AGN and stellar feedback in star-forming galaxies at redshift 2

Outflows, mass-loadings and quenching

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Introduction

Galactic-scale outflows are ubiquitous in observations of star-forming galaxies, up to high redshift (Steidel et al., 2010). Such outflows are mainly generated by internal sources of feedback: young stars, supernovae and active galactic nuclei (AGNs). Still, the physical origins of such outflows are not well understood, and their main driver is still debated. Up to now, most simulations take into account AGN feedback or stellar feedback but not both, because both phenomena happen on very different spatial and time scales. Most of them also still fail to reproduce all observed parameters from first principles. In this poster, we present the POGO project: Physical Origins of Galactic Outflows. With this suite of simulations, we model AGN and stellar feedback simultaneously based on physical assumptions for the first time at very high resolution (6 to 1.5 pc), and investigate their impact on the outflow parameters.

The POGO suite of simulations and the feedback models

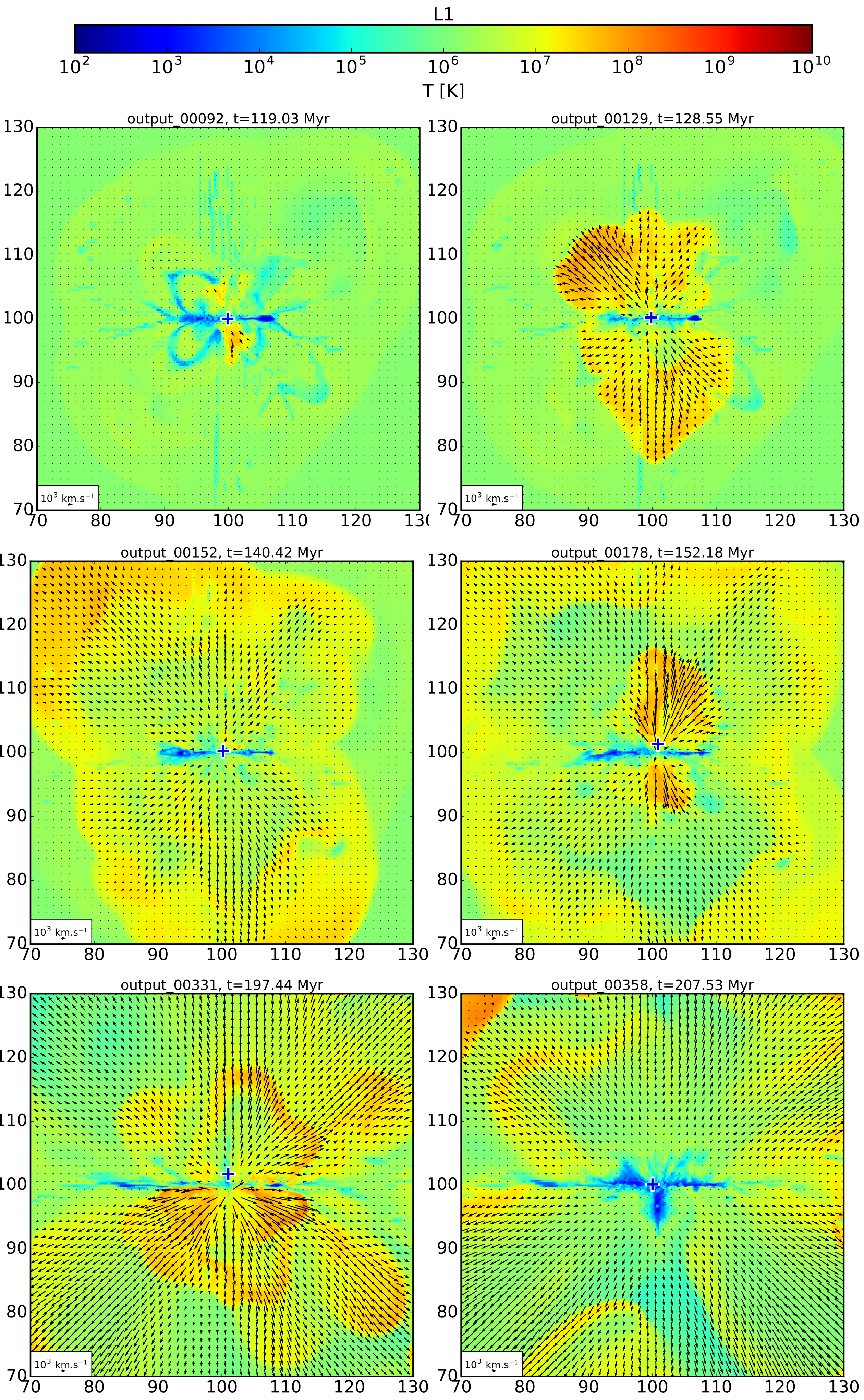

Figure 1 Time sequence of the low-mass star-forming galaxy with AGN and stellar feedback at 3 pc resolution, showing the propagation of outflows. AGN feedback was enabled at 115 Myr. The AGN is the main driver of the outflow at all masses and governs the temperature and density of the outflowing gas (Roos et al. in prep).

Name	Resolution [pc]	Feedback
M1, L1	1.5, 3	Stellar+AGN
M1_stellar, L1_stellar	1.5, 3	Stellar only
M1_AGN, L1_AGN	1.5, 3	AGN only
M2, L2	1.5, 3	Stellar+AGN
M2_stellar, L2_stellar	1.5, 3	Stellar only
M2_AGN, L2_AGN	1.5, 3	AGN only
M3, L3, LL3	1.5, 3, 6	Stellar+AGN

Table 1 The POGO simulations. The gas masses of simulations 1, 2 and 3 are respectively 1.5, 4.9 and 11.5×10^{10} $M_{\odot}$.

With the POGO project, we run a suite of 15 simulations with three galaxy masses, three spatial resolutions high enough to model the outflows from first principles, and three feedback configurations: thermal AGN feedback from Booth & Schaye (2009) ; thermal and kinetic supernova feedback from Dubois & Teyssier (2008) and young stars radiative feedback from Renaud et al. (2013) (hereafter, stellar) ; both simultaneously (hereafter, stellar+AGN ; see Table 1). Residual thermal supernova feedback is maintained in the AGN configuration in order to keep a realistic probability density function (PDF) of the gas in the interstellar medium (ISM). Accretion onto the BH is maintained in all runs: only AGN feedback (i.e.: re-injection of thermal energy in the cells surrounding the BH) is shut down in the stellar configuration. The respective magnitudes of these feedback models are coherent with observations: AGN feedback reproduces the $L_X/L_{IR} \sim 10^{-3}$ from Mullaney et al. (2012) and is thus not artificially boosted, and supernova feedback models were tuned according to the recipe of Martizzi et al. (2015), based on observations and high-resolution ISM simulations, and are thus not artificially hindered. The gas fraction is about 50 %, which is typical of redshift 2 galaxies (Daddi et al., 2010) and we use the adaptive mesh refinement (AMR) code RAMSES described in Teyssier (2002).

Mass-loadings and coupling of the outflows

The coupling of AGN and stellar feedback generates powerful outflows at all masses (see Figure 2 for the low-mass star-forming galaxy at 3 pc resolution). Also, the AGN is the main driver of the galactic outflows at all masses since the typical velocity, gas density and gas temperature in the outflows is the same whether there is stellar feedback or not (Figure 1). However, the mass-loadings of these outflows (the outflow rate divided by the star formation rate) highly depends on the mass of the host (see Figure 3). At low-mass, dense gas is lifted above the galactic disk by stellar plumes. This dense gas is then swept away by AGN bursts, resulting in powerful outflows with higher mass-loadings compared to the simulation with AGN feedback only. At intermediate mass, this positive non-linear coupling also occurs, but so much dense gas from the stellar plumes is lifted inside the main outflow that cooling is triggered, leading to a fraction of the gas actually falling back on the disk. For the high-mass galaxy, lower resolution runs are still running, to determine the effect of AGN and stellar feedback separately (Roos et al, in prep).

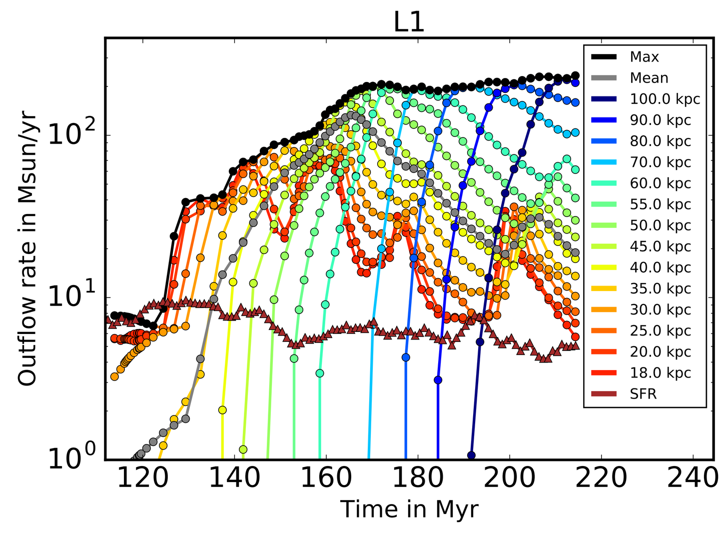

Figure 2 Outflow rate as a funciton of time of the low-mass typical star-forming galaxy at redshift 2 (3 pc resolution). AGN feedback was enabled at 115 Myr. The color codes the radius of the shell through which the outflow rate is computed. The black and grey curves respectively show the maximum and the mean outflow rate at a given time among the shells. The star formation rate is superimposed in brown triangles. AGN and stellar feedback couple non-linearly to generate powerful winds with a mass-loading of about 10 (Roos et al. in prep).

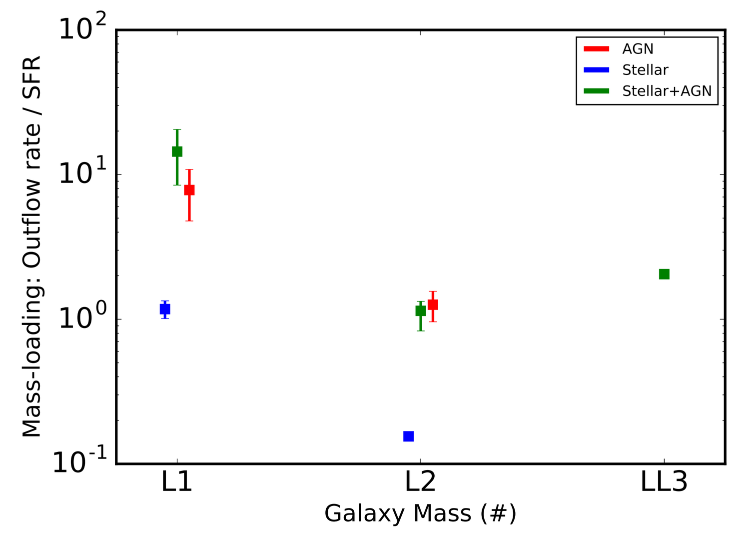

Figure 3 Mass-loading as a function of the mass of the galaxy for the stellar+AGN feedback configuration (green), the AGN feedback configuration (red) and the stellar feedback configuration (blue). The mass-loading is defined as the time average of the maximal outflow rate defined in Figure 2. While the coupling between AGN and stellar feedback is positive at low mass, the trend is the opposite at intermediate mass : dense gas in the outflow triggers cooling, resulting in some of the gas falling back onto the galaxy (Roos et al. in prep).

From the first results of Roos et al, in prep, we know that the properties of the powerful outflows generated by the combination of AGN and stellar feedback do not differ from AGN winds : only diffuse (10^{-4} cm^{-3}) and hot (10^7 K) gas is outflowing. Gabor & Bournaud (2013, 2014) already showed that such outflows do not destroy the galactic disk and do not impact the star formation rate of the host. Also, we know that AGN radiation coupled to AGN winds does not hinder star formation either (Roos et al., 2015). Even if the post-processing method to compute the effects of AGN radiation has not been applied to the POGO simulations yet, we expect the effects on the host to be similar.

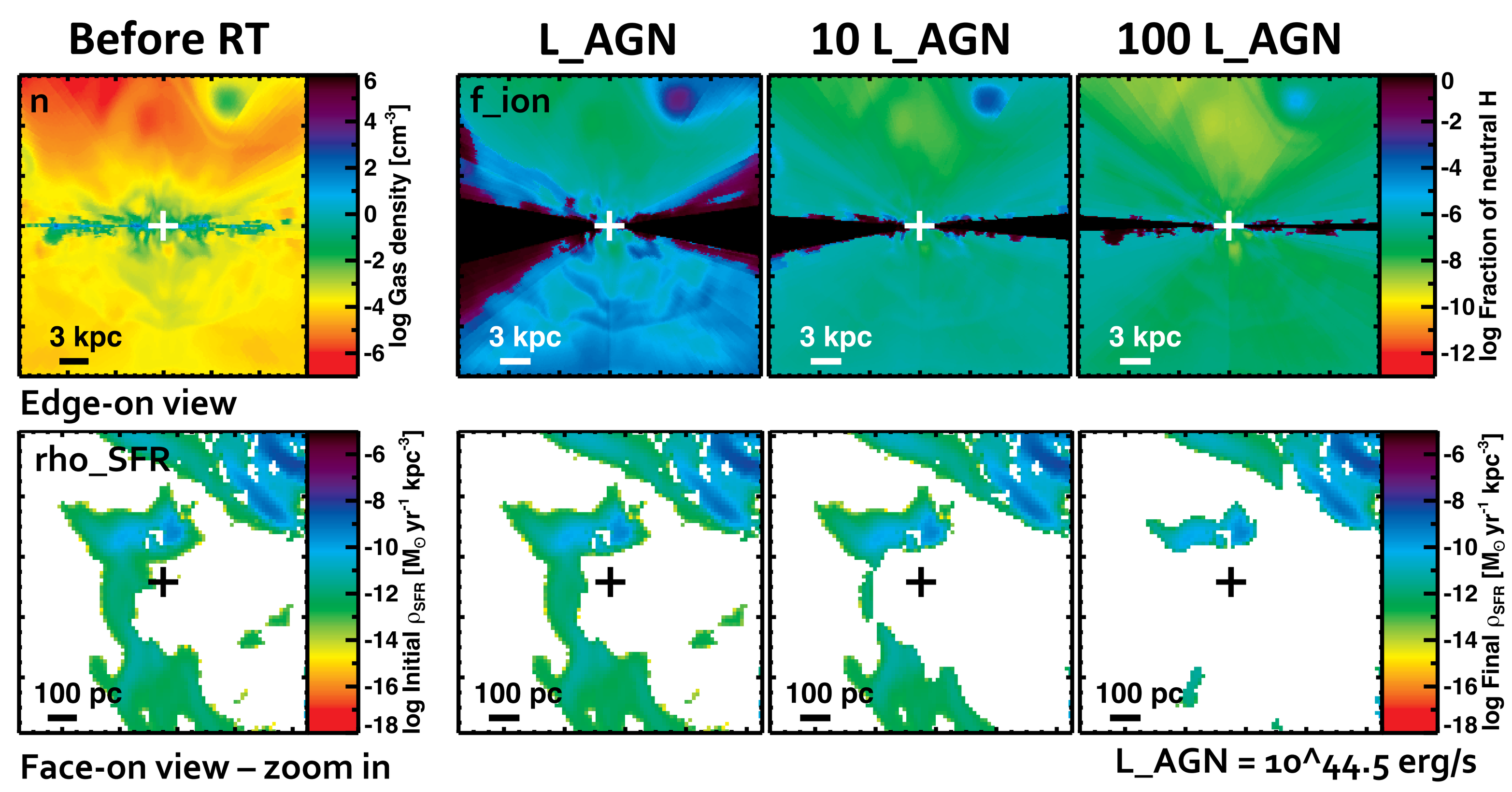

Figure 4 Top row: gas density and ionization fraction of hydrogen in a typical intermediate mass star-forming galaxy at redshift 2, after radiative transfer for three AGN luminosities ($L_{AGN} = 10^{44.5}$ erg.s^{-1}). Bottom row : density of star formation rate before and after radiative transfer for the three AGN luminosities. Even at the highest AGN luminosities, AGN radiation only ionizes diffuse gas (mainly in the halo), and only few diffuse star-forming regions are heated above the temperature threshold for star formation rate in the very center of the galaxy, leading to very small global star formation rate reduction (Roos et al., 2015).

Conclusions and forthcoming research

We have run a series of simulations at very high resolution (from 6 to 1.5 pc) to study the coupling between AGN and stellar feedback, identify the main driver of the outflows and investigate the impact on star formation. Our main results are summerized as follows (Roos et al, in prep):

- The AGN is the main driver of the galactic outflows at all masses;
- Nonetheless, the mass-loading of the outflows highly depends on the presence of stellar outflows and on the mass of the host:
  - at low mass, non-linear coupling between stellar and AGN feedback is positive and enhances the mass loading by a factor of 4. This likely comes from the fact that dense gas is pushed up by stellar feedback just above the galactic disk, and then pushed much further by the AGN bursts;
  - at intermediate mass, non-linear coupling is still there but negative processes dominate: dense gas from stellar feedback triggers cooling in the outflows, which decreases the mass-loading.

In a future paper, we will compute the long-range effects of AGN radiation as presented in Roos et al. (2015) and present the impact of such winds on the star formation activity of the host.

References

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