NOAO Observing Proposal *Standard proposal* **Panel:** *For office use.*
Date: March 28, 2013 **Category:** Galactic - Other

Homogeneous and Systematic Characterization of Bright Southern Stars in Support of the BRITE Nano-Satellites

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)***:**
We propose to acquire an uniform set of high-resolution, high S/N optical spectra, using the CHIRON spectrograph on the CTIO 1.5m telescope, for ≃160 stars with V<4^{th} magnitude in the southern sky during semester 2013B. These spectra will be used to determine, in an homogeneous and systematic manner, fundamental stellar parameters for each object (*e.g.,* RVs, V sin$i$, T_{eff}, log g, [Fe/H], [Li/H] *etc*). Our proposal is part of a programmatic follow-up observing campaign of objects that are currently being observed by the two recently-launched **BRITE** (BRight Target Explorer) nano-satellites, which will photometrically measure (to, at worst, 1-mmag precision) low-level oscillations and temperature variations for all stars with V<4, specifically concentrating on the most massive and luminous pulsators.

The PI, and most co-Is, are all members of the BRITE-Constellation International Advisory Science Team, and all applicants are members of the BRITE Ground Based Observations Team. Dr. Weiss is a co-PI of the BRITE-Constellation project, and is also on its Executive Committee.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	CT-1.5m-SVC	CHIRON	3	bright	Aug - Jan	Aug - Jan
2						
3						
4						
5						
6						

Scheduling constraints and non-usable dates *(up to four lines).*

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

This year, on the 25^{th}-February, at 12:36 (UT), UniBRITE and BRITE-AUSTRIA/TUGSAT-1, two nano-satellites, were successfully launched into a Sun-synchronous, polar dawn-dusk, low earth orbit with an orbital height of about 800 km. The two (of an eventual six) BRITE (BRight Target Explorer) satellites, each with a FoV of $\simeq$ 24 degrees, will photometrically measure low-level oscillations and temperature variations in all stars brighter than V=4^{th} mag. Each target field will be observed for a minimum of 15-minutes during the 100-minute orbit, which will yield a maximum point-to-point scatter of 1-mmag for all stars brighter than V=4^{th} magnitude.

The primary science drivers for these nano-satellites, which in post-launch commissioning tests are already attaining 1-mmag precision for V<4^{th} objects, are to study brightness oscillations and enable asteroseismology for the most massive, luminous stars in the solar neighbourhood (see Figure 1). Considering the typical time scales for their variability ranging from a few hours to several days, or even weeks, and aiming for a frequency resolution sufficient for asteroseismology, such stars will be continuously observed for at least three months per year of the 3-year mission. The in-flight performance is currently outstanding, and beating specification considerably, which will further allow the following secondary science programs to be vigorously pursued.

- Planet detection around a large sample of massive stars.
- Pulsations in G and K giants.
- Study and discovery of more classical pulsating stars down to very low amplitudes.
- Study of hot, high-mass stars in nearby clusters and associations.
- Investigation of large-scale structures (e.g., star-spots) on late-type stars and their temporal evolution.
- Enlarging the base of bright, photometrically invariant stars, which can be used as photometric standards.
- Granulation signature in the Hertzsprung Russell Diagram.
- Serendipitous astrophysical events (*e.g.,* bright comets, novae, flaring of late-type stars).

A major problem with interpreting the BRITE time-series photometric data however is going to be in establishing fundamental parameters for the bright target stars. Most surprisingly, and quite unexpectedly, many of the brightest stars in the sky are actually quite poorly studied spectroscopically, and their fundamental parameters (such as T_{eff}, V sin$i$, log g, line abundances, *etc.*) are oftentimes heterogeneously measured (if at all) to relatively low accuracy and precision, using a disparate range of instrumentation and quality, and hark back to the pre-1960 (*i.e.,* photographic) era.

We propose to acquire high-resolution (R=80,000), high S/N (>>100) CTIO-1.5m+CHIRON spectra for all V<4^{th} objects, south of DEC(2000):+10^{o}, available in the 2013B-semester – some 159 stars. In an homogeneous and systematic manner, we will employ the latest suite of spectral analysis tools, *Spectroscopy Made Easy* (Valenti & Piskunov 1996; Valenti & Fischer 2005), to derive fundamental parameters (*e.g.,* T_{eff}, log g, V sin$i$, [M/H], [Li/H], [Fe/H], [Na/H]) for each of the BRITE targets in the range $7000-3500$ K. For the hotter and cooler targets (where photospheric lines are sparse and V sin$i$ are oftentimes very high, or molecular bandheads dominate cool-star spectra), we will compare their spectra to existing spectral library data (*e.g.,* UVES POP – Bagnulo et al. 2003) for a comparative derivation of stellar parameters. It is of absolute necessity to the project to characterize the fundamental nature of the BRITE photometric variables in order to properly understand their physical properties, thereby enabling calibration and constraint of stellar pulsation theory.

References:

Bagnulo, S., et al., 2003, ESO *Messeger*, 114, 10
Buchhave, L. et al., 2013, *in preparation*
Dawson, R., & Johnson, J., 2012, ApJ, 756, 122
Gustafsson, B., et al., 2008, A&A, 486, 951
Hebb, L., et al. 2009, ApJ, 693, 1920
Macqueo Chew, Y., et al. 2013, ApJ, 2013, *accepted*; http://arxiv.org/abs/1302.6115
Stempels, H., et al. 2007, MNRAS, 379, 773
Valenti, J., & Piskunov, N., 1996, A&AS, 118, 595
Valenti, J., & Fischer, D., 2005, ApJS, 159, 141

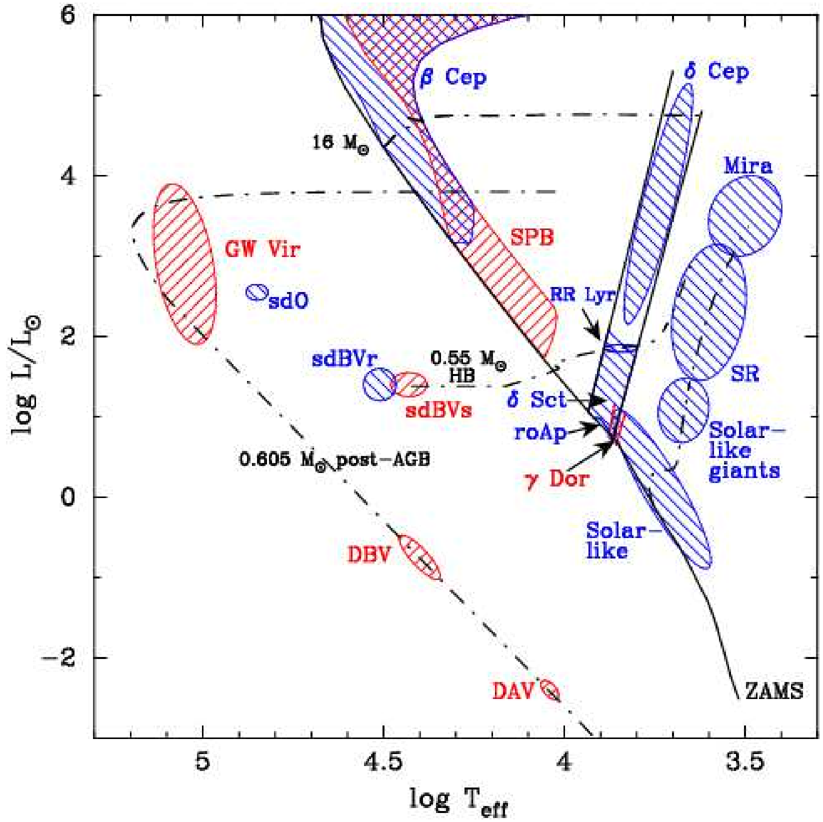

Figure 1: An Hertzsprung Russell Diagram is shown with regions of different types of pulsating star highlighted, which are the primary science targets of the BRITE nano-satellites.

Experimental Design *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science. (limit text to one page)*

We will observe each BRITE target star ($V \leq 4^{th}$; DEC(2000)$< +10^o$ and $15^{hr}<$RA$<10^{hr}$) using the CTIO-1.5m telescope with CHIRON in image slicer mode. We will require ThAr arc-lamp exposures (for wavelength calibration) about once per hour, and for the hotter targets ($T_{eff}>$7000K), a Quartz-lamp flat field exposure after the target exposure. These are necessary for the hotter targets in order to allow us to determine how to stitch-together CHIRON's multiple spectral orders (because for rapidly rotating, heavily pressure-broadened stars, stellar spectra lacking metallic lines are hard to spectrally analyze). We will use the CHIRON data reduction pipeline to obtain extracted, wavelength calibrated spectra.

Stellar parameters will be determined using an implementation of *Spectroscopy Made Easy* (SME; Valenti & Piskunov 1996). We base the general method of our SME analysis on that given in Valenti & Fischer (2005 - VF05); however, we use a line list, synthesized wavelength ranges, and abundance pattern adapted from Stempels et al. (2007) and Hebb et al. (2009), as well as incorporate the newest MARCS model atmospheres (Gustafsson et al. 2008). The details of our technique are outlined in the recent analysis of the exoplanet host WASP-13 by Maqueo Chew et al. (2013).

Briefly, we have also expanded on the technique outlined in VF05 that allows us to operate SME in an automated fashion by utilizing massive computational resources. We have developed an extensive Monte Carlo approach to using SME by randomly selecting 500 initial parameter values from a multivariate normal distribution with 5 parameters: T_{eff}, log g, [Fe/H], [M/H], and V sin$i$. We then allow SME to find a best-fit synthetic spectrum and solve for the free parameters for the full distribution of initial guesses, producing 500 best-fit solutions for the stellar parameters. We determine our final measured stellar properties by identifying the output parameters that give the optimal SME solution (*i.e.,* the solution with the lowest χ^2). The overall SME measurement uncertainties in the final parameters are calculated by adding in quadrature: 1) the internal error determined from the 68.3% confidence region in the χ^2 map, and 2) the median absolute deviation of the parameters from the 500 output SME solutions to account for the correlation between the initial guess and the final fit. Based on previous analysis, spectra with resolutions of R$\simeq$70,000 and SNR$\simeq$200 result in stellar parameters with $\sigma_{T_{eff}}\sim$50 K, $\sigma_{log\ g}\sim$0.05, $\sigma_{[Fe/H]}\sim$0.05, and $\sigma_{V\ sin\ i}\sim$0.05 km s^{-1}. Our technique also allows us to determine stellar properties while placing priors on constrained parameters. Several of the stars included in this proposal will have *a priori* determination for some of their properties due to their proximity (*e.g.,* stellar radius constrains from interferometric and astrometric observations), including photometric and spectral-type log g estimates, which are typically difficult to constrain from spectral synthesis alone.

For the hotter targets, with $T_{eff} > 7000$ K, we will match our spectra to existing spectral library data (*e.g.,* UVES POP) using the SPC spectral matching software (Buchhave et al. *in prep.*) and/or SpecMatch (Dawson & Johnson 2012). These algorithms use a grid of spectra (SPC uses a theoretical grid, SpecMatch an empirical grid) to determine the *best* spectral match using various *amoeba* algorithms.

We have acquired the large computational resources necessary for our technique through the NSF funded XSEDE, the NSF-funded super-computing system. Our team has been allocated an initial 100K CPU hours on the Stampede facility at the Texas Advanced Computing Center to carry out SME analysis for targets of interest. We will use a proportion of this allocation for this proposed stellar characterization analysis.

Proprietary Period: 18 months

Use of Other Facilities or Resources *(1) Describe how the proposed observations complement data from non-NOAO facilities. For each of these other facilities, indicate the nature of the observations (yours or those of others), and describe the importance of the observations proposed here in the context of the entire program. (2) Do you currently have a grant that would provide resources to support the data processing, analysis, and publication of the observations proposed here?"*

Spectroscopic follow-up of the northern BRITE sample is currently being pursued using:

- HERMES échelle spectrograph at the 1.2m Mercator Telescope on La Palma Island, Canary Islands, Spain (PI: P. Beck: Institute of Astronomy, KU Leuven). The spectra to be acquired, and their analysis are identical to those being proposed herein. The PI and each of the co-Is are being funded through their host institution.
- Sandiford échelle spectrograph at the McDonald Observatory 2.1m telescope, Texas (PI: G. Handler, Copernicus Astronomical Center, Warsaw). The spectra to be acquired, and their analysis are identical to those being proposed herein. The PI and each of the co-Is are being funded through their host institution.

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the PI during the last 2 years for regular proposals, and at any time in the past for survey proposals (including participation of the PI as a Co-I on previous NOAO surveys), together with the current status of the data (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal. Please include original proposal semesters and ID numbers when available.*

2011B-0322: Title: *A comprehensive radial-velocity survey of the two canonical Southern open clusters NGC 2516 and NGC 3532*: PI: Geller, A; co-I James, D.: 6-nights awarded. Data reductions completed, RV-curves analyzed, paper *in prep.*

2012B-3013: DECam-SV: Title: *Multi-epoch Absolute and Relative Photometry in one of the DES-footprint fields: Synoptic grizY Observations Centered on the Young, high-Galactic Latitude Open Cluster Blanco 1*: PI: James, D.J., co-I: Cargile, P.: 10hrs awarded. Data analysis on-going.

2012B-0569: Title: *DECam Near Earth Object Search Pilot Project*: PI: Allen, L; co-I: James, D.: 4-half nights awarded. Data analysis on-going.

2013A-0494: Title: *CTIO REU/PIA Observations: Targets of Opportunity*: PI: Kaleida, C.; co-I James, D.: 8-nights awarded. Data analysis on-going.

2013A-0724: Title: *DECam Near Earth Object Search*: PI: Allen, L; co-I: James, D.: 4-nights awarded. Observations scheduled for April 2013.

2013A-0526: Title: *DECam Near Earth Object Search*: PI: Allen, L; co-I: James, D.: 4-nights awarded. Observations scheduled for May 2013.

2013A-0723: Title: *DECam Survey for Benchmark Substellar Objects in the Nearest OB Association*: PI: Mamajek, E; co-I: James, D.: 2-nights awarded. Observations scheduled for May 2013.

Observing Run Details for Run 1: CT-1.5m-SVC/CHIRON

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for queue and Gemini runs).*

We will use CHIRON in Normal Mode, fast CCD readout (14-secs), with the image slicer and 3x1 binning, with the full wavelength (fixed) coverage of 4100-8700Å, which yields a spectral resolution of R=80,000.

Our stars are all brighter than V=4^{th} magnitude, and cover practically the entire spectral range for dwarfs and giants. Exposure times are estimated from A. Tokovinin's CTIO CHIRON webpages, are set to ensure S/N per resolution element of >>100, and will be fixed at 60-seconds for $3 < V < 4$ stars, 25-seconds for $2 < V < 3$, 10-seconds for $1 < V < 2$ stars, and 5-seconds for all brighter objects.

One could argue formally, in good seeing and transparency conditions, that these exposure times are over-estimated by perhaps $15 - 20\%$ – it is hard to read the exact value of the Texp vs SNR graphs (http://www.ctio.noao.edu/noao/content/chiron-overview). But given that we expect slew-and-acquire overheads of about eight (8) minutes per target, there seems little point on skimping on 5-10 seconds here and there, when the dominant time expenditure is slew-and-acquire overhead for our bright objects. This is especially true seeing as we desire as high a S/N as possible for the targets in order to perform SME spectral synthesis fits of the highest quality.

During the course of the program, standard star observations will be required to allow spectroscopic calibration of the entire dataset. At least three radial velocity standards of differing spectral types, three telluric standards (rapidly rotating B-stars, observed at low, medium and high airmass), and three magnetic activity minimum late-type stars (one early-G, early-K and early-M star, all to be slowly rotating) should also be observed. A high S/N, trailed exposure of the Moon will suffice for the early-G star.

We will also observe the eight (8) stars in common to our current BRITE sample and the Valenti & Fischer (2005) SPOCS program, for which they derive excellent-quality stellar parameters through SME fitting. This will allow us to cross-calibrate our own SME analysis, giving us a measure of the accuracy and precision of our own SME results.

If we assume 10-minutes of observation per star (includes slew-and-acquire overhead), for the 176-star target list (159-BRITE stars, 9-RV/telluric/activity standards, and 8 Valenti & Fischer SME stars), our total requested time for this proposal is 1760 minutes, or 29.33 hours.

FYI: Only five presentative stars of the 159 BRITE targets are shown in the Targets Table.

Instrument Configuration

Filters:	Slit: Fibre/Image Slicer	Fiber cable:
Grating/grism: echelle	Multislit: no	Corrector:
Order: fixed	λ_{start}: 4100	Collimator:
Cross disperser: fixed	λ_{end}: 8700	Atmos. disp. corr.:

R.A. range of principal targets (hours): 15 to 10

Dec. range of principal targets (degrees): +10 to -90

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

Target Table for Run 1: CT-1.5m-SVC/CHIRON

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment
1	HR 7150	18:57:43.8	-21:06:24.0	2000.0	3.53		60	1	14	spec	1.2-1.5	G8III
2	HR 3485	08:44:42.2	-54:42:31.8	2000.0	1.95		10	1	14	spec	1.2-1.5	A1V
3	HR 8698	22:52:36.9	-07:34:46.6	2000.0	3.77		60	1	14	spec	1.2-1.5	M2III
4	HR 338	01:08:23.0	-55:14:44.7	2000.0	3.97		60	1	14	spec	1.2-1.5	B6V+
5	HR 1336	04:14:25.5	-62:28:25.9	2000.0	3.34		60	1	14	spec	1.2-1.5	G8II-III

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