The history of the Milky Way told by its mergers

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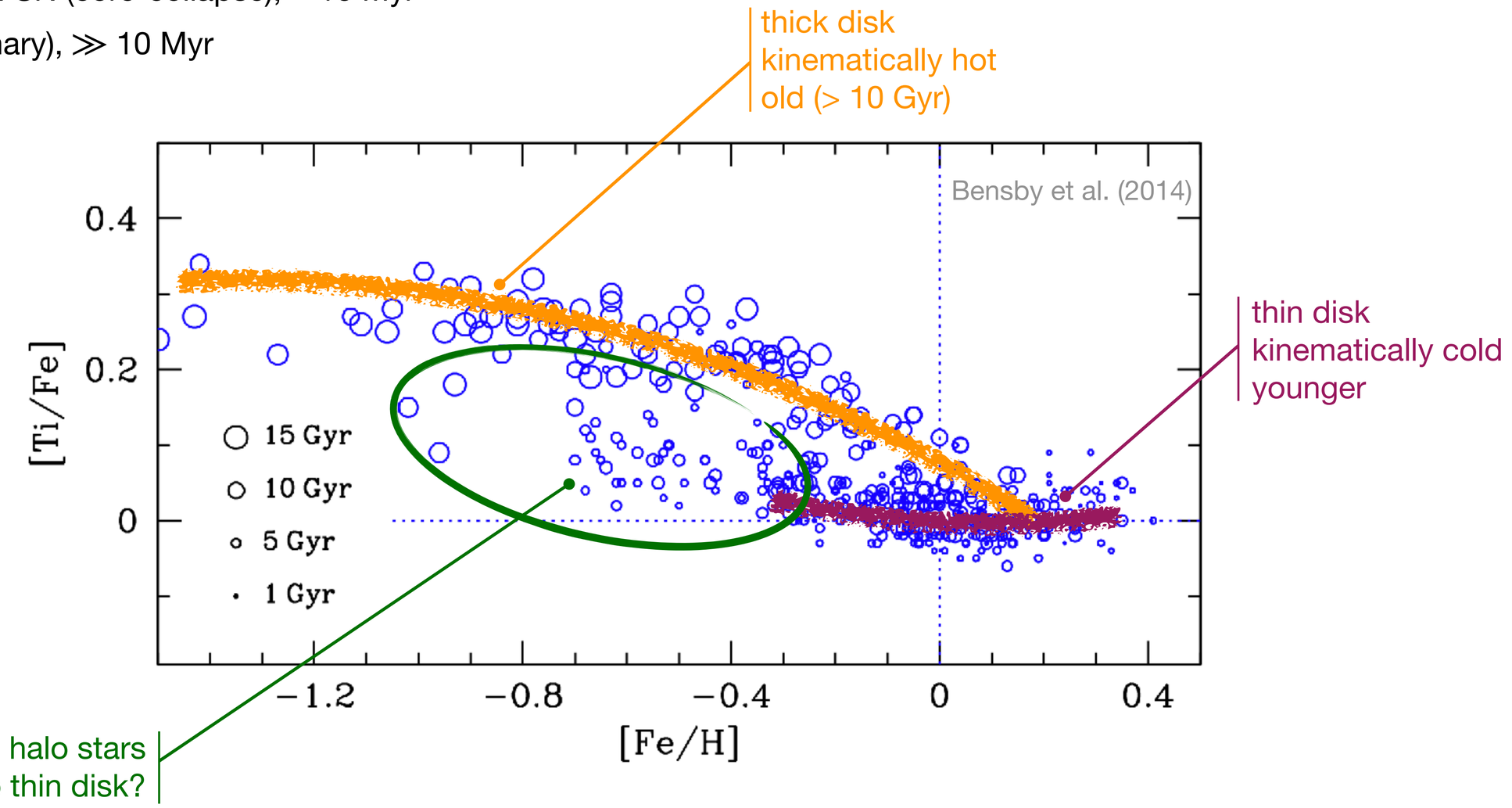
Knut and Alice Wallenberg Foundation

THE [α/Fe]-[Fe/H] PLOT

α elements ~ type II SN (core-collapse), ~ 10 Myr

Fe ~ type Ia SN (binary), $\gg$ 10 Myr



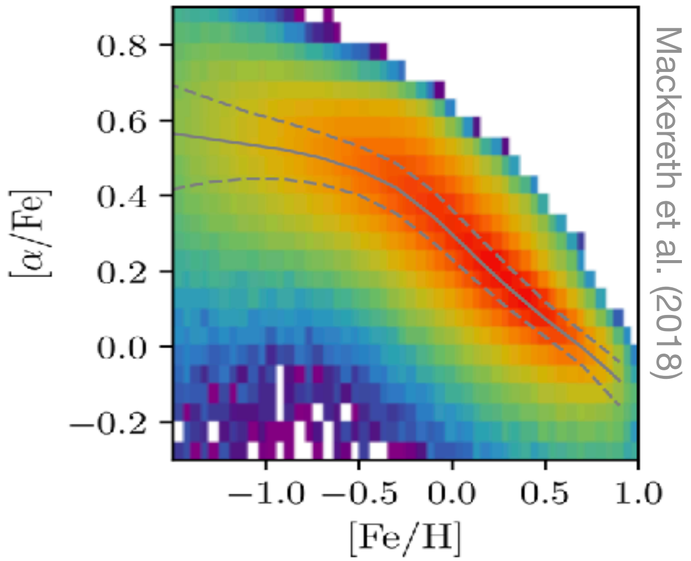
See also Recio-Blanco et al. 2014, Hayden et al. 2015, Nidever et al. 2015, Bovy et al. 2016, Rojas-Arriagada et al. 2017, Silva-Aguirre et al. 2018, Haywood et al. 2018, Hayden et al. 2019, Feuillet et al. 2019, Di Mateo et al. 2019 and many others

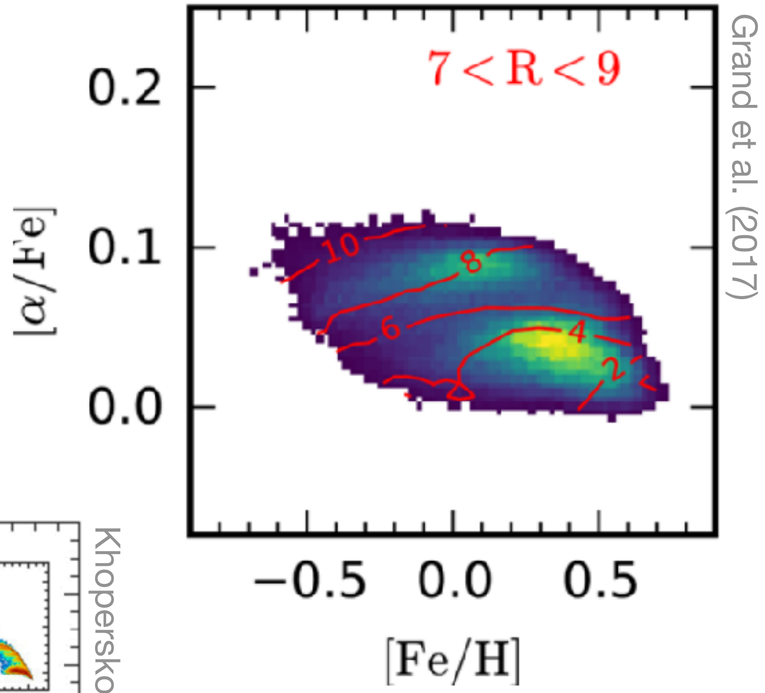
No consensus from the simulations

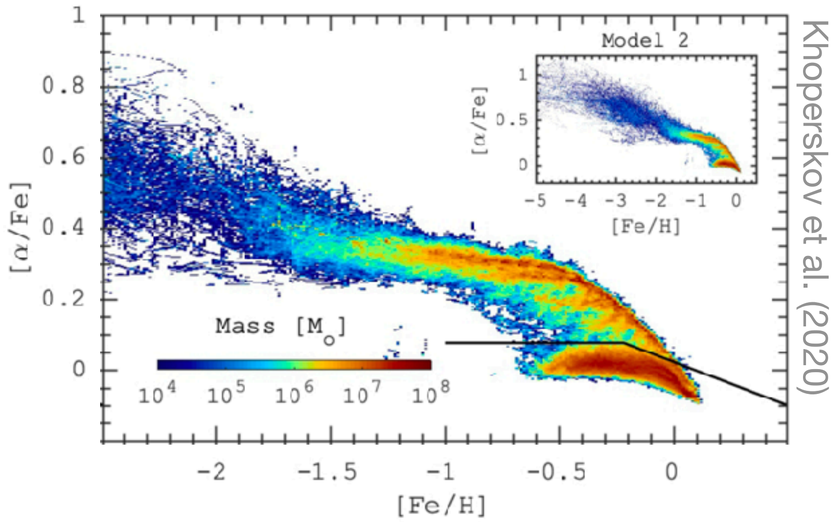
- No (or rare) bimodality
  e.g. Ma et al. (2017), Mackereth et al. (2018)

- Bimodality
  explained by 2 episodes
  of gas accretion
  e.g. Brook et al. (2012), Grand et al. (2017)

- Bimodality, without cosmo,
  explained by intrinsic evolution
  of the star formation regime
  e.g. Clarke et al. (2019), Khoperskov et al. (2020)







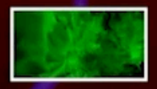
See also models from Snaith et al. 2015, Haywood et al. 2016, Côté et al. 2017, Rybizki et al. 2017, Prantzos et al. 2018, Grisoni et al. 2018 and many others

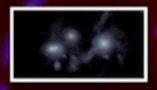
VINTERGATAN

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

MILKY WAY

UV heating
atomic + molecular cooling
fixed SFE per free-fall time
winds, radiative pressure, SN-II, SN-Ia
(Agertz et al. 2013)


IRON


STARS


GAS


DARK MATTER

Z = 6

12.9 GYR AGO

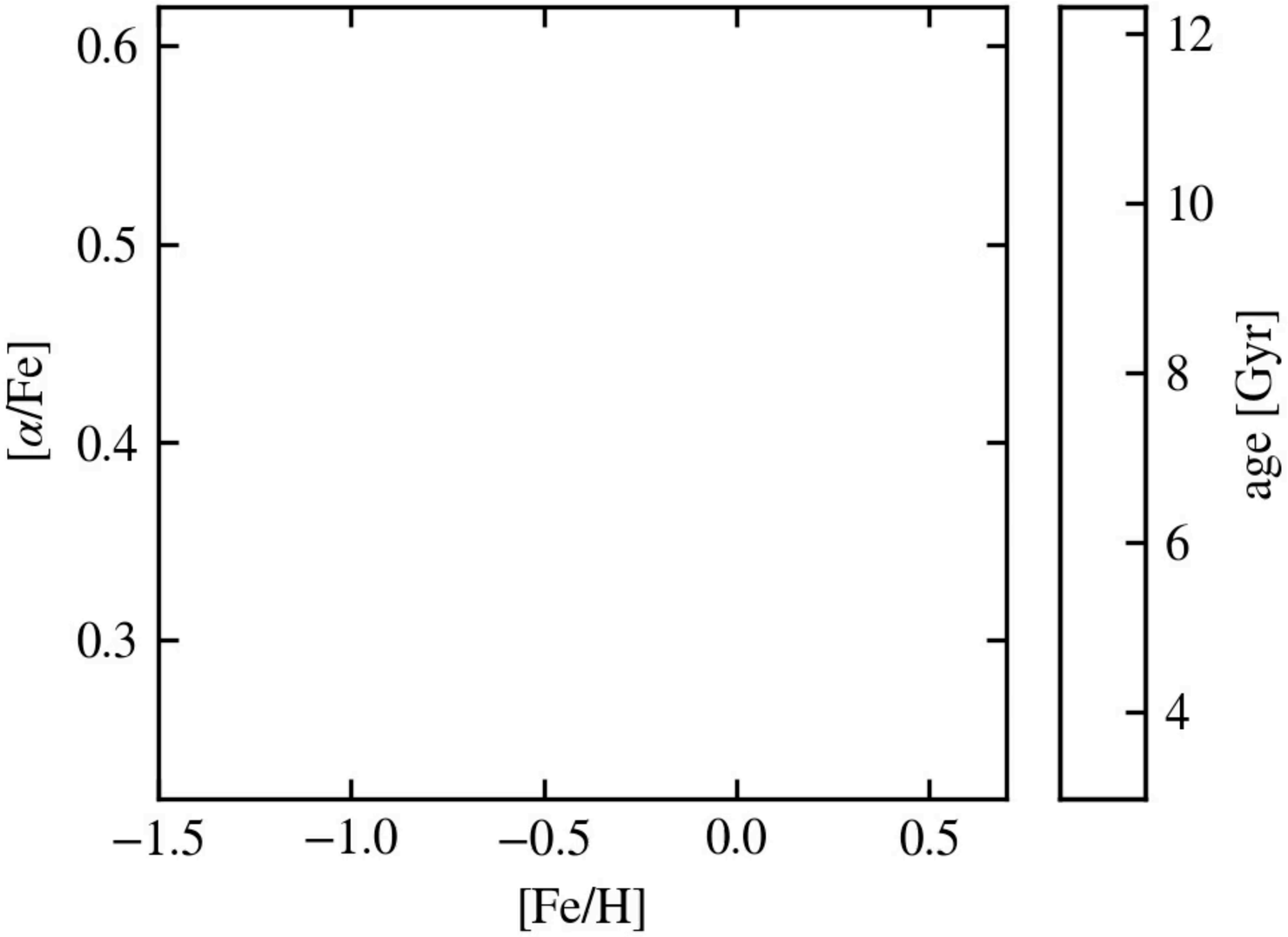
Bimodality? Yes!

In VINTERGATAN, α = Oxygen

Uncertainties on the yields, solar-abundances, binary fractions, SN-Ia rates etc.

$[\mathrm{Fe/H}]$ is ~OK
$[\alpha/\mathrm{Fe}]$ is too high

Bimodality arises at z~1
shortly after the epoch of
the last major merger



THE EFFECTS OF STARBURSTS

Starbursts = short depletion time $t_{\rm dep} = \frac{M_{\rm gas}}{\rm SFR}$

Short timescale of star formation

Faster than the enrichment in Fe

α increases, Fe ~ constant

→ Starbursts temporarily boost $[\alpha/\mathrm{Fe}]$

End of merger phase:

no more tidal excitation (lower turbulence)

→ no more starbursts

= no more boosted $[\alpha/\mathrm{Fe}]$

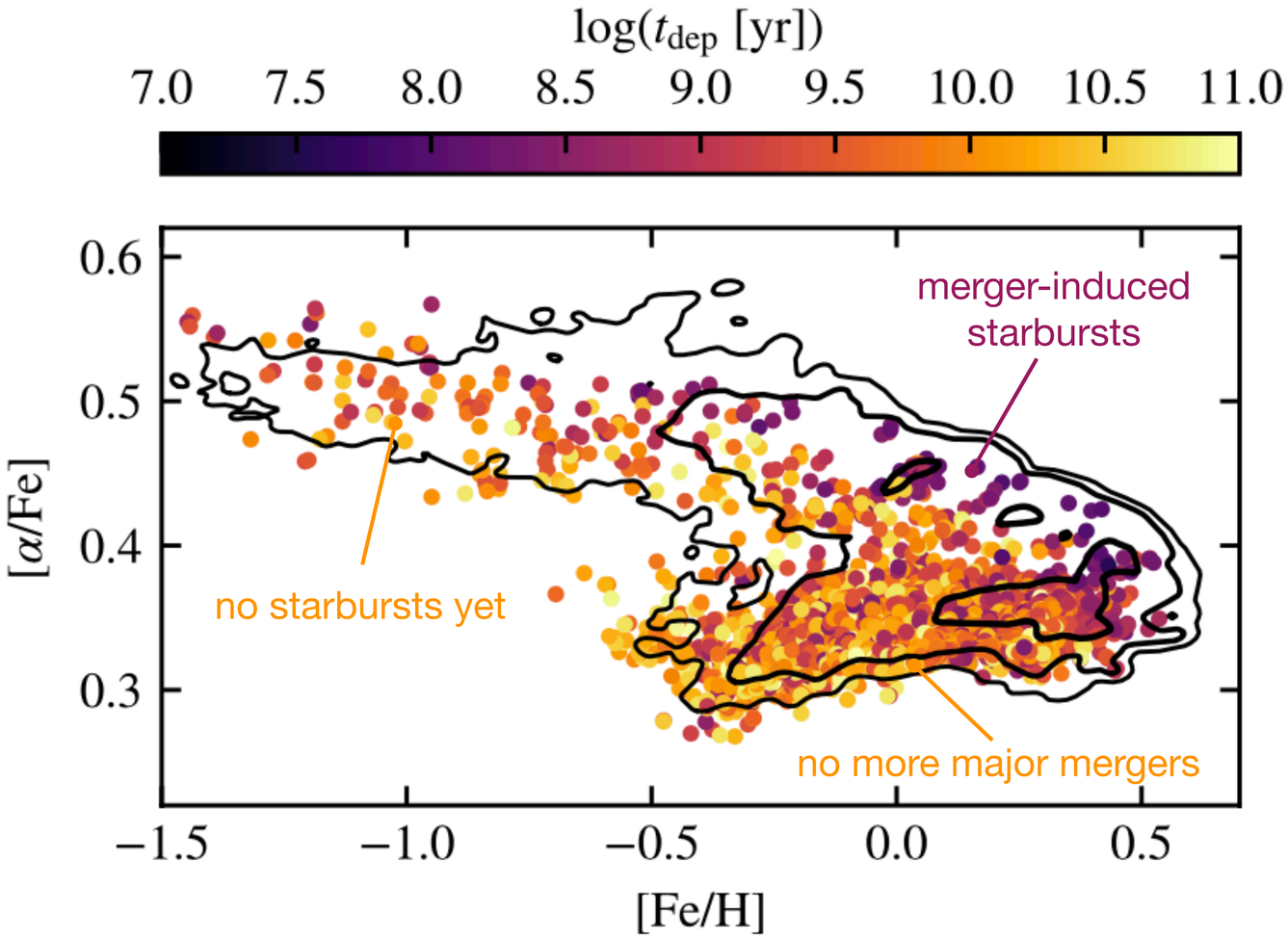
Decrease of the gas fraction:

change in the stability regime (Renaud et al. 2021c)

→ end of the clumpy phase → spirals

= less turbulence, colder disk etc.

Change of regime due to external AND internal factors

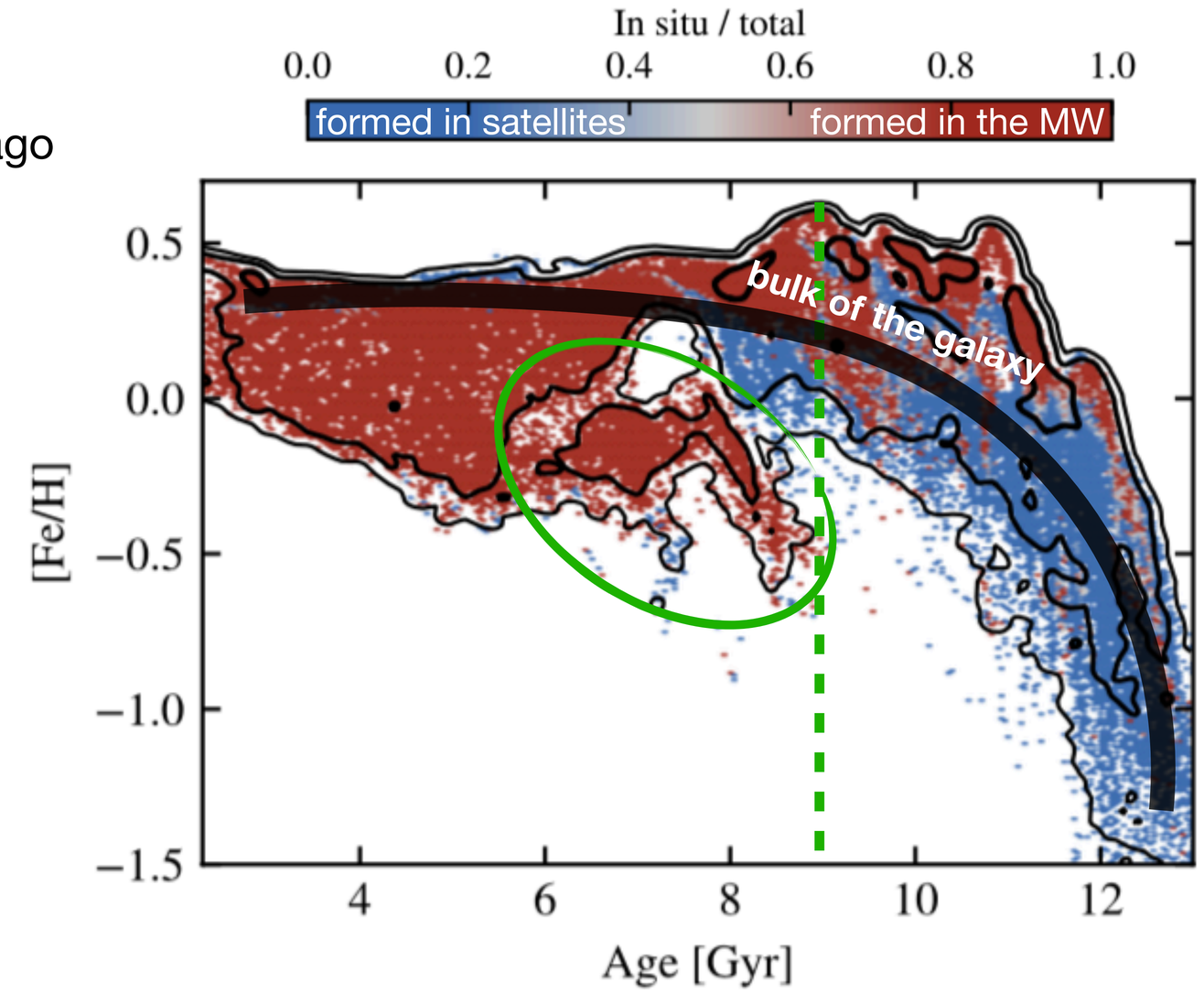


see Alvaro's talk next

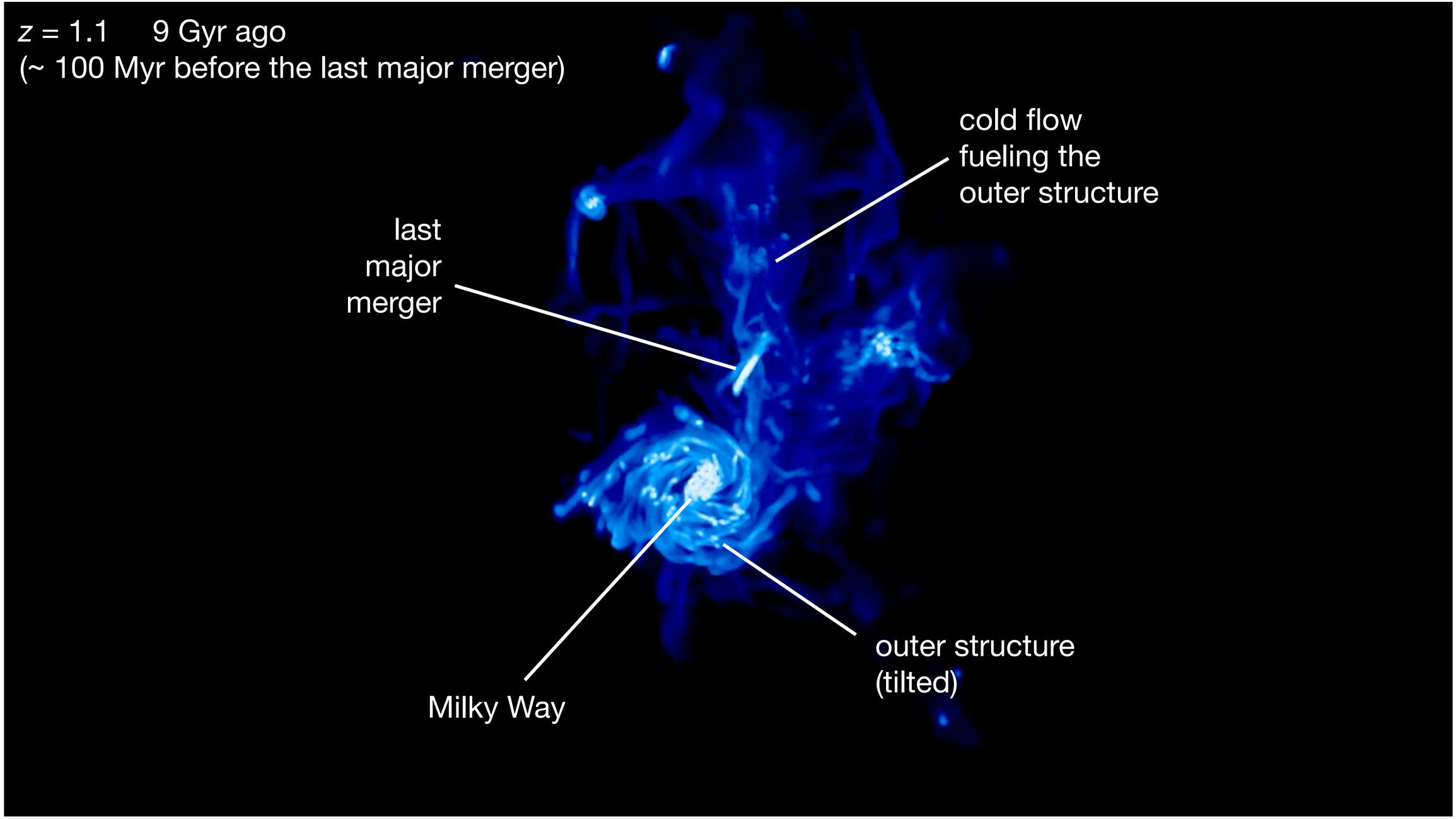
Ignition of a second star formation channel

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

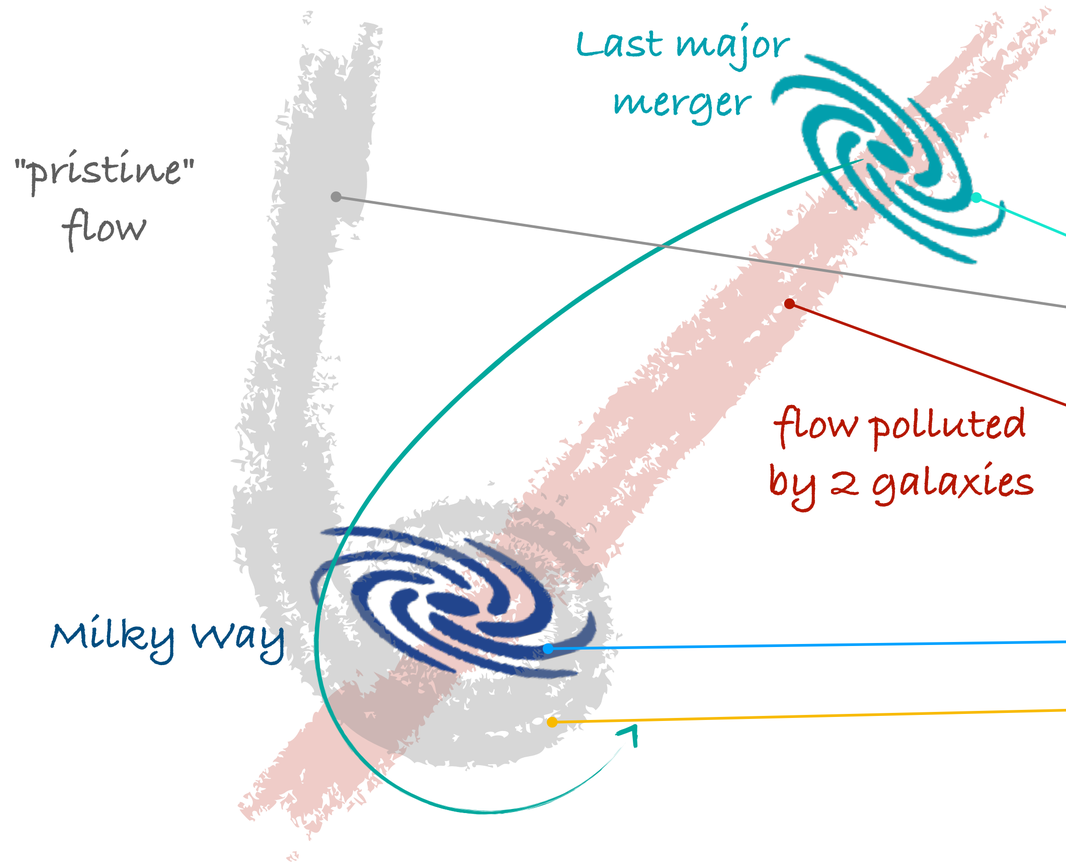
- Lower metallicity
- At the epoch of the last major merger
- But not as accreted stars
- Connects to the rest of the disk

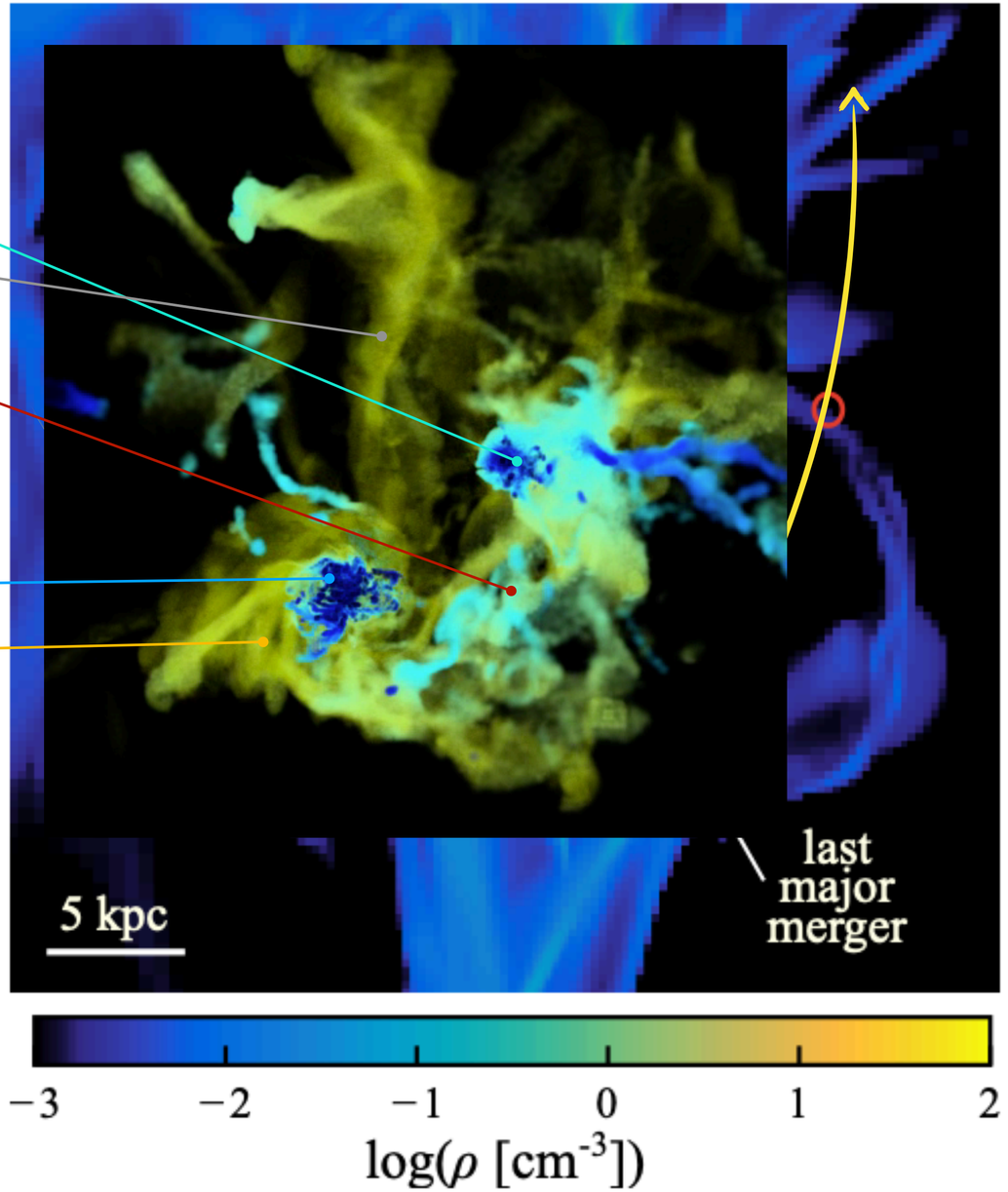


CHEMICAL BIMODALITY OF COSMOLOGICAL ORIGIN



INDIRECT EFFECT OF THE LAST MAJOR MERGER



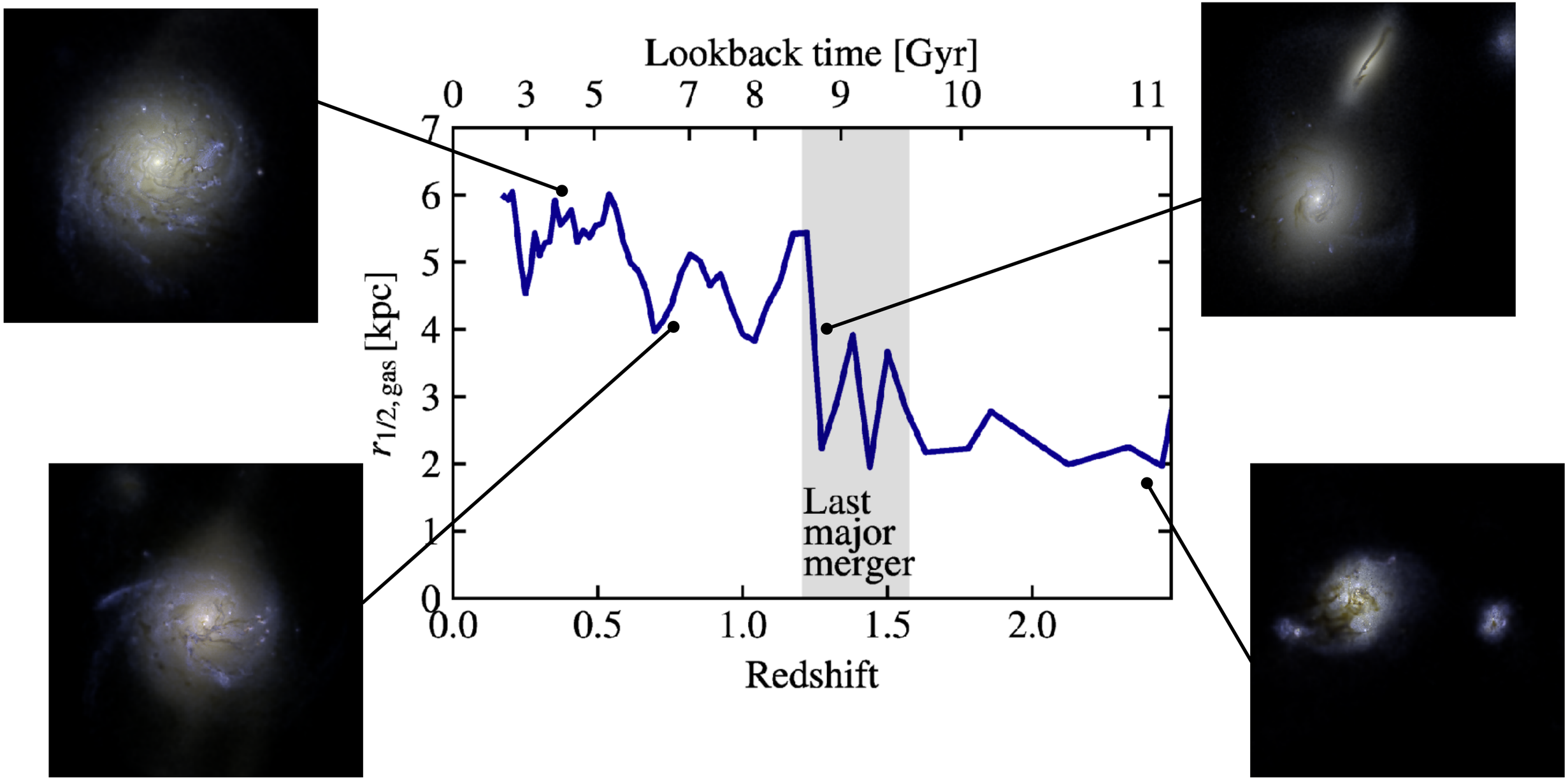


This scenario only requires 2 cosmic filaments

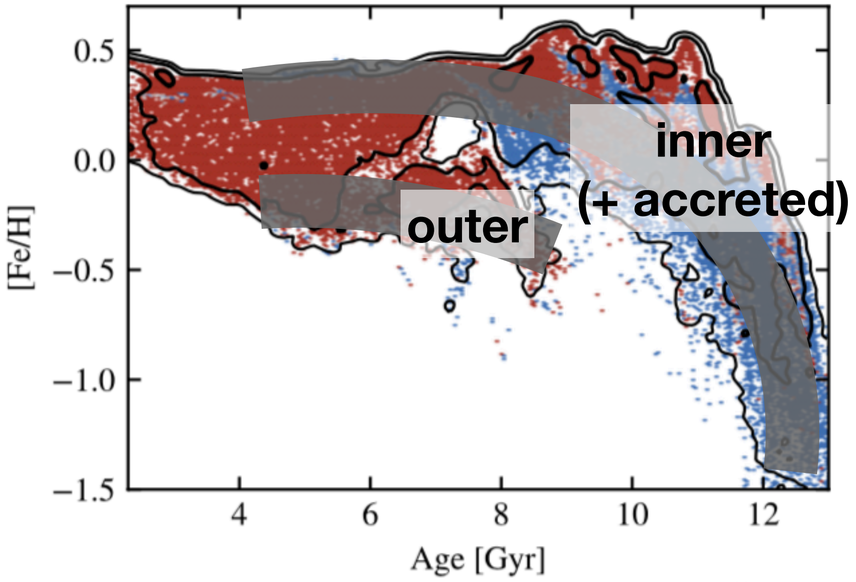
The major merger does the rest!

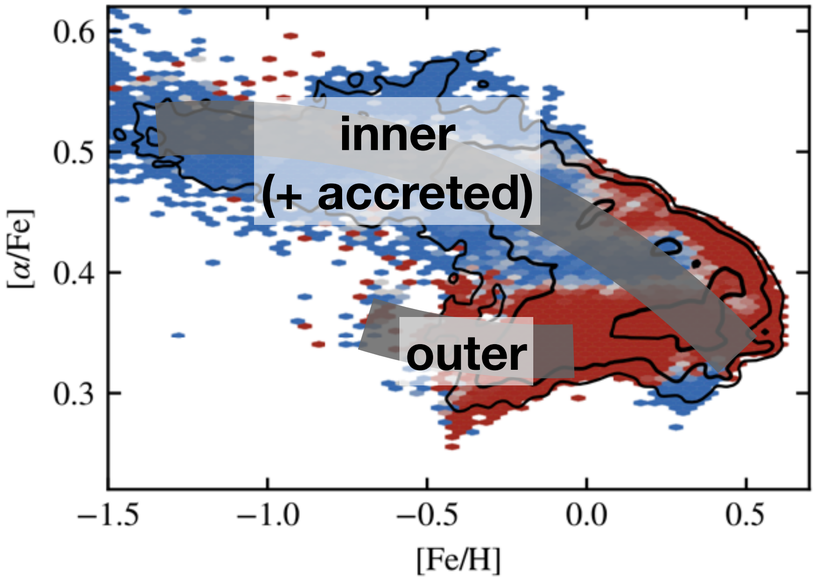
Commonly seen in large-volume cosmo simulations
(Khoperskov et al. 2021)

Inside-out formation

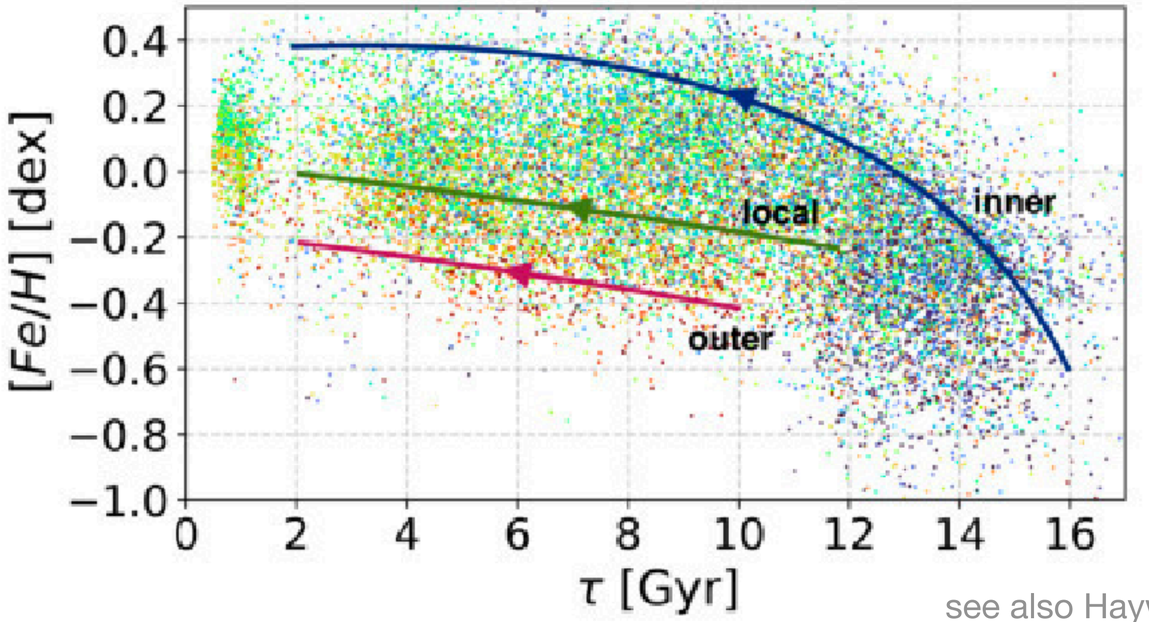


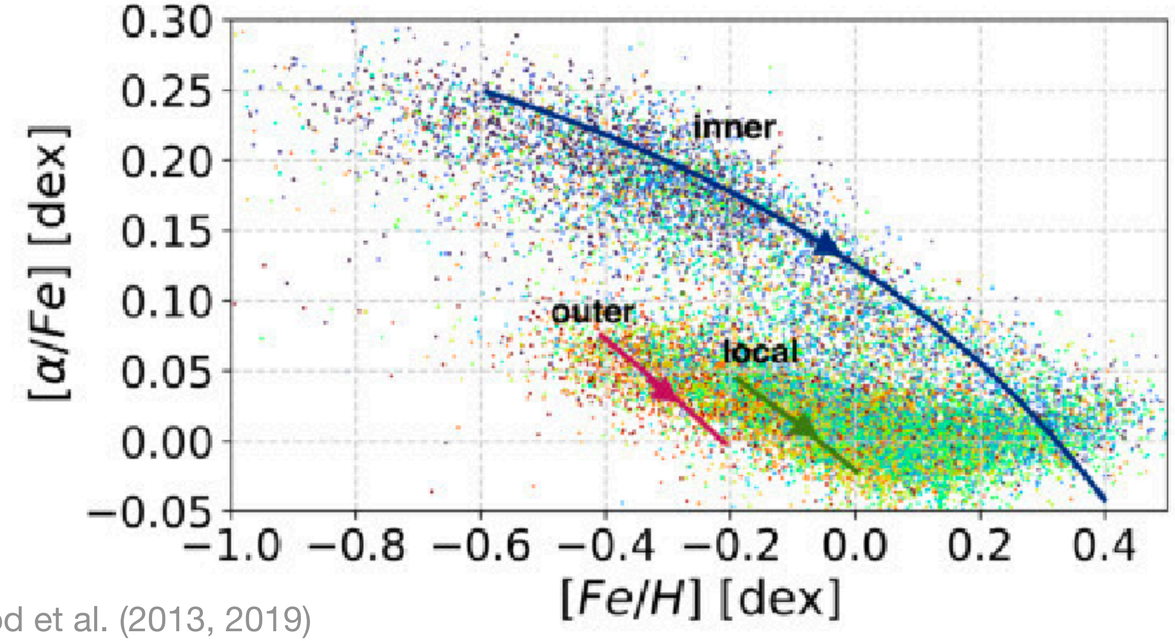
Confirmed by observations?





Ciucă et al. (2020)

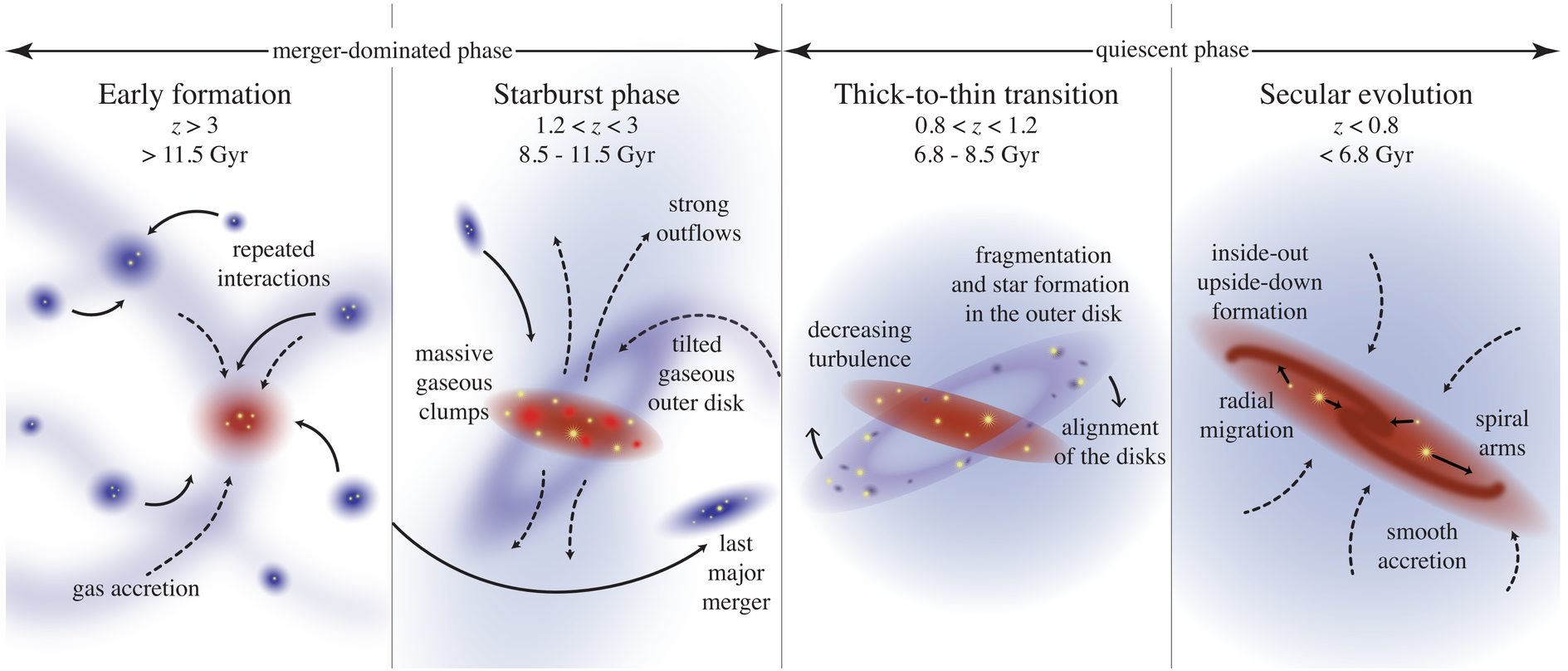




see also Haywood et al. (2013, 2019)

Conclusion: Toward a formation scenario for the Milky Way

see Section 5 of VINTERGATAN II



Movies, download etc:
www.astro.lu.se/~florent/vintergatan.php

For more information:

VINTERGATAN I
(Agertz et al. 2021)

- simulation details
- formation of disks
- radial migration

VINTERGATAN II
(Renaud et al. 2021a)

- mergers & starbursts
- in situ vs. accreted
- full scenario

VINTERGATAN III
(Renaud et al. 2021b)

- tilting disk scenario