# A Song of Fire and Feedback

# Quenching Galaxies with Large-Scale AGN Driven Winds


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**Priya Natarajan (Yale),**
**Urmila Chadayammuri (Yale),**
**Angelo Ricarte (Yale),**
**Nina Roth (AIA),**
**Hiranya V. Peiris (UCL),**
**Amélie Saintonge (UCL)**
**Nicole Sanchez (UW)**




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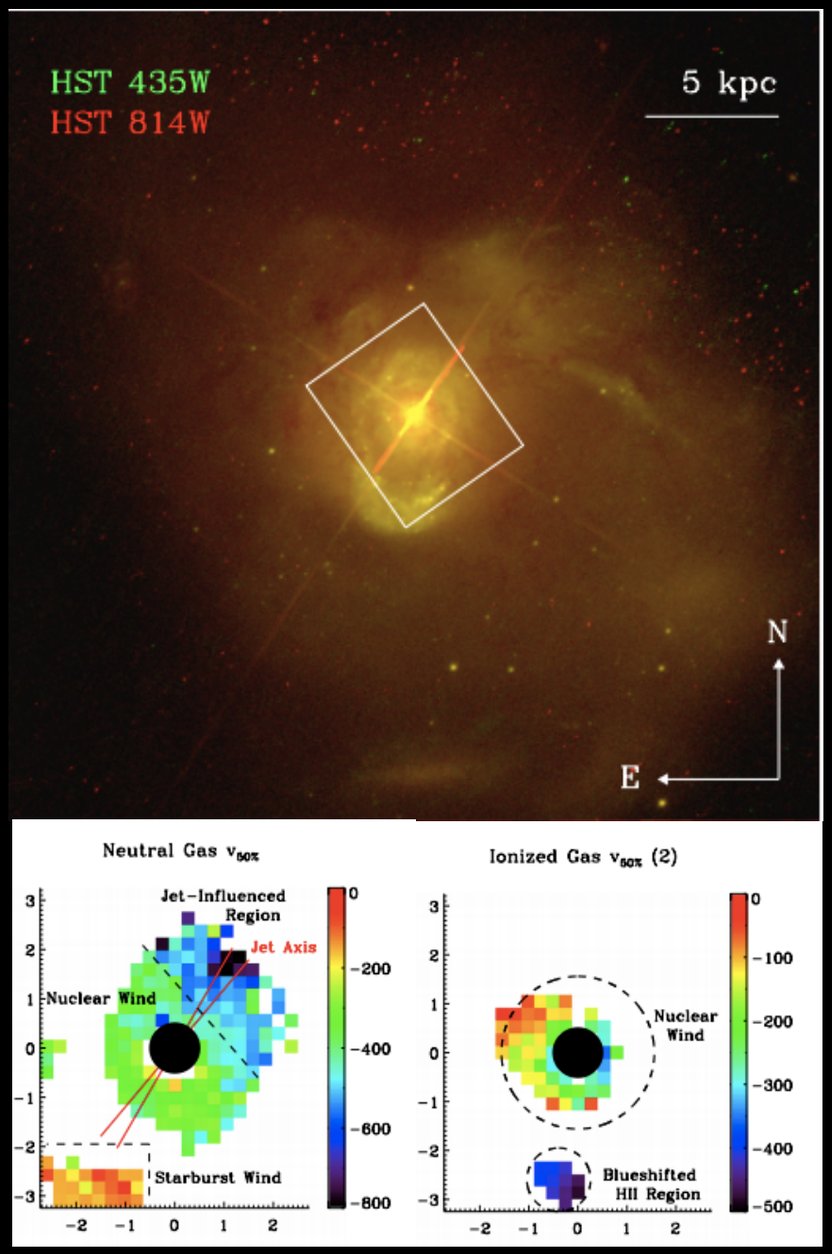
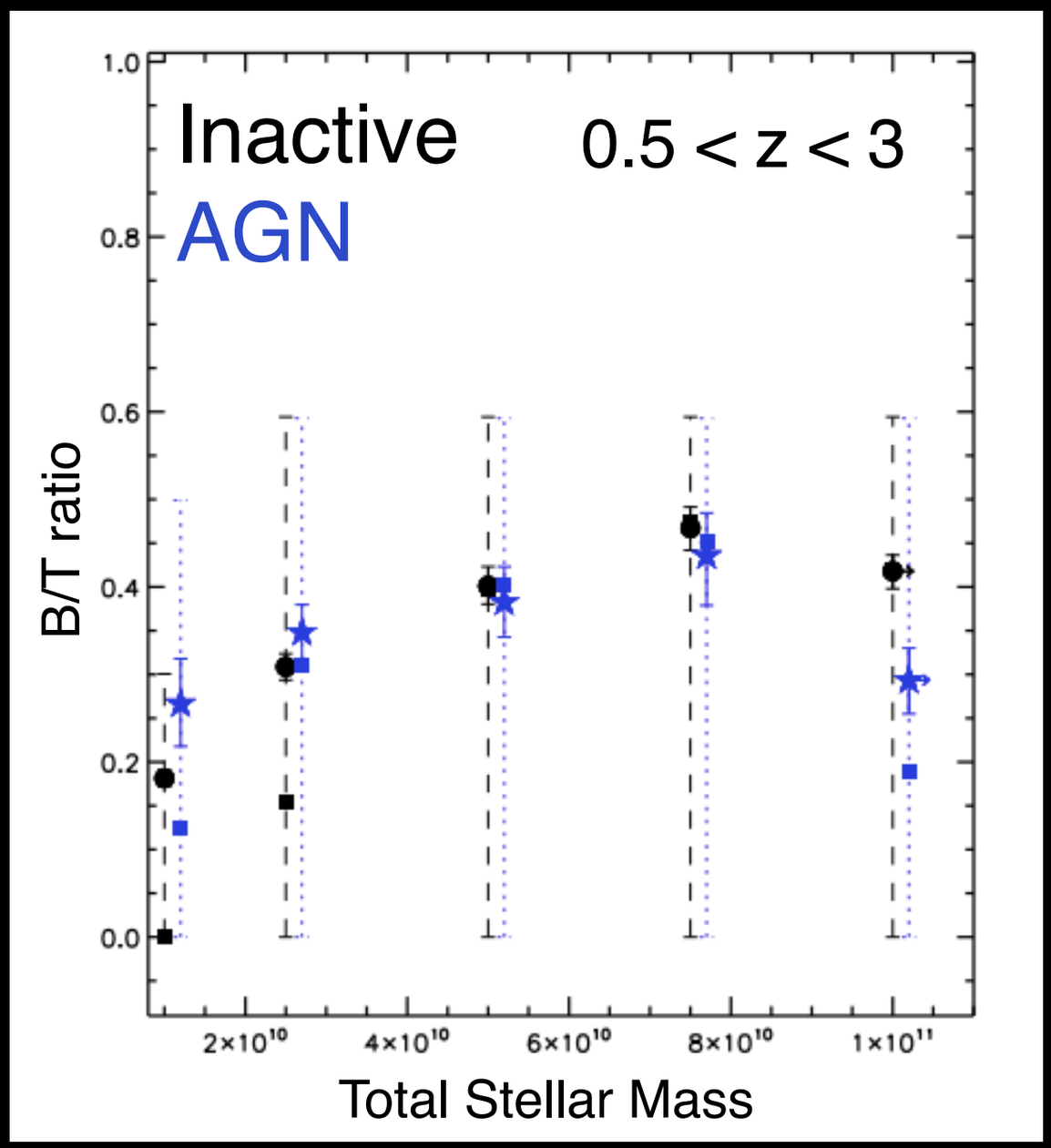
SUSTAINED PETASCALE COMPUTING

# AGN and Quenching

# How does AGN feedback regulate star formation in massive galaxies?




Rupke & Veilleux 2011

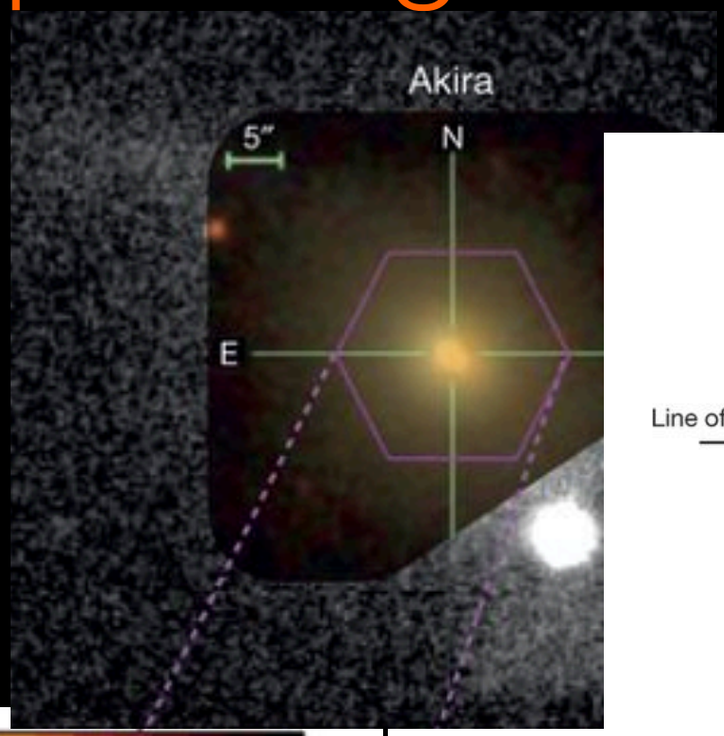



Bruce+ 2016

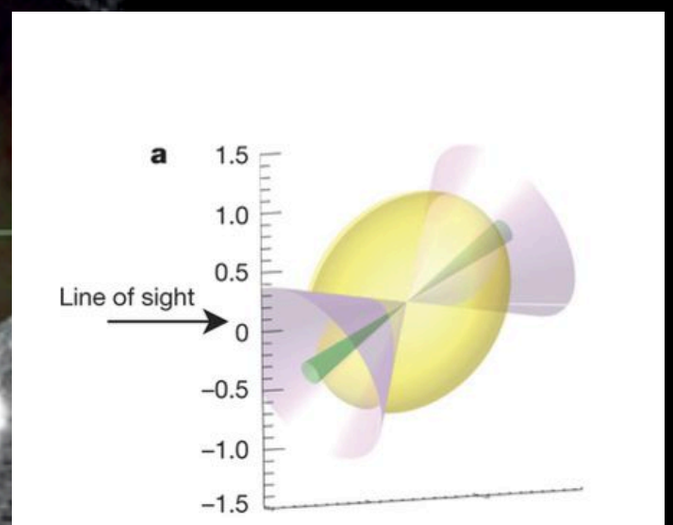
See Also:
Cisternas+ 2011;
Schawinski+ 2012;
Rosario+ 2013,2015;
Villforth+ 2014;
Forster Schreiber+ 2014

# AGN and Quenching

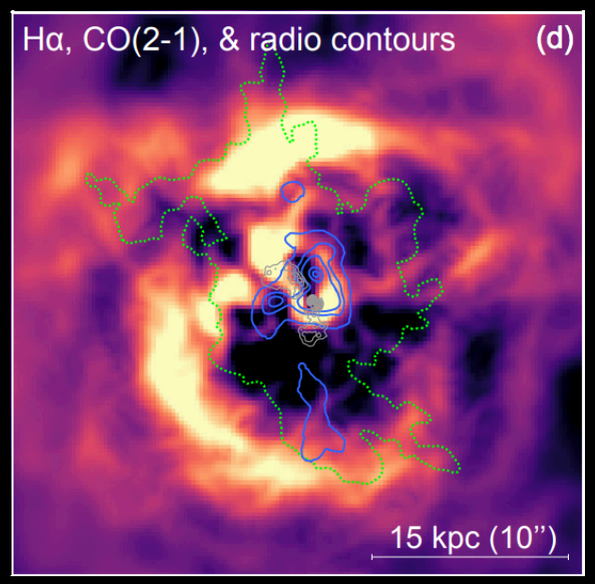
## Signatures of ongoing AGN feedback and multiphase gas in quiescent galaxies

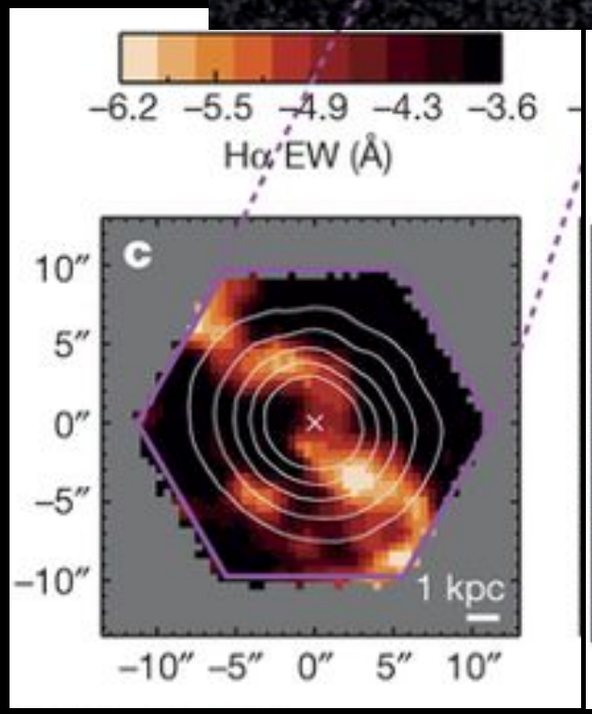


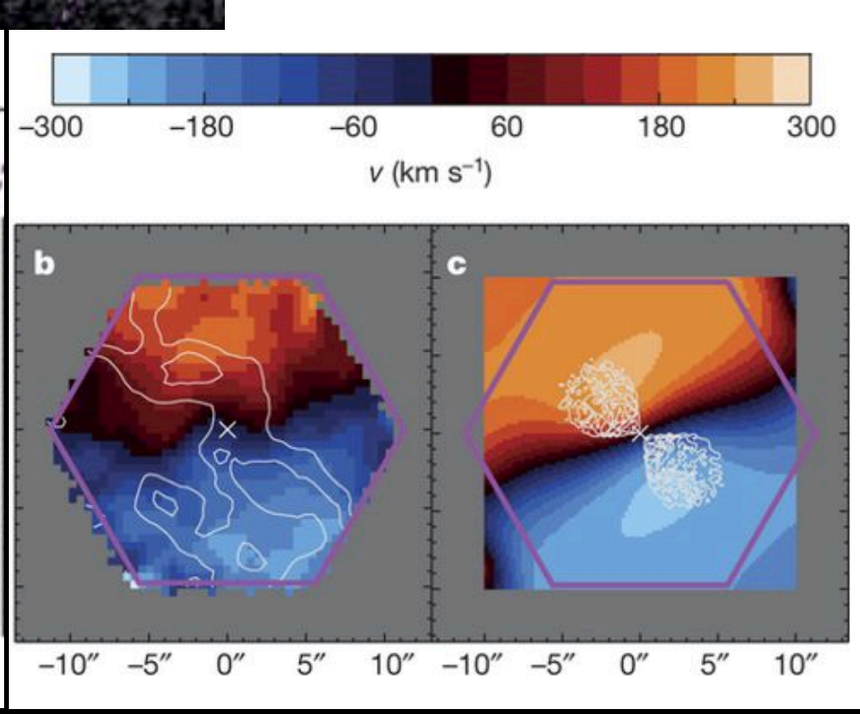

Cheung+ 2016

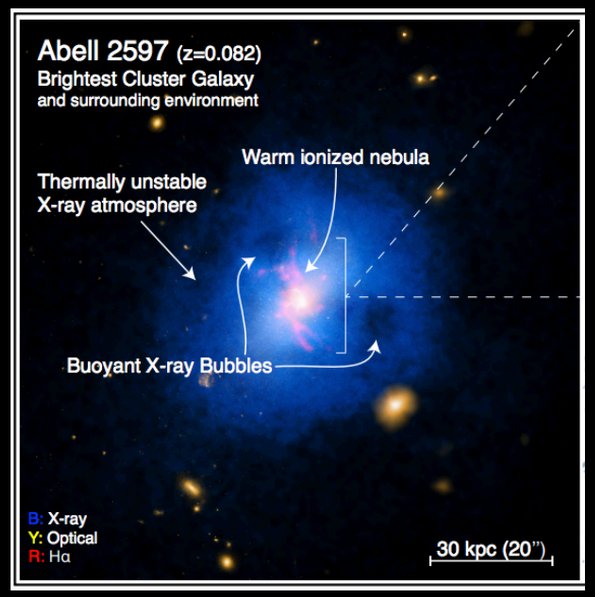



Tremblay+ 2018



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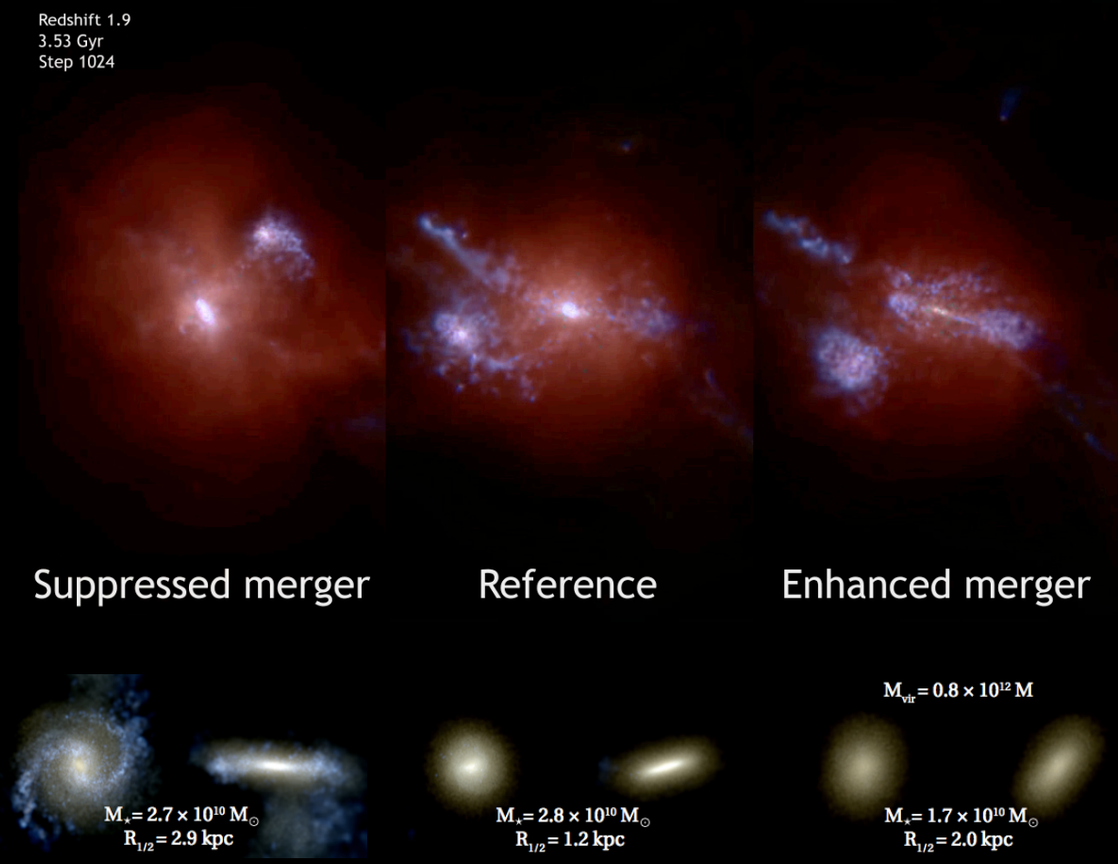
# AGN and Quenching

# How does AGN feedback regulate star formation in massive galaxies?

**Controlled experiments using "Genetic Modification"**
Pontzen, Tremmel+ 2017
see also Roth+ 2016, Rey+ 2018

Quenching "in the wild" with the Romulus25 simulation
Tremmel+, in prep

AGN feedback in the most massive galaxies with unprecedented resolution using the RomulusC simulation
Tremmel+ 2018, submitted



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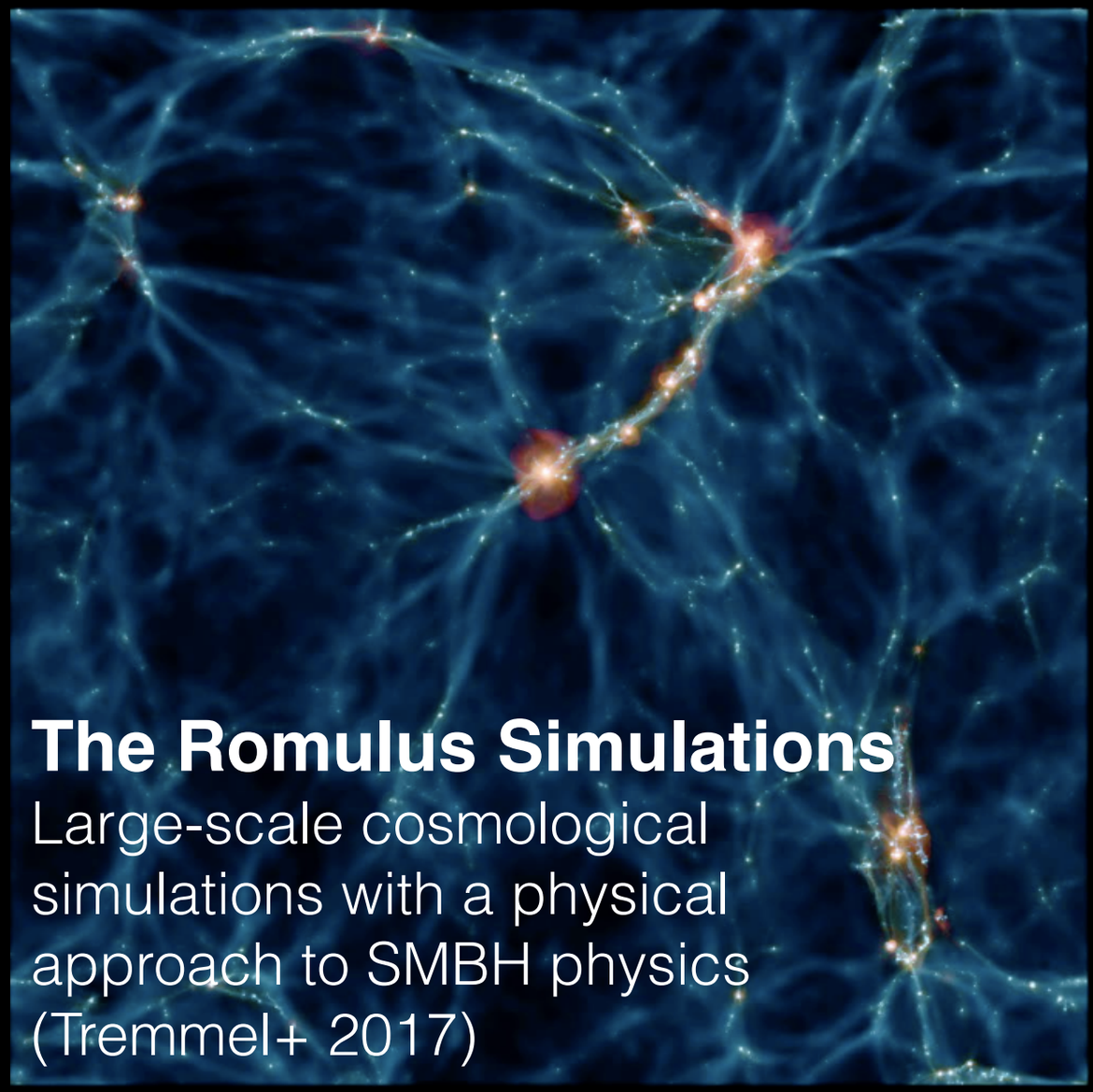

**The Romulus Simulations**
Large-scale cosmological simulations with a physical approach to SMBH physics (Tremmel+ 2017)

# AGN and Quenching

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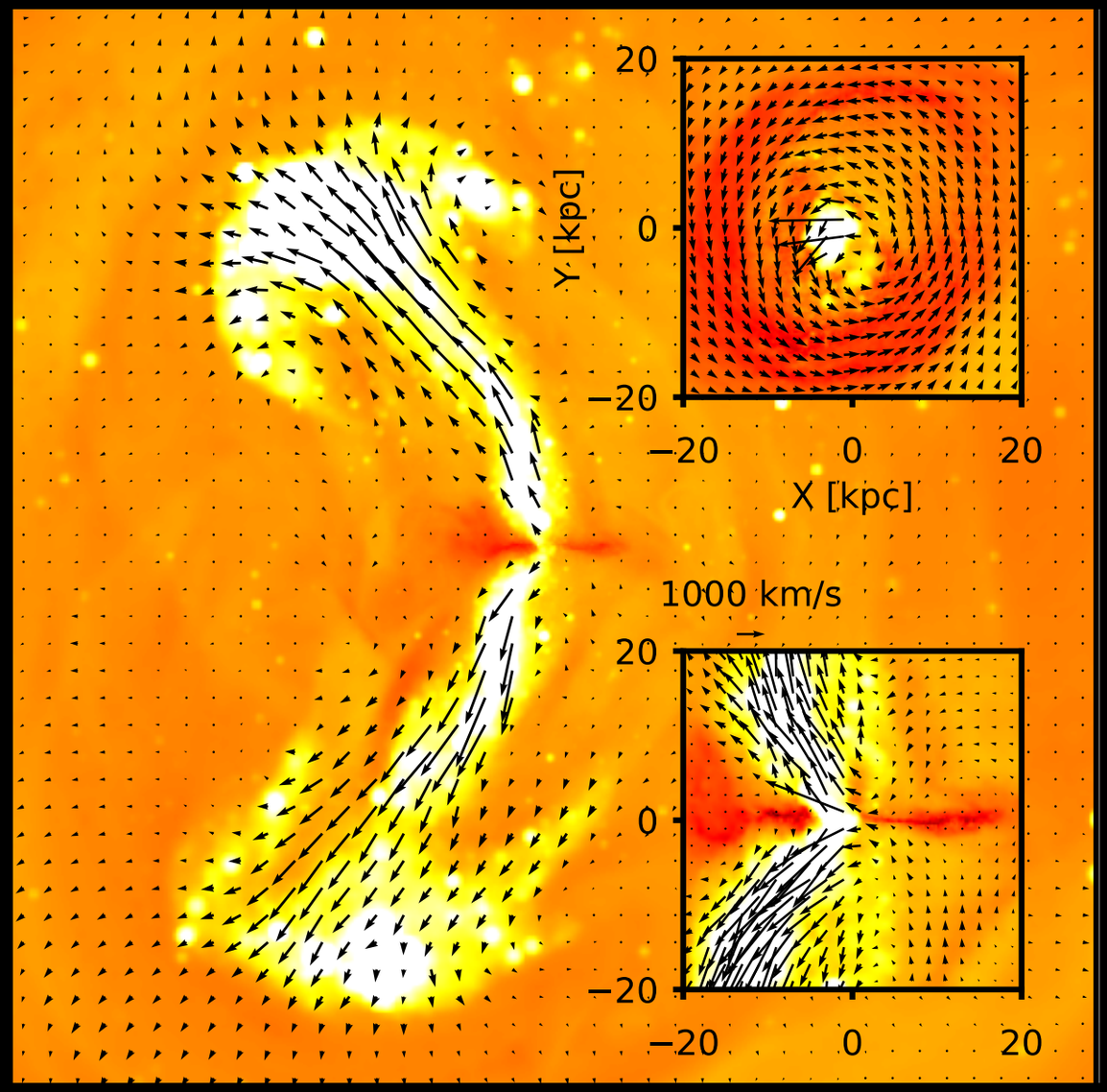
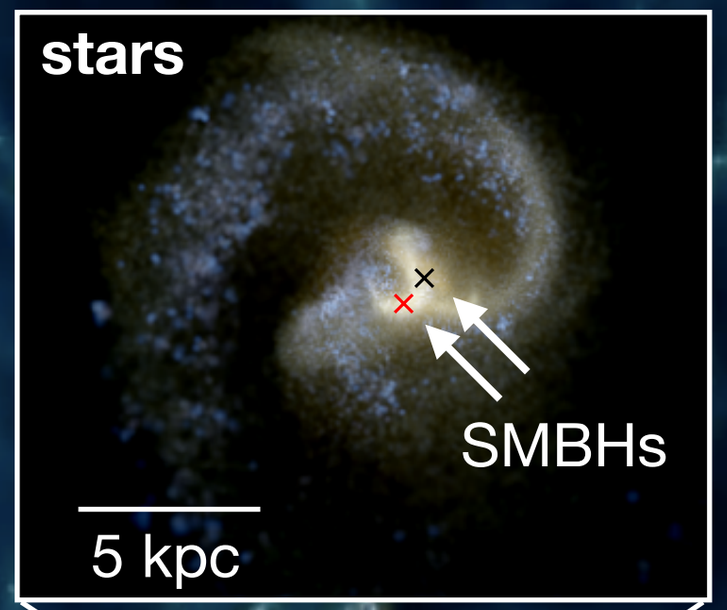


# The ROMULUS Simulations

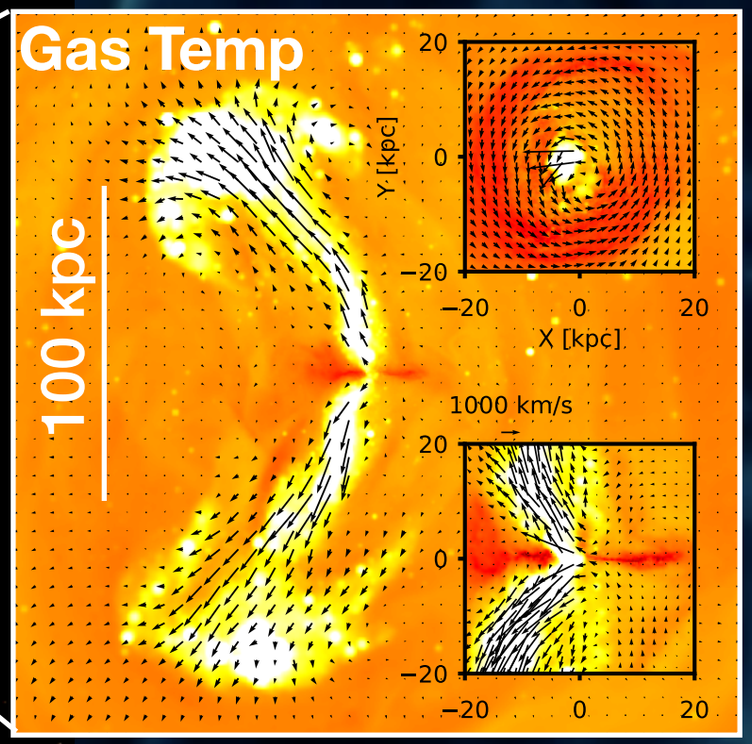
## Certified organic, free-range, locally grown supermassive black holes

- ✓ Early Seeding in low mass halos
- ✓ Self-consistent and physically motivated dynamics, growth, and feedback
- ✓ Naturally produces large-scale outflows
- ✓ No unnecessary additives or assumptions

**ROMULUS25**
25 Mpc Volume
Tremmel+ 2017
(gas temp)




**ROMULUSC**
$10^{14}$ $M_{sun}$ Galaxy Cluster
Tremmel+ submitted
(stars, uvj colors)




**Resolution:**
**250 pc (grav)**
**50 pc (hydro)**
**~1e5 $M_{sun}$**

CHANGA

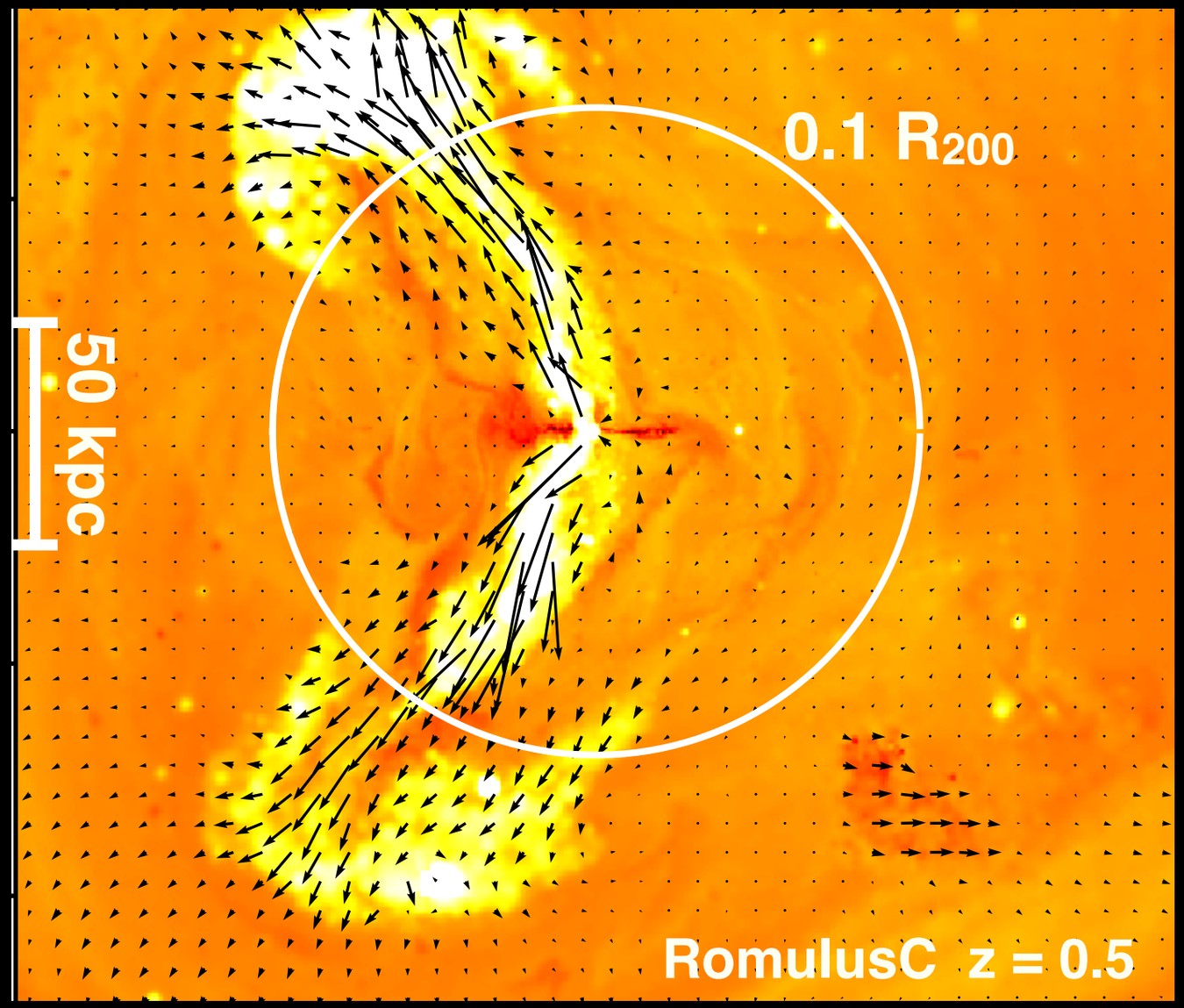
## Subgrid SMBH Physics

# **Thermally driven** outflows with angular momentum limited accretion

**0.2%** mass-energy transferred **thermally** to surrounding gas

- **spatial (250/50 pc) and time ($10^3$-$10^4$ yrs) resolution** for SMBH and gas
- Brief **cooling shutoff** ($10^3$-$10^4$ yrs)
- **Large-scale outflows launched from 100 pc scales**

**Sub-Grid models <u>not optimized</u> for halos more massive than 1e12 $M_{sun}$**



# Controlled Experiments with Genetic Modification

## Study the interaction between AGN feedback and galaxy mergers

Pontzen, Tremmel+ 2017
See also Roth+ 2016, Rey+ 2018


Suppressed merger 1:10 | Reference 1:5 | Enhanced merger 2:3

# Controlled Experiments with Genetic Modification

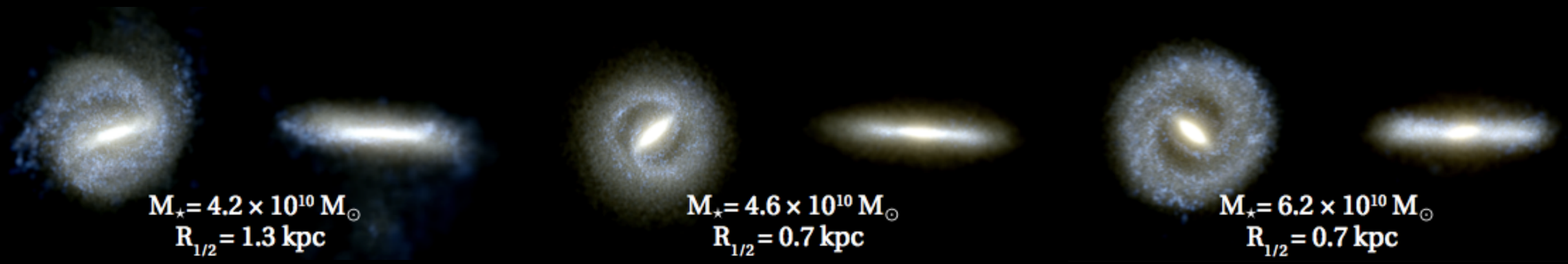
## Galaxy mergers have drastic consequences for star formation and morphology…. when coupled with AGN feedback

Suppressed (1:10) Merger

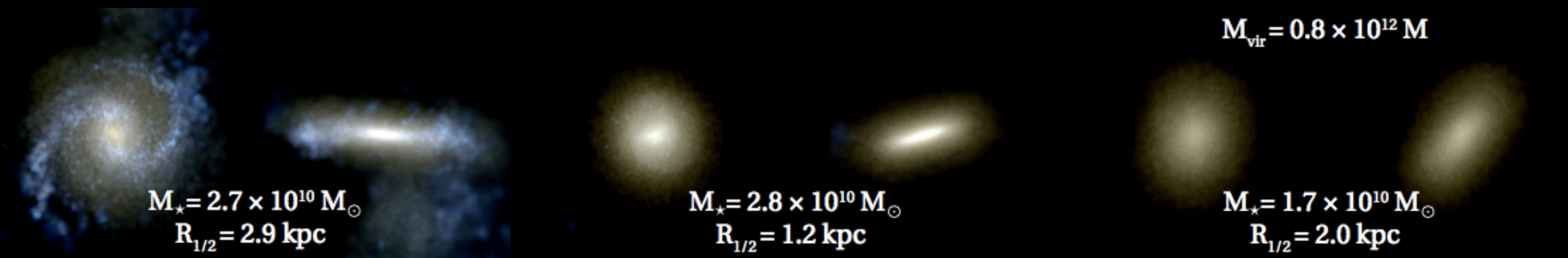
Reference (1:5) Merger

Enhanced (2:3) Merger

SN Only




SN+AGN




Pontzen, Tremmel+ 2017

# Controlled Experiments with Genetic Modification

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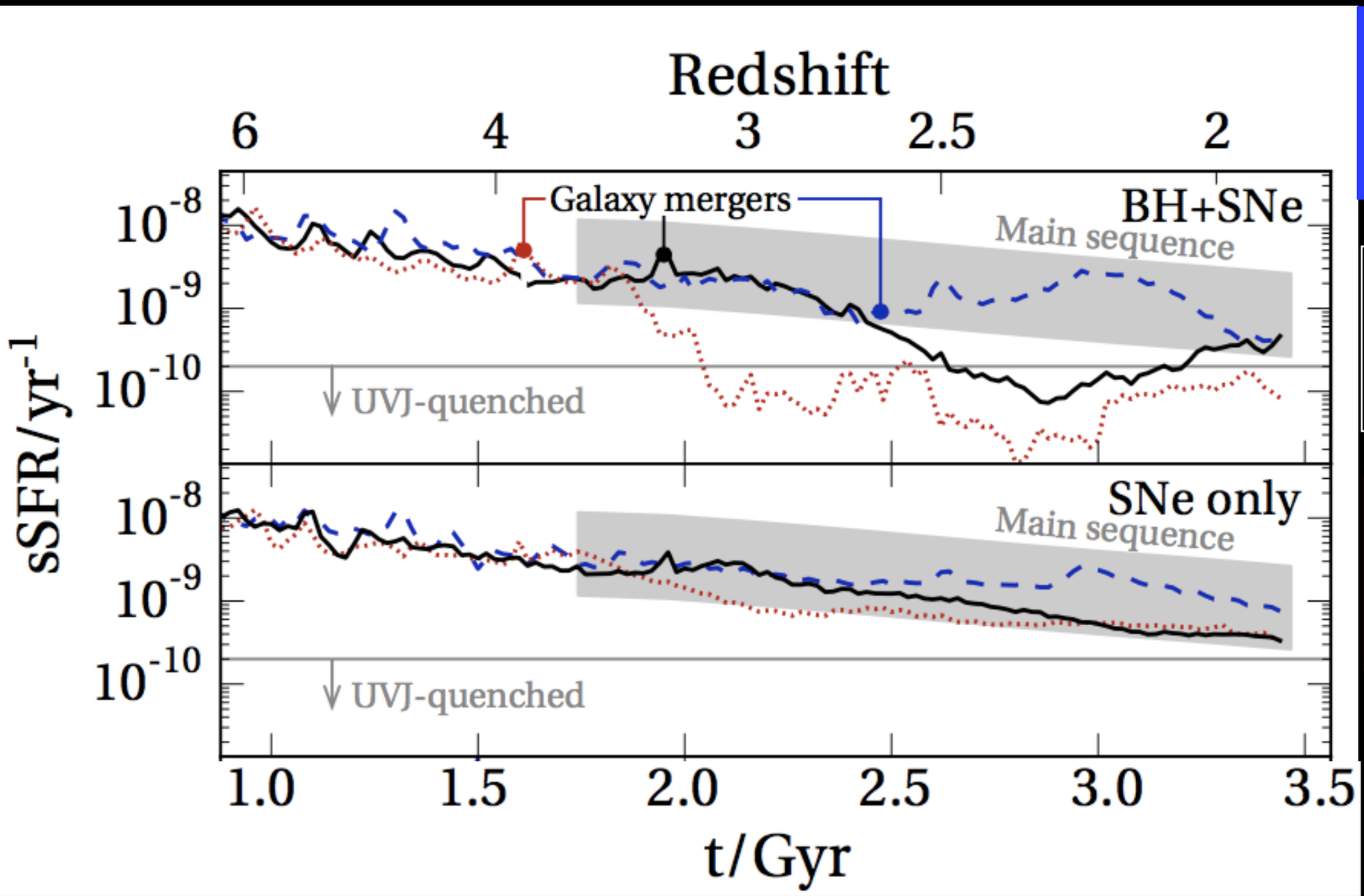


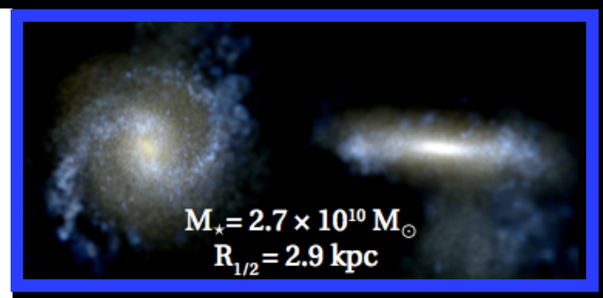


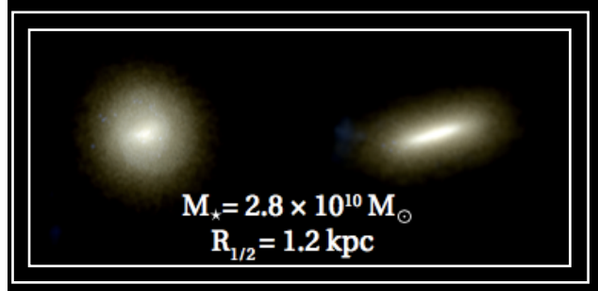


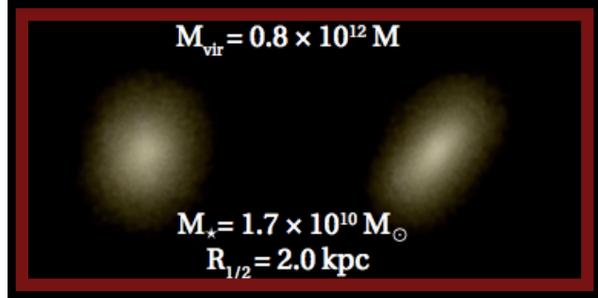


Pontzen, Tremmel+ 2017



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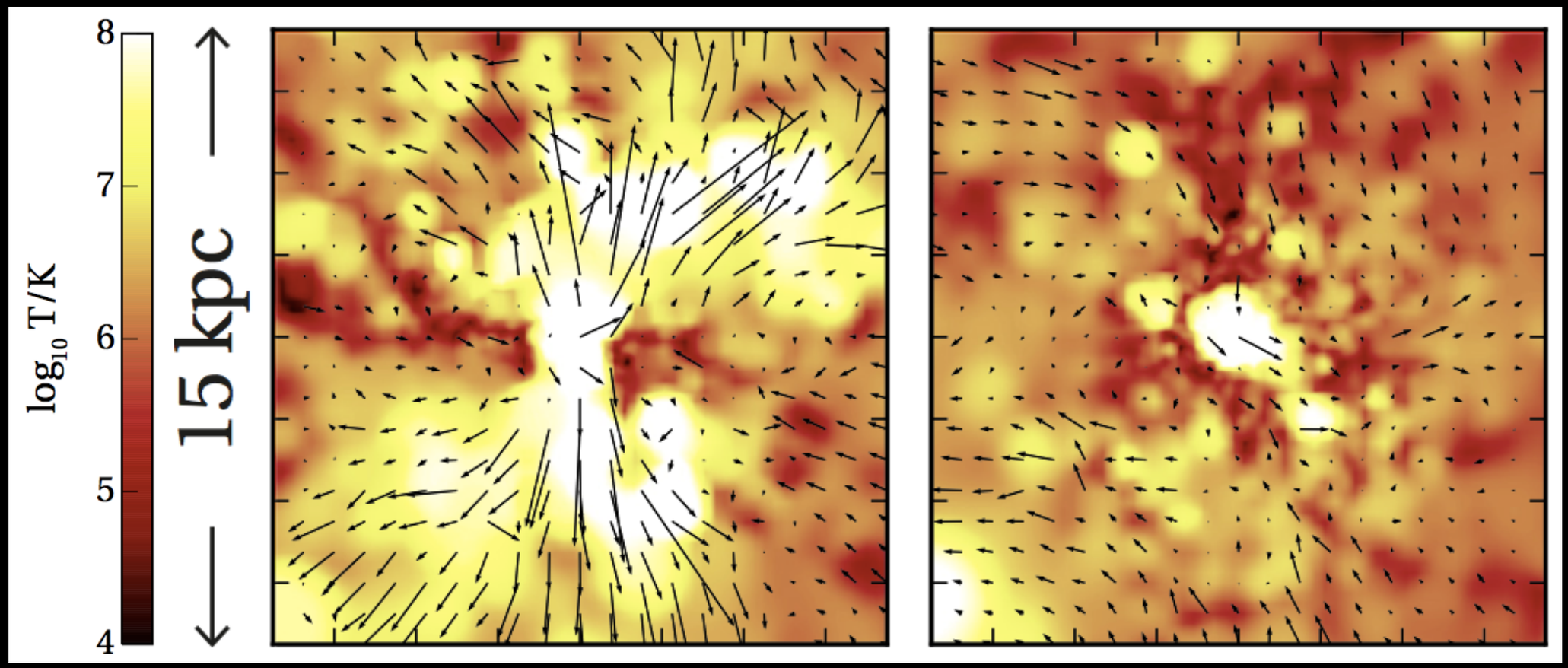
# Controlled Experiments with Genetic Modification

## Energetic outflows prevent the reformation of a gaseous disk

**Enhanced Merger** simulation just after it becomes quenched

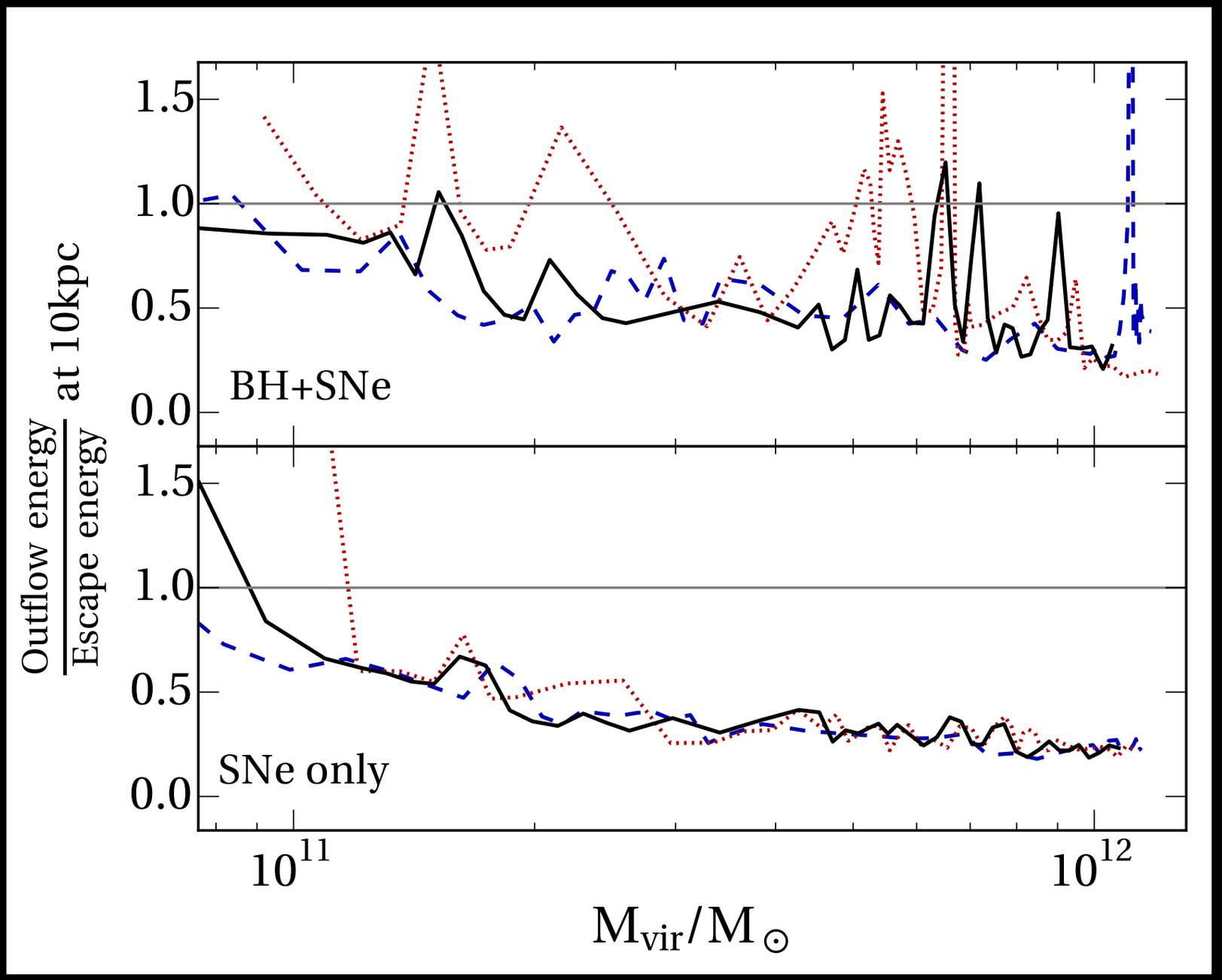



Inflowing gas fuels AGN activity, which generates large-scale winds, rather than re-form the star forming disk

Pontzen, Tremmel+ 2017

# Controlled Experiments with Genetic Modification

## Outflows need to reach **>10 kpc scales** to suppress ability of halo gas to reform disk

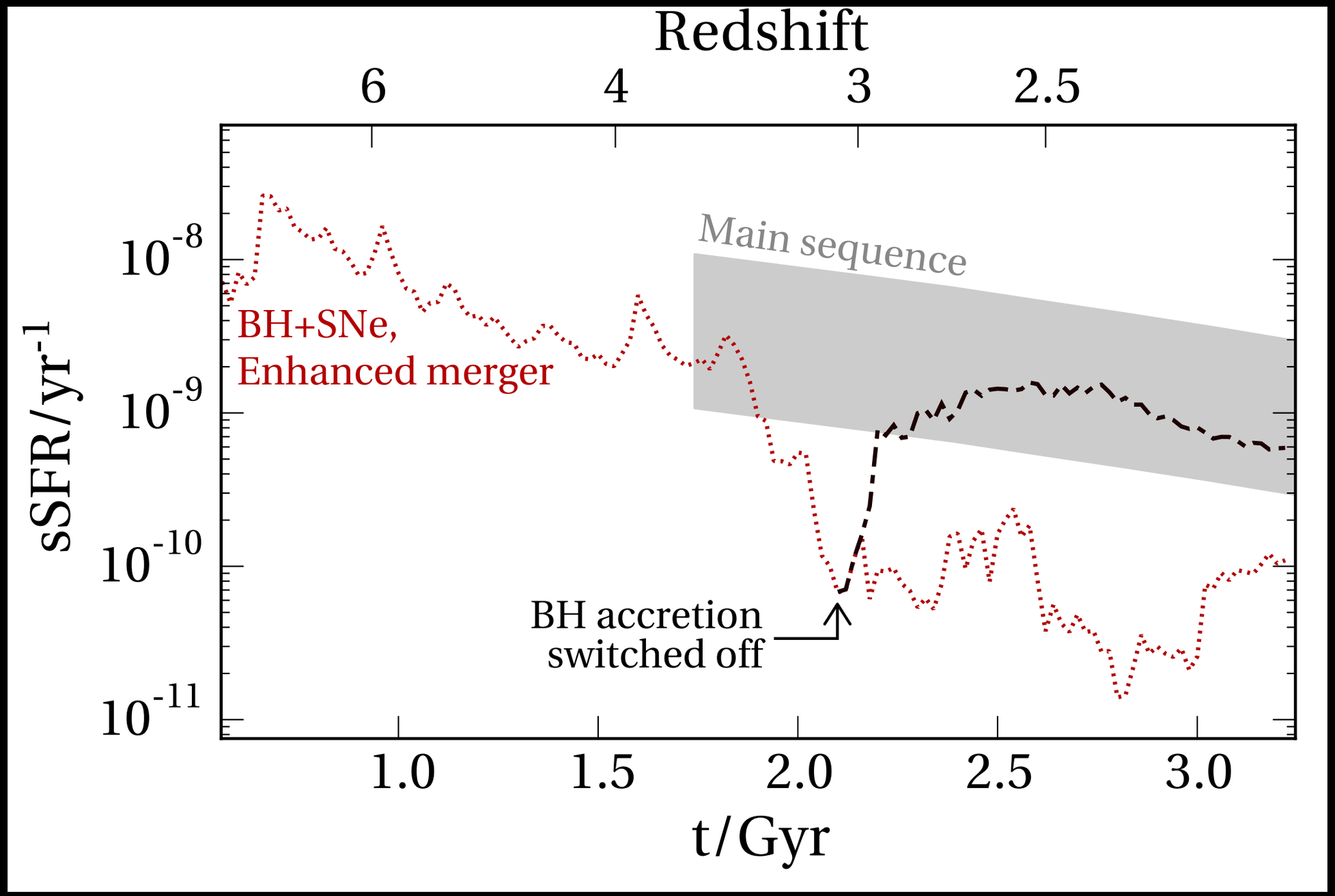



AGN that fail to drive such winds will not not be able to suppress star formation

Pontzen, Tremmel+ 2017

# Controlled Experiments with Genetic Modification

## AGN feedback required to **keep** galaxies quenched




Pontzen, Tremmel+ 2017



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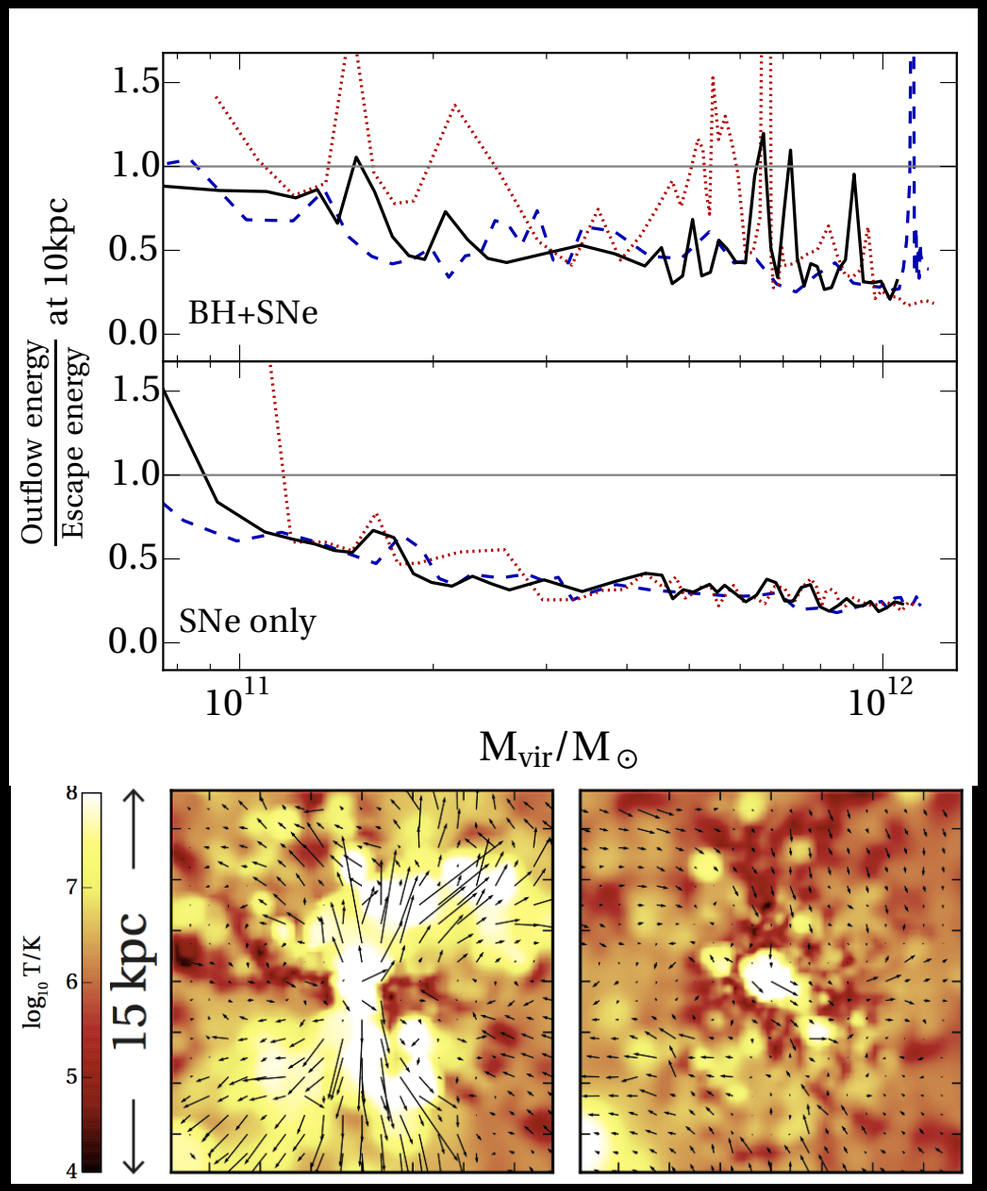
# Controlled Experiments with Genetic Modification

# A scenario for quenching star formation at high redshift



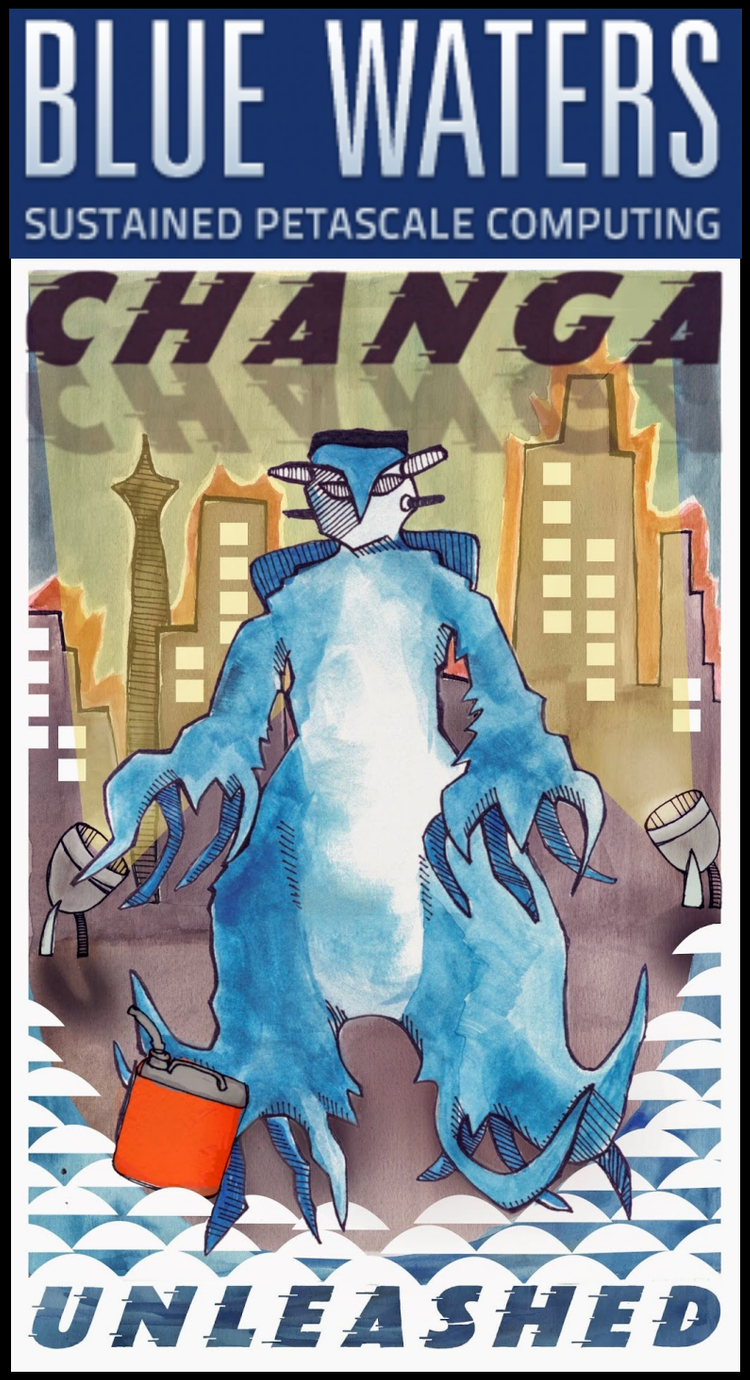

Major merger disrupts galactic disk with help of AGN feedback

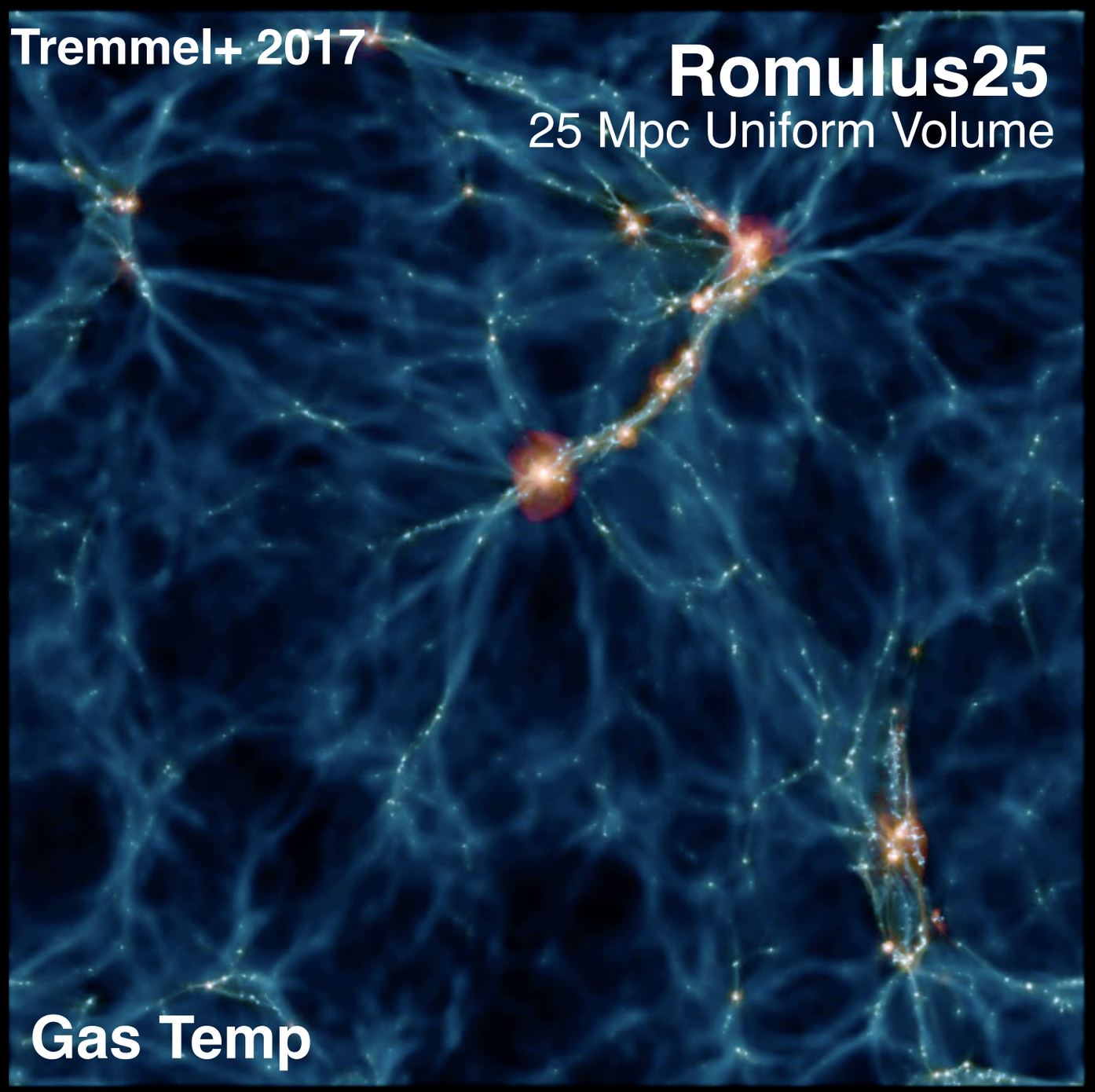
Further inflows feed SMBH, drive powerful winds

**Large -scale AGN winds suppress gas inflow, prevent rejuvenation**

# Quenching “In the Wild” with Romulus25

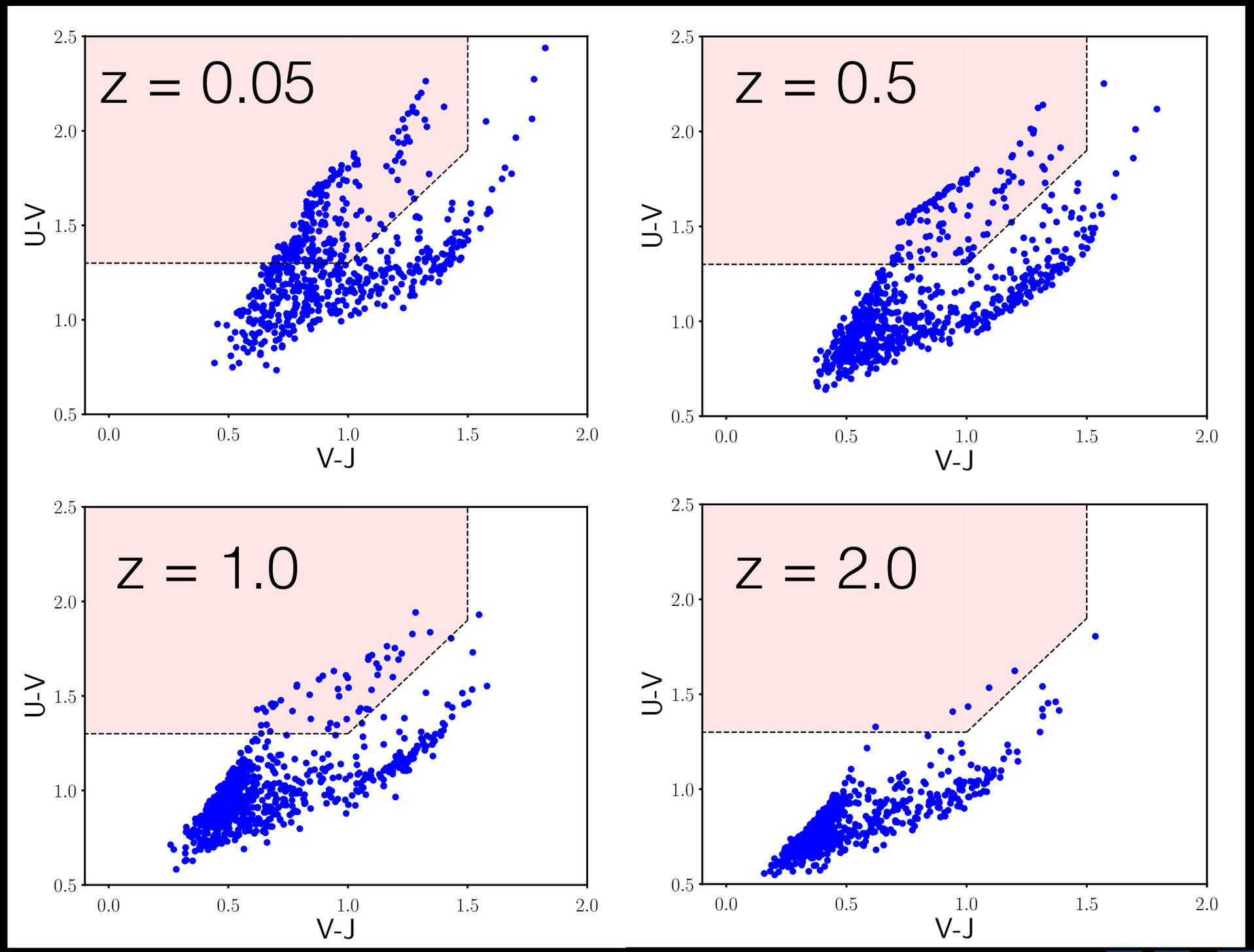
## A wider exploration of quenching



# Quenching “In the Wild” with Romulus25

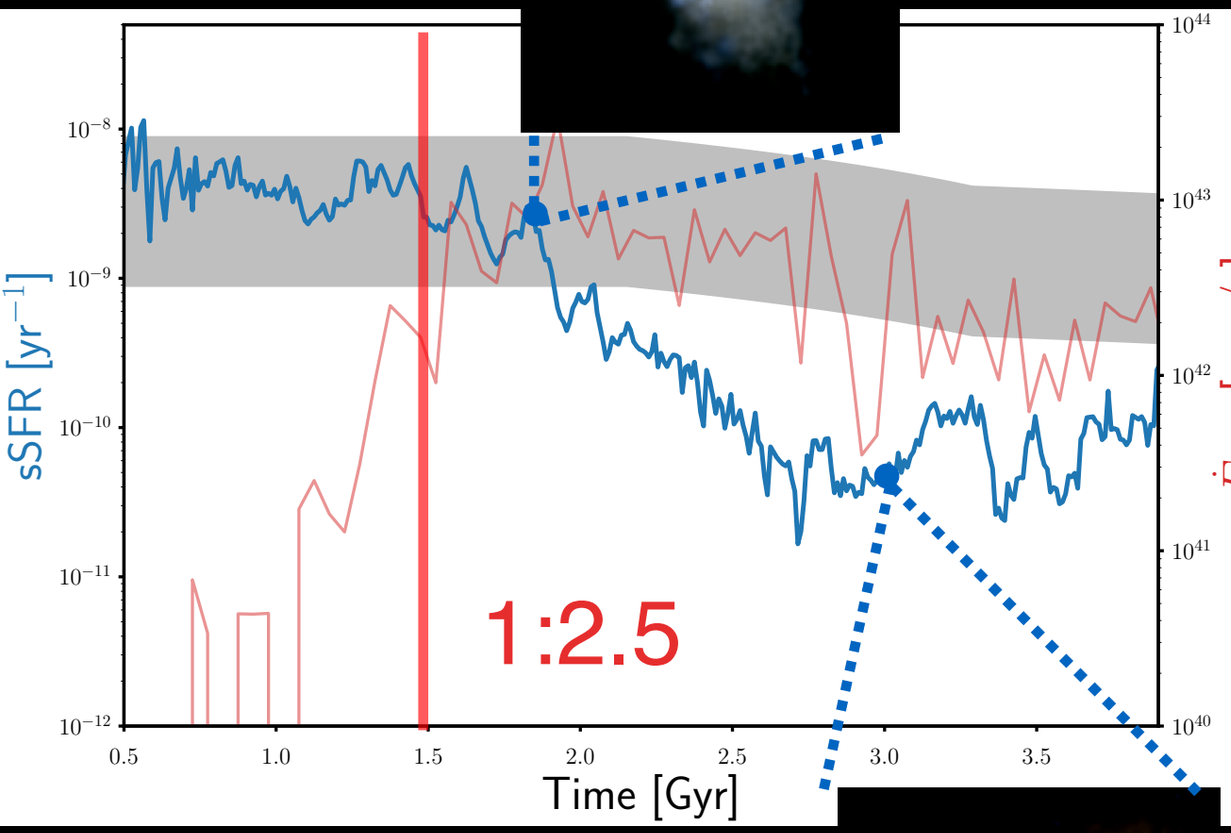
## The rise of the red sequence in Romulus

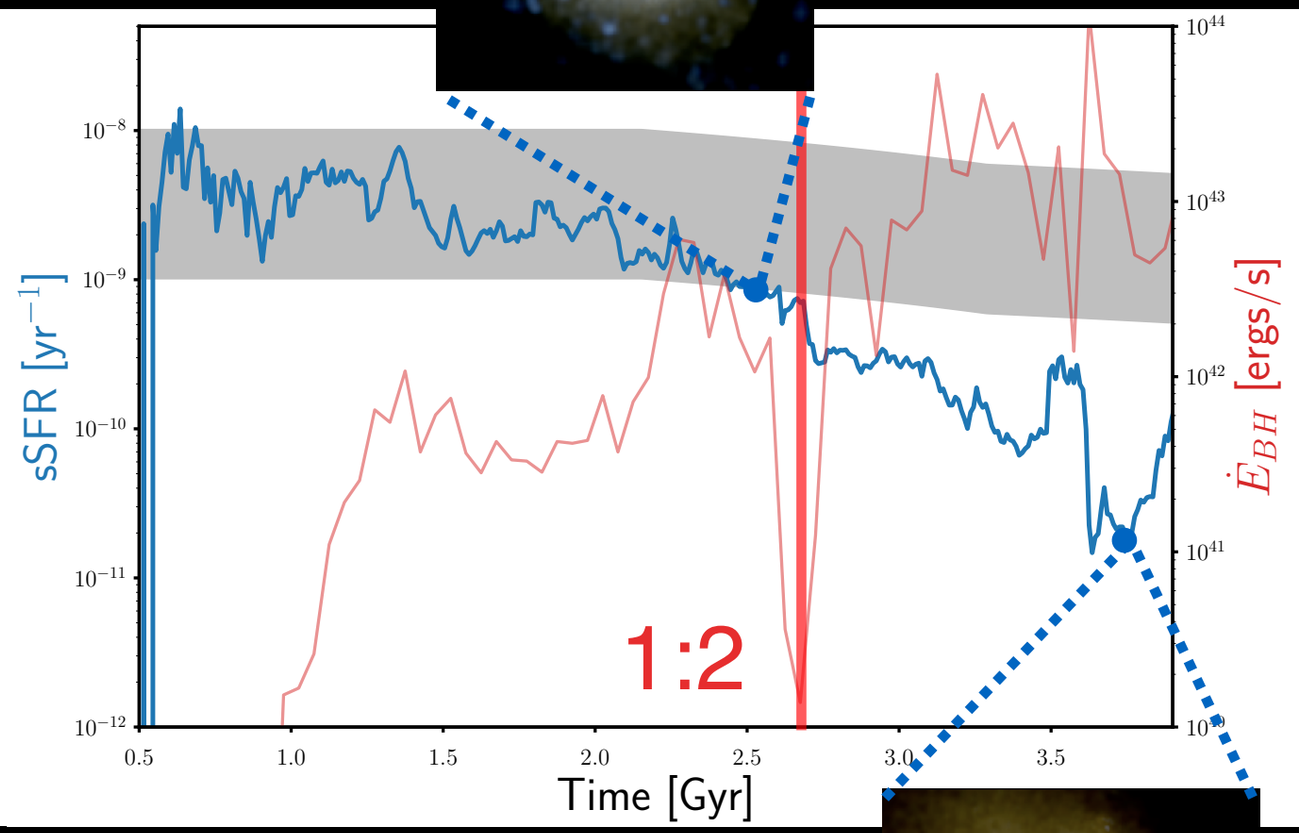



Tremmel+ in prep

# Quenching “In the Wild” with Romulus25

## Mergers cause quenching of massive galaxies at z ~ 2



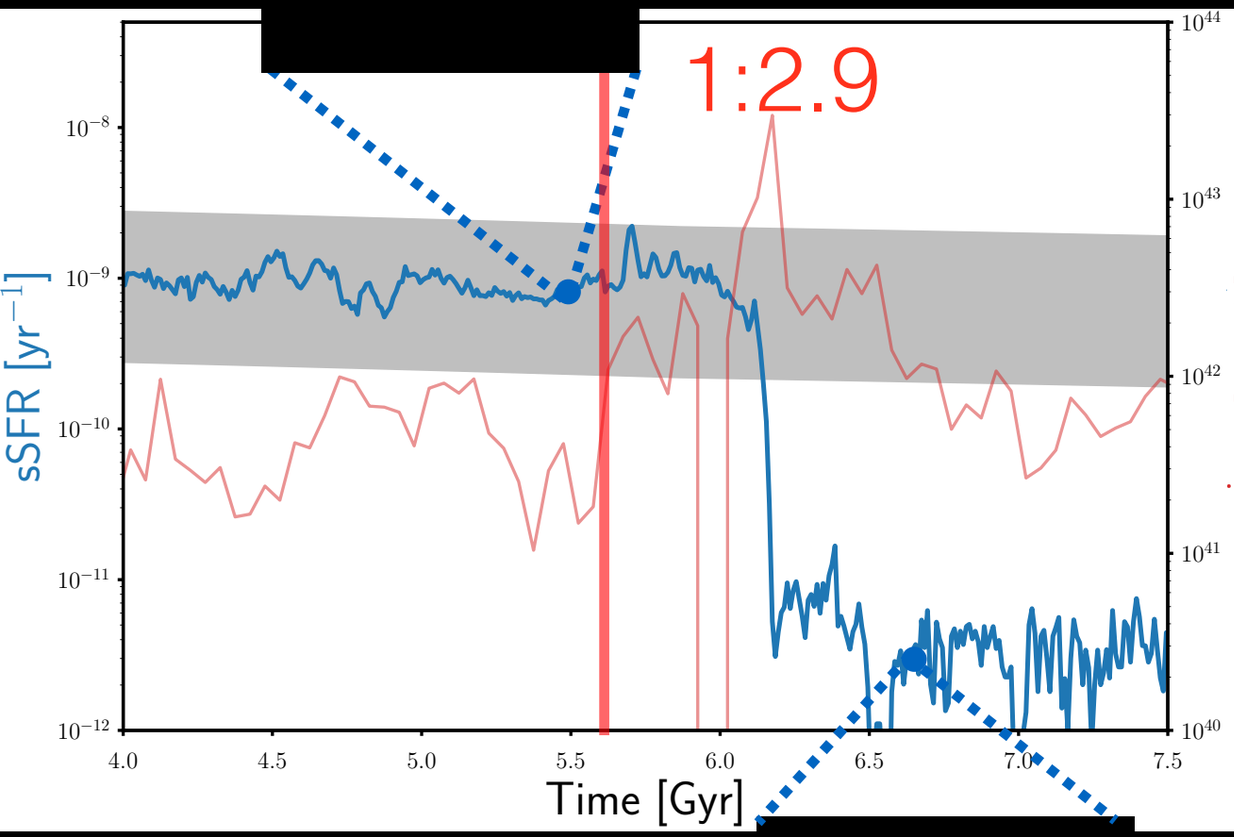



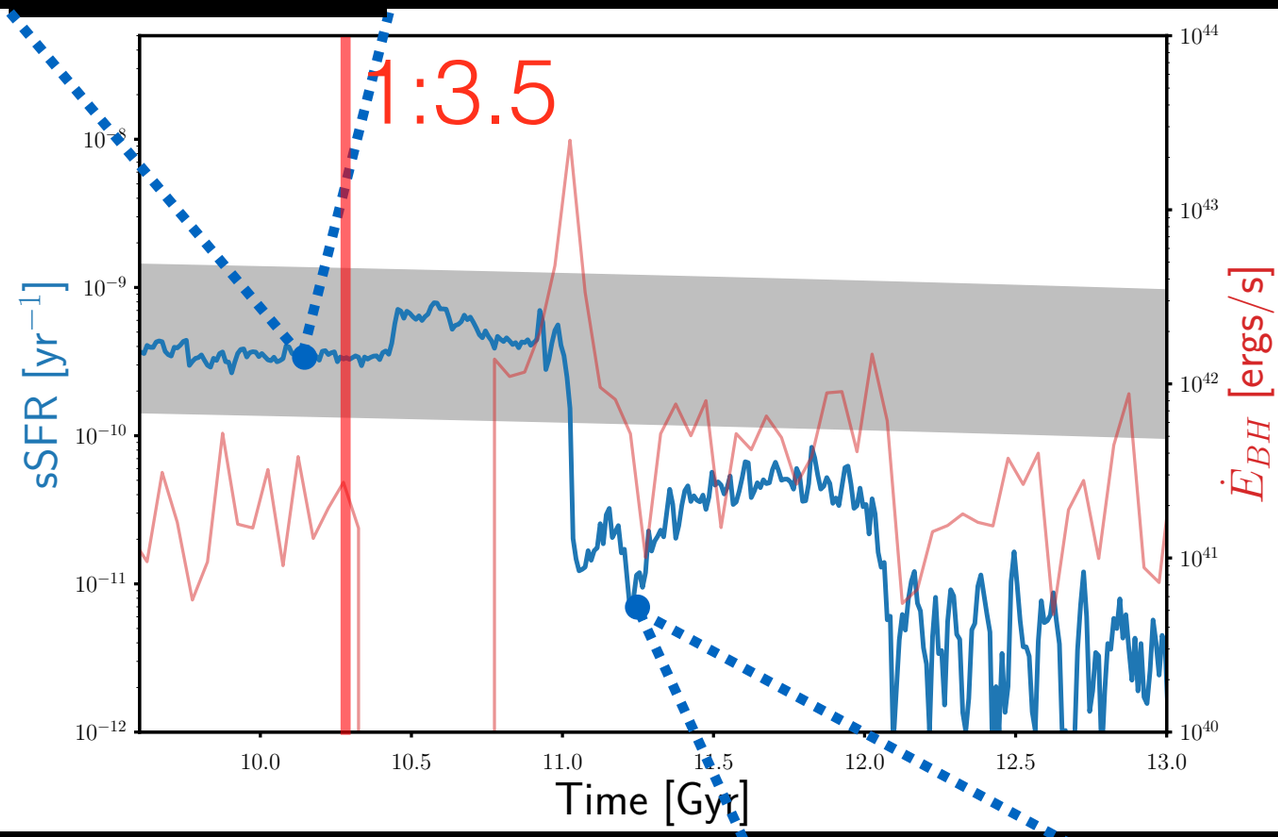
# Quenching “In the Wild” with Romulus25

## Lower redshift mergers can also lead to quenching

z ~ 1

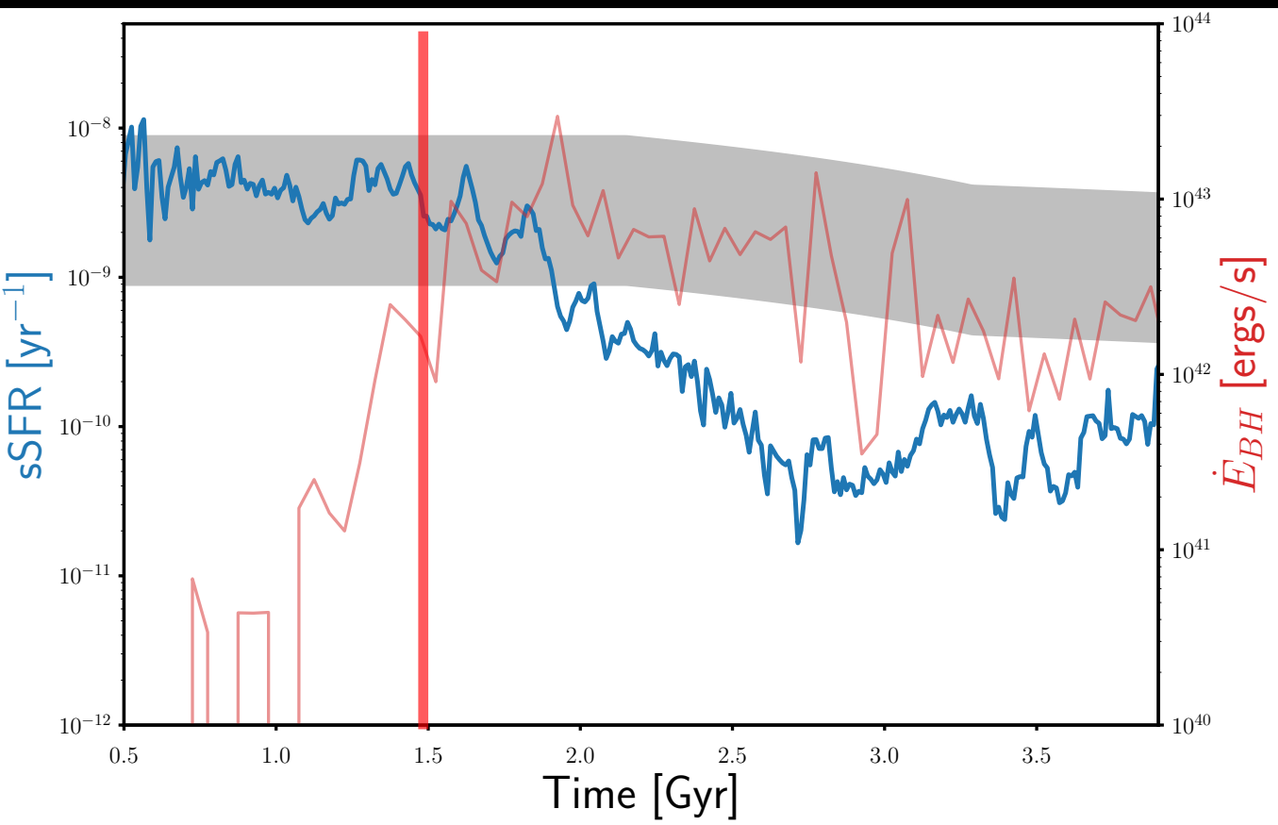
z ~ 0.2

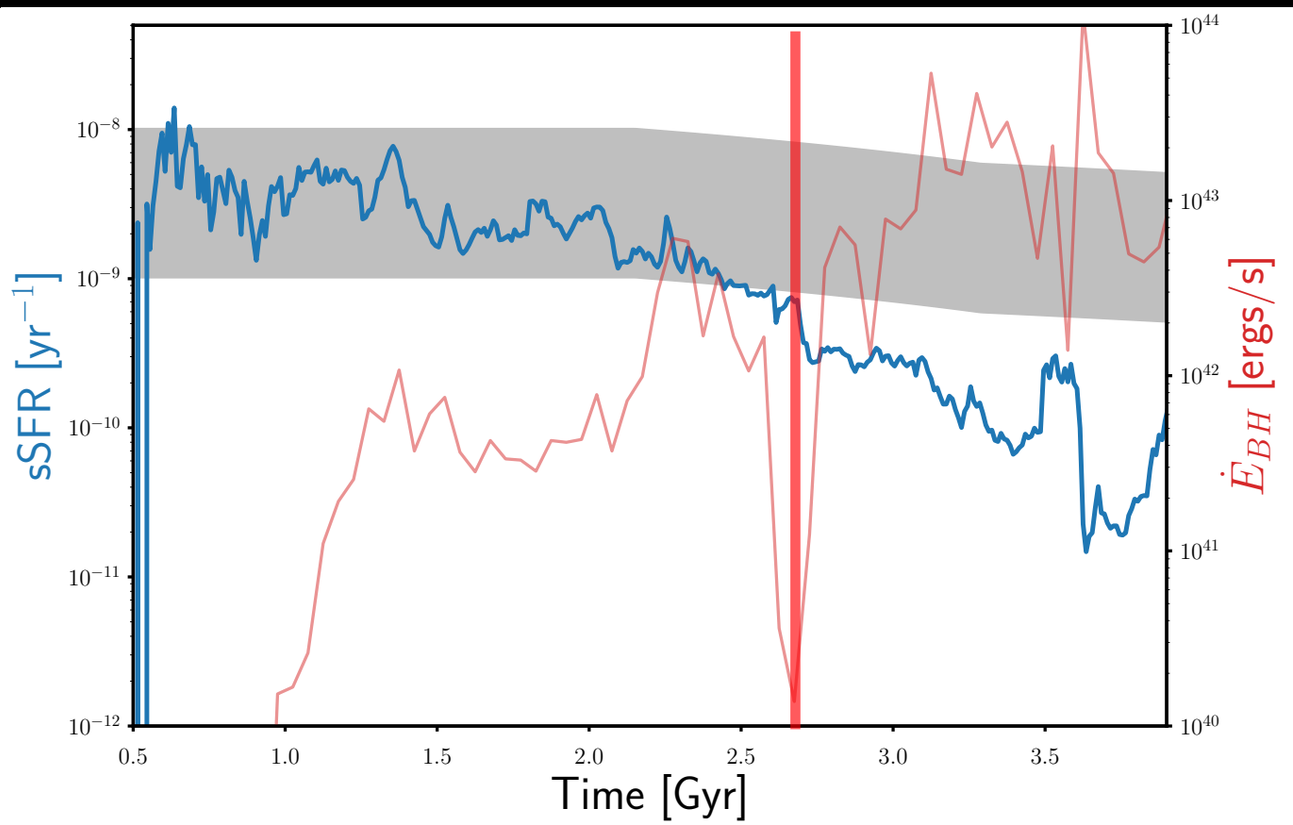


# Quenching “In the Wild” with Romulus25

## Rejuvenation/quenching can happen multiple times



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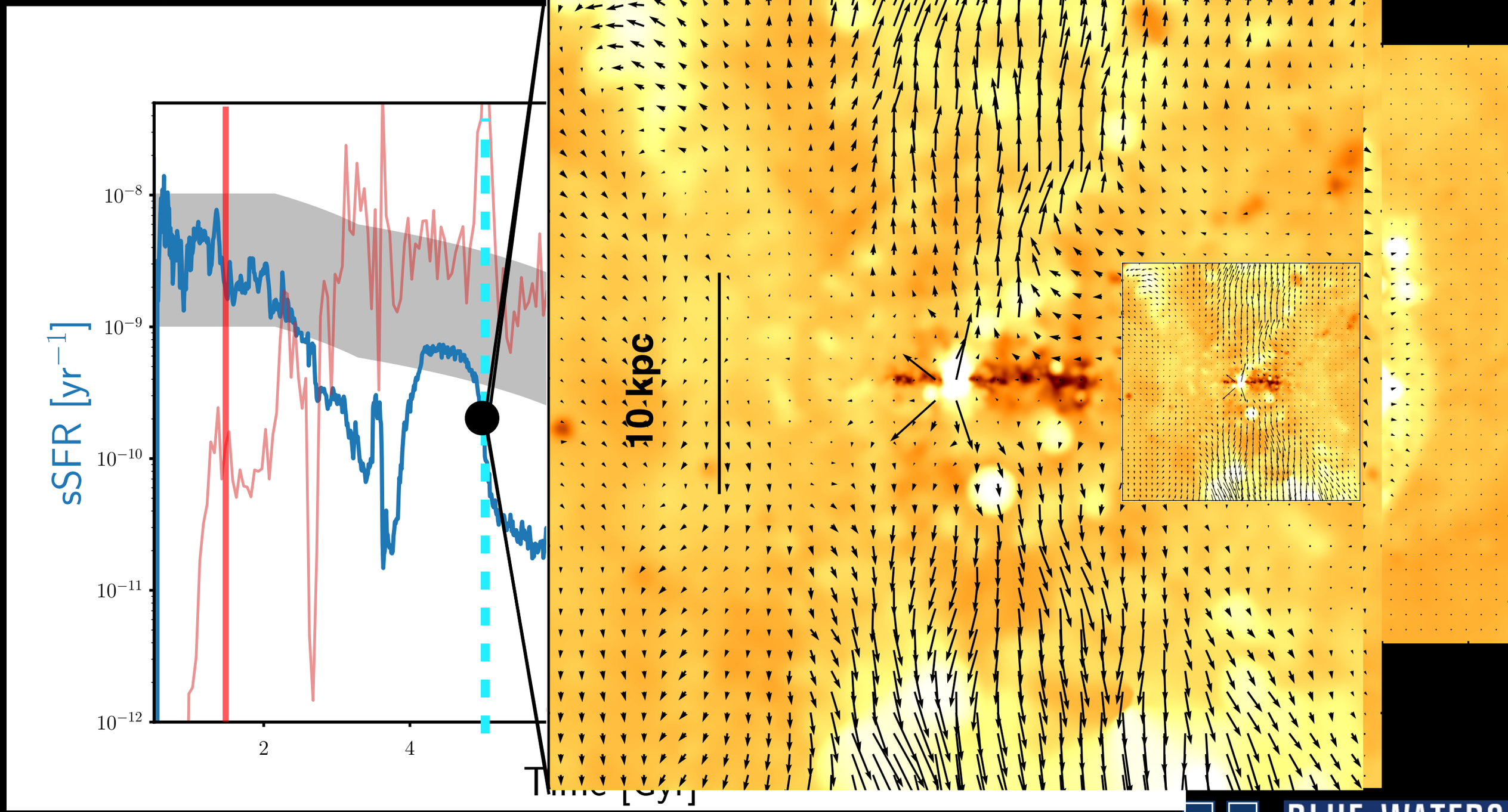
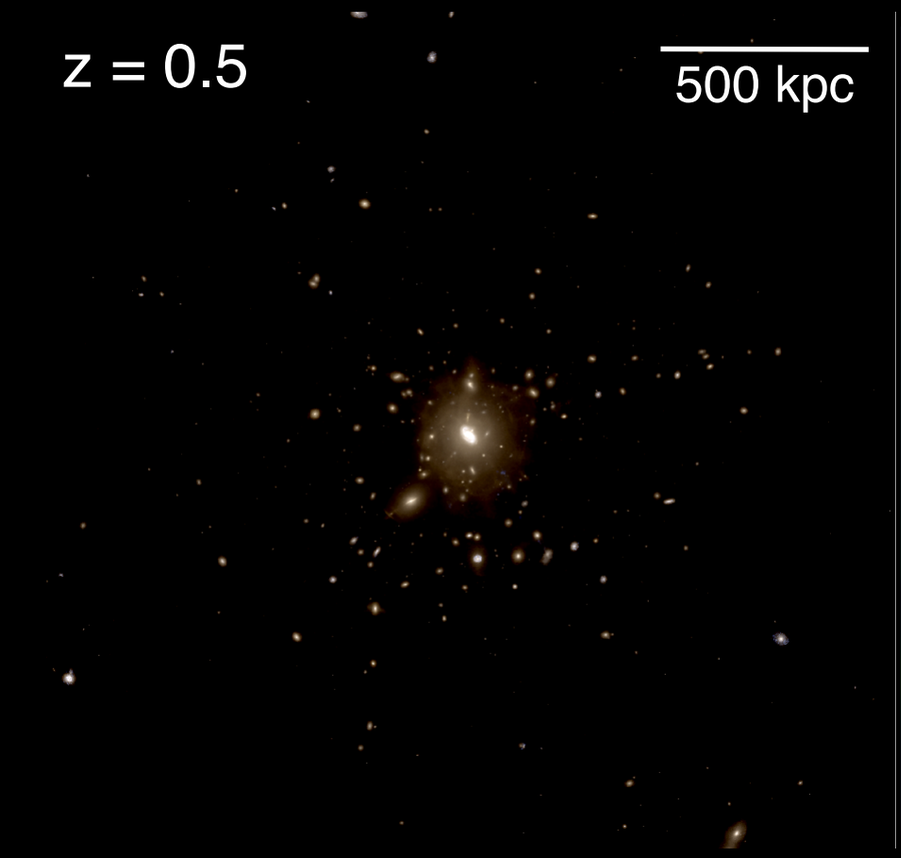
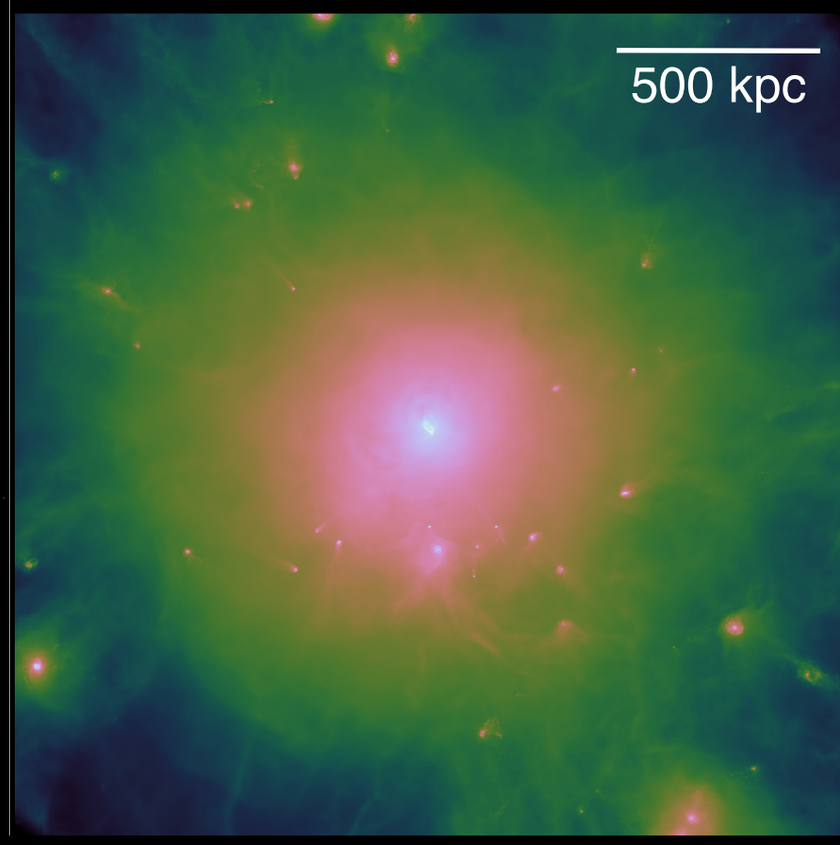
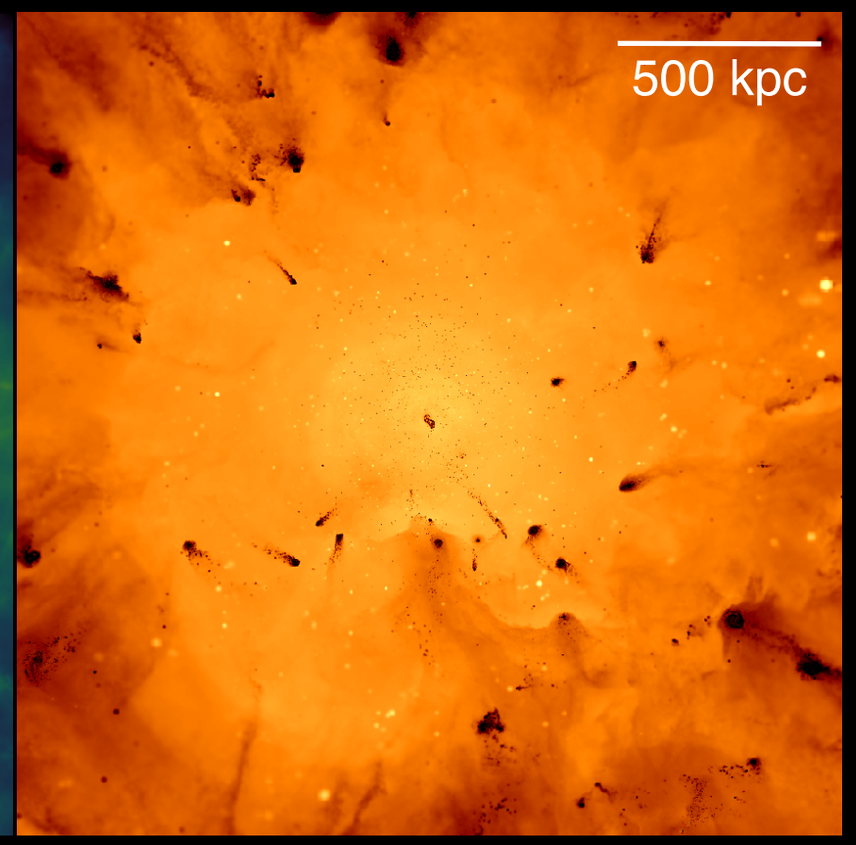


# Quenching of a Brightest Cluster Galaxy

## RomulusC: The **highest resolution** cosmological simulation of a galaxy cluster



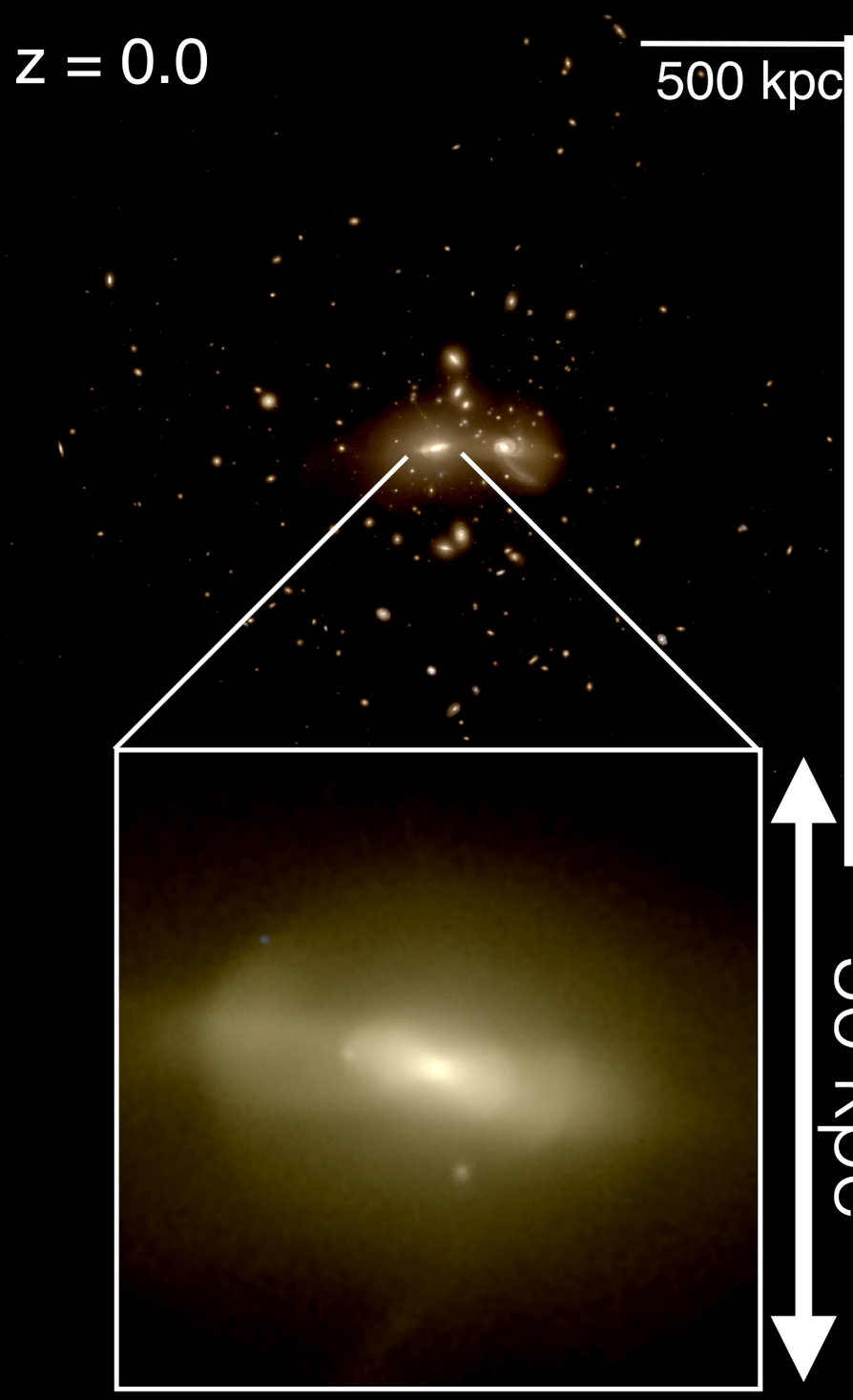



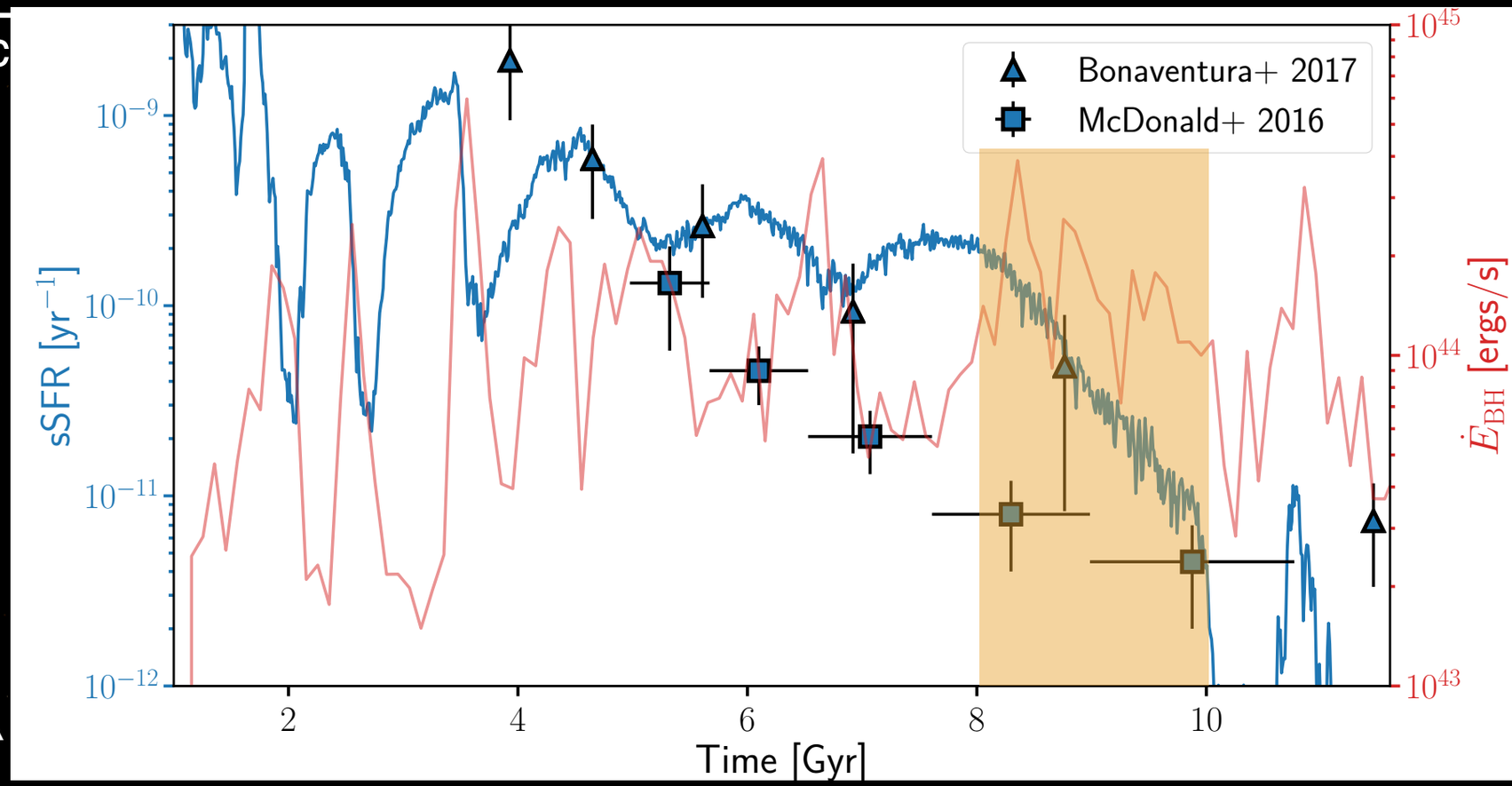

Resolution: 250 pc (grav), 50 pc (sph), 2e5 $M_{sun}$

Tremmel+ 2018, submitted
https://arxiv.org/pdf/1806.01282.pdf

# Quenching of a Brightest Cluster Galaxy

# AGN feedback quenches star formation




Tremmel+ 2018, submitted



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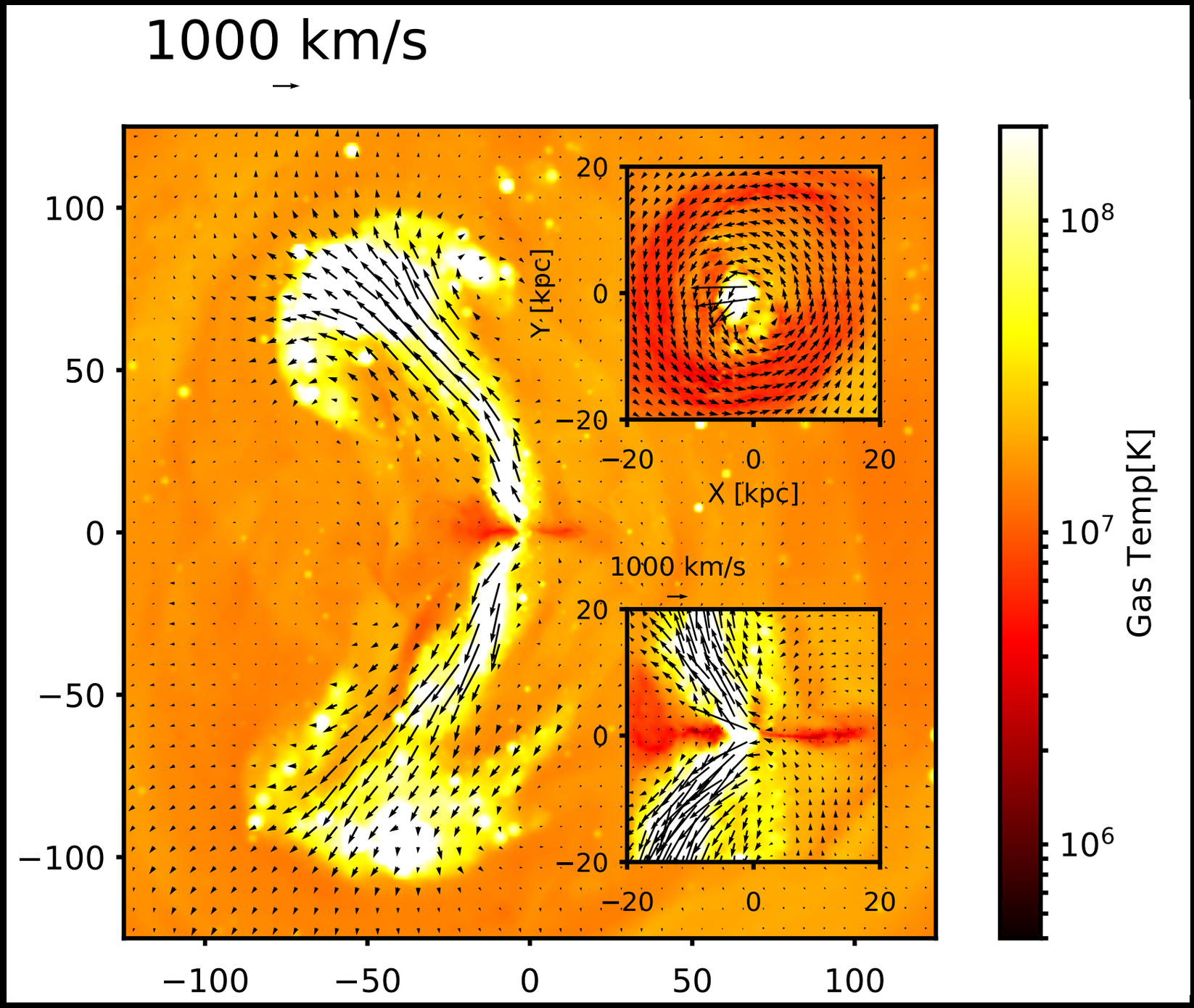
# Quenching of a Brightest Cluster Galaxy

## AGN FB drives large-scale, collimated outflows

z = 0.5




Tremmel+ 2018
submitted



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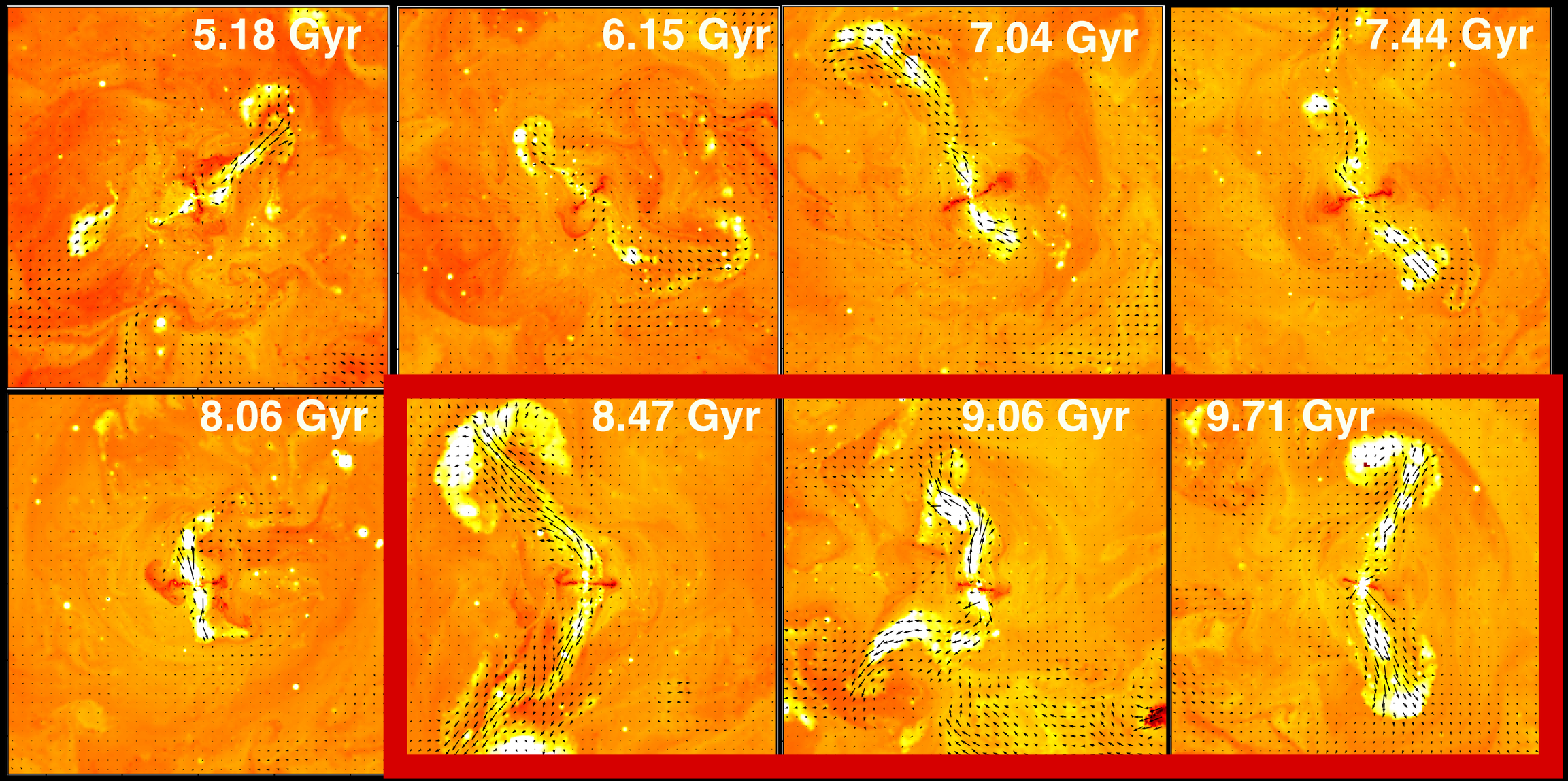
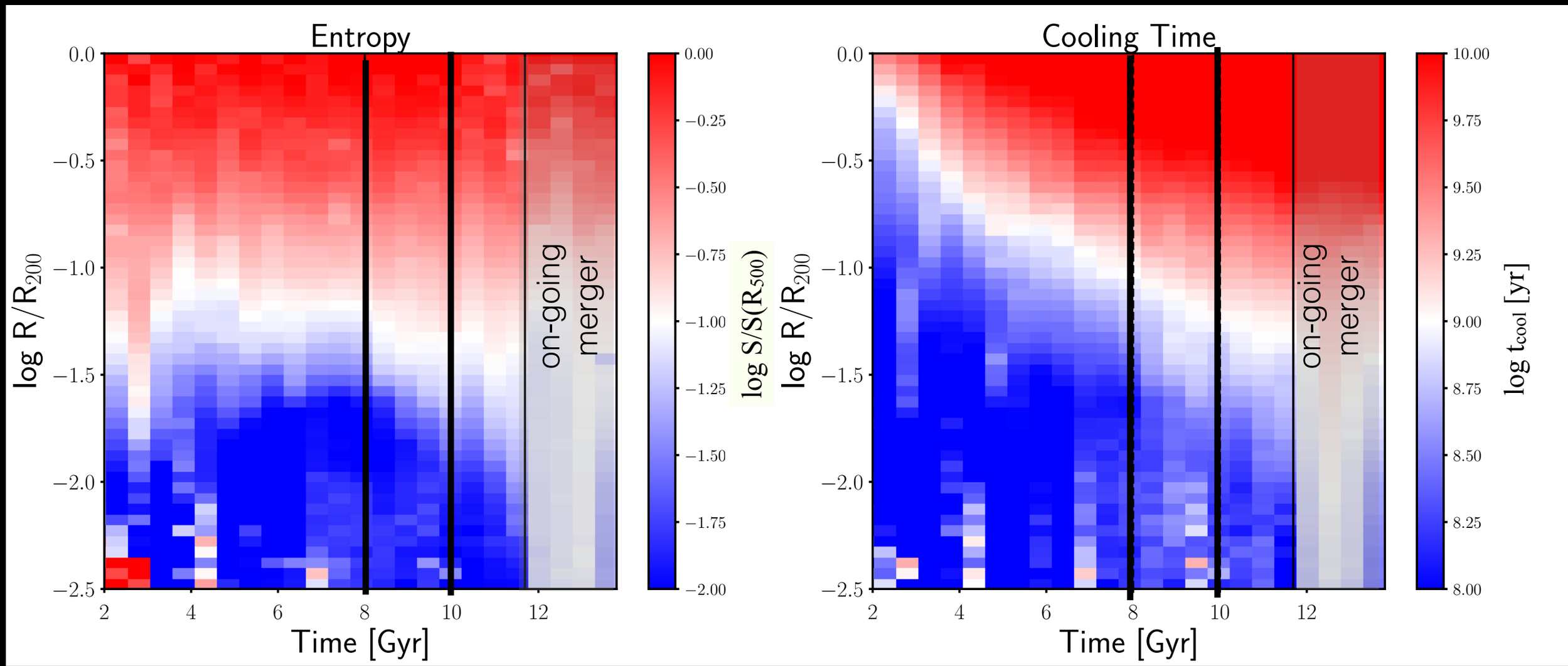


# Quenching of a Brightest Cluster Galaxy

## AGN quenches BCG without disrupting structure of Intracluster medium




Tremmel+ 2018, submitted



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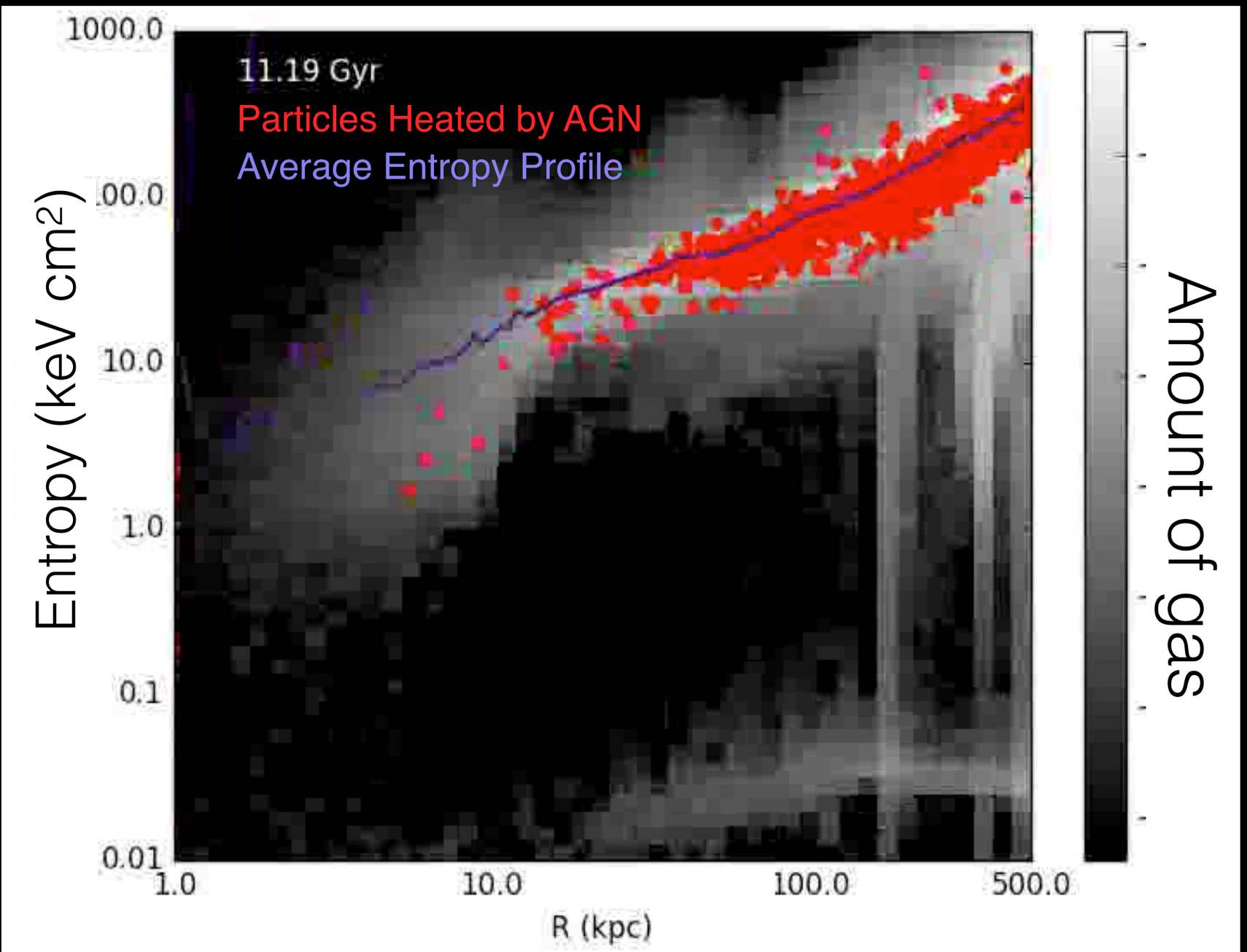
# Quenching of a Brightest Cluster Galaxy

## AGN outflows help **control rates of precipitation** of gas from the ICM




**Precipitation** of low entropy gas powers both SF and AGN

Voit+ 14,17,18
Li+ 14,15,17
Gaspari+ 13,17
Tremblay+ 18

Precipitation at **10-100 kpc** scales suppressed by AGN.

Steepening entropy profile at **<10 kpc** prevents infall of precipitated gas

Chadayammuri, Tremmel+ in prep



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# Summary

- Major mergers + AGN feedback is a robust mechanism for quenching SF in galaxies across cosmic time

- **Large-scale winds affect gas inflow from the halo**, regulating and in some cases quenching star formation

- BH outflows do not destroy, but rather **coexist with the galaxy/ nearby gas structure**

- **Regulation of gas precipitation** by AGN outflows