X-rays and γ-rays from classical novae: constraints on models from the observations

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- Basic scenario of classical novae
- γ-rays: theory, observations,challenges for instrumentation
- X-rays: lessons from XMM-Newton observations and from ROSAT (Nova Cyg 1992)

Origin of X-ray emission (I)

- Residual steady H-burning on top of the white dwarf: photospheric emission from the hot WD:

  $T_{eff} \sim (2\text{-}10) \times 10^5$K ($L \sim 10^{38}$erg/s) → supersoft X-rays

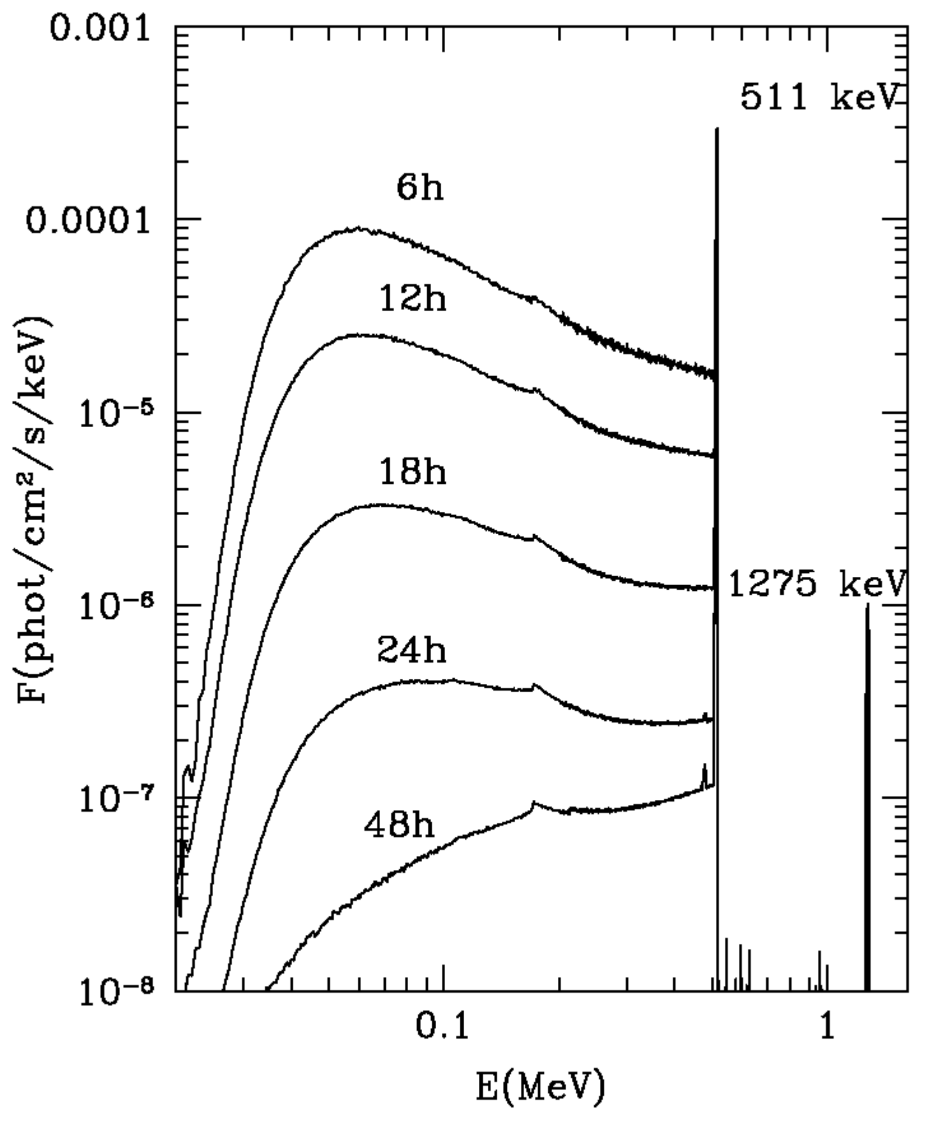
  - detected by ROSAT/PSPC in only 3 classical novae, out of 39 observed up to 10 years after explosion):
    GQ Mus (N Mus1983), N Cyg 1992, N LMC 1995

  - duration related to turn-off time (theory: $t_{nuc} \approx 100$yr; observations: <9 yr)

Origin of X-ray emission (II)

- Internal (external) shocks in the ejecta produce hard X-rays
  - ➢ detected early after explosion (N Her 1991, N Pup 1991, N Cyg 1992, N Vel 1999): internal shocks
- Reestablished accretion: emission “as a CV”. How and when?

Origin of X-ray emission (III)



Compton degradation of γ-rays emited by classical novae CAN NOT be responsible of their early hard X-ray emission:

•Cut-off at 20 keV (photoelectric abs.)

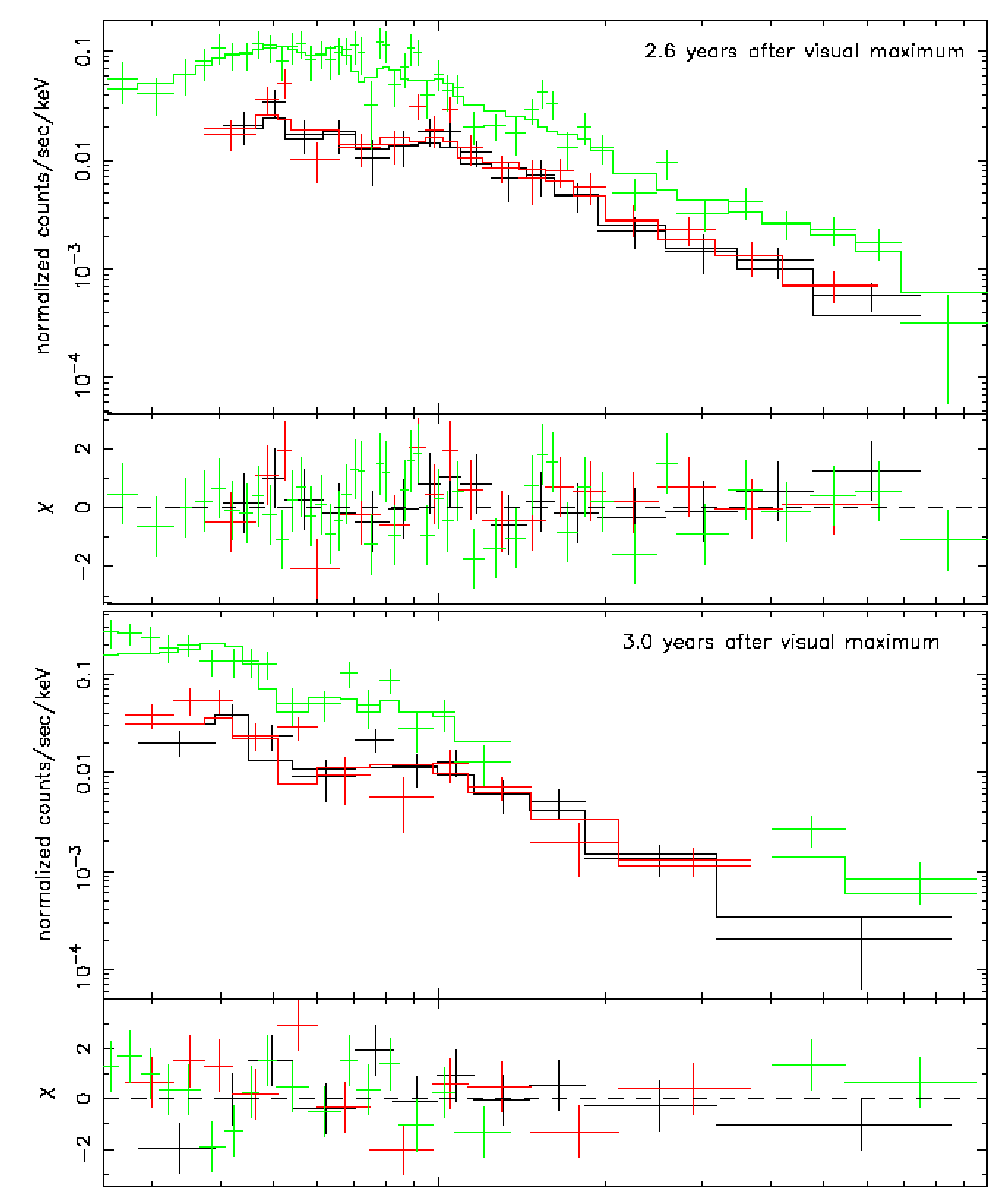
•Fast disappearence: 2days (w.r.t T_{max}, i.e., before visual outburst)

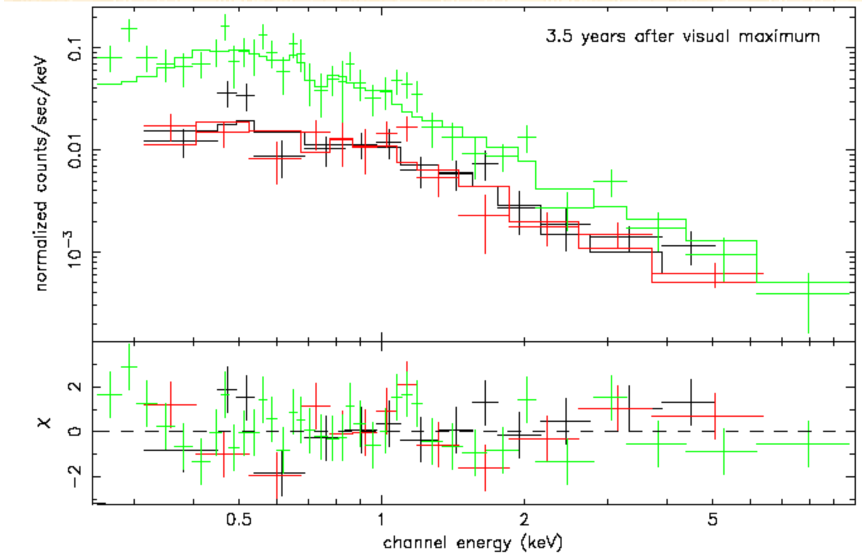
Gómez-Gomar,Hernanz,José,Isern, 1998, MNRAS

X-rays from novae: observations of recent post-outburst galactic novae with XMM-Newton

Target	Discovery date	Date of obs. – Time after outburst	XMM EPIC detection
N Sco 1997 V1141 Sco	June 5	Oct. 11, 2000 – 1224 d, 3.4 yr Mar. 24, 2001 – 1388 d, 3.8 yr Sep. 7, 2001 – 1555 d, 4.3 yr	
N Sgr 1998 V4633 Sgr	March 22	Oct. 11, 2000 – 934 d, 2.6 yr Mar. 9, 2001 – 1083 d, 3.0 yr Sep. 7, 2001 – 1265 d, 3.5 yr	Yes Yes Yes
N Oph 1998 V2487 Oph	June 15	Feb. 25, 2001 – 986 d, 2.7 yr Sep. 5, 2001 – 1178 d, 3.2 yr Feb. 2002 – 1352 d, 3.7 yr Sep. 24 2002 – 1559d, 4.3 yr	Yes Yes Yes Yes
N Sco 1998 V1142 Sco	October 21	Oct. 11, 2000 – 721 d, 2.0 yr Mar. 24, 2001 – 885 d, 2.4 yr Sep. 7, 2001 – 1052 d, 2.9 yr	
N Mus 1998 LZ Mus	December 29	Dec. 28, 2000 – 730 d, 2.0 yr Jun. 26, 2001 – 910 d, 2.5 yr Dec. 26, 2001 – 1093 d 3.0 yr	

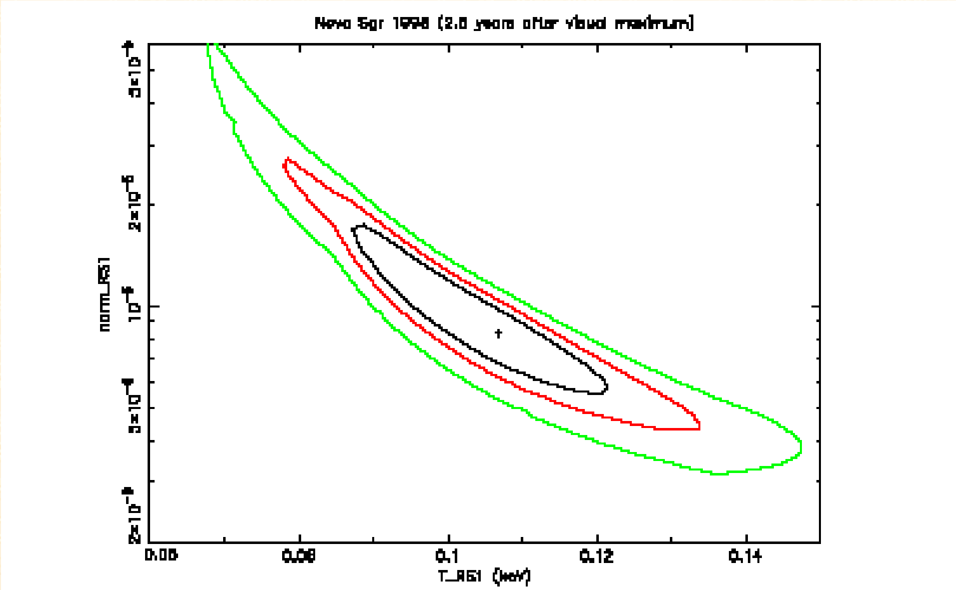
Nova Sgr 1998 – V4633 Sgr

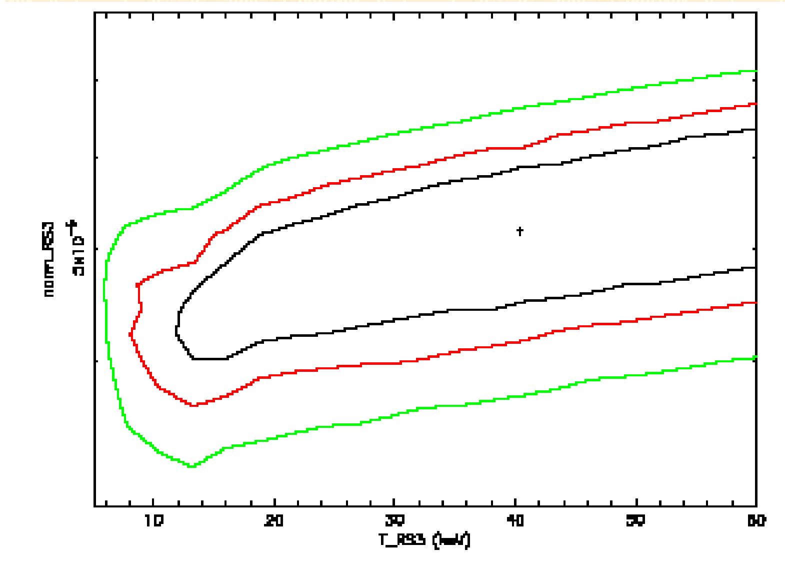


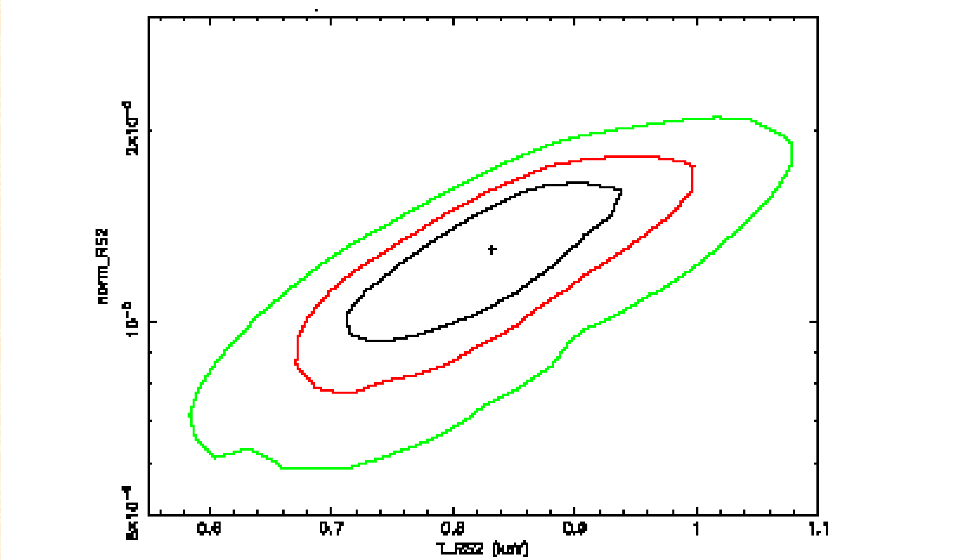


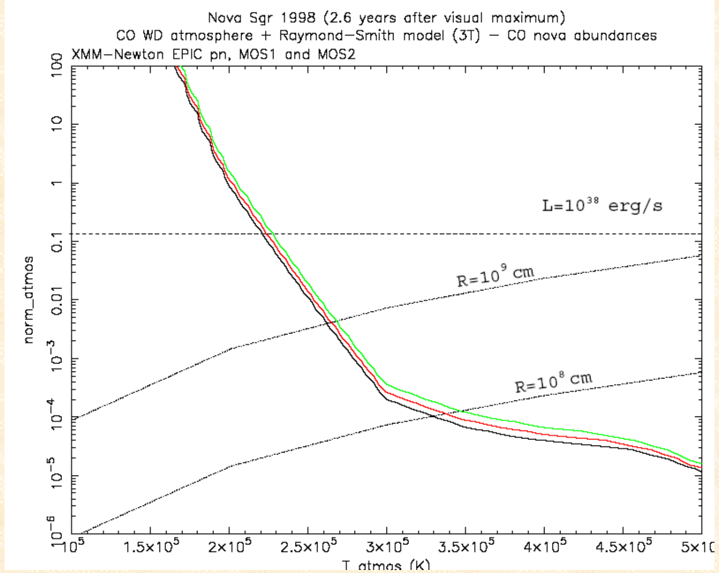
Hernanz & Sala, ApJ 2007

Nova Sgr 1998 – V4633 Sgr









Nova Sgr 1998 – V4633 Sgr

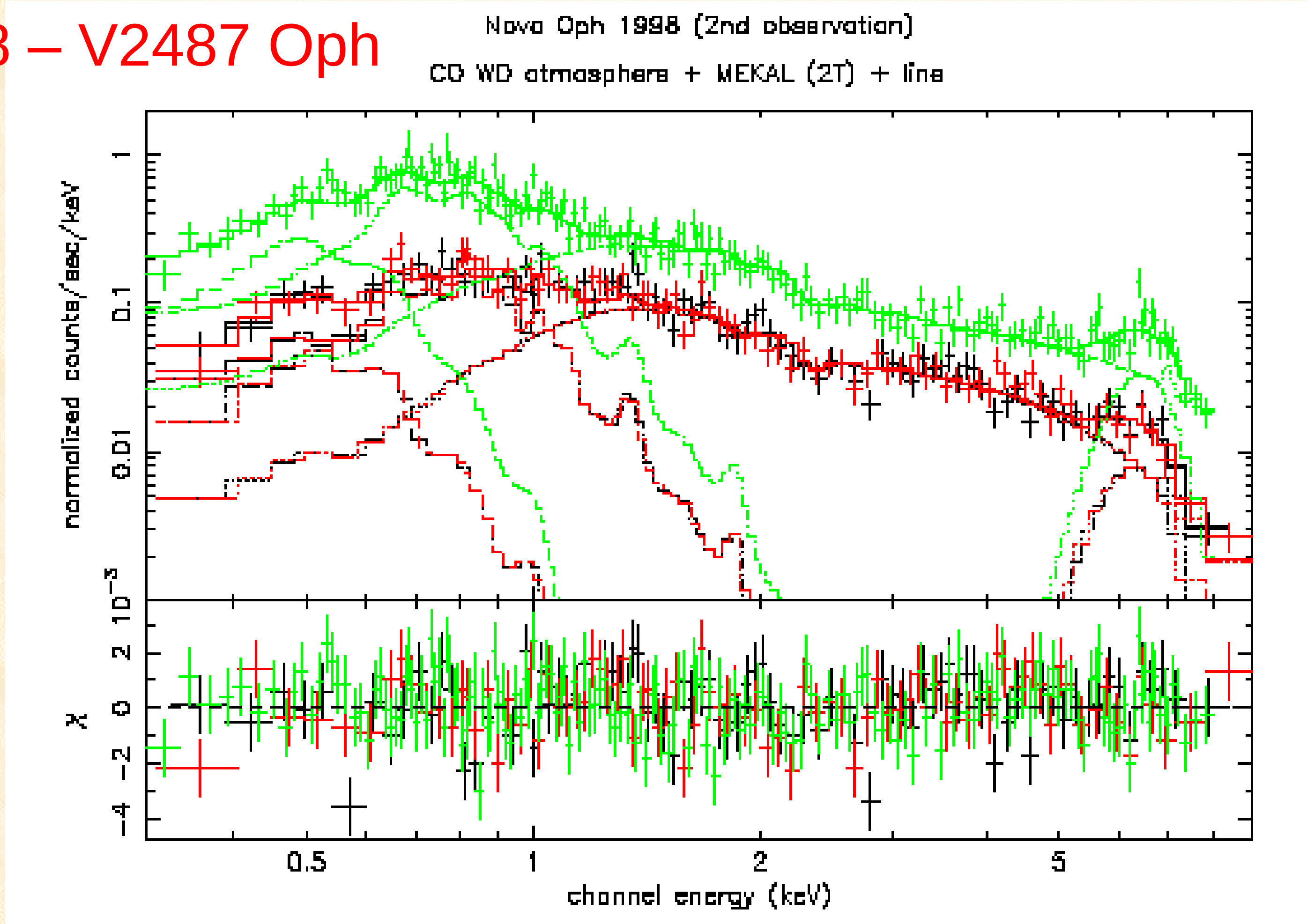
accretion ⟺ Solar abundances

	1st Observation	2nd Observation	3rd Observation
kT_{RS1}(keV)	0.07 – 0.16	0.03 – 0.05	0.06 – 0.10
$EM_{RS1}(\times 10^{57} cm^{-3})$	0.1 – 2.4	50 – 5000	0.5 – 6.4
kT_{RS2}(keV)	0.6 – 1.0	0.2 – 0.7	0.2 – 1.0
$EM_{RS2}(\times 10^{55} cm^{-3})$	0.9 – 3.7	0.5 – 3.9	0.4 – 2.0
kT_{RS3}(keV)	≥ 5	≥ 2	≥ 3
$EM_{RS3}(\times 10^{55} cm^{-3})$	8 – 14	5 – 10	6 – 10
$F_{unabs,0.2-10.0\,keV}(\times 10^{-13} erg\,cm^{-2}\,s^{-1})$	3 – 13	2 – 640	2 – 33
$L_{unabs,0.2-10.0\,keV}(\times 10^{33} erg\,s^{-1})$	3 – 13	2 – 620	2 – 32
χ^2_ν	1.16	1.40	1.22

ejecta ⟺ CO abundances

	1st Observation	2nd Observation	3rd Observation
kT_{RS1}(keV)	0.07 – 0.15	0.02 – 0.07	0.05 – 0.13
$EM_{RS1}(\times 10^{55} cm^{-3})$	0.3 – 5.8	14 – 500000	0.5 – 11.0
kT_{RS2}(keV)	0.6 – 1.1	0.4 – 1.2	0.4 – 1.1
$EM_{RS2}(\times 10^{55} cm^{-3})$	0.6 – 2.0	0.4 – 1.9	0.2 – 1.7
kT_{RS3}(keV)	≥ 5	≥ 2	≥ 3
$EM_{RS3}(\times 10^{55} cm^{-3})$	3 – 7	1 – 5	2 – 5
$F_{unabs,0.2-10.0\,keV}(\times 10^{-13} erg\,cm^{-2}\,s^{-1})$	2 – 8	1 – 5500	2 – 6
$L_{unabs,0.2-10.0\,keV}(\times 10^{33} erg\,s^{-1})$	2 – 8	1 – 5300	2 – 6
χ^2_ν	0.92	1.61	1.25

Nova Oph 1998 – V2487 Oph



~3 yrs after explosion

Soft component: hot emitting region on the WD photosphere (equivalent radius ~10^7cm, i.e., less than 1% of the whole surface)

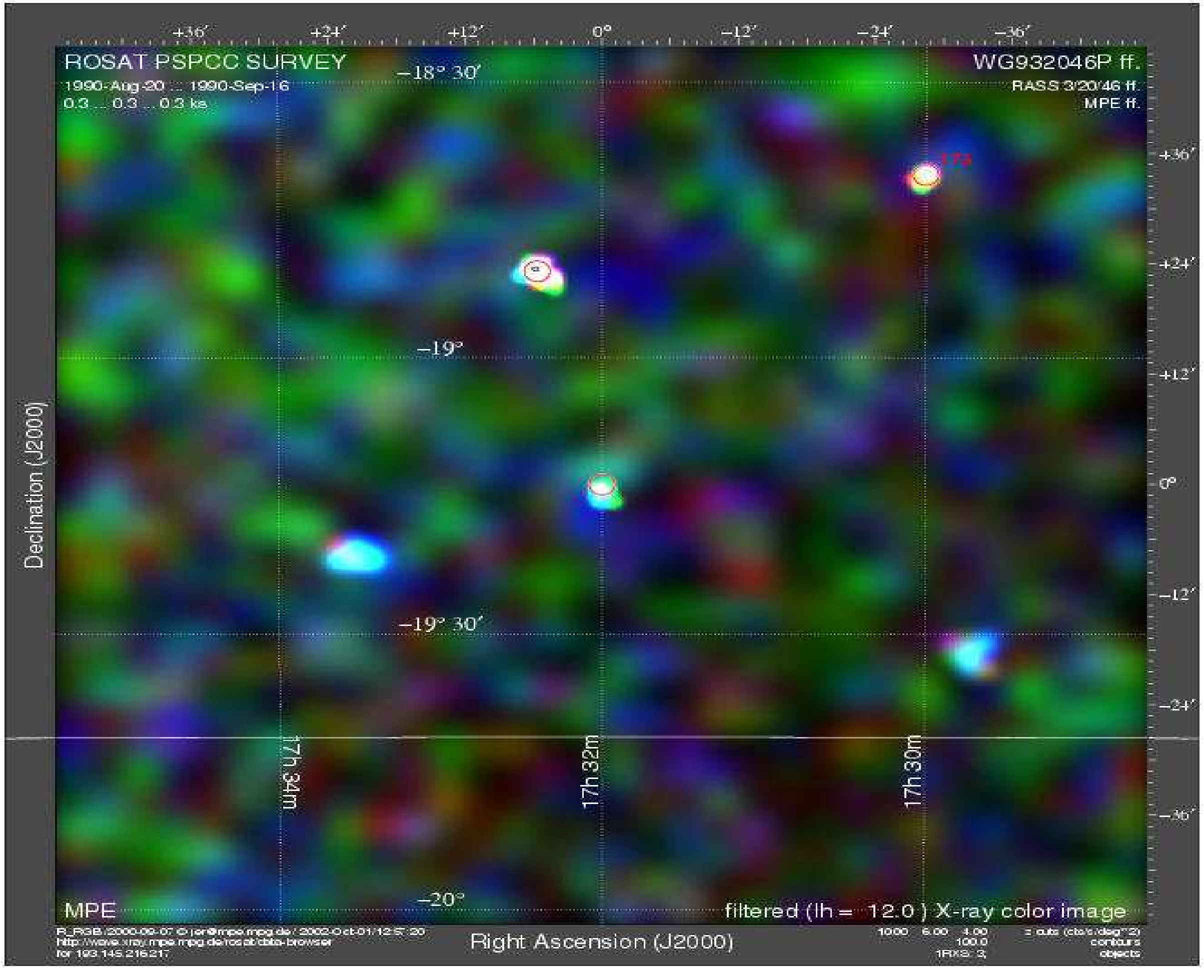
Hard component: thermal plasma (simulated with MEKAL) and fluorescent Fe Kα line(s): signature of *accretion, restablished as soon as 2.7 years after nova explosion*

L(0.3-8.0 keV)=5x(d/10kpc)^{2}x10^{34}erg/s (Hernanz & Sala 2002, Science, 298, 393)

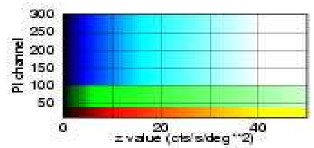
ROSAT PSPCC SURVEY WG932046P_N1_SI01 ff.

Field Title: RASS 3/20/46 ff.

August 1990



Projection center:	equ.: (RA,Dec) = (17h 32m 00s.00, −19° 13′ 49.0″)
	gal.: (l_II,b_II) = (6.6074°, 7.7752°)
Field of view:	1.59° × 1.59° / 1024 × 1024 pixel
	equatorial grid, 5.6″ / pixel
Image filter:	filter 5
	maximum blocking exponent 5; cell radius 5;
Observing period:	1990-Aug-20, 21:04:49 ... 1990-Sep-16, 09:01:06
Exposure:	344 s ... 287 s (315 s) (detector ontime 37733 s)
Events:	3027 (totals: 3027 accepted, 14907 rejected)
Contours:	100.0
Objects:	1RXS: 3;
PI:	MPE ff.

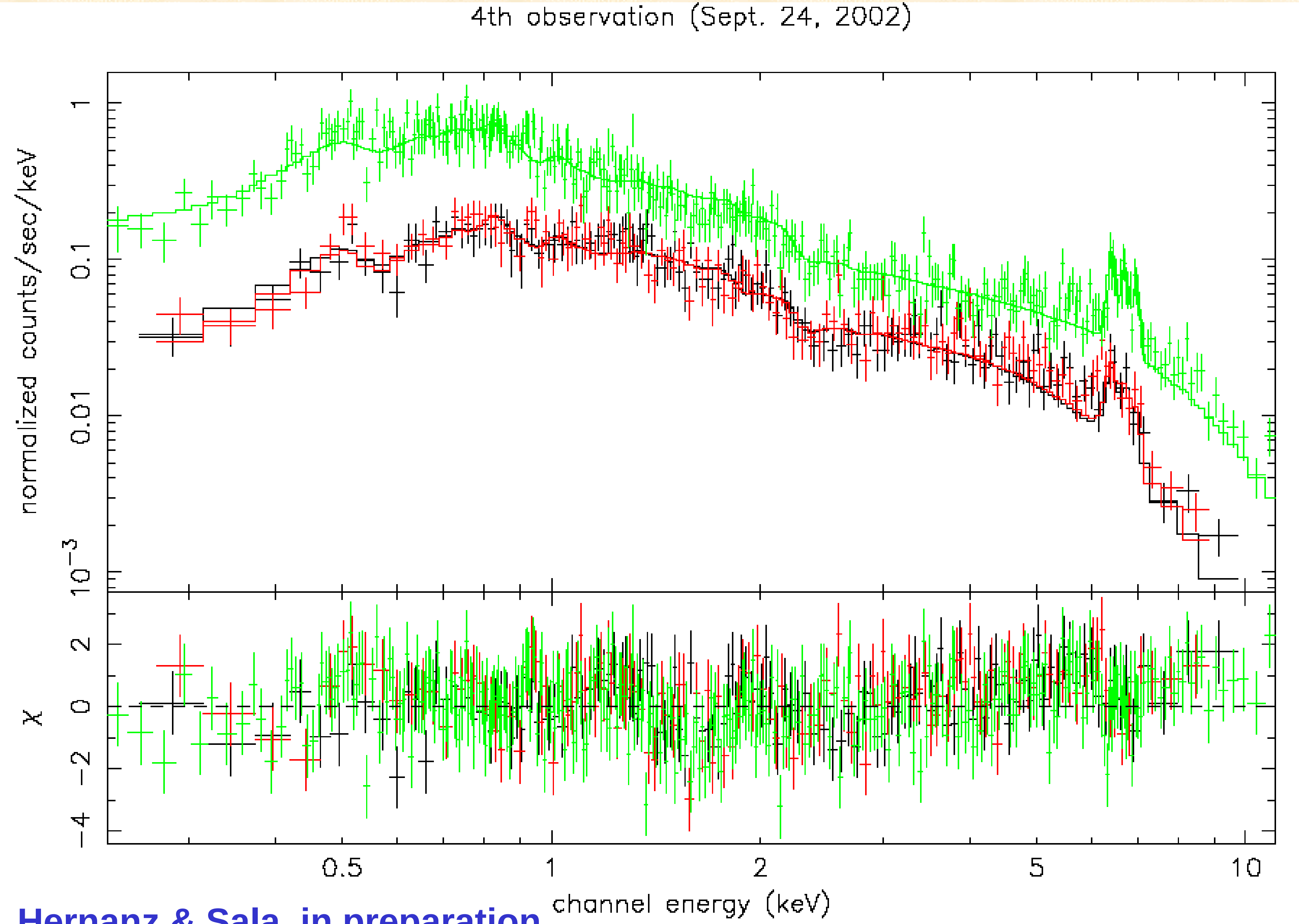


PI channels events	energy range z cuts (cts/s/deg**2)	min(z) max(z)
11 - 39	0.11 - 0.40 keV	0.00
1134	0.00 - 10.00	45.11
40 - 99	0.40 - 1.00 keV	0.00
1196	0.00 - 6.00	50.25
100 - 299	1.00 - 2.40 keV	0.00
697	0.00 - 4.00	26.77

Positional correlation with a source previously discovered by ROSAT (RASS) in 1990 suggests that the site of a nova explosion had been seen in X-rays before the outburst

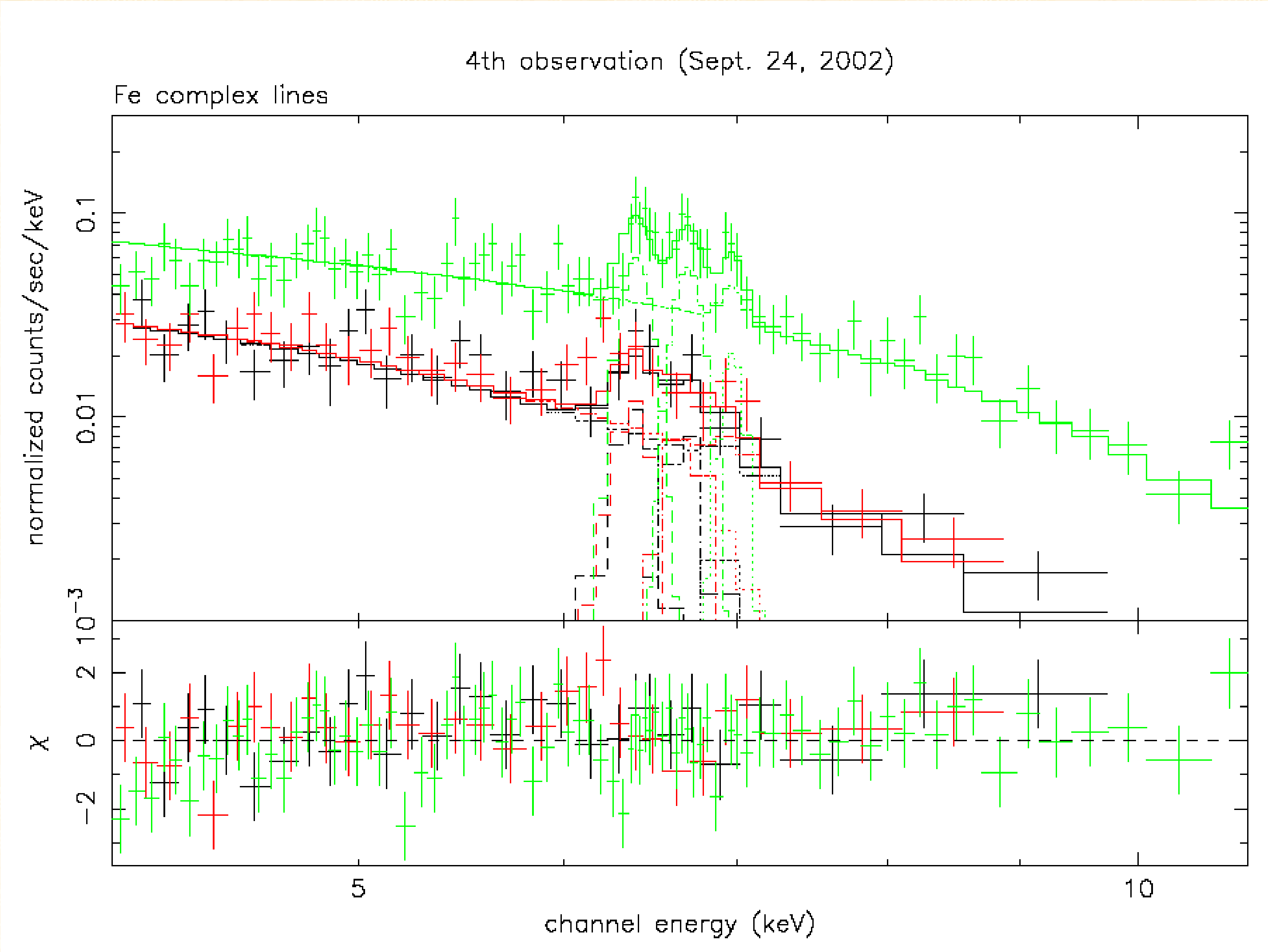
Nova Oph 1998 – V2487 Oph

Nova Oph 1998 – V2487 Oph



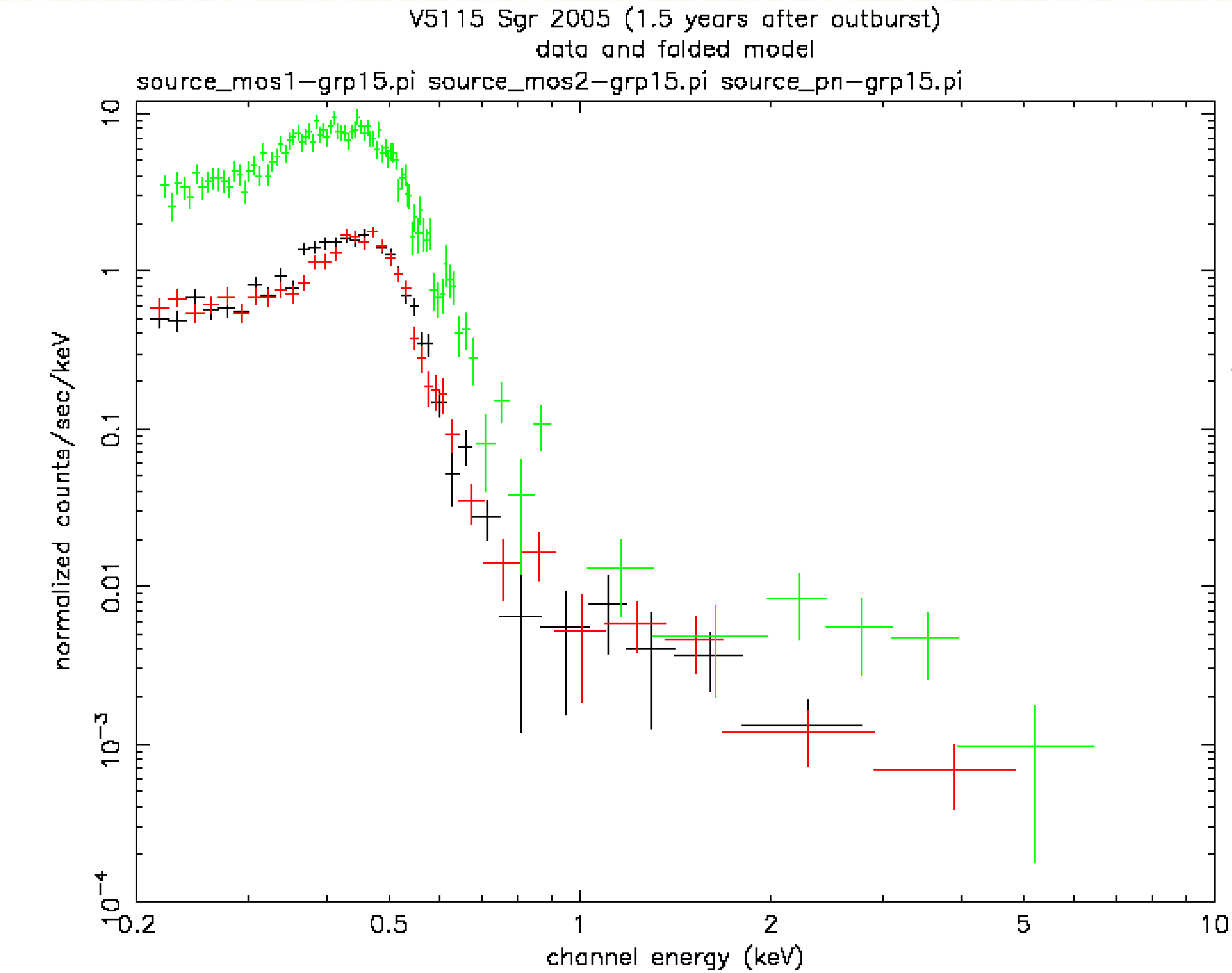
Ferri, Hernanz & Sala, in preparation

Nova Oph 1998 – V2487 Oph



three Gaussian lines at 6.4, 6.7 and 6.97 keV (σ=0.05, 0.05 and ~0 keV, respectively). These energies correspond to Fe Kα fluorescence line (6.4 keV) and to lines from highly ionized Fe (Fe XXV, around 6.7 keV and Fe XXVI, around 6.97 keV).

V5115 Sgr (2005) – 1.5 yrs after outburst



Supersoft emission

preliminary model fit:

- *CO atmosphere*
- *T_{eff}~7x10^{5}K*
- *L~9x10^{36} erg/s*

(d=5 kpc)

still burning H

not published

Different behaviours in X-rays of post-outburst novae (1-4 years old), as seen with XMM-Newton:

- supersoft, still burning H (not very often) - V5115 Sgr (2005):

➡ WD properties: M_{wd}, M_{env}, *chem. comp., turnoff*

- soft and hard X-rays, reaching E~10 keV

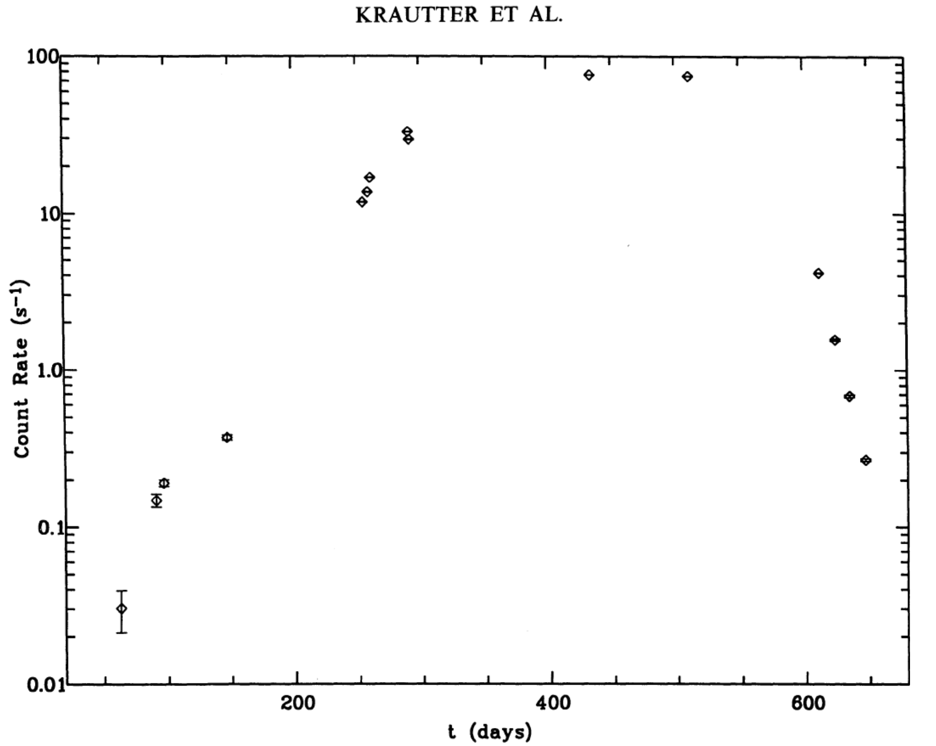
  - *ejecta* (heated by shocks) - V4633 Sgr 1998: T and n distribution, chemical com.

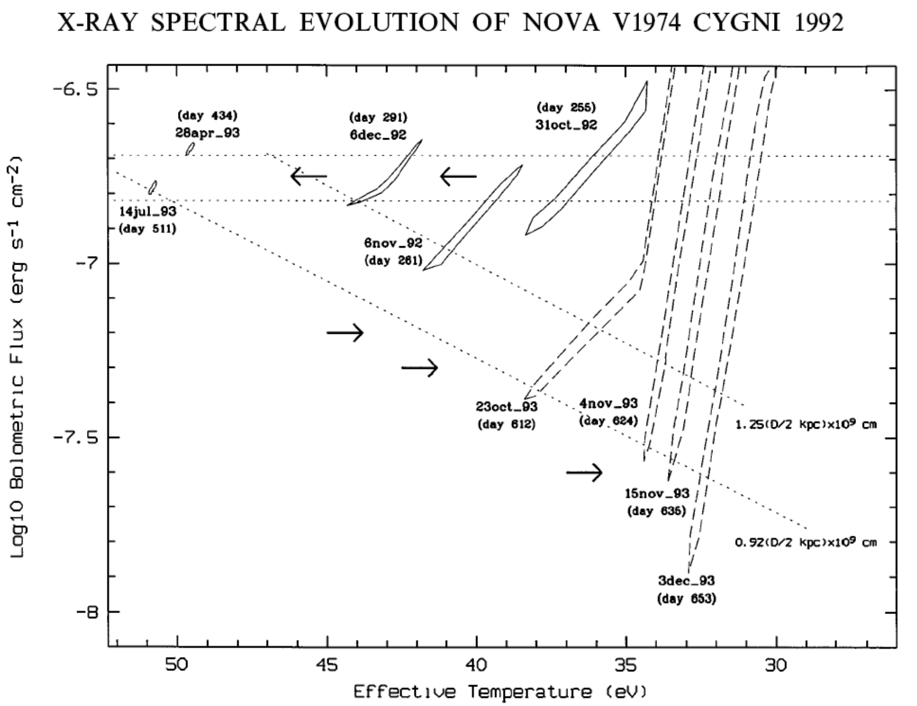
  - "cataclysmic-like" emission *accretion* - V2487 Oph 1998: accretion disk/stream, (magnetic field, periodicities)

X-rays from novae: constraints on models from ROSAT observations of V1974 Cyg 1992:

supersoft source during various months

V1974 Cyg: ROSAT's soft X-ray light curve





Krautter et al. 1996, ApJ

Balman et al. 1998, ApJ

Table 1. ROSAT observational results for V1974 Cyg.

	Day after outburst	$K^{a,b}$ 10^{-25}	$R^{c}_{\rm photos}$ (10^9 cm)	$kT^{b}_{\rm eff}$ (eV)
A	255	0.6–2.4	1.8–3.7	34.3–38.3
B	261	0.3–0.9	1.3–2.3	38.4–41.8
C	291	0.4–0.8	1.5–2.1	41.2–44.3
D	434	0.32–0.36	1.3–1.4	49.4–49.7
E	511	0.22–0.26	1.1–1.2	50.6–51.0

[a] Normalization constant of the white dwarf atmosphere model, $K = (R/D)^2$, where R and D are the photospheric radius and the distance to the source.

[b] Results from Balman et al. (1998).

[c] Photospheric radius for a distance of 2.5 kpc.

Balman et al. 1998, ApJ

A&A 439, 1061–1073 (2005)
DOI: 10.1051/0004-6361:20042622

Astronomy & Astrophysics

Models for the soft X-ray emission of post-outburst classical novae

G. Sala and M. Hernanz

A&A 439, 1057–1060 (2005)
DOI: 10.1051/0004-6361:20042587

Astronomy & Astrophysics

Envelope models for the supersoft X-ray emission of V1974 Cyg

G. Sala and M. Hernanz

stable high L branch

MODELS (steady H-burning)

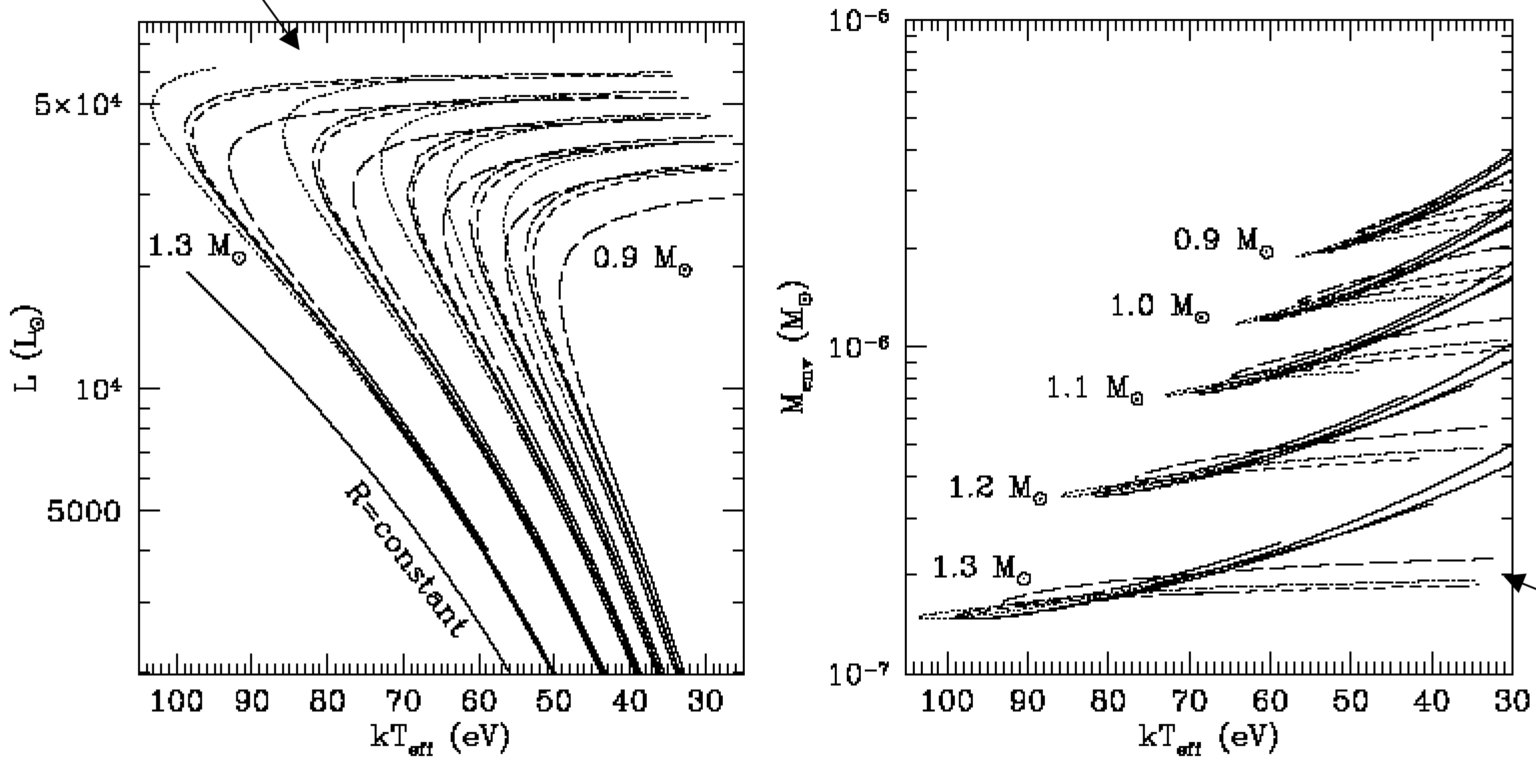


Fig. 1. Total luminosity (*left panel*) and envelope mass (*right panel*) versus effective temperature for our white dwarf envelope models: ONe75 (dotted line), ONe50 (short dash), ONe25 (long dash), and CO50 (short dash–dot). Effective temperature is given in eV, $kT_{\rm eff}$ (eV) = $8.617 \times 10^{-5} T_{\rm eff}$ (K) Solid lines indicate envelopes without convective regions. Five series of models are plotted for each chemical composition, corresponding to total masses 0.9, 1.0, 1.1, 1.2, and 1.3 $M_{\odot}$. A line indicating the luminosity-effective temperature relation for constant photospheric radius is over-plotted in left panel for comparison.

stable high L branch

Model	M_c ($M_\odot$)	$L^{plateau}$ (10^4 $L_\odot$)	kT_{eff}^{max} (eV)	T_{eff}^{max} (10^5 K)	M_{env}^{max} (10^{-6} $M_\odot$)	M_{env}^{min} (10^{-6} $M_\odot$)	$\Delta t_{10\ eV}^{(a)}$ (days)
ONe75 (X = 0.18)	0.9	3.9	57	6.6	2.3	1.9	47
	1.0	4.4	64	7.4	1.4	1.2	24
	1.1	5.2	73	8.5	0.84	0.71	12
	1.2	5.7	86	9.9	0.40	0.35	4.6
	1.3	6.2	103	11.9	0.16	0.15	1.1
ONe50 (X = 0.35)	0.9	3.5	53	6.1	2.7	1.5	160
	1.0	4.1	60	7.0	1.7	1.2	78
	1.1	4.7	69	8.0	0.99	0.72	37
	1.2	5.2	81	9.4	0.45	0.35	14
	1.3	5.6	98	11.4	0.19	0.15	4.9
ONe25 (X = 0.53)	0.9	2.9	49	5.7	3.0	2.2	430
	1.0	3.5	56	6.5	2.1	1.4	210
	1.1	4.0	64	7.5	1.20	0.81	98
	1.2	4.6	77	8.9	0.60	0.39	36
	1.3	5.2	93	10.8	0.22	0.16	12
CO50 (X = 0.35)	0.9	3.6	54	6.2	2.9	1.9	230
	1.0	4.2	61	7.1	1.8	1.2	90
	1.1	4.7	70	8.1	1.0	0.72	48
	1.2	5.4	82	9.5	0.49	0.35	19
	1.3	6.0	99	14.7	0.19	0.15	6

[a] Time needed for the envelope to evolve from $kT_{eff} \simeq kT_{eff}^{max} - 10$ eV to kT_{eff}^{max}.

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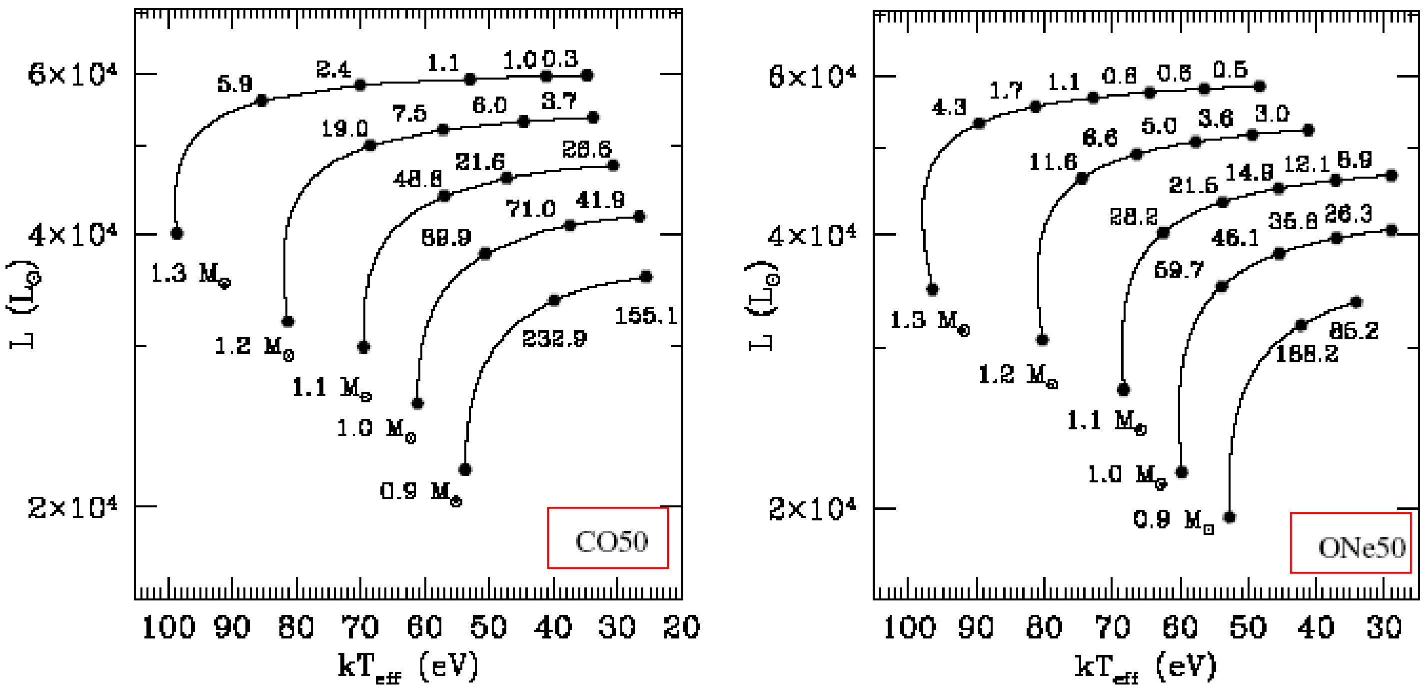
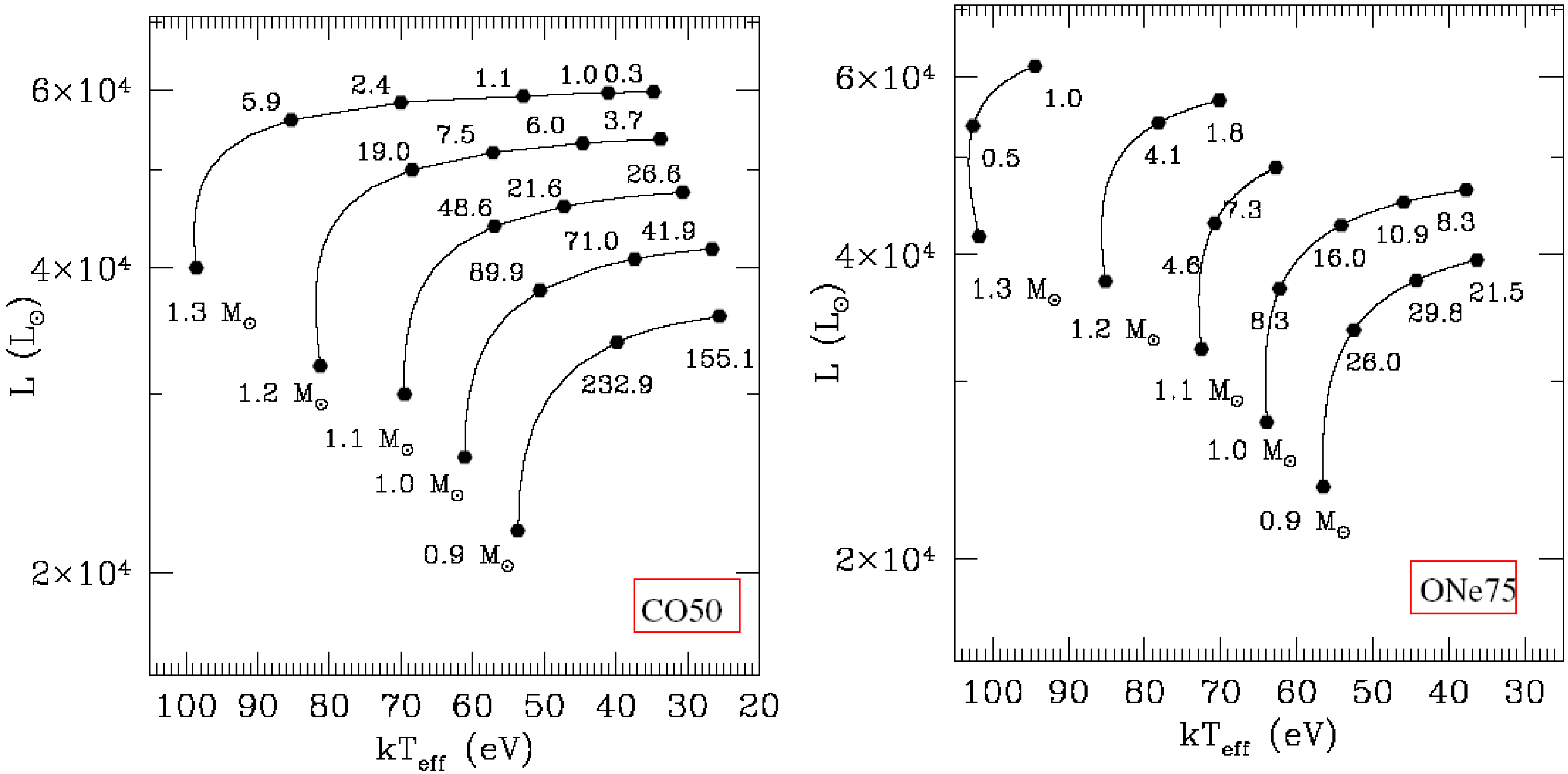


Fig. 10. Luminosity versus effective temperature for the high luminosity branch of CO50 and ONe50 envelopes. Time in days needed for the envelope to evolve between two adjacent ticks is indicated.

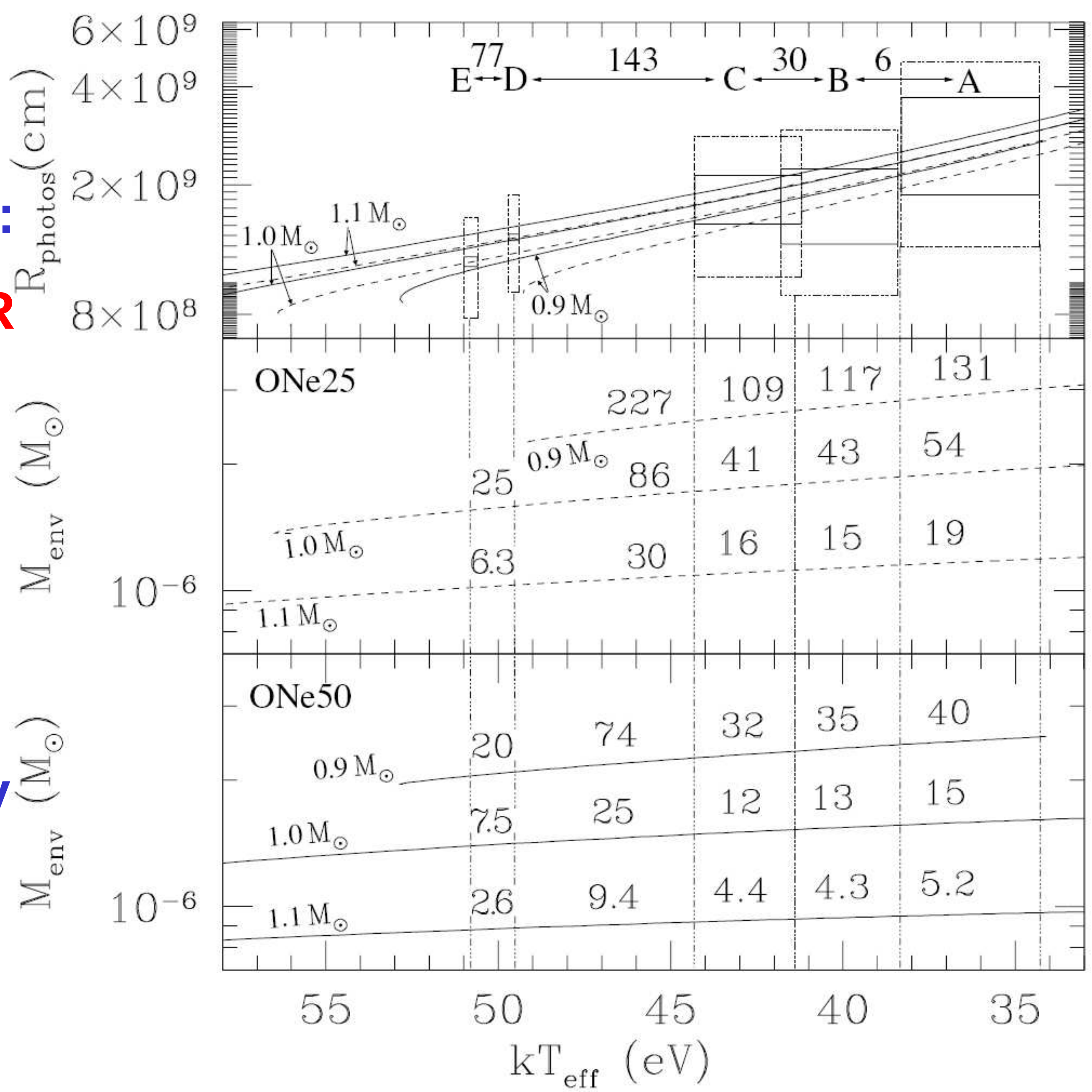
Quasi-static temporal evolution



Quasi-static temporal evolution

Comparison model-observation:

evolution of T_{eff} & R (or L)with time



- **IMPORTANT:**

T_{eff} max. would directly constrain M_{wd}, independently of distance

Models that best explain the supersoft X-ray emission of V1974 Cyg 1992 and its evolution

- M_{wd}=0.9 $M_\odot$, 50% mixing with CO core (but V 1974Cyg 1992 was a neon nova!)

or

- M_{wd}=1.0 $M_\odot$, 25% mixing with ONe core

[in goog agreement with recent models of the optical and UV light curve (Kato & Hachisu, 2006)]

- M_{env}~2x10^{-6} $M_\odot$