Paper walkthrough:

The multi-wavelength view of shocks in the fastest nova V1674 Her

LAT analysis by

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Paper overview

- To be submitted to: MNRAS – LAT cat 2 paper
- Completed steps
  - Presentations to Galactic group: Dec 21, Collab. meeting Gal. session in Sep.
  - LAT internal review by Xian
  - WAM walkthrough - NOW (Jan 20)
- Future timeline estimates / necessary next steps
  - **asap –** signup deadline for LAT authors
  - **asap –** Pub-bd and submission to MNRAS and arXiv

- Pub-board paper page: https://www-glast.stanford.edu/cgi-prot/pub_download?id=2028
- LAT Paper page: https://confluence.slac.stanford.edu/display/SCIGRPS/Nova+V1674+Her+2021+Paper+Page
- Analysis results: https://confluence.slac.stanford.edu/pages/viewpage.action?pageId=311557588

The authors

LAT + former e-Nova team + optical (Evryscope & AAVSO)

The multi-wavelength view of shocks in the fastest nova V1674 Her

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MW observations paper documenting shock signatures in an exceptionally fast Galactic classical nova.

ABSTRACT

Classical novae are shock-powered multiwavelength transients triggered by a thermonuclear runaway on an accreting white dwarf. V1674 Her is the fastest nova ever recorded ($t_2 = 1.1$ d) that challenges our understanding of shock formation in novae. We investigate the physical mechanisms behind nova emission from GeV γ-rays to cm-band radio using coordinated *Fermi*-LAT, *NuSTAR*, *Swift* and VLA observations supported by optical photometry. *Fermi*-LAT detected short-lived (18 h) 0.1-100 GeV emission from V1674 Her that appeared 6 h after the eruption began; this was at a level of $(1.6 \pm 0.4) \times 10^{-6}$ photons cm^{-2} s^{-1}. Eleven days later, simultaneous *NuSTAR* and *Swift* X-ray observations revealed optically thin thermal plasma shock-heated to $kT_{\rm shock} = 4$ keV. The lack of a detectable 6.7 keV Fe Kα emission suggests super-solar CNO abundances. The radio emission from V1674 Her was consistent with thermal emission at early times and synchrotron at late times. The radio spectrum steeply rising with frequency may be a result of either free-free absorption of synchrotron and thermal emission by unshocked outer regions of the nova shell or the Razin-Tsytovich effect attenuating synchrotron emission in dense plasma. The development of the shock inside the ejecta is unaffected by the extraordinarily rapid evolution and the intermediate polar host of this nova.

Intro: novae are exciting!

Nova is a non-destructive thermonuclear runaway on an accreting white dwarf.

- More like a *born-again star* than an H-bomb
- *Common envelope* interaction right before our eyes!
- *Shocks* in expanding nova envelope (TeV to radio)
- Model for other shock-powered transients

Reviews of this view on novae:

- Chomiuk, Metzger & Shen 2021, ARA&A, 59, 391
- Shen & Quataert 2022, ApJ, 938, 31
- Mukai & Sokoloski 2019, Physics Today, 72, 11, 38

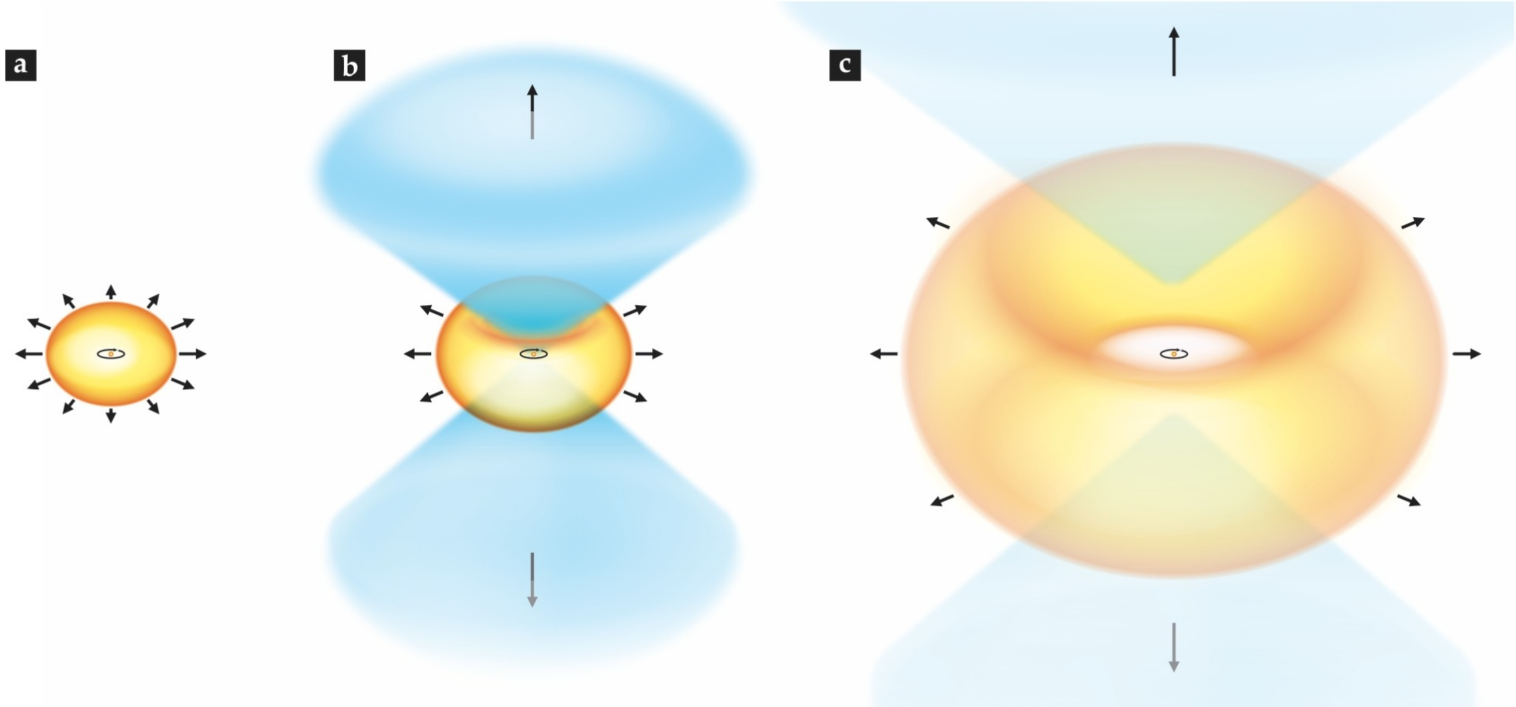
Unlike V407 Cyg and RS Oph

most novae have no companion red giant's wind for their expanding shell to slam into and produce shock

Artist's impression of
HESS array looking at RS Oph (DESY)

“Slow torus - fast wind” scenario

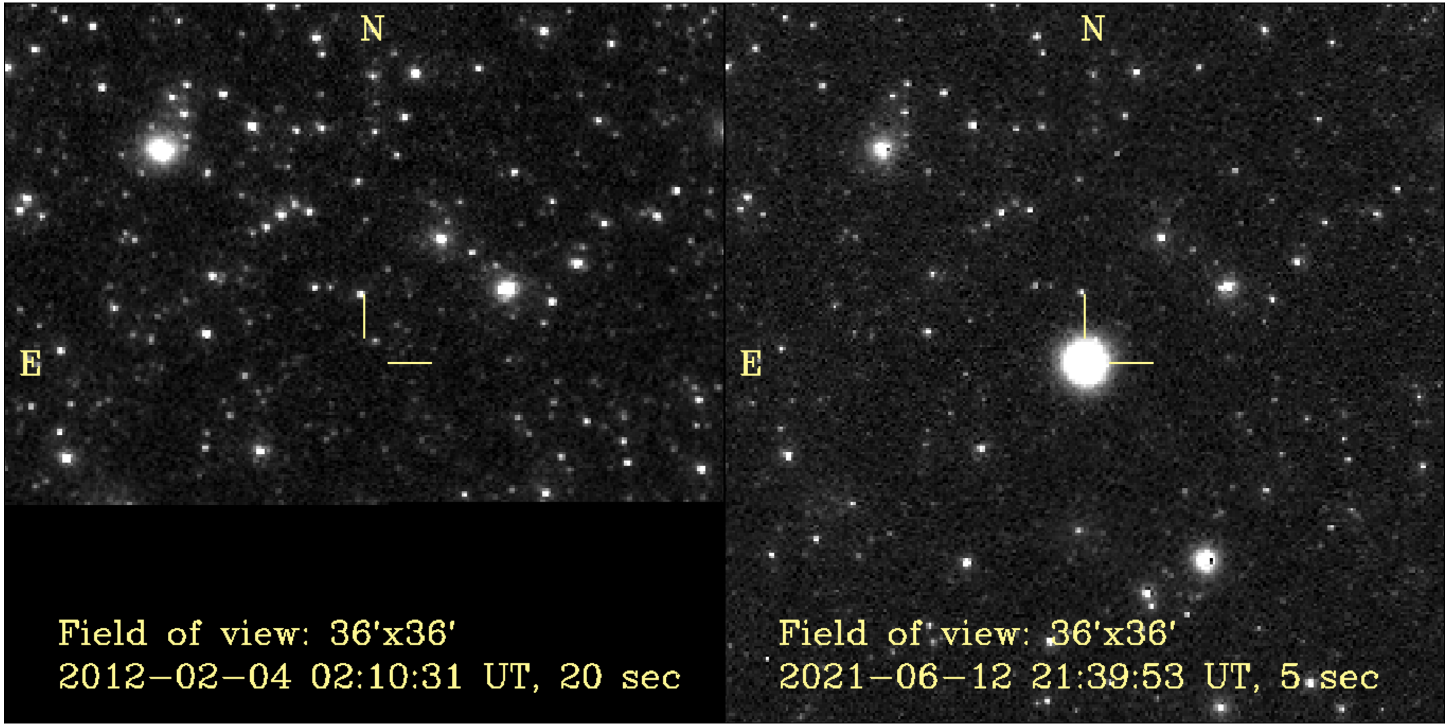
- *Optical spectra* revel 2+ velocity systems, with faster one overtaking the slower one around optical peak.
- *Line profile modeling* and high-res IR/radio *imaging*



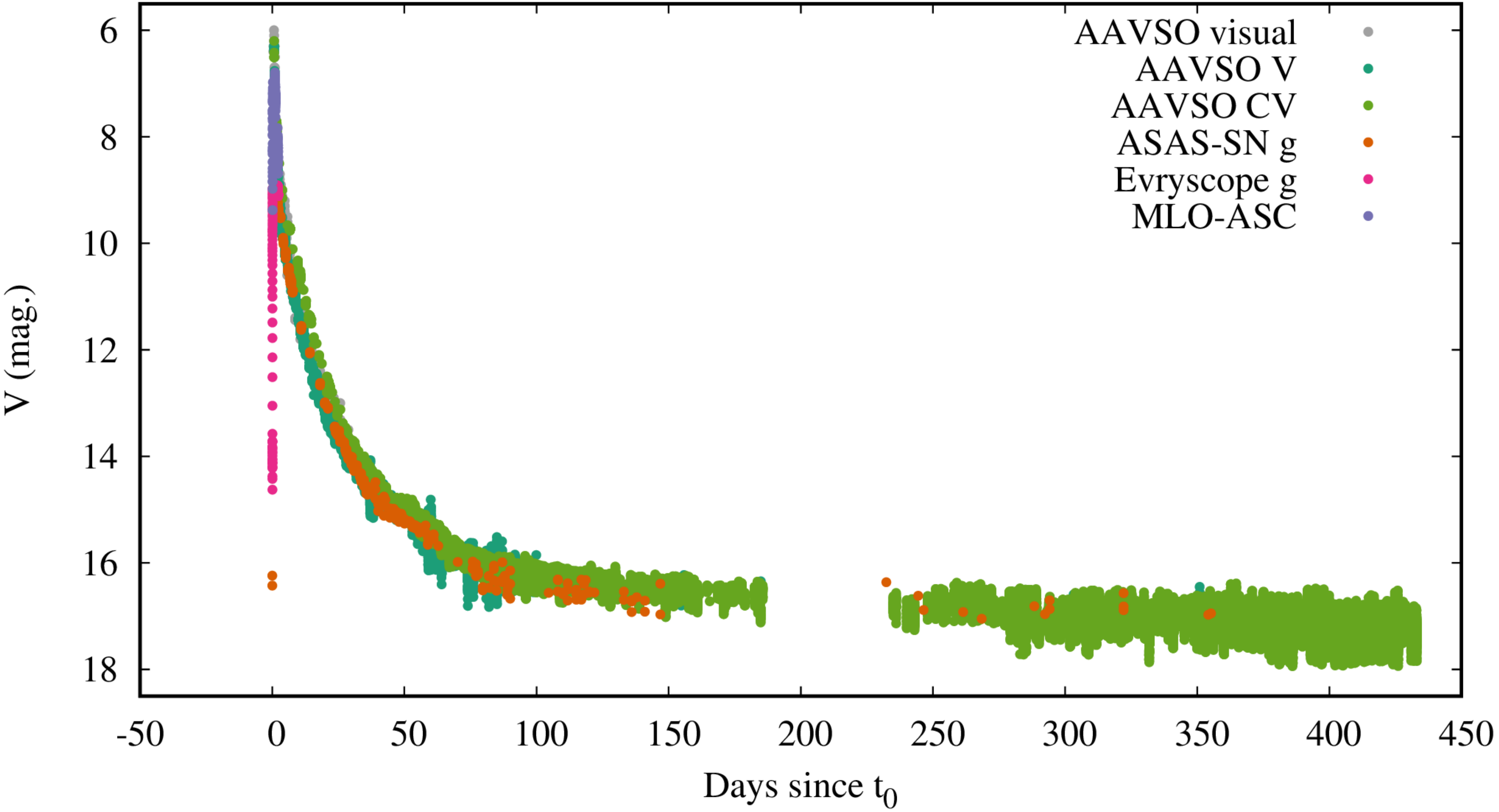
Nova Herculis 2021 = V1674 Her

discovered on 2021-06-12.548 UTC by Seiji Ueda at 8^m

- ASAS-SN detection 8^h before discovery (t_0) at g = 16.6
- Peaked at 6^m, 7^h post-discovery (rise in 15^h)



Optical lightcurve of V1674 Her



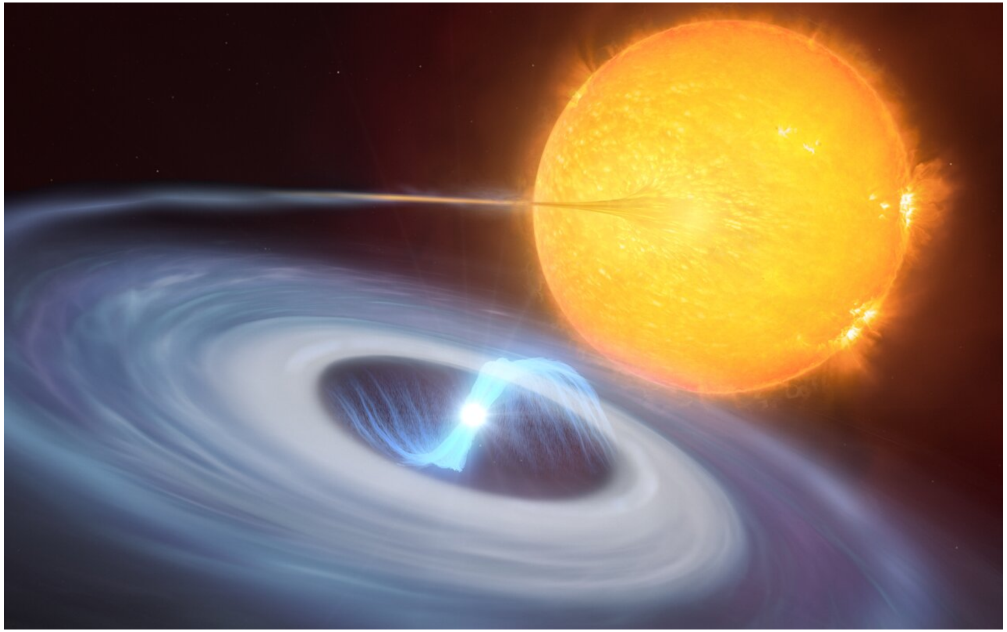
V1674 Her is notable for:

- The *fastest* nova ever (t_2 = 1.1^{day})
- *Orbital modulation* P_{orb} = 3.67^{h} optical/X-ray, t_0 + 4^{days}
- White dwarf *rotation* P_{rot} = 8.35^{min} optical/X-ray, t_0 + 12^{days}

Intermediate polar

(inner disk disrupted by WD's magnetic fields)

Patterson et al. 2022, ApJ, 940, L56



ESO/M. Kornmesser, L. Calçada

V1674 Her

detected by Fermi/LAT on the day of optical discovery

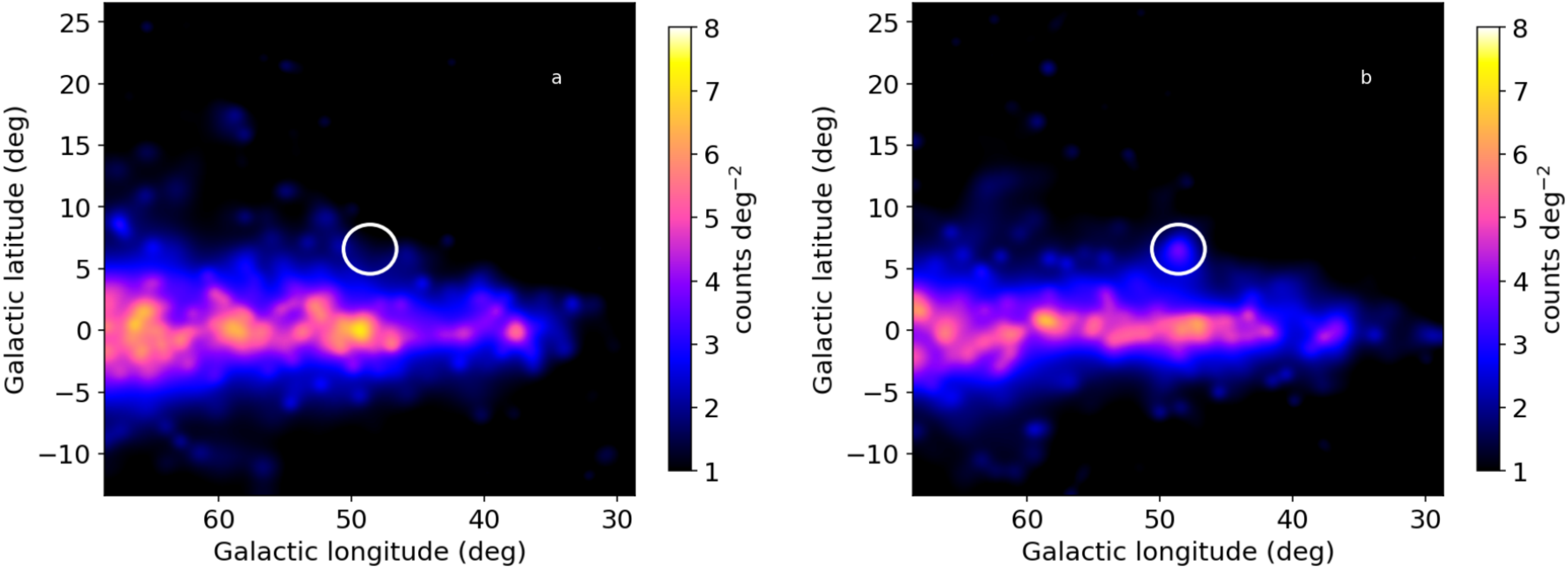


Figure 5. The *Fermi*/LAT smoothed 0.1–2 GeV count images centered on V1674 Her. The left image (a) covers the time interval 2021-06-10 10:34 to 2021-06-11 08:34 UT before the eruption. The right image (b) covers the 18 h interval when the γ-ray emission was detected. The white circle marks the optical position of the nova.

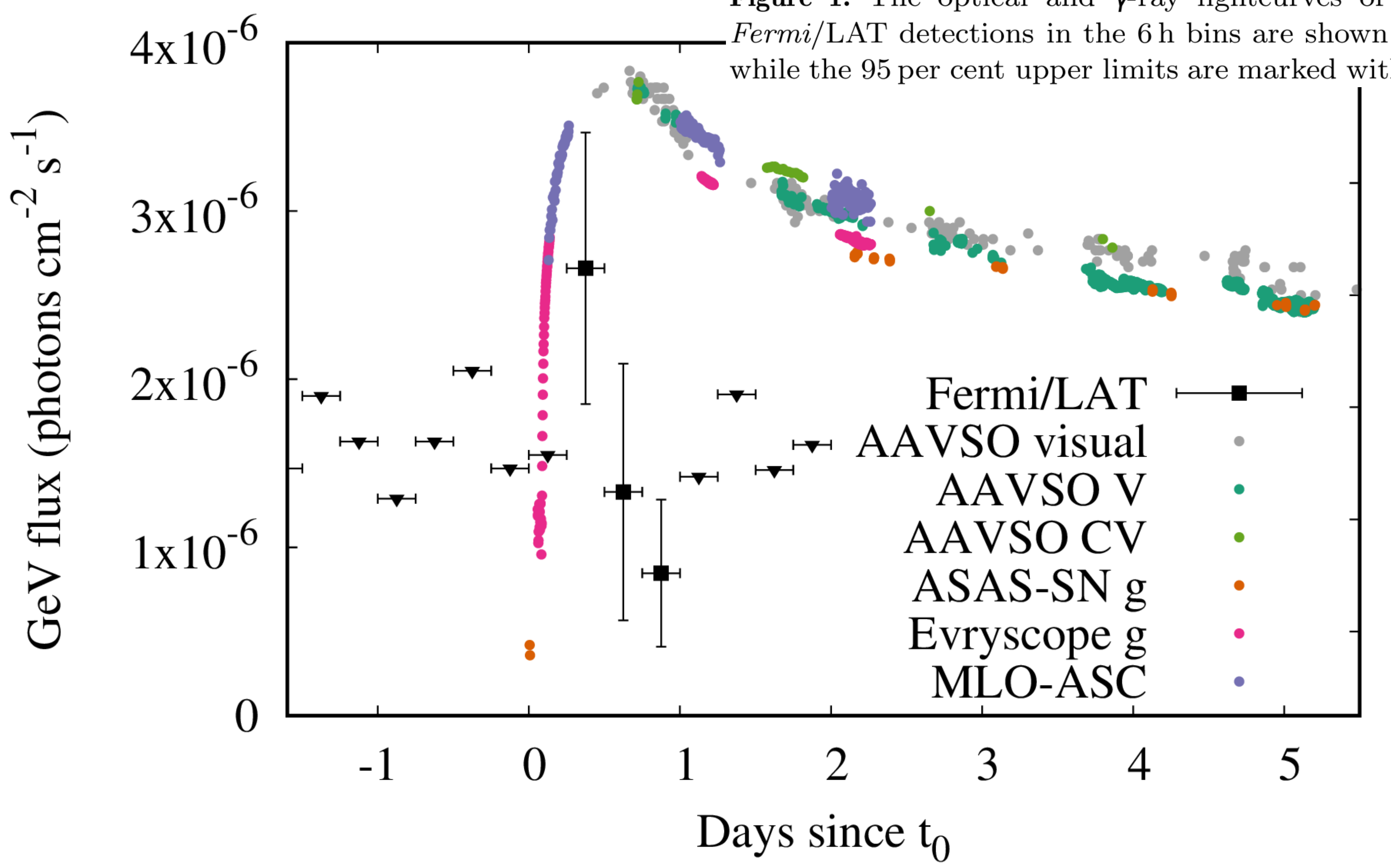
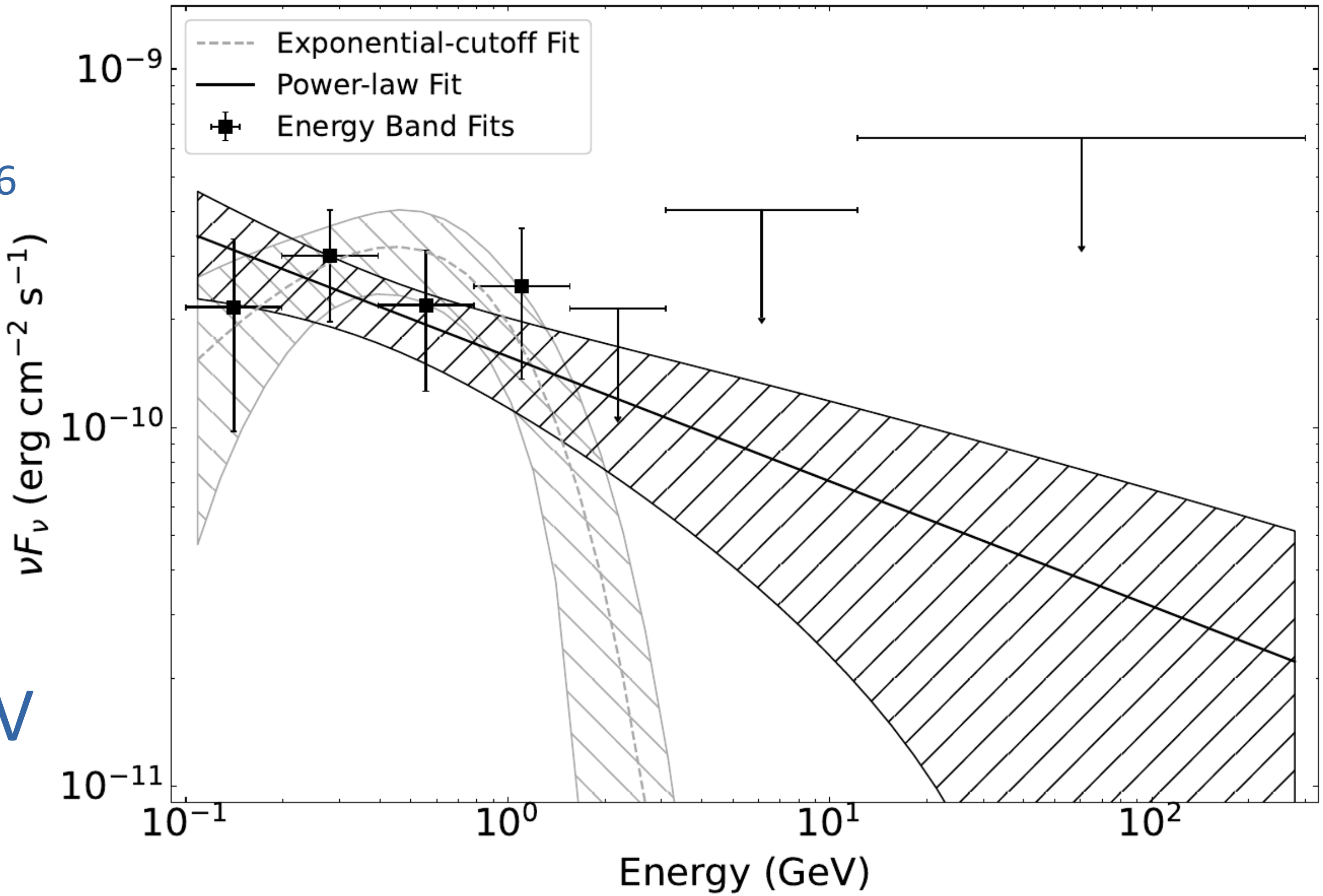


Figure 1. The optical and γ-ray lightcurves of V1674 Her. The *Fermi*/LAT detections in the 6 h bins are shown as black squares while the 95 per cent upper limits are marked with black triangles.

LAT SED

- 18^{h} integration
  TS=49
  (1.6 +/-0.4) x 10^{-6} ph/cm^2/s
- Good PL fit
  Γ=2.3+/-0.2
- PL+EC fit
  Γ=0.9+/-0.9
  EC=0.4+/-0.3 GeV



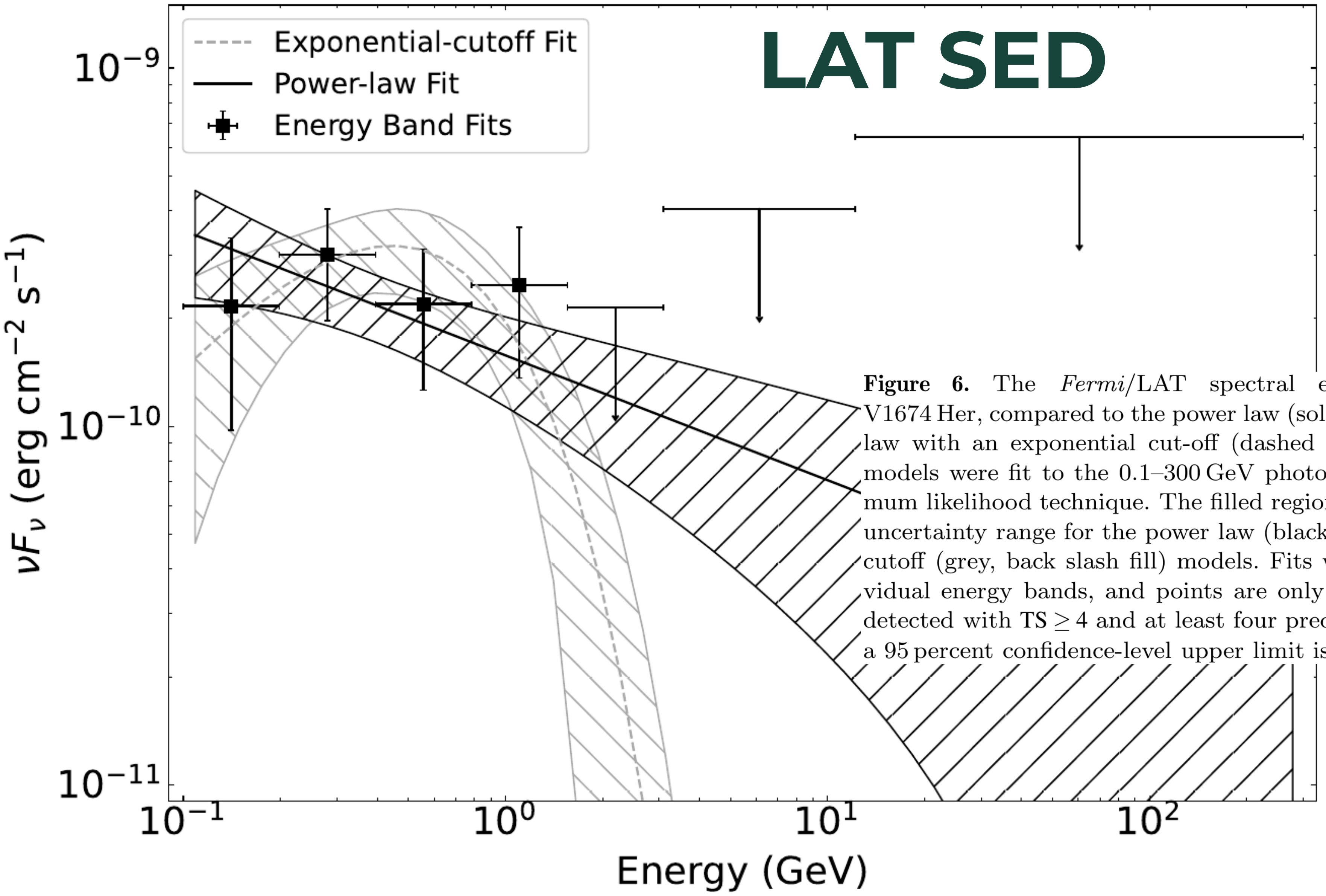
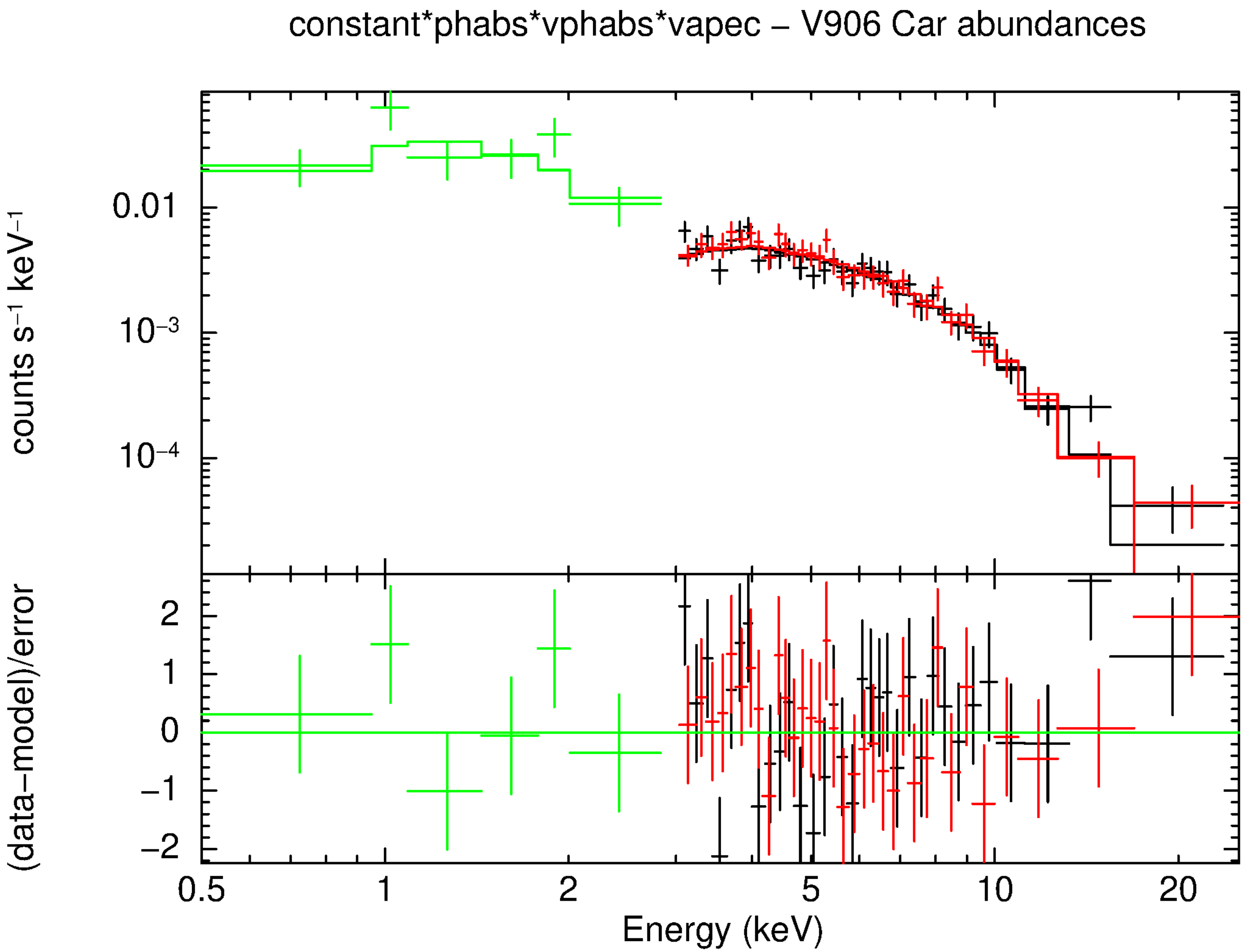
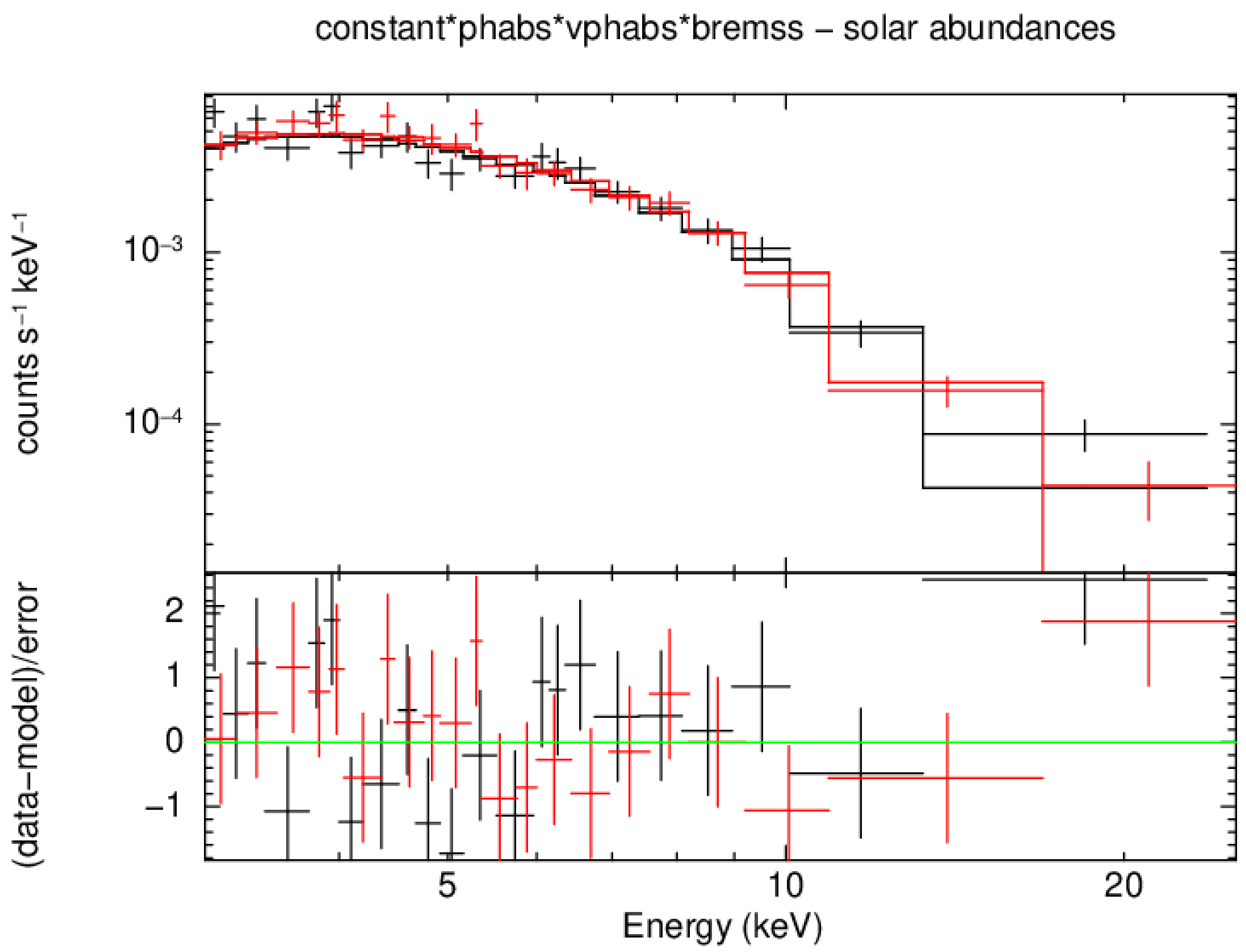


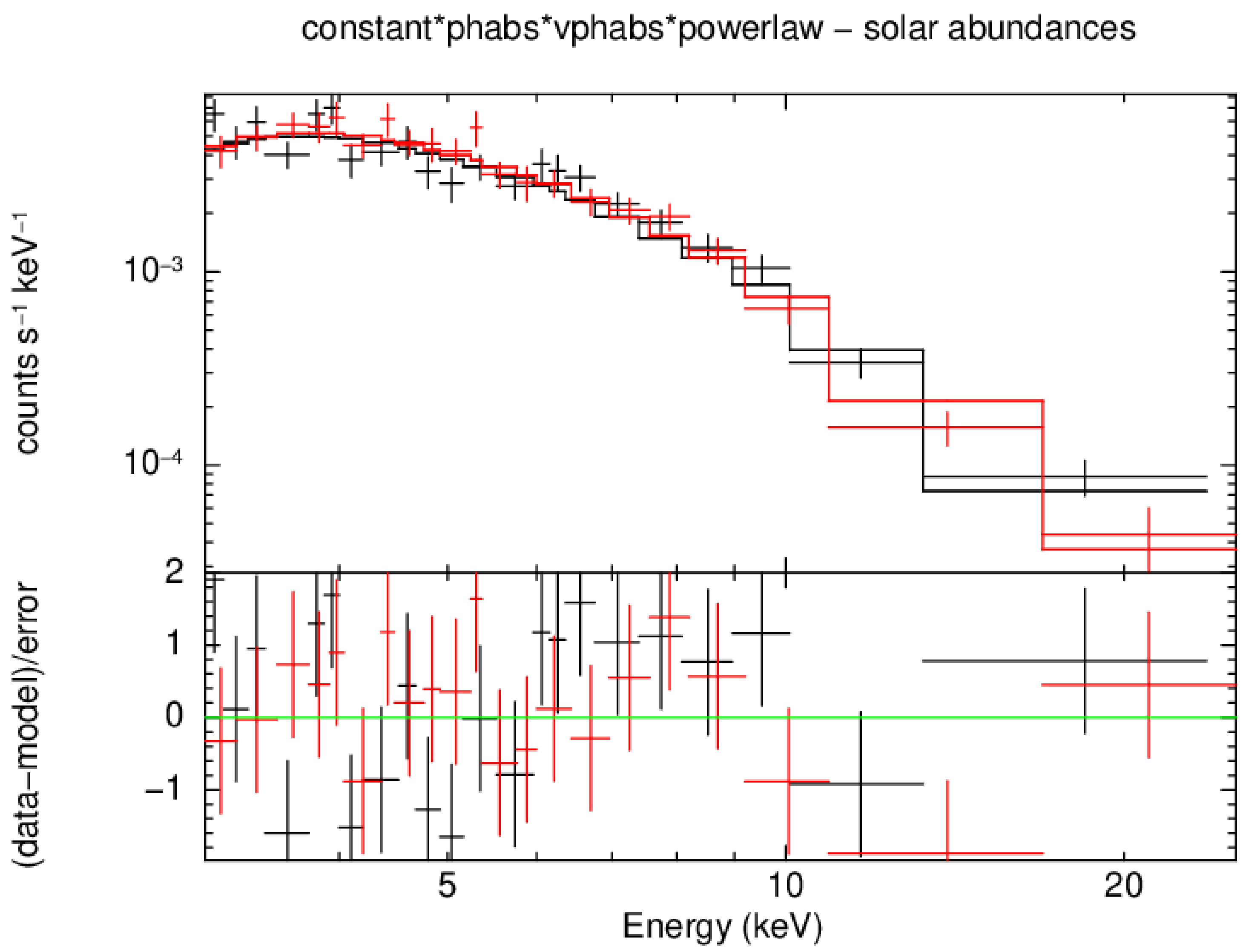
Figure 6. The *Fermi*/LAT spectral energy distribution of V1674 Her, compared to the power law (solid black line) and power law with an exponential cut-off (dashed grey line) models. The models were fit to the 0.1–300 GeV photon data using the maximum likelihood technique. The filled regions correspond to the 1σ uncertainty range for the power law (black, forward slash fill) and cutoff (grey, back slash fill) models. Fits were performed in individual energy bands, and points are only shown if the nova was detected with TS ≥ 4 and at least four predicted counts, otherwise a 95 percent confidence-level upper limit is reported.

X-ray spectrum (NuSTAR+Swift)

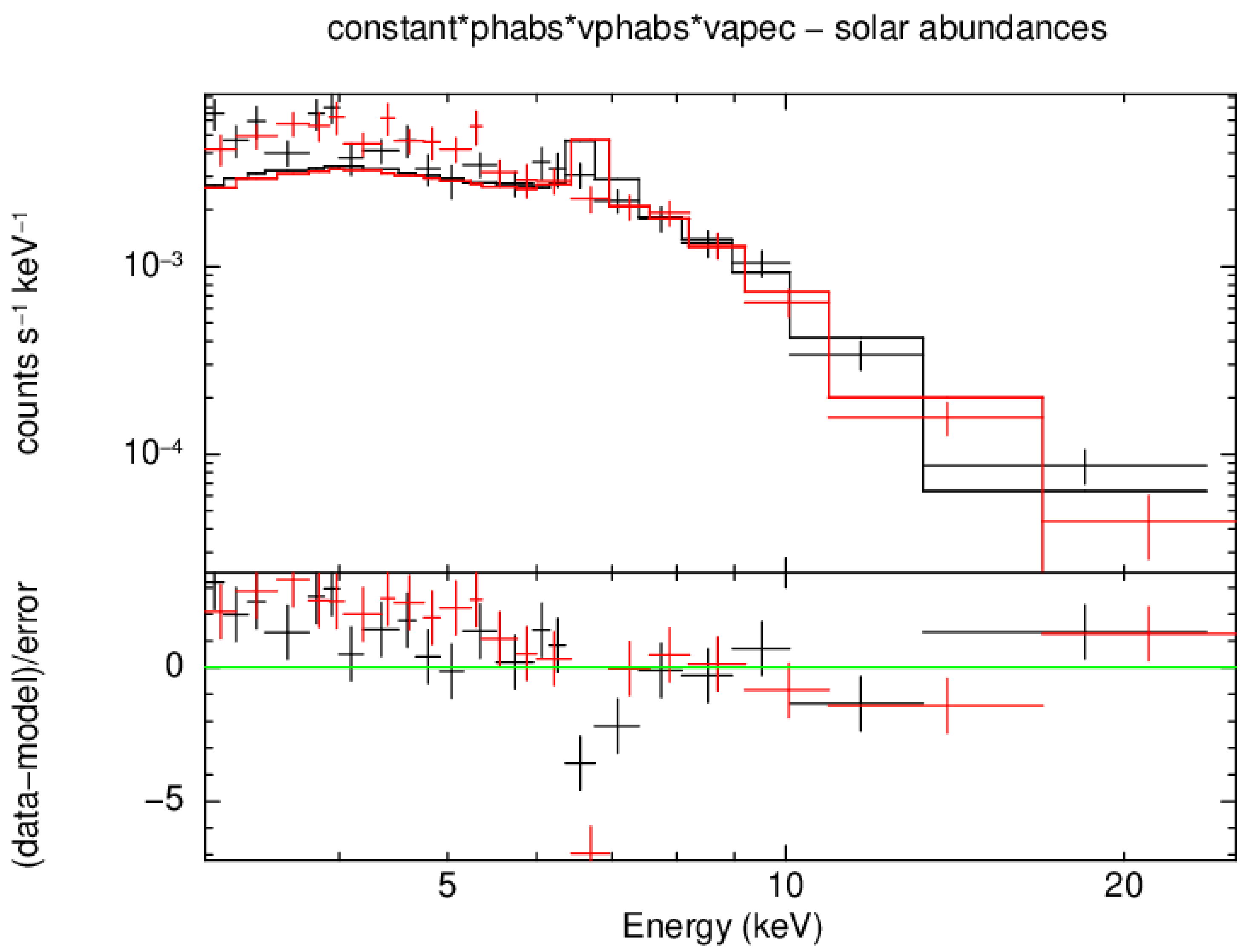
- $t_0 + 12^{days}$
- Thermal
  kT = 4 keV
- No intrinsic absorption
- Overabundance of CNO elements




constant*phabs*vphabs*bremss – solar abundances
counts s⁻¹ keV⁻¹
10^{-3}
10^{-4}
(data−model)/error
2
1
0
−1
5
10
20
Energy (keV)



constant*phabs*vphabs*powerlaw – solar abundances
counts s⁻¹ keV⁻¹
10⁻³
10⁻⁴
(data–model)/error
2
1
0
−1
5
10
20
Energy (keV)



constant*phabs*vphabs*vapec – solar abundances
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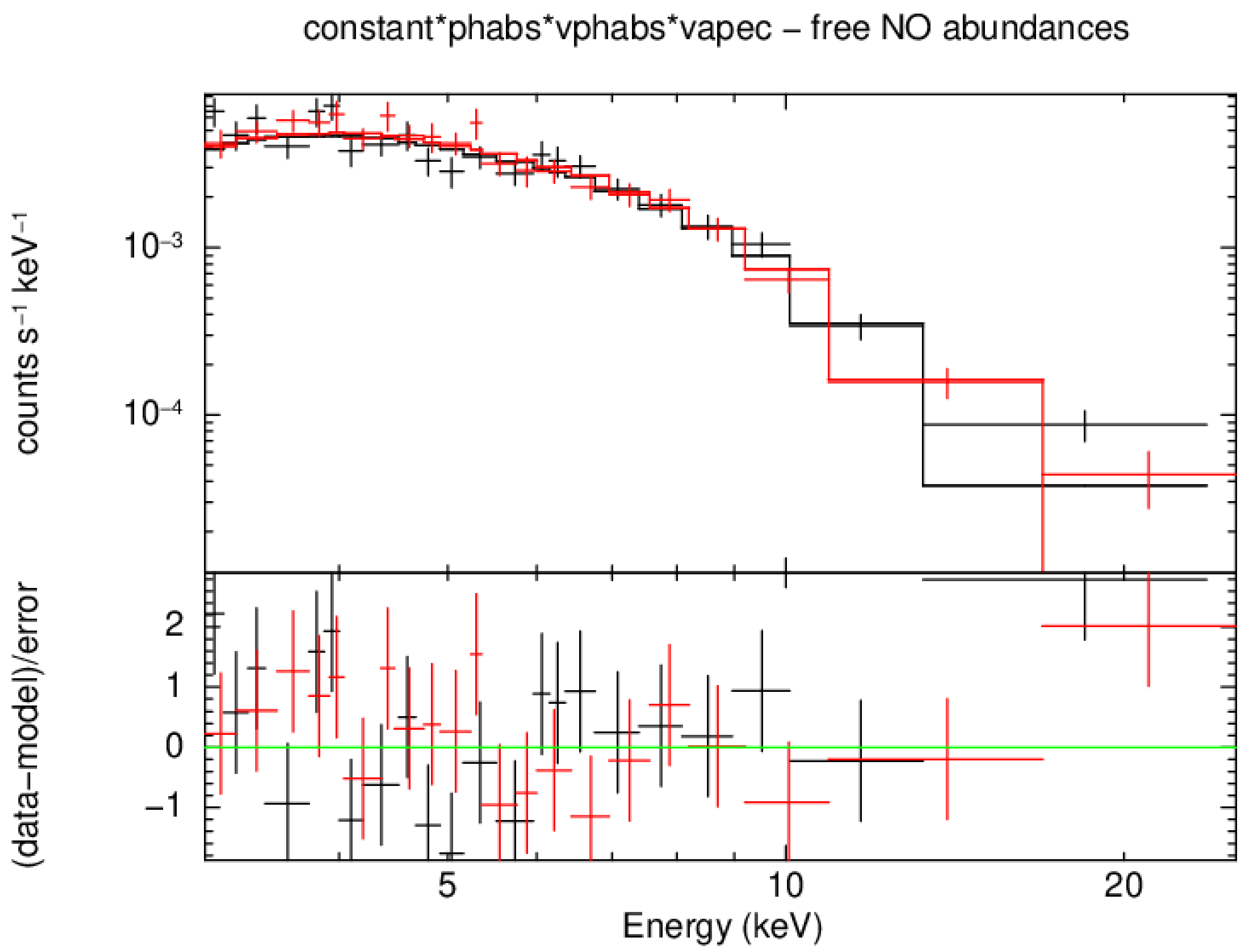
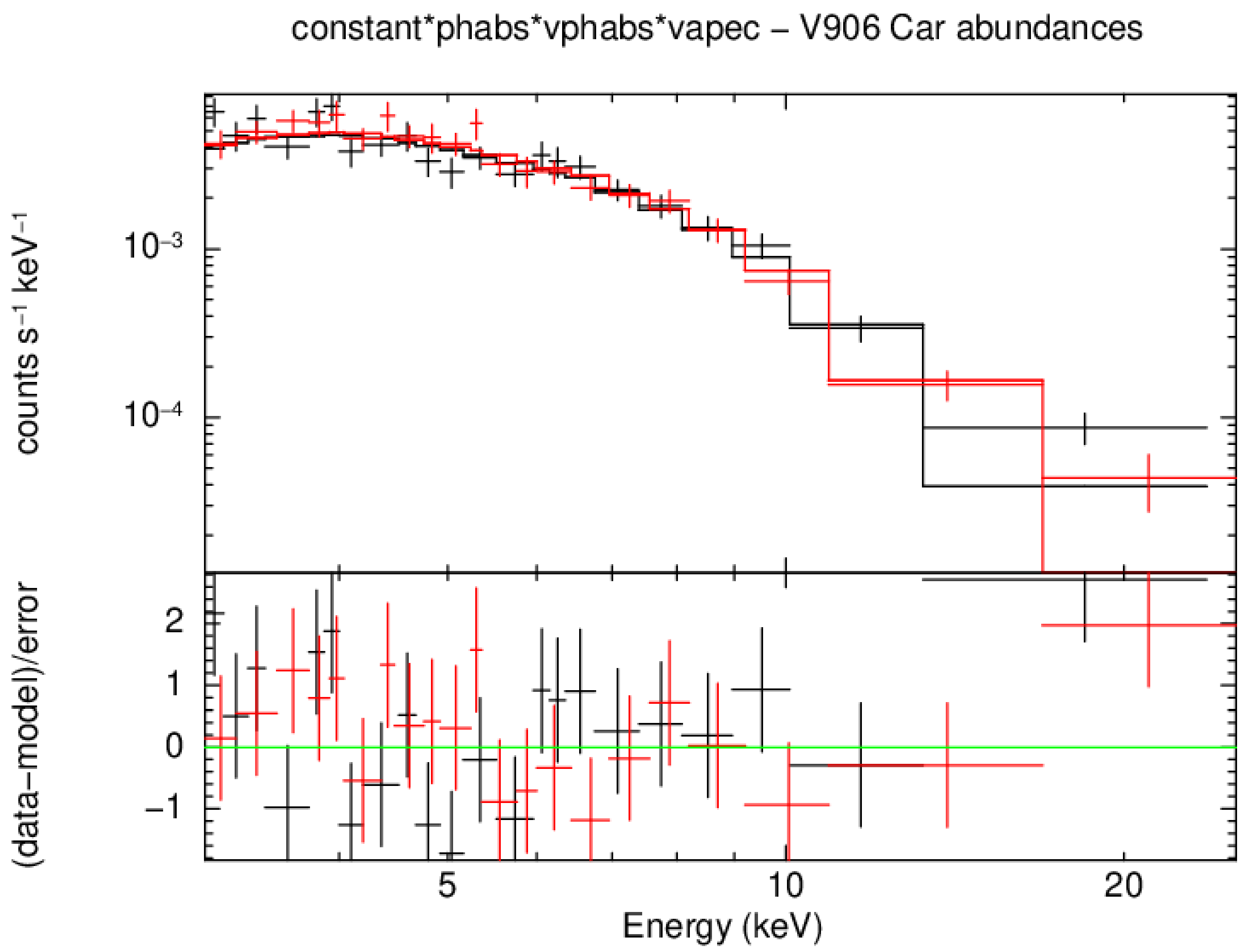
10⁻³
10⁻⁴
(data−model)/error
0
−5
5
10
20
Energy (keV)



constant*phabs*vphabs*vapec – free NO abundances
counts s⁻¹ keV⁻¹
10⁻³
10⁻⁴
(data–model)/error
2
1
0
−1
5
10
20
Energy (keV)



constant*phabs*vphabs*vapec – V906 Car abundances
counts s^{-1} keV^{-1}
10^{-3}
10^{-4}
(data–model)/error
2
1
0
−1
5
10
20
Energy (keV)

How do we know X-rays are thermal?

- Thermal model provides a good fit and CNO overabundance in novae ejecta known form optical spectra
- Power law also provides a good fit, but...

… the non-thermal X-ray emission mechanisms expected to operate in a nova should all produce hard photon spectra. Vurm & Metzger (2018) predict that the low-energy extension of the GeV emission should have a $\Gamma = 1.2$ to 1.0 in the *NuSTAR* band. The other possible non-thermal mechanism – Comptonization of the radioactive MeV lines – should produce even harder spectra with $\Gamma \lesssim 0$ below 30 keV (see fig. 1–4 of Gomez-Gomar et al. 1998). The observed soft photon index $\Gamma = 3.2 \pm 0.1$ contradicts these predictions.

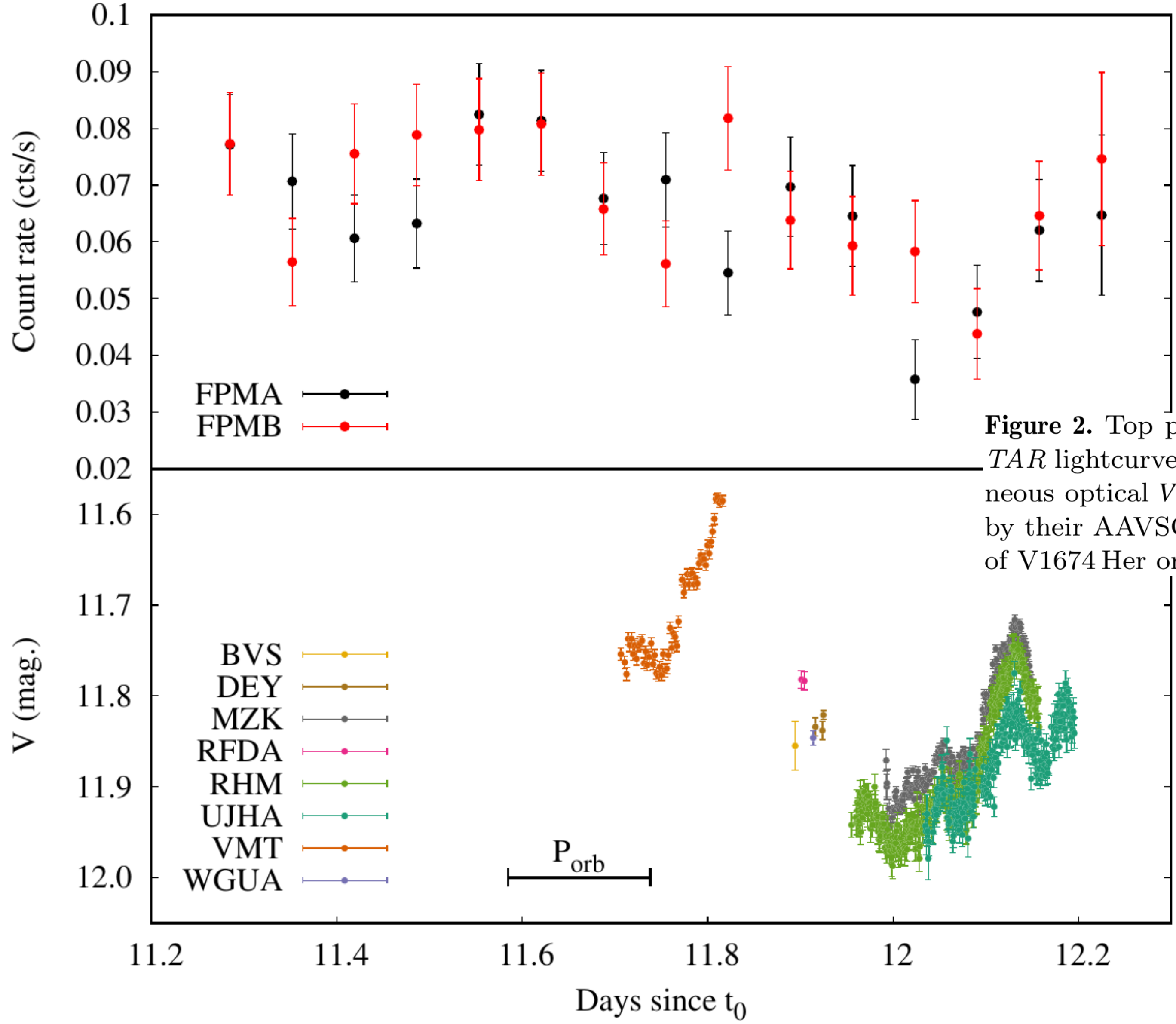


Figure 2. Top panel: the background-subtracted 3.0–30 keV *NuSTAR* lightcurve of V1674 Her (see § 2.1.1). Bottom panel: simultaneous optical *V* band photometry by multiple observers identified by their AAVSO codes. The horizontal bar indicates the duration of V1674 Her orbital period.

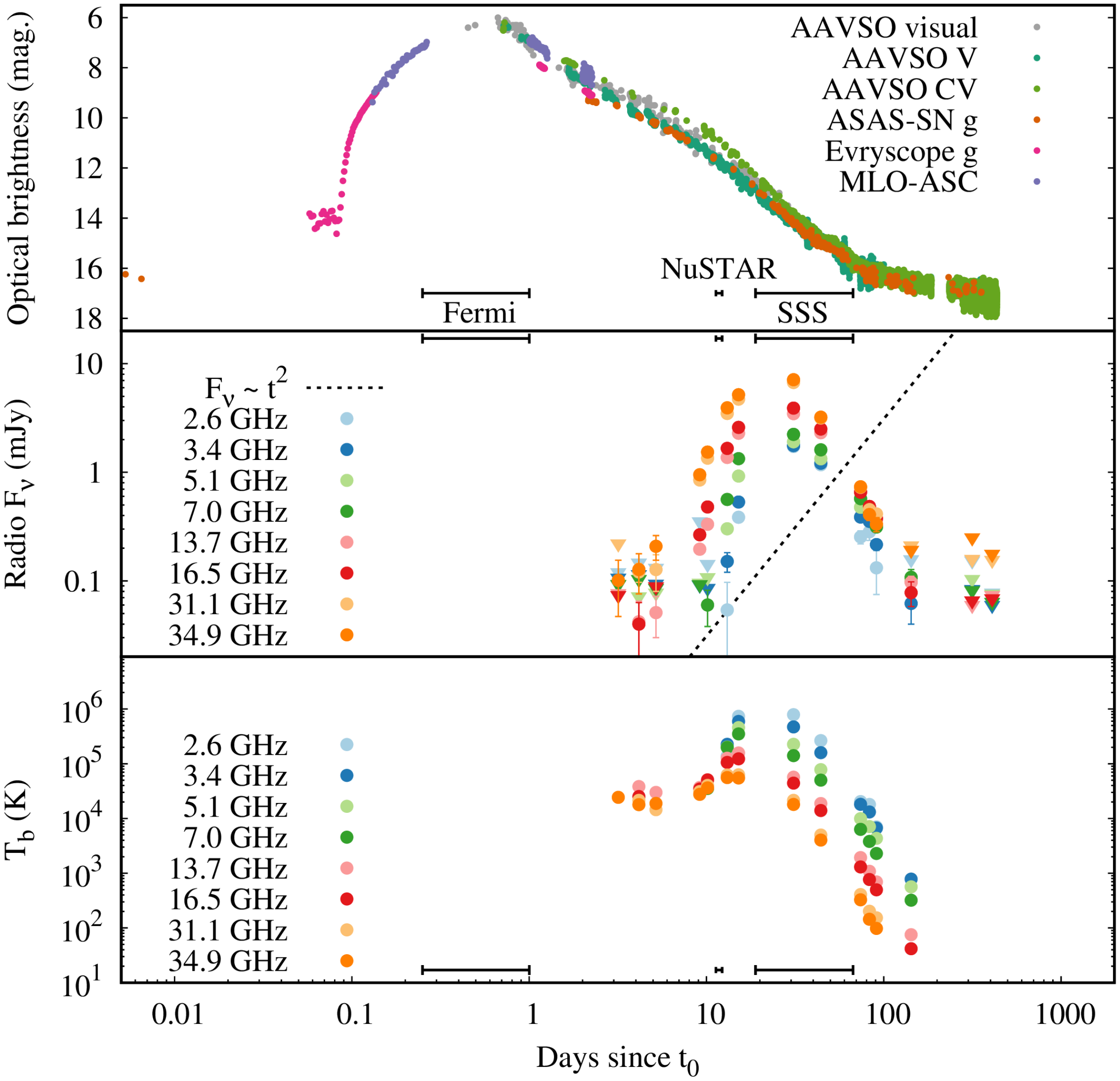
NuSTAR

X-ray 3-30 keV

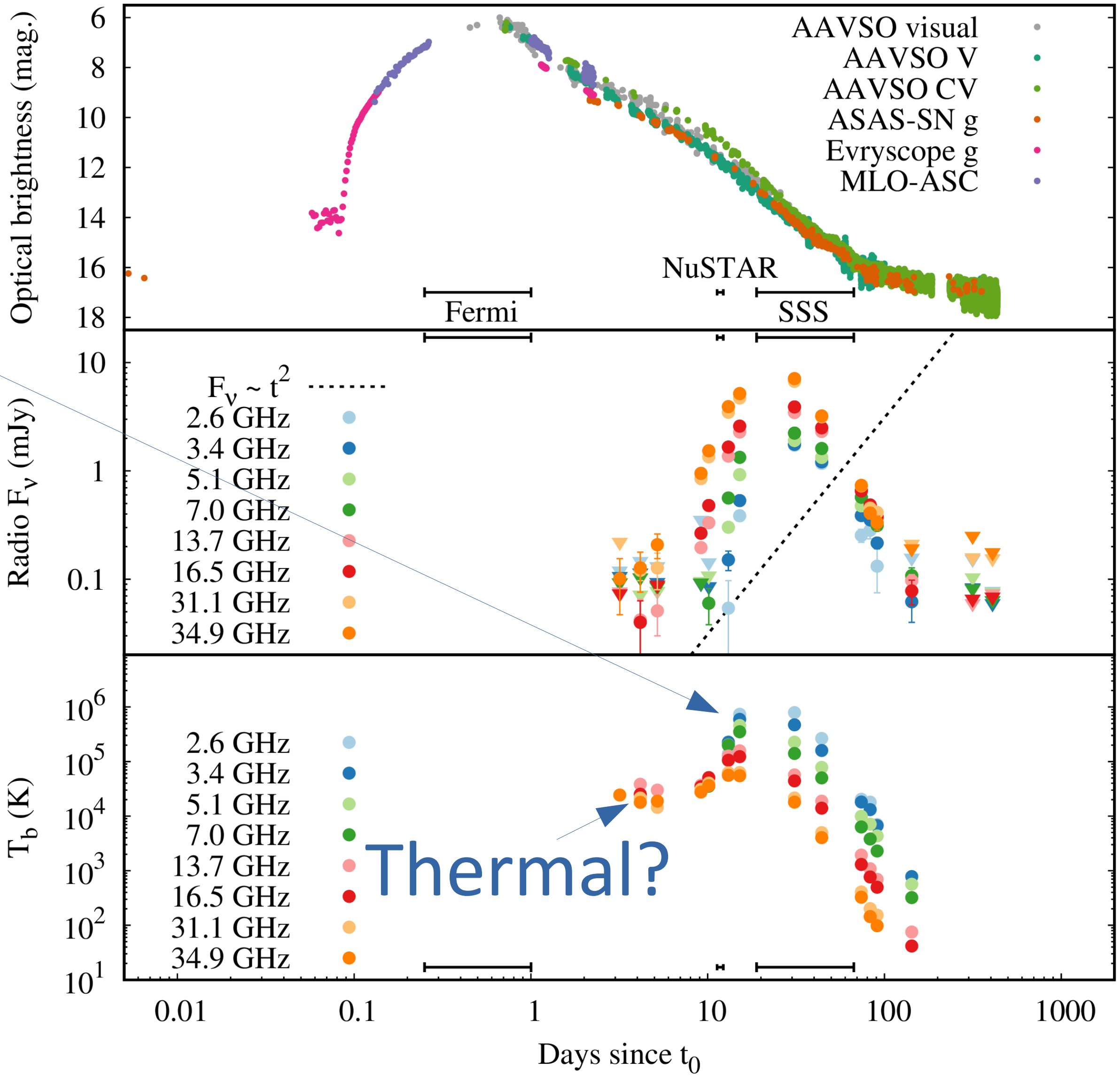
AAVSO

optical V filter

VLA


Optical brightness (mag.)
AAVSO visual
AAVSO V
AAVSO CV
ASAS-SN g
Evryscope g
MLO-ASC
Fermi
NuSTAR
SSS
Radio F_ν (mJy)
$F_\nu \sim t^2$
2.6 GHz
3.4 GHz
5.1 GHz
7.0 GHz
13.7 GHz
16.5 GHz
31.1 GHz
34.9 GHz
T_b (K)
Days since t_0

High T_b suggests synchrotron emission in radio



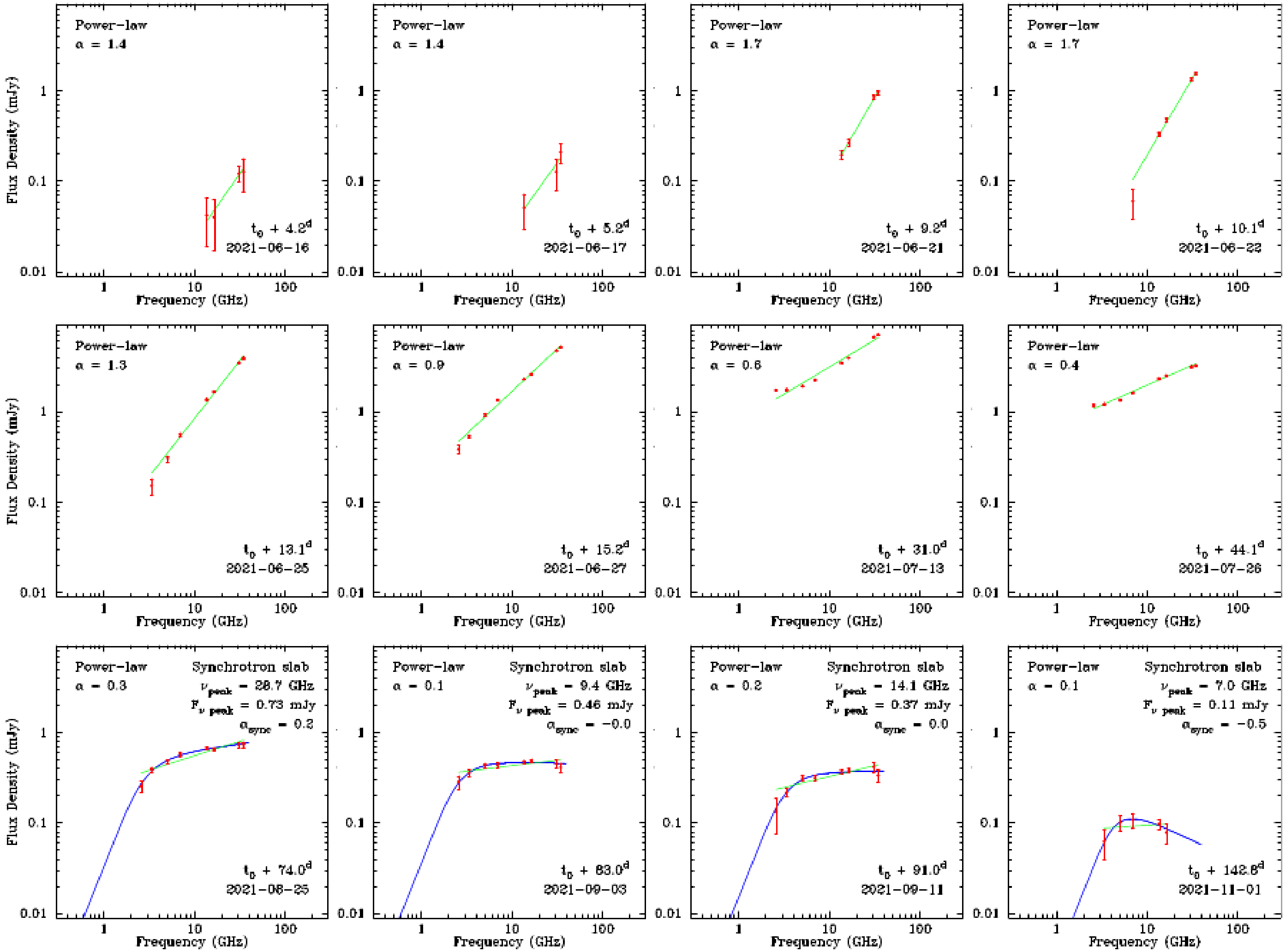


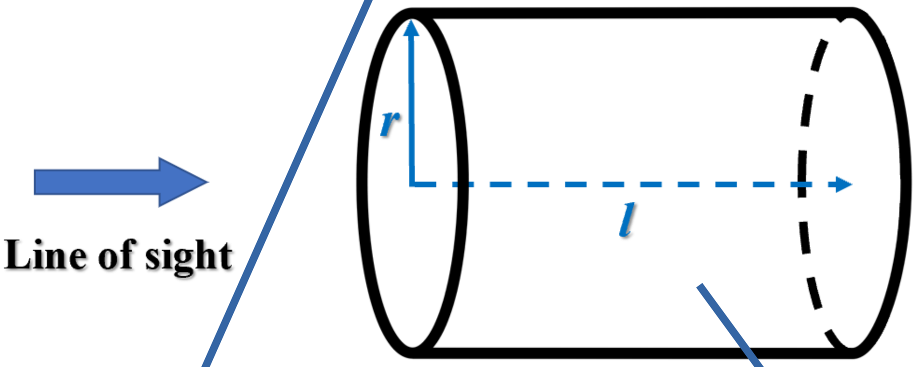
Figure 8. The evolution of the radio spectrum of V1674 Her. The VLA flux density measurements (red) are compared to the simple power-law fit (green line) and a spectrum of a uniform synchrotron-emitting slab. The uncertainty on the reported spectral index values is ~ 0.3 for the power law fits on 2021-06-16, 2021-06-17, 2021-11-01 and $\lesssim 0.1$ in all other cases. The synchrotron slab spectrum can approximate the observations only at late epochs. The spectrum shape is most likely determined by the non-uniform optical depth effects across the source.

Interpreting radio spectra

- High T_b -> non-thermal i.e. *synchrotron*
- Inverted ("hard") spectrum -> optically thick
- *Can't be synchrotron self-absorption* - would require ridiculously high magnetic field strength
- *Free-free absorption* on an external screen or *Razin-Tsytovich effect* (when synchrotron-emitting plasma is mixed with thermal)?

NuSTAR plasma does not contribute to radio

It's *too faint* and *optically thin*



$$\tau \approx 3.28 \times 10^{-7} \left(\frac{T}{10^4\,\mathrm{K}}\right)^{-1.35} \left(\frac{\nu}{1\,\mathrm{GHz}}\right)^{-2.1} \left(\frac{(\mathrm{EM})_{\mathrm{radio}}}{1\,\mathrm{pc\,cm^{-6}}}\right)$$

$$\tau = 10^{-3} - 10^{-6} \text{ for } \nu = 1 \text{ to } 30\,\mathrm{GHz}$$

$$T_b = (1 - e^{-\tau})T$$

$$(\mathrm{EM})_{\mathrm{X-ray}} = \int n_e n_i dV,$$

$$(\mathrm{EM})_{\mathrm{X-ray}} = \pi r^2 (\mathrm{EM})_{\mathrm{radio}}.$$

$$F_\nu = \frac{T_b}{1763\,\mathrm{K}} \left(\frac{\nu}{1\,\mathrm{GHz}}\right)^2 \left(\frac{\theta}{1\,\mathrm{arcsec}}\right)^2 \mathrm{mJy},$$

$$\mathscr{E} = \frac{10^{-14}}{4\pi D_{\mathrm{cm}}^2} (\mathrm{EM})_{\mathrm{X-ray}},$$

$$(\mathrm{EM})_{\mathrm{radio}} = \int n_e n_i dl,$$

$$F_\nu \approx 2\,\mu\mathrm{Jy}$$

Conclusions

Despite being exceptionally fast and magnetic...

- The shock-related properties (GeV/X-ray/radio) of V1674 Her look *remarkably normal* compared to other GeV-emitting novae
- GeV emission appears 6^h (*2 orbital periods*) after the start of the eruption - a *challenge for the common-envelope ejection + fast white dwarf wind scenario* of shock formation

Conclusions as presented in the paper:

5 CONCLUSIONS

We conducted a joint analysis of γ-ray (*Fermi*-LAT), X-ray (*NuSTAR*, *Swift*/XRT), optical (AAVSO, Evryscope, ASAS-SN), and radio (VLA) observations of an exceptionally fast Galactic nova V1674 Her.

(i) V1674 Her was clearly detected by *Fermi*-LAT, but only for the duration of 18 h near the optical peak. There is a delay of about 6 h between the onset of optical and detectable γ-ray emission. The shape and the cut-off energy of the γ-ray spectrum are poorly constrained taking into account the limited statistics.

(ii) The *NuSTAR* spectrum of V1674 Her is consistent with having been produced by shock-heated plasma with non-solar elemental abundances. It is remarkably similar to the spectra of three classical novae previously detected by *NuSTAR*. The lack of periodic variability in the hard X-ray flux at the spin period of the white dwarf suggests that the *NuSTAR*-detected X-rays from V1674 Her are associated with a shock within the nova ejecta, not accretion on the magnetized white dwarf.

(iii) Given the strong similarity between the high-energy properties of V1674 Her and those of other classical novae in the days to weeks after eruption, it appears that neither the exceptionally high speed of this nova, nor the intermediate polar nature of the host system affect the shock development within the ejecta.

(iv) We interpret the radio emission of V1674 Her as being shock-powered synchrotron emission attenuated by free-free absorption. Unlike many other novae, V1674 Her displayed weak thermal radio emission that contributed before the synchrotron emission reached its peak.

(v) The radio emission (§ 4.6.1) and X-ray emission and absorption (§ 4.6.2) point to a low ejecta mass of $\sim 10^{-7} M_{\odot}$, however the different ejecta mass estimation techniques do not necessarily probe the same parts of the ejecta.

(vi) Being an exceptionally fast nova, V1674 Her might serve as a stress test for the 'slow torus plus fast bipolar outflow' scenario (outlined in § 4.2 and 4.7) of shock formation in novae. For this scenario to hold in V1674 Her, common-envelop action must have been able to eject the envelope very quickly and the fast flow must have begun before the detection of γ-rays within 6 hours of t_0.