The feedback efficiency of restarting jets from Active Galactic Nuclei

Patrick Yates[1★], Martin Krause[1,2], Stanislav Shabala[1]
[1] University of Tasmania, [2] University of Hertfordshire
★patrick.yates@utas.edu.au

Abstract

Feedback from Active Galactic Nuclei is required to maintain the delicate heating/cooling balance in massive galaxies over the latter half of the Hubble time. The process usually invoked is kinetic feedback from radio jets, which do work on their host hot atmospheres through supersonic outflows, shocks and gas uplifting. An open question is whether the efficiency of this feedback mode depends on the jet duty cycle.

We present PLUTO numerical hydrodynamic simulations of radio jets interacting with a cluster-like environment. In each simulation, the same total energy is injected at the same time-averaged rate (i.e. using the same average jet power), but using a different number of jet episodes. We quantify the fraction of injected energy that couples to the surrounding gas, and compare AGN feedback efficiencies in different energy injection scenarios.

Background

It is well accepted that outflows from active galactic nuclei (AGN) play some role in slowing cooling flows via heating (Fabian 2012). Simulations of astrophysical jets are useful in understanding these astrophysical processes (see, e.g., Hardcastle & Krause 2013). The efficiency of this feedback, how much of the injected energy couples to the surrounding gas, is thought to depend on the method by which energy is injected into the surrounding environment. Observationally jet activity is known to be intermittent, as shown by spectacular multi-lobed radio sources (so-called double-doubles, e.g. Schoenmakers et al. 2000). Different jet duty cycles produce different jet structures and energy distributions, which could in turn affect how the injected energy couples to the gas.

Simulation setup

The simulation was carried out in 2D polar coordinates (r, θ) using the PLUTO code for computational astrophysics (Mignone et al. 2007), which is a high-resolution shock capturing code using a Godunov-type scheme. Only a quarter-plane was simulated (θ=0 to θ=π/2), and the total simulation domain in simulation units is r=[1,1098], θ=[0,π/2] which corresponds to r=[0.36,400] kpc. The total resolution of the simulation is (n_r, n_θ) = (2064, 448). The θ boundary conditions are symmetric, while the radial boundary conditions are reflective. The jet is injected as a pressure-matched mass inflow boundary condition on the lower radial boundary between θ=0 and θ=15°, with an external Mach number of M_x = 25.

Run code	Common parameters				Episodes	x	Duration
	Simulation		Jet				
m14.5-M25-n1	Halo Mass:	$10^{14.5} M_\odot$	Jet Power:	10^{37} W	1	x	40 Myr
m14.5-M25-n4	Total Active Time:	40 Myr	Half Opening Angle:	15°	4	x	10 Myr
	Total Simulation Time:	200 Myr	External Mach Number:	25			

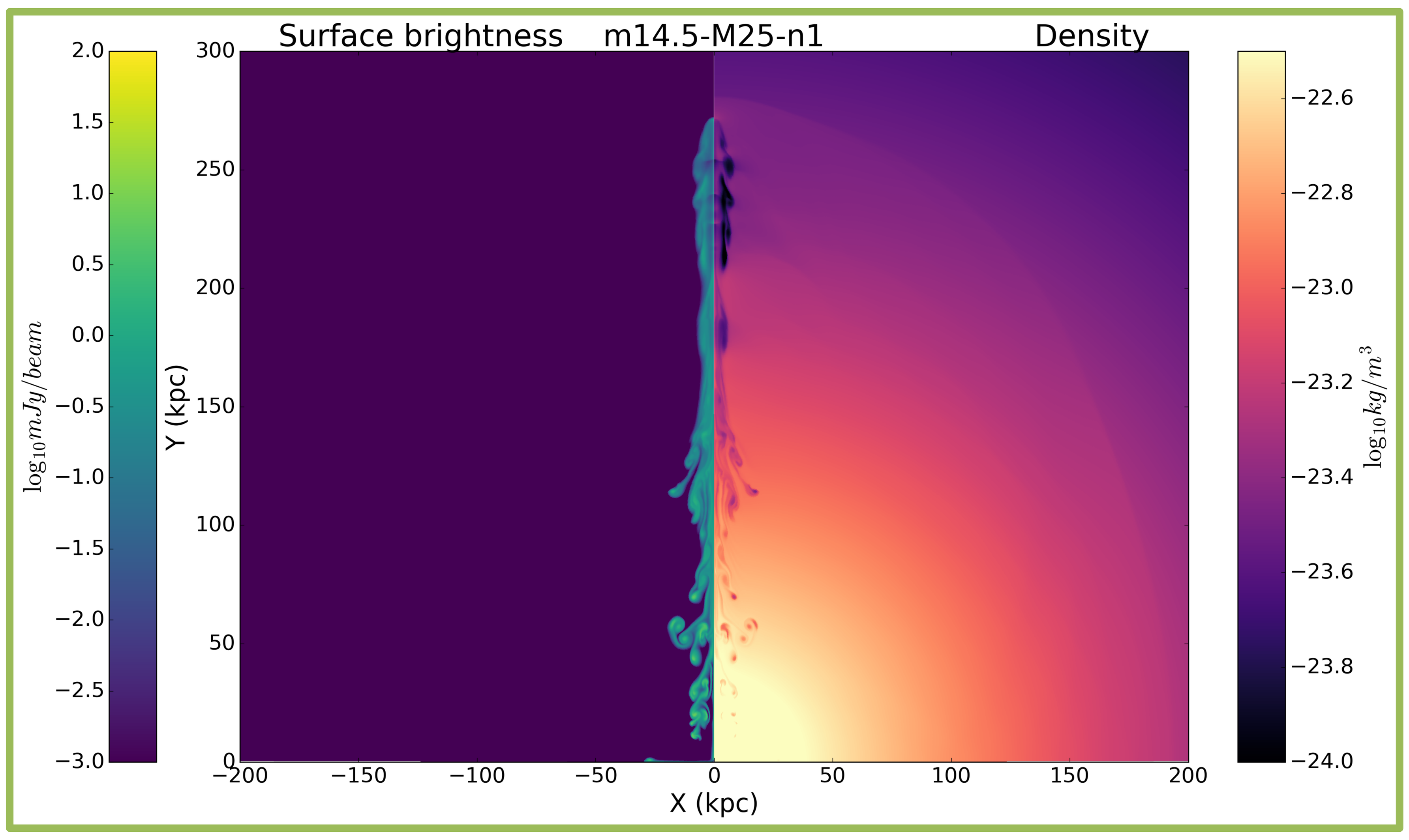

Figure 1. Run m14.5-M25-n1 at time 200 Myr, 160 Myr after the jet switched off. *Left:* Log of the surface brightness in mJy per beam. *Right:* Log of the density in kg m^{-3}. The bow shock is clearly visible in the density map, and infalling material is replacing the gas close to the core that was swept up by the jet.

Movie

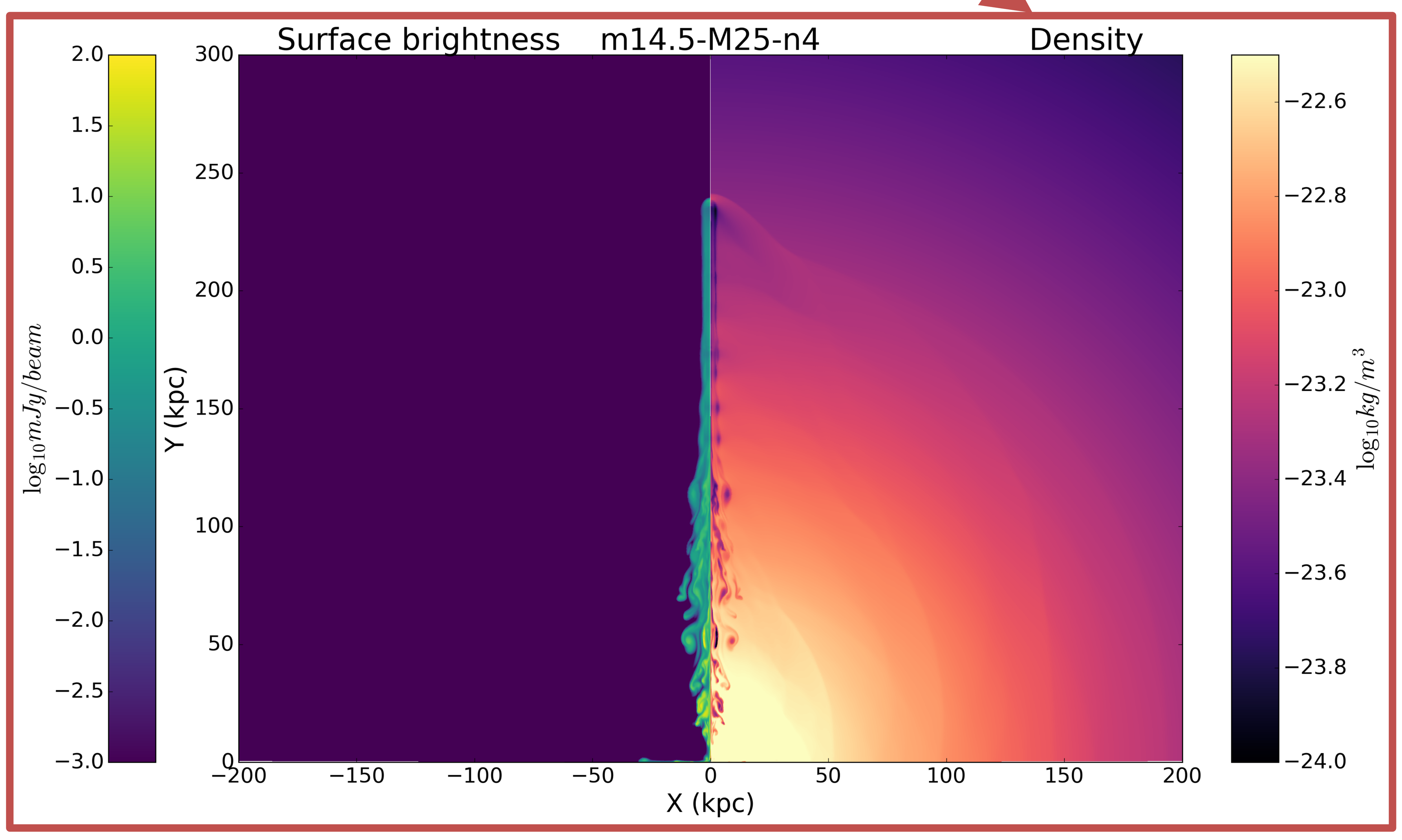

Figure 2. Same as Figure 1, but for the m14.5-M25-n4 run. Last jet episode finished at 160 Myr. The four bow shocks from four different jet episodes are visible in the density map. The resulting surface brightness and density maps are different from the single outburst case, showing that the injection timing of the jet affects the resulting morphology.

Movie

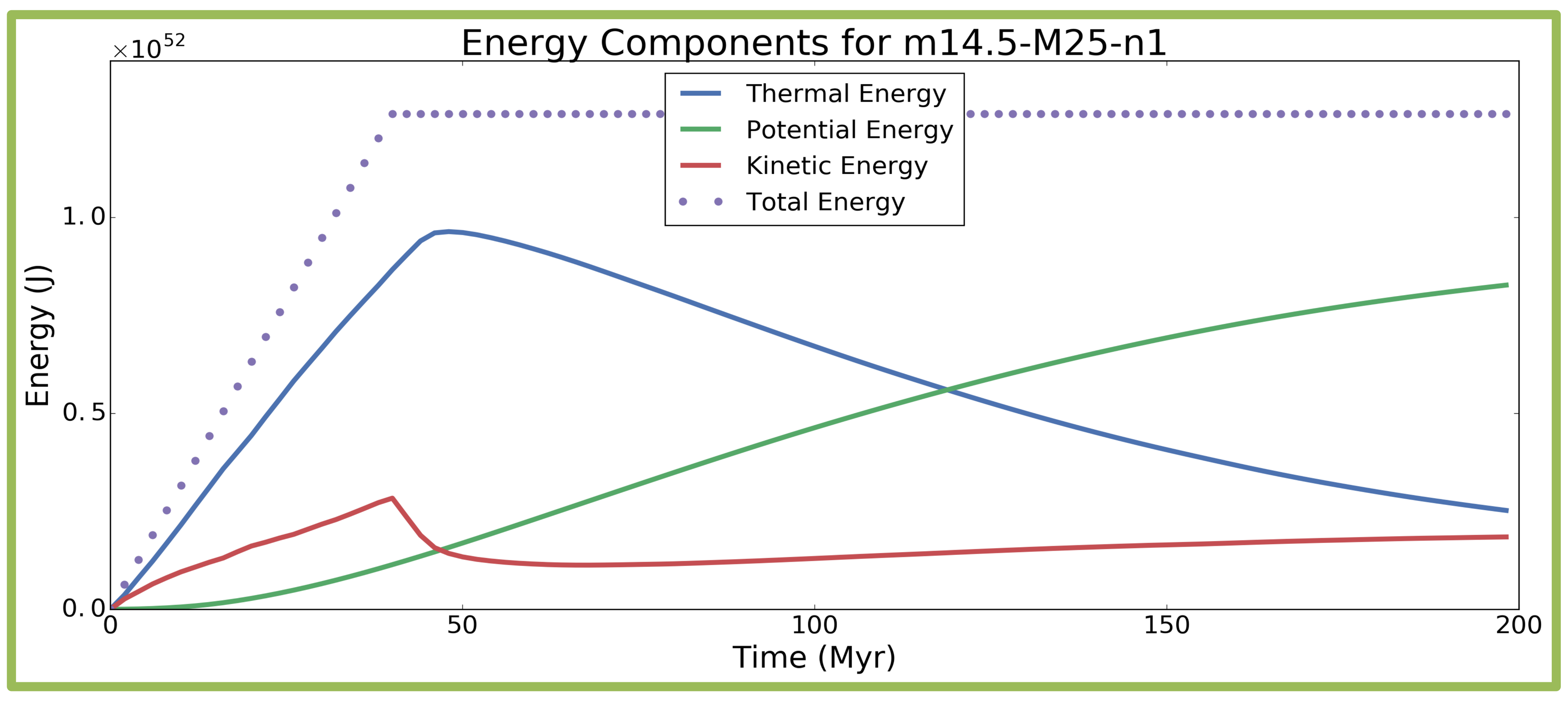

Figure 3. Injected energy from the m14.5-M25-n1 run, split into kinetic, thermal and potential components. The switching off of the jet at 40 Myr is reflected in both the kinetic and thermal energy components. The total energy injected by the jet in the simulation, $1.264 \times 10^{52} J$ agrees with the predicted total energy from a 10^{37} W jet on for a total of 40 Myr.

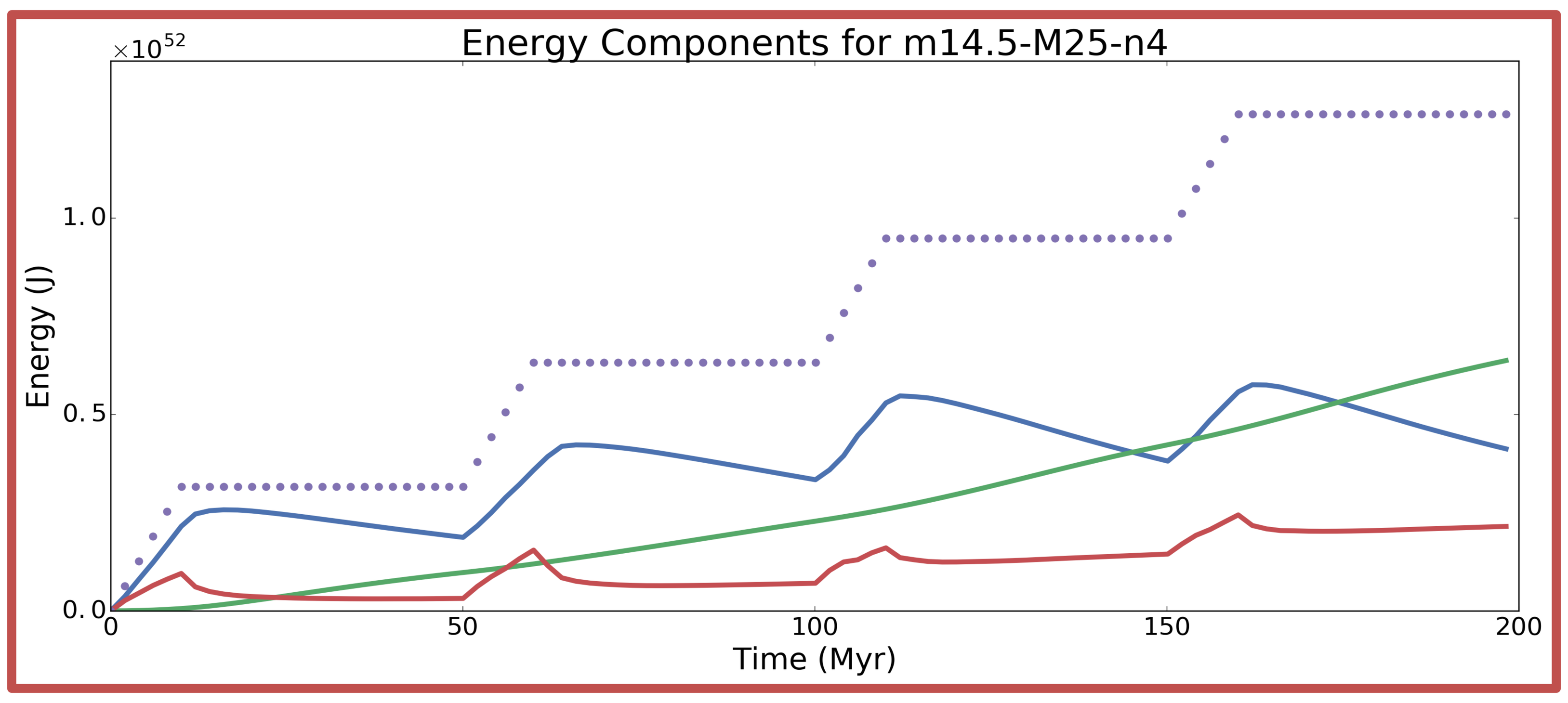

Figure 4. Same as Figure 3, but for the m14.5-M25-n4 run. The injection timing of the jet is reflected in both the kinetic and thermal energy components, and the switching off of the jet at 10 Myr, 60 Myr, 110 Myr and 160 Myr is clearly shown. The total energy injected by the jet is the same as for one jet episode, $1.264 \times 10^{52} J$.

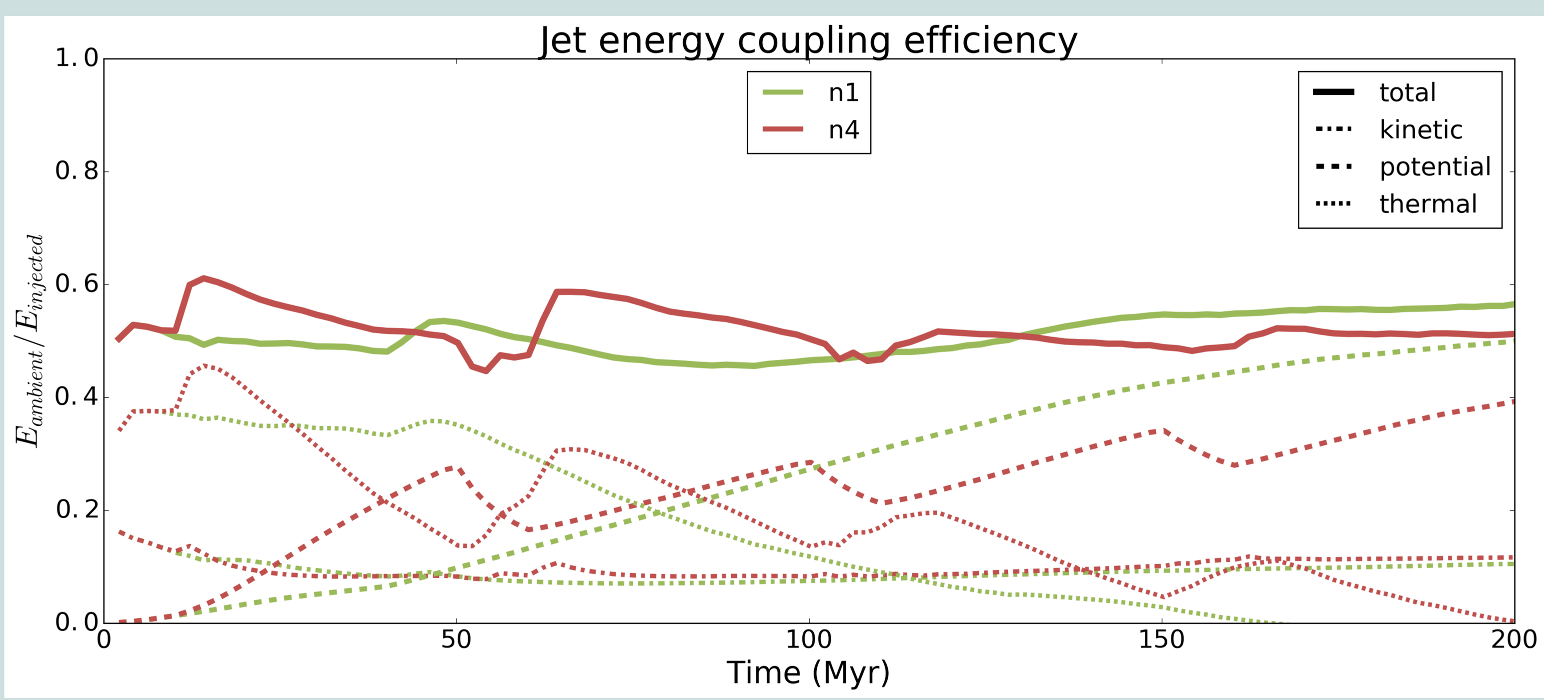

Figure 5. Fraction of energy coupled with ambient medium to injected jet energy. Division between ambient and jet material was made using tracer particles injected with the jet.

Conclusions

The number of jet episodes through which energy is injected plays a large role in both the resulting jet morphology and energetics.

- Jet morphology changes with injection timing (Figures 1 and 2).
- Distribution of injected energy between various energy components depends on the jet injection timing (Figures 3 and 4).
- The potential energy component is the most affected, likely due to the interaction between the jet injection timing and the refilling of displaced material through infalling gas.
- The efficiency of energy coupling to surrounding gas is not greatly affected by injection timing
- In 3D simulations we would expect to see more instabilities, and qualitatively expect the jet morphology differences to be more pronounced.

References

Fabian, A. C. 2012, ARAA, 50, 455
Hardcastle, M. J., & Krause, M. G. H. 2013, MNRAS, 430, 174
Mignone, A. et al. 2007, ApJS, 170, 228
Schoenmakers et al. 2000, MNRAS, 315, 371