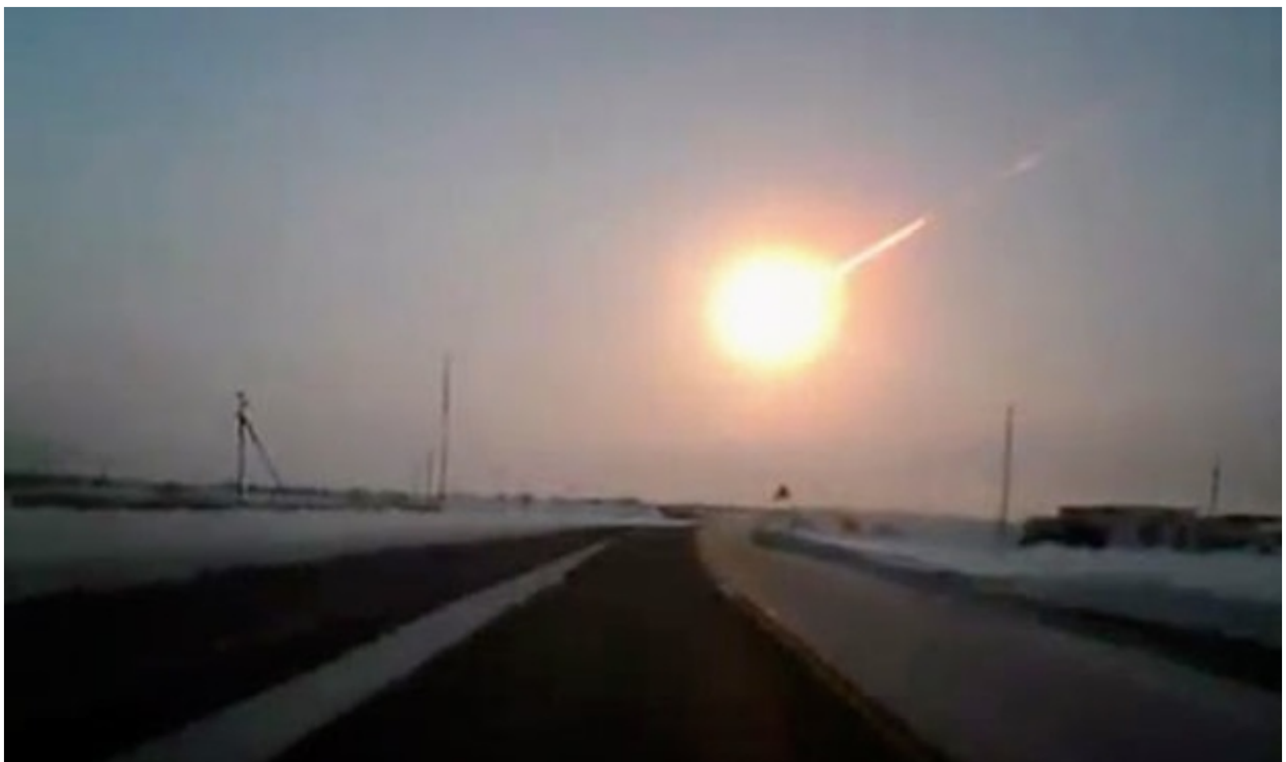
General Relativistic (GR) Precession in Small Solar System Bodies and Impact Scenarios on Earth

Aswin Sekhar, Stephanie Werner, Volker Hoffmann, David Asher, Jeremie Vaubaillon, Maria Hadjukova, Gongjie Li
CEED, University of Oslo, Norway
Armagh Observatory, United Kingdom
IMCCE, Paris Observatory, France
Astronomical Institute, Slovakian Academy of Sciences, Slovakia
Harvard-Smithsonian Center for Astrophysics, USA

Meteoroids 2016, ESA/ESTEC, Netherlands

Brief Background to Impacts on Earth

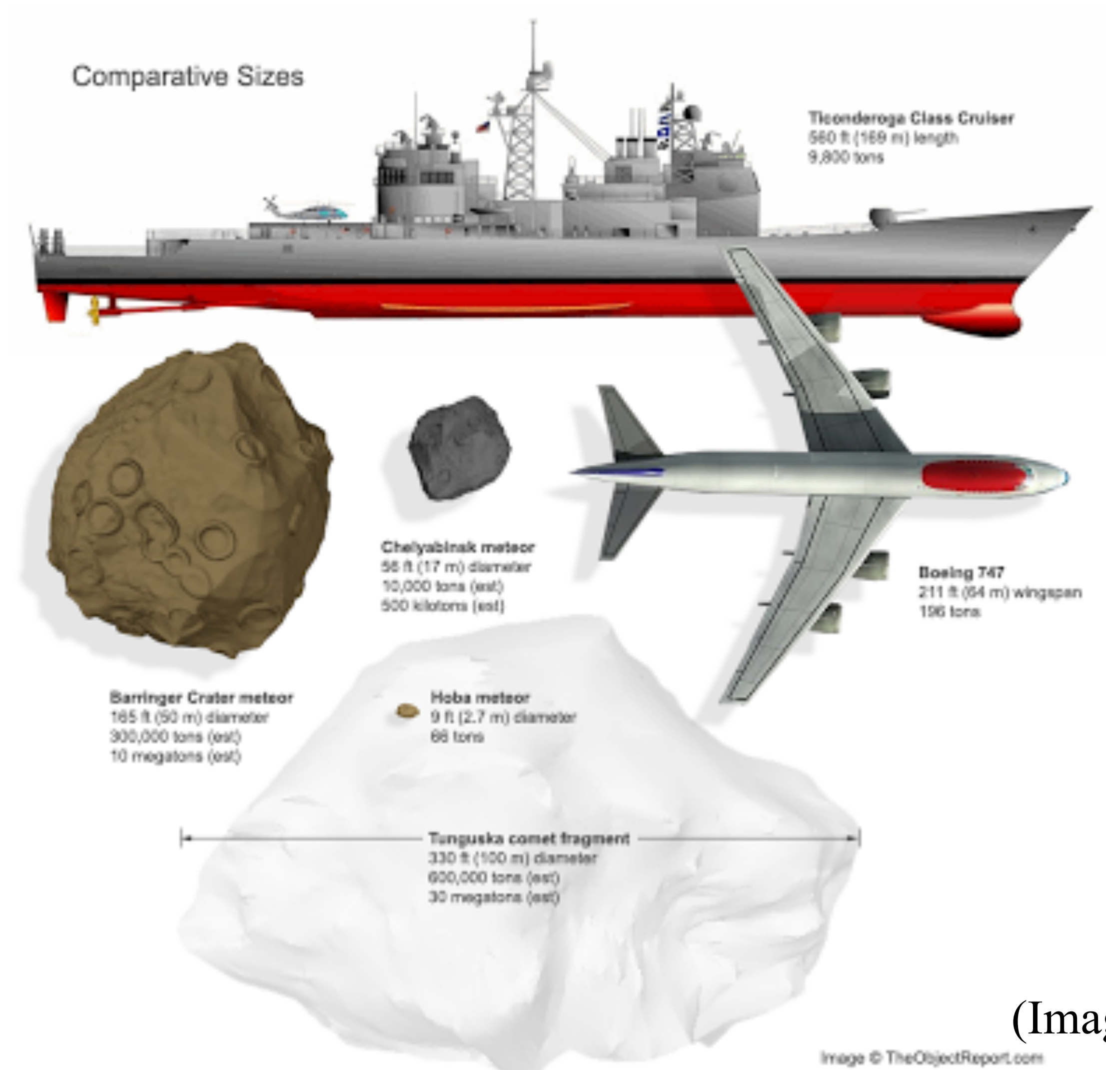
- Recent Chelyabinsk bolide event was unexpected & widely reported
- Numerous damage to buildings and human injuries in the region (Borovicka et al. 2013, Popova et al. 2013)
- Boosted public awareness regarding the dangers from small bodies



(Image credits: The Guardian)

Brief Background to Impact Risks

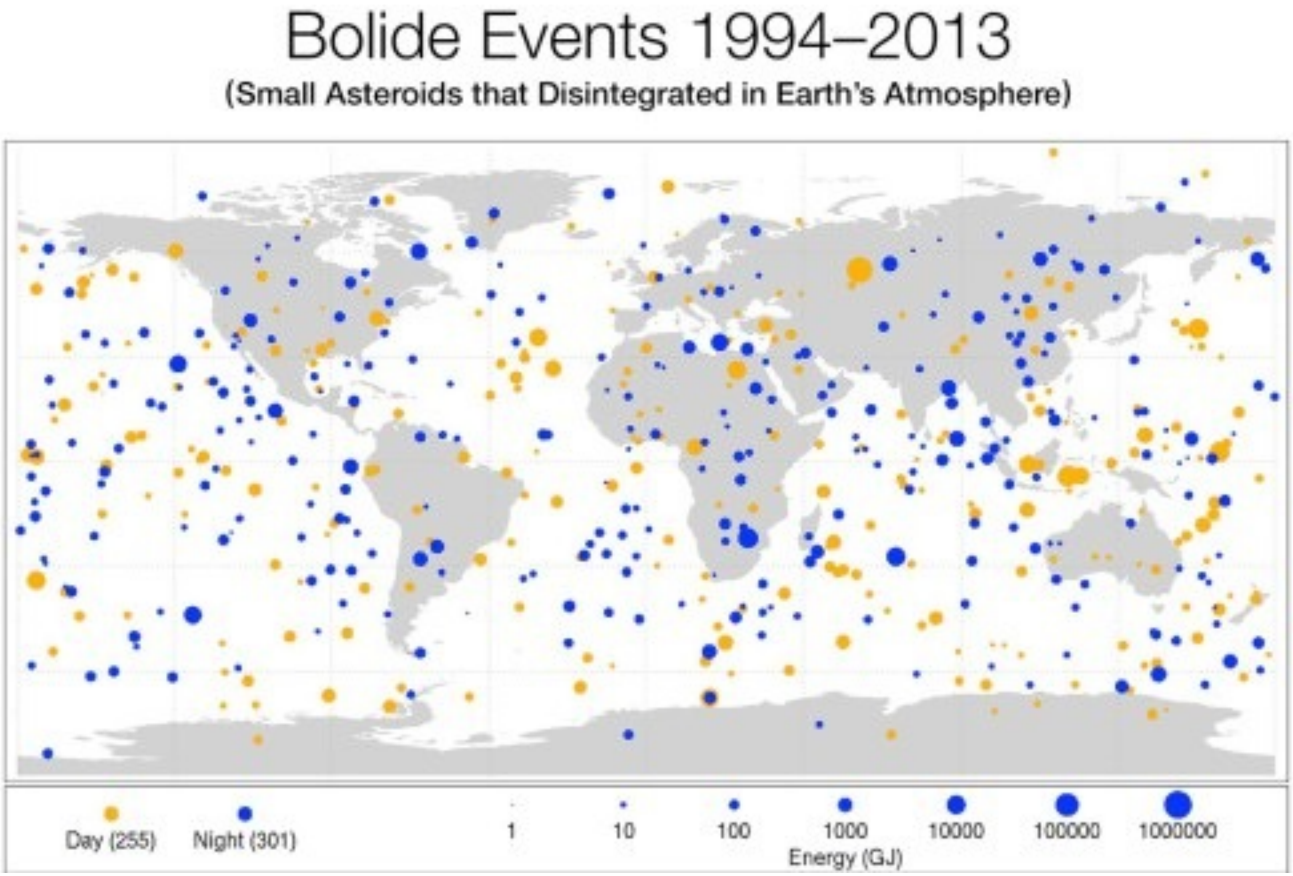
- Tunguska event was a much more powerful impact
- Tunguska like events were initially thought as rare



(Image credits: Tom Epps)

Brief Background to Impact Risks

- New observations and calculations show frequencies are higher (Brown et al. 2013, Werner & Ivanov 2015) than we thought before



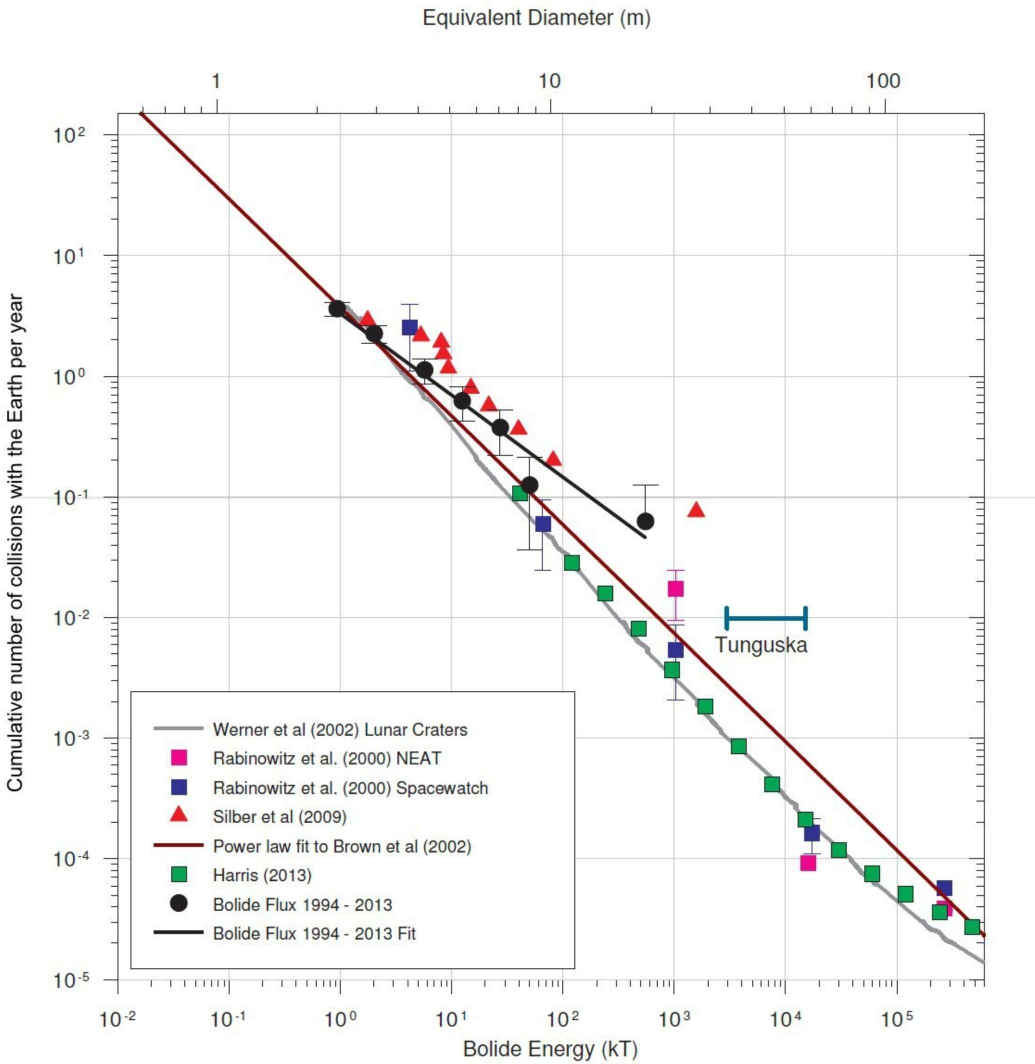
(Image credits: Planetary Science Group, NASA)

Interplanetary Material Entering Earth

- Amount of interplanetary dust influx at Earth per year is substantial & gets enhanced due to meteor storms & outbursts (McNaught & Asher 1999, Asher, Bailey & Emel'yanenko 1999, Jenniskens 2006)

Famous Wood Cut Engraving of 1833 Leonid meteor storm (about 10,000s of meteors per hour)

(Credits: Seventh Day Adventist)



(Credits: Brown et al. 2013, Letters to Nature)

- Tunguska like impactors (~50 m) every 100 years
- Chelyabinsk like impactors (~15 m) every few 10s of years

Improvement in Threat Estimation Models

- Analytical treatments (Valsecchi et al. 2003, Valsecchi 2006)
- Semi-analytical techniques (Opik-Greenberg-Wetherill algorithms)
- Numerical approaches (Full fledge N-body numerical integrations using MERCURY, SWIFT etc)
- Many scientists think dinosaurs got extinct because they didn’t have an active space monitoring & orbital dynamics programme!!!

Dinosaurs’ extinction
(Credits: astrocomics)

Minimum Orbit Intersection Distance (MOID) and Impact Scenarios

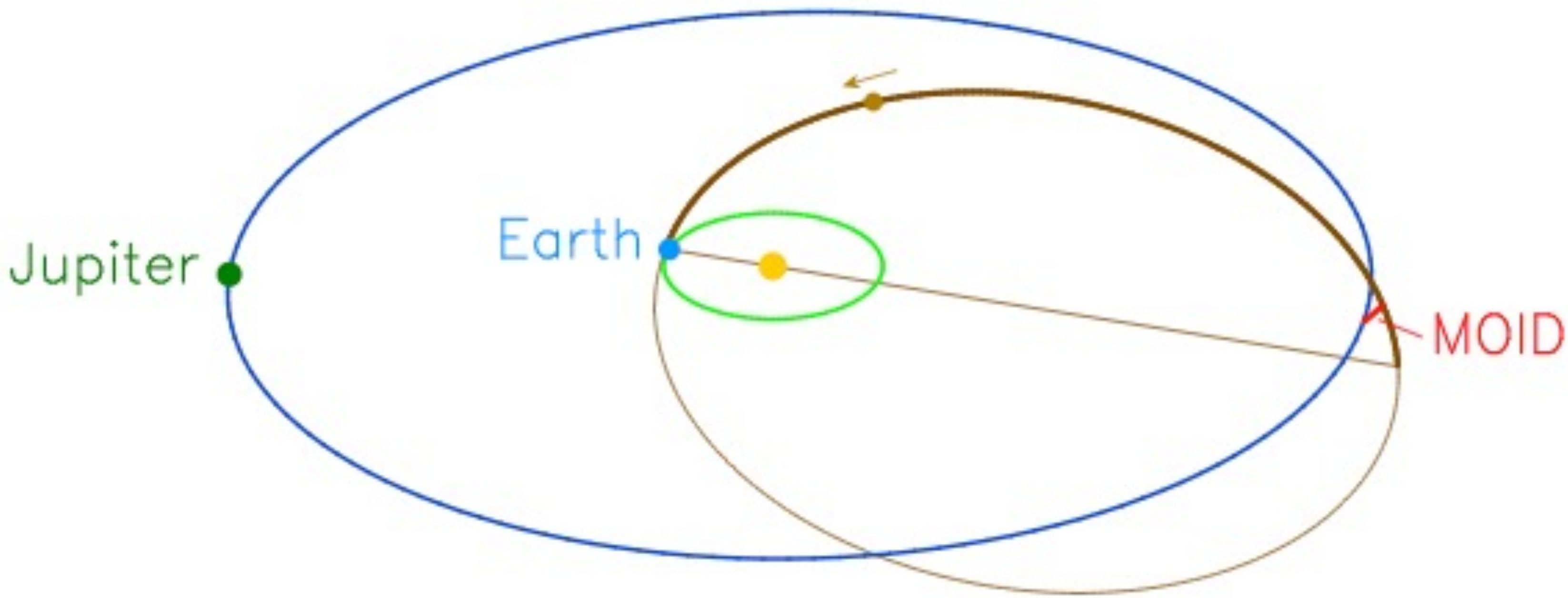


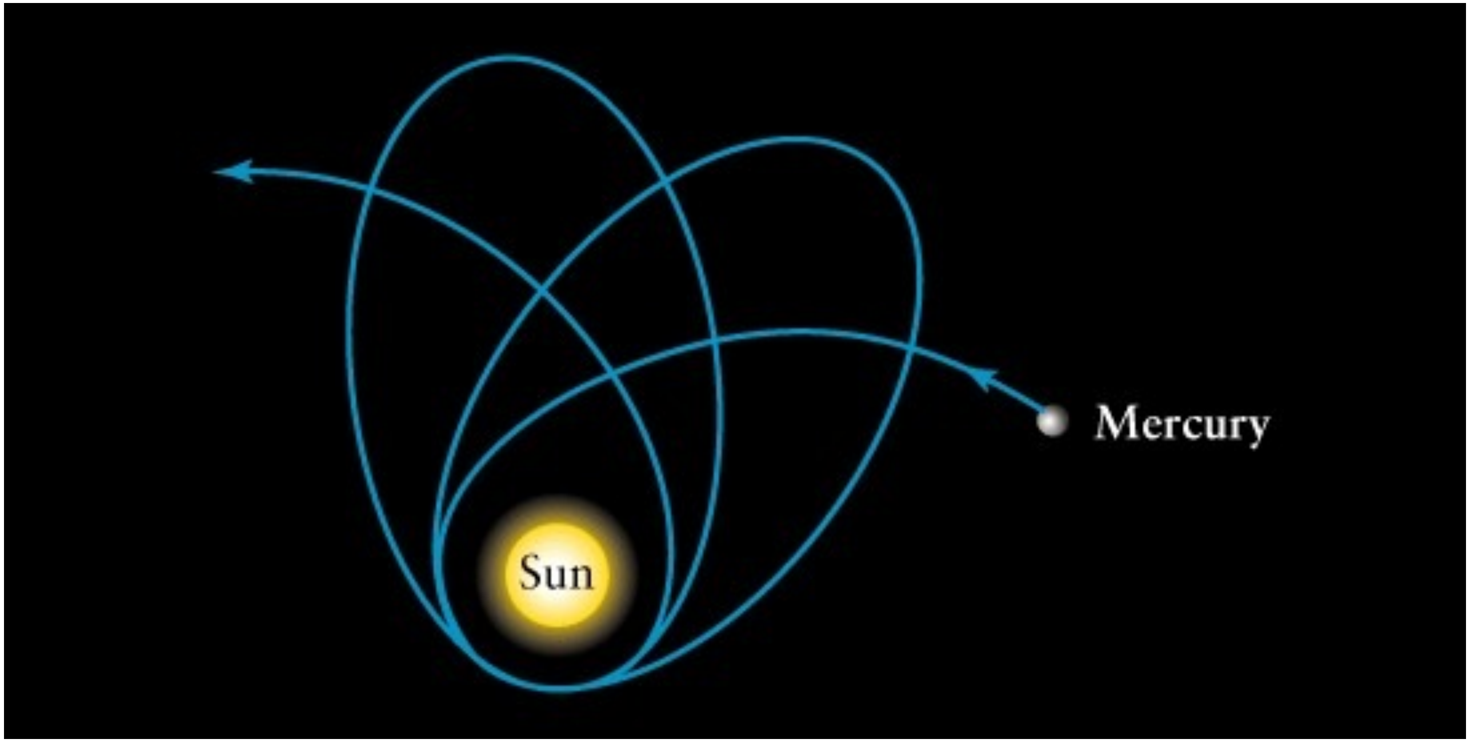
Image Credits:
David Asher, Armagh Observatory

- Calculation of MOID is crucial for assessing close encounter possibilities and geometrical impact scenarios (Valsecchi et al. 2003, Valsecchi 2006)

- Understanding the evolution of MOID over long time frames is important for impact risk assessment

Background to General Relativistic (GR) Precession

- Accurate prediction of the shift of perihelion of Mercury (Einstein 1915)
- Precession in the direction of motion of the body (Weinberg 1972)
- Additional shift of 43 arc seconds per century was predicted by theory and later confirmed from observations



(Image courtesy: Minnesota State University)

Present Project: Inclusion & Exclusion of GR precession effects

- We find that presently there are 264 objects (out of 876 bodies) in the International Astronomical Union-Minor Planet Center (IAU-MPC) database with moderate GR precession

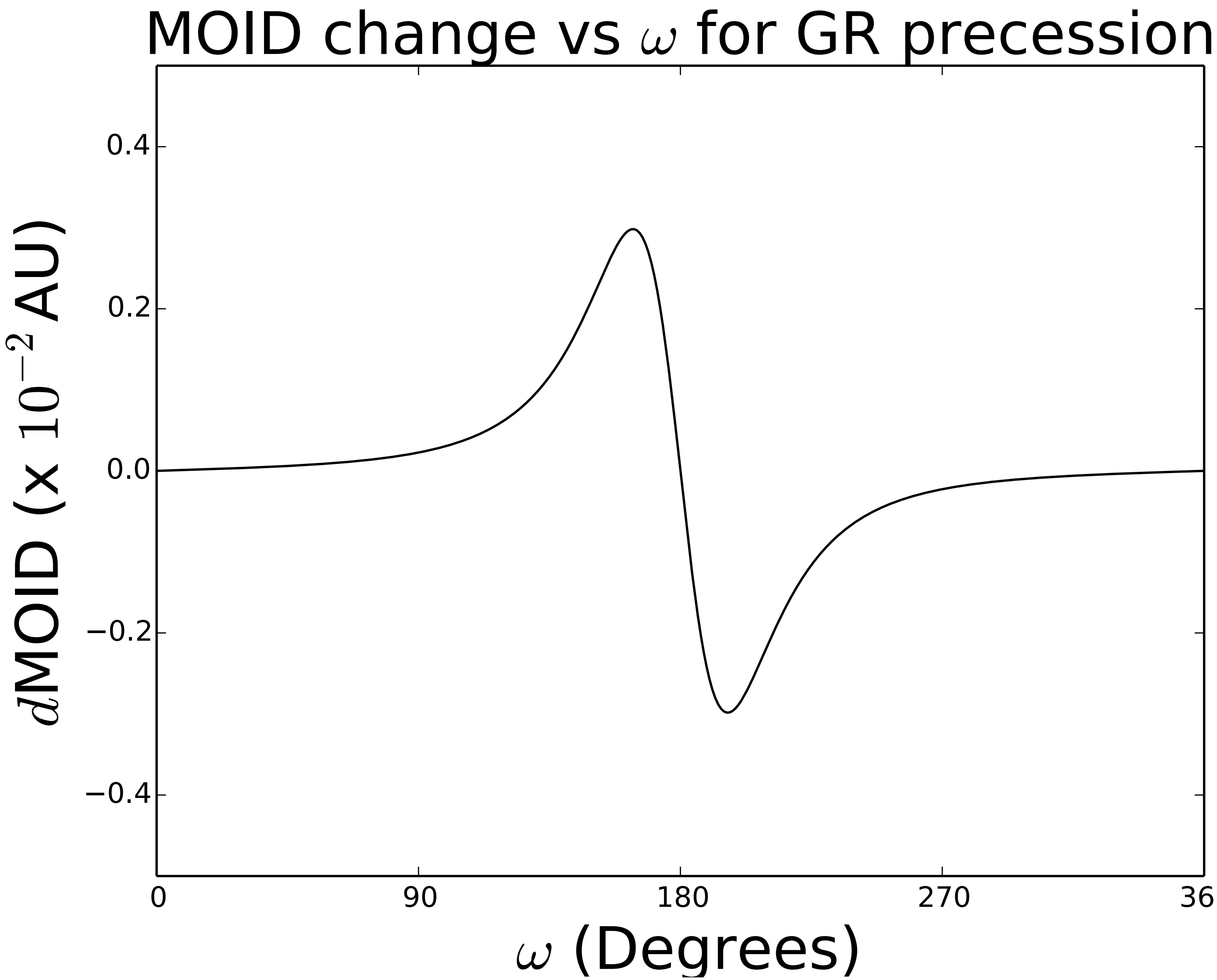
Table shows the GR precession in 10 kyr and the change in Minimum Orbit Intersection Distance (MOID) for present epoch with Earth

Body	q (AU) Perihelion Distance	a (AU) Semi-major Axis	e Eccentricity	Δω (Degrees Precession)	ΔMOID (km)
Icarus	0.187	1.078	0.827	0.28	344,080
Phaethon	0.140	1.271	0.890	0.27	299,200

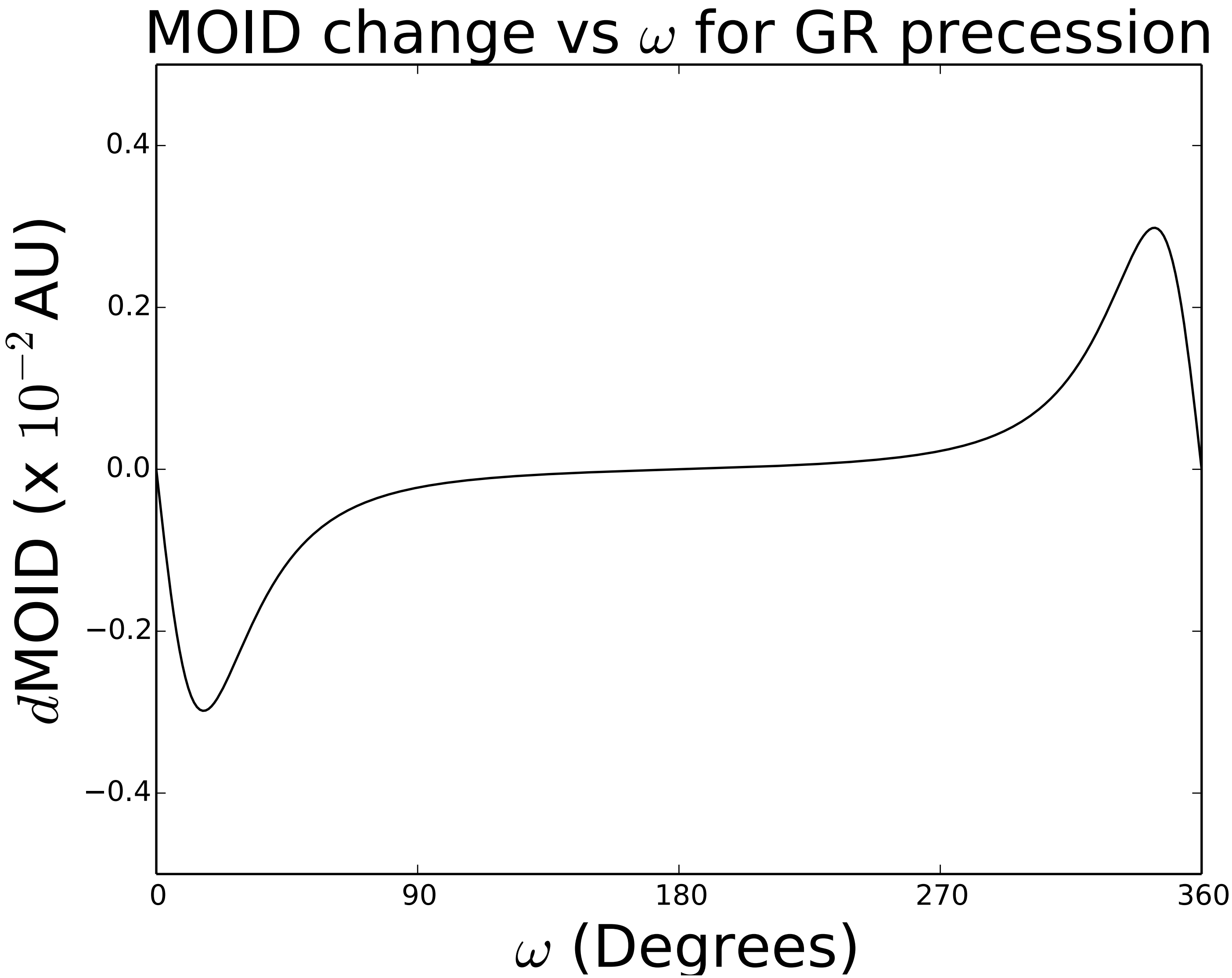
- **The long term MOID changes in some cases (if we neglect GR precession) can be as high as one lunar distance**

Previous works have looked into GR precession in asteroids (Sitarski 1992), comets (Shahed-Saless & Yeomans 1994) and Geminids (Fox, Williams & Hughes 1982, Galushina, Ryabova & Skripnichenko 2015).

Changes in MOID due to GR Precession

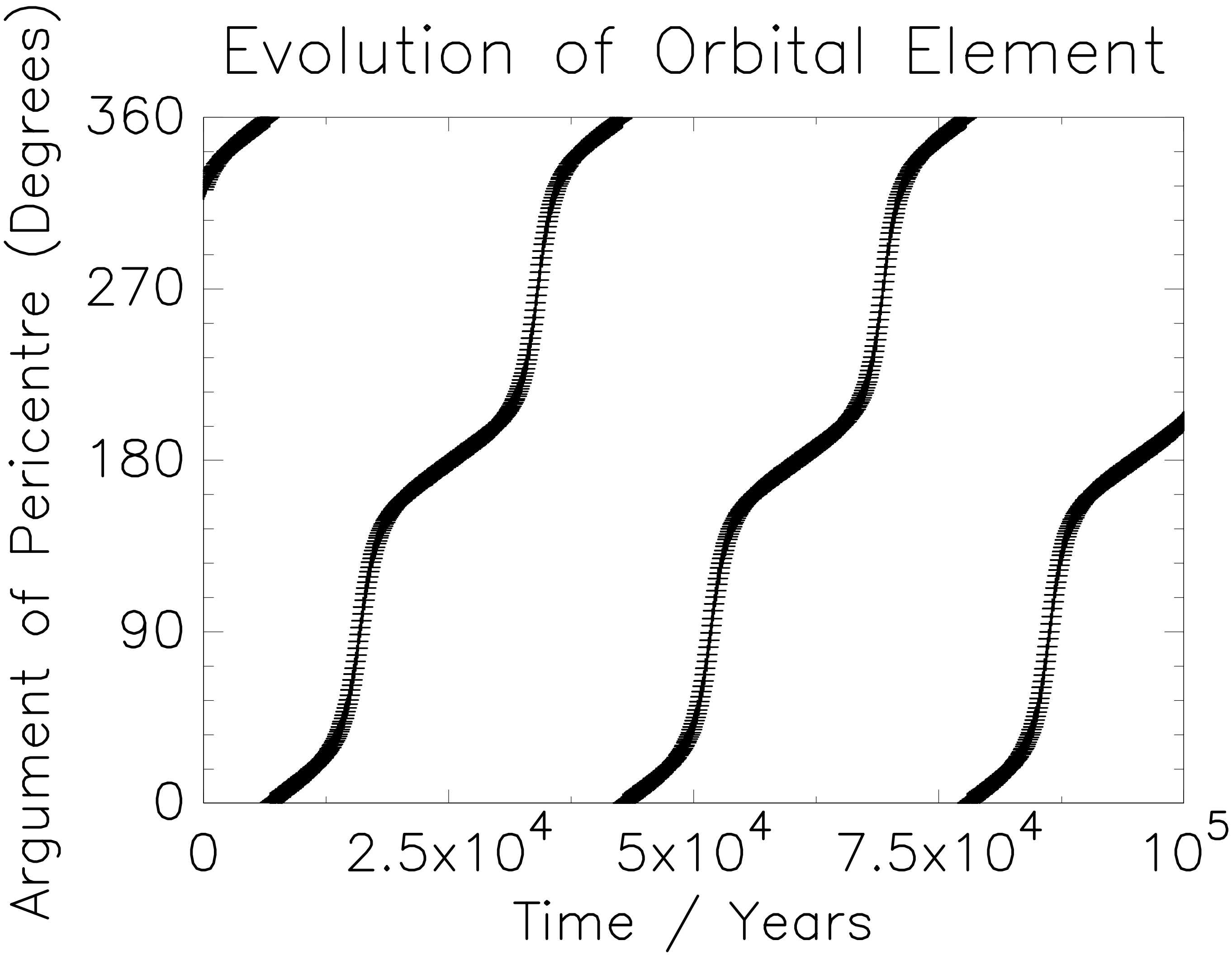


Changes in MOID due to GR Precession



GR Precession vs Kozai Mechanism

- GR precession suppresses Kozai resonances in the bodies discussed (Naoz et al. 2013, Li et al. 2014)



Summary & Future Work

- Exclusion of GR can lead to wrong impact rate estimates and collision predictions on long term evolution for some bodies
- Same applies for low q meteoroid streams like Daytime Arietids, Geminids etc.
- Aim to look for long term impact scenarios from GR active bodies on GR active planet Mercury
- Looking for sub-structures in low q streams where GR precession can be correlated with observed features

CEED
The Centre for Earth Evolution and Dynamics

Crater Clock
University of Oslo
CEED

TAKE AWAY MESSAGE:
Ignoring GR in some cases can lead to wrong impact predictions!

THANK YOU

"According to Einstein's theory, if we move the computer real fast, we can go back in time and recover the files you accidentally deleted."