76th Arthur H. Compton Lecture Series

Constructing the Solar System: A Smashing Success!

Lecture 5: When Asteroids Collide

Thomas Davison

November 10, 2012

1 Introduction

In the first four lectures, we have seen that during the epoch of planet formation collisions between planetesimals were frequent events. In this lecture, we will look at the physical processes that take place during a collision event, to understand the collateral effects of collisions on the remaining planetesimals in our Solar System: the asteroids.

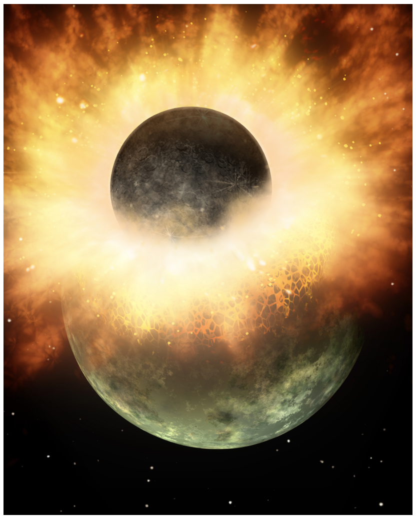


Figure 1: Artist's impression of a planetesimal collision, courtesy of NASA

2 Collisional outcomes

In any collision between planetesimals, several outcomes are possible:

- Catastrophic disruption of the target body
- Cratering of the target / merging of two bodies
- *Hit-and-run*, where the impactor grazes the target

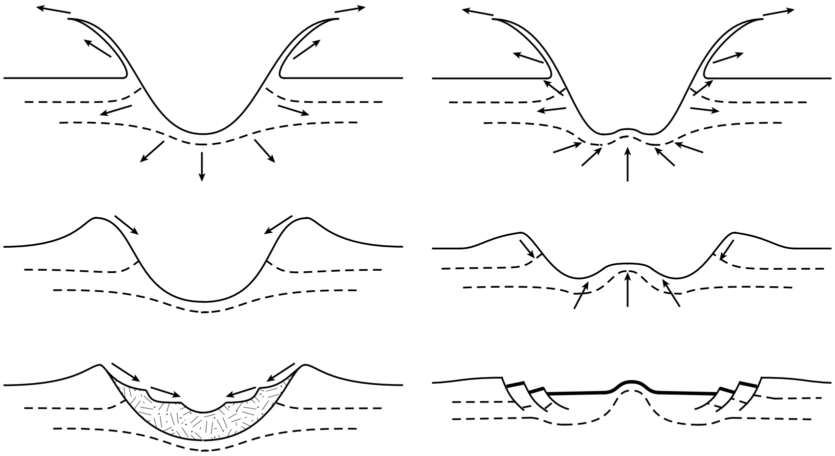
2.1 Catastrophic disruption

Whether or not an impact will destroy the target body has been quantified using laboratory experiments and numerical simulations, and is a function of the specific impact energy (i.e. the energy per unit mass of the target body). We define a disruptive impact as one in which the largest fragment resulting from the collision is less than half the mass of the original target body. In order to disrupt a body, the specific impact energy must be greater than the catastrophic disruption threshold, $Q_D^\star$. This threshold is a function of the size of the target body, and is dependant on whether the target is held together by the material strength or its own self gravity.

2.2 Impact cratering

A far more likely scenario when two planetesimals collide is that they will merge, and the smaller body will form an impact crater on the surface of the larger body. During an impact cratering event, there are three distinct stages:

1. Contact and compression
    - The impactor makes contact with the target, penetrates surface and slows down
    - The target material speeds up as it moves away from the impact site
    - These changes in velocity lead to the creation of a *shock wave*, which raises the material to very high pressure
    - Once the shock wave reaches a free surface (usually the back edge of the impactor), a rarefaction wave is initiated which releases the material from its high pressure state
2. Excavation
    - The shock wave weakens the material as it traverses it
    - The shock and release waves begin moving the material away from the impact site, opening a crater
    - When then gravity and/or strength of the target stop the crater growing, it is known as a *transient crater*
3. Modification
    - The transient crater is then modified by the gravity of the target body
    - The extent of this modification depends on the size of the crater (see Figure 2)
    - In smaller (simple) craters, the principal modification is the slumping of the crater walls to form a breccia lens in the bottom of the crater
    - In larger (complex) craters, material flows back into the crater to form a central uplift



(a) Simple (b) Complex

Figure 2: Schematic representations of the development of simple and complex craters. Top image shows the growth of the transient crater, the middle image shows the modification stage, and the bottom image shows the final crater. Adapted from Melosh (1989) and French (1998).

2.3 Hit-and-run collisions

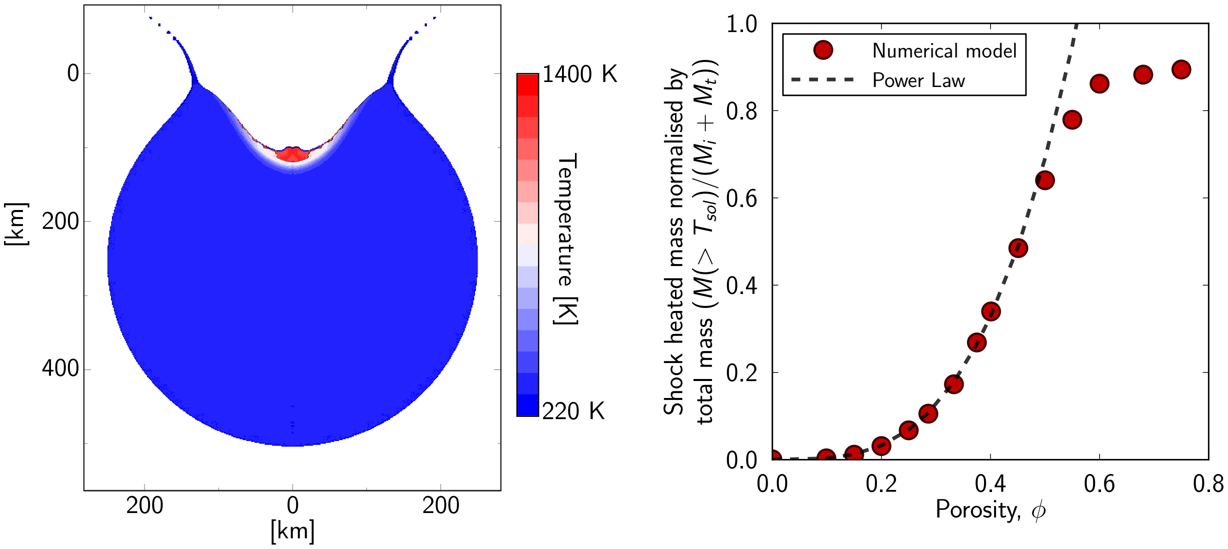
Another class of collisions are known as hit-and-run collisions. These collisions occur when the angle of impact is very oblique, and most of the impactor glances off the target. It has been speculated this class of collisions could provide a mechanism to strip the mantle and volatiles from asteroids and young planets (which may have been the case with Mercury, resulting in its high metal content).

3 Shock processes

The most important physical process that happens during a collision is the creation of a *shock wave*. A shock wave is an instantaneous increase in pressure, density and energy the travels away from the point of impact into the rock. It is this cycle of shock and release that can lead to greatly increased temperatures (and even melting) near the point of impact. As we learned in the earlier lectures, planetesimals probably formed with a high proportion of pore space. Porosity has two distinct effects on shock processing:

1. The shock wave is attenuated much more rapidly in porous materials than in fully compacted material, as lots of energy is required to close the pore spaces during the compression phase. This means that a smaller volume of material is affected by the shock wave.
2. In porous materials, a lower shock pressure is required to produce an equivalent temperature increase than in non-porous materials. This means that in shock processed regions, porous materials can get very hot.

Until recently, the interplay of these two processes on heating during planetesimal collisions was not known. Numerical models have shown that porosity can greatly increase the localized heating during an impact event, to many times greater than was previously estimated for non-porous planetesimals.



(a) A crater forming during an impact simulation

(b) The effect of porosity on impact heating

Figure 3: Numerical simulations of impact processes can help us to understand the collateral effects of planetesimal collisions. Increasing the porosity of a planetesimal can greatly increase the amount of heating during an impact.

4 Next lecture

Next week we will build on this knowledge of impact processes to investigate the role of collisions in the thermal evolution of meteorite parent bodies.