



Gaia, Trumpler 16, and Eta Carinae

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The star cluster Tr 16 contains four O3-type members and η Car—an extraordinary concentration of stars with $M \gtrsim 50 M_{\odot}$. Here we note that *Gaia* parallaxes reveal a discrepancy in η Car's distance, and also a serious overestimate of cluster membership.

For information about η Car, see various authors' reviews in Davidson & Humphreys (2012).

We employ *Gaia* Data Release 2 (Brown et al. 2018; Luri et al. 2018), assuming that the error estimates σ_i have the characteristics described by those authors. We assembled a list of fifty stars which are said to be members of Tr 16 (Walborn 1973, 1995; Massey & Johnson 1993), all having *Gaia* parallaxes ϖ_i with standard errors $\sigma_i < 0.05$ mas (Figure 1). Their weighted average is $\varpi_{\text{av}} \approx 0.373$ mas and their rms σ_i is 0.034 mas. (Each ϖ_i has relative statistical weight $1/\sigma_i^2$.)

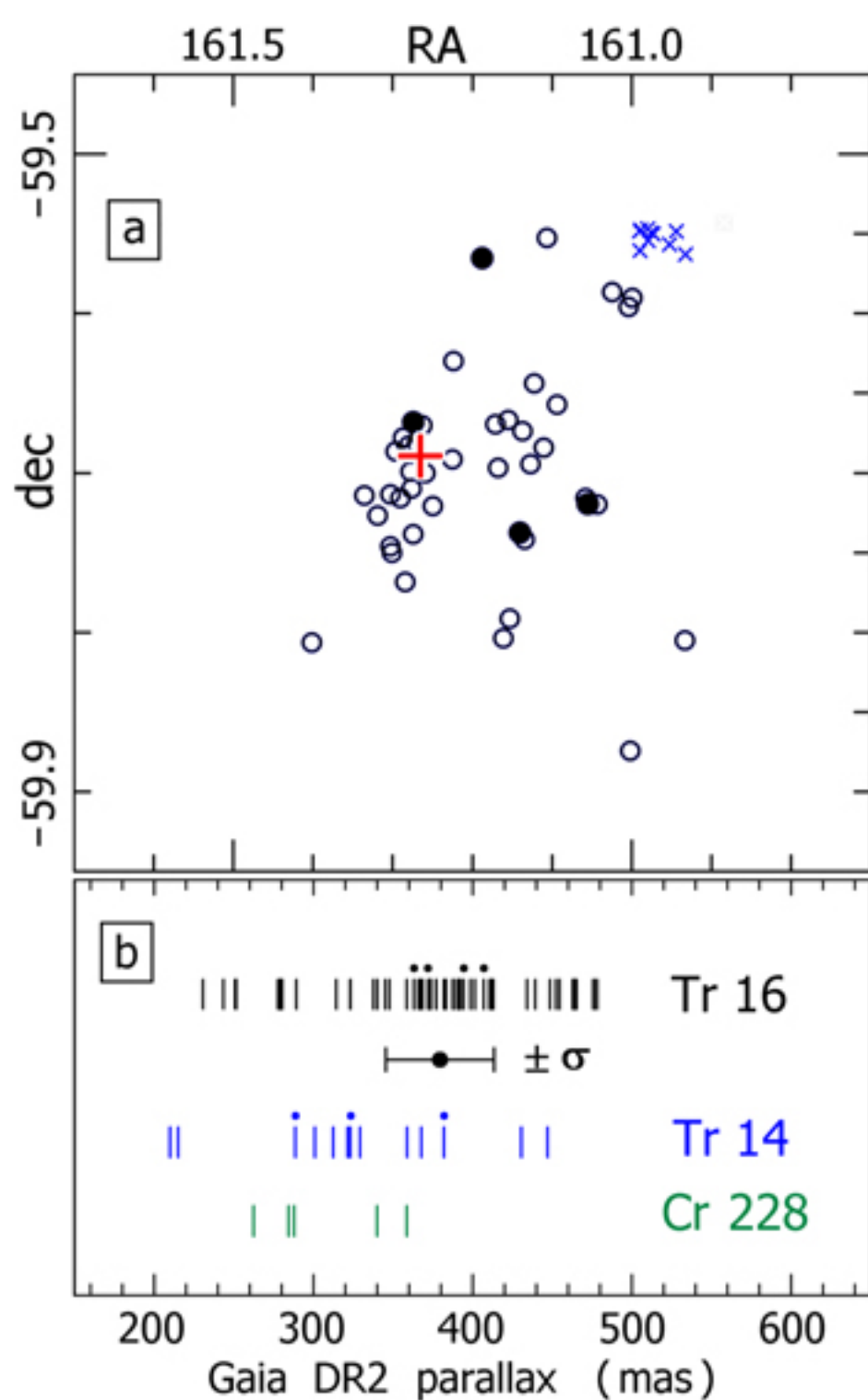


Figure 1. (a) Apparent positions of stars in the *Gaia* Tr 16 sample. Filled circles are O3 stars, the large cross is η Car, and the small x's belong to Tr 14. (b) Distribution of *Gaia* parallaxes in Tr 16, Tr 14, and Cr 228. Dots mark the O3 stars, and a $\pm 1\sigma$ error bar shows the rms individual error.

Gaia shows that many of the 50 stars do not belong to Tr 16. Its diameter, roughly 15 pc, corresponds to a range of only 0.002 mas in parallax. Thus its distribution of ϖ_i values should be indistinguishable from a sample with one true parallax and errors consistent with the σ_i 's. In fact, however, 13 of the 50 stars have $|\varpi_i - \varpi_{av}| > 2.5 \sigma_i$. If we model the observed ϖ_i distribution as a cluster superimposed on a set of stars randomly scattered along the Carina spiral arm, then we find N (nonmembers) $\gtrsim 20$. O- and B-type stars are very numerous along that line of sight, and distance-dependent factors played only a small role in the membership criteria for Tr 16. Hence the sample does not provide a robust estimate of the cluster parallax, because there is no good way to decide which stars to include. The formal error of their average is only about ± 0.005 mas, but this has little meaning for a contaminated sample.

Now consider only the four O3 stars: HD 93205, HD 93250, HD 303308, and MJ 257 (Massey & Johnson 1993; Walborn 1995). Here "O3" includes proposed subtypes O2, O2.5, O3, and O3.5. Only about a dozen O3's are known for the entire Galaxy, Tr 16 has four of them within a 0.2° circle (Figure 1(a)), and very massive stars tend to occur in groups (Humphreys & Davidson 1984). Thus we have clear reasons to postulate that these four belong to a physical group, identified long before *Gaia*. If they do, then they give a reliable collective parallax estimate.

The data support the hypothesis. The four O3 stars' weighted mean is $\varpi_{av} = 0.383$ mas, and all of them have $|\varpi_i - \varpi_{av}| < 0.8 \sigma_i$; so their spread in ϖ_i is quite reasonable—indeed, smaller than expected. Hence we propose that the parallax of Tr 16 is 0.383 ± 0.017 mas, where the rms error estimate is based on the *Gaia* σ_i 's for these four stars.

Eta Car, which is even more massive than the O3 stars, has long been considered a member of Tr 16, see Figure 1(a) and Walborn (2012). This object is unsuitable for parallax measurement, because it has bright, asymmetric, varying ejecta and orbital

motion. But its larger-scale ejecta provide another distance method, based on Doppler velocities and proper motions of outward-moving condensations (Thackeray 1956; Hillier & Allen 1992; Meaburn et al. 1993; Davidson et al. 2001). For statistical purposes the result is like a parallax, because the most difficult observables are proper motions, which are proportional to $1/D$. The 2001 *Hubble Space Telescope* result was $\varpi \approx 0.440 \pm 0.035$ mas, and no later improvement has yet been achieved. Our Tr 16 result (see above) disagrees, and is probably better.

Therefore we strongly suspect that η Car's distance is close to 2600 pc, rather than 2300 pc which nearly all recent authors have adopted. Of course this implies nearly a 30% increase in luminosity. In principle, η Car might be unrelated to Tr 16, or the *Gaia* DR2 results might have large systematic errors; but these possibilities seem less likely.

Tr 14, a compact group marked in Figure 1(a), contains three more O3 stars. Walborn (1995) concluded that it is distinct from Tr 16 because its stars are younger. *Gaia* data give $\varpi_{\text{av}} = 0.327 \pm 0.018$ mas for the Tr 14 O3 stars, placing them about 450 ± 200 pc beyond Tr 16. If this is correct, then Tr 14 has no relation to η Car. Cr 228, a large, relatively sparse cluster just below the bottom edge of Figure 1(a), does not alter the above discussion.

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