ESOP XLIV
Poznań
23–24 August 2025

Occultation Path shifts

A possible cause?

Robert Purvinskis, August 2025

ESOP-44, Poznan

Plan of talk

Path Shifts

- What is a path shift?
- What are possible causes?
- What does Jupiter have to do with this?
- Some examples & experiments
- Proposed solutions & future work

Path Shifts (aka ’99% problem’)

Typical features and known causes

- A **path shift** occurs when an occultation is not visible in the predicted location, but confirmed to be visible somewhere else
- Since the 1980s, when path uncertainties were high, path shifts have been observed
- A certain amount of shifting would be expected from the diameter uncertainty, statistics of orbit and star positions
- Recently some observers report seeing no occultation when they are located near the center of the predicted path. *Why does this happen?*

Path shifts

What a path shift is not…

- A single negative observation at 99% is not a path shift. It can be a *potential* indicator.
- Multiple negative observations inside the path can indicate a path shift, especially if they are widely distributed across the path
- Best indicator is an event with one positive observation seen either outside or on the edge of a path, with multiple negative observations inside a path
- Comets are regularly affected by path shifts but this is usually due to ‘nongravitational effects’ which are not easily predictable
- Some experience from lunar graze occultations already exists (altitude shift)

Path shifts

Possible causes

- On average roughly 5 % of observations are negative when a positive (> 90%) is expected.*
- Known causes include:
    - Poor star position (today : star is not in DR3, high RUWE value)
    - Relatively new asteroid (e.g. unnumbered object, TNO, NEO -> poor orbit knowledge)
    - Object near stationary point (Dunham) - slow-moving, prediction time incorrect
    - Asteroid moons / double asteroid / Double star (prediction path is empty, e.g. (1109) Tata, (102) Miriam)
    - Observer location (e.g. observers at high geographic altitude / mountains, though this is now adjusted in OCW) - graze experience helped identify this
    - ??? ("Known unknowns") - *is there a pattern to unexplained shifts?*

(Bill Hanna, TTSOA + groups.io, 2024)*

Path shifts

The Jupiter effect (perturbations)

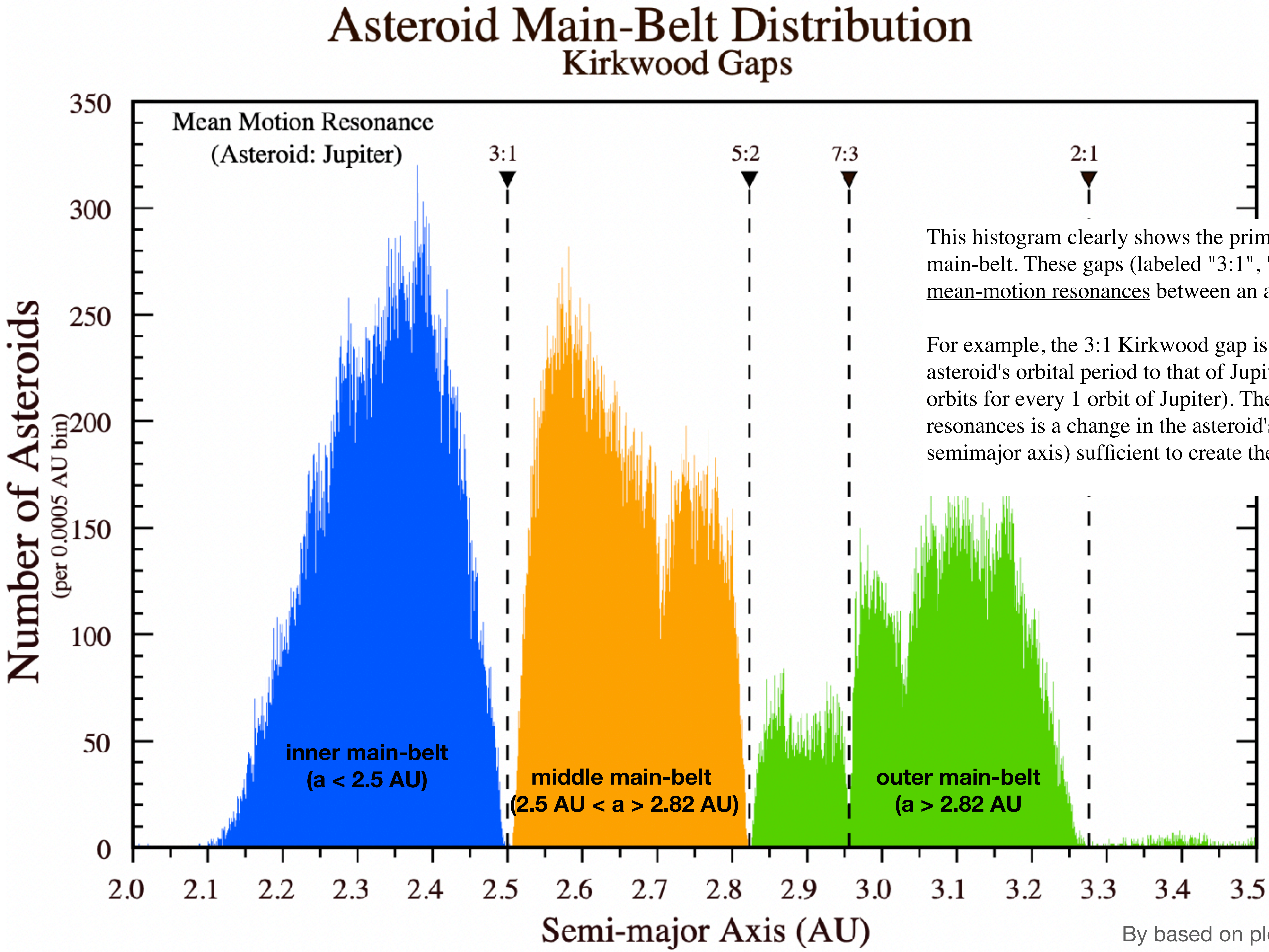
- Jupiter has the largest influence on all other planetary orbits. This is most clearly demonstrated by the *Kirkwood gap distribution,* which shows fewer asteroids at orbit locations in resonance with Jupiter.

- Most asteroids are regularly affected by the presence of Jupiter as they approach conjunction. This is cyclic and happens over several months.

- Orbit propagator algorithms usually take care of this, however if the orbit is changing particularly quickly, the time steps used may not be sufficient

- OCCULT has a ‘quick search’ calculation mode and a ‘slow detailed (HORIZONS)’ mode

- OWC can recalculate using latest HORIZONS data (?)



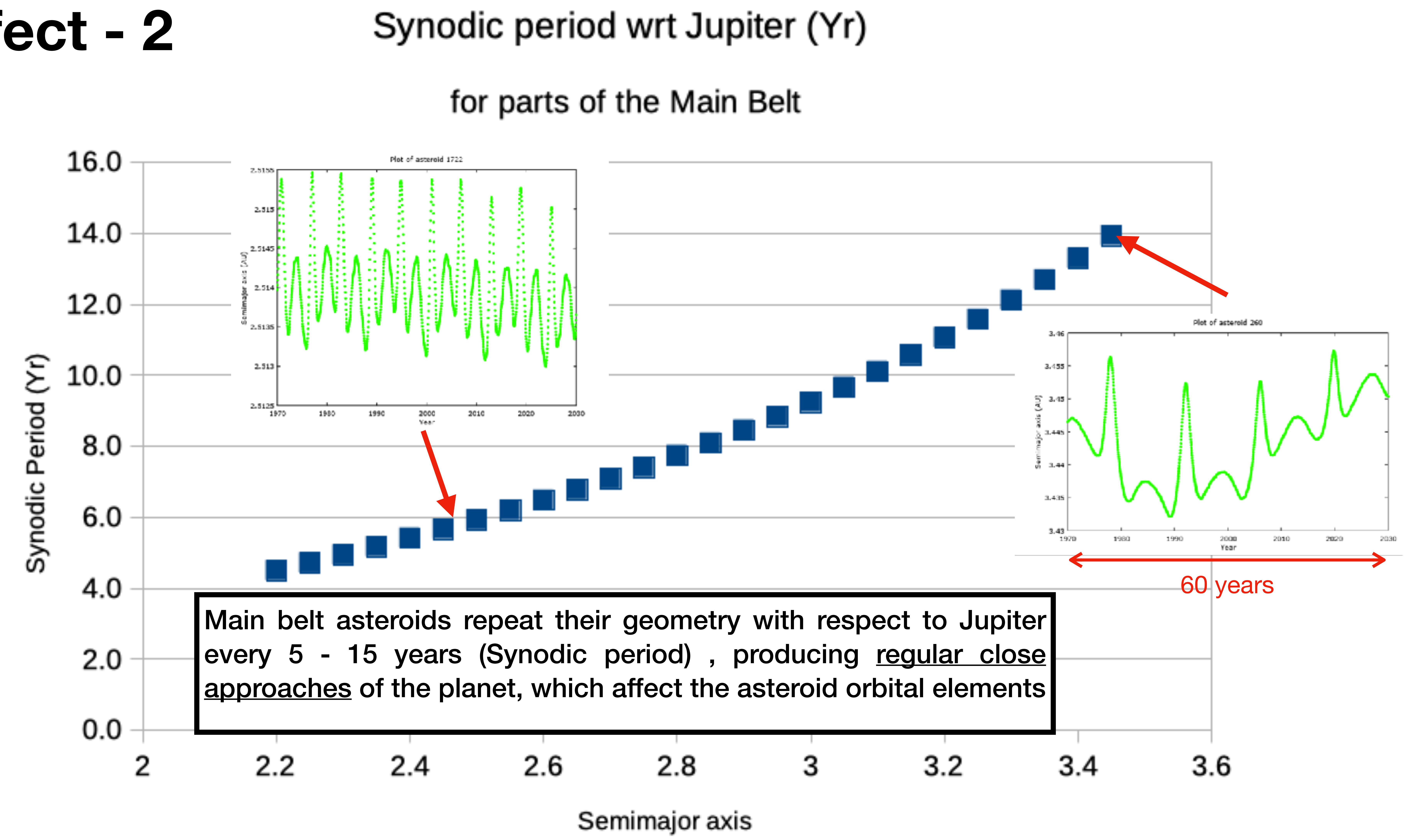
This histogram clearly shows the primary Kirkwood gaps in the asteroid main-belt. These gaps (labeled "3:1", "5:2", "7:3", "2:1") are caused by mean-motion resonances between an asteroid and Jupiter.

For example, the 3:1 Kirkwood gap is located where the ratio of an asteroid's orbital period to that of Jupiter is 3/1 (the asteroid completes 3 orbits for every 1 orbit of Jupiter). The effect of these mean-motion resonances is a change in the asteroid's orbital elements (particularly semimajor axis) sufficient to create these gaps in semimajor axis space.

Source: Wikipedia
By based on plot by Alan Chamberlain, JPL/Caltech

Path shifts

Jupiter effect - 2

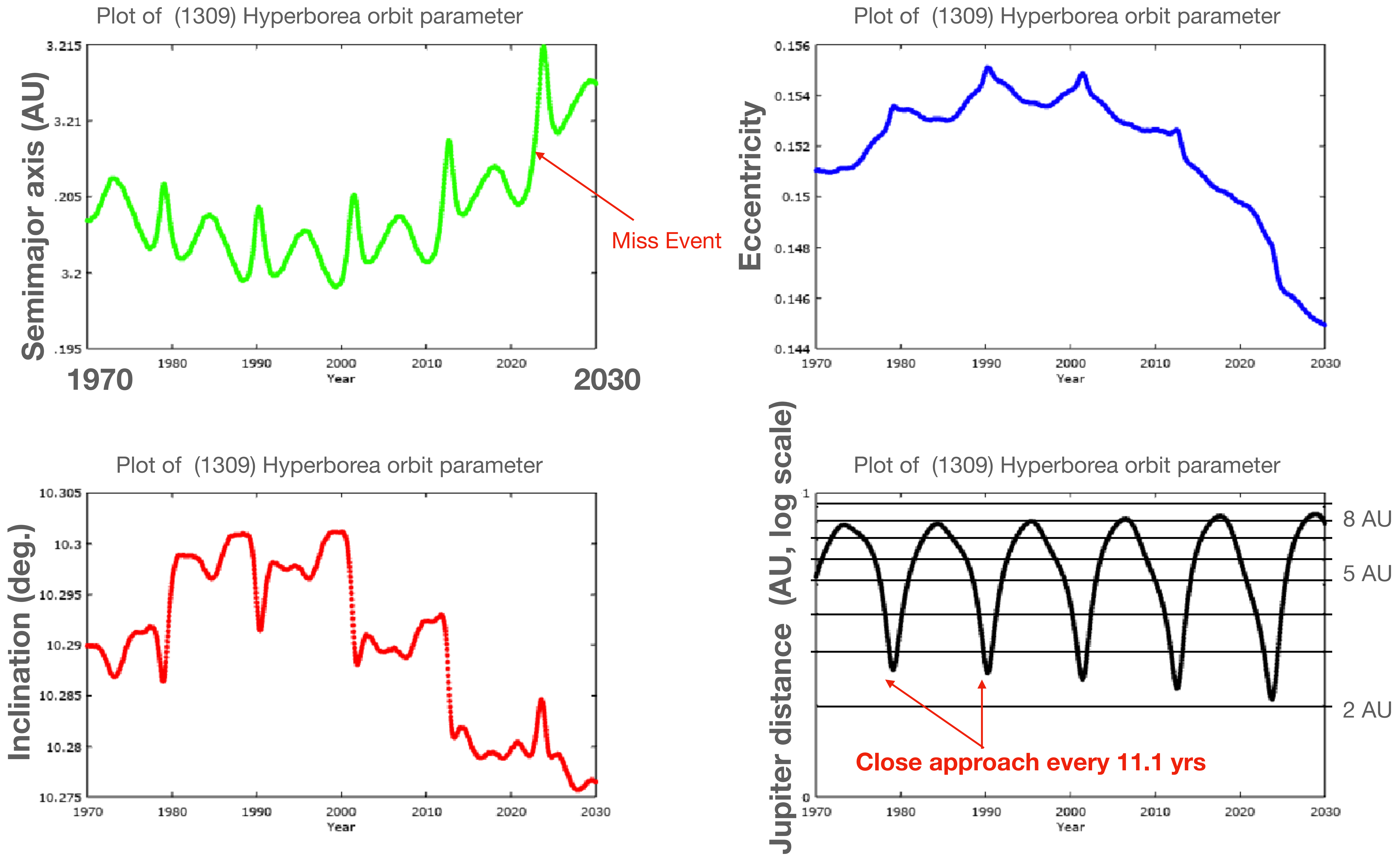


Path shifts

Jupiter effect - 3

- To demonstrate Jupiter's orbital influence, orbit elements were analysed for the same object over several decades (data source: JPL HORIZONS)
- Plots of several orbit parameters - semimajor axis (*a*), inclination (*i*), and eccentricity (*e*), show regular large jumps every several years (duration ca. 1 yr)
- A plot of Jupiter - object separation clearly indicates that Jupiter is the cause of these jumps
- Effect of Earth visibility not yet assessed
- Next step: demonstrate this affects a known occultation shift (Perturbation)

Jupiter effect - Long term effects on a typical asteroid orbit



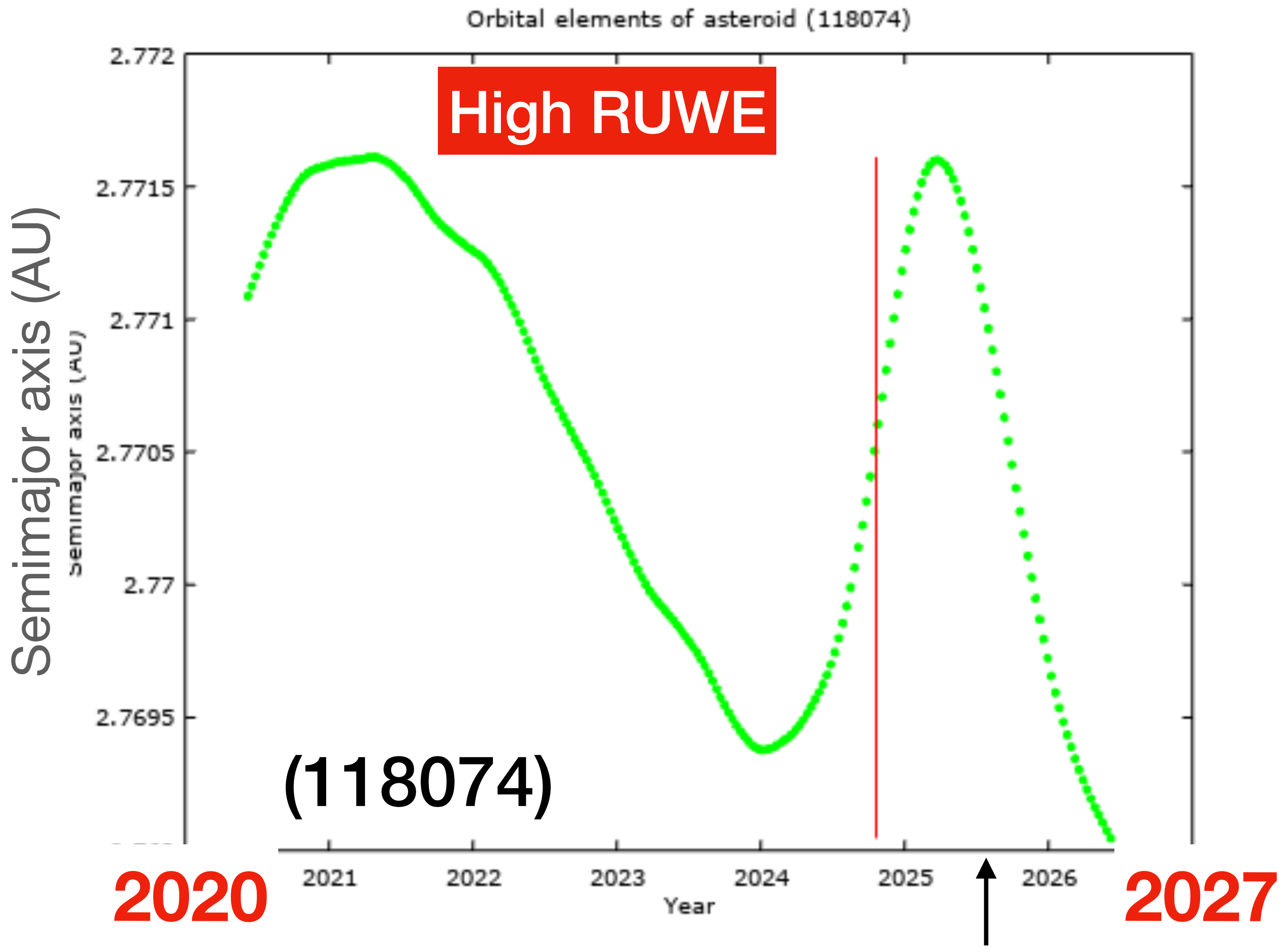
Path shifts

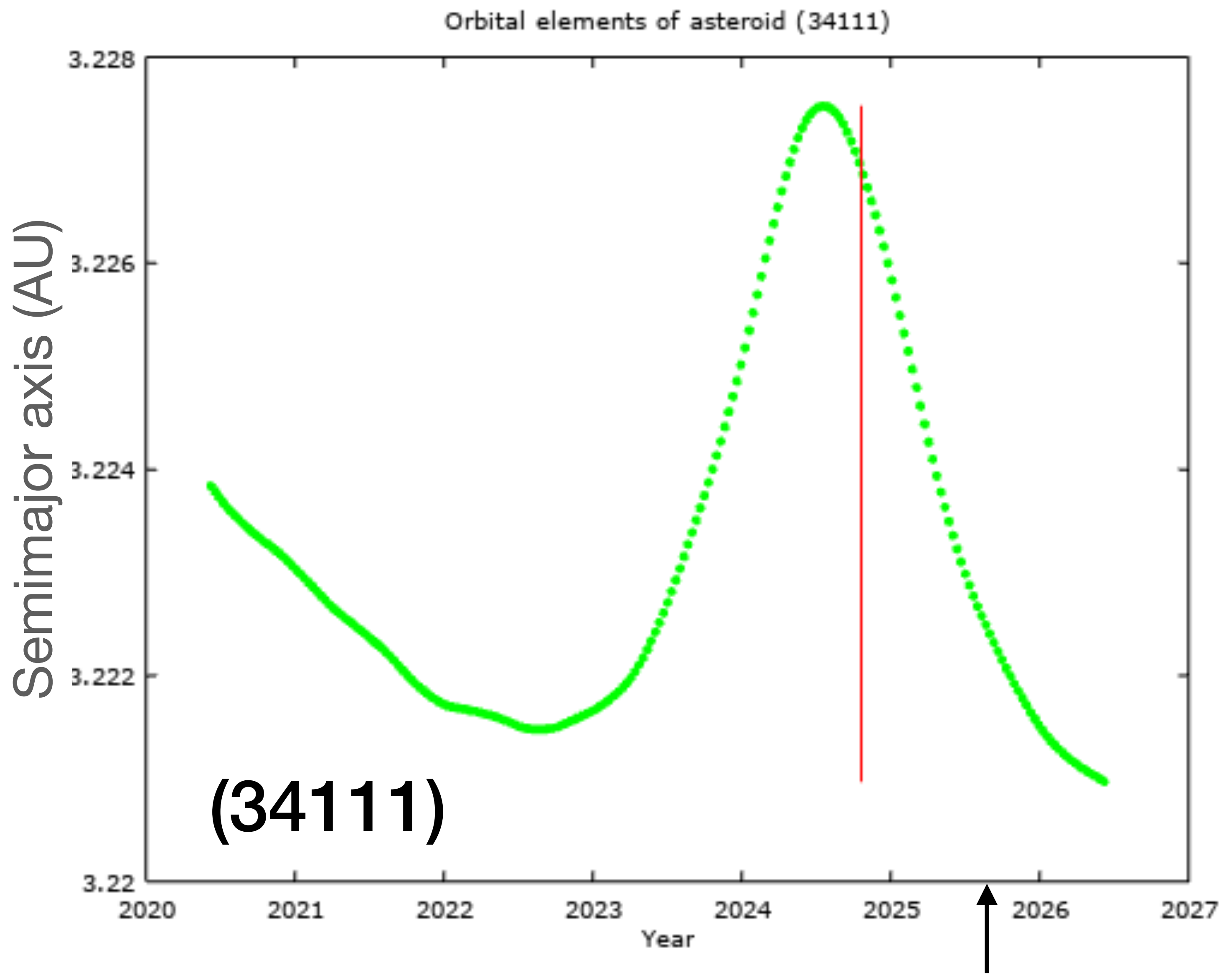
List of some observed (and unobserved) events since 2018

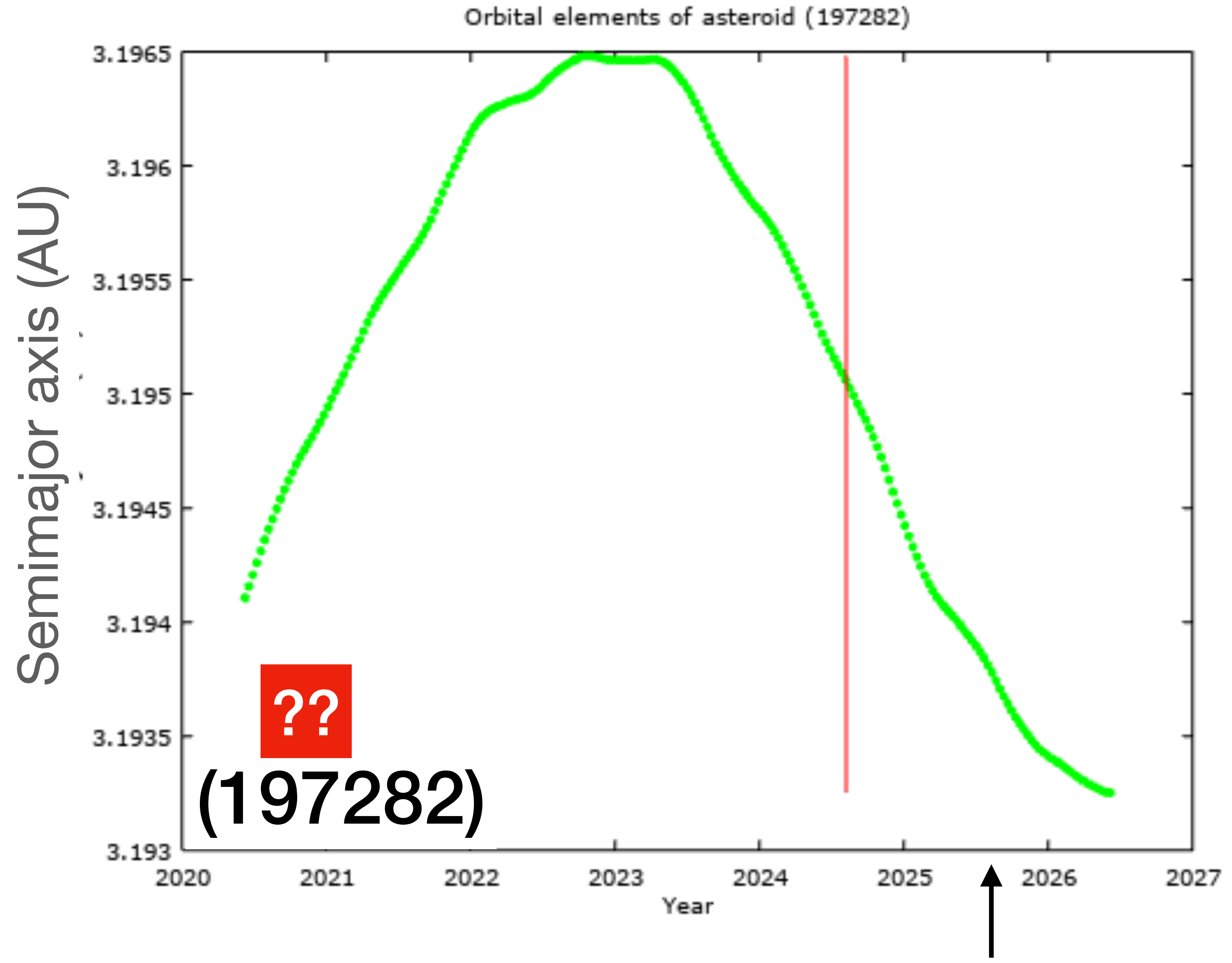
Observer / reporter	Object	Event Date	Diameter (km)	RUWE*	Jsyn (yr)	Notes & Other Obs?
Djounai Baba Aissa	(111)	28.08.2020	126	—		Obj near Stationary point. One +ve Sept 2024
Ferran Casarramona	(813)	28.11.2024	11.6	0.75	4.6	12.3.2022 (PS?), 21.08.2018, 18.8.2014 (PS?), 14.10.2011 (NB: Jsyn = 4.6 yrs)
	(62137)	16.12.2024	9	1.1	11.3	One positive, Aug 2024
	(50092)	23.12.2024	3	0.8	5.1	One negative, Feb 2025
Sposetti	(25540)	30.10.2024	4.5	0.95		No other events for this obj
	(2266)	30.10.2024	44	1.0	13.3	3 -ves inside the path; No +ve events in OWC
Purvinskis	(1309)	22.09.2022	58	0.85	11.1	2 events with +ves May 2021
Kubanek	(56227)	3.11.2024	7	1.05		1 +ve, 24.9.2024
	(21122)	23.9.2024	5.6	1.25		PS at least half a path, confirmed with 2x +ve
	(1291)	15.2.2023	26	1.25	9.3	3 positives since 2022
	(118074)	27.10.2024	8	3.45	7.5	3 -ves inside path - PS to West?
Meister	(34111)	27.10.2024	8	1.0	11.2	1 event Jan 2025 +ve/-ve (small PS?)
	(197282)	13.8.2024	10	1.1		1 event with 2 -ve in 2016

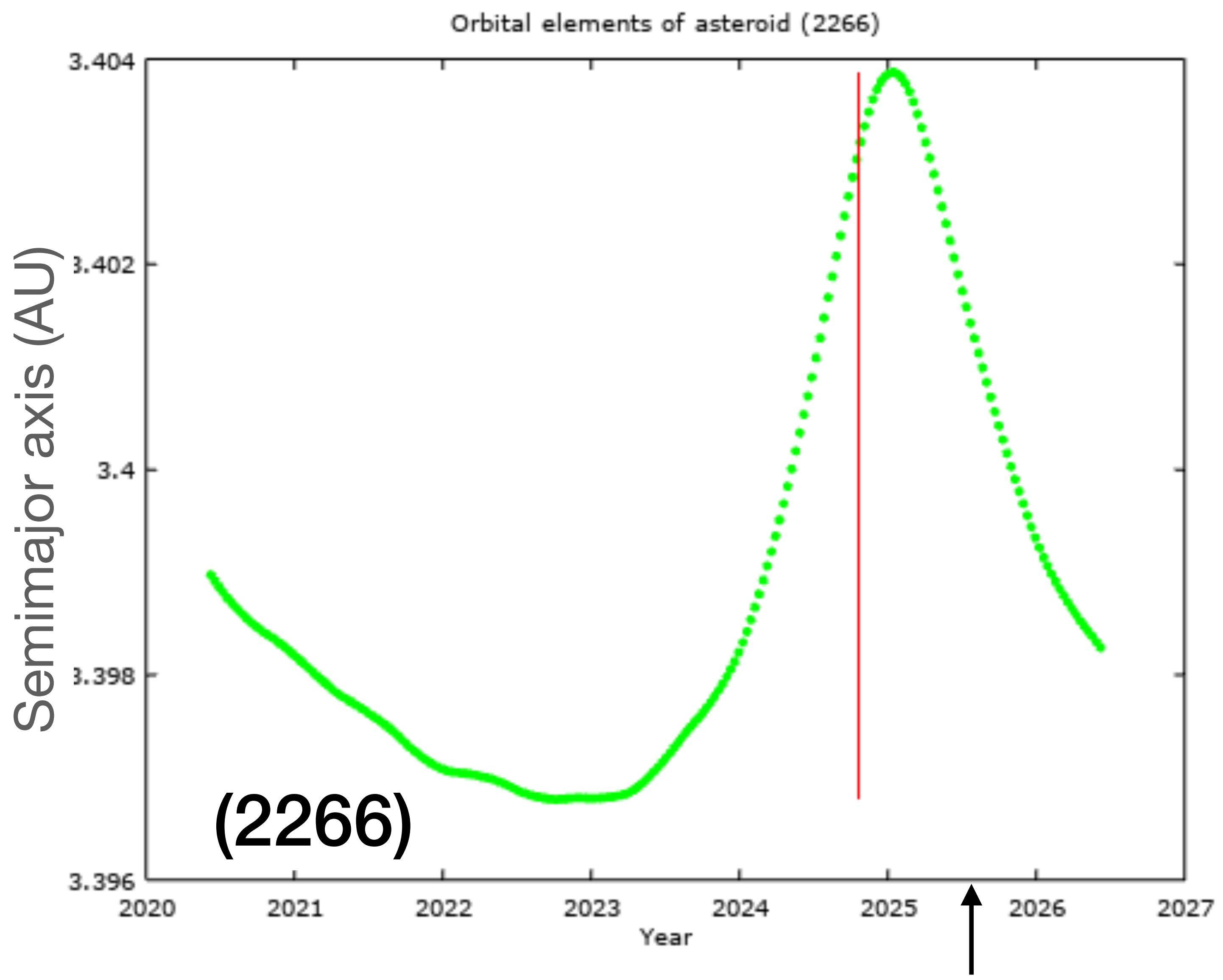
(RUWE = 0.5 - 1.4 is considered reliable)*

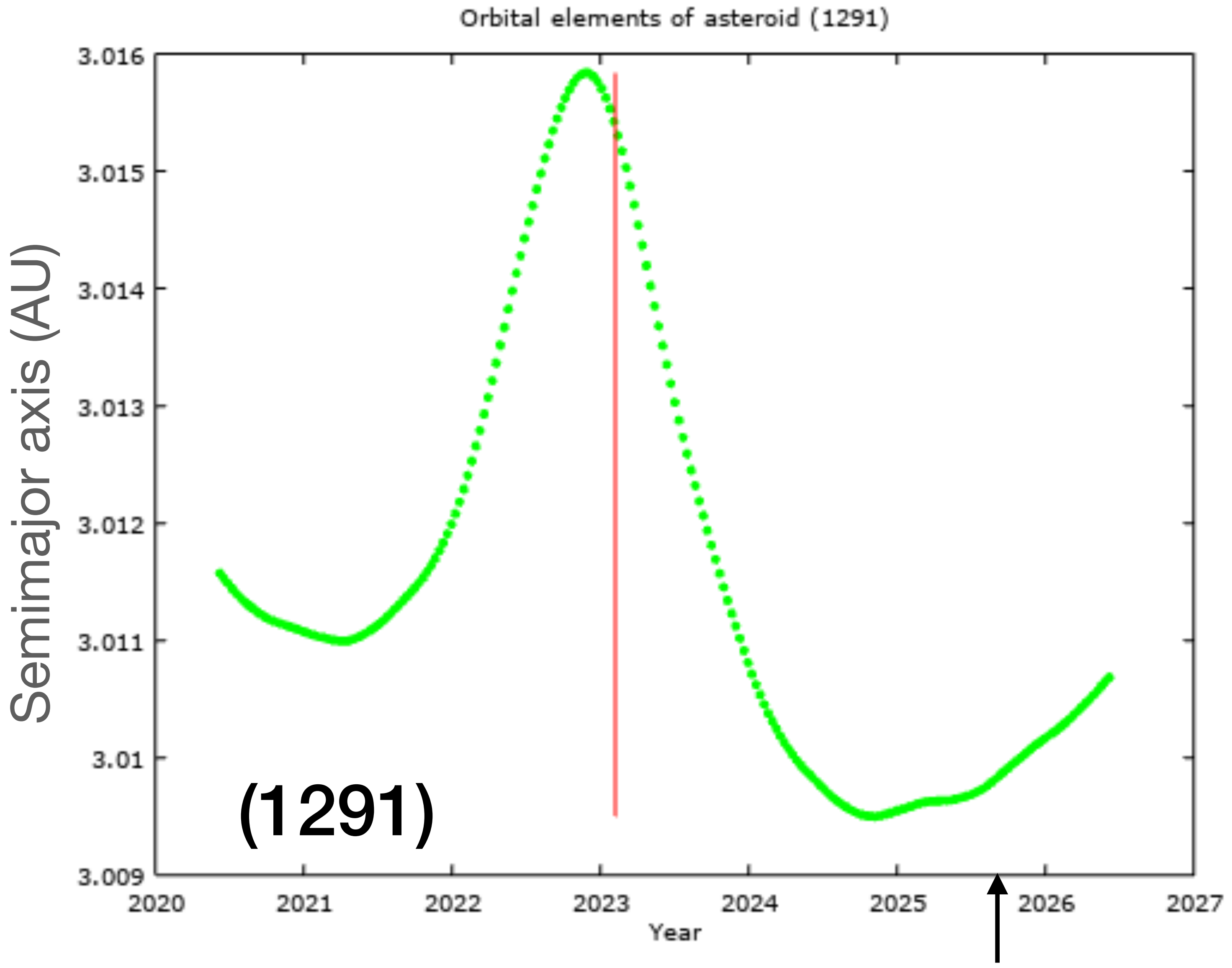
Some examples of recent path shift events - orbital elements

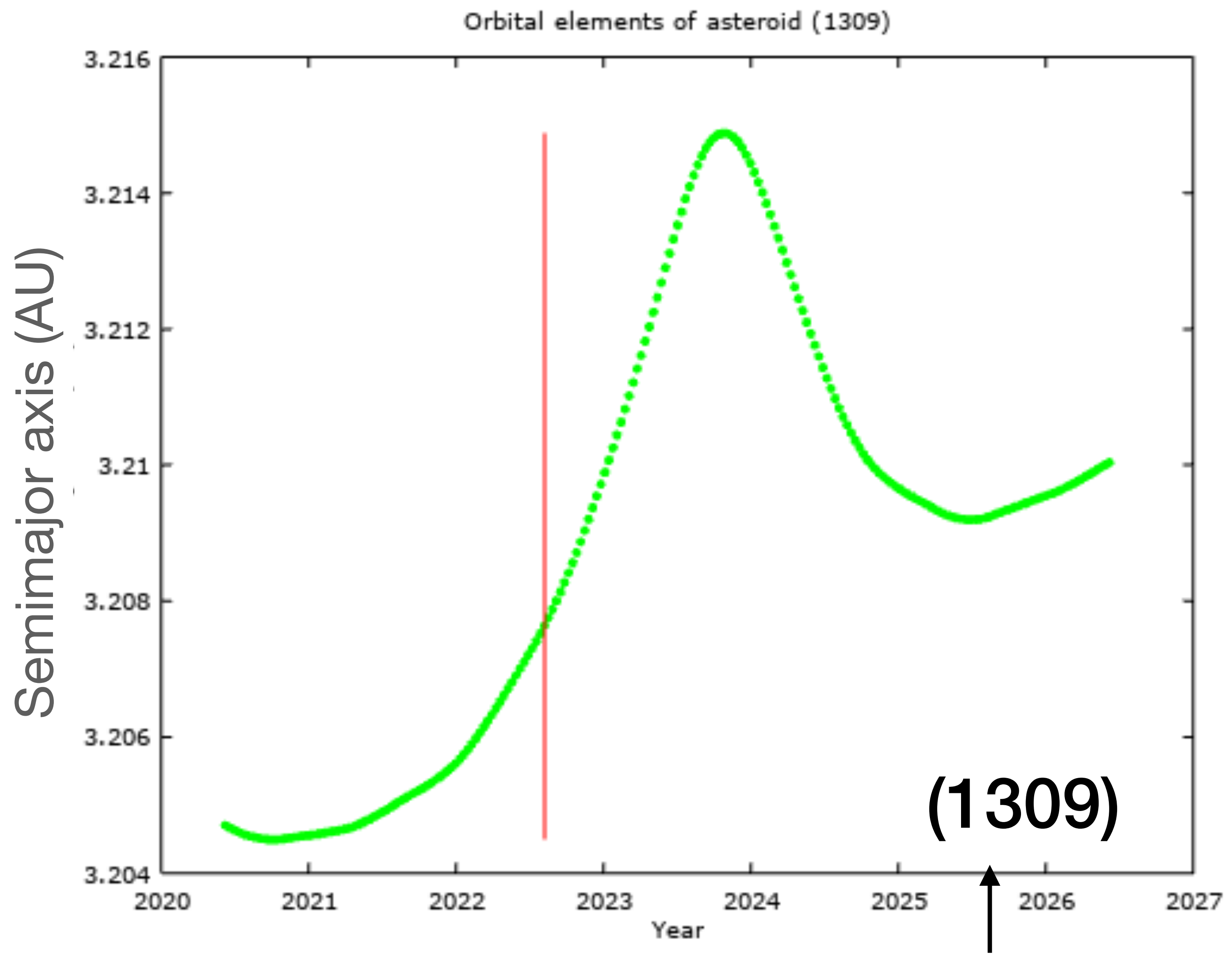










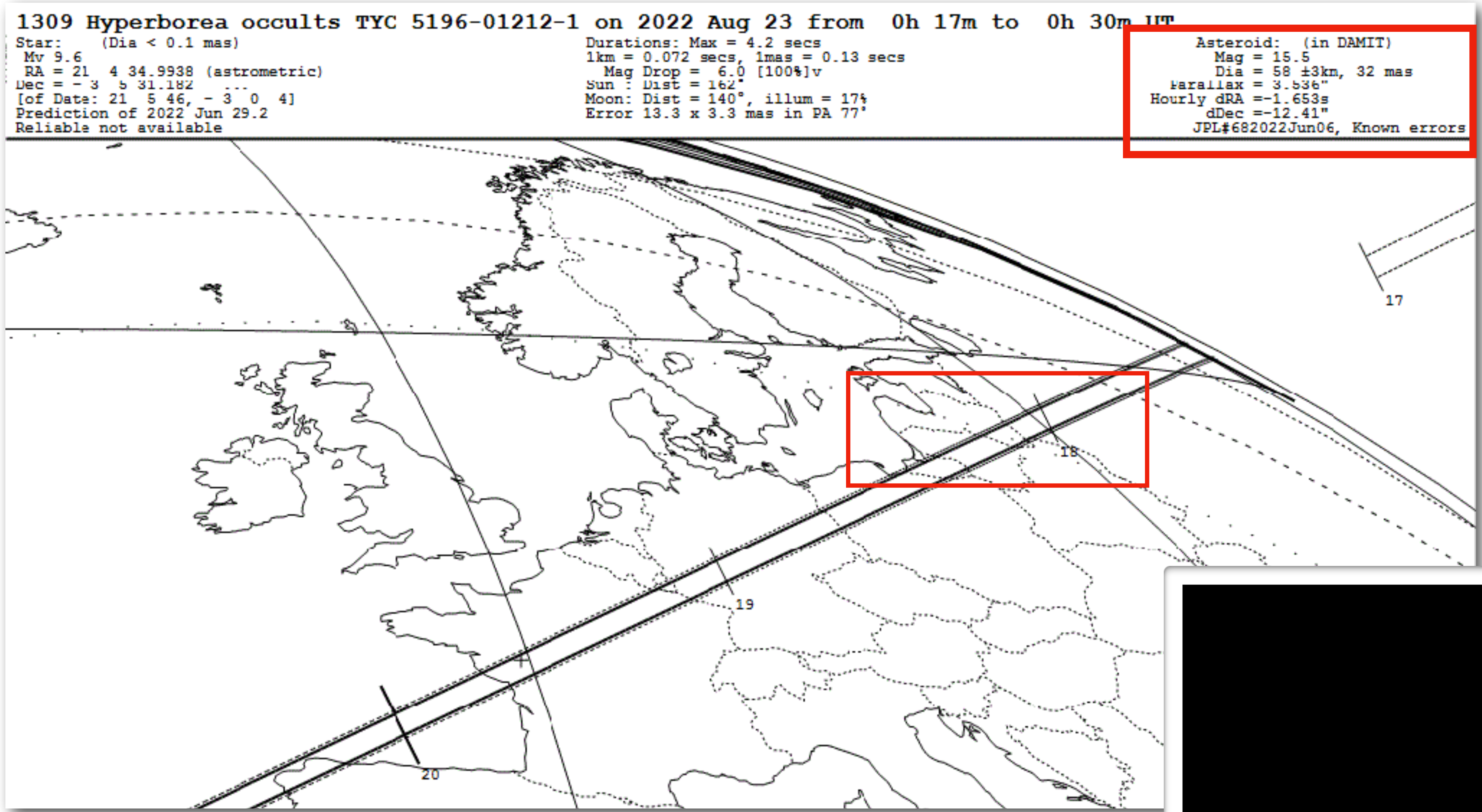


Path shifts - some examples

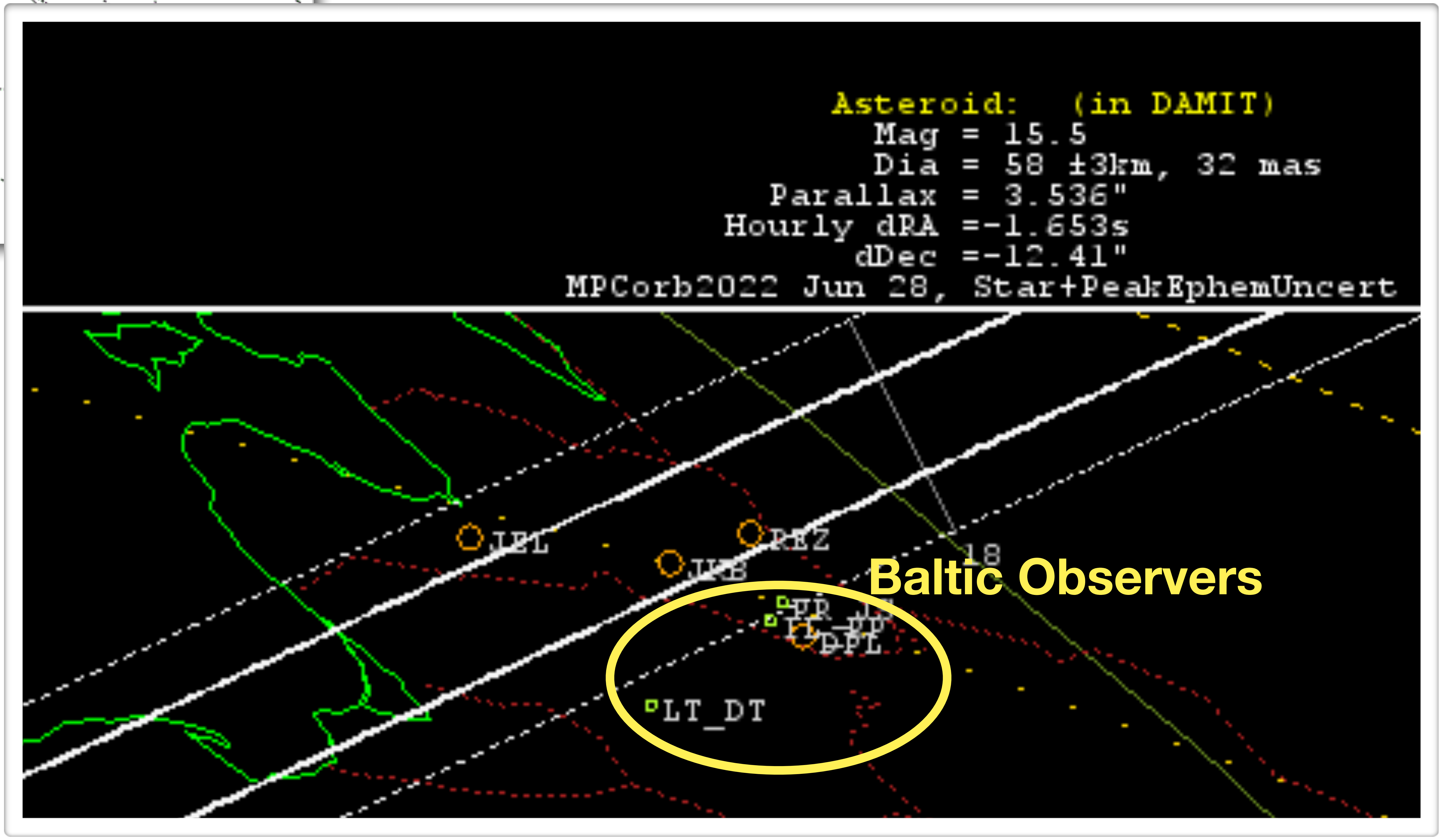
(1309) Hyperborea, 23 August 2022 *(i.e. 3 years ago this week)*

- 4 observers (in LV, F) all located on or near the path (one in the center)
- NONE saw an occultation
- Large (diameter 57 km), well-known object in outer main belt, already some occultations observed
- Synodic period wrt Jupiter (time between close approaches) 11.1 years
- OCW post-prediction (the next day) suggested the path had moved to the west by ca. one path width.

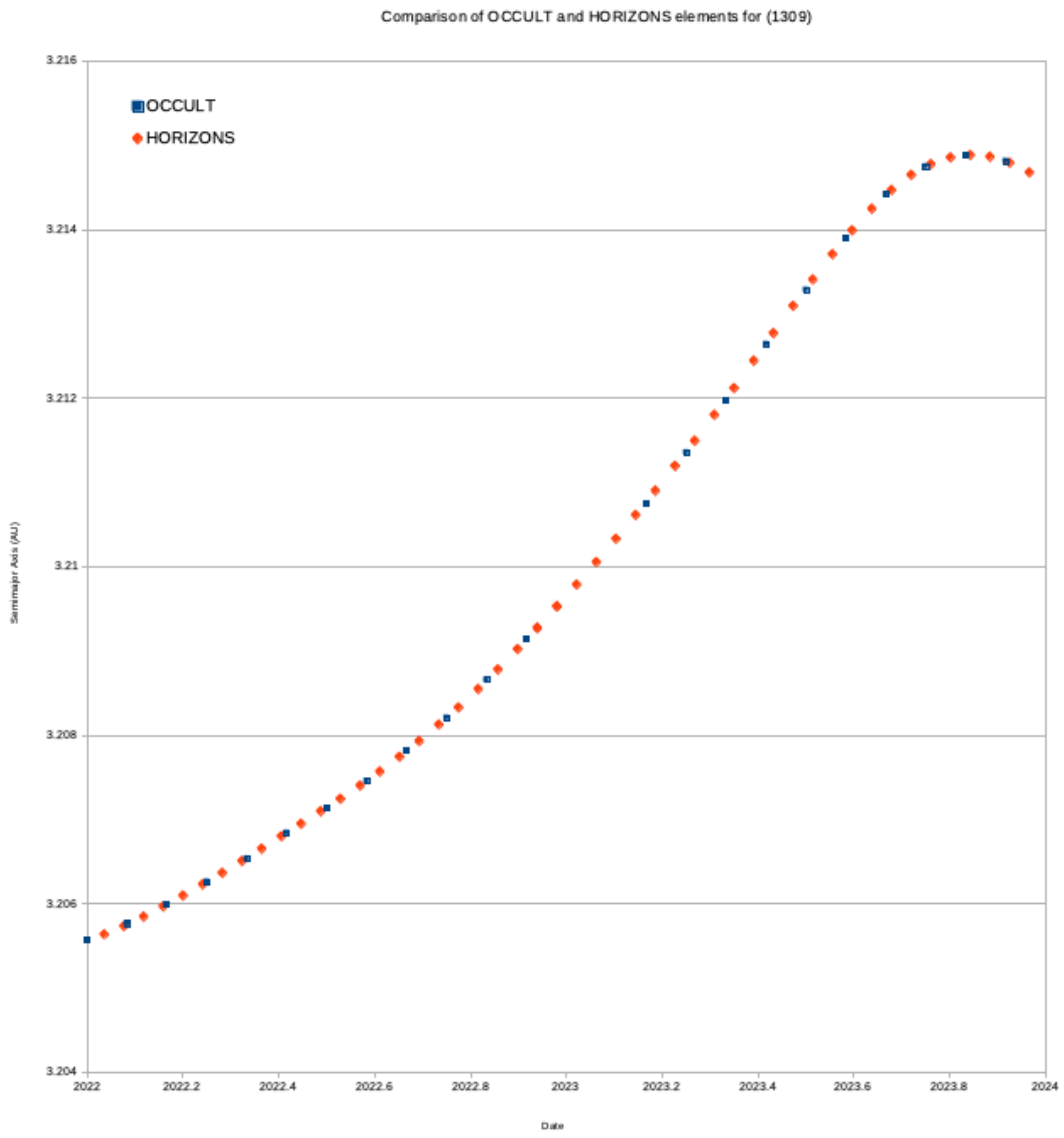
(For more info see presentation from 2023 ESOP)



Initial Prediction (June 29):
Used elements from 6 June / 3 Aug?



PATH SHIFT:
Prediction (Sept 04):
Used MPEC elements from late June?



- HORIZONS and OCCULT elements agree if suitable date is used for generation (< 90 days age)

Path shifts

Solutions and further work

- For specific asteroids, or parts of an asteroid orbit near Jupiter, care should be taken with the initial conditions for the prediction. Earth geometry (stat. pt.) also has an effect.
- In these cases, using *last minute orbit parameters* could help refine the path. Contact with astrometry teams may be advisable.
- Regular checks can be made of predictions of ‘usual suspects’, especially those near Jupiter orbital resonances or with shorter Jupiter synodic periods (cf. (813) Baumeia).
- A list of negative events and confirmed path shifts should be stored somewhere, or maybe a flag in SODIS(?). NEOs: a similar analysis could be made for NEOs during their Earth approaches (e.g Ra-Shalom)
- Comets : is there a way to include non-gravitional effects in predictions? Can object light curves tell us how to add them? Could this also be used for transitional asteroid-comet objects?

ESOP XLIV
Poznań
23–24 August 2025

Thanks for your attention