Ultra-compact binaries in the Catalina Real-time Transient Survey

Patrick Woudt, Brian Warner & Deanne de Budé
3rd AM CVn workshop, University of Warwick, 16-20 April 2012

The Catalina Real-time Transient Survey

A photometric study of CRTS dwarf novae

Phase-resolved spectroscopy with SALT

CSS111019:233313-155744

Astrophysics, Cosmology and Gravity Centre,
Department of Astronomy, University of Cape Town

Ultra-compact binaries in the Catalina Real-time Transient Survey

Optical transient survey using the Catalina Sky Survey, covering 30000 deg^2 of sky (-80° < d < +70°)

Telescopes:

- 0.68-m CSS telescope at Catalina (Arizona)
- 1.5-m Mt Lemmon (Arizona)
- 0.5-m Siding Springs Observatory (Australia)

Avoiding the Galactic Plane (|b| < 10°) and Magellanic Clouds

23 nights/months (avoiding full Moon):

- 2000 deg^2 / night to V ~ 19 - 20
- 200 deg^2 / night to V ~ 21.5

Ultra-compact binaries in the Catalina Real-time Transient Survey

Processing pipeline similar to Palomar Quest Event Factory

Objects that vary by 2 mag or more are classified as transients

Reported in open 'real-time' through various interfaces:

- web
- skyalert.org
- ipod apps

Discovered to date:

- ~ 1250 Supernovae,
- ~ 800 Cataclysmic variables (DNe, and fair fraction of polars)
- ~ 5500 Optical Transients in all

Ultra-compact binaries in the Catalina Real-time Transient Survey

http://nesssi.cacr.caltech.edu/catalina/AllCV.html

http://nesssi.cacr.caltech.edu/catalina/AllCV.html

Google

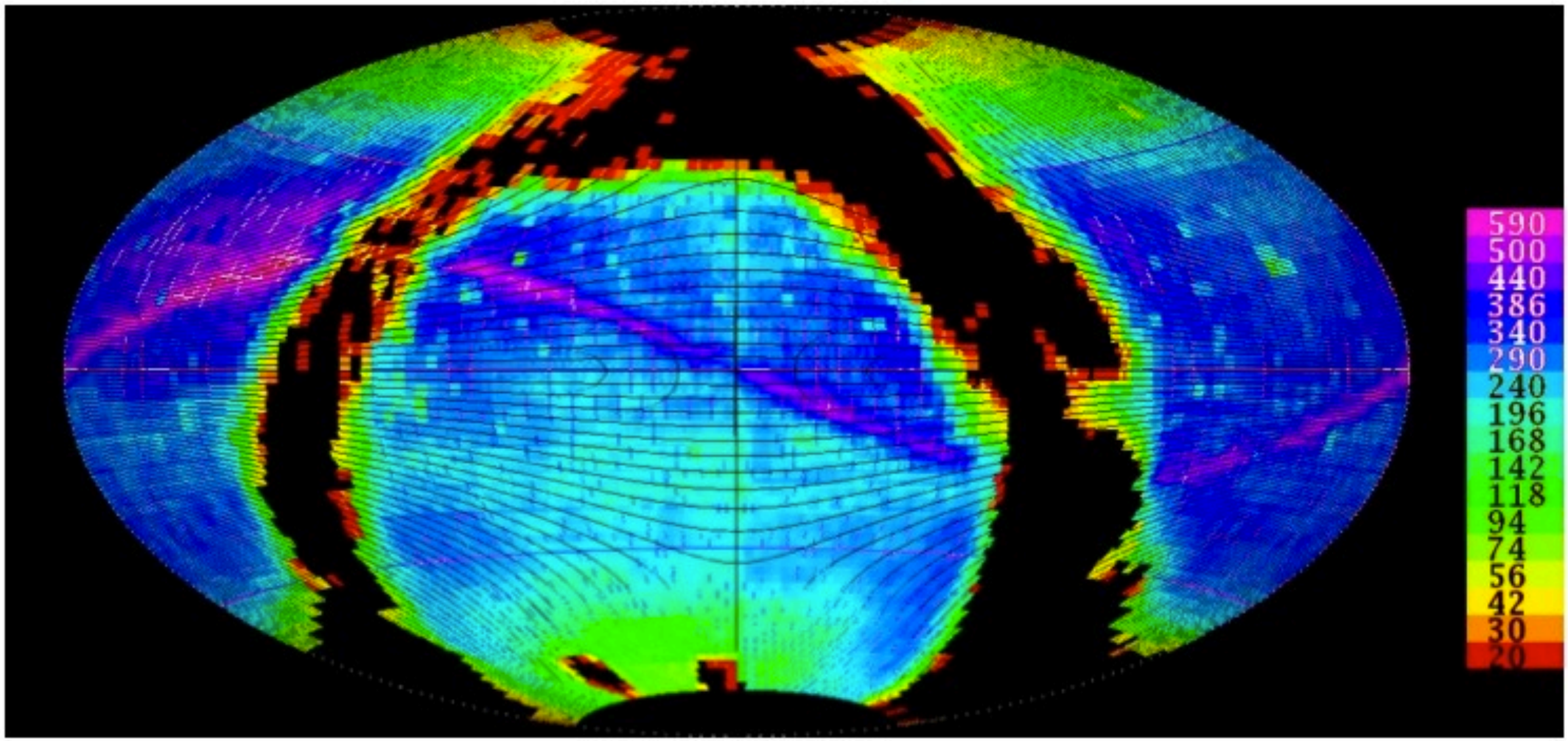
Genealogy Astronomy MeerKAT News NRF Observing Personal SALT Software Transients UCT Journals Travel

All Confirmed/Likely Cataclysmic Variables discovered by CRTS (in CSS data)

Info about the table

CRTS ID	RA (J2000)	Dec (J2000)	Mag	del mag	Date	CSS imgs	SDSS	Others	Followed	Last Obs	LC	Classification
CSS120330:151836-054803	229.65020	-5.80088	16.47	3.43	20120330	1203300070824160651	no	16065	no	2012-03-30	16065	CV mag 19,9
CSS120328:153451+072931	233.71298	7.49183	18.83	2.37	20120328	1203281070834142673	yes	14267	no	2012-03-28	14267	CV SDSS mag 21,2
CSS120327:141850-243305	214.70664	-24.55128	16.48	3.52	20120327	1203270230714118652	no	11865	no	2012-03-27	11865	CV mag 20,0
CSS120326:160411+145618	241.04402	14.93839	16.64	5.06	20120326	1203261150844117628	yes	11762	no	2012-03-26	11762	CV SDSS mag 21,7
CSS120323:110938+503929	167.40662	50.65810	17.52	3.28	20120323	1203231490404144289	yes	14428	no	2012-04-02	14428	CV SDSS mag 20,8
CSS120323:090239-062720	135.66417	-6.45544	18.06	2.94	20120323	1203230070484145267	no	14526	no	2012-03-23	14526	CV DSS mag 21
CSS120322:163848+405057	249.69890	40.84917	16.69	>5.31	20120322	1203221400694127604	yes	12760	no	2012-04-02	12760	CV SDSS mag >22
CSS120317:131514+424747	198.80968	42.79636	17.59	-0.39	20120317	1203171430534109123	yes	10912	no	2012-03-31	10912	CV SDSS mag 17,2
CSS120315:094854+014911	147.22483	1.81968	15.69	4.91	20120315	1203151010534135815	yes	13581	no	2012-03-29	13581	CV SDSS mag 20,6
CSS120313:131043-042600	197.67784	-4.43346	17.71	2.69	20120313	1203130040714120326	no	12032	no	2012-04-13	12032	CV mag 20,4
CSS120304:130755-202628	196.97973	-20.44116	15.34	2.16	20120304	1203040210674137242	no	13724	no	2012-03-25	13724	CV mag 17,5
CSS120303:145555-111957	223.97790	-11.33258	17.69	2.81	20120303	1203030120794158924	no	15892	no	2012-03-24	15892	CV mag 20,5
CSS120301:073208+413009	113.03389	41.50258	18.89	1.61	20120301	1203011400324135123	yes	13512	no	2012-03-16	13512	CV SDSS_073208 mag 20,5
CSS120301:161823-102500	244.59488	-10.41678	16.93	2.67	20120301	1203010090674127106	no	12710	no	2012-03-29	12710	CV mag 19,6
CSS120301:165742-041543	254.42473	-4.26188	17.27	1.73	20120301	1203010040914152637	yes	15263	no	2012-03-01	15263	CV mag 19
CSS120229:144547-060034	221.44444	-6.00948	16.53	3.27	20120229	1202290070794150520	yes	15052	no	2012-03-16	15052	CV mag 19,8
CSS120224:154818+153221	237.07312	15.53926	17.15	4.55	20120224	1202241150824131980	yes	13198	no	2012-03-17	13198	CV SDSS mag 21,7
CSS120222:092123+203858	140.34494	20.64948	17.89	1.31	20120222	1202221210484117870	yes	11787	yes	2012-04-11	11787	CV SDSS_J092122 SDSS mag 19,2
CSS120222:124602-202302	191.50847	-20.38399	16.36	2.04	20120222	1202220210654145270	yes	14527	yes	2012-03-25	14527	CV SDSS mag 18,4
CSS120222:055729-134305	89.36925	-13.71798	16.68	4.32	20120222	1202220120324111615	no	11161	yes	2012-02-28	11161	CV mag 21
CSS120210:081237+161946	123.15231	16.32931	17.58	4.72	20120210	1202101150434141552	yes	14155	no	2012-03-26	14155	CV SDSS mag 22,3
CSS120202:120620-032838	181.58267	-3.47730	17.62	2.38	20120202	1202020040654134554	yes	13455	no	2012-03-21	13455	CV SDSS mag 20,0
CSS120131:001952+433901	4.96768	43.65038	15.58	5.92	20120131	1201311430024134321	no	13432	no	2012-01-31	13432	CV DSS mag 21,5
CSS120130:161304+012125	243.26824	1.35688	17.06	3.94	20120130	1201301010874137575	yes	13757	no	2012-03-24	13757	CV PQ mag 21
CSS120127:154022+012231	235.09359	1.37532	18.95	2.55	20120127	1201271010844132020	yes	13202	no	2012-02-29	13202	CV SDSS mag 21,5
CSS120126:005021+331918	12.58574	33.32159	17.11	3.89	20120126	1201261320044143471	yes	14347	no	2012-01-26	14347	CV mag 21
CSS120120:080941+171528	122.42237	17.25784	16.30	4.20	20120120	1201201180424110668	yes	11066	yes	2012-04-10	11066	CV SDSS mag 20,5
CSS120120:084702-154158	131.76015	-15.69951	18.87	2.63	20120120	1201200150464142250	no	14225	yes	2012-03-22	14225	CV DSS mag 21,5
CSS120119:081602+584824	124.01025	58.80669	17.49	3.81	20120119	1201191570254149183	yes	14918	yes	2012-03-21	14918	CV SDSS mag 21,3
CSS120113:040822+141516	62.09121	14.25436	17.01	4.49	20120113	1201131150224104750	yes	10475	yes	2012-02-25	10475	CV (spec) SDSS mag 21,5
CSS120103:092250-144814	140.70655	-14.80401	15.59	5.41	20120103	1201030150494145299	no	14529	yes	2012-03-23	14529	CV DSS mag 21

Ultra-compact binaries in the Catalina Real-time Transient Survey

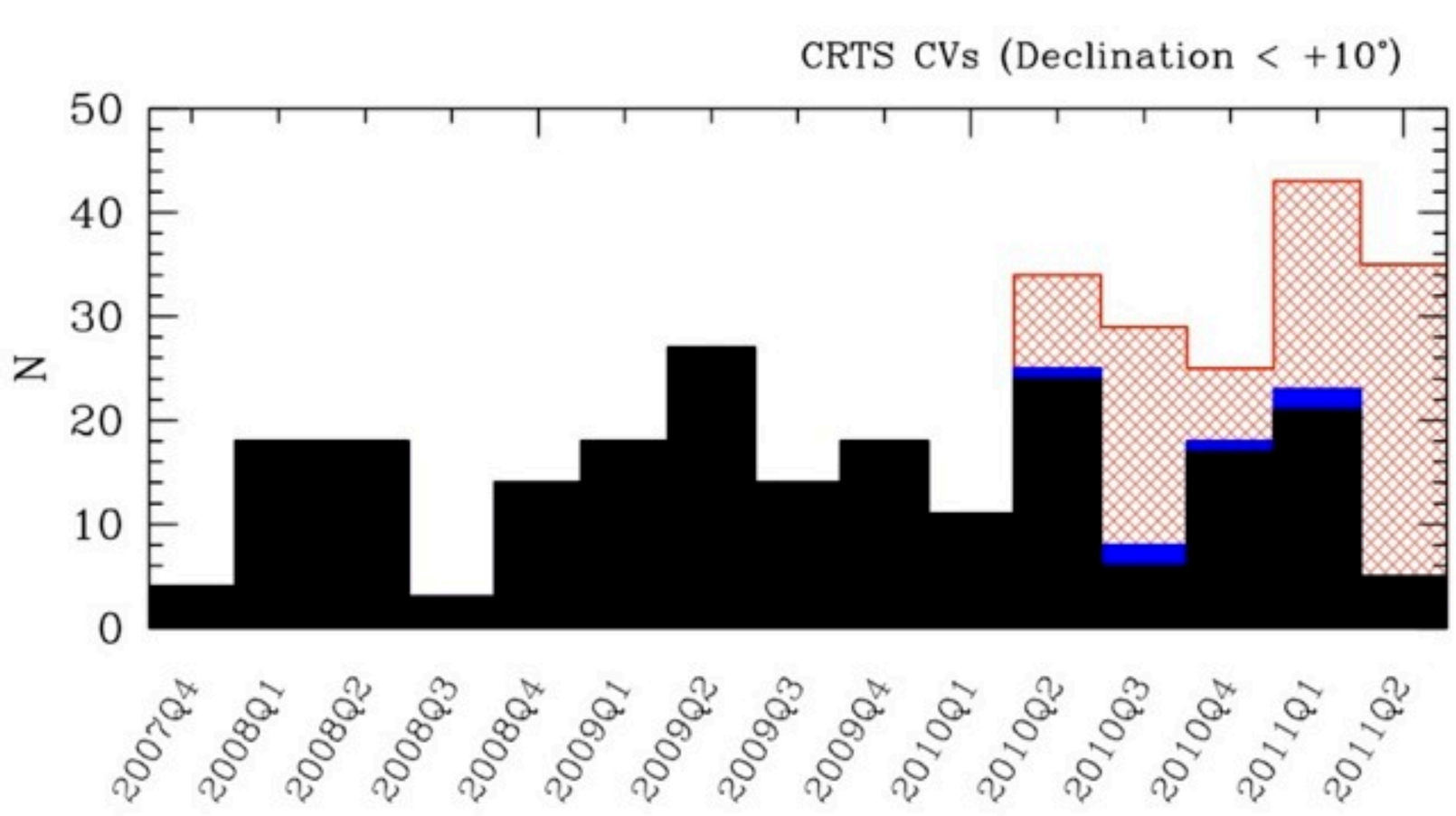


CSS sky coverage (as at 2011 September). Image from Andrew Drake.

Ultra-compact binaries in the Catalina Real-time Transient Survey

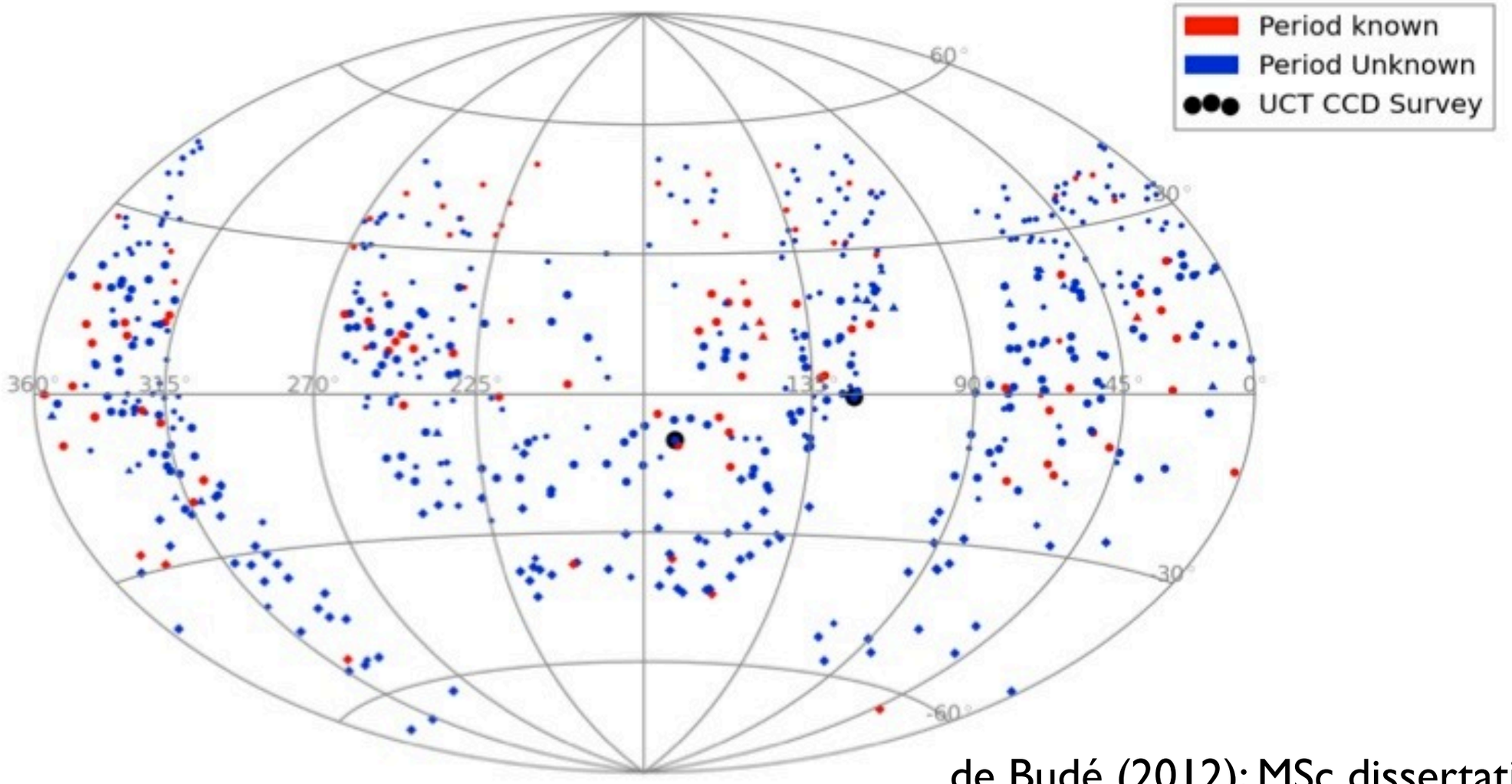
Rapid addition of southern CRTS CVs since 2010

How to follow up these targets and to identify interesting (AM CVn) targets for full characterisation?



Ultra-compact binaries in the Catalina Real-time Transient Survey

A photometric study of CRTS dwarf novae



de Budé (2012): MSc dissertation

CRTS CVs at 2011 October

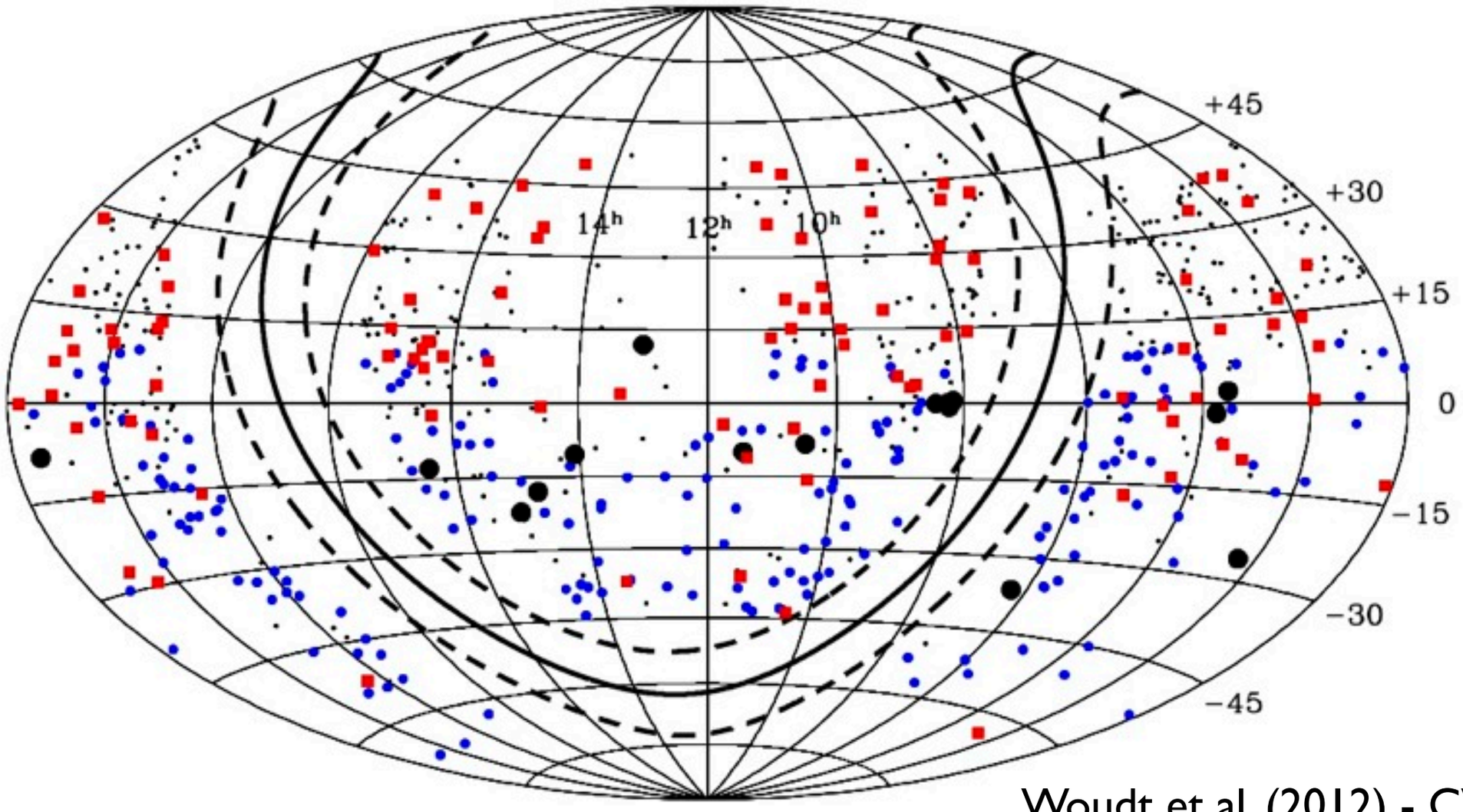
red (small/big): all CRTS CVs with known periods (N=100)

blue circles (small): CRTS CVs with unknown periods (decl > +20°)

blue circles (big): CRTS CVs with unknown periods (decl < +20°)

Ultra-compact binaries in the Catalina Real-time Transient Survey

A photometric study of CRTS dwarf novae



Woudt et al. (2012) - CV Survey VII

CRTS CVs as at 2011 October

red squares: CVs with known periods (N=100)

blue circles: CVs accessible from Sutherland (SALT)

black circles: CVs with periods from UCT CCD CV Survey (N=15)

Ultra-compact binaries in the Catalina Real-time Transient Survey

A photometric study of CRTS dwarf novae

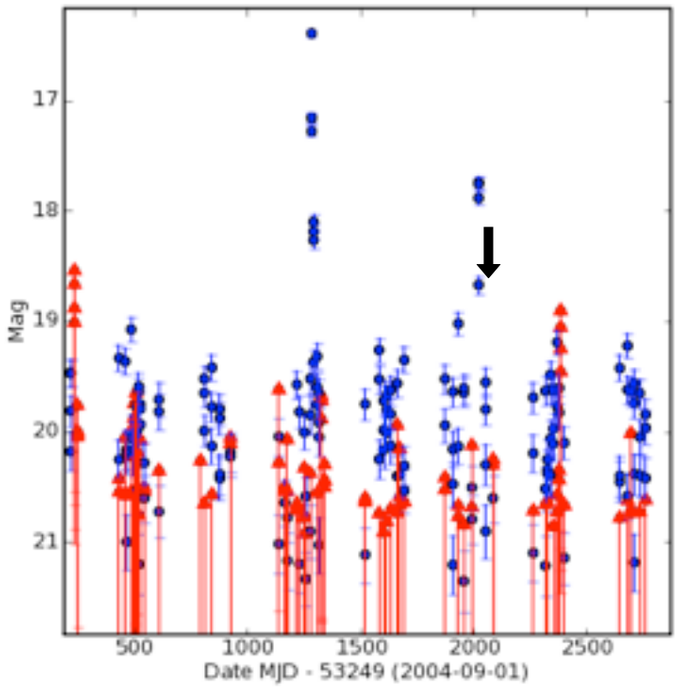
Object	Type	P_{orb} (h)	P_{SH+} (h)	P_{SH-} (h)	r	Remarks
CSS1028-08	DN SU	0.868 (10)	[0.914]		16.1-19.0	DNOs/QPOs
CSS2333-15	DN SU	1.0283 (2)	1.06 (1)		17-20.3	Shallow eclipse
CSS1404-10	DN SU	1.42990 (1)	1.464 (1)		16.6-19.6	Eclipsing, SHs in outburst
CSS0826-00	DN SU	1.4342 (2)		1.394 (1)	20.0	Eclipsing, SHs in quiescence
CSS0332+02	DN SU	1.469 (1)	1.5030 (2)	1.4386 (4)	20.2	Superhumps in quiescence
CSS1300+11	DN SU	1.5041 (2)	[1.545]		19.8	
CSS0345-01	DN	1.684 (1)			18.6	
CSS1443-17	DN SU	1.685 (4)	[1.7295]		19.1	
SSS0221-26	DN	1.692 (2)			19.3	
CSS0814-00	DN	1.796 (1)			18.6	
CSS1626-12	DN	1.811 (1)			20.4	Eclipsing
CSS2325-08	DN SU	1.823 (2)	[1.892]		19.3	
CSS1126-10	DN	1.8581 (1)			18.3	Eclipsing
CSS0810+00	Polar	1.9358 (1)			18.2	High State
CSS1503-22	Polar	2.2229 (4)			17.2	High State
SSS0617-36	CV	3.4404 (12)			17.7	

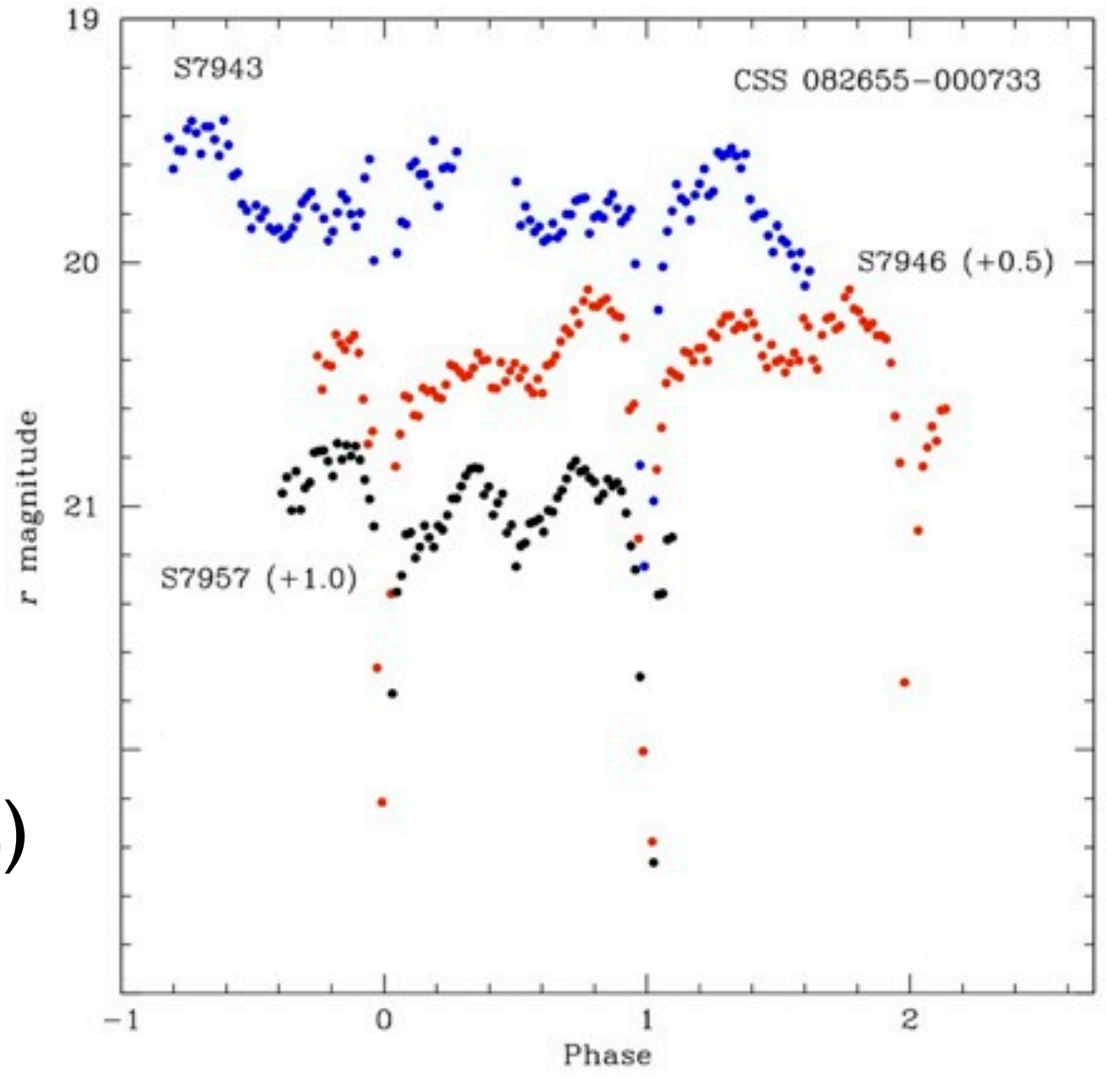
Woudt et al. (2010) - CV Survey VI
Woudt et al. (2012) - CV Survey VII

Ultra-compact binaries in the Catalina Real-time Transient Survey

A photometric study of CRTS dwarf novae

Eclipsing CRTS CVs (CSS0826-00)





Large spread at quiescence (CRTS LC)

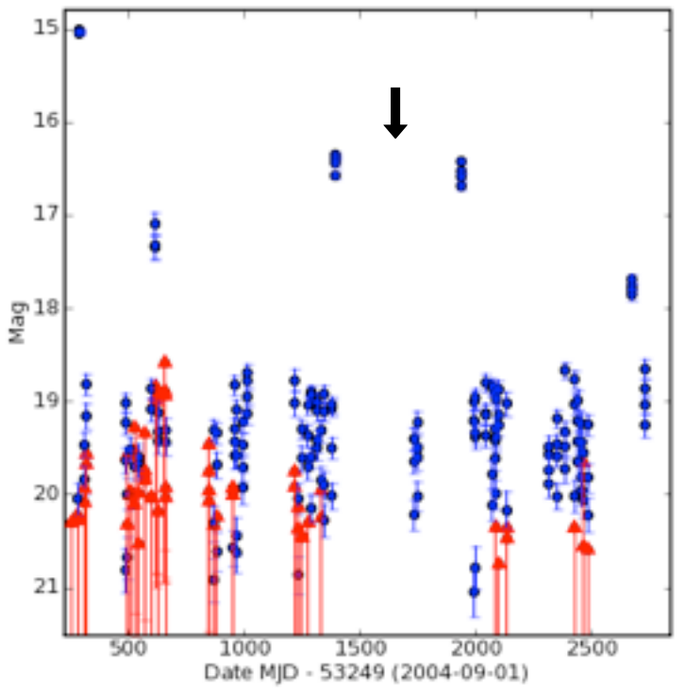
CSS0826-00: SHs at quiescence

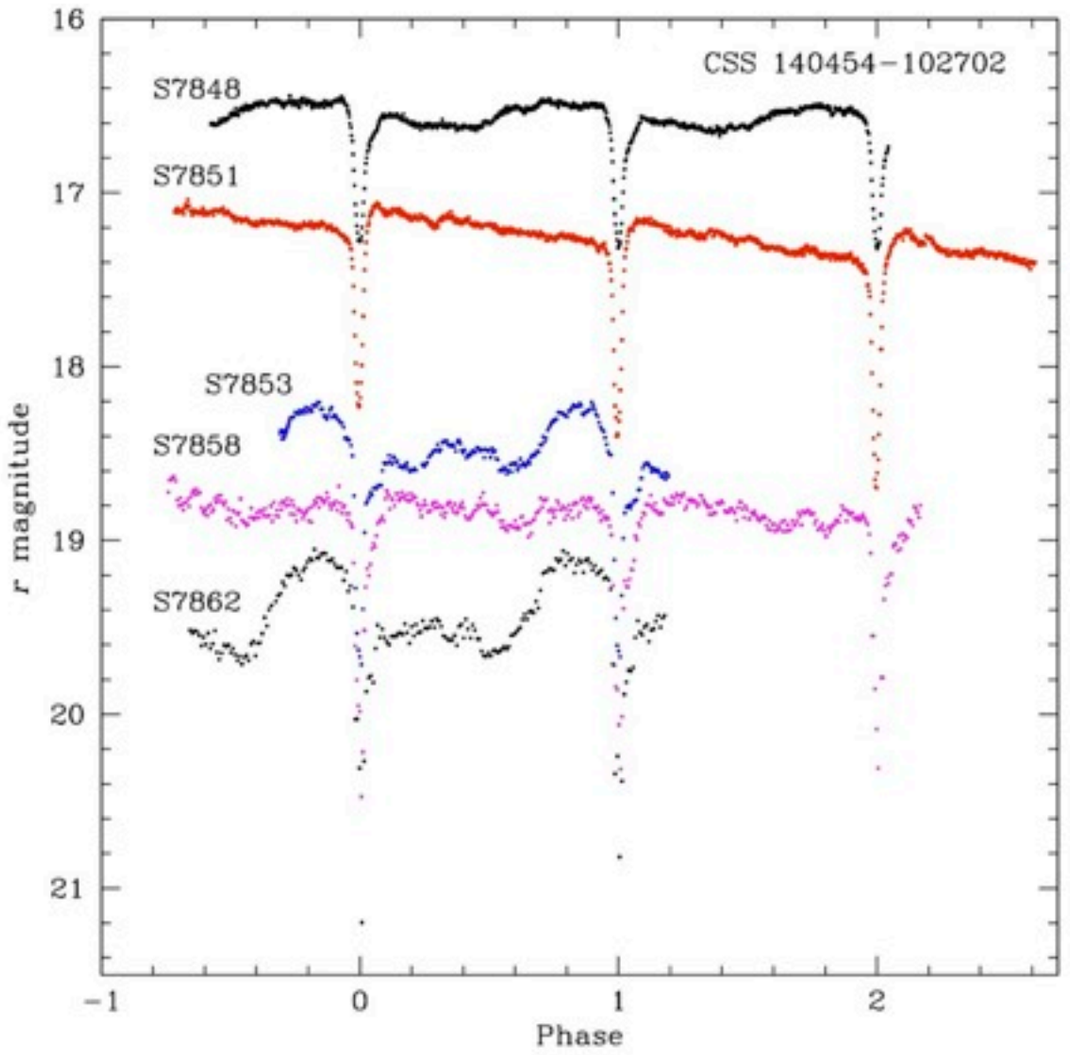
Woudt et al. (2012) - CV Survey VII

Ultra-compact binaries in the Catalina Real-time Transient Survey

A photometric study of CRTS dwarf novae

Eclipsing CRTS CVs (CSS1404-10)





Large spread at quiescence (CRTS LC)

CSS1404-10: followed through superoutburst (missed by CRTS)

Woudt et al. (2012) - CV Survey VII

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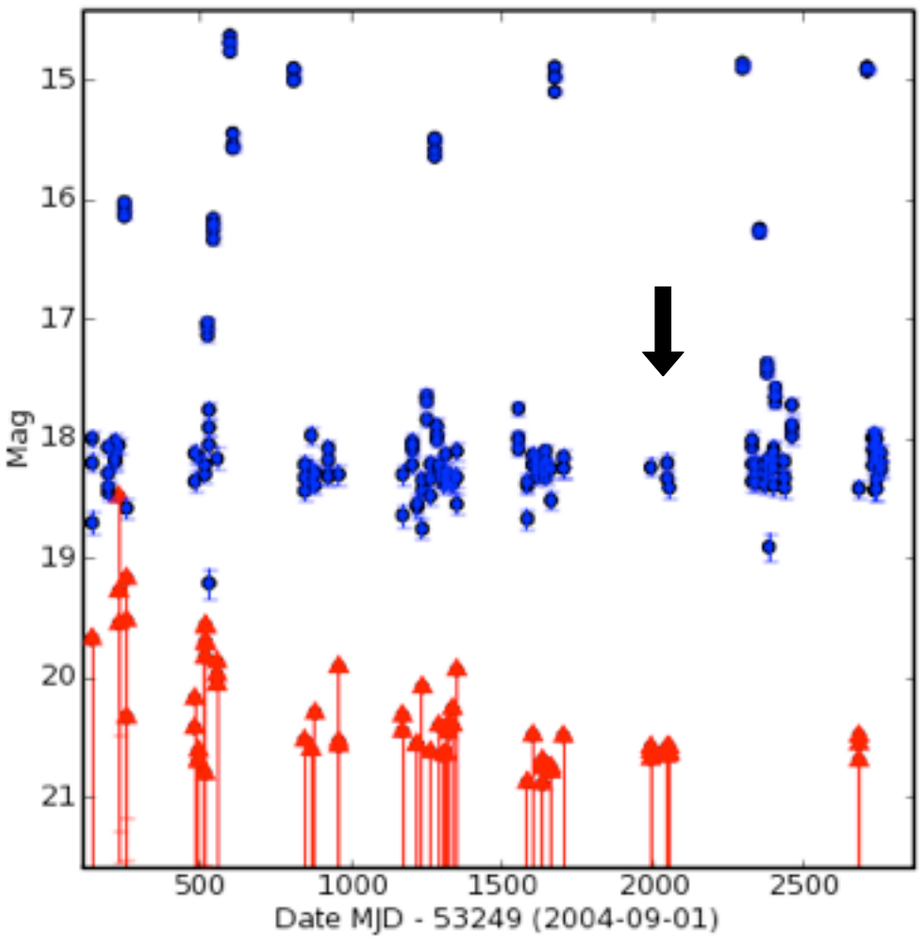
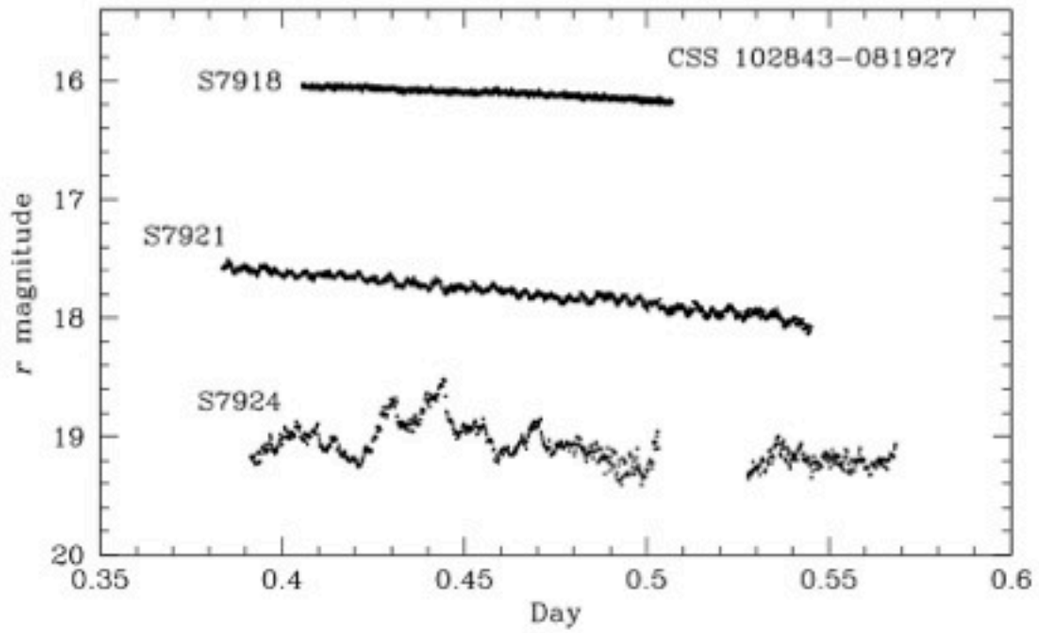
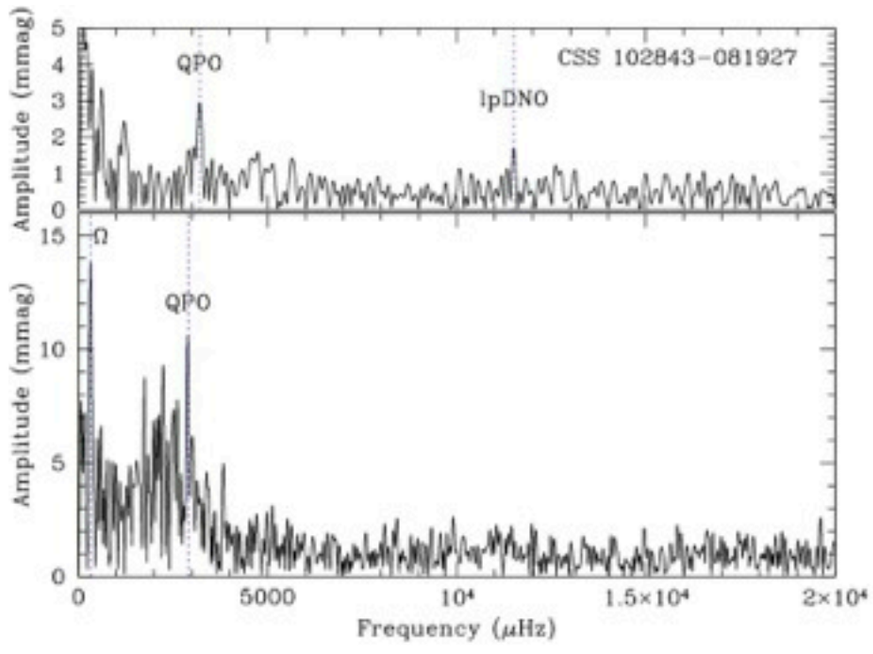
A photometric study of CRTS dwarf novae

CSS 1028-08

P_{orb} = 52.1 ± 0.6 min P_{sh} = 54.85 min
Regular (super)outbursts
QPOs/DNOs after its outburst (312 s in S7921)







Woudt et al. (2012) - CV Survey VII

Ultra-compact binaries in the Catalina Real-time Transient Survey

A photometric study of CRTS dwarf novae

CRTS CVs as at 2011 October

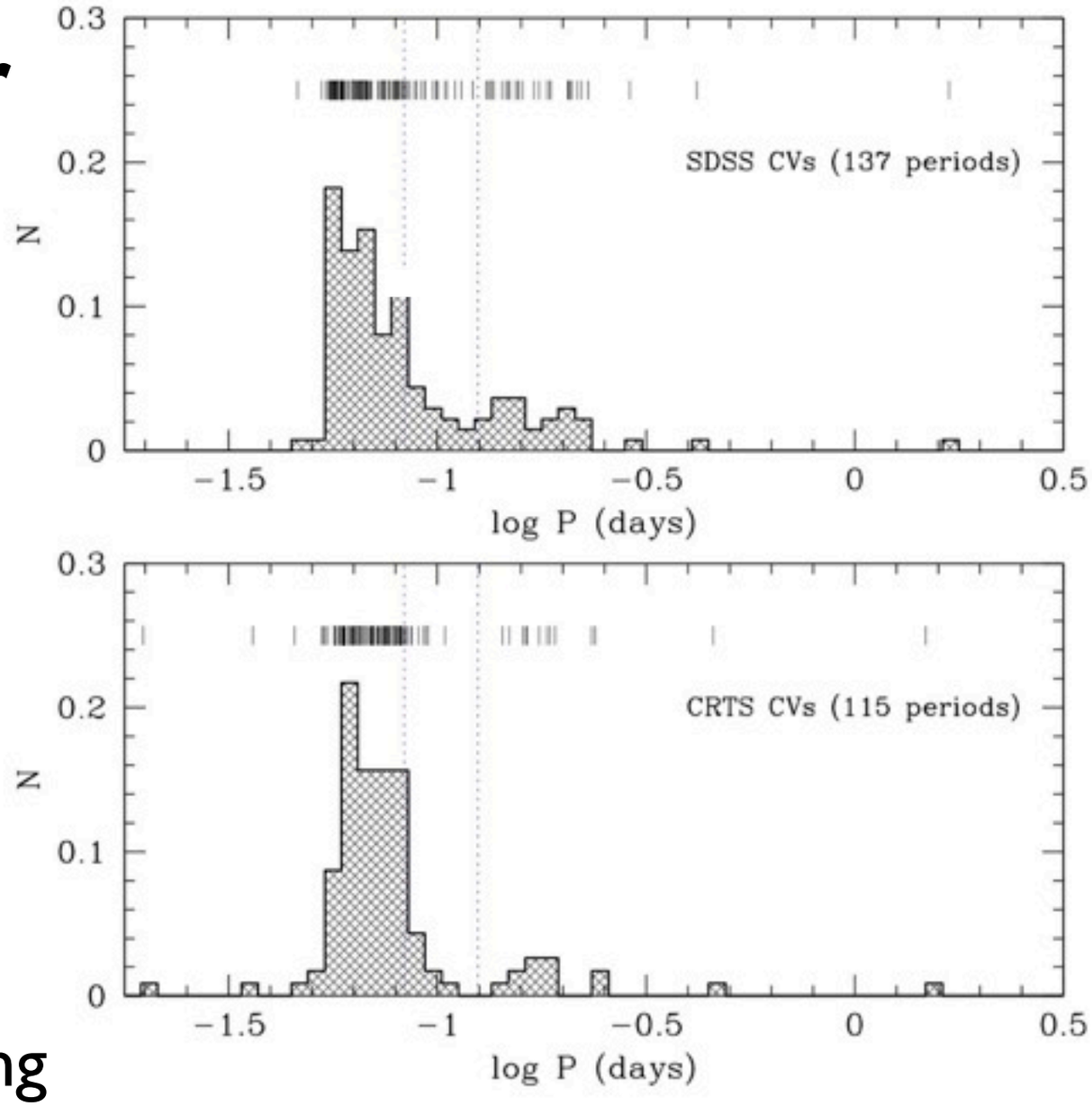
115 CRTS CVs with periods, including three short period (AM CVn) systems:

- CP Eri P_{orb} = 28.36 min
- CSS 1028-08 P_{orb} = 52.1 min
- CSS 1122-11 P_{orb} = 65.40 min

New one (see later):

- CSS 2333-15 P_{orb} = 61.70 min

CSS1028, 1122 and 2333 could belong to the 'evolved CV channel' of AM CVns

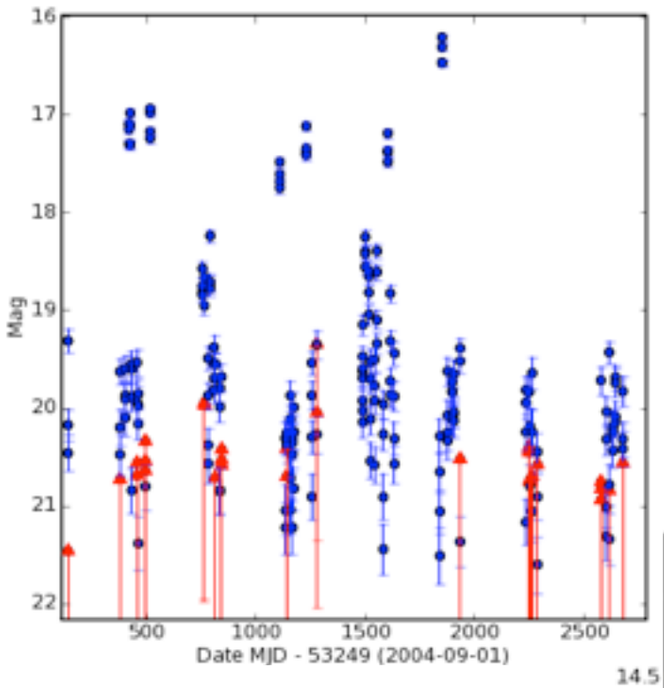


Woudt et al. (2012) - CV Survey VII

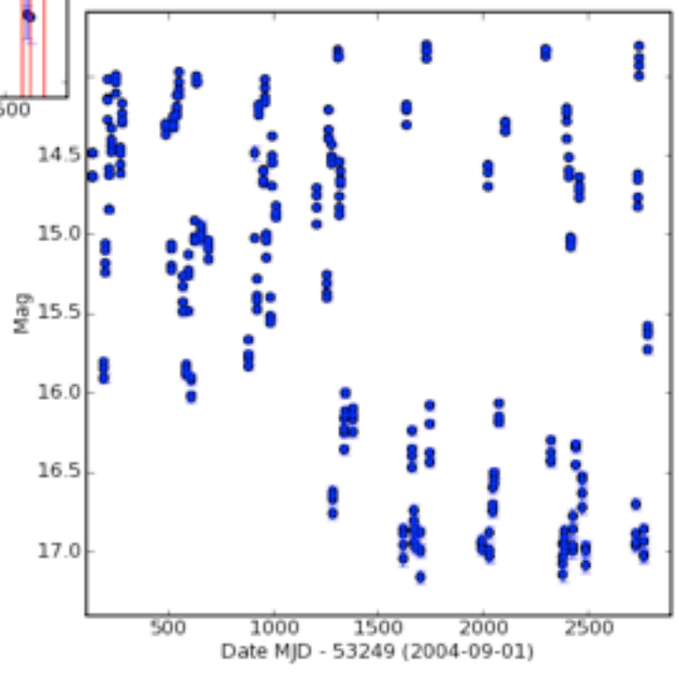
Ultra-compact binaries in the Catalina Real-time Transient Survey

A photometric study of CRTS dwarf novae

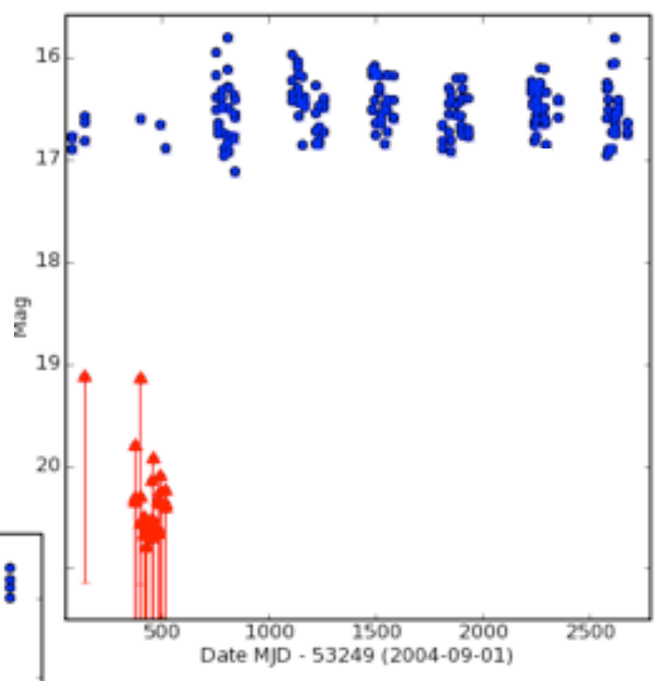
Monitoring known AM CVn systems



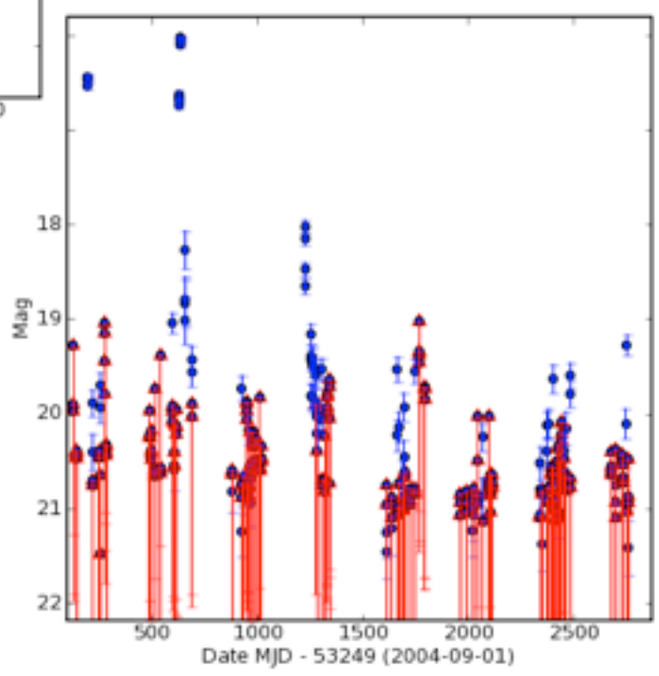
CP Eri



CR Boo



ES Cet



2QZ J1427-01

Ultra-compact binaries in the Catalina Real-time Transient Survey

A photometric study of CRTS dwarf novae

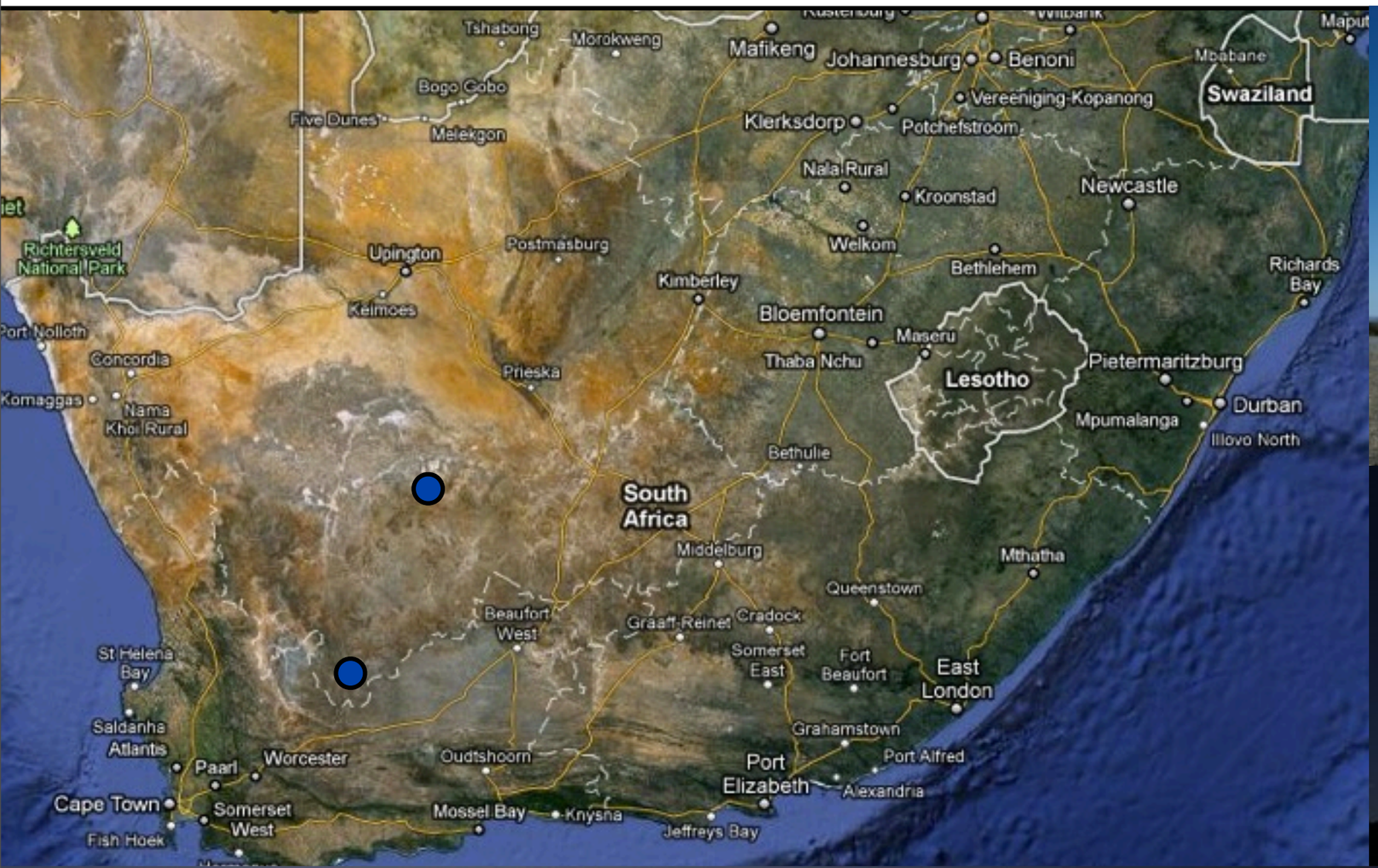
Monitoring known AM CVn systems

Facilities in South Africa to possibly monitor known AM CVn systems:

- MONET (MOnitoring NETwork)
- Las Cumbres Observatory Global Telescope Network (LCOGT)

Target of Opportunity trigger SALT / VLT observations when object goes into outburst (see Gavin's talk on Wednesday)

Multi-wavelength facilities in South Africa for astronomical transients



Ultra-compact binaries in the Catalina Real-time Transient Survey

Phase-resolved spectroscopy with SALT

First semester of SALT Science Operations underway

2011 September - 2012 February (extended to 2012 April)

2011-3-RSA_OTH-009 (Phase-resolved spectroscopy of helium-rich cataclysmic variables)

CSS1028-08, CSS1122-11 CSS2333-15 (outburst) - 8.5 ks

Second semester: 2012 May - 2012 October

2012-1-RSA_OTH-019 (Phase-resolved spectroscopy of helium-rich cataclysmic variables)

CSS1028-08, CSS1122-11, CSS2333-15 (quiescence) - 24.2 ks

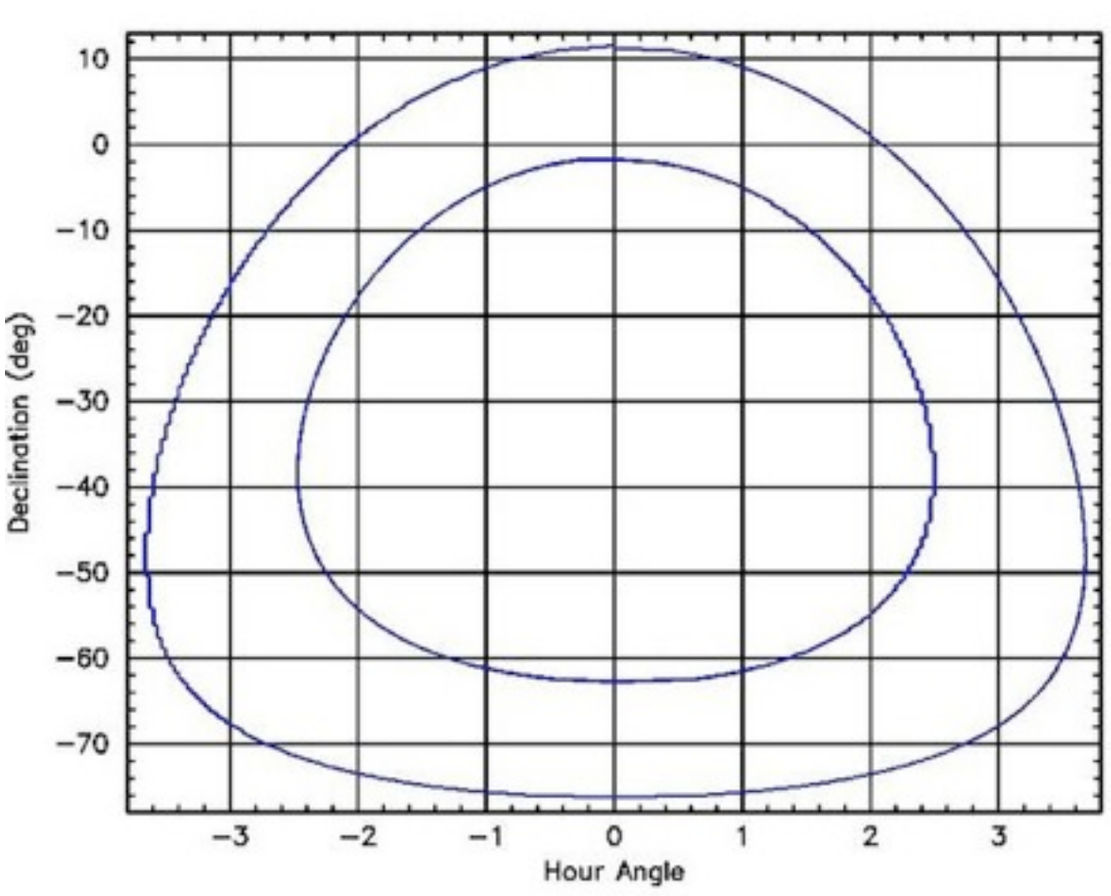
2012-1-RSA_OTH-018 (Quiescent properties of classical novae: the THEA sample)

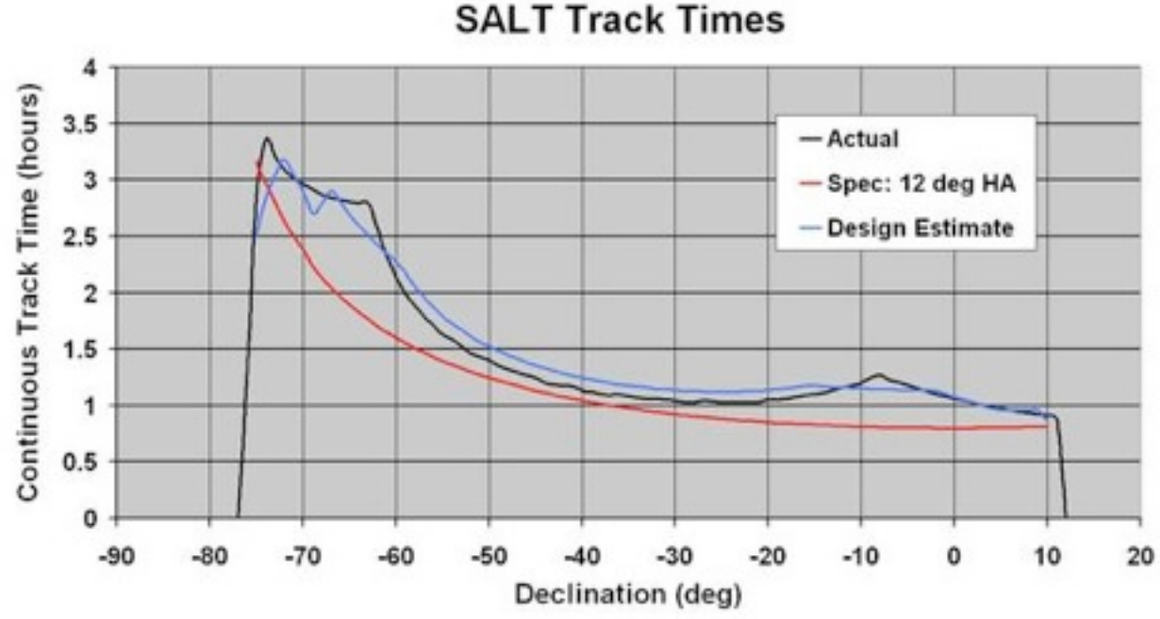
V382 Vel, V630 Sgr - 21 ks

Ultra-compact binaries in the Catalina Real-time Transient Survey

The Southern African Large Telescope: Track lengths

Track times equivalent to orbital periods of AM CVn systems, excellent facility for phase-resolved spectroscopy of compact binaries



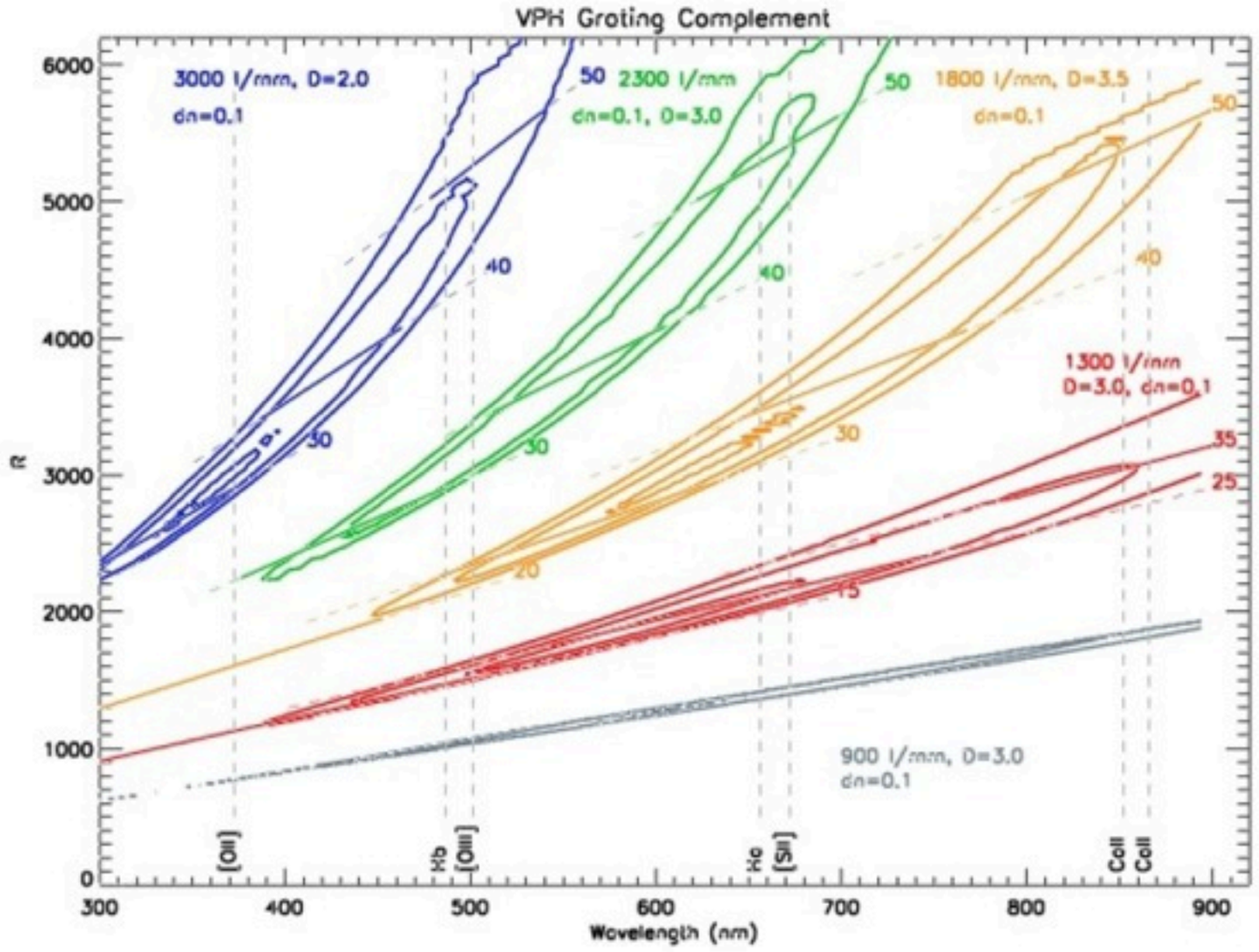


Ultra-compact binaries in the Catalina Real-time Transient Survey

Phase-resolved spectroscopy with SALT

The Southern African Large Telescope: The Robert Stobie Spectrograph

Low to intermediate resolution (R ~ 800 - 6000)

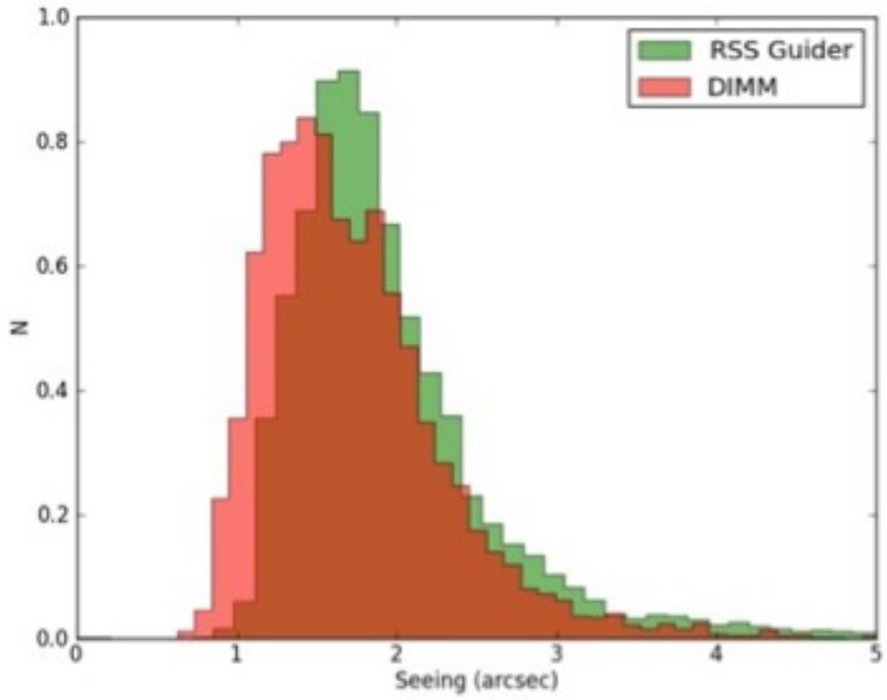


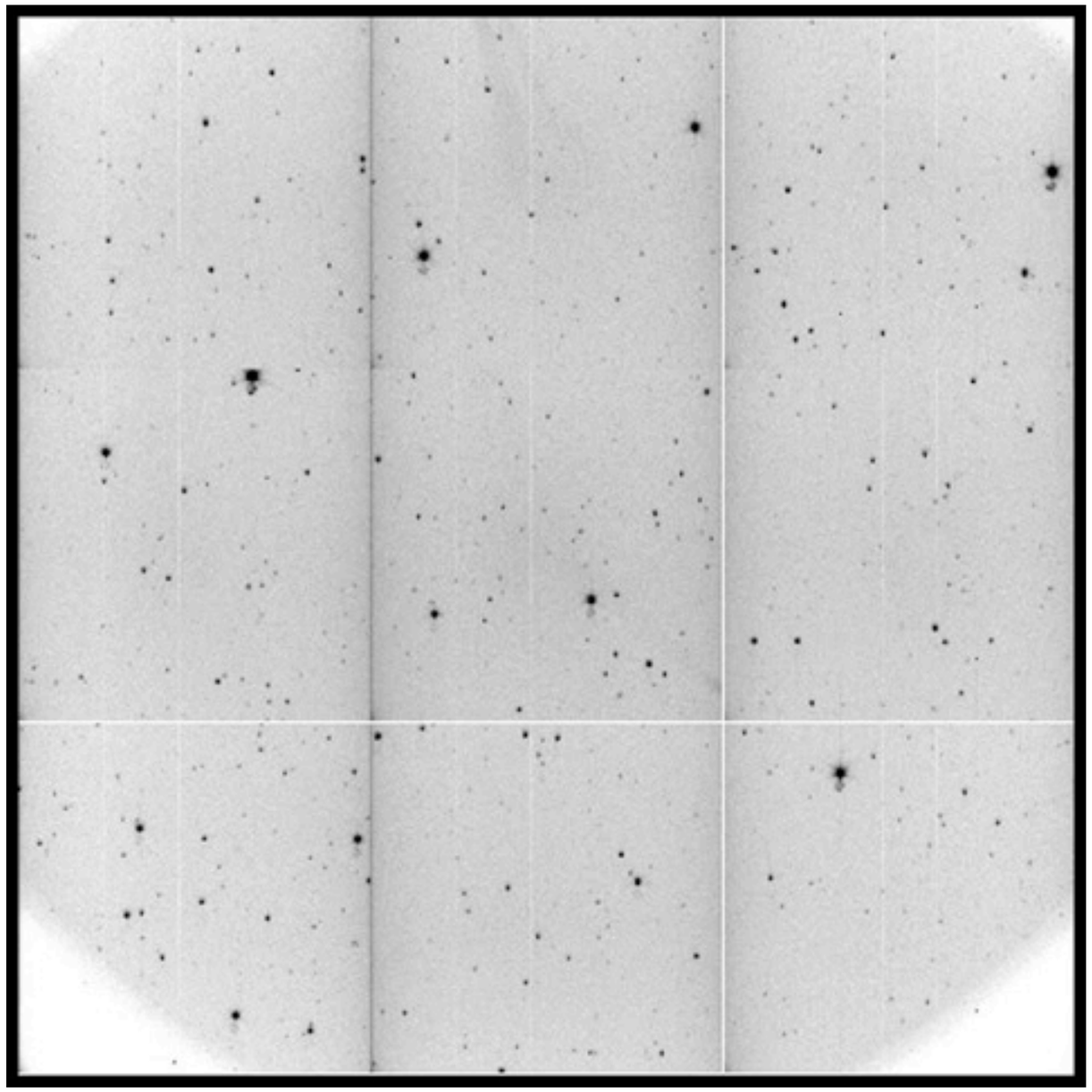
Ultra-compact binaries in the Catalina Real-time Transient Survey

Phase-resolved spectroscopy with SALT

The Southern African Large Telescope: Seeing characteristics

Q1 SALT: Sept - Nov 2011





Ultra-compact binaries in the Catalina Real-time Transient Survey

The Southern African Large Telescope: Detection limits (RSS)

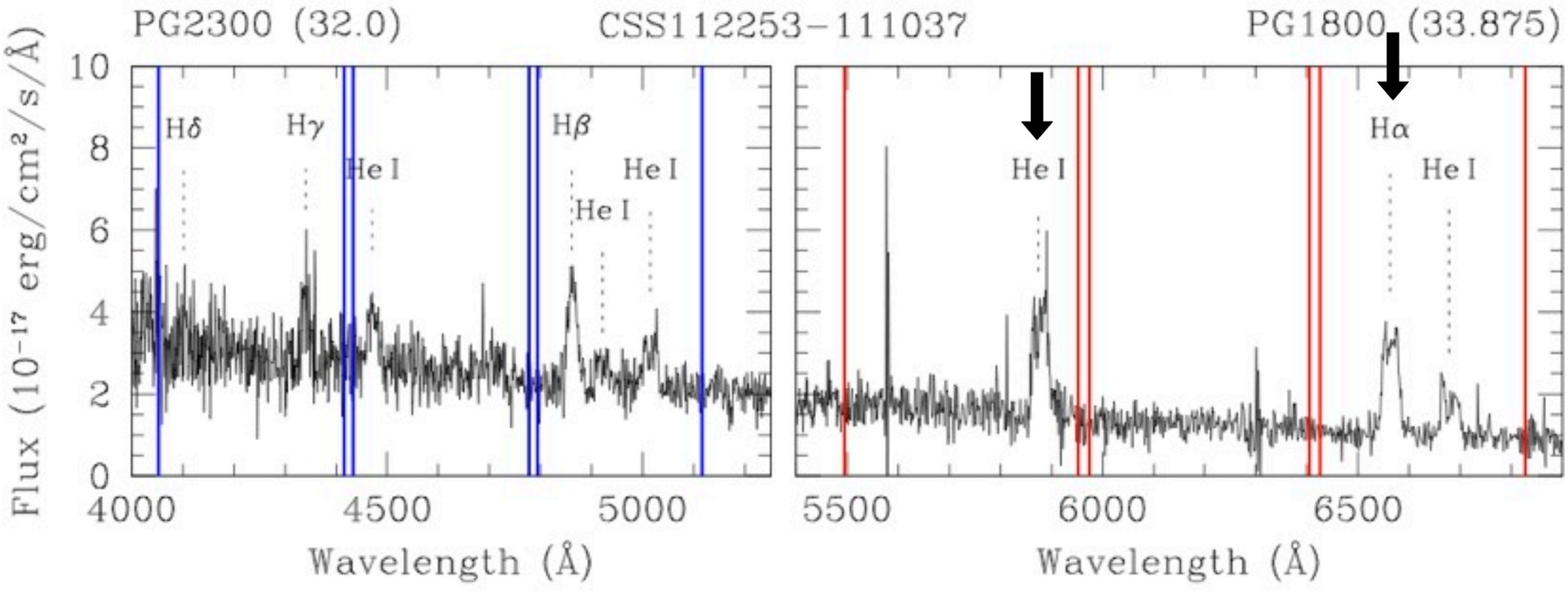
Grating	Central lambda	Resolution (R)	Mag limit (V)
PG0300	620 nm	350	21.9
PG0900	605 nm	1065	21.5
PG1300	665 nm	1800	21.1
PG1800	677 nm	2890	20.6
PG2300	566 nm	3220	20.7
PG3000	434 nm	3215	20.7

Numbers based on guide for SALT observers (2012):
30 minute exposure, 1.5” slid width, 1.3” seeing, dark, S/N of 5 per pixel in 2x2 binning over a 2x FWHM aperture spectral extraction at the central wavelength.

Ultra-compact binaries in the Catalina Real-time Transient Survey

Phase-resolved spectroscopy with SALT

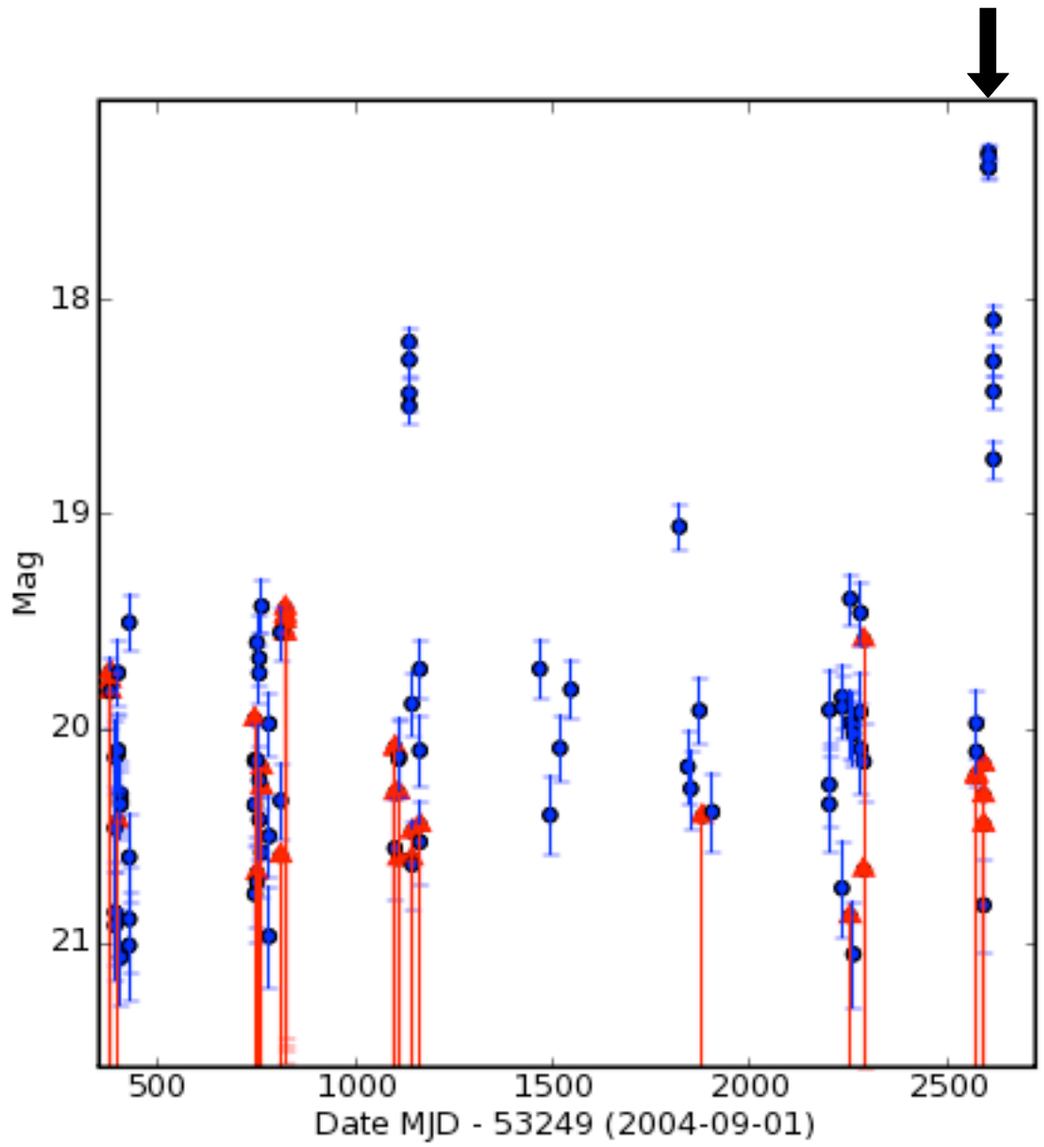
2011-3-RSA_OTH-009 / 2012-1-RSA_OTH-019



CSS1122-11: SDSS spectrum

Ultra-compact binaries in the Catalina Real-time Transient Survey

CSS111019:233313-155744



CSS2333-15

Outburst in 2011 October.

WW on 40-inch for science commissioning of SHOC

Immediate follow-up during outburst with SHOC and triggered SALT spectroscopy

Ultra-compact binaries in the Catalina Real-time Transient Survey

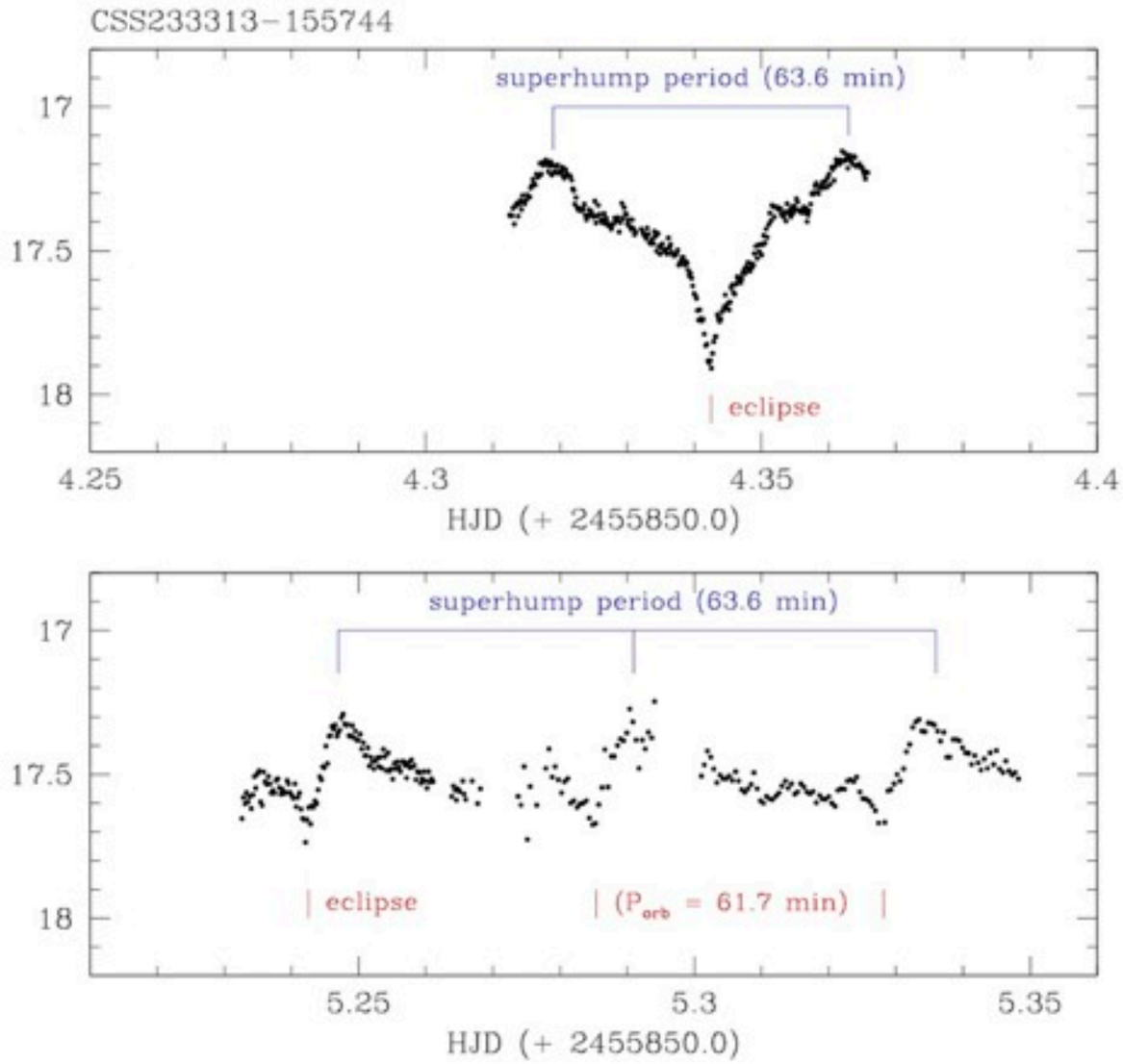
CSS111019:233313-155744

SHOC: Sutherland High-speed Optical Cameras (2x)

- Andor iXon X3 888 UVB camera
- Conventional and EM mode
- Science commissioning ongoing
- Replacement for UCT CCD

Two nights in October 2011:

- P_{sh} = 63.6 min
- P_{orb} = 61.7 min
- shallow eclipse



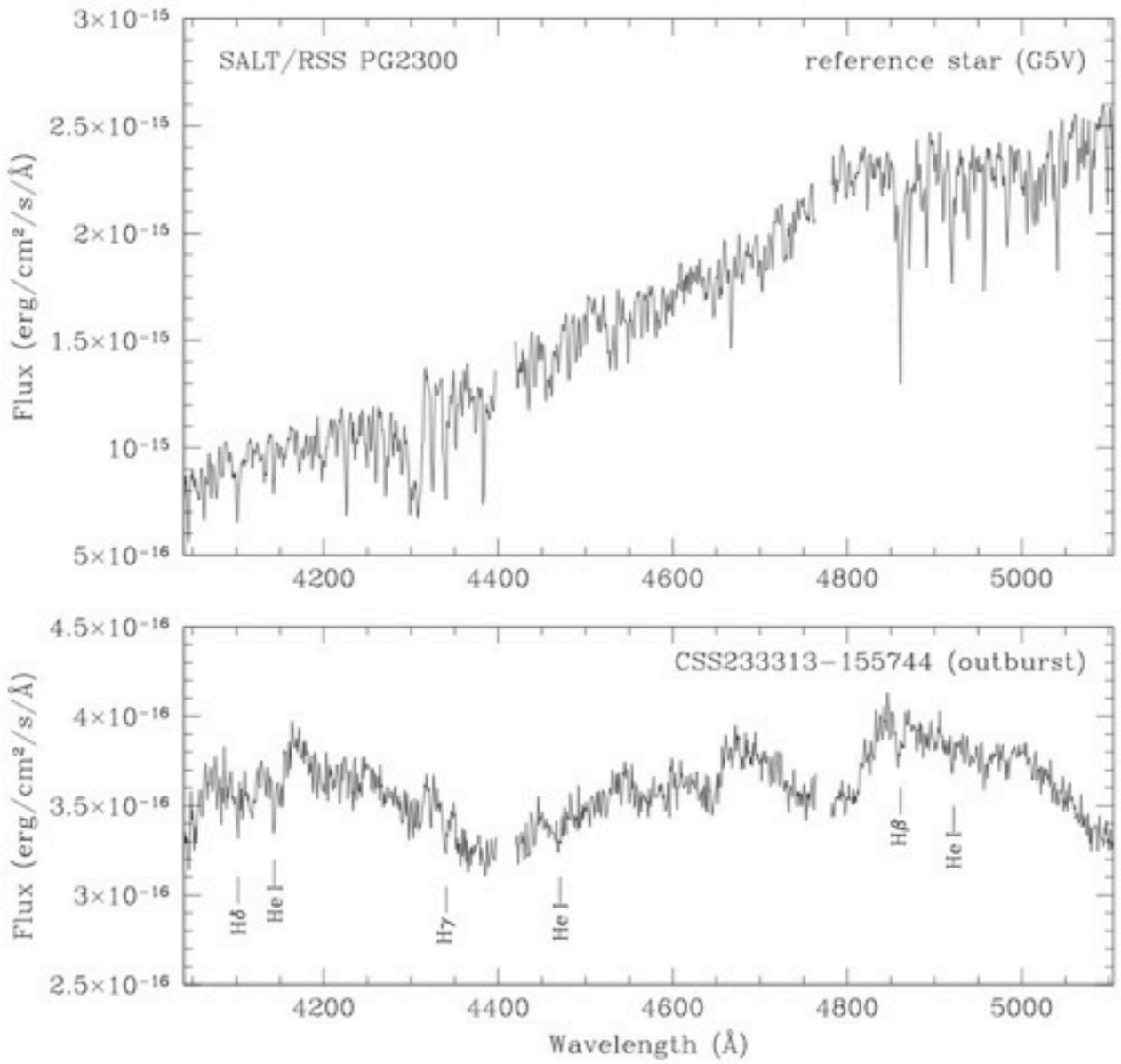
Woudt & Warner (2011, ATel 3705)

Ultra-compact binaries in the Catalina Real-time Transient Survey

CSS111019:233313-155744

SALT spectroscopy:

- PG2300 grating
- resampled at 1Å/pixel
- spectrophotometric standard
- 12 x 215 s exposures
- Excellent ToO machine!



CSS2333-15 in outburst (V~17.3)

Very unusual spectrum

- strange continuum shape
- unclear line ID

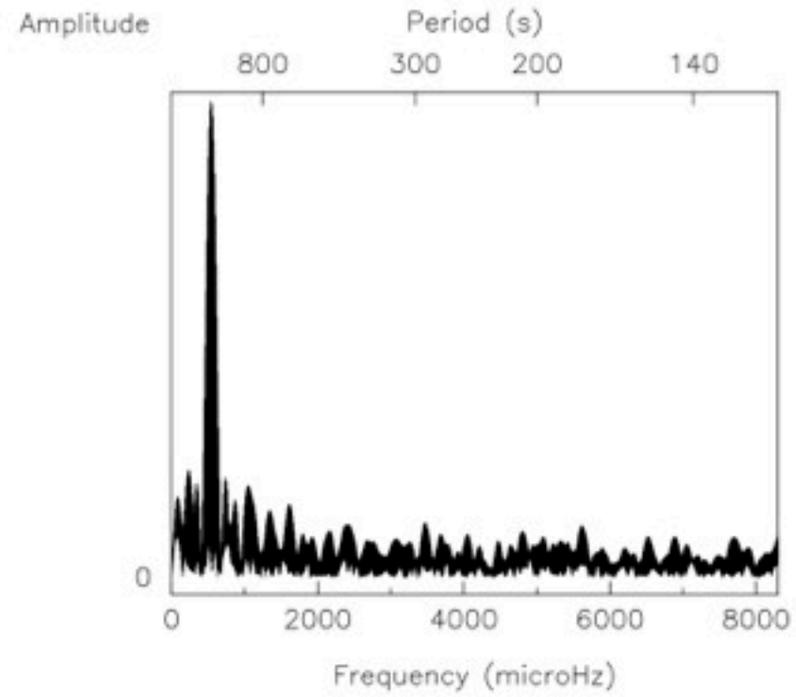
Need spectrum at quiescence (2012)

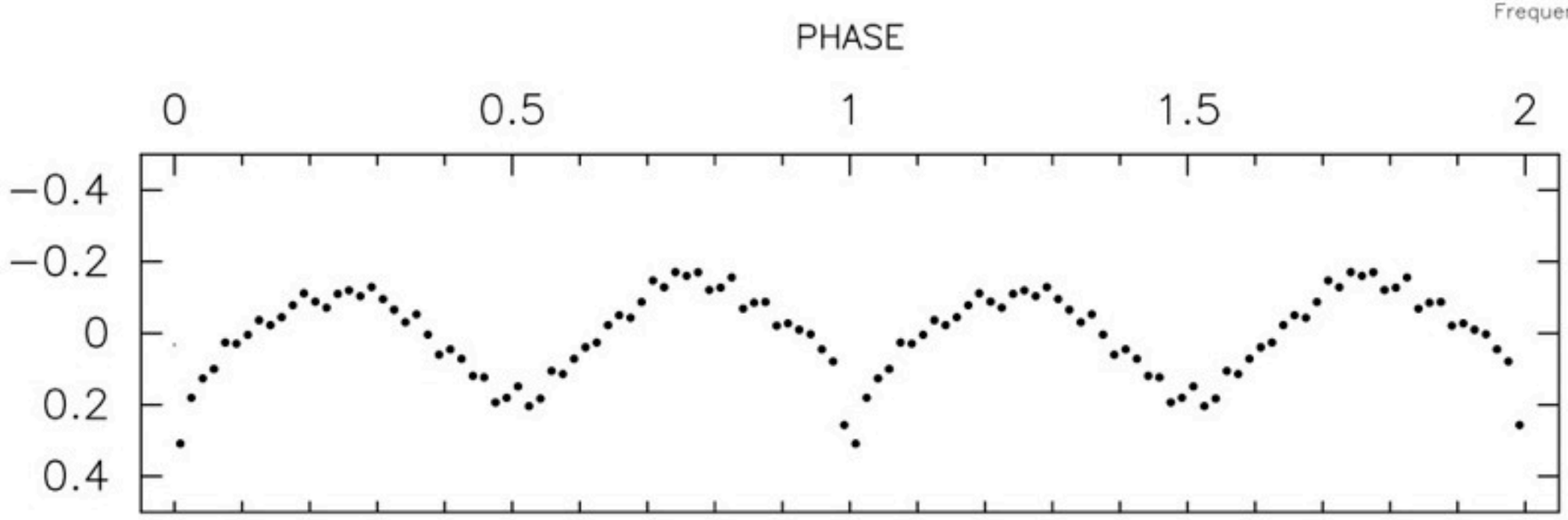
Ultra-compact binaries in the Catalina Real-time Transient Survey

CSS111019:233313-155744

Photometry in quiescence:

- 3 nights in December 2011
- V ~ 20.3 mag
- P_{orb} = 61.70 ± 0.01 min
- shallow eclipse confirmed
- double-humped profile (amplitude 0.15 mag)





Ultra-compact binaries in the Catalina Real-time Transient Survey

Summary

Catalina Real-Time Transient Survey an excellent source for monitoring and discovering **outbursting** AM CVn systems

Three new short-period outbursting systems discovered in CRTS to date: CSS1028-08, CSS1122-11 and CSS2333-15

Rapid increase in new southern systems with CRTS

Follow-up is key!

- Photometry (not just monitoring) on small telescopes (must be made more efficient given coming data deluge)
- Phase-resolved spectroscopy on 8-m class telescopes