The metallicity of M dwarfs: photometric calibrations with Markov Chain Monte Carlo and Bayesian inference

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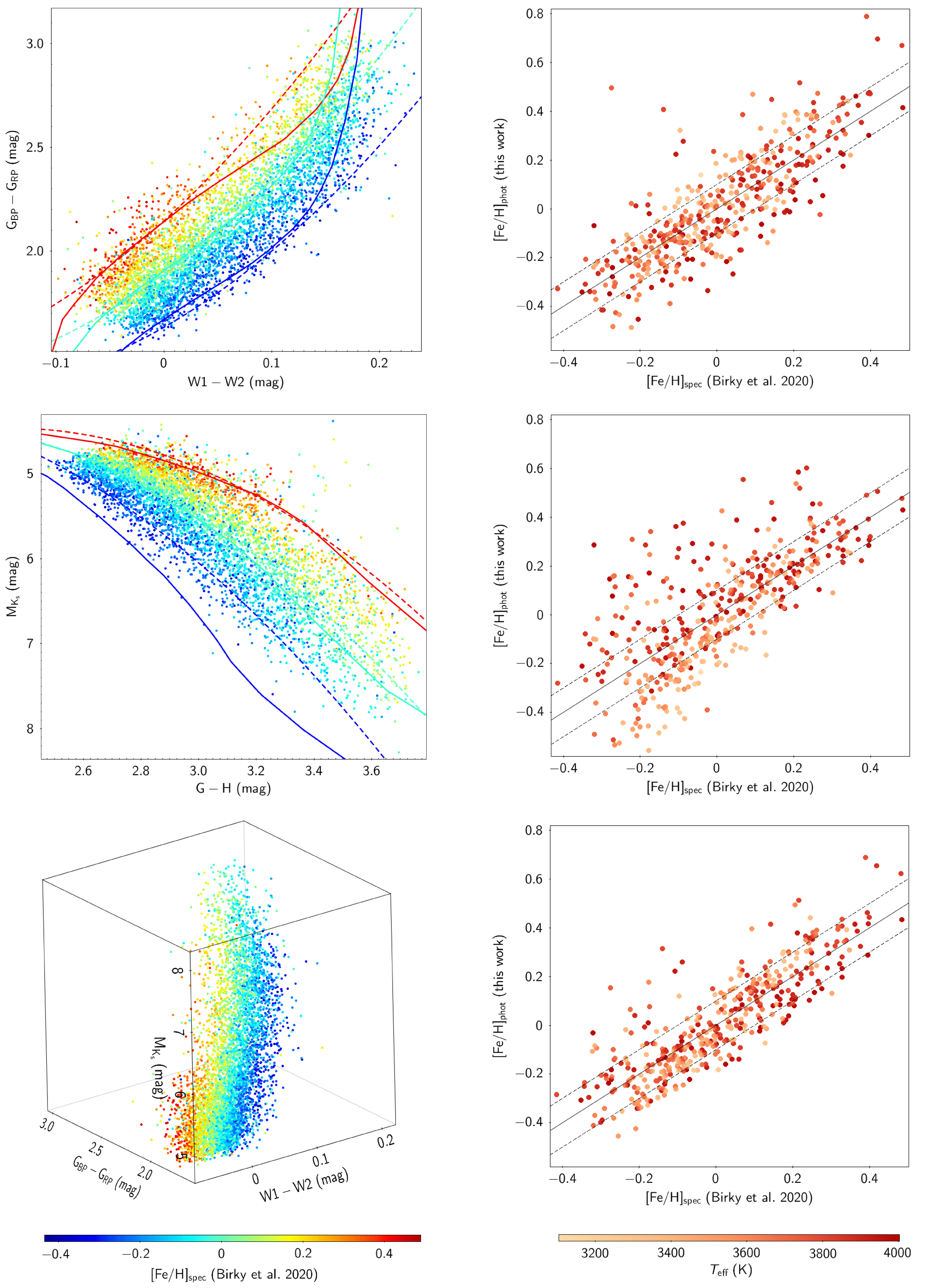
ABSTRACT. In our on-going effort to characterize M dwarfs, we have carried out **multi-band photometry calibrations of metallicity** for early and intermediate M dwarfs using ***Gaia* EDR3, *2MASS* and *AllWISE***. These catalogs, combined with a sample of 5435 M dwarfs with additional parameters determined by APOGEE high-resolution spectroscopy, allow us to study **the effect of the chemical composition in color-color and color-magnitude diagrams**. We train the calibrations using Bayesian statistics and Markov Chain Monte Carlo (MCMC) techniques and derive several photometric calibrations aplicable to M dwarfs with metallicities of $-0.4 \leq$ [Fe/H] $\leq +0.4$, obtaining **estimations reliable to 0.10 dex**. Lastly, we compare our results with previous photometric studies of metallicity for an additional sample of FGK+M common-proper-motion systems, finding a great predictive performance.

The sample of 5435 stars selected from Birky et al. (2020) is randomly divided into two sets: 5000 stars are used to train the calibrations with MCMC and the remaining 435 stars to test the accuracy of the estimations using Leave-One-Out Cross Validation (LOO-CV). Our best estimations rely on the $W1-W2$ and $G_{BP}-G_{RP}$ colors and the M_{K_s} absolute magnitude.

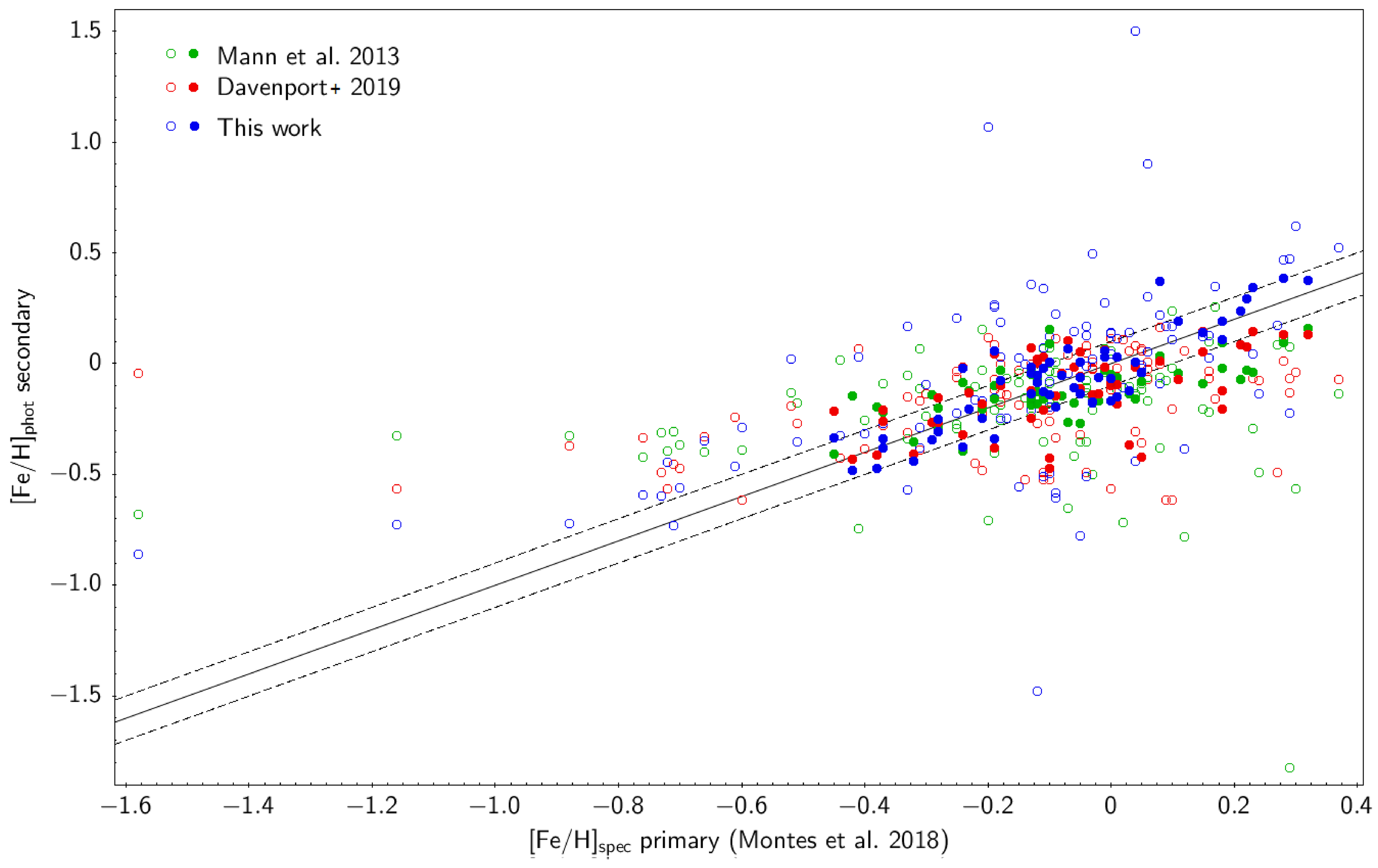
$$Y = a + bX + cX^2 + d[\mathrm{Fe/H}] + eX[\mathrm{Fe/H}] \quad (+fM)$$

$$[\mathrm{Fe/H}] = \frac{(G_{BP}-G_{RP}) - 0.596 - 2.336(W1-W2) - 0.498(W1-W2)^2 - 0.254 M_{K_s}}{0.618 + 0.960(W1-W2)}$$

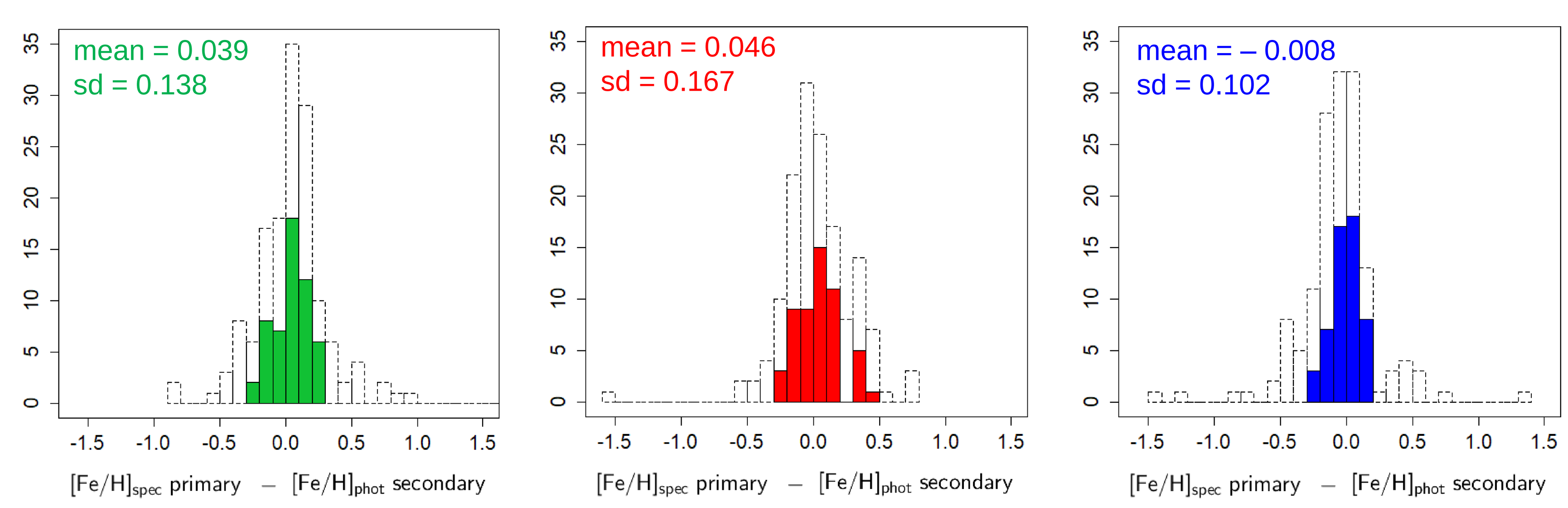


▲ **Fig. 1:** Left panels: Color-color, color-magnitude and color-color-magnitude diagrams of the stars from Birky et al. (2020), color-coded by spectroscopic [Fe/H], with theoretical isometallicity lines (solid lines, Bressan et al. 2012) and the respective calibrations given by this work (dashed lines). Right panels: Comparison between the spectroscopic metallicity reported by Birky et al. (2020) and the corresponding photometric estimations for the test subsample, color-coded by effective temperature. The solid lines denote the 1:1 relationship and the dashed lines denote the median absolute deviation (MAD).

We select 53 M dwarfs of the 148 in wide binary systems for having high-quality photometric and astrometric data. Since binaries are assumed to be born at the same time and from the same molecular cloud, the composition of the primary FGK star can be extrapolated to its secondary M dwarf.



▲ **Fig. 2:** Comparison between the spectroscopic metallicity of the primary stars reported by Montes et al. (2018) and the photometric estimations by Mann et al. (2013) (green), Davenport & Dorn-Wallenstein (2019) (red) and by this work (blue) for the secondary M dwarfs. The solid line denotes de 1:1 relationship and the dashed lines, the MAD. The open circles refer to the whole sample, while the filled circles refer to the stars with high-quality astrometric and photometric data.



▲ **Fig. 3:** Histograms of the deviation distributions $[\mathrm{Fe/H}]_{\mathrm{spec}}$ primary – estimated $[\mathrm{Fe/H}]_{\mathrm{phot}}$ secondary by Mann et al. (2013) (green), Davenport & Dorn-Wallenstein (2019) (red) and by this work (blue). The dashed histograms refer to the whole sample, while the solid ones refer to the stars with high-quality astrometric and photometric data.

References

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