Progress report of FOSSIL survey [S20A-096I]

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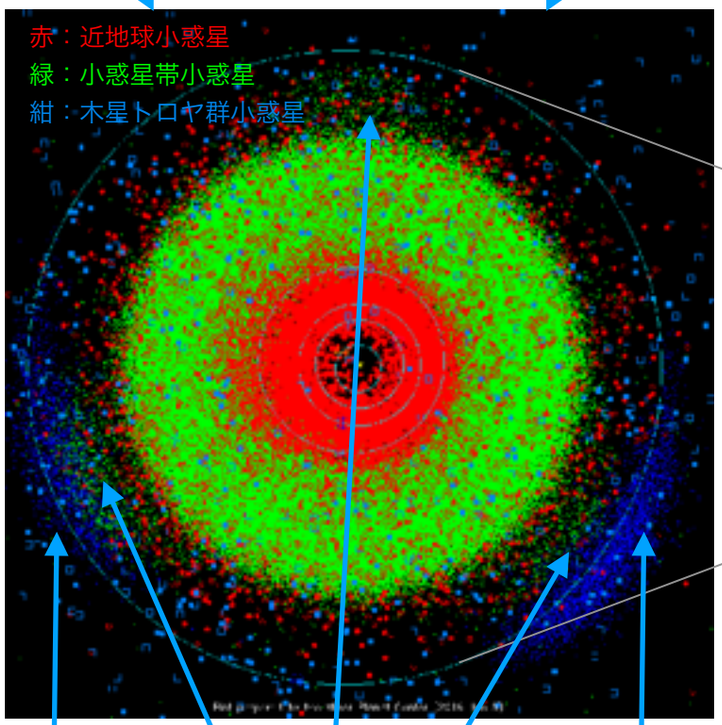
FOSSIL project

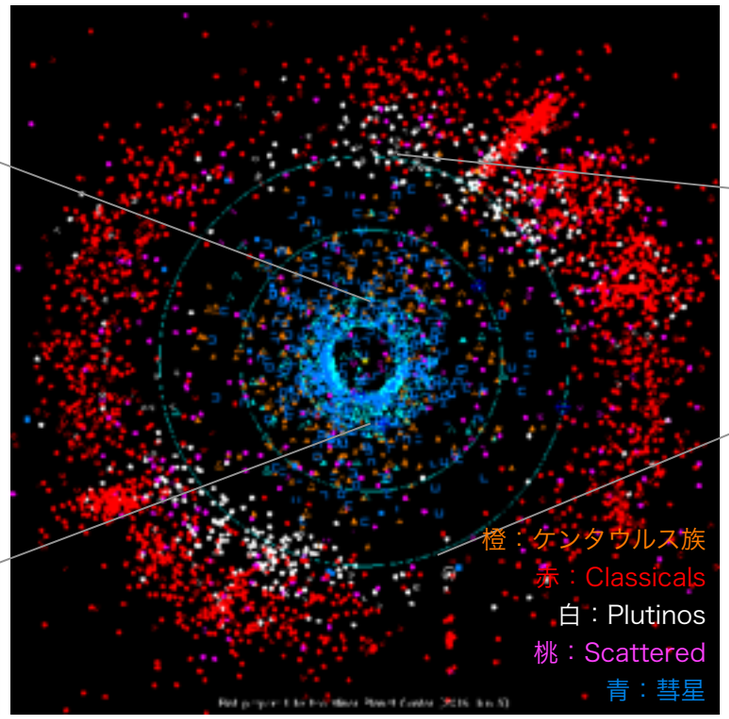
Formation of the Outer Solar System – an Icy Legacy

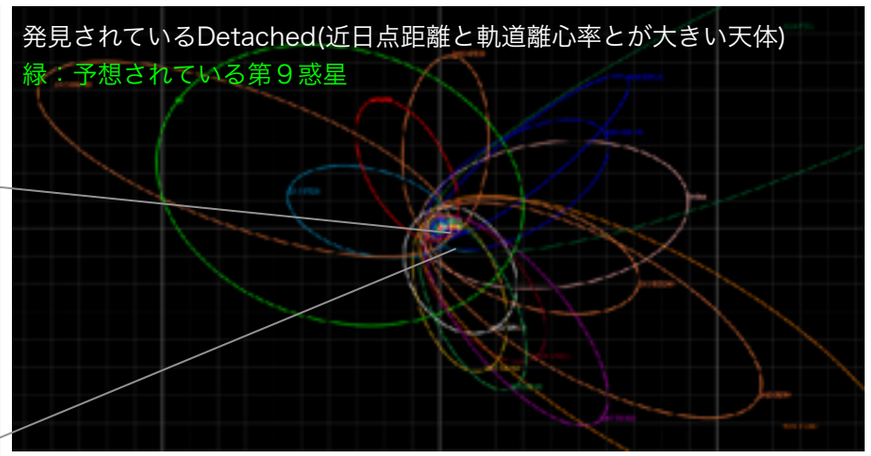
Solar system archaeology : Explore the history of the solar system by digging up fossils of past events. Explore the icy world.

Rocky world

Centaurs, TNOs, unseen planet(s?)







太陽系内の小天体の分布。 左：木星軌道より内側、中央：カイパーベルトより内側、右：カイパーベルトの外側。これらの天体の外側にオールト雲天体が球殻状に約10万auまで分布すると考えられている。Classicalsの経度分布に偏りが見えるのは集中したサーベイが行われた場所に多くの天体が発見されているからである。カイパーベルト以遠は天体サーベイにより2020年代にはさらに多くの天体が見つかるとはずである。
https://minorplanetcenter.net/iau/lists/MPLists.html

L5 JTs

L4 JTs

Hildas

Icy world

Located between the rocky and icy worlds

What kind of “fossils” will FOSSIL find?

The discovery of numerous exoplanets system has rendered obsolete the 20th century standard model of Solar System evolution. We must establish new and complete planetary system evolution model.

Solar System formation

FOSSIL explores these stages

dust → planetesimals formation → planets formation → current system

By detection of faint TNOs with shift and stack

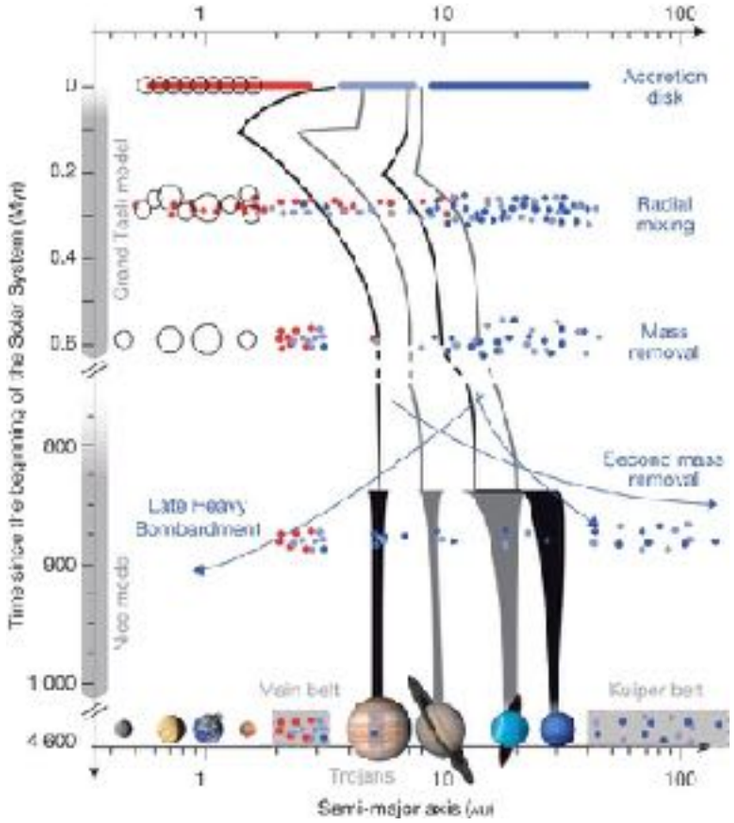
Size frequency distribution of TNOs can tell us a signature of the collapse size in the streaming in stability process.

Understanding the large scale mixing of small bodies by planetary migration in the solar system can clarify the origin of current JTs/ Hildas and TNOs.

These processes are common in the exoplanet systems. Based on the understanding of solar system formation/evolution, we would reach the common understanding of planetary formation/evolution in universe.

By collecting and comparing physical properties, color, size frequency distribution of JTs/Hildas, TNOs

Current knowledge of the icy world of our solar system

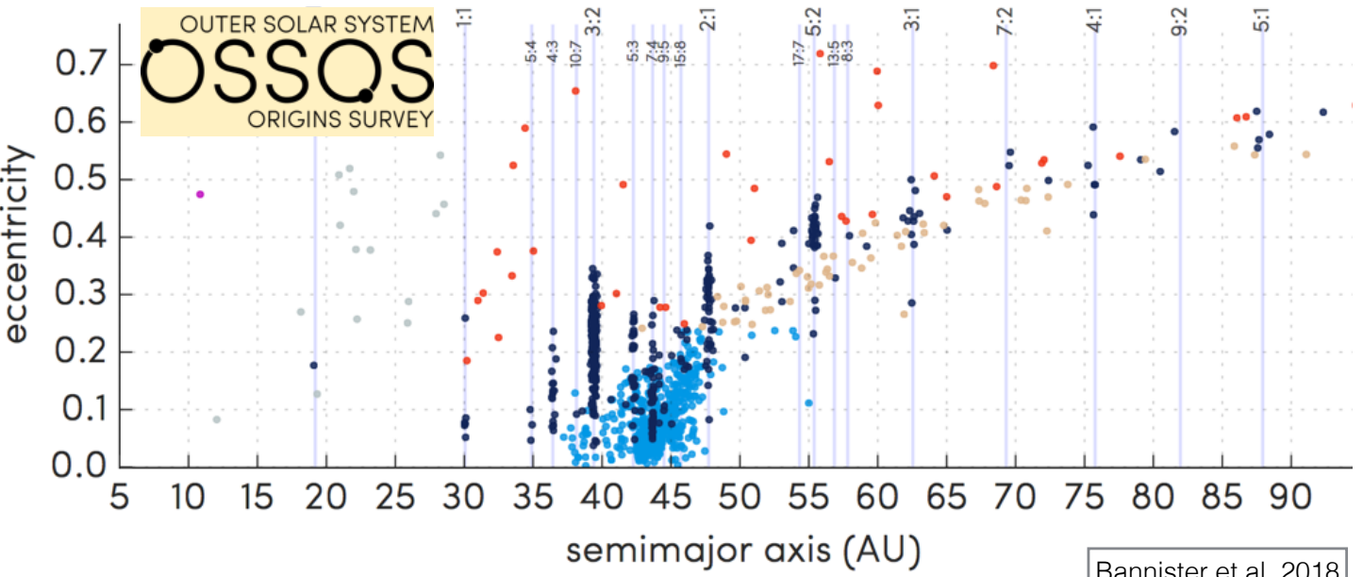


- Based on current distribution of small Solar System bodies and prediction from theoretical works, we believe significant mixing of small bodies probably happened at the early stage of Solar System history.

- However, we still don't know the exact process of planet migration.
- Where does it occur, and how violent is the process?

FE DeMeo & B Carry Nature 505, 629-634 (2014) doi:10.1038/nature12908

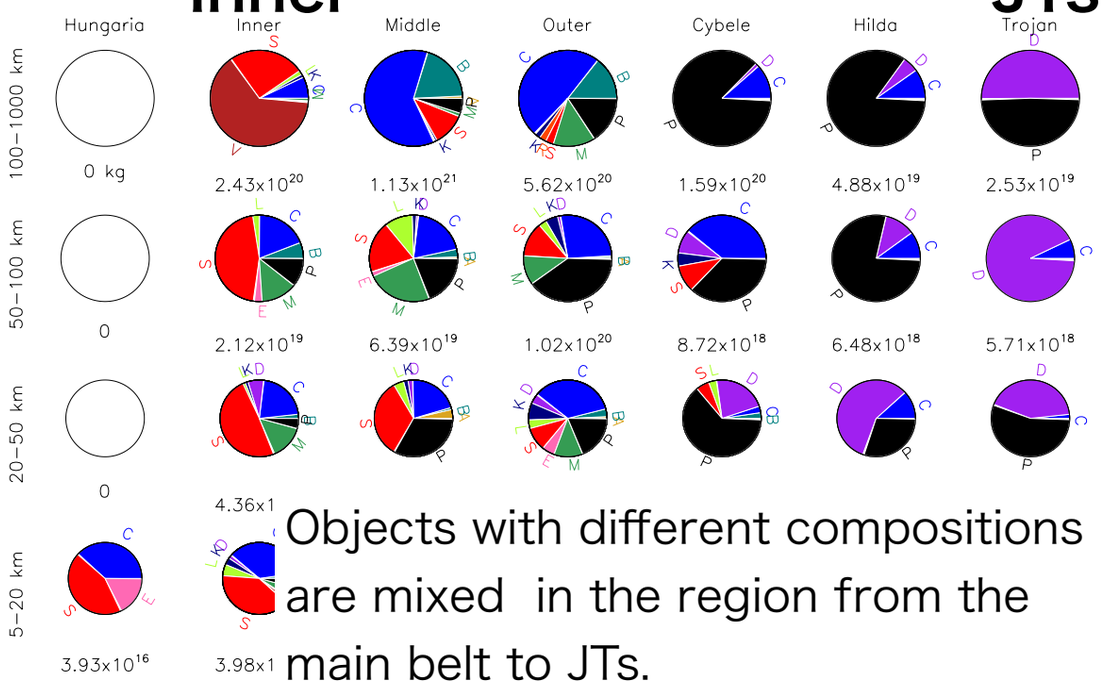
Current distribution of small Solar System bodies



Bannister et al. 2018

Complicated dynamical structure of TNO region

Kuiper belt region was undergone dynamical evolution by somebody, with some way



Objects with different compositions are mixed in the region from the main belt to JTs.

To investigate the early Solar System history,

We use the icy bodies of outer Solar System:

- **likely keep the material when they formed,**
- **orbit distribution can be frozen since the end of planet migration era, because they currently don't have frequent perturbation from planets.**

Solar System evolution models suggest

- **Trans-Neptunian Objects (TNOs)**
- **Neptunian Trojans (NTs)**
- **Jovian Trojans (JTs)**
- **Hilda**

They are born in the region beyond Neptune, where a massive planetesimal disk once existed.

If the suggestion is correct, physical properties, size frequency distribution, composition of the above 4 groups can be similar.

FOSSIL (proposed in S19B) : try to investigate the orbital/size/color distribution of above 4 groups, especially TNOs. ← Take longer time for orbit determination (we needed a few year's observation arc).

FOSSIL I (this proposal S20A-096I) : obtains physical properties (bulk density) and color distribution of JTs/Hildas by lightvurve survey, and size frequency distribution of small TNOs using a deep drilling analysis.

The FOSSIL Project team

gathered @ Kobe

Mike Alexandersen
Chan-Kao Chang
Ying-Tung Chen
Wesley Fraser
Takashi Ito
Youngmin JeongAhn
Jianghui Ji
Jj Kavelaars
Myung-Jin Kim
Samantha Lawler
Matthew Lehner
Jian Li
Zhong-Yi Lin
Patryk Sofia Lykawka
Hong-Kyu Moon
Surhud More
Keiji Ohtsuki
Rosemary Pike
Tsuyoshi Terai
Seitaro Urakawa
Shiang-Yu Wang
Fumi Yoshida (PI)
Haibin Zhao
Ji-Lin Zhou
Hui Zhang

New members

Edward Ashton★
Michele Bannister
Young-Jun Choi
Paula Granados
Dong-Heun Kim★
Hirohisa Kurosaki
Lowell Peltier★
Natsuho Maeda★
Marco Munoz
Liyong Zhou

★students

FOSSIL Kickoff Meeting 19-21 November 2018

Supported by Subaru

It is an international team

Researchers join FOSSIL project from 8 countries of Asia and the Pacific.
In total 35 members are working for FOSSIL project.

Japan 8, Taiwan 7 , China 6, Korea 5, Canada 5, India 1 , NY 1, USA 2

Our webpage

https://www.fossil-survey.org

Please visit our webpage. We opened this page on Feb. 23, 2021. It will be filled with more information and scientific results soon.

FOSSIL observations in May, August, and October, 2020 February , 2021

S20A-096I

8 nights in 20A and 20B

May 15-18 4 nights for L5 of Jupiter Trojans region

September 4 nights for L4 of Jupiter Trojans region

If we observe the Jupiter Trojan (JT) region, we can detect all of objects from JT to TNOs at the same time.

COVID19 forced us to change our observation plan.

May 18, 19 2 half nights for L5 of Jupiter Trojans region

August 19-22 4 half nights for L4 of Jupiter Trojans region

October 13-26 4 half nights for L4 of Jupiter Trojans region

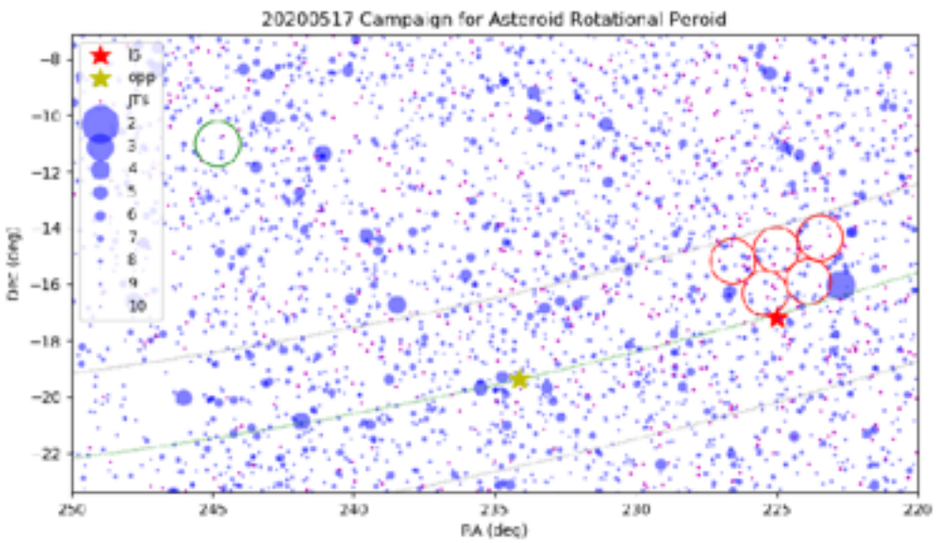
February 9-12 3 full nights and 2 half nights for TNO detection and g,r,z colors

Compensation for the first 3 night in May 2020.

May 2020

Observation: It was first assigned 4 nights. But it was canceled on May 15-17 due to COVID-19.

- What was actually assigned was only May 18 night.
- We asked Subaru to change the one night of May 18 to the first half of the 18th and 19th for better orbit determination (provisional code acquisition of MPC) and better detection of distant objects that require one-day observation arc.



5/18 average seeing size : 0.75 arcsec
68 images (including dome flat, bias, focusing…)

5/19 average seeing size : 0.75 arcsec
68 images (including dome flat, bias, focusing…)

Our plan was imaging 5 fields near the L5 point.
However, since the observation time got short, only 2 half nights, we observed 2 fields of the 5 fields.

Subaru Twitter
https://twitter.com/SubaruTelescope/status/1262993011165720576

Since our observation was the first observation after the operation of Subaru was stopped for a long time due to the influence of COVID-19, the observation was posted on Subaru's Twitter. People noticed that Subaru resumed observation safely.

August & October 2020

Observation: We were supposed to have observation in September. In our proposal, we specified the time that the L4 point come to near the opposition. However, the influence of COVID-19 again disturbed us. Our observation time was split in August and October. This changed our observation strategy. Because the L4 point was not located near the opposition any more in August and October.

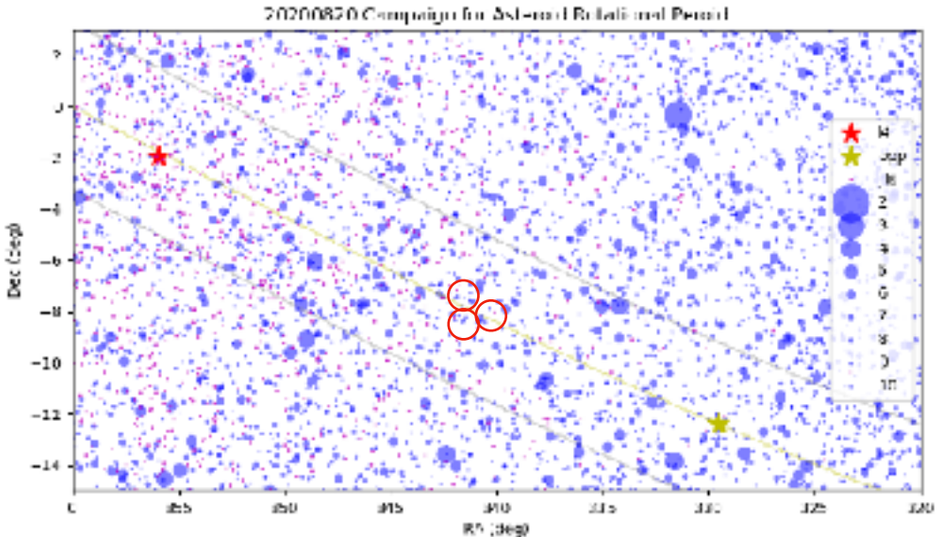
Target field

Aug : [RA, Dec] ~ [345, -5] deg, Oct : [RA, Dec] ~ [10, 6] deg

We observed 3 fields near L4 point for getting lightcurve

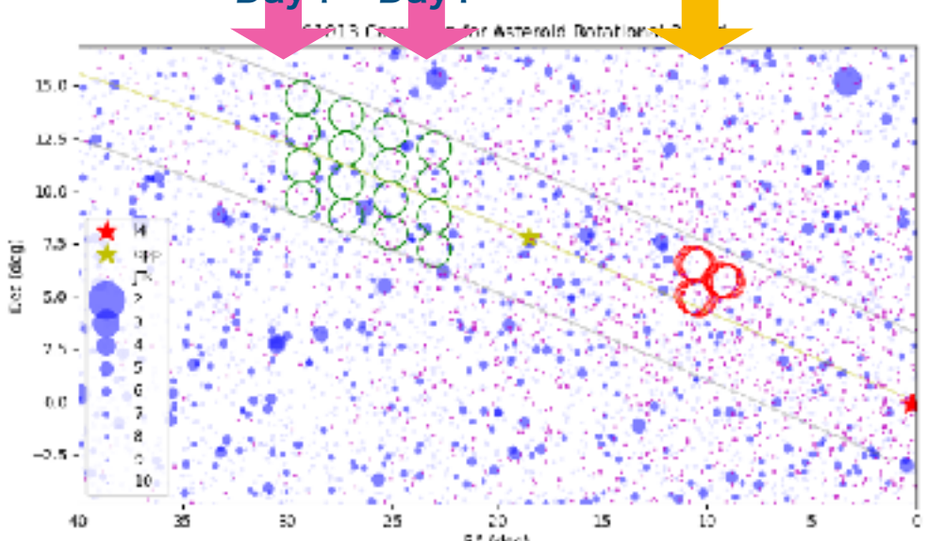
8/19 no data
8/20 average seeing : 0.88”
FSAU01, FSAU02, FSAU03
8/21 average seeing : 1.02”
FSAU01, FSAU02, FSAU03
8/22 average seeing: 1.03”
FSAU01, FSAU02, FSAU03

We observed 3 fields near L4 point for getting lightcurve
We also surveyed 4 fields near the opposition.
10/13 average seeing : 0.88”
FSOC01, FSOC02, FSOC03, FSOCBA, FSOCBB, FSOCBC, FSOCBD
10/14 average seeing : 0.73”
FSOC01, FSOC02, FSOC03, FSOCBA, FSOCBB, FSOCBC, FSOCBD
10/15 average seeing : 1.12”
FSOC01, FSOC02, FSOC03, FSOCBA, FSOCBB, FSOCBC, FSOCBD
10/16 average seeing : 1.27”
FSOC01, FSOC02, FSOC03, FSOCBA, FSOCBB, FSOCBC, FSOCBD



L4 JT number density **Lightcurve**

Day4 **Day1**



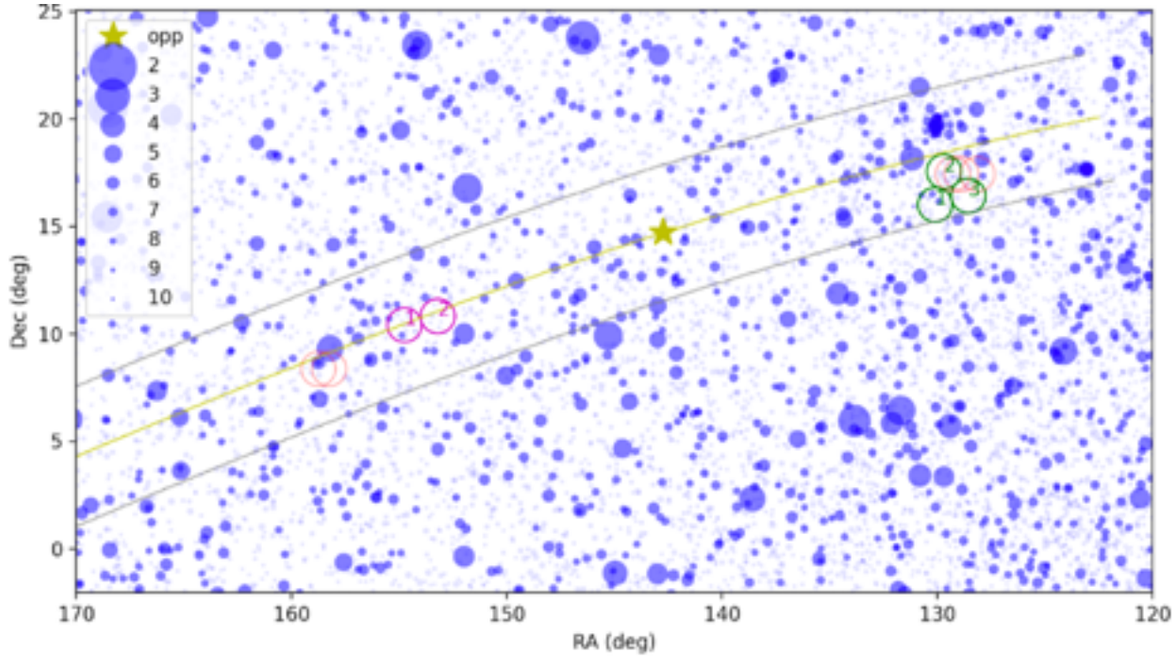
February 2021

Observation: Subaru SAC gave us 3 full nights as the compensation of the cancelation by COVID-19 in May. In February, we could not observe L5 Jupiter Trojan region any more. We chose near the opposition field for detecting TNOs. The detection of faint TNOs is also our main subjects in our proposal. We used g, r, z-filters to obtain the color distribution of TNOs.

We observed 3 fields, calling this Deep-Drilling-Light-Curve-Fields near the opposition for getting lightcurve of TNO. This data also uses for the detection of very faint TNO with shift and stack.

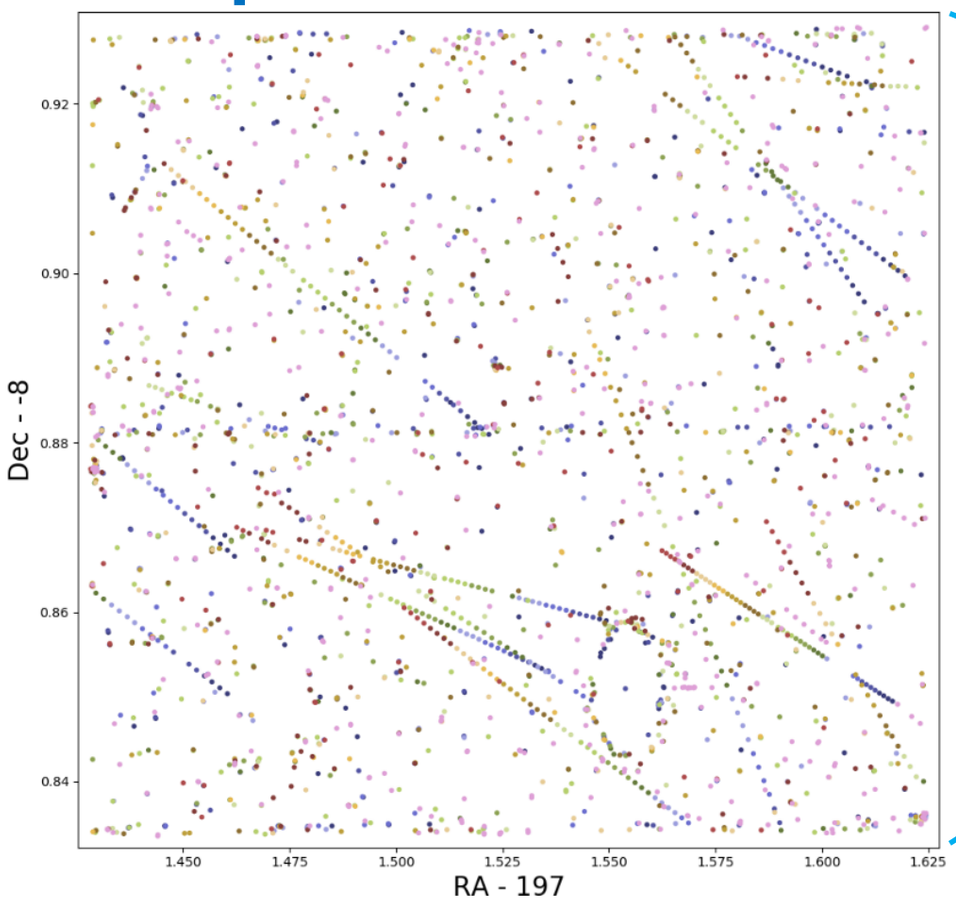
We also observed 2 fields near the opposition for getting colors of TNO with the r, g, z-bands.

2/9 full night
average seeing : 1.46”
DDLC-1, DDLC-2, DDLC-3, MBCF1, MBCF2 r-, g-bands
2/10 full night
average seeing : 1.11”
DDLC-1, DDLC-2, DDLC-3, MBCF1, MBCF2 r-, z-bands
2/11 half night
average seeing : 0.84”
DDLC-1, DDLC-2, DDLC-3 r-band
2/12 half night
average seeing: 1.62”
DDLC-1, DDLC-2, DDLC-3 r-band
We lost 1.5 hours because of very high wind.

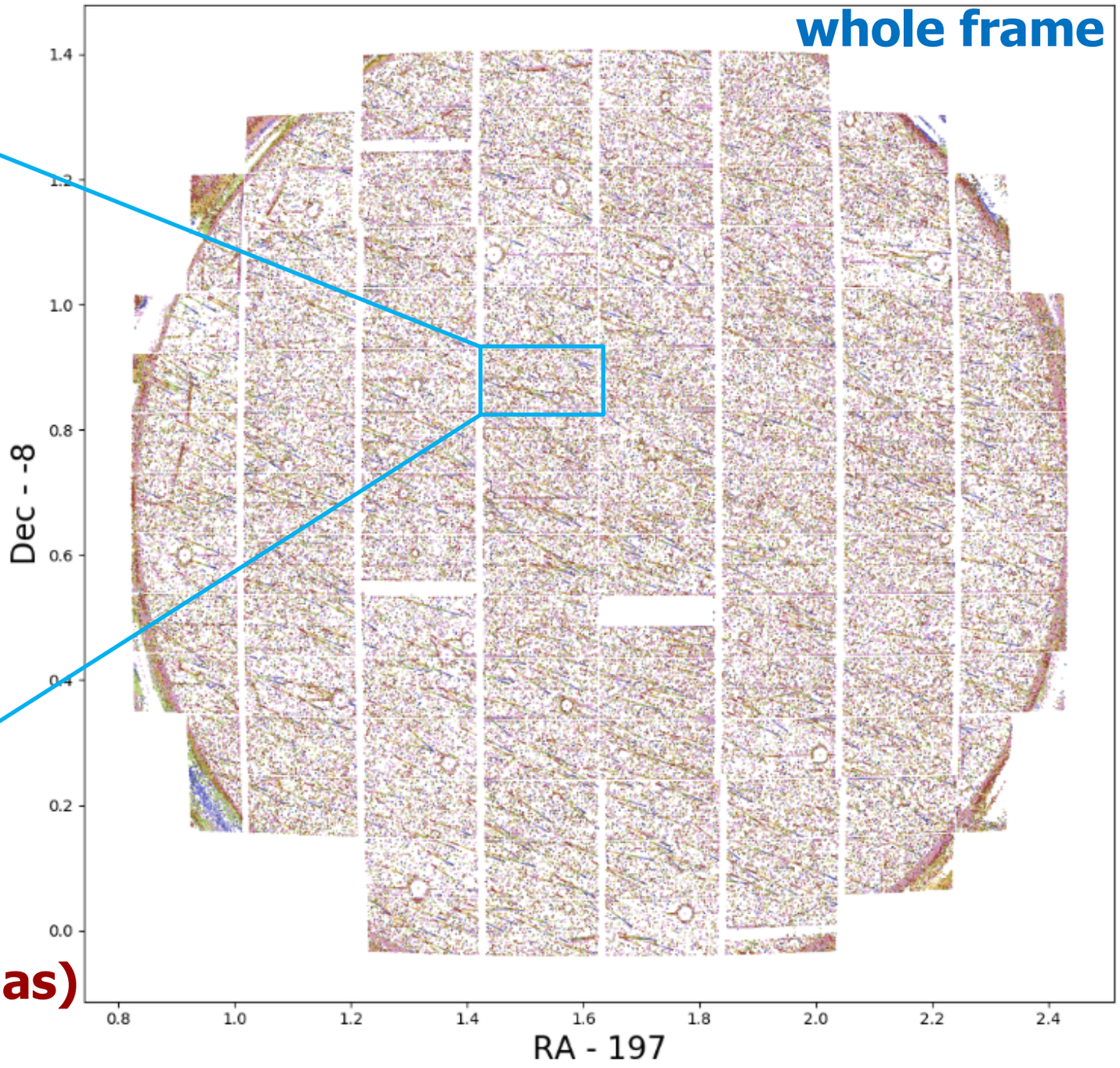


All data from May, August and October, 2020 have been reduced, and analyzed.

1 chip

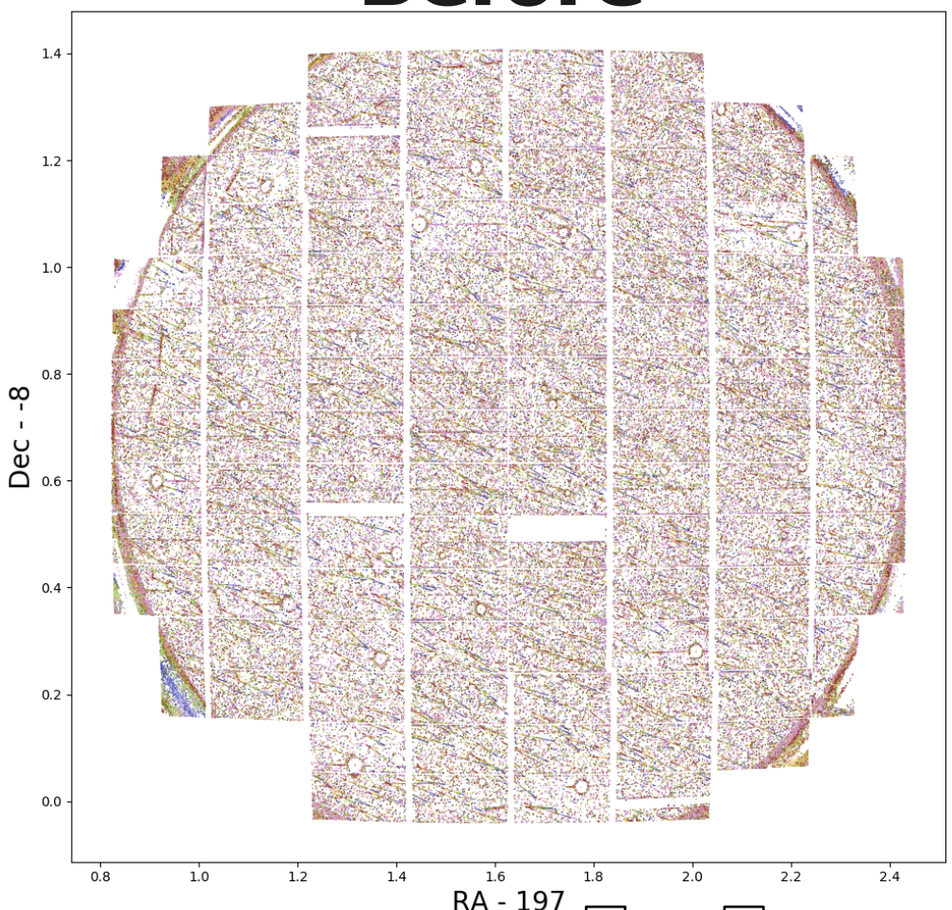


whole frame

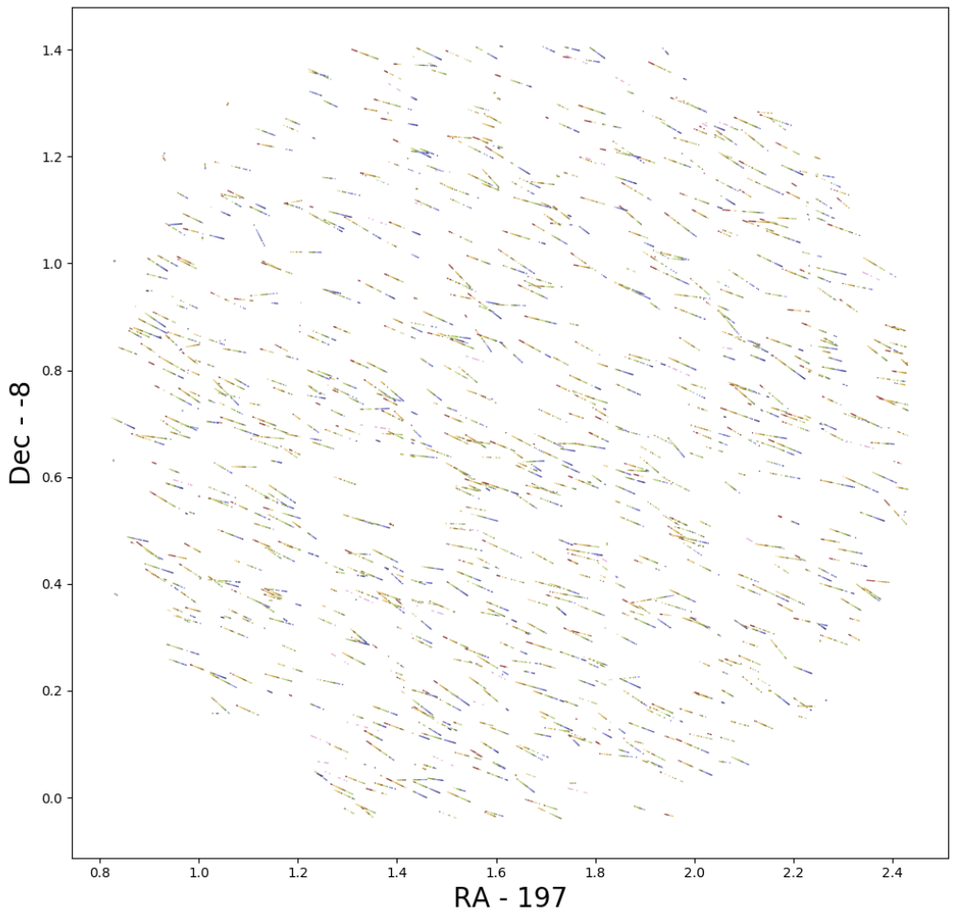


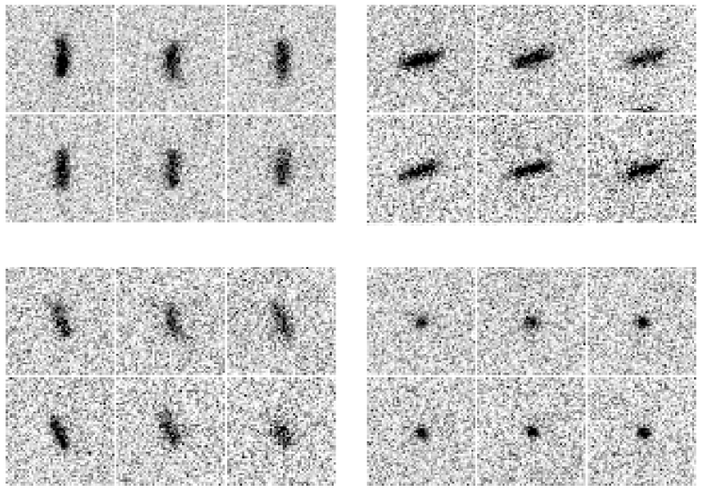
One field, ~1,000 SSSBs (including ~100 JTs and ~30 Hildas)

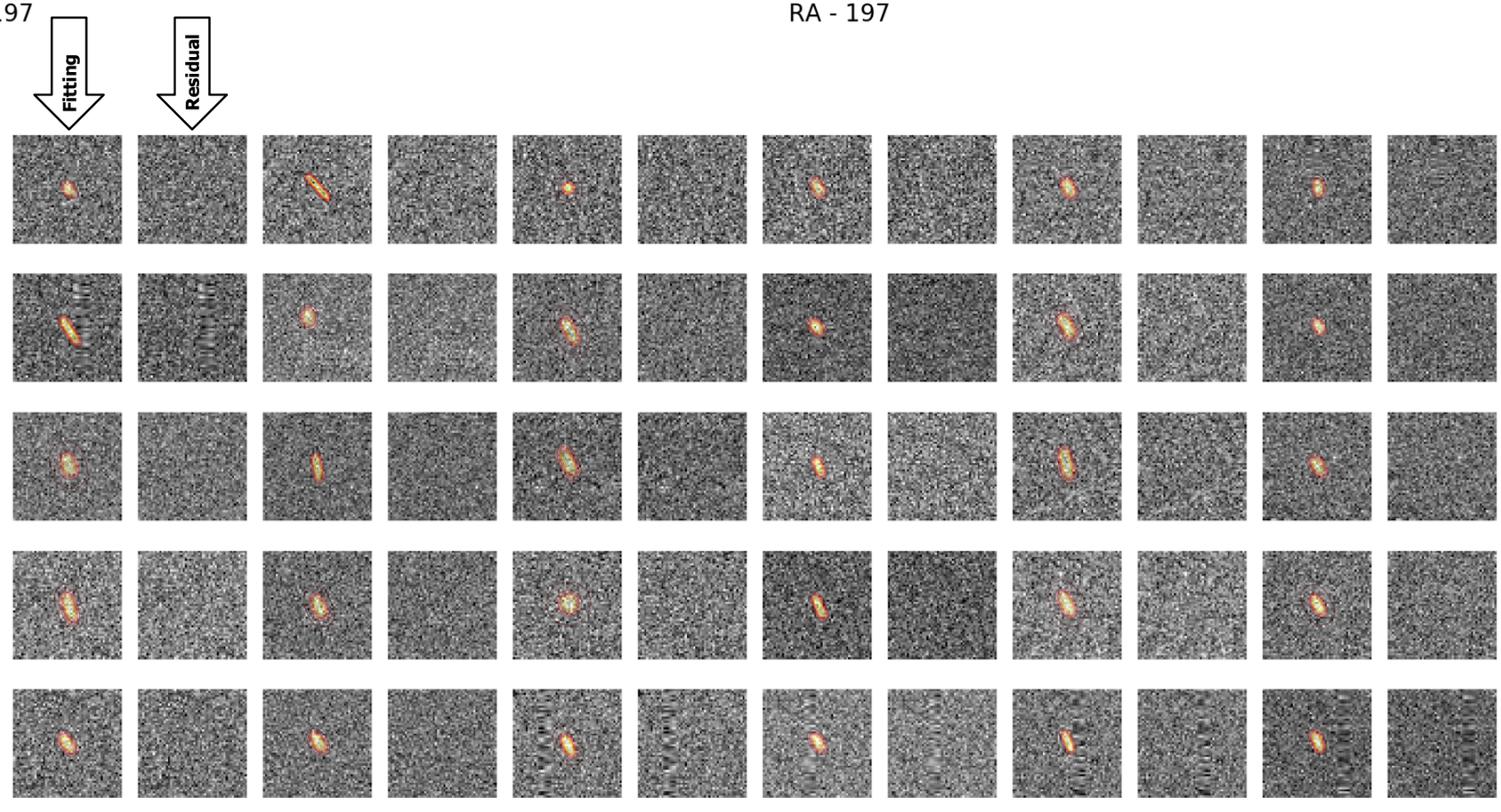
Before



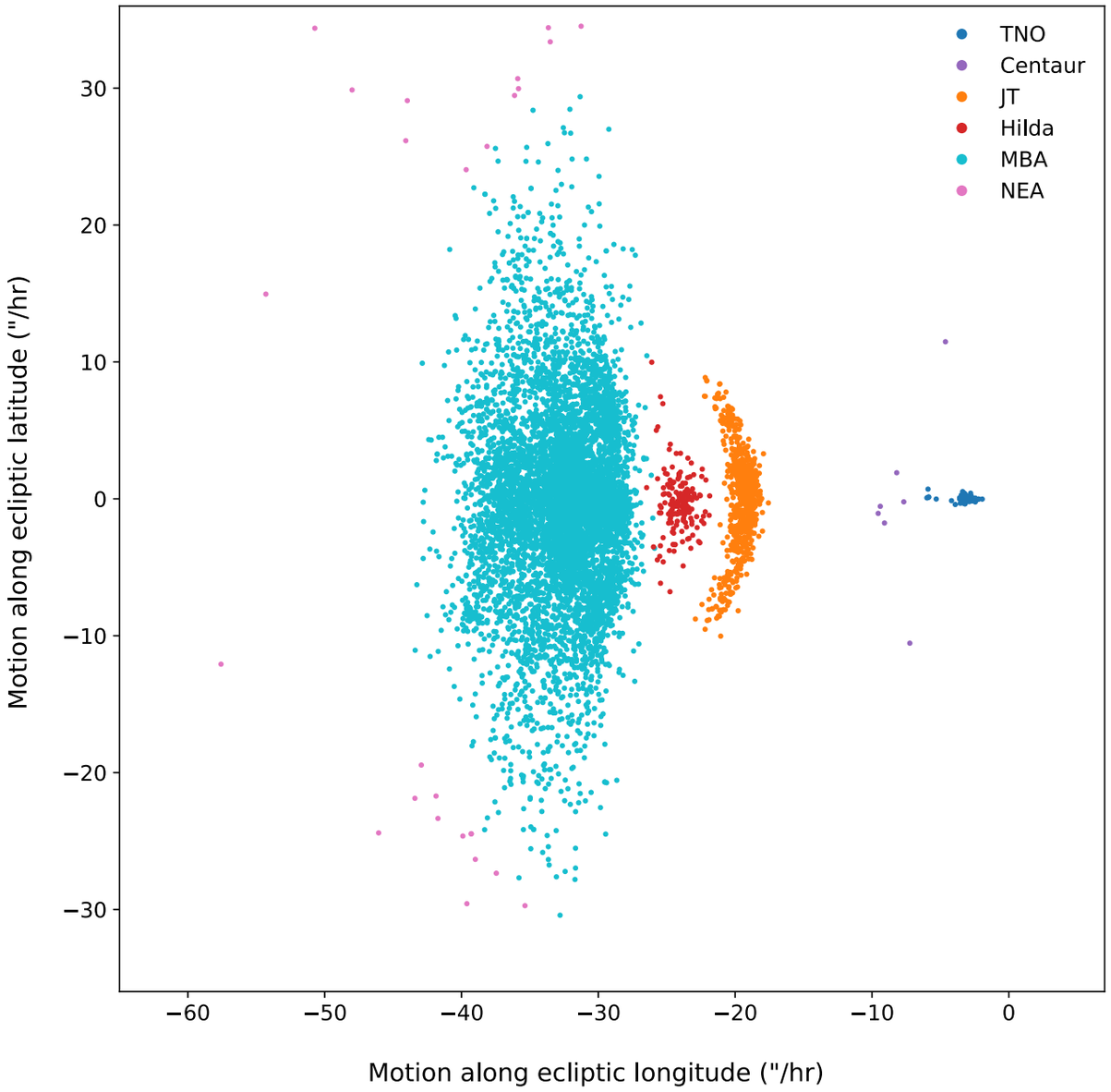
After

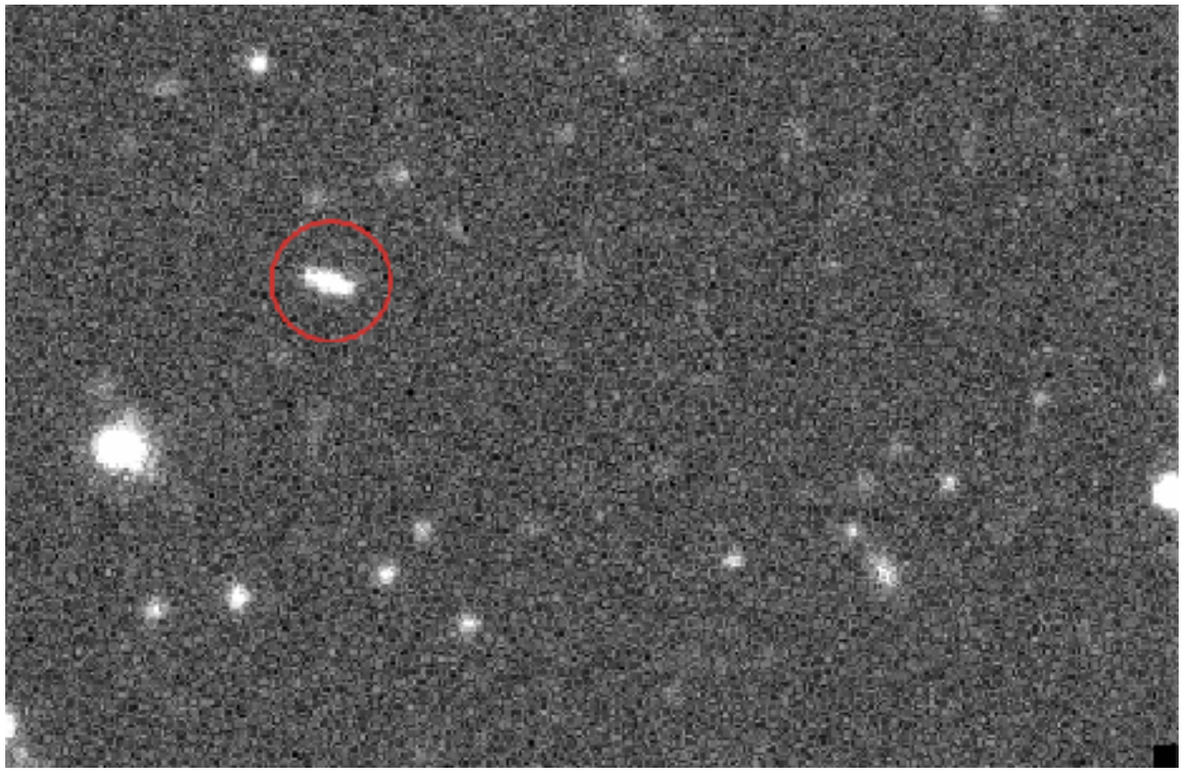




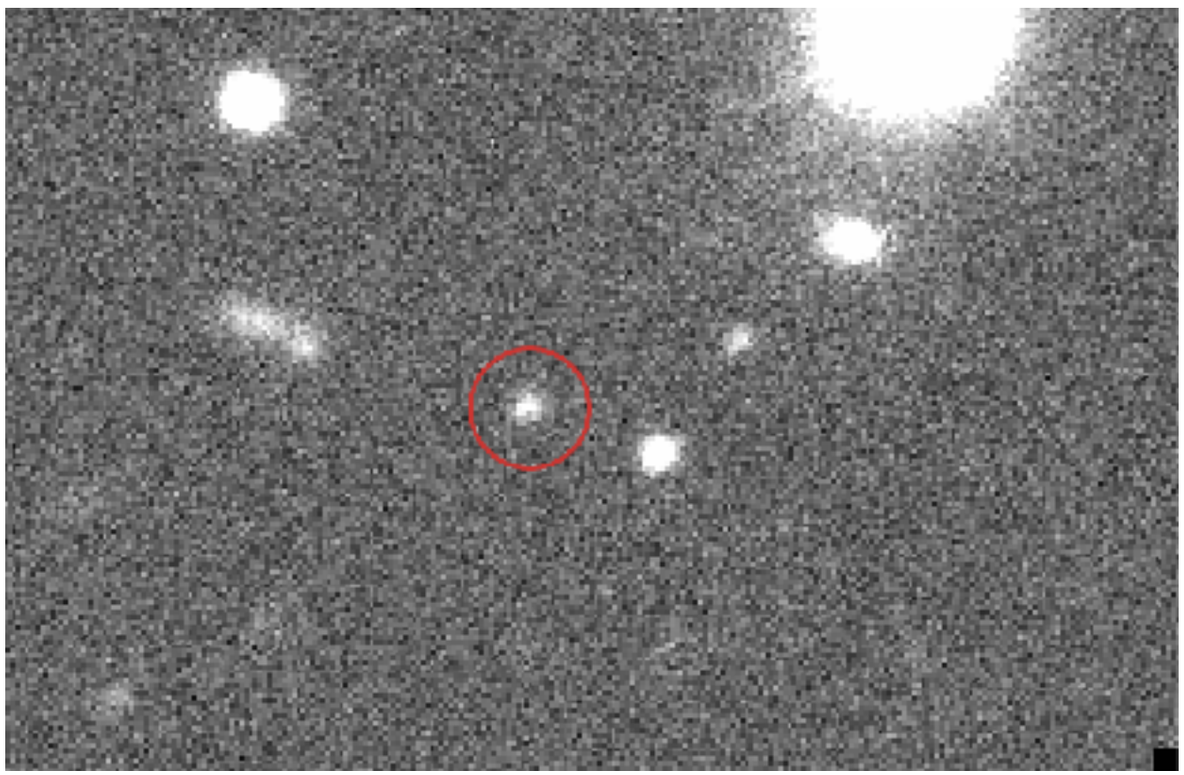


We found many moving objects!





A Jupiter Trojan discovered by FOSSIL on 21 August 2020.



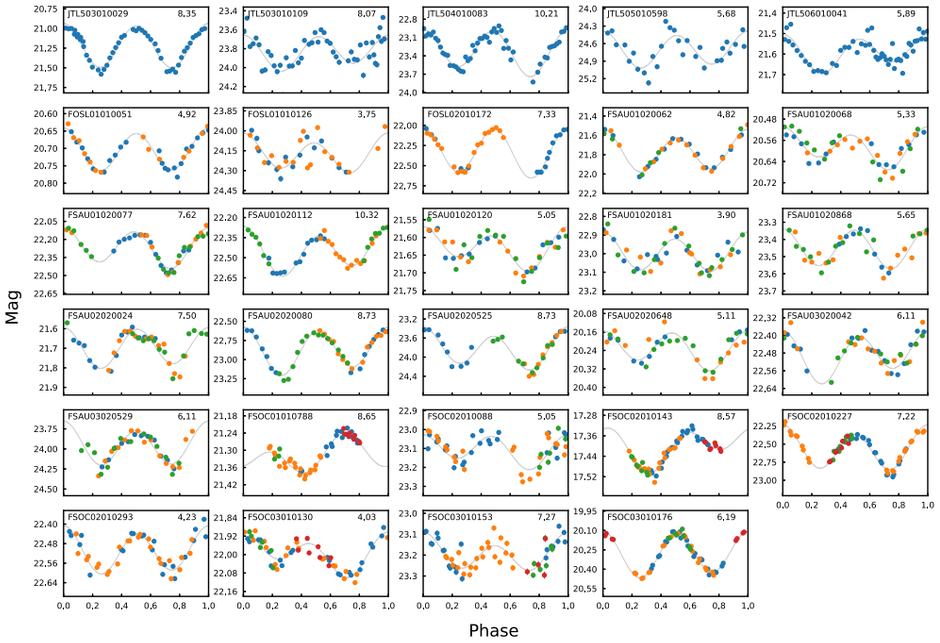
A Trans - Neptunian Object discovered by FOSSIL on 21 August 2020.

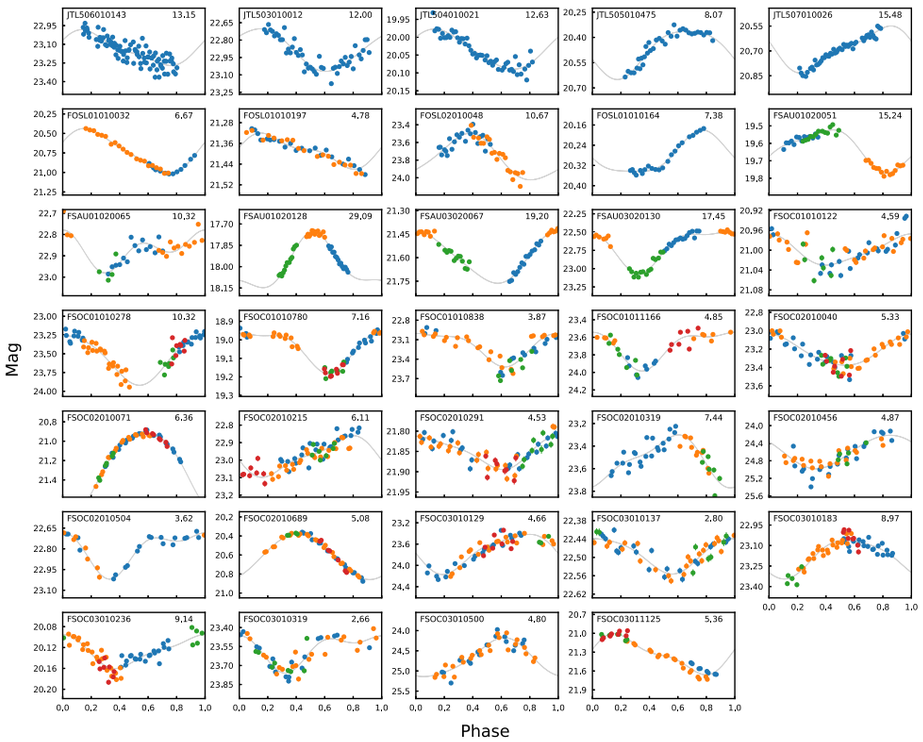
FOSSIL found:

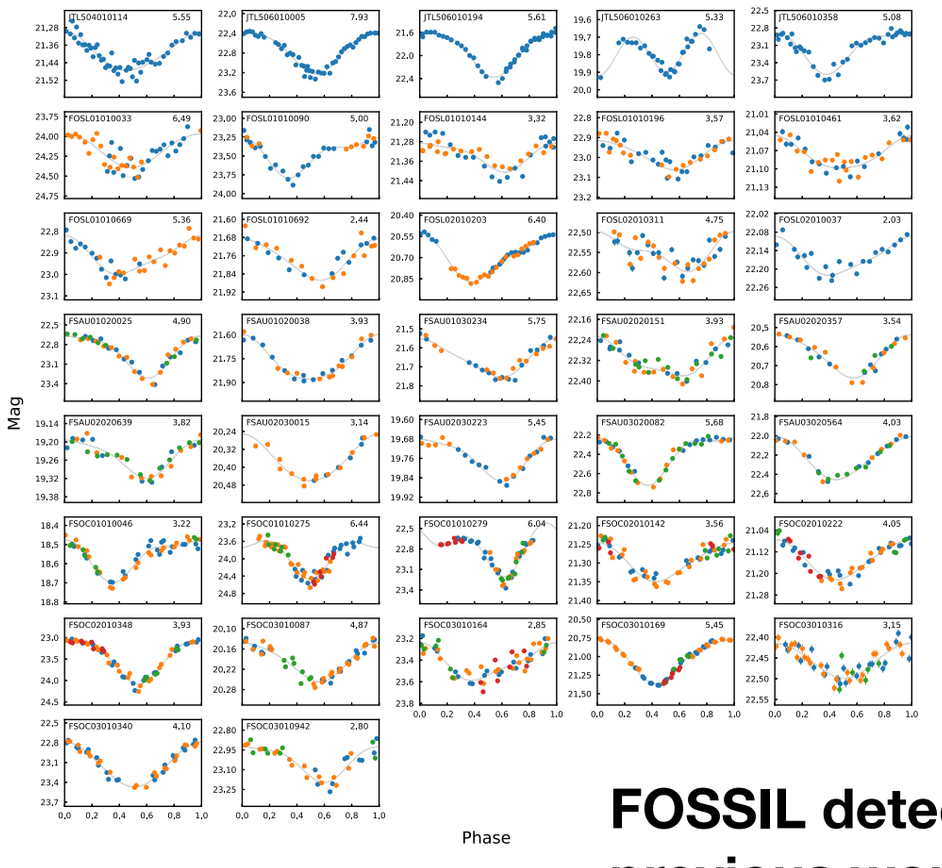
206 TNOs
779 JTs
176 Hildas
7106 MBAs
22 NEAs

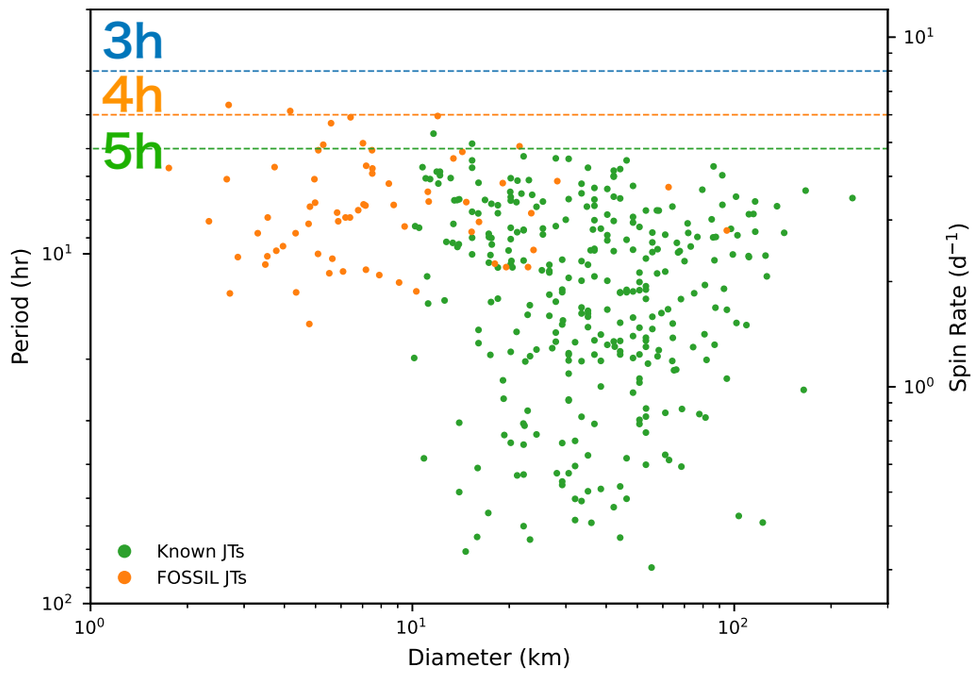
- We found 8289 moving objects in 2020 data.
- We still have 2021 February data.

Rotation periods of Jupiter Trojans









Covering full rotation period for 29 JTs, half rotation period for 37 JTs, and partial rotation period for 34 JTs.

FOSSIL measured light curves of 100 JTs and determined the spin limit of JTs can be ~4 hours instead of the previously published result of ~ 5 hr.
Assuming a rubble-pile structure for JTs, **a bulk density of ~ 1g cm^{-3}**

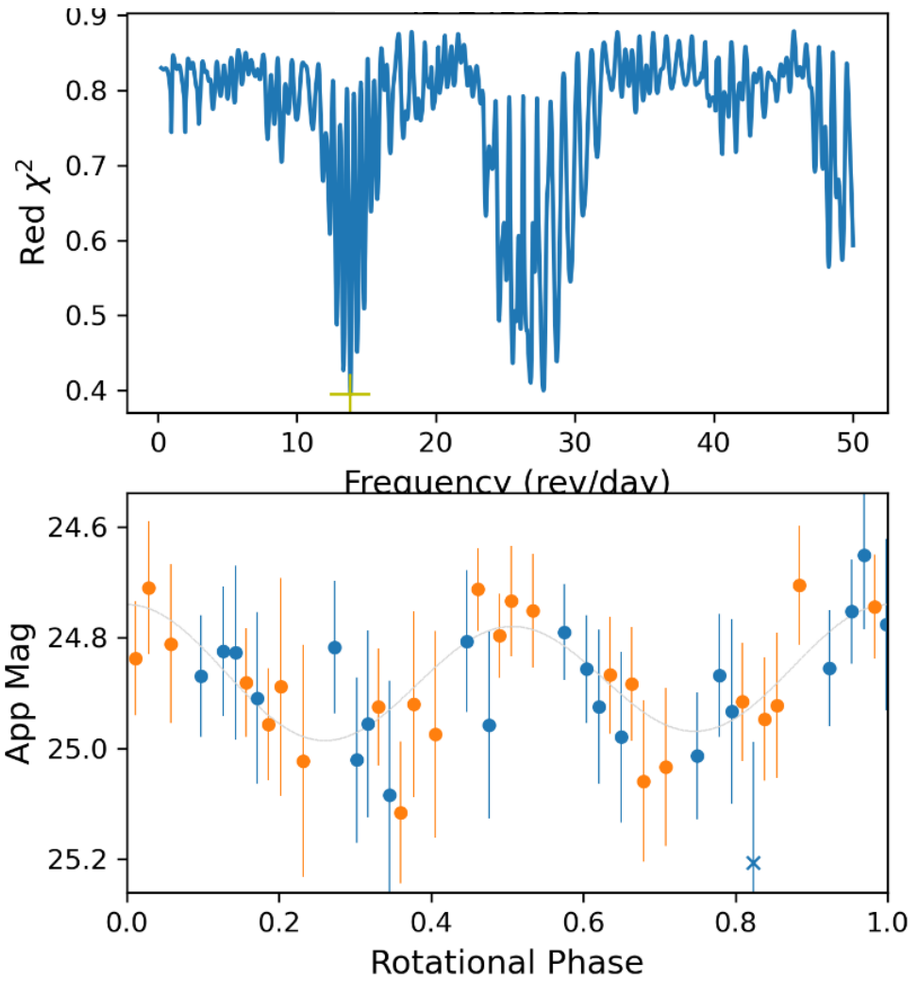
FOSSIL detected one order smaller JTs from previous work with other telescopes.

These results are presented in the following poster.

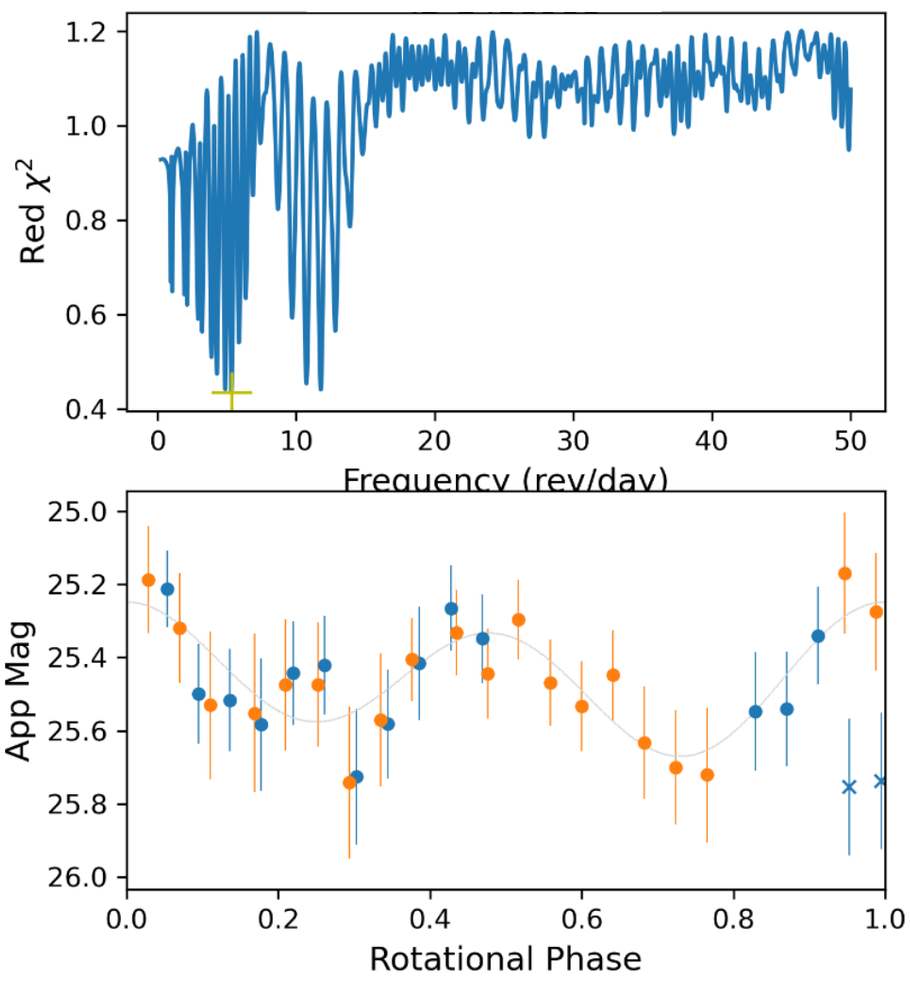
Chang, Chan-Kao et al., 2021, in preparation

From the preliminary analysis, **two fast rotator candidates happened to be discovered in the TNO population.**

P = 1.7 hr



P = 4.5 hr

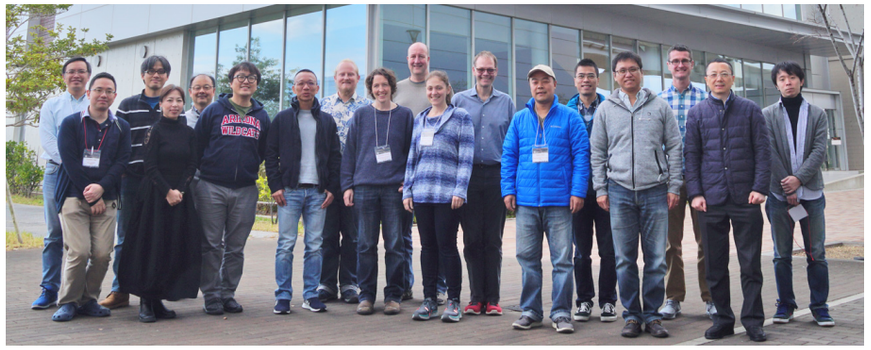


Their rotation is relatively fast, but we are waiting for followup observation.

Average rotation period of TNOs = 8.5 hr

We submitted a proposal to Gemini Fast Turnaround program.
The Proposal has been accepted. We are now waiting for Gemini to execute our observation.

Summary



We will have the second FOSSIL meeting including new members in 2021.

- In a word, the observation in 20A and 20B provided a good data.
- **The analysis of the 2020's data has done just last month. The first results are the spin limit and low bulk density of Jupiter Trojans.**
- The catalog of detected moving objects will be shared within our team soon. Members would produce papers on the size distribution of TNO sub-groups, investigation of Kuiper belt Cliff, rotation period of Hilda, detection of mainbelt comet, … etc.
- FOSSIL team is consisted of not only observers but also researchers working on planetary formation theory and celestial mechanics. So FOSSIL contributes to develop new Solar System evolution model soon.
- **COVID-19 gave us a large amount of change of observation schedule. We missed opportunities to obtain colors of Jupiter Trojans. We definitely need more observations to investigate colors of small solar system. So, we propose next FOSSIL observation: FOSSIL Phase-II, whose main objective is a survey of the icy bodies in the multi color mode.**