The Milky Way signature of spiral arms and their content through simulations

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SPIRAL ARMS WITH GAIA

The distribution of **chemical elements** in the Galactic disc can reveal fundamental clues on the physical processes that **led** to the current configuration of our Milky Way. Taking advantage of the **Gaia Data Release 3**, we aim at understanding the impact of the **spiral arms structure** on Galactic chemical evolution, detecting their signatures in **other stellar abundances than global metallicity**, like **calcium**. We selected **young giant stars** to represent a large volume of the disc.

In *Barbillon+2025a*, we have used stellar atmospheric parameters from **GSP-spec module** *(Recio-Blanco+2023)*, applying **quality flags** and **robust statistical** analysis due to high-quality chemical measurements, and calibrating abundances as a function of **T_{eff}. 11187 stars** were selected characterising preferentially **Blue Loop stars** and constitutes our main data base. We estimated the age of the sample thanks to isochrones coming from BaSTI models. It leads to an **approximate age range between 30 and 130 Myr (sample A)**. Moreover, similar maps and results were obtained for a sample of **old giants stars older than 2 Gyr (sample C)**.

RESULTS

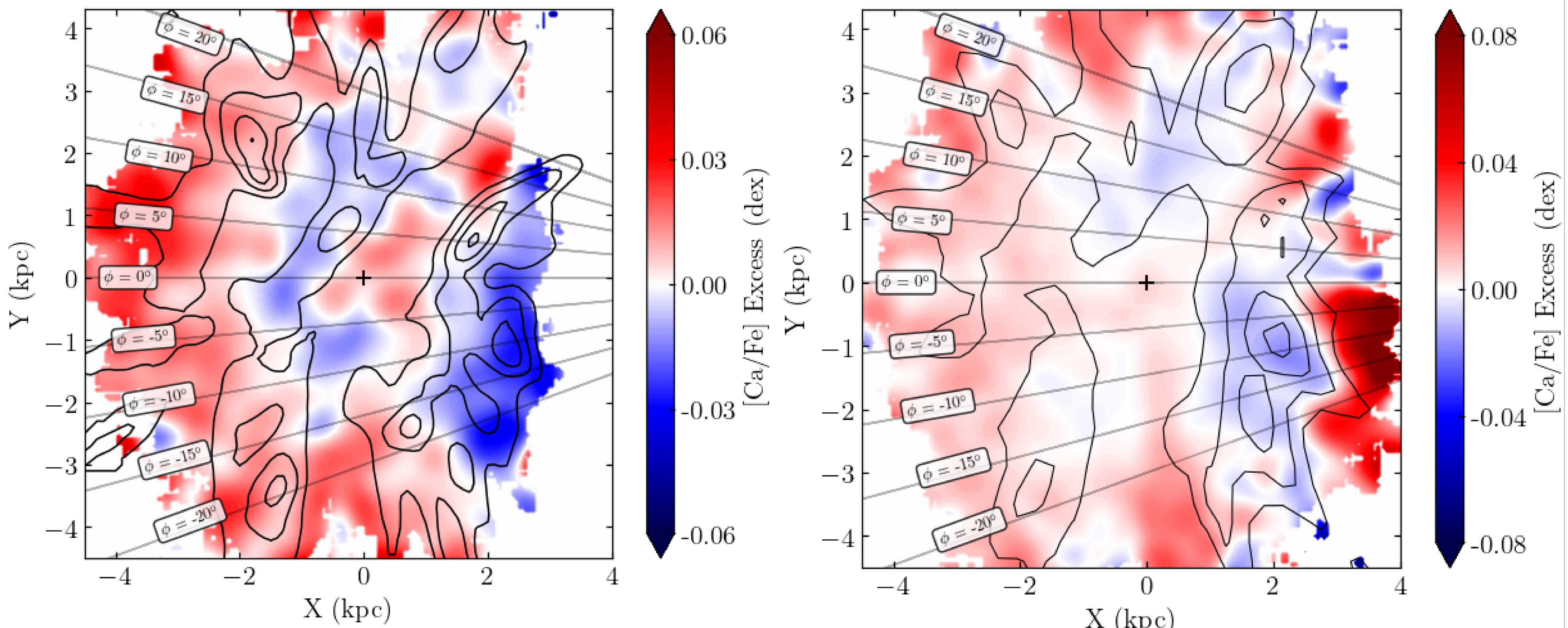

Fig 1: [Ca/Fe] excess map overlaid with azimuthal lines, with the Sun position in black cross. The Galactic centre is to the right. Left panel: excess maps for sample A. Black contours indicate the position of the spiral arms from UMS stars *(Poggio+2021)*. Right panel: same for the sample C with arms from old giants *(Palicio+2023)*.

Both for **old and young populations**, the inhomogeneities in α-abundances **are spatially coherent** with the respective overdensity contours.

Globally, stars **within** the spiral arms are:

➡ **More calcium-rich (metal-rich)** than the stars in the inter-arms regions.

➡ **More [Ca/Fe]-poor** than the stars in the inter-arms regions.

SIMULATIONS

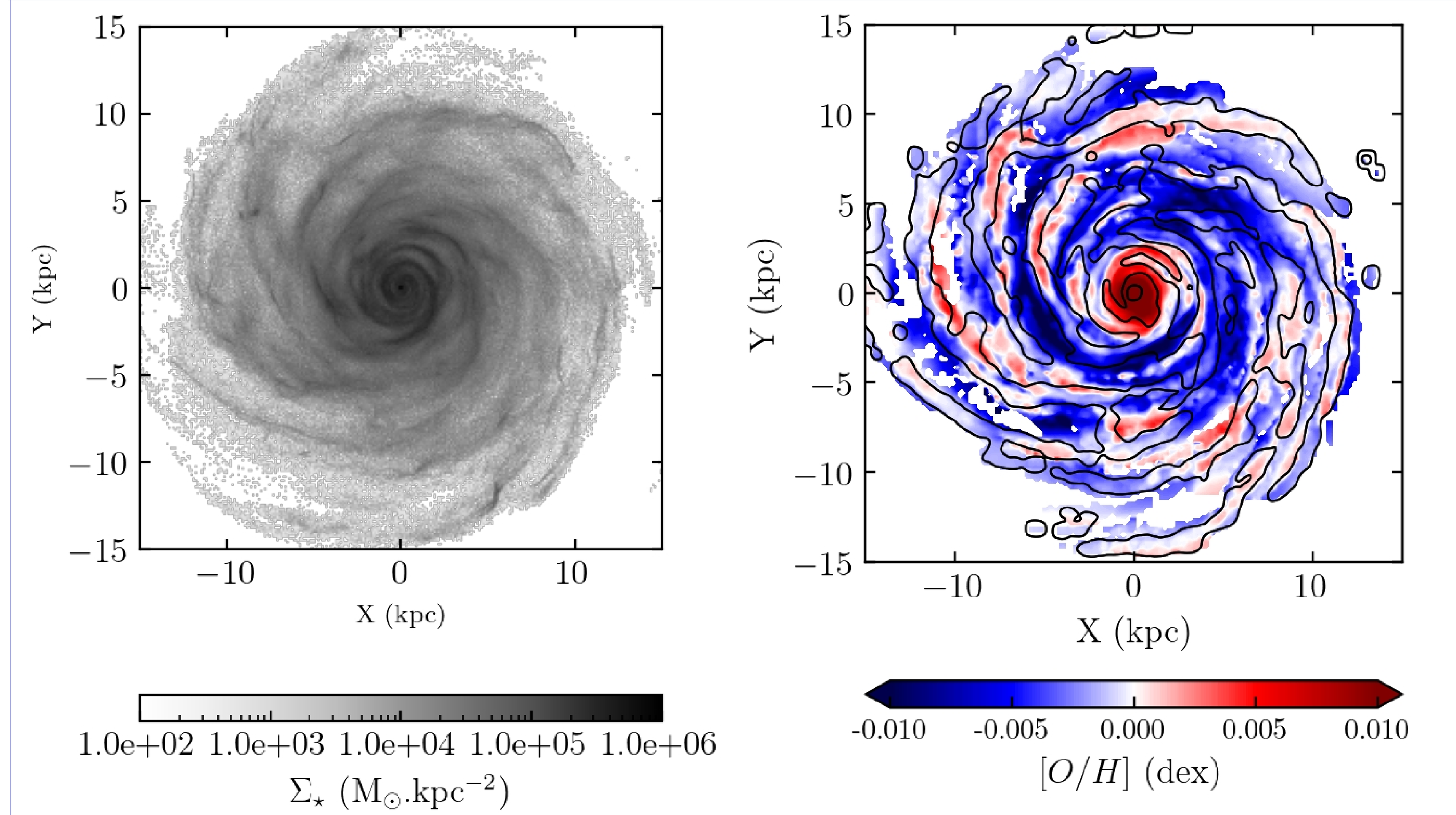

Fig. 2: *XY* view of the Nexus galaxy. Left panel: surface density of all stellar populations. Right panel: [O/H] excess for stars <300 Myr, with spiral arm density contours (solid black). This sample represents the young sample of Fig. 1.

To compare our Gaia observations, we used an **idealised simulation Nexus** (Tepper-García+2024) and a **cosmological zoom-in simulation (AMx05**, Cadiou+2019). The galaxies are **MW analogous** with well-defined spiral arms from mergers.

➡ **Rapid young-stars enrichment** splits arms from the rest of disc.

➡ The excess and density **match is not perfect** yet **best** in Nexus.

TEMPORALITY OF ESCAPEMENT IN SPIRAL ARMS

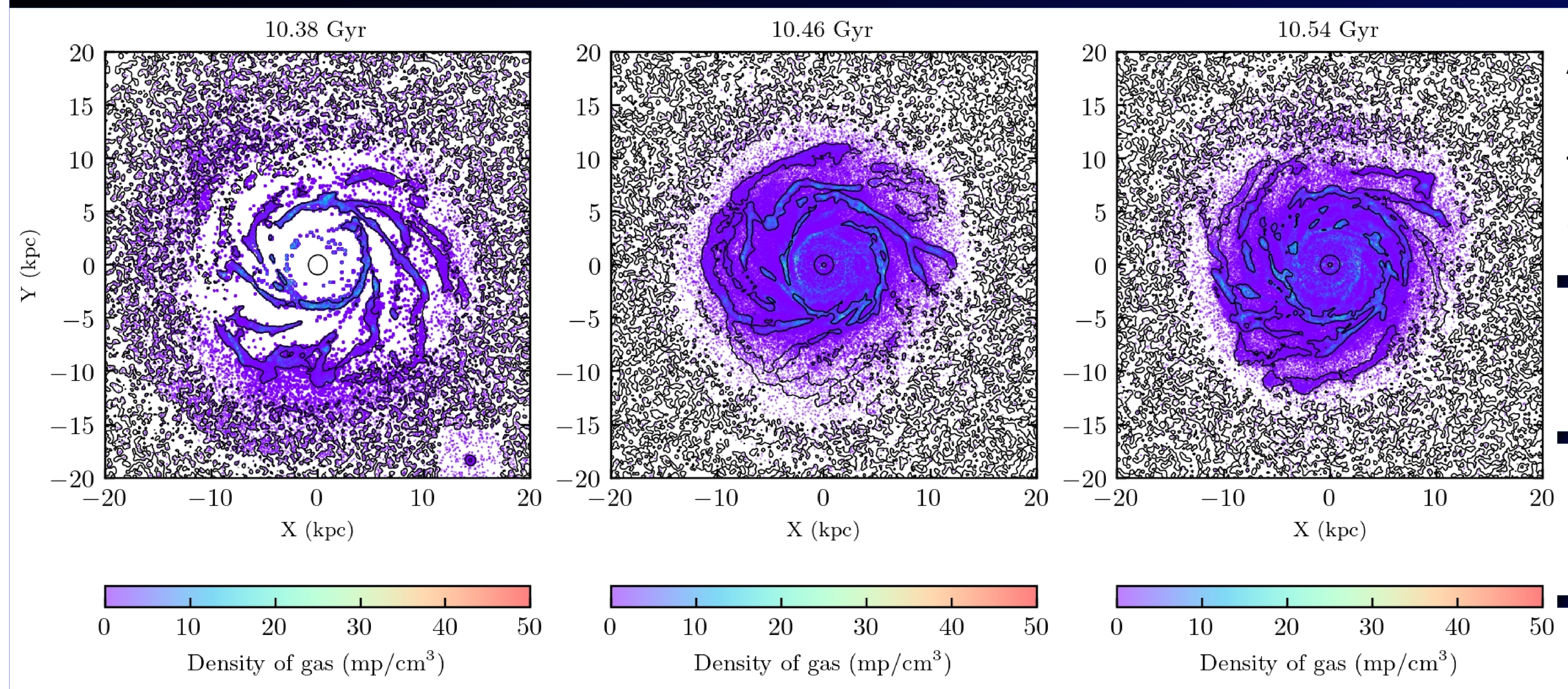

Fig 3: Gas particles selected at T=10.38 Gyr and followed overtime by steps of 80 Myr in AMx05.

AMx05 has the capability to **track gas particles.** We fixed a **density contrast of 17%** to discern spiral arms particles from the rest of the disc. It means that the stars or gas arms are at minimum 17% denser than the disc average.

➡ Gas particles selected with this density contrast **match the density contours** obtained by another independent method.

➡ This timescale illustrates **how gas begin to escape** the arms, whilst **remaining not far** by being confined in the disc.

➡ Gas particles are **more located in the spiral arms** even after 160 Myr.

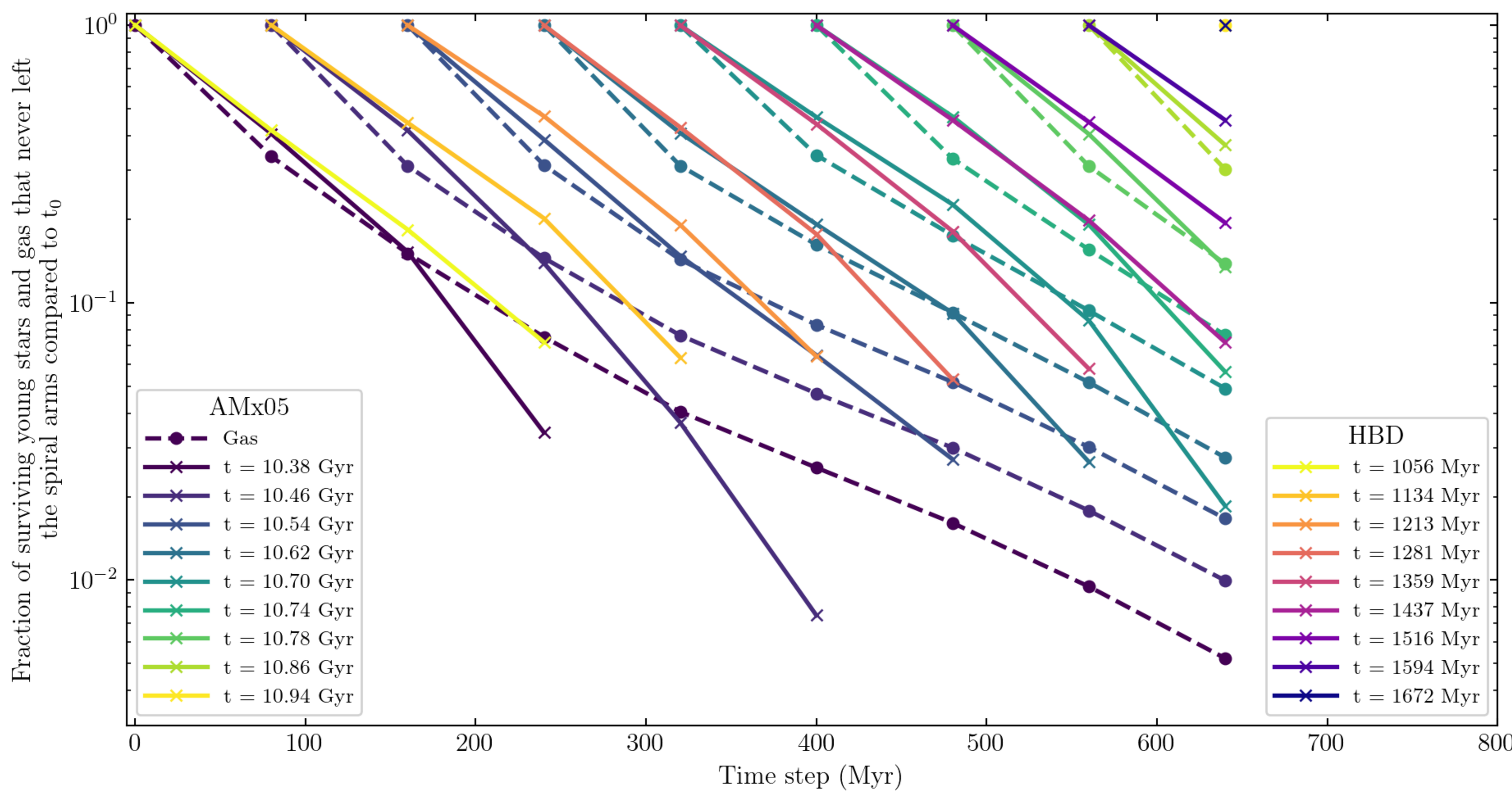

Fig. 4 : Fraction of young stars and gas particles that NEVER left the spiral arms over time.

Fig. 4 allows to **quantify this escapement temporality**. The viridis colours represent the AMx05 galaxy where the circle markers are the gas contribution in the spiral arms and the cross markers are the young stars contribution in the spiral arms. The jet colours with the cross markers are the young stars contribution in the spiral arms of Nexus. Curves show the fraction of **young stars or gas particles that never left** the arms at a snapshot *t*. The 80 Myr timesteps trace the tracer escape speed.

➡The escape timescale of **young stars** is **240 Myr** *(cf. Ardévol+2025)*.

➡The escape timescale of **gas** is **640 Myr**.

➡Spiral arms in **Nexus retain their young stars more efficiently than those in AMx05**. Indeed, Nexus galaxy has a **higher** mean density contrast in its entire disc.

CONTENT OF SPIRAL ARMS OVER TIME

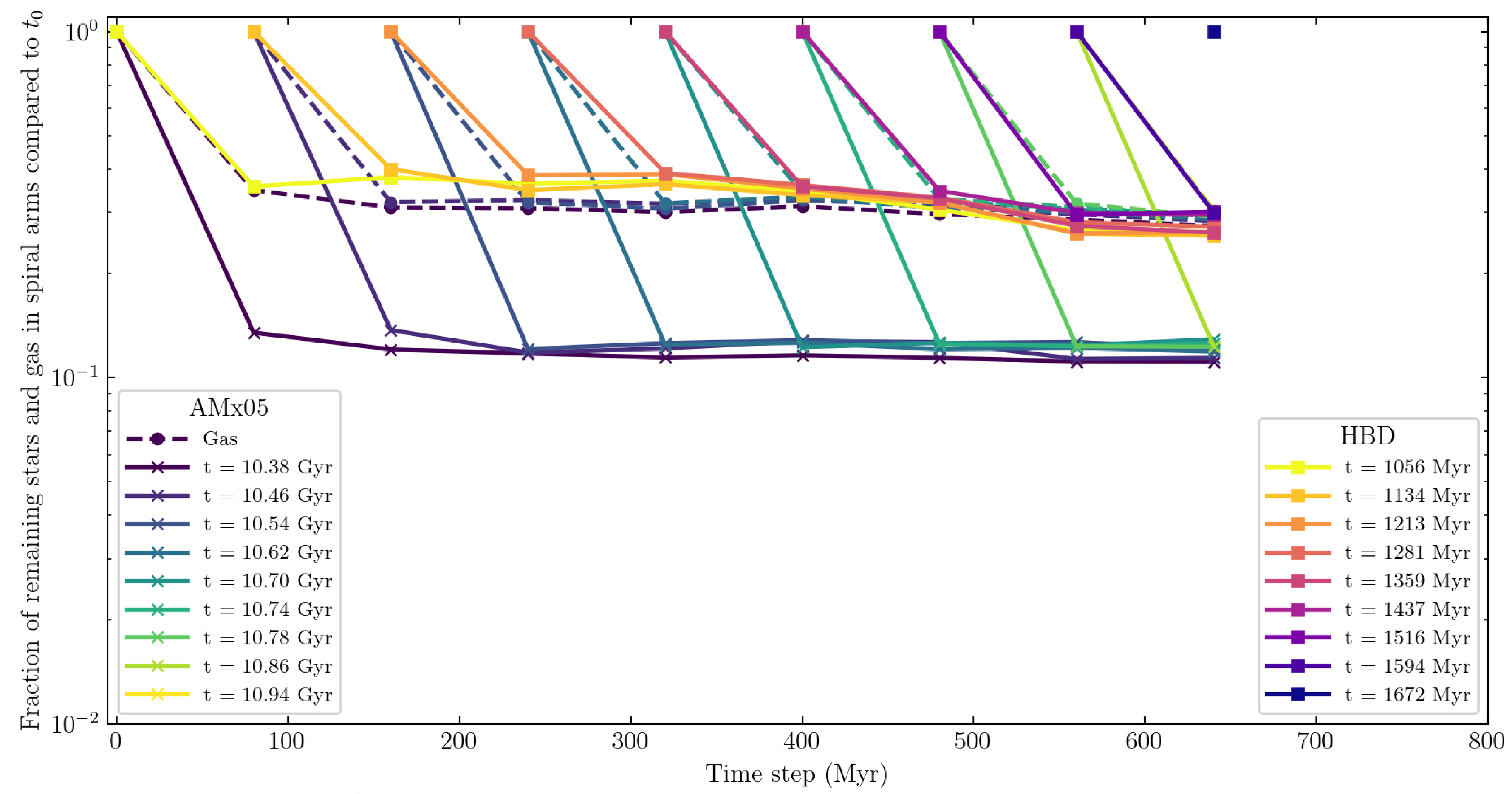

Fig. 5: Fraction of every star and gas particles that are still in the spiral arms over time.

Fig. 5 shows **the content of the spiral arms** over time for the two galaxies. Curves illustrate the fraction of **all stars or gas particles** that **are still in** the arms at a snapshot *t*.

➡In AMx05, the gas **is staying more preferentially in the spiral arms (~30%)**. While, **only 10% of stars of every age are still in the spiral arms after several Gyr.** In Nexus, this fraction of **stars of every age is 3 times higher with 30%.**

➡Gas and stars did not stay forever in the arms, they **move in and out of the pattern for several Gyr.** A non-negligible gas and stars fraction remain trapped in the spiral arms, **confining the chemical enrichment**. This fraction depends on the **amplitude and strength of the spiral arms. Nexus idealised simulation** presents a **good match of the Galactic spiral arm chemical properties observed by Gaia.**