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How cosmological filaments reset the formation of disk galaxies

How can we reconstruct the formation history of galaxies?

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Galactic archeology is hard!

- Huge uncertainties on stellar ages
- Dynamical mixing of structures (e.g. in bulges)
- Orbital migration
- Stellar ages do not trace the ages of the structures they make (e.g. bars)

(Some) workarounds when looking at chemical compositions

CHEMICAL ENRICHMENT

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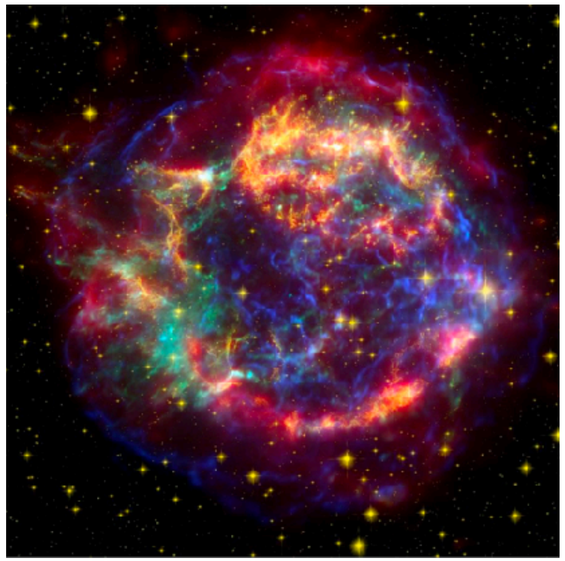
Star formation

Stars inherit the chemical composition of their parent cloud

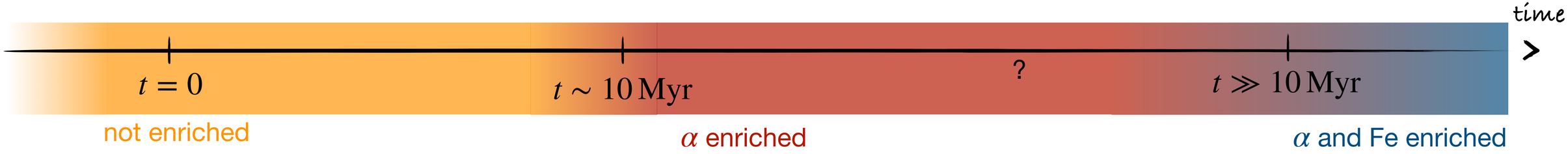


type-II supernovae
(core-collapse, > 8 $M_\odot$)

Release of α elements (from the fusion of ^{4}He) e.g. O, Mg, Ti ...

type-Ia supernovae
(binary mass transfer, thermonuclear reaction)

Release of Fe, Ni ...



[α/Fe]-[Fe/H] IN THE MILKY WAY

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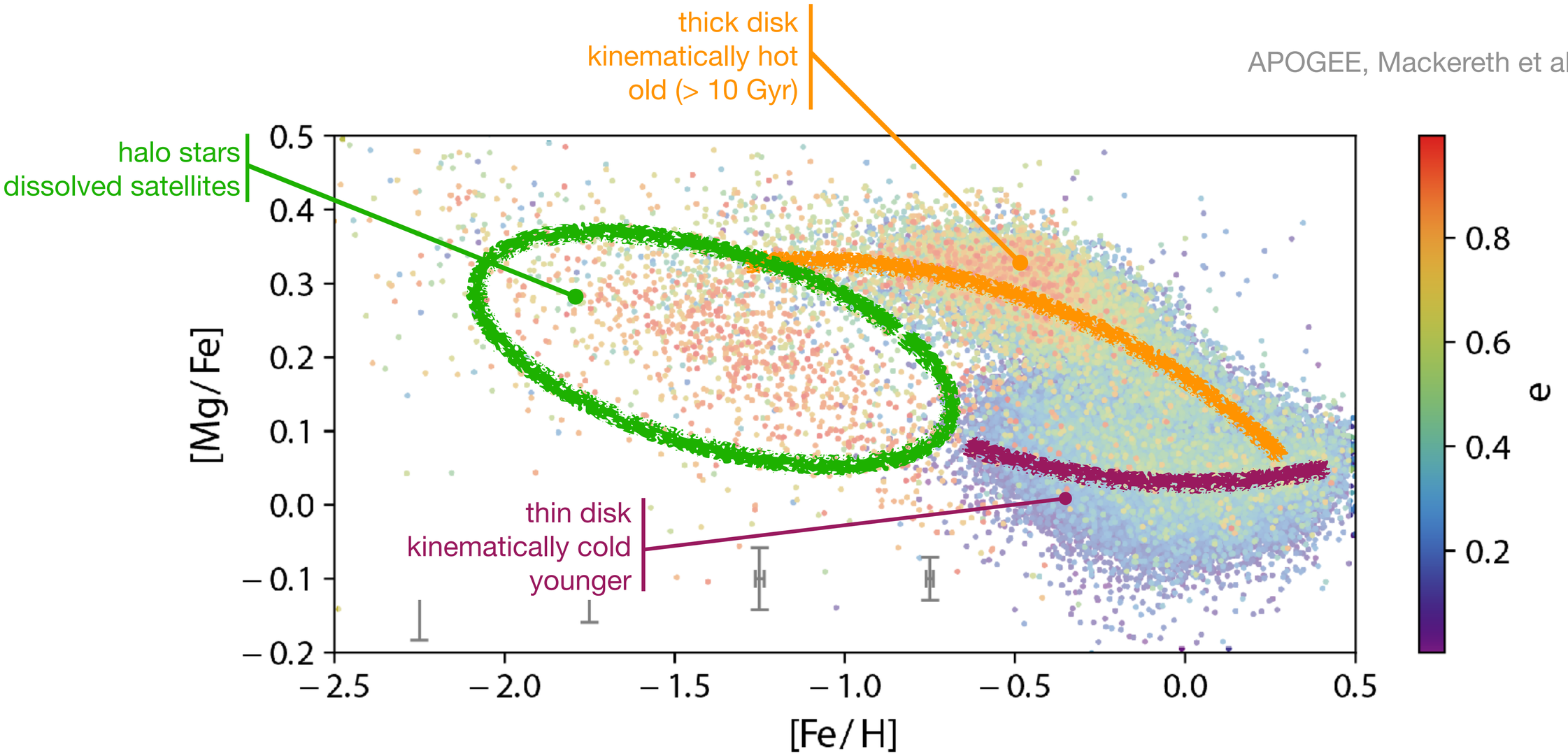
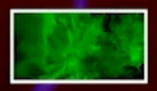


See also Haywood et al. 2013, Recio-Blanco et al. 2014, Hayden et al. 2015, Nidever et al. 2015, Bovy et al. 2016, Rojas-Arriagada et al. 2017, Silva-Aguirre et al. 2018, Haywood et al. 2018, Feuillet et al. 2019, Di Mateo et al. 2019, Ciuca et al. 2022 and many others

VINTERGATAN

Agertz, Renaud et al. (2021)
Renaud, Agertz et al. (2021a,b)

MILKY WAY


IRON


STARS


GAS


DARK MATTER

Z = 6

12.9 GYR AGO

ASSEMBLY HISTORY

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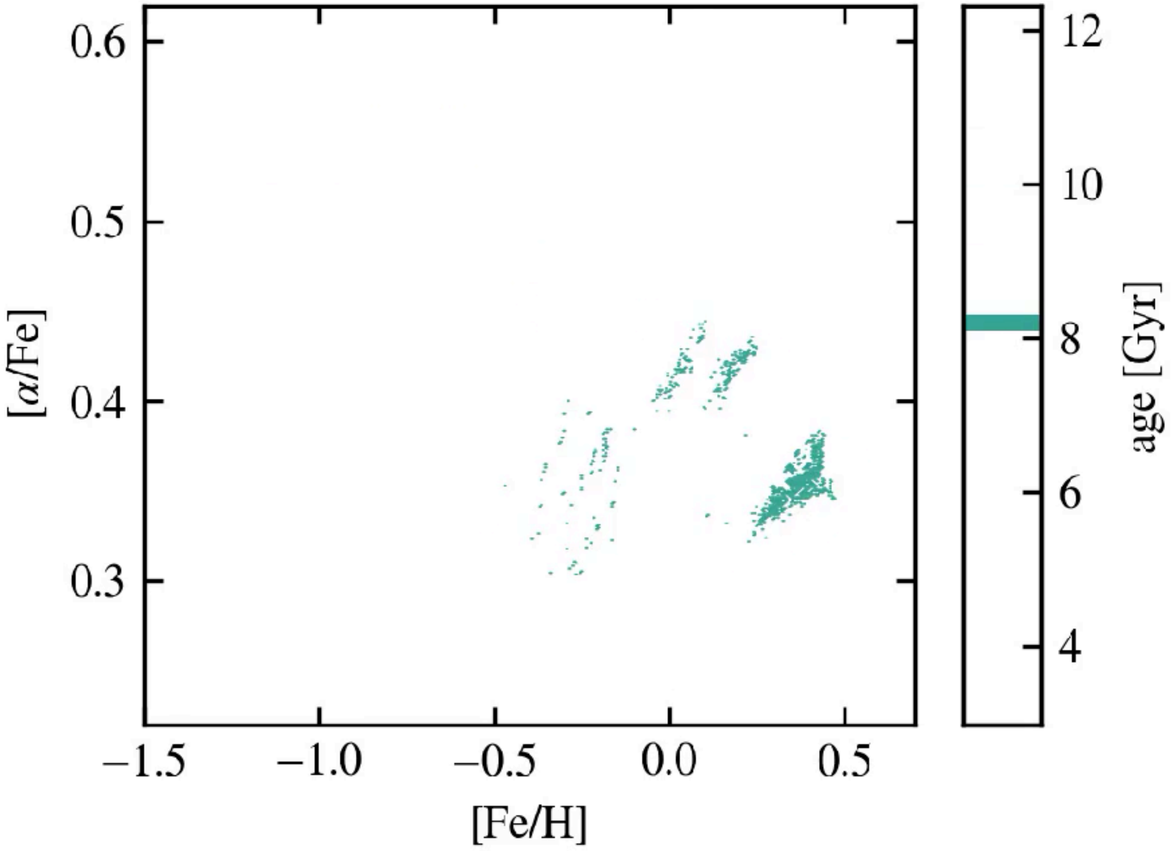
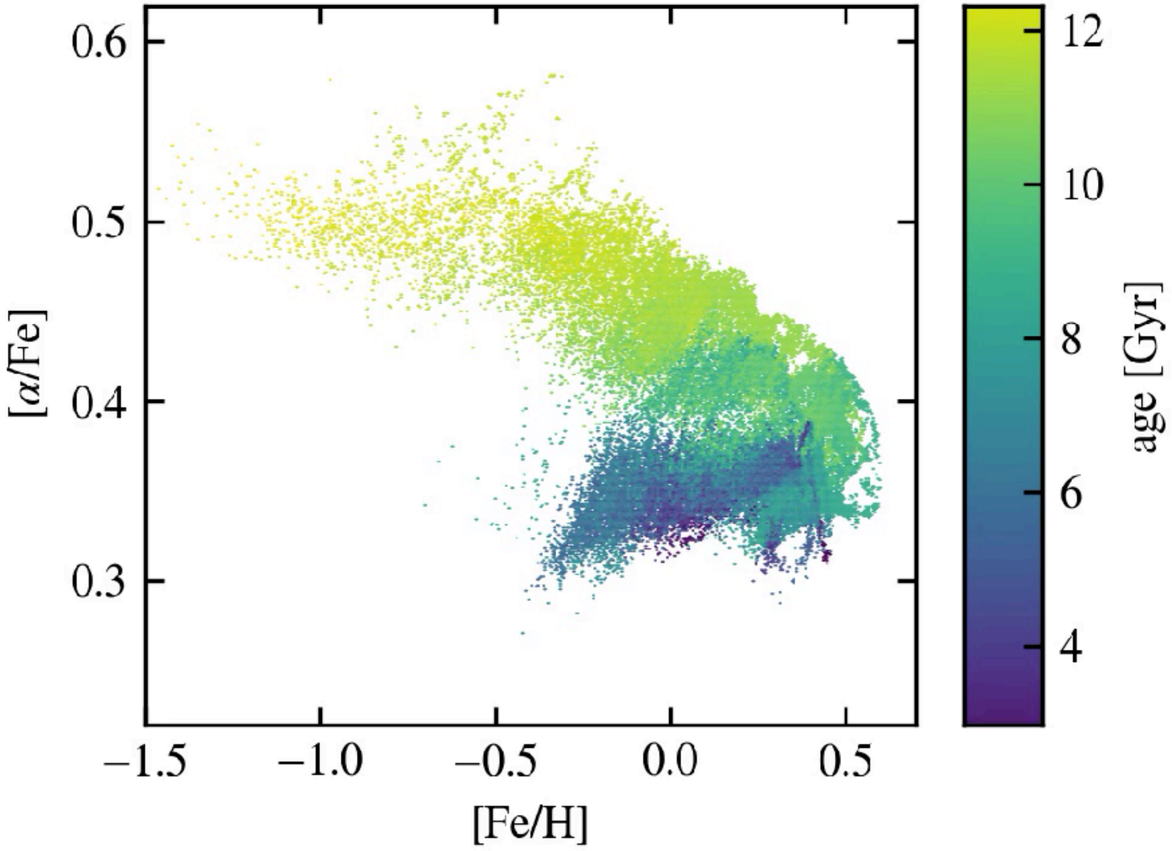
instantaneous



cumulative



Ignition of a second star formation channel

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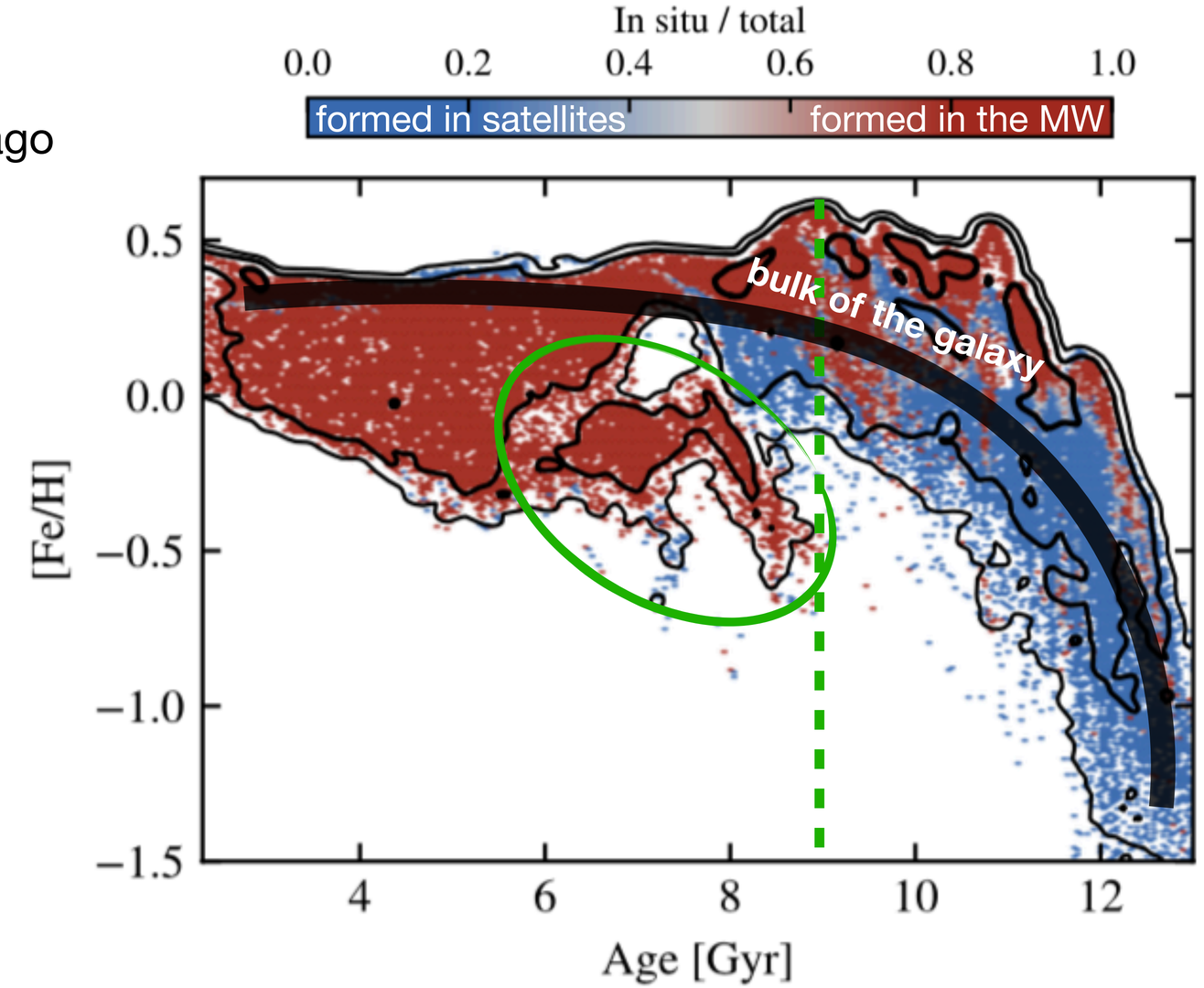
Ignition of a second formation channel ~9 Gyr ago
(seen in several other zoom simulations too)
e.g. Sanderson et al. (2020)

- Lower metallicity
- At the epoch of the last major merger
- But not made of accreted stars
- Connects later to the rest of the disc



VINTERGATAN II (Renaud, Agertz +2021a)

TILTED DISC

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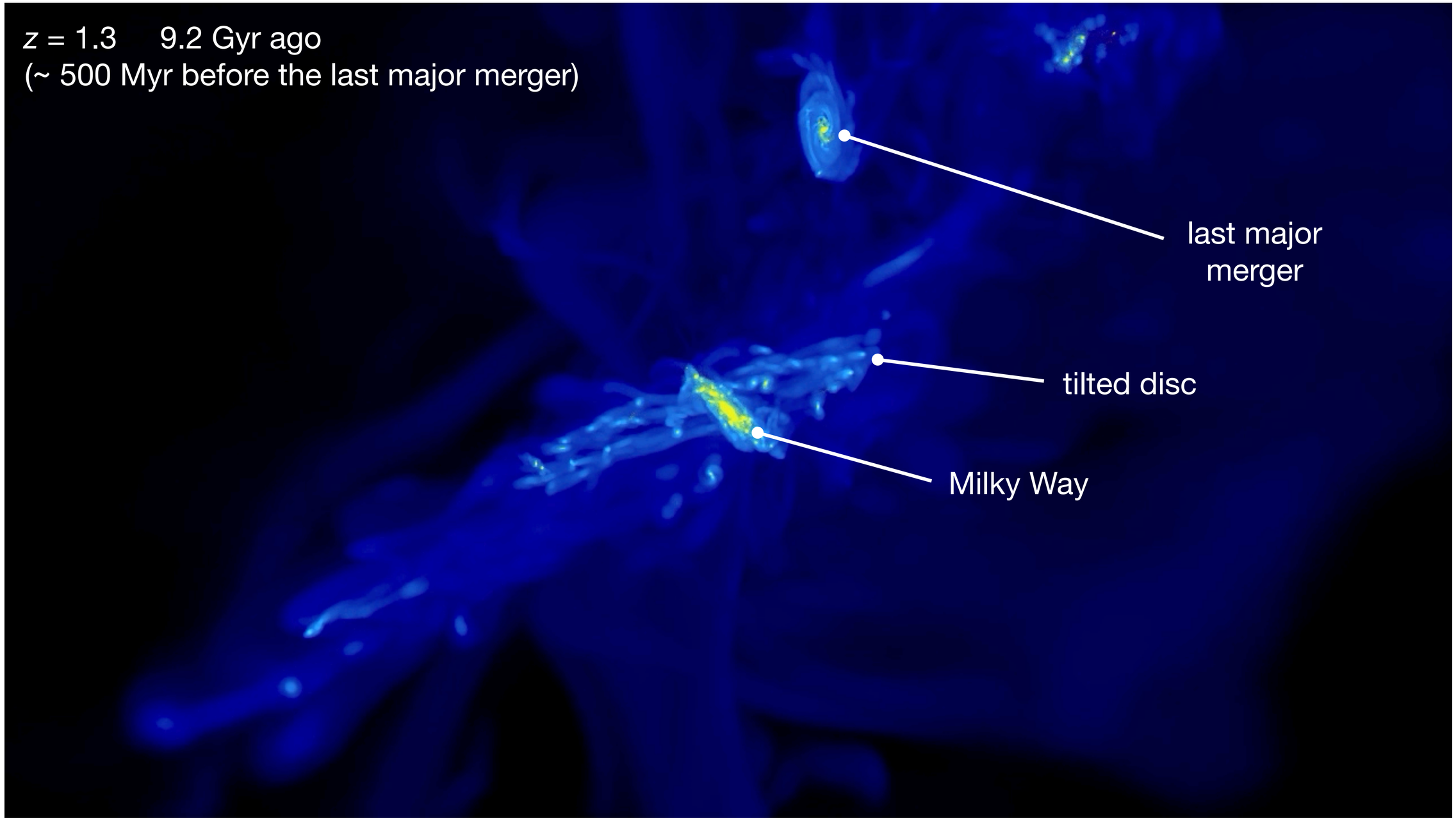

TILTED DISC

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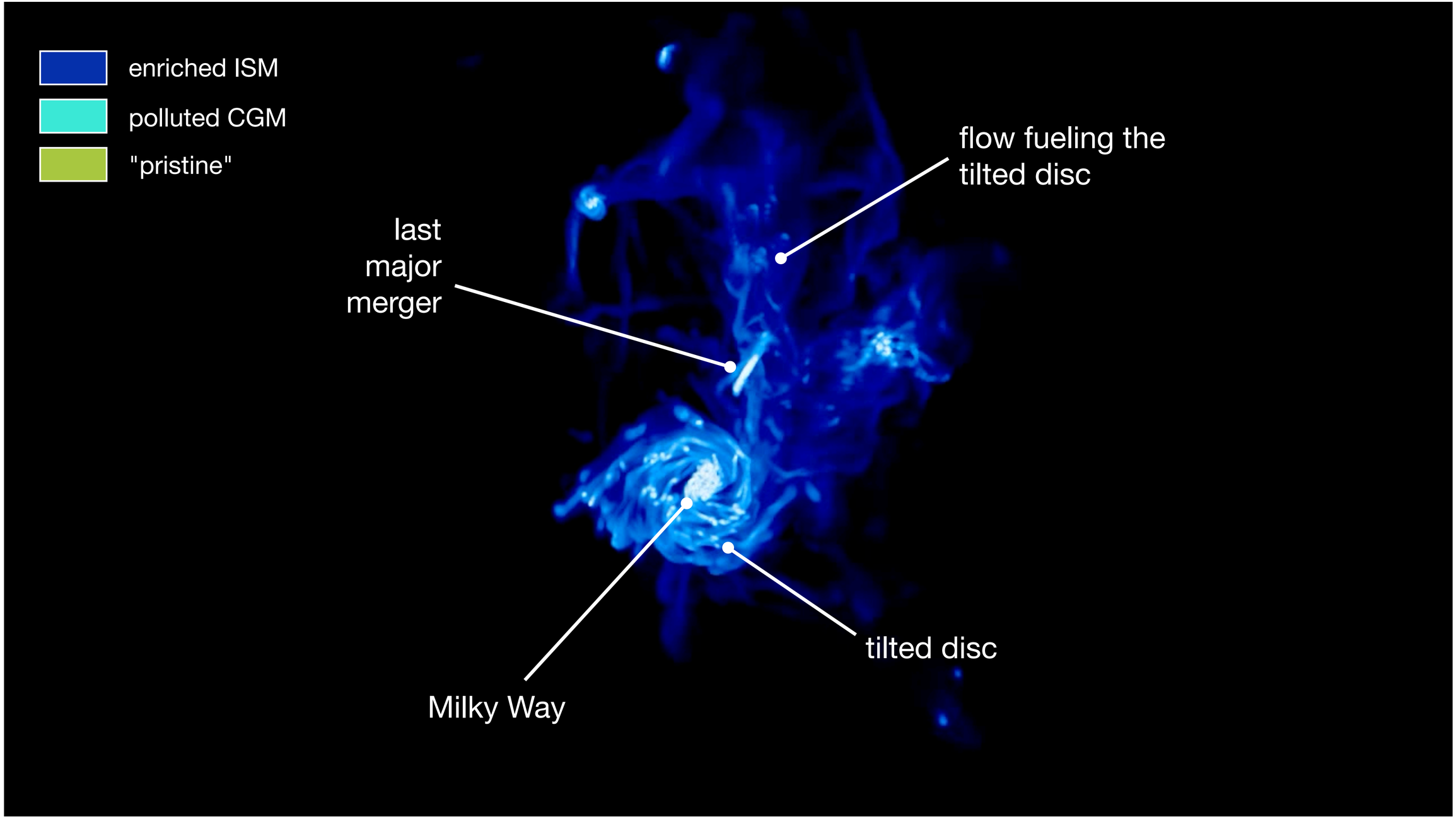

IGNITION OF STAR FORMATION IN THE TILTED DISC

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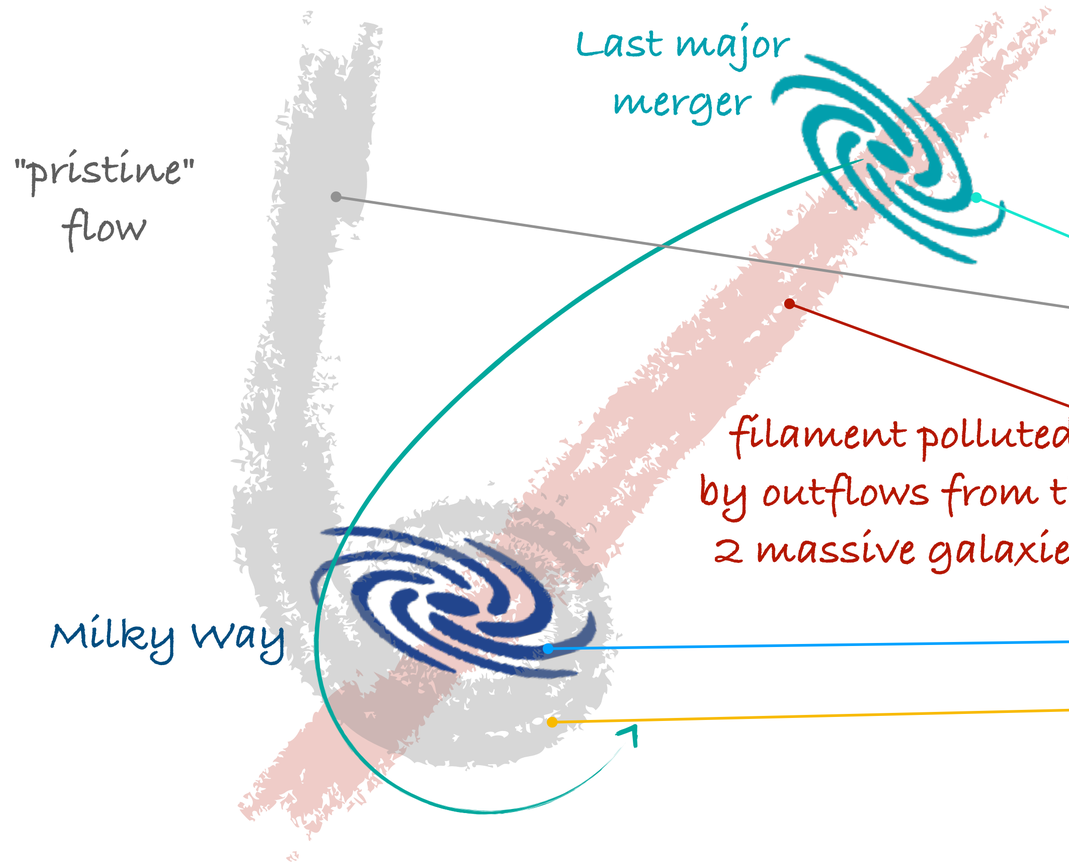
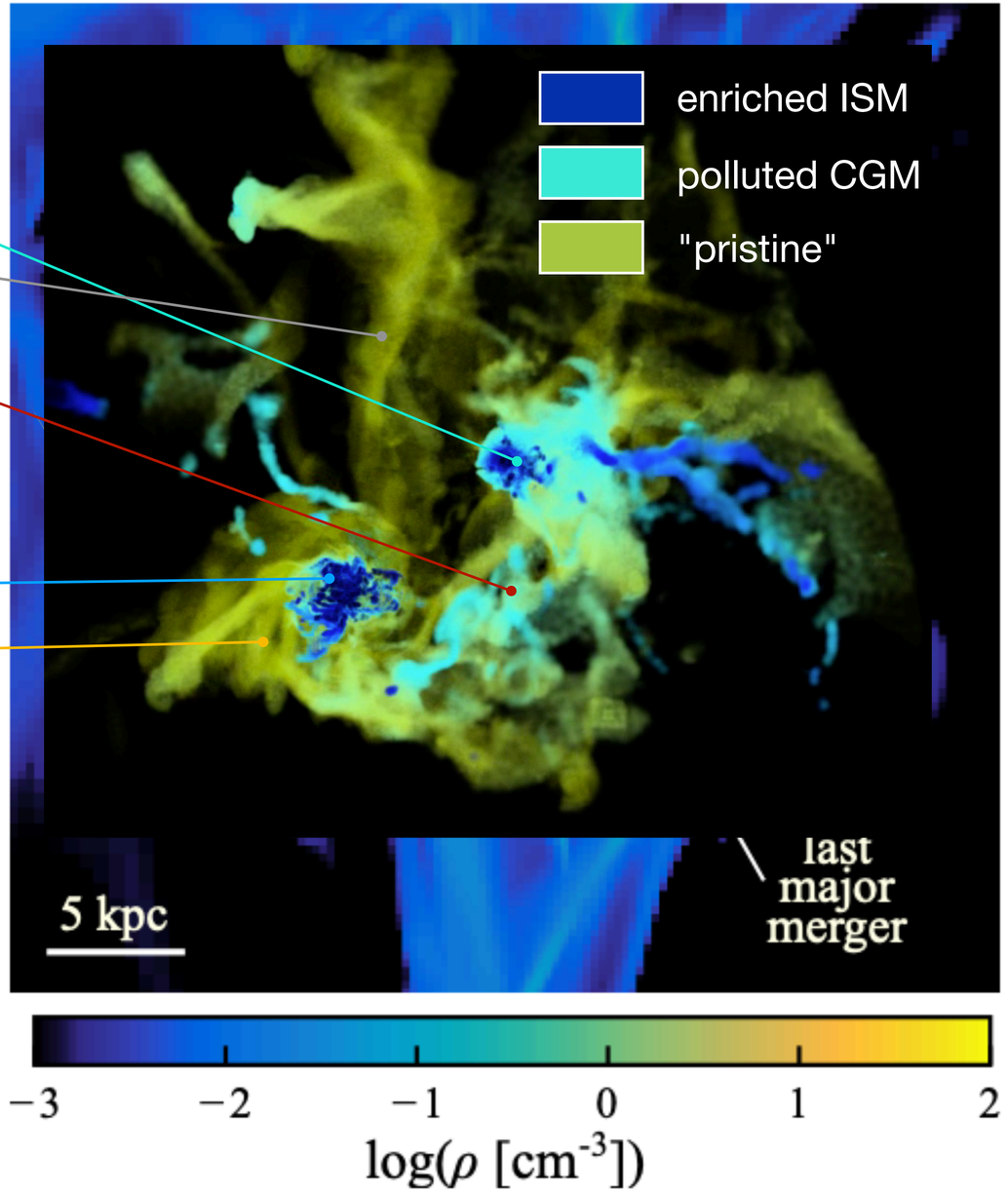


VINTERGATAN III (Renaud et al. 2021b)



This scenario only requires 2 cosmic filaments

The major merger does the rest!

Commonly seen in large-volume cosmo simulations
(e.g. Khoperskov et al. 2021)

THE TILTING DISK BECOMES THE OUTER DISK

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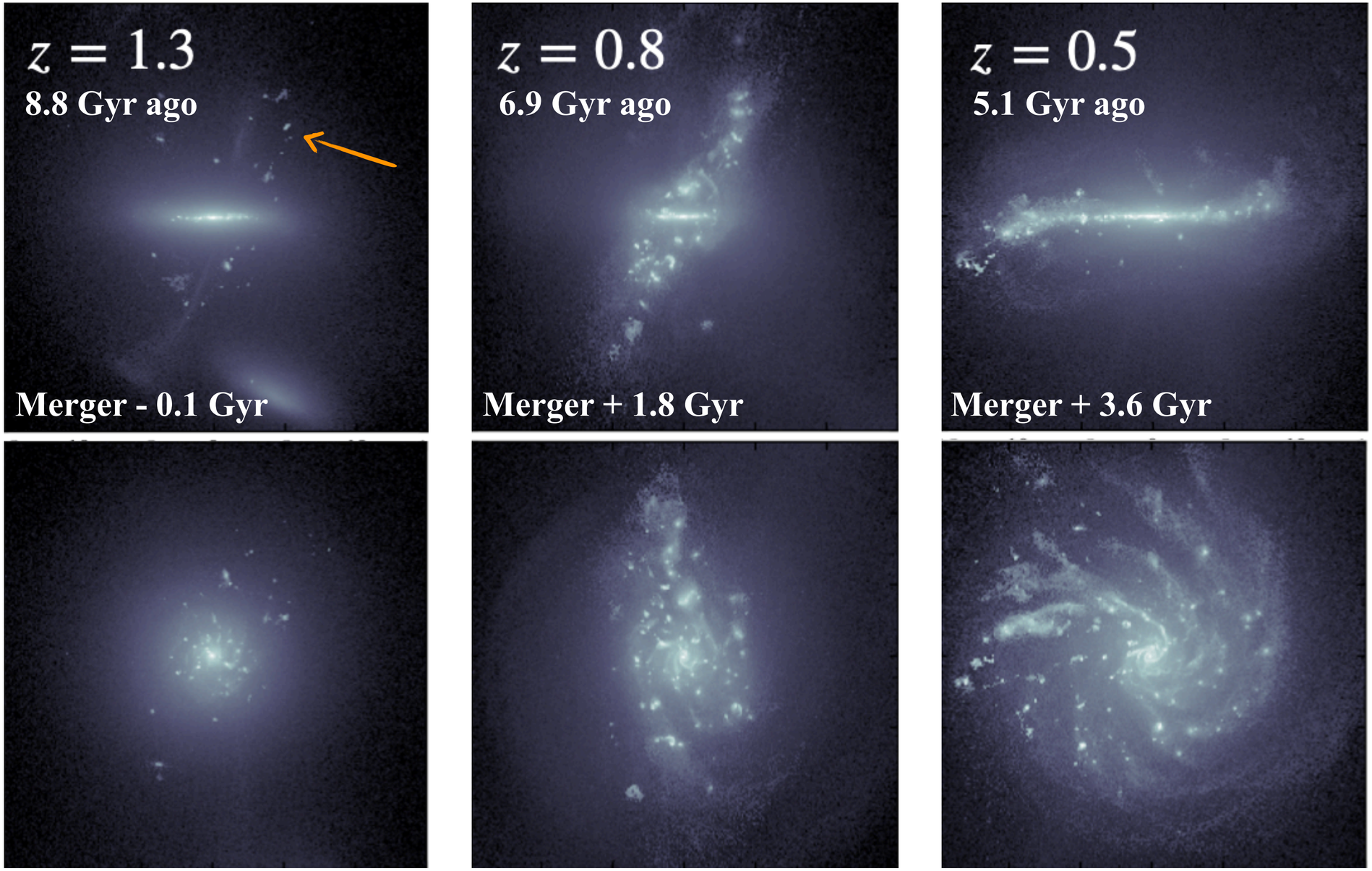
inner disk
edge-on

inner disk
face-on



INSIDE-OUT FORMATION

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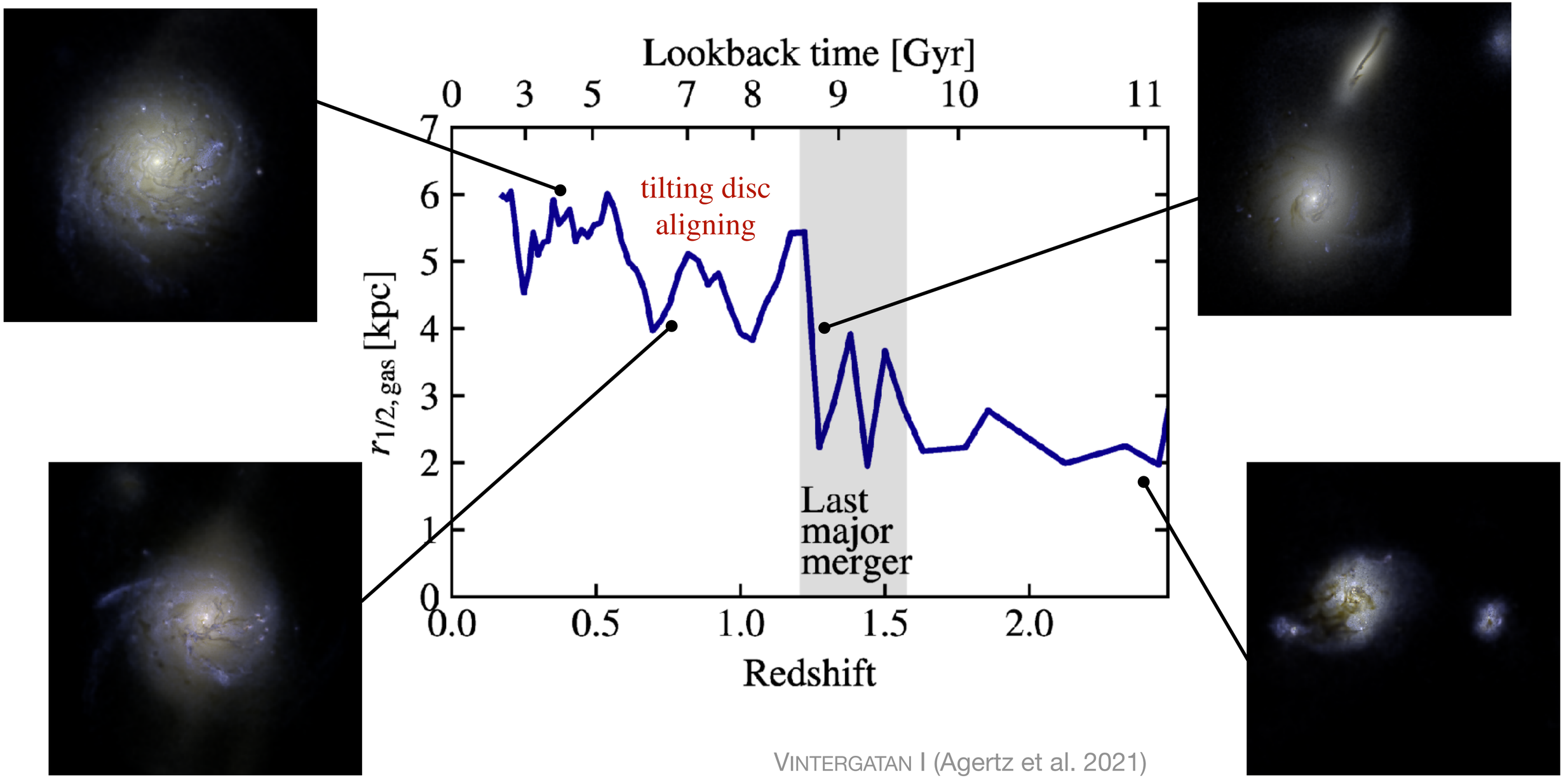


VINTERGATAN I (Agertz et al. 2021)

DETECTABLE?

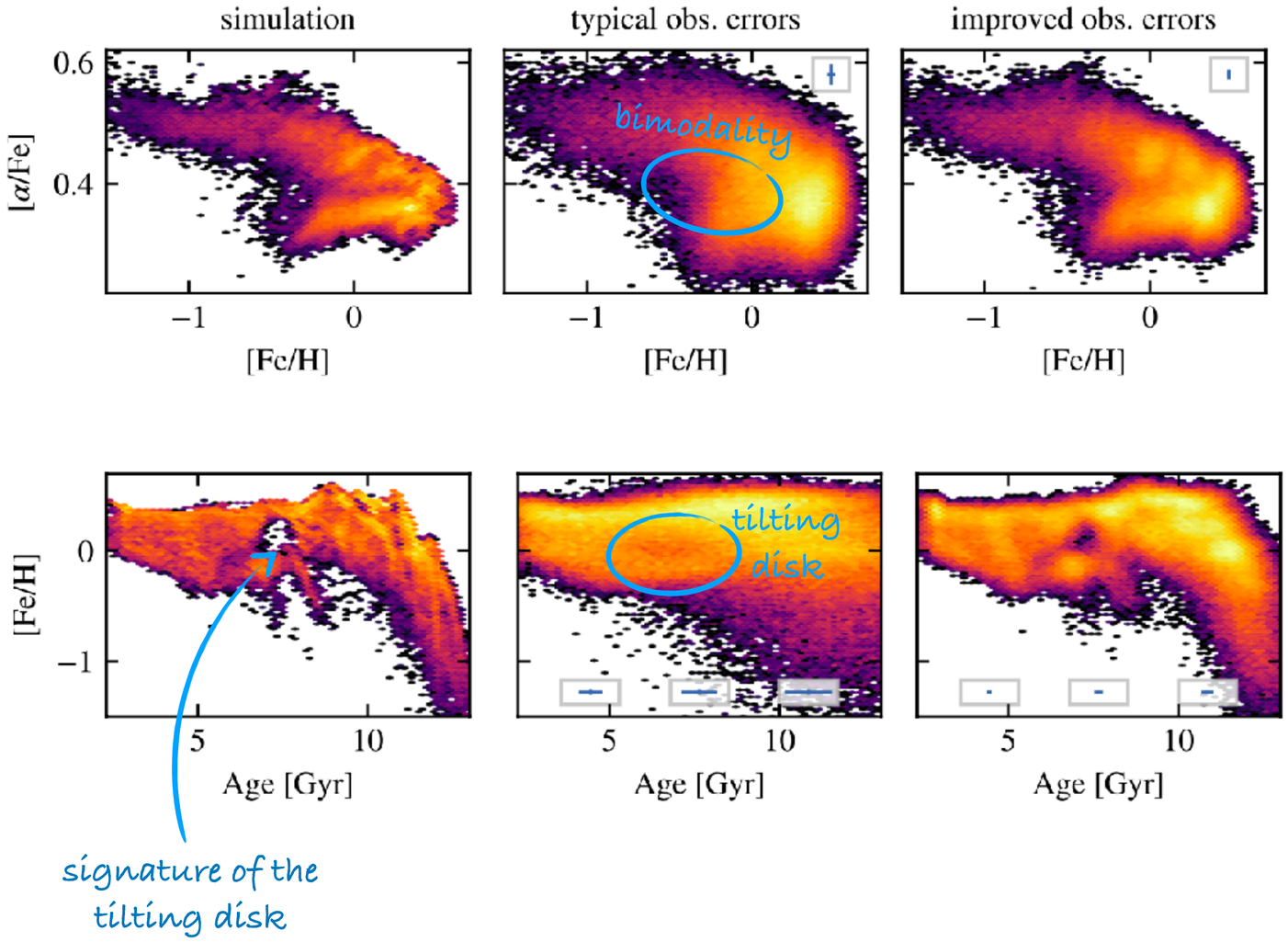
Typical errors (APOGEE-like)
age is the most critical
(Nidever et al. 2014, Feuillet et al. 2016)

General trends and most prominent features are visible

Much better with future generations of instruments
(e.g. large asteroseismology surveys)
(Rauer et al. 2014, de Jong et al. 2019)

Possible to test *details* in scenarios
(time-line, intensity of events etc.)

→ constraints on the time-evolution of the "local" cosmic web



DETECTED!

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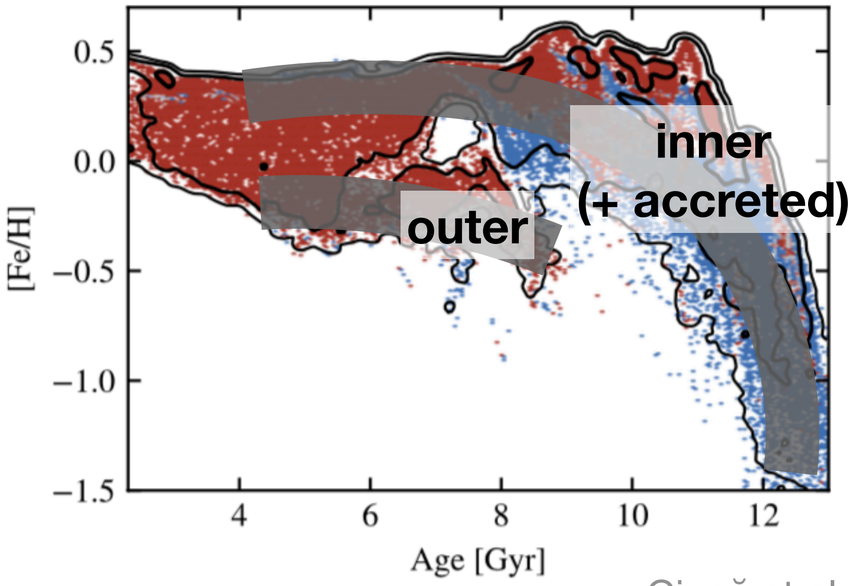
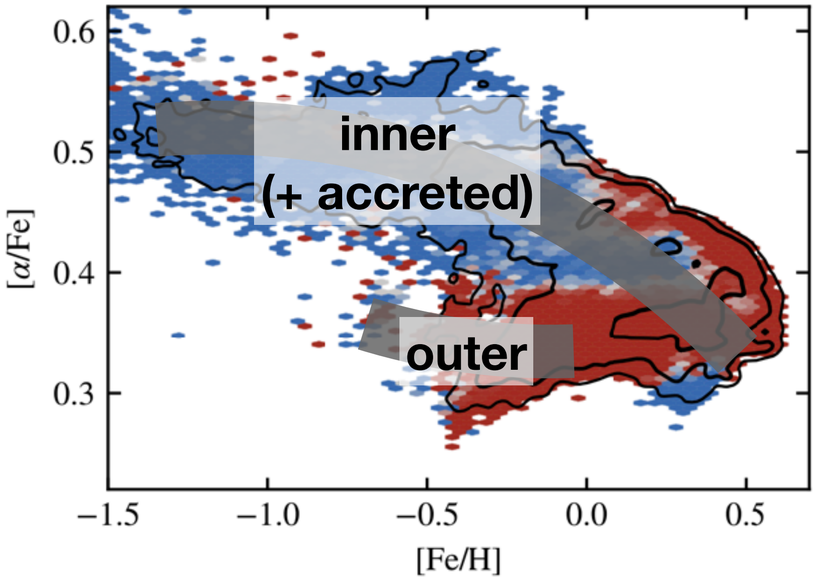
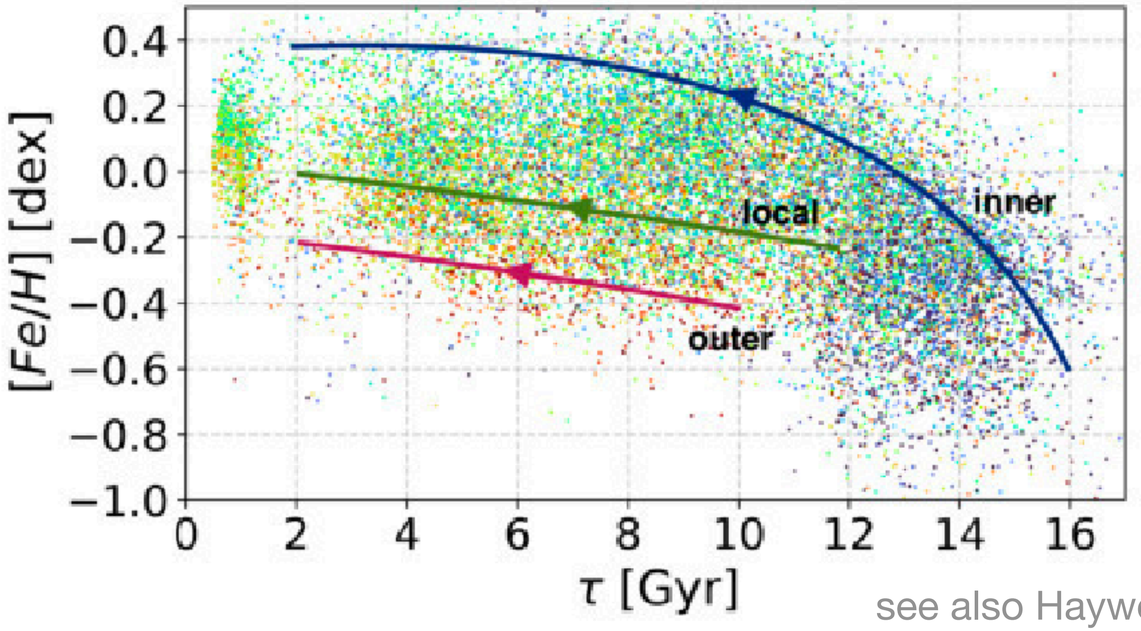
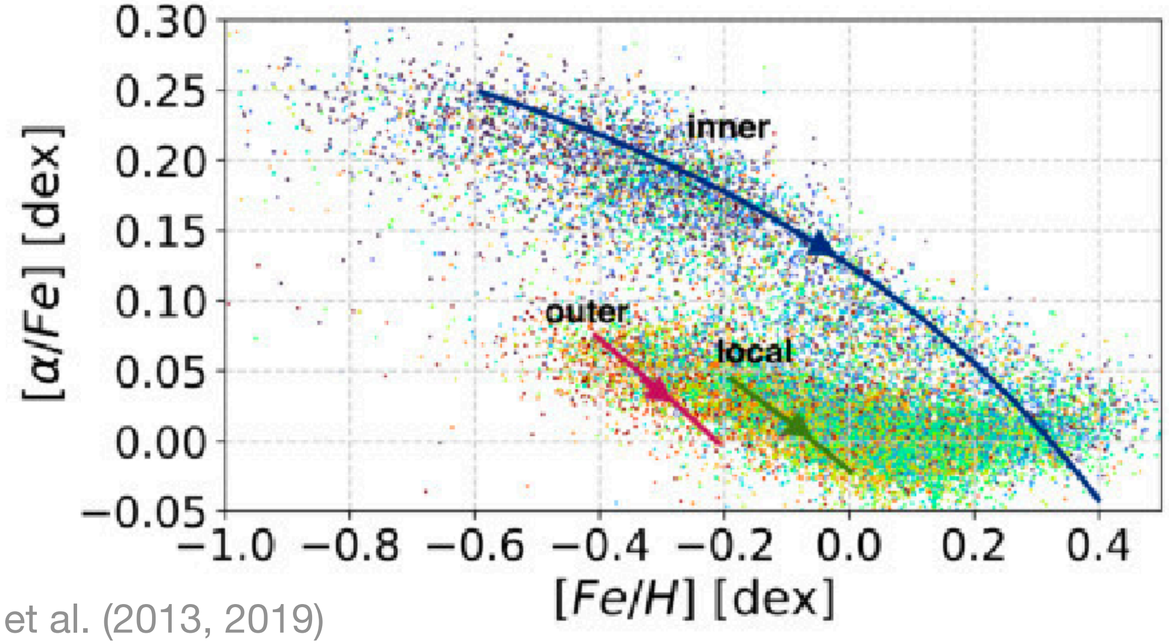




Ciucă et al. (2020)





see also Haywood et al. (2013, 2019)

CONCLUSIONS

For more details: *Vintergatan III* (Renaud et al. 2021b)

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The connection to the cosmic web influences the morphology and chemistry of the outer galaxy

The last major merger ignites star formation in the outer, tilted disc, at low metallicity

Different filaments build-up different parts of the "final" disk, in a detectable manner

The stellar build-up of the galaxy happens through *multiple* simultaneous channels

This could be a generic feature of disk galaxy formation...