Catastrophic Disruption on Core-Mantle Mixed Ice-Silicate Targets in the Laboratory

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Icy bodies?

- These are Solar system bodies, which can be small (10s of km) to large (1000s of km scale)
- Bulk density is not necessarily that of pure water ice.
- It can be in the range 1000 to 2000 kg m\(^{-3}\) suggesting a mixed composition
- There may be a layered interior
Kuiper Belt Objects

Consider Pluto and Charon.

Pluto has a density of 2.03 g cm$^{-3}$. Charon has a density of 1.65 g cm$^{-3}$.

Pluto dia. 2360 km
Charon dia. 1200 km
Structure

- Pluto is not just ice.
- Some sort of rocky content
- A Pluto like object is probably differentiated.
Our model

Sand:ice core

Pure ice mantle

Core radius 19.6 mm

Ice mantle thickness 1.3 mm
Properties

Core density $1.97 \pm 0.07$ g/cc (60% sand by wt)
Combined object density $1.77 \pm 0.10$ g/cc
Grain size $356 \pm 90$ µm
Core radius / total radius = 0.94
Core mass ratio = 0.92
Temperature: 255 K

Ice strength:
- Compressive: $1.7 \pm 0.9$ MPa

Core strength:
- Compressive: $5.8 \pm 1.7$ MPa
- Tensile: $1.2 \pm 0.2$ MPa
(Strain rate order $10^{-4} – 10^{-3}$ s)
Fig. 1 The compressive and tensile strength of ice and ice-silicate mixtures
Use a two stage light gas gun
## Projectiles and speeds

<table>
<thead>
<tr>
<th>Composition</th>
<th>Dia (mm)</th>
<th>Speed (km s(^{-1}))</th>
<th>#shots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel</td>
<td>0.8</td>
<td>1.1 – 6.9</td>
<td>10+6</td>
</tr>
<tr>
<td>Titanium</td>
<td>1.0</td>
<td>3.6 – 4.9</td>
<td>5</td>
</tr>
<tr>
<td>Glass</td>
<td>2.0</td>
<td>1.2 – 4.5</td>
<td>4</td>
</tr>
</tbody>
</table>

*Projectile dia. / mantle thickness is 0.6, 0.8 and 1.5*
Consequences of Impacts

- Cratering
- Transition
- Disruption

Energy Density $Q$ (J kg$^{-1}$)

Largest Surviving Mass Fraction $M/M_o$
Result

Semi-infinite (crater)  Finite (disruption)
Results

![Graph showing the relationship between \( M / M^* \) and energy density \( Q \) (J kg\(^{-1}\)). The graph includes data points labeled "Core (st. st. proj.)".](image-url)
Results

\[ \frac{M_f}{M_i} \]

Energy Density \( Q \) (J kg\(^{-1}\))

- Orange squares: Core (st. st. proj.)
- Black squares: Mantle:core (st. st. proj)
- Blue triangles: Mantle:core (titanium proj.)
Results

\[ \frac{M_f}{M_i} \]

Energy Density \( Q \) (J kg\(^{-1}\))

- Core (st. st. proj.)
- Mantle:core (st. st. proj)
- Mantle:core (titanium proj.)
- Mantle:core (glass proj.)
Results

![Graph showing the relationship between Energy Density Q (J kg⁻¹) and the ratio M₂/M₁. The graph includes data points for different projects: Core (st. st. proj.), Mantle:core (st. st. proj), Mantle:core (titanium proj.), and Mantle:core (glass proj.).]
Observations

\[ Q^* \sim 250 - 275 \text{ J kg}^{-1} \]

No large difference is seen between the values of \( Q^* \) for core bodies and core:mantle bodies.
At Kent we have previously found

<table>
<thead>
<tr>
<th>Target</th>
<th>$Q^*$ (J kg$^{-1}$)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice</td>
<td>7±2</td>
<td>Dawe et al. LPSC 2005, #1095</td>
</tr>
<tr>
<td>Sand : ice</td>
<td>189±25</td>
<td>Lightwing et al. LPSC 2006, #1565</td>
</tr>
<tr>
<td>Core</td>
<td>250 - 275</td>
<td>This work</td>
</tr>
<tr>
<td>Mantle:core</td>
<td>250 - 275</td>
<td>This work</td>
</tr>
<tr>
<td>Porous ice (45%)</td>
<td>650±150</td>
<td>(unpublished)</td>
</tr>
<tr>
<td>Snow (71%)</td>
<td>910±10</td>
<td>(unpublished)</td>
</tr>
</tbody>
</table>
Future Work

• Use low density (nylon) projectiles
• Build an ice firing gun (if funding agency agrees)
• Vary mantle thickness
• Vary ratio proj. dia/mantle thickness
• Change the core composition
Conclusions

- For icy bodies where the mantle is 6% of the body radius, and proj. dia / mantle thickness is 0.6 – 1.5, we see no influence on Q* of the presence of the mantle.
- Spheres and cylinders not quite equivalent
- A model of Q* vs. R for core:mantle bodies would be nice
- Then we can combine with fluxes and typical impact speeds to model lifetimes
Acknowledgments

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