Disentanglement of the chemodynamical assembly: mapping the Milky Way disks

Elvis Cantelli[1], Ramachrisna Teixeira[1]

1. Instituto de Astronomia, Geofisica e Ciências Atmosféricas, Universidade de São Paulo

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Abstract

Currently, with regard to observational data, mainly thanks to the Gaia space mission and large spectroscopic surveys, we are experiencing an exceptional moment of abundance and quality of available data, which further stimulates our quest to better understand the structure, origin and evolution of our galaxy.

As we know, one of the most important components of our galaxy, its disk, is still far from being completely understood when we think about its formation and structure. However, by harnessing the power of these massive surveys, it is now possible to explore new techniques in a more complete and general frame.

In this sense, we propose here a strategy using the T-SNE algorithm to segregate different stellar populations present in the Milky Way disk, taking into account their chemical, orbital, kinematic and age characteristics.

With a good degree of reliability, it was possible to isolate several different components of thick disks (classic and hot), halo populations associated with Gaia-Enceladus, as well as moving groups of the thin disks.

We present details of the developed strategy, an overview of the different populations that we could find as well as a discussion about our strategy and a speculative interpretation of our results.

Data selection

We obtained stars within a local 5kpc radius from Gaia DR3[1] which attended our selection criteria of completeness (determined radial velocity and G_{mag} <= 15) and cross-matched with the spectroscopic surveys APOGEE[2] and GALAH[3] (filtered to a maximum of 0.2 dex error in [Fe/H] and [Mg/Fe]) to obtain a total of 588571 and 450415 stars respectively. These samples were sub-divided into main sequence and giants.

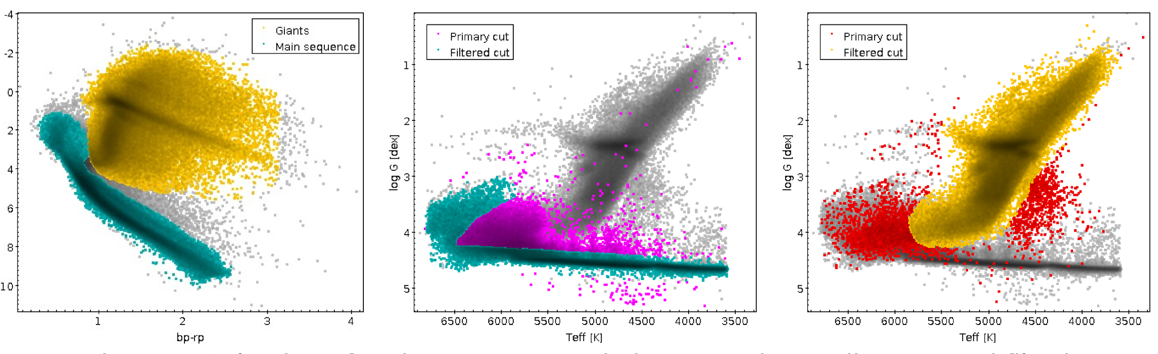

Figure 1: Selection of main-sequence and giant stars in CM diagram and filtering cuts in logG vs Teff diagram.

The elemental abundances selected for the analysis contained [Fe/H], [Mg/Fe] as the main alpha element, one light odd-z element, [Mn/Fe] as iron-peak element, and one heavy s-process element to constrain most of the chemical patterns that are used to segregate populations and are available in both surveys.

Unfortunately, in the absence of well measured and coincident elements for odd-z and s-process, we had to choose different chemical species in each survey, but keeping the nucleosynthetic origin as close as possible. Figure 2 show the abundance comparison and our final choice was Al in APOGEE and Na in GALAH for the odd-z, and Ce in APOGEE and Ba in GALAH for s-process elements.

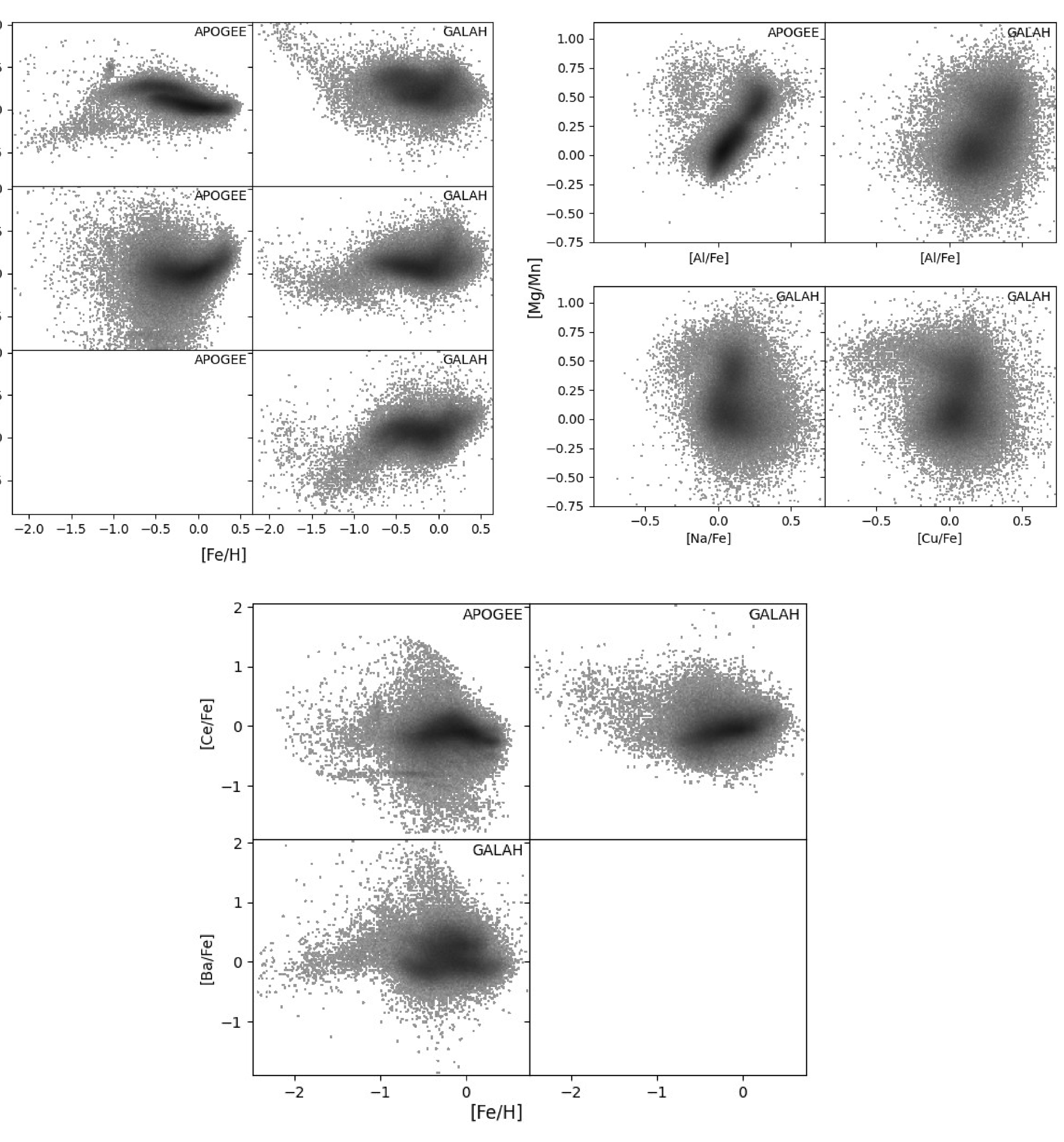

Figure 2: Abundance patterns of the studied elements from the two surveys.

Orbital analysis

The orbits of the stars were integrated from their 6-D phase space (with Gaia radial velocities and bayesian distances[4]) by employing *galpy*[5] *and* using a galactic potential with the addition of a bar with Ω_b = 39 km/s/kpc and R_Ω = 3.5 kpc[6]. The use of a barred galactic potential produces accumulation of orbits at the Lindblad resonances, and this can be used as a consistency check of the potential itself by comparing the orbit R_{avg} ridges with purely observational velocities[7] in figure 3.

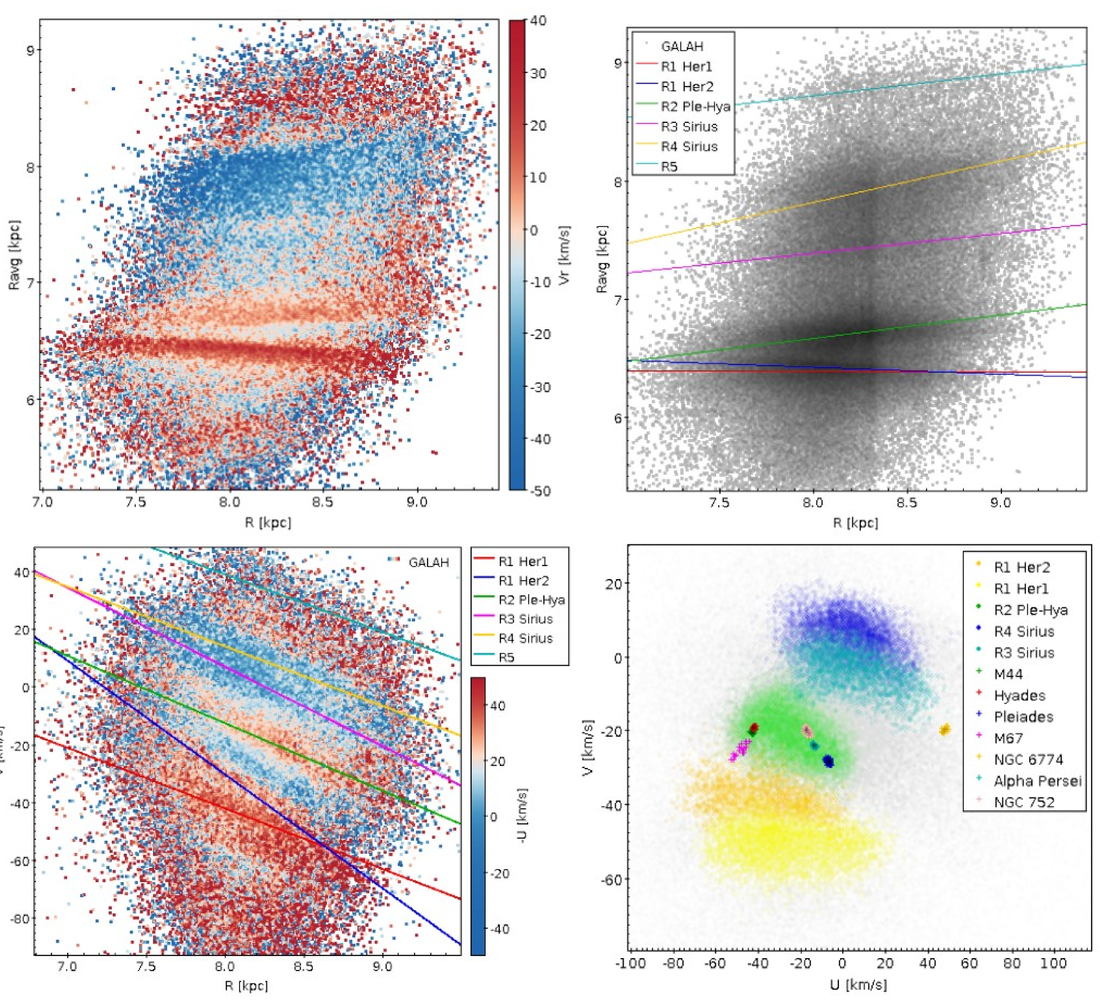

Figure 3: Velocity component planes for stars in the main-sequence sample of GALAH, showing that the ridges from mean orbital radius match the -U velocity ridges. Selected ridges appear as moving groups in the bottom-right panel.

Ages

The ages available in the spectroscopic surveys were determined by the isochrone method in GALAH (BSTEP) and asteroseismology (astroNN with K2) in APOGEE. By using a subsample of 8098 common stars between the surveys, we compared the age estimations of the two methods and found large inconsistencies, especially for astroNN.

We also explored different chemical abundance ratios as potential chemical clocks in comparison with BSTEP ages.

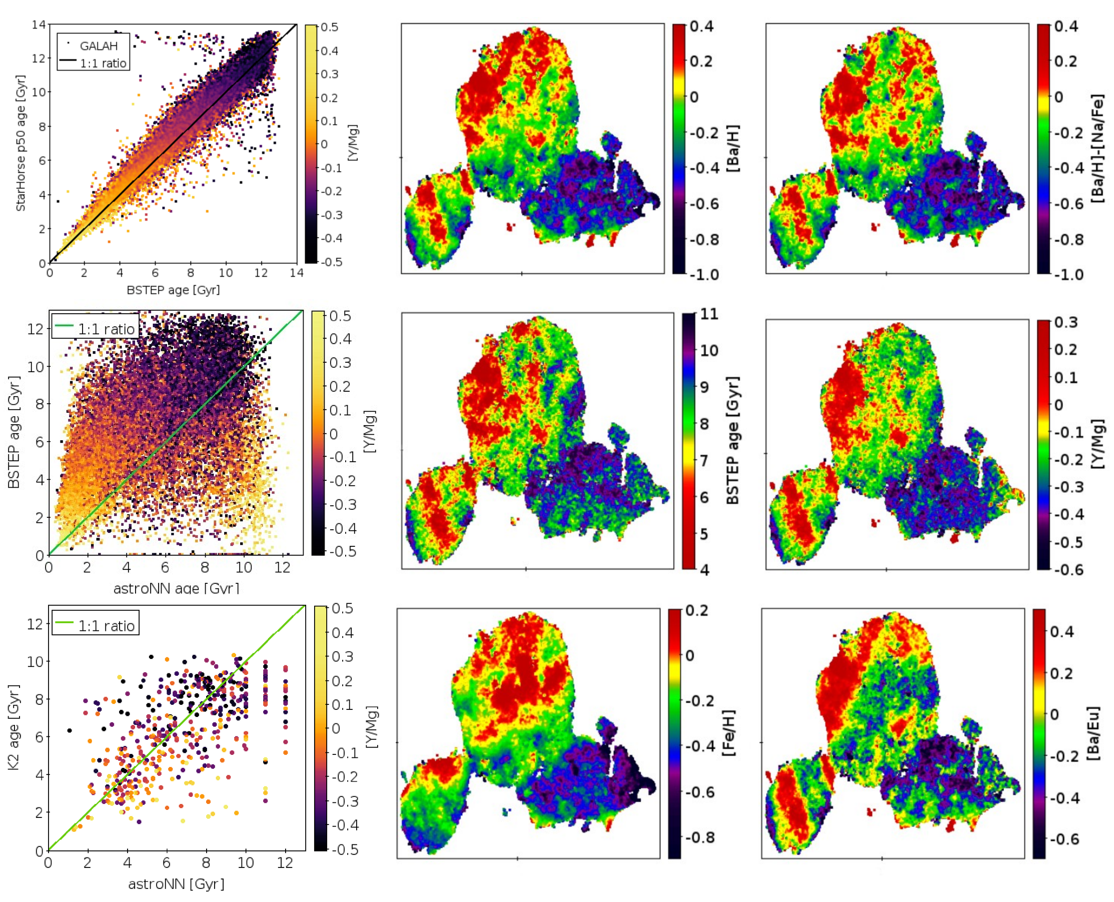

Figure 4: Age estimation from the different methods and pipelines (left) and T-SNE manifolds with ages and elemental abundances as potential chemical clocks.

T-SNE

In order to segregate the multiple components of the Milky Way disk, we have used the orbital parameters E, Z_{max}, L, L_z/L, V_t, *e*, R_{ap}, R_{per} and the selected chemical abundances of each survey as features for the dimensionality-reduction technique T-SNE[8] (t-distributed stochastic neighbour embedding), where the 2D manifold produced can be seen as a “map” of the local volume with grouped stars belonging to the different chemo-kinematic populations, as the algorithm seeks to preserve similarity between the stars along the given features.

Preliminary results

The resulting manifolds bring out the populations by colour-coding it with the main physical parameters employed, as shown in figure 5 for the APOGEE sample. Velocity dispersion and its components are shown in figure 6. A tentative classification is shown in figure 7.

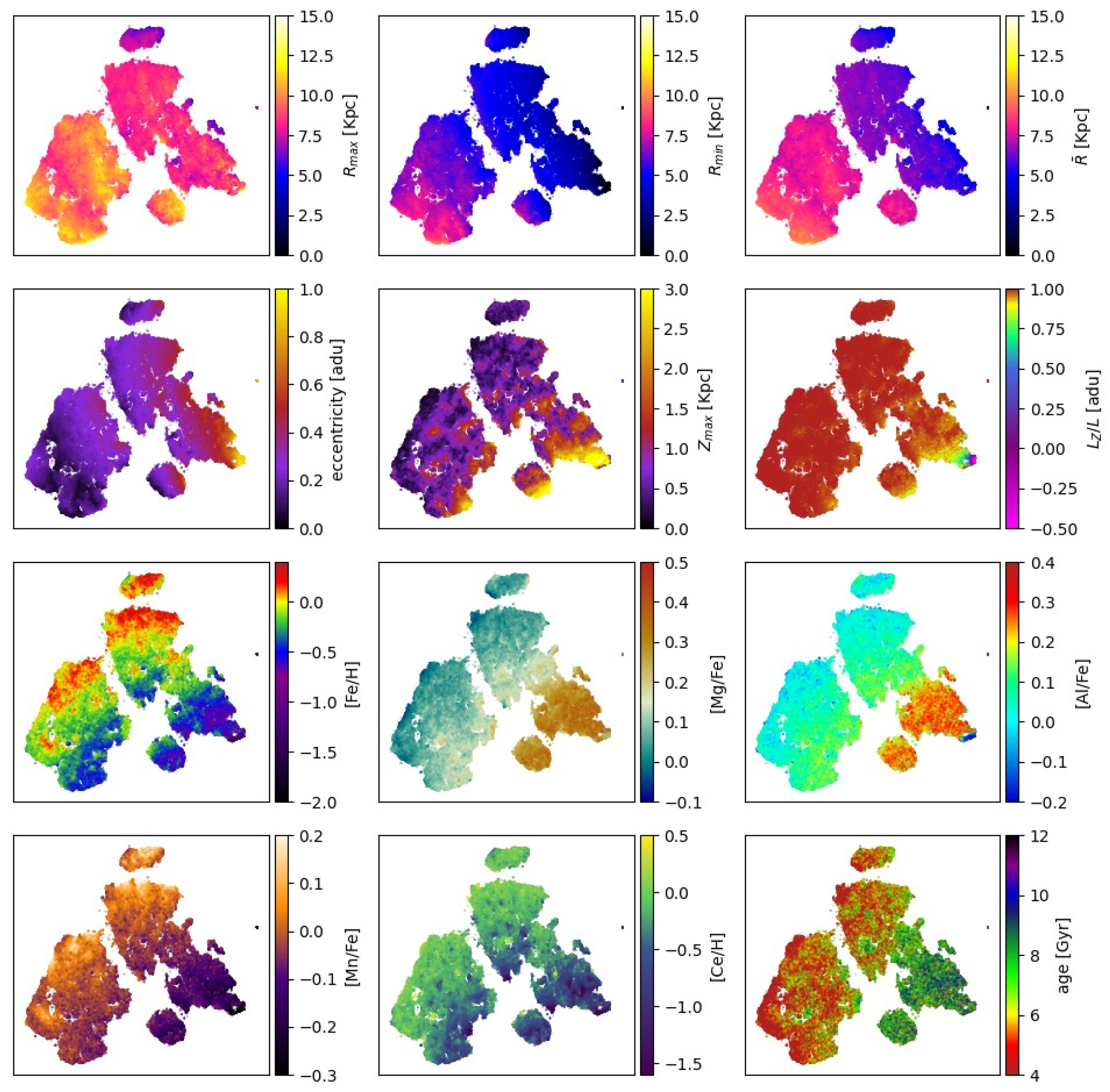

Figure 5: Colour-coded manifolds with physical quantities, enabling the distinction of many recognisable galactic features.

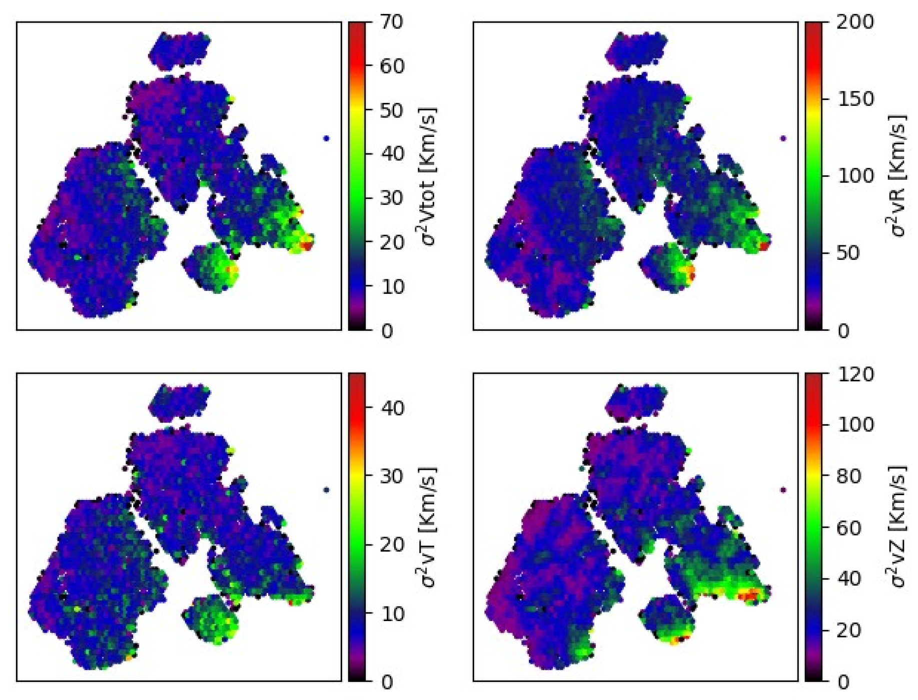

Figure 6: Manifolds hex-binned with velocity dispersion and its components.

We can identify the thick disk due to its alpha-enhanced character, the lower overall metallicity, higher Z_{max} and tilted orbits, and especially higher velocity dispersions. At the bottomost region of this population we can also notice a dinamycally hotter portion with even higher values of Z_{max} and highly tilted orbits, achieving negative values (retrograde orbits) in its right end. This is the "heated" or "splashed" thick disk[9] that is associated with the merger with GSE, where its low-Al right end is a piece of the dynamical halo with the accreted population[10]. The upper-central region is mostly comprised of dinamically colder thin disk stars with higher metallicities, mostly contained within the solar galactocentric radius within an "inner disk". One interesting feature is the higher eccentricity portion in the right with high V_r dispersion, which can be characterised as the Hercules moving group, where this bar-induced dynamical population is composed of stars that walk between the solar radius and the innermost regions of the galaxy[11]. The bottom-left region is mostly composed of an outer thin disk reaching the solar galactic radius and some metal-poor structures, which are consistent with a negative metallicity gradient towards the outer parts of the Milky Way.

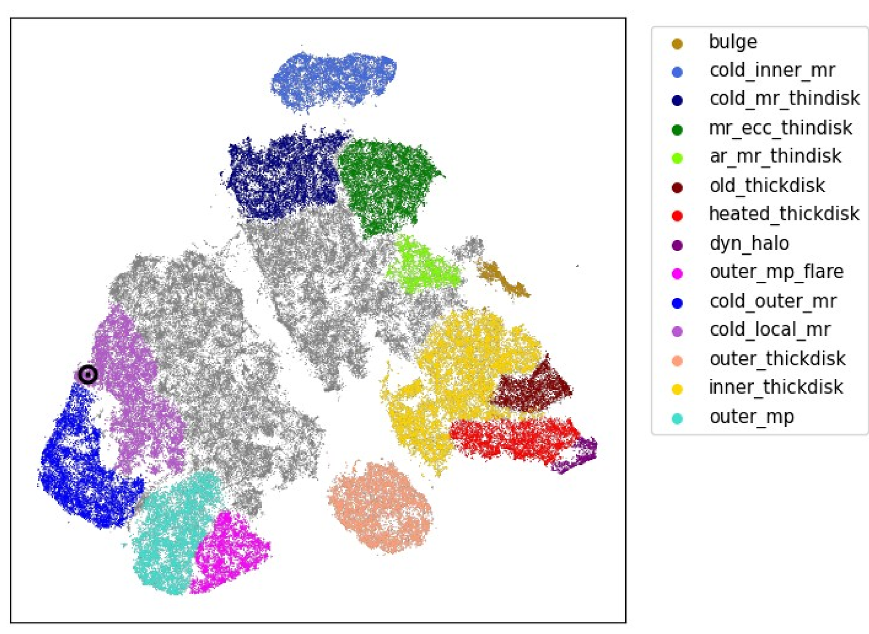

Figure 7: Manifold with coloured identified structures. The sun is displayed as the ⊙ mark. In the legend, the prefixes mr-, ar-, ecc- and dyn- stand for metal-rich, alpha-rich, eccentric and dynamic respectively.

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