Observations de novae classiques avec MAX

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Scenario

Mass transfer from the companion star onto the white dwarf (cataclysmic variable)

↓

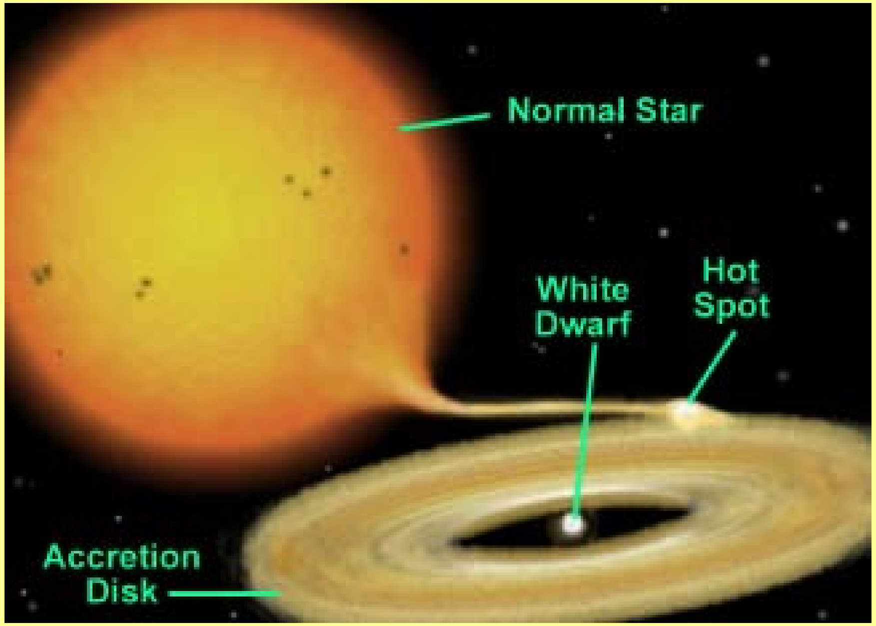
Hydrogen burning in degenerate conditions on top of the white dwarf

↓

Thermonuclear runaway

↓

Explosive H-burning ↗



Decay of short-lived radioactive nuclei in the outer envelope (transported by convection)

↓

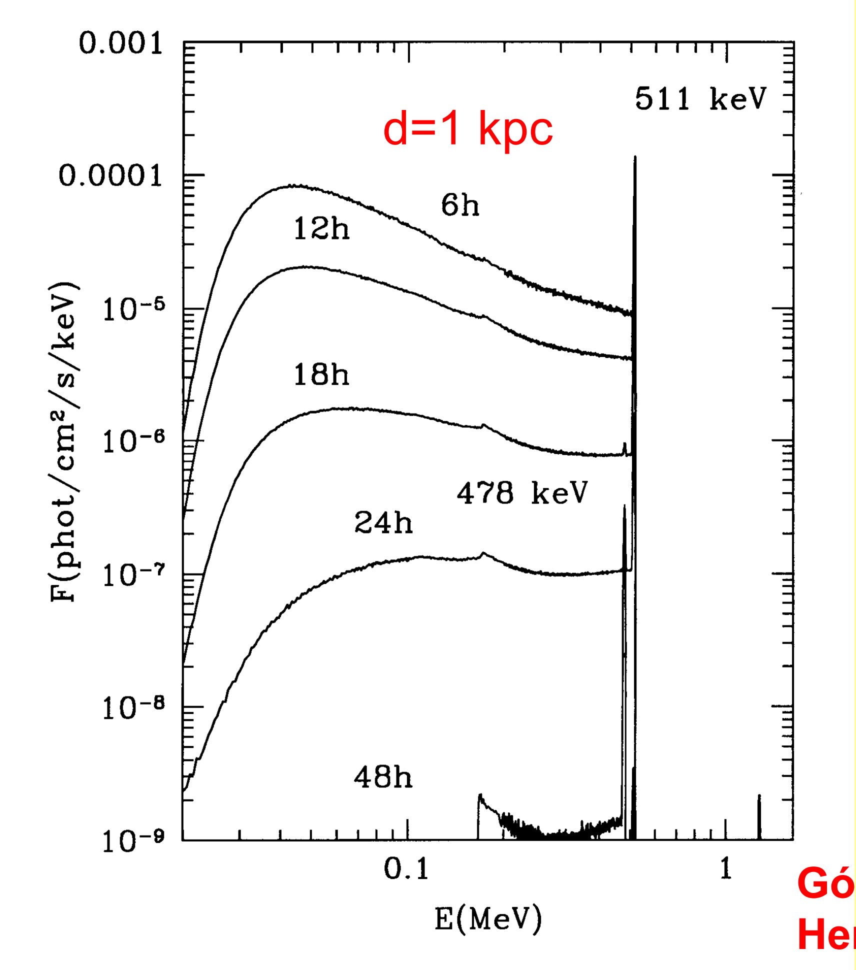
Envelope expansion, L increase and mass ejection

Main radioactive isotopes synthesized in classical novae

Nucleus	τ	Type of emission	Nova type
^{13}N	862 s	511 keV line continuum (E<511 keV)	CO and ONe
^{18}F	158 min	511 keV line continuum (E<511 keV)	CO and ONe
^{7}Be	77 days	478 keV line	CO mainly
^{22}Na	3.75 yr	1275 keV line	ONe
^{26}Al	$1.0X10^{6}$ yr	1809 keV line	ONe

Spectra of CO novae

$M_{WD} = 1.15\ M_\odot$



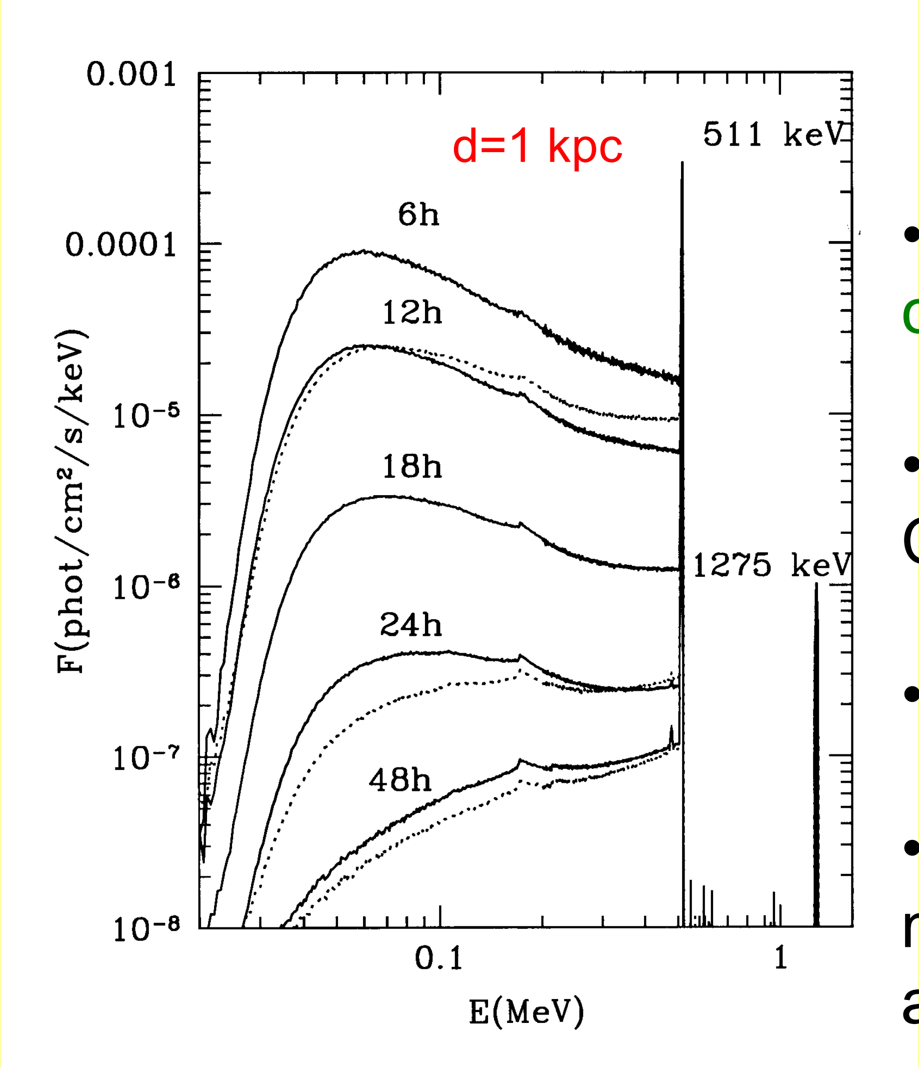
- e^--e^+ annihilation and Comptonization → continuum and 511 keV line; e^+ from ^{13}N and ^{18}F

→ predicted theoretically by Clayton & Hoyle 1974; Leising & Clayton 1987

- photoelectric absorption → cutoff at 20 keV
- 478 keV line from ^7Be decay
- transparent at 48 h

Gómez-Gomar, Hernanz, José, Isern,1998, MNRAS
Hernanz et al 1999, ApJL

Spectra of ONe novae



M_{WD} = 1.15 $M_\odot$ (solid)
1.25 $M_\odot$ (dotted)

- photoelectric absorption → cutoff at 30 keV
- continuum and 511 keV as in CO novae
- 1275 keV line from ^{22}Na decay
- similar behaviour for the 2 models, because of similar KE and yields

Observations: 1275 keV line (^{22}Na)

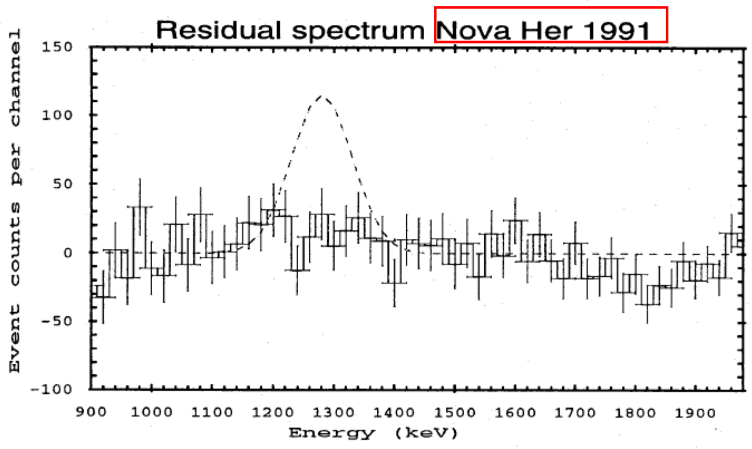


Fig. 1. Sum of residual spectra of Nova Her 1991 for the viewing periods 7.5, 13.0, 20 and 231. Statistical 1 σ error bars are shown. The dashed line represents the expected ^{22}Na line appearance according to the ejecta mass derived by Woodward et al. 1992, with a ^{22}Na mass fraction of model 3 of Starrfield et al. 1992. This signal would have been seen by COMPTEL at the significance level of $\sim 8\ \sigma$

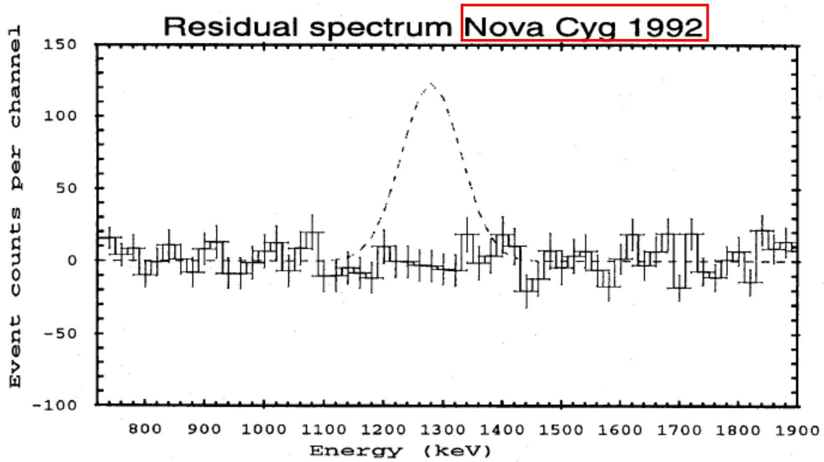


Fig. 2. Sum of the background-subtracted spectra of Nova Cyg 1992 for the viewing periods 34, 203 and 212. Statistical error bars are shown. The dashed line represents the expected ^{22}Na line appearance according to the predictions of Starrfield et al. 1992. This signal would have been seen by COMPTEL at the significance level of $\sim 17\ \sigma$

CGRO/COMPTEL: no detection; upper limits

Iyudin et al. 1995, A&A

➡ predicted theoretically by Clayton & Hoyle, 1974

Observations : 1275 keV line (^{22}Na)

Table 2. List of the recent novae searched for the presence of ^{22}Na line emission and the derived upper limits.

Nova name	Galactic l	b	Date of max m_v	Nova type	2 σ up. lim. ph./(cm^{2}s)
Cen 1991	309.5°	-1.04°	17-Mar-91	stand.	4.0E-05
Her 1991	43.3°	6.6°	24-Mar-91	neon	3.3E-05
Sgr 1991	0.18°	-6.94°	29-Jul-91	neon	6.2E-05
Sct 1991	25.1°	-2.80°	08-Aug-91	neon	3.6E-05
Pup 1991	252.7°	-0.72°	27-Dec-91	neon	5.5E-05
Cyg 1992	89.14°	7.82°	20-Feb-92	neon	2.3E-05
Sco 1992	343.8°	-1.61°	26-May-92	stand.	5.9E-05
Sgr 1992-1	4.75°	-2.0°	06-Feb-92	stand.	6.0E-05
Sgr 1992-2	4.56°	-6.96°	19-Jul-92	stand.	3.0E-05
Sgr 1992-3	9.38°	-4.54°	29-Sep-92	stand.	4.4E-05
Aql 1993	36.81°	-4.10°	17-May-93	stand.	6.2E-05

Upper limits in agreement with current theoretical predictions

Table 3. COMPTEL limits on the ejected ^{22}Na mass from recent novae.

Nova	m_v at max	M_v at max	t_3 days	d kpc	2 σ up. limit to ^{22}Na mass ej.
Her 1991	5.3	-9.5	4	3.4	$1.2 \cdot 10^{-7}$ $M_\odot$
Sgr 1991	~ 7	-9.5	47	12.5	$2.4 \cdot 10^{-6}$ $M_\odot$
Sct 1991	10.5	-8.9	10	12	$2.0 \cdot 10^{-6}$ $M_\odot$
Pup 1991	6.4	-8.5	26	3.5	$1.5 \cdot 10^{-7}$ $M_\odot$
Cyg 1992	4.4	-7.6	47	2.3	$3.0 \cdot 10^{-8}$ $M_\odot$
neon-type	-	-	-	2	$3.7 \cdot 10^{-8}$ $M_\odot$
standard	-	-	-	2	$4.9 \cdot 10^{-8}$ $M_\odot$

Iyudin et al. 1995, A&A

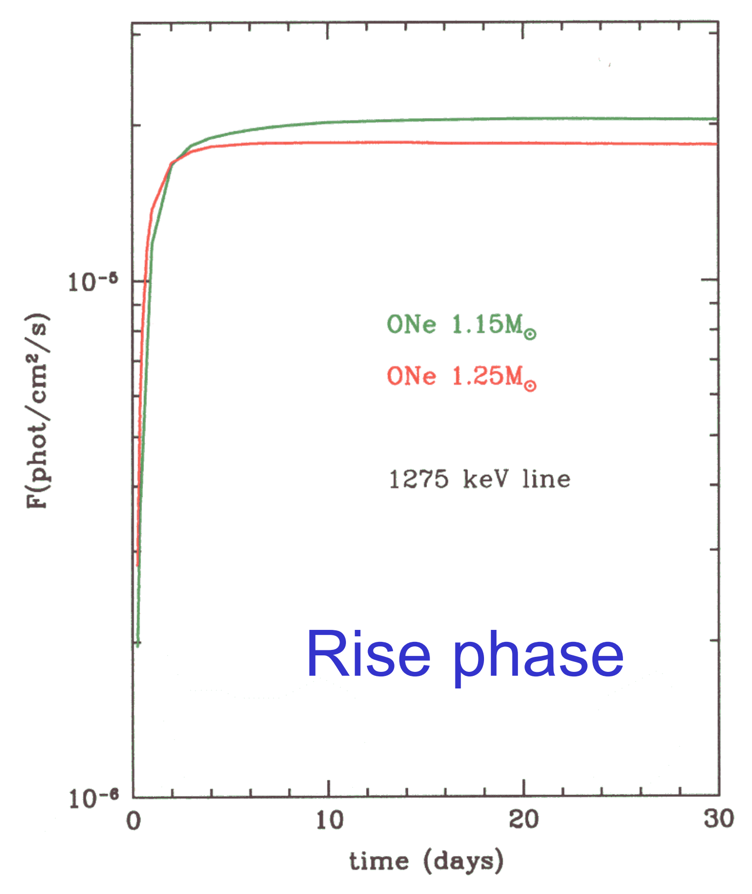
Theoretical predictions: ^{22}Na ejected masses by ONe novae

WD mass	Minimum	Best	Maximum*	Max/Min
1.15	$3.1\cdot10^{-9}$	$7.0\cdot10^{-9}$	$1.4\cdot10^{-8}$	4.5
1.25	$3.4\cdot10^{-9}$	$6.3\cdot10^{-9}$	$1.2\cdot10^{-8}$	3.5
1.35	$3.4\cdot10^{-9}$	$4.4\cdot10^{-9}$	$6.2\cdot10^{-9}$	1.8

(all in $M_\odot$) José, Coc and Hernanz 1999, ApJ

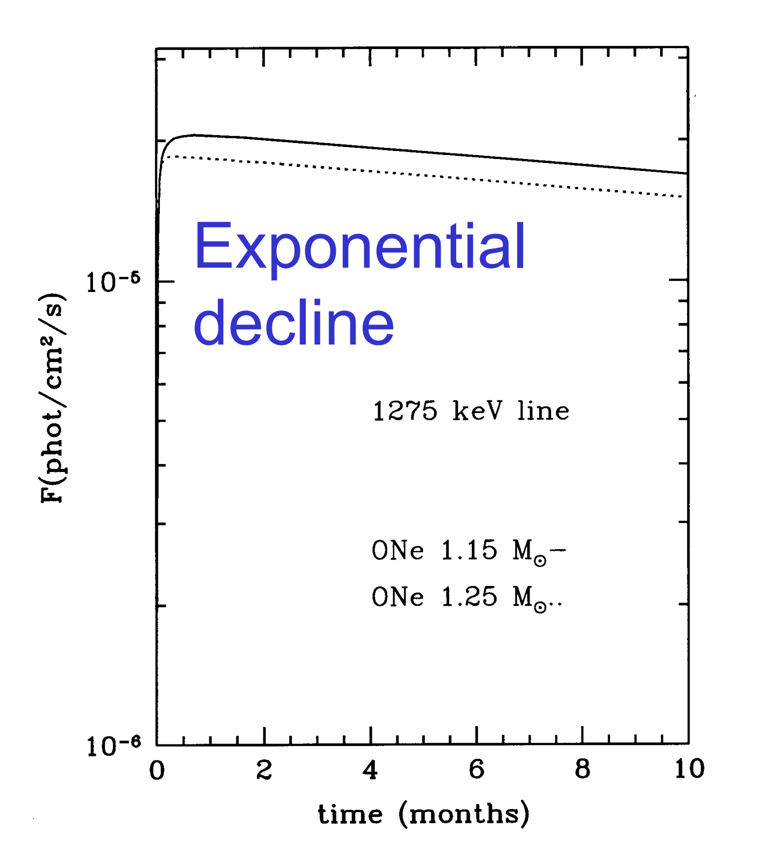
* Coc and Smirnova 2000, Phys.Rev. C: smaller Max/Min

Light curves: 1275 keV (^{22}Na) line



Only in ONe novae

d=1 kpc



t_{max}: 20 days (1.15M$_{ù}$), 12 days (1.25 M$_{ù}$), line width ~ 20 keV

duration: some months   Flux ~ 2x10^{-5} ph/cm^2/s

➡ predicted theoretically by Clayton & Hoyle, 1974

Detectability with MAX of the 1275 keV (^{22}Na) line from novae, if there was an "extra ring" with the same sensitivity at 1275 keV that the current one at 847 keV

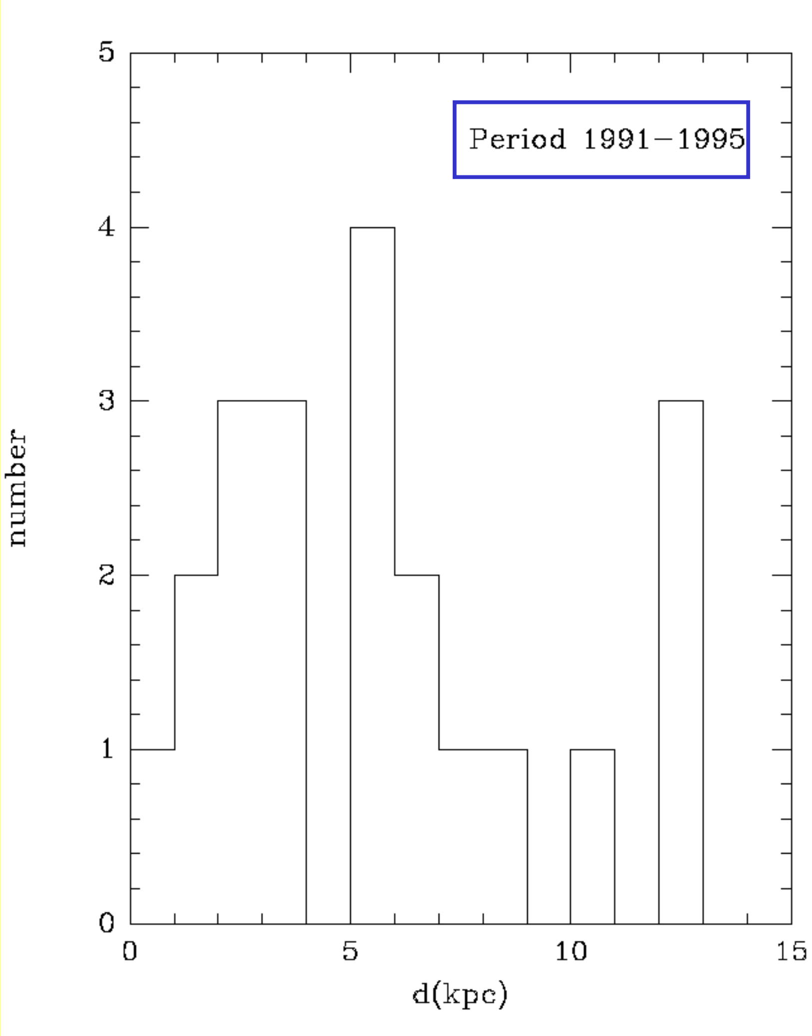
- If MAX sensitivity at 1275 keV were ~3 10^{-7} ph/cm^2/s (extrapolated from figure 4b in the MAX concept document, V2.0, 2/2003), it could detect the ^{22}Na line from novae up to 8 kpc (ideal case of a narrow line; the line has a width around 20 keV).

- Number of novae per year at d≤8 kpc: **16 every 5 years,** i.e. virtually ***all novae*** (or half of them, since only ONe emit produce ^{22}Na)

Novae distances (observed)

Distances from Shafter 1997, ApJ

These data have been used to estimate the previously mentioned probabilities to have novae at given distances



Observations: 478 keV line (^{7}Be)

TGRS

SMM

RESULTS FOR 478 keV LINE FLUXES AND ^{7}Be YIELDS

TARGET	DISTANCE[a] (pc)	ZENITH ANGLE (deg)	FLUX (γ cm^{-2} s^{-1}) Observed[b]	FLUX (γ cm^{-2} s^{-1}) Expected[c]	IMPLIED ^{7}Be MASS[b] ($M_\odot$ per Nova)
Individual Novae					
Undiscovered nova......		60	1.0×10^{-4}		
BY Cir....................	3160	45	6.8×10^{-5}	1.1×10^{-5}	3.0×10^{-8}
V888 Cen.................	4800	42	6.3×10^{-5}	4.9×10^{-6}	6.4×10^{-8}
V4361 Sgr	6700	95	1.1×10^{-4}	2.5×10^{-6}	2.2×10^{-7}
CP Cru	3180[d]	37	8.8×10^{-5}	2.2×10^{-6}	3.9×10^{-8}
V1141 Sco................	6120	97	1.6×10^{-4}	3.0×10^{-6}	2.7×10^{-7}
V1370 Aql[e]...............	3500		1.2×10^{-3}	1.8×10^{-6}	6.3×10^{-7}
QU Vul[e]..................	3000		7.5×10^{-4}	2.5×10^{-6}	3.1×10^{-7}
V842 Cen[e]................	1100		9.6×10^{-4}	9.3×10^{-5}	5.2×10^{-8}
GC Integrated					
TGRS.....................	8000	84.5	7.7×10^{-5}	$7.8R_N \times 10^{-8}$	$3.4 \times 10^{-6}/R_N$[f]
SMM	8000		1.5×10^{-4}	$1.6R_N \times 10^{-7}$	$3.5 \times 10^{-6}/R_N$[f]

Theory: $F<2.5\times10^{-6}/d_{kpc}^{2}$

Harris et al. 1991 and 2001

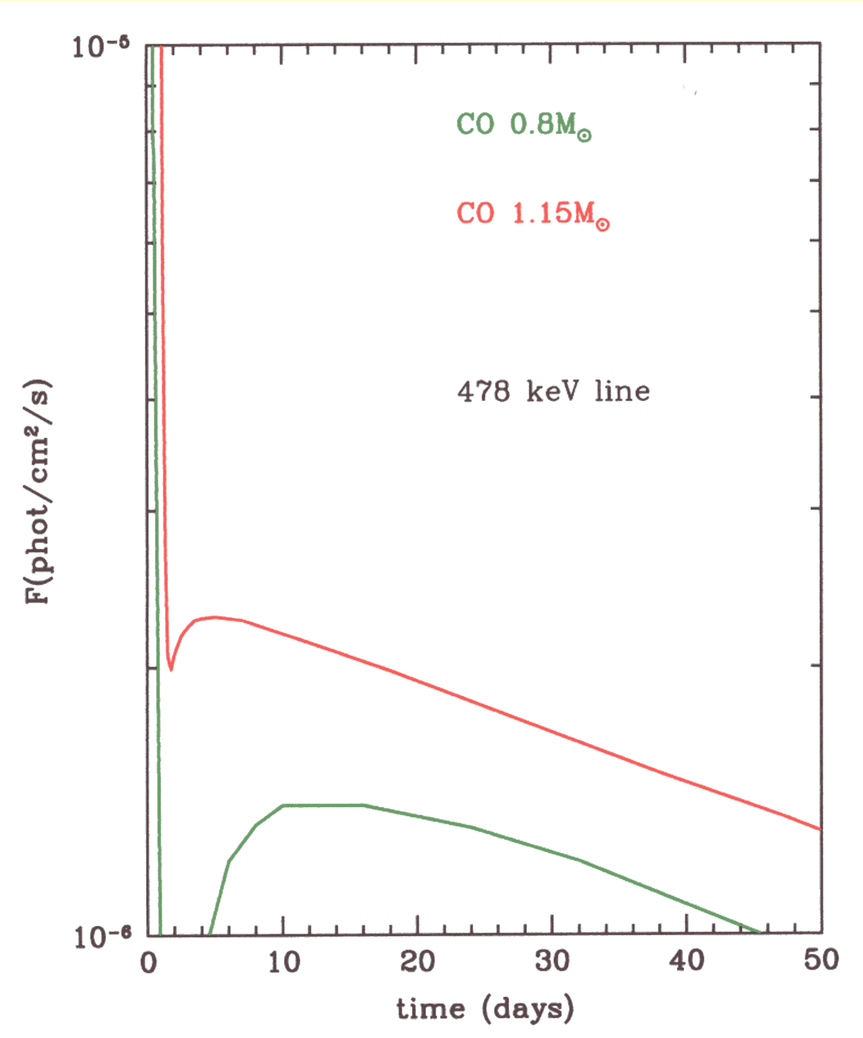
➡ predicted theoretically by Clayton 1981

Theoretical predictions: ^{7}Be ejected masses by novae

WD mass	Nova type	Ejected mass of ^{7}Be
0.8	C O	$6.0 \cdot 10^{-11}$
1.15	C O	$1.1 \cdot 10^{-10}$
1.15	O Ne	$1.6 \cdot 10^{-11}$
1.25	O Ne	$1.2 \cdot 10^{-11}$

(all in $M_{\odot}$)

Light curves: 478 keV (^{7}Be) line



Mainly in CO novae

t_{max}: 13 days (0.8M$_\odot$)

5 days (1.15 M$_\odot$)

duration: some weeks

Flux ~ (1-2)x10^{-6} ph/cm^2/s

Line width: 3-7 keV

d=1 kpc

➡ predicted theoretically by Clayton 1981

Detectability with MAX of the 478 keV (^7Be) line from novae

- If MAX sensitivity at 478 keV is ~3 10^{-7} ph/cm^2/s (taken from figure 4a in the MAX concept document, V2.0, 2/2003), it could detect the ^7Be line from novae up to 2 kpc (ideal case of a narrow line; the line has a width between 3 and 7 keV).

- Number of novae per year at d$\leq$2 kpc: 3 every 5 years (small number statistics $\Rightarrow$ large fluctuations)

Observations: 511 keV line

WIND/TGRS: no detection; upper limits

Upper Limits on 511 keV Line Emission from Novae

Nova	Angle of Incidence (deg)	Mean 3 σ Upper Limit in 6 hr (photon cm^{-2} s^{-1})
Nova Cir 1995	44.9	2.2×10^{-3}
Nova Cen 1995......	42.0	2.0×10^{-3}
Nova Sgr 1996	95.2	2.8×10^{-3}
Nova Cru 1996......	36.9	2.3×10^{-3}
Nova Sco 1997	83.4	2.9×10^{-3}

- Observation of 5 known Galactic novae in the broad TGRS FOV in the period 1995 Jan - 1997 June
- High E-resolution Ge detector: ability to detect 511 keV line blueshifted w.r.t. background line

Harris et al. 1999, ApJ

Observations: 511 keV line

WIND/TGRS: “constraining” the Galactic nova rate from a survey of the Southern Sky during 1995-1997

From the non detection, an upper limit of the Galactic nova rate was extracted:

$< 123\ yr^{-1}$ (CO novae; $r_{detect.}$: 0.9 kpc)

$< 238\ yr^{-1}$ (ONe novae; $r_{detect.}$: 0.7 kpc)

Promising for future wide FOV instruments sensitive in the soft γ-ray range (20-511) keV

Harris et al. 2000, ApJ

Summary of BATSE observations: 3-σ upper limits to the fluxes (ph/cm²/s)

Nova Cyg 1992 (model: 1.25$M_\odot$ ONe nova at d=1.7 kpc)

	F(obs)	F(model)
(250-511) keV	$5.2 \cdot 10^{-3}$	$2.3 \cdot 10^{-3}$
511 keV line (*)	$1.0 \cdot 10^{-3}$	$4.8 \cdot 10^{-4}$
511 keV line (**)	$2.4 \cdot 10^{-3}$	$4.8 \cdot 10^{-4}$

Nova Sco 1992 (model: 1.15$M_\odot$ CO nova at d=0.8 kpc)

	F(obs)	F(model)
(250-511) keV	$3.6 \cdot 10^{-3}$	$5.3 \cdot 10^{-3}$
511 keV line (*)	$7.1 \cdot 10^{-4}$	$1.0 \cdot 10^{-3}$
511 keV line (**)	$2.3 \cdot 10^{-3}$	$1.0 \cdot 10^{-3}$

Nova Vel 1999 (model: 1.25 $M_\odot$ ONe nova at d=2 kpc)

	F(obs)	F(model)
(250-511) keV	$5.3 \cdot 10^{-3}$	$1.7 \cdot 10^{-3}$
511 keV line (*)	$1.0 \cdot 10^{-3}$	$3.5 \cdot 10^{-4}$
511 keV line (**)	$1.6 \cdot 10^{-3}$	$3.5 \cdot 10^{-4}$

* using 250-511 keV data with assumed Comptonization; ** using 511 keV data only

Summary of BATSE observations

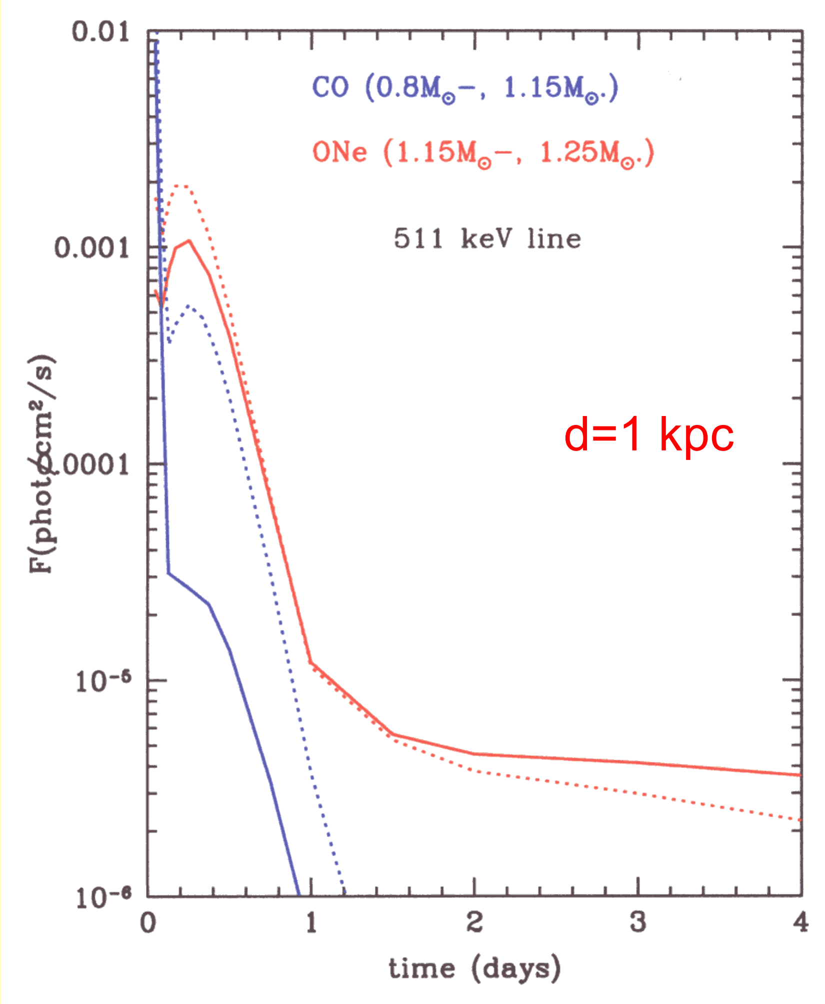
- All upper limits are compatible with theory except for Nova Sco92, which should either have $M < 1.15\ M_\odot$, $d > 0.8$ kpc, or both.

-The 3-σ sensitivity using the 511 keV line only is similar to that of Harris et al. 1999 with Wind/TGRS. But the sensitivity of Harris et al. requires a particular line blueshift, whereas ours is independent on the blueshift.

- The 3-σ sensitivity using the 250-511 keV data with assumed Comptonization is a little more than a factor of 2 better than Harris et al. 1999.

Light curves: 511 keV line

In CO and ONe novae



Model	t_{max} * (h)	F_{max} (ph/cm^2/s) **
CO, 0.8 $M_\odot$	- - -	2.6 x 10^{-5}
CO, 1.15 $M_\odot$	6.5	5.3 x 10^{-4}
ONe, 1.15 $M_\odot$	6	1.0 x 10^{-3}
ONe, 1.25 $M_\odot$	5	1.9 x 10^{-3}

- 511 keV line in ONe novae remains after 2 days until ~ 1 week because of e^+ from ^{22}Na
- Intense (but short duration)
- Very early appearence, before visual maximum (i.e, before discovery)

Detectability with MAX of the 511 keV line from novae

- If MAX sensitivity at 511 keV is ~10^{-6} ph/cm^2/s (taken from figure 4a in the MAX concept document, V2.0, 2/2003), it could detect the 511 keV line from novae up to 14-5 kpc, with an observation time of 10h, less than 24 h after outburst (ideal case of a narrow line; the line has a width between 3 and 8 keV).

- Number of novae per year at: d≤14 kpc: **16 every 5 years,** i.e. virtually ***all novae;*** d≤5 kpc: **9 every 5 years,** i.e., **~2 novae /year**

- *IMPORTANT*: tail related to e^+ from ^{22}Na has a longer duration (~2 weeks) with F~3 10^{-6} ph/cm^2/s: detectable with MAX up to ~2kpc (like ^{7}Be line), i.e., ~**3 every 5 years**

- *Cotinuum also very intense*