Ecole Polytechnique Fédérale de Lausanne

Galaxy evolution and spectral modelling

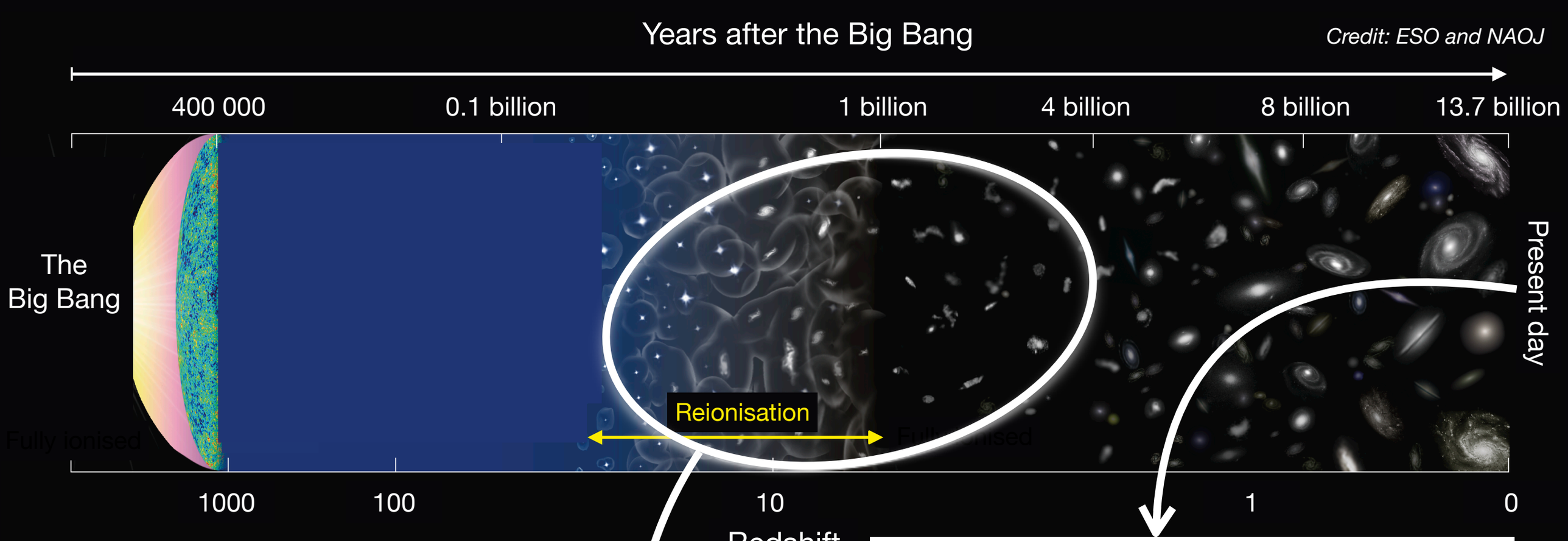
Cosmic ray and AGN feedback in low and high-mass high-redshift galaxies

Marion Farcy

Joakim Rosdahl - Yohan Dubois - Jérémy Blaizot - Sergio Martin-Alvarez

Michaela Hirschmann - Ena Choi - Rachel Somerville - Sophie Koudmani - Thorsten Naab

Galaxy evolution through cosmic times

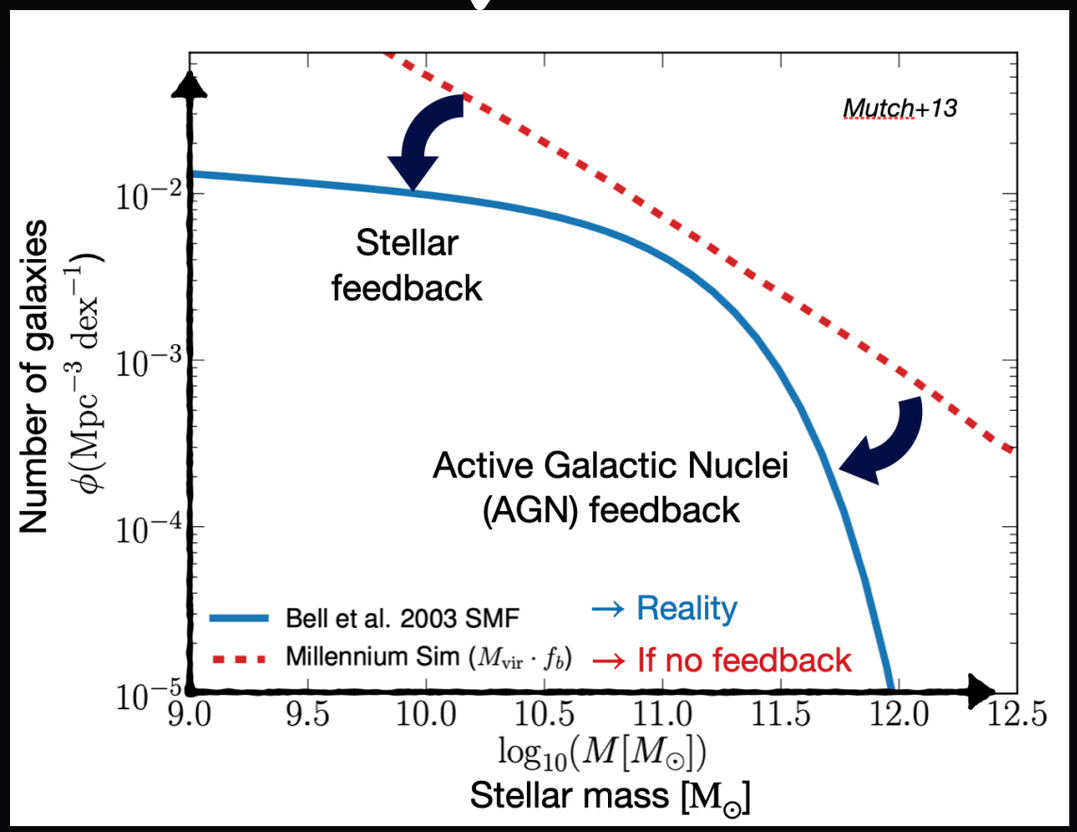


How did (massive) black holes and galaxies come into being?

What ruled the evolution of the first galaxies?

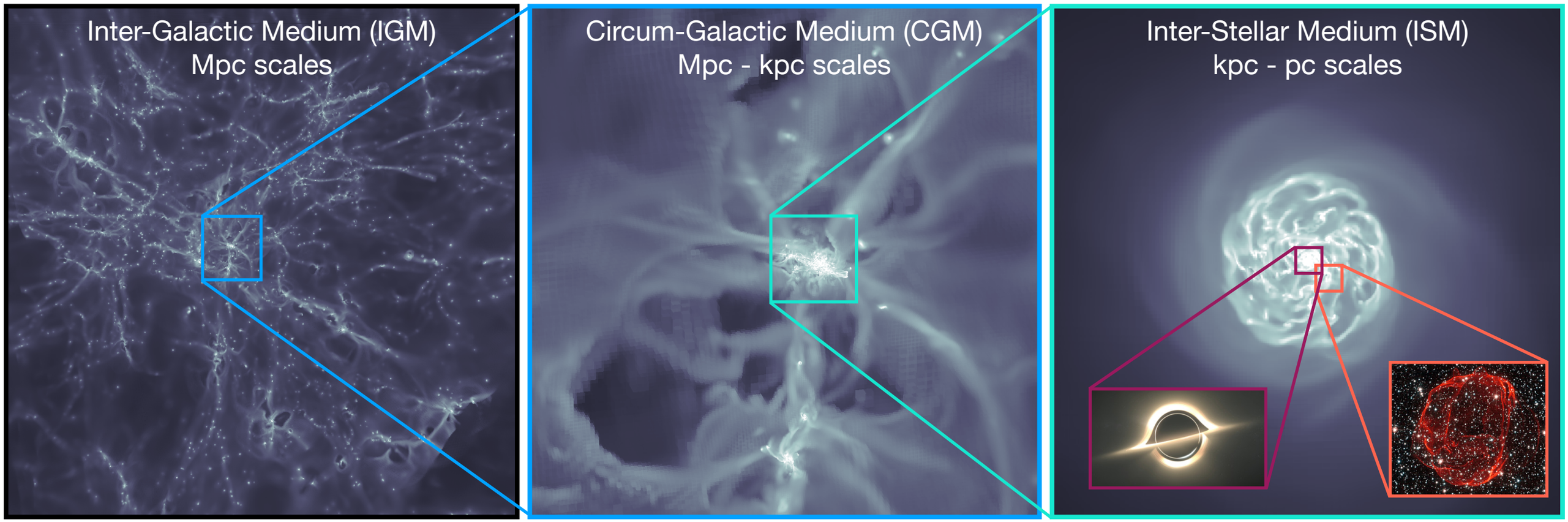
How did the intergalactic medium get reionised?

?



The evolution of galaxies: a multi-scale process ruled by feedback

Star formation, black hole growth



Stellar & AGN feedback

How does feedback affect the early Universe…

1

… by shaping
low-mass galaxies

… by impacting
the reionisation
of the Universe

2

… by regulating
the growth of SMBH

… by suppressing
star formation in
young massive galaxies

Stellar feedback:

Supernova
Radiation from stars
Cosmic rays

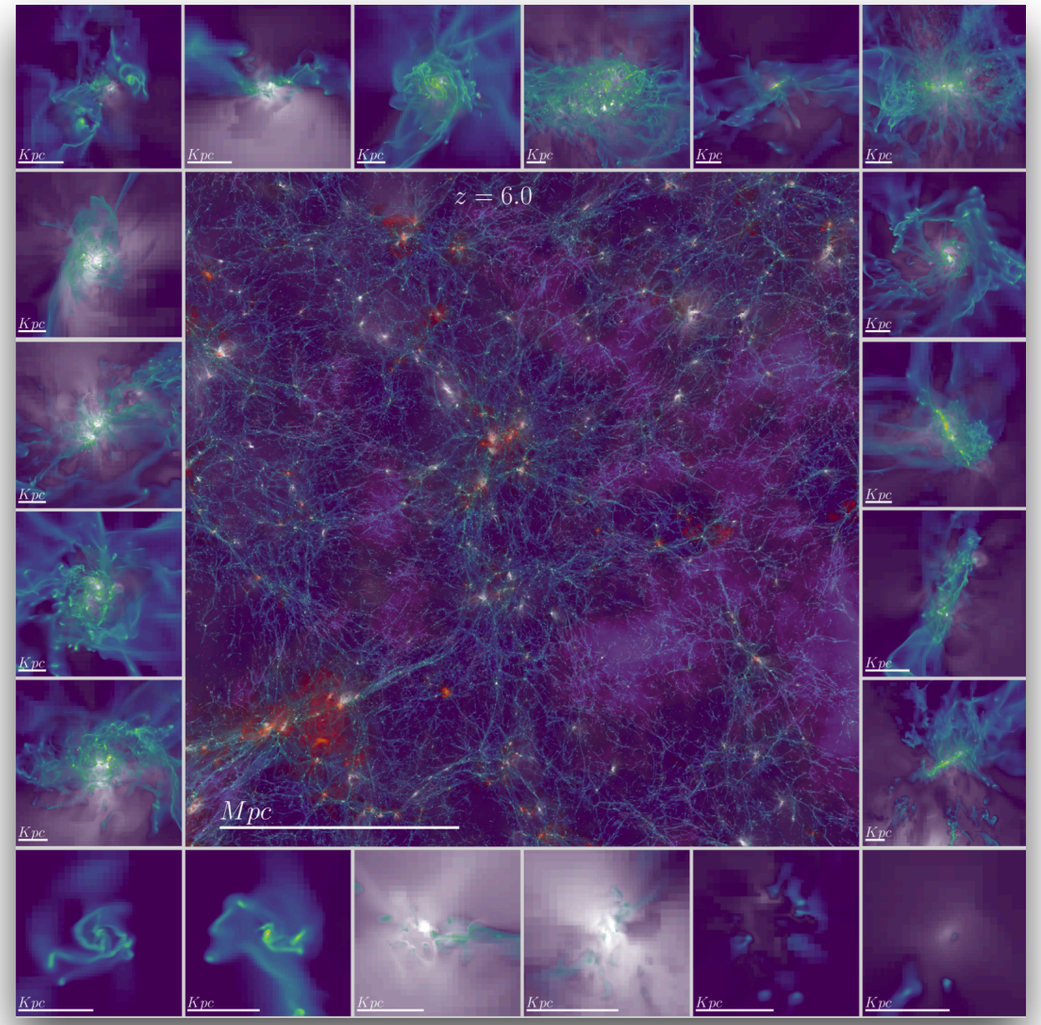
AGN feedback:

Winds
Jets

1 Stellar feedback during the Epoch of Reionisation

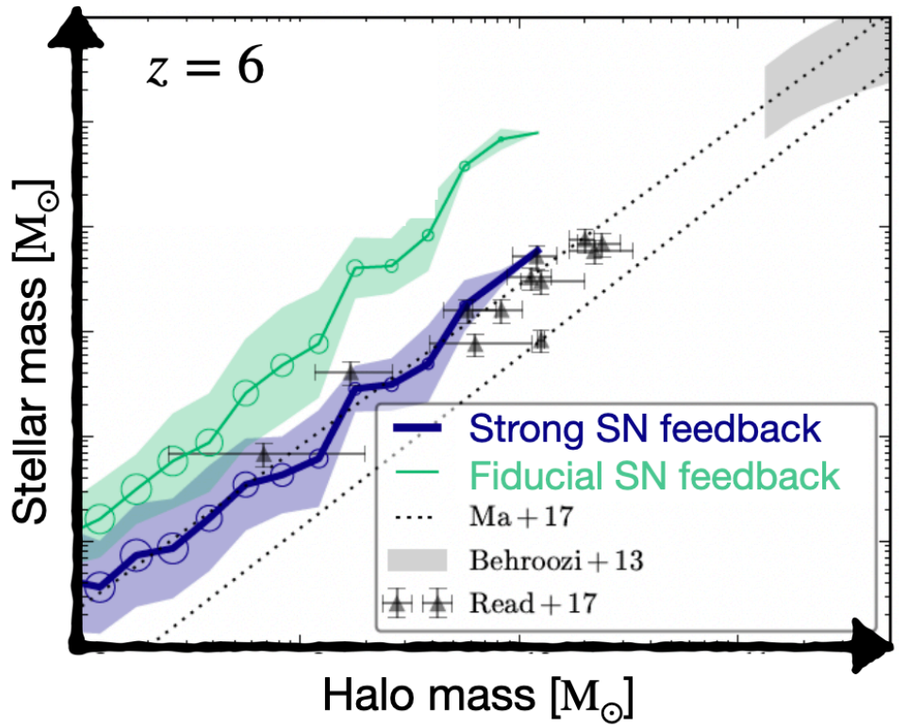
SPHINX cosmological simulations of the EoR

Credit: Rosdahl+18,22, Sphinx collaboration



See also Katz…MF+23 for the data release paper

Strong SN feedback model calibrated to match high-redshift observational constraints (SMHM, luminosity function, reionisation…)



Cosmic rays

Regulate star formation in dwarf galaxies
Carry dense and cold gas out of the ISM

See e.g. Salem & Bryan 2014, Girichidis+16, MF+22…
…And all previous talks from this session!

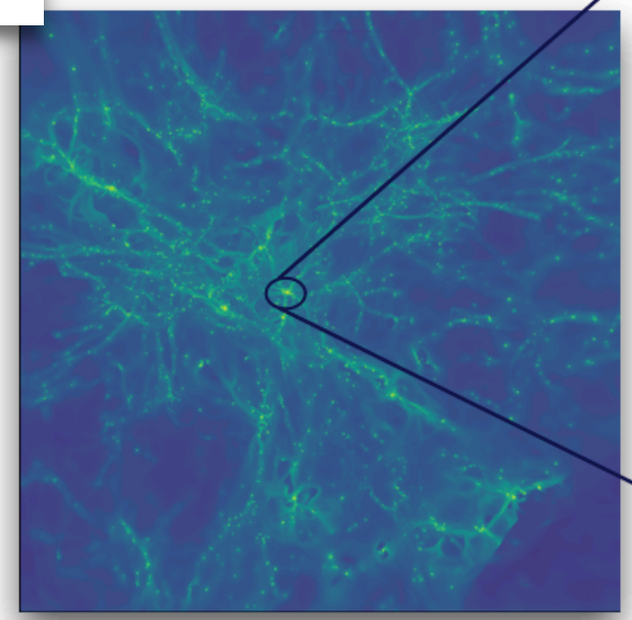
The effect of cosmic ray feedback at high-z

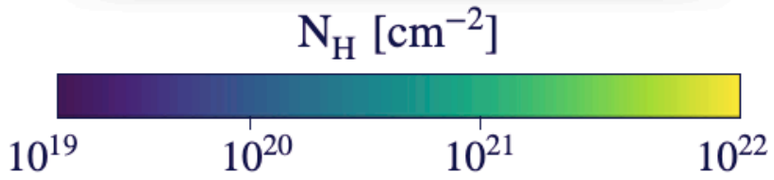
1st

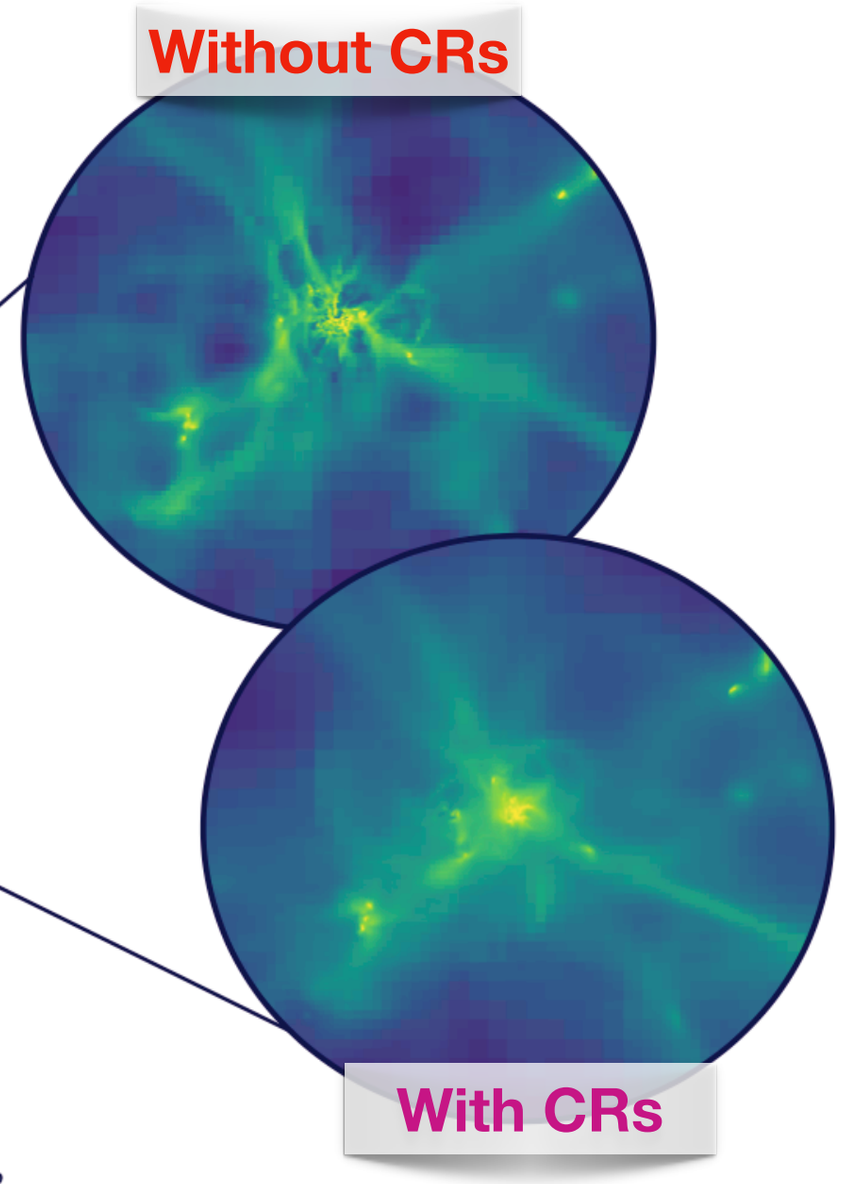
CR - RMHD simulations of thousands of high-z galaxies

RAMSES

Teyssier02, Rosdahl+13, Rosdahl & Teyssier 15, Dubois & Commerçon 16







2 SPHINX simulations

(10 cMpc)^3

~ 10 pc resolution

Down to z = 5

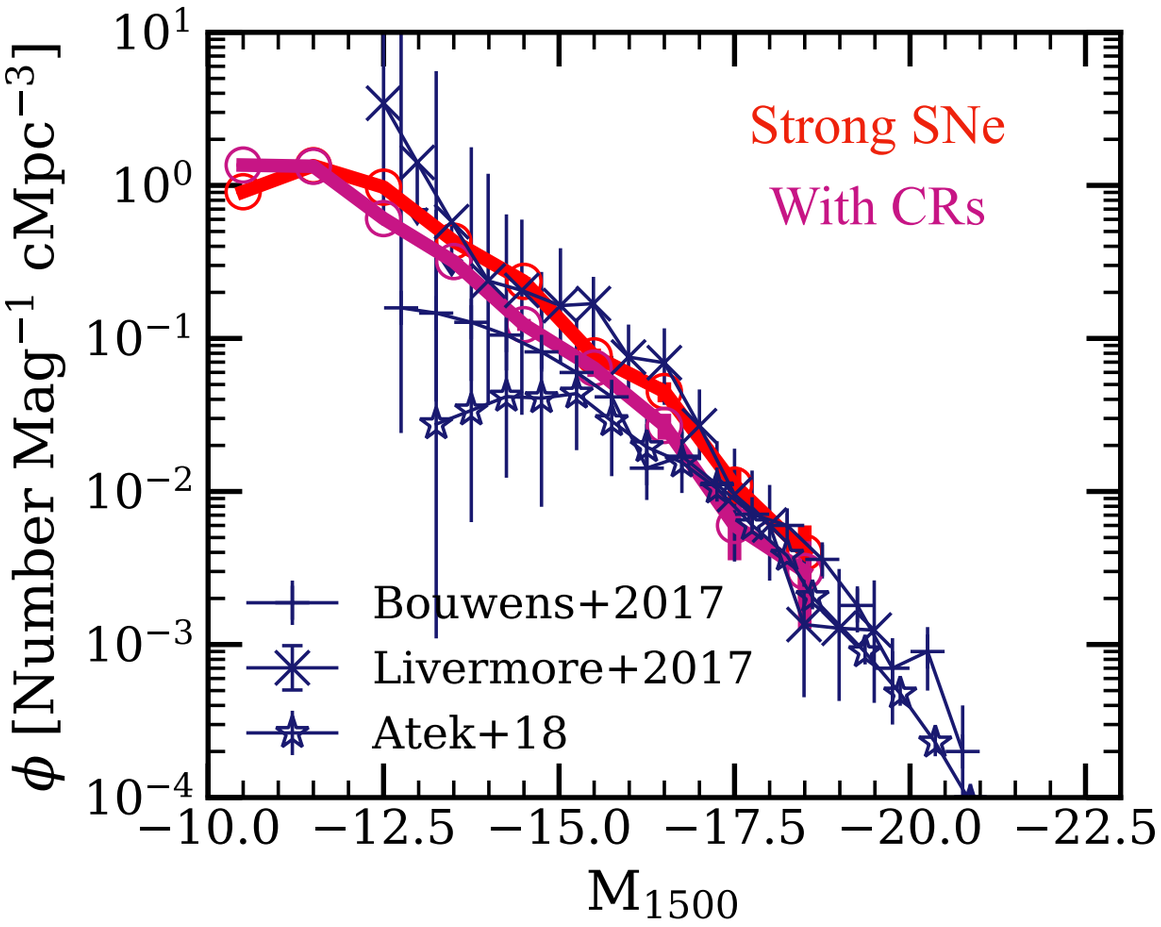
Sphinx "vanilla", strong SN feedback (4 SN / 100 $M_\odot$)

Moderate SN feedback + CRs (2 SN / 100 $M_\odot$ + $E_{cr} = 20\,\% E_{SN}$)

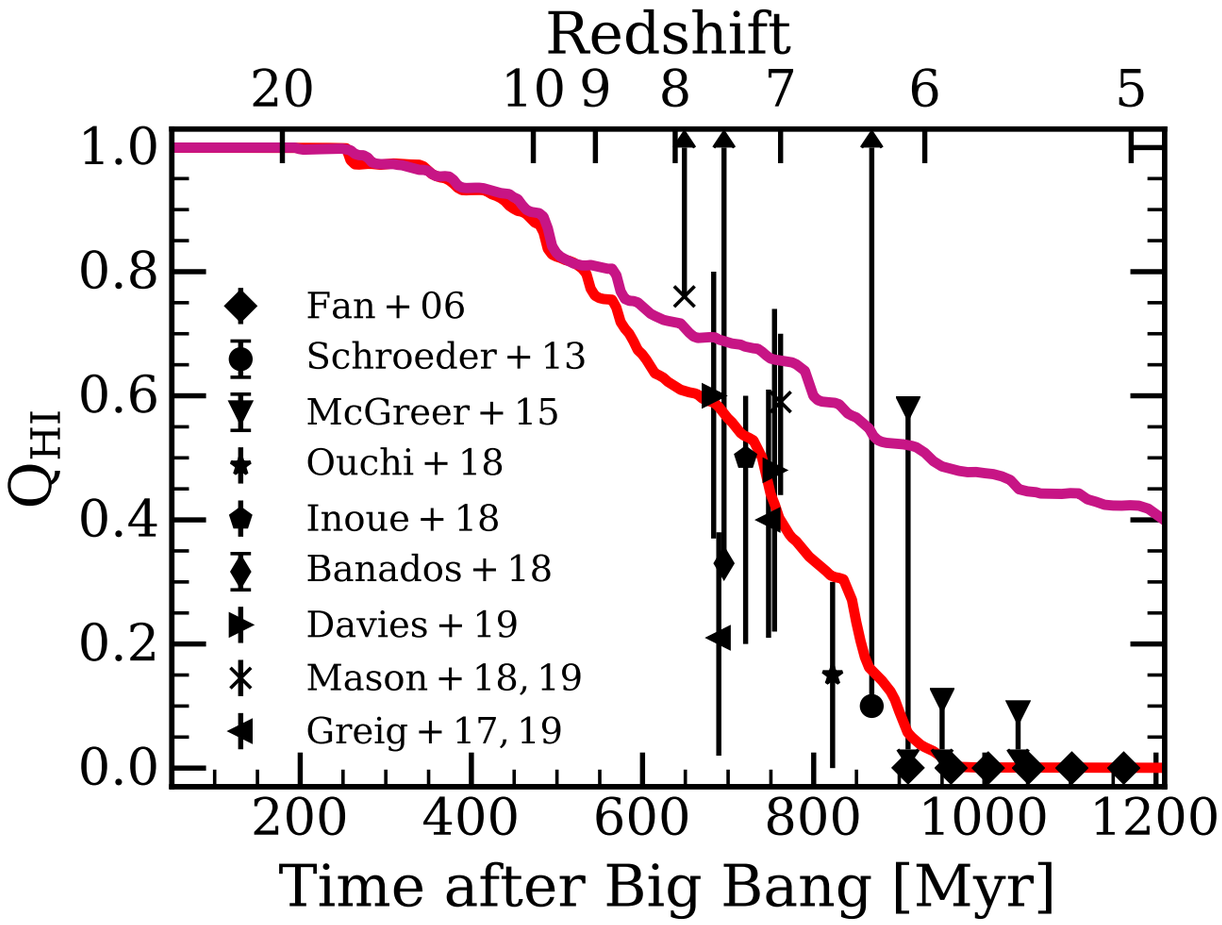
The impact of cosmic ray feedback at high-z

MF+in prep

Dust attenuated luminosity function at $z = 6$



Volume-filling fraction of neutral hydrogen

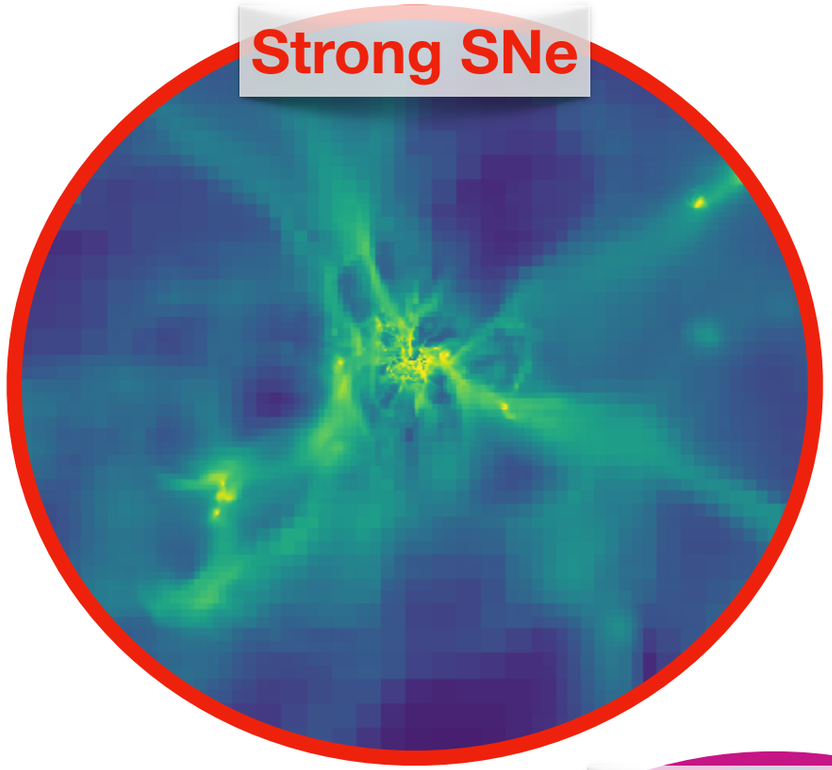


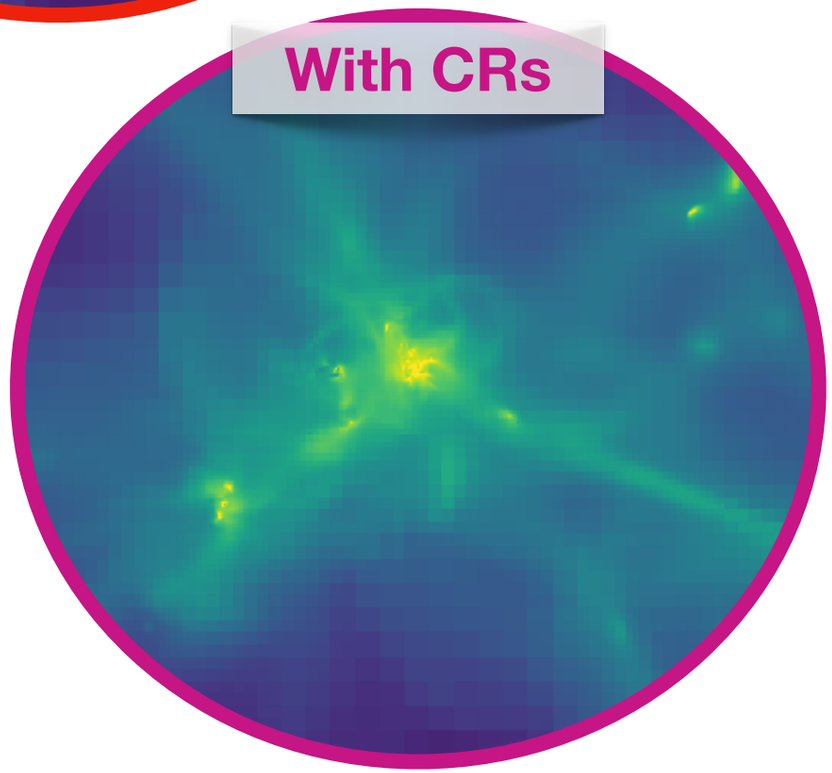
CRs: Contribute to regulate galaxy growth through cosmic times

CRs: Prevent the escape of ionising photons, which delays the reionisation…

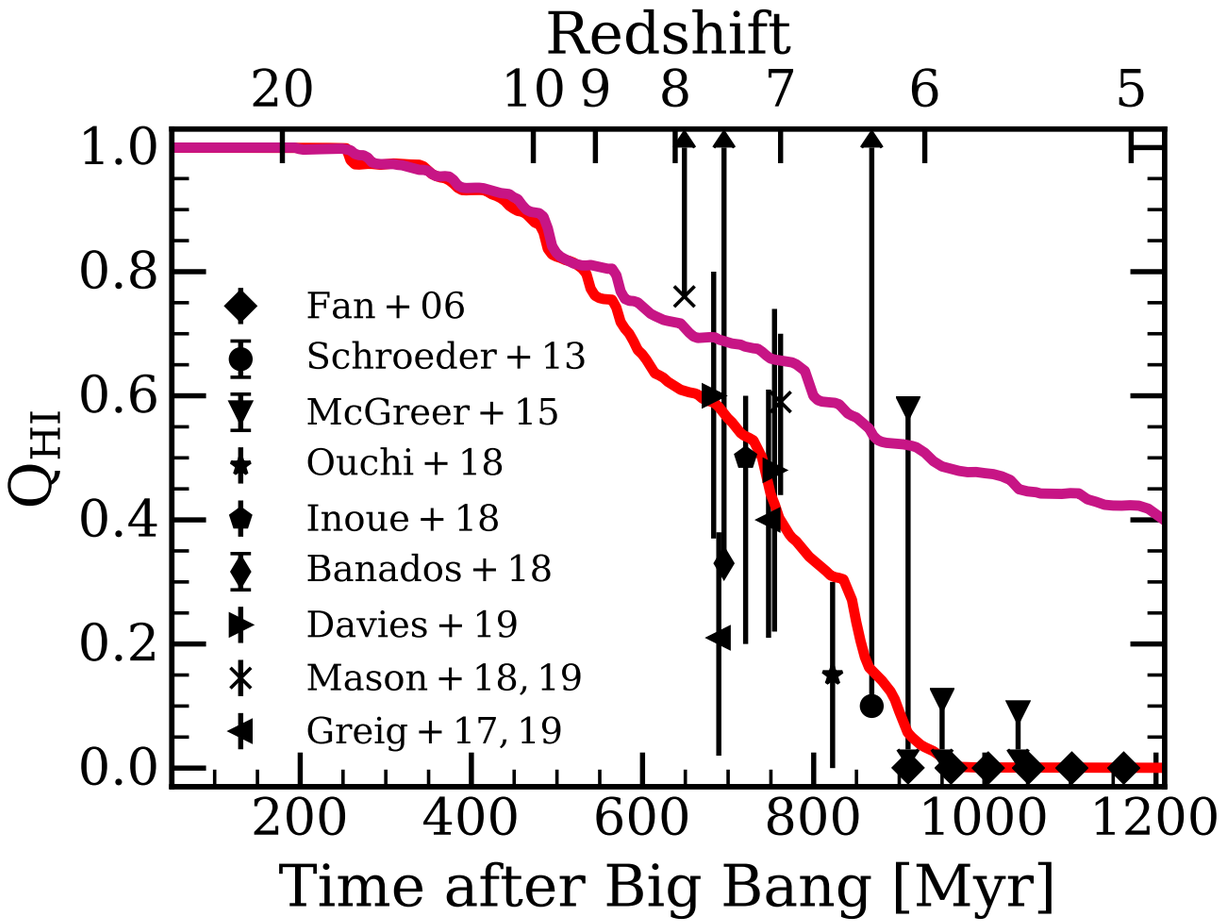
The impact of cosmic ray feedback at high-z

MF+in prep





Volume-filling fraction of neutral hydrogen



CRs: Prevent the escape of ionising photons, which delays the reionisation…

How does feedback affect the early Universe...

1

... by shaping
low-mass galaxies

... by impacting
the reionisation
of the Universe

2

... by regulating
the growth of SMBH

... by suppressing
star formation in
young massive galaxies

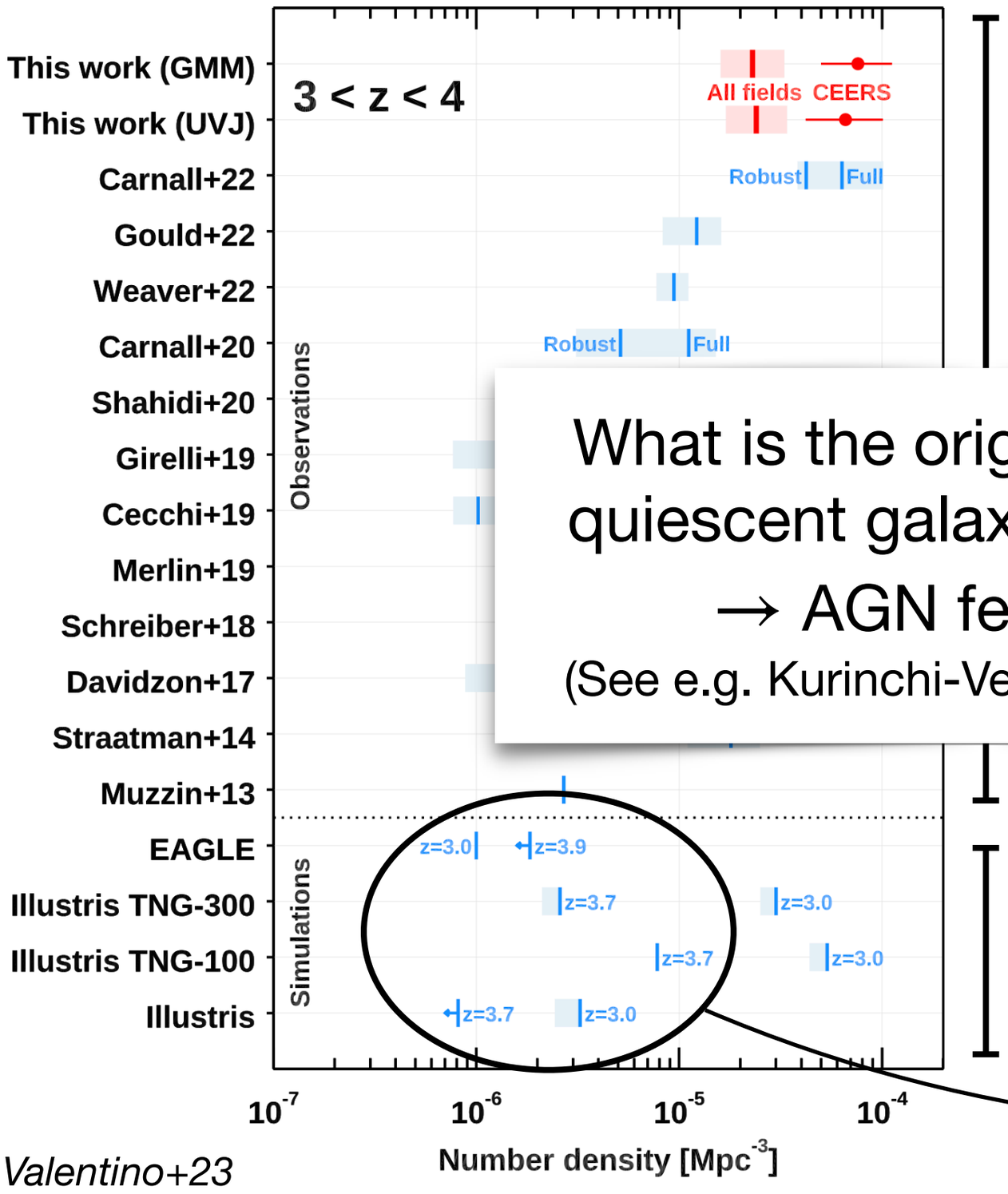
Stellar feedback:

Supernova
Radiation from stars
Cosmic rays

AGN feedback:

Winds
Jets

2 AGN feedback and star formation quenching at high-z



Valentino+23

Number density of massive ($M_{star} \geq 10^{10.6} M_{\odot}$) quenched galaxies in…

…Observations

…Simulations

What is the origin of massive quiescent galaxies at high-z?

→ AGN feedback?

(See e.g. Kurinchi-Vendhan, MF+subm)

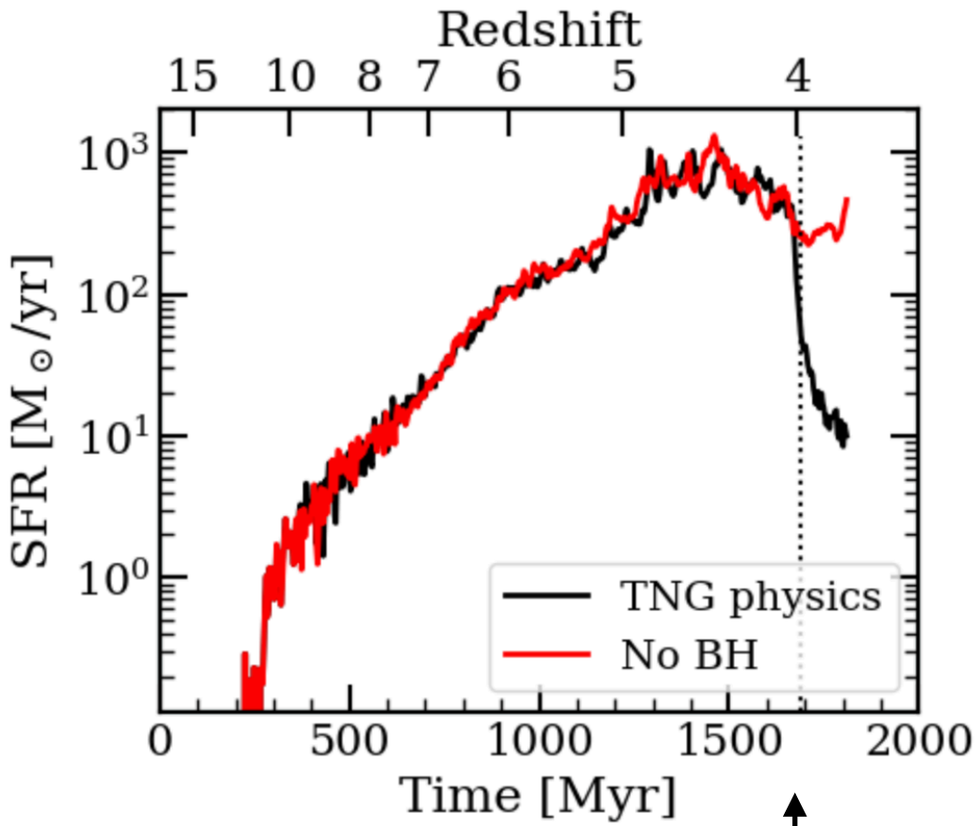
Simulations are in increasing tension with observations at z>3

AGN feedback and star formation quenching at high-z

MF+in prep

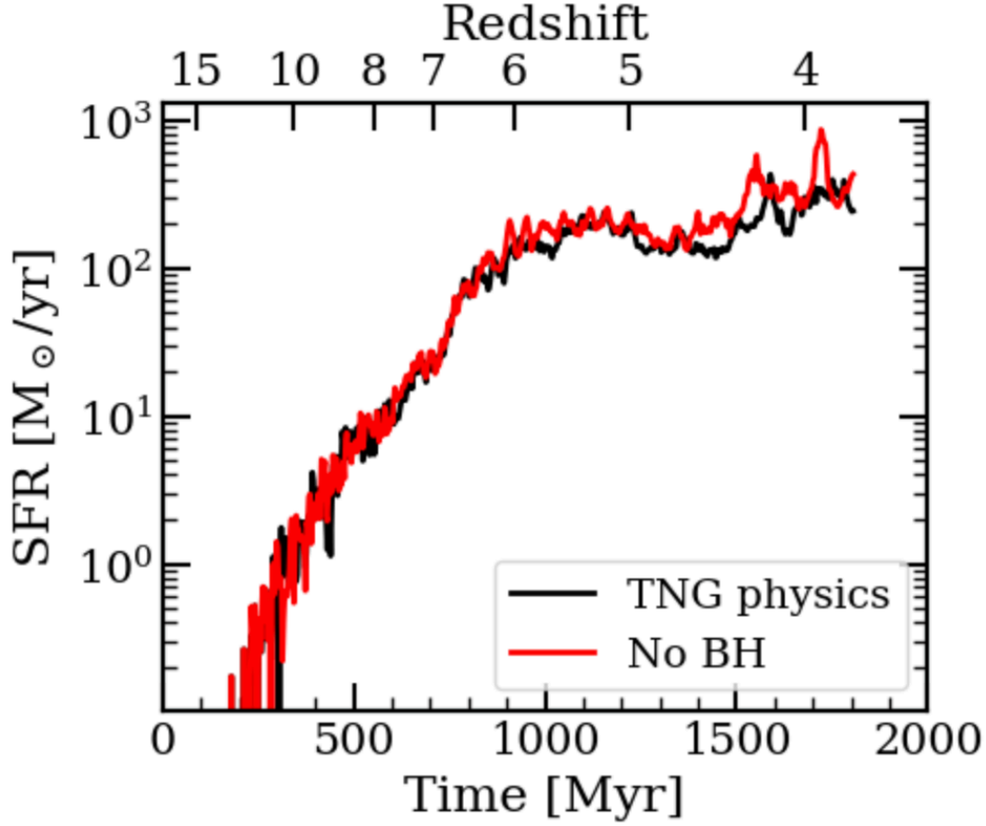
Zoom simulation of halos from Illustris-TNG100

Galaxy quenched (sSFR < 0.3 t_{Hubble}) at z=3.5



Jet mode kicks-in

Galaxy star-forming at z=3.5



Quenching coincides with the triggering of the AGN jet mode

AGN in the quasar mode only → inefficient in suppressing star formation

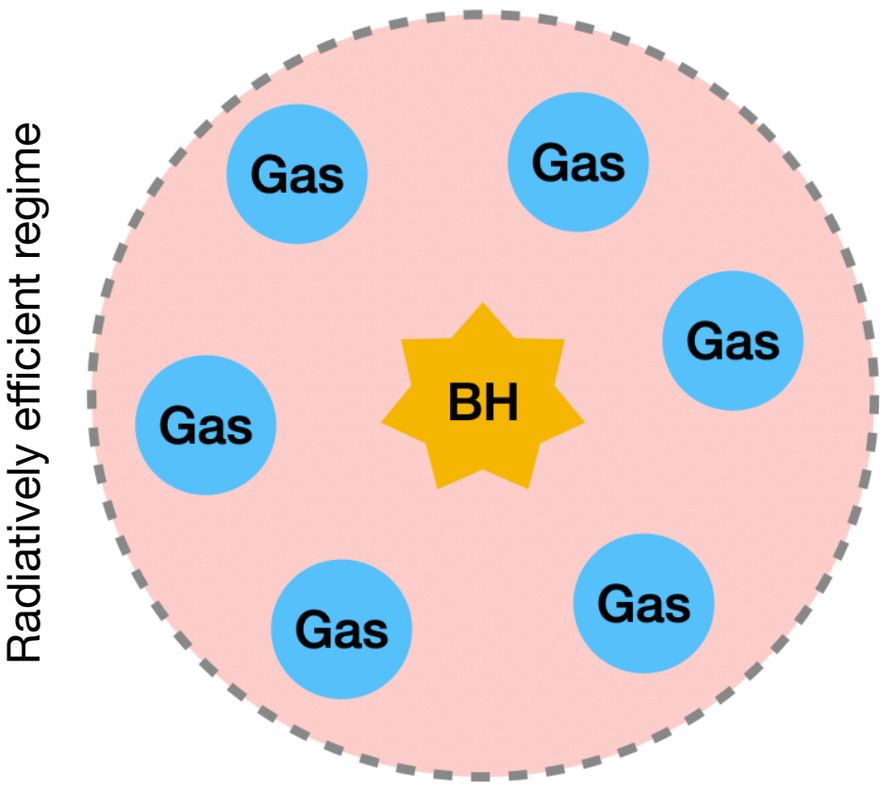
AGN feedback in the TNG simulations

See also Michaela Hirschmann's review talk this afternoon!

$$E_{AGN} = \epsilon_r \, \epsilon_f \, \dot{M}_{infl} \, c^2 \, \Delta t \propto \dot{M}_{BH}$$

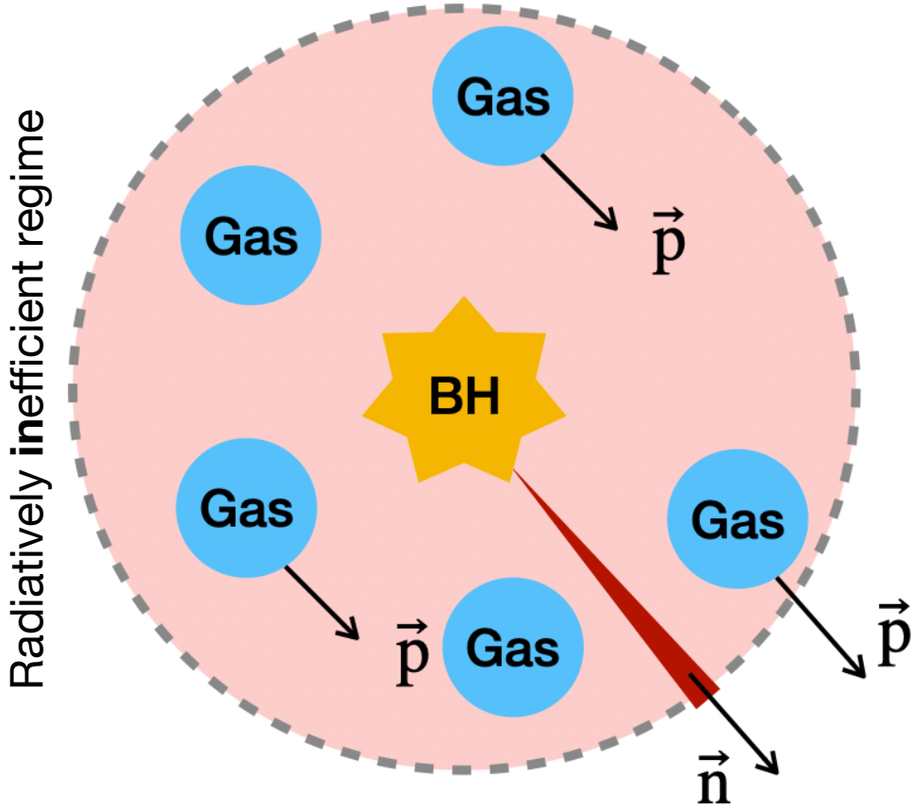
High accretion rate

Quasar mode
Isotropic, E_{th}



Low accretion rate

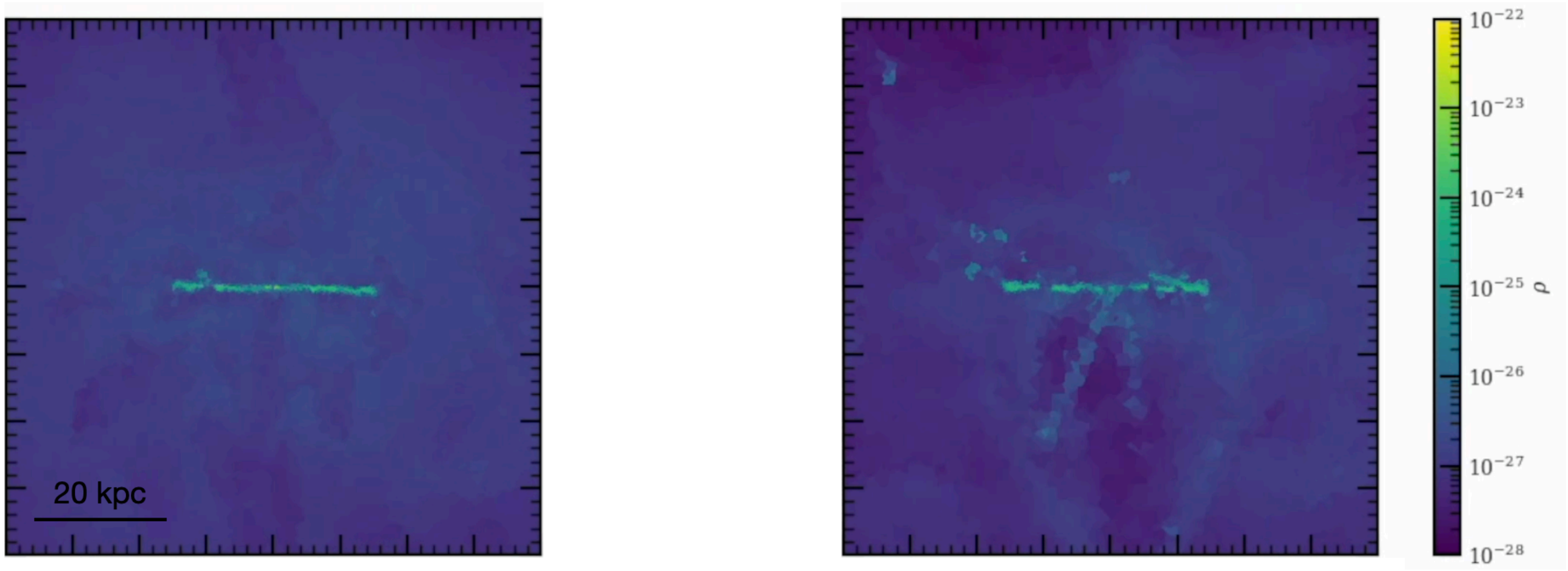
Jet mode
Random jet, E_{kin}

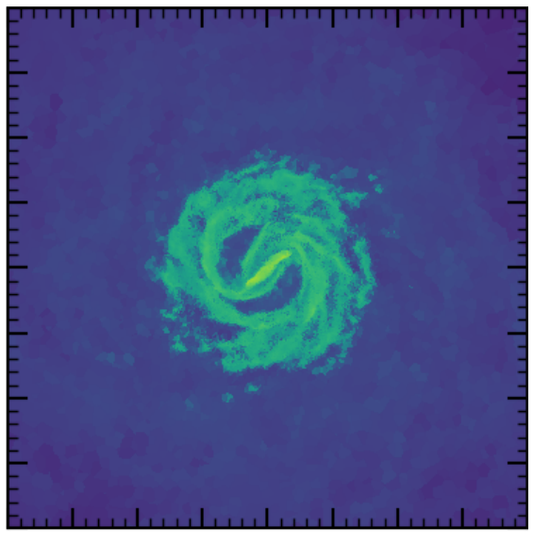


AGN feedback in the TNG simulations

High accretion rate

Low accretion rate

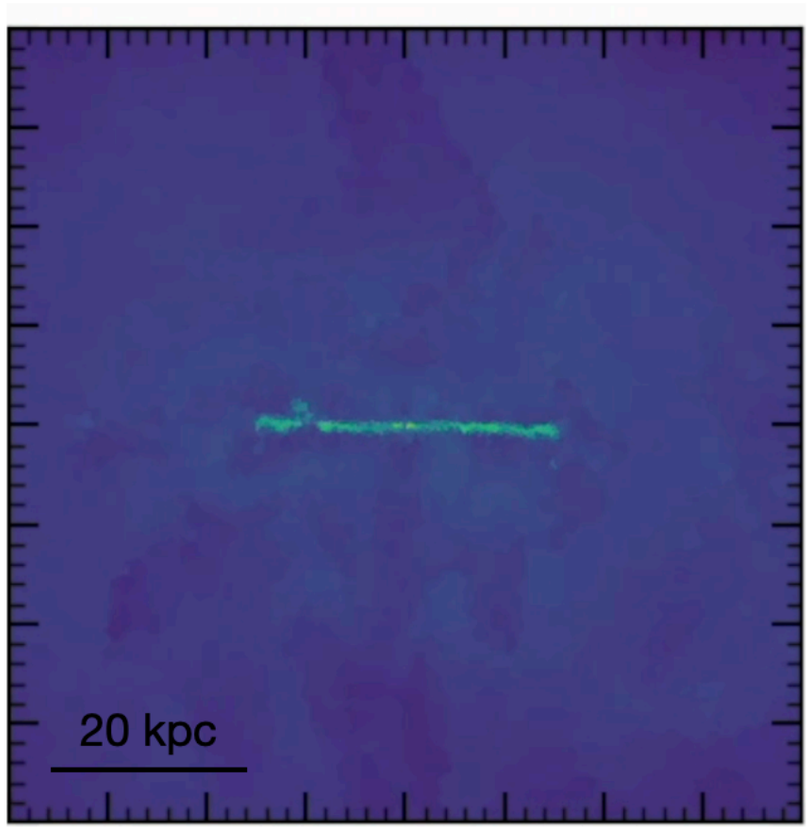




Milky-Way mass idealised galaxy
ICs from Kung-Yi Su (for GIZMO)
Adapted for Arepo by Bryan Terrazas

AGN feedback in the TNG simulations

High accretion rate



Does not reproduce AGN-driven outflows observed out to z=6
(Cicone+14, Genzel+14, Forster-Schreiber+14…)

→

Need a better modelling of the AGN winds in this regime

Towards a better modelling of AGN-driven winds

Developed by Ostriker+10,
Choi+12,15,17 in the Gadget code

Quasar mode in TNG → **"Mistral" AGN-winds (in Arepo)**

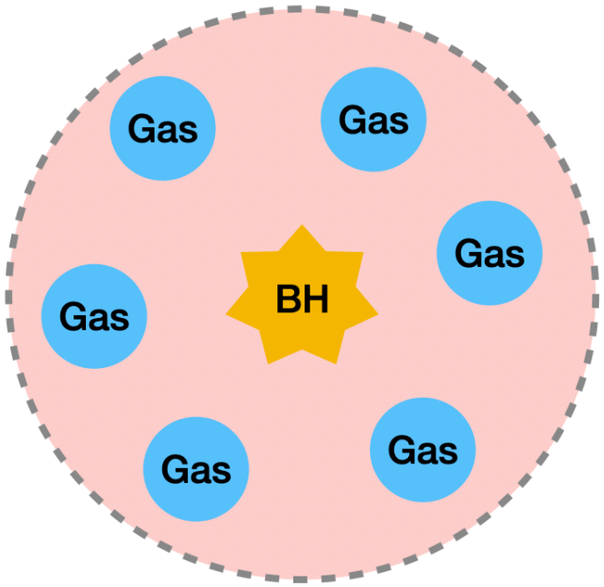
$$\dot{M}_{BH} = \dot{M}_{inflowing}$$

$$\dot{E}_{th} = \epsilon_f \, \epsilon_r \, \dot{M}_{inflowing} \, c^2$$

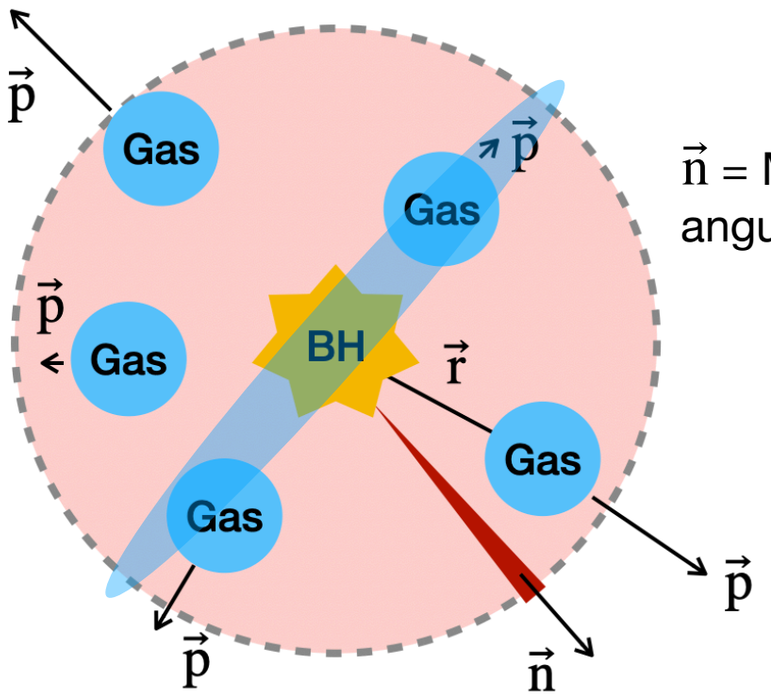
$$\dot{M}_{BH} = \dot{M}_{inflowing} - \dot{M}_{outflowing}$$

$$\dot{E}_w = \frac{1}{2} \dot{M}_{outflowing} v_w^2 = \epsilon_w \, \dot{M}_{BH} \, c^2$$

Isotropic thermal energy deposition



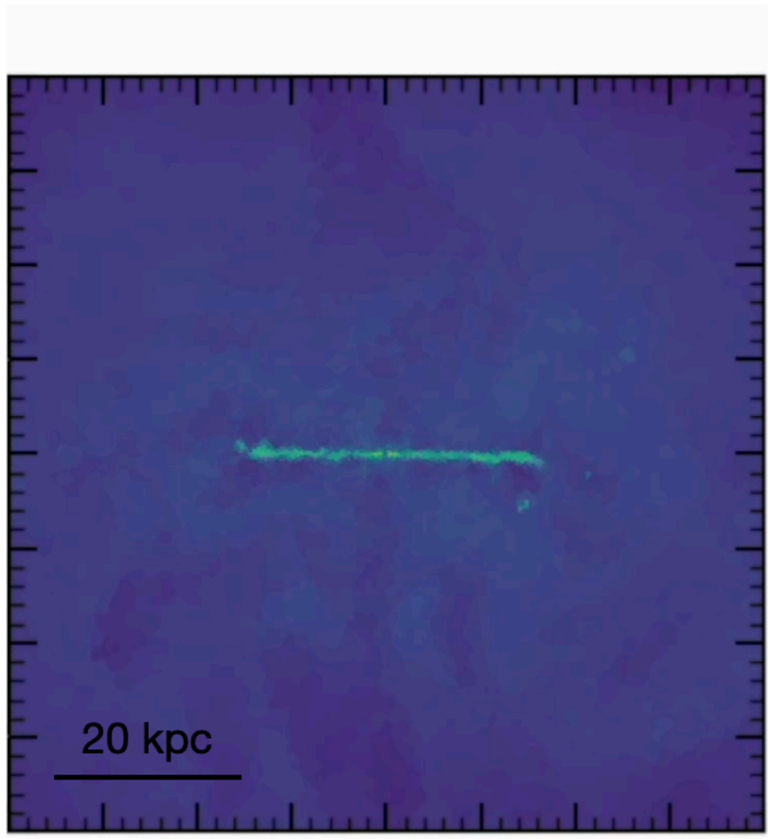
Subgrid modelling of AGN-driven winds



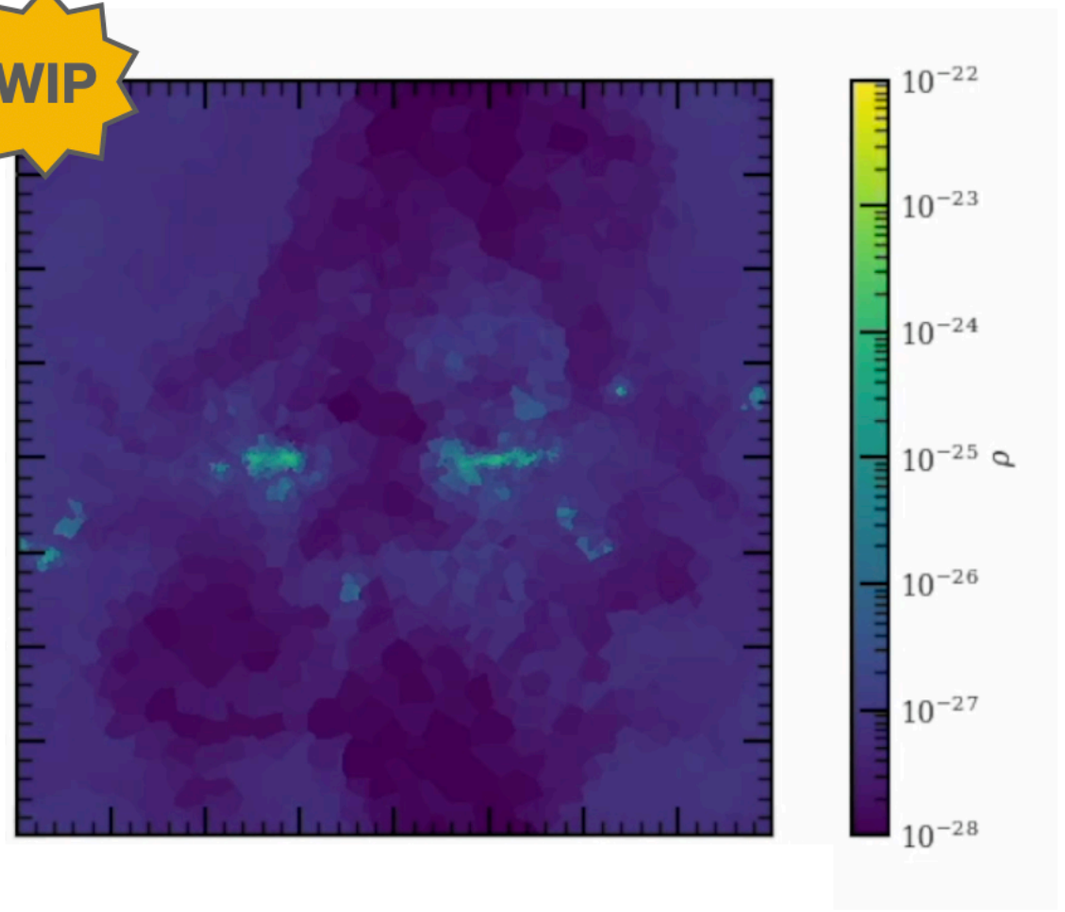
$\vec{n}$ = Mass-weighted angular momentum

AGN feedback in the TNG simulations

Quasar mode in TNG → “Mistral” AGN-winds (in Arepo)



WIP



CONCLUSIONS

How does feedback affect the early Universe…

1 Cosmic ray feedback

Regulates star formation in low-mass galaxies

Delays reionisation by suppressing the escape of photons

<u>BUT</u> very sensitive to the transport modelling!

&

2 AGN feedback

Suppresses star formation in massive galaxies

<u>BUT</u> only the kinetic jet mode is efficient!

We can use the EoR to understand feedback and constrain our models

We need to better model AGN-driven winds