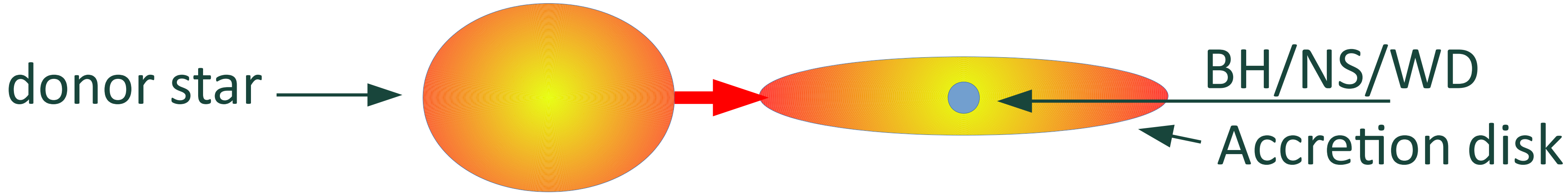
Observations of classical novae across the electromagnetic spectrum

Kirill Sokolovsky

Nova Car 2018 and η Car nebula
imaged by Joseph Brimacombe

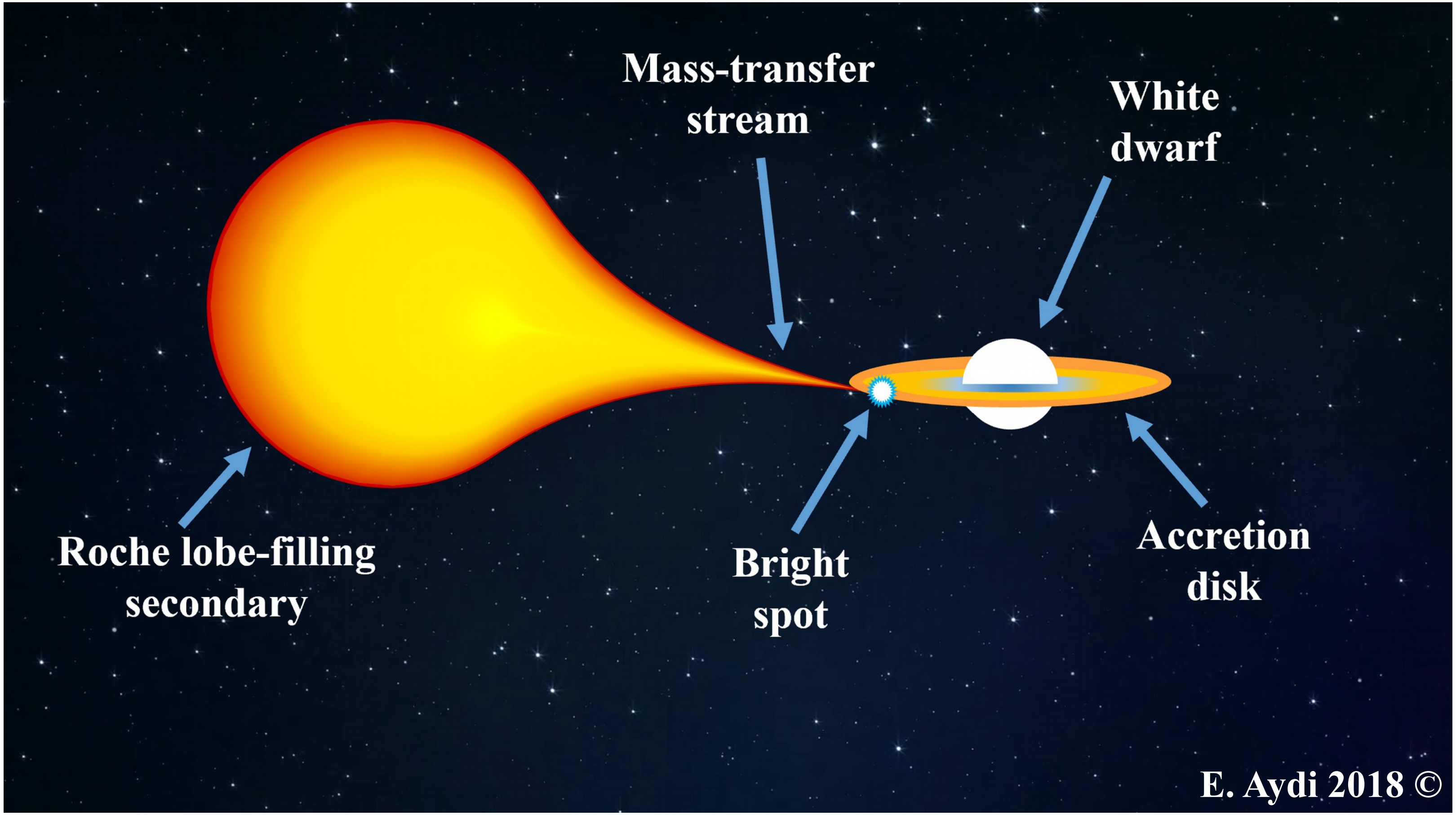
Classical novae are not...

- X-ray novae - BH/NS binary + disk instability; V404 Cyg
- Dwarf novae - as above, but with WD; SS Cyg
- Symbiotic novae - WD accreting from RG (wind), slow (years) thermonuclear-powered outburst; V1016 Cyg
- Classical novae in WD + RG system fast thermonuclear outburst, ejecta slams in RG wind; V407 Cyg



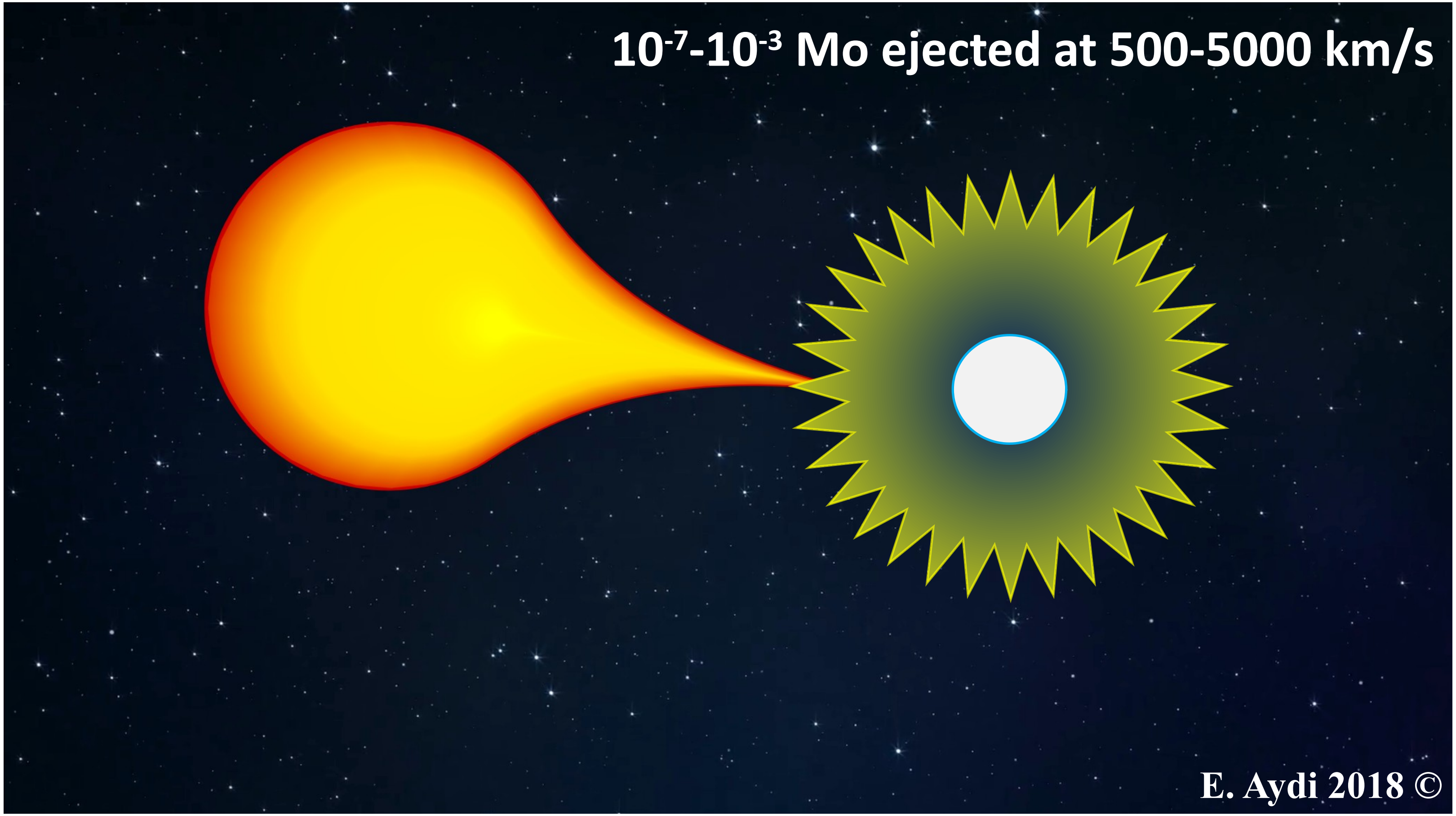
Nova

thermonuclear explosion on accreating white dwarf



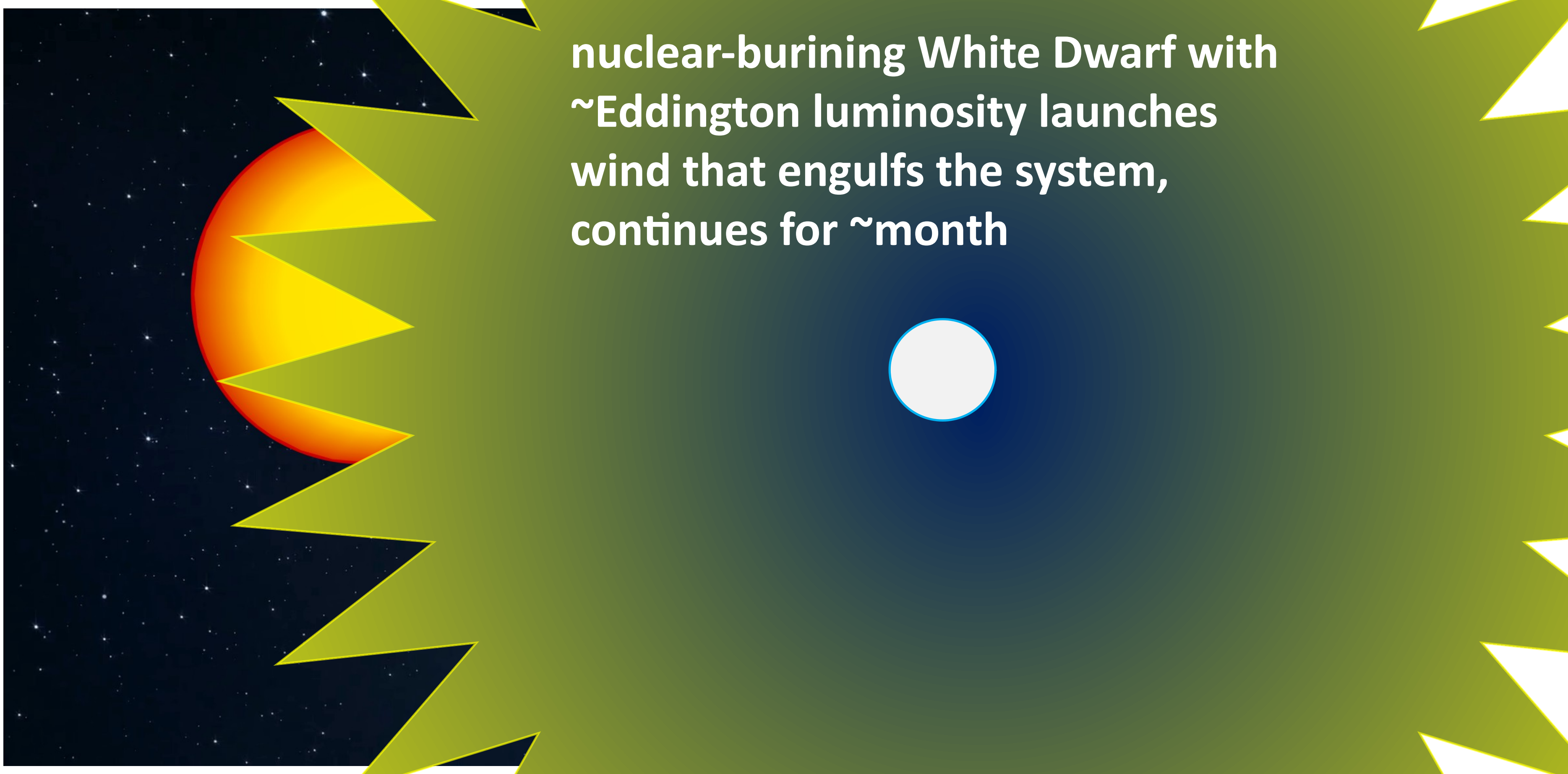
Nova

thermonuclear explosion on accreating white dwarf



Nova

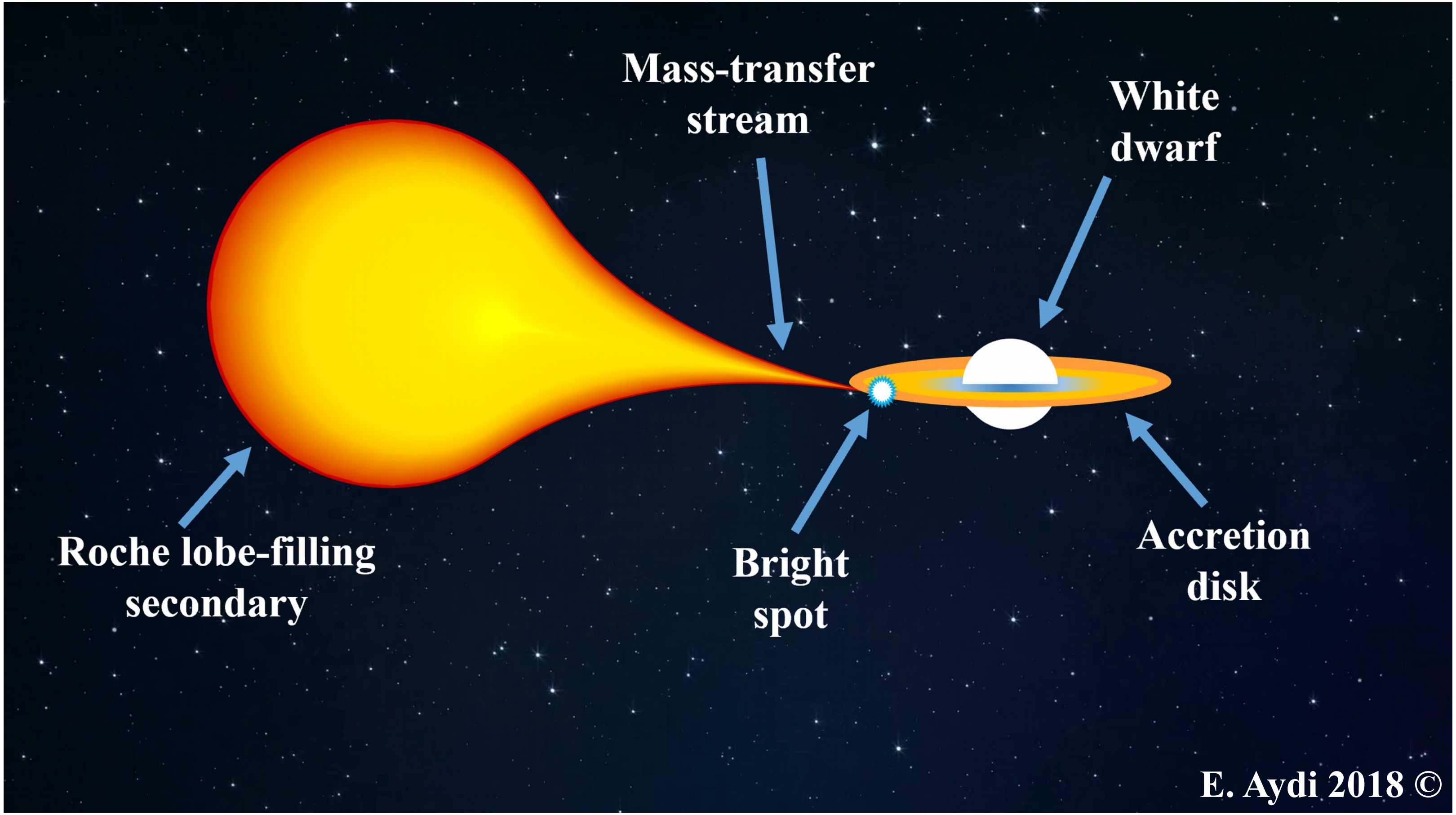
thermonuclear explosion on accreating white dwarf



nuclear-burining White Dwarf with ~Eddington luminosity launches wind that engulfs the system, continues for ~month

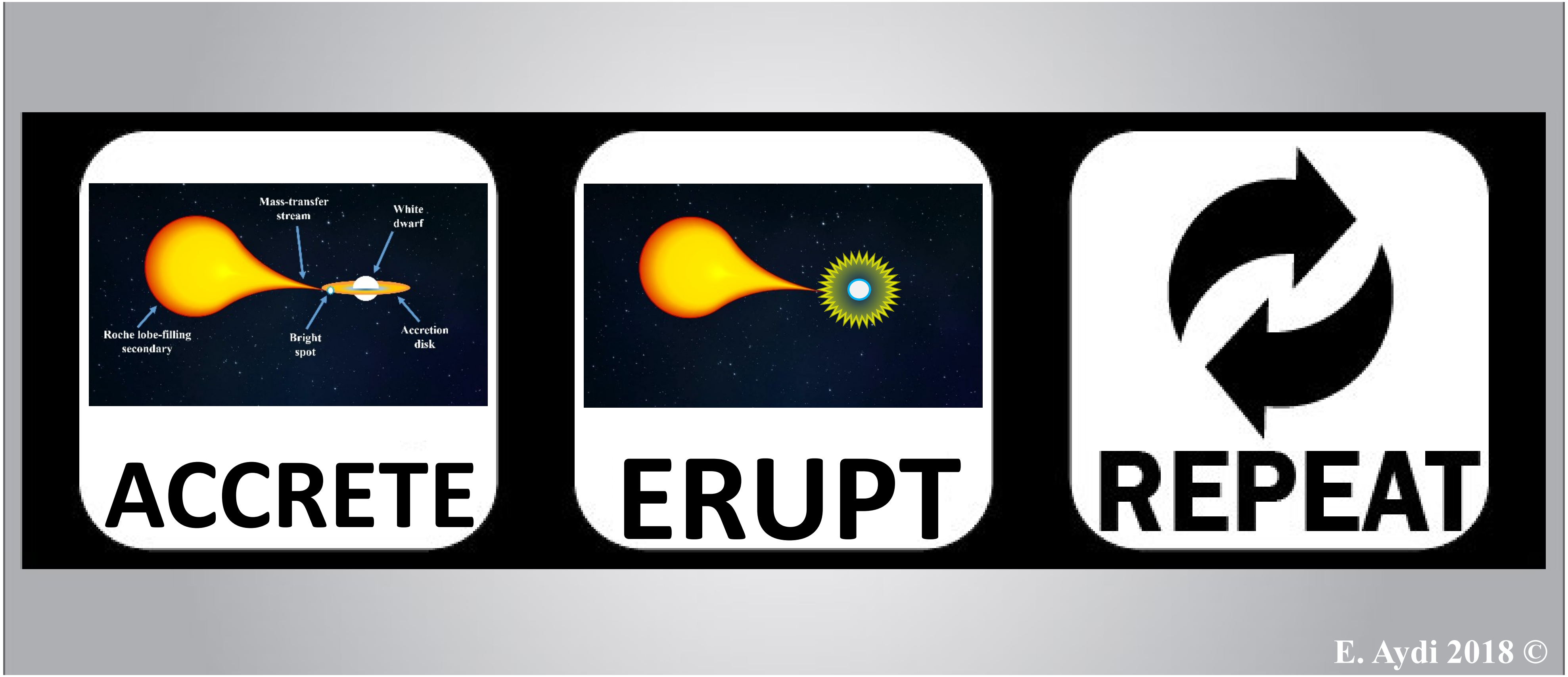
Nova

ejecta clears, accretion restarts,
mass accumulates for the next outburst



Nova

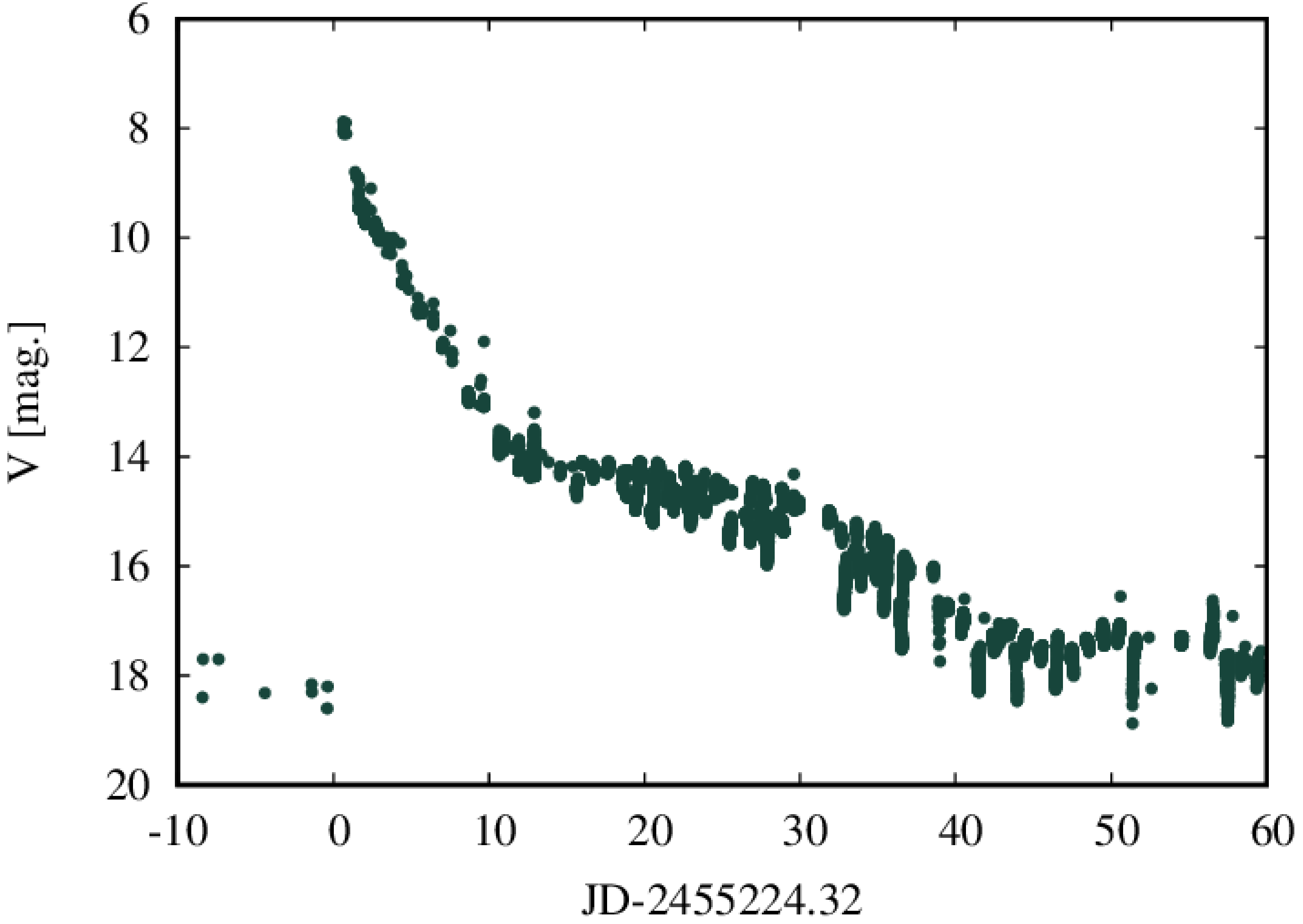
timescale: 1 year (extreme!) to >~ 10 000 years



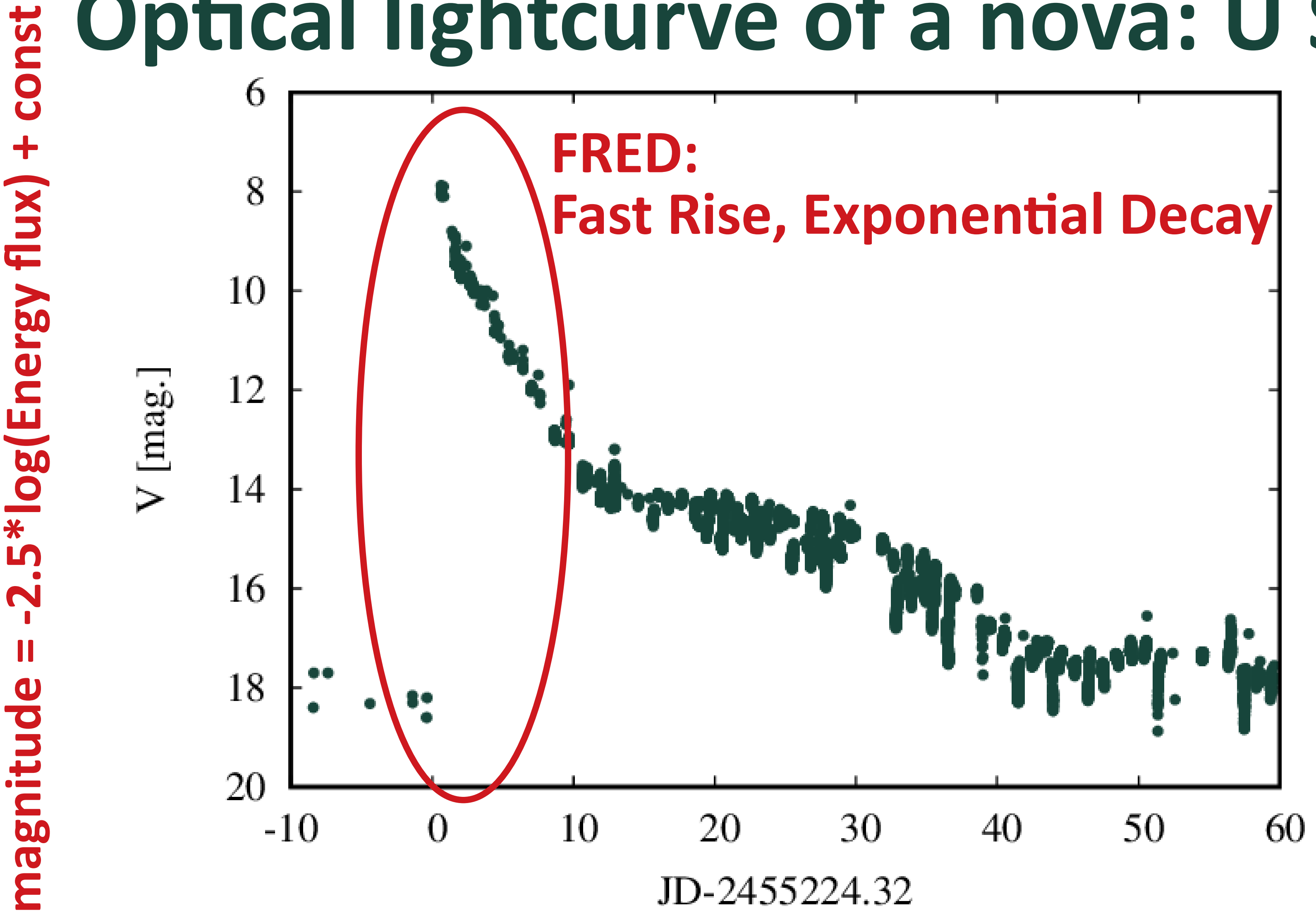
Nova population

- discovery rate ~10/year
- discovered in optical band by (mostly Japanese) amateurs and ASAS-SN (exception - V959 Mon)
- follow stellar density (mostly occur in disk and bulge)
- expected rate ~50/year Shafter et al. 2017 ApJ, 834, 196
- Galactic analogues of faint-fast novae seen in M31 and M87?

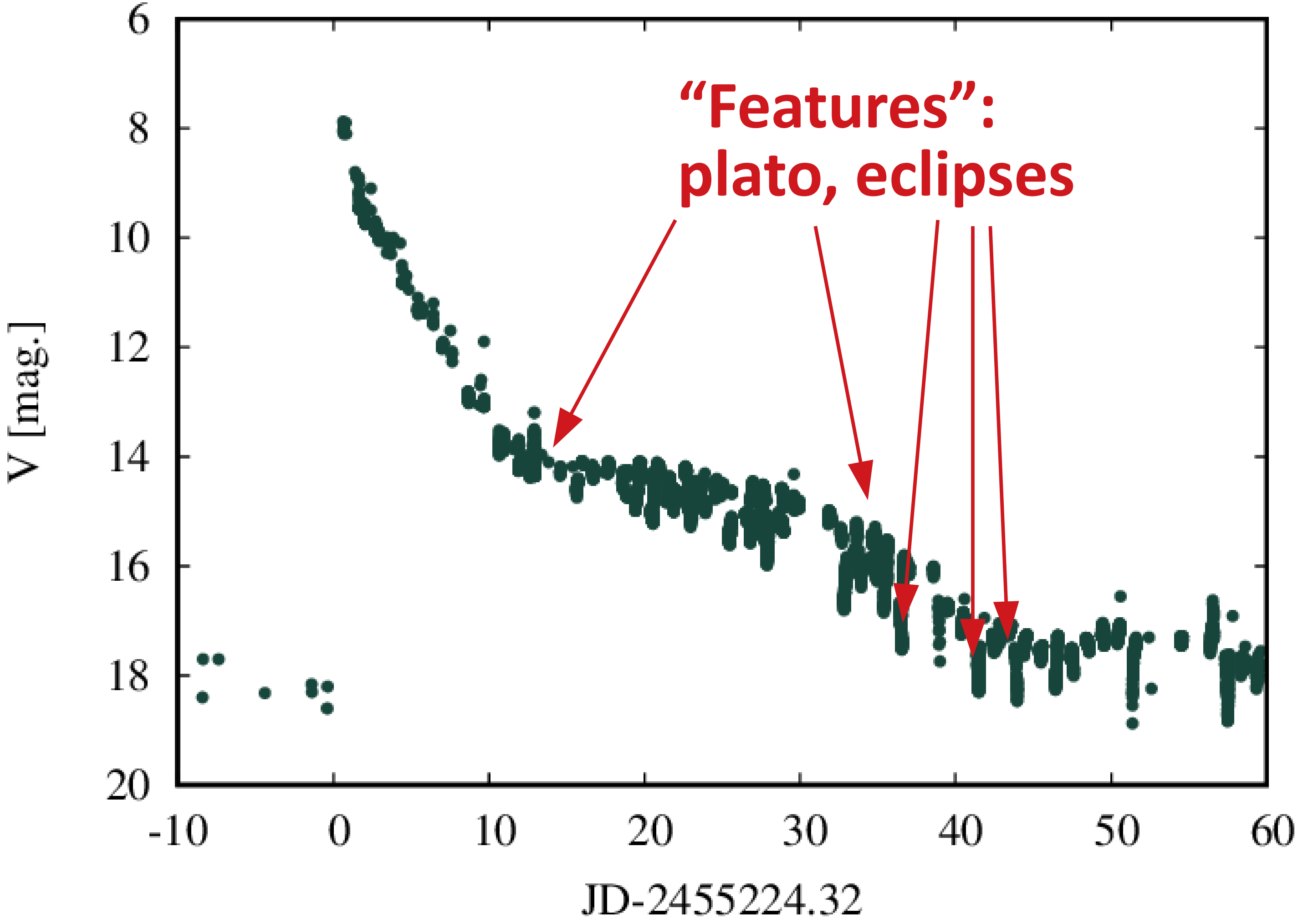
Optical lightcurve of a nova: U Sco



Optical lightcurve of a nova: U Sco



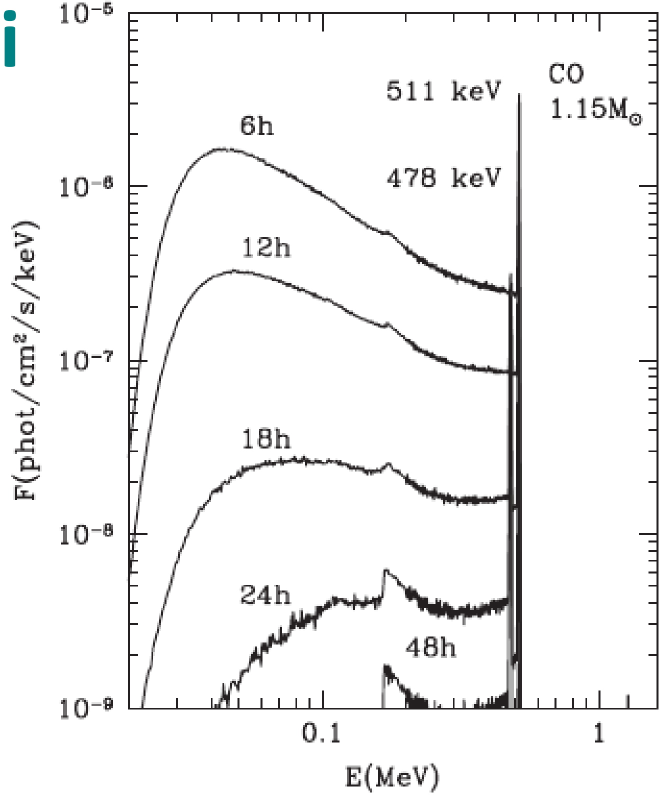
Optical lightcurve of a nova: U Sco

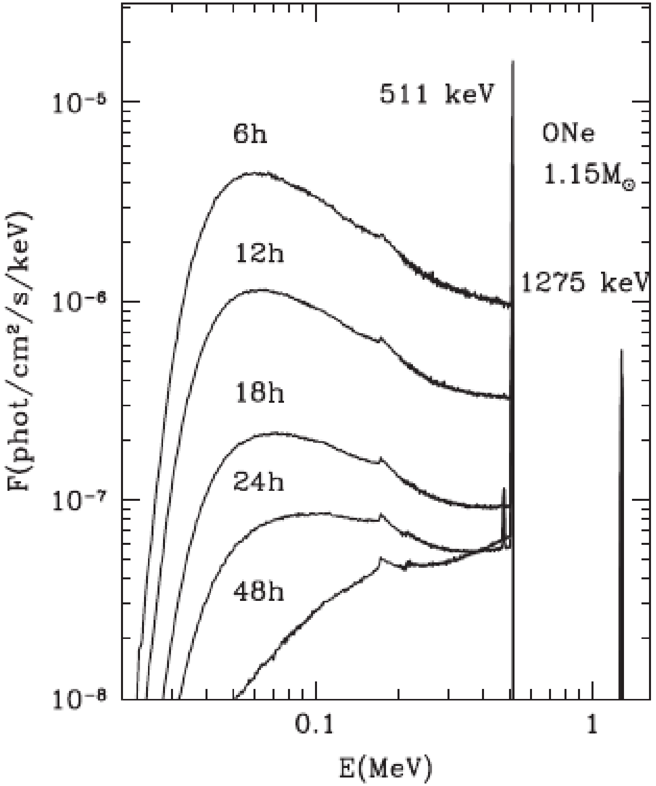


GeV and MeV emission from novae

Review by Hernanz (2014 ASPC, 490, 319)

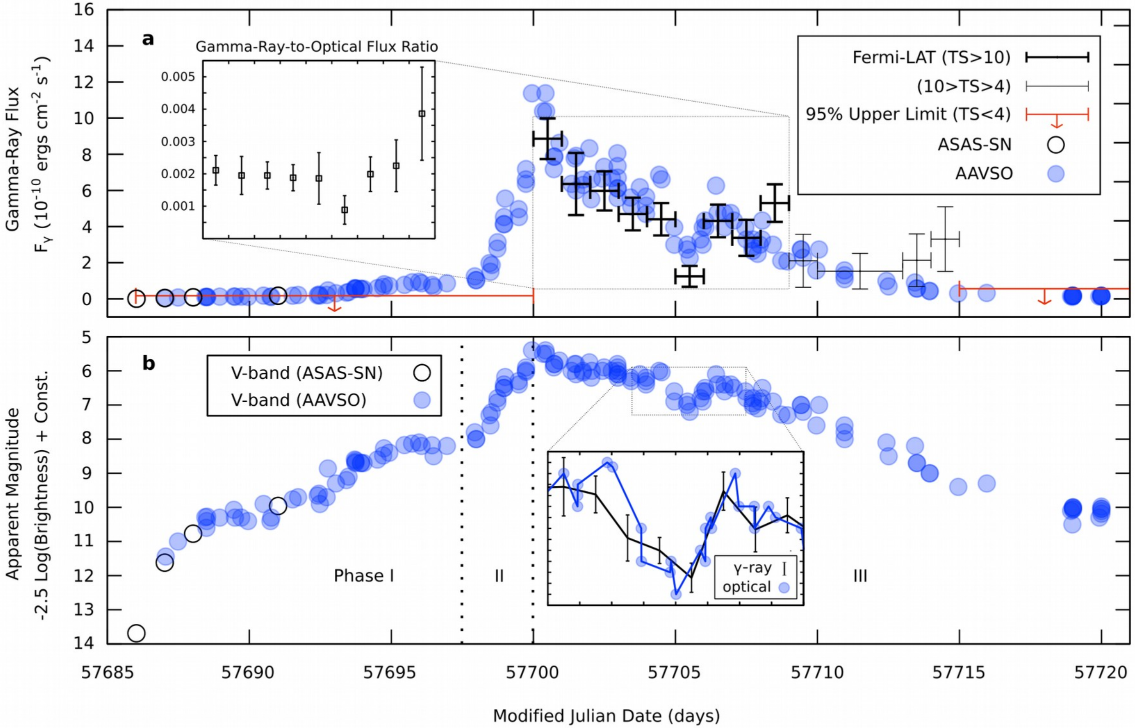
- E>100 MeV continuum emission detected from 14 novae by Fermi (AGILE saw one)
- MeV emission from radioactive decay predicted, but not found

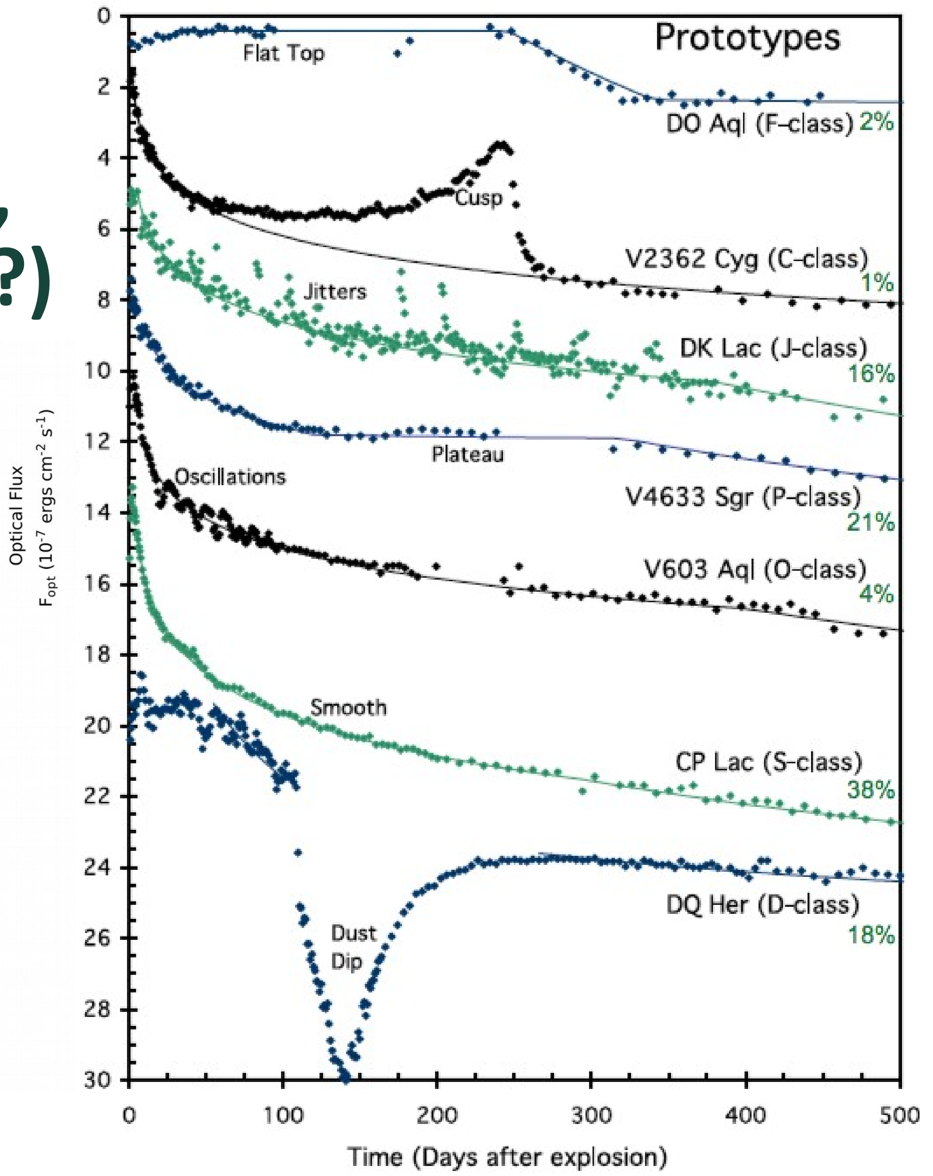




Shocks in Novae

gamma-rays, synchrotron radio, optical flares(?), cosmic rays(???)





ASASSN-16ma - Li et al. 2017, NatAs, 1, 697
White paper by Chomiuk et al. arXiv:1903.08134

ASASSN-18fv = N Car 2018 = V906 Car

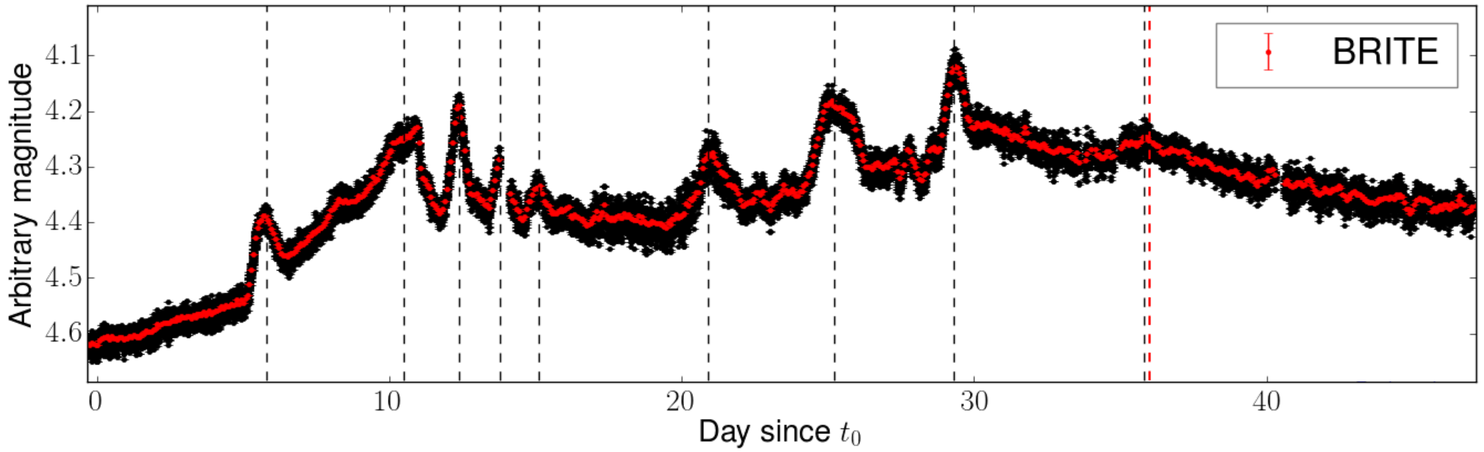
ASASSN-18fv and η Car nebula imaged by Joseph Brimacombe

Discovered 2018-03-20.32 UT
by the **ASAS-SN survey**

Optical flares caused by shocks?

ASASSN-18fv

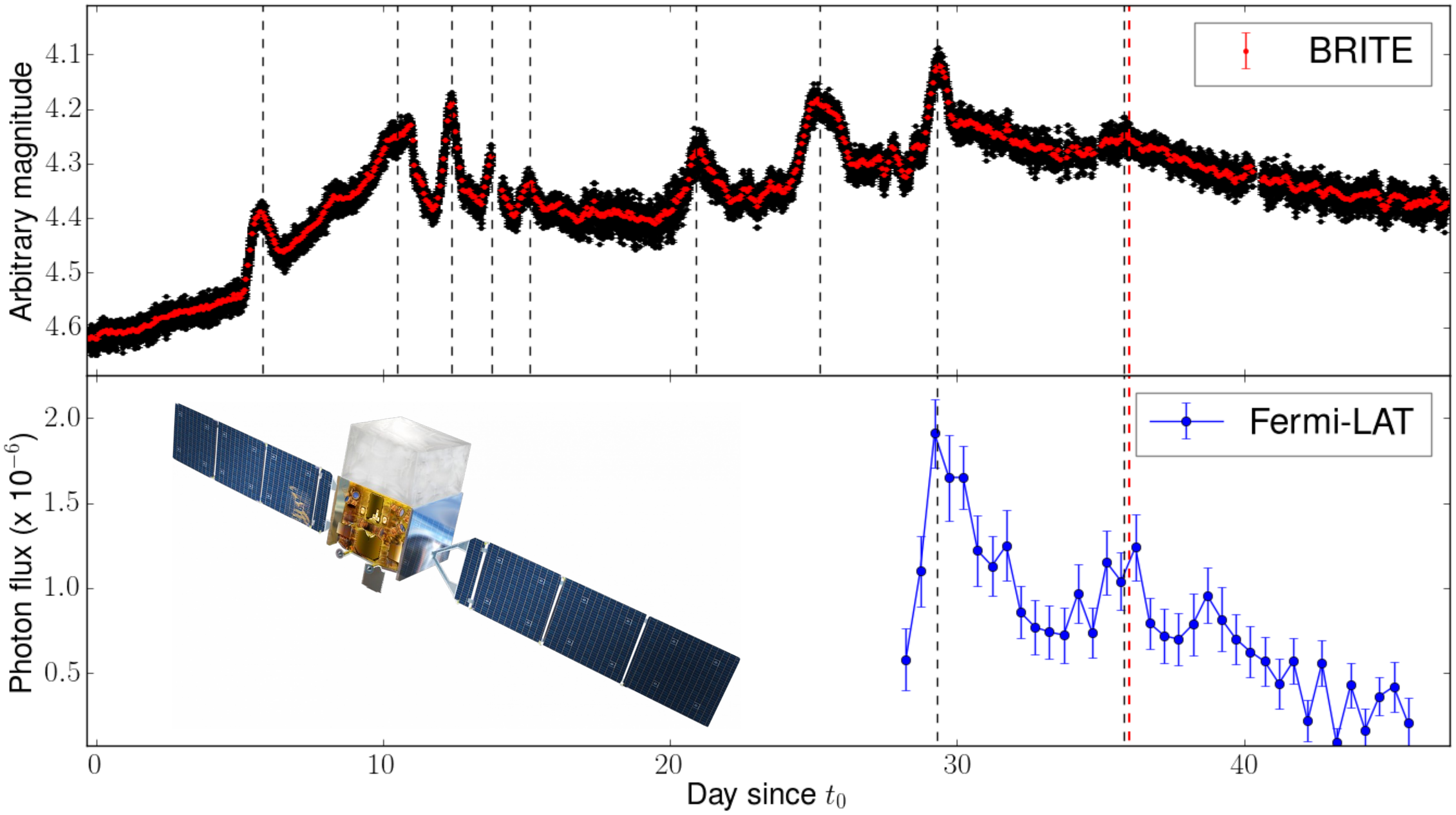
Aydi et al. in prep.



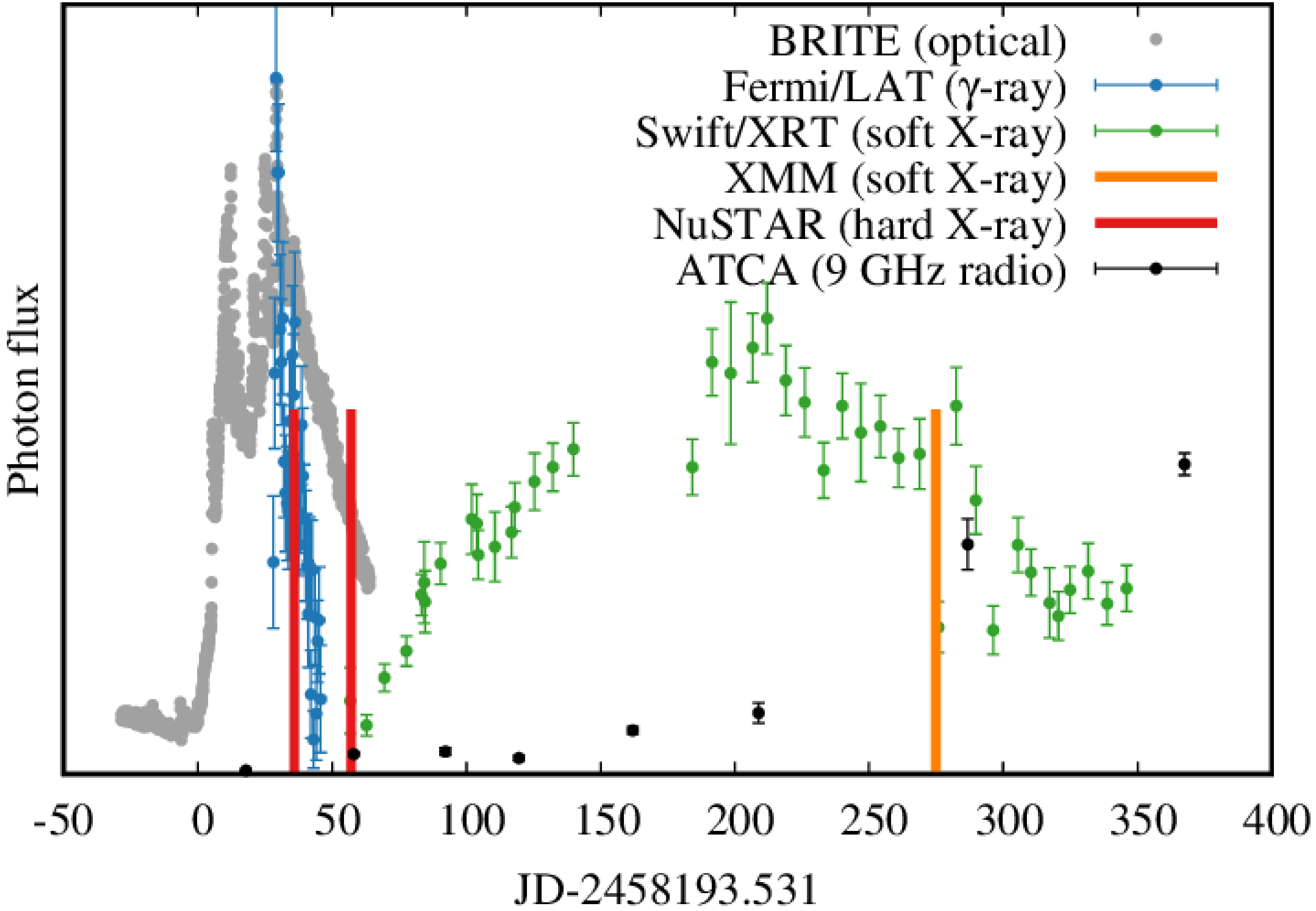
Optical flares caused by shocks?

ASASSN-18fv

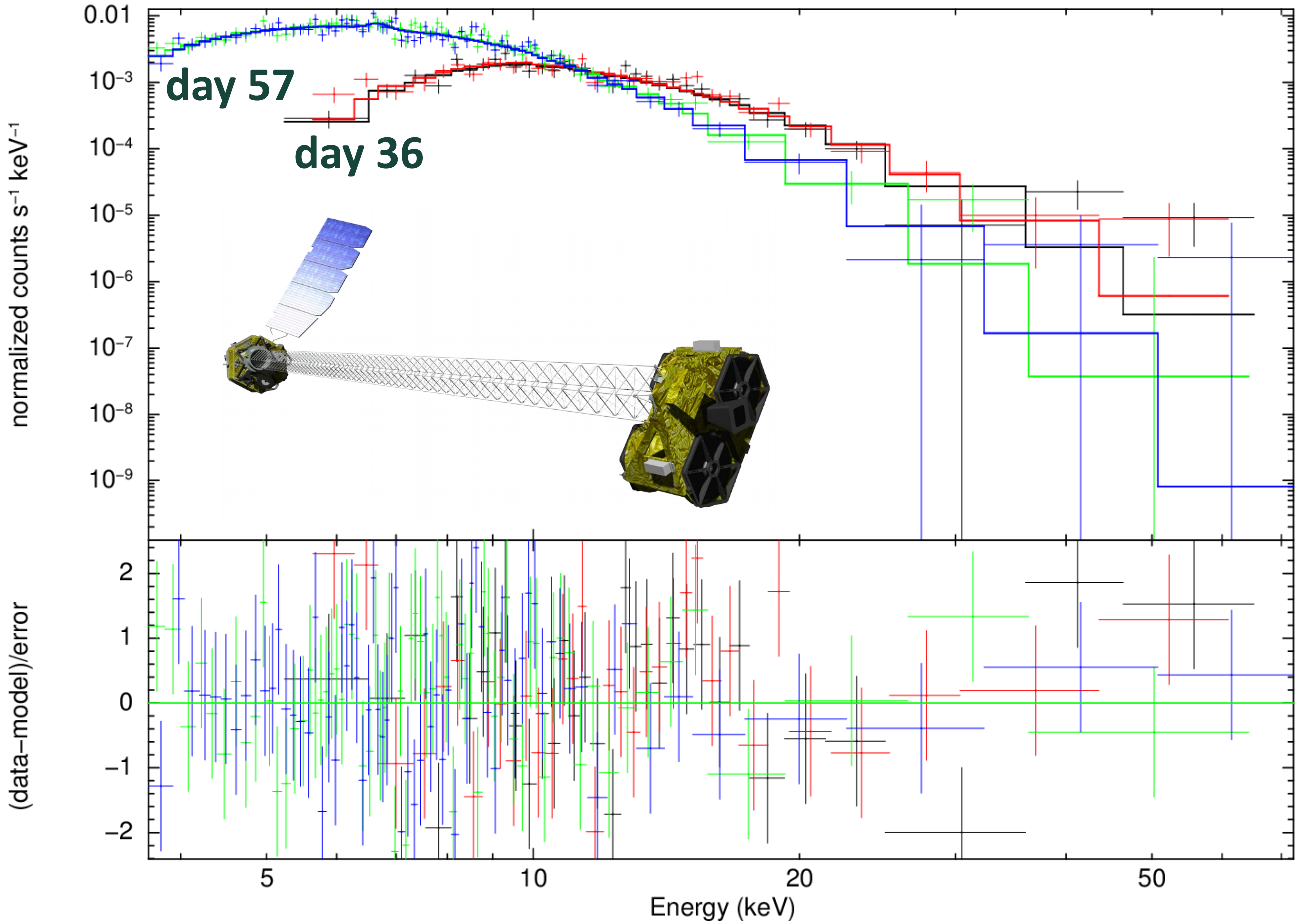
Aydi et al. in prep.



MW observations of ASASSN-18fv



ASASSN-18fv: NuSTAR spectra



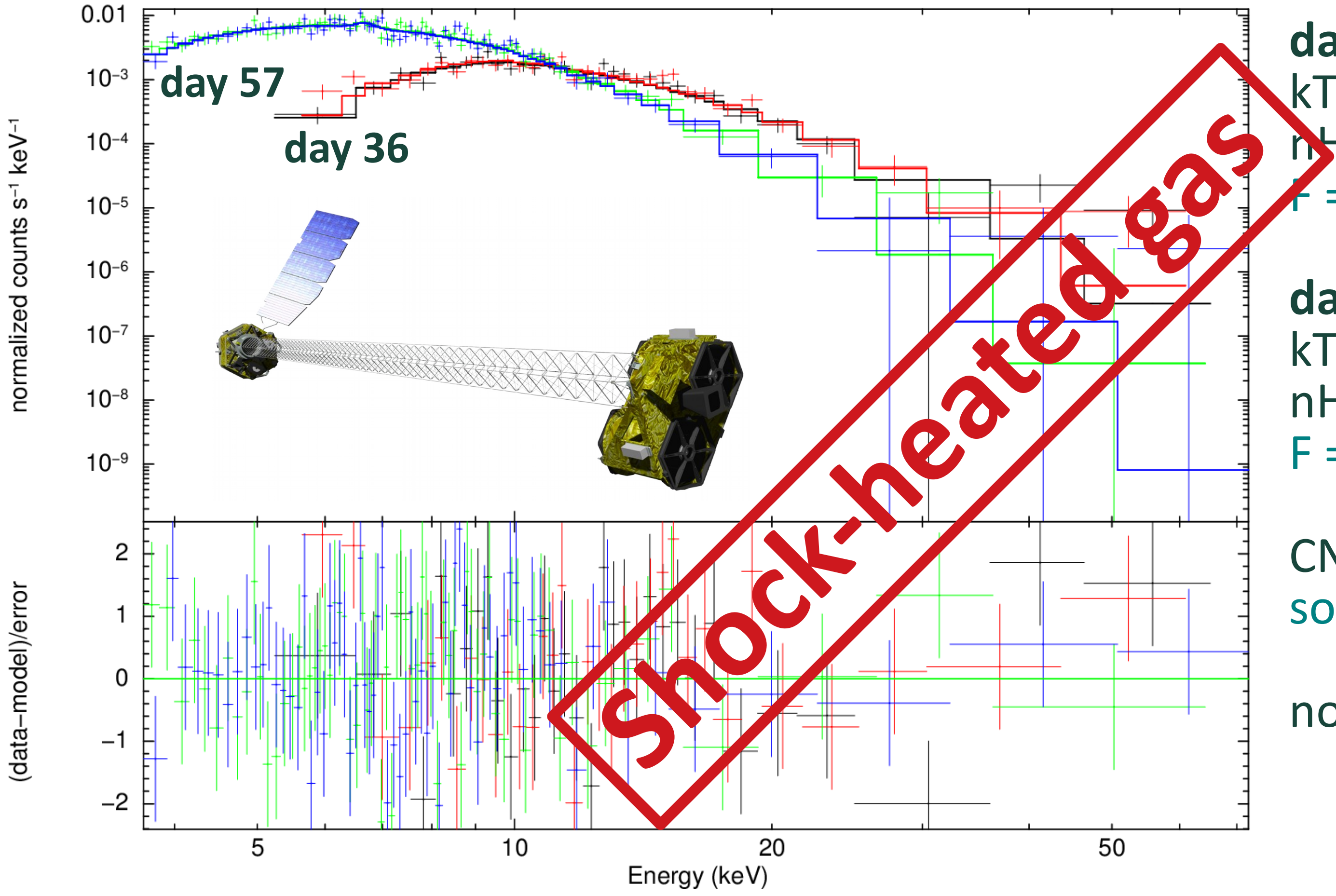
day 36:
kT = 8.6 +-0.9 keV
nHI = 4.3 +-2.3 x10^22 cm^-2
F = 2.7 x10^-12 ergs/s/cm^2

day 57:
kT = 4.4 +-0.2 keV
nHI = 0.6 +-0.3 x10^22 cm^-2
F = 3.5 x10^-12 ergs/s/cm^2

CNO overabundance w.r.t. solar = 210 +-110

no non-thermal emission

ASASSN-18fv: NuSTAR spectra



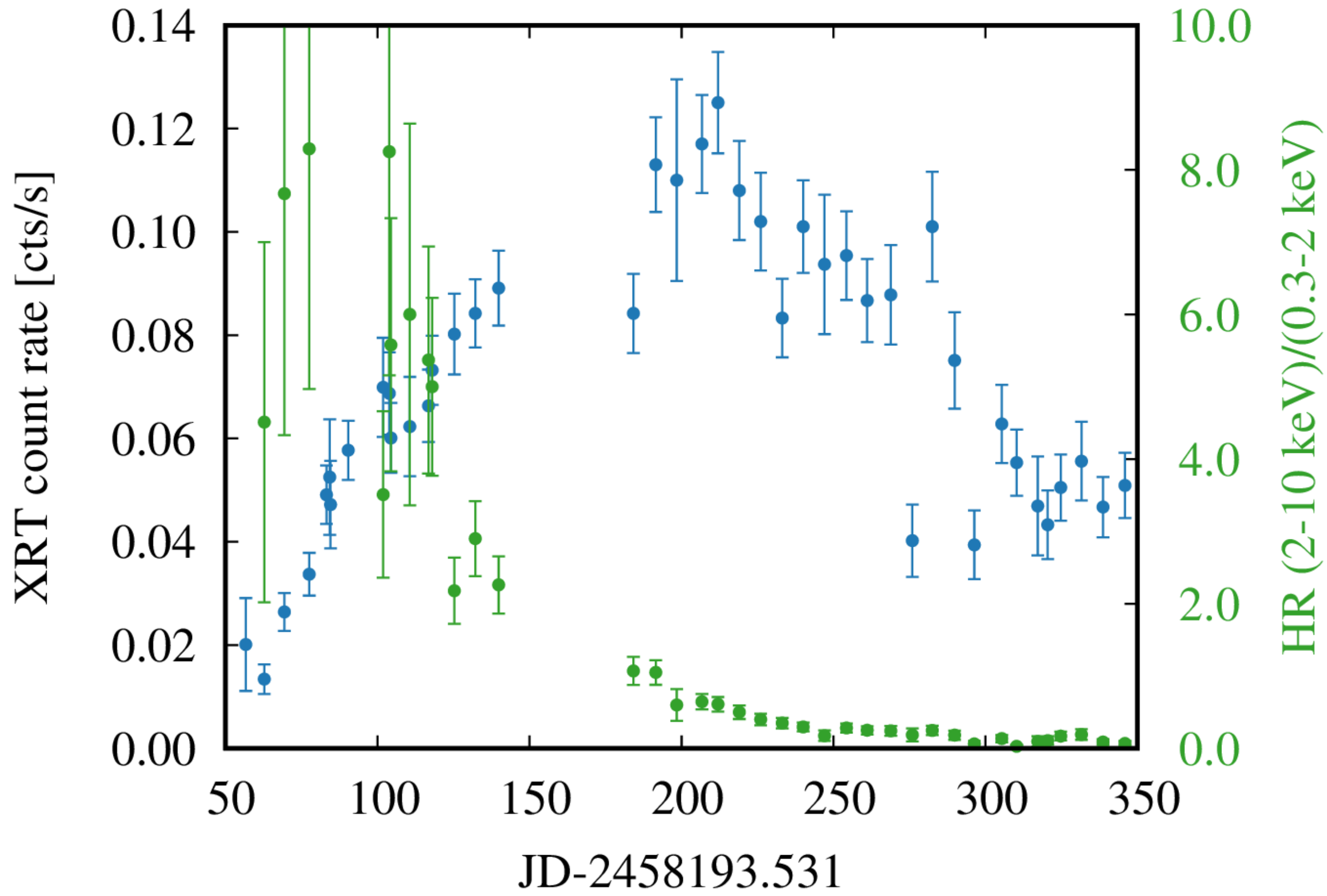
day 36:
kT = 8.6 +-0.9 keV
nHI = 4.3 +-2.3 x10^22 cm^-2
F = 2.7 x10^-12 ergs/s/cm^2

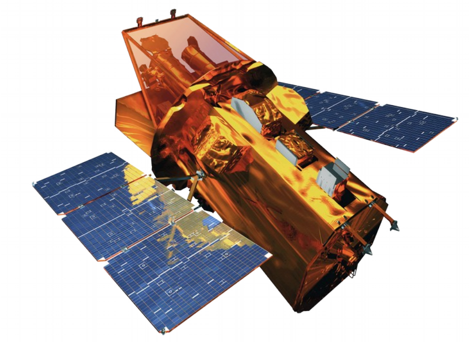
day 57:
kT = 4.4 +-0.2 keV
nHI = 0.6 +-0.3 x10^22 cm^-2
F = 3.5 x10^-12 ergs/s/cm^2

CNO overabundance w.r.t. solar = 210 +-110

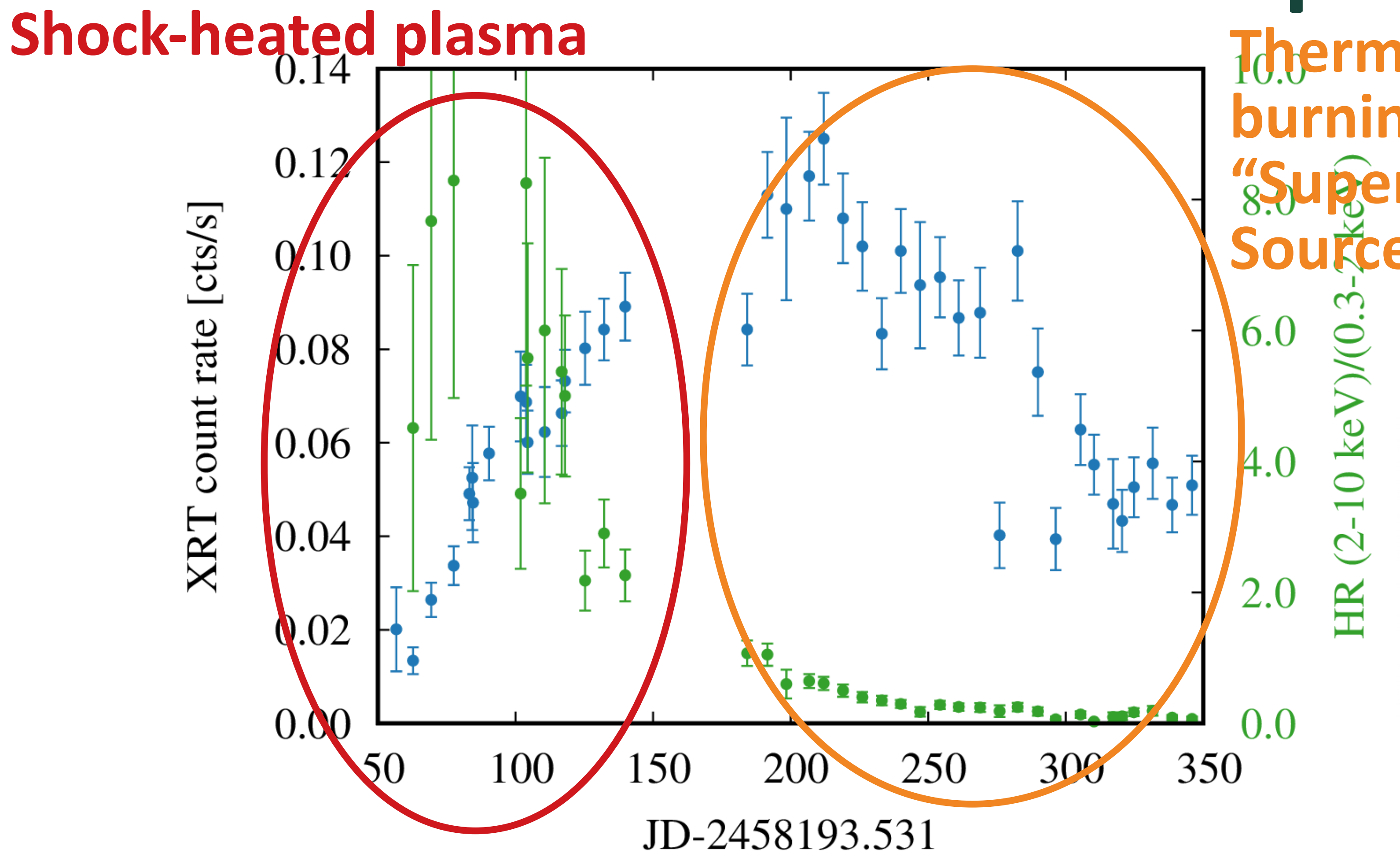
no non-thermal emission

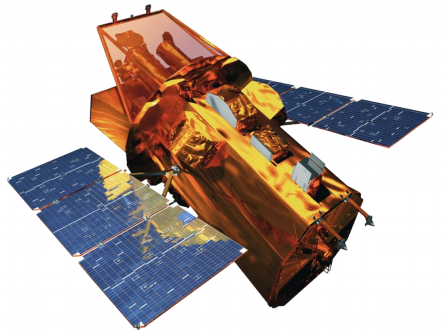
ASASSN-18fv: shocks to Super-Soft



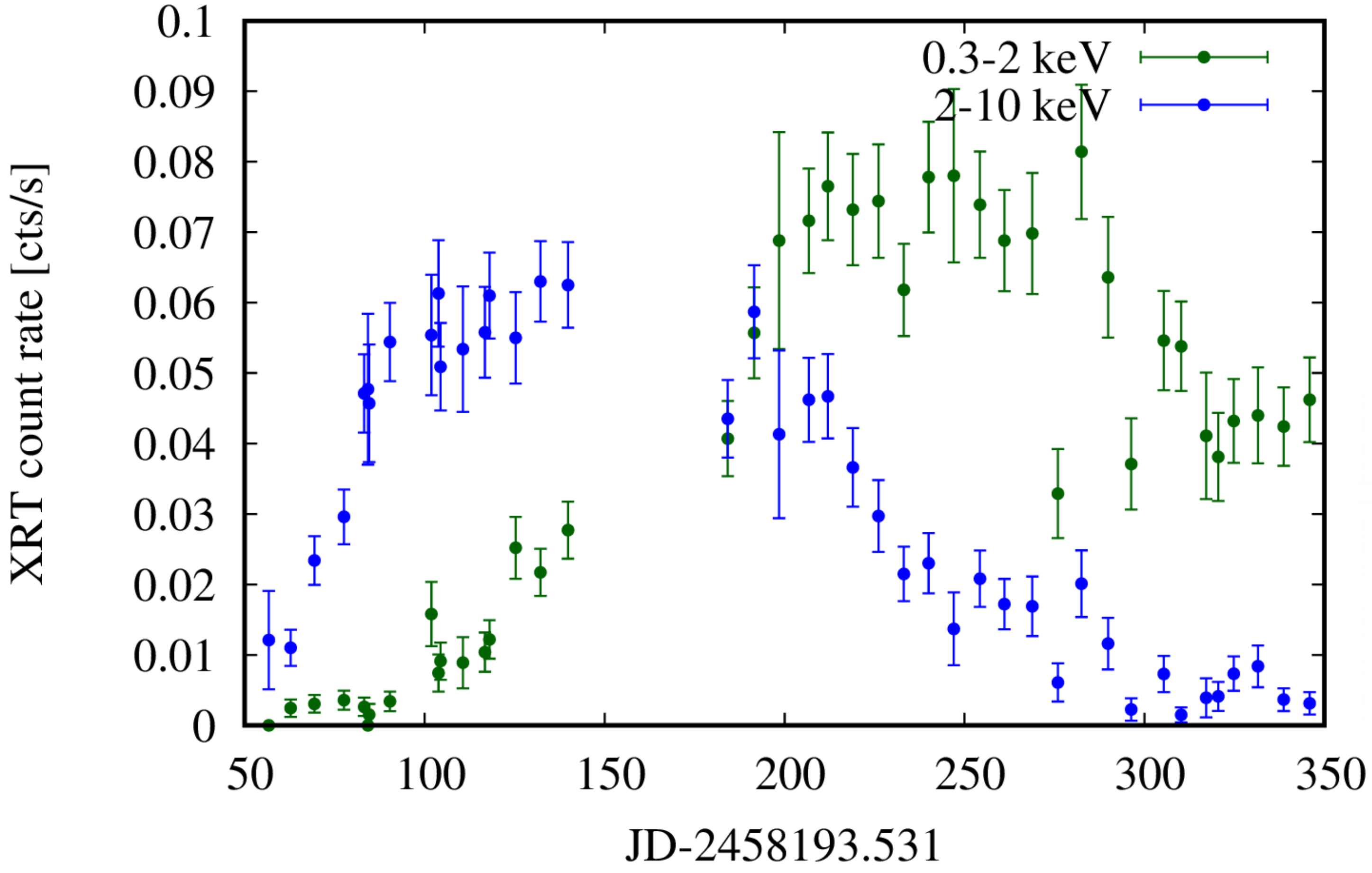


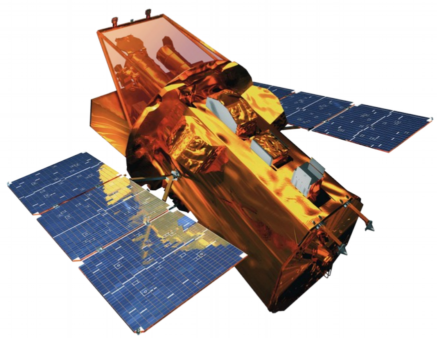
ASASSN-18fv: shocks to Super-Soft



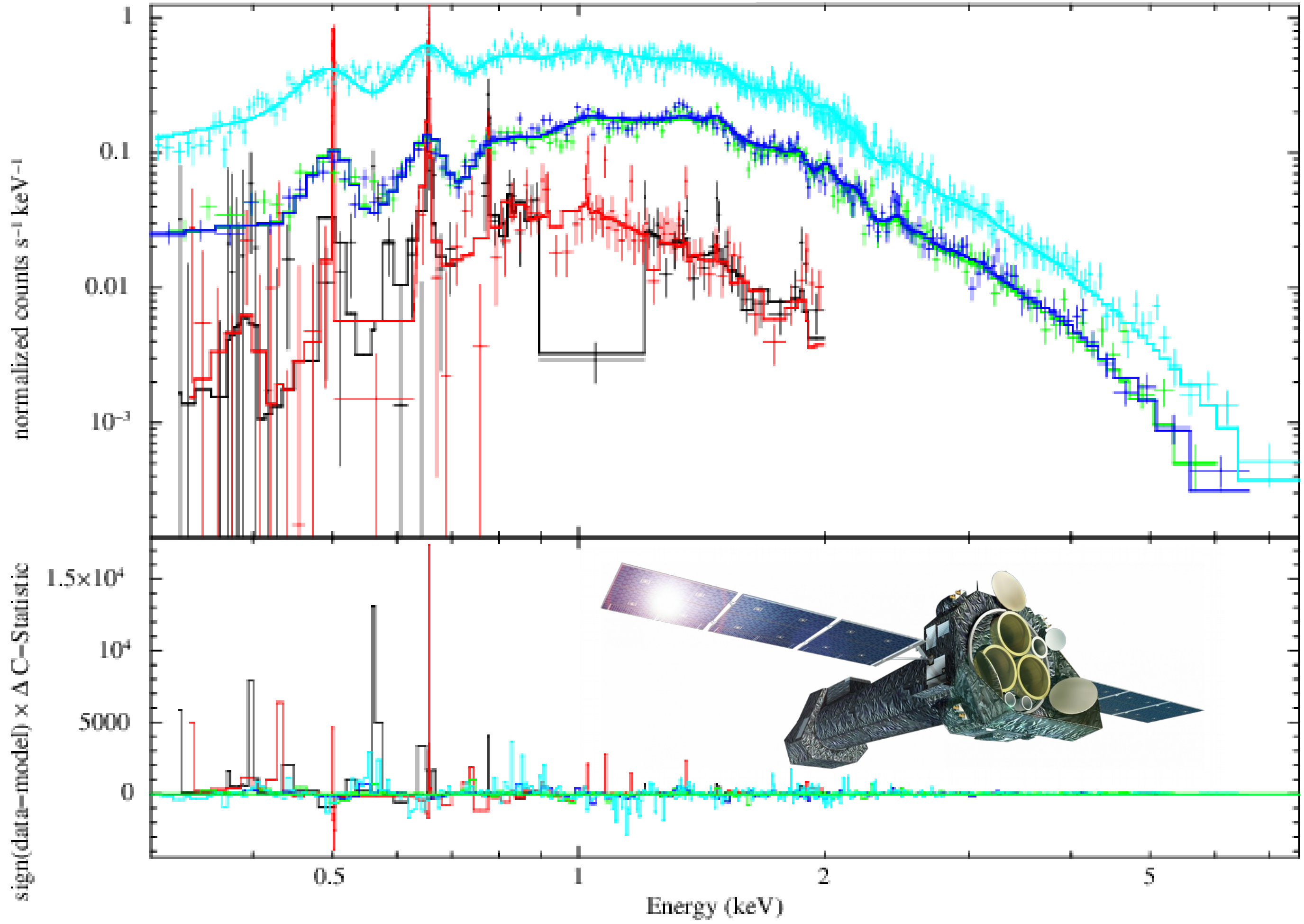


ASASSN-18fv: shocks to Super-Soft





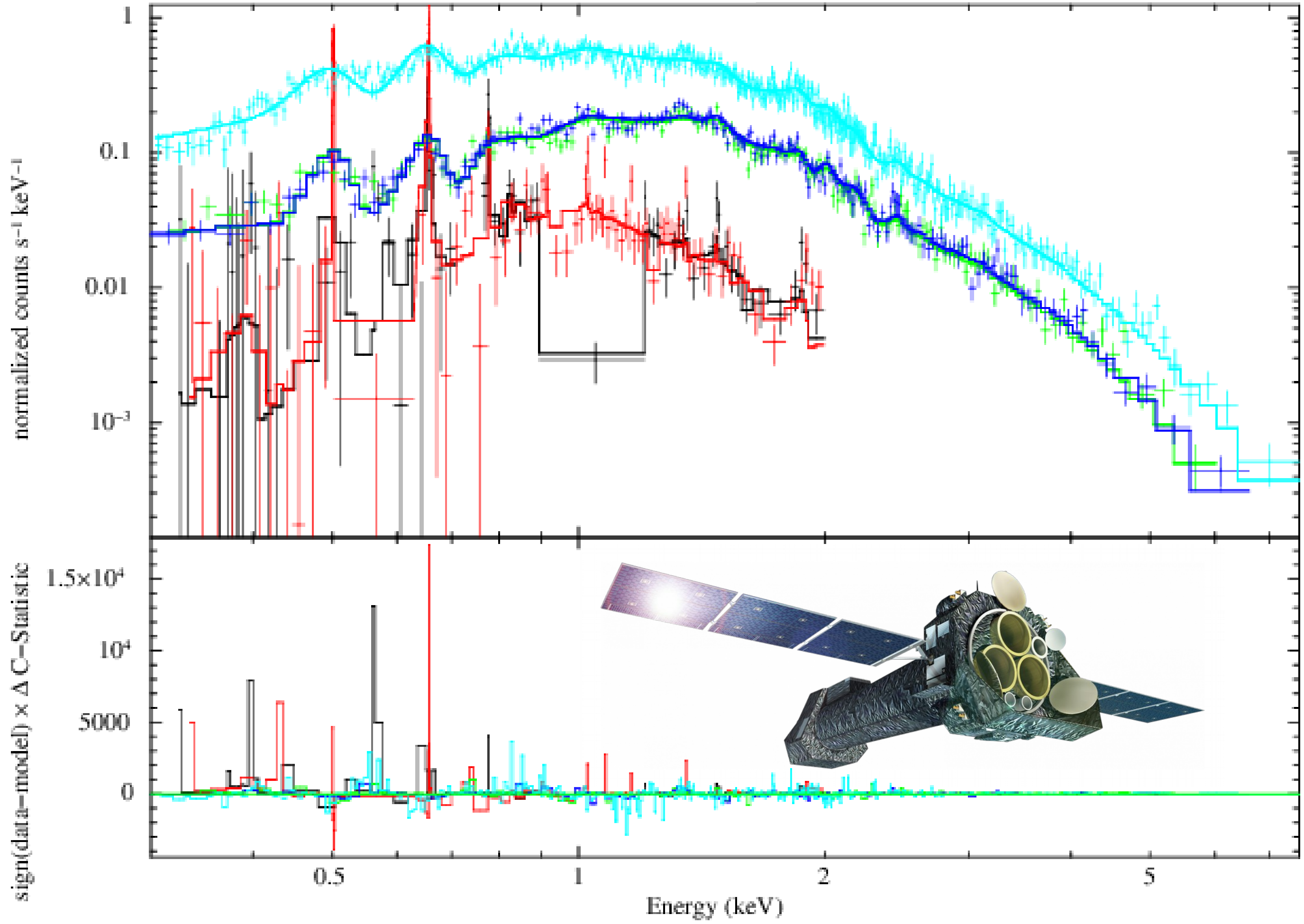
XMM observations of ASASSN-18fv



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

XMM observations of ASASSN-18fv

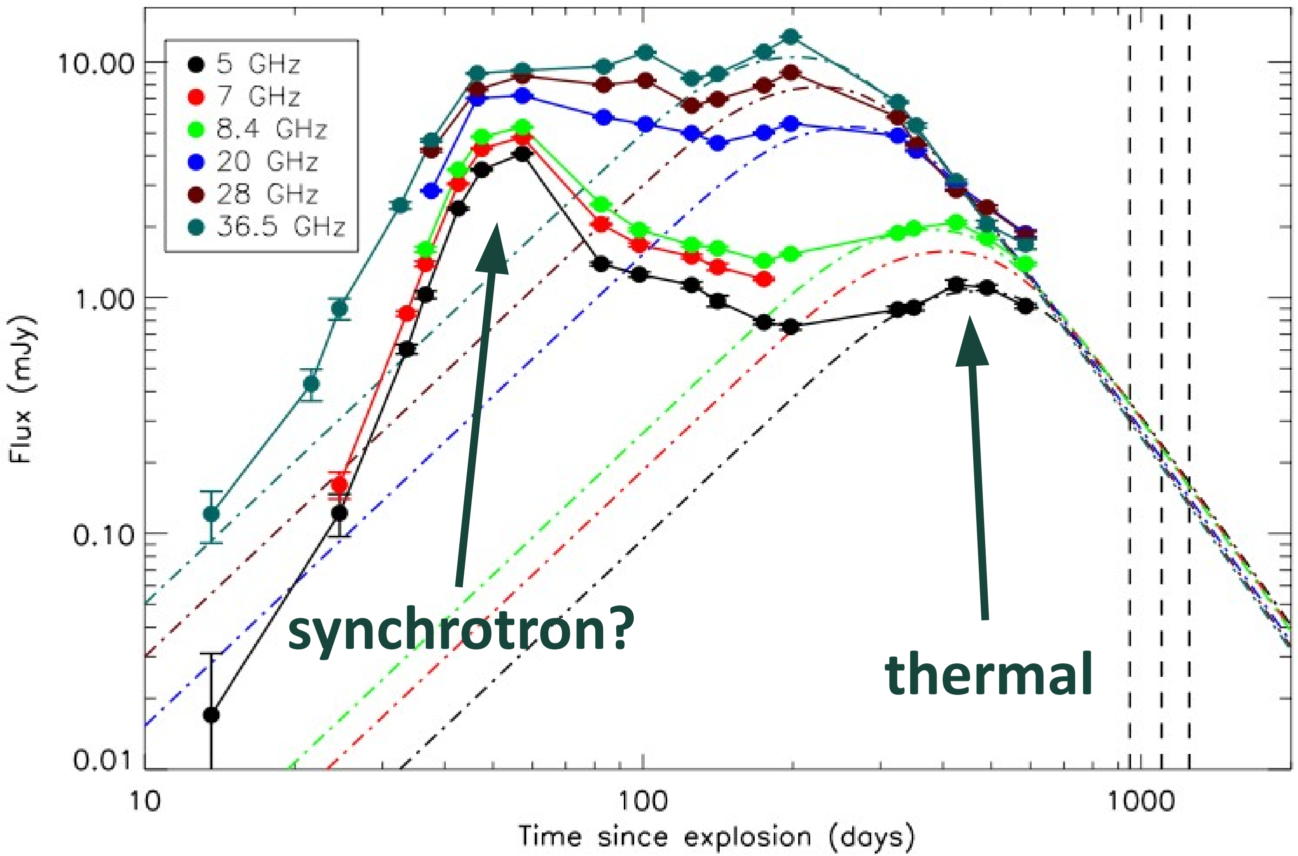


constant*phabs*vphabs*bvapec

	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

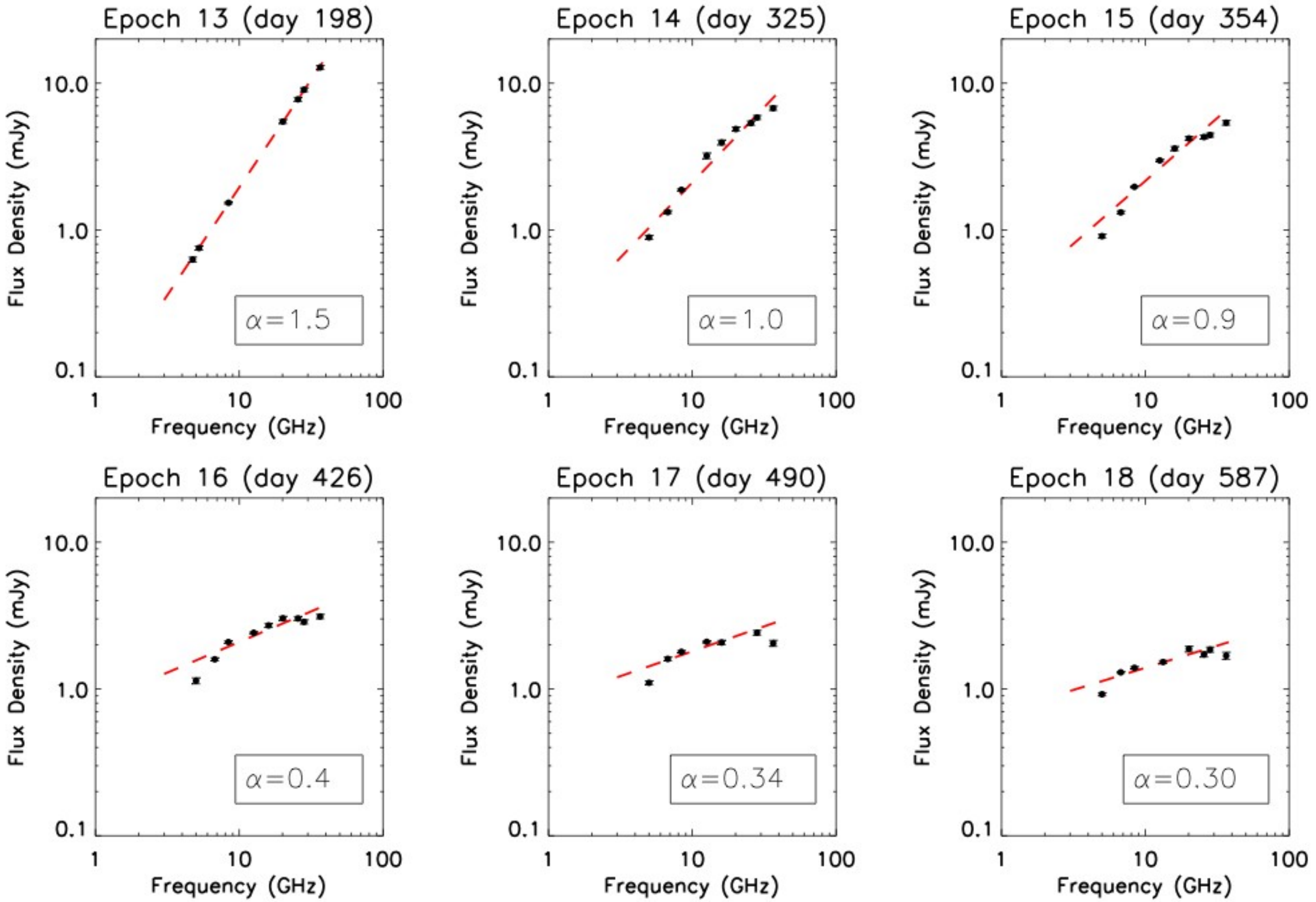
A "typical" radio lightcurve of a nova

V1723 Aql with VLA by Weston et al. 2016, MNRAS, 457, 887



Typical radio spectra of a nova

V1723 Aql with VLA by Weston et al. 2016, MNRAS, 457, 887

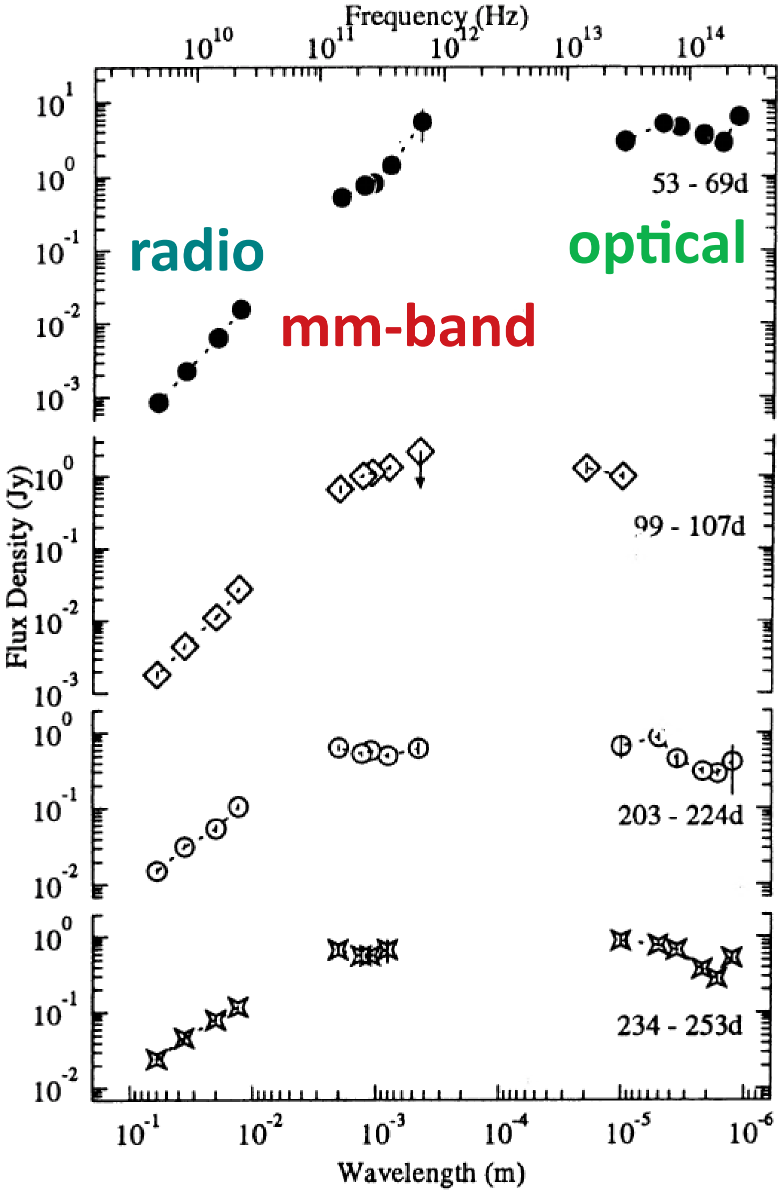


Best-observed nova at mm-band

V1974 Cyg with JCMT + VLA by

Ivison et al. 1993, MNRAS, 263, L43

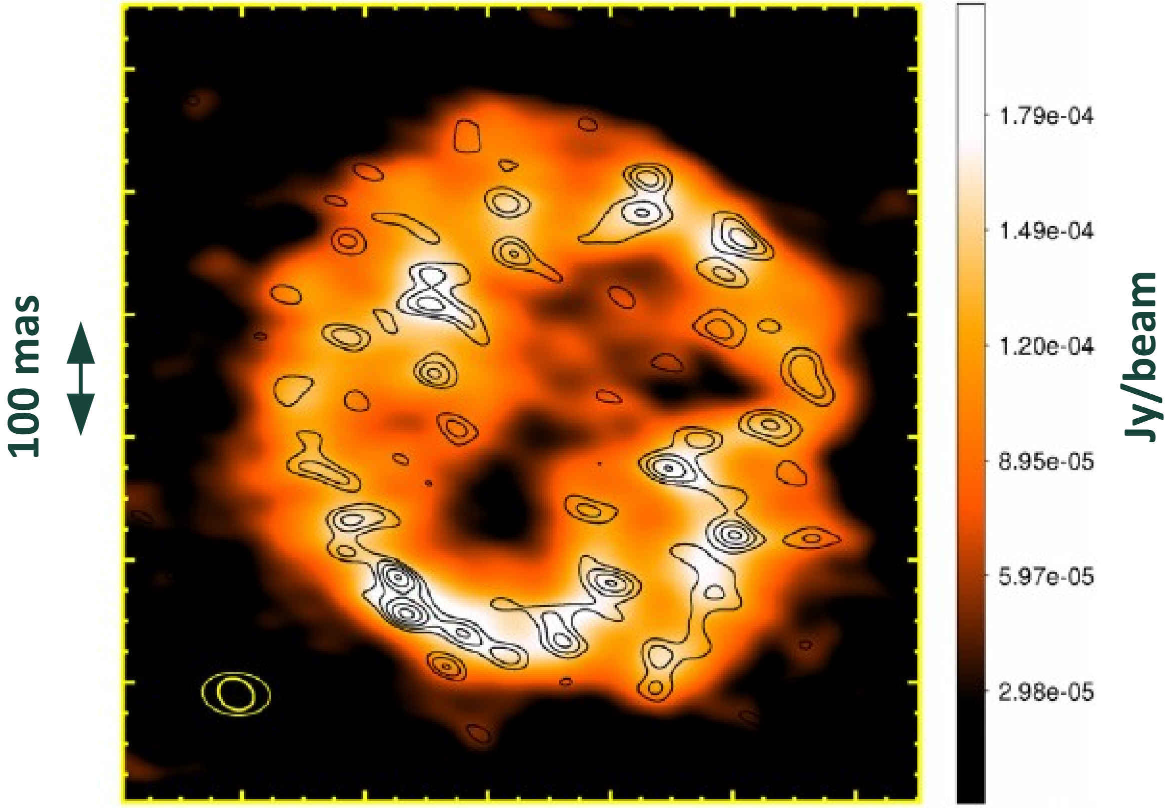
optically-thick free-free emitting nebula that gradually becomes optically thin



ALMA 230 GHz view of V5668 Sgr

by Diaz et al. 2018 MNRAS, 480, L54 2.5 years past nova

clumpy free-free emitting ejecta, ~7x10^{-7} Mo



Outlook

- mw-obs. provide a new window on nova physics
- Shock energy, abundances, ejecta mass, non-thermal emission
- Constrains on particle acceleration from X-ray/GeV
- Where, when and why shocks are formed?
- Relevant for distant shock-powered transients: Type IIn SNe, TDEs, stellar mergers

White paper on shocks by Chomiuk et al. arXiv:1903.08134

NuSTAR observations of ASASSN-18fv

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.

`constant*vphabs*vapec` model for the two *NuSTAR* observations

Epoch (days)	n_{HI} ($\times 10^{22}$ cm^{-2})	kT (keV)	CNO abundances	$C_{\rm FPMB}$	Model 3.5-78.0 keV flux $\log_{10}$(ergs/cm^2/s)
		$\chi^2_{\rm red} = 1.0457$, d.o.f. $= 199$, $p = 0.31$			
36	4.287 ± 2.288	8.59 ± 0.88	209.6 ± 110.4	1.107 ± 0.062	-11.564 ± 0.012
57	0.568 ± 0.288	4.38 ± 0.17		1.006 ± 0.034	-11.454 ± 0.007

	Case 1 EPIC+RGS	Case 2 EPIC+RGS	Case 3 EPIC+RGS	Case 4 RGS	Case 5 RGS
PHABS					
N_H ($\times 10^{21}$ cm^{-2})	$1.8^{+0.3}_{-0.2}$	$1.8^{+0.2}_{-0.2}$	$2.4^{+0.4}_{-0.3}$	$2.1^{+0.5}_{-1.0}$	$2.0^{+2.1}_{-1.0}$
VPHABS					
N_H ($\times 10^{21}$ cm^{-2})	$0.08^{+0.02}_{-0.02}$	$0.13^{+0.03}_{-0.02}$	$0.12^{+0.03}_{-0.03}$	<0.4	<0.4
BVAPEC					
kT (keV)	$1.06^{+0.01}_{-0.01}$	$1.11^{+0.01}_{-0.01}$	$1.07^{+0.04}_{-0.01}$	$0.79^{+0.04}_{-0.10}$	$0.98^{+0.15}_{-0.12}$
redshift	$(-2.9\pm0.1)\times10^{-3}$	$(-2.9\pm0.2)\times10^{-3}$	$-2.9\times10^{-3*}$	$(-3.1\pm0.2)\times10^{-3}$	$-2.9\times10^{-3(*)}$
velocity (km s^{-1})	394 ± 70	378 ± 72	$378^{(*)}$	386^{+72}_{-76}	378^{*}
$N/N_\odot$	728^{+232}_{-150}	403^{+99}_{-73}	345^{+93}_{-70}	230^{+236}_{-81}	212^{+197}_{-87}
$O/O_\odot$	30^{+7}_{-6}	24^{+4}_{-5}	29^{+7}_{-5}	14^{+15}_{-5}	17^{+12}_{-5}
$Ne/Ne_\odot$	$0.7^{+0.6}_{-0.5}$	$2.3^{+0.6}_{-0.5}$	$2.2^{+0.6}_{-0.5}$	$1.1^{+1.3}_{-0.5}$	$1.5^{+1.3}_{-0.7}$
$Mg/Mg_\odot$	$1.0^{+0.2}_{-0.2}$	$0.7^{+0.2}_{-0.1}$	$0.6^{+0.2}_{-0.1}$	$1.0^{+1.0}_{-0.3}$	$0.9^{+0.6}_{-0.3}$
$Si/Si_\odot$	$1.6^{+0.4}_{-0.3}$	$1.2^{+0.2}_{-0.2}$	$1.1^{+0.2}_{-0.2}$	$1.0^{+2.1}_{-0.7}$	$2.0^{+1.3}_{-0.5}$
$Fe/Fe_\odot$	$0.17^{+0.08}_{-0.05}$	<0.1	<0.1	<0.13	<0.04
χ^2_ν	1.25	1.16	1.15	1.01	1.01
d.o.f.	1847	1488	1837	987	977

Notes:
Model CONSTANT*PHABS*VPHABS*BVAPEC in four different cases:
Case 1: in the whole spectral coverage, without Gaussian lines;
Case 2: excluding spectral regions associated with (r,i,f) lines: 0.4-0.45 keV, 0.55-0.6 keV, 0.85-0.95 keV, and 1.3-1.4 keV;
Case 3: in the whole spectral coverage, including Gaussian lines associated with r,i,f lines (Table 3);
Case 4: only RGS, without Gaussian lines;
Case 5: only RGS, with Gaussian lines associated with r,i,f lines (Table 3);
Abundance table: aspl: Asplund M, Grevesse N., Sauval A.J. & Scott P., 2009, ARAA, 47, 481;