The Eagle nebula imaged by the Spitzer Space Telescope.

NASA/JPL-CALTECH/INSTITUT DASTROPHYSIQUE SPATIALE

INFRARED ASTRONOMY

The dusty cosmos comes to light

Michael Rowan-Robinson finds an account of NASA's Spitzer mission gripping but narrowly focused.

Infrared astronomy has revealed a dynamic cosmos. By harnessing infrared radiation — electromagnetic radiation with wavelengths longer than those of visible light — astronomers can study interstellar gas and the dust grains spread through it, the birth and death of stars, the formation of planets and the monster bursts of star formation when galaxies collide. After William Herschel used a thermometer to discover radiation beyond the red end of the visible spectrum in 1800, the field developed slowly. By the mid-to-late twentieth century, it had come into its own, evolving from ground-based observations to airborne and finally space telescopes.

In *More Things in the Heavens*, Michael Werner and Peter Eisenhardt focus on the Spitzer Space Telescope, the NASA mission, launched in 2003, on which they have both worked for decades. They unashamedly fly the flag for its achievements, from imaging dwarf planets in the outer Solar System to detecting the Universe's most distant galaxies.

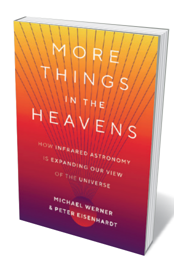
Spitzer, named after US astrophysicist Lyman Spitzer (1914–97), is an 85-centimetre telescope capable of cooling passively in space to 26 °C above absolute zero (26 kelvin); a helium cryostat further cools its three instruments to 1.2 kelvin. These instruments are the Infrared Array Camera, the Multiband Imaging Photometer and the Infrared Spectrograph. Launched in an unusual orbit of the Sun, trailing behind Earth, Spitzer is now two-thirds of the way to the opposite side of our planet's orbit.

Spitzer is only one of six infrared telescopes that debuted between 1983 and 2009. (I was lucky enough to have been involved with five of them, either as a member of the science team for the mission or one of the instruments, or as leader or co-leader of major survey programmes.) The first was the Infrared Astronomical Satellite (IRAS), launched in 1983 as a joint project of the United States, the Netherlands and the United Kingdom. That was followed by the European Space Agency (ESA) Infrared Space Observatory (1995), Japan's Akari (2006), ESA's Herschel Space Observatory (2009) and NASA's Wide-field Infrared Survey Explorer (WISE, 2009).

In some ways, Spitzer has been the most remarkable. As Werner and Eisenhardt note, it took 32 years to reach the launchpad. Originally proposed in 1971 as a mission based on the Space Shuttle, five years before the pioneering free-flying survey mission IRAS was conceived, Spitzer entered a saga of funding squeezes, cancellations and de-scoping. Yet the science team, including the authors, doggedly persisted, and brought the project to fruition. Perhaps because Spitzer's Byzantine path through the NASA system was vividly described by George Rieke in his 2006 book *The Last of the Great Observatories*, Werner and Eisenhardt relegate it to the appendix. Yet, by doing so, they miss an opportunity to share some of the pain and triumph.

The second unusual feature of Spitzer was that in 2009 — on completion of its nominal mission and when its coolant was exhausted — it entered an 'extended mission'. Although most of its instruments could no longer function, the two shortest-wavelength cameras on the Infrared Array Camera continued to operate at the spacecraft temperature of 26 kelvin. They are still going.

What has been achieved over that extra decade, related in *More Things in the Heavens*, was a complete revelation to me. Most notable is what Spitzer has revealed about exoplanets, outer Solar System objects and the disks of dust and debris that orbit stars, analogous to the Solar System's Kuiper belt. IRAS first detected disks around other stars in 1983, but Spitzer has enormously expanded our understanding of their connection to



More Things in the Heavens: How Infrared Astronomy Is Expanding Our View of the Universe
MICHAEL WERNER AND PETER EISENHARDT
Princeton University Press (2019)

planet formation. More than 140 Kuiper belt objects similar to Pluto have been found, and 45 imaged by Spitzer.

The sections dealing with these subjects, and with the outer Solar System and comets, are the most original; much of the material is relatively new. High points from 2014 to 2017 alone include the imaging and mass determination of a near-Earth asteroid, and detection of an exoplanet by measuring how its gravity affects light from a background star. Werner and Eisenhardt also discuss insights from infrared observations of the Milky Way, the close neighbouring galaxies called the Magellanic Clouds, and others. After a ponderous chapter on infrared galaxy counts come quasars and active galactic nuclei, galactic clusters, the history of star-formation and, finally, Spitzer's role in estimating the redshifts of the most distant galaxies, a remarkable achievement for a telescope of its size.

Werner and Eisenhardt mention, too, how NASA devoted a large proportion of Spitzer's first-year observation time to six 'large programmes intended to leave a lasting scientific legacy. These covered a wide range of scientific goals. GLIMPSE, for instance, was a survey of the Milky Way, whereas SWIRE, COSMOS and GOODS explored the extragalactic Universe to various depths. This — in my view — enlightened approach continued throughout the mission: in the end, more than 30 legacy programmes were approved. However, there is little systematic account of them here.

The book's title refers to Hamlet's declaration in William Shakespeare's eponymous play: "There are more things in heaven and earth, Horatio,/Than are dreamt of in your philosophy." There are also more things in the story of infrared astronomy than appear here. The contributions of other missions and ground-based efforts tend to be mentioned only in passing. I might have preferred to see a bit more on the theoretical work that makes sense of the Spitzer observations. And the general reader might find the many scientific diagrams perplexing.

Spitzer, however, merits a detailed and authoritative account of its successes, and *More Things in the Heavens* is just that. Eisenhardt was also a member of the science team for the WISE mission, launched in December 2009. Werner, by contrast, has devoted his entire scientific career to Spitzer, and deserves to bask in the glow of its success. ■

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SATELLITE IMAGING

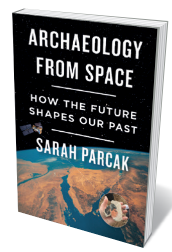
Adventures of a space archaeologist

A personal take on panning out to see the past both grips and frustrates **Jo Marchant**.

The ancient city of Tanis was Egypt's capital for more than 350 years before the centre of power shifted, and the city was eventually lost under centuries of silt. In 1939, archaeologists working there uncovered temples and tombs containing treasures to rival Tutankhamun's. But Tanis was largely forgotten amid the horrors of the Second World War, until a fictional version featured in Steven Spielberg's 1981 film *Raiders of the Lost Ark*. In one scene, archaeologist Indiana Jones sneaks into a map room in which the entire city is laid out, and discovers that the Nazis seeking the titular ark are digging in the wrong place.

In 2010, space archaeologist Sarah Parcak had her own map-room moment at Tanis. Most of the city remains buried beneath the desert, a huge area that would take centuries to excavate by conventional means. So, she chose two satellite images of the site — one low resolution and multispectral, the other higher resolution but black and white — and combined them. As she writes, "I thought I was hallucinating: an entire ancient city leapt off the screen." With details of houses, streets and suburbs, this was a trove indeed: the layout of the largest, most continuously occupied capital city in ancient Egypt.

Since then, Parcak has become famous — winner of a National Geographic Explorer grant and the US$1-million TED Prize (given for innovative, world-changing ideas), with



Archaeology from Space: How the Future Shapes Our Past
SARAH PARCAK
Henry Holt (2019)

multiple agents and high-profile media appearances. In *Archaeology from Space*, she sets out the story of the field for which she is the most recognizable face.

Parcak defines space archaeology (named after a 2008 NASA funding programme) as using "any form of air or space-based data" to look for ancient features or sites. An early practitioner was Antoine Poidebard, the 'Flying Priest', who spent much of the 1920s photographing archaeological sites in Syria and Lebanon from a biplane. From the 1960s, NASA missions such as the Landsat satellites began to provide a view from orbit, although archaeologists failed to catch on for two decades. US spy-satellite images from the cold war were declassified by then-president Bill Clinton in the 1990s; the field hit "warp speed", says Parcak, a few years later. Today, commercial projects such as Google Earth provide space-based images with ever-higher resolution, and drones scan landscapes from closer to Earth.

Interpreting the resulting flood of data is "part science and part art", Parcak explains.

MELISSA GOLDEN/REDUX/EYEVINE

Sarah Parcak identifies archaeological sites and monitors looting using aerial and satellite photography.