Intriguing Light Curves of Dwarf Novae: Testbeds for Accretion Disk Theories

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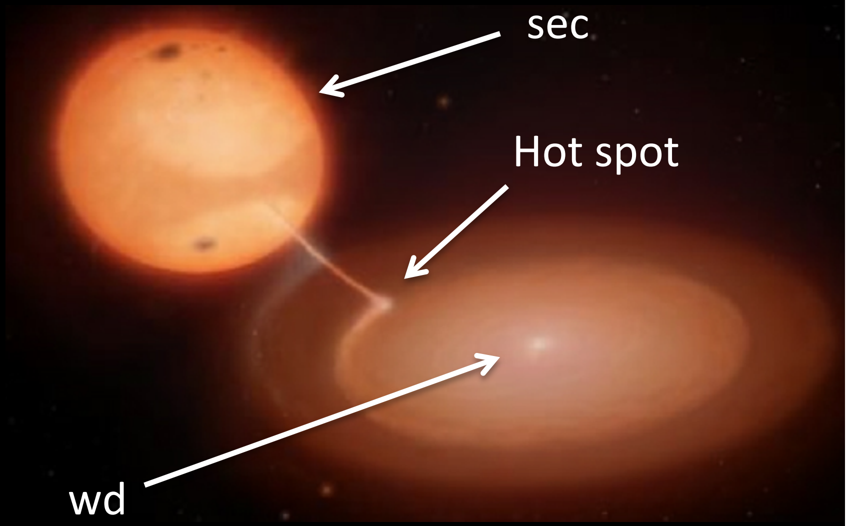
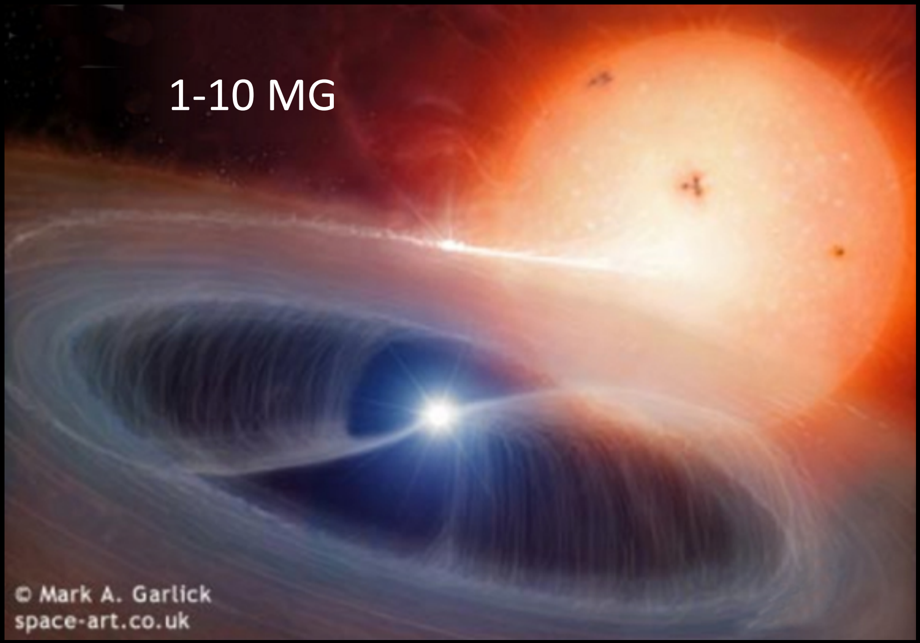
- **close binary systems** (P=1-10 hr)
- **white dwarf primary** ($0.8M_o$)
- **low mass secondary** (M4-L)
- **active mass transfer** (10^{-8}-10^{-11})



Dwarf novae, Novalikes

Disk Systems~2000



Intermediate Polars ~50

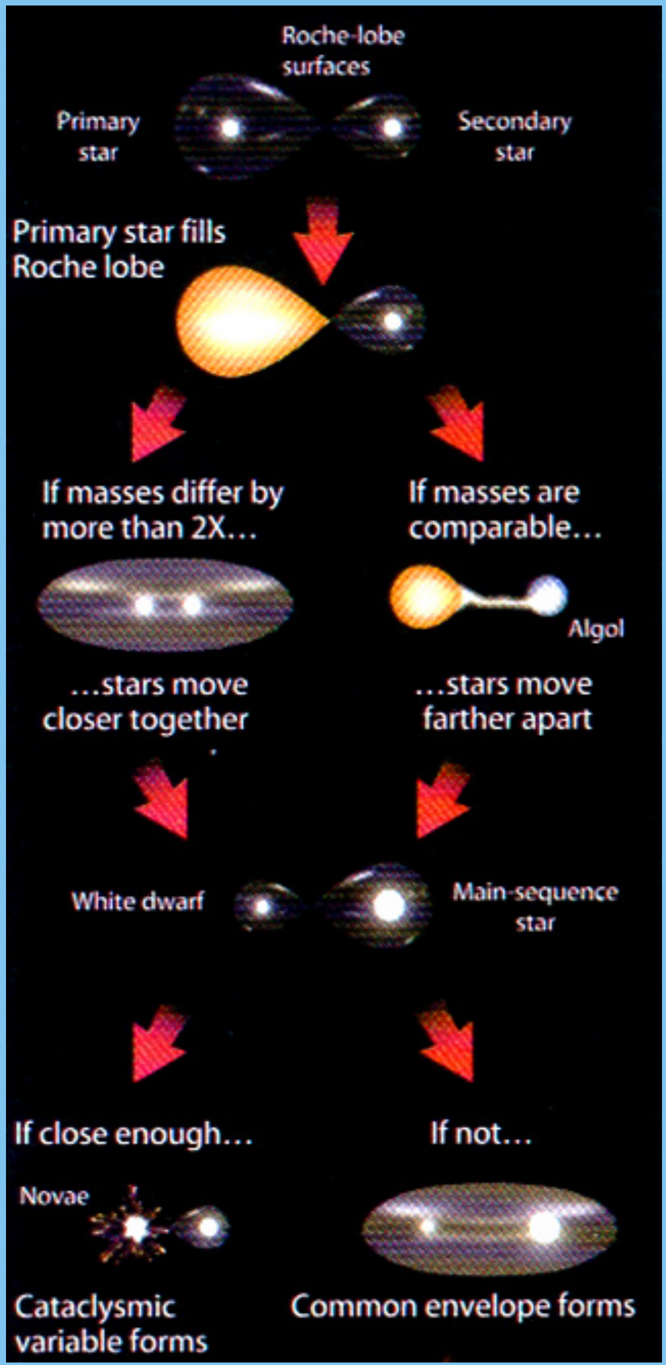
P_{orb}~3.5 hrs,
P_{spin}~20 min

Possible evolution path

common envelope phase

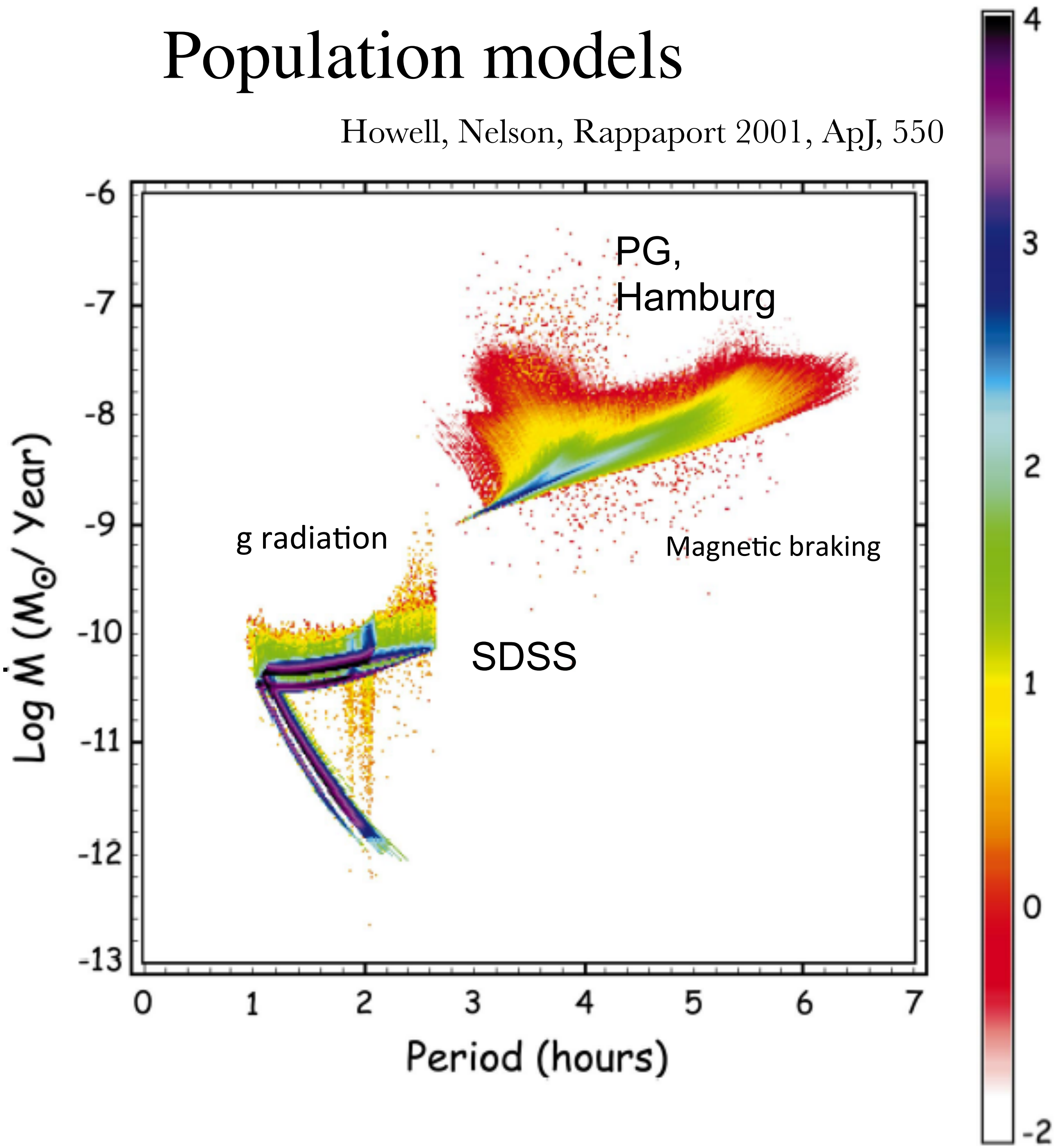
Pre-CV

Angular momentum losses



Population models

Howell, Nelson, Rappaport 2001, ApJ, 550

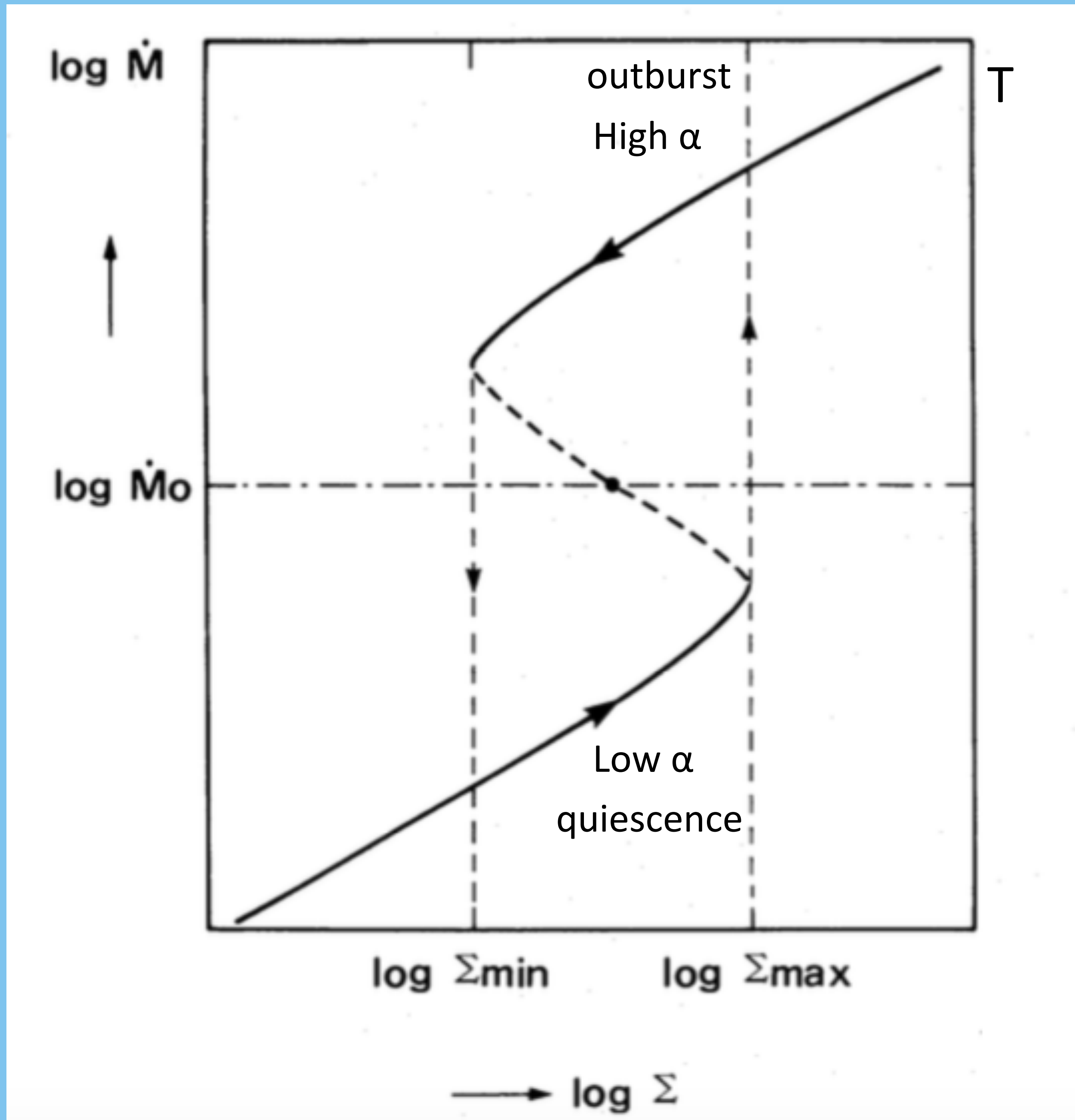


Log number of CVs

Goliasch & Nelson 2015

THEORY

accretion rate



Disk Instability Models (DIM)

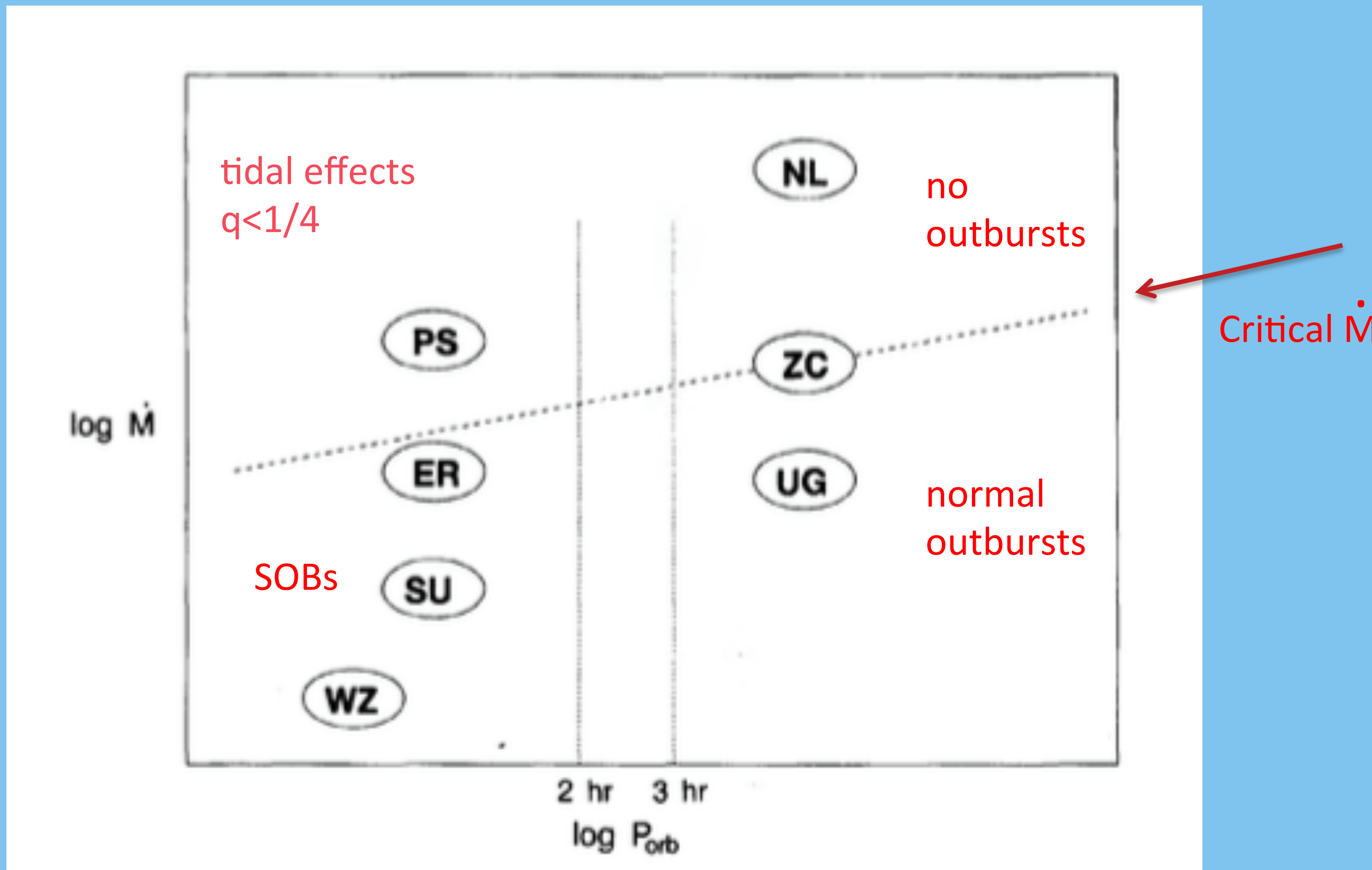
Smak, Lasota, Meyer, Cannizzo, Hameury

1980’s

+ tidal effects
+ MRI

steady mass transfer rate

OBSERVABLES

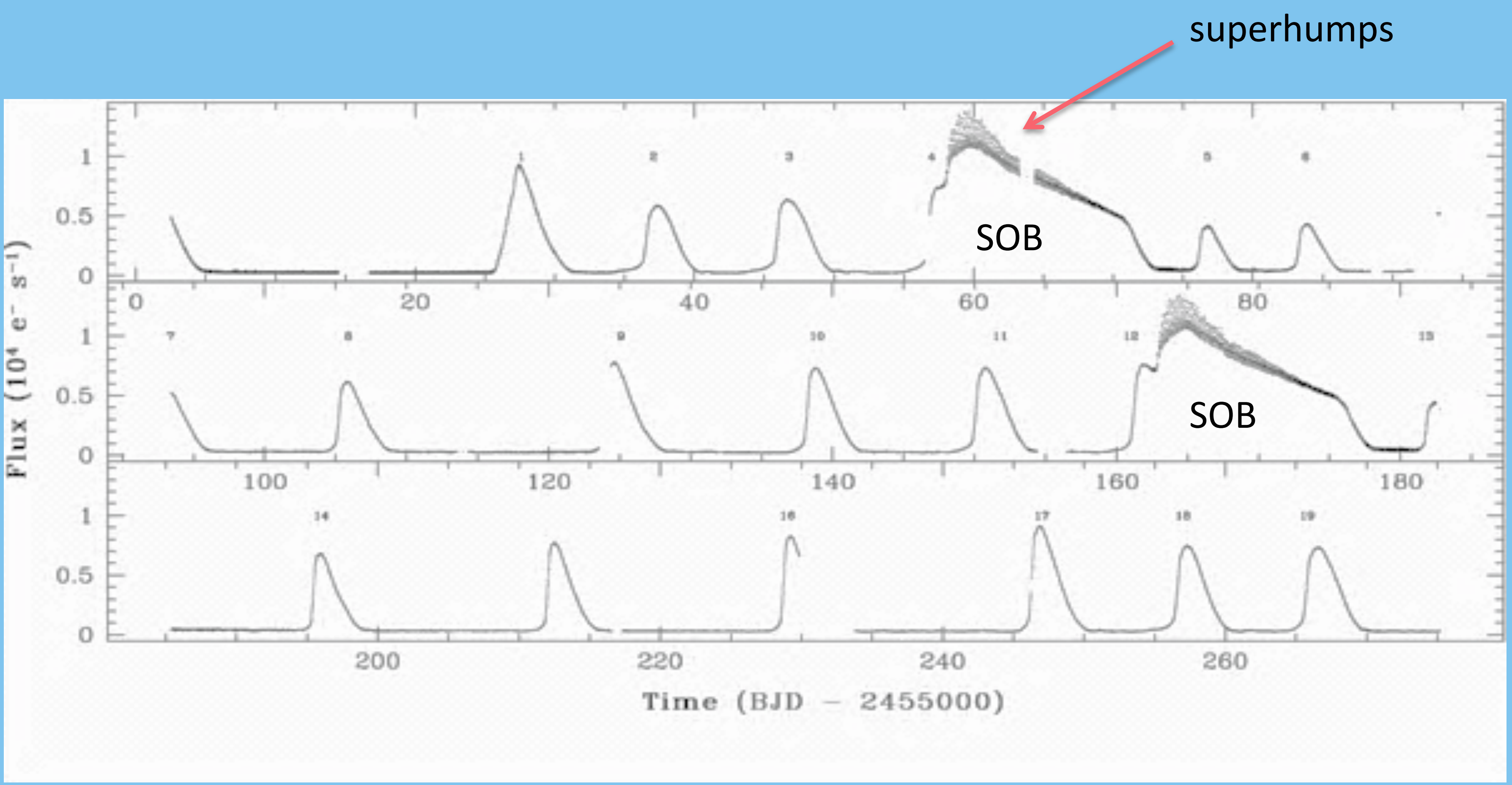


Osaki 1989

V344 Lyrae:

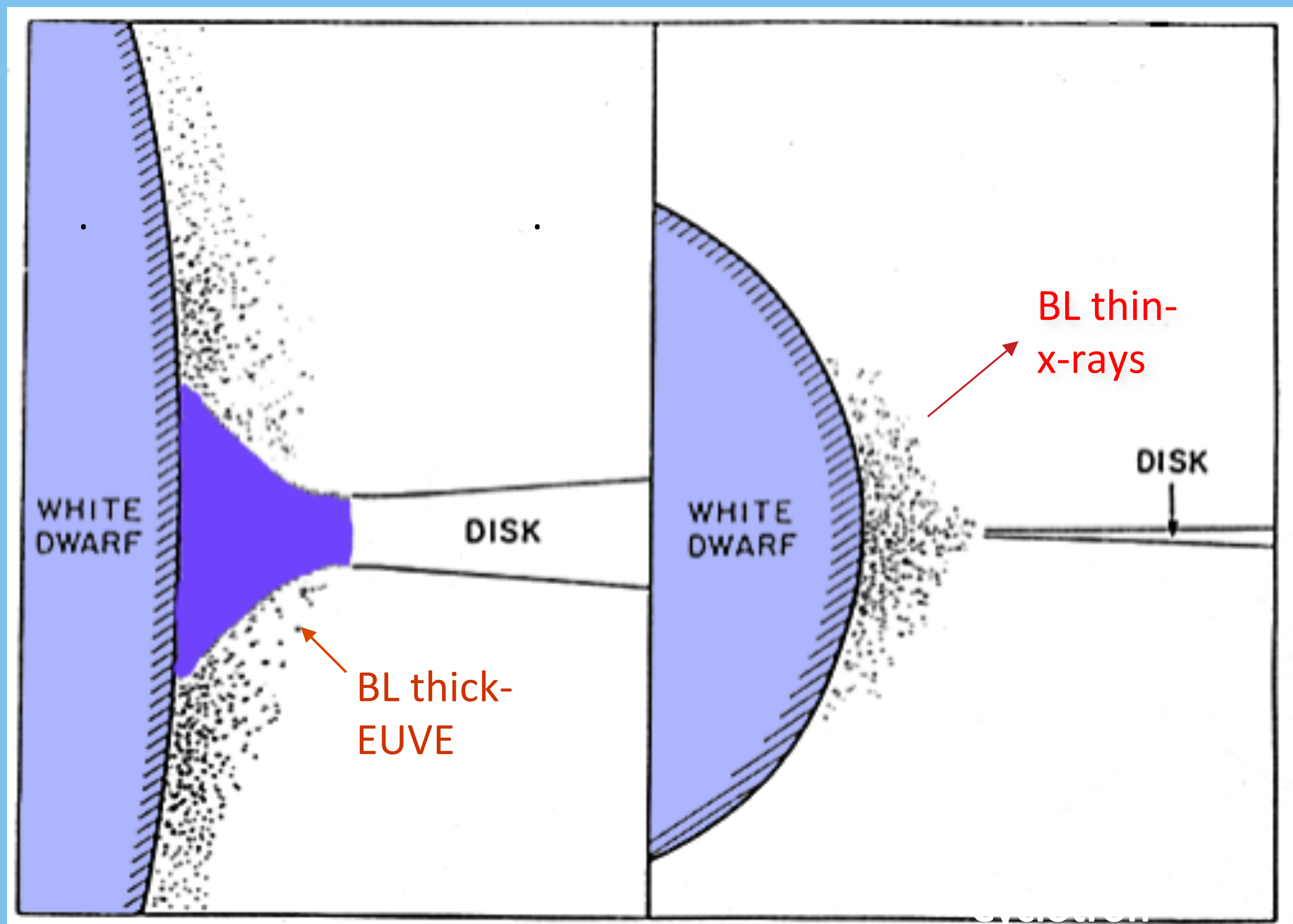
Matt Wood et al. 2011 ApJ 741 105

P_{orb}< 2hrs have normal and SOBs or just SOBs



DISK ACCRETION

High $\dot{M}$-DN outburst or NL   Low $\dot{M}$-quiescence



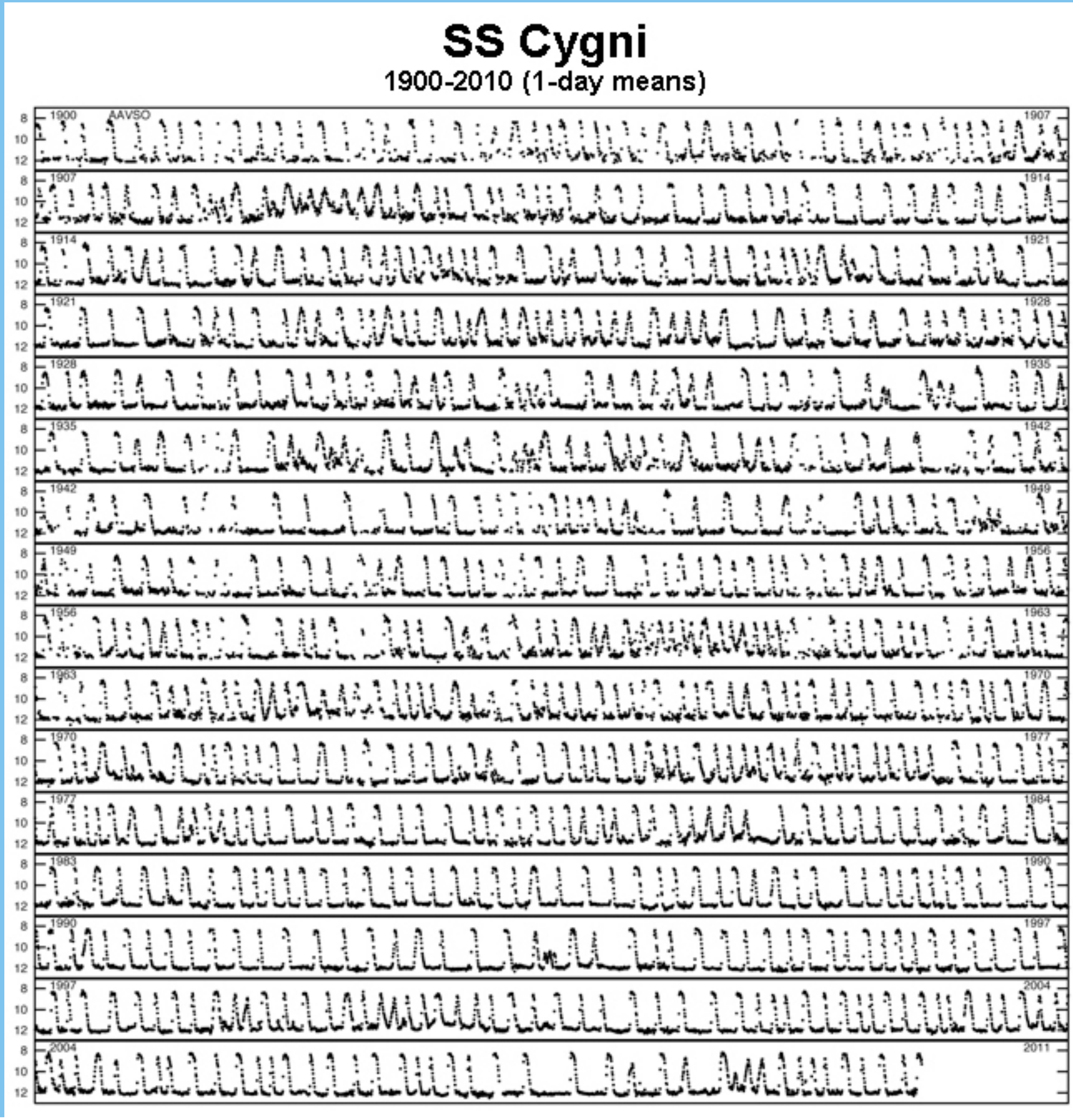
Four Areas Needing Attention:

- Peculiarities related to outbursts
- Long photometric periods in short P systems
- Rapid switches in disk visibility
- Double orbital humps in short P systems

Peculiarities related to Outbursts

- Shape (inside out vs outside in?)
- Precursors on long outbursts
- Late Decline from outbursts
- Standstills in Z Cam
- Intermediate Polar Outbursts

AAVSO amateurs

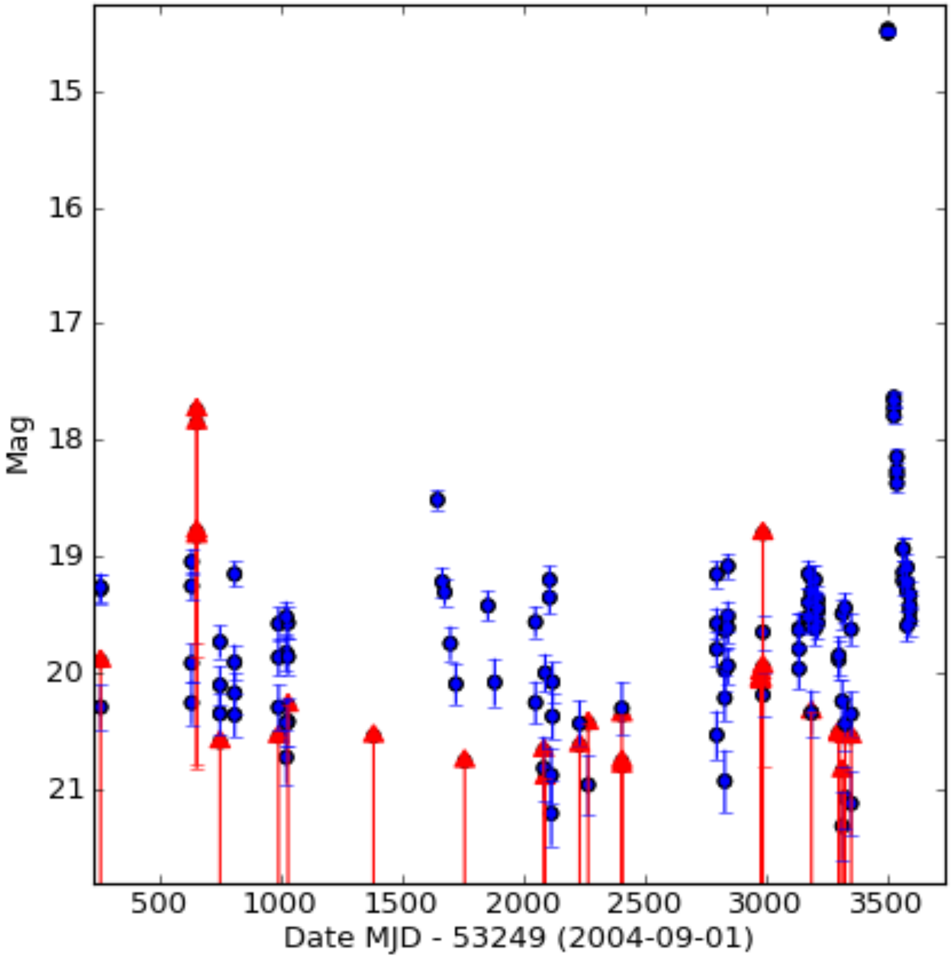


Each line= 7 yrs

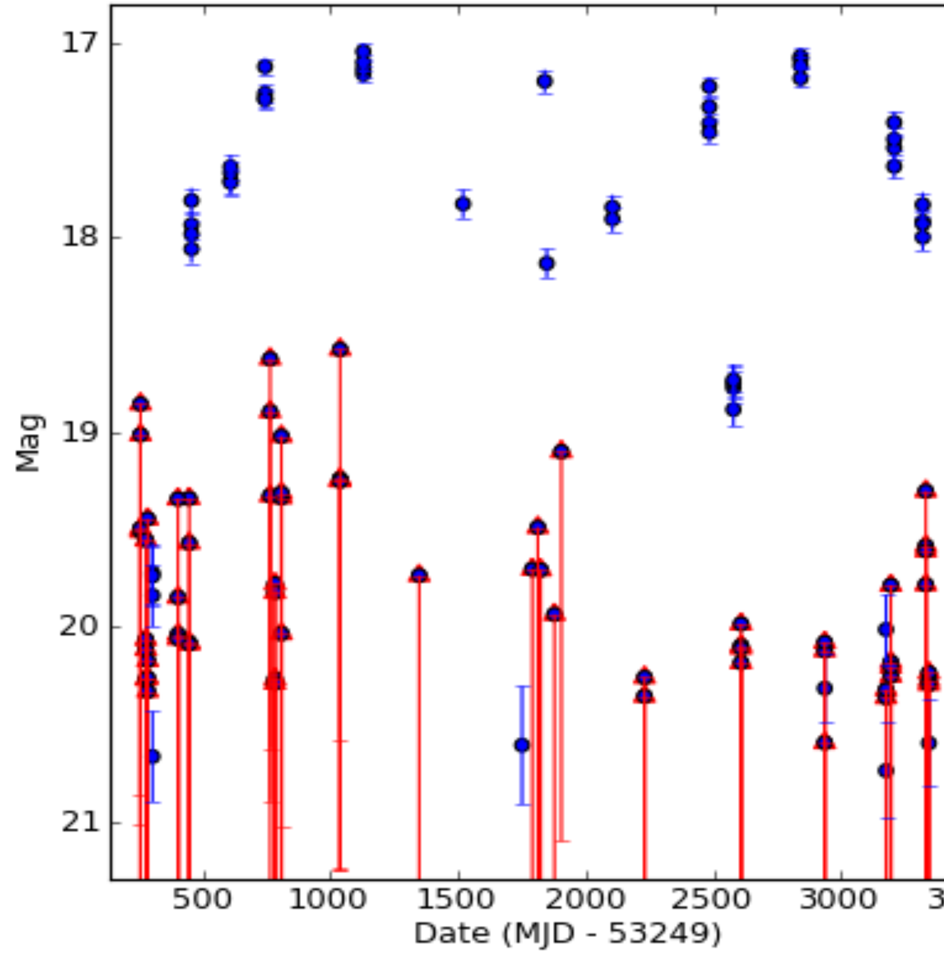
P_{orb}=6.6 hrs

Outbursts ~ 40 days

Low Mdot – long interval and high amp



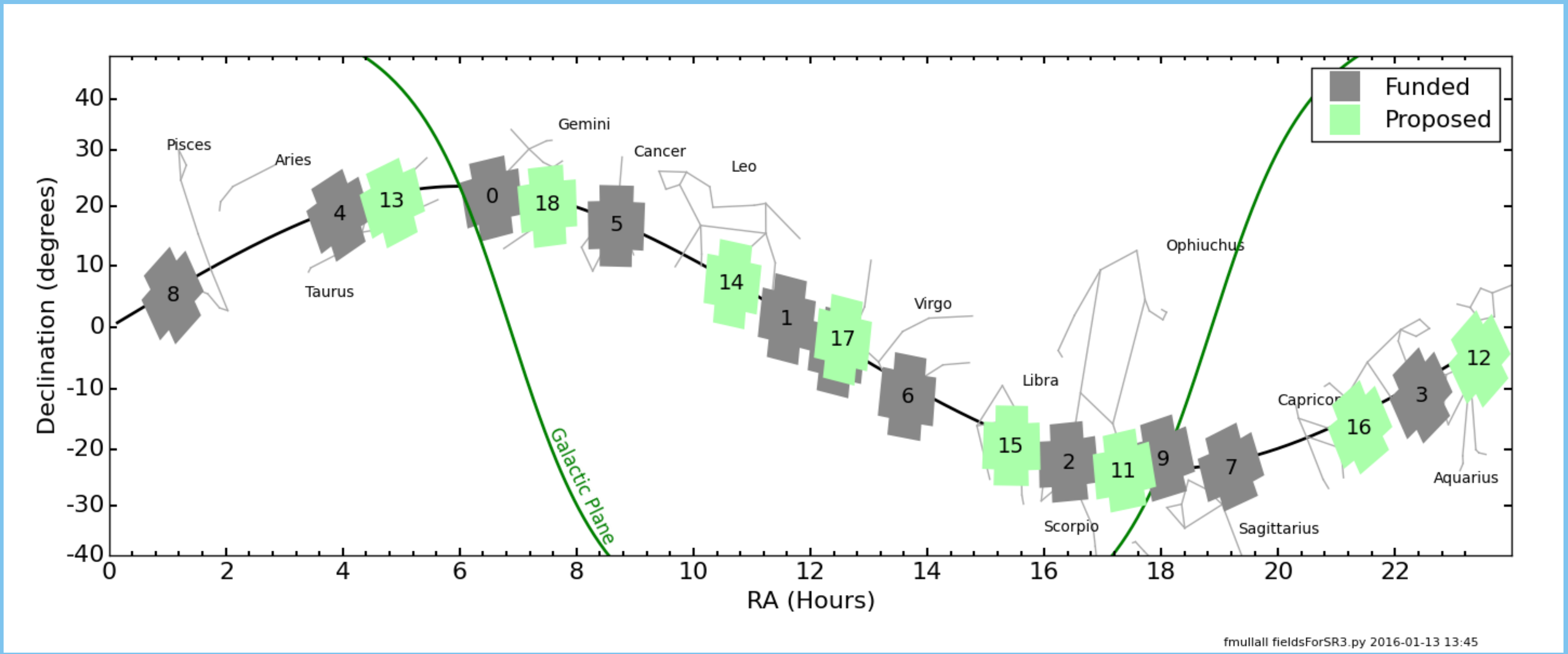
High Mdot- short interval and low amp



Catalina Real Time Sky Survey (CRTS) detecting outbursts

1376 listed CVs so far

Kepler K2 Fields

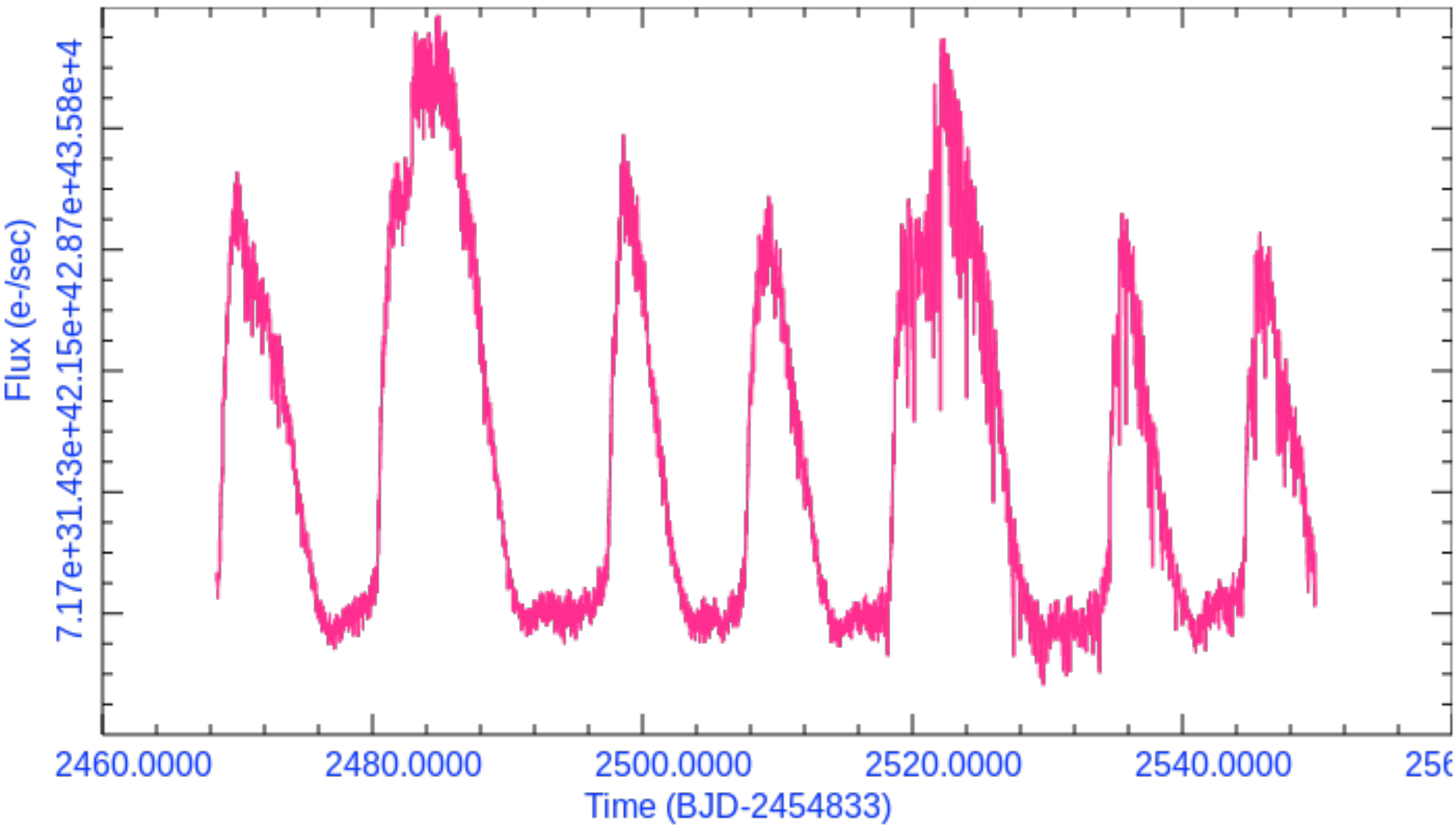


Continuous photometry for ~80 days!

Long cadence = 30 min
Short cadence = 1 min

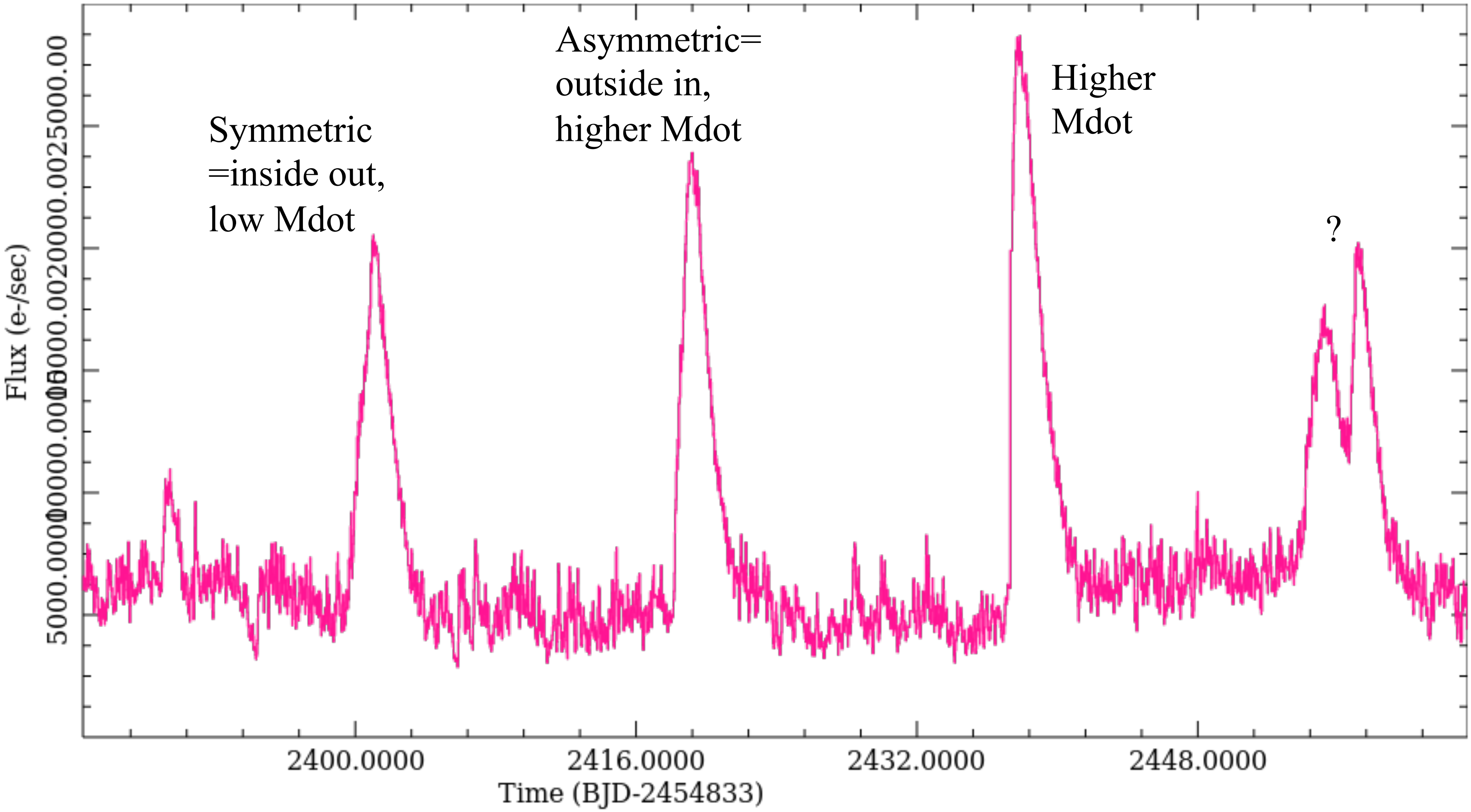
60 CVs observed so far-
K2-11 in progress

K2-7 V729 Sgr P_{orb}=4.2 hr

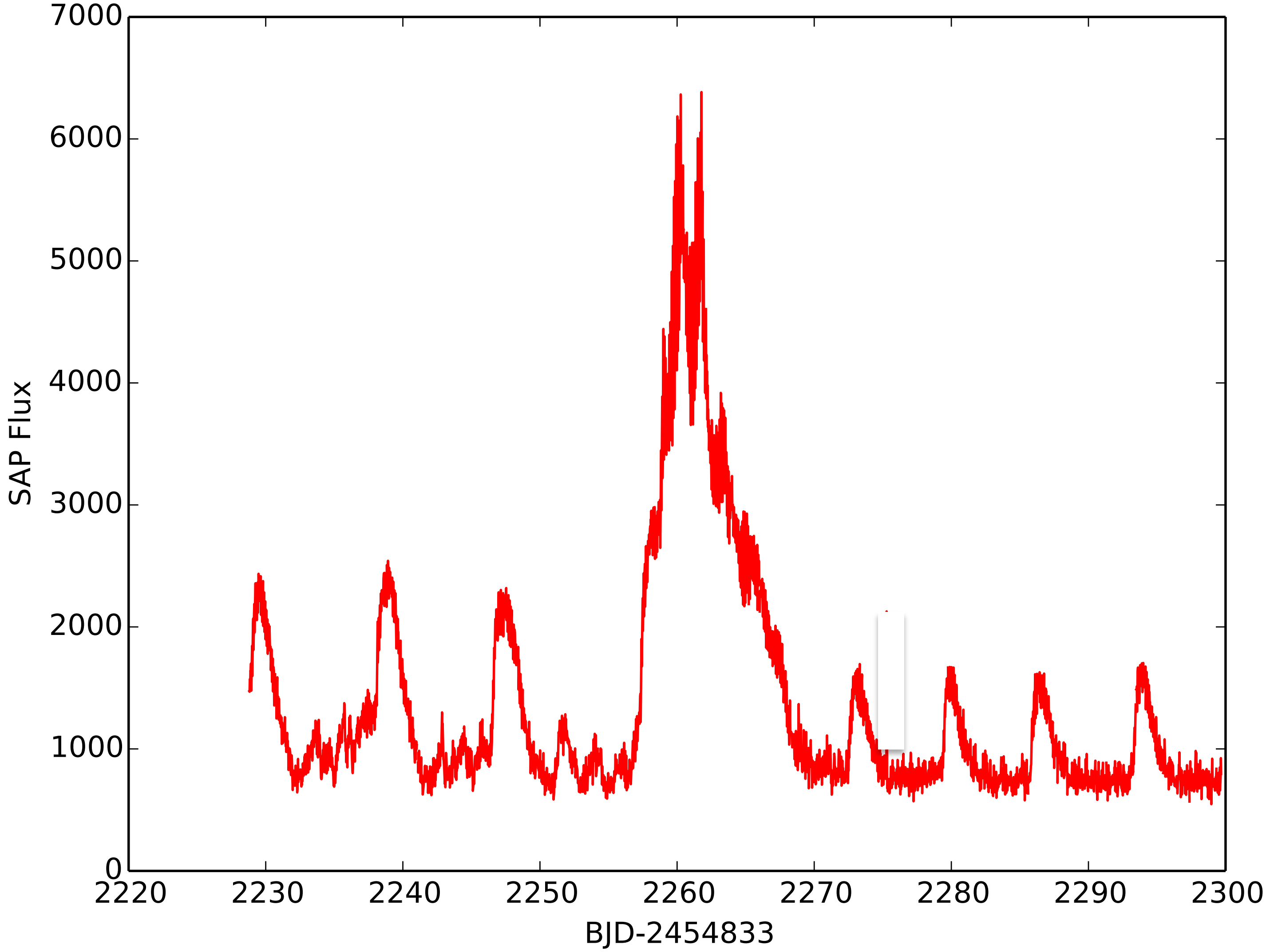


K2 detecting outbursts

K2-6 HS Vir P_{orb}=1.85 hr

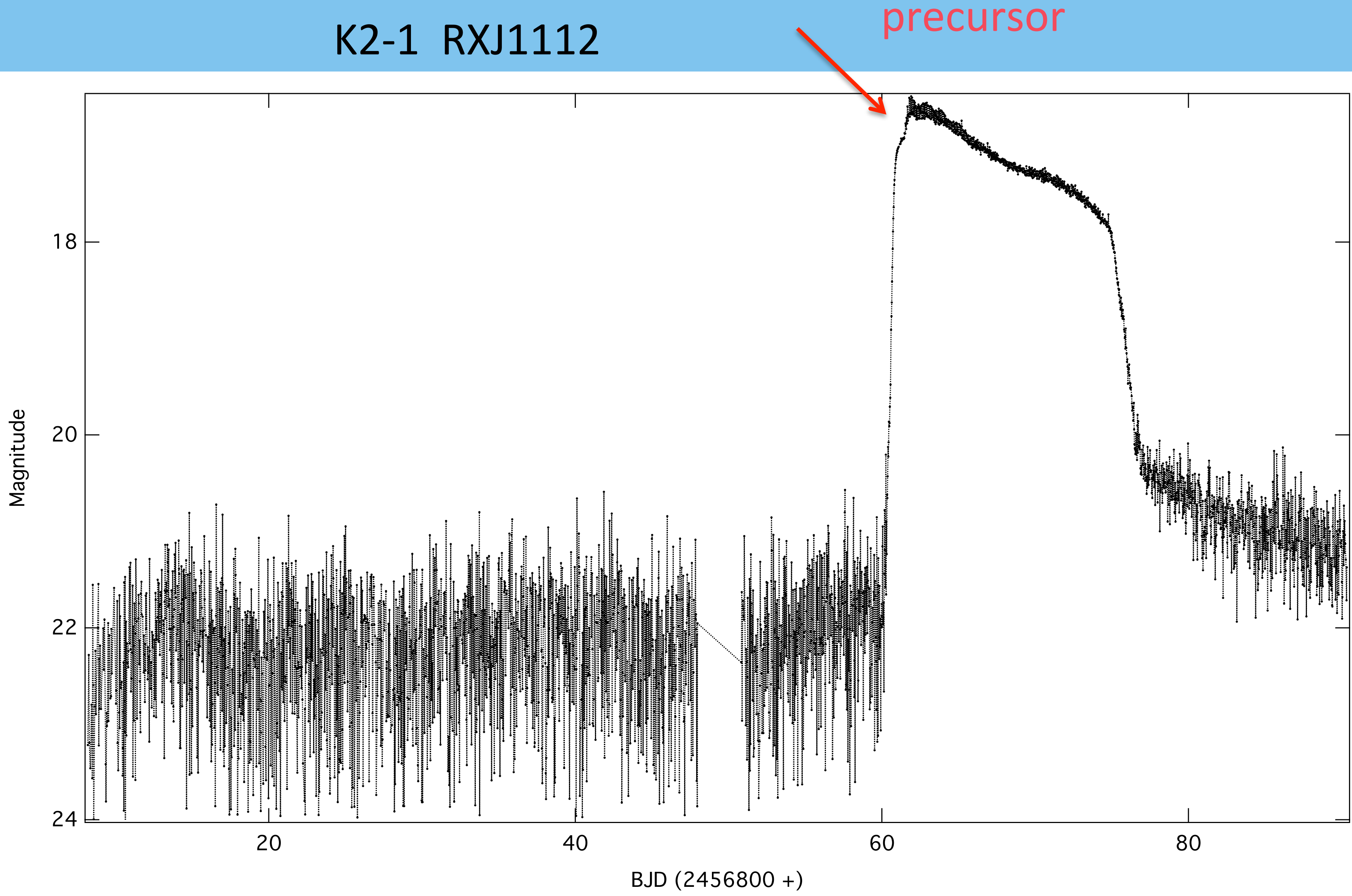


MLS0359+17 (SDSS0359 +17) K2-4

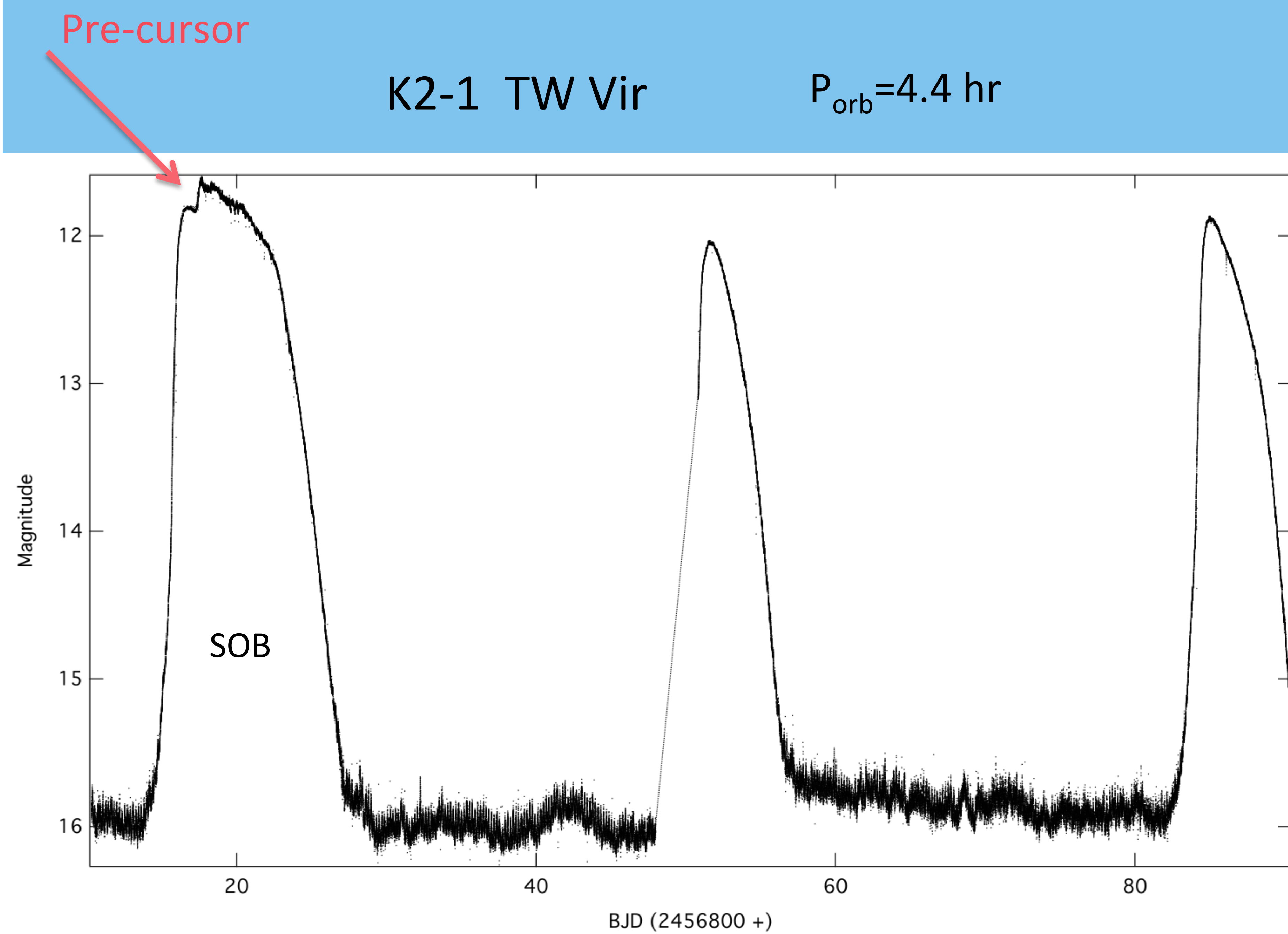


P_{orb}=115 min

K2-1 RXJ1112

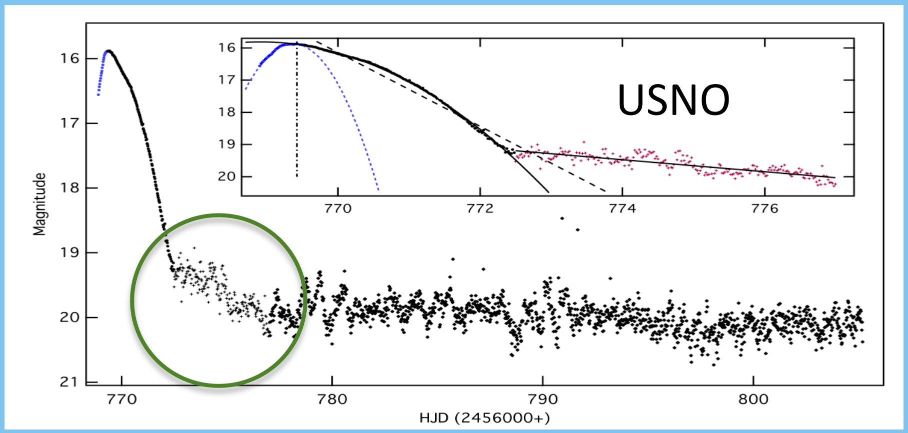


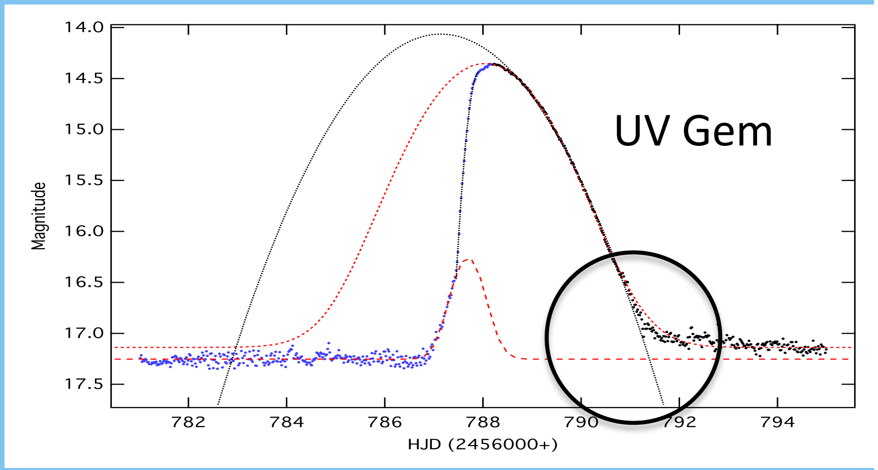
K2-1 TW Vir P_{orb}=4.4 hr

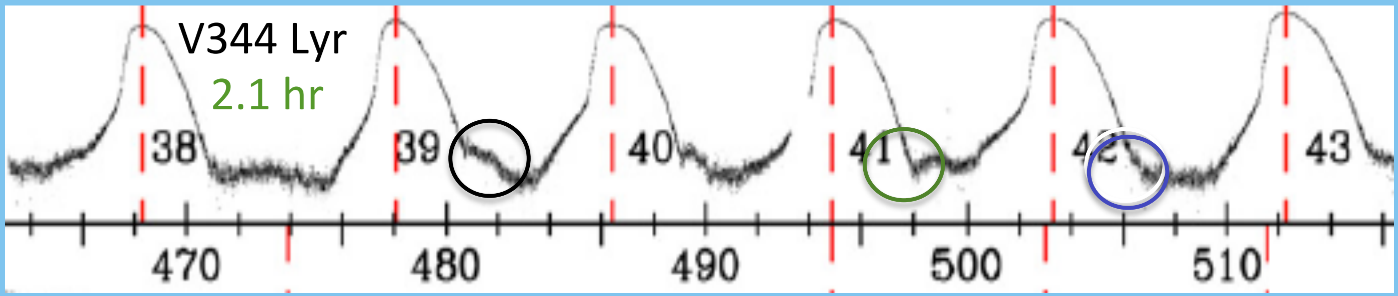


- ✧ The ends of normal outbursts are different. UV Gem has a smooth, fast decline, while USNO has a slow linear decline over 4.5 days
- ✧ V344 Lyr has the same orbital period (2.1 hr) as UV Gem.

Dai et al. 2016, AJ



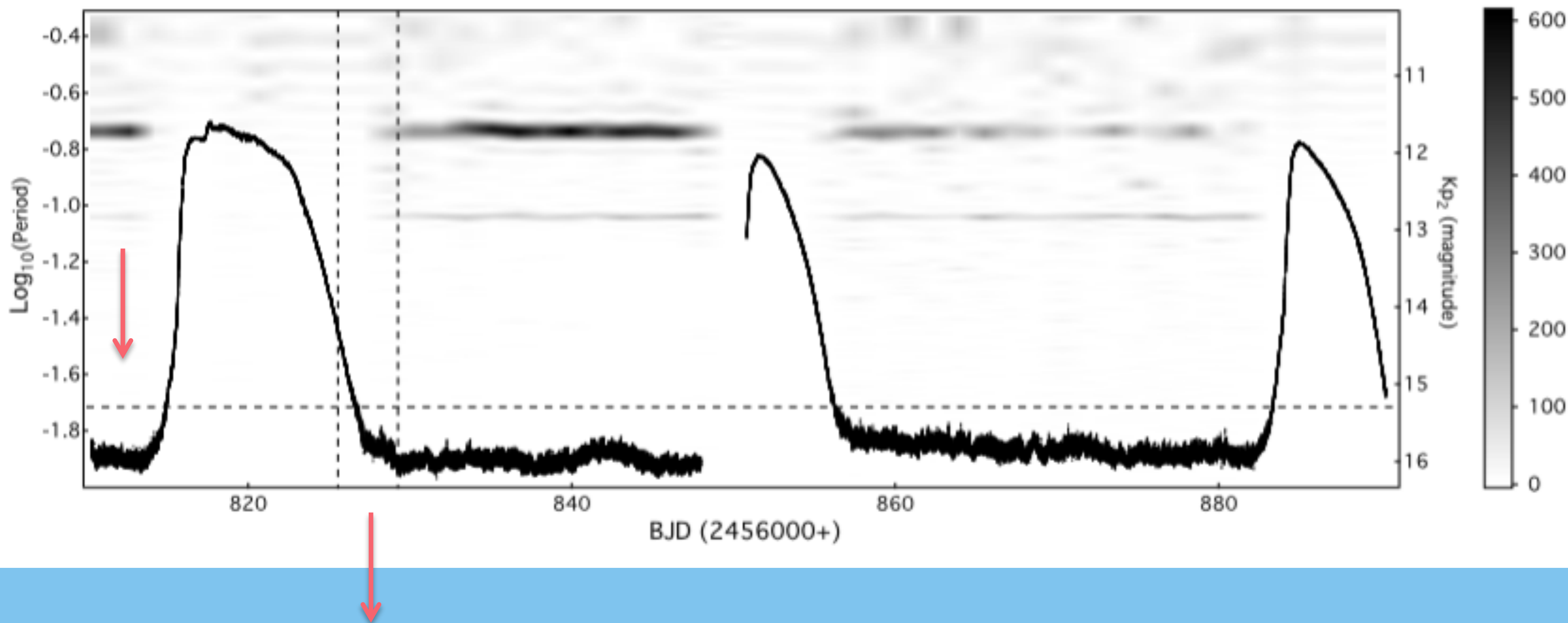




From Kepler data
Cannizzo et al. 2012, ApJ

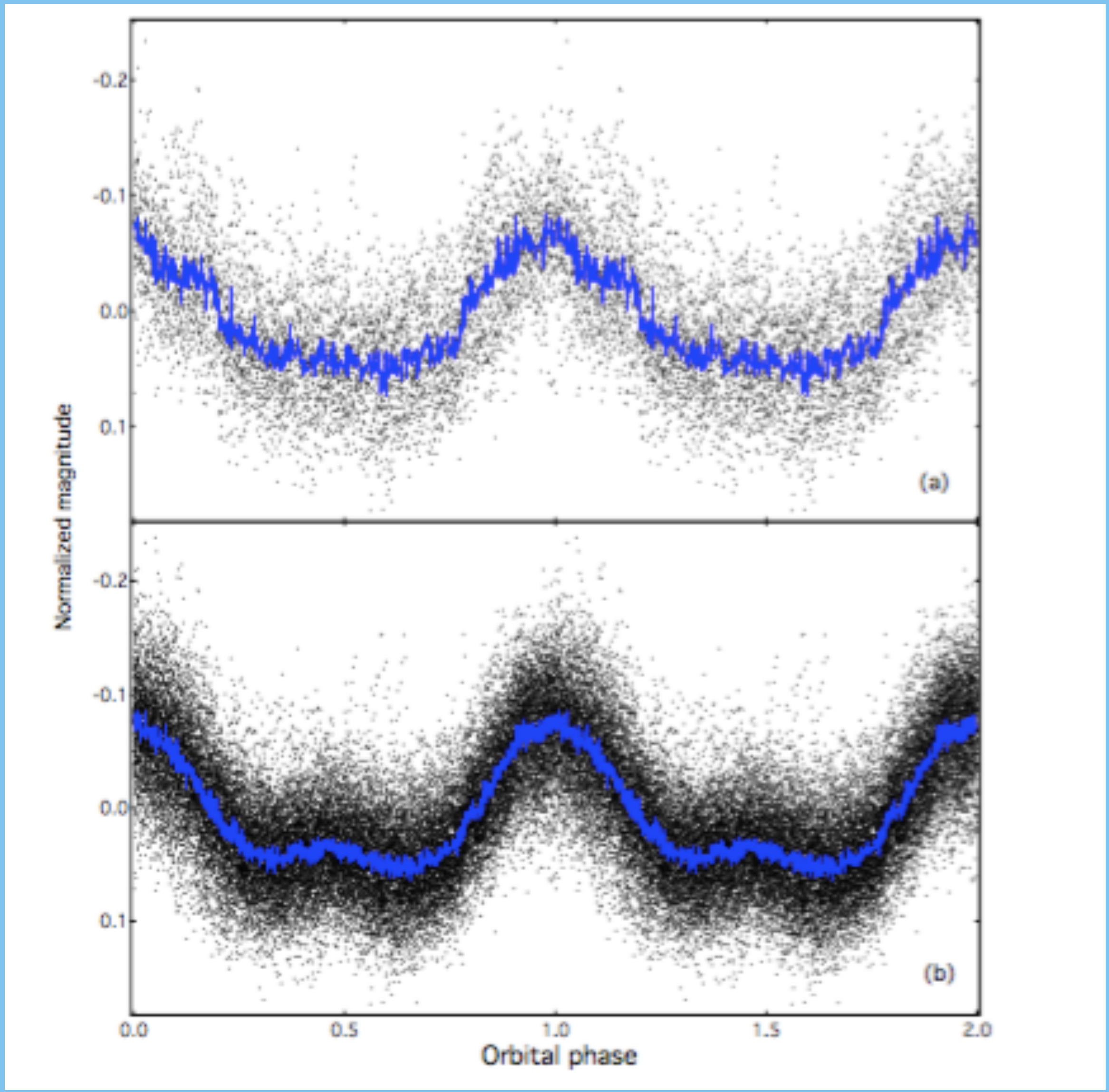
TW Vir orbital modulation pre- vs post SOB

Dai et al, 2017



Orbital reappears in 3.7 days

TW Vir orbital modulations

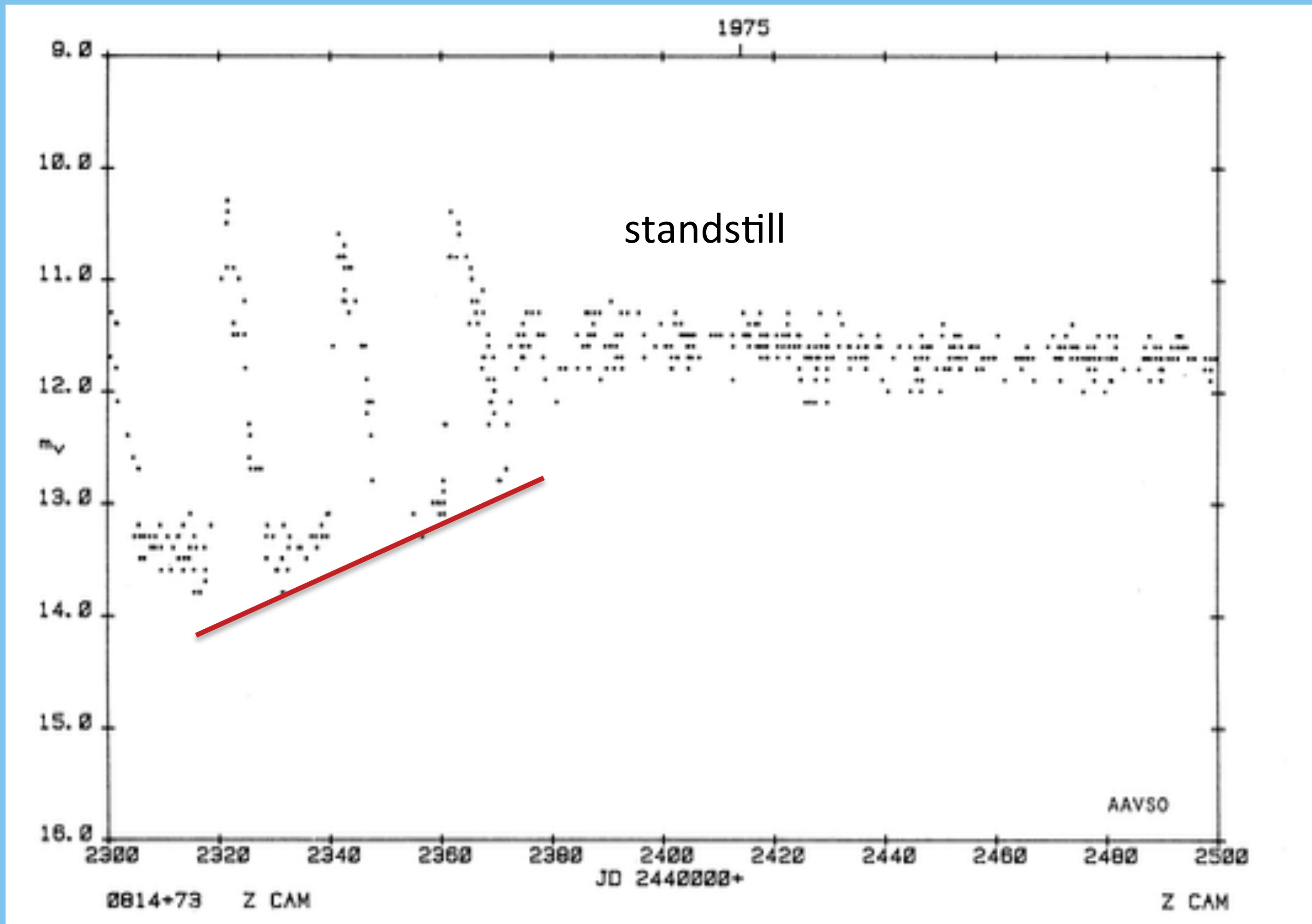


Pre-SOB

Post-SOB

P_{orb}=7 hr

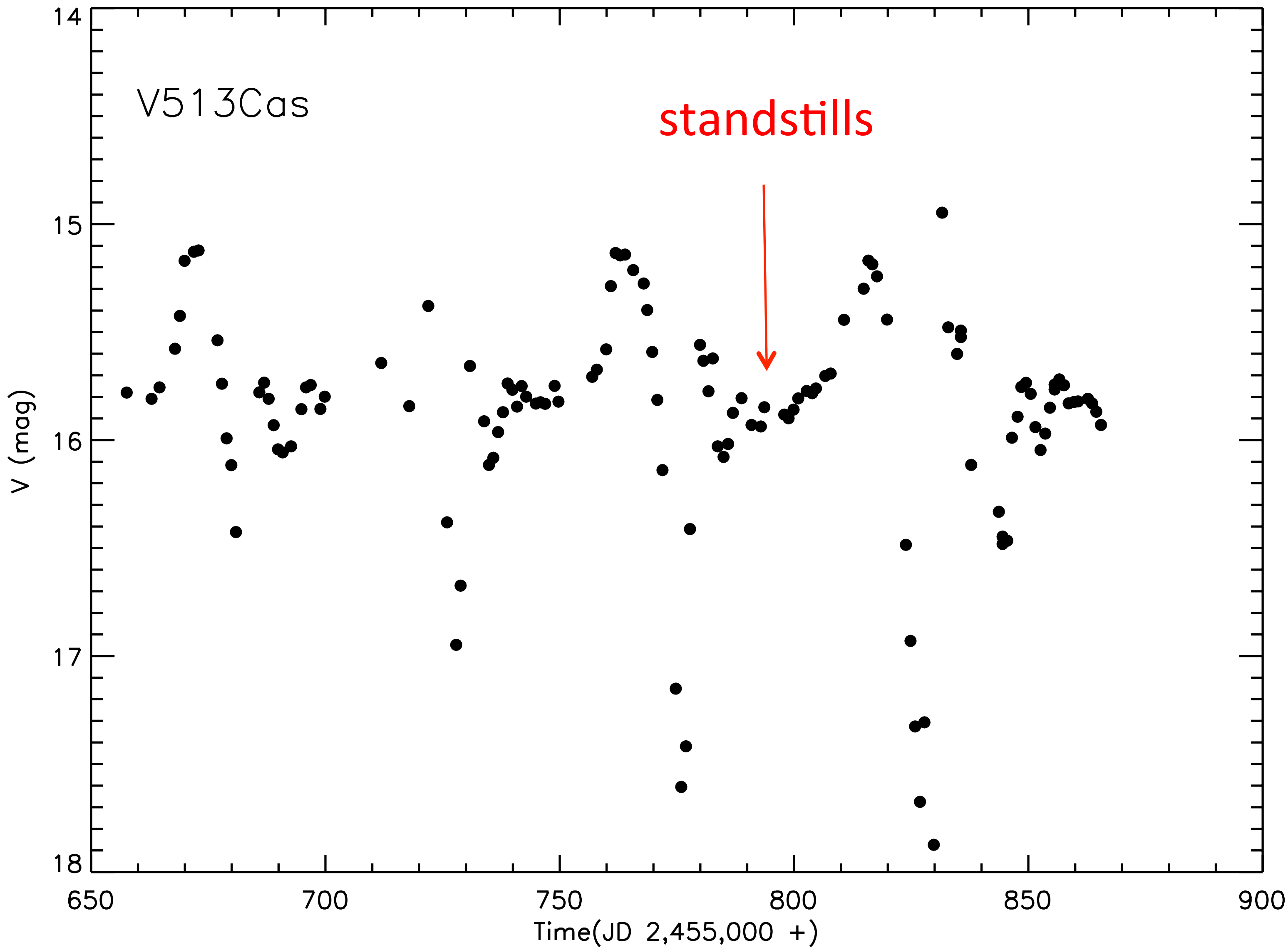
Z Cam going into standstill- at M_{crit}



goes to quiesence after standstill

Another Z Cam system

P_{orb}=5.2 hr



goes to outburst after standstill

Simonsen 2011
Szkody et al. 2013
Hameury & Lasota 2014

9 IPs Have Outbursts

- Shorter outbursts than DN
- Lower amplitude
- Emission lines at outburst, P Cyg

Object	Orb P (hr)	Out (d)	Amp(mag)	Rec
V455 And	1.35	>30	8	1 known
CC Scl	1.40	5-7	2-4	2 known
HT Cam	1.43	2	6	6 in 4 yrs
EX Hya	1.63	20	4	1 yr
V1223 Sgr	3.37	0.25	1.2	2 known
YY(DO)Dra	3.96	3	6	1 yr
TV Col	5.5	0.21	2	yrs
XY Ari	6.1	few	4	3 yrs
GK Per	**48**	**60**	**3**	**3 yrs**

Comparison with Other Outbursting Systems

Object	Rise	Duration	Decline	V (mag)
Dwarf novae	$<1^d$	1^d–5^d	1^d–3^d	4
X-ray bursters	5 s	20 s	10 s	1.5
Flare stars	3–100 s	minutes	min–hr	2–4
RS CVns	1 hr	>5 hr		0
LMC X-4	<2 hr	45 min	< hr	[ΔX = 1.8]
TV Col	<1 hr	1 hr	1 hr	2

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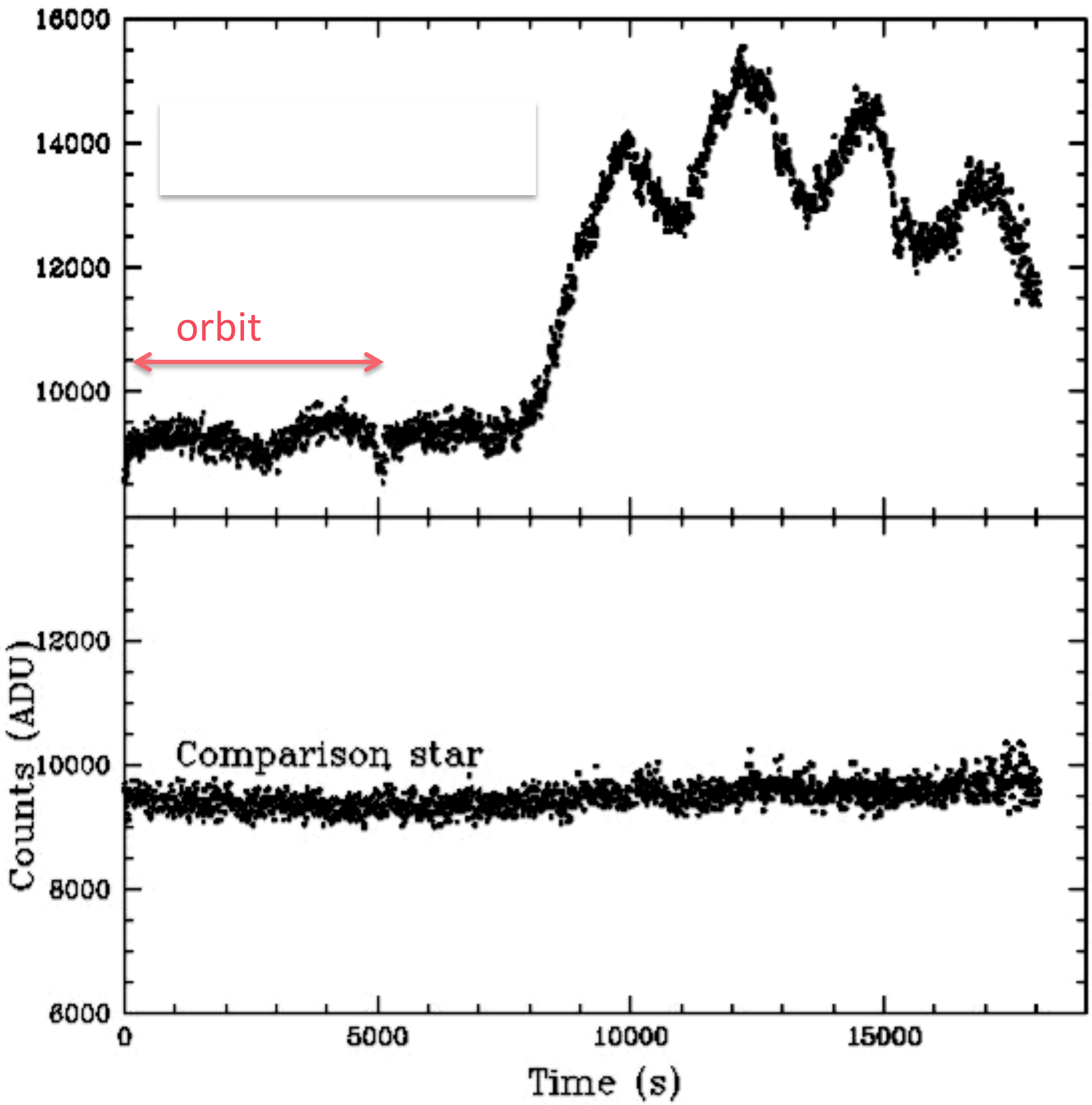
Object	$P_{\rm orb}$ (hr)	$P_{\rm phot}$ (hr)	Amplitude (mag)	Reference
GW Lib...	1.28	-4 2.08	0.05 -0.3	Woudt & Warner (2002)
FS Aur...	1.43	3.4	0.24	Tovmassian et al. (2002)
SDSSJ 1339...	1.38	5.7	0.025	Gänsicke et al. (2006)
SDSSJ 1238...	1.34	7–12	0.4	Zharikov et al. (2005)
SDSSJ 0804...	1.5	>5	0.4	This paper

2 like this now known

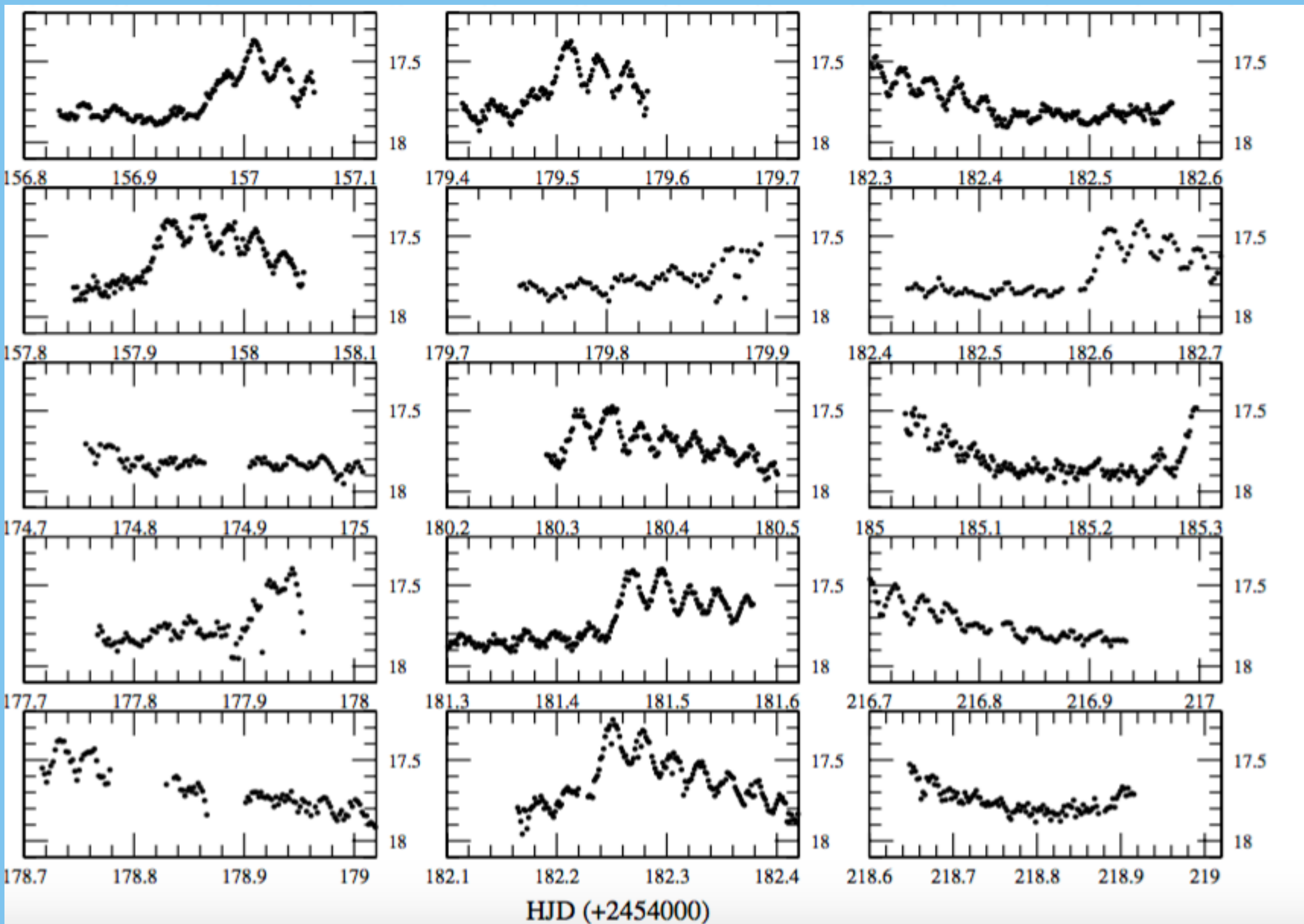
SDSS0804
Phot P: 40.25 min

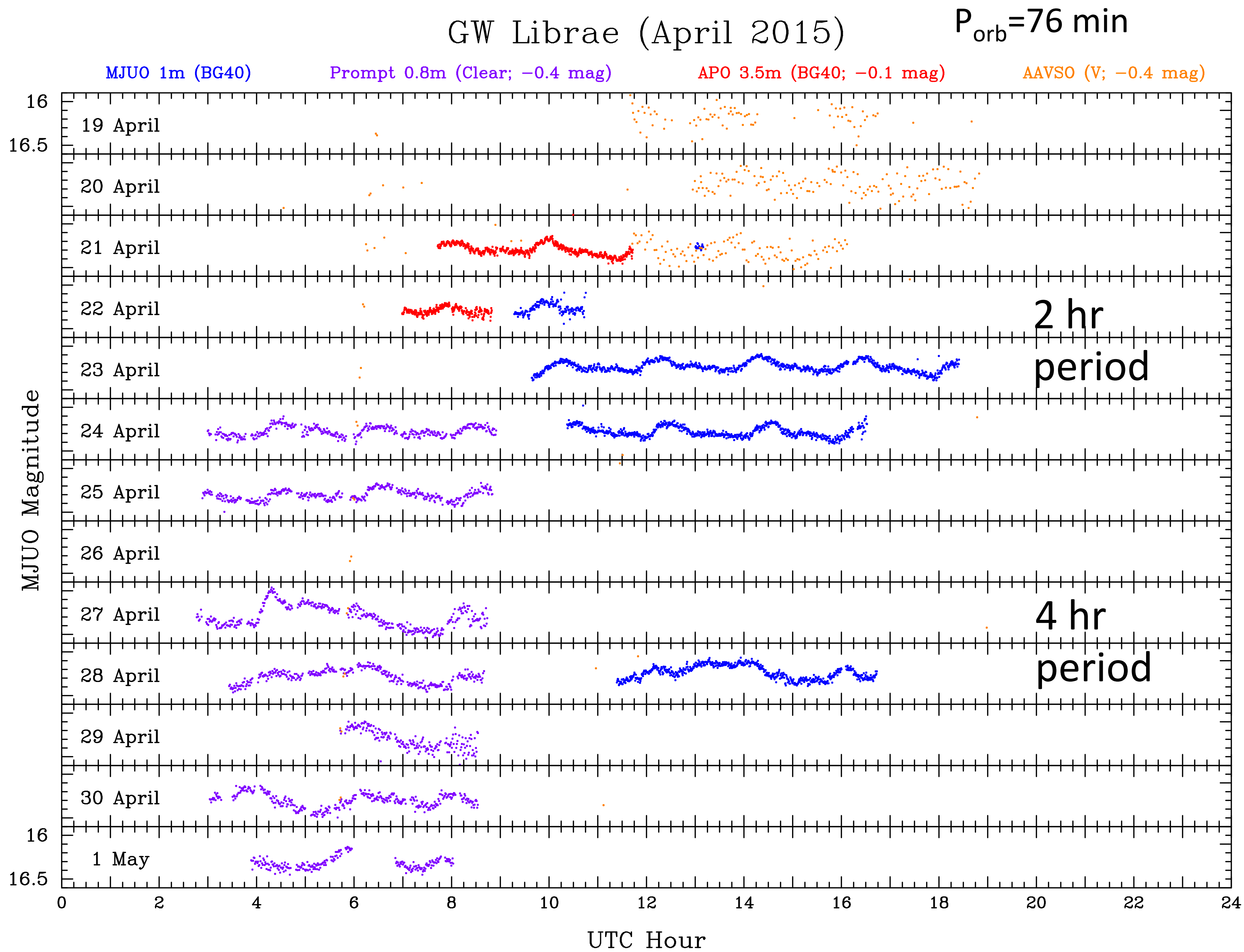
Spect P: 80.5 min

Long P: 8-12 hrs

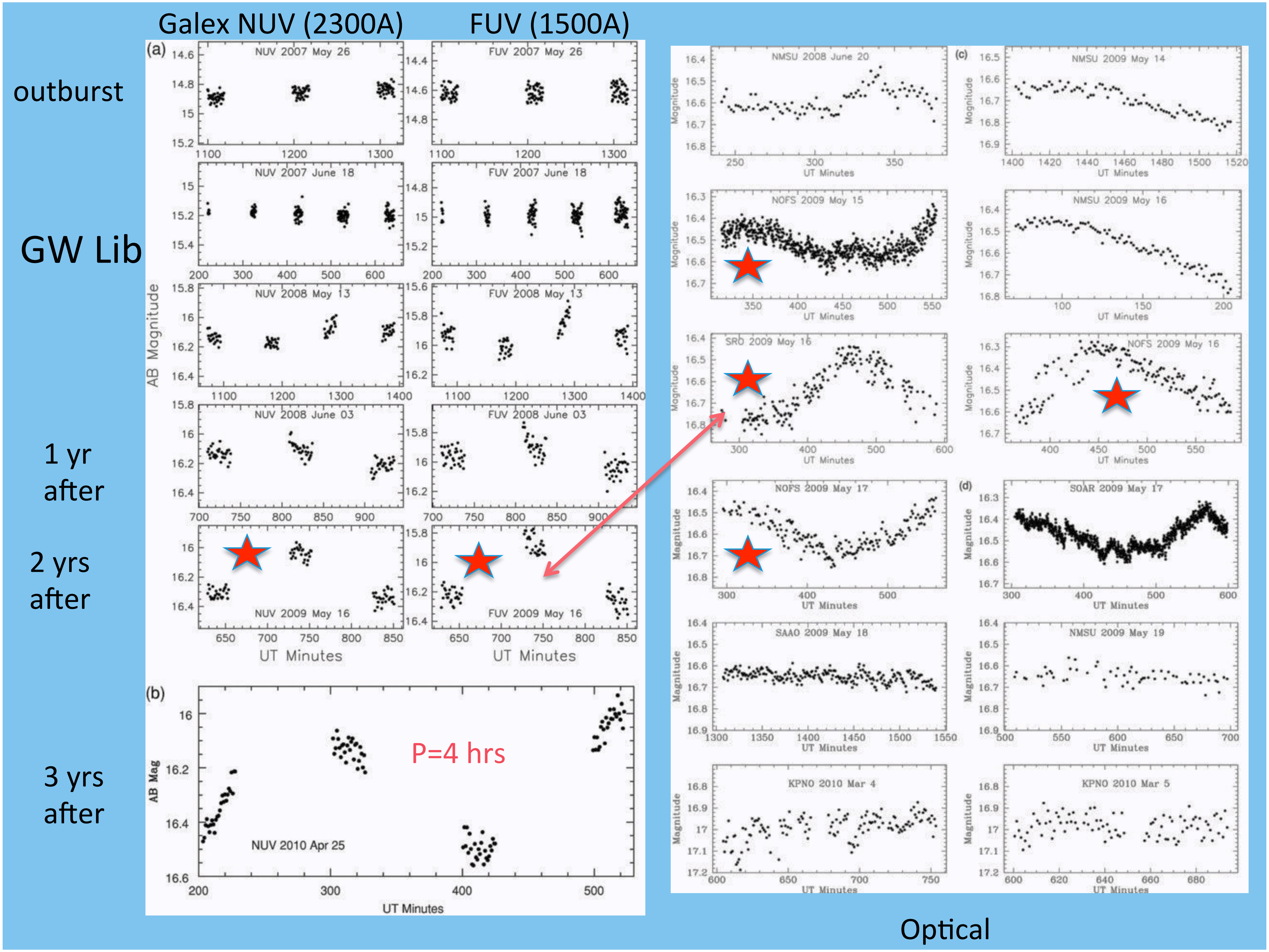


SDSS J123813-033933 P_{spect}=80.5 min, P_{phot}=40.25m, Long P=9 hrs Aviles et al. 2010





GW Librae (April 2015)
P_{orb}=76 min
MJUO 1m (BG40)
Prompt 0.8m (Clear; −0.4 mag)
APO 3.5m (BG40; −0.1 mag)
AAVSO (V; −0.4 mag)
16
16.5
19 April
20 April
21 April
22 April
23 April
24 April
25 April
26 April
27 April
28 April
29 April
30 April
16
16.5
1 May
2 hr
period
4 hr
period
MJUO Magnitude
0
2
4
6
8
10
12
14
16
18
20
22
24
UTC Hour


Galex NUV (2300A)
FUV (1500A)
outburst
GW Lib
1 yr after
2 yrs after
3 yrs after
(a)
NUV 2007 May 26
FUV 2007 May 26
NUV 2007 June 18
FUV 2007 June 18
NUV 2008 May 13
FUV 2008 May 13
NUV 2008 June 03
FUV 2008 June 03
NUV 2009 May 16
FUV 2009 May 16
AB Magnitude
UT Minutes
(b)
NUV 2010 Apr 25
P=4 hrs
AB Mag
UT Minutes
(c)
NMSU 2008 June 20
NMSU 2009 May 14
NOFS 2009 May 15
NMSU 2009 May 16
SRO 2009 May 16
NOFS 2009 May 16
NOFS 2009 May 17
(d)
SOAR 2009 May 17
SAAO 2009 May 18
NMSU 2009 May 19
KPNO 2010 Mar 4
KPNO 2010 Mar 5
Magnitude
UT Minutes
Optical

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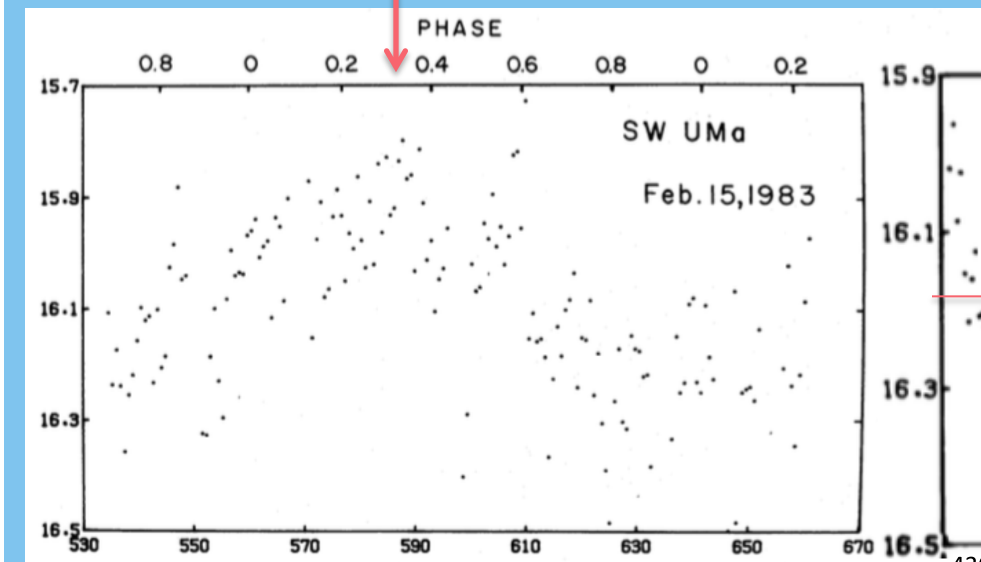
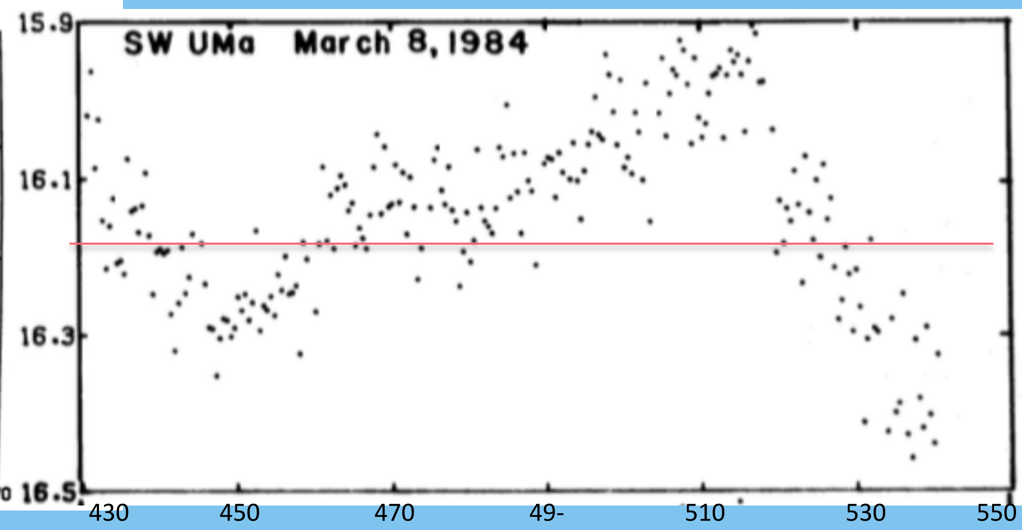
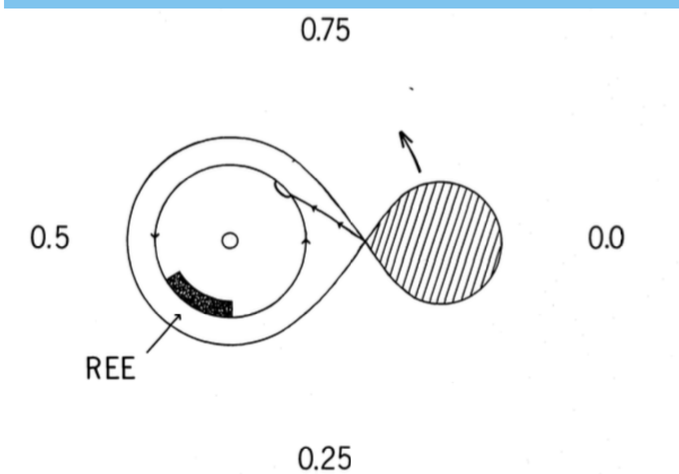
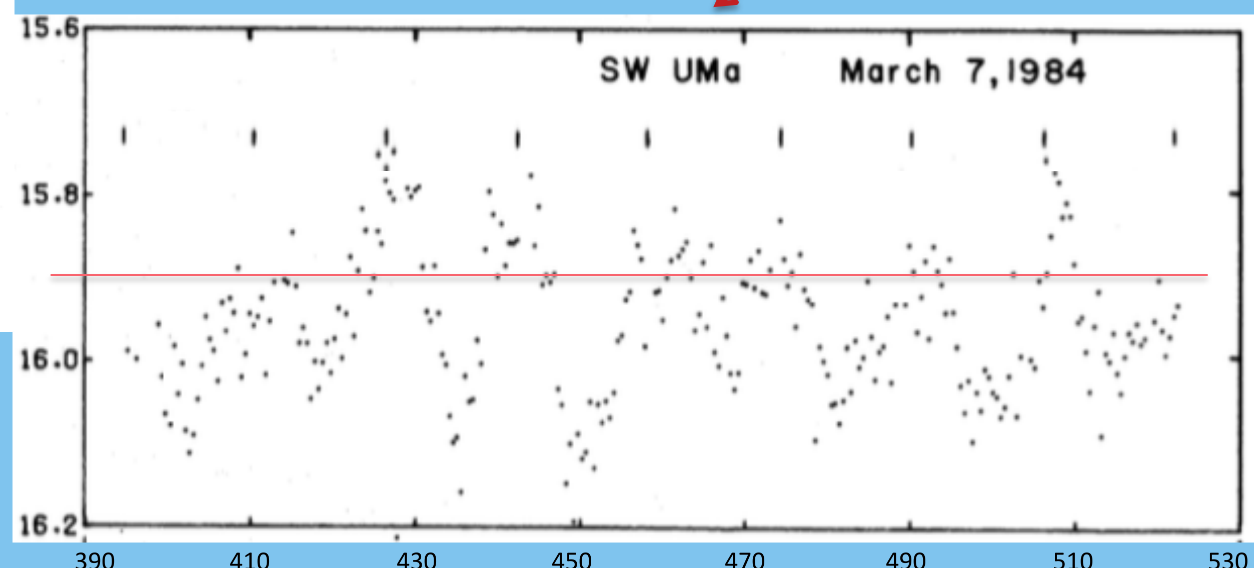
SW Ums P_{orb}=81.8 min



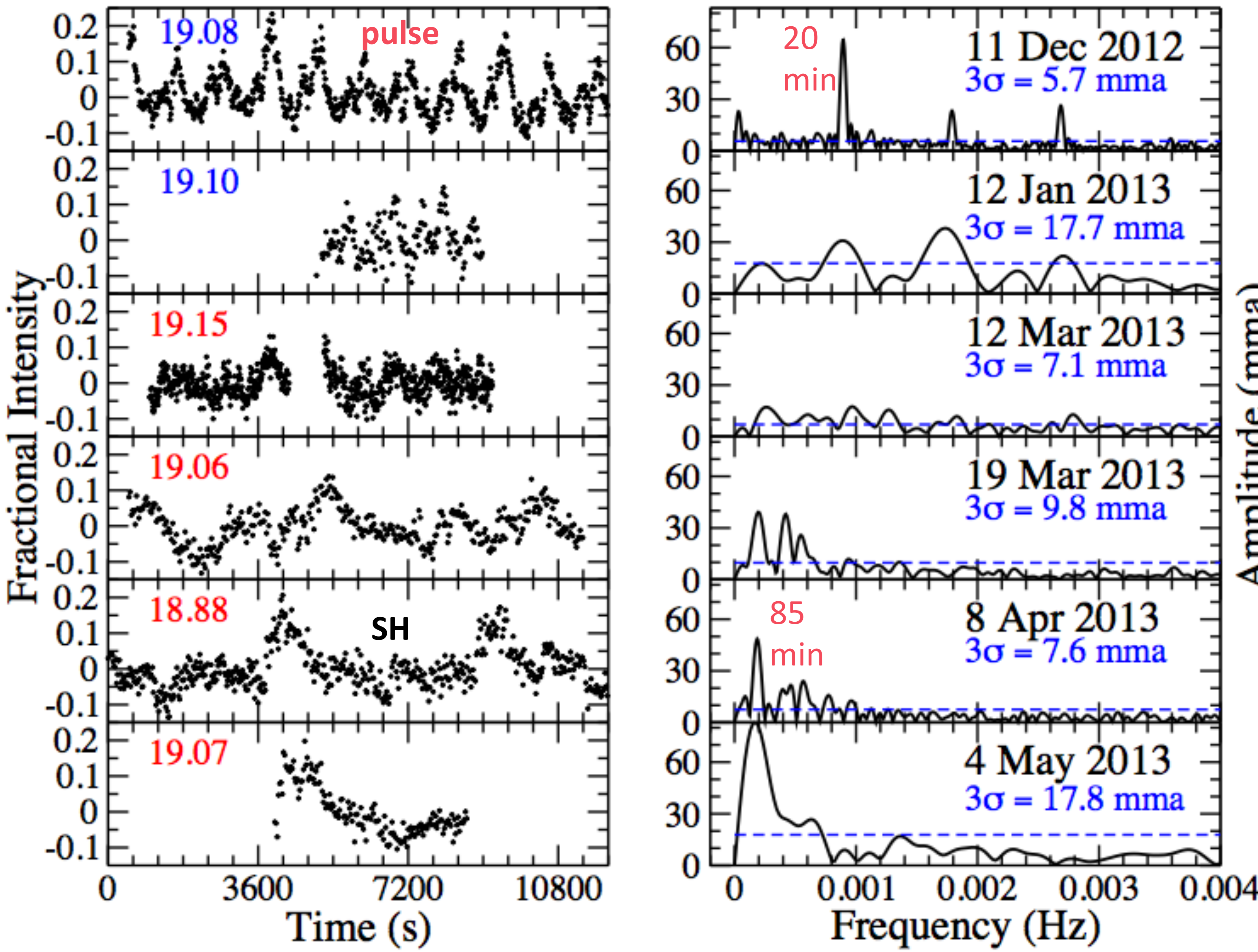






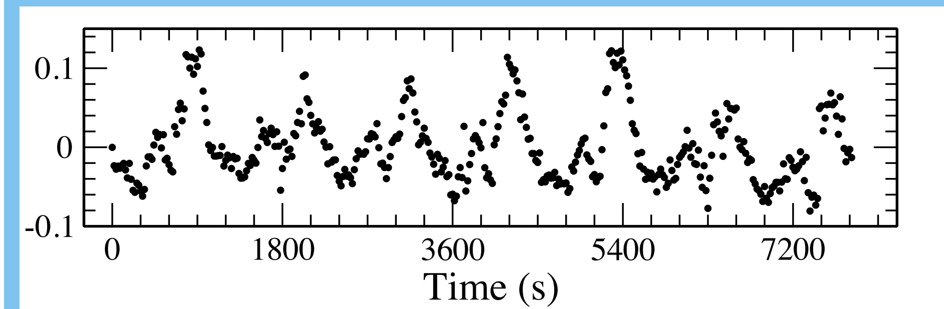
Shafter, Szkody & Thorstensen 1986

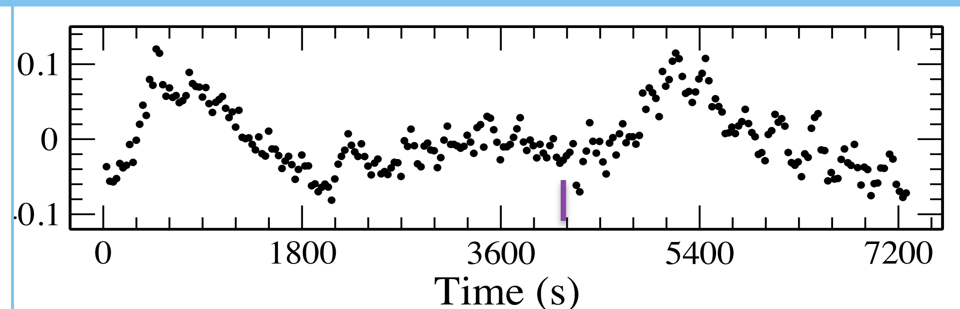
$P_?$=16 min



SDSS0745+45 Mukadam et al. 2013 AJ

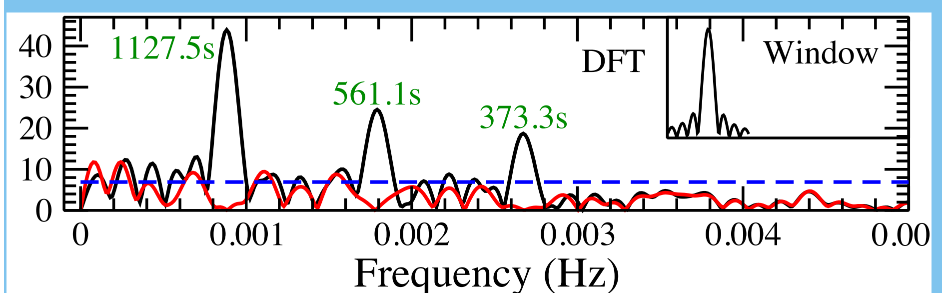
19 min Pulse **SH?**

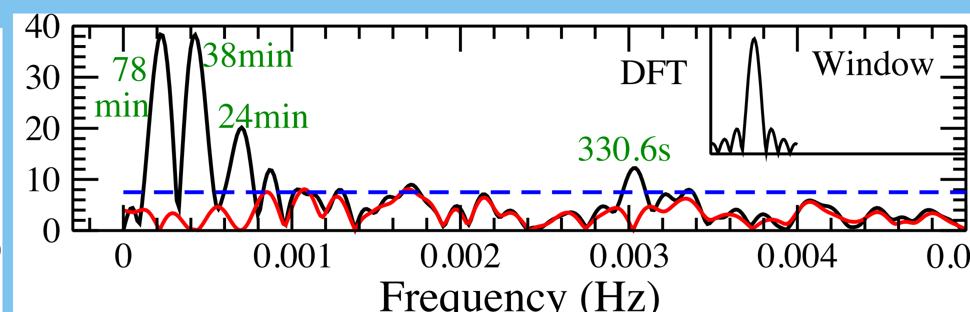




June 24, 2012 BG40=16.4

May 4, 2013 BG40=16.1





GW Lib P_{orb}= 76 min

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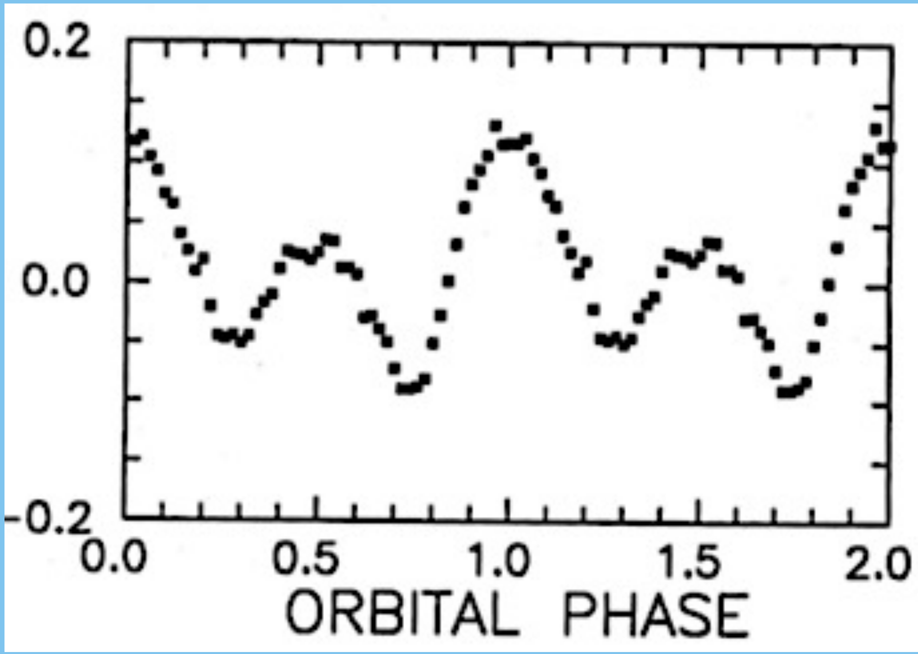
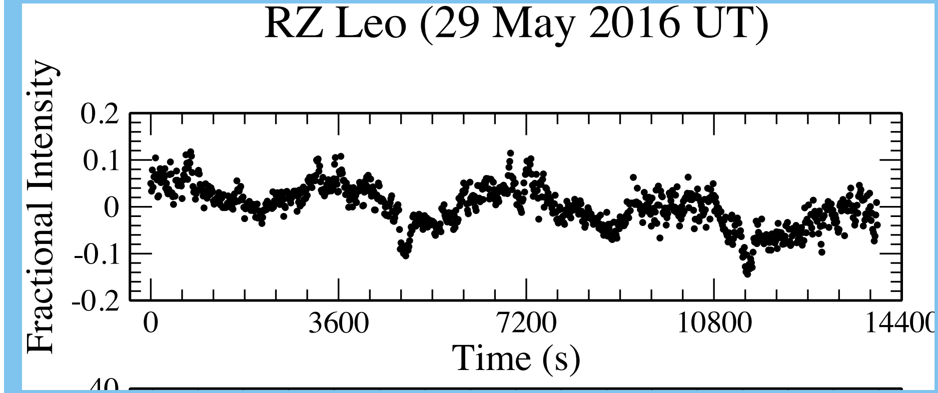
RZ Leo P_{orb} = 1.8 hr

Patterson 2003



Szkody et al. 2016

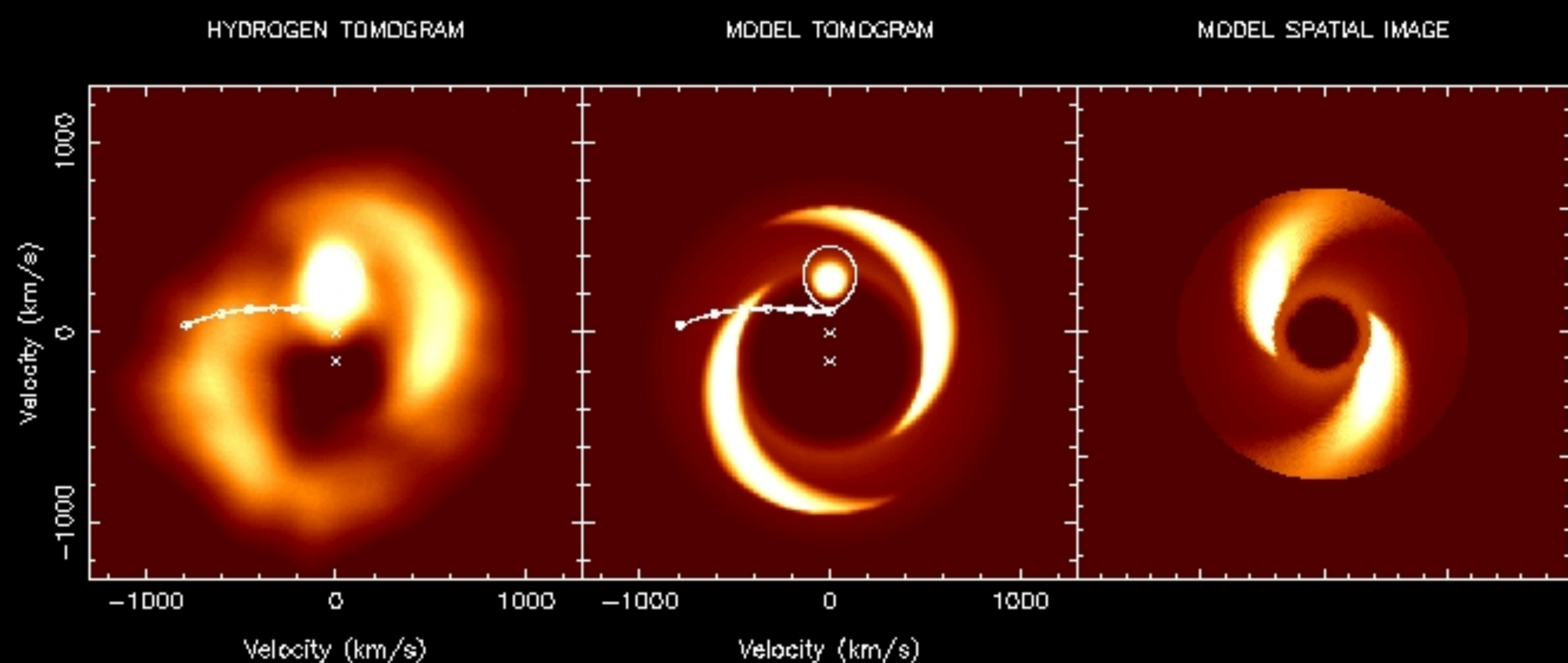


equal humps

unequal humps

Suggested Explanations:

- Hot spot overflow in disk
- Spiral arm structure in disk
- 2:1 resonance in disk



P_{orb}=3.8 hr

IP Peg - Steeghs et al. 1997 MNRAS

Summary of Unanswered Questions:

- How to explain shapes, timescales across all DN outbursts?
- What causes hrs modulations in short orbital P systems?
- Can the disk change structure without brightness changes?
- Do spiral waves/spots cause double humps in short P systems?