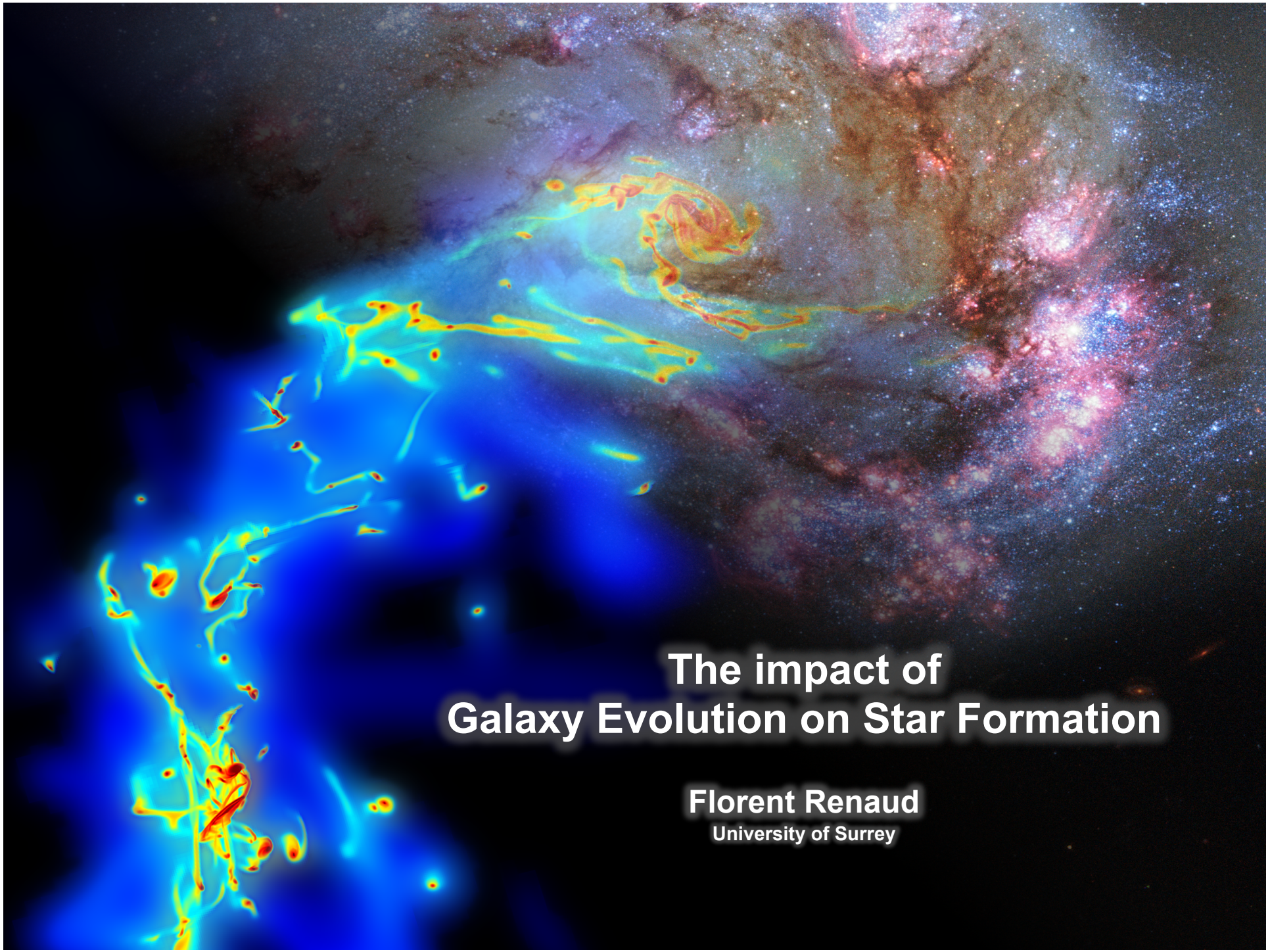


The impact of Galaxy Evolution on Star Formation

Florent Renaud
University of Surrey

(One of) The Problem of Cosmology Simulations

Sub-grid recipes
Galactic disk barely resolved (100 pc)

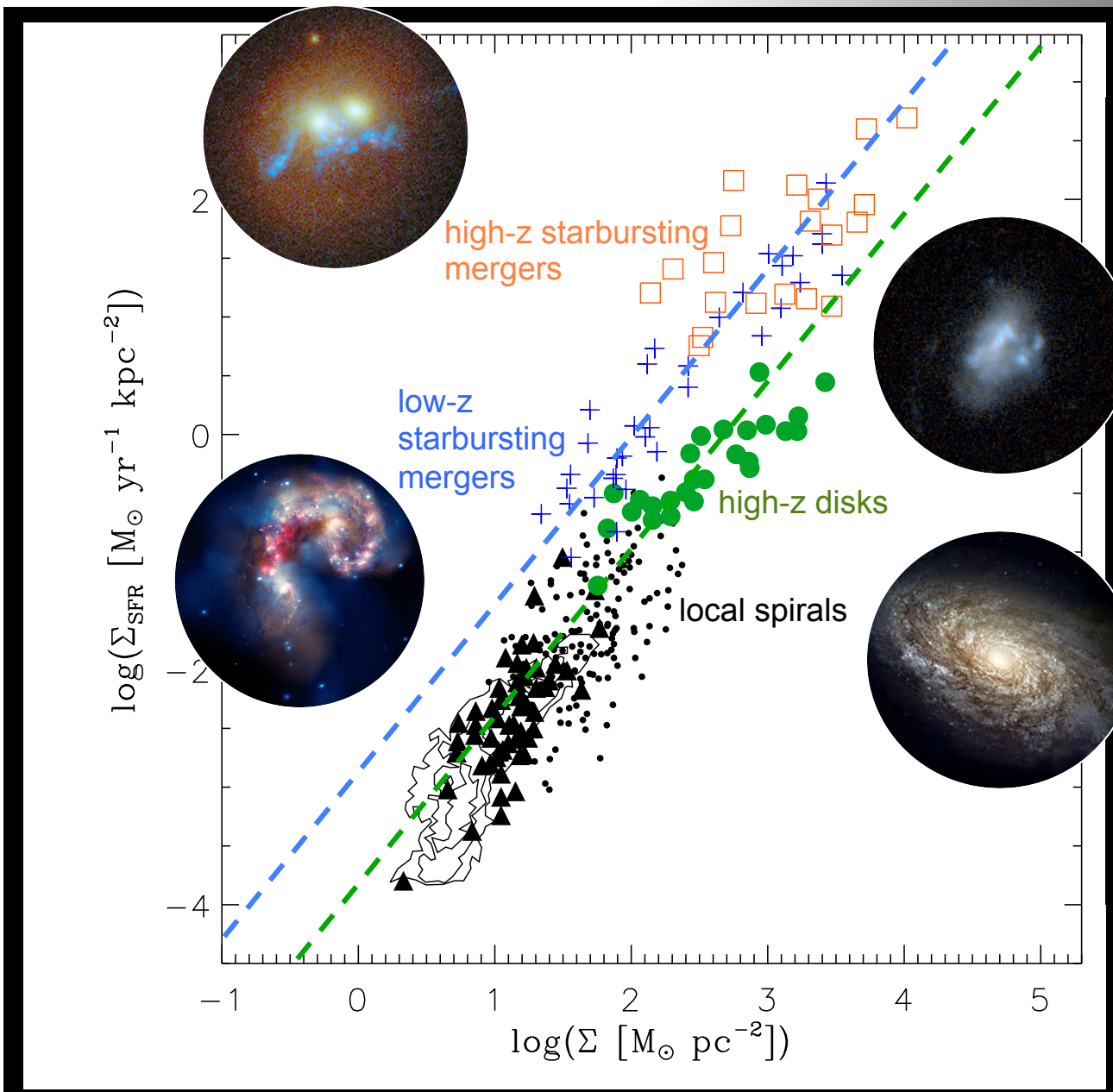
Movie by O. Agertz

(One of) The Problem of Small Scale Simulations

Movie by M. Bate

Arbitrary or idealised initial / boundary conditions
(geometry, turbulence spectrum ...)

UNIVERSALITY OF STAR FORMATION?



Kennicutt+1998

Kennicutt+2007

Bigiel+2008

Tacconi+2010 ; Daddi+2010a

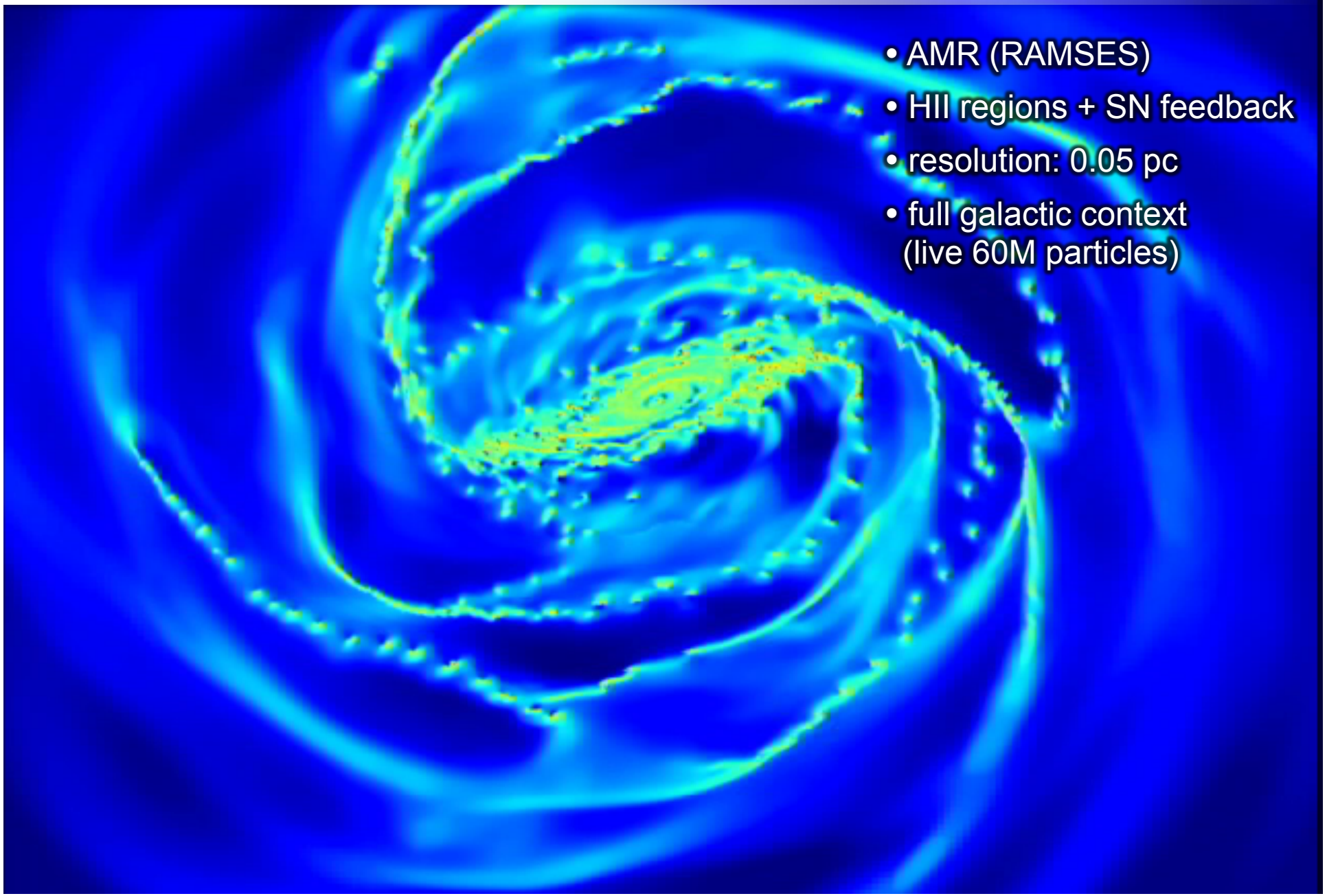
Kennicutt+1998

Bouché+2007 ; Bothwell+2009

widely inspired by Daddi+2010b
(see also Genzel+2010)

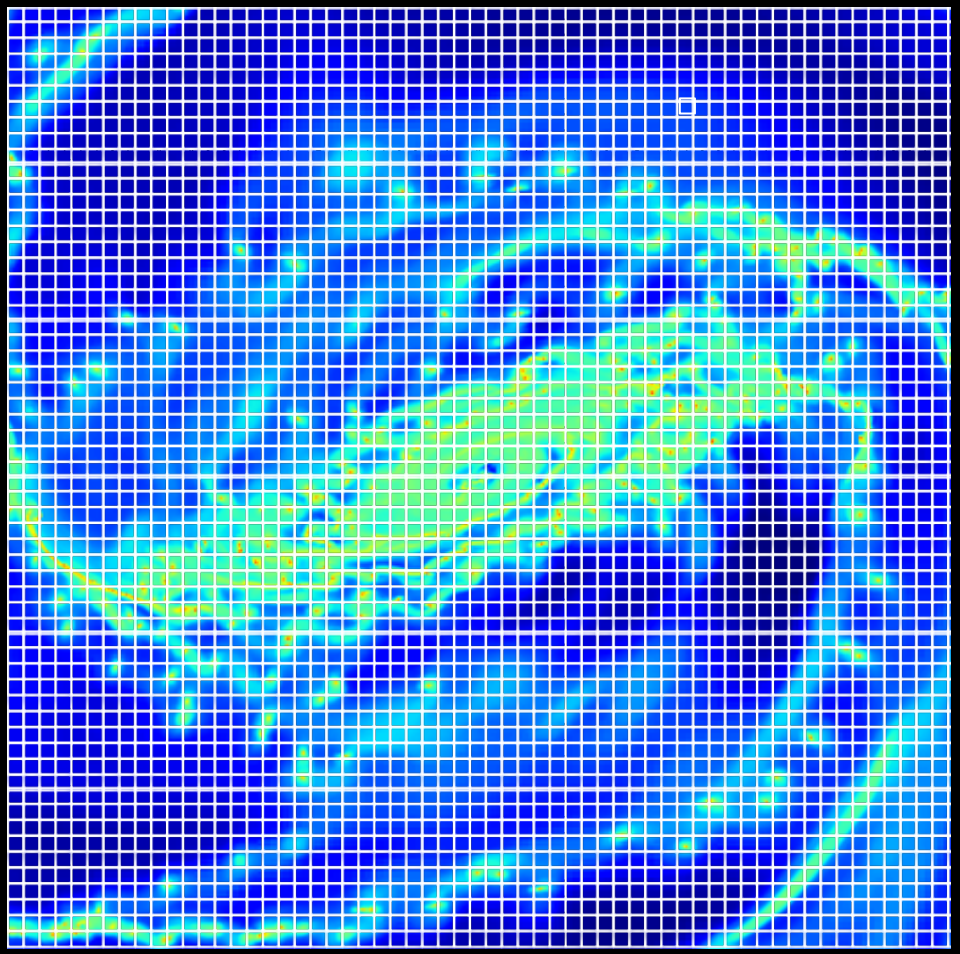
The Milky Way

Renaud et al. (2013)



SF at 100 pc Scale

Kraljic, Renaud et al. (2014)



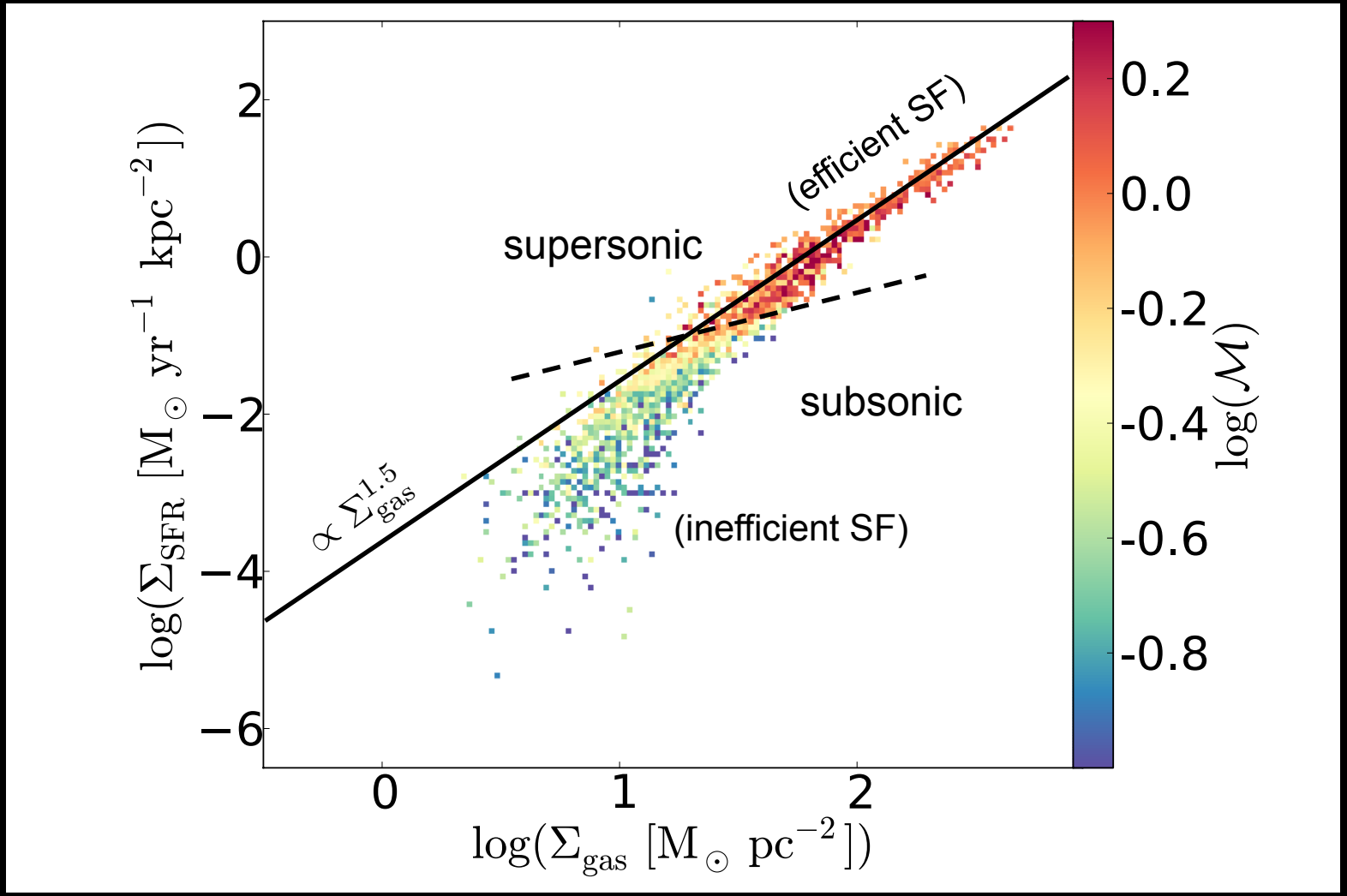
= 100 pc * 100 pc

Σ_{gas}

Σ_{SFR}

SCHMIDT-KENNICUTT RELATION

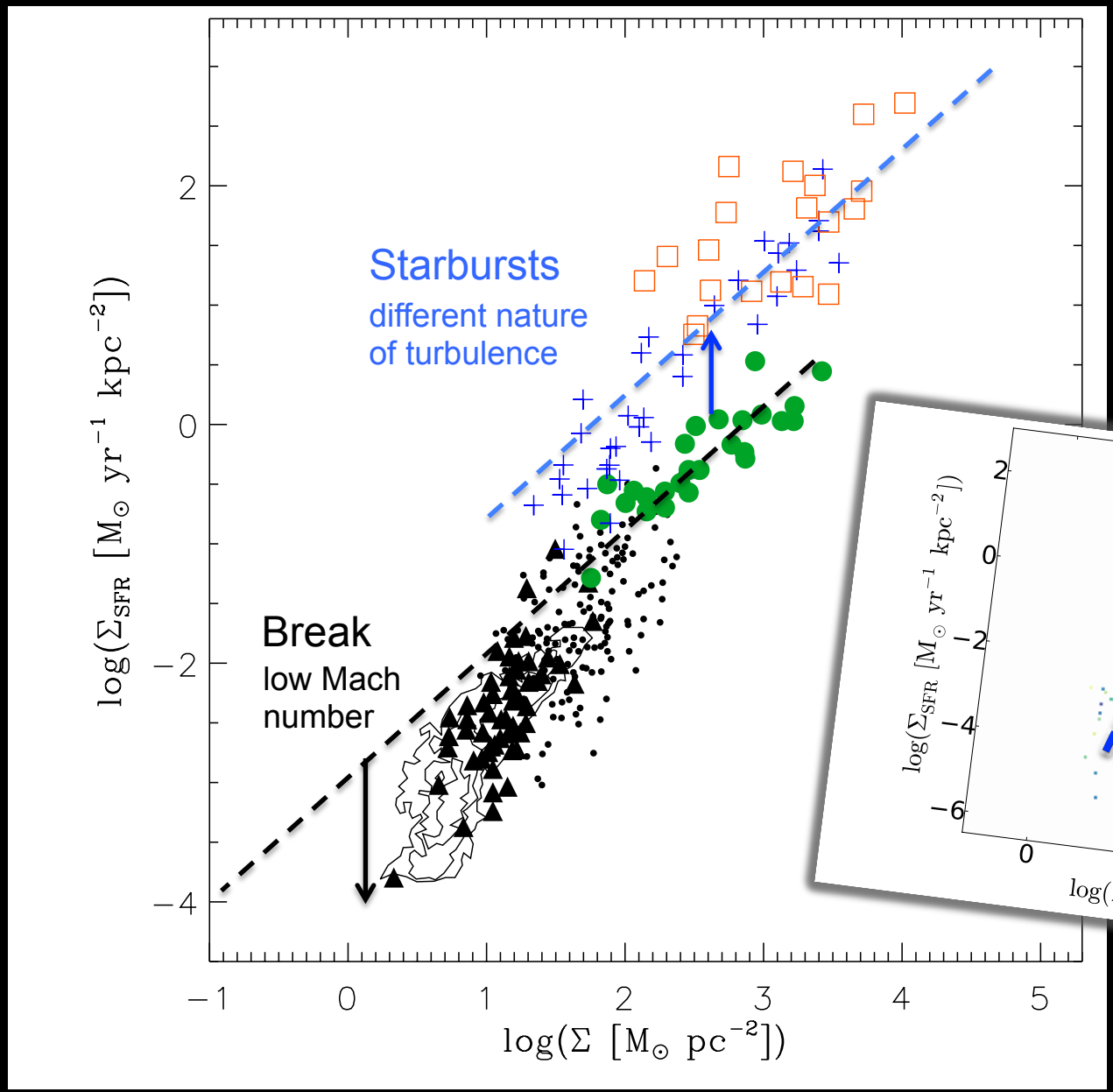
Kraljic, Renaud et al. (2014)

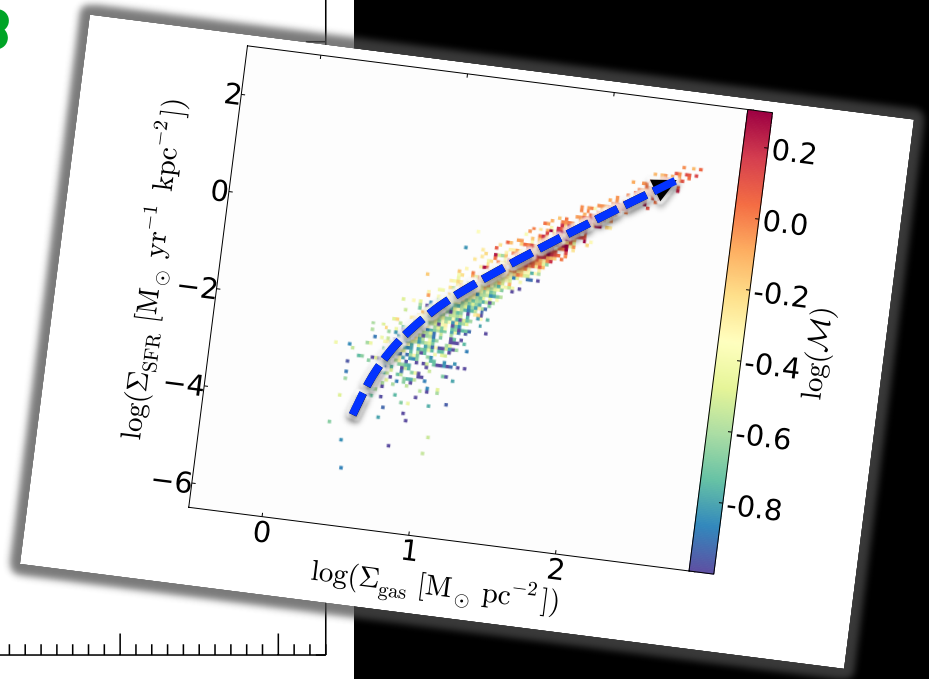


(See also theoretical prediction in Renaud, Kraljic & Bournaud 2012)

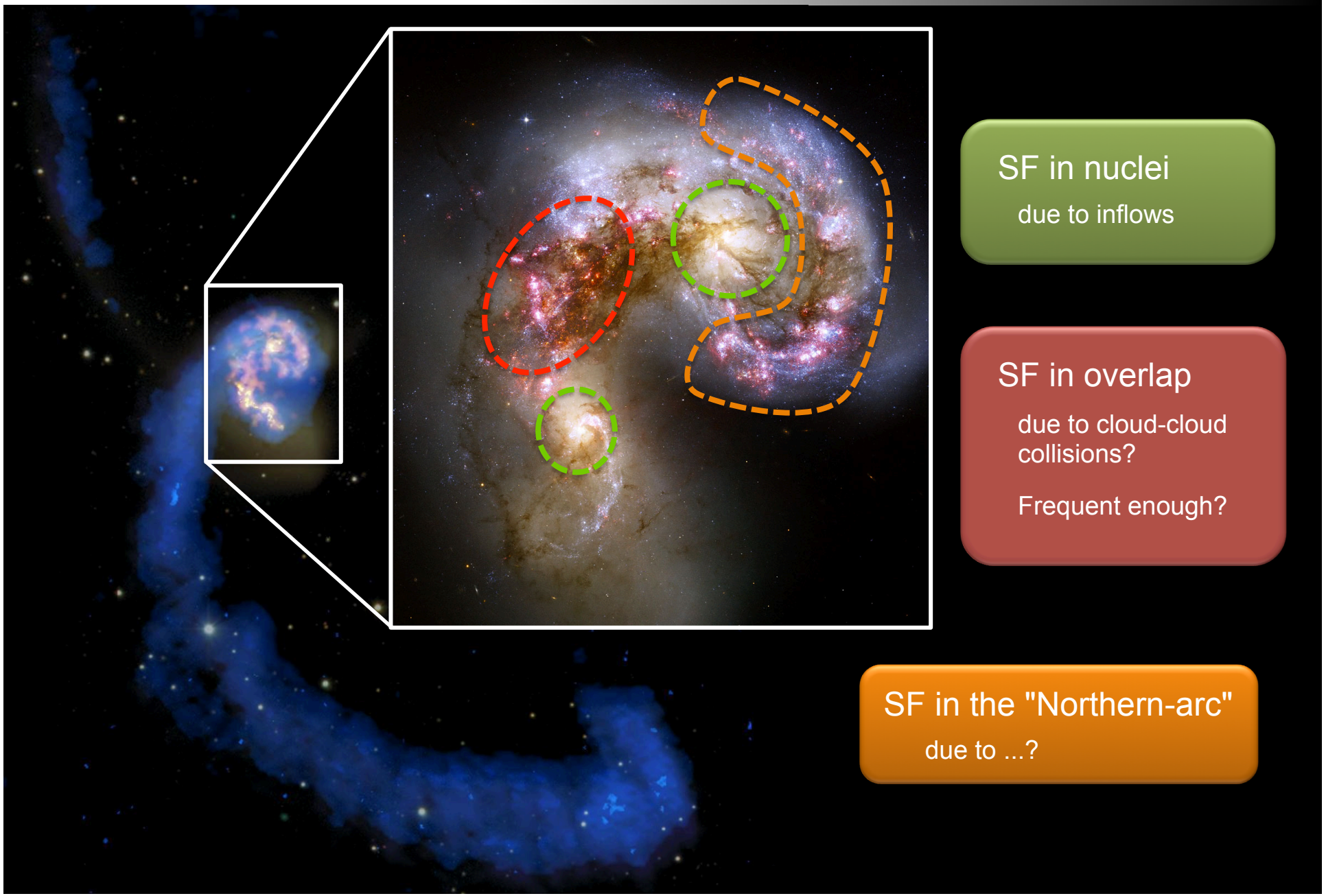
Variations of turbulence → spread in SF efficiencies

What about Starbursts?





Extended Starbursts



SF in nuclei

due to inflows

SF in overlap

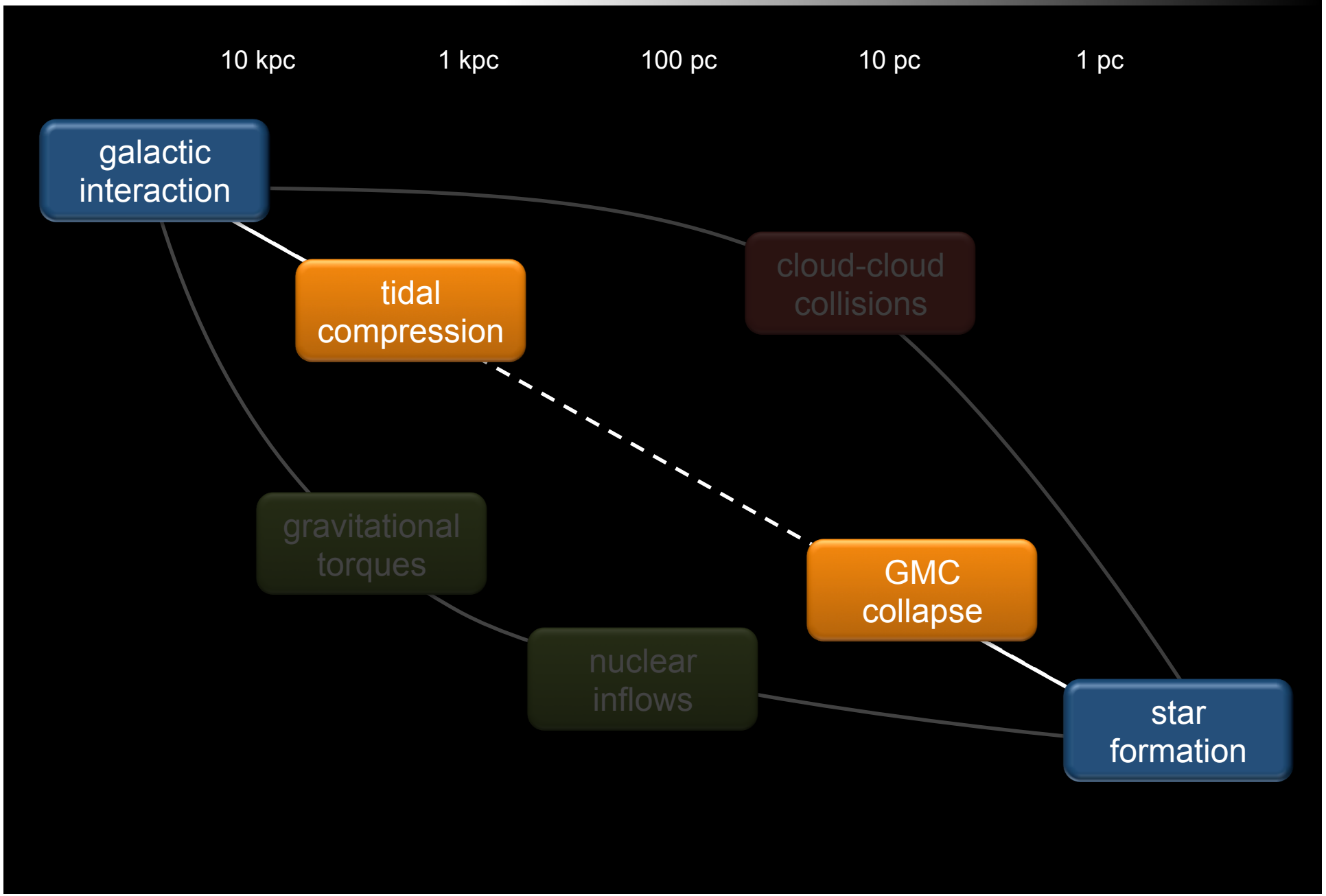
due to cloud-cloud collisions?

Frequent enough?

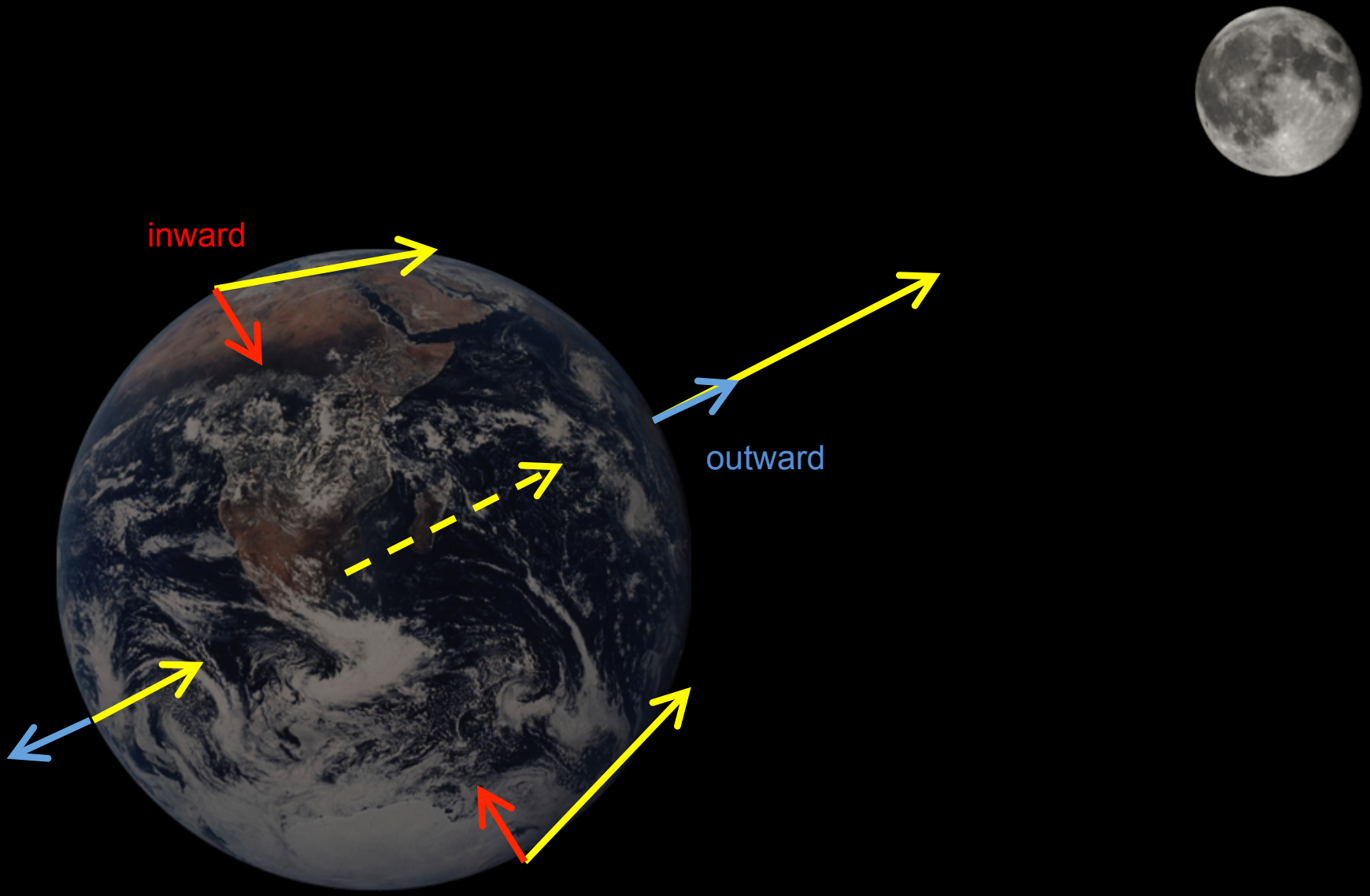
SF in the "Northern-arc"

due to ...?

Triggered, Enhanced Star Formation

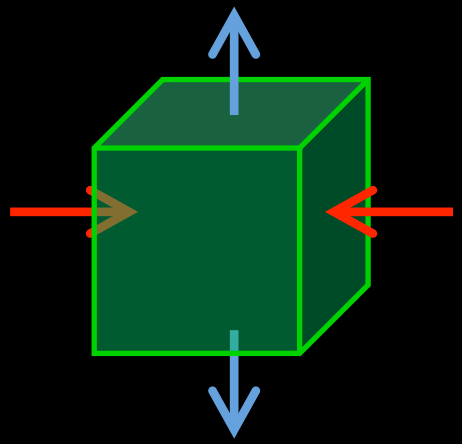


A Quick Reminder about Tides



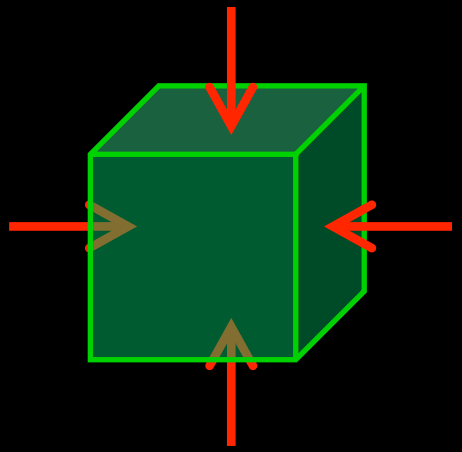
Tidal Modes

extensive mode



- Earth-Moon
- Dominant in galaxies

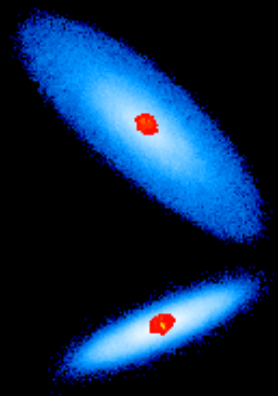
compressive mode



- Galactic cores
- Important in mergers

COMPRESSIVE TIDES

Renaud et al. (2008, 2009)



Simulation of the Antennae (no hydro yet ...)

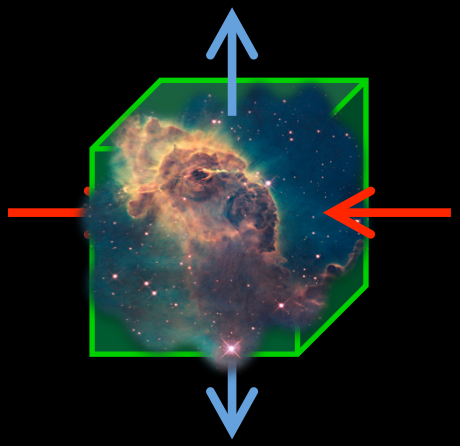
- triggered by the collisions
- Over large volumes
- Valid for all mergers

red = compressive tides

TIDES AND ISM STABILITY

Renaud et al. (2008, 2009)

extensive mode



- Earth-Moon
- Dominant in galaxies

$$\lambda > 0$$

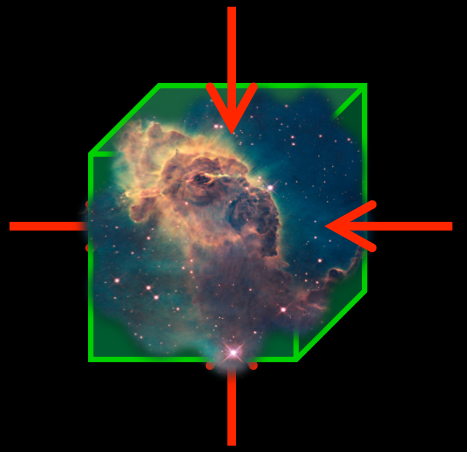
$$M'_{\rm Jeans} > M_{\rm Jeans}$$

no tides

$$\lambda = 0$$

$$M'_{\rm Jeans} = M_{\rm Jeans}$$

compressive mode



- Galactic cores
- Important in mergers

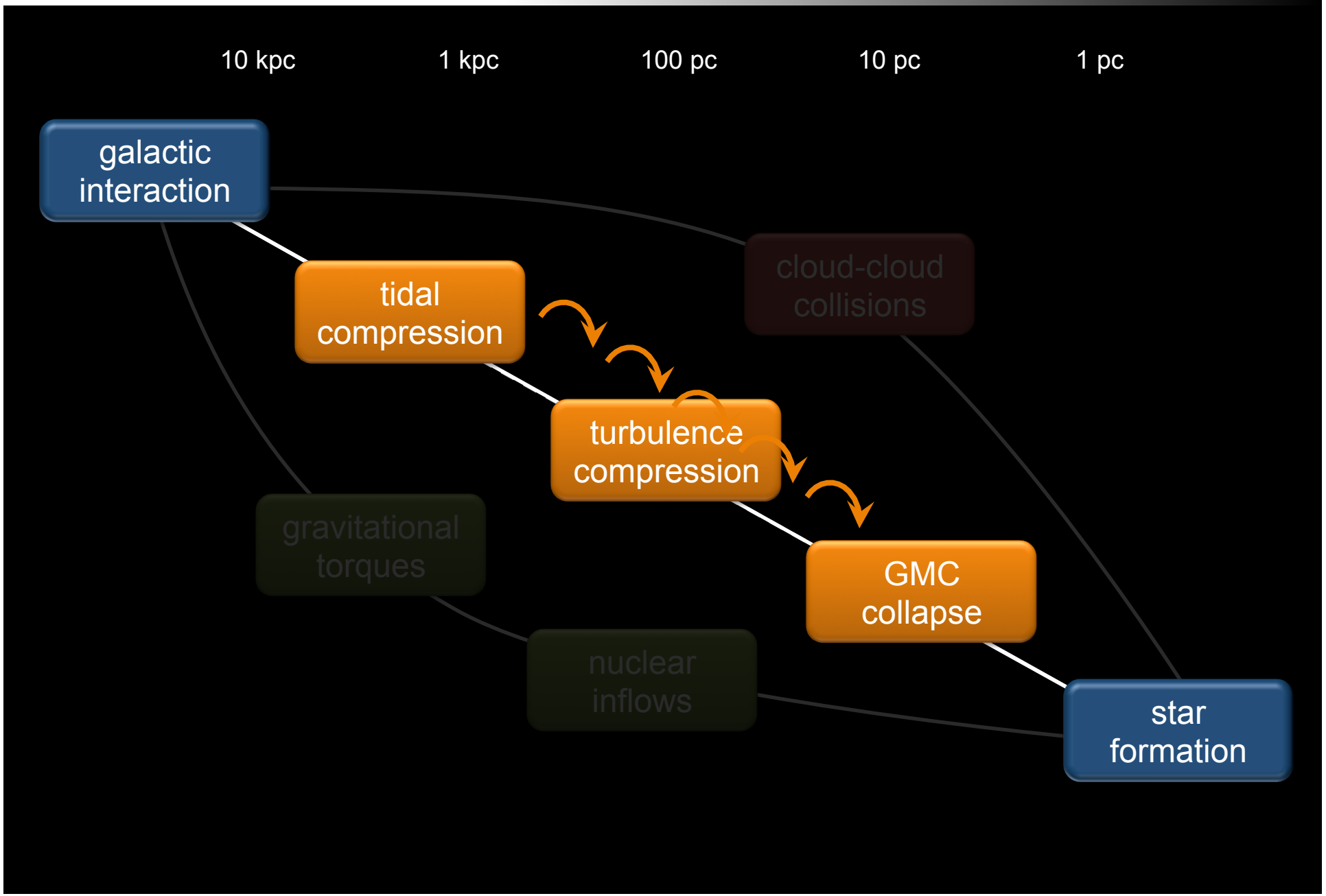
$$\lambda < 0$$

$$M'_{\rm Jeans} < M_{\rm Jeans}$$

$$M'_{\rm Jeans} = \frac{M_{\rm Jeans}}{(1-\lambda)^{3/2}}$$

Jog (2013,2014)

Triggered, Enhanced Star Formation



A Quick Reminder about Turbulence

Local velocity field =

net motion
(*average*)

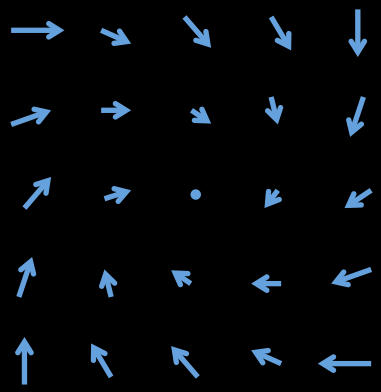
$\langle v \rangle$

Move it!

+

solenoidal
turbulence
(*curl*)

$\nabla \times v$

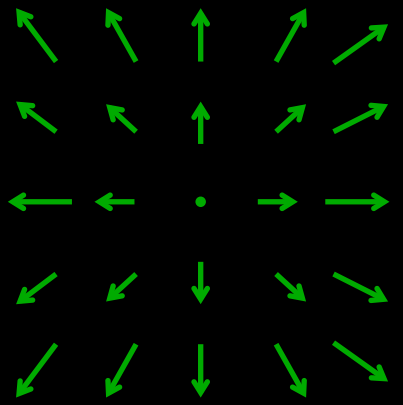


Mix it!

+

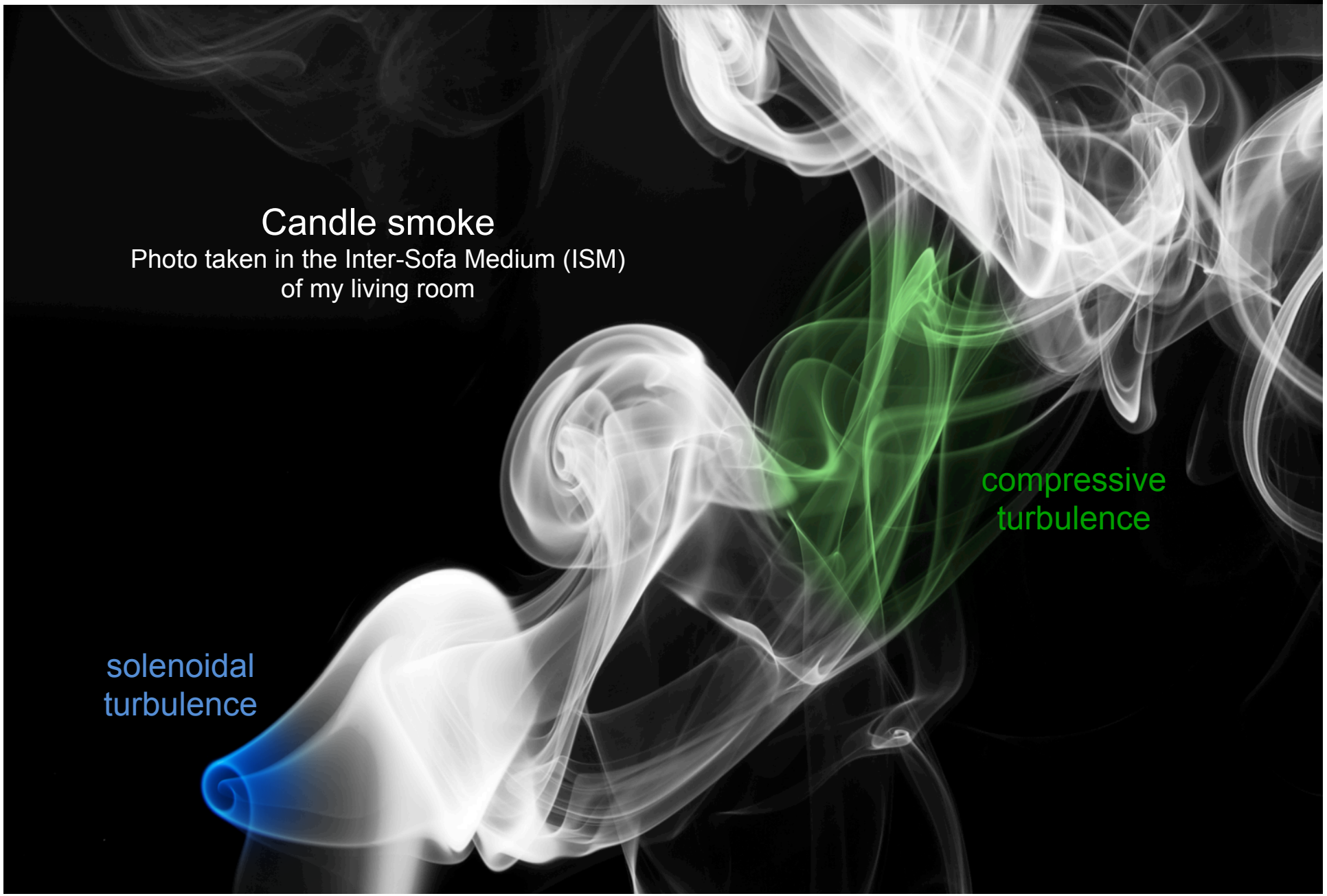
compressive
turbulence
(*divergence*)

$\nabla \cdot v$

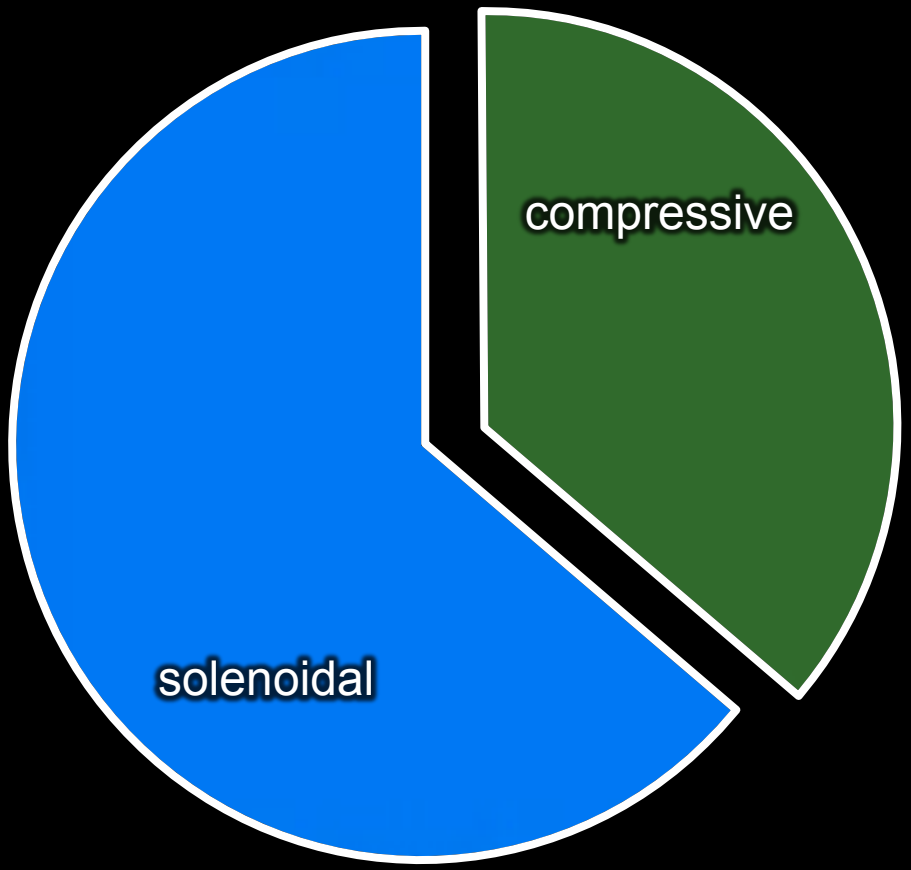


Pinch it!

Solenoidal and Compressive Turbulence



Solenoidal and Compressive Turbulence

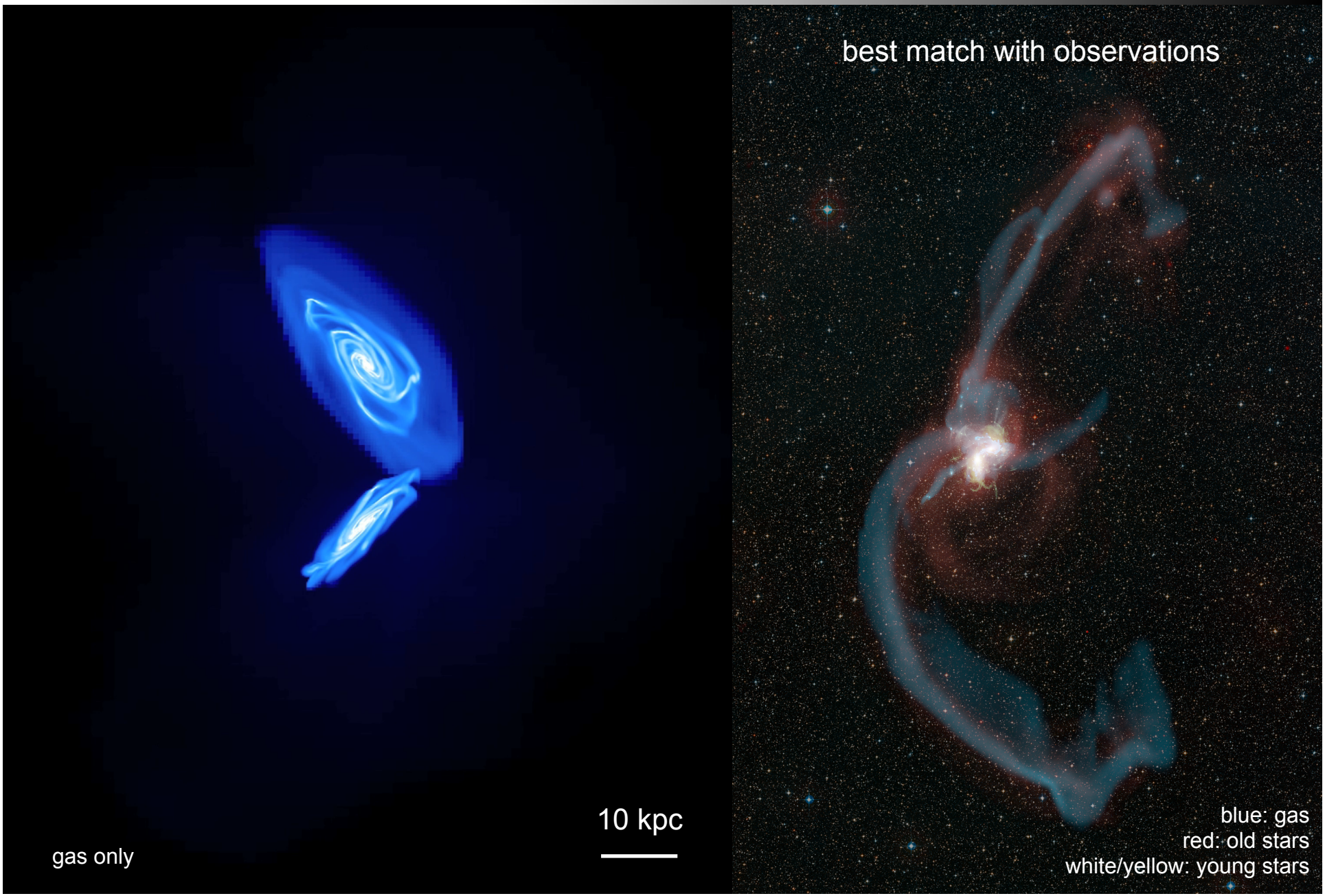


"Natural" turbulence energy budget
(i.e. with no external forcing)

Federrath et al. (2010)

Yet Another Simulation of The Antennae

Renaud, Bournaud & Duc (2014)



THE ANTENNAE

Renaud, Bournaud & Duc (2014)

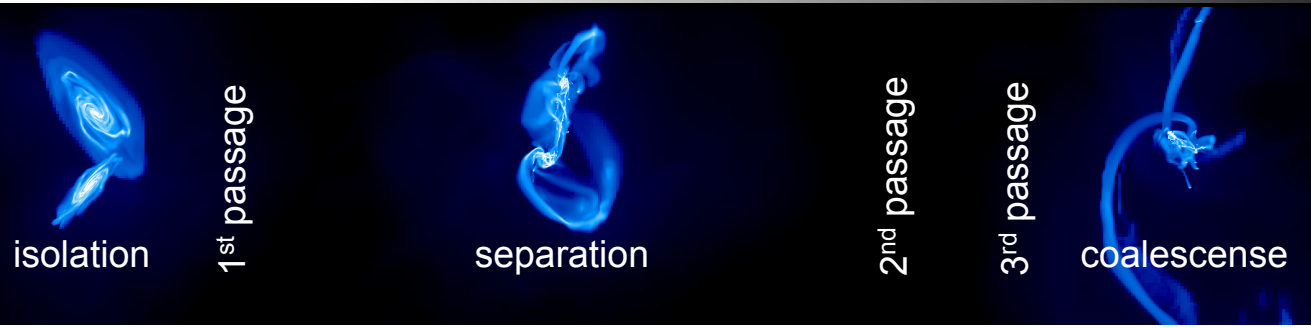
gas

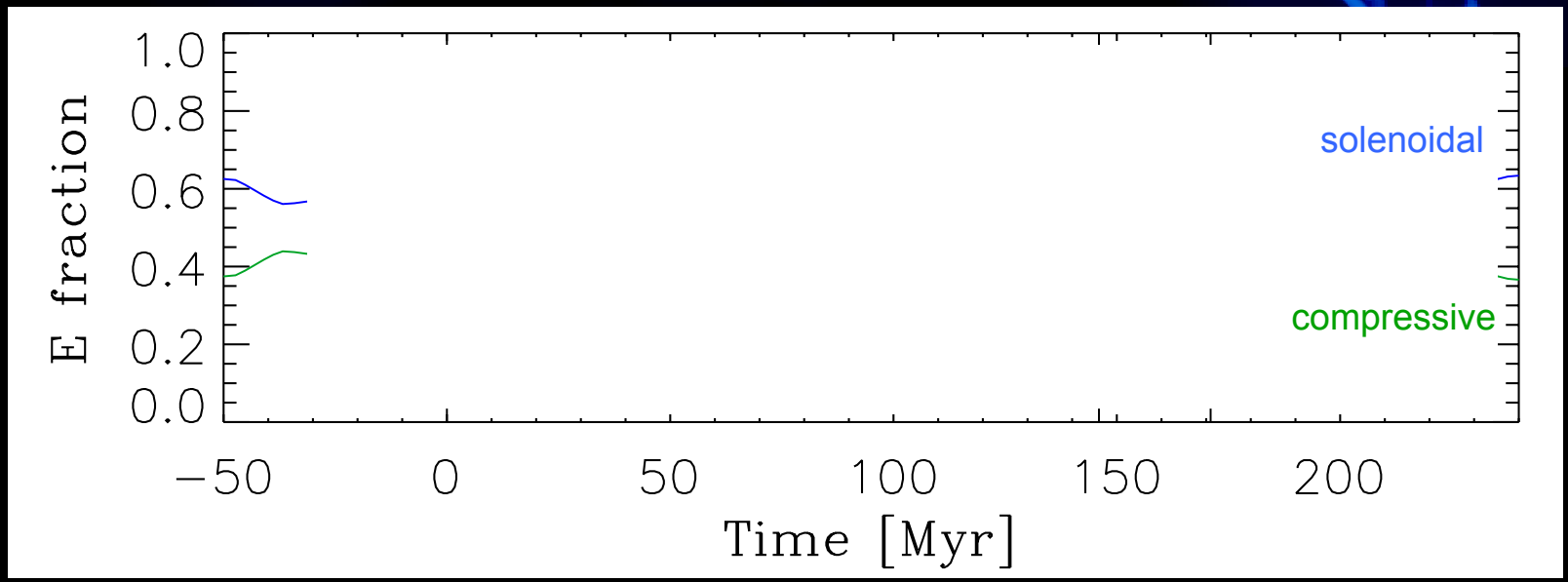
new stars

2 kpc

In a Merger

Renaud et al. (2014)



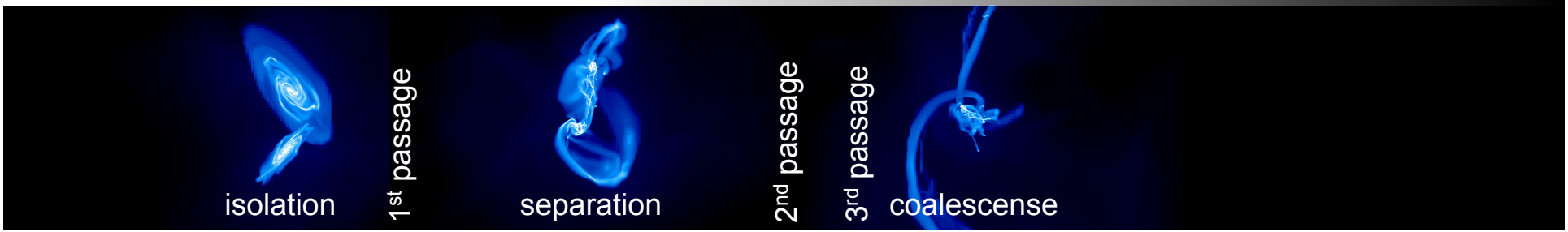


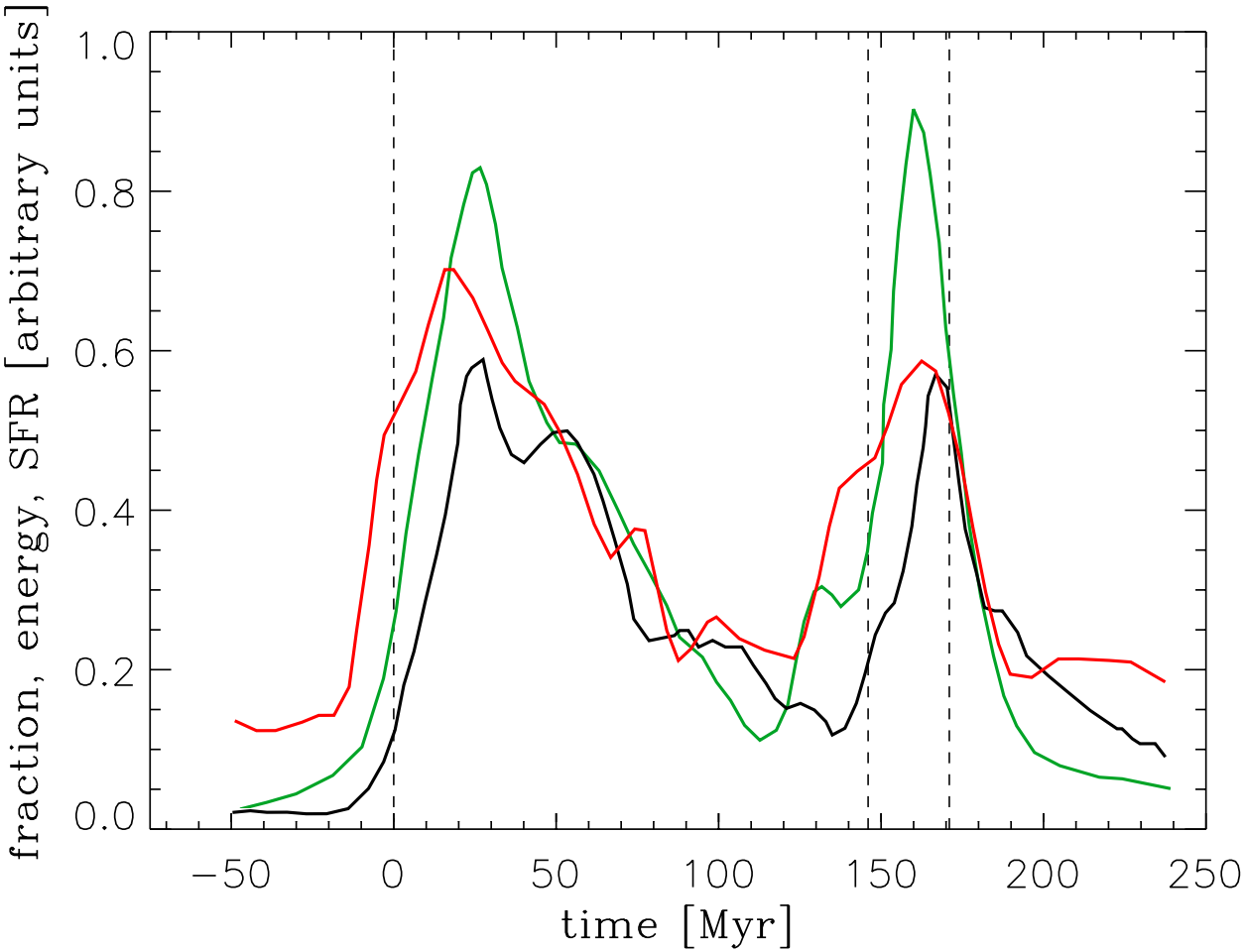
- Change the nature of turbulence
- Change how the ISM fragments
- Change the IMF (→ bottom-heavy)

Chabrier, Hennebelle & Charlot (2014)

TIME EVOLUTION

Renaud et al. (2014)





tides → turbulence → SF

20 – 30 Myr

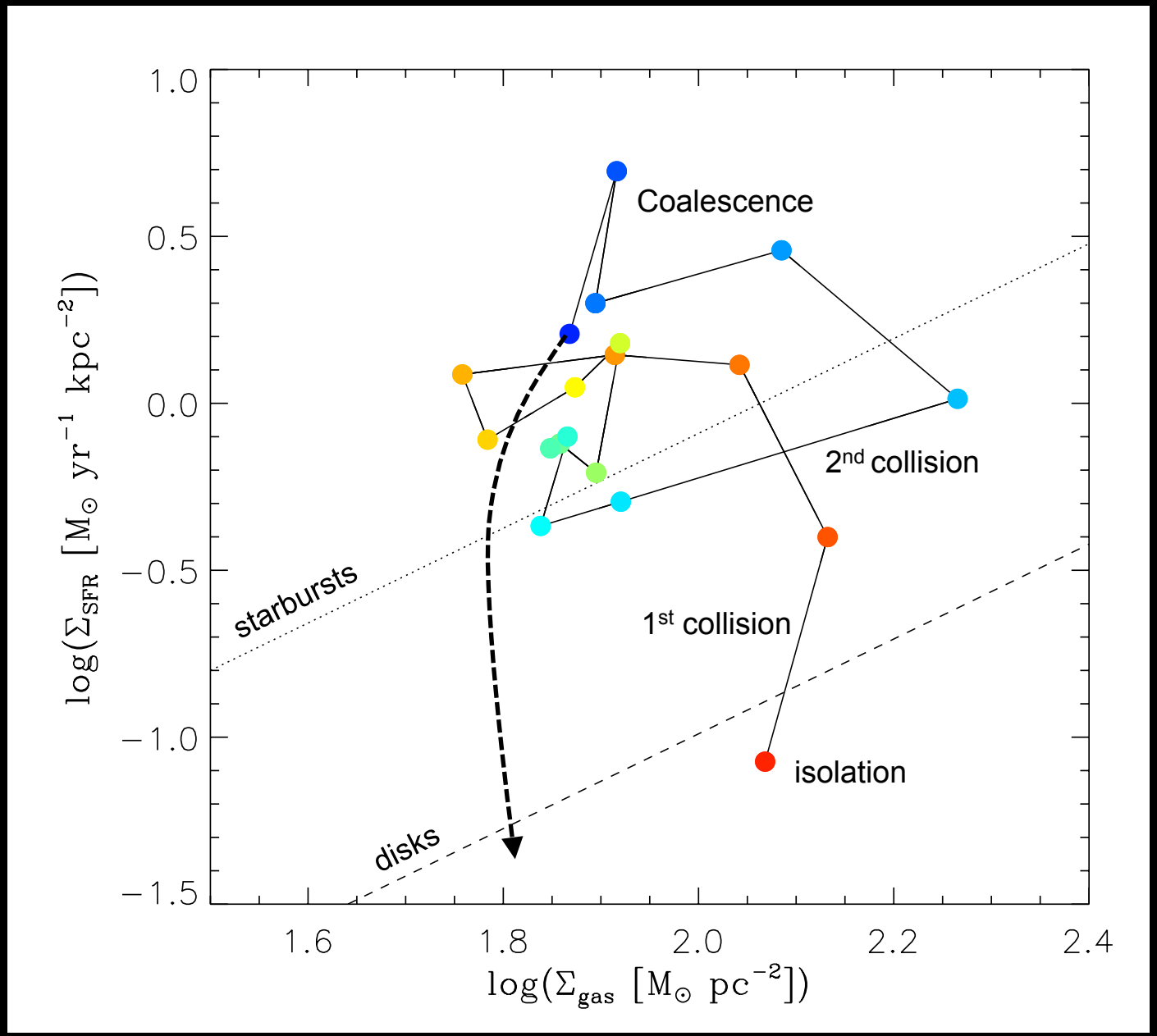
compressive tides (gas mass fraction)

compressive turbulence (energy)

SFR

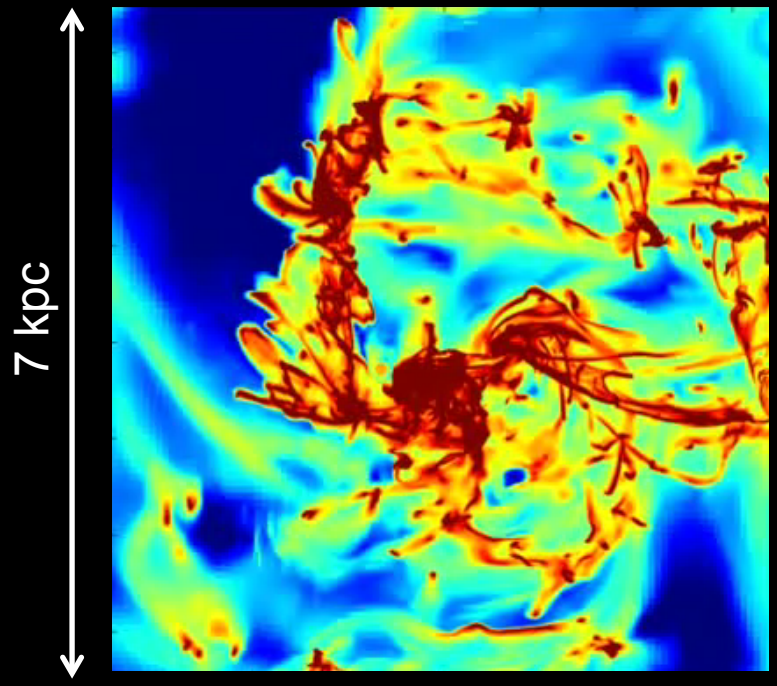
DISK VS MERGER

Renaud et al. (2014)

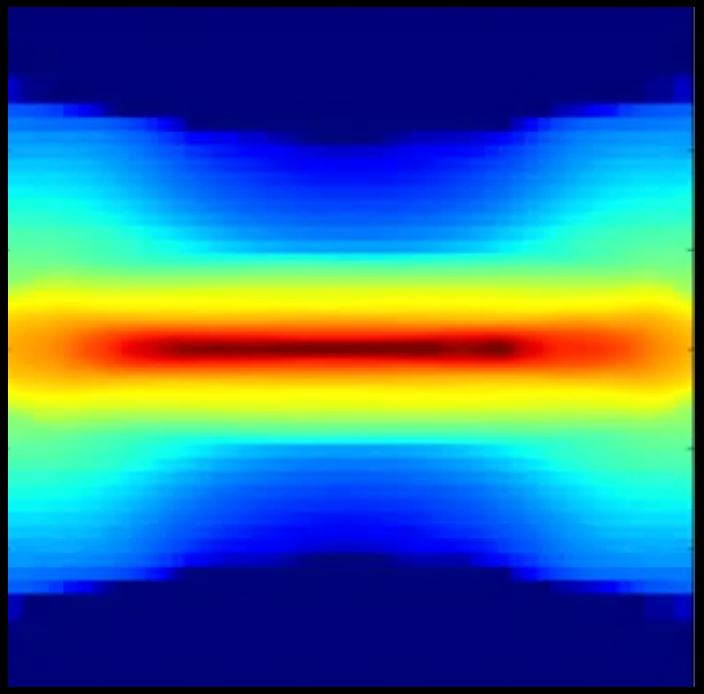


CLUMPY DISK

Bournaud, Perret, Renaud et al. (2014)



Milky Way progenitor at z~2
gas fraction ~50%

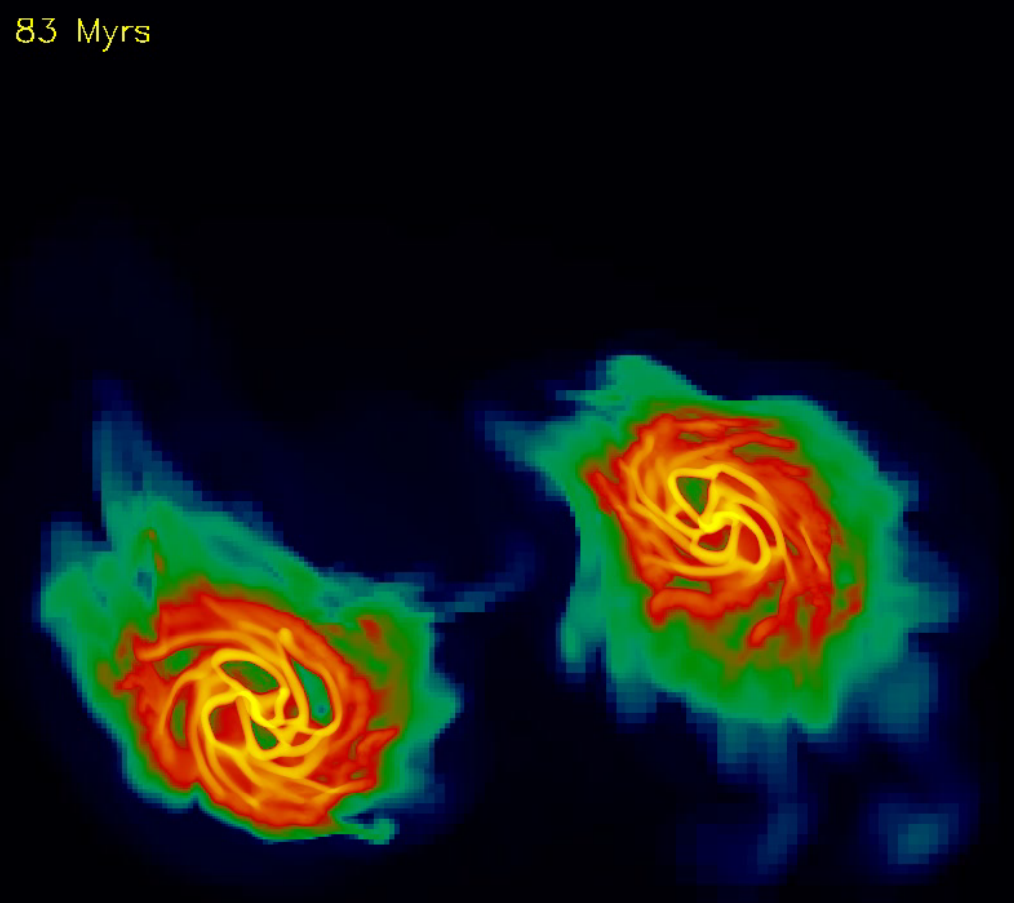


outflows

Formation of massive gas clumps (10^9 $M_\odot$)
High SFR (~50 $M_\odot$/yr)

High Redshift Mergers

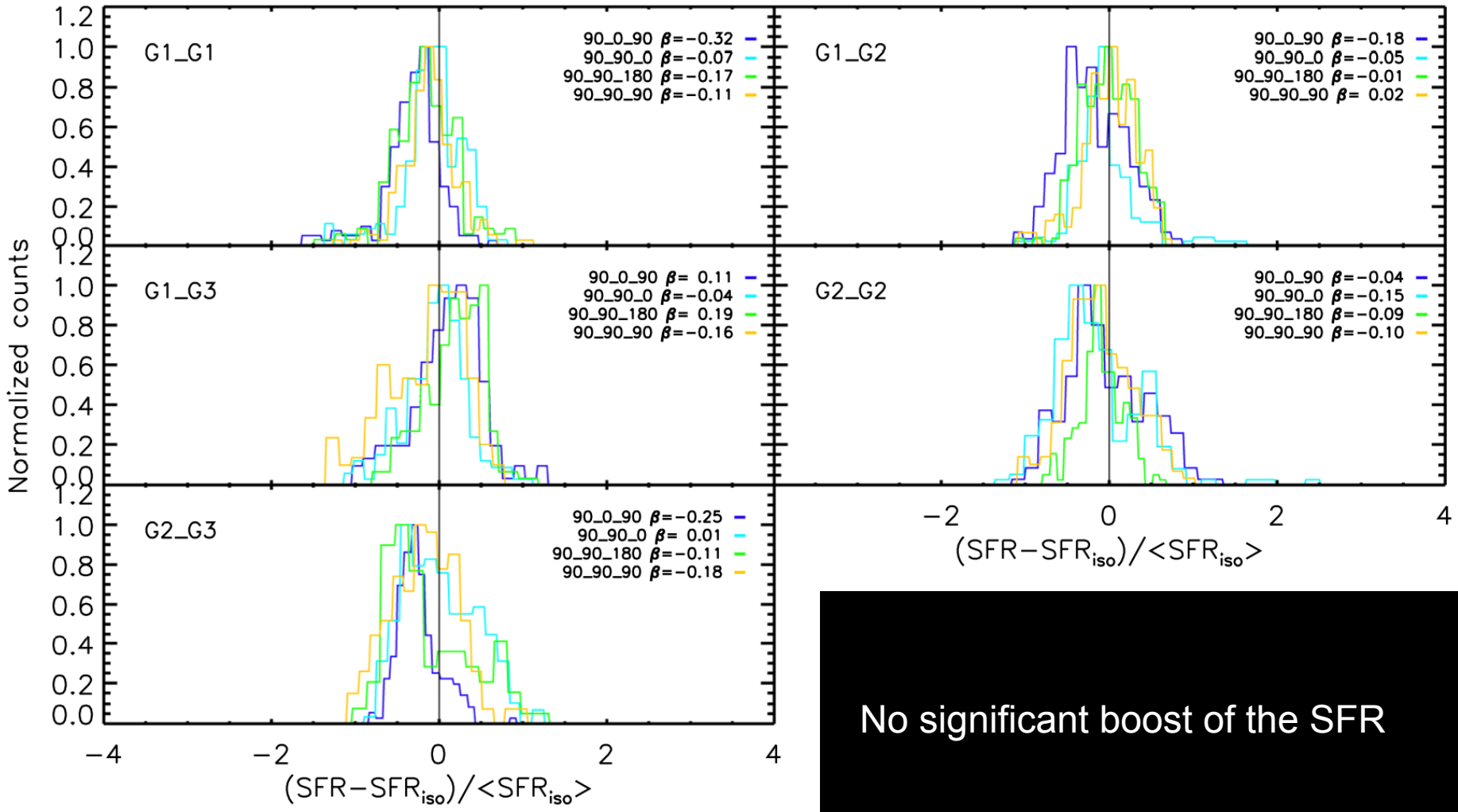
Perret, Renaud et al. (2014)



Merger of 2 gas-rich disks

HIGH REDSHIFT MERGERS

Perret, Renaud et al. (2014)



No significant boost of the SFR

Saturation due to the regulation by stellar feedback?

CONCLUSIONS

- Galaxy evolution leads to a diversity of environments, clouds, SF
- Coupling between large scales and small scales (turbulence, feedback...)
- SF closely related to supersonic turbulence.
- Galaxy mergers change the nature of turbulence
- (and probably the IMF)
- which explains properties of starbursts (e.g. off-nuclear SF)