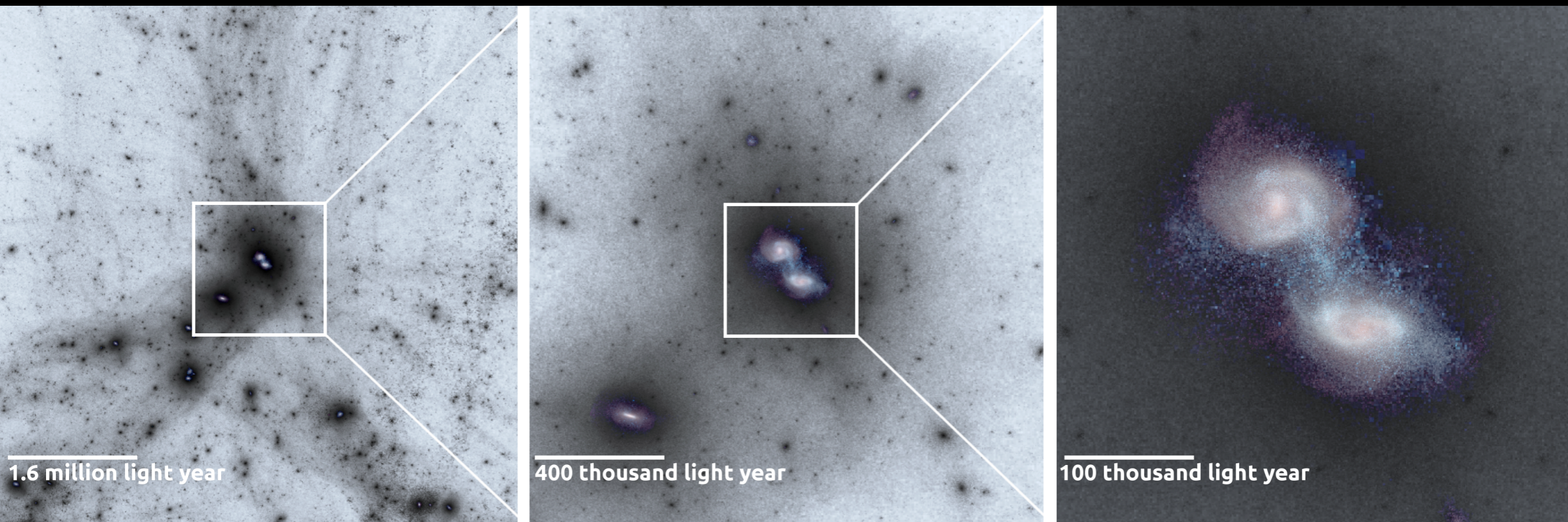


Starbursts and AGN feedback



Martin Sparre
Potsdam University & AIP Potsdam

Invited talk

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

THE DYNAMICS OF MERGERS



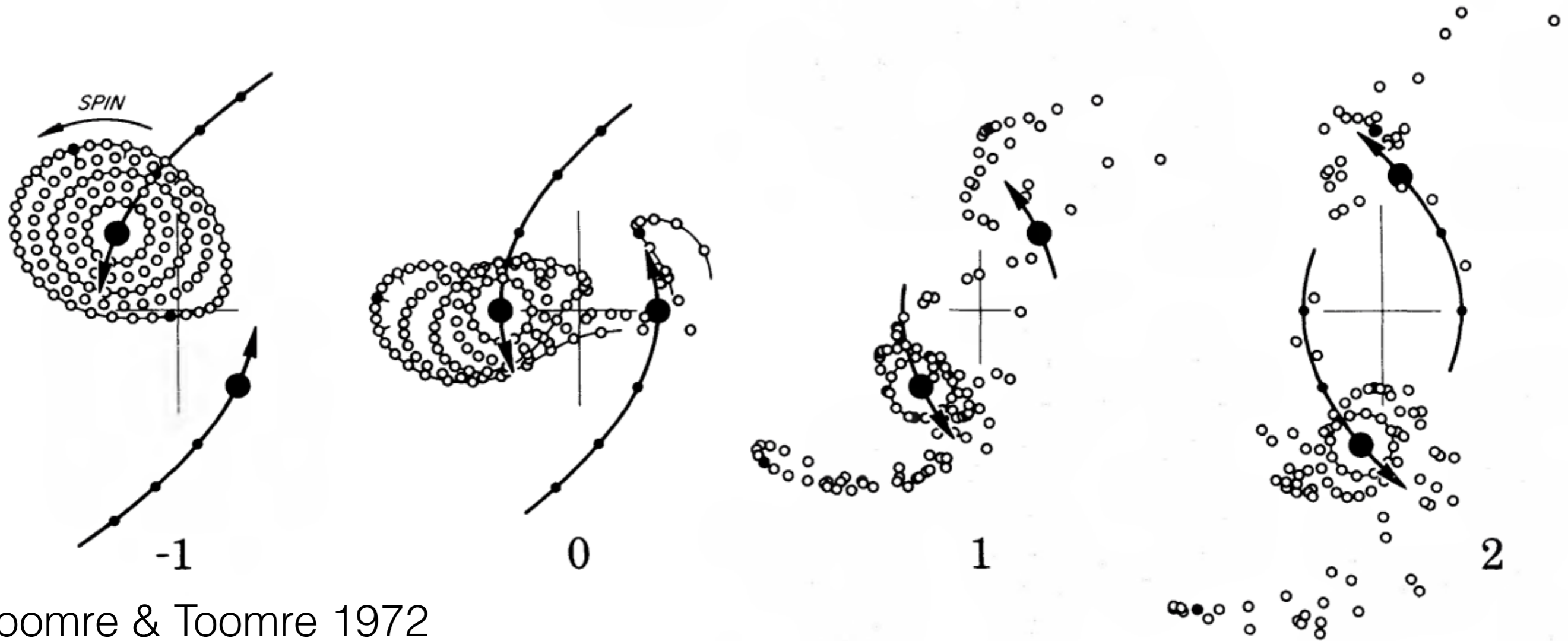
Image: ACS, NASA, Hubble.



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

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

GALACTIC BRIDGES AND TAILS

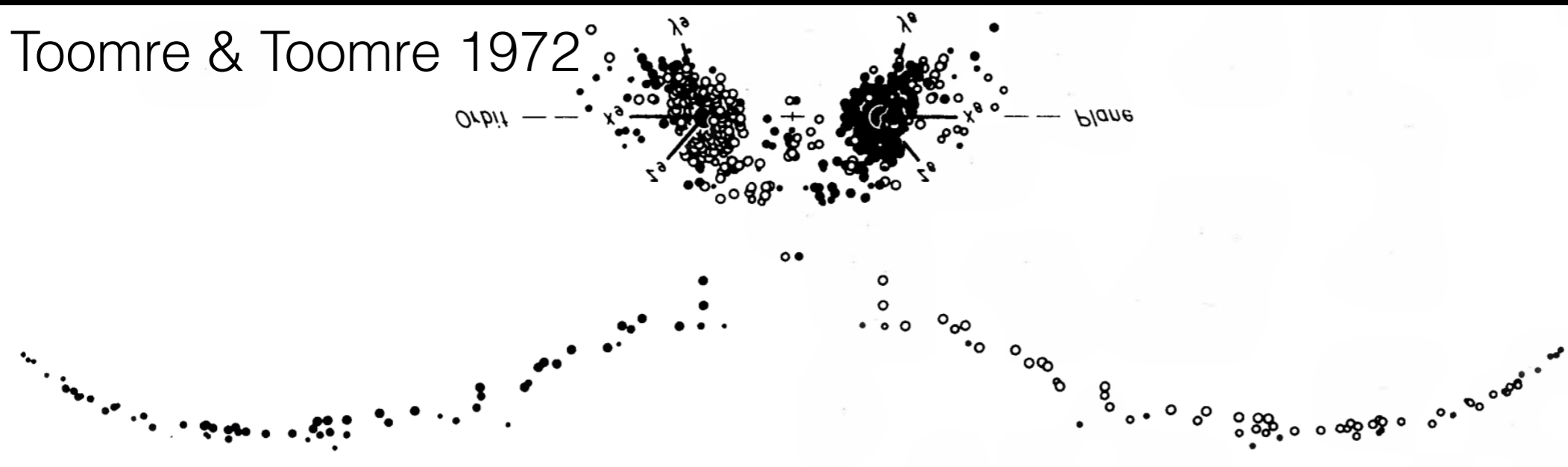


Toomre & Toomre 1972

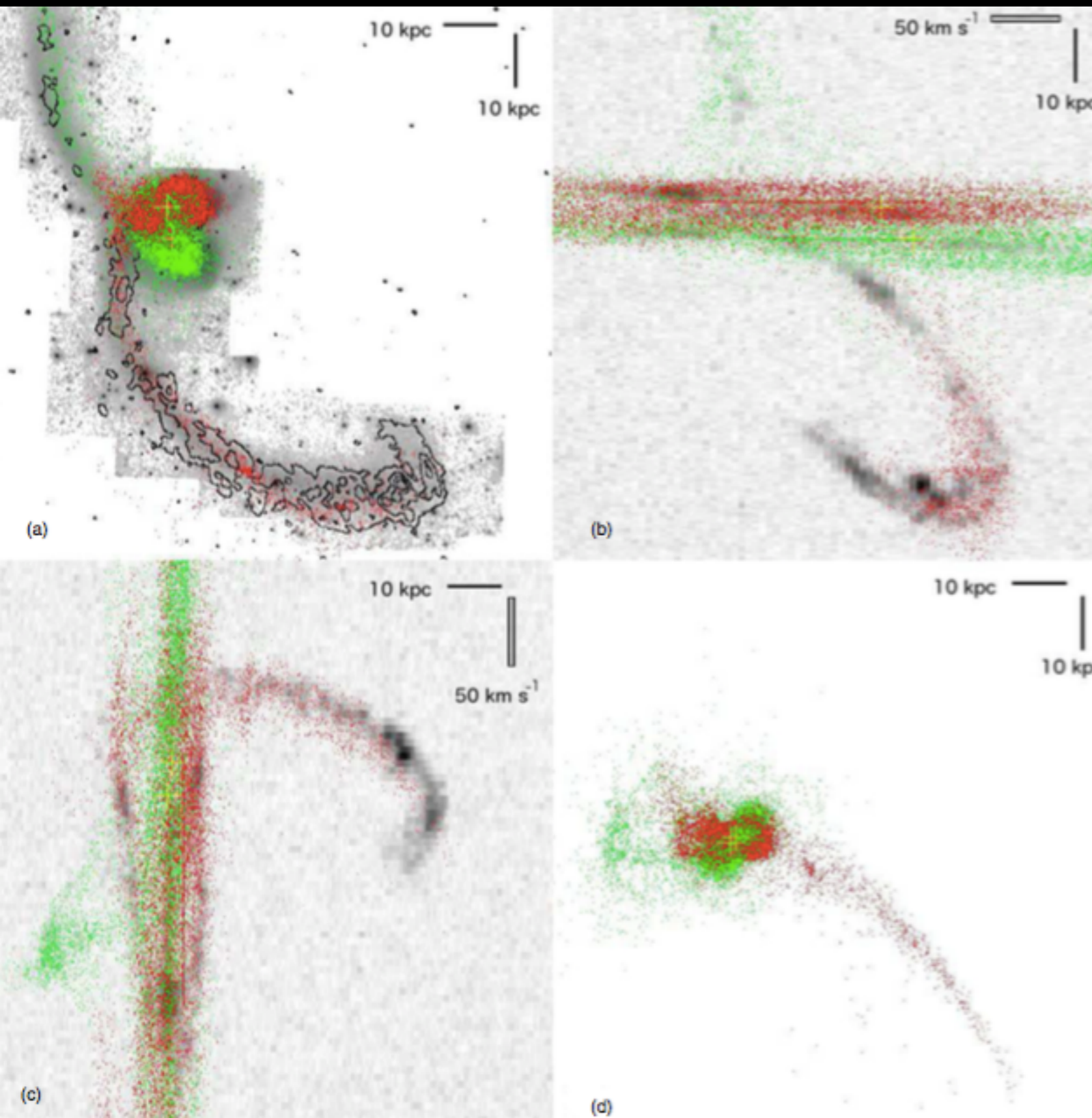
With test-particle-simulations **Toomre and Toomre 1972** found that the torques and forces in major mergers caused the formation of galactic ***bridges*** and ***tails***.

THE DYNAMICS OF MERGERS

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



Modern test-particle-simulations



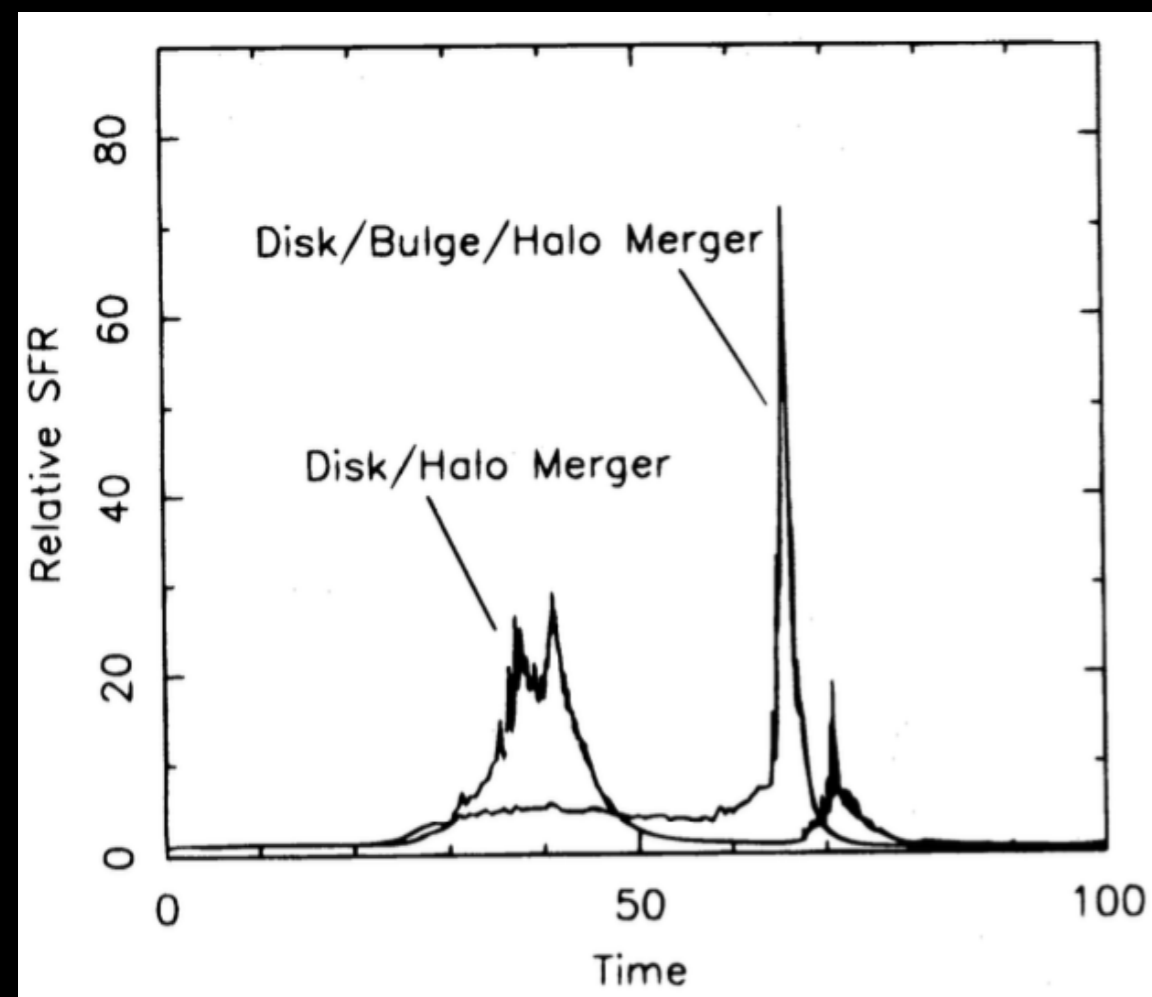
- a) (α, δ)
- b) (v, δ)
- c) (v, α)
- d) top-down view

Modelling of mergers
with *Identikit*

Fig. from **Privon+2013**,
see also **Barnes &
Hibbard 2009**,
Barnes 2011,
Pearson+2018

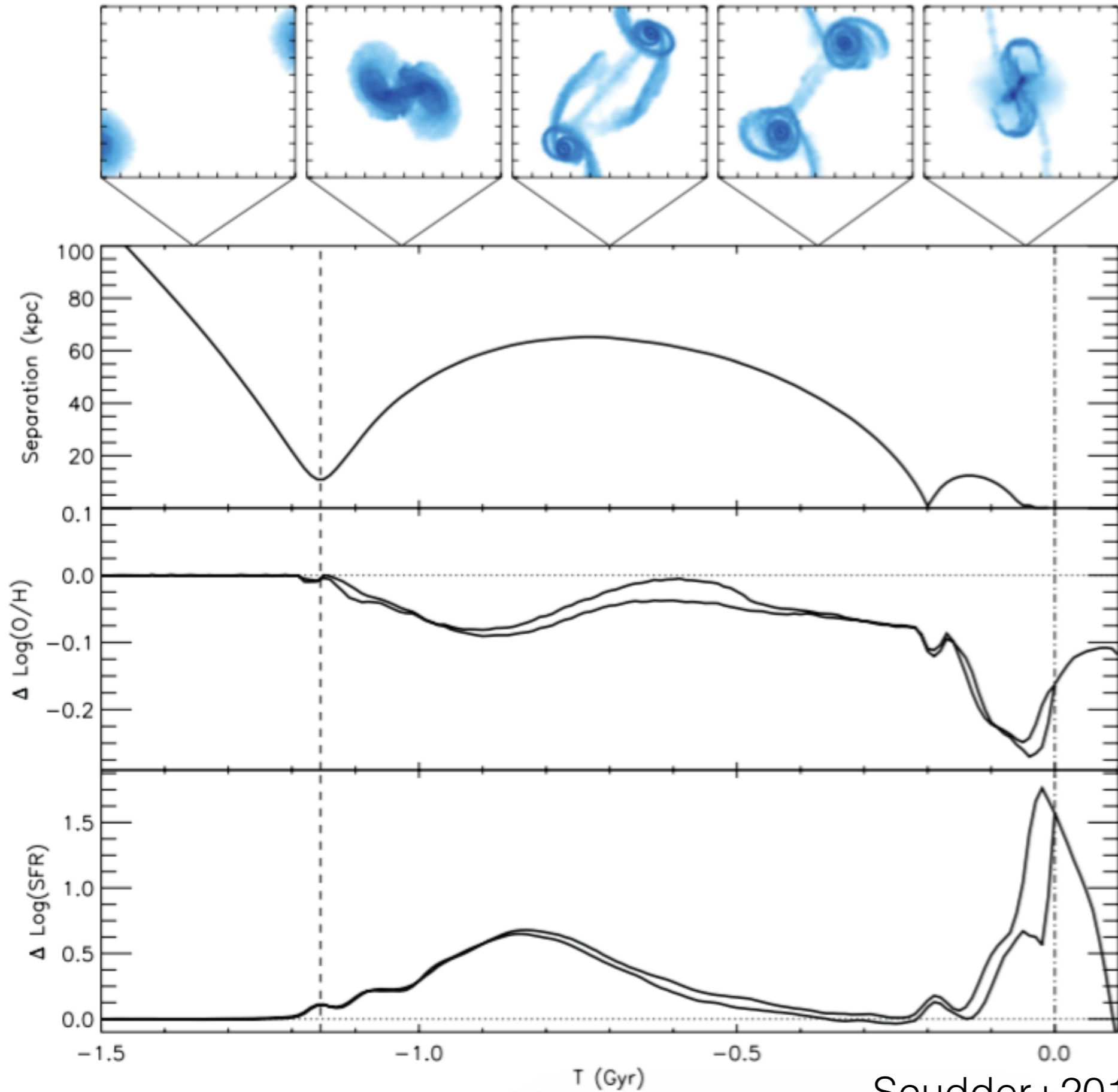
- The torques and forces involved in (major) mergers cause the formation of *bridges* and *tails*.
- Idealised galaxy simulations find that gas is tunneled into the center of galaxies, and thus causing a starbursts. (see e.g. Renaud 2019)

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



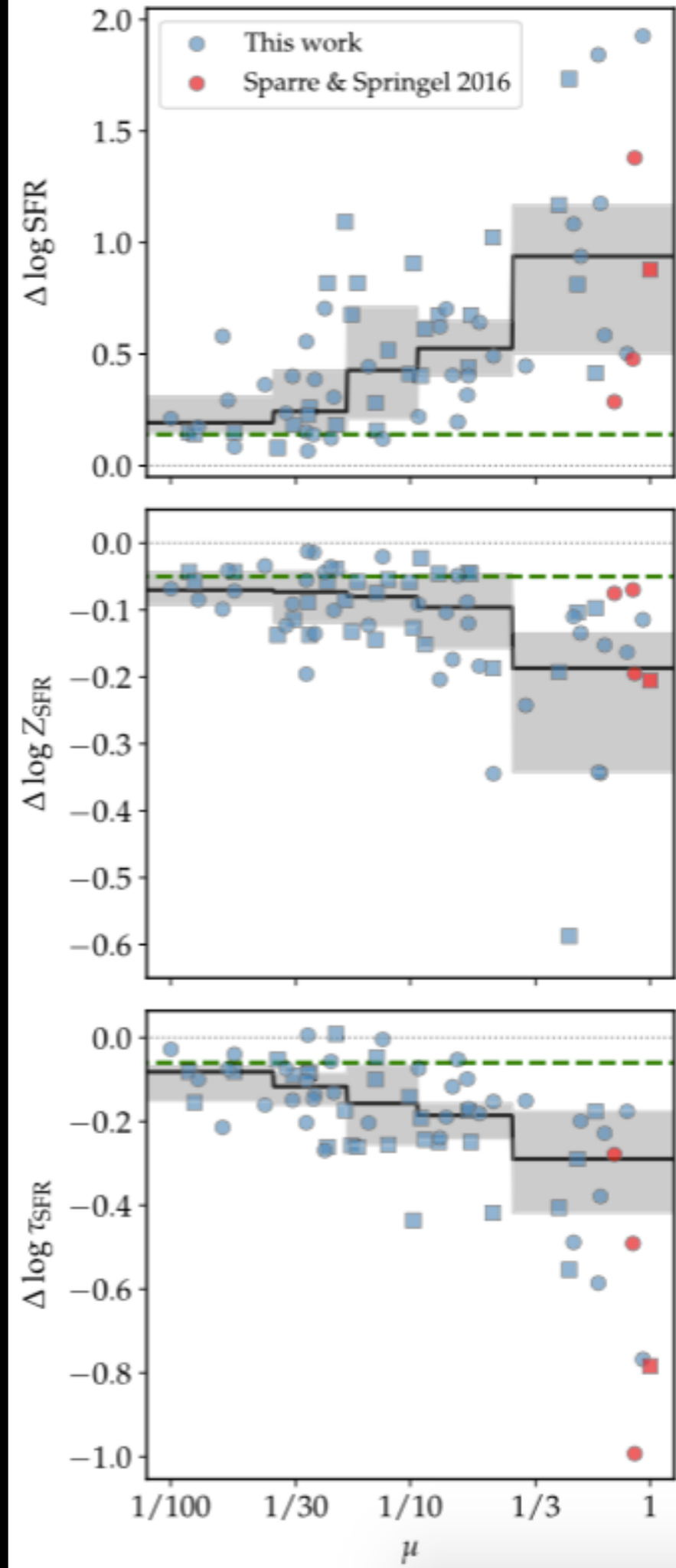
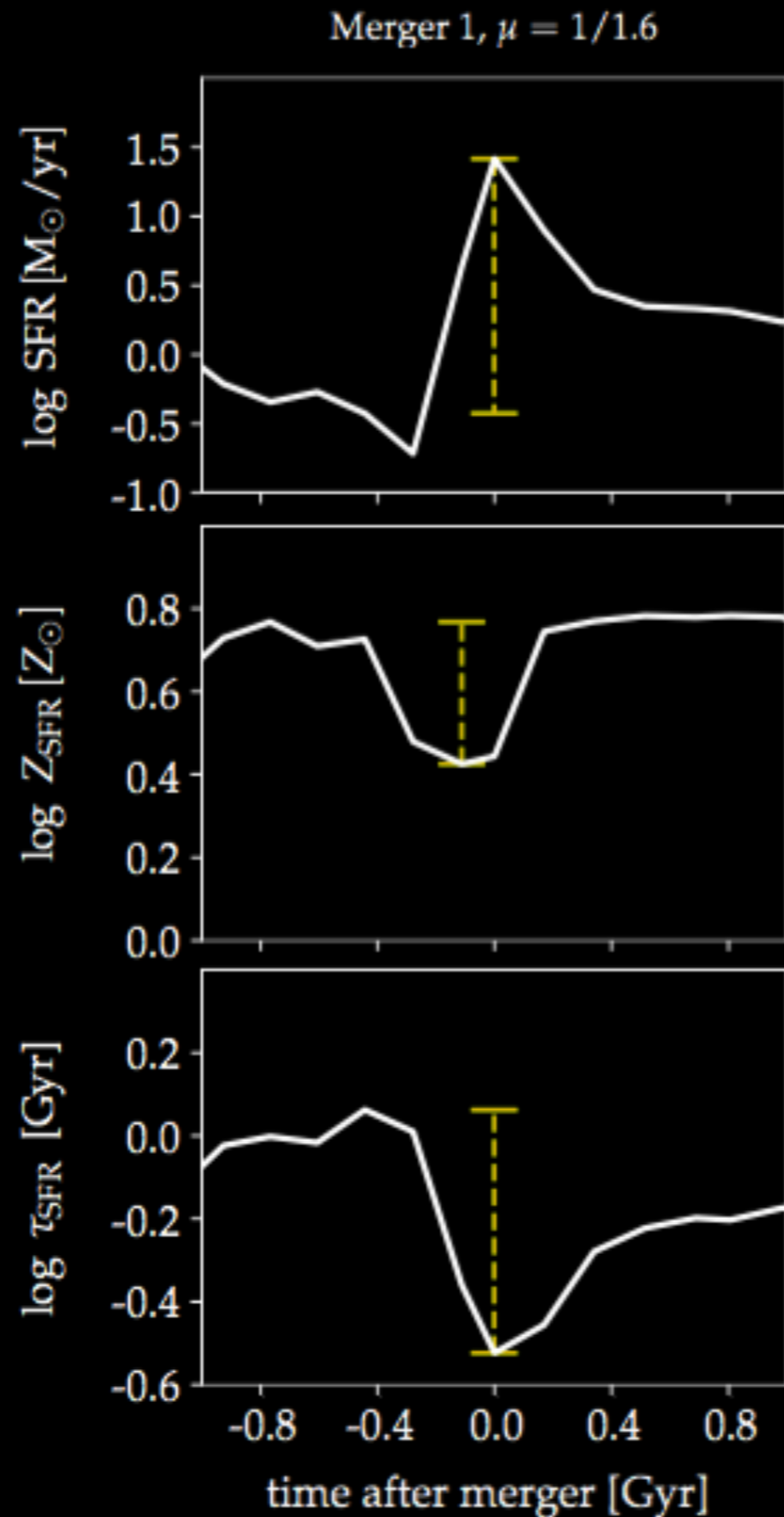
Scudder+2012

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

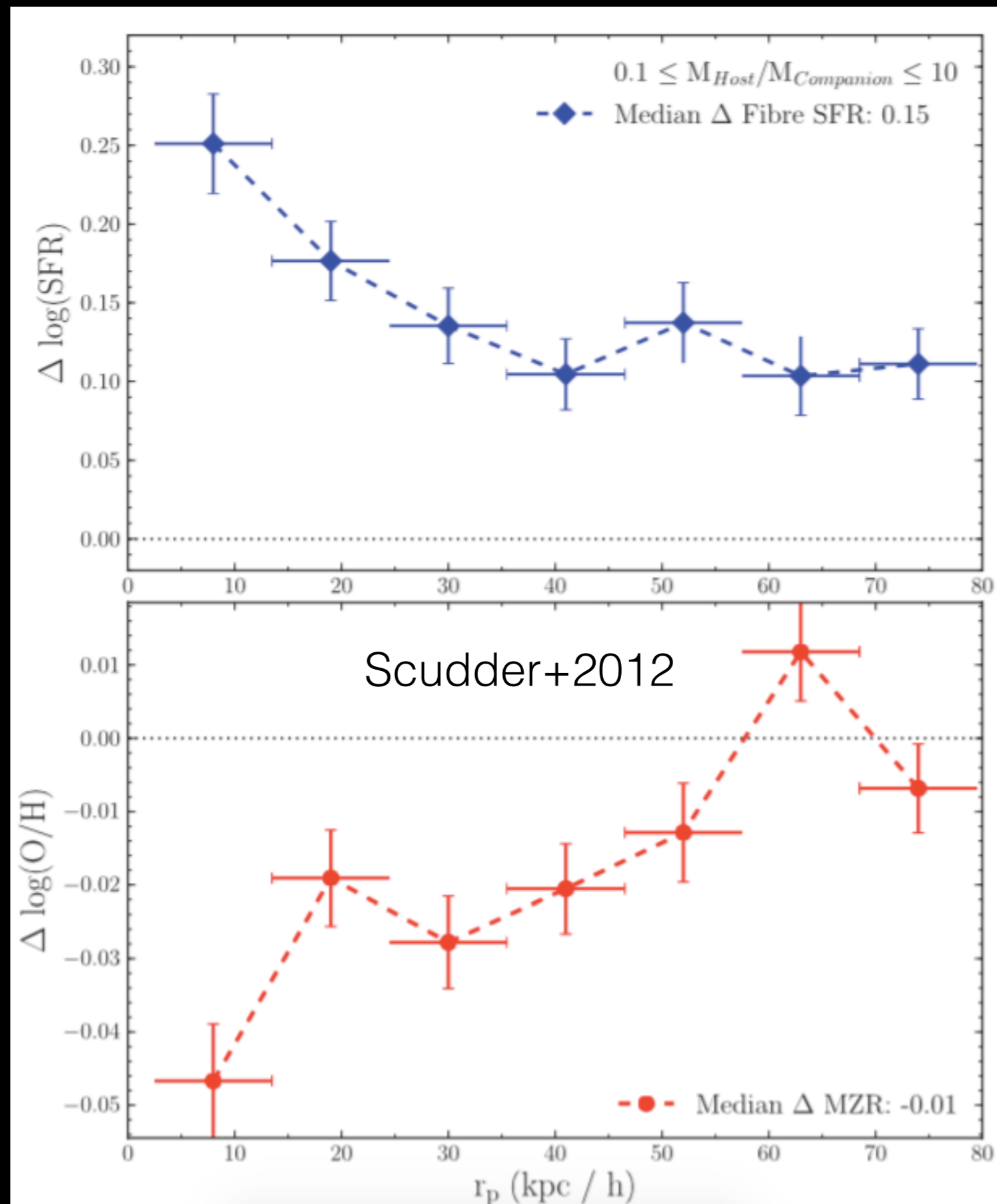
- 1) increased SFR.
- 2) metallicity dilution
- 3) short gas consumption timescales.



Observation of metallicity dilution

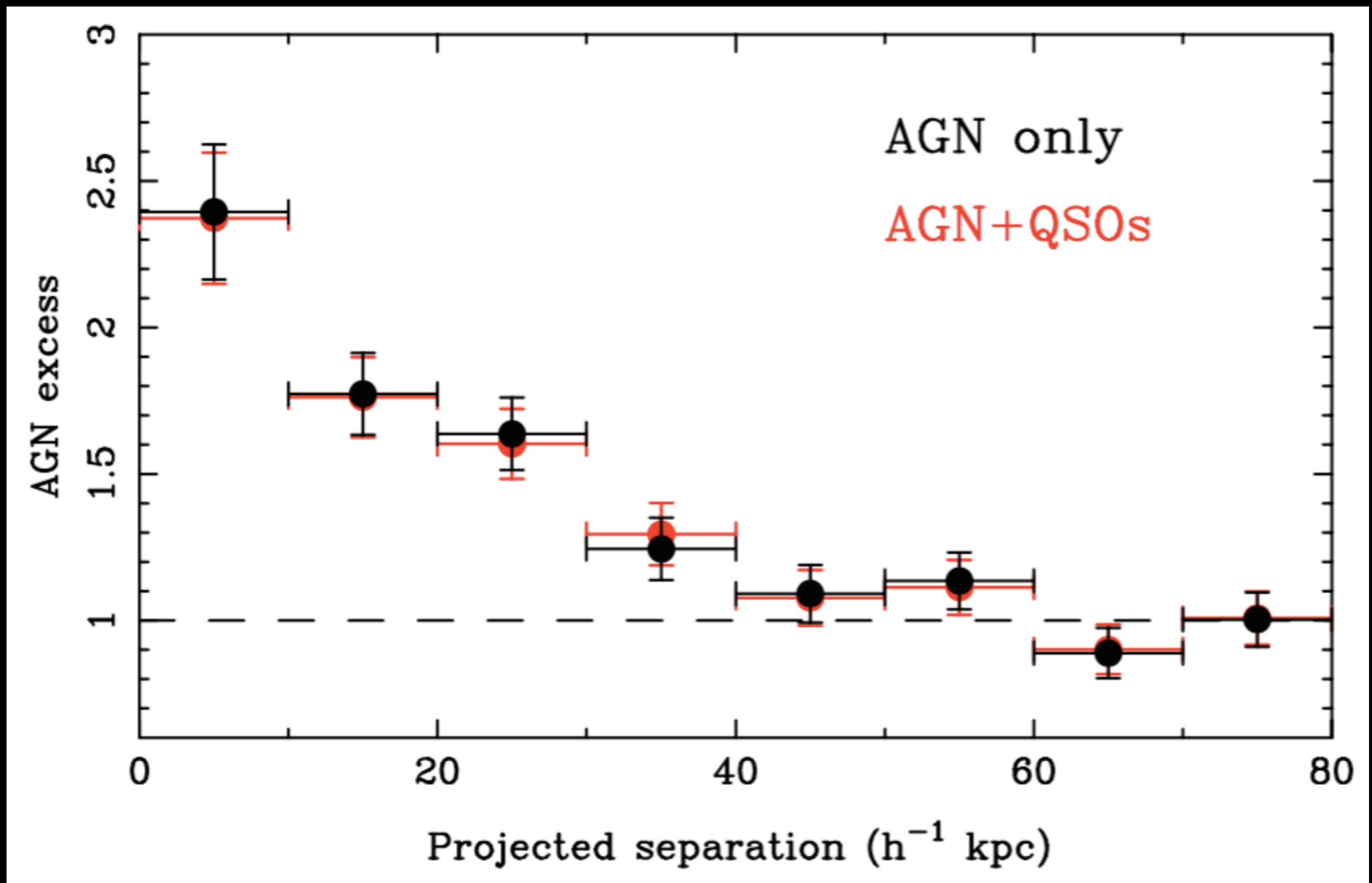
Metallicity dilution and SFR enhancement in observed galaxy pairs from SDSS.

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.



Does AGN feedback
quench merger
remnants?

(From a simulator's point of view!)

Black hole accretion and feedback

Bondi accretion

$$\dot{M}_B = \frac{4\pi\alpha G^2 M_{\text{BH}}^2 \rho}{(c_s^2 + v^2)^{3/2}}$$

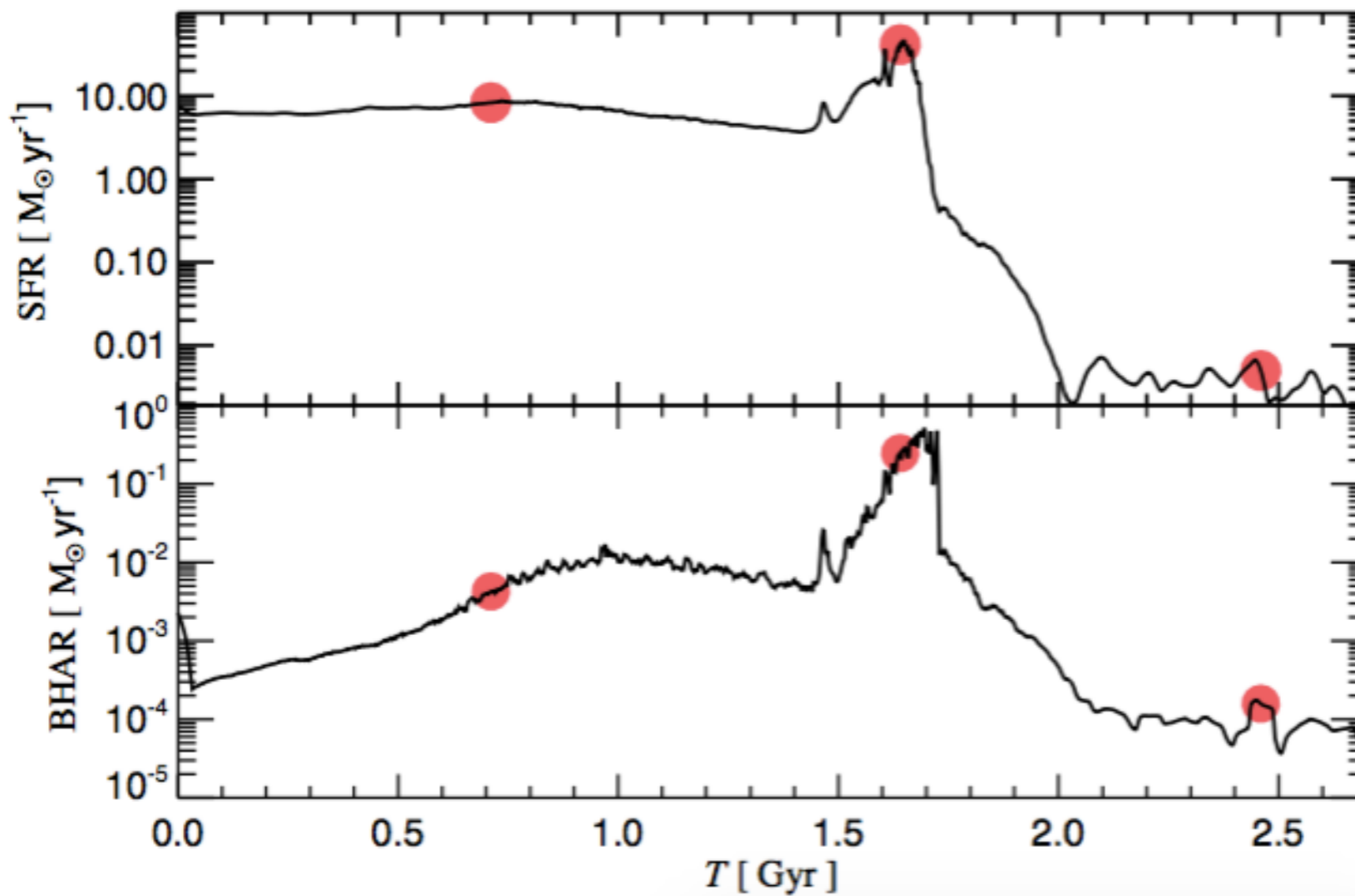
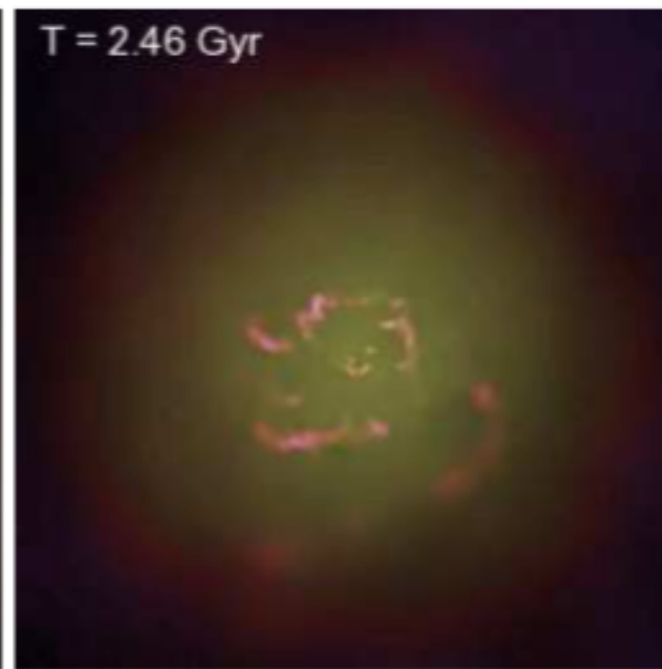
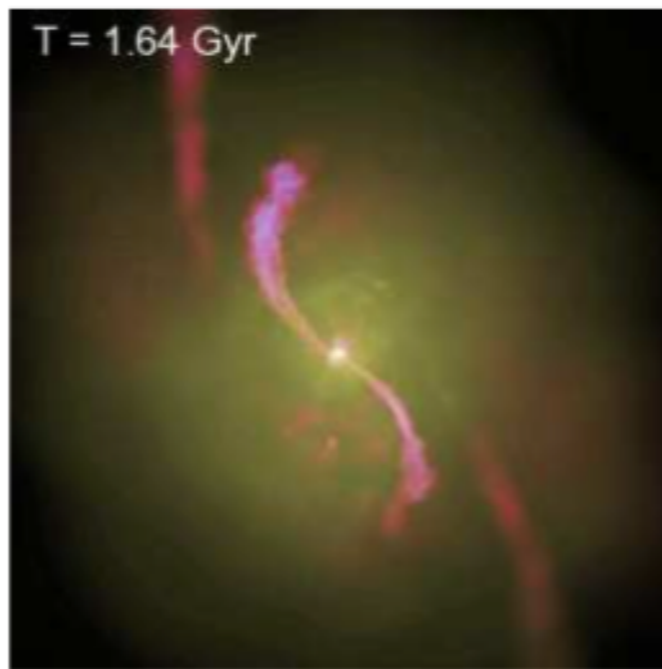
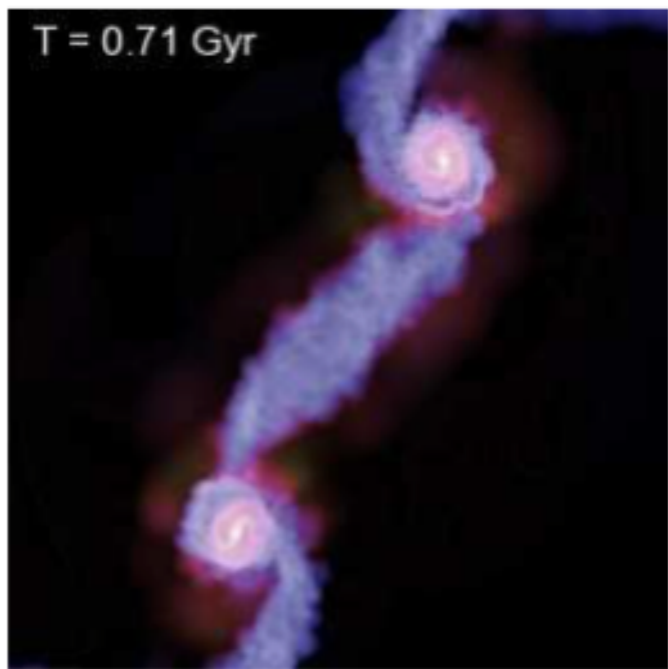
Eddington limited accretion:

$$\dot{M}_{\text{Edd}} \equiv \frac{4\pi G M_{\text{BH}} m_p}{\epsilon_r \sigma_T c} \quad \dot{M}_{\text{BH}} = \min(\dot{M}_{\text{Edd}}, \dot{M}_B)$$

Black hole feedback:

$$\dot{E}_{\text{feed}} = \epsilon_f L_r = \epsilon_f \epsilon_r \dot{M}_{\text{BH}} c^2$$

(from Springel, Di Matteo, Hernquist 2005)

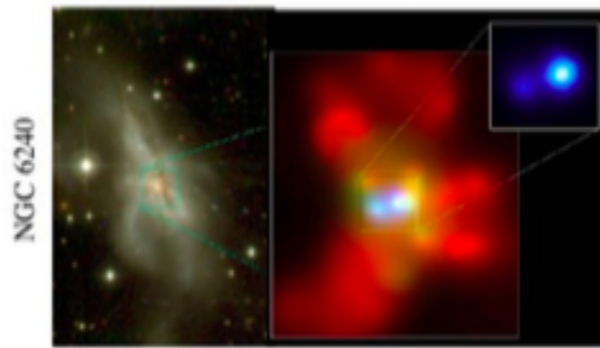


(c) Interaction/"Merger"



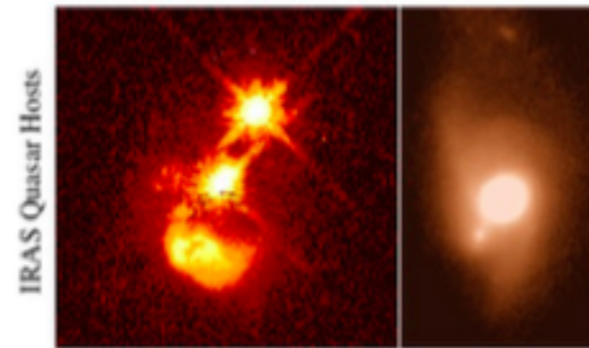
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG



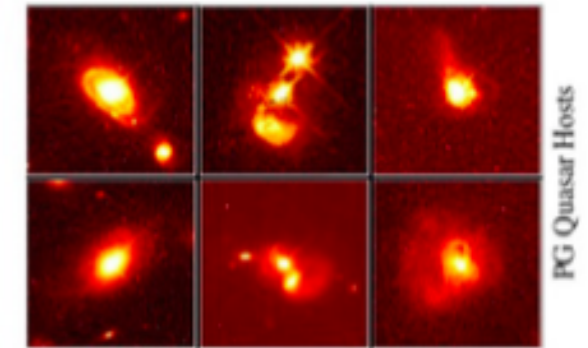
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(e) "Blowout"



- BH grows rapidly: briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO: recent/ongoing SF in host
- high Eddington ratios
- merger signatures still visible

(f) Quasar



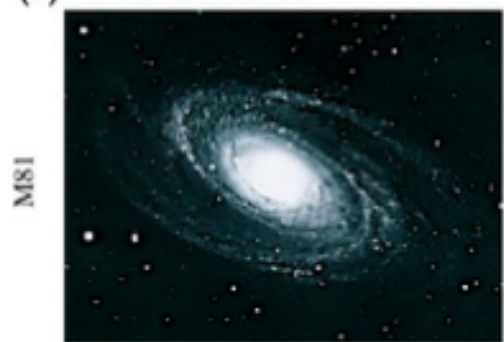
- dust removed: now a "traditional" QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

(b) "Small Group"

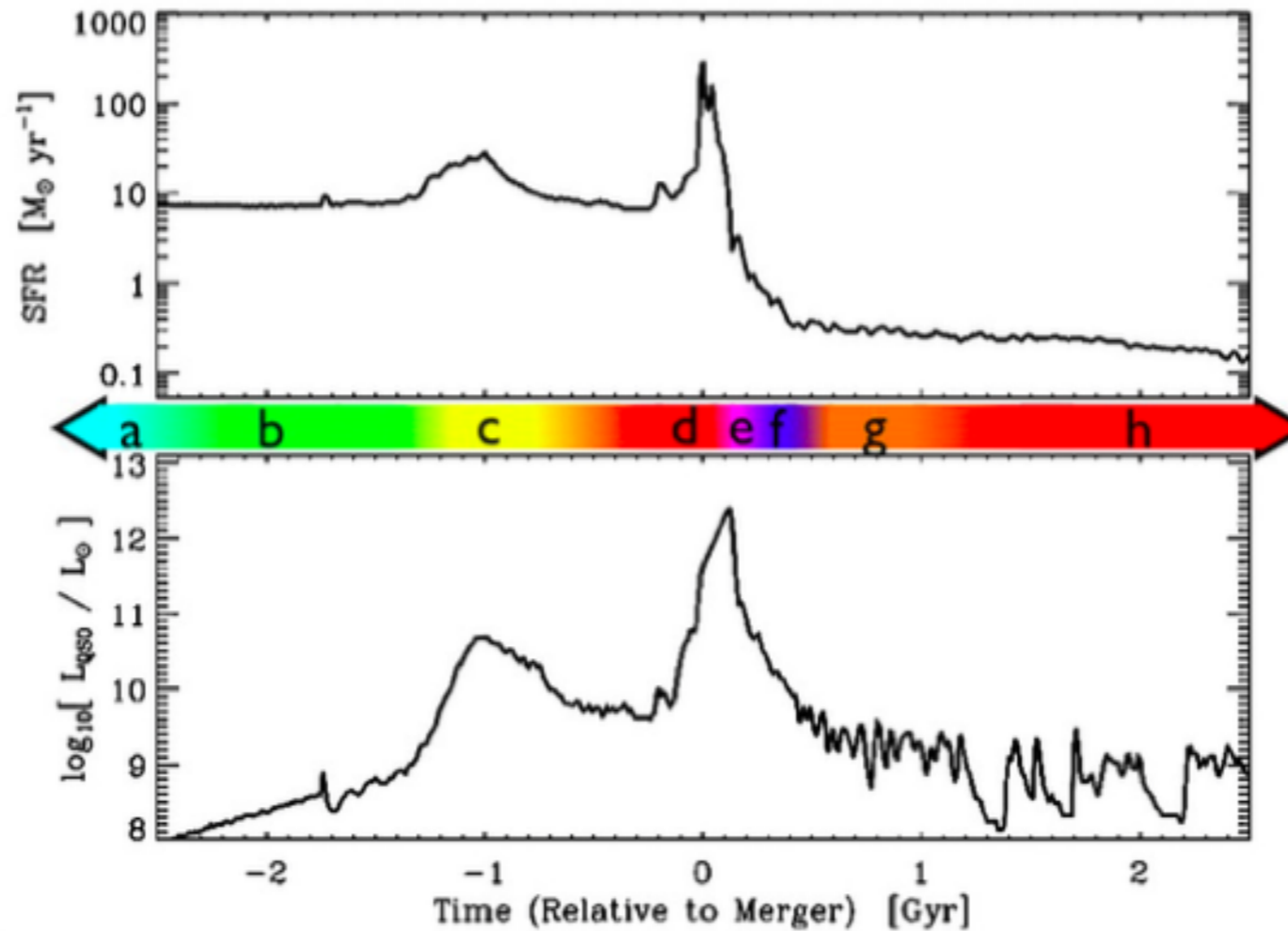


- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- M_{halo} still similar to before: dynamical friction merges the subhalos efficiently

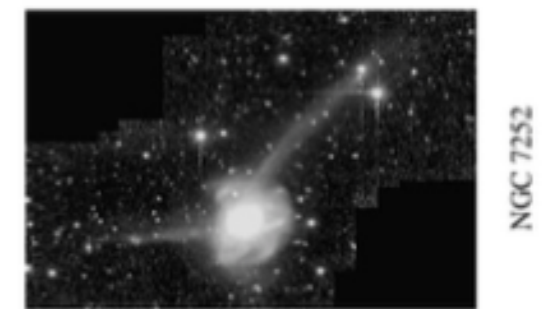
(a) Isolated Disk



- halo & disk grow, most stars formed
- secular growth builds bars & pseudobulges
- "Seyfert" fueling (AGN with $M_B > -23$)
- cannot redden to the red sequence



(g) Decay/K+A



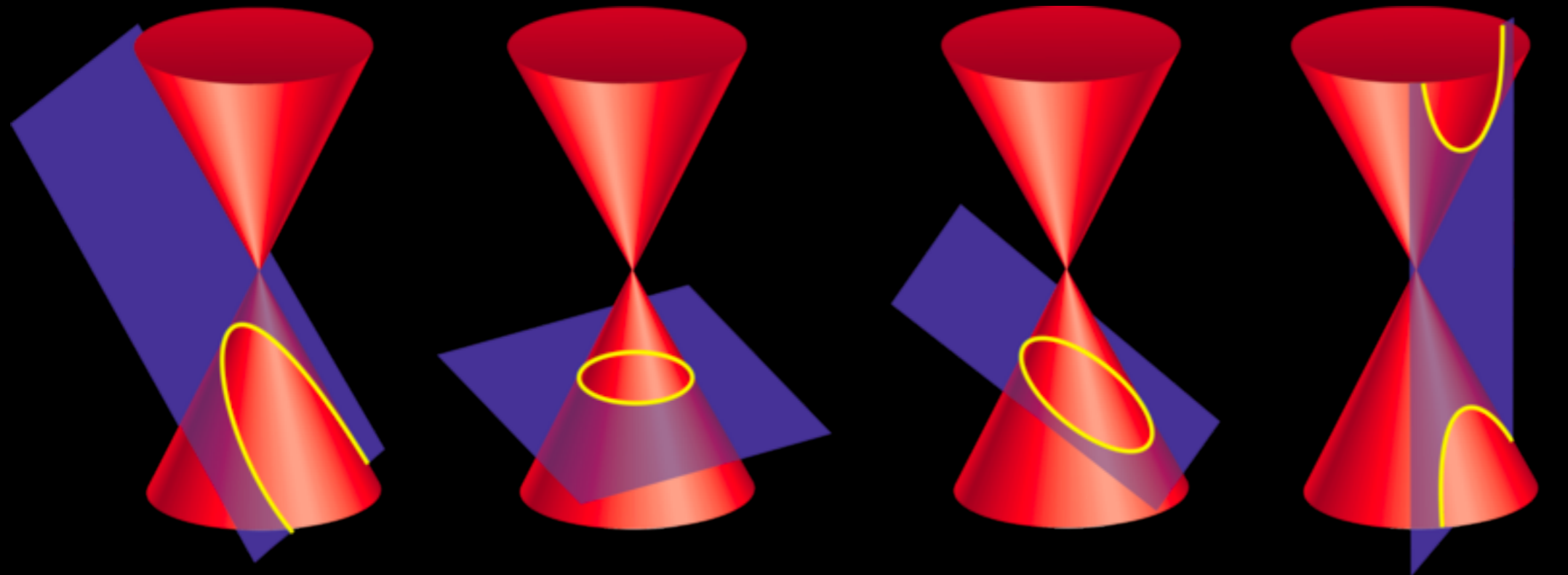
- QSO luminosity fades rapidly
- tidal features visible only with very deep observations
- remnant reddens rapidly (E+A/K+A)
- "hot halo" from feedback
- sets up quasi-static cooling

(h) "Dead" Elliptical



- star formation terminated
- large BH/spheroid - efficient feedback
- halo grows to "large group" scales: mergers become inefficient
- growth by "dry" mergers

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



parabola

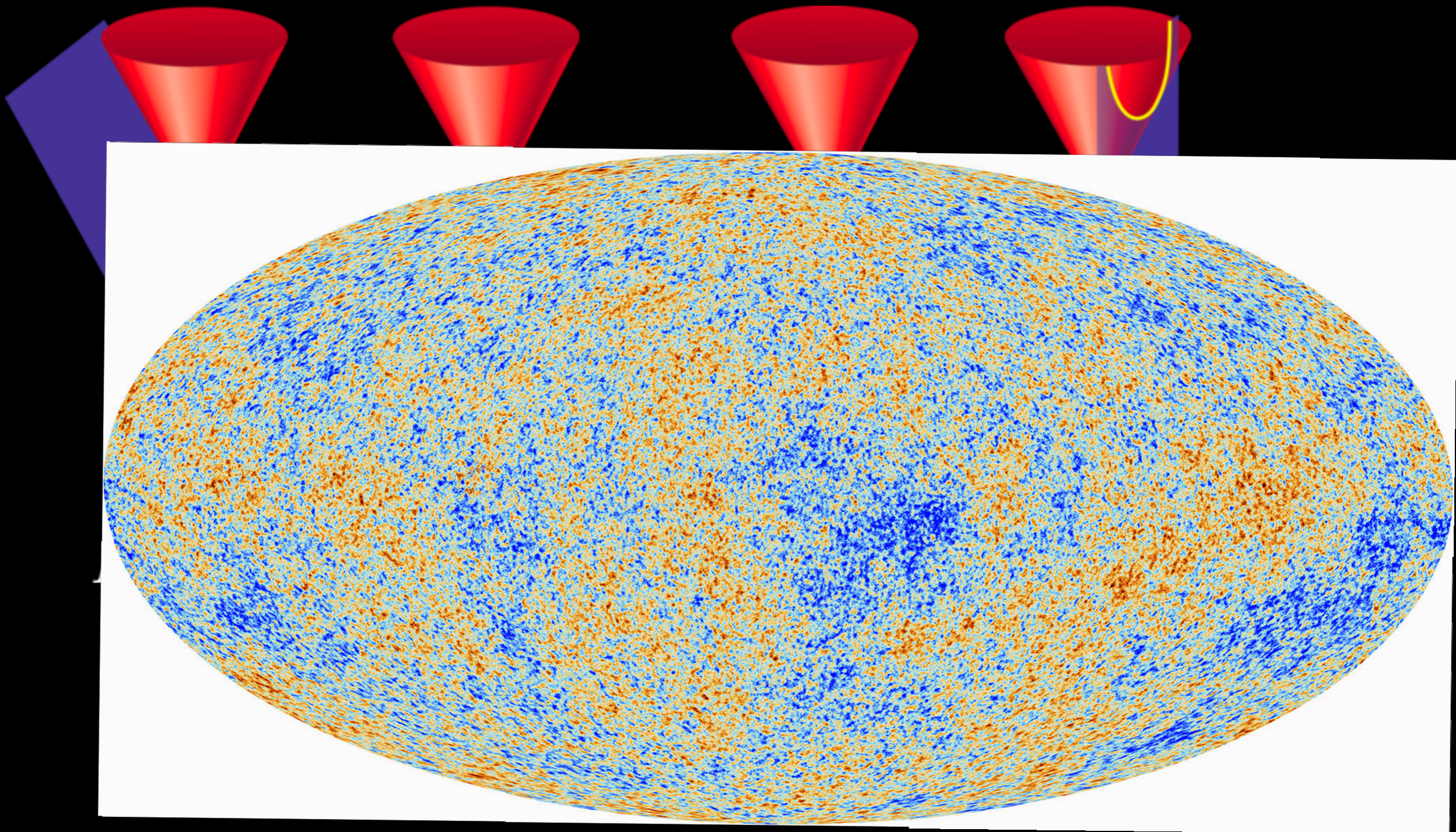
circle

ellipse

hyperbola

$$E = \frac{1}{2}\mu \left(\frac{dr}{dt} \right)^2 + \frac{1}{2} \frac{L^2}{\mu r^2} - \frac{GM_{\text{halo},1} M_{\text{halo},2}}{r}$$

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 $M_* \sim 10^{10} M_{\text{sun}}$.

Illustris resolution

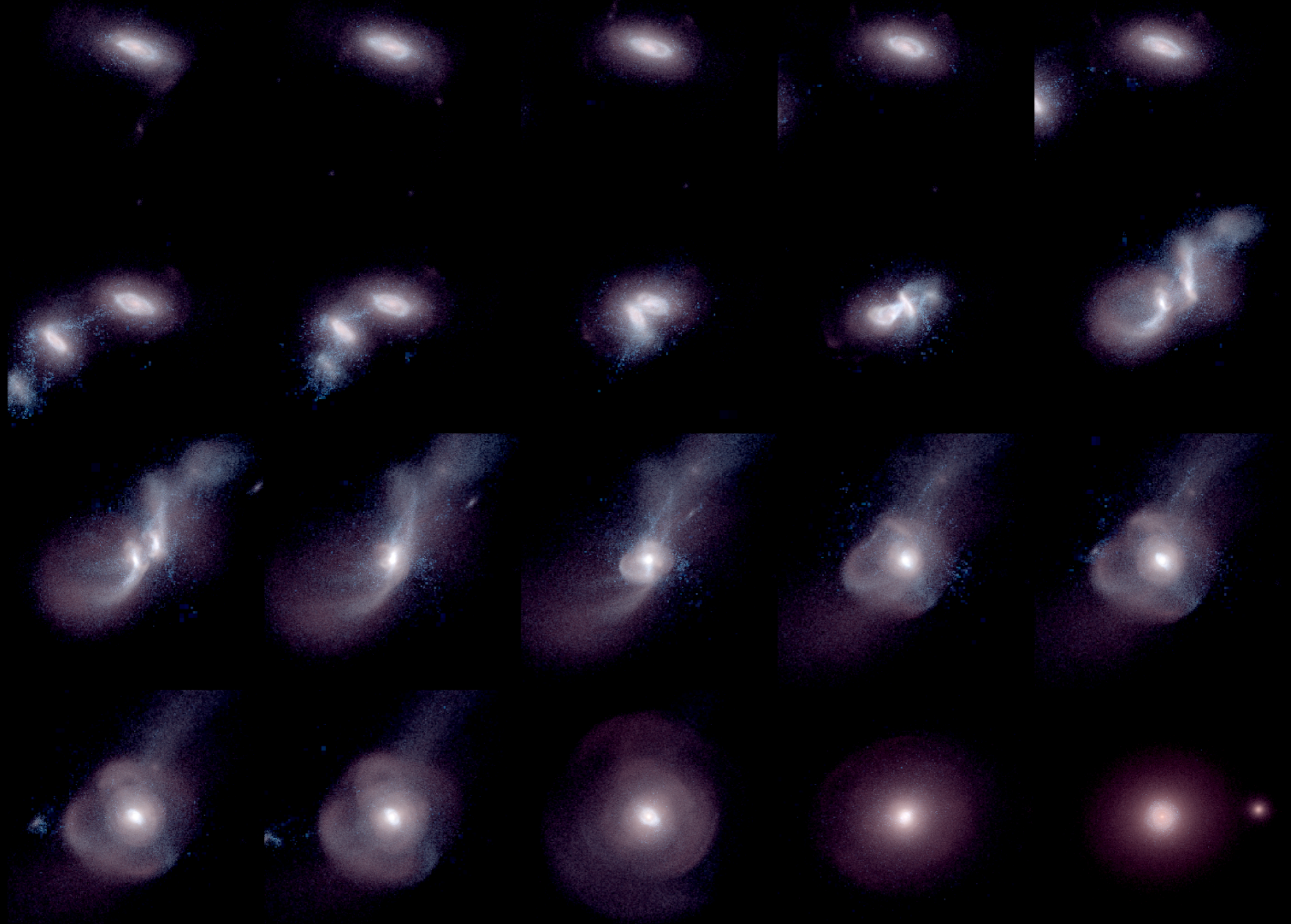


10 x Illustris

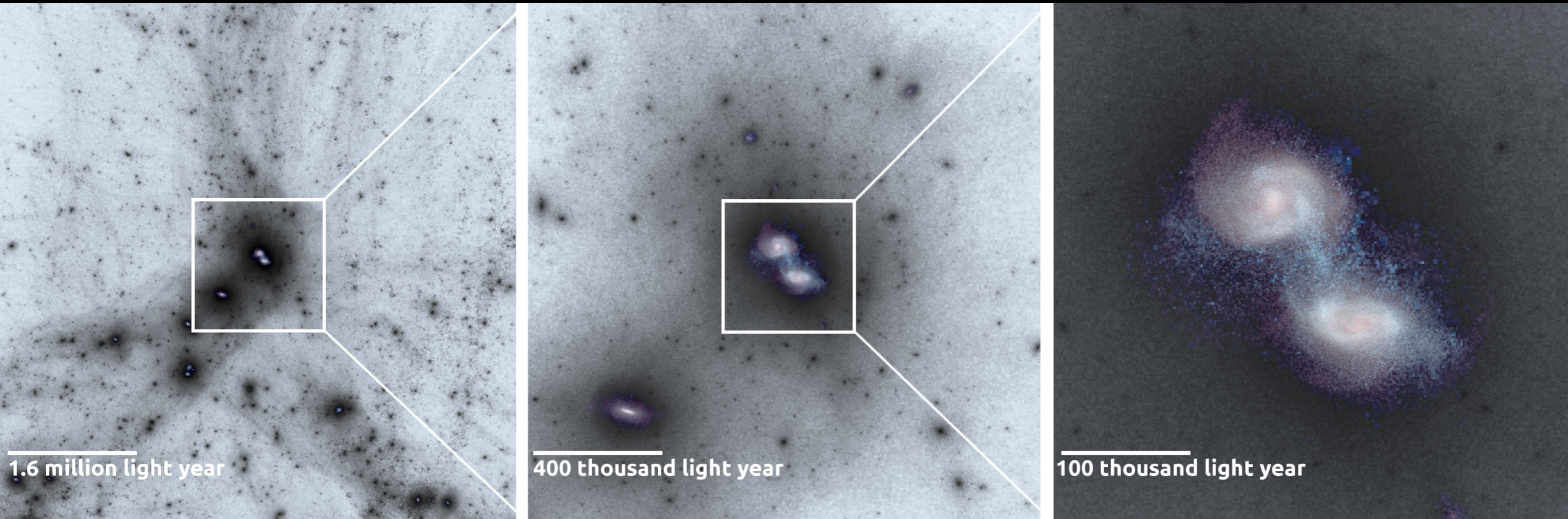


40 x Illustris





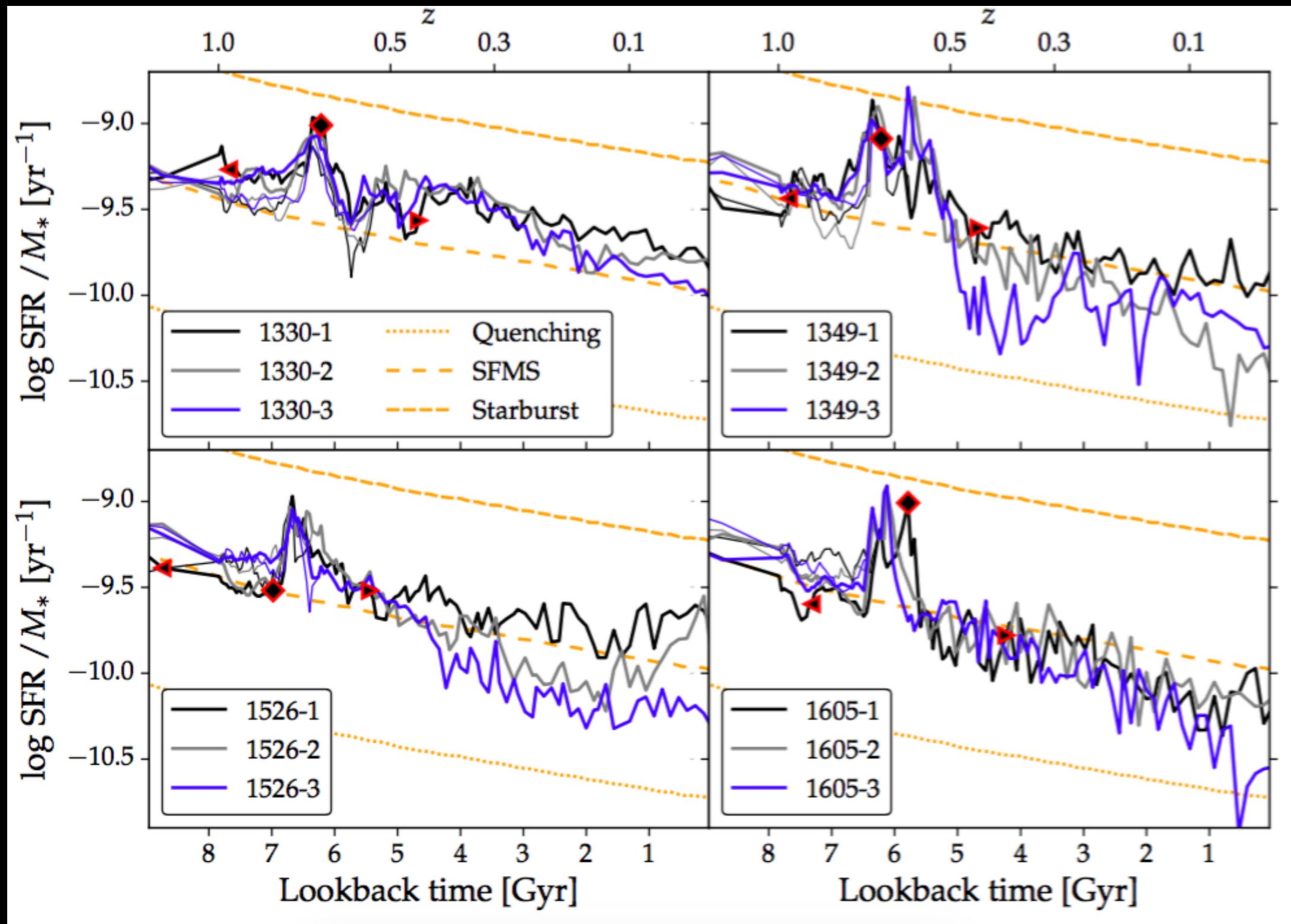
The cosmological structure around mergers



With cosmological merger simulations we can model:

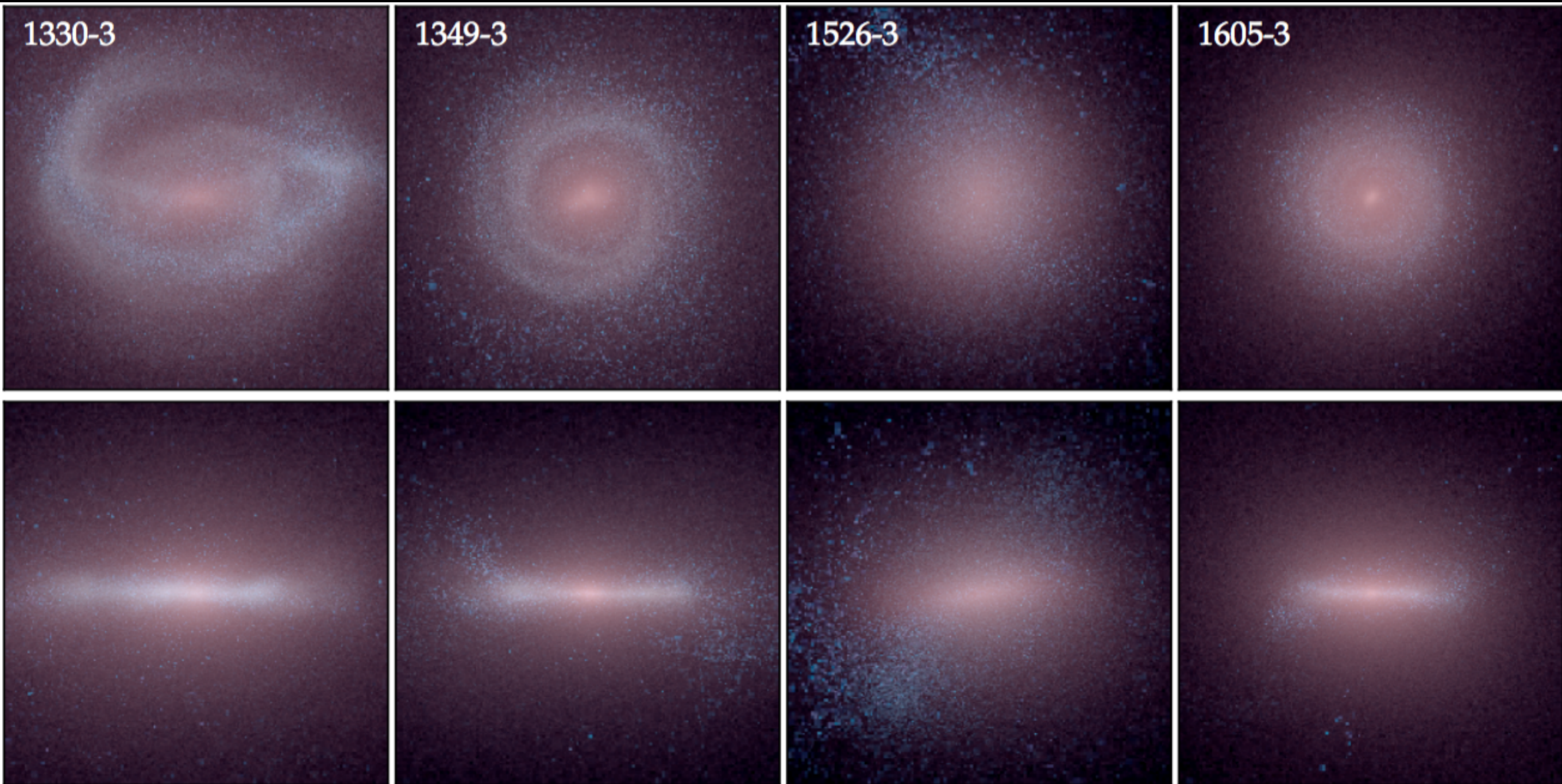
- rejuvenation of merger remnants.
- the circumgalactic medium.

Merger remnants are star-forming!



Rejuvenation of merger remnants.

Merger remnants at $z = 0$

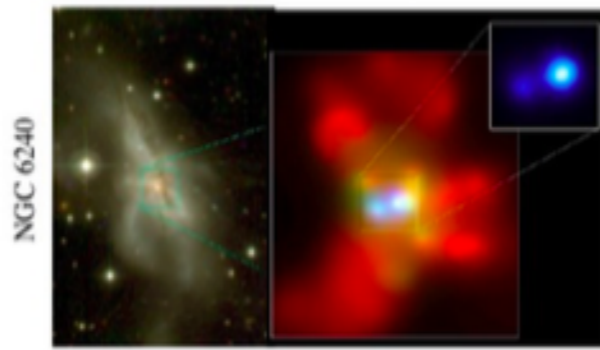


(c) Interaction/"Merger"



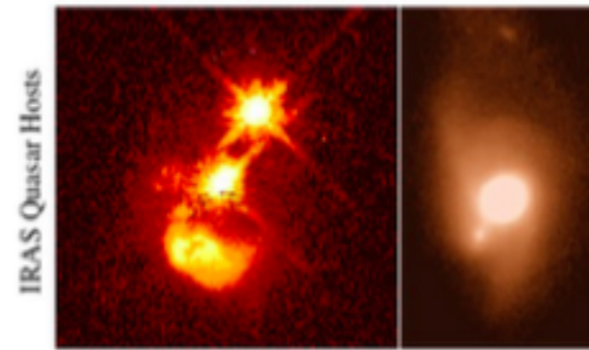
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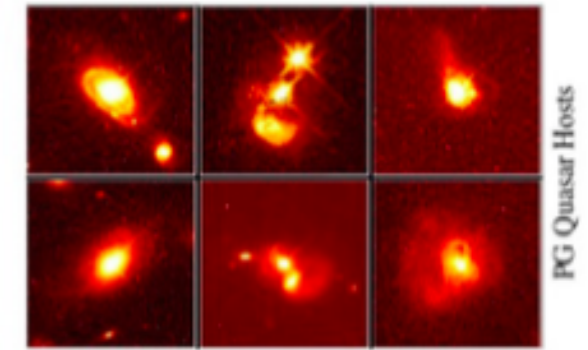
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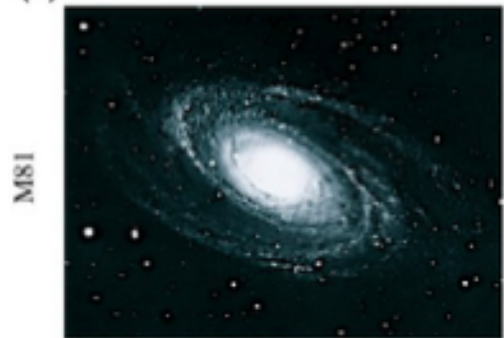
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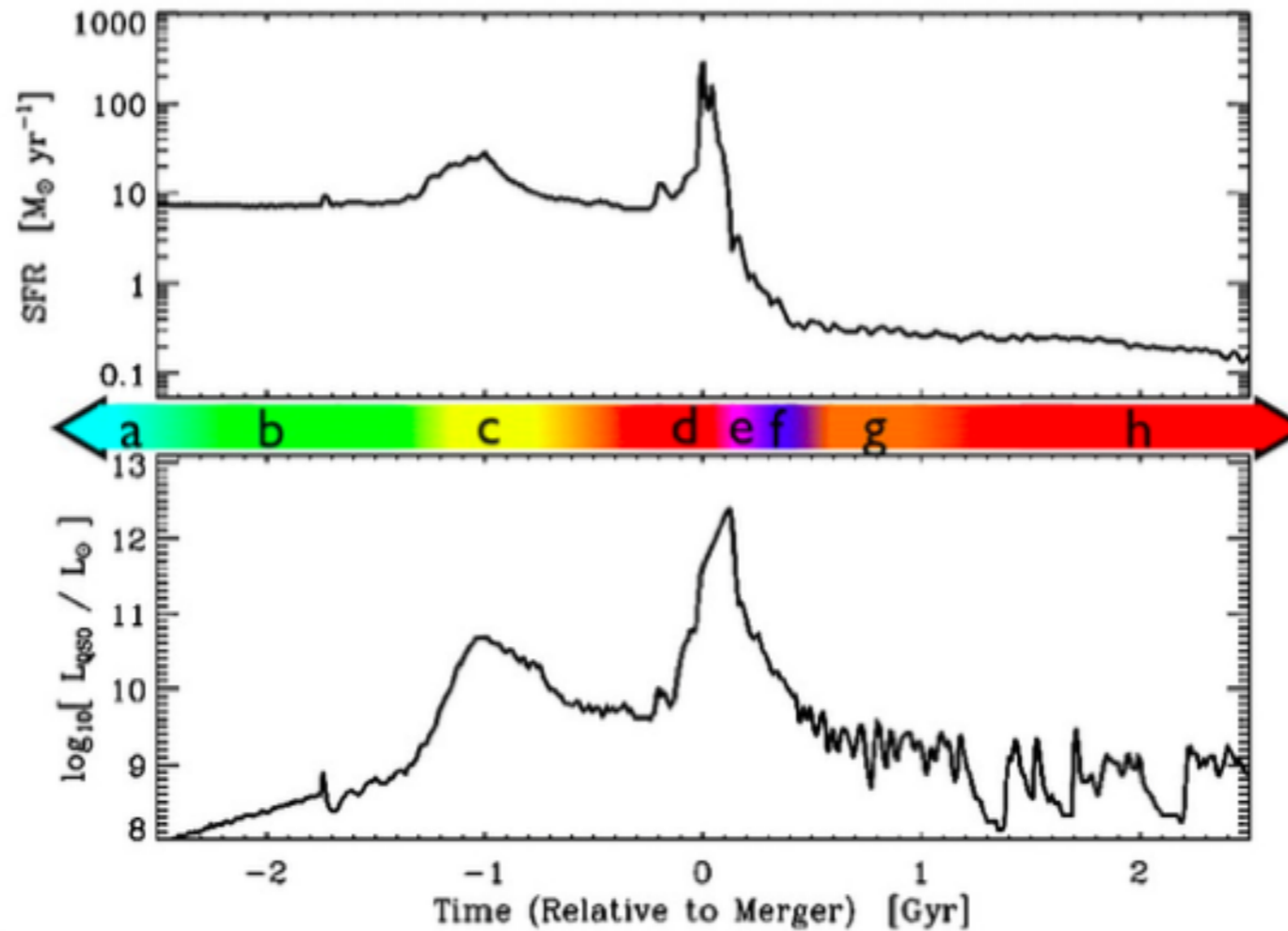


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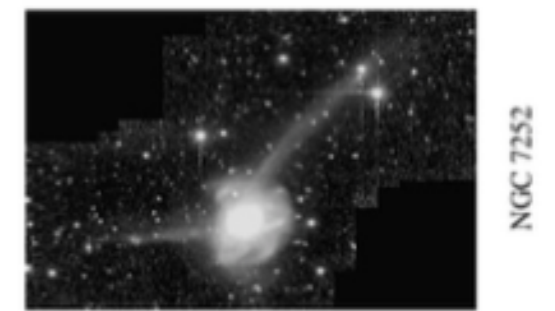
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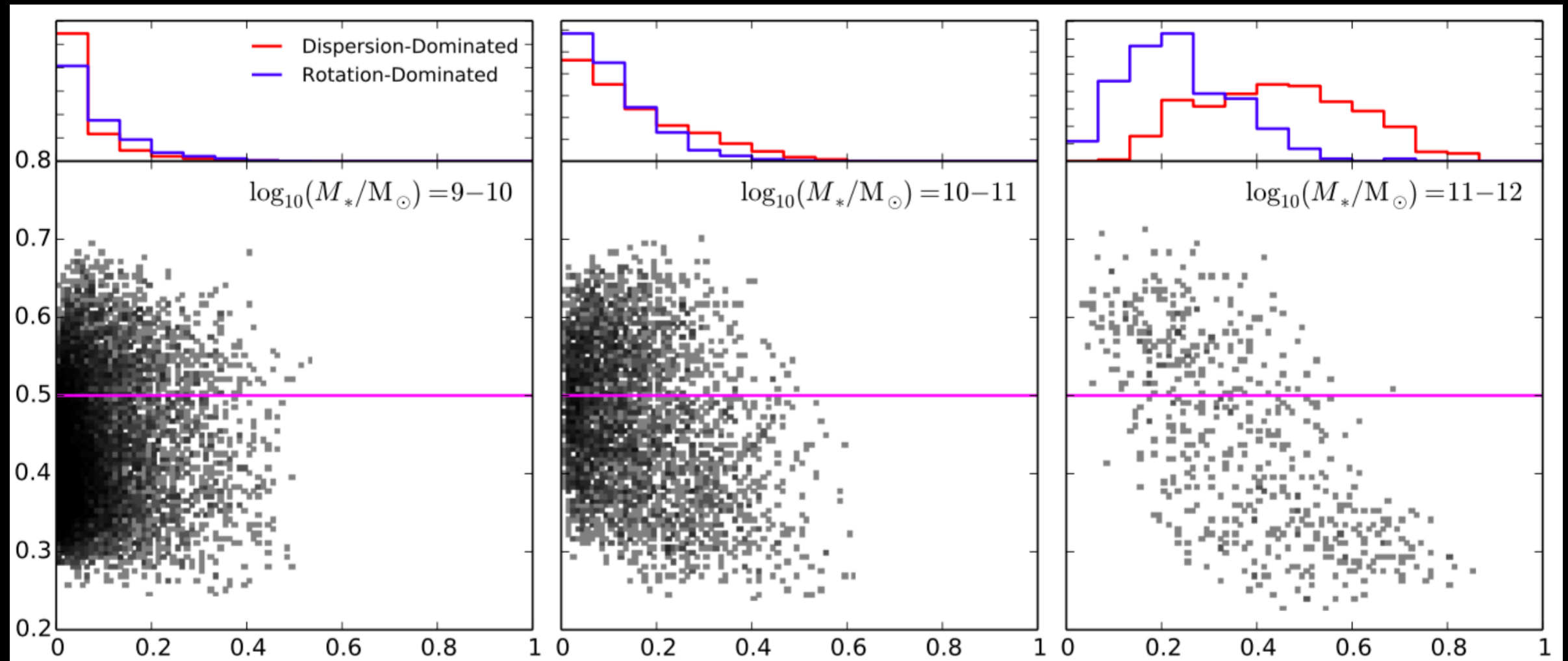
(h) "Dead" Elliptical



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Mergers in the Illustris simulation

Stellar disk fraction



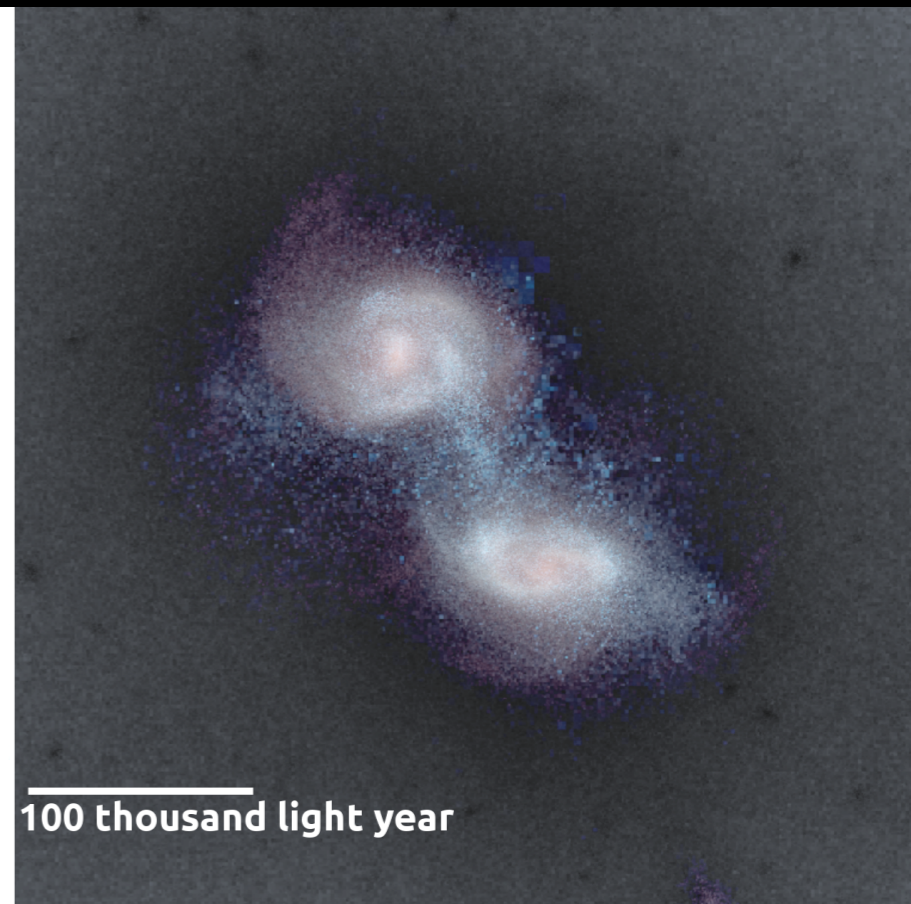
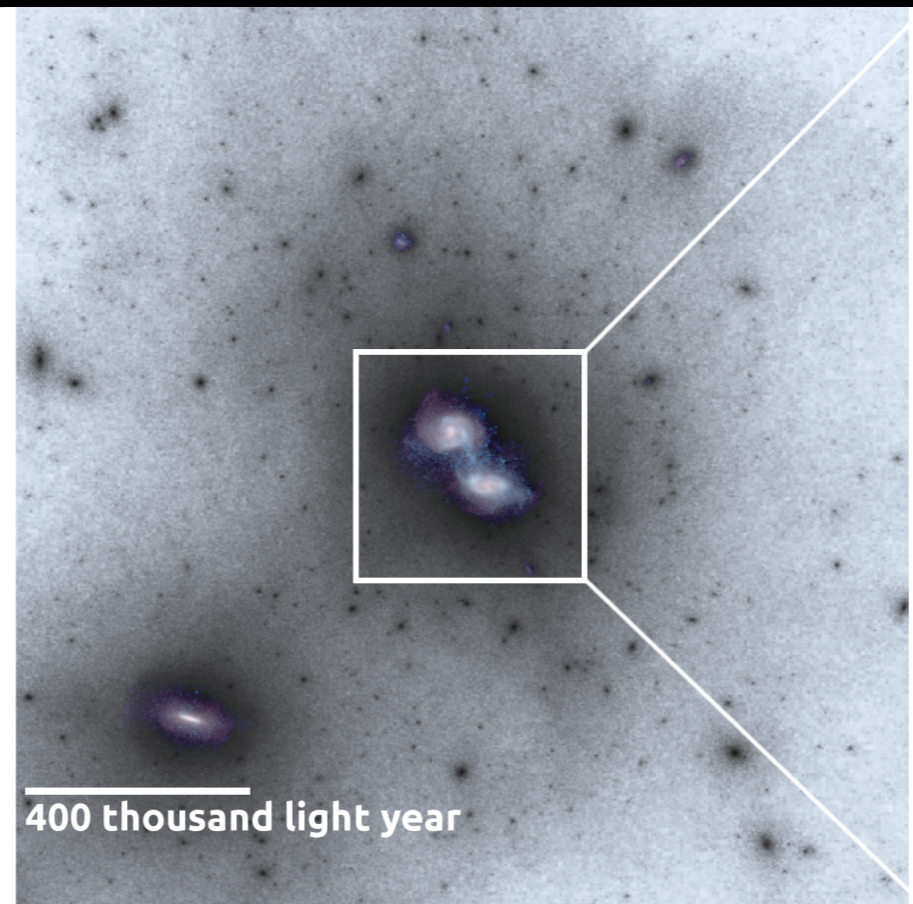
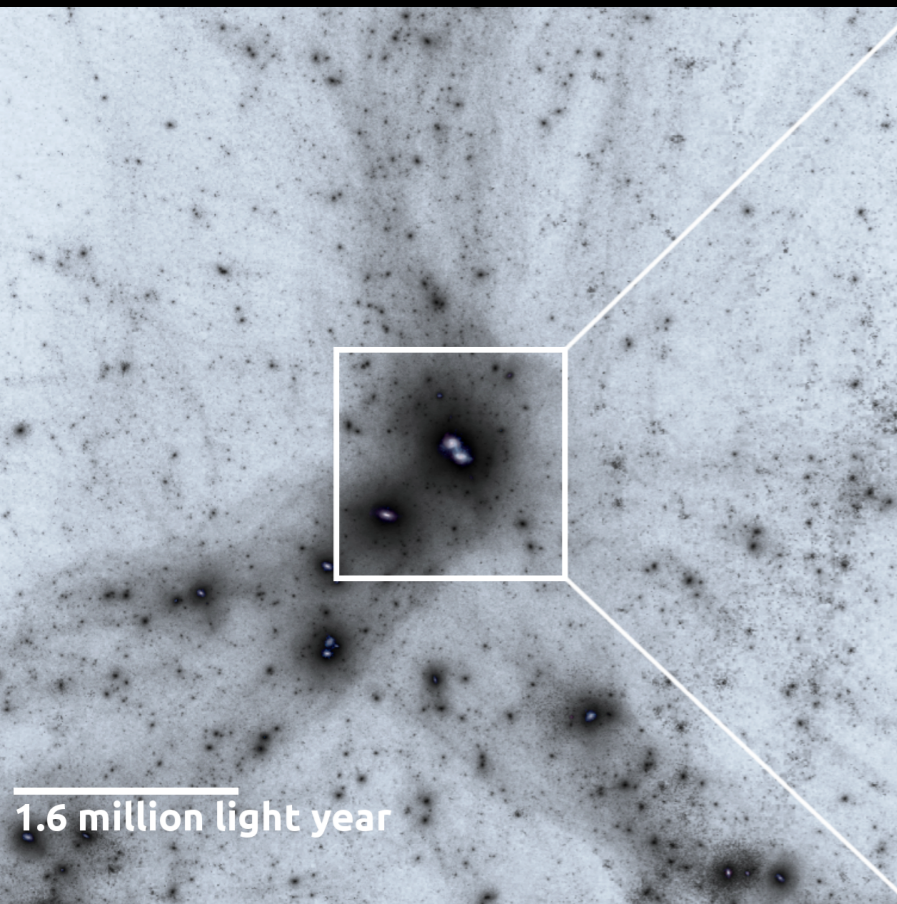
In-situ fraction

Mergers only destroys disks for massive galaxies.

The CGM

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

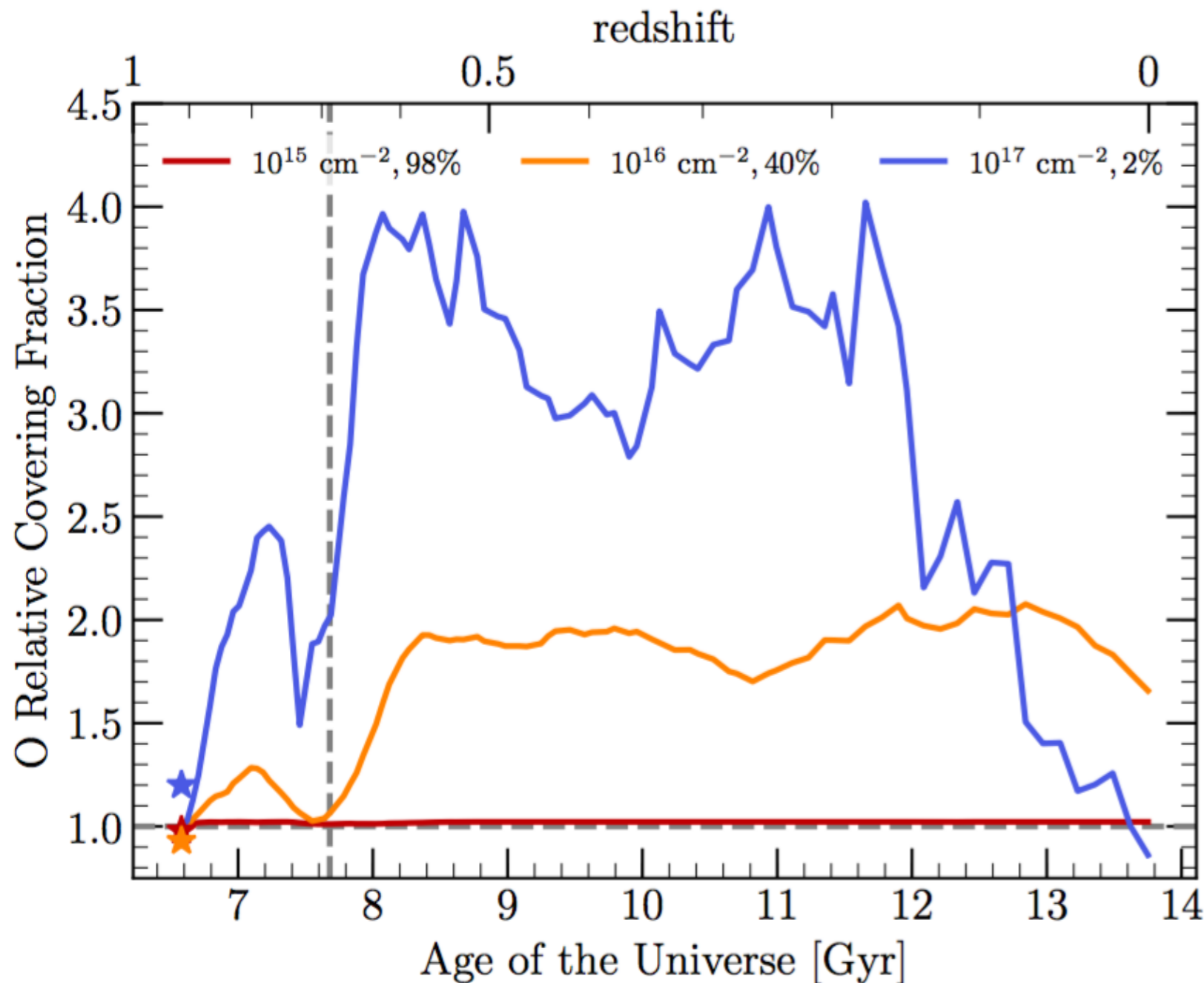
Maan H. Hani,^{1*}† Martin Sparre,^{2,3,4} Sara L. Ellison,¹ Paul Torrey,⁴ Mark Vogelsberger⁴



The CGM

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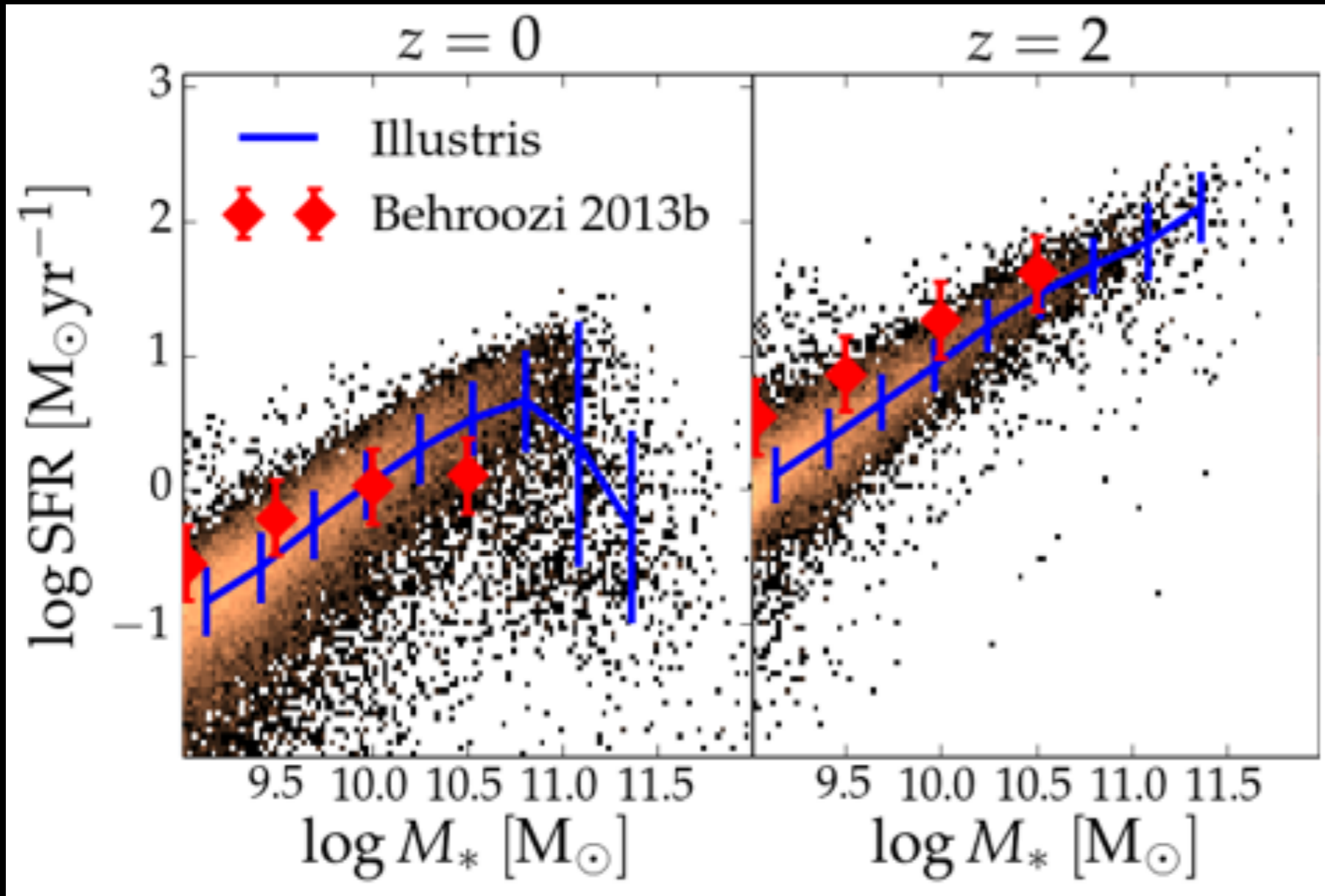
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Oxygen is enriched several Gyr after the merger. The CGM has a long memory about the merger history.

Starbursts in cosmological simulations

The main sequence in Illustris

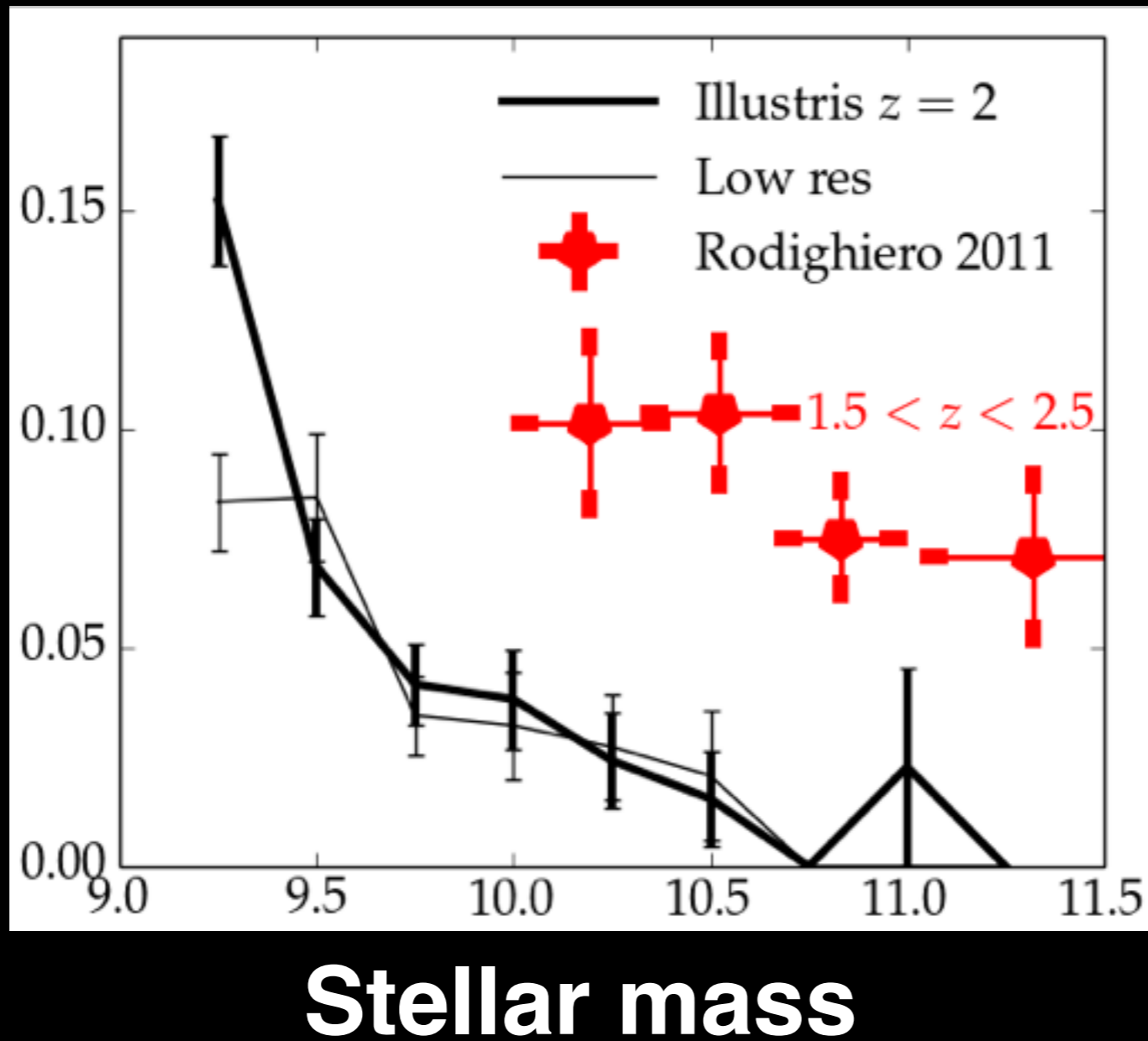


MS+2015

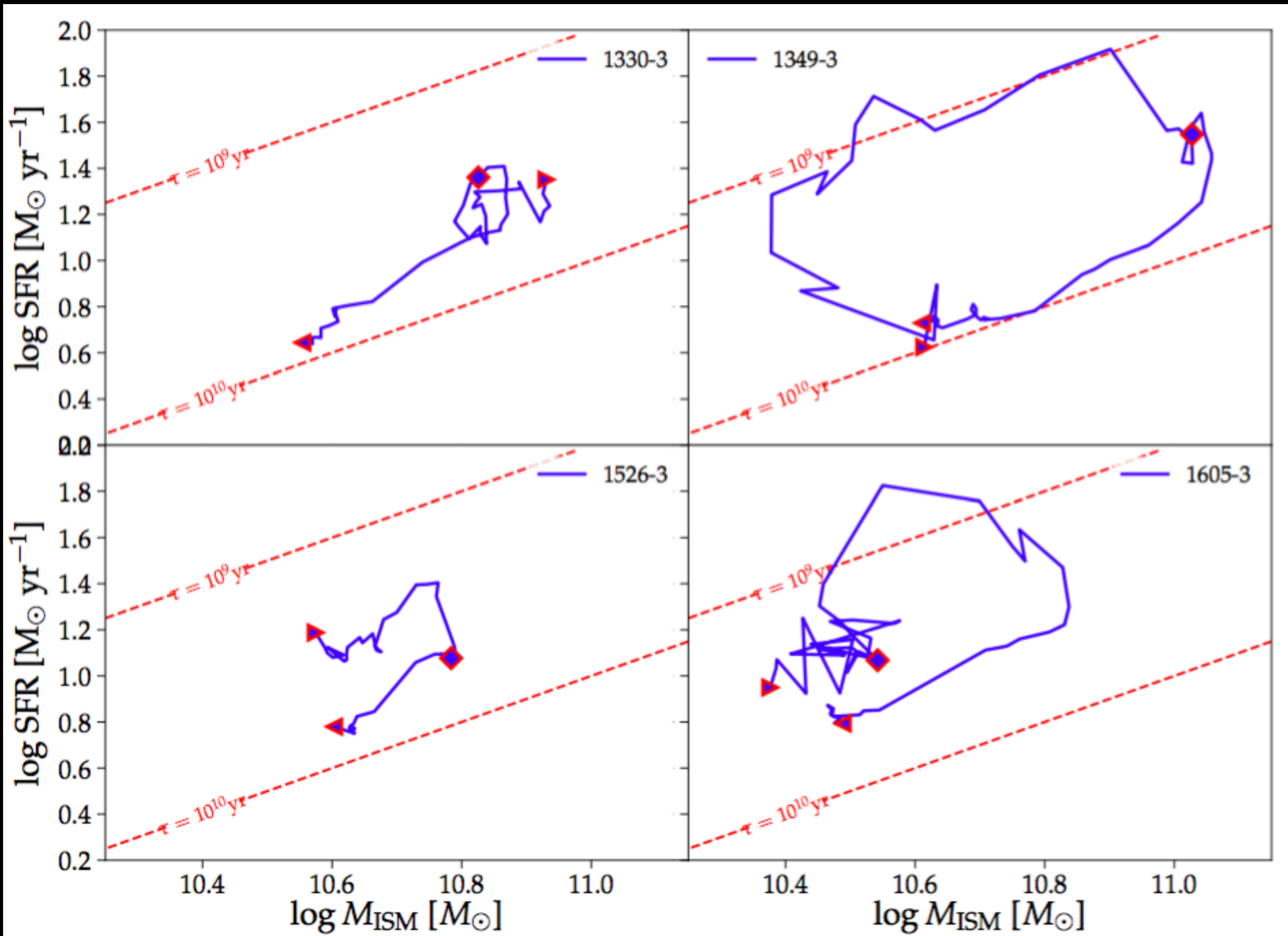
A similar reproduction of the Main Sequence is seen in Donnari 2019 (for Illustris TNG), Furlong 2015 (EAGLE), Kaviraj 2017 (Horizon-AGN)

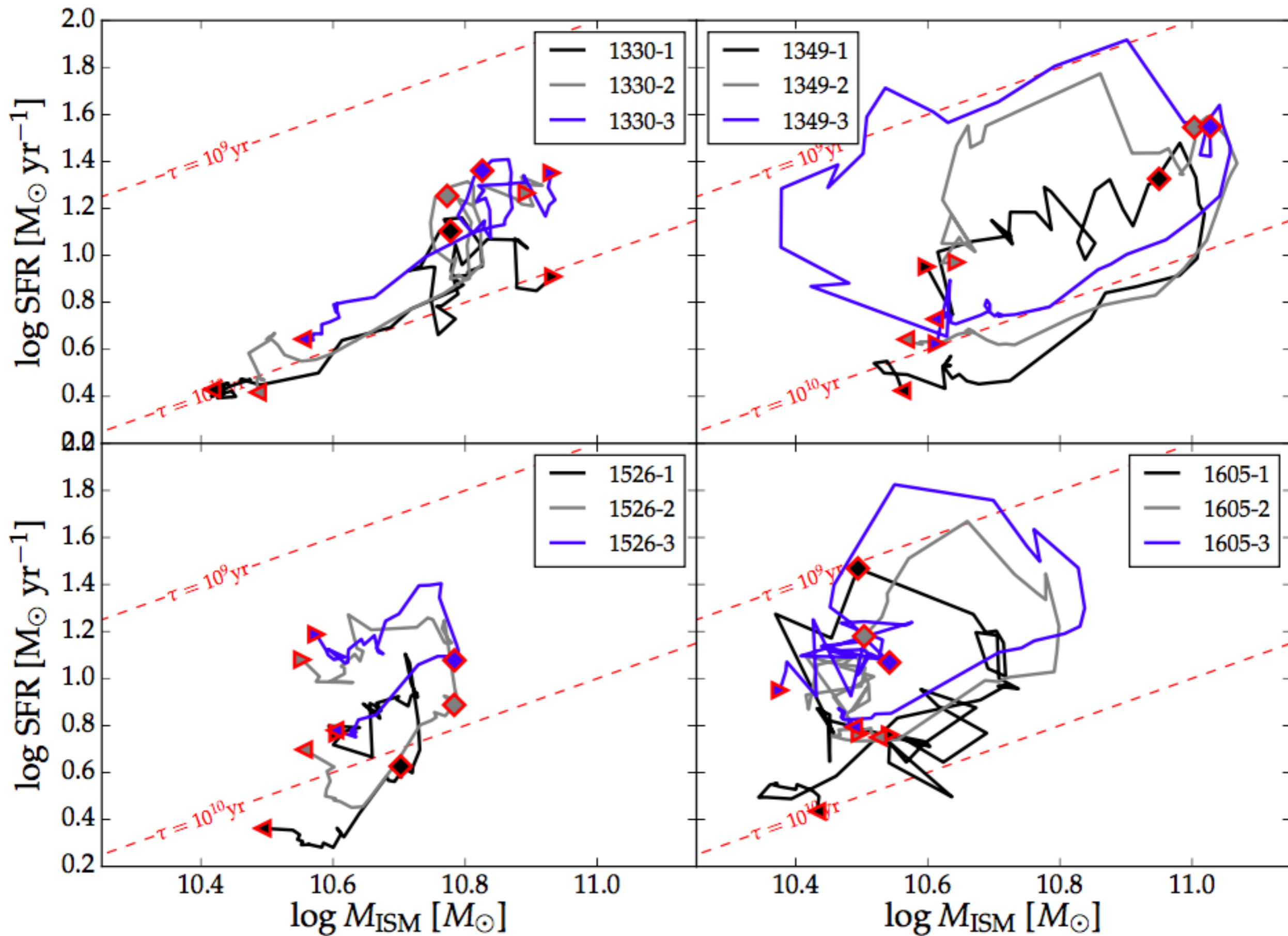
The lack of starbursts in Illustris

Fraction of SFR in starbursts



MS+2015





Submm galaxies in Illustris TNG

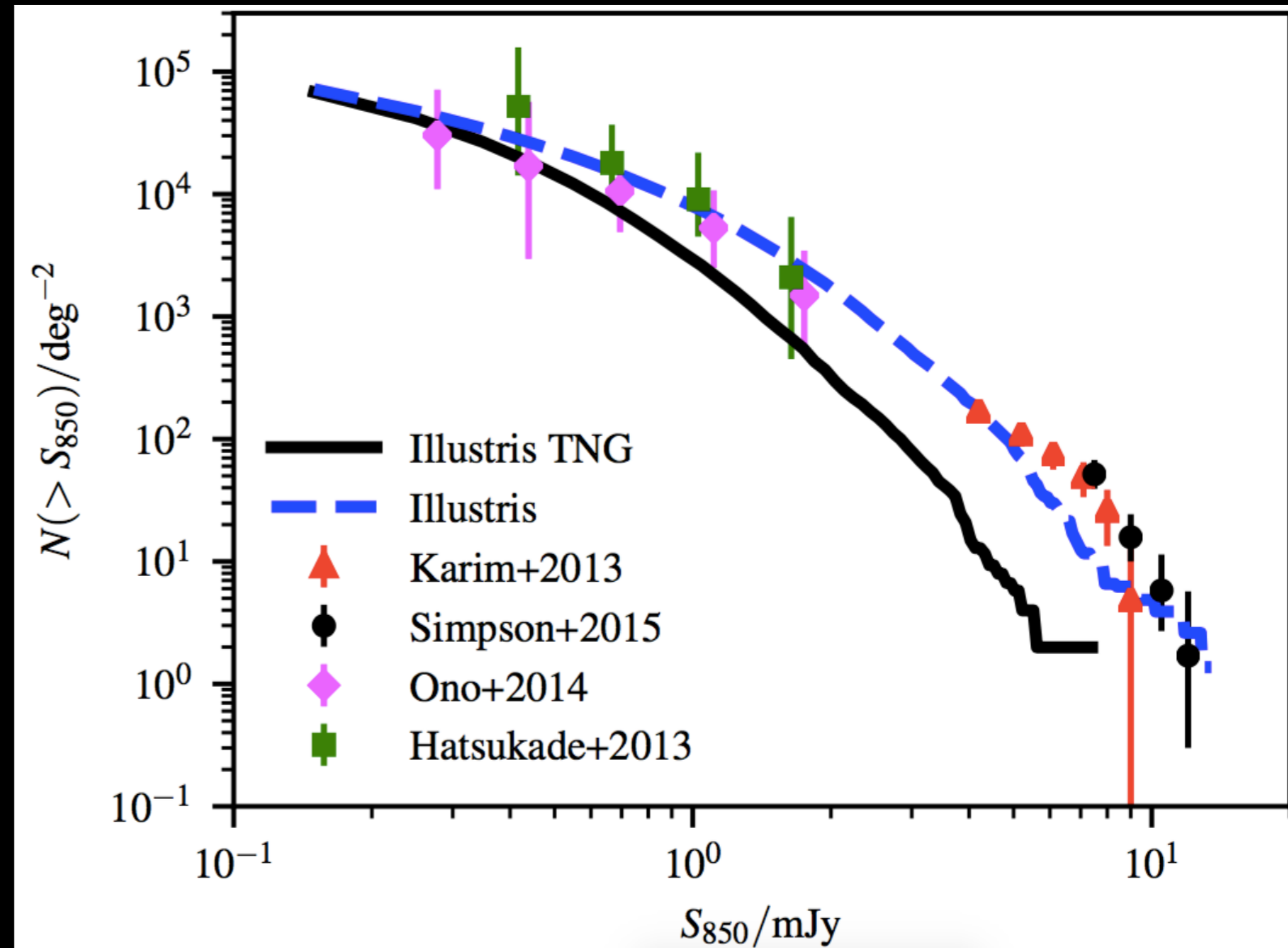
Submillimetre galaxies in cosmological hydrodynamical simulations – an opportunity for constraining feedback models

Christopher C. Hayward^{1*}, Martin Sparre^{2,3,4}, Lars Hernquist⁵, Dylan Nelson⁶, Rüdiger Pakmor^{6,7}, Annalisa Pillepich⁸, Volker Springel⁶, Paul Torrey⁹, Mark Vogelsberger⁴, and Rainer Weinberger⁵

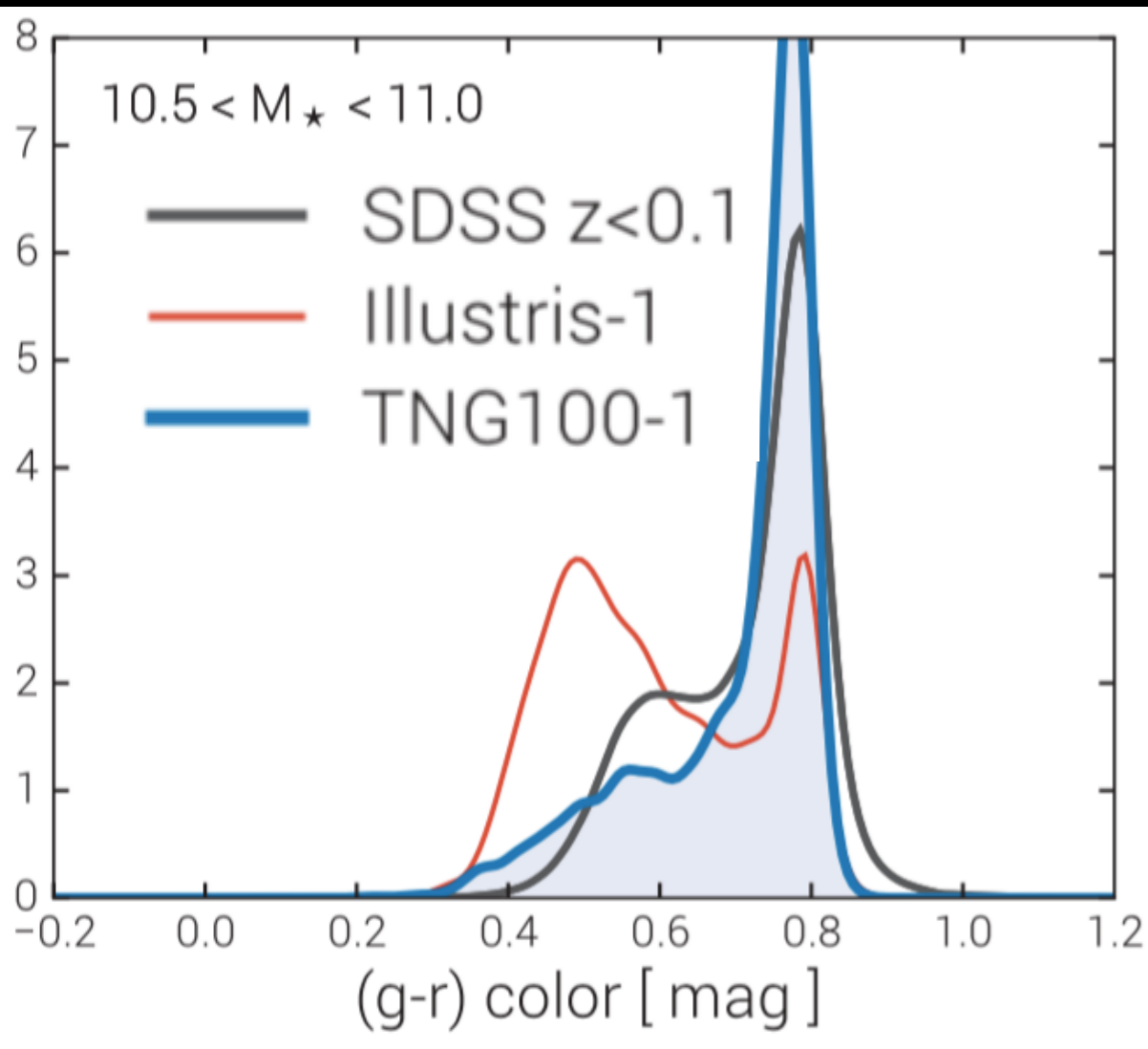
- Illustris TNG lacks a populations of bright submm-galaxies. AGN feedback quenches galaxies before they reach $S \sim 10$ mJy.

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

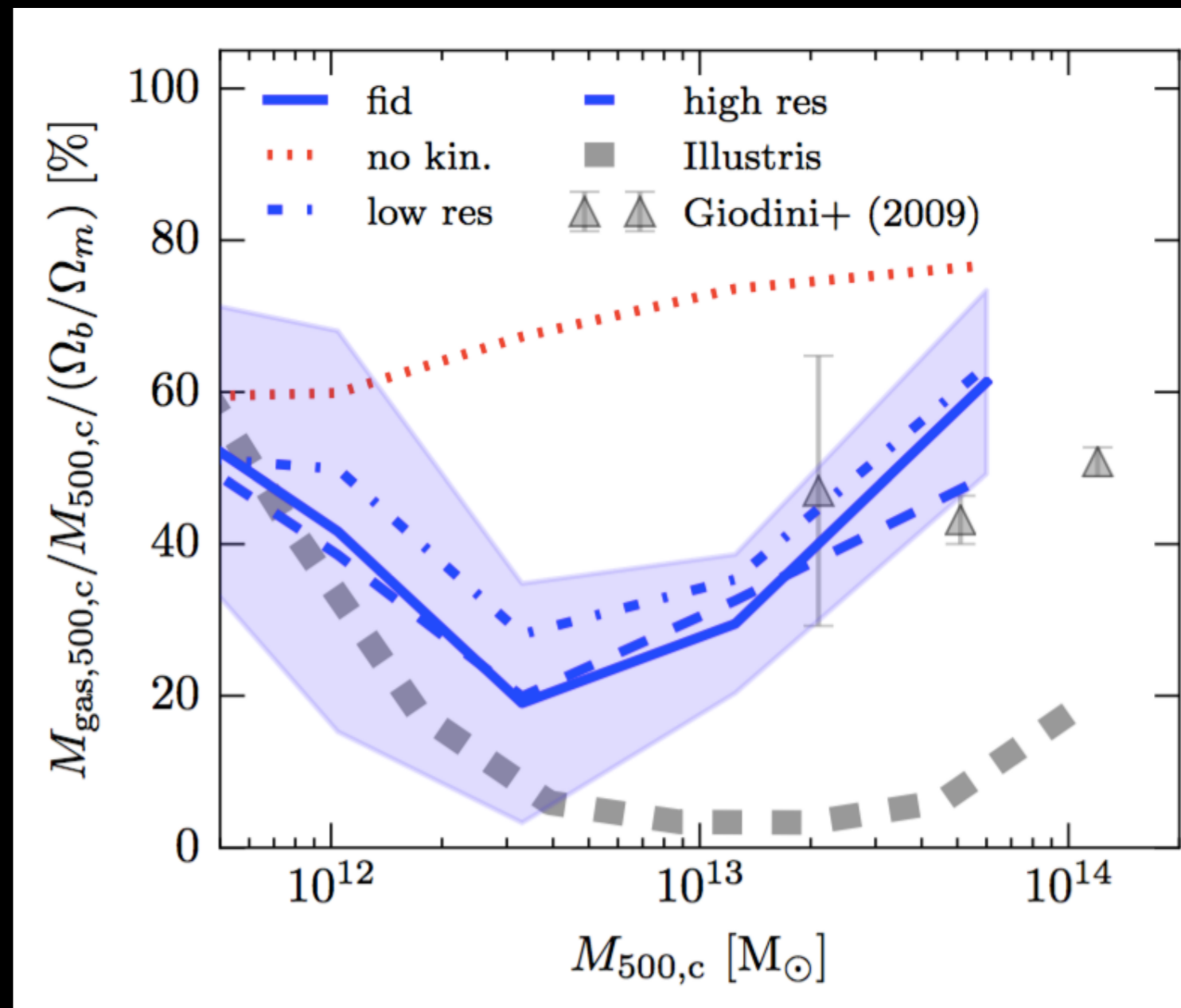
$$\frac{S_{850}}{[\text{mJy}]} = 0.81 \left(\frac{\text{SFR}}{100 [\text{M}_{\odot} \text{yr}^{-1}]} \right)^{0.43} \left(\frac{M_{\text{dust}}}{10^8 [\text{M}_{\odot}]} \right)^{0.54}$$



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



Nelson et al. 2018



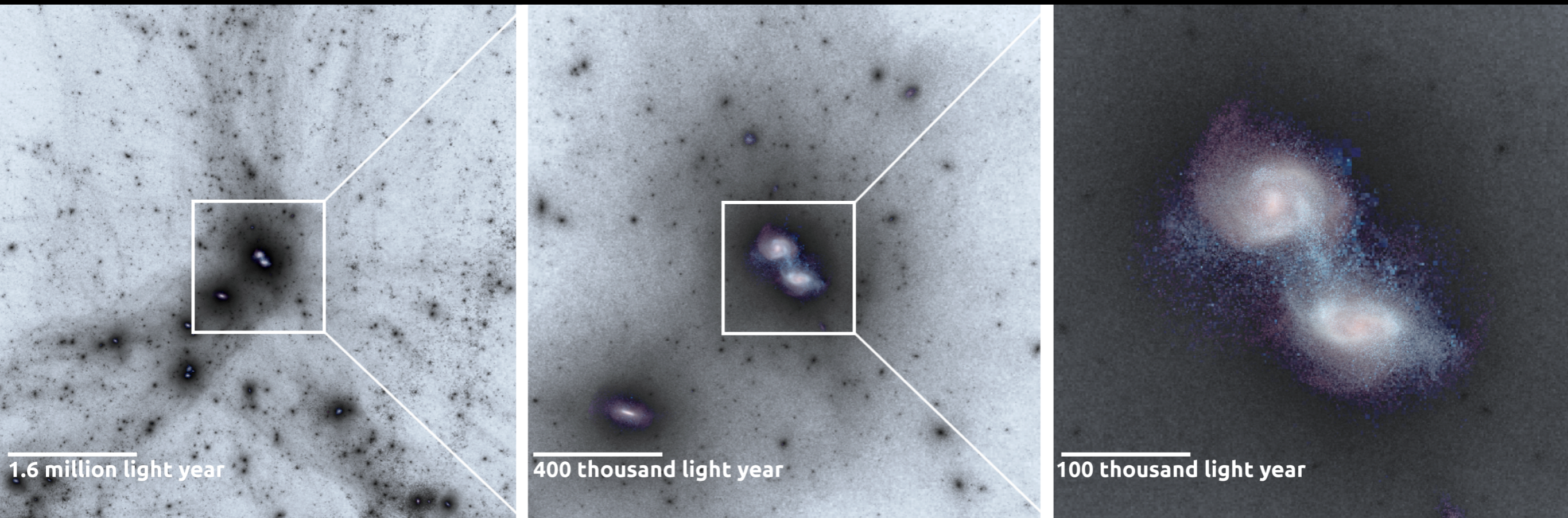
Weinberger et al. 2017

Open questions

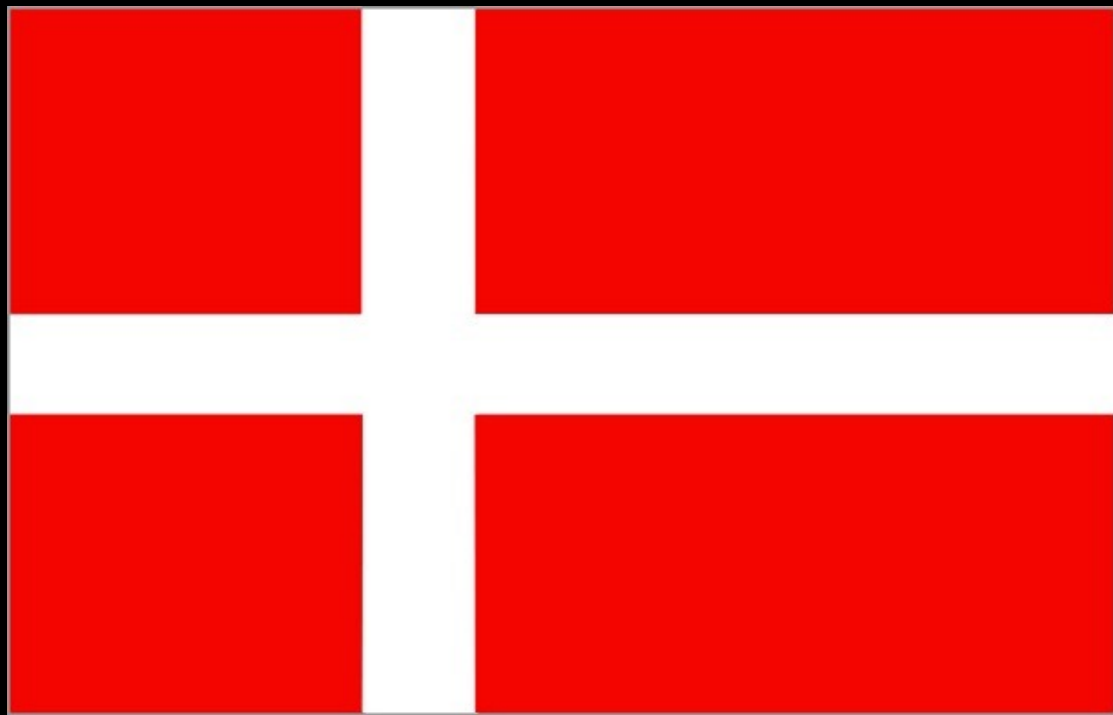
- How can we improve AGN models, so they can reproduce high submm-counts?
- Do major mergers quench galaxies? Previous simulations have overestimated the effect of mergers.

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.



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



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European Research Council under ERC-
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