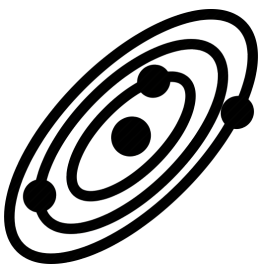
Solar System Science with ESA Euclid



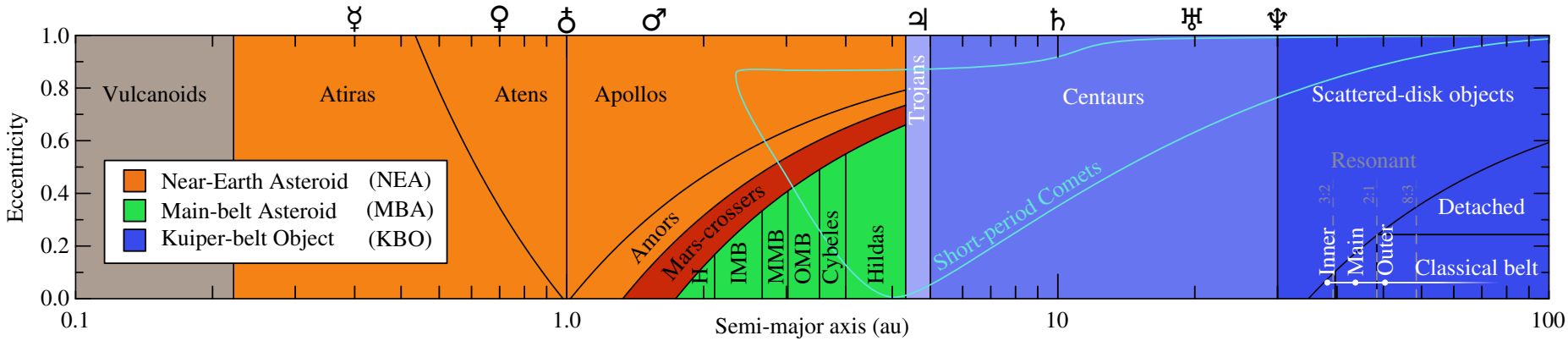
B. Carry

Lagrange, Observatoire de la Côte d'Azur

SSOs and planetary formation

- **Leftovers of the early solar system**
  - Remnants of building blocks
  - Limited dynamical evolution
  - Little mineralogical evolution
- **Constraints on planetary formation & evolution**
  - Orbital and size distributions
  - Distribution of composition
- **The triptych of SSO characterization**
  - **Dynamics:** census and orbits
  - **Composition:** V+NIR photo-spectrometry
  - **Physical properties:** spin, shape, size, multiplicity

A bit of nomenclature



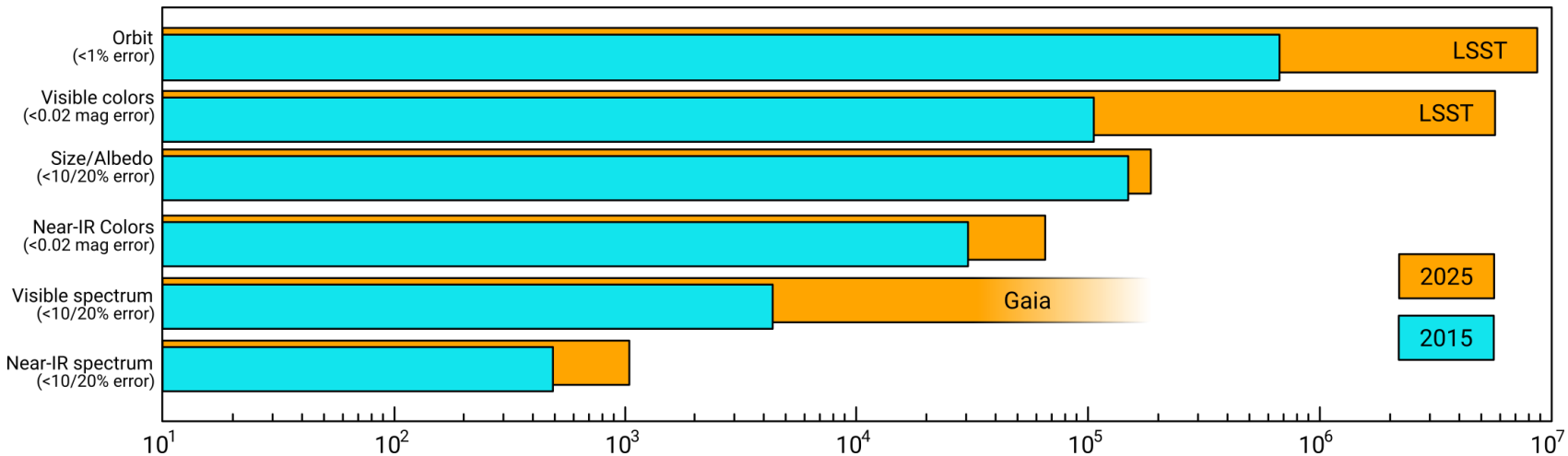
Inner solar system

- NEAs
- MCs
- MBAs
- Trojans

Outer solar system

- Centaurs
- KBOs
- Comets

State of the field



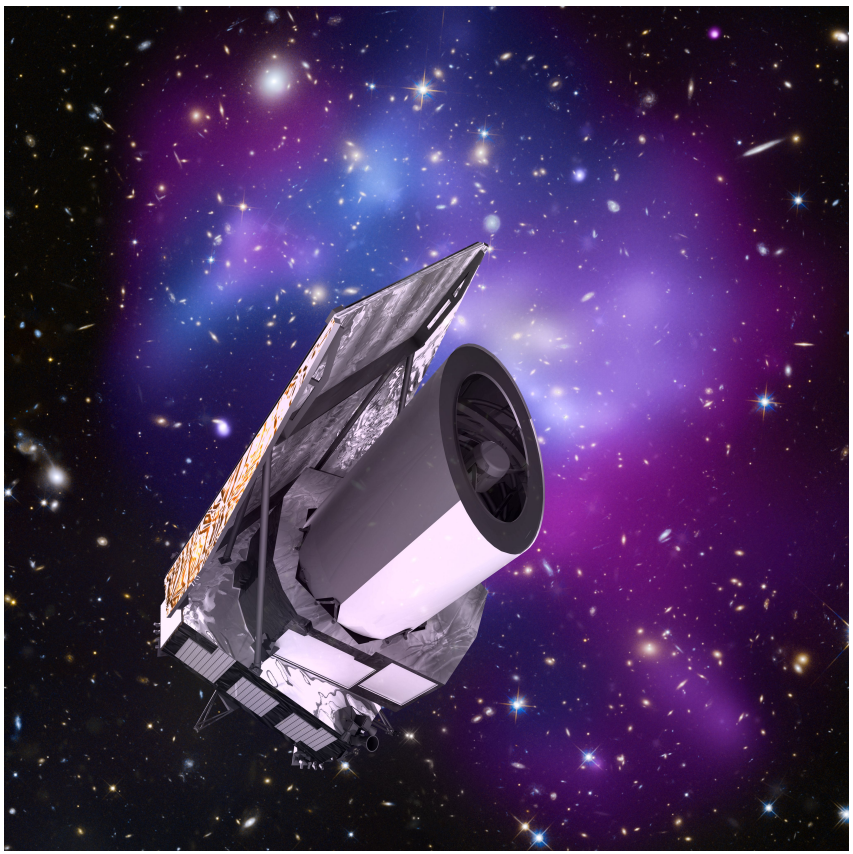
Dynamics & visible colors ☺

- Dedicated surveys
- Gaia... Wow!
- LSST.. re-Wow!

Spectra & near-infrared ☹

- Only a few programs
- VISTA by Popescu2016+
- ...

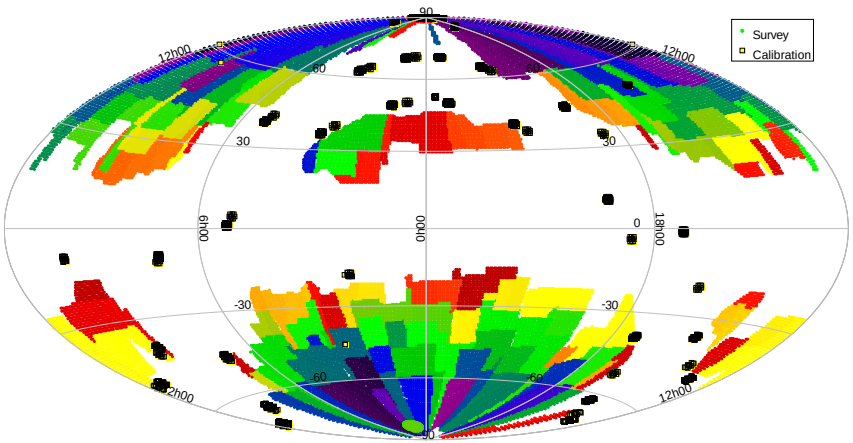
ESA Euclid



Euclid Consortium

1. Dark matter explorer
2. Other Science
   - Brown dwarfs
   - Galaxies
   - ...

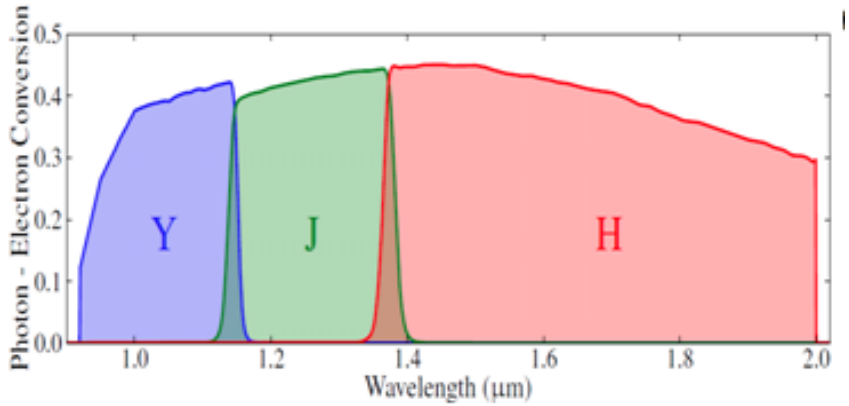
ESA Euclid

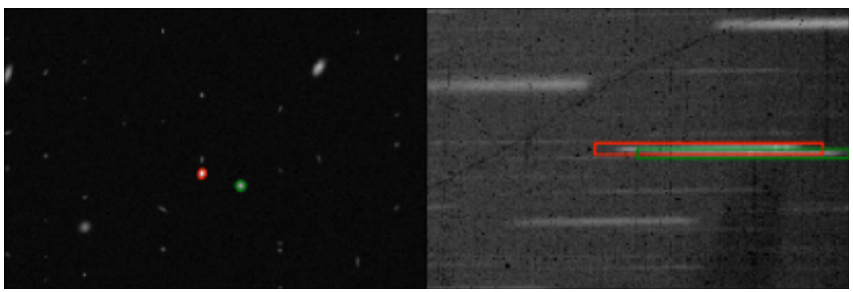


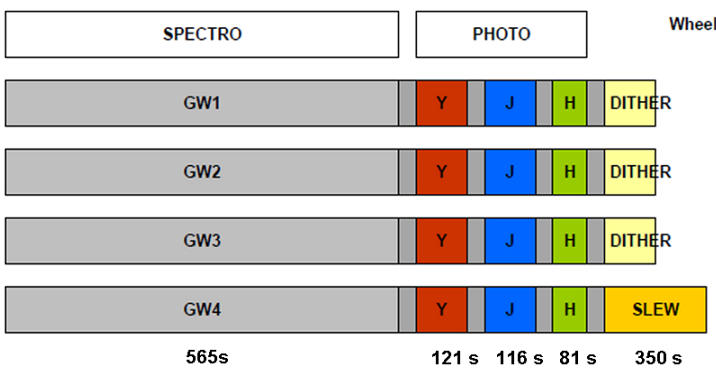
Euclid Reference Survey

1. Dark matter explorer
2. Other Science
   - Brown dwarfs
   - Galaxies
   - ...
3. Euclid surveys
   - Wide: 15,000 deg^2
   - Deep: 20 deg^2
   - 7100 calibrations
   - HST-like PSF
   - V$\leq$24.5 + 2

ESA Euclid







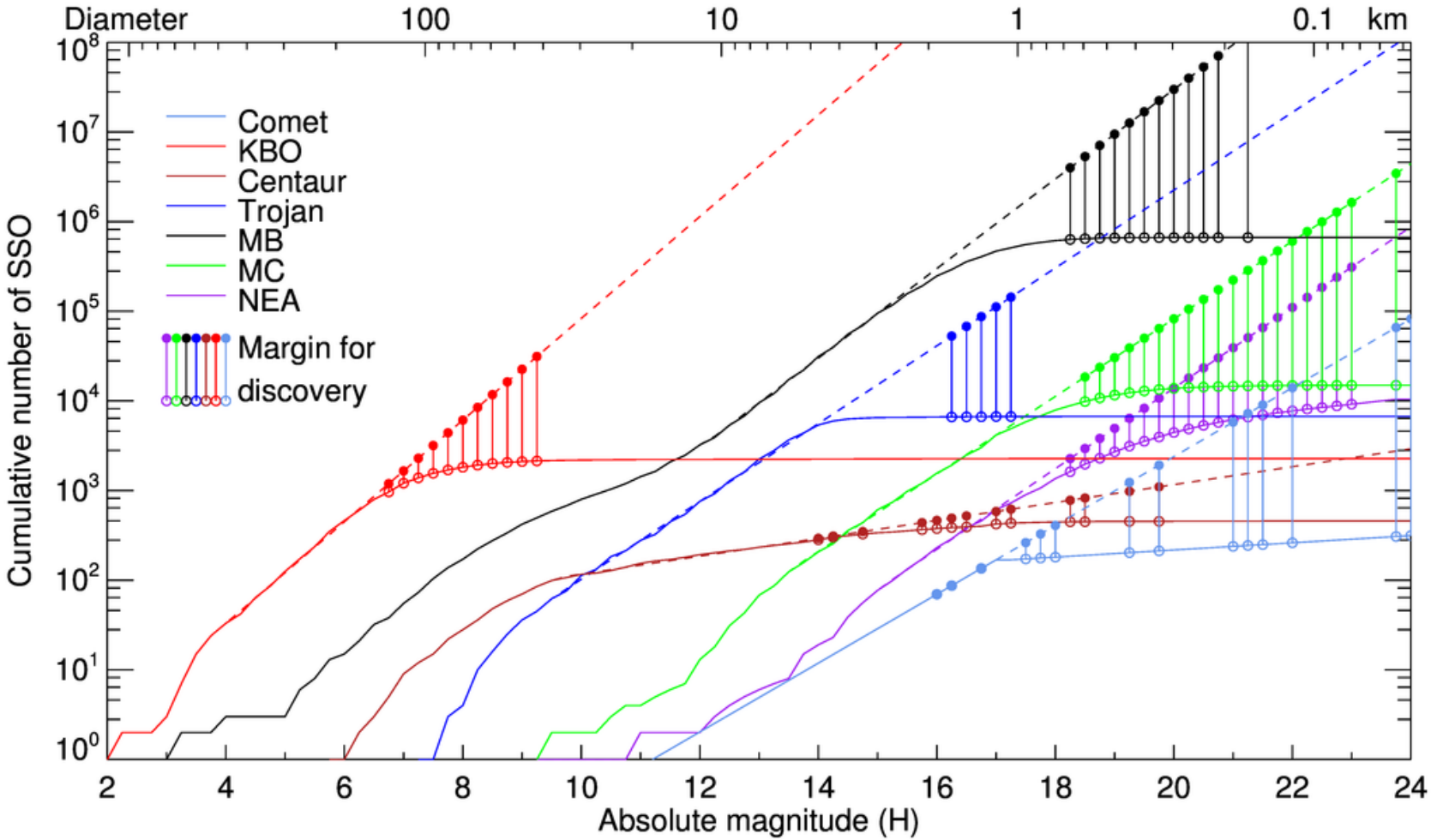
Euclid Consortium

1. Dark matter explorer
2. Other Science
   - Brown dwarfs
   - Galaxies
   - ...
3. Euclid surveys
   - Wide: 15,000 deg^2
   - Deep: 20 deg^2
   - 7100 calibrations
   - HST-like PSF
   - V$\leq$24.5 + 2
4. Euclid instruments
   - **VIS**: Camera
   - **NISP**: Camera and spectrograph

Extrapolating known population

- Model SSO cumulative SFD by power laws
  - Comets from Snodgrass et al. (2011)
  - Others based on ASTORB
  - ▷ Synthetic reference populations in absolute magnitude H
- Compute (H-V) index for each population
  - {a,e} → 25-50-75% quartiles
  - Euclid operations fix solar elongation ∈ [87°,110°]
  - ▷ Get r, Δ, α → (H-V) indices
- Fraction of SSO within Euclid survey
  - Ephemerides for all SSOs in 2020-2026
  - Count the fraction inside Euclid survey
  - ▷ Expected fraction of SSO in/out survey

Euclid observation of SSOs

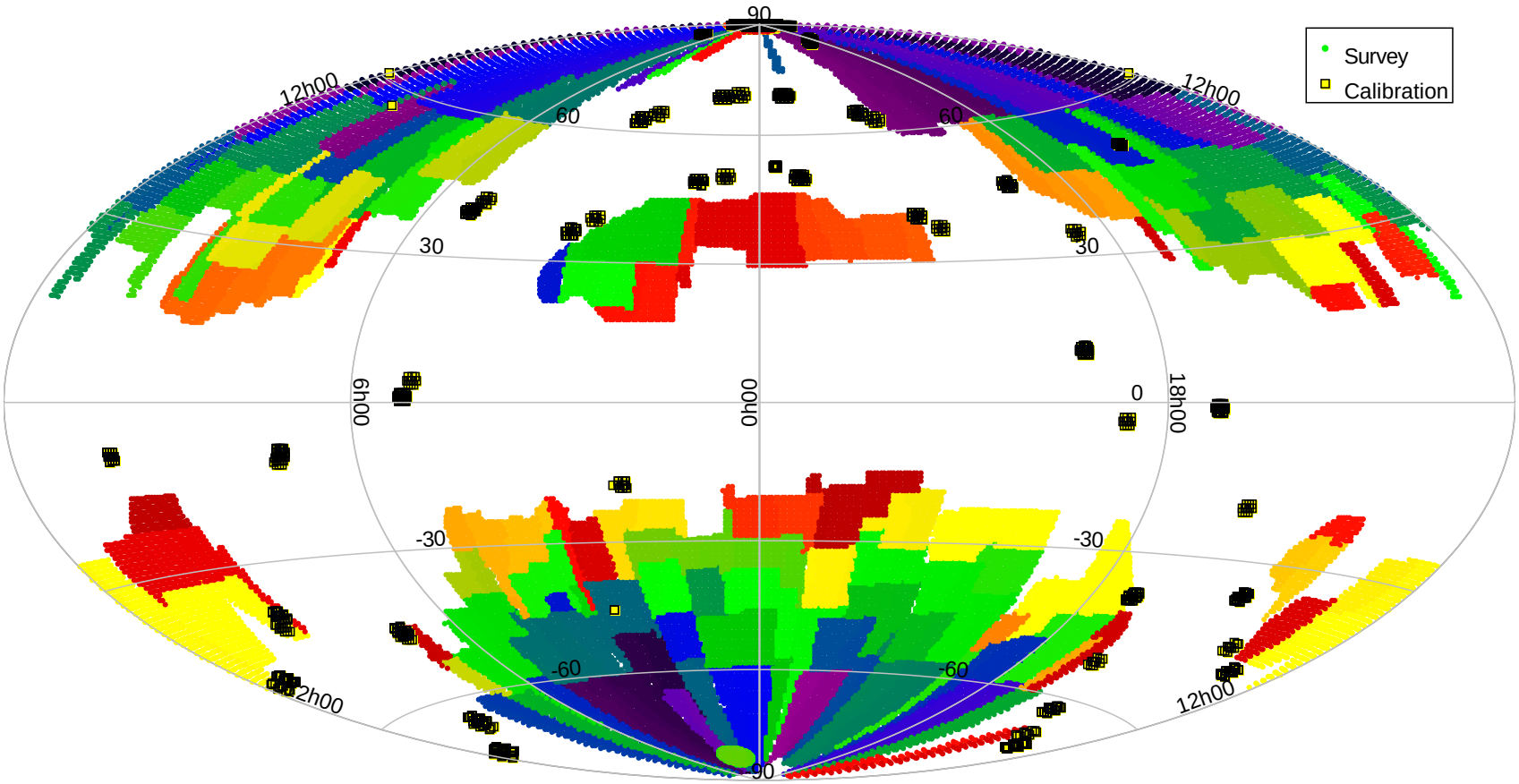


Euclid discoveries of SSOs

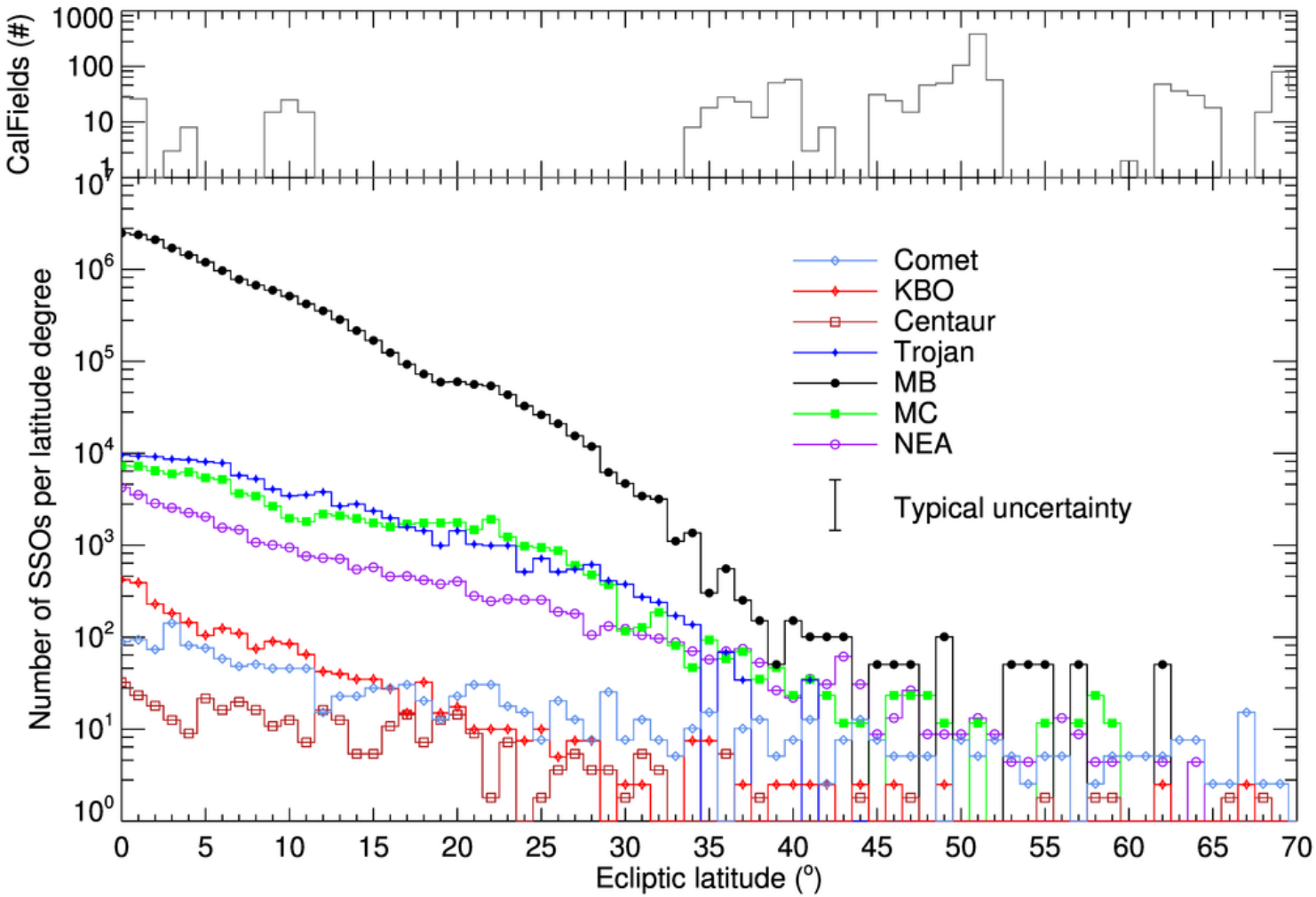
Population		All-Sky	f_S	Euclid
Name	$\mathcal{N}_{\rm now}$	$\mathcal{N}_{\rm obs}$	(%)	$\mathcal{N}_{\rm obs}$
NEA	14463	$3.90 \cdot 10^4$	5.6	$2.16 \cdot 10^3$
MC	14732	$2.20 \cdot 10^5$	6.9	$1.51 \cdot 10^4$
MB	674594	$2.20 \cdot 10^7$	1.1	$2.35 \cdot 10^5$
Trojan	6532	$8.70 \cdot 10^4$	4.3	$3.14 \cdot 10^3$
Centaur	423	$5.20 \cdot 10^2$	10.4	$5.25 \cdot 10^1$
KBO	2273	$6.10 \cdot 10^3$	4.4	$2.60 \cdot 10^2$
Comet	1195	$5.80 \cdot 10^3$	18.2	$1.04 \cdot 10^3$
Total	714212	$2.24 \cdot 10^7$		$2.57 \cdot 10^5$

Discoveries $\approx$ observations until LSST operates

Calibration fields

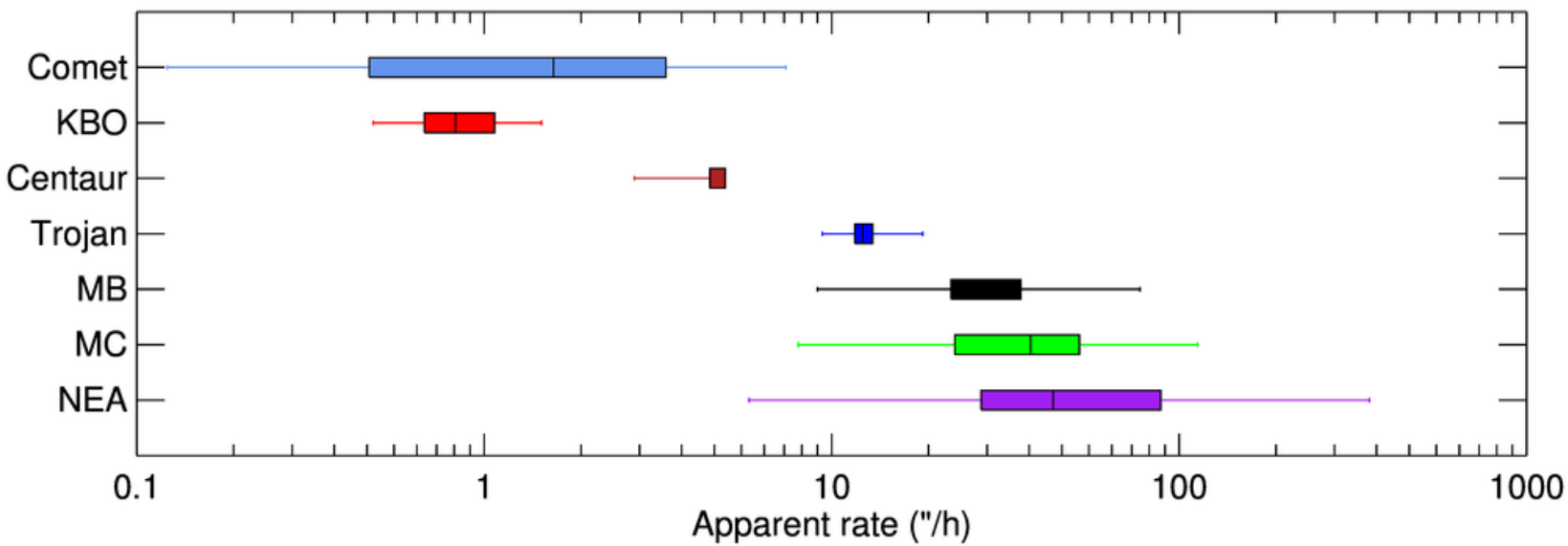


Calibration fields



$\Rightarrow$ **10^5 SSOs in 300 calibration fields!**

Apparent rate at quadrature



From known population projected on sky

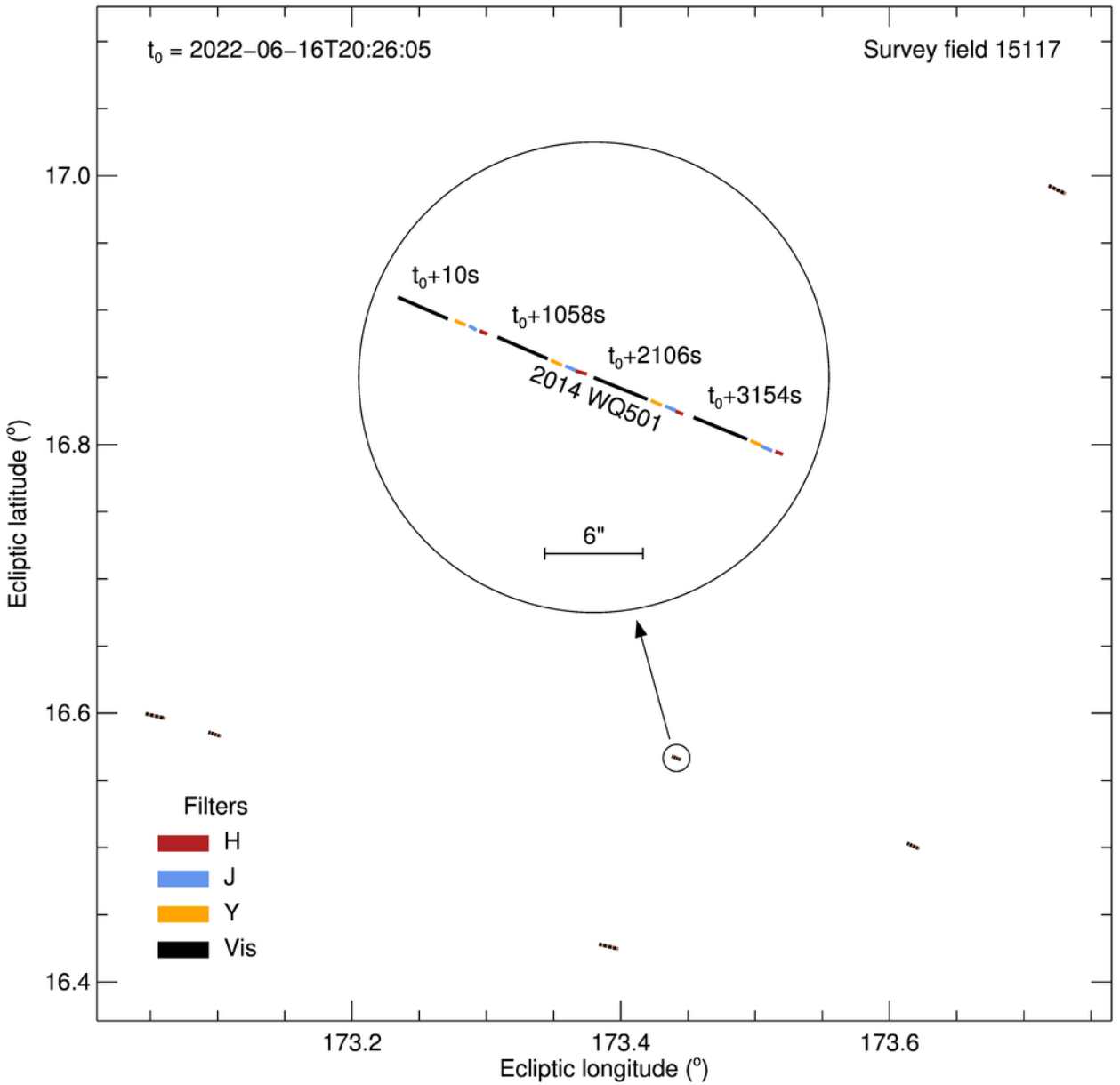
SSO motion in Euclid exposures

Population	Rate (″/h)	VIS (pix)	NISP (pix)	Y (pix)	J (pix)	H (pix)
NEA	$43.4^{+45.2}_{-16.4}$	68.1	22.7	4.9	4.7	3.3
MC	$37.4^{+14.2}_{-14.8}$	58.6	19.5	4.2	4.0	2.8
MB	$28.7^{+6.4}_{-6.6}$	45.1	15.0	3.2	3.1	2.2
Trojan	$12.3^{+0.8}_{-0.6}$	19.3	6.4	1.4	1.3	0.9
Centaur	$4.5^{+0.5}_{0.0}$	7.0	2.3	0.5	0.5	0.3
KBO	$0.8^{+0.2}_{-0.2}$	1.3	0.4	0.1	0.1	0.1
Comet	$1.6^{+1.8}_{-1.1}$	2.5	0.8	0.2	0.2	0.1

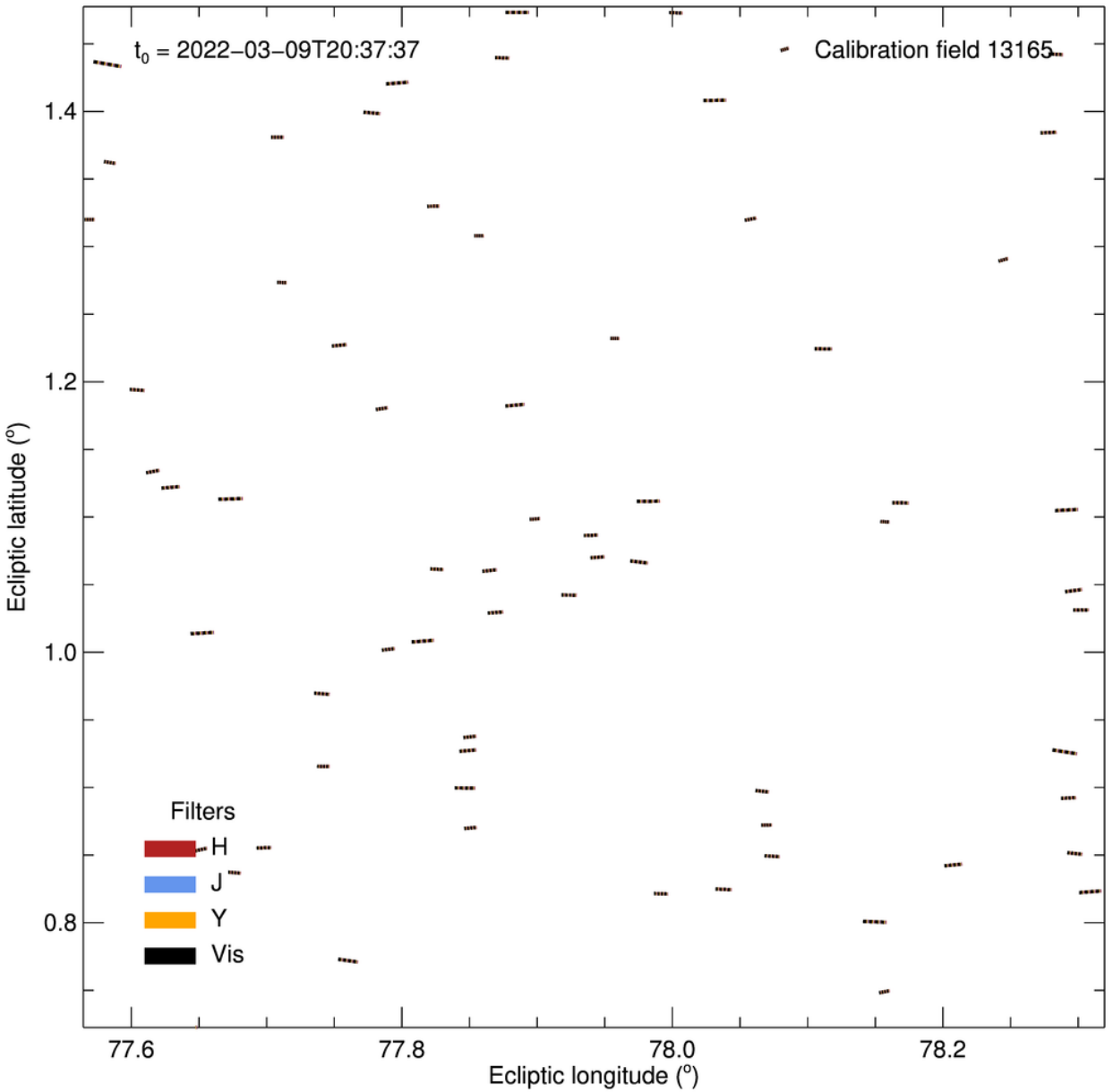
VIS-Y-J-H exposures of 565, 121, 116, 81 s.

$\Rightarrow$ Trailing of PSF is an issue in VIS and NISP spectroscopy

Euclid observations of SSOs

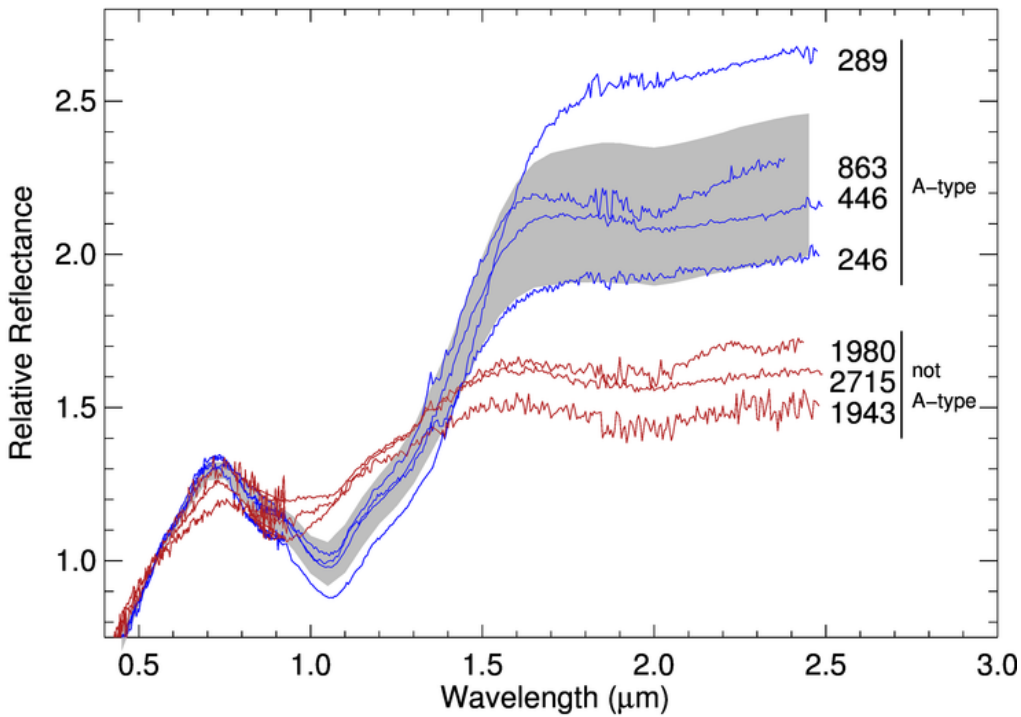


Euclid observations of SSOs



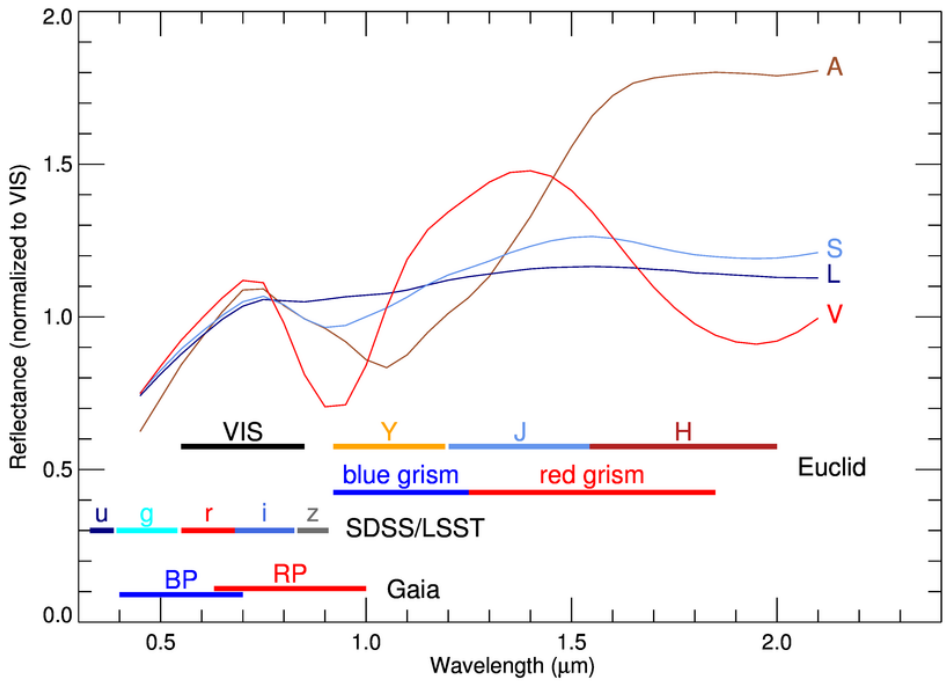
Mineralogy of SSOs

- Interest of NIR
  - Degeneration
  - Euclid VIS+NISP
  - ▷ Break degeneracy



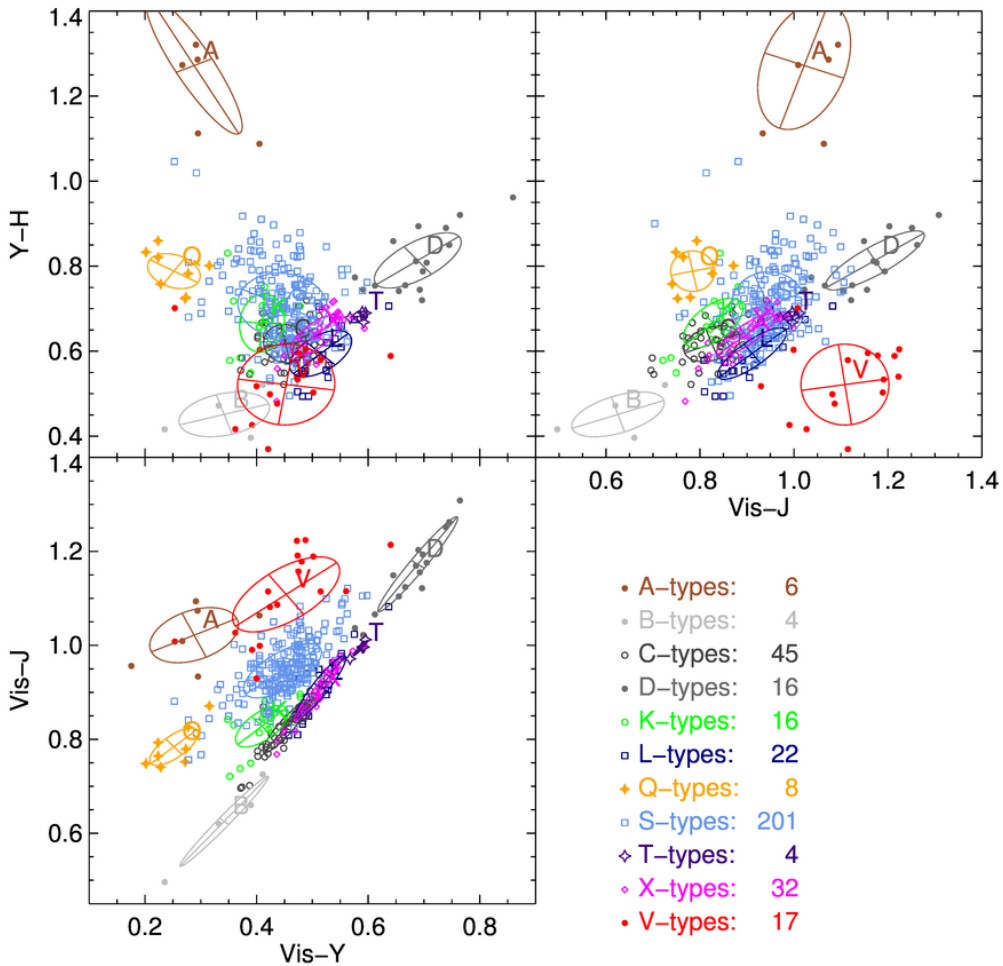
Mineralogy of SSOs

- Interest of NIR
  - Degeneration
  - Euclid VIS+NISP
  - ▷ Break degeneracy



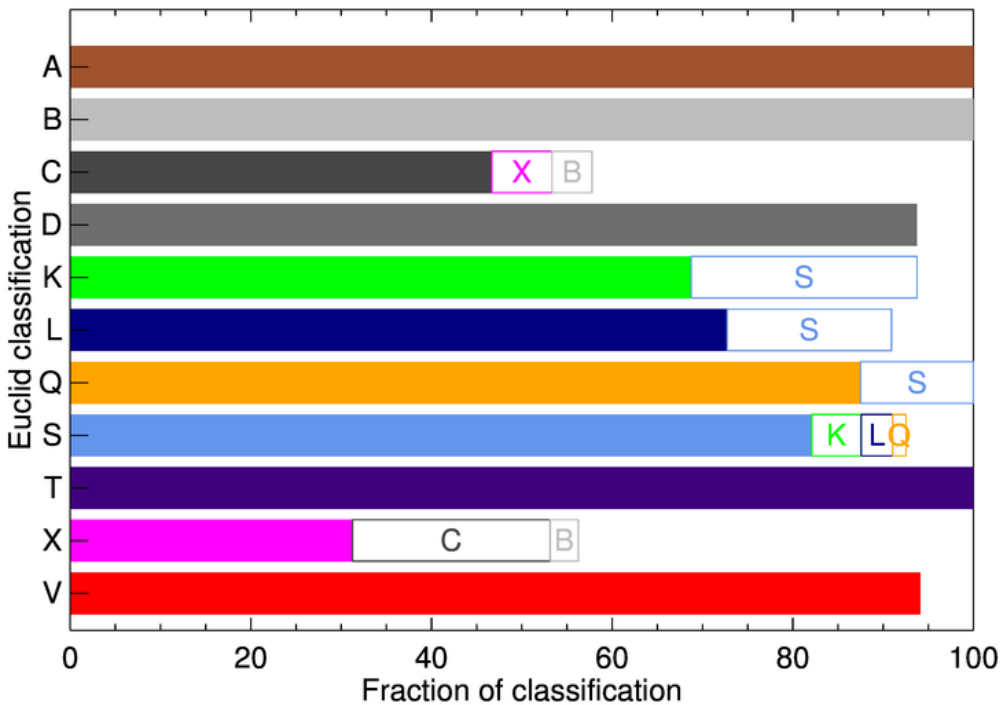
Mineralogy of SSOs

- Interest of NIR
  - Degeneration
  - Euclid VIS+NISP
  - ▷ Break degeneracy
- Euclid simulation
  - 371 known spectra
  - Convert to Euclid
  - Cluster analysis

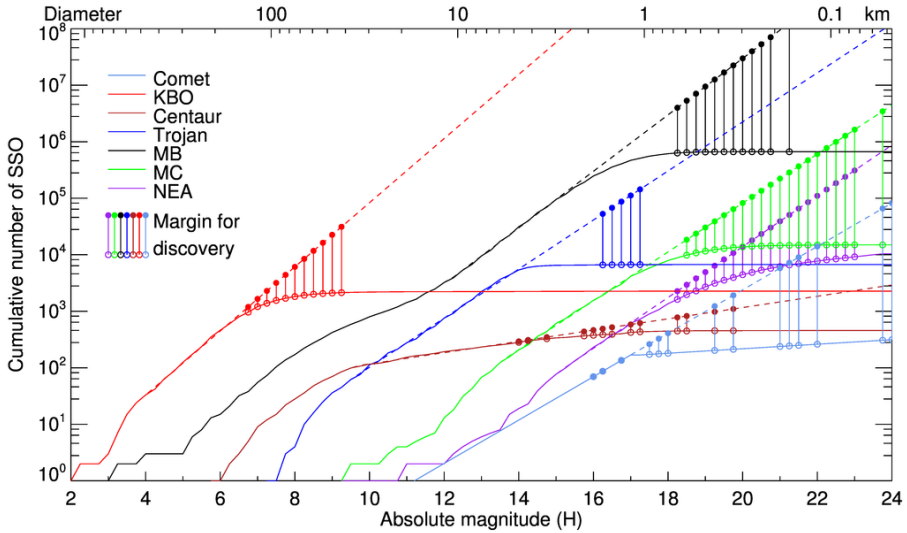


Mineralogy of SSOs

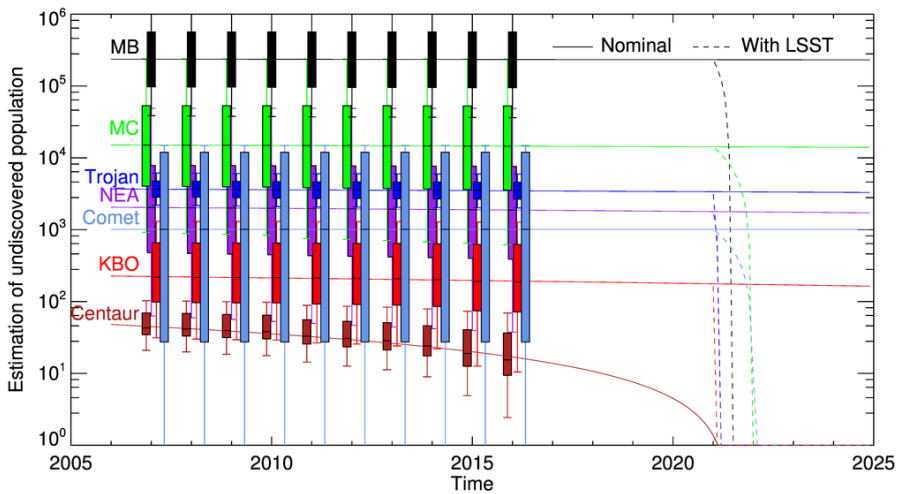
- Interest of NIR
  - Degeneration
  - Euclid VIS+NISP
  - ▷ Break degeneracy
- Euclid simulation
  - 371 known spectra
  - Convert to Euclid
  - Cluster analysis
- Success rate estimate
  - C/X are tough
  - 70+% success rate
  - ▷ Learning sample!



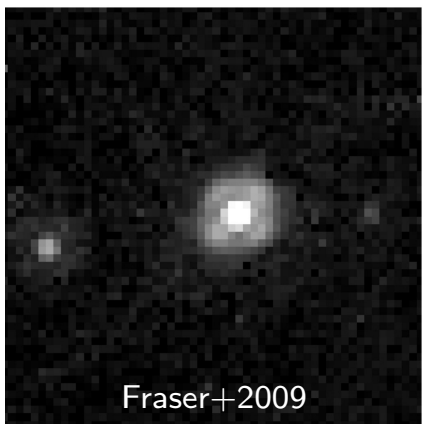
A HST-like (trailed) PSF

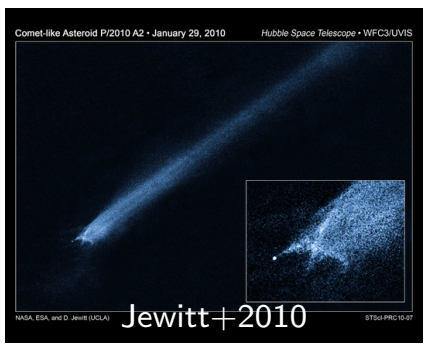


1. Discovery potential
   - KBOs
   - Comets
   - High-inclined SSO
   - Transients



A HST-like (trailed) PSF

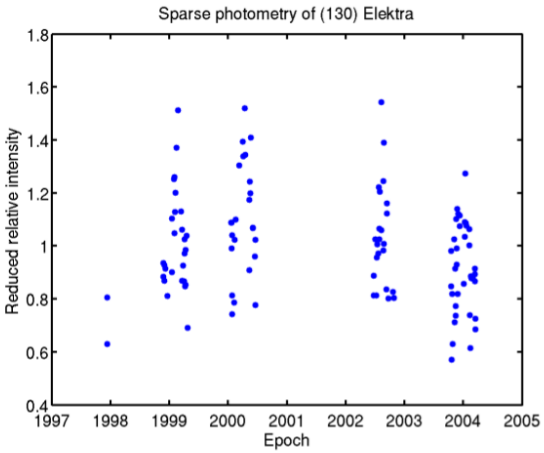


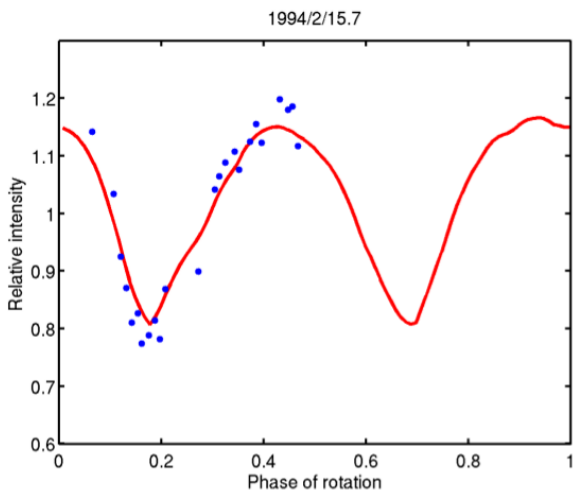


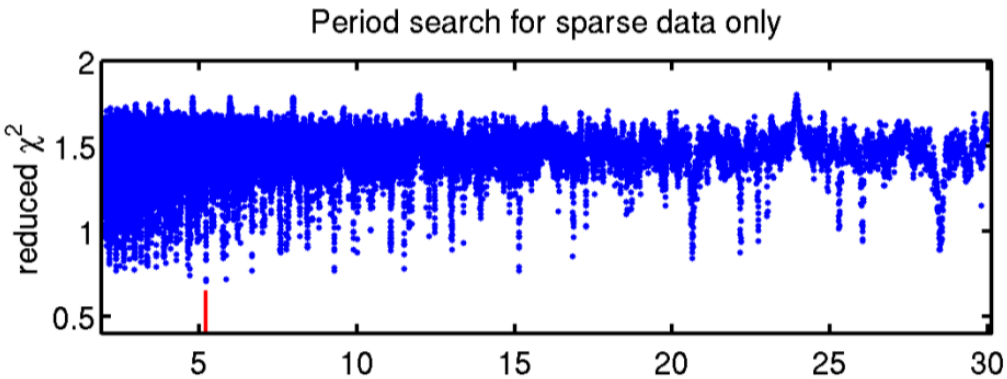
1. Discovery potential
   - KBOs
   - Comets
   - High-inclined SSO
   - Transients

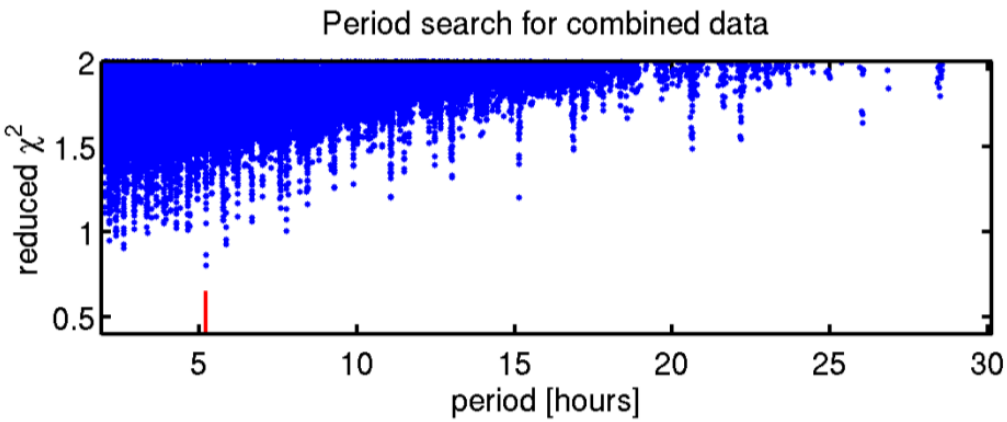
2. Source analysis
   - Binaries
   - Comets
   - Active asteroids

Euclid lightcurves of SSOs



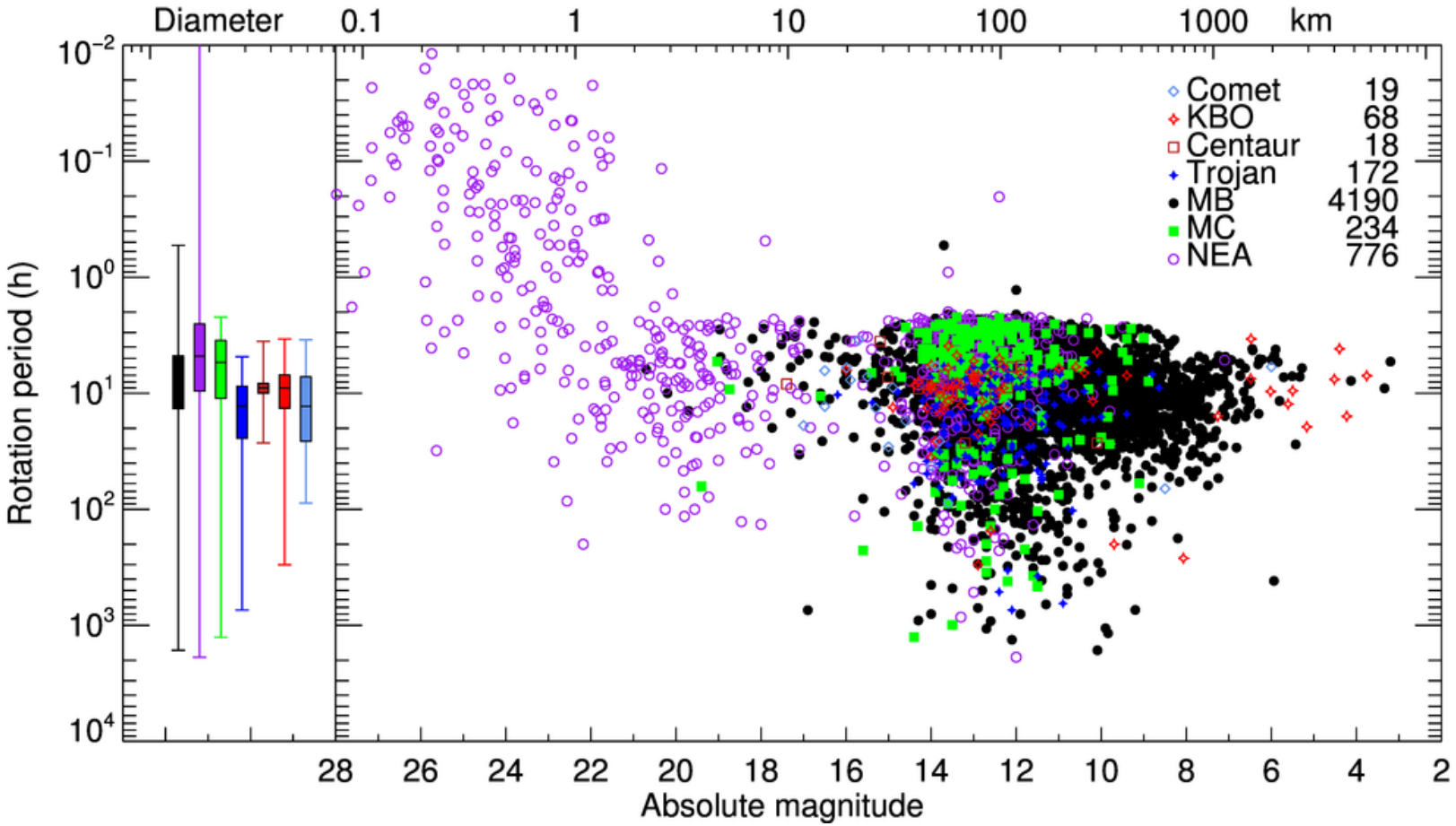






J. Durech (2010)

Euclid lightcurves of SSOs



$\Rightarrow$ Euclid will sample 5–40% of rotation period

3-D shape modeling & binarity

Summary

- Euclid will observe a few 10^5 SSOs in 6 years
  - Down to mag 24.5
  - VIS-Y-J-H filters
- Exquisite PSF stability and angular resolution
  - Discovery, astrometry, orbits
  - Binarity and activity
- Short lightcurves from repeated observations
  - One-hour sequence $\rightarrow$ 5–40% period coverage
  - Binary mutual events & 3-D shape modeling
- Surface composition from colors and spectra
  - Near-infrared complement to visible from Gaia/LSST
  - Great potential for study of composition