NuSTAR, Swift and XMM-Newton spectroscopy of the brightest gamma-ray nova ASASSN-18fv

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NuSTAR observations of the classical nova ASASSN-18fv conducted 36 (simultaneously with gamma rays) and 57 days past explosion reveal plasma heated to 10^7 K by shocks deeply embedded in the ejecta. The origin of these shocks remains uncertain.

Background

Nova explosions are powered by nuclear fusion that ignites at the bottom of a hydrogen-rich shell on the surface of an accreting white dwarf in a binary star system. The X-ray emission is produced during the following stages:

1. X-ray fireball in first hours of explosion (never observed)
2. Shock waves heat plasma and accelerate particles weeks-months after explosion
3. Hydrogen-burning white dwarf - Super-Soft Source
4. When accretion restarts, the gas hitting WD surface gets shocked and heated

ASASSN-18fv = Nova Carinae 2018 = V906 Car

Discovered on 2018-03-20.32 UT by the ASAS-SN survey (Fig. 1) and spectroscopically confirmed as a Fe-type nova. By a lucky coincidence, it was within the field of view of BRIGHT cubesats performing photometry of the nearby red giant. The nova lightcurve peaking at 5.9 mag, showed an unusual series of fast flares. It is suggested that these flares might be manifestations of shocks (Aydi et al. in prep).

NuSTAR spectroscopy of ASASSN-18fv

NuSTAR observed ASASSN-18fv 36 and 57 days after explosion (Table 1). The spectrum (Fig. 2) is consistent with being produced by thermal plasma (Table 3), presumably heated by shocks. The large column densities inferred from the NuSTAR spectra suggest, that the shocks are deeply embedded within the nova ejecta.

Summary of NuSTAR observations of novae

Five novae observed so far:

1. V745 Sco (giant companion) - detected (Orio et al. 2015 MNRAS, 448L, 35)
2. V339 Del - not detected (Mukai et al. in prep.)
3. V5668 Sgr - not detected (Mukai et al. in prep.)
4. V5855 Sgr - detected while still gamma-ray bright (Nelson et al. 2019 ApJ, 872, 86)
5. ASASSN-18fv - detected while still gamma-ray bright

The NuSTAR spectra of all three detected novae are consistent with thermal emission.

XMM-Newton spectroscopy

The NuSTAR spectrum of ASASSN-18fv presented a puzzle: it shows no signs of Fe emission and absorption while the optical spectrum of the nova exhibits strong Fe lines. The alternative to the Fe-deficient model is the model that has the Fe abundance fixed to the Solar value, but requires overabundance of CNO elements (Table 3). The two models also imply a factor of 70 difference in the total absorbing column and hence the ejecta mass. We requested XMM-Newton DDT to measure the abundances. The preliminary analysis of the spectrum (Fig. 3) suggests that both possibilities are realized at the same time: while the nova ejecta is enriched with Nitrogen and Carbon, its Fe abundance is sub-Solar (Table 3).

Swift monitoring

Swift was able to detect ASASSN-18fv right after the second NuSTAR observation when the ejecta became sufficiently transparent to soft X-rays (Fig. 5). The Swift/XRT hardness ratio (Fig. 4) follows the gradual decline in the absorbing column. These observations were crucial for planning the XMM-Newton DDT.

Acknowledgements

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Table 1. *NuSTAR* observing log

ObsID	Epoch (days)	Start UT	Stop UT	Exposure FPMA (ks)	Exposure FPMB (ks)	Net count rate FPMA (cts/s)	Net count rate FPMB (cts/s)
80301306002	36.3	2018-04-20 14:46	2018-04-22 02:01	48.8	48.5	0.01582 ± 0.00066	0.01630 ± 0.00067
90401322002	57.2	2018-05-11 16:26	2018-05-12 18:01	47.5	47.4	0.04343 ± 0.00102	0.04184 ± 0.00101

Column designation: Col. 1 – observation identification number; Col. 2 – time since outburst; Col. 3 and 4 – start and stop time of the observation (interrupted by Earth occultations and South Atlantic Anomaly passes); Col. 5 and 6 – total on-source exposure time for FPMA and FPMB, respectively; Col. 7 and 8 – source count rate (background-subtracted) for FPMA and FPMB, respectively.

Table 2. Parameters of the *NuSTAR* spectral model `constant*vphabs*vapec`

Epoch (days)	n_{HI} ($\times 10^{22}$ cm^{-2})	kT (keV)	FeCoNi abundances	CNO abundances	C_{FPMB}	Model 3.5-78.0 keV flux $\log_{10}$(ergs/cm^2/s)	Unabsorbed 3.5-78.0 keV flux $\log_{10}$(ergs/cm^2/s)
Fe-deficient model: $\chi^2_{\mathrm{red}} = 1.0281$, d.o.f. $= 199$, $p = 0.38$							
36	293.1 ± 20.3	8.04 ± 0.91	0.086 ± 0.030	1.0	1.109 ± 0.062	-11.570 ± 0.012	-11.068 ± 0.012
57	44.82 ± 2.72	4.43 ± 0.17	—"—	—"—	1.006 ± 0.034	-11.454 ± 0.007	-11.179 ± 0.007
CNO-overabundance model: $\chi^2_{\mathrm{red}} = 1.0457$, d.o.f. $= 199$, $p = 0.31$							
36	4.287 ± 2.288	8.59 ± 0.88	1.0	209.6 ± 110.4	1.107 ± 0.062	-11.564 ± 0.012	-11.142 ± 0.012
57	0.568 ± 0.288	4.38 ± 0.17	—"—	—"—	1.006 ± 0.034	-11.454 ± 0.007	-11.221 ± 0.007

Column designation: Col. 1 – time since outburst; Col. 2 – equivalent hydrogen column density; Col. 3 – plasma temperature; Col. 4 – abundances of Fe, Co and Ni (tied together) relative to the Solar values;Col. 5 – abundances of C, N and O (tied together) relative to the Solar values;respectively; Col. 6 – normalization factor of FPMB relative to FPMA; Col. 7 and 8 – absorbed and unabsorbed 3.5-78.0 keV fluxes, respectively.

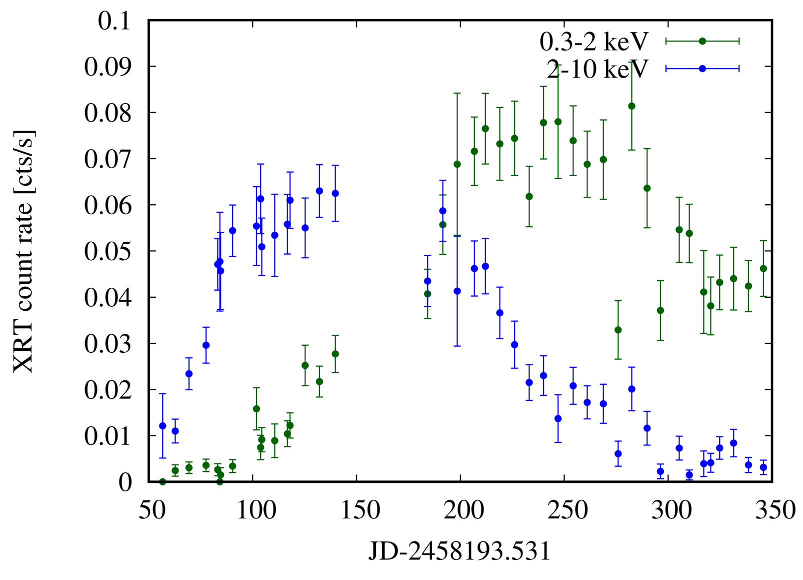

Fig. 4 **Swift/XRT** lightcurve of ASASSN-18fv in hard (blue) and soft (green) bands.

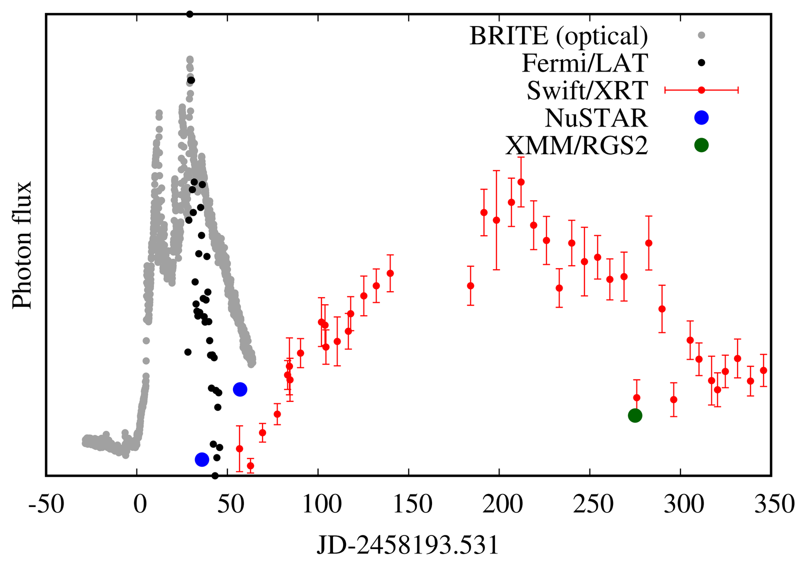

Fig. 5 Multiwavelength lightcurve of ASASSN-18fv showing relative duration of optical, gamma-ray and X-ray emission and marking the times of NuSTAR and XMM observations.

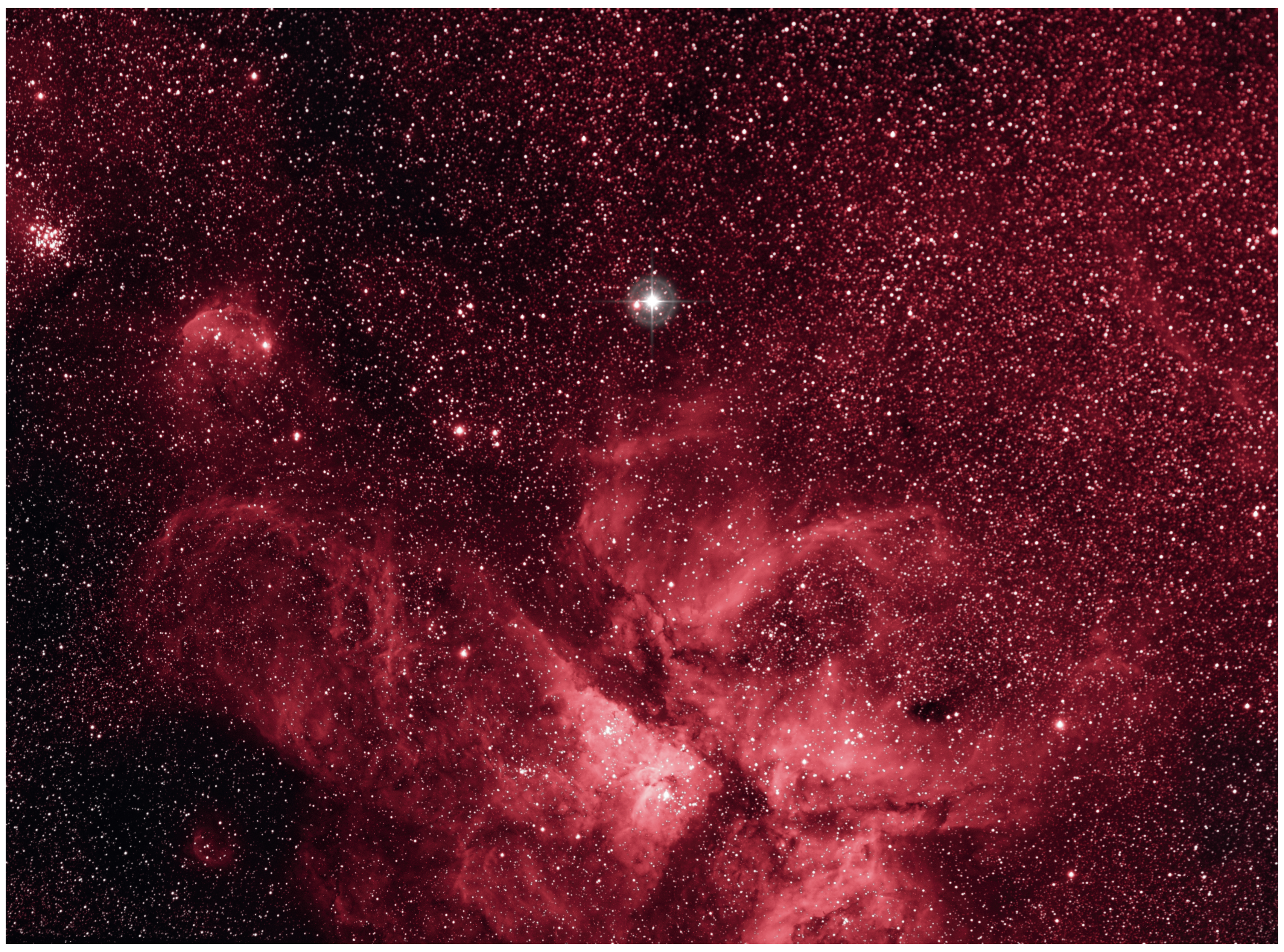

Fig. 1 The field of the Eta Carina Nebula with ASASSN-18fv (bright star above the image center). Image by Joseph Brimacombe.

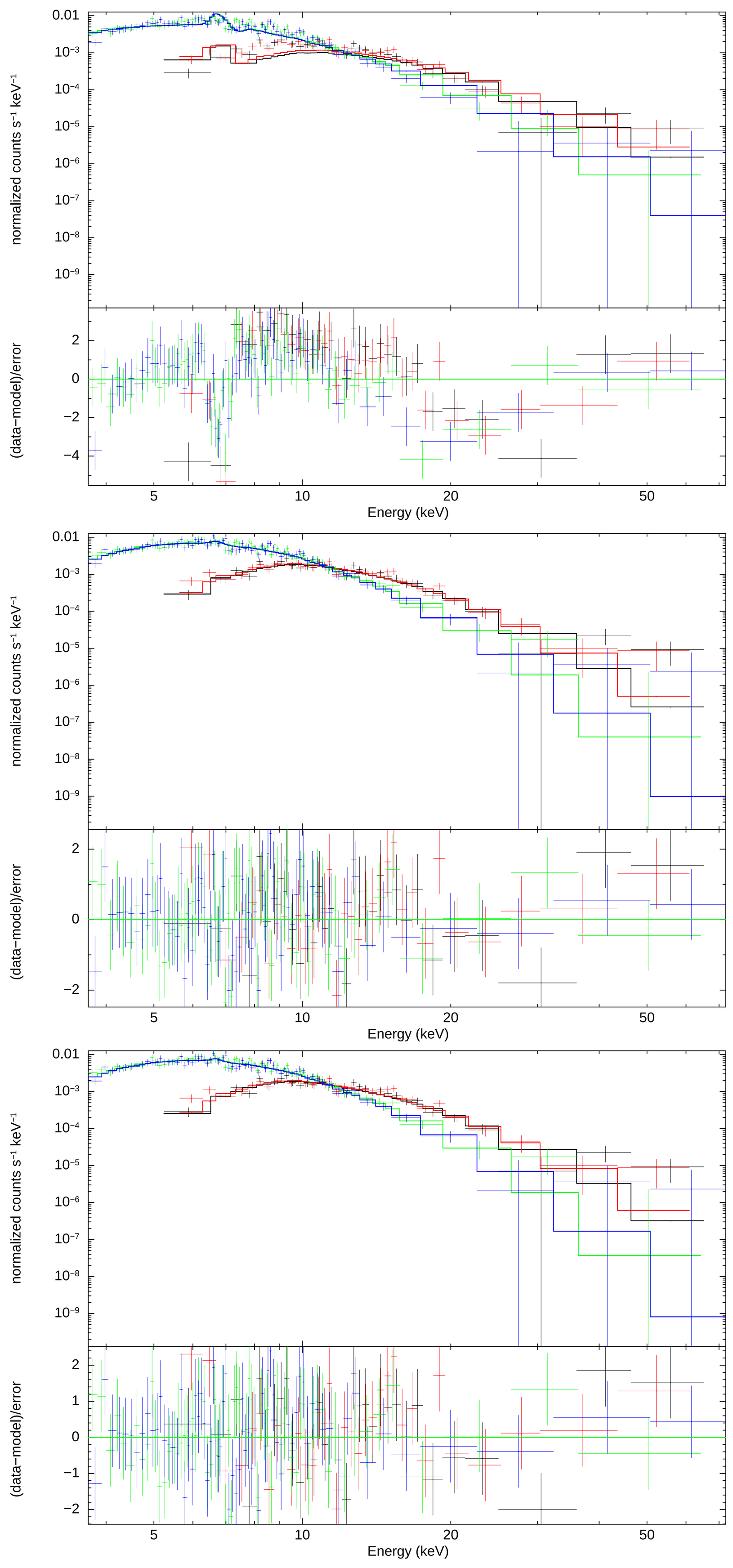

Fig. 2 **NuSTAR** observations compared to the absorbed thermal plasma emission model with the abundances fixed to Solar (top panel), FeCoNi abundances tied together and left free to vary (middle) and CNO abundances tied together and left free to vary, while FeCoNi are fixed to Solar values (bottom). Only the latter tow models produce a statistically acceptable fit. Black and red curves represent spectra obtained with two NuSTAR telescopes FPMA and FPMB during the first epoch (day 36) while green and blue are the FPMA and FPMB spectra obtained during the second epoch (day 57).

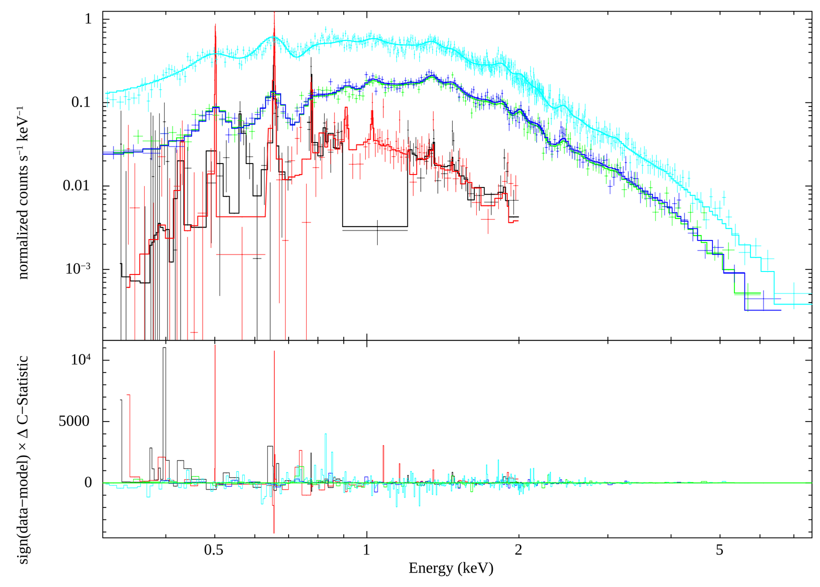

Fig. 3 **XMM-Newton** observations conducted on day 275 after explosion. Cyan, blue, green red and black curves represent EPIC-pn, EPIC-MOS 1/2 and RGS 1/2 spectra. Gaussian lines had to be added to the model to account for the line flux not fully described by bvapec **model.**

Table 3. XMM-Newton spectrum modeling: `constant*phabs*vphabs*bvapec`

	EPIC+RGS
PHABS	
N_H ($\times 10^{21}$ cm^{-2})	$2.4^{+0.4}_{-0.3}$
VPHABS	
N_H ($\times 10^{21}$ cm^{-2})	$0.12^{+0.03}_{-0.03}$
BVAPEC	
kT (keV)	$1.07^{+0.04}_{-0.01}$
redshift	$-2.9\times 10^{-3*}$
velocity (km s^{-1})	$378^{(*)}$
N/N$_\odot$	345^{+93}_{-70}
O/O$_\odot$	29^{+7}_{-5}
Ne/Ne$_\odot$	$2.2^{+0.6}_{-0.5}$
Mg/Mg$_\odot$	$0.6^{+0.2}_{-0.1}$
Si/Si$_\odot$	$1.1^{+0.2}_{-0.2}$
Fe/Fe$_\odot$	<0.1
χ^2_ν	1.15
d.o.f.	1837

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