1: The galactic centre as seen by 2MASS and MSX. The 1.25 µm 2MASS data are coded blue, the 2.17 µm 2MASS data are coded green, and the 6–11 µm MSX data are coded red. The picture is 5° long by 1° wide, and the galactic centre appears to be bright yellow. Even at 11 µm there are some dust clouds too dense to see through.

A brief history of i

Helen J Walker sums up the first 200 years of infrared astronomy.

It is 200 years since William Herschel discovered and began to explore infrared radiation. An exhibition on the many uses of the infrared part of the spectrum for the RAS President's evening earlier this year drew together the many discoveries and applications of this versatile waveband. Early observations focused on the usefulness of infrared as a measure of temperature, for example of the Moon and the solar corona. Advances in detector technology led to the first sky

Only a small part of the infrared region of the spectrum can be observed from the ground. There are several windows in Earth's atmosphere where we can see infrared radiation from astronomical objects, from red visible light (0.8 µm) to around 30 µm. From 30 µm to around 400 µm, astronomers must get above as much of Earth's atmosphere as possible, going to high mountains, flying balloons or aircraft, or going into space. Some of the main scientific reasons for using the infrared region of the spectrum are to probe dense dust clouds, to study molecules and to observe distant galaxies that emit most strongly in the infrared through their powerful bursts of star formation.

When we compare the view we get of the centre of our own galaxy in the visible with that from the infrared (even at 2 µm), the difference is obvious since the infrared penetrates the dust clouds between us and the galactic centre. However, some clouds have such dense cores, that even at 15 µm they can block the radiation from background objects. Instruments and detectors have improved enormously during the last four decades. In 1968, Gerry Neugebauer and Eric Becklin scanned across the galactic centre using a single detector on the 200 inch telescope at Palomar. In 1995 the same amount of time was used by Ian Gatley to map the whole galactic centre region in several infrared filters.

nfrared astronomy

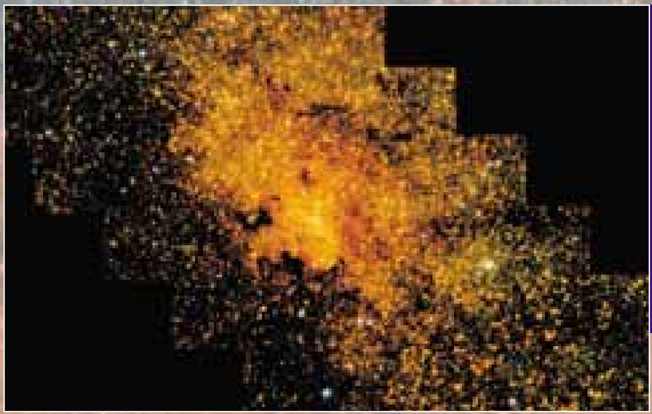
surveys in the 1960s and 1970s. Now infrared astronomy is part of the armoury of the modern astronomer interested in anything from the origins of the universe to the disposition of water and other molecules in interstellar space. Notable successes have come from instruments such as UKIRT, IRAS and ISO, and much is expected in the future from Gemini, the Next Generation Space Telescope, FIRST and Planck, among other planned instruments.

Early pioneers

Although Sir William Herschel discovered and explored infrared radiation in 1800, through his series of 881 experiments, little astronomical use was made of infrared until the 20th century. Piazzi Smyth detected the full Moon in the infrared in 1856, using a thermocouple. In 1881, Samuel Pierpont Langley (who is commemorated on a US stamp for his work towards heavier-than-air flight) invented an instrument he called a bolometer to study solar radiation. One of his students penned these "immortal" lines in celebration of his achievement:

Prof. Langley devised a Bolometer
It's really a sort of Thermometer
It'll detect the heat
Of a Polar Bear's feet
At a distance of Half-a Kilometre!

From 1868 to 1890, the Fourth Earl of Rosse tackled the problem of measuring the heat of the Moon, the brightest object in the sky after the Sun. His final result for the maximum lunar temperature at the equator during the lunar day differed from Langley's results, causing considerable controversy, but posterity has shown that Rosse was nearer the truth. Thomas Alva Edison also investigated the infrared, using an instrument he invented called the Tasimeter. He intended to measure the temperature of the solar corona by comparing it to Arcturus and attempted to measure the corona when the Sun's disk was obscured, during a total eclipse of the Sun in Wyoming. Anecdotally, he is said to have observed the eclipse from the door of a chicken run, all the best sites and best accommodation having been



2: A picture of the galactic centre region, taken with UKIRT. Data at J are coded blue, data at H are coded green, and data at K are coded red. The region covered is 7.5′ by 4.5′. (Image: Ant Chrysostomau.)

4: The Kuiper Airborne Observatory preparing for take-off at NASA Ames Research Center.

3: A map of the entire point source sky as seen by IRAS (in Aitoff projection), with the galactic centre in the middle of the picture. The data are colour coded, and generally stars appear blue, galaxies and young (dust-shrouded) stars appear yellow/green. (Infrared Processing and Analysis Center, Caltech/JPL. IPAC is NASA's Infrared Astrophysics Data Center.)

taken by "proper" astronomers. In the early 1900s, infrared radiation was detected from several astronomical sources such as Jupiter, Saturn and Vega, as well as the first systematic observations, made by Seth Nicholson and Edison Petit, and others, in America.

Modern infrared astronomy perhaps began in the 1950s, when lead sulphide detectors became available to astronomers. The PbS cell was cooled to 77 K in liquid nitrogen to increase the sensitivity. Around 1960, Harold L Johnson defined the first infrared magnitude system. His infrared photometer covered the wavebands R, I, J, K, L (out to 4 μm), and Johnson and his team measured thousands of stars.

Getting above the clouds

In the 1960s, infrared astronomy took off literally as well as metaphorically. Neugebauer and Leighton in California (at Mount Wilson) started work on a survey of the northern sky (giving us the NML, CIT and IRC objects), and Stephan Price made a similar survey of the southern sky. Frank Low invented the first germaniun bolometer (cooled using liquid helium to 4 K) which worked beyond 10 μm, and he made the first observations at 35 and 350 μm, as well as observing at 100 μm using a Lear jet to get above most of the atmosphere. Low and Johnson were using the 60 inch telescope sited on Mount Lemmon (in the Catalina Mountains of Arizona) in the 70s. Pioneering work in the UK in infrared astronomy was led by Jim Ring's group from Imperial College London, with the Infrared Flux Collector (IRFC) on Tenerife. The telescope was similar in size to the telescope used at Mount Lemmon, but as David Allen points out in his book *INFRARED The New Astronomy*, astronomers had to bring their own equipment (a big disadvantage).

Stars and Stellar Systems (Volume II) reported that, in 1959, a balloon experiment was launched by the group at Johns Hopkins University to look for water vapour in the atmospheres of Venus and Mars. Balloons could go as high as 25 miles above the Earth's surface. The Goddard Institute of Space Sciences used balloons in 1966 to survey the sky at 100 μm and they detected around 120 bright infrared objects near the galactic plane. In the 1970s and 1980s, many balloon experiments flew from Palestine, Texas. A typical experiment involved an ESA spectrometer on a UCL balloon platform. It operated between 40 μm and 100 μm, looking at fine structure lines of oxygen in the Orion and M17 nebulae. The UCL astronomy group, led by Dick Jennings, collaborated with the astronomy division of the Space Science Department at ESTEC (including Roger Emery and Brian Fitton). The balloon was filled with helium and its release with the experiment from the truck, Tiny Tim, was very carefully timed. Retrieval of the experiment after the flight often provided some exciting moments, from whether the experiment (and consequently the data) survived the landing to whether it landed at all (there is a photograph of a balloon experiment stuck 25 m above ground in "the only tree in Texas").

In 1967, the Mauna Kea Observatories site for astronomy was founded 4200 m above sea-level on an extinct volcano in Hawaii. The United Kingdom Infrared Telescope (UKIRT) was built there, using an exceptionally thin 3.8 m mirror, making the telescope a third as massive as a normal telescope of that size (6.5 tonnes). The site at Mauna Kea is home to many telescopes now, including the NASA Infrared Telescope Facility (IRTF) and the new Gemini North telescope, which has infrared capability out to 25 μm.

Another way in which astronomers beat the atmosphere was by flying to high altitudes. The C-141A jet transport plane, the Kuiper Airborne Observatory (KAO), based at the NASA Ames Research Center in California, started flights in 1974 (figure 4). The KAO could reach an altitude of 41 000 feet and it had a 0.9 m telescope on board (the hole through which it looked is just visible near the top of the plane). Astronomers brought their own experiments to put on to the telescope, or collaborated with groups which had suitable equipment. Planning the night's observing was more interesting on the KAO than on other telescopes, because the legs of the flight path (corresponding to the objects observed) had to return the aircraft to the airfield from which it took off at the start of the night. The rings around Uranus were found using the KAO in 1977.

SOFIA (Stratospheric Observatory For Infrared Astronomy) is a project funded by NASA

5: The Infrared Space Observatory (ISO) in the clean room at ESTEC.

and the German Space Agency DLR, to put a 2.5 m telescope into a Boeing 747-SP. SOFIA will have a set of observatory instruments for all astronomers to use, and is due to start flights in 2002.

Infrared in space

The Aerobee Infrared Telescope rocket was launched in 1967, to measure the infrared sky background. In 1976, a landmark catalogue was published from observations made with sounding rockets, the Air Force Geophysics Laboratory catalogue (AFGL) by Stephan Price and Russell Walker, with 2363 objects (wavelength coverage 4–30 μm). The data, from a full sky survey (taken during several rocket flights), took a total of 30 minutes to collect. IRAS (the Infrared Astronomical Satellite), a joint Dutch, American, and British project, was launched in 1983 and made an all-sky survey from 10 μm to 100 μm. The 0.6 m telescope and detectors were cooled with liquid helium. The mission lasted for nine months, but in its first 12 hours of operation IRAS detected more objects than were in the AFGL catalogue. The IRAS Point Source Catalogue contains 245 839 sources and in addition to the Point Sources, IRAS produced maps showing the extent of the warm and cool dust. COBE (the Cosmic Background Explorer satellite) was launched in 1989 to survey the infrared background. It confirmed the smoothness of the 2.7 K spectrum and detected ripples in the spatially smooth cosmic background (extremely small temperature variations) which may have led to the formation of galaxies.

ISO (the Infrared Space Observatory) was launched in 1995 (figure 5). It was an ESA mission, with a 0.6 m telescope and four instruments on board, operating between 2 and 240 μm. The satellite weighed around 2500 kg and was launched with over 2000 l of liquid helium coolant on board, which lasted for 29 months. ISO made around 30 000 observations of astronomical objects, from planets and stars to distant galaxies. The Japanese also launched an infrared satellite (IRTS) in 1995, although this had only a 28-day mission. The American MSX (the Midcourse Space Experiment) satellite was launched in 1996. It weighed 2700 kg, and was cooled by a solid hydrogen block, which lasted for 10 months. MSX operated between 4 and 26 μm, with much higher resolution than IRAS.

The future for infrared astronomy

Many ground-based telescopes now have infrared capabilities, including Gemini and Keck. Ground-based surveys at high sensitivity have been made, most notably DENIS (a deep near-infrared survey of the southern sky) and 2MASS (the 2 μm all-sky survey). NICMOS (the near-infrared camera and multi-object spectrometer) was fitted to the Hubble Space Telescope in 1997. The replacement space observatory, NGST (Next Generation Space Telescope), will also have infrared capabilities covering 0.6–20 μm using an 8 m telescope. The next infrared satellites planned for launch are SIRTF by the Americans (in 2002) and IRIS by the Japanese (in 2003). SIRTF will be launched into an Earth-trailing orbit rather than the conventional Earth orbit, and employ passive-cooling techniques in addition to liquid helium coolant.

In 2007, the ESA satellites FIRST (Far Infrared and Submillimetre Telescope) and Planck will share a launch. FIRST will be an observatory satellite making observations of specified targets, but Planck will follow COBE in making an all-sky survey of the cosmic background at higher sensitivity and higher spatial resolution. ESA is studying the Infrared Space Interferometer Darwin (IRSI Darwin), which involves between four and six 3.5 m telescopes (each mounted on a separate spacecraft) acting as an interferometer with baselines between 50 m and 500 m. The interferometer would be used for astrophysics and planetary systems research and would work between 5 μm and 28 μm. It is a candidate for an ESA Horizons 2000 cornerstone mission, for launch around 2012. NASA has a similar mission called TPF (Terrestrial Planet Finder). ●

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