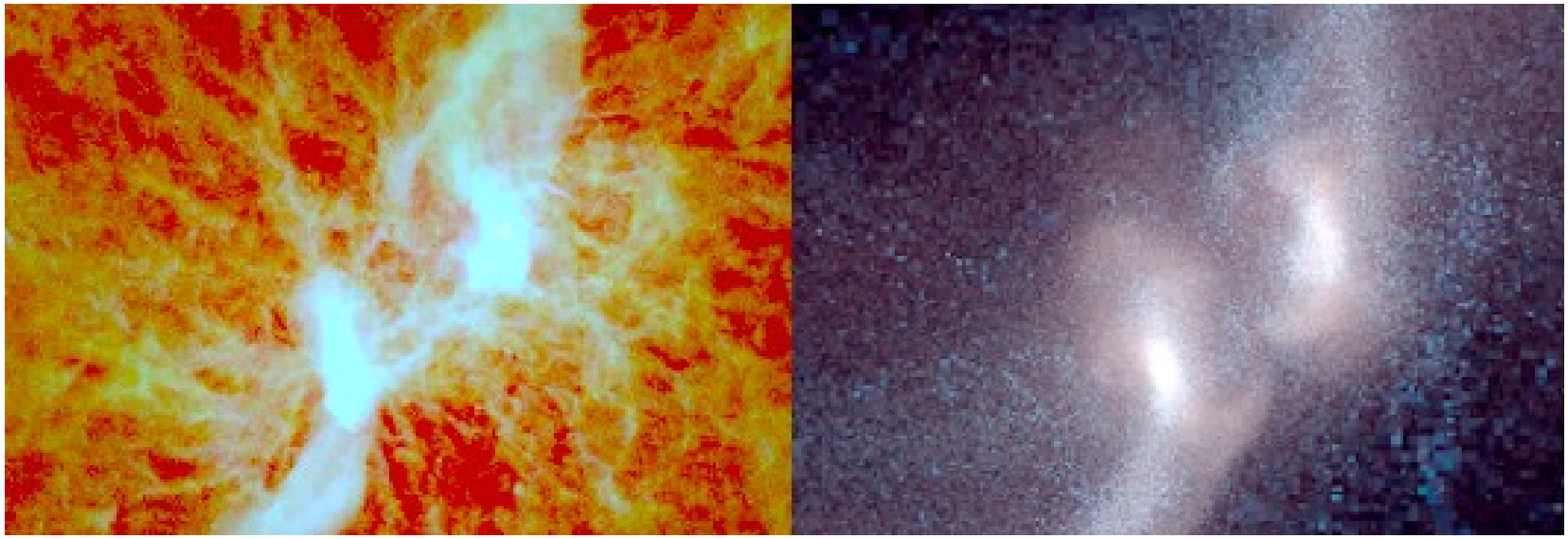
Cosmological simulations of major mergers



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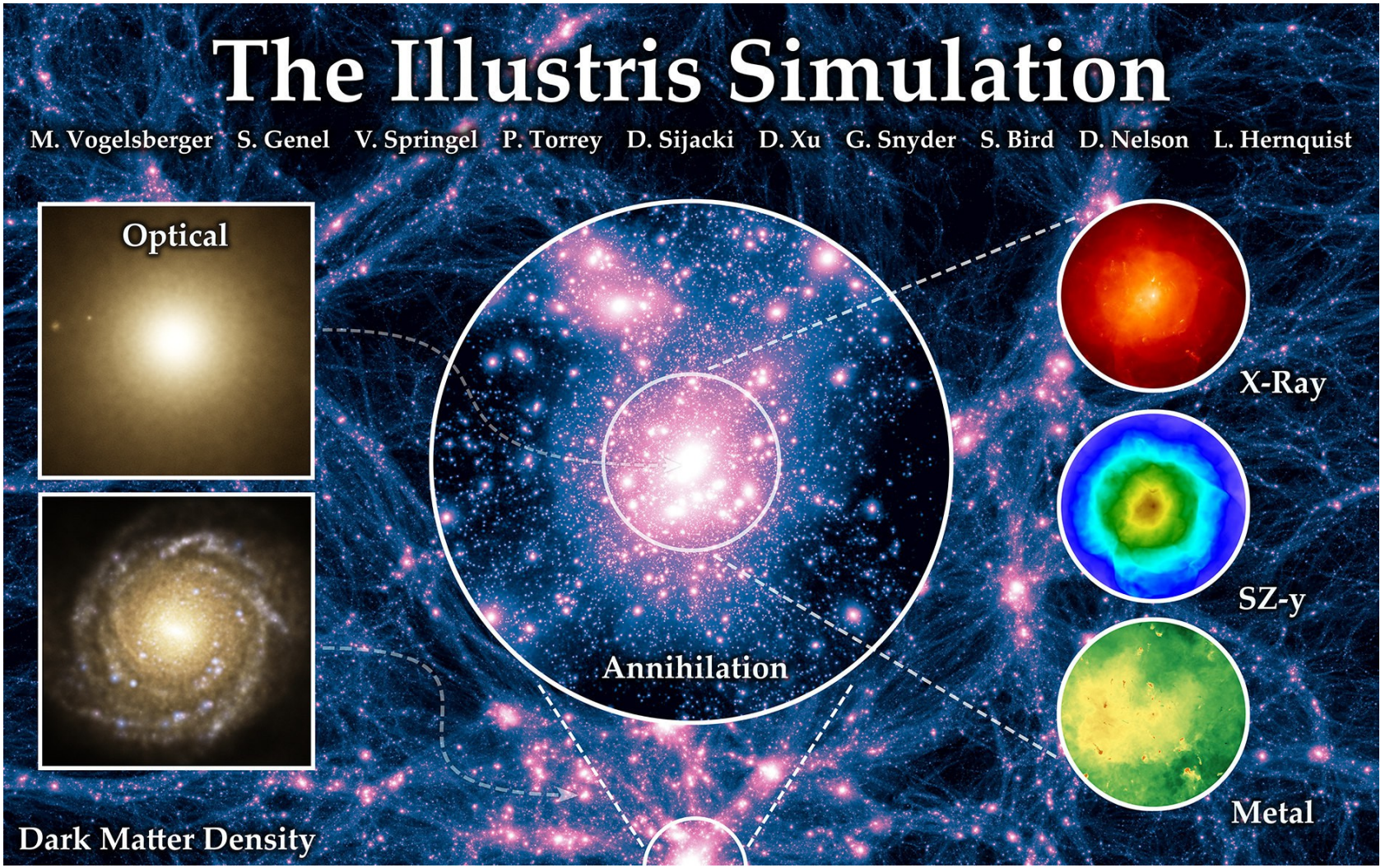
Collaborators:
- **Volker Springel (HITS)**
- **Chris Hayward (CCA ← Caltech)**
- **Illustris collaboration**
- **FIRE collaboration**

Zooming in on Illustris galaxies

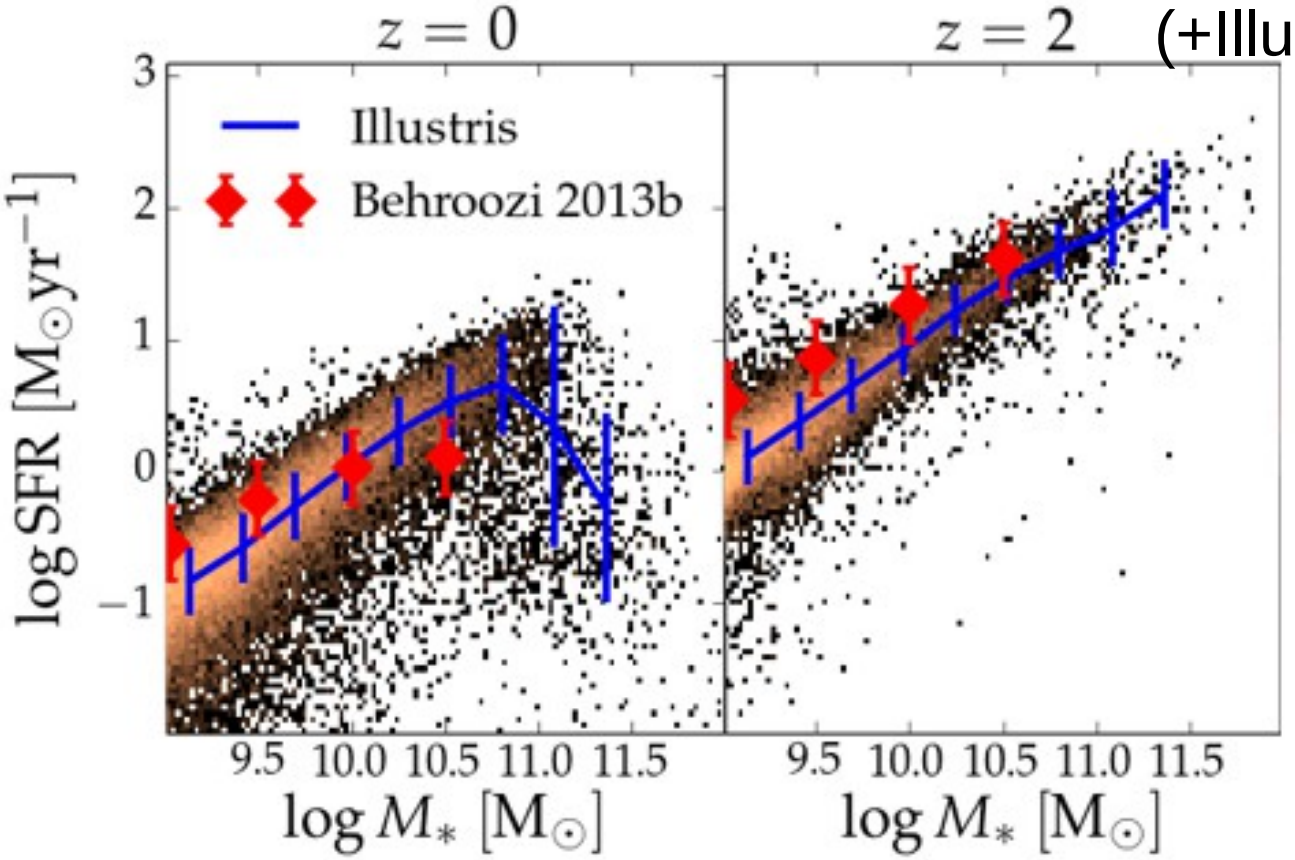


The SFR-M_* relation in Illustris

The star formation main sequence in Illustris

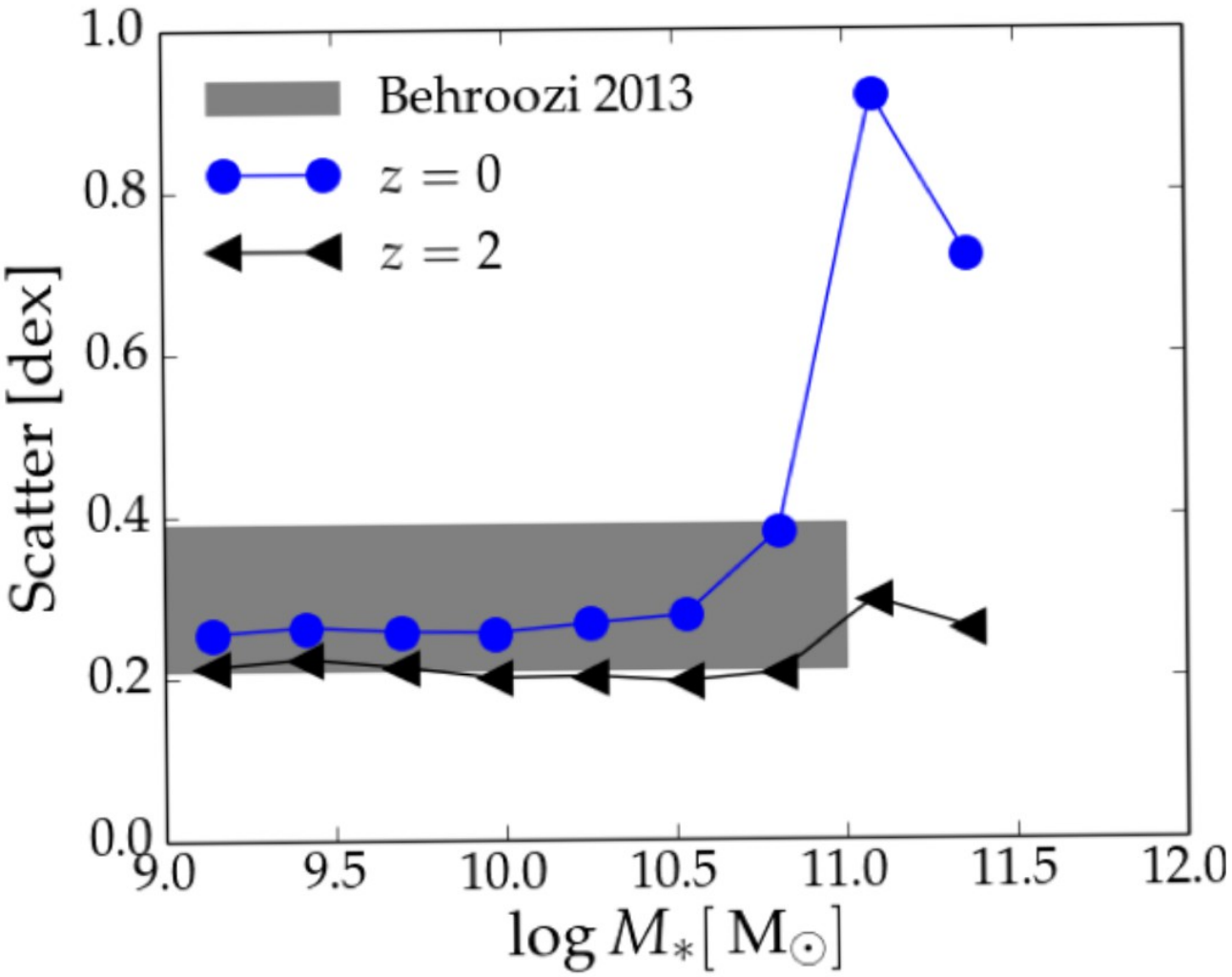
- **Illustris has a main sequence with a tight scatter**

MS, Hayward, Springel (+Illustris-collaboration) 2015



Scatter in the SFR-M_* relation agrees with observations

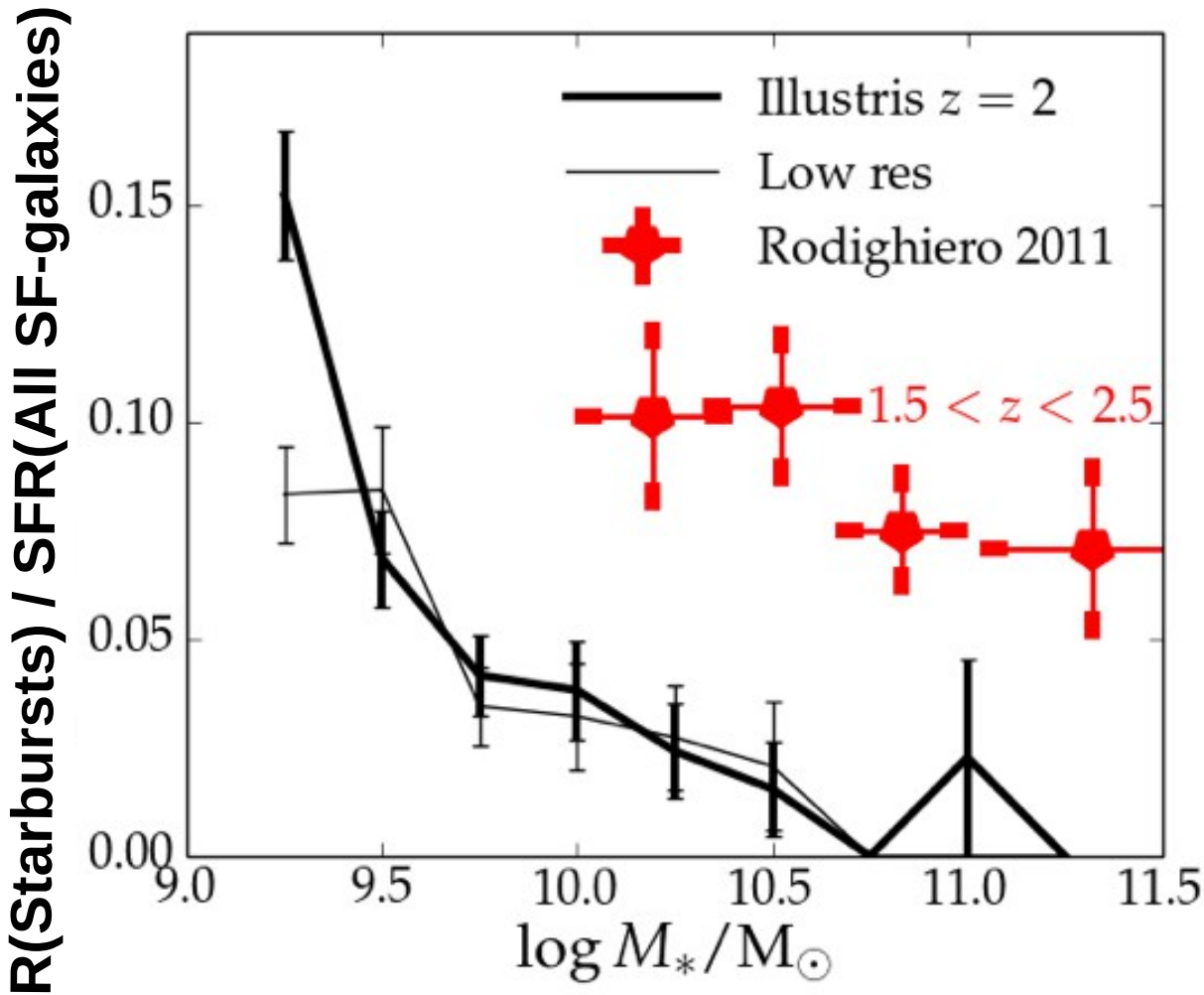
- **Scatter in Illustris is consistent with observations.**
- **The diversity of star formation histories is consistent with observations.**



MS, Hayward, Springel+ 2015

Too few starbursts in Illustris

- **Illustris had too few starbusts.**
- **A potential reason is the 700 pc resolution in Illustris (this is larger than typical starbursting regions).**



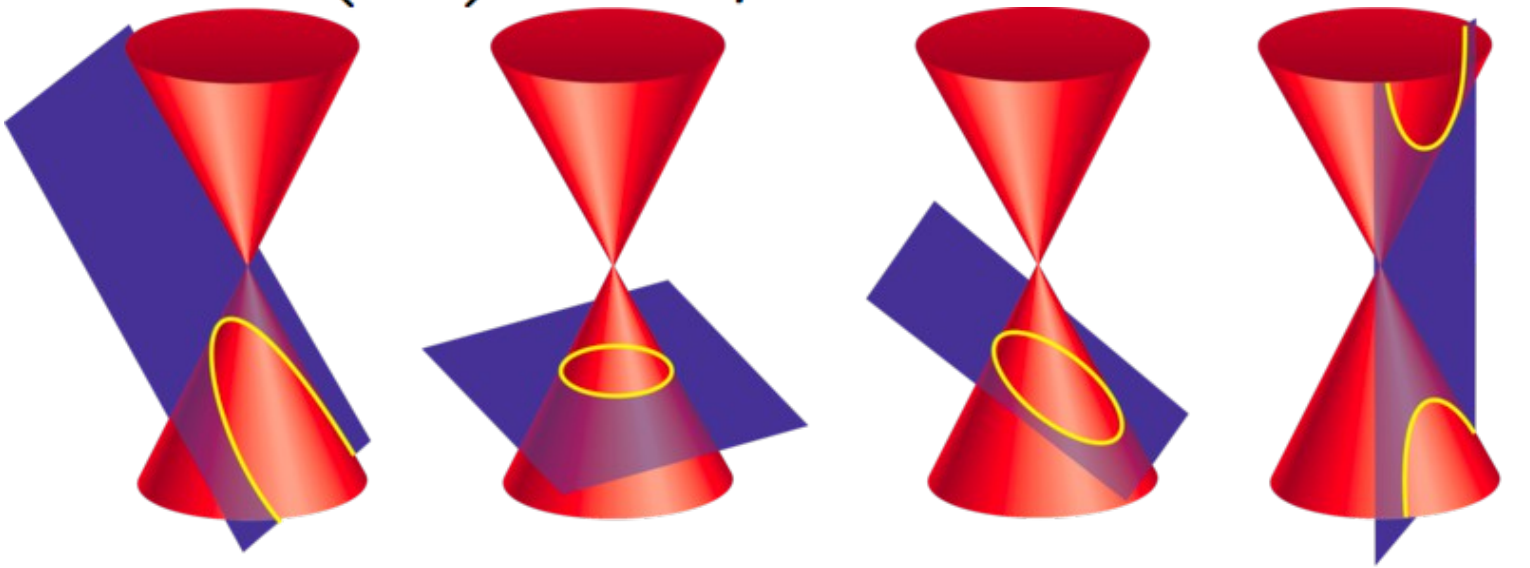
MS, Hayward, Springel+ 2015

High-resolution zoom-simulations of Illustris galaxies

- **Four major mergers at z=0.5 of galaxies with $M_* \sim 10^{10}\ M_{sun}$.**
- **Initial conditions are based on Illustris. The cosmological zoom-in method refines the resolution near the galaxy of interest.**
- **Mass resolution is 40 times finer than Illustris.**

Most idealized setups assume Keplerian orbits

$$E = \frac{1}{2}\mu\left(\frac{\mathrm{d}r}{\mathrm{d}t}\right)^2 + \frac{1}{2}\frac{L^2}{\mu r^2} - \frac{GM_{\mathrm{halo},1}M_{\mathrm{halo},2}}{r}$$



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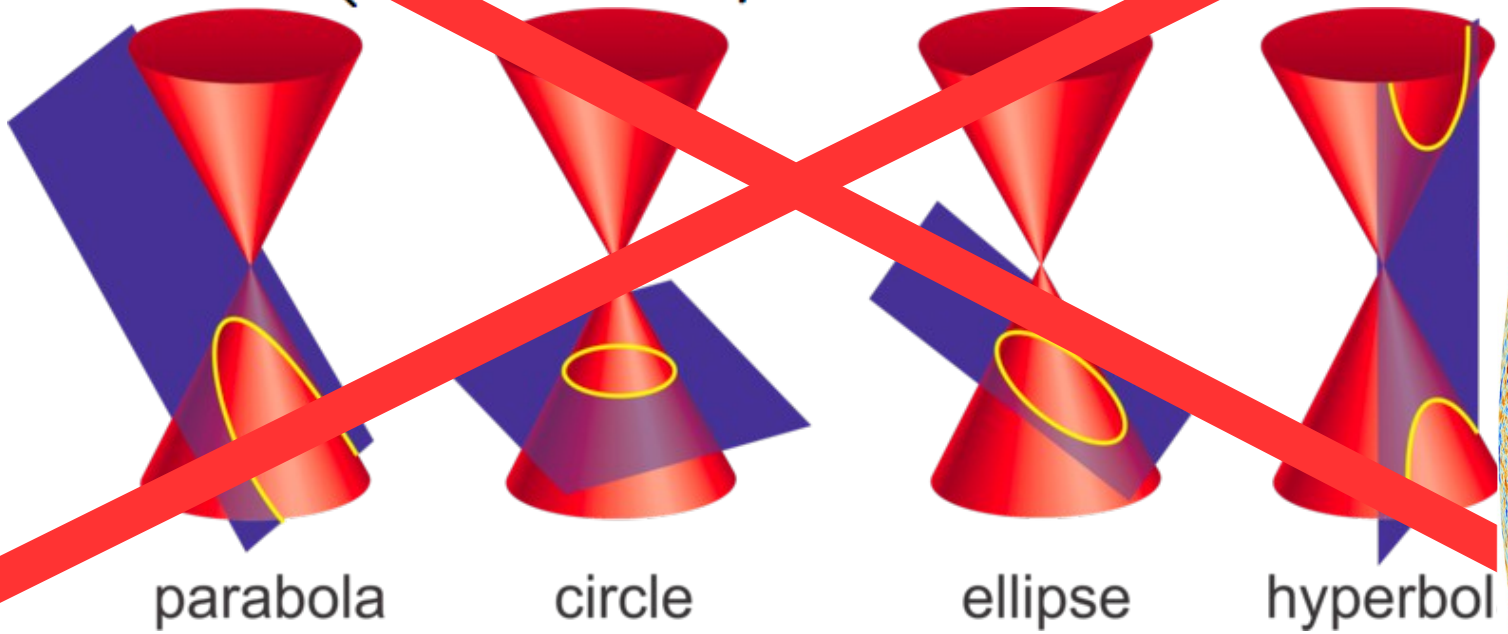
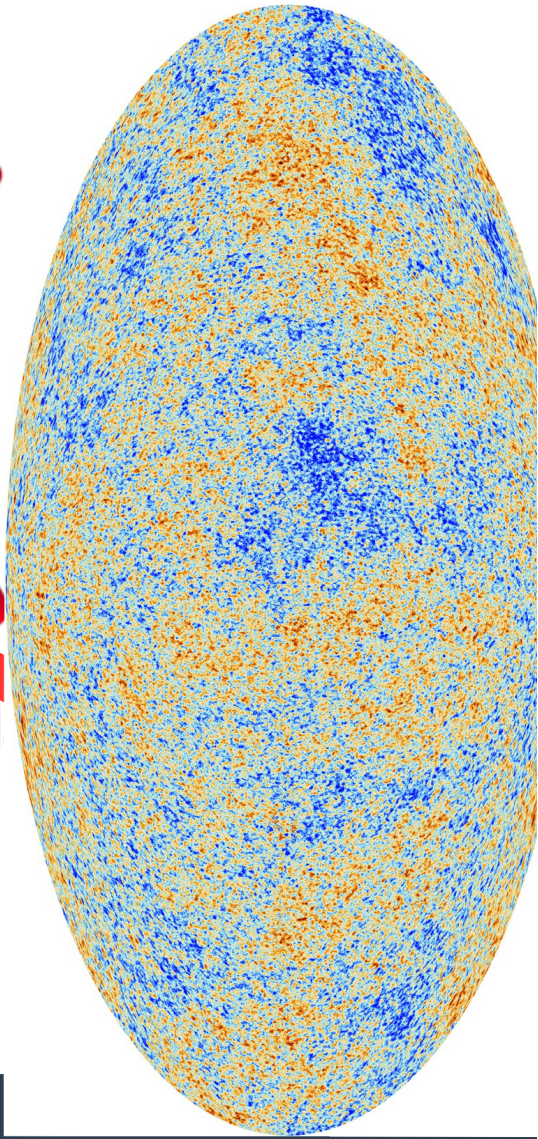
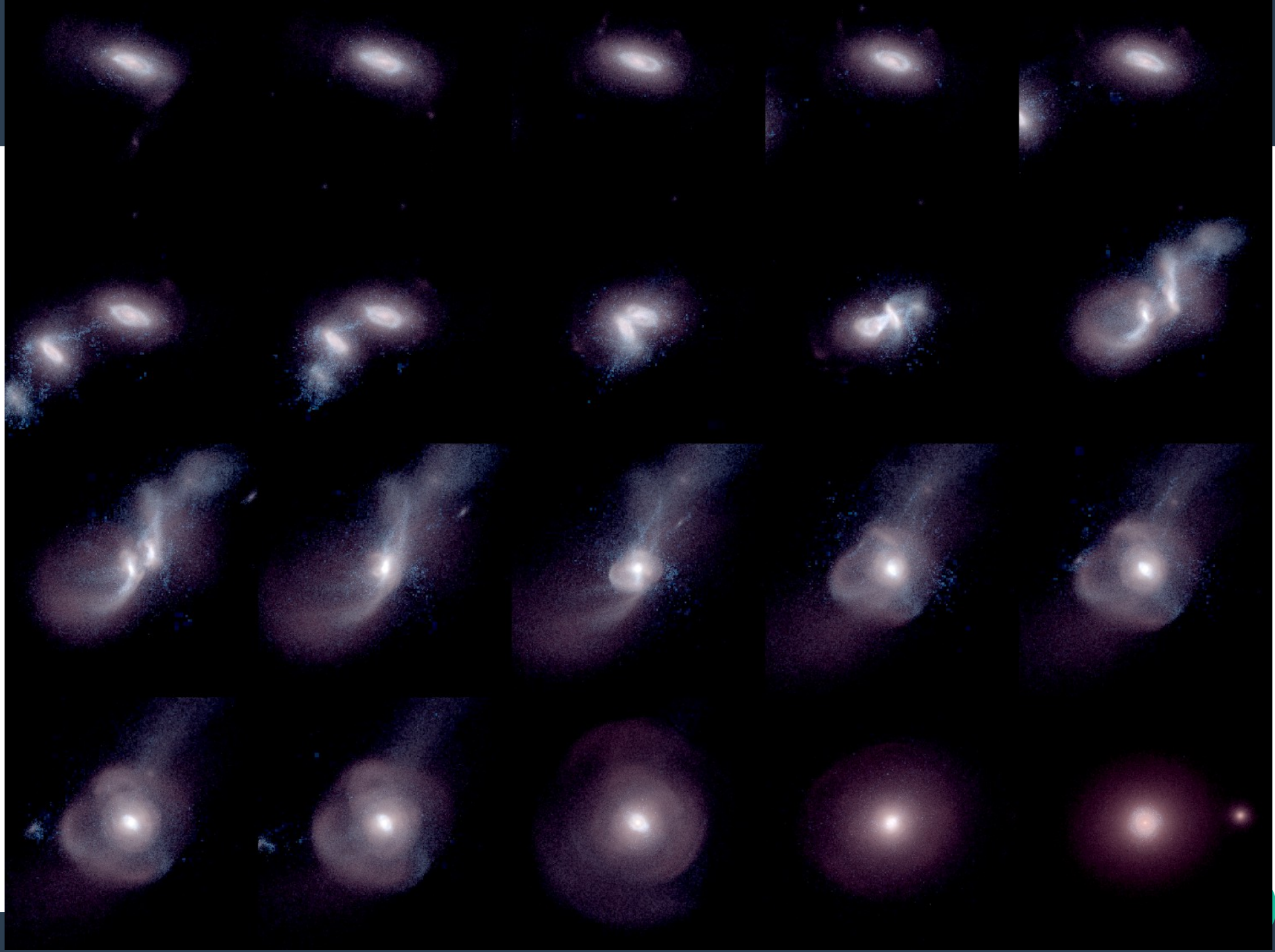
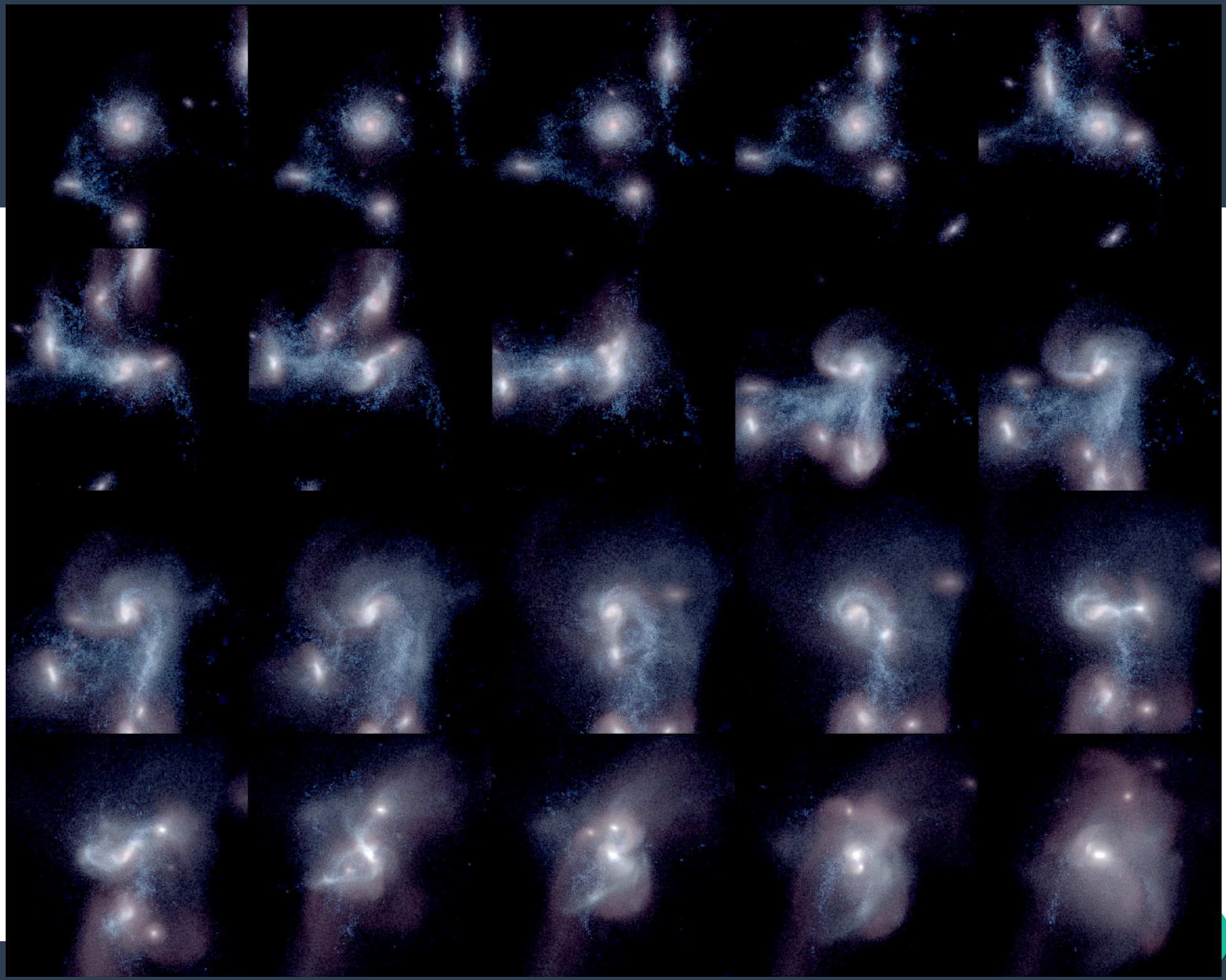




My setups are **self-consistent cosmological simulations**, without any assumption about the merger orbits.

A $M_*=10^{10}$ M_{sun} merger before merger at z=1 ($10^{10.8}$ M_{sun} at z=0)





Starbursting gas

Gas depletion timescale and mergers

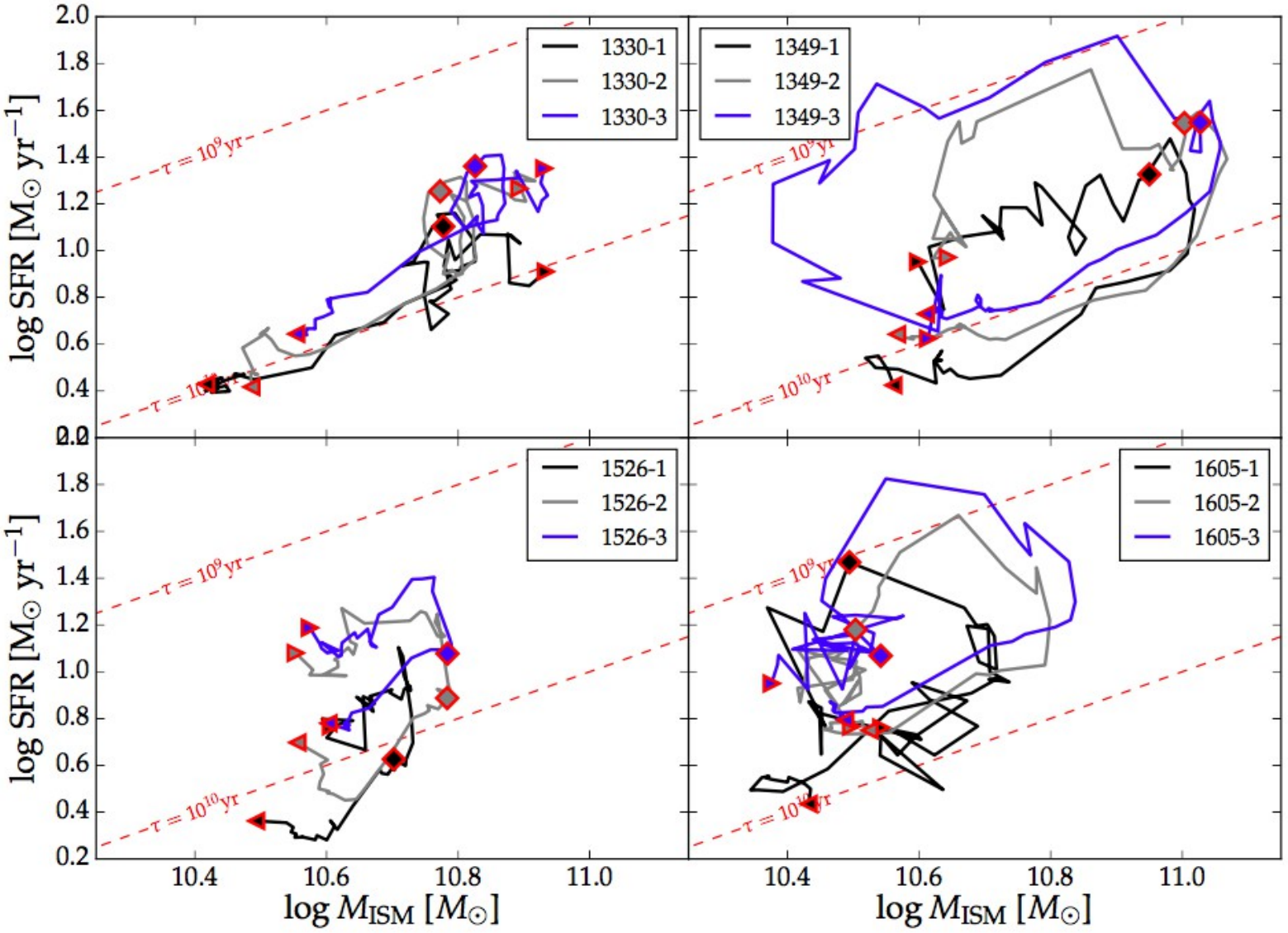
Observations show that star formation occurs in two modes:

1) A regime where star formation and feedback are self-regulated. Disk galaxies.

2) A starburst mode with a 10-20 times shorter gas depletion timescale. Higher SFRs than for disks. Starbursts are usually mergers.

e.g. Sanders+1991, Scoville+2013

The SFR – M_{ISM} plane



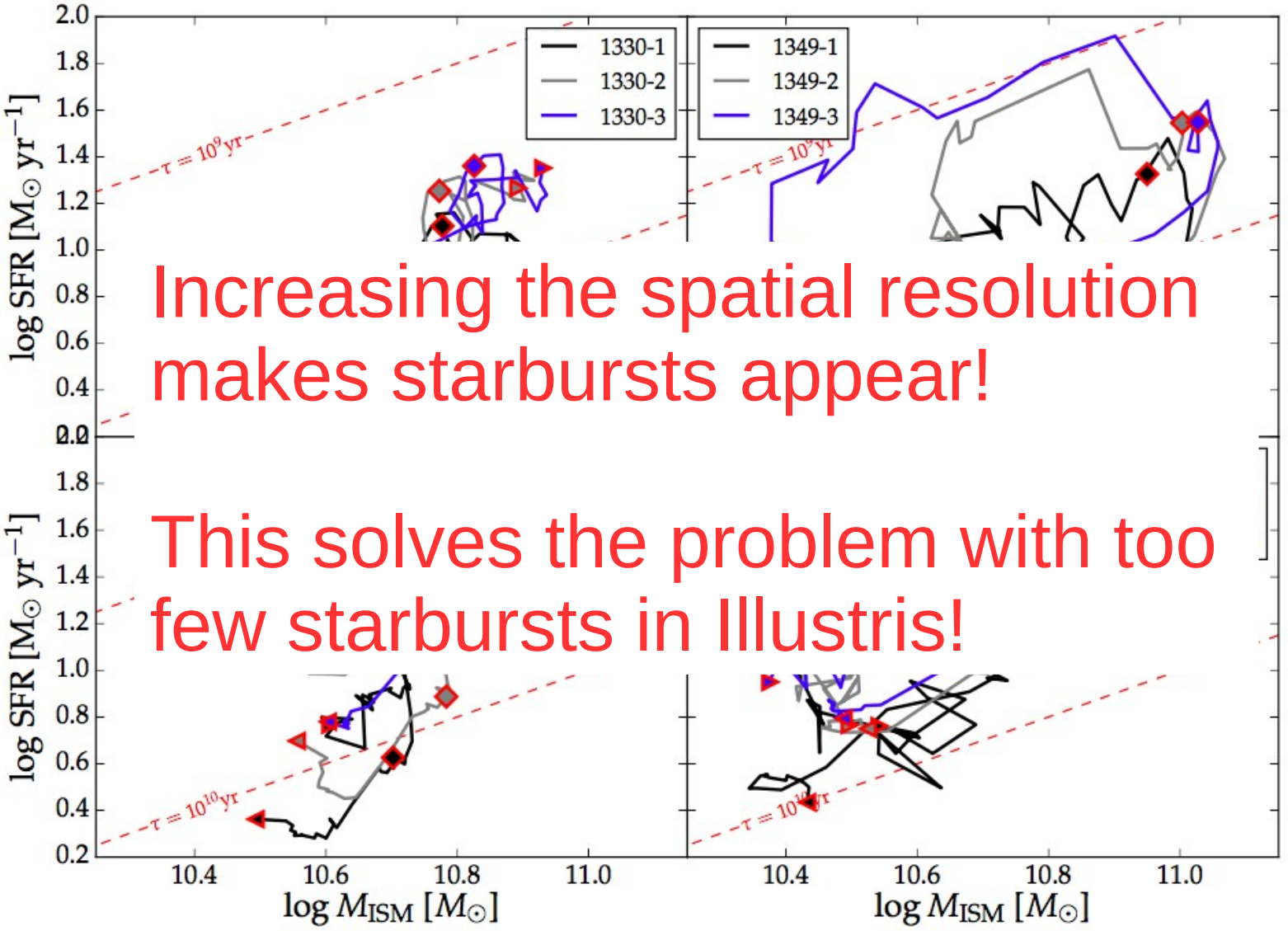
The gas consumption timescale becomes 10 times shorter during a nuclear starburst.

A bursty mode of star formation is present.

This bursty mode becomes more important at high resolution.

Sparre & Springel 2016

The SFR – M_{ISM} plane



Increasing the spatial resolution makes starbursts appear!

This solves the problem with too few starbursts in Illustris!

The gas consumption timescale becomes 10 times shorter during a nuclear starburst.

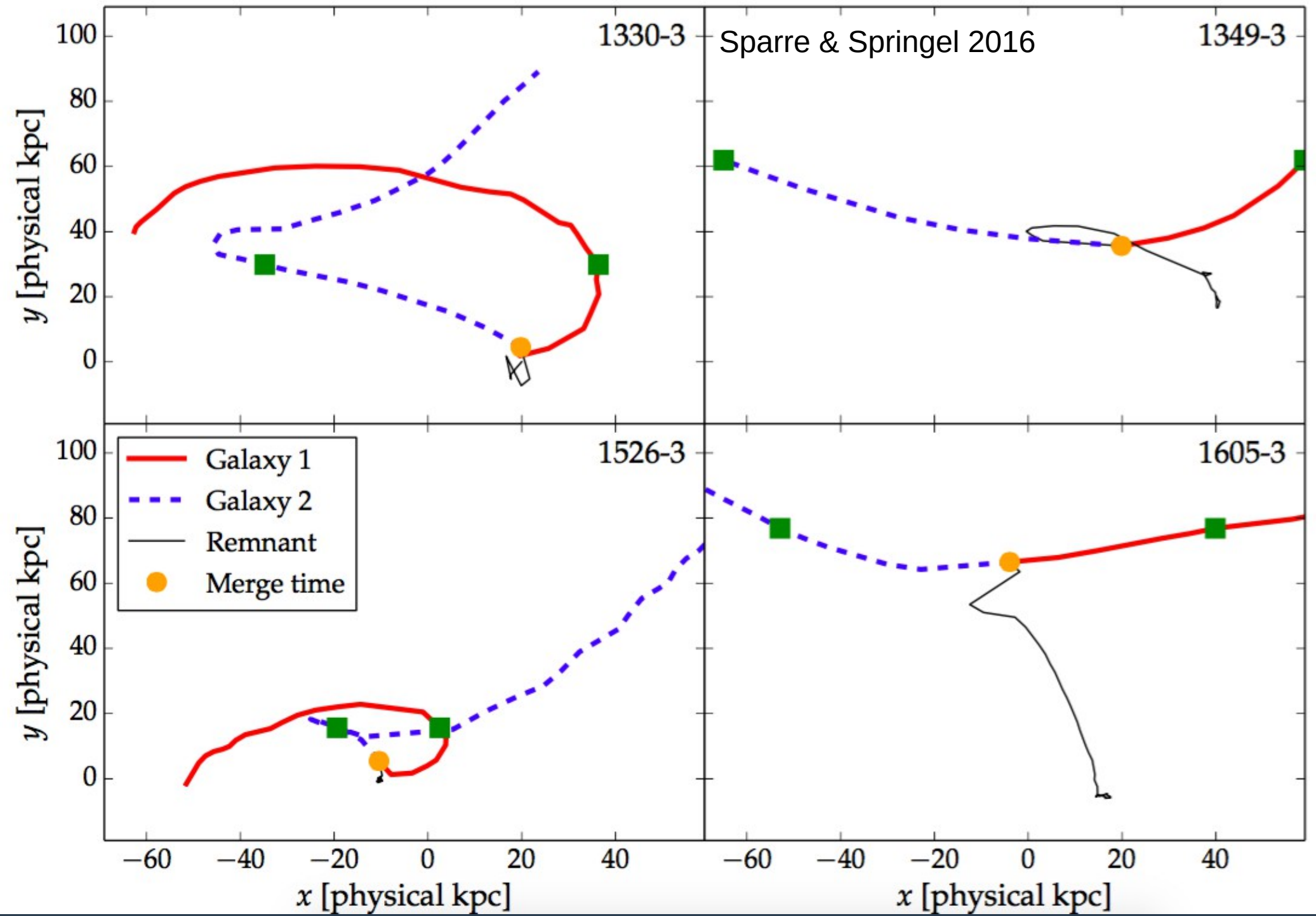
A bursty mode of star formation is present.

This bursty mode becomes more important at high resolution.

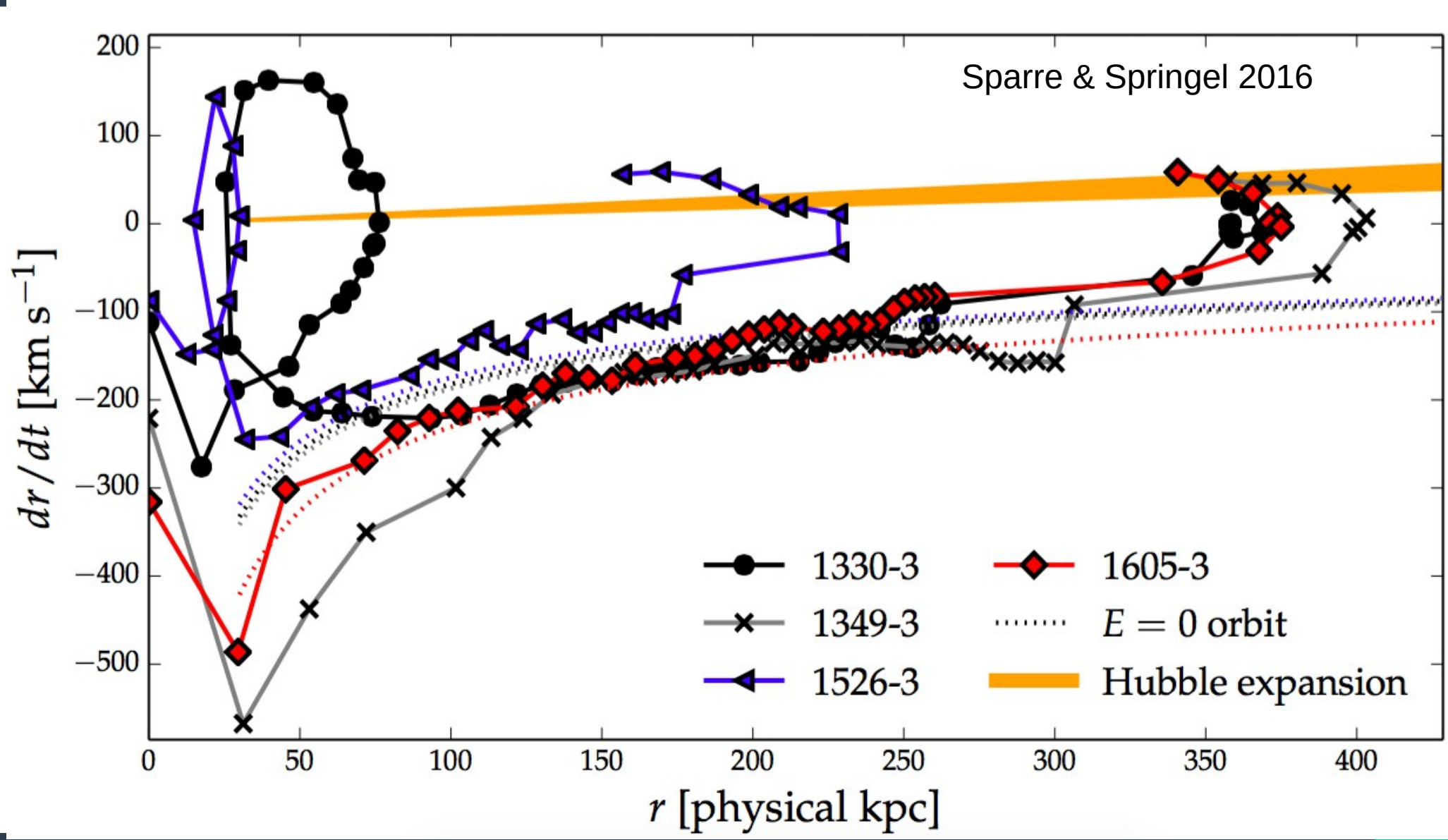
Sparre & Springel 2016

Merger orbits

Two of the mergers are head-on



Merger orbits

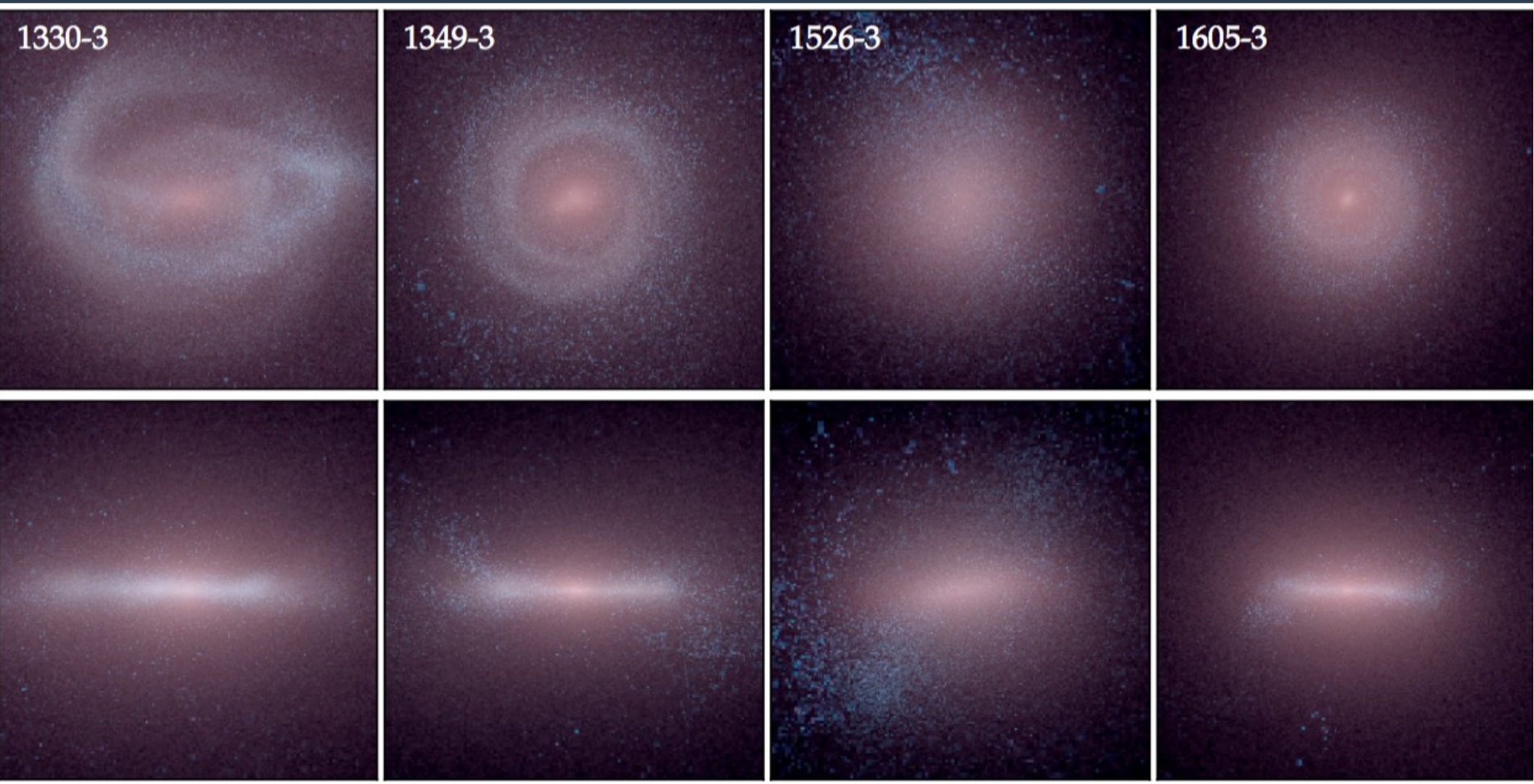


The orbit of cosmological mergers

- **Some mergers approach each other faster than predicted by (E=0) Keplerian orbits.**
- **Two of the four major mergers *collide directly* – they are on L=0 orbits.**
- **Interestingly, there is a correlation between collision speed and strength of starbursts.**

Morphological evolution and (the lack of) quenching

Merger remnants at z = 0



Sparre & Springel in prep.

Conclusions about morphology/quenching

- **The merger remnants are star-forming. Quenching does not occur.**

- **At z=0 the halo masses are 10^{12} Msun. AGN feedback kicks in at larger masses. This explains the lack of quenching.**

Conclusions

- **Increasing the resolution makes it possible to form nuclear starbursts within the 'Illustris framework'.**
- **Some galaxies have collision speeds larger than predicted by *E*=0 orbits.**
- **Merger remnants have a diverse morphologies, and they are not quenched.**