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PHOTOMETRIC EVOLUTION AND PECULIAR DUST FORMATION IN THE GAMMA-RAY NOVA Sco 2012 (V1324 Sco)

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Nova Sco 2012 was discovered on 2012 May 22.80 UT by Wagner et al. (2012) as the optical transient MOA 2012 BLG-320 during the Microlensing Observations in Astrophysics (MOA) survey (Abe et al. 1997). It appeared at equatorial coordinates RA = 17:50:53.90 and DEC = −32:37:20.46 (J2000), corresponding to Galactic coordinates l=357.4255 and b=−02.8723 deg, and has no obvious counterpart on DSS plates. Pre-outburst MOA photometry reported by Wagner et al. (2012) shows the progenitor varying around 19.0-19.5 mag in I band. Between May 14 and 16 UT, the source began a slow monotonic increase in brightness, modulated with an amplitude of about 0.1 mag and a period of about 1.6 hr, with the real outburst starting between June 1.77 and 2.55 UT. High-resolution spectroscopy obtained on June 4.08 UT by Wagner et al. (2012) with the ESO-VLT+UVES telescope confirmed the transient to be an FeII-class nova, with a FWHM$\sim$800 km/s for the Hα and Hβ lines.

The Fermi/LAT satellite detected γ-ray emission at >100 MeV from Nova Sco 2012 from June 16 to June 30, with the highest flux during June 18-24 (Cheung et al. 2012, Metzger et al. 2015). Only a very few other novae have been so far detected in γ-rays (Ackermann et al. 2014).

No description of the optical and infrared photometric evolution of Nova Sco 2012 has been provided to date. In this paper we present $BVR_{\rm c}I_{\rm c}JHK$ photometry of Nova Sco 2012 and discuss its light curve covering the evolution from pre-maximum to day +34 past optical maximum, when the nova had declined by more than 5 magnitudes below V maximum, plus some later B, V data. Our photometry is given in Tables 1 and 2. It was collected with ANS Collaboration telescope 036 (Munari et al. 2012), during the APASS all-sky survey (Henden et al. 2012), with AAVSOnet OC61 telescope (Mt. John University Observatory, NZ), and with the CTIO SMARTS 1.3 m telescope (Walter et al. 2012). The light and color-curves of Nova Sco 2012 are presented in Figure 1, with pre-maximum data from Wagner et al. (2012) and observations retrieved from VSNET and AAVSO international databases included. The AAVSO data are presented as the mean nightly value for a single observer when multiple entries are present. AAVSO and VSNET data have had obviously deviating points removed, and offsets have been applied to bring their zero points to agree with ANS, APASS and SMARTS properly calibrated data (0.15, −0.05 and −0.17 mag have been added to VSNET B, V and R_c data, respectively, and 0.05 mag to AAVSO B data). At 8 arcsec distance from the nova lies a field star, measured by APASS at B=16.23, V=15.32, g'=15.69, r'=14.95, i'=13.05.

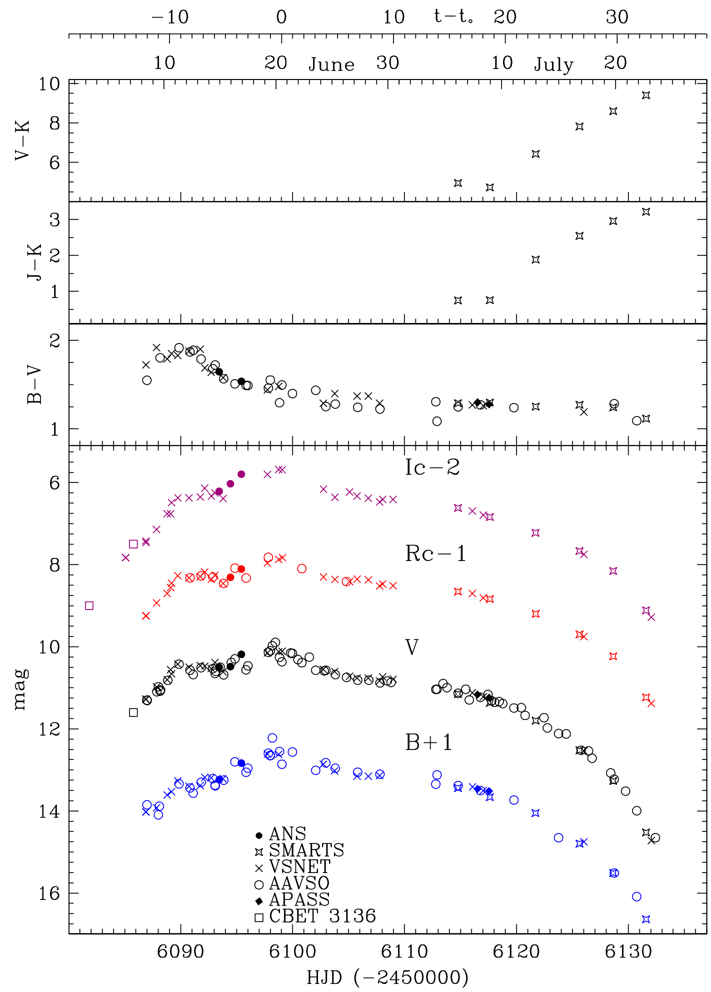

Figure 1. BVR_cI_c light curves and $B-V$, $J-K$ and $V-K$ evolution of Nova Sco 2012.

The rise of Nova Sco 2012 toward maximum in the I_c band covered the last 2.65 mag before the pre-max halt at a constant speed of 0.33 mag/day. The pre-max halt in Figure 1 is obvious in V, R_c and I_c and lasted ∼3 days (from day −9 to −6), after which the final ∼0.5 mag rise to maximum was completed in ∼6 days with superimposed large variability. The presence of the pre-max halt is much less obvious in B band.

The initial decline from maximum of Nova Sco 2012 was smooth and slow, with decline times of t_1^B=19, t_1^V=17 days, and a decline slope suggesting t_2^V ≈40 days (t_n is the time required to decline from maximum by n magnitudes in the given band). Initial JHK photometry (cf Figure 1, data points for days +16 and +19) is consistent with normal photospheric emission under heavy interstellar reddening. Around day +20, dust begun to form in the ejecta, which caused a rapid and large increase in $J-K$ and $V-K$ color indexes and a parallel drop in optical brightness. It is worth noticing that, as observed in many novae (e.g. Nova Aql 1993 by Munari et al. 1994; Nova Sct 2009 by Raj et al. 2012; Nova Cep 2013 by Munari et al. 2014), the dust condensation did not cause a reddening

Table 1: Optical photometry of Nova Sco 2012.

HJD	id	B	$\pm$	V	$\pm$	R_c	$\pm$	I_c	$\pm$
6093.438	ANS	12.239	0.013	10.501	0.006	8.213	0.008		
6094.438	ANS	10.483	0.004	9.306	0.008	8.028	0.014		
6095.419	ANS	11.833	0.017	10.184	0.006	9.105	0.008	7.795	0.014
6114.775	SMARTS	12.438	0.002	11.148	0.002	9.656	0.001	8.617	0.001
6116.511	APASS	12.464	0.004	11.164	0.002				
6117.547	APASS	12.515	0.004	11.236	0.002				
6117.628	SMARTS	12.661	0.002	11.365	0.002	9.840	0.001	8.840	0.001
6121.709	SMARTS	13.051	0.003	11.799	0.003	10.199	0.001	9.222	0.001
6125.640	SMARTS	13.794	0.004	12.523	0.004	10.698	0.002	9.665	0.001
6128.646	SMARTS	14.512	0.006	13.270	0.006	11.234	0.002	10.153	0.001
6131.584	SMARTS	15.638	0.012	14.523	0.011	12.231	0.004	11.115	0.002
6384.034	OC61	16.842	0.020						
6389.128	OC61	18.428	0.021	16.829	0.015				
6396.004	OC61	18.424	0.026	16.883	0.020				

of optical colors of Nova Sco 2012 (cf Figure 1). The fact that the wavelength-dependent absorption efficiency of the dust turned from neutral to selective at $\lambda \geq$6000 Å suggests a prevalent carbon composition with a diameter of dust grains of the order of 0.1 μm (Draine and Lee 1984; Kolotilov et al. 1996). In many novae forming dust, the dust condensation starts quite suddenly causing a marked knee in the light curve (cf the recent case of Nova Cep 2013, Munari et al. 2014). Such a knee is absent in the light curve of Nova Sco 2012 and substituted by a gradual *acceleration* of the extinction, suggesting a more gradual condensation of the dust grains. Nova Sco 2012 differs from many other dust condensing novae in two other respects: (1) dust formation usually occurs at the time of the transition from optically thick to optically thin ejecta, about 3-4 mag below maximum brightness, which led Shore and Gehrz (2004) to suggest that it is the photo-ionization from the central star that triggers dust grain condensation in the ejecta. In Nova Sco 2012, dust begun to condense at a much earlier phase, only 1 mag below maximum; (2) the slower a nova, the later dust begins to condense, as illustrated by the compilation of data for M31 and Galactic novae of Shafter et al. (2011). Their relation, applied to the predicted $t_2^V \approx$40 days for Nova Sco 2012, indicates that dust should have begun to condense $\sim$60 days past maximum ($\pm$10 days given the dispersion of the plotted data) and $\sim$60 days is also estimated from the theoretical modeling presented by Williams et al. (2013). Such a $\sim$60 day delay is much longer than the observed 20 days for Nova Sco 2012. The dust extinction caused the V magnitude of Nova Sco 2012 to drop below 19-20 mag (SMARTS and AAVSO data). When we re-observed the nova in April 2013 (day +285, see Table 1) the nova had rebrightened to V=16.8 and recovered the normal brightness decline, meaning the dust extinction had already cleared.

According to van den Bergh and Younger (1987), typical novae display $(B-V)_\circ = +0.23$ at B, V maximum brightness and $(B-V)_\circ = -0.02$ at t_2. The corresponding values for Nova Sco 2012 were $B-V$=+1.44 and $B-V$=+1.23 (from spline interpolation of the data in Figure 1), that provide E_{B-V}=1.21 and 1.25, respectively. The average E_{B-V}=1.23 is in excellent agreement with the E_{B-V}=1.23 derived by Finzell et al. (2015) from the intensity of interstellar NaI and KI in high resolution spectra of Nova Sco 2012. The corresponding extinction is A_V=4.18 mag from Fiorucci and Munari (2003) relations appropriate for the intrinsic colors of the nova and standard R_V=3.1 extinction law.

Table 2: SMARTS infrared photometry of Nova Sco 2012.

HJD	J	$\pm$	H	$\pm$	K	$\pm$
6114.773	6.942	0.006	6.637	0.004	6.193	0.005
6117.626	7.392	0.006	6.837	0.004	6.635	0.004
6121.707	7.252	0.006	6.380	0.003	5.370	0.003
6125.638	7.243	0.006	5.903	0.003	4.700	0.002
6128.644	7.635	0.007	5.960	0.003	4.675	0.002
6131.583	8.326	0.009	6.347	0.003	5.110	0.002

Nova Sco 2012 reached a maximum brightness of B=11.60, V=10.14, R_c = 8.85 and I_c = 7.68 around JD=2456099.0 (±0.5), 2012 June 20.5 UT, and the observed decline times were t_2^B=26, t_2^V=25, t_3^B=30.5, t_3^V=29.5, with t_3 times too short with respect to t_2 because of the undergoing extinction by dust condensing in the ejecta. These decline times are a popular means to estimate the distance to a nova. The most recent calibration of the absolute magnitude at maximum versus rate of decline (MMRD) relation has been presented by Downes and Duerbeck (2000). The distance to Nova Sco 2012, with the A_V=4.18 mag extinction, is 5.5 kpc for t_2^V=25 and the linear MMRD and 5.3 kpc for the S-shaped MMRD. For t_3^V=29.5, the linear MMRD yields 6.9 kpc. The large discrepancy of the distances estimated from t_2^V and t_3^V is a sign of the disturbance from the condensing dust. Considering t_2^V ≈40 days, estimated above as a feasible value in absence of condensing dust, the corresponding distance to Nova Sco 2012 would be 4.3 kpc from linear MMRD and 3.7 kpc from S-shaped MMRD.

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