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Significance Mode Analysis (SigMA) for hierarchical structures

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We present an innovative clustering method, Significance Mode Analysis (SigMA), to extract co-spatial and co-moving stellar populations from large-scale surveys such as ESA *Gaia*. The method studies the topological properties of the density field in the multidimensional phase space. The set of critical points in the density field gives rise to the cluster tree, a hierarchical structure in which leaves correspond to modes of the density function. Typically, however, non-parametric density estimation methods lead to an over-clustering of the input data. We propose an interpretable cluster tree pruning strategy by determining minimum energy paths between pairs of neighboring modes directly in the input space. We present a statistical hypothesis test that examines deviations from unimodality along these paths, which provides a measure of significance for each pair of clusters.
We apply SigMA to *Gaia* EDR3 data of the closest OB association to Earth, Scorpio-Centaurus (Sco-Cen), and find 37 co-moving clusters in Sco-Cen. These clusters are independently validated using astrophysical knowledge and, and to a certain extent, by their association with massive stars too bright for Gaia, both unknown to SigMA. Our findings suggest that the OB association is more actively star-forming and dynamically richer than previously thought. This application demonstrates that SigMA allows for an accurate census of young populations, quantify their dynamics, and reconstruct the recent star formation history of the local Milky Way.

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