Colors and spins of asteroids in LSST era

B. Carry[1], **J. Peloton**[2], **R. Le Montagner**[2], **M. Mahlke**[3], **J. Berthier**[4]

[1]Lagrange, [2]IJCLab, [3]IAS, [4]IMCCE

Small bodies and planetary formation

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

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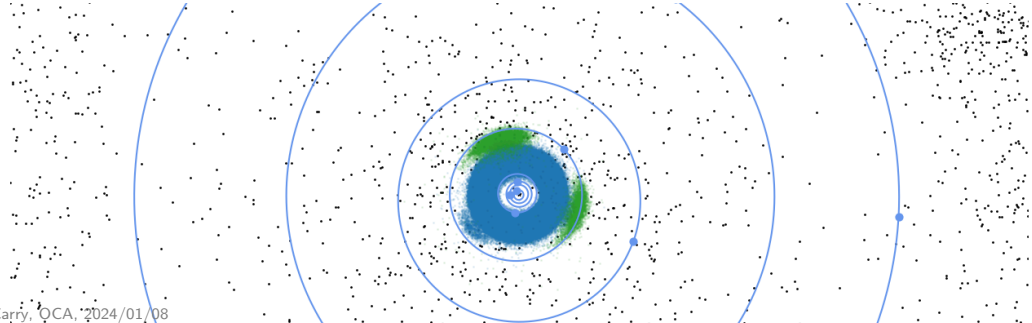

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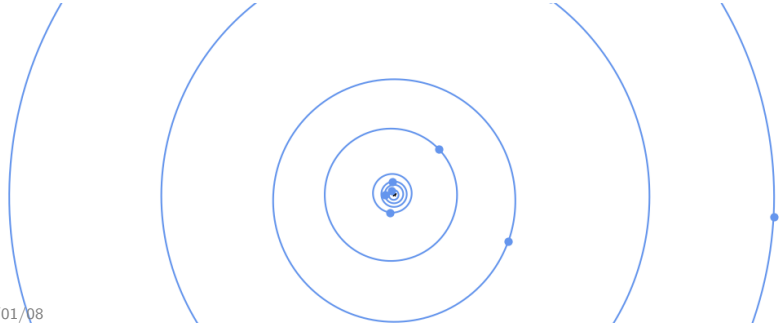

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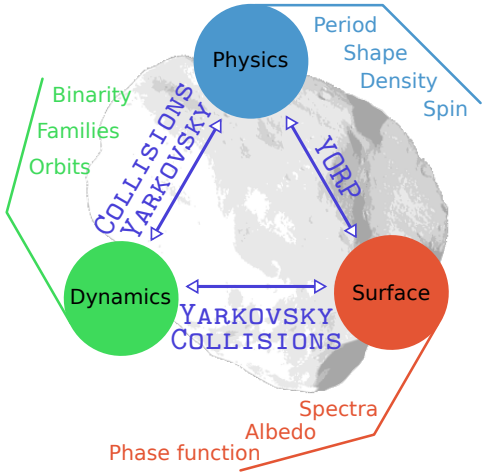
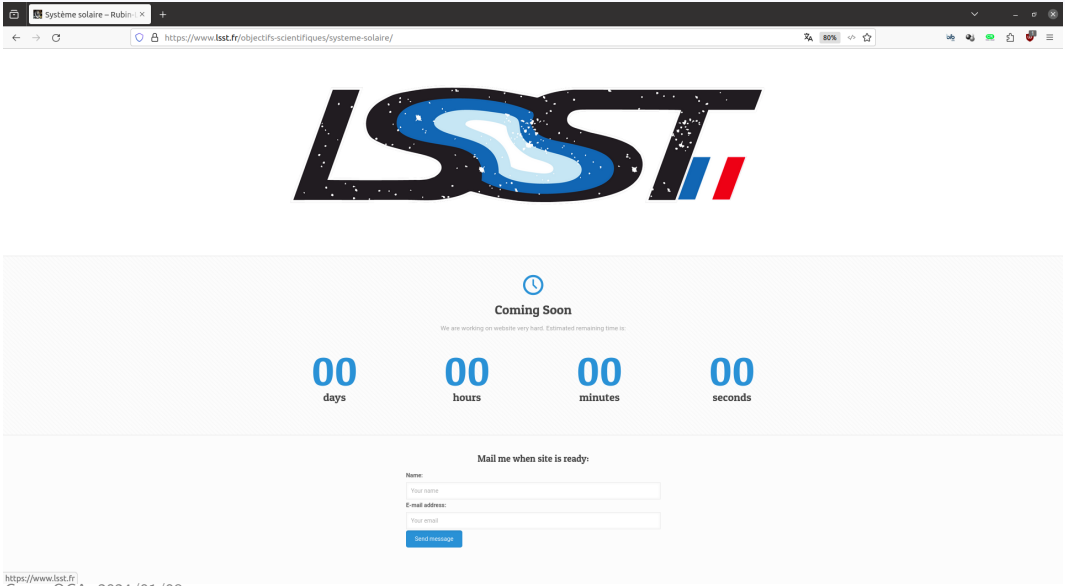
What do we need to study?



Complex interplay of properties

- **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
  - ▷ **Time serie photometry**

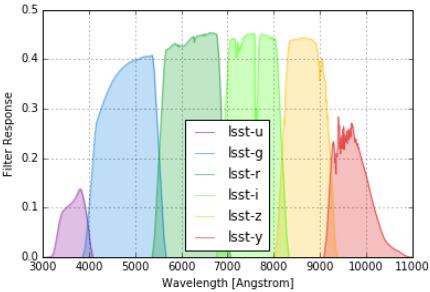
What LSST will bring to Solar System?



What LSST will bring to Solar System?

	Currently Known	LSST Discoveries	Typical number of observations
Near Earth Objects (NEOs)	~20,000	200,000	(D>250m) 60
Main Belt Asteroids (MBAs)	~650,000	6,000,000	(D>500m) 200
Jupiter Trojans	~7000	280,000	(D>2km) 300
TransNeptunian Objects (TNOs) + Scattered Disk Objects (SDOs)	~3000	40,000	(D>200km) 450
Comets	~3000	10,000	?
Interstellar Objects (ISOs)	2	10	?

LSST SSSC



LSST

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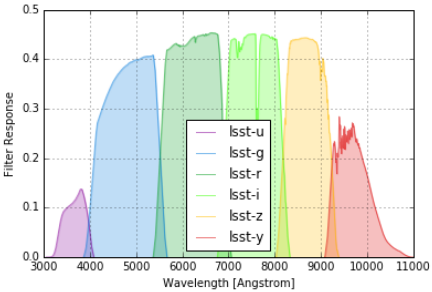
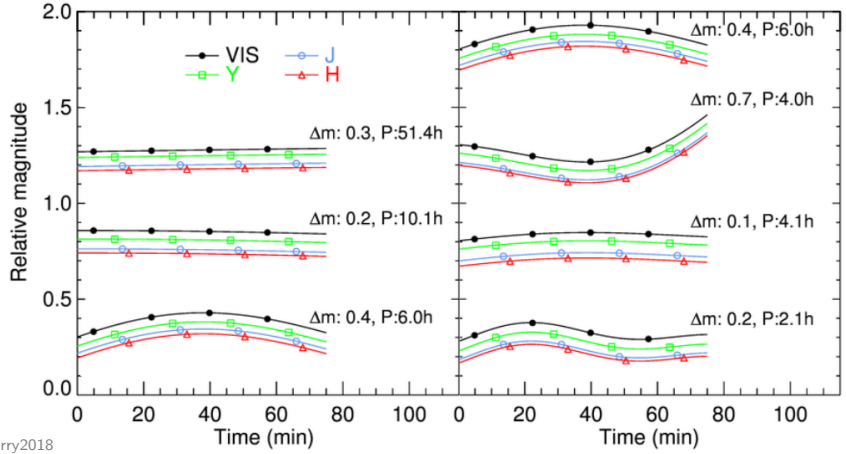


LSST

$\Rightarrow$ **Discovery, astrometry, colors, time series**

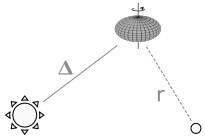
The challenge of SSO variability



Carry2018

Modeling the photometry of SSOs

- **Distance**



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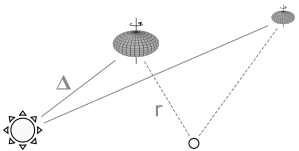

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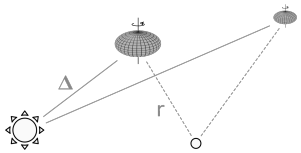

- HG Bowell1989

$$H = m - f(r, \Delta)$$

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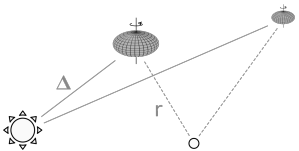

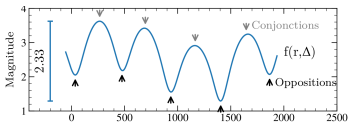

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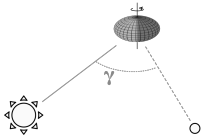

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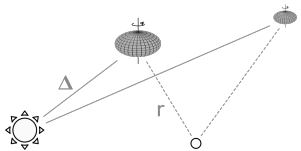

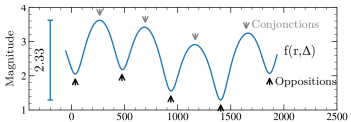

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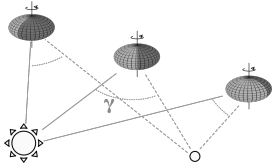

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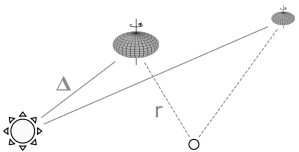

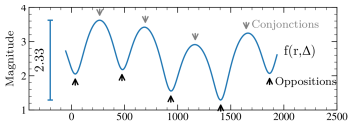

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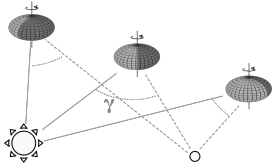

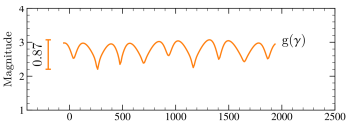

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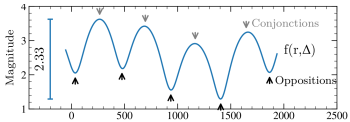

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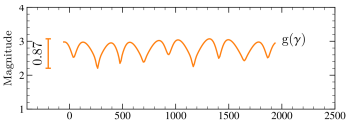
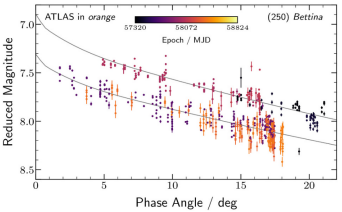


- **Aspect!**



Mahlke+2021

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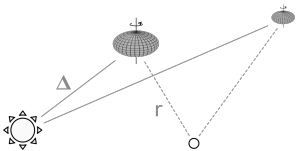

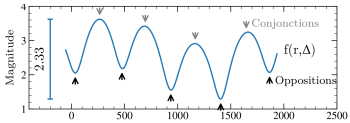

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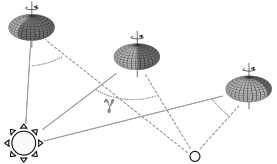

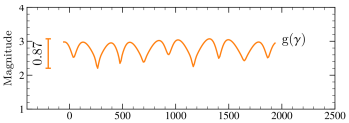

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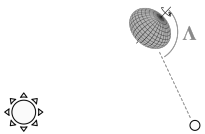

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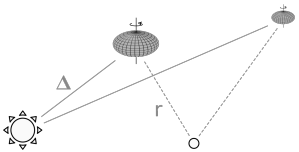

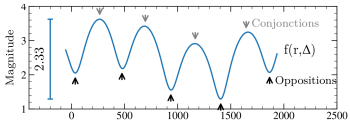

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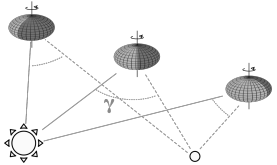

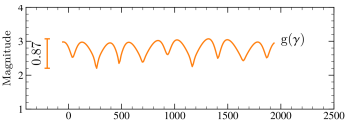

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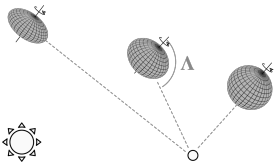

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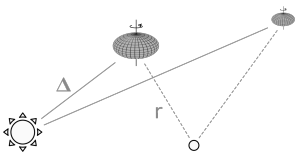

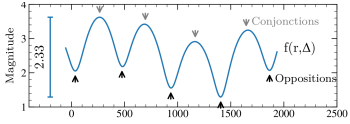

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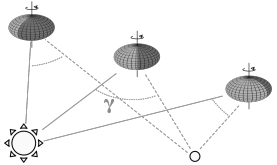

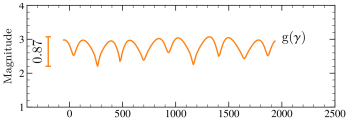

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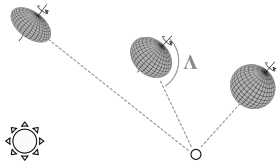

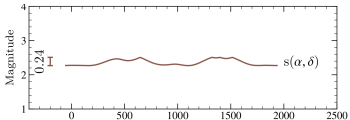

○ HG Bowell1989	○ HG Bowell1989	○ sHG$_1$G$_2$ Carry+2024
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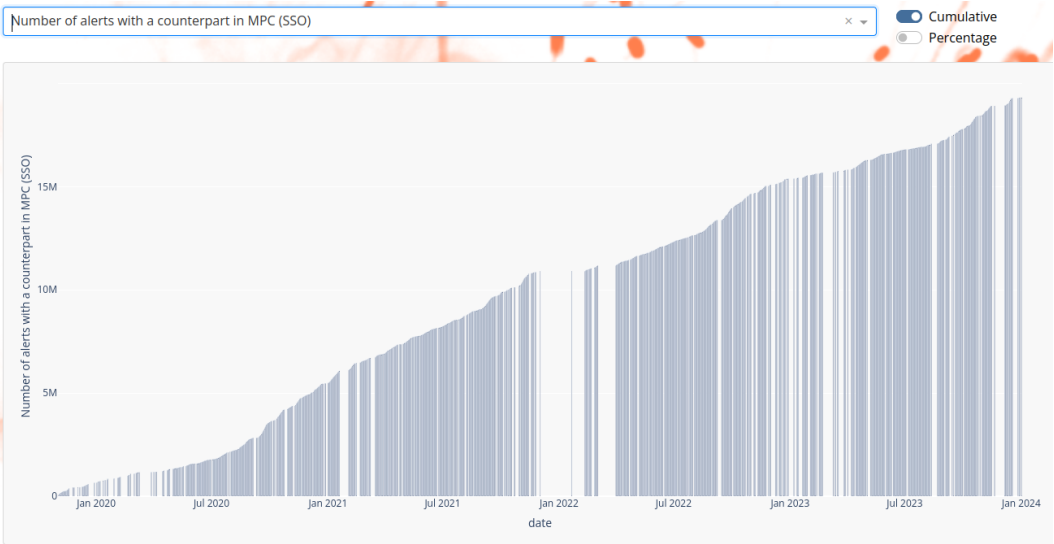
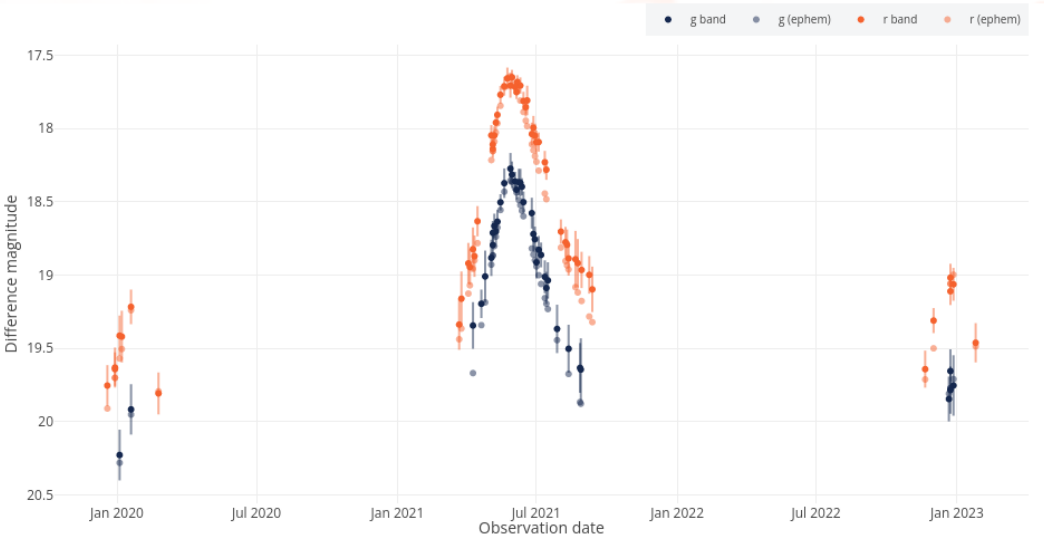
$H=m-f(r,\Delta)$	$H=m-f(r,\Delta)-g(\gamma)$	$H=m-f(r,\Delta)-g(\gamma)-s(\alpha,\delta)$

Data

Data: FINK!


Number of alerts with a counterpart in MPC (SSO)
Cumulative
Percentage
Number of alerts with a counterpart in MPC (SSO)
15M
10M
5M
0
Jan 2020
Jul 2020
Jan 2021
Jul 2021
Jan 2022
Jul 2022
Jan 2023
Jul 2023
Jan 2024
date

Data: FINK!... Julienpeloton



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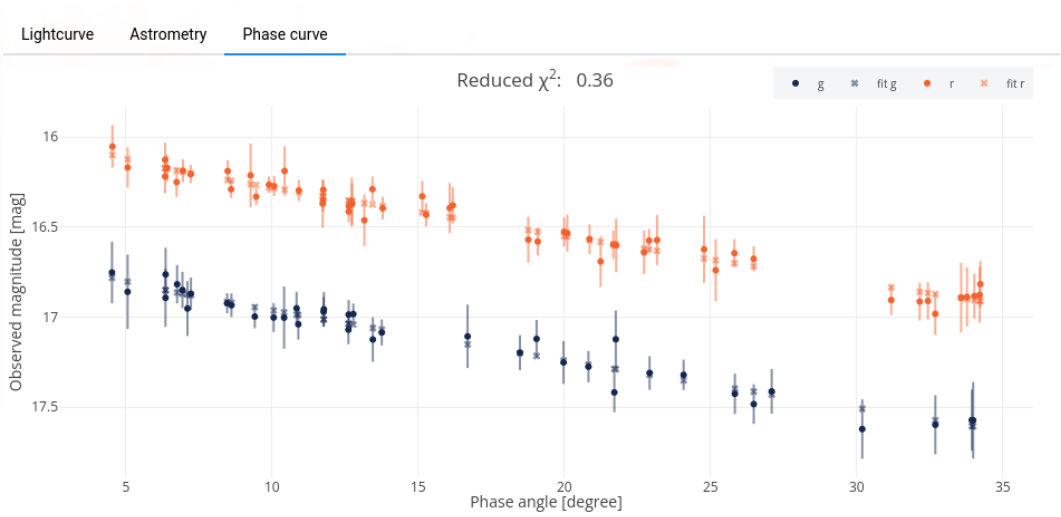
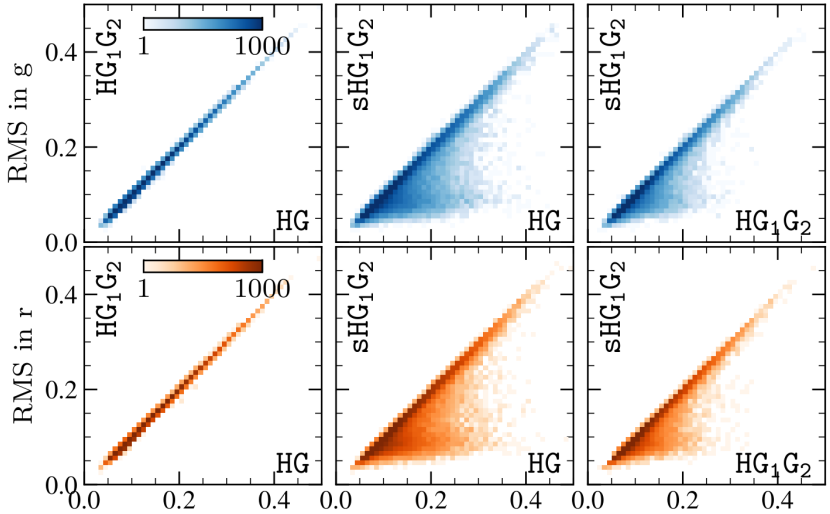
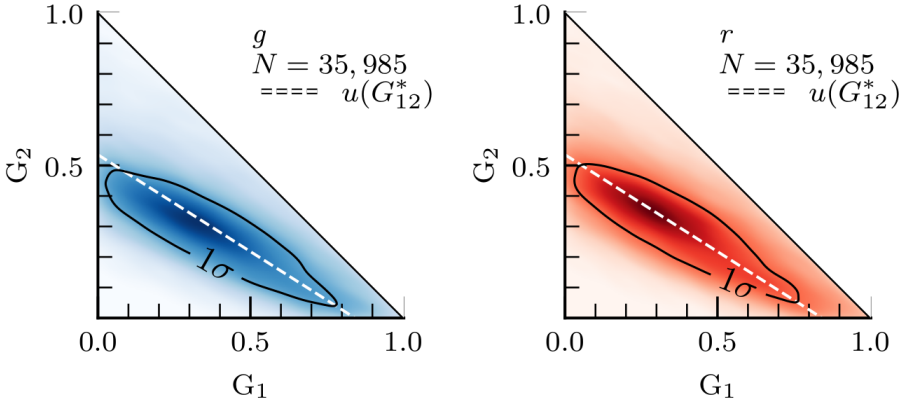


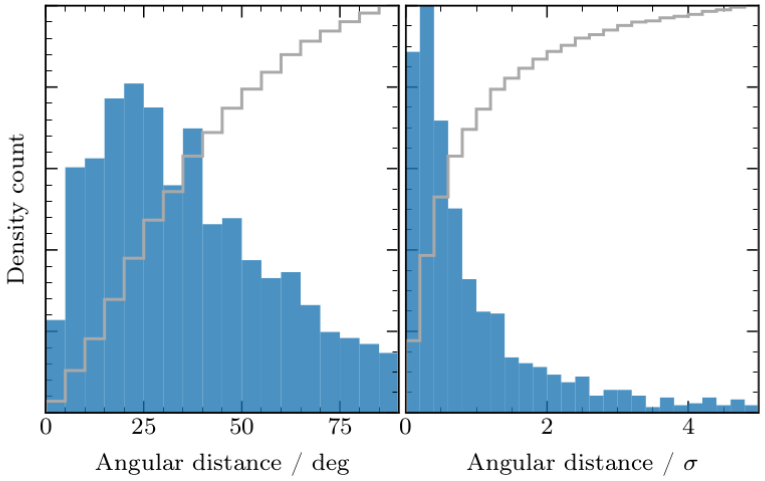
Validation: Fit



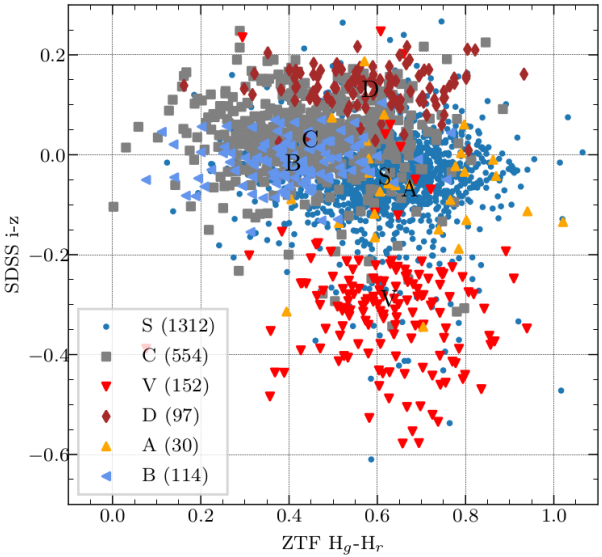
Validation of phase: $g(\gamma)$



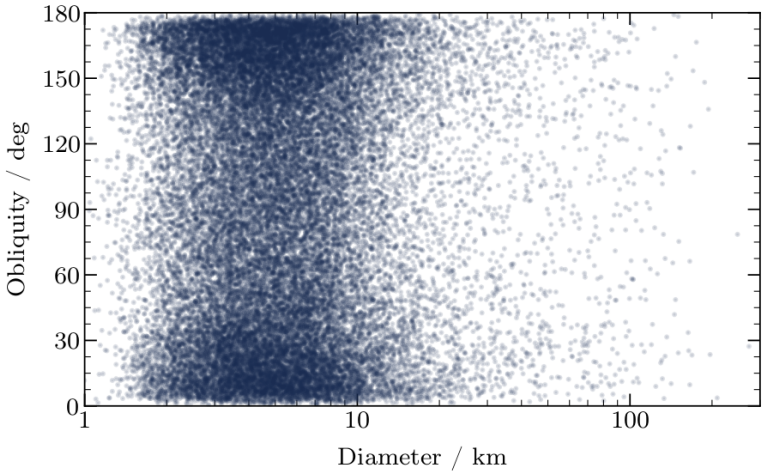
Validation of spins: $s(\alpha, \delta)$



Validation of colors: $\mathtt{sHG_1G_2}$



Spin orientation



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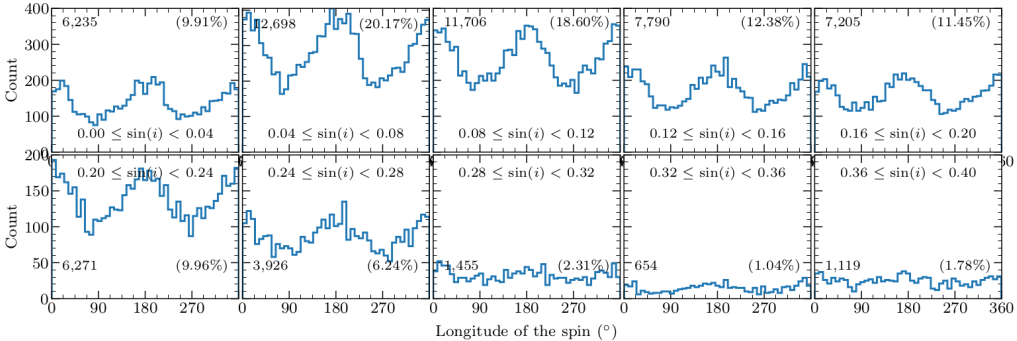

Summary

- **Questions on Solar System & Planetary formation require**
  - Discoveries for large statistics on SSOs
  - Including multi-filter and time-serie photometry
  - ▶ LSST of Vera C. Rubin is **highly** promising

- **Challenges linked with SSO photometry**
  - Combination of short- and long-term variability
  - ▶ New model put forward here: $\texttt{sHG}_1\texttt{G}_2$

- $\texttt{sHG}_1\texttt{G}_2$ **implemented in FINK over 2023**
  - Run monthly → Dec.2023 → 115,000 SSOs
  - $\texttt{sHG}_1\texttt{G}_2$ works and improves over previous models
  - Phase & spin parameters & g-r color for ≈50,000 SSOs
  - ▶ Ready for LSST!