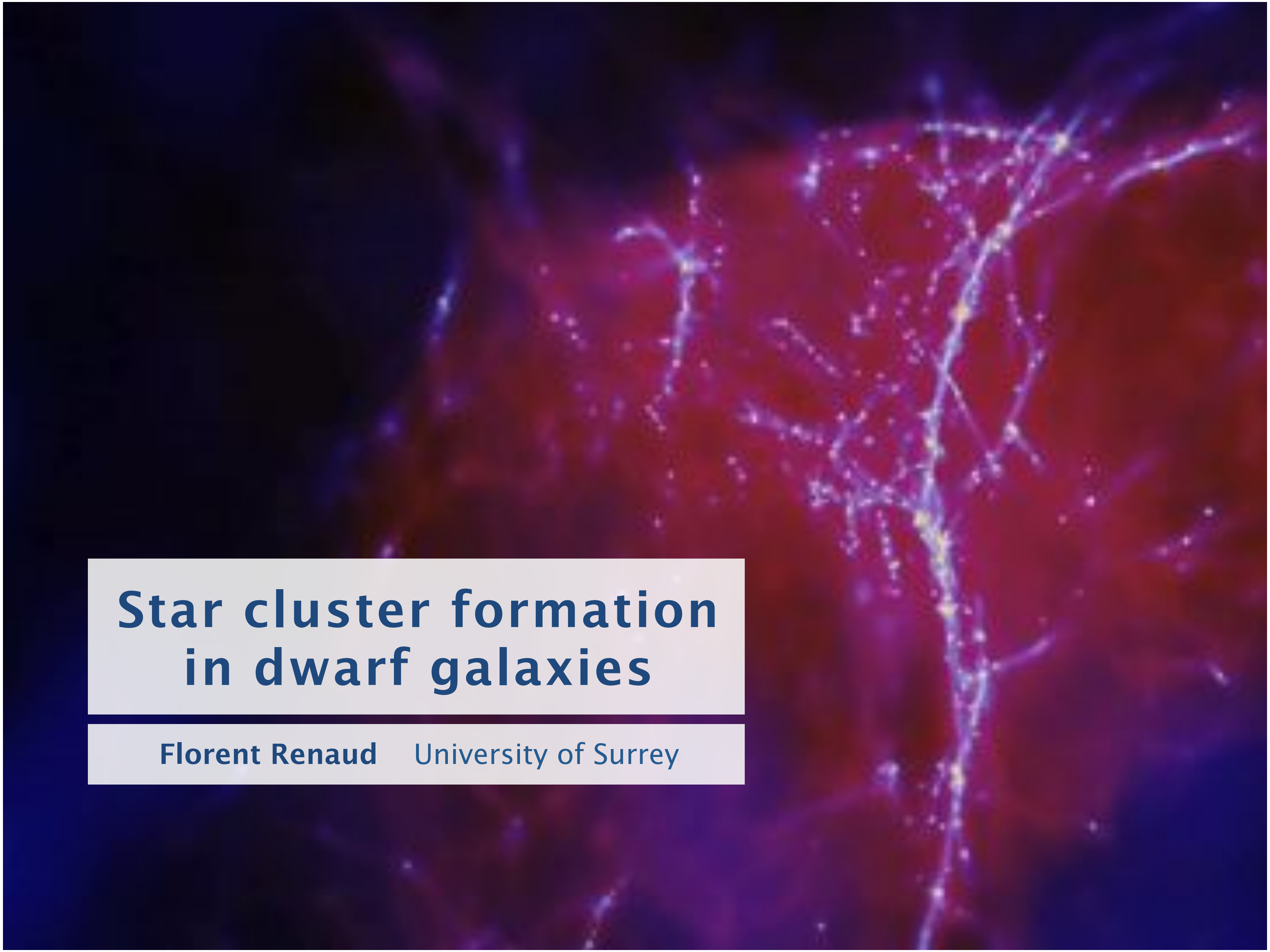
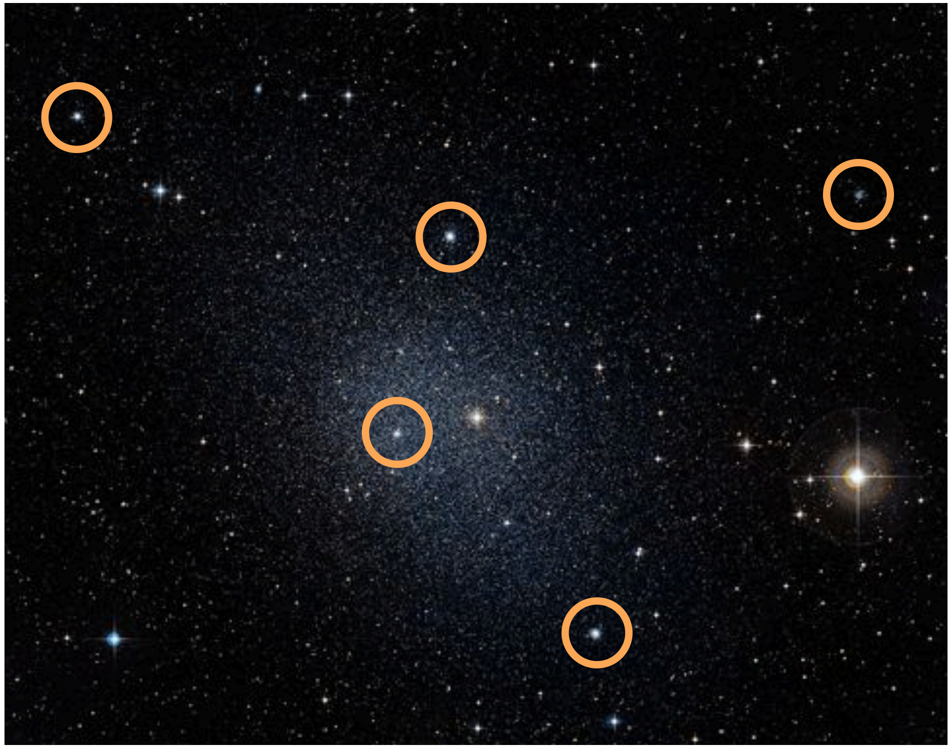


Star cluster formation in dwarf galaxies

Florent Renaud University of Surrey

Massive clusters in dwarf outskirts

Fornax dwarf galaxy, Larsen et al.

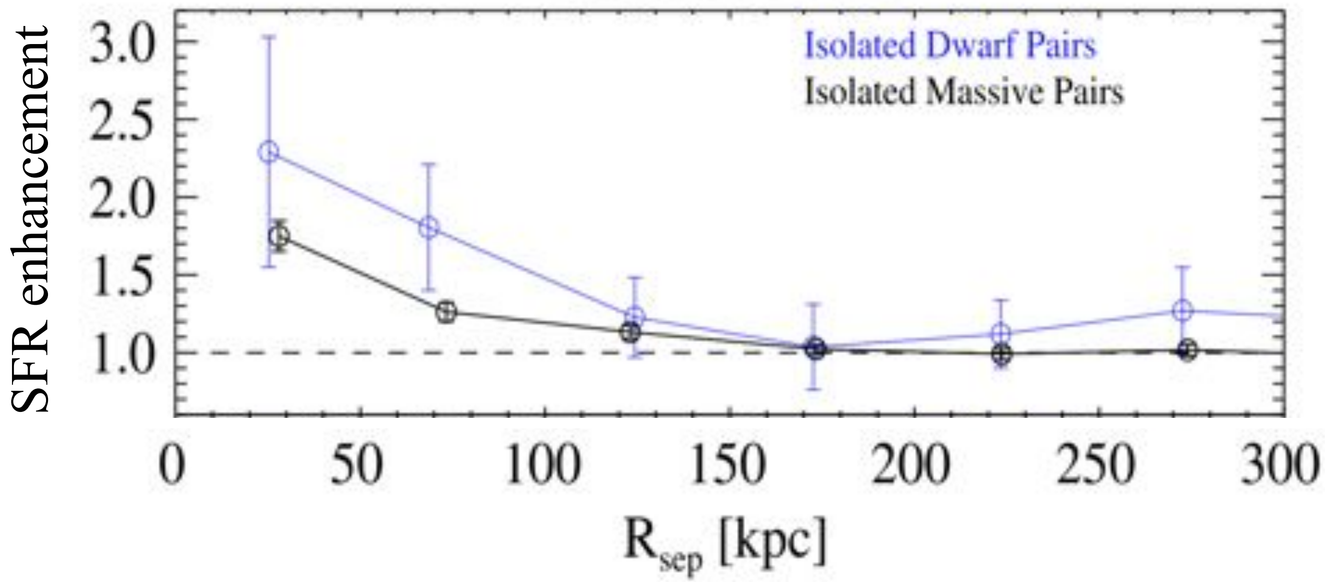


- High specific frequency
- Beyond optical radius
- In situ or migration?
- A (starbursting) interaction *can* explain:
  - SF in massive clusters
  - high specific frequency
  - migration and/or extended (in situ) SF
  - stripping of SF left-overs

see: Coleman et al. (2004)
Klimentowski et al. (2007)
Yozin & Bekki (2012)
Diakogiannis et al. (2017)

SFR boost in dwarf pairs

Stierwalt et al. (2015)



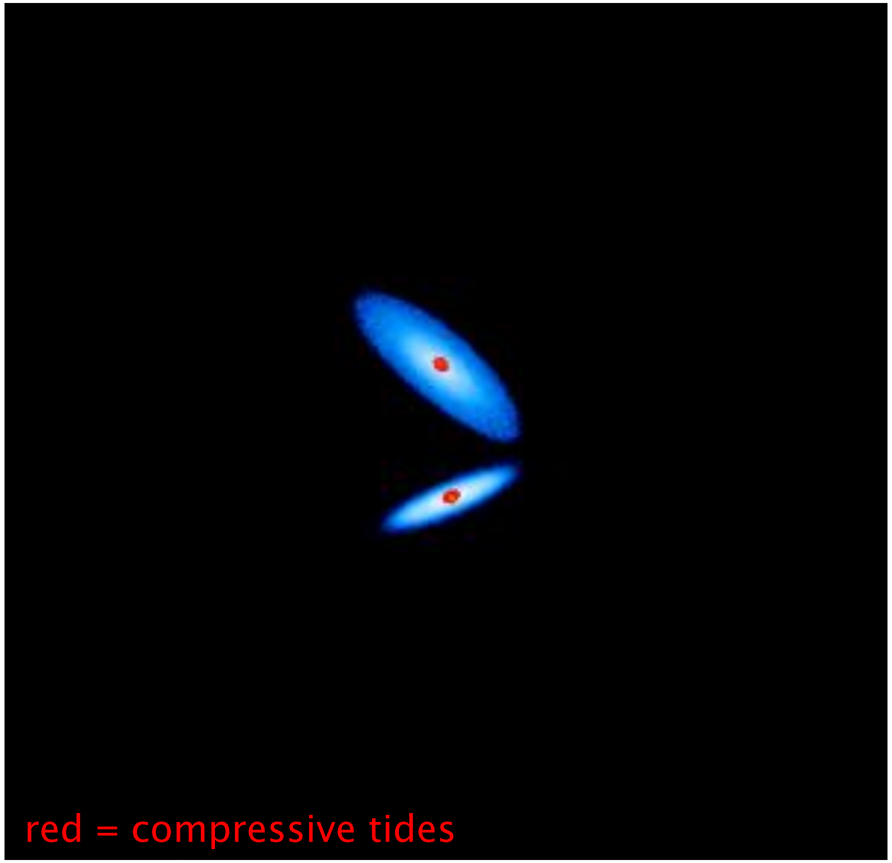
- Stronger in low-mass major interactions
- Extended and massive gas reservoirs
- More tidal and ram pressure stripping
- Weaker torques

→ Need to understand the physics of this boost

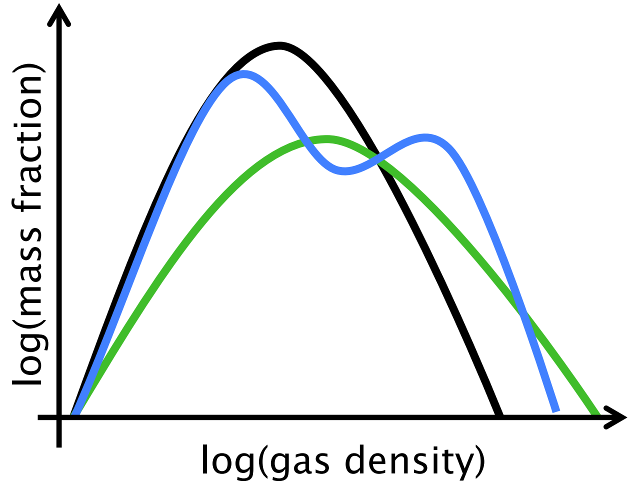
Tidal compression in interacting systems

- Compression at encounters
  - kpc scales
  - long-lived (~30-100 Myr)
  - nuclear *and* off-nuclear
- Also on the "other side" and in the debris (link with TDGs)
  Plöckinger (2015)
- Valid for all interactions
  Renaud et al. (2009)
- Triggers starburst
  Renaud et al. (2014)

Renaud et al. (2008)

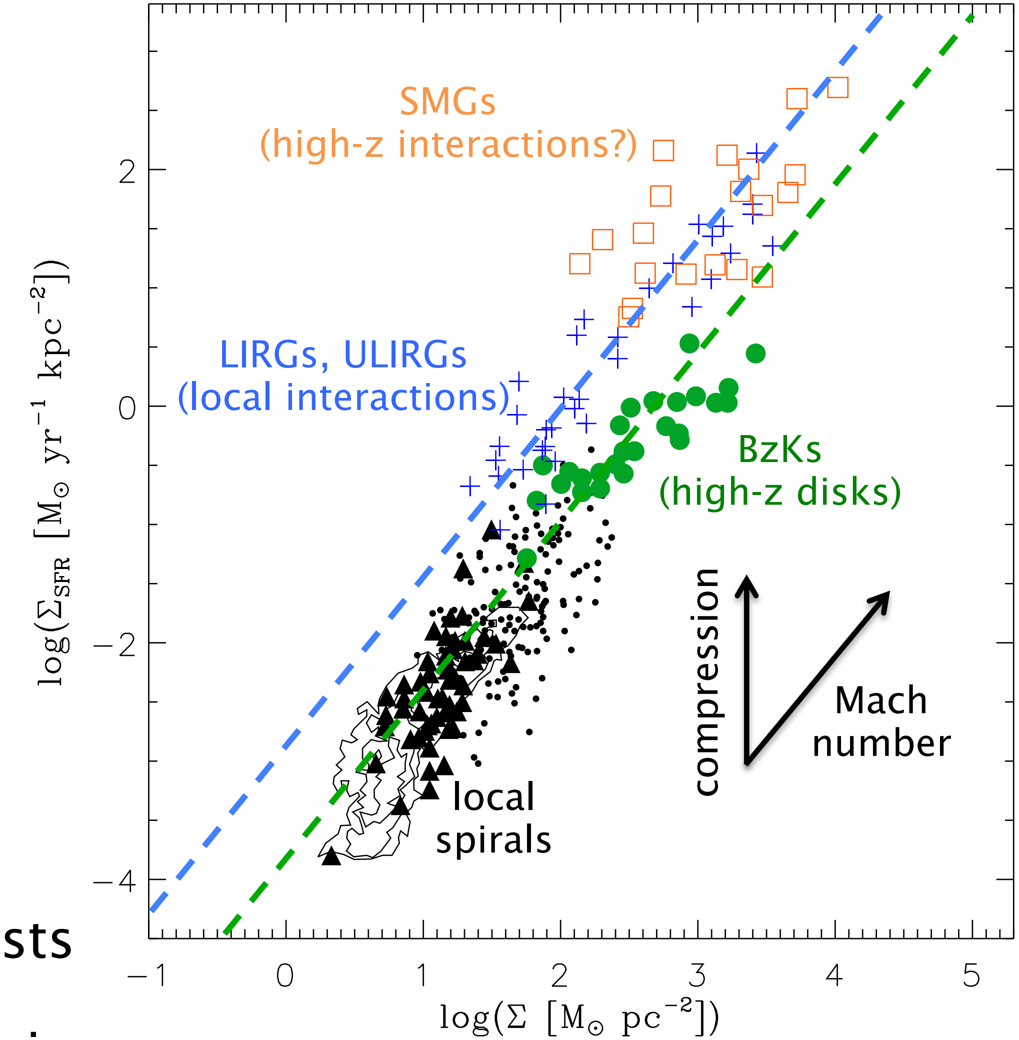


High SFE vs. high SFR



- Increase turbulence (e.g. at high-z) → higher SFR
- Does NOT explain starbursts
- Make turbulence compressive → higher SFE (explains starbursts)

(inspired by Daddi et al. 2010 and Genzel et al. 2010)



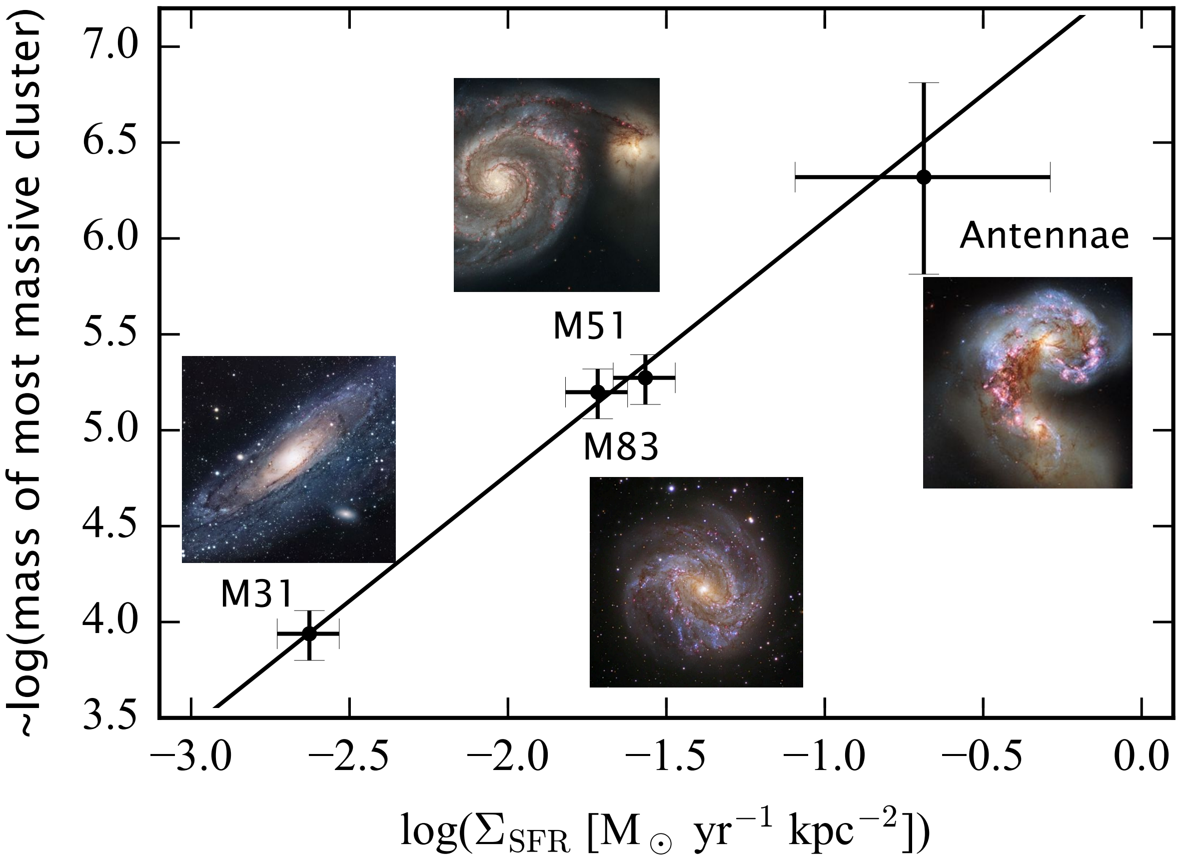
see Renaud et al. (2012) for the maths
Kraljic et al. (2014) for the simulations

Young massive clusters

from Johnson et al. (2017)

- Higher mass clusters in galaxies with high SFR

- Shape of the PDF → high mass end of the initial cluster mass function



Kravtsov & Gnedin (2005)
Confimed by pc-resolution simulations of the Antennae, Cartwheel and others (Renaud et al. 2015, and in prep.)

- SFE must play a role too

The theory

Galaxy interaction

→ compressive tides

→ compressive turbulence

→ excess of dense gas

→ high SFR **and** high SFE

→ starburst with young massive clusters

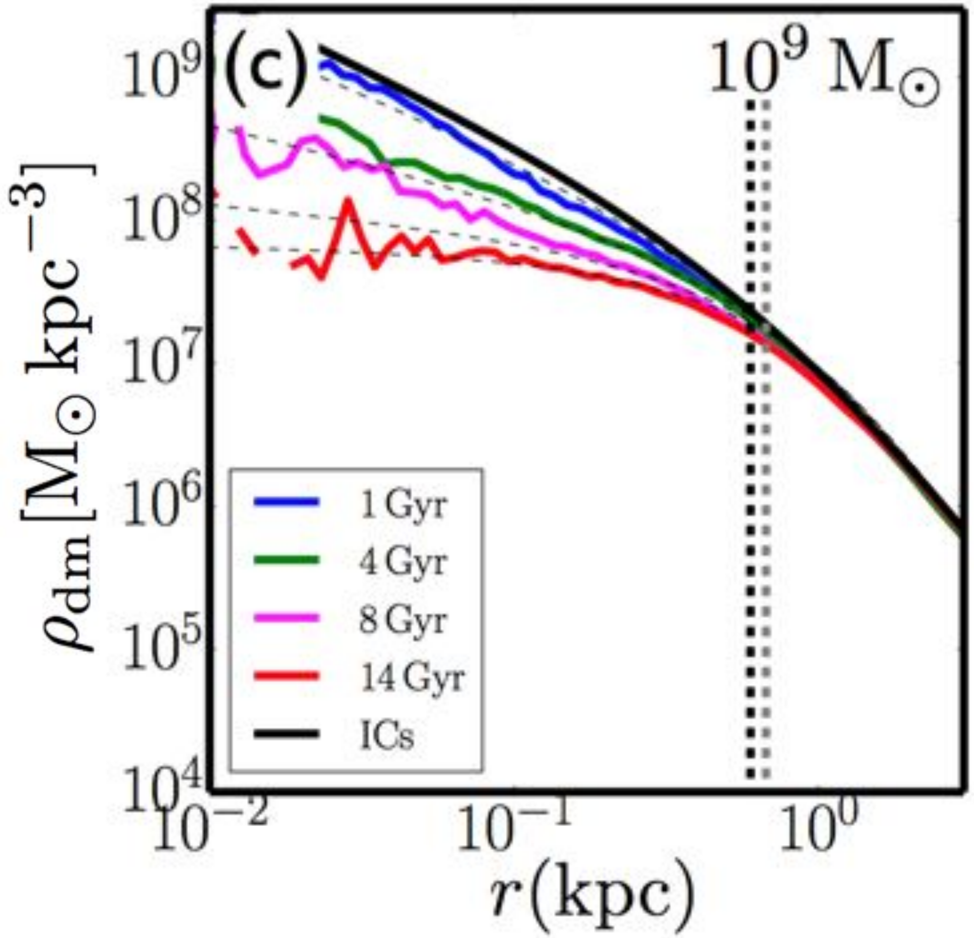
Renaud et al. (2014)

Cusps, cores and star formation

- Galaxies form in DM cusps
- Gas falls in potential well
- Gas forms stars
- Stellar feedback re-distributes matter
- Cusps are transformed into cores

cf. Mike's, Chris', Justin's talks

Read et al. (2016)



Cusps, cores and tides

$$\lambda(r) = -\frac{\partial^2 \phi}{\partial r^2}$$

- NFW (cusp)
  Navarro et al. (1997)

$$\rho_{\rm NFW}(r) = \frac{\rho_0 r_s^3}{r\left(r+r_s\right)^2}$$

$$\lambda_{\rm NFW}(r) = 4\pi G \rho_0 \left(\frac{r_s}{r}\right)^3 \left[2\ln\left(1+\frac{r}{r_s}\right) - \frac{3r^2+2rr_s}{\left(r+r_s\right)^2}\right]$$

$$> 0 \qquad \forall r$$

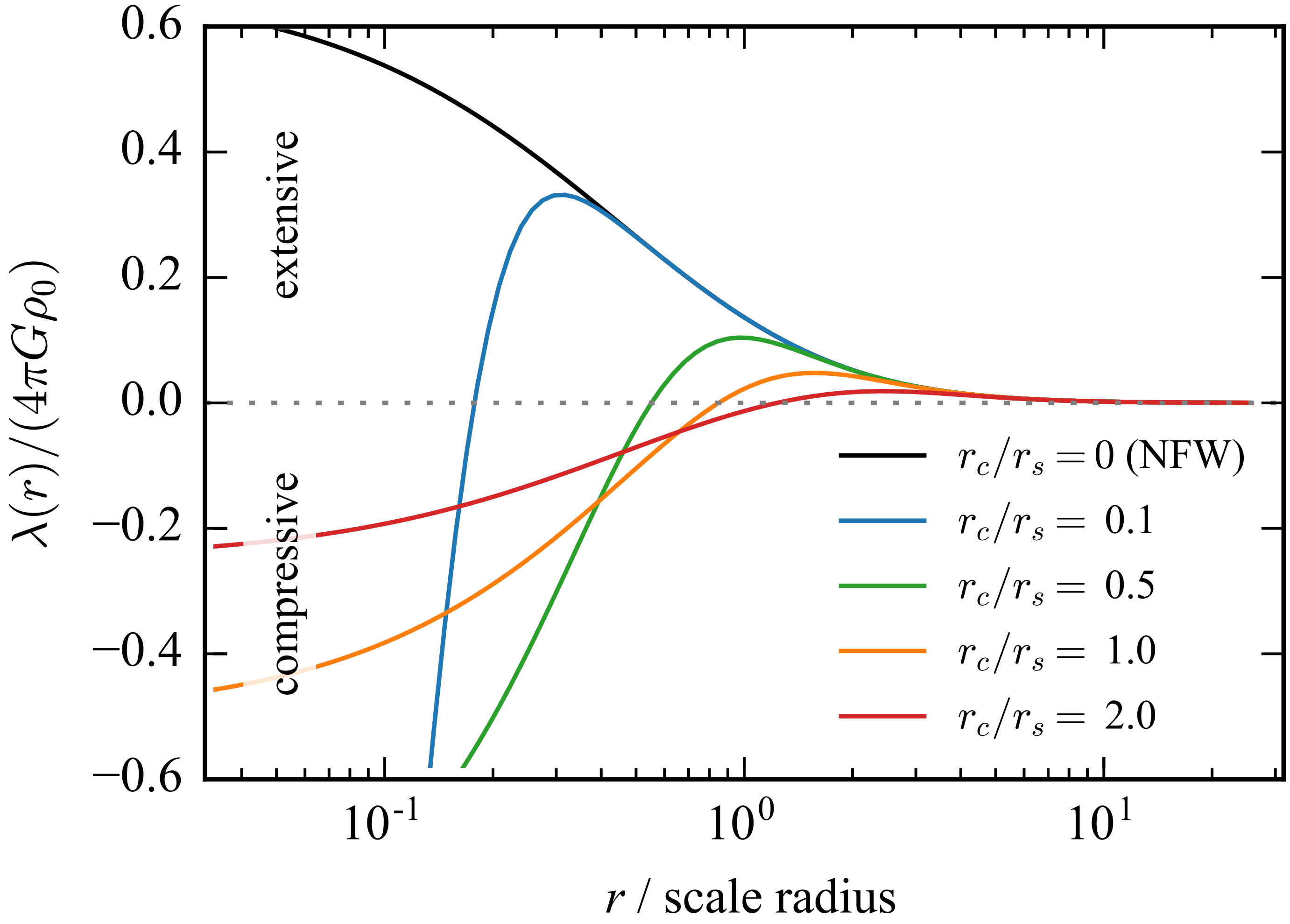
- Cored version of NFW
  Read et al. (2015)

$$M_{\rm cNFW}(<r) = M_{\rm NFW}(<r) f(r)$$

$$f(r) = \tanh\left(r/r_c\right)$$

$$\lambda_{\rm cNFW}(r) = 4\pi G \rho_0 r_s^3 \left\{ \ln\left(1+\frac{r}{r_s}\right)\left[2\frac{f(r)}{r^3} - \frac{\left[1-f(r)^2\right]}{r^2 r_c}\right] - \frac{f(r)}{r^2}\frac{3r+2r_s}{(r+r_s)^2} + \frac{\left[1-f(r)^2\right]}{r r_c (r+r_s)} \right\}$$

Cusps, cores and tides

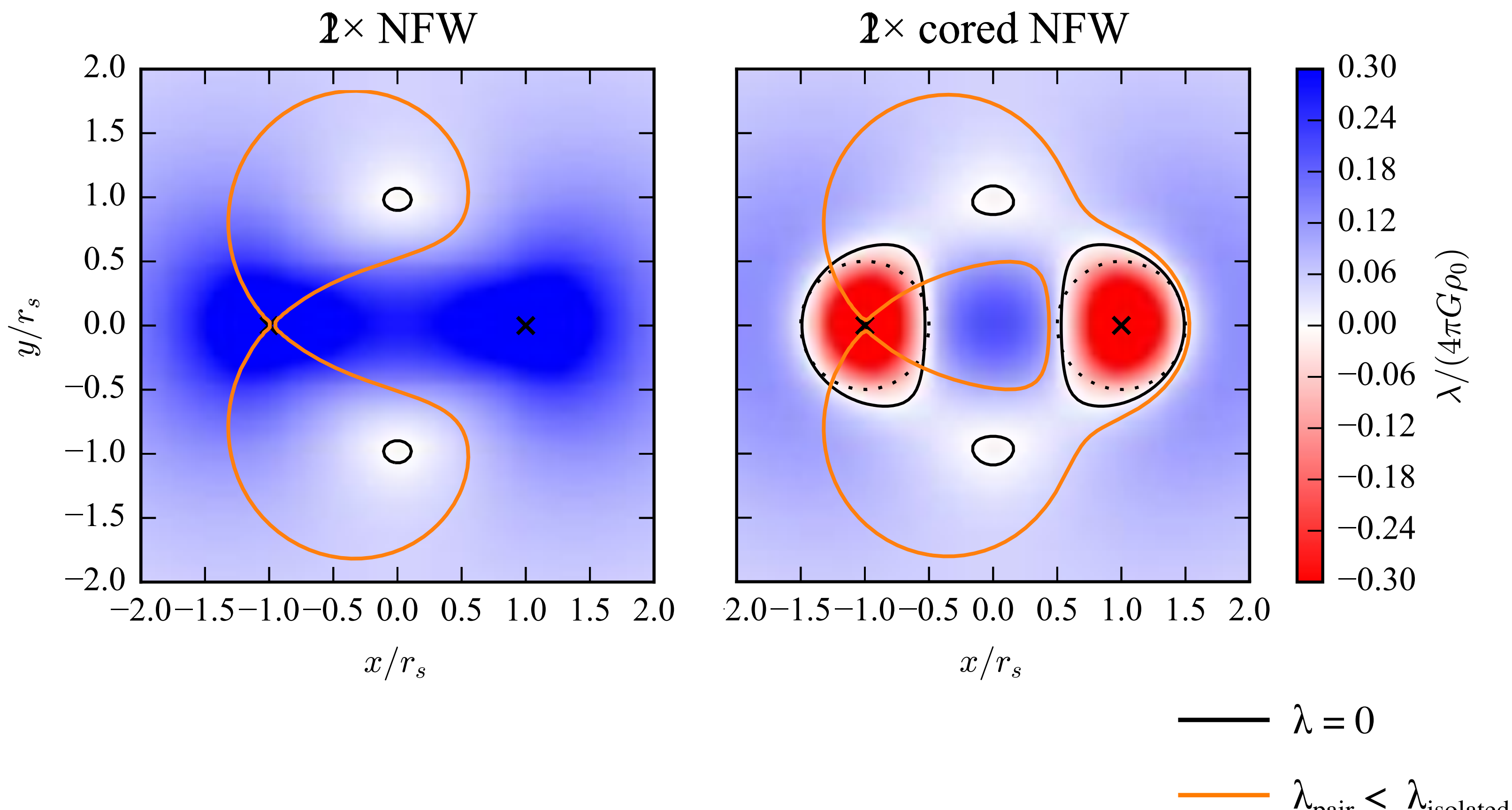


Comparable results for Einasto and $\gamma < 1$ models

(see Renaud 2010 for the maths)

Einasto (1965)
Dehnen (1993)
Tremaine et al. (1994)

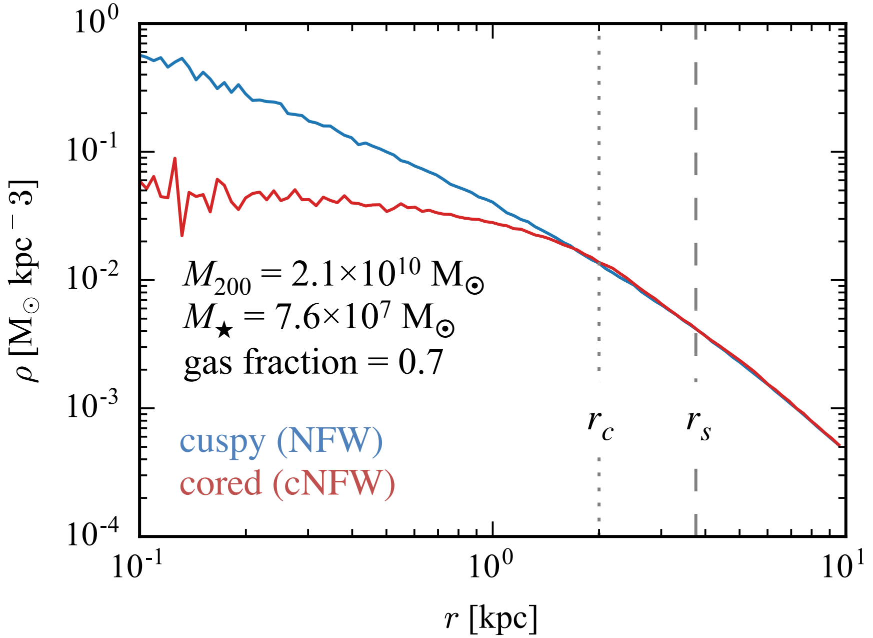
Tidal compression in pairs

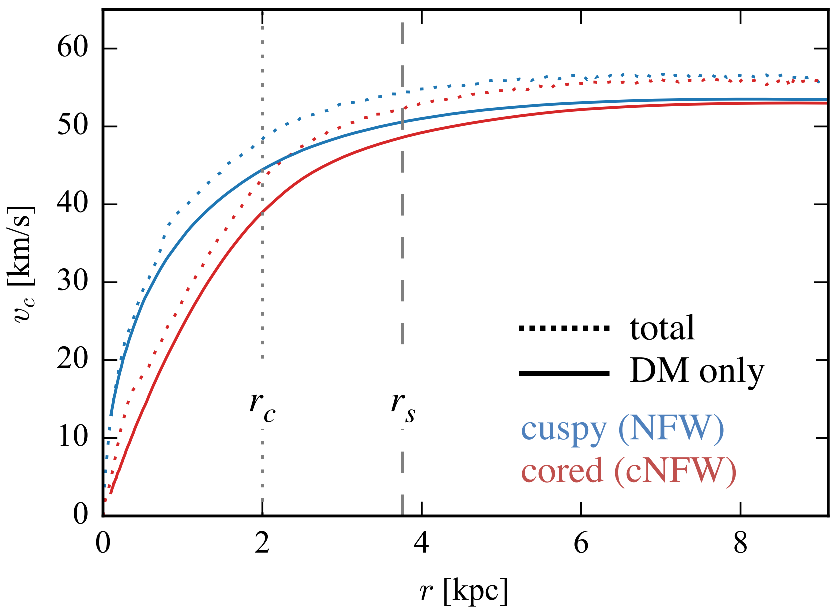


- Pair vs. isolated:

  more compressive tides, weaker extensive tides

Models of NGC 6822: 1 cuspy, 1 cored



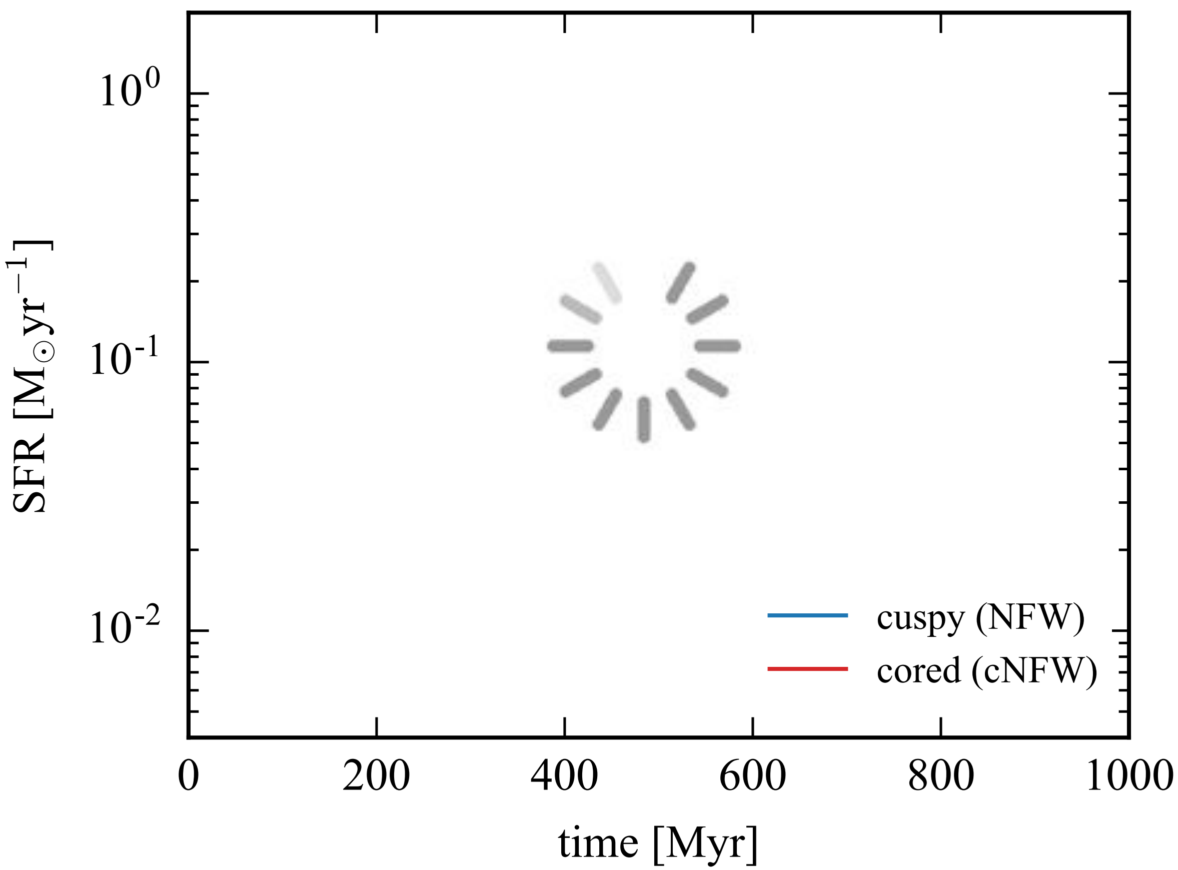


- Ramses Teyssier (2002)
  heating, cooling, SF, winds, SNe (II + Ia)
  as in Renaud et al. (2017),
  based on Agertz et al. (2013)

- Closed box, no (dirty) cosmo

- 3 pc (gas+stars), 5000 $M_\odot$ (DM)

SFR

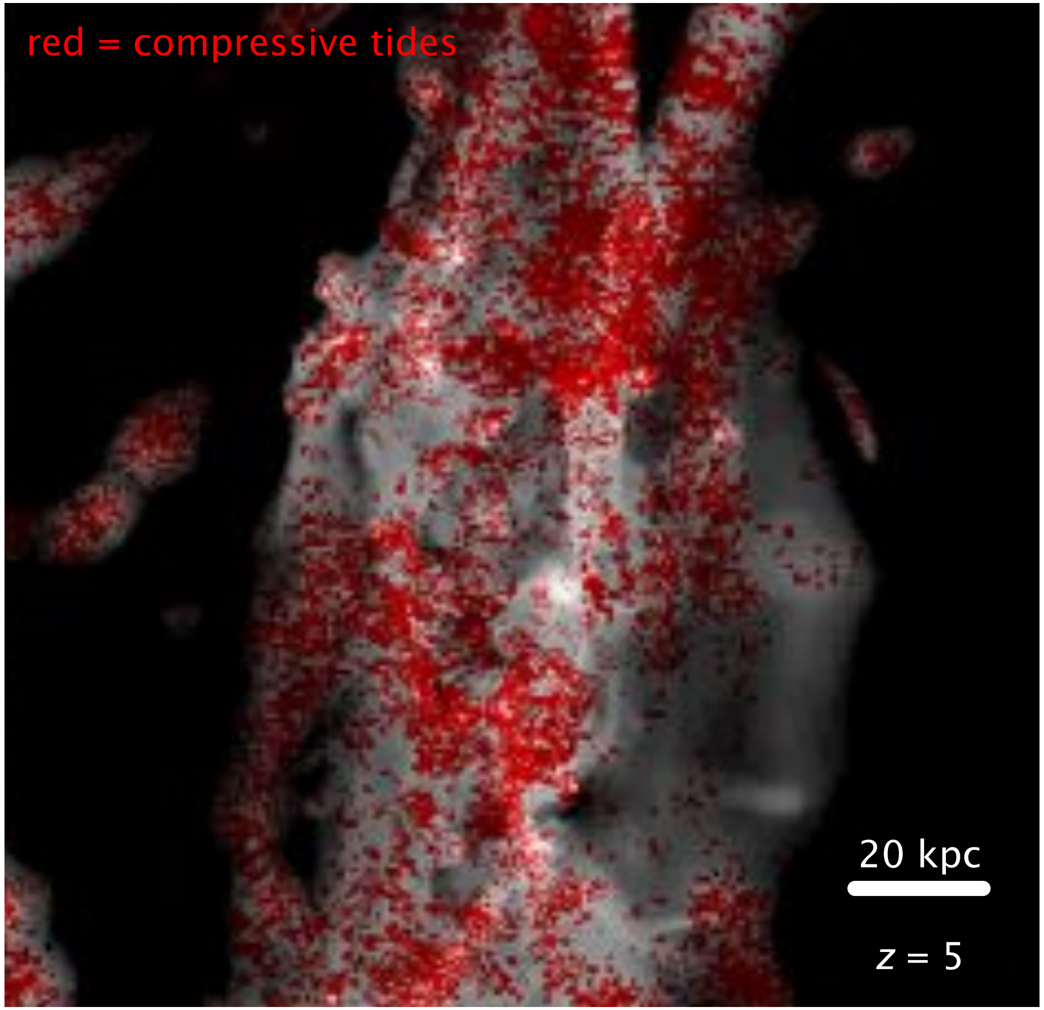


10^0
10^{-1}
10^{-2}
SFR [$M_\odot yr^{-1}$]
0
200
400
600
800
1000
time [Myr]
cuspy (NFW)
cored (cNFW)

Tidal compression at high redshift

Renaud, Agertz et al. (in prep)

- Universe is denser
- Large volumes in compressive tides
- Enhanced star formation?
- As young massive clusters (= future globulars) ?



Implications for cluster demographics in the end-product (e.g. MW)

Formation of many massive (dense) clusters in dwarfs

- Metal-poor clusters
- Loosely bound to their host
- Dense enough to survive tidal harrasment
- End up in the halo if/when dwarf is accreted

→ make the metal-poor (~ "blue") population
of massive galaxies (MW, centrals etc)

Renaud et al. (2017, and more in prep.)

Summary

- Simulations take time!
- Cored dwarfs have a lot of gas in compressive (or at least, low) tides
- Cores are a result **and** a cause of star formation
- Compressive tides **in between** galaxies at high-*z*
  (helps the formation of GCs?)
- How does enhanced massive cluster formation fit into the GC-mass vs halo-mass relation?
  (destruction needed, but is it sufficient?)