Seimei telescope
@ Okayama Observatory, Kyoto University

Tricolor simultaneous photometric observations of tiny Near-Earth Objects (NEOs) with Seimei/TriCCS

modified

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Overview

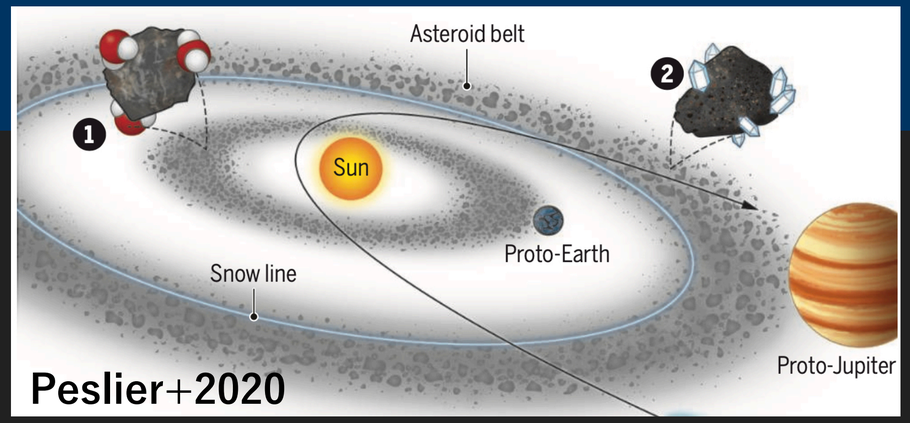
- **We conducted tricolor simultaneous photometric observations.**
  - Instrument : Seimei telescope / TriCCS camera (g + r + i or z)
  - Mode : video observation at 1 fps
  - Target : 5 tiny Near-Earth Objects (diameter < 100 m)

- **Rotational periods and spectral types** were derived.
  - Light curve -> rotational period
    (+ light curve of a reference star)
    Color -> spectral type
  - We fully characterized 1 NEO.
  - No spectral change was found in all 5 NEOs' light curves.

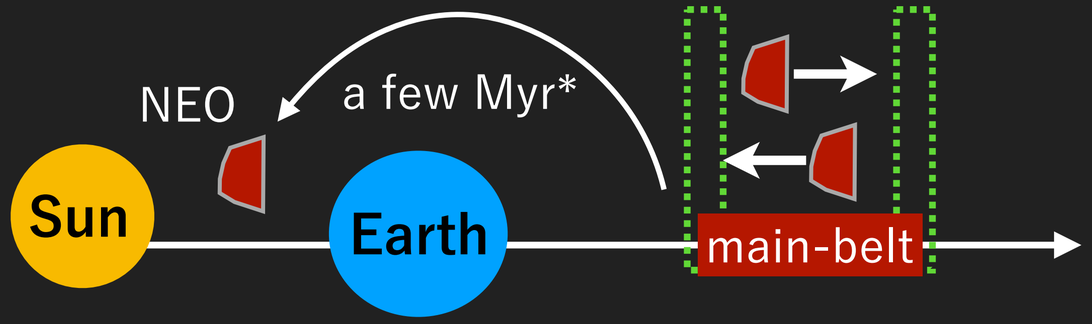
- Additional observations will be done in Semester 2021B.

Scientific motivation

- Material transportation by asteroids is related to the origin of the water and/or the life on the Earth.



- **Near-Earth Objects** (NEOs, perihelion distance q < 1.3 au) come from the main-belt (**~ 10 Myr**).
- NEOs can deliver materials to the Earth.



- Spectroscopic or **multi-band photometric observations** reveal the surface composition.
  - Stony : S-type
  - Carbonaceous : C-type

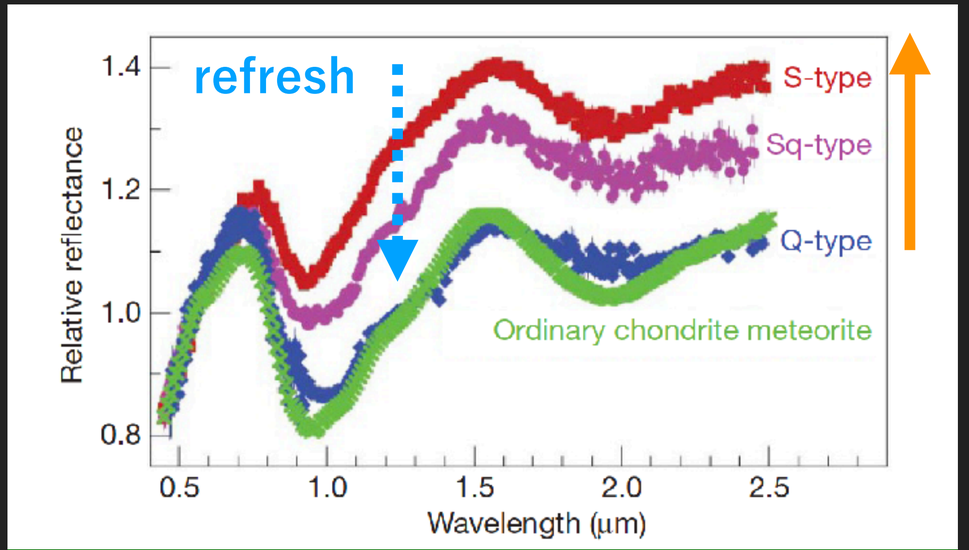
reflectance (0.45 – 2.45 micron)

From DeMeo+2009, Icarus, 202, 160, Fig.15

* Gladman+1997, Science, 277, 197

Space weathering and surface refreshing

- The surface property is altered by the **space weathering**
  : micro-meteorite impacts, solar wind, and cosmic rays.
- Asteroids' surfaces can be **refreshed** by other mechanisms, such as close encounters with planets and rotational fission.



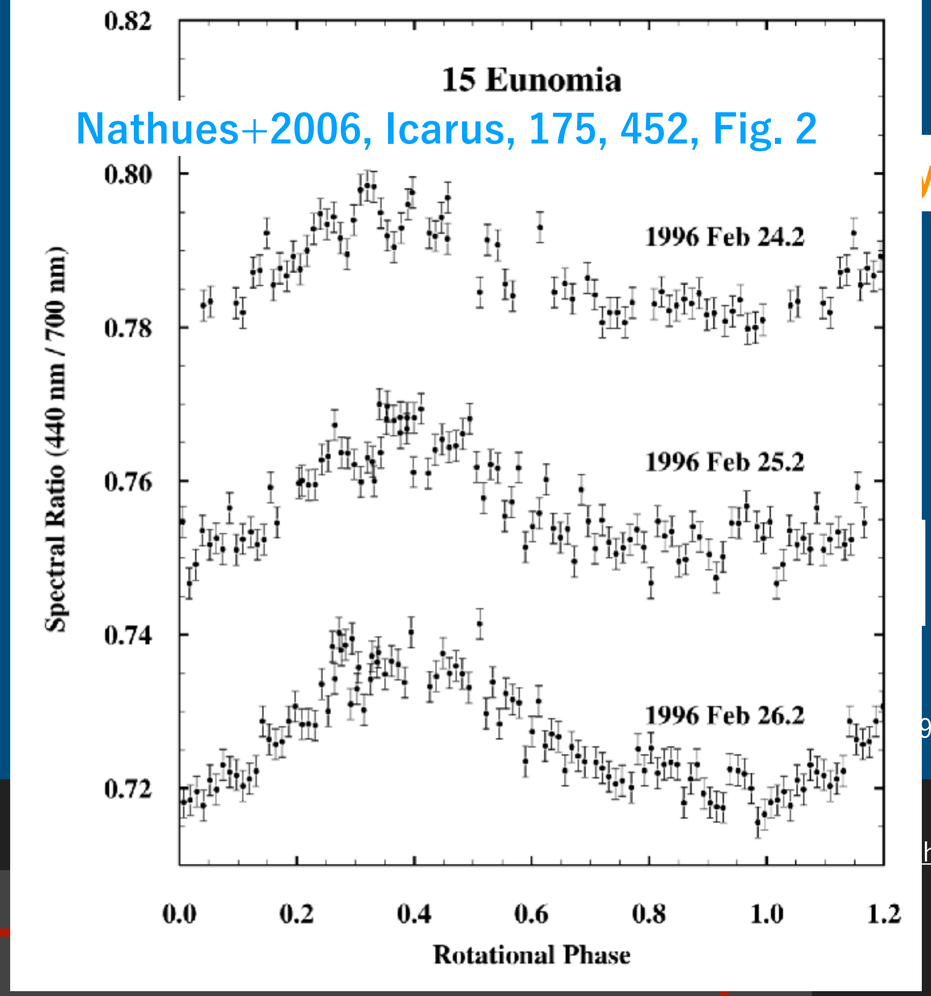
Binzel+2010, Nature let., 463, 331, Figure 1

- **Both space weathering and its refresh are being discussed.**
  - Which weathering agents are dominant : micro-meteorite impact vs. solar wind?
  - Is there any size dependence?

Difficulties and goals

- **Small NEOs are hard to observe.**
  - limited observational window (hours ~ a few days)
  - fast rotation (< 1 minute)
  - large apparent motion etc.

- **The numbers of tiny NEOs are not enough for statistical study.**



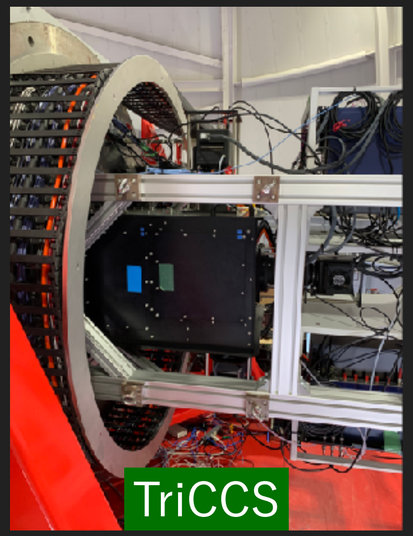
Goal of this study

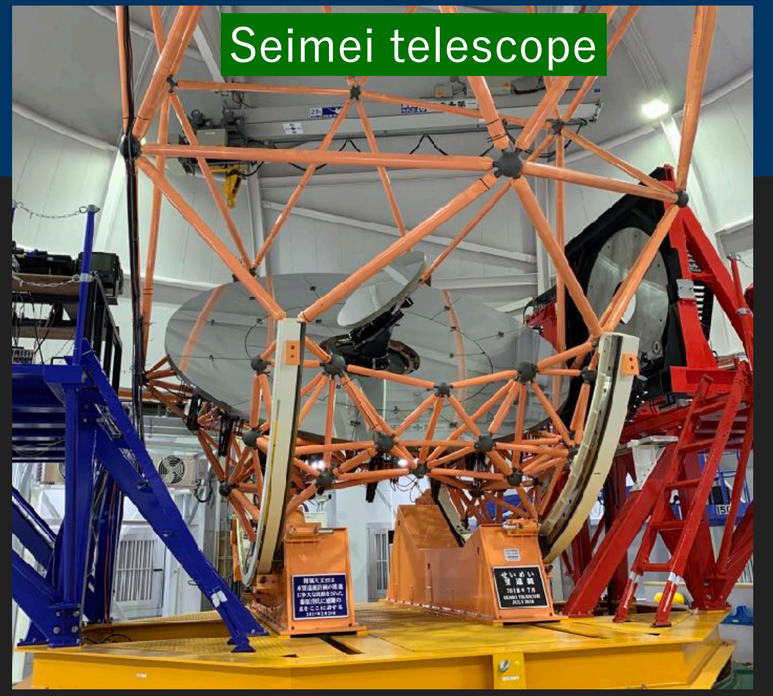
① Estimate **spectral types** of tiny NEOs (**tricolor** + **ToO**).

② Search for spectral changes in rotationally resolved colors.
(**tricolor** + **ToO** + **time-resolved**)

Observation

- **Instrument : TriCCS**
  - **TriC**olor CMOS **C**amera and **S**pectrograph
    @ Kyoto University 3.8 m telescope (the Seimei telescope)
  - g + r + i/z (Pan-STARRS) tricolor imager
  - S/N=10, lim.mag ~ 18 @ g, r band, 1 sec exposure
  - field of view 12.6 x 7.5 arcmin





- **Targets**
  - 5 NEOs (mean diameter ~ 50 m, soon after discovery ~ a few days)

- **Observation Date & Time**
  - Feb 22-24th, Mar 8th, 2021
  - 5 min – 60 min / NEO

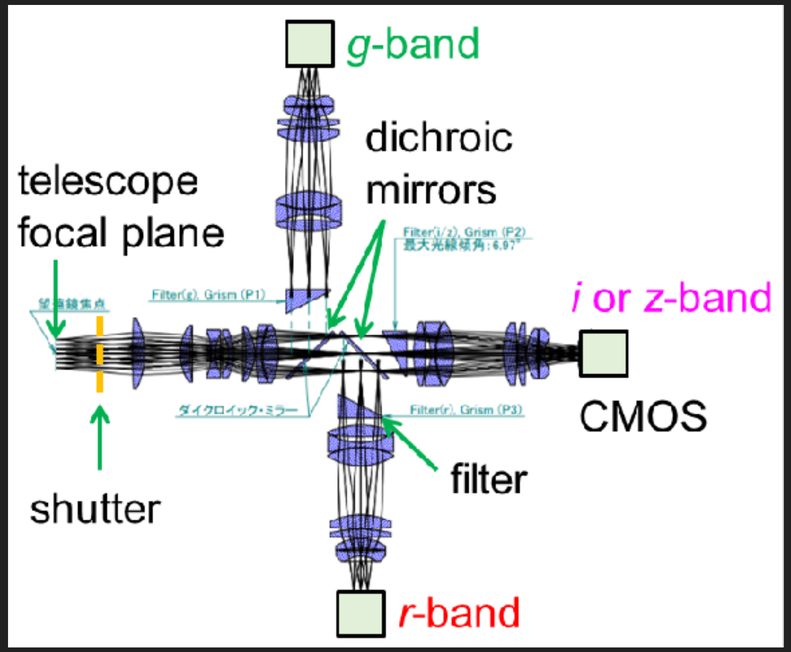


Image from web page of Kazuya MATSUBAYASHI
(http://www.kusastro.kyoto-u.ac.jp/~kazuya/p-triccs/overview/index.html)

Observed NEOs

Orbit diagram of a NEO (Feb 24th, 2021)

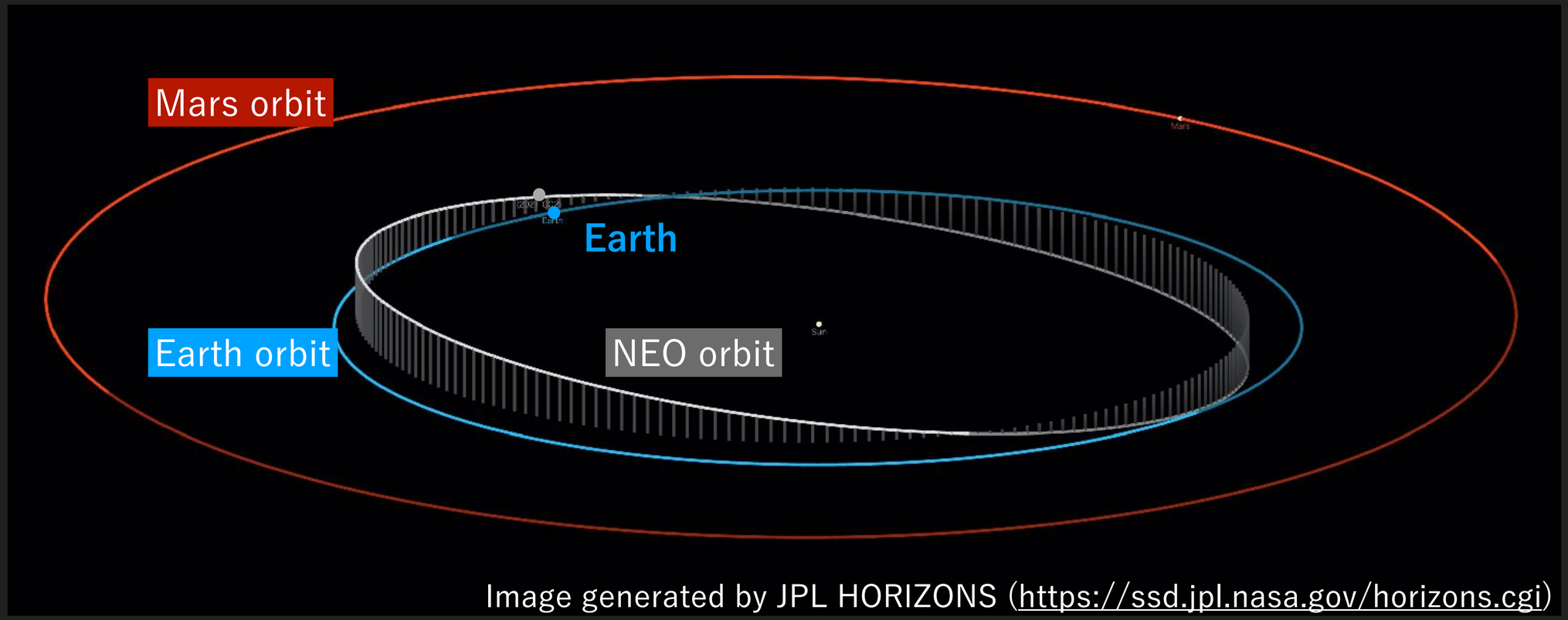
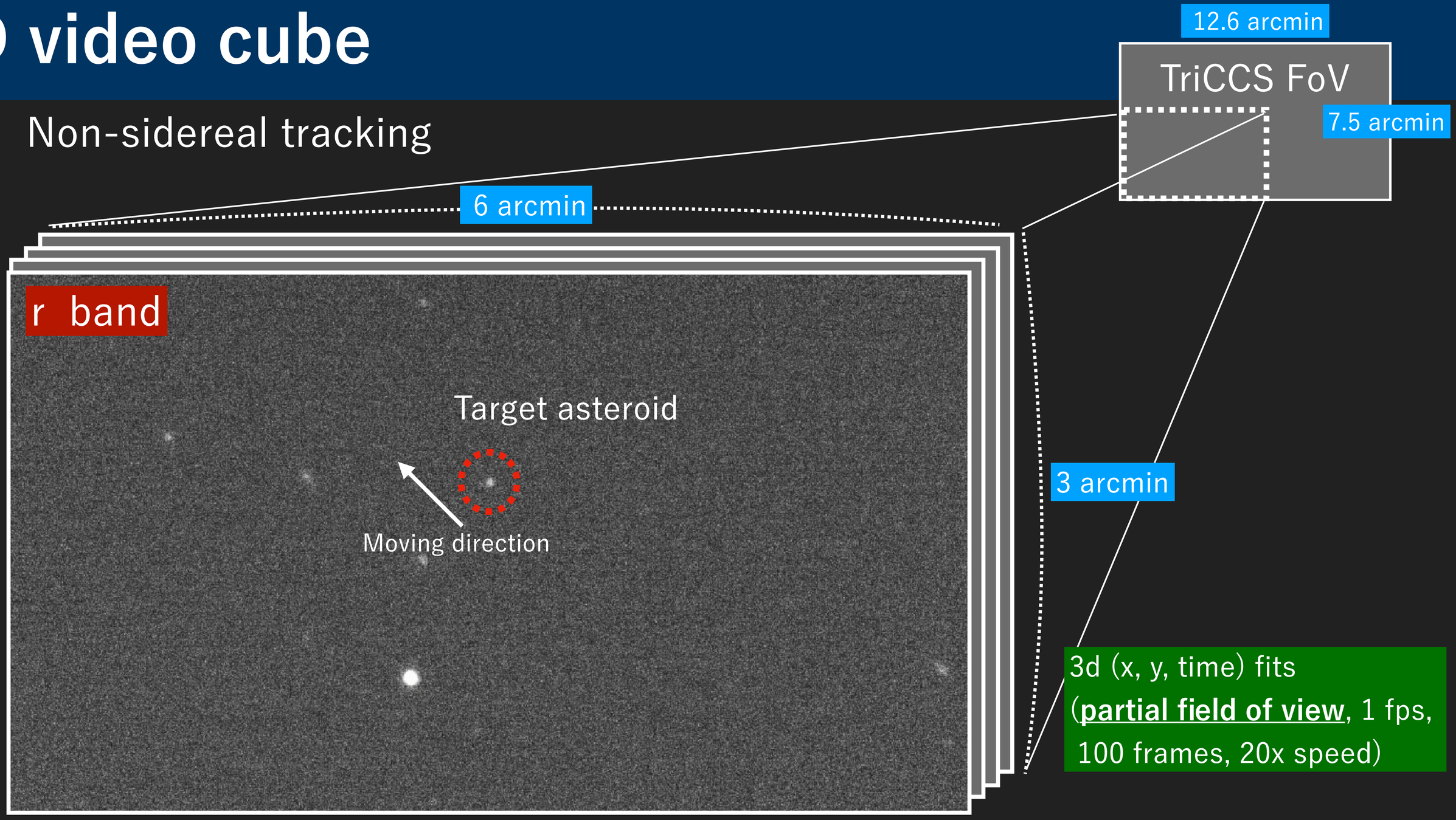


Image generated by JPL HORIZONS (https://ssd.jpl.nasa.gov/horizons.cgi)

3D video cube

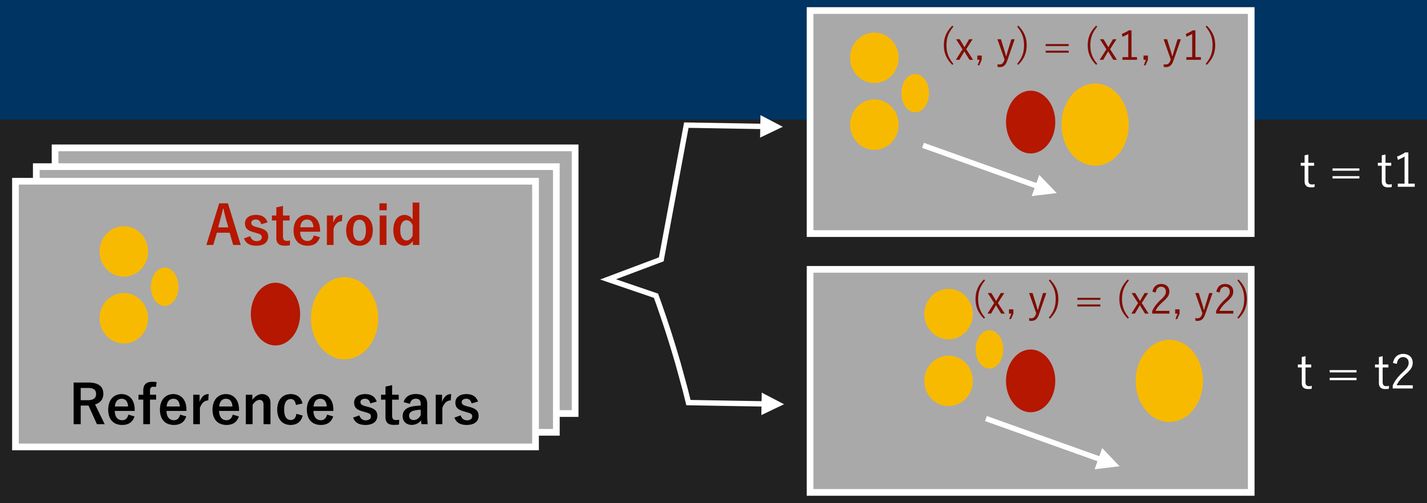
- Non-sidereal tracking



3d (x, y, time) fits
(**partial field of view**, 1 fps,
100 frames, 20x speed)

Data Reduction

0-1. bias & dark subtraction & flat-fielding
0-2. Split 3d (x, y, t) to 2d (x, y)
0-3. astrometry (WCS, astrometry.net*)



1. NEO location determination

predict location by interpolation of
(x, y) = (x1, y1), (x2, y2) …

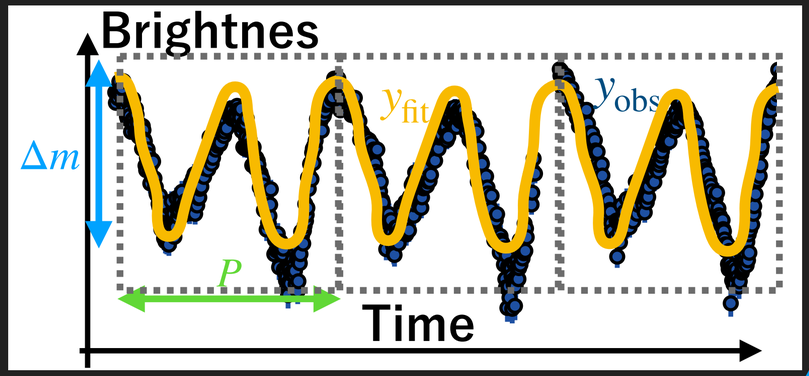
2. Aperture photometry

・circle aperture （python, SEP **）
radius = 2 – 3 FWHM (~ 5 arcsec)

・relative photometry
with Pan-STARRS catalog ***

3. Periodic analysis

・**Rotational periods** are estimated by Lomb-Scargle method
(Lomb 1976, Scargle1982, VanderPlas2018)

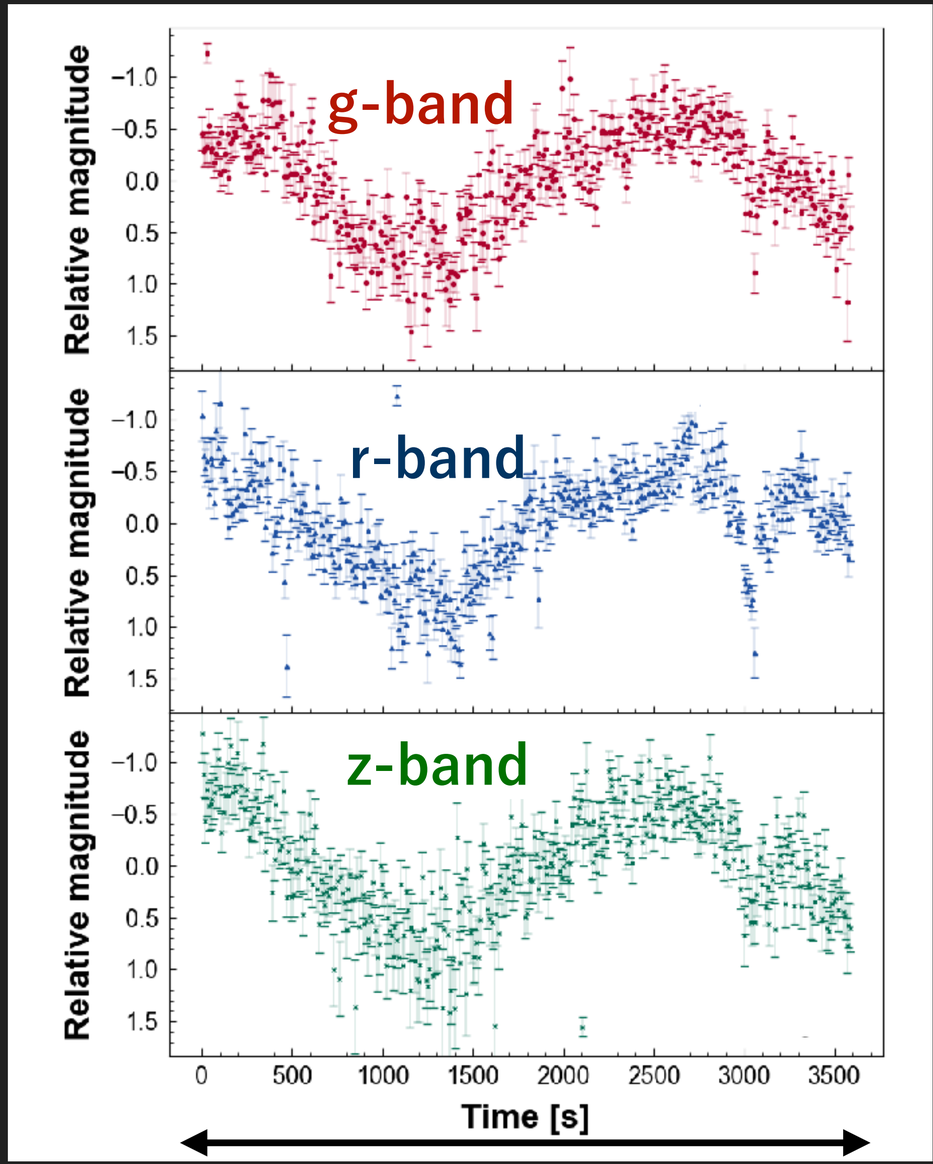


* Lang+2010, AJ, 131, 1682 ** Bertin+1996, AA, 117, 393, Barbary+2015, 10.5281/zenodo.15669
*** Chambers+2016, arXiv:1612.05560

Result 1. Light curve (NEO)

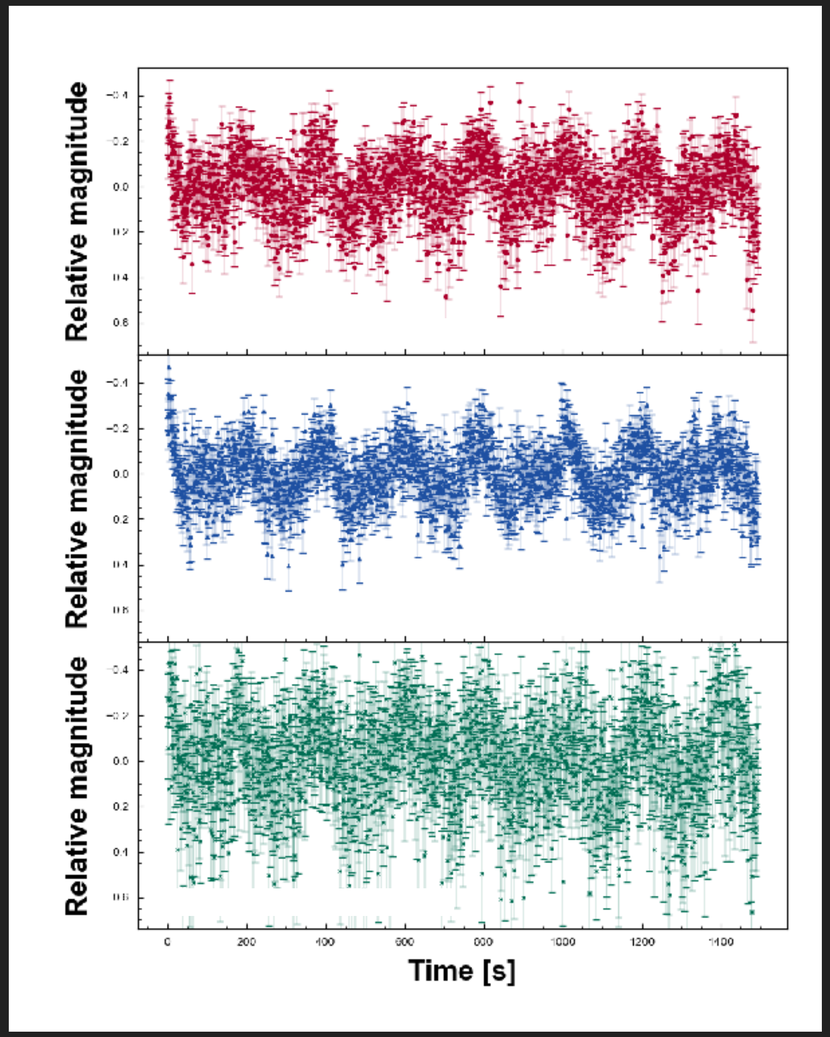
(Feb 24th, 2021)
t_{exp} : 10 sec (stack 1 sec x 10 frames)

- The rotational period is not estimated in observing time (1 hour).
  This is consistent with the period ~ 1.8 hour in a previous study*.

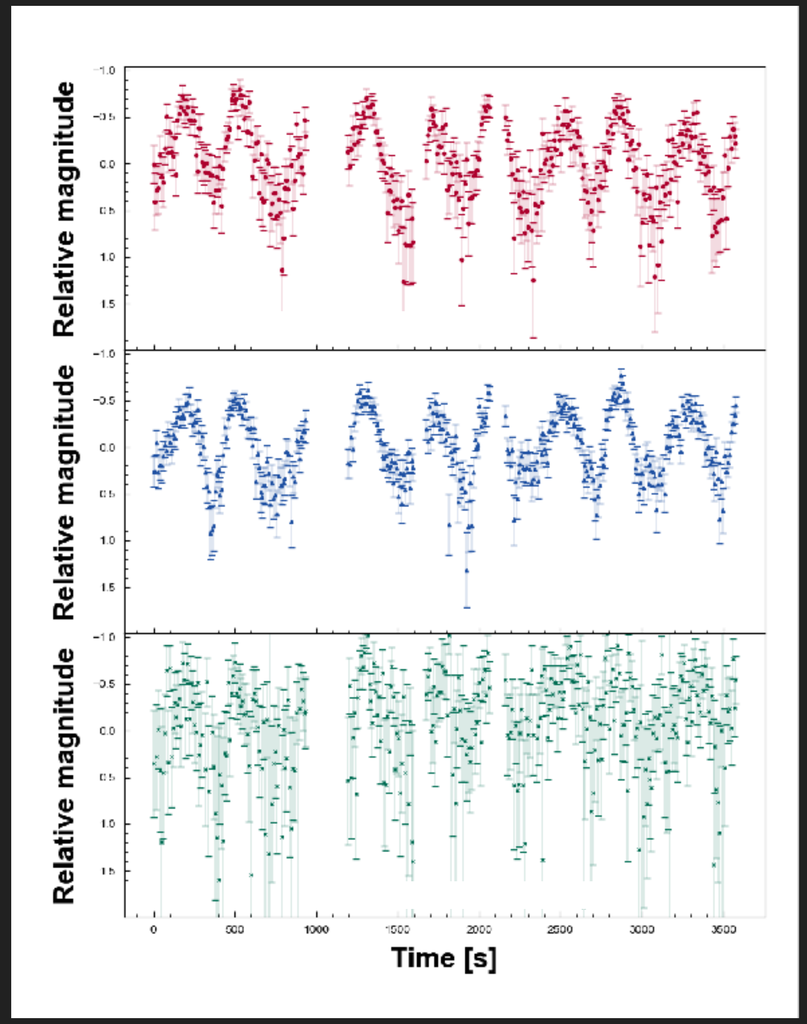


Result 1. Light curve (NEO)

(Mar 8th, 2021)
t_{exp} : 1 sec



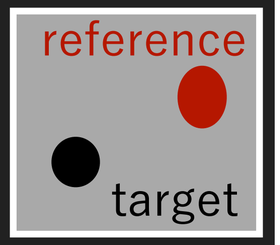
(Feb 24th, 2021)
t_{exp} : 10 sec (stack 1 sec x 10 frames)



Result 1. Light curve (Reference)

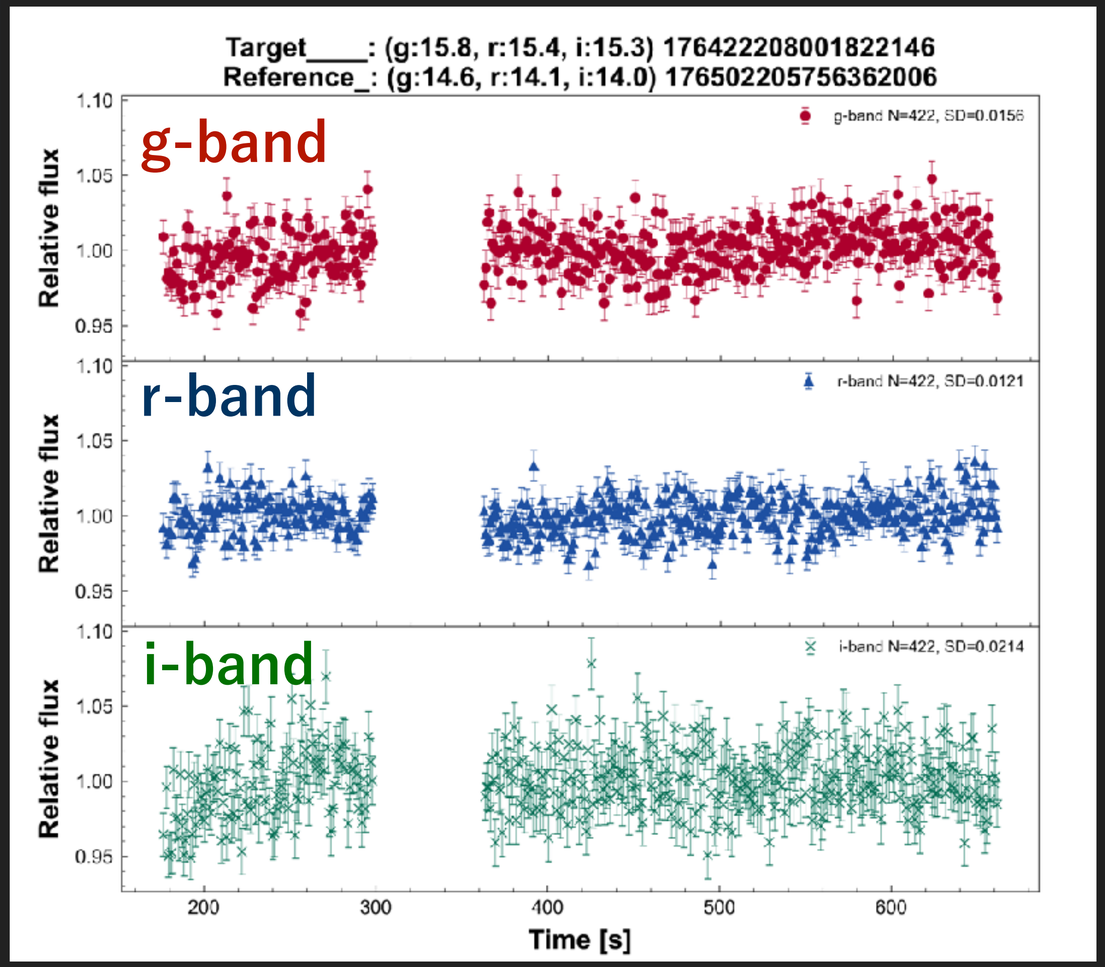
normalized

$$\frac{F_{\text{target}}}{F_{\text{reference}}}$$



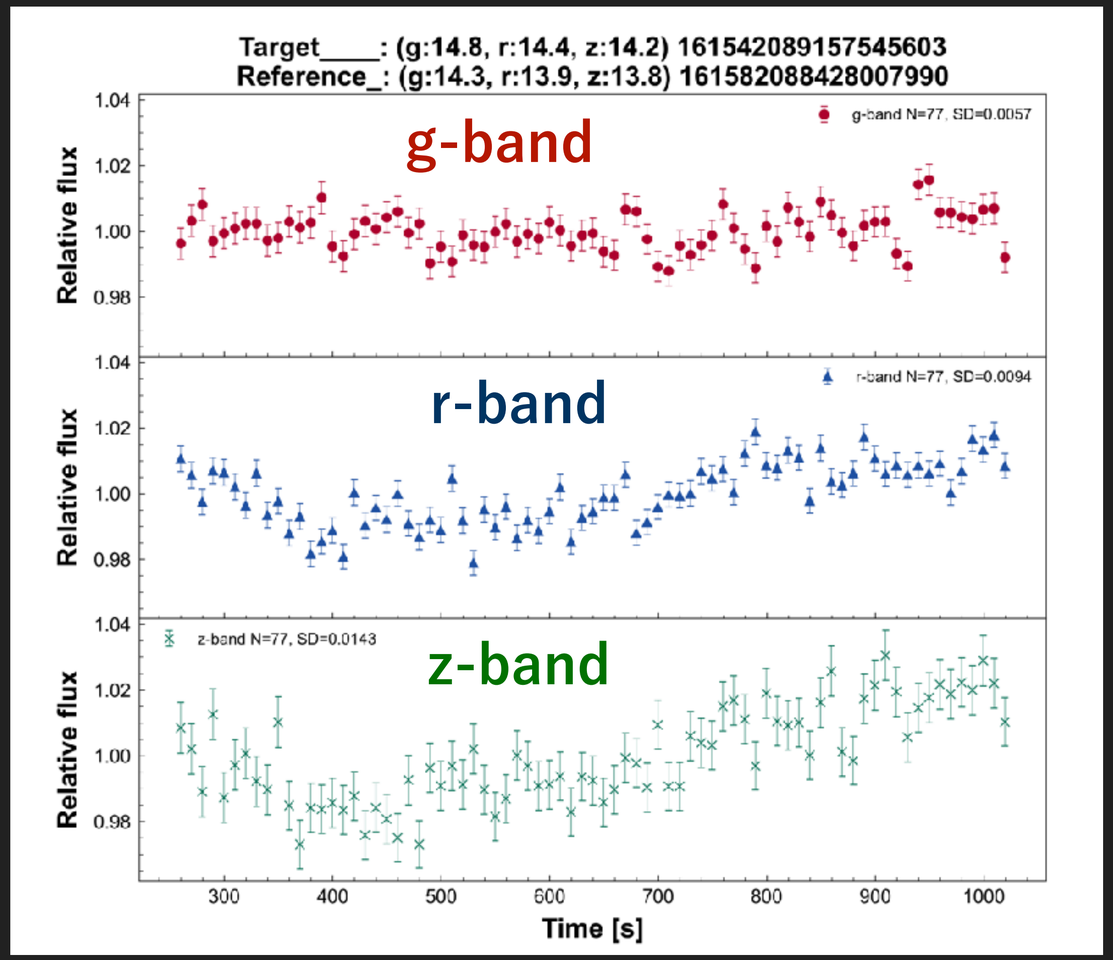
① 1 sec exp.

g, r, i = (15.8, 15.4, 15.3)
~ 1.6 %, 1.2 %, 2.1 %



② 10 sec exp.
(stack 1 sec x 10 frames)

g, r, z = (14.8, 14.4, 14.2)
~ 0.57 %, 0.94 %, 1.4 %



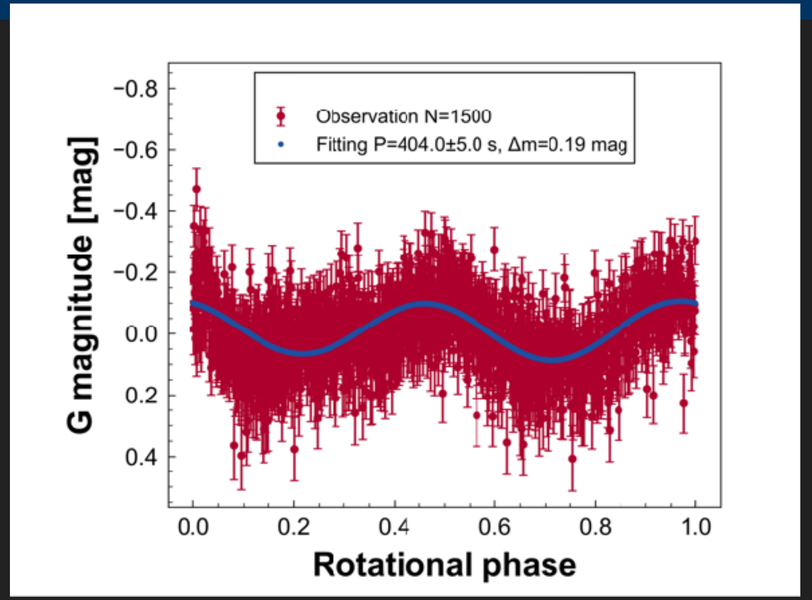
Note: Ref. stars are moving at ~1 pix/sec due to the non-sidereal tracking.

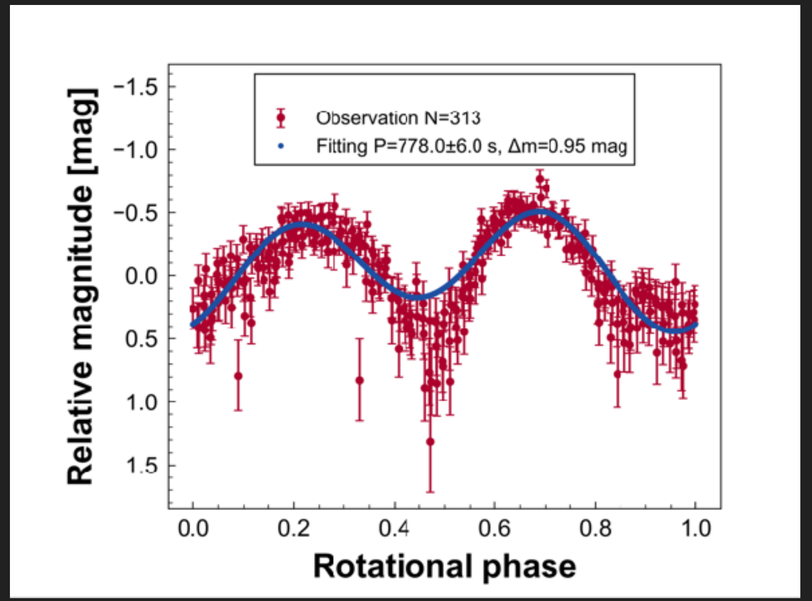
Result 2. Rotational period

- We derived the rotational periods of 2 NEOs :
  - (Mar 8th)

    rot. P = 404 ± 5 s
  - (Feb 24th)

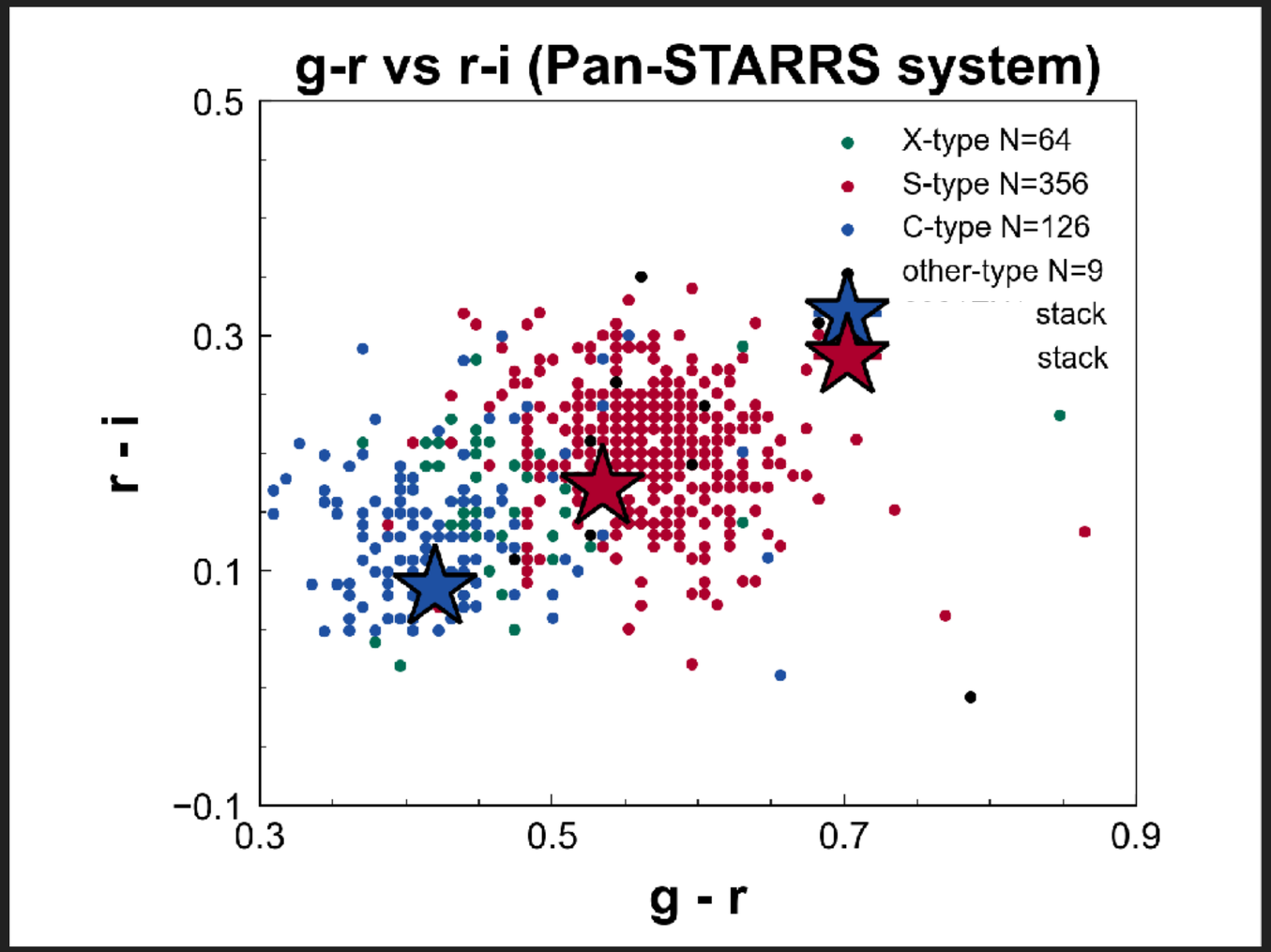
    rot. P = 778 ± 6 s





Result 3. Spectral type

- (preliminary) Spectral types of 2 NEOs are estimated.

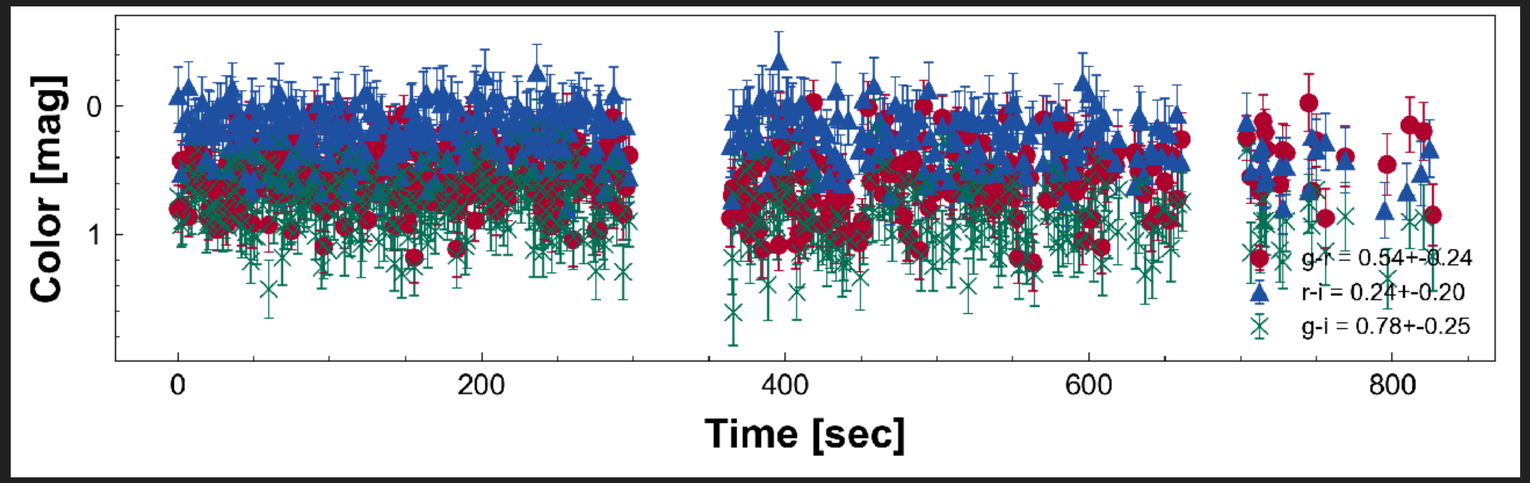


Reference objects are from SDSS Moving Object Catalog, Ivezic+2002, Proceedings of SPIE Vol. 4836, http://faculty.washington.edu/ivezic/sdssmoc/sdssmoc.html

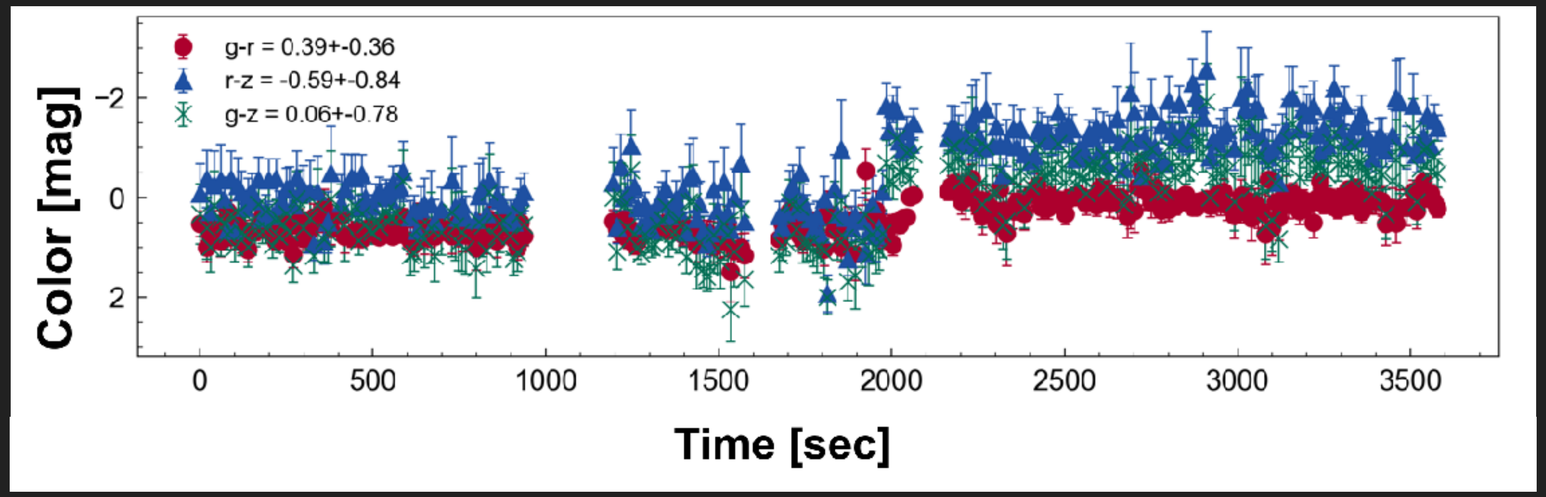
Result 4. Color variation

- (preliminary) No color variation is detected in all the 5 light curves.

(Feb 24th)



(Feb 24th)



More detailed
analysis are needed.
(c.f. color transformation)

Summary

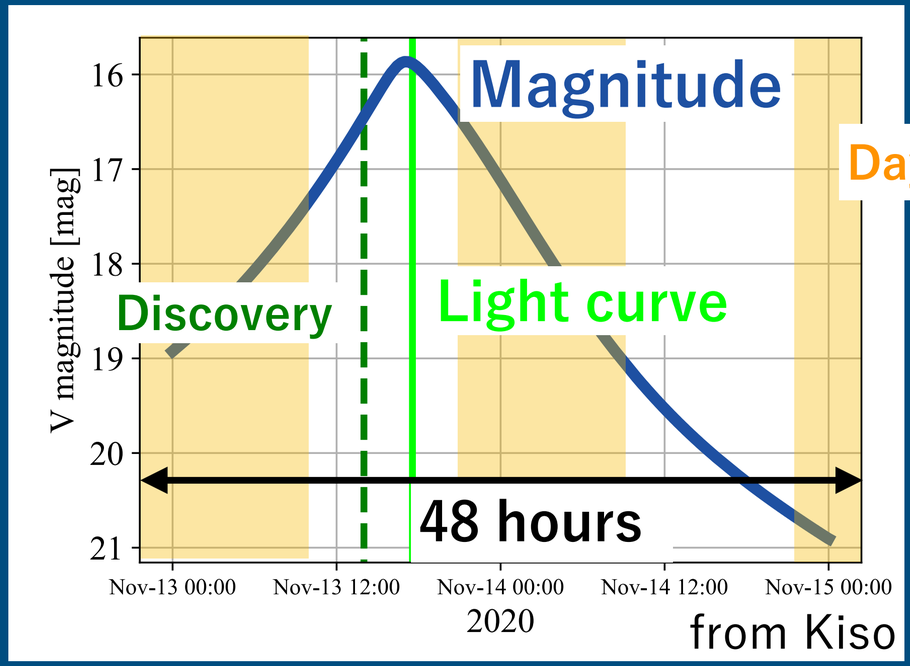
- We conducted **tricolor simultaneous photometric observations.**
  - Instrument : Seimei telescope / TriCCS camera (g + r + i or z)
  - Mode : video observation at 1 fps
  - Target : 5 Near-Earth Objects (diameter < 100 m)

- We estimated **both the rotational periods and the spectral types.**
- **No spectral change was found in all the 5 light curves** (preliminary)**.**

- Additional observations will be done in Semester 2021B.

2021B ToO観測へ向けて

- 当日または翌日のToO依頼が見込まれます。
  現地観測者や天文台の方にお願いする際は
  よろしくお願いします。
- NEO観測のための手順書に従い
  コマンド入力をすると観測が
  できるように整備しました。
  (8/11に整備予定)



Ephemeris of a tiny NEO (D = 5 m)

- データ解析用scriptを公開しています。
  1. TriCCS Data Reduction (tdr) https://bitbucket.org/jin_beniyama/triccs-data-reduction/src/master/
  2. Moving Object Photometry (movphot) https://bitbucket.org/jin_beniyama/movphot/src/master/

【観測所への要望】
即日や翌日ToOの観測ですので、リモート観測を心待ちにしています。