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Probing the drives of activity in Centaurs

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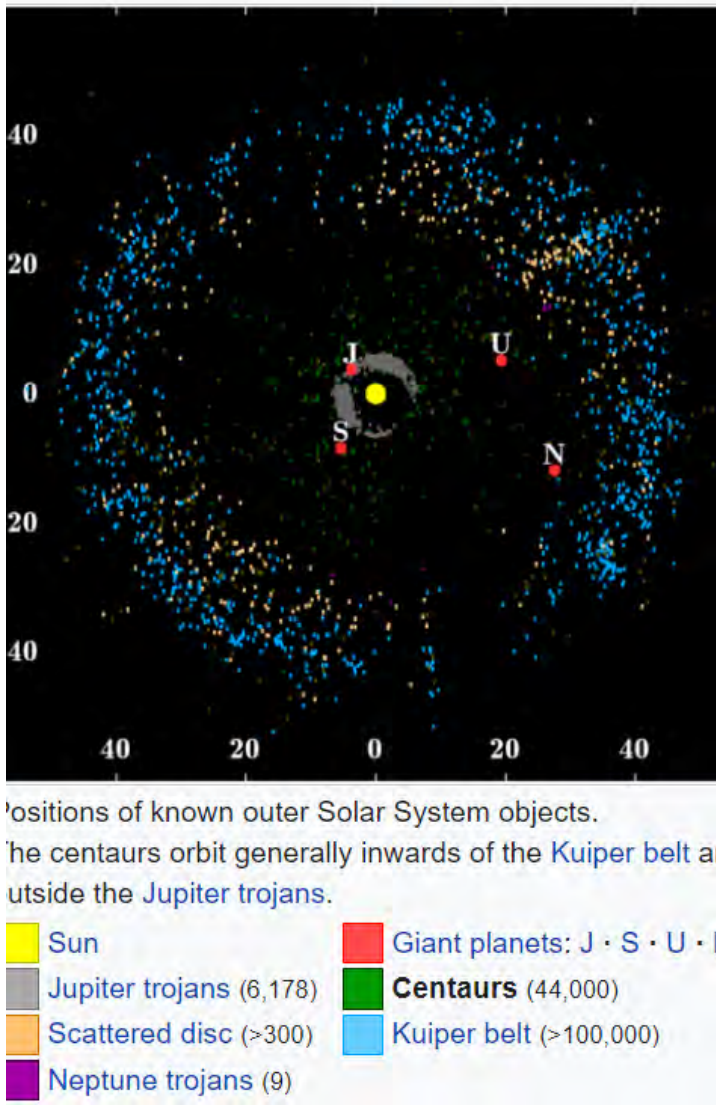
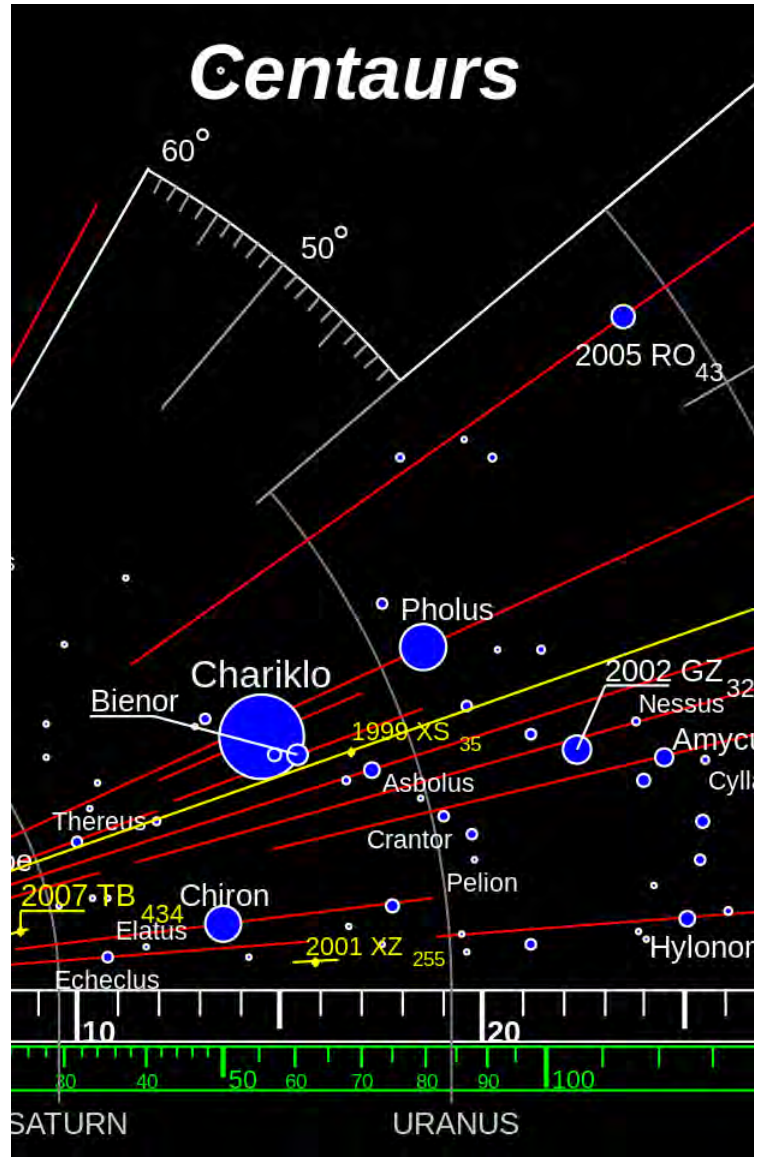
Introduction to Centaurs

Centaurs

- Population of small bodies in unstable orbits with perihelia between Jupiter and Neptune
- Transition group between Scattered disk objects (SDOs) and their potential end states as Jupiter Family Comets (JFCs)
- Provide the probe of the primitive chemistry and collisional evolution of its source population
  - Composition and physical properties of small trans-Neptunian objects (TNOs) beyond our observational limit
- More than 10% express comet-like behavior well beyond Jupiter's orbit
  - Source of the activity is unknown





Credit: Wikipedia

(https://en.wikipedia.org/wiki/Centaur_(small_Solar_System_body))

Link between SDOs and JFCs

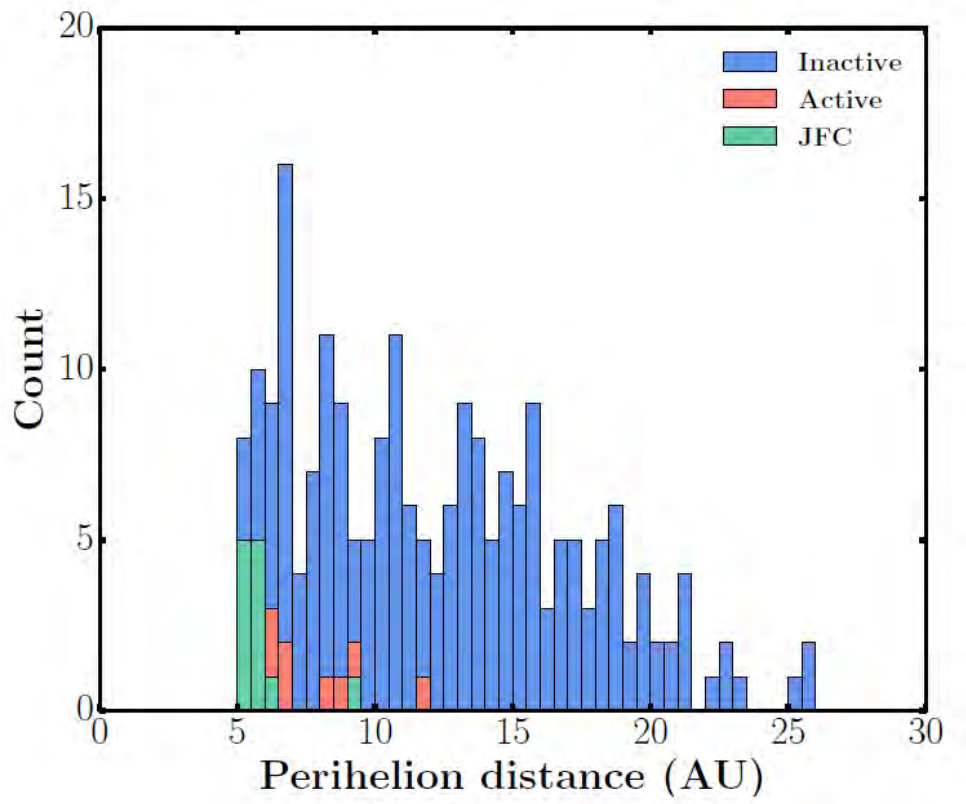
- Centaurs originated in the trans-Neptunian population
  - Majority comes from the SD (Di Sisto & Brunini, 2007)
  - escaped Plutinos contributes less than 6% (Di Sisto et al.,2010)
  - small fraction (high inclination, high eccentricity) comes from Oort cloud (Brasser et al., 2012)
- Three potential outcomes (Di Sisto & Brunini, 2007)
  - 30% will become JFC
  - Small percentage will collide with a giant planet
  - Most will be ejected from the Solar system
- Predicted numbers do not match the observations

The active Centaurs

- The activity on comets is driven by the sublimation and release of gases
  - Sublimation of water ice occurs at perihelion distances of 5-6AU
  - Activity due to the amorphous water ice crystallization occurs at perihelion distances of 6-13AU
  - At larger distances, the outgassing is driven by the sublimation of supervolatile materials (CO, CO_2)
- Several questions concerning Centaurs' activity
  - What is driving the activity?
  - Why are some Centaurs active and others not?
  - How significant the mass loss is in altering the Centaurs' SFD?

The active Centaurs

- No active Centaurs known beyond 13 AU
  - Consistent with crystallization of the amorphous ice being the main driver
- Too far form the Sun for the sublimation of water ice
- Centaurs are likely depleted of free volatile material
  - Numerous completed orbits within the relatively warm Centaurs region



Distribution of active and inactive Centaurs based on perihelion distance
(Credit: Lilly-Schunova et al., 2018)

The active Centaurs

- Thermal models confirm possibility of amorphous ice survival
- Process can not be sustained longer that ~10,000-100,000 years
    - Crystallization will either stop propagating, or will propagate too deep and will become weak

(Guilbert-Lepoutre, 2012)

- Active Centaurs are either new to the region or activity was due to the external process

(Di Sisto & Brunini, 2007)

Detecting the activity on Centaurs

- The simplest technique is visual inspection.
- Centaurs may exhibit only low-level activity that is challenging to identify visually.
- Two techniques for low-level activity determination:
  - Compare the target profile with the average profile (PSF) of background field stars.
    - If a target's PSF is broader than that of typical field stars, target is probably active.
  - Calculate the radial surface brightness profile (SBP) and compare it to the average SBP of the selected field stars.
    - This is done by averaging the signal within several concentric apertures around the center of the target.
    - This requires a low background and minimal relative apparent motion.

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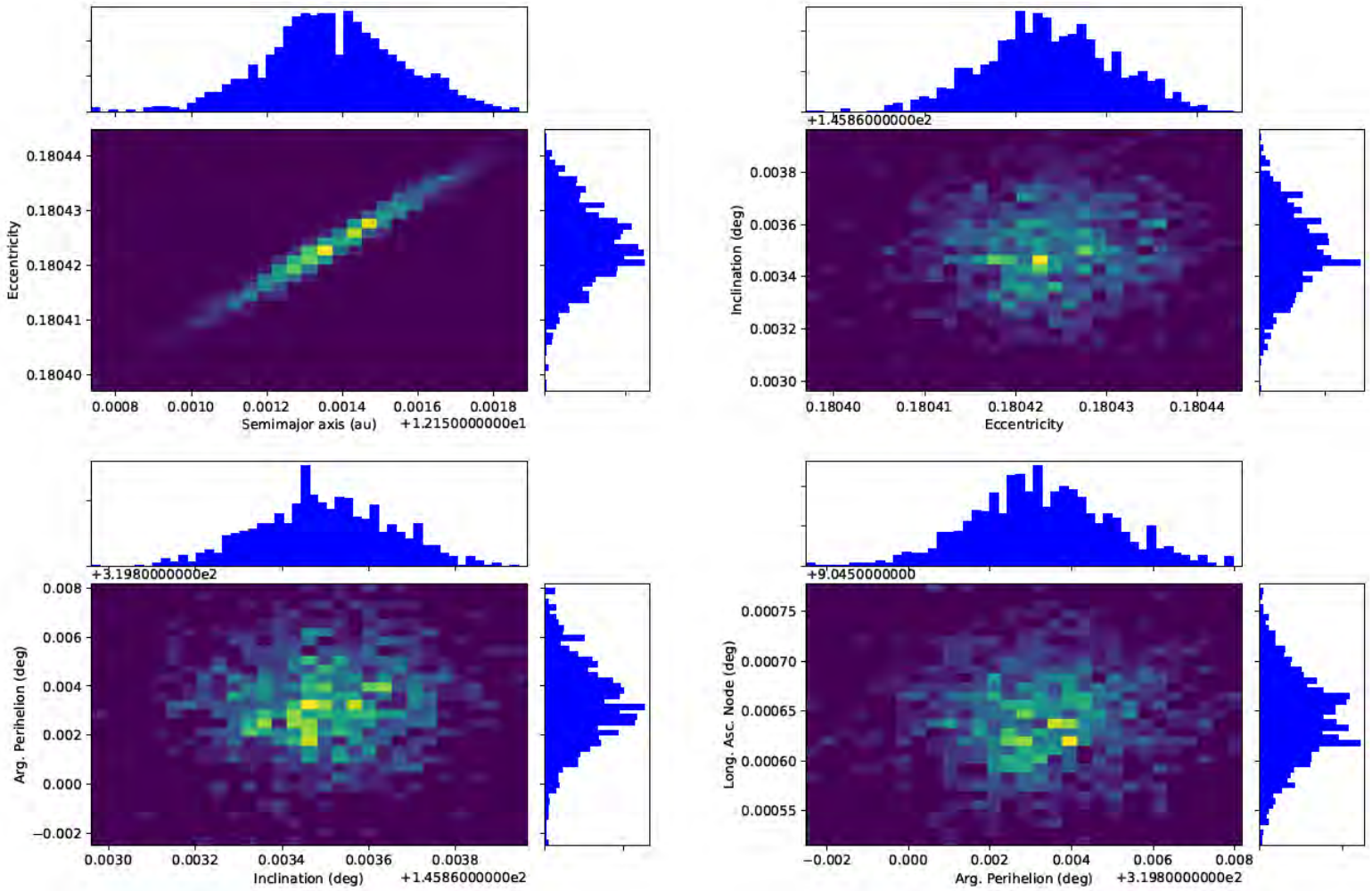
Orbital evolution and dynamical simulations of 12 Centaurs (Lilly et. al, 2021)

Orbital evolution and dynamical simulations

- Mercury6 integrator package with general Bulirsch-Stoer algorithm was used
- Objects were simulated as mass-less particles
- We simulated orbital evolution for:
  - 5,000 years into the past with timestep of 10 days
  - 100,000 years into the past with timestep of 30 days
- Particles were excluded from the simulation when they collided with the Sun or a planet, or were ejected from the Solar system

Orbital elements of selected targets

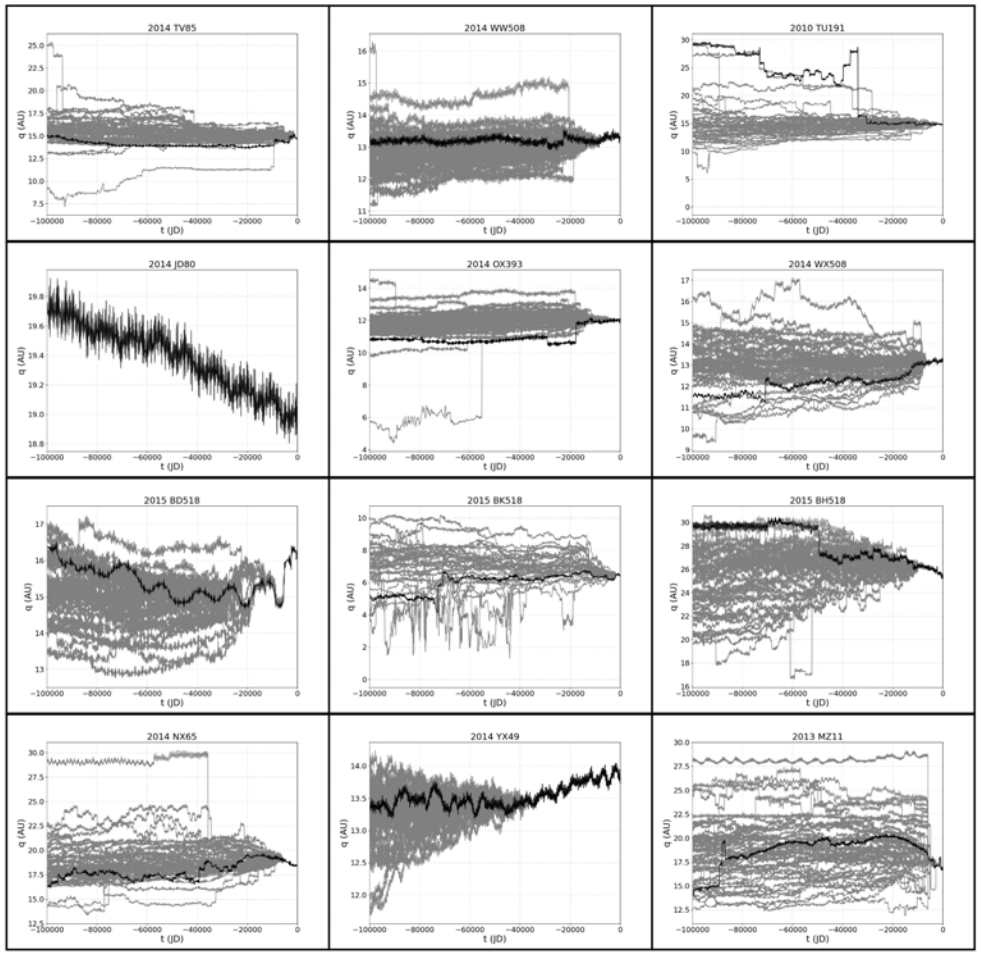
- The orbital elements were derived from the JPL Small Bodies Database
- Dynamical clones were generated using covariance matrices provided by JPL

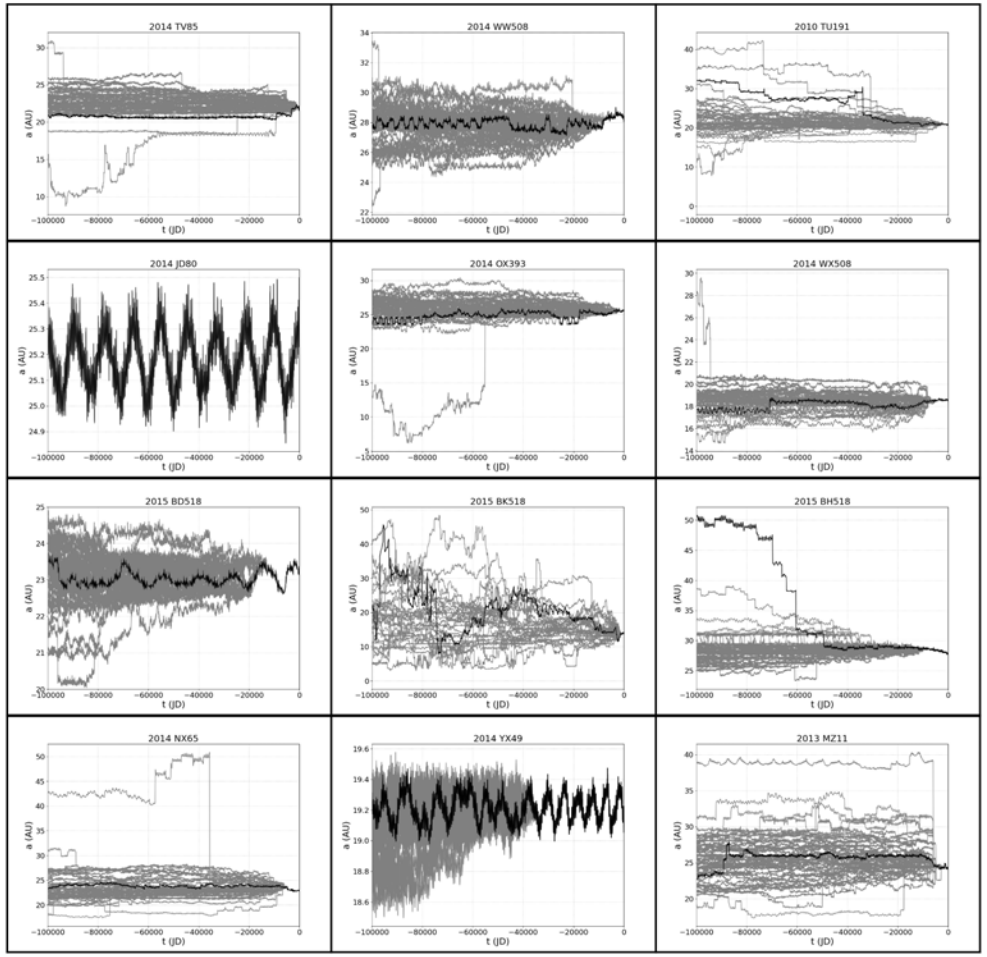


Distribution of orbital elements of Centaur 2014 OG392 and his 1000 clones

Long-term simulations

- Amorphous water ice survival is less than 100,000 years
- Most objects become chaotic after close encounter with giant planets
- Impossible to know past orbital evolution after that point (Morbidelli et. al, 2020)

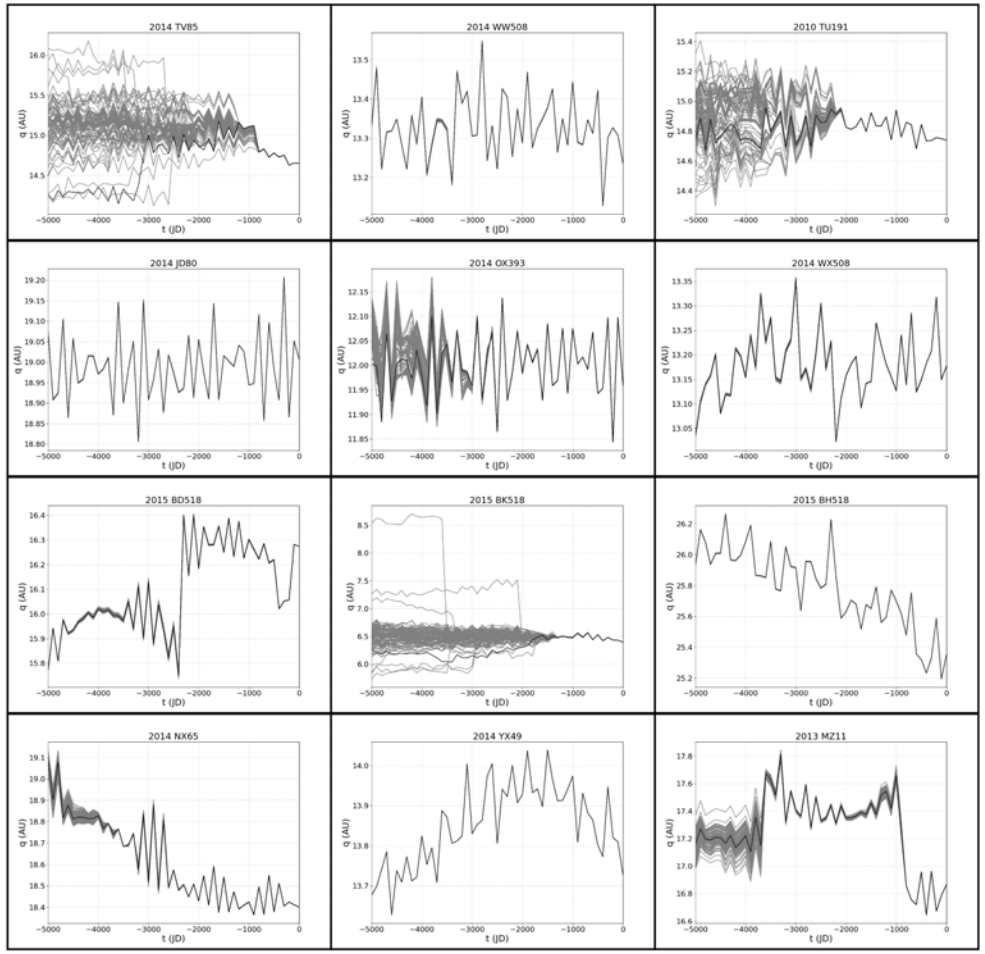


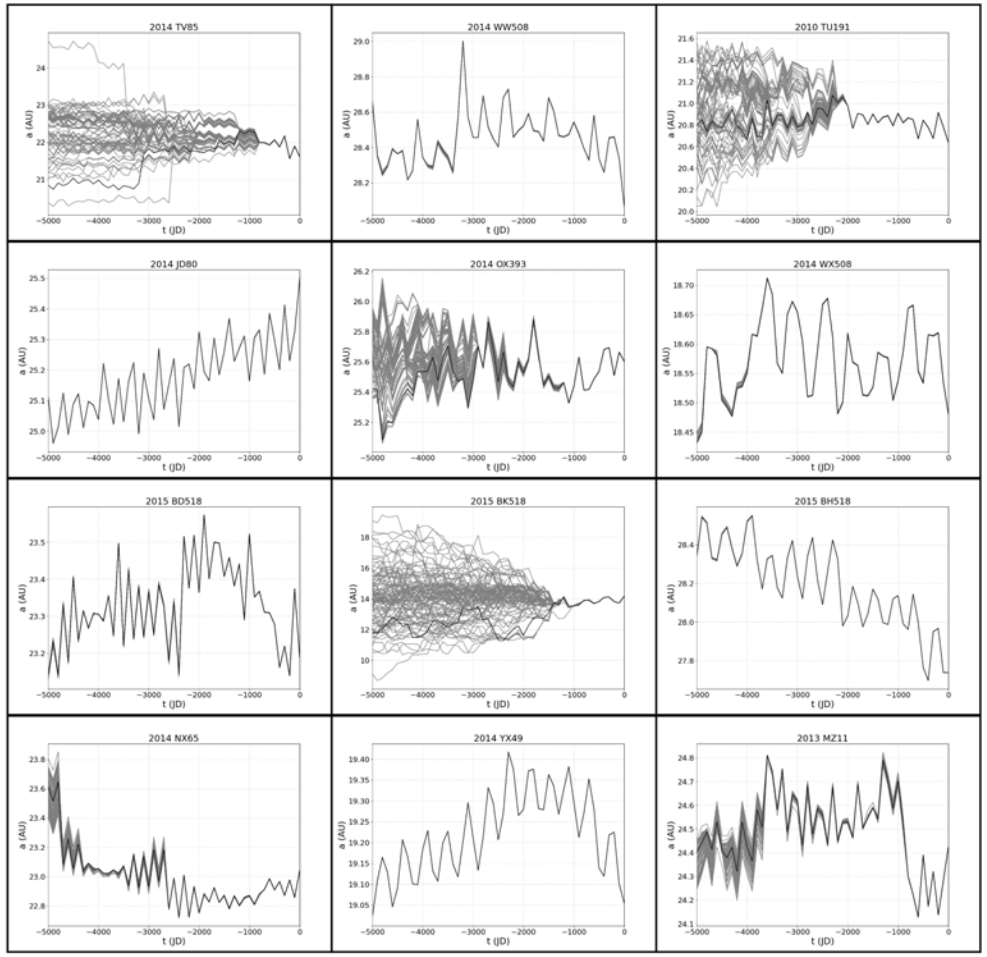


The orbital evolution of perihelion distance and semi-major axis of 12 Centaurs over the past 100,000 years

Short-term simulations

- Investigate recent sudden changes
- These changes could release trapped volatiles
- Objects have mostly stable orbits with minor changes





The orbital evolution of perihelion distance and semi-major axis of 12 Centaurs over the past 5,000 years

Observations

- 12 Centaurs were observed during the second half of the year 2017
- None of the objects showed obvious visual signs of activity (supported by surface brightness profile analysis)

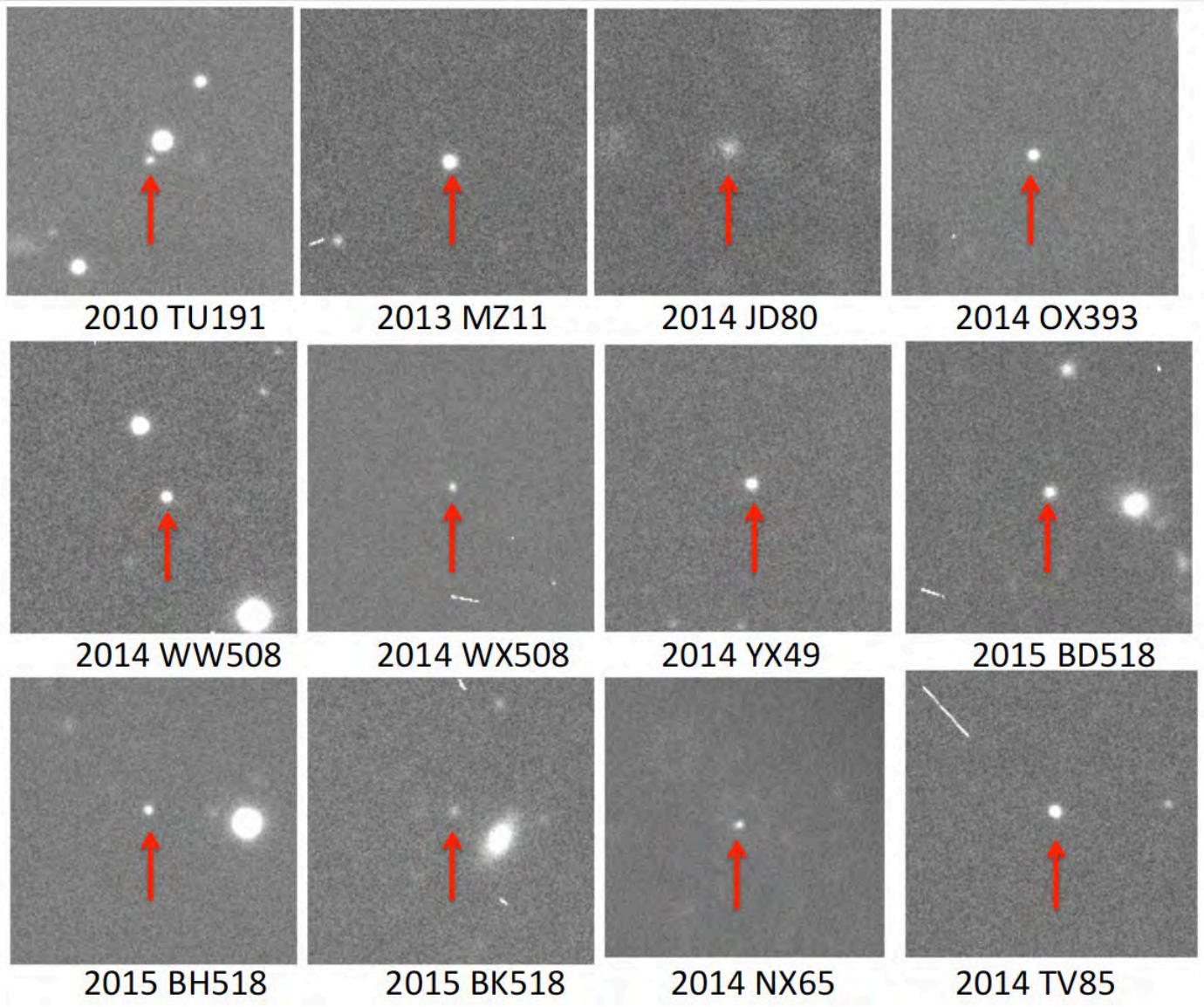


Image of 12 Centaurs observed during the second half of the year 2017. The spatial dimension of each image is 30 x 30 arcsec.

Future work

- Further investigate short term past evolution
  - Change in semi-major axis and perihelion could be indicator of activity
- Search for activity in newly discovered Centaurs

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