

Feature Articles

New Constraints on the Asteroid 298 Baptistina, the Alleged Family Member of the K/T Impactor

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Abstract

Bottke *et al.* (2007) suggest that a member of the Baptistina asteroid family was the probable source of the K/T impactor that ended the reign of the dinosaurs 65 Ma ago. Knowledge of the physical and material properties pertaining to the Baptistina asteroid family are, however, not well constrained. In an effort to begin addressing the situation, data from a collaboration of international observatories were synthesized to determine the rotational period of the family's largest member, asteroid 298 Baptistina ($P_R = 16.23 \pm 0.02$ hrs). Discussed here are aspects of the terrestrial impact delivery system, implications arising from the new constraints, and prospects for future work.

Dans leur rapport, Bottke *et al.* (2007) suggèrent qu'un astéroïde de la famille des Baptistinas est tout probablement la source de l'impact du K/T qui a mis fin au règne des dinosaures environ 65 millions d'années passées. Les connaissances des propriétés physiques et matérielles de la famille des astéroïdes Baptistinas sont plutôt limitées. Afin de pouvoir aborder cette situation, les données provenant de la collaboration d'observatoires internationaux ont été synthétisées pour déterminer la période de rotation du plus grand membre de la famille, l'astéroïde 298 Baptistina ($P_R = 16.23 \pm 0.02$ hs). Ce rapport examine les éléments du système de livraison de l'impact terrestriel, les conséquences de ces nouvelles contraintes et les perspectives de recherches à l'avenir.

Introduction

In this study, we begin by reviewing a scenario by which asteroids can escape otherwise benign orbits in the Main Belt and potentially strike Earth, we then revisit several lines of evidence put forth by Bottke *et al.* (2007), linking the asteroid 298 Baptistina to the terrestrial impactor that ended



Figure 1 — A cataclysmic encounter between Earth and a large asteroid as envisioned by artist / astronomer Inga Nielsen.

the reign of the Dinosaurs 65 Ma ago, and lastly, we provide observations that place new constraints on 298 Baptistina's rotational period and geometric morphology.

Terrestrial impactors (asteroids and comets) have been suggested to play a major role in modulating the existence of life on Earth, as the dating of craters linked to kilometre-sized impactors at Popigai and Chesapeake Bay, Chicxulub (Hildebrand 1993), and Morokweng and Mjølnir strongly correlate in age with three of the last major global extinctions (late-Eocene, Cretaceous-Tertiary, and Jurassic-Cretaceous respectively). Indeed, readers can view images of the corresponding impact craters at the *Earth Impact Database* (www.unb.ca/passc/ImpactDatabase), which is maintained by the Planetary and Space Science Centre at the University of New Brunswick.

One of the challenges, undoubtedly, is to explain how such impactors transition from otherwise benign orbits in the Solar System to become near-Earth objects (NEOs). Historically, it has been suggested that the cause of such extinctions may

be linked to an influx of comets by means of a perturbation of the Oort Cloud, a spherical zone of loosely bound comets thought to encompass the periphery of the Solar System. A litany of possible causes have been put forth as catalysts for such a perturbation, most notably density gradients (stars and the interstellar medium) encountered as the Sun travels throughout the plane of the Milky Way during its revolution about the Galaxy, or interactions with a suspected substellar companion to the Sun (Nemesis). Certain ideas are advocated because they inherently assume a periodicity to mass-extinction events, although unproven, rather than stochastic punctuations. A different impact delivery system, revisited below, is based primarily on orbital resonances, and favours a reservoir of projectiles from the asteroid belt located between Mars and Jupiter, in addition to comets from the Kuiper Belt and Oort Cloud, the former extending beyond Neptune from 35 AU to 50+ AU.

Resonances

Large bodies can be delivered from both belts into Earth-crossing orbits by means of resonances (secular and mean motion). Formally, a resonance occurs when the orbital periods of two bodies are commensurate (ratios of integers). For example, an asteroid that is near a 2:1 resonance with Jupiter will orbit the Sun twice for each orbit that Jupiter completes. Most importantly, asteroids near resonances may

(or Mars) are indeed devoid of asteroids (Kirkwood Gaps, Figure 2), securing the resonance phenomenon as a feasible mechanism for transporting objects from the belt. Inevitably, a fraction of the asteroids depleted by orbital resonances become near earth objects (NEOs)

A distribution analogous to the Kirkwood Gaps is also noted in computational models of the Kuiper Belt (Majaess 2004), where Neptune plays a major role in scattering comets. Moreover, simulations confirm that comets from the region could then enter other planet-crossing orbits, although the relevant impact probabilities are difficult to constrain because firm statistics on the Kuiper Belt's comet population lie beyond present limits of solid observational data. *The James Webb Space Telescope (JWST)*, scheduled for launch in 2014, and the ongoing Canada-France Ecliptic Plane Survey (CFEPS) should place firmer constraints on the Kuiper Belt demographic. Indeed, many Canadian astronomers and institutions are active partners in *JWST* (*i.e.* John Hutchings, NRC-HIA & René Doyon, Université de Montréal) and CFEPS (*i.e.* J.J. Kavelaars and Lynne Jones, NRC-HIA & Brett Gladman, UBC).

The Yarkovsky Effect

The Yarkovsky Effect (YE) is another component of the delivery system that can work to enhance the transport of asteroids (or comets) into resonances, essentially increasing the possibility that bodies not near resonances may eventually arrive at such locations. In its simplest form, the canonical YE arises from a temperature differential between the sunlit and dark sides of a rotating object exposed to the Sun. Thermal energy from the object is reradiated asymmetrically, causing the body to experience a thrust that may result in an outwards or inwards orbital migration, depending upon its sense of rotation and the direction of the resulting rocket force (see Rubincam (1998) for details).

The YE also allows constraints to be placed on the ages of asteroid families (Vokrouhlický *et al.* 2006) — which is used below to connect the Baptistina asteroid family to the K/T impactor — although such a framework is still in its scientific infancy. The force causes smaller asteroids to undergo a greater orbital migration in comparison with larger bodies, producing a characteristic distribution in semi-major axis space (see Figure 1, Bottke *et al.* 2007). Computer simulations can then determine at what time after the fragmentation of a parent body is the present day distribution of an asteroid family reproduced satisfactorily. Such analyses depend on knowledge of several different parameters, which in the case of the Baptistina asteroid family (BAF) are not well established, as discussed below. Lastly, it is noted that the YE has been invoked to describe the motion of asteroid 6489 Golevka (Chesley *et al.* 2003), and additional efforts to assess and confirm the effect are forthcoming.

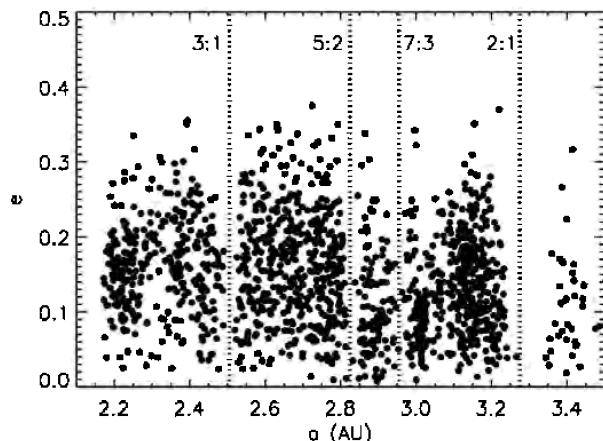


Figure 2 — The distribution of main-belt asteroids in semi-major axis (a) and eccentricity (e) space. Zones devoid of asteroids correlate with strong resonances.

experience periodic perturbations from a planet that could lead to an increasing eccentricity and a subsequent close encounter, resulting in the asteroid being gravitationally scattered. Observations confirm that areas in the Main Belt associated with strong resonances with the orbit of Jupiter

Summary

In sum, a three-component terrestrial impact delivery system could begin in the Belt, near a resonance, with the fragmentation of a parent body (*e.g.* by means of a collision) that spawns hundreds of smaller asteroids, thereby augmenting the statistical probability and likelihood of a terrestrial impactor. After fragmentation, a particular asteroid could then enter a nearby resonance, or drift there by means of the YE, where it may be scattered by a planet into an Earth-crossing orbit.

The Alleged Baptistina/KT Impactor Connection

In harmony with the delivery model revisited above, Bottke *et al.* (2007) postulate that the Baptistina asteroid family formed from the catastrophic breakup of its progenitor approximately 160 Ma ago, following which some debris entered a nearby resonance, leading eventually to the ejection of what would inevitably become the K/T impactor. Their proposal is argued, based in part (the reader is also referred to the comprehensive supplemental texts that accompany the Bottke *et al.* (2007) paper), on the following lines of evidence: (i) the asteroid family is located near a resonance capable of delivering passing asteroids into planet-crossing orbits. (ii) The purported destruction of the parent body 160 Ma ago, an age inferred from sorting the asteroids into orbital parameter space according to the YE, created a prodigious supply of BAF members that inevitably populated the NEO demographic, consistent with an alleged increase in the terrestrial impact rate during the same era. It should be noted, however, that the terrestrial record of impacts suffers from poor statistics owing to the subsequent erosion of craters with time, complicating any statistical interpretation. (iii) The K/T impactor and BAF share a similar composition (C-type). Yet the results of Reddy *et al.* (2008) appear to imply otherwise (*at least vis à vis* the family's largest member, 298 Baptistina), and moreover, the suggested C-type composition of BAF members would not be unique; such asteroids are found throughout the belt.

The final conclusions are based on statistical grounds, namely what is the probability that the impactor was a fragment from the creation of the BAF rather than a random C-type asteroid (or background population)? Bottke *et al.* (2007) suggest that there is a 90 percent chance that the K/T impactor was a BAF member, and that one or more BAF members of size $d \geq 10$ km impacted Earth in the past 160 Ma. Readers should be aware that contributions from the background population are difficult to assess. In addition, accurate modeling of the YE requires knowledge of both physical and material properties that are conducive to BAF members, sensitive parameters that are poorly constrained and require further research by the community at large. Indeed, the rotational period derived here for BAF member 298 Baptistina ($P_R = 16.23 \pm 0.02$ hrs, see below) is a factor of three greater than

the value used in the simulations, although Bottke *et al.* (2007) adopted a value that may be consistent with smaller-sized BAF members ($P_R \cong 6 \pm 2$ hours, Pravec & Harris (2000), Pravec *et al.* (2002)). The difference in rotational periods noted above is sufficient to warrant additional investigations to confirm the mean rotational period and material properties conducive to kilometre-sized BAF members. Such work needs to be pursued in conjunction with increasing the number of known family members and reaffirming the family's taxonomy. Efforts to secure such parameters will invariably lead to stronger constraints on the properties of family members and might permit a more confident evaluation of whether the source of the K/T impactor was indeed a ~ 10 -km sized BAF member. Lastly, and *most importantly*, irrespective of the conclusion regarding the putative source of the K/T impactor, the approach outlined by Bottke *et al.* (2007) provides the quantitative framework and a pertinent example needed to effectively characterize the terrestrial impact delivery system.

Observations

Asteroid 298 Baptistina was discovered over a century ago, in September 1890, by the French astronomer Auguste Charlois. The origin of the asteroid's designation (Baptistina) is unknown, an uncertainty that is also representative of the asteroid's rotational period, morphology, size, *etc.* A need to establish such parameters inspired the present study, especially in light of the asteroid's reputed status. Asteroid 298 Baptistina was therefore observed throughout March and April 2008 from the Abbey Ridge Observatory (ARO, Halifax, Canada), the Hunter Hill Observatory (HHO, Canberra, Australia), and the Calvin-Rehoboth Observatory (CRO, New Mexico, USA). Details regarding the observatories can be found elsewhere in Lane (2007) and Majaess *et al.* (2008) (ARO), Higgins *et al.* (2006) (HHO), and Molnar & Haegert (2007) (CRO). Image pre-processing and differential photometry were performed using *MPO Canopus* (Warner 2006) and *MaximDL* (George 2007).

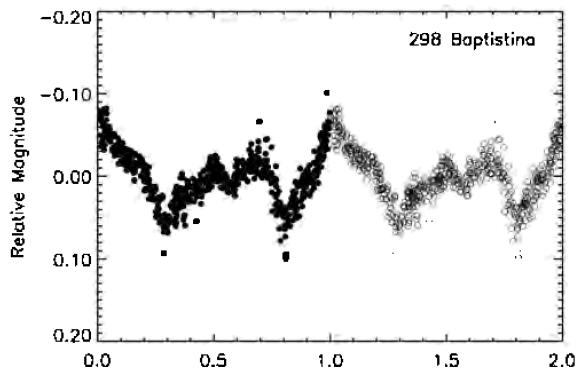


Figure 3 — The light curve for 298 Baptistina phased with a period of $P_R = 16.23 \pm 0.02$ hours.

The asteroid's large proper motion required the selection of different reference stars on each night (Warner 2006, Henden & Kaitchuck 1998), consequently the FALC algorithm was employed to search both magnitude and temporal space for a period solution (Harris *et al.* 1989). The period analysis was carried out in the *MPO Canopus* (Warner 2006) and *Peranso* (Vanmunster 2007) software environments.

A rotational period of $P_R = 16.23 \pm 0.02$ hours was determined for 298 *Baptistina* from the analysis, and the resulting phased light curve is presented in Figure 3.

The light curve exhibits a peak-to-peak amplitude of ~ 0.15 magnitude and displays complex characteristics that are likely indicative of irregular surface features. Continued photometric observations are envisioned to refine the rotational period, and in conjunction with archival observations by Wisniewski *et al.* (1997) and Ditteon & Hawkins (2007), to model the asteroid's shape and spin axis by light-curve inversion (Molnar & Haegert 2008, Kaasalainen & Torppa 2001). The data will also permit a detailed study of the asteroid's absolute magnitude and oppositional surge, fundamental for any subsequent research. Thermal imaging and spectroscopic follow-up would also be of value, permitting a precise determination of the asteroid's diameter and confirmation of its taxonomical class (e.g. Reddy *et al.* 2008). This paper's referee has estimated that 298 *Baptistina* may be *approximately* 20 km in size, which follows from the standard formula utilizing albedo (Reddy *et al.* 2008) and the H-magnitude.

Lastly, the present study appears to reaffirm the importance of small telescopes in conducting pertinent scientific research (Percy 1980, Turner *et al.* 2005). Indeed, modest telescopes can even be mobilized to help address questions surrounding the extinction of the dinosaurs.

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