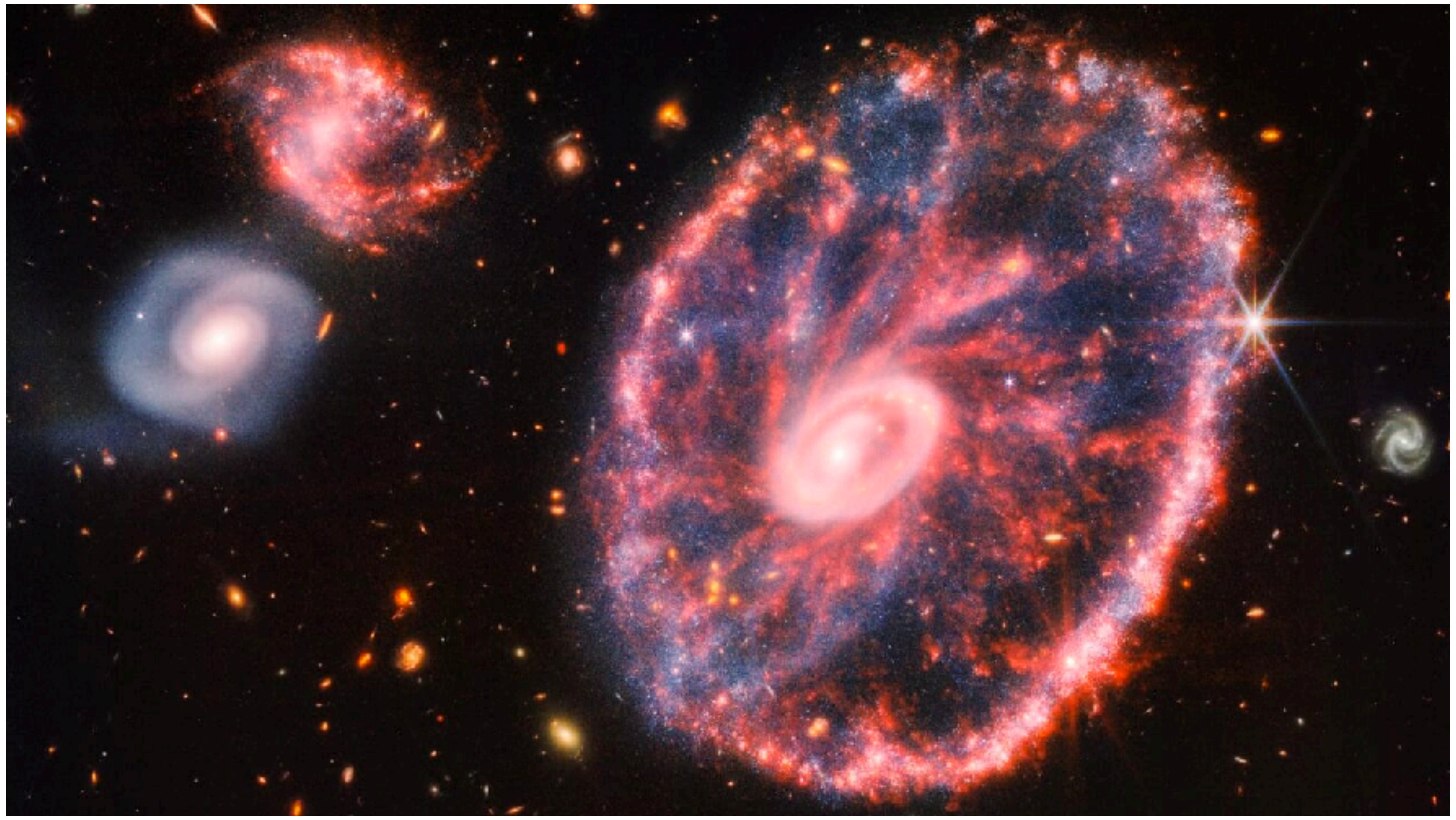
Florent Renaud
Lund Observatory

Knut and Alice Wallenberg Foundation

Why don't galaxy mergers always do what you expect from them?

What *can* mergers do?

- Mass growth
- Morphological transformation
  temporary or definitive
- Starbursts
- Quenching



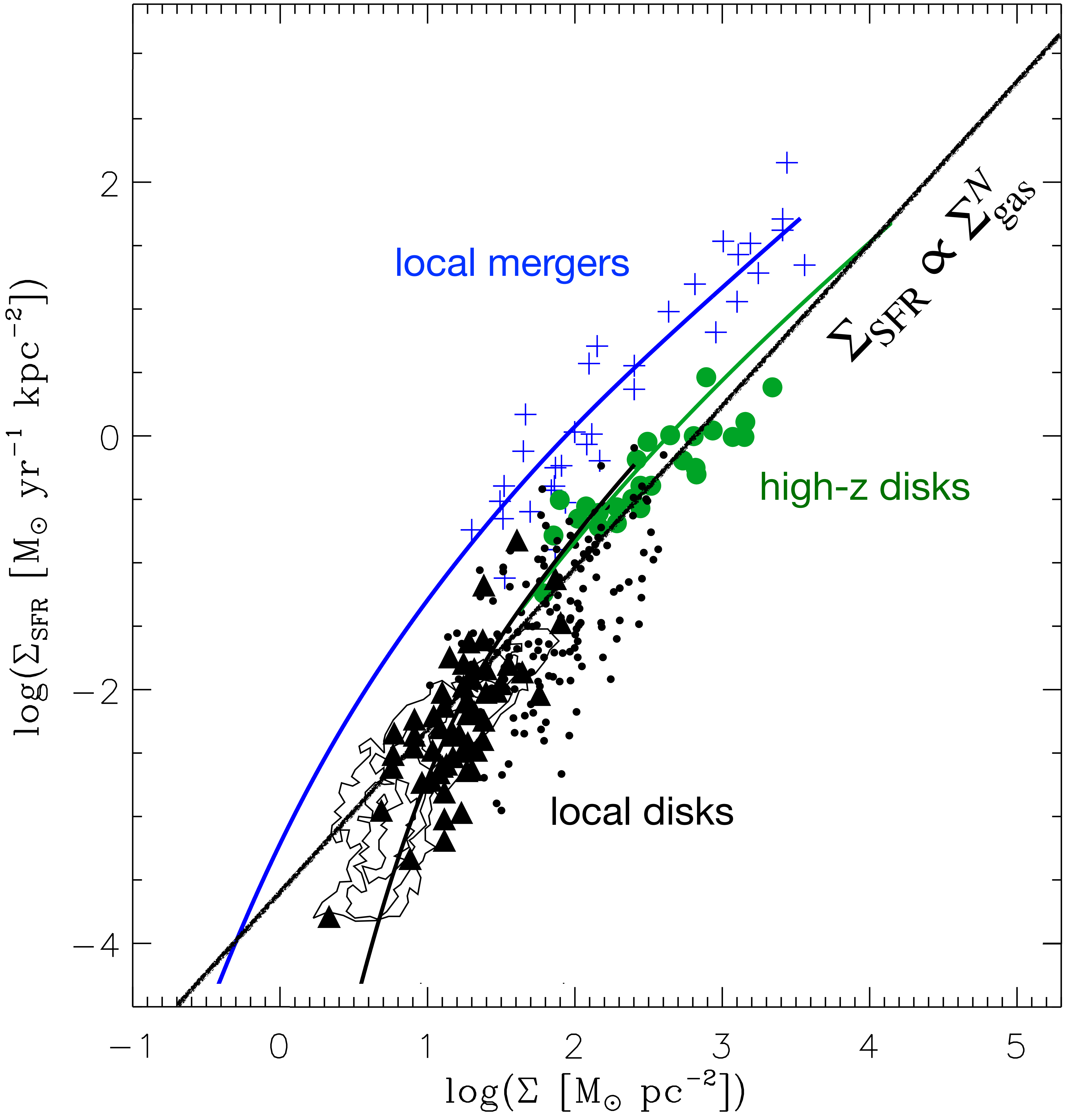
STARBURSTS IN LOCAL MERGERS

Uncertainties on the exact gas mass (α_{CO})

but starbursting mergers are outliers

Where do the progenitors come from?

Renaud et al. (2012), Kraljic et al. (2014)



Observations from Kennicutt et al. (1998, 2007),
Bigiel et al. (2008), Tacconi et al. (2010), Daddi et al. (2010)...

What makes a starburst starburst?

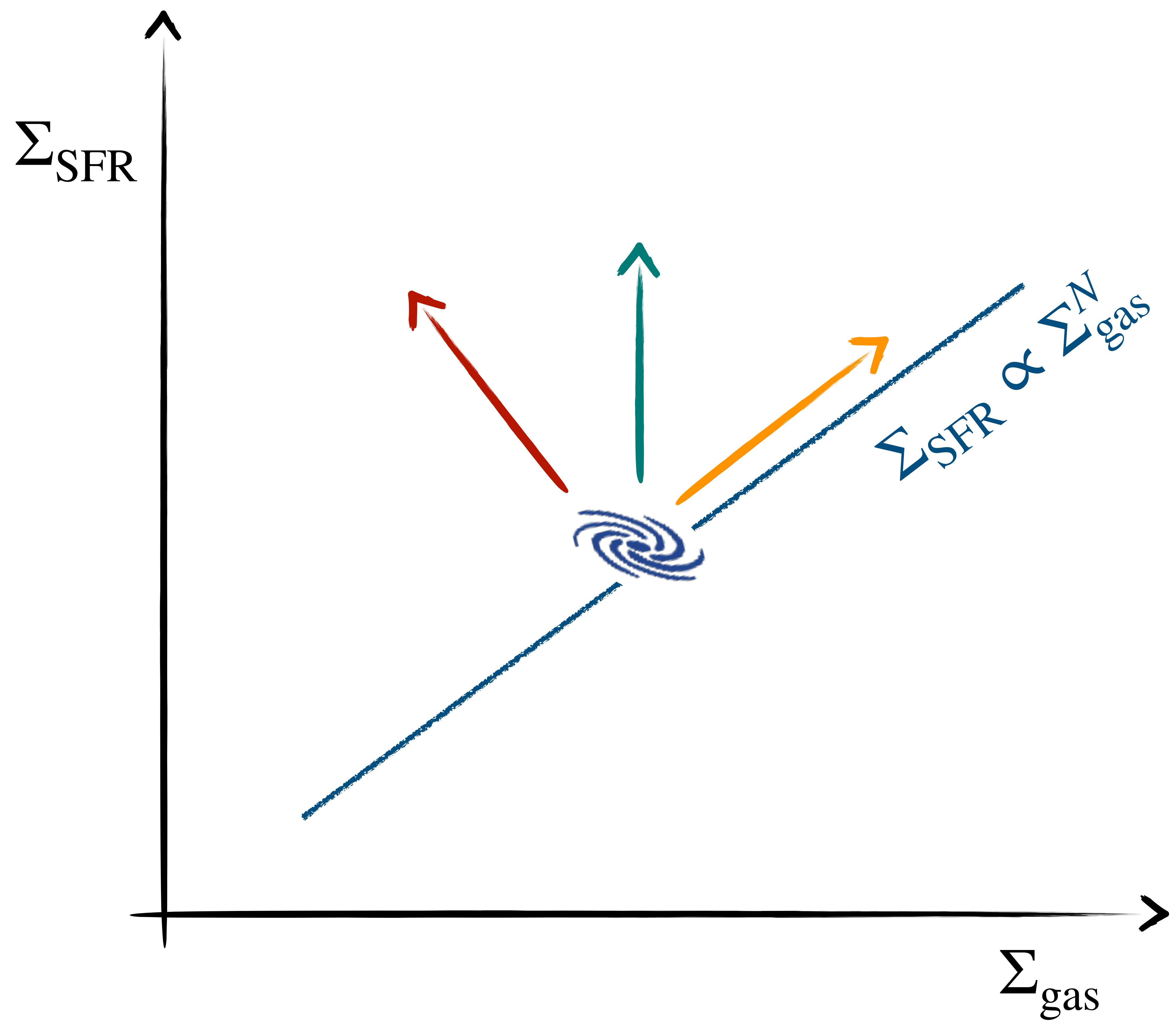
A boost of the star formation activity could be due to:

- increased mass of dense gas
  = more stars formed per unit time

- increased SFE
  = more stars formed per unit mass

- decreased depletion time
  = stars formed faster per unit mass

- combination(s) of the above



How to starburst: (1) Nuclear Inflows

Negative torques inside the orbital co-rotation of the satellite

Barnes & Hernquist (1991)

Accumulation of gas at the galactic center

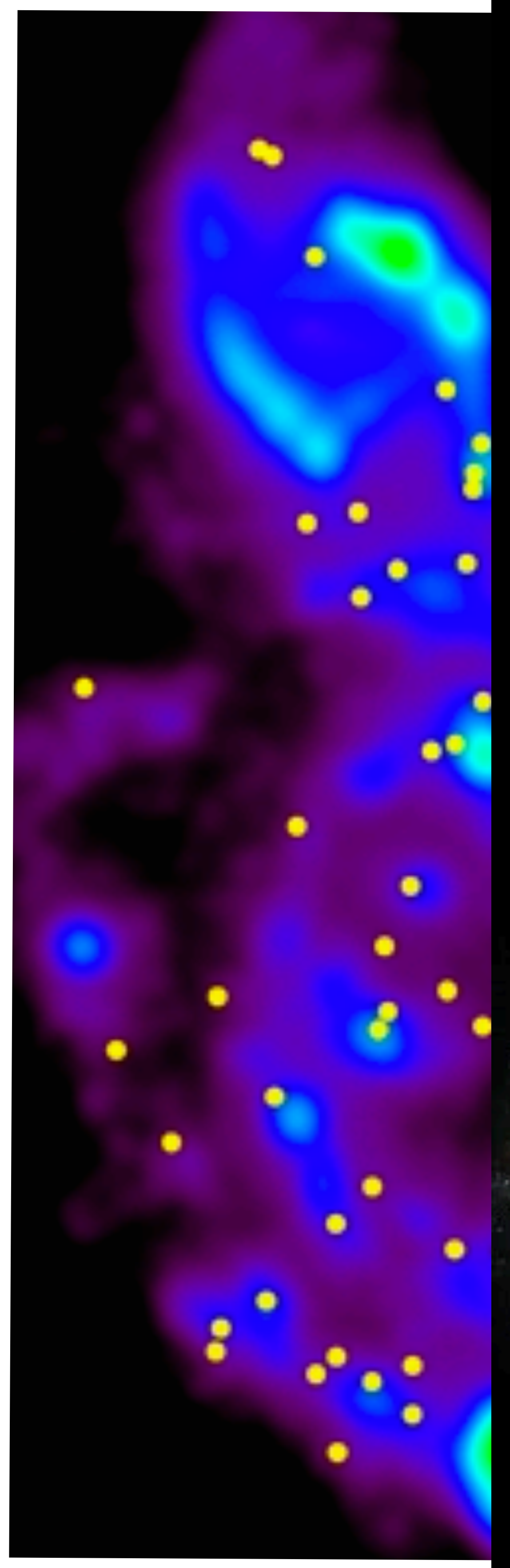
(Possible ignition/fueling of the AGN)

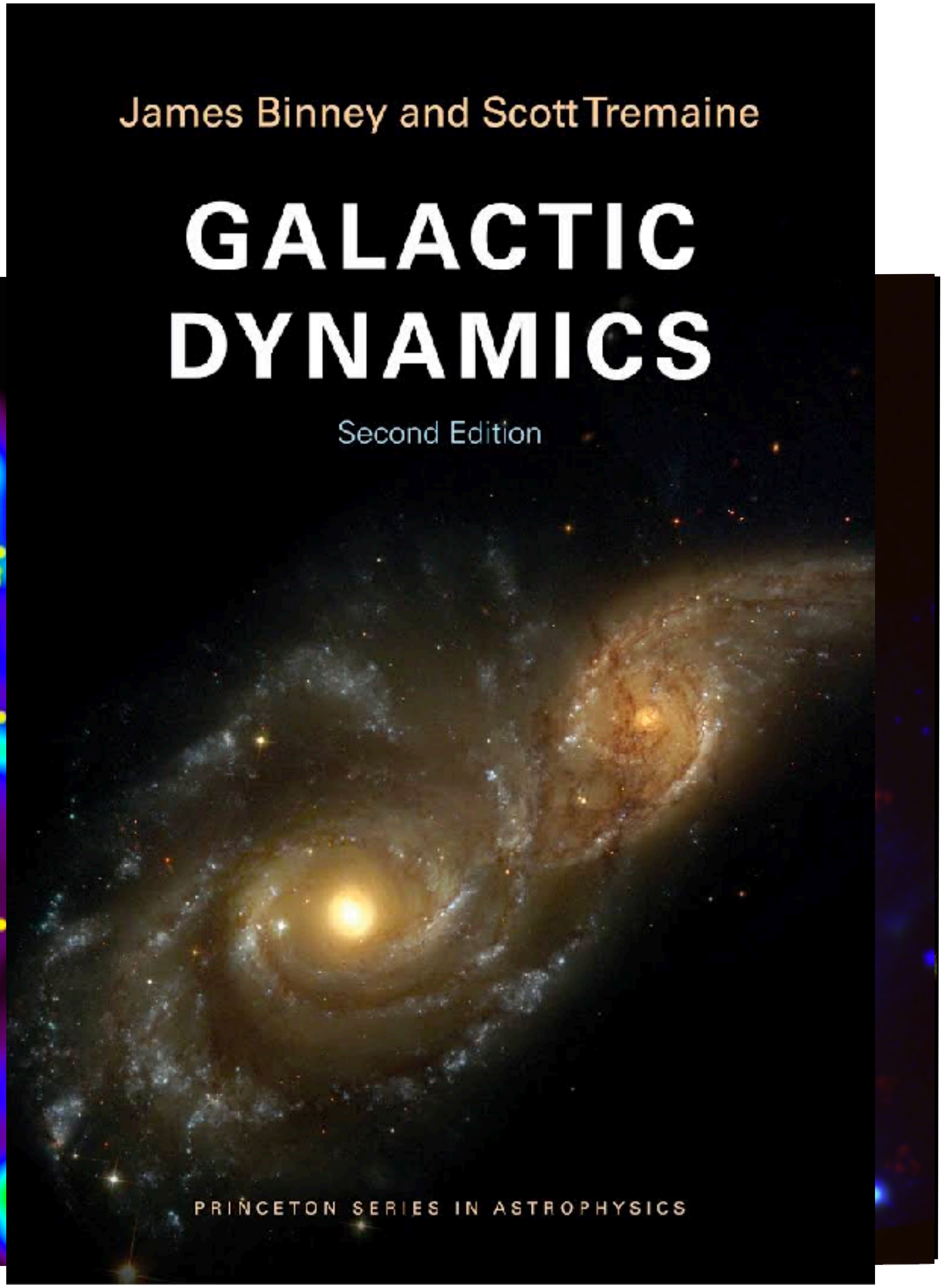
Boost of the SFR

OFF-NUCLEAR STARBURSTS

SFR density

U + 8μm +





Mineo et al. (2014)

Elmegreen et al. (2017)

NGC 2207

How to starburst: (2) Shocks, Cloud collisions

In overlaps, collisions occur between:

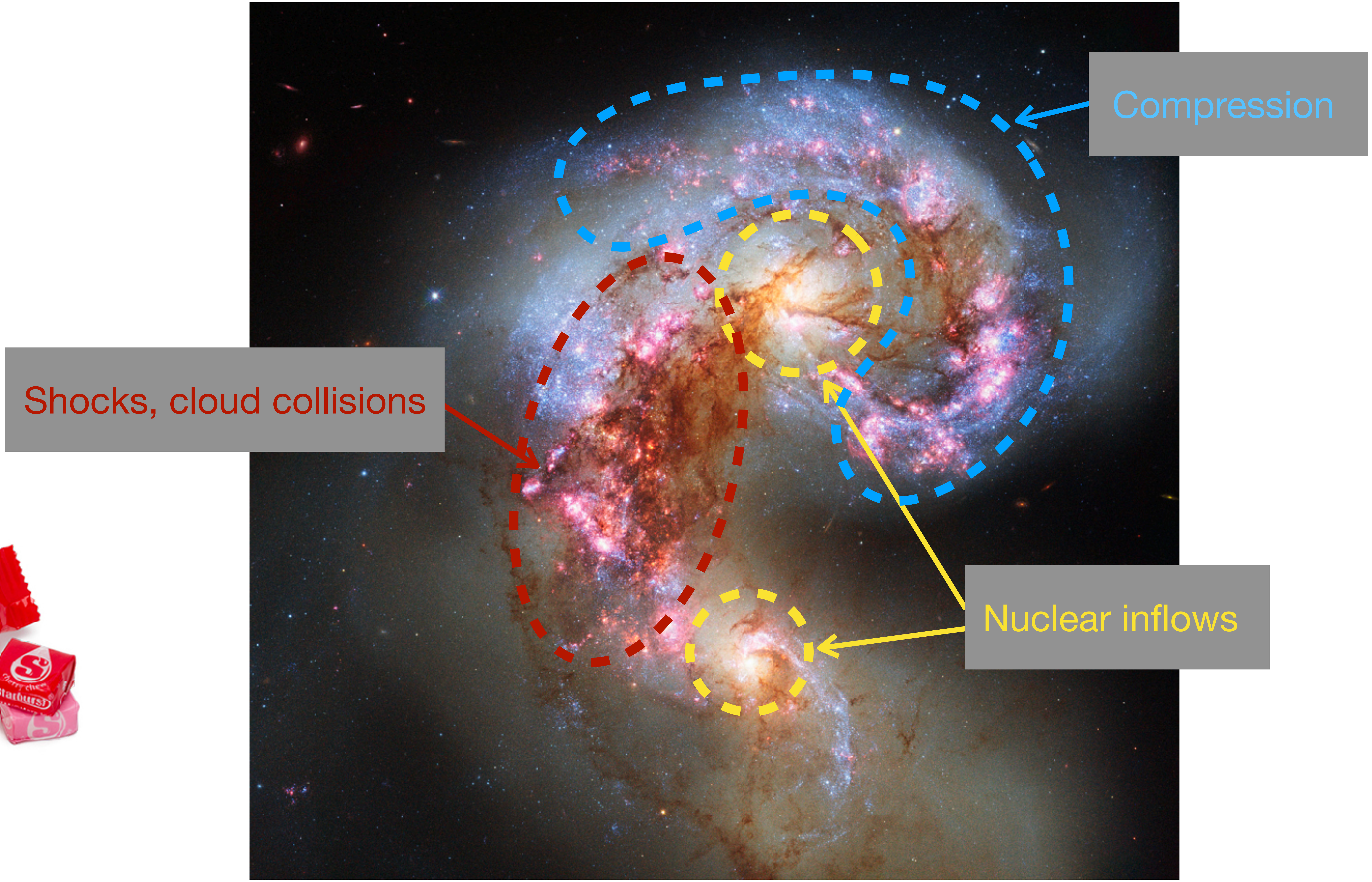
- 2 marginally stable clouds
- a cloud and a gas reservoir (HI)
  Jog & Solomon (1992)

Increases the Mach number
Renaud et al. (2015)

Triggers (massive) star formation
Tan et al. (2000)
Inoue & Fukui (2013)
Motte et al. (2014)

Hard to estimate their actual frequency

THE 3 FLAVORS OF STARBURSTS



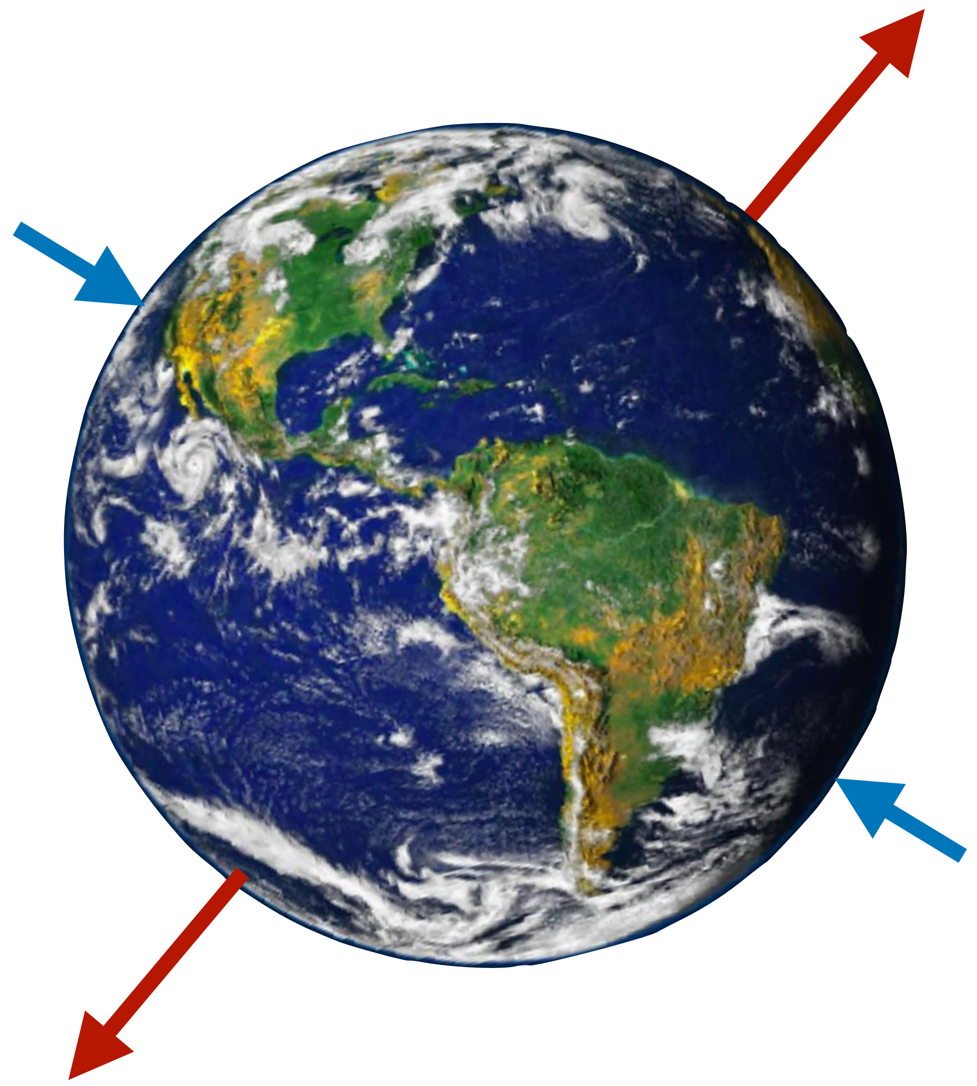
A FEW WORDS ON THE TIDAL TENSOR

Tidal tensor: $T^{ij} = -\frac{\partial^2 \phi}{\partial x_i \partial x_j}$

Diagonalisation → 3 eigenvalues: $\lambda_1 \geq \lambda_2 \geq \lambda_3$

Fun fact! $\mathrm{Tr}(T) = \sum_i \lambda_i = -\nabla^2 \phi = -4\pi G\rho$

Point mass: $\phi = -\frac{GM}{r} \implies \{\lambda_1, \lambda_2, \lambda_3\} = \frac{GM}{r^3}\{2, -1, -1\}$



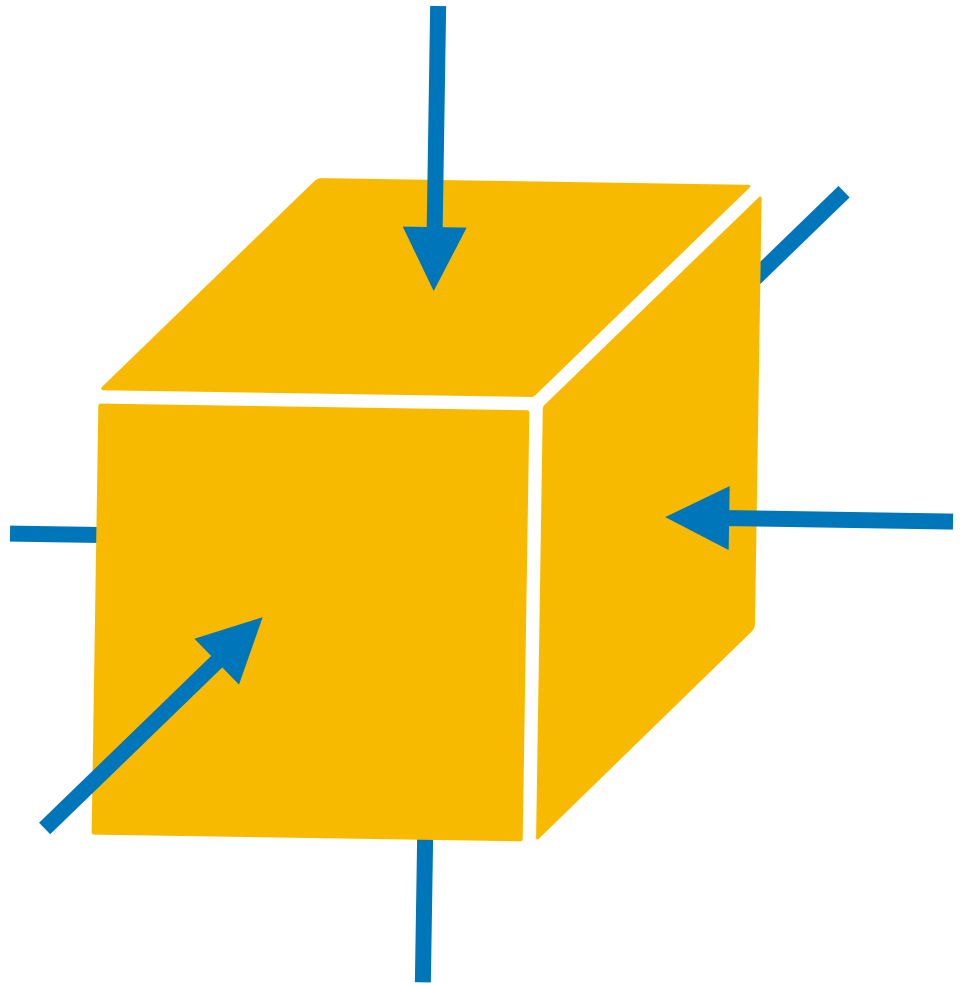
Fun fact #2 !!!! On circular orbits: λ_2 = - centrifugal force

Even more fun with tides in Renaud et al. (2011)

Compressive tides

Plummer: $\phi = -\dfrac{GM}{\sqrt{r^2 + r_0^2}} \implies \{\lambda_1, \lambda_2, \lambda_3\} = \dfrac{GM}{\left(r^2 + r_0^2\right)^{3/2}} \left\{ \dfrac{2r^2 - r_0^2}{r_0^2 + r^2}, -1, -1 \right\}$

$\forall i, \lambda_i < 0$ for $r < \dfrac{r_0}{\sqrt{2}}$ → (fully) compressive tides



Tides are compressive in cores of the potentials

Valluri (1993), Dekel et al. (2003), Renaud et al. (2008)

It stops the destruction of structures, and favors collapse

Jog (2013, 2014), Mondal & Chakraborty (2015)

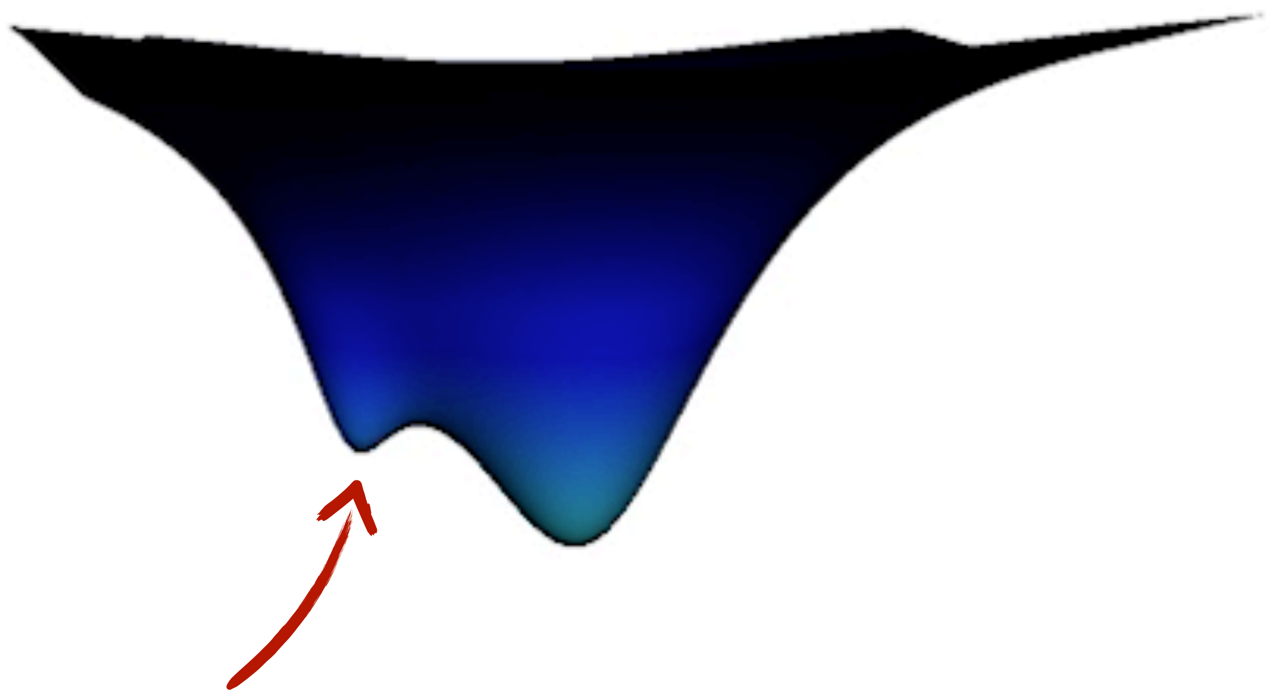
internal pressure

$$M_{\rm Jeans} \propto \left(\frac{v_s^2}{G\rho^{1/3}}\right)^{3/2}$$

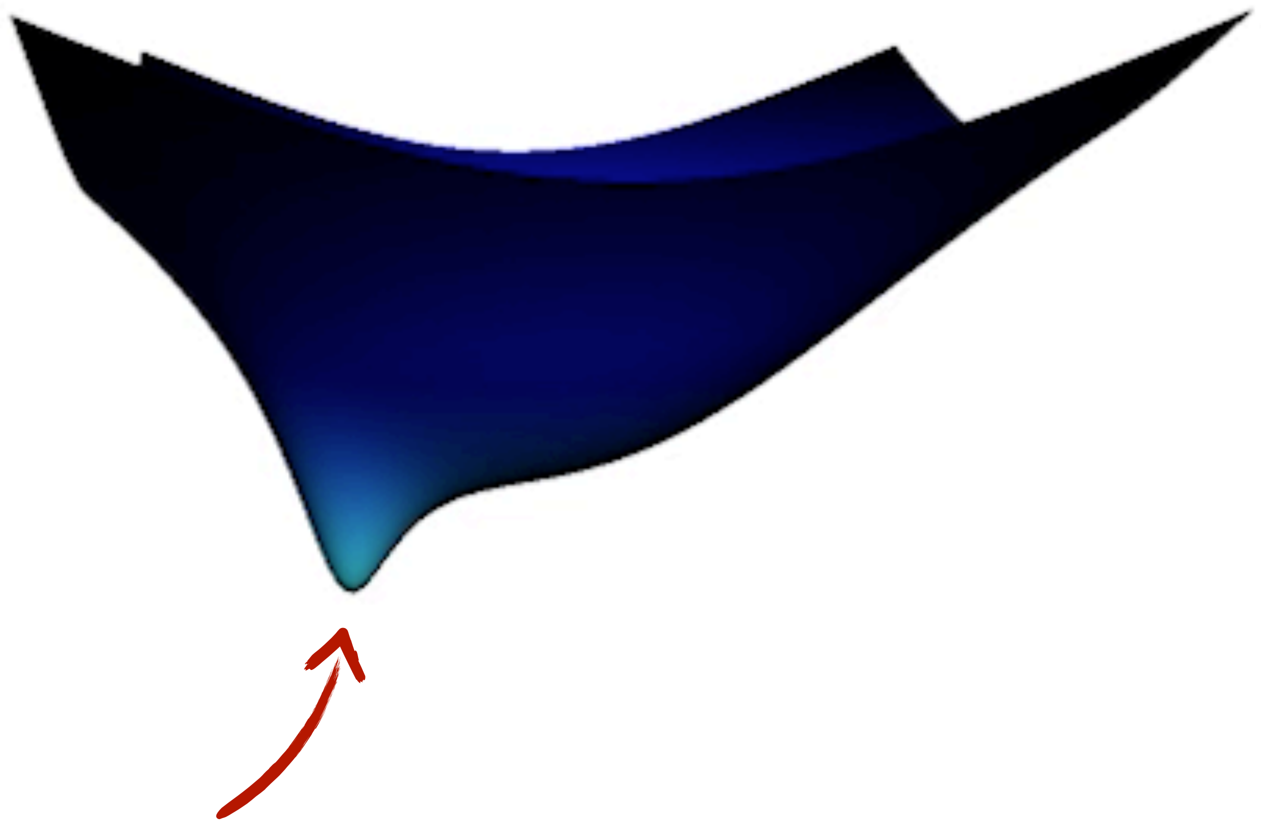
self-gravity

tides

Compressive tides in cores



cusped potential



cored potential

BTW: no tidal radius in cored potentials!

$$r_t = \left(\frac{Gm}{\lambda_1}\right)^{\frac{1}{3}}$$

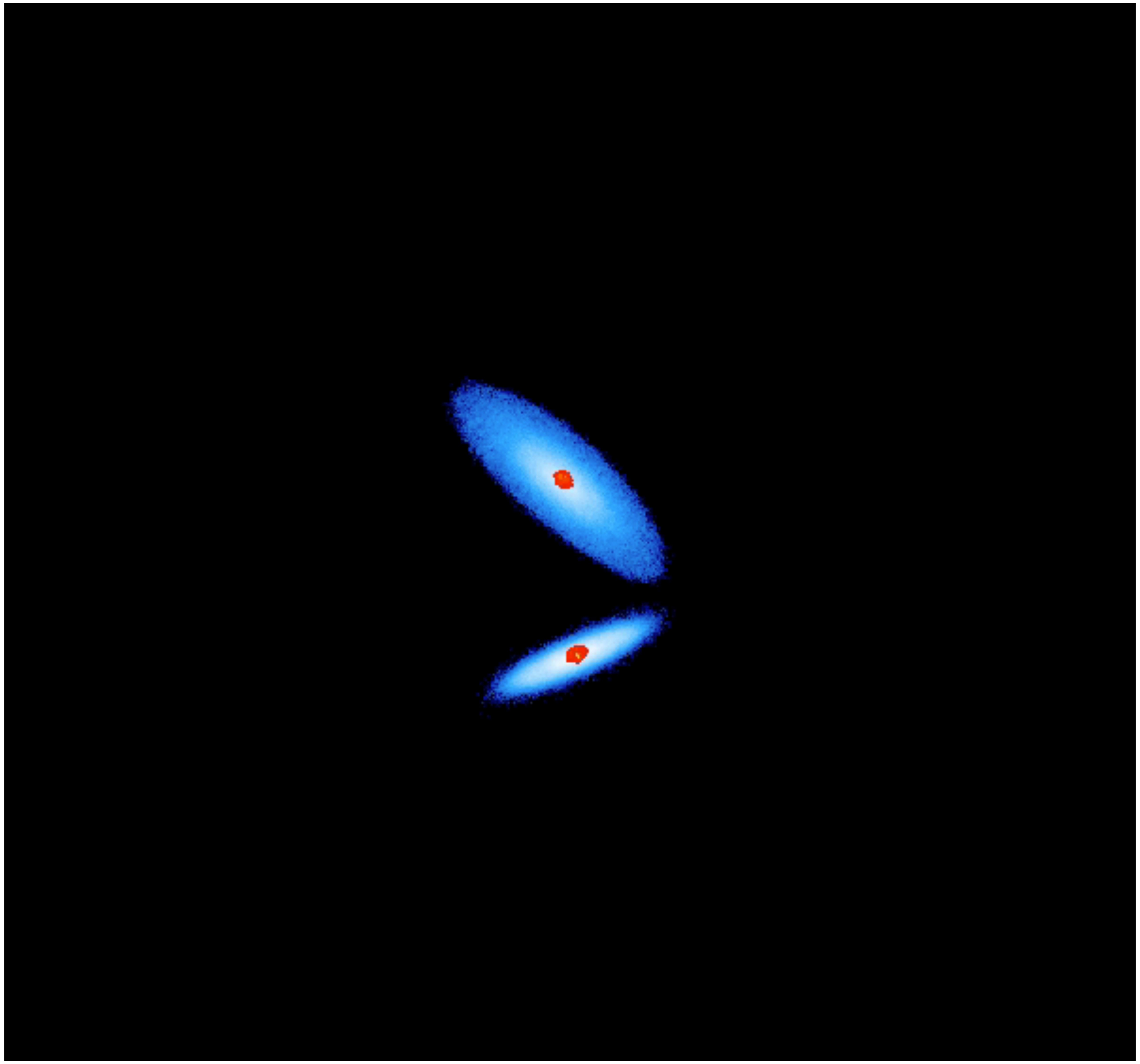
Renaud et al. (2011)

TIDAL COMPRESSION IN INTERACTIONS

Overlap of potentials → cores
= compressive tides

True for *all* interactions
Renaud et al. (2009)

Even if the potentials of the individual progenitors are cusps



red = tidal compression

TURBULENT MODES

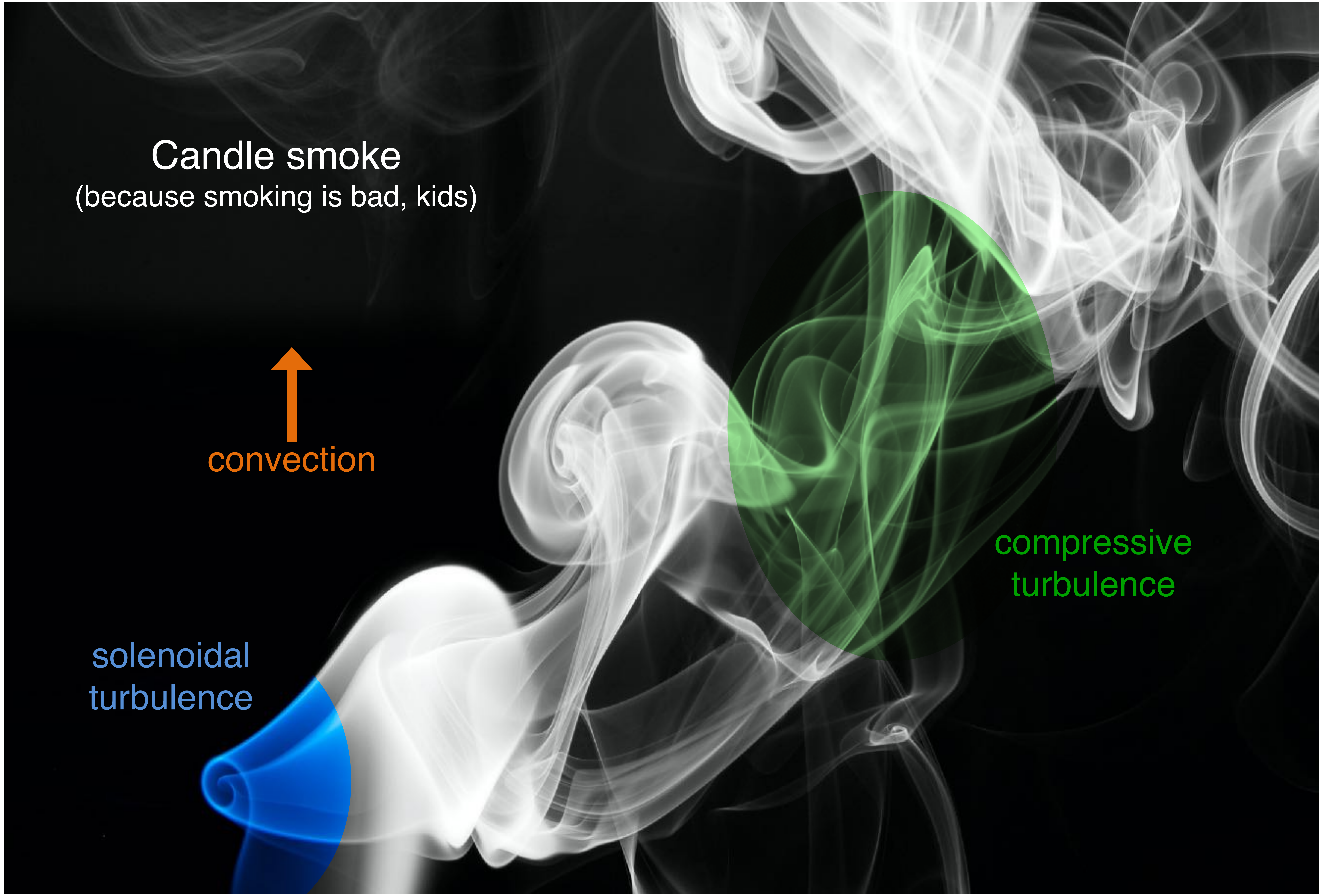
"When I meet God, I am going to ask him two questions: Why relativity? And why turbulence? I really believe he will have an answer for the first."   *-- W. Heisenberg*

Solenoidal
(divergence-free)

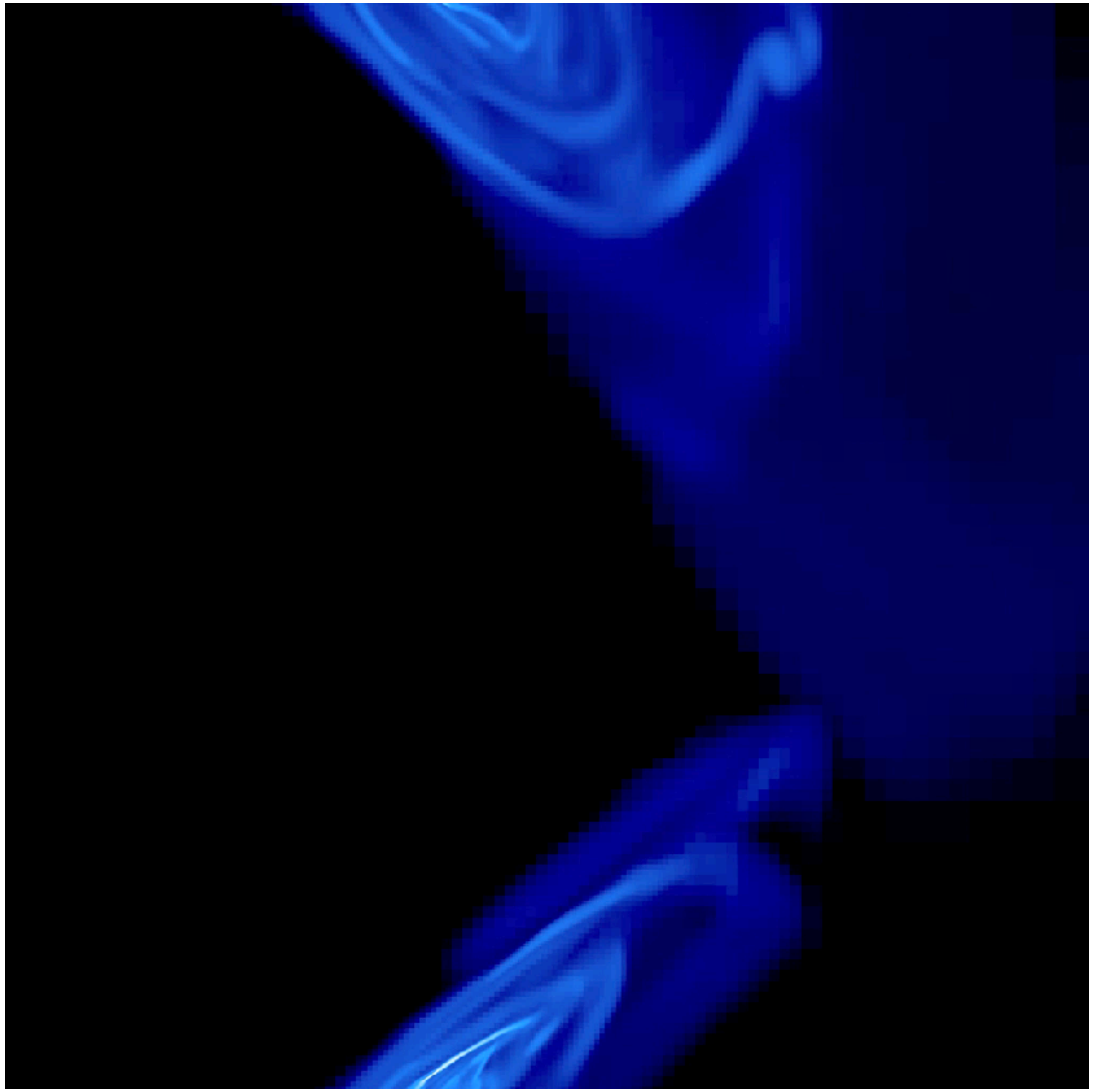
Compressive
(curl-free)

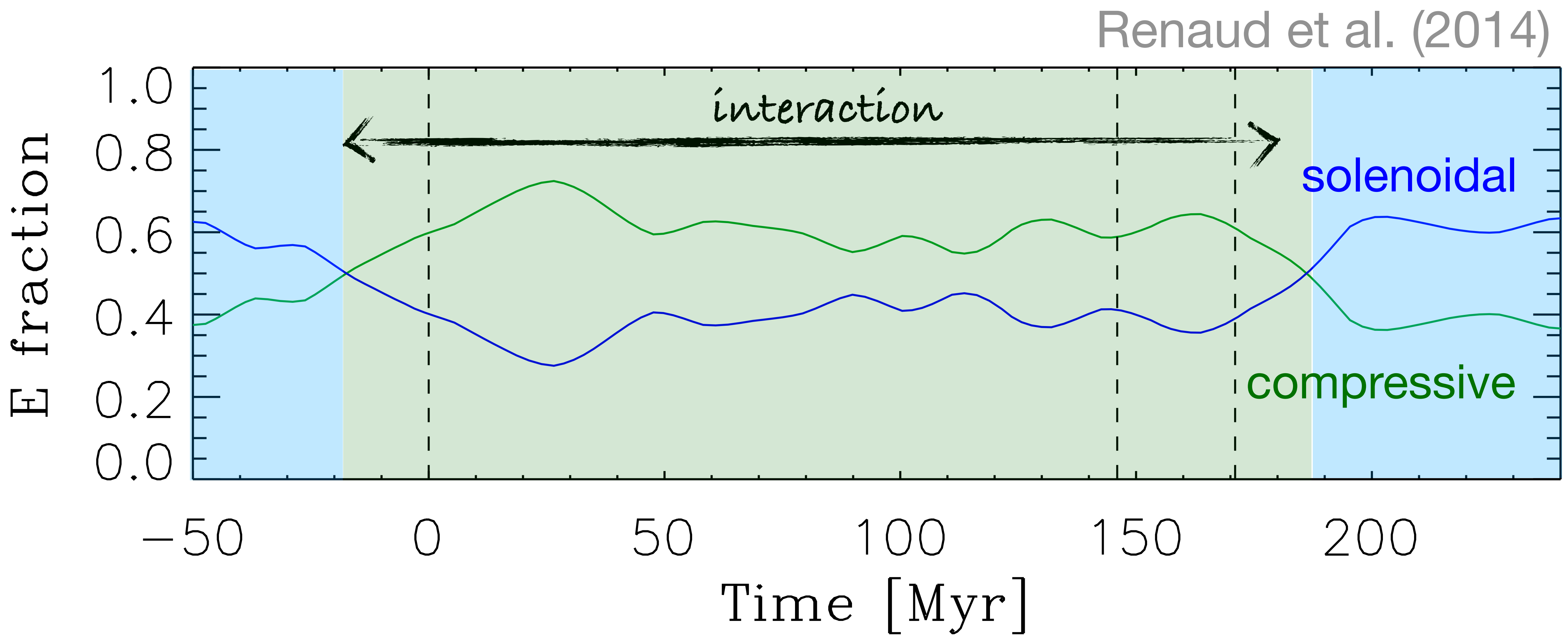
Kritsuk et al. (2007), Federrath (2010), Hennebelle & Falgarone (2012)

In the ISM (inter-sofa medium) of my living room



Interactions change the nature of turbulence





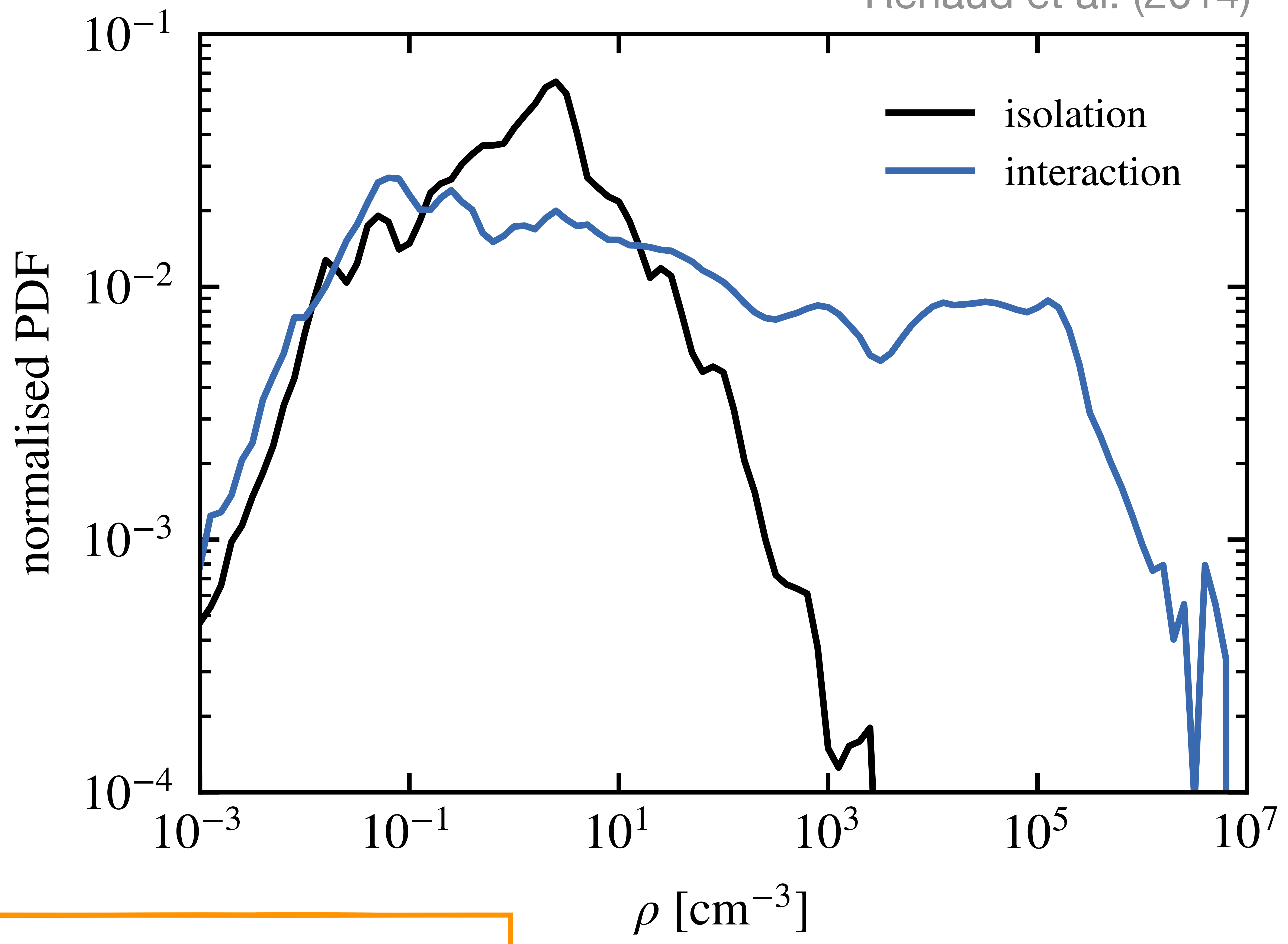
In interacting galaxies: Excess of dense gas

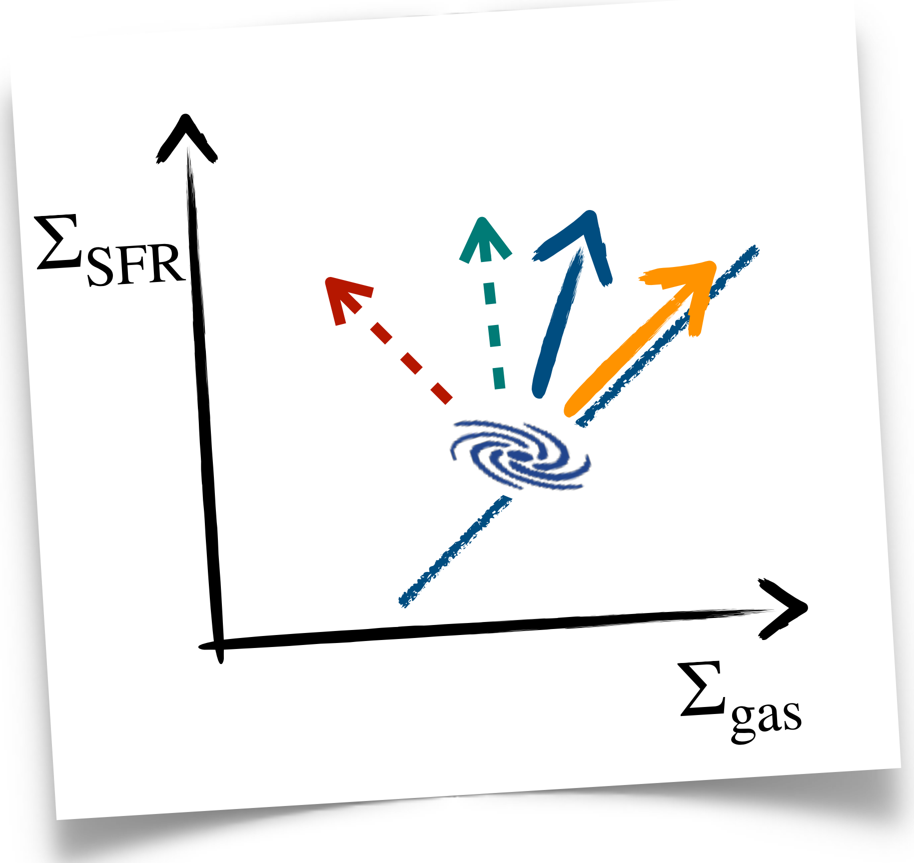
Before interaction: ~log-normal PDF
Vazquez-Semadeni (1994)

During interaction: excess of dense gas

Change of the shape
not a shift, not a widening!

Renaud et al. (2014)



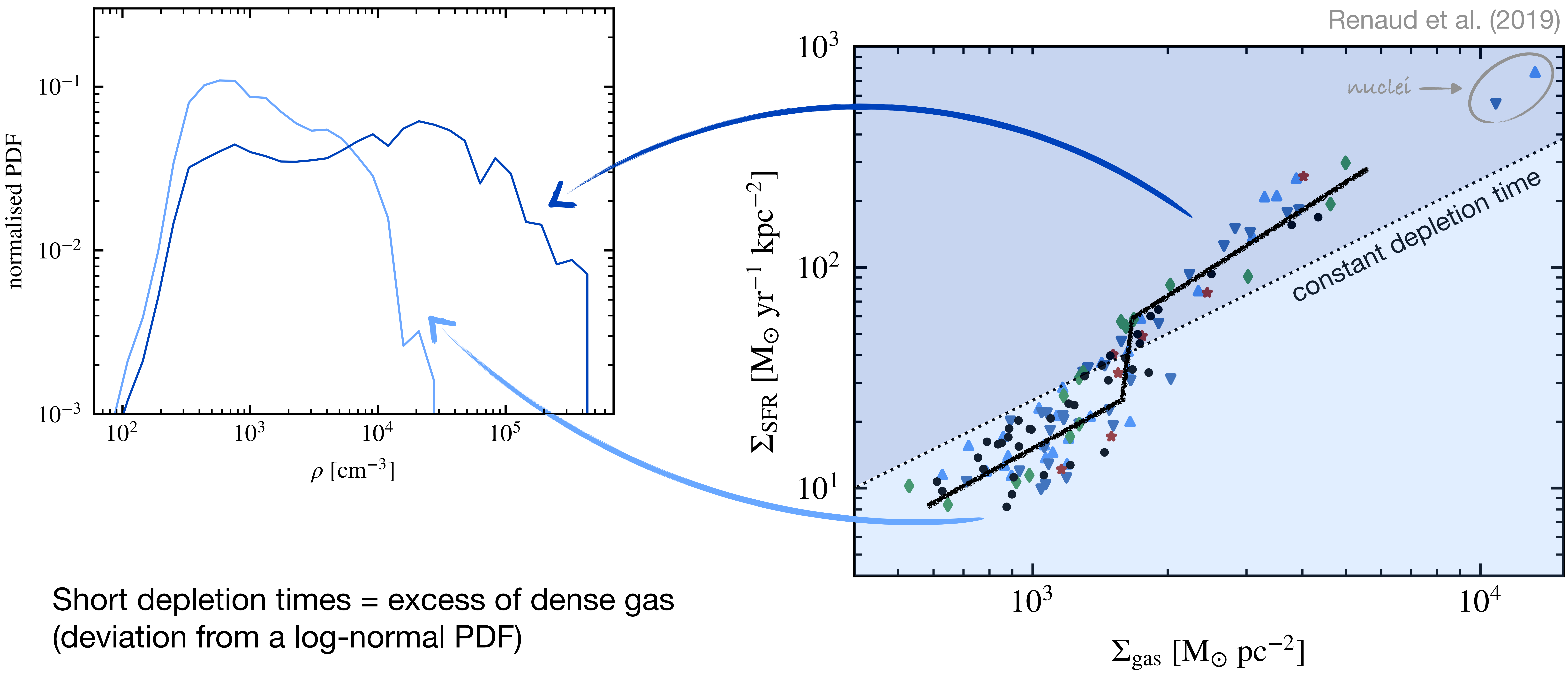


Log-normal vs. excess:

- More gas with the same log-normal distribution
  → move along the disk regime

- Excess of dense gas (e.g. mergers)
  → different regime (not canonical KS anymore)

Cloud-by-cloud



Short depletion times = excess of dense gas
(deviation from a log-normal PDF)

How to starburst: (3) Tidal and turbulent compressions

(1) Gravitational trigger
long-range, large-scale

(2) Hydro conveyor
cascading to small-scales

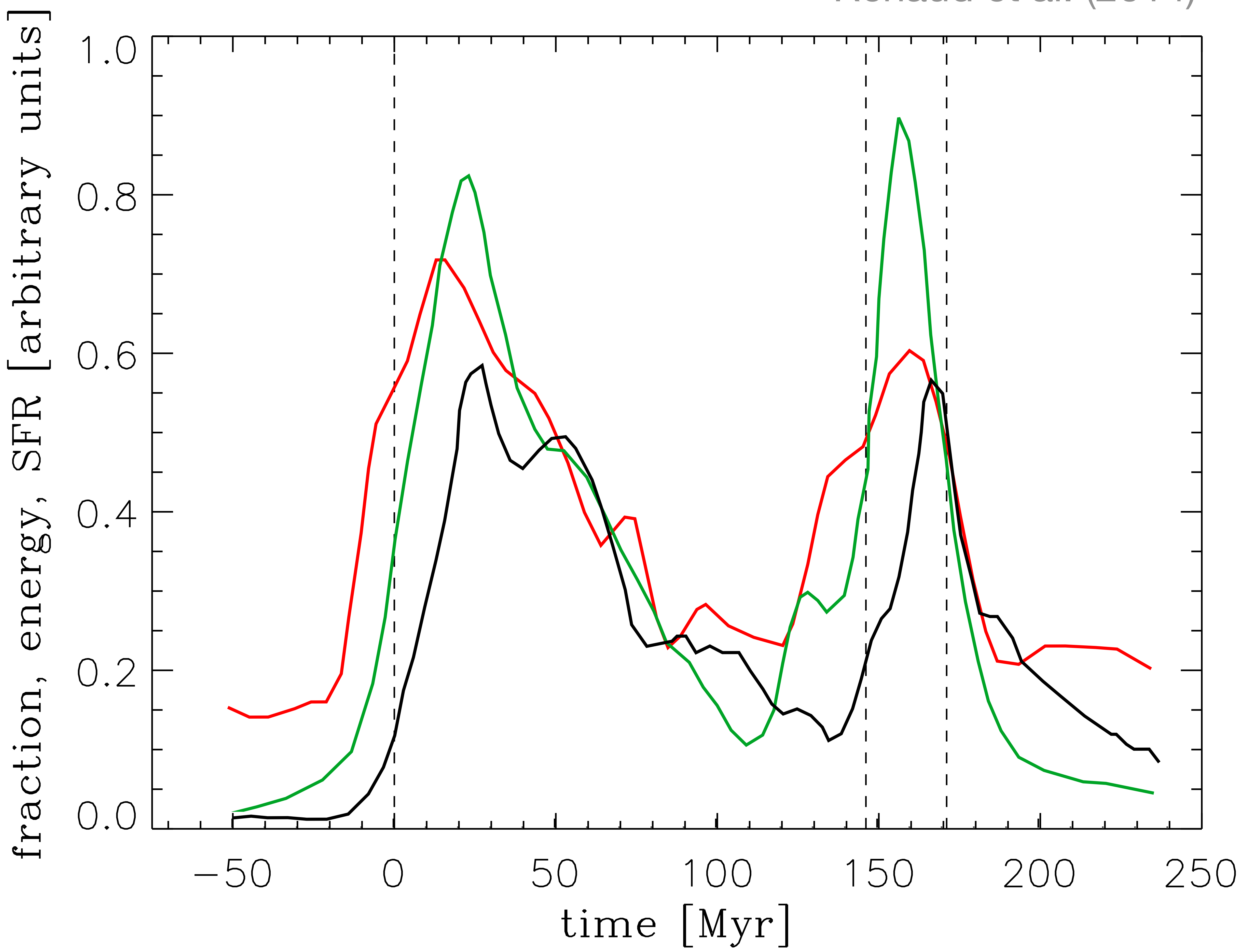
(3) Result
starburst

— compressive tides
(gas mass fraction)

— compressive turbulence
(energy)

— SFR

Renaud et al. (2014)




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

Effects of mergers

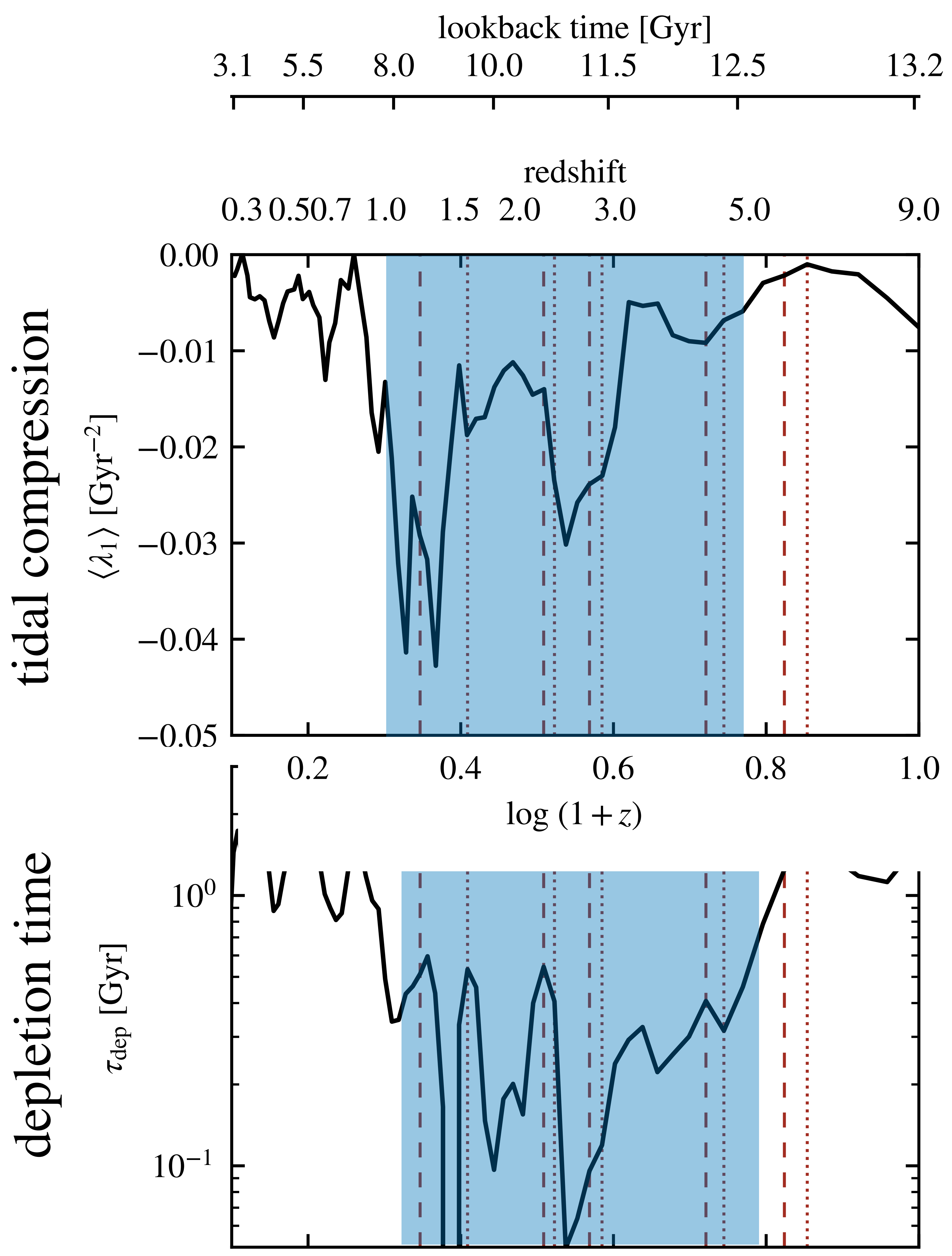
Renaud et al. (2022)

Major mergers induce strong tidal compression...

... which triggers starbursts (= short depletion time)

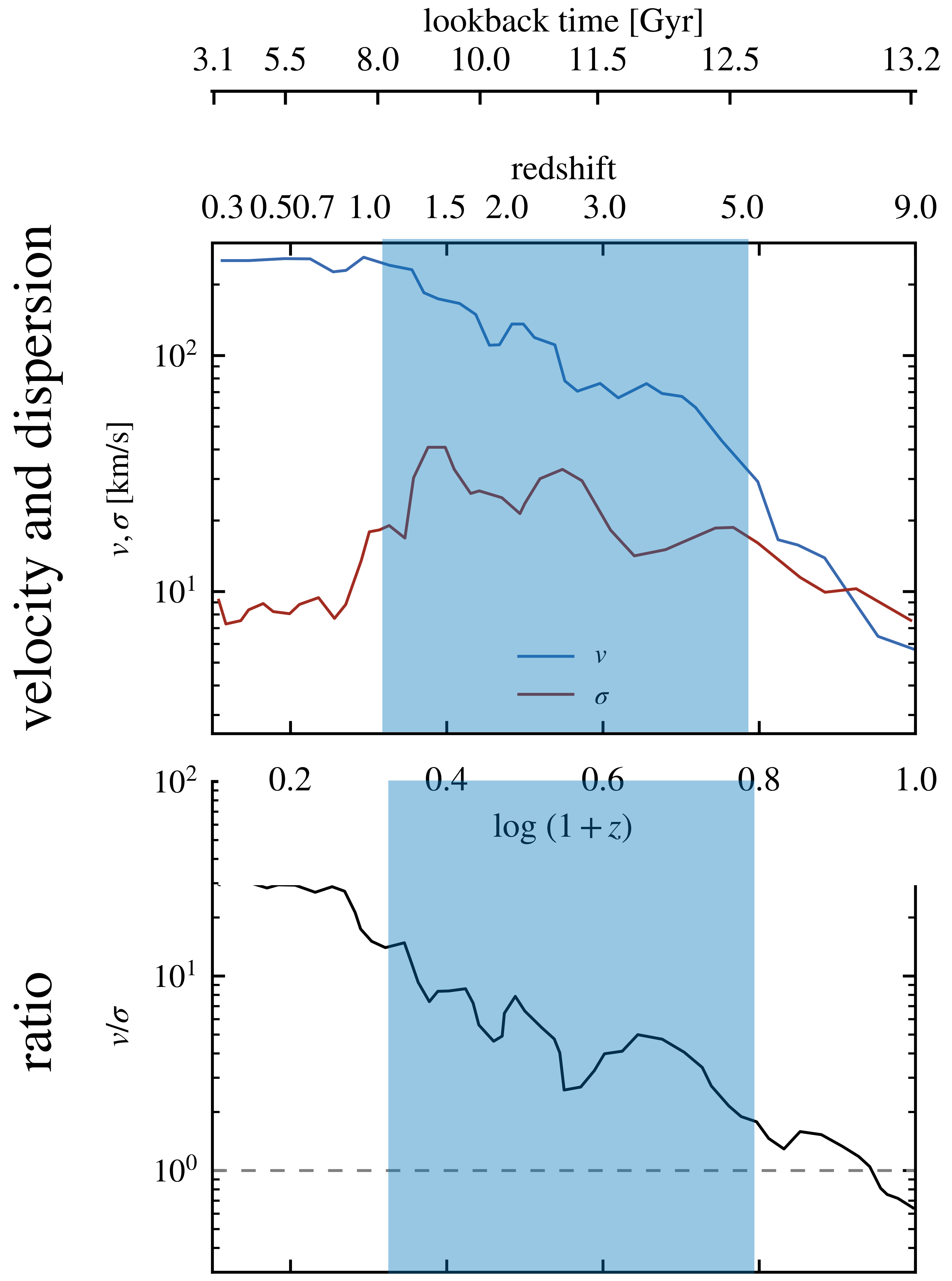
Same as in isolation

But not at high redshift...



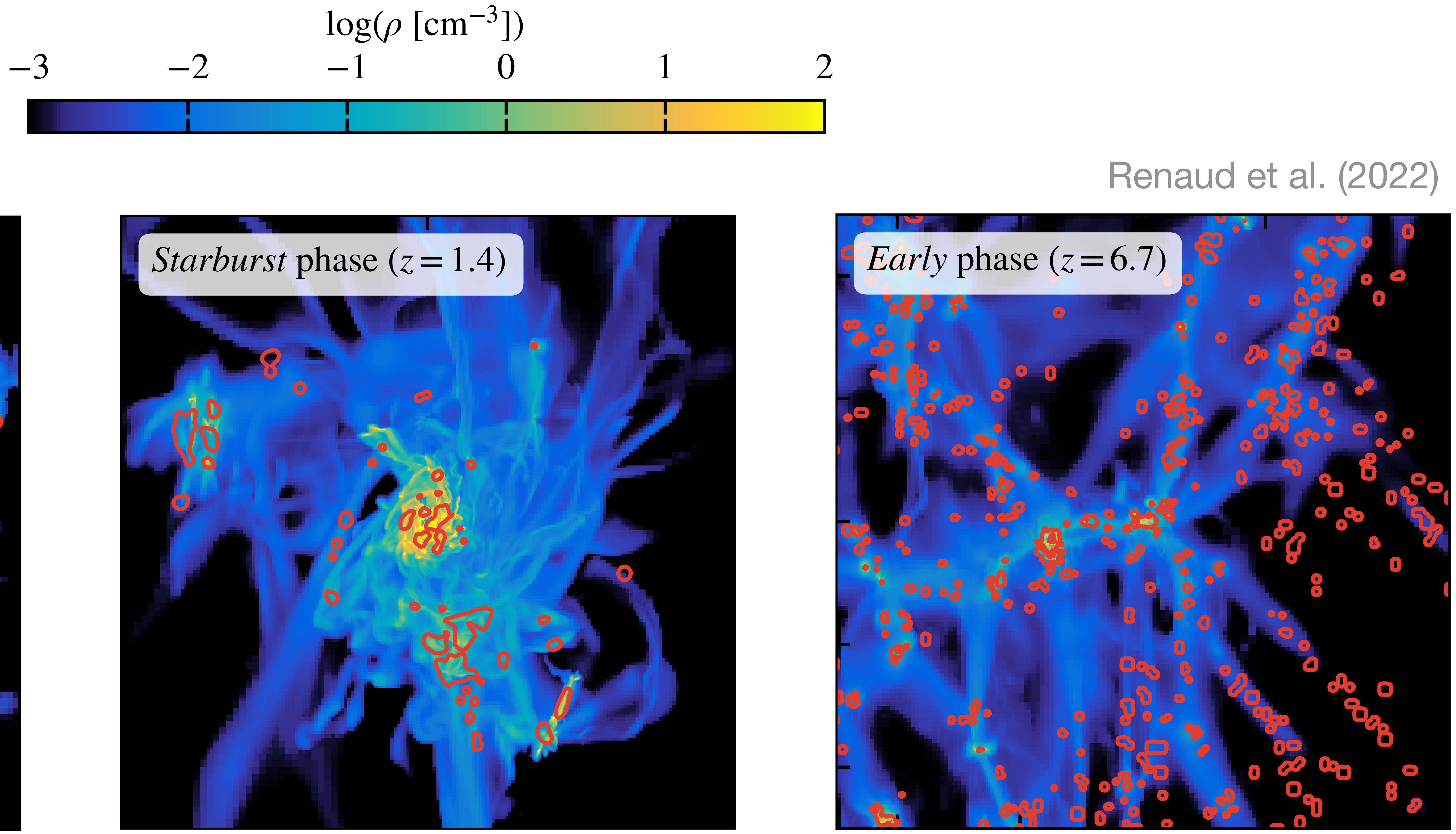
DISK EMERGENCE

No coherent response to interactions before organized motions are in place



VINTERGATAN IV (Segovia Otero et al. 2022)

Compressive volumes



Large volumes of **weak** compression

Large volumes of **strong** compression

Many small volumes of **very weak** compression

Instabilities leads to the formation of massive gas clumps
Elmegreen et al. (2007), Genzel et al. (2008), Guo et al. (2015), Huertas-Company (2020), Renaud et al. (2021) ...

Intrinsic high SFR
Bournaud et al. (2011), Zanella et al. (2015)

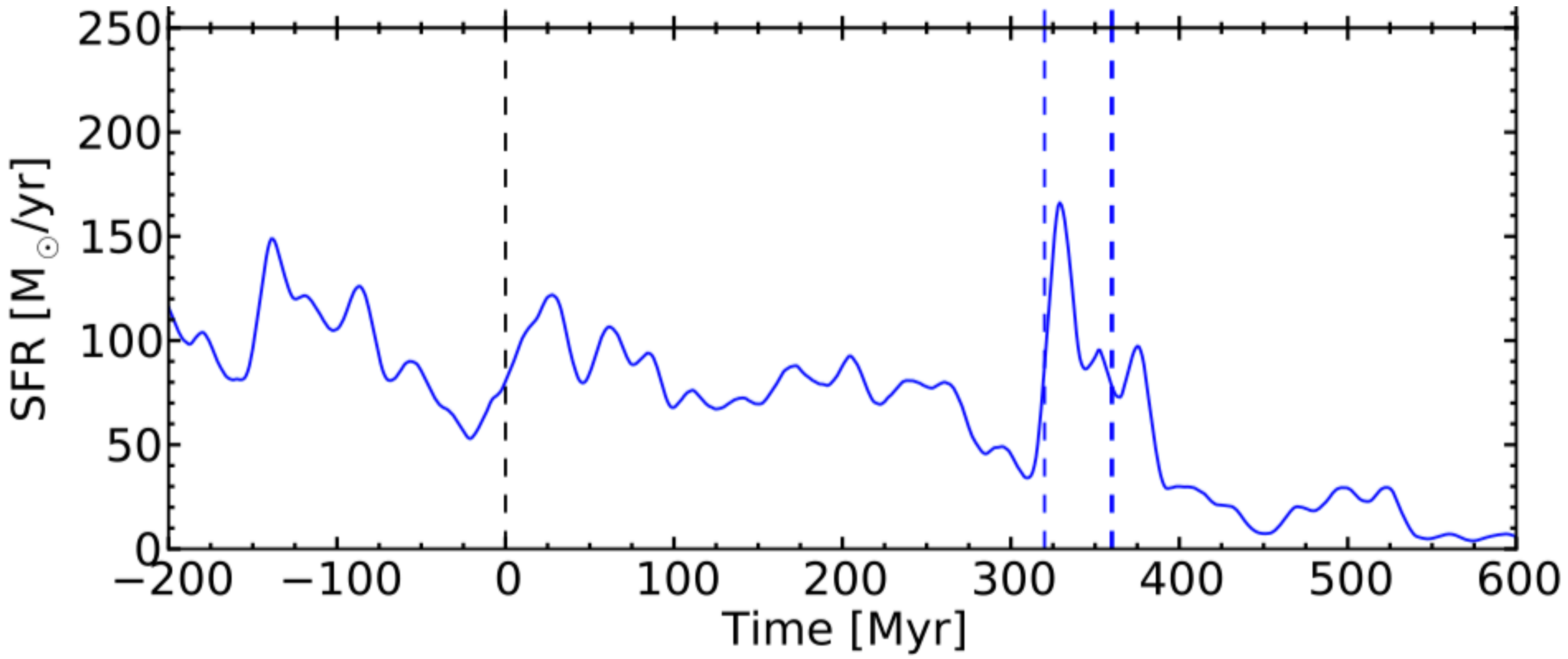
Very weak starburst in these mergers
Hopkins et al. (2013), Perret et al. (2014), Scudder et al. (2015), Fensch et al. (2017)

Saturation of the SF triggers?

Not visible in all cosmological simulations

Too low resolution? Too fast gas consumption?

Too much "effect" of the cosmic web?
but Avishai claims cold flows help clump formation...



Conclusions

Interactions *can* trigger starbursts because of

- torque-driven nuclear inflows
- cloud-cloud collisions
- tidally-induced turbulent compression

But not before the disk is in place

Not in clumpy disks. Why?