High-redshift major mergers weakly enhance star formation

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Collaborators: F. Renaud & F. Bournaud

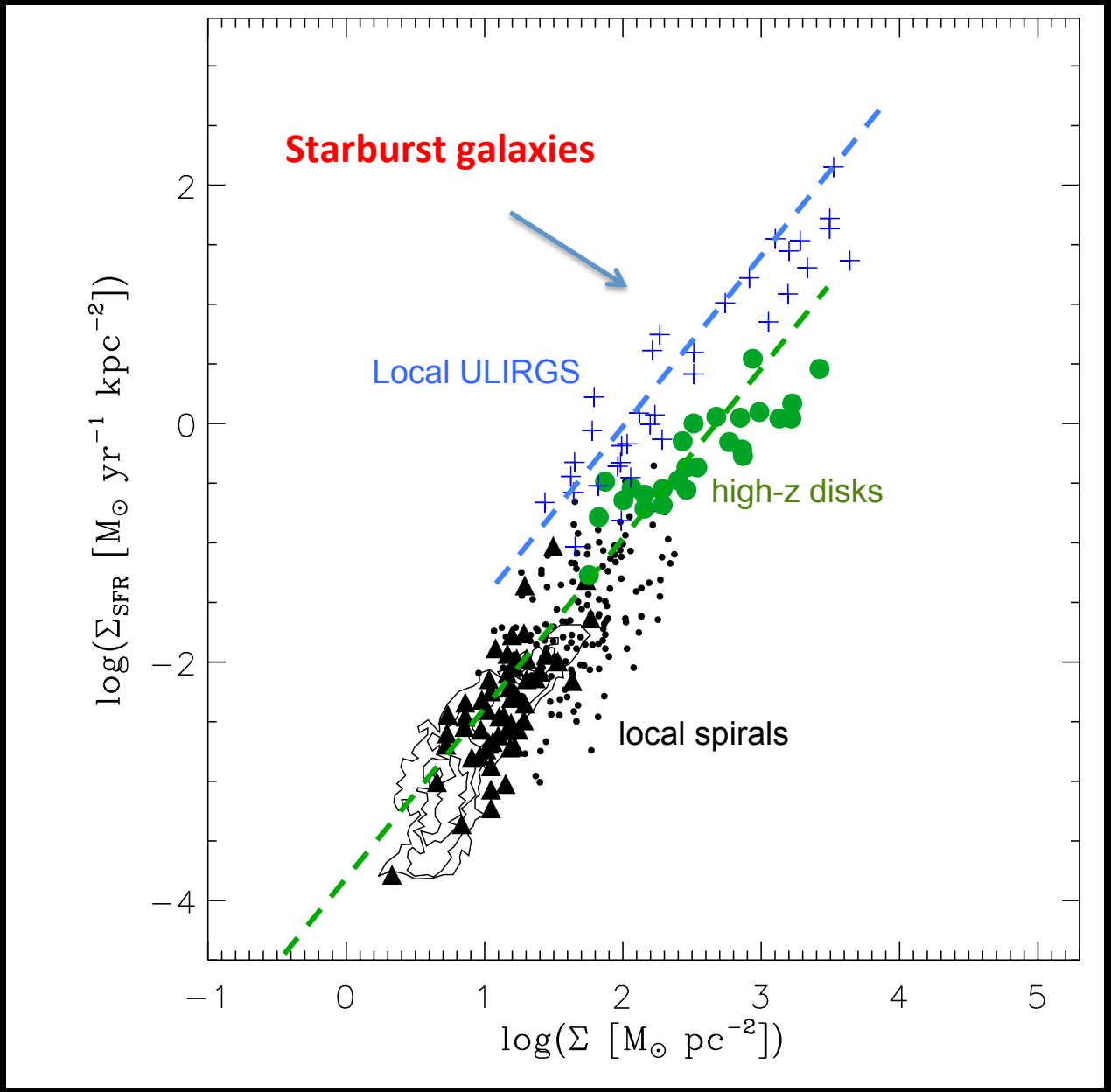
Context

We know that ***local*** major mergers trigger galaxy starbursts

Hubble Heritage

Is it also true at high-redshift ?

What do I call a starburst galaxy?



Local Spirals:

- Kennicutt+98
- Kennicutt+07
- Bigiel+08

High-z disks:

- Tacconi+10, +13
- Daddi+10a
- Freundlich+13

Renaud+12
Daddi+10b
Genzel+10

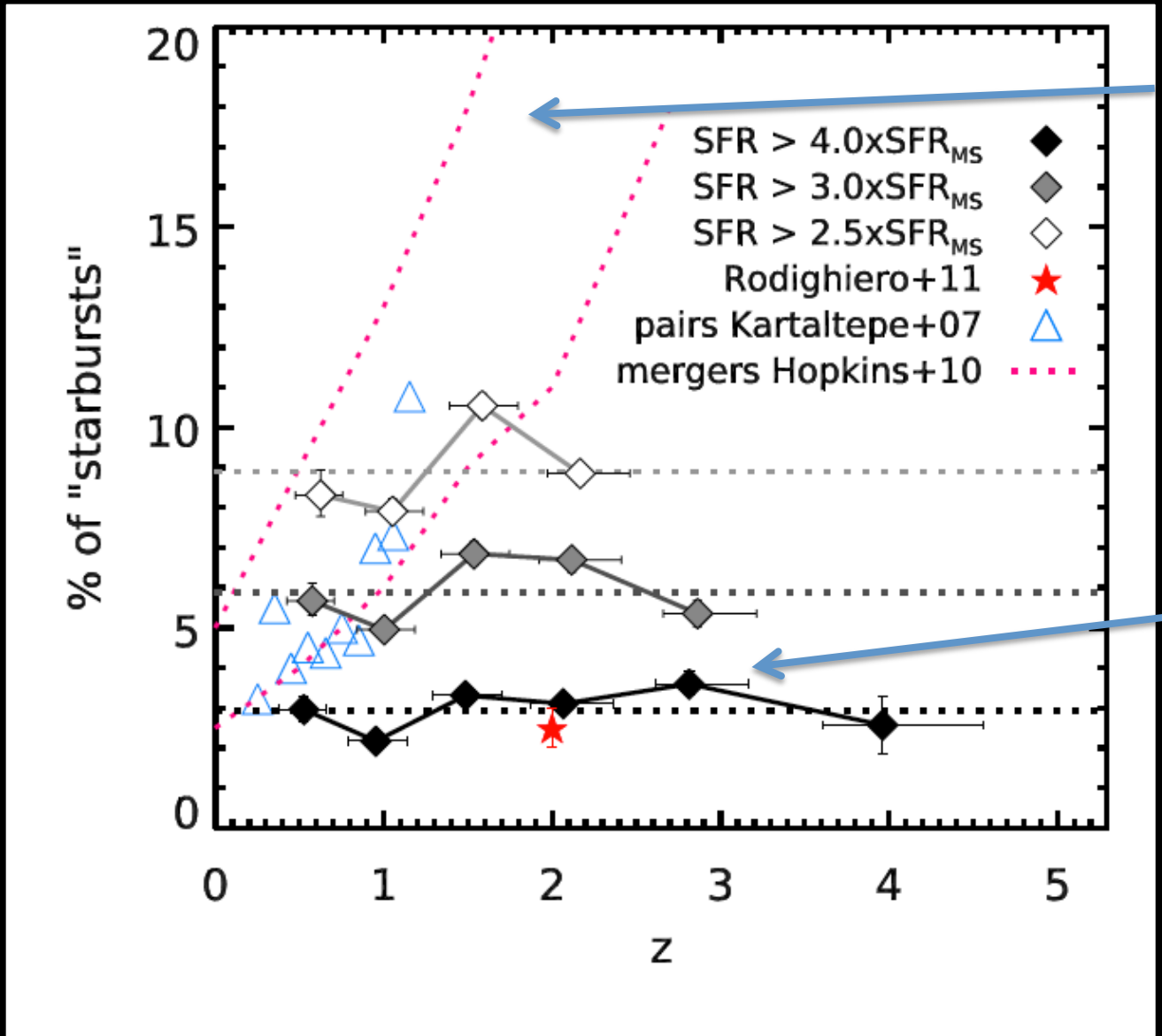
Local Universe Starbursts

They all show signs of interactions : LOCAL starburst <-> major merger

See review by Sanders&Mirabel 1996

Guo et al., 2016

Constant number of starbursts over cosmic time

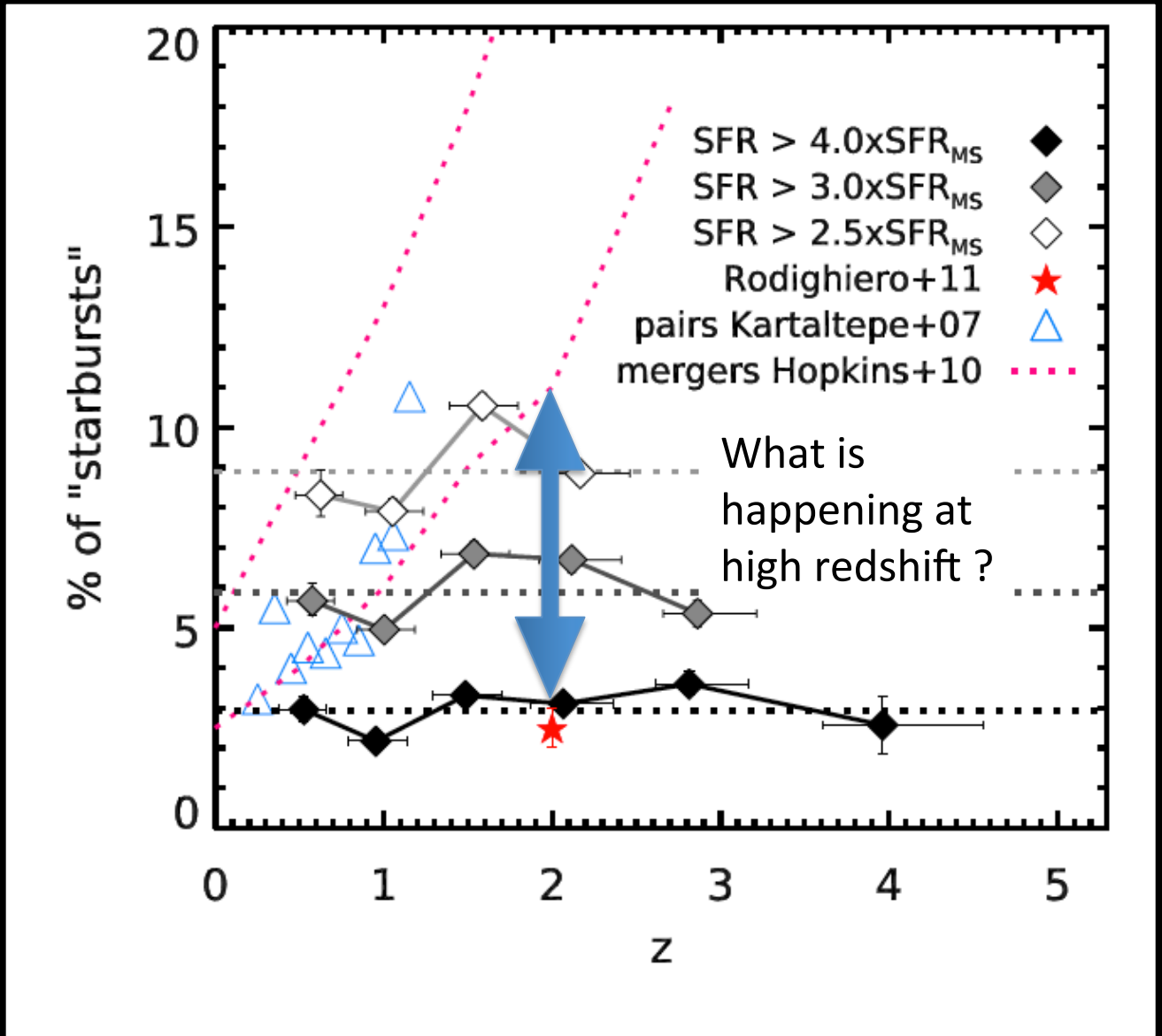


Number of mergers with redshift

Fraction of starbursts stays constant ….

Schreiber+15
See also Rodighiero+11 and Lofthouse+16

Constant number of starbursts over cosmic time



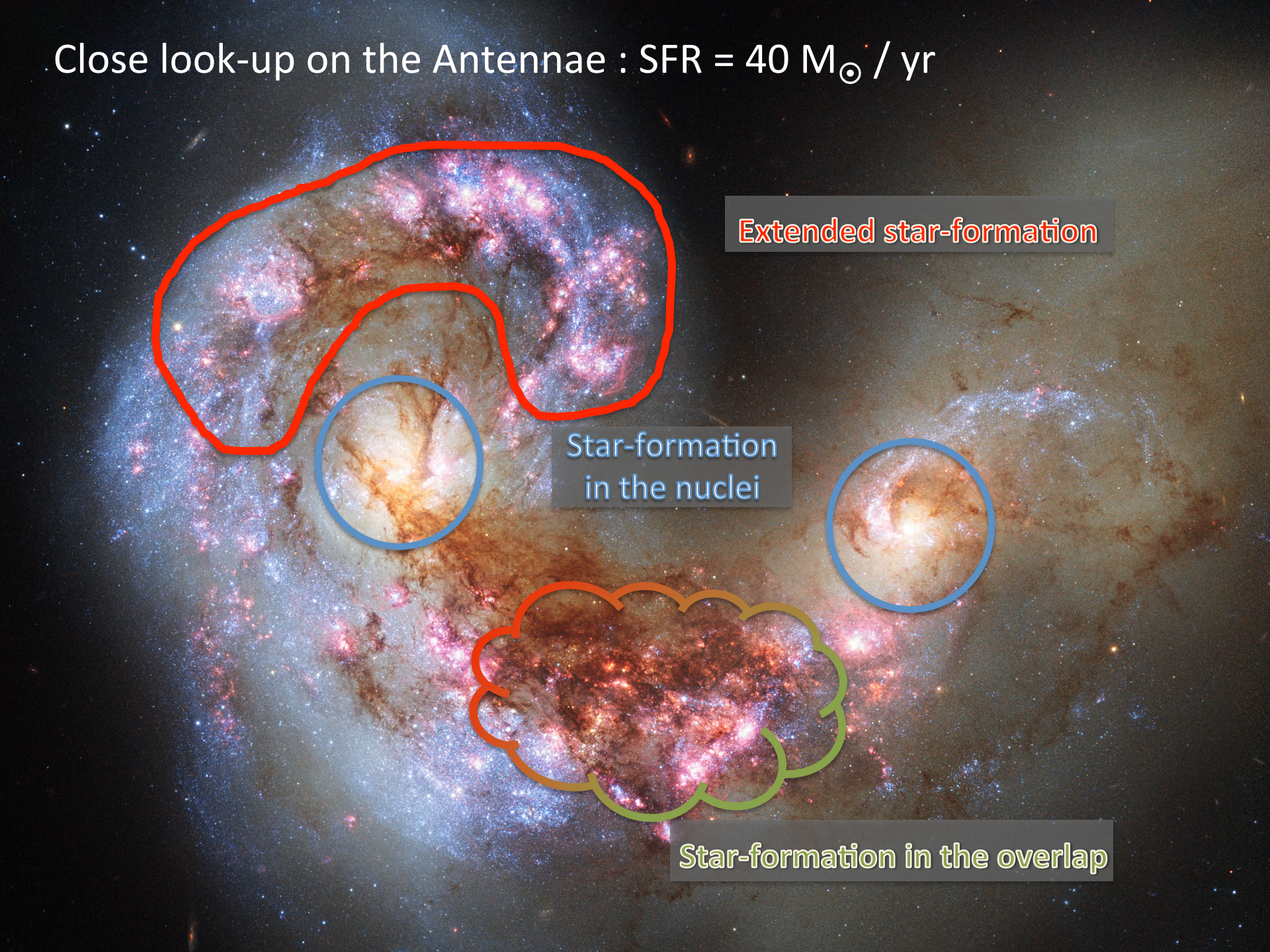
Schreiber+15
See also Rodighiero+11 and Lofthouse+16

Outline

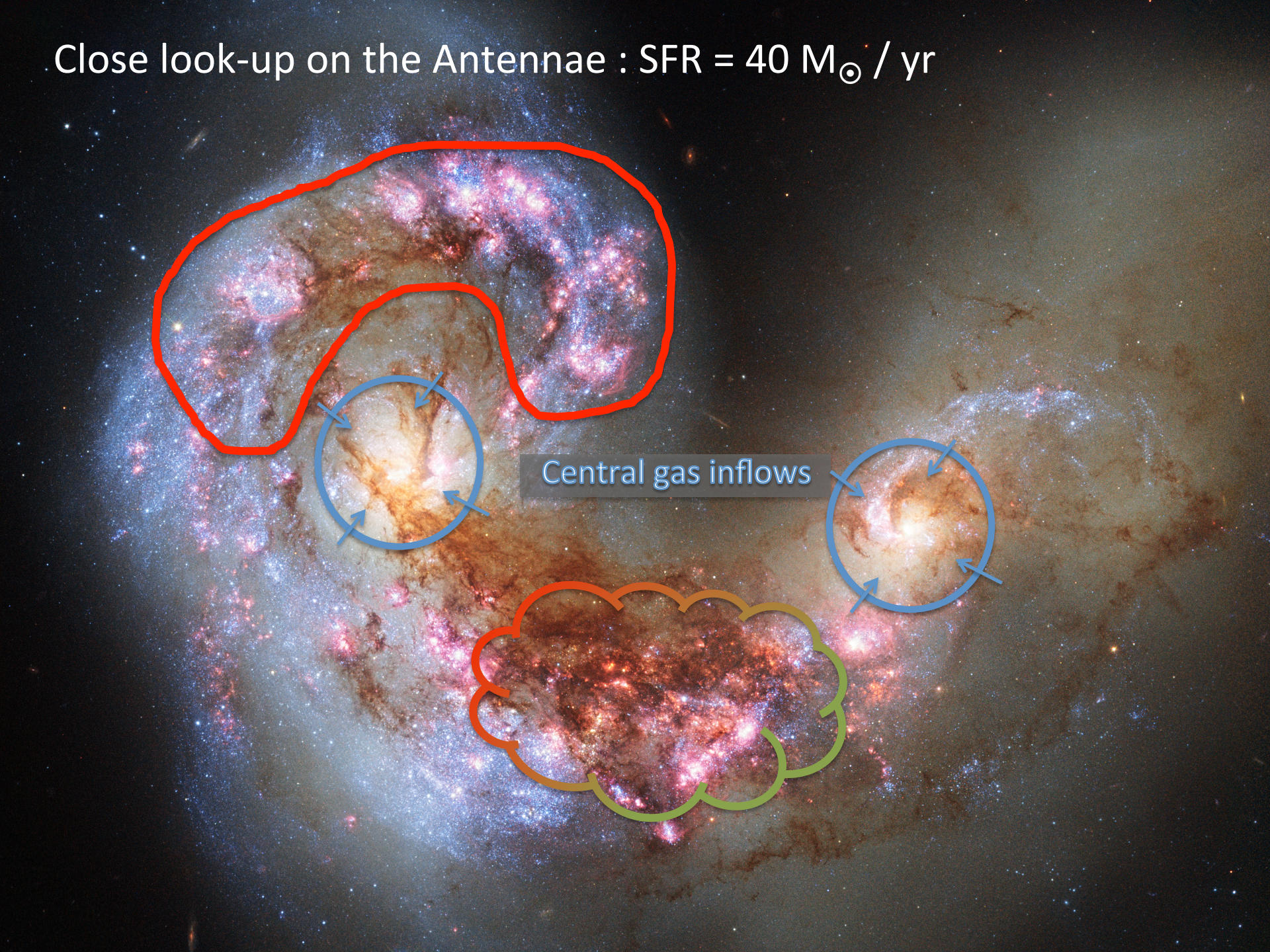
1/ Star formation bursts in local mergers

2/ Going to high-redshift

Close look-up on the Antennae : SFR = 40 $M_{\odot}$ / yr

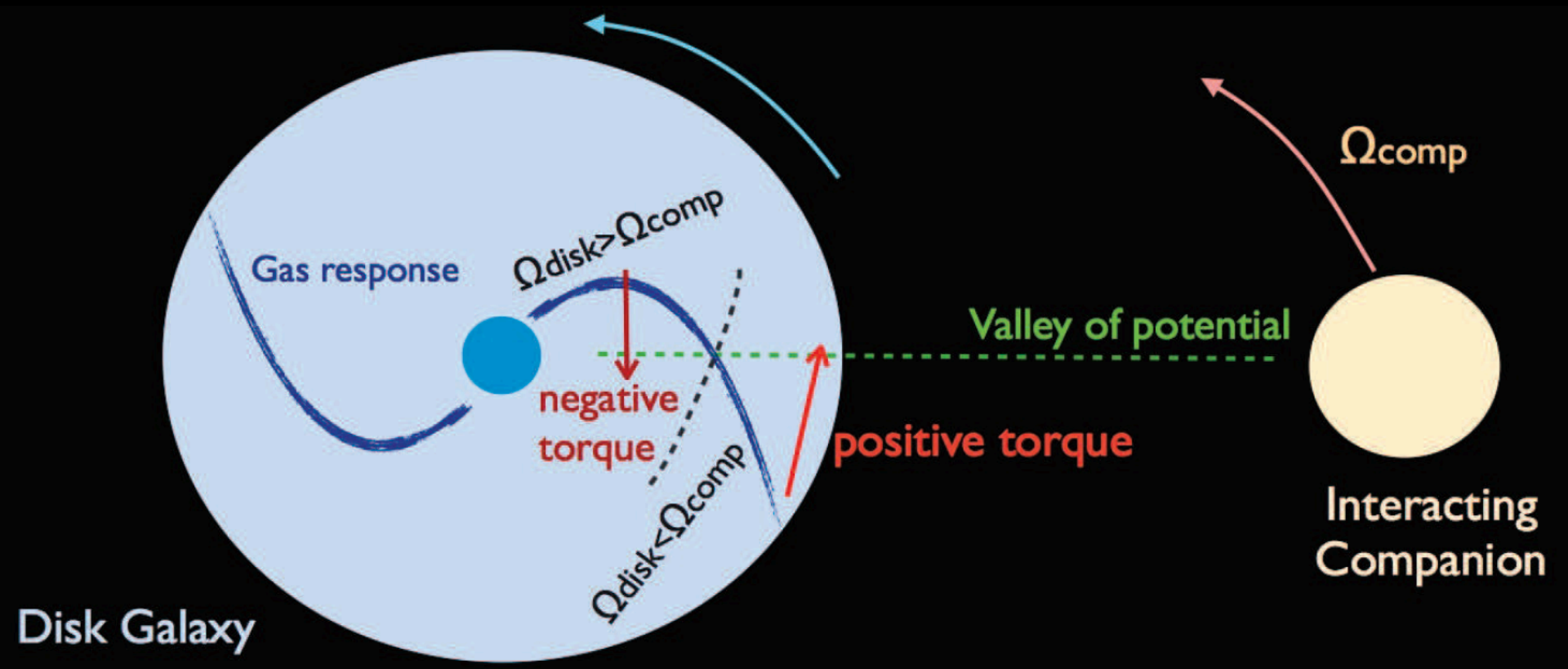


Close look-up on the Antennae : SFR = 40 $M_{\odot}$ / yr



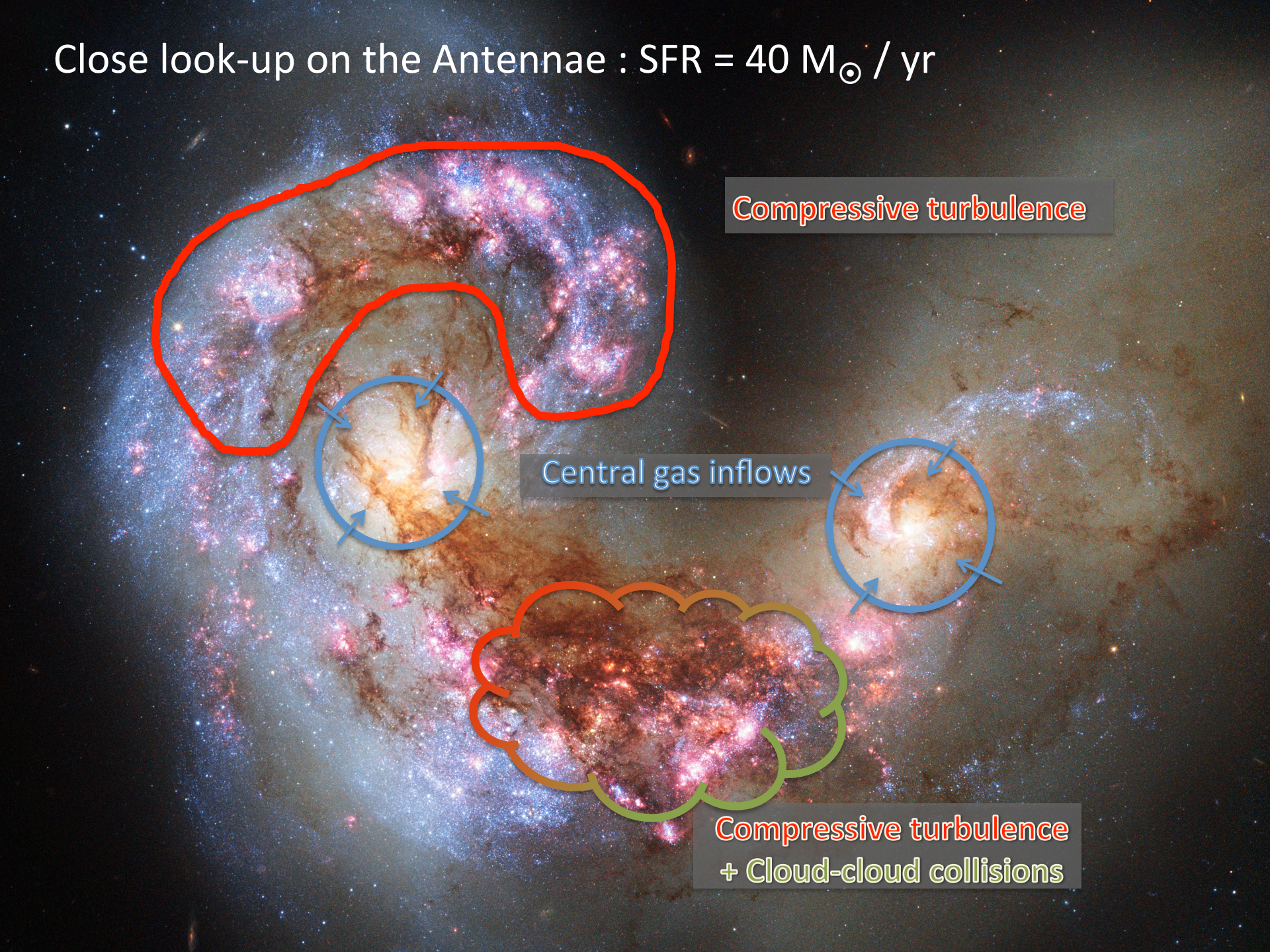
Physical processes

1/ Gas inflows increase



See Barnes & Hernquist 1991; Mihos & Hernquist 1996
and review by Bournaud 2010

Close look-up on the Antennae : SFR = 40 $M_{\odot}$ / yr



Physical processes

2/ Gas fragmentation increase:

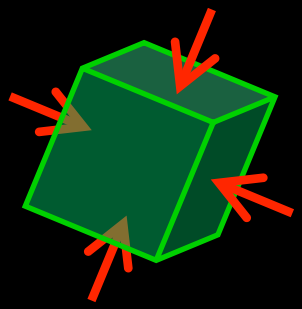
Interaction

DRIVES

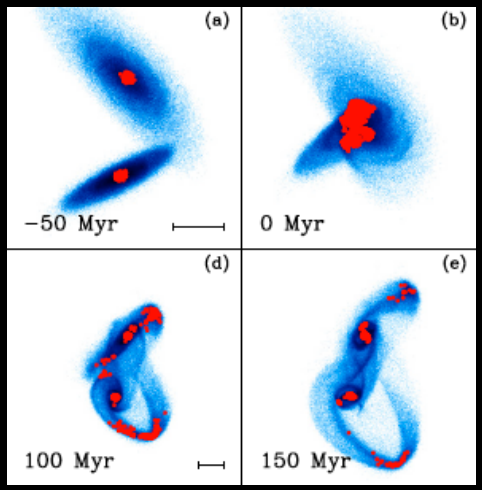
- compressive tides
- turbulence

INDUCE

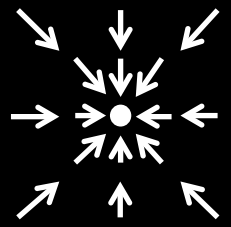
Increase of ***compressive*** turbulence



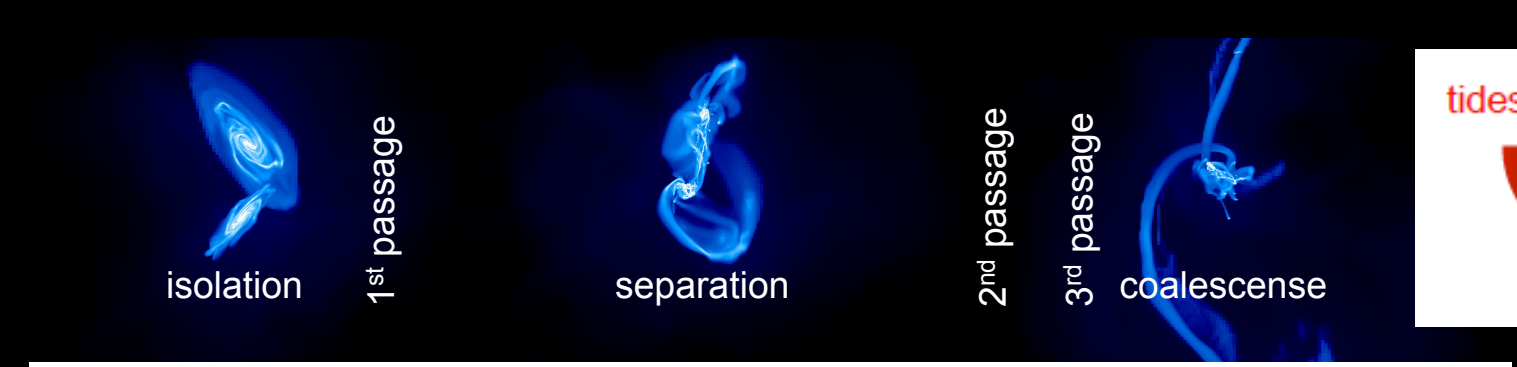
Renaud+08

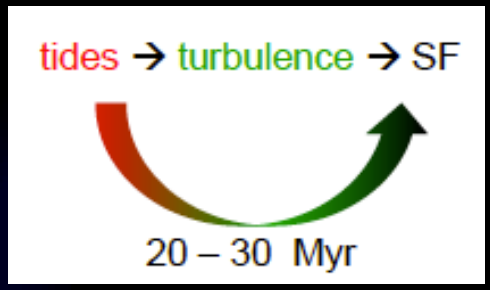


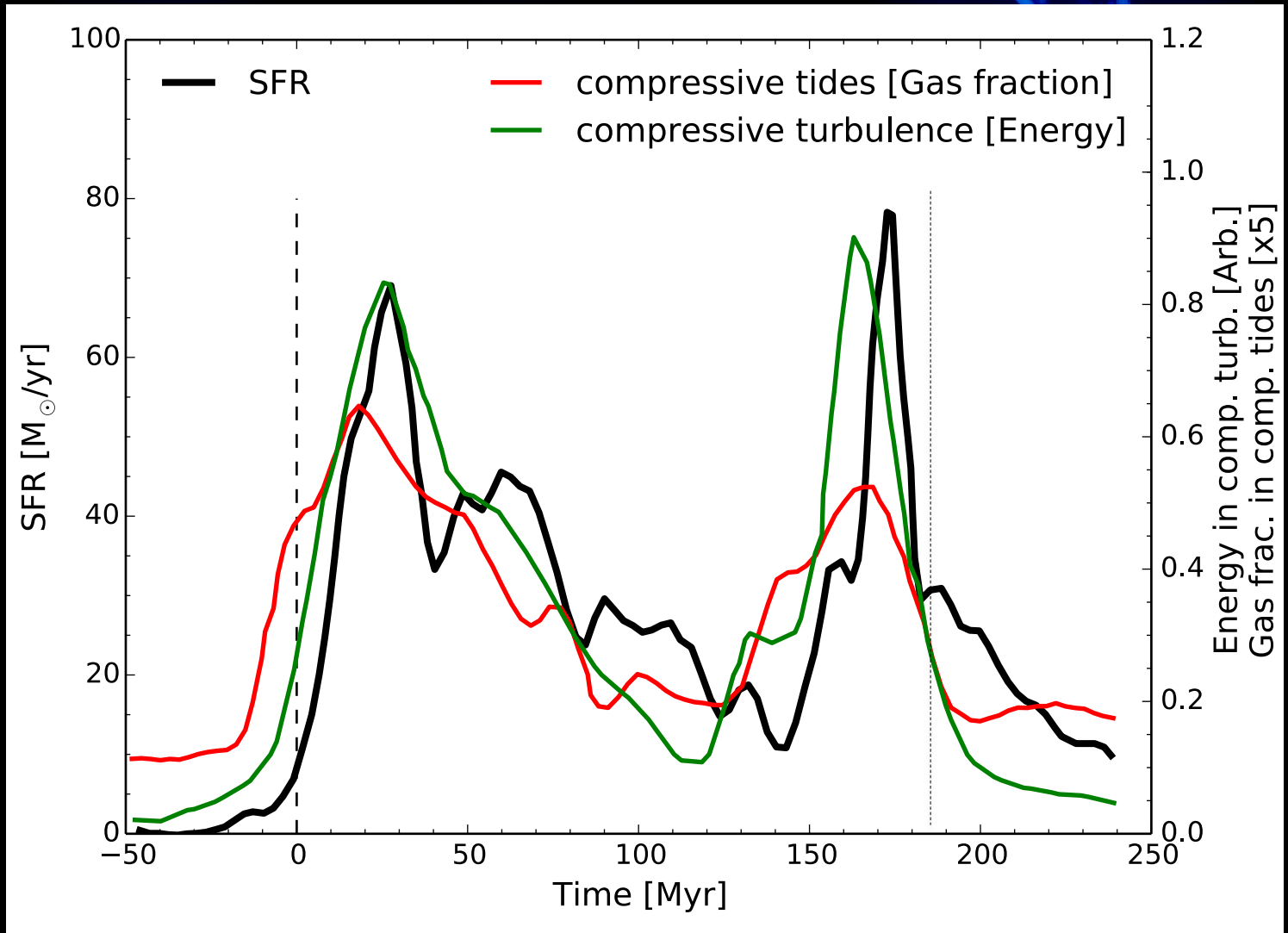
$\nabla \times \sigma = 0$



See Renaud et al, 2014







Renaud et al., 2014

Local mergers summary

- Gas inflows → Nuclear starburst

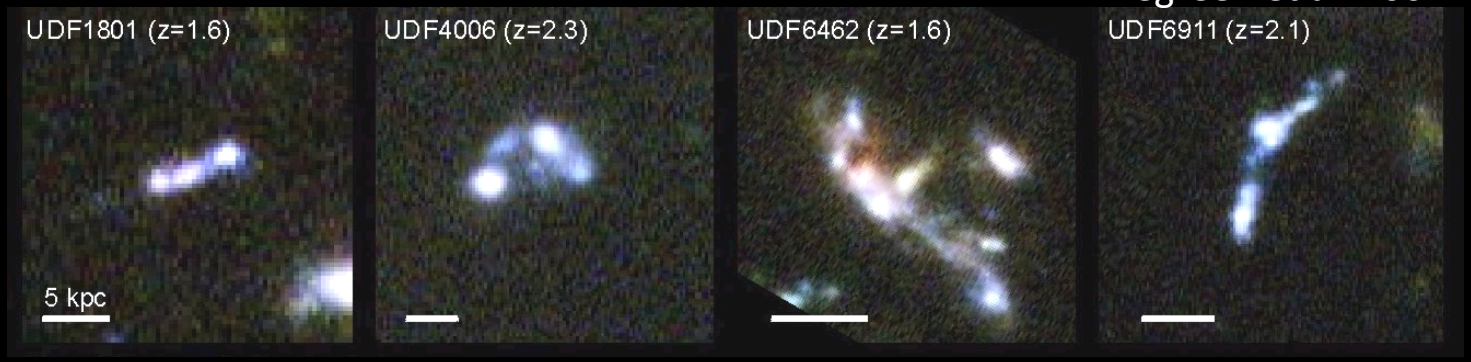
- Compressive tides
- Turbulence

↓

Compressive turbulence → Extended starburst

Star forming galaxies at z=1-3: gas-rich clumpy disks

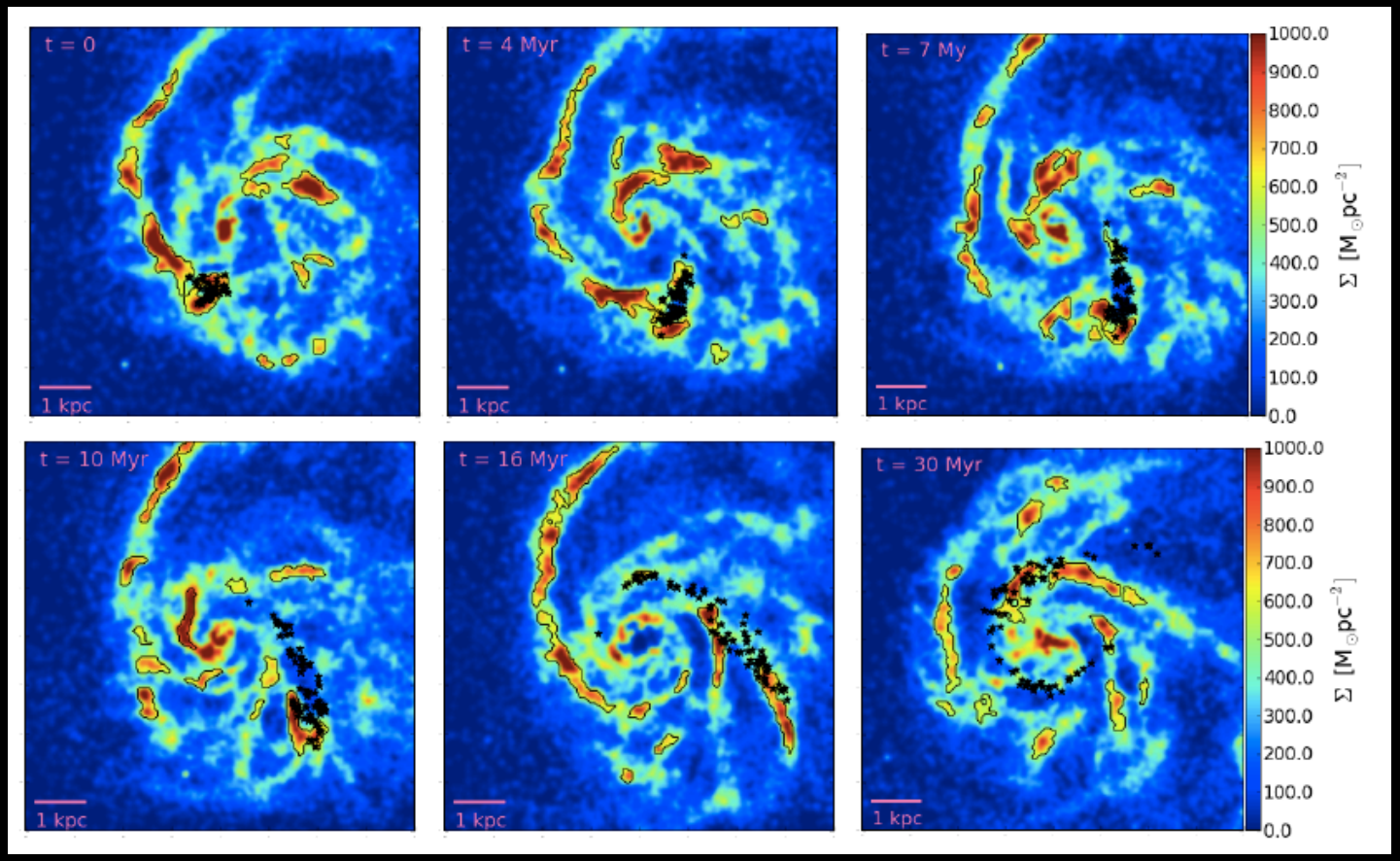
Elmegreen et al. 2007



Star forming galaxies with Mstars=$10^{10\text{-}11}$ at z=1-3:

- Clumpy
- high gas fractions ~50%
- Giant clumps of size ~500pc and stellar masses ~$10^{8\text{-}9}$Msun

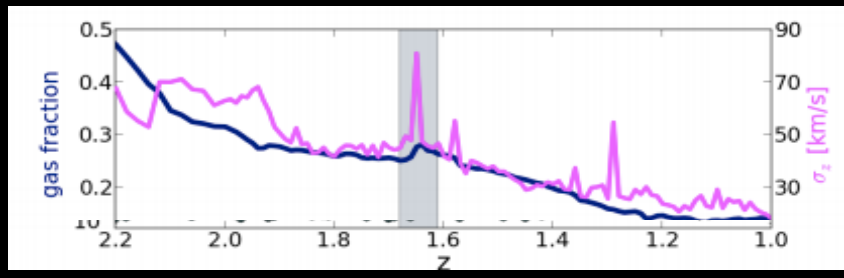
High gas fractions and clumps in cosmological simulations



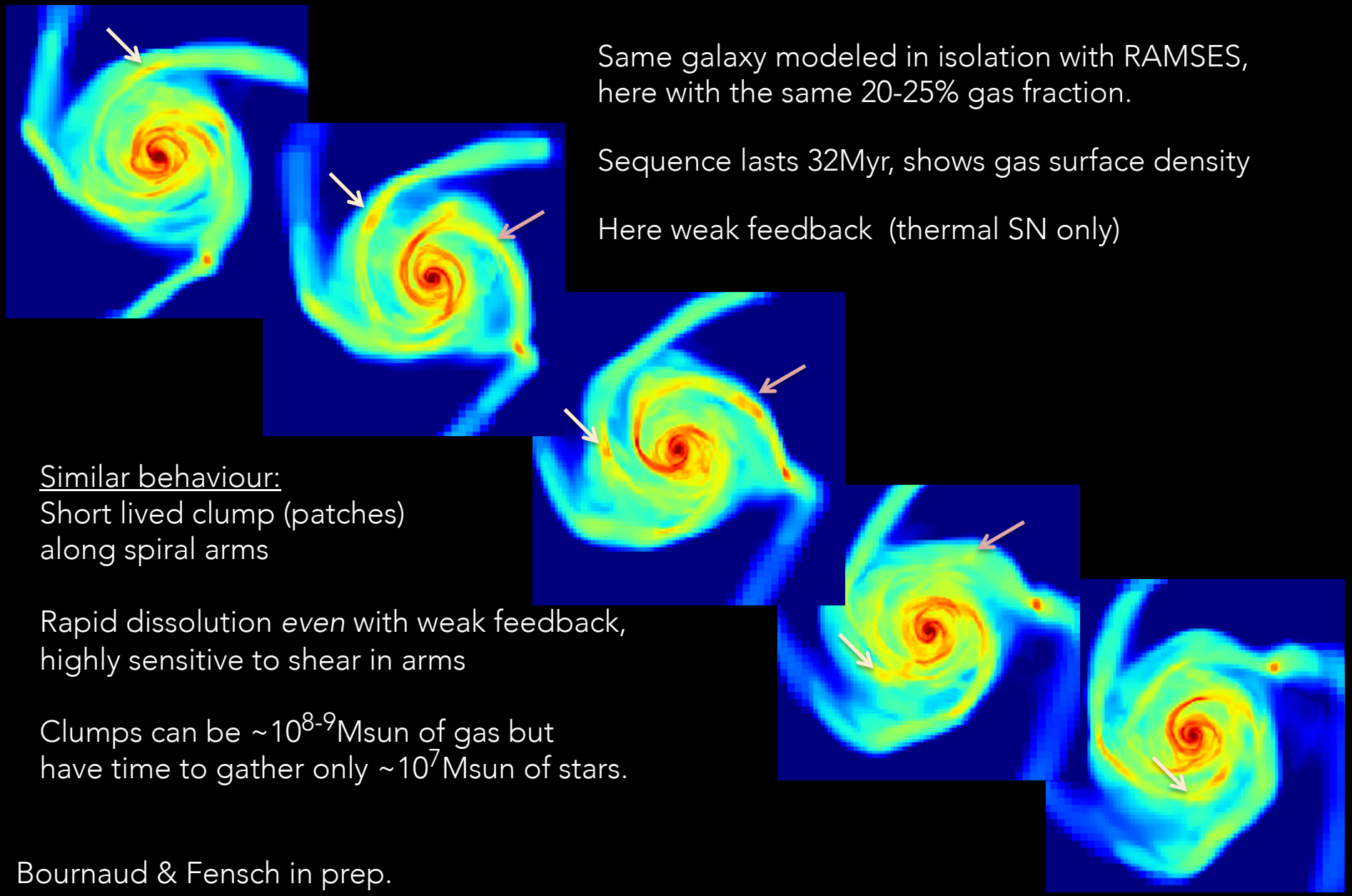
Hopkins et al. 2015, Oklopcic et al. 2016, *FIRE* cosmological simulations

Cosmological simulations show transient clumps

But generally have too low gas fractions in disks



High gas fractions and clumps in cosmological simulations



Same galaxy modeled in isolation with RAMSES, here with the same 20-25% gas fraction.

Sequence lasts 32Myr, shows gas surface density

Here weak feedback (thermal SN only)

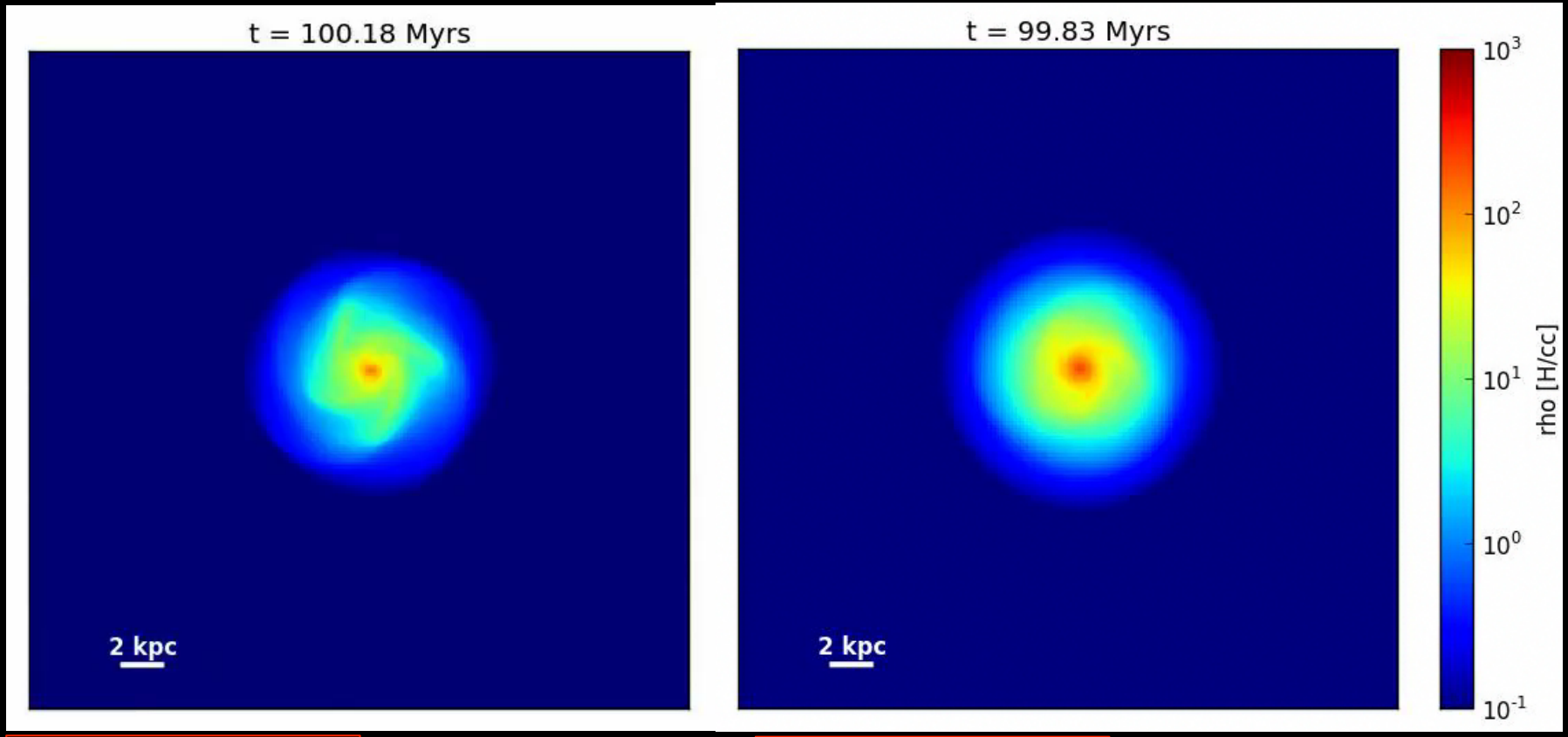
<u>Similar behaviour:</u>
Short lived clump (patches) along spiral arms

Rapid dissolution *even* with weak feedback, highly sensitive to shear in arms

Clumps can be ~$10^{8\text{-}9}$Msun of gas but have time to gather only ~10^{7}Msun of stars.

Bournaud & Fensch in prep.

Clumps sensitive to gas fraction and shear more than feedback



20-25% gas fraction
Weak feedback:
thermal SN only

50-60% gas fraction / same total mass profile
Stronger feedback:
thermal+kinetic SN + HII + radiation P.

Same DM halo, same total gas+star mass distribution
Gas/star ratio is the only parameter varied

Bournaud & Fensch in prep.

Simulations

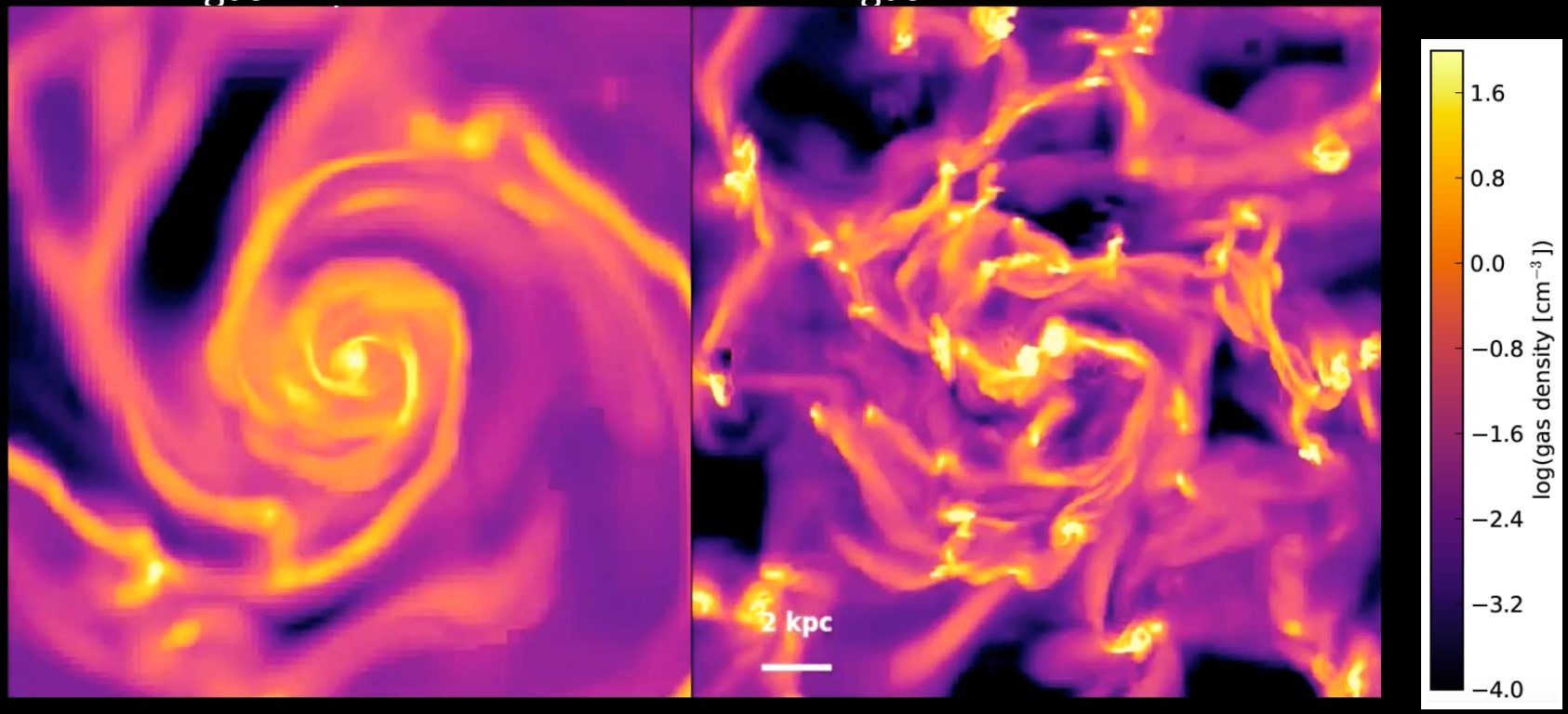
- Spatial resolution of 6 pc
  - Density-based refinement
- Star formation above a density threshold
- Feedback: same as Renaud et al., 2013
  - HII regions ionization (Renaud et al., 2013)
  - Radiative pressure (Renaud et al. 2013)
  - SNe (Dubois & Teyssier 2008, Teyssier et al. 2013)

Simulations with different gas fractions

Same DM halo, same total gas+star mass distribution
Gas/star ratio is the only parameter varied

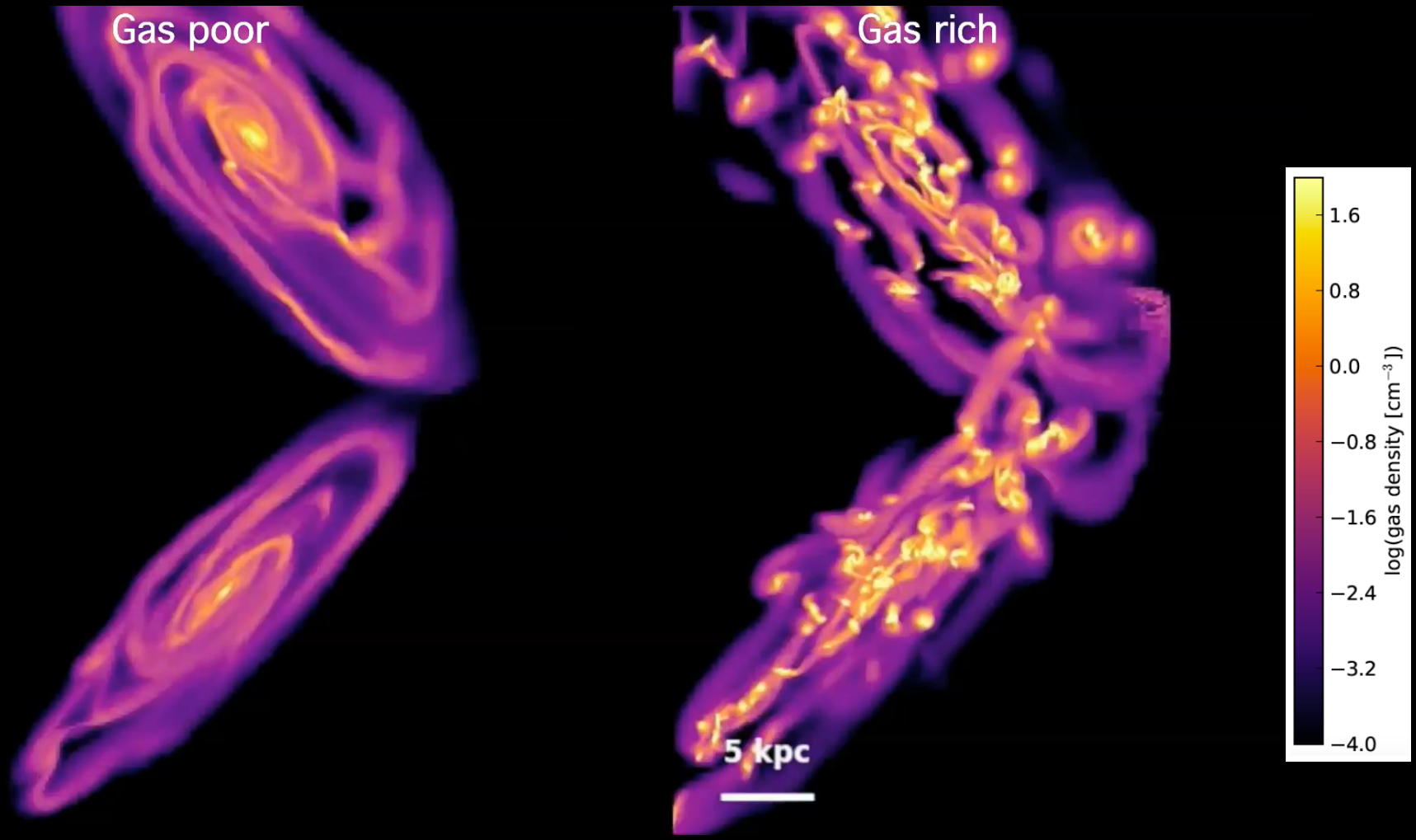
f_{gas} = 10 %

f_{gas} = 60 %



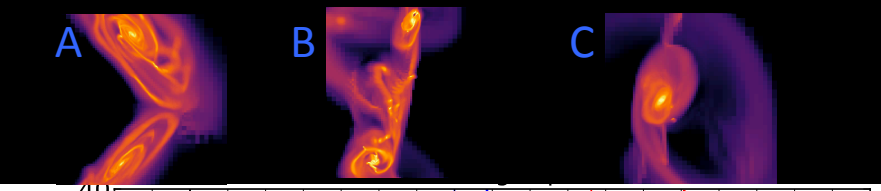
Fensch et al., subm.

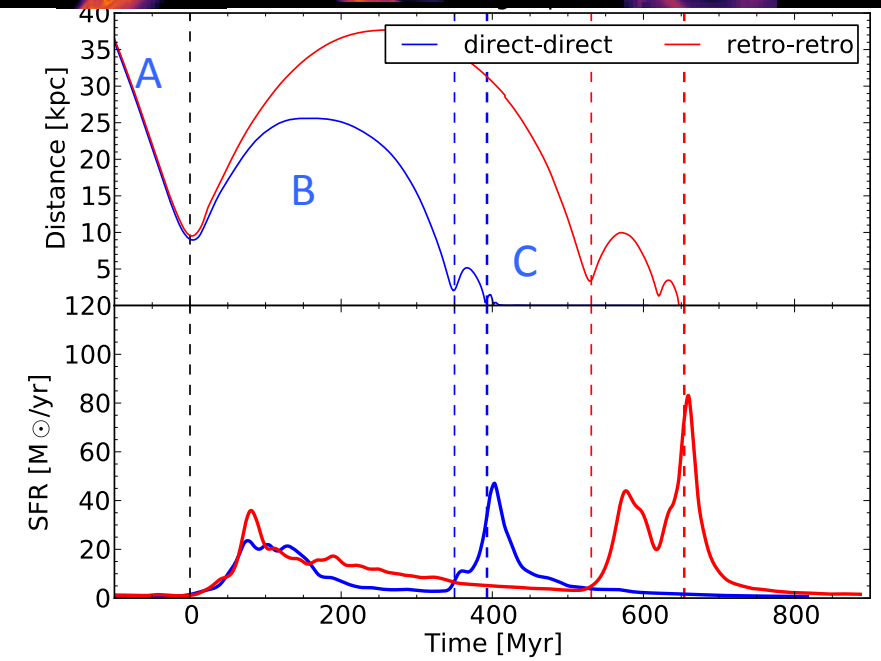
Merger simulations



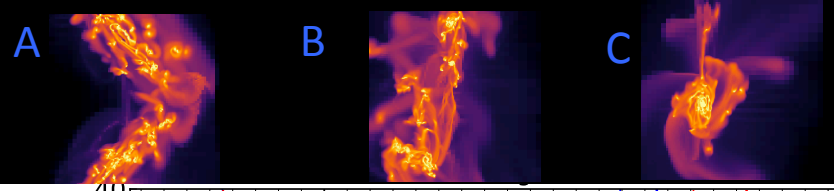
Fensch et al., subm.

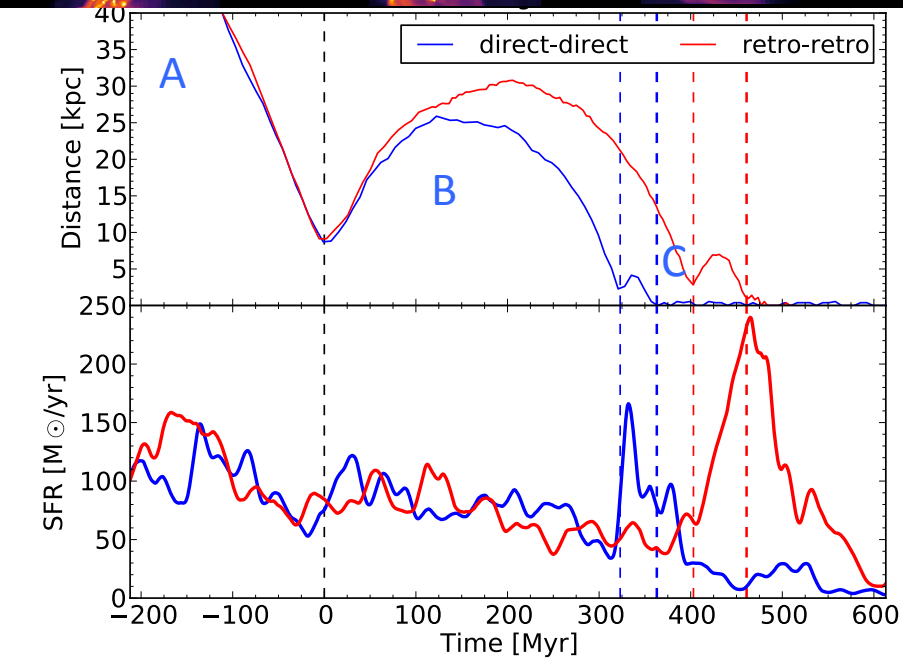
Star formation rates (SFR)





SFR *: x 40*

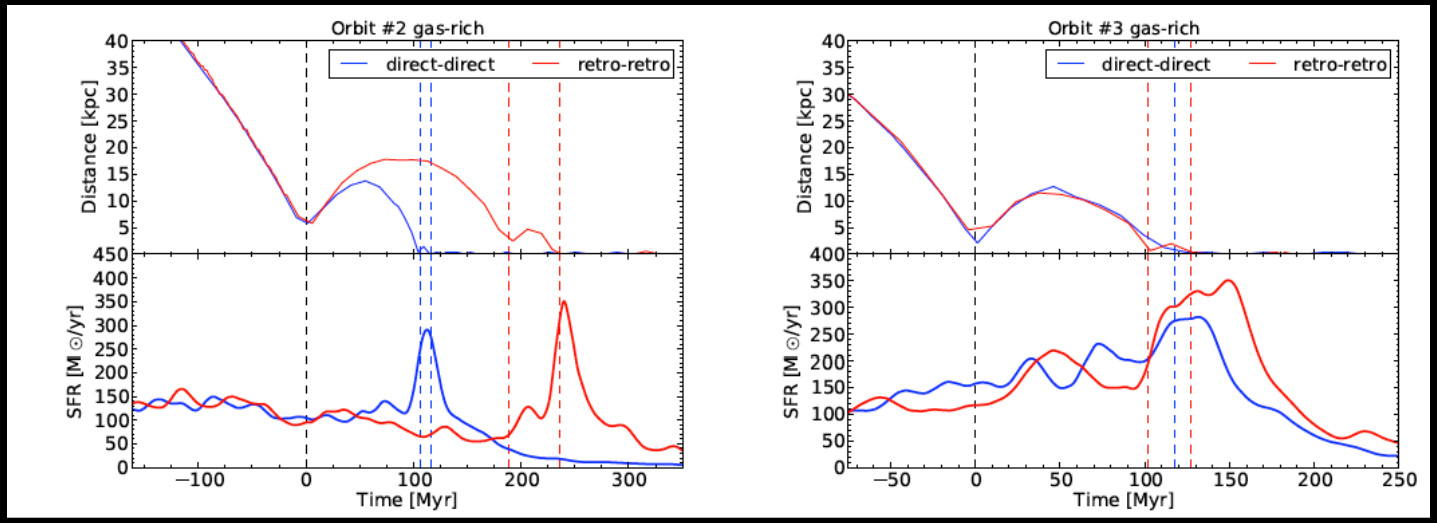




SFR *: x 3-5 max.*

Fensch et al., subm.

Star formation rates (SFR)



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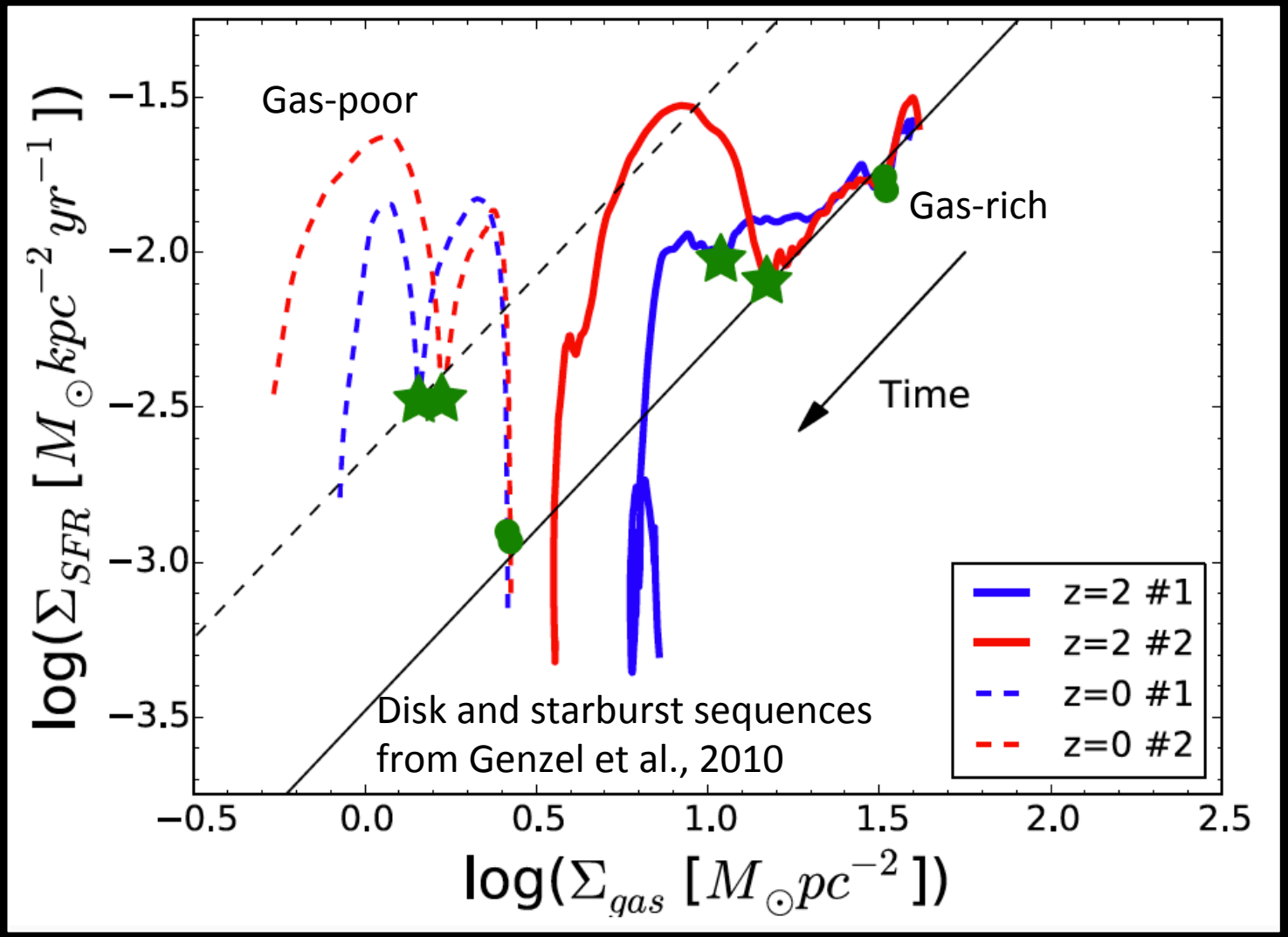


Fensch et al., subm.

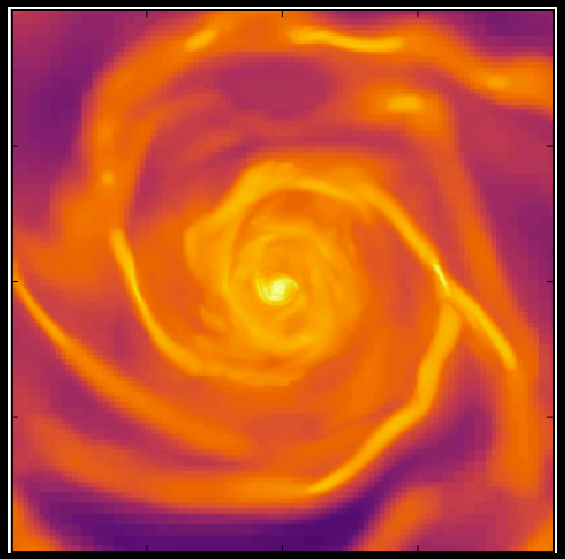
Physical processes checking-list

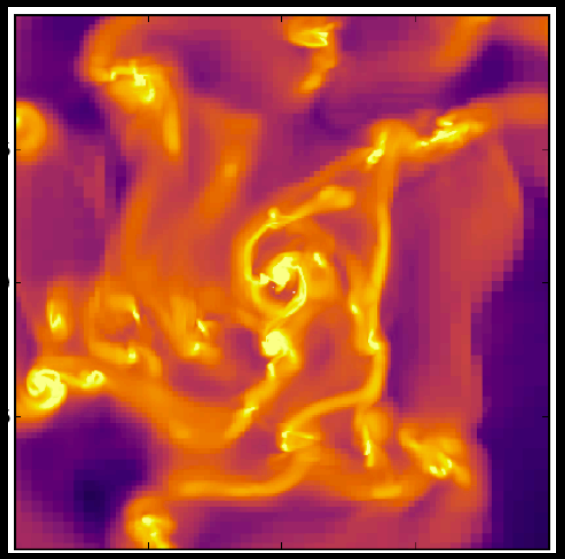
- Gas inflows
  - Gravitational torques

- Gas fragmentation
  - Compressive tides
  - Turbulence

Gas Inflows

1/ Gas inflows:



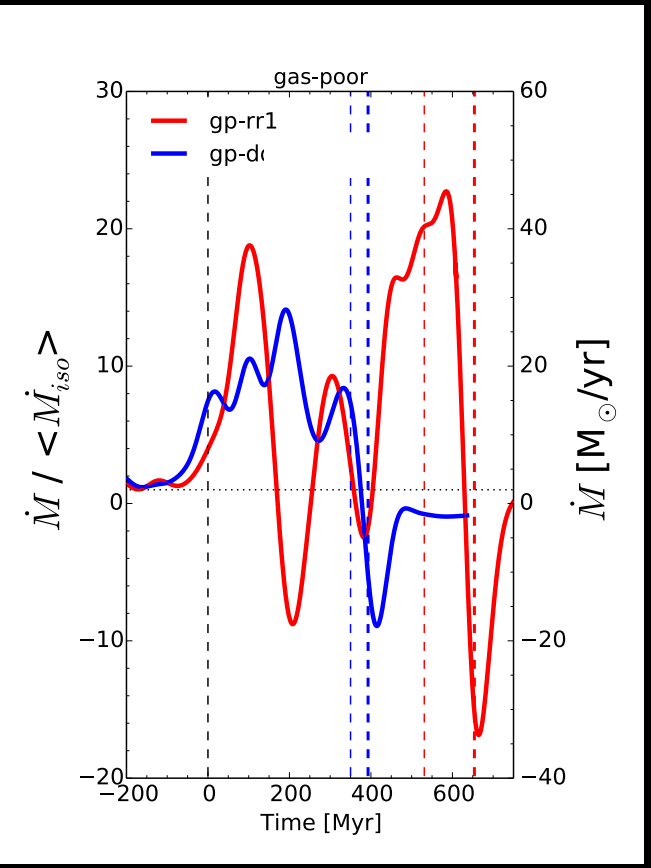


Strong inflows in gas rich ***isolated*** clumpy disks from VDI

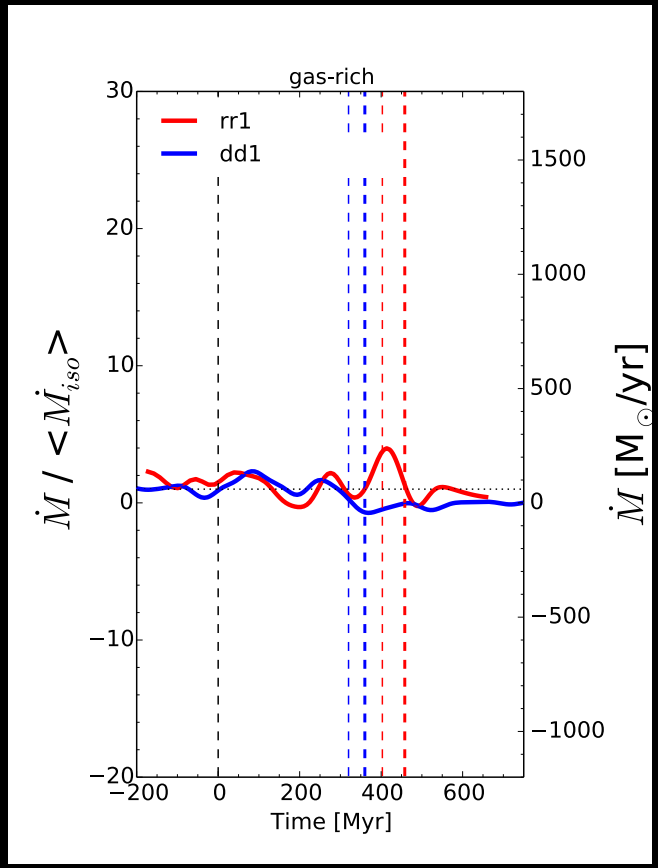
See alsoDekel+09, Elmegreen & Burkert 2010,
Krumholz & Dekel 2011, Bournaud Dekel+12

Gas Inflows

Gas-poor case



Gas-rich case



Relative increase of inflows :

factor ≈ 15-20 for gas-poor
factor ≈ 3-5 for gas-rich

Weak increase in gas inflows

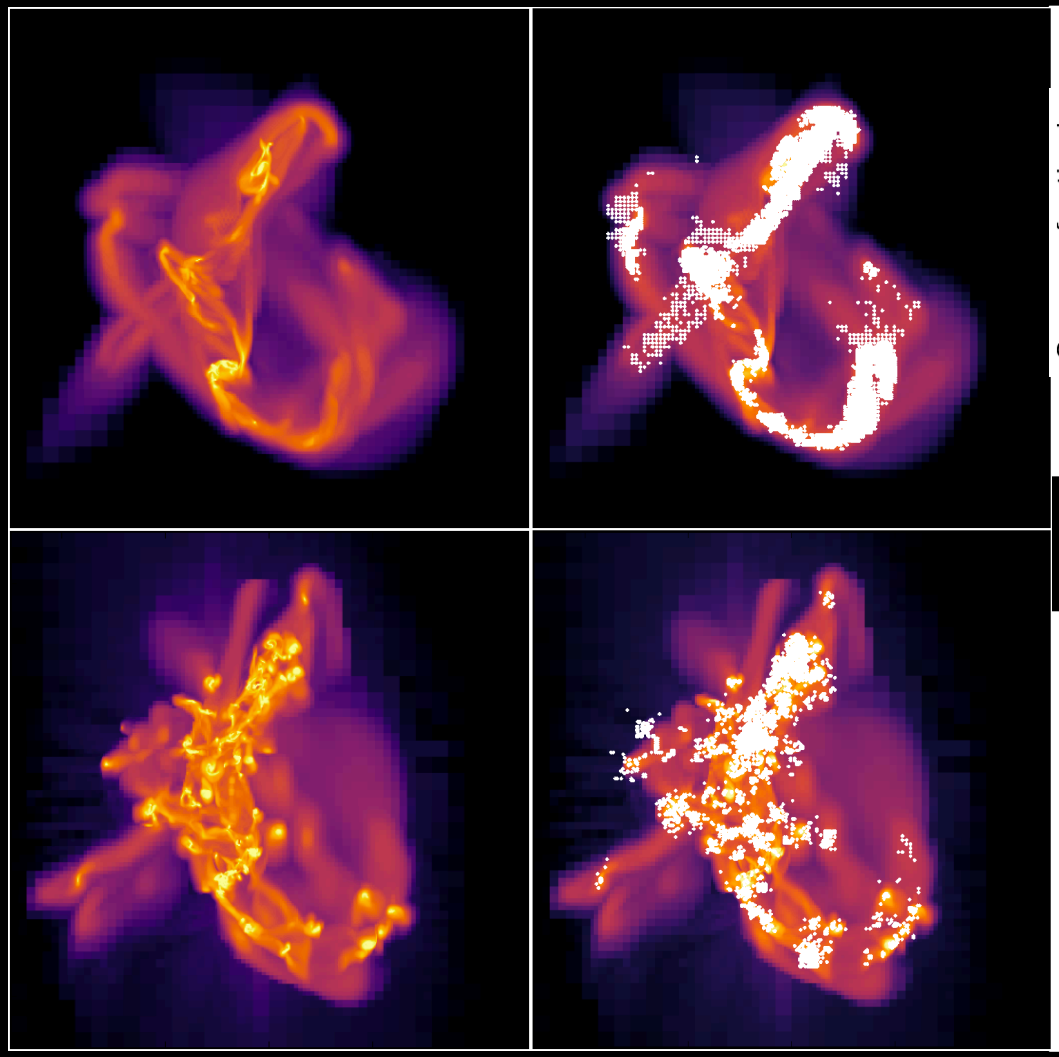
Fensch et al., subm.

Physical processes checking-list

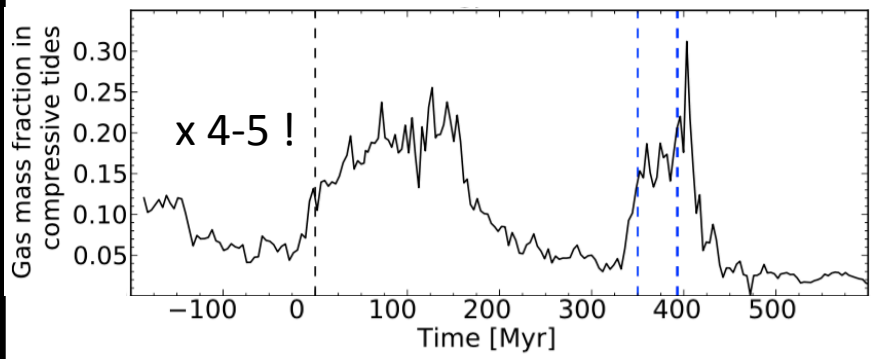
- 1/ Gas inflows
  - Gravitational torques ✔ ***Weaker increase***

- 2/ Gas fragmentation
  - Compressive tides
  - Turbulence

Compressive tides

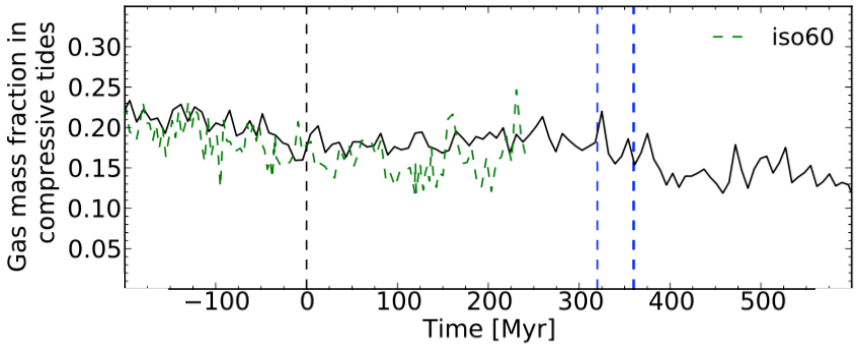


Gas poor



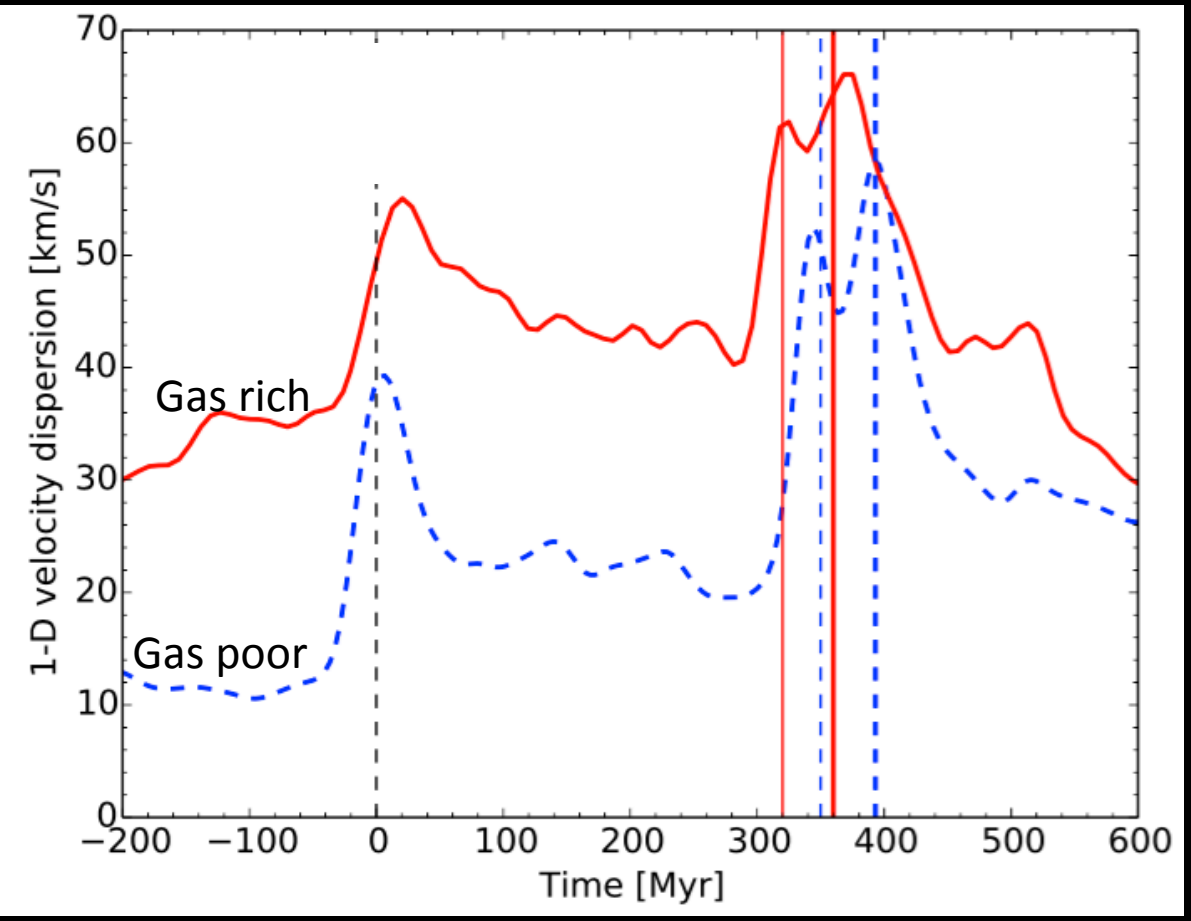
See also Renaud+08,+09

Gas rich



Fensch et al., subm.

Turbulence



Pre-merger:
Gas-rich ***more*** turbulent

(see Förster-Schreiber et al., 2009)

Interactions increase turbulence

Gas-poor : x 4
Gas-rich : x1.5

Saturation of turbulence increase

Fensch et al., subm.

Physical processes checking-list

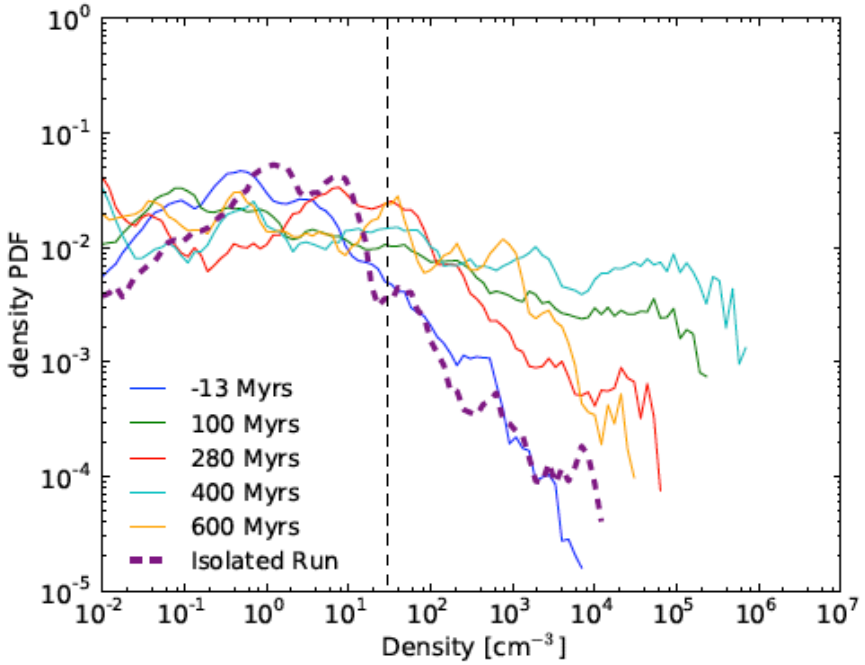
- 1/ Gas inflows
  - Gravitational torques ✔ ***Weaker increase***

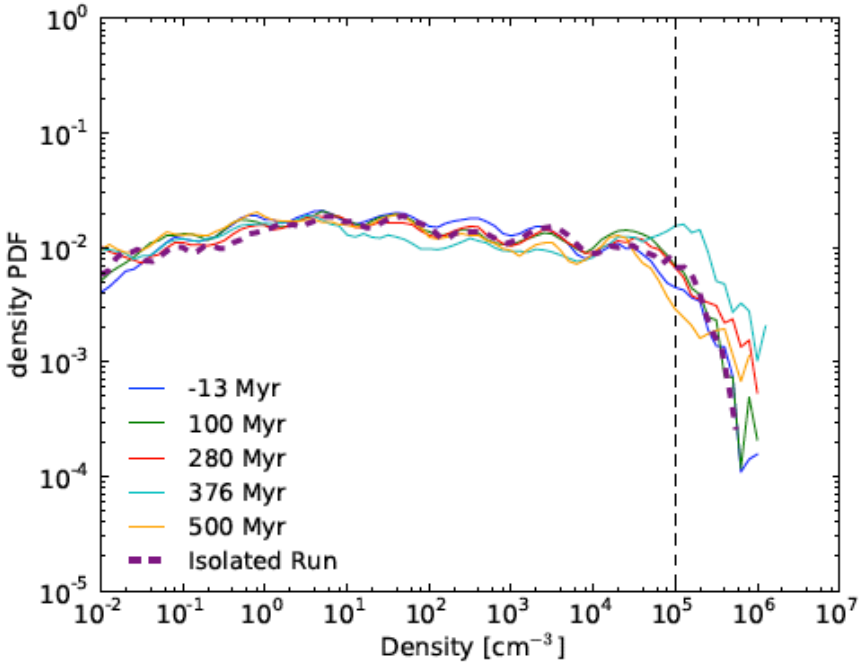
- 2/ Gas fragmentation
  - Compressive tides ✔ ***Not triggered***
  - Turbulence ✔ ***Weaker increase***

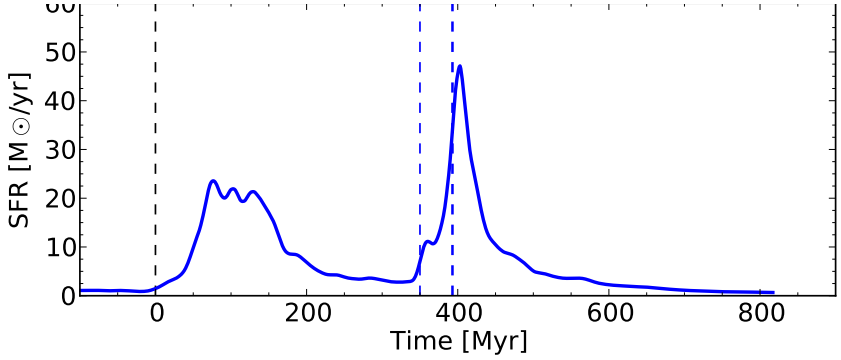
Both mechanisms are **less enhanced** by the interaction

→ **Star formation less enhanced**

Density PDFs



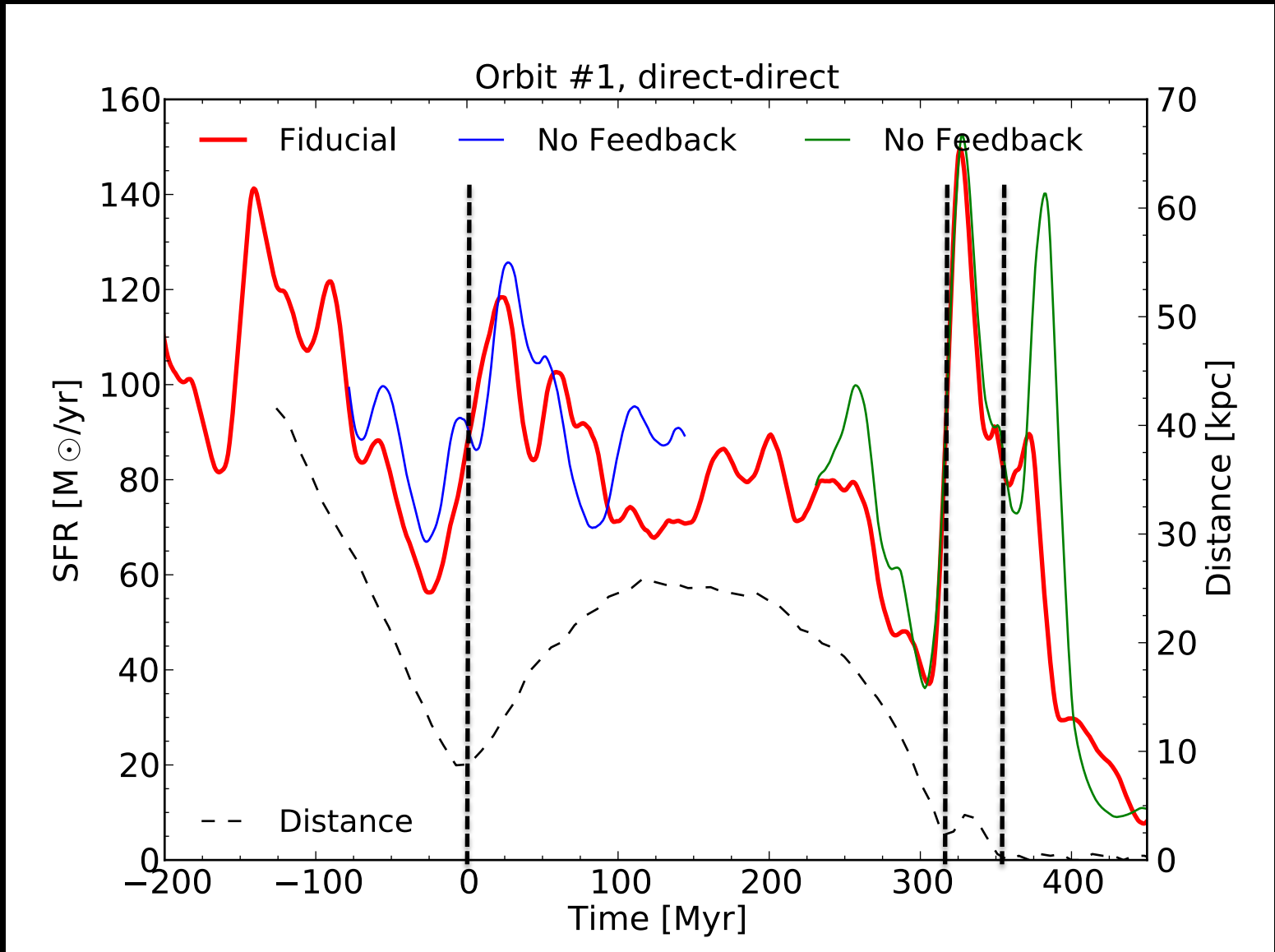




No change at all
during the interaction !

Fensch et al., subm.

Epilogue : …and feedback ?



Summary

Fensch et al. (submitted)

Local major mergers increase:

- Turbulence
- Compressive tides

→ Extended starburst

- Gas inflows

→ Nuclear starburst

Does not hold for high gas fraction major mergers:

the gas fraction and clumpy morphology prevent a strong burst of star formation