# The SSS Phase in Novae

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**I. Appearance of super-soft radiation**

**II. Basic properties - V1974 Cyg**

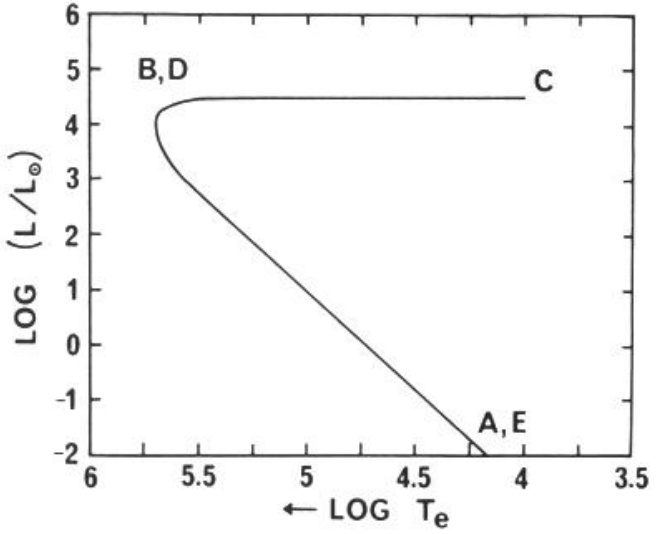
**III. Duration of super-soft phase**

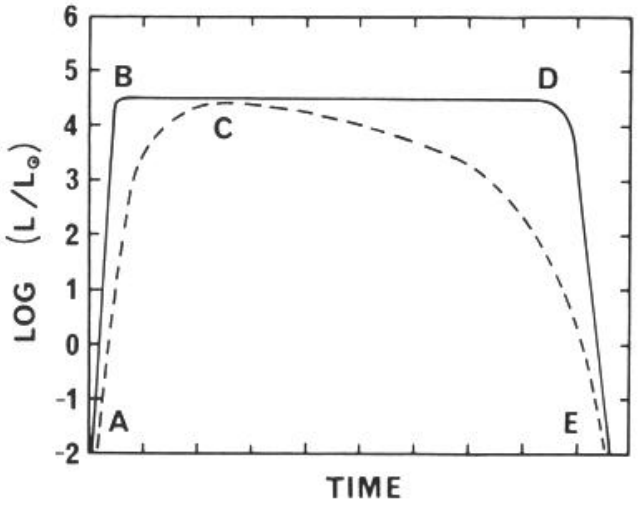
**IV. Variability**

**V. Conclusions**

# I. Appearance of super-soft radiation

- Early very hot („**Fireball**“) phase (**$T >> 10^5$ K**)
  - hot stellar atmosphere (super-soft SED)
  - very short never observed so far



- Phase of **constant bolometric luminosity**
- Only part of accreted envelope ejected
- Remnant material returns quickly into quasi-static equilibrium  size of a giant star
- Hydrogen burning on top of WD continues at constant L
  - Mass of shell decreases
  - **Radius decreases**
  - **Temperature increases** (L=cons.)
  - **T >> $10^5$ K** (several 100000 K)

# II. Basic properties - V 1974 Cyg (1992)

Discovery: February 20, 1992

$V_{max}$ ~ 4.4 mag

$t_3$ ~ $35^d$

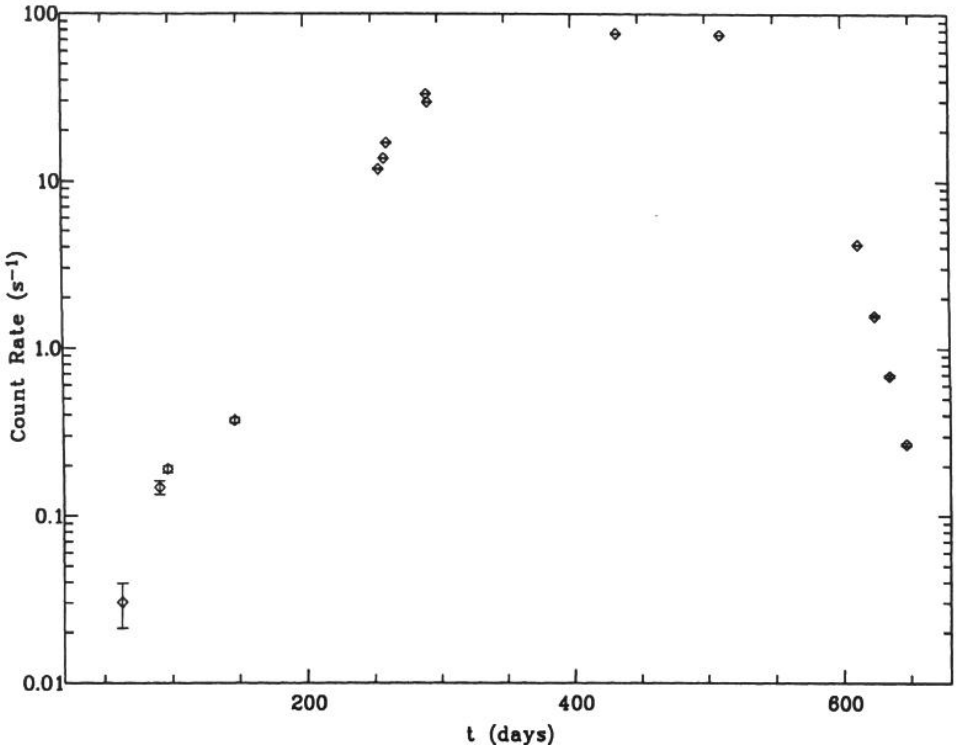
ONeMg nova

**X-ray lightcurve**

(**Krautter et al. 1996**)

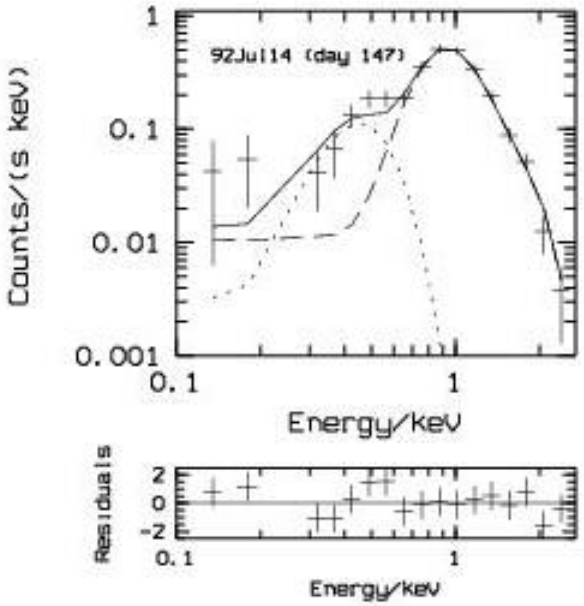
3 phases:

- rise phase
- plateau phases
- decline phase

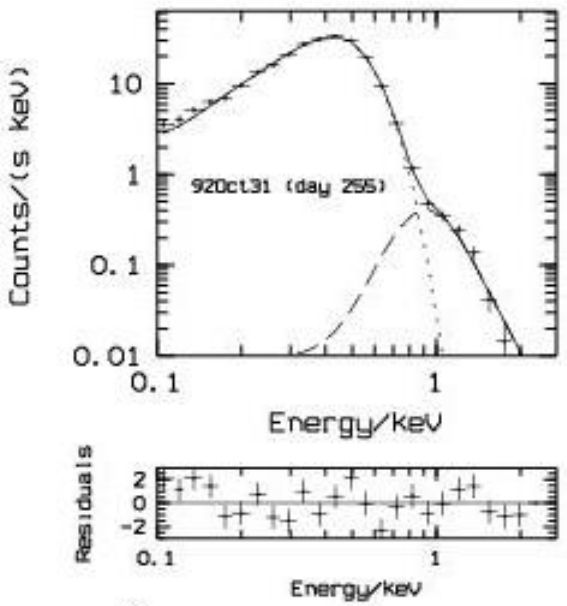



X-ray lightcurve of V1974 Cyg

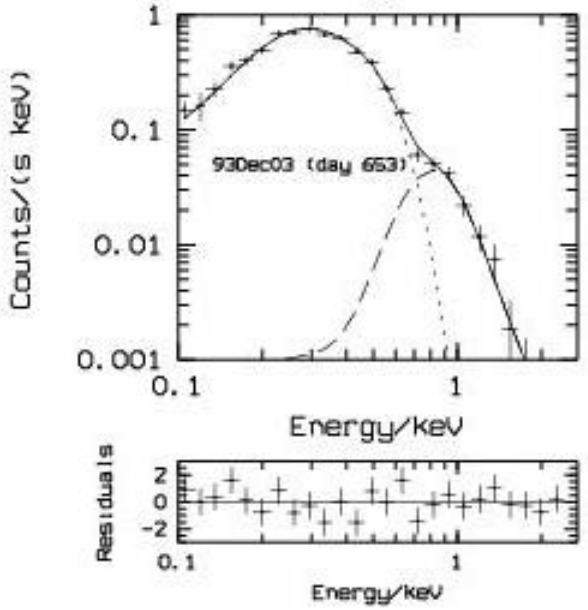
**day 147**




**day 255**




**day 653**

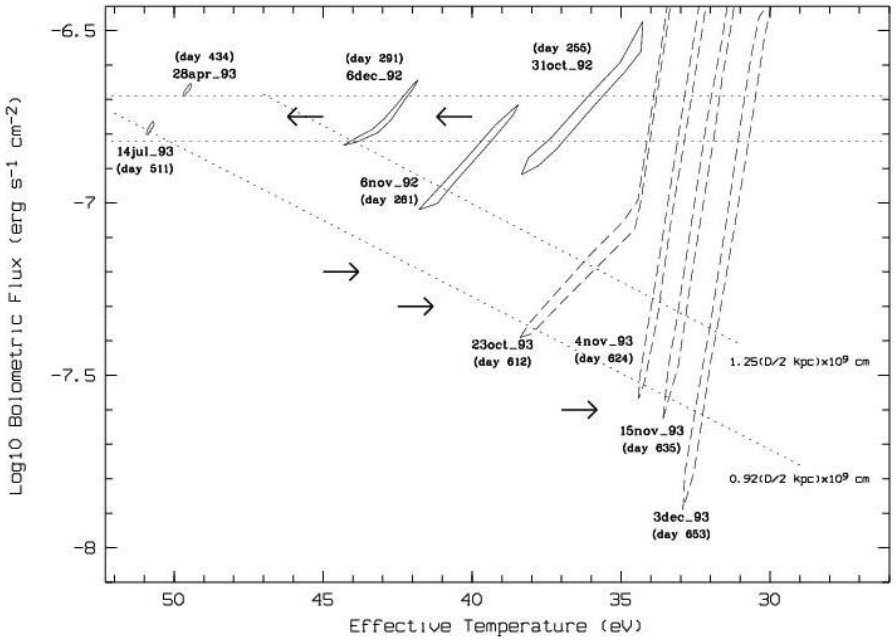



Spectral energy distribution of V1974 Cyg on 3 different epochs.

# Spectral analysis

**Soft component**:

- LTE WD model atmospheres (**MacDonald & Vennes**) with O-Ne overabundances. (**Balman, Krautter &Ögelman 1998**).
- T increases at constant L while $r_{WD}$ decreases by factor 2.
- Decline: both T and L decrease.




$L_{bol}$ vs. $T_{eff}$ for V1974 Cyg

**Hard component**: From shocks in expanding envelope.

# III. Duration of super-soft phase

## GQ Muscae (1983)

- Discovered on January 18, 1983 (Liller).
- First nova in outburst discovered in X-rays.
- Detected in RASS 1991 on day 3118 (~ 8.5 yr) and on subsequent pointed observations

| Day | Count rate | |
|---|---|---|
| 6 | 0.143±0.035 | **Ögelman et al. 1993** |
| 7 | 0.127±0.006 | **Shanley et al. 1995** |
| 8 | 0.007±0.002 | **Balman & Krautter 2001** |
| 9 | <0.003 (3σ) | |
| 10 | <0.0015 (3σ) | |

- GQ Mus „on“ for **~8.5-9 yr**

**V723 Cas (1995)**: Still on, **> 12 years**

- Search of **ROSAT archive** for X-ray emission of postnovae (survey and serendipitous sources). (Orio et al. 2001)
- Positions of 108 classical and recurrent novae analysed. Only 3 novae with super-soft spectrum found!!

  (**V1974 Cyg, GQ Mus, N LMC 1995**)
- Within 10 years after explosion: 30 galactic and 9 MC novae.
- After ROSAT: Few novae with soft X-ray emission
- Estimate (Orio et al.): **~15%** of observed postnovae are as **soft X-ray sources** observed

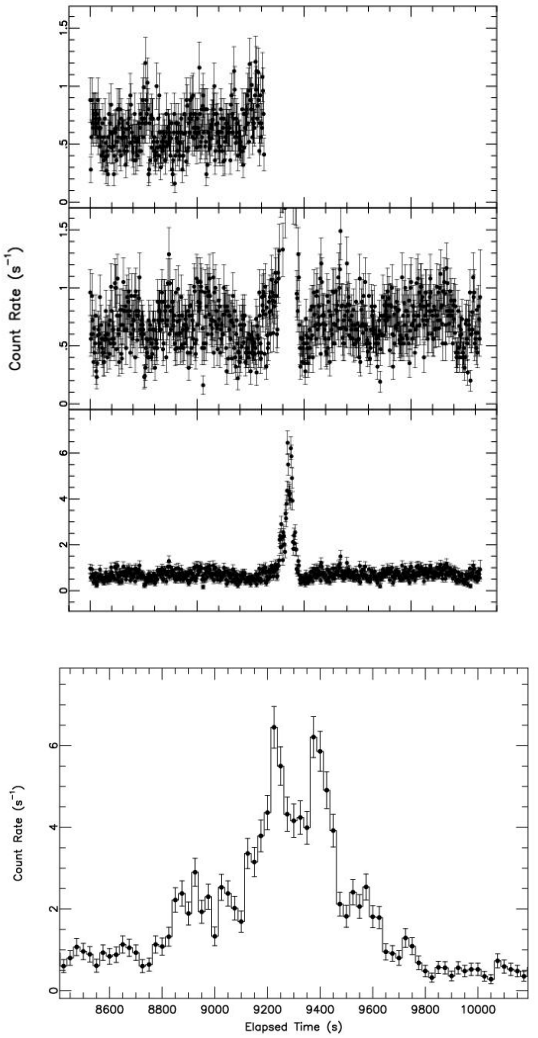
  **Most novae switch off soon**

  **Most WDs have high mass**!

# IV. Variability

## V1494 Aql (1999)

- $m_{max}$ ~ 4 (brightest nova on norther sky since N Cyg 1975
- X-ray lightcurve in super-soft phase shows two extraordinary features.
- **X-ray burst**:
  - Duration ~ 1000 sec.
  - Count rate rises by ~ factor 6
  - Two peaks and other structure
  - spectrum slightly harder
  - No good explanation yet

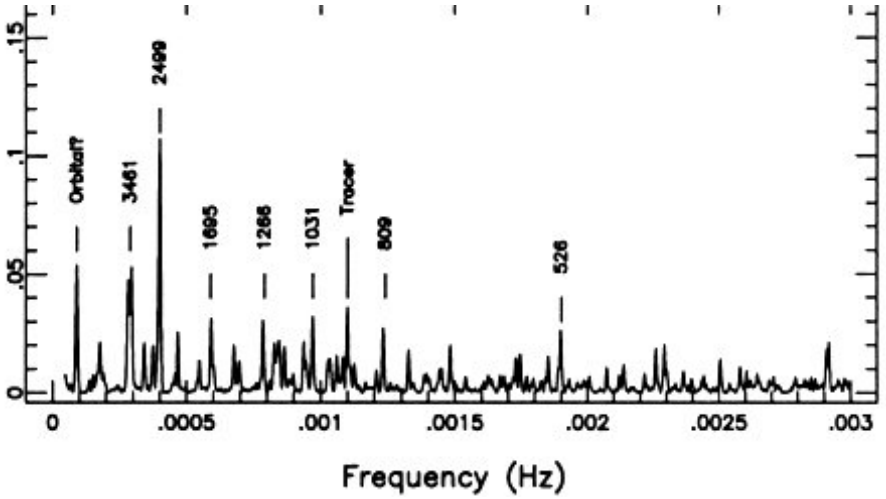



X-ray lightcurve of V1494 Aql

# **Periodic variations**:

- **P = 2500 sec**
- Other prominent peaks, suggesting a spectrum of frequencies.
- Periodicity both in zeroth order and in dispersed data.
- Artefact due to spacecraft motion or dithering? Periodograms of hot WDs (HZ43 and Sirius B) flat highly probable that **period(s) are real**!

Cleaned power spectrum of V1494 Aql

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## Interpretation of periodic variations

- Rotation of WD? But several periods!
- Power spectrum and light curve very similar to the hot central star of the planetary nebula K 1-16.
- **Oscillations** found in other central stars of PN

  (**Ciardullo & Bond 1996**).
- Structure of WD in nova very similar to that one of WDs in PN:
  - CO core and thin layer of accreted+core material.
  - On top of WD ongoing **nuclear burning** ($T_{eff} > 10^5$ K).
- **Pulsations** driven by **$\kappa/\gamma$** effects in partial ionization zones of C and O near the surface

  detection of **non-radial G+ mode pulsations** in the hot white dwarf.

# **V4743 Sgr** (2002)

- Detected on Sep 20, 2002
- $m_{max} \sim 5$ mag
- $t_3 < 15$ days (very fast nova)
- $v_{exp} \sim 1200$ km $s^{-1}$

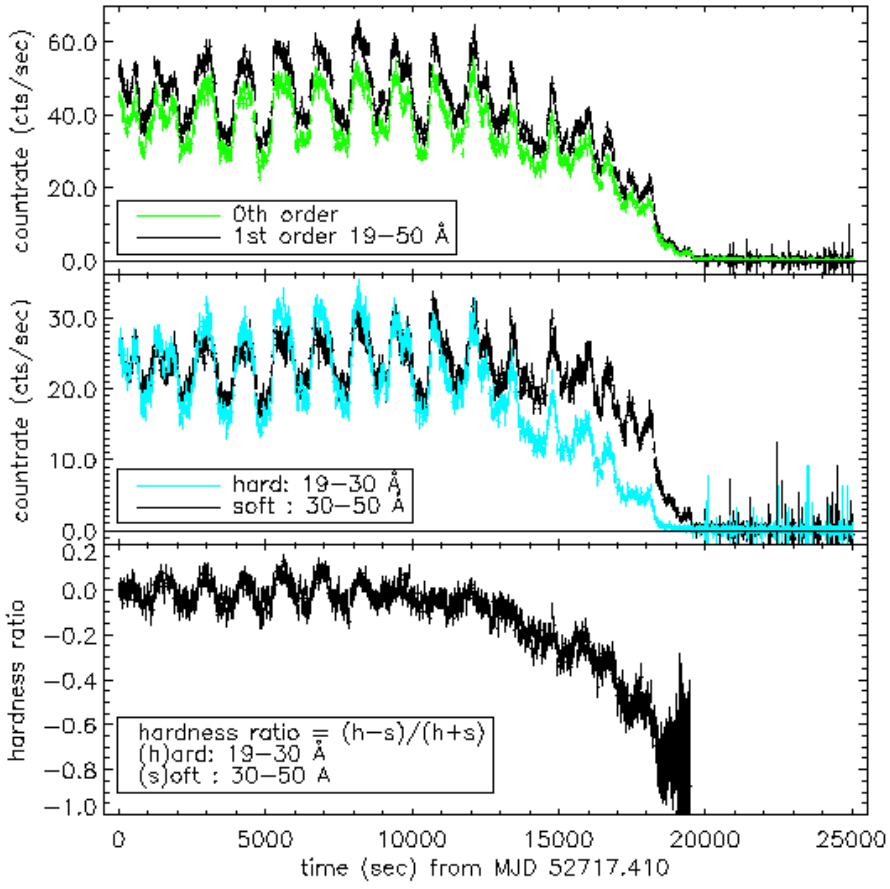
**X-ray observations** with

-- CHANDRA LETGS
ACIS-S

-- XMM-Newton RGS

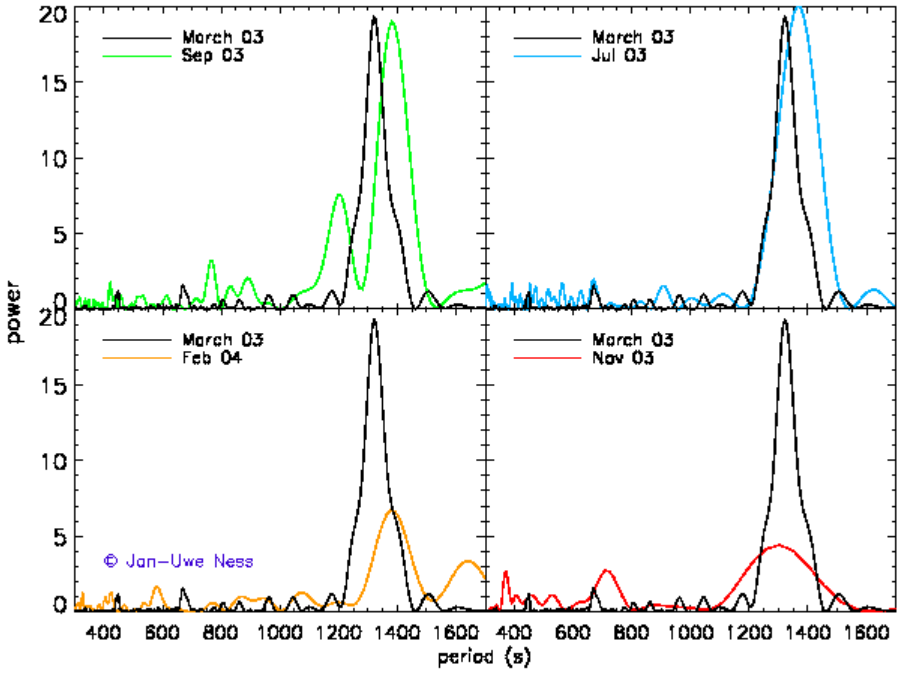
# X-ray lightcurve

**March 03**: (Extracted from LETGS observations)



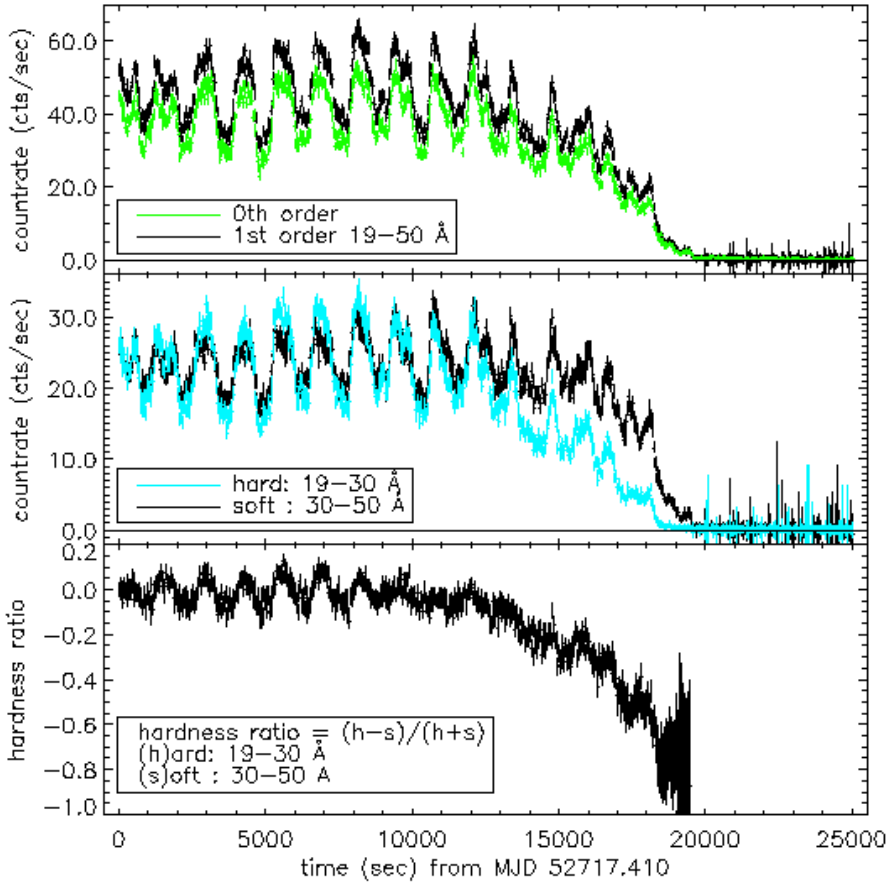

- Strong variability; Range 30-60 cts $s^{-1}$
- Hardness ratio changes during oscillations. WD is slightly hotter when it is brighter.
- Hard component oscillates with higher amplitude than soft component

# Period of oscillations



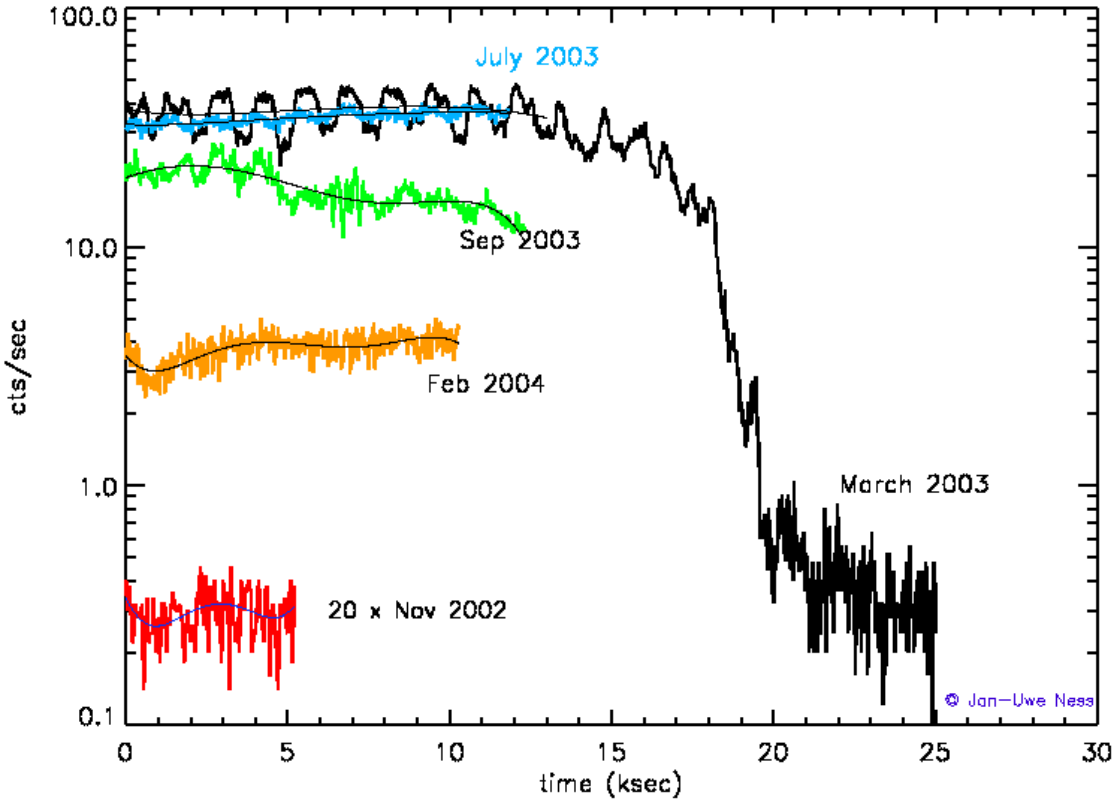

Periodograms of the V4743 Sgr light curves.

- Period **P ~ 1300 sec**
- Also **harmonic overtones** at 600 and 400 sec).
- Interpretation: Probably **oscillations of WD**; (like V1494 Aql), but problems with large amplitude. Rotation cannot be excluded.



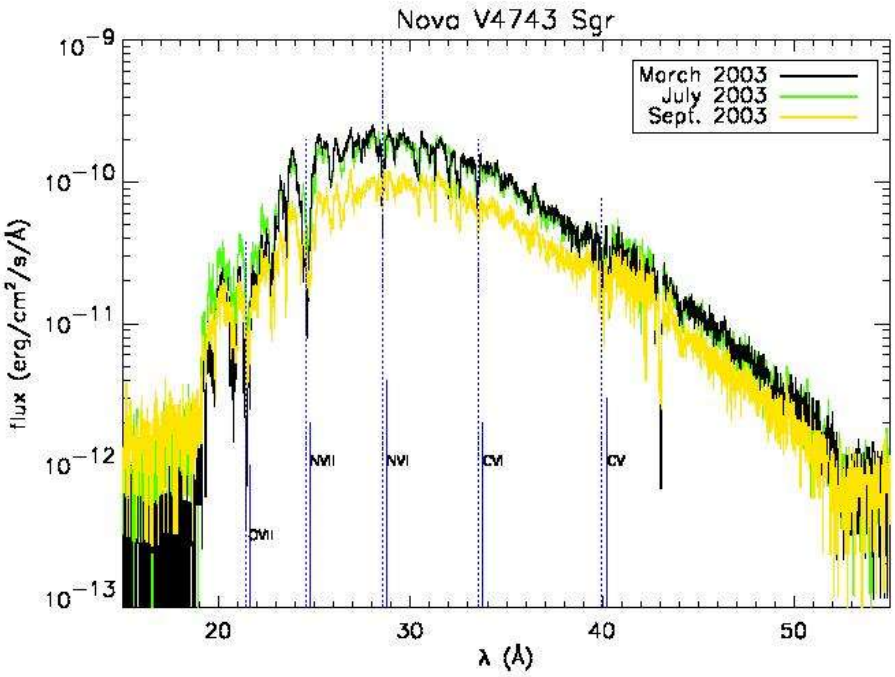

- At about 13 ksec count rate starts to decline, drops effectively to 0!
- Hard component declines first, soft component drops more rapidly
- Interpretation: Not quite clear, eclipse by 3rd component?.

# Long-term X-ray lightcurve




- Strong increase of **count rate** from day 50 to 180; decrease from day 290 to 525
- Strong **variability**
  - **periodic variations**
  - **sudden decrease** of count rate (day 180; **Ness et al. 2003**).
- Amplitude of periodic variations decreases.

# Spectroscopy




- Strong **continuum** emission of thermal origin.
- Strong **absorption** features; can be identified with resonance lines of highly ionized ions.
- Absorption lines blueshifted by ~ 2400 km $s^{-1}$ (due to expanding envelope)

- **Model calculations** (**Petz et al. 2005**) :
  Stationary, expanding Non-LTE calculations with PHOENIX:
  $T \sim 5.7 \cdot 10^5$ K, $v_{exp} = 2500$ km $sec^{-1}$, $N_H = 5 \cdot 10^{21}$ $cm^{-2}$

# V. Conclusions

- X-ray observations crucial for study of super-soft phase
- Novae observed so far differ widely in their behavior
- Many different kinds of variability
- Duration of super-soft phase: months - years
- Problem: Only few long-term X-ray observations