The X-ray Evolution of the Symbiotic Star V407 Cygni during its 2010 outburst

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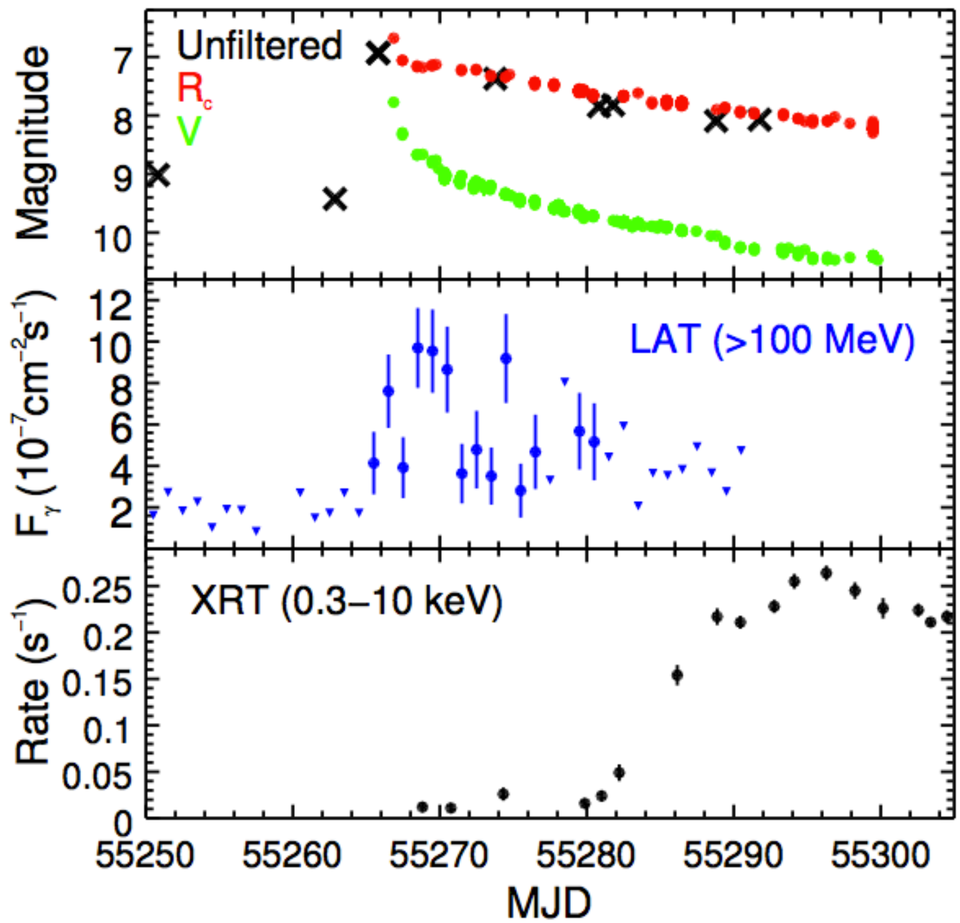
Fermi/LAT detection of V407 Cyg



V407 Cyg was discovered as a transient source of GeV gamma-rays shortly after the peak of the 2010 March outburst.

- ✧ Positional and temporal agreements leave little doubt as to the identification of the Fermi source
- ✧ Swift X-ray monitoring started soon after the outburst; after a period of low-level detection, X-ray count rate increased just as the Fermi source faded dramatically.

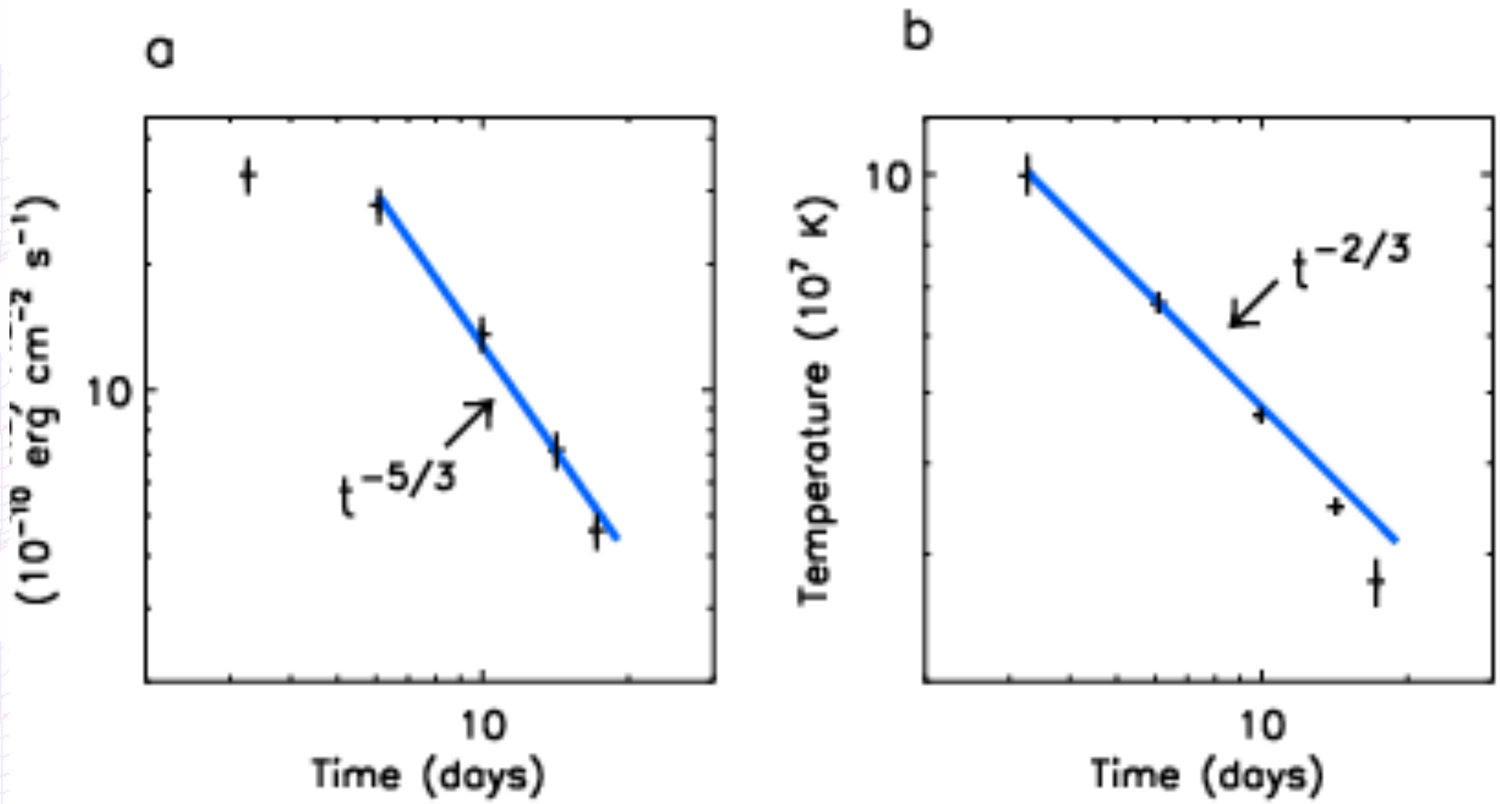
What is V407 Cyg?

- ✧ A poorly studied symbiotic star consisting of
  - ❖ An AGB star (cf. red giant as in many symbiotics)
  - ❖ A white dwarf accreting from the wind of the AGB star (mass loss rate of ~10^{-6} M_{sun}/yr?)
- ✧ Orbital period of 43 years was suggested but not firmly established; orbital separation is large (>10 AU)
  - ❖ Symbiotics with RG donors have 1-3 year orbital period and orbital separation of order 1 AU
- ✧ Small outbursts known in V407 Cyg since the 1930s (accretion events); the March 2010 event, however, is a thermonuclear runaway ("nova") that ejected ~5×10^{-7} M_{sun} of matter at ~2,000 km/s

X-ray Emissions during nova outbursts

- ✧ Compton-degraded gamma-ray emission (undetected, so far)
- ✧ Supersoft Emission from the WD surface
- ✧ Shock emission usually modeled with mekal
  - ❖ Internal shocks in ~main sequence donor cases
  - ❖ Shocks against RG/AGB winds in symbiotic systems
    - Chance to estimate the total ejecta mass
    - Chance to study the RG wind
    - Interesting test case of shock physics and X-ray emission mechanisms
- ✧ Cf. RS Oph (a recurrent nova with a RG donor)

Flux & Temperature evolution of RS Oph

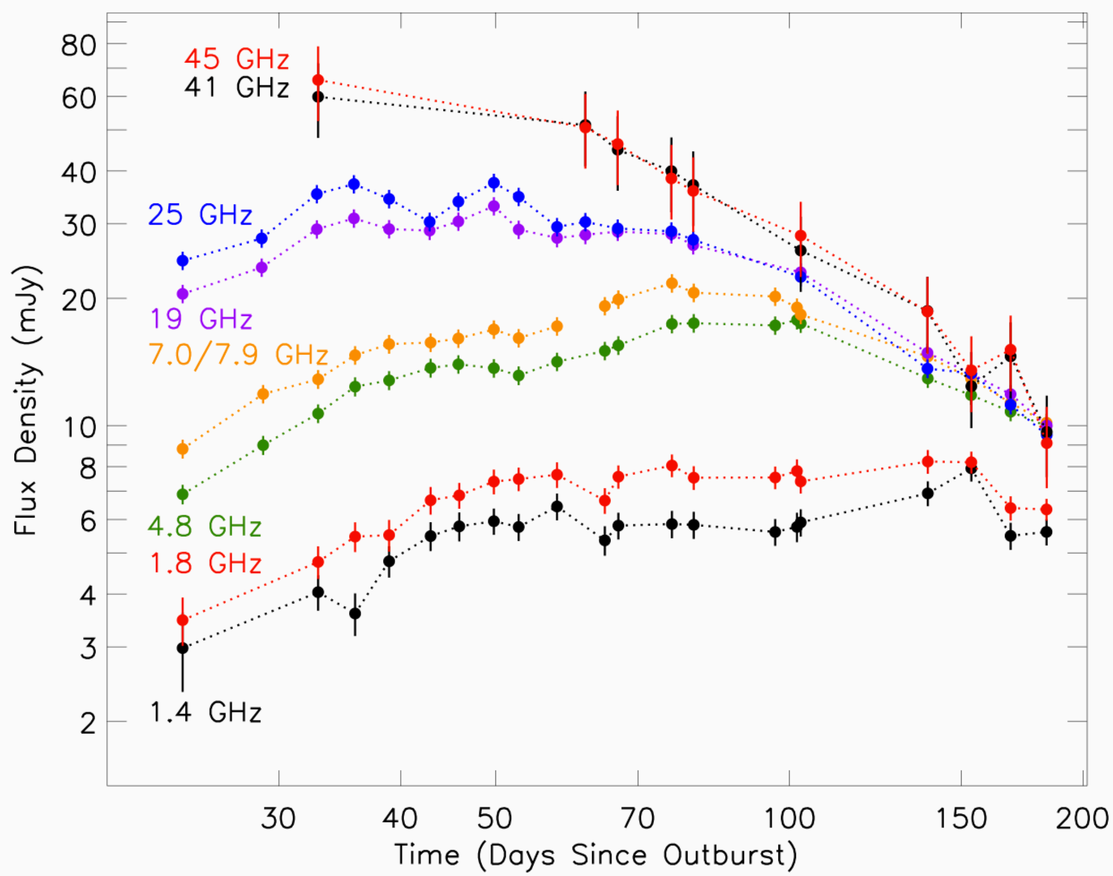


RS Oph exhibited a luminous and fast-evolving shock X-ray component – its evolution was used to estimate the ejecta mass, for example.

Swift and Suzaku observations

- ✧ Swift/XRT campaign was proposed by several groups, notably by Donate, to track the X-ray flux evolution
  - ❖ 24 pointings from 2010-03-13 (day 3.8) to 2010-05-06 (day 57), with ~1-10 ks exposures
- ✧ Mukai proposed Suzaku TOO for detailed X-ray spectroscopy, which was scheduled very soon after V407 Cyg entered the visibility window
  - ❖ 1 pointing on 2010-04-09 (day 30) for 42.2 ks
- ✧ Shore et al. included the XRT data although the focus was on optical spectroscopy
- ✧ Nelson et al. (in prep) analyzed both in combination, in collaboration with Chomiuk et al. who are analyzing the radio (EVLA) monitoring data

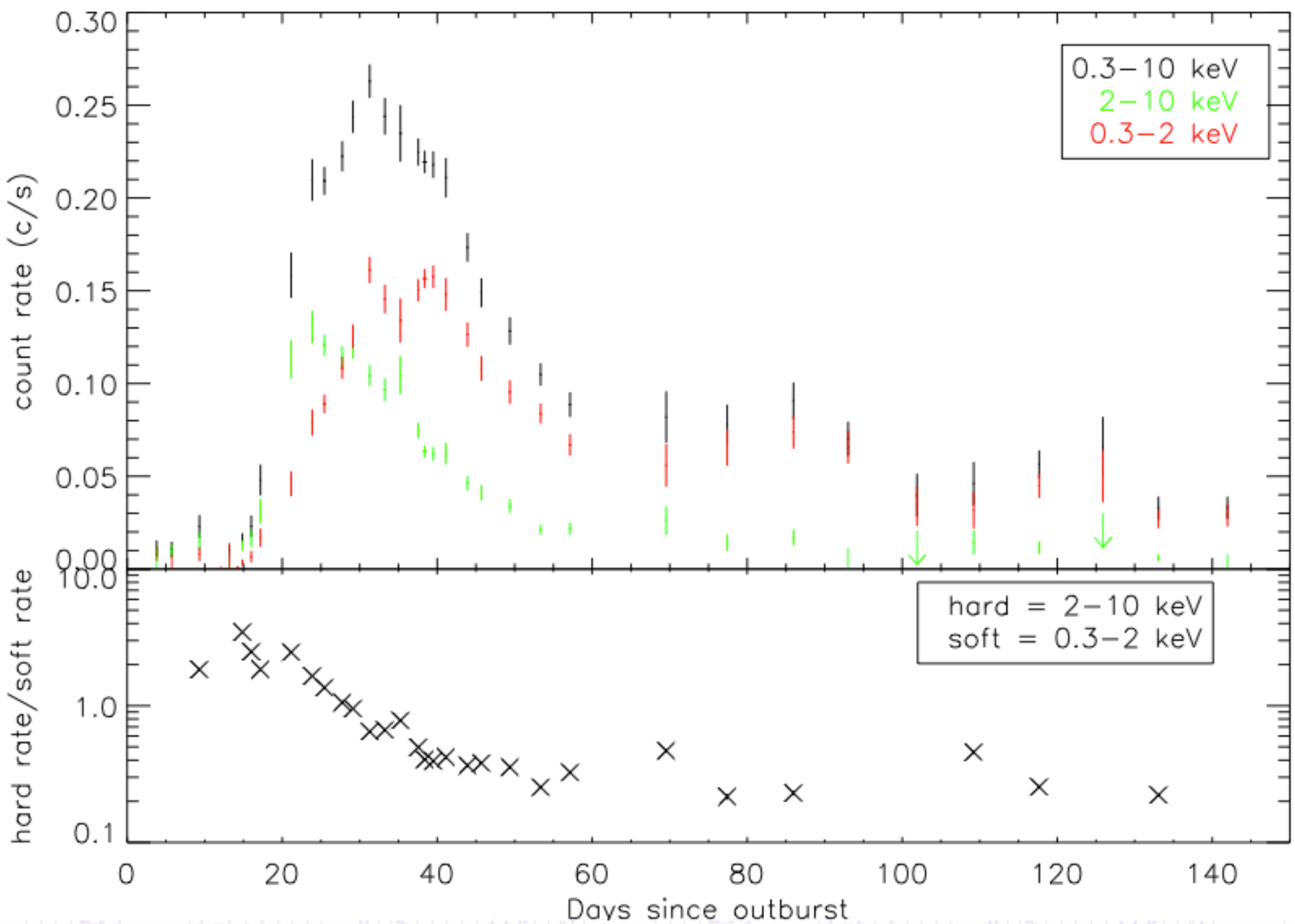
EVLA Monitoring



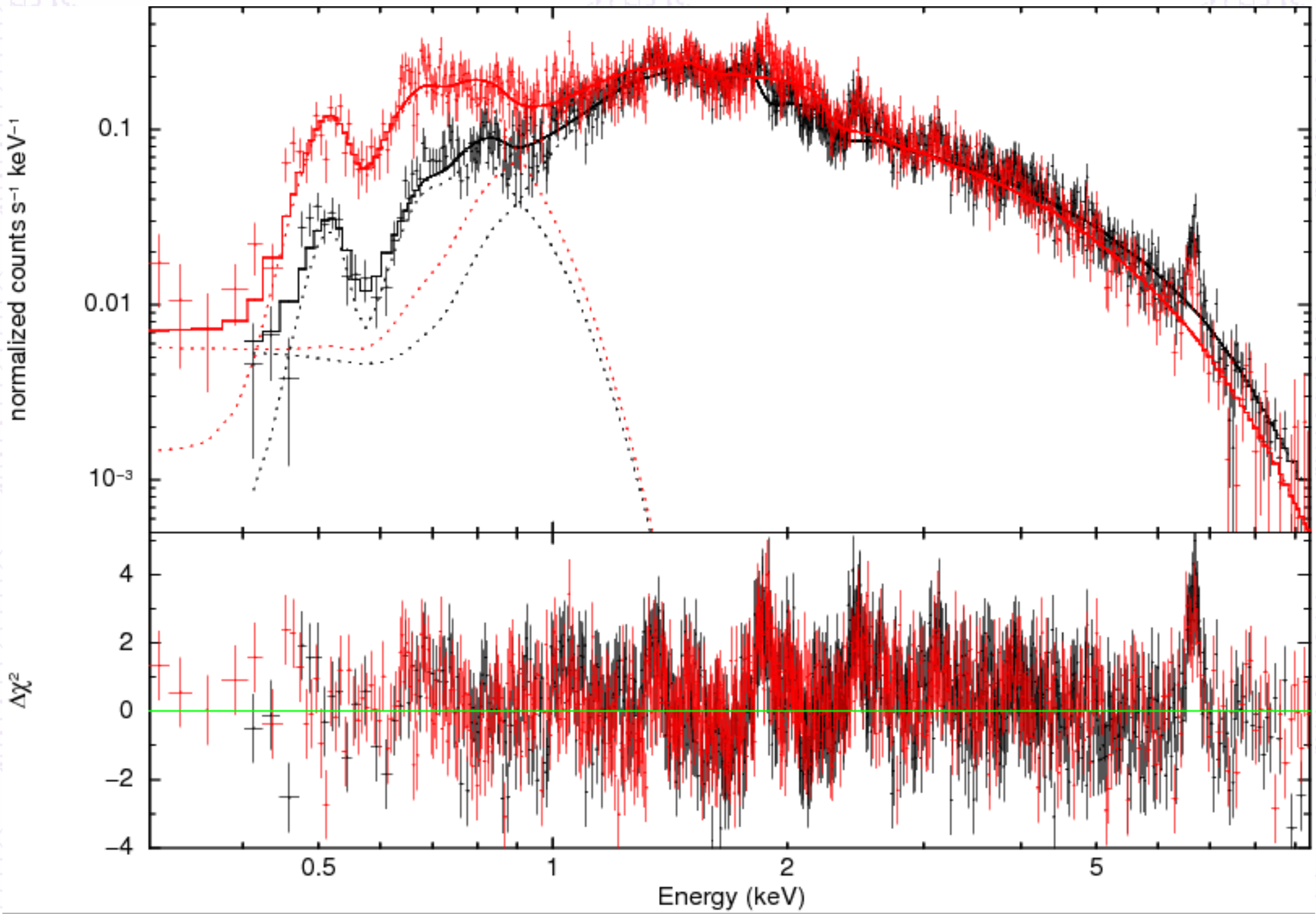
The improved capabilities of EVLA allowed us to obtain multi-frequency data of unprecedented quality for V407 Cyg.

- ✧ The radio emission originates in the (predominantly) cool part of the nova ejecta
- ✧ The standard model needs to be updated

Evolution of Swift X-ray Count Rate



Suzaku: Continuum Only Fits



2 component continuum is required – the hard is Brems at kT~2.8 keV

He-like lines of Fe, S, Si, and probably more seen.

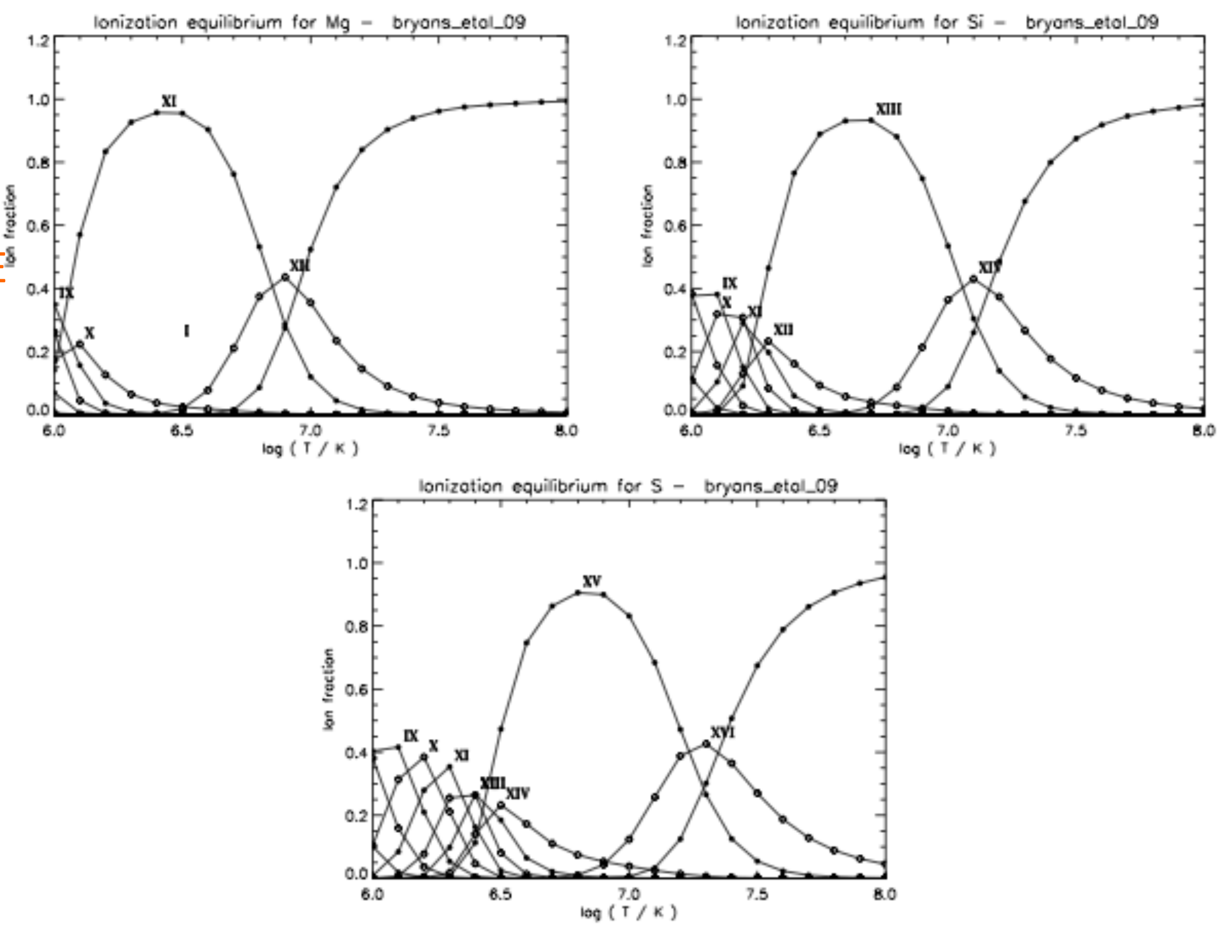
kT~2.8 keV is hot enough to completely ionize Si & S

Collisional Ionization Equilibrium

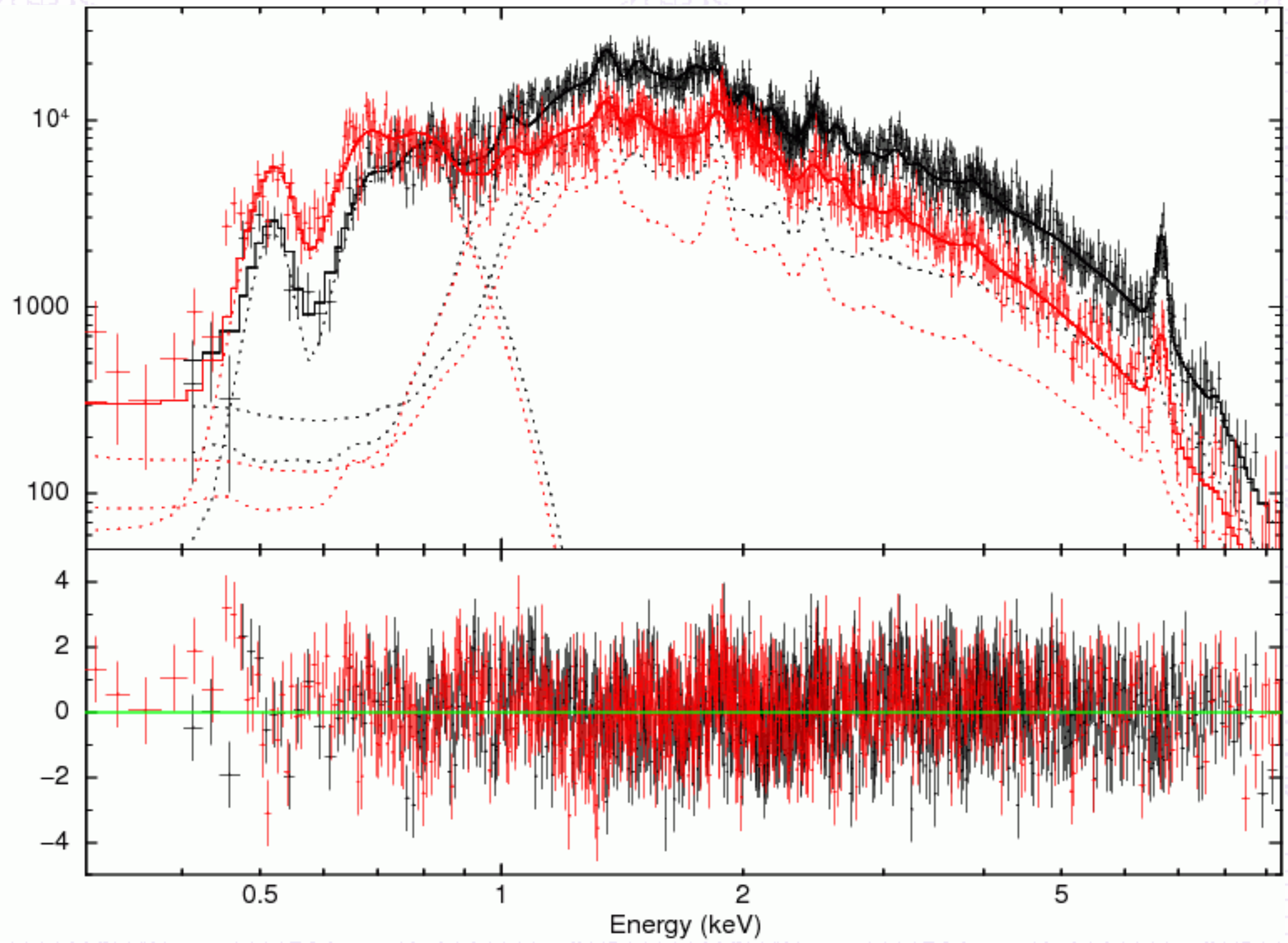
Given the continuum temperature, Mg, Si, and S should be fully ionized – if the plasma is in CIE. First detection of non-CIE plasma in a nova!

Our detailed fits shows a mixture of CIE and non-CIE plasma in V407 Cyg.

These X-rays are likely to be from the forward shock driven into the AGB wind – data constrain the wind density

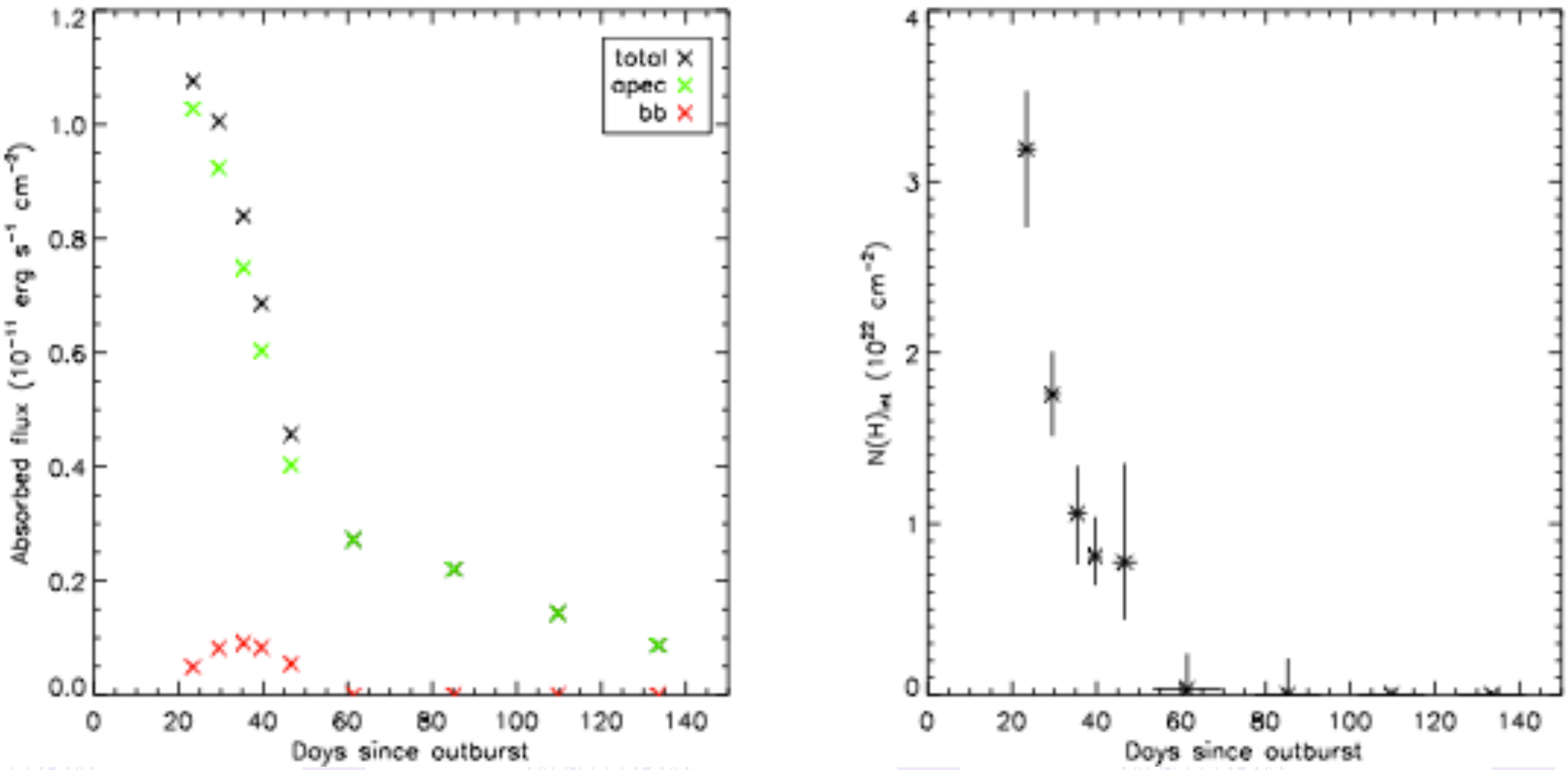


Best Fit Suzaku Spectrum

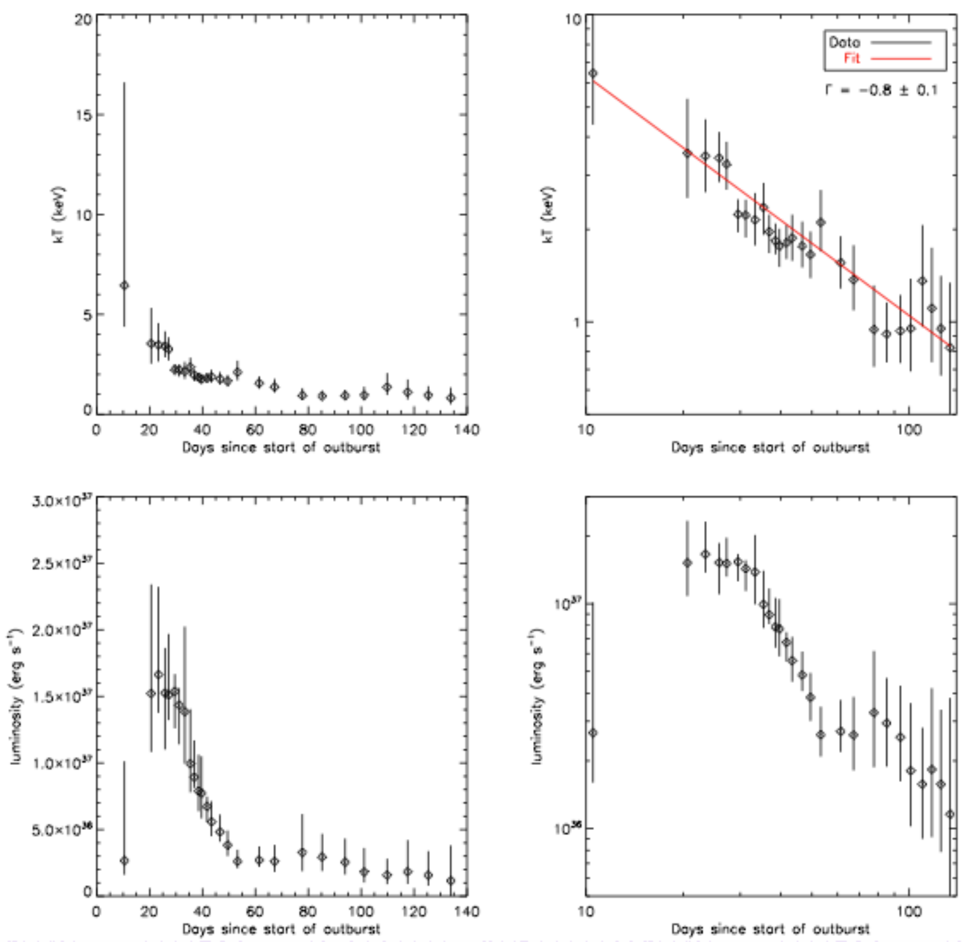


- 2.3 keV CIE (80% of hard flux)
- 3.9 keV NIE ($n_e t \sim 2.4 \times 10^{10}$)
- A supersoft component – BB fit to the Suzaku data gives kT~38 eV and L~8.4×10^{39} erg/s with large uncertainties and caveats

Swift Evolution Revisited



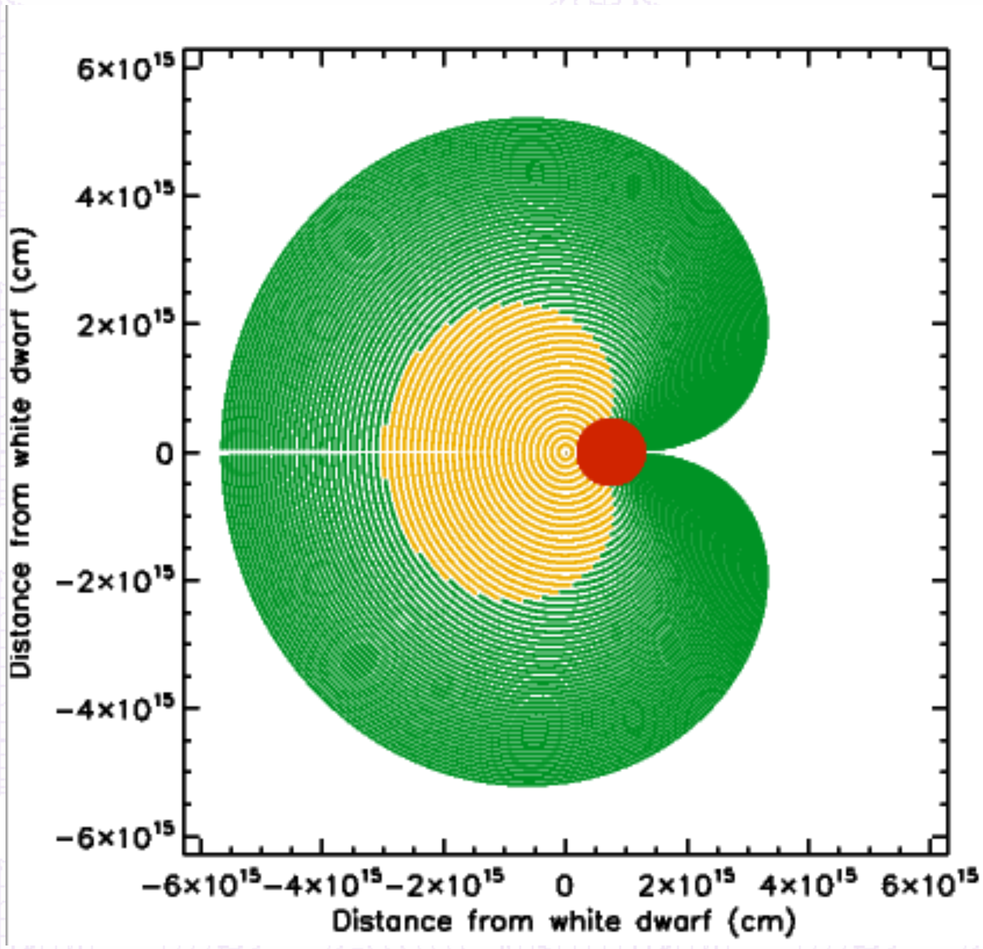
More on Swift Evolution



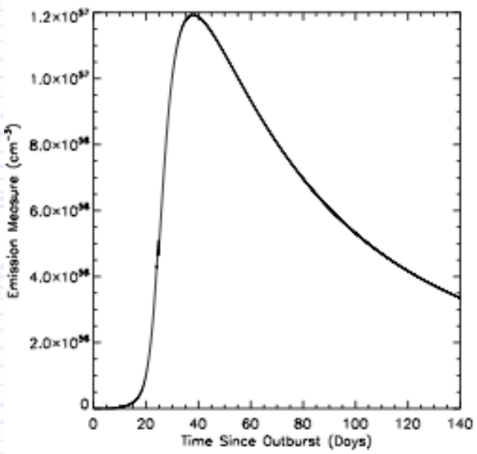
- ✧ Supersoft component visible from day ~20-40 (parameters uncertain) – faster than RS Oph
- ✧ Low level hard emission initially, with a sudden increase at about day ~20, with a steady decline – much slower than RS Oph
- ✧ Intrinsic N_H and kT decreased with time
- ✧ Can we provide a framework for understanding this behavior?

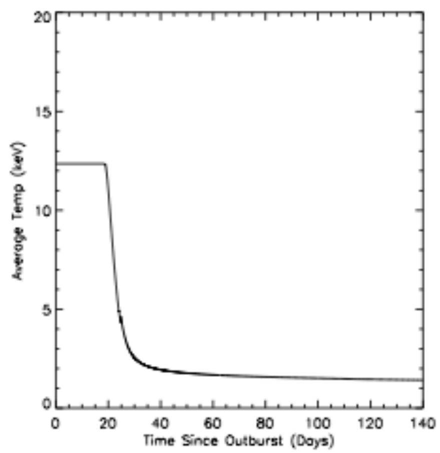
Toy Model for V407 Cyg

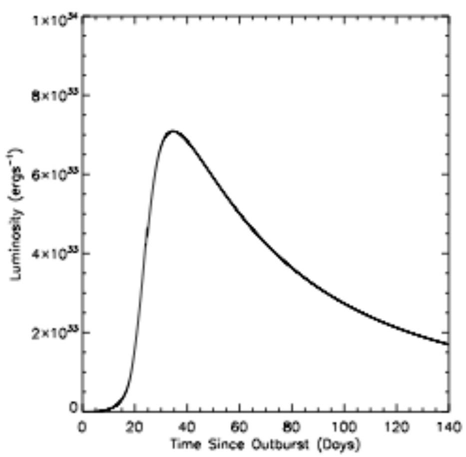
- Initially spherical ejecta (symmetric around WD) expanding inside the AGB wind (r^{-2} density profile centered on the AGB)
- The density encountered by the ejecta depends on the angle wrt the line of centers.
- We track the swept up AGB wind mass, velocity, shock temperature, emission measure and the luminosity
- We vary the ejecta mass, binary separation, wind mass loss rate, …
- We are also applying the same model to the radio data



Inferences and Limitations





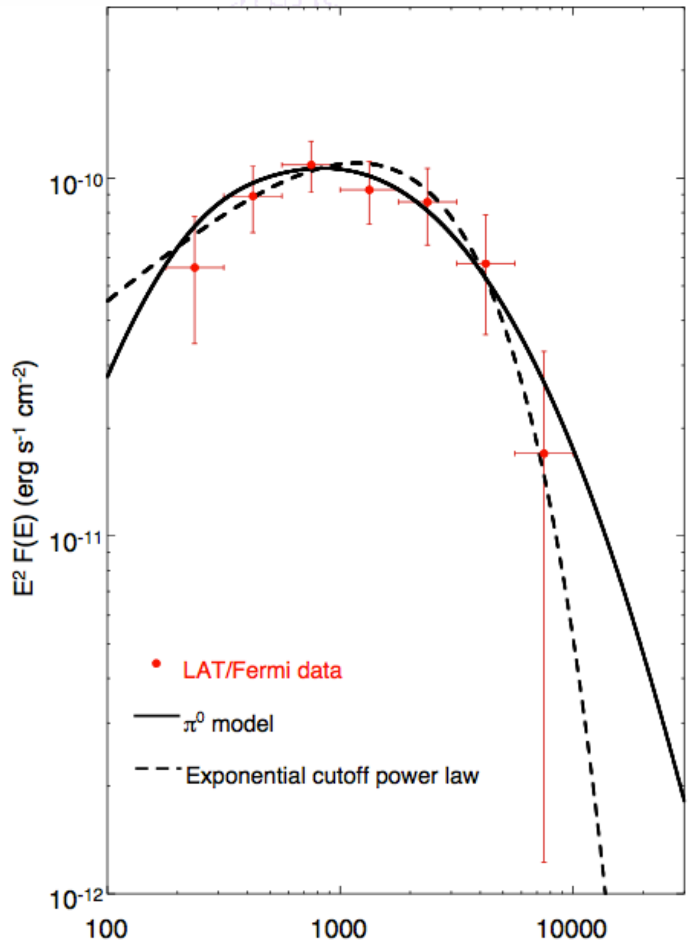


- ✧ The best (and so far only) way to explain the sudden X-ray luminosity increase at day ~20 is for the ejecta to reach the vicinity of the AGB photosphere at that time – separation of order 40 AU
- ✧ Dense AGB wind leads to rapid evolution of the shock near AGB to CIE and cooling
- ✧ Shock away from AGB evolves more slowly – NIE, less cooling, … particle acceleration continues but without the RG target.

Gamma-ray production mechanism

Can a thermonuclear runaway event in a symbiotic system really produce GeV gamma-rays? Abdo et al. (2010) answered yes:

- ✧ Stage 1: Particle Accelration
  - ❖ Strong shock in the Sedov-Taylor accelerates particles (more later)
  - ❖ Also considered in RS Oph case
- ✧ Stage 2: Gamma-ray Production – two possible mechanisms
  - ❖ Case 1: Protons are accelerated, hits a target, and produces pions
  - ❖ Case 2: Electrons are accelerated, and Compton up-scatters seed photons
- ✧ The AGB star provides the target and/or the seed IR photons



Conclusions

- ✧ High S/N Suzaku spectrum is fit well with a CIE+NIE+BB model
- ✧ Swift campaign shows that the supersoft component was seen days 20-40
- ✧ The ejecta probably reached the AGB ~photosphere around day 20, implying a large separation (3,000 km/s x 20 days ~ 40 AU)
  - ❖ The shock rapidly reaches CIE and cools towards the AGB
  - ❖ Slower evolution of the shock away from the RW wind
- ✧ Particle acceleration and a target are both necessary for gamma-ray emission – a fortuitous circumstance in V407 Cyg
- ✧ The gamma-ray flux declined as the X-ray emission increased – accelerated protons no longer hit AGB as the ejecta overtook the star? Particle acceleration may have continued to later epochs.
- ✧ The model overpredicts X-ray luminosity (not enough micro-physics?)
- ✧ The model also apparently requires relatively low wind mass loss rate
  - ❖ Towards the AGB: 10^{-5} M_{sun}/year wind would start decelerating the ejecta before they reach the star
  - ❖ Other directions: hard not to reach CIE if density is high