SUMMARY REPORT

"How active black holes shape the Universe: beyond Hubble"

Super-massive black holes in the centers of galaxies have active phases during which they are believed to expel large amounts of gas, quench star formation and shape the evolution of the entire galaxy. Multi-wavelength searches for this destructive `feedback' force are ongoing, with the goal of answering two key questions: is black-hole feedback devastating and common enough to play a key role in the evolution of the Universe? And what is the physical mechanism behind this force of evolution? Driven by scientific and technical developments, the search is narrowing in on the crucial role of the cold gas, which is the raw ingredient for star formation.

The scientific objective of this Marie Curie Fellowship was to use novel techniques on high quality data obtained with the world's largest telescopes to quantify the effect that black-hole feedback has on cold gas in galaxies, and study how this influences galaxy evolution throughout the Universe. The coming years offer a crucial window to get involved in scientific preparations to exploit the `next generation' of world-class telescope facilities, with a leading role for Hubble's successor, the James Web Space Telescope. This Marie Curie project has contributed to maintaining Europe at the forefront of multi-wavelength optical, infrared and mm research on active black holes during this exciting new era in observational astronomy.

As part of this project, we started 9 different projects on active black holes at world-leading telescopes, including Europe's Very Large Telescope (VLT) in Chile, the Atacama Large Millimeter Array (ALMA) in Chile and the Very Large Array (VLA) in New Mexico, USA. The data obtained from these telescopes was reduced with state-of-the art data-reduction software. We then analysed these data and published any new results in renowned peer-reviewed journals.

The main results from this work are that we used 3D mapping of cold and hot molecular gas to better understand the co-evolution of active black holes and their host galaxies.

One highlight is a series of papers on *"The Dragonfly Galaxy"*. This involves an ALMA cycle-2 and Hubble Space Telescope study of the Dragonfly Galaxy, which is a hyper-luminous infrared galaxy at redshift 2. The Dragonfly Galaxy produces stars at a rate that is hardly rivaled by any other galaxy in the Universe, and has powerful radio jets that emanate from the central black hole. We revealed that this system is actually a rare triple galaxy merger, with molecular gas that is violently re-distributed among the merging cores and which –on larger scales– aligns with the radio jets. The unusually high IR luminosity represents dust-obscured star formation that was triggered by the merger. This discovery makes the Dragonfly Galaxy a prime target for a mid-IR study with JWST.

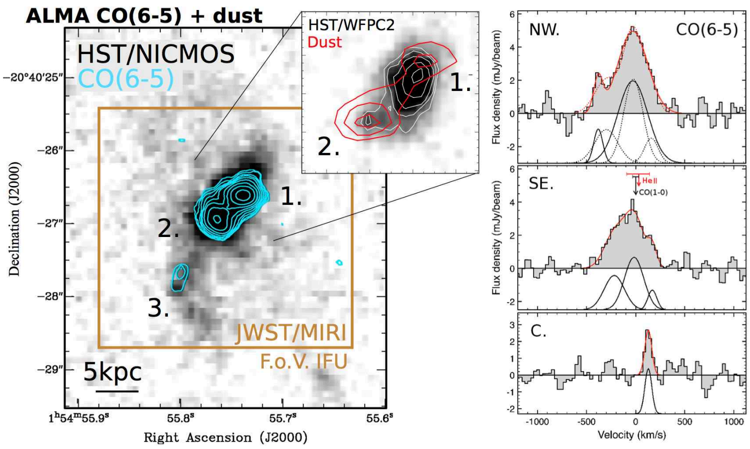

Fig 1. The Dragonfly Galaxy (Emonts et al 2015, A&A, 584, A99). Shown is the merger morphology in an image taken with the Hubble Space Telescope (grey) with overlaid the contours of three CO(6-5) components (blue). The inset shows the 1.3mm dust-continuum of the brightest two CO-emitters. CO spectra are shown on the right.

Conclusions from this Marie Curie project are that active black hole can drive outflows of warm and cold molecular gas, which influence the evolution of galaxies. We also showed that active black holes can affect the wider environments of galaxies, through powerful jets of charged particles that leave the black hole and reach far beyond the host galaxy. These jets can enrich and cool gas far outside the galaxy, which may potentially lead to the formation of new stars. This provides us with the new insight that the destructive force of an active black hole in a galaxy's nucleus can in turn also create the conditions for new stars to form in the very outskirts of galaxies.