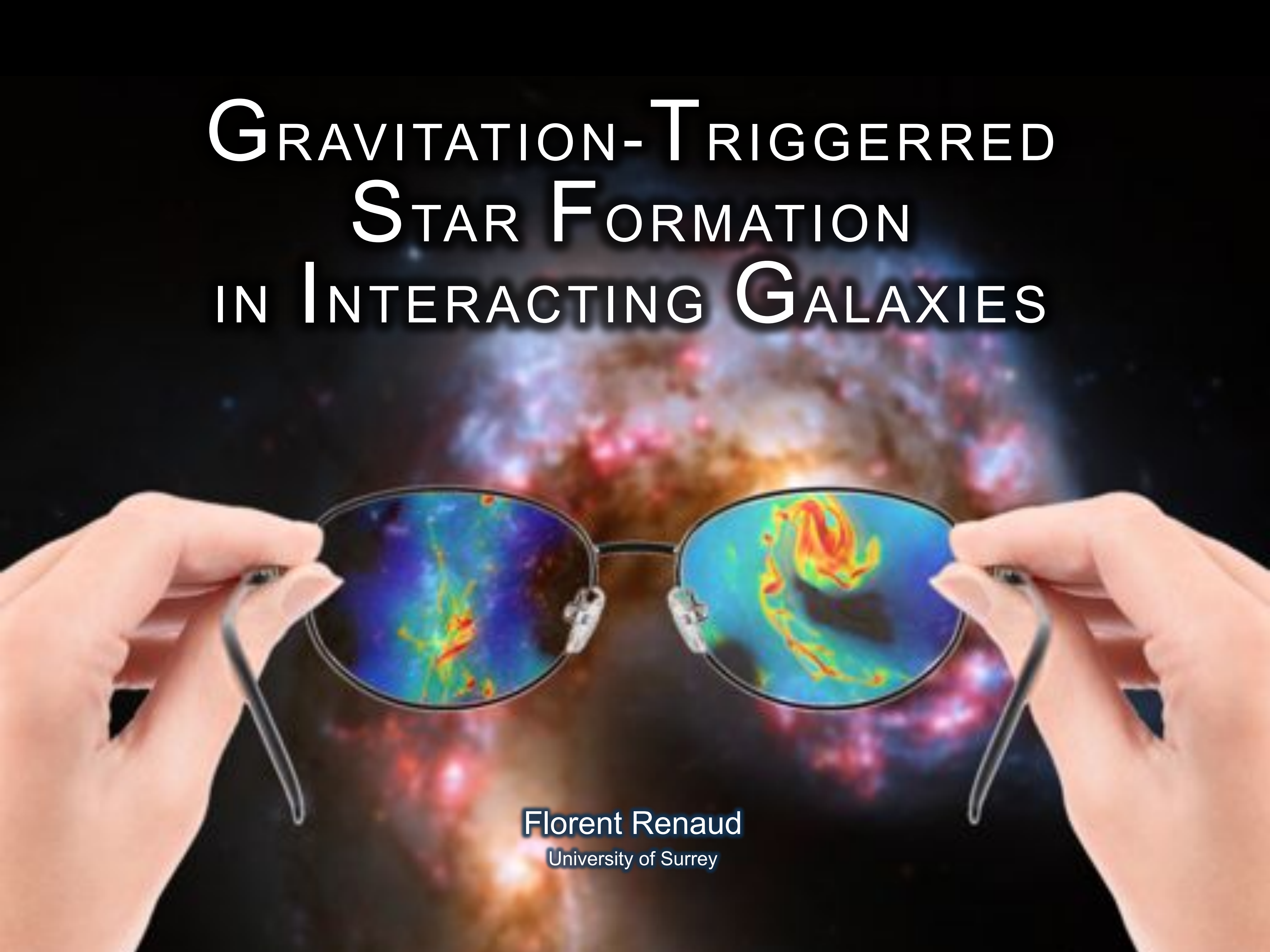
Gravitation-Triggerred Star Formation in Interacting Galaxies



Florent Renaud
University of Surrey

Outline

- Star formation and turbulence
- Turbulence and tides

Background & Motivations (from Λ-CDM)

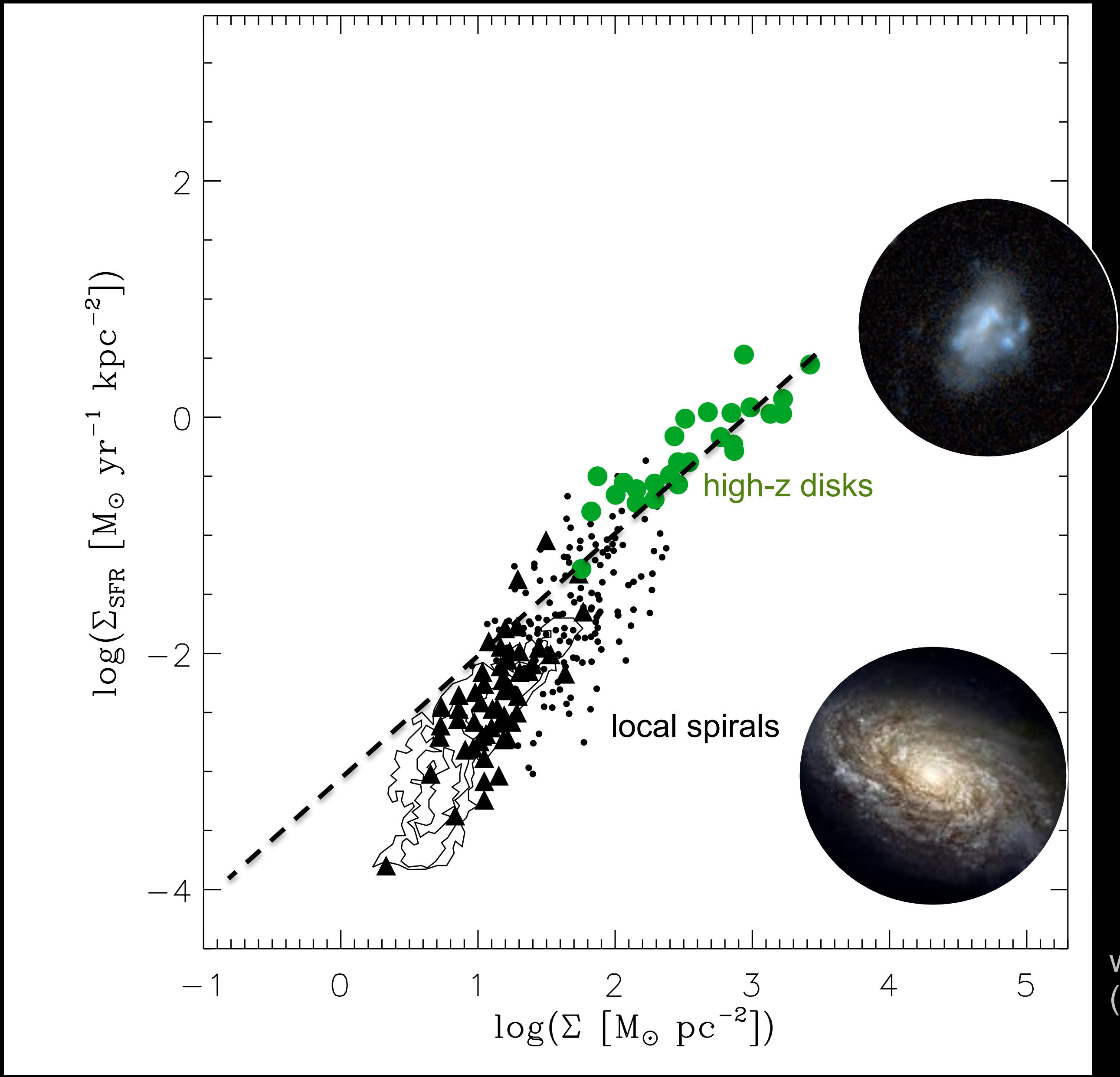
- Changing the tides

MOND & PoR

With the help of

B. Famaey, F. Bournaud, P.A. Duc, K. Kraljic, B. Elmegreen, F. Combes, R. Teyssier ...

Universality of Star Formation?



Kennicutt+1998

Kennicutt+2007

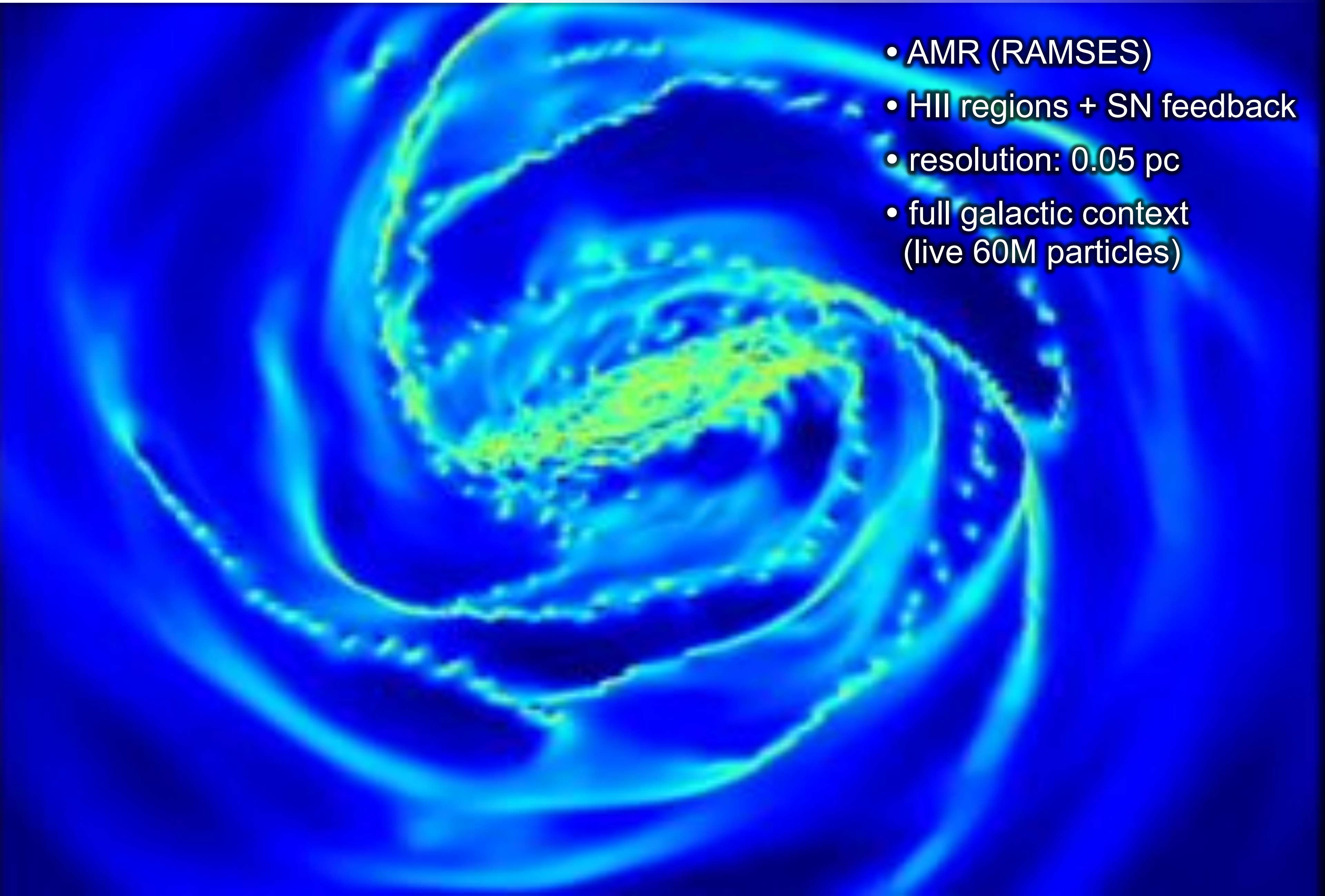
Bigiel+2008

Tacconi+2010 ; Daddi+2010a

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

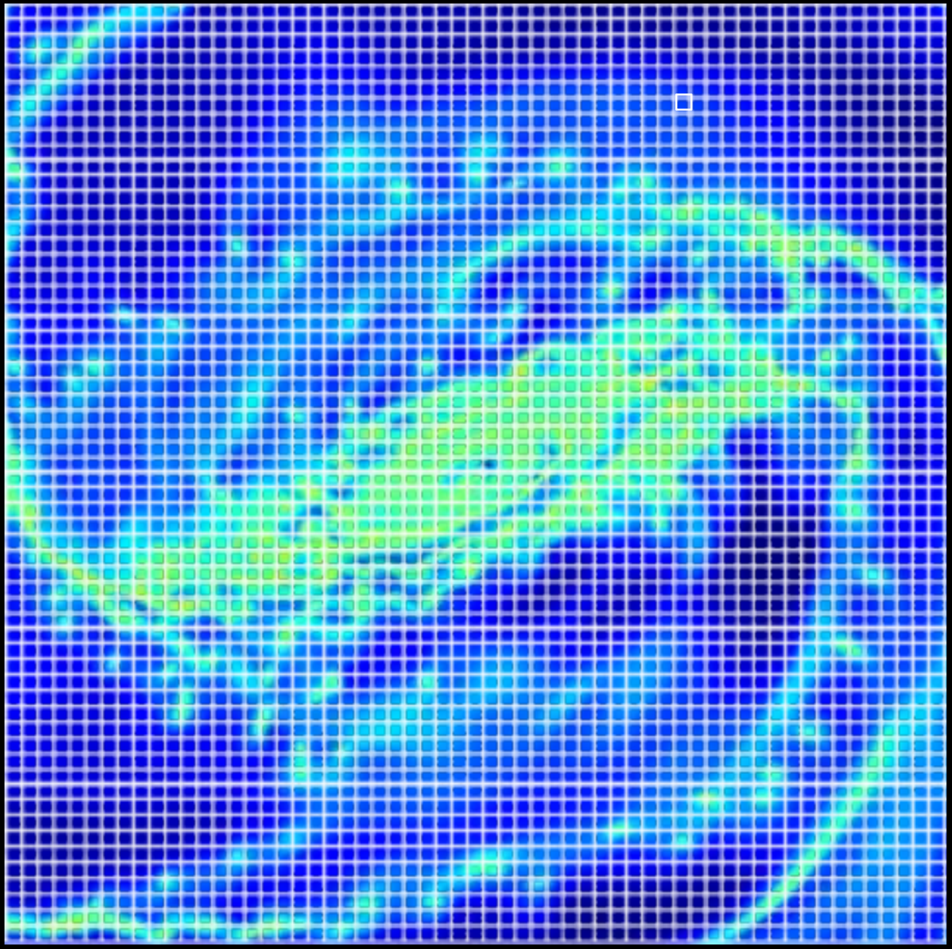
THE MILKY WAY

Renaud et al. (2013)



SF AT 100 PC SCALE

Kraljic, Renaud et al. (2014)



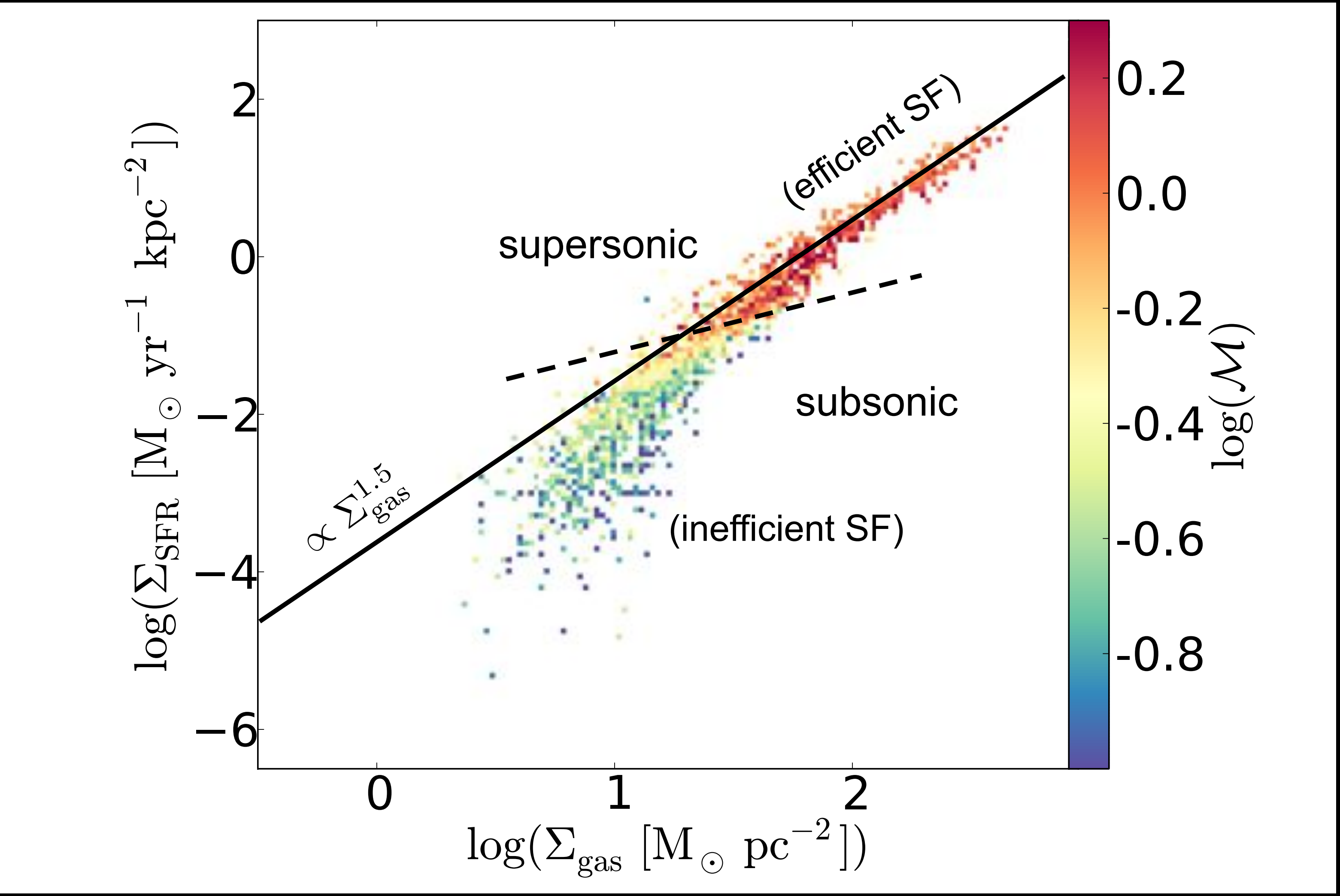
= 100 pc * 100 pc

Σ_{gas}

Σ_{SFR}

Schmidt-Kennicutt Relation

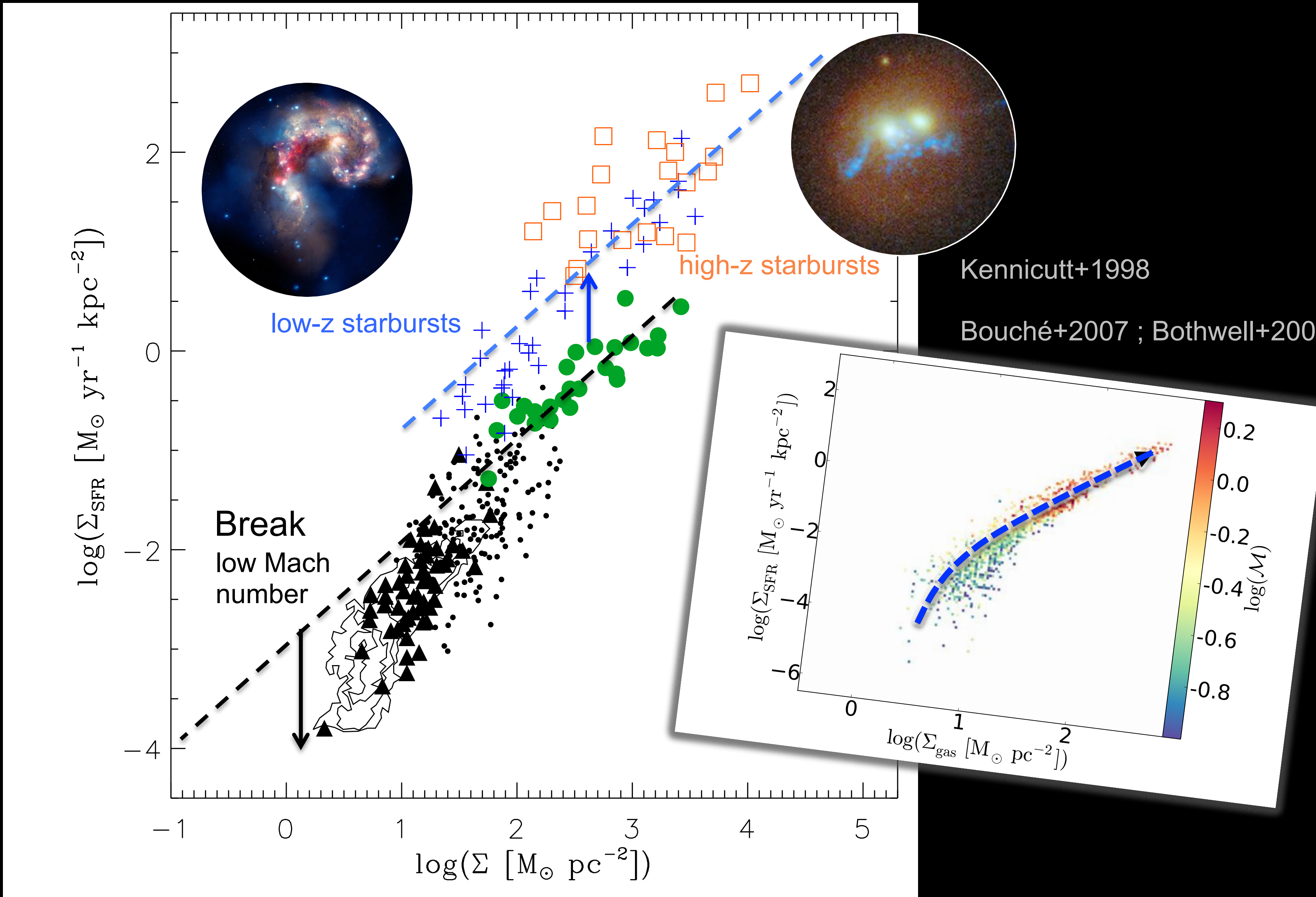
Kraljic, Renaud et al. (2014)



→ Variations of turbulence within the disk explain the break at low Σ_{gas}.

see also Padoan & Nordlund 2011, Hennebelle & Chabrier 2011

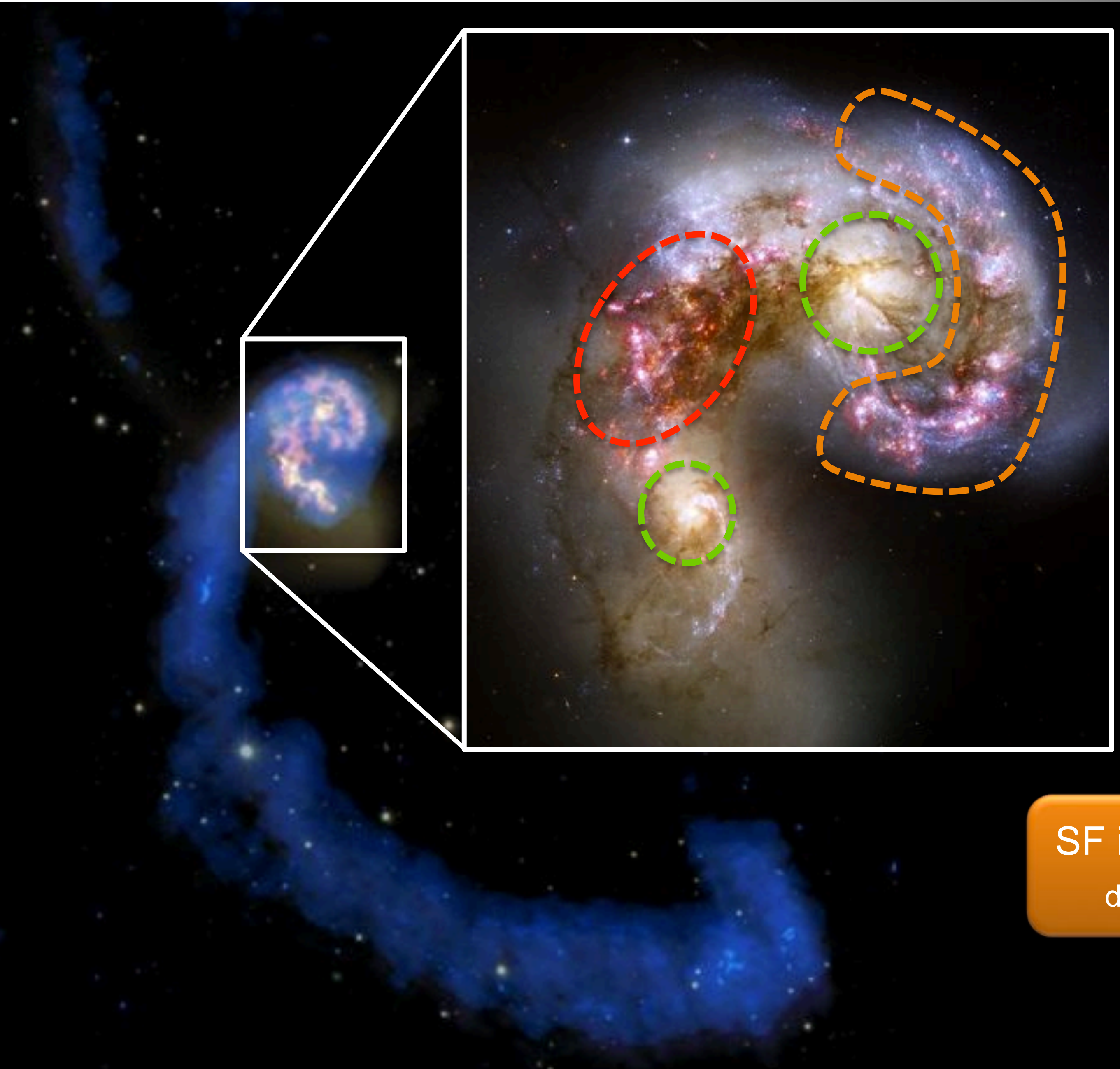
What about Starbursts?



Kennicutt+1998

Bouché+2007 ; Bothwell+2009

Physics of Starbursts



SF in nuclei

due to inflows

SF in overlap

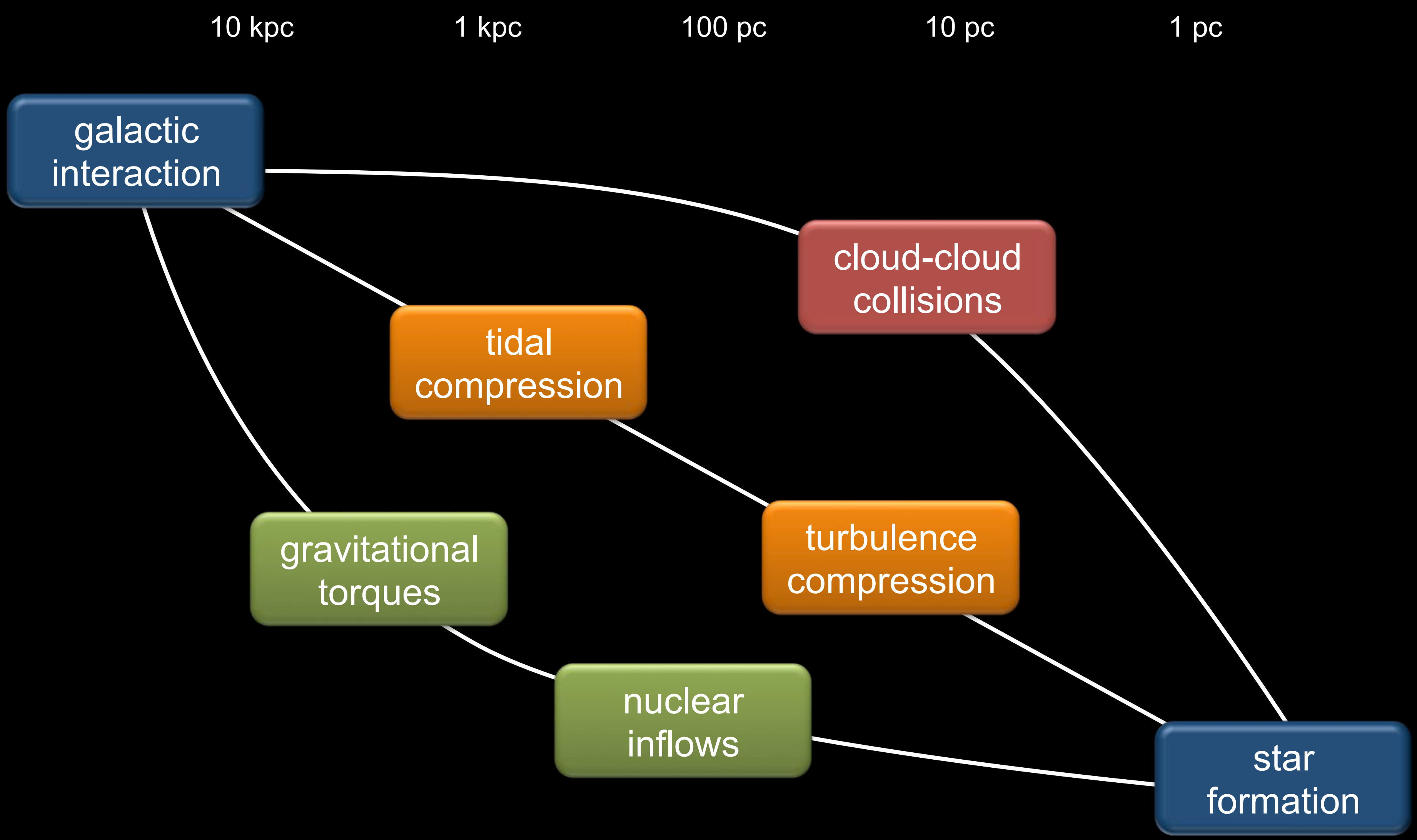
due to cloud-cloud collisions?

Frequent enough?

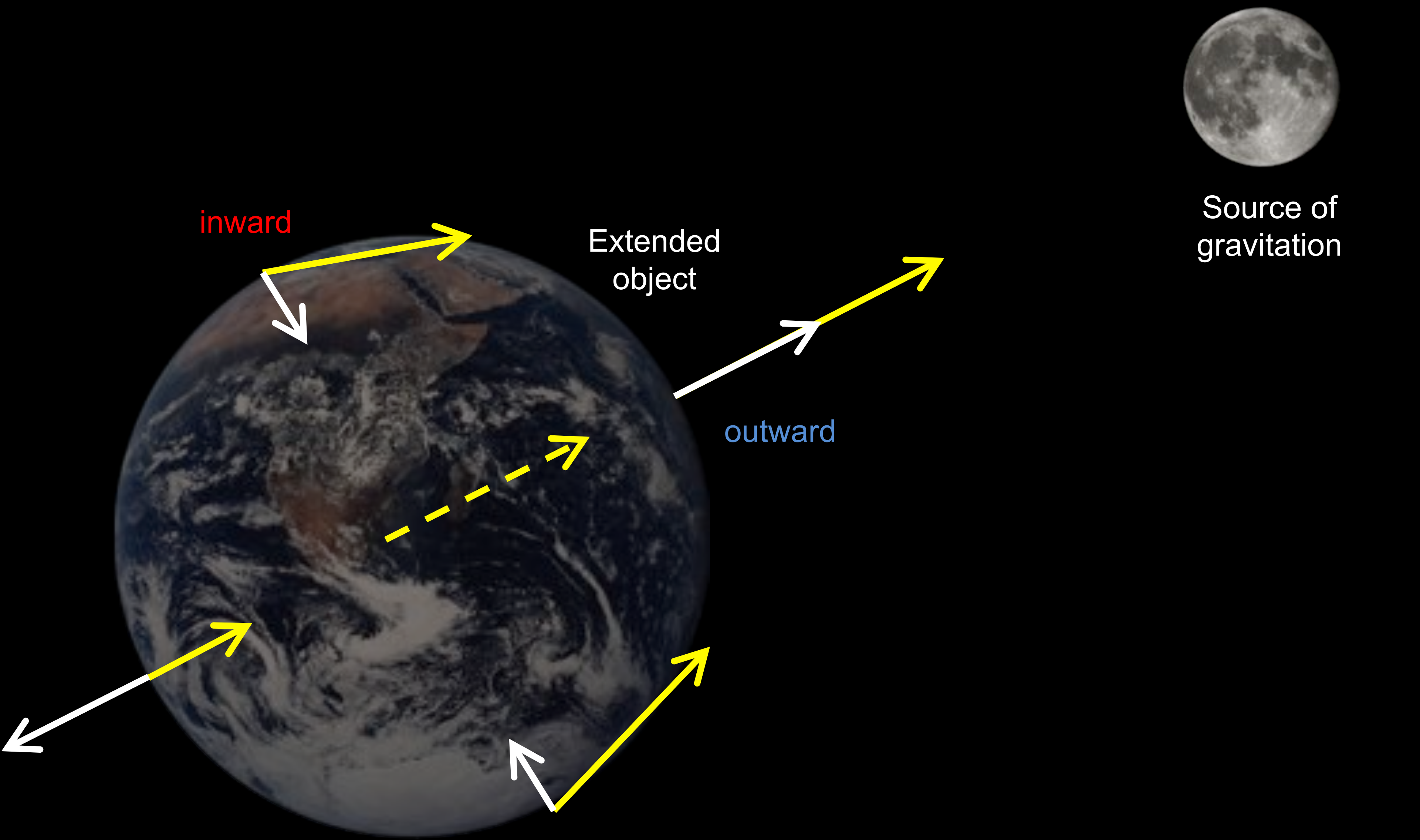
SF in the "Northern-arc"

due to ...?

Triggered, Enhanced Star Formation

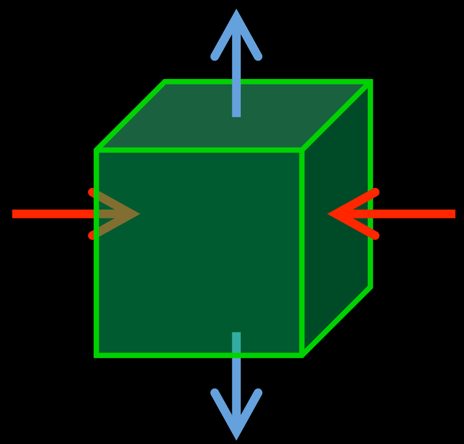


A Quick Reminder about Tides



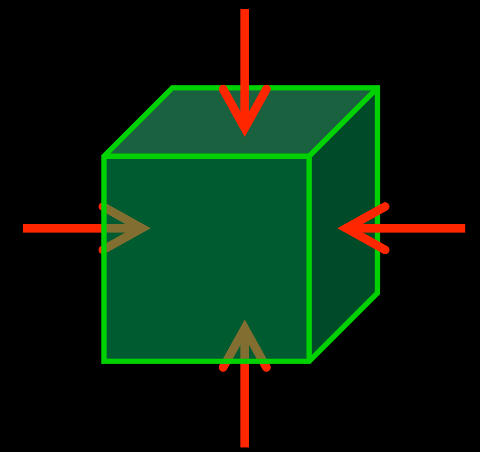
TIDAL MODES

extensive mode



- Earth-Moon
- Dominant in galaxies

compressive mode



- Galactic cores
- Important in interactions

COMPRESSIVE TIDES

Renaud et al. (2008, 2009)

- Galactic collisions change the nature of tides
- Over large volumes
- Valid for all interacting galaxies

red = compressive tides

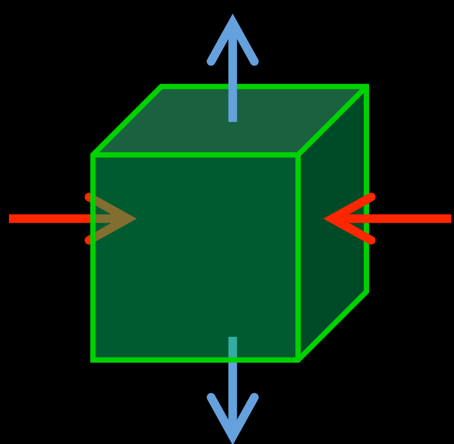
Tides and ISM Stability

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

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

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

extensive mode



$$\lambda > 0$$

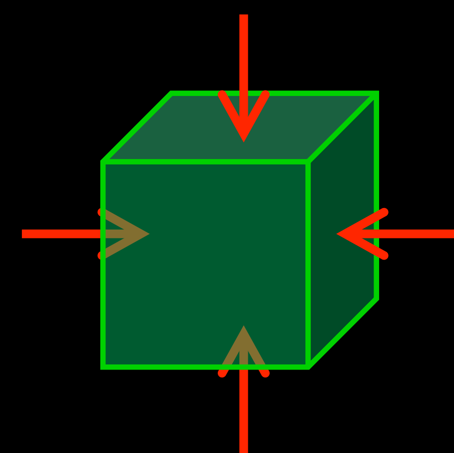
$$M'_{\mathrm{Jeans}} > M_{\mathrm{Jeans}}$$

no tides

$$\lambda = 0$$

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

compressive mode



$$\lambda < 0$$

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

A Quick Reminder about Turbulence

Local velocity field =

net motion
(*average*)

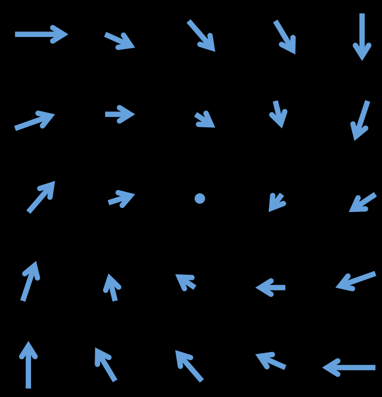
$$\langle v \rangle$$

Move it!

+

solenoidal turbulence
(*curl*)

$$\nabla \times v$$

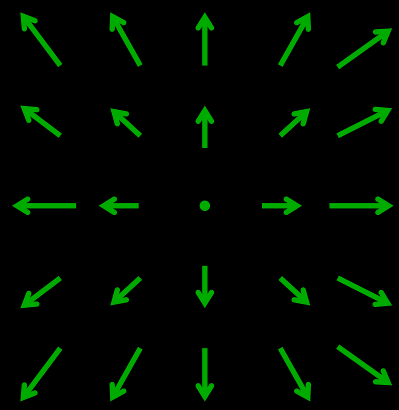


Mix it!

+

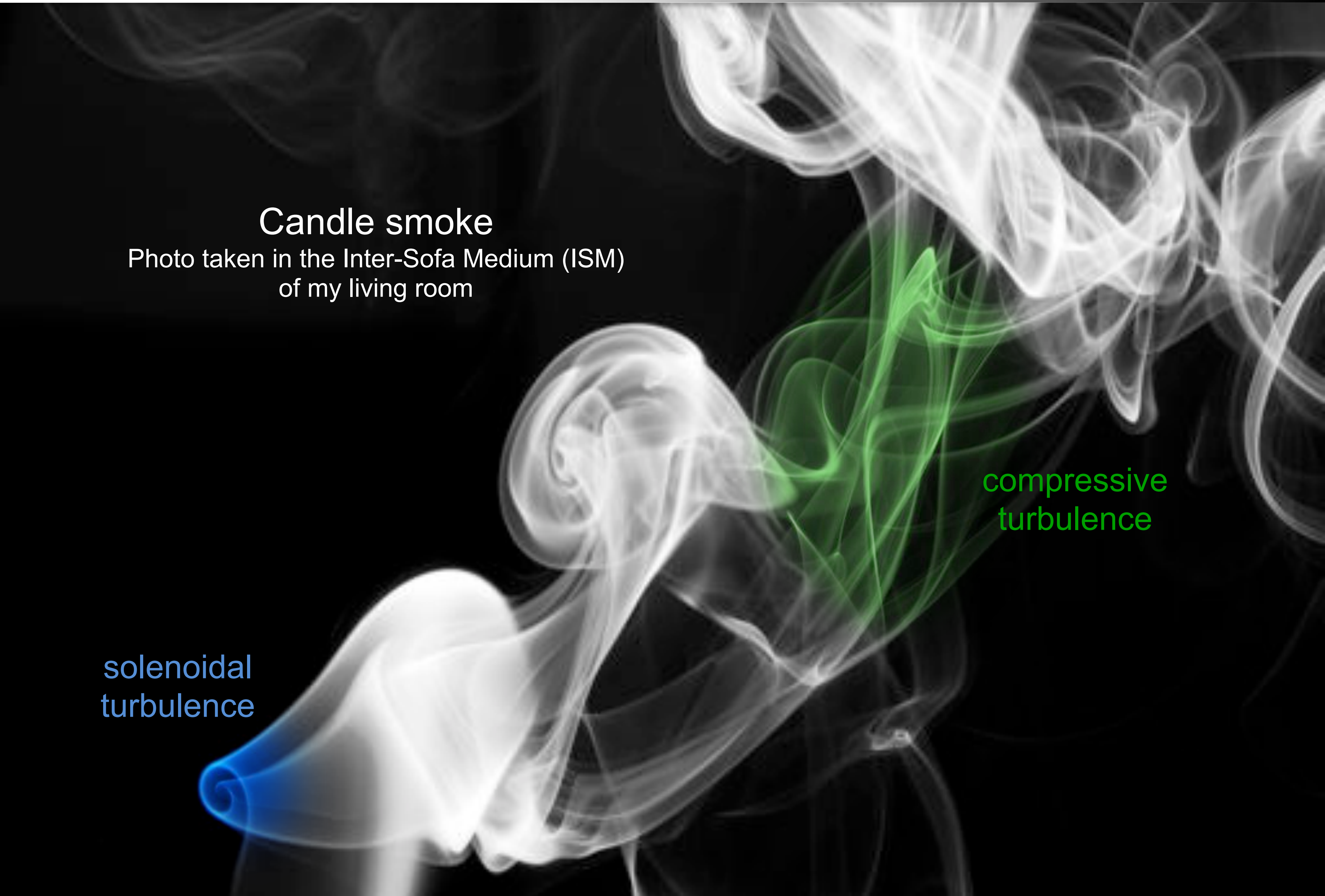
compressive turbulence
(*divergence*)

$$\nabla \cdot v$$

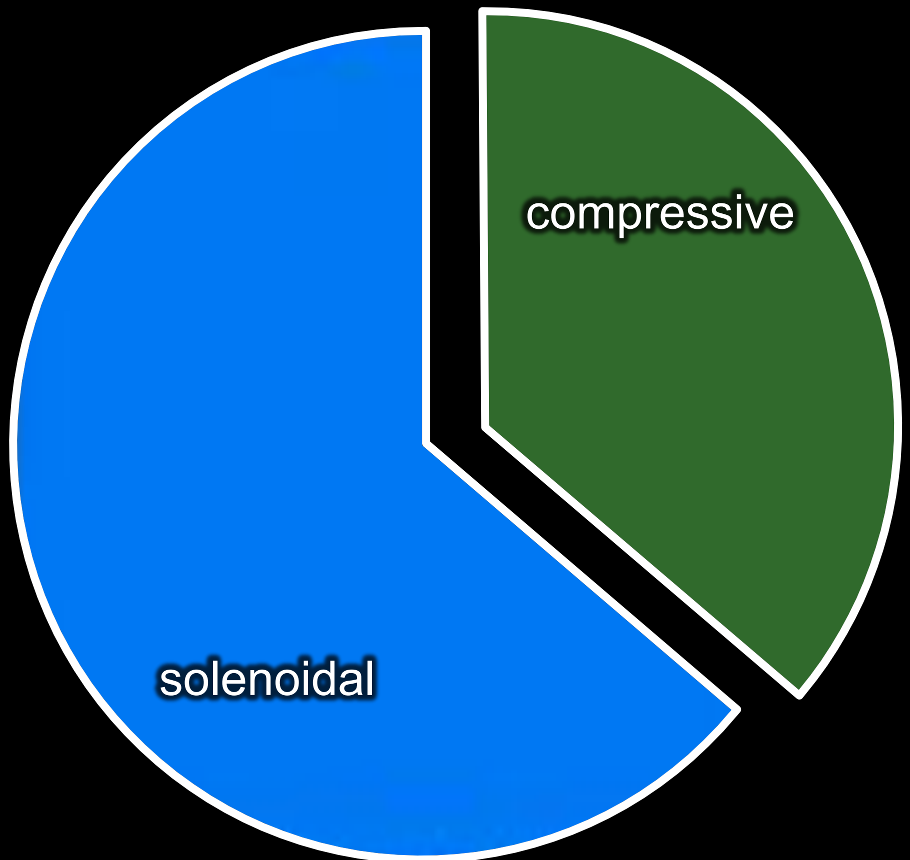


Pinch it!

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 (2015)

gas

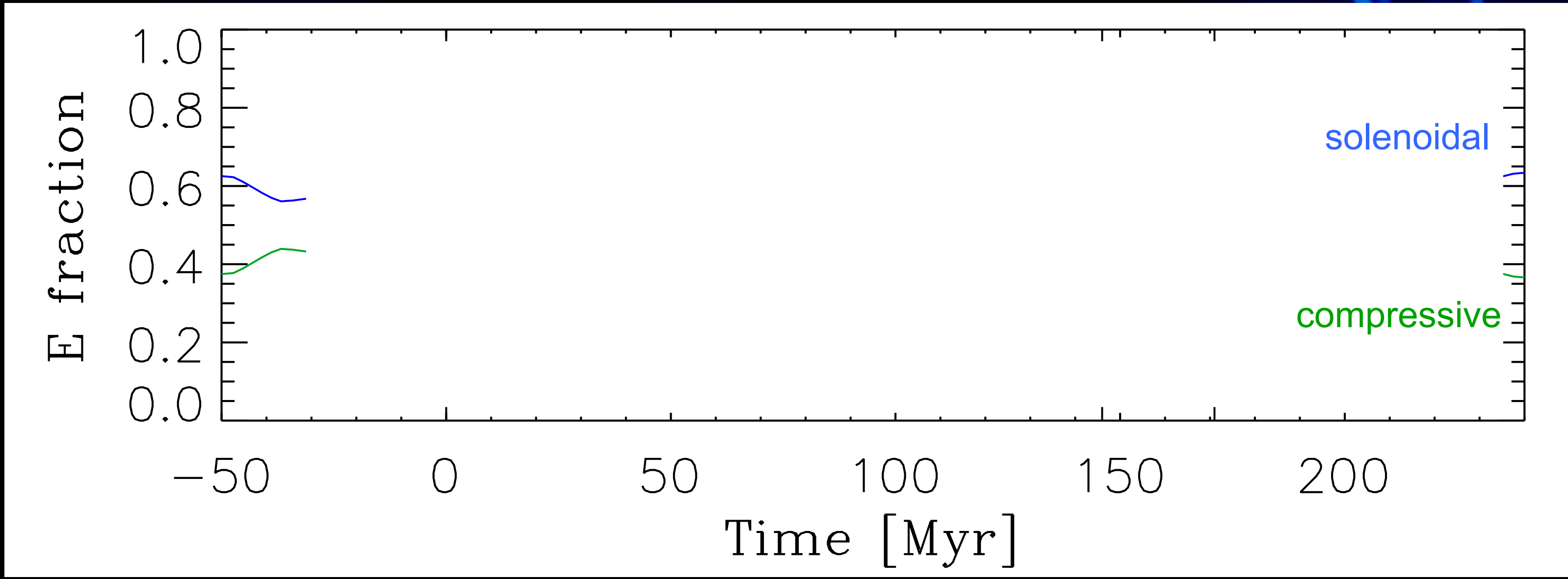
new stars

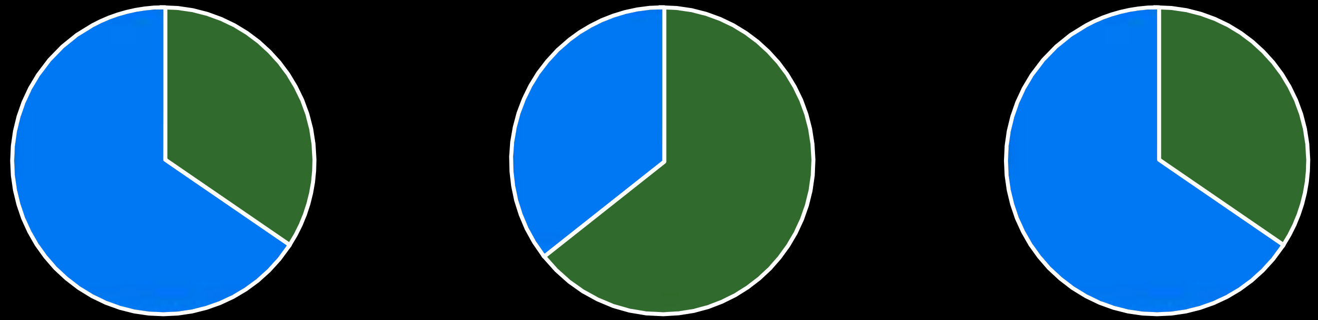
2 kpc

RAMSES, 1 pc, heating+colling, SF, HII, radiative pressure, SNe ...

IN A MERGER

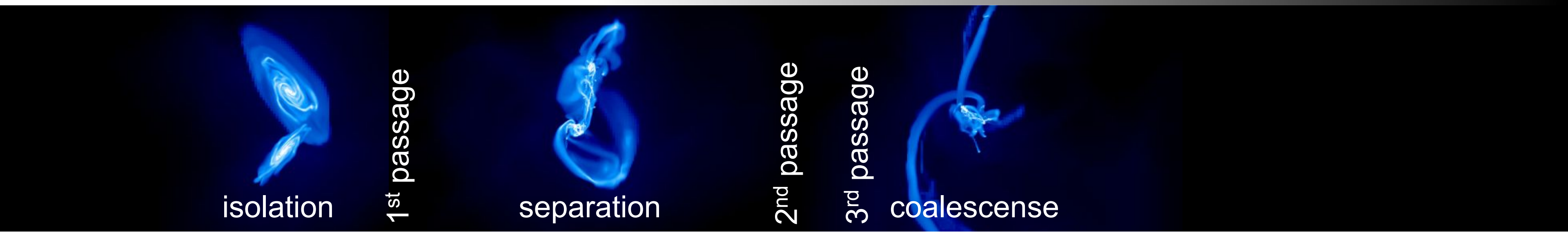
Renaud et al. (2014)

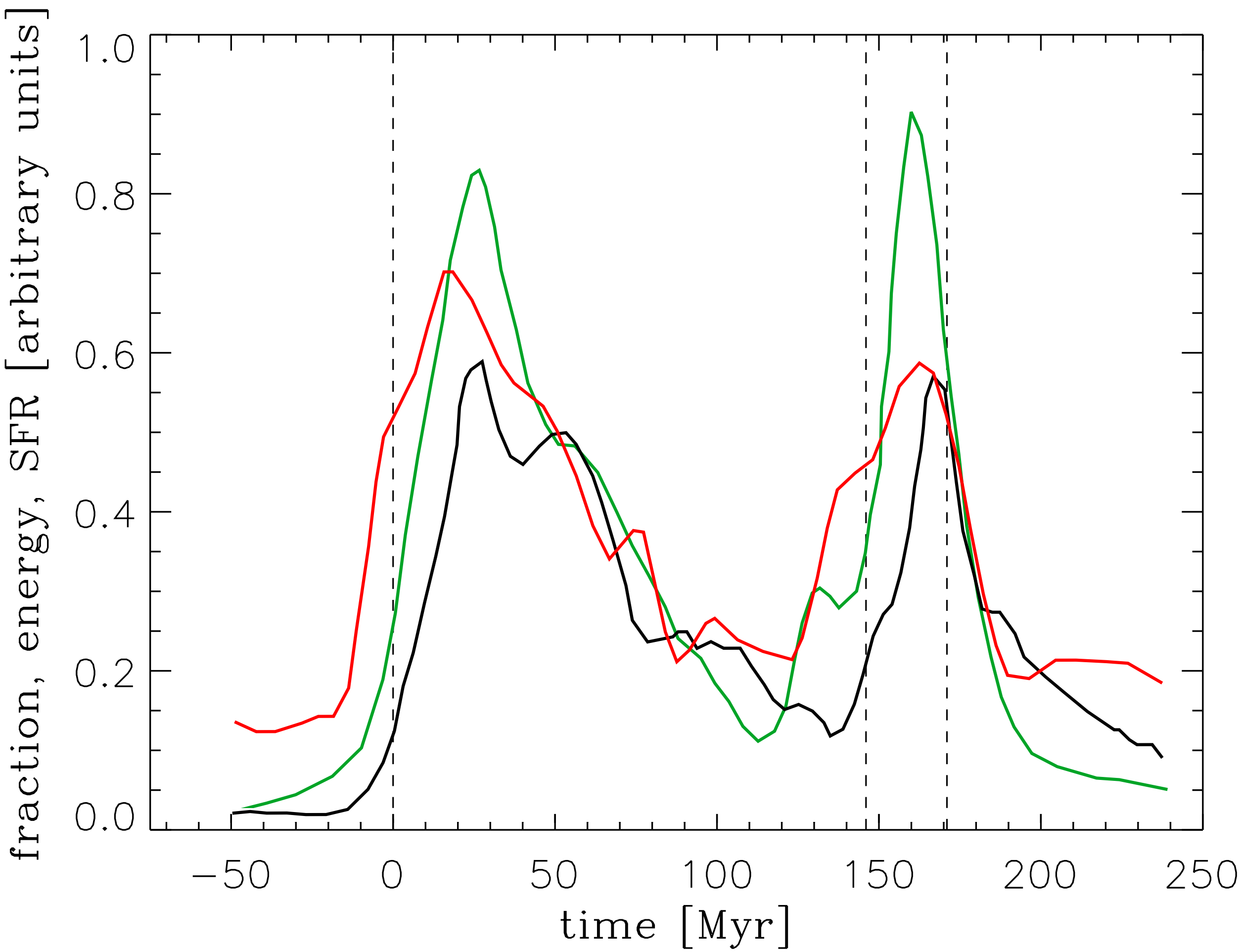




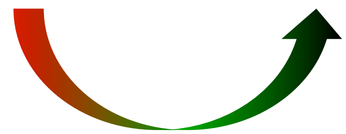
Relation to the SFR

Renaud et al. (2014)





tides → turbulence → SF



20 – 30 Myr

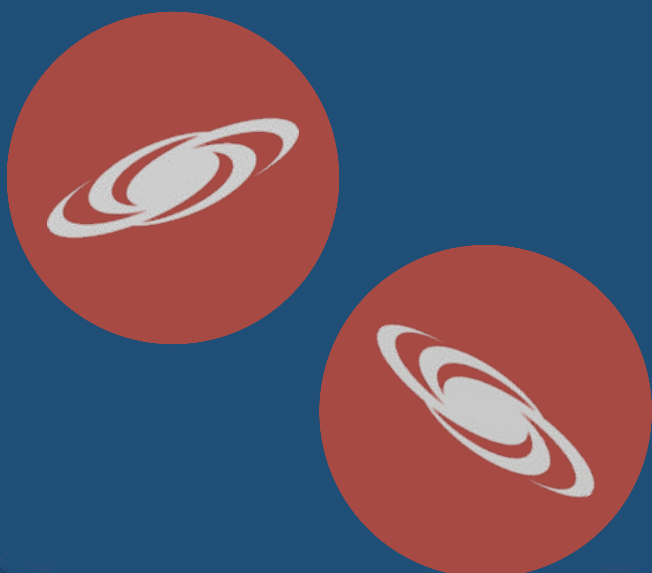
compressive tides (gas mass fraction)

compressive turbulence (energy)

SFR

PoR to the Rescue!

Newton
RAMSES
(Teyssier 2002)



vs.

MOND
PoR
(Lüghausen, Famaey & Kroupa 2014)

2 Ways

(A) Same setup

based on previous works (Newton)

→ PoR will not match the observations

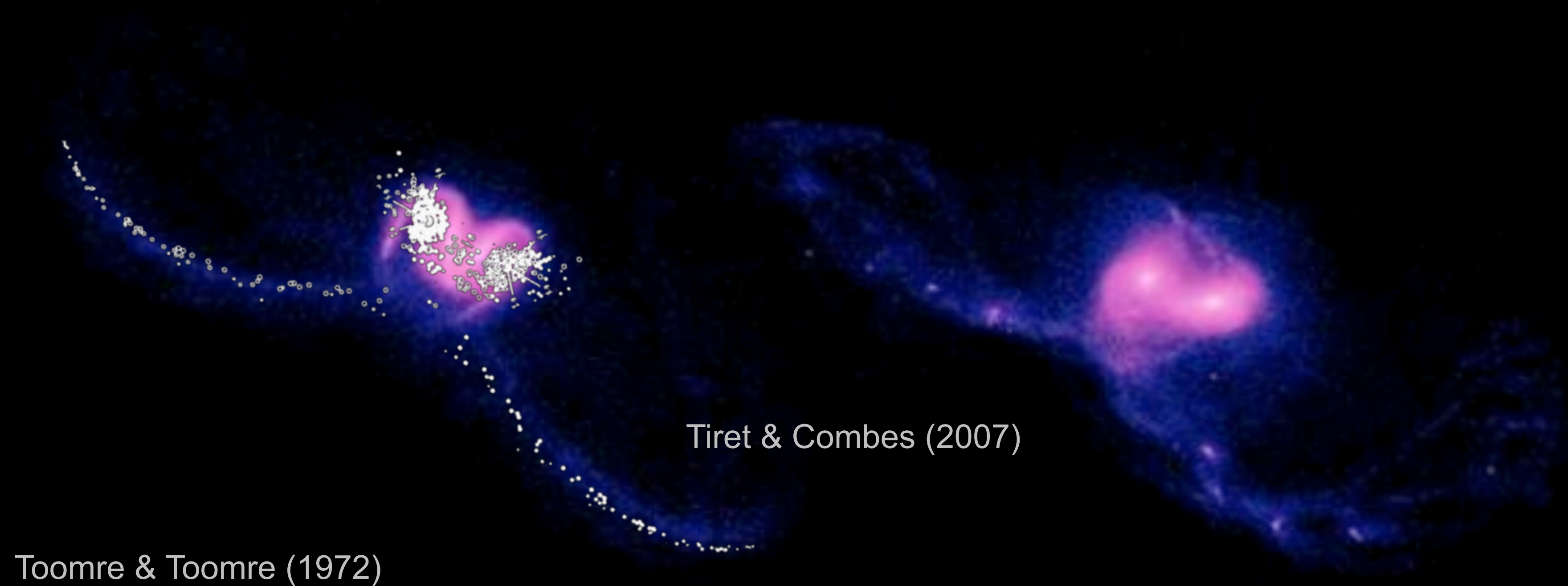
(B) Same results

parameter search for best match

→ more fair, but less direct comparaison

Not yet

Pioneer Work



Sticky particles, 290 pc, based on Toomre & Toomre (1972) model

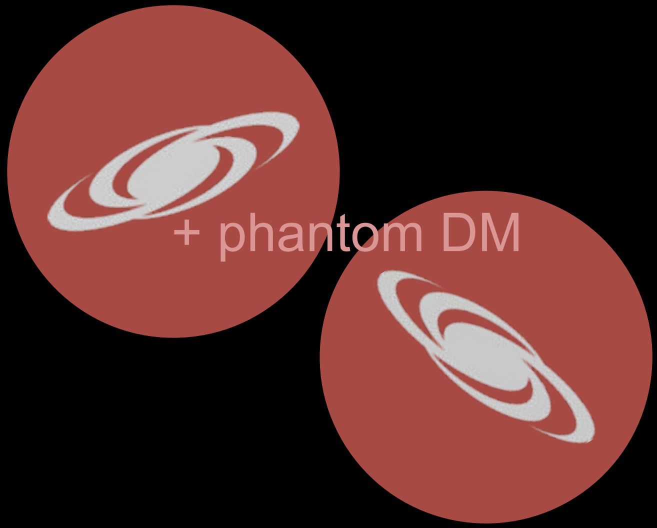
Nothing about the star formation ...

Initial Conditions

Same baryonnic components

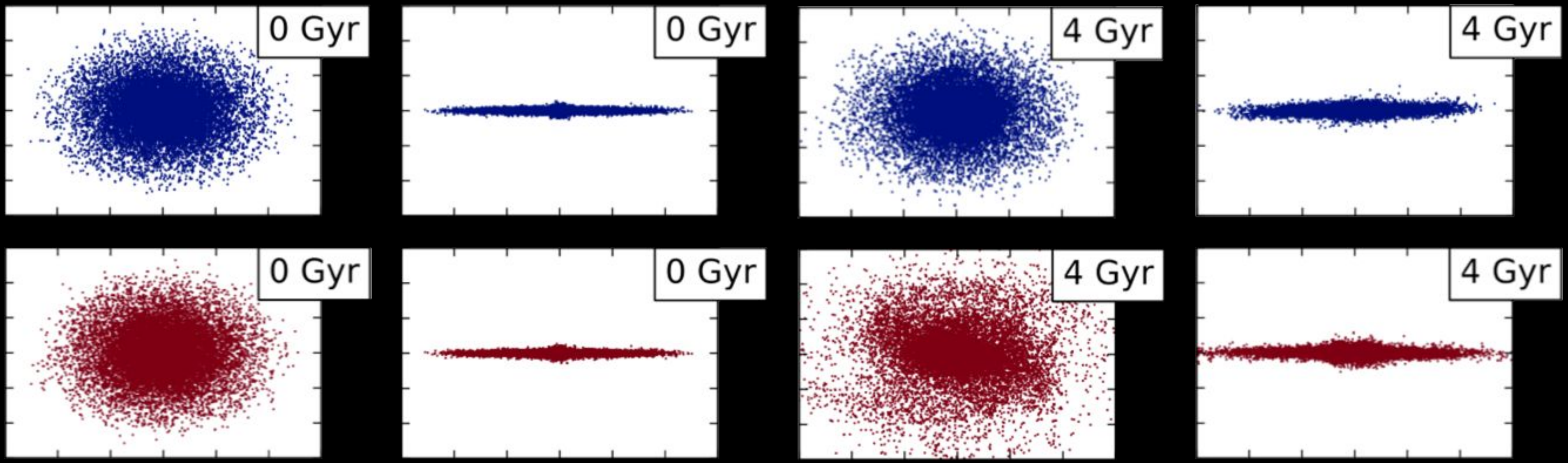
→ disk structures, instabilities (bars, spirals, clumps ...)

Same rotation curve

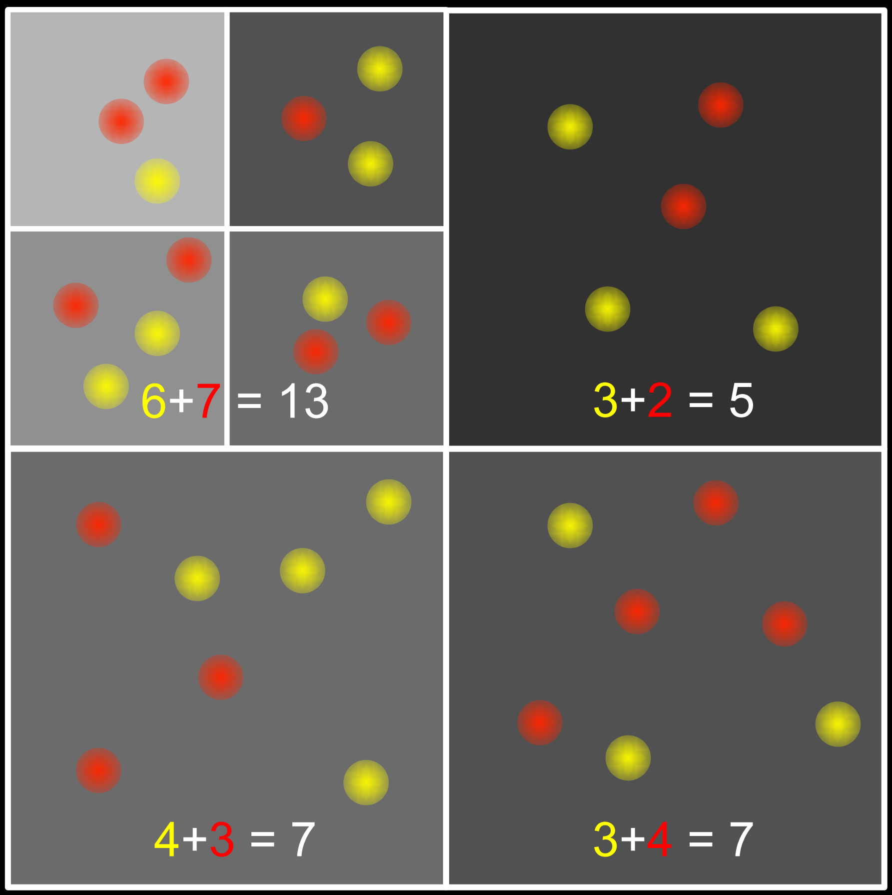


MW-A

Kuijken & Dubinski (1995)
as already noted by Calendish et al. (2014)



Fair Comparison?



Baryons (stars)

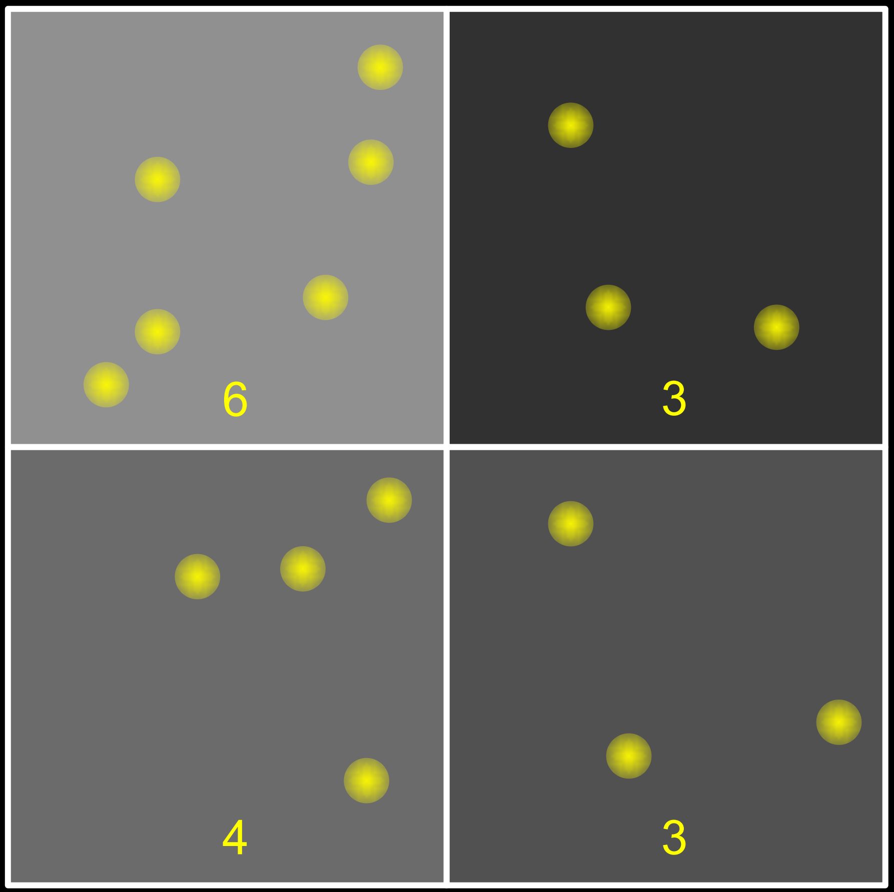
Dark matter

Refinement on number of particles
(*m_refine*)

Refinement on mass
(*mass_sph * m_refine*)

if $(N > 8)$ then refine

Fair Comparison?



Baryons (stars)

Dark matter

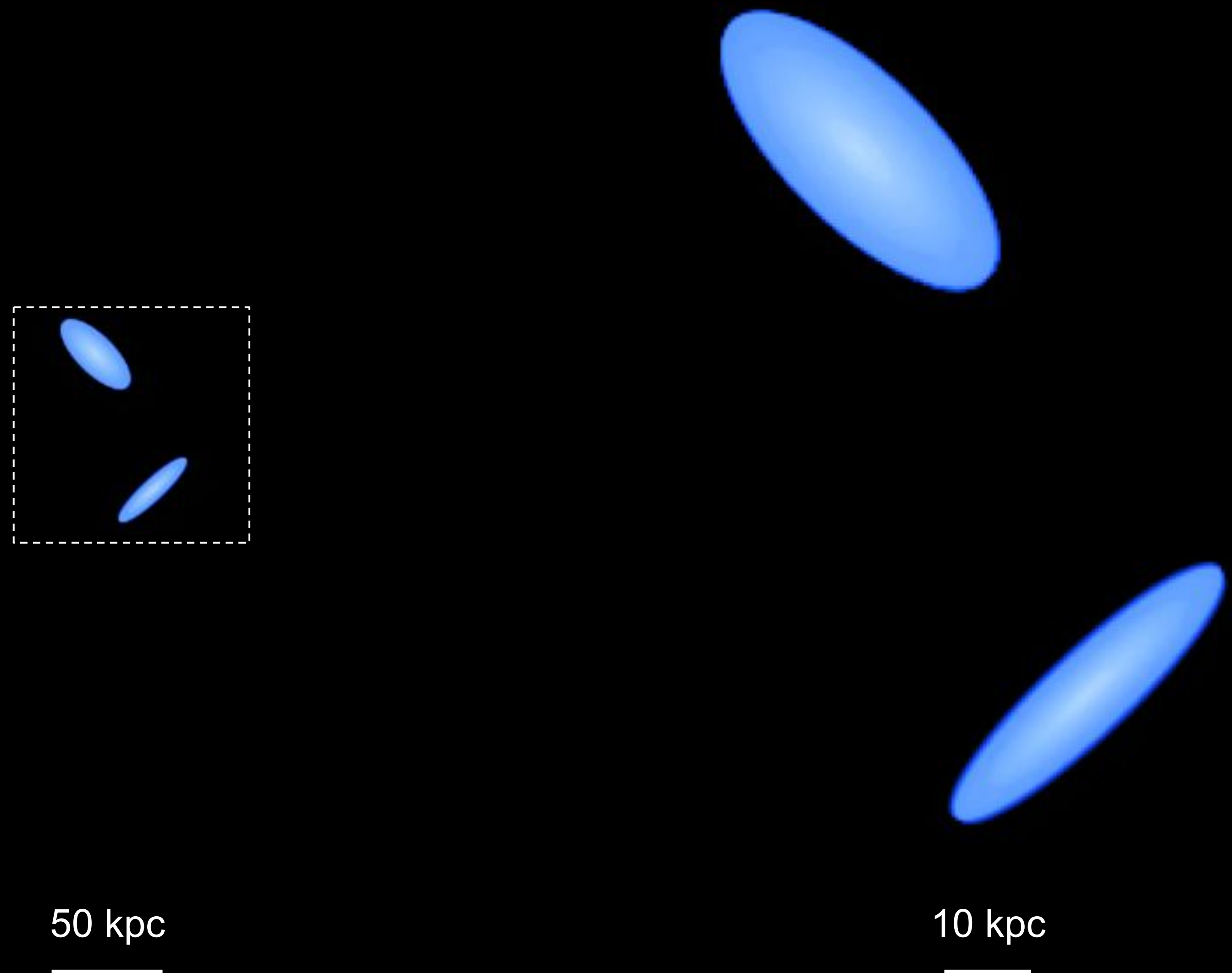
Refinement on number of particles
(*m_refine*)

if ($N > 8$) then refine

UNFAIR COMPARISON

Different cell size
density
temperature
star formation
feedback injection
...

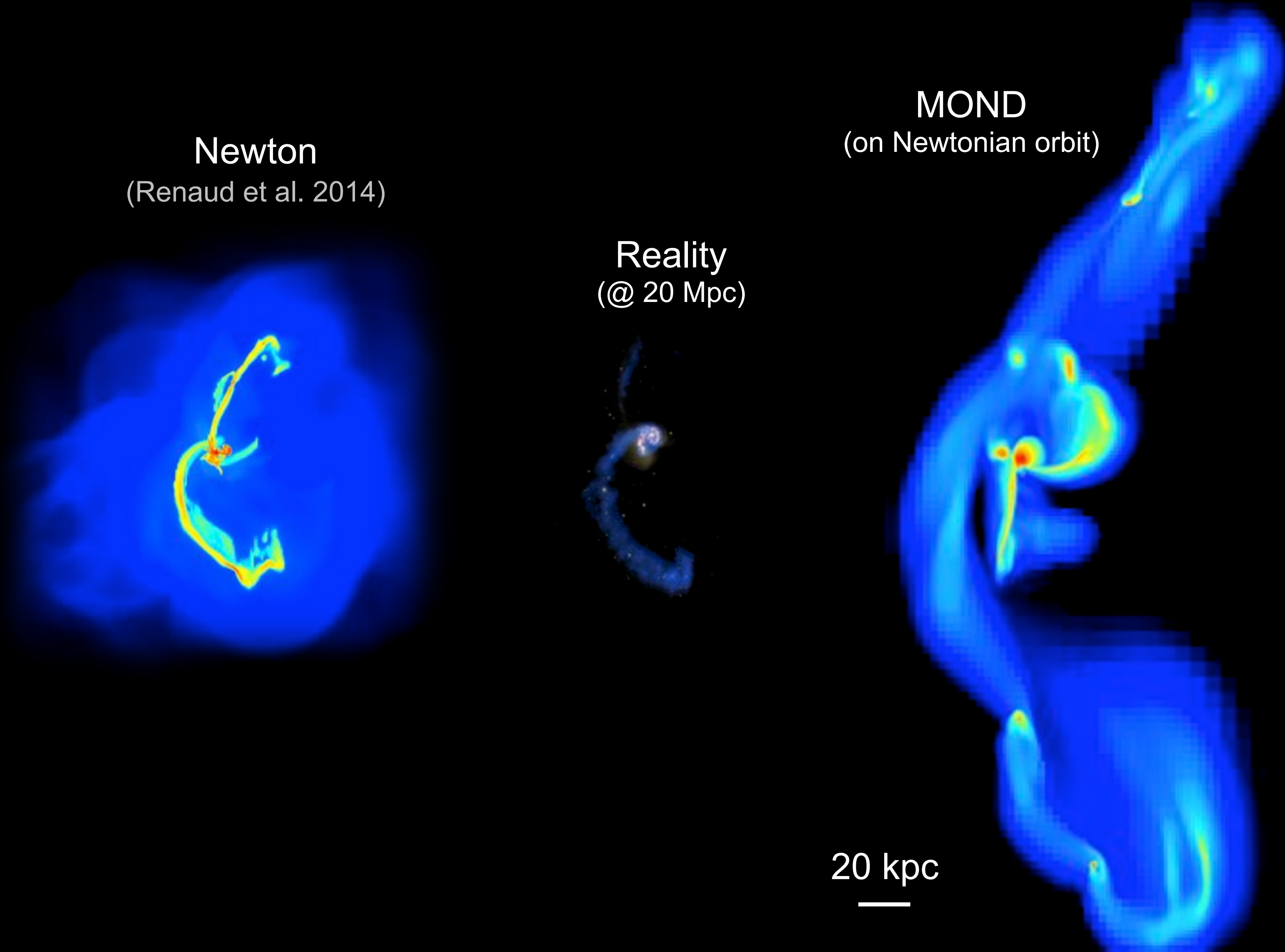
PoR on a ΛCDM Orbit



30 Myr per second

PoR, 6 pc, MW-A progenitors, heating+colling, SF, HII, radiative pressure, SNe ...

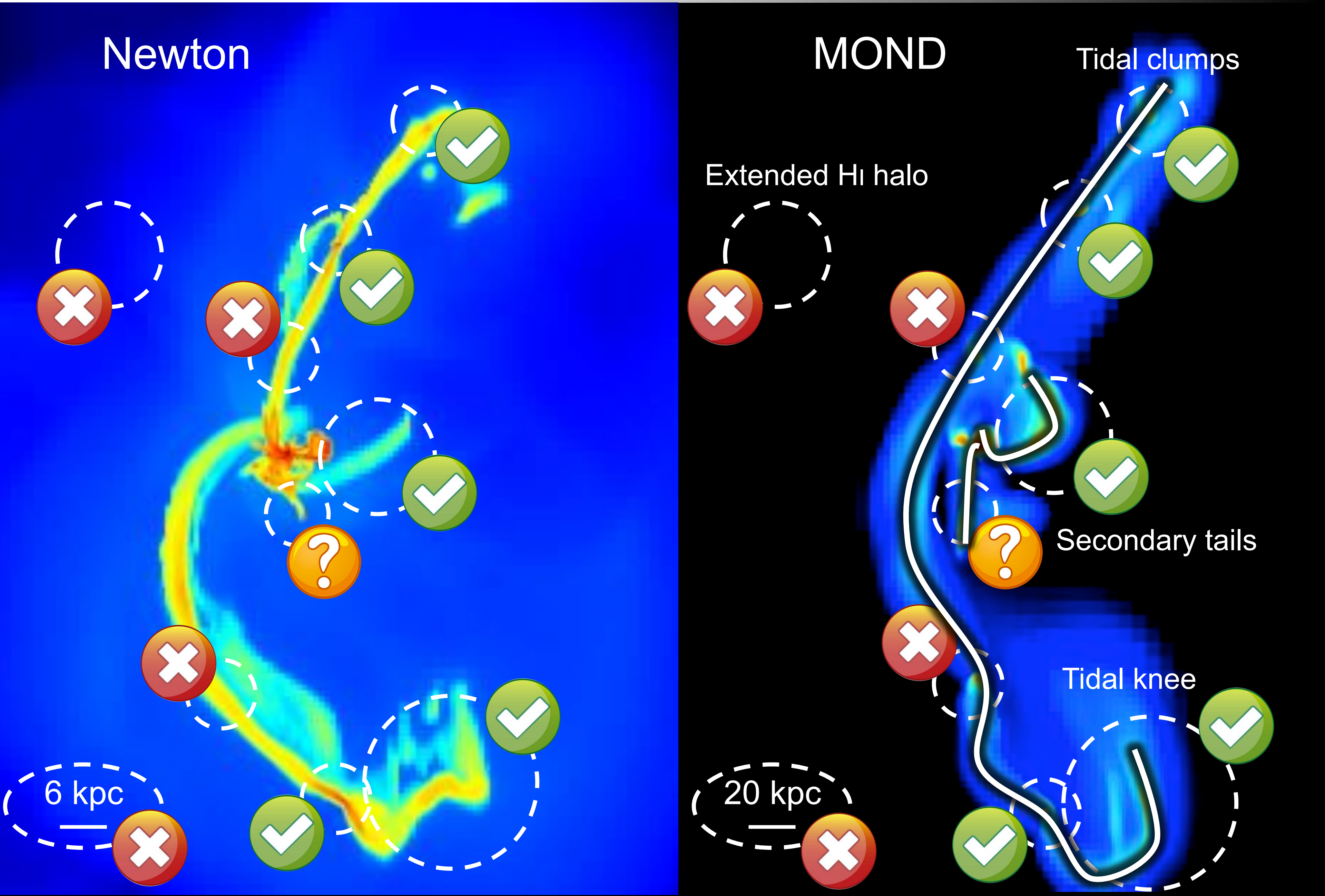
MORPHOLOGY


Newton
(Renaud et al. 2014)
Reality
(@ 20 Mpc)
MOND
(on Newtonian orbit)
20 kpc

BUT ....

Tiret & Combes (2007)

Spot the Differences



STAR FORMATION RATE

Wow!

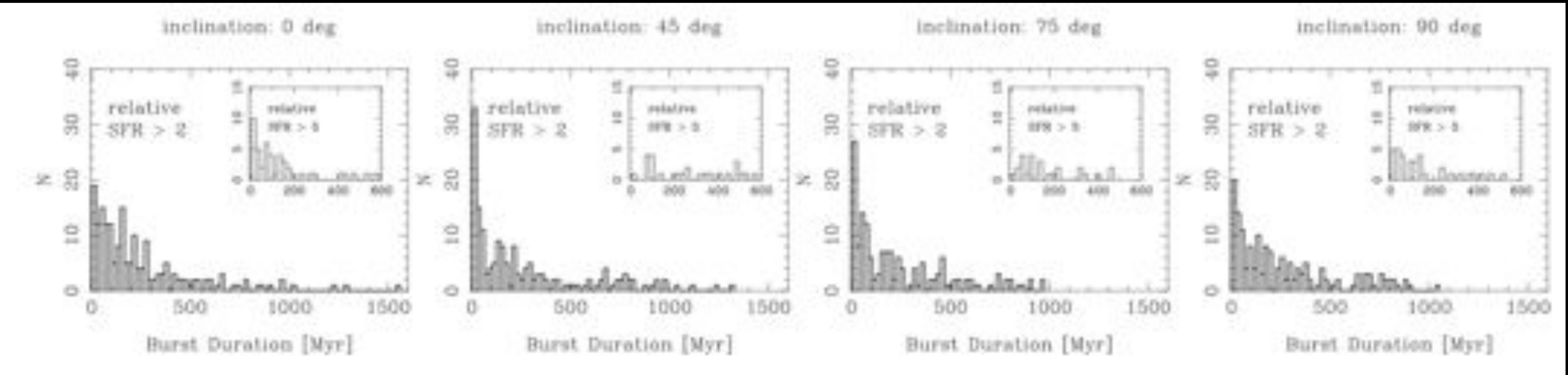
Newton says:

intense, bursty, short → star*burst*

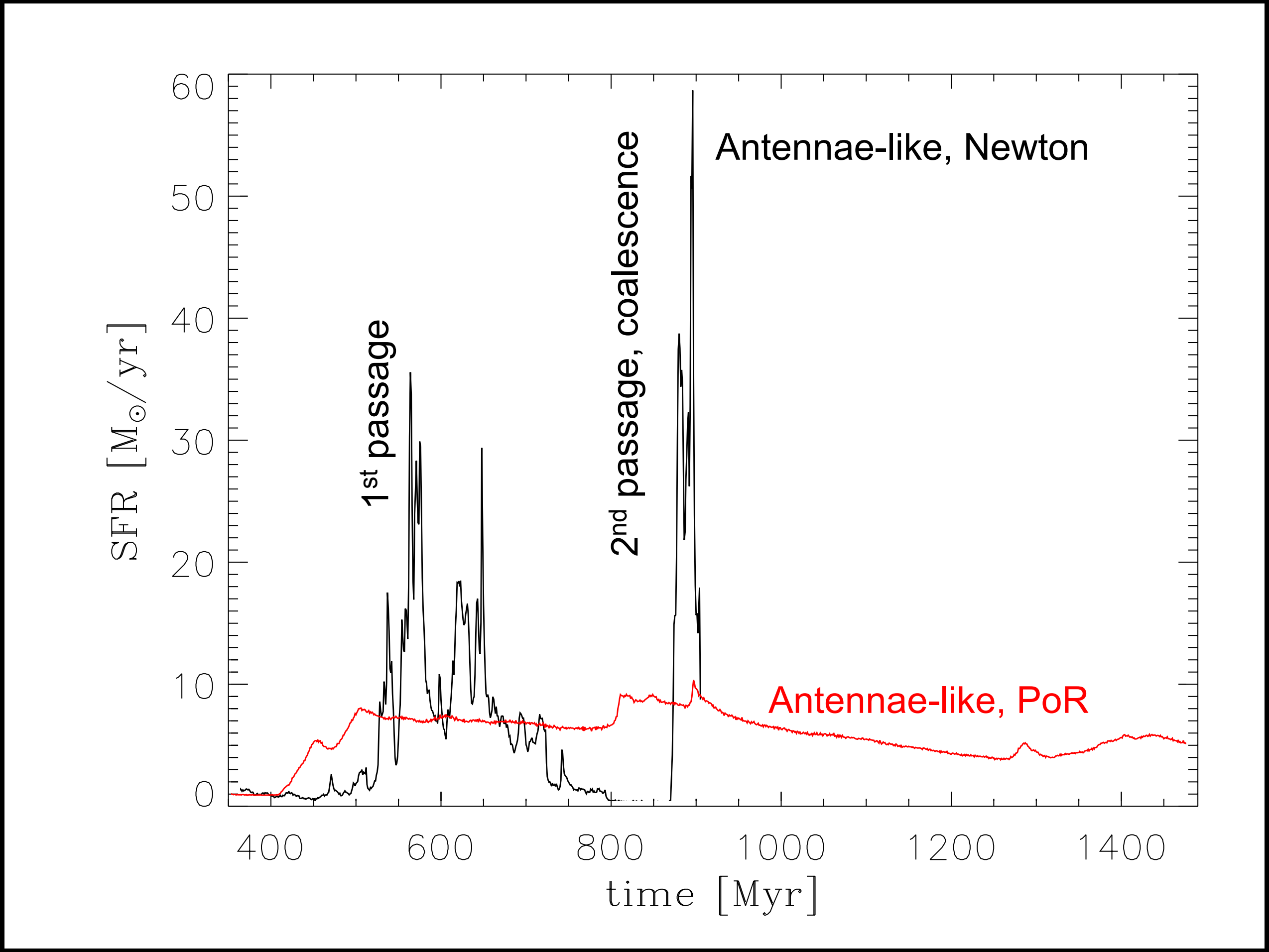
For the Antennae ... but not only

→ Rather insensitive to orbits and progenitors

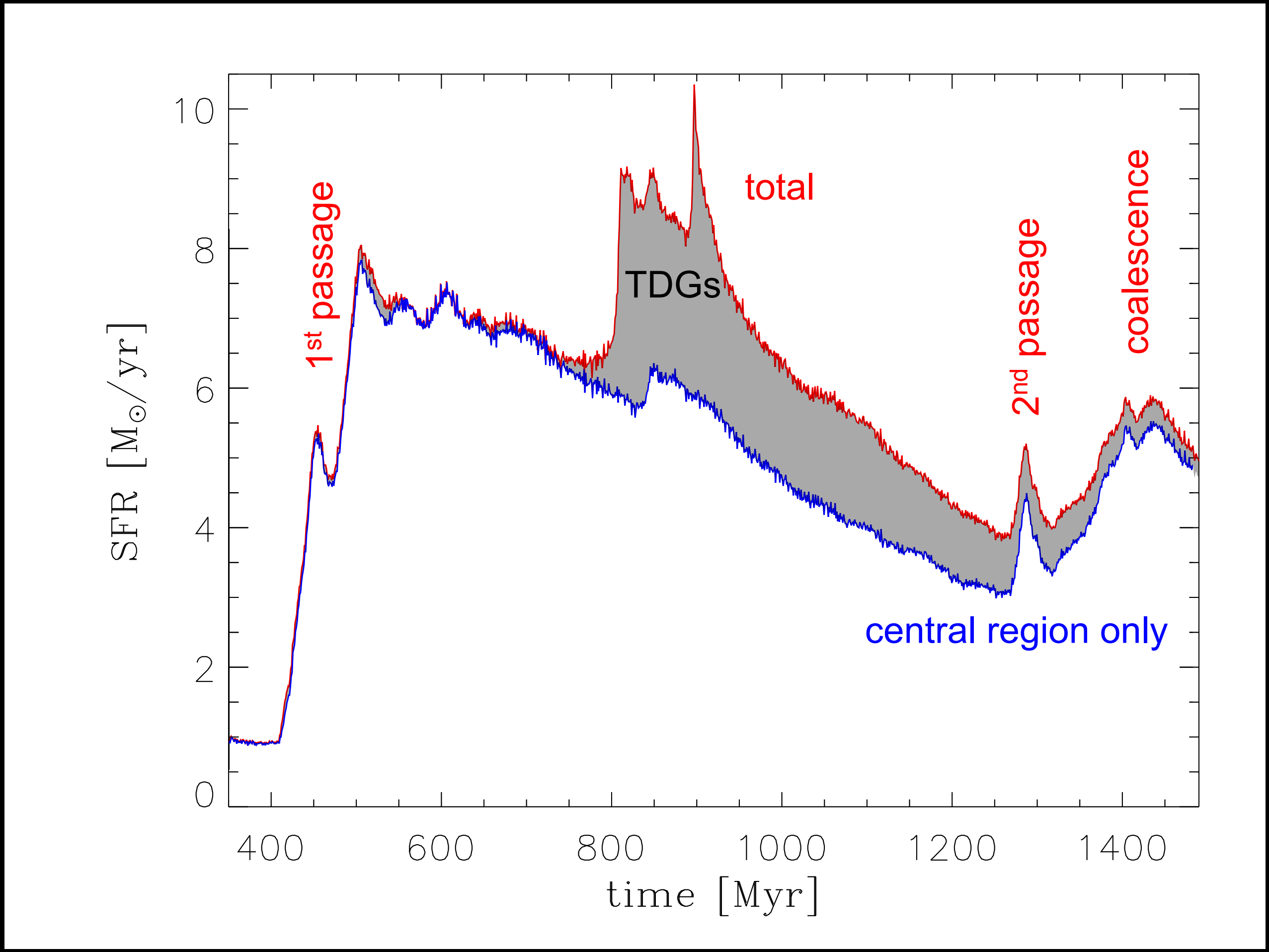
di Matteo et al. (2008)



Star Formation Rate



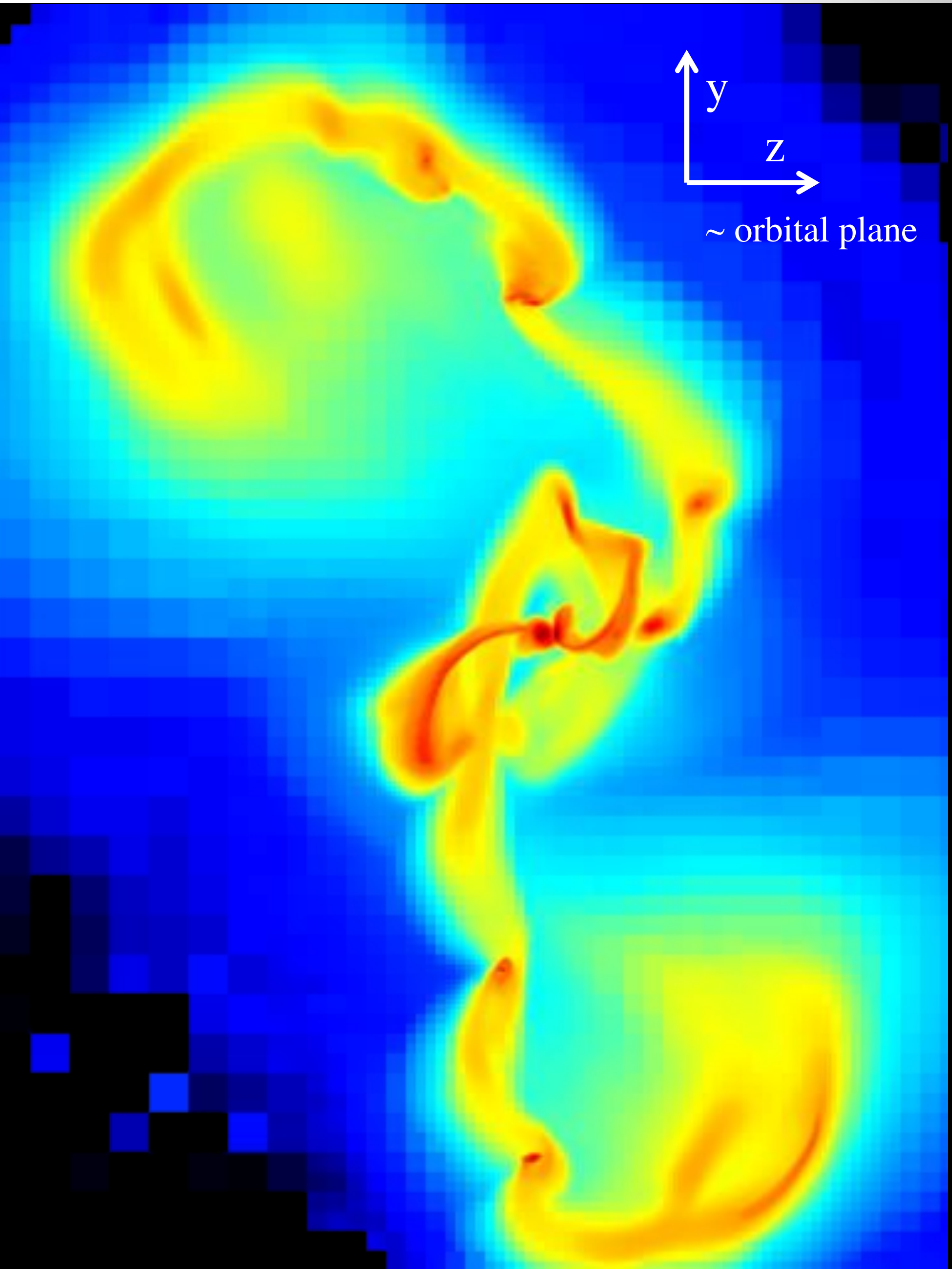
Star Formation Rate



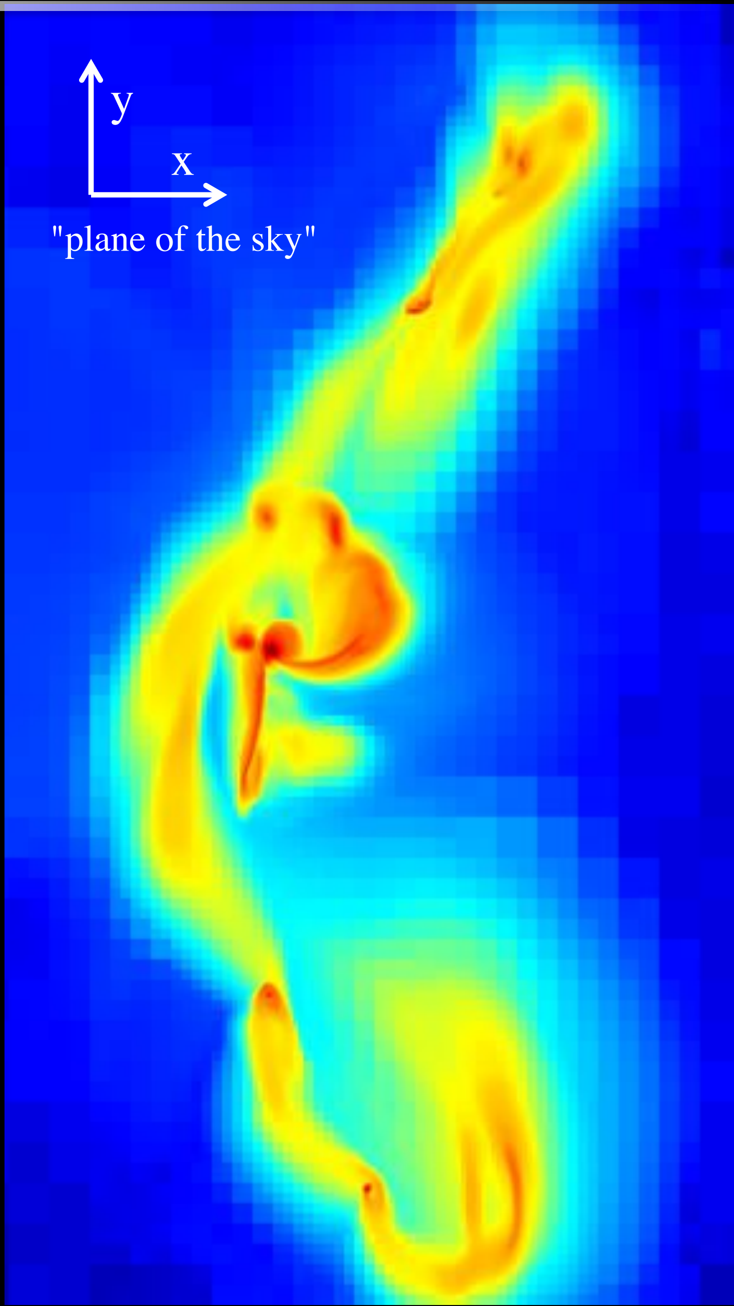
Observational constraint? Maybe but difficult

(model degeneracy, SFH uncertainties ...)

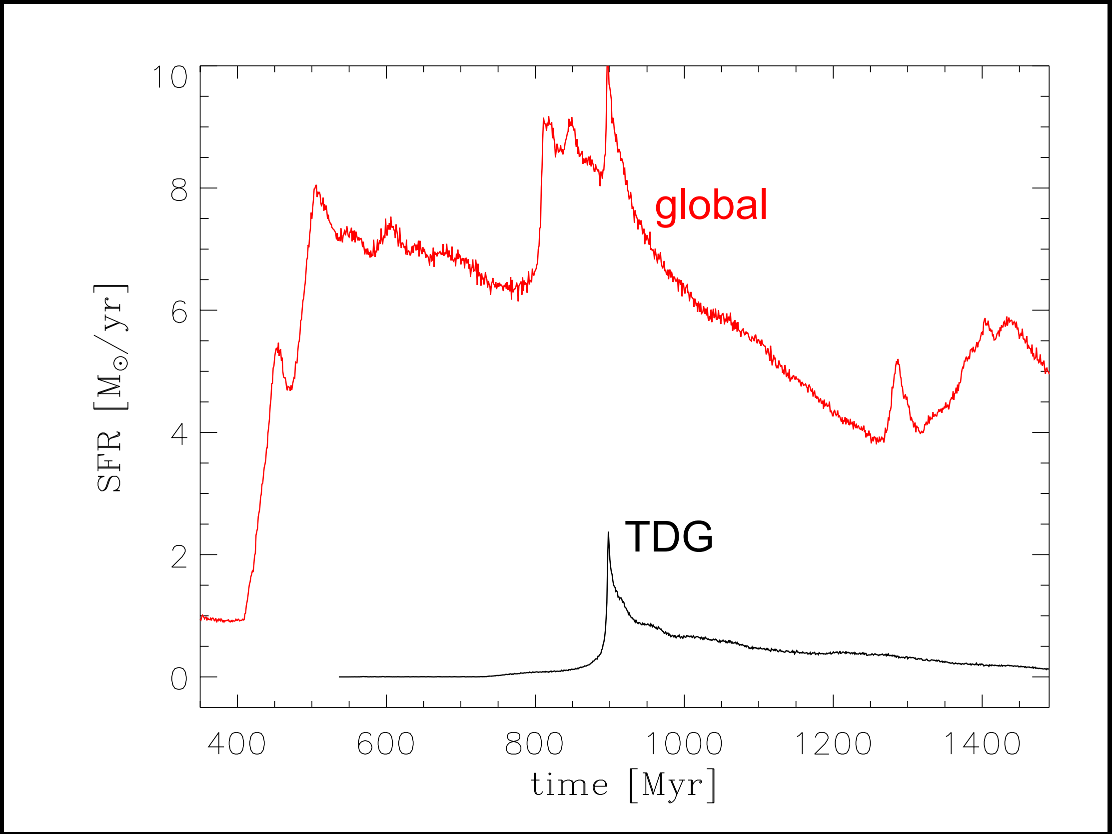
Tidal Dwarf Galaxies

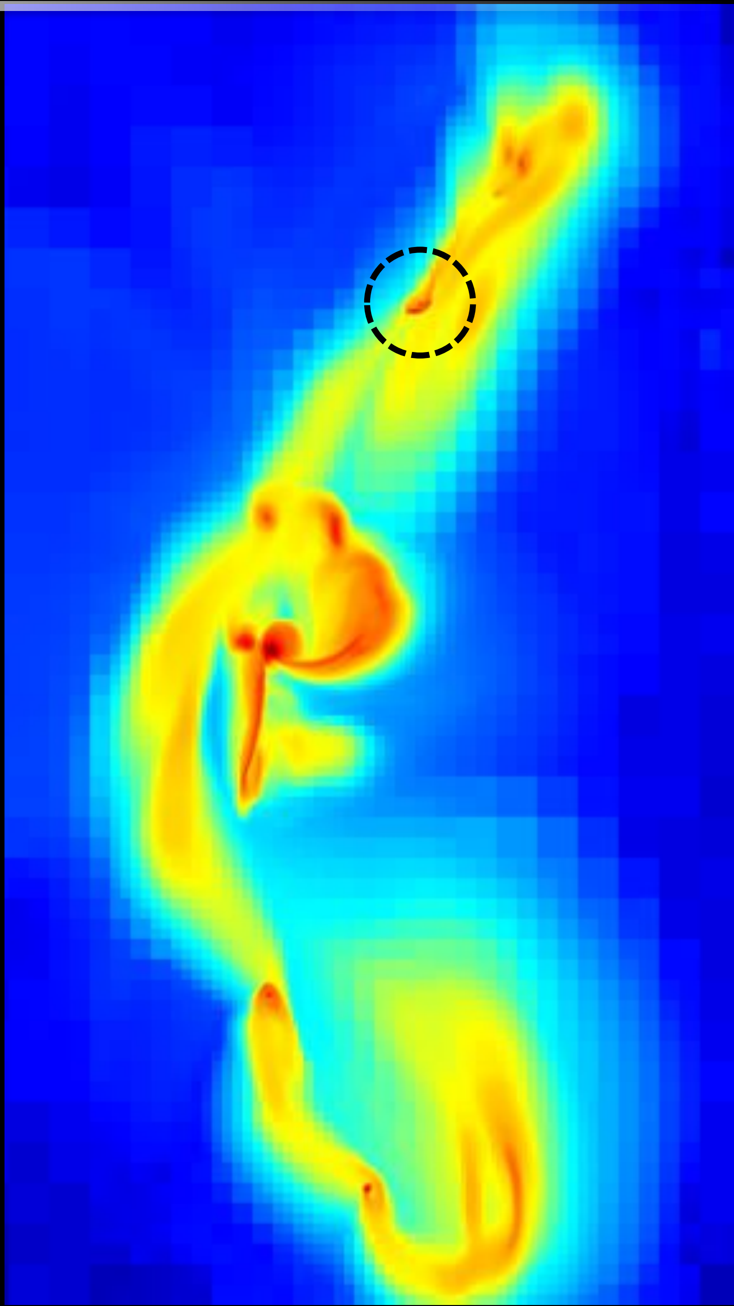


20 kpc



Tidal Dwarf Galaxies





In-situ SF

Delayed collapse

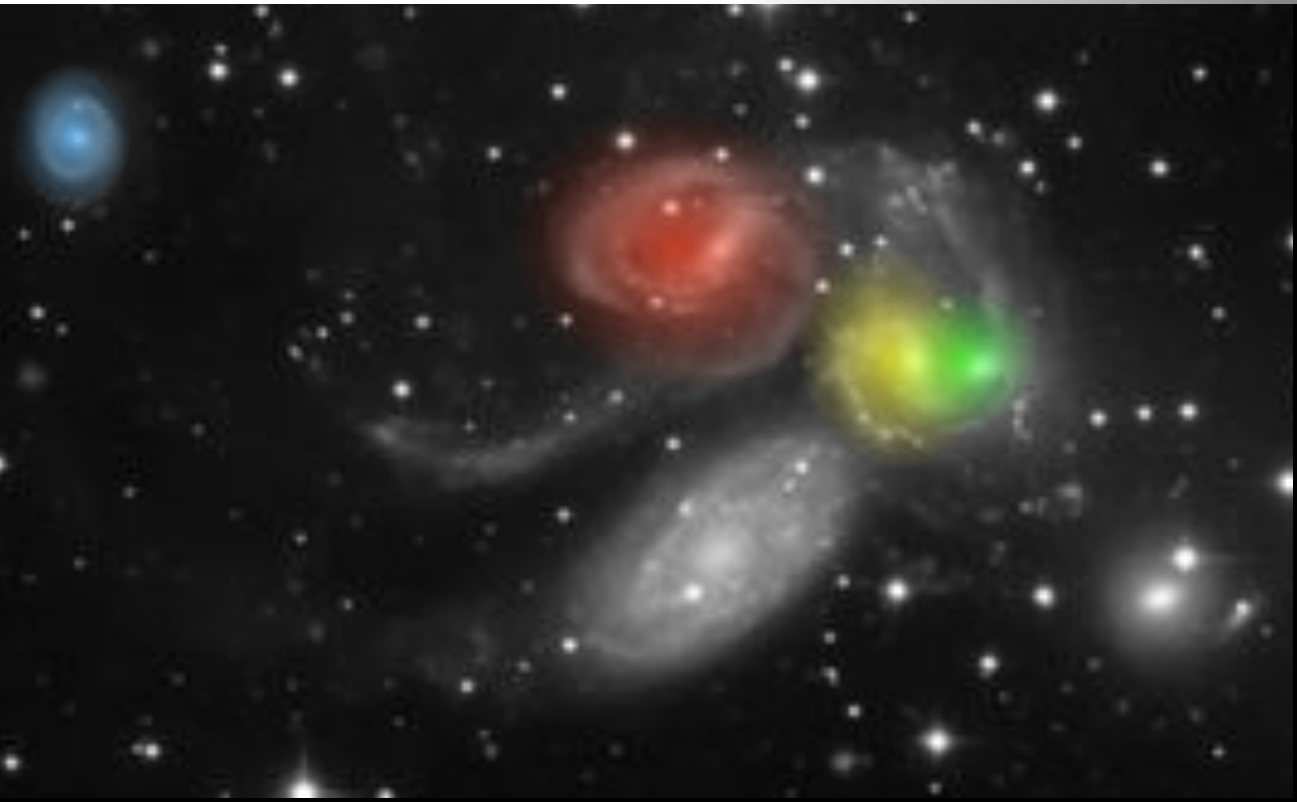
10% (up to 20%) of total SFR

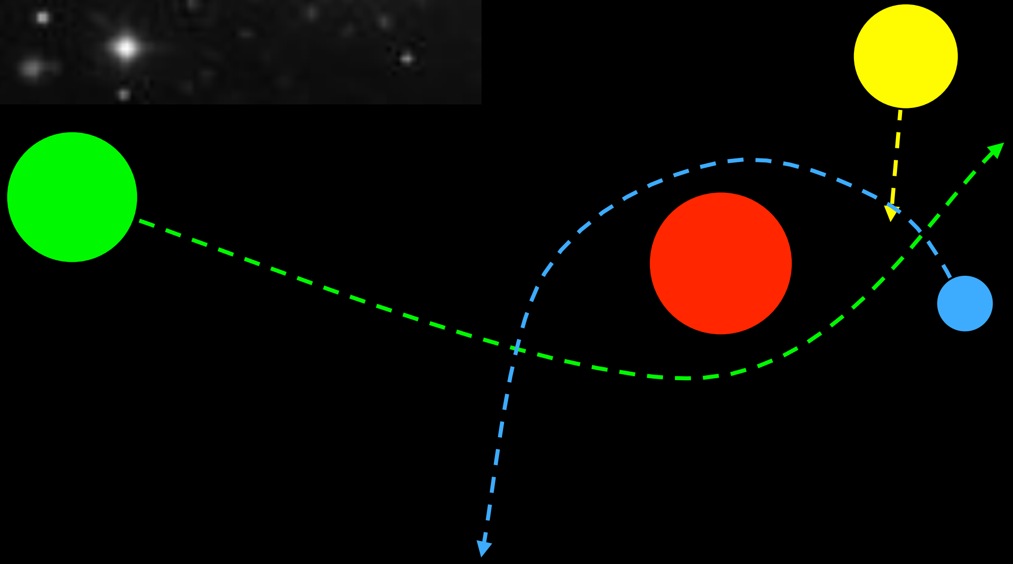
compared to < 1% observed

Boquien et al. (2009, 2010)

STEPHAN'S QUINTET OBSERVATIONS

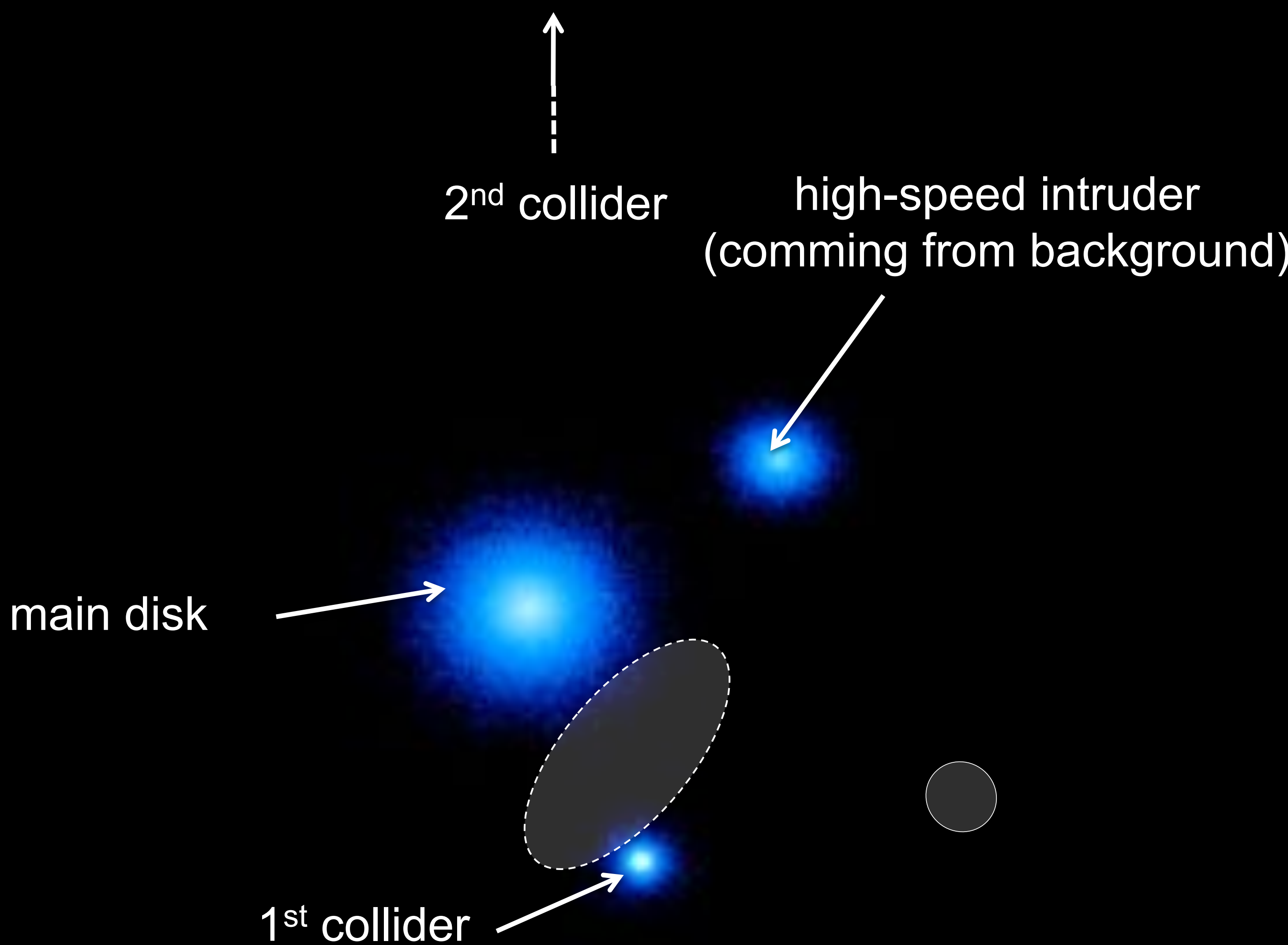
Stephan's Quintet Model





Stephan's Quintet Simulation

Renaud, Appleton & Xu (2010)



Future of Stephan's Quintet?

Renaud, Appleton & Xu (2010)