#### KATHERINE VIEIRA (UDA, CHILE), ALEJANDRO GARCÍA-VARELA & BEATRIZ SABOGAL (UNIANDES, COLOMBIA)

# Red Be stars in the Magellanic Clouds Universidad de Atacama (UDA) Instituto de Astronomía y Ciencias Planetarias (INCT)





East (milliarcseconds)

**CHARA 6 X 1 M INTERFEROMETRY** 

# The first direct image of a main-sequence star

other than the Sun ... is a Be star



# **Be stars**

- Non-supergiant (II-V) B-type stars
- Have had Balmer emission lines, episodically from days to decades
- IR free-fee emission from flattened circumstellar gas envelope/disk
  - Rapid rotation (CBe)
  - Radiation-driven winds
  - Non-radial pulsation
  - Flare-like magnetic activity
  - Binary interaction



# Gravitational darkening

### High rotation produces an oblate shape

Poles	Equator		
Higher g	Lower g		
Higher luminosity	Lower luminosity		
Brightening	Darkening		





Archernar, B6 Vep. Models based on VLTI data. Polar axis inclined 50° from the line of sight. https://www.eso.org/public/images/eso0316c/



FIRST INVESTIGATION - 2015 - 2017

### **Proper motion separation** of Be candidate stars

Sabogal et al. (2005) MNRAS, 361: 1055 Sabogal et al. (2008) A&A, 478: 659 Sabogal et al. (2014) PASP, 126: 219 SPM4 Catalogue, Girard et al. 2011, AJ, 142:15



# Variability selected Be candidate stars

- Type 1: outbursts
- Type 2: sudden luminosity jumps
- Type 1/2: 1 & 2
- Type 3: periodic or near periodic variations
- Type 4: random light curves

ΔI [mag] ~ 0.2 - 1





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### Proper motion separation of Be star candidates in the Magellanic **Clouds and the Milky Way**

Katherine Vieira 🖾, Alejandro García-Varela, Beatriz Sabogal

Monthly Notices of the Royal Astronomical Society, Volume 469, Issue 4, August 2017, Pages 4175–4182, https://doi.org/10.1093/mnras/stx1047 Published: 03 May 2017 Article history

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#### Abstract

We present a proper motion investigation of a sample of Be star candidates towards the Magellanic Clouds, which has resulted in the identification of separate populations, in the Galactic foreground and in the Magellanic background. Be stars are broadly speaking B-type stars that have shown emission lines in their spectra. In this work, we studied a sample of 2446 and 1019 Be star candidates towards the Large

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### **Proper motion separation of Be star candidates in the Magellanic Clouds and the Milky Way**

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- colors as expected for Be stars.

Paul et al. (2012): enigmatic subgroup of red Be candidates in the LMC should be analyzed spectroscopically.

Blue Be candidates are truly Magellanic objects and have near-infrared

• Red Be candidates are contaminants, probably Milky Way red giants.





LET US TAKE A LOOK

# **GAIA DR2**

- Very precise proper motions
- Parallaxes!!!

## Sample of Be candidates toward the MCs

#### Original Be candidates (Sabogal et al. 2005, Mennickent et al. 20

**Cleaning for repeated entries (<2")** 

Matched with GAIA DR2 (lowest posmag\_ranking)

With plx, pmra & pmdec

	LMC	SMC
02)	<b>2446</b>	1019
	2393	1004
	<b>2393</b>	1004
	2351	<b>991</b>



## Getting the right crossmatch







# Parallaxes & Proper Motions



# Problematic parallaxes

For faraway stars, with very small parallaxes, measurement errors can easily *disrupt/affect* the parallactic shifts, and they can end up with: \* Positive parallaxes but very large

- errors (that cross the zero value).
- \* Negative parallaxes.



Luri et al. (2018)







# Negative parallaxes



# We are looking for the ugly ones...

- Rejecting negative parallaxes:
  - Loose about 50% of the MCs stars!
- MCs stars can be recognized by their poorly measured parallaxes!
  - LMC = 50 kpc = 0.020 mas.
  - SMC = 60 kpc = 0.017 mas.
    - We are lucky: Proper motion of the MCs can be easily measured.
    - rejects poorly measured parallaxes.



• Careful: In this dataset, rejecting poorly measured proper motions systematically





# Q-Q plots

	LMC1 1853 stars	SMC1 868 stars
plx	-0.015 ± 0.081	-0.024 ± 0.075
pmra	1.865 ± 0.250	0.681 ± 0.201
pmdec	0.301 ± 0.306	-1.220 ± 0.140



## Normalization of data

When data dispersion dominated by measurement errors, normalization takes into account their effect.

Normalized data should follow a N(0,1) distribution.

 $\Box$  If dispersion </> 1 then data individual errors are over/under-estimated



*datum* – *population mean* datum norm = datum error

	LMC1 1853 stars	SMC1 868 stars
plx	-0.029 ± 1.526	-0.028 ± 1.535
pmra	-0.044 ± 2.859	0.037 ± 1.989
pmdec	0.037 ± 2.713	0.019 ± 1.794



### LMC normalized data - for all stars







### Standardization of

Normalized data show underestimation of individual stars errors.

Multiply the individual errors by the corresponding scale to "standardize" the normalized data.

data	datum	$std = \frac{datum - population mean}{datum error}$					
		LMC1 1853 stars		SMC1 868 stars			
pla	X	-0.029 ±	1.52	26 -0	.028 ±	1.535	
pm	ra	-0.044 ±	2.85	<b>59</b> O.	037 ±	1.989	
pmc	lec	<b>0.037 ±</b>	2.71	3 0.	019 ±	1.794	



**Chi** = 
$$\sqrt{(plx_{std})^2}$$



+  $(pmra_{std})^2$  +  $(pmdec_{std})^2$ 



## Final best samples: LMC = 2104 stars

![](_page_23_Figure_1.jpeg)

![](_page_23_Figure_3.jpeg)

![](_page_23_Figure_4.jpeg)

![](_page_23_Picture_5.jpeg)

### Final best samples: SMC = 971 stars

![](_page_24_Figure_1.jpeg)

![](_page_24_Figure_2.jpeg)

![](_page_24_Figure_3.jpeg)

![](_page_24_Picture_4.jpeg)

![](_page_25_Picture_0.jpeg)

# **Be confirmed stars in the MCs**

- Compilation of various references and databases found in the literature:
  - Martayan et al. (2007, 2010)
  - Paul et al. (2012)
  - Reid & Parker (2012)
  - Cieslinski et al. (2013)
  - Sheets et al. (2013)
  - BeSS database

![](_page_26_Figure_8.jpeg)

### All Be confirmed stars belong to the Magellanic Clouds Chi<10

![](_page_27_Picture_0.jpeg)

## Infrared magnitudes of the Be star candidates

in our MCs samples

#### **Credit: Bill Pounds**

![](_page_27_Picture_4.jpeg)

![](_page_28_Figure_0.jpeg)

# Infrared magnitudes

- IRSF JHKs
- SAGE IRAC
  [3.0, 4.5, 5.8, 8.0] μm

![](_page_28_Picture_4.jpeg)

![](_page_29_Figure_0.jpeg)

# Infrared magnitudes

- IRSF JHKs
- SAGE IRAC
  [3.0, 4.5, 5.8, 8.0] μm

![](_page_29_Picture_4.jpeg)

# The result

- Blue Be candidates are truly Magellanic objects and have near-infrared colors as expected for Be stars.
- Red Be candidates are contaminants, probably Milky Way red giants.
- But ... we found
  - A population of bona fide Magellanic red Be candidates in both Clouds.
  - 6 bona fide Magellanic red spectroscopically **confirmed Be stars** towards the LMC and 3 reddish ones in the SMC.

Paul et al. (2012): enigmatic subgroup of red Be candidates in the LMC should be analyzed spectroscopically.

**VIEIRA ET AL. (2020), SUBMITTED TO MNRAS** 

# **Red Be stars** in the **Magellanic Clouds**

![](_page_30_Picture_10.jpeg)

![](_page_30_Picture_15.jpeg)

There are red Be confirmed and candidate stars in the LMC, and may be? a smaller and/or less red population in the SMC.

**Metallicity?** 

**Nearby red companion?** 

Stay tuned for the next paper ...

**Dust?** 

![](_page_31_Picture_6.jpeg)

### Thanks

Katherine Vieira, INCT, UDA. November 2020.

![](_page_32_Picture_2.jpeg)