Study on SN 2018agk and detectability of early flux excess in light curves of SNe Ia in high cadence survey

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Introduction

Despite their fundamental importance to cosmology, the exact progenitor systems of type Ia supernovae (SNe Ia) are not known. Theories suggest that signatures of some SNe Ia progenitors could be seen as bumps or flux excess in the early light curve, e.g. the collision of SN ejecta with the non-degenerate binary companion (Kasen 2009). With high cadence light curves from Kepler and TESS, we can search for such signals to identify progenitor systems of SNe. We present the 30-min cadence Kepler/K2 light curve of SN 2018agk that is fully consistent with a single power-law rise, giving strong limits on any early excess flux features. Combined with early ground-based observations, SN 2018agk has similar color evolution with other SNe Ia without early bumps and is a prototypical example for future study in early color evolution. Using the high-S/N light curve of SN 2018agk, we also study the detectability and characterization of early excess flux with high cadence survey and it will have substantial implication to similar studies with TESS.

Light curve fit and early excess detection

The early Kepler/K2 light curve shows a clear power-law rise. Using Bayesian Information Criteria (BIC) test, we find that a single power-law fit with a power-law index α = 2.35±0.10 is more preferable than canonical fireball model (L∝ t^2) and double power-law fit, and there is no indication of any excess flux in its early light curve.

Traditionally (e.g., Dimitriadis et al. 2019), excess flux is detected by fitting a power-law to a time interval well after the explosion, and subtracting this power-law from the light curve. The excess flux can then be determined from the flux residuals. This is illustrated in Fig. 1: the upper panel shows SN 2018agk's raw Kepler/K2 light curve (red), and with an companion-interaction model fitted to SN 2018oh light curve added (blue). The Power-laws fitted to these light curves in between -13 to -10 days before peak (light-gray shaded area) are then subtracted from the light curves (lower panel). We note that the excess flux caused by companion-interaction only slowly declines. Therefore, at phases of -13 and later, a significant fraction of the flux is still due to the shock interaction, even though the light curve nicely follows a power-law. This means that the excess flux determined from the residuals vastly underestimates the true excess flux (dashed gray and purple lines in the lower panel of Fig. 1, respectively). It is therefore important to improve the fitting and characterization of the excess flux in high cadence surveys.

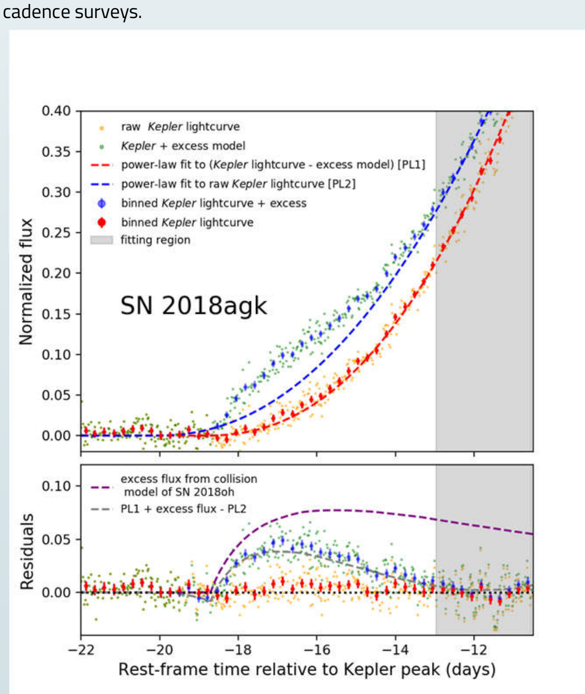

Figure 1: (Wang et al in prep) Comparison between SN 2018agk's Kepler/K2 light curve with (blue) and without (red) excess from the companion-interaction model added. The top panel shows the light curves with a power-law fit (dashed lines) to phases between -13 and -10 days (light-fray shaded area). The bottom panel shows the residuals relative to each power-law fit, and the true excess flux (dashed purple line). We note that the excess flux determined from the residuals significantly underestimates the true excess flux.

Early color evolution

Combined with DECam-g and i observations in the first ~ 4 days after first light in Kepler/K2, we calculated the early color evolution and found the similarity when compared with other SNe Ia without early bumps (SN 2011fe, SN 2015F and SN 2018gv). In g-i band, SNe Ia in our sample have very low level of variability, in contrast to steep evolution in g-r and B-V bands as discussed in Bulla et al 2020 and Stritzinger et al 2018.

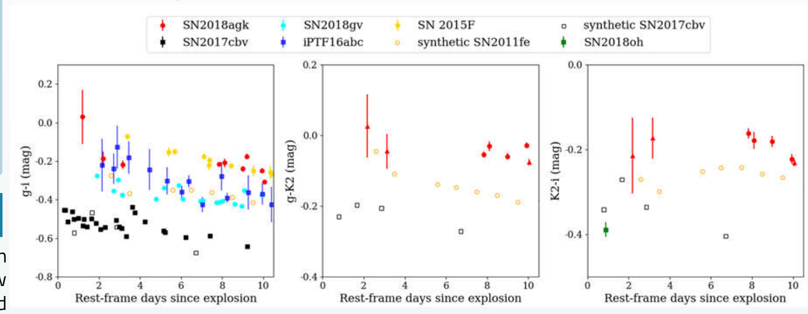

Figure 2: (Wang et al in prep) Color evolution of SN 2018agk in g-i (left), g-Kepler (middle) and Kepler-i (right). We also include other SN Ia with early observations, such as photometric measurements of SN 2015F, SN 2017cbv, SN 2018oh and SN 2018gv (in g and i band), alongside synthetic magnitude of SN2011fe and SN 2017cbv calculated from photometrically calibrated spectra. All photometric measurements include uncertainties, but may be too small to be seen. The SNe Ia without bump and iPTF16abc concentrate in *g-i* band within a range of -0.2±0.2, while SN 2017cbv is bluer than this normal SNe Ia group. All SNe Ia in our sample have relatively stable color evolution in the first ~10 days.

Constraints on progenitors

We run the same algorithm on excess for a large set of different θ and α and plot the color map of the peak of summed S/N with regard to these two parameters in Fig. 3. The blue and red region represents the regions of detectable and non-detectable excess in the parameter space, and we add a black dashed line marking approximate detection limit for the SD progenitor system of SN 2018agk in Fig. 3. Such diagnostic could be constructed for all SNe Ia with early lightcurves in Kepler and TESS to thoroughly constrain the excess models statistically.

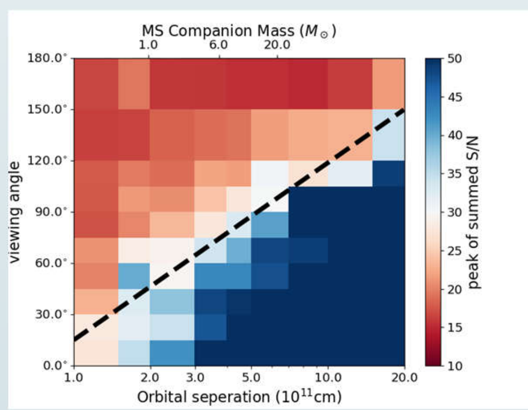

Figure 3: (Wang et al in prep) The peak of rolling summed S/N with Gaussian window for companion-interaction model with different orbital separation and viewing angle We empirically set the detection limit to be S/N ~ 30, corresponding to the white blocks in the color map, and blue region represents the detectable excess, while in red region the excess is non-detectable. The black dash line qualitatively marks the bounds of detectability of excess in parameter space. The mass of a main sequence companion in the MS-WD binary system undergoing Roche lobe filling with certain orbital seperation is labeled at top.

Reference

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