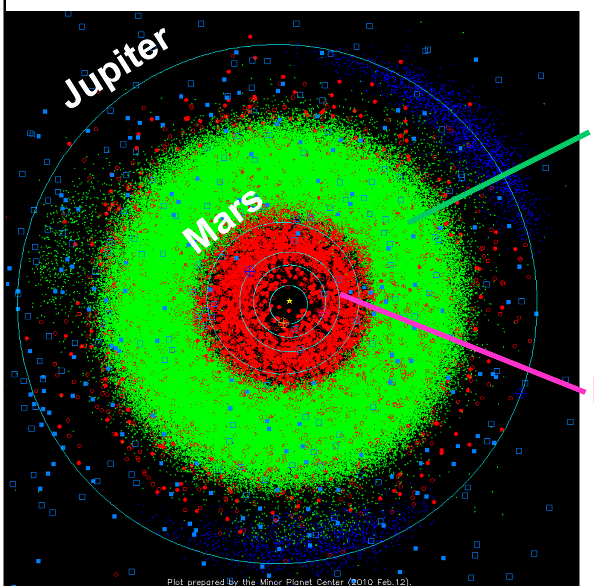
# Time-series Photometry of Earth Flyby Asteroid 2012 DA$_{14}$

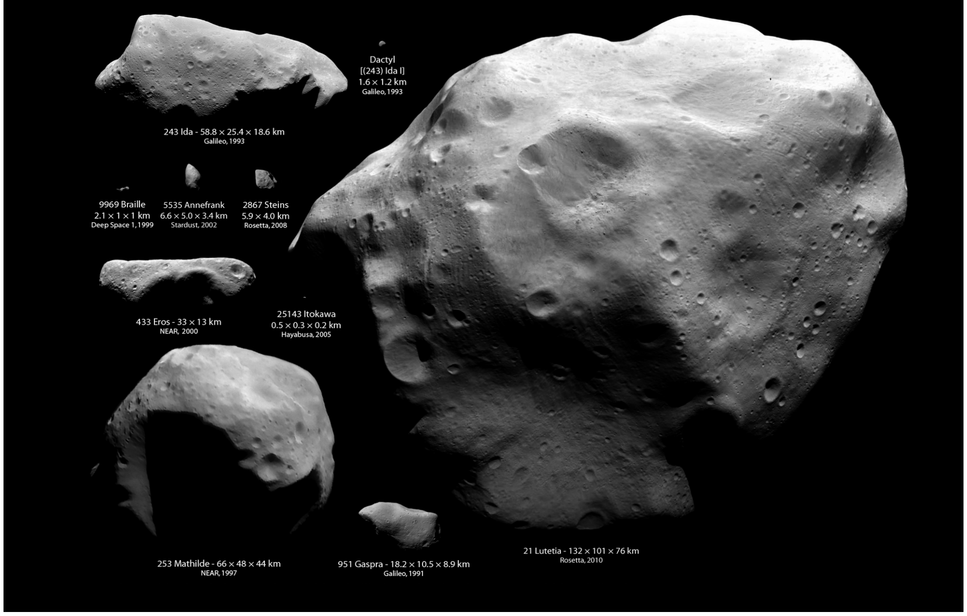
Tsuyoshi Terai

Subaru Telescope

## Asteroid populations



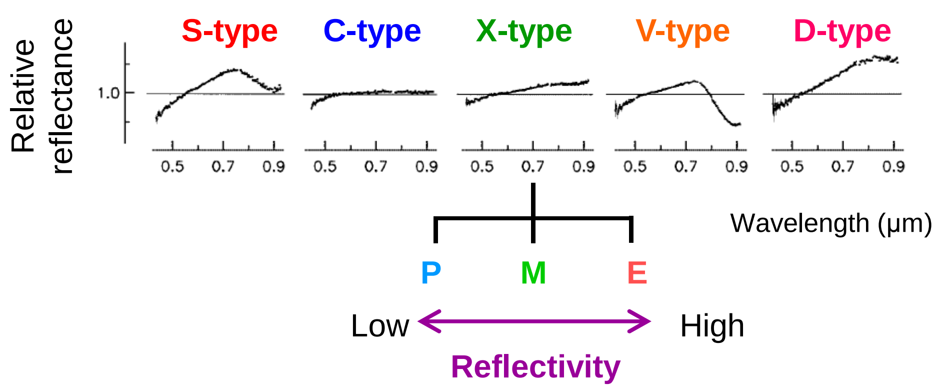
# Asteroids




# Spectral classification

Surface composition of asteroids depends on formation environments and several evolution processes (e.g. thermal, chemical, weathering)

**Asteroid classification by reflectance spectra**




(Bus & Binzel 2002)

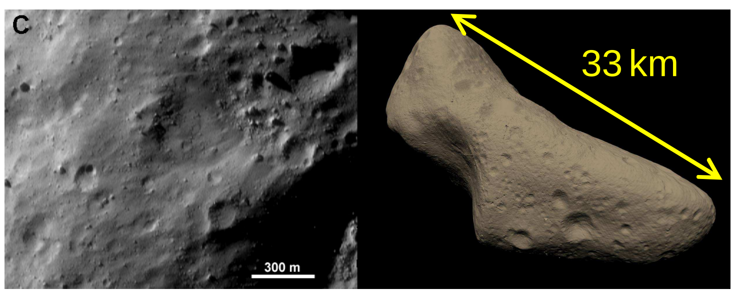
## Surface properties

**Composition → spectra , reflectivity**

**Structure → light scattering characteristics**

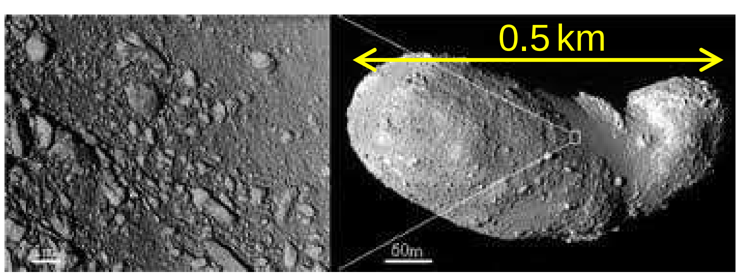
**Providing important clues as to**

- Internal materials / structure
- Collisional evolution
- Thermal / aqueous alterations
- Linkage between asteroids and meteorites




→ covered with
small particle layer

**433 Eros**

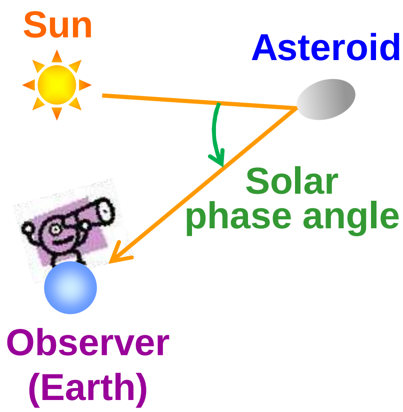


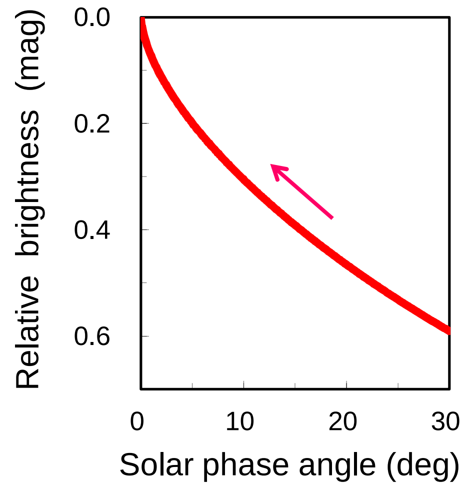

→ covered with
large rocks

**25143 Itokawa**

# Phase curve

Brightness increases with decreasing solar phase angles



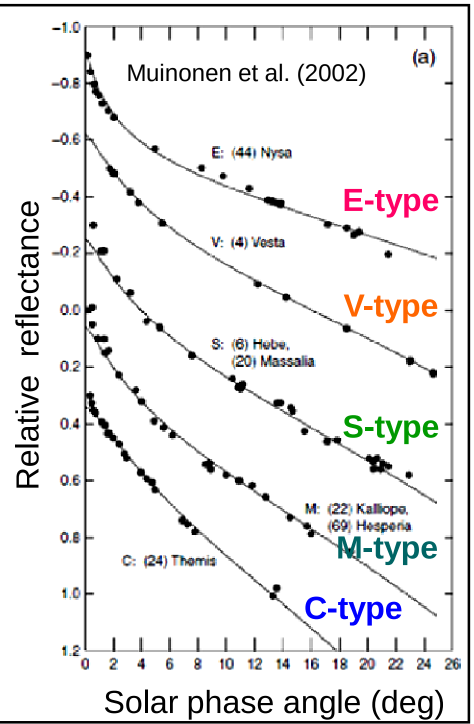




# Phase curve

The shape of phase curve depends on

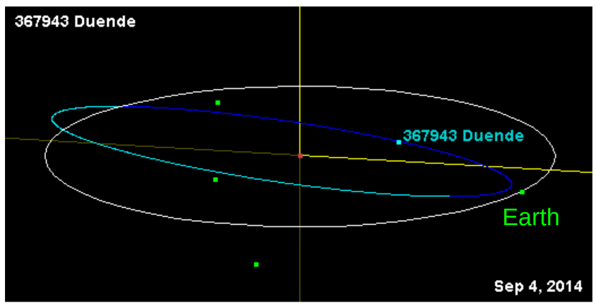
- **Composition (reflectivity)**
- **Structure (roughness)**

**Useful indicator of surface properties**



# Asteroid 2012 $DA_{14}$

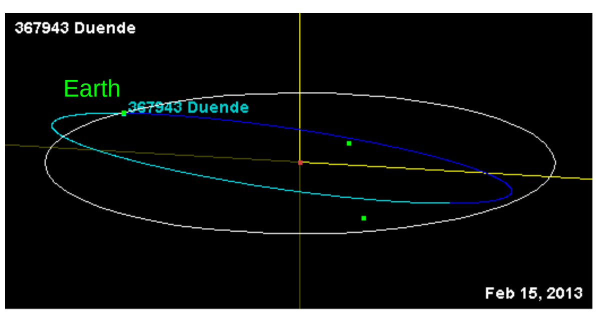
- Near Earth asteroid named “**Duende**”
- Discovered on February 23, 2012, in Spain
- Tiny body with diameter of about **50 m**




**Today**

# Earth Flyby of 2012 $DA_{14}$

- Passed closely to the Earth on Feb 15, 2013
- Approached to the distance of **~28,000 km**

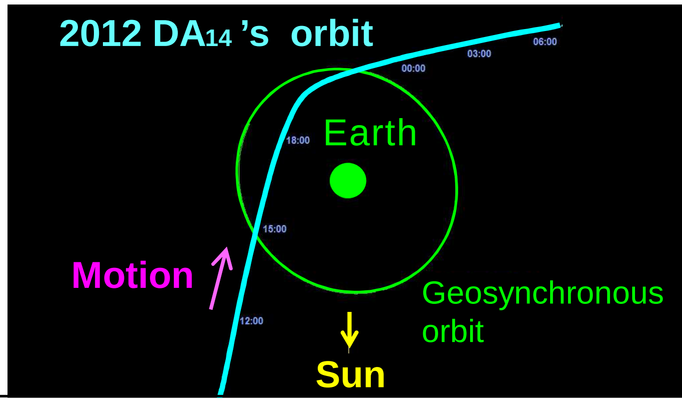



**Feb 15, 2013 (UT)**

## Earth Flyby of 2012 $DA_{14}$

- Passed closely to the Earth on Feb 15, 2013
- Approached to the distance of **~28,000 km**

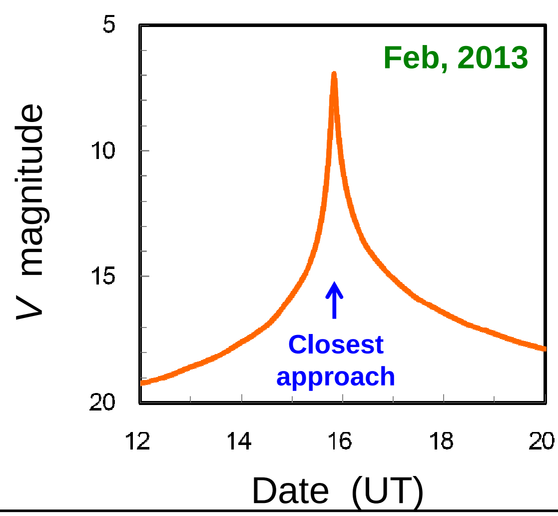
→ **inside a geosynchronous orbit !**




## Brightening

Brightness highly increased to ***V* = 7 mag** *!*

→ Easy to perform high accuracy photometry

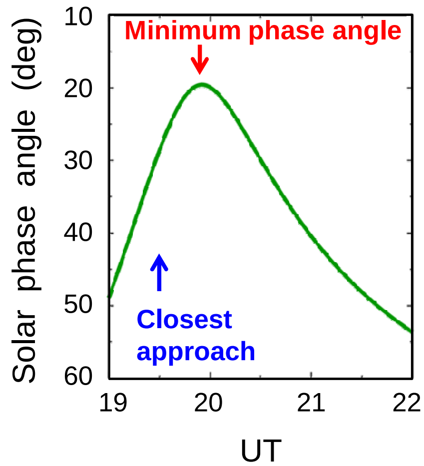


## Aim of observation

Solar phase angle varied **20° – 50°** during 2 hours around the closest approach

Allowing us to measure the phase curve precisely and efficiently

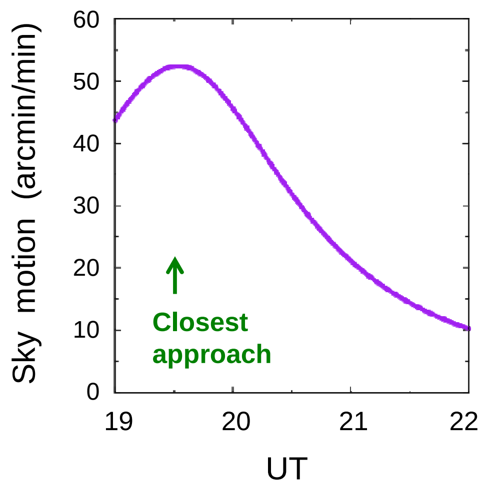
**Great opportunity for investigating surface properties of tiny bodies**



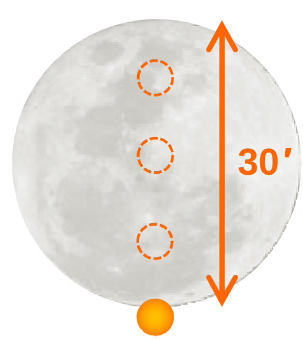

## Difficulty

(1) Extremely rapid sky motion

→ More than **50 arcmin min$^{-1}$** in maximum

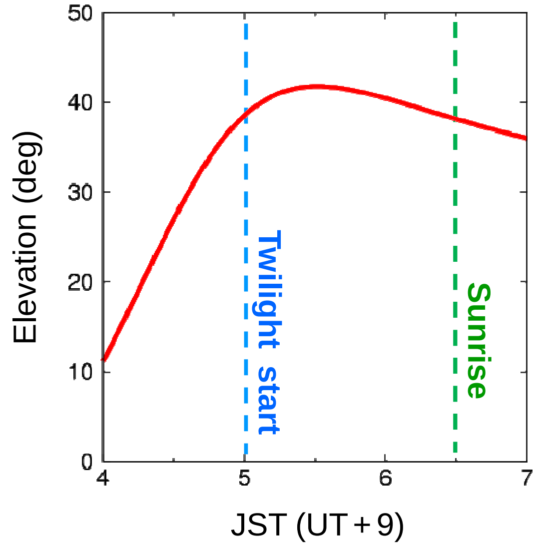



Pass through the moon within 36 sec only !



# Difficulty

(2) Observable within only a short time (in Japan)

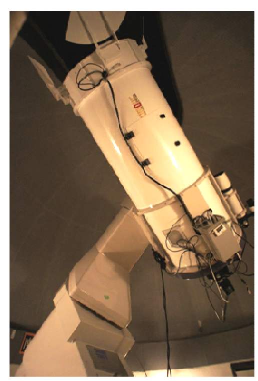



# Strategy

1. Using **0.55-m Saitama-Univ. Telescope**
   - Bright objects are not easy to saturate
   - High mobility and operability
   - Allows pointing toward low elevation

2. With an 1k x 1k CCD camera mounted on **the prime focus**

   → Wide field of view (**32′ x 32′**)

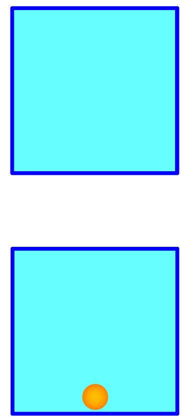


0.55-m telescope at Saitama Univ.

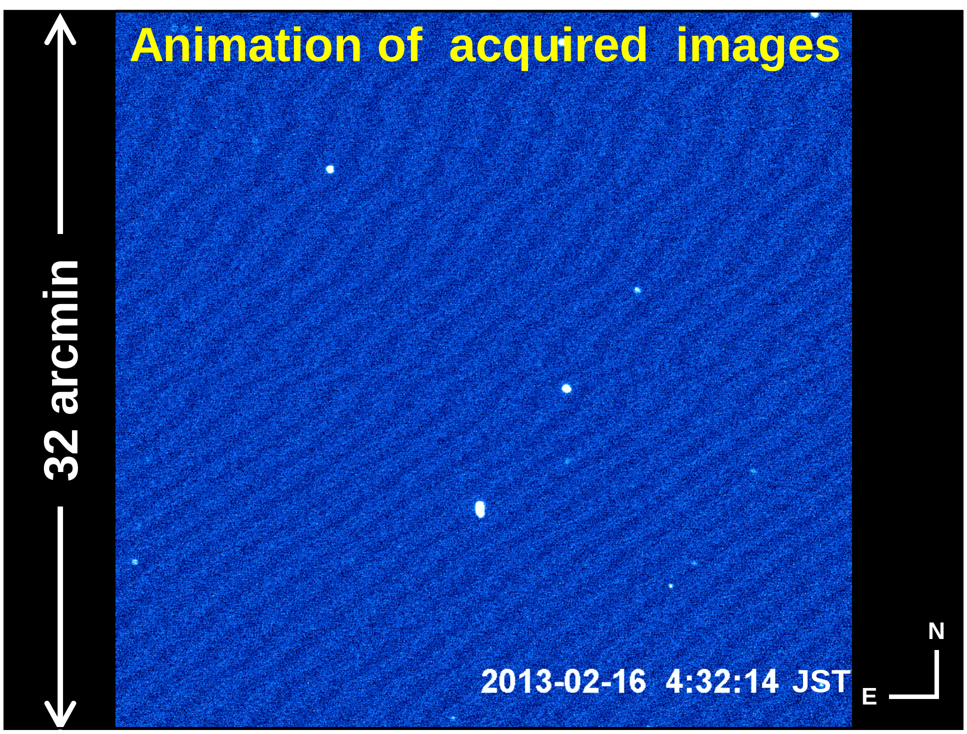
3. High-rate continuous imaging with very short exposure

# Observation

- 2013 Feb 16 4:00–6:10 (JST; UT+9)
- *R*-band imaging with **0.5-sec** exposure
- Data acquisition **every 2 sec**
- Under sidereal tracking
- Keep the target in the field-of view with manual telescope operation

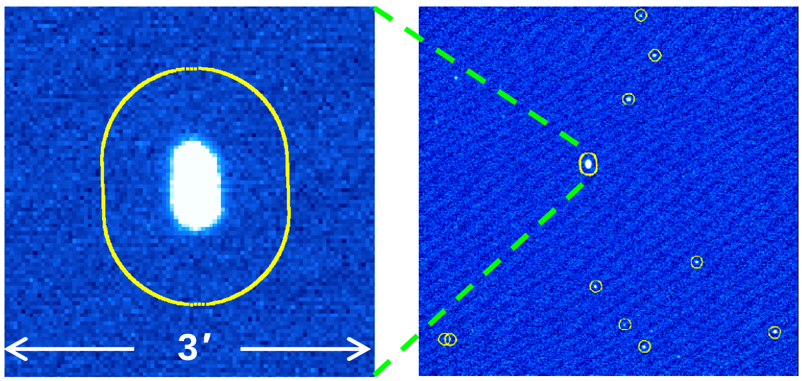


More than **2000** images have been obtained with good sky condition all over 2 hours

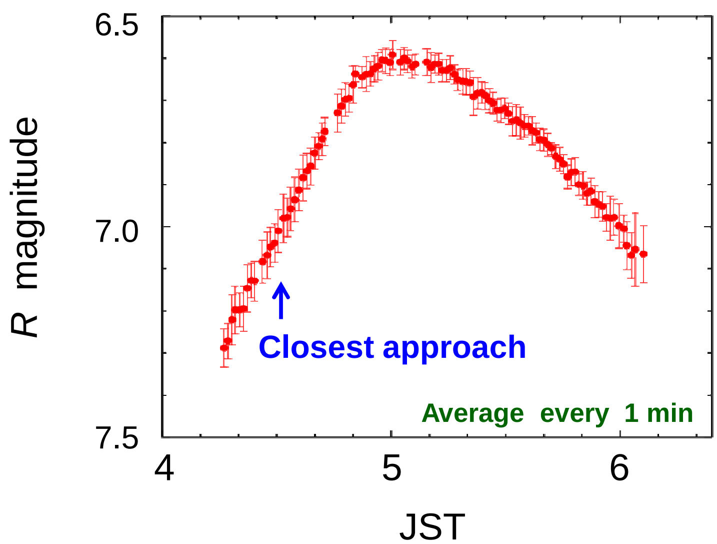


## Measurements

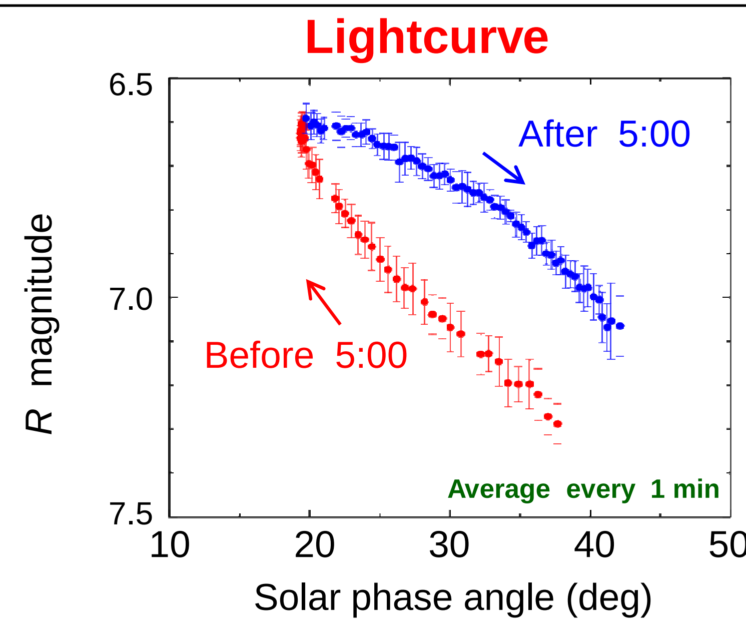
- Photometry with an elongated circular aperture
- Flux calibration using background USNO stars




## Lightcurve




The magnitude was adjusted for the heliocentric/geocentric distances to those at the closest approach.

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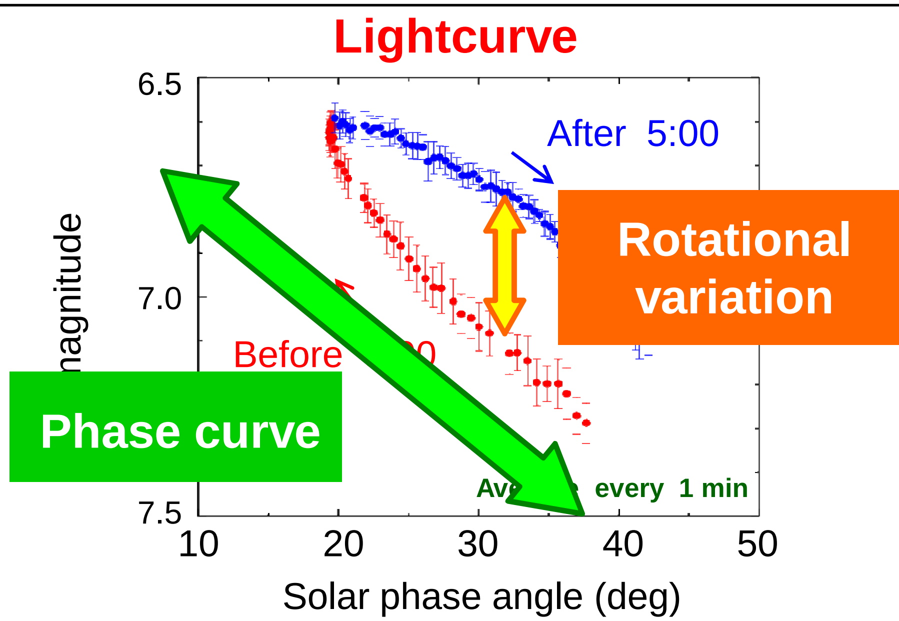



The magnitude was adjusted for the heliocentric/geocentric distances to those at the closest approach.

## Additional observation

In the next night (Feb 16, 2013), 2012 $DA_{14}$ had

- **Constant solar phase angle**
  ( 82.2°– 82.6° in the latter half night)

  → **Possible to obtain a brightness variation due to only the asteroid rotation**

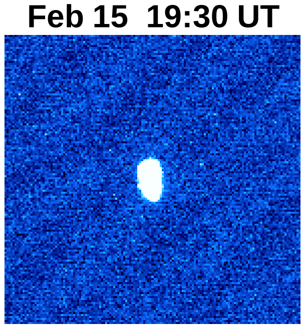
- Slower sky motion (~10 arcmin $hr^{-1}$ )

- Fainter brightness of $V$ ~ 15 mag

**Follow-up observation with continuous *R*-band imaging of $T_{exp}$ = 10–60 sec over 5 hours**

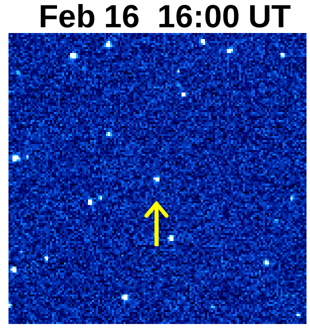
## 1st night vs. 2nd night

**Feb 15 19:30 UT**



**20.5 hr**

**Feb 16 16:00 UT**



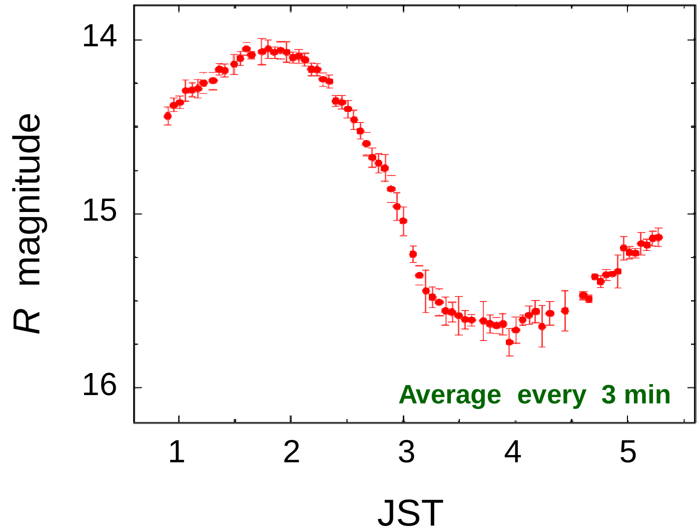
**Texp = 0.5 sec**

**Texp = 20 sec**

***R* ~ 7 mag**

***R* ~ 14 mag**

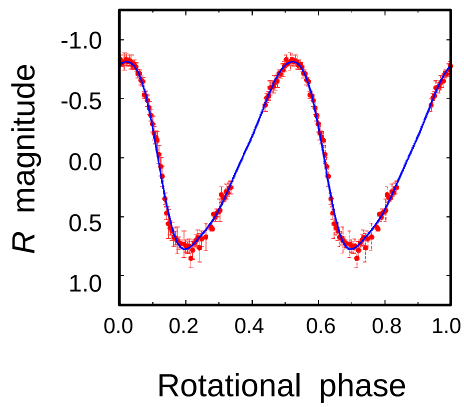
## Lightcurve of the 2nd night




The magnitude was adjusted for the heliocentric/geocentric distances to those at the beginning of the observation.

## Rotation model

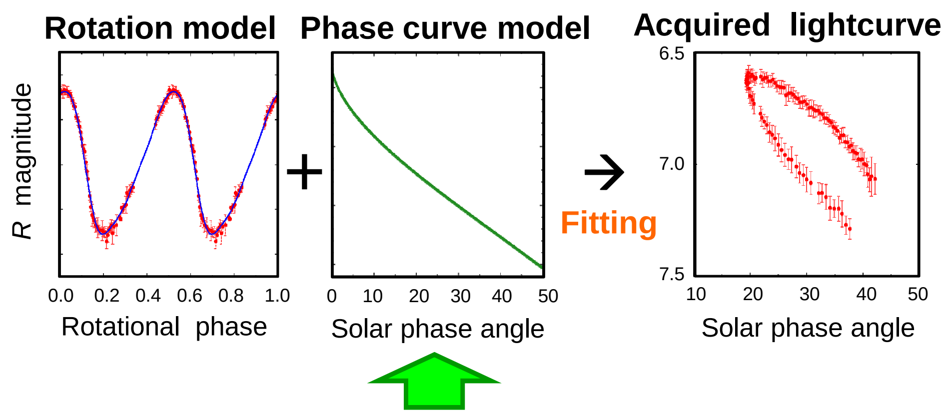
Fitting with a 4th-order Fourier series formulation




**Rotational period = 11.0 $^{+1.8}_{-0.6}$ hr**

**Peak-to-peak amplitude = 1.59 ± 0.02 mag**

# Phase curve model




**"*H-G* phase function"** ( Bowell et al. 1989 )

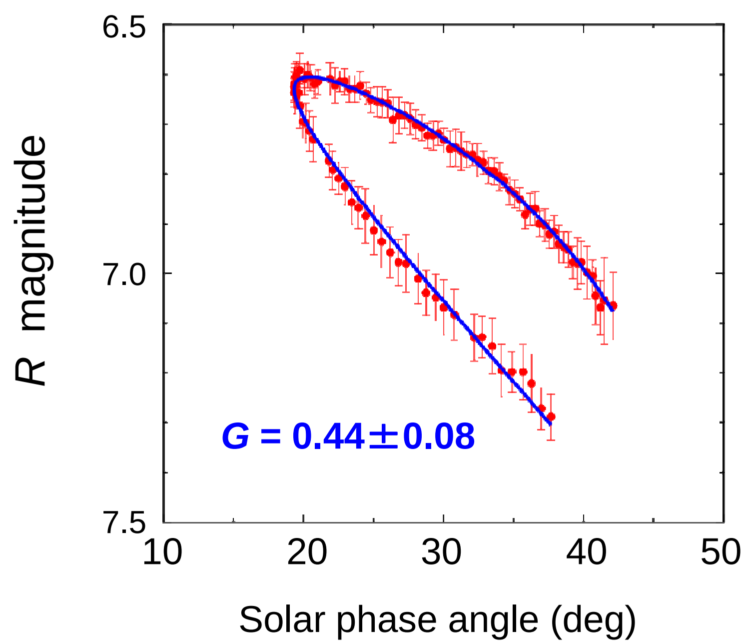
$$m(\alpha) = m(0) + 2.5\log[(1-G)\,\Phi_1(\alpha) + G\,\Phi_2(\alpha)]$$

$m$ ($\alpha$) : apparent magnitude at a phase angle $\alpha$

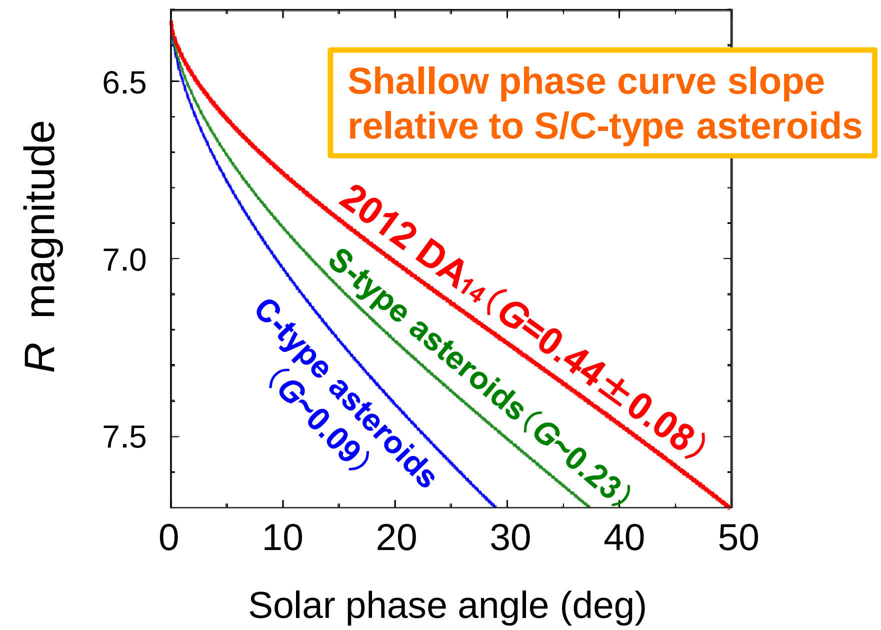
**$G$ : slope parameter ($0 < G < 1$)**

$\Phi_1$ , $\Phi_2$ : specified phase functions

# Best-fit model



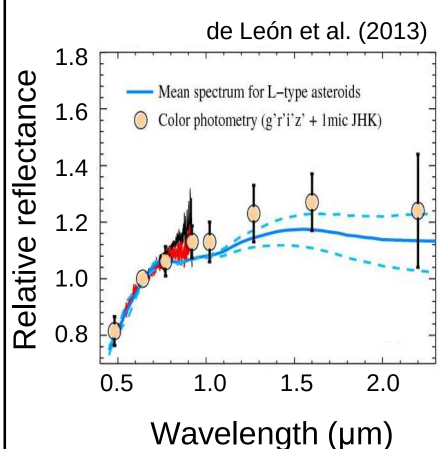
## Best-fit model

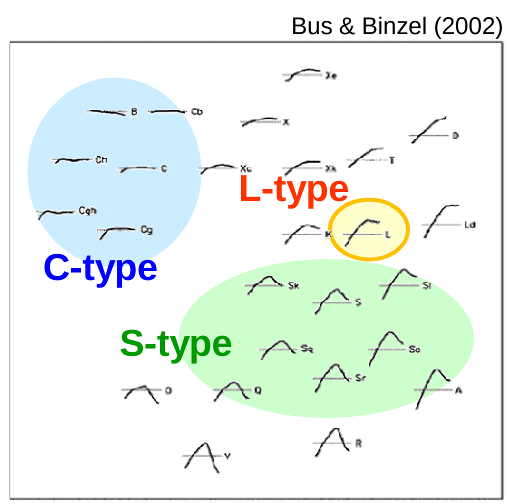



## Spectral type

Visible spectra + Visible/NIR colors (de León et al. 2013)

→ Classified as an **L-type asteroid**



## Interpretation

**Previous observations**

Slope of asteroid phase curve is inversely correlated with surface reflectivity (10° < $\alpha$ < 50°)

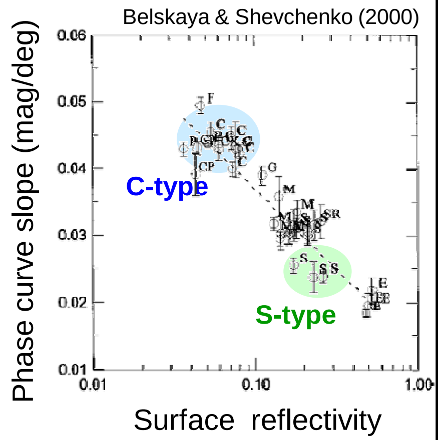
(Belskaya & Shevchenko 2000)

**Mean reflectivity**

S-type : ~ 0.23

**L-type : 0.14 – 0.18**

(Mainzer et al. 2011 ; Usui et al. 2013)




Should have steeper phase curve than S-type asteroids

→ **Our observation shows the opposite result**

→ **2012 DA14 could have a peculiar surface property**

## Interpretation

**Possible cause I**

Weak gravitational field of a tiny asteroid has difficulty in retaining fine particles on its surface

→ Coated with coarse particles

→ Less effect of brightness decrease with phase angle

**Possible cause II**

2012 DA14 may have a high reflectivity surface

- Young age (~ Myr) → less surface modification ?
- Frequent encounters with Earth freshen the surface by tidal stress (Binzel et al. 2010) ?

## Summary

- We performed time-series observations for a tiny asteroid 2012 $DA_{14}$ around its closest approach

- It is likely to rotate with a period of about 11 hours

- Our measurements show a significantly shallow phase curve, which is inconsistent with known L-type asteroids

- 2012 $DA_{14}$ may be covered with a coarse particles and/or high reflectivity surface