Early X- and HE γ-ray emission from the symbiotic recurrent novae V745 Sco & RS Oph

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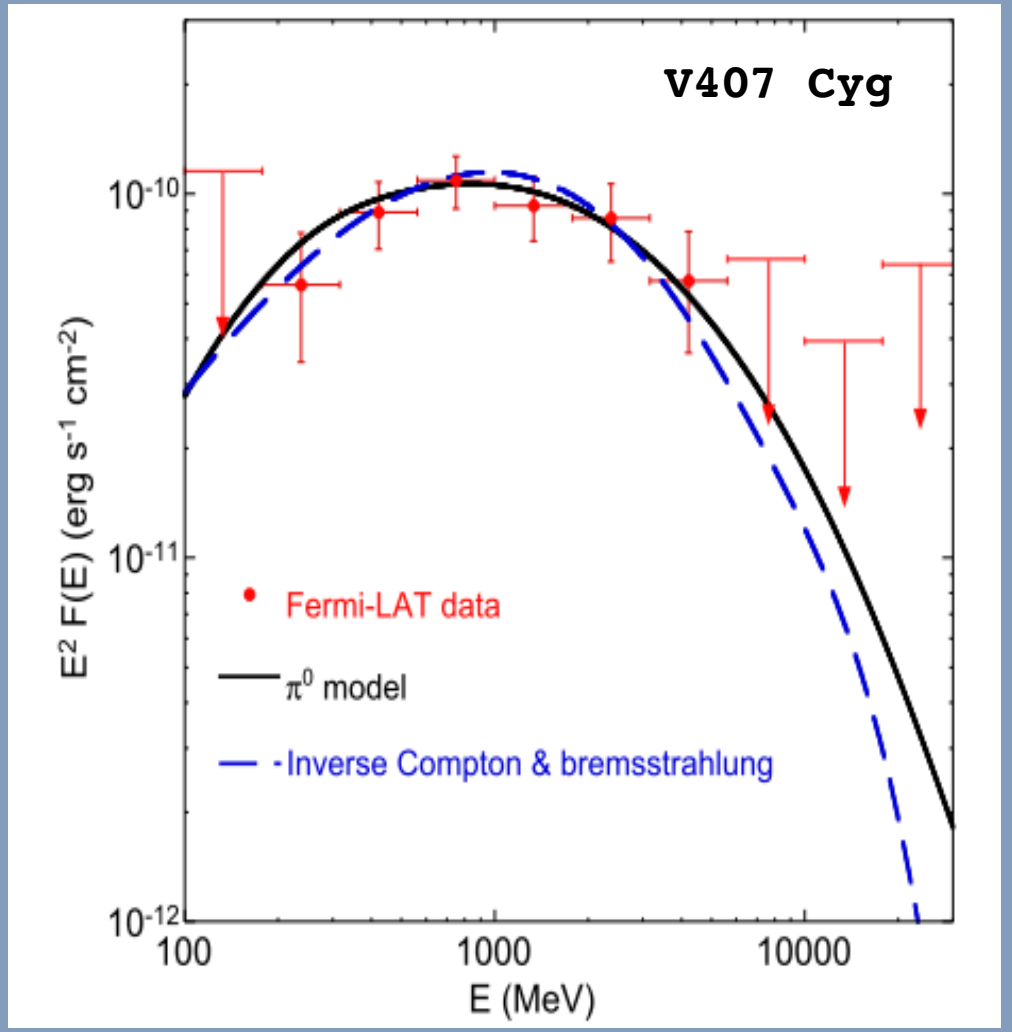
Early high-energy emission in Novae

Novae have been detected at E~GeV suggesting that particles are accelerated to relativistic energies by strong shocks

- **Recurrent Novae:** External shocks between ejecta and dense red giant wind
- **Classical Novae:** Internal shocks within the nova. Mechanism is not well understood
- **IC** (leptonic) or **π^0 decay** (hadronic) (E>100 MeV)

This emission has been detected in 10 Novae by Fermi

- ★ **Classical Novae**: V1324 Sco (2012), V959 Mon (2012), V339 Del (2013), V1369 Cen (2013) , V5668 Sgr (2015), Nova Lup (2016), V5855 Sgr (2016) and ASASSN-16ma (2016)
- ★ **Recurrent Novae**: V407 Cyg (2010), V745 Sco (2014) and (RS Oph (2006))



The Fermi-LAT collaboration (2014)

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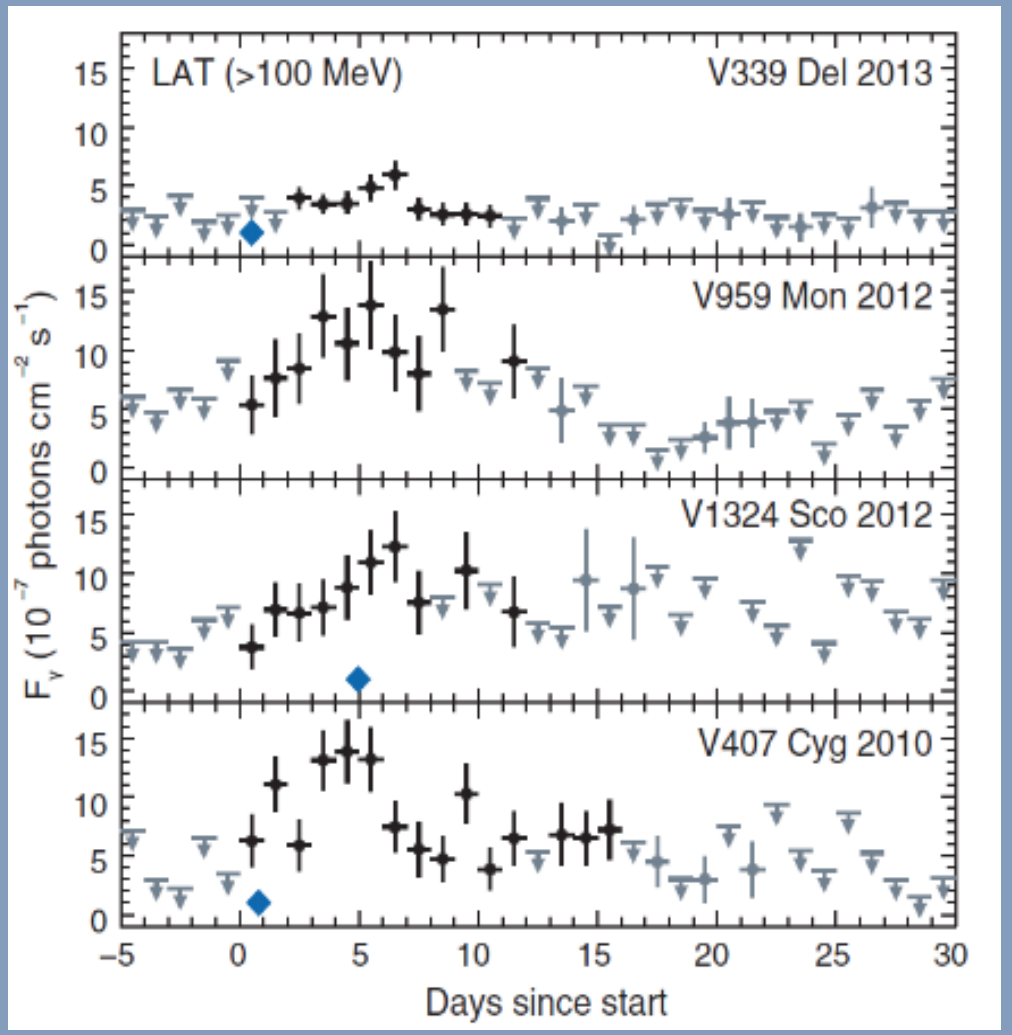

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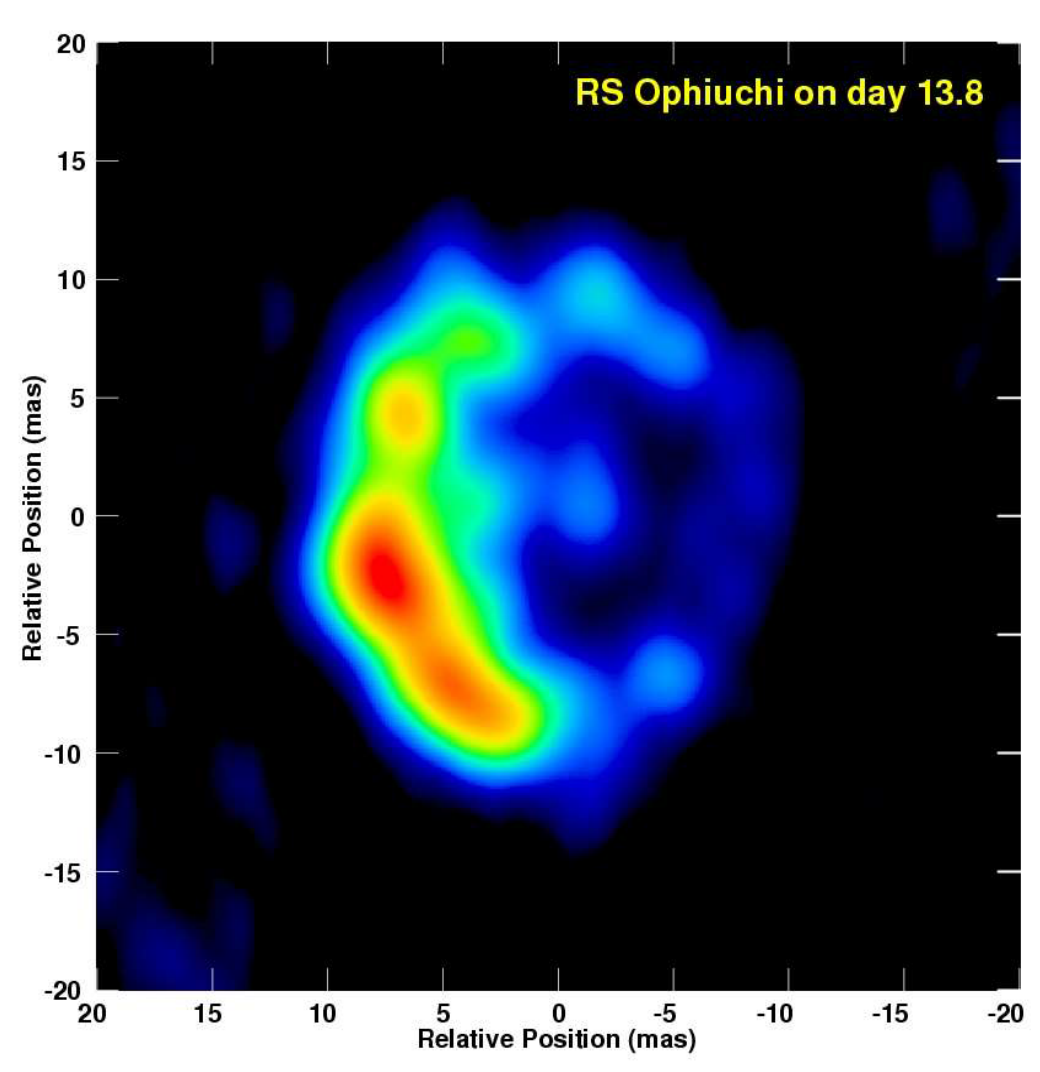
RS Oph



O'Brien et al. (2006)

"Miniature SN remnant"

- Evolving much faster and much dimmer
- Study of cosmic ray acceleration in a blast wave

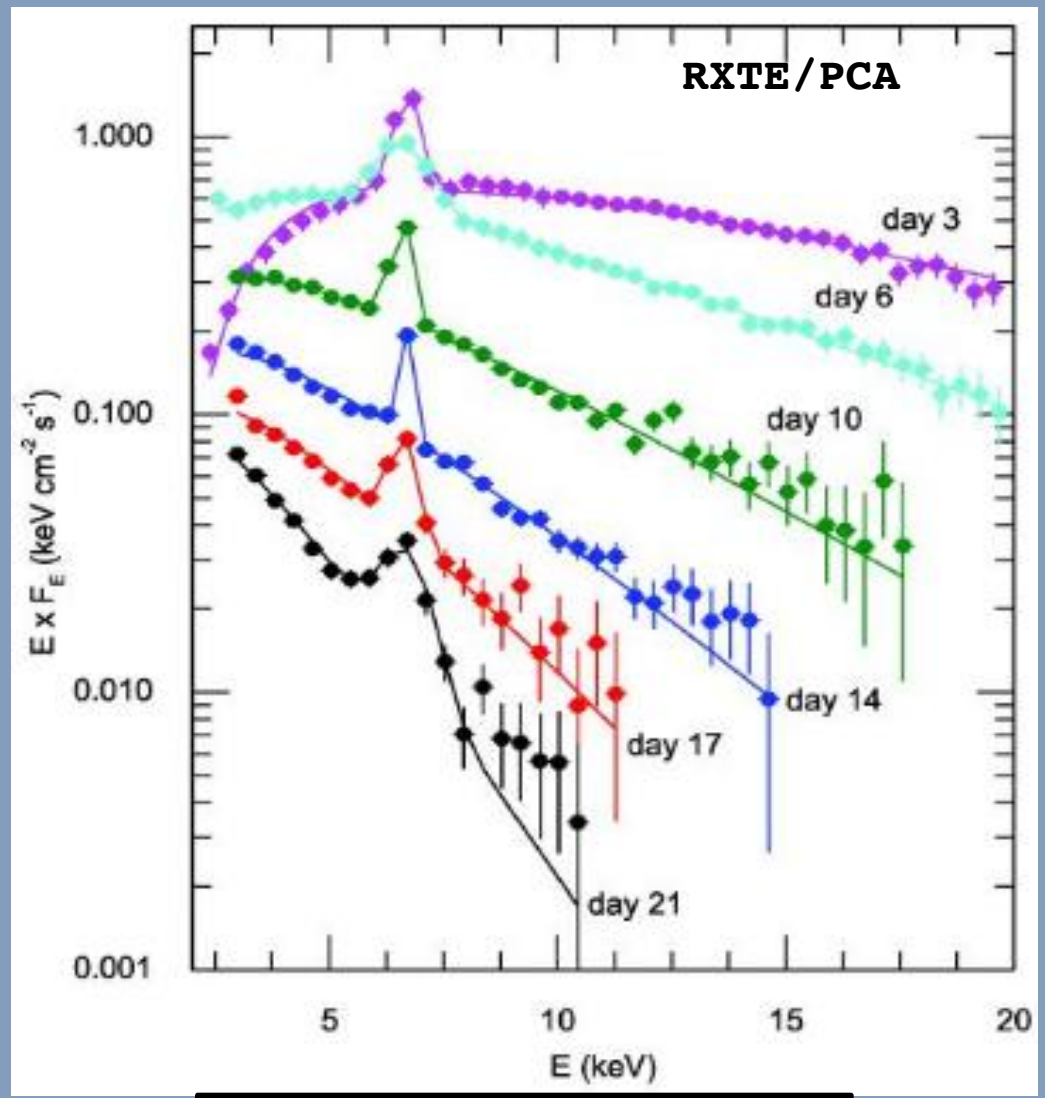
Characteristics

- WD + RG (M2III)
- $P_{orbital}$ = 456 days
- Distance ≈ 1.6 kpc
- Recurrent nova. P_{rec} ≈ 20 years
- Outbursts: 1898, 1933, 1958, 1967, 1985 and 2006

2006 Outburst - Observations of Shocks

Early hard X-ray emission:
Shock between ejecta and red giant wind

- RXTE: Temperature of 10 keV (Sokoloski et al.2006)
- Detection with Swift/BAT and XRT (Bode et al. 2006)
- The shock wave decelerated faster than expected (Tatischeff & Hernanz 2007)
  - Acceleration of particles in the shock. The accelerated particles escape.
  - Test-particle strong shock: $v_s=(16kT_s/3\mu m_H)^{0.5}$. Underestimate v_s when particle acceleration is efficient
  - V_{shock}(X-ray)< V_{shock} (IR)
  - RS Oph would have been detected by Fermi



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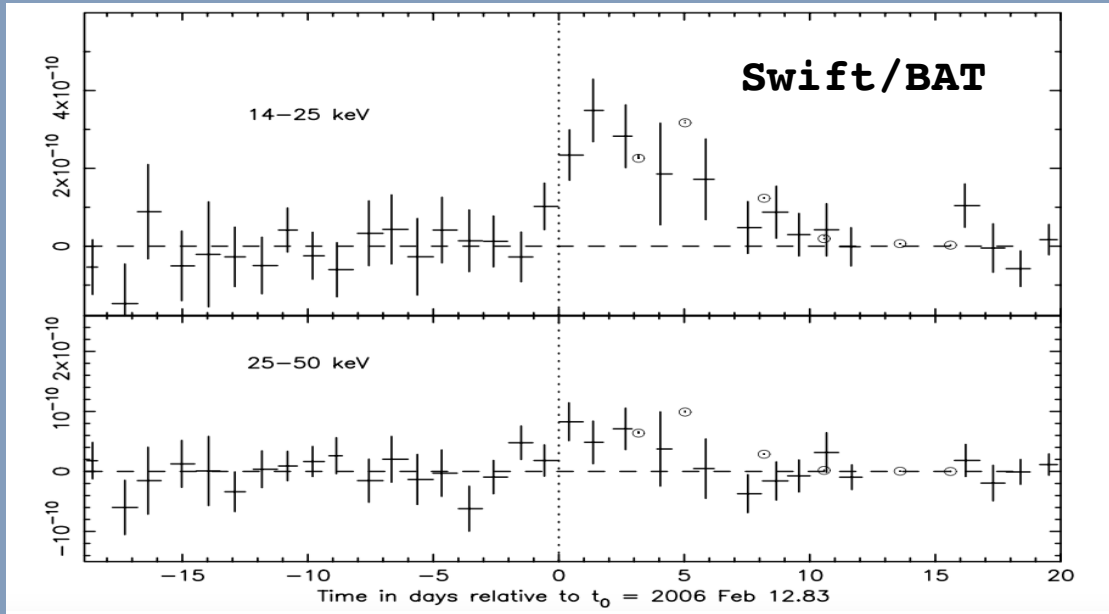

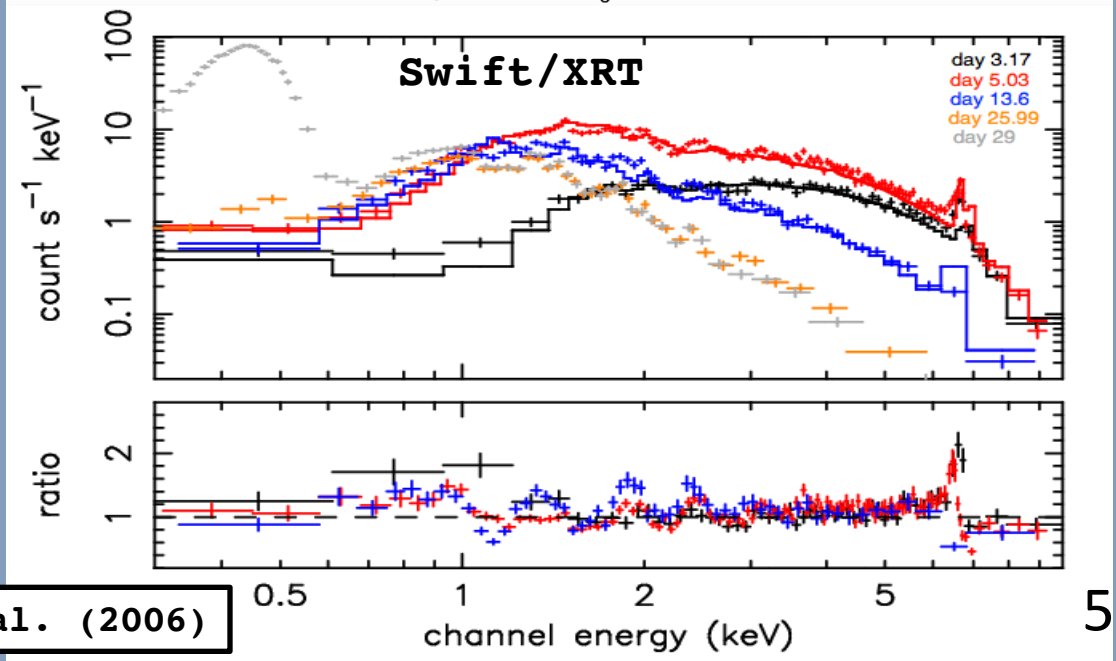

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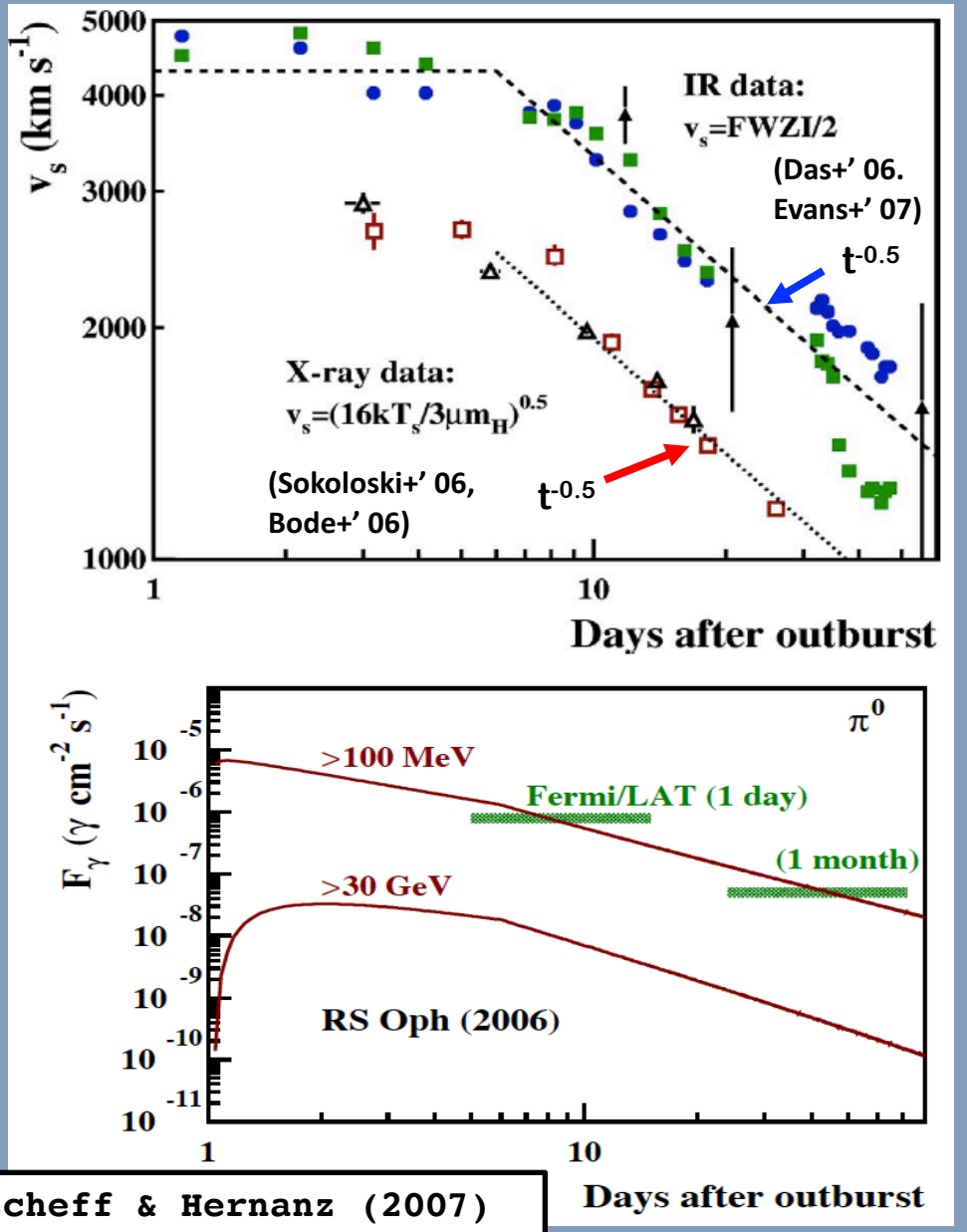
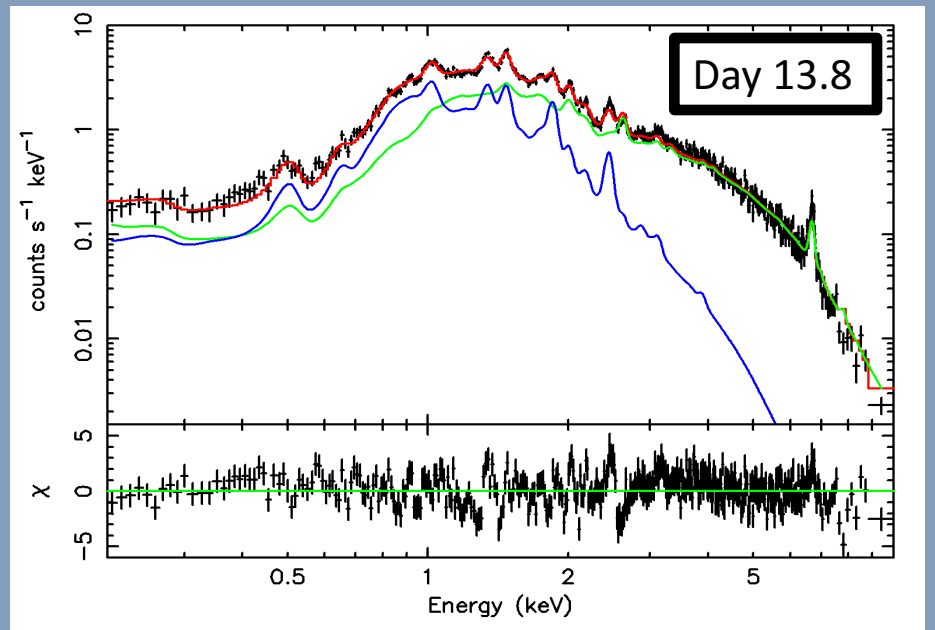
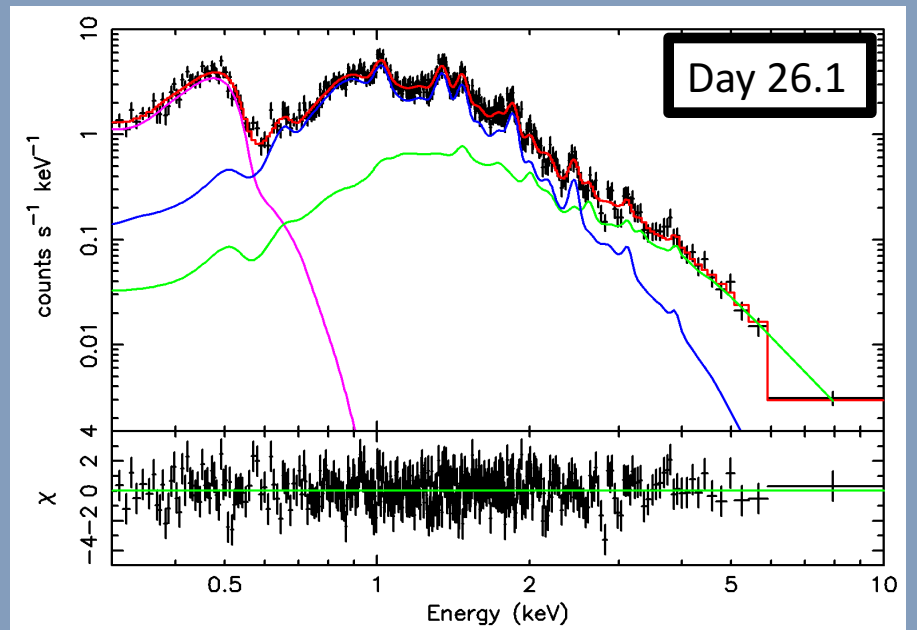


Tatischeff & Hernanz (2007)

RS Oph: XMM -Newton

- Day 13.8 & 26.1 after outburst
  - Collisionally ionized plasma with 2 temperatures (T_{high} and T_{low})
- Day 26: Hot WD photosphere starts to be seen (T_{bb} ~10^5 -10^6 K)
- **Temperature evolution crucial for the understanding of particle acceleration**





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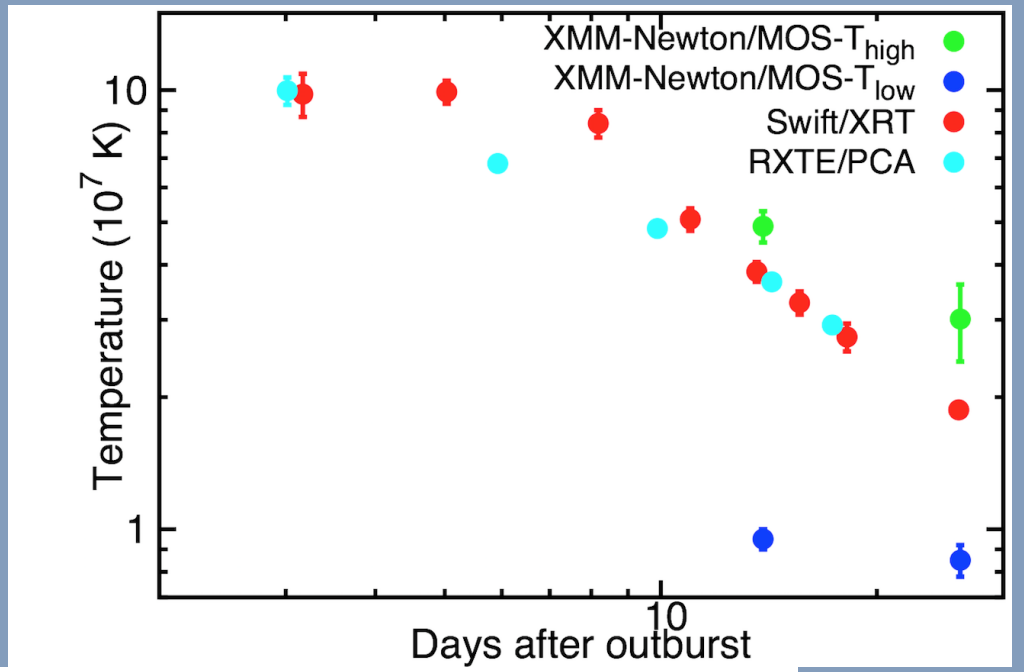
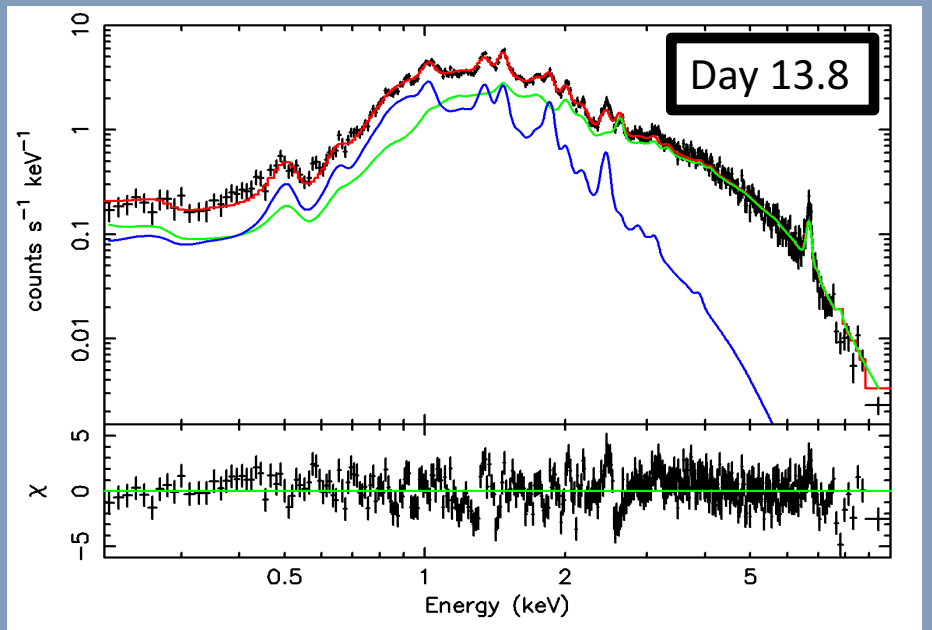
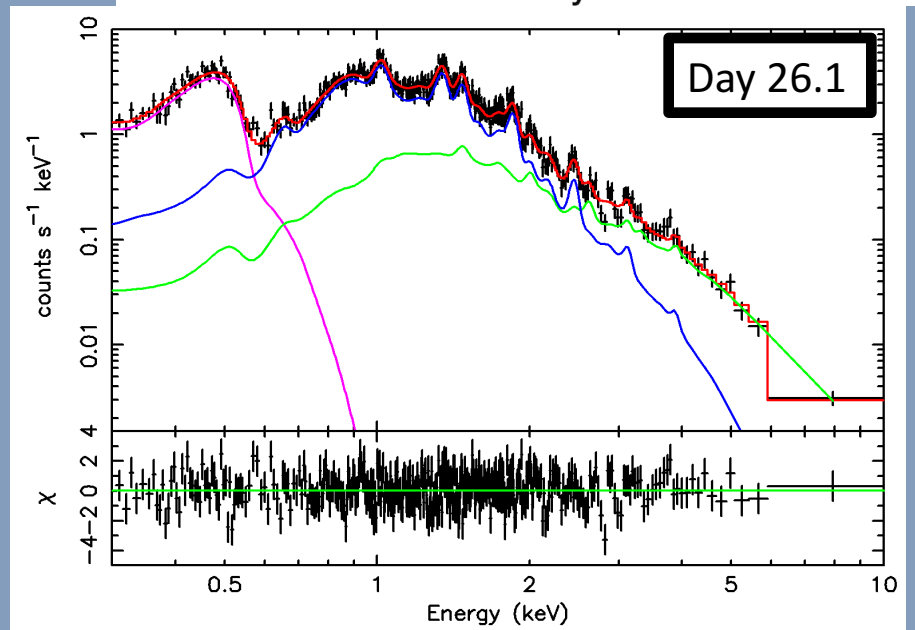


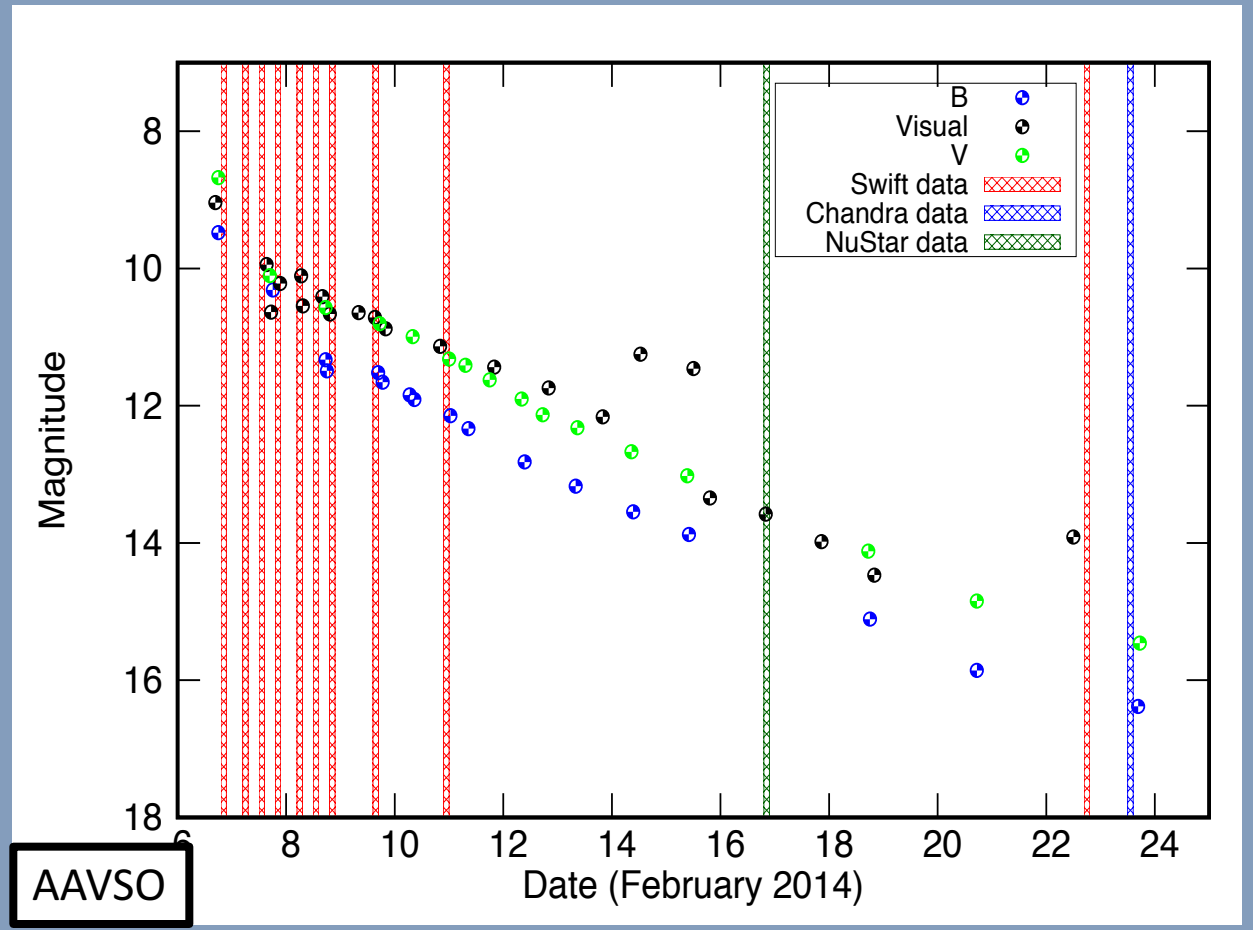




V745 Sco

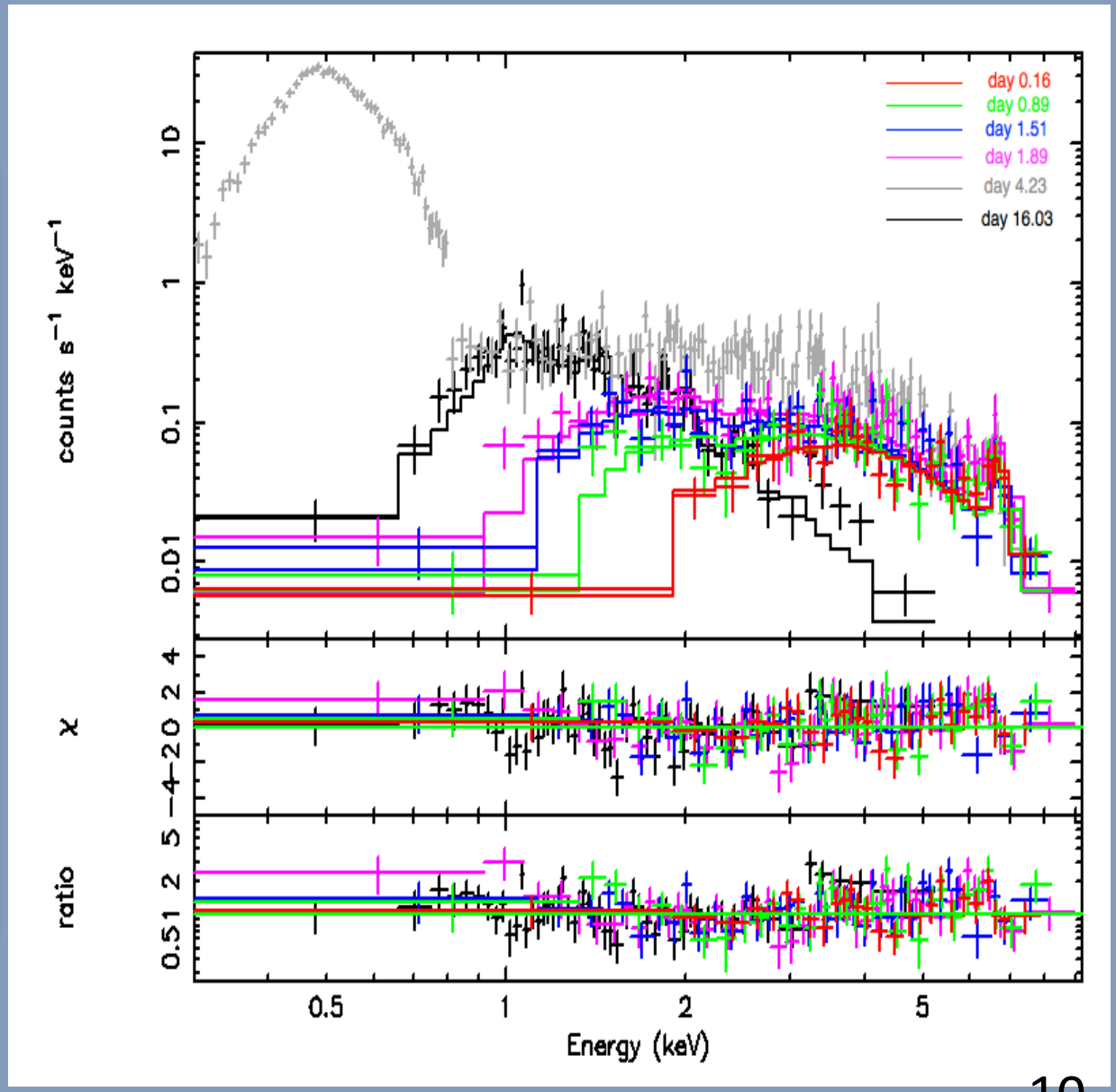
Characteristics

- WD + RG (M6III)
- $P_{orbital}$ ≈ 510 days
- Distance ≈ 7.8 kpc.
- Recurrent nova. P_{rec} ≈ 25 years
- Outbursts: 1937, 1989 and 2014
- t_3=7 days & V_{max}= 9 mag
- Very fast and very faint



V745 Sco

- **Fermi** detection 1st day after outburst: F(E>100 MeV) ≈ 3 x10^{-7} ph/cm^2 s. Upper limit 4 days later
- Detection with **Swift/XRT**, not with **Swift/BAT.** Temporal evolution. Hard X-ray emission. Shock between the ejecta and the RG wind
- Detection by **NuStar.** Plasma temperature 2.6 keV. 10 days after outburst
- **Chandra** observation after SSS turns off



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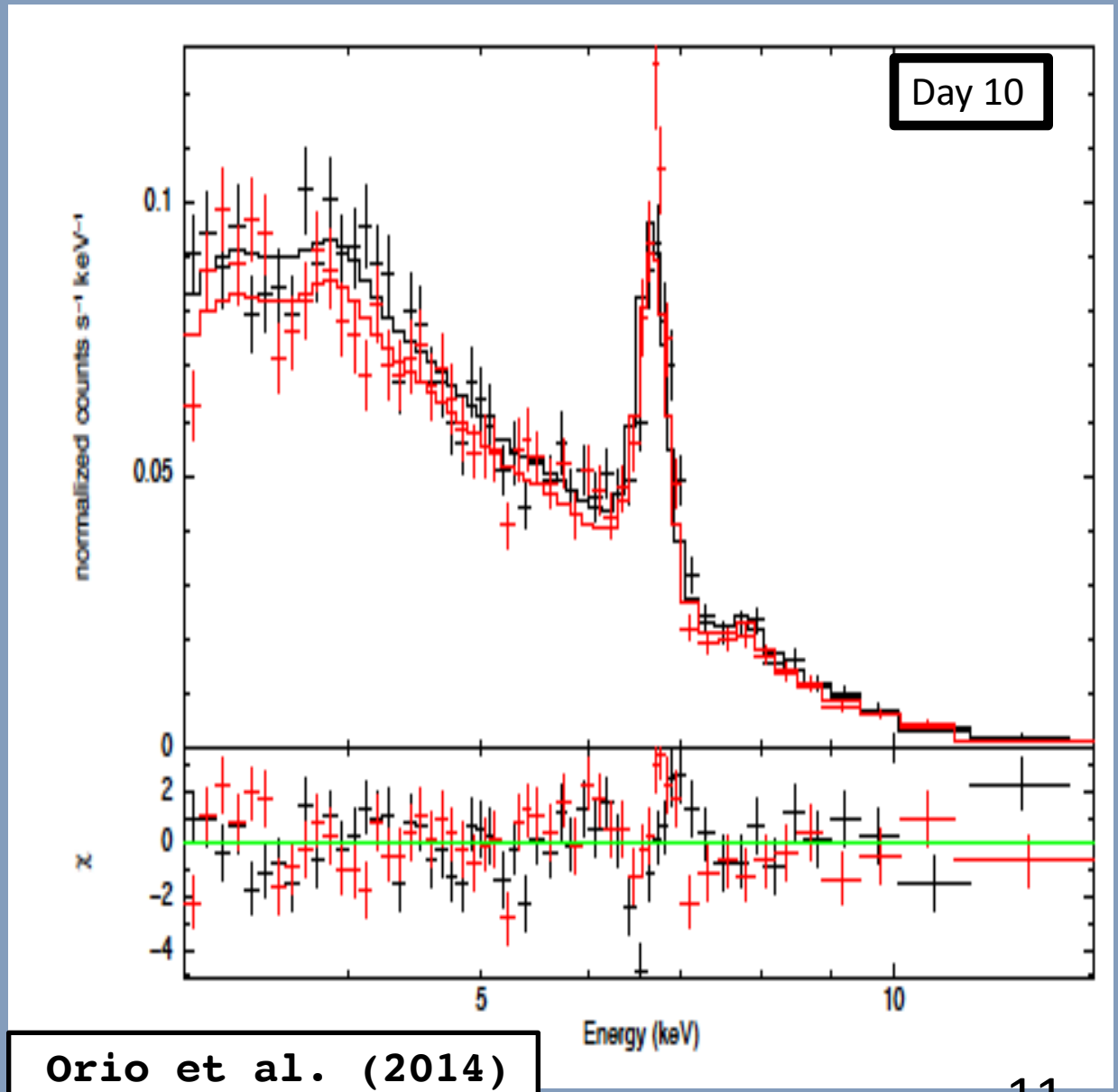

Orio et al. (2014)

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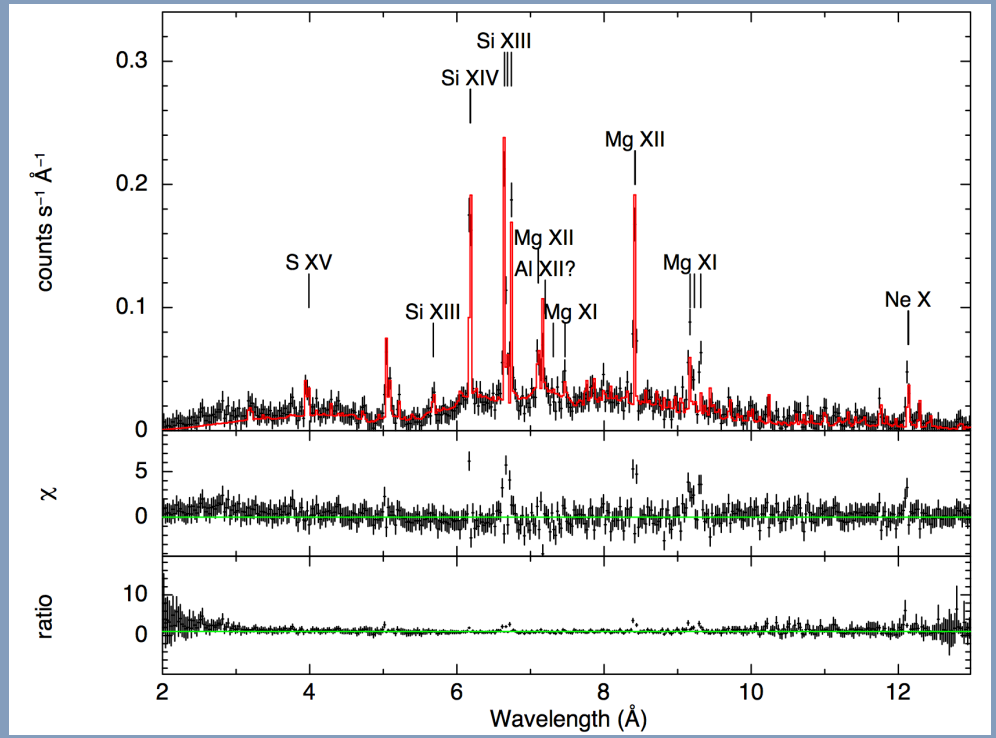

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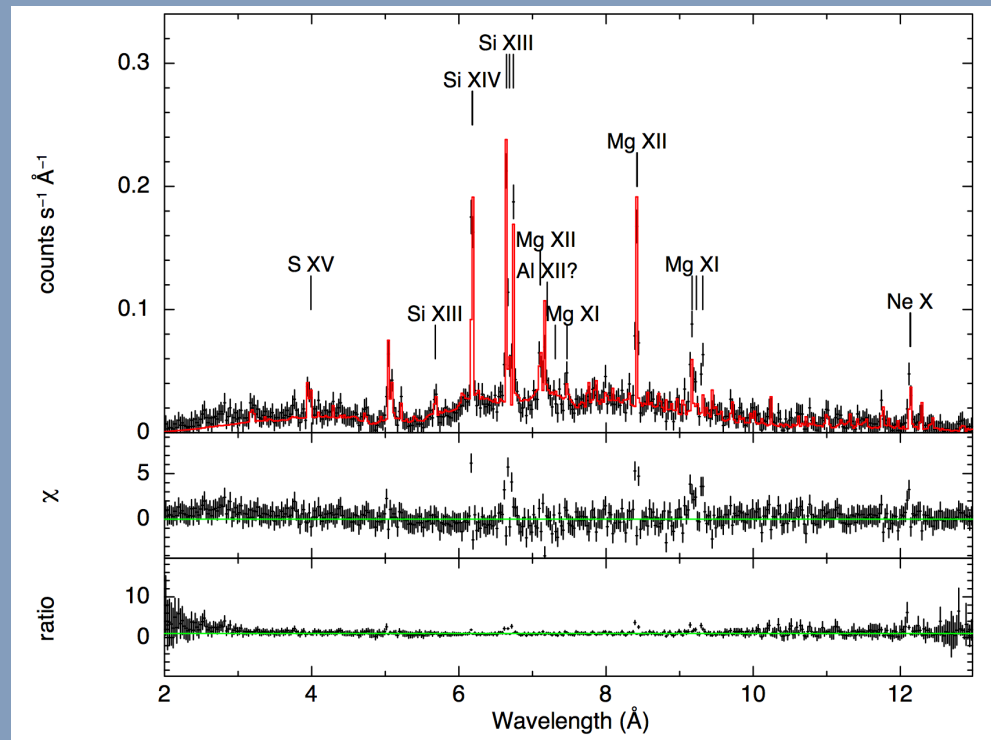
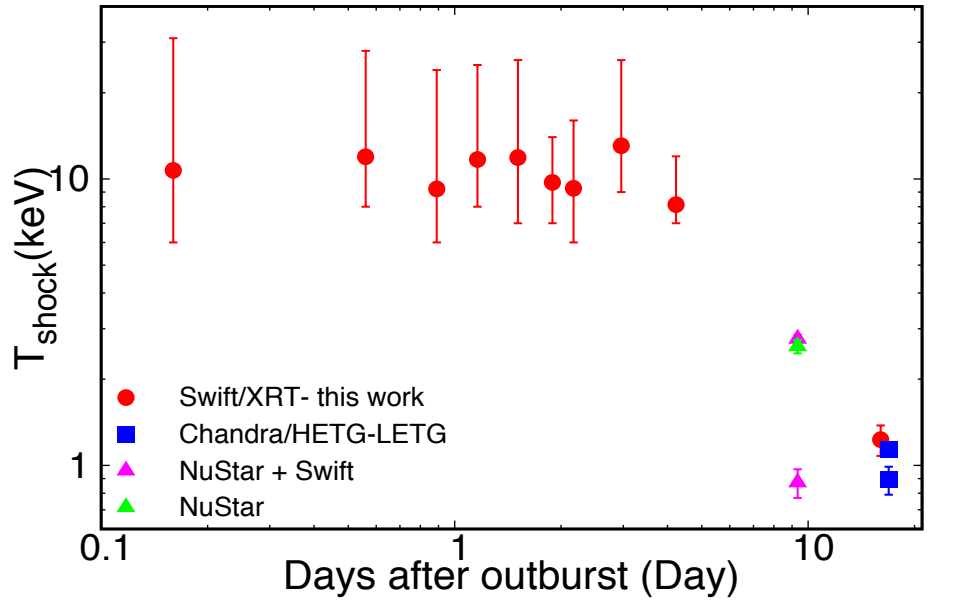
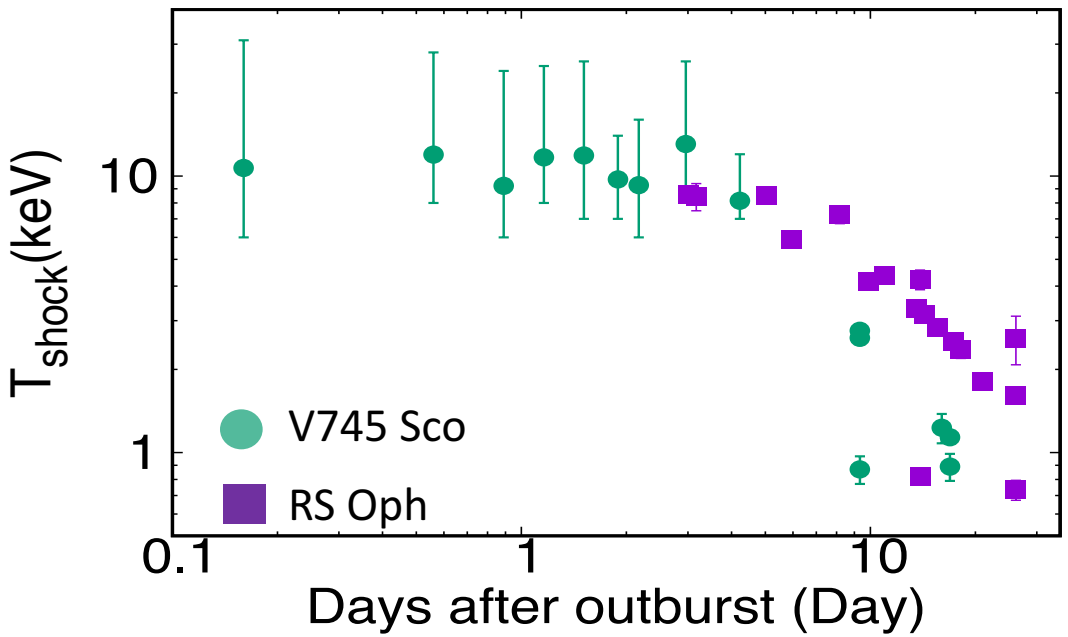
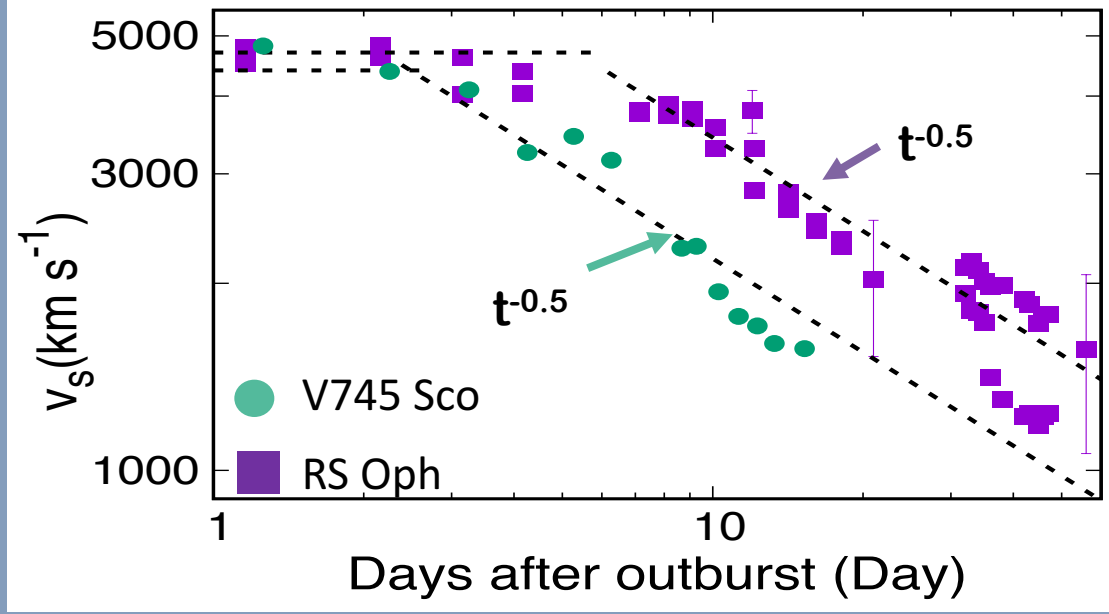


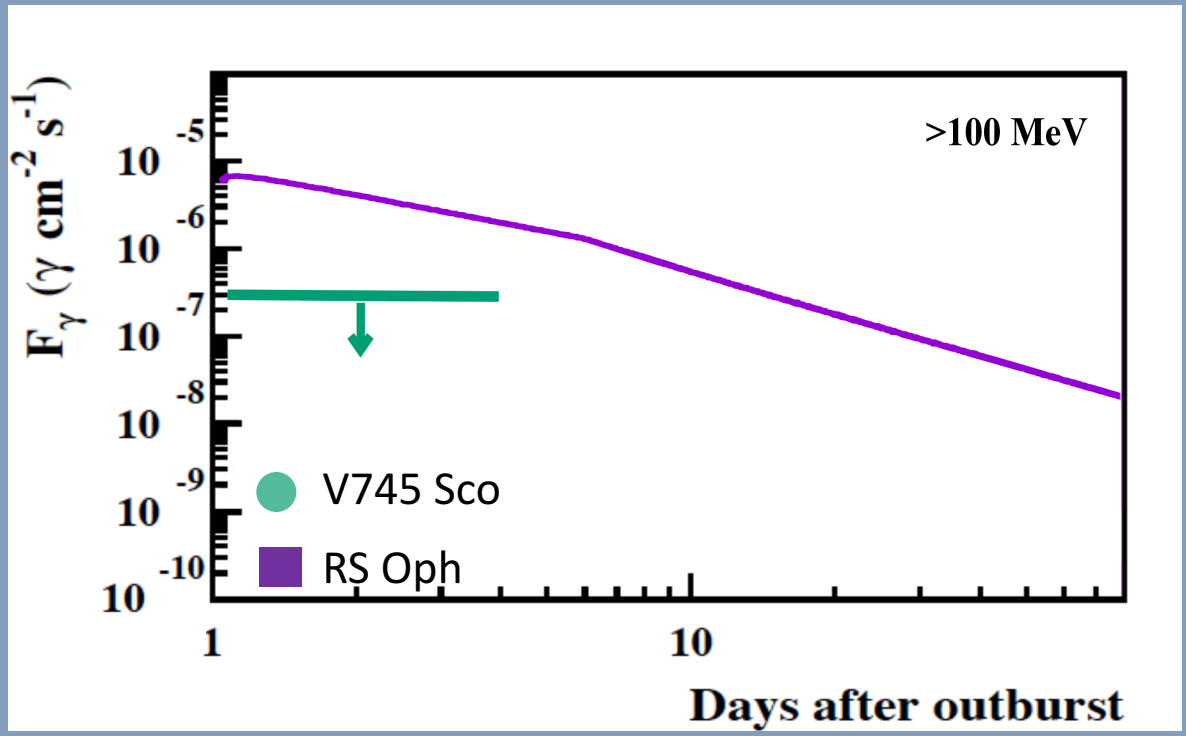


RS Oph &V745 Sco





RS Oph and V745 Sco show strong similarities



Summary

- Particles are accelerated to high energies (E>100 MeV) by strong shocks in nova ejecta
- The early hard X-ray emission is originated from the shocks within the ejecta and the circumstellar medium.
- The study of the early X-ray emission allows to obtain the global properties of shocked plasma and to understand the HE γ-ray emission.
- We have analysed the recurrent novae RS Oph and V745 Sco which show strong similarities.
- Novae contribute to galactic cosmic rays.