feature

Knowing our Universe

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The ***Institute of Space Sciences and Astronomy*** *(ISSA) has recently celebrated its tenth anniversary. Jonathan Firbank speaks with the ISSA's leading staff about their contributions to the field and some of the most important research projects today, which place ISSA at the intersection of modern astronomy.*

Founded by Prof. Kristian Zarb Adami, a leading figure in Maltese Space Sciences, the Institute of Space Sciences and Astronomy (ISSA) has flourished as an organisation at the intersection of fields crucial to our understanding of the universe.

Collaboration is ISSA's bedrock. The institute works on flagship projects with institutions and space agencies from across the globe. Many readers will be familiar with eye-catching achievements such as European Space Agency missions and the James Webb telescope. Soon, many will also become familiar with the Square Kilometre Array, which is capturing radio images of the universe's infancy and, in many respects, represents the field's future.

ISSA has produced over a dozen Ph.D. graduates and benefits from a broad swathe of affiliate and support staff. However, the easiest way of examining its multidisciplinarity is through its key members. Its director, Prof. Alessio Magro, along with Dr Andrea De Marco and Prof. Jackson Levi Said, each pursue distinct yet interconnected areas of astronomy.

THE SOUND OF SPACE – PROF. ALESSIO MAGRO

As Magro explains, 'Currently, ISSA has three main research areas. I'll let Jackson and Andrea discuss theirs, but my focus is what's called "instrumentation".'

Instrumentation refers to the development of devices vital to astronomy – the telescopes, satellite dishes, and antennae required to study the stars. 'These instruments generate a huge amount of data, which must be processed. A key focus is on building software that can handle this. More specifically, my focus is on radio astronomy, including the search for "fast radio bursts". These are bursts of extremely high energy originating outside the Milky Way. Nobody knows what causes them.' Magro's goal is to identify as many of these fast radio bursts as possible in order to lay the groundwork for a deeper investigation.

Another main focus of Magro's research involves detecting "21 centimetre emissions" – radio wavelengths emitted by hydrogen atoms, some of which may have originated only a few hundred million years after the Big Bang. At that time, hydrogen was so abundant and dense that it obscured all detectable light, creating the "dark ages of the universe", invisible to optical instruments. The radio wavelengths produced by hydrogen can be used to map its distribution from eons ago, and through it, the structure of the early universe. As hydrogen was ionised by ultraviolet light, the dark ages came to an end, allowing optical instruments to become viable once again.

Magro describes searching for the earliest perceptible light as 'trying to spot a match's flame drowned out by foglights.' These primordial emissions are overwhelmed by the visual noise of later cosmic epochs. Detecting them requires incredibly well-calibrated instruments – vast telescopes with equally vast exposure times.

Magro's field is concerned with maximising the information we can glean from the stars. But all that information must be processed and analysed. 'This is a computationally expensive procedure, so we must create systems that can keep up.'

THE PLACE FOR ARTIFICIAL INTELLIGENCE – DR ANDREA DE MARCO

The sheer scale and breadth of astronomical data are making machine learning an increasingly important tool. This leads us to one of De Marco's specialities: AI and machine learning. Integration with machine learning began shortly after the ISSA's inception in 2014.

As De Marco describes, 'There was already an interest in the application of AI and machine learning to astronomical data. ISSA was working with other institutions in designing the Square Kilometre Array.' This is an enormous radio telescope being built in South Africa and Australia – a product of equally enormous international collaboration. It promises to be far more powerful than existing instruments, meaning there will be exponentially more data to process. 'In its early days, this raised the question of how we would ingest but also process and utilise this data – and whether this process could be automated in an intelligent way using deep learning. My work explores the analysis and application of which machine learning techniques are good for radio astronomy and what we can do with them.'

ISSA's growth coincides with the rapid development of AI, meaning the institute must continually update its hardware to keep pace. 'The complexity of AI models is measured in terms of "parameters". Originally, we were working with models that had a few million to 20 million parameters. Now, we are working with models with up to 10 billion parameters – and one more than twice as powerful is currently being developed. These models don't just label data; they have a contextual understanding of it.'

The Square Kilometre Array's first operational subset is located in Australia. 'They had their first simulated data release a few years back, and we are currently applying cutting-edge vision AI models to the survey,' De Marco notes. 'The idea is to detect radio sources – remnants of supernovas, or traces of uninvestigated radio galaxies. Individually, these tasks are not too difficult for an astronomer.

ISSA group photo from the 10-year anniversary event
Photo courtesy of Xjenza Malta

But there is so much data coming in all the time that it would take an army of astronomers to stay on top of it.' AI is ideally suited to perform what De Marco describes as a "first pass" of this analysis – a methodology that could eventually be applied beyond his current focus on radio astronomy, including in the analysis of optical data.

QUESTIONING THE UNIVERSE – PROF. JACKSON SAID

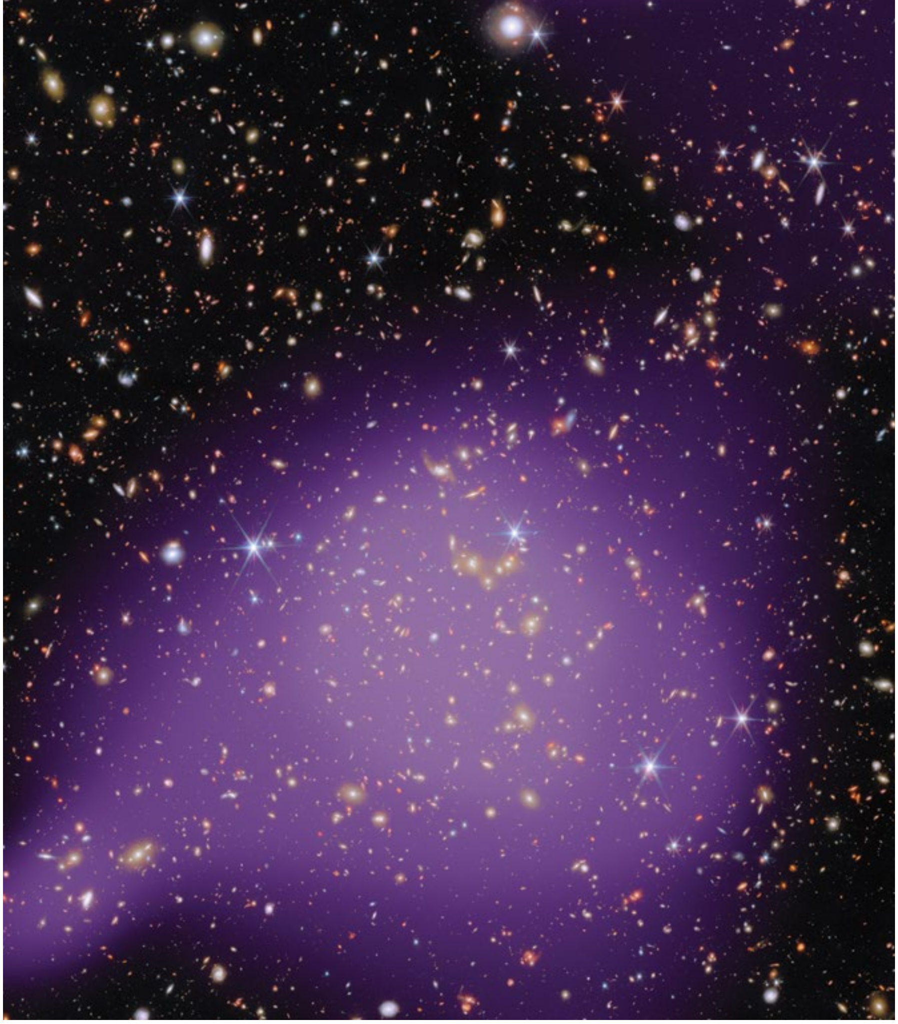
In overly simplified terms, the instruments Magro develops observe our universe, both from beyond our galaxy and from billions of years in the past. The immense volume of data they generate is then processed using De Marco's AI techniques. This brings us to Said's work: comparing and interpreting the results.

Said explains, 'As Magro was saying, he is working on these huge telescopes, which are observing data from the very, very early universe. Our data analysis team works on applying that data to what is known as the standard cosmological model – our current understanding of the Big Bang and the universe's subsequent evolution to today. One thing our research group does is suggest new cosmological models that tackle open questions arising from these observations, and questions arising from relevant theory.'

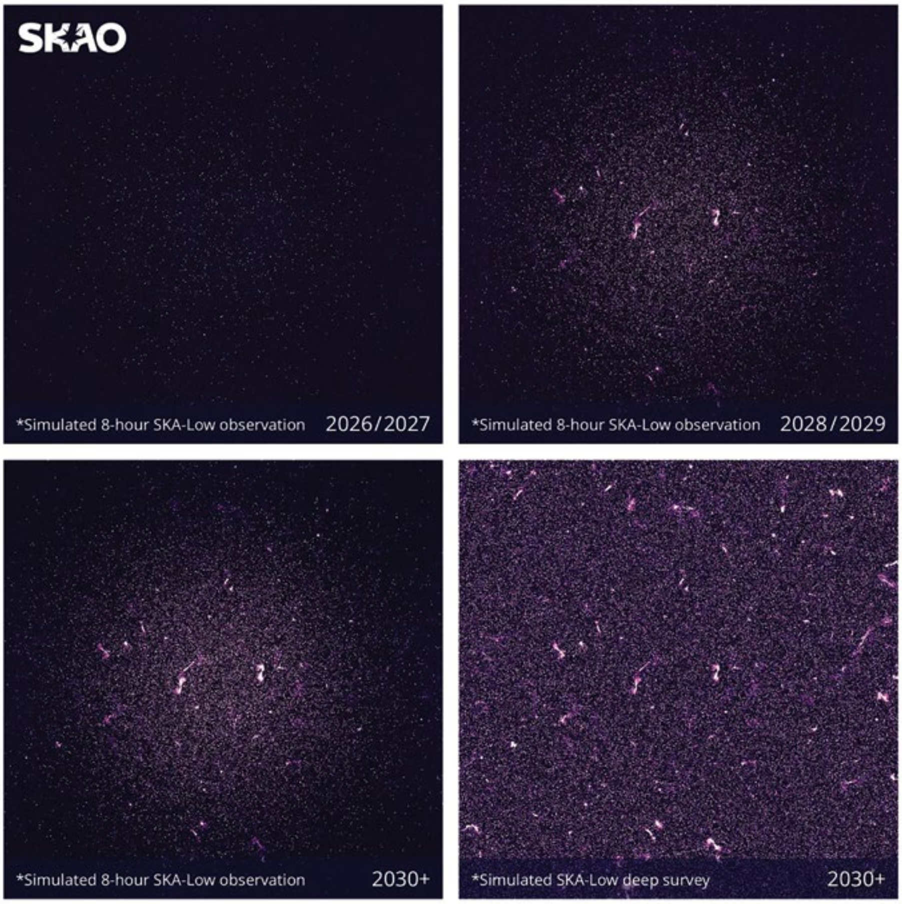
Said is the chairperson of CosmoVerse, a large, international network of researchers working on "cosmic tensions" – mismatches between different measurements of the universe. 'We're working on developing models that tackle this issue, among others, and to that end, we're also developing machine learning tools that will derive new models from existing data. This turns theory on its head a little,' he explains, as normally a model is theorised before comprehensive data is available. 'We can then compare these models to established ones.' This will raise new questions or answer old ones, further consolidating our understanding of the universe.

These questions cut to the core of who we are. Said continues, 'One of the first questions we asked as a species was, "What are the dots in the sky?" And now we're asking, "Where did the universe begin?" These investigations are always something we have cared deeply about. We have always been ready to invest time and effort into them as a society. Now we have the technological tools – the instruments developed by academics like Magro; the data analysis tools that De Marco specialises in; and the analytical models investigated in my field. These unlock the capacity to really understand what happened after the Big Bang, in the epoch of reionisation that followed the universe's dark ages, and beyond.'

ISSA stands at the intersection of three pillars of modern astronomy that are bringing us tantalisingly close to understanding our origins. It bridges past and present, near and far, and the global human effort to know our universe. T



Infrared, optical, and X-ray views of a galaxy group
Photo by ESA/Webb, NASA & CSA



Simulated views of the evolving capabilities of SKA-Low, showing increasing sensitivity from 2026 to 2030+

Image of simulated observations by the Square Kilometre Array Observatory