No dilute core produced
in simulations of giant impacts onto Jupiter

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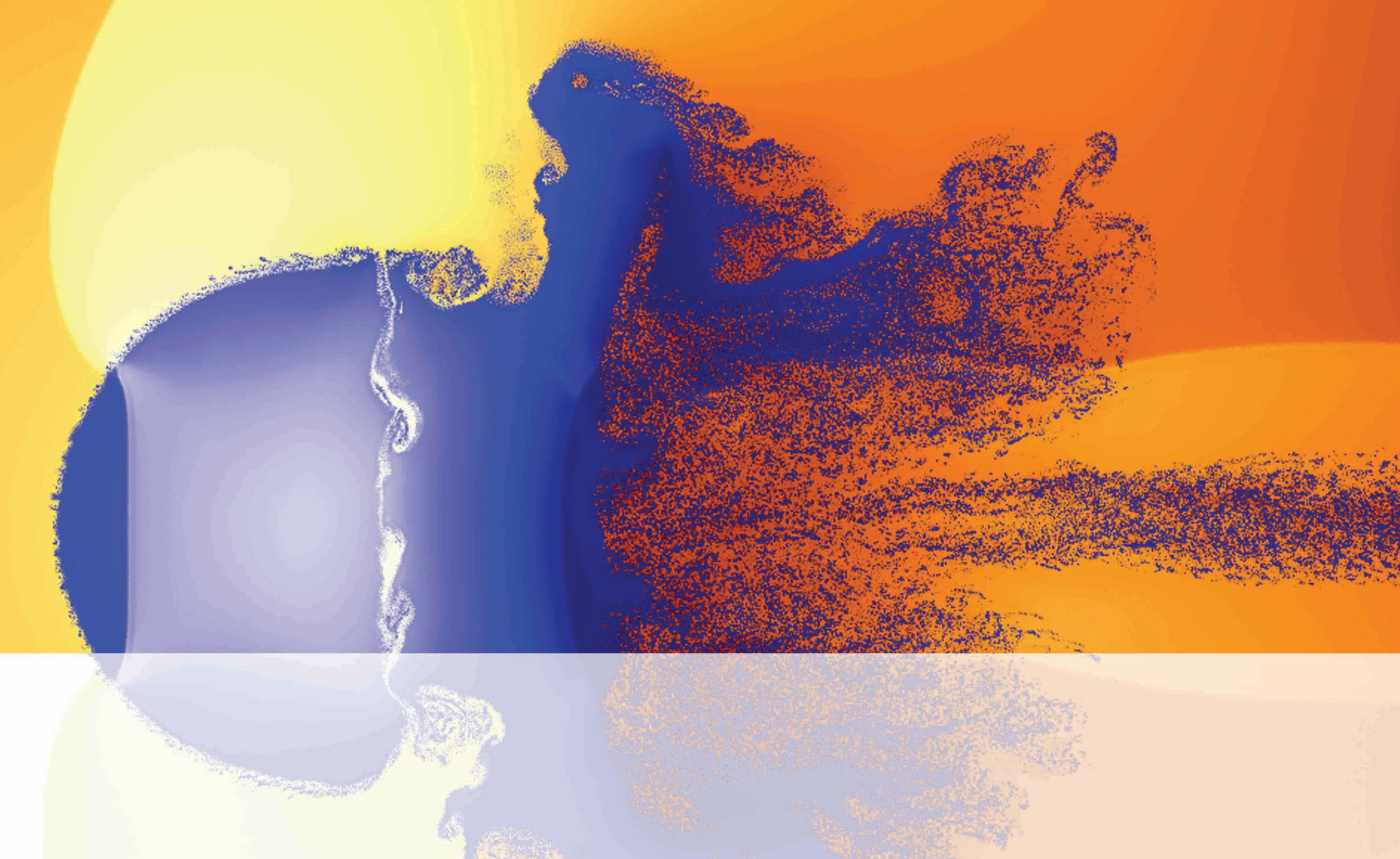
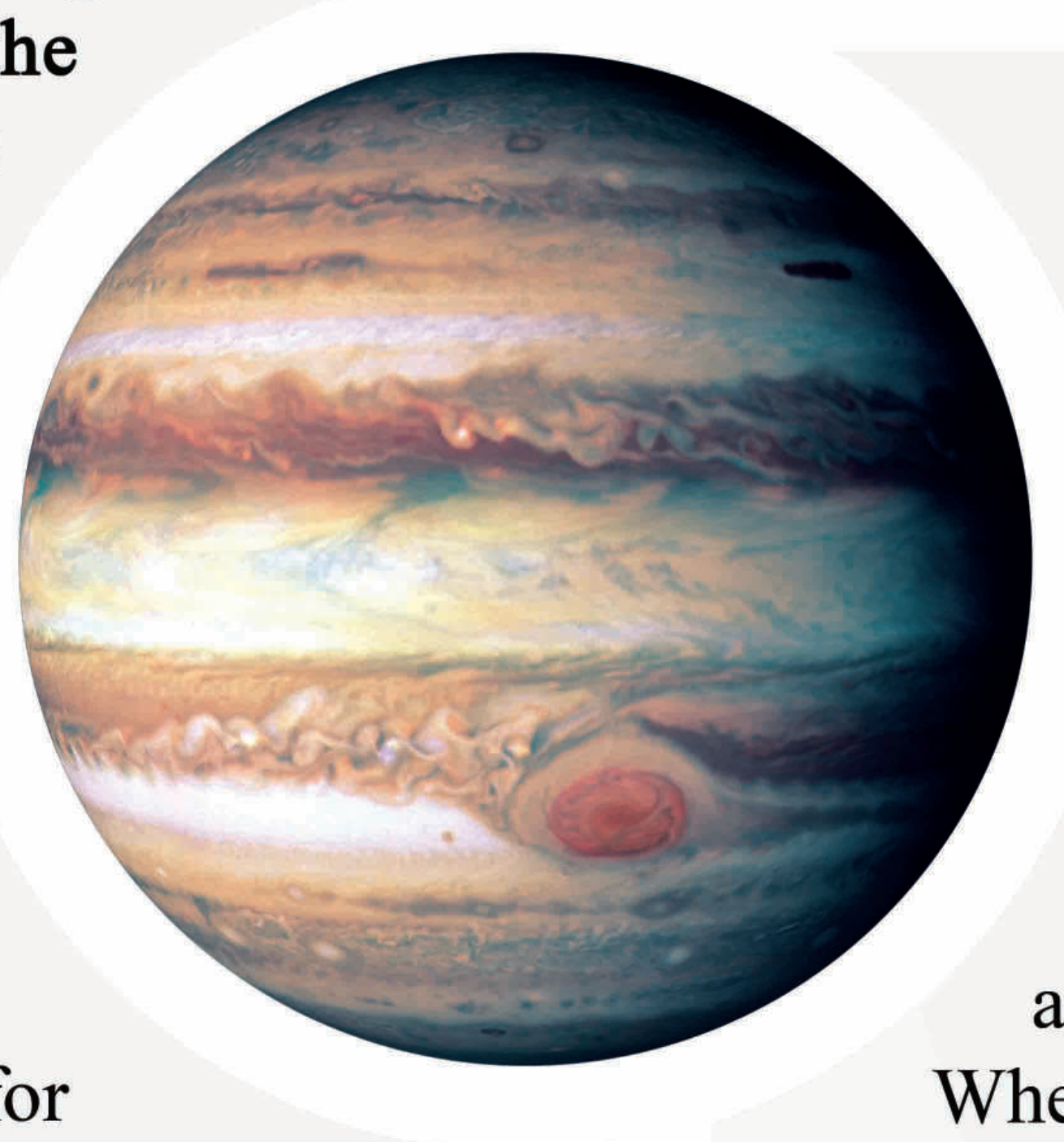


Figure 0. Snapshot showing core disruption in a simulation of a head-on impact onto Jupiter with a resolution of $10^{8.5}$ SPH particles, the largest number of particles used in a planetary impact simulation to date.

Overview

We simulate giant impacts onto Jupiter, to test whether this mechanism could have formed the planet's dilute core. Our high-resolution simulations include a novel method that corrects the treatment of material mixing in SPH. In all our simulations, the disrupted core of heavy elements settles over short timescales to form a differentiated structure. No dilute core is produced.



Background

Measurements of Jupiter's gravitational moments by the Juno spacecraft have led to new models for the planet's interior that suggest the existence of a dilute core: an extended compositional gradient between Jupiter's central core of heavy elements and its hydrogen–helium envelope[1,2].

Liu et al. (2019) found dilute core formation in their giant impact hydrodynamical simulations under specific and extreme impact conditions[3]. Our simulations are set up to closely reproduce these initial conditions with a variety of numerical methods.

Scan me for impact!

http://icc.dur.ac.uk/giant_impacts/jupiter_impact.mp4

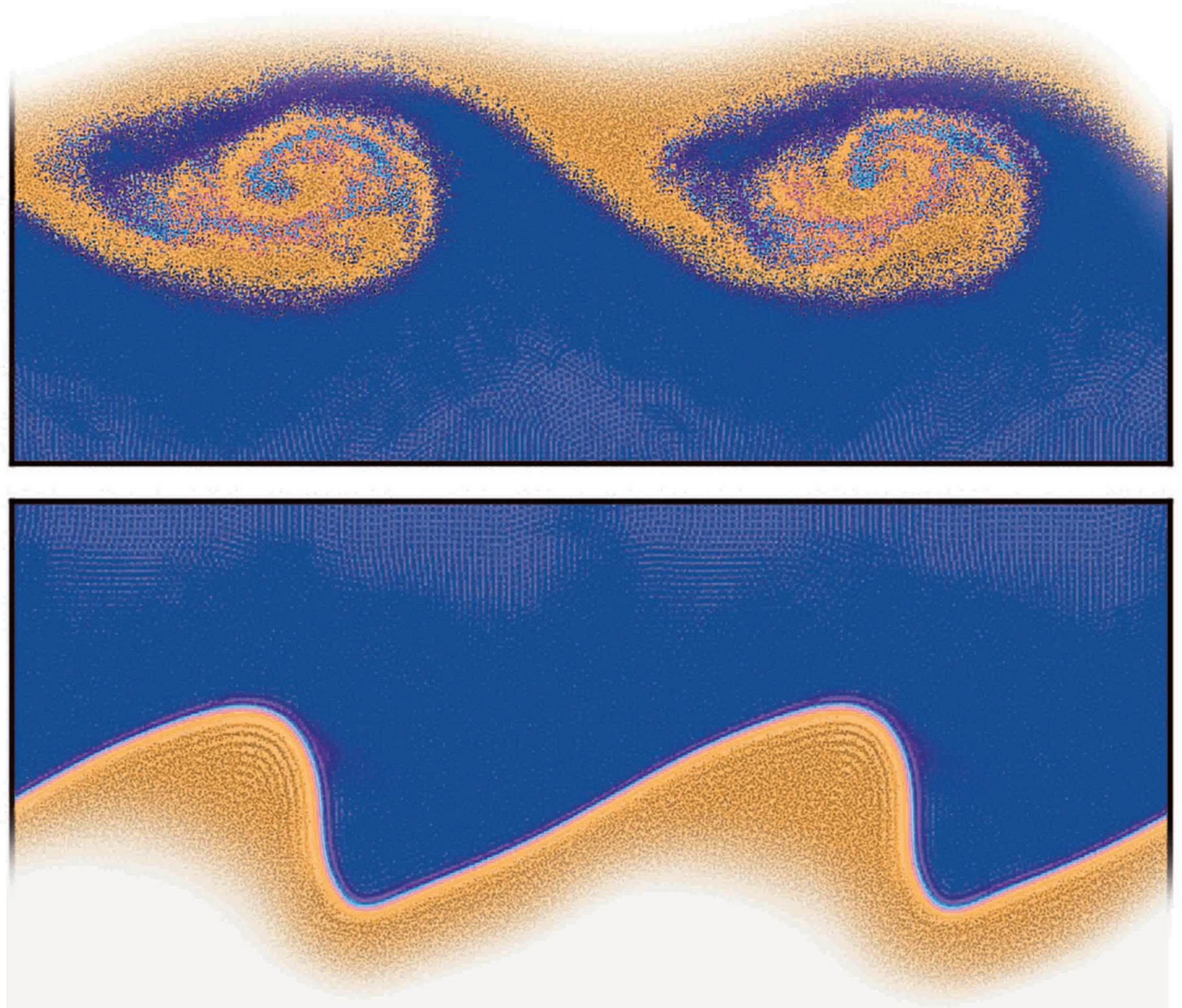
Methods

Smoothed particle hydrodynamics (SPH) is widely used for simulations of planetary giant impacts[4]. The suppression of mixing across density discontinuities is a well established shortcoming of SPH[5].

We develop a novel method for identifying and correcting density discontinuities in SPH. When combined with other newly developed methods[6], this greatly reduces the artificial suppression of mixing in our impact simulations. We use our publicly available hydrodynamics and gravity code SWIFT for all simulations presented[7].

Figure 1 shows the growth of a Kelvin–Helmholtz instability simulated using our improved SPH scheme (top). With traditional SPH, artificial surface tension at the density discontinuity prevents this instability from growing (bottom).

Figure 1. Snapshots from simulations of Kelvin–Helmholtz instabilities using traditional SPH (bottom) and our improved SPH scheme (top). Materials, densities and pressures are set up to reflect conditions in Jupiter's deep interior.



Giant Impacts

We use our improved SPH scheme to simulate 3D giant impacts onto Jupiter, with initial conditions set up to closely resemble those in which Liu et al. (2019) produced a dilute core[3]. Figure 2 shows snapshots from this head-on impact scenario. The impactor disrupts the core of the proto-Jupiter to a temporarily mixed state. However, the heavy elements then rapidly settle under gravity to form an undiluted core. This is in contrast to the results of Liu et al. (2019), who find that over 50% of the post-impact core is ideal gas at the centre, with a smooth radial compositional gradient.

We find similar non-diluted outcomes with both ideal gases and more sophisticated equations of state, alongside other numerical improvements. Most of our simulations are carried out at a high resolution of 10^7 SPH particles. However, as shown in Figure 0, we also simulate head-on impacts with up to $10^{8.5}$ particles.

We simulate impacts over a range of speeds ($v = 1$, $1.5v_{\rm esc}$) and impact parameters ($b = 0.0$, 0.2, 0.4, 0.6). Snapshots from some of these simulations are shown in Figure 3. All simulations produce a post-impact planet with an undiluted core of heavy elements, even under these extreme impact conditions.

Our results suggest that it is unlikely that a giant impact was the formation mechanism for Jupiter's dilute core.

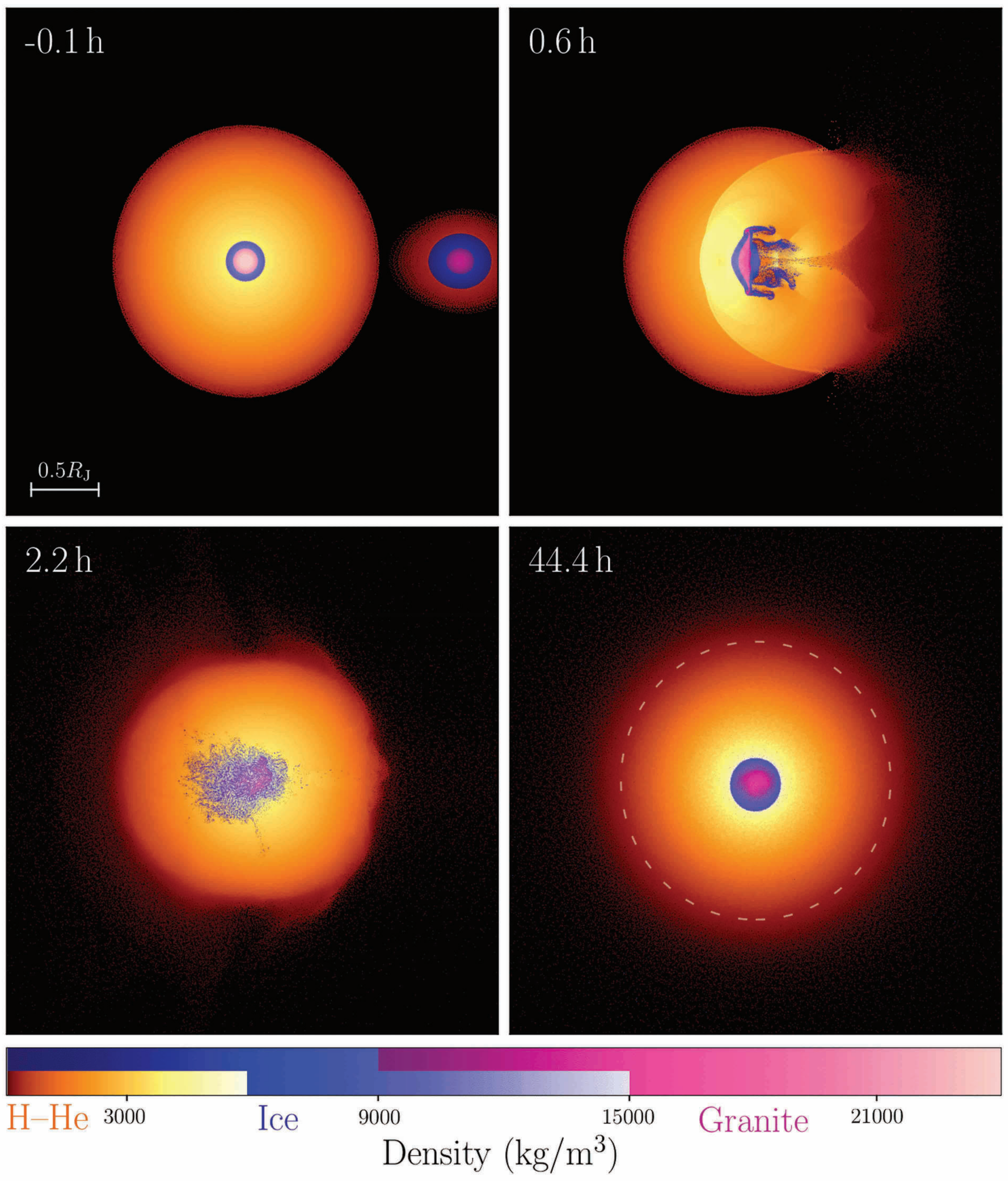


Figure 2. Snapshots from the impact scenario in which Liu et al. (2019) found immediate dilute core formation[3]. Snapshots show times: before impact (−0.1 h); during core disruption (0.6 h); after the core has reached a well-mixed state (2.2 h); long after impact (44.4 h). Particles are coloured by density and material. The dashed line corresponds to the radius of present-day Jupiter.

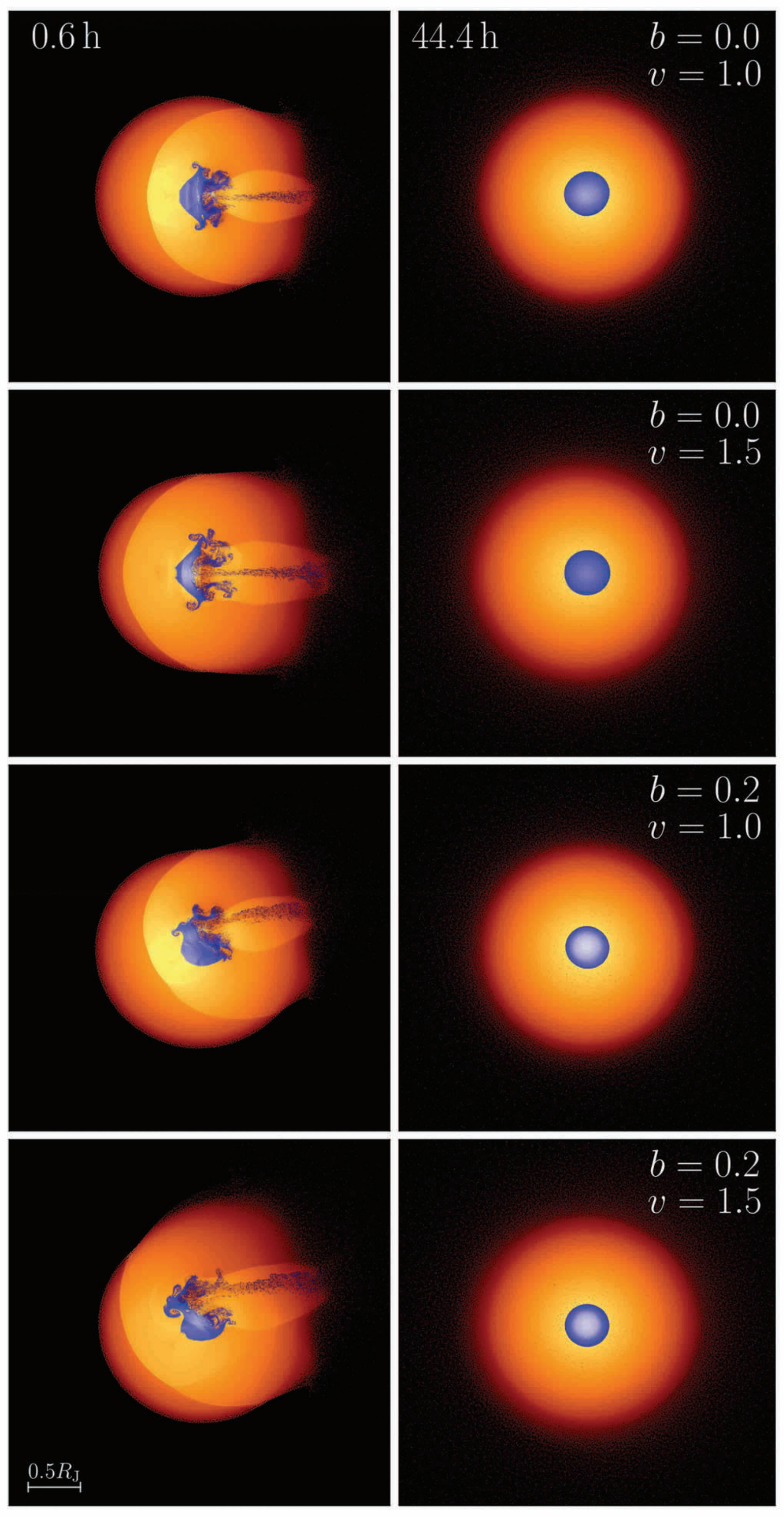


Figure 3. Snapshots from impact simulations varying the impact speed ($v = 1$, $1.5v_{\rm esc}$) and angle ($b = 0.0$, 0.2). Snapshots show times during core disruption (0.6 h) and long after the impact (44.4 h).

Save poster for later!

http://icc.dur.ac.uk/giant_impacts/jupiter_poster.pdf

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