# Recurrent Swift Observations of Recurrent Novae

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# Novae

Novae are binary star systems, comprising a white dwarf which accretes H-rich material from a companion star, until the temperature and pressure are sufficient for a thermonuclear runaway to occur. At this point, material is flung outwards, obscuring the white dwarf surface. A new optical source is typically seen at this point, with the peak brightness occurring at the maximum expansion of the photosphere. As the ejecta become optically-thin, the nuclear burning on the WD surface (usually) becomes visible, and we see the super-soft X-ray emission.

There are two main groups of novae: classical and recurrent.

Classical novae have only been seen in eruption once - though are expected to re-erupt on timescales of 1000s of years.

Recurrent novae have had at least 2 detected eruptions, so have recurrence times of up to ~100 yr (something of a selection effect, dependent on historical records).

# Recurrent Novae

Swift has observed many novae, both classical and recurrent. Of the sample of recurrent novae, Swift has observed four during repeated eruptions.

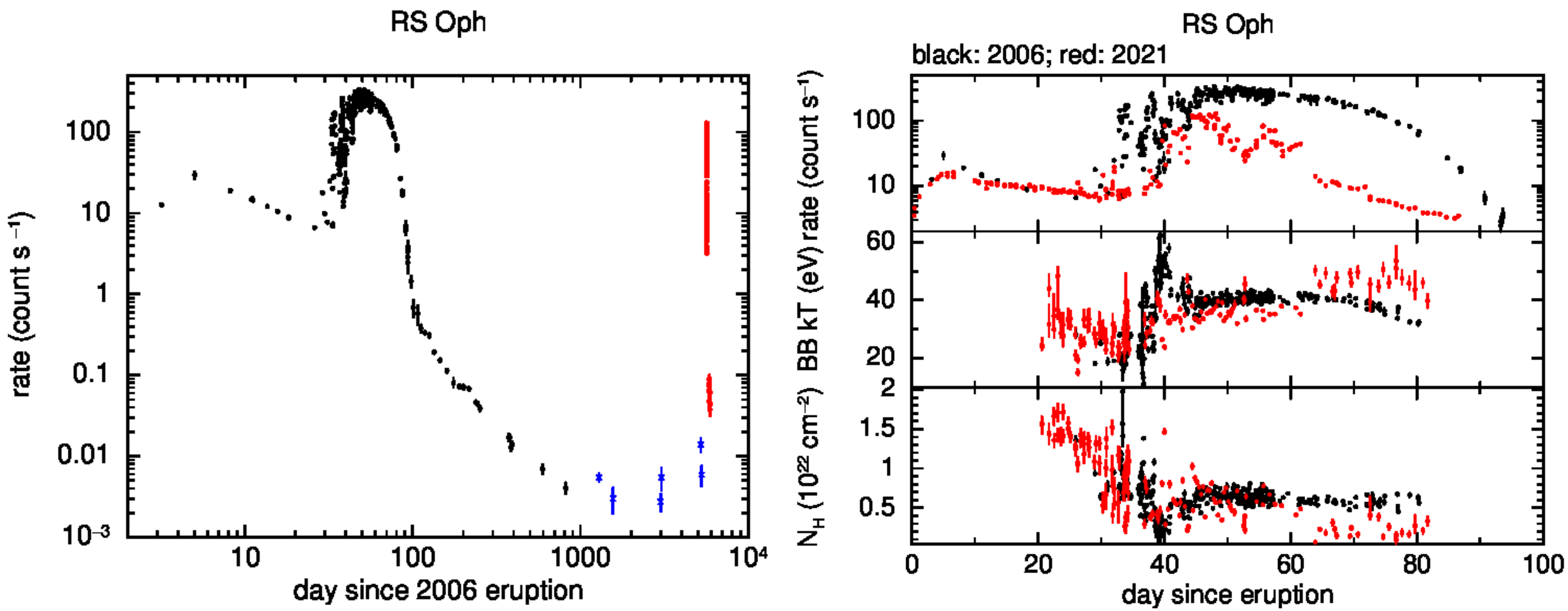
RS Oph – 2006 and 2021

U Sco – 2010 and 2022

Nova LMC 1968 – 2016, 2020 and 2024

M31N 2008-12a – every year since 2013!

# RS Ophiuchi: 2006 & 2021

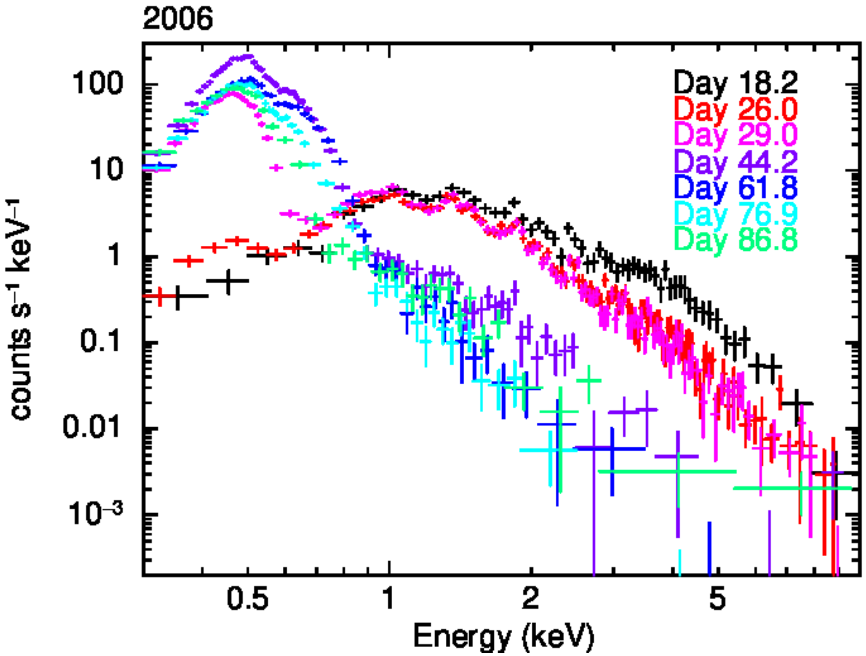


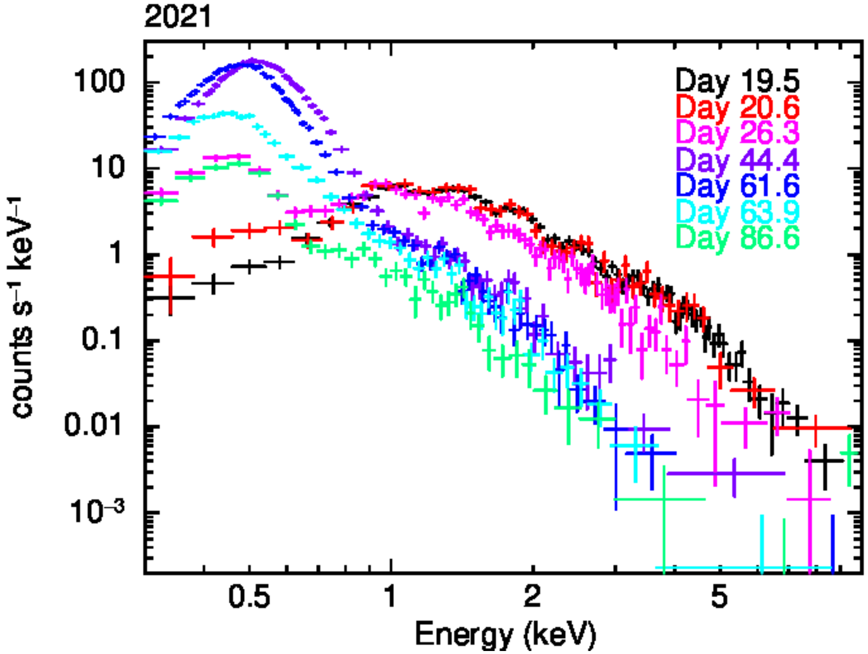

Fit details:

- Galactic $N_H$ ($2.4\times10^{21}$ $cm^{-2}$) plus excess (plotted)
- Fitting 0.3-10 keV, with BB for SSS, and two optically-thin APEC components for shock emission.

Throughout, spectra from https://www.swift.ac.uk/user_objects/ have been used.

# RS Oph Spectra



# RS Oph Results

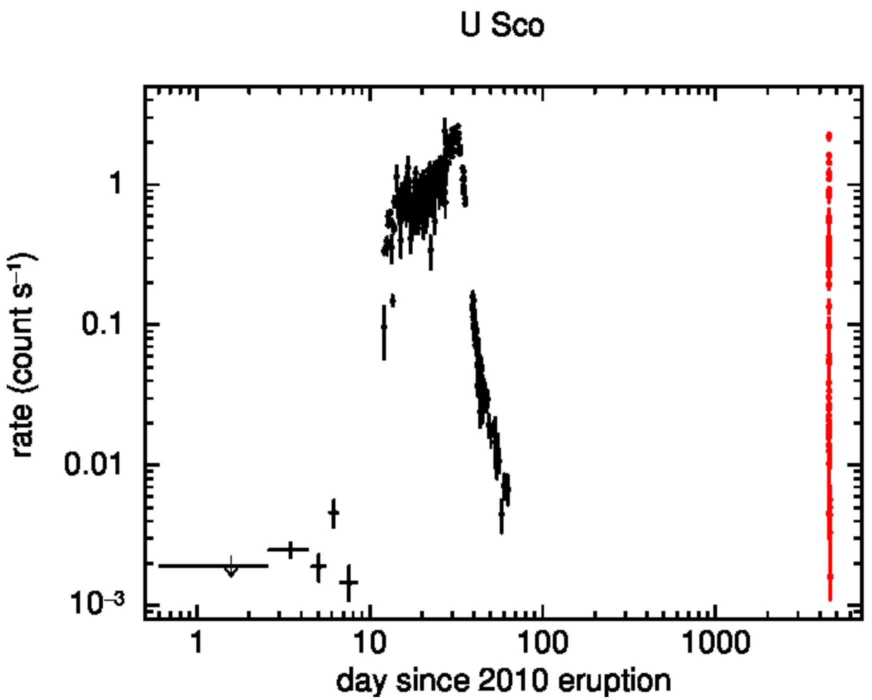
- 7 recorded nova eruptions, another 2 inferred.
- The last 2 eruption periods were 21 and 15.5 yr.
- The soft X-rays were much brighter in 2006.
- The 2006 spectra show stronger evidence for superimposed ionized absorption edges, while the 2021 data appear featureless.
- After around day 60 post eruption, the 2021 X-ray emission appears hottter.

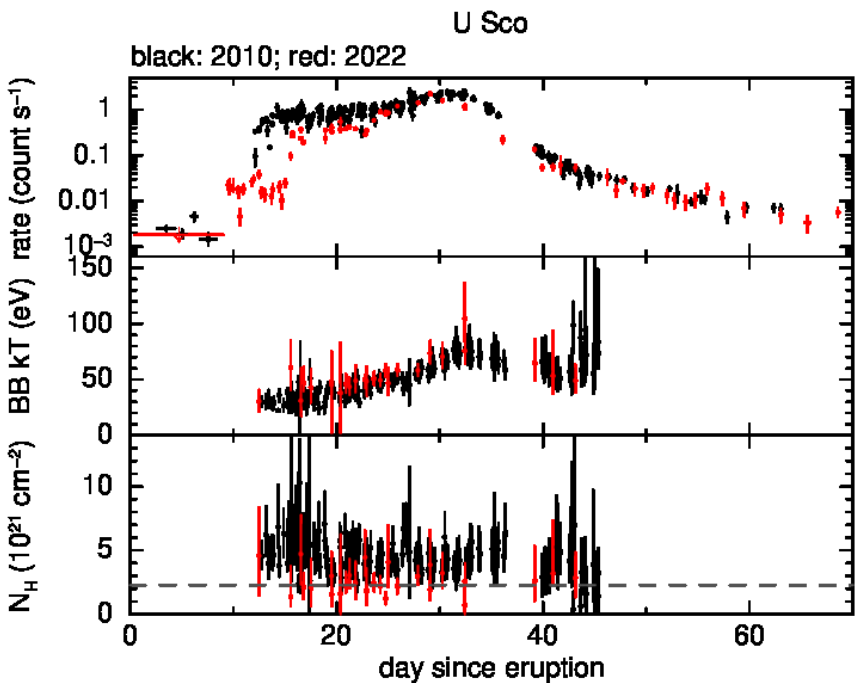
While assuming a basic, neutral absorption model applied to our Swift-XRT CCD data does not appear to explain why the X-rays appeared fainter in 2021, using high-resolution spectra from XMM and Chandra suggests a combination of cold (neutral) and hot (ionized) absorption may be able to explain the differences seen.

See also:

Bode et al., 2006, ApJ, 652, 629
Osborne et al., 2011, ApJ, 727, 124
Page et al., 2022, MNRAS, 514, 1557
Ness et al., 2023, A&A, 670, A131

# U Scorpii: 2010 & 2022

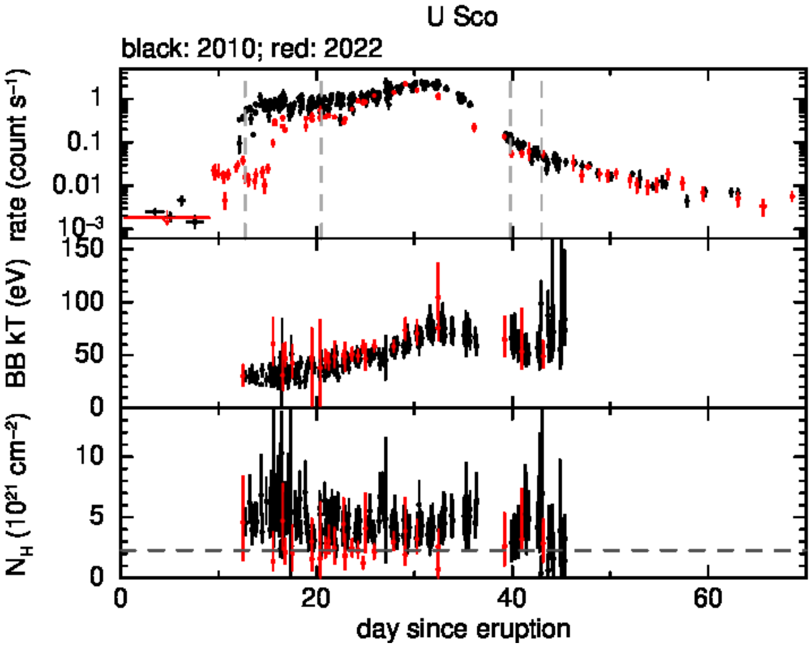


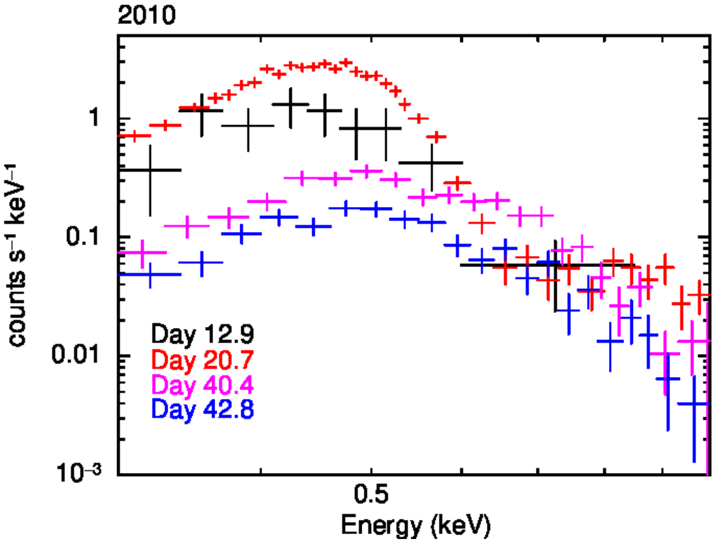



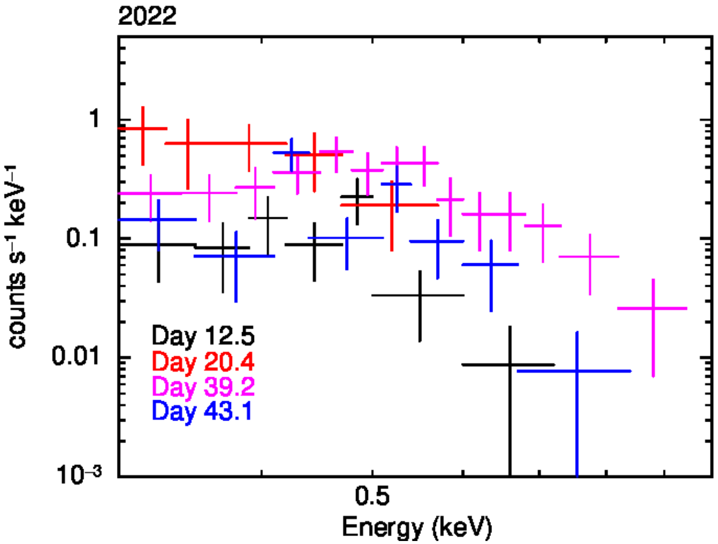

Fit details:

- Free $N_{H;}$ Galactic value ($2.28\times10^{21}$ $cm^{-2}$) shown as dashed line.
- Fitting BB over 0.3-1 keV, since very few counts at higher energies.

# U Sco Spectra



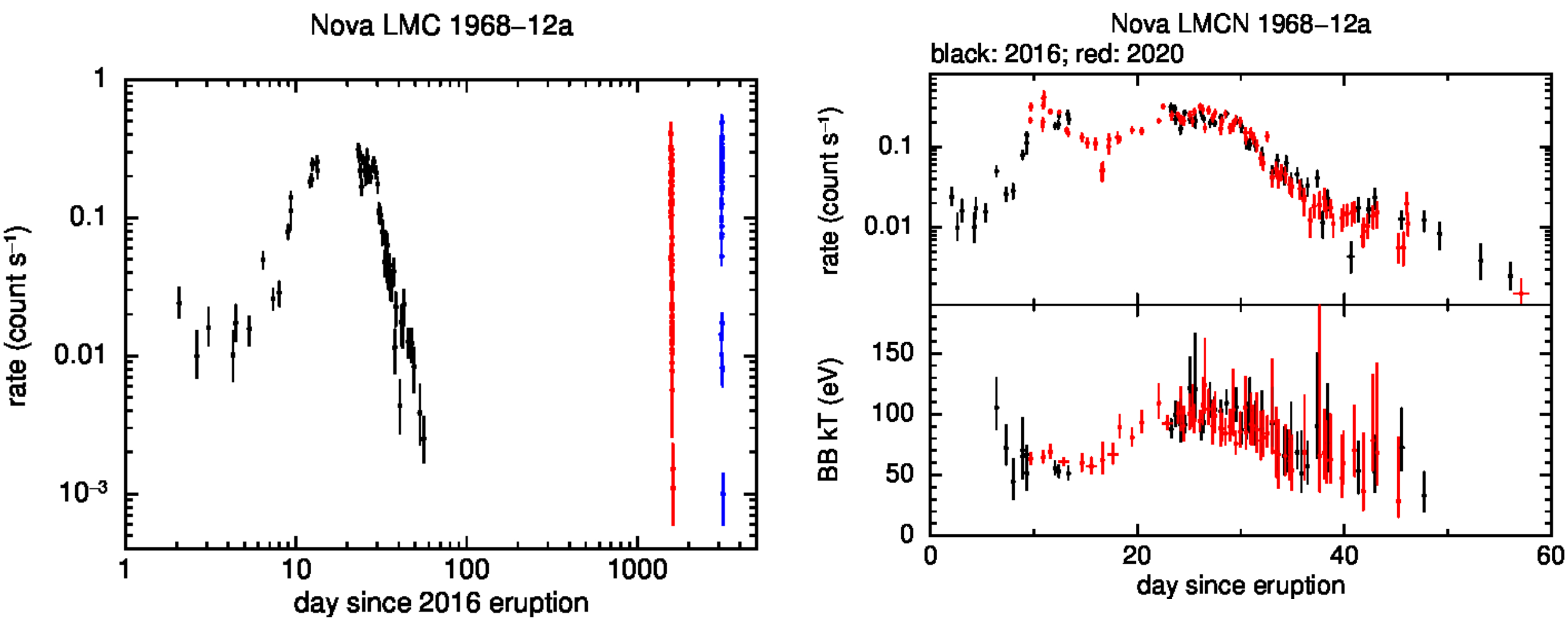
# U Sco Results

- 11 known nova eruptions
- Last 2 eruption intervals were 10.9  yr and 12.3 yr.
- 2022 eruption was slower to rise to peak SSS, though peaked earlier, with the SSS fading away sooner – so a shorter, less luminous SSS duration.
- The peak count rate is approximately the same both times, though, as are the BB temperatures.

See also:
Ness et al., 2012, ApJ, 745, 43
Pagnotta et al., 2015, ApJ, 811, 32
Evans et al., 2023, MNRAS, 522, 4841

A comparison between the XRT light-curves has also been presented in Muraoka et al., 2024, PASJ, 76, 293

# Nova LMC 1968: 2016 & 2020 & 2024

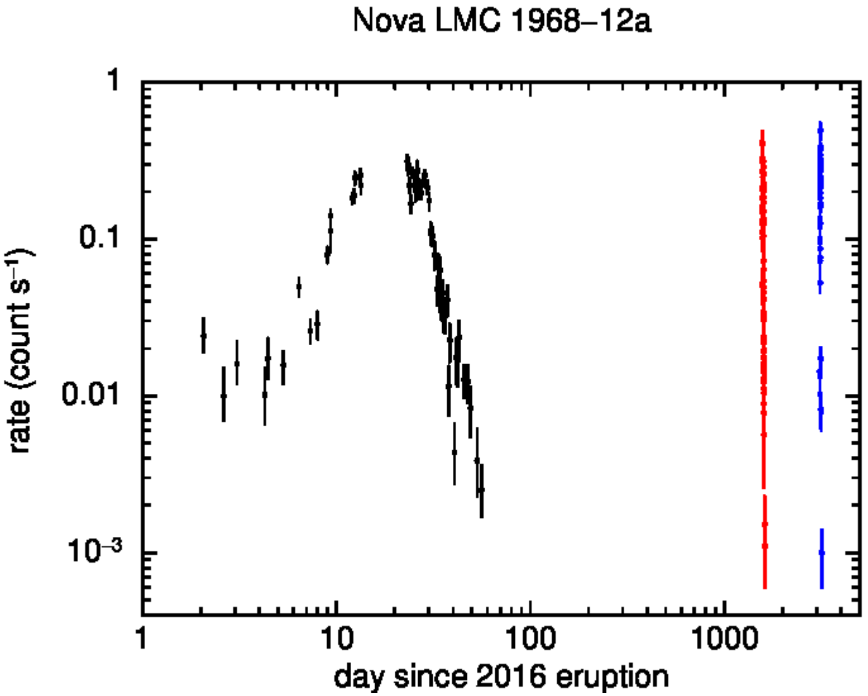


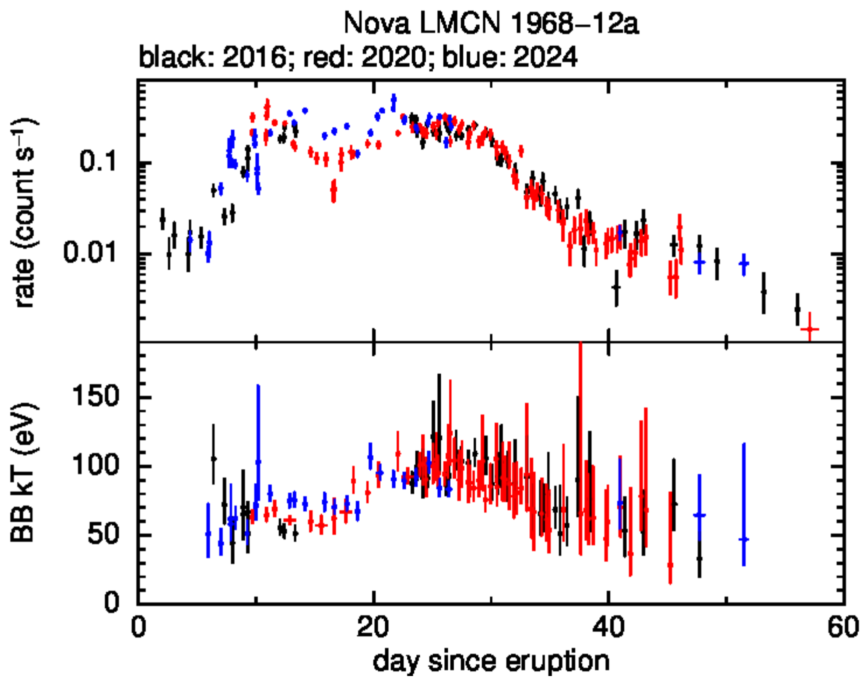

Fit details:

Galactic $N_H$ ($1.78 \times 10^{21}$ $cm^{-2}$); no excess required.

Fitting BB over 0.3-1 keV, since very few counts at higher energies.

# Nova LMC 1968: 2016 & 2020 & 2024



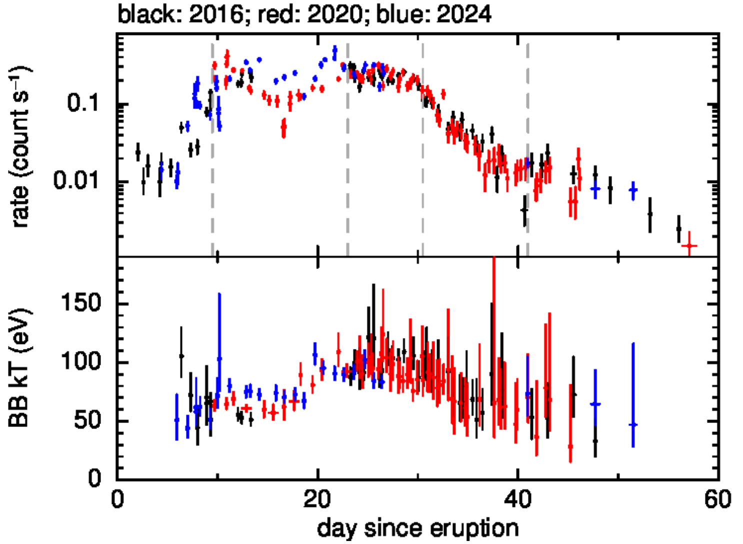



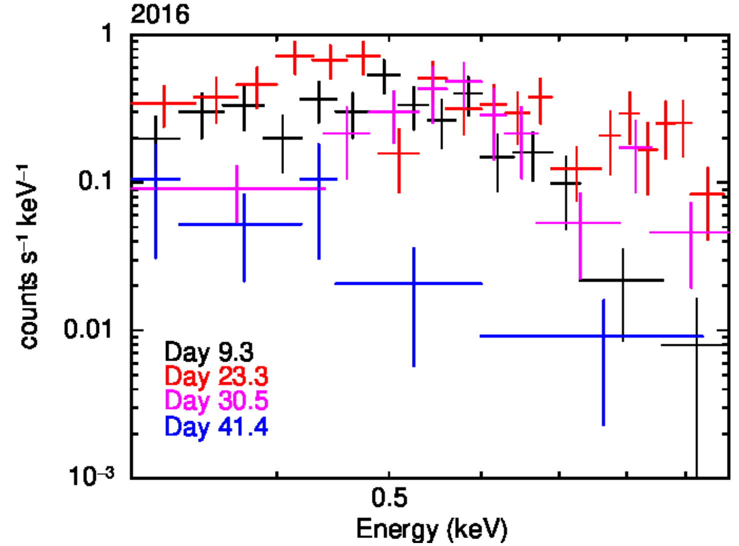

Fit details:

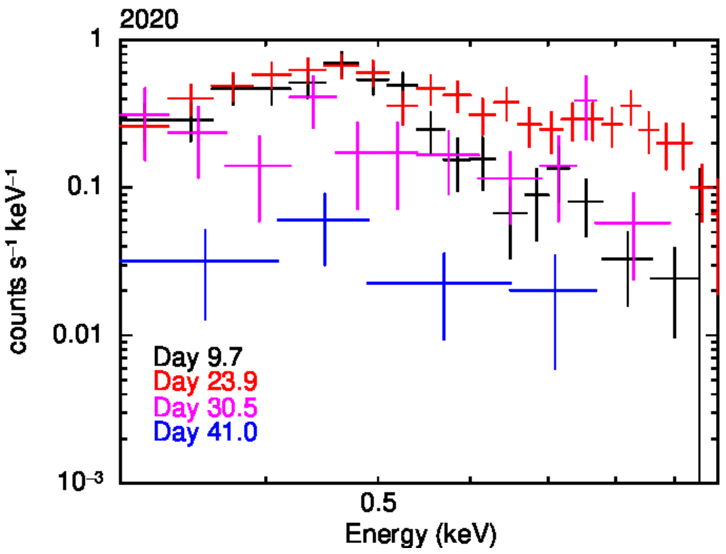
Galactic $N_H$ ($1.78 \times 10^{21}$ $cm^{-2}$); no excess required.

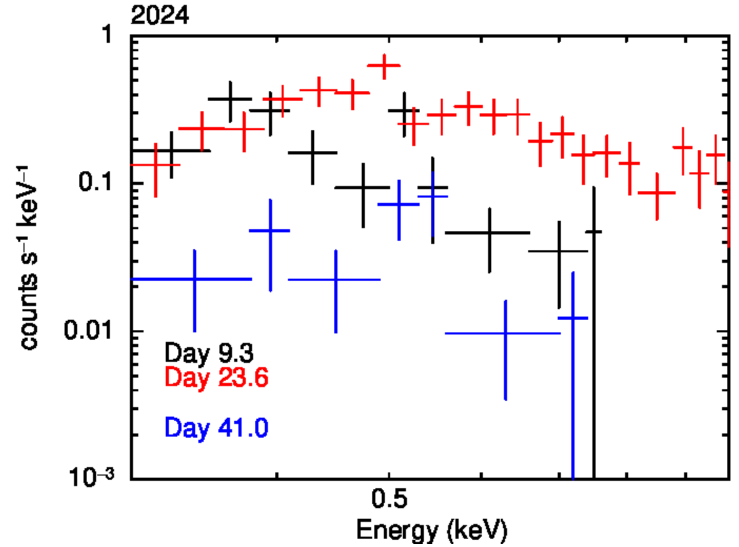
Fitting BB over 0.3-1 keV, since very few counts at higher energies.

# Nova LMC 1968 Spectra



# Nova LMC 1968 Results

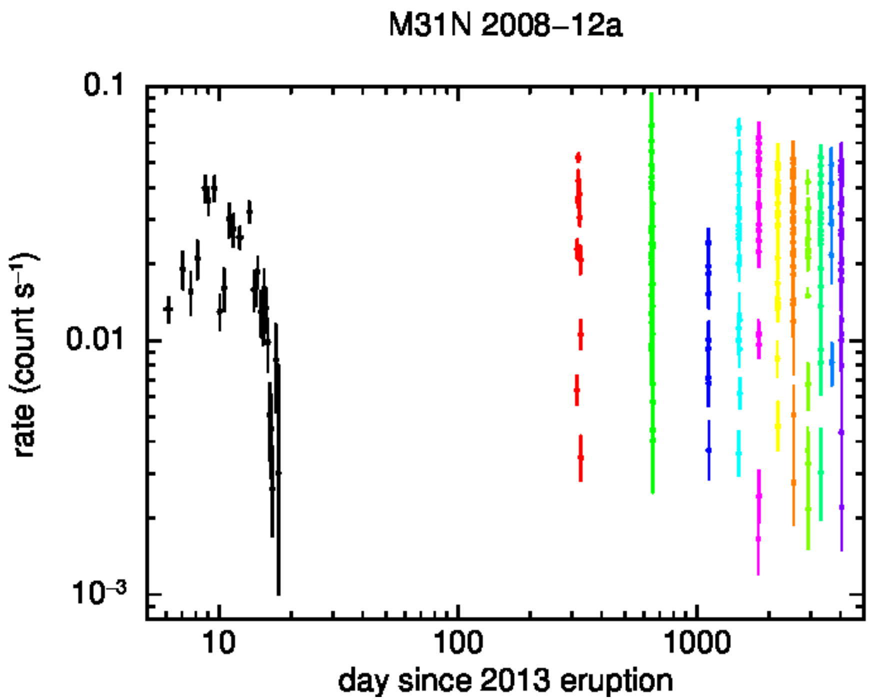
- 7 known nova eruptions.
- Last 3 eruption intervals were 5.2 yr, 4.3 yr and 4.2 yr.
- Light-curves basically identical where they overlap in time for 2016 and 2020; 2024 appears slightly brighter than 2020 between days 13 and 22.
- The spectral fits also appear remarkably similar, with BB temperatures following the same trends.

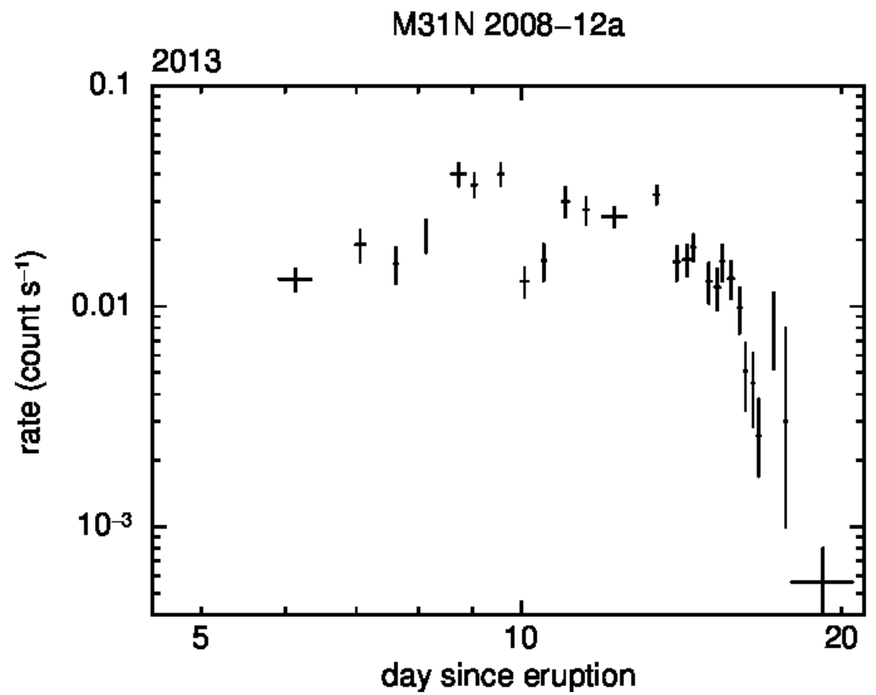
See also:

Kuin et al., 2020, MNRAS, 491, 655

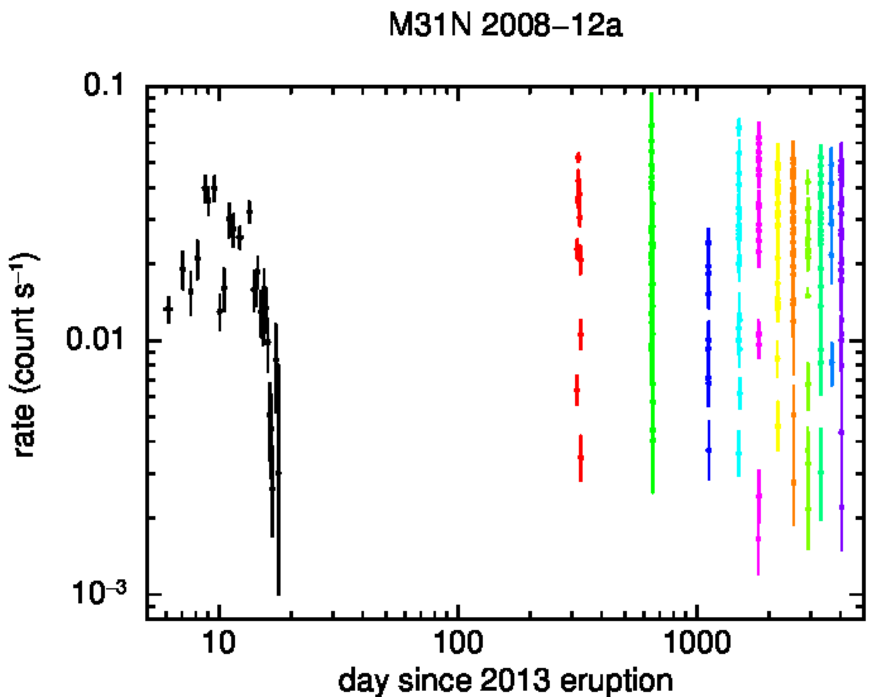
Schwarz, Page, Kuin & Darnley, 2020, RNAAS, 4, 142

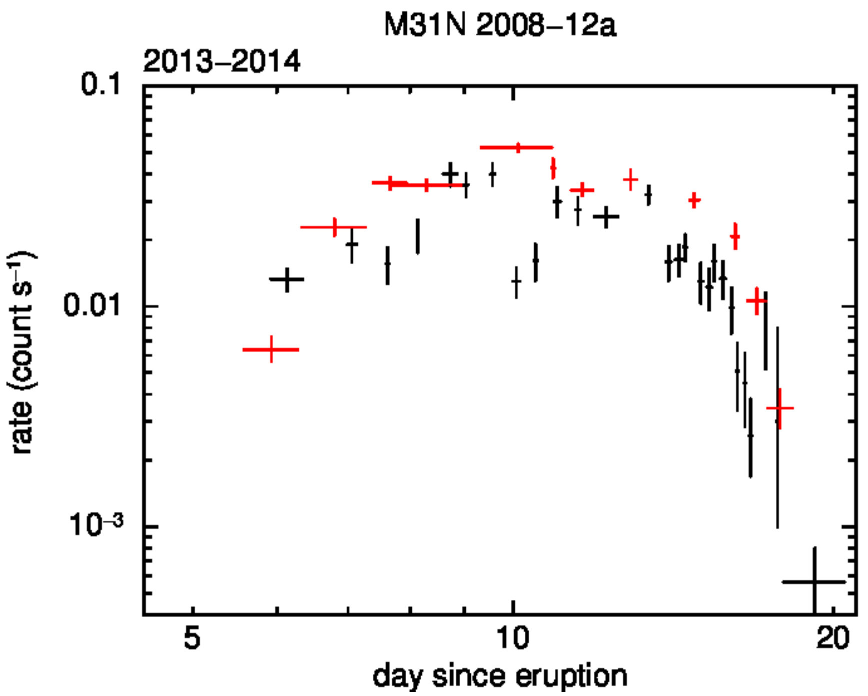
# M31N 2008-12a: 2013 - 2024



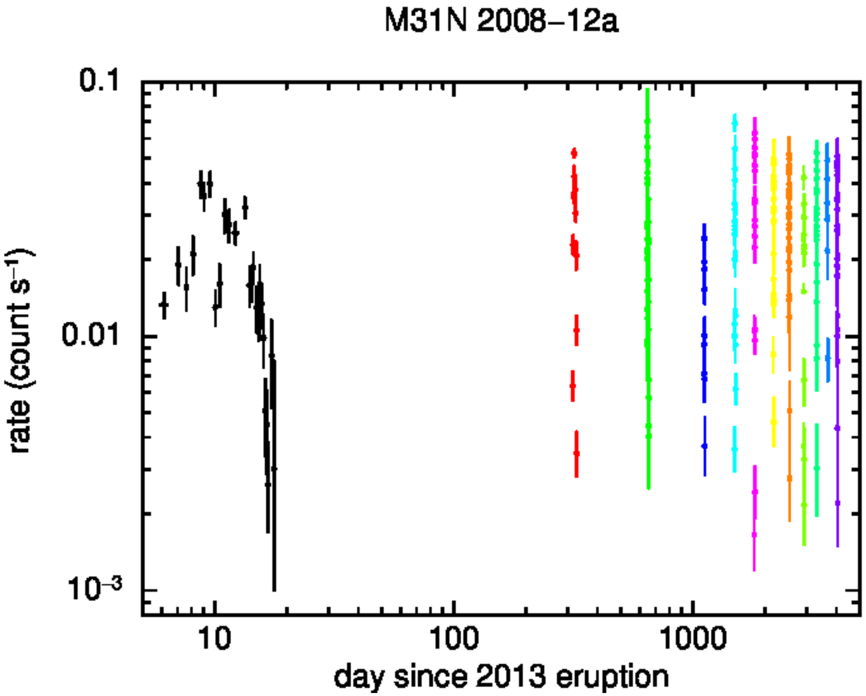



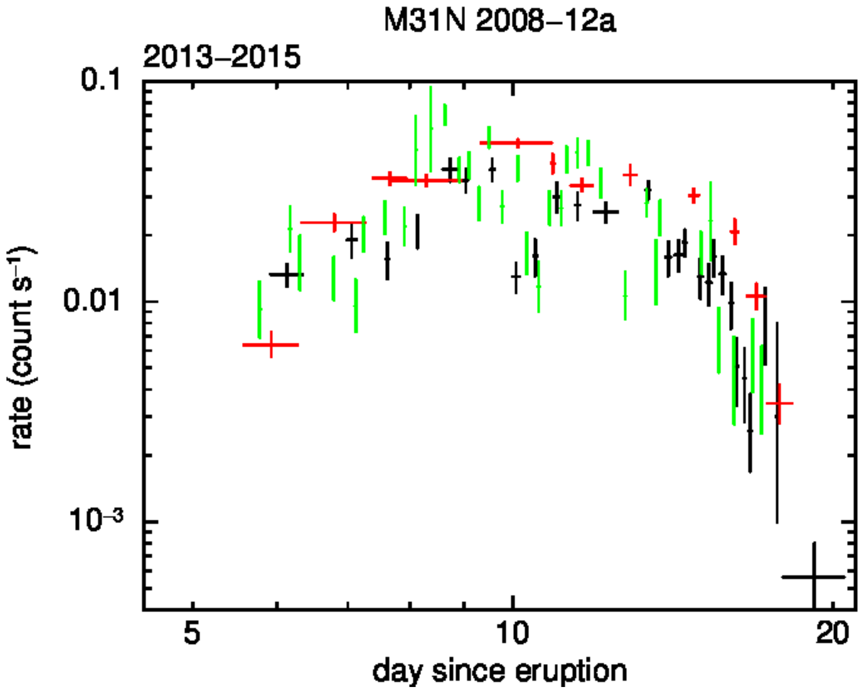
# M31N 2008-12a: 2013 - 2024



# M31N 2008-12a: 2013 - 2024



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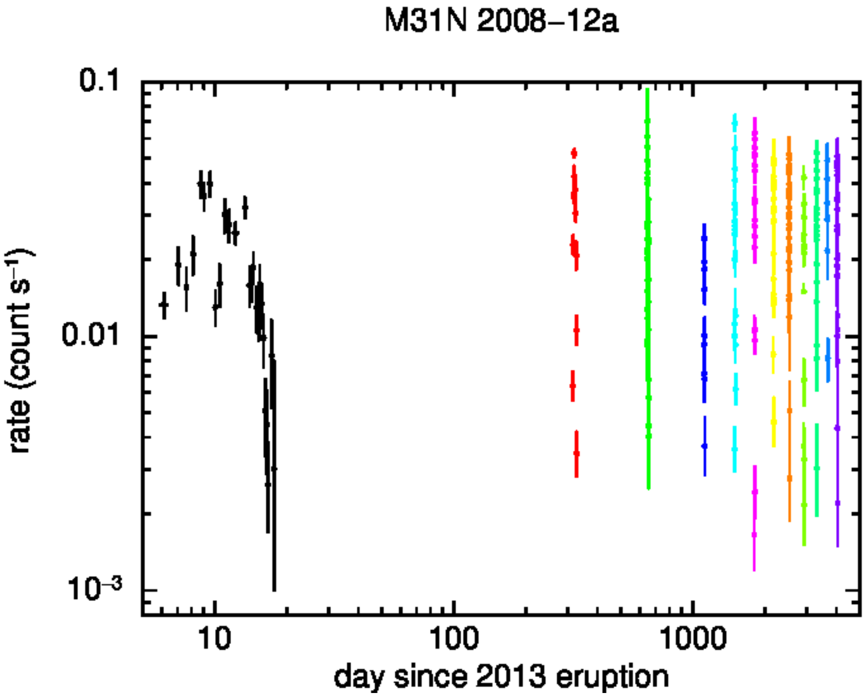
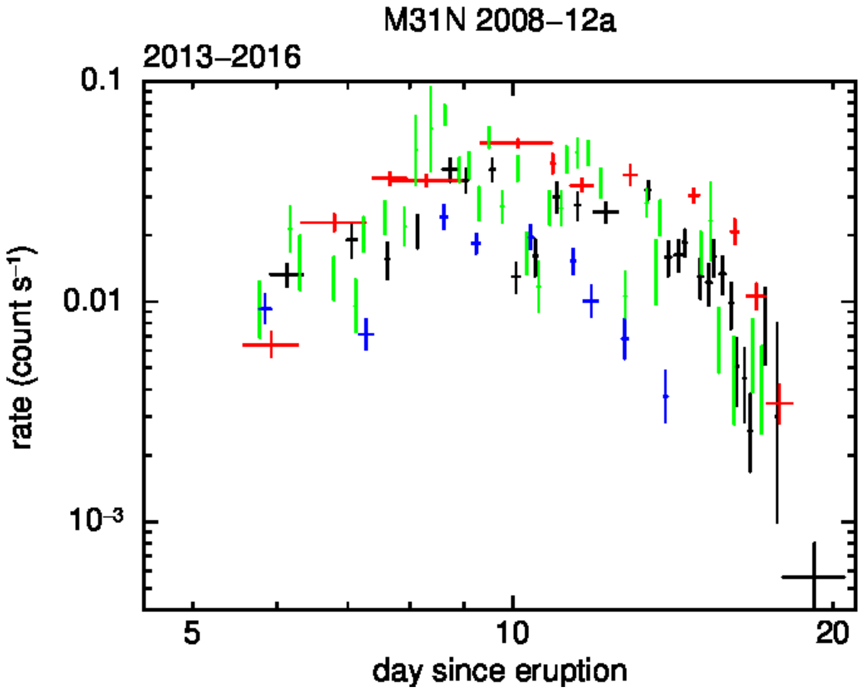
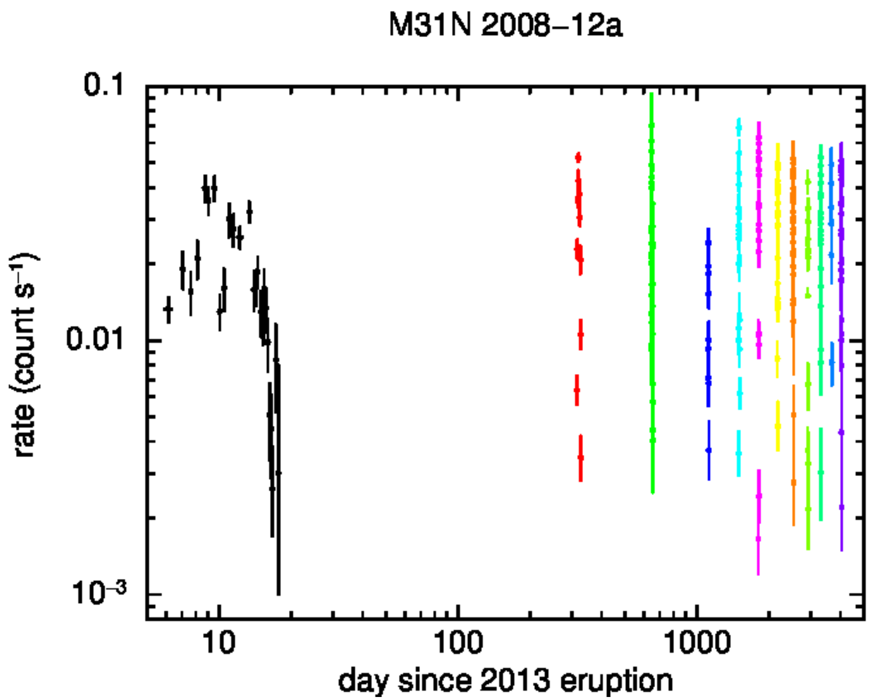
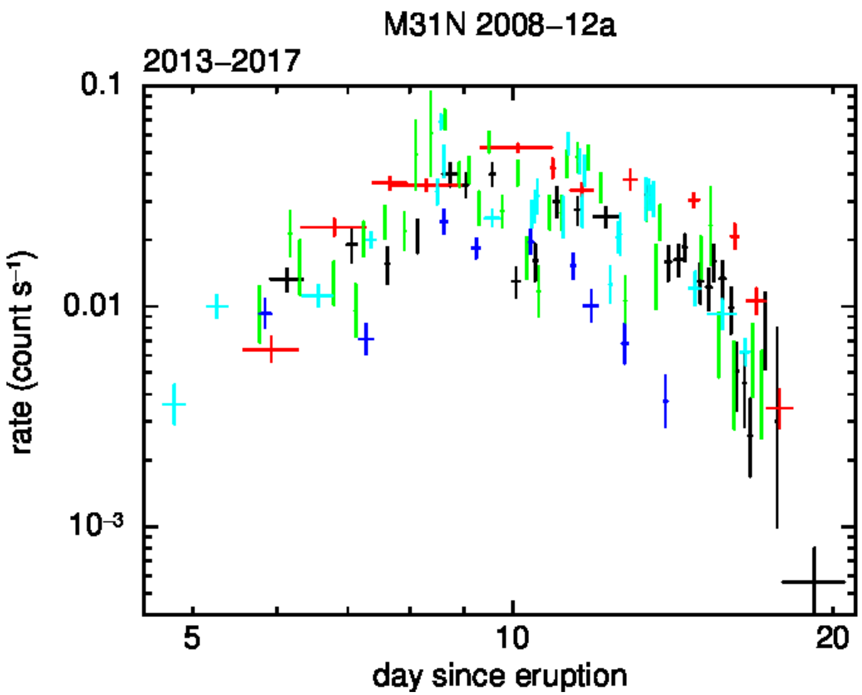



The 2016 eruption was notably different…

# M31N 2008-12a: 2013 - 2024



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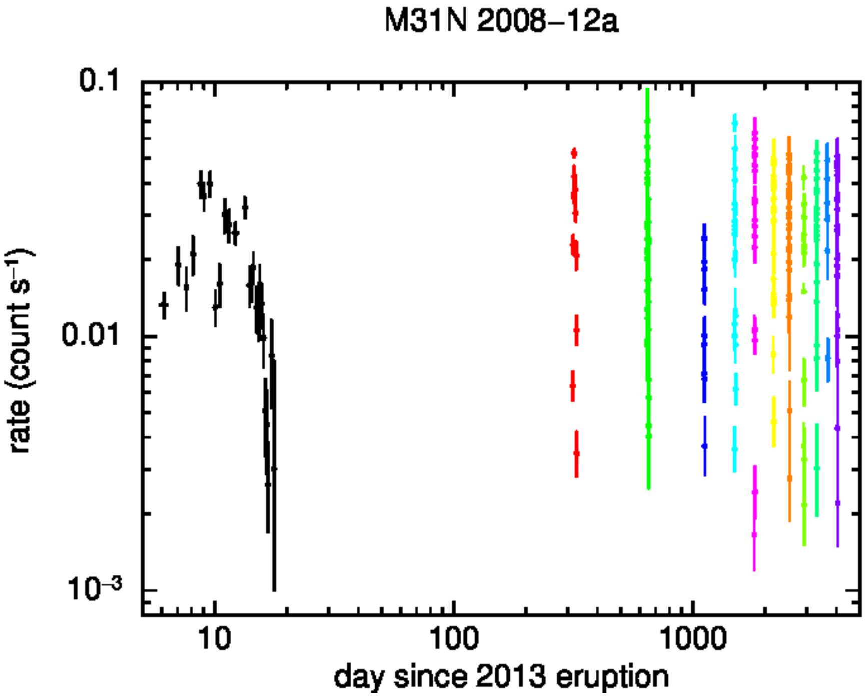


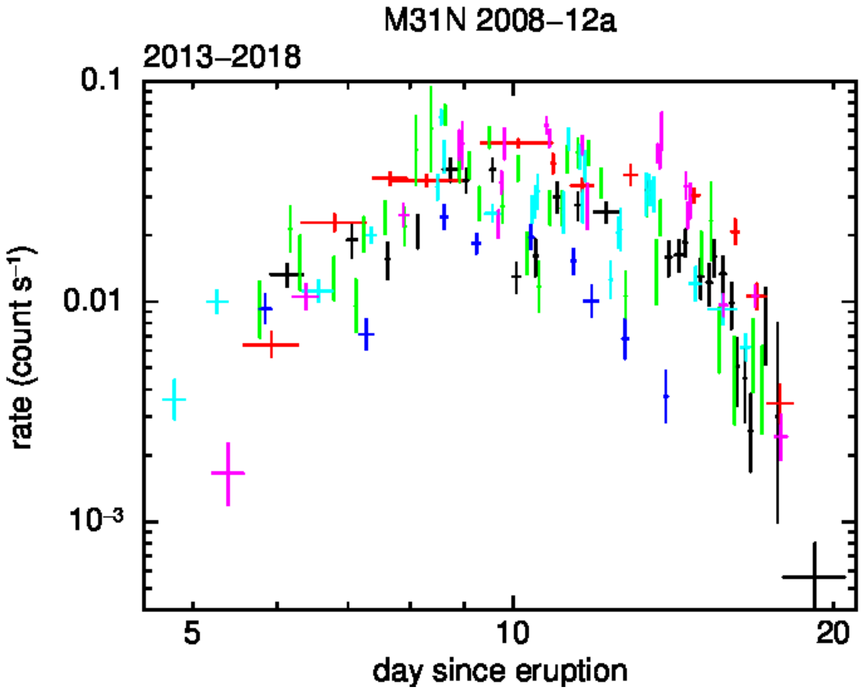

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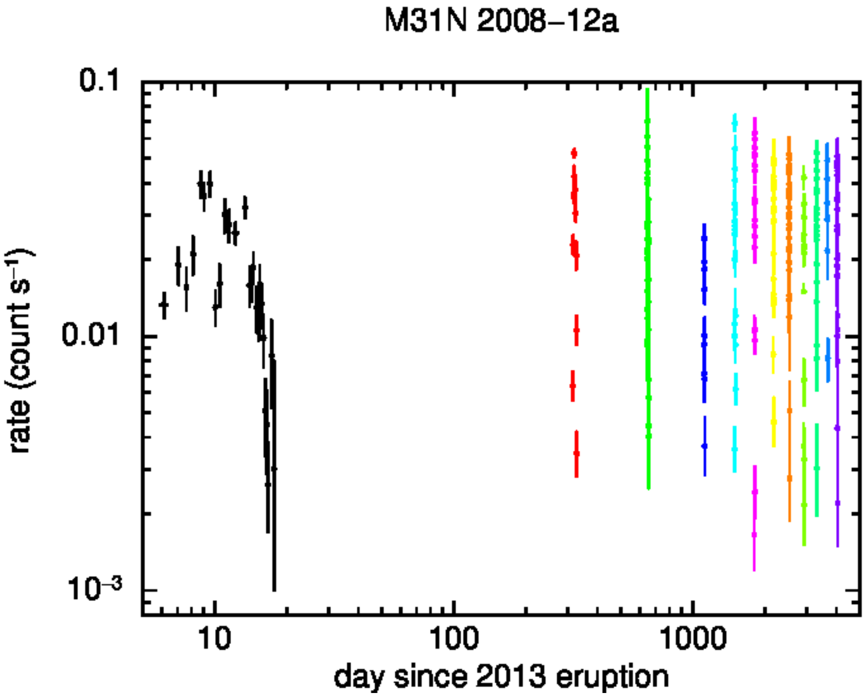


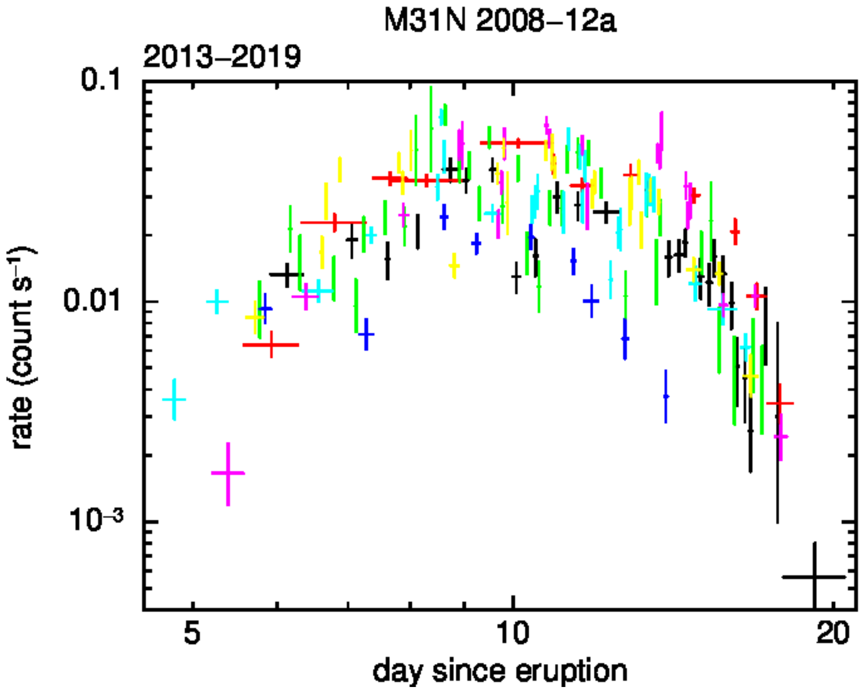

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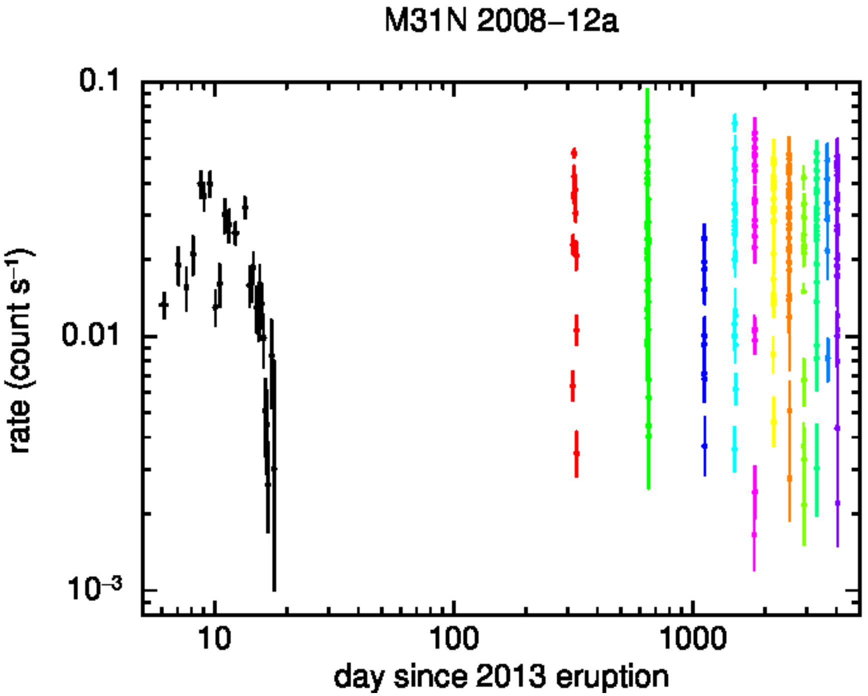


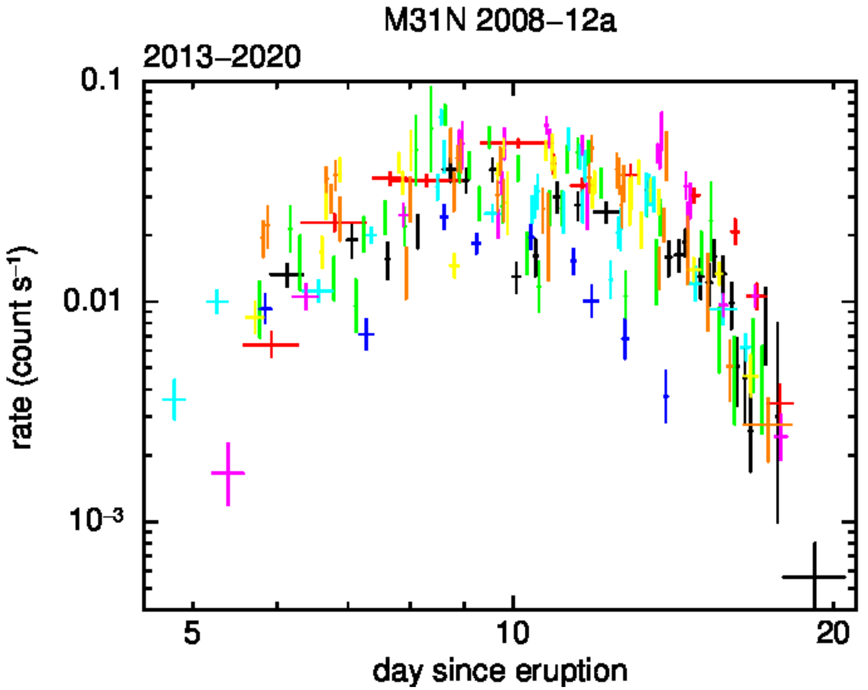

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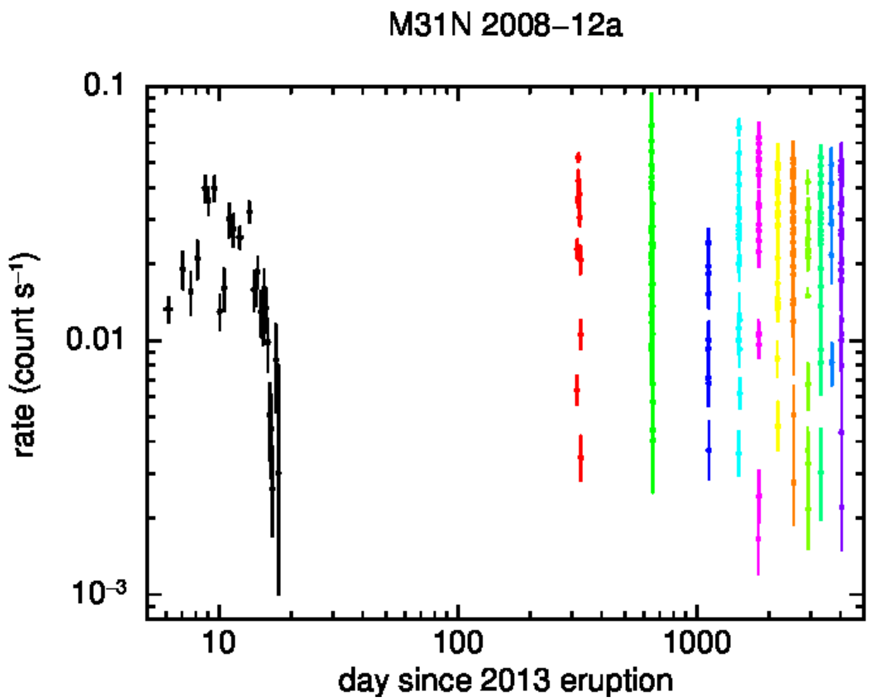
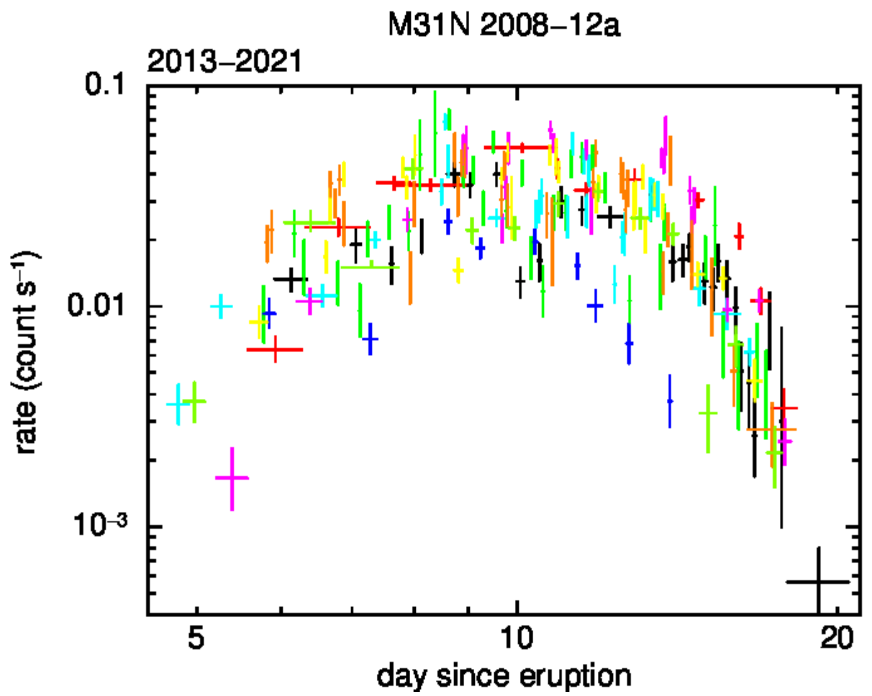
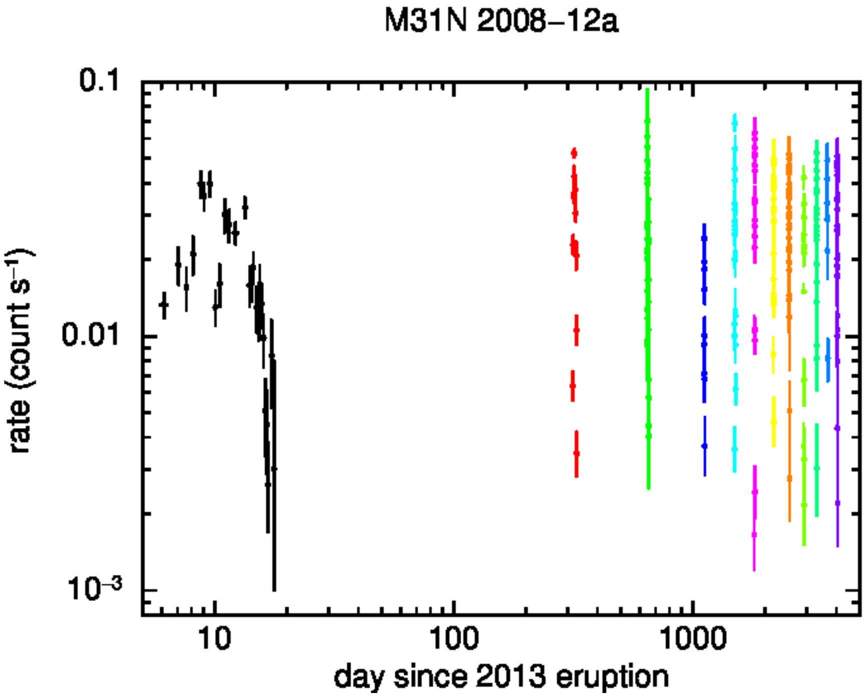
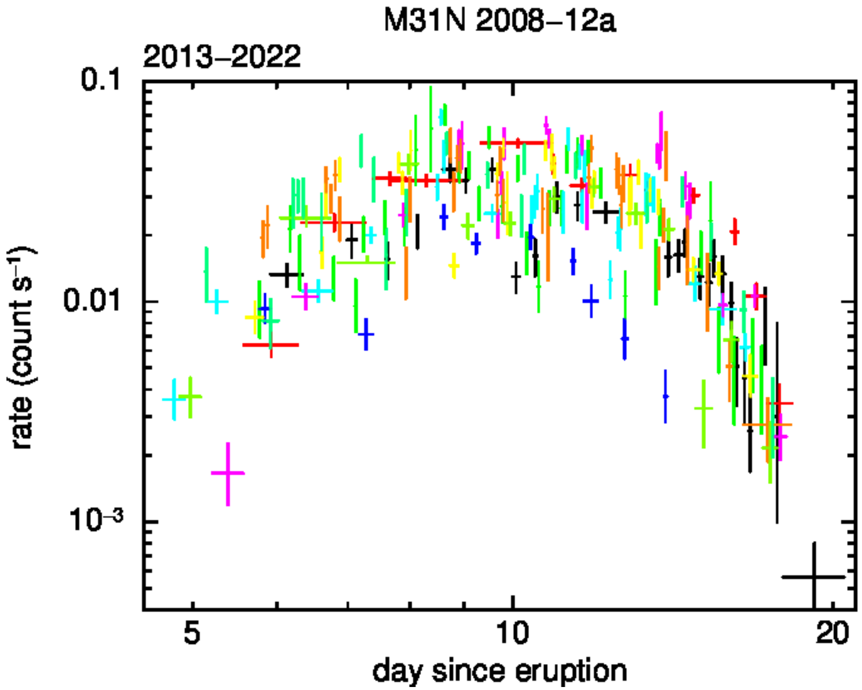


# M31N 2008-12a: 2013 - 2024



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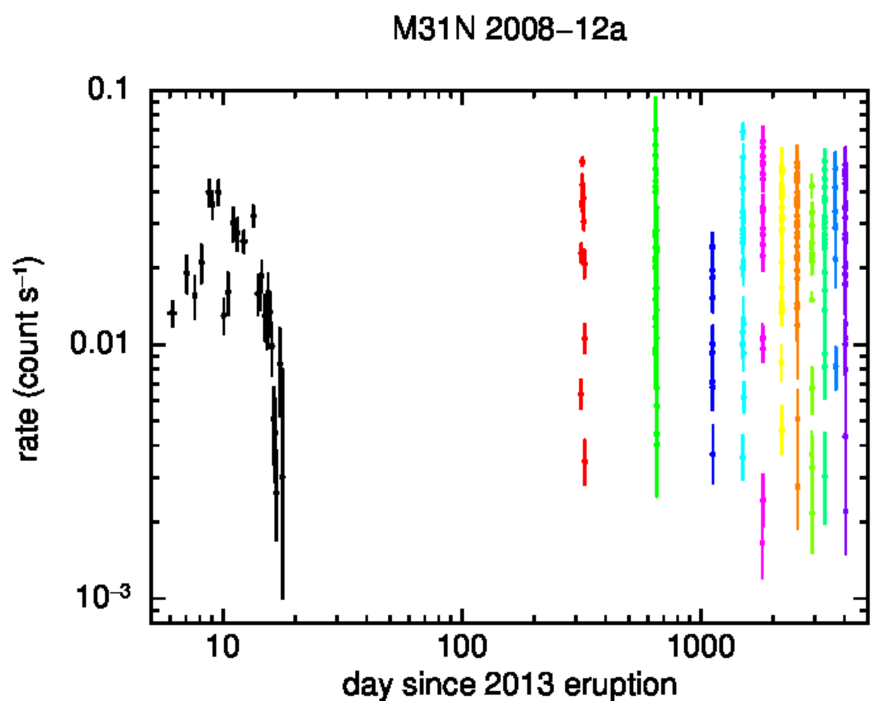


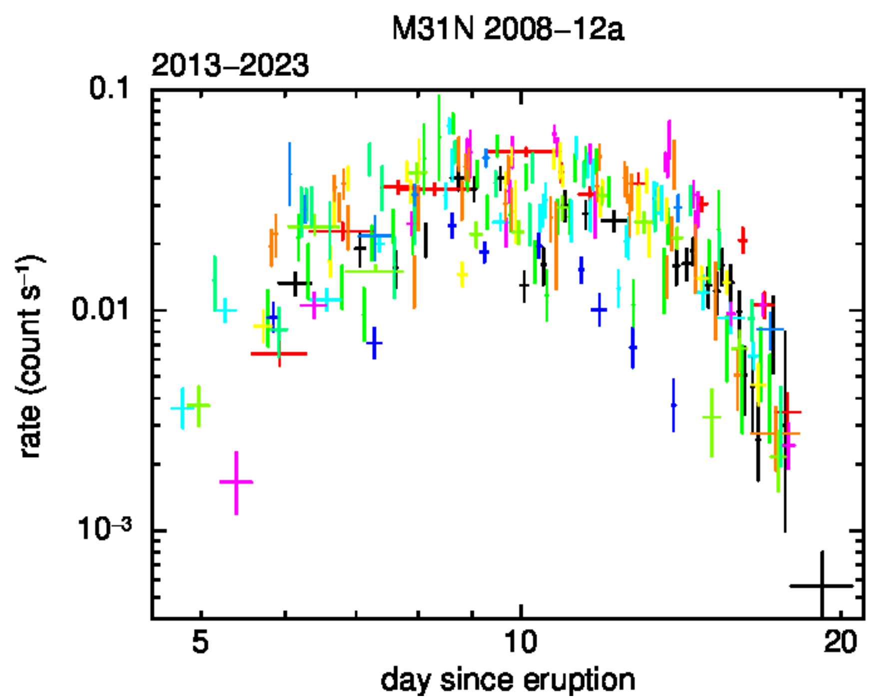

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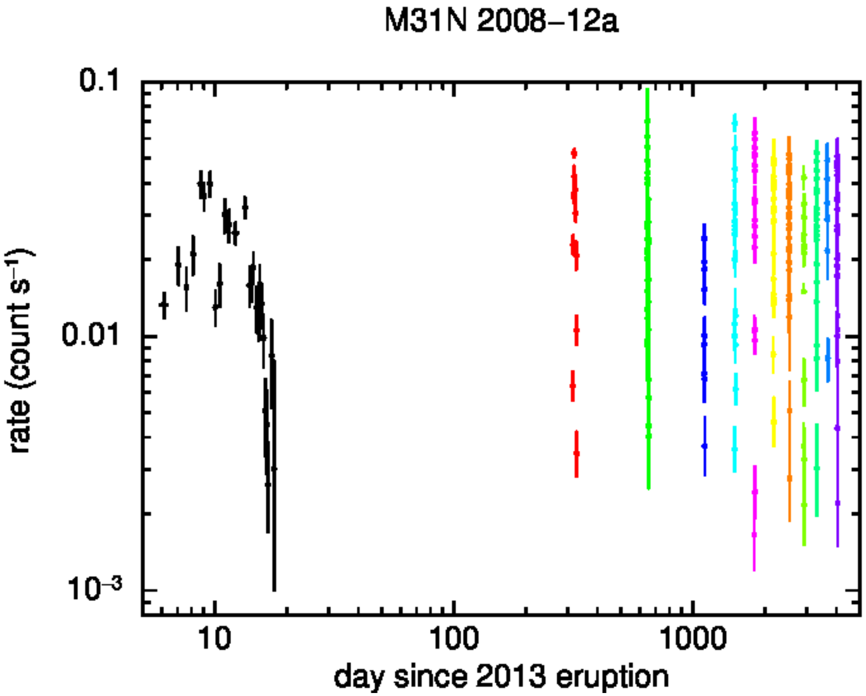


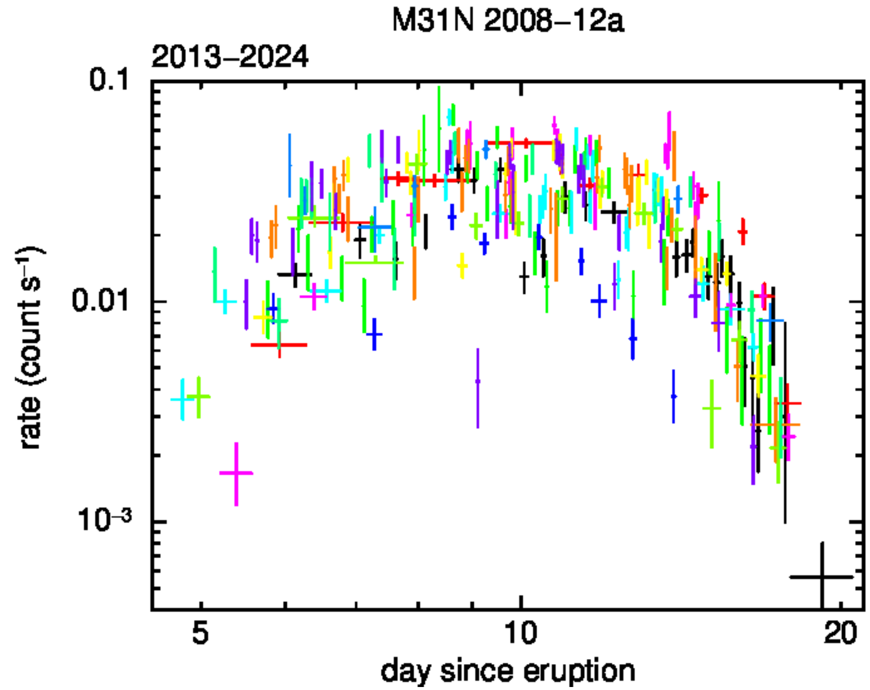

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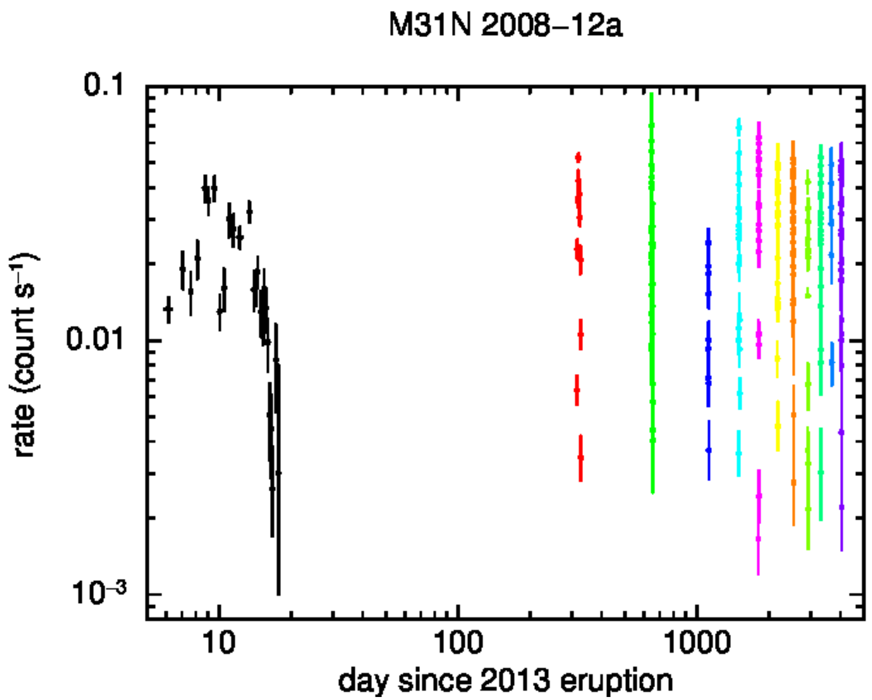
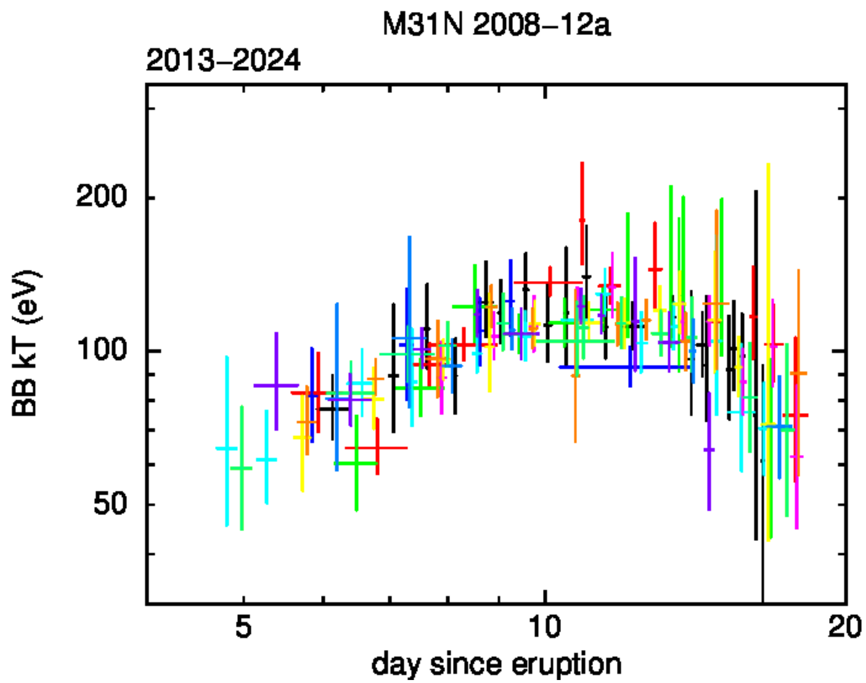



Fit details:

- Galactic $N_H$ ($7.0 \times 10^{20}$ $cm^{-2}$); no excess required.
- Fitting BB over 0.3-1.5 keV, since very few counts at higher energies.

# M31N 2008-12a Results

- 20 known nova eruptions (discovered in 2008, but 3 archival observations found in 1992, 1993, 2001)
- Eruptions occur yearly.
- Light-curves basically very similar, though 2016 was an outlier (delayed eruption, brighter optical peak mag, shorter SSS phase), and there was a brief dropout in 2024.
- The different effects in 2016 can be consistently caused by a lower accretion rate during quiescence (Henze et al. 2018).

See also:

Henze et al., 2018, ApJ, 857, 68
Darnley et al., 2017, ApJ, 849, 96
Darnley et al., 2016, ApJ, 833, 149
Kato et al., 2016, ApJ, 830, 40
Henze et al., 2015, A&A, 580, A46
Darnley et al., 2015, A&A, 580, A45
Henze et al., 2014, A&A, 563, L8

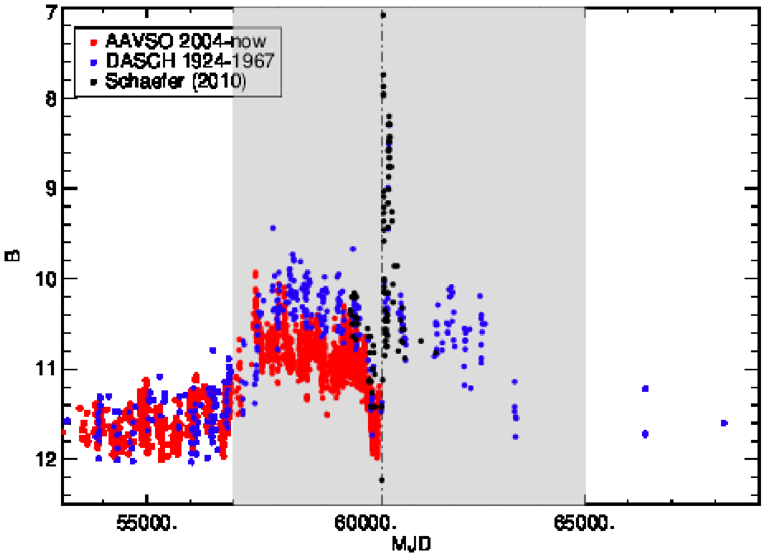
# Coming soon... (hopefully!)

T CrB!

Recurrence period of ~80 years, with the last eruption in 1946 (independently discovered by a 15yo schoolboy in Newport, South Wales!)
Expected to be one of the brightest novae seen (V~2 at peak – though fades quickly); it's nearby, < 1 kpc.

Previous nova outbursts have shown precursor activity around a decade before eruption, and in 2014, optical and X-ray observations showed changes consistent with an increase in accretion rate.
There was also a pre-eruption "dip" 1 year before the 1946 eruption, and a similar fading in March/April 2023 (2 years ago...)

We have been warned!




Credit: G.J.M. Luna

Examples of predictions:

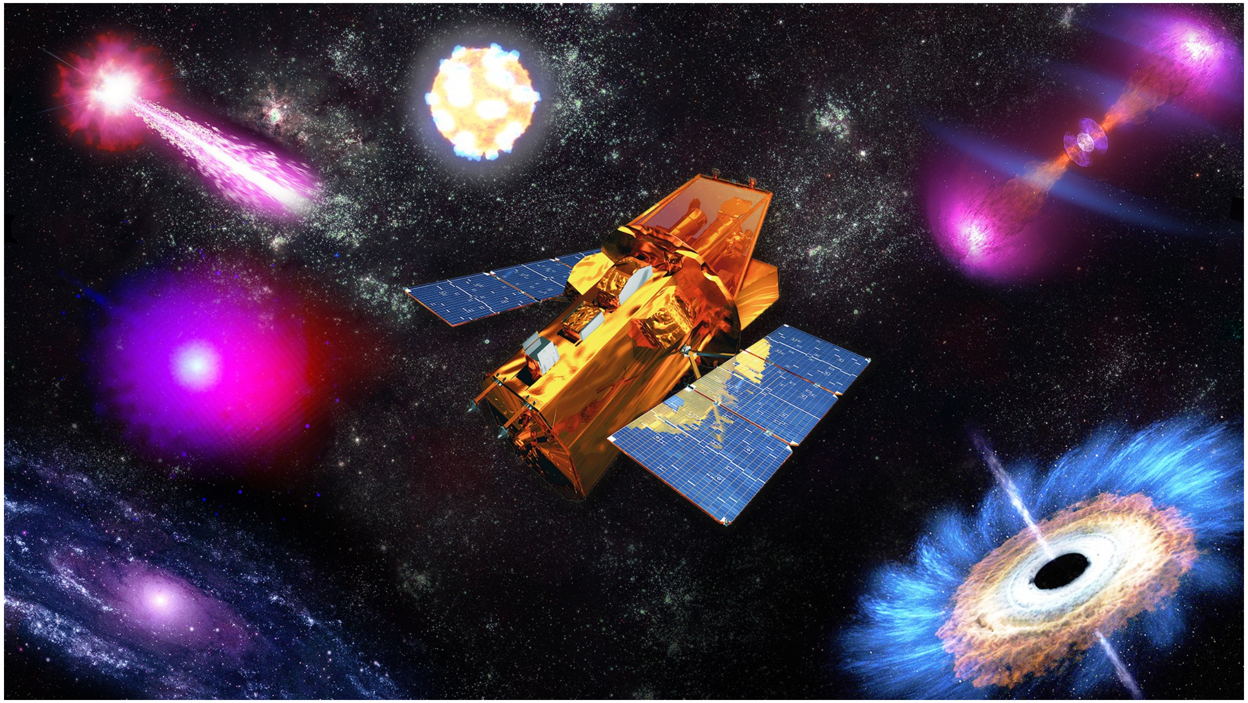
Schaefer (2023, MNRAS, 524, 3146): 2025.5 +/- 1.3 from change to high state
Schaefer et al. (2023, ATel 16107): 2024.4 +/- 0.3 from pre-eruption dip
Luna et al. (2020, ApJL, 902, L14): 2026 +/- 3

Sky At Night magazine: 2024 Feb-Sept
NASA article published June last year: by 2024 Sept. SVS page says "late 2024"
The Guardian in July last year: "just weeks or even days to go"

Schneider (2024, RNAAS, 8, 272): 2025 March 27 – ie tomorrow! (Also gives other quite exact dates, based on orbital period; an empirical extrapolation only)

# Finally

Being able to monitor any given nova through multiple eruptions using the same instruments is extremely helpful, since it avoids cross-calibration uncertainties.



Credit: NASA/GSFC