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運用終了した技術試験衛星「きく8号」のライトカーブと形状モデル Observed light curve and its shape model of the decommissioned satellite ETS-8

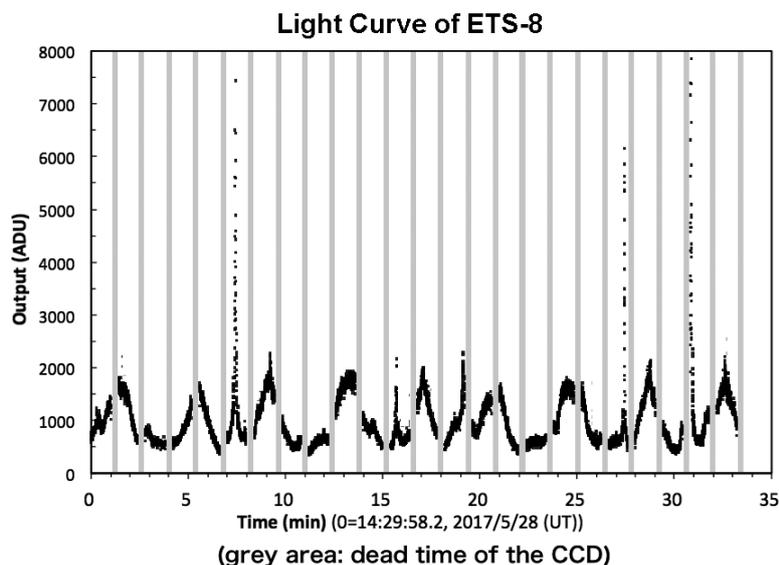
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2017年1月に運用を停止した技術試験衛星「きく8号」(ETS-8)のライトカーブを取得し、得られたライトカーブからその回転状態について考察を行った。目的衛星を望遠鏡で追尾した状態で、シャッターを開けたまま露出を行う方法(TDI)によりトレイルしたイメージを取得し、その時間方向のプロファイルから光度の時間変動の情報(ライトカーブ)を得た。得られたライトカーブを再現するために衛星を衛星本体、太陽電池パドル、大型アンテナの各パーツに分けたモデルを考え、各パーツにおける形状と反射特性を仮定し、太陽光の反射光の強度変化を計算した。本体については拡散反射、アンテナについては拡散反射と鏡面反射の両方の成分を仮定、太陽電池パドルのパネルは拡散反射と鏡面反射の中間的な反射特性を仮定した。ある特定軸の周りに回転している状態を仮定し、各パーツからの反射光の変動に各パーツの反射率と面積をかけた係数を乗算し、それを足し合わせる事により観測されたライトカーブを再現することができた。

Inactive artificial objects, such as old satellites, spent rocket bodies, and fragments from disintegration, are often rotating and tumbling. Light curves derived from photometric observations are one of the most effective techniques for examining the physical characteristics of such space objects. Light curve observations were done for the Engineering Test Satellite, ETS-8, decommissioned in January 2017. It exhibits time variation in its brightness after the decommission. Observations of ETS-8 were done using the CCD device with TDI method, of which an exposure is made by shifting electrical charge while a mechanical shutter is open. Light curve data was extracted from the profile of the trailed image caused by parallel charge transfer. We tried to reproduce the observed light curve using a simple shape model. In the model, the satellite was divided into three parts (main body, solar cell paddle, and large antenna).

The characteristic of each surface was assumed to be diffuse reflection and/or specular reflection, then the brightness variation in each surface was calculated when rotating. The brightness of each part was added together after multiplied by each appropriate reflectance and surface area, then the observed light curve was reproduced.



8th Space Debris Workshop (2018.12.5)

Observed light curve and its shape model of the decommissioned satellite ETS-8 運用終了した技術試験衛星「きく8号」の ライトカーブと形状モデル

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- Light curve of a space object
 - ▶ TDI, a method to obtain a short-period light curve
- Light curve of the ETS-8
- Analysis result of the light curve and comparison with its shape model

Introduction

Introduction

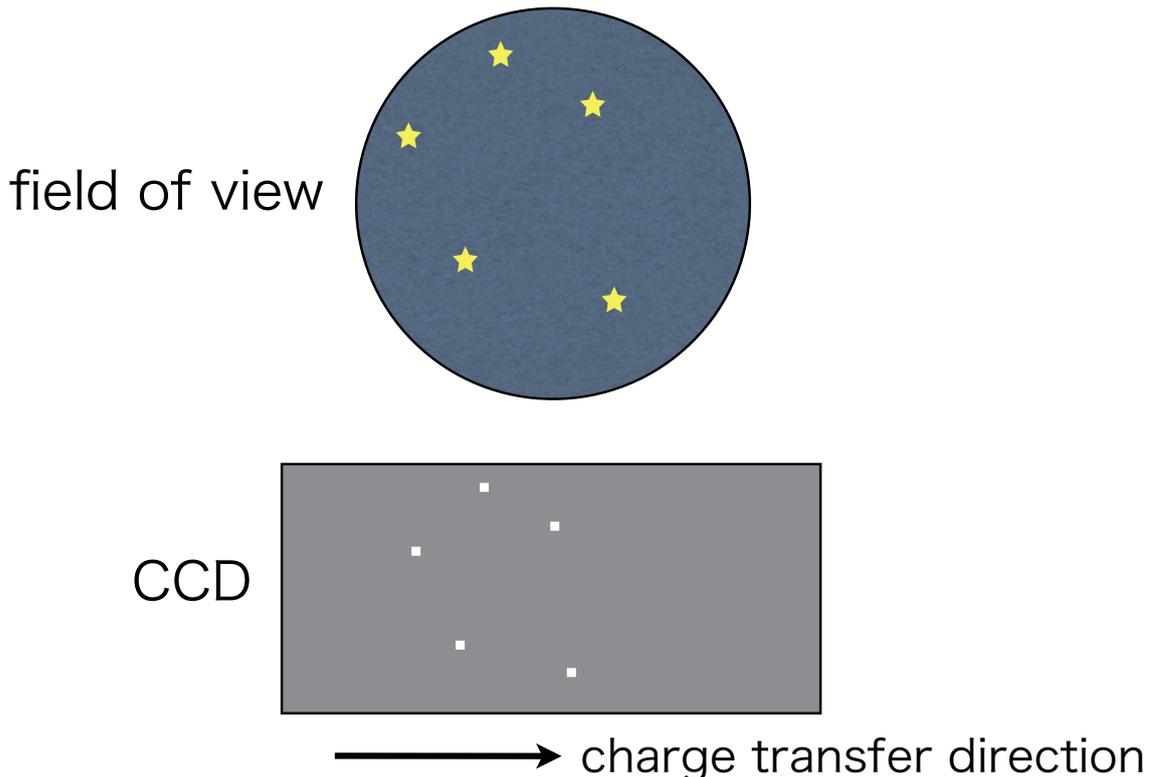
- Light curve (brightness variation)
 - effective techniques for examining the physical characteristics of space objects
- Images by CCD sensors
 - can not measure shorter period variation than the readout time
- Methods for examining shorter period variation
 - videocamera, high-speed CCD, or CMOS
 - streak detection by sidereal tracking w/ CCD
 - streak detection by target tracking & TDI method w/ CCD

TDI technique

- TDI: Time Delay Integration
exposure made by shifting electrical charge while a mechanical shutter is open.
CCDの読み出し方式の一つ
露出をしながら電荷を読み出す手法
(シャッターを開けたままで(光を受けながら)電荷転送)

Originally, a technique which captures the image of a moving object across the field of view, by adjusting the CCD angle and charge transfer timing.
本来はCCDの角度と電荷転送のタイミングを合わせるにより移動物体を点状に写すための手法

“normal” astronomical observation with TDI
(telescope tracking is turned off)

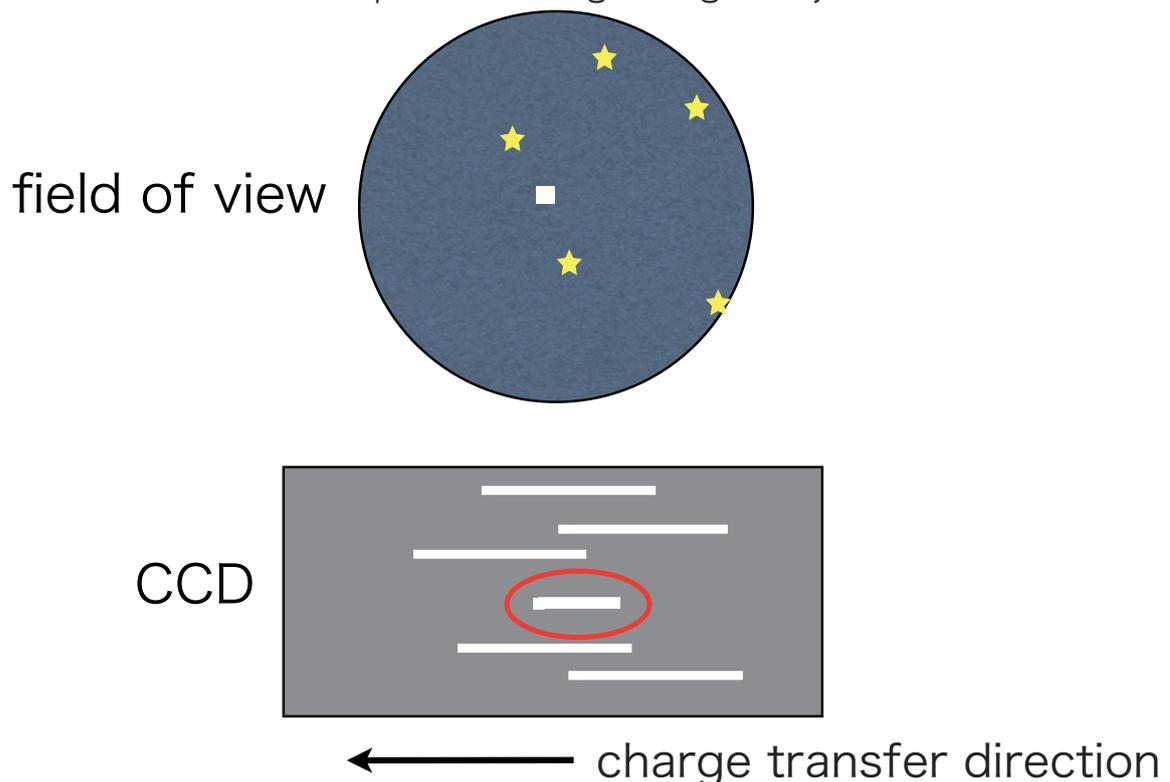


TDIのライトカーブ観測への応用

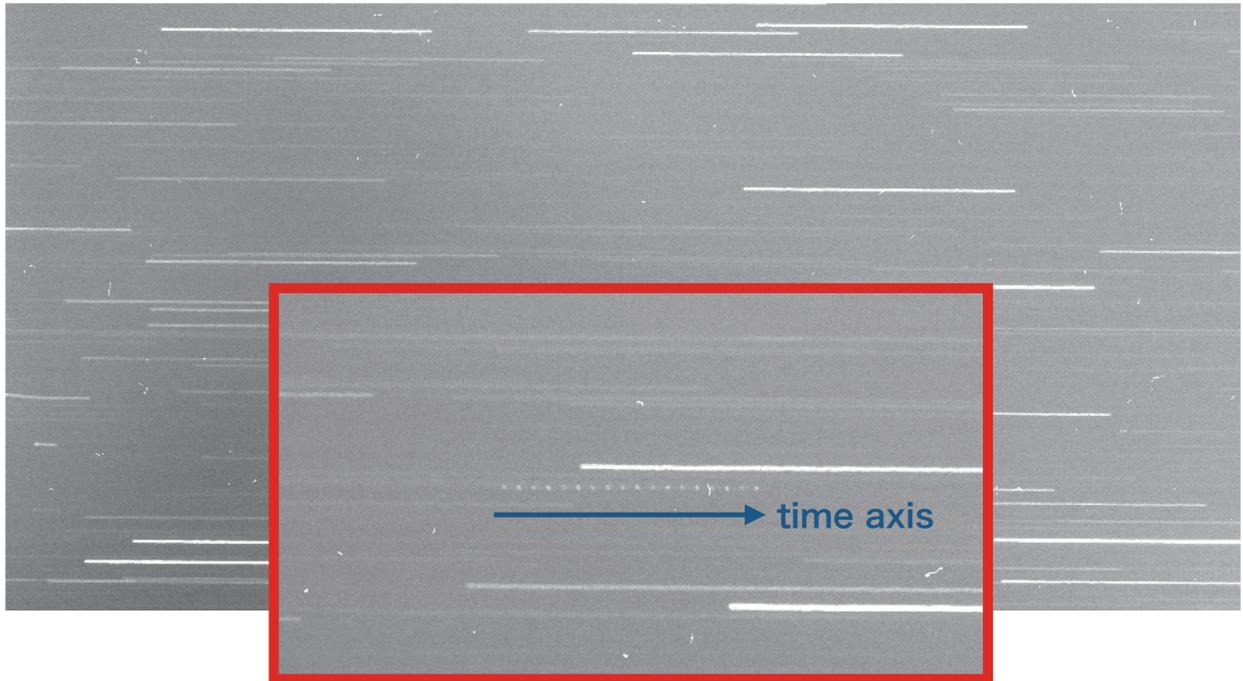
Application of TDI to light curve observation

- light curves can be extracted from the streak (trailed) image obtained by the TDI method.
TDIを利用しシャッターを開けたままで電荷を読み出す事により、延びた像を取得し1枚のCCD画像から時間情報を得る

Application of TDI to light curve observation (telescope is tracking a target object)

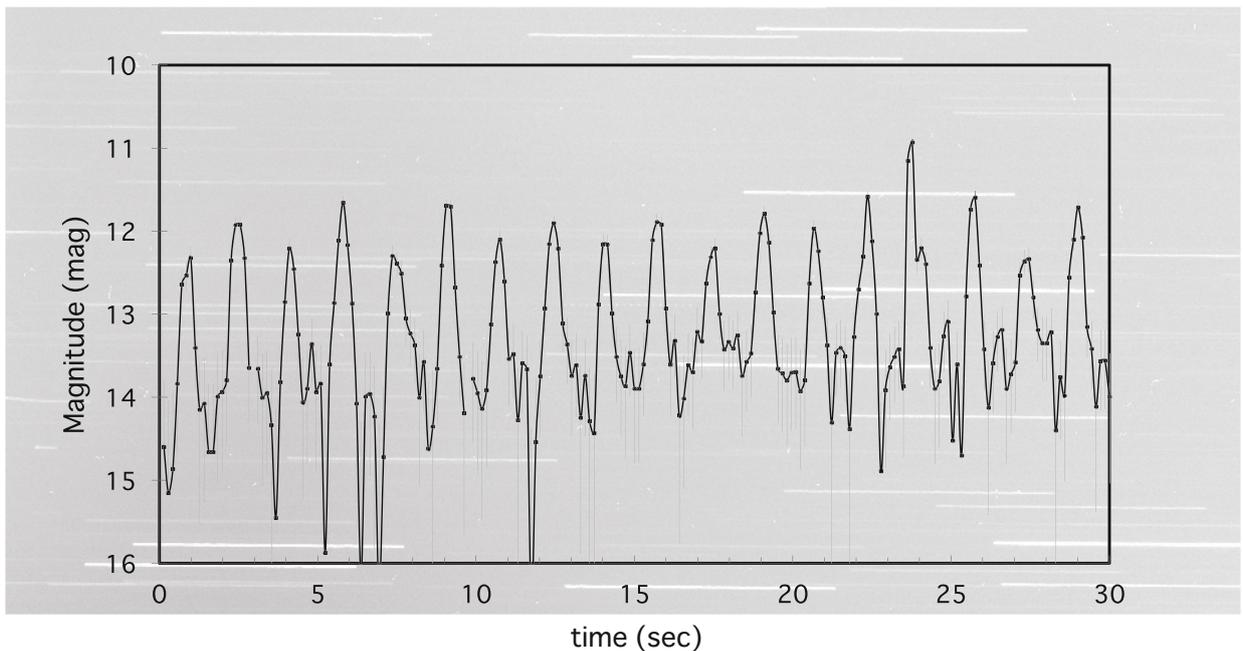


Light curve observations with TDI



30sec exposure with TDI while target tracking

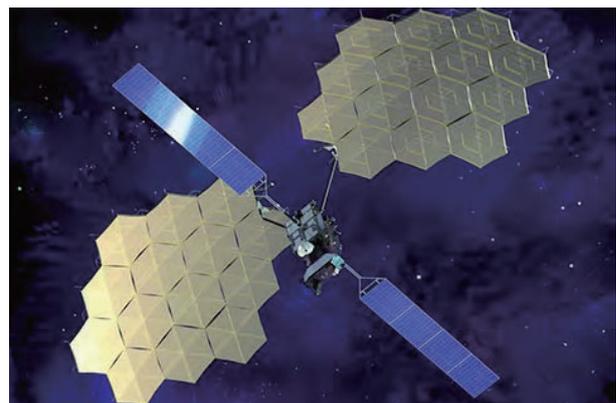
Light curve observations with TDI



Light curve of ETS-8 (KIKU No.8)

- ETS-8 satellite

- Engineering Test Satellite launched in 2006
- One of the largest geostationary satellites
- Equipped with two Large Deployable Antenna Reflectors (as large as a tennis court)
- Completion of operation on Jan. 2017



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Light curve observations of ETS-8 with TDI

- 1m telescope+CCD, at the Bisei SpaceGuard Center
- Observed on May 28, 2017,
14:30(UTC)(23:30(JST))- about 30 minutes,
60sec exposure×24 w/TDI



Previous research (Kucharski et al.)

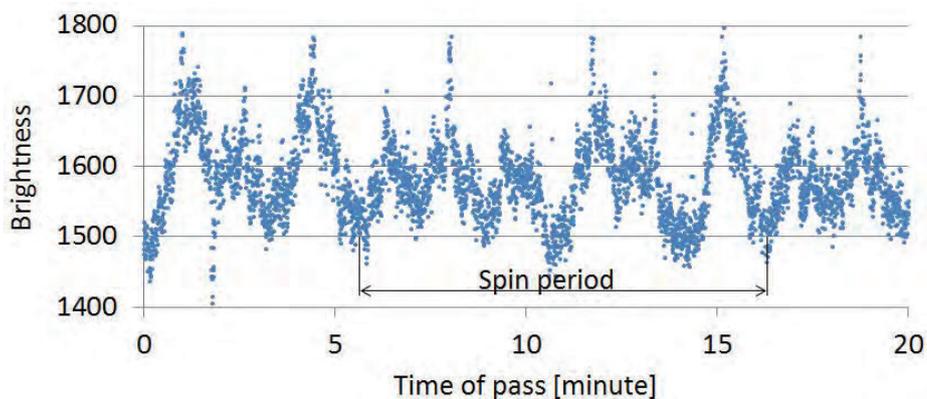
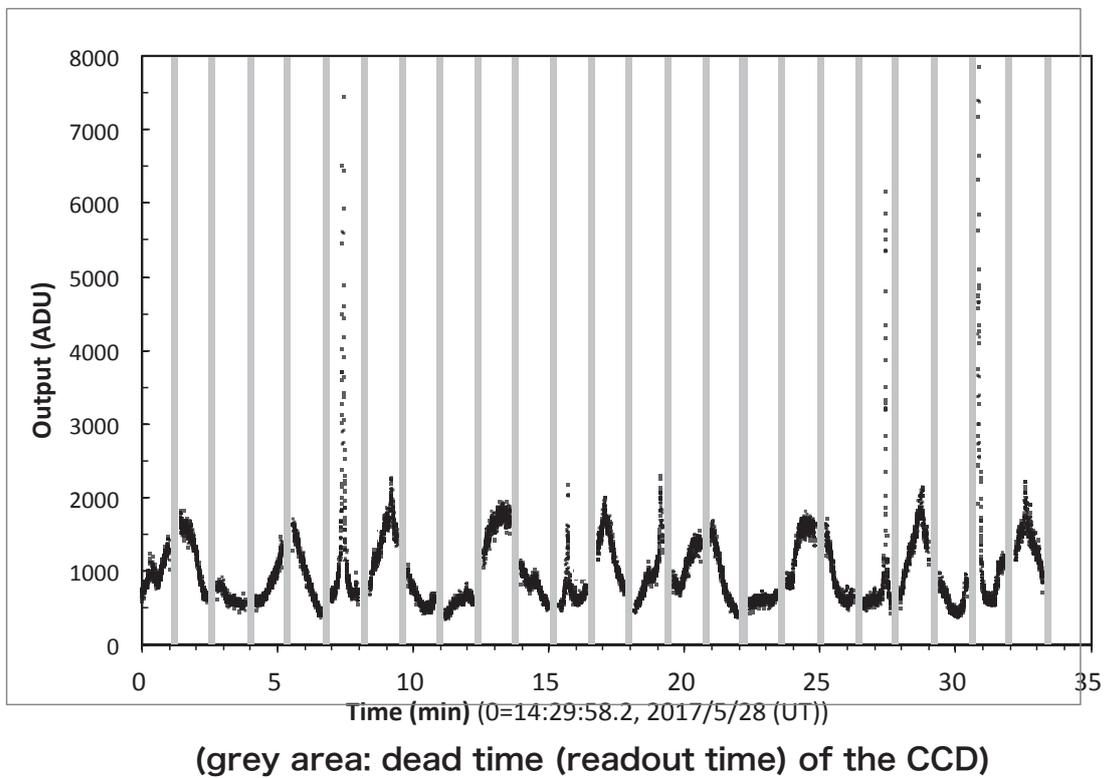


Figure 6. Light curve of ETS-8 measured by EOS Mount Stromlo station on March 8, 2017.

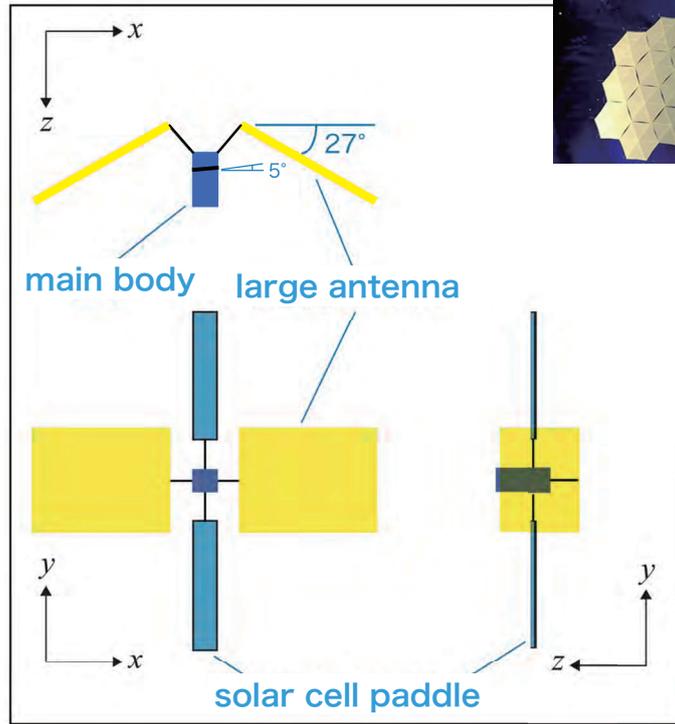
from "SPIN-UP OF SPACE DEBRIS CAUSED BY SOLAR RADIATION PRESSURE,"
Proc. 7th European Conference on Space Debris., 2017.

Light curve of ETS-8



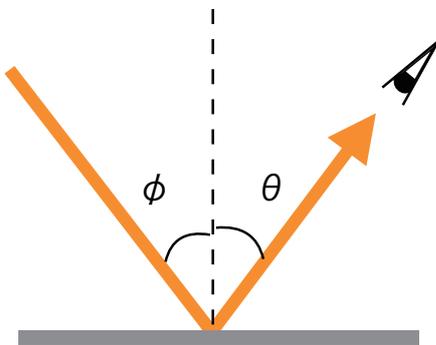
Modelling

Model

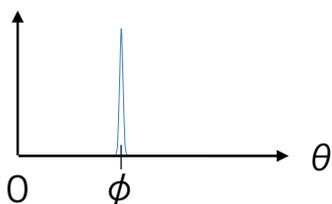


specular reflection & diffuse reflection

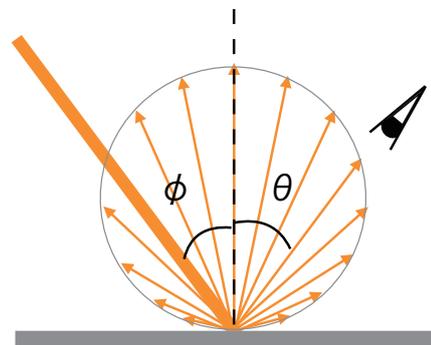
鏡面反射
specular reflection



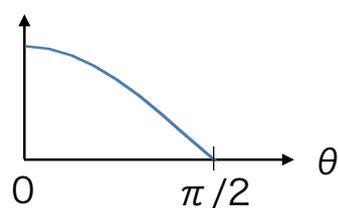
$$I \propto \cos\phi \times \cos^n(\theta - \phi)$$

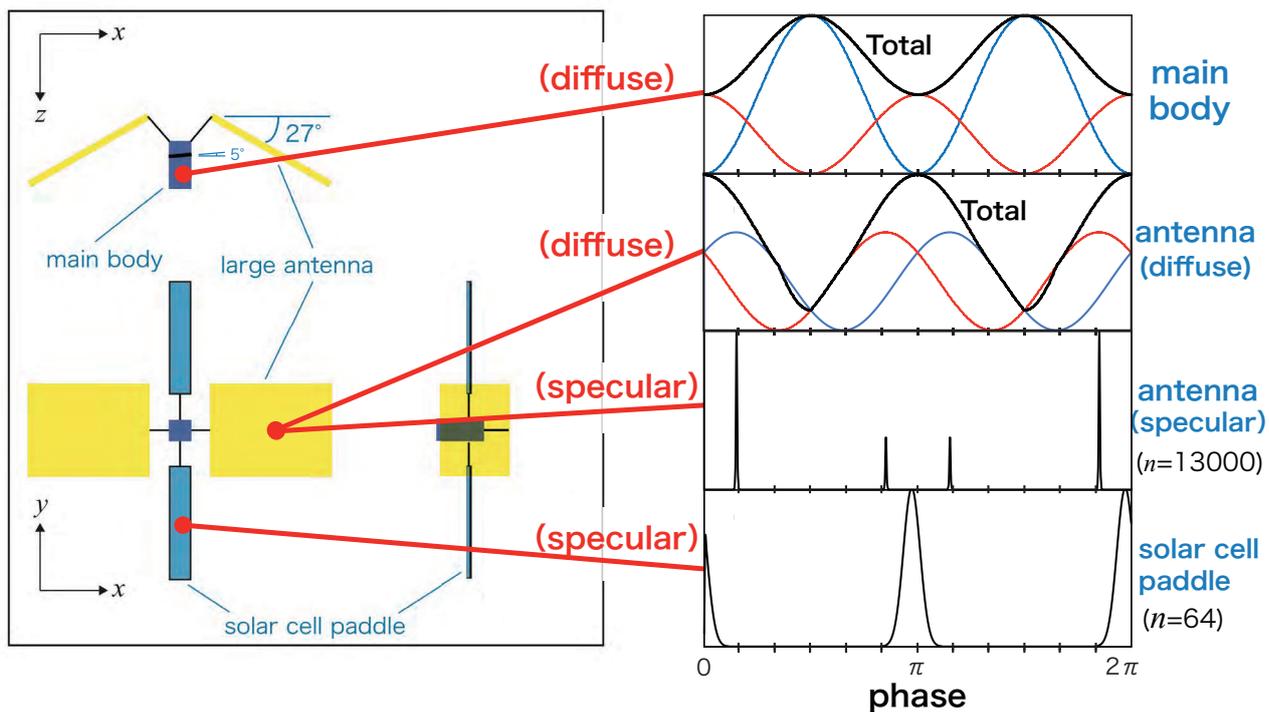
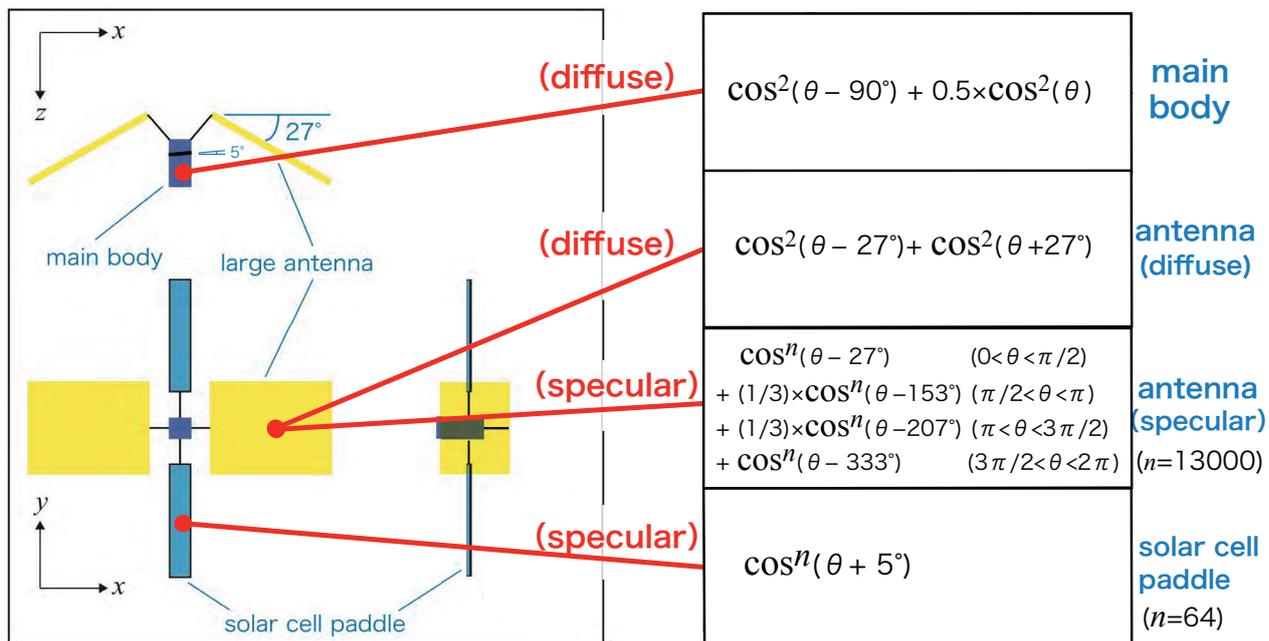


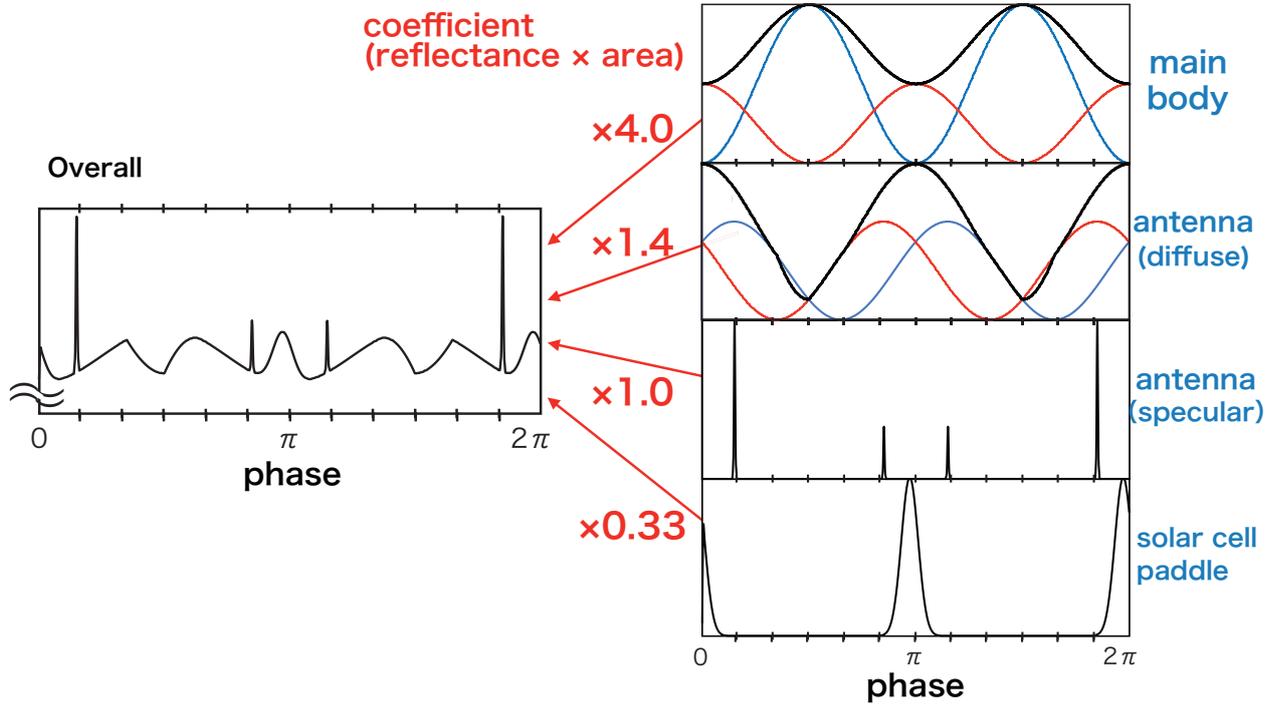
拡散反射
diffuse reflection



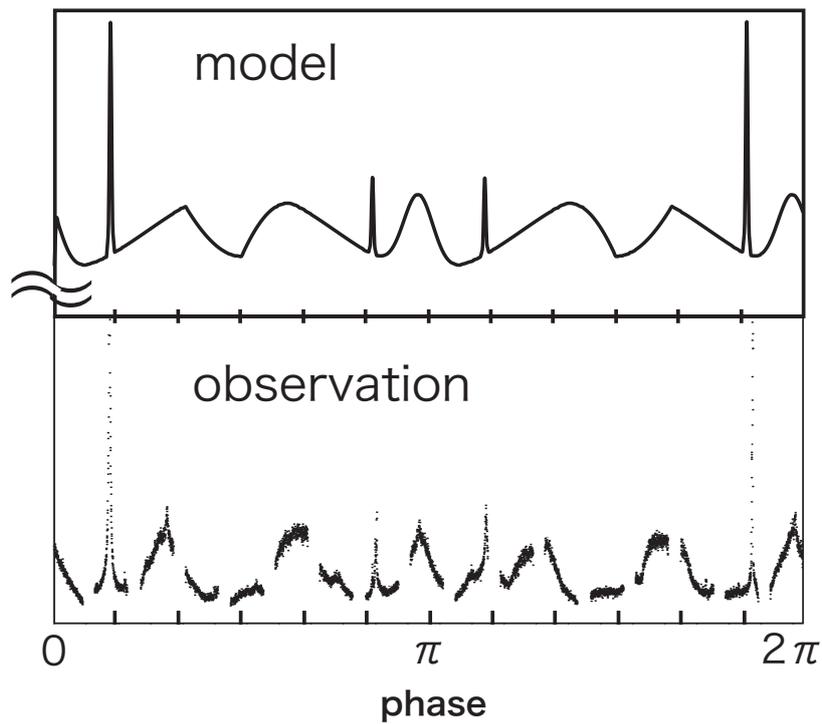
$$I \propto \cos\phi \times \cos(\theta)$$







Comparison between model and observation



Summary

- Short-period light curve of space objects, obtained with TDI
- Light curve of ETS-8 and its shape model
Light curve was roughly reproduced with a simple model, consist of the main body, large antenna and solar cell paddle

Acknowledgments (in Japanese)

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