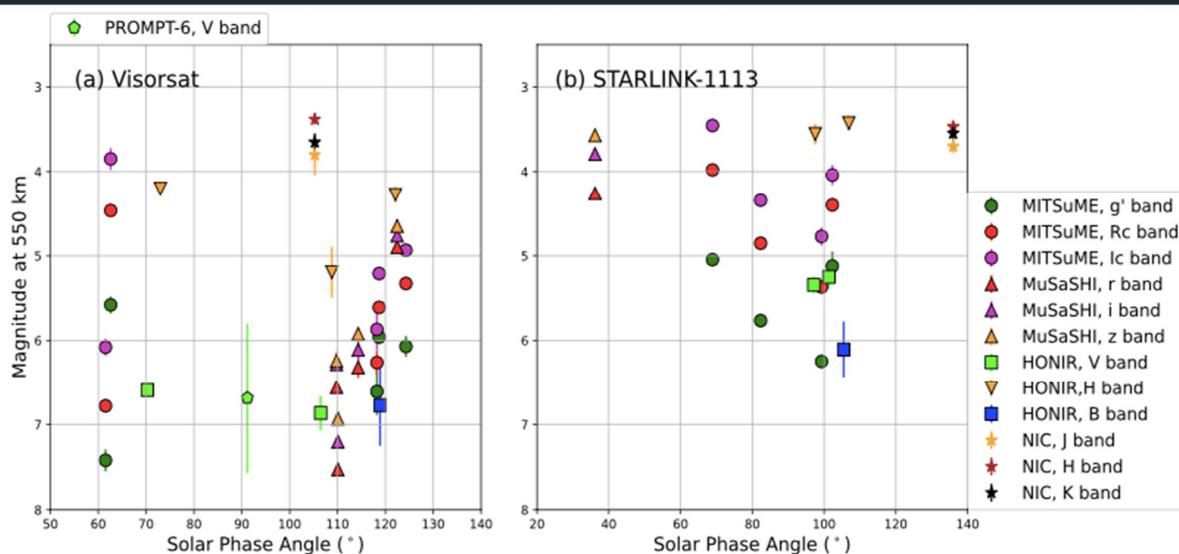
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- Magnitudes at a 550 km height.
- U band magnitude was not able to obtain because of the sensitivity of Pirka/MSI (Hokkaido Univ.).
- Visorsat is dimmer than STARLINK-1113 as a trend.
- The longer the observed wavelength, the brighter the satellite magnitudes become.

Band	Visorsat (mag)	STARLINK-1113 (mag)
B	$6.77 \pm 0.48$	$6.11 \pm 0.33$
V	$6.61 \pm 0.12$	$5.25 \pm 0.13$
g'	$6.07 \pm 0.12$	$5.12 \pm 0.17$
Rc	$5.32 \pm 0.04$	$4.40 \pm 0.08$
Ic	$4.94 \pm 0.07$	$4.04 \pm 0.12$
r	$4.90 \pm 0.02$	$4.26 \pm 0.03$
i	$4.76 \pm 0.02$	$3.79 \pm 0.03$
z	$4.65 \pm 0.02$	$3.57 \pm 0.02$
J	$3.80 \pm 0.24$	$3.70 \pm 0.08$
H	$3.38 \pm 0.06$	$3.47 \pm 0.05$
K	$3.65 \pm 0.11$	$3.55 \pm 0.07$

## Phase angle dependence on magnitudes

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- The satellite magnitudes are minimized around solar phase angle (Sun-Sat-Observer) of 90° .
- The magnitudes of Visorsat are ~ 1 mag dimmer than those of STARLINK-1113.



# Blackbody model of the satellite flux

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- In order to estimate the albedo,  $a_{\text{mod}}$ , of the starlink satellites, we construct the blackbody model of the satellite (AB) flux.

- Assuming  $a_{\text{mod}}(\text{STARLINK-1113}) \sim a_{\text{mod}}(\text{Visorsat})$ , we estimated covering factor,  $C_f$ , of the sun visor on Visorsat (where  $U_f = 1 - C_f$ ).

$$F_{\text{RS}} = \pi \left( \frac{R_{\odot}}{1 \text{ au}} \right)^2 B(\lambda, T_{\odot}) a_{\text{mod}} p(\theta) U_f \left( \frac{r_{\text{sat}}}{h_T} \right)^2 \frac{\lambda^2}{c}$$

$$F_{\text{REs}} = a_E \left( \frac{R_{\oplus}}{R_{\oplus} + h_T} \right)^2 \left\{ 1 - \left( \frac{R_{\oplus}}{R_{\oplus} + h_T} \right)^2 \right\} \frac{p(\phi)}{p(\theta) U_f} F_{\text{RS}}$$

$$F_{\text{TS}} = \pi \epsilon \left( \frac{r_{\text{sat}}}{h_T} \right)^2 B(\lambda, T_{\text{sat}}) \frac{\lambda^2}{c}$$

$$F_{\text{TE}} = \pi \epsilon \left( \frac{R_{\oplus}}{R_{\oplus} + h_T} \right)^2 B(\lambda, T_E) a_{\text{mod}} \left( \frac{r_{\text{sat}}}{h_T} \right)^2 \frac{\lambda^2}{c},$$

$F_{\text{RS}}$  : sunlight reflection

$F_{\text{REs}}$  : earthshine reflection

$F_{\text{TS}}$  : thermal radiation of the satellite

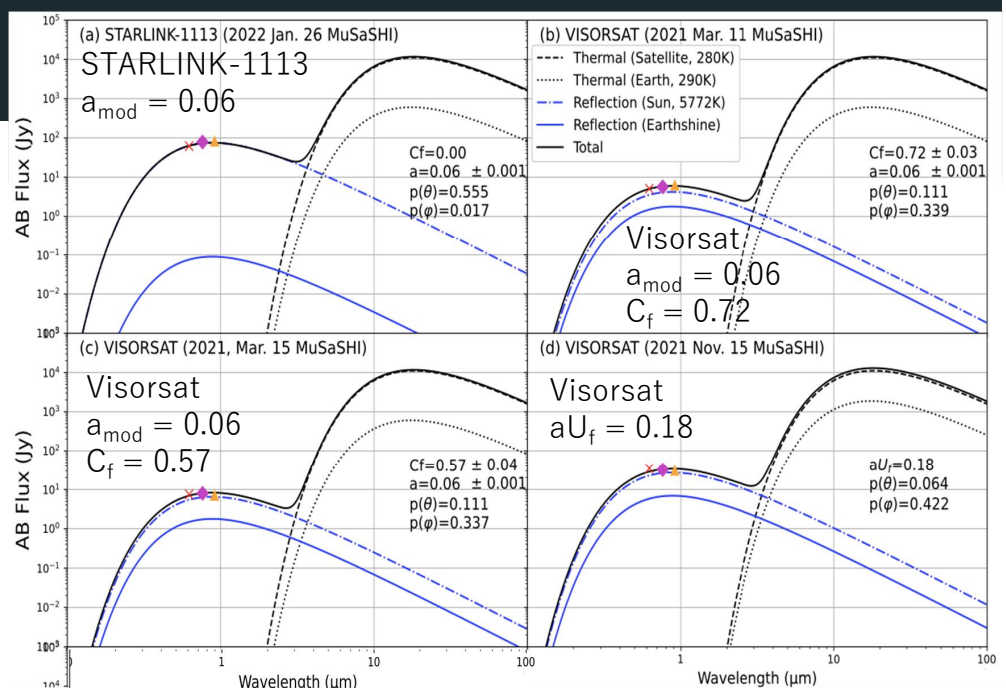
$F_{\text{TE}}$  : reflection of Earth's thermal radiation

## Blackbody fitting to the satellite flux (ex1)

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- Model fitting to r, i, and z band flux obtained with SaCRA/MuSaSHI (Saitama Univ.).

- Together with the results with other telescopes, the range of the covering factor is  $0.18 < C_f < 0.92$ .

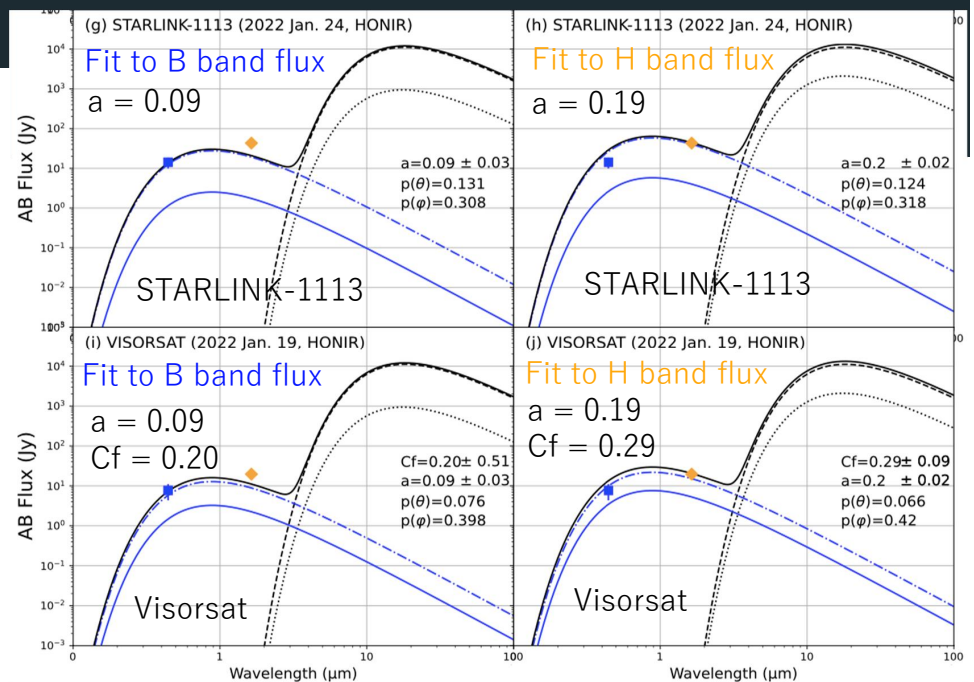


# Flux model for B and H bands (ex2)

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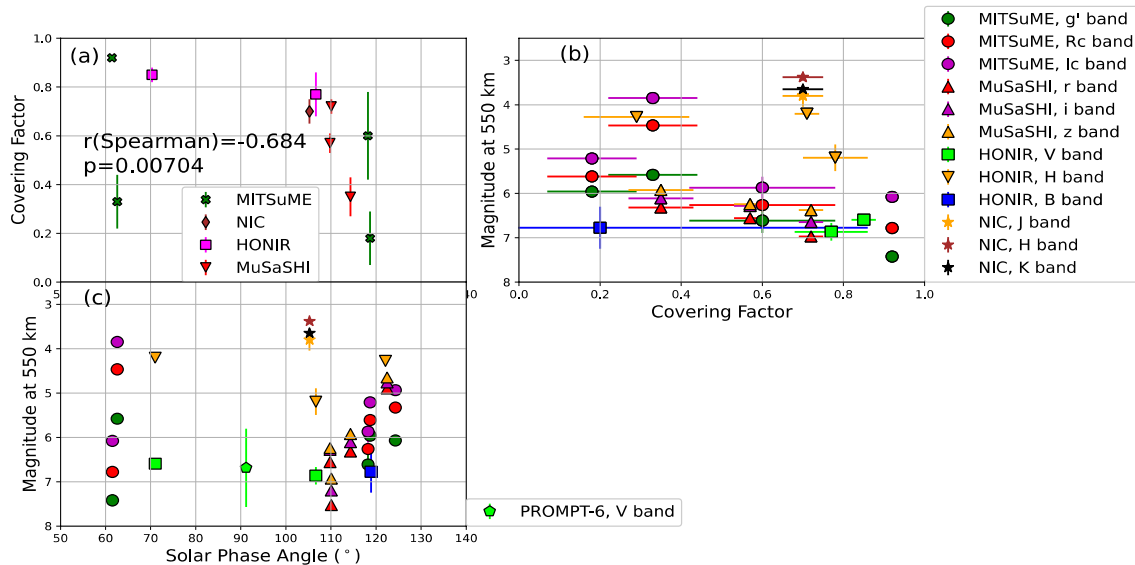
□ B and H bands flux obtained with Kanata/HONIR (Hiroshima Univ.)

- The albedo of H band is about twice larger than that of B band.
- The reflectivity of satellite surface materials likely become higher at the longer wavelength.



## The relation between covering factor, brightness, and phase angle

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The smaller the covering factor is, the brighter the magnitudes of Visorsat tend to become.

# Summary

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□ We observed Visorsat and STARLINK-1113 with the OISTER collaboration.

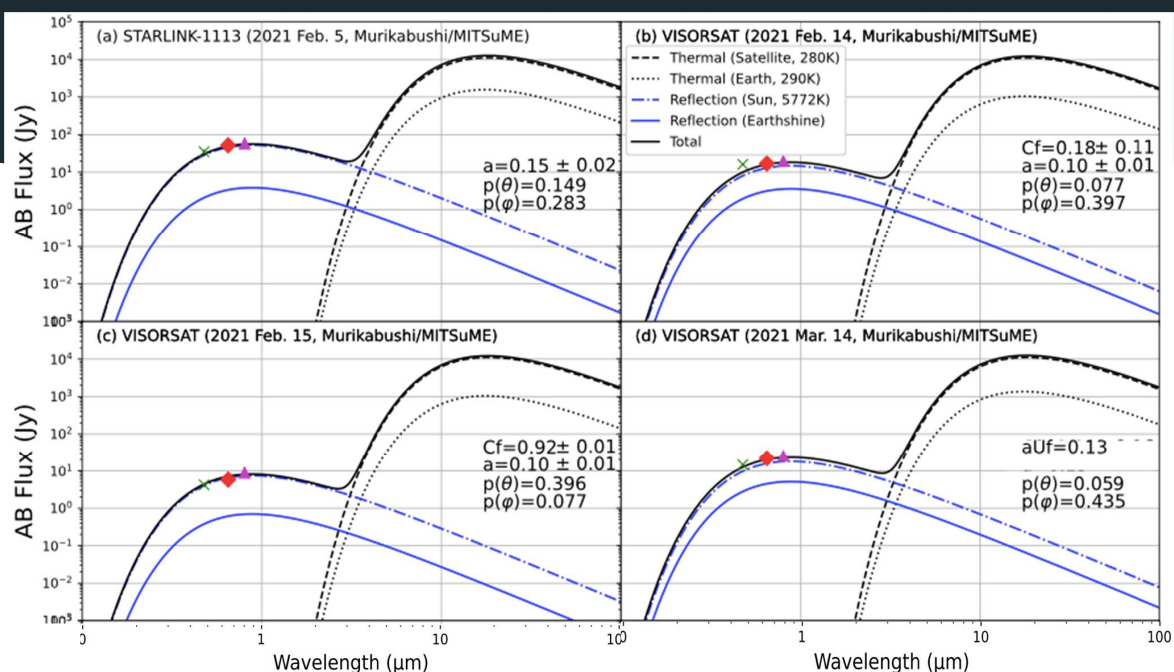
- In most cases, **Visorsat is dimmer than STARLINK-1113** as a trend.
- By assuming the blackbody radiation, we estimated a covering factor,  $C_f$ , and its range of  $0.18 < C_f < 0.92$ .
- The reflectivity of satellite surface materials likely become higher at the longer wavelength.

☆ While we showed the shading effect of the sun visor of Visorsat, the observational impact from Visorsat is still profound.

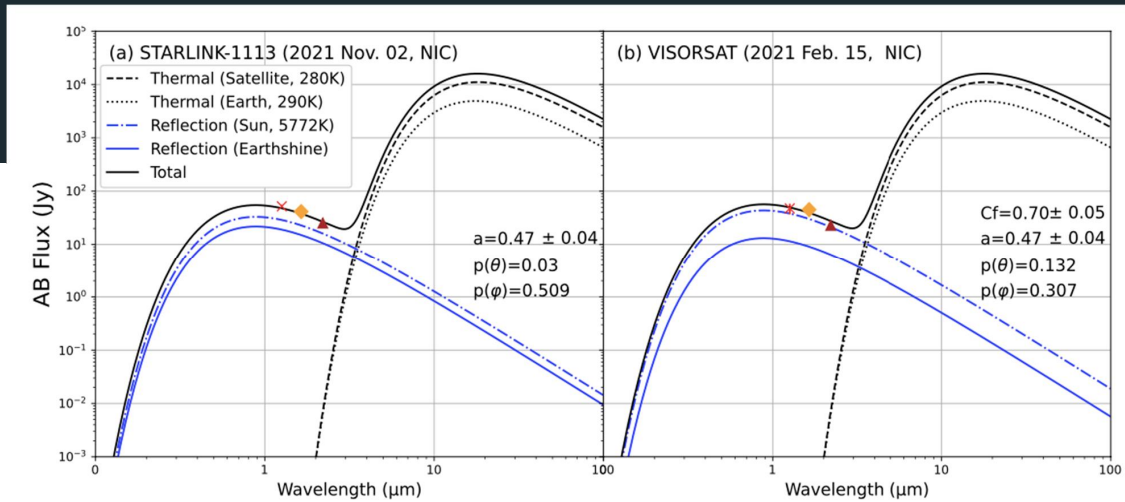


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## Blackbody fitting to the satellite flux (ex3)



# Blackbody fitting to the satellite flux (ex4)



- The albedo of near infrared bands (J, H, and K) is somewhat higher than that of optical region.

## Az, El dependence of magnitudes

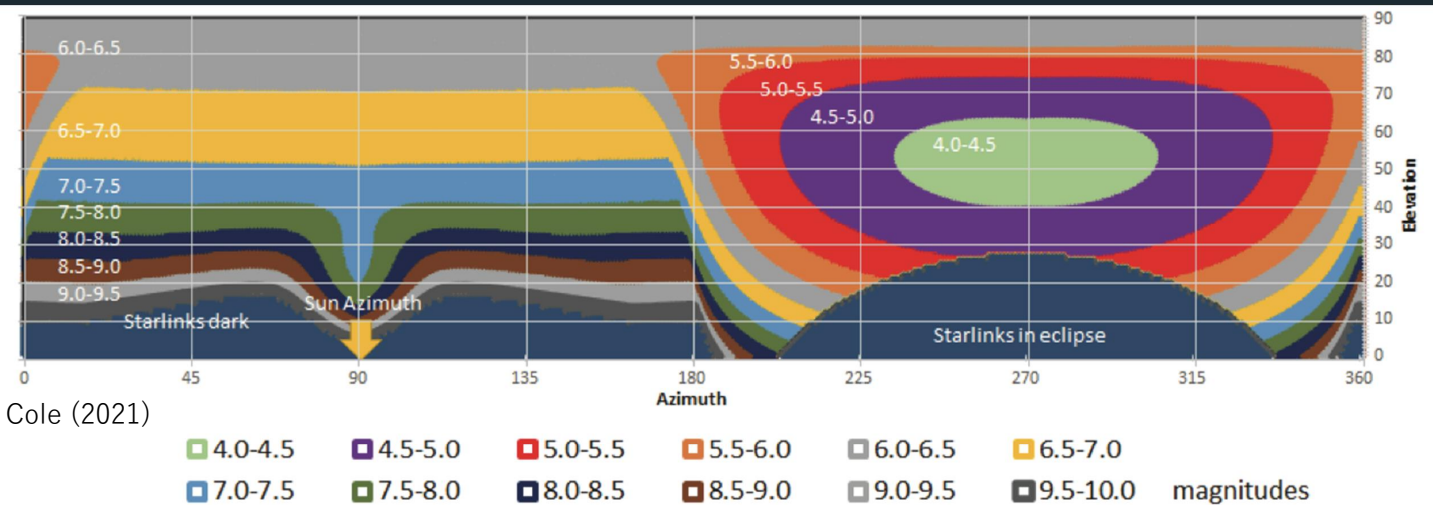


Figure 21: The modelled apparent magnitude of the visorsat across the sky using updated best-fit parameters for the June 2021 dataset. This plot is for the pointing mode with the solar-panel at a fixed angle with respect to the local vertical at the spacecraft, in this case  $5^\circ$  towards the Sun-azimuth. The modelled solar azimuth is  $90^\circ$  and depression angle  $15^\circ$ .

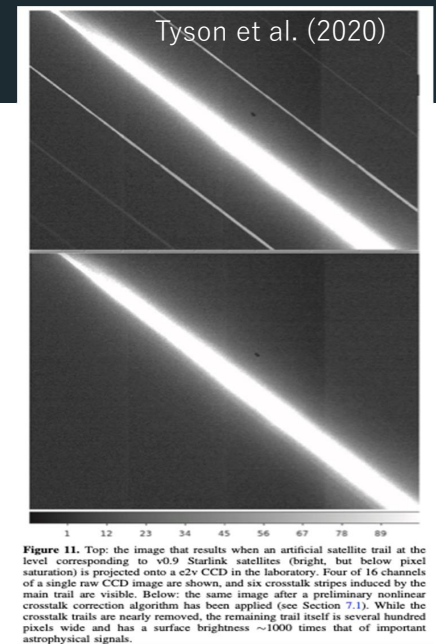


## Simulation of the impact on astronomical observations with a large telescope

Tyson et al. (2020) simulated the impact from the Starlink satellites on LSST observations

- Using artificial satellite trails at the level corresponding to v0.9 Starlink satellites, they showed the negative impact on CCDs

-- the main trail is  $\sim 1000$  times brighter than important astronomical signals.

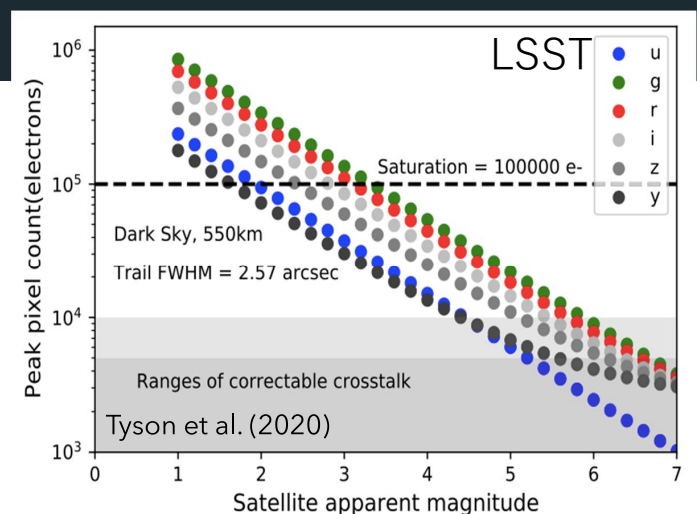


## Simulation of the impact on astronomical observations with a large telescope

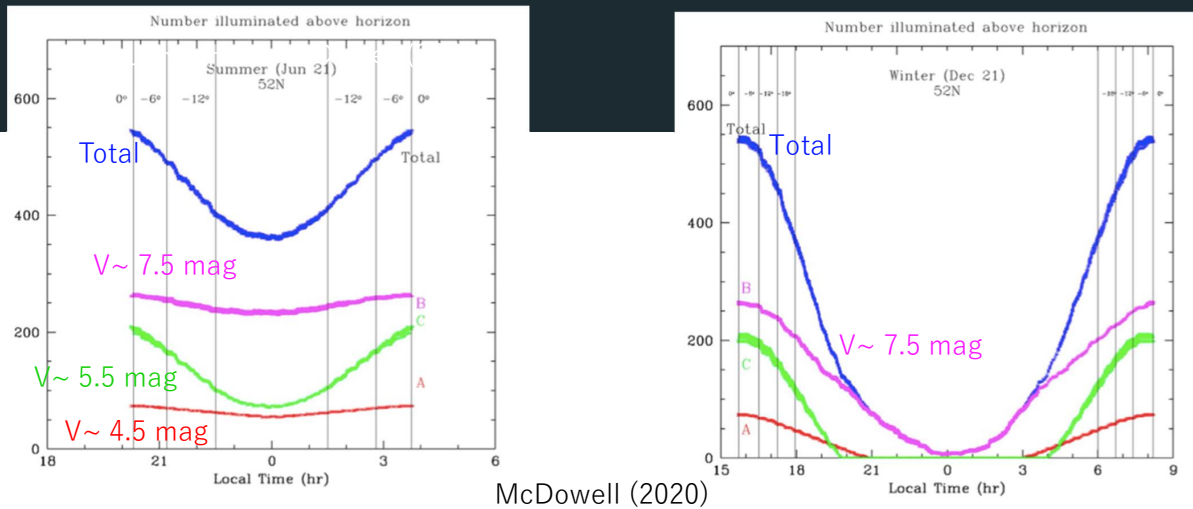
Tyson et al. (2020) simulated the impact from the Starlink satellites on LSST observations

- a satellite magnitude - CCD counts (e-) relation was verified in six passbands: u, g, r, i, z, and y bands

-- the CCD will saturate at  $\sim 3.5$  and  $\sim 1.5$  mag in g and y bands, respectively.

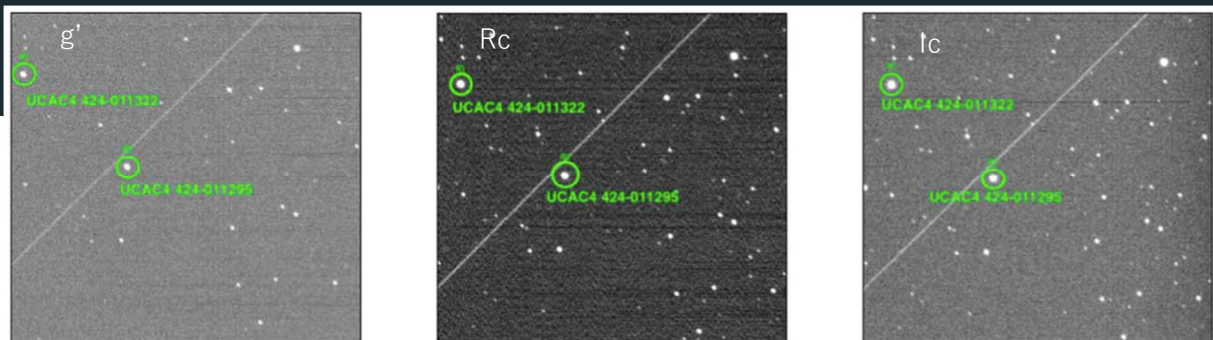


## Relation between time of day and number of satellites



The Starlink satellites can be observed even in the middle of the night.

## Simultaneous multicolor observations



Horiuchi+(2020)

Starlink satellites move too fast to track with telescopes (e.g.,  $\sim 2000 \text{ arcsec s}^{-1}$ )

- we pointed the telescope to the calculated position, and waited for the satellite to pass through the field of view.

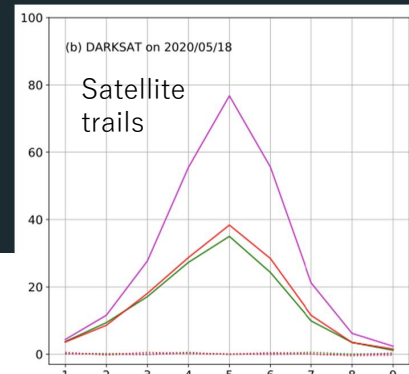
# Magnitude estimation

Using “Projection” in DS9, we estimated average cross section counts of satellite trails ( $f_{\text{sat}}$ ) and “elongated” star images ( $f_{\text{star}}$ ).

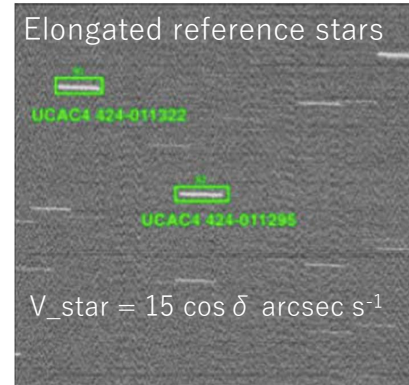
The observed flux is inversely proportional to the satellite velocity,  $V_{\text{sat}}$ .

Apparent magnitudes of the satellites,  $m_{\text{sat}}$

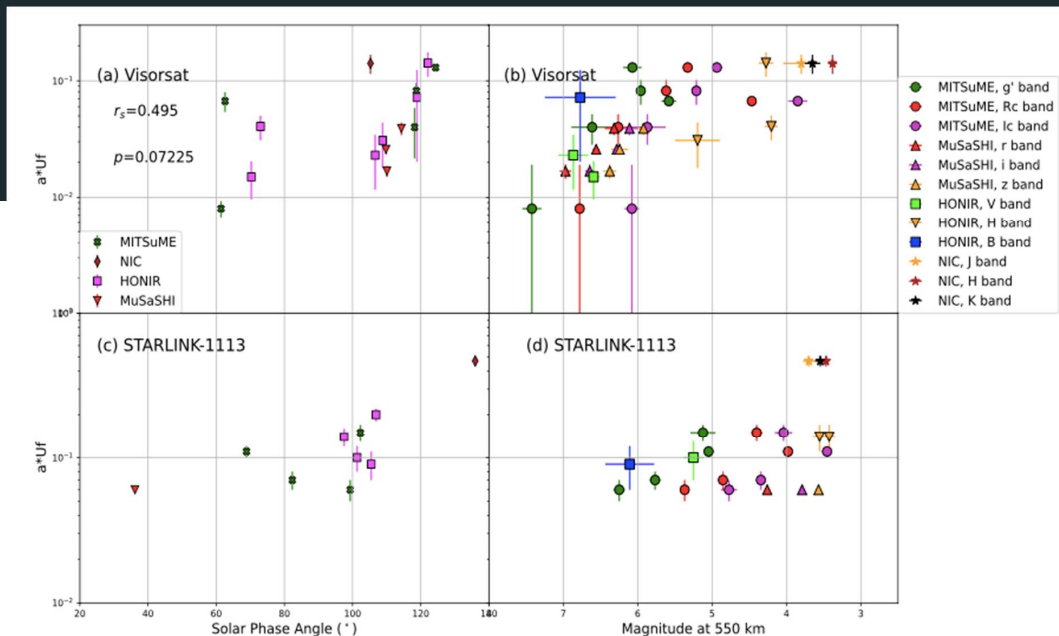
$$m_{\text{sat}} = m_{\text{star}} - 2.5 \log \left( \frac{V_{\text{sat}} f_{\text{sat}}}{V_{\text{star}} f_{\text{star}}} \right)$$



Horiuchi+(2020)



## The relation between covering factor, brightness, and phase angle



The smaller the covering factor is, the brighter the magnitudes of Visorsat tend to become.