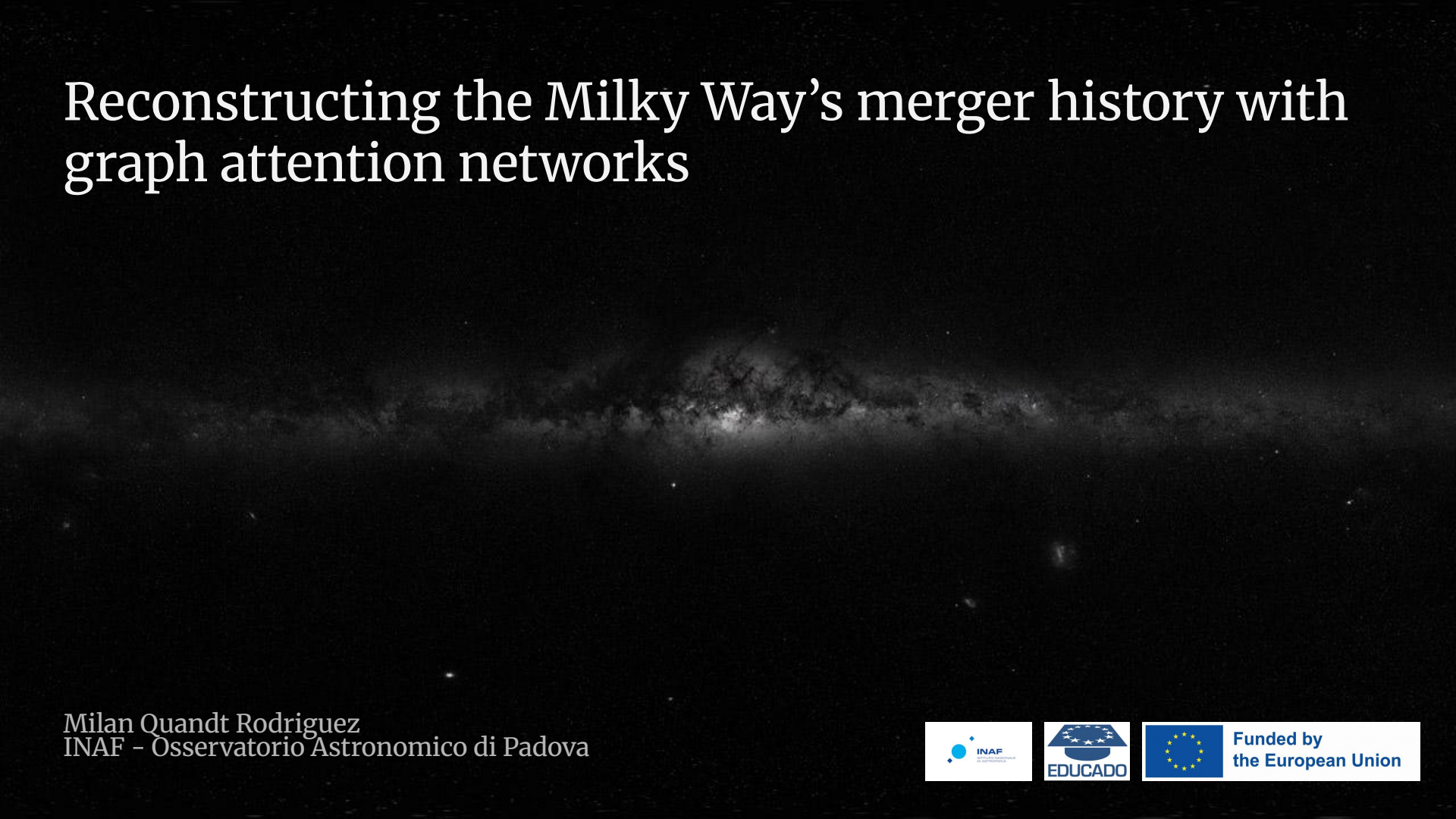
Reconstructing the Milky Way's merger history with graph attention networks



Milan Quandt Rodriguez
INAF - Osservatorio Astronomico di Padova

Funded by the European Union

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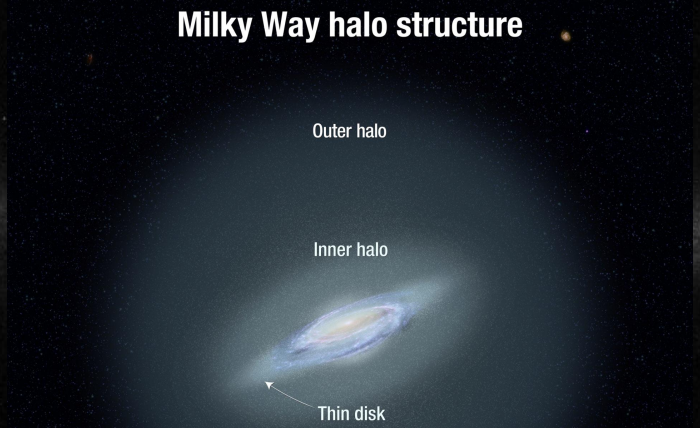
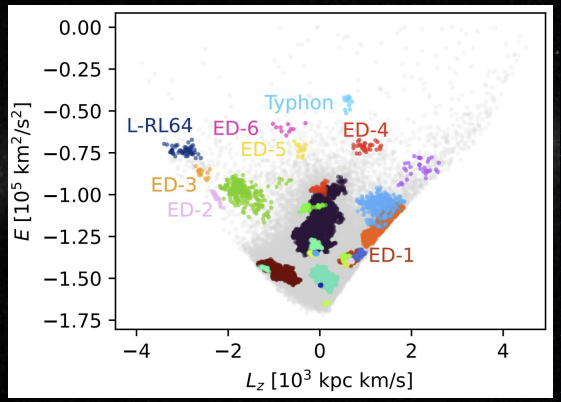


Chemodynamical tagging

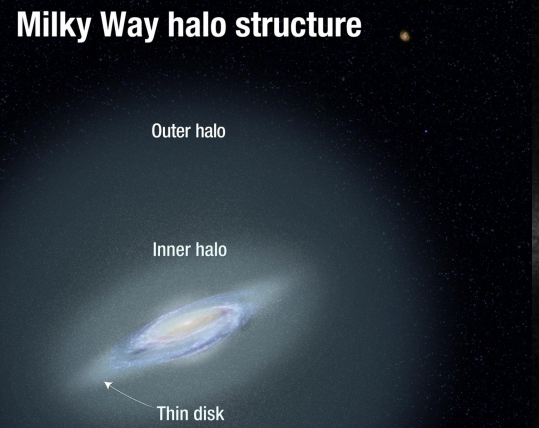
Dynamics



Dodd et al. 2023

Not strictly conserved

Jean-Baptiste et al. 2017, Dillamore et al. 2023



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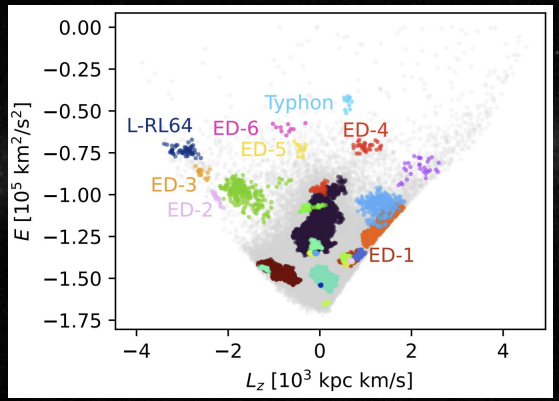

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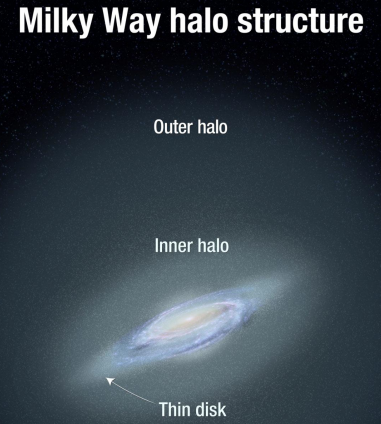
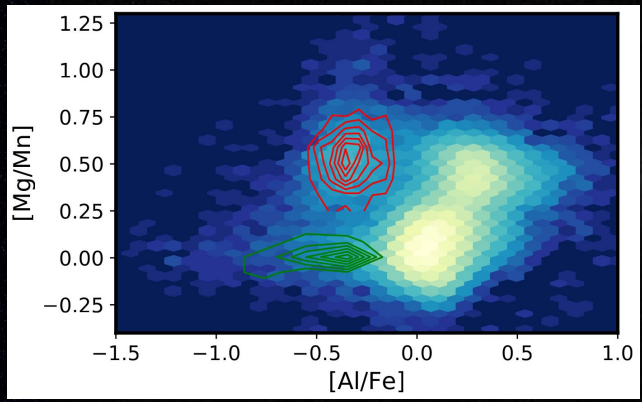


Chemical abundances

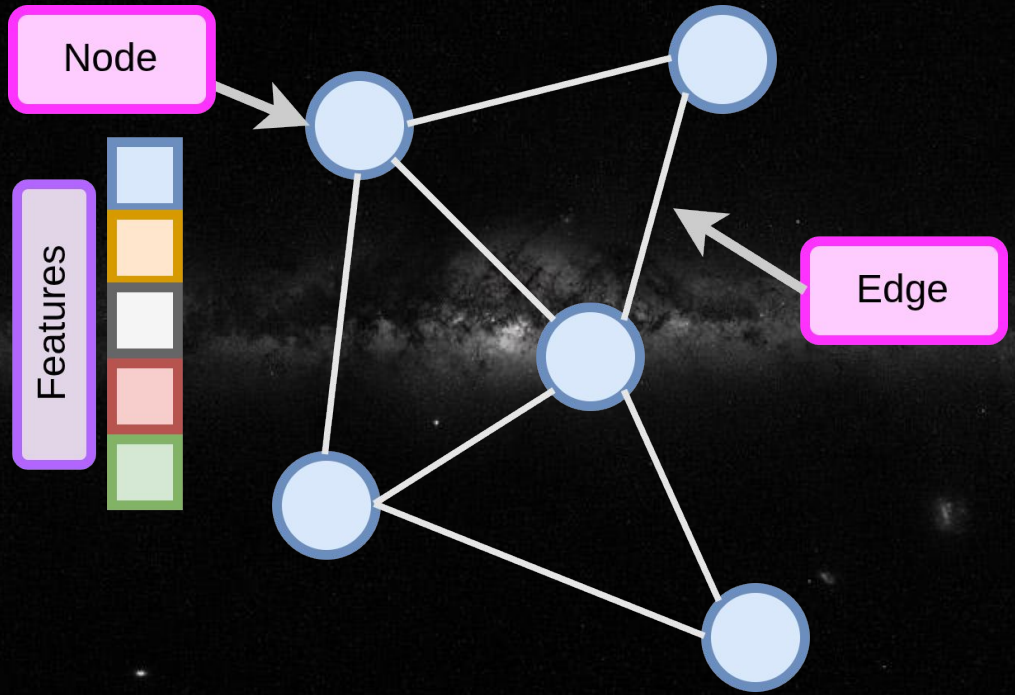


Das et al. 2019

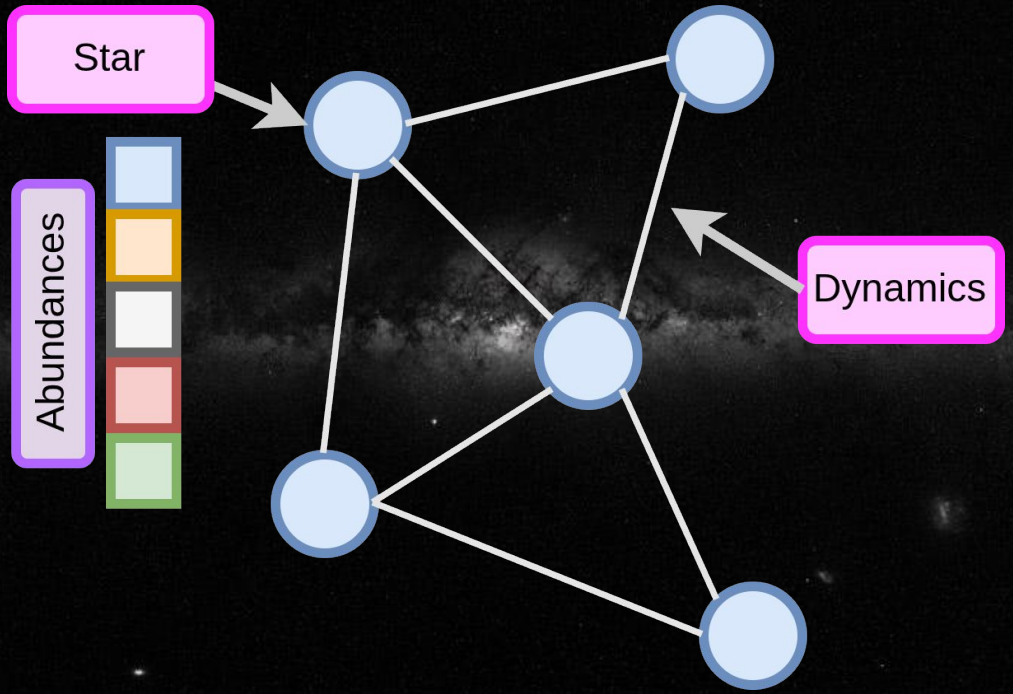
Strictly conserved

Freeman & Bland-Hawthorn 2002

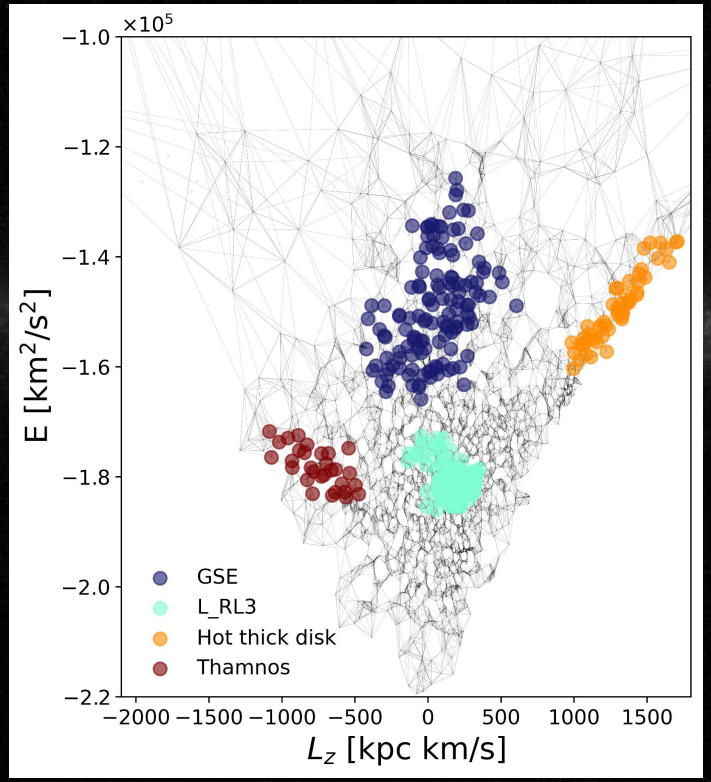
Graph structure



Graph structure

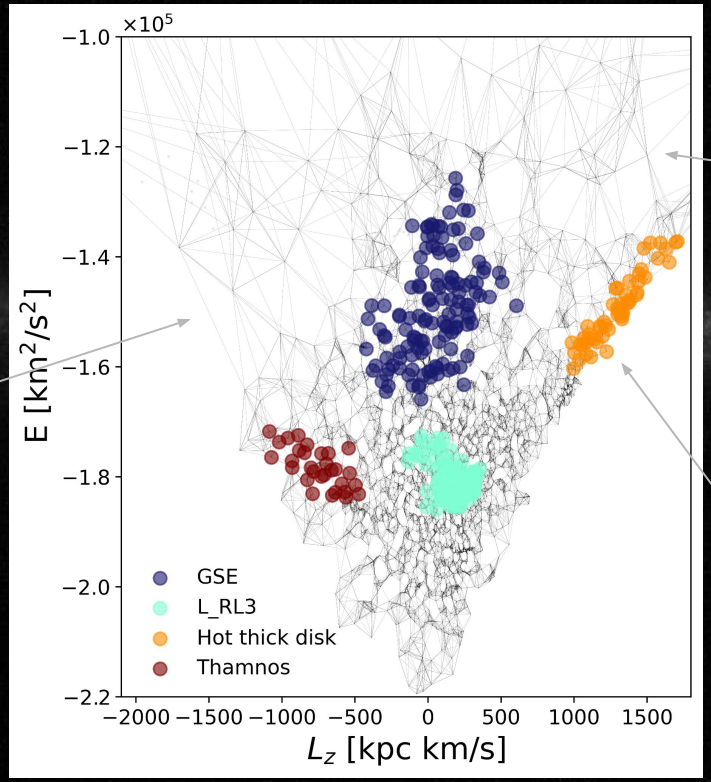


Combining Gaia and GALAH DR4



Quandt-Rodriguez et al. 2026

Combining *Gaia* and GALAH DR4



Quandt-Rodriguez et al. 2026

E, L_z

Gaia DR3 (Gaia Collaboration 2023)

Mg, Ca, Ti, Sc, Fe, V, Mn, Cu, Na, Zn, Ba, Y, Nd

GALAH DR4 (Buder et al. 2025)

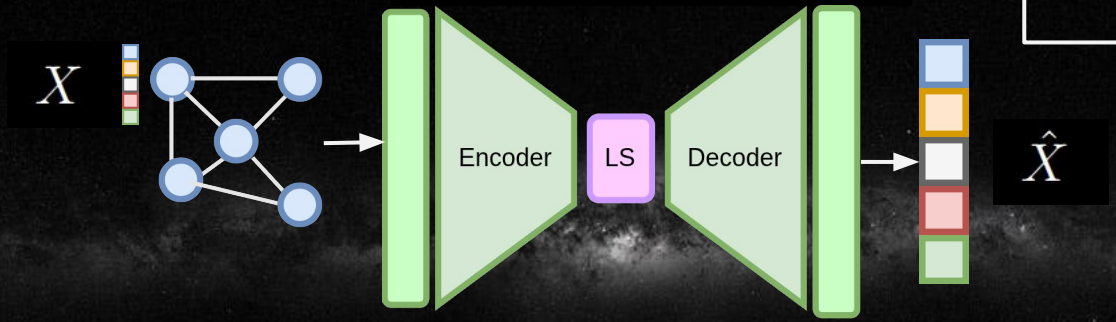
Dynamical substructure and GCs

Dodd et al. 2023

Graph attention networks (GATs)

$$\mathcal{L}_{\mathrm{MSE}} = \mathrm{MSE}(X, \hat{X})$$

Loss function: Reconstruct node features only! (abundances)



GAT architecture: Veličković et al. 2017, Brody et al. 2021

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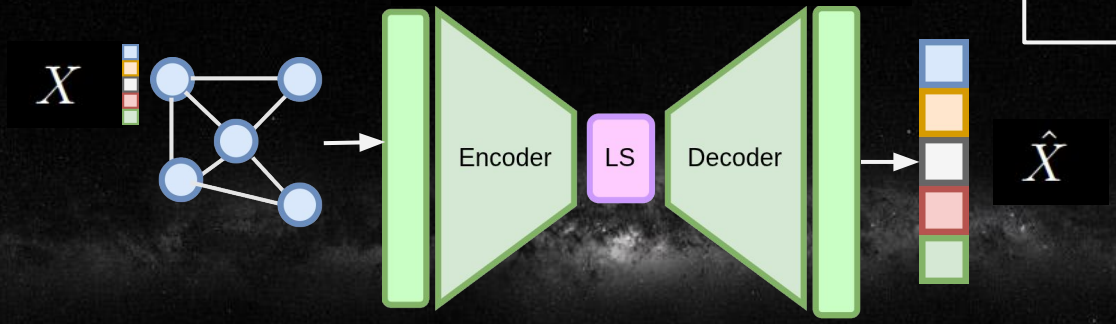
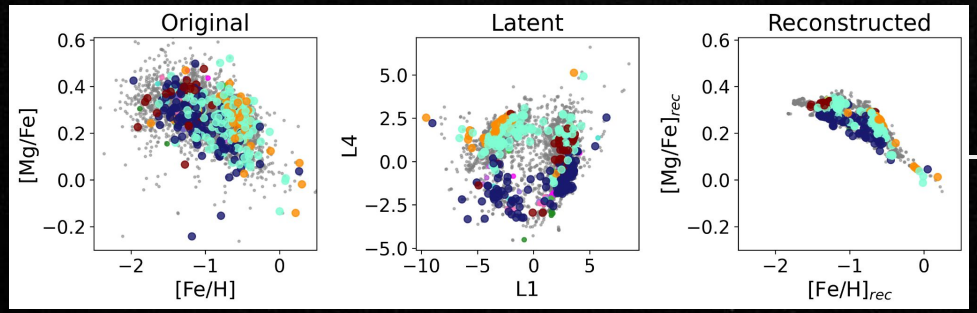




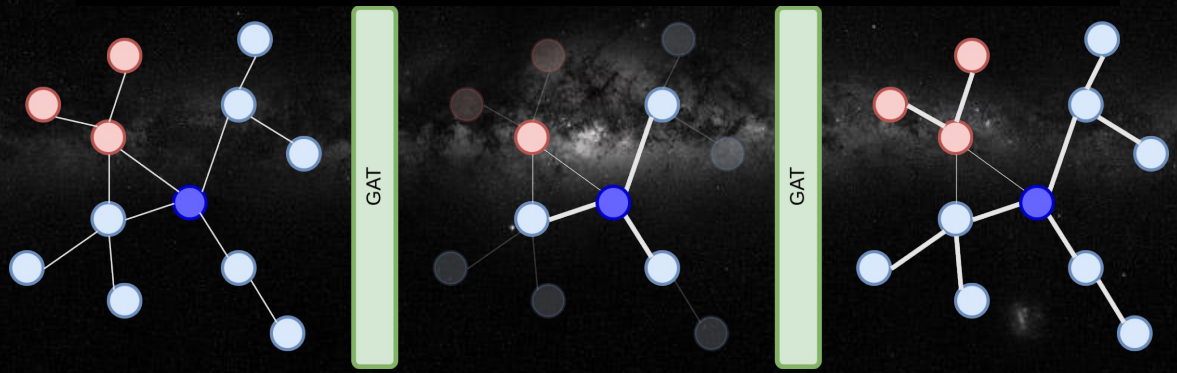
Dynamics-informed, denoised abundance space

GAT architecture: Veličković et al. 2017, Brody et al. 2021

Quandt-Rodriguez et al. 2026

Why attention?

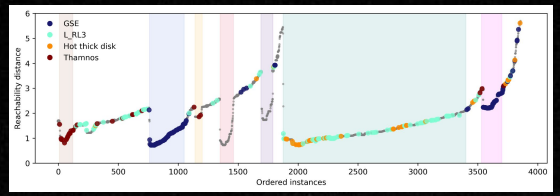
$$h_v^{(k)} = \sigma\Big(\underbrace{W\, h_v^{(k-1)}}_{\text{self / standard NN}} + \underbrace{\sum_{u \in \mathcal{N}(v)} \alpha_{vu} W\, h_u^{(k-1)}}_{\text{neighbors / attention-weighted message passing}} \Big)$$

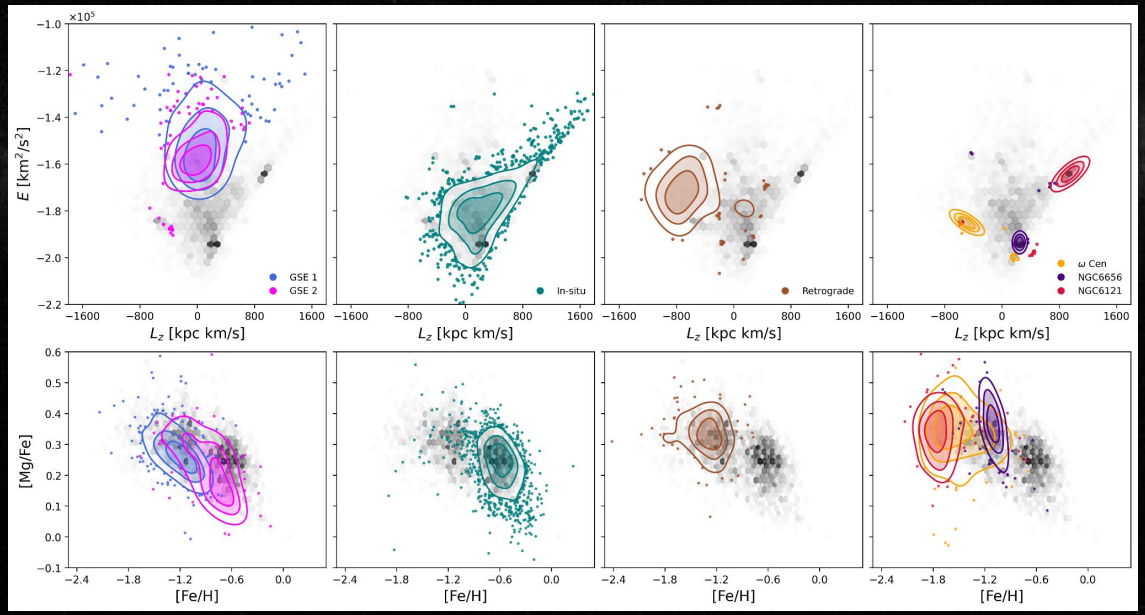


Edges are built on dynamical similarity, but might connect stars with very different chemistry

GAT architecture: Veličković et al. 2017, Brody et al. 2021

Clustering with OPTICS





Two chemically distinct clusters for GSE

In situ ≃ 41%

Globular clusters: ωCen, NGC6656, NGC6121

Quandt-Rodriguez et al. 2026