Nova M31N 2007-12b: supersoft X-rays reveal an intermediate polar?

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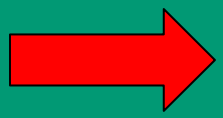
A&A 531, A22 (2011)

M31 optical nova/SSS observations for many novae simultaneously

- Optical
  - Detection
  - Light curves
  - Spectral classification
- X-ray
  - Light curves (start and end of SSS phase)
  - Spectra (temperature, absorption, luminosity)
- Results
  - Mass of ejected matter
  - Burned mass
  - White dwarf masses



Some recurrent novae precursor of type Ia Supernovae?

Modeling of nova SSS state

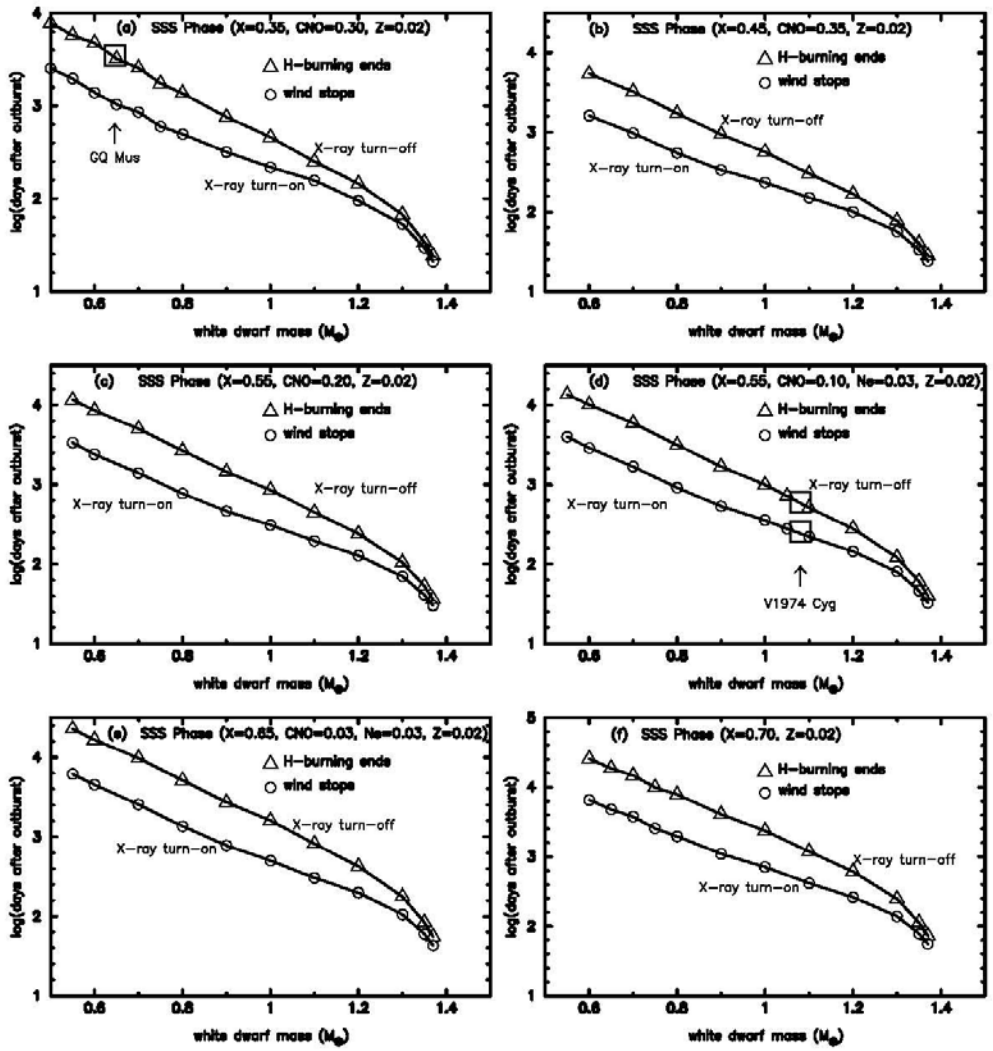


FIG. 3.—Turn-on (*circles*) and turnoff (*triangles*) times of supersoft X-ray are plotted against the WD mass. X-ray turn-on corresponds to the epoch when optically thick winds stop, while X-ray turnoff corresponds to the epoch when hydrogen shell-burning ends. A total of 72 cases are plotted for six different chemical compositions: (*a*) case CO 2 in Table 2, a large square indicates the epoch of supersoft X-ray turnoff for GQ Mus 1983 (Shanley et al. 1995); (*b*) case CO 3; (*c*) case CO 4; (*d*) case Ne 2, two large squares indicate the epochs of supersoft X-ray turn-on and turnoff for V1974 Cyg 1992 (Krautter et al. 1996); (*e*) case Ne 3; (*f*) solar composition. [*See the electronic edition of the Supplement for a color version of this figure.*]

Ejected mass
Burned mass
WD mass
Chem. Comp.

e.g.

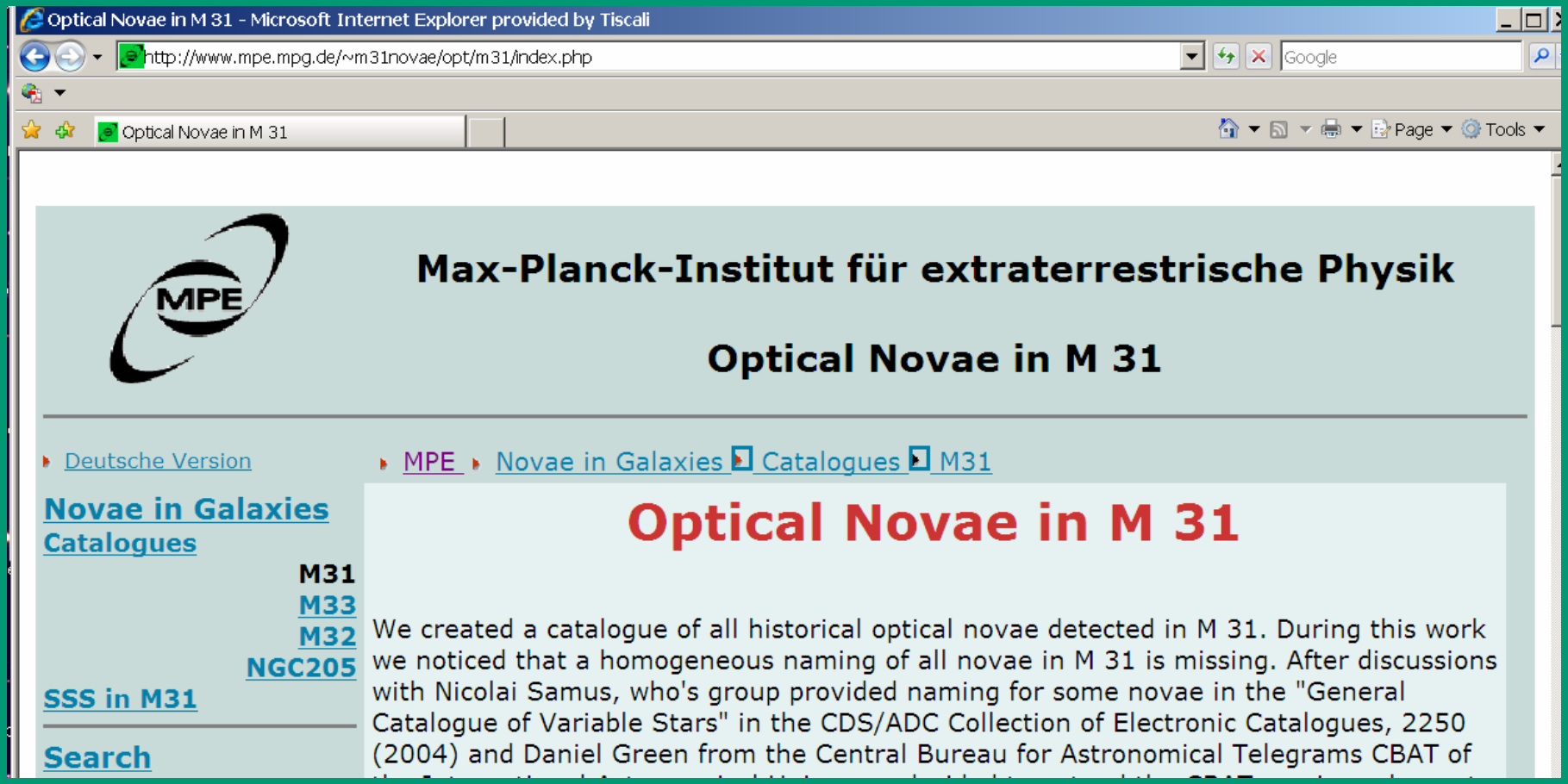
Sala & Hernanz 2005
A&A 439, 1061

Hachisu & Kato 2006
ApJS 167, 59

Observations of optical novae in M31

- >50 novae per year in M31
- More than half of the novae in bulge area
- Several candidates for recurrent novae
- Monitoring of bulge area gives light curves of many novae simultaneously in one XMM-Newton/Chandra field (Galactic novae can only be monitored one by one, i.e. observation time used much less efficient)
- Only X-ray observations with good low energy sensitivity can detect SSS efficiently (EPIC pn, HRC-I, ACIS-S)
- Archival X-ray observations have un-regular sampling
- Dedicated XMM-Newton/Chandra proposals accepted
  - AO5: eight observations with 1.5 month separation distributed over one year
  - AO6 - AO10: 5x ten observations with 10 day separation distributed over about 3 months + several additional Chandra GTO observations
- Detection of novae in the optical and classification of optical spectra essential for interpretation of X-ray data
- Statistical analysis: talk by Martin Henze before Coffee break

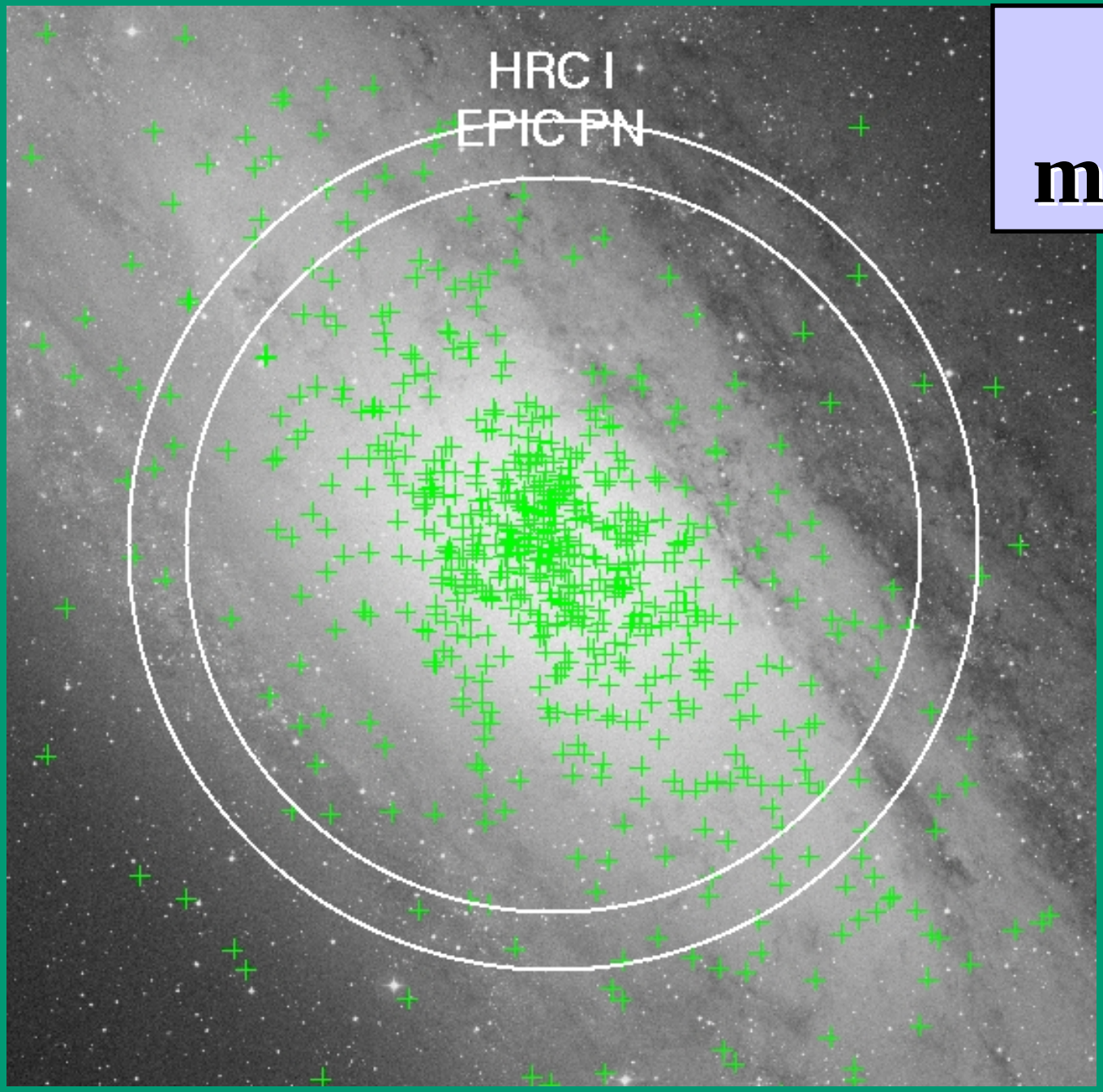
M31 optical nova catalog I



M31 optical nova catalog II

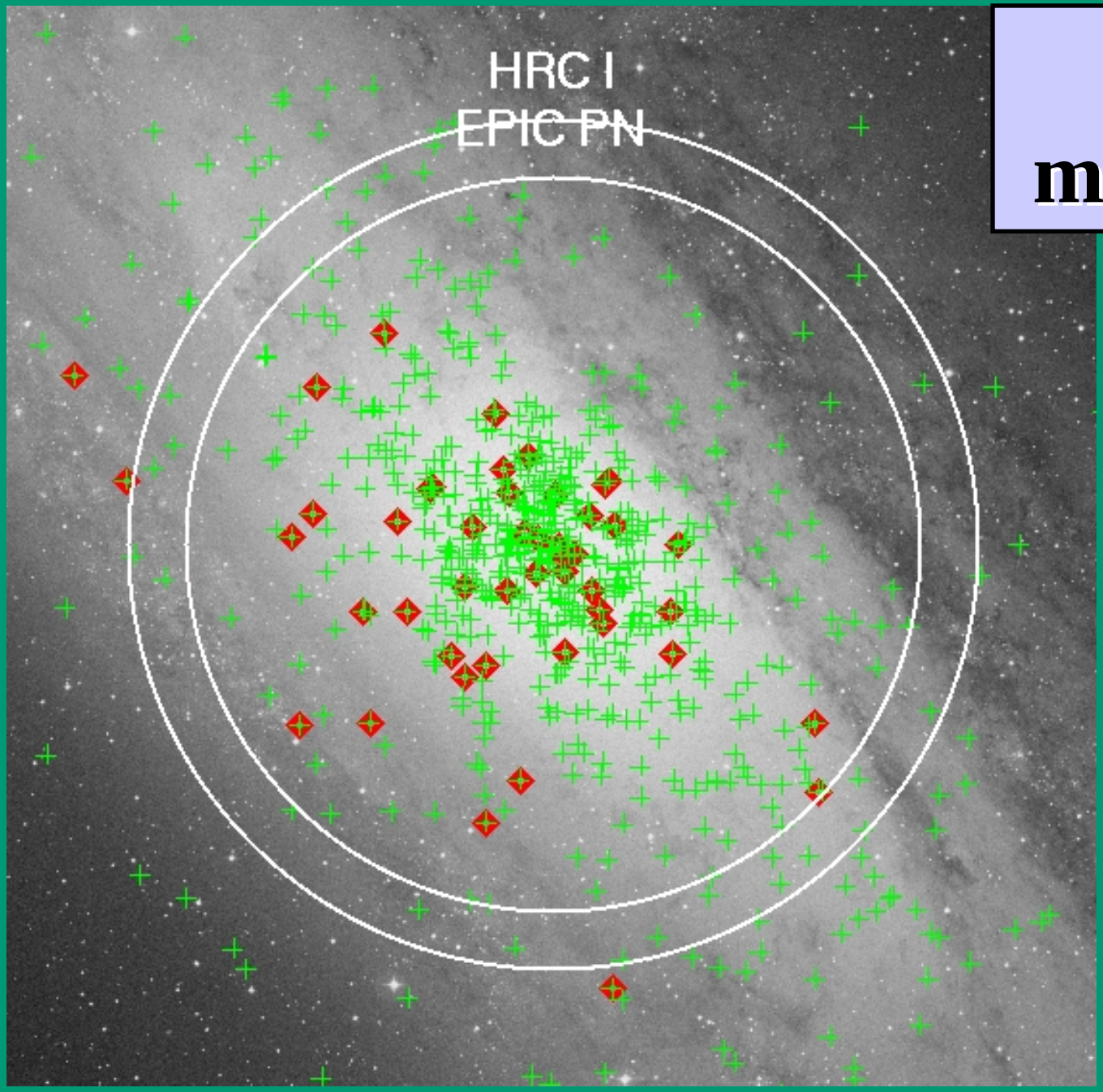
name M31N	RA DEC	error	Pos_ref	JD	JD_ref	ID_out	ID_ref	MAG	Filt	M_ref	T2_1	T2_2	T2_ref	alt. name
2009-02b	00 : 42 : 27.77 + 41 : 13 : 42.4	0.3 0.3	364	2454882.63	364			18.5	R	364				
2009-02a	00 : 43 : 43.81 + 41 : 36 : 38.8	1.0 1.0	360	2454868.93	360	a	360	16.8	w	360				
2009-01a	00 : 44 : 44.03 + 41 : 23 : 28.3	0.5 0.5	356	2454859.92	356			18.5	w	356				
2008-12b	00 : 43 : 04.85 + 41 : 17 : 51.6	0.3 0.3	353	2454830.21	354	a	353	16.8	w	353				P60-M31-081230
2008-12a	00 : 45 : 28.80 + 41 : 54 : 10.1	0.5 0.5	352	2454826.98	352			18.7	w	352				
2008-11c	00 : 43 : 18.62 + 42 : 10 : 14.2	0.5 0.1	342	2454797.00	342			18.2	w	342				

alt. names	alt. ref.	spectral ref.	x-ray ref.	finding charts	spectra	com
	365 , 366 , , ,	, ,	, ,	SuperLOTIS , LGS		rec. cand. 99.44y M31N1909-09b (367)
	361 , , , ,	362 , ,	, ,	Nishiyama , LGS		FeII (362)
	, , , ,	359 , ,	, ,	Nishiyama , LGS		FeII, slow nova? (359)
)	355 , , , ,	354 , ,	, ,	Nishiyama , LGS		FeII (354)
	, , , ,	, ,	, ,	Nishiyama , LGS		
	345 , , , ,	343 , 344 ,	, ,	Itagaki , DSS2		not a nova, SN z=0.07 (343, 344)



M 31 monitoring

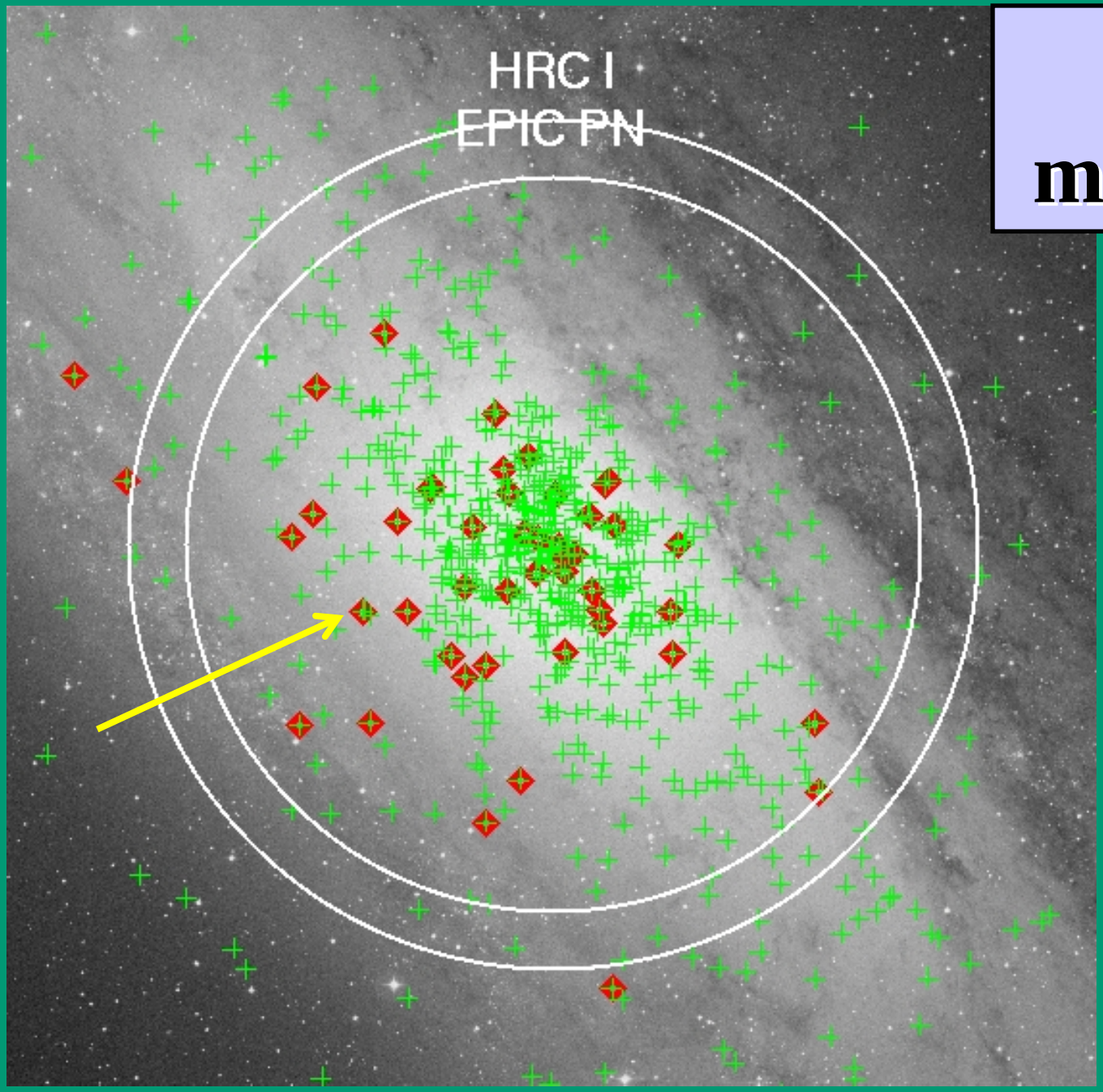
Optical novae over-plotted



M 31 monitoring

Optical novae over-plotted

X-ray novae over-plotted



M 31 monitoring

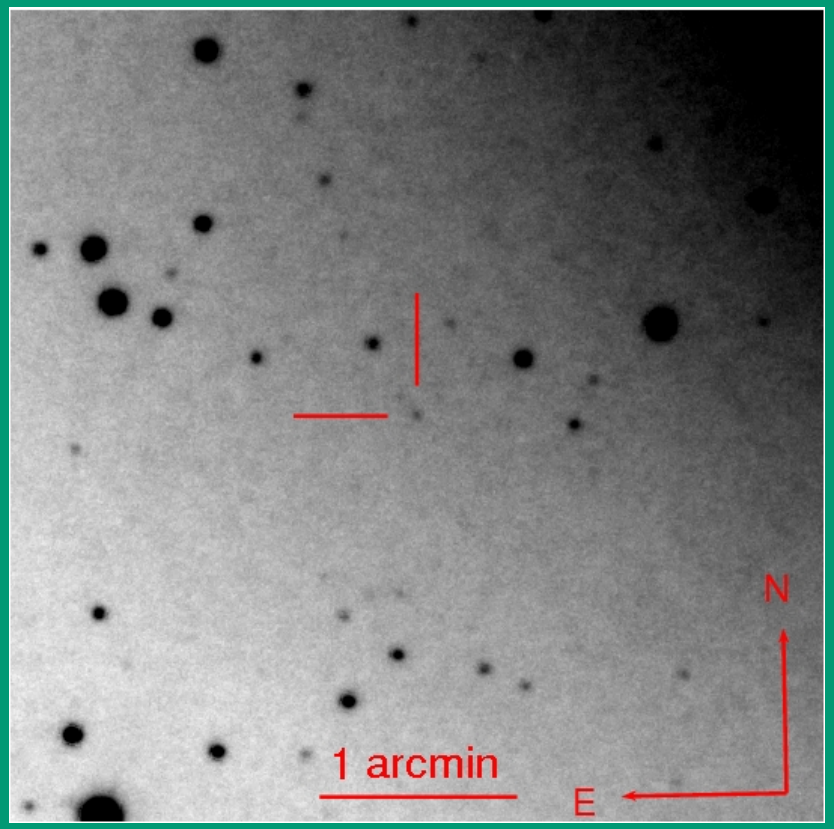
Optical novae over-plotted

X-ray novae over-plotted

M31N 2007-12b

M31N2007-12b: optical image

Local group survey



SuperLOTIS

He/N nova M31N 2007-12b

- Optical detection 2007 Dec 9.5 (16.1 w)
  at Miyaki-cho — Nishiyama & Kabashima
  at Wendelstein — Lee et al. ATel 1324
  and — Kamil Hornoch
- Optical Spectrum at HET: Hα 4500 km/s FWHM, He/N type — Shafter ATel 1332
- X-ray Swift till 2007 Dec 30 out, 2008 Jan 13 bright
  Kong & Di Stefano ATel 1360
  2008 May 26 out
  recurrent nova? 1.3 M_{sun} white dwarf
  Bode et al. 2009, ApJ 705, 1056
- Our monitoring: XMM-Newton
  starting 2008 Jan 8 bright
  Start of SSS within 30 days, duration, pulsations?

M31N 2007-12b: UV observations

Table 2. XMM-Newton OM and Swift UVOT observations of the M31N 2007-12b field around and after the optical nova outburst

Observatory	Instr.	ObsID	Obs. start (UT)	Filters	Exposure (s)	Δt^* (d)	Brightness** (mag)
Swift	UVOT	00031027002	2008-12-02.64	U	1002	-6	> 19.8
Swift	UVOT	00031027003	2008-12-03.25	UVW1	375	-6	> 19.3
				UVM2	399	-6	> 19.5
				UVW2	399	-6	> 19.6
Swift	UVOT	00031027004	2008-12-16.78	UVM2	3853	8	17.82 ± 0.04
XMM-Newton	OM	0505720201	2007-12-29.57	UVW1	4800	21	19.92 ± 0.03
Swift	UVOT	00031027005	2008-12-30.02	U	3977	21	19.77 ± 0.18
XMM-Newton	OM	0505720301	2008-01-08.29	UVW1	4720	30	20.27 ± 0.16
Swift	UVOT	00031027006	2008-01-13.74	UVM2	841	36	> 19.9
XMM-Newton	OM	0505720401	2008-01-18.63	UVW1	3500	41	20.62 ± 0.05
XMM-Newton	OM	0505720501	2008-01-27.94	UVW1	3300	50	> 20.5
XMM-Newton	OM	0505720601	2008-02-07.21	UVW1	3680	60	> 20.5

Notes and references:

* : time after optical outburst (assumed 2007 December 9.0 UT)

** : Swift magnitudes in UVOT photometric system (Poole et al. 2008), for XMM-Newton OM instrumental magnitudes

M31N 2007-12b: X-ray observations

Table 1. XMM-Newton EPIC pn, *Chandra* HRC-I and Swift XRT observations of the M31N 2007-12b field around and after the optical nova outburst

Observatory	Instr.	ObsID	Obs. start (UT)	Exposure (ks)	Δt^* (d)	Count rate** (ct ks^{-1})	$L_X^{***,**}$ (10^{37} erg s^{-1})	Comment
Chandra	HRC-I	8529	2007-12-07.57	19.1	-1	< 1.3	< 1.2	off
Swift	XRT	00031027004	2008-12-16.78	3.9	8	< 3.9	< 9.2	off
Chandra	HRC-I	8530	2007-12-17.49	20.2	8	< 0.9	< 0.8	off
XMM-Newton	EPIC pn	0505720201	2007-12-29.57	22.3	21	1.0 ± 0.4	0.11	faint
Swift	XRT	00031027005	2008-12-30.02	4.0	21	< 3.4	< 8.0	off or faint
XMM-Newton	EPIC pn	0505720301	2008-01-08.29	22.1	30	260 ± 3	77	bright, dip
Swift	XRT	00031027006	2008-01-13.74	4.0	36	15 ± 2	35	bright
XMM-Newton	EPIC pn	0505720401	2008-01-18.63	18.2	41	395 ± 5	61	bright, dip
XMM-Newton	EPIC pn	0505720501	2008-01-27.94	17.3	50	479 ± 5	76	bright, dip
XMM-Newton	EPIC pn	0505720601	2008-02-07.21	17.4	60	291 ± 4	37	bright
Swift	XRT	00037719001	2008-05-26.71	4.9	170	< 2.3	< 5.4	off
XMM-Newton	EPIC pn	0560180101	2008-07-18.26	17.4	222	< 1.5	< 0.1	off

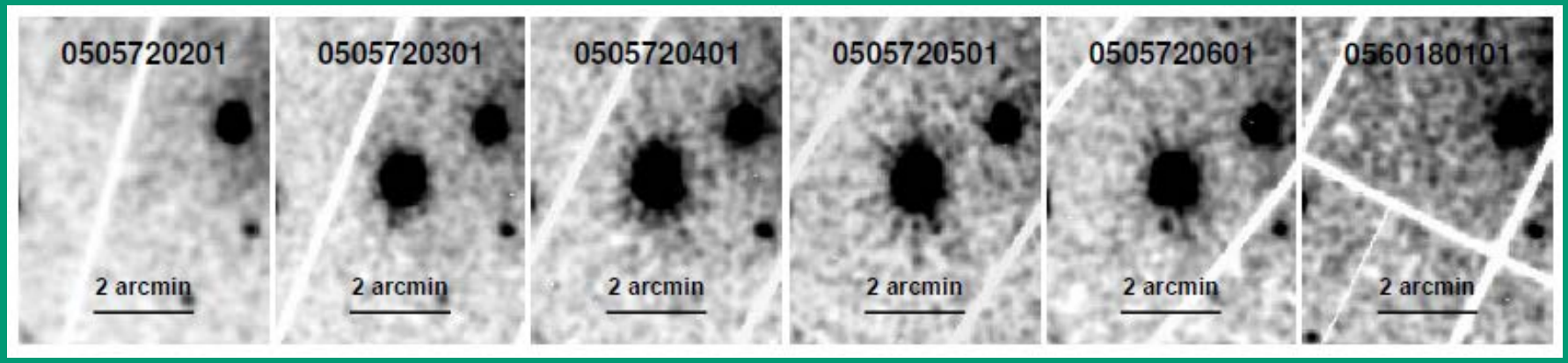
Notes and references:

* : time after optical outburst (assumed 2007 December 9.0 UT)

** : upper limits are 3σ

***: 0.15–1.0 keV absorption corrected luminosity assuming an absorbed black body spectrum as determined in the spectral fit (see Table 5). For observations where spectral fitting was not possible we assumed a black body spectrum with $N_H = 1.0\times10^{21}$ cm^{-2} and a temperature kT = 60 eV. We use a distance of M 31 of 780 kpc (Holland 1998; Stanek & Garnavich 1998) throughout the paper

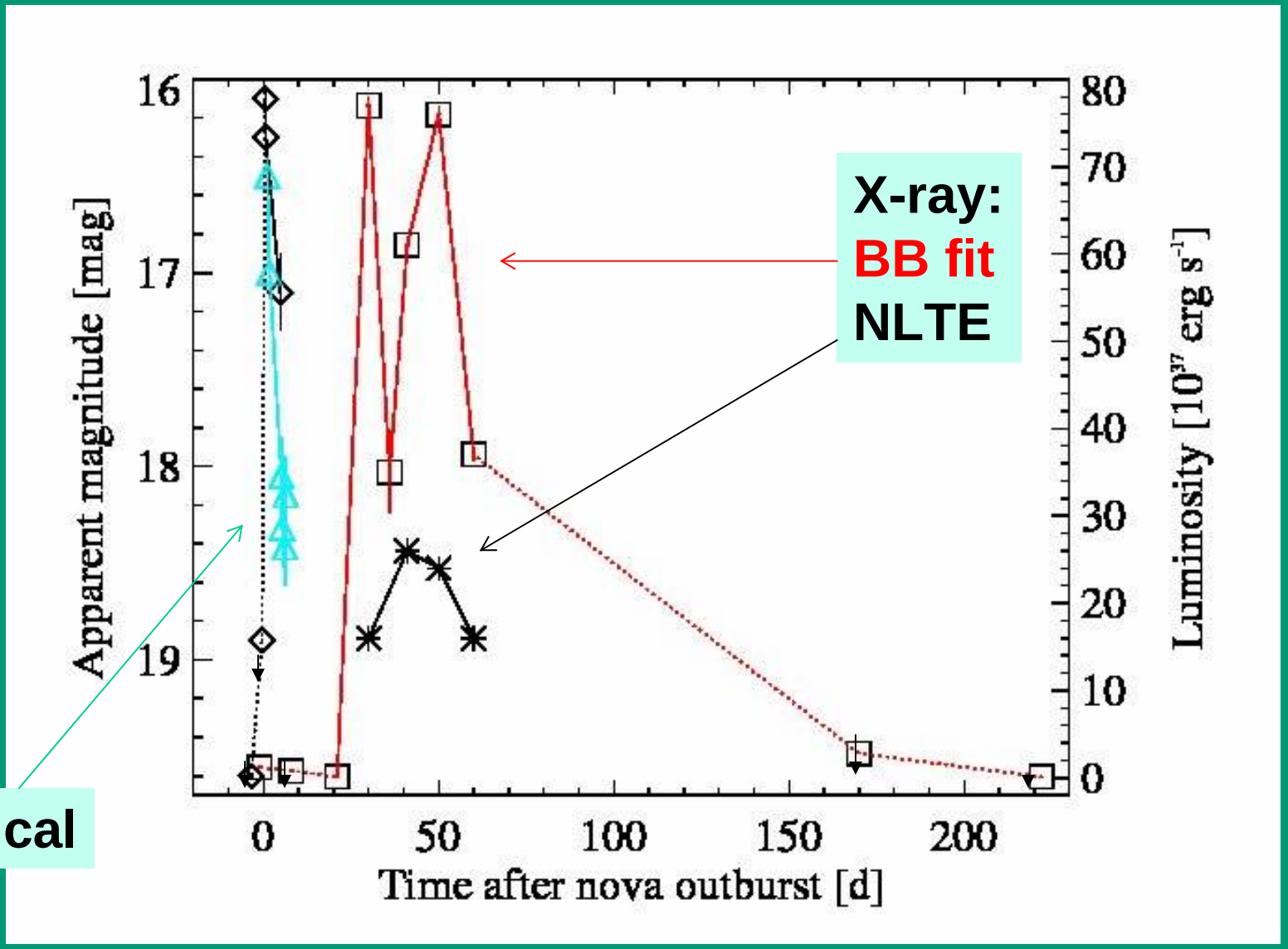
M31N 2007-12b EPIC pn images



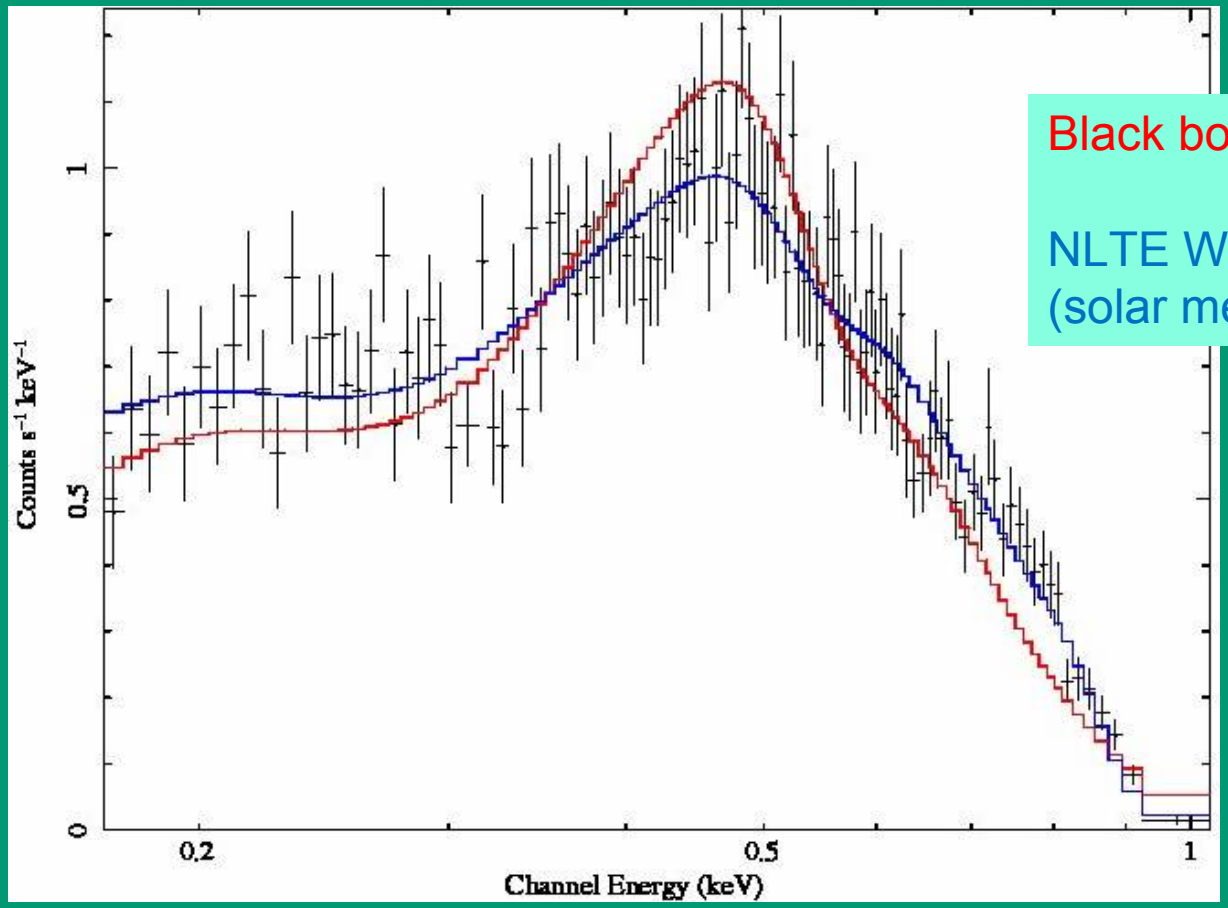
Dec 29 2007	Jan 8 2008	Jan 18 2008	Jan 28 2008	Feb 7 2008	Jul 18 2008

XMM-Newton EPIC pn 200-1000 eV

M31N 2007-12b: light curve



M31N 2007-12b: X-ray spectrum



Black body

NLTE WD atmosphere
(solar metal abundance)

XMM-Newton EPIC pn, 2008 Jan 28

M31N 2007-12b: X-ray spectrum

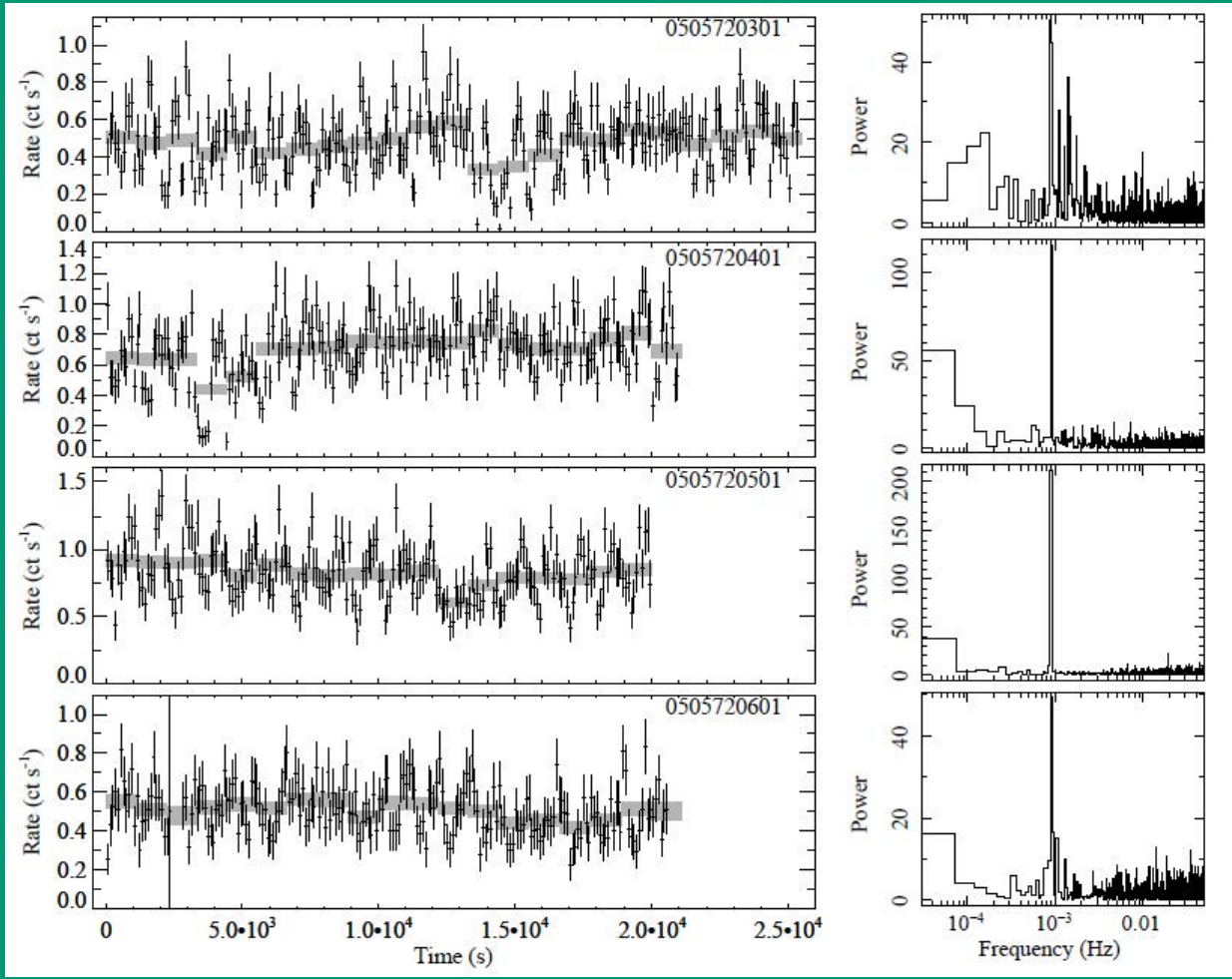
Table 5. Bright state XMM-Newton EPIC pn spectral best fit parameters and derived parameters for M31N 2007-12b using black body and WD atmosphere models with halo and solar element abundances (see text for details).

ObsID	t_{int} (ks)	Rate[a]	Sp.[b]	N_H^c (10^{21} cm^{-2})	kT (eV)	ν	χ^2/ν	L_x^d (10^{38} erg s^{-1})	L_{bol}^e	$L_{bol}/L_\odot$ (10^4)	R^f (10^9 cm)
0505720301	22.08	260±3	BB	$1.33^{+0.15}_{-0.14}$	$57.7^{+2.2}_{-2.1}$	78	1.12	7.7	11.0	28.8	2.78
			WD H	$0.70^{+0.08}_{-0.07}$	$61.0^{+0.3}_{-0.3}$	78	1.36	1.9	2.3	5.9	1.12
			WD S	$0.61^{+0.06}_{-0.06}$	$69.4^{+0.2}_{-0.2}$	78	1.28	1.6	1.8	4.8	0.78
0505720401	17.94	395±5	BB	$1.50^{+0.19}_{-0.14}$	$76.2^{+2.4}_{-2.8}$	96	1.63	6.1	8.4	21.9	1.31
			WD H	$0.85^{+0.07}_{-0.06}$	$70.0^{+0.3}_{-0.3}$	96	1.47	2.4	2.7	7.2	0.94
			WD S	$0.95^{+0.14}_{-0.11}$	$75.1^{+1.6}_{-1.3}$	96	1.29	2.6	3.0	7.7	0.85
0505720501	16.86	479±5	BB	$1.81^{+0.21}_{-0.17}$	$81.1^{+2.4}_{-2.4}$	112	2.68	7.6	10.2	26.6	1.27
			WD H	$0.83^{+0.06}_{-0.08}$	$75.6^{+1.3}_{-1.3}$	112	1.06	2.4	2.7	7.0	0.80
			WD S	$0.86^{+0.10}_{-0.09}$	$80.1^{+0.8}_{-0.7}$	112	0.98	2.4	2.7	6.9	0.71
0505720601	17.42	291±4	BB	$1.36^{+0.21}_{-0.16}$	$78.4^{+2.8}_{-3.0}$	71	1.76	3.7	5.0	13.1	1.06
			WD H	$0.77^{+0.09}_{-0.08}$	$70.9^{+0.5}_{-0.5}$	71	0.93	1.6	1.8	4.7	0.75
			WD S	$0.78^{+0.10}_{-0.08}$	$77.8^{+0.4}_{-1.0}$	71	0.89	1.6	1.7	4.6	0.61

Notes and references:
[a]: Net count rate in 10^{-3} ct s^{-1} as given in XSPEC (0.15–1 keV)
[b]: Model spectra. BB: black body, WD H and WD S: NLTE WD atmosphere assuming halo or solar abundances, respectively (see text)
[c]: Absorption with Galactic metal abundances (Wilms et al. 2000)
[d]: un-absorbed X-ray luminosity (0.15–1 keV)
[e]: bolometric luminosity
[f]: WD radii, for WD atmosphere models calculated as for BB

BB luminosities significantly above Eddington limit for WD, NLTE atm. more realistic

M31N 2007-12b: Pulsations, dips



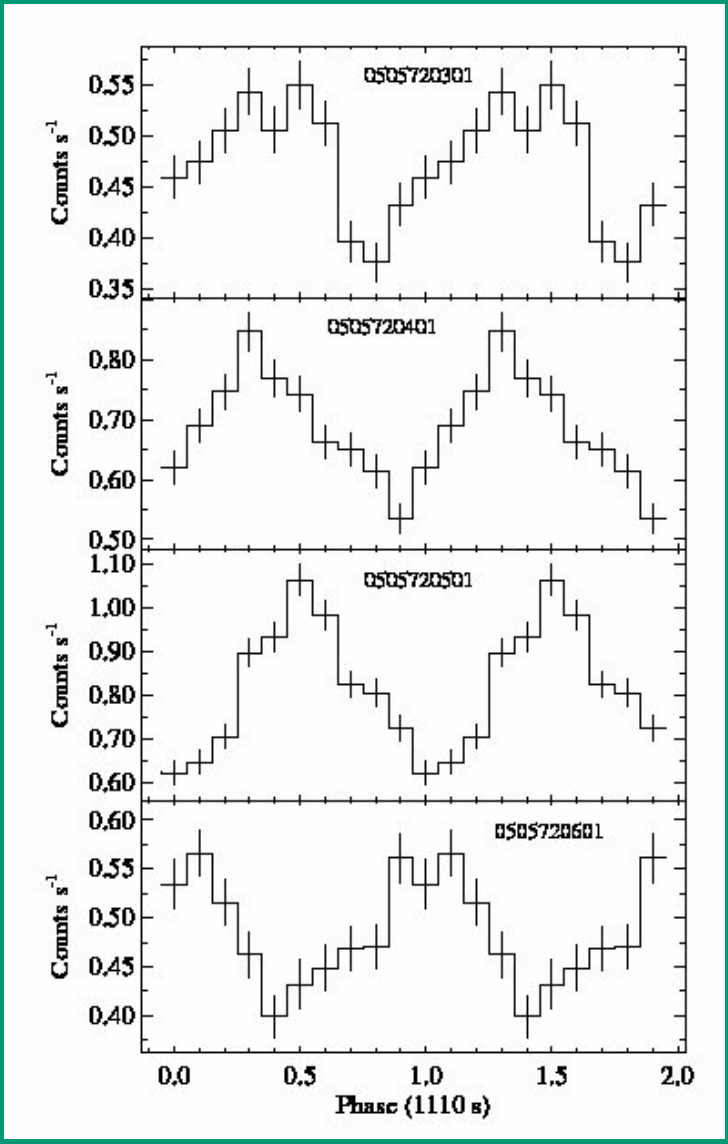
1110 s period WD rotation
"dips" in 3 obs.
4.8 or 9.8 h binary orbit?

CV with massiv magnetic WD "Intermediate polar?"

Similar to 865 s pulsating SSS detected with XMM-Newton in June 2000 (no nova counterpart known)

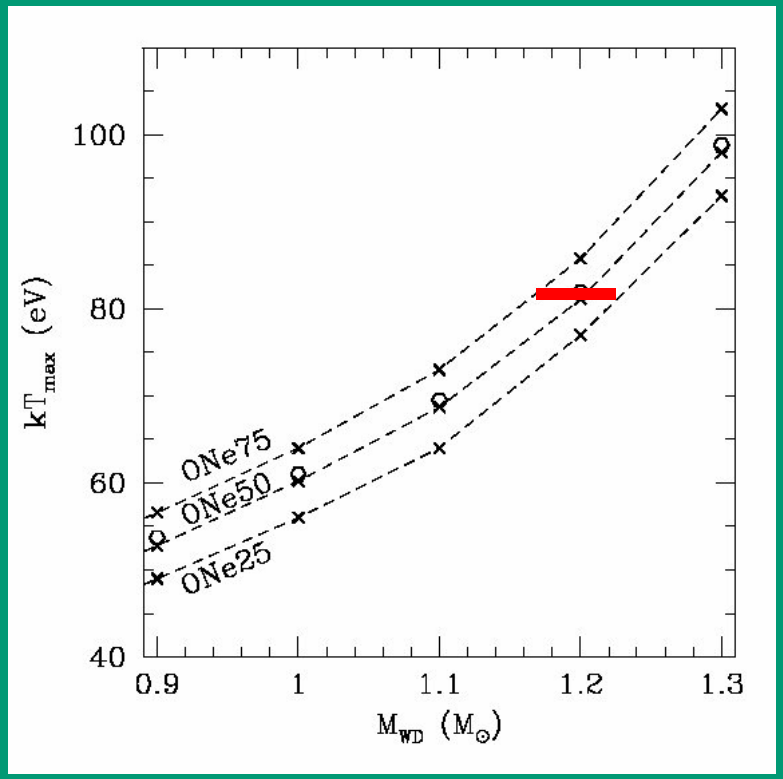
Osborne et al. 2001, A&A 378, 800

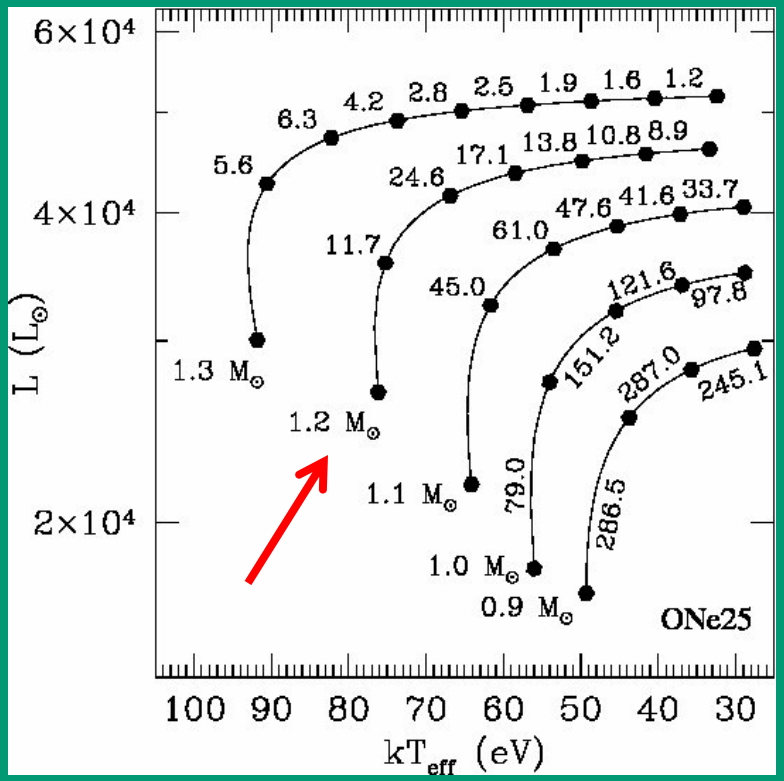
M31N 2007-12b: 1110 s pulsations



- Period constant between observations within errors
- Pulsed fraction ~20% (0.15-1 keV)
- No change in sub-bands (0.15-0.4, 0.4-1 keV)

M31N 2007-12b: system and outburst parameters





Sala & Hernanz 2005, A&A439, 1061

M31N 2007-12b: system and outburst parameters

- SSS start 21 - 30 d, end 60 - 120d after outburst
  nova with one of the shortest SSS states known
- Nova envelope model with <50% mixing between solar-like accreted material and O/Ne degenerate core
- White dwarf mass 1.2 M_{sun}
- Ejected mass 2.0 x 10^{-6} M_{sun}
- Burned mass 2-6 x 10^{-7} M_{sun}
- White dwarf rotation 1110 s
  - Indication of inhomogeneous brightness distribution over surface of WD
  - Why already visible during SSS phase?
  - Accretion already restarted?
- Intermediate polar?
  - 4.9 h or 9.8 h orbital period?
  - Radius of emission region indicates magnetic WD
- Recurrent nova?
  - SN Ia progenitor?