An Asteroid Shower Over the Cretaceous Period

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(with thanks to David Vokrouhlicky and David Nesvorny)
**Motivation**

- **Question.** How do big disruption events in the asteroid belt affect the impact flux on the Earth and Moon?

- The answer involves understanding these issues:
  - Nature and timing of breakup events in the asteroid belt.
  - Asteroid evolution and delivery to the inner Solar System.
  - Impact record on the Earth and Moon. Is there anything unusual?

*Sample references: Zappala et al. (1999); Bottke et al. (2002).*
The Recent Impact Flux on the Earth and Moon
Craters show two distributions.

Sample references: Grieve and Shoemaker (1994); Earth Impact Database; Harnack and Kleppinger (1997)
Impact Rates on Earth and Moon

Craters show two distributions.

Possible reasons:

- Erosion for craters older than 120 My.
- Biases in crater record
- Surge in number of big impacts on Earth starting >100 My ago.

Sample references: Grieve and Shoemaker (1994); Earth Impact Database; Harnack and Kleppinger (1997)
**Impact Rates on Earth and Moon**

Additional terrestrial and lunar data supports factor of 2 change in crater production rate over last 120 My.

<table>
<thead>
<tr>
<th>Location of Crater Data Set</th>
<th>Time Period (My Ago)</th>
<th>Production Rate $D &gt; 20$ km Craters ($10^{-15}$ km$^{-2}$ yr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Moon, Australia</td>
<td>500-3200</td>
<td>3-4</td>
</tr>
<tr>
<td>US Mississippi Lowlands; N. American, European Cratons</td>
<td>&lt;120</td>
<td>~6</td>
</tr>
</tbody>
</table>

Sample references: Grieve and Shoemaker (1994); McEwen et al. (1997); Shoemaker et al. (1998)
Asteroids Evolution and Delivery to the Inner Solar System
Collisions in the Asteroid Belt

- Asteroids strike one another and create ejecta.
- Most fragments are ejected at low velocities ($V < 100$ m/s).

Sample references: Benz and Asphaug (1999); Michel et al. (2001); Durda et al. (2004)
Collisions in the Asteroid Belt

Interval between $D > 100$ km breakup events is $\sim 200$ My.

Sample references: Bottke et al. (2005); Durda et al. (2007)
Yarkovsky Drift into Resonances

Koronis family
- Observed
- Model

Bottke et al. (2001)
The inner main belt ($a < 2.3$ AU) is much more efficient at producing impactors than the remaining belt.

- IMC Region

Gladman et al. (1997); Bottke et al. (2006)
Big family forming events in the inner main belt have best chance to modify impact flux on Earth and Moon.
The Baptistina Asteroid Family: Source of an Asteroid Shower?
The Baptistina Asteroid Family (BAF)

The BAF has mostly been overlooked to date because:

- It is a dark, hard-to-see C-complex family in the inner main belt with only one $D > 20$ km member (298 Baptistina; $D \sim 40$ km).
- It partially overlaps the large S-type Flora family along the inner edge of the main belt.
The Baptistina Asteroid Family (BAF)

- BAF overlaps the 7:2 and 5:9 MMR with Jupiter and Mars (J7:2 and M5:9).
- Few asteroids are near the J7:2/M5:9! What happened?
Age of the BAF

- Yarkovsky-YORP model used to get family’s age.
  - Model
  - Observed
  - Many Interlopers

Best fit age is 160 ± 20 My.
The initial BAF had many small members.

- 300 objects with $D > 10$ km
- 140,000 with $D > 1$ km.

SPH/N-body modeling indicates the parent body was $D \sim 170$ km.

- ~88% of the BAF’s mass was initially in the form of $D < 10$ km bodies.
Overall, 10-20% of all km-sized BAF members escape over 160 My.

Simulation:

$D > 10 \text{ km}$ bodies near J7:2 and M5:9.
The BAF produces a surge in the terrestrial planet impact flux that peaks 40-60 My after the family-forming event.
Results

We input our collisional and dynamical simulations into a Monte-Carlo code and found for the Earth:

<table>
<thead>
<tr>
<th>Projectile size</th>
<th># BAF impacts over 160 Ma</th>
<th># background impacts over 160 Ma</th>
<th>Increased by Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D &gt; 1$ km</td>
<td>$200 \pm 60$</td>
<td>$250 \pm 20$</td>
<td>1.8</td>
</tr>
<tr>
<td>$D &gt; 5$ km</td>
<td>$6 \pm 2$</td>
<td>$3 \pm 2$</td>
<td>3</td>
</tr>
<tr>
<td>$D &gt; 10$ km</td>
<td>$1 \pm 1$</td>
<td>$0.5 \pm 0.7$</td>
<td>3</td>
</tr>
</tbody>
</table>

The BAF increased impact flux on the Earth and Moon by 2-3 times over last 160 My!
Implications
The Cretaceous/Tertiary (K/T) Impactor

The K/T mass extinction event/Chicxulub crater was caused by impact of a $D > 10$ km projectile 65 My ago.
The Cretaceous/Tertiary (K/T) Impactor

K/T projectile was a CM2-type carbonaceous chondrite.
  - Consistent with fossil meteorite found in North Pacific sediments from K/T boundary.
K/T projectile was a CM2-type carbonaceous chondrite.

- Good match to $^{54}$Cr isotopes taken from samples found at 3 well-characterized K/T boundary sites (i.e., all have strong Ir enhancement).
BAF as the Source of the K/T Impactor

**BAF impactors:**

- ~1 $D > 10$ km projectile hit Earth over last 160 My.

**Background impactors:**

- Prior to BAF formation event, >70% of $D > 10$ km NEOs were S-types. *These bodies have the wrong composition to produce K/T impact!*
- Only 40% of all carbonaceous chondrite meteorite falls are “CM”.
- We estimate the interval between CM impacts was 1800-2600 My.

> 90% probability that BAF is source of K/T impactor!
The age of Tycho crater (109 ± 4 My) falls in the peak of the Baptistina asteroid shower.

Using a Monte Carlo code, we find ~70% chance that BAF projectiles made 85 km Tycho crater.
Conclusions

- The breakup of the 170 km Baptistina parent body ~160 My ago triggered an asteroid shower.

- It increased the impact flux of $D > 1$ km bodies on the terrestrial planets by a factor of 2-3.

- It is currently responsible for 20% of all NEOs and 40% of dark, C-type NEOs.

- The Baptistina family is the most likely source of:
  - The K-T impactor (> 90% probability) and the Tycho impactor (> 70% probability).
  - The CM meteorites