DISTANCE MODULUS OF THE DWARF GALAXY IC10

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Abstract.
*We used three new metallicity dependent distance indicators based on the **K**-luminosity function of red supergiants in the field of the dwarf galaxy **IC10** to derive the distance modulus and the total extinction along that sightline. The obtained values: $(m–M)_0 = (24.3 \pm 0.3)^m$ and $A_K = (0.46 \pm 0.05)^m$ are in a good agreement with the recent results based on the **TRGB** method.*

The irregular dwarf galaxy **IC10** (**RA**(**J2000**) = $\mathbf{00^h\ 20^m\ 23.16^s}$; **DEC**(**J2000**) = +**59° 17**' **34.7**") is a member of the Local group, laying close to the Galactic equator (**b** = **–3.3°**). The high and uncertain value of the foreground extinction combined with the peculiarities of **IC10** itself (a widespread burst of star formation and a significant amount of varying internal extinction) lead to contradictive results when the distance modulus has been considered. The values of the obtained $(m–M)_0$ fall in the range of $(23.86 \pm 0.12)^m$ as derived in [1] and $(24.95 \pm 0.20)^m$ – in [2].

In this work we used three new distance indicators based on the luminosity function in **K**-passband for red supergiants (**RSGs**) in order to obtain a distance to **IC10**, taking for the first time into account the metallicity effect.

Our study is based on data provided by Two Micron All Sky Survey (**2MASS** - http://ftp.ipac.caltech.edu/pub/2mass/allsky/) as **J**&**K** magnitudes of ~ **2000** point-like sources (stars) in a target field, centered on **IC10** and covering total area of **360** square arcmin. For the metallicity we adopted values **[O/H]+12 = 8.25** of [3] and **[Fe/H]** = **–0.5** of [4], corresponding to 0.006 in terms of metallicity **Z**. We also assumed a standard extinction law ($R_V = 3.1$) along all sightlines toward **RSGs** in **IC10**.

We used theoretical evolutionary tracks for the most massive in the **RSGs** phase on the **CMD** M_K vs. $(J-K)_0$ with varying metallicity **Z = 0.004, 0.016, 0.028** to obtain an universal liner fit relating the luminosity and the colour (Fig. 1). The adopted linear fit allows selection of the **RSGs** branch on the **CMD**, taking into account the errors of photometry. Its slope was found to be quite steep: -14.7 ± 1.1 and not very sensitive to the metallicity

Initially, we divided the stars samples in the target field of **IC10** into two sub-samples, covering equal area inside and outside the galaxy, respectively. The next step was to construct the **CMDs** (Fig. 2) for the inner (upper left panel) and the outer field (upper right panel). The **RSGs**' branch is identified via numerical subtraction (applying an algorithm, removing the closest neighbouring points on the **CMD**s for the inner and outer field), resulting in a new **CMD**, shown in lower left panel of Fig. 2. The adopted line for metallicity **Z = 0.006** (corresponding to mean true colour $(J-K)_0 = 0.85^m$) is slided along reddening vector in order to fit the cloud of **RSGs**. This allowed us to estimate the mean total (foreground + internal) extinction of the **RSGs**: $A_K = (0.46 \pm 0.05)^m$. Finally, we constructed (see, the lower right panel of Fig. 2,) the apparent **K**-luminosity function found to be complete for the first four bins. Thus, we applied a completeness correction for the fifth bin in order to use the distance indicators, calibrated for the brightest 5 half magnitude bins.

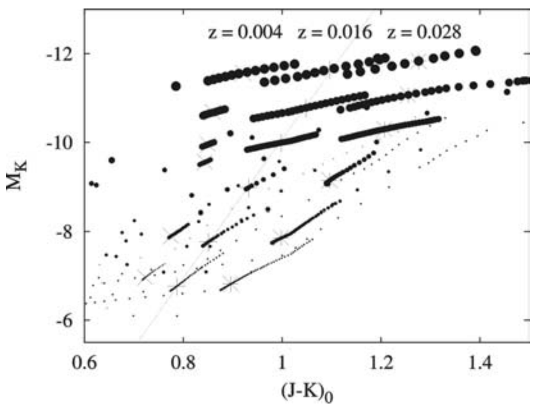


Fig. 1: Theoretical evolutionary tracks for massive stars in **RSGs**' phase on **CMD** diagram M_K vs. $(J-K)_0$. The size of the symbols is proportional to the

stellar mass in the range 7÷30 Solar masses. The metallicity Z varies between 0.004 and 0.028. Thin dashed line represents the linear fit with a slope of –14.7.

Table 1. Distance modulus of **IC10** galaxy and mean extinction toward it as derived by different authors

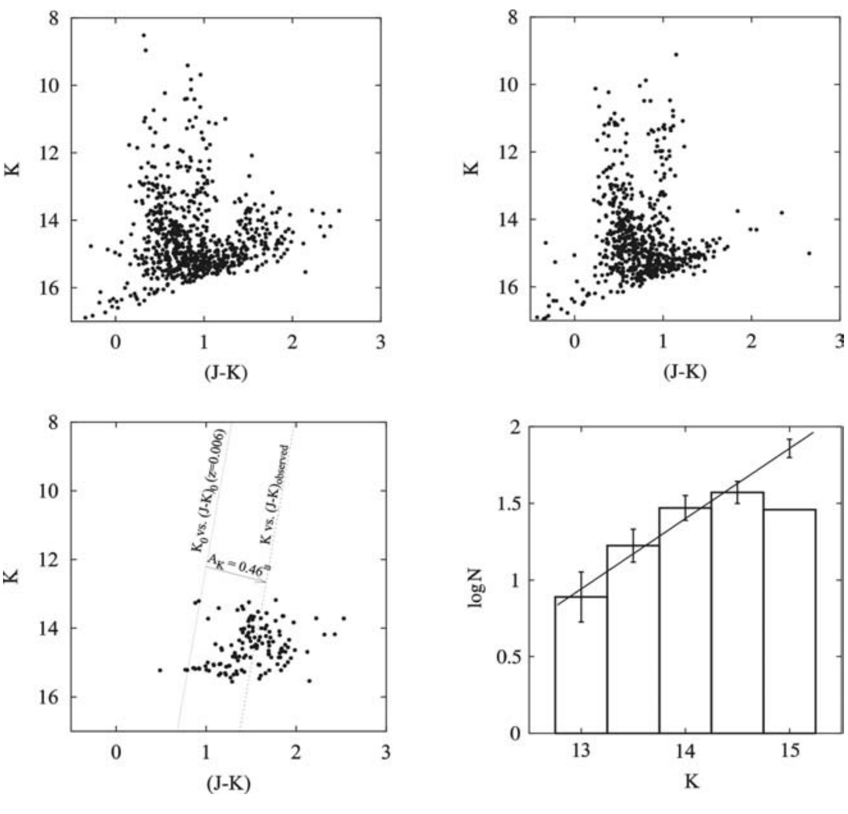
Parameter	Value	Reference
$\mathbf{(m - M)_0}$ **[mag]**	24.95 ± 0.20	[2]
	23.86 ± 0.12	[1]
	24.10 ± 0.19	[7]
	24.59 ± 0.30	[6]
	24.57± 0.21	[9]
	24.90 ± 0.10	[3]
	24.30 ± 0.30	this work
$\mathbf{A_K}$ **[mag]**	0.35 (total)	[1]
	0.52	[8]
	0.40 (total)	[7]
	0.27 (total)	[3]
	0.30	[10]
	0.46 (total)	this work

We used the selected **RSGs**, ordered by increasing apparent **K**-magnitude, and the constructed **K**-luminosity function, to determine three parameters, namely **K**(**0.12**) – the apparent magnitude of a real **RSG** with a consecutive number **N**, defined as $\mathbf{N/N_{tot} = 0.12}$, where $\mathbf{N_{tot}}$ is the total number of **RSGs** in the first five half magnitude bins, **K**(**12%**) and **K**(**21%**) - apparent magnitudes, corresponding to the value of the linear fit **"log**(**N**) **– K**" defined as $\mathbf{N/N_{tot}}$ **= 12%** and **21%**. The values of **K**(**0.12**), **K**(**12%**) and **K**(**21%**) are related to the distance indicators $\mathbf{M_K}$(**0.12**), $\mathbf{M_K}$(**12%**) and $\mathbf{M_K}$(**21%**), calibrated by [5] as a function of metallicity and easily obtained via substitution with the adopted values of **[O/H]+12** and **[Fe/H]**. Finally, the distance modulus is estimated are via the equation: $\mathbf{(m - M)_0 = K - A_K - M_K}$.

The obtained values are (**23.84 ± 0.26**)$^{\mathbf{m}}$, (**24.18 ± 0.29**)$^{\mathbf{m}}$ and (**24.44 ± 0.29**)$^{\mathbf{m}}$, respectively. They are consistent at **2σ** level, but only the last two are really luminosity function based on. Their mean (**24.3 ± 0.3**)$^{\mathbf{m}}$, together with other results, is given in Tab. 1.

Their own **IR**-photometry was used by [1] to select **RSGs** and to derive a distance modulus of (**23.86 ± 0.12**)$^{\mathbf{m}}$. However, they did not take into account the difference of **0.4** in metallicity between **IC10** and **IC1613**. Our result is in best agreement with $\mathbf{(m{-}M)_0}$ of [7]: (**24.10 ± 0.19**)$^{\mathbf{m}}$,

Fig. 2: Infrared **CMDs** and luminosity function in the field of **IC10** galaxy: upper panels - **CMD** for the inner field (left) and outer field (right); lower left panel – the difference “inner field **CMD** -outer field **CMD**”; lower right panel – the apparent **K**-luminosity function of **RSGs**.



which is somehow expected, because all distance indicators are based on distances, calibrated by the Tip of the Red Giant Branch (**TRGB**) method.

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