A photometric variability study of massive stars in Cygnus OB2

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Survey description

- One-and-a-half-year-long (25 June 2012 to 27 November 2013) variability study of Cygnus OB2.
- Johnson R_J and I_J bands (not Cousins), Optec Inc. filters.
- 35 cm Meade LX200-ACF telescope with an SBIG ST10-XME 3.2 Mpix. camera.
- Suburban location in Zaragoza, Spain, at an altitude of 260 m.
- Over 300 epochs per filter.
- Four $22.5' \times 15'$ fields (Figure 1).
- Coverage to R_J = 15 and I_J = 14 (S/N limited): 1425 objects.
- Only four saturated stars in the four fields: HD 195 988, Cyg OB2-5 A, Cyg OB2-8 A, and BD +40 4241 (Figure 1).

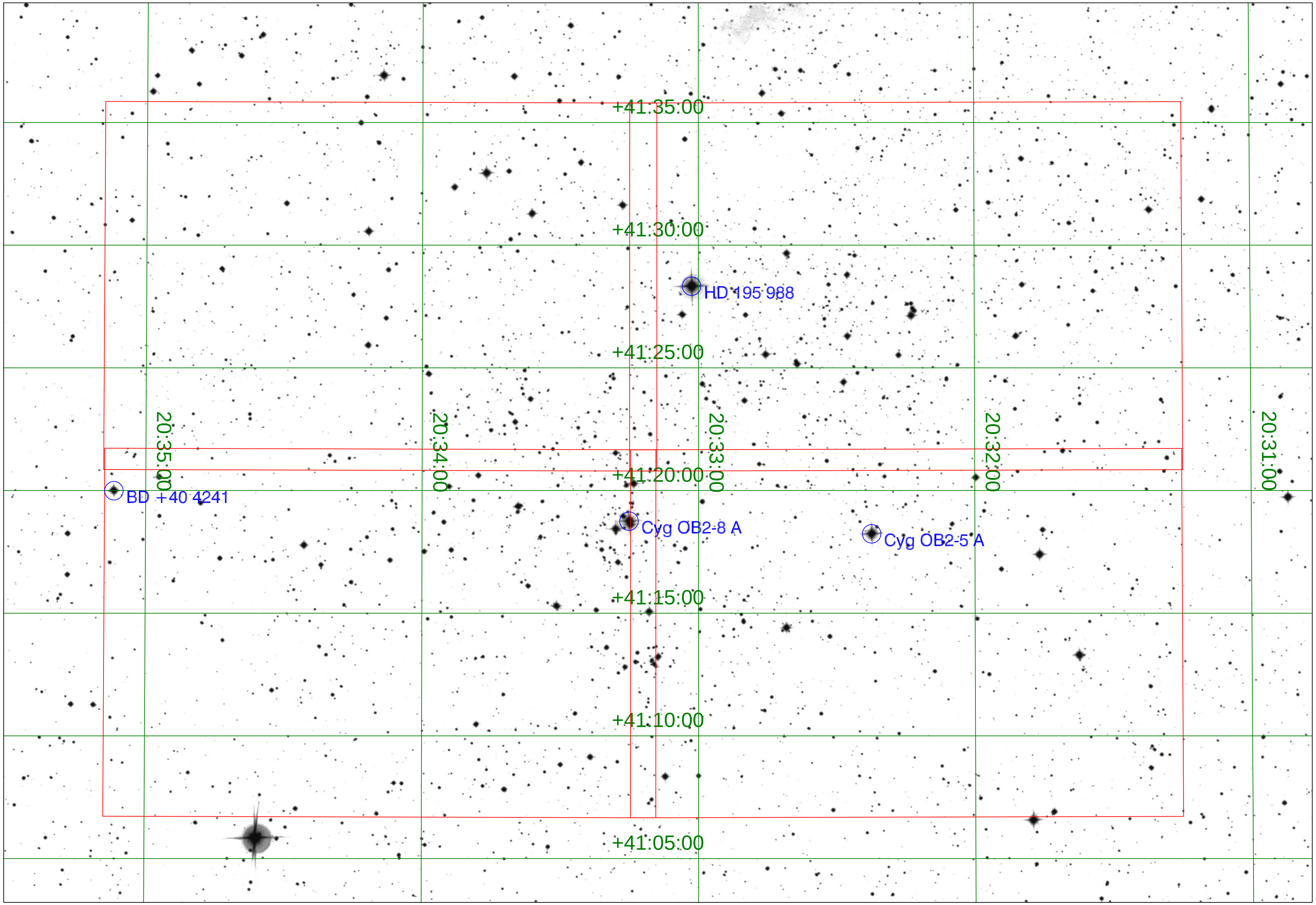

Figure 1. The four fields used in this work on a DSS2 Red image.

Why Cygnus OB2?

- The best region to study O stars in the northern hemisphere.
  - Young and massive: two O3 stars (only cases with $\delta > 0$).
  - Well-populated IMF.
  - Nearby ($\sim$1.7 kpc) but mid-to-high extinction (A_V = 4-10 mag).
- It is an OB association, not a cluster (and it was born that way, Wright et al. 2014), so it is relatively extended in the sky.
- Spectral types from the Galactic O-Star Catalog (Maíz Apellániz et al. (2004); Sota et al. 2008) and the Galactic O-Star Spectroscopic Survey (Maíz Apellániz et al. 2011).

Data taking and reduction

- Automated observations: CCD AutoPilot and MaxImDL / MaxPoint software.
- Image processing under Pyraf with additional Python packages and scripts.
- Astrometric calibration using Astrometry.net.
- Aperture photometry with four different apertures. Selection based on optimal S/N and minimal neighbor contamination on a case-by-case basis.
- Absolute photometric calibration using several reference stars by interpolating between V_J from Massey & Thompson (1991) and J from 2MASS using Maíz Apellániz (2013) and Maíz Apellániz et al. (2014).
- Photometric dispersion of 0.01 mag or less for the calibration stars.

Searching for variables

- First pass: Dispersion - mean magnitude diagrams (Figure 2).
- Second pass: Specific search algorithms for eclipsing binaries
- Periodogram analyses using the Fourier method of Horne & Baliunas (1986) and the information entropy method of Cincotta et al. (1995).
- Types of variables considered: (a) eclipsing, (b) pulsating, (c) irregular/long period, and (d) Be stars.
- Detection categories assigned: Non-variable, candidate, and confirmed variable.
- Comparison with previous studies of Henderson et al. (2011) and Kiminki et al. (2012).

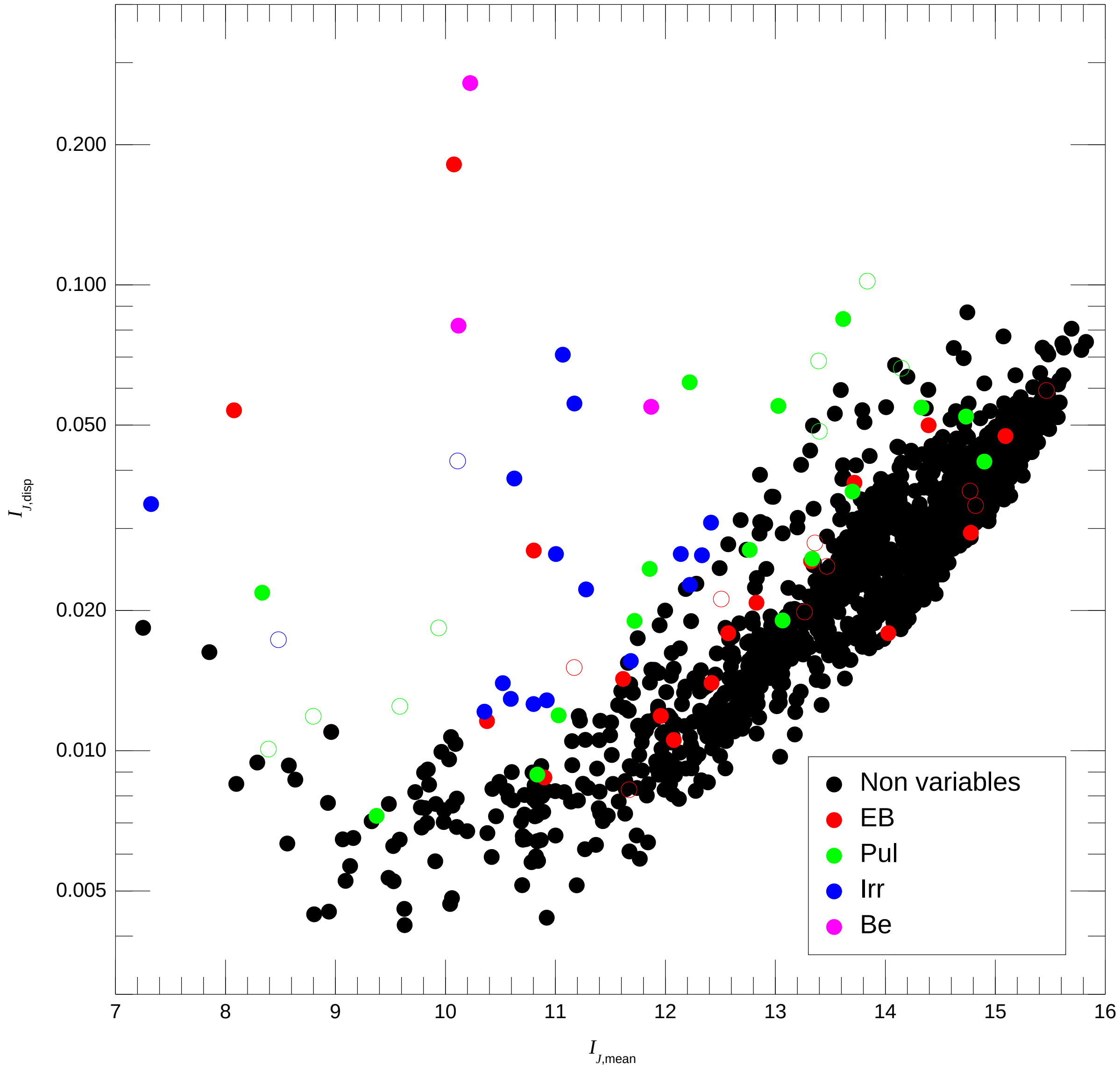

Figure 2. Dispersion - mean magnitude diagram for I_J. Non-filled symbols indicate candidate detections. The increase in dispersion in the range I_J = 7-8 is due to the onset on non-linearity on the CCD.

Results

- We have detected:
  - 17 confirmed and 9 candidate eclipsing binaries (Table 1).
  - 16 confirmed and 8 candidate pulsating variables (Table 2).
  - 16 confirmed and 2 candidate irregular/long period variables (Table 3).
  - 3 spectroscopically confirmed Be variable stars (Table 4).
- Cyg OB2-4 B is a newly discovered Be star that underwent a brightening of 0.57 mag in R_J and 0.69 mag in I_J during the observing period (Salas et al. 2013, Figure 3). The event was accompanied by spectral changes e.g. Hβ shifted from absorption to a double-peaked emission, as seen in GOSSS data.
- Some of the eclipsing binaries have eccentric orbits (Figure 5).
- Cyg OB2-12 and Cyg OB2-IRS 7, two massive objects in the association, are irregular variables (Figure 8).

Table 1. Confirmed and candidate eclipsing binaries.

RA (J2000)	dec (J2000)	Names	Cand.?	R_J	I_J	Period (d)	ΔI_J
20:32:42.9	41:20:16	ALS 21 109, [MT91] 311	—	13.0	12.0	6.2797(5)	0.14
20:31:20.6	41:14:36	2MASS J20312066+4114363	—	13.4	12.1	8.52651(5)	0.13
20:31:23.4	41:19:25	2MASS J20312331+4119257	—	16.3	14.8	7.9102(6)	0.42
20:32:23.6	41:19:24	[MT91] 242	—	14.8	14.1	5.6239(2)	0.52
20:33:08.4	41:15:43	[MT91] 849	—	16.2	15.1	2.8926(1)	0.35
20:33:09.6	41:12:59	Cyg OB2-22 C, [MT91] 421	—	11.7	10.4	4.1621(1)	0.10
20:33:30.5	41:20:17	V2191 Cyg, [MT91] 554	—	13.5	12.4	5.9504(3)	0.28
20:31:27.8	41:29:17	[MT91] 94	—	13.9	12.8	5.4669(5)	0.30
20:31:41.6	41:28:21	[MT91] 129	—	13.5	12.5	2.15175(3)	0.07
20:33:10.5	41:22:22	V2186 Cyg, [MT91] 429	—	12.0	10.9	2.97864(6)	0.15
20:31:37.5	41:13:20	Cyg OB2-3 A, BD +40 4212	—	9.2	8.1	4.74565(5)	0.22
20:31:59.0	41:07:31	2MASS J20315898+4107314	—	13.0	11.6	2.53133(5)	0.22
20:33:59.5	41:17:35	Cyg OB2-27, [MT91] 696	—	11.2	10.1	1.46917(2)	0.64
20:34:06.0	41:08:08	ALS 15 146, [MT91] 720	—	12.2	10.8	4.3619(1)	0.25
20:34:41.4	41:07:45	2MASS J20344143+4107456	—	14.8	13.3	2.89862(4)	0.26
20:33:20.9	41:18:01	V2189 Cyg, [MT91] 506	—	15.5	14.4	1.31385(5)	0.30
20:34:45.5	41:14:31	2MASS J20344555+4114314	—	15.3	13.7	6.56500(5)	0.25
20:32:38.3	41:28:56	[MT91] 298	Y	13.4	12.5	—	0.61
20:32:34.1	41:22:55	[MT91] 280	Y	14.4	13.3	—	0.26
20:32:11.3	41:25:04	2MASS J20321130+4125045	Y	16.5	15.5	—	0.60
20:32:26.8	41:22:35	[MT91] 254	Y	15.8	14.8	—	1.42
20:32:14.0	41:22:24	2MASS J20321399+4122240	Y	15.8	14.7	—	1.27
20:31:57.0	41:12:33	Tyc 3157-00779-1	Y	12.2	11.7	—	0.32
20:32:25.2	41:08:25	[MT91] 245	Y	13.8	13.3	—	0.26
20:32:24.6	41:09:19	2MASS J20322463+4109202	Y	15.3	13.5	—	0.25
20:33:18.5	41:24:38	2MASS J20331846+4124383	Y	11.8	11.2	—	0.10

Table 2. Confirmed and candidate pulsating variables.

RA (J2000)	dec (J2000)	Names	Cand.?	R_J	I_J	Period (d)	ΔI_J
20:33:04.3	41:24:39	[MT91] 396	—	14.9	14.3	1.3823(3)	0.18
20:31:51.3	41:23:23	[MT91] 152	—	12.3	11.9	0.99838(4)	0.08
20:31:23.6	41:29:49	2MASS J20312356+4129489	—	15.7	14.7	0.9630(1)	0.17
20:33:01.1	41:11:11	[MT91] 382	—	14.2	13.7	0.93799(3)	0.26
20:33:08.8	41:18:51	Schulte 57	—	16.2	15.0	0.7275(1)	0.17
20:33:30.8	41:15:22	Cyg OB2-18, [MT91] 556	—	9.7	8.3	1.1192(1)	0.07
20:34:04.0	41:14:43	2MASS J20340404+4114430	—	14.4	12.6	7.92(1)	0.08
20:33:23.0	41:12:22	[MT91] 514	—	14.4	13.7	0.84634(1)	0.12
20:33:18.3	41:17:39	V2187 Cyg, [MT91] 487	—	14.3	13.1	0.25385(2)	0.06
20:33:13.3	41:13:28	ALS 15 148, [MT91] 448	—	12.3	10.9	3.170(5)	0.03
20:34:29.6	41:31:45	ALS 15 114, [MT91] 771	—	10.7	9.4	1.4316(6)	0.02
20:33:45.0	41:22:32	[MT91] 626	—	12.2	11.7	1.11035(5)	0.06
20:34:29.1	41:32:47	2MASS J20342909+4132476	—	15.5	12.1	0.9833(2)	0.20
20:33:43.0	41:30:00	2MASS J20334299+4130005	—	14.2	13.0	0.95787(1)	0.17
20:33:42.1	41:22:22	[MT91] 617	—	14.0	13.3	1.6424(2)	0.08
20:31:22.1	41:12:02	Cyg OB2-A30	—	13.6	13.0	3.719(1)	0.04
20:33:47.8	41:20:41	Cyg OB2-26, [MT91] 642	Y	10.8	9.6	—	0.04
20:33:18.0	41:18:31	Cyg OB2-8 C, [MT91] 483	Y	9.3	8.4	—	0.03
20:33:39.1	41:19:26	Cyg OB2-19, V1393 Cyg, [MT91] 601	Y	10.0	8.2	—	0.04
20:35:02.5	41:21:27	GSC 0316101176	Y	13.9	13.4	—	0.23
20:33:31.5	41:20:57	[MT91] 916	Y	15.4	14.1	—	0.33
20:33:25.0	41:31:35	Schulte 80	Y	14.7	13.4	—	0.16
20:33:49.8	41:23:58	2MASS J20334982+4123585	Y	15.1	13.8	—	0.35
20:33:39.8	41:22:52	[MT91] 605	Y	10.9	9.9	—	0.06

Table 3. Confirmed and candidate irregular/long period variables.

RA (J2000)	dec (J2000)	Names	Cand.?	R_J	I_J	Period (d)	ΔI_J
20:32:03.7	41:25:10	[MT91] 187	—	12.3	11.3	222.3(3)	0.07
20:32:14.0	41:23:23	2MASS J20321405+4123237	—	13.0	10.9	187.0(60)	0.06
20:31:18.3	41:21:21	ALS 15 133, [MT91] 70	—	11.7	10.3	192.0(40)	0.04
20:31:39.4	41:21:38	2MASS J20313935+4121387	—	14.5	12.3	126.0(10)	0.15
20:32:30.8	41:10:00	Cyg OB2-B12	—	14.1	12.4	52.8(2)	0.15
20:31:21.3	41:09:29	2MASS J20312131+4109286	—	13.0	12.2	171.0(10)	0.08
20:33:34.3	41:18:11	[MT91] 575	—	12.1	10.8	209.0(90)	0.04
20:33:31.7	41:18:53	[MT91] 895	—	14.5	11.7	34.40(3)	0.09
20:33:25.5	41:20:39	[MT91] 911	—	15.0	12.2	59.5(6)	0.14
20:33:15.7	41:20:17	Cyg OB2-23, [MT91] 470	—	11.6	10.6	192.0(90)	0.04
20:31:36.2	41:22:03	Cyg OB2-A4	—	13.4	11.0	96.0(10)	0.13
20:32:32.3	41:27:57	2MASS J20323232+4127571	—	14.3	11.2	36.295(1)	0.27
20:32:41.0	41:14:29	Cyg OB2-12	—	9.5	7.3	54.0(1)	0.18
20:33:42.1	41:07:53	[MT91] 615	—	11.0	10.5	309.0(90)	0.05
20:33:39.6	41:10:18	2MASS J20333961+4110192	—	14.4	11.0	73.5(2)	0.33
20:33:39.5	41:22:36	Cyg OB2-IRS 7	—	13.8	10.6	109.0(10)	0.22
20:31:43.1	41:06:56	Tyc 3157-01040-1	Y	10.5	10.1	—	0.18
20:33:14.8	41:18:42	Cyg OB2-8 B, [MT91] 462	Y	9.5	8.5	—	0.11

Table 4. Confirmed Be stars.

RA (J2000)	dec (J2000)	Names	Cand.?	R_J	I_J	Period (d)	ΔI_J
20:32:13.2	41:27:25	Cyg OB2-4 B, [MT91] 213	—	11.0	10.8	—	0.70
20:33:18.5	41:15:35	Schulte 64, V2188 Cyg, [MT91] 488	—	13.5	11.8	—	0.22
20:34:43.6	41:29:04	Schulte 30, [MT91] 793	—	11.2	10.1	—	0.29

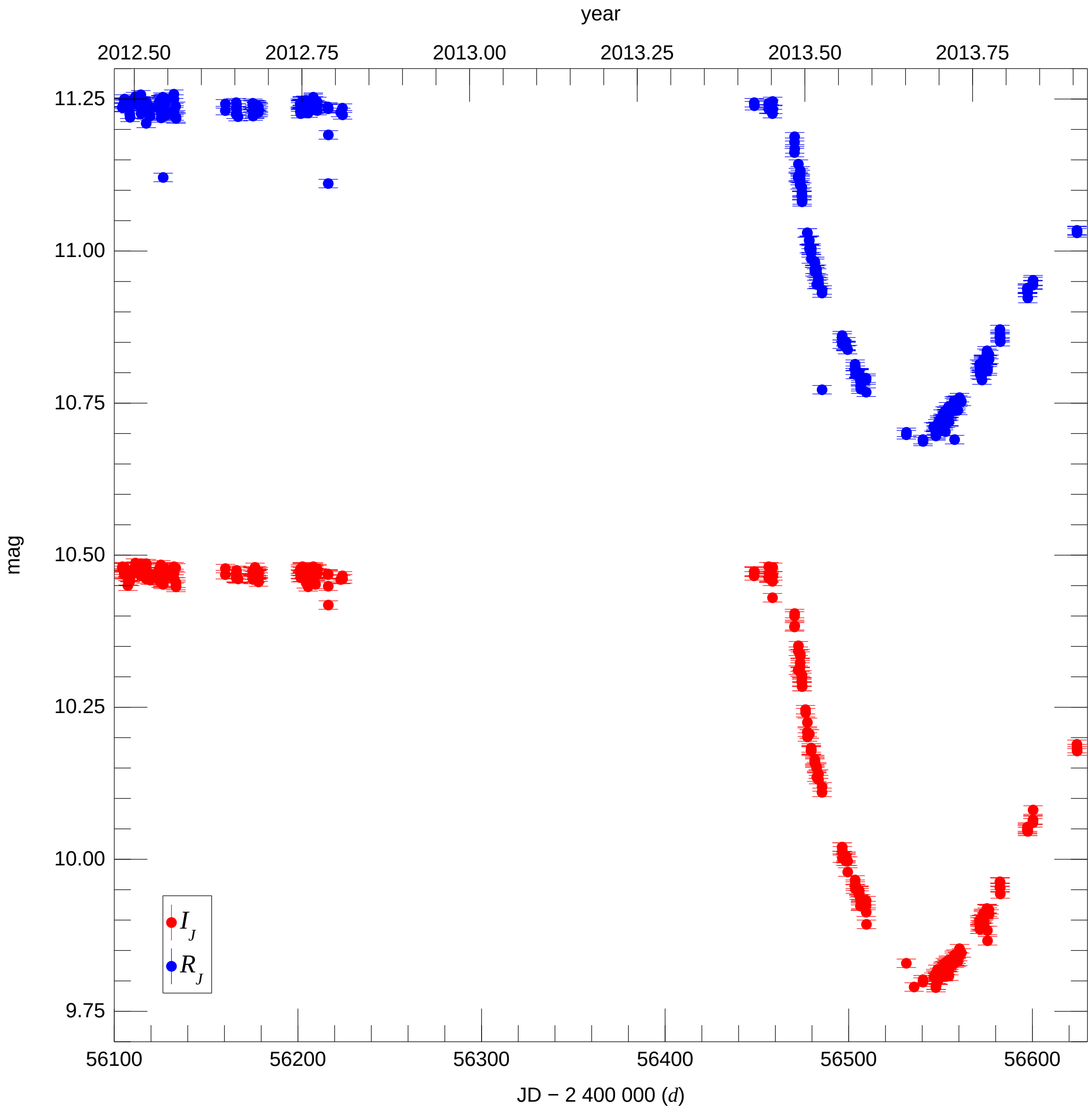

Figure 3. Light curves for Cyg OB2-4 B.

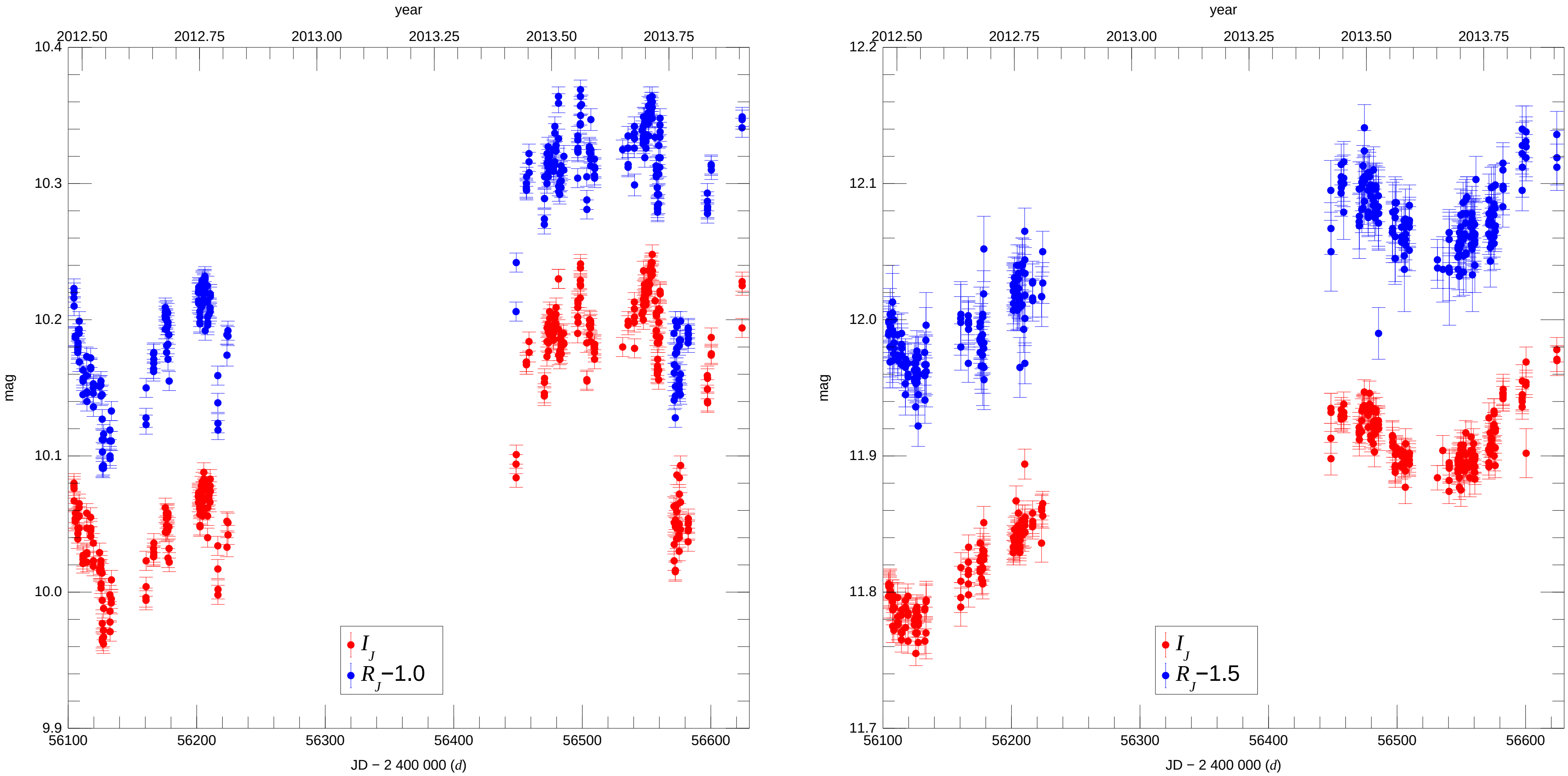

Figure 4. Light curves for two Be stars, Schulte 30 (left) and Schulte 64 (right).

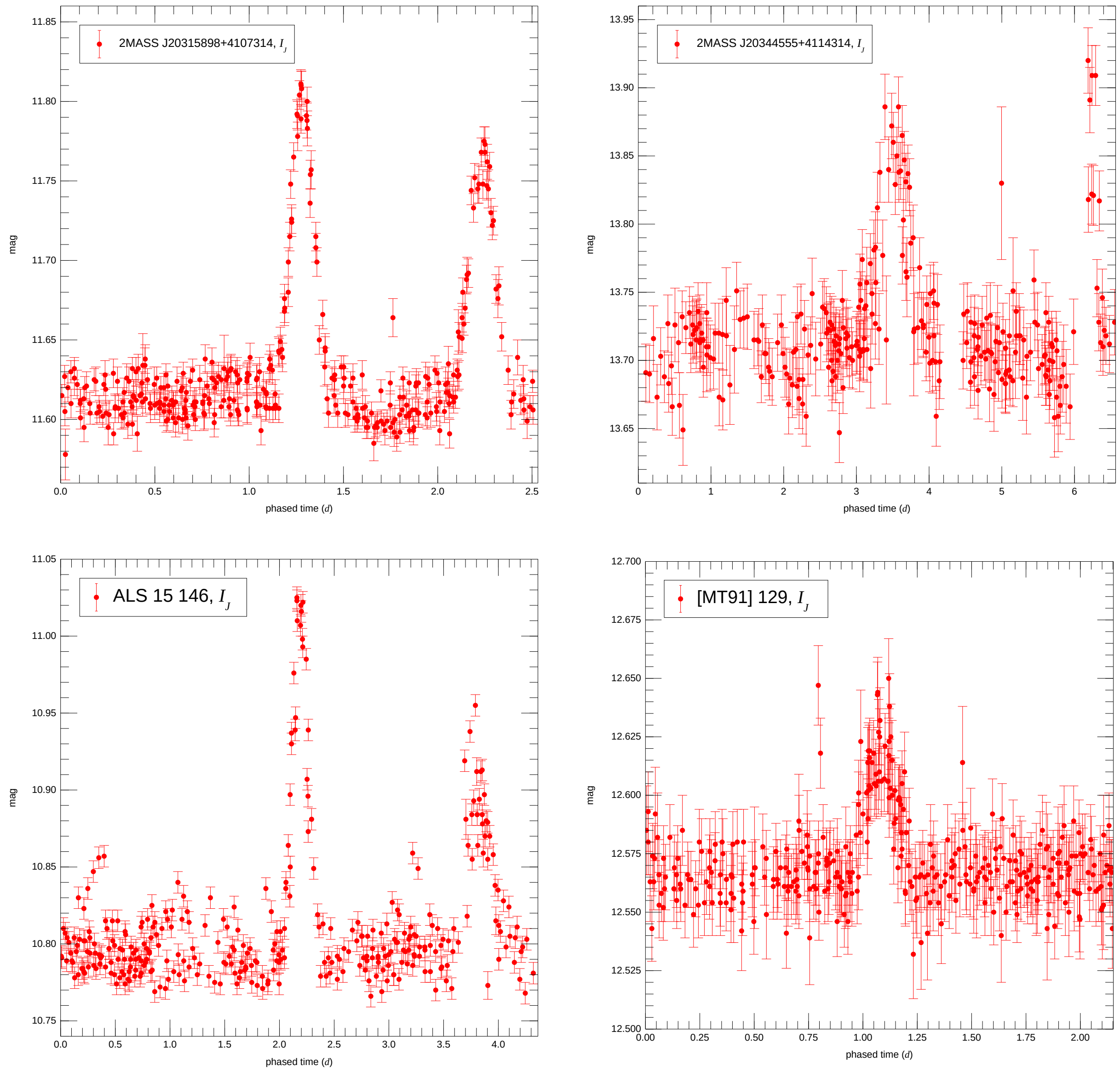

Figure 5. Phased light curves for four eclipsing binaries. Note that the first three orbits are eccentric.

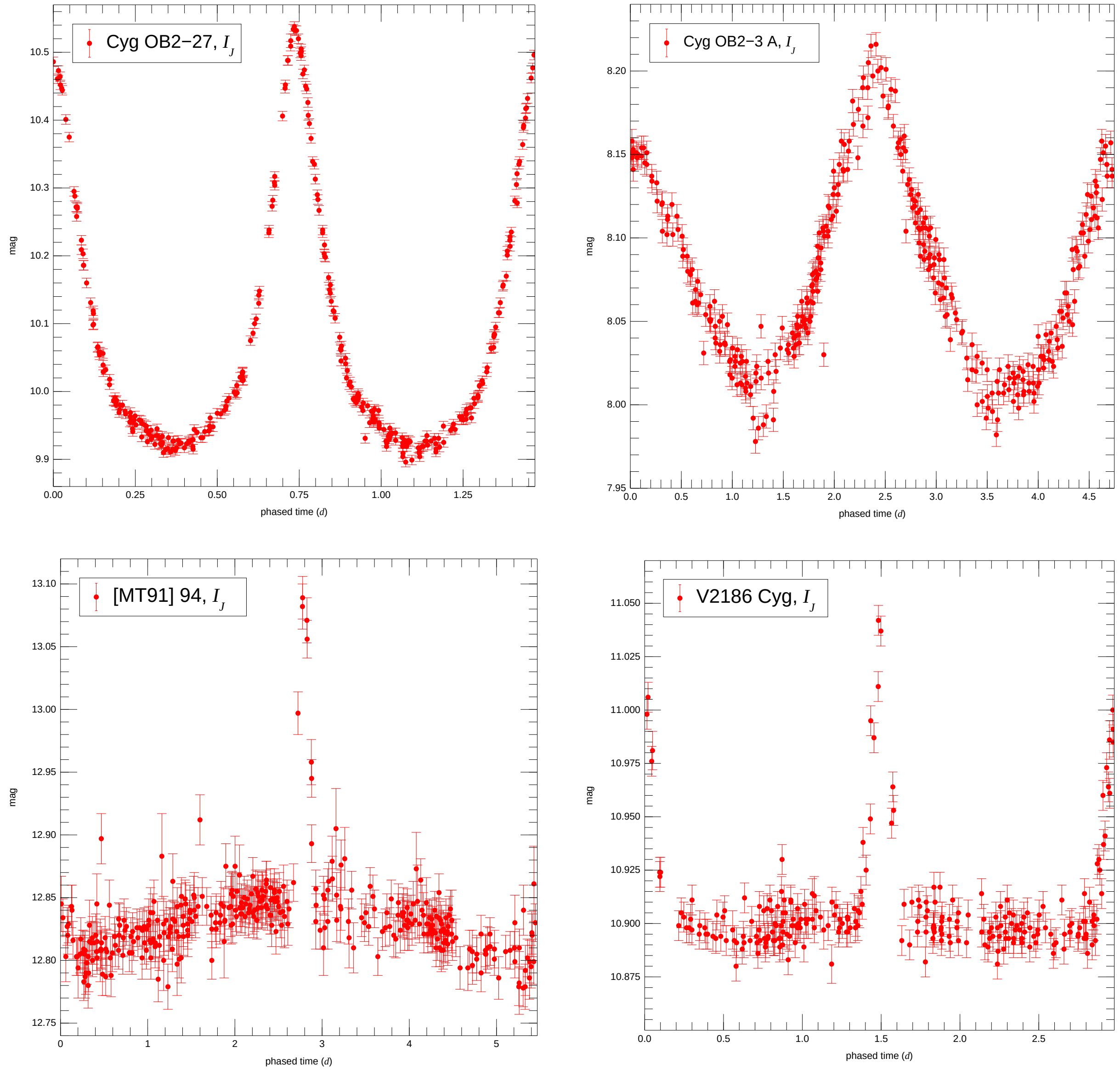

Figure 6. Phased light curves for four eclipsing binaries.

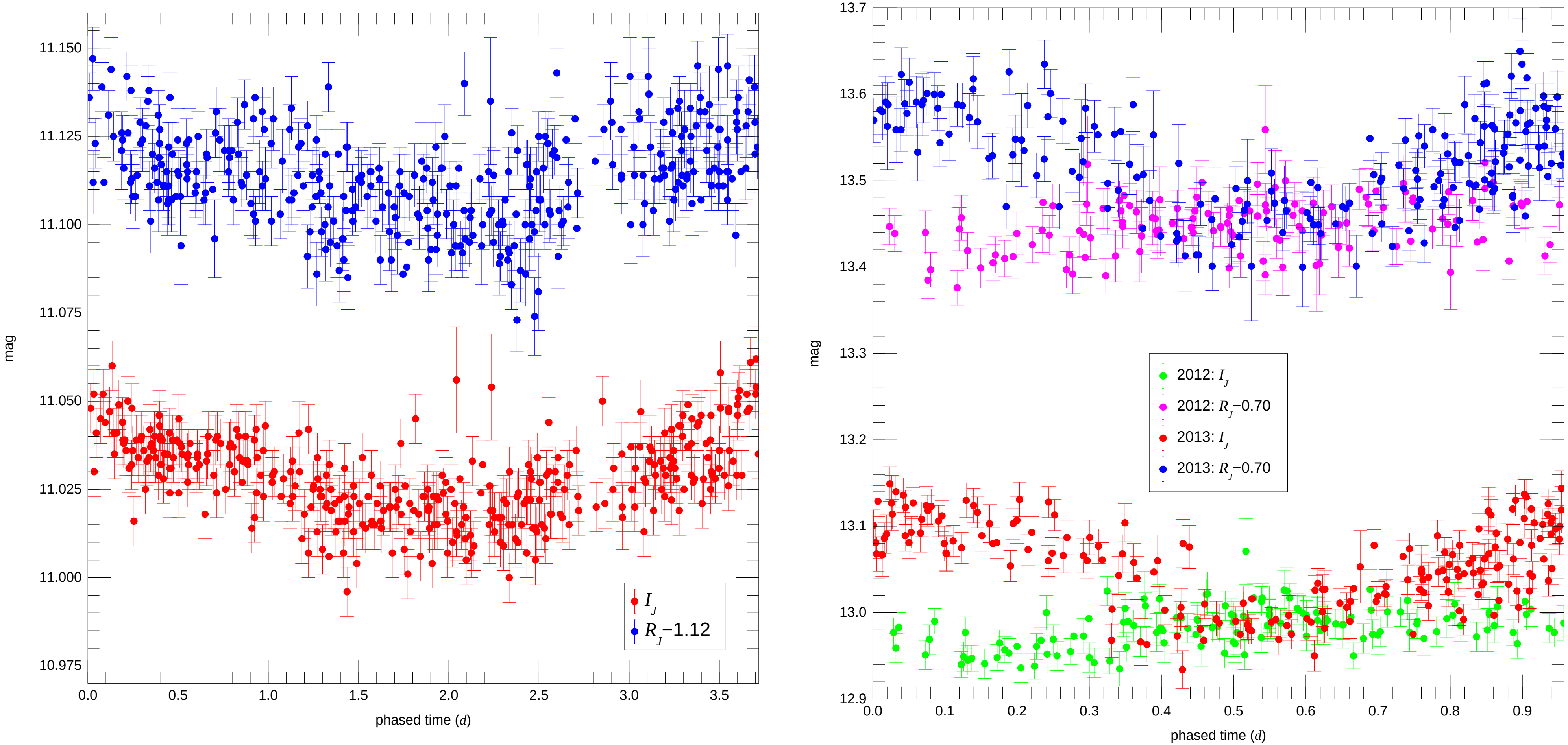

Figure 7. Phased light curves for two pulsating stars, Cyg OB2-A30 (left) and 2MASS J20334299+4130005 (right). Note how for the second case the pulsations appear only for the 2013 data.

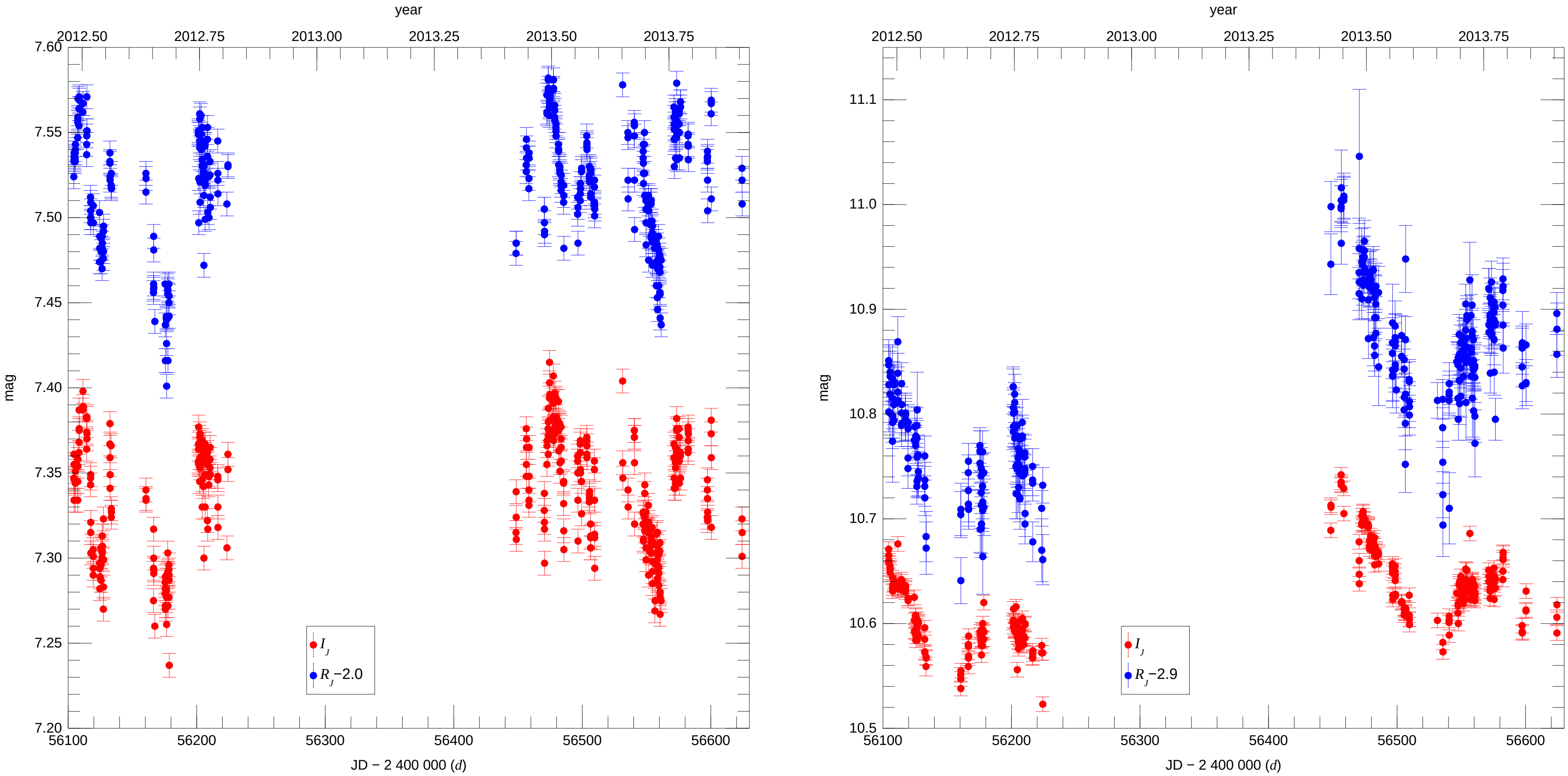

Figure 8. Light curves for two highly extinguished irregular variable stars, Cyg OB2-12 (left) and Cyg OB2-IRS 7 (right).

References

- Cincotta, P. M., Méndez, M., & Núñez, J. A. 1995, *ApJ* **449**, 231.
- Henderson, C. B. et al. 2011, *ApJS* **194**, 27.
- Horne, J. H. & Baliunas, S. L. 1986, *ApJ* **302**, 757.
- Kiminki, D. C. et al. 2012, *ApJ* **747**, 41.
- Maíz Apellániz, J. 2013, *Highlights of Spanish Astrophysics VII*, 657.
- Maíz Apellániz, J. et al. 2004, *ApJS* **151**, 103.
- Maíz Apellániz, J. et al. 2011, *Highlights of Spanish Astrophysics VI*, 467.
- Maíz Apellániz, J. et al. 2014, *A&A* **564**, A63.
- Massey, P. & Thompson, A. B. 1991, *AJ* **101**, 1408.
- Salas, J. et al. 2013, *ATel* 5571.
- Sota, A. et al. 2008, *RvMxA&A (conf. series)* **33**, 56.
- Wright, N. J. et al. 2014, *MNRAS* **438**, 639.