

## Short Summary:

This paper presents a new numerical algorithm, called “*AstroComb*” for cyclostratigraphic analysis of proxy data derived from sedimentary sequences. Key suggested innovations relate to (i) the combined analysis of different proxy data (“Multi-channel”), and (ii) an uncertainty formulation on the model-derived sedimentation rate / age-depth model parameters. The new model is applied to a Cambrian high-resolution XRF elemental core scanning dataset, first on a single proxy (i.e. Al), and then with a combination of three proxies (i.e. Al, S, Mn). The discussion also features a test case with an artificial record, distorted by a high degree of red noise. MATLAB code for *AstroComb* is provided.

## Main comments:

Dear authors,

The algorithm, and the ideas behind, “*AstroComb*” are a welcome addition to the cyclostratigraphic toolbox. Both multi-channel analysis, and uncertainty formulation are much debated aspects of (numerical) cyclostratigraphic analysis. However, the current presentation of the new method feels very brief and might give the reader not all the information needed to truly appreciate the contribution.

Below you may find a series of detailed suggestions, indicating where things might not have been entirely clear to me, or where certain aspects of the discussion could be expanded. Main comments are highlighted in bold font, and are briefly listed below:

- Recognition, discussion, and comparison of previous related work: especially the (evolutionary) average spectral misfit work presented by (Meyers & Sagemann, 2007, *AJS*: <https://doi.org/10.2475/05.2007.01>) should be incorporated. Also see other suggestions below, e.g. Sinnesael et al., 2016 on instantaneous estimates.
- A general case could be made for why multi-channel and probabilities might be good to introduce, it does not need to be motivated by (a challenging) Cambrian case study alone.
- Explain explicitly what uncertainties are reported here (error on the fit only), or not. What about uncertainties in the astronomical component selections, etc...
- More user guidance in the script and/or “Readme” file would be beneficial for user experiences.
- Explain more clearly, maybe in different wording, what exactly is meant by “non-linear”, “discontinuities”, ...
- The real case study represents a re-analysis of a record that is already interpreted in terms of cyclostratigraphy. It would be valuable to explicitly compare both. What is potentially different when using *AstroComb*? Or not. Geological implications? Etc...
- Maybe most importantly for a paper presenting a new method/algorithm. The Discussion opens with “*Extensive tests were carried out to study the accuracy and stability of the algorithm.*” But the current manuscript starts with the presentation of a (Cambrian) real case study, briefly discusses a synthetic example in the discussion, but a more systematic documentation of testing with various synthetic examples, a maybe simpler real case study, to end with a complex Cambrian case study could be valuable to really document how the new method works. Comparison with existing methods that do similar/related

analyses might also be informative. Part of such work could be presented in supplementary materials.

Kind regards,

Matthias Sinnesael

### **Detailed comments (with main comments highlighted in bold font):**

#### Abstract:

Line(L)17: why do the anchor points need to be astronomical, and for example not radio-isotopic dates?

#### Introduction:

L26: "... these Milankovitch cycles". The previous sentence is very general and does not introduce the concept of Milankovitch cycles.

L28: would it be specific spectral features, or repetitive features in a depth series, but not repetitive features in a spectrum?

L29: astronomical frequencies would be a wider term here, as strictly speaking the orbital parameter is limited to eccentricity (i.e. actual changes to the orbit of the Earth around the Sun).

L31-33: Does TimeOpt not rather assess a fit relative to certain astronomical frequencies (optionally combined with the assessment of amplitude modulation patterns in the converted time series) rather than comparing against astronomical solutions?

L41: diagenesis happens after sediment accumulation

L43-49: Shales typically have a lower sedimentation rate compared to many other sedimentary deposits. Is low sedimentation rate what is meant with "shorter stratigraphic thickness representing shorter time scales"? **From the current motivation it is not clear why these particular type of records would benefit from a probabilistic perspective? Can there no argument be developed for the advantages of a probabilistic approach in cyclostratigraphy in general?** And then a particular case study can be presented to illustrate the newly developed method?

L55: on the topic of instantaneous (non-stationary) sedimentation rate estimates (with a limited component of uncertainty estimates) in cyclostratigraphy, see for example Sinnesael et al. (2016, GMD) and references therein: [www.geosci-model-dev.net/9/3517/2016/](http://www.geosci-model-dev.net/9/3517/2016/)

L59: explain how a piecewise continuous process is different from for example windowed approaches, some of which cited earlier in the manuscript, or other methods suggested to be able to deal with abrupt changes in sed rates (e.g. Sinnesael et al. (2018, PP) and references therein: <https://doi.org/10.1029/2017PA003293> )

**L65-67: What about the average spectral misfit (ASM) work, and the evolutive adaptation (eASM), done by S. Meyers and B. Sagemann (e.g. Meyers & Sagemann, 2007, AJS: <https://doi.org/10.2475/05.2007.01>). This seems to be a key reference that is missing and deserves incorporation in the introduction/discussion.**

L68: specify “high-speed computing” and “large datasets” in this context. It might be nice to already mention the programming language used as well.

L69: see earlier suggestion on windowed approaches

L71: are these “discontinuities” detected by AstroComb, or can they be included by the users based on external information, important to explicitly formulate.

**L76: in the case of for example XRF multi-channel data, many elemental variations are probably correlated, is this considered in the “full probability distribution”?**

L77: clarify why the sub-precession scale is so important here?

L78: explain what “ProBE4T” is.

**L78: The “Fernandes et al. (2026)” reference can currently, 26/03/2026, not be found on the mentioned GMD website, or is not available to the reviewers? This is not according to the guidelines of the journal.**

L79: upper Cambrian... Formation

L80: give thickness (m)

L82: is this “so extremely slow”, e.g. in pelagic settings?

L87: “reveal” as is newly detected, not interpreted in the previous studies?

L89: not clear what “chemical oscillations” mean here.

L93: if it is optimised for a specific application, what would a suitable minimal “high-resolution” be? E.g. x samples per Y cycle?

**L100; “detect Milankovitch signals”. Does AstroComb aim at identifying potential Milankovitch cycles, or can it be applied when it has been demonstrated/suggested that certain Milankovitch cycles are present in a signal/record?**

**L101: it would be interesting to know what exactly the (sources of) “uncertainties” are. E.g. uncertainties on the fit? Uncertainties in component identification? Uncertainties in the periodicity of the astronomical cycles for the Cambrian?**

L101-112: these do not seem to be four components of the method.

L113-117: mostly repetition

#### Theory and Methods:

**L121: “certain”, so it is not important that all the individual channels contain an imprint of astronomical forcing? E.g. I can feed all the XRF core scanning elemental data to the**

**algorithm, no matter if they have an astronomical component or not, and it will not affect the performance/uncertainty estimates?**

L128: there is some uncertainty for Cambrian “predefined target astronomical spectra” – how does this affect AstroComb?

L129: **is this “stretching” and “compressing” done linearly or not?** And could this be a different with the ASM approach of Meyers & Sagemann (2007). Fig.1 looks a lot like Fig.1 in M&S 2007, and seems to suggest a linear scaling? L165 and Eq. (2) suggest a constant  $r$  per window as well.

L150-156: an orbital solution will typically only consider the eccentricity part, not for example obliquity and precession, “astronomical solution” might be more appropriate. The F2022 and W2015 solutions have different estimates for Cambrian values, and R. Zeebe also has different solutions available (<https://www.sciencedirect.com/science/article/pii/S0012825224002873>, and: <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2024PA004861>). How exactly are the suggested values determined. Is the uncertainty in the astronomical solutions reflected in the “full” AstroComb uncertainty estimate? It should be specified what the assumptions and approximations are (e.g. the different astronomical components are not single sinusoids).

L177: **in what units are  $a$  and  $b$  expressed?** Spectral power? Significance level – but what noise model is then used? E.g. see discussion in Meyers (2012, PP): <https://doi.org/10.1029/2012PA002307>, or Weedon (2022, ESR): <https://doi.org/10.1016/j.earscirev.2022.104261>

L180-182: define “local”. Are these the mean and standard deviation from the different channel spectra? If so, see previous question on inclusion of channels without astronomical signals.

L190: what are the window sizes used for the calculations of the spectra? The provided MATLAB script mentions “16384”? But what is the unit? Number of samples? mm? What is the influence of the window size for example?

**The MATLAB script contains a relative long list of input variables, with only a short comment (e.g. not discussed in readme file) like “% Relative uncertainty input basic elements data” it is not clear to the user (reviewer in this case) what this exactly means. The determination of every parameter should be clearly explained to a new user who might not be familiar with the method, or particular dataset used here.**

Results:

**Would it be more educative to first show how the new algorithm works on a simple synthetic example, instead of one real-world case study. One might wonder how the algorithm might perform with a series of different input parameters for the same case study, or how an application to a different case study might look like. One application with one (optimized) set of parameters might give a limited overview of some of the potential model sensitivities. One can always design more sensitivity tests of course, but (the reporting of) none is rather limited when presenting a new method.**

L232: give exact core depths of studied interval

L238: if it is 18 m, one can just use 18 m (instead of ~20m, ~19 m...)?

L240: area

**L244: the model is presented as multi-channel, after which an analysis of a single element (AI) is presented. Maybe a few sentences could be added explaining the reasoning behind this (step-by-step) approach?**

L247: why a window of 3.3 m?

L251: the Kullback-Leibler information measure should be introduced and explained in the Methods, not within the Results.

L255: what does this uniform distribution mean? How is it defined?

L255-256: "*Figure 3 shows that Milankovic cycles information is present in the core*". This is not intuitively clear, please explain in more detail.

**L266: Why S, AI and Mn? Why not all elements? See previous questions on element selection. What do these proxies mean? Correlated or not, in relative variations?**

L267: which "resolution"?

#### Discussion:

L277: See earlier comment, I might be nice to document some of these tests in the supplementary information of the paper.

L278; "severe" is a bit of an arbitrary term

L278: what type of noise? White noise?

L281: should refer to Fig. 9?

**L287: what about the discontinuities? Or does that mean, "sudden changes in sedimentation rates"? "Discontinuities" might also be interpreted as breaks in sedimentation, hiatuses. Is this what is meant with "non-liner" in the title as well? If so, this is not so clear in its current formulation, and might be worth reformulating, spelling out a bit more.**

L287; any idea why you get these artefacts? (e.g. other ratio`s that could fit a certain combination of astronomical components as well)?

L294: it would be nice to see the uncertainty component applied for the artificial test case.

L297-300: Indeed, see earlier comments. Could this sensitivity be tested?

**L304: there is no explicit comparison with the previous published cyclostratigraphic interpretations from the same sections (see two papers referenced). Why not add to current Fig.7 the sedimentation rate profiles from those papers? And discuss how these compare. Did AstroComb find the same, or not? Especially as several co-authors were involved in the previous and present work. Is it better or not? Etc...**

L310-311: see for example discussion on noise contributions to spectral properties (for spectral moments approach) in Sinnesael et al. 2018

L326: “discovered abrupt changes in sedimentation rate”, what are these? Geological implications? This aspect deserves to be detailed more.

**It would also be valuable to analyse the same record with existing techniques to see how the AstroComb performance relates to existing algorithms (e.g. eASM, eTimeOpt, Spectral Moments etc...**

#### Conclusion:

L335: the multi-channel component is presented as one of the major innovations of this study (next to the probabilistic component), but its features are only discussed in a minimal way in the present manuscript (i.e. one of the three presented analyses). It would be valuable to show in more detail what this approach add, or not, and document related sensitivity studies. It could also be worth spelling out if the multi-channel component is an averaging of single channel information, or the algorithm actually looks at the relationships between the various analysed channels (or not).

L336; Explain what is meant with “quality control”.

#### References:

Clear, inclusion of DIO’s encouraged by journal.

L399: L406: Cambrian

Several suggestions for additional references are made above.

#### Figures:

Figure 1: Clear, but see similarity with: Meyers & Sagemann, 2007, AJS: <https://doi.org/10.2475/05.2007.01>

#### Figure 2:

- Give sense of depth/mm scale in y axis (e.g. guide the reader who might not be familiar with the case study to what the precession cycles might be, for example). Units x-axes?

#### Figure 3:

- What are the “Information content”, and “Kullback-Leibler measure” should be explained in Methods, not Results. The caption of the text could be expended to explain the reader how to interpret the figure – currently not clear/intuitive.
- Units on both x-axes?
- Can the AI profile of the selected interval also be shown?

#### Figure 4:

- Why are the Y-axes is not labelled, differently scaled per depth?

Figure 5:

- ~~ky~~ => ka
- marked by "a red dot"
- Title, this is not expressed in relative time, but absolute age

Figure 6:

- Why are the Y-axes is not labelled, differently scaled per depth?
- **It might be nice to plot figures 4 and 6 together, so that one can easily assess the difference, without having to look at different pages. Same for Figures 5 and 7 – they can easily be combined.**

Figure 8:

- X-axis: concentrations or sedimentation rates?
- "significant discontinuities" => explain exactly what these are (+ show on Fig. 8).

Incorporation of for example the age-depth models of Sorensen et al. (2020) could be valuable.

Supplement:

It is appreciated that the code, data, and test data are provided. To be more user friendly it could be advisable to expand the "Readme" file with more detailed user instructions, and/or provide more detailed comments in the MATLAB script.