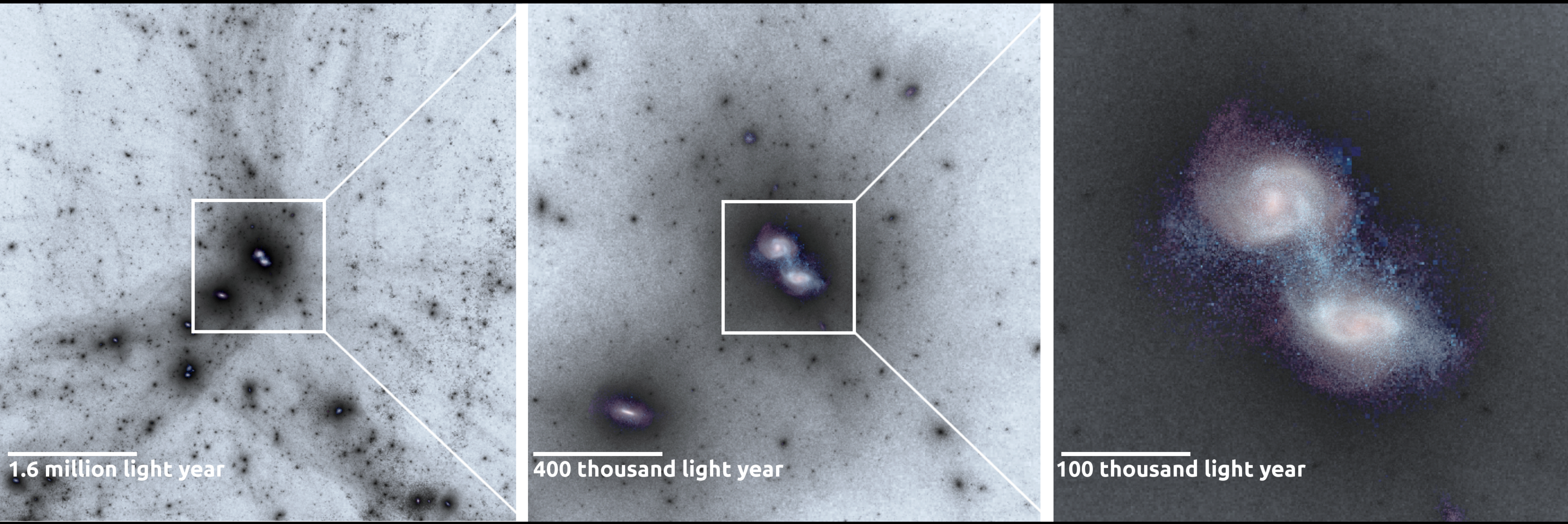
Starbursts and AGN feedback



Martin Sparre
Potsdam University & AIP Potsdam

Invited talk

- Mergers and starbursts.
- Black hole accretion and feedback. Does AGN feedback quench merger remants?
- Submm-galaxies as probe of AGN feedback.

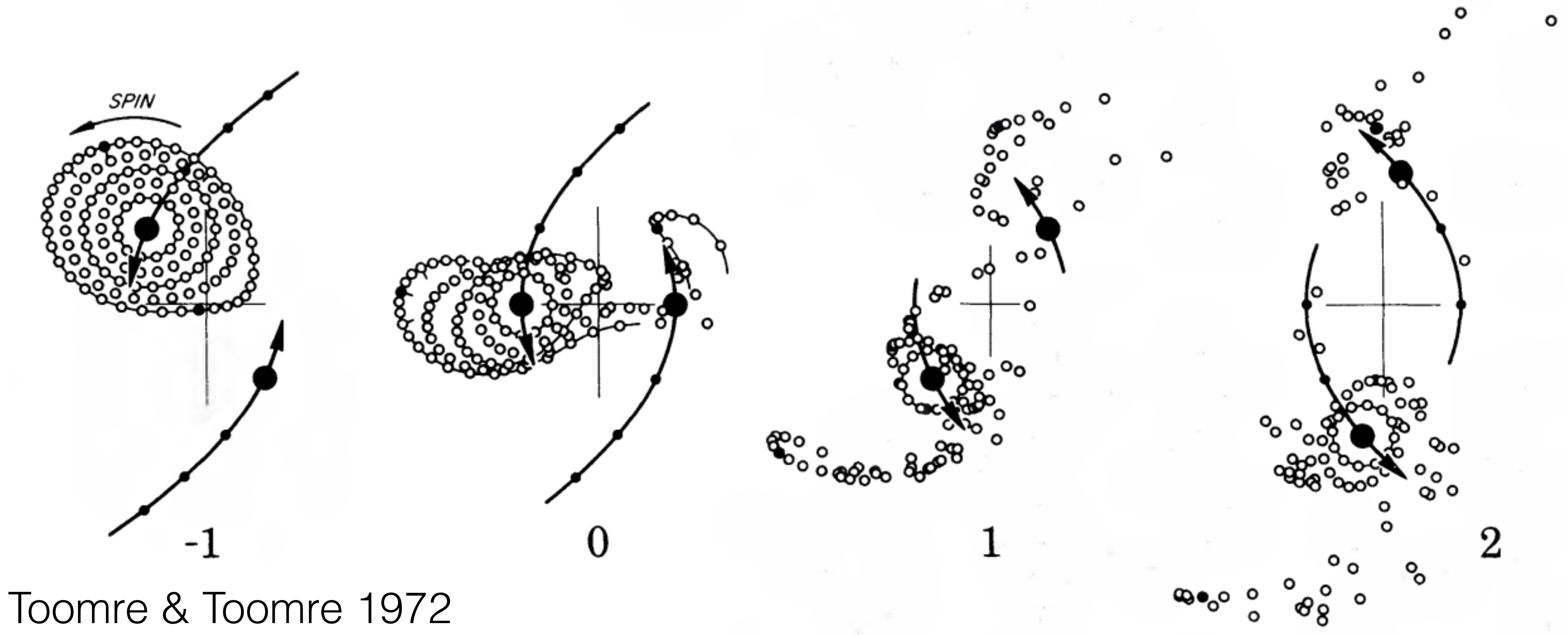
THE DYNAMICS OF MERGERS

Image: ACS, NASA, Hubble.

Image: Subaru, NAOJ, NASA, ESA, Hubble.

Observed galaxy mergers have a disturbed, irregular morphology with visible bridges and tails.

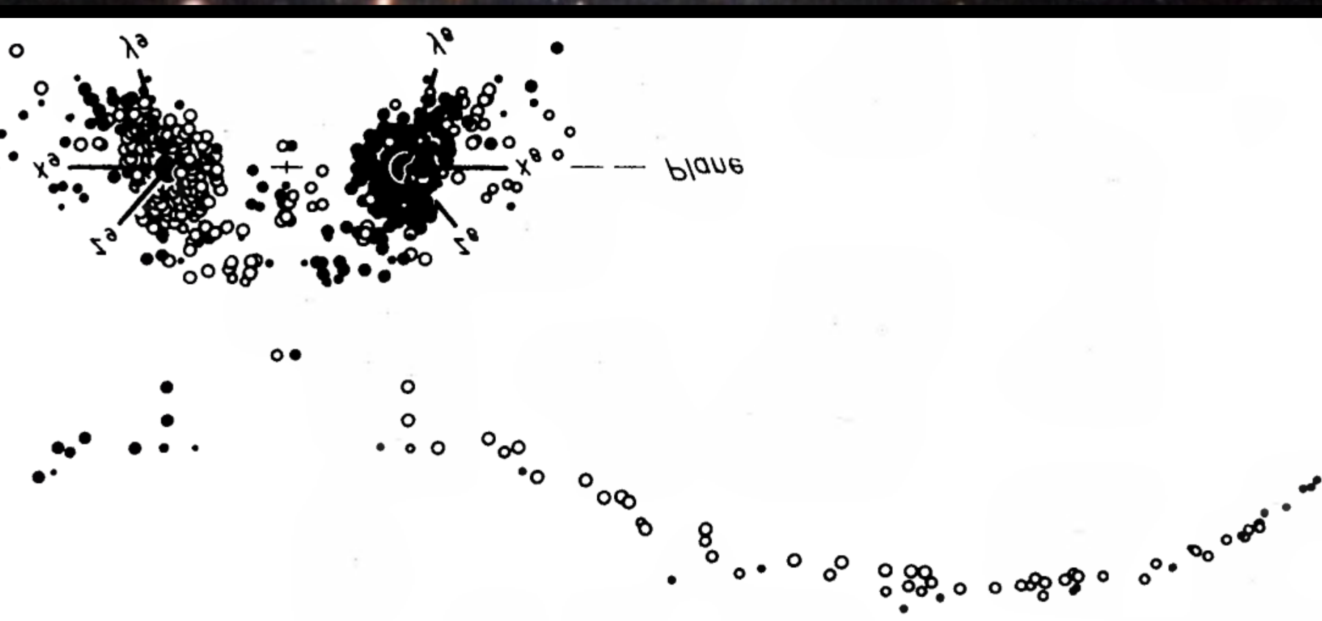
GALACTIC BRIDGES AND TAILS



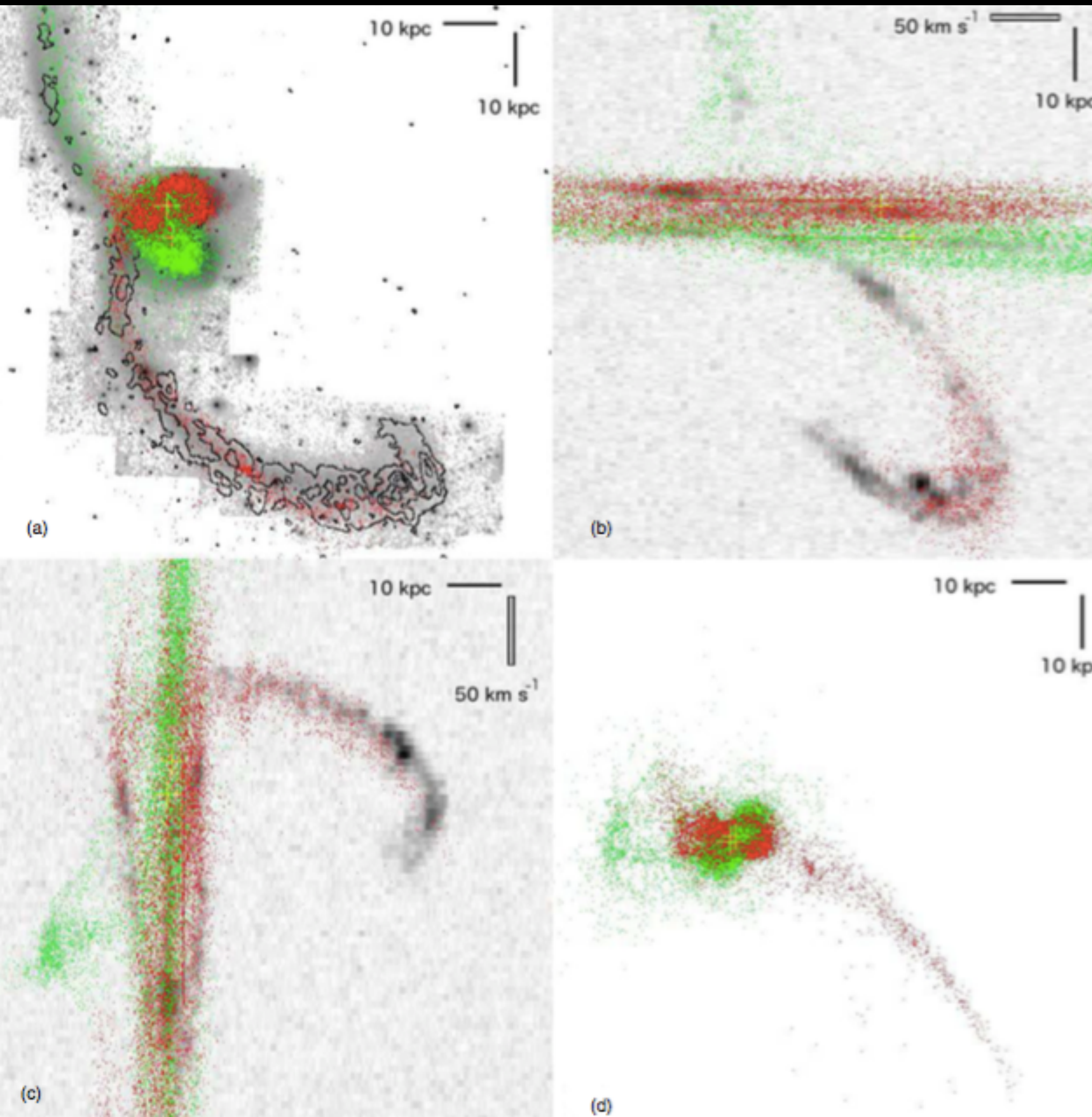
Toomre & Toomre 1972

With test-particle-simulations **Toomre and Toomre 1972** found that the torques and forces in major mergers caused the formation of galactic ***bridges*** and ***tails***.

THE DYNAMICS OF MERGERS


Toomre & Toomre 1972

Modern test-particle-simulations

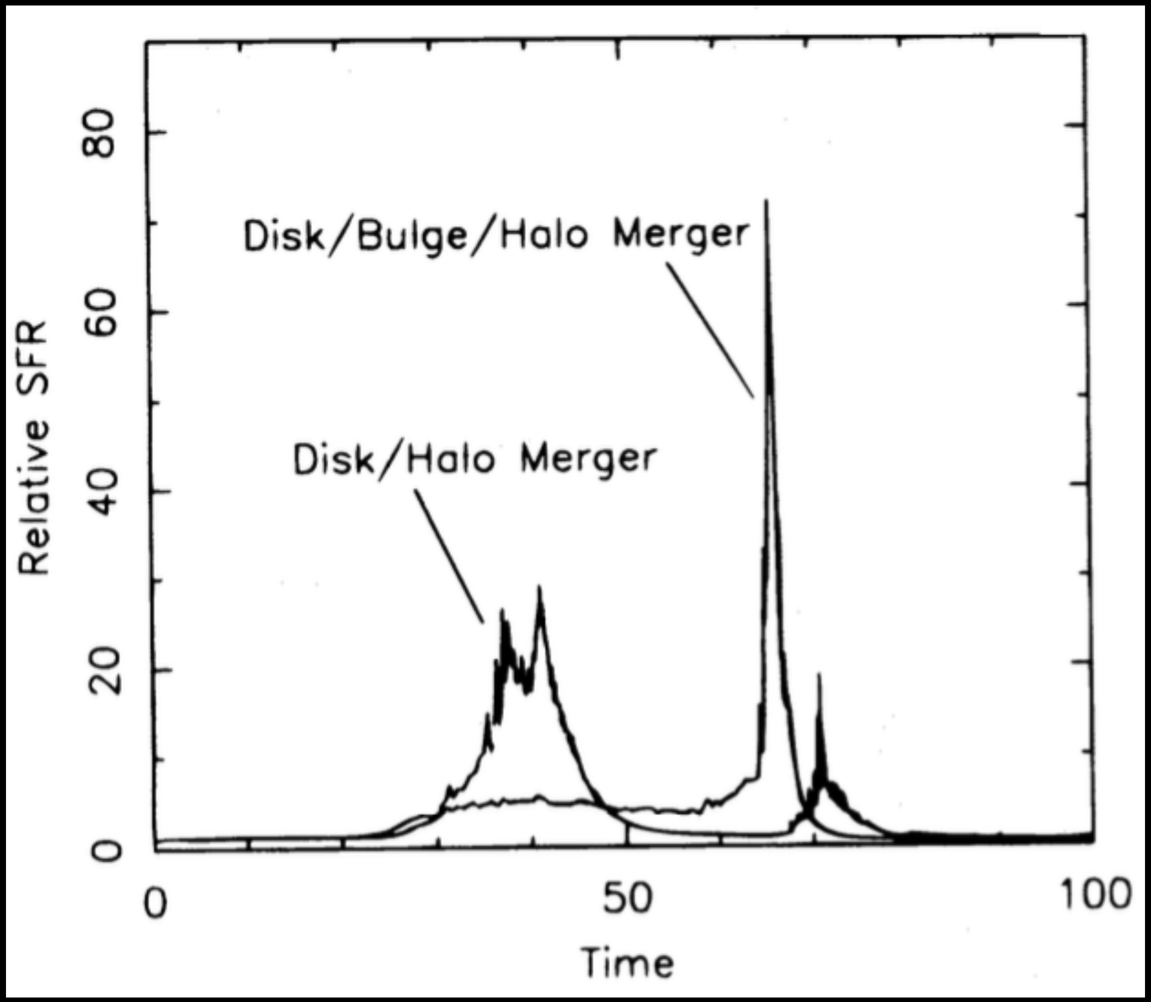


a) (*alpha,delta)*
b) (v,*delta*)
c) *(v,alpha*)
d) top-down view

Modelling of mergers with *Identikit*
Fig. from **Privon+2013**, see also **Barnes & Hibbard 2009**, **Barnes 2011**, **Pearson+2018**

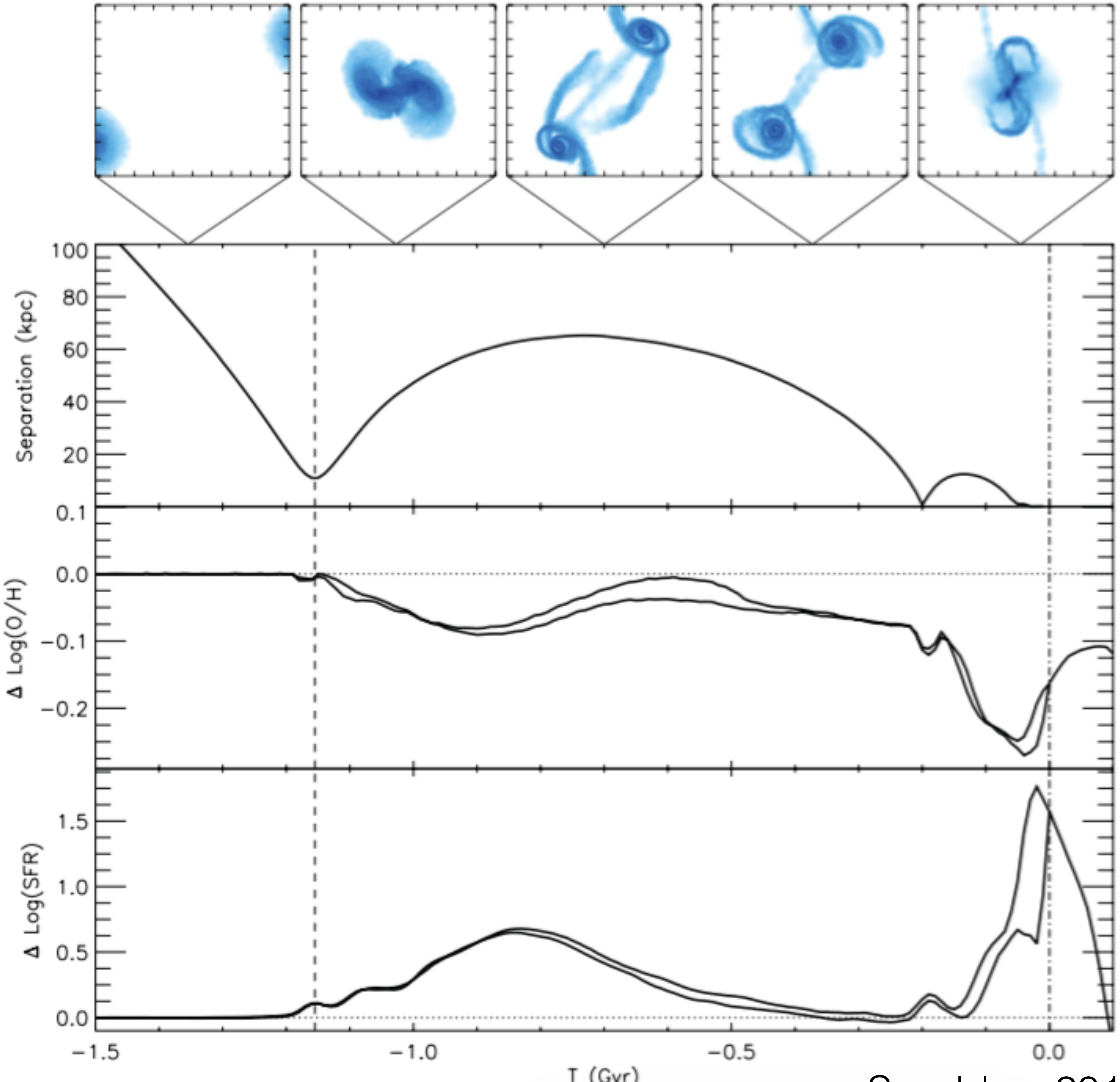
- The torques and forces involved in (major) mergers cause the formation of *bridges* and *tails*.
- Idealised galaxy simulations find that gas is tunneled into the center of galaxies, and thus causing a starbursts. (see e.g. Renaud 2019)

Mihos and Hernquist 1996



Mihos & Hernquist 1994, Springel+2005, Hopkins+2008, Teyssier, Chapon, Bournaud 2010, Hayward+2014, Renaud+2015, Moreno+2015, MS+2016, Blumenthal & Barnes 2018, Moreno+2019.

Simulations showing metallicity dilution



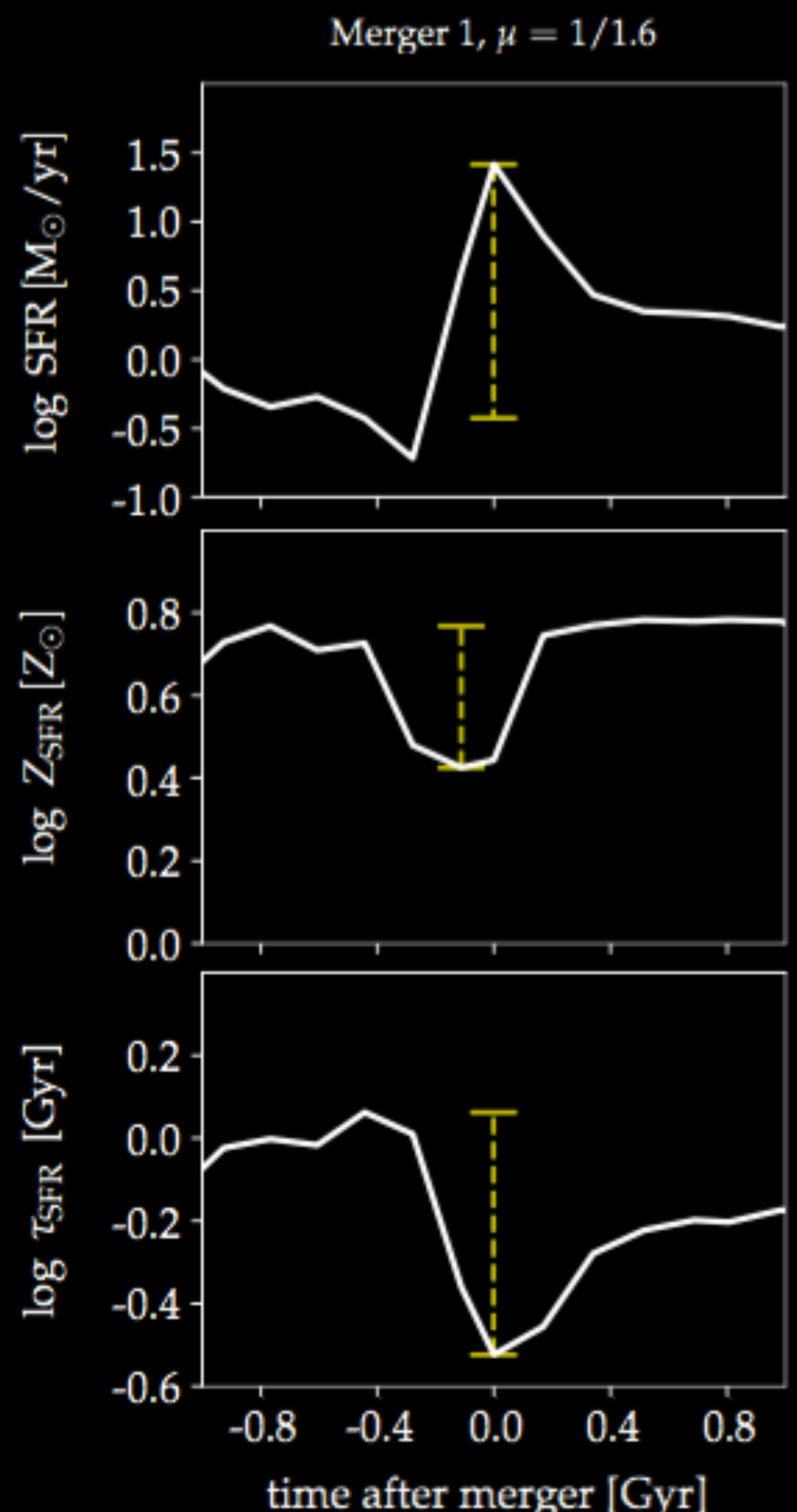
Scudder+2012

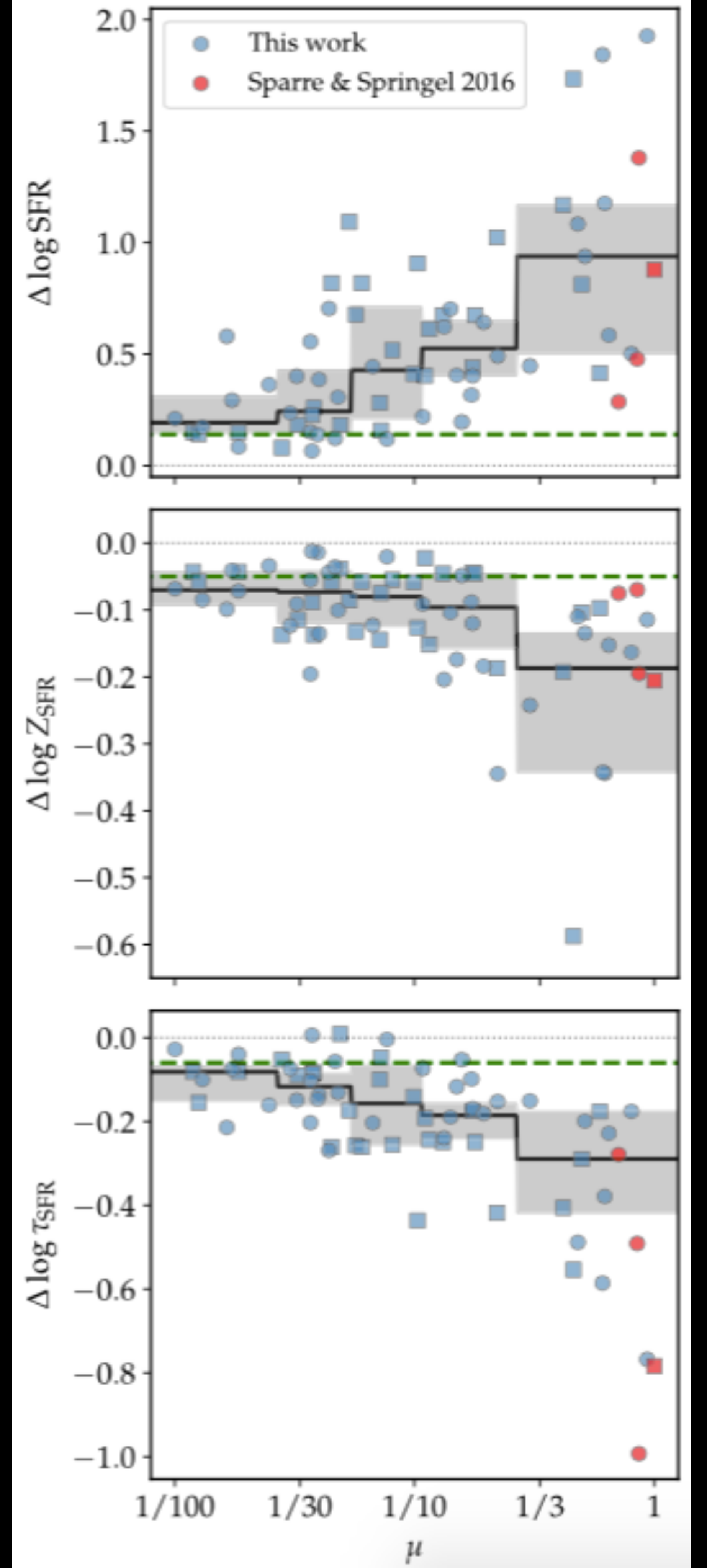
In addition to a starburst, metallicity dilution also appears

Metallicity dilution in cosmological simulations

Gas is drawn into the center in mergers. This leads to

1) **increased SFR.**
2) **metallicity dilution**
3) **short gas consumption timescales.**



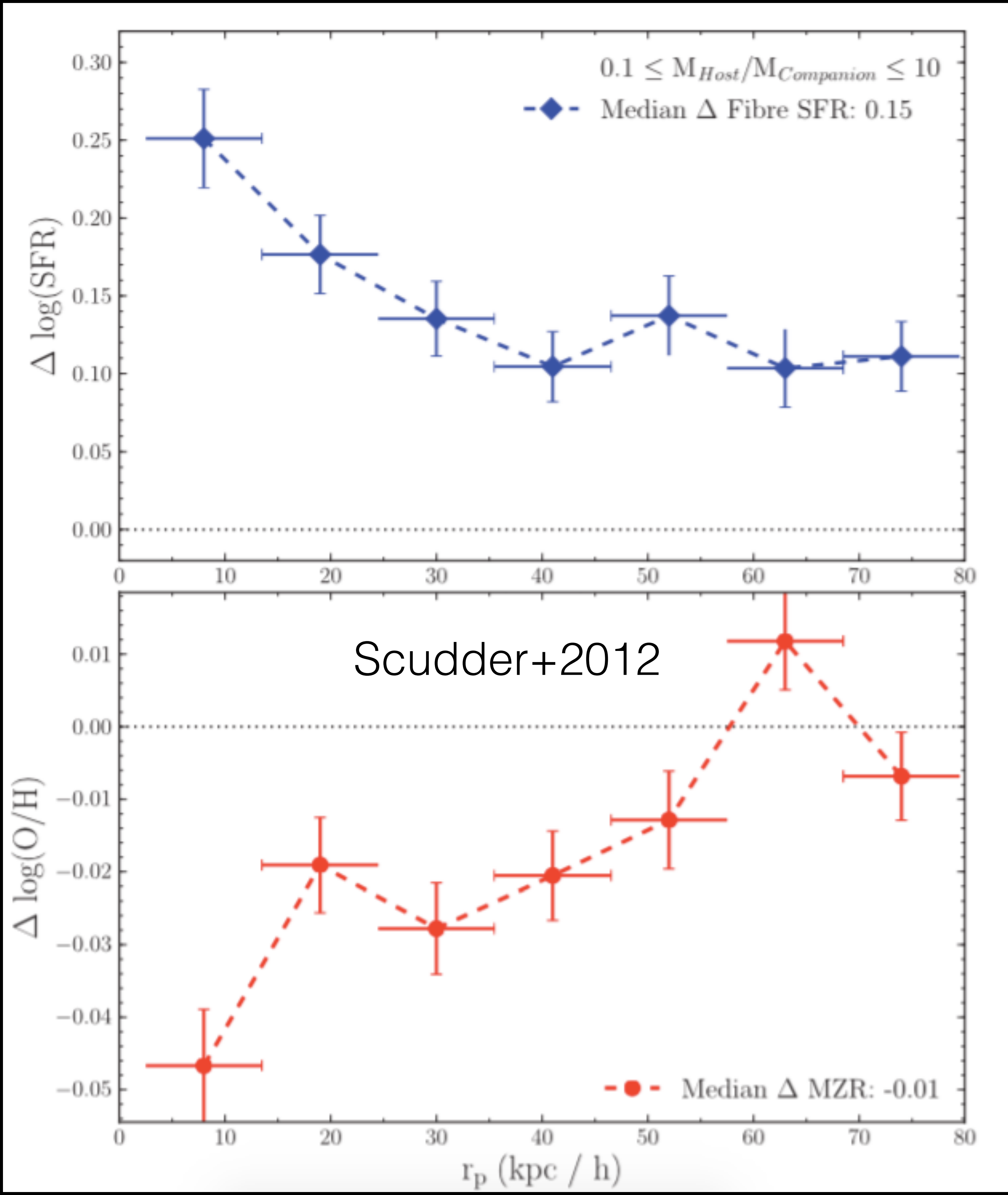


Bustamante, MS+ 2018

Observation of metallicity dilution

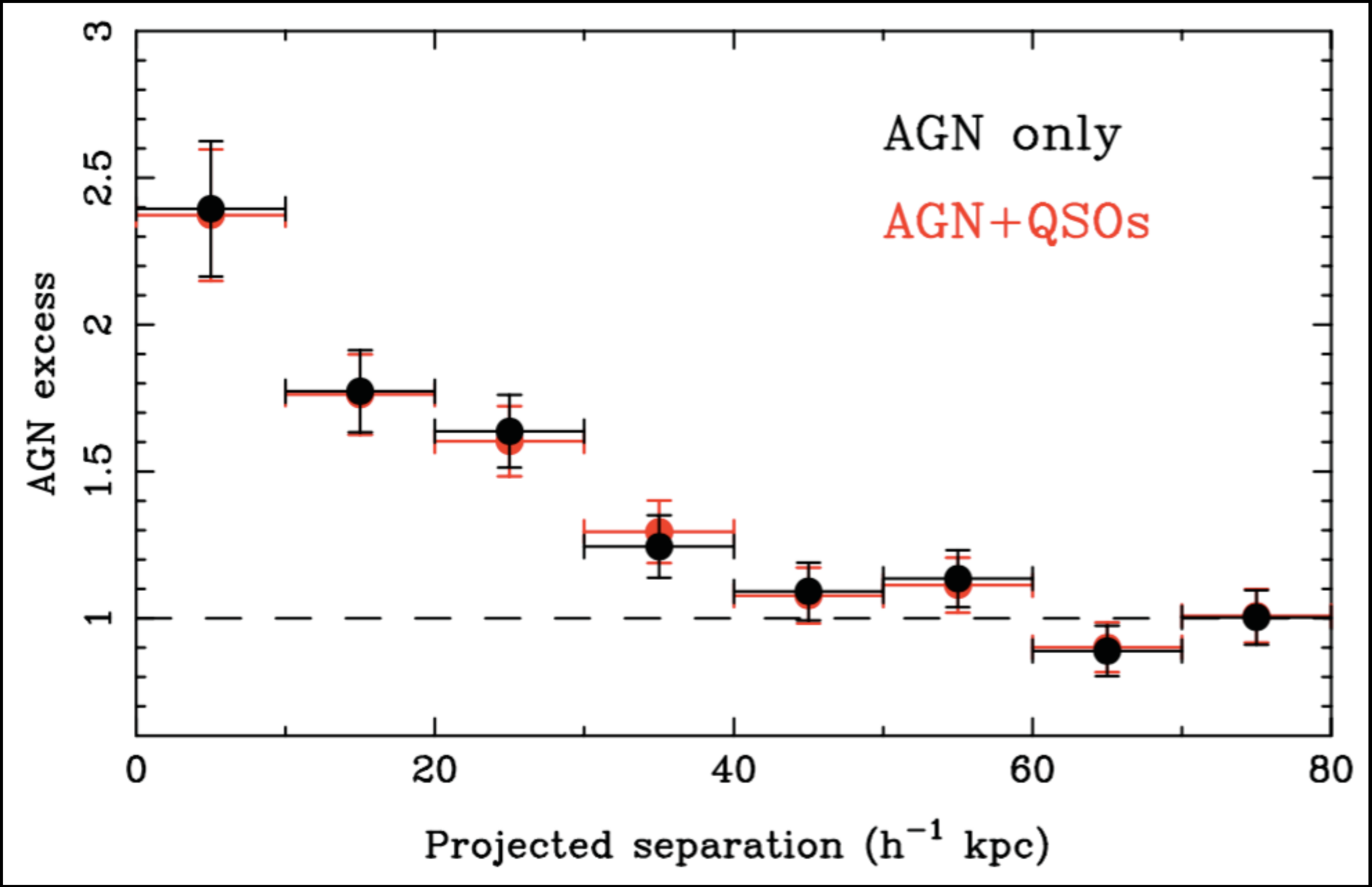
Metallicity dilution and SFR enhancement in observed galaxy pairs from SDSS.

Also seen in radial profiles in IFU observations of post-mergers (Thorp et al. 2019)



Pair separation

Galaxies in pairs have a larger AGN fraction than field galaxies.



Ellison+2011

Does AGN feedback quench merger remnants?

(From a simulators point of view!)

Black hole accretion and feedback

Bondi accretion

$$\dot{M}_{\rm B} = \frac{4\pi\,\alpha\,G^2 M_{\rm BH}^2\,\rho}{\left(c_{\rm s}^2 + v^2\right)^{3/2}}$$

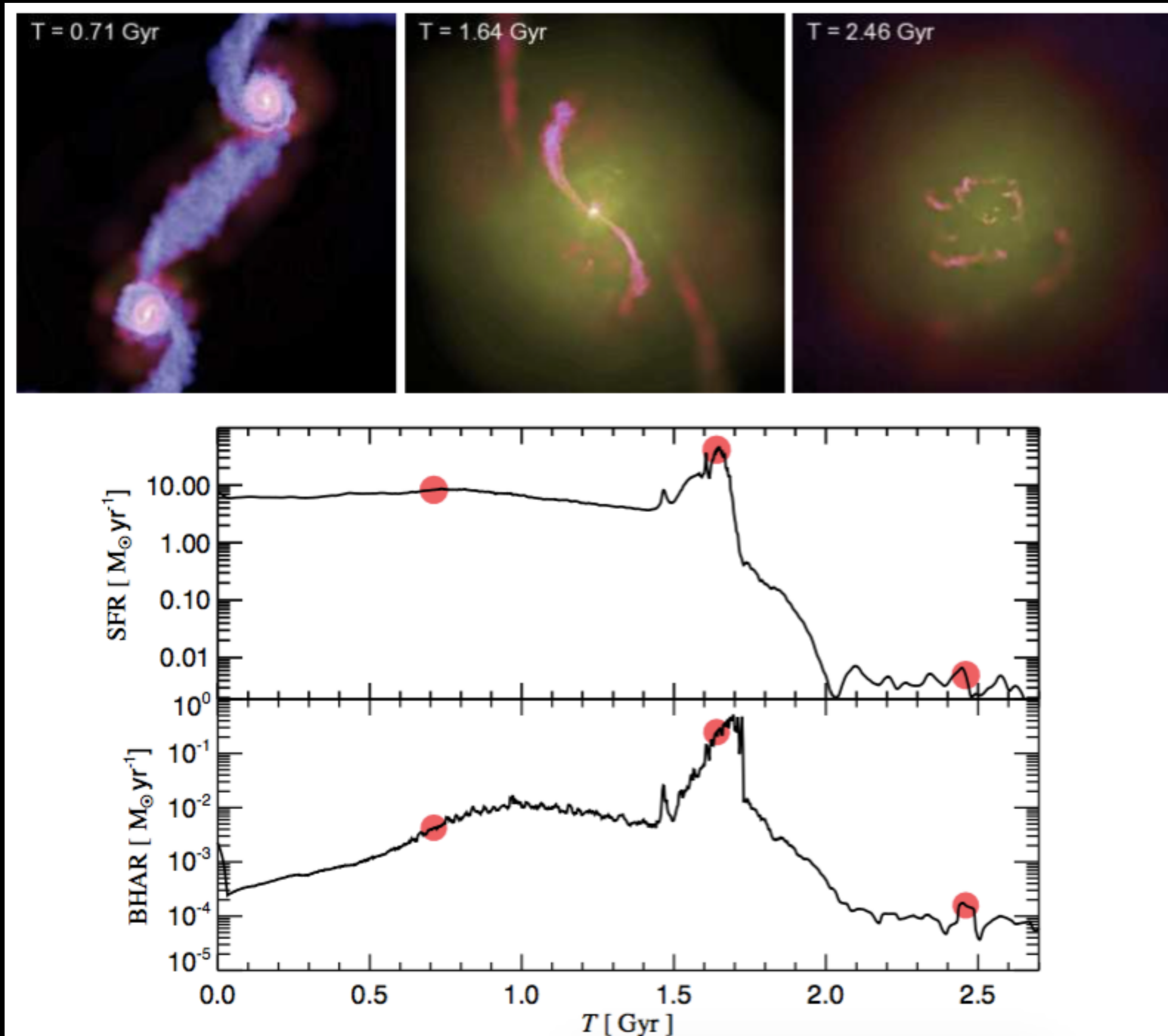
Eddington limited accretion:

$$\dot{M}_{\rm Edd} \equiv \frac{4\pi\,G\,M_{\rm BH}\,m_{\rm p}}{\epsilon_{\rm r}\,\sigma_{\rm T}\,c} \qquad \dot{M}_{\rm BH} = \min(\dot{M}_{\rm Edd}\,,\ \dot{M}_{\rm B})$$

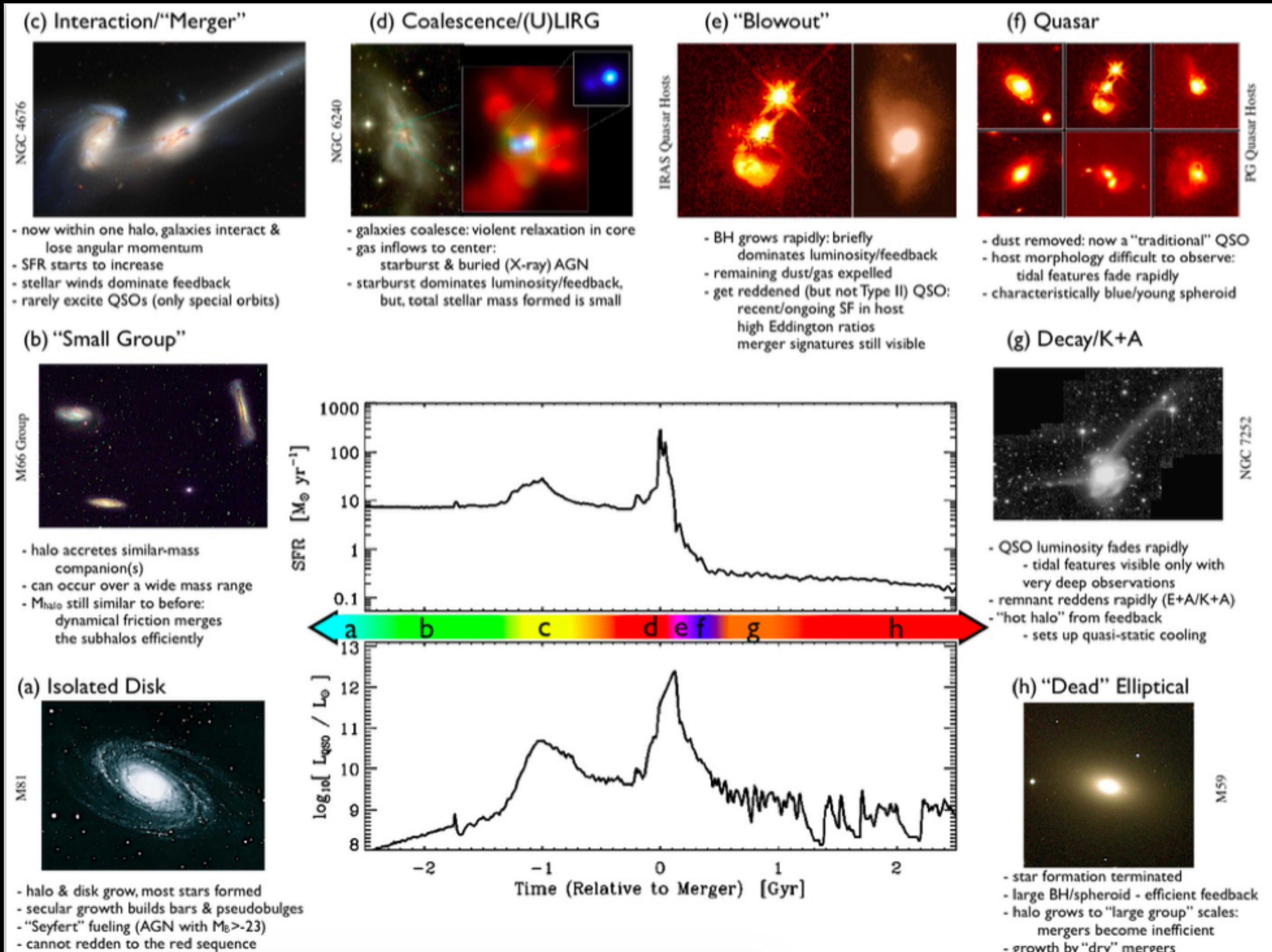
Black hole feedback:

$$\dot{E}_{\rm feed} = \epsilon_{\rm f}\,L_{\rm r} = \epsilon_{\rm f}\,\epsilon_{\rm r}\,\dot{M}_{\rm BH}\,c^2$$

(from Springel, Di Matteo, Hernquist 2005)

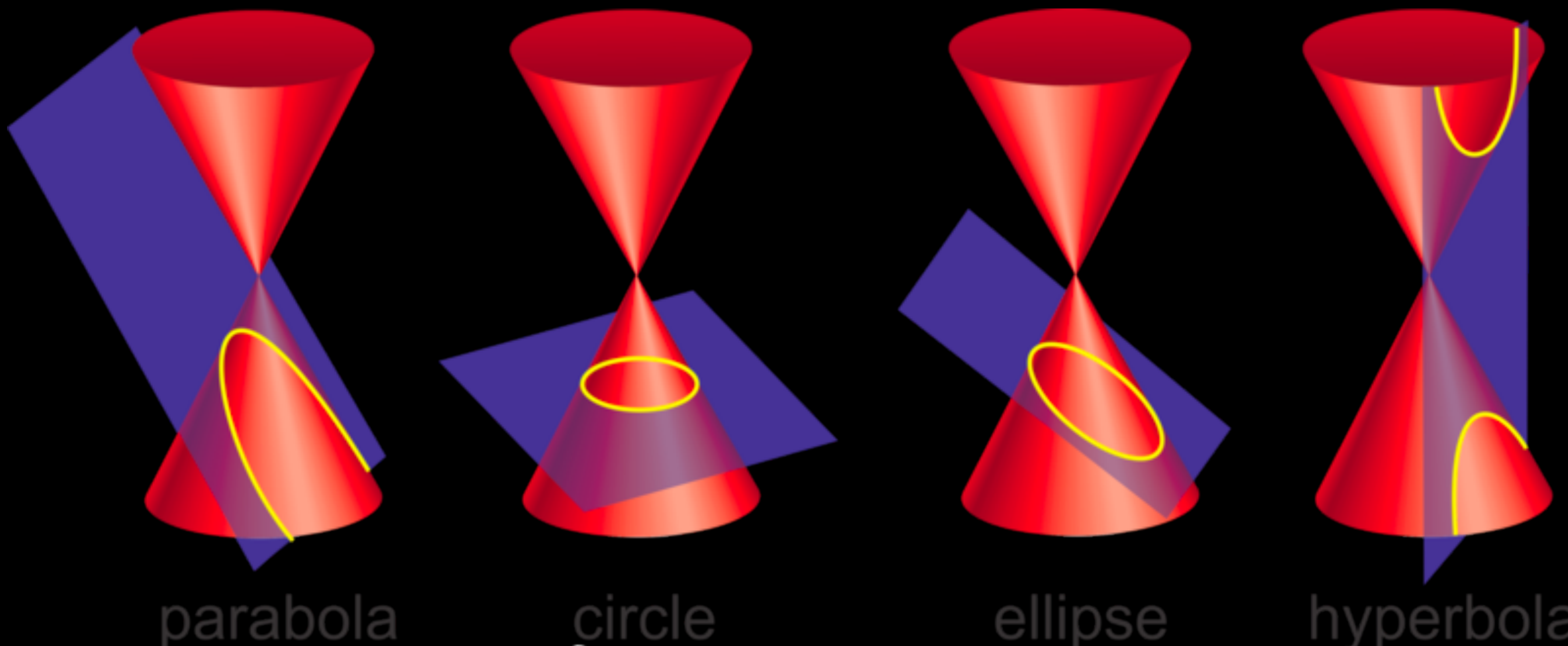


Springel, Di Matteo, Hernquist 2005



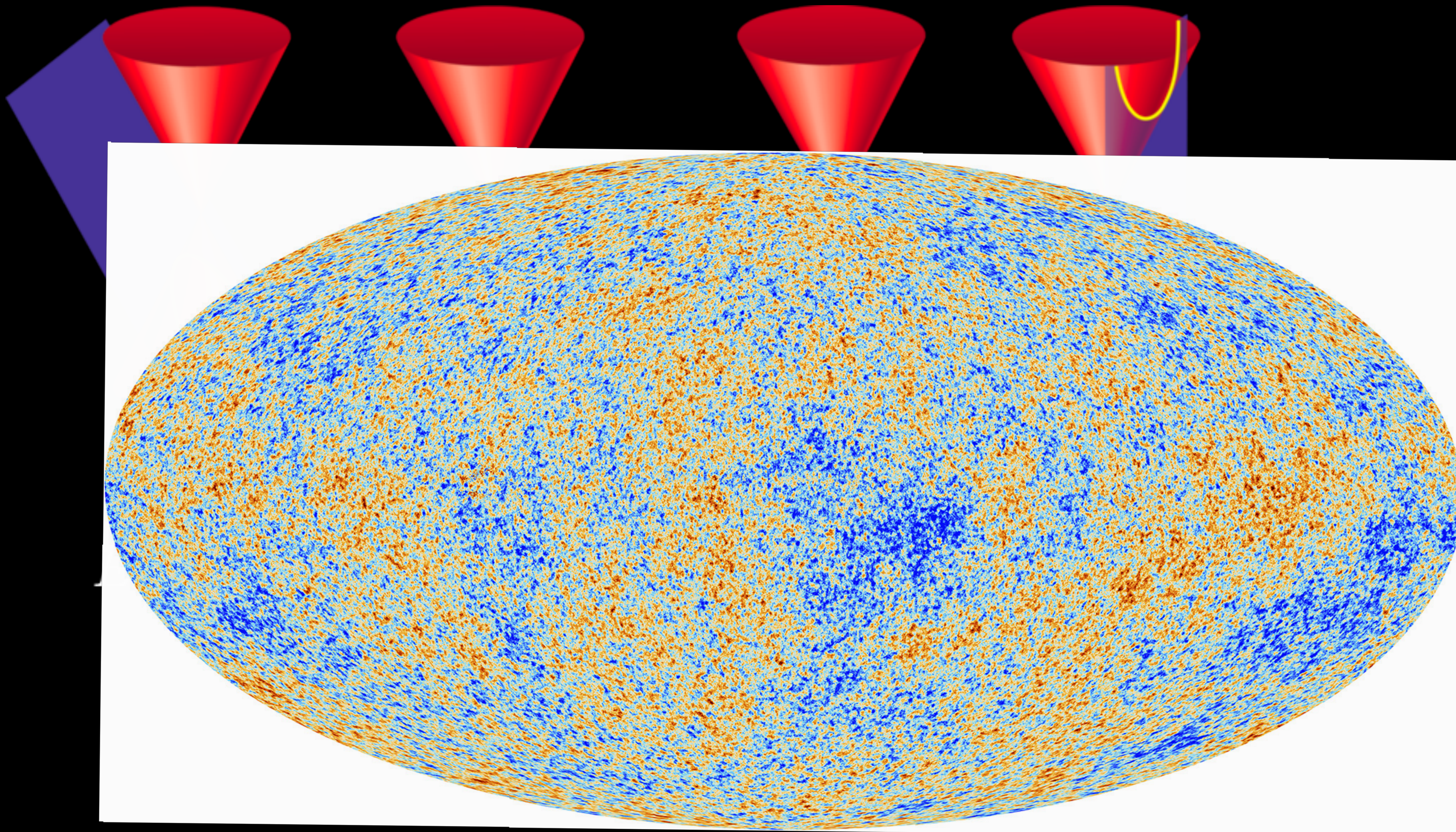
Evolution scenario from Hopkins 2008

These studies of mergers are *idealised* and assume Keplerian orbits



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

See e.g. talks from **Moreno**, **Renaud**, and **Remus**.



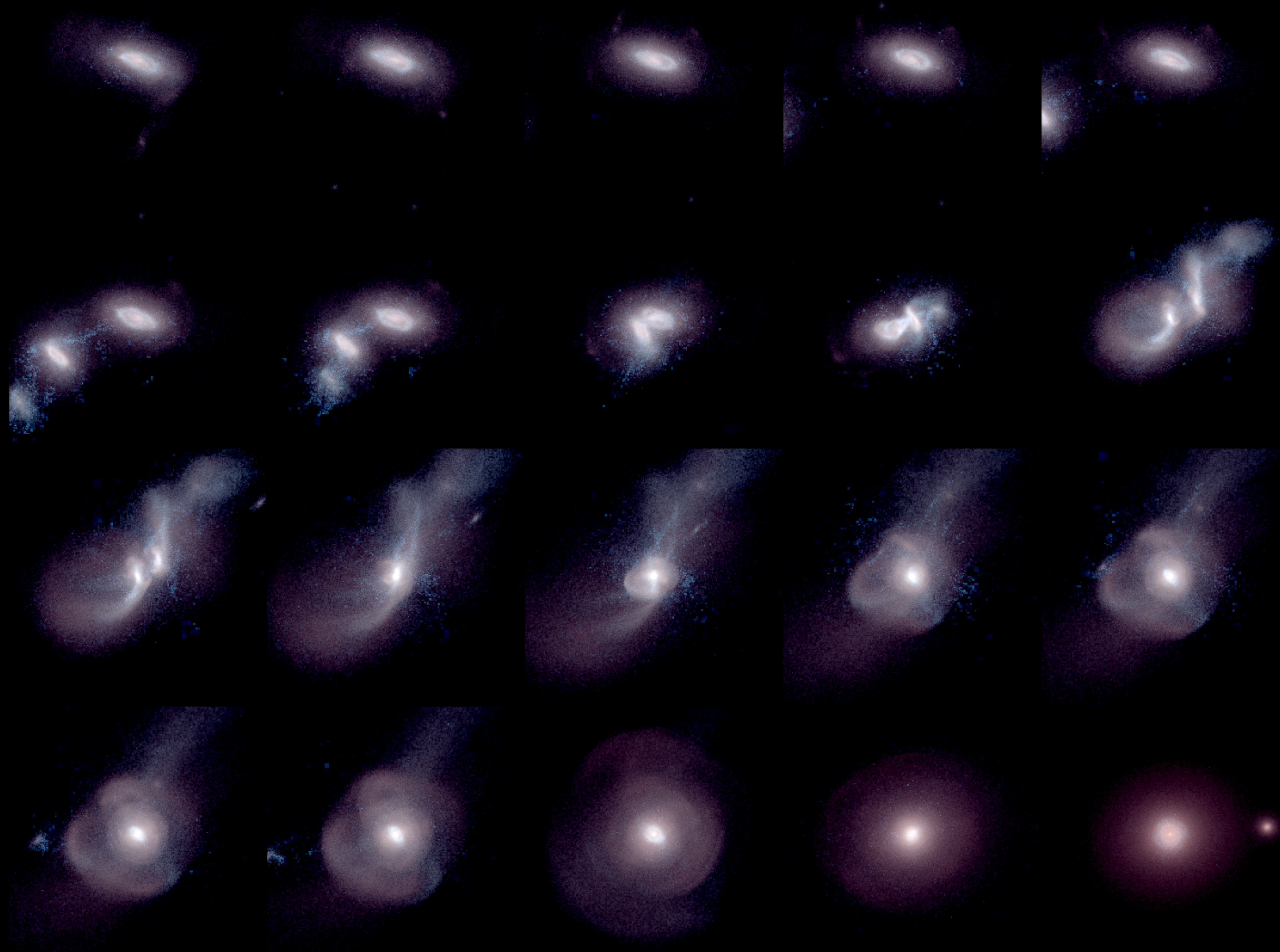
In Sparre and Springel 2016, 2017 we run cosmological zoom simulations of major mergers

Cosmological merger simulations

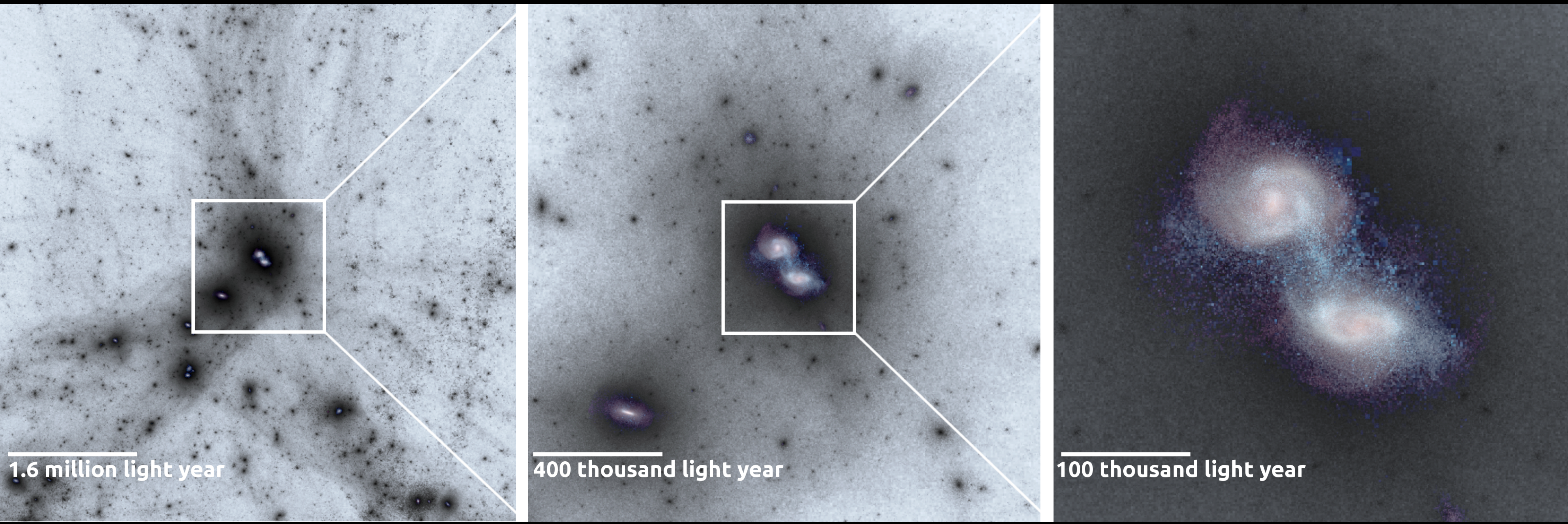
Illustris zoom simulations

Initial conditions are based on Illustris.

In Sparre & Springel 2016 we selected four major mergers at z = 0.5 of galaxies with $M_* \sim 10^{10}$ Msun.



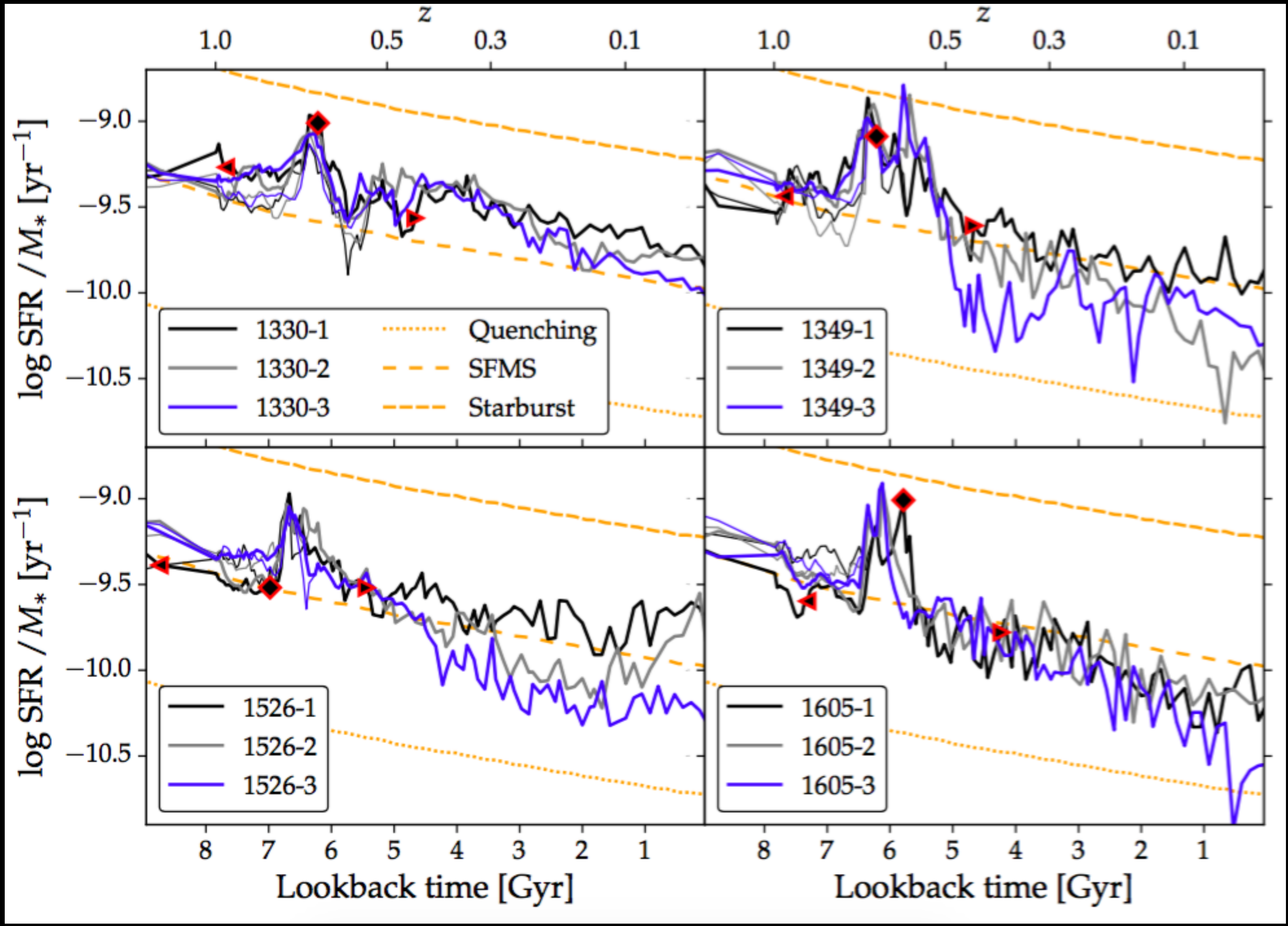
The cosmological structure around mergers



With cosmological merger simulations we can model:

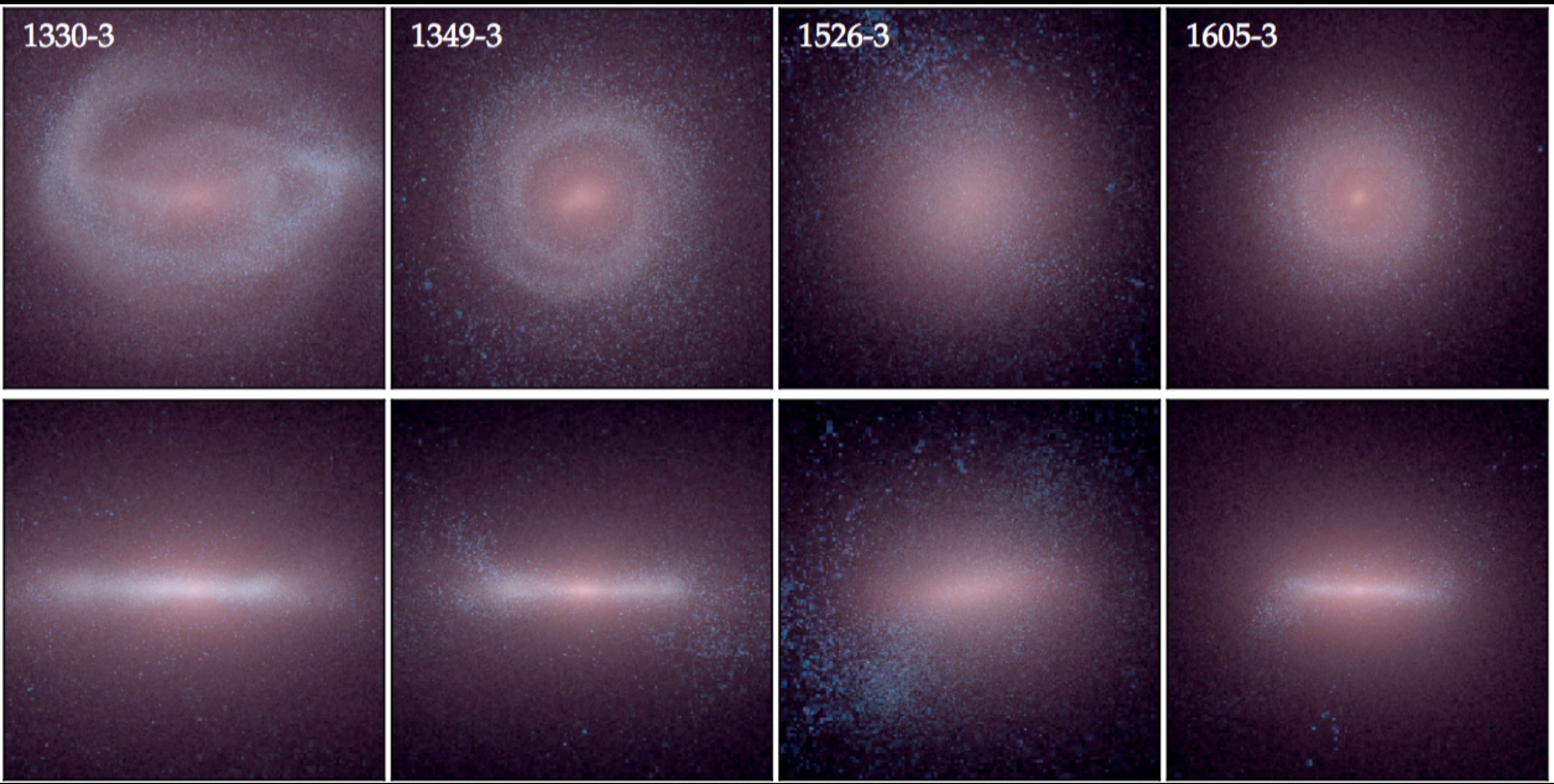
- **rejuvenation of merger remnants.**
- **the circumgalactic medium.**

Merger remnants are star-forming!

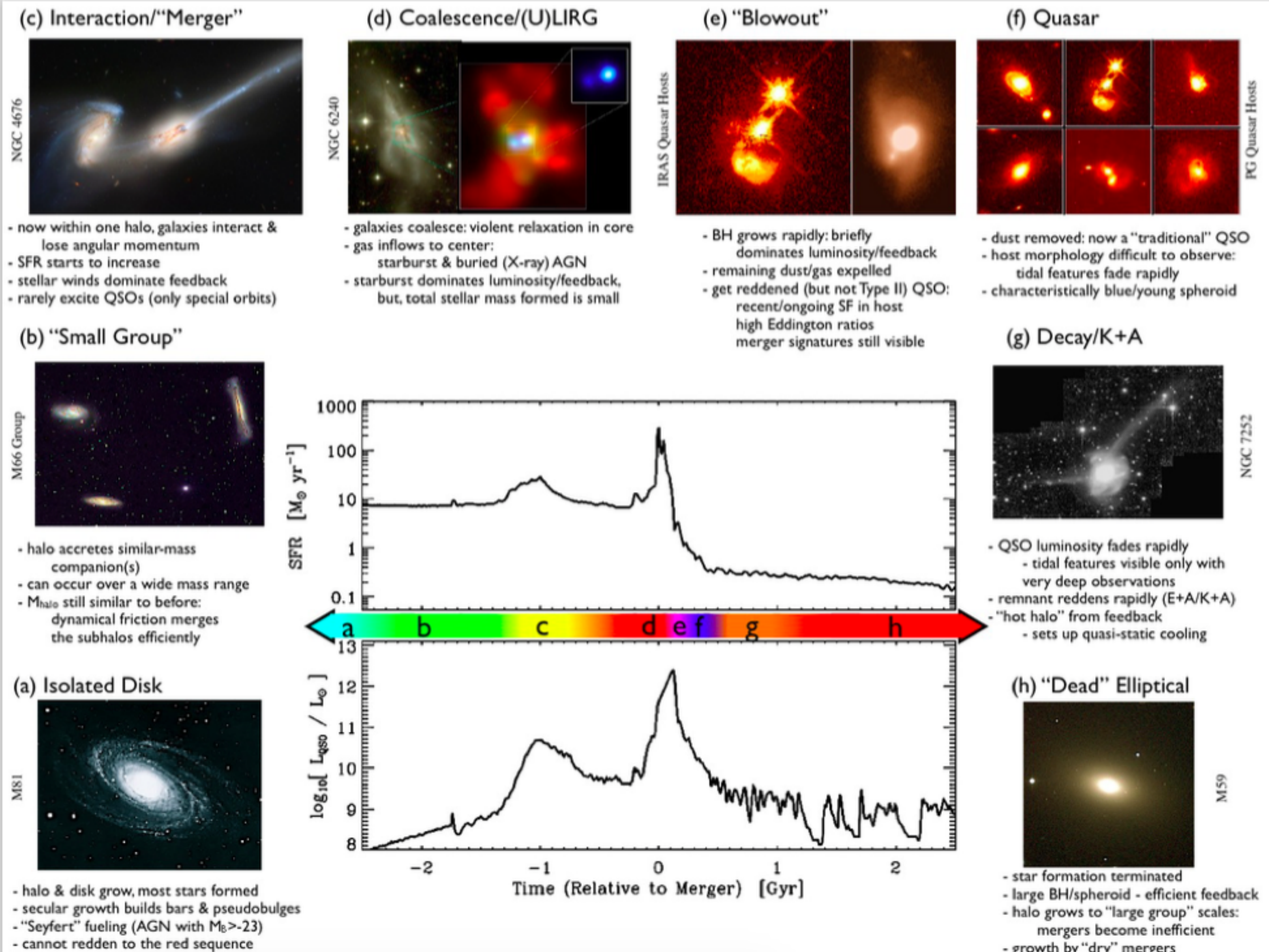


Sparre & Springel 2017

Rejuvenation of merger remnants.
Merger remnants at $z = 0$

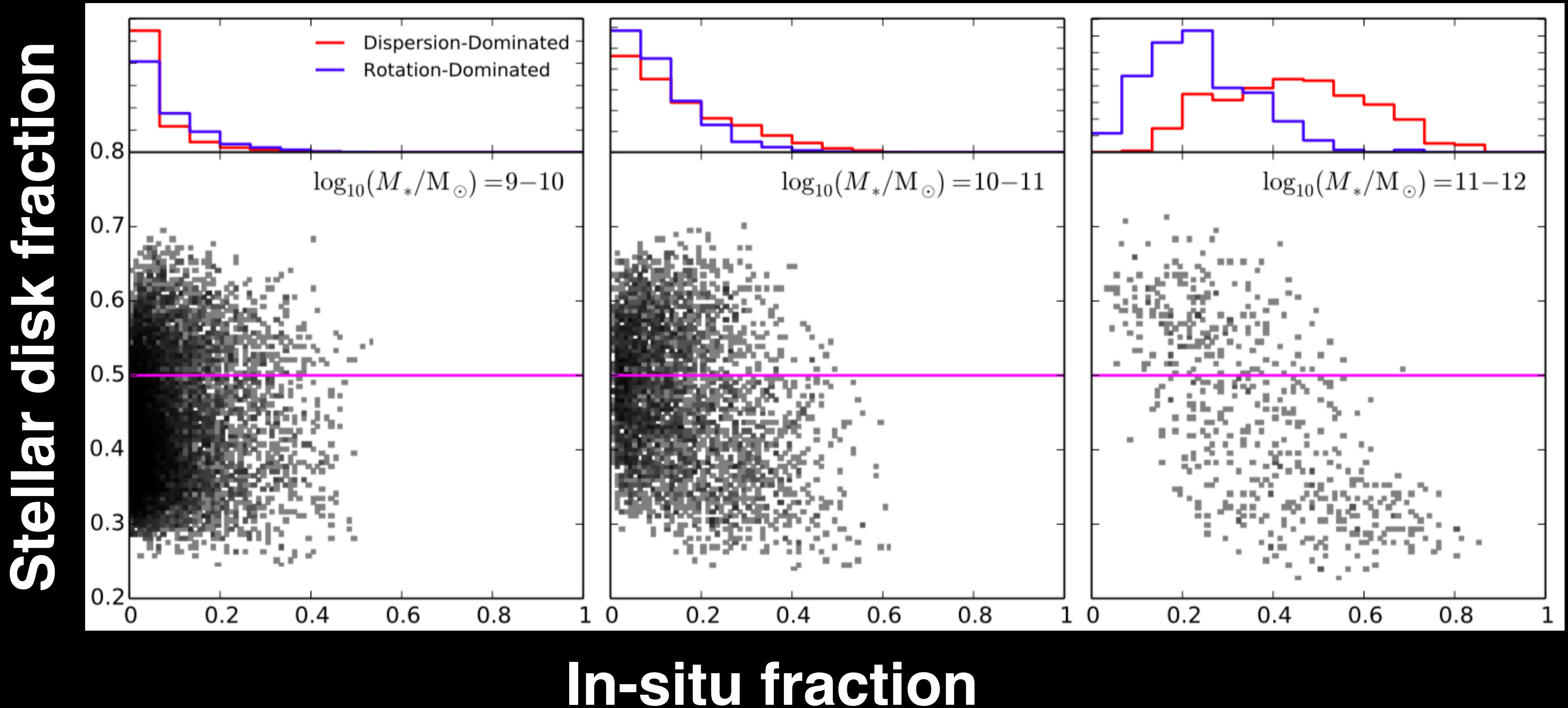


Sparre & Springel 2017



Evolution scenario from Hopkins 2008

Mergers in the Illustris simulation



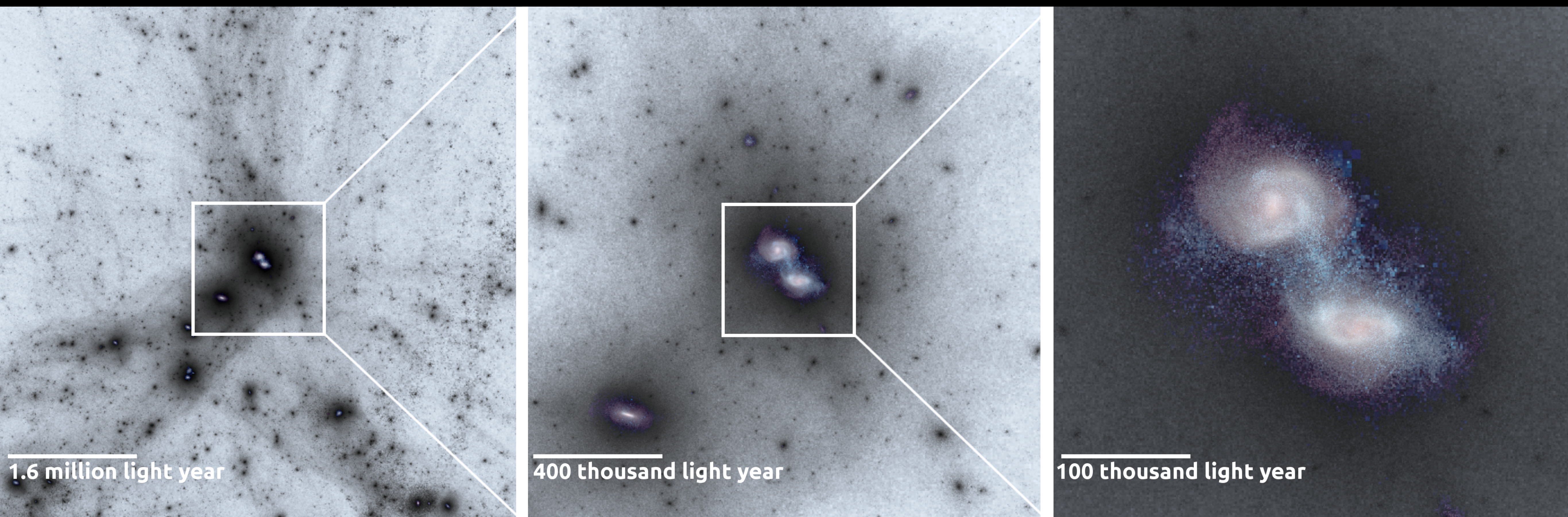
Mergers only destroys disks for massive galaxies.

Rodriguez-Gomez+2017

The CGM

Galaxy mergers moulding the circum-galactic medium – I. The impact of a major merger

Maan H. Hani,[1★†] Martin Sparre,[2,3,4] Sara L. Ellison,[1] Paul Torrey,[4] Mark Vogelsberger[4]



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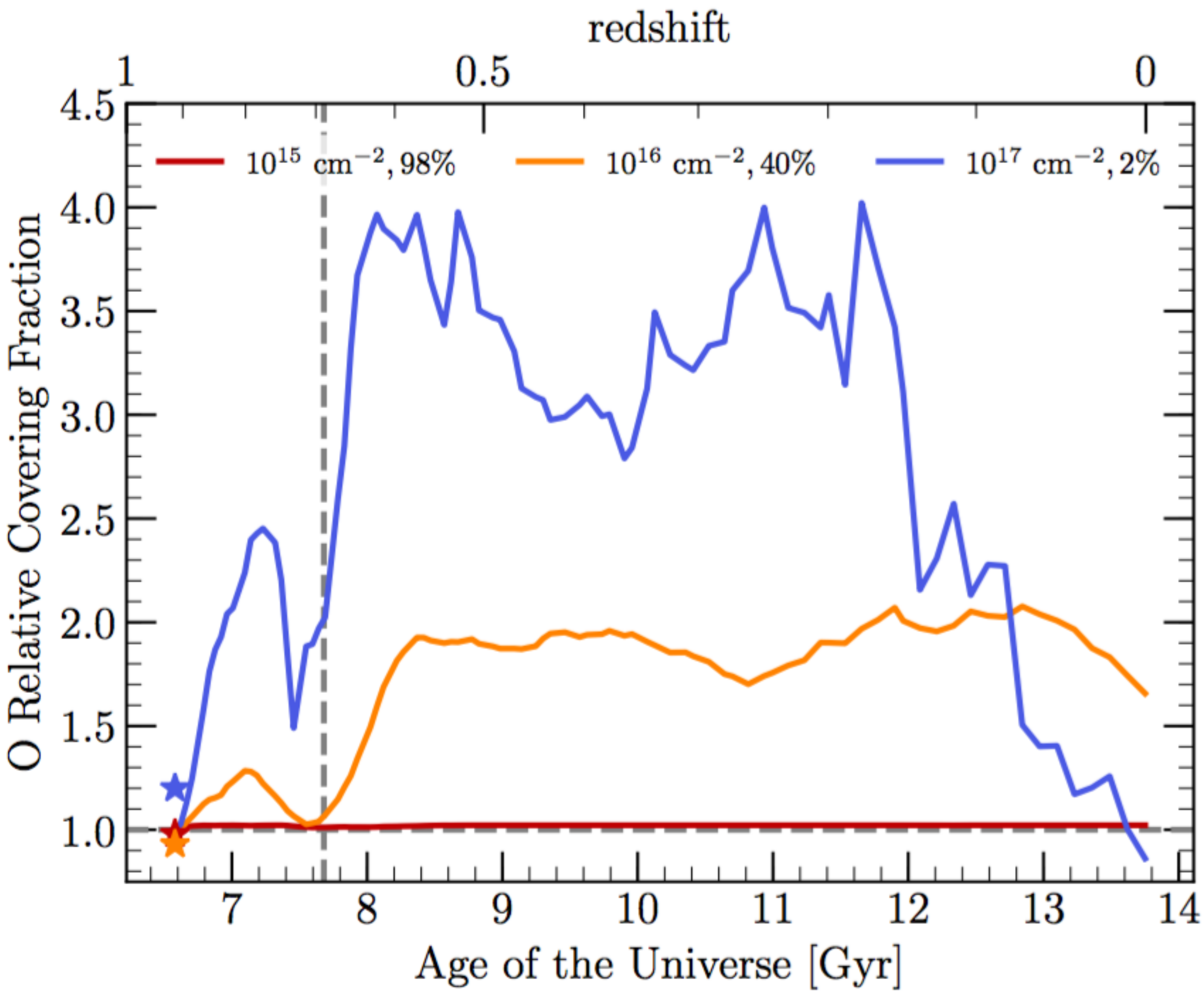
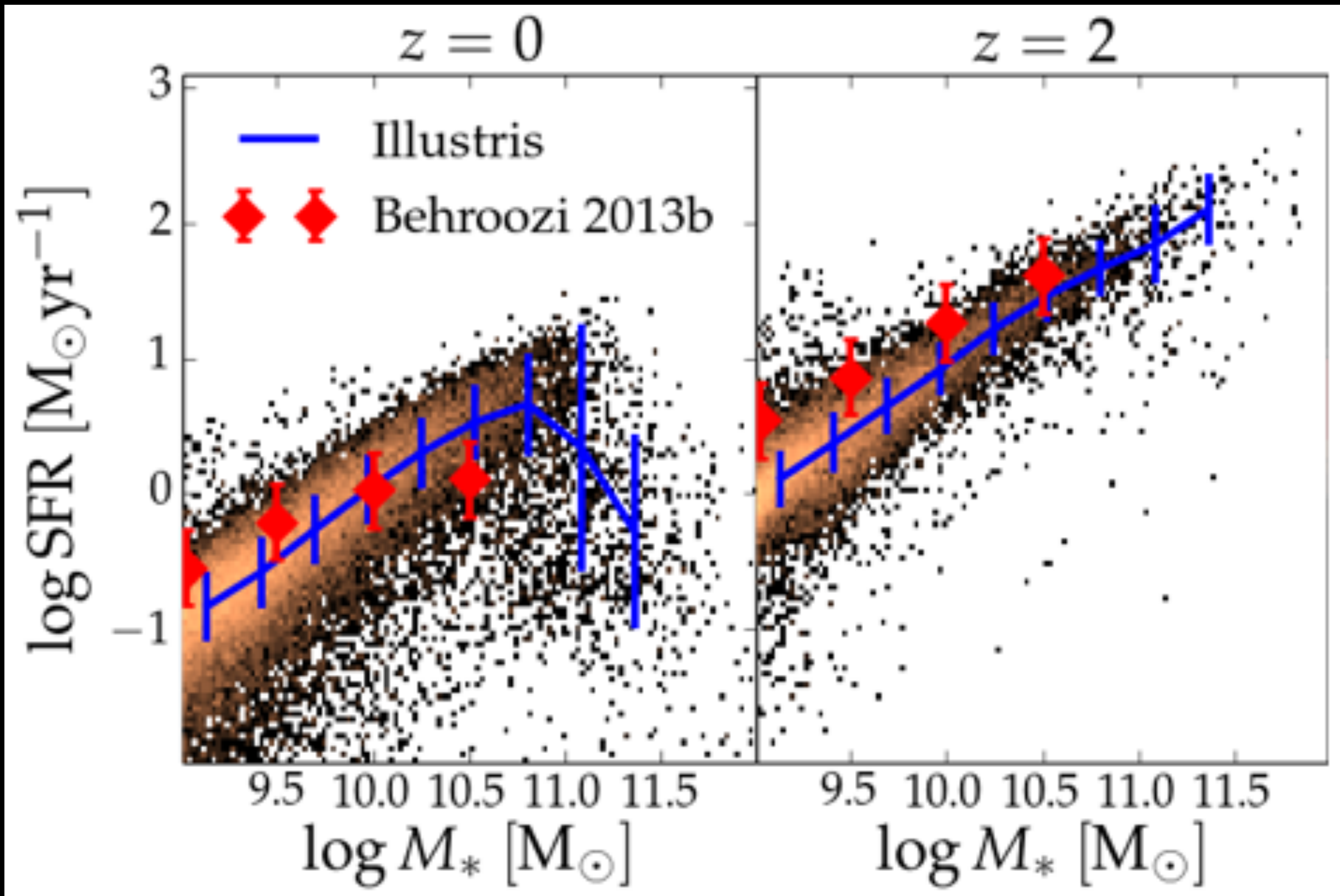


Oxygen is enriched several Gyr after the merger. The CGM has a long memory about the merger history.

Starbursts in cosmological simulations

The main sequence in Illustris



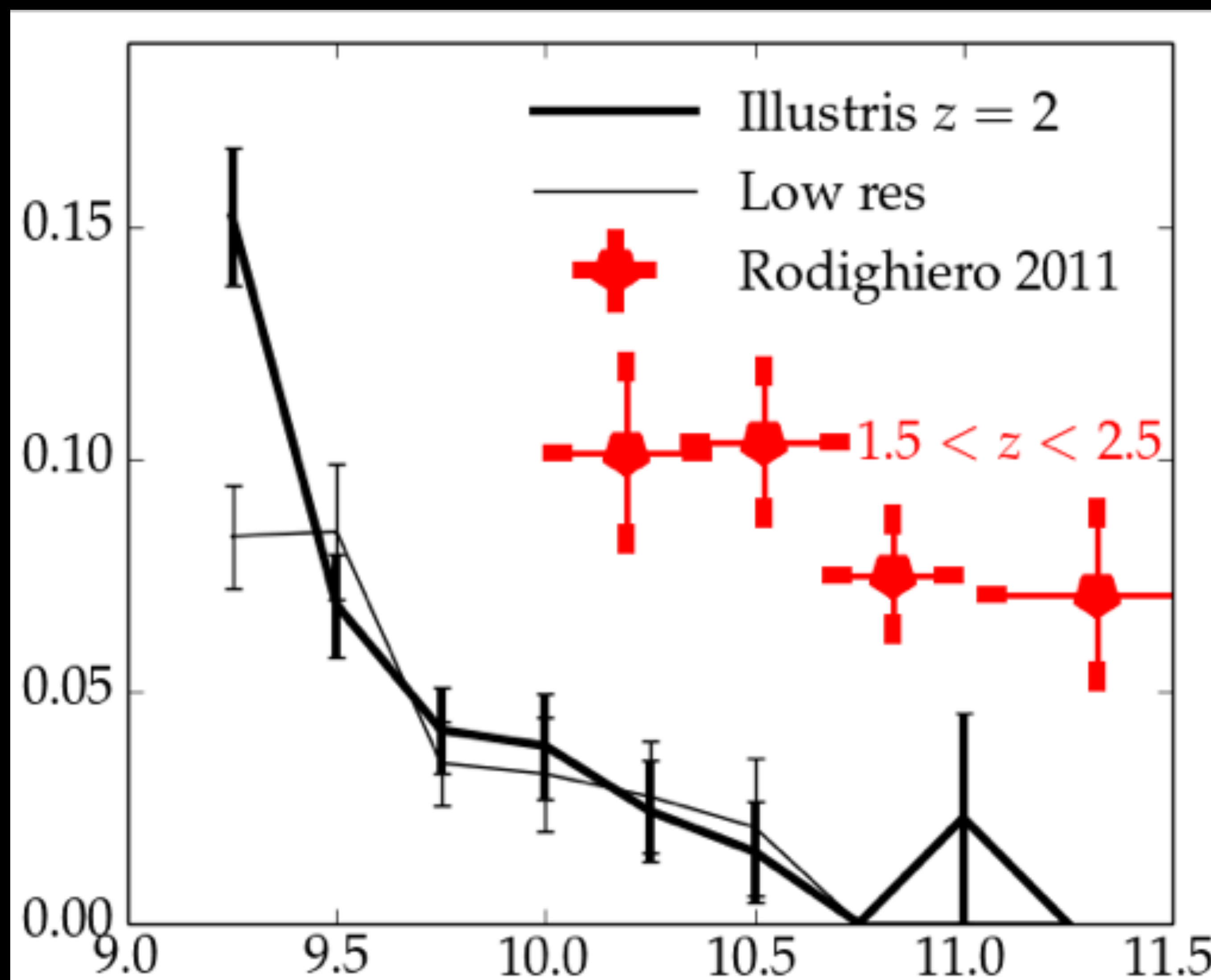
MS+2015

A similar reproduction of the Main Seqeunce in seen in Donnari 2019 (for Illustris TNG), Furlong 2015 (EAGLE), Kaviraj 2017 (Horizon-AGN)

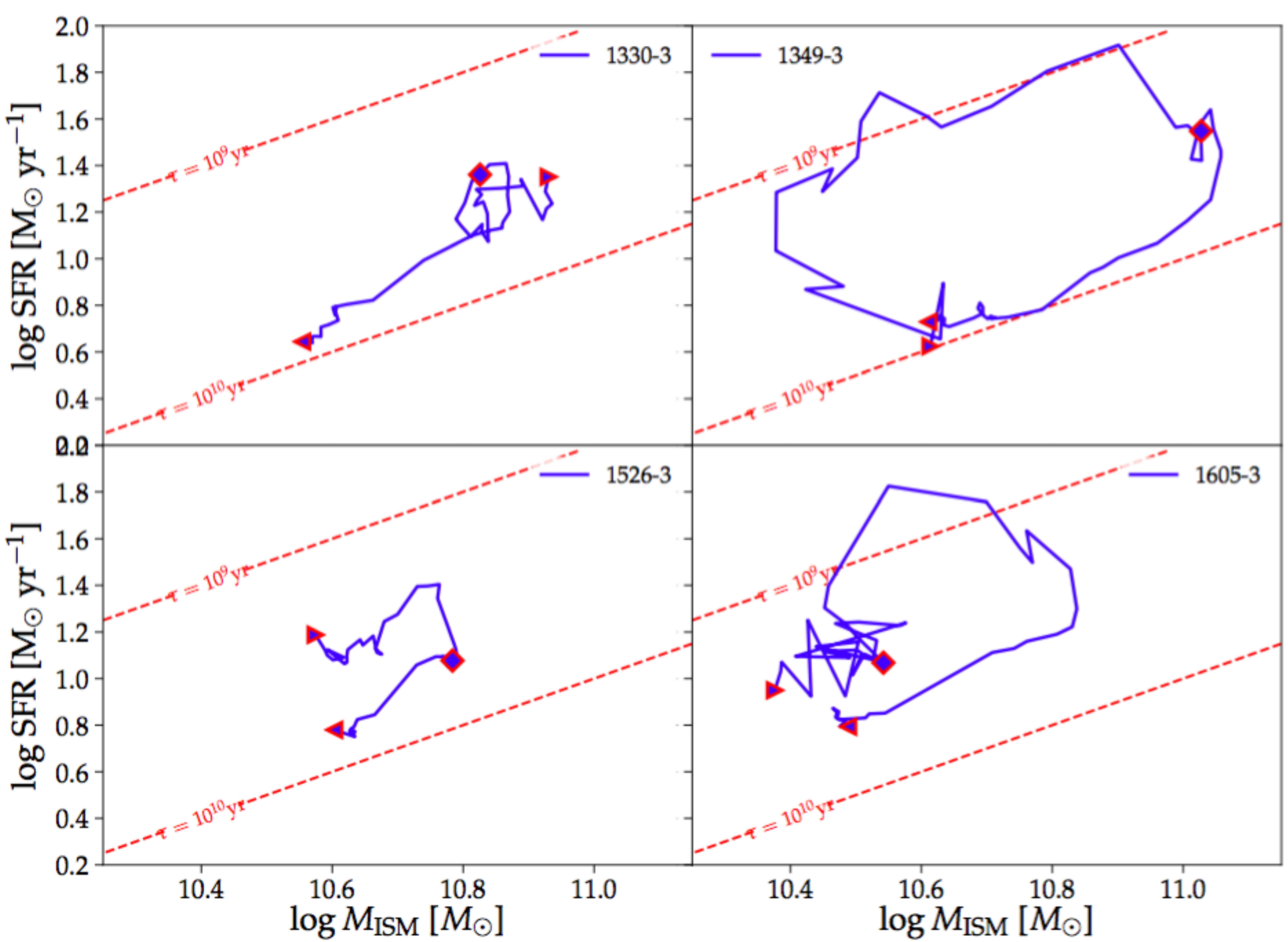
The lack of starbursts in Illustris

MS+2015

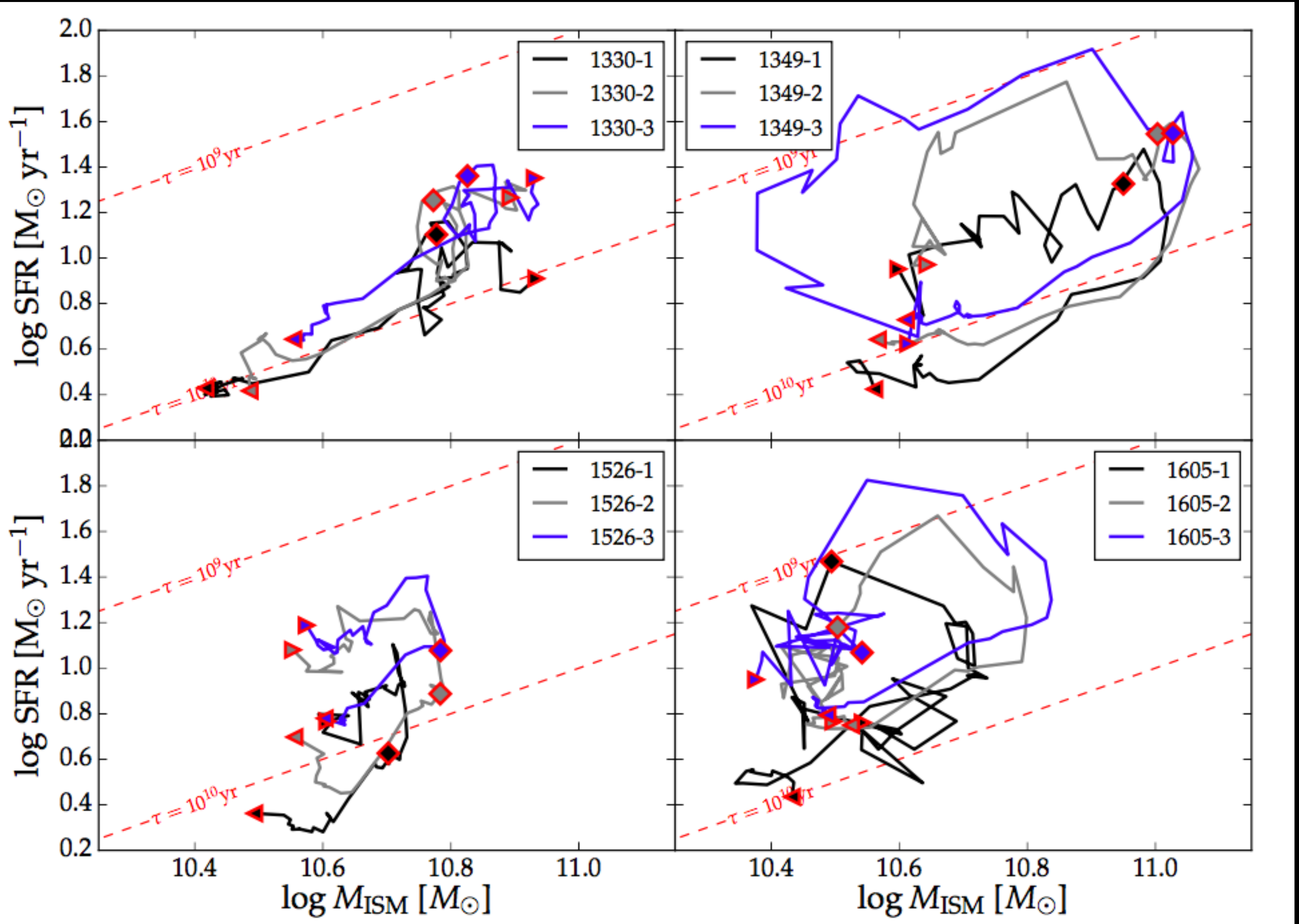
Fraction of SFR in starbursts



Stellar mass



Sparre and Springel 2016



Sparre and Springel 2016

Submm galaxies in Illustris TNG

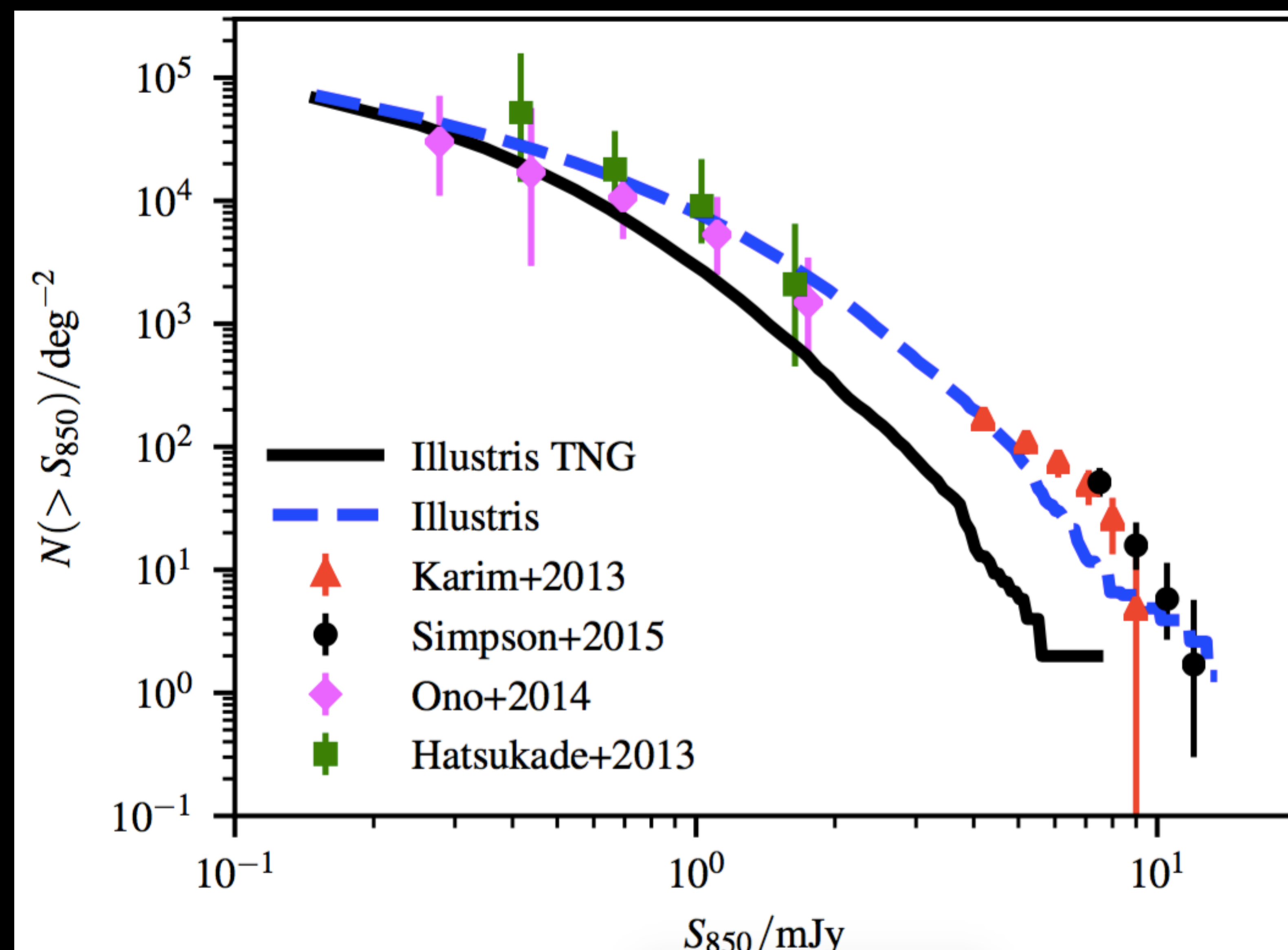
- Illustris TNG lacks a populations of bright submm-galaxies. AGN feedback quenches galaxies before they reach S~10 mJy.

- Submm number count observations can be used to constrain AGN feedback models.

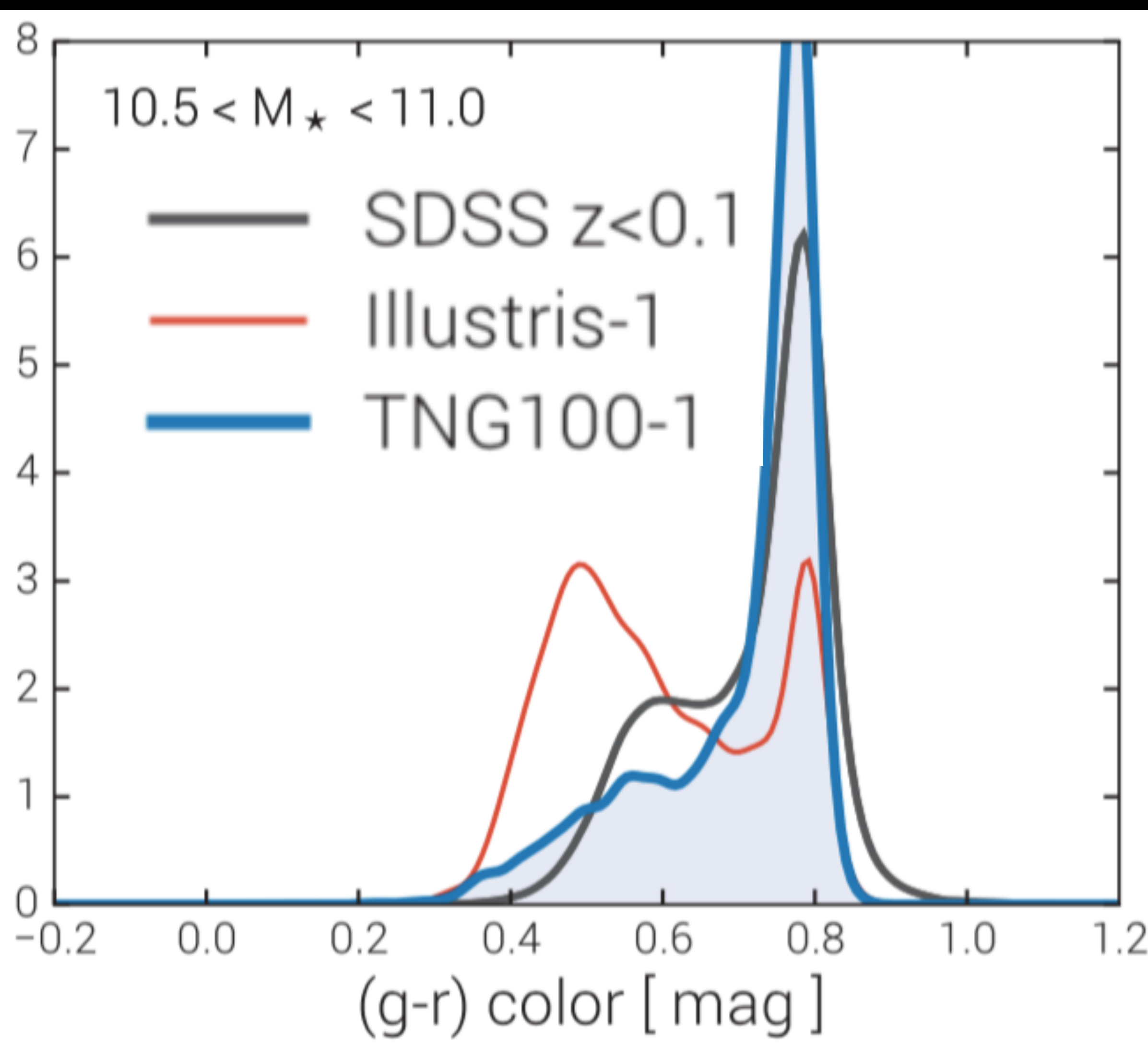
Submillimetre galaxies in cosmological hydrodynamical simulations – an opportunity for constraining feedback models

Christopher C. Hayward[1★], Martin Sparre[2,3,4], Lars Hernquist[5], Dylan Nelson[6], Rüdiger Pakmor[6,7], Annalisa Pillepich[8], Volker Springel[6], Paul Torrey[9], Mark Vogelsberger[4], and Rainer Weinberger[5]

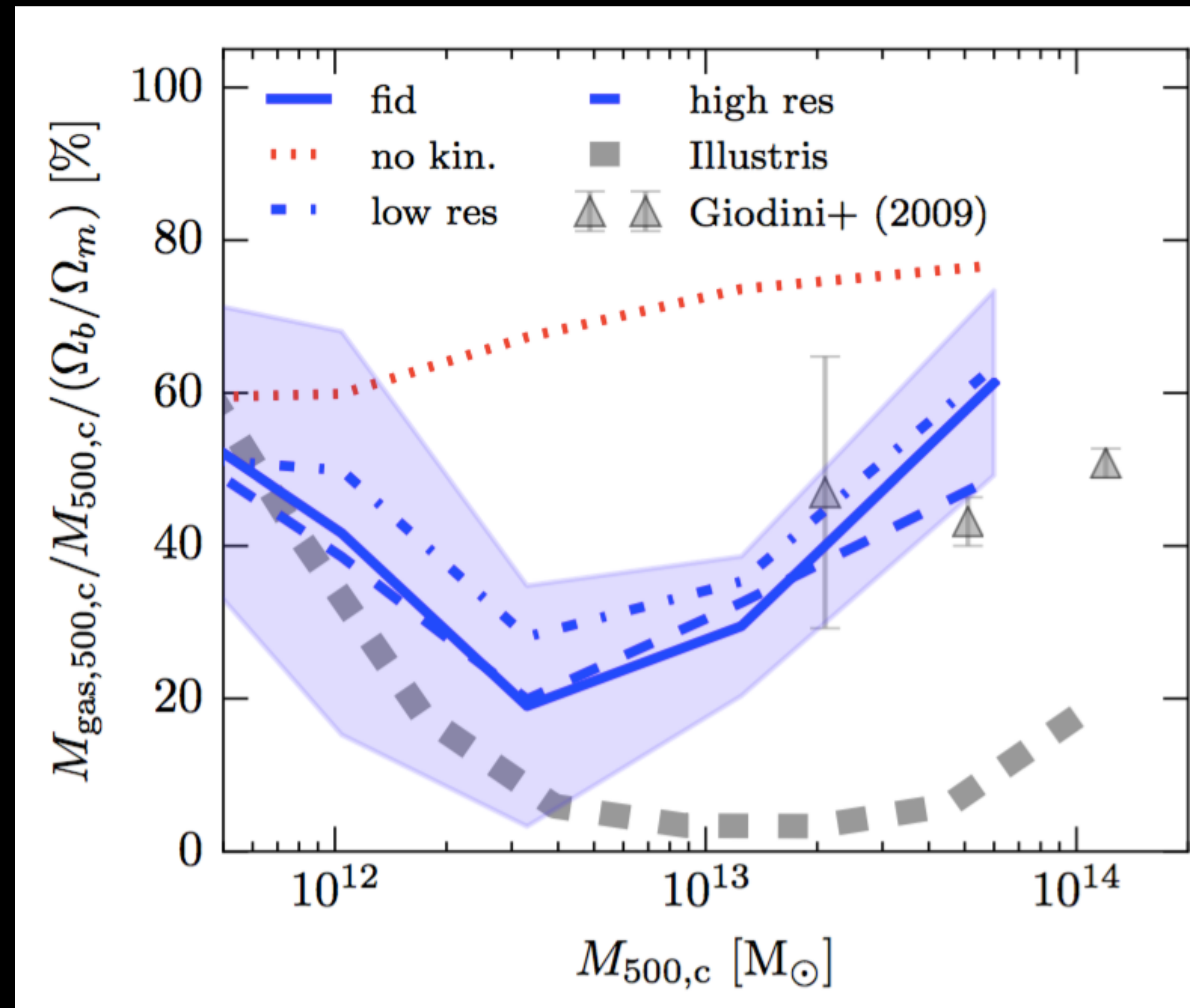
$$\frac{S_{850}}{[\mathrm{mJy}]} = 0.81 \left(\frac{\mathrm{SFR}}{100\ [\mathrm{M}_\odot\,\mathrm{yr}^{-1}]} \right)^{0.43} \left(\frac{M_{\mathrm{dust}}}{10^8\ [\mathrm{M}_\odot]} \right)^{0.54}$$



The kinetic feedback mode ensures gas fractions and red galaxy fractions consistent with observations



Nelson et al. 2018



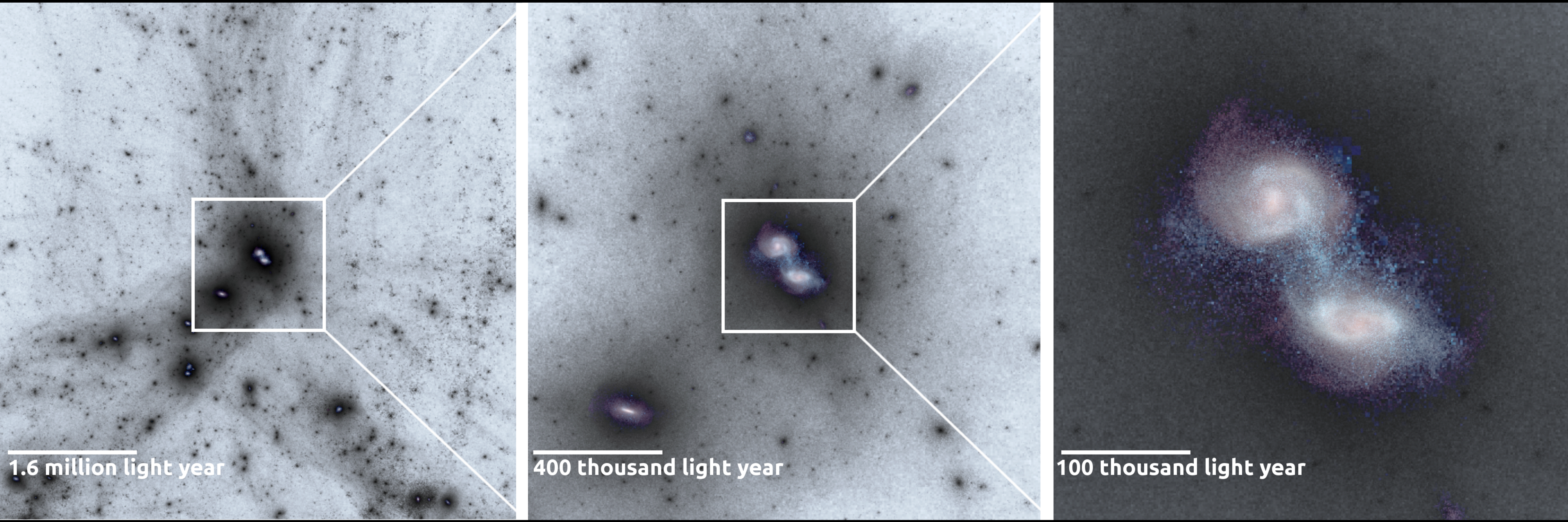
Weinberger et al. 2017

Open questions

- How can we improve AGN models, so they can reproduce high submm-counts?
- Do major mergers quench galaxies? Previous simulations have overestimated the effect of mergers.

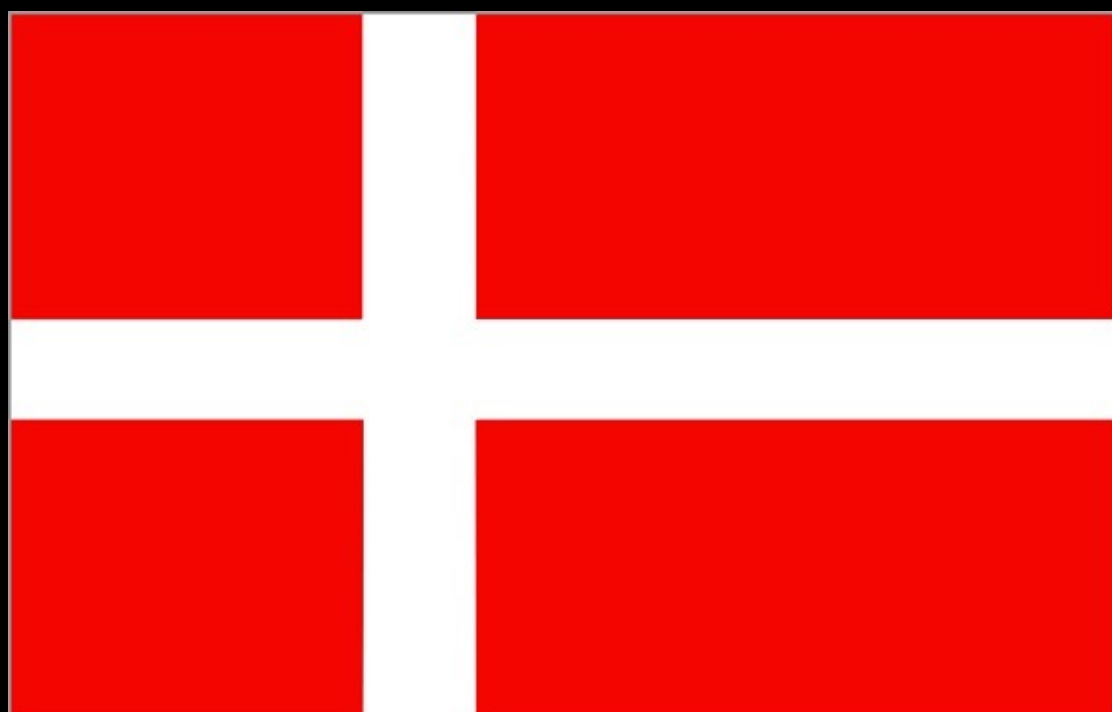
Conclusions

- Gas inflows in mergers cause SFR-enhancements, metallicity dilution and increased black halo feedback.
- Submm. observations can constrain AGN feedback models.
- Previous idealised simulations have overestimated the role of quenching in mergers - they ignore post-merger gas accretion.



Martin Sparre

Thanks to Danish, German and EU taxpayers for supporting my research!



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