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Numerical Modeling of the 2009 Impact Event on Jupiter

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Abstract

We have studied penetration depth and plume formation of the 2009 Jovian impact event using the ZEUS-MP 2 hydrodynamics code. We compare these 3D models with those of the 1994 Shoemaker-Levy 9 (SL9) event on Jupiter. We find that the 2009 impactor, which likely collided at a shallower angle, produced a narrower, slower plume, yet possessed a similar “pinch-off” point to that of the SL9 event. These slower speeds could explain the observed lack of atmospheric disturbance below the 10 mbar level in the 2009 event. The 2009 impactor did not penetrate as far into Jupiter as the SL9 impactors but went deep enough to explain ammonia observations. Our simulations show striking differences between the 2009 and SL9 events, and we are currently exploring more of the observationally constrained parameter space of the 2009 event to fully explore the extent of these differences.

1. Introduction

Before July 2009, the rate of 0.5-1.0 km bodies impacting Jupiter was estimated at 1 per 50-350 years [1]. However, between 9 and 11 UT on 2009 July 19, an object of unknown origin collided with the Jovian atmosphere [1]. This event increased the estimated frequency with which kilometer-sized objects impact Jupiter and reasserted Jupiter's atmosphere as an important laboratory for impact dynamics. Unfortunately, the event occurred unexpectedly and on the night side of Jupiter. The first professional observations of the 2009 impact site ([3]) did not begin until $\sim$ 30 minutes after the event rotated into view. Subsequent observations by [1], [2], [3], [4], & [5] were performed over the following days. Thus, we turn to numerical simulations of the 2009 event to gain knowledge of what occurred during and immediately after impact. Analysis of the impact site suggests an object of asteroidal composition ([2], [3], [4]) impacted at an angle of $\sim 69^\circ$ from the vertical [1]. Here we present hydrodynamic simulations of the 2009 impact event and compare them to simulations of the 1994 SL9 event.

2. Impact Model

As with [6] and [7], the ZEUS-MP 2, 3D, parallel hydrodynamics code was used for impact simulations [8]. Our ZEUS-MP-based code can model both the impact and entry-response/blowout phases of the impacts in one run. We carried out simulations within a computational grid that moves with the impactor along what we call the “along-track coordinate.” The along-track coordinate is rotated from Jupiter's true vertical by the incident angle. Grid spacing remains constant within and in close proximity to the impactor at a resolution of 16 grid cells across the radius of the impactor (R16). Grid spacing then increases geometrically in all directions away from the R16 area [6]. At the grid's tail end, where the impact plume develops, the resolution is again held constant for modeling of plume evolution.

3. Results and Conclusions

Figure 1 shows results of a 2009 impact simulation of a 1 km impactor of porous rock density ($\rho = 1.76$ g cm^{-3}) (left) and results for a 1 km SL9 impactor of porous ice density ($\rho = 0.60$ g cm^{-3}) (right) [7]. Initial impactor speeds are 61.4 km s^{-1}. The width of the 2009 impact plume is much less than the width of SL9 impact plume, with the former's diameter more than half the size of the latter's. The 2009 case also shows significantly lower speeds in the plume, reaching only $\sim$ 10.5 km s^{-1}, while the SL9 case produces a plume traveling at speeds up to $\sim$ 15 km s^{-1} [7]. These lower velocities limit the height reached by the 2009 plume compared to SL9 plume heights, possibly limiting the extent of debris distribution. The 2009 impactor penetrated down to approximately $z \approx -125$ km below the 1 bar level while the SL9 impactor reached depths of $z \approx -150$ km below the 1 bar level.

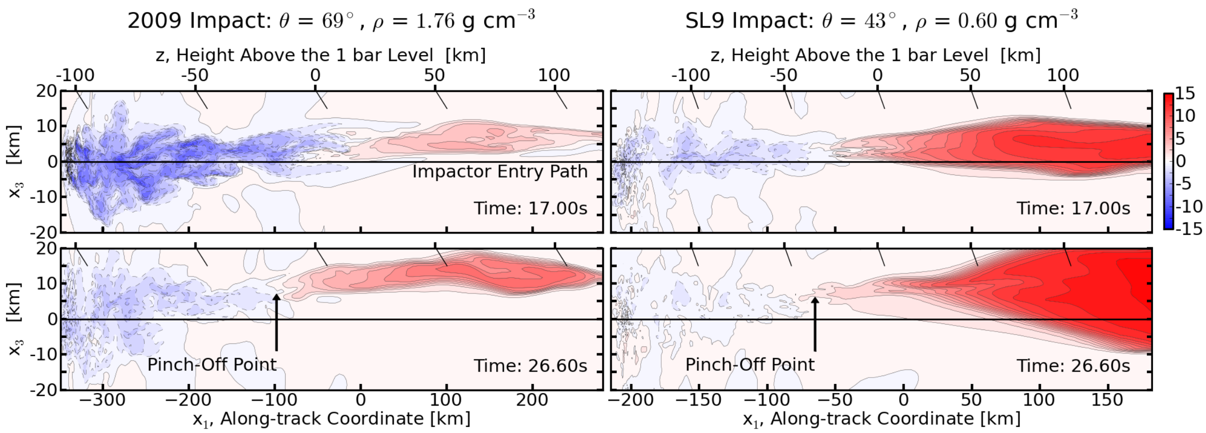

Figure 1: Plume structures of the 2009 (left) and the Shoemaker-Levy 9 (right) cases. A red color indicates an upward velocity [km/s], moving higher into the Jovian atmosphere; a blue color indicates a downward velocity [km/s], moving deeper into the atmosphere. The red areas are indicators of the rising plumes. The along-track coordinates are given at the bottom of the plots. The top of the plots indicates lines of constant height in Jupiter's atmosphere. $x_1 = z = 0$ occurs at the 1 bar pressure level. The 2009 plume does not expand as drastically as the SL9 plume. The 2009 plume diameter is $\sim$ 15 km, where as the SL9 plume expands to a diameter grater than 30 km. 2009 plume speeds reached only ~ 10.5 km s^{-1} compared to the ~ 15 km s^{-1} attained by the SL9 plume.

The "pinch-off" point that appears in the SL9 simulations of [7] also appears in the 2009 impact simulations. These points are indicated in Figure 1. Above this level, heated Jovian atmosphere containing a small fraction of impactor material rises and expands as a plume (shades of red in Figure 1); below this level, a majority of the impactor material continues downward (shades of blue in Figure 1). The 2009 pinch-off point occurs about 36 km below the 1 bar pressure level. The SL9 pinch-off point occurs at about 48 km below the 1 bar level. These levels are within a Jupiter scale height. We are currently investigating the exact causes of these pinch-off points and are determining the reasons, if any, that the pinch-off points occur at similar heights in the Jovian atmosphere in both cases. We expect to have results by the 2011 DPS conference.

[3] suggests that the low amounts of observed ammonia levels around the 2009 impact site imply that an impactor smaller than 1 km collided with Jupiter. We will continue to investigate the parameter space constrained by observations of the 2009 impact site, such as smaller impactor sizes (Pond et al. 2011, in preparation) and slower impact speeds. We expect to have these results by the 2011 DPS conference.

Acknowledgements

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