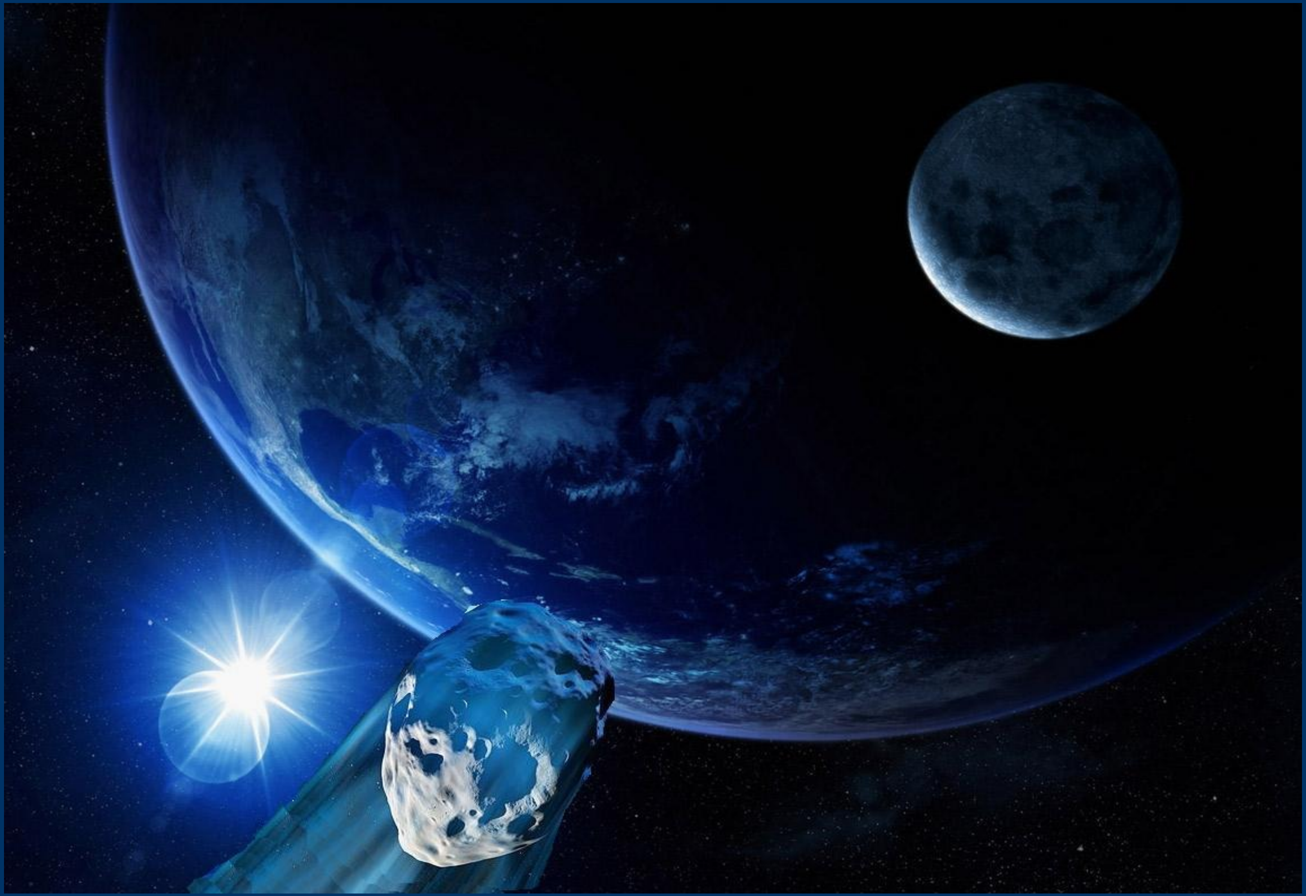
A statistical dynamical study of meteorite impactors: case study from Bosumtwi.



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Doctoral School : “Planetology: From Asteroids to Impact Craters (NEO asteroids and Impact Crater Studies)”

Four PhD students from this doctoral school.
Two positions are dedicated to earth sciences (with Prof. Koeberl, Libowitzky and Ntaflos), and
Two in astronomy (Prof. Dvorak).

- http://lithosphere.univie.ac.at/ik-planetology/doctoral-school/
- http://lithosphere.univie.ac.at/ik-planetology/phd-topics/

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Hypothesis

Orbital elements of an impactor can be reconstructed based on numerical integrations and geological data using a statistical approach

↓

It may be possible to determine the probable origin of impactors for paleo-impact events for which the orbit is unknown.

There are 182 confirmed impact structures on Earth.

Why Bosumtwi?

- Young

  Geological information is relatively fresh

- Relatively large

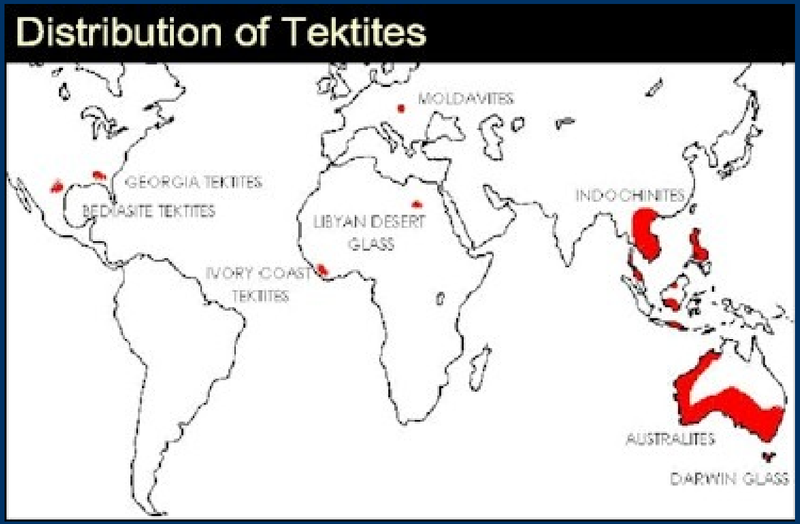
  Importance of study

- Associated with tektites

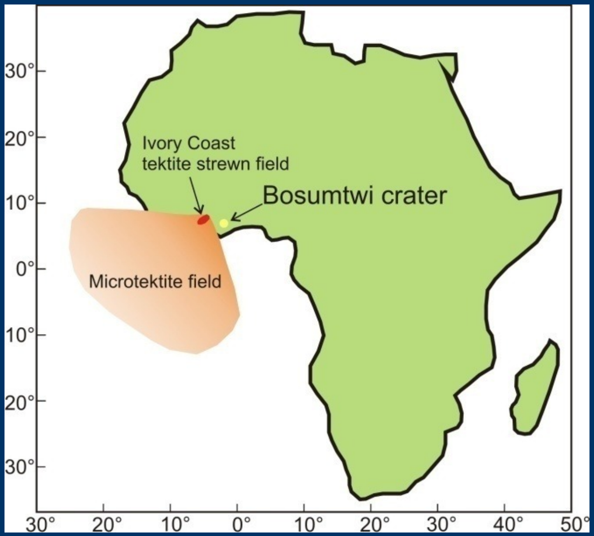
  Properties of impactor can be assesed with more detail.

Ivory Coast tektites

- Tektites – natural glasses ejected from impact craters.

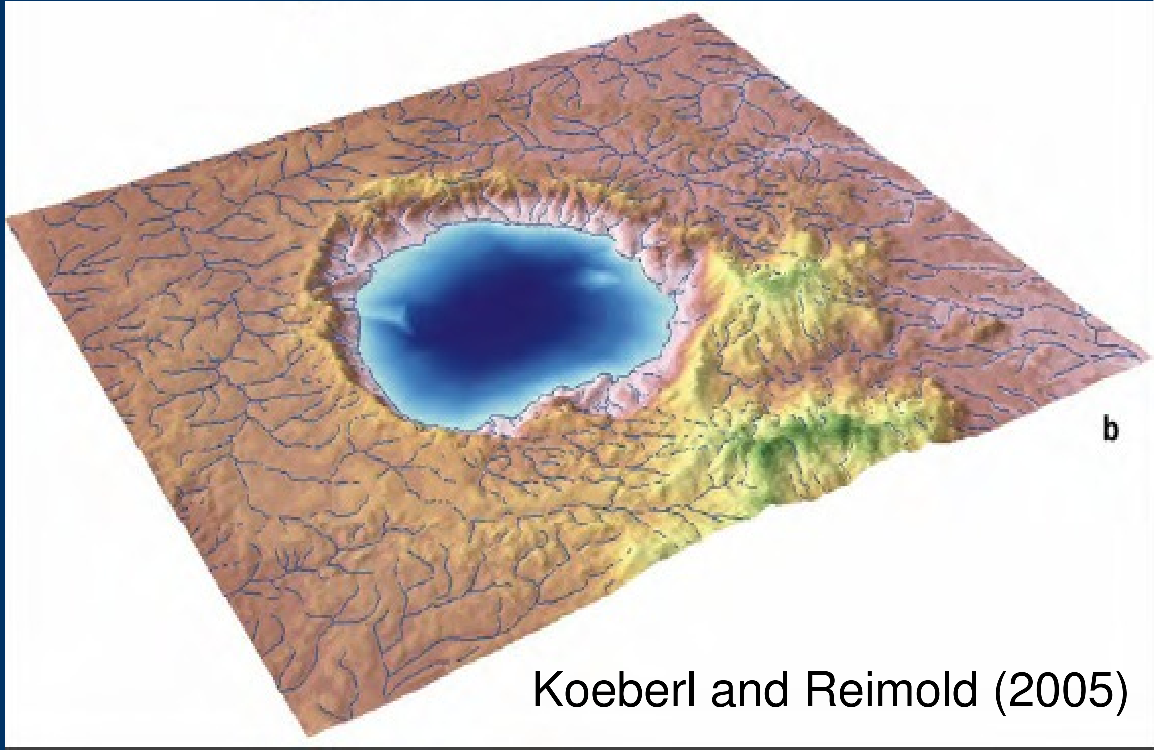


Harris and Tobin (2002)



Bosumtwi crater

- 10.5 km in diameter
- 1.07 Ma old
- Lake is 72 m deep (crater depth is ~450m)
- Complex crater
- ICDP Drilling of Lake Bosumtwi (2004)



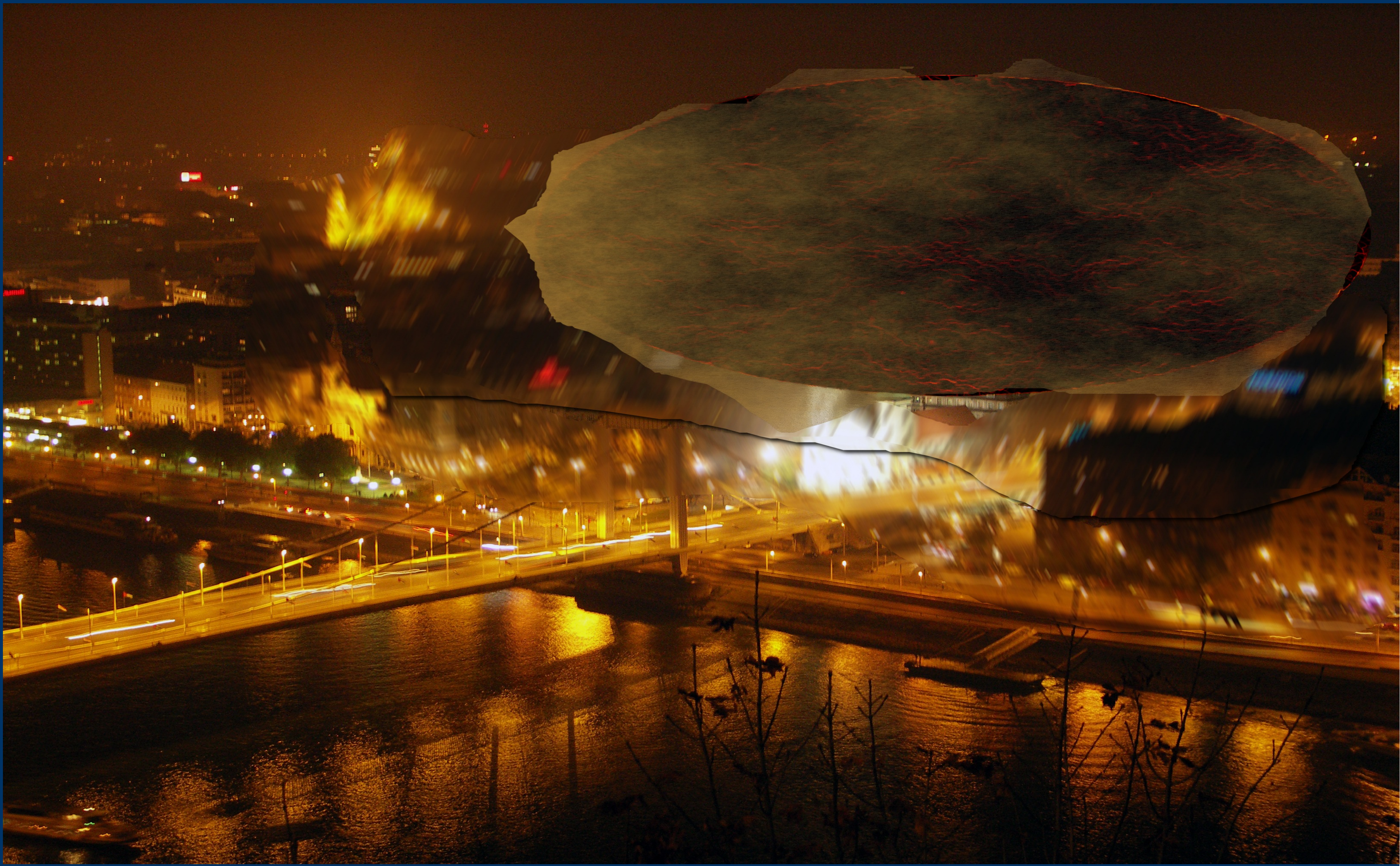
Koeberl and Reimold (2005)

What do we know about Bosumtwi impactor from geological data?

- 0.75 to 1 km in diameter (Artemieva et al. 2004)
- Velocity more than 15 km/s (")
- Incoming direction from N-NE to S-SW (")
- Impact angle 30-45° (")
- Age 1.07 Ma (Koeberl et al. 1997)
- Ordinary chondrite impactor (Koeberl et al. 2007)

How Budapest can be during such an impact: NOW.......

AFTER!



Method

- Initial conditions for the planets: **1.18 My (1.07±0.11)** Backward integration with Radau-Integrator, all planets (+ Moon and Pluto) + Ceres, Vesta, Pallas and Juno + *relativity*

- 2 main cases: backward integration, Lie-integrator for ~100Myr, Venus → Neptune (+ Moon):

  1) *Fixed origin* (known impact point: right position of the Earth in the solar system and of the impact on the Earth).

  2) *General origin* (known parameters, the rest with some distributions that cover a general reasonable case).

Fixed Case

- 384 fictitious impactors:
  (i) 32 different velocities,
  (ii) 4 random impact angles,
  (iii) 3 directions each velocities.

- ”Geocentric” velocities → Gaussian distrib. around 20 km/s (11.2 – 40 km/s and standard deviation=7.2 km/s)

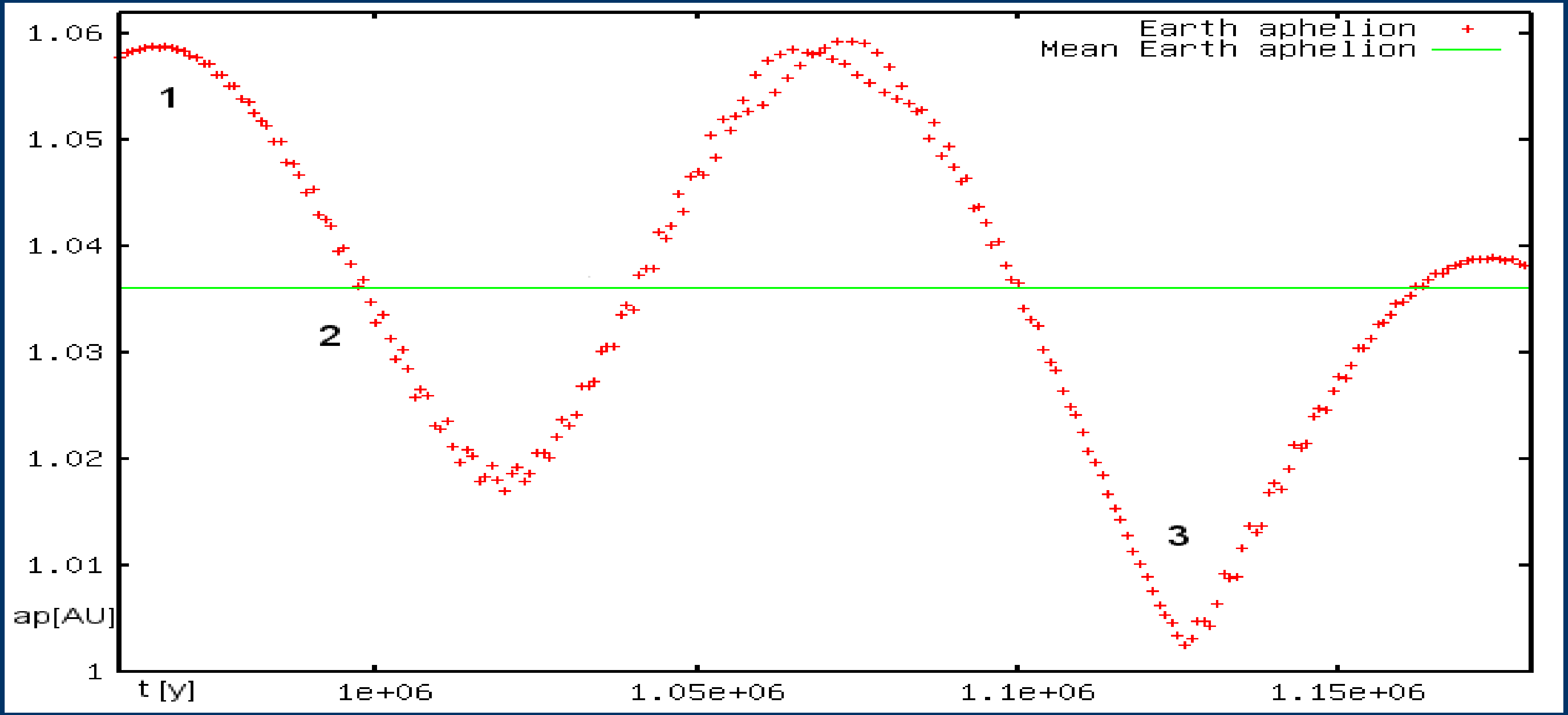
  → v =15 km/s - 40 km/s, random number generator .

- Impact angle random distribution: Θ=37.5°±7.5°
- Directions: 78.75°, 67.5° (NNE), 56.25° from E
- Lat. & long. of present Bosumtwi position.

General Case

- 540 fictitious impactors:

  similar to the “Fixed Case” but with different earth orbital-origin positions: 60 longitude each one with random latitude in a fixed range (lat.$_{\_now}$±1.3°,Laskar, 2004) and 3 different position of the Earth in the Solar System.



Regions and MBA Groups

Inner Main Belt (IMR)	$a \le 2.0641$ AU (J4:1) $p \ge 1.7043$AU(Q_{Mars})	(4081/9022)
MiddleMainBelt (MMR)	$2.0641 < a < 3.2766$ AU (J2:1)	(114338/552939)
Outer Main Belt (OMR)	$3.2766 \le a < 5.0500$AU	(202/7986)
Jupiter Trojans (TRO)	$5.0500 \le a \le 5.3500$AU	(5/5190)
Centaurs (CEN)	$5.3500 < a \le 30$ AU	(3/357)
TransNeptunians (TNOs)	$a > 30$ AU	(1/1482)

Groups inside main belt→ Zappalà 1990

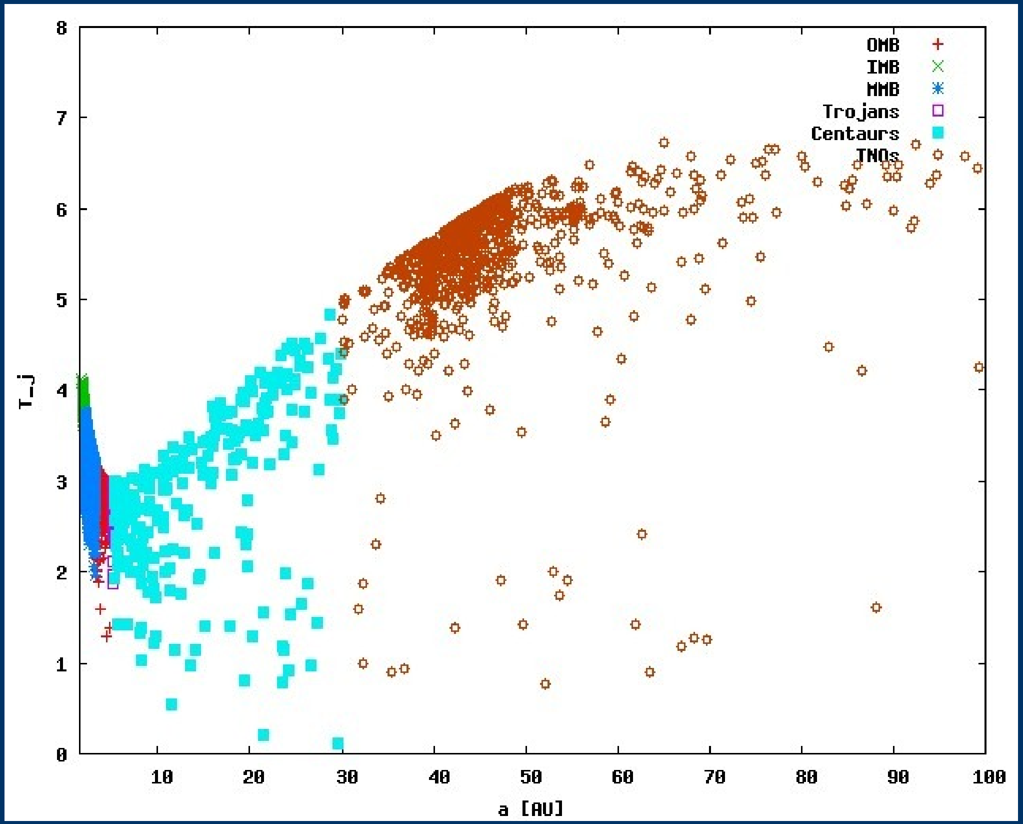
(Data from astorb.dat → Minor Planet Center)

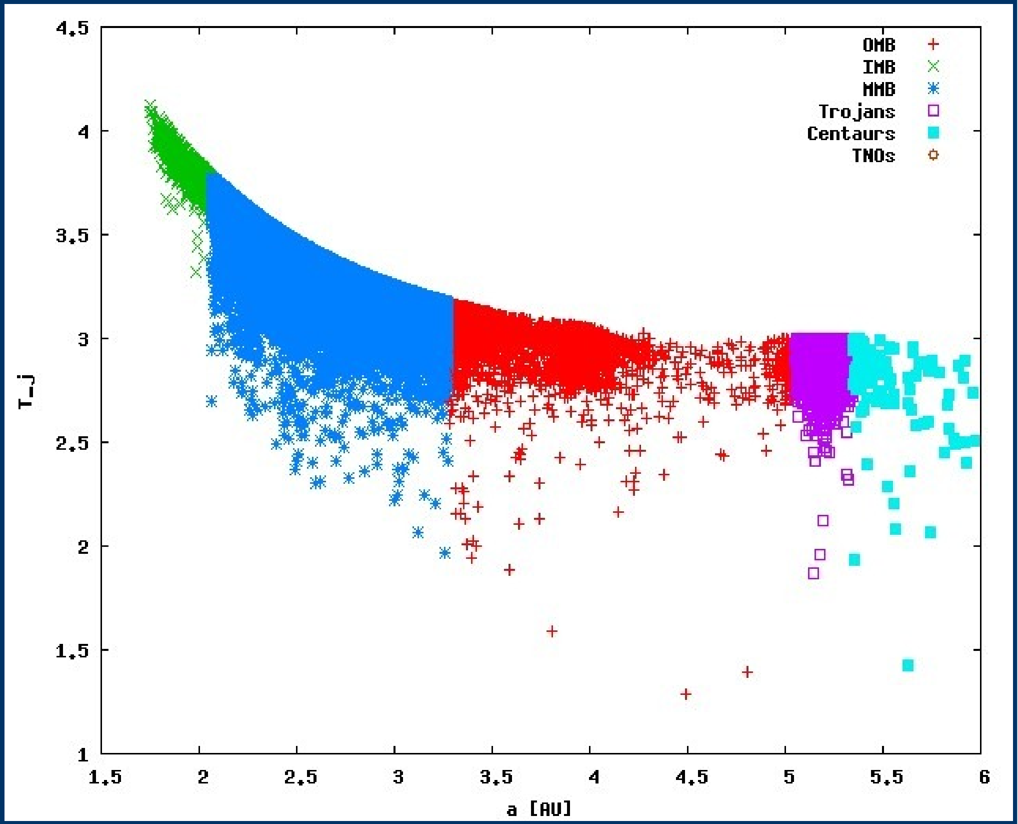
Origin via Tisserand Parameter + Spectra Types + Absolute Magnitude

$$T = a_p/a + 2[(1-e)^2 a/a_p]^{1/2} \cos i$$

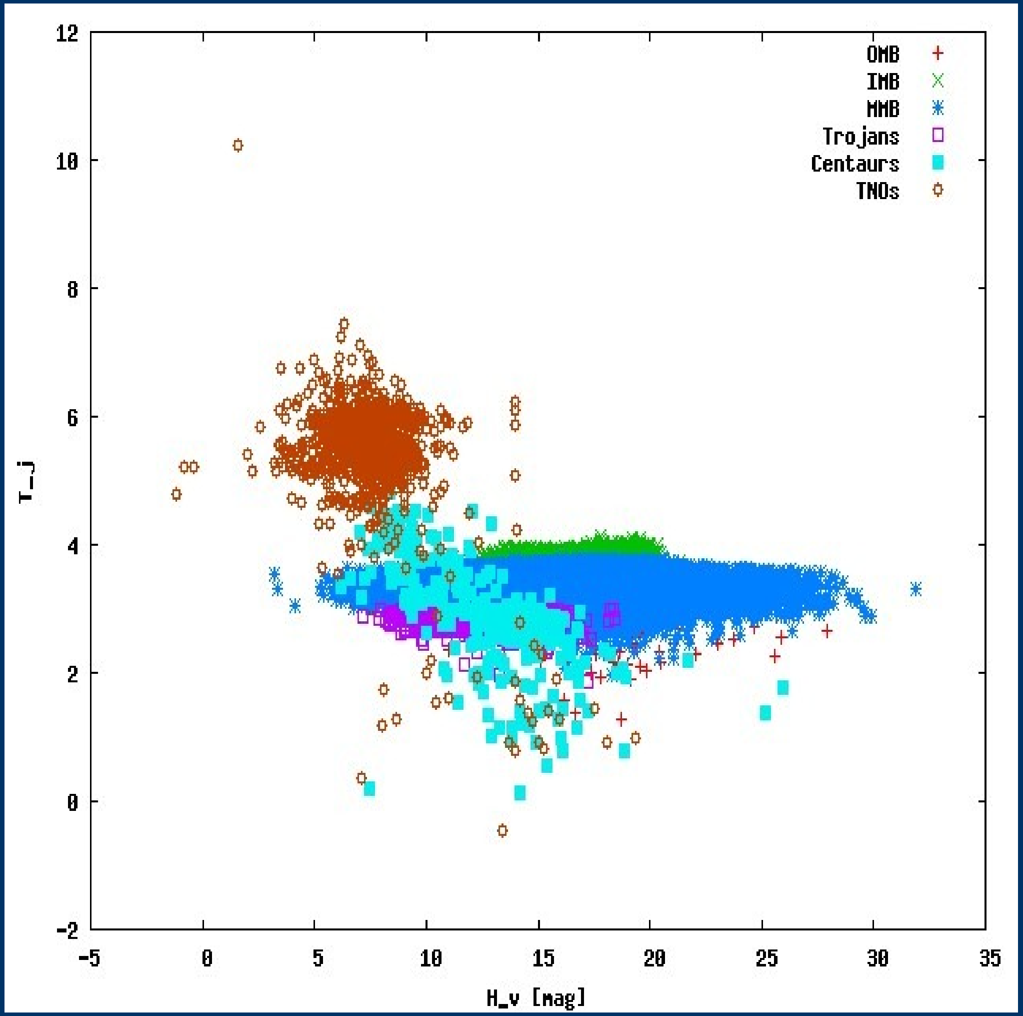
The Tisserand Parameter related to the impactor inside the range of a Region. If Main Belt, we will watch inside relatives groups (Hungaria, Flora, Vesta etc.).

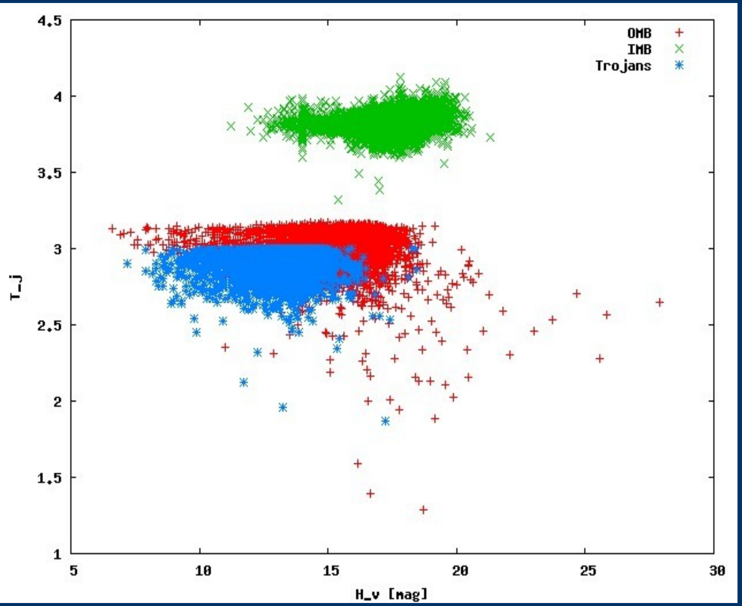
T_j *vs a between the Regions*

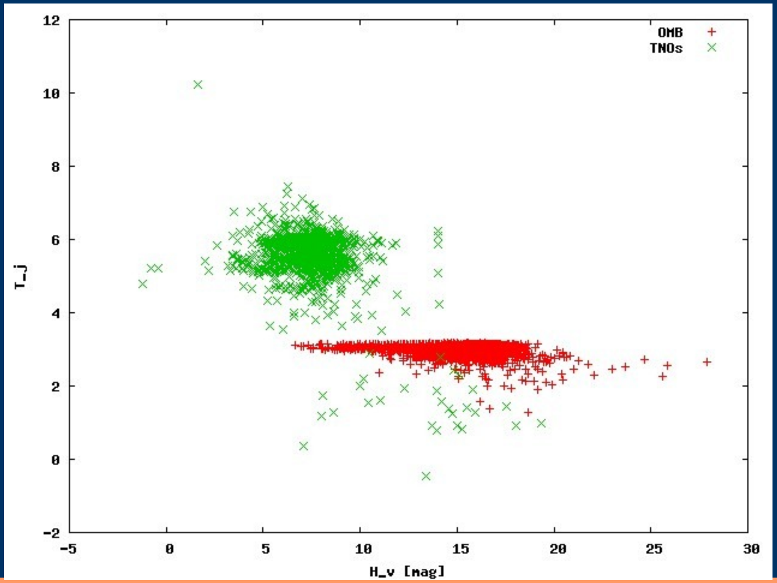




T_j *vs* H_v *between the Regions*







Methods for results

- **Tast-criterion** (Galiazzo et al. 2012):

(Tisserand parameter + spectra types of similar dynamical bodies + size (H_v) + statistics & probability).

- D-criterion (for meteorites):

$$D=(a_1-a_2)^2/3+(e_1-e_2)^2+(2\sin[(i_1-i_2)/2])^2$$

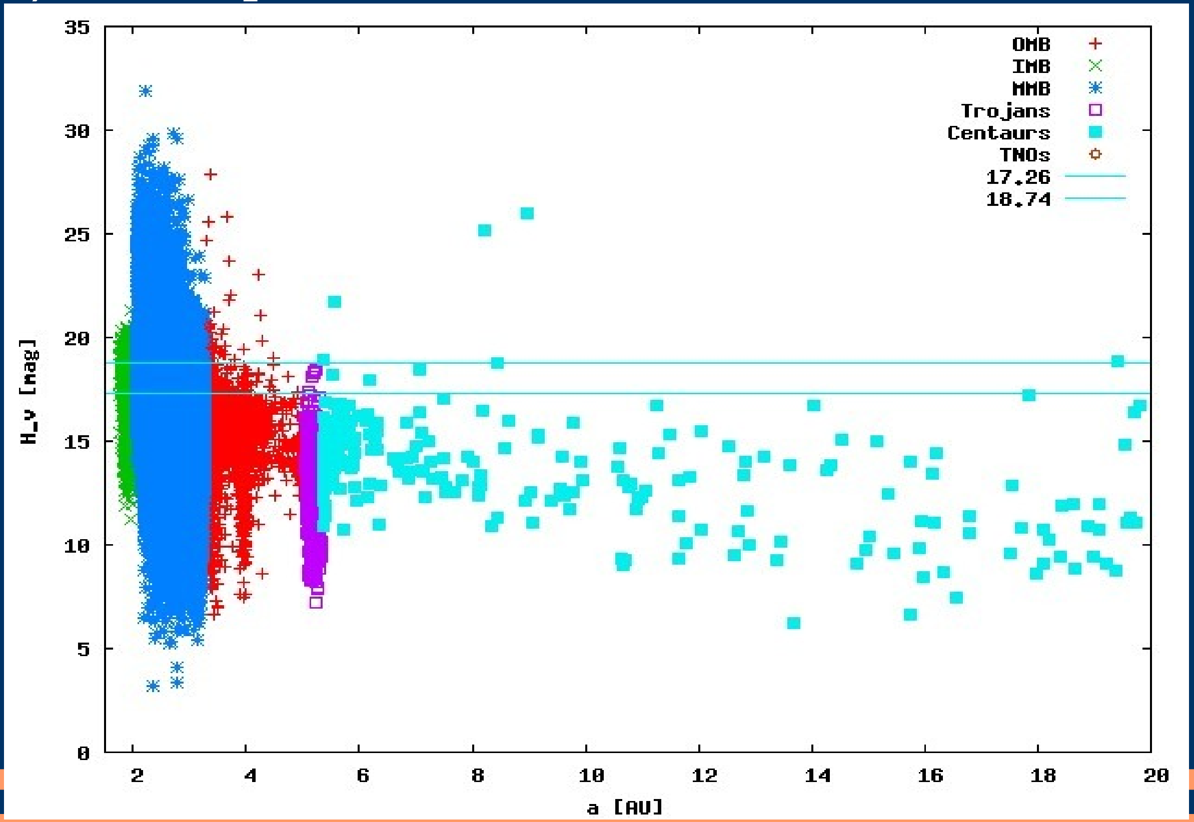
and plot vs longitude of perihelion.

Results via Photometry+Geology

***H_v_Maakmaan (min – max) = 17.26 -18.74 mag_V (S-type albedo 0.11 -0.22)

$H\_v = -5 \times \log_{10}[(D\ p_v^{1/2})/1329]$ (via Fowler and Chillemi, 1992)

IMB: 45.2%
MMB: 20.7%
OMB: 2.5%
TRO: 0.1%
CEN*: 0.8%
TNO*: <0.1%



Results via Celestial Mechanics

- Probability for the impactor-Tj inside the Regions_Tjs.

$P_{IMB}=0.0133$

$P_{MMB}=0.0299$

$P_{OMB}=0.0000$

$P_{CEN}=0.0109$

$P_{TNO}=0.0000$

Preliminary results.

Results from Spectroscopy

Spectra types:Ordinary chondrites are associated to S-types (personal communication with Dr. Magrin – University of Padova) asteroids. They are predominant in the IMB, so the most probable origin is from the IMB and in particular from the:

1) **<u>Flora-Ariadne</u> group** (Florczak et al. 1998)
2) **Hungaria region, 17% of them** (Warner at al. 2009).

Then less probable, but not to exclude

3) MMB and OMB, in particular: Eunomia-,Maria, Koronis-,Gefion-,Agnia-group (Cellino et al. 2002).

Jupiter Trojans rejected: H_v << (so size>>) + predominance of non - S-types (Bendjoya 2004)

CONCLUSIONS

- **Most likely origin of the Bosumtwi impactor is the IMB. (Probably Flora group or there is also an important percentage for high inclined groups in the IMB).**

- But........

- Work in progress: Results from 55% of the entire sample of (only) the "Fixed-case" (Fixed physical parameters as today). So......

Conclusions' considerations

***Uniting all the results with an opportune statistics (i.e. bayesian statistics): more confident probabilities (so conclusions) on the origin from the singular osculating elements and Tisserand-Parameter at least after 20-30Myr of orbits' integration → deeper discrimination → asteroids families/groups + especially from the general case.

Who is blonde HERE?

⧫⧫THANK YOU!KOSZONOM!GRAZIE!⧫⧫

Each Dynamical Group has its own favorite "Motorway" (resonance) to arrive HERE!

- MMRs and SRs in the asteroid belt per Gladman 1997. (Family → **J2:1, J3:1, $\boldsymbol{\nu}_6$** ecc.)
- *Michel 1997: SR in the asteroid belt 1.36 < a < 3.5 and e_x =0.1 (i≲30 : $\boldsymbol{\nu_2, \nu_3, \nu_4, \nu_5}$; 1.5<a≲1.8 : $\boldsymbol{\nu_{14}, \nu_{13}}$; a>2.05 and I < 22° : $\boldsymbol{\nu_6}$)
- Milani 2010: $\boldsymbol{\nu_{16}}$, 3:1, **2° SR** → Hungarias
- Carruba 2011: Vesta, **3bMMR** and non-linear SR.

Statistical study on orbits in resonances.