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Australia's strengths in space science

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Abstract

Australia has a long history of space science discoveries. Recent Australian discoveries include the discovery of the most pristine star known, the most distant spiral galaxy, and a massive explosion from the black hole in our own Milky Way, 3.5 billion years ago. These discoveries provide crucial tests of star formation theory, galaxy evolution modelling, and models of the gas around supermassive black holes. Australian astronomers are also extensively involved in the development of new astronomical instrumentation for space, including the Skyhopper satellite, and laser-guided space debris tracking and de-orbiting systems. Finally, Australian astronomers are poised to take advantage of the upcoming James Webb Space Telescope, due to be launched in 2021.

Introduction

Space telescopes are critical to Australian astronomy. Astronomers require space telescopes for multiple key reasons. Our atmosphere absorbs and scatters light at ultraviolet wavelengths, rendering ultraviolet astronomy almost impossible from the ground. Ultraviolet astronomy is necessary for understanding star formation in galaxies, and for modelling the full spectral energy distribution from individual stars and from entire stellar populations.

Our Earth and our atmosphere emit significant amounts of infrared radiation, making infrared astronomy of faint sources extremely difficult. The light from distant galaxies is redshifted, such that the rest-frame optical or UV light is shifted into the infrared spectrum, and is only visible from space.

Finally, our atmosphere blurs and distorts images of astronomical objects. This effect, called "seeing," is seen most often on low-altitude sites where the ground layer or higher layers in the atmosphere experience substantial turbulence. The best sites in the world for astronomy are at high altitude (2500–4000 m above sea level), enabling the telescopes to operate above the typical local cloud inversion layer. Even at these altitudes, seeing affects these observations.

Astronomical instrumentation laboratories around the world, including the Advanced Instrumentation and Technology Centre at the ANU, have developed laser-guided adaptive optics to help overcome these limitations. Space avoids seeing entirely, and offers the best solution for targets where high-precision images are required.

Space telescopes are now operating at all wavelengths, from the gamma-rays and X-rays, through to the UV, optical, infrared, sub-mm, and microwave wavelengths.

In this paper, I outline some of the fundamental areas where Australia is producing leading research using space telescopes. I also briefly discuss the recent Australian astronomy developments in cube satellites.

Chemical evolution of the elements

One of the key goals of the Australian Research Council Centre of Excellence for All-Sky Astrophysics in 3-Dimensions (ASTRO 3D) is to understand the chemical evolution of the elements from the first stars in the universe to the evolution of the chemical elements in our own Milky Way. Within ASTRO 3D, Australian astronomers are combining the GAIA satellite with ground-based data from the Skymapper telescope and the world's largest 8–10 m telescopes to search for the first stars in the universe. Some of these first stars are likely to exist in our own Milky Way, and are identified by their spectra containing the least amount of chemical elements known. ANU astronomers have discovered the top three most pristine stars in the universe (Nordlander et al. 2019).[1]

The first galaxies in the universe are being searched for by University of Melbourne researchers with the Hubble Space Telescope (e.g., Livermore et al. 2018). This team are analysing galaxies that are at redshifts of z~8, looking back 13 billion years ago, when the infant universe was only 5% of its current age.

Researchers at the ANU and the University of Sydney are tracking back the chemical history of the Milky Way. This field, called Galactic Archeology, uses the Milky Way's fossil record of stars. The Galactic Archeology (GALAH) team combines data from the GAIA satellite with high-resolution spectroscopy from the world-leading HERMES instrument on the Anglo-Australian Telescope. This combination of space- and ground-based data allows astronomers to measure the ages and chemical abundances of hundreds of thousands of stars in the Milky Way. So far, this team has measured ages and chemical abundances of 500,000 stars in the Milky Way. Theoretical models predict that when we reach 1,000,000 stars, we will be able to track back the chemical and accretion history of the Milky Way to its formation.

Exciting discoveries have been made along the way. The GALAH used the Hubble Space Telescope to show that a massive flare was produced by the supermassive black hole in the centre of our galaxy 3.5 million years ago. The impact of this massive explosion was felt 200,000 light years away (Bland-Hawthorn et al. 2019).

Galaxy evolution

Australian astronomers use space telescopes to understand the formation and evolution of galaxies across cosmic time. To observe the most distant galaxies, Australian astronomers use gravitational lensing. Predicted by Einstein, a large mass in the universe (such as a cluster of galaxies) bends light around it, mimicking the light path through a refracting telescope that has a diameter many galaxies across). The combination of space telescopes, gravitational lensing, and 8–10 m class telescopes have led Australian astronomers to make major discoveries in galaxy evolution, including the discovery of the most distant spiral galaxy (Yuan et al. 2017). This discovery provides a major test of galaxy formation and evolution models, which have predicted a later formation of spiral arms.

1 See this and the other references for figures, diagrams, and images. [Ed.]

Australian space instrumentation development and testing

Recently, Australian astronomers have been involved in the development of CubeSats for space astronomy. A CubeSat is a miniature satellite that is made of 10 cm × 10 cm × 10 cm units. The weight limit of CubeSats is stringent; it must be less than 1.33 kg per unit. Multiple CubeSats can be launched into orbit simultaneously, and launch is relatively inexpensive.

ANU astronomer Brad Tucker is developing a completely different space astronomy mission. GLUV is a program to place telescopes onto Google's balloons (called Google Loon). The Google Loon program aims to launch balloons over rural regions around the world to improve world-wide internet connectivity. While Google Loon is looking down at earth, GLUV telescopes are looking up into space to understand core collapse supernovae. Core-collapse supernovae are massive explosions produced by giant stars when they complete their fusion processes in their core. The outer layers are blown off in supernovae, with the core collapsing into a neutron star or a black hole.

University of Melbourne astronomer Michele Trenti is leading an international team to build a CubeSat called Skyhopper. Skyhopper is a 22 kg satellite with an infrared camera with rapid response capabilities. The infrared detector needs to be cooled to –130 degrees C to reduce detector noise and obtain high sensitivity to astronomical objects. The detector is currently being built and will be used to search for extrasolar planets, as well as to look for the first stars and galaxies.

The Advanced Instrumentation and Technology Centre at the ANU houses the largest space satellite testing facility in the southern hemisphere. This facility includes thermal and vacuum test facilities, vibration and shock testing facilities, and an anechoic chamber to test communications systems for space.

ANU InSpace and EOS Space Systems are developing a world-class laser space debris tracking and de-orbiting system. They have developed a photon pressure laser that is capable of nudging space debris to de-orbit them. They will first use low-powered lasers to detect and follow space satellites and identify debris to be de-orbited.

InSpace is also developing the first space laser communications system, touted as being an "un-hackable" system. Laser communications systems have many applications, including quantum encryption, distributed quantum computing, synchronising atomic clocks, and long-baseline quantum sensing.

The future

Astronomers in Australia and around the world are looking forward to the upcoming launch of the James Webb Space Telescope. Due to launch in 2021, the James Webb Telescope is an all-infrared telescope, designed to detect the first galaxies in the universe, and to reveal Earth-like planets around other stars. Australian astronomers are part of world-wide teams that will receive the first data from the James Webb Space Telescope, called the Early Release Science Program. Stay tuned!

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