

# Stellar rotation in the intermediate-age massive cluster NGC 1783: Clues about the nature of UV-dim stars<sup>★</sup>

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## ABSTRACT

Over the past decade, stellar rotation has emerged as a key factor in shaping the morphology of color–magnitude diagrams of young and intermediate-age star clusters. In this study, we use MUSE integral-field spectroscopy to investigate the stellar rotation of  $\sim 2300$  stars in the 1.5 Gyr old cluster NGC 1783 in the Large Magellanic Cloud. The effective temperature, surface gravity, radial velocity, and projected rotational velocity ( $v \sin i$ ) of the entire sample were obtained within a Bayesian framework to derive robust estimates of these parameters along with their associated errors. The analysis shows that stars along the extended main sequence turn-off (eMSTO) cover a wide range of rotational velocities, from values consistent with no or slow rotation up to  $v \sin i \sim 250 \text{ km s}^{-1}$ . The distribution of stellar rotation velocities appears to play a crucial role in explaining the broadening of the eMSTO in this cluster, and a correlation is observed between  $v \sin i$  and the color of the eMSTO stars, with  $v \sin i$  increasing as the color becomes redder. Among the eMSTO stars, we investigate the peculiar population of stars strongly dimmed in the UV (so-called UV-dim stars), recently discovered in NGC 1783. UV-dim stars show clear photometric evidence of self-extinction and mild spectroscopic signatures typically observed in shell stars, suggesting that they have likely a decretion disk observed nearly equator-on. Interestingly, the study also shows that a significant fraction of UV-dim stars are slow rotators. We discuss potential implications these results may have on our understanding of the formation and evolution of UV-dim stars and we propose that the rotational properties of the UV-dim stars should vary with cluster age.

**Key words.** Hertzsprung–Russell and C–M diagrams – stars: rotation – galaxies: star clusters: individual: NGC 1783

## 1. Introduction

The Magellanic Clouds host a sizable population of young and intermediate-age (less than a few gigayears) massive ( $\sim 10^5 M_{\odot}$ ) stellar clusters that are largely absent in the Milky Way. These clusters are the only recently formed massive stellar systems close enough to be resolved in individual stars. Therefore, they represent ideal laboratories for constraining the physical mechanisms at the basis of cluster formation, studying their early evolution with a level of detail that cannot be achieved for distant systems, and understanding the complex stellar evolutionary properties of relatively young stellar populations.

It is now well established that the color-magnitude diagrams (CMDs) of young and intermediate-age stellar clusters display features that are not well reproduced through simple single stellar models. One of the most striking aspects that characterizes virtually all clusters younger than  $\sim 2$  Gyr is that they show

extended main sequence turn-off regions (hereafter eMSTOs; Mackey & Broby Nielsen 2007; Girardi et al. 2009; Goudfrooij et al. 2011, 2014; Correnti et al. 2014; Milone et al. 2015, 2023a; Kamann et al. 2020, 2023) and clusters younger than  $\sim 500$  Myr also exhibit split or dual main sequences (MSs; see e.g., Milone et al. 2016, 2017, 2023a). Interestingly, these phenomena are also observed in lower-mass Galactic open clusters (e.g., Marino et al. 2018a; de Juan Ovelar et al. 2020; Cordini et al. 2024), suggesting that the underlying mechanisms work irrespective of cluster masses, metallicity, and birth environments.

The presence of eMSTOs and split MSs has traditionally been interpreted as being due to stars that formed at different epochs within the parent cluster, with age spreads of 150–500 Myr (e.g., Girardi et al. 2009; Goudfrooij et al. 2011, 2014; Correnti et al. 2014). However, recent photometric and extended spectroscopic studies of stars along the eMSTOs of massive Magellanic Clouds clusters and open clusters in the Milky Way (e.g., Bastian et al. 2018; Marino et al. 2018b; Kamann et al. 2020, 2023; Bodensteiner et al. 2023; Dresbach et al. 2023) have demonstrated a direct correlation between the color of stars in the MSTO region and their projected equatorial velocity ( $v \sin i$ ).

<sup>★</sup> Based on observations collected at the European Southern Observatory under ESO programme 111.24LZ.001 (PI: Dalessandro).

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These studies reveal that rotational velocity increases from blue to red, reaching values of up to approximately  $250 \text{ km s}^{-1}$ . Indeed, rotation modifies the internal structure of stars and influences their evolution in several ways (see, e.g., [Meynet & Maeder 2000](#)). The centrifugal support and rotationally induced mixing in the stellar interior may alter the hydrostatic equilibrium and the hydrogen content in the core of the star compared to non-rotating stars of the same mass and composition. This results in a different evolutionary path of the rotating stars, leading to changes in their MS lifetimes and, consequently, their positions in the CMD with respect to the non-rotating stars (see e.g., [Wang et al. 2023](#)). Furthermore, (fast) rotation can make stars oblate, and the resulting loss of spherical symmetry leads to effective temperature variations across their surface. In particular, rotation causes the so-called gravity darkening ([von Zeipel 1924](#)): as the centrifugal force reduces the effective gravity at the equator, the equatorial regions become dimmer and cooler than the polar regions. As a result, the observed magnitude and color of a rotating star become a function of its angular velocity and of the inclination of its rotation axis toward the line of sight, with a star seen pole-on appearing bluer and brighter than the same star observed equator-on at a fixed spin velocity.

The physical mechanisms responsible for the distribution of rotation rates ( $0\text{--}250 \text{ km s}^{-1}$ ; e.g., [Kamann et al. 2023](#)) needed to reproduce the observed morphology of the eMSTOs are still a matter of debate. For example, [D'Antona et al. \(2015, see also Abt & Boonyarak 2004\)](#) suggested that binary stars can play a role. In this framework, the idea is that all stars were born with relatively high rotational velocities, with a subset subsequently slowing down due to the tidal torques in binary systems. However, based on large and multi-epoch spectroscopic observations it has recently been shown (e.g., [Kamann et al. 2020, 2021](#)) that there is no significant difference in the binary fraction of the red and blue MS stars, possibly suggesting that binarity is not a dominant mechanism in the formation of the observed bimodal rotational distributions. On the other hand, the presence of unresolved binaries may shift the positions of stars along the MS, potentially blurring the expected correlation between the color of the stars along the eMSTO and their rotational velocities. Alternatively, it has been suggested that the observed rotation distributions are the result of the difference in the lifetimes of stars' pre-MS disks ([Bastian et al. 2020](#)) or of stellar mergers (e.g., [Wang et al. 2022](#)).

[Milone & Marino \(2022\)](#) and [Milone et al. \(2023b\)](#) have recently unveiled the existence of an additional peculiarity on the eMSTOs of intermediate and young clusters in the Magellanic Clouds. In [Milone et al. \(2023b\)](#), in a selection of clusters younger than  $\sim 200 \text{ Myr}$ , they discovered a group of bright MS stars that are distributed at significantly redder colors than the MSTO mean locus in CMDs involving the F225W and F275W UV bands. [Milone et al. \(2023b\)](#) observed that these stars overlap with the other eMSTO stars in optical color combinations and therefore they argue that UV-dim stars are on average slow rotators. However, arguments based on the distribution and fraction of UV-dim stars in the CMDs of massive clusters with different ages ( $< 2 \text{ Gyr}$ ; [Martocchia et al. 2023](#)) have been used to suggest that, contrary to previous assumptions, these stars are more likely to be fast rotators. Interestingly, these results have been directly confirmed by the direct rotational velocity measurements of eMSTO stars in the very young massive cluster NGC 1850 by [Kamann et al. \(2023\)](#). In particular, the spectroscopic analysis of MUSE data by [Kamann et al. \(2023\)](#) suggests that the UV-dim stars in NGC 1850 are Be stars (i.e., fast rotating B stars with decretion disks) observed almost equator-on, such that they

are seen through their excretion disks (e.g., [Rivinius et al. 2006](#)) and they are thus self-extincted. This is also supported by the shell-like features observed in these stars ([Kamann et al. 2023](#)). However, it is still unclear whether the same mechanism can be applied to lower-mass stars in intermediate-age clusters, in part because the disk properties of A-type stars are more difficult to study because these stars do not ionize their disks. Along similar lines, based on a large suite of simulations, [D'Antona et al. \(2023\)](#) have recently pointed out that self-extinction due to the presence of a disk can in principle reproduce the observed width of eMSTOs in young- intermediate-age clusters.

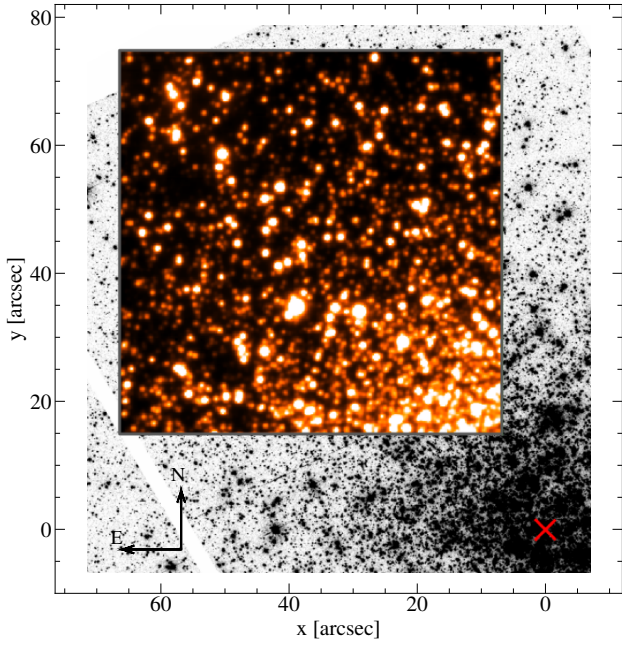
In this paper, we study the relevant aspects related to the impact of stellar rotation on the distribution of stars in the CMDs of young and intermediate-age clusters, by targeting the 1.5 Gyr old ([Mucciarelli et al. 2007; Zhang et al. 2018](#)) and massive ( $2 \times 10^5 M_{\odot}$ ; [Song et al. 2021](#)) stellar cluster NGC 1783 in the Large Magellanic Cloud (LMC). This system represents an ideal target in this context as it is located in a region of the LMC characterized by low extinction ( $A_V < 0.1 \text{ mag}$ ) and by a negligible field contamination. The paper is structured as follows. In Section 2 the adopted dataset is described, while in Section 3 we present the data-reduction procedure. The analysis methodology is presented in Section 4. In Section 5, we introduce the final data sample. Results are reported in Section 6 and Section 7 focuses on UV-dim stars. In Section 8, we summarize the main findings and discuss their implications.

## 2. Observations

The observational dataset used in this work was obtained with the integral-field spectrograph MUSE@ESO-VLT ([Bacon et al. 2010](#)) in the wide-field mode (WFM) configuration. MUSE/WFM covers a field of view of  $1' \times 1'$  with a spatial sampling of  $0.2''/\text{pixel}$ . The data were collected in the nominal mode, which provides a wavelength coverage from  $4750 \text{ \AA}$  to  $9350 \text{ \AA}$  and a resolving power ranging between 1800 in the blue part and 3500 in the red part of the spectral range. The dataset consists of 10 MUSE acquisitions of NGC 1783 obtained between September and November 2023 (program: 111.24LZ.001, PI: Dalessandro). All pointings target a region of the cluster that is slightly offset from the center by about  $10''$  toward the north-west direction (see Fig. 1), to avoid contamination effects due to the overcrowding of the central regions. Each acquisition consists of four exposures of  $\sim 660 \text{ s}$  integration time each, executed applying a derotator offset of  $90^\circ$  and a small dithering pattern between consecutive exposures to remove possible resolution differences between the individual spectrographs, for a total of 40 independent exposures.

The data reduction was performed using the standard MUSE pipeline ([Weilbacher et al. 2020](#)) through the EsoReflex environment ([Freudling et al. 2013](#)). The pipeline first performs the basic reduction (bias subtraction, flat-fielding, and wavelength calibration) for each individual integral-field unit (IFU). Then the sky subtraction is applied, all the preprocessed data are converted into physical quantities by performing the flux and astrometric calibrations, and the heliocentric velocity correction is applied. Afterward, the data from all 24 IFUs are combined in a single datacube for each exposure.

To maximize the signal-to-noise ratio (S/N) of all sources in the observed field of view, we combined all the available observations into a single datacube, by taking into account dithering offsets and rotations among different exposures, for a total integration time of  $\sim 8 \text{ hours}$ . As a last step, we removed residual sky contamination from the MUSE datacube using the dedicated



**Fig. 1.** Stacked image created from the combined MUSE/WFM datacube obtained for NGC 1783 in this work (see Section 2). For reference, we show the HST/ACS image in the F555W filter (colored in gray-scale) in the background, while the cluster center is marked by the red cross.

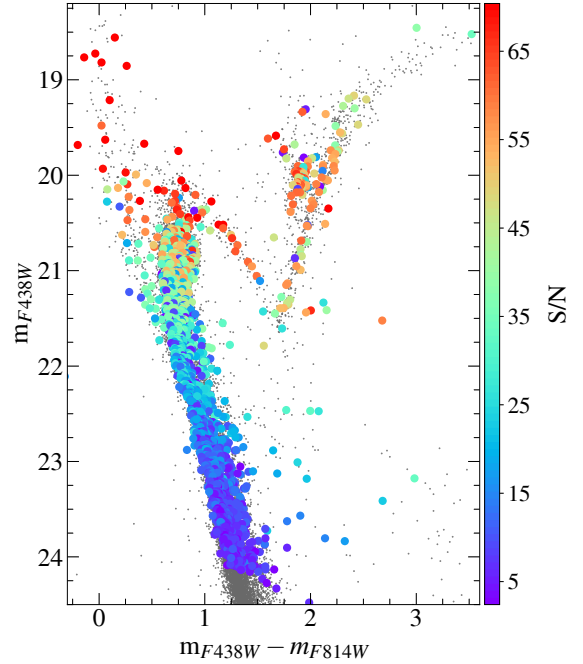
workflow included in ESO reflex, `use_zap.xml`, which is based on the Zurich Atmosphere Purge code (ZAP, Soto et al. 2016). In Fig. 1 we show the stacked image of the MUSE datacube created from the combination of all the available observations.

In the MUSE datacube, we observe a significant diffuse emission from a close star forming region. This emission is evident in several spectral lines, including  $\lambda 4861$  ( $H\beta$ ),  $\lambda 5007$  (O III),  $\lambda 6563$  ( $H\alpha$ ),  $\lambda 6584$  Å (N II), and  $\lambda 6716$  and  $\lambda 6731$  (S II). Unfortunately, these emission lines are also visible in the MUSE spectra of individual stars, particularly affecting the spectra of fainter stars. This is especially true for the  $H\alpha$  line, making it unusable in our analysis.

### 3. Extraction of the spectra

Stellar spectra were extracted from the combined MUSE datacube by using PampelMuse (Kamann et al. 2013). This is a software optimized for the deblending of resolved sources in integral-field spectroscopic data. The code uses an astrometric reference catalog to determine the position of each star in the MUSE datacube and to fit the sources from the reference catalog to the data by using a wavelength-dependent MUSE point spread function (PSF) model. Based on this information, PampelMuse extracts the deblended spectra of all the resolved stars in the MUSE field of view. In our analysis, we used as astrometric reference catalog the *Hubble Space Telescope* (HST) multi-band photometric catalog presented in Cadelano et al. (2022).

The extraction procedure yielded a total of 2293 spectra of individual stars, for which the deblending algorithm was able to extract the contribution of a single source. Fig. 2 shows the distribution of the obtained sample of stars in the ( $m_{F438W}$ ,  $m_{F438W} - m_{F814W}$ ) CMD of NGC 1783 color-coded according to the S/N of the spectra. The extracted spectra sample a wide magnitude range from  $m_{F438W} \sim 18$  down to a magnitude threshold of  $m_{F438W} \sim 24$ , about 3 magnitudes below the MSTO. Also, we note that the distribution of the extracted spectra guarantees



**Fig. 2.** CMD of NGC 1783 produced from the HST photometric catalog described in Cadelano et al. (2022, gray dots). The MUSE targets for which useful spectra were extracted from the combined datacube are shown by the large circles color-coded according to the spectral S/N.

an excellent sampling of the eMSTO of NGC 1783 with  $\sim 600$  extracted stars in the magnitude range  $20.5 \leq m_{F438W} \leq 22.0$ , and with S/N typically larger than  $\sim 30$ .

## 4. Data analysis

To analyze the MUSE spectra we developed an algorithm based on a Bayesian approach to determine the best-fit stellar parameters of individual stars. This method enables one to simultaneously estimate the effective temperature ( $T_{\text{eff}}$ ), surface gravity ( $\log g$ ), radial velocity (RV), and projected rotational velocity ( $v \sin i$ ) of the stars by means of a direct comparison between the observed spectra and a library of synthetic spectra exploring reasonable ranges of values for each parameter. We generated a library of synthetic spectra through the code SYNTHÉ (Sbordone et al. 2004 and Kurucz 2005) using the ATLAS9 atmosphere model (Kurucz 2005). The grid of synthetic spectra was computed assuming values of  $T_{\text{eff}}$  ranging from 3500 K to 8800 K, in steps of 50 K, and of  $\log g$  ranging from 0.4 to 5.0, in steps of 0.1. This fine and uniform sampling of the atmospheric parameters ensures a comprehensive coverage of all the evolutionary stages sampled by the observed targets and thus avoids the introduction of bias in the subsequent fitting procedure. Synthetic spectra were obtained by adopting a solar  $[\alpha/\text{Fe}]$  abundance ratio and the cluster metallicity  $[\text{Fe}/\text{H}] = -0.35$  dex (Mucciarelli et al. 2008). Finally, the spectra were computed in the wavelength range covered by MUSE (4900–9300 Å), with a similar spectral resolution ( $R=3000$ ), by convolving with a Gaussian profile, and the same spectral sampling (0.125 nm/pixel).

### 4.1. Spectral fitting

To compare each observed spectrum with the synthetic spectra, we used a Markov Chain Monte Carlo (MCMC) sampling

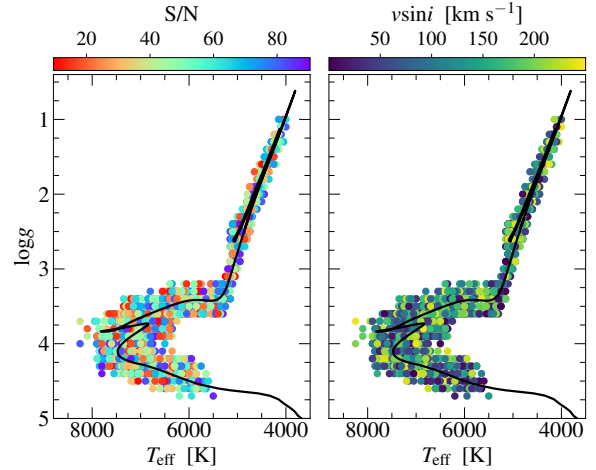
technique. This approach provides also robust uncertainty estimates for all output parameters. The fitting algorithm can be schematically described as follows.

1. As a first step, the observed spectra were normalized to the continuum. Then, for each spectrum, the S/N was estimated as the ratio between the average of the counts and its standard deviation in the 8000–9000 Å wavelength range. Finally, the spectral region to use for the following fit was selected. In particular, instead of using the full MUSE spectrum, we applied the fitting procedure to the wavelength range 7750 – 8900 Å. This range was chosen as it contains the most prominent spectral features at the MUSE resolution, namely the Ca II triplet lines and the hydrogen Paschen lines, and to avoid regions strongly affected by residuals of telluric absorption bands, which can potentially lead to mismatches between the observed and synthetic spectra. We note that the selected spectral region is particularly suitable for our aims because the Ca II triplet and Paschen lines are sensitive to variations in  $T_{\text{eff}}$  (especially the Paschen lines) and  $\log g$ . These lines are also ideal for measuring RVs and rotational velocities from line broadening along the line of sight, since they are well defined even at lower S/N. We have verified that the procedure gives consistent results across different stellar parameters (e.g.,  $T_{\text{eff}}$ ,  $\log g$ , and rotational velocity) when using the full spectrum masking the strong telluric absorption band regions. However, since the use of the full spectrum is more computationally and time expensive and our dataset includes a large number of targets, the results presented in the following are obtained by only using the selected portion of the spectrum.
2. In the second step, uniform priors were defined for  $T_{\text{eff}}$ ,  $\log g$ , RV, and  $v \sin i$  across a wide range of values:  $T_{\text{eff}}$  from 3500 to 8800 K,  $\log g$  from 0.4 to 5.0, RV from 70 to 470 km s<sup>-1</sup>, and  $v \sin i$  from 0 to 300 km s<sup>-1</sup>, ensuring a thorough exploration of the parameter space. During each MCMC iteration, the parameters were sampled from these prior distributions, starting with random values as first guesses, and the synthetic spectrum with the nearest  $T_{\text{eff}}$  and  $\log g$  was selected from the grid. The rotational broadening, corresponding to the sampled value of  $v \sin i$ , was applied to the selected synthetic spectrum using the `PyAstronomy.pyasl.rotBroad`<sup>1</sup> (Czesla et al. 2019) Python function. The synthetic spectrum was then shifted in wavelength based on the Doppler effect according to the sampled value of RV. Finally, the similarity between the resulting synthetic and the observed spectrum was quantified by computing the following logarithmic likelihood function within the spectral range selected in the step 1:

$$\ln \mathcal{L} = -0.5 \sum_i \left[ \frac{(f_{\text{obs},i} - f_{\text{syn},i})^2}{\sigma_i^2} \right], \quad (1)$$

where  $f_{\text{obs},i}$  and  $f_{\text{syn},i}$  are the fluxes of the  $i^{\text{th}}$  spectral pixel in the selected wavelength range (7750–8900 Å) of the observed and synthetic spectra, respectively. While  $\sigma_i$  is the uncertainty of the observed flux at the  $i^{\text{th}}$  spectral bin, computed as the quadratic sum of the inverse of the S/N and the variance of the flux of the corresponding spectral pixel<sup>2</sup>.

The algorithm searches for the best-fit synthetic model – the combination of parameters that maximizes the previous



**Fig. 3.** Position of the simulated targets (large circles) in the  $\log g$ – $T_{\text{eff}}$  plane. The circles are color-coded according to the S/N and rotational velocity ( $v \sin i$ ) of the simulated spectra in the left and right panels, respectively. The black curve is the isochrone computed for a stellar population of 1.5 Gyr and  $[\text{Fe}/\text{H}] = -0.35$ .

likelihood function – by sampling the parameter space ( $T_{\text{eff}}$ ,  $\log g$ , RV, and  $v \sin i$ ) using the `emcee` code (Foreman-Mackey et al. 2013). As a result of the procedure, the best-fit values for  $T_{\text{eff}}$ ,  $\log g$ , RV, and  $v \sin i$  were obtained, together with the associated uncertainties corresponding to the 50th, 16th, and 84th percentiles of the posterior distributions, respectively.

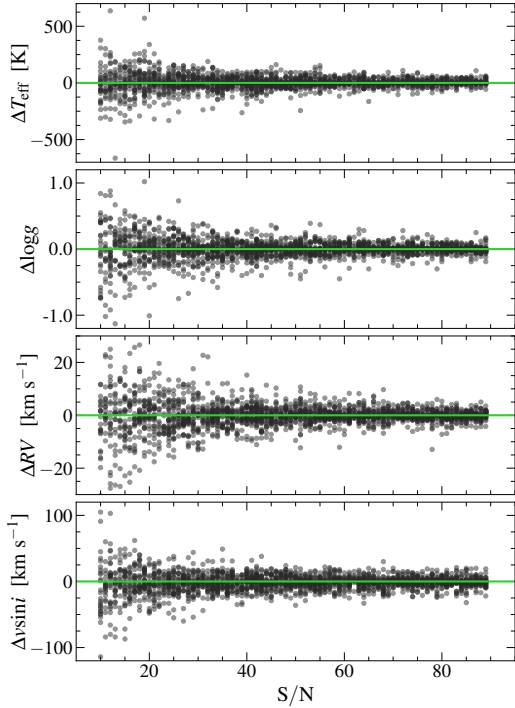
#### 4.2. Validation of the method

To validate the accuracy and reliability of the adopted method, we tested the procedure on a set of simulated spectra. To construct the simulated dataset, we generated 2000 pairs of  $T_{\text{eff}}$  and  $\log g$  values using a BaSTI-IAC isochrone (Hidalgo et al. 2018) of appropriate age (1.5 Gyr) and metallicity ( $[\text{Fe}/\text{H}] = -0.35$ ) for NGC 1783, as a reference to ensure a close match to the observational dataset. Then, for each  $T_{\text{eff}}$ – $\log g$  pair, we extracted the corresponding spectrum from the library of synthetic models described in Section 4. The RV was set to zero for all simulated targets, while each spectrum was broadened to a certain rotational velocity with random values ranging from 0 to 250 km s<sup>-1</sup>. We also added random amounts of Poisson noise to the selected synthetic models to simulate spectra with S/N ranging from 10 to 90 to match the observations. The position in the  $\log g$ – $T_{\text{eff}}$  diagram of the resulting simulated dataset is shown in Fig. 3, where the color scale represents the S/N and  $v \sin i$  values in the left and right panels, respectively.

We applied the spectral fitting method described in the previous section to the simulated data to verify that the procedure is able to recover the input values of the parameters without introducing bias, and to test the effectiveness and the robustness of the adopted MCMC algorithm. The results obtained are shown in Fig. 4 as the distribution of the difference between the best-fit parameters resulting from the fitting procedure and the input values, as a function of the S/N of the simulated spectra. Fig. 4 shows that all distributions are centered on zero at all S/N values, meaning that the values of  $T_{\text{eff}}$ ,  $\log g$ , RV, and  $v \sin i$  are on average accurately recovered. This also suggests that there are no systematic trends between the recovered parameters and the input (i.e., true) values. As expected, the scatter of the

<sup>1</sup> <https://github.com/sczesla/PyAstronomy>

<sup>2</sup> The variance values are provided by the MUSE data reduction pipeline.



**Fig. 4.** Difference between the parameter values recovered by the fitting algorithm and the known input values as a function of the S/N of the simulated spectra, for  $T_{\text{eff}}$ ,  $\log g$ , RV, and  $v \sin i$  from top to bottom panels.

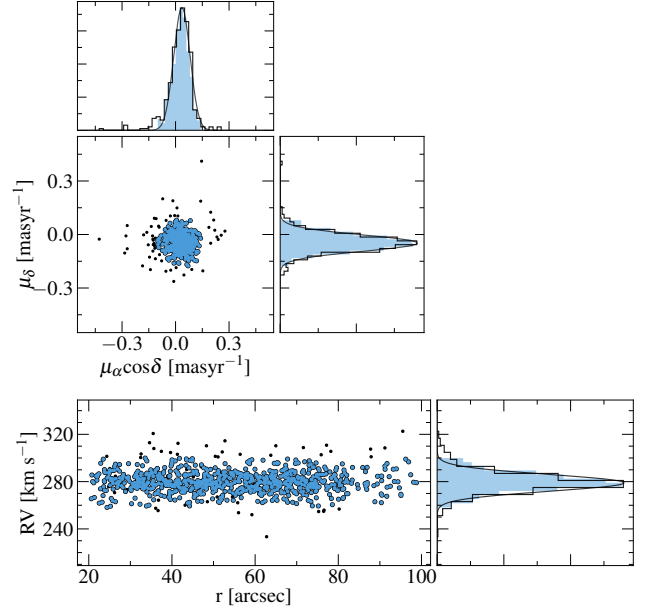
distributions increases with decreasing S/N and it provides an indication of the average uncertainty on the parameter estimates. The results of the comparison between the recovered parameters and the input values provide a crucial benchmark for the procedure, confirming that the method does not introduce any systematic effect.

It is important to note that the moderate spectral resolution of MUSE imposes a lower limit on the measurement of the rotational velocity. In particular, the analysis of the synthetic spectra shows that we are only poorly sensitive to detect  $v \sin i$  values smaller than  $\sim 50 \text{ km s}^{-1}$ . As a result, for stars in the slow rotation regime ( $\lesssim 50 \text{ km s}^{-1}$ ) we can only provide upper limits.

## 5. Selection of the bona fide sample

We applied the fitting procedure described in Section 4 to all the extracted MUSE spectra of NGC 1783 to derive the best-fit values of  $T_{\text{eff}}$ ,  $\log g$ , RV and  $v \sin i$  for each star. The following analysis is then applied only to a subsample of bona fide stars selected as follows. First, as shown in Fig. 2, our dataset samples a wide range of magnitudes and, as a consequence, of S/N, which ranges from 80 down to 2 for the fainter targets. Therefore, in order to ensure the highest reliability of our results, we performed the subsequent analysis only on stars with S/N (on the combined spectra) larger than 15, which roughly corresponds to magnitude  $m_{F438W} < 22.5$ .

Secondly, the following analysis (Section 6) targets likely cluster member stars. Cluster membership was defined by adopting a combination of proper motion (PM)-based and RV-based selections. To do this, we used the PMs measured by Cadelano et al. (2022). We performed a Gaussian fit on both the PM components independently. Stars with PM smaller than  $3\sigma_{\text{PM}}$ , where  $\sigma_{\text{PM}}$  is the best fit Gaussian width, were selected

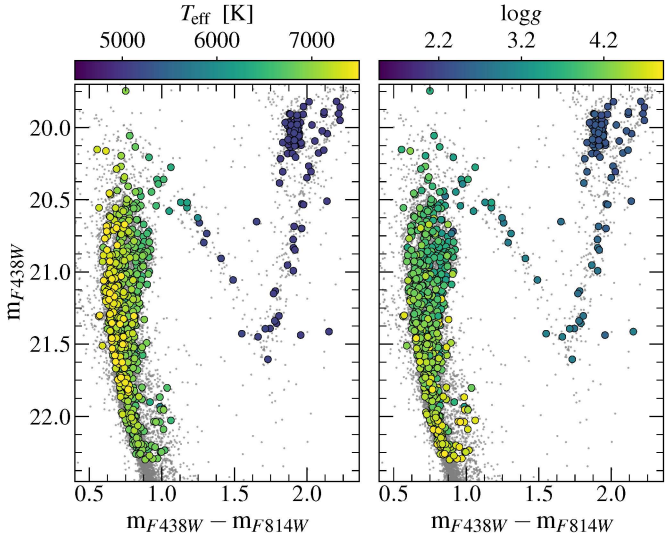


**Fig. 5.** Top panels: VPD of NGC 1783 based on the PM measurements by Cadelano et al. (2022). The blue circles show the MUSE targets selected as likely cluster's member stars, while the black circles are the MUSE targets classified as non-members. The smaller panels at the top and on the right show the distributions of both the PM components: the empty histograms represent the entire MUSE sample with the corresponding Gaussian fit indicated by the black curves, while the blue histograms are relative to the bona fide cluster members. Bottom panels: distribution of the RVs of the MUSE sample with S/N > 15. The left panel shows the RVs as a function of the distance from the cluster center. The blue circles highlight the bona fide sample selected according to the criteria discussed in the Section 5, while the black dots are the excluded targets. The empty histogram on the left panel shows the number distribution of the entire RV sample, while the blue histogram corresponds to the final subsample of bona fide stars.

as cluster's members. The vector-point diagram (VPD) of NGC 1783 and the distributions of the two PM components are shown in the upper panels of Fig. 5, with the stars selected as members highlighted in blue. We included also a selection using the RVs computed from the spectral fitting. The bottom left and right panels of Fig. 5 show the RVs of the MUSE targets with S/N > 15 as a function of the distance from the cluster center and the corresponding distribution, respectively. We first removed obvious outliers with  $\text{RV} < 230 \text{ km s}^{-1}$  and  $\text{RV} > 327 \text{ km s}^{-1}$ , and then computed the  $\sigma_{\text{RV}}$  of the distribution through a Gaussian fit on the remaining stars. The targets having RV higher than  $3\sigma_{\text{RV}}$  have been excluded. For stars having the three velocity components, we adopted both the PM-based and RV-based selection criteria, while for the targets with no PM measurements we used only the RVs to identify the members. The combination of S/N and membership selections provide us with a bona fide sample of 662 member stars, which are highlighted as blue circles in the bottom-left panel of Fig. 5.

## 6. Stellar rotational velocities

Fig. 6 shows the color-magnitude distribution of the bona fide MUSE stars, color-coded by their best-fit values of  $T_{\text{eff}}$  and  $\log g$  in the left and right panels, respectively. As expected, we observe pretty clearly a correlation between  $T_{\text{eff}}$  and the photometric color, and between  $\log g$  and stellar luminosity. This



**Fig. 6.** CMDs of NGC 1783. The stars of the bona fide sample are color-coded according to their best-fit values of  $T_{\text{eff}}$  (left panel) and  $\log g$  (right panel).

represents an independent test about the reliability of the results obtained with our fitting method. In Figure 7, the bona fide stars are color-coded by their best-fit value of  $v \sin i$ . The figure shows that the rotational velocities cover a wide range of values, going from  $v \sin i < 50 \text{ km s}^{-1}$  (consistent with no or slow rotation) to  $v \sin i \sim 250 \text{ km s}^{-1}$  (fast rotation). In particular, signatures of weak rotation are found among sub-giant stars while red giants are non-rotating or at most slow rotators. Stars along the eMSTO sample the full range of the observed  $v \sin i$  values, as shown in the zoomed-in view of Fig. 7.

The blue and red star symbols in the right panel of Fig. 7 are two representative cases of slow and fast rotator stars, for which the results of the fitting method are shown in the left and right panels of Fig. 8, respectively. The two targets were selected on the opposite edge of the eMSTO; that is, with different photometric colors, but with approximately the same magnitude ( $m_{F438W} \sim 21$ ) and about the same S/N. In the bottom panels of Fig. 8, the best-fit synthetic spectra (red and blue curves) are overplotted to the observed ones (black curves), showing an excellent match. The one- and two-dimensional posterior probability distributions for all the parameters considered in the analysis are represented as corner plots in the top panels. The best-fit analysis (the results are given in the top panels of Fig. 8) yields a temperature difference of  $\sim 350 \text{ K}$  between the two targets, with the rapidly rotating star being cooler. We also find that there is a difference of  $\sim 170 \text{ km s}^{-1}$  in rotational velocities between the two stars. The effect of stellar rotation on the spectral profile is clearly visible in the bottom panels of Fig. 8. The direct comparison of the two spectra in Fig. 9 shows even more clearly how the rapid rotation significantly broadens the spectral lines.

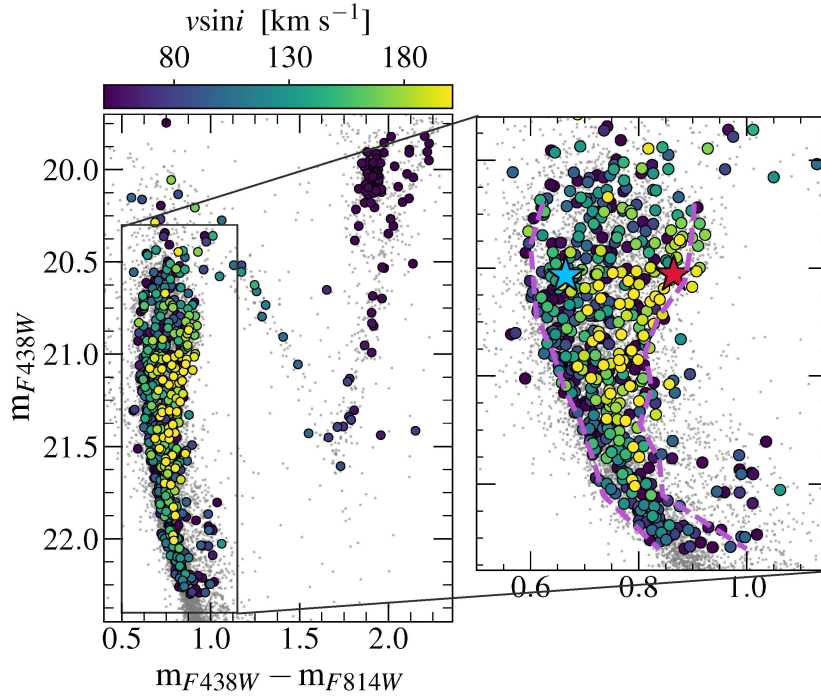
We note that the posterior probability distribution of  $v \sin i$  exhibits a well-defined peak for the fast rotator star, while for the slow rotator, it shows a roughly constant plateau for values smaller than  $\sim 40 \text{ km s}^{-1}$ . As was already pointed out in Section 4, this is due to the intrinsic limited ability to measure small  $v \sin i$  values as a result of the relatively poor MUSE spectral resolution.

Figure 10 shows the distribution of rotational velocities of the eMSTO stars. The figure highlights the wide range of  $v \sin i$

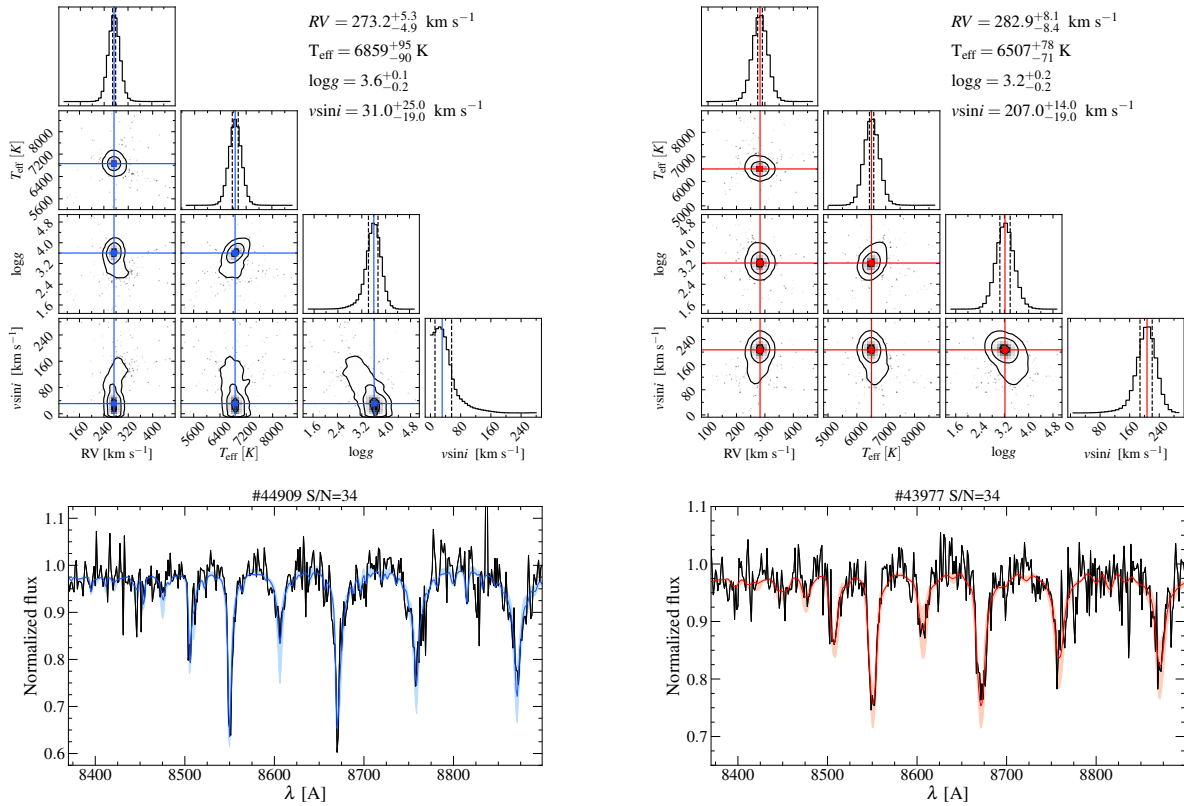
values sampled by the eMSTO targets, spanning from slow or no rotation to fast rotation. The distribution shows that there is a non negligible fraction ( $\sim 18\%$ ) of stars having slow rotation velocity ( $v \sin i < 50 \text{ km s}^{-1}$ ). At larger rotational velocities, the number of stars decreases progressively as  $v \sin i$  increases. About 75% of the stars have  $v \sin i$  values between 50 and  $200 \text{ km s}^{-1}$ . The distribution also shows a tail at higher rotational velocities, with  $\sim 7\%$  of stars exceeding  $v \sin i > 200 \text{ km s}^{-1}$ . Additionally, in Fig. 7, we observe that the majority of the fastest rotating stars ( $v \sin i > 200 \text{ km s}^{-1}$ ) are concentrated in the magnitude range  $21 < m_{F438W} < 21.3$ , whereas in the brightest part of the eMSTO, fast rotators exhibit velocities below  $200 \text{ km s}^{-1}$  (see also Fig. 11). This behavior is also observed in NGC 1846 by Kamann et al. (2020) and may suggest that the brighter eMSTO stars have been braked during the end of their MS lifetimes. However, the evolution of rotational velocity during the MS is complex and depends on multiple factors, including stellar expansion, the efficiency of angular momentum transport, and wind mass loss (see, e.g., Ekström et al. 2008; Zorec & Royer 2012; Hastings et al. 2020). Consequently, drawing a definitive interpretation of the observed trend remains challenging, but future theoretical models may provide valuable insights to better understand these observations. On the other hand, at fainter magnitudes ( $m_{F438W} > 22$ ) the number of fast rotators decreases drastically likely due to the effect of magnetic braking. Interestingly, the zoomed view around the eMSTO region in Fig. 7 shows clearly that there is a correlation between the derived  $v \sin i$  values and the color of the eMSTO stars, with  $v \sin i$  increasing as the color increases. This trend is in very nice agreement with results found in previous studies of young and massive clusters in the Magellanic Clouds and Galactic young open clusters (see e.g., Bastian et al. 2018; Kamann et al. 2018, 2020; Cordoni et al. 2021, 2024), further strengthening the role played by stellar rotation in shaping the CMDs of young and intermediate age clusters.

To further investigate the behavior of the  $v \sin i$  along the eMSTO and the upper MS, we followed the same approach used in Kamann et al. (2020, see also Bastian et al. 2018). We selected the eMSTO and MS stars in the magnitude range  $20.7 \leq m_{F438W} \leq 22.3$  and limiting the color range to  $0.59 \leq m_{F438W} - m_{F814W} \leq 1.0$  to remove any outliers. Using this sample of stars, we computed the 4th and 96th percentiles of the distribution in  $m_{F438W} - m_{F814W}$  color as a function of  $m_{F438W}$  magnitude, defining two fiducial lines at the bluest and reddest edges of the MS, respectively. The resulting MS edges are shown as dashed lines in Fig. 7. We then measured the normalized color distance of each star to the red edge, defining the pseudo-color  $\Delta_{F438W, F814W}$ . The resulting verticalized color distribution is shown in the left panel of Fig. 11. The central panels of the same figure display the  $v \sin i$  distributions by splitting the sample into four magnitude bins, while the right panels show the  $v \sin i$  values as a function of pseudo-color for the same magnitude bins as in the central panels. The panels are shown in order of increasing magnitude, and the magnitude range of each bin is labeled at the top of each central panel.

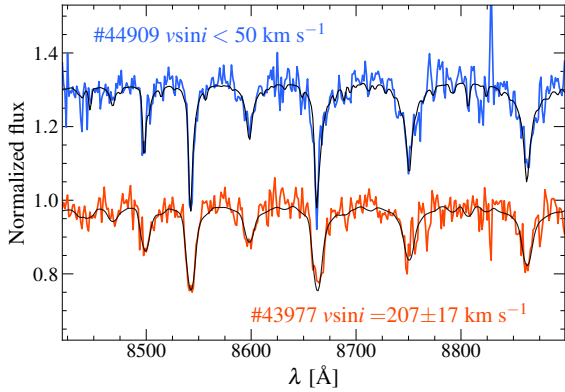
The histograms in the central panels show that while the three brightest bins sample the full range of rotational velocities, ranging from slow (or no rotation) to fast rotation, the faintest bin lacks almost entirely of stars with  $v \sin i > 140 \text{ km s}^{-1}$ . The lack of a high-rotating component suggests that magnetic braking process start becoming efficient in slowing down stars in the mass regime sampled in the faintest magnitude bin ( $\sim 1.2 M_{\odot}$ ). Interestingly, there is also a hint of bimodality in the  $v \sin i$  distribution in the two brighter magnitude bins. Finally, in agreement with



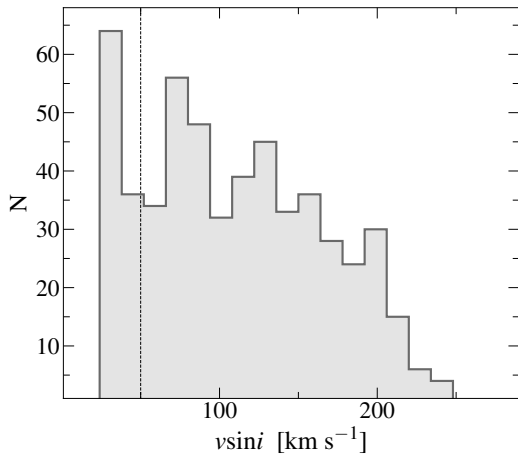
**Fig. 7.** CMD of NGC 1783 with the bona fide stars color-coded according to their best-fit  $v\sin i$  values. The box highlights the eMSTO region, which is shown as a zoomed-in view in the right panel. The blue and red star symbols mark the slow-rotating target #44909 and the fast-rotating target #43977, respectively, for which the spectral fitting results are shown in Fig. 8, and their spectra are compared in Fig. 9. The dashed violet lines are the fiducial lines adopted to verticalize the color distribution.



**Fig. 8.** Results of the spectral fitting procedure for the target #44909 on the left panels and the target #43977 on the right panels. Top panels: corner plots showing the one- and two-dimensional posterior probability distributions for all the parameters derived from the MCMC algorithm. The contours correspond to the 68%, 95%, and 99% confidence levels, and the best-fit parameter values are also labeled. Bottom panels: the black curves are the observed MUSE spectra in the Ca II wavelength region, plotted together with the corresponding best-fit synthetic models shown by the solid blue and red curves for the targets #44909 and #43977, respectively. The shaded blue and red regions represent the solutions within the  $1\sigma$  confidence level.



**Fig. 9.** Comparison of MUSE spectra in the Ca II region of two eMSTO stars with a low value of  $v\sin i$  (target #44909, blue curve), consistent with no or slow rotation, and a high rotational velocity (target #43977, red curve). For both spectra, the black curves show the respective best-fit synthetic models. Note that the blue and red spectra are the same as those shown in Fig. 8, and correspond to the targets marked by the star symbols in Fig. 7, using the same color code.



**Fig. 10.** Distribution of  $v\sin i$  of the eMSTO stars. Note that all measurements below the threshold value of  $50 \text{ km s}^{-1}$  (dashed line) represent upper limits (see Section 4 for details).

what observed in Figure 7, the three brighter bins of the right panels of Fig. 11 indicate a mild correlation between the rotational velocity and the pseudo-color of the targets, in the sense of increasing  $v\sin i$  values toward redder colors, as has already been observed in previous works (see e.g., Bastian et al. 2018; Kamann et al. 2020). An ideal correlation between stellar color and rotational velocity is likely attenuated by the effect of multiple factors, including different inclination angles of the rotation axis and the presence of unresolved binaries.

To better illustrate the effect of stellar rotation in shaping the eMSTO, in Fig. 12 we compare the observed CMD in the eMSTO region with a set of PARSEC<sup>3</sup> v2.0 isochrones (Nguyen et al. 2022) with different initial angular rotation rates ( $\omega_i$ ) and with different inclination angles of the line of sight with respect to the stellar rotation axes,  $i$ . The rotation rate is defined as  $\omega = \Omega/\Omega_c$ , where  $\Omega$  is the angular velocity, and  $\Omega_c$  is the critical angular velocity (or breakup velocity), in other words the angular velocity at which the centrifugal force is equal to the effective gravity at the equator. In particular in Fig. 12 we show three sets of isochrones computed assuming an age of

<sup>3</sup> <https://stev.oapd.inaf.it/PARSEC/index.html>

1.5 Gyr,  $[\text{Fe}/\text{H}] = -0.35$  (as appropriate for NGC 1783) and different initial rotation rates,  $\omega_i = 0.0, 0.5, 0.9$ . Each panel shows the same set of isochrones but for different inclination angles,  $i = 0^\circ$  (left),  $i = 60^\circ$  (middle), and  $i = 90^\circ$  (right). To overplot the isochrones to the CMD, we used a distance modulus of  $(m - M)_0 = 18.47$  and an extinction value of  $E(B - V) = 0.06^4$ . For all inclination angles, the observed trend between eMSTO stars and  $v\sin i$  is nicely matched (at least qualitatively) by the models. Interestingly, the trend shown in Fig. 12 is consistent with other sets of models including the effect of rotation, such as the MIST models (Choi et al. 2016), while it goes in the opposite direction than what predicted by the SYCLIST models (see, Brandt & Huang 2015; Eggenberger et al. 2021), in which fast-rotating models appear bluer than the slow-rotating ones in the TO region. Interestingly we note that at odds with the PARSEC and MIST models, the SYCLIST ones adopt efficient rotational mixing. Hence, the qualitative agreement between the observed distribution of  $v\sin i$  and predictions by the PARSEC (and MIST) models in the specific case of NGC 1783, together with previous analysis (e.g., Marino et al. 2018b; Kamann et al. 2020, 2023), would possibly suggest that rotational mixing is inefficient.

The isochrones in Fig. 12 also show the effects of different inclination angles on the color-magnitude distribution of stars along the eMSTO. The rotating isochrones with an inclination angle of  $i = 0^\circ$  (pole-on, left panel) appear brighter and bluer than the isochrones with the same rotation rate but with  $i = 90^\circ$  (equator-on, left panel). As a result, relative differences among models with different rotation rates increase for increasing values of  $i$  thus showing that also projection effects contribute in shaping the color distribution of rotating stars along the eMSTO.

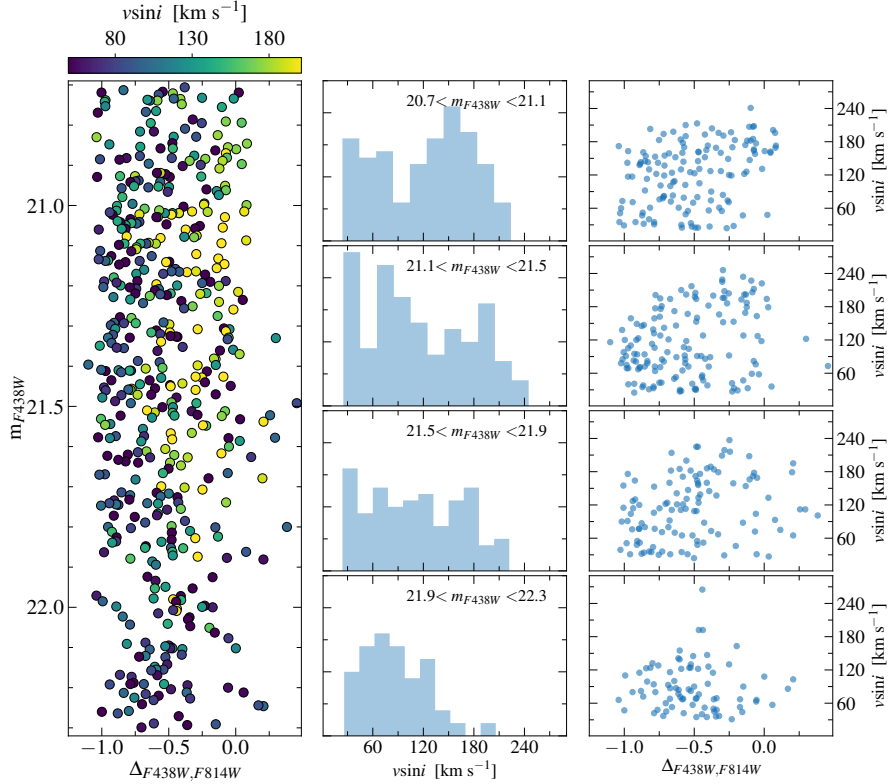
## 7. UV-dim stars

NGC 1783 is well-known to host a large population of UV-dim stars and it has been the subject of numerous investigations in this respect (Milone et al. 2023a; D’Antona et al. 2023; Martocchia et al. 2023; Milone et al. 2023b). Various hypotheses have been proposed regarding the nature of the UV-dim stars, however a definitive understanding remains elusive. In this work, we used MUSE spectra to add new constraints on the stellar rotational properties of these peculiar objects.

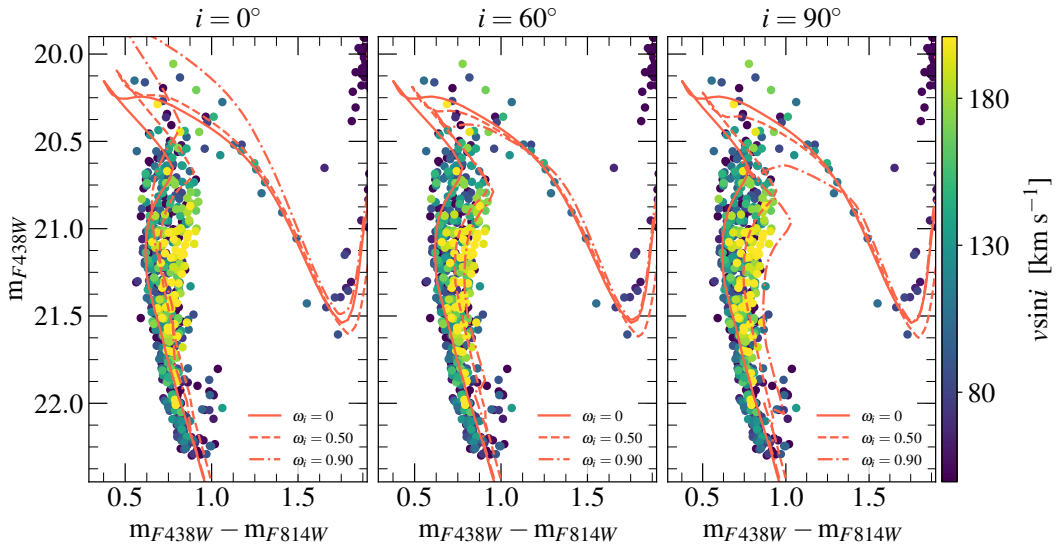
### 7.1. Photometric selection of UV-dim stars

To ensure a sufficiently high statistic, UV-dim stars were selected from the HST photometric catalog (Cadelano et al. 2022) by schematically following the procedure described in Martocchia et al. (2023). In particular, we first selected eMSTO stars in the  $(m_{F438W} - m_{F814W}, m_{F814W})$  CMD and in the magnitude range  $19.6 < m_{F814W} < 21.2$ . Then, we computed the mean ridge line of the thus selected eMSTO stars in the  $(m_{F275W} - m_{F438W}, m_{F814W})$  UV CMD. To this aim we computed the mean of a smoothing spline fit of a first-degree polynomial (solid green line in Fig. 13) to the color distribution of stars. Finally, the distance of each eMSTO star from the ridge line was computed, obtaining the  $\Delta(m_{F275W} - m_{F438W})$  verticalized color. The distribution of the verticalized color is well fit by two Gaussian functions, as shown in the right panel of Fig. 13. The fit was performed by

<sup>4</sup> These values of distance modulus and extinction differ slightly from those adopted by Cadelano et al. (2022) for the same photometric dataset. However, this difference is not of concern, as it is due to the use of different isochrone models in the two studies.



**Fig. 11.** Distribution of  $v \sin i$  along the eMSTO of NGC 1783. The left panel displays the verticalized color distribution of the eMSTO of NGC 1783, with the targets color-coded according to their  $v \sin i$  values. The central panels show the histograms of the  $v \sin i$  measurements for the targets in the magnitude bins labeled at the top of each panel. The right panels represent the  $v \sin i$  values as a function of the pseudo-color  $\Delta_{F438W,F814W}$  of the targets in the same magnitude bins as in the central panels.

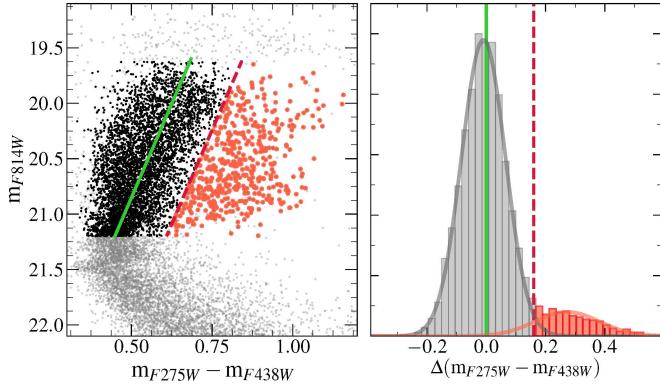


**Fig. 12.** Comparison between the CMD of the bona fide stars in the eMSTO region of NGC 1783 and a set of PARSEC rotating isochrones (red curves) computed for an age of 1.5 Gyr, a metallicity of  $[Fe/H] = -0.35$  and different initial rotation rates ( $\omega_i = 0.0, 0.5, 0.9$ ). In each panel the same set of isochrones is shown while varying the inclination angles of the rotation axis with respect to the line of sight,  $i = 0^\circ$  (left),  $i = 60^\circ$  (central), and  $i = 90^\circ$  (right). The targets are color-coded according to their  $v \sin i$  values.

using a Gaussian mixture model (GMM), and the Bayesian Information Criterion (BIC) was employed to determine the optimal number of components. To identify the UV-dim stars, we set a color threshold at  $\Delta(m_{F275W} - m_{F438W}) = 0.16$  (dashed red line in Fig. 13). This value corresponds approximately to the intersection point of the two Gaussian components. Specifically, stars

with  $\Delta(m_{F275W} - m_{F438W}) > 0.16$  were selected as UV-dim stars and are highlighted with red circles in the CMD shown in the left panel of Fig. 13.

The left panel of Fig. 14 shows the  $(m_{F275W} - m_{F438W}, m_{F814W})$  CMD of the bona fide MUSE targets color-coded according to their  $v \sin i$  values. The dashed red box highlights



**Fig. 13.** Left panel:  $m_{F275W} - m_{F438W}$ ,  $m_{F814W}$  CMD of NGC 1783. The black circles show the selected MSTO stars, while the red circles represent the stars identified as UV-dim. The solid green and dashed red lines indicate the MSTO ridge line and the selection threshold for the UV-dim stars (see right panel), respectively. Right panel: histogram of the verticalized color distribution ( $\Delta(m_{F275W} - m_{F438W})$ ) for the MSTO stars. The dashed red line represents the threshold in the verticalized color,  $\Delta(m_{F275W} - m_{F438W}) = 0.16$ , used to select the UV-dim stars, which are highlighted in red. Gray and red Gaussian curves indicate the respective GMM fit components. The green line is the same as in the left panel.

the region occupied by the UV-dim stars, which are marked with open red circles. The oblique edge of the box represents the adopted color threshold ( $\Delta(m_{F275W} - m_{F438W}) = 0.16$ ) while the two horizontal lines correspond to the previously defined magnitude limits ( $m_{F814W} = 19.6$  and  $m_{F814W} = 21.2$ ).

## 7.2. Properties of the UV-dim stars

A preliminary visual inspection of Fig. 14 suggests that the majority of UV-dim stars are slow rotators. This trend becomes even more evident when examining the right panels of Fig. 14. The central panel shows the  $v \sin i$  of the eMSTO stars (in the magnitude range  $19.6 < m_{F814W} < 21.2$ , gray circles) as a function of the verticalized color. The UV-dim stars, as selected in the left panel, are indicated by red circles, and the dashed red line marks the color threshold  $\Delta(m_{F275W} - m_{F438W}) = 0.16$ . The right-hand panel presents the normalized histograms of the  $v \sin i$  distribution for both the entire eMSTO sample (in gray) and the UV-dim stars (in red). The distribution clearly shows that the majority ( $\sim 60\%$ ) of UV-dim stars are non-rotating or at most slow rotators with  $v \sin i < 50 \text{ km s}^{-1}$ . The remaining 40% is distributed along a declining tail for increasing values of  $v \sin i$  almost ending at  $\sim 150 \text{ km s}^{-1}$  and with one single star with  $\sim 180 \text{ km s}^{-1}$ , which is however very close to the blue edge of our selection, meaning that its classification as a UV-dim star may be uncertain.

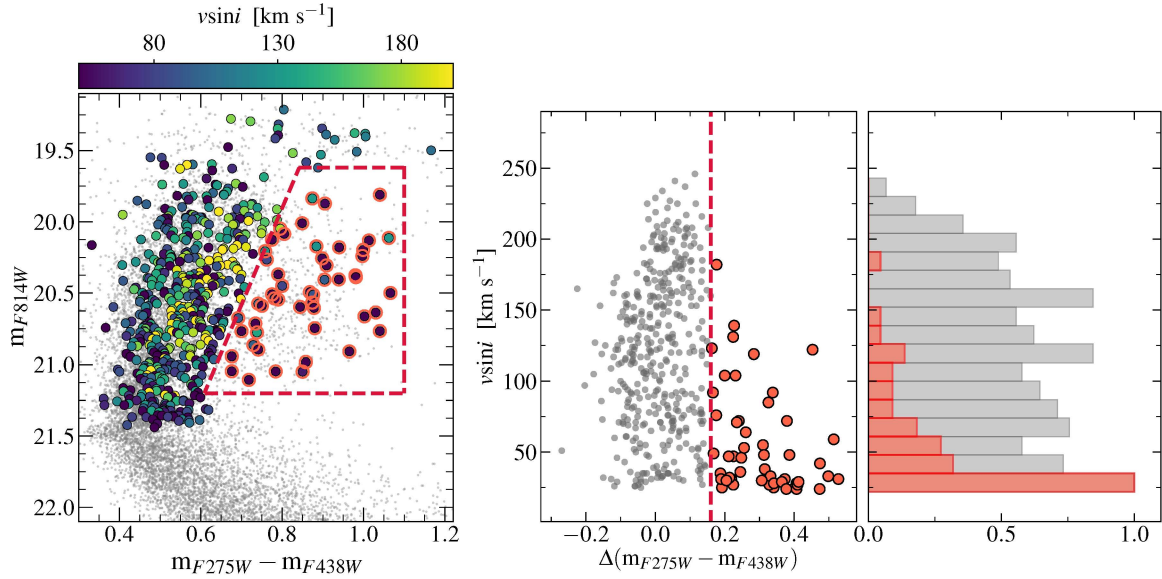
The observational evidence that the UV-dim stars in NGC 1783 are preferentially slow rotators appears to be in tension with the results of the spectroscopic analysis based on MUSE data performed by Kamann et al. (2023) for the very young massive cluster NGC 1850, and with the results presented by Martocchia et al. (2023) based on photometric arguments. In NGC 1850, UV-dim stars are among the fastest rotators in the cluster, with rotational velocities reaching values of up to  $\sim 250 \text{ km s}^{-1}$ . Interestingly, most of the UV-dim stars in NGC 1850 show also clear evidence of disk-like features in their spectra (such as a number of narrow Fe II and Si II absorption lines), which suggest they are likely fast-rotating Be stars that are seen nearly equator-on (shell stars). To further explore this scenario also in the case

of NGC 1783, we created two stacked spectra: one combining all the selected UV-dim stars, and the other including eMSTO stars with  $v \sin i < 80 \text{ km s}^{-1}$ . This approach enables a direct comparison in terms of stellar rotation. We first checked for the presence of the absorption feature characteristic of shell stars (see Kamann et al. 2023) in the UV-dim stacked spectrum. The top and the middle panels of Fig. 15 show that the Si II and Fe II lines of the UV-dim stacked spectrum (red curve) are slightly stronger than those observed in the spectrum obtained for eMSTOs (blue curve), possibly suggesting that UV-dim stars may have a disk also in the case of NGC 1783. While we note that the differences observed here are significantly smaller than those observed in the case of NGC 1850, we also stress that MSTO stars in NGC 1783 are significantly cooler ( $\sim 7000 \text{ K}$ ) than in NGC 1850 ( $\sim 12000 \text{ K}$ ) and that the strength of disk-related lines depends on the properties (e.g., mass and density) of the disks.

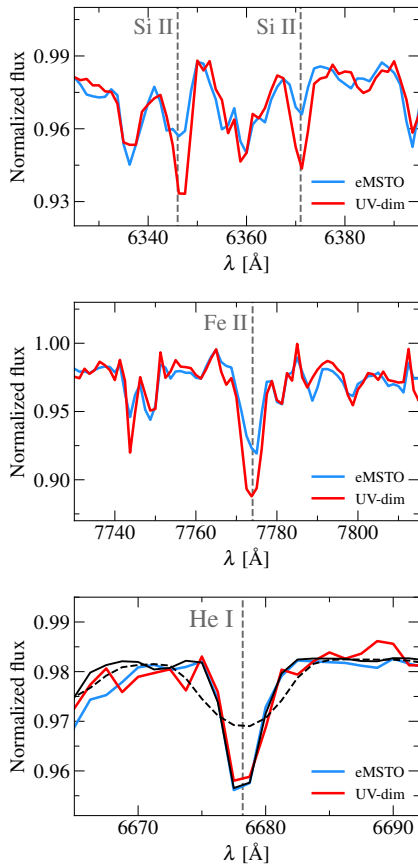
In the hypothesis that also the UV-dim stars in NGC 1783 are shell stars, then the rotational velocity constrained by using the Balmer and Paschen lines may be affected by the presence of the disk. In particular, the presence of the disk can lead to narrow cores of the hydrogen lines, resulting in smaller  $v \sin i$  values. As an independent check on the derived rotational velocities, we used the He I line at  $6678.2 \text{ \AA}$  of the UV-dim stars stacked spectrum, which is the only non-hydrogen features not affected by the shell. We find that, in agreement with what obtained by using the fitting procedure described in Section 4, the He I width is compatible with a small rotation of  $v \sin i < 70 \text{ km s}^{-1}$  (see bottom panel in Fig. 15). Interestingly, a similar result is found when using the stacked spectrum of the slow-rotator eMSTOs, as shown by the blue curve in the bottom panel of Fig. 15.

To further test the scenario in which UV-dim stars in NGC 1783 detected in our analysis have a disk, we took advantage of the HST multi-band photometric catalog of Cadelano et al. (2022). We derived the verticalized colors of the eMSTO stars following the method discussed in Section 7 for different color combinations, including  $(m_{F275W} - m_{F814W})$ ,  $(m_{F336W} - m_{F814W})$ ,  $(m_{F434N} - m_{F814W})$ ,  $(m_{F438W} - m_{F814W})$ , and  $(m_{F555W} - m_{F814W})$ . The verticalized color distributions obtained are illustrated in Fig. 16, with the eMSTO and the UV-dim stars marked by black and red circles, respectively. As expected, the UV-dim stars populate a separate region at significantly redder colors when the UV filter (F275W) is used. As the adopted filter becomes redder, the UV-dim stars progressively shift toward bluer colors, until they completely mix among the average colors of the normal eMSTO stars in the optical ( $m_{F814W}$ ,  $m_{F555W} - m_{F814W}$ ) CMD. We also computed the median values of the verticalized colors of the eMSTO and the UV-dim stars, represented in each panel by vertical, dashed gray and red lines, respectively. It is evident that the distance between the two midlines gradually decreases until it disappears in the optical diagram. This results is well represented in Fig. 17, which shows the difference between the two median values as a function of the wavelength. The uncertainty on the median values was estimated as the 68% confidence interval calculated using a bootstrap algorithm with 10 000 resamples. The resulting trend suggests that UV-dim stars are likely affected by self-extinction, as expected in the case they host an excretion disk produced by mass loss. Interestingly, this result is in quite good agreement with what is expected from the theoretical models presented in D'Antona et al. (2023, see their Fig. 4, central panel, cyan curve), which describe the presence of UV-dim stars at the level of the eMSTO in NGC 1783 by self-dust absorption.

Finally, it is interesting to note that at the age of NGC 1783 the pulsating stars instability strip broadly intersects the location of the UV-dim stars in the ( $m_{F275W} - m_{F438W}$  vs.  $m_{F814W}$ ) CMD,



**Fig. 14.** Left panel: CMD focusing on the eMSTO region of NGC 1783. The MUSE targets are represented as large circles, color-coded according to their  $v \sin i$  values. The dashed red box outlines the selection region for UV-dim stars (see text), which are highlighted by open red circles. Central panel:  $v \sin i$  of the eMSTO targets in the magnitude range  $19.6 < m_{F814W} < 21.2$  as a function of the verticalized color. The dashed red line marks the selection edge for the UV-dim stars, corresponding to  $\Delta(m_{F275W} - m_{F438W}) = 0.16$ , with the selected UV-dim stars indicated by red circles. Right panel: normalized histograms of the  $v \sin i$  distributions for the stars shown in the central panel. The gray histogram represents the eMSTO stars, while the red histogram shows the  $v \sin i$  distributions for the subsample of UV-dim stars.



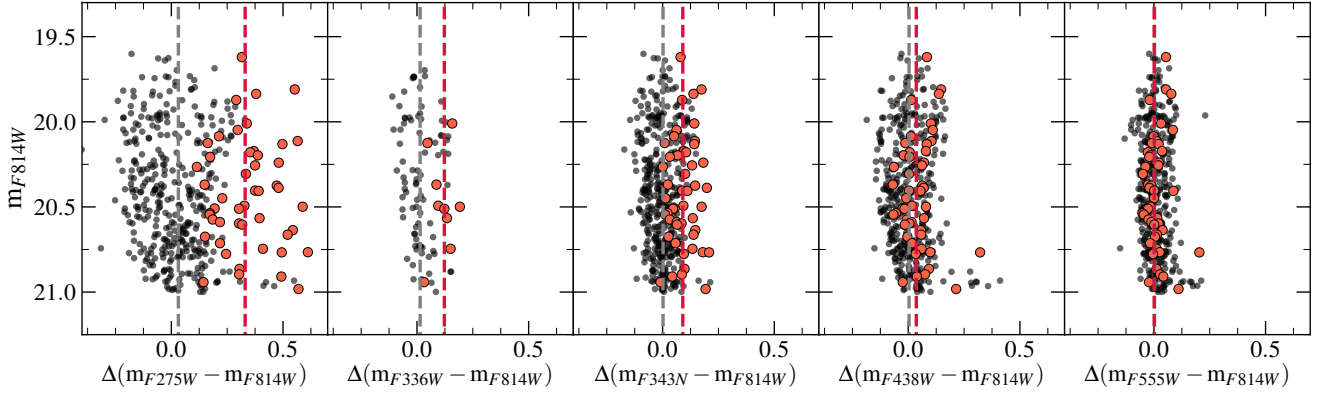
**Fig. 15.** Comparison between the stacked spectra obtained by combining the UV-dim stars and slow-rotating eMSTO stars, shown by the red and blue curves, respectively. In the bottom panel, the solid and dashed black curves represent a synthetic spectrum computed with  $v \sin i = 60 \text{ km s}^{-1}$  and  $v \sin i = 200 \text{ km s}^{-1}$ , respectively.

thus suggesting they might be variable stars observed at random phase (see e.g., [Salinas et al. 2018](#)). We took advantage of the large available photometric dataset to test whether UV-dim stars show any evidence of photometric variability. To this aim, we used the variability index ([Stetson 1996](#)) computed by DAOPHOT and we performed a visual inspection of the magnitude distribution of the UV-dim stars as a function of the observation epoch for all the available filters. While admittedly the adopted dataset is not suited for a detailed variability analysis and the expected amplitudes are relatively small ( $\sim 0.2$  mag), especially at red wavelengths, we do not find any evidence of variability among the selected UV-dim stars.

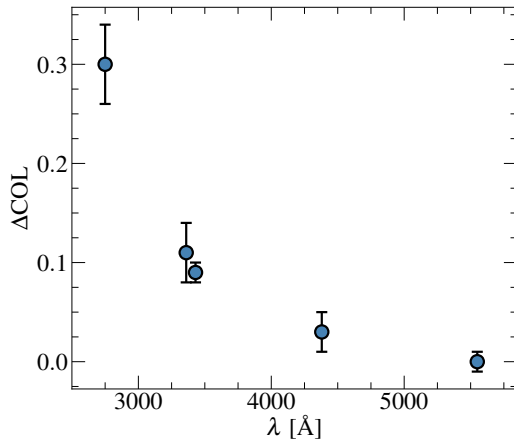
## 8. Summary and discussion

As part of a larger effort aimed at providing observational constraints on the physical mechanisms at the basis of cluster formation and early evolution (e.g., [Dalessandro et al. 2019, 2021, 2022, 2024](#); [Cadelano et al. 2022](#); [Della Croce et al. 2023, 2024](#)), here we present the first extended spectroscopic analysis of the intermediate-age massive LMC cluster NGC 1783 based on deep MUSE observations providing spectra for about 2300 stars. We derived the stellar parameters –  $T_{\text{eff}}$ ,  $\log g$ , RV, and  $v \sin i$  – via spectral fitting following a Bayesian approach and we compared each observed spectrum with a grid of synthetic spectra by using a MCMC sampling technique. This approach offers a number of significant advantages, as it simultaneously provides reliable estimates of the best-fit values for all the parameters and the robust determinations of their associated uncertainties, taking into account the correlations among them.

In this work, we focus in particular on stellar rotation. We derived  $v \sin i$  values for about 700 stars that are likely cluster members. In agreement with previous studies about stellar rotation in young massive clusters (e.g., [Kamann et al. 2020, 2023](#)), our analysis shows that it plays a critical role in shaping the



**Fig. 16.** Verticalized color distributions of the eMSTO stars of NGC 1783 in different combination of colors. The black circles represent eMSTO stars in the magnitude range  $19.6 < m_{F814W} < 21.2$ , while the red circles mark the UV-dim stars selected as discussed in Section 7. The vertical dashed grey and red lines mark the median values of the verticalized colors for the eMSTO and UV-dim stars, respectively.



**Fig. 17.** Difference between the median of the verticalized colors of the eMSTO and UV-dim stars (see Fig. 16) as a function of the wavelength.

color-magnitude distribution of stars. In particular, we find that while sub-giant and red-giant branch stars are typically slow rotators, the eMSTO encompasses the full range of observed rotational velocities ( $0 < v \sin i < 250 \text{ km s}^{-1}$ ).

Interestingly, we observe a pretty clear correlation between rotational velocities and stellar colors along the eMSTO, with rotation increasing as the color gets redder. However, as was expected, such a correlation is partially blurred by the possible interplay between additional factors (including for example the different inclination angles and unresolved binaries) that can contribute in shaping the eMSTO morphology.

By using UV-optical HST CMDs, our analysis also confirms the presence of a sizable population ( $\sim 10\%$  of the eMSTOs) of UV-dim stars (see also Milone et al. 2023a; Martocchia et al. 2023). In the case of the very young (age  $\sim 100$  Myr) and massive cluster NGC 1850, these stars have been suggested to be likely rapidly rotating stars with decretion disks seen nearly equator-on (i.e., shell stars; Martocchia et al. 2023), based on direct spectroscopic observations (Kamann et al. 2023). The idea is that UV-dim stars undergo non-negligible mass-loss through their equator triggered by their large rotational velocities and thus they develop an excretion disk (D’Antona et al. 2023). If the disk is observed at high inclination angles with respect to the line-of-sight then it can selectively absorb the stellar flux causing self-extinction. As a consequence, while shell stars are

indistinguishable from eMSTOs at optical wavelengths, they move significantly to the red in color combinations involving UV filters. In nice agreement with this emerging scenario, in the present analysis we find both direct and indirect evidence for the presence of a disk surrounding the UV-dim stars in NGC 1783. We observe stronger FeII and SiII spectral lines than those observed for standard eMSTO stars, which are typical disk-like features. We also find a monotonically decreasing distribution of the color offsets between UV-dim stars and the mean loci defined by eMSTOs, which nicely match expectations in the case they host a (excretion) disk. Interestingly, however, we find that UV-dim stars are typically intermediate to slow rotators, with about 60% of them having  $v \sin i < 50 \text{ km s}^{-1}$ , which is compatible with no rotation given the spectral resolution of MUSE (see Section 4.2). These observational evidence may suggest that UV-dim stars observed in NGC 1783 and NGC 1850 could represent distinct populations of objects at different stellar mass ranges. Alternatively, a possible explanation involves the characterization of the magnetic field of eMSTO stars and the possibility it plays a role in shaping the observed rotation distribution. Among O- and B-type stars, as those observed along the eMSTO of NGC 1850, only a small fraction ( $\sim 5\%$ ) is expected to host detectable magnetic fields. On the contrary, among A-type stars, as those populating the eMSTO of NGC 1783, up to  $\sim 20\%$  of stars (e.g., Abt 2000; Briquet 2015) are expected to host intermediate-strength (of up to  $\sim 1 \text{ KG}$ ) magnetic fields (Briquet 2015). Interestingly, in this context Barnes et al. (2001) suggested that (see also Matt & Pudritz 2004) the development of a disk in a rotating magnetic star can slow down its stellar spin (so-called disk-locking) in a relatively short timescale ranging from 5 Myr to 30 Myr, depending on the disk’s rotation distribution (solid-body or differential rotation). This mechanism is also invoked at the level of pre-MS stars to reproduce the distribution of rotational velocities in MSTO stars in young and intermediate-age clusters. However, as a cautionary note, it is worth mentioning here that the presence of magnetic fields may also inhibit the formation of circumstellar disks (e.g., ud-Doula et al. 2018).

In the framework where differences in the magnetic field properties play a role, we can speculate that UV-dim stars in the very young cluster NGC 1850 and those in the intermediate-age cluster NGC 1783 may arise from the same underlying physical mechanism. In particular, in both cases these stars were originally intermediate to fast rotators that lost a fraction of their mass through their equatorial regions, mainly driven by their high spin rate. In both cases, these stars developed an excretion disk, and

the fraction of them that are now observed equator-on are classified as UV-dim. In NGC 1850, where virtually all eMSTO stars lack significant magnetic fields, the presence of a disk does not substantially affect the stellar rotation velocity, resulting in UV-dim stars in this object predominantly being intermediate- to fast-rotators. Conversely, in NGC 1783, the presence of mild to relatively strong magnetic fields can decelerate the stellar spin, shifting the overall  $v\sin i$  distribution toward intermediate or low values (see Figure 14).

The present study tentatively suggests an evolutionary explanation for the varying properties of UV-dim stars, proposing that the fraction of rapidly rotating UV-dim stars decreases with increasing cluster age due to a growing fraction of magnetic stars among the eMSTOs. This idea can be directly tested through the combined analysis of the photometric and spectroscopic properties of UV-dim stars in clusters at different ages. In addition, high-resolution spectroscopic investigation could also provide clues about the existence of peculiar chemical patterns expected to be induced by the presence of magnetic fields, as anomalous abundances of Eu, Sr, or Cr, as is commonly observed in Ap-stars.

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