Professor Evan Scannapieco and his team at Arizona State University have been investigating the puzzle of why the largest galaxies in the universe, once the most active, have become dormant and ceased to produce stars. They were one of the first to propose a mechanism that involved colossal feedback from supermassive black holes at the centre of the galaxies and they set out to prove the theory using the Cosmic Microwave Background radiation as a tool.

Astrophysicists deal with distances that are so vast and timescales that are so long that they are difficult for humans to comprehend. The enormity of these scales first came into view roughly 90 years ago through the work of Henrietta Leavitt and Edwin Hubble. Leavitt analysed special stars called Cephids and discovered that their luminosities were directly related to the periods of their pulsations. Hubble then used this relation and the observed brightness of Cephids to measure the distances to galaxies outside the Milky Way. He found that they are so distant that their light takes millions of years to reach the Earth. Now we know of galaxies whose light takes over 10 billion years to reach us, revealing them as they appeared in the early universe.

A MATTER OF SCALE
The billions of galaxies that fill the universe can be broadly grouped into moderate-sized disks, like our own galaxy the Milky Way, and giant elliptical galaxies with typical stellar masses that are more than ten times greater. By comparing the more distant galaxies, which are observed as they appeared long in the past, with the more nearby galaxies, which are observed as they appear closer to the present, astronomers are able to examine how these types of galaxies evolved over time.

To compare to these observations, theoretical models were developed that predicted hierarchical galaxy formation — in which gravity collects material together to form stars and solar systems, like our own. However, some parts of the universe did not fit the existing models: the largest galaxies, once the most active in star formation, had become dormant with older stars dying without replacements being created. In 2004, Professor Scannapieco and his team set out to determine why this was the case. They proposed a physical model, backed by rigorous mathematics, that suggested an intergalactic feedback mechanism was operating, associated with the supermassive black holes discovered at the centres of elliptical galaxies.

THE AGN FEEDBACK THEORY
Nearly fourteen billion years have passed since the Big Bang, the formation point of the universe. During the intervening time, galaxies have been created by the accretion of material from the Intergalactic Medium (IGM), the tenuous material that lies between galaxies. Innumerable galaxies have been formed, each containing countless stars. Some galaxies

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The feedback hypothesis was very innovative at the time it was proposed. How did you reach the conclusion that AGN feedback was a possible reason as to why giant elliptical galaxies might be dormant? We had two big hints. The first was that the most massive galaxies stopped forming stars first, a trend that is very hard to explain without a large energy source to suppress gas cooling. The second hint was that the number of stars that elliptical galaxies contain and the masses of their central black holes are closely related, suggesting that the central black holes might have a way of somehow "telling" their host galaxies when to stop forming stars.

The supermassive black hole feedback mechanism has gained tractions since you and your team suggested it. What scientific progress has been made due to the interest you have triggered? Through our work and those of others, black hole feedback has become an essential component in our modern understanding of how galaxies form. At the same time, there are many different points of view on how this feedback mechanism may have played out in detail. Thermal Sunyaev–Zel’dovich effect measurements are one of the main tools we have in constraining this process.

Using the Thermal Sunyaev–Zel’dovich effect to measure the energy levels of the IGM has given credence to the ‘feedback’ theory. How will you confirm that your measurements are accurate? Our measurements are accurate but still not very precise, because these are difficult measurements at the limits of current instruments.

Can anything be salvaged from the apparently defunct hierarchical model of the universe? The most massive galaxies were the first to stop forming stars, as more time went by they continued to group together into even larger structures called galaxy groups and galaxy clusters. Today, the largest galaxy clusters contain thousands of galaxies, swarming around each other like bees.

How has our understanding of the universe improved since the start of your research? As an astrophysicist, I am fortunate to be working in an era where the most active areas of modern science. Some of the most exciting results since 2004 have included observations of distant galaxies that appear as they were during the universe’s infancy, discoveries of earth-mass planets around other stars, and the detection of gravity waves from merging neutron stars and black holes.

What do you and your team suggested it. What is your measurement to allow for contamination from other sources of light, delivered a result that was somewhat higher than suggested by hierarchical models that neglected the effect of AGN feedback. These initial measurements made with existing telescopes suggest that AGN feedback may be at work. Professor Scannapieco and his group are now working with the team building the TolTEC Camera for the Large Millimeter Telescope to make higher resolution measurements, which they hope will prove to be definitive.

Professor Scannapieco’s research focuses on better understanding feedback processes in galaxy formation and the evolution of the elements across cosmic time.

RESEARCH OBJECTIVES
Professor Scannapieco’s research focuses on better understanding feedback processes in galaxy formation and the evolution of the elements across cosmic time.

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The PI of the TolTEC Camera is Grant Allison at UMass Amherst and the ASU lead is Prof Philip Maukof.

BIO
Professor Evan Scannapieco studied at Harvard University and the University of California, Berkeley and then worked as a postdoc at Arcetri Observatory in Italy and the Kavli Institute of Theoretical Physics in Santa Barbara. He moved to Arizona State University (ASU) in 2007 and is now an Associate Professor in the School of Earth and Space Exploration.

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