Memento feedback

Galaxies hosting actively accreting supermassive black holes make up roughly 10% of all galaxies in the Universe. Nevertheless, due to their immense energy output, active galactic nuclei are widely regarded as regulators of their host galaxy growth. But does observational evidence stack up?

Despite the lack of direct observational evidence, the extragalactic astronomy community has been confident for at least a few decades now that every massive galaxy (and some not so massive ones) hosts a supermassive black hole at its centre. For the fraction of a galaxy's life that this supermassive black hole accretes matter, the resulting active galactic nucleus (AGN) can outshine its host galaxy. If only a small fraction of the AGN energy output couples with the galaxy's interstellar medium, the energy would be sufficient to summarily blow out the whole gas reservoir of the galaxy; and this is exactly the idea that John Magorrian, and Joseph Silk and Martin Rees had in the 1990s. Their seminal papers ushered in the era of what is now known as AGN feedback and with it a cavalcade of theoretical and observational studies looking to identify and characterize it.

Some of the earliest adopters of AGN feedback were cosmological simulations. The problem at the time was that galaxies tended to grow inordinately massive due to continuous cooling of hot gas in their dark matter haloes. The resulting simulated mass function clearly deviated from what was observed for both the smallest and biggest galaxies in the Universe. For the former, the solution was found to be the feedback from powerful supernova explosions. Yet such feedback is rather puny compared to the very deep gravitational potential of massive galaxies. Something else was needed. Enter AGN feedback. Here we had a relatively long-lasting mechanism that can continuously (or quasi-continuously given what we now know about the duty cycle of AGNs) inject energy into the interstellar medium of the galaxy and as a consequence prevent hot gas from cooling down and condensing into new stars. Case solved!

The hunt for AGN feedback had begun. Countless hours of observations across the whole electromagnetic spectrum have been devoted since then to try and pinpoint the galaxies where this feedback process could be caught in the act. Early successes included the clear link between radio jets — extremely collimated relativistic outflows launched by an AGN — and cavities of hot gas within clusters, a clear sign of energy injection from the AGN into the galactic halo. Yet such powerful radio jets are rare — only 5–10% of the whole AGN population has them or 0.25–1% of all galaxies — and due to their highly collimated nature, their impact on the gas actually inside a galaxy was strongly debated. Meanwhile, on the other side of the spectrum, optical studies started revealing ionized interstellar gas that was decoupled from its cospatial stellar population, moving at velocities as high or even higher than the escape velocity of its host galaxy. Researchers soon established that such extreme kinematics were preferentially seen in galaxies hosting an AGN, thus giving rise to a new hope that this was the long-sought signature of AGN feedback.

We now know that interstellar gas outflows are prevalent in galaxies hosting an AGN. Indeed, observations imply that these outflows become stronger, faster and more massive the more luminous the AGN at the centre of the galaxy is. For the most energetic AGNs in the Universe — quasars — outflows are observed to affect all phases of the interstellar gas and reach out to tens of kiloparsecs and beyond, effectively breaking out of their host galaxies. There is even evidence — sparse as it might be due to the difficult nature of the observations — that several hundred solar masses of molecular gas are carried away within these outflows, efficiently depleting their host galaxy of its star-building material. Surely, this must be a sign of AGN feedback in action.

But a crucial piece of evidence is still missing. What is the impact of AGN feedback? Numerous studies have looked for evidence that the efficiency with which new stars are formed — typically measured as the mass in new stars per year per unit mass of the host galaxy — is in some way reduced by the presence of these outflows or that galaxies hosting an AGN show depleted gas reservoirs compared with their non-AGN counterparts. The results have been, at best, contradictory. Studies with the highest resolution and sensitivity have now revealed a complex picture where new stars can form within the very same outflows to which AGN feedback is attributed. In another variant, stars are formed at the edges of outflows but not within. The crux of the problem that hinders these studies is the lack of spatially resolved tools that cleanly separate the emission of the AGN from that of the host galaxy. Twenty years on from the first outing of the AGN-as-galaxy-growth-regulator idea, the jury is still out as to whether and to what extent AGN feedback plays an appreciable role in regulating the growth of galaxies.

Yet a cursory look through the non-expert and oftentimes even the specialized literature will reveal a certainty about the importance of AGN feedback that is surprising given the conclusively inconclusive evidence at hand. A number of very successful cosmological simulations keep inserting by hand sub-grid recipes emulating the presumed effects of AGN feedback. Similarly, observers keep looking for AGN outflows, interpreting their presence as the manifestation of AGN feedback. Despite our increasingly nuanced understanding of AGN outflows, our handle on their energetics is still remarkably poor (see the Perspective by Chris Harrison et al.), our understanding of how different phases of the interstellar gas participate in these outflows is limited (see the Comment by Claudia Cicone et al.), their power source is under debate (see the Comment by Dominika Wylezalek and Raffaella Morganti) and their effects on their host galaxies are far from being settled (see the Comment by Giovanni Cresci and Roberto Maiolino).

In the extremely pluralistic field of AGN feedback — a pluralism facilitated by a recent boom in spectroscopic observational facilities that allow us to perform spatially resolved spectroscopy — it is all the more crucial that we stop, take stock, regroup and perhaps cast the problem of AGN feedback in a different light. 'The reality and myths of AGN feedback' workshop at the Lorentz Center (see the Meeting Report by Bernd Husemann and Chris Harrison) was one such effort to bring together experts on the topic to try and make sense of the disparate evidence at hand. This focus issue reflects the discussions that took place at that meeting. The take away message? AGN feedback is dead. Long live AGN feedback! ❐

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