Empirical correlations between stellar parameters such as rotation or radius and magnetic activity diagnostics require estimates of the effective temperatures and the stellar radii. The aim of this study is to propose simple methods that can be applied to large samples of stars in order to derive estimates of the stellar parameters. Good empirical correlations between red/infrared colors (e.g., \((R-I)\)) and effective temperatures have been well established for a long time. The more recent \((R-I)\) color–\(T_{\text{eff}}\) correlation using the data of Mann et al. (hereafter M15) and Boyajian et al. (hereafter B12) shows that this color can be applied as a temperature estimate for large samples of stars. We find that the mean scatter in \(T_{\text{eff}}\) relative to the \((R-I)\)–\(T_{\text{eff}}\) relationship of B12 and M15 data is only ±3σ = 44.6 K for K dwarfs and ±3σ = 39.4 K for M dwarfs. These figures are small and show that the \((R-I)\) color can be used as a first-guess effective temperature estimator for K and M dwarfs. We derive effective temperatures for about 1910 K and M dwarfs using the calibration of \((R-I)\)–\(T_{\text{eff}}\) from B12 and M15 data. We also compiled \(T_{\text{eff}}\) and metallicity measurements available in the literature using the VizieR database. We determine \(T_{\text{eff}}\) for 441 stars with previously unknown effective temperatures. We also identified 21 new spectroscopic binaries and one triple system from our high-resolution spectra.

**Key words:** stars: fundamental parameters – stars: late-type – stars: activity

**Supporting material:** machine-readable tables

1. Introduction

The determination of fundamental stellar parameters (\(T_{\text{eff}}, R_*,\) and \([M/H]\)) is essential to many astrophysical studies such as the determinations of exoplanet properties, the comparison to stellar interior models, and the determinations of rotation–activity correlations (RACs) and another type of magnetic activity-related correlation presented in this series of papers, e.g., the mass–activity empirical correlations (MACs hereafter). In exoplanet studies, the precise determinations of the stellar parameters are required to establish the radius of a transiting planet. Also, the mass of an exoplanet detected with a given orbital period scales as the mass of the star to the power of two-thirds.

The determinations of estimates of stellar radii are also important in order to obtain RACs and MACs with a minimum amount of scatter (e.g., Houdebine et al. 2017; E. R. Houdebine et al. 2019, in preparation). We estimate that the uncertainties in the determination of rotation periods are due to the uncertainties in stellar radius determinations by an amount of about 50%. In the present series of papers, estimates of stellar radii are also central in order to obtain meaningful empirical correlations between magnetic activity diagnostics, i.e., the Ca II resonance lines and \(R_{\text{HK}}\), and various quantities related to the stellar radius: \(L_{\text{bol}}, M_V, M_*,\) or \(R_*\). In this paper, we focus on quantities that are relevant to determining values of stellar radii and \(T_{\text{eff}}\) for a large sample of 1910 K and M dwarfs from dK3 to dM7. We shall postpone the discussion of activity indices to Paper II, when the MACs will be constructed.

The stellar parameters of K and M dwarfs were sometimes estimated by direct comparison to models (e.g., Casagrande et al. 2008; Paletou et al. 2015). However, in the case of M dwarfs, there are still numerous atomic and molecular lines that are not included in currently existing models, although there is continuing effort to improve the models (e.g., Baraffe et al. 2015). Also, the current models do not include possible NLTE effects nor the presence of spots and the chromosphere. The stellar radii obtained from the studies of low-mass eclipsing binaries (LMEBs) indicate that stellar models tend to underpredict the radii (e.g., Spada et al. 2013; Kraus et al. 2014). Mullan & MacDonald (2001) showed that these discrepancies may be due to the high activity levels of the LMEBs. On the contrary, Mann et al. (2015, hereafter M15) found some consistency between their derived values of \(L_{\text{bol}}, R_*, M_*,\) and \(T_{\text{eff}}\) and those predicted by their model calculations. Specifically, M15 found that their models systematically overpredict \(T_{\text{eff}}\) and underpredict \(R_*\) by −2.2% and 4.7%, respectively, for their hotter stars, in agreement with previous comparisons of models and LMEBs and single main-sequence field stars. M15 also found that for values of \(T_{\text{eff}}\) below 3500 K, where stars on the main sequence are predicted to be fully convective, \(F_{\text{bol}}\) was systematically underestimated by the models at the 0.2% level. For stars hotter than 3500 K, the models overestimate \(F_{\text{bol}}\) by about 0.4%. M15 also reported systematic differences between their model-based masses and those from Delfosse et al. (2000). The models predict systematically lower masses above 0.50 \(M_\odot\) and systematically higher masses below this threshold. They proposed that their model-derived masses are more precise than those from the Delfosse et al. (2000) relation.

Boyajian et al. (2012, hereafter B12) compared the luminosity–temperature, luminosity–radius, temperature–radius, and mass–radius empirical relationships for their sample of 33 K and
For radii less than 0.7
increases as $R$, line mean EW, Yonsei-Yale M dwarfs to the models of Padova, Dartmouth, BCAH, and

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M dwarfs to the models of Padova, Dartmouth, BCAH, and Yonsei-Yale (Baraffe et al. 1998; Girardi et al. 2000; Demarque et al. 2004; Dotter et al. 2008). They found that the Dartmouth and BCAH models reproduce the trends of their data the best. In their temperature–radius plane, they found that there is a lot of scatter in the radius of a star for a given temperature. B12 also found that models overpredict temperatures by an average of 6%. For radii less than 0.7 $R_\odot$, they found that models underestimate radii by about 10%, and the difference between their observations and models increases with decreasing radii up to ~50% for radii of ~0.4 $R_\odot$.

Houdebine (2008, Paper VII) found a relatively tight correlation between [M/H] and $R_\odot$ in a sample of M2 dwarfs. [M/H] decreases with decreasing $R_\odot$ in normal dwarfs and subdwarfs, such that all subdwarfs have very low [M/H] and $R_\odot$. In Houdebine et al. (2016), we performed extensive compilations of [M/H] from the literature for late-K, M3, and M4 dwarfs and correlated [M/H] and $R_\odot$. These empirical radius–[M/H] correlations emphasize that stellar radii diminish markedly with decreasing [M/H]. These empirical correlations can explain (at least in part) the scatter observed in the temperature–radius plane in B12 and M15.

As far as the current series of papers is concerned, we aim in E. R. Houdebine et al. (2019, in preparation, hereafter Paper II) to determine the efficiency of the dynamo mechanisms as a function of stellar radius and mass. An initial empirical correlation was found between the CaII line mean EW and absolute magnitude $M_V$ by Houdebine (1996) for a sample of M2 dwarfs. Later, Houdebine & Stempels (1997, Paper VI) also found correlations between the CaII line mean EW and $M_V$ for a larger sample of M2 dwarfs. In an effort to constrain the dynamo mechanisms at spectral type M2, Houdebine (2011, hereafter Paper XV) also found correlations between the CaII line mean EW, $M_V$, and [M/H] for a much larger sample of M2 dwarfs. He also found a correlation between the CaII line surface fluxes corrected for metallicity effects and radius: $F_{\text{CaII}} \propto R_\odot^{1.6}$. A consequence of this is that $L_{\text{CaII}}$ grows roughly as the power of 5.6 of the stellar radius in their M2 dwarf sample. Similar correlations were found with the H$_\alpha$ line diagnostic.

In the current series of papers, preliminary results indicate that the CaII line luminosity, $L_{\text{CaII}}$, for the samples of low activity stars from Houdebine et al. (2017) increases roughly as the power of 8 of the stellar radius, a value significantly larger than that found in Paper XV. For the active stars, $L_{\text{CaII}}$ increases as $R_\odot$ to the power of 6.6. This means that the CaII luminosity depends most sensitively on the stellar radius (or stellar mass). The power-law index for $R_\odot$ is much larger (in magnitude) than that of the corresponding index for the dependence of $L_{\text{CaII}}$ on the rotation period. For the latter, the absolute value of the power-law index is largest for dM4 stars (where the magnitude is 3.77; see Houdebine et al. 2017) and smallest for dK5 stars (for which the magnitude is 0.70). These results suggest that the efficiency of the dynamo mechanism may depend primarily on the stellar radius (or mass) in M dwarfs.

We stress that the contents of the present paper are only a first step in a two-step process that aims to derive MACs for our complete stellar sample. The second step in this process will be discussed in Paper II. The present paper focuses on obtaining estimates of the data for the “Radius” or “Mass” axis of the MACs. The subsequent paper will focus at first on obtaining reliable data for the “Activity” axis of the MACs. Once reliable data are available for both axes, a search will then be undertaken (in Paper II) to determine the correlation between radius- or mass-related parameters and activity-related diagnostics for our stellar sample.

In the aim to gather estimates of the activity parameter for a large sample of M and K dwarfs, we are currently gathering high-resolution/high signal-to-noise ratio (S/N) spectra with the SOPHIE (Haute-Provence Observatory) and NARVAL (Pic-du-Midi Observatory) high-resolution spectrographs. We aim to gather about 500 such spectra of stars that have never been observed in high-resolution spectroscopy so far. We currently have obtained high-resolution spectra for about 350 stars.

The present paper focuses on the determination of effective temperature based mainly on a correlation between the $(R - I)_c$ color and $T_{\text{eff}}$. To use this correlation, we have relied on the measurements of $(R - I)_c$ colors reported by B12 and M15. We believe that B12 provide probably the most accurate determinations of $T_{\text{eff}}$ for a sample of 33 K and M dwarfs; our belief is based on the fact that the method used by B12 is nearly independent of stellar models. As is widely recognized, models are inevitably subject to uncertainties based on incomplete opacity sources in the calculations. Moreover, the models also assume that LTE conditions hold true throughout the atmosphere. In contrast to B12, the approach used in M15 is to rely to some extent on deriving stellar parameters by taking advantage of certain models. However, M15 did not rely solely on the models: they also used the constraints provided by precision interferometry in order to derive the stellar parameters. Therefore, in the present paper, by relying in part on M15, it is important to note that interferometric measurements of stellar radii provide a first step in the process by means of which we derive stellar parameters. In a second step, we compile $T_{\text{eff}}$ and [M/H] measurements from the literature for most of our targets. When we compare our $T_{\text{eff}}$ with the values that already appeared in the literature, we find that the agreement between our results and those in the literature is generally good. As a third step in our process, we also use the Gaia DR2 parallaxes in order to ensure more reliable estimates of the stellar radii.

### 2. Selection of the Samples of Stars

It is now well established that red/infrared colors are well correlated with effective temperatures in late-K and M dwarfs (e.g., Veeder 1974; Mould & Hyland 1976; Bessel 1979; Leggett 1992; Ramirez & Melendez 2005; Boyajian et al. 2012; Mann et al. 2015; Houdebine et al. 2017). Based on our previous studies, we have found that the most suitable initial selection parameter when we wish to identify a homogeneous sample of K or M dwarfs belonging to a specific subtype is the $(R - I)$ color: this color is sensitive to $T_{\text{eff}}$, but less so to metallicity (e.g., Leggett 1992; Ramirez & Melendez 2005). Moreover, broadband colors of high precision (typically of the order of 3%, Leggett 1992) are widely available in the literature for many of the cool dwarfs that are of interest to us. Observations of $(R - I)_c$ (Cousin’s photometric system) or $(R - I)_K$ (Kron photometric system) for our samples of K and M dwarfs were taken from the following papers: Eggen (1971, 1974, 1976a, 1976b, 1978, 1979, 1980, 1987), Veeder (1974), Rodgers & Eggen (1974), Mould & Hyland (1976), Weis & Upgren (1982), Upgren & Lu (1986), Booth et al. (1988), Leggett & Hawkins (1988), Dawson & Forbes...
Table 1
Effective Temperatures and \((R - \text{I}_C)\) Colors for K and M Dwarfs

| Star     | \((R - \text{I}_C)\) (mag) | \(T_{\text{eff}}^a\) (K) | \(T_{\text{eff}}^b\) (K) | \(T_{\text{eff}}^c\) (K) | \(T_{\text{eff}}\) Diff (K) |
|----------|-----------------------------|---------------------------|---------------------------|---------------------------|-----------------------------|
| Gl 70A   | ...                         | ...                       | ...                       | ...                       | ...                         |
| Gl 75    | 0.39                        | 5346                      | 5398                      | +52                       | ...                         |
| Gl 63    | 0.39                        | 5346                      | 5337                      | -9                        | ...                         |
| Gl 53A   | 0.41                        | 5259                      | 5348                      | +89                       | ...                         |
| Gl 764   | 0.41                        | 5259                      | 5246                      | -13                       | ...                         |
| Gl 166A  | 0.45                        | 5085                      | 5202                      | +117                      | ...                         |
| Gl 144   | 0.46                        | 5041                      | 5077                      | +36                       | ...                         |
| Gl 33    | 0.47                        | 4998                      | 4950                      | -48                       | ...                         |
| Gl 892   | 0.53                        | 4737                      | 4699                      | -38                       | ...                         |
| Gl 105A  | 0.53                        | 4737                      | 4662                      | -75                       | ...                         |
| Gl 845   | 0.56                        | 4606                      | 4555                      | -51                       | ...                         |
| Gl 570A  | 0.563                       | 4598                      | 4507                      | -91                       | ...                         |
| Gl 70B   | 0.620                       | 4456                      | 4393                      | -63                       | ...                         |
| Gl 820A  | 0.644                       | 4396                      | 4451                      | +55                       | ...                         |
| Gl 488   | 0.767                       | 4084                      | 4124                      | +38                       | ...                         |
| Gl 820B  | 0.785                       | 4040                      | 4021                      | -19                       | ...                         |
| PM 23099+1425 | 0.786             | 4038                      | 4035                      | +5                        | ...                         |
| Gl 380   | 0.80                        | 4002                      | 4115                      | +113                      | ...                         |
| Gl 82B   | 0.80                        | 4002                      | 3954                      | -48                       | ...                         |
| Gl 338A  | 0.80                        | 4002                      | 3907                      | -95                       | ...                         |
| Gl 380   | 0.801                       | 4000                      | 4131                      | +131                      | ...                         |
| Gl 488   | 0.829                       | 3962                      | 3989                      | +27                       | ...                         |
| Gl 169   | 0.831                       | 3960                      | 4124                      | +164                      | ...                         |
| gL 172   | 0.849                       | 3935                      | 3929                      | -6                        | ...                         |
| Gl 56.3B | 0.858                       | 3923                      | 3935                      | +12                       | ...                         |
| Gl 338A  | 0.860                       | 3921                      | 3920                      | -1                        | ...                         |
| Gl 208   | 0.875                       | 3901                      | 3966                      | +65                       | ...                         |
| Gl 525   | 0.876                       | 3899                      | 3828                      | -71                       | ...                         |
| Gl 338B  | ...                         | ...                       | 3867                      | ...                       | ...                         |
| Gl 281   | 0.923                       | 3836                      | 3771                      | -65                       | ...                         |
| Gl 642   | 0.923                       | 3836                      | 3834                      | -2                        | ...                         |
| Gl 458.2 | 0.939                       | 3828                      | 3900                      | +72                       | ...                         |
| Gl 875   | 0.942                       | 3825                      | 3740                      | -85                       | ...                         |
| Gl 239   | 0.943                       | 3824                      | 3801                      | -23                       | ...                         |
| PM 22290+0139 | 0.946              | 3822                      | 3903                      | +81                       | ...                         |
| Gl 471   | 0.947                       | 3821                      | 3726                      | -95                       | ...                         |
| Gl 3108  | 0.954                       | 3815                      | 3852                      | +37                       | ...                         |
| Gl 79    | 0.961                       | 3809                      | 3900                      | +91                       | ...                         |
| Gl 838.3B| 0.970                       | 3802                      | 3771                      | -31                       | ...                         |
| Gl 864   | 0.980                       | 3793                      | 3916                      | +123                      | ...                         |
| Gl 846   | 0.988                       | 3787                      | 3848                      | +61                       | ...                         |
| Gl 678.1A| 0.990                       | 3785                      | 3675                      | -110                      | ...                         |
| Gl 709   | 0.992                       | 3783                      | 3785                      | +2                        | ...                         |
| Gl 740   | 1.002                       | 3775                      | 3834                      | +59                       | ...                         |
| Gl 459.3 | 1.005                       | 3772                      | 3993                      | +221                      | ...                         |
| Gl 809   | 1.011                       | 3767                      | 3791                      | +24                       | ...                         |
| Gl 353   | 1.014                       | 3764                      | 3692                      | -72                       | ...                         |
| Gl 505B  | 1.018                       | 3760                      | 3709                      | -51                       | ...                         |
| Gl 96    | 1.019                       | 3759                      | 3785                      | +26                       | ...                         |
| Gl 894.1 | 1.030                       | 3749                      | 3910                      | +161                      | ...                         |
| Gl 277.1 | 1.036                       | 3744                      | 3681                      | -63                       | ...                         |
| Gl 3408B | 1.062                       | 3720                      | 3656                      | -64                       | ...                         |
| Gl 809   | 1.064                       | 3718                      | 3692                      | -26                       | ...                         |
| Gl 514   | 1.065                       | 3717                      | 3727                      | +10                       | ...                         |
| Gl 412A  | 1.076                       | 3707                      | 3497                      | -210                      | ...                         |
| Gl 205   | 1.077                       | 3706                      | 3801                      | +95                       | ...                         |
| Gl 887   | 1.079                       | 3704                      | 3688                      | -16                       | ...                         |
| Gl 272   | 1.081                       | 3703                      | 3703                      | +0                        | ...                         |
| Gl 212   | 1.085                       | 3699                      | 3765                      | +66                       | ...                         |
| Gl 887   | 1.088                       | 3696                      | 3676                      | -20                       | ...                         |
| Gl 701   | 1.091                       | 3693                      | 3614                      | -79                       | ...                         |
| Gl 649   | 1.094                       | 3691                      | 3700                      | +9                        | ...                         |
| Gl 685   | 1.096                       | 3689                      | 3846                      | +157                      | ...                         |

(Continued)
Table 1 (Continued)

| Star     | (R − I) <sub>C</sub> (mag) | T<sub>eff</sub><sup>a</sup> (K) | T<sub>eff</sub><sup>b</sup> (K) | T<sub>eff</sub><sup>c</sup> (K) | T<sub>eff</sub> Diff (K) |
|----------|-----------------------------|-------------------------------|-------------------------------|-------------------------------|------------------------|
| PM 06077–2544 | 1.433                        | 3403                          | 3356                          | ...                          | −47                    |
| GJ 1236   | 1.433                        | 3403                          | 3335                          | ...                          | −68                    |
| GJ 4040   | 1.437                        | 3399                          | 3470                          | ...                          | +71                    |
| GJ 849    | 1.438                        | 3398                          | 3530                          | ...                          | +132                   |
| GJ 388    | 1.452                        | 3386                          | 3370                          | ...                          | −16                    |
| GJ 251    | 1.456                        | 3383                          | 3448                          | ...                          | +65                    |
| GJ 3388   | 1.464                        | 3376                          | 3326                          | ...                          | −50                    |
| GJ 725B   | 1.474                        | 3367                          | 3345                          | ...                          | −22                    |
| GJ 3992   | 1.478                        | 3364                          | 3432                          | ...                          | +68                    |
| PM 09555–2715 | 1.480                      | 3362                          | 3346                          | ...                          | −16                    |
| GJ 3325   | 1.480                        | 3362                          | 3365                          | ...                          | +3                     |
| GJ 480    | 1.487                        | 3356                          | 3463                          | ...                          | +107                   |
| GJ 403    | 1.491                        | 3353                          | 3298                          | ...                          | −55                    |
| GJ 643    | 1.491                        | 3353                          | 3279                          | ...                          | −74                    |
| PM 00118+2259 | 1.527                       | 3222                          | 3359                          | ...                          | +37                    |
| GJ 545    | 1.539                        | 3311                          | 3341                          | ...                          | +30                    |
| GJ 896A   | 1.546                        | 3305                          | 3353                          | ...                          | +48                    |
| GJ 628    | 1.561                        | 3292                          | 3272                          | ...                          | −20                    |
| PM 15354+6005 | 1.572                      | 3283                          | 3252                          | ...                          | −31                    |
| GJ 876    | 1.574                        | 3282                          | 3247                          | ...                          | −35                    |
| GJ 3378   | 1.575                        | 3281                          | 3340                          | ...                          | +59                    |
| GJ 1148   | 1.582                        | 3274                          | 3304                          | ...                          | +30                    |
| GJ 273    | 1.585                        | 3272                          | 3317                          | ...                          | +45                    |
| GJ 699    | 1.585                        | 3272                          | 3228                          | ...                          | −44                    |
| GJ 699    | 1.592                        | 3266                          | ...                            | ...                          | −42                    |
| GJ 15B    | 1.595                        | 3263                          | 3218                          | ...                          | −45                    |
| GJ 3707   | 1.599                        | 3260                          | 3385                          | ...                          | +125                   |
| GJ 4065   | 1.599                        | 3260                          | 3223                          | ...                          | −37                    |
| GJ 118.2C | 1.600                        | 3259                          | 3227                          | ...                          | −32                    |
| GJ 105B   | 1.607                        | 3254                          | 3284                          | ...                          | +30                    |
| GJ 1207   | 1.608                        | 3254                          | 3229                          | ...                          | −25                    |
| GJ 729    | 1.610                        | 3252                          | 3240                          | ...                          | −12                    |
| GJ 402    | 1.616                        | 3248                          | 3238                          | ...                          | −10                    |
| GJ 3150   | 1.617                        | 3248                          | 3216                          | ...                          | −32                    |
| GJ 4269   | 1.622                        | 3244                          | 3226                          | ...                          | −18                    |
| GJ 4333   | 1.623                        | 3244                          | 3324                          | ...                          | +80                    |
| PM 19321–1119 | 1.626                     | 3242                          | 3211                          | ...                          | −31                    |
| GJ 1129   | 1.631                        | 3239                          | 3243                          | ...                          | +4                     |
| GJ 3379   | 1.633                        | 3237                          | 3214                          | ...                          | −23                    |
| GJ 783.2B | 1.633                        | 3237                          | 3217                          | ...                          | −20                    |
| GJ 4367   | 1.633                        | 3237                          | 3221                          | ...                          | −16                    |
| GJ 1092   | 1.639                        | 3233                          | 3207                          | ...                          | −26                    |
| GJ 213    | 1.643                        | 3231                          | 3250                          | ...                          | +19                    |
| PM 20525–1658 | 1.643                    | 3231                          | 3205                          | ...                          | −26                    |
| GJ 555    | 1.648                        | 3227                          | 3211                          | ...                          | −16                    |
| GJ 544B   | 1.659                        | 3220                          | 3191                          | ...                          | −29                    |
| GJ 324B   | 1.660                        | 3219                          | 3166                          | ...                          | −53                    |
| GJ 3991   | 1.663                        | 3217                          | 3284                          | ...                          | +67                    |
| GJ 3105   | 1.674                        | 3210                          | 3269                          | ...                          | +59                    |
| GJ 53.1B  | 1.675                        | 3210                          | 3232                          | ...                          | +22                    |
| PM 18453+1851 | 1.675                   | 3210                          | 3214                          | ...                          | −4                     |
| GJ 3142   | 1.677                        | 3208                          | 3257                          | ...                          | +49                    |
| GJ 1289   | 1.677                        | 3208                          | 3173                          | ...                          | −35                    |
| GJ 232    | 1.679                        | 3207                          | 3165                          | ...                          | −42                    |
| GJ 447    | 1.697                        | 3198                          | 3192                          | ...                          | −6                     |
| GJ 102    | 1.698                        | 3194                          | 3199                          | ...                          | +5                     |
| GJ 3323   | 1.706                        | 3189                          | 3143                          | ...                          | −46                    |
| GJ 166C   | 1.726                        | 3176                          | 3167                          | ...                          | −9                     |
| GJ 585    | 1.737                        | 3169                          | 3164                          | ...                          | −5                     |
| GJ 1230A  | 1.740                        | 3167                          | 3232                          | ...                          | +65                    |
| GJ 1151   | 1.761                        | 3153                          | 3118                          | ...                          | −35                    |
| GJ 3668   | 1.781                        | 3140                          | 3109                          | ...                          | −31                    |
| PM 03361+3118 | 1.787                     | 3136                          | 3086                          | ...                          | −50                    |

Notes. In Column 3, we list the T<sub>eff</sub> values we have obtained in the present paper using our (R − I)<sub>C</sub>−T<sub>eff</sub> calibration. In Columns 4 and 5, we list the T<sub>eff</sub> values reported by M15 and by B12, respectively.

* Effective temperature from the (R − I) <sub>C</sub> color−T<sub>eff</sub> calibration.

† Effective temperature from Mann et al. (2015).

‡ Effective temperature from Boyajian et al. (2012).

(This table is available in machine-readable form.)

(1989, 1992, Laing (1989), Bessel (1990), Weis (1991a, 1991b, 1993, 1996), Leggett (1992), Ryan (1992), Ruiz & Anguita (1993), Reid et al. (2004), and Koen et al. (2010).)
**Table 2**

Parameters of Our Sample of Mid-K, Late-K Stars, M0–M1, M2, M3, M4, M5, M6, and M7 Dwarfs

| Star      | V (mag) | (R − D$_C$) (mag) | $T_{\text{eff}}^a$ (K) | $T_{\text{eff}}^b$ (K) | $T_{\text{eff}}$ ± 3σ$^c$ (K) | Spect. Type | M$_V$ (mag) | $R_*$ (R$_\odot$) | [M/H] | Hi. Res. Spectra | Comments |
|-----------|---------|------------------|-----------------|-----------------|-------------------------------|-------------|-------------|----------------|--------|------------------|----------|
| GJ 1139   | 9.567   | 0.656            | 4366            | 4391            | 4378 ± 13                     | dK5.4       | 43.4531 ± 0.0293 | 7.757 ± 0.021 | 0.592 ± 0.016 | −0.33   |                 |          |
| GJ 1176   | 9.225   | 0.620            | 4456            | 4509            | 4482 ± 27                     | dK4.3       | 40.6674 ± 0.0433 | 7.271 ± 0.022 | 0.686 ± 0.025 | +0.07   |                 | 35       |
| GJ 1189   | 9.30    | 0.566            | 4591            | 4577            | 4584 ± 7                      | dK3.6       | 30.6458 ± 0.0552 | 6.732 ± 0.024 | 0.813 ± 0.018 | +0.04   |                 |          |
| GJ 1190   | 9.839   | 0.644            | 4396            | 4333            | 4364 ± 31                     | dK5.4       | 38.8659 ± 0.0589 | 7.787 ± 0.023 | 0.591 ± 0.024 | −0.95   |                 |          |
| GJ 1257   | 9.811   | 0.694            | 4270            | 4310            | 4340 ± 30                     | dK5.6       | 41.3937 ± 0.0643 | 7.896 ± 0.023 | 0.572 ± 0.023 | −0.23   |                 |          |
| GJ 1259   | 8.770   | 0.674            | 4321            | 4398            | 4359 ± 39                     | dK5.5       | 41.5127 ± 0.0553 | 6.861 ± 0.023 | 0.908 ± 0.043 | +0.01   |                 | 2        |
| GJ 2018   | 9.956   | 0.572            | 4576            | 4563            | 4569 ± 6                      | dK3.6       | 27.5963 ± 0.0422 | 7.160 ± 0.023 | 0.675 ± 0.014 | −0.17   |                 | 2        |
| GJ 2096   | 9.10    | 0.638            | 4411            | 4328            | 4369 ± 41                     | dK5.4       | 38.1457 ± 0.7610 | 7.007 ± 0.063 | 0.842 ± 0.058 | −0.73   |                 |          |
| ...       | ...     | ...              | ...             | ...             | ...                           | ...         | ...         | ...            | ...    | ...             | ...      |
| ...       | ...     | ...              | ...             | ...             | ...                           | ...         | ...         | ...            | ...    | ...             | ...      |
| GJ 1111   | 14.855  | 2.339            | 2800            | 2786            | 2793 ± 7                      | dM7.2       | 279.2901 ± 0.1345 | 17.085 ± 0.021 | 0.086 ± 0.006 | −0.13   |                 | 3        |
| GJ 3517   | 18.959  | 2.252            | 2832            | 2582            | 2707 ± 125                    | dM8.3       | 115.3036 ± 0.1132 | 19.268 ± 0.022 | 0.040 ± 0.019 | +0.21   |                 | 3        |
| GJ 3622   | 15.60   | 2.374            | 2800            | 2717            | 2758 ± 41                     | dM7.7       | 219.1159 ± 0.1567 | 17.303 ± 0.022 | 0.085 ± 0.014 | −0.26   |                 | 5        |
| GJ 3877   | 17.141  | 2.39             | 2781            | 2700            | 2740 ± 40                     | dM7.9       | 141.6865 ± 0.1063 | 17.898 ± 0.022 | 0.068 ± 0.011 | 8       |
| GJ 4281   | 17.08   | 2.34             | 2800            | ...             | 2800 ± 54                     | dM7.2       | 91.8949 ± 0.0948 | 16.896 ± 0.022 | 0.092 ± 0.019 | 4       |
| GJ 658    | 12.81   | 2.22             | 2845            | ...             | 2845 ± 54                     | dM6.6       | 372.1631 ± 0.2503 | 15.664 ± 0.022 | 0.146 ± 0.031 | −0.21   |                 | 7        |
| GJ 653B   | 15.698  | 2.23             | 2838            | 2530            | 2681 ± 151                    | dM8.6       | 109.0542 ± 0.0827 | 16.884 ± 0.022 | 0.127 ± 0.074 | ...     |                 | ...      |
| GJ 406    | 13.507  | 2.210            | 2848            | 2812            | 2830 ± 18                     | dM6.8       | 418.3 ± 2.5       | 16.614 ± 0.033 | 0.098 ± 0.010 | 52      |
| GJ 444C   | 16.916  | 2.061            | 2767            | 2745            | 2756 ± 11                     | dM7.7       | 153.8139 ± 0.1148 | 17.851 ± 0.022 | 0.067 ± 0.005 | −0.14   |                 | 5        |
| GJ 752B   | 17.370  | 2.283            | 2821            | 2670            | 2745 ± 75                     | dM7.8       | 168.9620 ± 0.1299 | 18.509 ± 0.022 | 0.051 ± 0.014 | +0.05   |                 | 8        |
| LHS 325A  | 18.67   | 2.24             | 2836            | ...             | 2836 ± 54                     | dM6.7       | 47.5722 ± 0.1323 | 17.057 ± 0.026 | 0.079 ± 0.015 | ...     |                 | ...      |
| LHS 2351  | 19.560  | 2.34             | 2800            | 2710            | 2755 ± 45                     | dM7.7       | 46.8910 ± 0.1620 | 17.915 ± 0.027 | 0.065 ± 0.012 | −0.44   |                 | ...      |
| LHS 2397  | 19.24   | 2.300            | 2814            | 2700            | 2757 ± 57                     | dM7.7       | 18.9008 ± 0.1590 | 15.622 ± 0.038 | 0.186 ± 0.043 | ...     |                 | ...      |
| LSPM J0253+1652 | 15.133 | 2.400 | 2776 | 2719 | 2747 ± 28 | dM7.8 | 261.0147 ± 0.2690 | 17.216 ± 0.022 | 0.092 ± 0.012 | ... |

**Notes.** We also indicate the number of high-resolution spectra for the stars that we have observed.

- $^a$ From the (R − D$_C$) color.
- $^b$ Compiled from the literature.
- $^c$ Mean effective temperature.

(This table is available in its entirety in machine-readable form.)
found to have higher temperatures (we included in the M0–M1 sample stars down to the spectral type dM1.5).

We note, however, that spectral classification may differ from one author to another. In this regard, in previous papers on dM1 stars (Houdebine 2008, Paper VII; Houdebine 2009, Paper XIII; Houdebine 2009, Paper IX; Houdebine 2010a, Paper XIV; Houdebine 2010c, Paper X; Paper XV; Houdebine et al. 2012, Paper XIX), we used a different calibration. According to their infrared colors and the classification of Leggett (1992), these stars are in fact dM2 stars. We shall use this calibration in the future, and therefore, all our previous work on “dM1” stars in this series of papers should be considered as papers referring to dM2 stars.

Our principal goal in this series of papers is to constrain the MACs by determining the radii of our sample stars as well as the level of magnetic activity in the CaII and Hα spectral lines. Searching through databases at the European Southern Observatory (ESO) and Observatoire de Haute Provence (OHP), we identified spectra of about 800 different stars which are suitable for our purposes. These spectra will be studied in E. R. Houdebine et al. (2019b, in preparation). The spectra of these databases are completed by our own observations with the spectrograph SOPHIE (OHP) and NARVAL (Pic-Du-Midi). These observations include about 430 high-resolution spectra of dwarfs never observed in the CaII lines in high-resolution spectroscopy before, from late-K to M5.

Here, we focus on the determination of the effective temperature and radius for the stars in our samples. In the samples presented here, we do not include all the stars in the lists above except for the M6 and M7 samples in which all our stars are included in order to obtain better statistics. For our samples, we notably included all stars with determined metallicities. The final list of our samples of stars is provided in Table 2.

### 3. Stellar Parameters

Here, we discuss the methods we use to derive $T_{\text{eff}}$ and radius for each of our samples of stars. Reliable estimates of the radii and masses are important if we wish (as in Paper II) to determine reliable MACs.

#### 3.1. Effective Temperatures

B12 used interferometric observations to determine with high precision (better than 5%) the diameters of 33 K and M dwarfs. They derived empirical correlations linking the effective temperature to broadband colors including $(V - R)$ and $(V - I)$ (from which we derive $(R - I)$). Their correlations were obtained for stars ranging in spectral type from K0 to M4. Similarly, M15 derived accurate stellar parameters, notably the

![Figure 1: Values of $T_{\text{eff}}$ as a function of the $(R - I)_c$ color for the data of B12 (filled circles) and M15 (open circles) and a smoothing of these data (solid line). Also shown for comparison: the calibration of Kenyon & Hartmann (1995). This later calibration agrees well with the more recent measures of Mann et al. (2015) up to $(R - I)_c = 1.3$, but tends to overestimate $T_{\text{eff}}$ for later spectral types. We overplot the $(R - I)_c$ domains of our samples of stars from mid-K to dM7.](image)
radii of K7–M7 single stars with a precision of 2%–5%, as well as model-independent relations between $T_{\text{eff}}$ and broadband colors. We show the empirical relationships between $T_{\text{eff}}$ and the $(R-I)_C$ color in Figure 1 for these two calibrations. We give the measurements of $(R-I)_C$ and $T_{\text{eff}}$ from B12 and M15 in Table 1. We can see in Figure 1 that the two parameters are tightly correlated for dwarf stars ranging in spectral type from K0 to M7. We also show the calibration of $T_{\text{eff}}$ as a function of $(R-I)_C$ from Kenyon & Hartmann (1995) in Figure 1 for comparison. We overplot a smoothing of the data of B12 and M15 (continuous line) to the calibrations of B12 and M15, we have determined values of $T_{\text{eff}}$ from our compilations of $(R-I)_C$ measurements for all our target stars (see Tables 1 and 2). In Table 2, values of $T_{\text{eff}}$ that we have derived from our smoothed continuous line in Figure 1 are listed in column 4.

We also aim in this study to provide an extensive compilation of previous measurements of $T_{\text{eff}}$, we queried all catalogs in the VizieR database (CDS, Strasbourg, France). To this end, we used the tutorial developed by Paletou & Zolotukhin (2014). The results of the queries provide us with thousands of measurements for several thousands of stars in all our target lists.

Figure 2. Comparison between two sets of values of $T_{\text{eff}}$: (i) taken from the literature and (ii) derived from the $(R-I)_C/T_{\text{eff}}$ correlations that have been derived by M15 and B12. Continuous line: the correlation that would exist if there was an exact one-to-one correspondence between the two sets of $T_{\text{eff}}$. Dashed line: the best-fit correlation when the data are smoothed by a Gaussian of FWHM 30 K. Note that there exists a good overall agreement between the smoothed data and the expectations of a one-to-one correspondence.
Table 3
The List of Effective Temperatures from Some Authors (Morales et al. 2008; Jenkins et al. 2009; Wright et al. 2011; Lepine et al. 2013; Stelzer et al. 2013; Gaidos et al. 2014) for Our Sample of dM4 Stars

| Star       | $T_{\text{eff}}$ (K) | $T_{\text{eff}}$ (K) | $T_{\text{eff}}$ (K) | $T_{\text{eff}}$ (K) | $T_{\text{eff}}$ (K) | $T_{\text{eff}}$ (K) |
|------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
|            | This Work            | Morales et al. (2008)| Jenkins et al. (2009)| Wright et al. (2011)| Stelzer et al. (2013)| Lepine et al. (2013)| Gaidos et al. (2014) |
| GJ 1001A   | 3297                 | ...                  | ...                  | ...                  | ...                  | ...                  |
| GJ 1005AB  | 3315                 | ...                  | ...                  | ...                  | ...                  | ...                  |
| GJ 1006A   | 3273                 | ...                  | ...                  | ...                  | ...                  | 3250                 |
| GJ 1006B   | 3263                 | ...                  | ...                  | ...                  | ...                  | 3100                 |
| GJ 1013    | 3304                 | ...                  | ...                  | ...                  | ...                  | 3243                 |
| GJ 1034    | 3250                 | ...                  | 3035                 | ...                  | ...                  | ...                  |
| GJ 1092    | 3251                 | 3093                 | ...                  | ...                  | ...                  | ...                  |
| GJ 1105    | 3315                 | ...                  | ...                  | ...                  | 3241                 | 3280                 |
| GJ 1129    | 3246                 | ...                  | ...                  | ...                  | ...                  | 3209                 |
| GJ 1134    | 3223                 | ...                  | 2996                 | ...                  | ...                  | 3158                 |
| GJ 1138    | 3233                 | ...                  | ...                  | 3089                 | 3140                 | 3161                 |
| GJ 1174    | 3317                 | ...                  | ...                  | ...                  | 3230                 | 3201                 |
| GJ 1207    | 3270                 | ...                  | ...                  | 3241                 | ...                  | 3206                 |
| GJ 1218AB  | 3304                 | ...                  | ...                  | ...                  | ...                  | 3281                 |
| GJ 1222    | 3291                 | ...                  | ...                  | ...                  | ...                  | 3162                 |
| GJ 1235    | 3231                 | ...                  | ...                  | 3089                 | 3060                 | 3099                 |
| GJ 1254    | 3287                 | ...                  | ...                  | ...                  | 3280                 | 3226                 |
| GJ 1263    | 3336                 | ...                  | ...                  | ...                  | ...                  | 3252                 |
| GJ 1265    | 3231                 | ...                  | ...                  | ...                  | ...                  | 3023                 |
| GJ 1270    | 3254                 | ...                  | ...                  | ...                  | ...                  | 3133                 |
| GJ 1289    | 3223                 | ...                  | 2969                 | ...                  | 3165                 | 3100                 |
| GJ 2043B   | 3246                 | 3130                 | ...                  | ...                  | ...                  | ...                  |
| GJ 2069A   | 3263                 | ...                  | ...                  | ...                  | 3100                 | 3374                 |
| GJ 3149B   | 3263                 | 3190                 | ...                  | ...                  | ...                  | 3209                 |
| GJ 3198    | 3338                 | ...                  | ...                  | ...                  | ...                  | 3447                 |
| GJ 3225    | 3302                 | ...                  | ...                  | ...                  | ...                  | 3256                 |
| GJ 3263AB  | 3340                 | ...                  | ...                  | ...                  | ...                  | 3290                 |
| GJ 3322A   | 3283                 | ...                  | ...                  | ...                  | ...                  | 3348                 |
| GJ 3374B   | 3330                 | ...                  | ...                  | ...                  | ...                  | 3240                 |
| GJ 3466    | 3208                 | ...                  | ...                  | ...                  | ...                  | 3100                 |
| GJ 3522AB  | 3254                 | ...                  | ...                  | 3241                 | 3140                 | 3170                 |
| GJ 3577A   | 3304                 | ...                  | ...                  | 3500                 | ...                  | ...                  |
| GJ 3612    | 3343                 | ...                  | ...                  | ...                  | 3290                 | 3440                 |
| GJ 3631AB  | 3246                 | ...                  | 2966                 | ...                  | ...                  | ...                  |
| GJ 3666    | 3325                 | ...                  | ...                  | ...                  | 3250                 | 3239                 |
| GJ 3707    | 3273                 | ...                  | 3033                 | ...                  | ...                  | 3270                 |
| GJ 3764    | 3351                 | ...                  | ...                  | ...                  | 3473                 |
| GJ 3779    | 3278                 | ...                  | ...                  | ...                  | 3130                 | 3259                 |
| GJ 3780    | 3288                 | ...                  | ...                  | ...                  | ...                  | 3320                 |
| GJ 3789    | 3263                 | ...                  | 2951                 | ...                  | 3150                 | 3389                 |
| GJ 3800    | 3216                 | ...                  | ...                  | ...                  | ...                  | 3265                 |
| GJ 3801    | 3336                 | 3240                 | ...                  | 3241                 | 3280                 | 3157                 |
| GJ 3804    | 3348                 | 3300                 | ...                  | ...                  | ...                  | 3274                 |
| GJ 3839    | 3224                 | ...                  | ...                  | ...                  | 3130                 | 3242                 |
| GJ 3843    | 3353                 | ...                  | ...                  | ...                  | 3283                 |
| GJ 3873    | 3272                 | ...                  | ...                  | 3240                 | 3403                 |
| GJ 3900    | 3283                 | ...                  | ...                  | ...                  | 3300                 |
| GJ 3919    | 3269                 | ...                  | ...                  | 3100                 | 3238                 |
| GJ 4063AB  | 3315                 | ...                  | 3265                 | ...                  | ...                  | 3342                 |
| GJ 4185B   | 3304                 | ...                  | ...                  | 3260                 | 3302                 |
| GJ 4186B   | 3293                 | ...                  | ...                  | ...                  | 3302                 |
| GJ 4207    | 3341                 | ...                  | ...                  | ...                  | 3340                 |
| GJ 4333    | 3258                 | 3150                 | ...                  | ...                  | 3280                 |
| GJ 4333B   | 3246                 | ...                  | ...                  | ...                  | 3150                 |
| GJ 4367    | 3248                 | ...                  | ...                  | ...                  | ...                  |
| GJ 4378A   | 3293                 | ...                  | ...                  | ...                  | ...                  |
| GJ 4387AB  | 3309                 | ...                  | ...                  | ...                  | ...                  |
| GJ 9652B   | 3309                 | 3260                 | ...                  | ...                  | ...                  |
| GI 15B     | 3270                 | ...                  | ...                  | 3241                 | 3260                 |
| GI 46      | 3338                 | 3260                 | ...                  | ...                  | ...                  |

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Table 3
(Continued)

| Star | $T_{\text{eff}}$ (K) | $T_{\text{eff}}$ (K) | $T_{\text{eff}}$ (K) | $T_{\text{eff}}$ (K) | $T_{\text{eff}}$ (K) | $T_{\text{eff}}$ (K) |
|------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|      | This Work       | Morales et al.  | Jenkins et al.  | Wright et al.   | Stelzer et al.  | Lepine et al.   |
|      |                 | (2008)          | (2009)          | (2011)          | (2013)          | (2013)          |
| Gl 54.1 | 3188           | ...             | ...             | 3089            | ...             | 3062            |
| Gl 84.1B | 3348           | 3190            | ...             | ...             | ...             | 3400            |
| Gl 102 | 3394            | ...             | ...             | 3165            | 3130            | 3190            |
| Gl 105B | 3254           | 3130            | 3042            | ...             | 3165            | 3130            |
| Gl 166C | 3239           | 3070            | ...             | 3301            | ...             | ...             |
| Gl 169.1A | 3259          | 3272            | 3000            | ...             | 3165            | 3100            |
| Gl 179 | 3352            | ...             | ...             | ...             | 3260            | 3457            |
| Gl 206AB | 3336           | 3137            | ...             | ...             | 3200            | 3292            |
| Gl 213 | 3242            | ...             | ...             | 3165            | 3100            | 3122            |
| Gl 232 | 3207            | 3019            | ...             | 3089            | 3060            | 3099            |
| Gl 268AB | 3192           | 3184            | ...             | 3089            | 3130            | 3069            |
| Gl 273 | 3294            | ...             | 3093            | 3089            | 3130            | 3317            |
| Gl 277B | 3302            | ...             | 3079            | ...             | 3400            | 3604            |
| Gl 285 | 3196            | ...             | 2975            | 3482            | 3089            | 3130            |
| Gl 299 | 3187            | ...             | 3036            | ...             | 3089            | 3050            |
| Gl 300 | 3206            | ...             | ...             | 3165            | ...             | 3212            |
| Gl 317 | 3314            | ...             | ...             | ...             | 3400            | 3490            |
| Gl 319B | 3325            | ...             | ...             | ...             | ...             | 3555            |
| Gl 324B | 3226            | 3130            | ...             | ...             | 3166            | 3166            |
| Gl 347B | 3246           | 3080            | ...             | ...             | ...             | 3498            |
| Gl 375A | 3344           | 3260            | ...             | 3834            | ...             | 3354            |
| Gl 398 | 3328            | ...             | ...             | ...             | 3140            | 3367            |
| Gl 402 | 3099            | ...             | 3038            | ...             | 3165            | 3100            |
| Gl 431 | 3354            | 3300            | ...             | 3580            | ...             | 3399            |
| Gl 445 | 3328            | 3240            | 3137            | ...             | 3241            | 3300            |
| Gl 447 | 3198            | ...             | 2966            | ...             | 3165            | 3130            |
| Gl 452.1 | 3354           | ...             | ...             | ...             | 3270            | 3298            |
| Gl 458B | 3325           | 3320            | ...             | ...             | ...             | ...             |
| Gl 469 | 3329            | 3260            | ...             | ...             | 3180            | 3239            |
| Gl 486 | 3313            | 3240            | 3086            | ...             | 3241            | 3290            |
| Gl 490B | 3263            | 3130            | 3055            | ...             | ...             | 3150            |
| Gl 512B | 3225            | 3130            | ...             | ...             | ...             | 3577            |
| Gl 520C | 3273            | 3150            | ...             | ...             | ...             | ...             |
| Gl 545 | 3321            | ...             | ...             | ...             | ...             | 3253            |
| Gl 553.1 | 3355           | 3260            | ...             | ...             | ...             | 3231            |
| Gl 555 | 3240            | 3150            | 2984            | ...             | 3165            | ...             |
| Gl 568AB | 3312           | 3240            | ...             | ...             | 3280            | 3185            |
| Gl 590 | 3252            | ...             | ...             | ...             | ...             | 3103            |
| Gl 592 | 3293            | ...             | ...             | ...             | ...             | 3263            |
| Gl 609 | 3263            | ...             | ...             | 3165            | 3100            | 3105            |
| Gl 630.1A | 3204           | ...             | 2887            | ...             | ...             | 3073            |
| Gl 643 | 3305            | 3210            | 3104            | ...             | 3241            | 3438            |
| Gl 669A | 3319            | ...             | 3104            | 3660            | ...             | 3260            |
| Gl 682 | 3268            | 3190            | ...             | ...             | 3241            | 3190            |
| Gl 695B | 3345            | 3300            | ...             | ...             | 3241            | ...             |
| Gl 699 | 3266            | ...             | ...             | 3165            | 3100            | 3237            |
| Gl 712B | 3304            | 3210            | ...             | ...             | 3200            | 3239            |
| Gl 725B | 3336            | ...             | 3172            | ...             | 3241            | 3290            |
| Gl 729 | 3276            | 3240            | ...             | 3191            | 3241            | ...             |
| Gl 732A | 3293            | ...             | ...             | ...             | ...             | 3207            |
| Gl 766AB | 3223           | ...             | ...             | ...             | 3100            | 3278            |
| Gl 781.1B | 3274           | 3190            | ...             | ...             | ...             | 3412            |
| Gl 783.2B | 3247           | 3150            | ...             | ...             | ...             | ...             |
| Gl 791.2A | 3212           | ...             | 2896            | 3264            | 3089            | 2980            |
| Gl 810A | 3249            | ...             | ...             | ...             | ...             | 3253            |
| Gl 812A | 3319            | ...             | 3141            | ...             | ...             | 3399            |
| Gl 855A | 3337            | 3280            | ...             | ...             | ...             | 3396            |
| Gl 865B | 3377            | 3280            | ...             | ...             | ...             | 3326            |
| Gl 873A | 3325            | 3260            | 3168            | 3521            | 3241            | 3270            |
| Gl 876A | 3304            | ...             | 3172            | ...             | 3165            | ...             |
| Gl 896A | 3358            | 3280            | 3090            | 3328            | 3089            | 3290            |

*This Work* / Morales et al. (2008) / Jenkins et al. (2009) / Wright et al. (2011) / Stelzer et al. (2013) / Lepine et al. (2013) / Gaidos et al. (2014)
However, the queries are carried out for all objects around the coordinates of the target stars. For instance, in the case of binaries, most often, measurements of the two binary components are included in the compilations. Also, some other brighter or fainter stars (for instance, white dwarfs) may be included. As a consequence, many spurious $T_{\text{eff}}$ measurements are included in our compilations. In order to be sure we have only the correct measurements of our target stars, we had to

### Table 3 (Continued)

| Star | $T_{\text{eff}}^a$ (K) | $T_{\text{eff}}$ (K) | $T_{\text{eff}}$ (K) | $T_{\text{eff}}$ (K) | $T_{\text{eff}}$ (K) | $T_{\text{eff}}$ (K) |
|------|------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| This Work | Morales et al. (2008) | Jenkins et al. (2009) | Wright et al. (2011) | Stelzer et al. (2013) | Lepine et al. (2013) | Gaidos et al. (2014) |
| Sum | 121949 | 91596 | 38068 | 104369 | 190843 | 363121 |
| No meas | 38 | 30 | 11 | 32 | 60 | 111 |
| Mean | 3209.18 | 3053.2 | 3460.73 | 3261.53 | 3180.72 | 3271.36 |
| Mean | 125150 | 97951 | 36190 | 104069 | 196308 | 364322 |
| Mean | 3293.42 | 3265.03 | 3290.0 | 3252.16 | 3271.8 | 3282.18 |
| Diff. | −84.24 | −211.83 | +170.73 | +9.37 | −91.08 | −10.82 |
| Diff. % | −2.56% | −6.49% | +5.19% | +0.29% | −2.78% | −0.33% |

Note.

$^a$ From the $(R-I)_C$ color.

(This table is available in machine-readable form.)

**Figure 3.** Values of $T_{\text{eff}}$ compiled in the present study as a function of $(R-I)_C$ for our complete samples of stars. Solid line: the heteroscedastic least-squares fit to the data (see text).
query separately many catalogs individually for many of our targets. Our compilation of temperatures includes all measurements regardless of the methods used to derive them.

The sources of the published effective temperatures for our K dwarf samples are Blackwell & Lynas-Gray (1998), Soubiran et al. (1998, 2008, 2010), Cenarro et al. (2001, 2007), Borde et al. (2002), Gray et al. (2003, 2006), Le Borgne et al. (2003), Wright et al. (2003, 2011), Yong & Lambert (2003), Clem et al. (2004), Kovtyukh et al. (2004), Valenti & Fischer (2005), Ammons et al. (2006), Casagrande et al. (2006, 2008, 2011), Masana et al. (2006), Sanchez-Blazquez et al. (2006), Sousa et al. (2006, 2008), Barney et al. (2008), Morales et al. (2008), Cortés et al. (2009), da Silva et al. (2009), Jenkins et al. (2009), Manteiga et al. (2009), Oenéhag et al. (2009), Lafras et al. (2010), Valenti & Munari (2010), Malyuto & Shvelidze (2011), Prugniel et al. (2011), McDonald et al. (2012), Bermejo et al. (2013), Molenda-Zakowicz et al. (2013), Pace (2013), Stelzer et al. (2013), Tsantaki et al. (2013), Chen et al. (2014), Cottaar et al. (2014), Franchini et al. (2014), Gaidos et al. (2014), Munari et al. (2014), and Kopytova et al. (2016).

For the M dwarfs, the effective temperatures come from the following authors: Silva & Cornell (1992), Blackwell & Lynas-Gray (1998), Cenarro et al. (2001, 2007), Malkan et al. (2002), Gray et al. (2003, 2006), Le Borgne et al. (2003), Wright et al. (2003, 2011), Allende Prieto et al. (2004), Clem et al. (2004), Valdes et al. (2004), Valenti & Fischer (2005), Ammons et al. (2006), Butler et al. (2006), Sanchez-Blazquez et al. (2006), Sousa et al. (2006, 2008), Schiavon (2007), Baines et al. (2008), Casagrande et al. (2008, 2011), Morales et al. (2008), Soubiran et al. (2008, 2010), Jenkins et al. (2009), Schroeder et al. (2009), van Belle & von Braun (2009), Brown (2010), Gazzano et al. (2010), Houdebine (2010a, 2012), Lafrasse et al. (2010), Malyuto & Shvelidze (2011), Prugniel et al. (2011), Christiansen et al. (2012), Houdebine et al. (2012), Koleva & Vazdekis (2012), McDonald et al. (2012), Rojas-Ayala et al. (2012), Bermejo et al. (2013), Lepine et al. (2013), Cesetti et al. (2013), Molenda-Zakowicz et al. (2013), Pace (2013), Rajpurohit et al. (2013, 2014), Stelzer et al. (2013), Gaidos et al. (2014), Loyd & France (2014), Munari et al. (2014), and Eker et al. (2015), Frasca et al. (2015), Mann et al. (2015), and Newton et al. (2015).

We found from these authors that differences in $T_{\text{eff}}$ between different sources are commonly of the order of 100–200 K and may even exceed 400–500 K! We found that these differences

![Figure 4. Stellar radius as a function of $T_{\text{eff}}$ for our samples of K and M dwarfs. We show the heteroscedastic least-squares fit as the continuous line. The dashed line shows the fit determined by Mann et al. (2015) for their sample of stars. The large scatter present in this figure is due (in large part) to the effects of different values of metallicity among the individual stars in any sample.](image-url)
are the greatest among the mid-K, late-K, dM6, and dM7 samples. They are somewhat smaller among the dM0–dM1, dM2, dM3, dM4, and dM5 samples. We found, for instance, that the $T_{\text{eff}}$ measurements of Jenkins et al. (2009) and Lepine et al. (2013) are systematically underestimated. We found in general that the $T_{\text{eff}}$ are underestimated for M0–M5 dwarfs compared to our values derived from the $(R - I_C)$ calibration of B12 and M15. Nevertheless, our values are in good agreement with those from Gaidos et al. (2014), and may even be slightly underestimated.

We computed the means of the temperature differences between our measurements from $(R - I_C)$ and from the literature for all our samples. We find that on average, the $T_{\text{eff}}$ differences are $34.78$ K, $41.40$ K, $22.11$ K, $29.81$ K, $25.50$ K, $27.60$ K, $32.08$ K, $17.90$ K, and $54.36$ K for our mid-K, late-K, dM0–dM1, dM2, dM3, dM4, dM5, dM6, and dM7 stellar samples, respectively. We assigned these values as estimates of the $\pm 3\sigma$ uncertainty on our measurements of $T_{\text{eff}}$ derived from $(R - I_C)$. We can see from these values that the $T_{\text{eff}}$ measurements from the literature are best determined for mid-K, dM3, and dM6 stars, but are determined the worst for late-K, dM5, and dM7 stars. We emphasize the relatively large uncertainty on the determinations of $T_{\text{eff}}$ for the dM7 stars (over $\pm 100$ K). We also would like to emphasize that the differences between our measurements of $T_{\text{eff}}$ derived from $(R - I_C)$ and those from the literature directly depend on the number of literature measurements, i.e., the largest ones are the numbers of measures, the smallest are the differences with our measurements. On the contrary, when only one measurement is available from the literature, the difference with our $T_{\text{eff}}$ derived from $(R - I_C)$ is generally large. The means of the temperature differences provide us with estimates of the $\pm 3\sigma$ uncertainty on our $T_{\text{eff}}$ determinations from $(R - I_C)$. We stress here that these uncertainties are relatively low (as low as $\pm 18$ K) compared to the typical $\pm 100$ K uncertainty claimed by most authors. This underlines the fact that the $(R - I_C)$ color is a reasonable effective temperature diagnostic for most K and M dwarfs and that the calibrations we use in this study are reasonably reliable. We also stress that the $(R - I_C)$ color gives good effective temperature estimates even for substellar objects (e.g., Gl 130, Gl 333, Gl 438, Gl 563.2A, Gl 563.2B, Gl 637, and Gl 817 in the dM2 sample). This highlights the relatively low sensitivity of the $(R - I_C)$ color on the metallicity. We emphasize that the $(R - I_C)$ color varies in time for many M dwarfs, due to the presence of spots. This somewhat alters the precision of the $(R - I_C)$ measurements from the literature for active dwarfs. This is especially true for M6 and M7 objects that are most often very active (see E. R. Houdebine et al. 2019b, in preparation).

We give in Table 2 the mean (column 6) of the temperatures derived from $(R - I_C)$ (column 4) and the temperatures compiled from the literature (column 5). We also give in Table 2 the uncertainties on our final $T_{\text{eff}}$ measurements as the differences between the $T_{\text{eff}}$ derived from $(R - I_C)$ and the $T_{\text{eff}}$ from the literature. When this value is not available (no measurements from the literature), we assigned the uncertainty as the mean of the temperature differences.

### 3.2. Effective Temperatures: Systematic Errors

In order to better estimate the agreement between our final $T_{\text{eff}}$ and the $T_{\text{eff}}$ from previous authors, we plot these two parameters in Figure 2. In Figure 2, the continuous (solid) line indicates the correlation that would exist if there was perfect correspondence between the two approaches we have used to evaluate $T_{\text{eff}}$ (i) from the literature and (ii) from the color–temperature relationships obtained by B12 and M15. It can be seen that the agreement between the data sets is rather good. The scatter of the measurements around the mean curve is typically lower than $100$ K at all spectral subtypes. We note that this scatter is lower for instances for mid-K dwarfs than for late-K dwarfs. This better agreement among mid-K dwarfs is due mostly to the larger number of $T_{\text{eff}}$ measurements from the literature for these stars. On the other hand, in general we have fewer estimates of $T_{\text{eff}}$ from the literature for late-K dwarfs. We again stress that a large part of the scatter observed in Figure 2 is due to few measurements of $T_{\text{eff}}$ from the literature. When large numbers of measurements of $T_{\text{eff}}$ are available from the literature (e.g., for the Gliese stars), the agreement with our $T_{\text{eff}}$ derived from the color is generally good. We also note that the scatter is lower among M dwarfs compared to late-K dwarfs and especially for M4 to M7 stars.

The data in Figure 2 show that, for late-K dwarfs, when we compare the $T_{\text{eff}}$ values obtained by the two methods, the literature values of $T_{\text{eff}}$ are on average larger by about $6\%$ than the values of $T_{\text{eff}}$ which are obtained from the B12 calibration. In contrast to such behavior, the results in Figure 2 indicate that for mid-K dwarfs, we find that the literature values of $T_{\text{eff}}$ are on average smaller by about $9\%$ than the B12 values. Also for M dwarfs, the behavior is similar to that for the mid-K stars, i.e., the literature values of $T_{\text{eff}}$ are smaller by typically $5\%$ than the B12 values. We note that Mann et al. (2013) also reported that their effective temperatures were slightly larger than those from other authors in the literature by about $50$ K. M15 found that their estimated $T_{\text{eff}}$ were typically $100$ K warmer than those from the work of Casagrande et al. (2008). On the other hand, Mann et al. (2013) reported a good agreement between their $T_{\text{eff}}$ estimates and those of Rojas-Ayala et al. (2012). During the course of our data compilation, it is worth noting that we found good agreement between our $T_{\text{eff}}$ values derived from $(R - I_C)$ and the recent estimates of $T_{\text{eff}}$ reported by Gaidos et al. (2014).

As an example of a compilation of temperatures from the literature, we list in Table 3 the temperatures obtained by six different teams of authors for various subsets of stars that overlap with those in our dM4 sample. For the six teams as listed from left to right in Table 3, the number O(i) of stars that overlap with our sample is O(i) = 38, 30, 11, 32, 60, and 111, respectively: the largest overlap (111) is with the team of Gaidos et al. (2014), while the smallest overlap (11) is with the team of Wright et al. (2011). We list, at the bottom of Table 3, the mean temperatures obtained by those six teams for their respective subset of dM4 stars. We also list, for each team (i = 16), the mean temperatures that we have obtained for the dM4 stars in our sample (numbering O(i)) that overlap with the stars observed by Team (i). We also list the mean temperature differences between our values and those of the six authors: the differences are listed in absolute terms (in degrees K) and also as a percentage. These figures highlight the systematic differences between the results obtained by means of our approach and those obtained by six other sets of authors.

We note that, in the case of two of the six teams, there is very good agreement, $\pm 0.3\%$ on average, between our estimates of $T_{\text{eff}}$ and theirs: these are the teams of Gaidos et al. (2014) and of Stelzer et al. (2013). To understand why there is such a good
overlap between ourselves and Gaidos et al. (2014), we note that Gaidos et al. followed the procedure of Mann et al. (2013) in order to estimate $T_{\text{eff}}$, $R_s$, and the luminosity $L_s$ for their sample. Gaidos et al. first determined $T_{\text{eff}}$ by finding the best-fitting model stellar spectrum, and then they used the best-fitting temperature in empirical relations to determine the other stellar parameters. This procedure was calibrated against nearby stars with known radii, distances, and bolometric fluxes (Boyajian et al. 2012). Therefore, their method is essentially the same as that used by M15: because the approach we adopt in the present paper also relies in part on M15, it is perhaps not too surprising that we have found a very good agreement with the results obtained by Gaidos et al. (2014). Moreover, the overlap of stars between our sample and the sample of Gaidos et al. is the largest (111 stars), and this may also contribute to improving the agreement between our results.

On the other hand, the good agreement that we have found with the results of Stelzer et al. (2013) cannot be attributed to the similarity of approach. In fact, Stelzer et al. (2013) used a completely different technique based on the spectral-type calibration reported by Lepine et al. (2013). The latter calibration is based on the $(V-J)$ color and is therefore quite distinct from the method (based on the $(K-I_c)$ color) we have used in the present paper. Once Stelzer et al. had determined the spectral type for each star, they then used the temperature scale reported by Bessel (1991) and Mohanty & Basri (2003) in order to derive $T_{\text{eff}}$. In view of the difficulties associated with assigning a precise spectral type and then also converting to a temperature, this method is expected to be subject to several uncertainties. Nevertheless, as shown in Table 3, it is encouraging to see that we have actually found good overall agreement between the Stelzer et al. temperatures and ours. We note that the number of overlapping stars between our sample of dM4 stars and that of Stelzer et al. is only 32: thus, we cannot claim that the largeness of the example might be helping to bring our samples into agreement.

Turning now to the results of a third team, we note that Morales et al. (2008) used the TiO5 index to derive spectral types for their sample of M dwarfs: the TiO5 index is based on the strongest TiO feature in M dwarf spectra, with a bandhead at 7050 Å. Effective temperatures were computed using the spectral-type–temperature correlation reported by Bessel (1991). Morales et al. used an iterative procedure to ensure that their $T_{\text{eff}}$ values were consistent with the bolometric correction in the $K$-band $BC_K$. We find (see Table 3) that the values of $T_{\text{eff}}$ obtained by Morales et al. for M4 dwarfs lie about 84 K below our own measures for the dM4 sample. We believe that this significant difference in $T_{\text{eff}}$ values can be attributed to the presence of a systematic difference between the calibration of Bessel (1991; see also Leggett et al. 1996) and the calibration of M15.

The team of Jenkins et al. (2009) used the $(V-K_S)$–$T_{\text{eff}}$ relation reported by Casagrande et al. (2008). The latter investigators claimed a typical internal uncertainty of $\pm 17$ K. In preparation for using the Casagrande et al. relation, Jenkins et al. first computed the absolute $V$ and $K$ magnitudes. The $V$ magnitudes were taken from SIMBAD, while the $K_S$ magnitudes were taken from the 2MASS catalog (Skrutskie et al. 2006). We find that, on average, the $T_{\text{eff}}$ values obtained by Jenkins et al. are lower than ours by about 212 K. This figure is larger than the differences we found relative to those of other teams. For this reason, we rejected some of the Jenkins et al. results in cases where the difference was significantly larger than the mean $T_{\text{eff}}$ values obtained by ourselves and by other teams.

The team of Wright et al. (2011) used a combination of techniques in order to estimate the temperatures for their targets. For most stars, they adopted two methods, both involving isochrones from Siess et al. (2000): (i) for cluster stars, they combined the isochrones with an estimate of the age of the appropriate cluster; (ii) for field stars, they assumed an age of 1 Gyr. For the field stars with unknown distances, the $(V-K)$ color led them to derive a temperature using the relationships of Casagrande et al. (2008) for M dwarfs, and those of Casagrande et al. (2010) for FGK stars. Their results for M4 dwarfs are found to lie about 171 K hotter than our measurements (+5.19%). The study by the Wright et al. (2011) team is the only one of the six teams that clearly overestimates the temperatures in mid-M dwarfs compared to the tabulation of Mann et al. (2015). We note that the sample of Wright et al. (2011) has the smallest overlap with our sample of dM4 stars: only 11 stars contribute to the overlap. This smallness of the overlap may serve to enhance the difference in the mean values of $T_{\text{eff}}$.

Finally, the team of Lepine et al. (2013) obtained results for the most complete survey of M dwarfs in the northern sky. They determined the stellar parameters using a complex method based on fitting stellar atmosphere models from Allard et al. (2011). They fitted their spectra in the wavelength range 5600–9000 Å, but excluding the problematic TiO bands between 6400 and 6600 Å. Between the average values of $T_{\text{eff}}$ obtained by of Lepine et al. and the averages we have obtained, there is a systematic difference of $-91$ K ($-2.78\%$).

By taking a grand average of the six mean differences in $T_{\text{eff}}$ in Table 3, we find a value of $-36$ K. Compared to the typical $T_{\text{eff}}$ values listed in Table 3, this grand average amounts to a fractional error of about 1%.

As we saw above, the rather good agreement between our values of $T_{\text{eff}}$ and those in the literature may be considered as somewhat surprising in view of the systematic differences between the various approaches adopted by the different authors. We believe that the sources of these systematic differences may include (but are not limited to) the following: missing opacities, the LTE assumption in the models, and metallicity effects on the $(R-I_c)$ color. Differences of typically 100 K or 200 K between different authors are common in our compilation of effective temperatures, mainly because of systematic errors. However, it appears that, on average, these differences cancel out one another to a greater or lesser extent, thereby yielding values that are not so far removed from our calibration based on the work of B12 and M15. Without doubt, we can assert that the best reference is the work of B12.

It is true that we found some discrepancies between the literature values of $T_{\text{eff}}$ and our values in the mean mid-K and late-K subsamples. These discrepancies may point to systematic errors in the methods used to derive values of $T_{\text{eff}}$ in the literature. Because our compilation includes works by authors who have relied on many different techniques, we believe it is beyond the scope of this paper to discuss in detail all possible sources of uncertainties in detail. We can only say that, on average, systematic errors for individual stars are typically less than 10%, while the errors that appear in the grand average value of $T_{\text{eff}}$ are of order 1%. In the case of the K dwarfs, we find that there are systematic errors of about 5% for the $T_{\text{eff}}$. 

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values that we derive for K dwarfs: we find that the sign of the systematic error is positive for late-K stars and negative for mid-K stars.

For M dwarfs, our results for $T_{\text{eff}}$ are based mostly on the approach that was developed by M15. The uncertainties associated with their results were already discussed in the Introduction. The M15 work seems to be one of the most precise studies so far, essentially because it includes results from interferometry. Because we rely heavily on M15, we recognize that whatever sources of error contribute to the results in M15 also apply to our results. Moreover, we find that our $T_{\text{eff}}$ values are systematically larger than the literature values for most authors, with the notable exception of Gaidos et al. (2014). We found that the systematic differences in $T_{\text{eff}}$ are of order 5% for M4 and M5 dwarfs. However, the percentage errors are larger for the less well known M7 dwarfs. On the other hand, we have found good agreement for the M2 and M3 subsamples.

In summary, our results for $T_{\text{eff}}$ include systematic errors of about 5% overestimates, in addition to which we should allow for the uncertainties in the results of M15 (see Introduction).

In Table 2, the errors given in column 6 are the differences between the estimated effective temperature and the solid line curve in Figure 1. This definition means that the difference is between our $T_{\text{eff}}$ value and the mean of the values of $T_{\text{eff}}$ in the literature. However, it is important to note that errors on the literature values of $T_{\text{eff}}$ may be as large as 200 K! Therefore, the mean errors on our samples given above are only statistical measures of the mean of the scatter relative to the solid line in Figure 2. It is difficult at this stage to estimate absolute errors for our $T_{\text{eff}}$ values because many different sources contribute to the errors.

Another additional source of systematic error is the effect of $[\text{M}/\text{H}]$ on the $(R-I)_{\text{C}}$ color. Leggett (1992) found that for a given $(R-I)_{\text{C}}$ color, there exists one spectral subtype difference between young disk and halo M dwarfs. In other words, for a given $(R-I)_{\text{C}}$, low-metallicity M dwarfs tend to be cooler than solar metallicity dwarfs. The consequence is that our values of $T_{\text{eff}}$ derived from $(R-I)_{\text{C}}$ tend to be cooler for subdwarfs. This is one reason why we compiled metallicities for our targets. Even if this systematic trend has been well established by other authors, we find (see Table 2) that in general, for the vast majority of our subdwarfs, the difference between our $T_{\text{eff}}$ values and the values in the literature remains small, except for very low-metallicity subdwarfs (e.g., the sdM2 VB 12).

Moreover, it is also a fact that the presence of inhomogeneities on the surface of an M dwarf (especially on a dMe star) can have an effect on the value of $T_{\text{eff}}$ measured for such a star. This effect applies to our data as well as values of $T_{\text{eff}}$ that appear in the literature. Systematic errors due to this effect can hardly be determined with any reliability unless full investigations of the spectral variations in time have been established. We note also that there are some variations of the $(R-I)_{\text{C}}$ colors in our compilations, which may yield uncertainties up to about 100 K for certain objects. For the best known objects, we have sometimes found several reported measurements of $(R-I)_{\text{C}}$, and for such objects, we use the mean. Such variability in the actual color of a particular star can be responsible for a significant part of the scatter in Figure 2.

We show in Figure 3 the values of our final effective temperatures as a function of $(R-I)_{\text{C}}$ for our complete samples of stars. One can see in this figure that the correlation between $T_{\text{eff}}$ and $(R-I)_{\text{C}}$ is good. This confirms that $(R-I)_{\text{C}}$ is a good first-guess effective temperature diagnostic for K and M dwarfs. We show the heteroscedastic least-squares fit to the data as the solid line. Weights are proportional to the inverse of the error on the final temperature determination. This least-squares fit of order 5 yields

$$T_{\text{eff}}/3500 = -2.3365 \times (R-I)_{\text{C}}^5 + 4.1056 \times (R-I)_{\text{C}}^4 - 3.7582 \times (R-I)_{\text{C}}^3 + 2.4905 \times (R-I)_{\text{C}}^2 - 0.06876 \times (R-I)_{\text{C}} + 0.646327. \quad (1)$$

The $\chi^2$ is 3.56 $\times 10^{-6}$ for this fit, which is good. Most stars in our sample lie within $\pm 100$ K of the least-squares fit. This fit could be used as a complementary calibration of $T_{\text{eff}}$ as a function of $(R-I)_{\text{C}}$ for K and M dwarfs as it is based both on the work of B12 and M15, and our complete compilation of $T_{\text{eff}}$ from the literature.

### 3.3. Stellar Radii

In order to derive radii for our samples of stars, we used the classical formula (e.g., Lang 1980)

$$M_v + BC_V = 42.36 - 5 \times \log \left( \frac{R_s}{R_\odot} \right) - 10 \times \log(T_{\text{eff}}), \quad (2)$$

where symbols take their usual meaning. We used the $BC_V$ calibration as a function of $T_{\text{eff}}$ from Lejeune et al. (1998). We assumed that their tabulation yields an uncertainty of about 10% in $BC_V$. Using Equation (2), we obtained the radii for our samples of stars as listed in Table 2. The errors on the radii in Table 2 were computed by taking into account the combination of the error on the absolute magnitude, an assumed error of 0.02 mag on the $(R-I)_{\text{C}}$ color, an error of 0.005 mag when $V$ is known to three decimals, 0.02 mag when $V$ is known to two decimals, and 0.2 magnitudes when $V$ is known to one decimal. We also took into account the errors on $T_{\text{eff}}$.

Our source for the parallaxes comes mostly from the recent Gaia DR2 compilation (Gaia Collaboration et al. 2016, 2018b). Other sources are Jenkins (1952), Gliess & Jahreiss (1991), van Altena et al. (1995), Salim & Gould (2003), Costa et al. (2005), van Leeuwen (2007), Subasavage et al. (2009), Dieterich et al. (2014), and Lurie et al. (2014). The errors on the parallaxes were included in our calculations of the $V$-band absolute magnitude $M_V$. We found that the Gaia DR2 data allow a tremendous improvement on the precision of the stellar radii especially over the older data of Gliess & Jahreiss (1991). In some instances, we found radii different by a factor of 2 or 3 between these two sources. We also found some significant differences with the Hipparcos parallaxes in many instances, notably for faint Hipparcos sources.

We show the stellar radii as a function of $T_{\text{eff}}$ in Figure 4 for all of the (1910) stars in our samples. We show the weighted least-squares fit as the continuous line for stars restricted to $-0.5 \leq [\text{M/H}] \leq +0.5$. The dashed line represents the polynomial fit determined by B12 for their sample of (33) K and M stars. We also show as the dotted–dashed line the polynomial fit obtained by M15, for their sample of (183) K and M dwarfs. For our present samples of stars, we obtained the following
weighted polynomial fit:

\[ R_* = 2.8102 \times X^6 - 7.5796 \times X^5 + 1.2666 \times X^4 + 9.0658 \times X^3 - 2.8046 \times X^2 - 3.9200 \times X + 1.5606, \]  

where \( X = T_{\text{eff}}/3500 \). The weights on each data point were assigned as the inverse of the errors on the radii.

We overplot for each of our spectral subtype domain the mean of the errors on \( T_{\text{eff}} \) as well as the mean of the errors on \( R_* \). We show these error bars in the lower part of Figure 4.

The first striking characteristic of the data represented in Figure 4 is the very large scatter among the radii for a given effective temperature. This scatter can be attributed partly to uncertainties on \( T_{\text{eff}} \) and \( R_* \) as can be seen on the means of the error bars plotted in Figure 4. However, the scatter is still significantly larger than these typical error bars, notably for the earliest K dwarfs in our sample as well as the early M dwarfs. Such a large scatter in the radii was also observed among M dwarfs by Mann et al. (2015). They showed that the differences between radii at a given effective temperature is mainly due to differences in metallicities: stars with large radii are metal-rich and stars with small radii are metal-poor (e.g., subdwarfs). Houdebine (2008) found that there exists an empirical correlation between stellar radius and metallicity among his sample of M2 dwarfs. Later, Houdebine et al. (2016) also found analogous empirical correlations among their samples of late-K, M3, and M4 dwarfs. Although it appeared in this later study that for M4 dwarfs, the dependency of the stellar radius on the metallicity is somewhat smaller than in say, late-K or M2 dwarfs, it seems that both parameters do correlate among K and M dwarfs. The very small dependency of late M dwarf radii on metallicity may explain why we observe a smaller scatter in Figure 4 for spectral types equal to or greater than M5, compared to earlier spectral-type M dwarfs. Note also that there are probably some (so far) unidentified binary stars in our samples (stars with abnormally large radii) and that our samples also contain subdwarfs.

We find a generally good agreement between our fit and the fits of B12 and M15 from late-K to M3. However, we note some differences for early-K stars and stars later than M3. For M4 and particularly M5, the B12 curve lies 40% or more below our fit and the fit of M15. The fit from M15 agrees well with our fit from M1 to M5 stars, which is not surprising as for M dwarfs, our temperature determinations depend 50% on their calibration, and the other 50% depend on our literature compilation. For lower effective temperatures, the fit of M15 lies above our fit by up to about 70%. Undoubtedly, our sample is larger than that of M15 by a factor of 12 and larger than the B12 sample by a factor of 80. If we trust that the B12 and M15 temperature determinations give “accurate” values, and that our final temperature determinations rely on a compilation from all other authors by up to 50%, we may be tempted, considering our much larger sample, that our fit should yield a better description of the temperature–radius plane. But this is somewhat open to discussion because the errors on the temperatures may still be large.

We note that our fit does not reproduce well the radii of M6 and M7 dwarfs. This is due to the fact that errors on the radii for those stars are proportionally larger than those in M4 and M5 dwarfs, and as a result, the weights assigned to M6 and M7 dwarfs are lower. The much larger samples of M4 and M5 dwarfs “force” the slope of the fit at M6 and M7 to be larger than expected.

The Gaia DR2 parallaxes allow a major improvement on the precision of the stellar radii of our nearby stars. Before, uncertainties on the parallaxes accounted for a large part of the uncertainties on the radii, especially for the faint M dwarfs. In the present study, we find that the largest uncertainty now arises from the uncertainty of the effective temperatures. The better precision on the radii now allows us to isolate possible spectroscopic binaries or stars with large metallicities that stand significantly above the main trend, and probable low-metallicity stars (probable subdwarfs) that stand significantly below the main trend in the radius–temperature plane. The comparison of the radii of those stars with those of stars in our samples with [M/H] < −0.5 or [M/H] > +0.5 (from our compilation of [M/H] from the literature) indicates stars with possible metallicities below −0.5 or above +0.5. We show the known and possible metal-poor stars as squares in Figure 4. We also show in this figure the possible metal-rich and/or spectroscopic binaries that display abnormally large radii. We identified 211 possible low-metallicity dwarfs and 184 metal-rich and/or spectroscopic binaries. We also found 30 possible PMS dwarfs that have abnormally large radii and are known to be neither metal-rich nor spectroscopic binaries according to our high-resolution spectra. From the analysis of our high-resolution spectra, we have identified 21 new spectroscopic binaries and one new triple system.

Our correlation between radius and \( T_{\text{eff}} \) can be compared to the Hertzsprung–Russell diagrams for nearby stars from the Gaia Collaboration et al. (2018a). They note a steepening of the slope at about \( M_G \sim 11 \) in their Figure 6. Our data do not show a clear evidence for a similar increase in the slope in Figure 4. The radius–\( T_{\text{eff}} \) diagrams in Rabus et al. (2019) show that there are two possible regimes in their diagrams, and they propose that their results are possible evidence for a change between partially convective stars and fully convective stars (the transition to complete convection, TTCC). They locate this transition at about \( T_{\text{eff}} \sim 3300 \) K. This result agrees with the finding of Houdebine et al. (2017), who found that the RACs undergo important changes between dM2 and dM3 where they located the TTCC. This finding suggests that important changes occur in the dynamo mechanisms at the TTCC.

4. Conclusion

From our compilations of \((R-I)_C\) measurements from the literature, we report on new derivations of effective temperatures for 1910 K and M dwarfs, based on the calibrations of B12 and M15. We also compiled previously published effective temperatures for most stars in our sample. We derived our final effective temperature estimates by computing the mean of the effective temperatures derived from the \((R-I)_C\) color and those from the literature. We find in general a good agreement between our temperatures derived from \((R-I)_C\) and the published effective temperatures (see Table 2).

We derive a new heteroscedastic polynomial fit to the \( T_{\text{eff}} \) versus \((R-I)_C\) correlation. Our correlation is based both on the B12 and M15 calibrations and our compilation of \( T_{\text{eff}} \) from the literature for thousands of measurements. We find a rather good \((R-I)_C-T_{\text{eff}}\) correlation in agreement with the results from previous authors.

The recent release of the Gaia DR2 data allows us to compute the stellar radii for most of the targets in our stellar
sample. We now find that the largest uncertainties on the radii arise from the measurements on the effective temperatures. We are currently carrying out a long-term observing program dedicated to the measurements of chromospheric lines in M and K dwarfs. So far, we have identified 21 new spectroscopic binaries and one triple system. We find that the precision on the stellar radii may allow new low-metallicity stars as well as new high-metallicity and/or spectroscopic binaries to be identified. Our data suggest that 425 new such objects may be present in our data sets.

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### References

Allende Prieto, C., Barklem, P. S., Lambert, D. L., & Cunha, K. 2004, *A&A*, 420, 183
Ammons, S. M., Robinson, S. E., Strader, J., et al. 2006, *ApJ*, 638, 1004
Baines, E. K., Mcalister, H. A., Ten Brummelaar, T. A., et al. 2008, *ApJ*, 680, 728
Baraffe, I., Chabrier, G., Allard, F., & Hauschildt, P. H. 1998, *A&A*, 337, 403
Baraffe, I., Homeier, D., Allard, F., & Chabrier, G. 2015, *A&A*, 577, A42
Bermejo, J. M., Asensio Ramos, A., & Allende Prieto, C. 2013, *A&A*, 553, 95
Bessel, M. S. 1979, *PASP*, 91, 589
Bessel, M. S. 1990, *A&AS*, 83, 357
Bessel, M. S. 1991, *AJ*, 101, 662
Blackwell, D. E., & Lynas-Gray, A. E. 1998, *A&AS*, 129, 505
Booth, J., Caruso, J., & Weis, E. W. 1988, *PASP*, 100, 749
Borde, P., Coude du Foretto, V., Chagnon, G., & Perrin, G. 2002, *A&A*, 393, 183
Boyajian, T. S., von Braun, K., van Belle, G., et al. 2012, *ApJ*, 757, 112 (B12)
Brown, T. M. 2010, *ApJ*, 709, 355
Butler, R. P., Wright, J. T., Marcy, G. W., et al. 2006, *ApJ*, 646, 505
Carney, B. W., Latham, D. W., Stefanik, R. P., & Laird, J. B. 2008, *AJ*, 135, 196
Casagrande, L., Flynn, C., & Bessell, M. 2008, *MNRAS*, 389, 585
Casagrande, L., Portinari, L., & Flynn, C. 2006, *MNRAS*, 373, 13
Casagrande, L., Ramirez, I., Meléndez, J., Bessell, M., & Asplund, M. 2010, *A&A*, 512, 54
Casagrande, L., Schoenrich, R., Asplund, M., et al. 2011, *A&A*, 530, A138
Cenarro, A. J., Cardiel, N., Gorgas, J., & Marang, F. 2004, *MNRAS*, 356, 959
Cenarro, A. J., Peletier, R. F., Sanchez-Blazquez, P., et al. 2007, *MNRAS*, 374, 664
Cesetti, M., Pizzella, A., Ivanov, V. D., et al. 2013, *A&A*, 549, A129
Chen, C. H., Mittal, T., Kuchner, M., et al. 2014, *ApJS*, 211, 25
Christiansen, J. L., Jenkins, J. M., Caldwell, D. A., et al. 2012, *PASP*, 124, 1279

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5 http://www.astropy.org/ and http://astroquery.readthedocs.org/en/latest/.
