Author: Thinh Nguyen

Title: Revealing the Age of NGC 2509 with Gaia EDR3

Research Summary:

NGC 2509 is an open cluster. The age of the cluster has been debated with studies publishing various results ranging from 861 million to 8 billion years old. This paper uses Gaia Early Data Release 3 (Gaia EDR3) data of NGC 2509 to give a new estimate of the age. Once the data were downloaded, data missing photometry, proper motion, or parallax measurements were disregarded. Three additional requirements were used to filter out non-members of the cluster: (1) a renormalized unit weight error less than or equal to 1.4, (2) an astrometric excess noise less than or equal to 2, and a parallax measurement at least 5 times larger than its uncertainty. Membership probably was calculated using pyUPMASK. This algorithm works by dividing the cluster into sub-clusters with 25 members per sub-cluster, and a kernel density estimation is compared to a 2-D uniform distribution. If the two kernels are similar, the star is rejected. This continues in a loop until no more stars are dismissed (or 25 iterations have been completed). This process is repeated 25 times. The membership probability is calculated as the average number of times the star is classified as a member in each outer loop. At the end of this process, only stars with membership probabilities of 0.5 or greater were considered members. Next, BASE-9 was used for isochrone fitting by using 30,000 MCMC simulations. logAge, [Fe/H], parallax, and extinction were taken as free parameters, and the helium mass fraction and carbonicity were specified but kept frozen. From the results, there appears to be correlations between [Fe/H] and parallax and [Fe/H] and absorption. By examining a corner plot and using robustness analysis, the MCMC results show gaussian-like distributions, and the results are relatively consistent when changing initial values of logAge and absorption. The resulting age of the cluster, 1.6 billion years, is consistent with literature.

Recommendation: Accept with minor revision

The methodology is good and mostly detailed. The main issues with the paper are places where things should be clarified or issues of consistency. Some more detailed explanations are needed, which if not provided, could compromise the integrity of the paper (see below), and uncertainties need to be provided on all values reported.

Concerns:

Major points:

- All results need uncertainties or error estimates with them, especially those stated in the abstract and in Table 2. Whenever a value is stated in the text of the paper it should also be accompanied by an uncertainty.
- In the introduction, papers are listed that calculated the age of NGC 2509, but the author states that these different values result from using Gaia DR2 data vs. CCD photometry. This should not affect the age estimates that

much. Also, it says that both Sujatha & Babu (2003) and Ahumada (2000) used CCD photometry, but they got age estimates of 8 billion and 1 billion years old respectively. It does not make sense, then, to say that the method of data collection affects the age estimate when these two papers report the same method and drastically different results. Lastly, for all the papers mentioned, either in this section of the introduction or compared in the conclusion, the age estimate should explicitly be stated to facilitate comparisons for the reader.

- The author should explain what do the correlations between [Fe/H], absorption, and parallax mean or imply. Does this say anything new about the cluster itself? Are these correlations expected?
- Future work or implications of the project should be stated in the conclusion of the paper. This gives the paper much more scientific merit.

Minor points:

Abstract:

- Author uses "we" and "us" (plural) when there is only one author on the paper.
- "Whose probability is larger than 0.5" should be stated as "whose membership probability is..." to make it clear what the probability is referring to.
- The abstract is descriptive but might be too specific. The number of MCMC iterations or the chosen membership probability cutoff of 0.5 does not need to be mentioned.

Introduction:

- The first paragraph is unnecessary. It provides background information that is not needed considering that the reader of this paper will be astronomer or expert in the field.
- Change instances of HR diagram to color-magnitude diagram (CMD) to be more specific to open clusters.
- In paragraph 2, "a stellar population with similar age" should be reworded as "the age of a stellar population."
- In paragraph 3, RA and dec can be more concisely reported as: RA 08^h 00^m 48^s, dec -19° 03' 06"

Methodology:

- All color-magnitude diagrams in the figures should be in terms of absolute magnitude, not apparent magnitude for comparisons.

Contamination Removal:

- In Figure 1, G can be redefined as absolute magnitude, so your CMDs (when all changed to absolute magnitude) can be in terms of G mag. Also, in the legend, "contamination removed" is confusing and should be changed to something like "after contamination removal."

- Equation 1 should be removed and restated in the text of the paper and the code-like formatting should be removed. It can be listed as bullets or a numbered list if the author choses. It can then be combined with the following paragraph so that each restriction is stated with the explanation directly after.
- It should be explicitly stated why parallax is required to be at least 5 times larger than its uncertainty.

Membership Probability:

- In explaining pyUPMASK, it should be quantified how similar the two kernels need to be to reject a star as a member rather than just stating that they need to be similar in general.
- The author says, "all stars in that sub-cluster are rejected as field stars." This is confusing and should be reworded to something like "…rejected and consisted of field stars."
- It says, "the inner loop ends when no more sub-clusters are dismissed." I think the author meant "…when no more stars are dismissed."
- The author mentions that the cluster is divided whenever it is fed into the inner loop. It should be stated if this division is random or different each time and how the division is determined.
- "Mini-batch k-means for the clustering method" should be explained.
- At the end of section B3, the author mentions that red giants are not noticeable and there are no white dwarfs or blue stragglers in the final cluster data. Is this expected, or should these stars be in the cluster? If they should be there, then why are they not in the final CMD?

Fitting Isochrone:

- The sentence "We refer to literature as much as possible for our prior" is unnecessary and can be deleted.
- "…and set its prior sigma to be 0.1" can be deleted, but it should be mentioned that the prior sigma is 0.1 for all free parameters.
- "The weight is the negative inverse of the log of the unnormalized posterior probability" should be restated as an equation or in math symbols.
- The "two burnin stages" should be explained, and it should be explicitly stated how many iterations or Markov chains this was.
- All instances of [Fe/H] should have brackets. It does not have brackets in Table 1.
- In Figure 4, the x-axis should be relabeled as "B_P-R_P".
- In Figure 4, the isochrone fit looks a little suspicious for higher B_P-R_P values as it crosses over itself. Maybe the graph should be remade, and the isochrone can be points rather than a connected line to get rid of this.

Membership Comparisons with Literature:

- Values of total stars in the cluster are cited as 253 from Cantat-Gaudin et al. (2018) and 254 in this paper, and 203 of these targets' coordinates overlap. The author should go into more detail about why these numbers are

different and if there is a correlation between the targets that do not overlap.

Corner Plot:

- In Figure 5, I assume the confidence levels in the contour plots are 1, 2, and 3 sigma, but this should be stated.
- Fe/H should have brackets in the axes in the corner plot.

Conclusion:

- The conclusion should not introduce any new information. The last 2 paragraphs can be stated in the discussion section, and they can be mentioned briefly in the conclusion.
- For the papers mentioned in paragraph 2, the age estimates they report should be explicitly stated to facilitate comparisons for the reader. Also, it should be explained why the results are different between this paper and the results of other studies.

Evaluation of Criteria:

Is the length appropriate?

The length of the paper may change after the revisions noted above are made, but in general, the length of the paper is reasonable.

Are the title and abstract sufficiently informative?

The title could be a bit more descriptive (maybe "Age Determination of NGC 2509 using Bayesian Techniques"?). Also, the title only mentions determining the age while the abstract mentions the other free parameters used in MCMC, so the title should be more general, such as "Bayesian Analysis of NGC 2509 with Gaia EDR3". The abstract is descriptive but might be too specific. The number of MCMC iterations or the chosen membership probability cutoff of 0.5 does not need to be mentioned.

Is the contribution to science significant?

The contribution is significant in that it provides another estimate of the age of NGC 2509. It does not completely result the debate about the age of this cluster, but it demonstrates consistency of an age of about 1 to 1.6 billion and gives more merit to these estimates.

Is level of English adequate?

Some clarifications are needed, but overall, the level of English is adequate.

Is the literature properly cited?

Yes, the work is properly grounded in literature.

Are the results clearly and accurately presented?

The numbers presented need to be reported with uncertainties.

Is the topic appropriate for the journal?

Yes, this is appropriate for the journal.

<u>Data Management Plan:</u>

The algorithms used are available online or by contacting the authors of the original sources. The methodology presented is reproducible with the use of these programs, and all results are presented in the paper.

<u>Additional Comment:</u> The author's methodology and analysis are well carried out and impressive considering the short period of time for the project.

Author: Thinh Nguyen

Title: Revealing the age of NGC 2509 with GAIA EDR3

Summary:

This study aims to determine the parameters of NGC 2509, including age, metallicity, parallax and absorption. The photometric and astrometric data was obtained from GAIA. The data query was set to return all stars within a 14 arcmin radius of NGC 2509. Next, contaminated and unreliable sources were removed. Since cluster membership is highly dependent on astrometric parameters, restrictions were applied to remove targets with poorly measured proper motions and parallaxes. pyUPMASK was used to determine cluster membership. The cut-off was set to 0.5. Using this, pyUPMASK determined 254 cluster stars. The detailed tables containing the cluster membership data will be released with the online version of this paper. After cluster stars were determined, isochrones were fitted using BASE-9 which uses MCMC. MCMC was run for 30,000 iterations with a set of prior and initial distributions. From this, the best set of parameters were determined, and an isochrone was selected and fit to the measurements. From Figure 4, the isochrone fits the data well. Next, the paper discusses the results from the MCMC runs. The posteriors are presented in Table 1. The amount of cluster stars and the overlap of cluster stars to a previous study is high. Corner plots are created and discussed to evaluate the convergence of the MCMC run and the correlation between specific parameters. Lastly, the MCMC results are re-run with different sets of priors to confirm the status of the results. In the conclusion, the determined parameters are listed and compared to the values in the literature.

Rating: Accept with minor revision

Minor Revisions:

- In the introduction, the ages determined in previous studies are listed. The value reported by Sujatha & Babu (2003) is drastically different than the other studies. Is there a reason for this discrepancy? An explanation for this major difference should be offered.

- In Section B.3, the presence of red giants and the lack of white dwarfs and blue stragglers is mentioned. In Figure 2, there seems to be a clear main sequence parallel due to the presence of binary stars. This feature should be mentioned.

- In Section C.2, The correlation between different parameters is discussed. While these correlations are mentioned they are not really explained. If there is mention of strong correlation between parameters in the parameter space, then there should be some attempt to physically explain the correlation.

- While the numerical results are listed, they are buried in other tables. A list of all the determined values and their errors should be given in a separate table.

Major Revisions:

- There is no affiliation given for the author

- For assessing MCMC convergence, it is useful to consult more than one test. Using a log-probability plot or trace plots would indicate whether convergence has been reached and the use of more than one test would place more confidence in the claim of convergence. I think the addition of one of these plots would be beneficial to the paper

- Why is there a prior on metallicity? Priors are usually used when there is a reliable estimate from the literature or another determination from the study. However, there is no

previous knowledge of the metallicity of NGC 2509 so it doesn't seem like a prior distribution should be given.

Evaluation of Criteria:

Is the length appropriate?

- Yes

Are the title and abstract sufficiently informative?

- Yes, however for the numerical results presented in the abstract, the associated errors should also be given

Is the contribution to science significant?

- Yes, due to the issues of age determination for NGC 2509, an updated study using Gaia EDR3 data is an important contribution to the field of open cluster studies.

Is the English adequate?

- Yes, but at times there is come colloquial language

Is the literature properly cited?

- Yes, all the background and introduction are rooted in literature and all the programs utilized are properly cited.

Are the results clearly and accurately presented?

- A separate table displaying just the results and errors would be beneficial. Right now, the results are buried in other tables

Is the topic appropriate for this journal?

- Yes

Data Management Plan?

- The numerical results determined by this study and their errors could be better formatted in their own table. The other results, such as the membership probabilities, will be released with the online version of the paper.

Additional Comments:

- The paper was extremely interesting and enjoyable to read. I would like to thank the author for all the hard work they have put into this study. I think this paper is important and is a step forward in resolving the conflict in NGC 2509's age.

Note to the Editor – Thinh

To the Editor-

I stand by my review of this paper. You are free to disclose my identity to the author, should they request it. I found no major issues with this paper. I would have liked to see more discussion of the results and their significance and meaning; however, this may require an additional paper to accurately review. I would recommend the publication of this paper in order to add another point to the proposed age of NGC 2509. It is possible that this cluster is a special case and the results of this paper are in preparation of a much bigger find in the study of open clusters!

Best regards,

Danielle Mortensen

Thinh Review

Summary:

The author conducts a study of the open cluster NGC 2509 to determine its age, metallicity, parallax, and absorption. The data used for this study was from the *Gaia* Early Data Release 3. The initial data set included stars which were present in a 14 arcminute radius around the central position of NGC 2509. The dataset was cut down by available data; restrictive parameters such as ruwe, astrometric excess noise, and parallax over-error; and finally membership probability. The membership probability was calculated using pyUPMASK which uses a 2-loop procedure. Membership probabilities under 0.5, determined by pyUPMASK, were not included in the final dataset. An isochrone was fit to this final dataset using the BASE-9 software which utilizes MCMC. Initial values put into BASE-9 were determined through literature, and the final values, were 9.2037 (logAge), 0.3469 ([Fe/H]), 0.4422 (parallax in mas), and 0.0206 (absorption). The results from BASE-9 were assessed using a corner plot and a robustness analysis, which determined that the MCMC run was significantly converged after 30,000 iterations. Other priors were also considered and run through BASE-9, and each of these three additional runs resulted in posteriors which were similar to the initial run. The resulting age of 1.6 billion years for NGC 2509 was compared to other results in literature, and the other resulting posteriors were discussed.

Recommendation:

I would recommend that this paper be **accepted with minor modifications**.

Justification:

- *Major Points:* None.
- *Minor Points:*
    - Section B.2: "We take the recommended value by *Gaia* of 1.4 (Lindegren, 2018) for ruwe."
        - Is this meant to indicate that the author is looking primarily for single stars in this cluster? Why?
    - Section B.3: "The method will compare the kernel density estimation of the coordinate space to that of a two-dimensional unform distribution in the same range."
        - What is the significance of this? Why are similar kernels rejected from being members?
    - Section B.3: "…we do not have any white dwarfs or blue stragglers in our sample."
        - Might there be a reason for this? Would having these data points influence the results at all?
    - Section C2: "…the elliptical shapes of their contour plots demonstrate that there are correlations between [Fe/H], parallax, and absorption Av samplings."
        - From the text, it is unclear whether these correlations are good, bad, or simply present in the results.

- ▪ Perhaps it would be worth examining these correlations and their potential impact on the posteriors.
  - o Section D: "Also, the absorption value is small compared to the great distance that the cluster is at."
    - ▪ Is there any possible explanation for this?
    - ▪ It would be valuable for the author to address reasons for this small absorption. Maybe the cluster is located in a place where the in between space is not as populated with ISM?
    - ▪ Did this resulting absorption have a significant impact on determining the other values using MCMC?

Evaluation:

- *Is the paper length appropriate?*
  - o Yes. The paper is appropriate in length to explain every detail of the research concisely but still in detail.
- *Are the title and abstract sufficiently informative?*
  - o Considering one of the primary points of the research is to determine the age of NGC 2509, perhaps the estimated age should be reiterated in standard form instead of listed among other attributes in log form in the abstract. This would make the results easier to digest for every reader and more comprehensive after reading through the introduction section.
  - o The title is wonderfully short and informative. I understood immediately the intent of the research.
- *Is the contribution to science significant?*
  - o Yes. A cluster age has not yet been calculated using the new EDR3 from *Gaia*, therefore, the results of this research have provided conclusions based on data which is much higher in quality than previous *Gaia* data releases.
- *Is the level of English adequate?*
  - o Yes. Each concept was explained both in technical terms and in layman terms making the information accessible to the reader.
- *Is the work properly grounded in literature?*
  - o Yes. Wonderful representation of all papers which have addressed this topic before.
  - o It was appreciated that the paper which estimated the cluster age to be 8 billion years was still included and given due assessment despite its major disagreement with the research results.
- *Are the results clearly and accurately presented?*
  - o Yes. The results are clearly stated.
  - o As mentioned before, the abstract may benefit from a more focused presentation of the cluster age results being around 1.6 billion years old. This is the answer to the title and is therefore a piece of information to be highlighted as much as possible.
- *Is the topic appropriate for the Journal?*
  - o Yes. The author's research is a clear fit for this Journal being on the topic of open cluster parameter analysis.

- *Is the data management plan good?*
  - Yes. The author explicitly states their intention of making this research fully repeatable and accessible to the public. The membership data set will be released in the online version of the paper and the software and programs used are fully available for repetition of this research.

Final Comments:

This was a very interesting paper with thought-provoking results awaiting further analysis and explanation! It seems to have fulfilled its job in aiding the resolution of the discrepancies surrounding the age of NGC 2509. I hope these comments are accepted as constructive criticisms and the author finds them helpful. My best wishes in their success!

Summary:

This paper gives an analysis of the open cluster NGC 2509. Data used was gathered from the *Gaia* EDR3 public archive. The analysis portions followed steps and methods from several other papers that conducted similar analyses on this object and other objects. The data was parsed down to remove all invalid data, and data that was considered unreliable due to quality. Membership probability was calculated using the pyUPMASK algorithm for each star in the dataset. Membership was determined as any object with a probability greater than 0.5. Isochrone parameters were fitted using the BASE-9 software. The priors for the runs were chosen from previous literature values as well as from gaussian fits on parameters from the specific dataset (parallax). The mean posterior parameters from the BASE-9 analysis were utilized as the parameters to compute the average isochrone to be fit to the color-apparent magnitude diagram of the cluster. The paper goes on to compare the found values and parameters with previously published values. A corner plot was used to display the relationship between the various parameters and valid the convergence of the BASE-9 results. A robustness analysis was carried out on the results. This involved more runs using different prior values to determine if the convergence values were true or if there existed degeneracy. The robustness test confirmed the found results.

Recommendation:

Accept with minor revision

Points of Consideration:

Major:

None

Minor:

§B3 ¶1 an explanation of kernels and how the chosen method is valid would aid in understanding

§B4 ¶1 a brief explanation of what a Bayesian approach is would aid in understanding

§B4 ¶2 the metallicity prior σ is set to 0.1. If the range is from -0.3 to 0.3 why isn't the chosen prior higher?

An explanation of why a gaussian is the best choice for finding the prior for the parallax would aid in understanding

§B4 ¶3 author could explain more about the weight from BASE-9 and what it is

§B4 ¶3 burnin phase mentioned but length not given

Paper would benefit from an additional proofread

Evaluation:

Length:

Length is appropriate

Title and Abstract Sufficiency:

Both title and abstract sufficiently describe the research conducted

Contribution to Science:

Paper provides an additional analysis on the open cluster NGC 2509. The method used as well as the corroboration of *Gaia* EDR3 data is successfully demonstrated in this paper

Level of English:

Paper is easy to read, and language used is understandable

Literary Citations:

All credit is given where due. Introduction and values used are all properly cited

Clarity and Accuracy of Presentation:

Results and process are clearly worked out step by step with all determined properties clearly listed and labeled

Topic Appropriate for Journal:

The topic of this paper is appropriate for this Journal

Data Management Plan:

All data is publicly accessible as well as software used. Process is repeatable

Additional Comments:

This paper is very well constructed. The presentation of necessary background information as well as the process by which the analysis was carried out is clearly described. In the hope that the author accepts these comments, I accept the author's work and compliment them on their hard work and results. My strongest compliments to the author.

Title: Revealing the age of NGC 2509 with Gaia EDR3

Author: Thinh Nguyen

Summary: The author begins the paper by explaining the importance of open clusters in astronomy as laboratories because stars inside share all variables (ie. Age, distance, and chemical composition) except mass. This allows mass determination of stars within an open cluster by fitting isochrones to an HR diagram. Despite the many successes of isochrone fitting in astronomy, previous studies found conflicting ages for the open cluster NGC 2509 using the same method. The author uses the more recent data from the *Gaia* Early Data Release 3 and robust techniques to redetermine the parameters for the cluster. After filtering the data, the author determines the membership probability for each star in the data. He then applies Bayesian Analysis for Stellar Evolution with nine Variables to fit isochrones and determine the cluster parameters. He finds an age of 1.6 billion years for NGC 2509, which agrees with some of the previous studies. He also finds that the posterior logAge and parallax remain consistent, while the posterior metallicity and the absorption differ from previous studies.

Recommendation: Accept after minor revisions.

Justification of Recommendation:
Major points:
- Some decisions in the data analysis process still need to be supported by an explanation/ justification in the paper. This includes using the default settings for pyUPMASK and choosing a cut-off value of 0.5 for a cluster member.
- In section C.1, the author should explain why he chose the 2018 study by Cantat-Gaudi to crossmatch with for membership probability. He previously mentioned numerous studies that conducted isochrone fitting, so it is unclear why he chooses this one study to crossmatch for the membership section of the paper.

Minor points:
- In Figure 2, it is unclear whether the bars on each data point show error or probability. A legend or clarification in the caption would help with this.

- The author should read through the paper fix some typos that change the meaning of the science he is trying to explain.
- The caption for Figure 5 provides an insufficient description of the corner plots. The caption should reference the MCMC sampling to briefly explain the importance of the plots.
- The formatting for Table 2 disrupts the flow of the paper because the caption is on top of the table rather than below it.

Evaluation:

1. Is the length appropriate?
   a. Yes – the length is appropriate.
2. Are the title and abstract sufficiently informative?
   a. Yes – both the title and the abstract are sufficiently informative.
3. Is the contribution to science significant?
   a. Yes – the project addresses conflicting results from previous study. The conflicting results indicate the need for a new study, as the author successfully completed. The study provides more reliable parameters for NGC 2509. These parameters can be applied for work with the cluster in future studies.
4. Is the level of English adequate?
   a. Yes – the level of English is adequate.
5. Is the literature properly cited?
   a. Yes – the author sufficiently cites necessary resources.
6. Are the results clearly and accurately presently?
   a. The results are presented clearly and accurately with a detailed discussion on them as well.
7. Is the topic appropriate for this journal?
   a. Yes – the topic is appropriate for this journal.
8. Data management plan?
   a. The author clearly displays the results from his study. These updated parameters for NGC 2509 would be made available to the public through the publication of this paper.

Additional Comments: Kudos to the author for recognizing conflicting results for NGC 2509 in literature and taking on the challenge of improving previous studies. It required hard work to complete this intricate study in such a short and busy time frame.

Author: Thinh Nguyen

Title: Revealing the age of NGC 2509 with Gaia EDR3

Summary:

The author provides a brief overview of open star clusters along with their importance in terms of determining parameters for member stars. Due to the only varying property between the member stars is their mass, just about everything else should be identical. Pipeline projects such as the Gaia data releases have made this possible and more efficient, as each data release is more accurate than the previous one. The author details the confusion surrounding the properties of open cluster NGC 2509 from different literature of studies made over the years. Previous literature has utilized Gaia Data Release 2 as well as individual photometry performed, and now Gaia's EDR3 will be utilized to conduct the study. In theory, the results should be much more accurate than the previous data release. From the data release, constraints on distance were placed to filter out the stars that are too distant to be considered a member. Further constraints are placed which dramatically cuts the number of stars to 1683 stars. From there, membership probability can be determined through pyUPMASK, an algorithm meant to designate membership probabilities. Stars with a membership probability below 0.5 were considered field stars. With the member stars, isochrone fitting was conducted utilizing the BASE-9 software. The software also provided parameters utilized later on. The member stars were then compared to previous literature and found a good amount of overlap (80%). This highlights the consistency between the study and previous literature. The accuracy of the average posterior parameters from BASE-9 were evaluated utilizing corner plots. Robustness analysis is utilized to further look at the MCMC effectivity. Looking at the results, the determined logAge was somewhat consistent with a few of the previous literature, but not all. With no prior metallicity value, there was no comparison made with that property.

Recommendation: Accept with minor revisions.

Justification

Major Points:

- No major points.

Minor Points

- The author could include a date/time as to when the planned rollout of the study's results will be made available.
- There is no denying the scientific contribution this paper will add, but the author could include a couple sentences on how this could affect the field or even future work.
- Perhaps briefly explain what robustness analysis consists of a bit more.

Evaluation:

1. Length of Paper
   a. Yes, the length of the paper is adequate.
2. Title and Abstract
   a. Yes both the title and the abstract section are sufficiently informative and efficiently provide a brief look into what the study was about.
3. Scientific Contribution
   a. Yes, the author sets out to settle a debate as to the properties of open cluster NGC 2509. However, the author should also consider how this study could further contribute to the field itself.
4. English level
   a. Yes, the level of English is adequate.
5. Literature
   a. Yes, the literature is properly cited.
6. Results
   a. Yes, the results are presented in a clear and accurate manner. There is no confusion.
7. Topic
   a. Yes, the topic of this study is appropriate for the journal.
8. Data Management Plan
   a. The author does make note that data utilized in this study as well as the results will be available for public use. However, no time stamp is indicated as to when that could occur.

Additional Comments: The topic at hand is interesting, especially when it has been a subject of debate for a couple of years. The fact that the author is working with the latest Gaia release further places emphasis on the accuracy of the results. Great job!

Summary
The age of the open cluster NGC 2509 is uncertain and there have been many studies completed in the past trying to figure it out. The author suspects that the difference in age is due to data inconsistencies and the fact that it has a narrow main sequence turn-off point. There was a new data set just released, Gaia Early Data Release 3, which the author aims to use to redetermine the age of the cluster since it is way more precise and accurate than any of the previous data releases. First, the author decontaminates the data by using specific parameters to eliminate sources that are lacking information, and limits the size of the targets to 1683 stars. Then, he calculates membership probabilities of all the targets using pyUPMASK and based on specific criteria, he finds that 254 stars are cluster members. Then, he uses BASE-9 to fit a set of theoretical already existent isochrones with the observational distribution of stars in NGC 2509 to find out additional properties of the cluster. He compares the results with what already exists in the literature to demonstrate that they are consistent with what has been done in the past. Then, he created and explained a corner plot, which mainly shows the accuracy of the parameters he found for the cluster. Finally, he created a robustness analysis to also evaluate the convergence of the MCMC run.

Recommendation
Accept with minor revision.

Justification of Recommendation
Major points
1. The style should be more consistent throughout the entire paper. What I mean by this is that the level of expertise that the reader needs to understand the paper rapidly increases as it goes along. For example, the very first paragraph of the introduction is unnecessary background information. I think that it is too basic and the author should assume that the reader has this knowledge already. But then, in the discussion regarding the corner plot and the robustness analysis, these are concepts that I was quite confused about and were explained at such a high level that I had a lot of trouble understanding what they were talking about and what the point of them was in the analysis.
2. Going off of the point above, there are many concepts that need to be explained more. I did not completely understand what the MCMC technique does, so I would like to see another sentence or two clarifying this. Also, in the Corner Plot section, I do not know what convergence means, and it seems to be a very important part of this section and the next.
3. At the end of the Membership Probability section, the author begins to talk about the type of stars in the plots. Specifically, he says that we can see red giants but there are no white dwarfs or blue stragglers. I think that there is not enough analysis/explanation here about the types of stars, since the types of stars in a cluster can provide information about the cluster. Additionally, I have no clue in Figure 2 about which points correspond to which types of stars. I think there should be a legend that shows each type of star corresponding to a different color so that it is easier to notice what is present in the cluster.

Minor points
1. In the introduction, the author mentions that the HR diagram has a main-sequence turn off point, but I thought that only the color magnitude diagram displayed this.
2. There could be more literature in the second paragraph of the introduction.
3. I have always thought that the citations go at the ends of sentences, but that might be more about my own style preferences than what is considered to be 'correct.'
4. The author uses the word and variations of "confusing" many times throughout this paper, and I think that this takes away from the professionalism. It would be better to see words such as "ambiguous" or "unknown" to increase the professionalism of the paper.
5. In the Data section, I am still confused on why the author chose 14 arcmin as the cluster radius. I know that he wanted to include all of the possible members, but is it possible that this might be too much of an overestimation? I would like to see some additional explanation.
6. I do not think the Data and Contamination Removal sections should be under Methodology. Since they specifically deal with reducing the data itself, I think that they should have their own Observations section.
7. Equation 1 is not an equation, just specific parameters. They should not be listed in the equation format but as an in-text list of parameters.
8. Why isn't there a lower limit to the rwue value in the parameters?
9. Why is the cluster membership cutoff value .5?
10. The author lists figure 1 as a color absolute magnitude diagram and figure 2 as a color apparent magnitude diagram. I think the type of diagram should be consistent in the entire paper, and if not, maybe the reason for this change should be explained.
11. In the Fitting Isochrone section, the author uses an entire paragraph to list out the parameters only to then say that Table 1 contains all of the parameters. This paragraph seems unnecessary, and the only explanation should be any important points the author wants to bring up.
12. In the last paragraph on page 5, the author says that "Figure 4 demonstrates a good match…." What does 'good' entail? I do not think it is acceptable to use qualitative words like "good," especially since I have nothing to compare it to that would make me think it is "good."
13. Figure 4 needs to be explained more. I would like to know what is going on in the top right of the graph. This figure seems to be the culmination of the entire project but it is just shown and briefly mentioned and then the author quickly moves on.
14. This is not completely necessary, but in the Conclusion, I would like to see more on how these results will be used in the future or what future studies of this cluster look like.

Evaluation
1. Paper length
    a. I think the paper is a little bit wordy and some paragraphs and explanations could be more concise to shorten the length of the paper. However, at the same time some areas do need additional explanation, but also in a concise manner.
2. Title & abstract

      a. The title and abstract definitely both reflect the summary and do a good job of explaining the paper.
3. Contribution to science
      a. The contribution to science is significant. Calculating the specific properties of a cluster with a new dataset definitely aids toward the ambiguity around this cluster from the past.
4. Level of English
      a. The level of English is mostly adequate. There are some phrases that could be worded differently because at some points, it took me longer than I would have liked to understand what the author was trying to say.
5. Literature
      a. For the most part, the literature was properly cited. There were a few instances in the introduction, where the author most likely found the information from another source, that should have a citation.
6. Presentation of results
      a. Even though the figures could have some additional explanation, the numerical results are presented very well and clearly. There are error bars in Figure 2 and Figure 4, but none in the Tables (unsure if BASE-9 and the robustness analysis should have errors listed).
7. Topic appropriateness
      a. The topic is appropriate for the journal.

Data Management
These results are likely reusable as they are presented in a clear tabular format. Future scientists can use them for comparisons, as contributions to larger studies on open clusters, etc.

Additional Comments
This study was very well done in a short period of time. It is clear that the author worked quite hard on this and the paper is very reflective of a job well done.