OBSERVING GIANT, PLANET FORMING IMPACTS IN EXOPLANETARY SYSTEMS.

Alan P. Jackson[1], Kate Y.L. Su[2], Ruobing Dong[2], George Rieke[2] and Andras Gaspar[2]. [1]Centre for Planetary Sciences, University of Toronto, Toronto, ON, Canada (ajackson@cita.utoronto.ca), [2]Steward Observatory, University of Arizona, Tucson, AZ, USA.

Introduction: Giant impacts – collisions between similarly-sized, gravity dominated bodies – are a key component of planet formation, representing the mechanism for the final assembly of terrestrial planets[1,2]. In our own inner solar system giant impacts have been proposed to explain Mercury's large core fraction [3], the formation of the Moon [4], and the Martian hemispheric dichotomy (MHD)/Borealis basin impact [5]. Giant impacts have a wide range of possible outcomes, from efficient mergers to disruption[6], but the production of substantial quantities of small debris is universal. Averaged over a typical sequence of impacts the formation of an Earth mass planet is expected to result in the release of around a Mars mass of debris[7].

Dynamical evolution of the debris: Once released during the impact the debris will enter into orbit around the parent star. Initially the debris will be in a tight clump (Fig. 1a), however since the debris is launched with a range of velocities it will have a range of different orbital periods and so Keplerian shear will spread the initial clump out into an arc and then a spiral (Fig. 1b). The spiral will wind tighter and tighter until the individual windings merge into a smooth asymmetric disk (Fig. 1c). The pinch that can be seen at the right in Figs. 1b,c and the face-on view in Fig. 2 is the collision-point, this is the point at which the original giant impact occurred, and since all of the debris originates from this point all of the debris orbits must continue to pass through it, leading to the pinch observed which is a fixed point in space. Since all of the orbits pass through the disk mid-plane at the collision-point they also all share the same line of nodes, which leads to existence of a line on the other side of the star, the anti-collision line, along which all of the orbits again cross the disk mid-plane. This leads to the bow-tie like structure seen in Fig. 2 when the disk is viewed along the line of nodes. Finally over longer timescales differential precession smears out the collision-point, eventually producing an axisymmetric disk (fig. 1d).

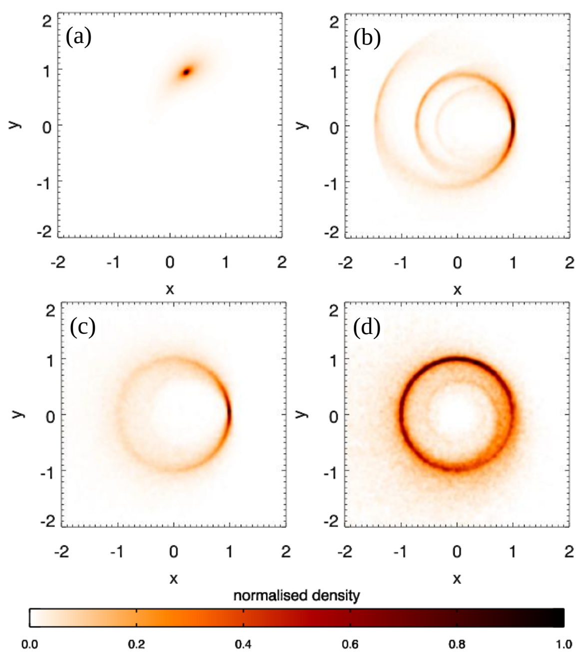

Fig 1: Dynamical evolution of giant impact debris created at (1,0) at $t = 0$ from a progenitor on a circular orbit. *Top left*: appearance after 0.2 orbits. *Top right*: after 2 orbits. *Bottom left*: 200 orbits. *Bottom right*: 10 000 orbits. Precession due to a Jupiter-mass planet at 0.2 semimajor axis units is included. All images are normalized individually and have a Gaussian smoothing with FWHM 0.05 semimajor axis units applied.

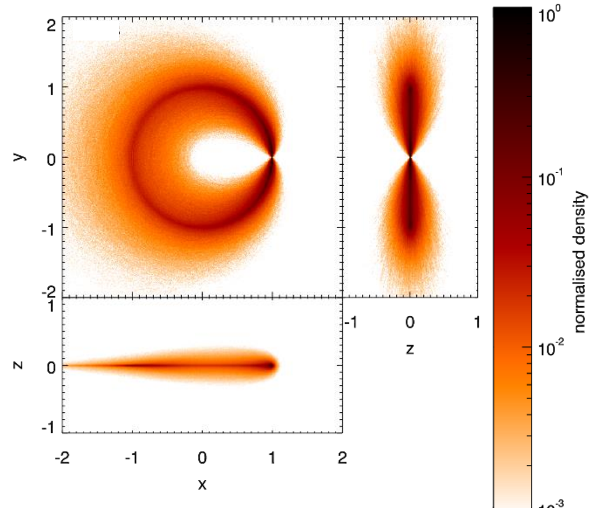

Fig 2: Detailed view of the asymmetric disc phase with logarithmic density map. Face-on view at top left, edge-on views at right and bottom.

Vapour production and optical thickness: For Mars-sized bodies the escape velocity is equal to the sound speed in silicates (~5 km/s) and thus we can expect shocks to be a ubiquitous feature of giant impacts. Shocks substantially heat material and some will be vaporised. This rock vapour subsequently

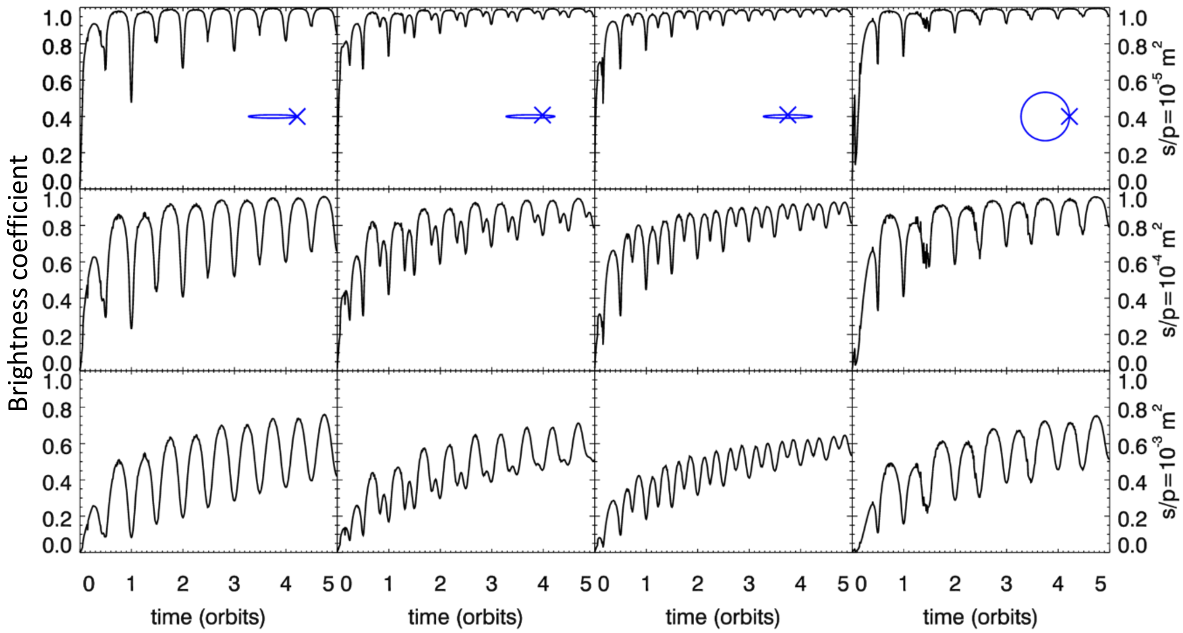

Fig 3: Temporal variation of the brightness coefficient for a range of orientations and values of total dust cross-sectional areas. The blue diagrams in the upper row show the four different orbital configurations, the orbit of the progenitor is a blue circle and the cross shows the location of the collision-point. Each row uses the same value of total dust cross-sectional area, which increases by a factor of 10 each row.

recondenses into droplets with a characteristic size of mm to cm[8].

1% of an Earth mass in mm-size grains has a cross-sectional area of 0.8 AU^2. It is thus easy to see that the production of vapour condensates can easily lead to an optically thick debris cloud.

Variability due to changing optical thickness: As the initial clump of debris moves away from the collision-point it expands, and for an optically thick dust cloud this expansion increases the available absorbing/emitting area and the cloud increases in brightness. When the clump then approaches the anti-collision line and is funnelled down into a smaller volume the available absorbing/emitting area will decrease again. Overall this leads to two peaks and drops in brightness every orbit.

If we view the disk in a close to edge-on configuration then an additional effect comes into consideration from the disk ansae. When the clump of debris passes through the disk ansa the clump is oriented with its long axis along the line of sight, increasing the column of dust we are looking through and decreasing the emitting area we can see, resulting in a drop in the brightness of the disk. The disk ansae thus also lead to two peaks and drops in brightness every orbit. We then have two sets of peaks and drops with the relative phase between them determined by the angle between the collision-point and the disk ansa. This leads to complex behaviour that can be apparently bi-periodic depending on the viewing orientation, as shown in Fig. 3. The shape of the curve also depends on the quantity of dust as this influences how optically thick the cloud is, and on the velocity dispersion in the debris as this influences how rapidly the initial clump is sheared out.

By examining the light curve of a system we can gather a wealth of information about the forming planetary system, including the mass and orbital location of the bodies that collided. With spectra we can also access the composition of the forming planets.

Example systems: Our team have been monitoring a small sample of bright debris disc systems to look for variability resulting from ongoing planet formation. Two systems are particularly good candidates for the processes described here. P1121, a G9V star in the 80 Myr old open cluster M47, and ID8, a G6V star in the 35 Myr old open cluster NGC2547. More details on the observational program can be found in the abstract of Su et al.

References:

[1] Kenyon S., Bromley B., 2006, *AJ*, 131, 1837.
[2] Kokubo E., Genda H., 2010, *ApJL*, 714, L21.
[3] Benz W., et al (2007) *Space Sci. Rev.*, 132, 189–202.
[4] Canup R.M. (2004) *ARA&A*, 42, 441-475.
[5] Marinova M.M., et al. (2011) *Icarus*, 221, 960–985.
[6] Asphaug E., 2010, *Chemie der Erde*, 70, 199.
[7] Stewart S., Leinhardt Z., 2012, *ApJ*, 751, 32.
[8] Johnson B.C., Melosh H.J., 2012, *Icarus*, 217, 416.