Precise modeling of solar radiation pressure acceleration for spherical geodetic satellites

Ajisai (JAXA http://www.jaxa.jp/projects/sat/egs/images/egs_main_001.jpg)

Akihisa Hattori[1], Toshimichi Otsubo[2], Daniel Kucharski[3]

1: SOKENDAI (The Graduate University for Advanced Studies)

2: Hitotsubashi University

3: Space Environment Research Centre

Outline

- Introduction

    Solar radiation pressure / Cannonball model

- Estimation of C_R

    Precise orbit determination

- Modelling C_R : Ajisai / BLITS

    Optical properties of materials on the surface

    Variation of cross-sectional area

    Total solar irradiance

First half

"Ajisai"

In comparison with "LAGEOS 1 and 2"

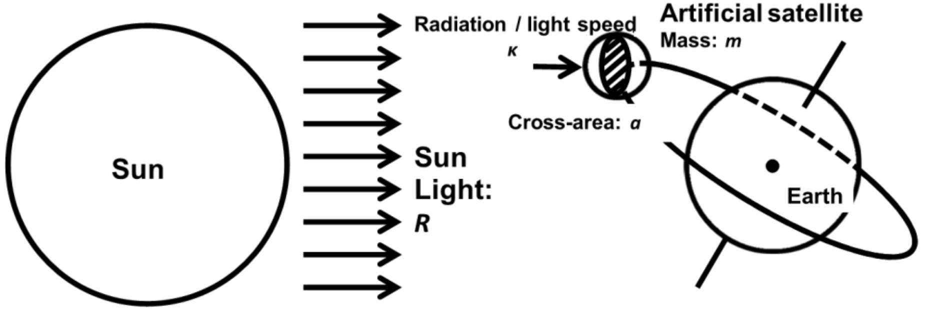
Second half

"BLITS"

Introduction:
Solar radiation pressure

- One of the major error sources in orbit determination
- Cannonball model is applied for geodetic satellites

$$\ddot{\vec{r}} = \mu\kappa \left[\frac{A}{|\vec{R}|}\right]^2 C_R \frac{a}{m}\frac{\vec{R}}{|\vec{R}|}$$



- SRP acceleration varies in accordance with
  - a/m: the ratio of the cross-sectional area to the mass
  - C_R: the scaling coefficient

Estimation of C_R: Precise orbit determination Configuration

- Configuration

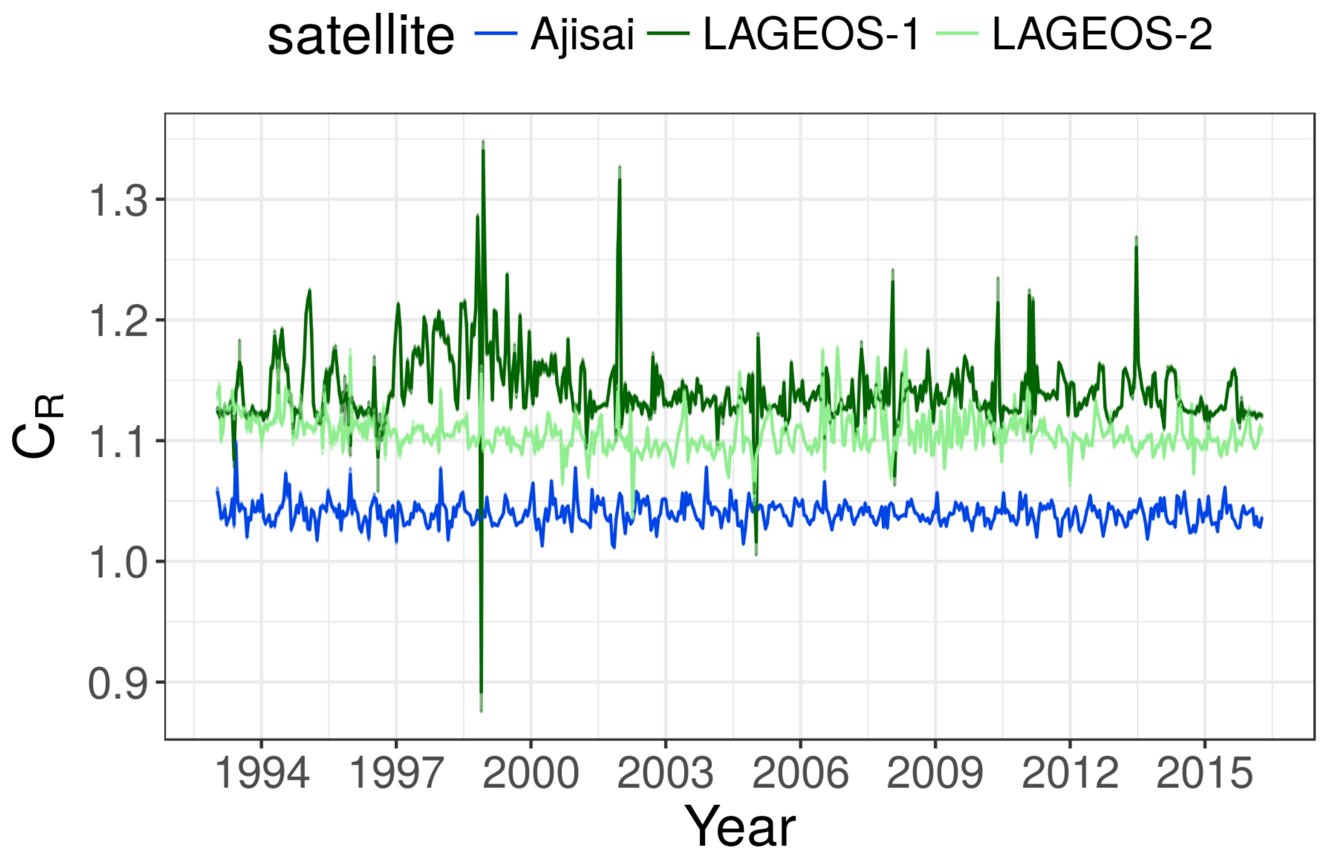
software	“c5++” Release:889
satellite	Ajisai, LAGEOS-1 & LAGEOS-2
data	SLR observations 1993-2015
gravity field	EGM2008
station position	ITRF2014
and others	IERS Conventions 2010

- Solve-for parameters

arc length	5 days
6 orbital elements	per arc
C_R	per 15 days
atmospheric drag	per arc (only Ajisai & BLITS)
empirical accel. (along-track, const)	per arc (only LAGEOS-1 & LAGEOS-2)
gravity field & geocenter position	~4x4 Stokes coefficients

Estimation of C_R: Precise orbit determination

Results

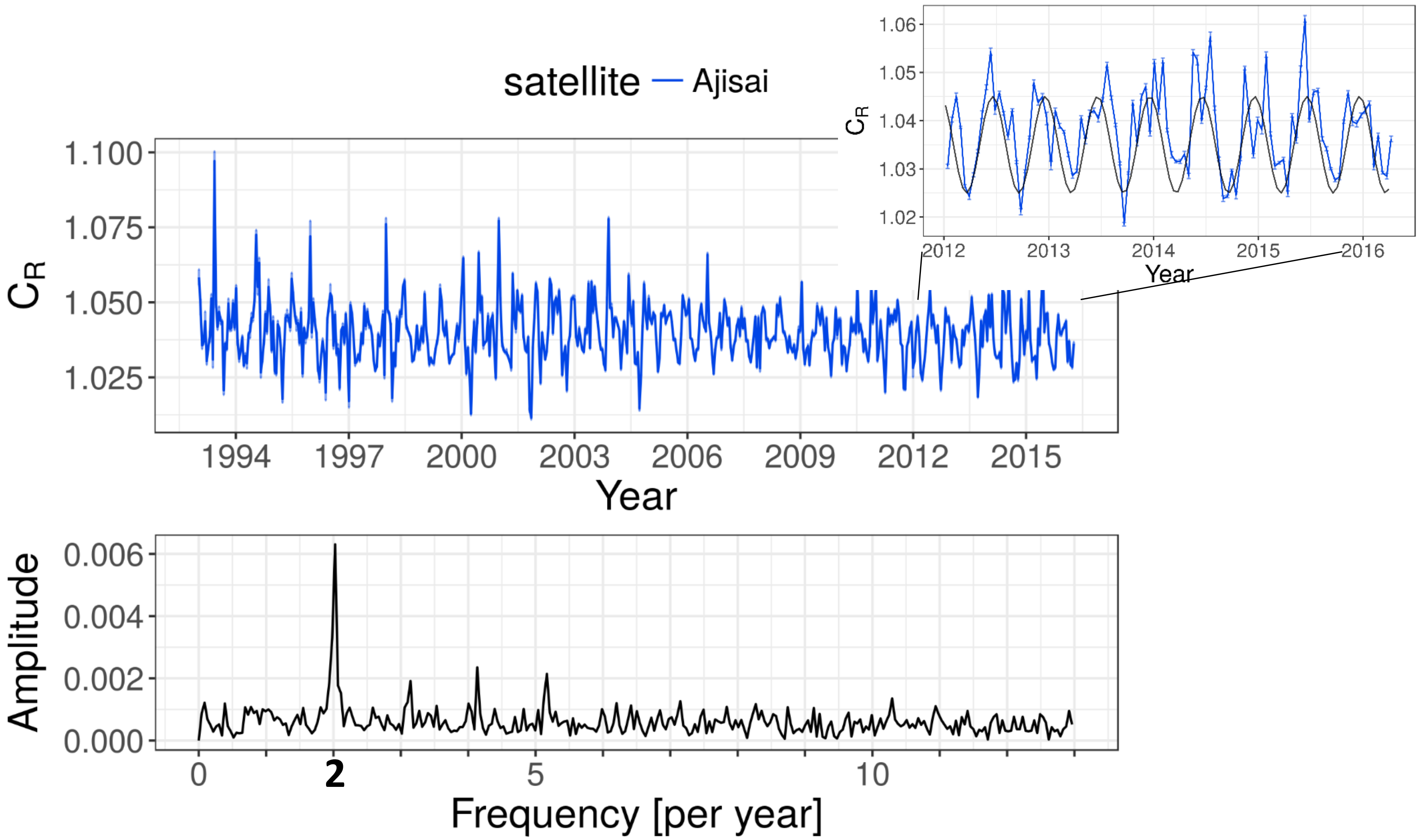


satellite	RMS of range residuals	mean of C_R	SD of C_R
Ajisai	0.028 [m]	1.040	0.010
LAGEOS-1	0.016 [m]	1.142	0.030
LAGEOS-2	0.014 [m]	1.106	0.016

Ajisai C_R is more stable and smaller than LAGEOS-1 & LAGEOS-2

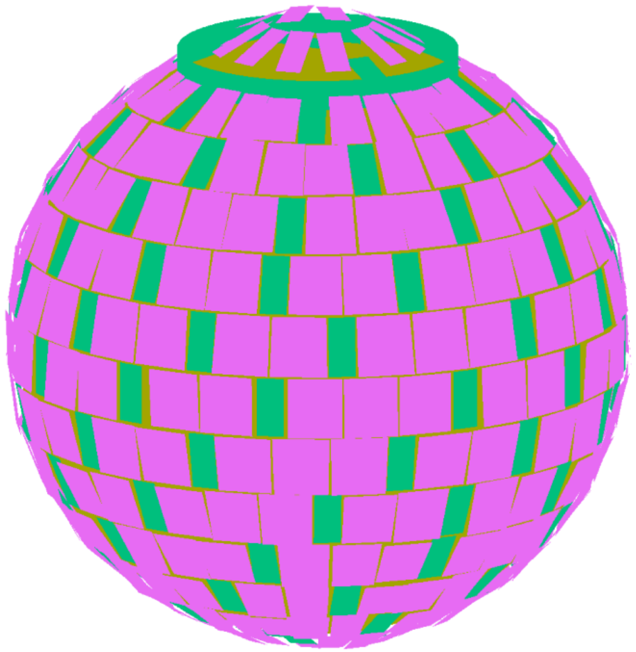
Estimation of C_R: Precise orbit determination

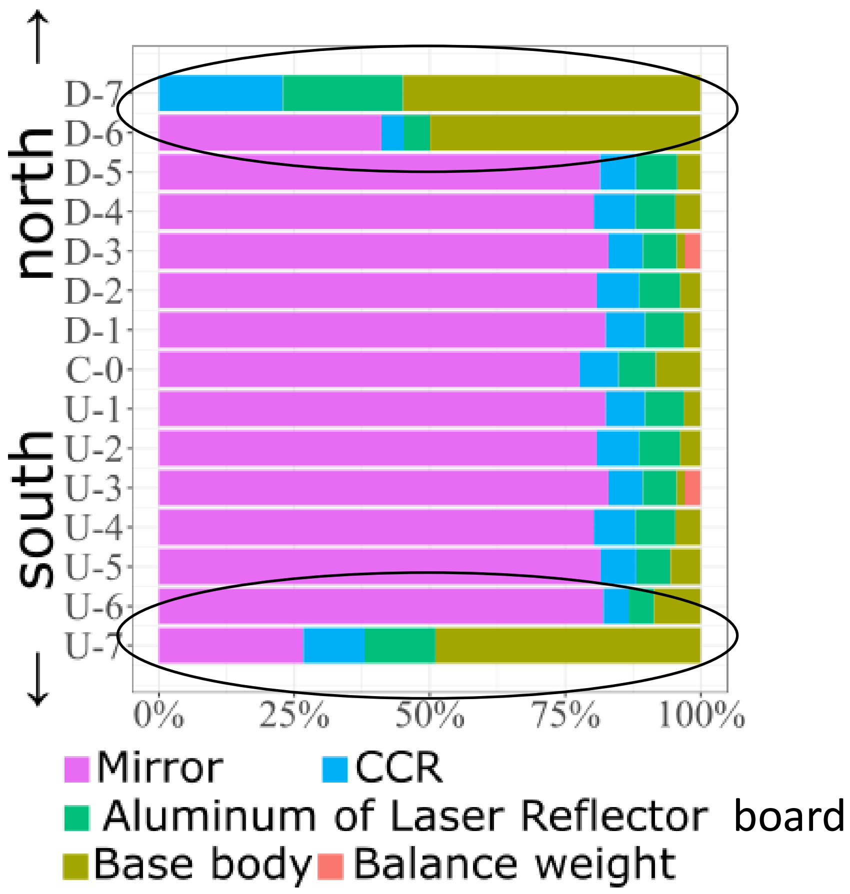
Results – Ajisai



Modelling C_R:
Ajisai Optical properties

- The surface of Ajisai is not fully symmetric





Modelling C_R:
Ajisai Cross sectional area variation

- We use a constant value $3.63\ [m^2] = (2.15\ [m]/2)^2\ \pi$ as the cross-section area of Ajisai

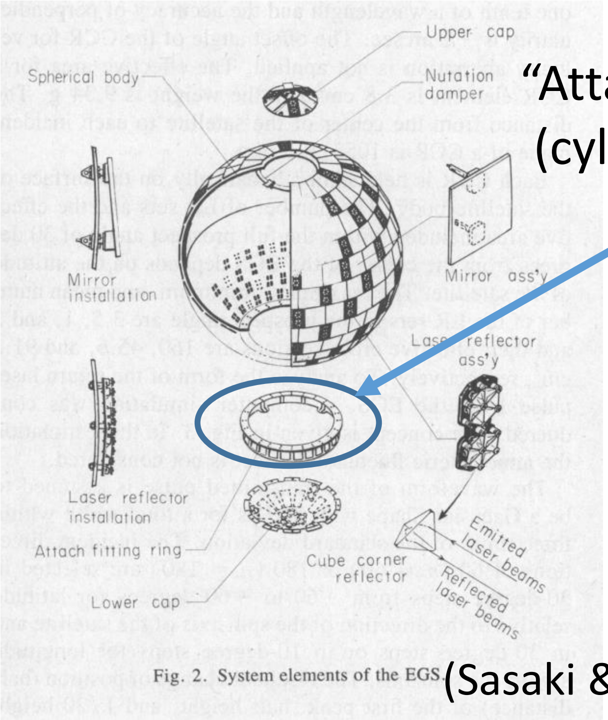
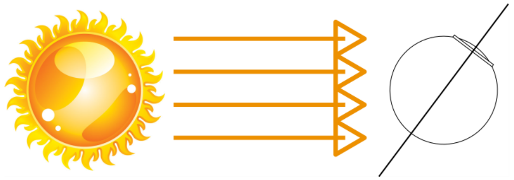


Fig. 2. System elements of the EGS

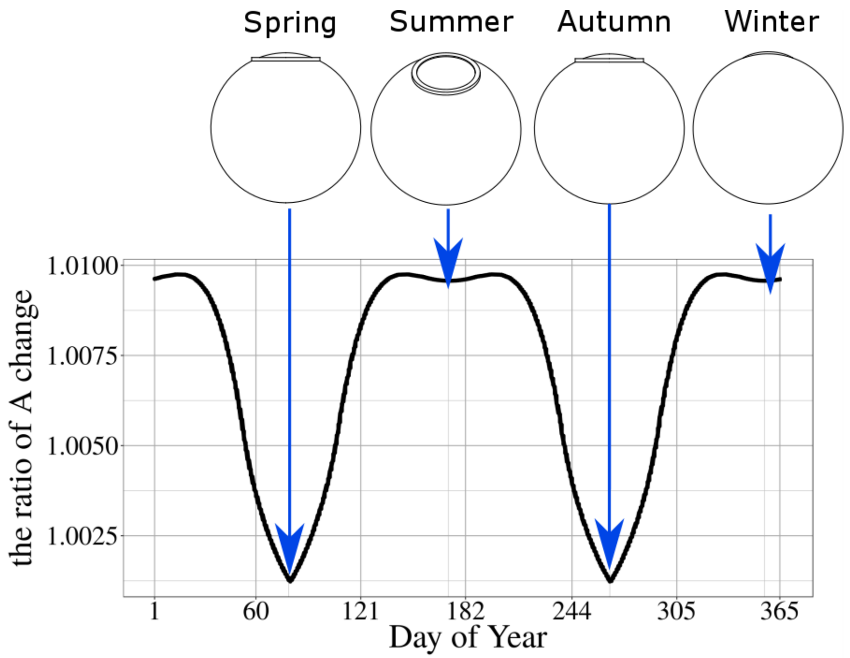
"Attach fitting ring" (cylindrical shape)

(Sasaki & Hashimoto, 1987)

- The spin axis of Ajisai is almost parallel to that of the earth rotation axis

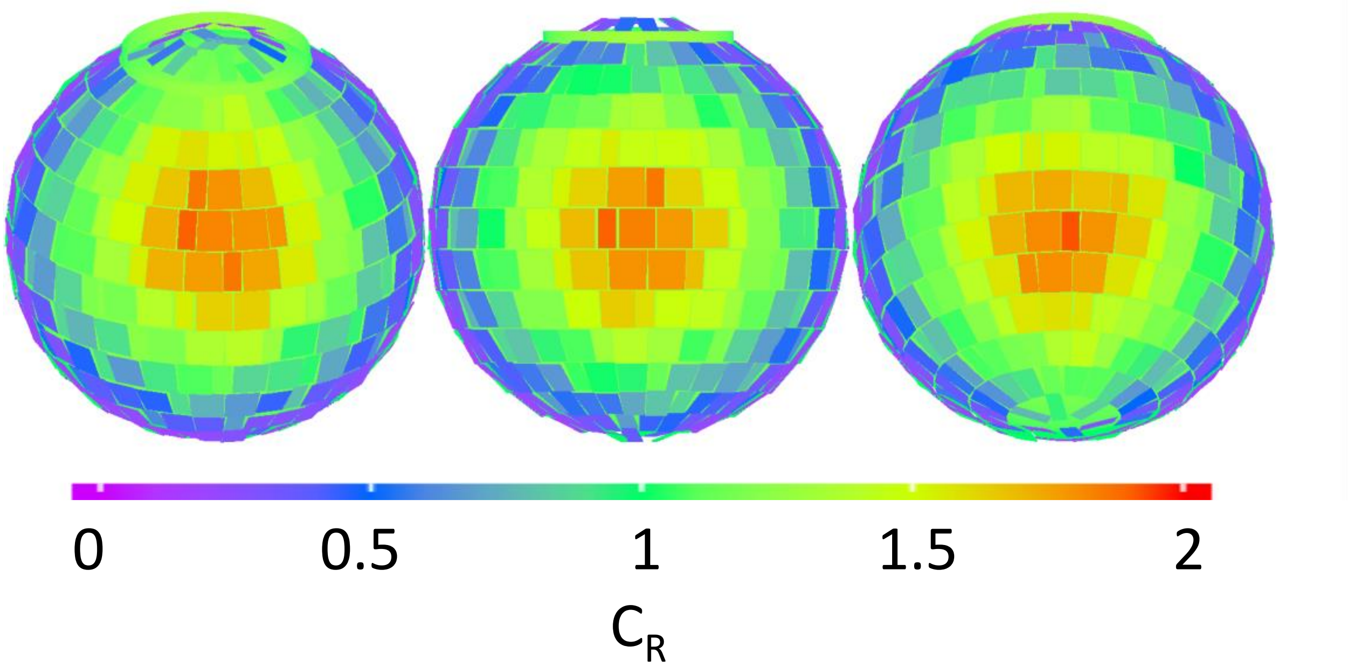


→ cross-sectional area varies semi-annually

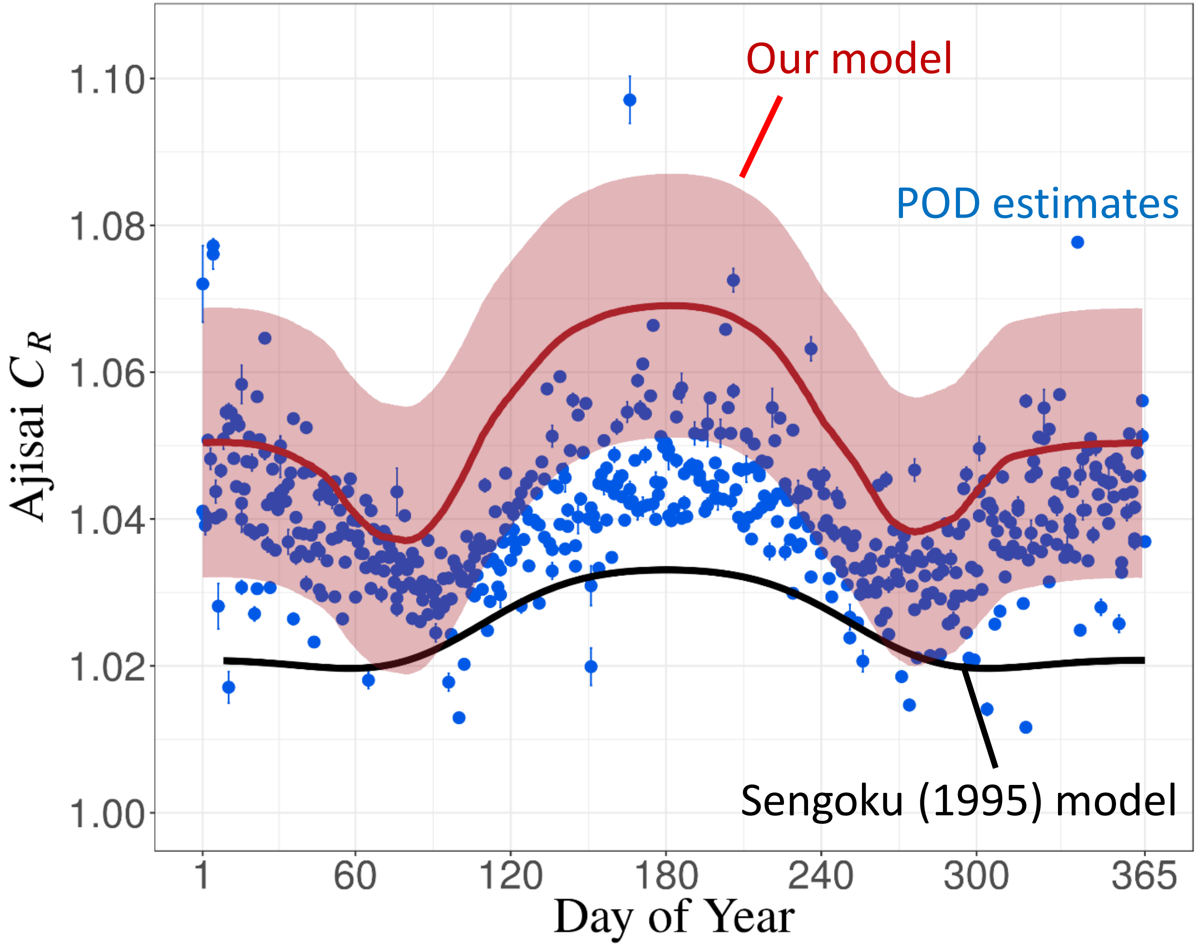


Modelling C_R:
Ajisai Modelled with optical properties and cross-sectional area

- To calculate Ajisai C_R with ray-tracing, the distribution of material on the surface and the detailed shape are taken into account.



Modelling C_R: **Ajisai** Modelled with optical properties and cross-sectional area

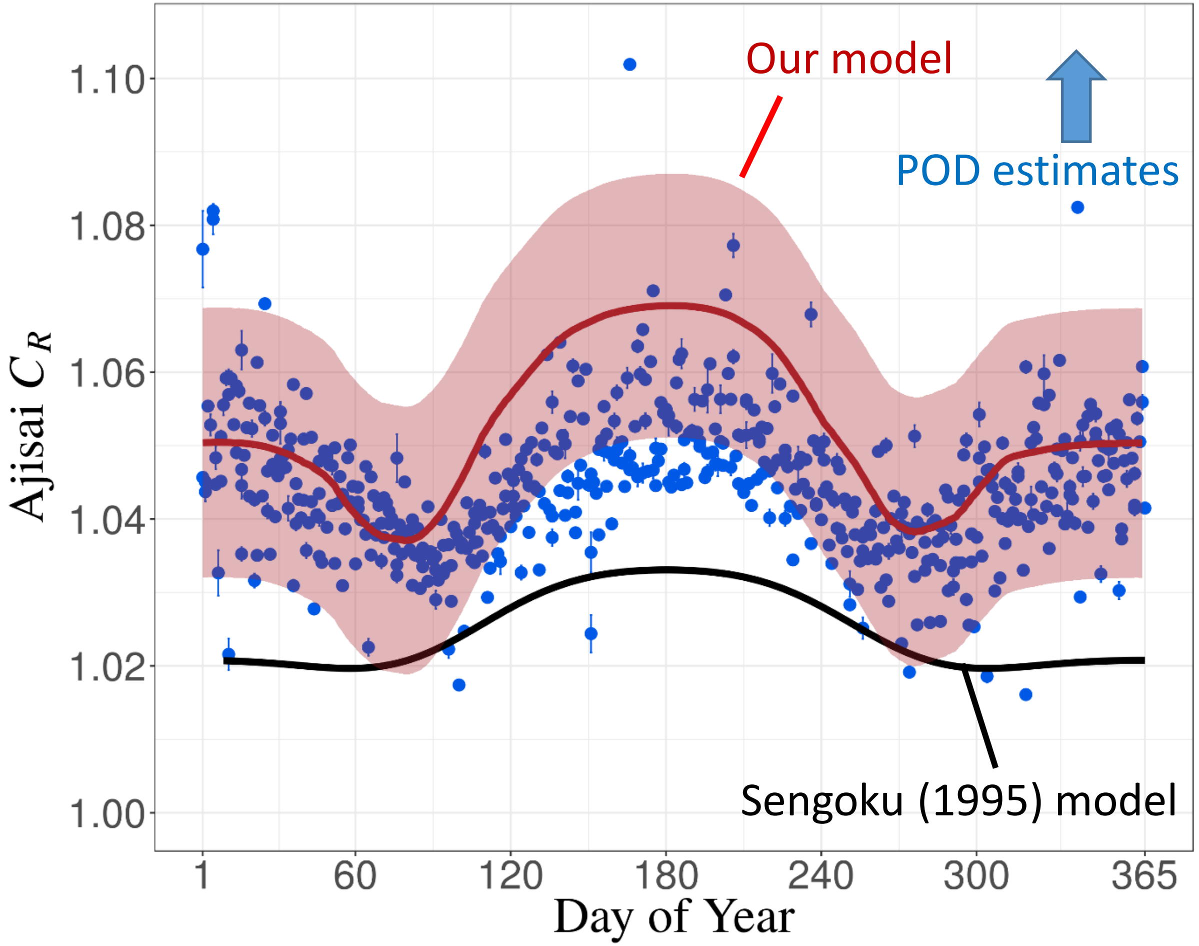


Red zone represents uncertainty due to loss of the detailed optical properties

Semi-annual component is larger than previous model

+ Total Solar Irradiance

Modelling C_R:
Ajisai Modelled with optical properties and cross-sectional area



Kopp & Lean (2011) reports TSI value is 1360.8 ± 0.5 [W/m²]

=> $\kappa = 4.54 \times 10^{-6}$ [N/m²]

(cf. the conventional value: 1367 [W/m²])

=> $\kappa = 4.56 \times 10^{-6}$ [N/m²]

↓

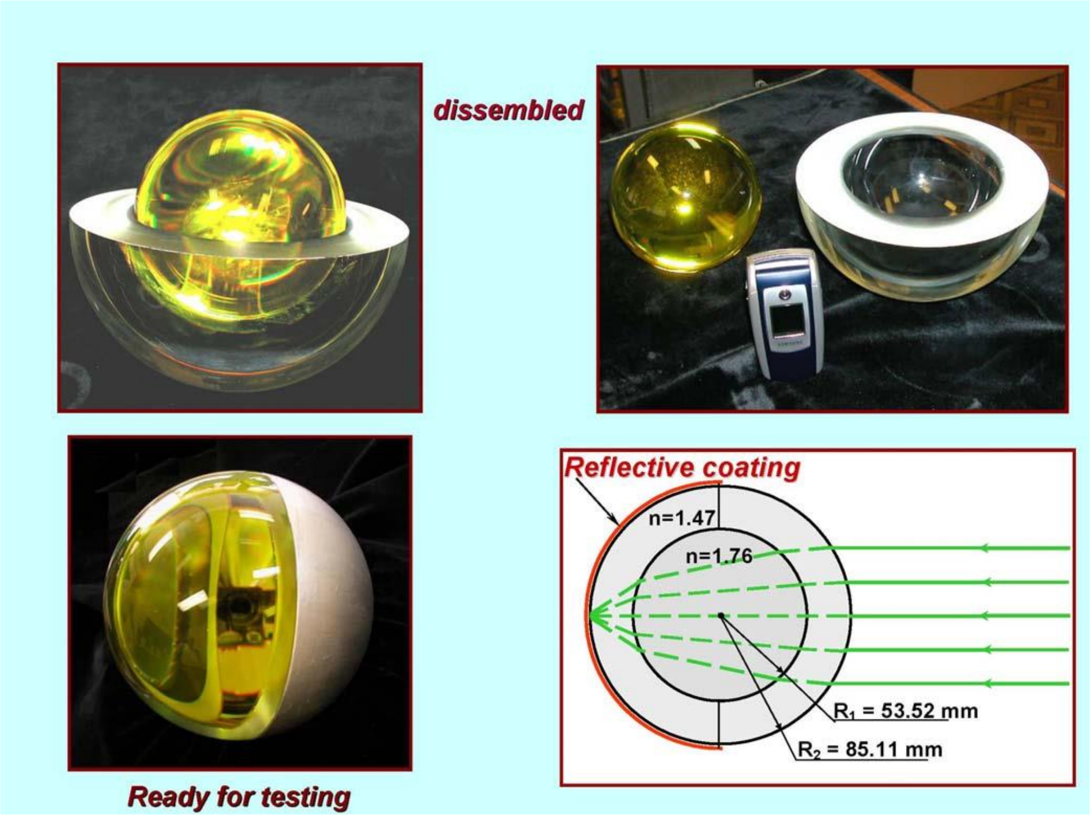
underestimation of C_R about 0.4 %

SRP on BLITS (**B**all **L**ens **I**n **T**he **S**pace)

BLITS

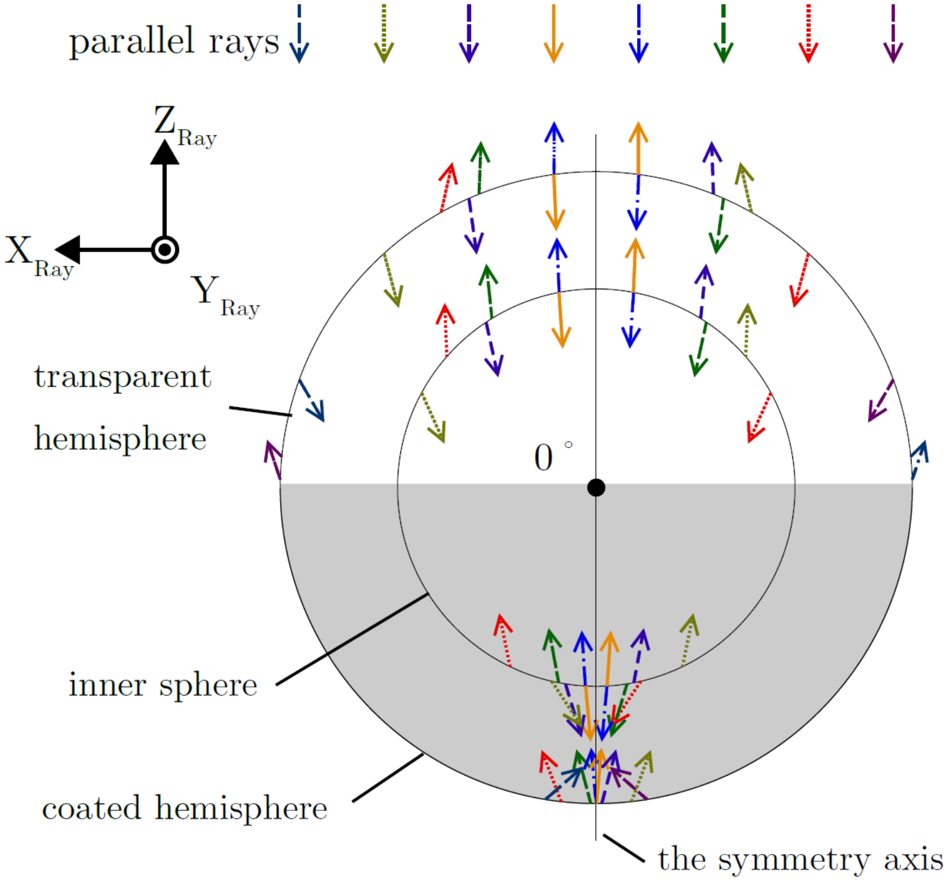
- Retroreflector satellite by itself
- Consists of glass with different refractive index

Launch	September 17, 2009
Collision	January 22, 2013
Diameter	170.32 mm
Mass	7.53 kg
Altitude	832 km
Inclination	98.77 degrees

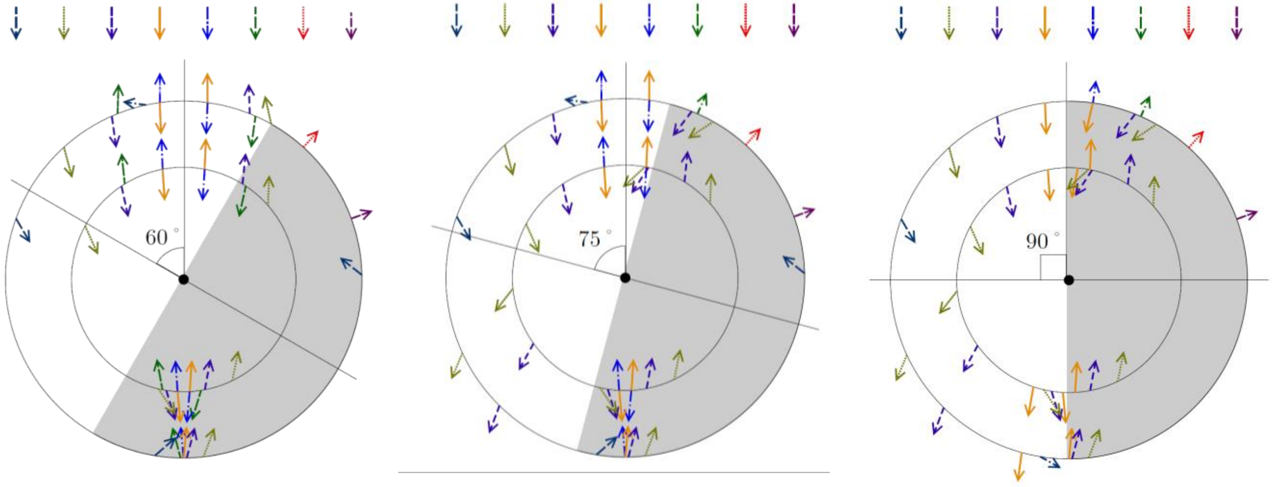


BLITS (from ILRS website)

Modelling C_R:
BLITS Ray-tracing

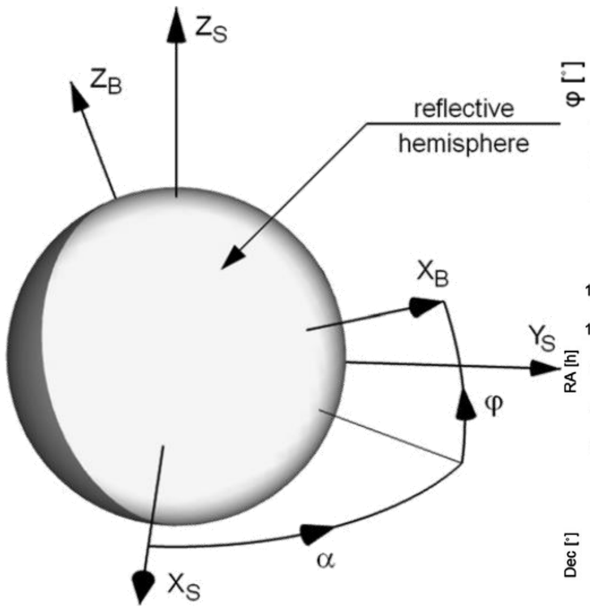


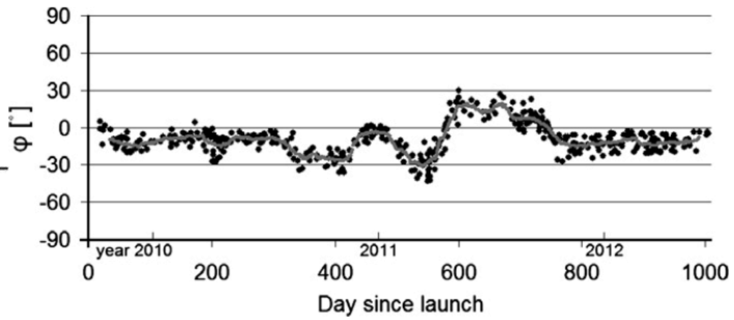
- The sunlight's reflection on surface / refraction in internal of BLITS varies **greatly** depending on the incident angle

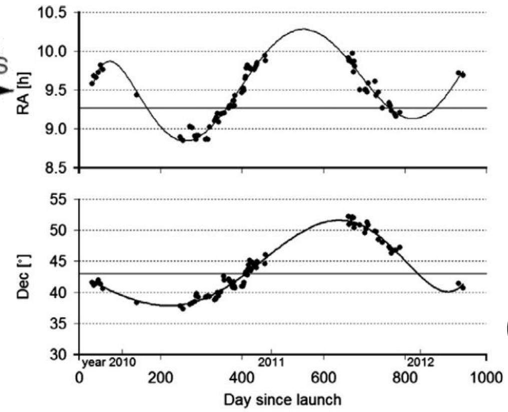


Modelling C_R: BLITS Spin

- The spin axis of BLITS does **NOT coincide** with the axis of symmetry

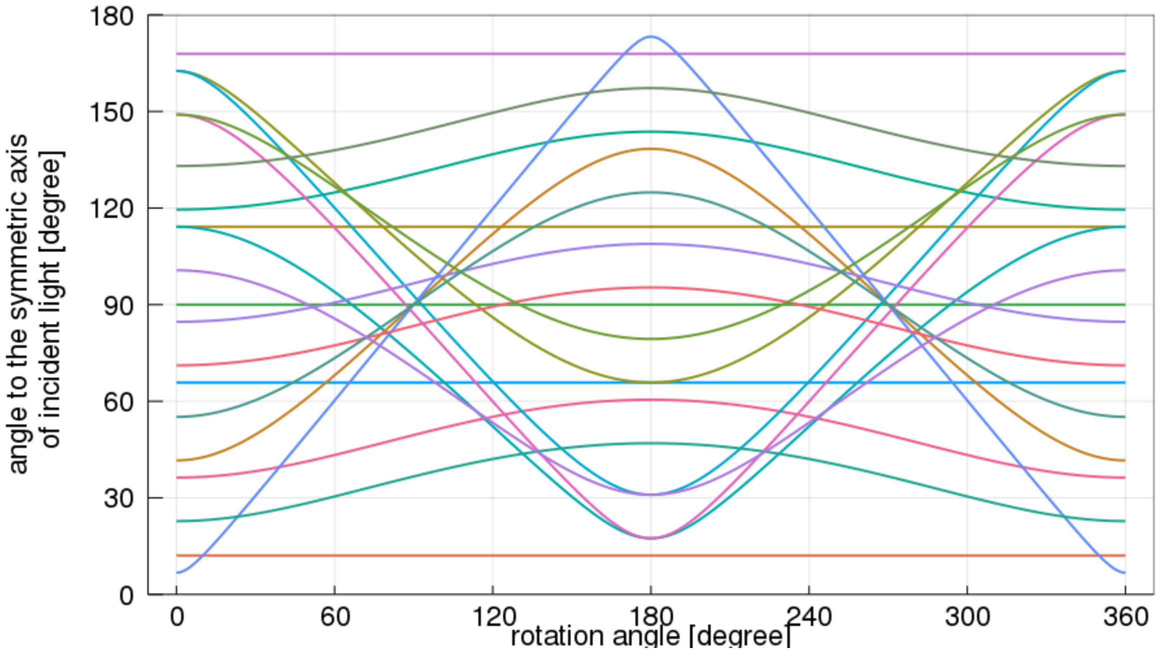


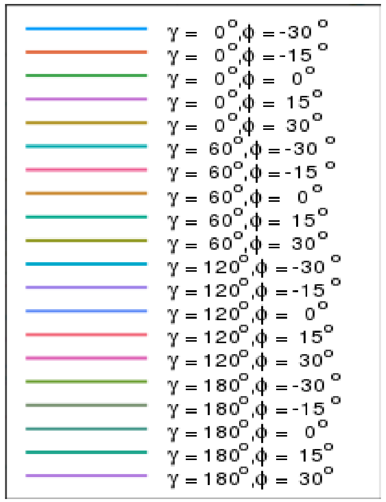




(Kucharski et al., 2013)

- Incident angle of sunlight greatly varies depending on the direction of the spin axis during a revolution

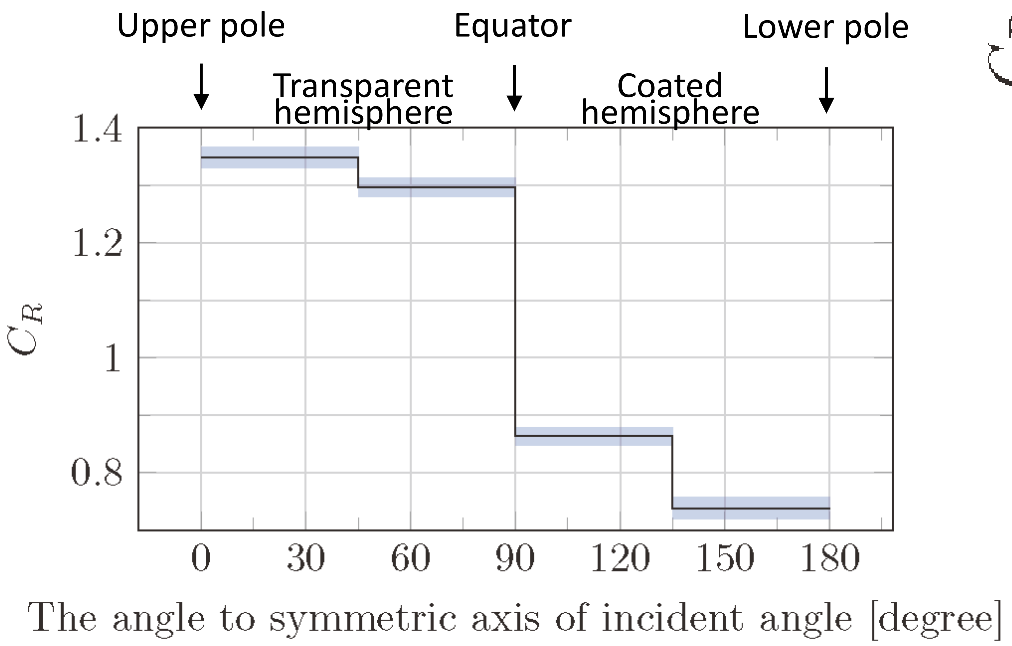


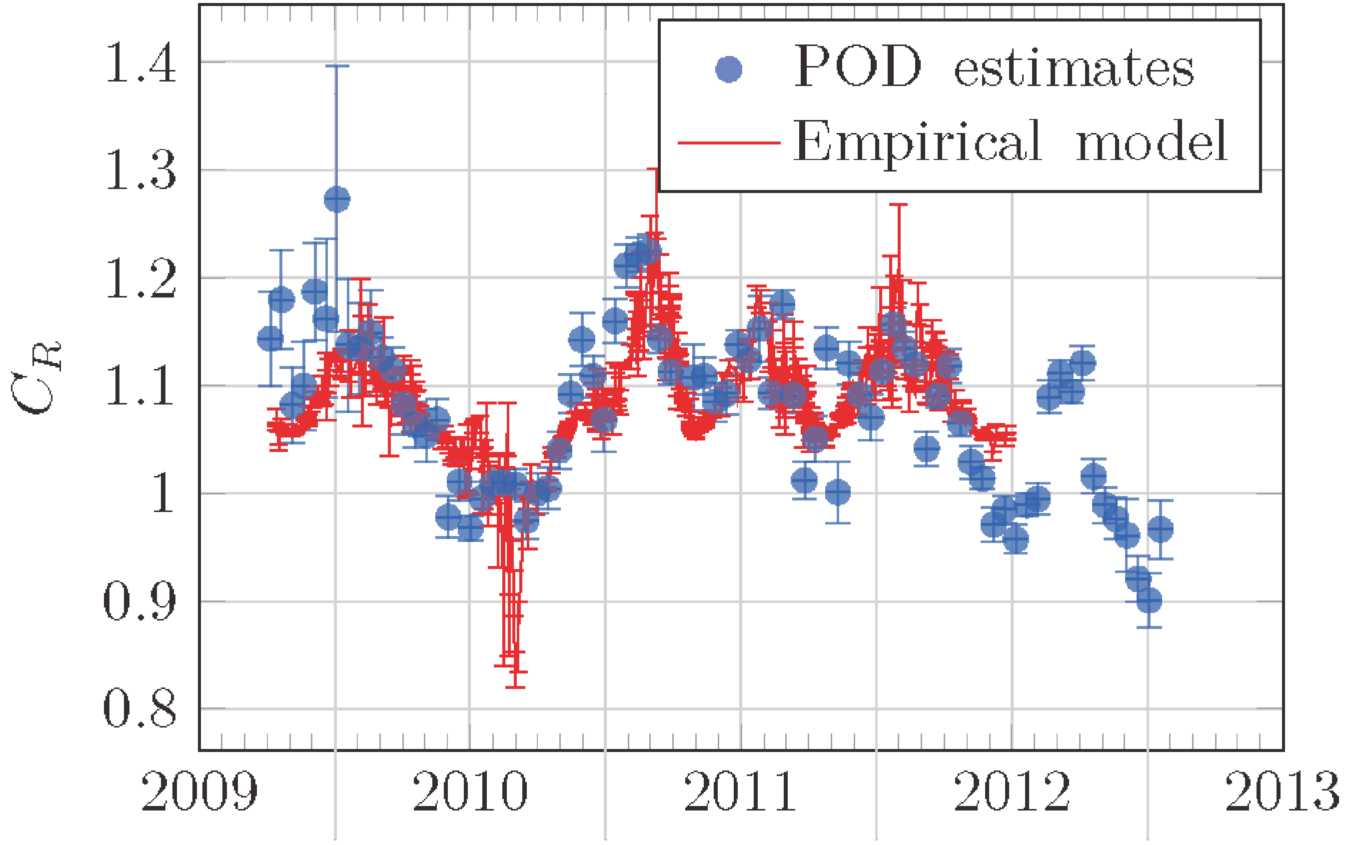


γ is the angle between spin axis and sunlight

Modelling C_R: BLITS Spin

- Assuming the following empirical reflection model, C_R model values agree well with POD estimates.





Summary

- The solar radiation pressure coefficient C_R is estimated by precise orbit determination with SLR observation data. It is found that C_R of Ajisai and BLITS varies systematically in time.
- The time series of C_R of Ajisai is well explained by:
  - Optical properties of materials on surface
  - Non-constant cross-sectional area
  - Total solar irradiance = 1360.8 W/m^2

Please read Hattori A. & T. Otsubo, in press, Time-varying solar radiation pressure on Ajisai in comparison with LAGEOS satellites, Adv. Space Res.

- The time series of C_R of BLITS is well explained by:
  - Empirically adjusted optical properties and spin parameters
- Spinoff: LAGEOS-1 C_R is consistently larger than LAGEOS-2 C_R .
- The material information and spin parameters are necessary for improvement of POD.
- We hope the successful launch of BLITS-M 1 and 2!