Intense Time-Series Photometry of Windy Massive Stars from Space with BRITE-Constellation: Connecting with Ground-Based Spectroscopic Observers

Anthony Moffat, Project PI & Coordinator, moffat@astro.umontreal.ca - 22 Nov 2015

Executive summary

Going after massive stars with strong winds using time-dependent precise photometry from space combined with high-quality simultaneous spectroscopy from the ground

Massive stars, particularly those that start out with 20 solar masses or more, blow strong winds during their whole lifetimes right to and including the final dramatic supernova explosion. Thus, massive stars are the main ecological drivers of the Universe on rapid timescales (due to their short but intense lifetimes), stirring up and enriching the interstellar matter for the next generation of cosmic machines, i.e. stars. Without their nuclear furnaces to produce the heavy elements that the Big Bang lacked the time to make, we would not be here to ponder it! This has happened thousands of times since the first primordial stars were formed from the ever-expanding cosmic fabric. All this despite the rarity of massive stars compared to lower-mass stars. And it will continue as long as stars are still forming for a long time yet.

But our understanding of these massive windy stars is shaky at best. Do they pulsate? What is their internal structure? How does rotation affect their evolution? What is the role of binaries among them? These and many other questions remain at the forefront of astronomical enquiry. Without viable answers to these questions, our understanding of these vital machines will remain obscure and thus unsatisfactory at best.

A promising avenue to shine some proverbial light on these problems is offered by a new bunch of nanosatellites called BRITE-Constellation. Launched in 2013-14 these satellites are now producing reams of extraordinary photometric time-series data for many of the brightest stars in the whole sky in the quest mainly for pulsations, rotation and binary properties of many types of stars, but in particular those that are massive and blow strong winds. The power of such a venture can be significantly enhanced by repeated spectra of high quality and frequency obtained in parallel with the typical 6-month space photometric runs with the five functioning BRITE satellites. We are hoping that many astronomers worldwide, both professional and amateur, will join in this venture, the details of which are outlined in the more detailed accompanying document.

The detailed document follows ….

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Abstract

BRITE-Constellation is an array of independent astronomical nanosatellites that is being used in one of its prime modes with high-precision time-dependent dual-band photometry to probe luminous Galactic massive stars with strong winds as cosmic engines in a blind survey of their mainly oscillatory, rotational and binary properties. This includes all 20 stars down to V = 4 (73 stars between V = 4-6 for some of the satellites) in the whole sky, whose spectral types encompass all 8 (31) O & WR stars and 12 (42) B-supergiants in the current Bright Star Catalogue. Such stars have initial masses above ~20 Mo, the lower limit for a single star at solar metallicity to have a strong enough stellar wind to be able to evolve through the WR phase and explode as an H-poor type Ib or Ic supernova. Many of these windy massive stars occur in loose groups in the 24-degree BRITE field of view, allowing them to be observed in parallel. Simultaneous ground-based spectroscopic monitoring by professionals and amateurs around the world will also be obtained for as many of these stars as possible, to provide complementary, essential constraints. Massive stars with strong winds dominate the ecology of the Universe – not only as supernovae, but also during their entire lifetimes, with far-reaching consequences.

Scientific Rationale: Background

Massive stars are normally taken to be those stars that exceed initial masses at birth Mi ~ 8 Mo (Mo = the solar mass) and end up exploding as supernovae (SNe) (Hansen et al. 2004). Windy massive stars with Mi >~20 Mo are an important subset, which additionally exhibit strong winds that allow them to evolve into He-burning Wolf-Rayet (WR) stars and explode as hydrogen-less type Ib/c SNe leaving behind a black hole (BH) in most cases (or complete explosions as pair-instability supernovae for the most massive stars). (For Mi ~ 8-20 Mo the winds are relatively weak, leading to mostly red supergiants that explode as H-rich SNe of type II with a remnant neutron star (NS).) The presence of a close companion can, via Roche-lobe overflow (RLOF, i.e. tidally induced mass flow from one star towards the other), significantly modify the evolution scenario based on single stars (Vanbeveren et al. 1998).

Massive stars represent the most luminous stellar component in the Universe and contain the furnaces in which the lion's share of heavy chemical elements are fused and ejected. Evolving rapidly, they drive the chemistry, structure and evolution of galaxies. Thus, they dominate the ecology of the Universe - not only as supernovae, but also from their strong winds if Mi >~20 Mo during their entire lifetimes - with far-reaching consequences (e.g. Maeder & Meynet 2000).

It is therefore a wonderful coincidence that the bulk of the stars in the sky for which the small 30 mm telescopes of BRITE-Constellation are best adapted, i.e. with apparent brightness down to V ~ 4 mag, are also *intrinsically* among the brightest (and if hot, massive) stars known. This is a result of the fact that because of their extreme intrinsic brightness, the spatial volume they sample down to a given apparent magnitude limit is much larger than for intrinsically fainter stars, thus more than compensating for their relatively sparse spatial density according to known luminosity and mass functions. As one goes to fainter apparent magnitudes, however, the large amounts of accumulated interstellar dust along the lines of sight in the Milky-Way plane where young, massive stars tend to lie, rapidly turn in favour of closer, intrinsically fainter stars. Massive stars also tend to have longer pulsation times (hours to months, depending on their mass and their evolutionary state) compared to less-luminous, lower-mass stars and are well suited to BRITE-Constellation's longer sampling time at the highest precision (c. 1 mmag) of the 100-minute orbital cadence for up to 6 months. These long timescales also require stability control over months or even years, something which BRITE-Constellation can do well given its wide field of view, where up to 30 bright stars can be observed simultaneously, and later inter-compared. BRITE-Constellation's niche thus clearly favours the intrinsically luminous stars, many of which are also among the most massive.

Scientific Rationale: Present Project

The main goals of this project are to take advantage of the long uninterrupted time-series one can get with BRITE (along with dual-filter information) to look for and quantify pulsation, rotation and binary properties of a viable sample of windy massive stars from the main sequence to later phases (blue supergiants = BSG, WR) before they explode as SNe. From the pulsations, we will be able to use asteroseismology to constrain their inner structure, which for massive stars is notoriously plagued by serious uncertainties in the size of their convection cores and the influence of rotation (Maeder & Meynet 2004). (Note that massive hot stars carry away energy generated in their cores by central fusion via motion of hotter gas upwards & cooler gas downwards, i.e. convection, while low-mass stars transfer their excess central-core energy via radiation. On the other hand, massive hot star cores are surrounded by radiative envelopes while low-mass stars have convective envelopes.) In this way, we can effectively follow the horizontal evolution of massive stars as they digress across the Hertzsprung-Russell diagram from H-burning to He-burning. Regarding rotation properties, it is becoming clear that some windy massive stars reveal rotating structures such as bright spots that, along with driving the ubiquitous co-rotating interaction regions (CIRs) and associated discrete absorption components (DACs), might find their origin in a relatively thin layer of subsurface convection (Cantiello et al. 2009), as might also be the case for the ubiquitous stellar-wind clumps. In the case of binaries, very common among massive stars (Sana et al. 2012), one can additionally constrain the basic properties of such stars, how they interact with one another at different orbital separations, and examine how windy massive stars in close binaries evolve from O+O through WR+O, cc+O (~10% survival rate as a bound system), cc+WR and finally to cc+cc (very rarely surviving bounded). (Vanbeveren et al. 1998; “cc” stands for compact companion, here either BH or NS.)

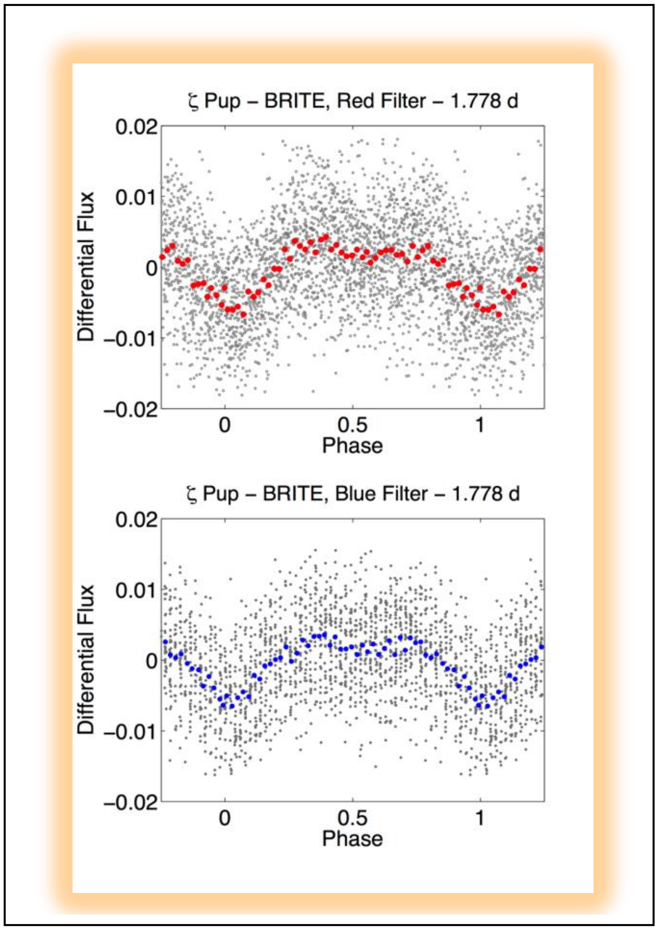
As with many modern approaches to astrophysical problems, we propose to carry out a blind, unbiased survey with no regard to previous known behavior in the selection process. (Of course, all relevant previous work will nevertheless be fully incorporated in any final publications.) To this end, we use the best appropriate archival source for bright stars, the Bright-Star Catalogue (Hoffleit & Jaschek 1991; version V online) to initially select all stars in the sky brighter than V = 4.0 (and 6.0) mag. After this first cut, we then use the most efficient way to rapidly select intrinsically massive windy stars initially above ~20 $M_{\odot}$, i.e. via their combined spectral and luminosity classes: this includes all O stars, along with all BSGs, LBVs and massive WR stars. The target information of this proposal (see Appendix) includes all 20 stars to V = 4.0 (93 to V = 6.00) that satisfy these criteria. We hope to observe a good fraction of them intensely with BRITE-Constellation during many months, and years in some cases. Along the way, we will motivate ground-based teams to obtain simultaneous spectra of high quality and cadence of the same stars.

Technical Considerations

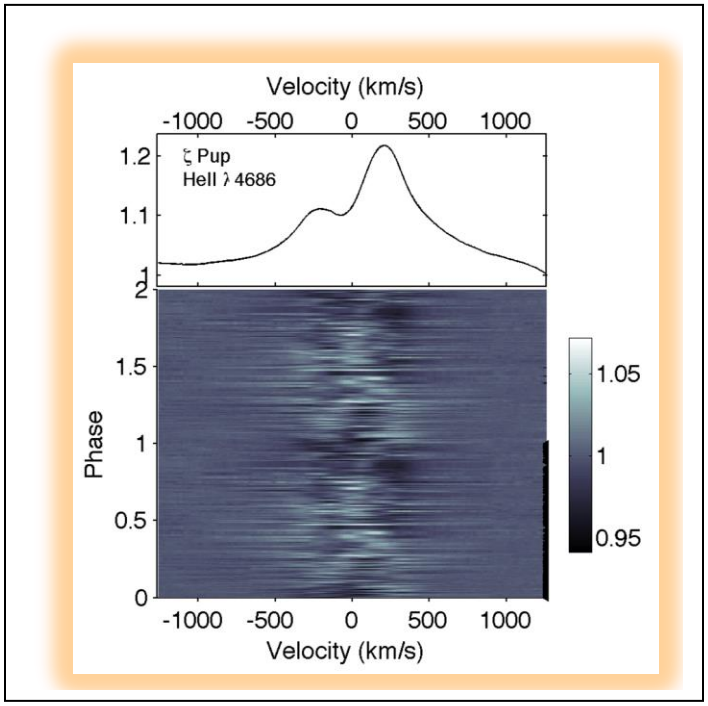
Most of the 20 windy massive stars brighter than 4^{th} mag have familiar “household” names. However, none has been scrutinized with the same photometric precision and homogeneity over as long a contiguous interval (up to 6 months, with the possibility to repeat over years) as will be possible from space with BRITE-Constellation. However, with BRITE’s typical 4 arcminute point-spread-function, some (~1/3) of the 20 (93) stars will be somewhat crowded and may be challenging to interpret.

Given their long pulsation time scales and low amplitudes, only few massive stars have been scrutinized with sufficiently precise and intense photometric data, although some interesting and unique results with respect to pulsation properties have come from monitoring selected massive stars with other previous satellites (MOST, CoRoT, Kepler). We are optimistic that a minimum photometric precision of <~0.001 mag per BRITE orbit over many months will provide adequate, perhaps in some cases even spectacular, results, especially on an unbiased sample.

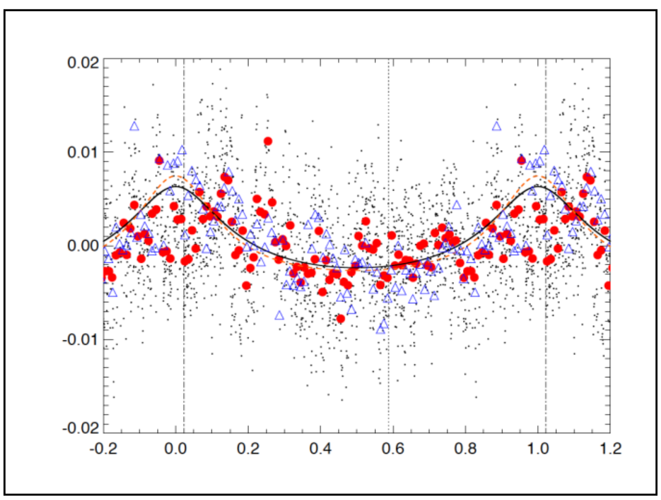
Such is already the case with BRITE for two key bright windy massive stars: the rapidly-rotating runaway single star zeta Pup, O4If(n)p, and the 78.5d elliptical binary gamma-2 Vel, WC8 + O7.5III. For zeta Pup, a clear rotational period of 1.78d (as first seen with the SMEI satellite by Howarth & Stevens 2014) with slowly evolving light-curve shape and 1% amplitude has been found (probably arising in rotating bright spots in the photosphere, with link to CIRs in the wind based on simultaneous ground-based spectroscopy), along with short-term stochastic variability at the ~1% rms level of unknown origin (Ramiaramanantsoa et al., in prep.). For gamma-2 Vel, we see orbital modulation at the 1% level going as 1/d (d is the variable orbital separation), along with short time-scale random variability (Richardson et al., in prep.).



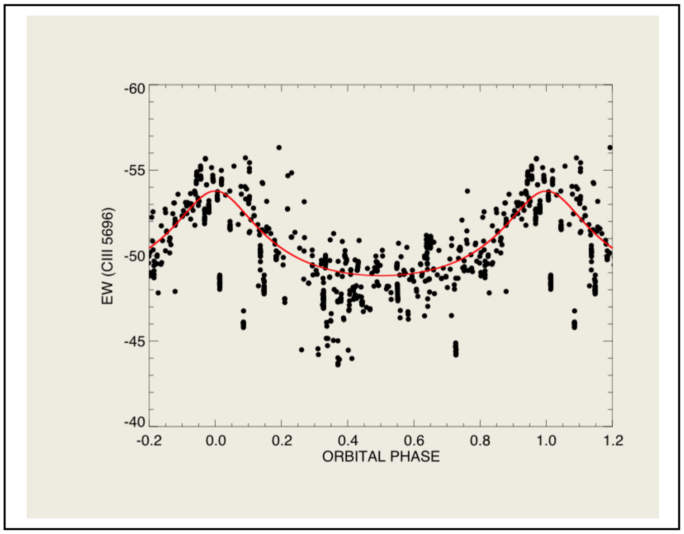
BRITE light-curve of zeta Pup in red (upper panel binned mean) and blue (lower) filters, phased to the sole clearly detected period of 1.78d. If this is the rotation period of the star, as seems likely, the two bumps (whose form changes over monthly timescales) imply two major bright spots separated by ~40% of a rotation cycle , compatible with previous findings from UV spectra regarding DACs separated by ~20h. With instrumental rms errors of 1 mmag, the large (1%) random scatter around the mean curves is highly significant and may be related to turbulent activity at the stellar surface which may ultimately drive wind clumping seen clearly in zeta Pup and all hot luminous winds.



Dynamic spectrum of zeta Pup phased with the 1.78d period (also found clearly and independently in the spectra) for the HeII 4686 emission-line, whose mean is shown in the top panel. The clear wavy structures are likely due to CIRs that are correlated with the rotating bright spots seen in the above figure.



BRITE light-curve of the 78.5d eccentric (e = 0.3) WC8 + O7.5III binary gamma-2 Vel, phased to periastron. Large red dots are bins of the smaller observed points. Vertical lines at phases 0.02 and 0.58 indicate superior and inferior conjunction, respectively, of the WR component. The curve is a 1/d fit, with d = orbital separation. This follows the same adiabatic colliding-wind trend as seen in parallel spectroscopic observations of the density-sensitive CIII 5696 line. Such a low amplitude (1%) orbital modulation has never been seen before in this star. With error bars close to 1 mmag, the remaining scatter may be related to CIRs or other effects in the WR wind.



Spectroscopic evidence of colliding winds in gamma-2 Vel, in which excess emission in the density-sensitive CIII 5696 line varies with orbital phase in a similar way as does the continuum light from BRITE. The solid curve is a 1/d fit as expected for adiabatic processes.

Given that massive stars tend to be located near their place of birth in the Galactic plane, the majority of even bright massive stars lie along the Milky Way plane. There are many areas in the sky that are rife for efficient monitoring of close to the maximum number (30) of sub-rastered fields that can be monitored with BRITE-Constellation. Furthermore, some of the 20 (for $V < 4$; 93 for $V < 6$) massive windy bright stars listed in this proposal may overlap with other more focused, specific projects being requested by other teams, but this only means that such stars have an especially wide interest. Ultimately, this should lead to collaboration among the proposing parties, which can only benefit the quality of the scientific output from BRITE-Constellation.

Photometric Data Analysis

As with MOST (which normally only observes one prime target at a time, along with as many secondary targets as are available in the surrounding ~1-degree field), for BRITE data we recommend using the usual well-developed techniques of data reduction and analysis for photometric time-series in general and for BRITE in particular. Although pipe-line reduced data are supplied by the BRITE consortium, it is then necessary for the user to clean these data up using various decorrelation techniques as outlined in an updated cookbook (see the BRITE wiki: http://brite.craq-astro.ca/doku.php). Once this is accomplished, one can begin the science, e.g. looking for periodicities, making corresponding phase-plots, etc.

Need for Parallel Ground-based Spectroscopy

While photometric monitoring especially from space allows one to easily obtain very long data-strings without long gaps that are detrimental to proper period extraction and quantifying other kinds of variability, photometry normally does not resolve the star in any way. To get around this at least partly, one often tries to secure complementary spectroscopic data, preferably simultaneous with the photometry. Radial velocities and other line-profile distortions do allow one to partly resolve the star. In addition, spectra allow one to study the physical properties in the photosphere and in the surrounding wind. Spectroscopy can be done well from the ground, using the star's continuum itself to calibrate the lines. This is even better if carried out consecutively at different sites around the globe, like a kind of poor-man's satellite bound to the Earth's surface. With BRITE one has the additional advantage that the stars are bright and can be easily accommodated spectroscopically from the ground with relatively small telescopes. We are interested in binary as well as single stars. For this project, we strongly suggest obtaining optical spectra of as many key lines as possible in the blue-red optical region (with emphasis on the line-rich blue region between 3800 A and 4900A) with continuum S/N at least 200 and R = lambda/delta-lambda >~10 000. We have even seen amateurs reach S/N = 500 in 30 minutes at R = 10 000 for a 2nd mag star on a 30cm telescope.

One of several major observatories around the world which will join in this effort to obtain frequent ground-based spectra of windy massive stars. Jamammad Rustamov will lead in having the 2m telescope of the Shamakhy Astrophysical Observatory in Azarbaijan observe in the North down to slightly negative declinations.

Target List

Below in the Appendix we give a complete list form the Bright Star catalogue of all windy massive stars (all O & WR stars and BSGs above Mi ~ 20 Mo) sorted by increasing RA for (a) V < 4 mag and (b) 4 < V < 6 mag. Observers in the North or South can choose those targets of interest that are available to them. In order to know which stars will be observed by BRITE and when, please consult the BRITE web site http://www.brite-constellation.at/ and click on Ground Segments at the left for various options, including whom to contact for any given targets. If you would like to more formally join BRITE-Constellation GBOT (Ground-Based Observing Team), please contact the current GBOT chair Konstanze Zwintz (konstanze.zwintz@uibk.ac.at). You can also email the PI(s) of each target, as indicated on the wiki (when available). At the same time, please contact me and I will coordinate the effort.

Publication

When it comes to publishing all papers that use BRITE data, please follow the BRITE Bylaws regarding publication policy as follows:

The contact-PI of an approved BRITE target (listed on the BRITE wiki) oversees the timely analysis and dissemination of the results and should seek involvement of the BRITE executive science team. For the first publication of a data set, all voting BEST members at the time when the data were made available to the contact-PI are to be invited to participate actively as co-authors. Each publication must include the footnote "Based on data from BRITE-Constellation Consortium jointly operated by Austria, Canada and Poland." BRITE-Constellation data will be made public one year after release to the proposing team(s).

Note that all actively participating collaborators will be co-authors of any publications that arise from this project.

References

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Maeder, A., Meynet, G. 2004, A&A, 422, 225
Sana, H., et al. 2012, Science, 337, 444
Vanbeveren, D., Van Rensbergen, W., De Loore, C. 1998, The Brightest Binaries (Dordrecht: Kluwer)

Appendix:

Tables of bright windy massive stars with Mi > ~20 Mo

(a) V < 4 mag

HR	Name	HD	ADS	VarID	RAJ 2000	DEJ2000	Vmag	B-V	Sp Type	P	e	Rem.
1203	44 Zet Per	24398	2843	1397	03 54 07.9	+31 53 01	2.85	0.12	B1Ib			
1713	19 Bet Ori	34085	3823	1882	05 14 32.3	-08 12 06	0.12	-0.03	B8Ia			
1852	34Del Ori	36486	4134	Del Ori	05 32 00.4	-00 17 57	2.23	-0.22	O9.5II			
1879	39Lam Ori	36861	4179	2240	05 35 08.3	+09 56 03	3.54	-0.18	O8III((f))			
1899	44Iot Ori	37043	4193	2334	05 35 26.0	-05 54 36	2.77	-0.24	O9III			
1903	46Eps Ori	37128		Eps Ori	05 36 12.8	-01 12 07	1.70	-0.19	B0Ia			
1931	48Sig Ori	37468	4241		05 38 44.8	-02 36 00	3.81	-0.24	O9.5V			
1948	50Zet Ori	37742	4263	2553	05 40 45.5	-01 56 34	2.05	-0.21	O9.7Ib			
2004	53 Kap Ori	38771		2641	05 47 45.4	-09 40 11	2.06	-0.17	B0.5Ia			
2653	24 Omi2CMa		53138		07 03 01.5	-23 50 00	3.02	-0.08	B3Iab			
2827	31 Eta CMa		58350		07 24 05.7	-29 18 11	2.45	-0.08	B5Ia			
3165	Zet Pup	66811			08 03 35.1	-40 00 12	2.25	-0.26	O5f			
3207	Gam 2Vel	68273		Gam 2Vel	08 09 32.0	-47 20 12	1.78	-0.22	WC8+O9I			
3940	Phi Vel	86440			09 56 51.8	-54 34 04	3.54	-0.08	B5Ib			
4133	47Rho Leo	91316		Rho Leo	10 32 48.7	+09 18 24	3.85	-0.14	B1Ib			
6175	13 Zet Oph		149757	Zet Oph	16 37 09.5	-10 34 02	2.56	0.02	O9.5Vn			
6462	Gam Ara	157246			17 25 23.6	-56 22 39	3.34	-0.13	B1Ib			
6714	67 Oph	164353	10966		18 00 38.7	+02 55 54	3.97	0.02	B5Ib			
6743	The Ara	165024			18 06 37.9	-50 05 30	3.66	-0.08	B2Ib			
6812	13 Mu Sgr	166937	11169	Mu Sgr	18 13 45.8	-21 03 32	3.86	0.23	B8Iap			

(a) 4 < V < 6 mag

HR	Name	HD	ADS	VarID	RAJ 2000	DEJ2000	Vmag	B-V	Sp Type	P	e	Rem.
130	15 Kap Cas		2905	Kap Cas	00 33 00.0	+62 55 54	4.16	0.14	B1 Ia			
589	53 Cas	12301			02 03 00.3	+64 23 24	5.58	0.38	B8Ib			
1035		21291	2544	1152	03 29 04.1	+59 56 25	4.21	0.41	B9Ia			
1228	46 Xi Per	24912		Xi Per	03 58 57.9	+35 47 28	4.04	0.01	O7.5III(n)((f))			
1542	9 Alp Cam	30614			04 54 03.0	+66 20 34	4.29	0.03	O9.5Ia			
1712		34078	3843	AE Aur	05 16 18.2	+34 18 43	5.96	0.22	O9.5V			
1804		35600			05 27 08.3	+30 12 31	5.74	0.16	B9Ib			
1843	25Chi Aur	36371			05 32 43.7	+32 11 31	4.76	0.34	B5Iab			
1895	41 The1 Ori	37022	4186	2294	05 35 16.5	-05 23 23	5.13	0.02	O6p			
1897	43The2 Ori	37041	4188	2320	05 35 22.9	-05 24 58	5.08	-0.09	O9.5Vp			
1996	Mu Col	38666		2630	05 45 59.9	-32 18 23	5.17	-0.28	O9.5V			
2135	62Chi2 Ori	41117		2809	06 03 55.2	+20 08 18	4.63	0.28	B2Ia			
2173	3 Gem	42087	4751	2846	06 09 44.0	+23 06 48	5.75	0.21	B2.5Ib			
2409	46769				06 35 15.8	+00 53 24	5.80	0.00	B8Ib			
2456	15 Mon	47839	5322	SMon	06 40 58.7	+09 53 44	4.66	-0.25	O7V((f))			
2781	29 CMa	57060		UW CMa	07 18 40.3	-24 33 32	4.98	-0.15	O7Ia:fp			
2782	30 Tau CMa	57061	5977	3528	07 18 42.4	-24 57 15	4.40	-0.15	O9Ib			
3090		64760			07 53 18.2	-48 06 11	4.24	-0.14	B0.5Ib			
3203		68161			08 09 09.6	-48 41 04	5.70	-0.12	B8Ib-II			
3456		74371			08 41 56.9	-45 24 39	5.23	0.21	B6Iae			
3494		75149			08 46 30.6	-45 54 46	5.46	0.27	B3Ia			
3654		79186		GX Vel	09 11 04.4	-44 52 05	5.00	0.23	B5Ia			
3708		80558	4454		09 18 42.2	-51 33 38	5.87	0.54	B6Iae			
4198		92964	4948		10 42 40.6	-59 12 57	5.38	0.26	B2.5Iae			
4250		94367			10 52 30.9	-57 14 26	5.25	0.16	B9Ia			
4338		96919		V371 Car	11 08 34.0	-61 56 50	5.13	0.22	B9Ia			
4887		111904	6008		12 53 21.8	-60 19 43	5.76	0.33	B9Ia			
4890	Kap Cru	111973			12 53 49.1	-60 22 37	5.90	0.20	B5Ia			

4908		112244	6024		12 55 57.0	-56 50 10	5.32	0.01	O9.5Ib
4952	The Mus	113904		The Mus	13 08 07.0	-65 18 23	5.51	-0.02	B0Ia+WC5
5036		116084			13 22 16.2	-52 10 59	5.83	0.12	B2.5Ib
5358		125288			14 20 19.5	-56 23 12	4.33	0.12	B6Ib
5664	Del Cir	135240	6998		15 16 56.7	-60 57 27	5.09	-0.06	O8.5V
5680		135591			15 18 48.9	-60 29 47	5.46	-0.10	O7.5III((f))
6131		148379		QU Nor	16 29 42.3	-46 14 36	5.35	0.56	B1.5Iape
6142		148688	7781		16 31 41.7	-41 49 01	5.33	0.33	B1Iae
6155	Mu Nor	149038		Mu Nor	16 34 05.0	-44 02 43	4.94	0.05	B0Ia
6164		149404		V918 Sco	16 36 22.5	-42 51 32	5.47	0.40	O9Ia
6187		150136			16 41 20.3	-48 45 47	5.65	0.13	O5III(f)
6188		150168			16 41 40.2	-49 39 06	5.65	-0.03	B1Iab-Ib
6219		150898			16 47 19.5	-58 20 29	5.58	-0.08	B0.5Ia
6245		151804	7992		16 51 33.7	-41 13 50	5.22	0.07	O8Iaf
6260		152234			16 54 01.8	-41 48 23	5.45	0.19	B0.5Ia
6262	Zet1 Sco	152236		Zet1 Sco	16 53 59.7	-42 21 44	4.73	0.49	B1Iape
6272		152408	8031		16 54 58.4	-41 09 04	5.77	0.15	O8:Iafpe
6334		154090			17 04 49.4	-34 07 22	4.87	0.26	B1Ia
6397		155806	8388		17 15 19.3	-33 32 54	5.53	-0.01	O7.5V[n]e
6447		156942			17 24 18.7	-60 40 25	5.77	-0.08	B8Ib-II
6523		158799			17 33 07.4	-41 10 25	5.84	0.06	B9Ib-II
6535		159176	9167		17 34 42.5	-32 34 54	5.70	0.04	O7V+O7V
6716		164402	10983	9996	18 01 54.4	-22 46 50	5.77	0.00	B0Ib
6736	9 Sgr	164794			18 03 52.4	-24 21 38	5.97	0.00	O4V((f))
6822	15 Sgr	167264			18 15 12.9	-20 43 42	5.38	0.07	B0Ia
6823	16 Sgr	167263	11191		18 15 12.9	-20 23 17	5.95	0.02	O9.5II
7589		188209		Var	19 51 59.1	+47 01 39	5.62	-0.07	O9.5Ia
7678		190603	13335	V1768 Cyg	20 04 36.1	+32 13 07	5.64	0.54	B1.5Ia
7767		193322	13672		20 18 07.0	+40 43 56	5.84	0.10	O9V
7977	55 Cyg	198478	14337	V1661 Cyg	20 48 56.3	+46 06 51	4.84	0.41	B3Ia
8020		199478			20 55 49.8	+47 25 04	5.67	0.47	B8Ia
8023		199579			20 56 34.7	+44 55 30	5.96	0.05	O6V((f))

8143	67 Sig Cyg	202850		13640	21 17 25.0	+39 23 41	4.23	0.12	B9Iab
8154	68 Cyg	203064		V1809 Cyg	21 18 27.2	+43 56 45	5.00	-0.01	O7.5III:n((f))
8209	69 Cyg	204172		14969	21 25 47.0	+36 40 03	5.94	-0.08	B0Ib
8279	9 Cep	206165		V337 Cep	21 37 55.2	+62 04 55	4.73	0.30	B2Ib
8281		206267		15184	21 38 57.6	+57 29 21	5.62	0.21	O6.5V((f))
8327		207198			21 44 53.3	+62 27 38	5.95	0.31	O9Ib-II
8371	13 Cep	208501	13963		21 54 53.2	+56 36 41	5.80	0.73	B8Ib
8406	14 Cep	209481		LZ Cep	22 02 04.6	+58 00 02	5.56	0.06	O9Vn
8428	19 Cep	209975		15624	22 05 08.9	+62 16 48	5.11	0.08	O9.5Ib
8469	22 Lam Cep		210839	14069	22 11 30.7	+59 24 52	5.04	0.25	O6I(n)fp
8541	4 Lac	212593			22 24 31.0	+49 28 35	4.57	0.09	B9Iab
8561	26 Cep	213087			22 27 05.3	+65 07 56	5.46	0.37	B0.5Ibe
8622	10 Lac	214680		16148	22 39 15.7	+39 03 01	4.88	-0.20	O9V
