Small bodies and Extreme astrometry

B. Carry

Lagrange, Observatoire de la Côte d'Azur

Remnants of our dynamical past

(Exo)planet formation

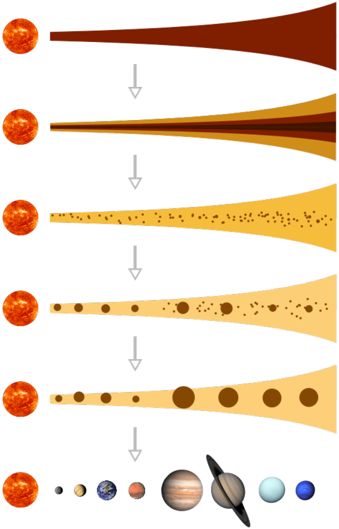
- Protoplanetary disk
- Accretion of solids
- Planetesimals

Fundamental processes

- Planetary migrations
- Dynamical instability
- ▷ Solar system?

Asteroids are Relics

- No compositional evolution
- ▷ Direct witnesses



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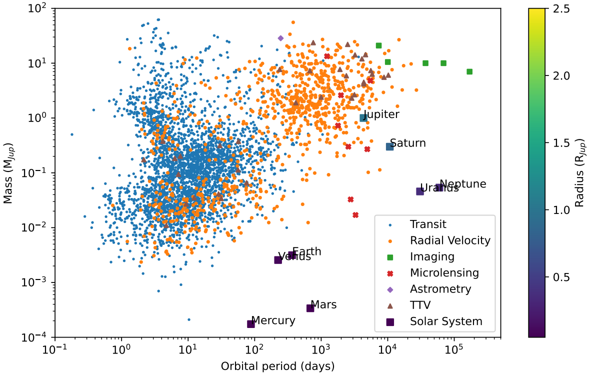

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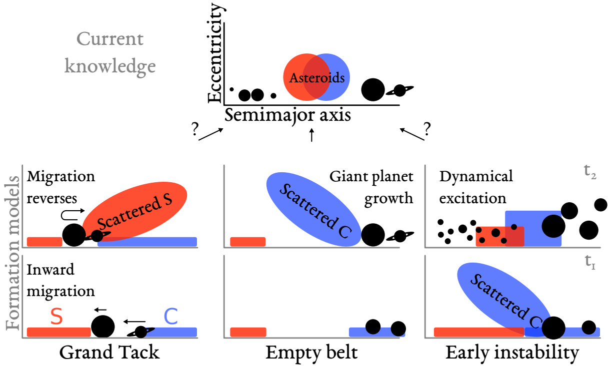
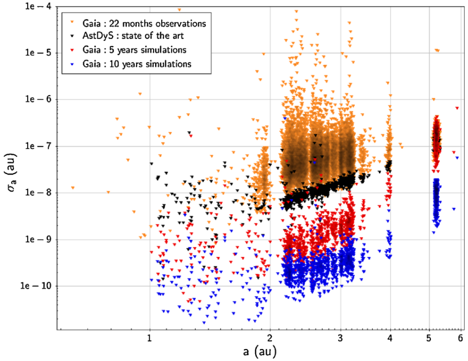


Adapted from Raymond+2018

What do we need to study?



Spoto+2018

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  - Dynamical structure
  - Origins & evolution
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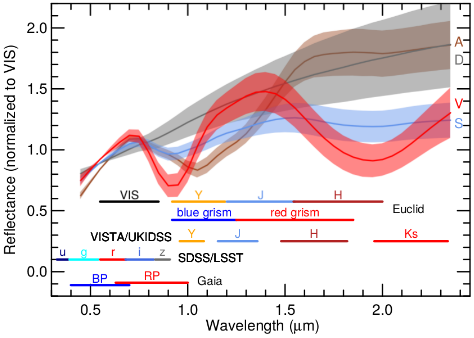

Carry2018

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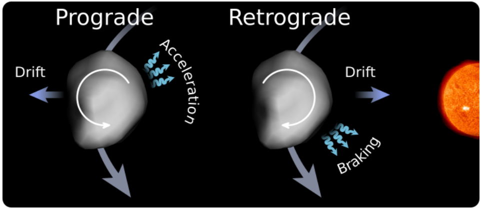
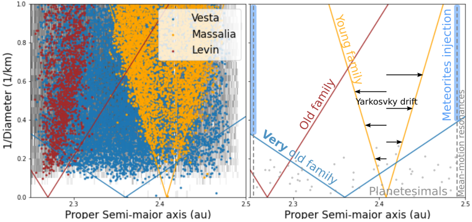


Adapted from Bottke+2022



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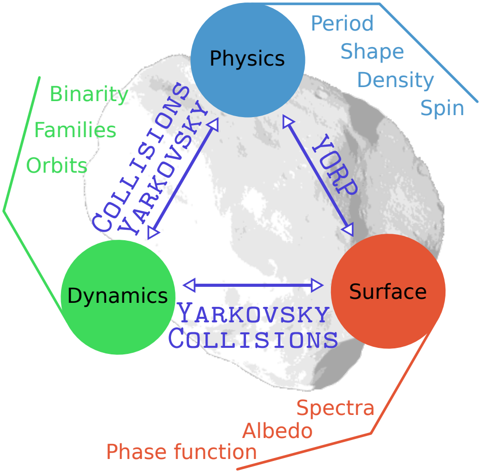

Complex interplay of properties

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Challenges for Solar System Objects

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

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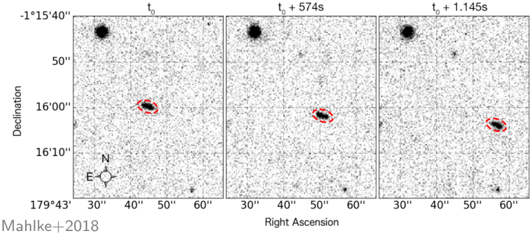
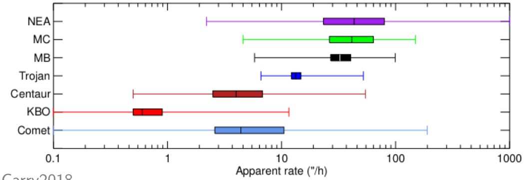
  - Asteroids: 10–100 ″/h
  - 1-10 ″/h beyond Jupiter



Mahlke+2018



Carry2018

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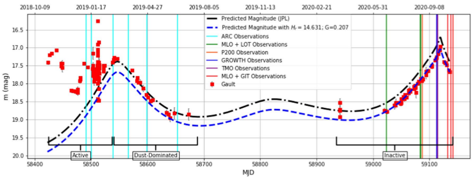
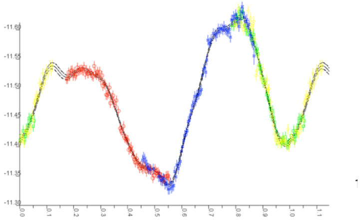


Purdum+2021



Mousis+2014

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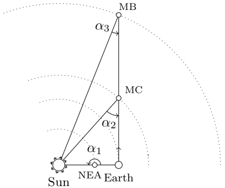
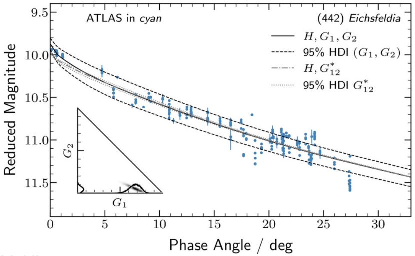
- **Variable SED** around a G2 basis
  - Function of phase
  - Wavelength dependent IR?

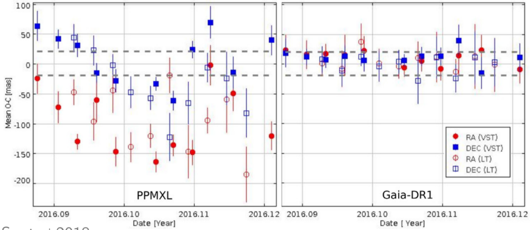




Mahlke+2021

The landscape in 2020s for SSOs

- **Gaia Astrometry**
  - Stellar catalog
  - SSOs



Spoto+2018

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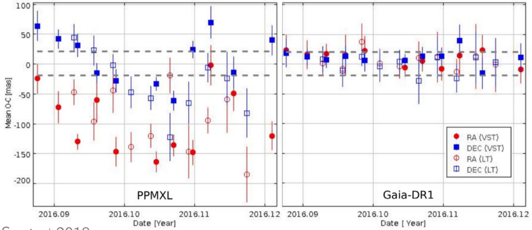

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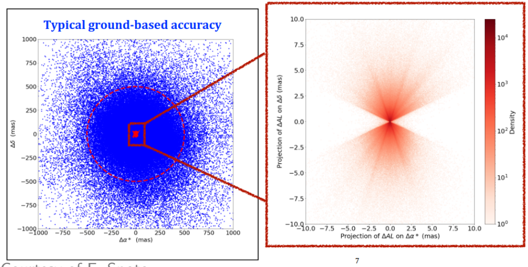

Courtesy of F. Spoto

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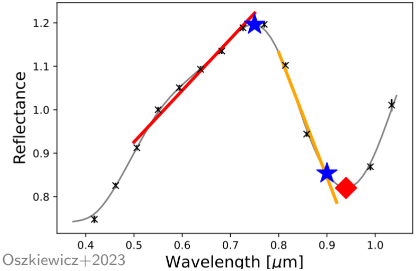
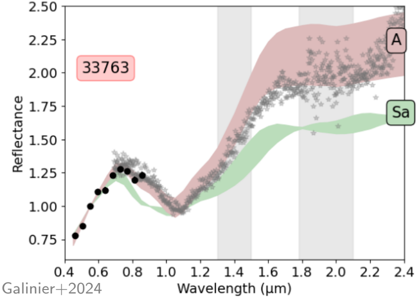


Oszkiewicz+2023



Galinier+2024

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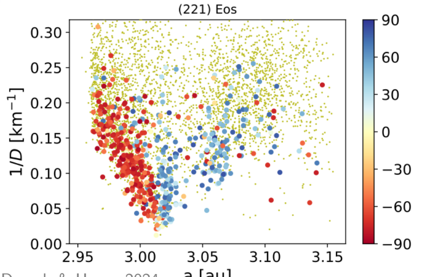
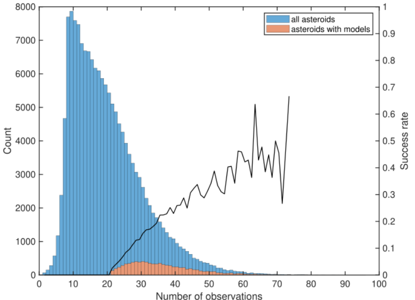


Durech & Hanus 2024



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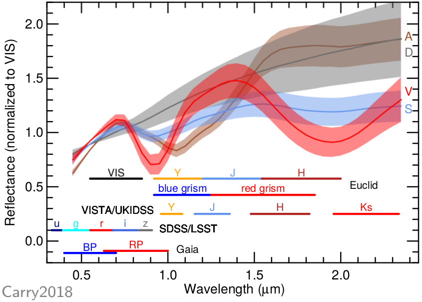
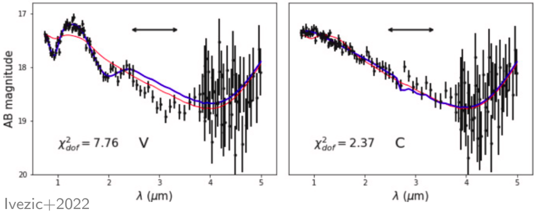


Carry2018



Ivezic+2022

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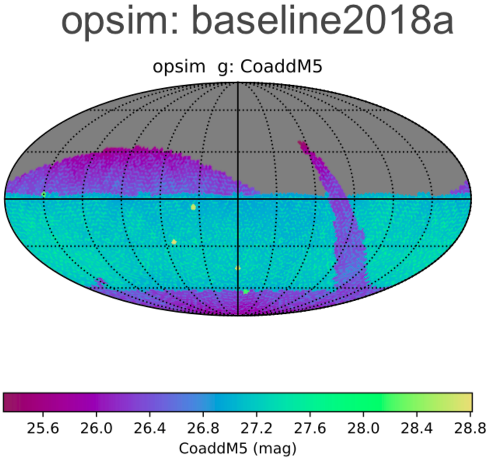
- **LSST** T for tsunami
  - 5 M SSOs, 200-300× each
  - ugrizy filters



LSST Collaboration

What comes next?

- Regular 4π sr observations will remain necessary
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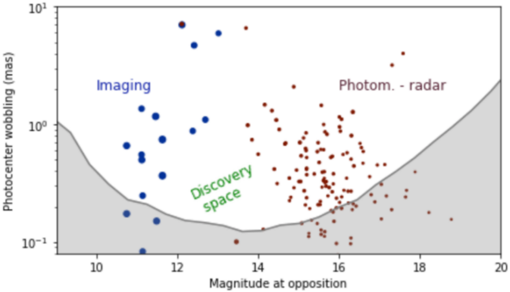
  - Main driver of dynamical evolution
  - Critical for chronology

Case 1. Characterization of binary asteroids

- **Current sensus**
  - Light curves
  - Direct imaging
  - ▶ Strong **biases**



Tanga+, ANR GaiaMoons

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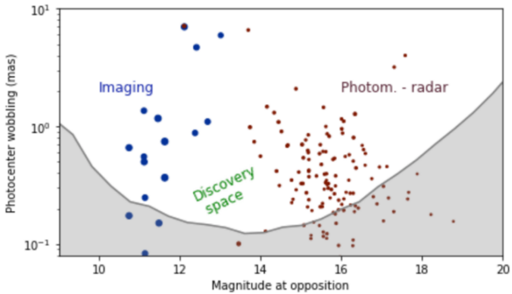

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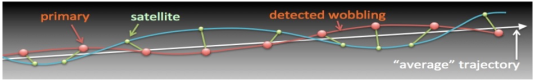

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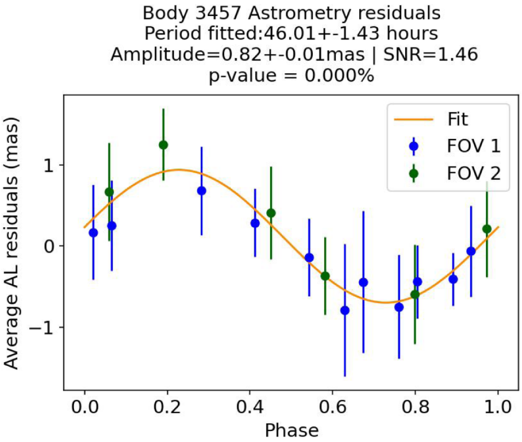

Liberato+2024

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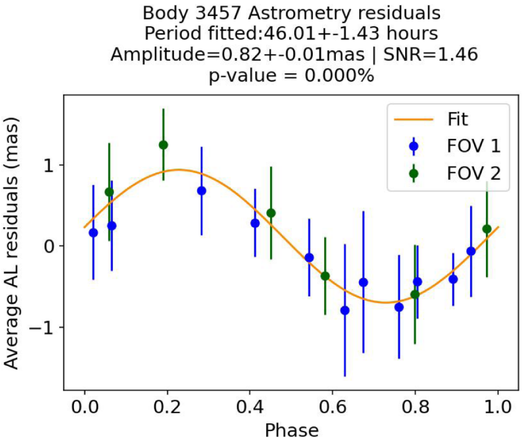
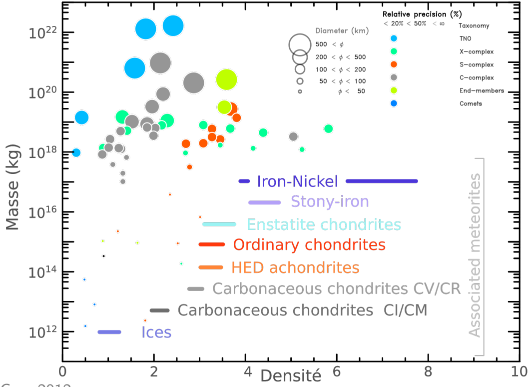
- **A case for extreme astrometry**
  - Regular observations (10-20)
  - Over a few periods (days)
  - At mas / sub-mas level
  - V ∈ [13,18+]



Liberato+2024

Case 2. Masses from close encounters



Carry2012

- **Density is fundamental**
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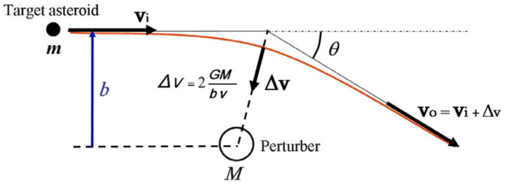

Mouret+2008

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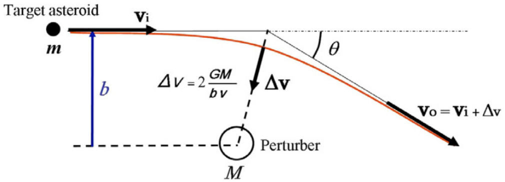

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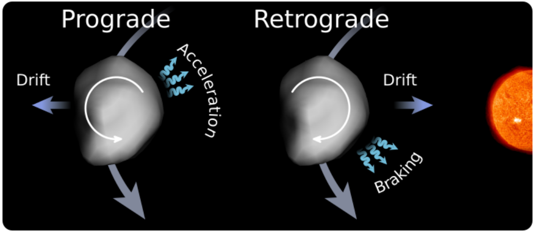
  - ▶ **Density**
- **A case for extreme astrometry**
  - Before/after encounter
  - Weeks/Months (few points)
  - At mas / sub-mas level
  - $V > 18$

Case 3. Direct Yarkovsky detection

- **Yarvkosky effect**
  - Non-gravitational
  - Delayed thermal radiation
  - ▶ **Main** evolutionary process



Adapted from Bottke+2022

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  - Striking in the population
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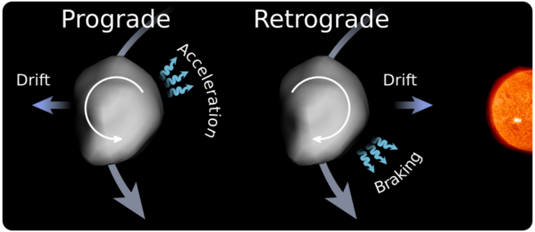

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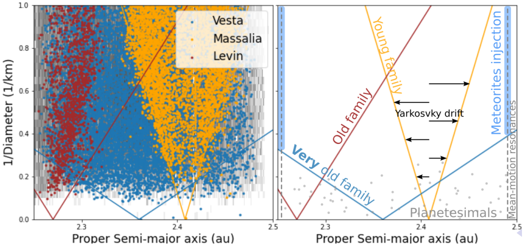

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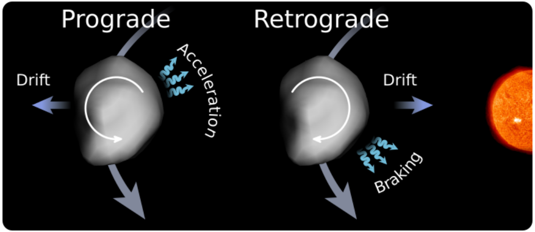
  - On favorable candidates
  - At mas / sub-mas level
  - V $\in$ [18,20+]



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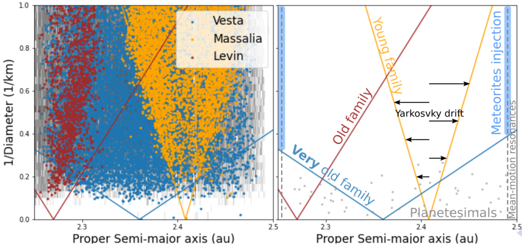

Summary

- Solar System Objects are keys to understand planetary formation
  - Why is Solar system so different?
  - Sequence of events $\rightarrow$ (exo)planet formation

- Main-stream observational requirements for progresses
  - 4π astrometry with spectro- and time-photometry

- Some niches for targeted extreme-precision astrometry

Case 1. Characterization of binary asteroids
Case 2. Masses from close encounters
Case 3. Direct detection of Yarkovsky drift

- Solar System Objects specificities
  - Motion $\rightarrow$ limitation on exposure time or co-adds
  - Changing brightness $\rightarrow$ geometry of observation?