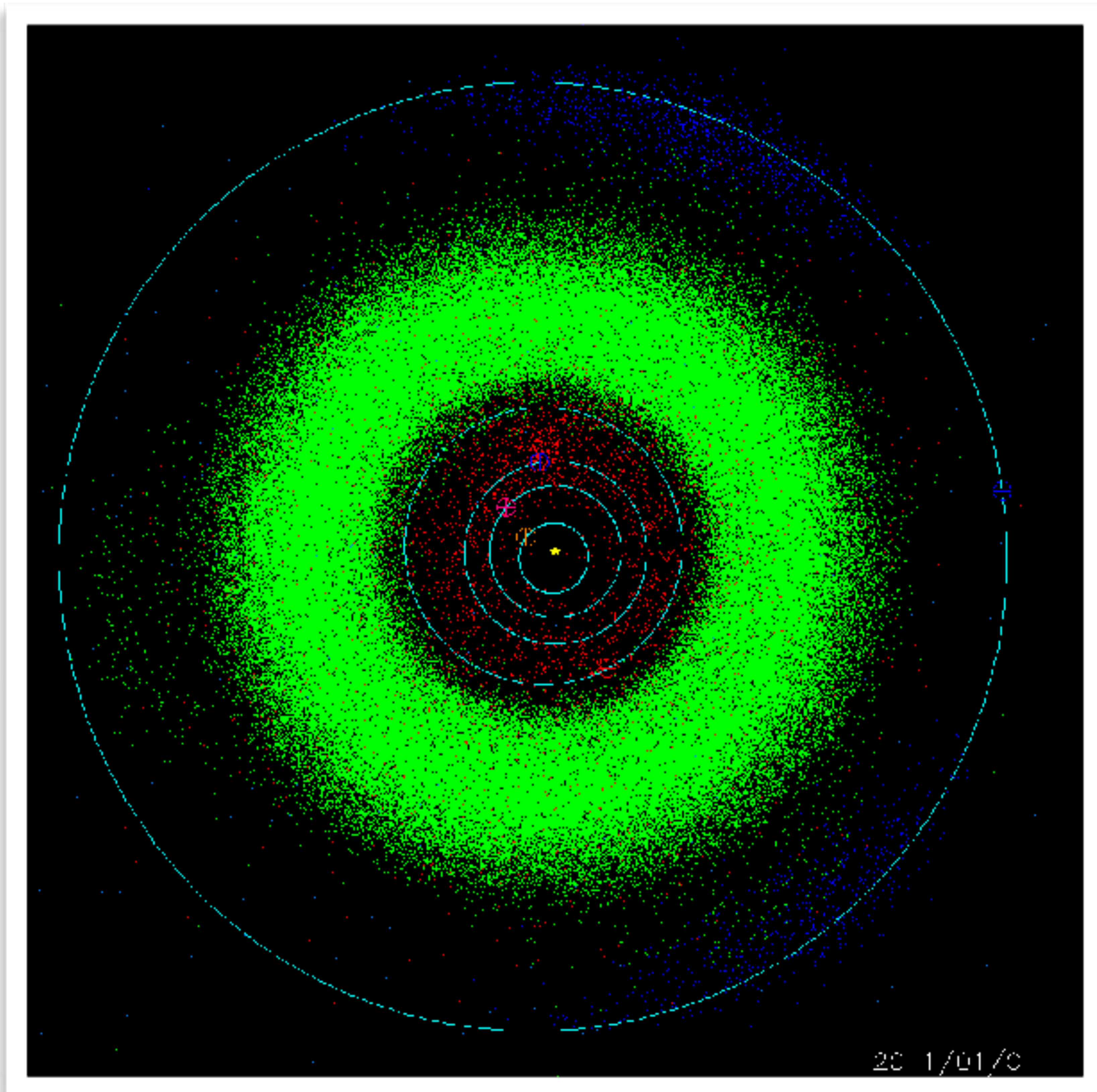
UK LSST Solar System Science
Looking ahead to Phase B

Wes Fraser, Alan Fitzsimmons, Dave Young

(Astrophysics Research Centre QUB)

and the SSSC

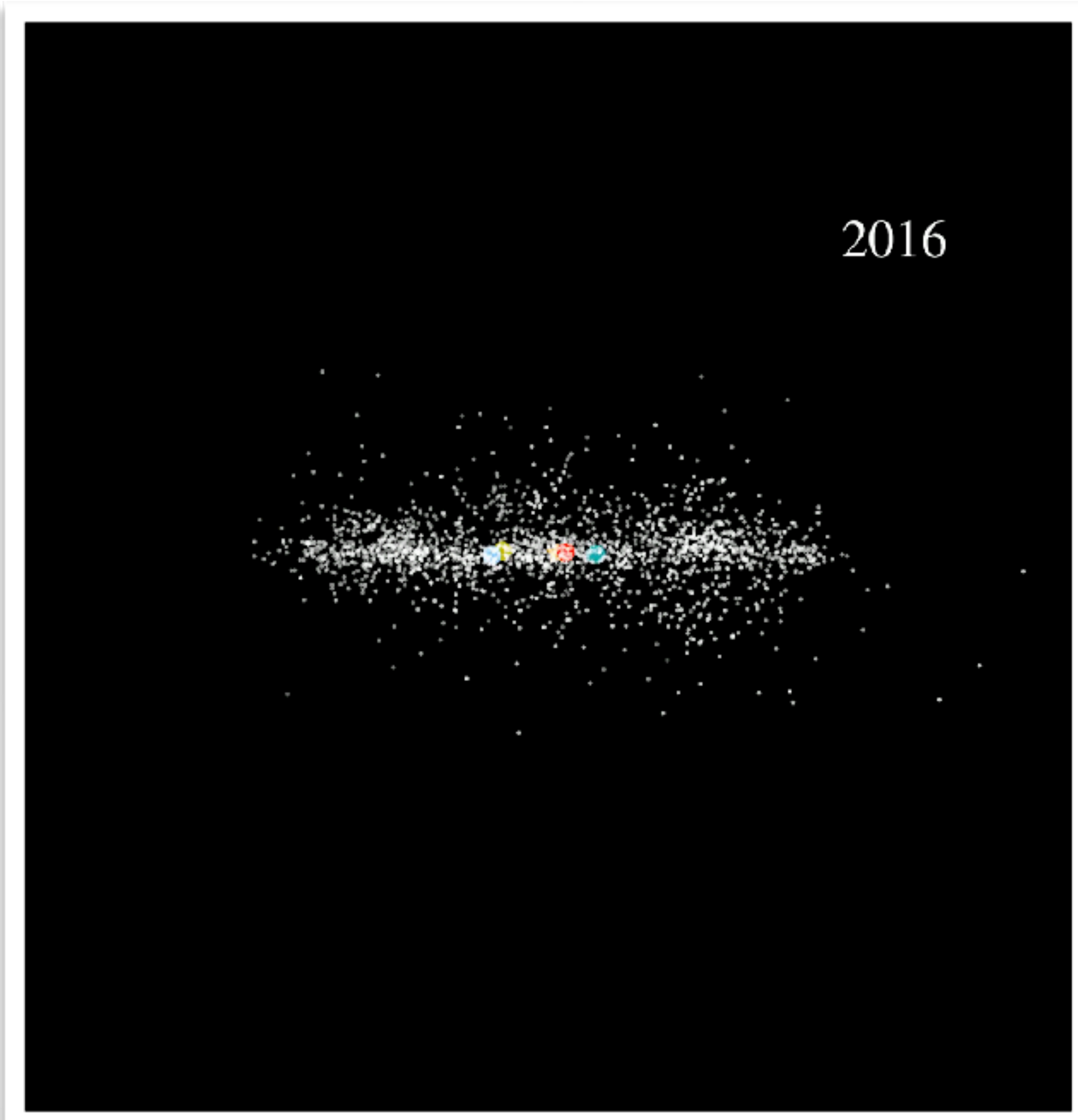
Inner Solar System



>700,000 asteroids (green)

Courtesy of the Minor Planet Centre

Outer Solar System



~1,800
KBOs

LSST Data Products

By 2022 we will have:

- Accurate orbits allowing complex dynamical studies from GAIA to mag~20
- An effectively complete inventory of the Solar system down to r mag~21 (ignoring comets!)

LSST will push down to r mag~24.7, factor ~5 smaller in diameter, factor ~10 increase in number

Diameters for Completeness	GAIA Orbits	Pre-LSST orbits and magnitudes	LSST orbits and magnitudes
Inner asteroid belt	~1.1km	~0.5km	**~0.1km**
Kuiper-Belt	~860km	~340km	**~70km**

Level 1 Data Products will provide identification, photometry and orbits for *SSObjects* (~4,000 objects per exposure at r~24.5).

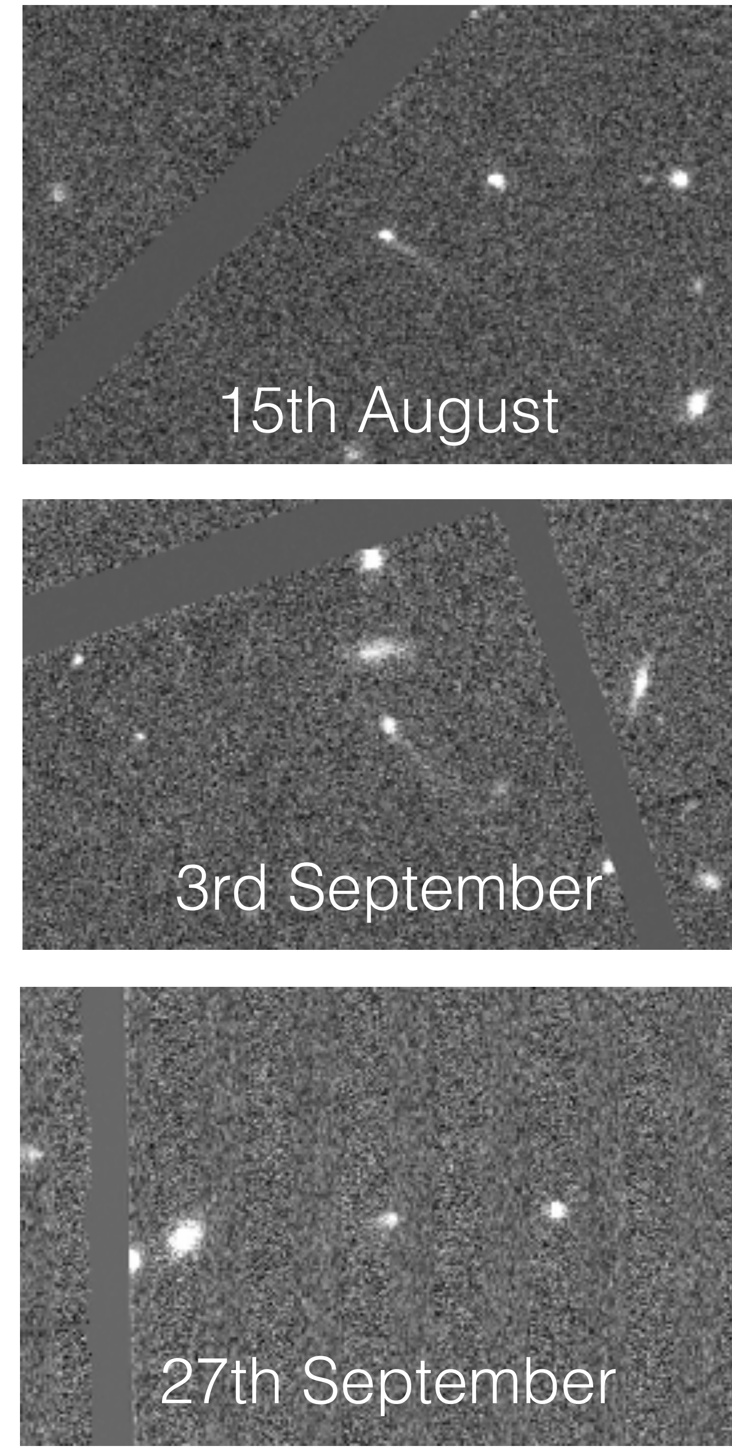
Primary UK science goals and science leaders:

- Identify and study specific bodies (outer planet impactors, spacecraft mission targets etc.) –*OU, Oxford*
- Study of cometary and collisional activity – *OU, Belfast, Kent*
- Dynamics of outer solar system - *Belfast*
- Colours/spectra of outer solar system populations – *Belfast*
- Light-curve analysis of sub-populations (shape/size/internal) – *Kent, Belfast, Armagh*

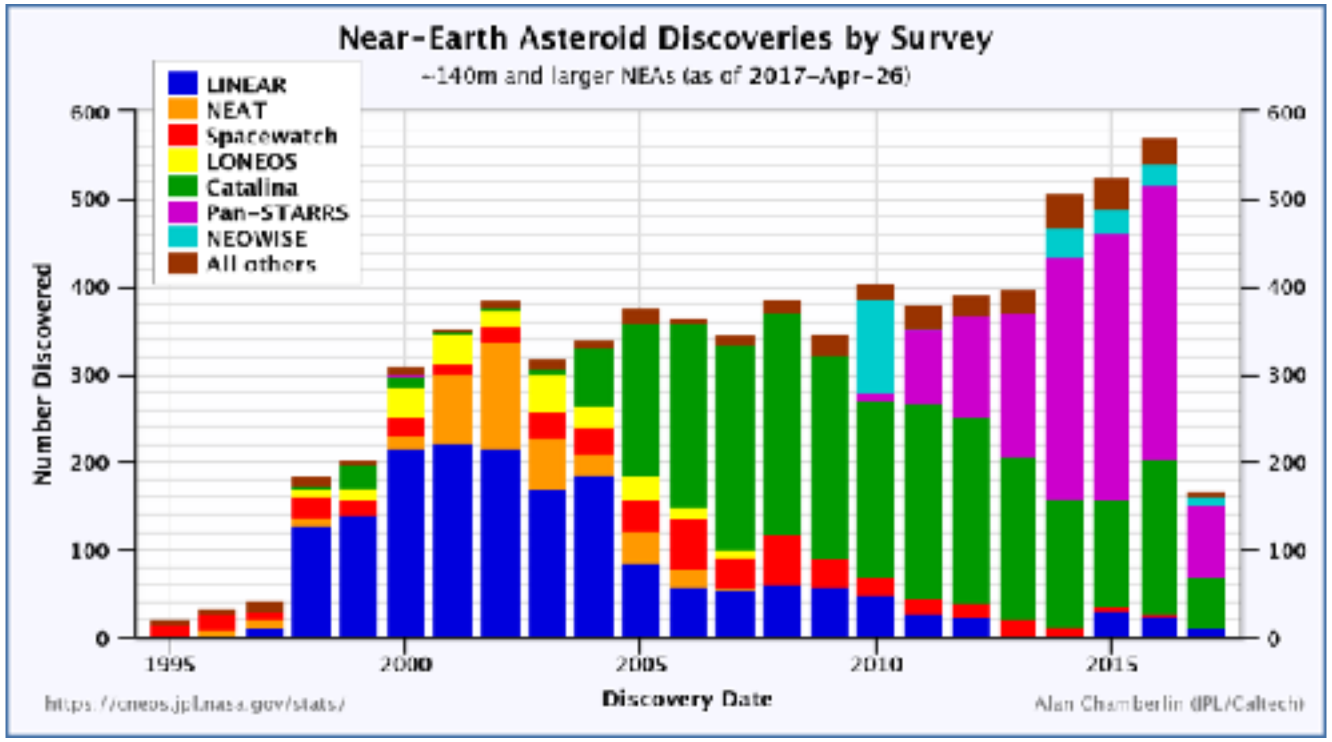
Phase A funding:

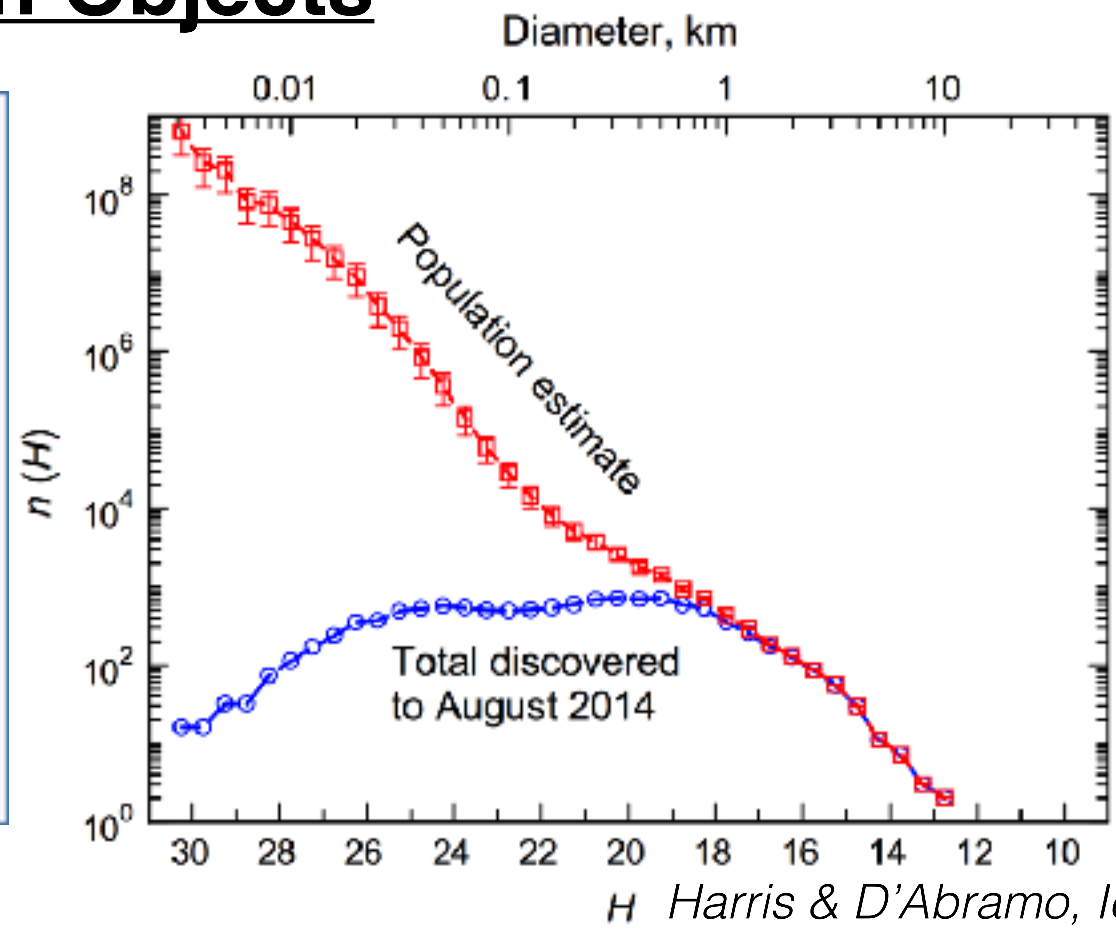
- Automated stacking and analysis of moving objects.
- Light-curve analysis of moving objects to identify activity/collisions.

Active Asteroid
P/2013 P5 PANSTARRS

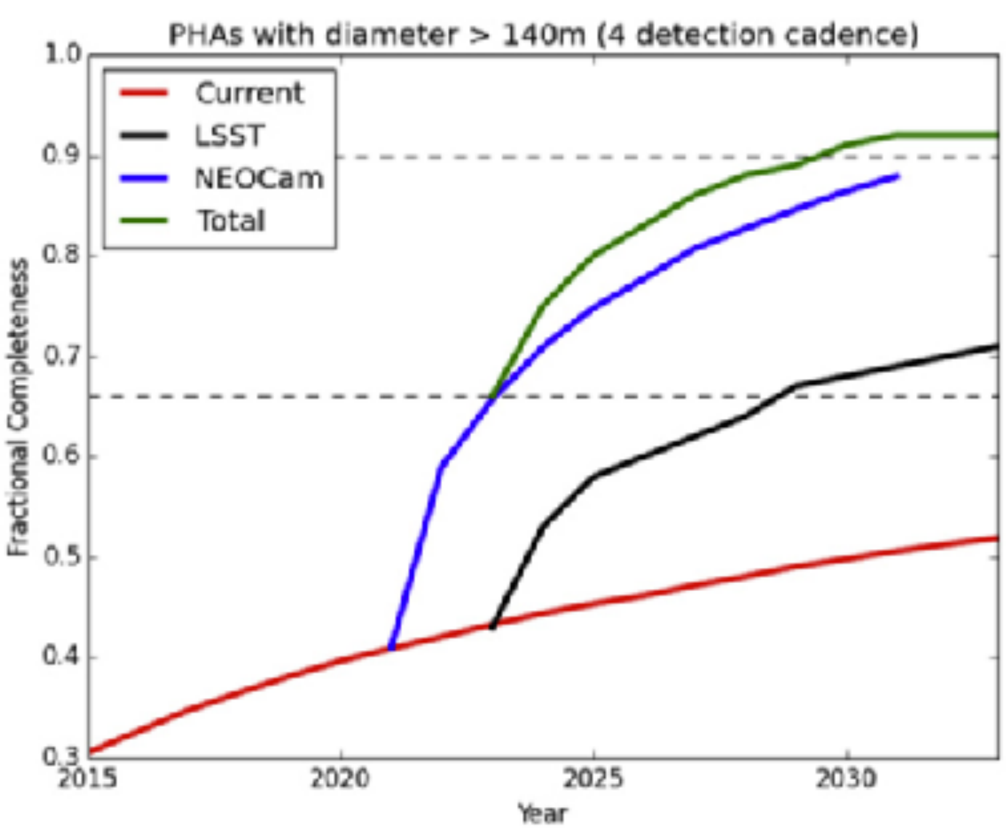


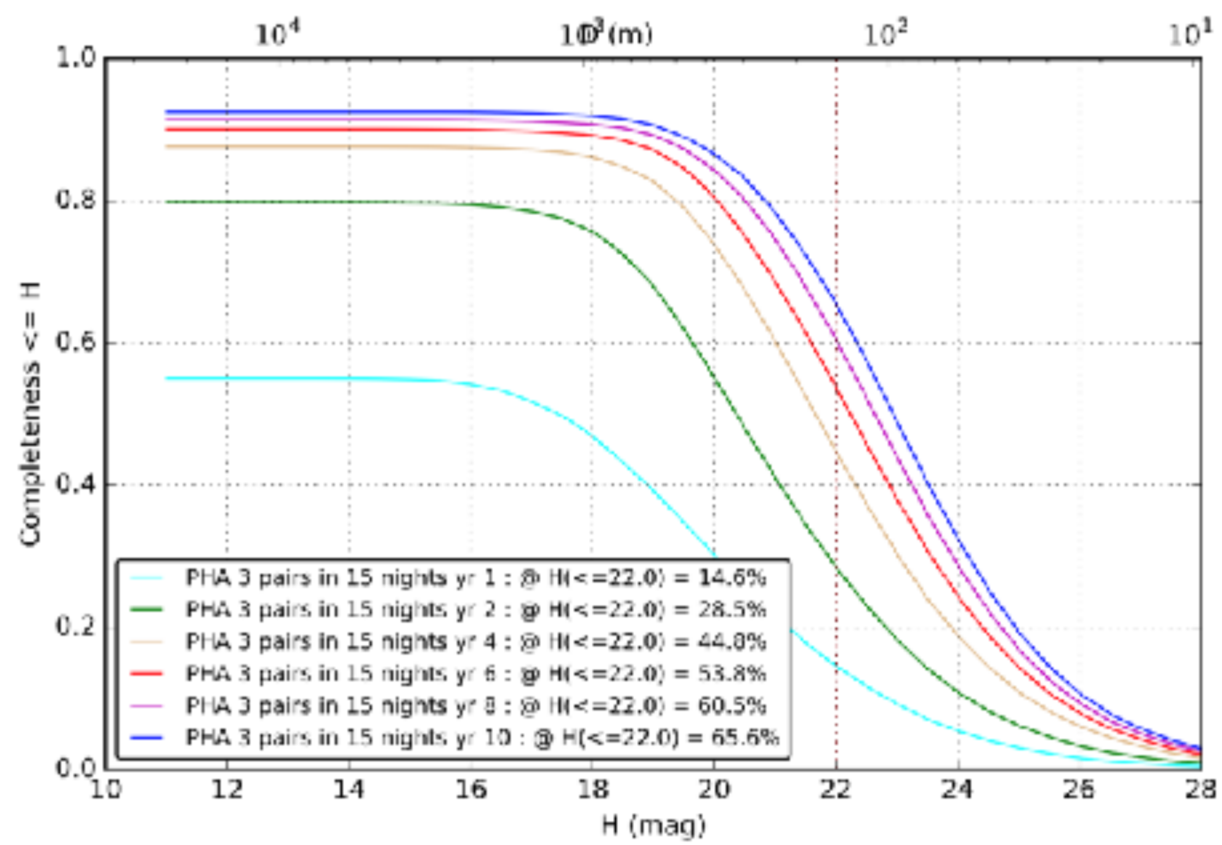
Near-Earth Objects





Harris & D'Abramo, Icarus, 2015

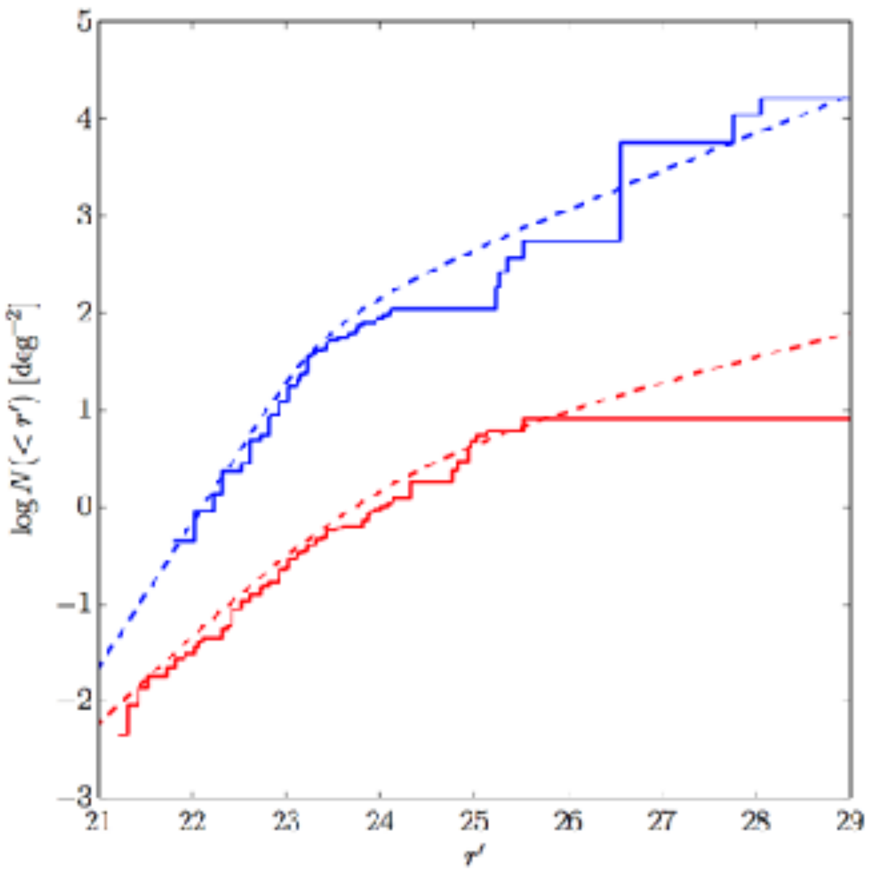




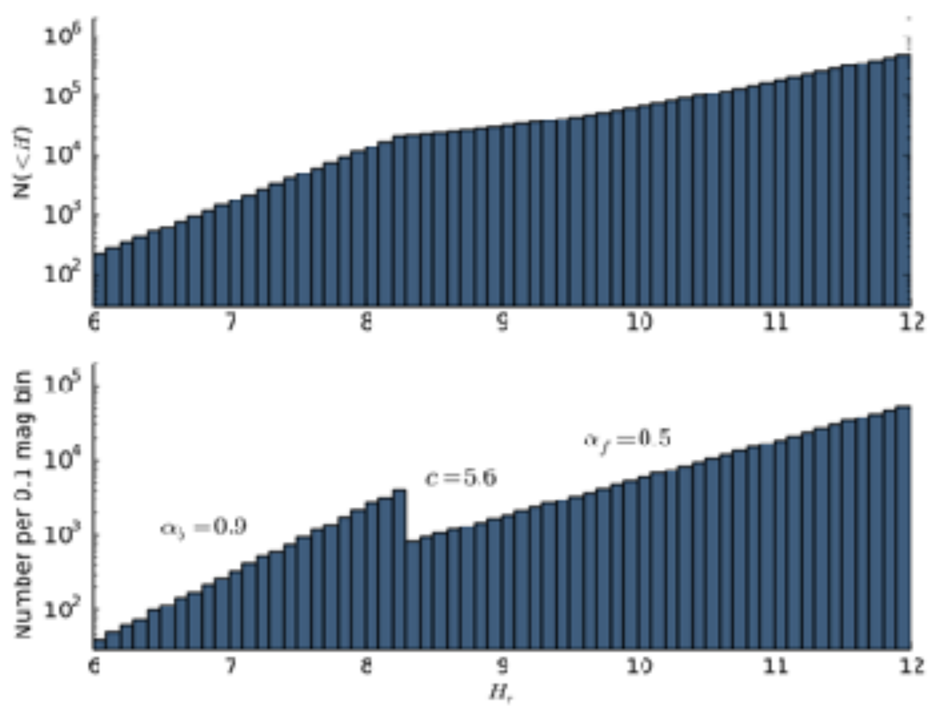
Grav et al., AJ, 2016

Ivezic & Jones, Observing Strategy White paper, 2017

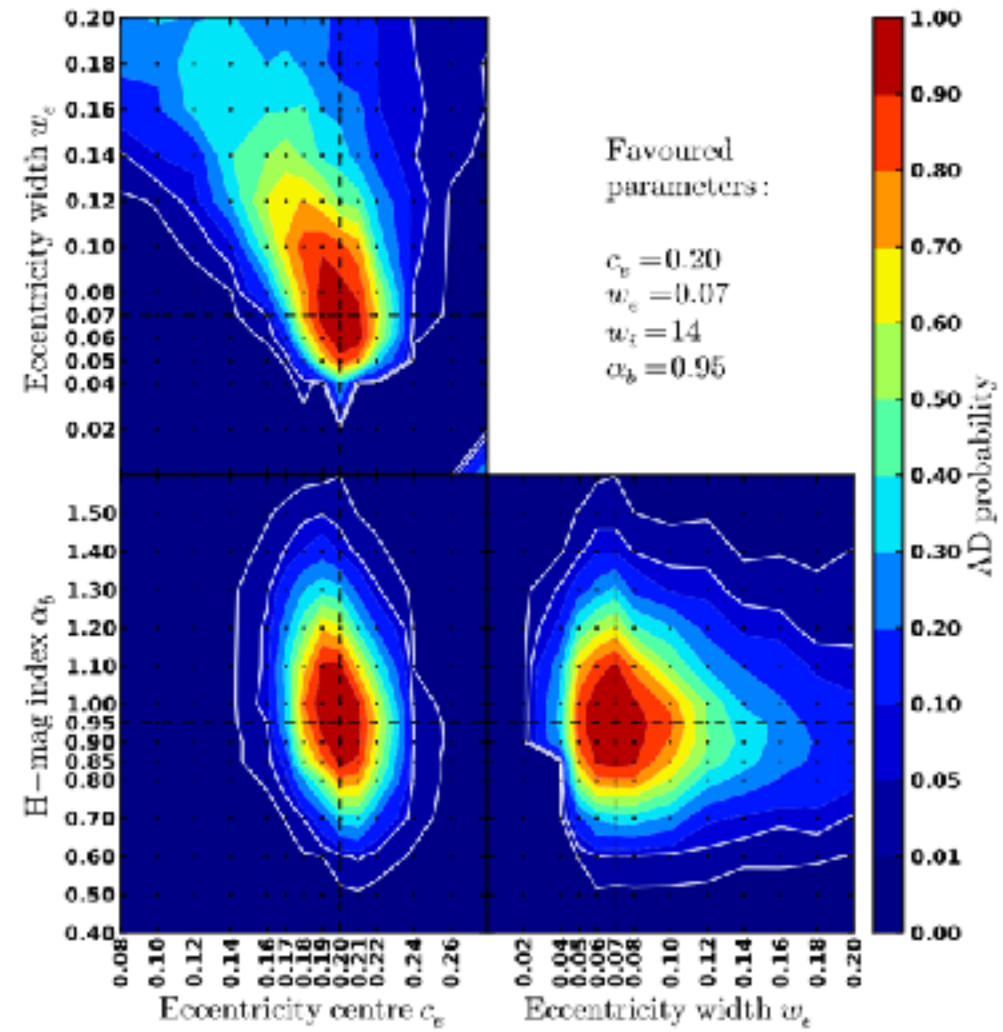
Size Distributions



Fraser et al., ApJ, 2014



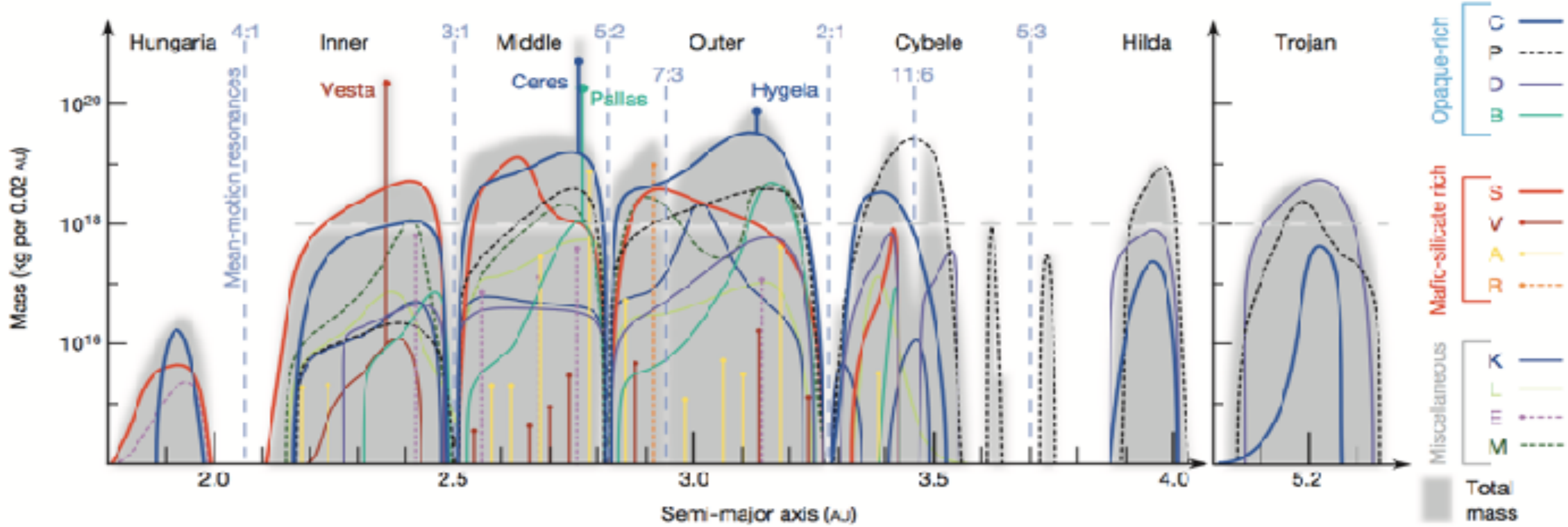
Shankman et al., AJ, 2016



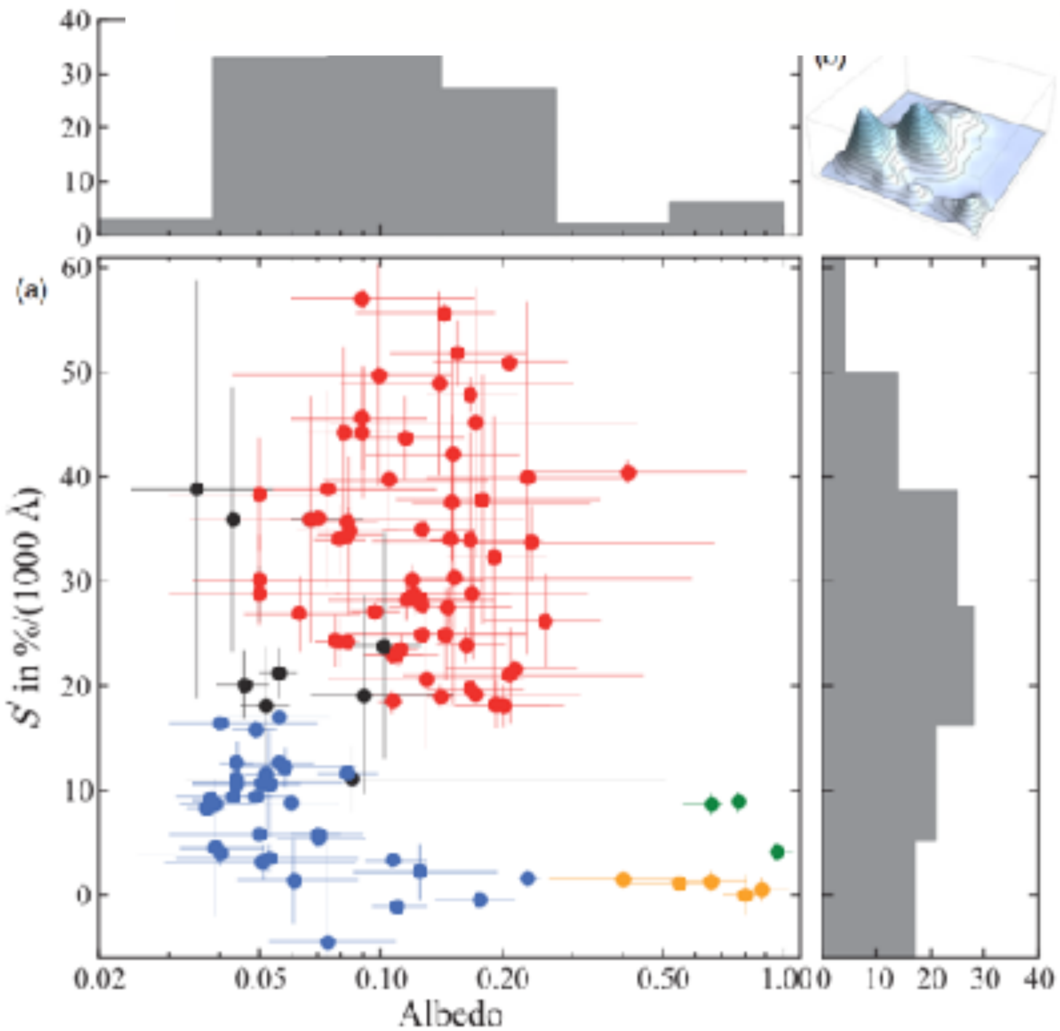
Alexanderson et al., AJ, 2014

- NEO/Main-belt size distributions.
- TNO luminosity/size distributions show breaks in the power law.
- Size distributions a function of dynamical class.
- Heavy UK involvement in this area.

Colour Taxonomies



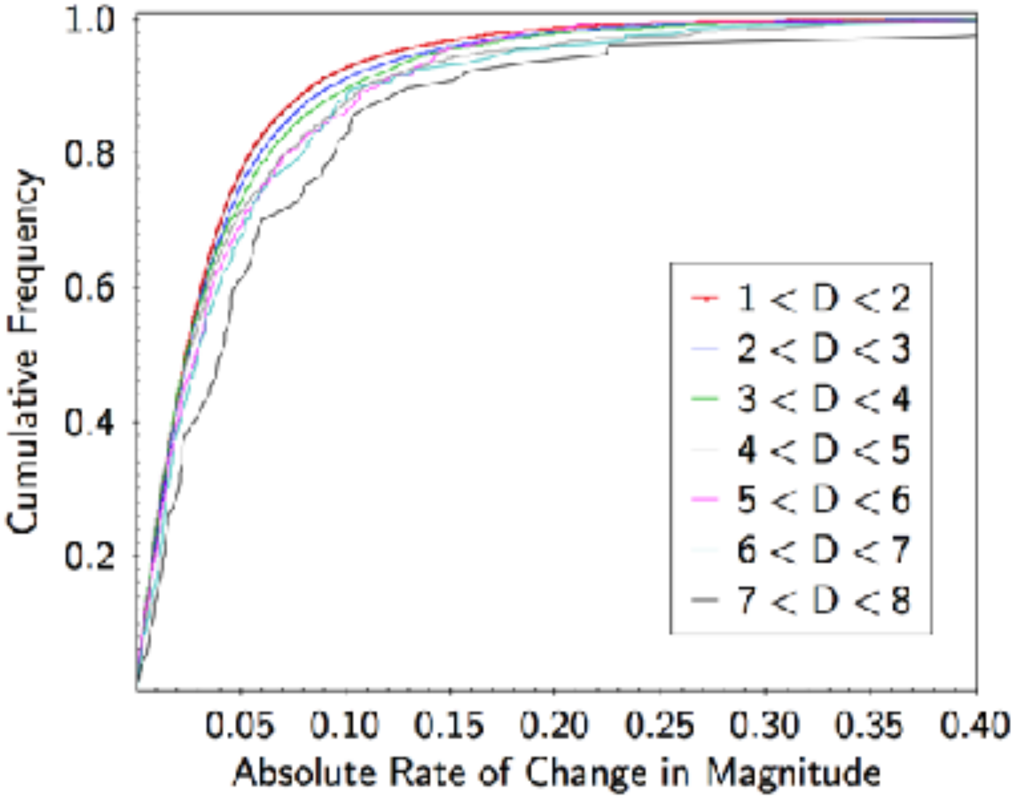
DeMeo & Carry, Nature, 2016



Lacerda et al., ApJLett, 2014

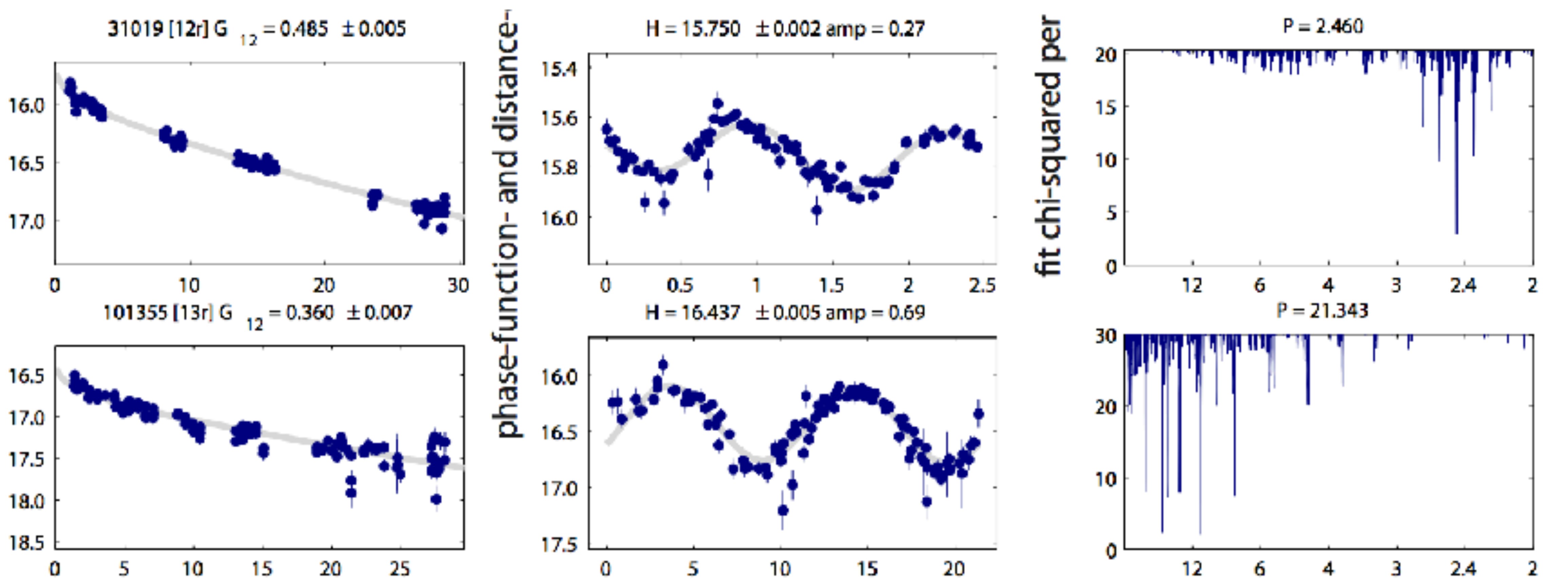
- LSST will give first colour stats throughout main-belt at D<1km.
- Sensitive to small MBA space weathering, evolution due to Yakovsky.
- LSST will provide large-scale colour stats for resonant, cold-classical, scattered and extreme TNOs.
- Significant UK work in outer solar system.

Sparsely Sampled Lightcurves



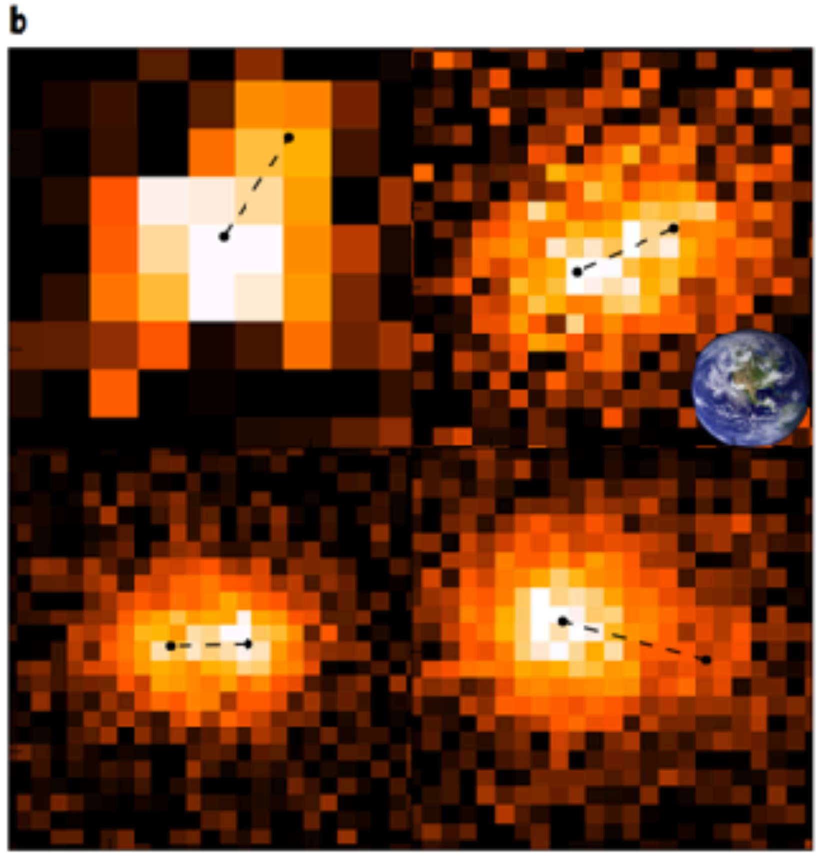
McNeill et al., MNRAS 2016

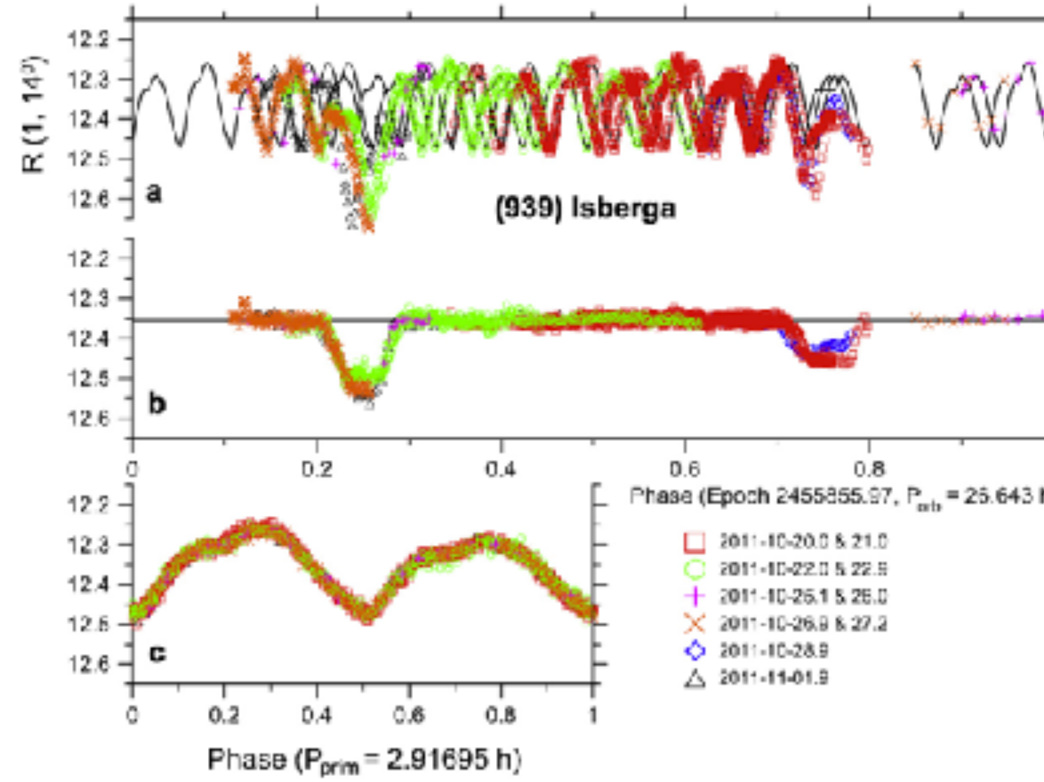
- Sparse light-curve observations give constraints on projected shape of body.
- LSST cadence will allow derivation of spin periods or tumbling states on a <u>small fraction</u> of bodies.
- 3+ years gives measurement of spin poles, allowing investigations of YORP alignment and spin-orbit resonances.



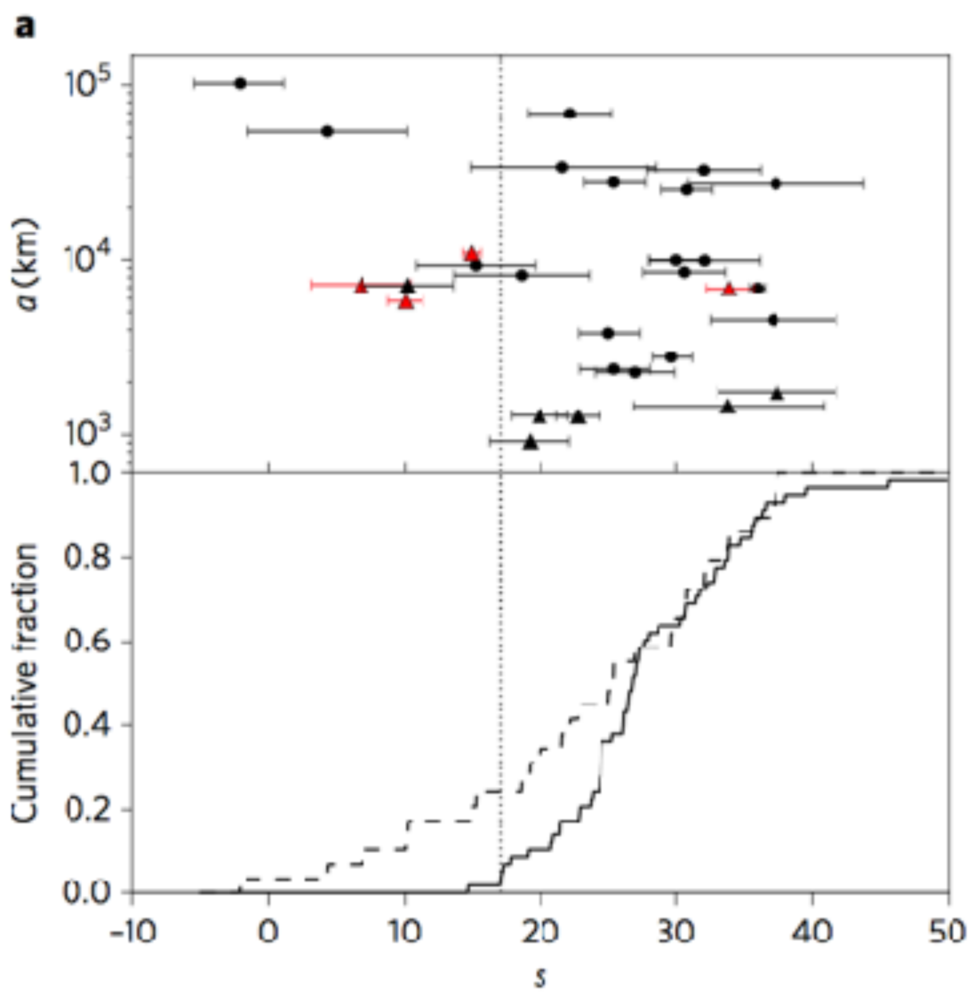
Waszczak et al., AJ ,2015

Binary Census





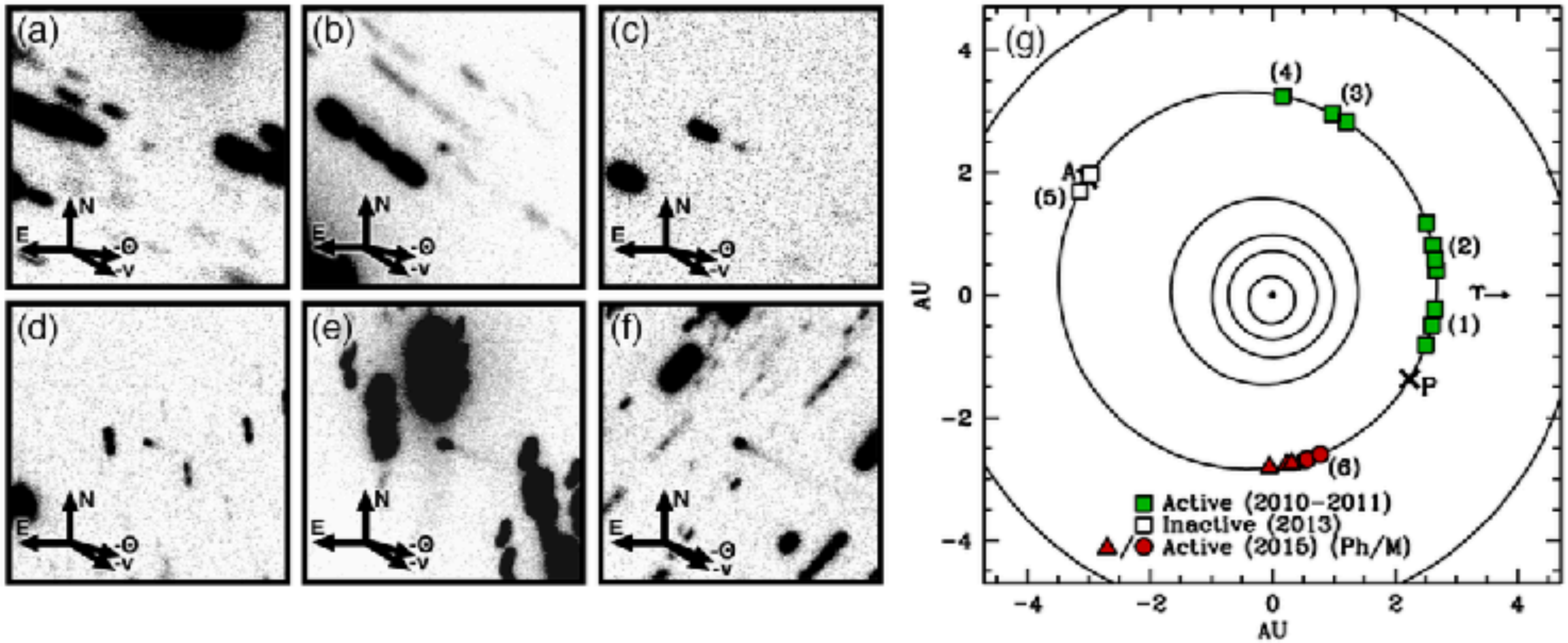
Carry et al., Icarus, 2015



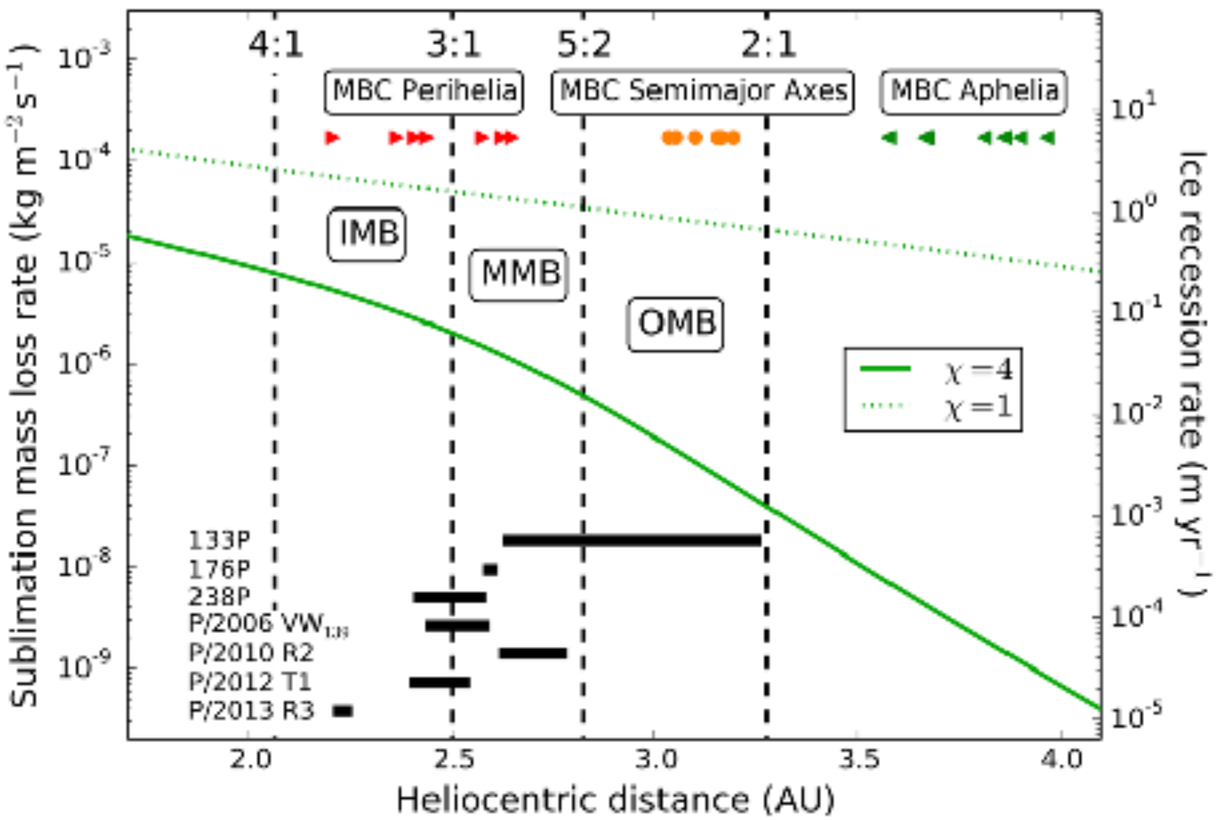
Fraser et al., Nat. Ast, 2017

- >15-20% of all TNOs are binary.
- Eclipsing binaries now common in main-belt, but rare in TNO region.
- Strong constraints on formation and evolution of the outer Solar system
- UK activity - strong in outer solar system.

Main-Belt Comets



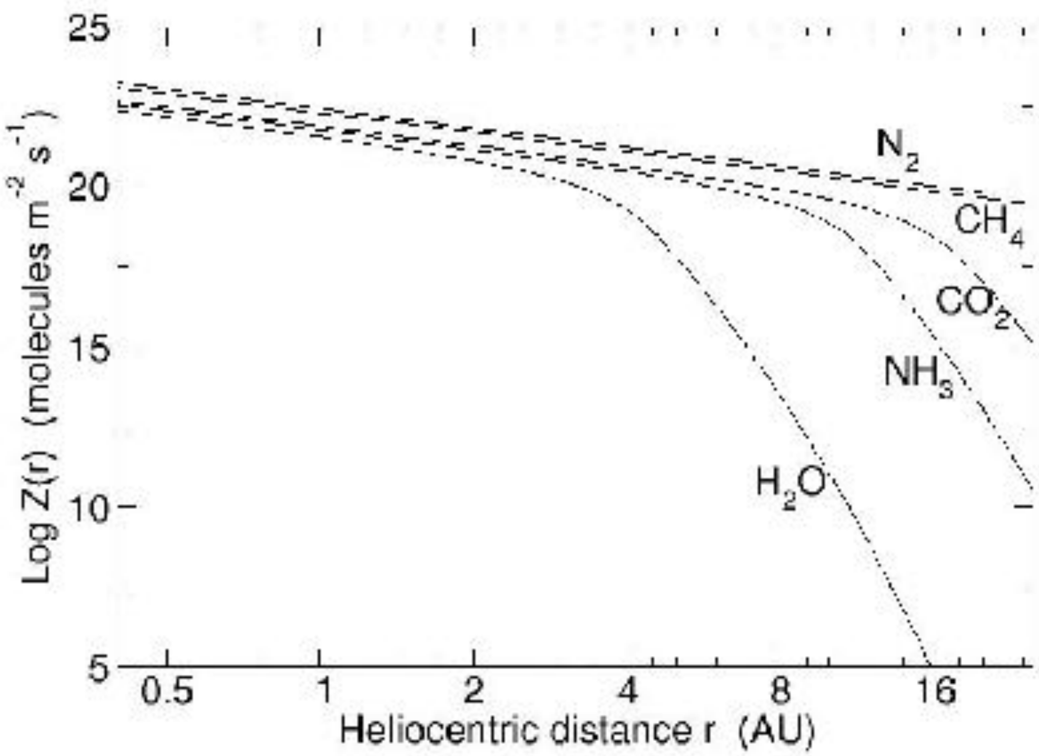
324P La Sagra: Hsieh & Sheppard, MNRAS, 2015

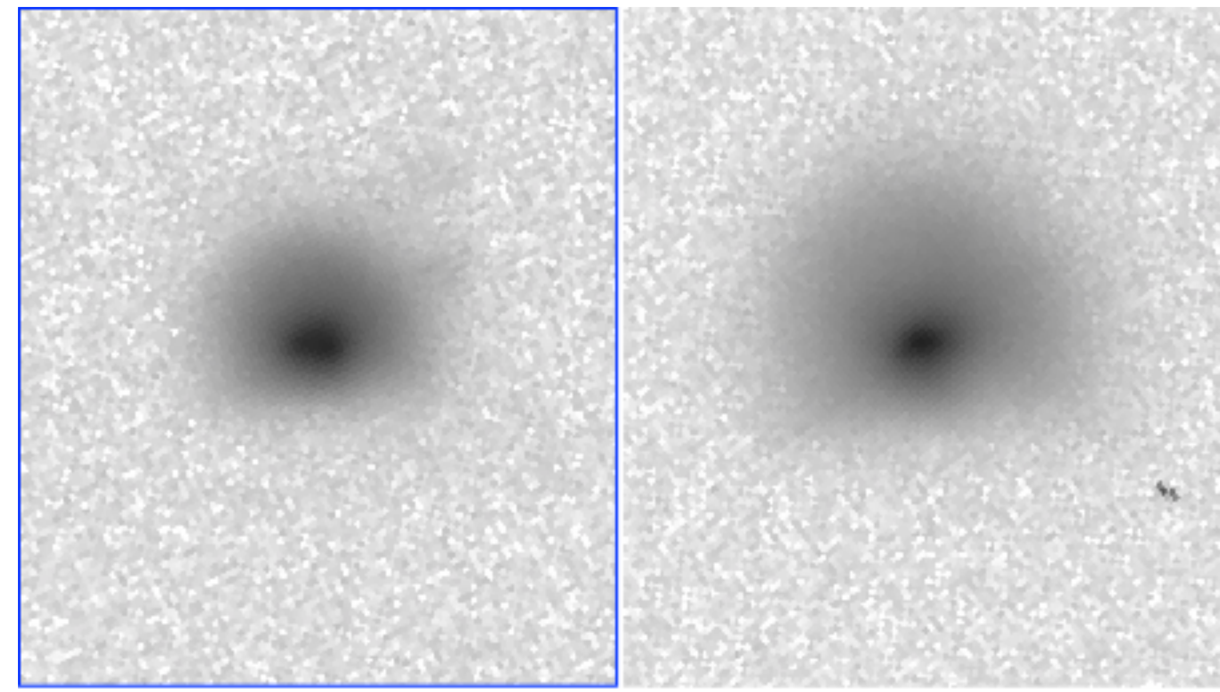


Hsieh et al., Icarus, 2015

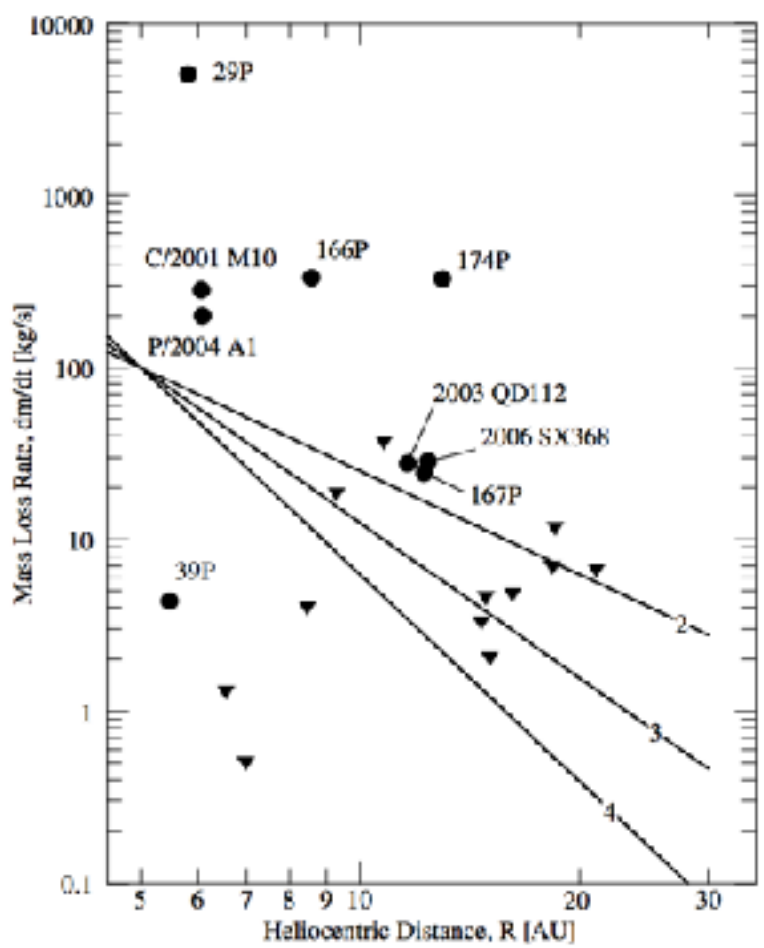
- Activity from subsurface ices (water) in outer main belt.
- important as potential source of inner Solar system water.
- ~8 currently known, ~140 extrapolated.
- Should expect large population of fainter MBCs.
- Some UK work in this area.

Solar System Activity - Ice Sublimation





Echeclus: Fitzsimmons et al., in prep, 2017

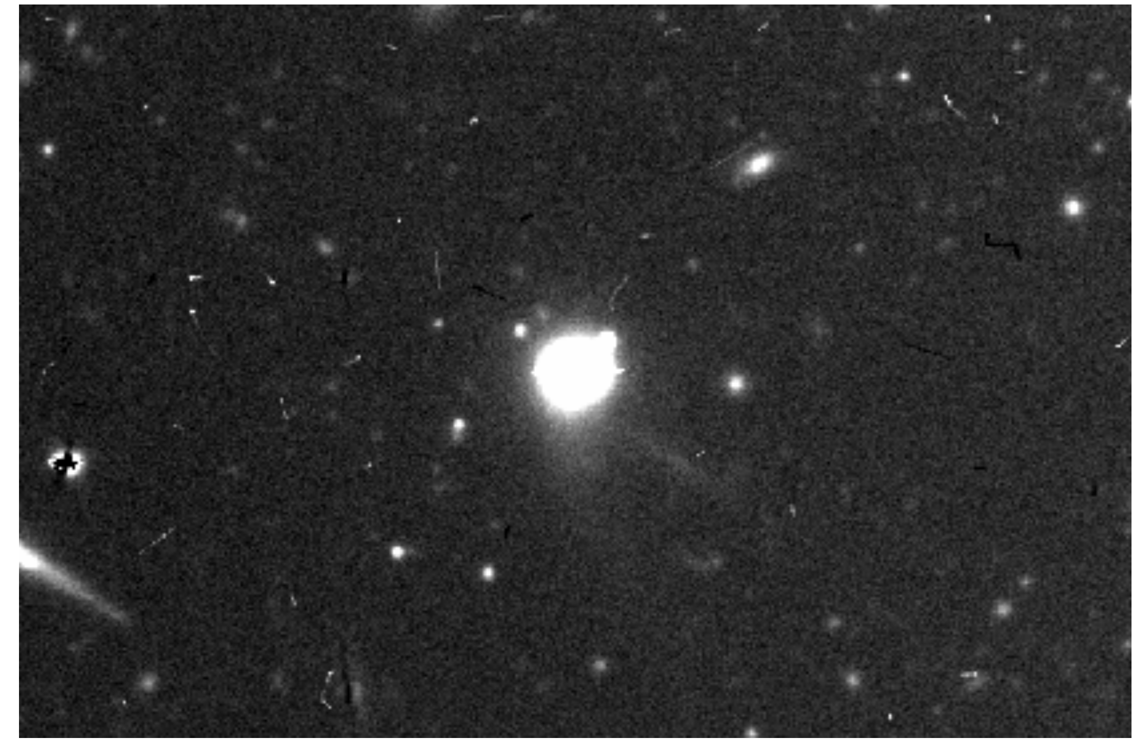


Jewitt, AJ, 2009

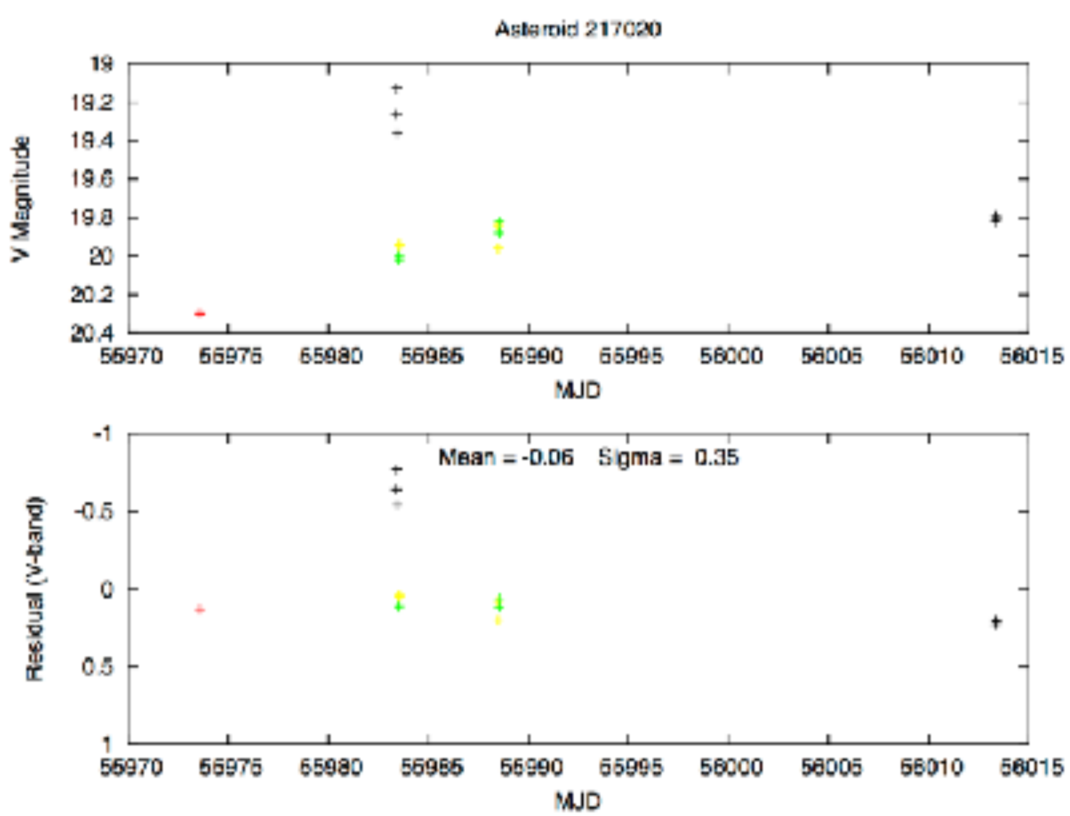
- Significant activity occurs at 5-15 AU
- Relative importance of steady-state versus outbursting mass loss unknown.
- Sublimation extends out to ~ Kuiper-Belt, but not yet seen anywhere except Pluto.
- UK activity - strong.

Solar System Activity - Collisions

P/2010 A2: Kim et al., AJ, in press 2017

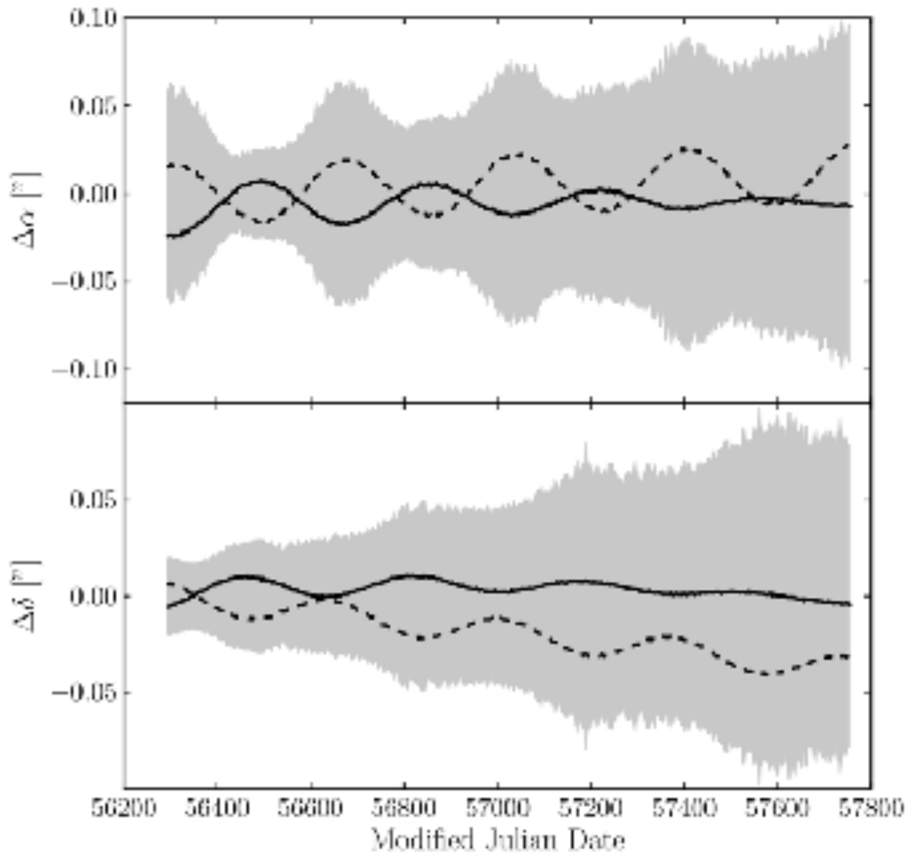


493 Griseldis: Tholen, 2015

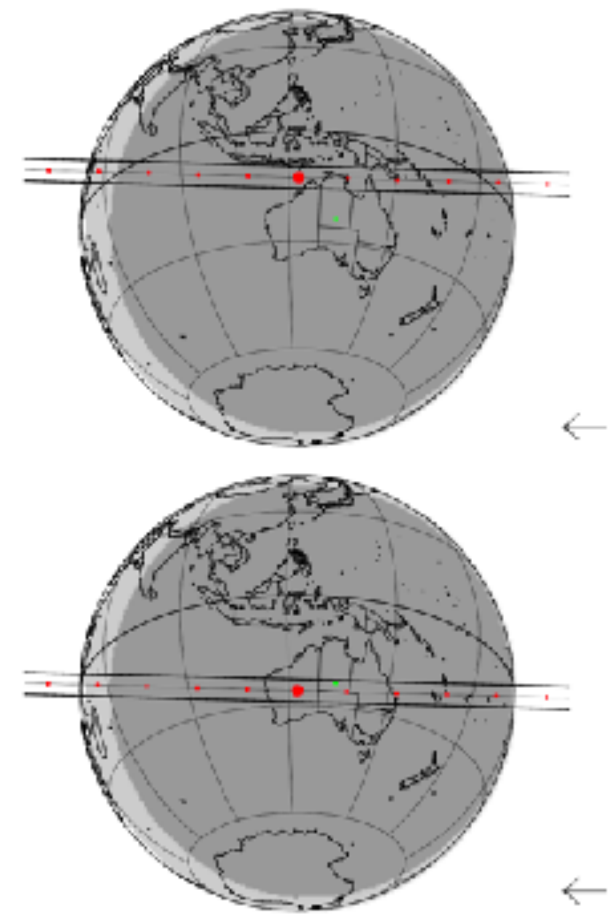


- Collisional evolution of objects now being seen in main-belt, not seen yet in outer solar system.
- Sub-critical impacts visible via brightening plus ejected debris.
- Requires good cadence, 2 out of 4 events detected significantly after collisions.
- Some UK activity.

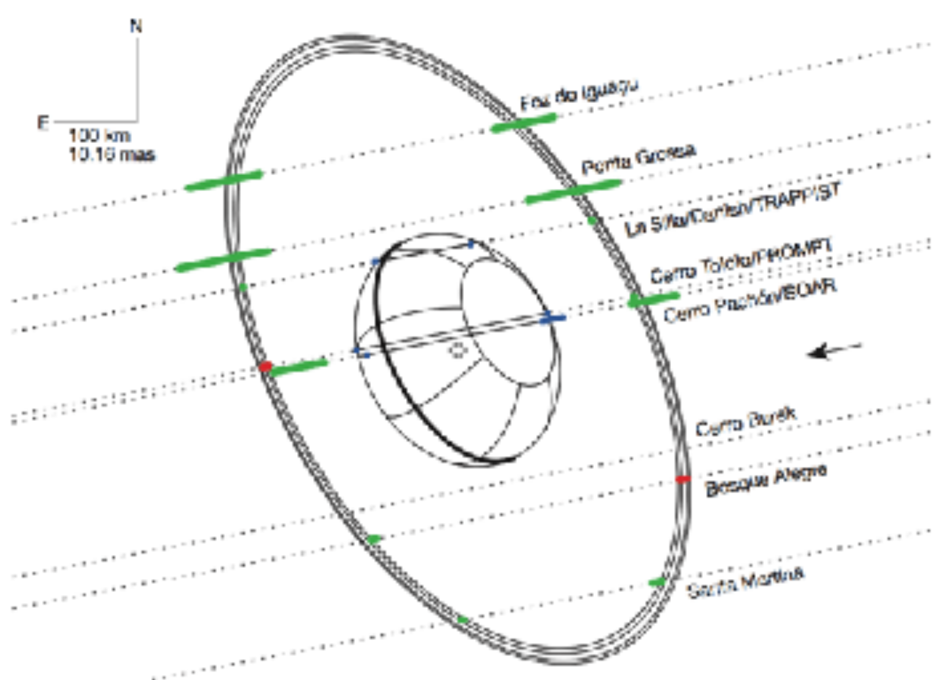
Occultation Predictions



Fraser et al., PASP, 2013



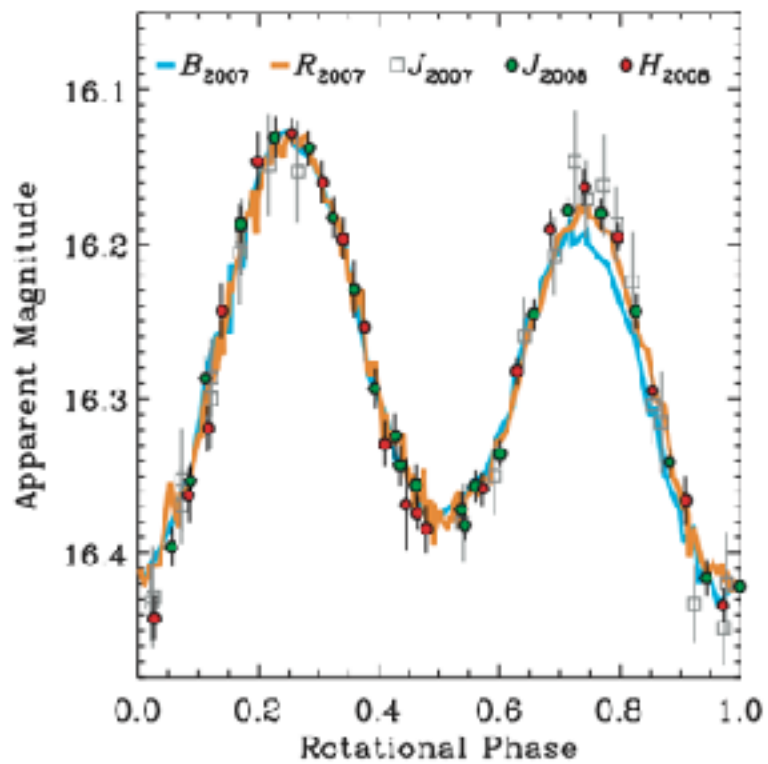
Desmars et al., A&A, 2015



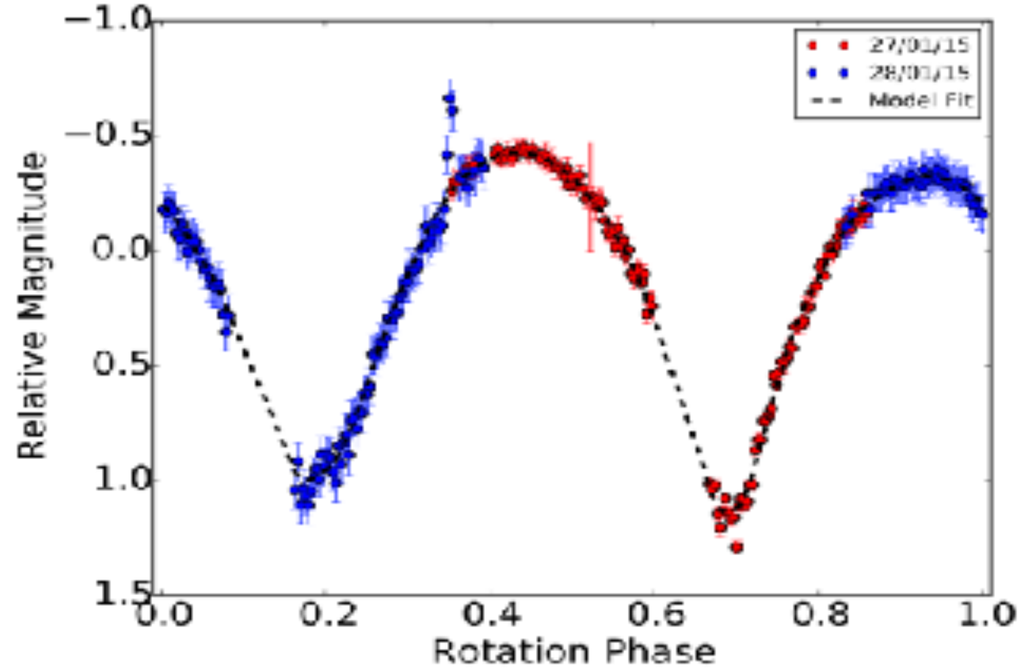
Braga-Ribas et al., Nature, 2014

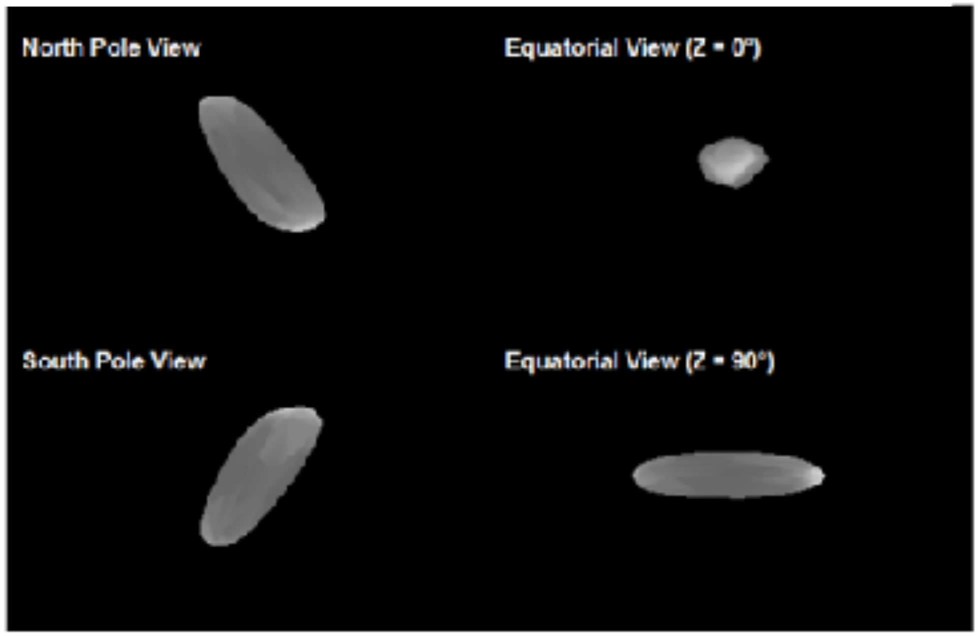
- Occultation predictions require a combination of high-accuracy and orbital modelling.
- Only method for probing sub-km scales in outer Solar system.
- Pre-imaging needed at weeks - months.
- Will open up occultation science to a wide community of planetary scientists.

Extreme Objects - "Oddballs"

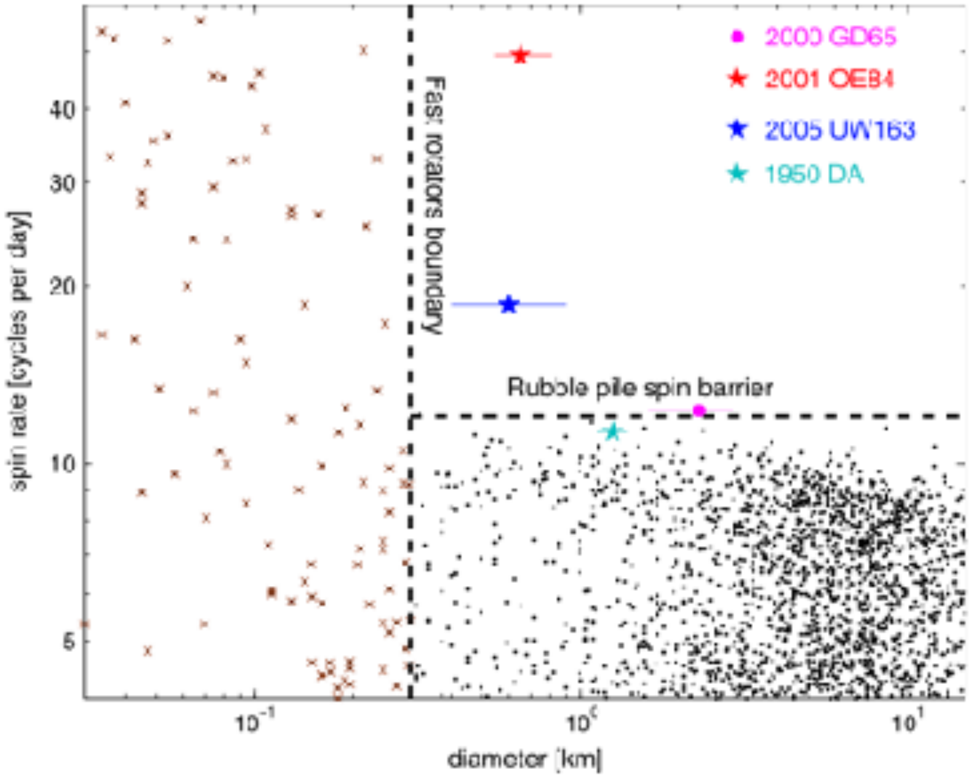


Haumea: Lacerda, AJ, 2009





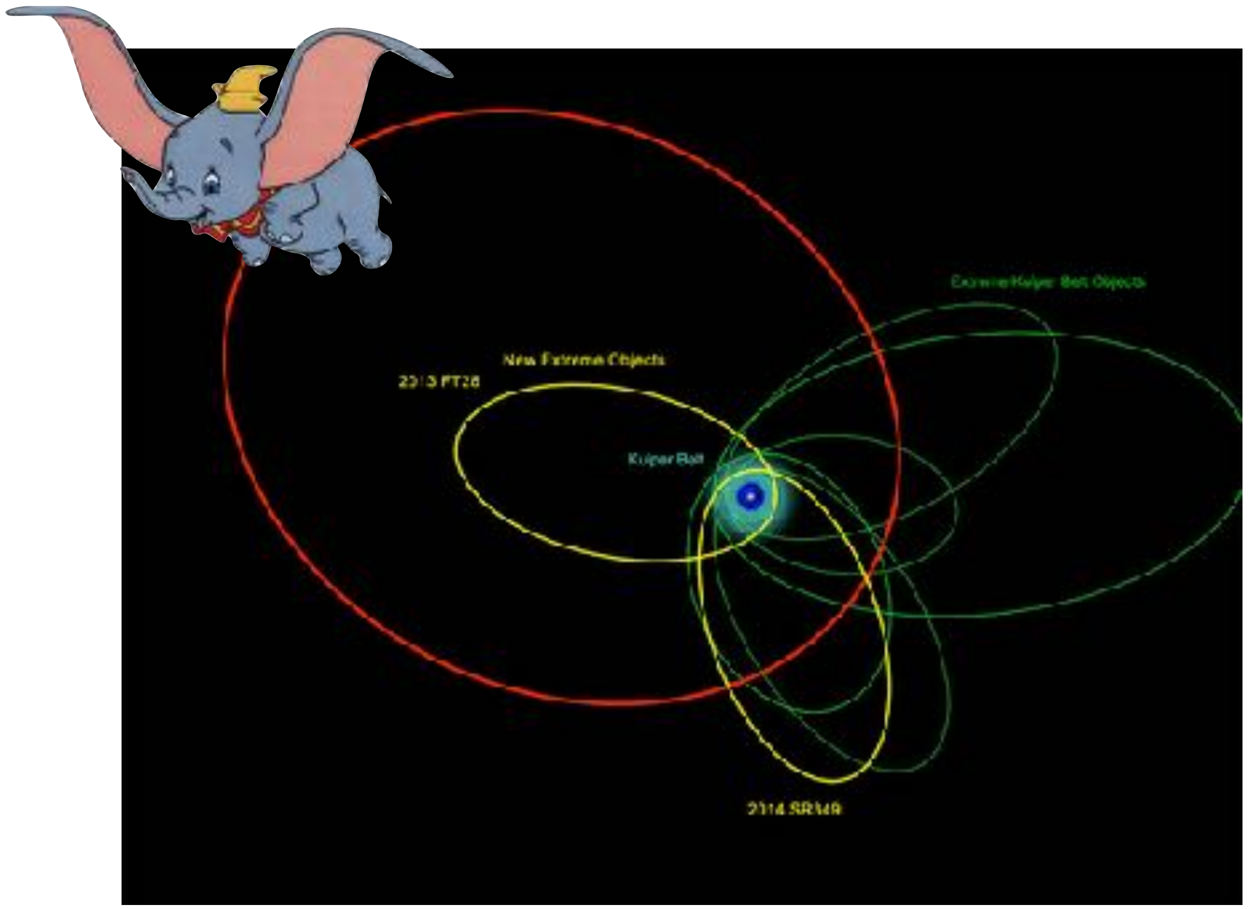
McNeil et al., in prep, 2017

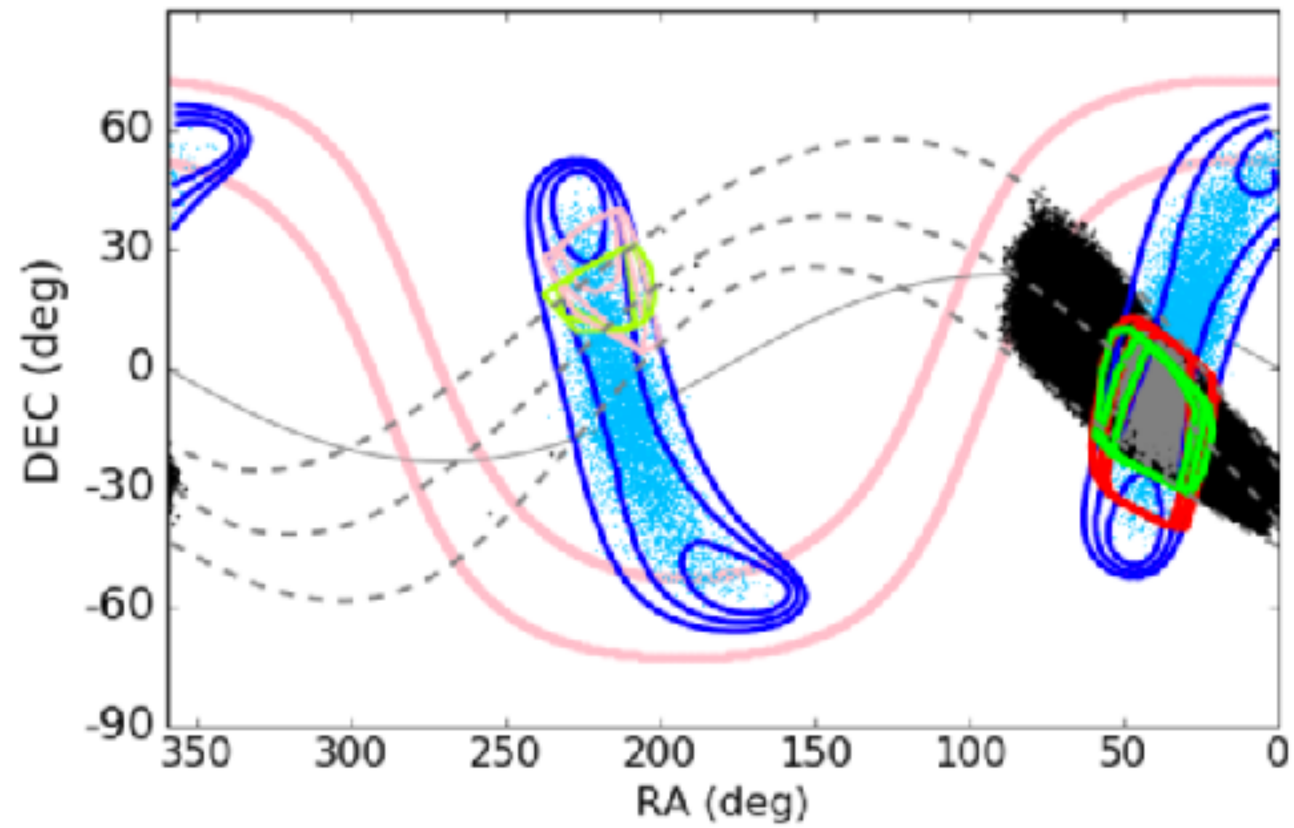


Polishook et al., Icarus, 2016

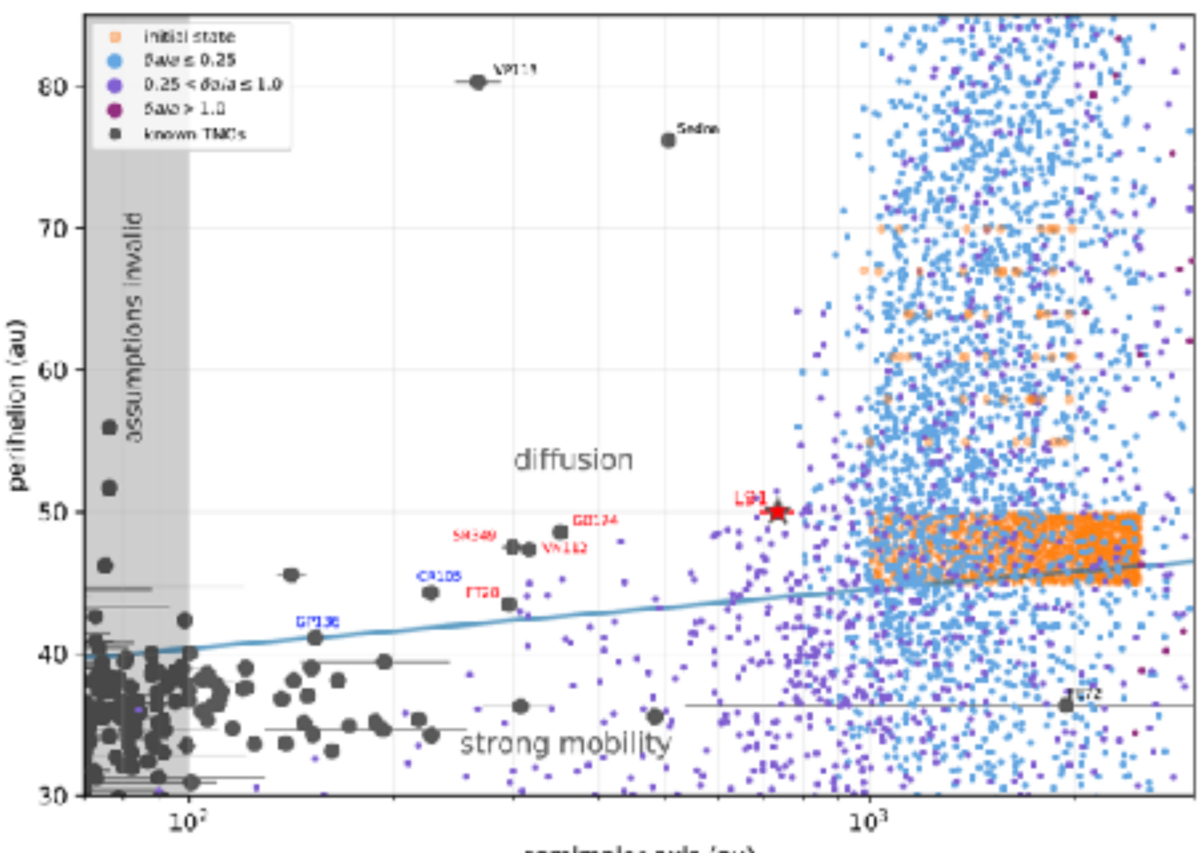
- Identification of extreme elongations, contact binaries, super-fast rotators, YORP targets.
- Exploration of collisional processes and internal structure.
- Significant UK work in this area.

Planet "9": The Elephant in the Room





Planet 9 search regions: Holman & Payne, AJ, 2016



2013SY99: Bannister et al., ApJ, 2017

- Planet 9 could fall out in the 1st year of LSST operations (if it exists).
- Extreme (orbit) TNOs are critical for constraining history of outer Solar system.
- Significant UK work in the study of extreme TNOs.

Current Activities

- Shift'n'stack (Alan Fitzsimmons, Dave Young - QUB)
  - stacking across 1-2 lunation's
  - search for activity, secondary objects, etc.
  - practice on ATLAS
- Light/Phase Curves (QUB)
  - generate an automated system with methods not utilized inside L1/2
- Cutouts database and L3 integrations system (Henry Hsieh - LPI)
- MOPS-specific alerts brokerage (ROE)
- Trailed object photometry techniques (Wes Fraser - QUB)
- Collaboration communications and website (Wes Fraser, Meg Schwamb, David Trilling)