

Solar System Science with Vera C. Rubin

Legacy Survey of Space and Time

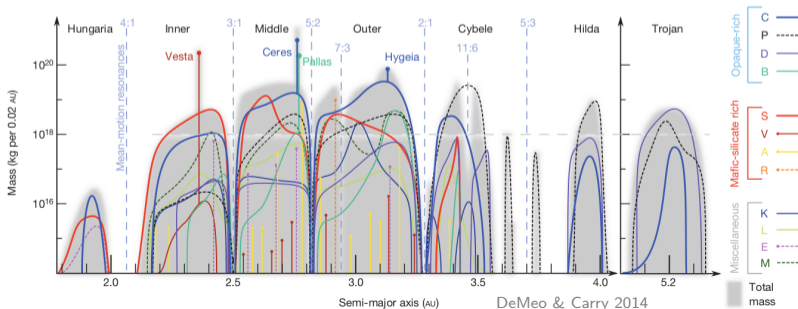


B. Carry

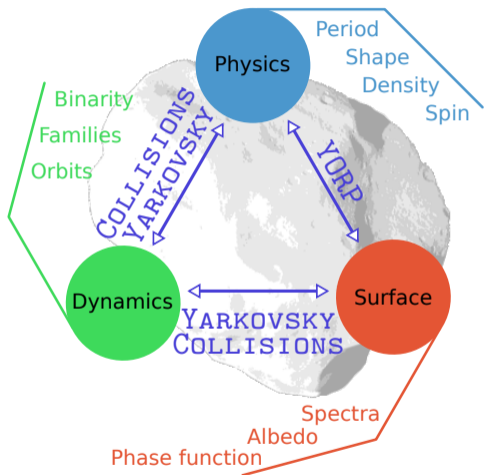
Lagrange, Observatoire de la Côte d'Azur

Small bodies and planetary formation

- **Leftovers of the early solar system**
 - Remnants of planet building blocks
 - Limited dynamical evolution
 - Little mineralogical evolution
- **Constraints on planetary formation & evolution**
 - Orbital and size distributions
 - Distribution of composition



What do we need to study?



• Discovery & Dynamics

- Dynamical structure
- Origins & evolution
- ▷ **Astrometry**

• Composition

- Location & timing of formation
- Compositional structure
- ▷ **Vis-NIR spectro-photometry**

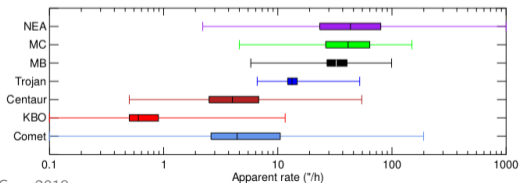
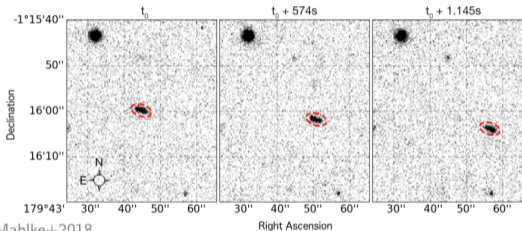
• Physical properties

- Diameter, Spin, ...
- Main evolutionary drivers
- ▷ **Light curves**

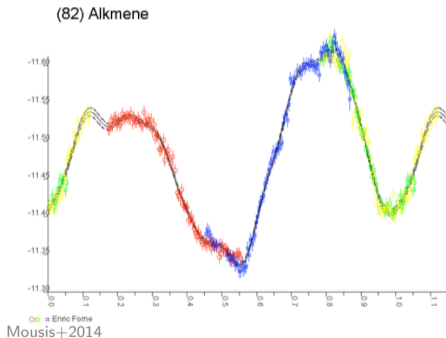
Legacy Survey of Space and Time

Solar System Objects (SSOs) are **THE** transients!

• Variable position



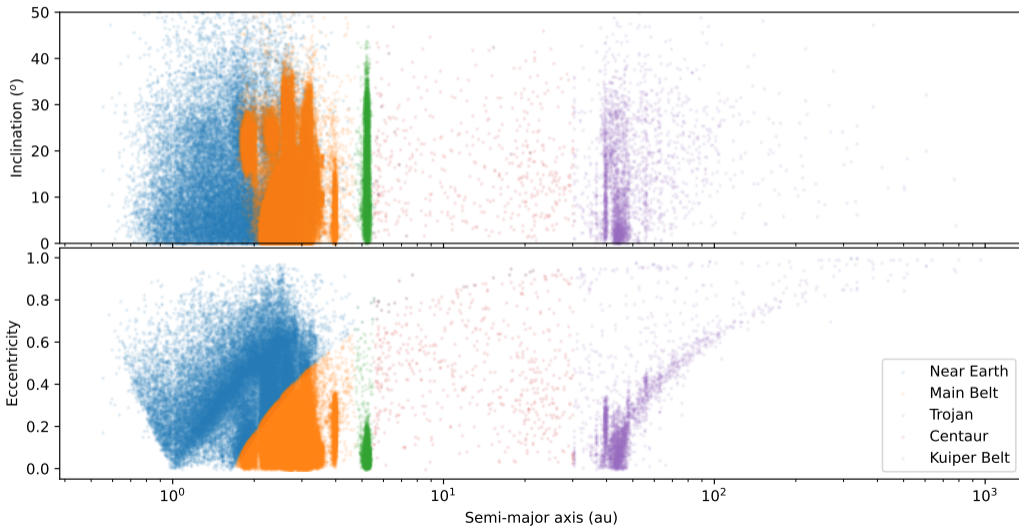
• Variable photometry



Amplitude: 0–1.5 mag

Period: 2–20h

SSOs in space



Expected discoveries by LSST

Class	Now	LSST
NEA	46,000	200,000
MBA	1,000,000	5,500,000
Trojans	10,000	300,000
Centaur	500	30,000
KBOs	3,500	40,000
Comets	4,400	10,000
Interstellar	2	10(?)

LSST collaboration 2009

• Current situation

- 1M SSOs
- 280M observations
- 5M aliases

• With LSST

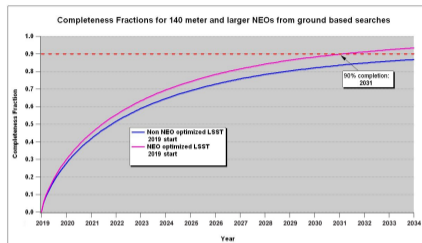
- 6M SSOs
- 2,400M observations (!)
- Aliases?

• Practically

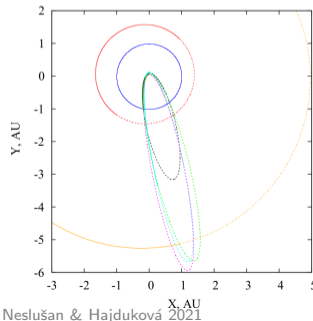
- Rubin → Minor Planet Center
- Daily orbits including other data sets

Dynamics of SSOs

- **Near-Earth asteroids**
 - Incoming impactors
 - Origin in the belt?
 - Meteor streams



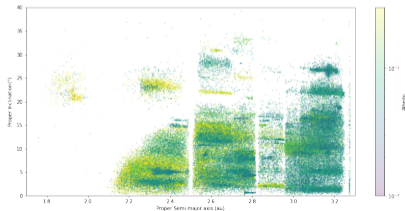
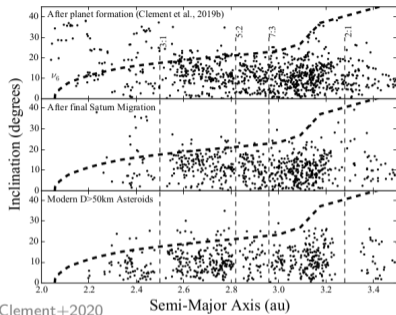
LSST.org



Neslušan & Hajduková 2021

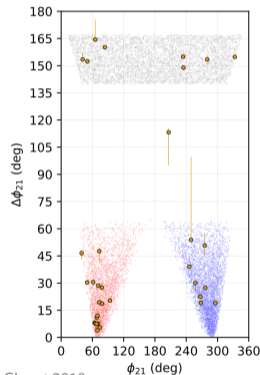
Dynamics of SSOs

- **Near-Earth asteroids**
 - Incoming impactors
 - Origin in the belt?
 - Meteor streams
- **Structure of the main belt**
 - Confirm current view Formation models
 - Young/small structures
 - Sources of NEAs and meteorites

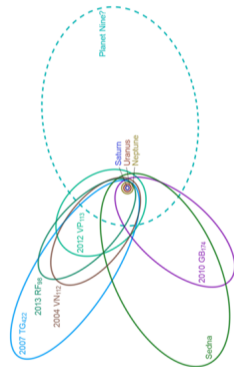


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- **Structure of the main belt**
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- **Structure of Kuiper Belt**
 - Dynamics → Formation models
 - Planet 9?



Chen+2019



Batygin & Brown 2016

Dynamics of SSOs

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- Incoming impactors
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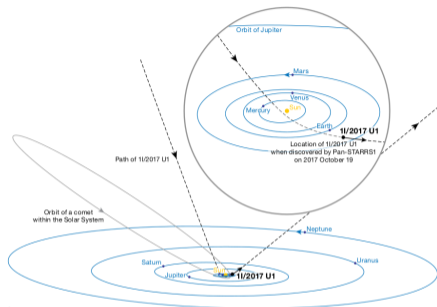
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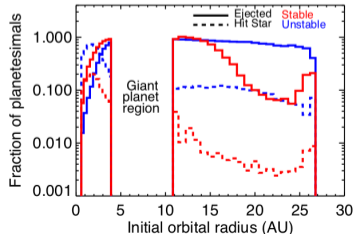
• Structure of Kuiper Belt

- Dynamics → Formation models
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• Interstellar objects

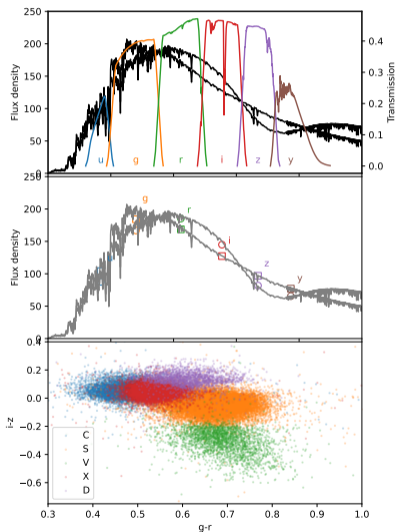


Meech+2018



Raymond+2018

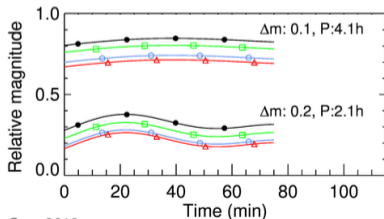
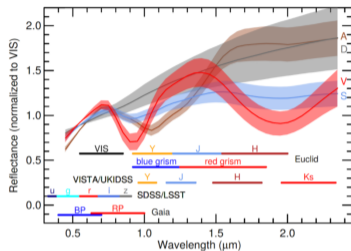
Composition of SSOs



• LSST filters

- Nicely adapted to SSOs :-)
- Experience from SDSS
- Promising y band

Composition of SSOs



Carry2018

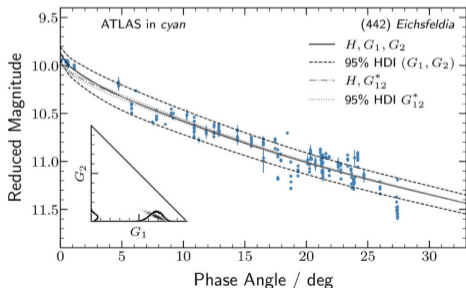
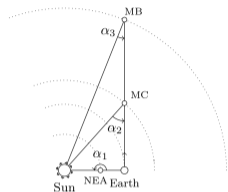
LSST filters

- Nicely adapted to SSOs :-)
- Experience from SDSS
- Promising y band

Two drawbacks

- VIS degenerated Euclid synergy
- Photometric variability

Composition of SSOs



Mahlke+2021

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- Nicely adapted to SSOs :-)
- Experience from SDSS
- Promising **y** band

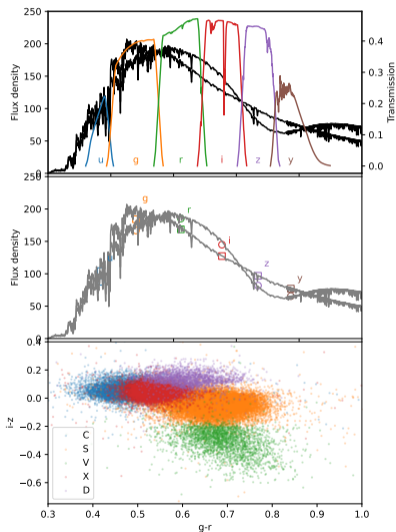
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• LSS-Time... be patient

- Phase \rightarrow Absolute mag. H
- ▷ Colors 1..2..3 years?
- Required phase $\leq 5^\circ$ Mahlke+2021

Composition of SSOs

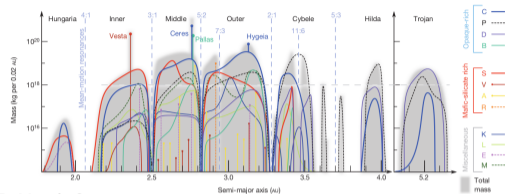


- **LSST filters**
 - Nicely adapted to SSOs :-)
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- **Two drawbacks**
 - VIS degenerated Euclid synergy
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- **LSS-Time... be patient**
 - Phase \rightarrow Absolute mag. H
 - ▷ Colors 1..2..3 years?
 - Required phase $\leq 5^\circ$ Mahlke+2021
- ▶ **Colors for several 10^6 SSOs**
 - ▷ Composition of SSOs

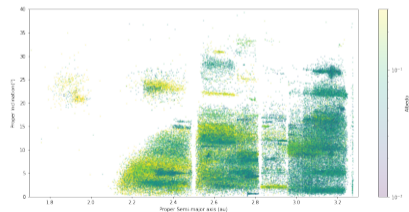
Composition of SSOs

• NEA - MBA

- Overall structure
- ▷ Formation/evolution models
- Young/small structures
- ▷ Sources of NEAs and meteorites



DeMeo & Carry 2014



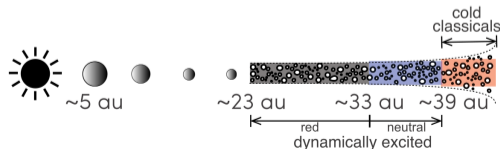
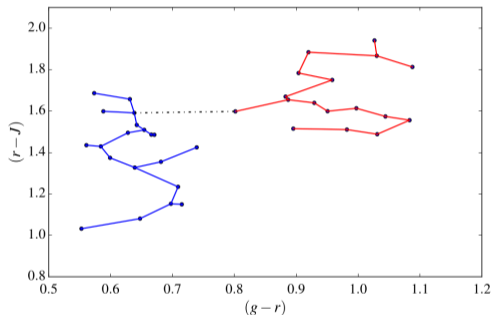
Composition of SSOs

• NEA - MBA

- Overall structure
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• Kuiper Belt

- Colors vs Dynamics
- ▷ Formation/evolution models



Schwamb+2019

Composition of SSOs

• NEA - MBA

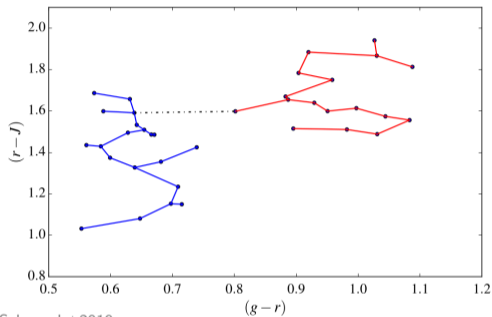
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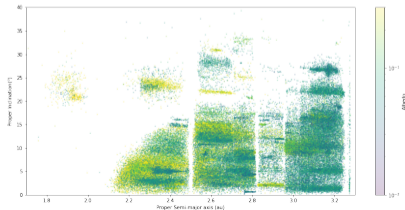
- Colors vs Dynamics
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• Challenges

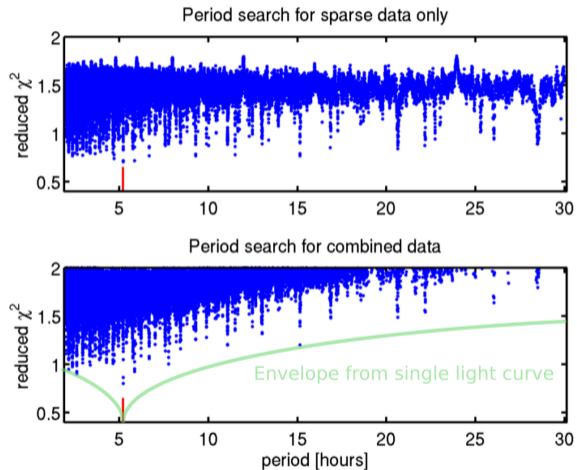
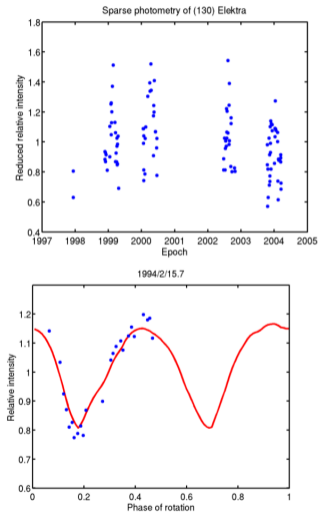
- *Big data* For us...
- Cluster identification



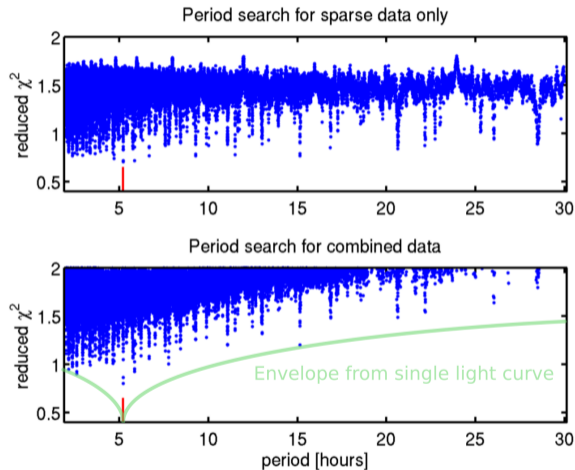
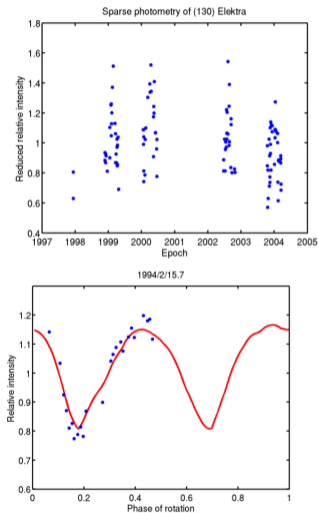
Schwamb+2019



Time-series & 3D shapes

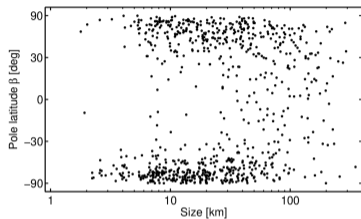


Time-series & 3D shapes

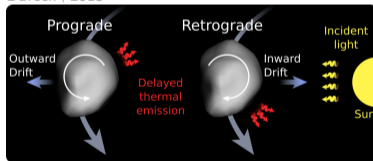


- Works 10-20% of time From 3k to 500k!
- Interesting synergy with Euclid

Time-series & 3D shapes

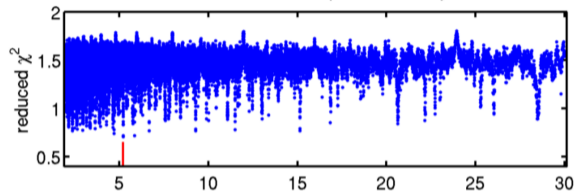


Durech+2015

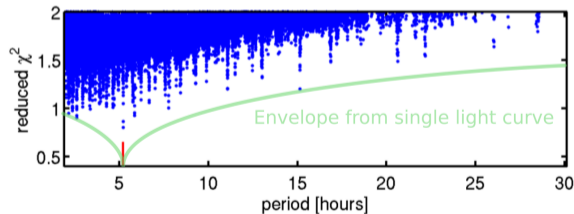


Main dynamical evolution

Period search for sparse data only

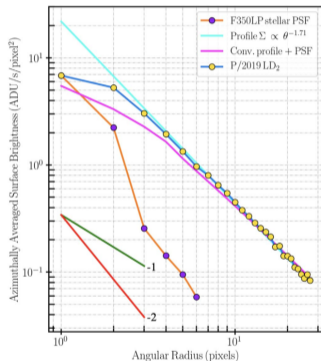


Period search for combined data



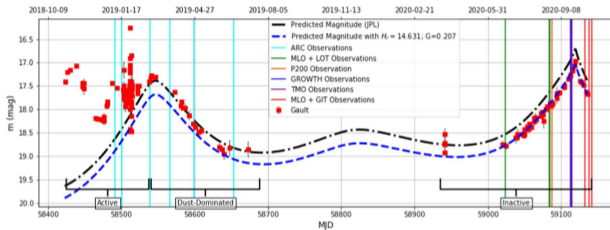
Activity

• From the PSF



Bolin+2021

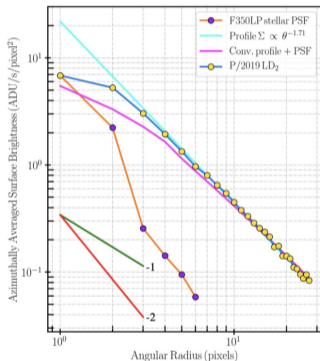
• From the photometry



Purdum+2021

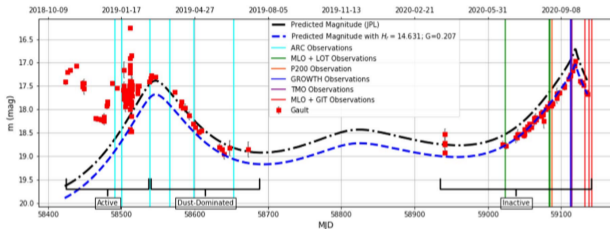
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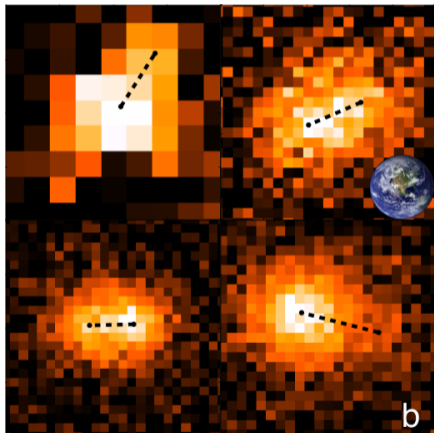
• From the photometry



Purdum+2021

- Fraction of active SSOs?
- Mechanisms of activity? Sublimation, spin fission, collisions, ...
- Location of water in Solar System

Multiplicity



Fraser+2017

- **Census of binaries**
 - KBOs & Centaurs
 - Fraction **vs** populations
- **Mutual orbits**
 - LSST → Multi-epochs
 - Mass → density
 - Composition constraints
- **Colors of binaries**
 - Track origins
 - Fraction in population
 - ▷ Formation models

SSSC

- Firstly focused on discoveries
 - Astrometry → MPC secured
- Discussion on cadences
 - Analysis of metrics for simulations post SCOC Meeting 2020
 - White papers: Twilight NEO survey? Simultaneous Euclid observations?
 - Coverage of opposition?
- Composition & physical activity
 - Daily computation of phase curve → absolute magnitudes
 - Source characteristics (PSF-like, extended...)
 - Period estimate
- What will we do then?
 - Orbital structure: inner and outer solar system
 - Color → Distribution of compositions
 - Characterization of activity
 - Link between physical characteristics and dynamics