Dear Dr. Sarajedini,

We thank you for organizing the review of our paper, and also thank the referee for constructive criticism. We have considered the referee's remarks carefully and revised our manuscript accordingly.

Below, we have reproduced the relevant portions of the referee's report, alongside our responses. A list of changes is appended to the manuscript using the trackchanges AASTeX macros. A figure expanding on the comparison between the field and cluster star rotation periods has also been uploaded for inspection (f13_corehalosplit.png).

Sincerely,

Luke Bouma

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REFEREE COMMENT

At this stage the referee is more inclined to believe that the authors have identified a set of young stars in that region of the sky than actual halo member stars of NGC 2516.

RESPONSE

> We agree that the stars with rotation periods similar to those of
> the Pleiades, and showing Li EWs similar to those of the Pleiades,
> are likely to have comparable ages as stars in the Pleiades.
>
> Figures 4 and 7 show that the stars from KC19 and M21 (the "halo")
> overlap both with the Pleiades, and also with stars in the core of
> the cluster (those from CG18). They share the same
> gyrochronological and Li tracks, and therefore share the same age
> to within measurement precision. The stars in this "halo"
> population are also mostly within 2 km/s of tangential velocity
> separation from the main core population (see panel in top left of
> Figure 6). Spatially, they lead and lag the core of the cluster
> population, in a similar manner to that seen for eight other open
> clusters by Meingast et al 2021 (Figure 2 of our manuscript;
> Figure 8 of Meingast et al 2021, Astronomy & Astrophysics, Volume
> 645, id.A84).
>
> Despite these lines of evidence for the halo stars being
> associated with NGC 2516 -- same ages; same tangential velocities;
> spatial correlation with the cluster center -- for the sake of
> caution we analyzed rotation periods of randomly drawn field stars
> in this region of sky. This exercise was described in Appendix C,
> and the results are shown in Figure 13 of the manuscript. The

> randomly selected field stars (orange points) does not show any
> evidence for an overdensity of Pleiades-age stars. Their period
> detection rates within the relevant ~150 Myr gyrochrone regime are
> also three times lower than the kinematically selected sample (see
> added text in Appendix C).   As a clarification on Figure 13, we
> have attached "f13_corehalosplit.png" as a supplement in the
> response, which shows the same data, but splitting NGC 2516 into
> halo and core stars. Stars in the halo (blue) have a very
> different rotation-color distribution than randomly selected field
> stars (orange).
>
> In short, most of the halo stars i) have similar tangential
> velocites as core stars, ii) are coeval with other halo stars,
> iii) have the same age as the core stars, iv) are spatially
> correlated with the location of the core stars, and v) have a
> different rotation-color distribution from a randomly selected
> sample of fields stars (with a large overdensity of rotators
> falling on the same sequence as the core of NGC 2516).
>
> The suggestion that we "have identified a set of young stars in
> that region of the sky [rather] than actual halo member stars of
> NGC 2516." is equivalent to asserting that the clustering
> techniques used by KC19 and M21 yielded a set of stars that is
> identical to the cluster core according to all age measurements,
> and is spatially and kinematically correlated with the cluster
> core, but is otherwise unrelated. While the spatial and kinematic
> correlations are tautological -- this is what clustering methods
> should do if they are working correctly -- the age measurements
> have no a priori reason to be identical between the core and halo
> unless the two populations are in fact related.

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REFEREE COMMENT

The authors begin by concatenating a very large collection of stars
identified by CG18 (which they term the core members), and those of
KC19 and M21, the last two having very relaxed criteria for
association with NGC 2516. At this stage, as one can see from the
distributions in Fig.1, the sample is completely bloated with field
stars which now clearly have to be excised. The question is how?

The authors justifiably look first to the HR diagram and
understandably find that that is not very helpful in rejecting
non-members because almost all stars in the extended sample lie
close to the ridge line of the canonical cluster members.
(Nevertheless, this is already a basis for rejecting stars below the
main sequence and those significantly above it, including giants.
The authors should consider this.) Incidentally, the Gaia photometry
for the brightest stars is likely not good enough for fitting any

isochrones of this age, so in this referee's estimation, the cluster
turnoff is perhaps still the best one can do, keeping in mind the
persistence of photometric problems for bright stars.

RESPONSE

> While we agree the HR diagram is not very helpful in rejecting
> non-members, it does indicate that the distribution of field stars
> in this region of ra/dec/parallax is different from stars in both
> the core and halo of the cluster. In particular, the lack of a
> sub-giant branch or red giant branch (e.g., at G_BP-G_RP =1.2,
> M_G=3.0) in the core and halo suggests that both populations have a
> different age distribution than the field stars, and is consistent
> with the suggestion that the halo population has a single age.
>
> We agree that the ~five halo stars lying significantly above the
> main sequence must be field interlopers. This is noted at the end
> of Section 3.1, Paragraph 2. The ~four halo stars, and ~four core
> stars lying well below the main sequence could have poorly
> determined parallaxes, or could be blended in the Gaia BP or RP
> spectra with unresolved white dwarf companions. We do not consider
> their presence below the MS to support their exclusion from
> consideration as cluster members.

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REFEREE COMMENT

The authors then go on to consider the rotation periods and lithium
abundances of the extended sample, to compare them with
previously-known distribution of similarly young stars.

The conceptual problem here is that stars that deviate from the
known/expected rotational distribution for NGC 2516 are again not
excised from the sample. As prior studies (e.g. Fritzewski+2020)
have shown, there are no rotators above the slow sequence in NGC
2516. So such stars most certainly have to be excised from further
consideration. (Some of these are even older than Praesepe, as the
authors themselves show in Fig.4.) The authors should consider
whether other regions of the color-period diagram merit similar
treatment.

RESPONSE

> We agree that stars showing rotation periods above the slow
> sequence are most likely not "genuine", in the sense that they are
> most likely either not cluster members, or they are cluster
> members, but with unresolved binary companions contaminating the
> rotation period measurement (e.g., Stauffer+2016, AJ 152 115,

> Section 5.1).
>
> At the referee's suggestion, we have therefore opted to redefine
> Set B, in order to excise the stars above the slow sequence from
> consideration.
>
> The definition of Set A remains the same in the resubmitted
> manuscript; Set B is now Set A, with the added requirement that
> the rotation periods fall roughly below the expected slow sequence
> (see revised Figure 4, top).
>
> This change ultimately clarifies our results for the following
> reason. Set A comprises 987 stars. 947 of these have
> (Bp-Rp)_0>0.4, and so make some degree of sense to assess
> gyrochronologically. 892 of the latter stars are below what by
> eye can be identified as the "slow sequence boundary". While
> there is subjectivity in where this line is drawn, the big-picture
> result is that roughly 90% of the "Set A" stars are in or below
> the slow sequence. The arguments we initially drew using Set A
> are therefore still applicable.
>
> This change we feel improves the quality of the manuscript for a
> separate reason as well: manual inspection revealed that many of
> our Stellingwerf Phase Dispersion Minimization (SPDM) rotation
> periods were less congruous with the data than the Lomb Scargle
> periods. Our suspicion is that the SPDM method is more susceptible
> to the gaps in the TESS data). We therefore have also opted to
> remove the SPDM periods from Table 1, since their primary purpose
> was in the definition of Set B.

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REFEREE COMMENT

An additional concern is that the authors construct two samples A
(where rotation periods from multiple types of measurements don't
agree) and B (where rotation periods agree), but then go further
with sample A (for instance Fig.6). Had the authors gone forward
with the tightest-possible sample, and had then shown that this
tight rotation-lithium sample still has a far greater extent on sky
and in the canonical parallax, proper motion, RV etc. spaces, then
readers would be far more willing to believe the authors' claims
about a more extensive cluster.

RESPONSE

> The top two rows of Figure 6 now use the redefined Set B --
> rotational outliers have been excised. For the reasons discussed
> above, the conclusions do not change.

>
> An alternative visualization of Fig 6 in the canonical "parallax,
> proper motion, RV etc." space has been added in the new Appendix
> E. We preferred the visualizations we adopted since the latter
> visualization approach gives the false impression of near-perfect
> rotation period detection near the center of the cluster.
> Nonetheless, we agree that it has pedagogical value.

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REFEREE COMMENT

The referee notes that the prior work of Healy & McCullough 2020,
who also used TESS data to measure a sizeable group of stars in NGC
2516 has been completely ignored. The authors should include a
discussion of the H+M2020 work in relation to the results in this
paper.

RESPONSE

> Healy & McCullough 2020 (HM20) was referenced in the second
> paragraph of Section 4.1, in relation to their discussion of the
> contraction rate of the core NGC 2516, and the corresponding rate
> at which stars are escaping the core. The form in which Healy &
> McCullough quantified the contraction rate does not readily
> translate (to our knowledge) to an estimate of the rate at which
> stars escape from the cluster's tidal radius, or an analogous
> surface. So, the reference was rather brief.
>
> The main result of our paper -- that the halo is the same age as
> the core and therefore most easily explained as being associated
> with NGC 2516 -- does not clearly translate to the main result of
> HM20 -- that the stellar spins in the core of NGC 2516 are either
> isotropically oriented, or perhaps mildly aligned. Therefore we
> did not highlight HM20 prominently in our discussion.
>
> Nonetheless, to address the general idea behind this suggestion,
> we have i) added a reference to HM20 in the introduction, when we
> discuss TESS and NGC 2516, and ii) included the HM20 rotation
> periods in Figure 10. The overall point of the figure has not
> changed.

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REFEREE COMMENT

While on the subject, it should also be mentioned that the
Introduction of the paper is only from the galactic structure
perspective, and is lacking in introducing readers to the
rotation-lithium perspective. Given that the latter constitute the

bulk of the paper, doing that would clearly help the argument being
laid out.

RESPONSE

> We have added a paragraph in the introduction giving some context
> to this effect -- thank you for the suggestion.

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REFEREE COMMENT

This referee came away with the general impression that the authors
have likely identified a number of young stars in a vast halo around
NGC 2516, but did not find the association with NGC 2516 itself to
be particularly convincing. Perhaps they can think about how to
make their arguments tighter, and the inclusion criteria stricter in
the next iteration, to be able to better convince the community of
the association with NGC 2516.

RESPONSE

> As discussed above, the "halo" stars i) have similar tangential
> velocites as core stars, ii) have the same age as other halo
> stars, iii) have the same age as the core stars, iv) are spatially
> correlated with the location of the core stars, and v) have a
> different rotation-color distribution from a randomly selected
> sample of fields stars (with a large overdensity of rotators
> falling on the same sequence as the core of NGC 2516).
>
> Points (i) and (iv) are the definitions of being associated
> kinematically and spatially with the cluster core. Points (ii),
> (iii), and (v) have no reason to be the case if the "halo" stars
> were a random population of young stars in the field. Why would
> this population itself be coeval? Why would it happen to share an
> age with the cluster core? There are no known nearby populations
> that it can plausibly be linked to (we searched the Kounkel & Covey
> 2019 catalog). So would it therefore constitute a new stand-alone
> ~150 Myr population? The simpler explanation is that stars that are
> kinematically and spatially linked with the cluster core, and that
> have the same age as the cluster core, are in fact related to the
> cluster.

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DATA EDITOR'S COMMENT

The .csv file attached with Table 1 has a large number of
significant digits in most columns. In the revised manuscript, the
authors should include a new version that has only the required

precision. This document outlines the typical uncertainties for Gaia data:

https://gea.esac.esa.int/archive/documentation/GDR2/

Fewer significant digits will result in a smaller file that will be easier to read, manipulate, and transfer.

RESPONSE

> The CSV file has been updated with an appropriate number of
> significant digits in each column; thank you for the suggestion.