Illuminating the Black Hole-Galaxy Connection

Once thought to be exotic and rare objects, black holes are now known to play an important role in the evolution of nearly every galaxy formed since the Big Bang. Super-massive black holes, with masses up to ten billion times that of our Sun, do not form at such large sizes: they grow and co-evolve with the galaxies in which they are embedded. Simultaneous study of growing black holes and their extended host galaxies is crucial to understanding the mechanisms of their co-evolution.

When a black hole grows via accumulation of matter, some of the matter falling into the black hole is converted to radiation. We thus observe growing black holes in galactic nuclei as bright points of light, emitting at all energies of the electromagnetic spectrum. These signatures mix with a galaxy's signal and must be separated in order to analyse both. I have developed and tested new analysis techniques to accurately characterise the growth rates of central black holes along with the detailed properties of their host galaxies, and applied them to galaxies out to 80% of the way to the edge of the visible Universe.

As a result of this work, we now know that the most likely mechanism for co-evolving the brightest, rarest growing black holes and host galaxies – namely, the violent, train-wreck collision of two galaxies – plays only a small role in evolving the more moderate main population.

Summary of Research Programme

My current research seeks to use newly available data to determine the primary mechanism(s) for the majority of co-evolving galaxies and black holes. There are currently two main candidates for the drivers of co-evolution:

- **Minor Mergers.** Galaxies can collide or interact in many ways. When a small galaxy encounters a larger one, the disruption to the large galaxy is typically much less severe than in the train-wreck "major mergers" that we know feed the brightest growing black holes. Not long after the smaller galaxy has been consumed, the remaining galaxy may only show minor signs of an interaction. Yet these more slight disruptions may be enough to both spur the creation of new stars in the galaxy and to channel matter toward the galaxy's central black hole.

  Teasing out the subtle signs of minor mergers has in the past been a challenge, but my previous work separating galaxy from black hole signal places me in a unique position to quantify the rate of minor mergers and the star formation history in galaxies with actively growing black holes compared to those in galaxies with quiescent central black holes. Combined with the parametric and spectral analysis techniques I have developed, the Oxford-led Galaxy Zoo project is crucially important in this study, providing a more robust characterisation of the subtle visual signatures of a minor merger than any other galaxy analysis method. As a core team member of Galaxy Zoo, I am leading the data reduction and analysis of over 8,500,000 classifications of more than 165,000 galaxies, allowing me to examine an evolutionary period spanning 11 billion years.

- **Merger-Free Evolution.** Galaxies form and evolve largely through mergers, both minor and major. Therefore, we should expect to find growing black holes in some merging systems even if the merger is not the cause of the black hole growth, simply because mergers are fairly common. Yet it is quite possible that a large portion of black hole growth is due to normal processes occurring in a galaxy independent of whether it is interacting with another galaxy.

  In order to properly study the extent to which black holes and galaxies can co-evolve without mergers, we must study a rare subset of galaxies which have undergone no significant mergers in their history. Because galaxies with such a history have a unique visual signature, the large, robust sample of proprietary Galaxy Zoo visual classifications provides a powerful means of identifying merger-free galaxies. I recently led a study identifying growing black holes in host galaxies with no history of mergers and showing for the first time that they may follow the same black hole-galaxy relation as that of systems with merger-driven evolutionary histories; I am currently preparing a follow-up paper expanding the evolutionary baseline by 6 billion years using a much larger sample. I am also leading a project, in collaboration with Dr Chris Lintott and Dr Julien Devriendt at Oxford, to determine the number and overall properties of merger-free galaxies in the Universe and compare with predictions from advanced cosmological simulations. Our current and planned work will constrain for the first time the role of merger-free processes in feeding an actively growing black hole.

By combining newly-available data and methods with analysis techniques which I developed, I can for the first time quantify the roles of these different pathways in feeding the growth of black holes as they evolve with the galaxies around them. This potentially represents a fundamental step forward in our understanding of one of the key outstanding puzzles in galaxy evolution, which in turn informs our understanding of the overall growth of structure in the Universe.