Cosmic rays as a feedback agent in primordial galactic ecosystems

Ellis R Owen

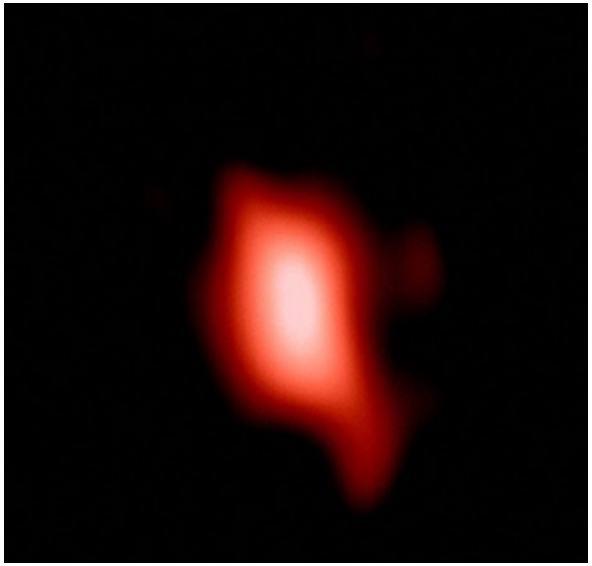
CICA Fellow

ellisowen.org

erowen@gapp.nthu.edu.tw

Institute of Astronomy
National Tsing Hua University

In collaboration with:
Kinwah Wu (UCL), Qin Han (UCL),
Pooja Surajbali (MPIK), Xiangyu Jin (Arizona)



MACS1149-JD1 with HST. Credit: NASA

27th ECRS – Nijmegen [virtual] – July 2022

Related publications

Owen, Jacobsen, Wu & Surajbali 2018 *MNRAS 481, 1, p.666*
(arXiv: 1808.07837)

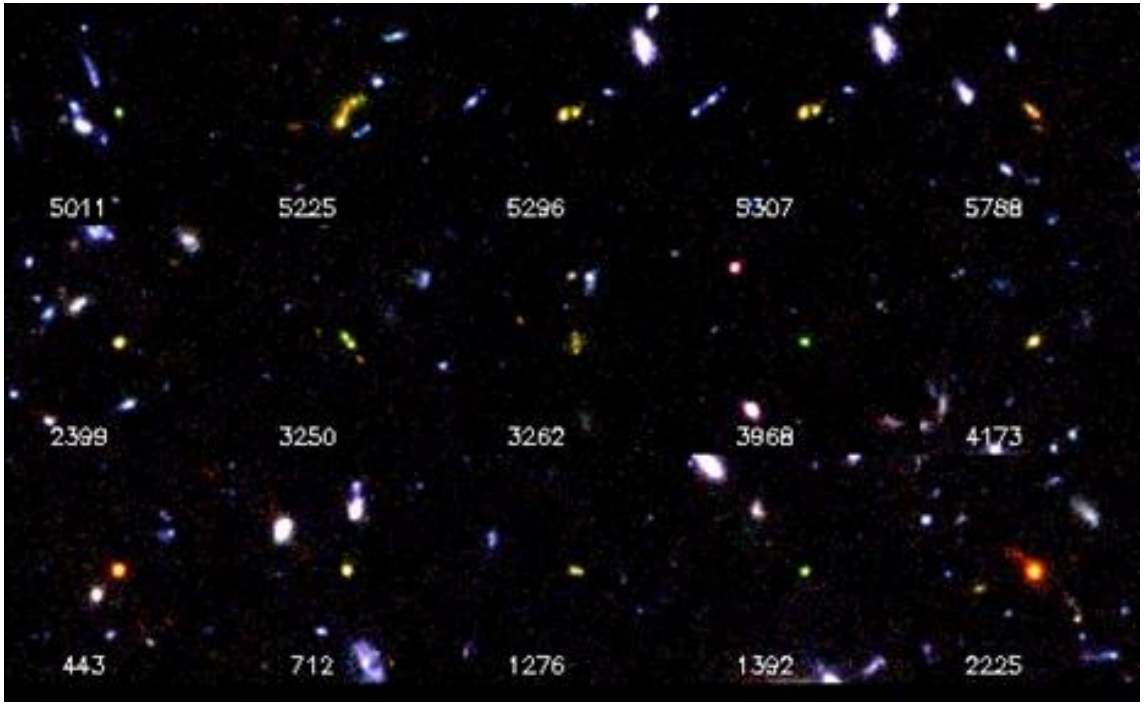
Owen, Jin, Wu & Chan 2019 *MNRAS 484, 2, p. 1645*
(arXiv: 1901.01411)

Owen, Wu, Jin, Surajbali & Kataoka 2019 *A&A 626, A85*
(arXiv: 1905.00338)

Claim

Cosmic rays in primordial protogalaxy ecosystems deliver a powerful, progressive feedback effect. This can bring about the downfall of their star-formation.

Primordial galaxies



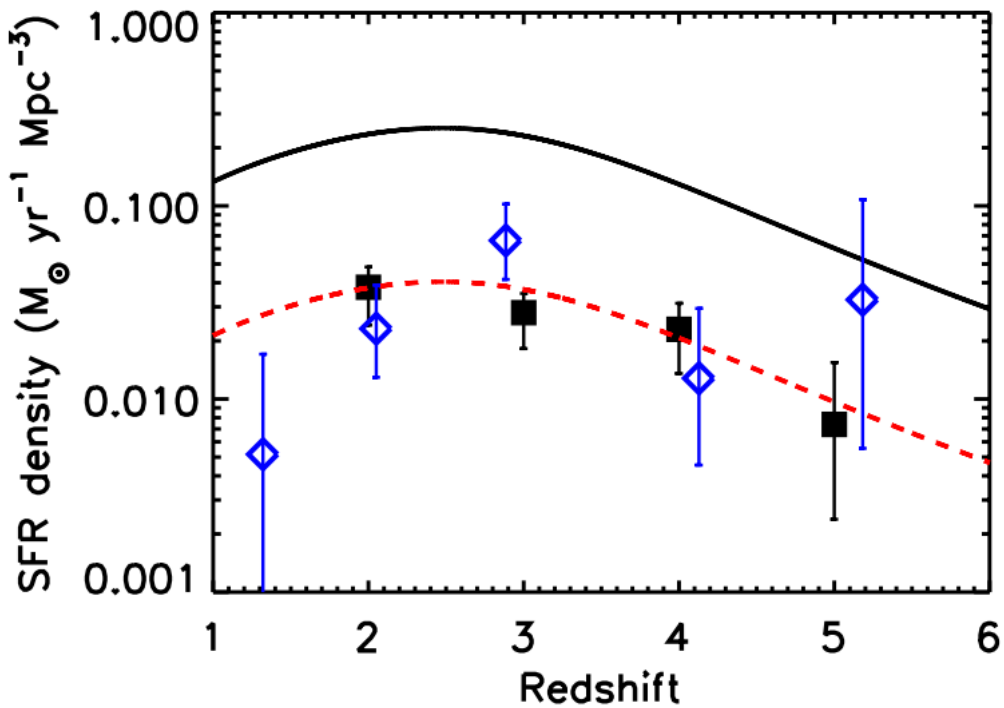
Isolated or in small associations

Small, closed ecosystems

HST/ACS images of galaxies at redshift z ~ 5 - 6

(Bremer and Lehnert 2005)

Primordial galaxies



SFR per co-moving volume inferred from SCUBA-2 sample

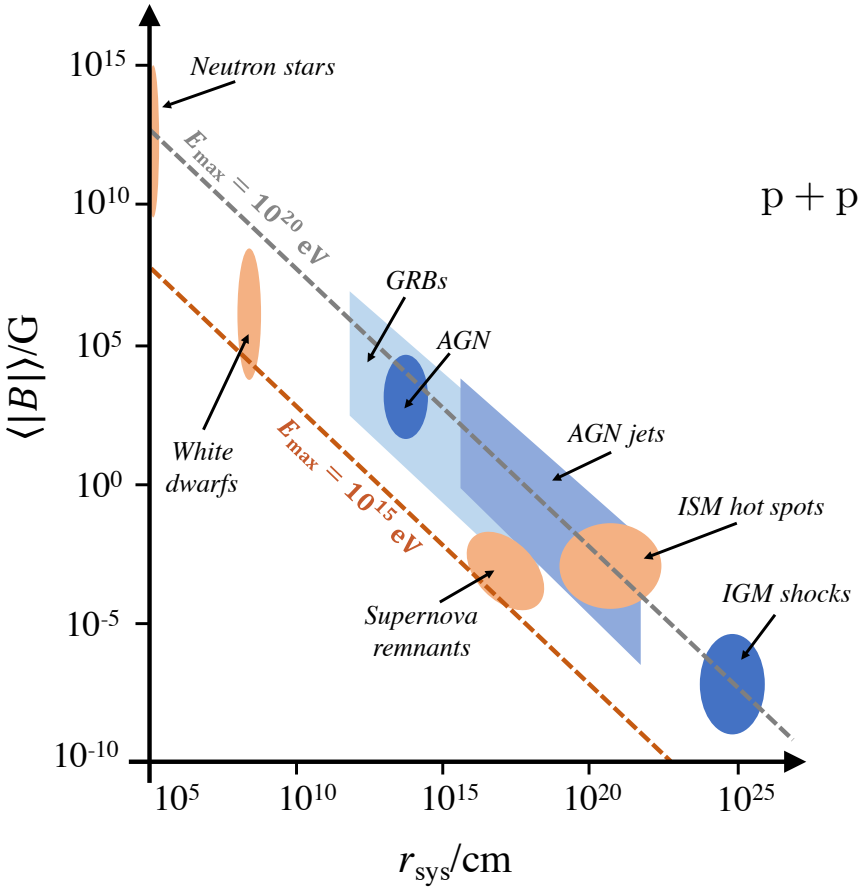
SFR of galaxies in this sample

$$\langle \mathrm{SFR} \rangle > 500\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$$

$$\mathrm{SFR}_{\mathrm{max}} \sim 6000\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$$

(Barger et al. 2014)

Cosmic rays in primordial galaxies



$$\mathrm{p} + \mathrm{p} \rightarrow \begin{cases} \mathrm{p} + \mathrm{p} + \pi^0 \\ \mathrm{n} + \mathrm{p} + \pi^+ \\ \mathrm{p} + \mathrm{p} + \pi^+ + \pi^- \end{cases}$$

+ pion multiplicities at higher energies

Pions decay to photons, muons, neutrinos, electrons, positrons, antineutrinos

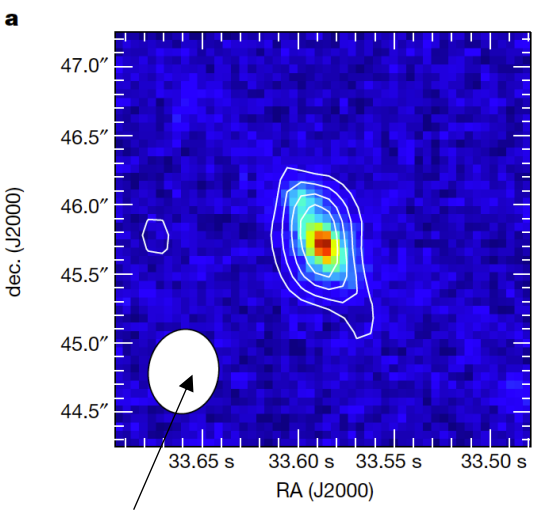
CR secondaries can thermalize in dense, pre-stellar gas clouds to drive heating, change the initial conditions of star-formation or even cause quenching

(Owen 2019, PhD thesis)

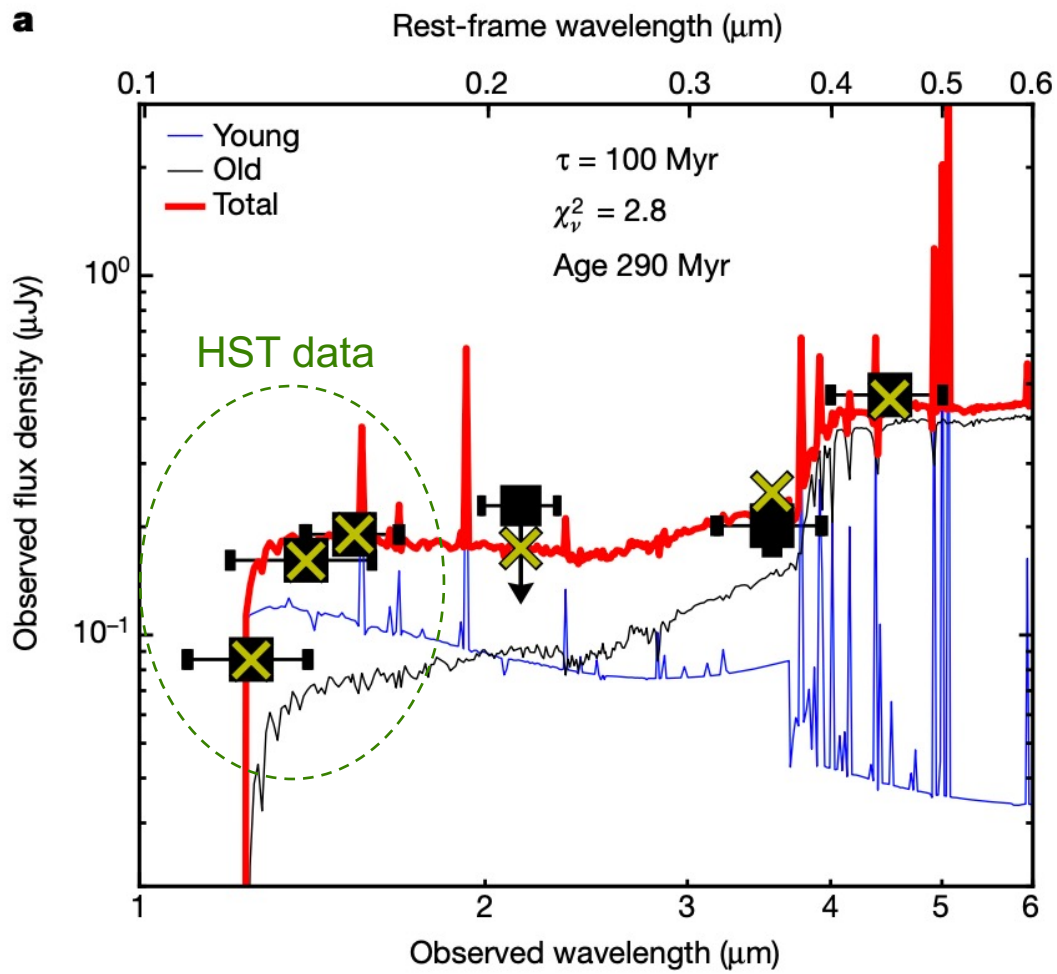
The curious case of MACS1149-JD1

[OIII] flux sets the SFR at epoch of observation; SED model fitting for star-formation history

ALMA [OIII] contours



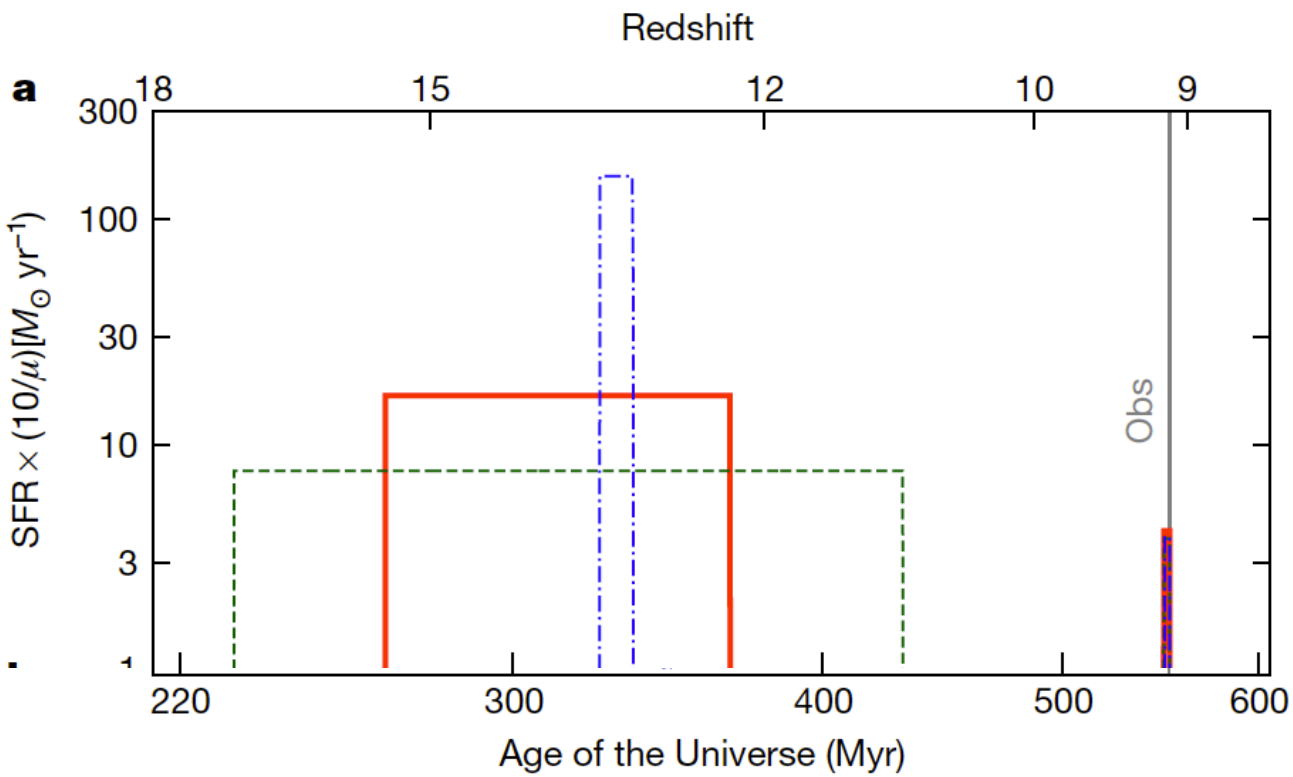
synthesized beam size



Data from HST, VLT, Spitzer/IRAC (Hashimoto et al. 2018)

The curious case of MACS1149-JD1

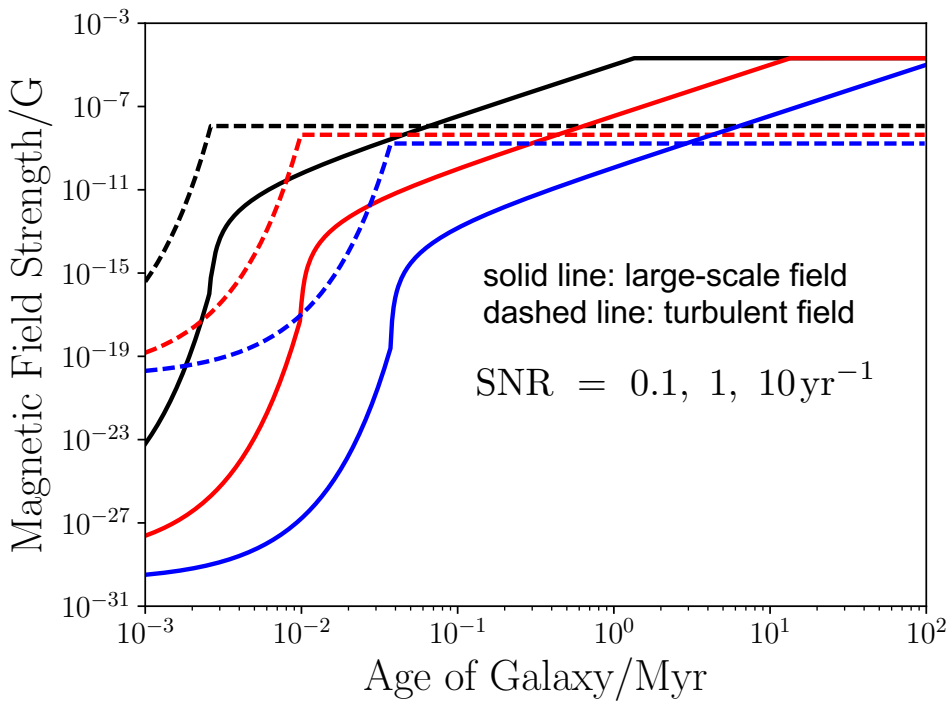
Spectral fitting gives a range of cases
All show burst phase and quenched phase



(Hashimoto et al. 2018)

Cosmic ray containment inside galaxies

Evolution of magnetic fields in proto-galaxies
(adopting the Schober et al. 2013 prescription)



two scale components:
– local scale
– turbulent forcing

SN turbulent dynamo amplification

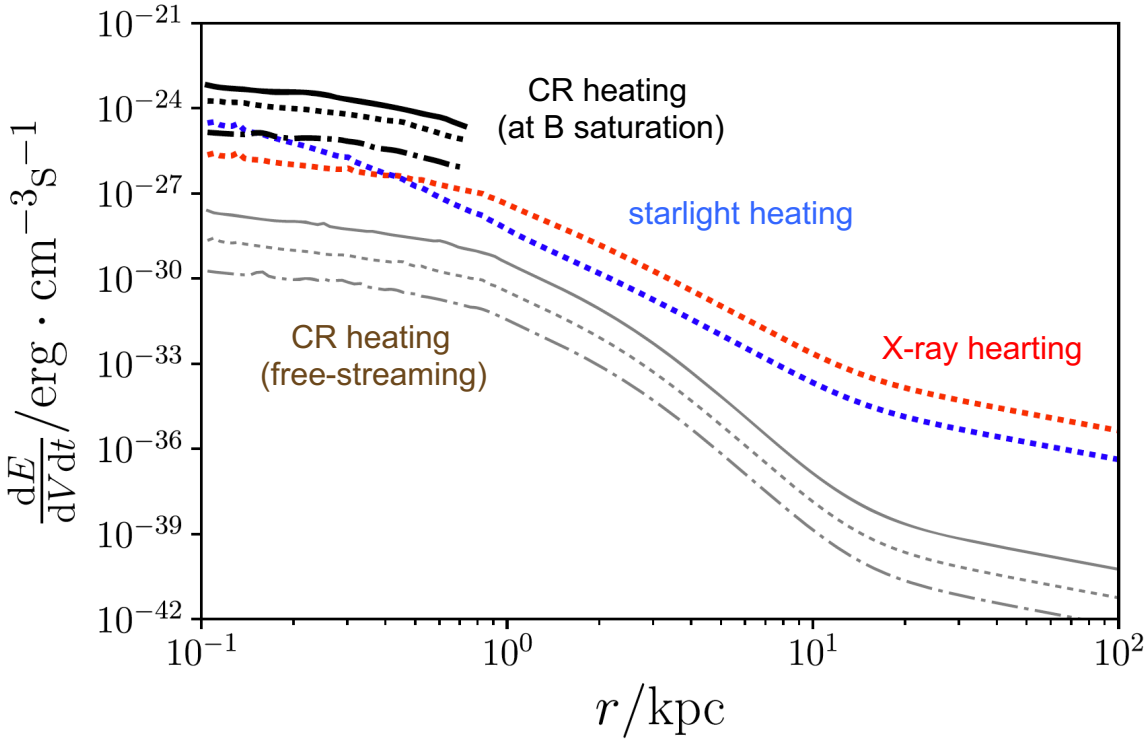
$$B \longrightarrow \sim \text{a few } \mu\mathrm{G}$$

$$B_{\mathrm{sat}} = \sim \sqrt{8\pi(\mathrm{KE}_{\mathrm{part}})}$$

(Owen, Jacobsen, Wu et al. 2018)

Cosmic ray heating inside galaxies

Cosmic-ray heating in comparison with other sources



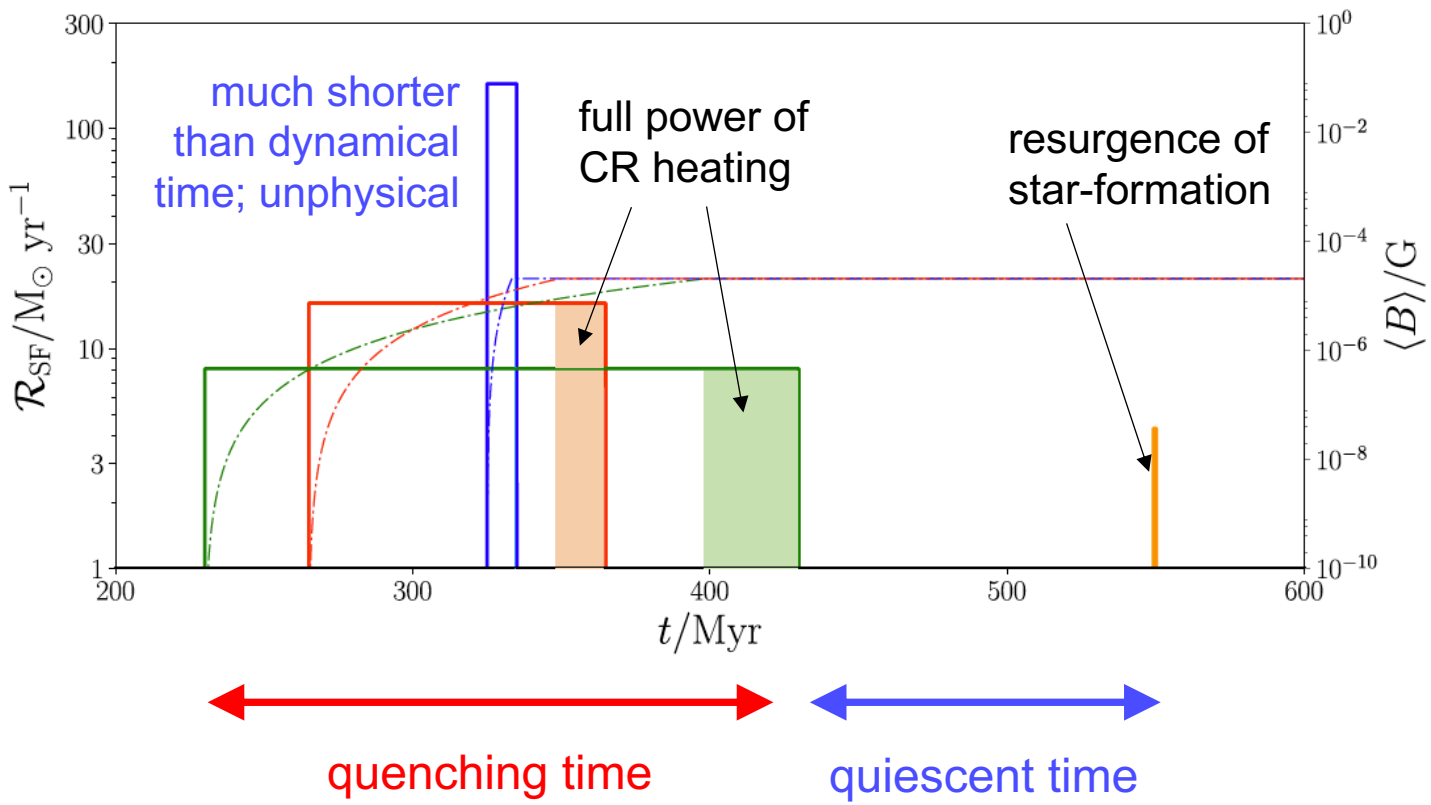
$$\mathrm{SNR} = 0.1,\ 1,\ 10\,\mathrm{yr}^{-1}$$

(Owen, Jacobsen, Wu et al. 2018)

Cosmic rays and structural evolution of the Universe

(Owen, Jin, Wu et al. 2019)

MACS1149-JD1



Unravelling feedback mechanisms

Conventional means to stop star-formation in primordial systems:

- Starlight
- AGN feedback
- **Violent supernova/hypernova activity**
- **Cosmic rays**

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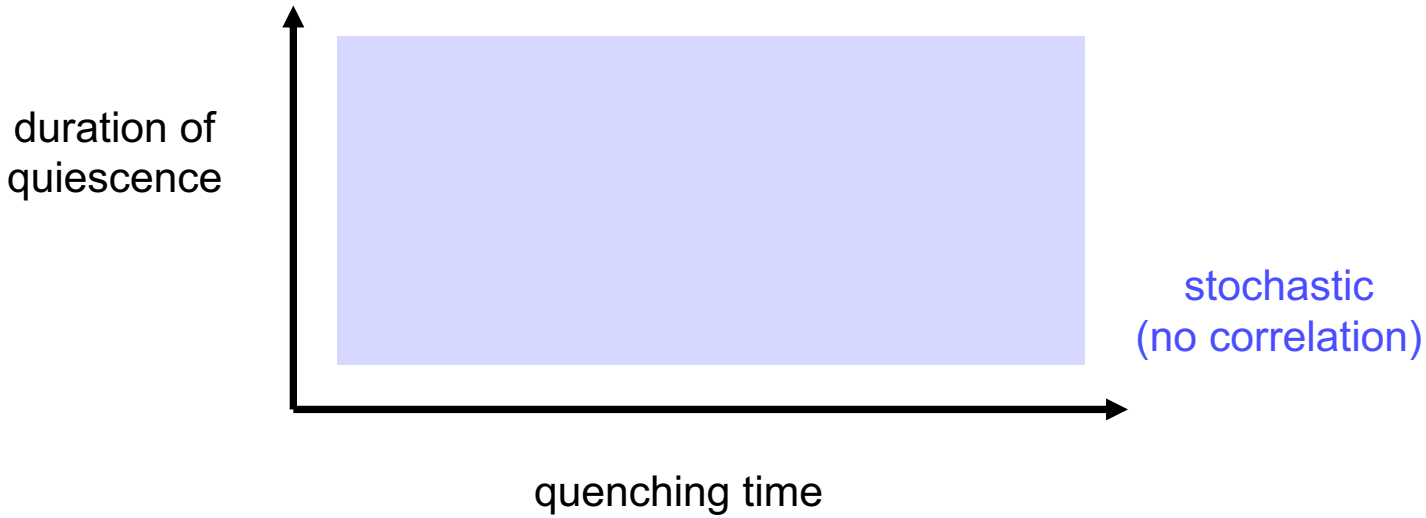

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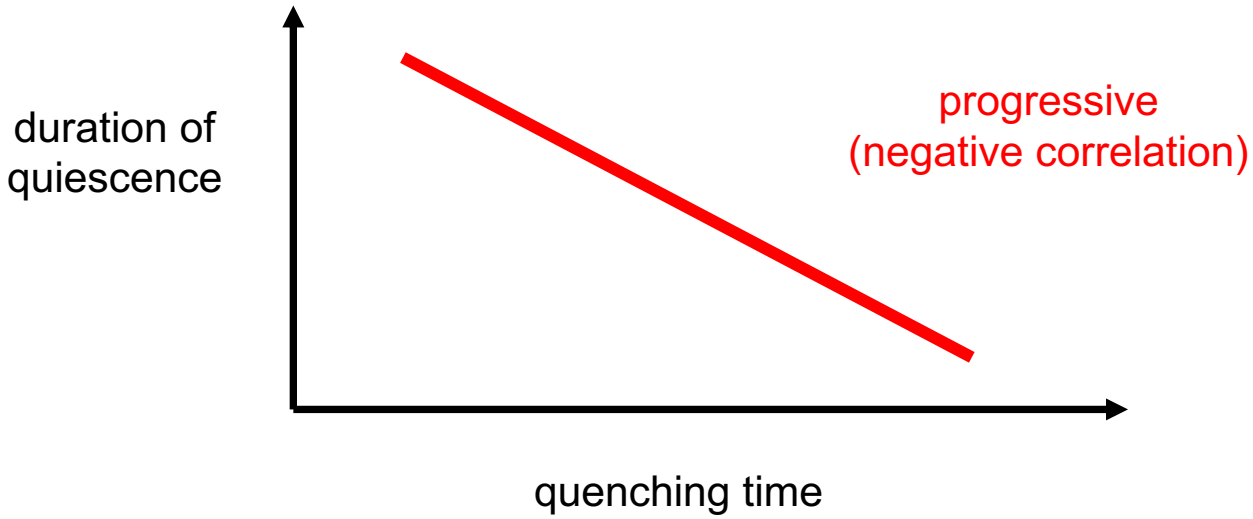
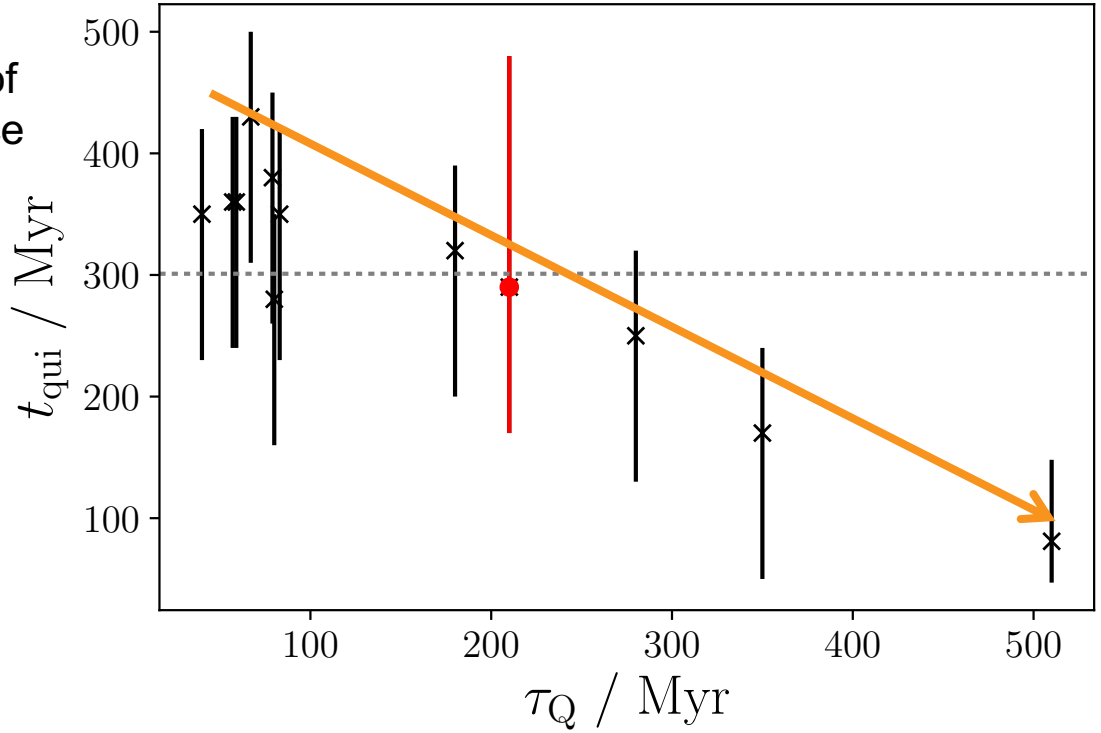


Post-starburst galaxies

11 post-SB high-z galaxies (archive data)

Selected for: high stellar mass, low SFR, no AGN indications

duration of quiescence



quenching time

possible indication of negative correlation

in tension with a sudden/stochastic process

(Owen, Wu et al. 2019)

Future opportunities

Requirements:

Expanded surveys to pin-down progressive (CR) feedback in promordial galaxy populations

Opportunities:

1. ALMA

[OIII] emission line at 88 μm can reach high-z with high angular resolution to access SFR in young galaxies at z>9

2. James Web Space Telescope

Crucial to improve constraints on SED models & stellar populations to resolve star-formation histories. Can reach more and more distant systems than HST.

Summary

1. CR feedback leaves a distinctive progressive feedback effect in the IR/NIR SEDs of primordial galaxies
2. We can access this with new facilities (ALMA and JWST)
3. With broader population studies, we can resolve the feedback activity of high energy CRs in galaxies in early epochs and unveil their role in the structural evolution of the Universe

Owen, Wu, Jin, Surajbali & Kataoka
2019 *A&A 626, A85* (arXiv: 1905.00338)