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Intermittent jets in groups and clusters

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The questions

- How important is environment to observable properties of radio lobes on scales of 10s and 100s of kpc?
  - Radio morphology – environment relation
  - Dynamical models predict a strong scaling of luminosity with gas density
- How does jet intermittency affect observable properties and feedback efficiency?
  - Does *how* (not just *how much*) energy is supplied matter?
- 2D axisymmetric simulations of non-relativistic, initially conical jets, using the PLUTO code
- Same total energy and jet power, supplied in different ways, to different environments

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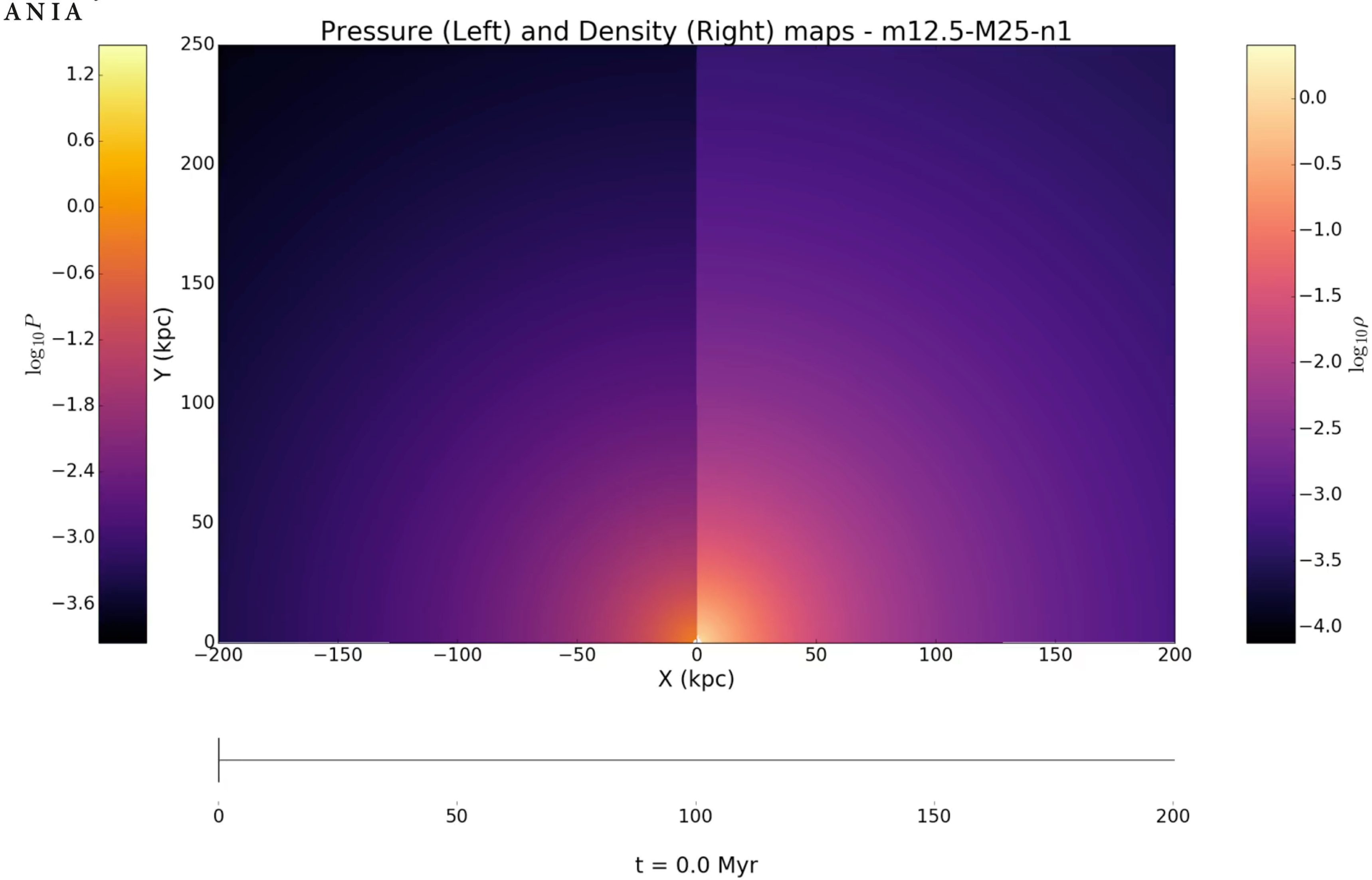

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Simulation setup

Environment	# outbursts	Code
Poor Group (3 x 10^{12} M_{sun})	1	M12.5-M25-n1
	2	M12.5-M25-n2
	3	M12.5-M25-n3
	4	M12.5-M25-n4
Cluster (3 x 10^{14} M_{sun})	1	M14.5-M25-n1
	2	M14.5-M25-n2
	3	M14.5-M25-n3
	4	M14.5-M25-n4

Inject the same energy, at the same *time-averaged* rate:

- Into different environments (cluster vs group)
- Using different number of episodes

Constant parameters:

- **Jet power**: 10^{37} W, representative of a weak FR-II jet
- Total **active** time: 40 Myr
- Total **quiescent** time: 160 Myr

How important is intermittency of feedback, to observables and feedback efficiency?

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Environments

Environment	# outbursts	Code
Poor group (3 x 10^{12} M_{sun})	1	M12.5-M25-n1
	2	M12.5-M25-n2
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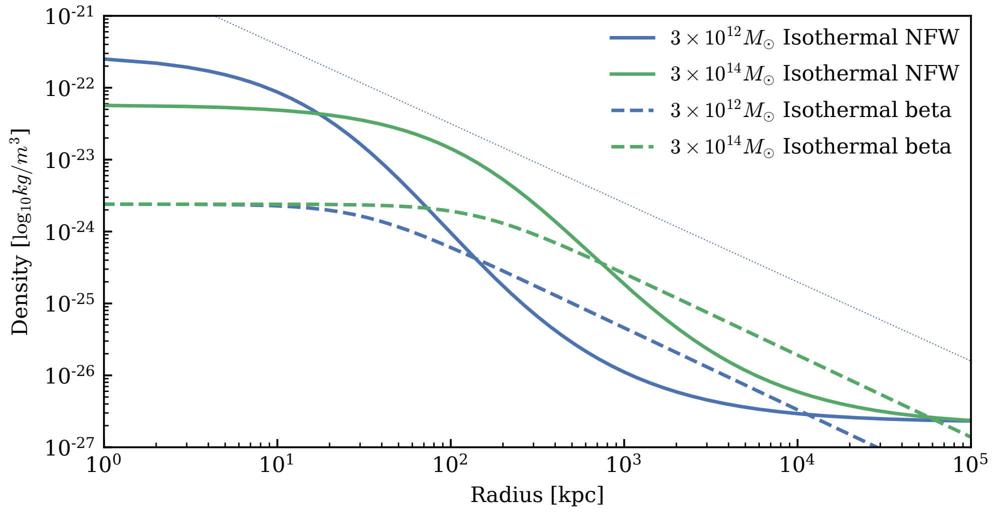
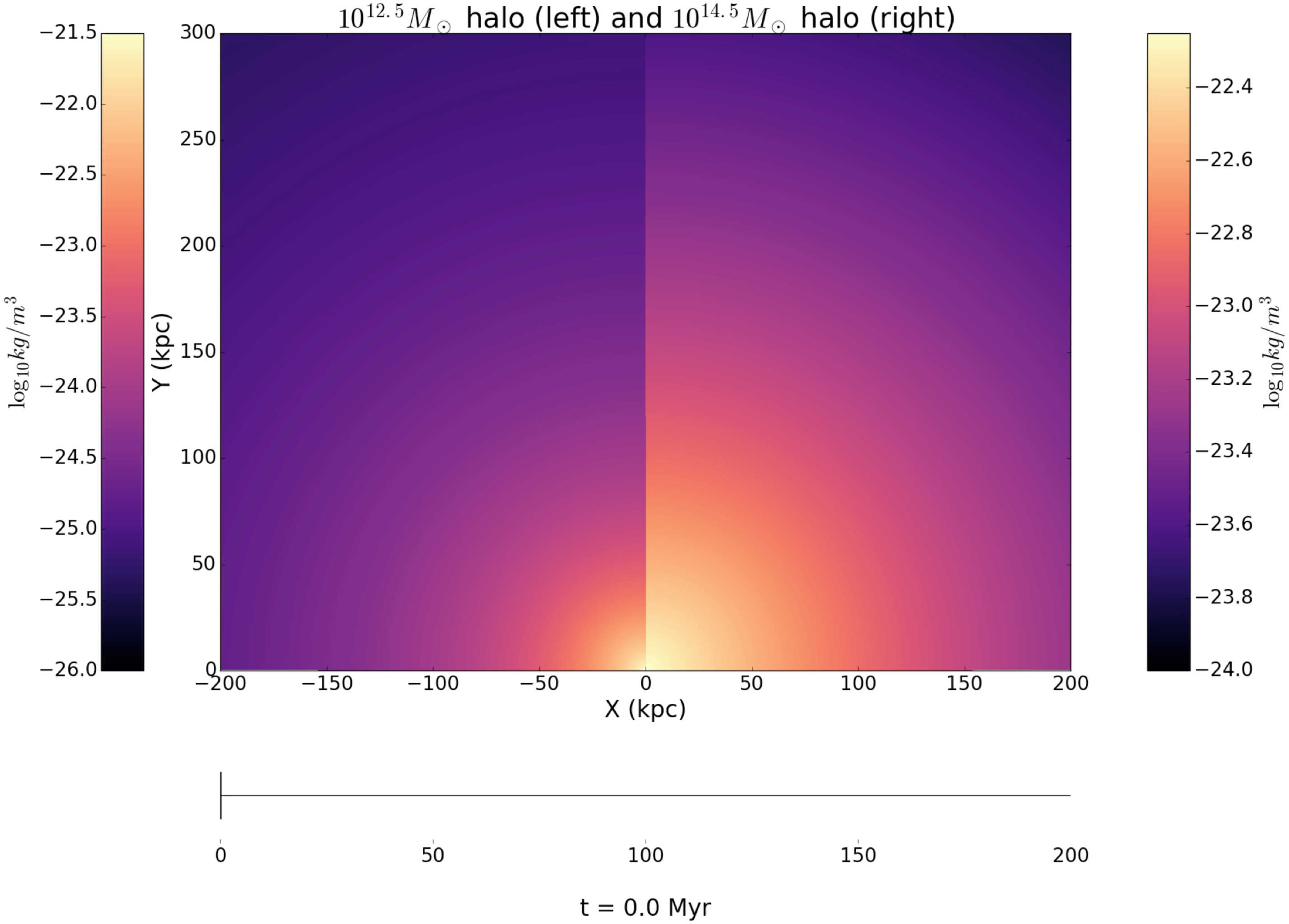


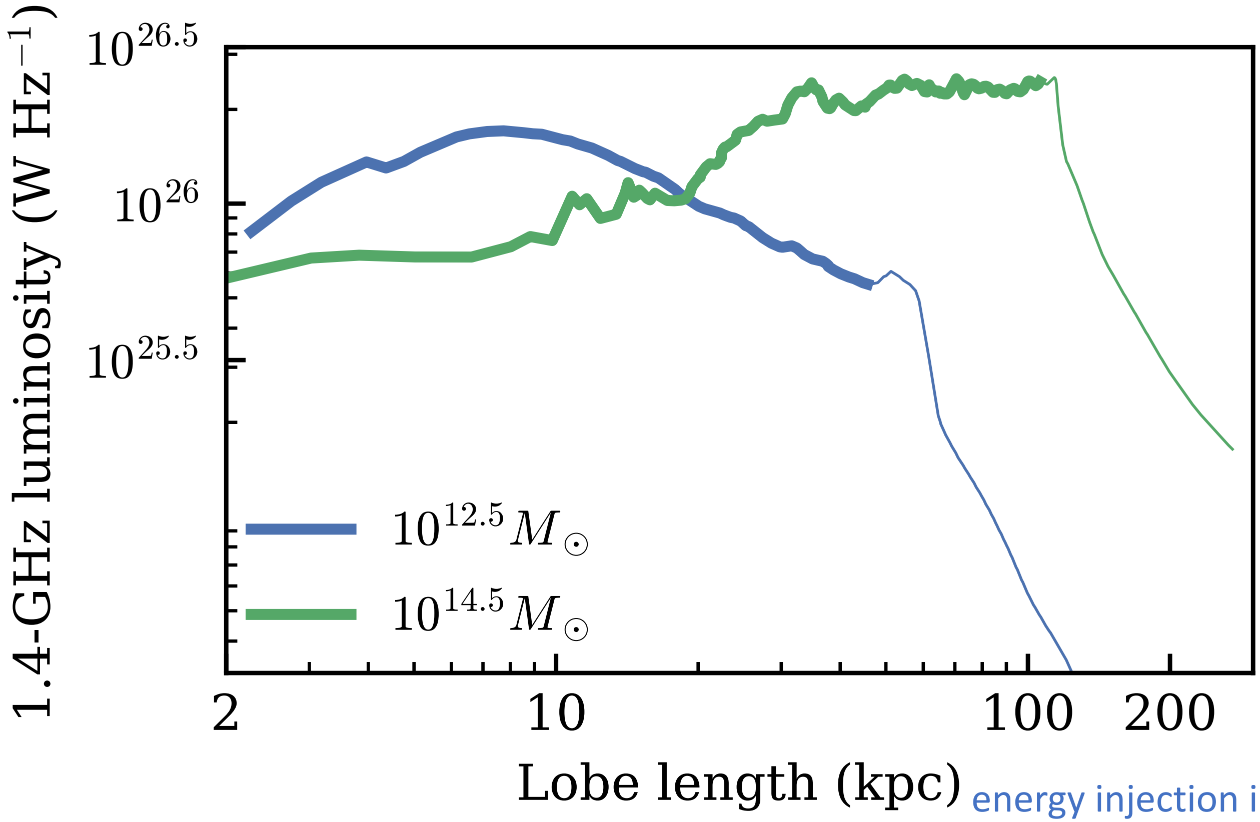
Isothermal hydrostatic equilibrium vs King profiles
discuss isothermal NFW, but King profile results are qualitatively similar

- Mach=25 for all simulations
- FR-II radio galaxies
- Initially conical jet is collimated by pressure of the external medium

Role of environment



Size-luminosity evolution



energy injection index

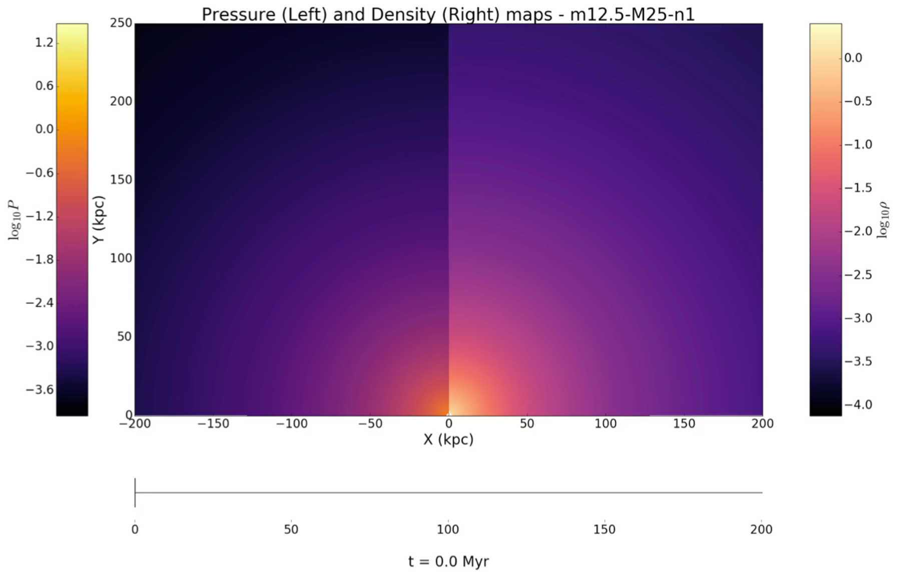
length scale

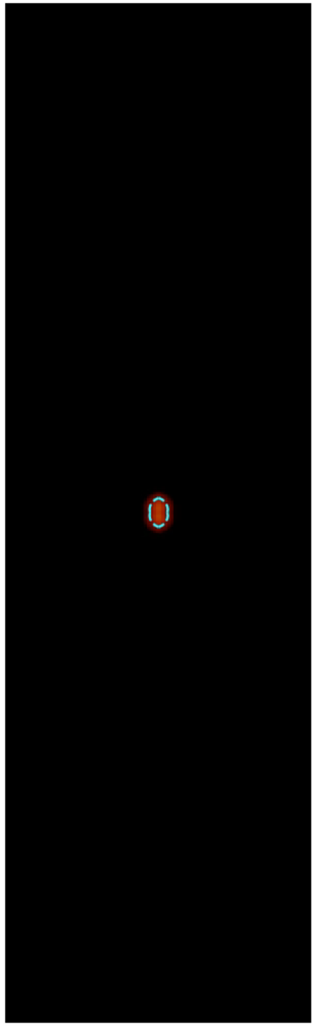
Pressure → radio continuum emissivity
assume only adiabatic losses
upper limit on luminosity

$$L(\nu) = L_0 \left(\frac{\nu}{1\,\mathrm{GHz}}\right)^{-\frac{q-1}{2}} \left(\frac{p_0}{10^{-11}\,\mathrm{Pa}}\right)^{\frac{q+5}{4}} \left(\frac{L_1}{\mathrm{kpc}}\right)^3$$

$$N(E) \propto E^{-q}$$

Surface brightness





Single jet in cluster, shifted to z=0.05 (1kpc ~ 1 arcsec)

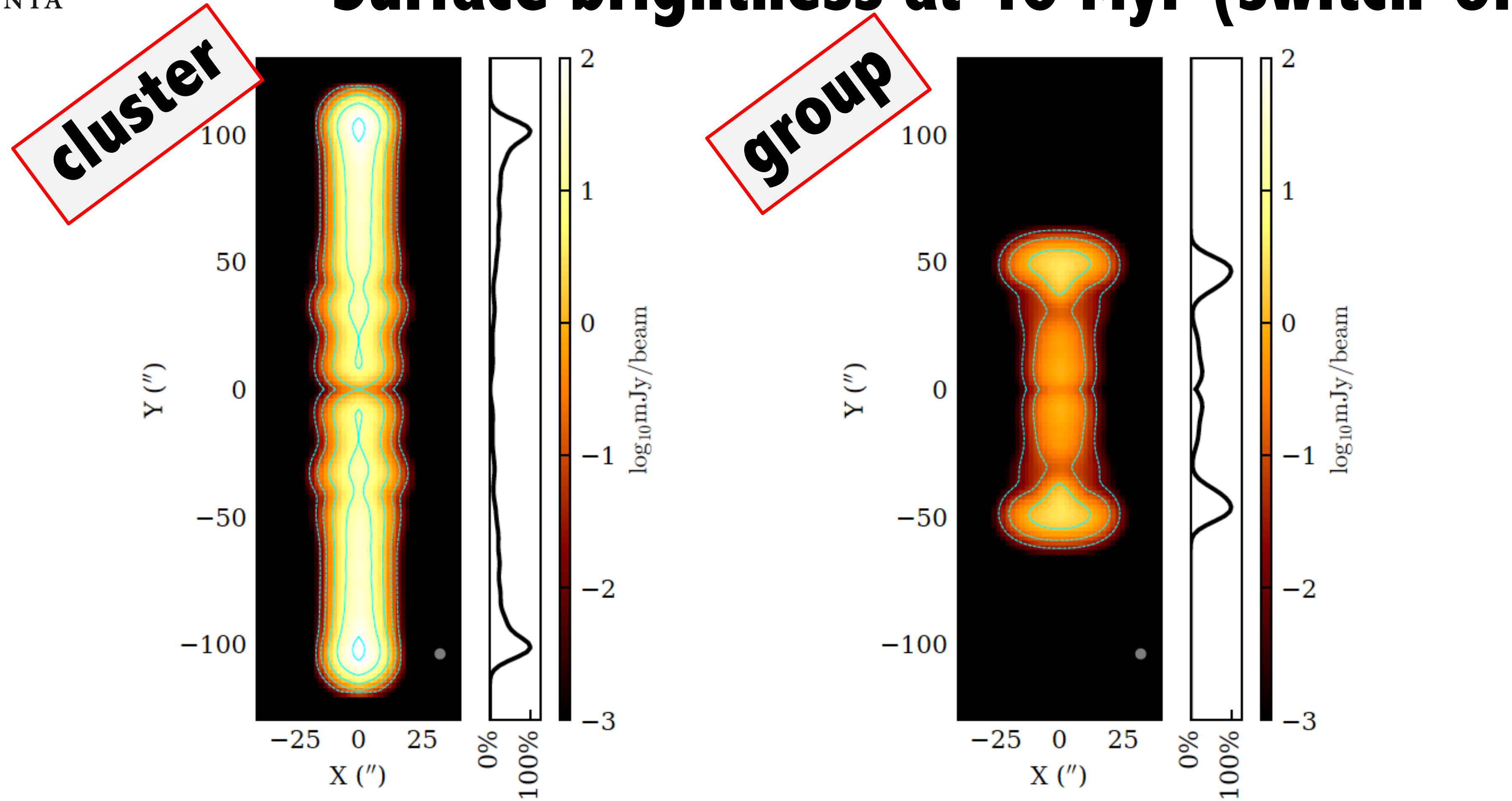
Observed at 1.4 GHz with beam FWHM = 5 arcsec

Contours at:

0.01, 0.1 mJy/beam (dashed)

1, 10 mJy/beam (solid)

Surface brightness at 40 Myr (switch-off)



Contours:

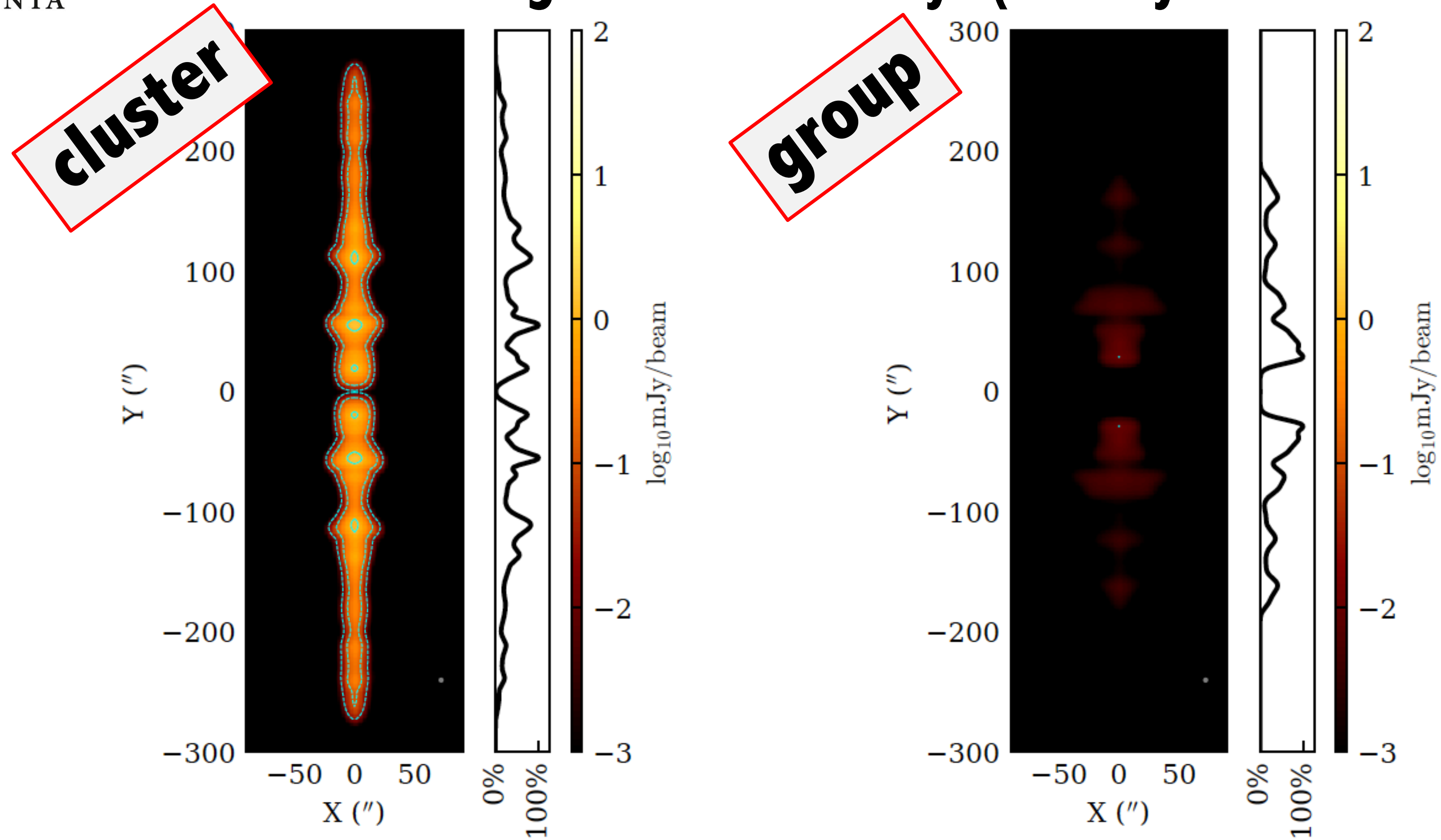
0.01, 0.1 mJy/beam (dashed)
1, 10 mJy/beam (solid)

Cluster: clear pair of lobes with hotspots, connected to core

Group: two unconnected blobs.

? Would this be identified as an FR-II if the source was asymmetric ?

Surface brightness at 200 Myr (160 Myr after switch-off)

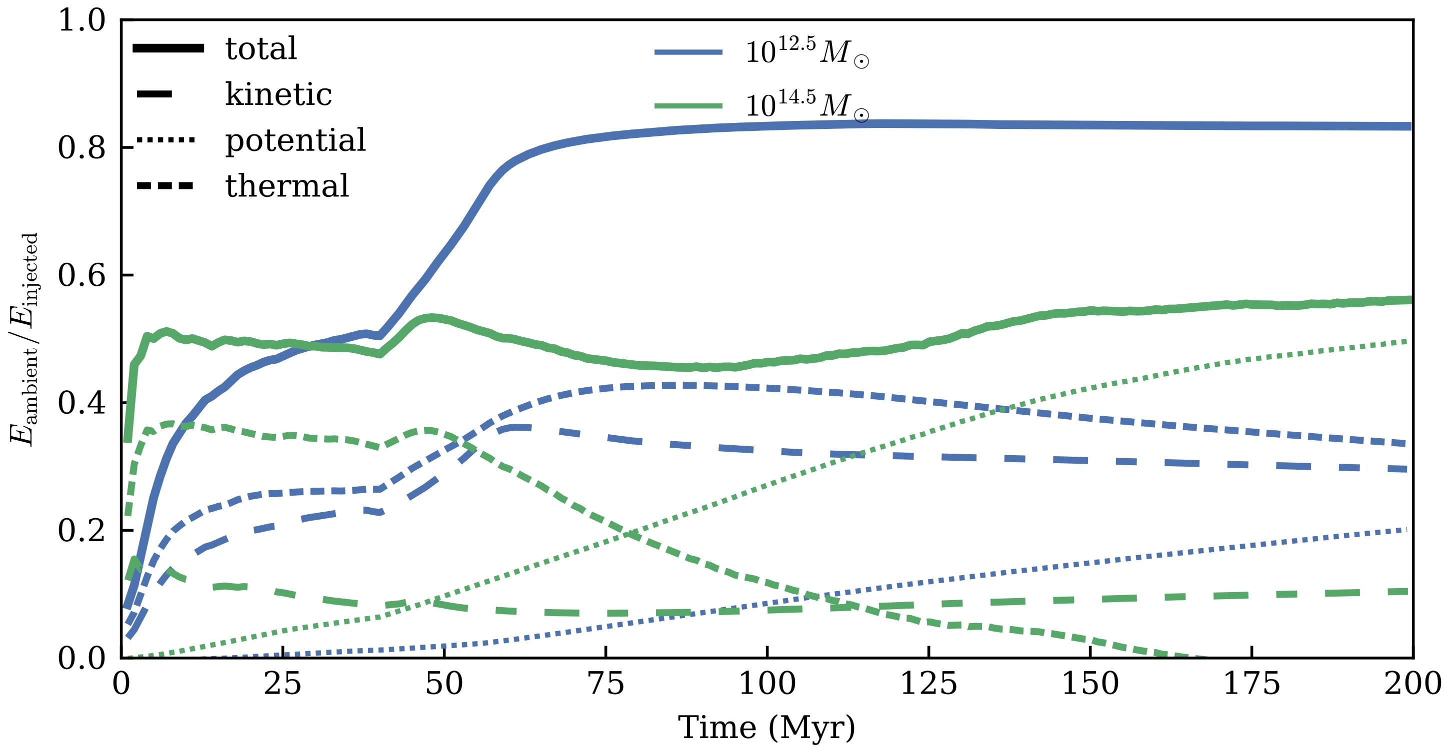


Contours:

0.01, 0.1 mJy/beam (dashed)
1, 10 mJy/beam (solid)

Remnant detectability depends on environment

Feedback efficiency

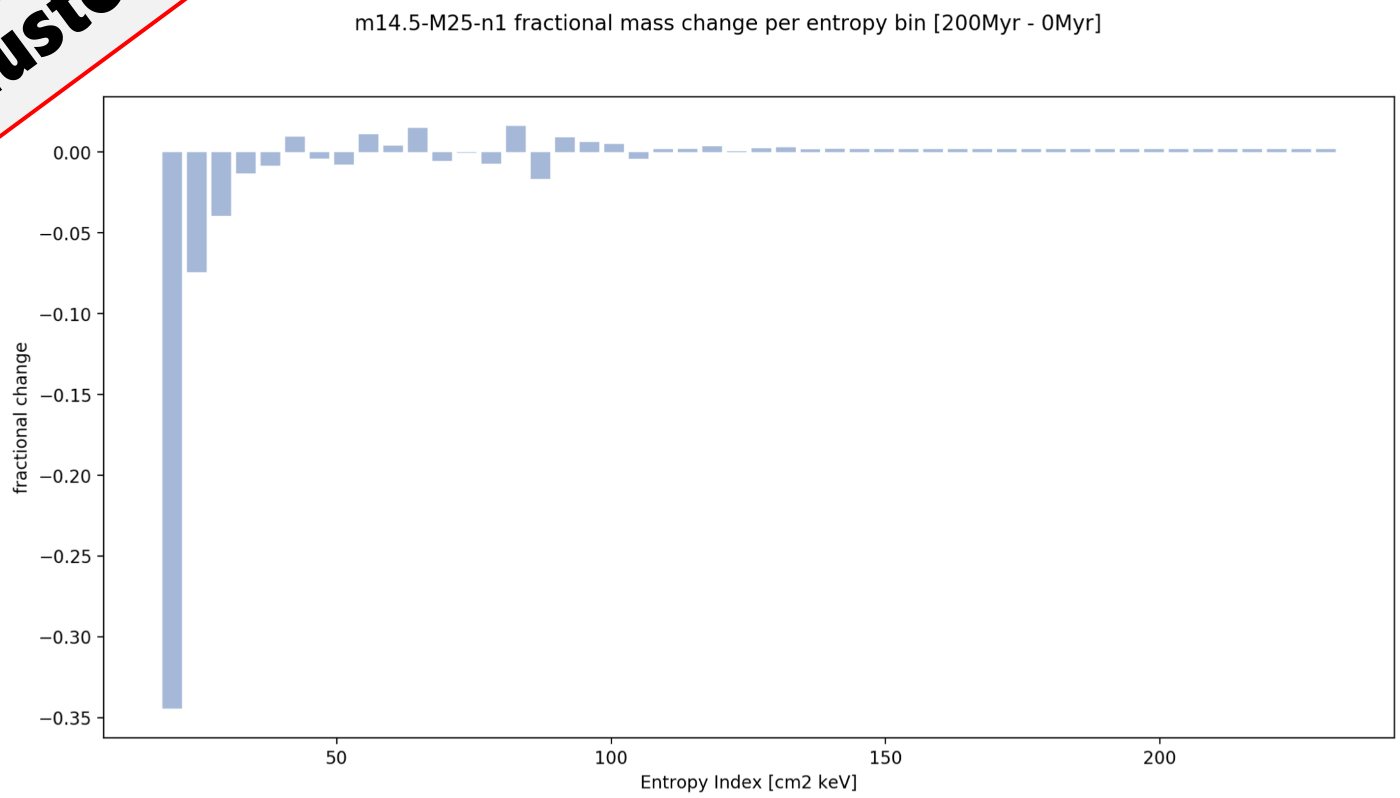


Fraction of jet energy coupling to the gas depends on environment

- 50% efficiency in **clusters** (*cf* Hardcastle & Krause 2013, 2014)
- more efficient in **poor group**

Where is the feedback ?

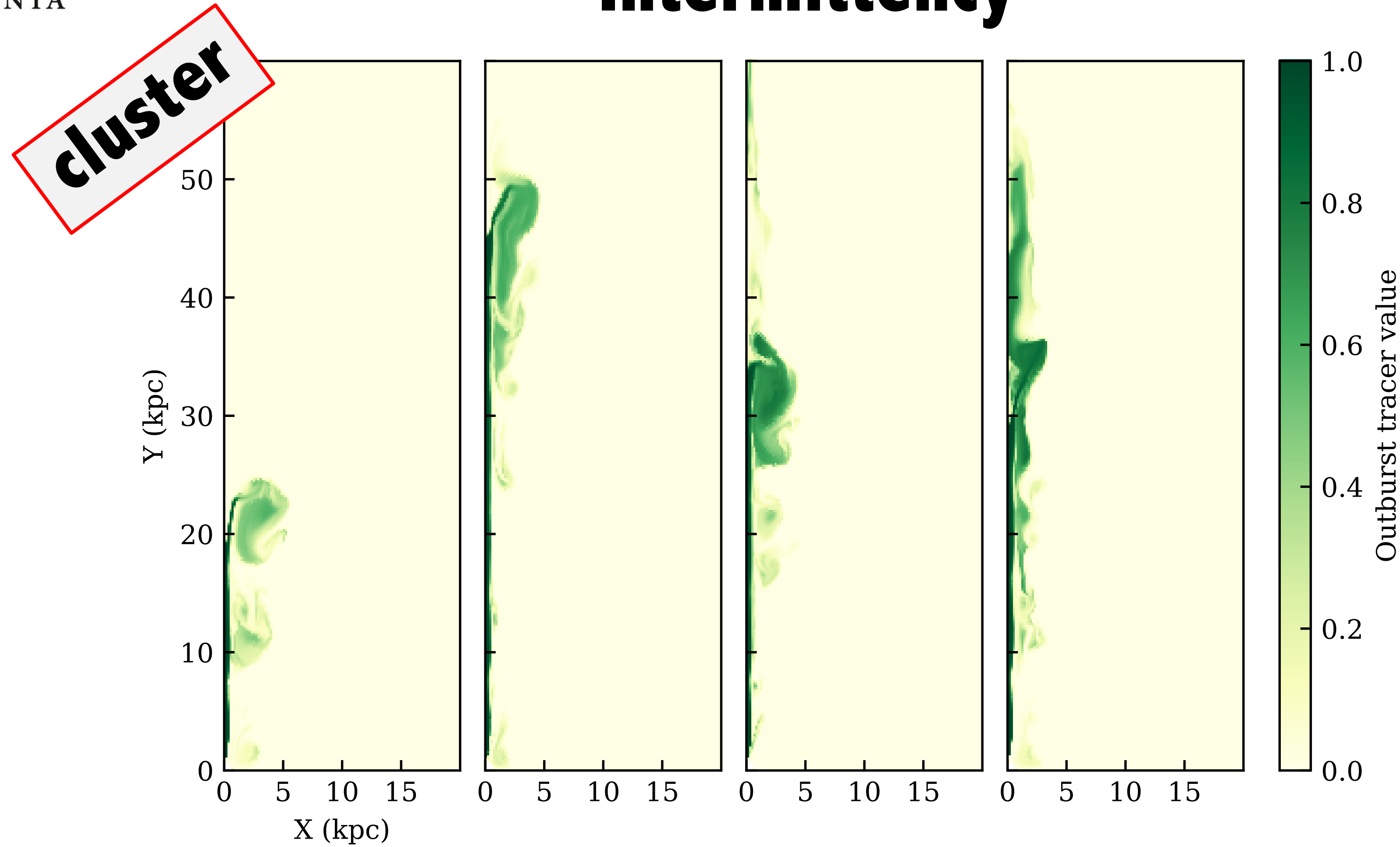
cluster



$$\text{entropy} = \frac{T}{n^{2/3}}$$

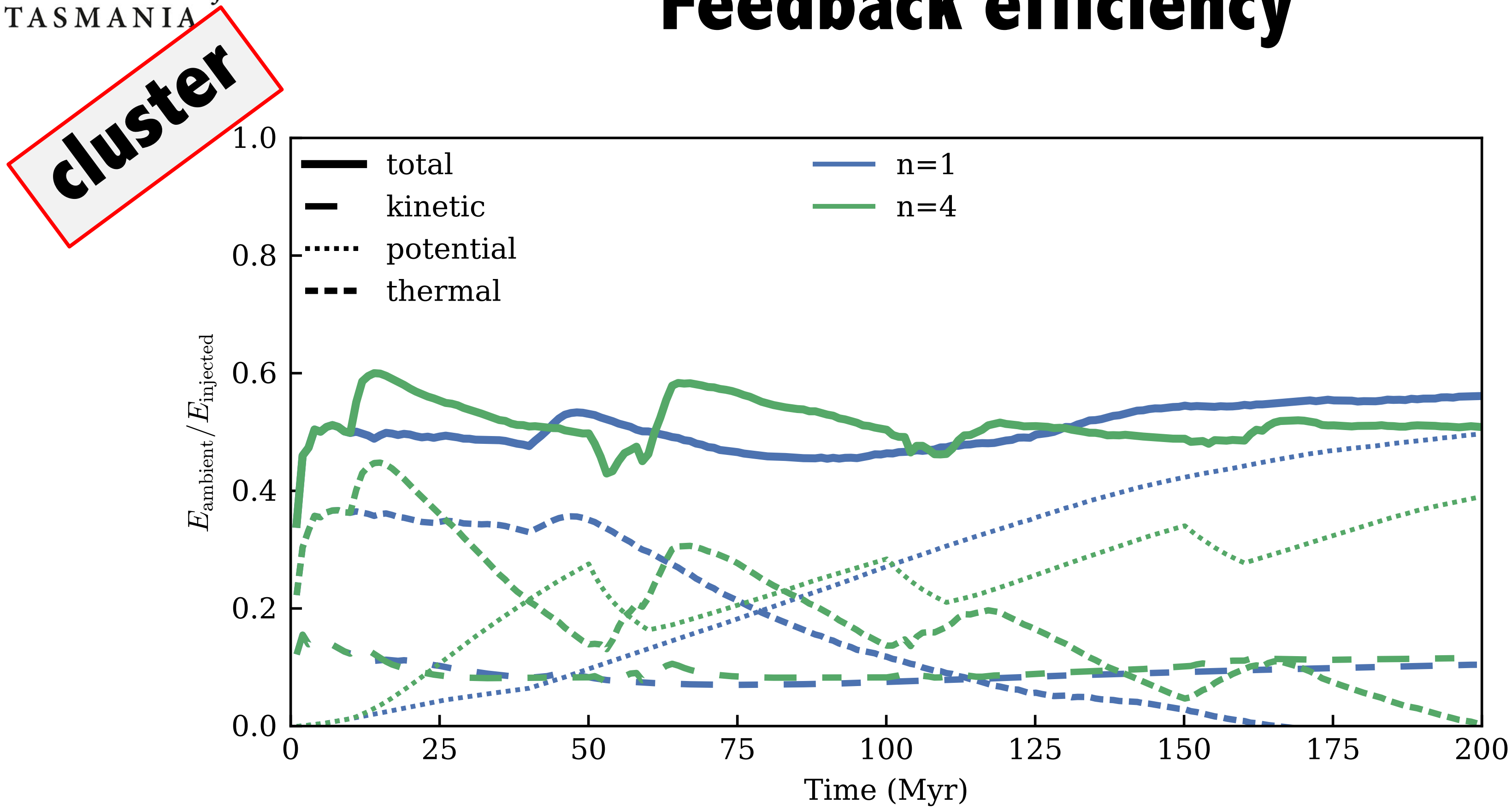
Lowest entropy gas is removed – as needed in galaxy formation models

Intermittency



Pre-conditioning of the ICM by earlier outbursts

Feedback efficiency



Coupling efficiency ~ 50% for n=1 and n=4 outbursts

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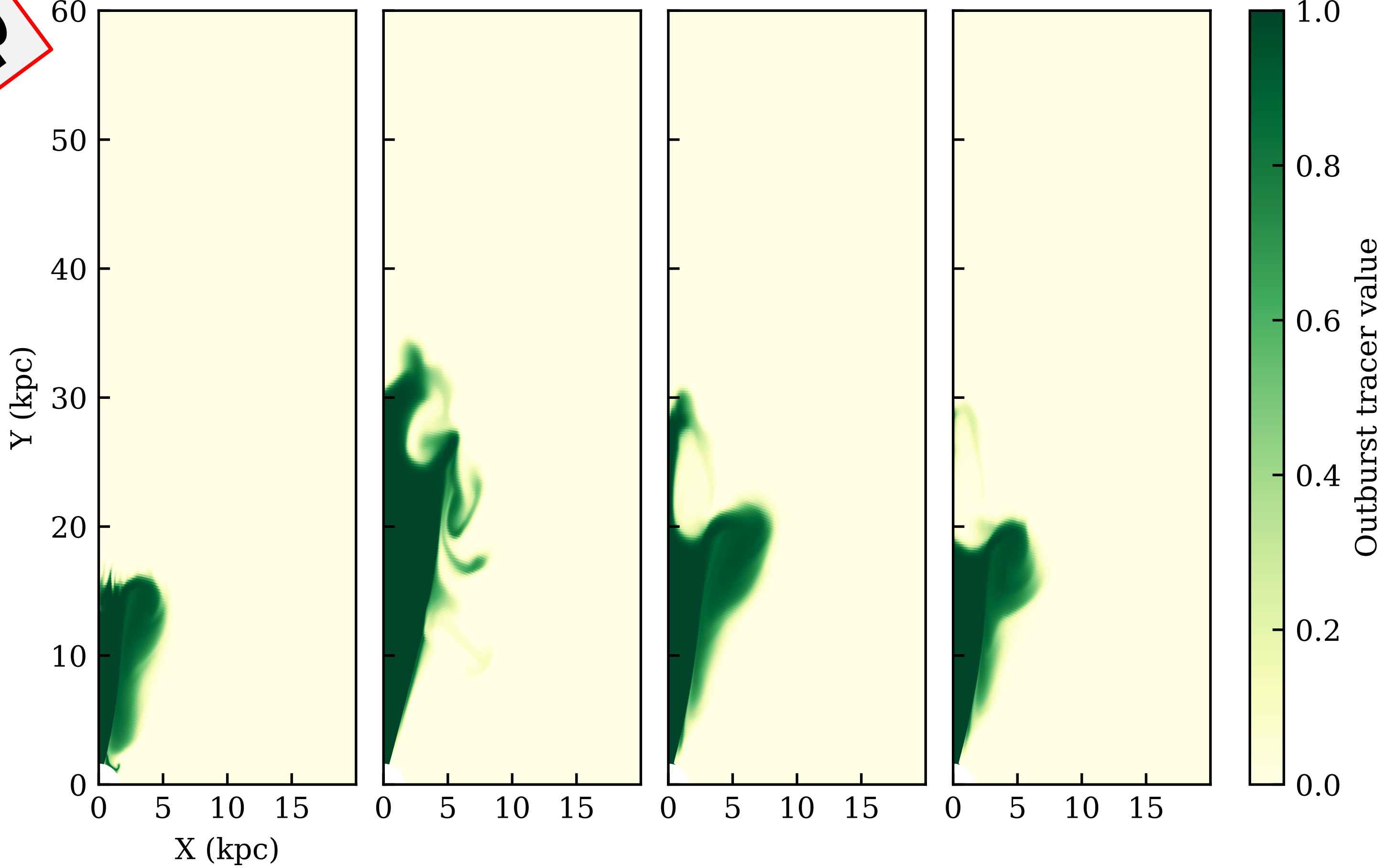
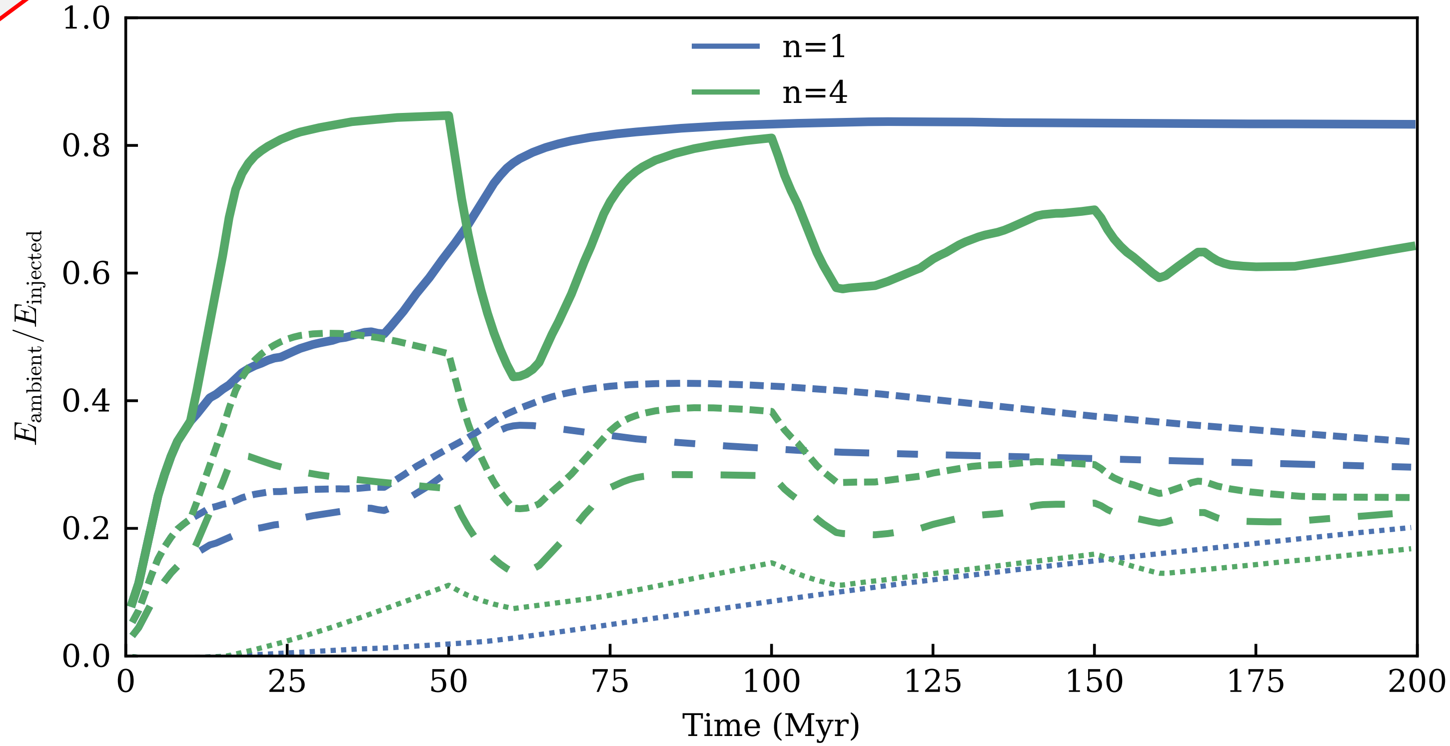
Intermittency

group



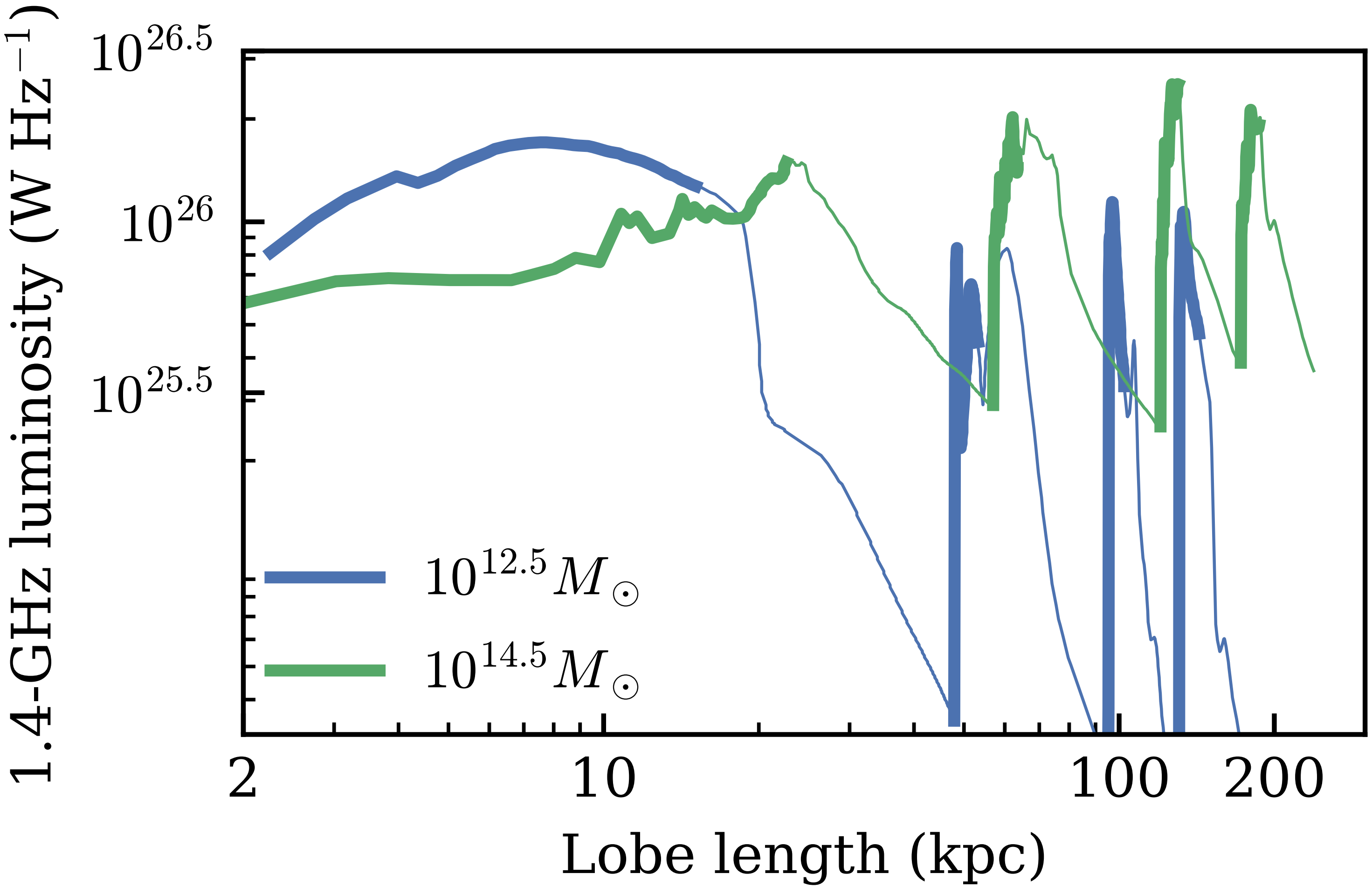
Feedback efficiency



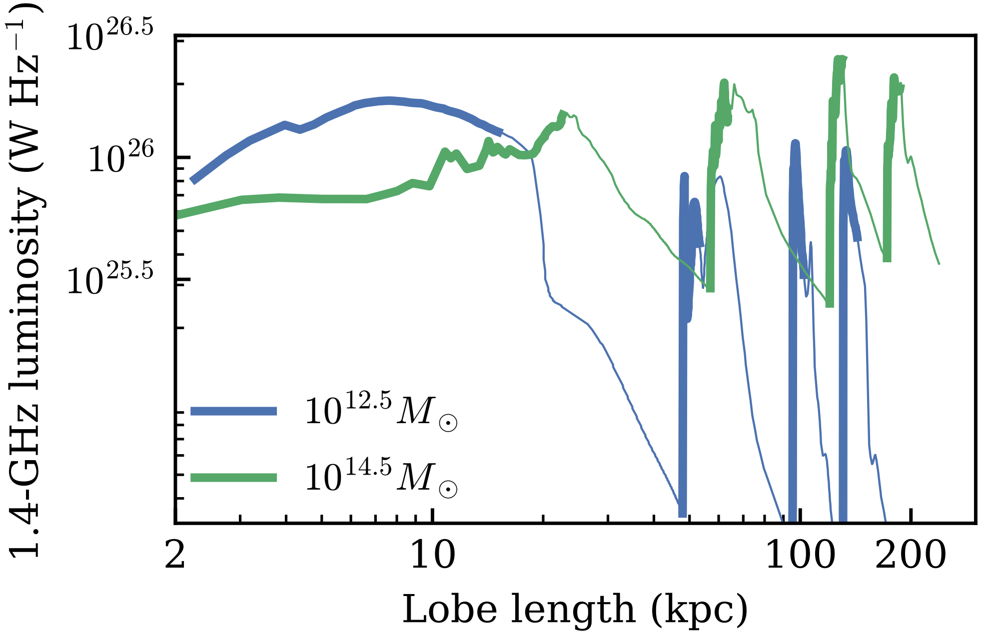
Intermittency more important in group

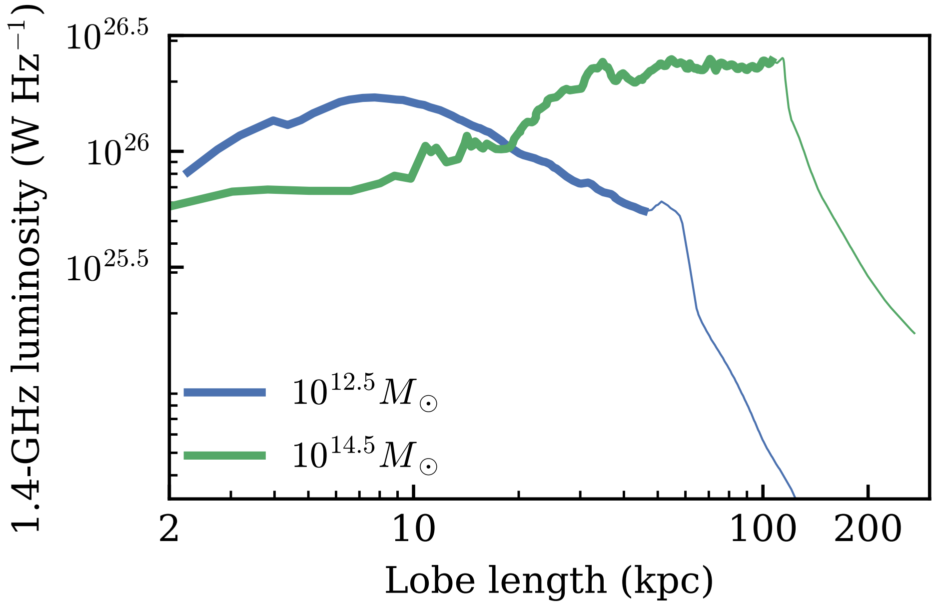
- Less kinetic and thermal energy imparted to gas in n=4 simulation
- Cluster simulation dominated by gravitational potential energy

Size-luminosity evolution



Size-luminosity evolution





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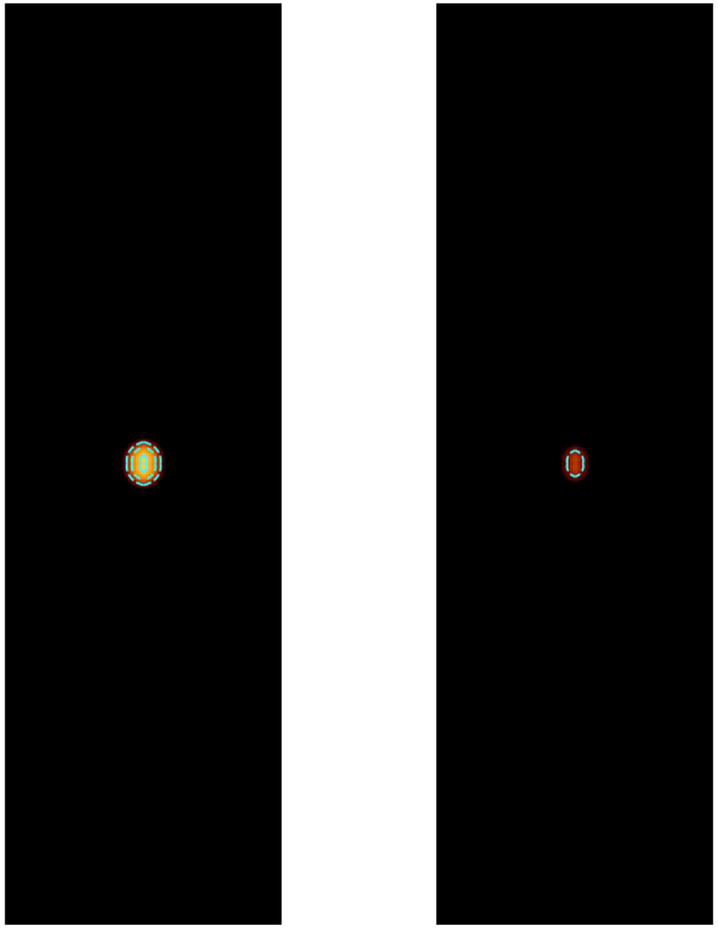
Surface brightness



- Detectability of multiple episodes of AGN activity depends on environment
- Double-double radio galaxies?

Contours:

0.01, 0.1 mJy/beam (dashed)
1, 10 mJy/beam (solid)

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Conclusions

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- 2D axisymmetric simulations of non-relativistic, initially conical jets
- Same total energy and jet power, supplied in different ways
  - Cluster vs poor group environment
  - 1 x 40 Myr episode vs 4 x 10 Myr episodes
  - Total evolution over 200 Myr
- Environment is important
  - Cluster radio galaxies are brighter, and hence easier to detect
  - Cluster jets are collimated earlier by external pressure
  - Group feedback efficiency is higher
- Intermittency is important
  - Preconditioned IGM/ICM affects jet propagation
  - Coupling efficiency changes by ~20%
- Need to consider effects of environment and intermittency in current and future radio continuum surveys