Gaia, Trumpler 16, and Eta Carinae

Kris Davidson\textsuperscript{1}

Greta Helmel\textsuperscript{2}

Roberta M. Humphreys\textsuperscript{1}

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The star cluster Tr 16 contains four O3-type members and $\eta$ Car – an extraordinary concentration of stars with $M \gtrsim 50 M_{\odot}$. Here we note that Gaia parallaxes reveal a discrepancy in $\eta$ Car’s distance, and also a serious overestimate of cluster membership. For information about $\eta$ 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 $\sigma_i$ 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 $\varpi_i$ with standard errors $\sigma_i < 0.050$ mas (Fig. 1). Their weighted average is $\varpi_{av} \approx 0.373$ mas and their r.m.s. $\sigma_i$ is 0.034 mas. (Each $\varpi_i$ has relative statistical weight $1/\sigma_i^2$.)

The Gaia data show that many of the 50 stars probably do not belong to Tr 16. This cluster’s diameter, roughly 15 pc, corresponds to a range of only 0.002 mas in parallax. Thus its distribution of $\varpi_i$ values should be indistinguishable from a sample with one true parallax and errors consistent with the $\sigma_i$’s. In fact, however, 13 of the 50 stars have $|\varpi_i - \varpi_{av}| > 2.5 \sigma_i$. If we model the observed $\varpi_i$ 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

\textsuperscript{1}Minnesota Institute for Astrophysics, 116 Church St. SE, Minneapolis, MN 55455 U.S.A.

\textsuperscript{2}Department of Physics and Astronomy, Macalester College, 1600 Grand Ave. St. Paul, MN 55105 U.S.A.
Fig. 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. Seven stars with the most discrepant parallaxes have been omitted. (b) Distribution of Gaia parallaxes in Tr 16, Tr 14, and Cr 228. For Tr 16 the entire 50-star sample is included. Dots mark the O3 stars, and a ±1σ error bar shows the r.m.s. individual σ; in the Tr 16 sample.
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 (Walborn 1995; Massey & Johnson 1993). Here “O3” includes proposed subtypes O2, O2.5, O3, and O3.5, since the distinctions between them have no significance for this discussion. Only about a dozen O3’s are known for the entire Galaxy; Tr 16 has four of them within a 0.2° circle (Fig. 1a); 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 \( \varpi \) is quite small – indeed, smaller than expected. Hence we propose that the parallax of Tr 16 is \( 0.383 \pm 0.017 \) mas, where the r.m.s. error estimate is based on the Gaia \( \sigma_i \)'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 Fig. 1a and Walborn (1995, 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 much 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 improvement has been achieved since that time, since the HST had the best spatial resolution for this problem. But our Tr 16 Gaia result (see above) disagrees, and is probably better.

Therefore we strongly suspect that \( \eta \) Car’s distance is close to 2600 pc, rather than 2300 pc which nearly all recent authors have adopted. Of course this implies a 25%–30% increase in luminosity. In principle \( \eta \) Car might be unrelated to Tr 16, or the Gaia DR2 results may have large systematic errors; but these possibilities appear considerably less likely.

Two other clusters Tr 14 and Cr 228 are often mentioned in connection with Tr 16. Tr 14, a compact group marked in Fig. 1a, contains three more O3 stars, but Walborn (1995) concluded that it is distinct from Tr 16 because its stars are younger. Gaia data give \( \varpi_{av} = 0.327 \pm 0.018 \) 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 \( \eta \) Car. Cr 228, a large, relatively sparse cluster just below the bottom edge of Fig. 1a, does not affect the above discussion.

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