the use of equipment such as the Space Telescope will optical astronomers have a chance to catch up slightly, but by then plans will doubtless be laid for interferometry with radio telescopes in space!

One quite different astronomical use of dish-type radio telescopes is to emit very short radio pulses from them to the planets and to meteors. This **radar** technique of emitting pulses and timing the interval from their emission to their return has many applications. In planetary studies it is possible to obtain accurate distances for the Sun, Moon and planets in this way and, by a more elaborate analysis of a multiplicity of signals, build up a relief picture of a planetary surface. When applied to meteors, the method allows not only meteor tracks but also their velocities to be determined, even in daylight.

Other instruments

Recently astronomers have developed special instruments to answer particular research questions, and of these the **neutrino detector** (sometimes called a neutrino telescope) and the gravitational wave detector are the most significant. The first have been established down disused gold mines in South Dakota and Salt Lake City, U.S.A., Witwatersrand in South Africa and Kolar in southern India, and consist of giant tanks holding hundreds of tonnes of dry cleaning fluid (tetrachloroethylene, C_2Cl_4). Neutrinos will pass through any material with little chance of capture, but encounters with the tetrachloroethylene molecules cause change of the chlorine into radioactive argon. Measurements of the number of changed molecules give a measure of the neutrinos present. The tanks are situated at depths of a kilometre or more to shield them from any effects due to cosmic rays (page 184), and gold mines have been chosen since these are the deepest mines known. Results from these detectors show far less neutrinos than expected, and this has brought about the search for modified theories of the processes occurring in the solar interior (page 91). Other forms of detector including gallium-germanium detectors are being built, in the hope of investigating both high- and low-energy neutrinos.

Several theories of gravitation predict the existence of gravity waves. Various forms of **gravity wave detector** have been built, with the original form being a large aluminium cylinder nearly 1 m in diameter, 1·5 m long and weighing just over 3·5 tonnes, the whole contained within a vacuum chamber. Despite the existence of several potential sources of gravity waves, such as the binary pulsars (page 72), no waves have yet been detected, although there have been one or two false alarms. Calculations show that current sensors are probably insufficiently sensitive to detect the waves which may be reasonably expected to exist, and the development of better devices is under way. In addition to the possible use of the Pioneer spacecraft for the detection of perturbing bodies close to the Solar System (page 152–153), it has also been suggested that if the Doppler shift in the signals from these and other spacecraft could be detected, they could function as gravitational wave detectors. Experiments have already been made in this manner using one of the Voyager craft, but without success. If all these schemes fail to provide any evidence for the existence of gravity waves, fundamental revision of gravitational theories will be required.

Observing from space

The importance of being able to overcome the observing limitations imposed by the Earth's atmosphere cannot be overemphasized. Mention of its adverse effects on optical telescope resolution is only one aspect, and far more serious is the fact that some wavelengths never penetrate down to Earth-based observers. The absorption in the infrared region can, to some extent, be overcome by siting telescopes at very high altitude observatories – such as on Hawaii – but even so that only solves part of the problem. Radiation in the extreme ultraviolet (XUV), X-ray and γ-ray end of the spectrum – all radiation, that is, shorter than about 300 nm in wavelength – is filtered out, yet such high-energy radiation is vital for a full investigation of the universe, as too is observation of cosmic rays, those high speed atomic nuclei whose terrestrial effects only (the emission of 'secondary' particles in the atmosphere) can be observed on Earth.

One method of getting above at least the densest parts of the atmosphere is to use high-altitude balloons which can carry telescopes and other equipment to heights of some 25 km; another is the use of sounding rockets which can be launched to heights of around 160 km before they fall back to Earth. But although much more expensive, full investigations over long periods necessitate the launching of spacecraft, both for direct observation as well as for making close approaches to or soft landings on members of the Solar System.

Because of the cost and complexity of large spacecraft, except in the cases of manned exploration and the use of Skylab, all extra-terrestrial observing has one thing in common – the observing equipment has to be as compact and light in weight as possible, and able to produce its results in a form suitable for radio transmission back to Earth. Every spacecraft, manned or unmanned, is launched by rocket since a rocket receives its impulses from the reaction of its hot gases as they escape from it; it does not have to push on anything to be propelled, as an aircraft, ship, or land vehicle does on Earth. Indeed, a rocket works most efficiently in the airless regions of inter-planetary or interstellar space. To get away from the Earth – to reach **escape velocity** – a spacecraft must reach a speed of 11·18 km per s, and multiple stage launching rockets are used so that once some of the heavy fuel tanks have been exhausted, they may be jettisoned, so that the mass of the vehicle continually decreases and the escape velocity may be more readily reached. The majority of spacecraft devoted to purely astronomical research are placed into Earth orbits (where a minimum velocity of 7·9 km per s must be maintained), but a number are placed into a solar orbit (as, of course, are the planetary probes). In some cases, such as with the Pioneer and Voyager spacecraft, interaction with the gravitational fields of