Disconnecting the Dots: Re-examining the Nature of Stellar “Strings” in the Milky Way

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Abstract

Recent analyses of Gaia data have resulted in the identification of new stellar structures, including a new class of extended stellar filaments called stellar “strings,” first proposed by Kounkel & Covey. We explore the spatial, kinematic, and chemical composition of strings to demonstrate that these newfound structures are largely inconsistent with being physical objects whose members share a common origin. Examining the 3D spatial distribution of string members, we find that the spatial dispersion around the claimed string spine does not improve in the latest Gaia DR3 data release—despite tangible gains in the signal-to-noise ratio of the parallax measurements—counter to expectations of a bona fide structure. Using the radial velocity dispersion of the strings (averaging $\sigma_v = 16 \text{ km s}^{-1}$) to estimate their virial masses, we find that all strings are gravitationally unbound. Given the finding that the strings are dispersing, the reported stellar ages of the strings are typically $120 \times$ larger than their measured dispersal times. Finally, we validate prior work that stellar strings are more chemically homogeneous than their local field stars but show it is possible to obtain the same signatures of chemical homogeneity by drawing random samples of stars from spatially, temporally, and kinematically unrelated open clusters. Our results show that while some strings may be composed of real substructures, there is no consistent evidence for larger string-like connections over the sample. These results underscore the need for caution in over-interpreting the significance of these strings and their role in understanding the star formation history of the Milky Way.

Unified Astronomy Thesaurus concepts: Star clusters (1567); Stellar dynamics (1596); Interstellar filaments (842); Milky Way Galaxy (1054)

Supporting material: animation, figure set, machine-readable table

1. Introduction

It is commonly accepted that most stars in the Milky Way were born in close proximity to other stars, constituting a stellar structure that formed at the same time within the same parental molecular gas structure (e.g., Lada & Lada 2003). These stellar siblings should be similar to one another in terms of their location, age, kinematics, and chemistry. As these stellar structures dissolve into the Galactic field, they offer an opportunity to study the star formation history of the Milky Way and the chemodynamical evolution of its disk. As the largest and most accurate astrometric catalog of stars ever produced, Gaia (Gaia Collaboration et al. 2016) offers an unprecedented opportunity to study these stellar structures from their formation to their dissolution. By constraining the distances and proper motions to over a billion stars, as well as the radial velocities of millions of stars, Gaia has not only shed new light on the spatial and dynamical properties of existing stellar structures but has also enabled the discovery of new ones. These discoveries include hundreds of previously unknown open clusters (e.g., Castro-Ginard et al. 2020), as well as new classes of stellar structures with much more extended spatial distributions (see, e.g., the discussion in Section 3.5 of Cantat-Gaudin 2022), including stellar “streams” in the Galactic disk (Meingast et al. 2019), extended stellar coronae (Meingast & Alves 2019; Ratztenböck et al. 2020; Meingast et al. 2021), stellar “pearls” (Coronado et al. 2022), stellar “relic filaments” (Jerabkova et al. 2019; Beccari et al. 2020), stellar “snakes” (Wang et al. 2022), and stellar “strings” (Kounkel & Covey 2019) (see also Kounkel et al. 2020).

In Table 1, we compare and contrast the properties of these proposed extended stellar structures, including their velocity dispersions, claimed coevality, gravitational boundedness, lengths, and widths. All extended structures have similar lengths (spanning $\approx 100–400$ pc) and widths ($\approx$ few tens of parsecs) with typical aspect ratios between 3:1 and 10:1. None of the studies in Table 1 explicitly require the structures to be gravitationally bound, though Kounkel & Covey (2019) argue that strings are “weakly bound” while Meingast et al. (2019, 2021) argue that the recently discovered streams in the disk and extended coronae around open clusters are gravitationally unbound. All structures are argued to be coeval with the exception of stellar “pearls,” which are distinct clusters following similar orbits in the Galaxy that manifest as overdensities in action-angle space (Coronado et al. 2022). Stellar strings are similar to stellar “snakes” and stellar “relic filaments” in that all three structures are identified in part via clustering algorithms in 5D space (e.g., DBSCAN, HDBSCAN, Friends-of-Friends) and have radial velocity dispersions spanning $\approx 5 \text{ km s}^{-1}$ (relic filaments) to $\approx 15 \text{ km s}^{-1}$ (strings). The filamentary structure seen in strings, snakes, and relic filaments is argued to be primordial, likely forming in elongated giant molecular filaments (Goodman et al. 2014; Ragan et al. 2014; Wang et al. 2015; Zucker et al. 2015, 2018, 2019). In contrast, stellar streams in both the disk (Meingast et al. 2019) and the halo (Kuzma et al. 2015; Giallombardo et al. 2021), as well as recently discovered extended stellar
# Table 1

Proposed Extended Stellar Structures in the Galactic Disk

| Name                     | ID                | Claimed Coeval? | \(\sigma_0\) | Length | Width | Bound?         | Formation                     | Publication                                      |
|--------------------------|-------------------|-----------------|-----------|--------|-------|---------------|-------------------------------|-------------------------------------------------|
| String                   | HDBSCAN (5D)      | Yes             | 15        | 200    | 30    | Weakly Bound  | Primordial Filaments          | Kounkel & Covey (2019), Kounkel et al. (2020)  |
| Snake                    | FoF (5D)          | Yes             | 10        | 200    | 90    | Not claimed   | Primordial Filaments          | Tian (2020), Wang et al. (2022)                 |
| Relic Filament           | DBSCAN (5D)       | Yes             | 5         | 90–260 | 10–50 | Not claimed   | Primordial Filaments          | Jerabkova et al. (2019), Beccari et al. (2020) |
| Extended Corona          | Convergent Point (Deproj. 5D) | Yes | 1 | 100–400 | 50–75 | Unbound | Tidally Disrupted Clusters | Meingast et al. (2019), Ratzenböck et al. (2020) |
| Stream                   | Wavelet Decomposition (6D) | Yes | 1 | 400 | 50 | Unbound | Tidally Disrupted Cluster | Meingast et al. (2019), Ratzenböck et al. (2020) |
| Pearl                    | Orbit-phase Space FoF (6D) | No | ... | ... | ... | Unbound | Primordial Filaments | Coronado et al. (2022) |

**Notes.** Comparison of the identification, properties, and physical interpretation of extended stellar structures recently discovered in the Gaia era. (1) Name of the extended stellar structure. (2) Primary identification method of the structure, specifying whether initial identification was made in 5D (not including radial velocities) or 6D (including radial velocities) space. See the references for full details on the multistep structure identification. (3) Whether the structures are claimed to be coeval in their original publications. (4) Typical radial velocity dispersion of the structure. (5) Average length or the range of lengths over the sample. (6) Average width or range of widths over the sample. (7) Whether the structures are suggested to be bound or unbound in their original publications. (8) The proposed formation mechanism for the structures, specifically whether their filamentary morphology is argued to be primordial (in filamentary giant molecular clouds) or whether it is the result of tidal stretching dissolving a central cluster. (9) Original publications describing the identification and properties of the proposed extended stellar structures. No length, width, or radial velocity dispersion is provided for the pearls, as they are not argued to be monolithic structures, but rather sets of distinct clusters that follow similar orbits.

*See also Moranta et al. (2022) for extended coronae identified in 5D space via HDBSCAN.*
dispersions (Meingast et al. 2021), have much smaller velocity dispersions ($\approx 1 \text{ km s}^{-1}$) with the filamentary structure forming as a result of dynamical tidal forces dissolving a central cluster.

There are four attributes that members of a newly discovered stellar structure (like those in Table 1) should share in order to plausibly be considered coeval, or born at the same time within the same parental molecular gas structure. First, stars in a structure should have largely similar ages. Second, members of a stellar structure should be close enough to one another in 3D space such that they could have been born in the same location. Third, members of a stellar structure should share similar motions, as evidenced by the small dispersion in their Gaia tangential and radial velocities. Finally, members of a stellar structure should have similar metallicities, as evidenced by small dispersion in elemental abundances (e.g., as measured by spectroscopic surveys like GALAH and APOGEE; Jónsson et al. 2020; Buder et al. 2021).

With these attributes in mind, we take a closer look at the spatial, kinematic, and abundance variations of the most extreme population in Table 1—the stellar strings—first proposed by Koukel & Covey (2019, hereafter KC19). KC19 present a sample of 328 claimed coeval stellar strings. While KC19 do not quantitatively define a string, they argue that strings should appear to be filamentary, roughly parallel to the Galactic plane, coherent both spatially and kinematically, and that their stellar members can generally be characterized by a single isochrone. The median projected length and width of a string are 190 pc and 30 pc, respectively.

KC19 identify the strings in a multistep process. First, they apply the HDBSCAN algorithm (McInnes et al. 2017) in 5D space ($l, b, \pi, \text{ and proper motions}$) to a sample of stars out to 1 kpc from the Sun detected in Gaia DR2. Specifically, they perform several iterations of the HDBSCAN algorithm over different parallax ranges, primarily with the “leaf”-clustering method, to obtain a set of stellar groups with similar 5D properties. Then the authors manually merge and split the groups detected in the various iterations by hand. Next, KC19 assign an age to each group using a combination of isochrone fitting and a convolutional neural network. Finally, once a sample of stellar groups is identified via HDBSCAN, KC19 manually assemble the strings by either (i) connecting the individual groups with similar ages using the tool TOPCAT (Taylor 2005) or (ii) deciding that a single group possesses enough filamentary morphology to be classified as a string. Finally, KC19 visually check that the strings are “fully continuous [and] coherent in all kinematic [i.e., tangential velocities] and spatial [i.e., $l, b, \pi$] dimensions.” After the groups are connected, KC19 compute a “spine” for the string in 5D space by averaging the star-by-star ($l, b, \pi, \text{ and kinematics}$) results in different plane-of-the-sky longitude bins along the projected string, before smoothing with a Savitzky–Golay filter to avoid strong fluctuations in the averages.

In this work, we independently test the kinematic, spatial, and chemical coherence of the stellar strings using data not fully considered by and/or available at the time of KC19. In Section 2 we present the publicly available spatial and kinematic data for stellar strings from Gaia DR2 and DR3 utilized in this work, along with ancillary spectroscopic data used to examine the elemental abundance variations within a subset of the strings. In Section 3 we use these data to derive estimates of the stars’ 3D spatial dispersion around their respective string “spines,” their radial velocity dispersions, their predicted virial masses, their predicted dynamical lifetimes, and their elemental abundance variations. We then use these constraints to show that nearly all of these stellar strings are inconsistent with being coeval physical entities and are rather artificial structures affected by limitations in the manual assembly process used in their selection. In Section 4 we discuss the implications of the strings’ nonphysical nature within the wider context of the Gaia literature on extended stellar structures. Finally, we conclude in Section 5.

2. Data

KC19 identify 1312 stellar groups and 328 stellar strings. A group is a single set of stars identified in HDBSCAN with similar 5D properties ($l, b, \pi, \text{ and proper motions}$), while a string is either a collection of connected HDBSCAN groups or a single HDBSCAN group deemed to be filamentary in KC19. We only consider stellar strings in this work. We obtain the Gaia DR2 data (Gaia Collaboration et al. 2018) (sky coordinates, parallaxes, and parallax errors) on the string stars directly from KC19 (see their Table 1), and we crossmatch their Table 1 with Gaia DR3 (Gaia Collaboration et al. 2021) to obtain updated constraints on the parallax and parallax errors of the string stars. The XYZ positions (the Heliocentric Galactic Cartesian Coordinates) of string spines (defined using Gaia DR2 data) are obtained from Table 3 in KC19 and will be used to calculate the 3D dispersion of string members around their respective spines in Section 3.1. To analyze the kinematic coherence of the strings in Section 3.2, we adopt the updated radial velocity measurements from Gaia DR3, which provides radial velocity data for $\pi < 5 \times 10^4$ more stars than available in Gaia DR2 in KC19. To explore the metallicity distribution within the strings, we use the catalog from Manea et al. (2022, hereafter MHM22). MHM22 leverages GALAH DR3 (Buder et al. 2021) elemental abundance measurements (e.g., $[\text{Fe}/\text{H}]$) and their reported uncertainties to analyze the chemical homogeneity of stars in nearby stellar structures, including 10 strings (see their Supplementary Data). To compare the chemical homogeneity of the strings to a benchmark sample of open clusters, we adopt the catalog from Spina et al. (2021; see their Table 1), which compiles a similar set of elemental abundance measurements from GALAH (Buder et al. 2021) and APOGEE (Jónsson et al. 2020) for a sample of stars in hundreds of open clusters across the Galactic disk.

3. The Spatial, Dynamical, and Chemical Composition of Stellar Strings

In this section, we re-examine the spatial (Section 3.1), dynamical (Section 3.2), and chemical (Section 3.3) distribution of the strings in KC19 and present a summary of their derived properties in Table 2.5

3.1. 3D Spatial Properties of Stellar Strings

In Figure 1 we show a top-down $XY$ Gaia DR2 view of the stellar strings as reproduced from KC19 (see their Figure 13). We highlight a selection of strings (over a range of ages) to convey the relationship between each string and its underlying

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5 On Zenodo, we provide a Jupyter Notebook that reproduces all the results in this section, including the values in Table 2, and the data behind Figures 1, 2, 3, 4, and 5: (Zucker 2022).
stellar membership. Similar plots for the rest of the string sample are shown in Figure Set A1 in the Appendix. The distances to the string stars are very well constrained: The median signal to noise of the parallax measurements per string surpasses 44:1 in DR2 and 61:1 in DR3. For a majority of the strings, the dispersion around the spine is much larger than the average distance uncertainty. Many strings are composed of discrete stellar groups that lack clear connections in 3D physical space, despite that interpretation in KC19.

Leveraging the improved astrometric precision of Gaia DR3, we compare the 3D spatial dispersion of stars around the string spine in Gaia DR2 versus Gaia DR3 to determine whether the dispersion around the spine decreases as parallax errors improve, as expected for real structures. For each star, we compute its 3D offset from the string’s spine in Gaia DR2 and DR3 and then average the results per string. The results are presented in Figure 2, which shows the average percentage that the stars move closer to or further from the spine as a function of the increase in the signal to noise of the parallax measurements. Despite the signal to noise of the parallaxes improving by 20%–120% in Gaia DR3, there is no improvement in the stars’ offsets from the spine. The lack of improvement in the stars’ 3D spatial dispersion is inconsistent with the claim that strings are coeval physical entities whose members share a common origin. However, we do observe (see Figure Set A1 in the Appendix and https://faun.rc.fas.harvard.edu/czucker/Paper_Figures/String_Gallery_Interactive.html) that in some cases the 3D spatial dispersion within individual stellar groups inside a string does improve. This suggests these strings may be partly composed of real stellar subgroups; however, we see no evidence for the larger string connections.

3.2. The Dynamical Properties of Stellar Strings

While the lack of improvement in the 3D spatial dispersion of stars around the string spines raises concerns about their fidelity, one way to validate the authenticity of the strings is to show that their stellar members still share similar motions. KC19 analyze the dispersion in the tangential velocities of string members and find them to be $<2.5 \text{ km s}^{-1}$. We expect a small dispersion in the tangential velocities because the stellar groups that were manually assembled into strings must share similar 5D properties ($l$, $b$, parallax $\pi$, and proper motions) to be detected with HDBSCAN. As such, the fairest way to evaluate the authenticity of the strings is to characterize their velocity dispersion in the sixth dimension—the radial velocity dimension—not considered in the original 5D clustering algorithm. KC19 find that the dispersion in the radial velocities, $\sigma_{RV}$, span $5$–$40 \text{ km s}^{-1}$ with an average radial velocity dispersion of $16 \text{ km s}^{-1}$, a factor of $5$–$10$ larger than that for the tangential velocities (see Figure 12 from KC19). The typical Gaia-based radial velocity dispersion for loosely bound open clusters is $\approx 1 \text{ km s}^{-1}$ (Soubiran et al. 2018), making these strings at least dynamically very atypical for known coeval structures.

Leveraging the expanded catalog of radial velocities in Gaia DR3—providing $5\times$ more measurements than available at the time of KC19—we compute updated, error-weighted radial velocity dispersions for the strings. Before calculating the error-weighted radial velocity dispersion, we mask out stars classified as astrometric, spectroscopic, or eclipsing binaries in Gaia DR3 by requiring the non_single_star flag to be 0. We adopt the same methodology used in Soubiran et al. (2018) to calculate the error-weighted radial velocity dispersion for open clusters:

$$\sigma_{RV}^2 = \frac{\sum w_i (\sum w_i)^2 - \sum w_i^2}{\left(\sum w_i\right)^2 - \sum w_i^2} \sum_i w_i (RV_i - RV_{\text{str}})^2,$$

where $w_i$ is the weight for the $i$th star ($w_i = \frac{1}{RV_{\text{err},i}}$), $RV_{\text{err},i}$ is the star’s radial velocity error, $RV_i$ is the star’s radial velocity measurement, and $RV_{\text{str}}$ is the error-weighted mean velocity of all stars in the string. Despite significantly enlarging the radial velocity sample, removing known binaries, and implementing
error-weighting, the average string radial velocity dispersion stays the same at 16 km s\(^{-1}\). Figure 3 shows the distribution of the error-weighted radial velocity dispersion for the strings as a function of their reported ages from KC19, alongside comparable measurements for extended stellar coronae and stellar streams in the disk (see Table 1).

Using the updated radial velocity dispersions, we estimate the predicted virial mass of each string as

\[
M_{\text{vir}} = \frac{\sigma_V^2 \times \eta \times r_{\text{hm}}}{G},
\]

where \(r_{\text{hm}}\) is the adopted half-mass radius of the string (see Column 4 in Table 2). The parameter \(\eta\) is a dimensionless constant that depends on the shape of the density profile, for which we very conservatively adopt \(\eta = 1\).\(^6\) We find that the average predicted virial mass of the strings is \(\approx 2 \times 10^6 M_\odot\). We approximate the observed mass of each string by counting the number of members and assuming an average stellar mass of 0.61 \(M_\odot\) based on the initial mass function from Maschberger et al. (2010) (see also e.g., Kuhn et al. 2019). We find a typical observed mass of \(M_{\text{observed}} = 134 M_\odot\), meaning that strings on average require \(> 10^5\times\) larger masses than their observed masses to be in virial equilibrium. Even assuming a very poor completeness fraction, all strings are gravitationally unbound, counter to the claim in KC19 that strings are “weakly bound.”

While the unbound state of the strings does not in itself imply that strings are unphysical, it does provide constraints on their predicted lifetimes. If a string is gravitationally unbound, it should disperse on roughly a crossing time, \(t_{\text{cross}}\):

\[
t_{\text{dispersal}} \approx t_{\text{cross}} \approx \frac{r_{\text{hm}}}{\sigma_V}.
\]

We find a median predicted dispersal time for the strings of only 2 Myr. Because KC19 determine ages of between 4 Myr and 9 Gyr for the strings, the strings’ reported ages are on average 126 \(\times\) larger than their dispersal times. In Figure 4 we plot \(M_{\text{dispersal}} / M_{\text{observed}}\) as a function of \(M_{\text{dispersal}} / M_{\text{observed}}\) Dispersion Time.

3.3. The Chemical Homogeneity of Stellar Strings

We perform a final test to determine the physicality of the stellar string members by examining the uniformity in their chemical composition with respect to open cluster members. If a set of stars is born within the same parental molecular gas structure, they should be chemically homogeneous (e.g., Feng & Krumholz 2014). To examine the chemical homogeneity of the strings, we build on the study of MMH22, who leverage GALAH data (Buder et al. 2021) to characterize the intrinsic chemical dispersion \(\sigma_{X/H}\) of a sample of 10 strings. MMH22 fit the following likelihood function assuming that the chemical profile of each string is Gaussian with some mean abundance

\(^6\) The \(\eta\) parameter is typically assumed to be \(\approx 10\) for a Plummer model (Plummer 1911) characterized by steep density profiles. Because recent studies have shown that \(\eta\) can be smaller (consistent with much broader density profiles), particularly for younger systems due to e.g., mass segregation (Portegies Zwart et al. 2010), we adopt a much lower value of \(\eta = 1\) as larger values of \(\eta\) only raise the threshold necessary for the strings to be in virial equilibrium.
μ[X/H] and intrinsic dispersion σ[X/H]:

\[
\mathcal{L} = \prod_{i}^{N} \exp \left[ -\frac{(x_i - \mu_{[X/H]})^2}{2(\sigma^2 + \delta_i^2)} \right] \times \frac{1}{\sqrt{2\pi(\sigma^2 + \delta_i^2)}} ,
\]

where \(x_i\) and \(\sigma\) are the GALAH mean abundance and its reported uncertainty for the \(i\)th star in the string in a given element \(X\). MHM22 characterize the intrinsic chemical dispersion across a range of elements with a sample size between 7 and 19 stars per string. In the left panel of Figure 5, we reproduce the original results of MHM22 (see their Figure 4), showing the intrinsic dispersion \(\sigma_{[X/H]}\) for each of the 10 strings. MHM22 find that all but one of the strings is more homogeneous than their local field stars, with half of the sample as homogeneous as the well-studied open cluster M67 in several elements (Gao et al. 2018).

To test whether it is possible for a string to appear chemically homogeneous in several elements without being...
coeval, we draw random subsamples of stars from the Spina et al. (2021) catalog, which curate a sample of open cluster members detected in GALAH. Specifically, following MHM22, we draw between 7 and 19 per subsample and restrict to open clusters that span the same broad age range for the strings considered in MHM22 \((7.52 < \log(\text{Age}) < 9.23)\), have a detection in GALAH, and high membership probability \(p > 0.75\). These subsamples consist of stars that do belong to well-studied open clusters, but each subsample is drawn from many clusters that are unrelated. We then fit the same likelihood function as MHM22, repeating this procedure over many trials. Because we argue strings are likely agglomerations of unrelated open clusters and other dynamically cold field stars, this experiment provides a more direct comparison point to interpret the apparent homogeneity found in MHM22.

As seen in Figure 5, we can match the chemical homogeneity of the strings with the random draws, which we attribute to two causes. First, the uncertainties on the GALAH abundance variations for an individual star \(i\) (i.e., \(\sigma_i\) in Equation (4)) are similar to the intrinsic abundance variation of a cluster like M67 \((\sigma_i \approx \sigma_{[X/H]} \approx 0.1 \text{ dex})\). Because Equation (4) is designed to capture the intrinsic uncertainty by modeling the observational error, any overestimation of the error in GALAH can lead to unrealistically small estimates for the intrinsic scatter when the errors are large. And second, these random subsamples can appear more homogeneous than field stars simply by virtue of the stars being members of open clusters, even if these clusters are physically unrelated.\(^7\)

Our results are consistent with the scenario that, while these strings may sometimes contain real clusters, their abundance patterns are not discriminatory enough to favor a scenario where members of the string have the same origin, versus a range of origins in potentially real, yet physically unrelated,\(^7\)

\(^7\) The local field star sample from Manea et al. (2022) (showing poorer chemical homogeneity than the strings) also likely includes some thick-disk stars, which will have a wider metallicity dispersion than the thin disk string stars selected by KC19.
4. Discussion

Through a spatial, kinematic, and chemical reanalysis of their stellar membership, we have shown that strings are inconsistent with being coeval stellar structures with a common physical origin. KC19 select all 328 strings through a manual assembly process, stitching together stellar groups by hand and visually confirming kinematic and spatial coherence by eye. Our work underlies the need for a more systematic, reproducible selection process when declaring the existence of a new type of stellar structure: Not only should these structures remain spatially coherent and continuous when viewed in true 3D physical space, but their radial velocity dispersions should also be significantly smaller than measured for the Galactic field. In the solar neighborhood, the age–velocity dispersion relation (describing how the velocity dispersion of stars appears to increase with age due to dynamical heating) shows typical vertical velocity dispersions of ≈5 km s$^{-1}$ for stars <1 Gyr, about 3× smaller than the typical string radial velocity dispersion of 16 km s$^{-1}$ (see Casagrande et al. 2011; Bird et al. 2021). The age–velocity dispersion relation has also been explored in 3D using open clusters. Specifically, for open clusters in the same age range as the typical string (150–250 Myr), Tarricq et al. (2021) find a 3D velocity dispersion of 13 km s$^{-1}$, meaning that the velocity dispersion over a sample of many open clusters is less than the typical radial velocity dispersion within an individual string in KC19 (see Figure 11 and Table 3 in Tarricq et al. 2021).

While we argue against the physicality of strings in KC19, several other studies in the Gaia era present compelling evidence for filamentary stellar distributions identified through more reproducible selection algorithms, some of which are summarized in Table 1. Meingast et al. (2019) identify an extended 400+ pc long, 2000 $M_\odot$ stream in the disk called Meingast-1 (also known as Pisces–Eridanus; e.g., Hawkins et al. 2020) through a wavelet decomposition of the 3D velocity space distribution of nearby stars. Not only do Meingast et al. (2019) find that the stream is spatially continuous in 3D space, but they also find a 3D velocity dispersion of 1.3 km s$^{-1}$. Similarly, Meingast et al. (2021) present a new method for identifying highly extended coronae around 10 nearby open clusters. The Meingast et al. (2021) technique accounts for projection effects in proper motion space in an automated way (inspired by the “convergent point technique”; see van Leeuwen 2009) before deconvolving the spatial distribution with a Gaussian mixture model to mitigate Gaia measurement errors. The coronae are likewise validated via their 3D space motions, showing typical 3D velocity dispersions of 1.4 km s$^{-1}$.

Both the extended coronae and the Meingast-1 stream have velocity dispersions on par with open clusters. Using a sample of a few hundred nearby open clusters, Soubiran et al. (2018) find typical intracluster radial velocity dispersion of 1.0–1.5 km s$^{-1}$. Only four strings in KC19 have radial velocity dispersions <5 km s$^{-1}$ (Theia 127, 161, 605, and 998), while ≈90% of the open clusters do (Soubiran et al. 2018), as well as 100% of the newly identified extended structures in Meingast et al. (2019, 2021). The unphysical nature of the strings is not due to their claimed unique filamentary morphologies, but rather their lack of true 3D kinematic and spatial coherence stemming from limitations in the manual assembly process. Since we argue that some strings can be composed of open clusters and other dynamically cold field stars, dedicated follow-up studies (e.g., Andrews et al. 2022) would be needed to characterize the extent to which individual strings may contain physically relevant substructure.

5. Conclusions

We investigate the spatial, dynamical, and chemical composition of stellar strings, a proposed collection of highly extended filamentary stellar structures identified in KC19 by manually linking stellar groups with similar 5D properties (l, b, parallax π, and proper motions). Our conclusions are as follows:

1. Using updated constraints on the distances to stellar string members from Gaia DR3, we find that the 3D spatial dispersion of stars around the string spine does not improve over Gaia DR2: The average percentage that stars move closer to their respective string spines is consistent with zero, despite the signal to noise on the parallax measurements per string increasing by 20%–120%. Real structures should tighten with higher-fidelity distance measurements.

2. The average dispersion in the radial velocity of the strings is 16 km s$^{-1}$, about 15 times larger than the typical radial velocity dispersion both of open clusters in Gaia (Soubiran et al. 2018) and in other catalogs of extended stellar structures (e.g., stellar “streams” in the disk from Meingast et al. 2019, 2021).

3. Given the radial velocity dispersions, the virial masses of the strings are on average $>10^4\times$ larger than their observed masses. Even assuming very low completeness fractions, all strings are gravitationally unbound.

4. Given their unbound state, the strings should disperse on roughly a crossing time, which we estimate to be typically 2 Myr, while the ages of the strings from KC19 range from 4 Myr to 9 Gyr. Thus, the strings should not exist based on their predicted dynamical lifetimes and should have dispersed in <1% of their reported ages, on average.

5. Using complementary constraints on stellar chemical abundances from GALAH DR3 (Buder et al. 2021), we compare the intrinsic abundance dispersion of the strings found in MHM22 to a random sample of stars drawn from physically unrelated open clusters. We find that the chemical homogeneity of the strings is similar to the chemical homogeneity seen in random stellar draws across clusters.

6. The combined spatial, dynamical, and chemical evidence rules out the scenario that stars within a typical string were born at the same time within the same parental molecular gas structure. However, some subset of the stars within a string may still be coeval, as many of these strings contain real clusters that have been linked together to form the larger string-like structure.

Ultimately, by evoking simple spatial and dynamical arguments, our work provides a straightforward, yet discerning, lens to evaluate the fidelity of newfound classes of objects, which should be considered when declaring the existence of new coeval stellar structures in the Gaia era.
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Appendix

Gallery of Stellar Strings

In Figure A1, we show a compilation of the Gaia DR2 and Gaia DR3 top-down stellar distributions alongside the claimed string spines for the full sample of 328 strings.

**Figure A1.** Top-down view of stellar strings, with each panel showing the Gaia DR2 (red) and Gaia DR3 (blue) stellar distribution of stars in the string, alongside the “spine” shown in black. The lower right-hand corner of each panel shows the typical distance errors for stars in the string. The complete figure set (37 images) is available in the journal and at faun.rc.fas.harvard.edu/czucker/Paper_Figures/String_Gallery_Interactive.html. (The complete figure set (37 images) is available.)
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