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Triennial Report of Division G Working Group on Active B Stars, 2015 - 2018

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1. Introduction

The Working Group on Active B Stars (WGABS, formerly Working Group on Be Stars) was re-established under IAU Commission No. 29 in 1979 to promote and stimulate research and international collaboration in the field of active B stars. The focus of the WG has increasingly shifted from Be stars to all types of active B stars including topics such as mass loss and accretion, pulsations, rotation, magnetic fields, and binarity, X-ray phenomena, fundamental parameters, and to promote collaboration and interaction between scientists specializing in these studies. Please see our website for more information.

http://activebstars.iag.usp.br/bstars/index.php
We note that our website fell victim to a cyber attack and it took some time to make the site available again. We are also working to find an appropriate forum to share our Newsletter, suitable for modern scientific communication.

The WGABS is open to all researchers interested in the field. Currently there are 120 members of WG Active B stars under Division G Stars and Stellar Physics.

2. Developments within the past triennium

2.1. *Meetings held in the reporting period*

In the reporting period, the active B star community engaged, among others, in the following meetings.

• BRITE-Constellation consists of five nano-satellites that can acquire very high precision photometry of luminous stars over an significant uninterrupted period. Active B stars, owing to their relative brightness and variation properties, are well suited science objects for the observational capabilities of the BRITE project, and BRITE data is available for dozens of emission-line B stars and pulsating B stars, as well as several magnetic B stars. BRITE science group meetings were held in 2015 in Gdansk, Poland, in 2016 in Innsbruck (Zwintz & Poretti 2017), Austria, and 2017 in Lac Taureau, Canada. In June 2017, the BRITE-Constellation team organized a Special Session "Science with the BRITE-Constellation nano-satellite photometry mission" at the European Week of Astronomy and Space Science, EWASS 2017 in Prague. Participants at all four meetings delivered presentations about active B stars including invited reviews.

• A meeting fully dedicated to another sub-group of active B stars, the B[e] stars, was held in 2016 in Prague under the title "The B[e] Phenomenon: Forty Years of Studies" (Miroshnichenko et al. 2017a). It was the third meeting on studies of the group since its discovery in 1976 and has gathered 78 people from over 20 countries. New results on all sub-groups of objects with the B[e] phenomenon which include B[e] supergiants, Herbig Ae/Be stars, proto-planetry nebulae, symbiotic binaries, and FS CMa type objects (a group of possible binaries, whose circumstellar envelopes are created at a stage of rapid-mass transfer) and related objects (e.g., Be stars) were presented. Talks included information on long-term projects of spectroscopic and photometric observations, such as SDSS-IV and observing programs at individual observatories (e.g., Ondřejov, Observatorio Astronómico Nacional San Pedro Martir) where a number of new B[e] objects have been discovered (e.g., Miroshnichenko et al. 2017b). An overview of the current state of investigation of individual sub-groups of B[e] objects and suggestions for further observations can be found in several papers published after the Prague meeting (e.g., Korčáková et al. 2017; van Winckel 2017; Maravelias et al. 2017).

• In March 2017, a conference on "Phenomena, Physics, and Puzzles of Massive Stars and their Explosive Outcomes" was held at the Kavli Institute for Theoretical Astrophysics, as part of a three month long program on "The Mysteries and Inner Workings of Massive Stars". Presentations on Be stars were invited to both events since their evolution gives clues on the mixing of both chemical elements as well as the angular momentum inside the star at the highest rotation rates.
https://www.kitp.ucsb.edu/activities/stars17

• In August 2017, the meeting Stars with a stable magnetic field: from pre-main sequence to compact remnants was held in Brno, Czech Republic. There were 80 participants and the proceedings were published in Contributions of the Astronomical Observatory Skalnaté Pleso, 2018, Volume 48, Number 1. Researchers with a variety of interests such as the fields of Molecular Clouds, PMS, classical CP stars, (sub)giants to neutron stars and white dwarfs came together. Magnetic fields were uniting astrophysical property. Both theoretical and observational aspects were discussed together with the future prospects of new instruments and space based missions. The continuous evolutionary connections of the magnetic field stability from the PMS to the WD regime was noted as a promising research area for the future.

• In September, 2017 the third meeting in the series about Be/X-ray binaries was held in Heraklion. This meeting represented follow-up from the previous meetings that occurred in July of 2011 and 2014. In addition to topics focusing on high-energy properties of these systems, there were sessions and talks about Be stars, Be disks and modeling in the context of explaining the BeXRB phenomenon. Sessions included participants from the traditional classical Be star community.

• The spectroscopic data archive on Be stars, BeSS, was the focus of a small workshop hosted in Paris at the Meudon observatory, in October 2017, that brought together professional and amateur astronomers to maximize the scientific outcome obtained from amateur observations. One of the outcomes of the meeting was that the participants agreed to enlarge the BeSS catalog (so far containing only classical Be stars and Herbig Be stars) to include other B stars with emission, in particular B[e] supergiants and magnetic B stars with emitting magnetospheres. A second spectroscopic data archive became available online recently, focusing on Southern Be stars observed at the Universidad de Chile in the BeSOS survey (Arcos et al. 2018).

• A new database was just released to the public with the results of a 12-year long polarimetric survey of about 70 bright Be stars (the BeACoN survey). The survey, which is still ongoing, is being conducted at the Pico dos Dias Observatory, Brazil. The data is available at the BeACoN website: http://beacon.iag.usp.br. Researchers are encouraged to submit requests for observations of new targets brighter than $V = 10$.

2.2. *Upcoming Events*

• IAU Symposium 346 "High mass X-ray binaries" to be held in August 2018 in Vienna will feature a session on Be stars, including an invited review, as these rapidly rotating massive stars are possible progenitor objects for BH-mergers. If chemically homogeneous evolution does exist, the consequences of one of the potential formation paths of close BH binaries, should be observable in Be stars.

• The nature of the massive Be star with strong and hard X-ray emission, γ Cassiopae, remains enigmatic. In the last decades it became clear, that γ Cas is a prototype for a whole new class of stars - there may be thousands of γ Cas analogues lurking in the Galaxy. "The γ-Cas phenomenon in Be stars" workshop to be held in September 2018 in Strasbourg. The goal of the workshop is to obtain a comprehensive overview of γ Cas analogues, review existing theoretical scenarios on the origin and physics of these objects, and pave new ways to finally resolve the γ Cas puzzle.

2.3. *Scientific highlights*

New investigations reported in the literature reveal the study of active B stars as an active and productive area of research that is providing new scientific results. In this report we focus on five main topics discussed in the subsections below.

2.3.1. *Satellite Observations: BRITE and CoRoT*

Baade et al. (2016) used the BRITE Constellation of nanosatellites to document the millimagnitude variations in the Be stars η and μ Cen. They compared the variability of the former to contemporary spectroscopy and found a link between the Hα emission and the frequencies of two modes of nonradial pulsation. In a similar investigation of the Be star 28 Cyg, they find evidence that the difference-frequency variability is related to the modulation of the star-to-disk mass transfer. These investigations indicate that the combination of fast rotation and pulsational beating may be the basic requirements to eject gas into a circumstellar disk. The article, (Baade et al. 2017), entitled, BRITEning up the Be Phenomenon, expands on previous work with the study of 25 Ori and discusses remaining questions.

The CoRoT (Convection, Rotation and planetary Transits) satellite which allows a sample of stars observed with seismology tools is providing impactful results for the study of Be stars. See for example, https://doi.org/10.1051/0004-6361/201629243.

2.3.2. *Ground-Based Observations: Interferometry, photometry, spectroscopy*

Interferometric investigations of Be disks continues in work at the CHARA Array, the VLT Interferometer, and the Naval Precision Optical Interferometer. An important case study of o Aqr by Sigut et al. (2015) uses Hα spectroscopy and NPOI interferometry to model the physical parameters of the Be decretion disk.

Be star photometric variability has been investigated with the KELT transit survey, with a typical cadence of 30 minutes, a baseline of up to 10 years, photometric precision of about 1%, and coverage of about 60% of the sky. Labadie-Bartz et al. (2017) present KELT light curves of 610 known Be stars, and discuss the nature of the ubiquitous variability. This includes variability associated with non-radial pulsations (25%), outbursts (36%), and long-term trends in the circumstellar disk (37%).

Chojnowski et al. (2015) provide an in-depth exploration of the near-infrared spectra of 238 Be stars from the APOGEE survey. This spectral region is dominated by features that originate in Be star disks, so time series H-band spectroscopy provides an important documentation of disk growth and decay cycles, as described in Chojnowski et al. (2017).

Arcos et al. (2017) present some of the first results from the Be Stars Observation Survey (BeSOS; besos.ifa.uv.cl), a high dispersion optical survey of southern sky Be stars. They use the BEDISK and BERAY codes by Sigut to model the Hα emission and derive disk masses. Their work shows that the specific angular momentum of the disks increases in more massive stars as would be expected if the disk radius scales with the stellar radius.

2.3.3. *Disk structure*

The disk growth and dissipation processes are examined in detail in a key paper by Vieira et al. (2017) through model fits of the infrared continuum excess. They find that the mass loss rates range between 10^{-12} and 10^{-9} $M_\odot$ yr^{-1}. Furthermore, their work suggests that mass injection episodes may often be shorter than the longer mass dissipation processes.

Carciofi et al. (2012) were the first to show that light curves of Be stars can be used to track the dynamics of the gas in order to determine two key parameters of the disk that otherwise would be very hard to probe: the bulk viscosity of the gas (the so-called α parameter, Shakura & Sunyaev 1973), and the mass decretion rate through the disk. Rímulo et al. (2018) used this principle to study 81 disk events (here understood as the formation of a new disk around a previously naked Be star, followed by its dissipation) of 54 Be stars the LMC. They found that the values of α are typically of a few tenths, and α is systematically larger during the disk formation phase than during its dissipation. The authors also measured the rate at which angular momentum is lost by the central star, and found it to be at least one order of magnitude smaller than the predictions of the Geneva evolutionary models (Granada et al. 2013), a discrepancy that is still unexplained and may trigger a revision of the models. These two results indicate that Be stars are laboratories for phenomena (mass and angular momentum transport inside fast-spinning stars and the value of viscosity, in this example) that may have broad impact in other astrophysical areas of interest. In order to deal with the large number of lightcurves as automatically and homogeneously as possible, Rímulo et al. developed a pipeline that combines a pre-computed model grid with Markov Chain Monte Carlo fitting schemes. The pipeline is now being applied to lightcurves in the LMC (data from OGLE survey) and the Galaxy (data from the KELT survey).

2.3.4. *Be/Xray, γ Cas anologues and binary systems*

Peters et al. (2016) show that in the case of the extreme Be star HR2142 that a low mass companion forms a gap in the disk and that gap-crossing gas is seen in shell episodes near the orbital phase when the companion is in the foreground.

Rapidly rotating B stars may be formed through redistribution of angular momentum near the terminal age main sequence (Granada & Haemmerlé 2014) or through mass and angular momentum transfer in an interacting binary star (Shao & Li 2014). The latter process will strip the mass donor star of its envelope, revealing the stripped down He core. Such companions are faint and low mass, and thus hard to detect. However, they are also very hot, so that their detection is favored at shorter wavelengths in the ultraviolet region. He-star companions have recently been detected in archival IUE spectra of HR2142 (Peters et al. 2016) and 60 Cyg (Wang et al. 2017), and many more await discovery (Wang et al. 2018). Mourard et al. (2015) used the CHARA Array interferometer to detect and map the orbit of the hot companion of ϕ Per, and their work demonstrates that the Be disk gas orbits in the same sense as the orbit, as predicted if the high angular momentum of the Be star originated in the orbital angular momentum of the mass donor star. The detected hot companions may represent the brightest cases that are experiencing He-shell burning (Schootemeijer et al. 2018), and there may be many fainter companions like those orbiting the late B-type rapid rotators β CMi (Dulaney et al. 2017) and KOI-81 (Matson et al. 2015).

Be disks are subject to several kinds of disk instabilities that may result in the formation of large scale structures. Panoglou et al. (2016) explore physical models of such disk structures for Be stars with a binary companion. In many such cases, the tidal action of the companion may excite a spiral wake in the disk, and these density enhancements create emission lines that vary in shape with the orbital period.

In a follow-up paper, Panoglou et al. (2018) showed that the binary-induced perturbations of the disk cause V/R variations on the H emission lines that are locked in phase with the orbital period. The binary-origin of some of the V/R variability observed in Be stars has long been postulated in the literature, and only after 3-D hydrodynamics was combined with 3-D radiative transfer this was finally confirmed.

A great deal of activity has been carried out on the so called γ Cas stars (O9.7e-B1.5e IV-V). These are stars with markedly high X-ray luminosity, X-ray variability, and a hard spectrum. Most but not all research has been designed in order to determine the source of the X-rays. See Smith et al. (2016) for a review of γ Cas stars in the context of their anomalous X-ray emission.

Some recent important results on individual and sub-groups of B[e] objects include the following. Forbidden emission line of [Ca II] at 7291 and 7324 Å were found in the spectra of B[e] supergiants and suggested to be signs of the presence of dense disks around high-luminosity B[e] objects (Aret et al. 2016). Spectroscopic data taken for the second brightest B[e] object, HD 50138 (V ∼6.6 mag), during the last 20 years showing complicated variations were summarized in Jeřábková et al. (2016). A changing structure of the circumstellar disk of this object was detected with the PIONEER instrument at VLTI by Kluska et al. (2016). de la Fuente et al. (2015) found two B[e] objects in Galactic clusters, suggested that they are more likely related to the FS CMa group, and proposed that they were formed by star mergers. Orbital periods were measured in two FS CMa objects, MWC 728 (27.5 days, Miroshnichenko et al. 2015) and AS 386 (131.3 days, Khokhlov et al. 2018, ApJ, in press). The latter one most likely contains a black hole as a secondary component.

2.3.5. *MiMeS and BinaMIcS*

The MiMeS (Magnetism in Massive Stars, Wade et al. (2016b) project showed that ∼7% of O and early B stars are magnetic (Grunhut & Neiner 2015; Grunhut et al. 2017). These statistical results qualitatively agree with the 5-10% incidence rate reported historically for the Ap/Bp stars, confirming a similar mechanism for the magnetic field generation: a fossil field (Neiner et al. 2015c). There are 2 exceptions to this rate: 100% of the Of?p stars are magnetic, and none of the classical Be stars studied by MiMeS has been found to host a detectable magnetic field. However, one cannot rule out very weak magnetic fields for this sample of Be stars (Wade et al. 2016a). Dedicated complementary observing programs have also been undertaken on specific groups of targets. For example, a search for the presence of magnetic fields was undertaken in particle-accelerating colliding wind binaries (Neiner et al. 2015b) and in interacting or post-interaction massive binary systems (Nazé et al. 2017). None of these groups of stars stand out as peculiar in terms of magnetic fields.

As of today, stable, organized magnetic fields are known to exist in ∼70 OB stars with a temperature hotter than or equal to 16000 K (e.g. Neiner et al. 2015a; Nazé et al. 2016; Buysschaert et al. 2017; Shultz et al. 2017, 2018). Magnetospheres present around magnetic OB stars give rise to rotational modulation of various observable quantities, such as the Hα emission (Sikora et al. 2015) or IR emission (Oksala et al. 2015).

The BinaMIcS (Binarity and Magnetic Interactions in various classes of Stars, Neiner et al. (2015d)) showed that, contrary to single OB stars, only ∼2% of massive stars in binaries are magnetic. The lack of magnetic detections in massive binary stars could be related to the formation of massive stars, in particular to the amount of fragmentation that can occur in the original molecular cloud depending on the magnetic flux (Commerçon et al. 2011). Nevertheless, some magnetic massive binaries exist and are being studied in the frame of the BinaMIcS project (e.g. Alecian et al. 2016; Landstreet et al. 2017).

3. Closing remarks

• **Future Objectives:** To expand the BeSS catalog that currently contains classical Be stars and Herbig Be stars to include other B stars with emission, in particular B[e] supergiants and magnetic B stars with emitting magnetospheres.

• The last decade saw a large increase in the complexity of physical models and simultaneous advancements in observations for active B stars. A 10,000 core cluster, currently in development, at the Astronomy Department of the Universidade de São Paulo will be operating in 2019. This cluster will provide a major step forward in the ability to model the circumstellar material around active B stars.

WGABS main goal is to promote research and collaboration in the field of Active B-type stars. The phenomena that occurs within the B-type stars is unique and different from the more massive O-type stars and our group, therefore, provides an important forum for researchers in this area. With our website now up and running, we expect the activities in this area to continue to ramp up.

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