High-school **scientists**

Dr Puragra 'Raja' GuhaThakurta is an expert on galaxy evolution, but also aims to inspire the next generation of scientists. Here, he shares details of the Science Internship Program he started at the University of California, Santa Cruz, which engages high-school students in experiential learning

How did the Science Internship Program (SIP) at the University of California, Santa Cruz (UCSC) come to fruition?

The Program started with three students from one high school in 2009. They had a very persistent science teacher who had tried for a few years to engage one of my colleagues and hadn't succeeded, but managed to find me. I decided to take on all three students who came on board that year. They ended up working with me for most of that summer, and did exceptionally well, tasting a couple of different flavours of success.

Most notably, they had success in two prominent science competitions in the US. One is the Siemens competition, in which all three entered and two of the three went to the semi-finals. And in the other – the Intel Science Research competition – one of the three was a national finalist , while the other two were semi-finalists.

After the Program, all three applied and were accepted into Harvard University. The success of these three students launched us into what has now become SIP: we went from three students in 2009, to 15 in 2010, 29 in 2011, 43 in 2012, 61 in 2013 and 68 this year.

What are the main objectives of SIP?

The Program is completely open to all schools and the main objective is to educate young students about the nature and process of research. It is not so much about them learning sophisticated technical content or obtaining results, although that does happen along the way, but instead the emphasis is very much on the process of research and the process of answering open-ended grey questions. Another of my objectives is to impress upon students the collaborative nature of research; no matter how great you are as a researcher, your work ties into that of other people.

Why is it important to have good representation of women in the Program?

When SIP started, it was clear there were opportunities out there for high-school students but most were in lab-based, bio- or medicine-related sciences. What was really lacking were computationally heavy projects, which have traditionally come from the physical sciences. Men continue to outnumber women among physical sciences/engineering faculty, researchers and professionals. The gender balance is somewhat better among students in these fields. It could be that the tide is turning with the new generation, but it is also the case that the attrition rate in STEM fields is higher among women than it is among men as you move through the academic/professional ranks. We felt there was a real need.

How have you gone about attracting young female students to SIP?

Single-gender schools aren't that common anymore but there are some, so we decided to partner with one all-girls school. There was a real desire to beef up the STEM programme in this school through experiential learning – learning from experiencing the science rather than reading from a textbook. SIP has made a huge difference already in terms of the students' level of interest in science internships and competitions.

How would you like to see the Program develop in the next few years?

Having a high percentage of women is already filling one diversity need. This year for example we have 38 girls in the Program and 30 boys. However, I would like to increase the level of diversity in the Program in other respects. We are certainly privileged to work with schools and students who have tremendously powerful academic backgrounds – students who have a lot of support from their schools and families. But there are other diamonds in the rough – very bright students who don't have those advantages. One of the missions of SIP going forward is to increase diversity so we can reach out to these students, have them engage in the Program and do just as well as any student on the planet. This year, for the first time, we're charging money for the Program, but this also means we have money to give out scholarships to underprivileged students. We are looking forward to working with students from a wide range of backgrounds.

Beyond diversity, I actively encourage other universities to consider similar programmes to SIP at their campuses. My standpoint is that if your institution can provide the experience, we at UCSC can provide the framework. I'd like to think of ways to scale up SIP so that other institutions can benefit from our experience and provide opportunities for local students. To impact students all over the world, programmes like these must spring up in other university campuses. That's my dream!

Galactic exploration

Investigators from the University of California, Santa Cruz are exploring the evolution of galaxies, using Andromeda as a model for understanding how the Milky Way and other galaxies formed. Revealing the cannibalistic behaviour of the cosmos, this work is uncovering some of the secrets of the Universe

FAR FROM STATIC objects in the night sky, galaxies are dynamic, evolving entities, interacting and changing in often dramatic ways. How galaxies form and evolve is a fascinating topic that has been the subject of intense scientific investigation for decades. Fundamental to understanding our existence is knowledge of how our own galaxy, the Milky Way, formed and continues to evolve. However, the problem with studying our own galaxy is that we live within it. For this very reason, it is incredibly difficult to gain a global view.

OUR ASTRONOMICAL BACKYARD

Puragra GuhaThakurta, Professor at the Department of Astronomy and Astrophysics at the University of California, Santa Cruz (UCSC), is fascinated by galaxy evolution. He is studying our galactic neighbour – Andromeda – to gain a detailed view of how galaxies form and change.

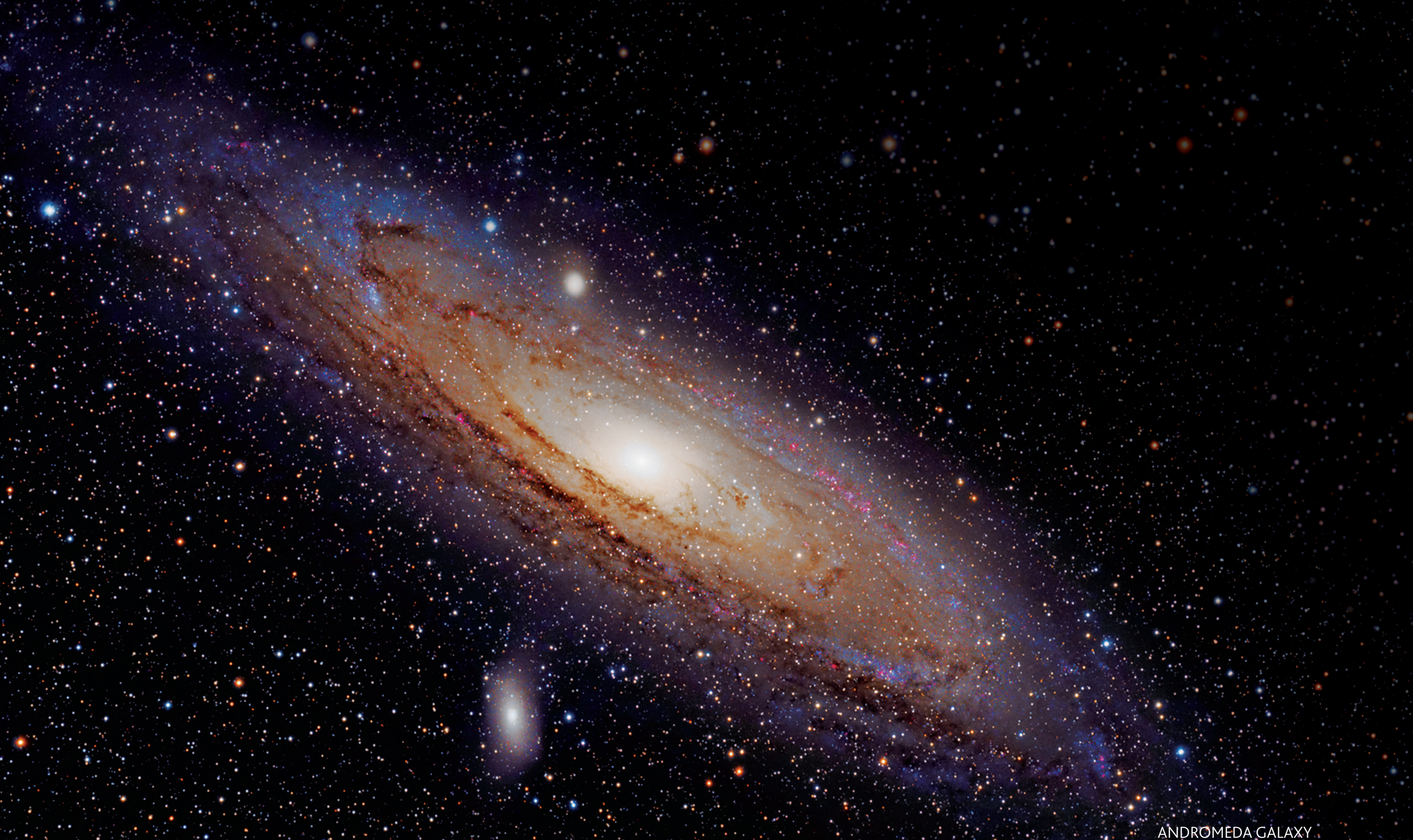
Although 2.5 million light years away, Andromeda is the closest large galaxy to the Milky Way. As a consequence, it represents the best opportunity scientists have of examining the complete structure of a large spiral galaxy in detail; far enough away to present a global view, yet close enough for telescopes to image individual stars within it.

GALAXY CANNIBALISM

Andromeda can be seen with the naked eye and so has been known to humanity for millenia. We know it is a spiral galaxy like our own, consisting of a flat, rotating disc of stars with a central bulge, contained inside a spherical halo. However, astronomers do not understand everything about its structure, and great efforts have been devoted to precisely characterise its history and dynamics.

The limits of our understanding were revealed in the early 2000s. Until this time, astronomers believed Andromeda's halo to be metal-rich, comprising stars containing a relatively high proportion of heavy elements, formed late in the history of the Universe. The stars in the halo were thus estimated to be between 6 and 8 billion years old, almost 4 billion years younger than their counterparts in our own galaxy, leading to suggestions that Andromeda was formed much later.

However, GuhaThakurta challenged this assumption. Using the world's largest optical and infrared telescopes at the Keck Observatory, he led a collaborative project – Spectroscopic and Photometric Landscape of Andromeda's Stellar Halo (SPLASH) – that discovered a halo of metal-poor stars, separate from the bulge. By studying stars far from its centre, the team challenged conventional wisdom, showing Andromeda to be five times larger than previously thought and containing stars as chemically pristine as those found in the halo of our own galaxy. GuhaThakurta



ANDROMEDA GALAXY

and colleagues found relics of smaller galaxies, suggesting Andromeda had grown by consuming stars from dwarf galaxies and supporting the notion of 'galaxy cannibalism'. This indicated that Andromeda and the Milky Way likely evolved through similar processes involving interactions with earlier galaxies.

TIDAL DISTORTION

Once GuhaThakurta had revealed the true nature of Andromeda's halo, he was able to progress with investigations into its assembly. In 2001, researchers had discovered a large stream of stars – known as a tidal stream – through the halo, termed the Giant Southern Stream (GSS). Soon after, the GSS became the focus of intense research efforts to determine its progenitor and find other tidal streams within the galaxy. Using the 8.3 m Subaru telescope in Hawaii, SPLASH investigators found two further streams of stars. Moving in unison, the stars could 'remember' the orbital speed of their ancestor dwarf galaxy.

> GuhaThakurta has made an astounding contribution to astronomy, playing an important role in revealing the surprising ubiquity of galaxy cannibalism and tidal streams, and helping characterise Andromeda's past

Alongside the GSS, a sharp ledge called the Western Shelf is another tidal feature found in Andromeda's halo. GuhaThakurta's team recently conducted a spectroscopic survey of the Shelf, providing robust evidence for two distinct components. Again using the Keck telescopes, his team conducted one of the most detailed kinematic studies of shells in galaxies, uncovering a pattern characteristic of a radial shell.

STAR BIRTH

Understanding star formation is a crucial part of the quest to elucidate galaxy evolution. Studying Andromeda, it is possible to resolve faint stars and reveal the complex processes that govern star formation in their full context.

In 2009, using the Advanced Camera for Surveys (ACS) on the Hubble Space Telescope (HST), GuhaThakurta was a member of a team that obtained detailed optical images of Andromeda to probe the star formation history of the galaxy. Using these data, the team was able to reconstruct star formation history at a number of points in the spheroid, disc and GSS. This enabled detailed comparisons with studies in nearby galaxies and helped plan additional observations in Andromeda. Building on these findings, GuhaThakurta joined another team that launched a new imaging survey of Andromeda: the Panchromatic Hubble Andromeda Treasury (PHAT) programme. Again using the HST, the researchers were able to resolve the galaxy into millions of individual stars, providing unsurpassed detail for further investigation.

CHANGING COMPOSITIONS

The abundance of different chemical elements in the Universe is constantly changing, a process with importance for understanding our galaxy and others. It is also important for understanding ourselves: the recycling of elements within galaxies helps explain our place in the Universe, as almost every element on Earth was formed in stars and supernovae.

Under the project title M31 Satellites Past and Present, GuhaThakurta has been attempting to elucidate the formation and evolution of dwarf spheroidal satellite galaxies orbiting Andromeda. Such satellites include the least luminous galaxies known, and are useful for testing ideas about star formation in the smallest dark matter halos and at the earliest times.

The metal content of a galaxy correlates with its mass, with larger galaxies being more metal-rich. Last year, GuhaThakurta co-authored an article that presented the metallicities of individual stars in dwarf irregular and dwarf spheroidal galaxies. Although the average metallicities of these galaxies depend on stellar mass alone, the article showed that the distribution of metallicity depends on galaxy type, as these two galaxy types appear to be shaped by environmental factors. The processes that eject metals (such as supernova feedback) also expel gas, the fuel that drives star formation. GuhaThakurta and his collaborators revealed that, although metal and gas loss affects metallicity distribution, the universal stellar mass-stellar metallicity relation is preserved.

HISTORIES INTERTWINED

Through his diverse research efforts, GuhaThakurta has begun to provide answers to three key aspects of galaxy evolution: dynamics and assembly; star formation history; and chemical evolution. Yet many questions remain, particularly relating to the ever-enigmatic dark matter, and GuhaThakurta hopes to use Andromeda, as well as the Milky Way and more distant galaxies, to help answer them.

GuhaThakurta has made a significant contribution to astronomy, playing an important role in revealing the surprising ubiquity of galaxy cannibalism and tidal streams, and helping characterise Andromeda's past – which seems to be more complex than that of our own galaxy. But perhaps most importantly, he is helping to explain how we arrived on the third rock from an average star in the disc of the Milky Way.

INTELLIGENCE

M31 SATELLITES PAST AND PRESENT

OBJECTIVES

To conduct spectroscopic investigations of the Andromeda galaxy in order to discover the mechanisms of three main aspects of galactic evolution: dynamics and assembly; star formation; and chemical evolution.

KEY COLLABORATORS

Rachael Beaton; **Steve Majewski**, University of Virginia, USA • **Tom Brown**; **Karoline Gilbert**; **Jason Kalirai**; **Roeland van der Marel**, Space Telescope Science Institute, USA • **James Bullock**; **Evan Kirby**, University of California, Irvine, USA • **Masashi Chiba**, Tohoku University, Japan • **Julianne Dalcanton**, University of Washington, USA • **Claire Dorman**; **Katherine Hamren**, University of California, Santa Cruz, USA • **Mark Fardal**, University of Massachussetts, USA • **Marla Geha**; **Erik Tollerud**, Yale University, USA • **Kathryn Johnston**, Columbia University, USA

FUNDING

National Science Foundation

NASA

CONTACT

Dr Puragra 'Raja' GuhaThakurta
Professor/Astronomer

UCO/Lick Observatory
University of California, Santa Cruz
271 Interdisciplinary Sciences Building
1156 High Street
Santa Cruz, CA 95064
USA

T +1 831 459 5169
E raja@ucolick.org

PURAGRA 'RAJA' GUHATHAKURTA completed his BSc in Physics at the University of Calcutta, India, in 1983 and received his PhD in Astrophysical Sciences at Princeton University, USA, in 1989. In 1994, he moved to his current position as a professor/astronomer at the UCO/Lick Observatory, University of California, Santa Cruz, USA. In addition to his research and service responsibilities, he spends much of his time on teaching and outreach activities for young upcoming students.

Spectroscopic and Photometric Landscape of Andromeda's Stellar Halo

Photo credit: Dr. Andrew Davidhazy