A New NEO Model Shows the Disruption of Asteroids Near the Sun

William Bottke (SwRI)

Mikael Granvik, Alessandro Morbidelli, Robert Jedicke, Bryce Bolin, Edward Beshore, David Vokrouhlicky, David Nesvorny, & Patrick Michel
Where Do NEOs Come From?
Inner Solar System Objects

- **Unstable over ~10 My**
- **Unstable over ~0.1 My**
- **NEOs**
How Do Near-Earth Asteroids Get Here? (Part 1)

Asteroid Belt

Near Earth Objects

Jupiter Family Comets

Asteroid Collision

Plot prepared by the Minor Planet Center (2002 Apr. 23)
Collisions in the Asteroid Belt

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

Sample references: Benz and Asphaug (1999); Michel et al. (2001); Durda et al. (2004)
How Do Near-Earth Asteroids Get Here? (Part 2)

- Asteroid Collision
- Near Earth Objects
- Dynamical Escape
- Asteroid Belt
- Jupiter Family Comets
Yarkovsky Effect Allows Fragments to Reach “Escape Hatches”

Bottke et al. (2001)
Asteroids reach NEO orbits by combo of Yarkovsky drift, resonances, and planet encounters.
Residence Time Probability Distribution

NEOs from $\nu_6$ region

- The plot shows where NEOs are *statistically* spend their time in $(a,e,i)$ space.
- This probability distribution is *equal* to the steady state orbital distribution from the source.

Bottke et al. (2002)
Modeling the NEO Population

Old: Bottke et al. 2002
New: Granvik et al. 2015
Years of study allow us to identify main NEO sources. Each source produces distinctive orbital histories.
We add NEO components with weighting parameters to get combined NEO model population.
NEO Detections by CSS’s 2005-2012

Mt. Lemmon (G96)
Narrow and deep

Catalina (703):
Wide and shallow

- We want to compare different NEO probability distributions to > 4500 NEO detections by Catalina Sky Survey.
- Need to account for observational biases!
Bright objects above limiting mag. even from far away. Dim objects most easily detected near the Earth.
Bright objects above limiting mag. even from far away. Dim objects most easily detected near the Earth.
Excellent fits for orbits $(a,e,i)$ and absolute magnitude $(H)$.
Debiased NEO Population

**Granvik et al. (2014)**
15 < $H$ < 25

**Bottke et al. (2002)**
13 < $H$ < 22

- New NEO model for 15 < $H$ < 25 (0.1 < $D$ < 5 km). Similar overall shapes, yet more Amors and changes with $H$. 
Model Absolute Magnitude Distribution

Best Estimates $D > 1$ km ($H < 17.75$)

- Stuart & Binzel (2004): $1090 \pm 180$
- Mainzer et al. (2011): $981 \pm 19$
- Harris (2012): $976 \pm 30$
- OUR MODEL: $987 \pm 100$

Our model $15 < H < 25$

Observed $H < 18$
Problems Close to the Sun?
Disruption of NEOs Close to Sun?

- Model results compared to Catalina Sky Survey detections.
- **NOTE:** NEOs with perihelion < 0.3 AU are missing!
**NEOWISE.** Low albedos likely C-complex. High albedos are mostly S-complex. Most NEOs have albedo > 0.09.

Mainzer et al. (2012)
Asteroids reach NEO orbits by combo of Yarkovsky drift, resonances, and planet encounters.
Albedos and colors in source (from WISE and SDSS) can be fed forward to predict nature of NEOs in \((a,e,i,H)\) cells. Parker et al. (2008); Masiero et al. (2011; 2013)
Low albedo NEOs are not found at low perihelion! This suggests volatiles related to disruption close to Sun.
Asteroids can get close to Sun when leaving main belt. The values above show fit where objects need to disrupt to match CSS orbits.
Effects of Extreme Heating

“Preventing Armageddon,” National Geographic, 2010

- **Melosh**: Rock samples placed in “solar furnace” designed to simulate heat from nuclear blasts.
- 350 W/cm² delivered. Surface of samples quickly heated to several thousand deg. C.

Jay Melosh at the White Sands Missile Range, New Mexico
Experiments on serpentine (hydrated olivine), chosen to be analog for carbonaceous chondrite.

Minerals are vaporizing, with water blasting chips out.

Jay Melosh at the White Sands Missile Range, New Mexico
Conclusions

- New NEO model consistent with Bottke et al. (2002), but orbital distribution changes with NEO size.

- Importance of NEO source regions change with size:
  - Bigger NEOs are more from inner main belt
  - Smaller NEOs are more from central main belt

- Many asteroids disrupt when they come close to Sun.

- Low albedo NEOs are missing! This suggests volatiles may play role in disruption.
The Model Equation

\[ n(a, e, i, H) = \varepsilon(a, e, i, H) \sum_{i=1}^{N_S} f_i N_i(H) R_i(a, e, i) \]

- Objects detected by a survey
- Source ratios (to be determined)
- Survey efficiency function (bias)
- Source H-distribution (to be determined)
- NEO orbital distribution from source (from numerical integrations)
Bright objects above limiting mag. even from far away. Dim objects most easily detected near the Earth.
We want to compare different NEO probability distributions to > 4500 NEO detections by Catalina Sky Survey.

Need to account for observational biases!
The plot shows where NEOs are *statistically* spend their time in \((a,e,i)\) space.

This probability distribution is *equal* to the steady state orbital distribution from the source.

Bottke et al. (2002)
We add NEO components with weighting parameters to get combined NEO model population.
Bright objects above limiting mag. even from far away. Dim objects most easily detected near the Earth.
Source results fairly similar to Bottke et al. (2002). Most NEOs come from inner and central main belt.