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Spectroscopic studies of Galactic classical Be stars using Indian optical telescope facilities

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aries

3rd BINA WORKSHOP

Scientific potential of the Indo-Belgian cooperation

Graphic Era Hill University, Bhimtal

22-24 March, 2023

Azadi Ka Amrit Mahotsav

MISSION
CHRIST is a nurturing ground for an individual's holistic development to make effective contribution to the society in a dynamic environment

VISION
Excellence and Service

CORE VALUES
Faith in God | Moral Uprightness
Love of Fellow Beings
Social Responsibility | Pursuit of Excellence

Emission-line stars

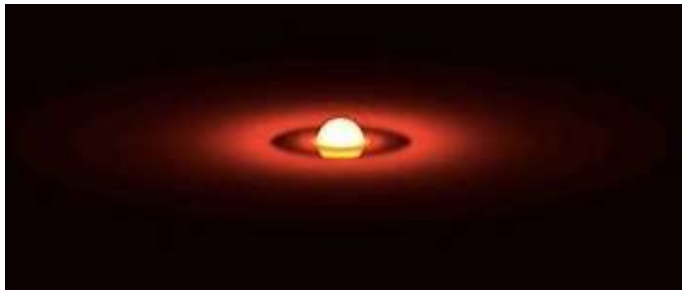
- Classical Be
- Herbig Ae/Be
- T Tauri
- Classical Ae
- Oe/ Of, etc.

Credit: Bill Pounds (http://www.limber.org/sts98/)

- A surrounding disc of mostly gas and dust orbits these stars
- **Emission lines are produced from this disc**

Introduction: classical Be stars

- Massive B-type main sequence stars
- Exhibits emission line features, indicating presence of circumstellar discs (Meilland et al. 2007, Struve 1931)
- Rapid rotators (Slettebak 1982)
- Peak incidence at B2 spectral type (Banerjee et al. 2021, Arcos et al. 2017, Mathew et al. 2008, Slettebak 1982, Mermilliod 1982)
- Variability in emission lines (Carciofi et al. 2009, Porter & Rivinius 2003)



Credit: Sigut, A (Western University, Canada)

Why study Be stars?

- Natural laboratories to study stellar disc physics
- Probing rotation of stars
- Evolutionary status of Be stars – an open issue
- Better understand the ‘Be phenomenon’ - disc formation mechanism
- Discs show transient nature: less studied area

Study of Be stars using Indian facilities

- To analyze major emission lines present in a large sample of field Be stars

- To study the disc opacity in field Be stars considering the effect of extinction parameter

- To understand the Ca II triplet emission line formation region in Be stars, which is an open question

- To evaluate the disc dissipation and formation timescales of Be stars using multi-epoch optical spectra

Studying Be stars: Our Team

- **Mr. Gourav Banerjee, Mr. Suman Bhattacharyya, Mr. Madhu Kashyap;** PhD scholars, Dept. of Physics & Electronics, CHRIST (Deemed to be university), Bangalore
- **Ms. Anusha R**, PhD scholar, Univ. of Western Ontario, Canada

- **Late Dr. Paul K T,** HOD, Dept. of Physics & Electronics, CHRIST (Deemed to be university)
- **Dr. Blesson Mathew,** Associate Prof., CHRIST University
- **Dr. Sreeja Kartha;** Asst. Prof., CHRIST University

- **Dr. Annapurni Subramanium,** Director, Indian Institute of Astrophysics (IIA), Bangalore

Data collection

- 118 Be stars selected from Jaschek & Egret (1982) catalog
- Obtained low resolution spectra of these 118 stars in the λλ 3800– 9000 Å during December, 2007 to January, 2009.

Observing instrument & analysis tools:

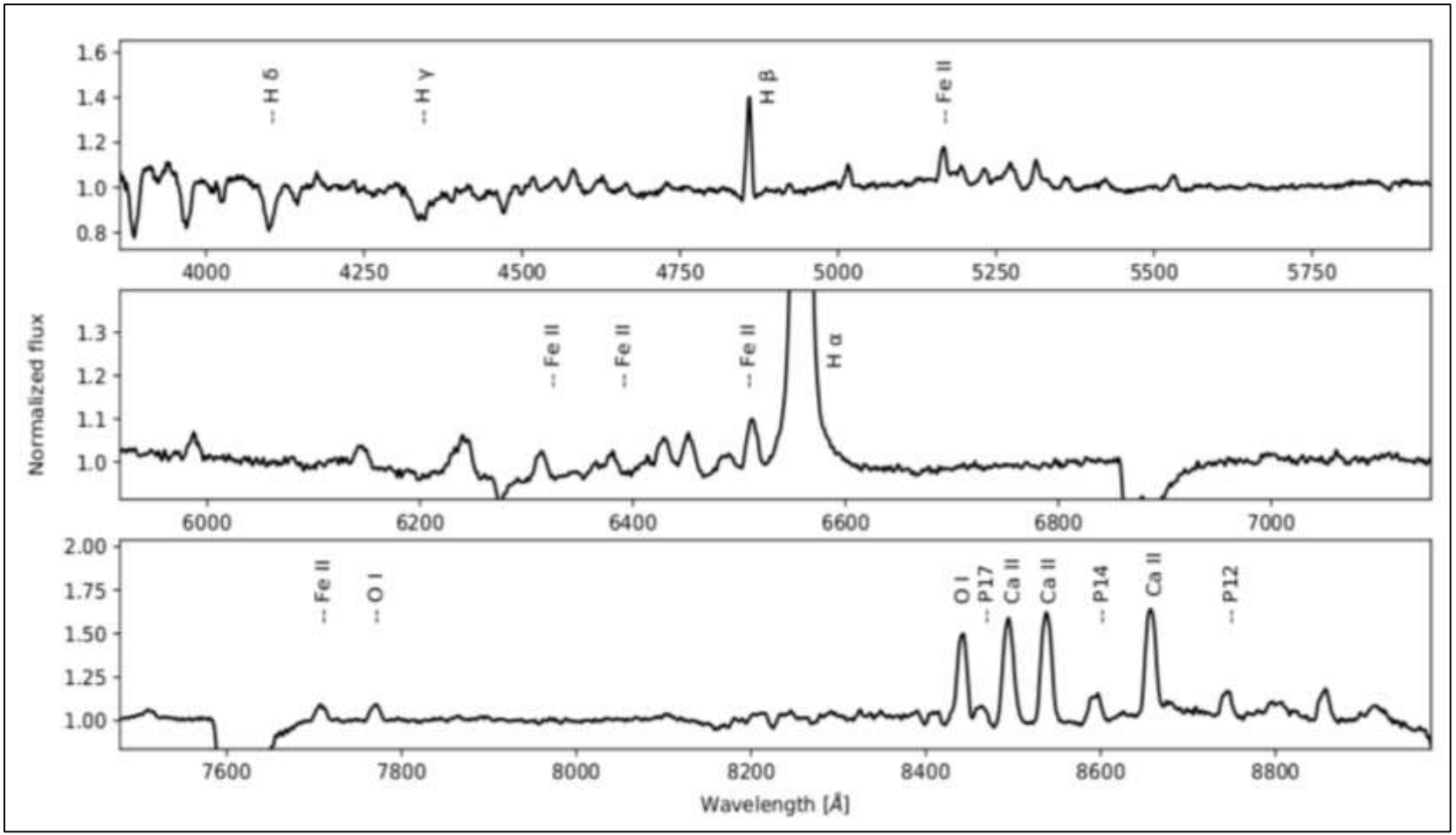
- HFOSC mounted on the 2.1-m Himalayan Chandra Telescope, located at IAO, Hanle, Ladakh
- IRAF and Python programming for analysis

Effective resolution:

- 10 Å around Hβ in the blue region (3800 Å −5500 Å)
- 7 Å around Hα in the red region (5500 Å −9000 Å)

INDIAN ASTRONOMICAL OBSERVATORY (IAO), HANLE, LADAKH

Spectral features present in optical spectra of Be stars

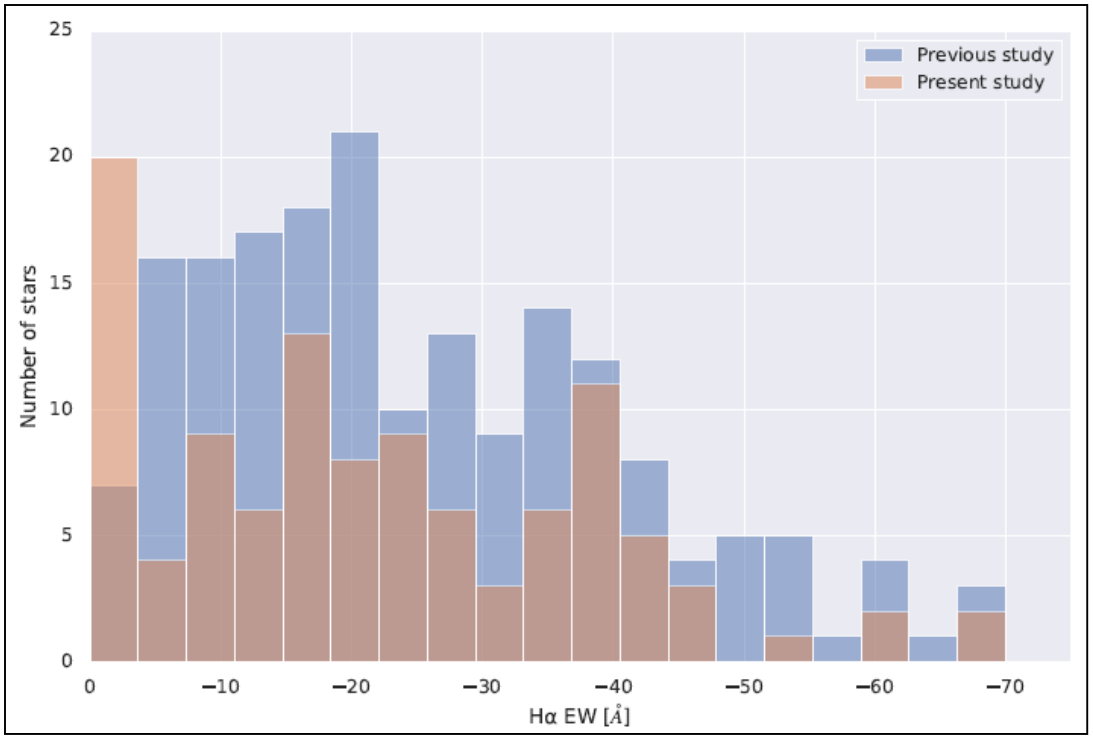


2.1-m HCT spectra of HD 55606 (Banerjee et al. 2021)

Spectral lines identification

- **Hα in emission: 114, absorption: 01 star**
- **Hβ in emission: 110, absorption: 3 stars**
- **47 (~ 40%) stars show Paschen lines in emission**
- **95 (~ 83%) stars display Fe II emission lines**
- **O I 7772 (72-74-75) Å line in emission seen in 44 cases, whereas O I 8446 Å emission line detected in 66 stars**
- **Rare He I emission lines (5876, 6678, 7065 Å) found in 13 stars**
- **Ca II triplet emission lines found in 17 stars**

Hα EW distribution of the sample Be stars



Banerjee et al. (2021)

- Selected previous studies (Barnsley & Steele 2013, Mathew & Subramaniam 2011, Slettebak et al. 1992, Hanuschik 1988, Dachs et al. 1986, 1992)
- Hα EW values for ~86% field, ~77% young and ~94% old cluster Be stars are found to be lower than -40 Å.

Balmer decrement study for the program stars

- Balmer decrements, D_{34} = I(Hα / Hβ) and D_{54} = I(Hγ / Hβ)
- Formula used (adopted from Dachs et al. 1990):

$$D_{34} = EW\ (H\alpha/H\beta) \times F_C\ (H\alpha/H\beta) \quad \text{..... (1)}$$

$$D_{54} = EW\ (H\gamma/H\beta) \times F_C\ (H\gamma/H\beta) \quad \text{..... (2)}$$

- Useful in understanding the optical thickness of Be star discs
- We considered the re-estimated A_V values for the stars to calculate the D_{34} and D_{54} values for each star
- We estimated the corrected D_{34} and D_{54} values for program stars following the method in Banerjee et al. (2021)

First study to measure D_{34} and D_{54} values for Be stars considering the effects of extinction parameter, A_V

Results

Obtained D_{34} values: 0.1 (HD 61205) -- 9.0 (HD 251726).

- Theoretically $D_{34} \sim 2.7$ for gaseous nebula (Hummer & Storey, 1987) considering T ~ 10000 K, electron density ~ $10^{9} – 10^{11}$/ cm^3

- Among our stars, 19 (~ 20%) show $D_{34} > 2.7$

Indication: Their circumstellar discs are optically thick in nature

15 among these 19 stars are reported to be of earlier spectral types (within B0 -B3)

(details in Banerjee et al. 2021)

Analysis of Ca II triplet emission lines for the sample

- Ca II triplet emission lines (8498-8542-8662 Å) are not expected to form in Be star discs
- They need a cooler region to form (T~5000K), but Be discs are hotter, T~10000 - 20000K (Mathew et al. 2012a; Sigut & Jones 2007).
- Polidan & Peters (1976) and Andrillat et al. (1988) observed Ca II lines in ~20% and ~27% among their sample stars.
- Role of binary companion proposed to explain Ca II emission lines in Be stars (Polidan & Peters, 1976), not matching with current census (Koubsky et al. 2012, Porter & Rivinius, 2003)

So, where does Ca II triplet emission originate in Be star discs?

- In low resolution spectra, Ca II emission lines get blended with P13, P15 and P16 lines.
- We noticed that P14 is the most intense line among P12 − P19 which is not affected by any other feature.
- We used this P14 emission feature to extract the Ca II emission components for 12 stars showing both Ca II and Paschen emission lines.

Ca II emission line formation region: two possibilities

- We explored various formation regions of Ca II emission lines around the circumstellar disc of Be stars (Banerjee et al. 2021)
- Our study suggests the possibility that in Be stars, Ca II triplet emission can originate either

(1) in the circumbinary disc or,
(2) from the cooler outer regions of the disc which might not be isothermal in nature.

However, 5 out of 17 stars are confirmed binaries

Hence, non-isothermal disc scenario seems to be more likely

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Optical spectroscopy of Galactic field classical Be stars

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ABSTRACT

In this study, we analyse the emission lines of different species present in 118 Galactic field classical Be stars in the wavelength range of 3800–9000 Å. We re-estimated the extinction parameter (A_V) for our sample stars using the newly available data from *Gaia* DR2 and suggest that it is important to consider A_V while measuring the Balmer decrement (i.e. D_{34} and D_{54}) values in classical Be stars. Subsequently, we estimated the Balmer decrement values for 105 program stars and found that ≈20 per cent of them show $D_{34} \geq 2.7$, implying that their circumstellar disc are generally optically thick in nature. One program star, HD 60855 shows Hα in absorption – indicative of disc-less phase. From our analysis, we found that in classical Be stars, Hα emission equivalent width values are mostly lower than 40 Å, which agrees with that present in literature. Moreover, we noticed that a threshold value of ∼10 Å of Hα emission equivalent width is necessary for FeII emission to become visible. We also observed

Reference: Gourav Banerjee et al., 2021, MNRAS, 500, 3, pp. 3926- 3943

Transient nature of Be stars

- Be stars usually exhibit variability in spectral line profiles.
- Extreme case leads to complete disappearance of Hα emission line, indicative of a disc-less state in Be stars.
- Different Be star discs show such transient nature.
- Disc formation mechanism in Be stars still poorly understood. Hence, no clear idea about disc formation and dissipation timescales.
- However, **disc loss and reappearing phases of Be stars can be identified** by studying their Hα line profiles on a regular basis.

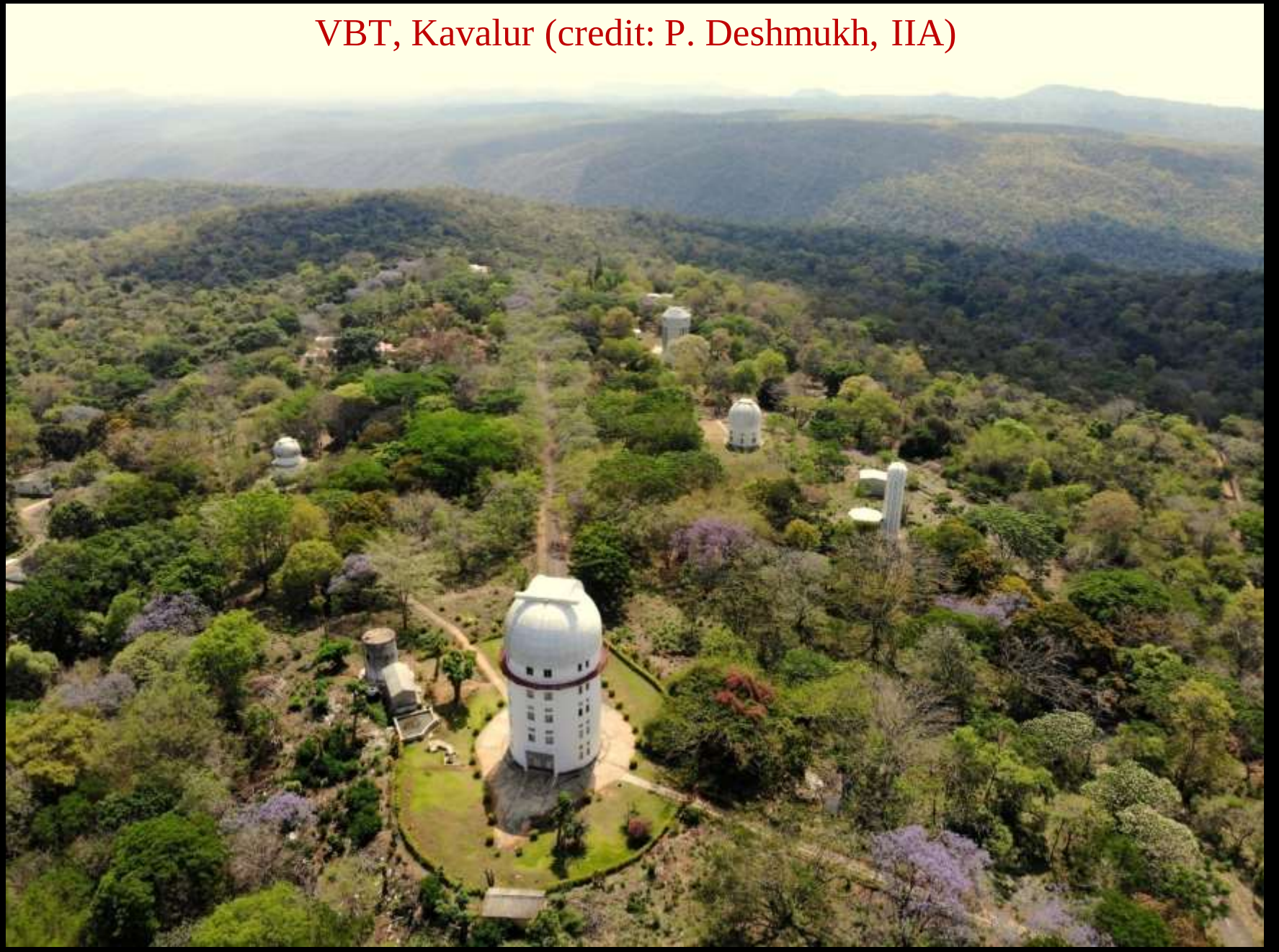
Observations and Data inventory

- Continuous monitoring of 9 selected, bright Be stars since June, 2017.
- 140 medium resolution spectra obtained in λλ 6200 – 6700 Å, particularly centred at Hα for time series analysis (Banerjee et al. 2022)
- Baush and Lomb 1800 lines/mm grating used to provide 1 Å resolution at Hα in combination with slit.

Observing instrument & analysis tools:

- UAGS mounted on the 1.0-m reflecting telescope located at VBO, Kavalur, Tamil Nadu.
- Multiple exposures of 10-40 mins. required to receive good signal.
- IRAF for data reduction and Python program for analysis.

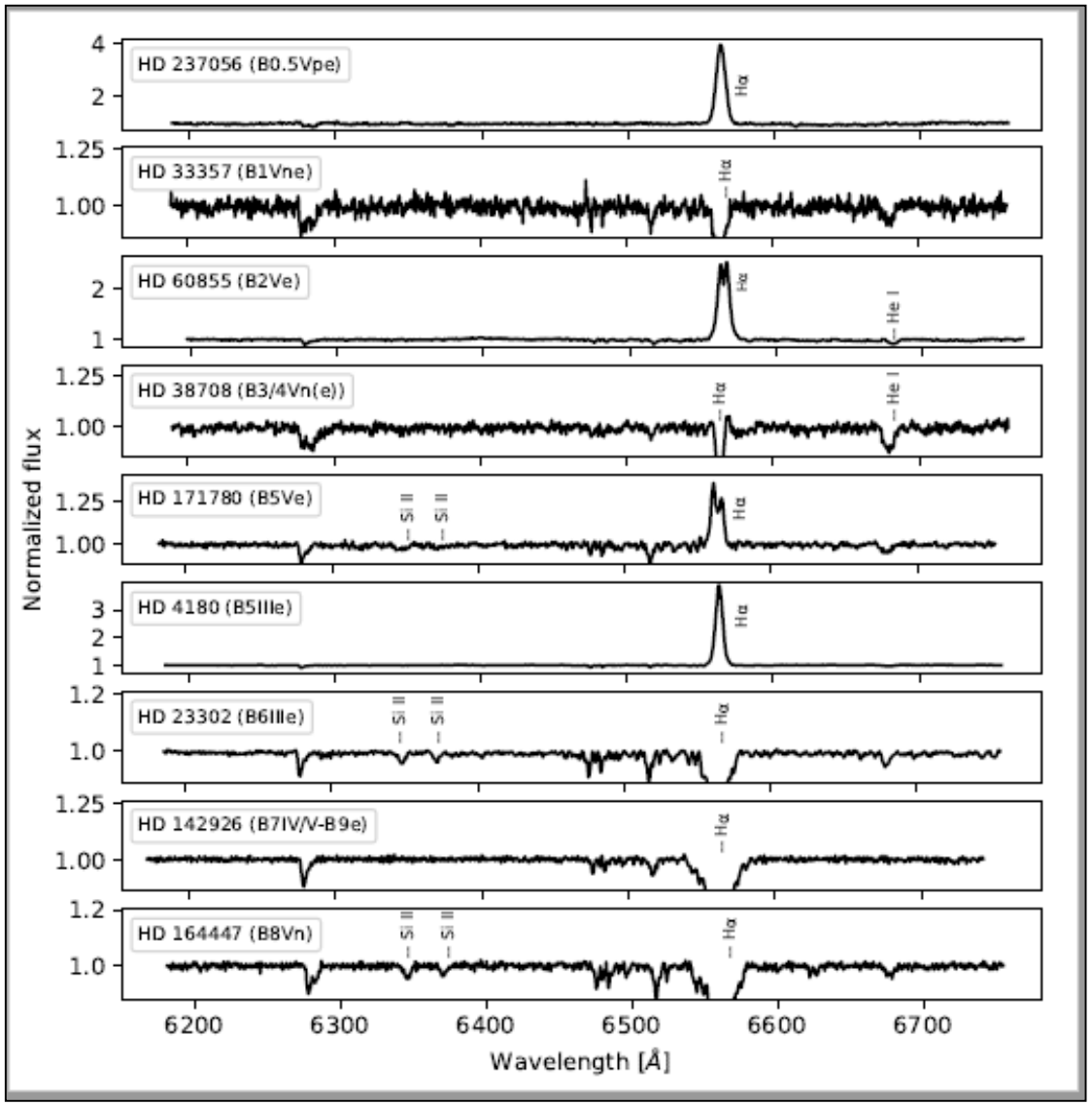
VBT, Kavalur (credit: P. Deshmukh, IIA)



Log of our observations

Name	Alias	RA	DEC	V mag	sp. type	No. of spectra obtained
HD 4180	Omi Cas	00 44 43.52	+42 17 03.71	4.5	B5III	5
HD 237056	BD+57 681	03 02 37.88	+57 36 46.06	8.9	B0.5Vpe	7
HD 23302	17 Tau	03 44 52.54	+24 06 48.01	3.7	B6IIIe	22
HD 33357	SX Aur	05 11 42.93	+42 09 52.28	8.6	BIVne	15
HD 38708	V438 Aur	05 48 53.65	+29 08 10.02	8.2	B3/4Vn(e)	31
HD 60855	V378 Pup	07 36 03.89	-14 29 33.98	5.7	B2Ve	22
BD+42 2652	4 Her	15 55 30.59	+42 33 58.29	5.8	B7IVe shell	16
HD 164447	V974 Her	18 00 27.66	+19 30 20.83	6.4	B8Vn	14
HD 171780	HR 6984	18 35 13.51	+34 27 28.88	6.1	B5Ve	8

We selected 9 program stars on the basis of our previous study (Banerjee et al. 2021), literature survey and visibility through 1-m telescope



Representative spectra for Be stars

Here, 4 stars show Hα in emission, whereas rest 5 exhibit Hα in absorption

(Banerjee et al. 2022)

Analysis of Hα line profile variations

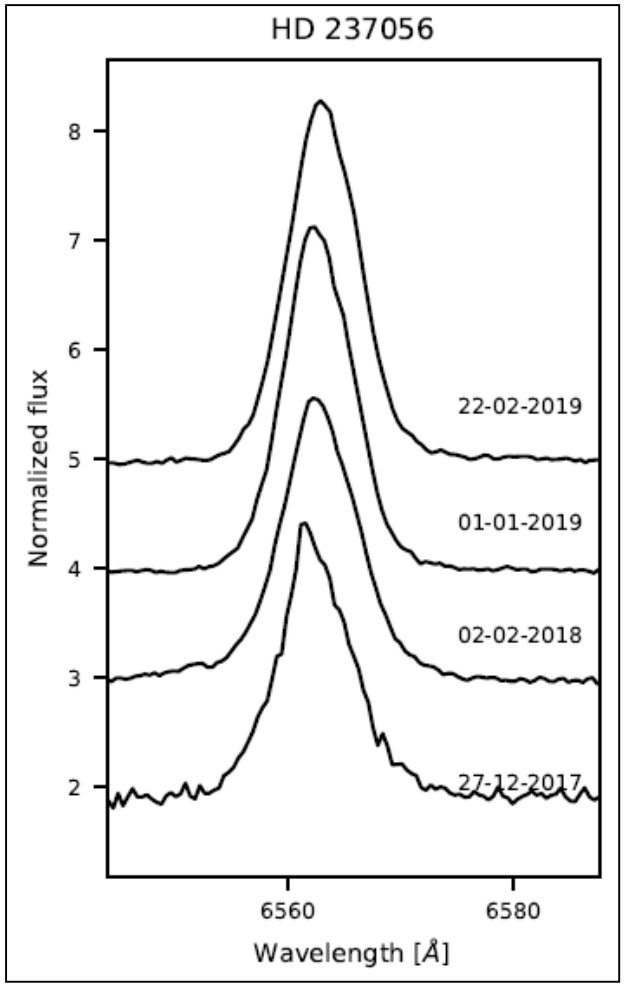
- Our study suggests: 4 among 9 stars (HD 237056, HD 33357, HD 38708 and HD 60855) are possibly hosting stable discs in recent epochs.

- One star (HD 23302) might be passing through disc formation phase.

- Rest 4 stars, namely HD 4180, BD+42 2652, HD 164447 and HD 171780, are probably undergoing disc-loss episodes.

- In addition, 2 out of 9 stars (HD 33357 and HD 38708) might be weak Hα emitters in nature (exhibiting Hα EW < -5 Å).

Case 1: stable disc scenario

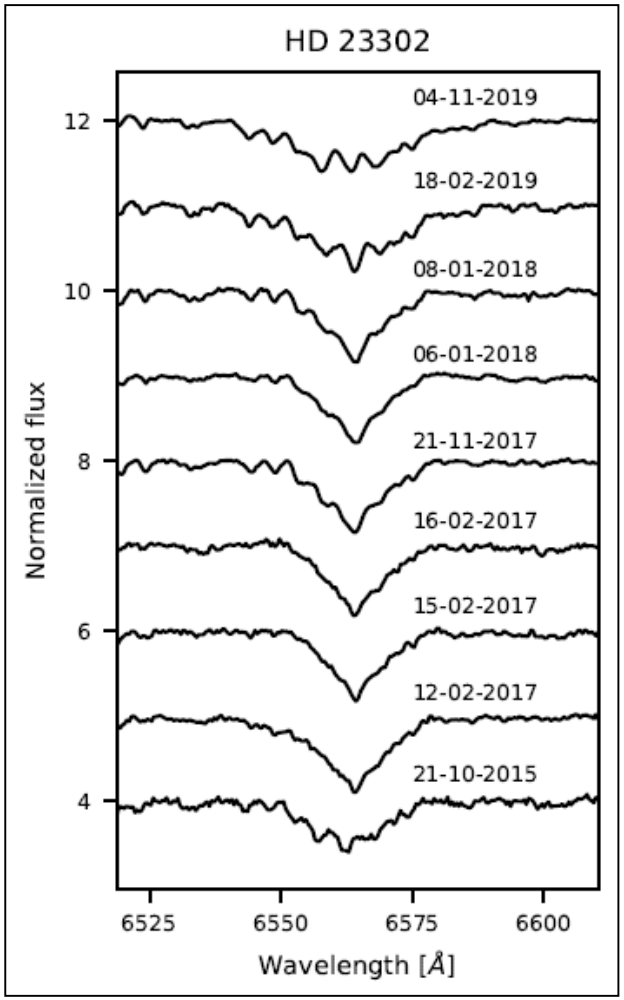


- Hα found to be in absorption by Steele et al. (1999), Barnsley & Steele (2013)
- Hα EW calculated by Banerjee et al. (2021) when observed in 2007= -2.8 Å
- Kavalur spectra shows Hα EW = -22.8 to – 28.1 Å

Suggests the presence of a stable disc currently

Details in Banerjee et al. (2022)

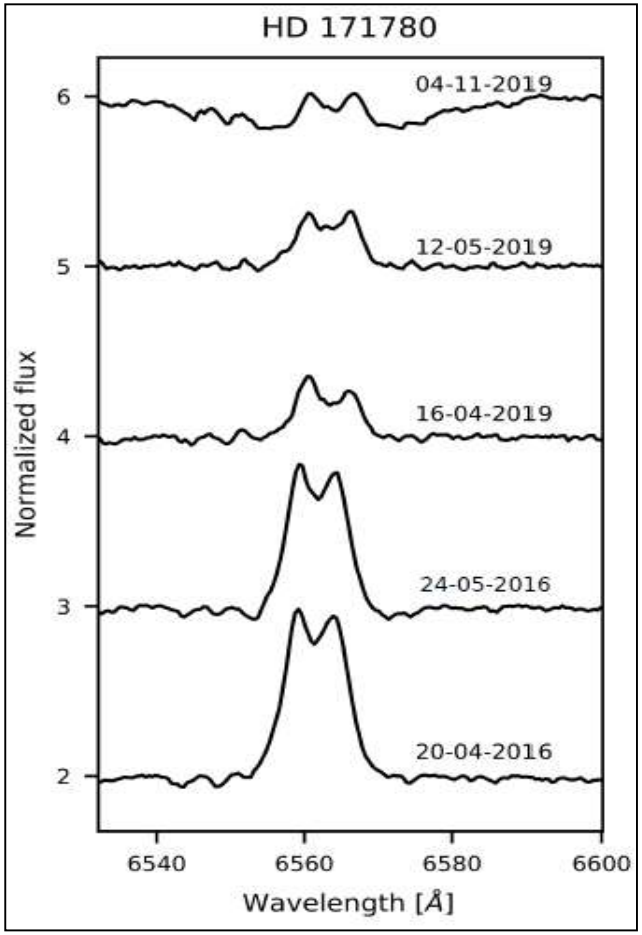
Case 2: disc formation scenario



- Hα present in absorption during 1955 - 1976 (Hubert-Delplace & Hubert 1979)
- Hα in *dpe* found by Banerjee et al. (2021): Hα EW = -7.5 Å, Andrillat & Fehrenbach (1982)
- Kavalur spectra shows Hα EW = -3.3 to – 7.5 Å
- Hα EW < -5 Å till March 02, 2018, whereas Hα EW > -7 Å since February 18, 2019 (*dpe*)

Suggests disc formation happening since 9 months

Case 3: disc dissipation scenario for HD 171780

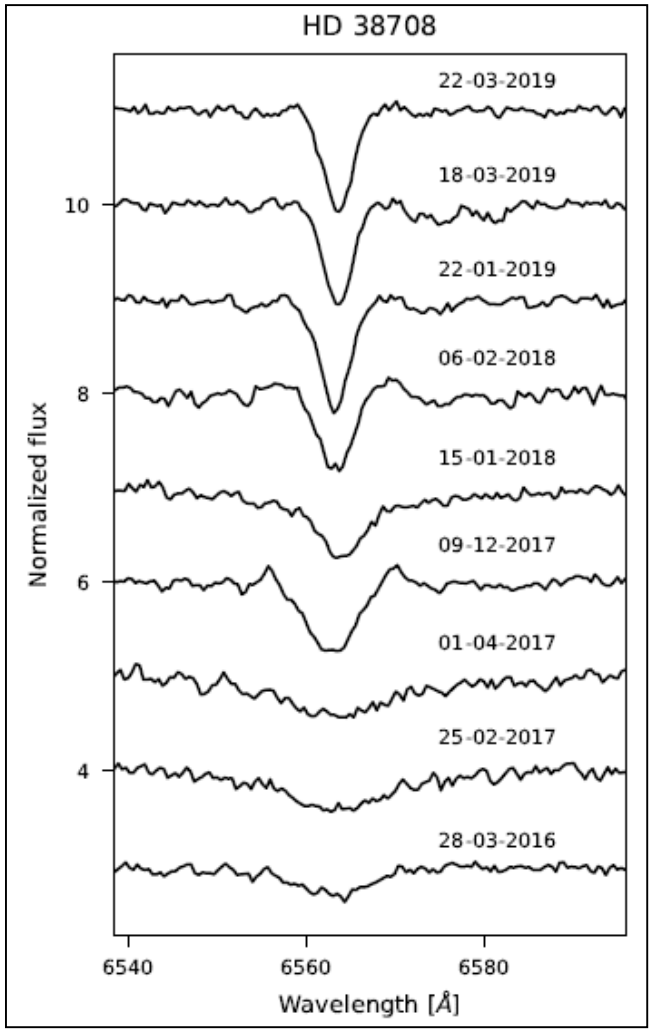


Date of observation	Hα EW_c (Å)
20/04/16	-15.7
21/04/16	-15.4
24/05/16	-15.3
25/05/16	-15.1
14/04/19	-9.2
16/04/19	-9.2
12/05/19	-9.4
04/11/19	-8.4

Gradual decrease of Hα EW detected (from -15.7 to -8.4 Å)

Implying disc dissipation happening in a timescale ~ over 43 months (April 2016 - November 2019)

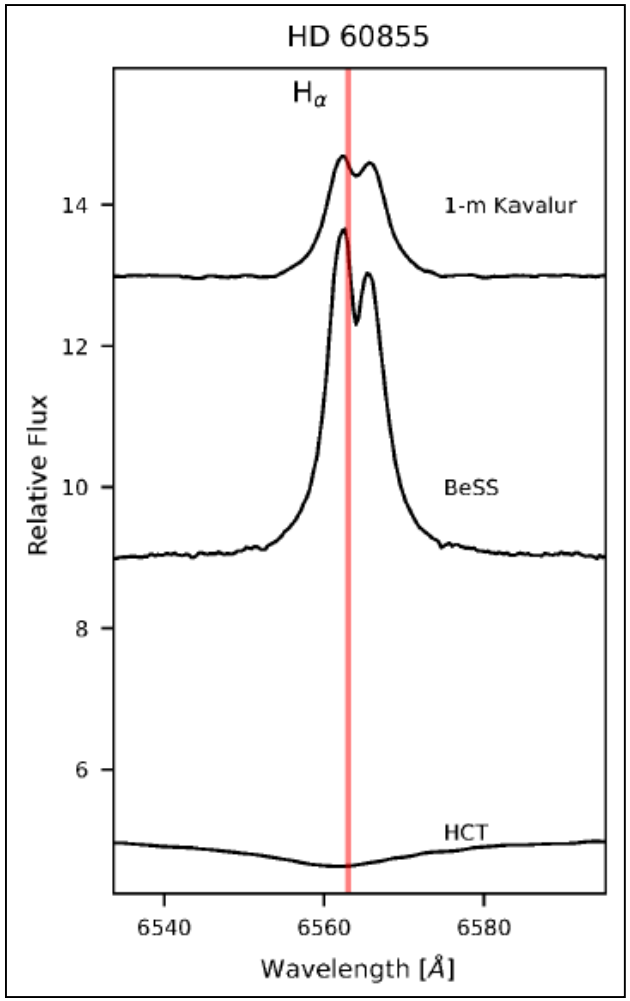
Case 4: weak Hα emitter



- Hα is observed in absorption
- Taking care of the underlying stellar photospheric contribution, corrected Hα EW is found to be within -2.3 to -4.6 Å
- Banerjee et al. (2021) found its Hα EW = -2.3 Å

Indicates HD 38708 might be a weak emitter (Hα EW < -5 Å)

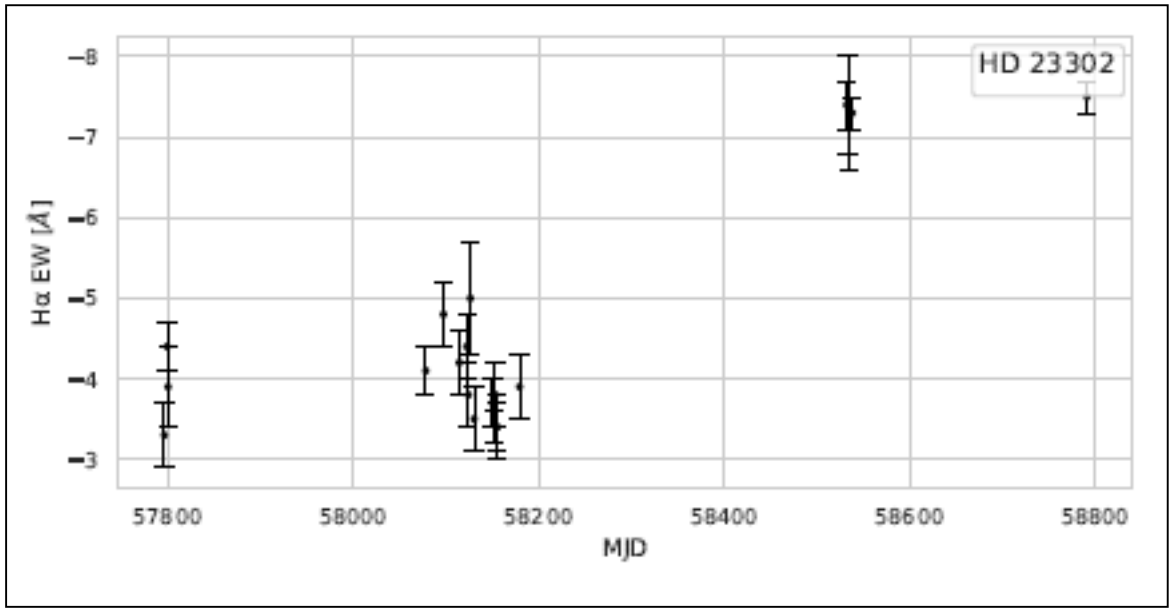
Interesting case of HD 60855



- Our observation with HCT on January 11, 2008 showed Hα in absorption (EW = 4.9 Å) (Banerjee et al. 2021)
- BeSS data on March 15, 2008 (Guarro Fló, Spain): Hα present in emission
- **Suggests disc formation of HD 60855 took place within a timescale of 2 months, from January – March 2008 .**

Classification of stars using epoch-wise Hα variation analysis

- Overall variation observed in the Hα EW for the sample stars
- **Group I** - stars possessing stable disc during our observation period
- **Group II** - stars where disc building happening during the period of observation
- **Group III** - stars undergoing disc dissipation



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Study of the transient nature of classical Be stars using multi-epoch optical spectroscopy

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Abstract. Variability is a commonly observed property of classical Be stars (CBe) stars. In extreme cases, complete disappearance of the Hα emission line occurs, indicating a disc-less state in CBe stars. The disc-loss and reappearing phases can be identified by studying the Hα line profiles of CBe stars on a regular basis. In this paper, we present the study of a set of selected 9 bright CBe stars, in the wavelength range of 6200 - 6700 Å, to better understand their disc transient nature through continuous monitoring of their Hα line profile variations for 5 consecutive years (2015 – 2019). Based on our observations, we suggest that 4 of the program stars (HD 4180, HD 142926, HD 164447 and HD 171780) are possibly undergoing disc-loss episodes, whereas one other star (HD 23302) might be passing through disc formation phase. The remaining 4 stars (HD 237056, HD 33357, HD 38708 and HD 60855) have shown signs of hosting a stable disc in recent epochs. Through visual inspection of the overall variation observed in the Hα EW for these stars, we classified them into groups of growing, stable and dissipating discs, respectively. Moreover, our comparative analysis using the BeSS database points out that the star HD 60855 has passed through a disc-less episode in 2008, with its disc formation happening probably over a timescale of only 2 months, between January and March 2008.

Reference: Gourav Banerjee et al., JApA, 43, 2, article id.102

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Thank You all