SHORT-TERM DISK FLUX MODULATIONS DUE TO THE ORBITAL EVOLUTION OF IMPACT PRODUCED CLOUDS OF DUST IN NGC2547-ID8.

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NGC2547-ID8 – A 35 Myr-old Exoplanetary System: ID8 is a solar-like (G6V) star in the 35 Myr-old open cluster NGC 2547 [1] at a distance of 360 pc [2]. The star shows a weak (0.01 mag) modulation of 5 days in the optical due to spots on the stellar surface, suggesting its rotation axis is unlikely to be pole-on from our line of sight [3, 4]. The spectral energy distribution of the ID8 system shows prominent solid-state features, suggesting the presence of abundant small silicate-like grains. Olofsson and colleagues [5] presented a detailed SED study by simultaneously determining the dust composition and disk properties. They found that ~10% of the small dust in the ID8 system is in the form of crystalline silicates with ~2/3 of them belonged to the Fe-rich crystalline grains. The location of the debris is estimated to be 0.3–0.64 au, and is dominated by sub-μm size grains in a steep power-law size distribution with a total dust mass of 2.4×10^{-6} Earth mass.

Expected Short-Term Evolution of an Impact Produced Cloud of Dust: Jackson and colleagues [6] presented a detailed description on the dynamics of debris released by a giant impact. In their dynamical calculations, there are two spatially fixed locations for the evolution of impact produced debris: the collision-point and the anti-collision line. The collision-point is where the impact occurred, which is a fixed point in space through which the orbits of all of the fragments must pass since they originated from there. The anti-collision line is a line exactly on the other side of the orbit from the collision-point through which all of the orbits of fragments must also pass (the alignment of the ascending/descending nodes). For simplicity, here we refer them as collision and anti-collision points. The two opposite points in the orbit of an impact produced cloud naturally explain the bi-periodicity because the extension of the cloud reaches minimum at these two locations. For a system viewed at nearly edge-on geometry like ID8, the projected area of the cloud also reaches minimum as it passes the disk ansae, naturally explaining another bi-periodicity [3]. The combination of disk ansae and collision and anti-collision points predicts an intermixed nature of periodicity without invoking an eccentric orbit. The detailed evolution of the expected disk light curves, their dependency on geometry, impact condition and orbital eccentricity are further discussed by the presentation of Jackson et al. in this conference [7].

3-D Radiative Transfer Calculations: The simple geometric, dynamical model presented in [7] qualitatively describes the expected modulations in the cross section of an impact produced debris cloud. We further carried out 3-D radiative transfer calculations and confirmed the expected flux modulation during its orbital motion. Fig. 1 shows the flux modulation of an optically thick cloud at different orbital phases from two viewing angles: face-on (an inclination of 0°) and close to edge-on (an inclination angle of 85°). The initial point of the orbital phase is defined at the collision point (phase of 0.0). The orbital phase of 1.0 is at the same point but after one orbit of evolution, and the orbital phase of 1.5 is its corresponding anti-collision point. For the face-on case, the disk flux reaches local minimum when the cloud passes the collision and anti-collision points. For the inclined case, the collision point is set exactly between the disk ansae behind the star, i.e., the disk ansae are at the orbital phases of 0.25 and 0.75 after the impact. The flux of the cloud drops whenever it passes the collision and anti-collision points and disk ansae.

Application to the Modulations in ID8: Fig. 2 shows the ID8 flattened (after subtraction of the long-term flux upward and downward trends) disk light curve observed in 2013. By associating the big dips with possible collision and anti-collision points, we identified the true orbital period of the cloud is 108 days. An orbital period of 108 days suggests that the impact occurred at a distance of 0.44 au from the star within the expected debris location. By examining the nearby, secondary dips around the identified collision and anti-collision points, we further identified that the disk ansae are likely at the orbital phases of 0.2 and 0.7, i.e., the cloud reached the disk ansae 21.6 days after passing the collision and anti-collision points. The phase difference between the disk ansa and collision point suggests that the angle between the collision point and the disk ansa is about ~70°. Given the flat disk light curve observed in 2012 (prior to the 2013 event) and the orbital period of 108 days, we also identified that the 2013 impact occurred at BMJD 56227 (2012 Oct 26).

Fig. 3 shows the ID8 flattened disk light curve in 2014, which is very different from the one observed in 2013. Since there is one single period (10.4 days) identified (rather than two intermixed periods), the disk ansae are exactly at the half way between the collision and anti-collision points, suggesting a true orbital period of

41.6 days. This orbital period suggests that the cloud responsible for the 2014 modulation was at an orbital distance of 0.24 au, implying that the modulations in the 2013 and 2014 light curve are caused by two different impact events. We also folded 2015–2017 light curves in phase space with the 2014 one using the same period of 41.6 days to identify additional modulations that might be produced by the same cloud. The flux dips in the 2015 light curve (Fig. 4) are likely associated with the orbital phases of 6.5, 7.0 and 8.0 for the 2014 event. The overall modulation behavior is consistent with the expected evolution – the impact produced clump in the disk lasts for ~10 orbits and the disk flux modulation is strong and observable during this clump phase [6, 7].

Summary: Using the simple geometric, dynamical model presented in [7], we successfully explain the short-term disk modulation observed in the ID8 system. Our analysis suggests that the modulations are caused by two impacts occurred at two different locations and time. The 2013 event occurred in 2012 Oct 22 at 0.44 au (an orbital period of 108 days) while the 2014 event likely occurred in early 2014 at 0.24 au (an orbital period of 41.6 days). The terrestrial zone in the ID8 system is undergoing vigorous evolution.

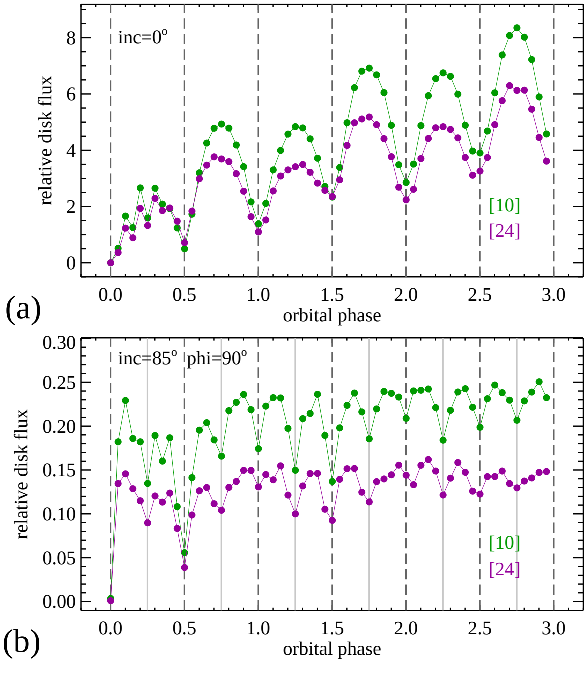

Figure 1- Simulated disk light curves for an impact produced, optically thick cloud at 10 and 24 µm from our 3-D radiative transfer calculations, viewed from (a) face-on and (b) included. The disk emission is suppressed when the cloud passes the collision (phase of integer numbers) and anti-collision (phase of half integer numbers) points, marked by vertical dashed lines. For the inclined case, the collision point is set exactly between the disk ansae, i.e., the disk ansae locate exactly between the collision and anti-collision points (marked by vertical grey lines).

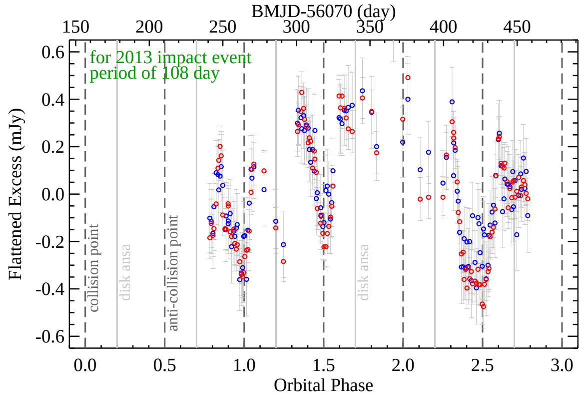

Figure 2 – ID8 flattened disk light curves observed in 2013 (blue: 3.6 µm, red: 4.5 µm). The 2013 impact occurred at BMJD 56227 (phase 0) at an orbital distance of 0.44 au.

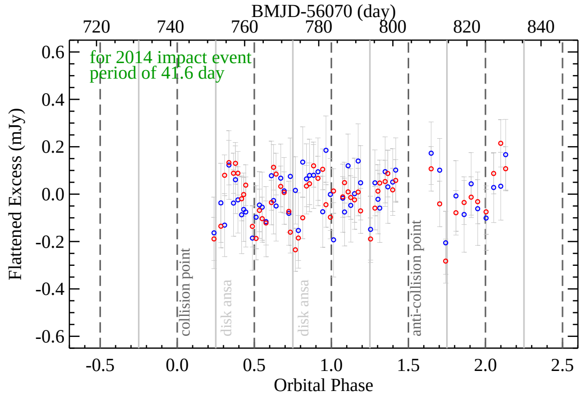

Figure 3 – ID8 flattened disk light curve observed in 2014. Symbols and lines are the same as in Fig. 2. This impact occurred at early 2014 at an orbital distance of 0.24 au.

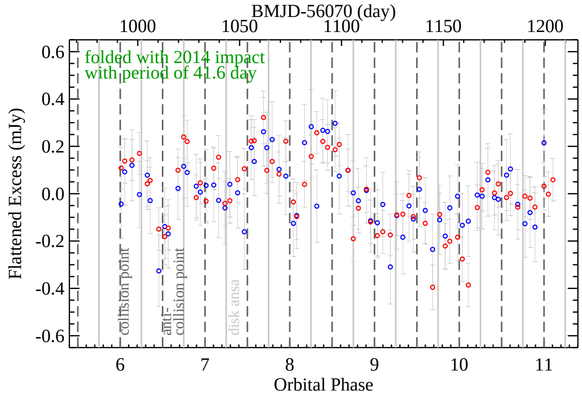

Figure 4 – ID8 flattened disk light curve observed in 2015, folded with the 2014 impact event. Possible dips due to the 2014 cloud are marked.

References: [1] Gorlova et al. (2007) *ApJ*, 670, 516. [2] Gaia Collaboration. (2016) *A&A*, 595, A1. [3] Meng et al. (2014) *Science*, 343, 1490. [4] Su et al. (2018) submitted to *ApJ*. [5] Olofsson et al. (2012) *A&A*, 542, A90. [6] Jackson et al. (2014) *MNRAS*, 440, 3757. [7] Jackson et al. (2018) in prep. (presentation in this conf.).