Outbursts in AM CVn binaries

Gavin Ramsay
(Armagh Observatory, N Ireland)

Tom Barclay (NASA/Ames), Peter Wheatley (Warwick), Simon Rosen (Leicester), Danny Steeghs (Warwick), Iwona Kotko (Cracow), Pasi Hakala (FINCA)

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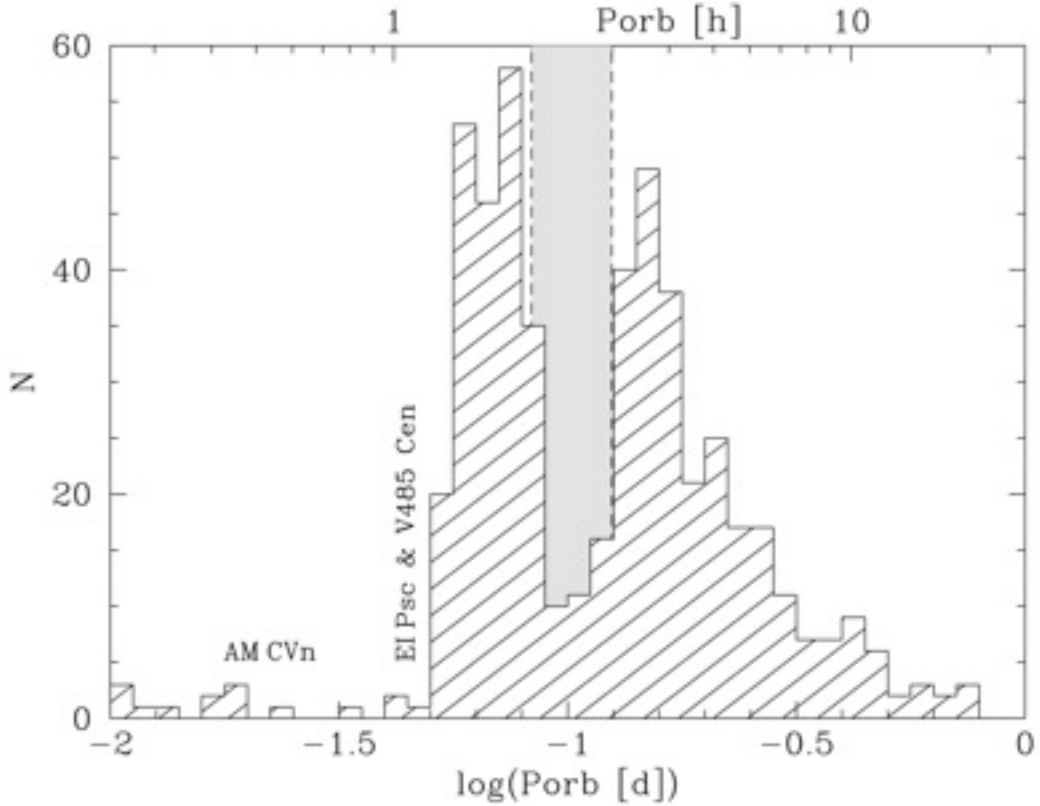
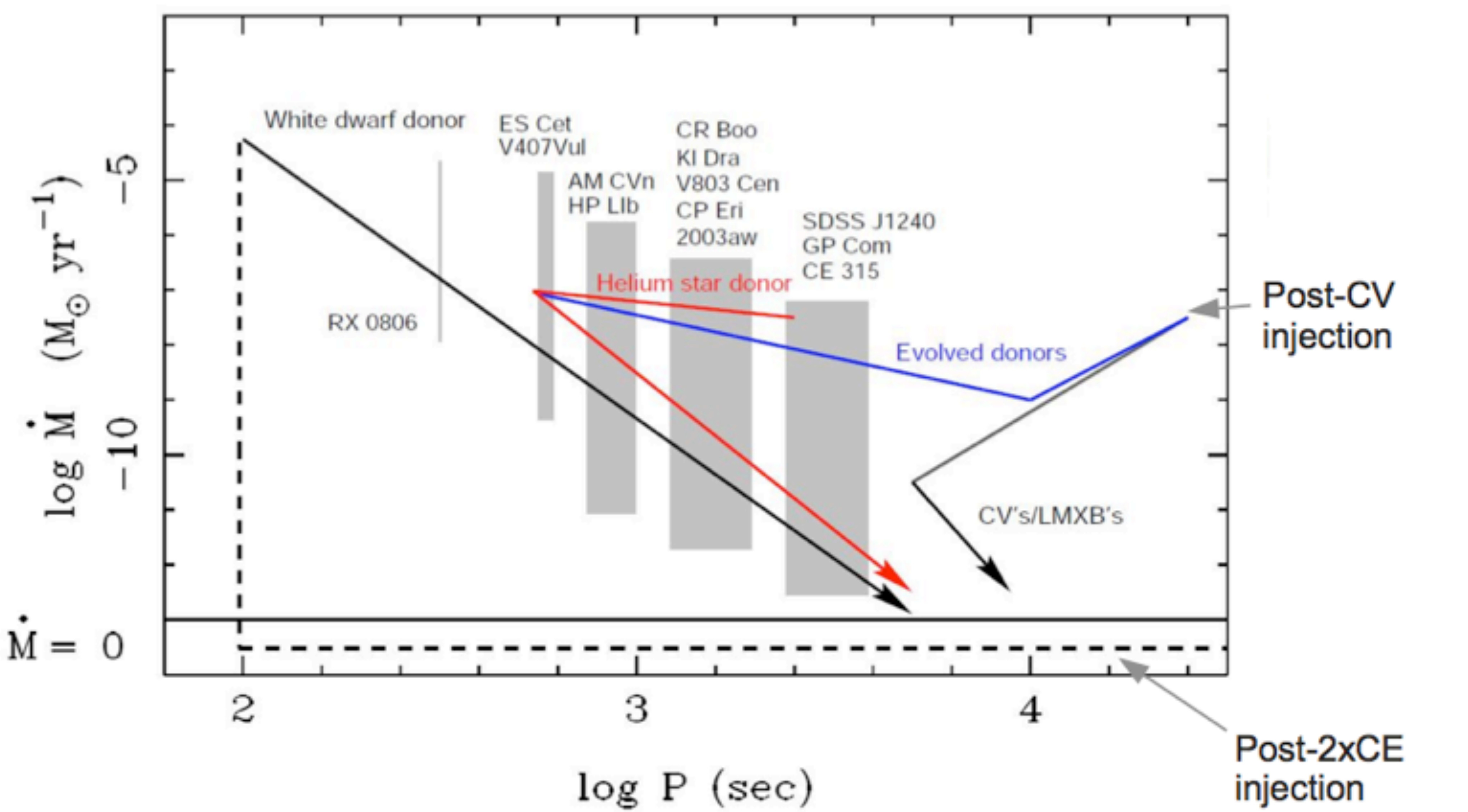
What are AM CVn Binaries?



Accreting binaries with white dwarf primaries and main sequence secondaries have binary orbital periods greater than 80 mins. For shorter period systems the secondary must have degenerate or semi-degenerate. eg white dwarf - white dwarf binaries.

Currently 36 known systems

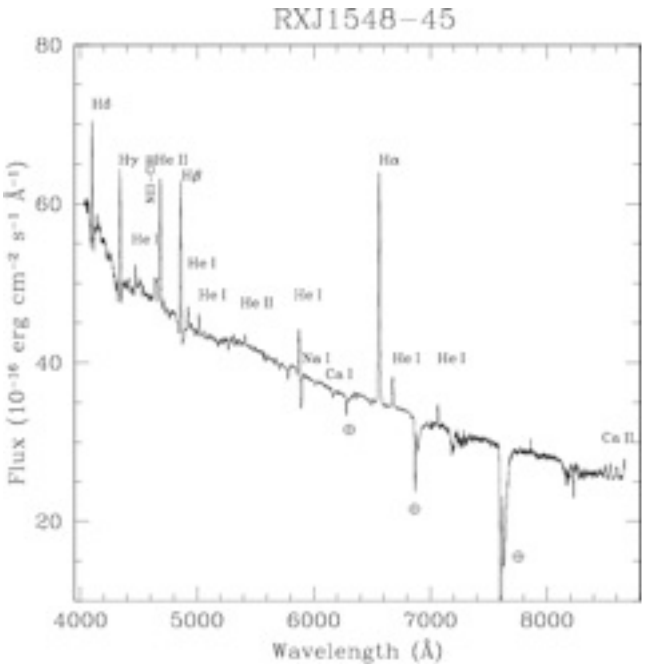
How are they formed?



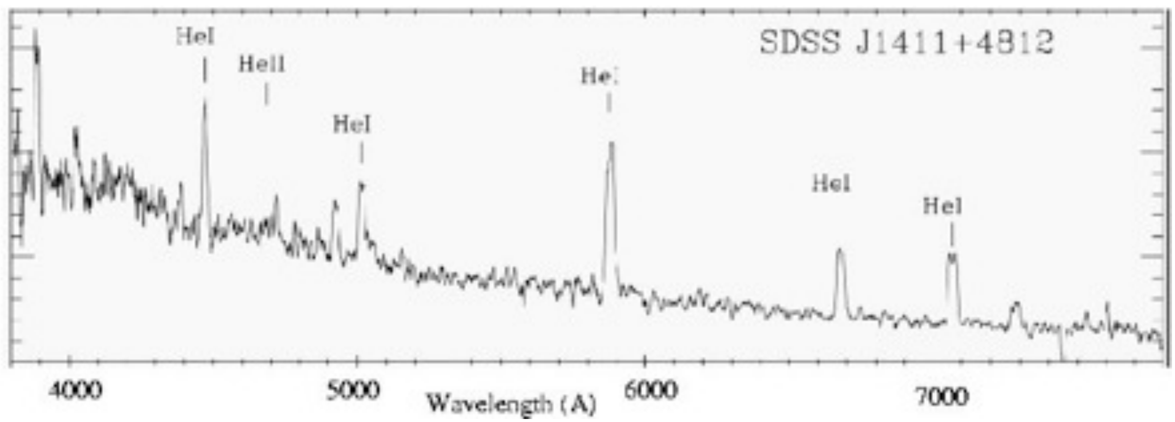
Taken from Nelemans (2005)

Spectra of AM CVn's:

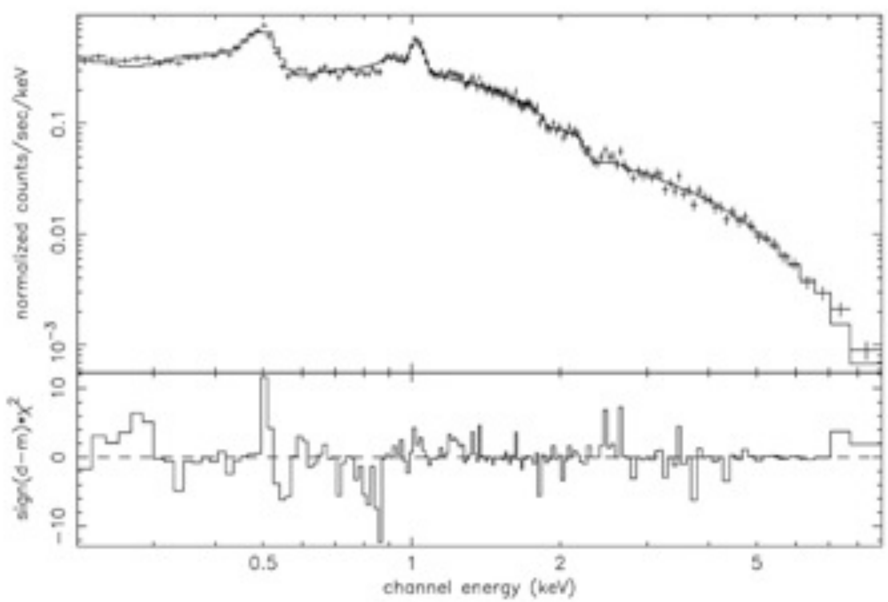
The most obvious observational signature is their optical spectrum - lack of hydrogen lines.



Spectrum of typical hydrogen accreting binary
(de Martino et al 2006)



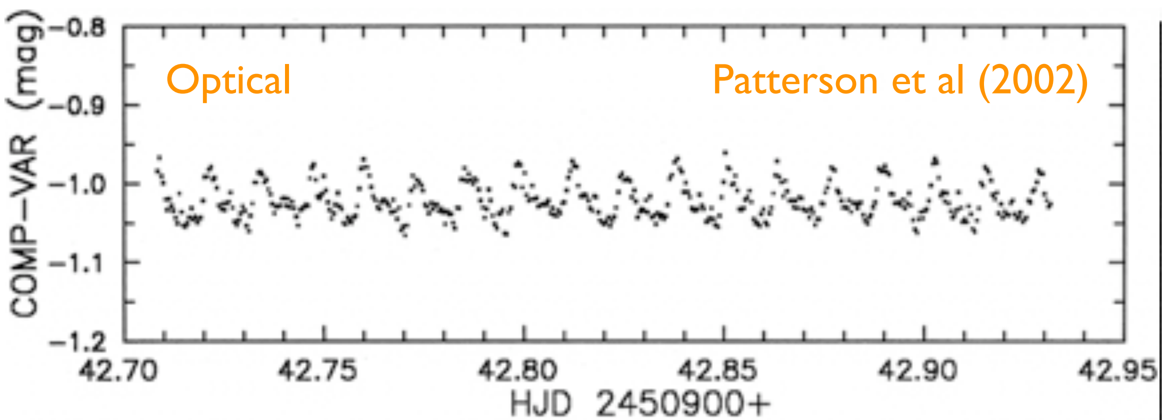
Optical Spectrum of typical UCB (Anderson et al 2006)

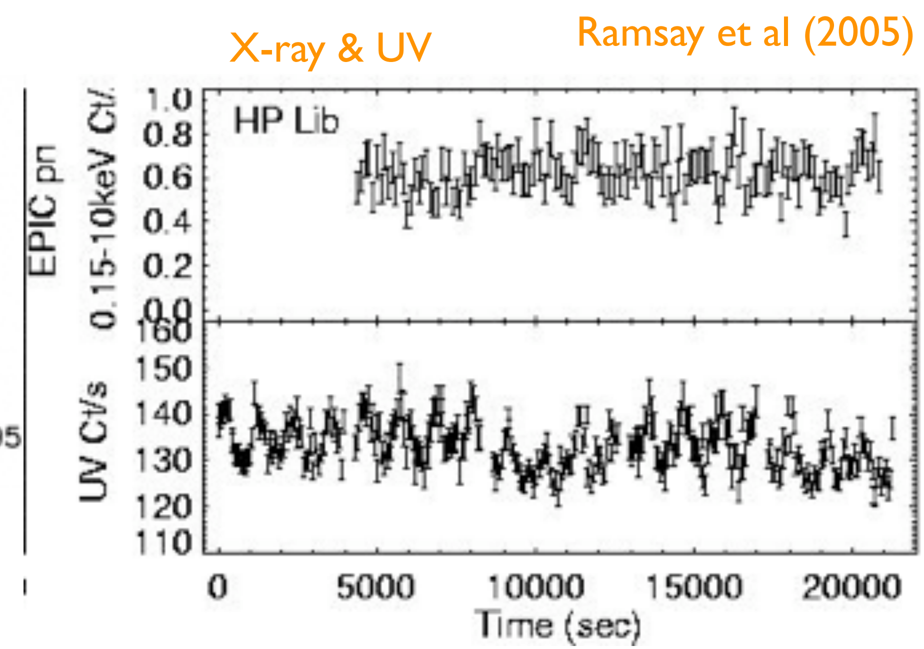


X-ray Spectrum of typical GP Com (Ramsay et al 2005)

Light curves of AM CVn's:

Can be split into systems in low state, high state and those which undergo outbursts. Systems in outburst and in a high state show characteristic modulations in their optical light curve.





HP Lib (Porb=18.4min) Optical and UV light curves show modulation due to precession period of the accretion disc.

First observed outbursts

Outbursts have been known in CR Boo, V803 Cen & CP Eri for decades. eg CR Boo B~13.6-17.2, mostly in high state. Quasi-Period of 4-5 days (Wood et al 1987).

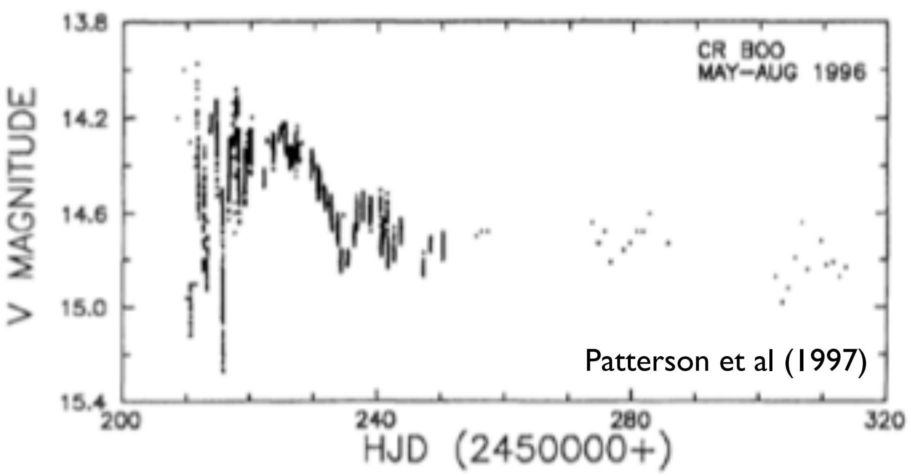


Fig. 2—Light curve of CR Boo in 1996. The star cycled between magnitude 15 and 14 for the first 10 d, followed by a "high state" lasting > 80 d (assuming no downward excursions in light during gaps in the observational record).

Long period changes in brightness and quasi-periodic on 19 hrs: Patteron et al (1997)

Patterson et al (1997)

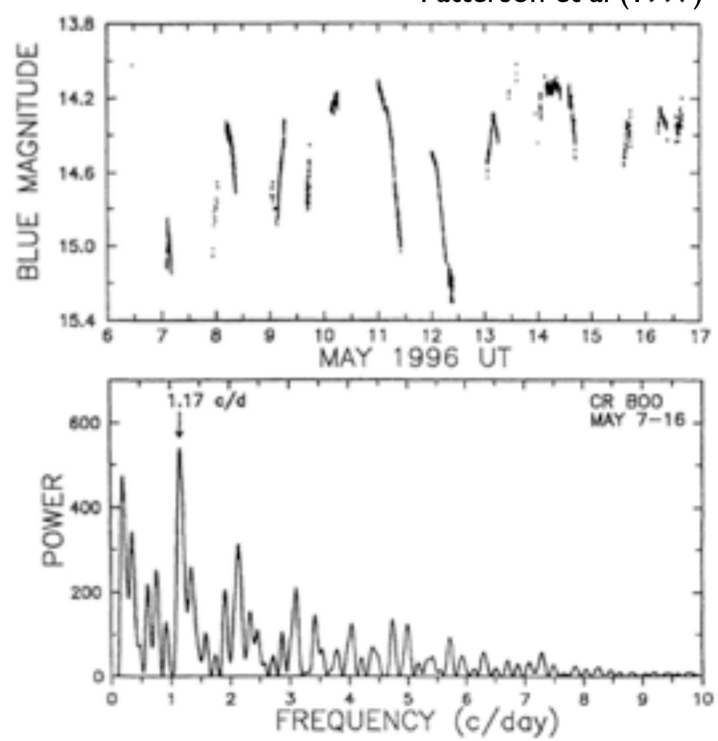
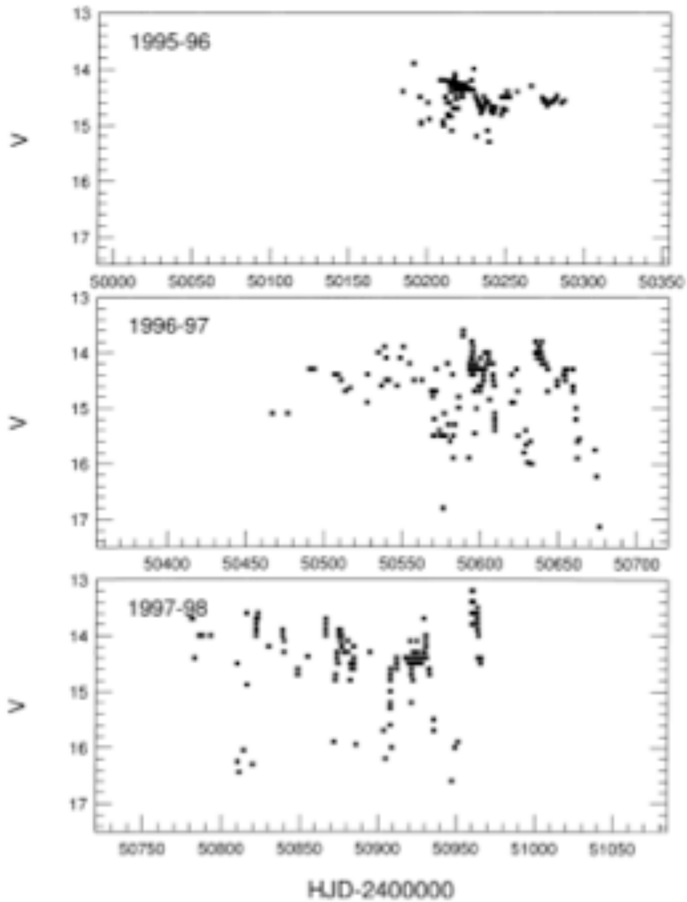
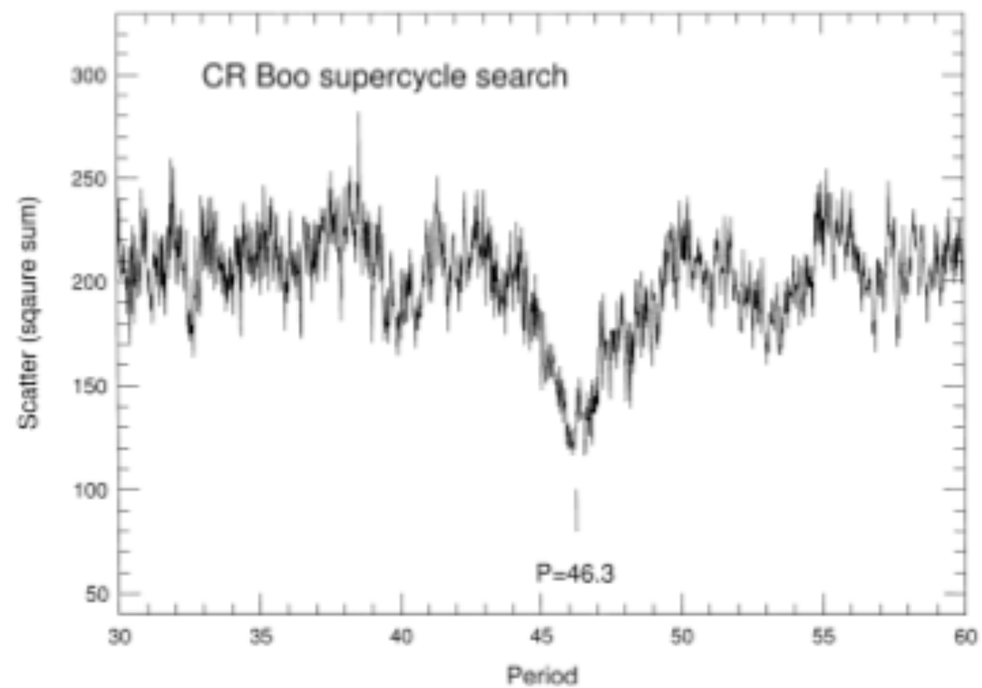


Fig. 3—Upper frame: expanded view of the first 10 d of the 1996 campaign, showing rapid cycling with $P \lesssim 1$ d. Lower frame: power spectrum of this light curve, showing a signal at 1.17 ± 0.04 c/d.

Longer periods in CR Boo

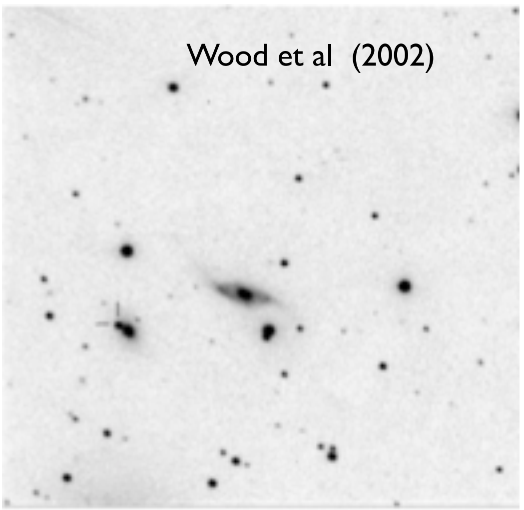




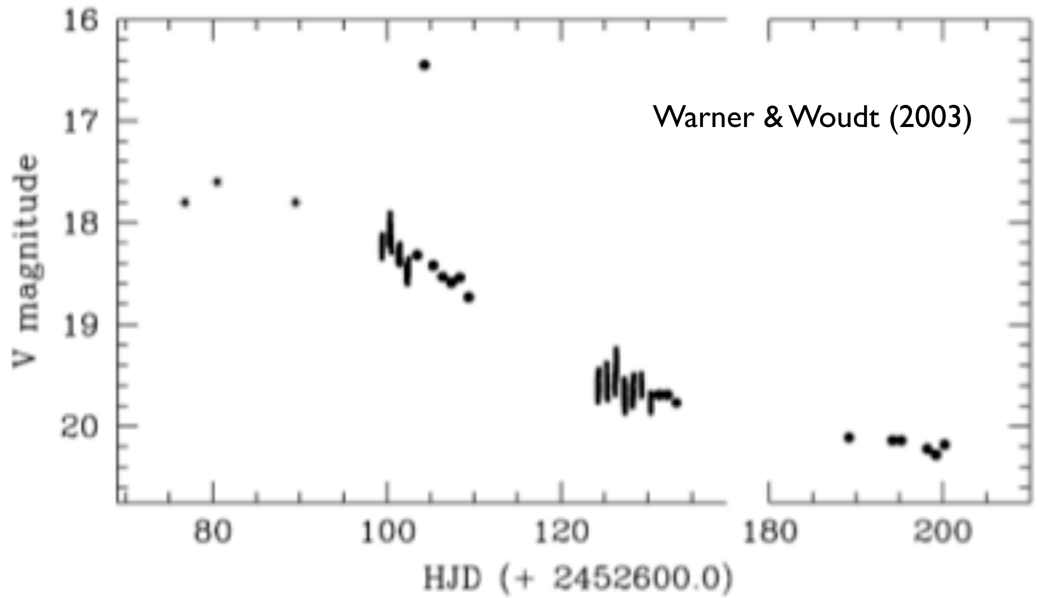
Alternates between high/low states on period of 46.3 days. In the faint state outbursts on 4-8 day timescale, Kato et al (2000).

AM CVn's as `supernovae':

SN 1998di = KL Dra



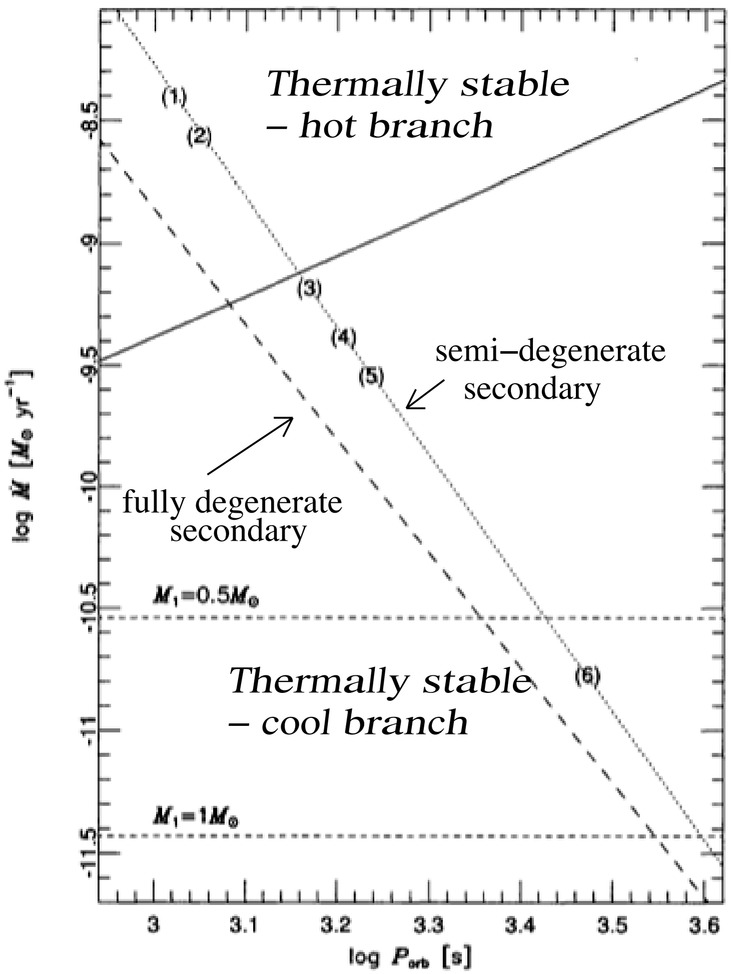
SN 2003aw = V407 Hya



Many more examples coming from all-sky variability surveys
eg PTF and CRTTS

Maybe the best way to detect AM CVn systems in the ~25-45 min period range?

Outbursts as function period:



From Tsugawa & Osaki (1997)

From Nelemans (2005): *(Note less than a dozen systems even in 2004 the year of that conference!)*

Name	P_{orb}^{a} (s)		P_{sh}^{a} (s)	Spectrum	Phot. var[b]	dist (pc)	X-ray[c]	UV[d]
ES Cet	621	(p/s)		Em[1,2]	orb		C[3]X	GI
AM CVn	1029	(s/p)	1051	Abs	orb	235[4]	RX	HI
HP Lib	1103	(p)	1119	Abs	orb		X	HI
CR Boo	1471	(p)	1487	Abs/Em?	OB/orb		ARX	I
KL Dra	1500	(p)	1530	Abs/Em?	OB/orb			
V803 Cen	1612	(p)	1618	Abs/Em?	OB/orb		Rx	FHI
CP Eri	1701	(p)	1716	Abs/Em	OB/orb			H
2003aw	?		2042	Em/Abs?	OB/orb			
SDSSJ1240-01	2242[5]	(s)		Em	n			
GP Com	2794	(s)		Em	n	70[6]	ARX[7]	H[8]I
CE315	3906	(s)		Em	n	77[9]	R(?)[e]X	H[10]
Candidates								
RXJ0806+15	321	(X/p)		He/H?[11]	"orb"		[12–15]CRX	
V407 Vul	569	(X/p)		K-star[16]	"orb"		[17–19]ARCRxX	

High State systems: short period; absorption lines;
Low State systems: longer period: emission lines;
Outburst systems: known to have >1mag outbursts.

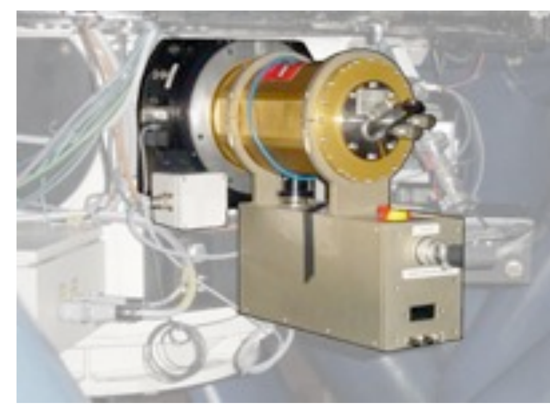
With the increasing number of AM CVn systems, it was an obvious idea to determine the outburst characteristics and period range of these groups.

A survey of AM CVn binaries using the robotic Liverpool Telescope

Ran from Feb 2009 until June 2011 and 18 systems were observed.

Source	Period (mins)	LT Target?	LT Range g (mag)	LT mean g (mag)	LT rms g (mag)	Outbursting System?
HM Cnc	5.4	✗				N
V407 Vul	9.5	✗				N
ES Cet	10.4	✓	16.5–16.8	16.66	0.09	N
SDSS J190817.07+394036.4	15.6	✗				N
AM CVn	17.1	✗				N
HP Lib	18.4	✓	13.6–13.7	13.51	0.02	N
CR Boo	24.5	✓	13.8–17.0	15.00	1.00	Y
KL Dra	25.0	✓	16.0–19.6	17.68	1.19	Y
PTF1 J0719+4858	26.8	✗				Y
V803 Cen	26.9	✗				Y
SDSS J092638.71+362402.4	28.3	✓	16.6–19.6	19.31	0.52	Y
CP Eri	28.4	✓	16.2–20.2	19.30	1.33	Y
V406 Hya (2003aw)	33.8	✓	14.5–19.7	18.89	1.34	Y
2QZ J142701.6-012310	36.6	✓	20.0–20.5	20.35	0.18	Y
SDSS J012940.05+384210.4	:37	✓	14.5–20.0	19.31	1.31	Y
SDSS J124058.03-015919.2	37.4	✓	19.0–19.8	19.62	0.17	Y
SDSS J080449.49+161624.8	44.5	✓	17.8–19.0	18.54	0.30	Y
SDSS J141118.31+481257.6	:46	✓	19.4–19.7	19.58	0.09	N
GP Com	46.6	✓	15.9–16.3	16.22	0.05	N
SDSS J090221.35+381941.9	48.3	✗				N
SDSS J155252.48+320150.9	56.3	✓	20.2–20.6	20.44	0.10	N
V396 Hya	65.1	✗				N
SDSS J120841.96+355025.2		✓	18.9–19.4	19.09	0.07	N
SDSS J152509.57+360054.5		✓	19.8–20.2	19.91	0.11	N
SDSS J164228.06+193410.0		✗				N
SDSS J172102.48+273301.2		✓	20.4–20.7	20.53	0.17	N
SDSS J204739.40+000840.1		✓	17.0–17.4	17.13	0.03	Y

2m Liverpool Telescope on La Palma

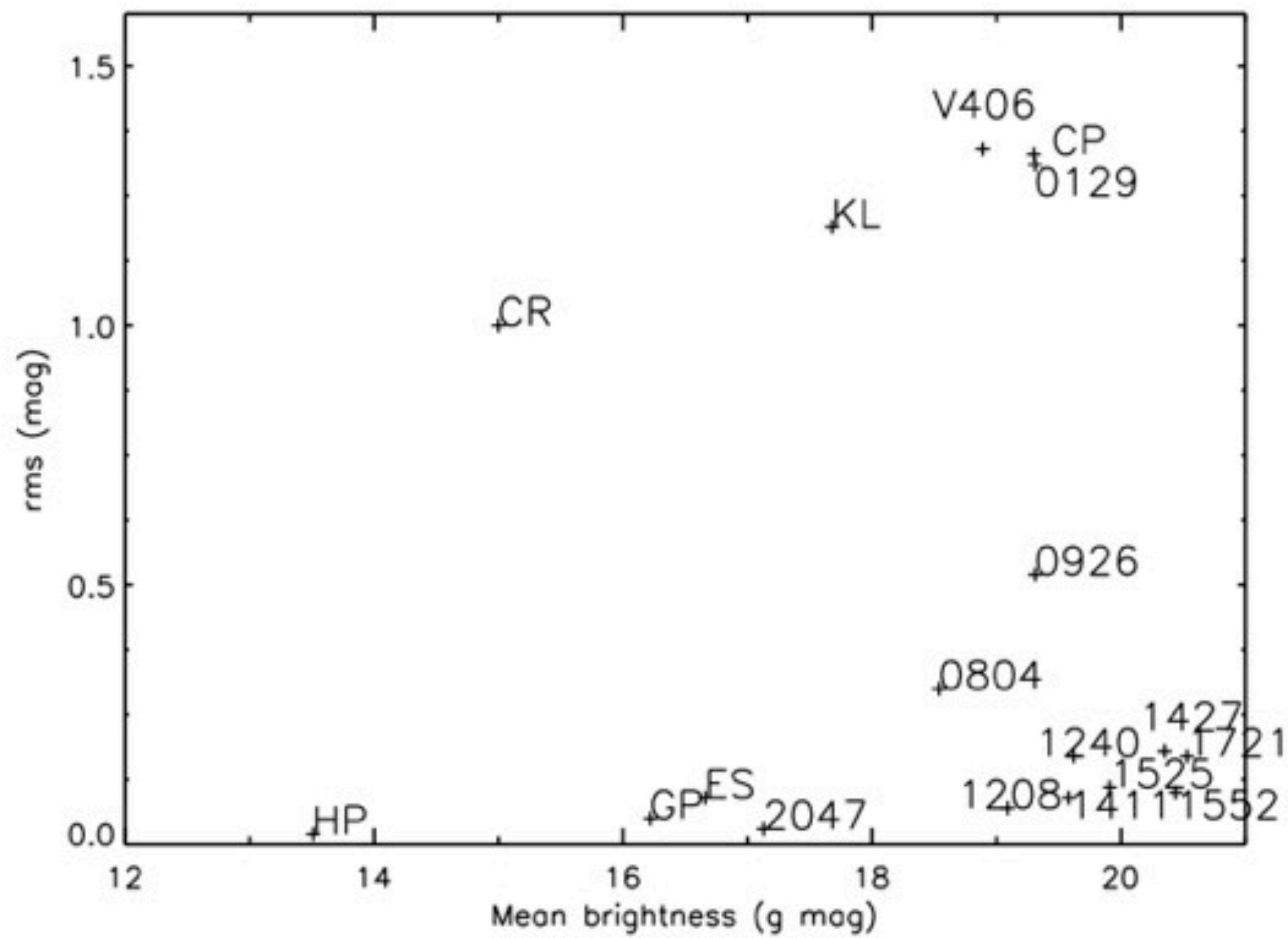


RATCAM. Images taken in g band.

Ramsay et al (2012)

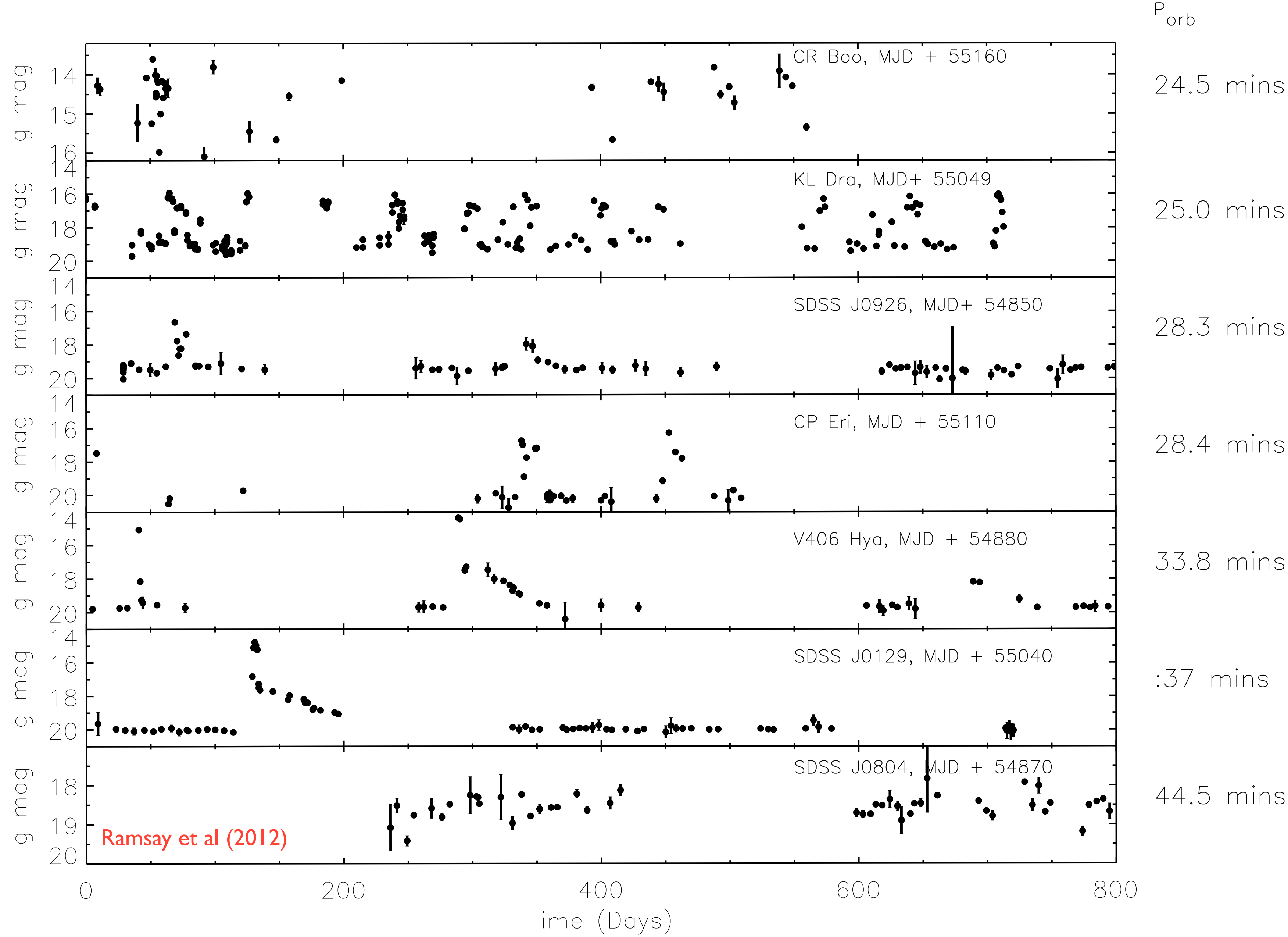
Overview:

Out of 18 systems, 7 showed outbursts >1mag. 1/3 of AM CVn binaries show outbursts. cf 45% in 2004.

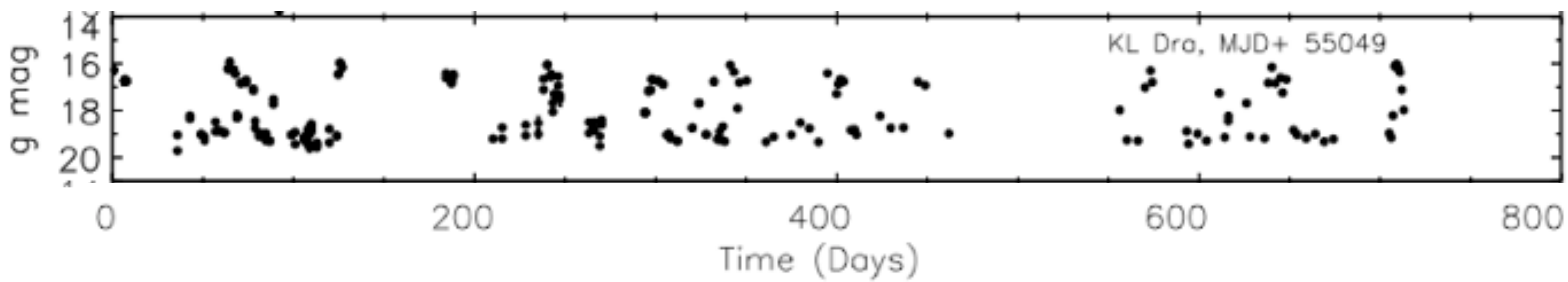


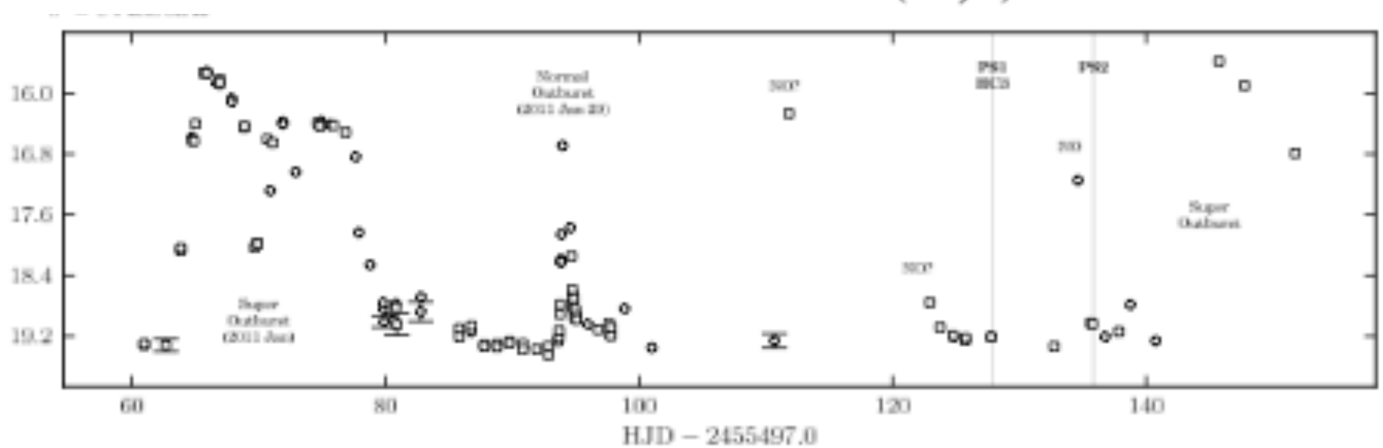
Ramsay et al (2012)

Systems which showed outbursts



Outbursts/Superoutbursts



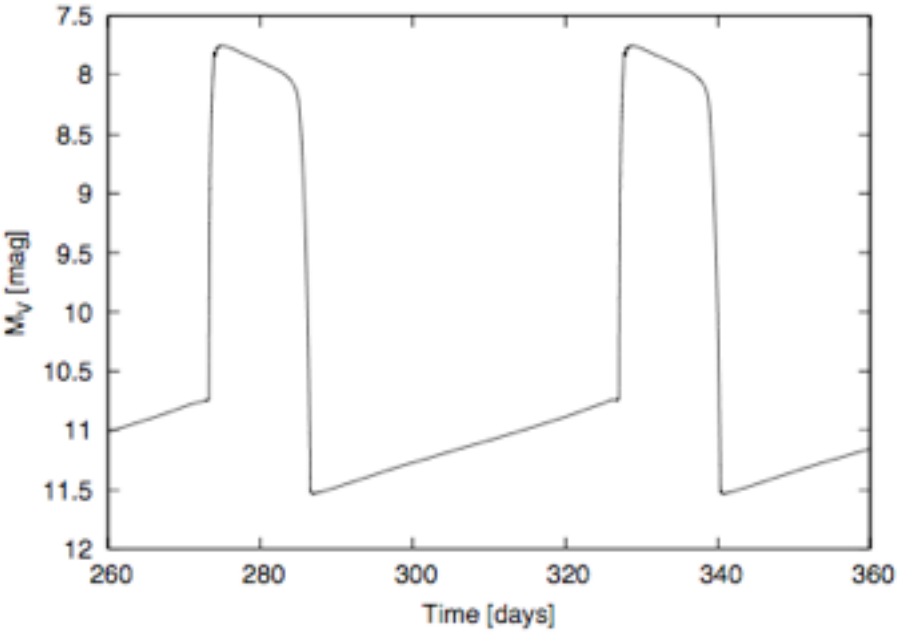


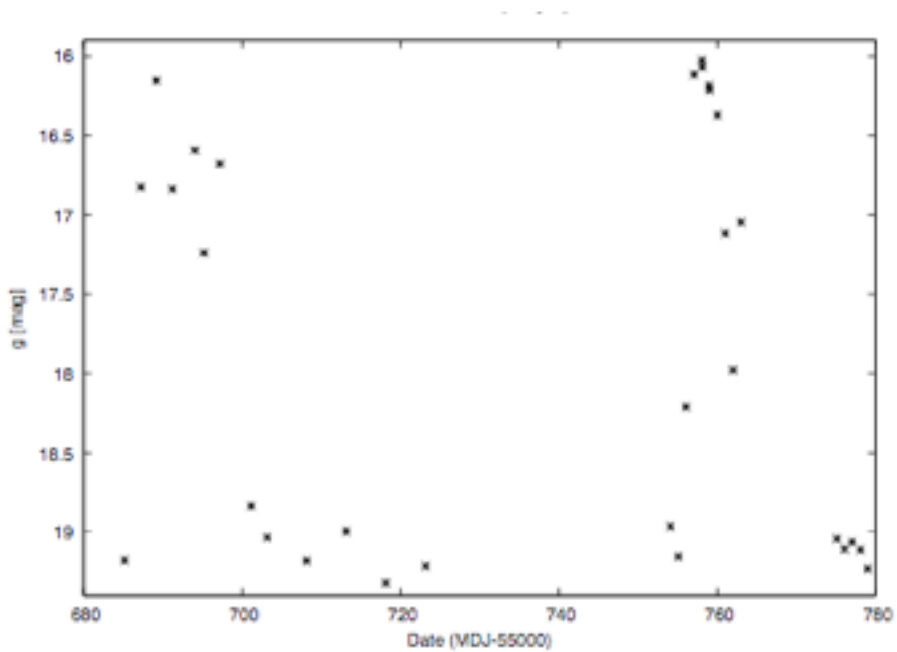
PTF J0719 Levitan (2011)

Some systems show two kinds of outbursts - short duration (normal outbursts) - and much longer duration (super outbursts).

KL Dra -excellent test source for the outburst model

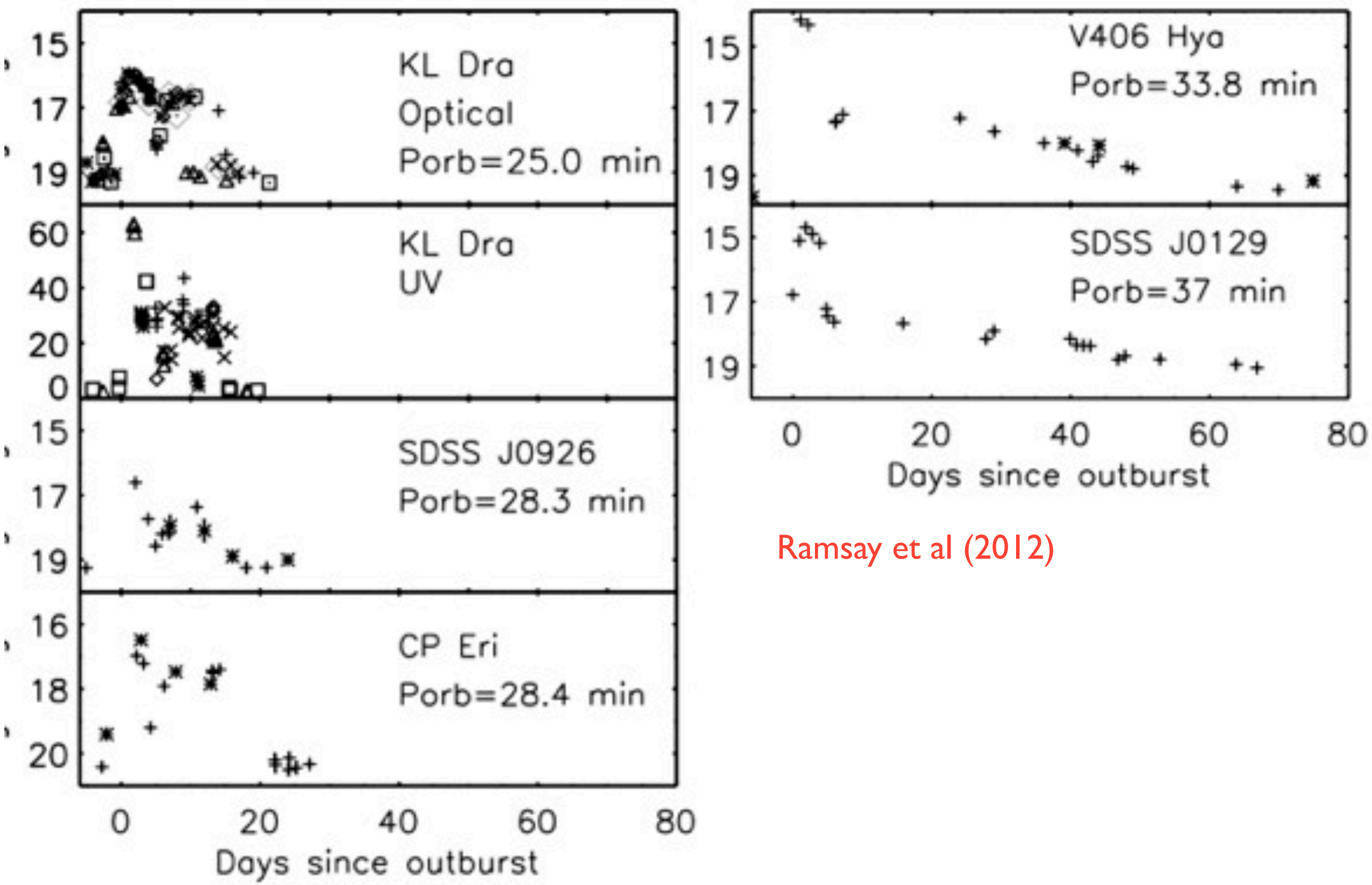
AM CVn systems showing dwarf nova outbursts are excellent systems to determine how composition affects the outburst characteristics and test outburst models.





Simulations from Kotko, Lasota, Dubus & Hameury (2012).
Can get correct amplitude and duration of super-outbursts in KL Dra assuming alpha_cold=0.035, alpha_hot=0.2, Mdot_trans=2x10^16 g/s.
Assumes appropriate chemical composition and enhanced mass transfer due to variable irradiation of the secondary.
The predicted brightening between outbursts is not observed.

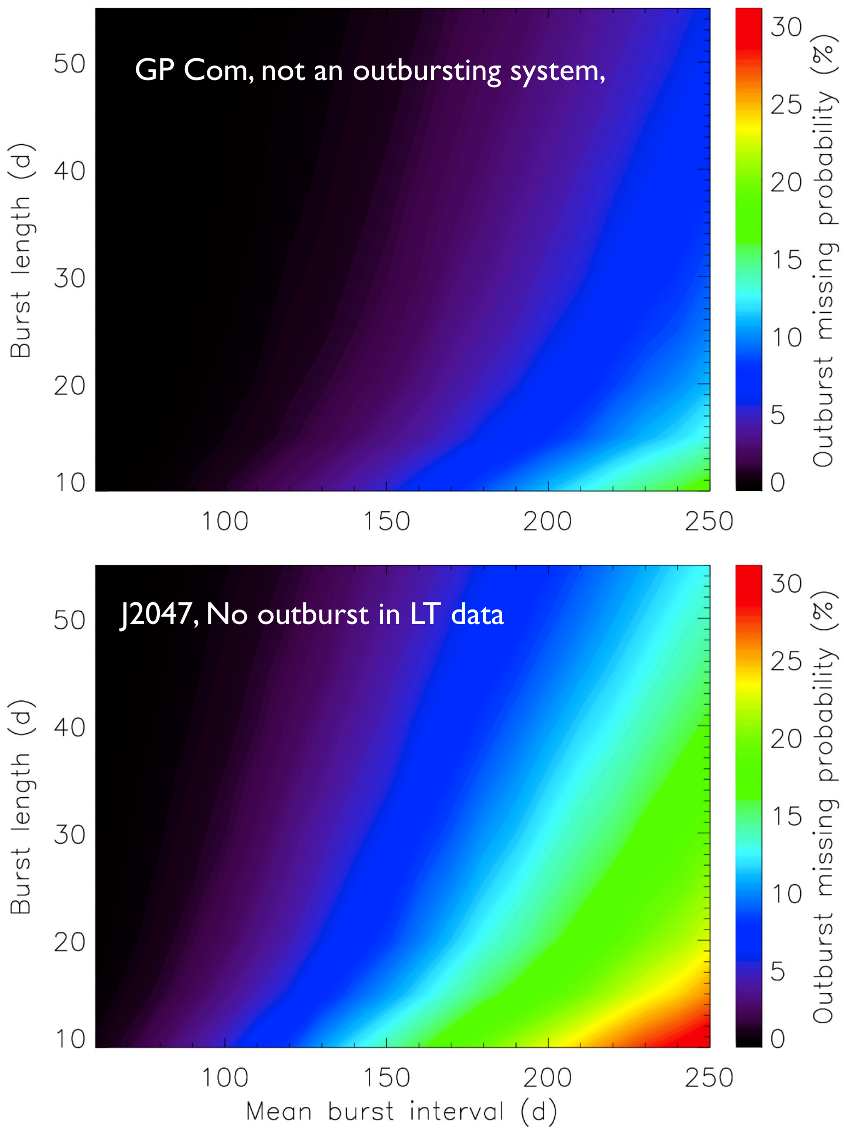
Outburst profile as a function of orbital period



Ramsay et al (2012)

Systems with 25<Porb<30 min, short duration outbursts (a week or two), recurrence time several to many months. 30<Porb<40mins high amplitude, rapid decline and then long duration decline. Outburst lasts several months. Systems with shorter and longer periods more erratic.

How many bursts did we miss?



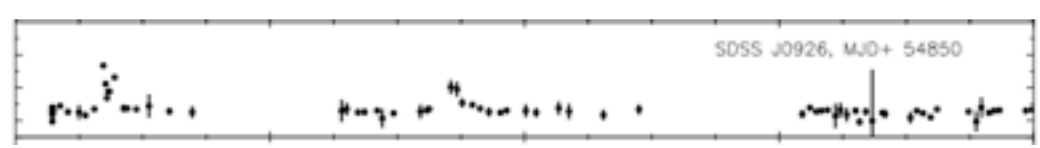
Observations planned every 5 days. Weather conditions meant some weeks went by with no data on individual sources.

Created synthetic light curves with different outburst duration and recurrence interval.

The results for two representative systems are shown.

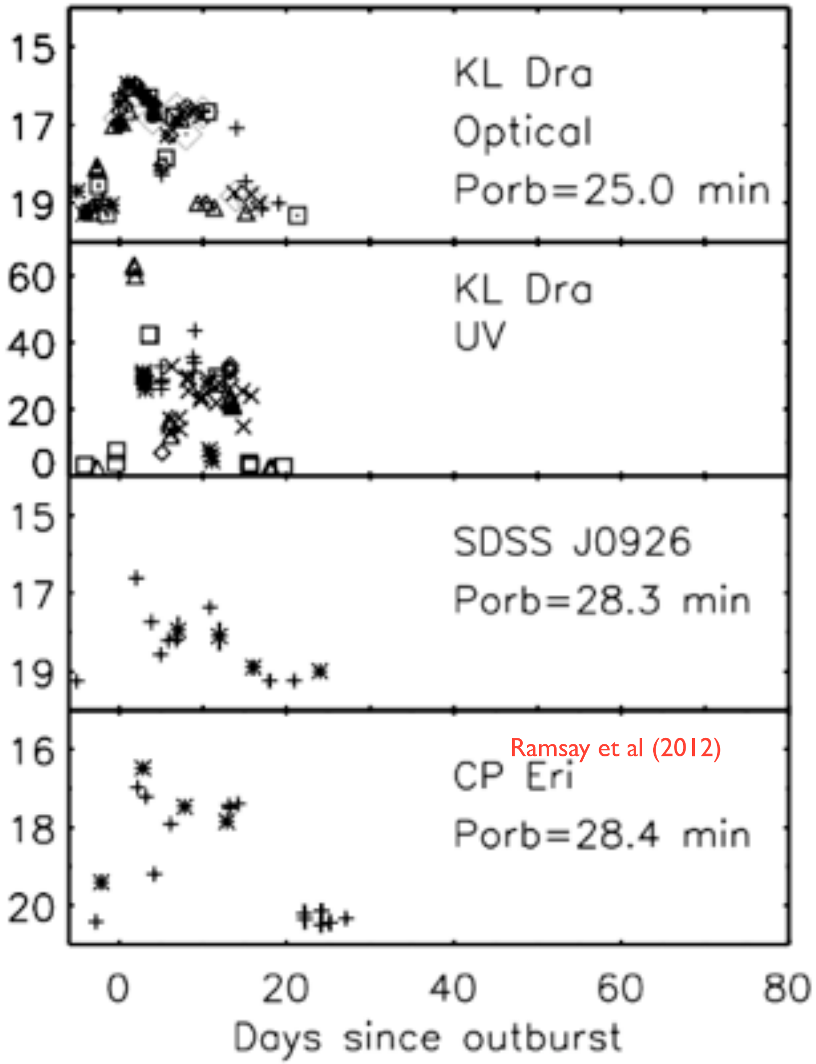
Less than 10% chance of missing a burst for recurrance time < 150 days.

Also did simulations for SDSS J0926:

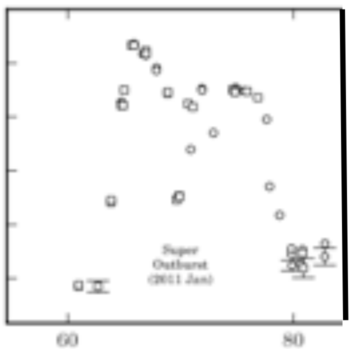


These suggest we missed one burst.

What are the dips seen in super-outbursts?

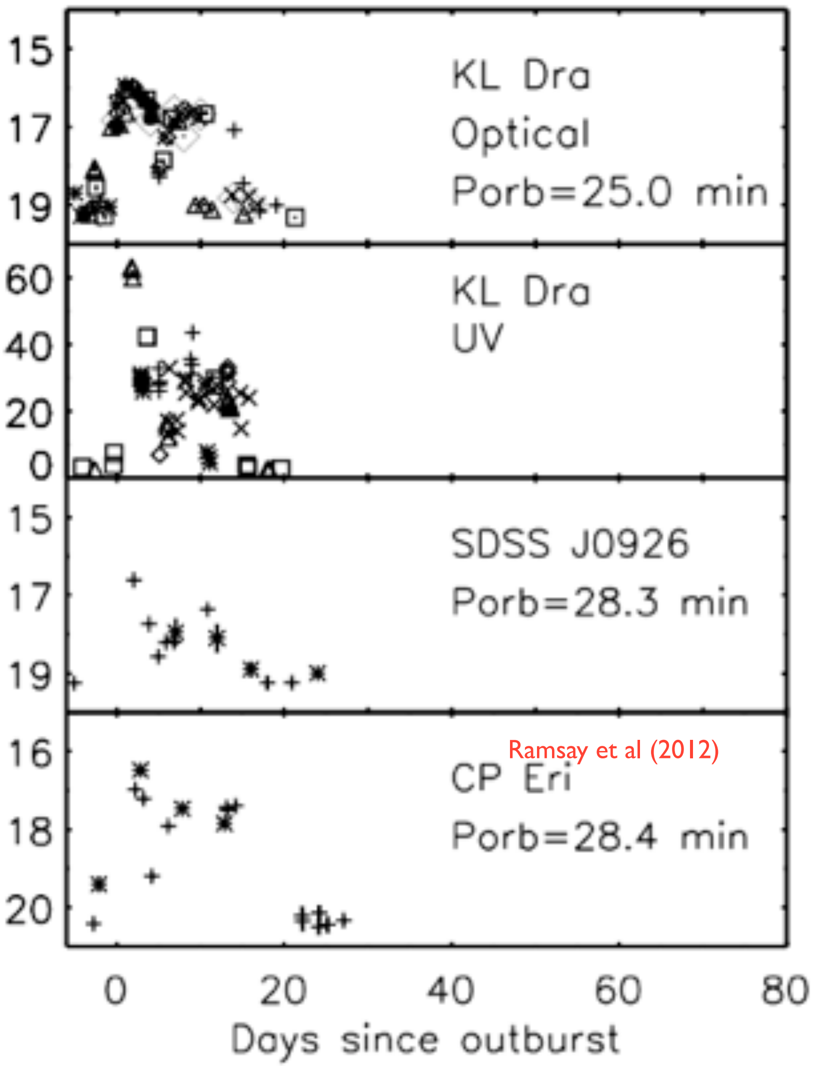


PTF J0719+4858 Levitan et al (2011)

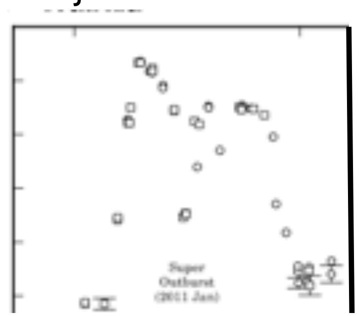


Due to the data sampling, not clear if these dips are seen in *every* super-outburst.

What are the dips seen in super-outbursts?



PTF J0719+4858 Levitan et al (2011)



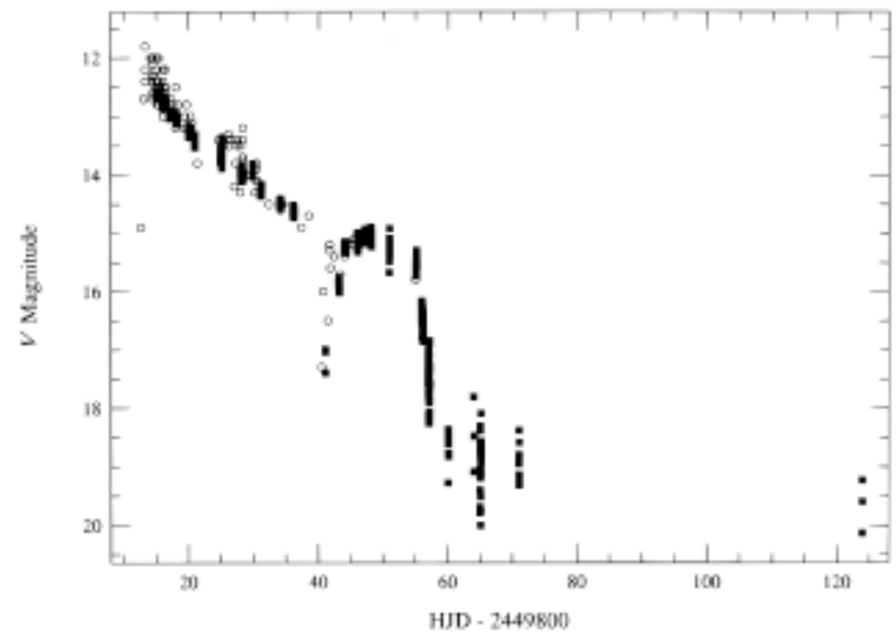


FIG. 1.—General light curve of the 1995 superoutburst in AL Com. Filled squares represent our data, and open circles represent visual observations.

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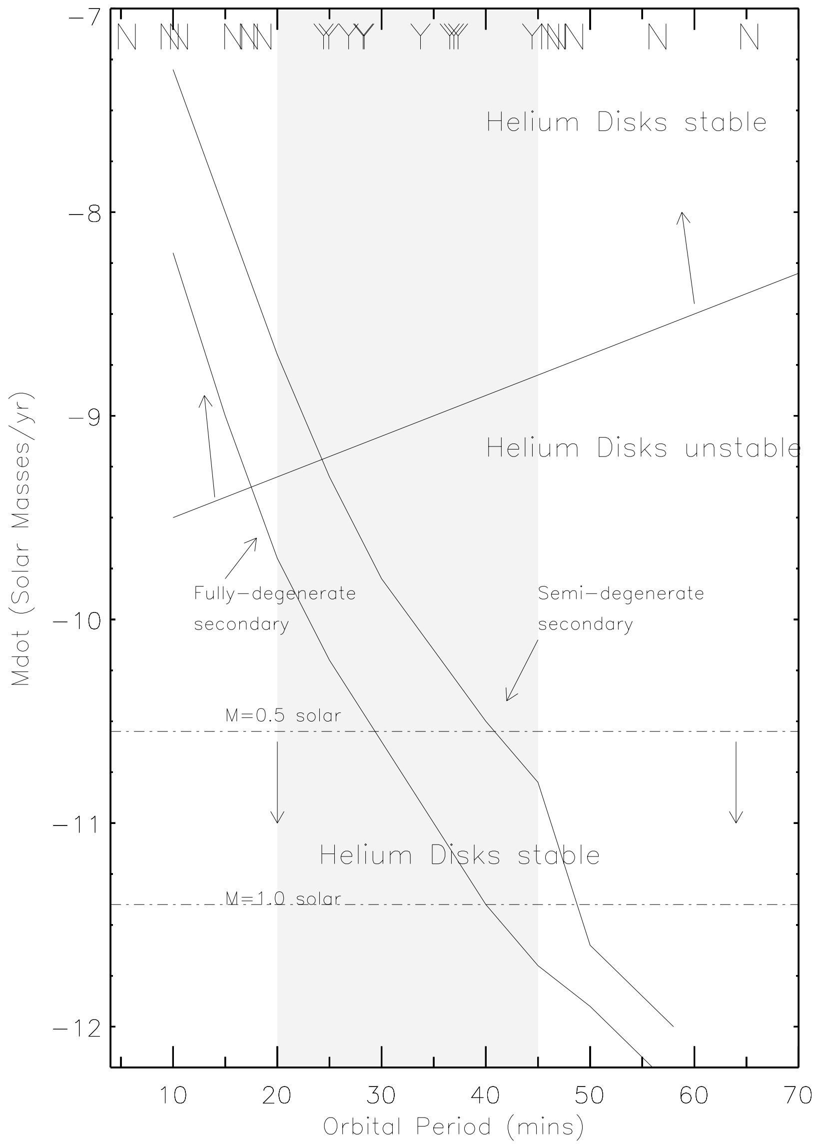
Reheating of accretion disc or related to dips seen in outbursts in dwarf novae?

Comparison with predictions



Adapted from Tsugawa & Osaki (1997)

Outbursts 24min<Porb<44 min. Consistent with predictions.

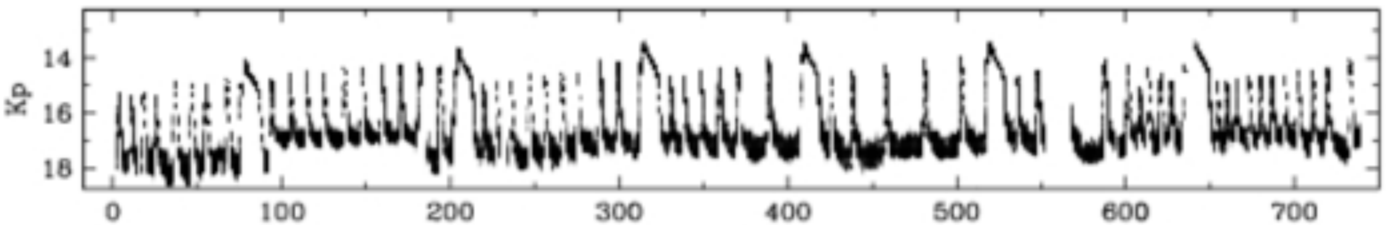
Porb<24 mins, disc always hotter than ionisation state of helium;

Porb>44 mins, disc always cooler than ionisation state of helium.

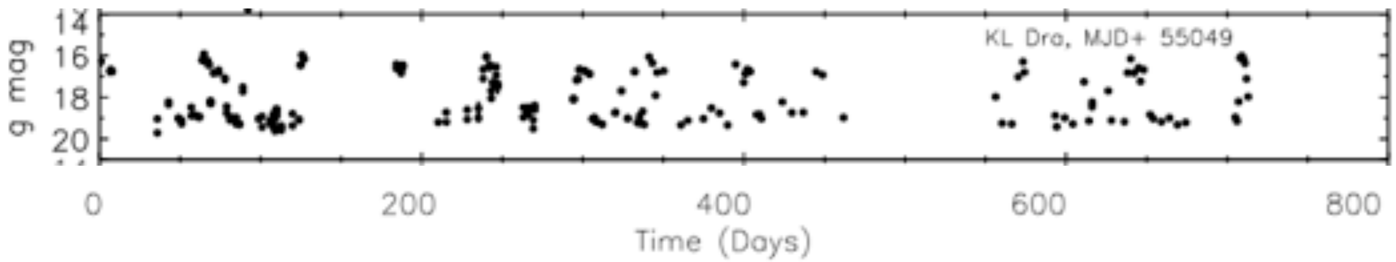
KL Dra and CR Boo very similar Porb, but very different outburst properties. Not just related to Porb. State of secondary?

KL Dra - a helium analogue SU UMa

The Kepler light curve of the hydrogen accreting dwarf nova V1504 Cyg



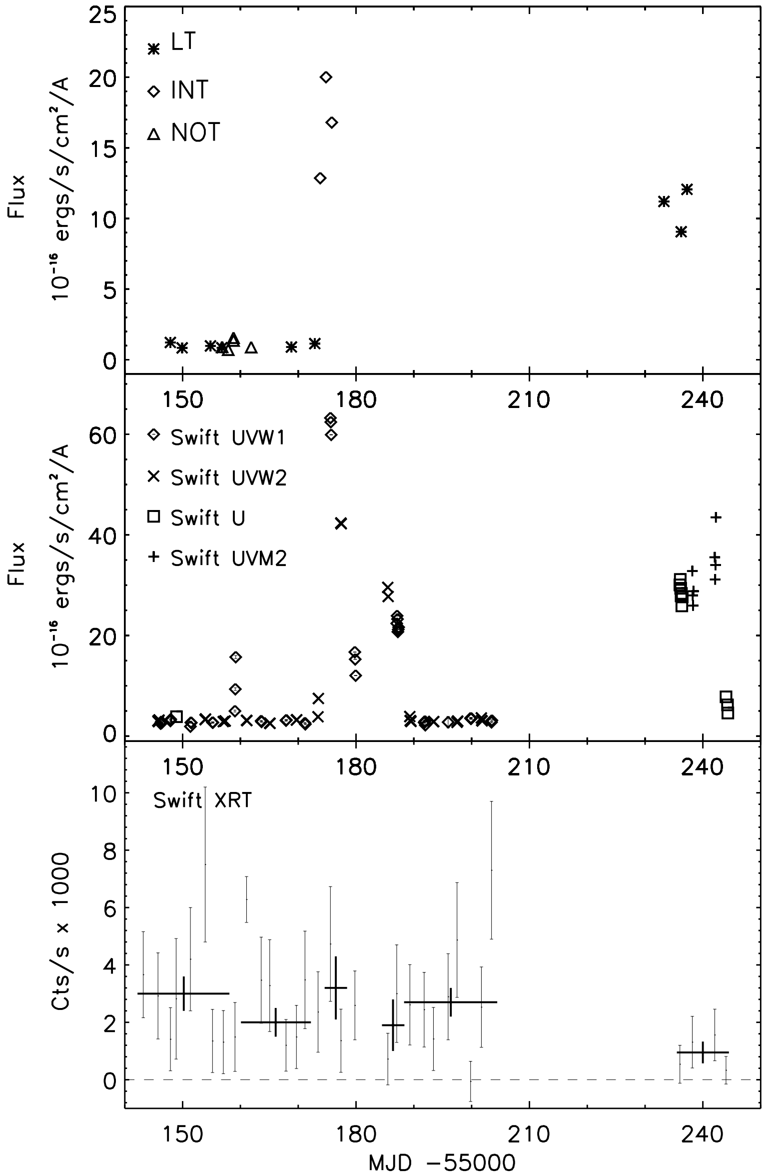
V1504 Cyg, Cannizzo et al (2012)



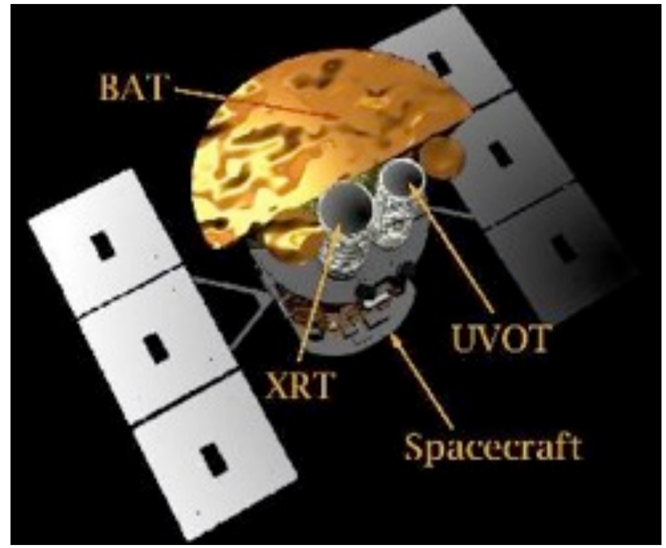
KL Dra, Ramsay et al (2010, 2012)

Orbital period close to 25 mins, and shows normal outbursts and super-outbursts.

KL Dra: Swift Nov-Dec 2009 observations



Ramsay et al (2010).



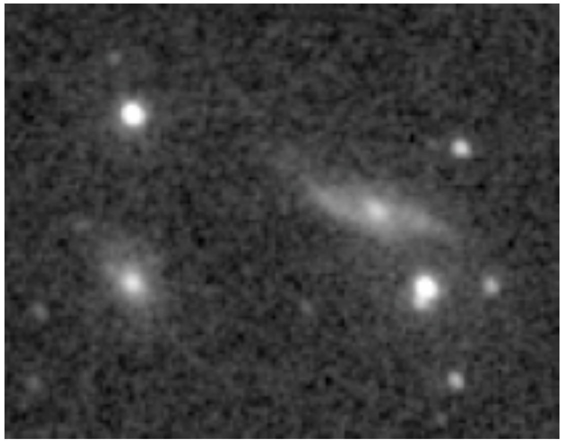
\`Spare' time to observe non-GRB targets.

Simultaneous X-ray/UV observations in Nov-Dec 2009. UV flux mirrors optical flux. No clear change in X-ray flux over the course of the outburst.

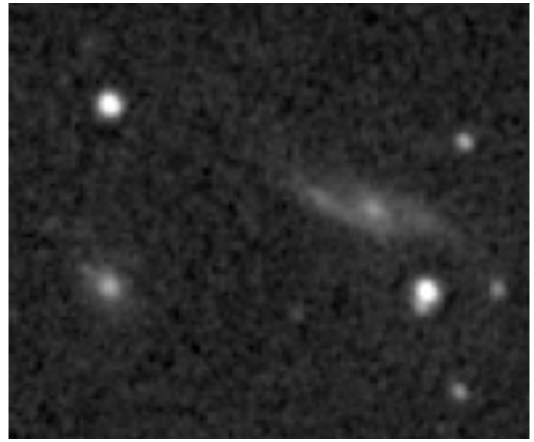
Comparing X-ray flux with systems with parallax measurements suggests distance 550-850pc.

Swift observations of KL Dra

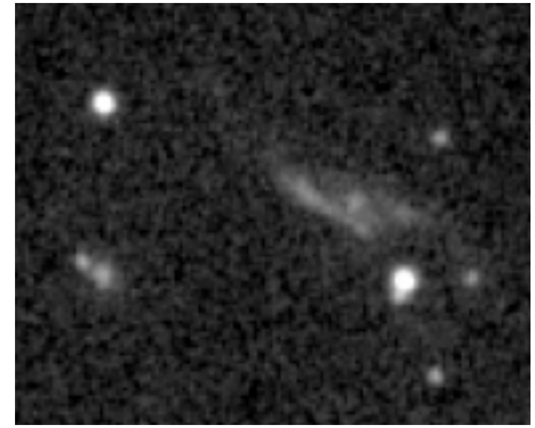
Swift-UVOT images



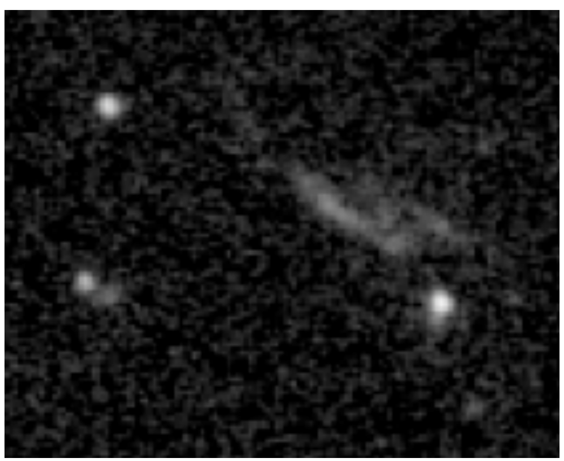
V band



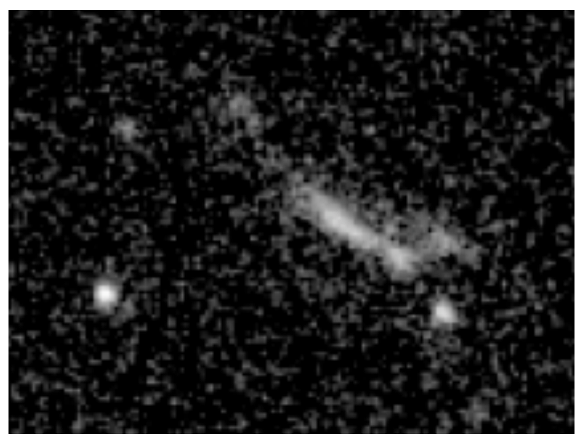
B band



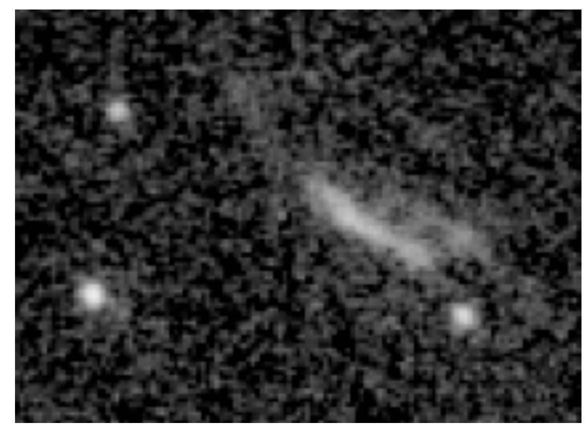
U Band



2600A



2250A

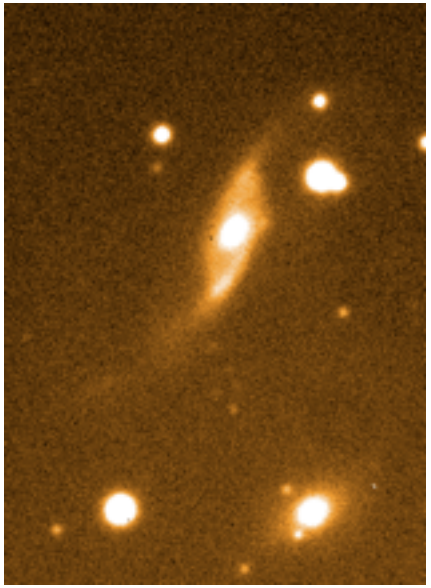


1930A

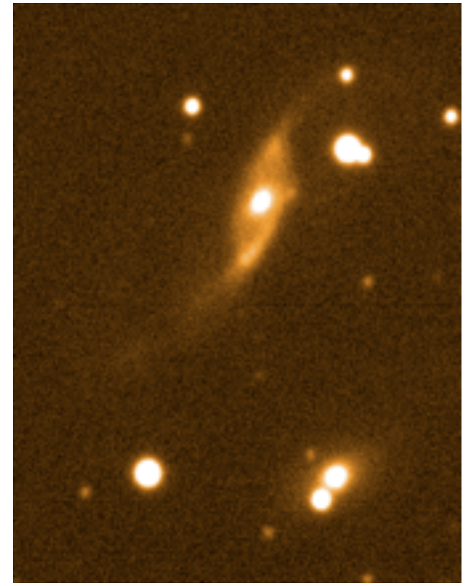
KL Dra - the Nov 2009 outburst

Optical

NOT 2009-11-25

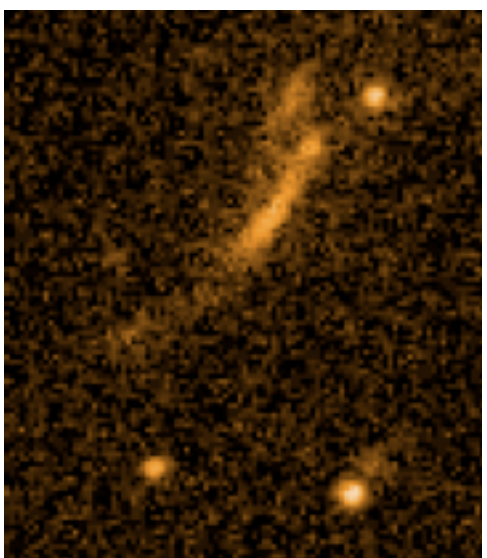


INT 2009-12-10

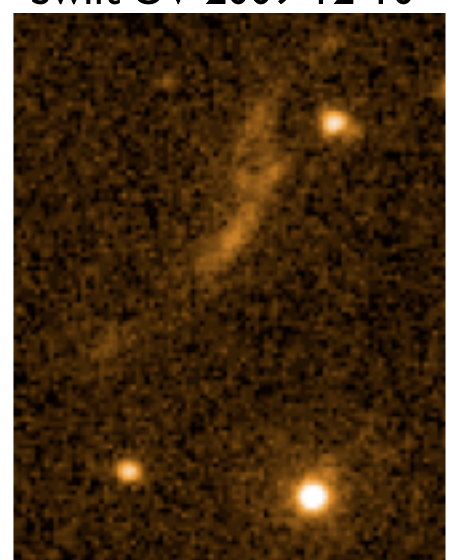


UV

Swift UV 2009-11-26

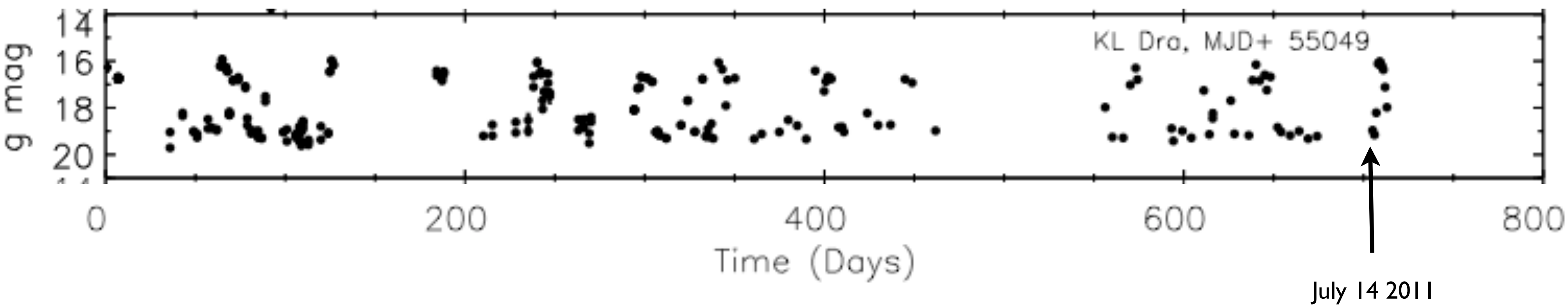


Swift UV 2009-12-10



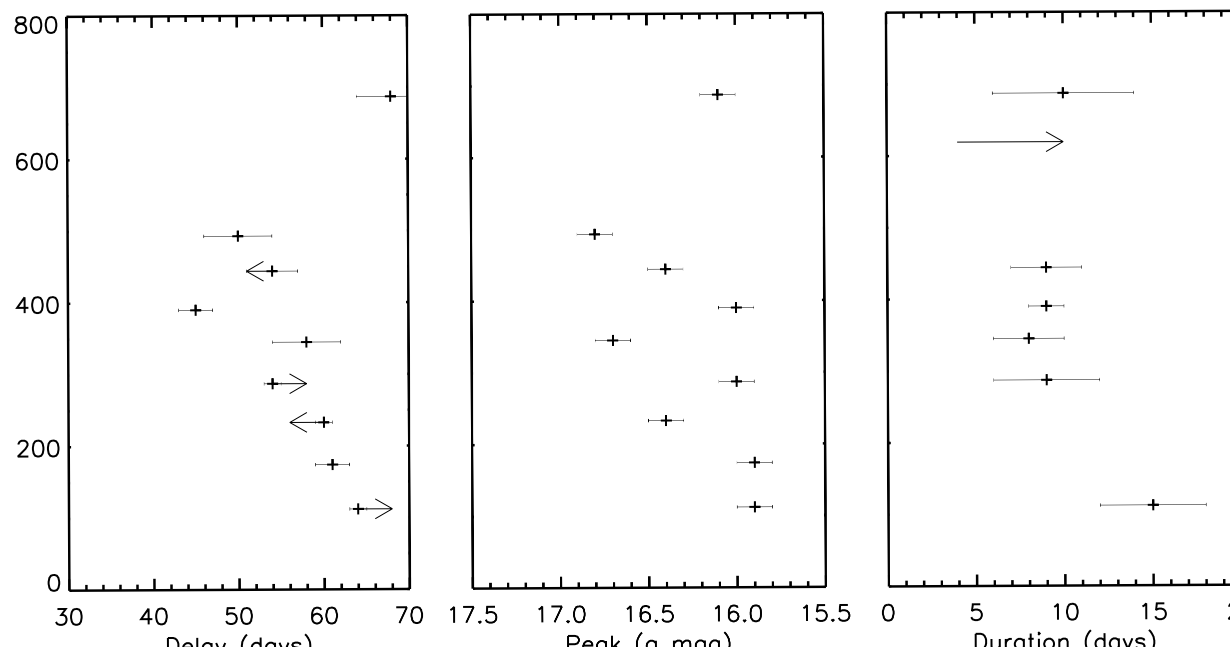
XMM-Newton observations of KL Dra Sept 2011

Most sensitive X-ray observations of an AM CVn Binary in outburst



Instead of an intensive monitoring campaign we used the trend in recurrence time to predict the time of the next outburst to trigger an XMM-Newton ToO. Set for Sept 19th 2011. Outburst in fact started 5-6 days earlier than predicted. Eight epochs of data each 3-5 hrs in duration.

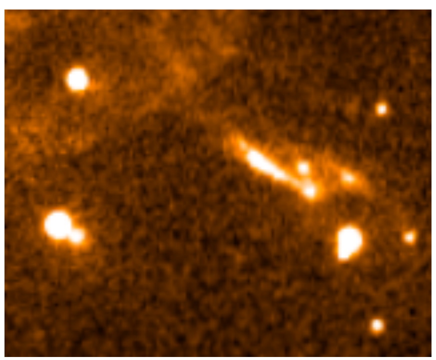
Launched in 1999; three X-rays telescopes and a Optical/UV telescope.



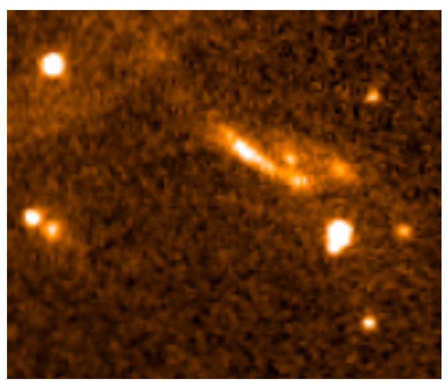
XMM-Newton observations of KL Dra Sept 2011

X-rays suppressed in optical outburst. Increase after end of outburst. X-ray softness ratio changes marginally over course of outburst, especially at the softest energies.

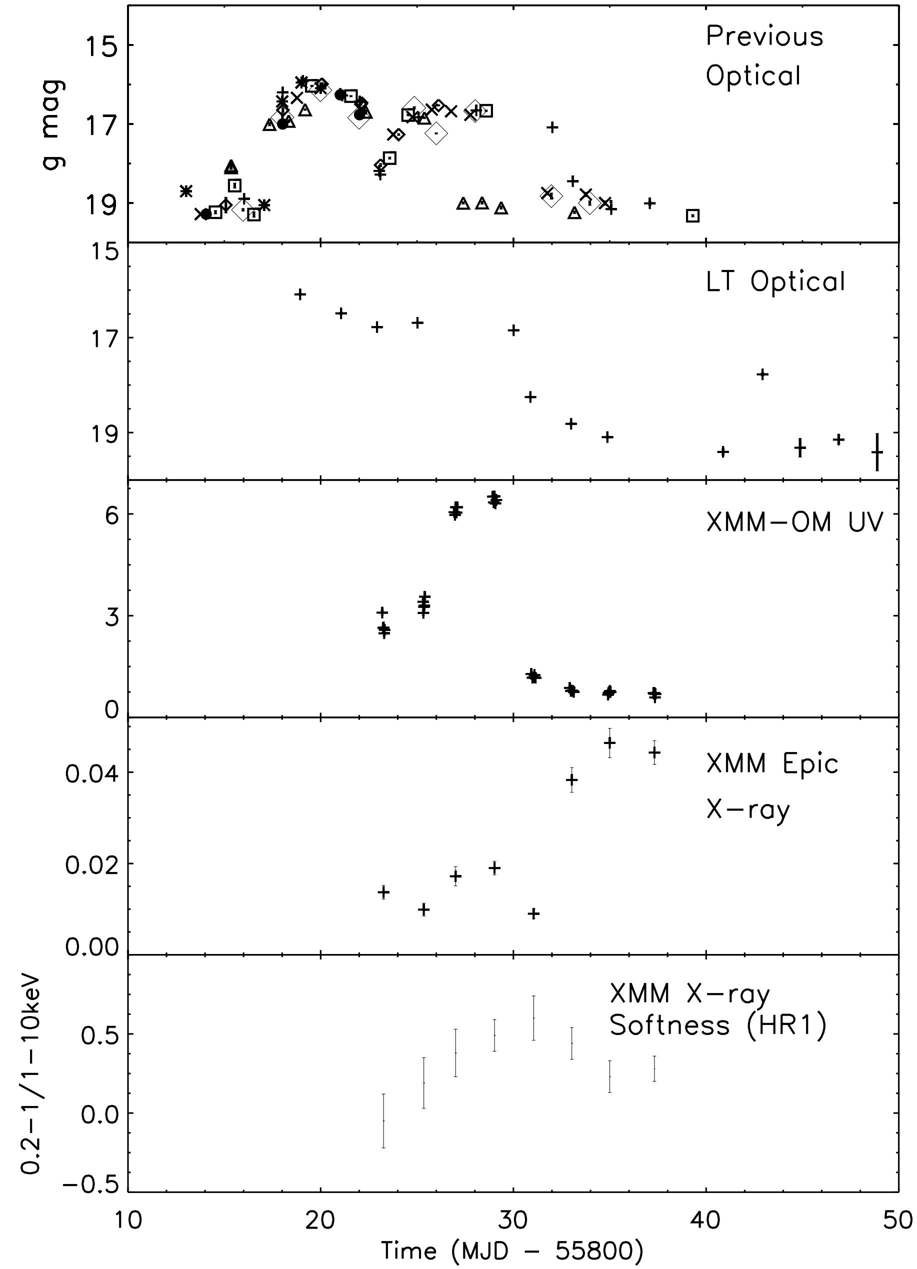
UV images



Outburst State

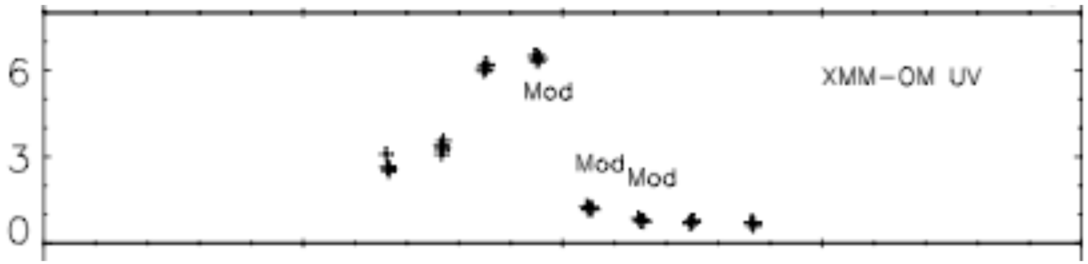


Low State



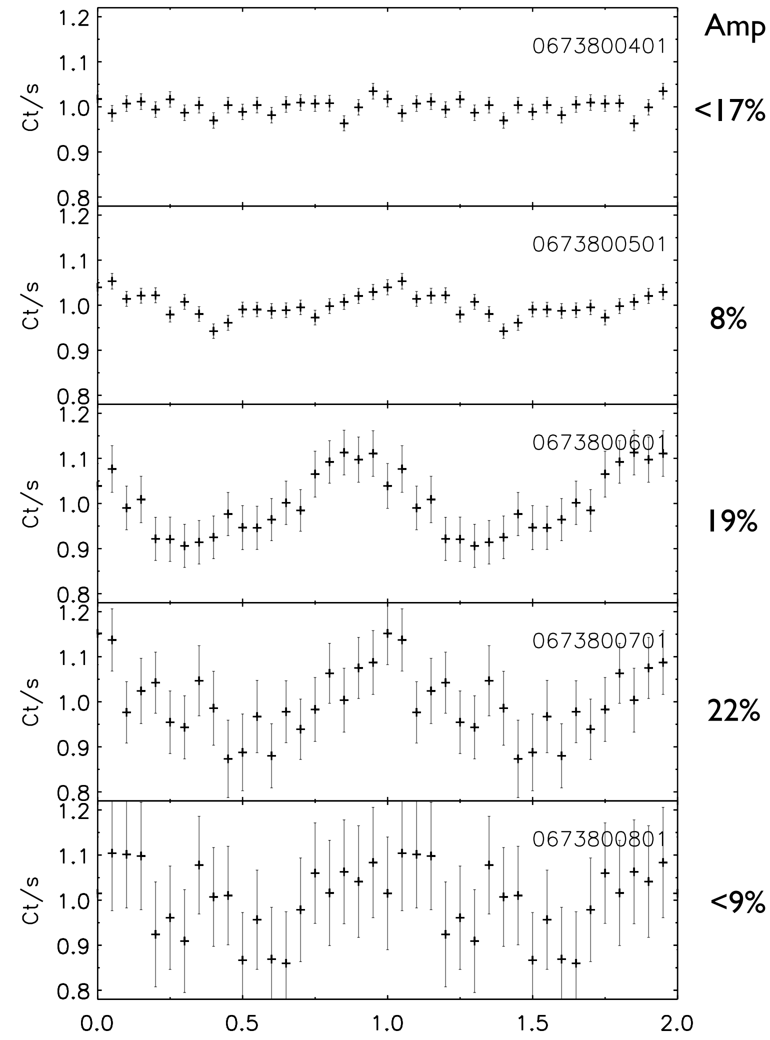
Ramsay et al (2012)

XMM-Newton OM/UV observations



Modulation seen at three epochs - cannot distinguish between signature of orbital period and super-hump period.

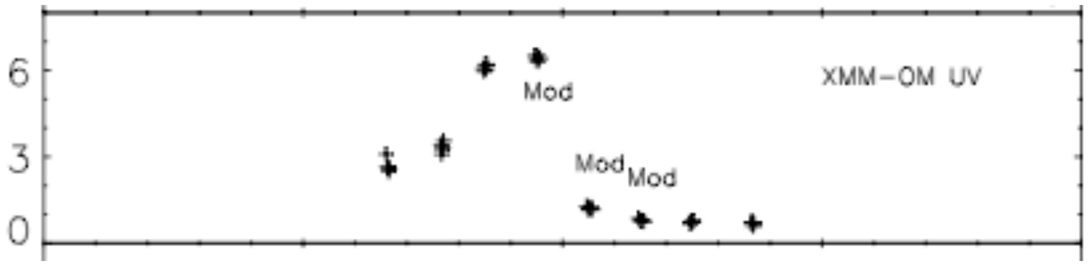
Long thoughts super-humps were seen only in super-outbursts ...



Ramsay et al (2012)

Differences in light curve folded on super-hump period can give insight to accretion process

XMM-Newton OM/UV observations



Modulation seen at three epochs - cannot distinguish between signature of orbital period and super-hump period.

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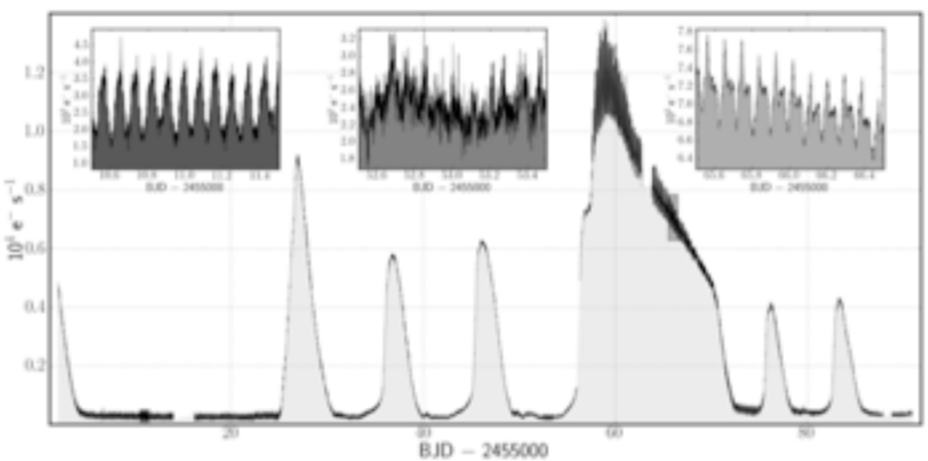
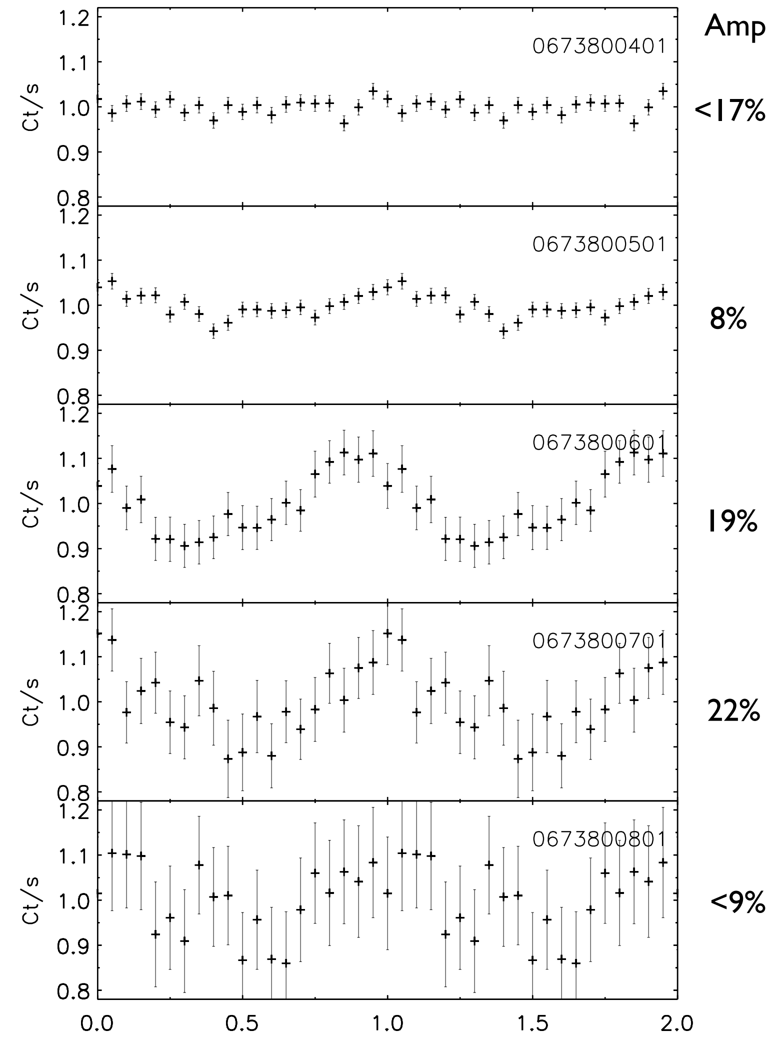
However, seen in quiescence, normal outbursts and superoutbursts in Kepler observations of CVs



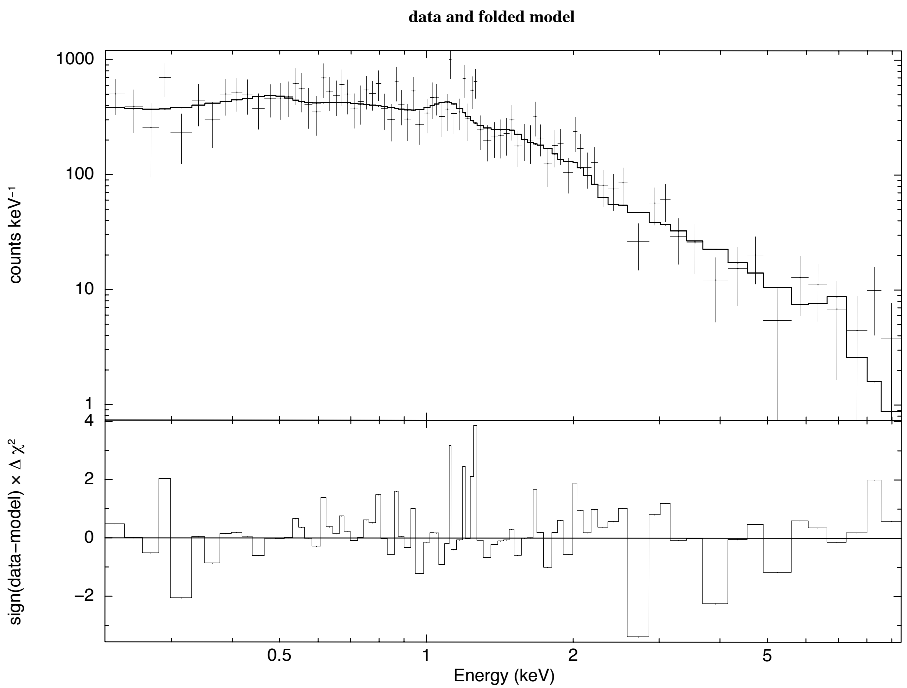
V344 Lyr, Still et al (2010)

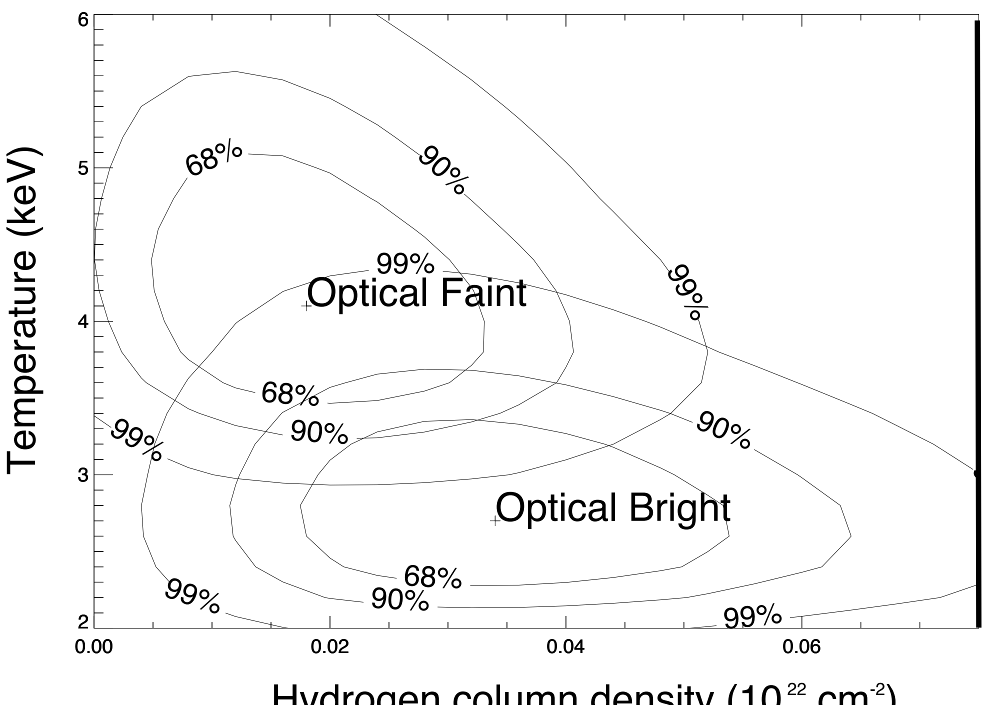


Ramsay et al (2012)

Differences in light curve folded on super-hump period can give insight to accretion process

XMM-Newton observations of KL Dra Sept 2011



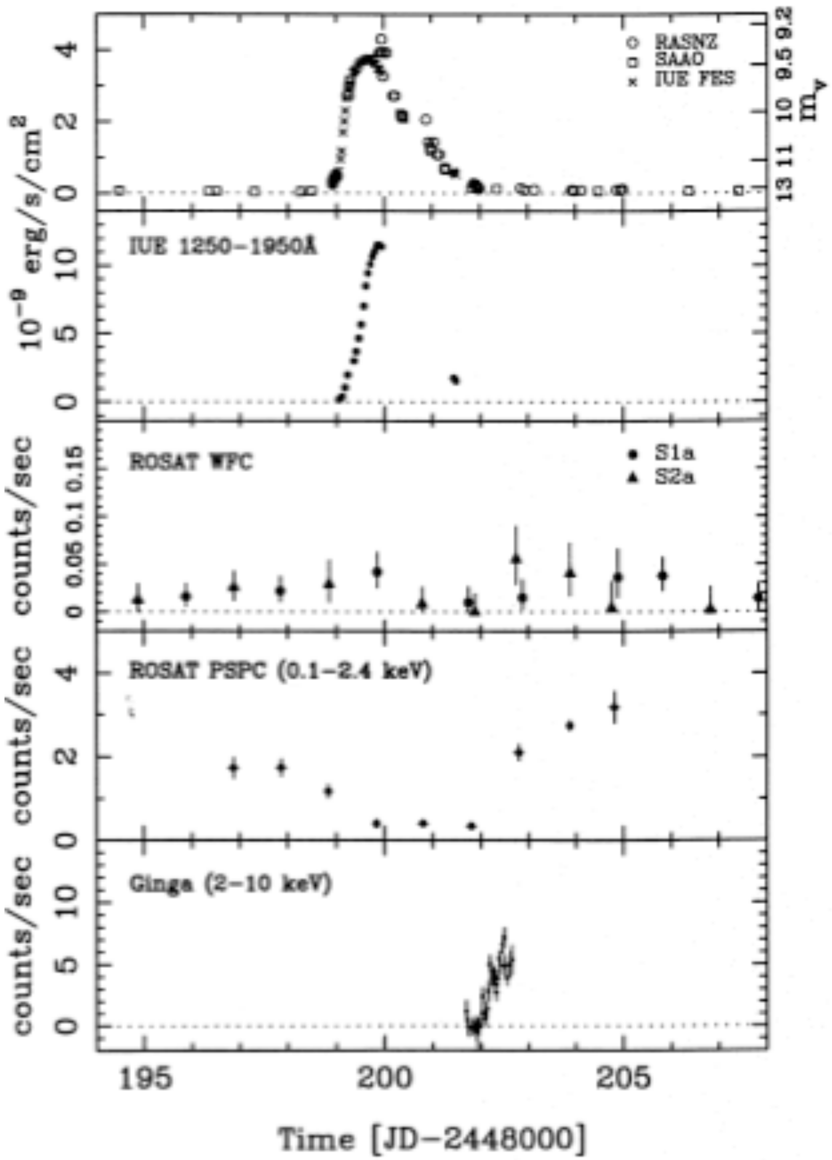


X-ray spectra well modelled using an absorbed thermal plasma model. Metalicity not well constrained. Weak evidence for temperature cooler during optical outburst compared to quiescence. Ramsay et al (2012)

Comparison with dwarf novae

X-rays tend to be suppressed during optical outburst

VW Hyi Wheatley et al (1996)



U Gem appears to be the one of the few exceptions (Mattei, Mauche & Wheatley 2000)

see talk by Balman for more details ....

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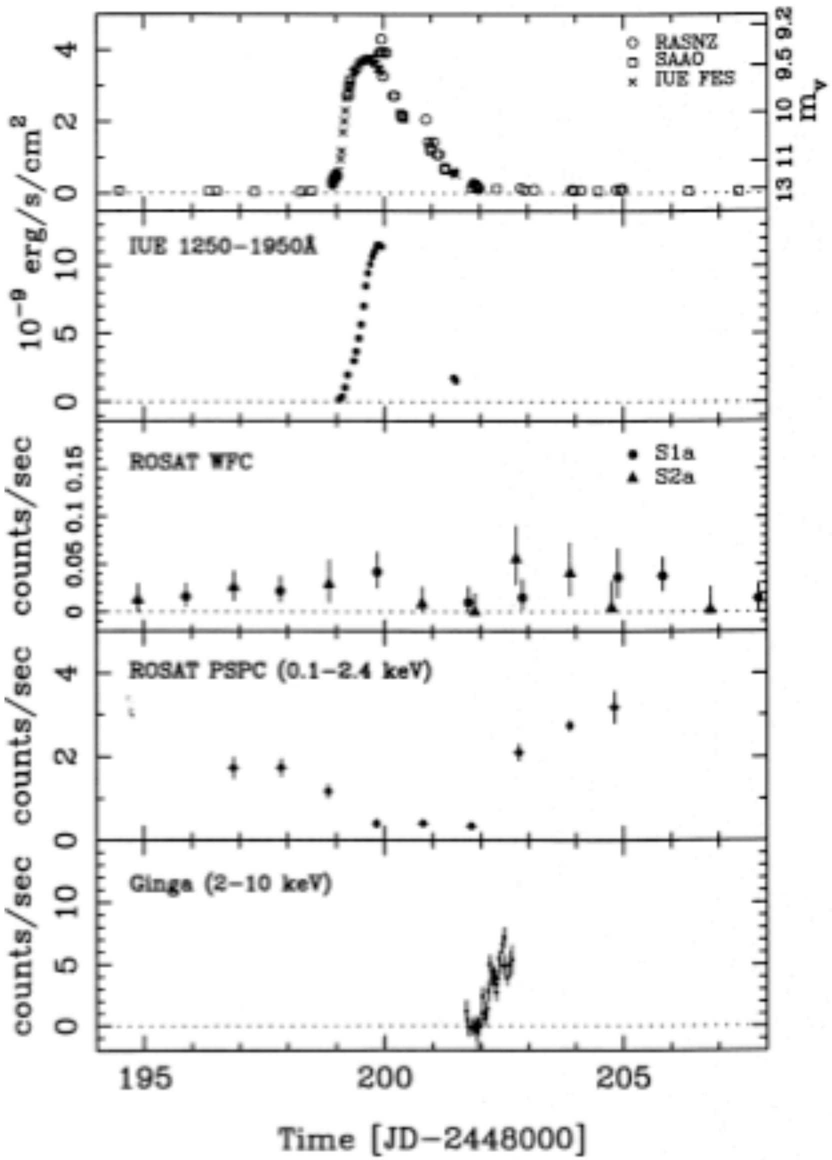

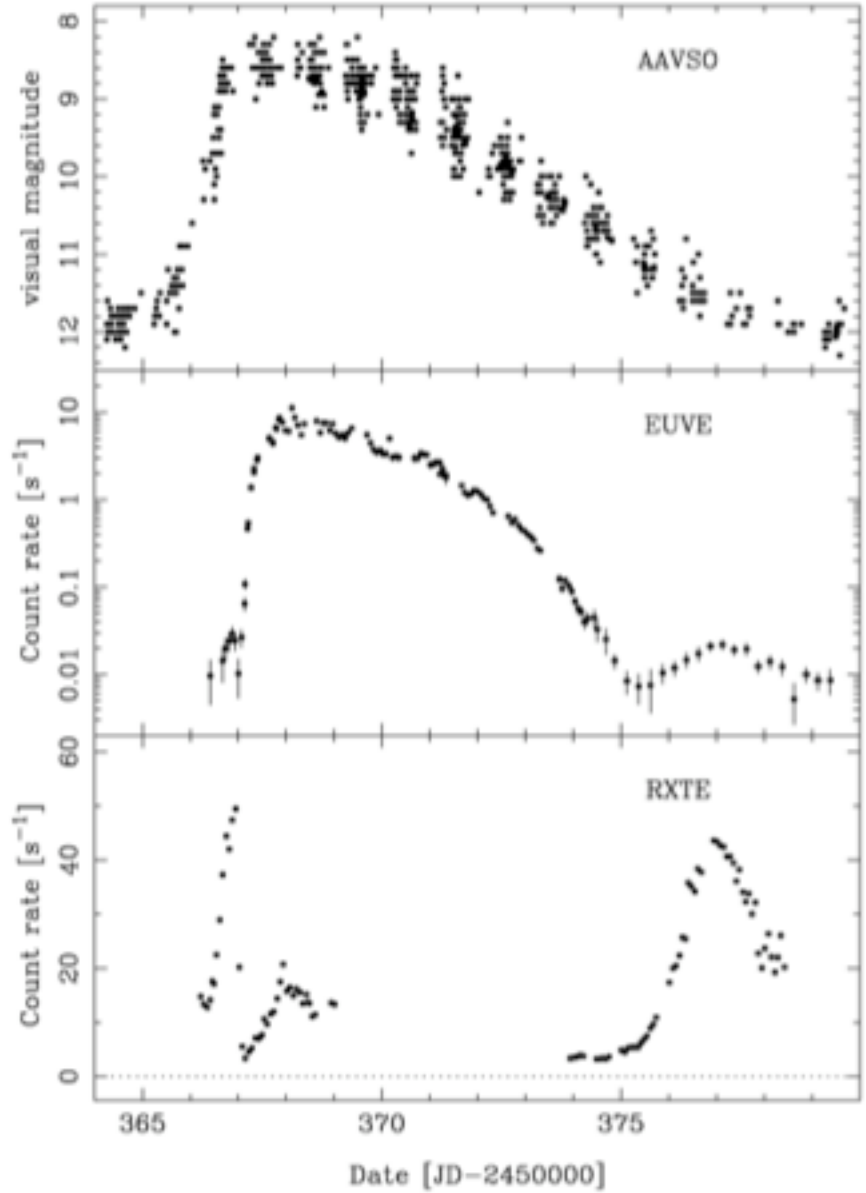

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SS Cyg (Wheatley, Mauche & Mattei 2003)

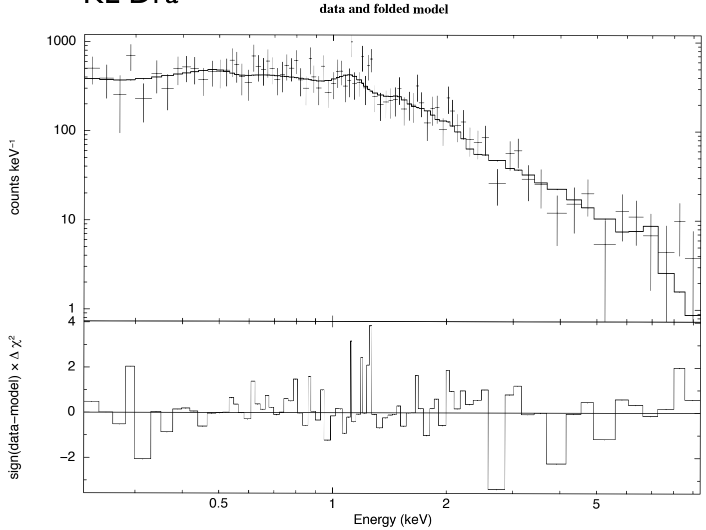
see talk by Balman for more details ....

Similarities and differences in outburst of KL Dra and dwarf novae

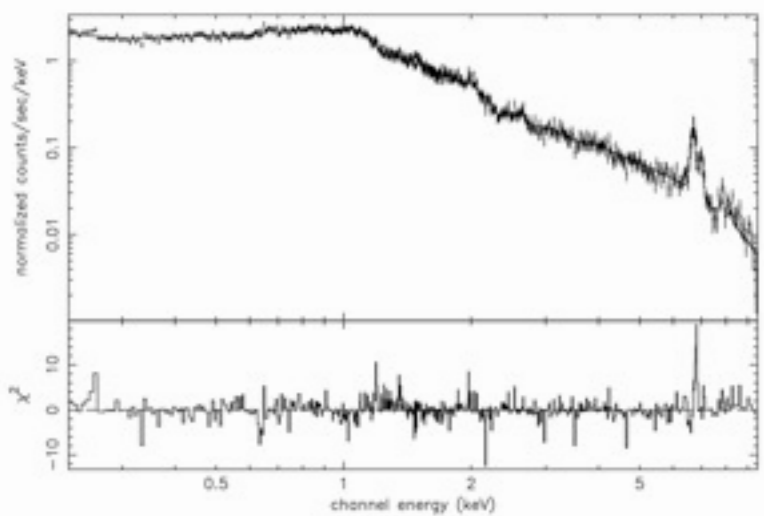
The shock temperature, Ts, if proportional to, mu, the mean molecular mass of the gas. For solar composition, mu=0.615, and a helium flow, mu=4/3.
The temperature for a helium flow should therefore be ~ twice that seen in dwarf novae. Not what is observed.

Temperature in dwarf novae and magnetic CVs can reach many10's of keV.

KL Dra



YZ Cnc - dwarf novae - Hakala et al (2004)



Significant proportion of X-rays generated in wind from white dwarf or accretion disc?

Final thoughts

AM CVn systems showing dwarf nova outbursts are excellent tests of disc instability models;

With the discover of new systems can begin to search for correlations between super-outburst period and parameters such as orbital period;

Additional targets to determine how X-rays vary over the outburst cycle.

What is the origin of the `dips' seen in some super-outbursts?