

WHAT'S NEW IN ASTRONOMY?

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BROADLY SPEAKING, astronomy refers to the observations of the cosmos — of the star-studded night sky, including objects that cannot be visually detected but whose existence can nevertheless be confirmed with telescopes of various kinds. Astrophysics is concerned mainly with the application of physical laws to the study of the heavenly bodies. This division of responsibility is somewhat artificial, however. For, it would be hard for an astronomer to devise meaningful methods of observation without a proper background knowledge of the physical laws that govern the Universe. Equally rightly we may imagine an astrophysicist getting out of contact with reality if he were to ignore observational data while formulating his theories.

It is the interlinking of theory with observations that has made astronomy and astrophysics so full of vitality today. The challenges in this field are not limited to practitioners of the subject — they reach out to advance technology on the one hand and fundamental physics on the other.

What are the "challenges"?

The general relativist Jurgen Ehlers once remarked, "The subject of gen-

eral relativity now has two kinds of problems left: those which can be solved but are not interesting and those which are interesting but which cannot be solved." Such a phase comes now and then to any fundamental science, astronomy and astrophysics not being an exception.

It is usual to dismiss the first class of problems as being of no consequence and to dignify the second class to "challenges". We should remember, however, that in calling something "interesting" we often exercise a value judgement that may be wrong. Science is full of graveyards of ideas that once appeared challenging to the majority of its practitioners. It also has instances wherein ideas fully worked out and set aside as uninteresting turned out to play pivotal roles later. Thus, the notion that we are located at the centre of the Milky Way, so firmly believed in by the astronomical establishment in the last century, proved to be entirely wrong by 1920. The idea of spinors introduced by Dirac in his famous theory of the electron turned out to be based on an algebra previously worked out by mathematicians and set aside.

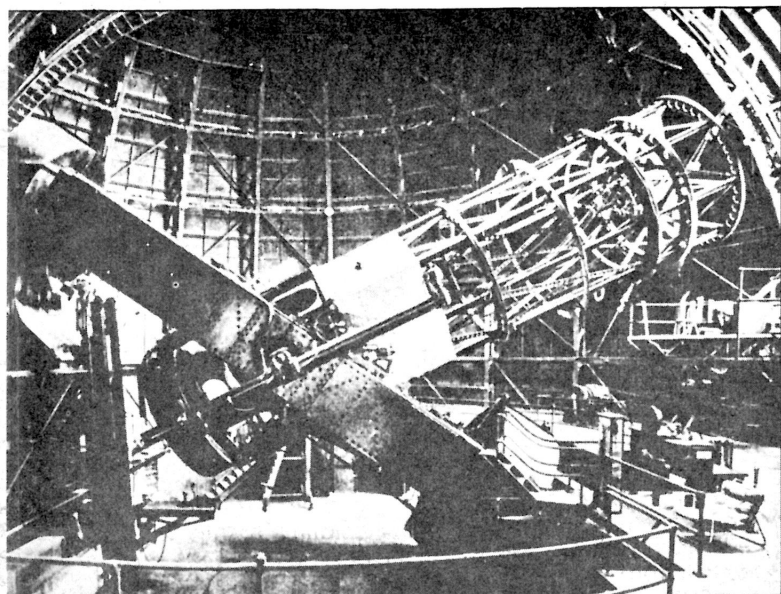
So, as we consider today's challenges, we have to remind ourselves that our

value judgements may not all be correct. Like a good motorist who now and then looks into the rear-view mirror while driving forward, our speculations about the future should be tempered with reminders from the past.

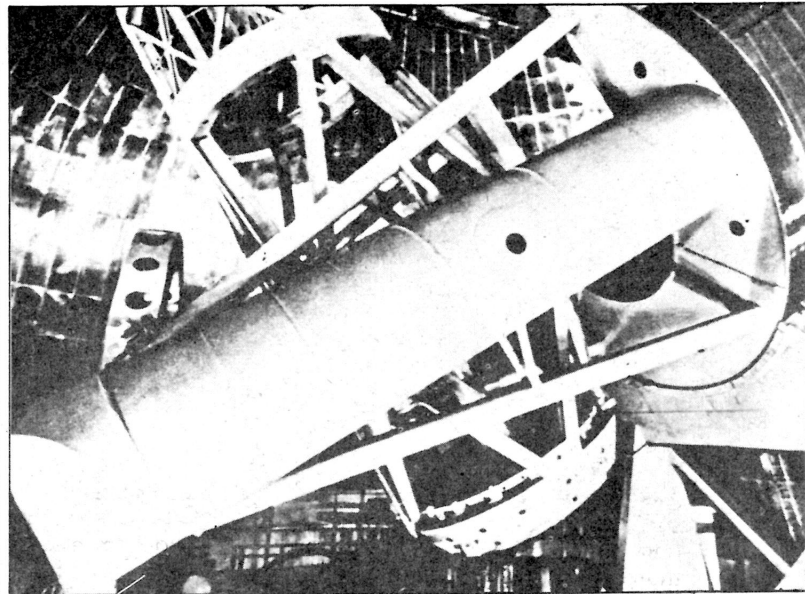
With these words of caution let us indulge in our speculations on the likely future directions

Astronomical instruments

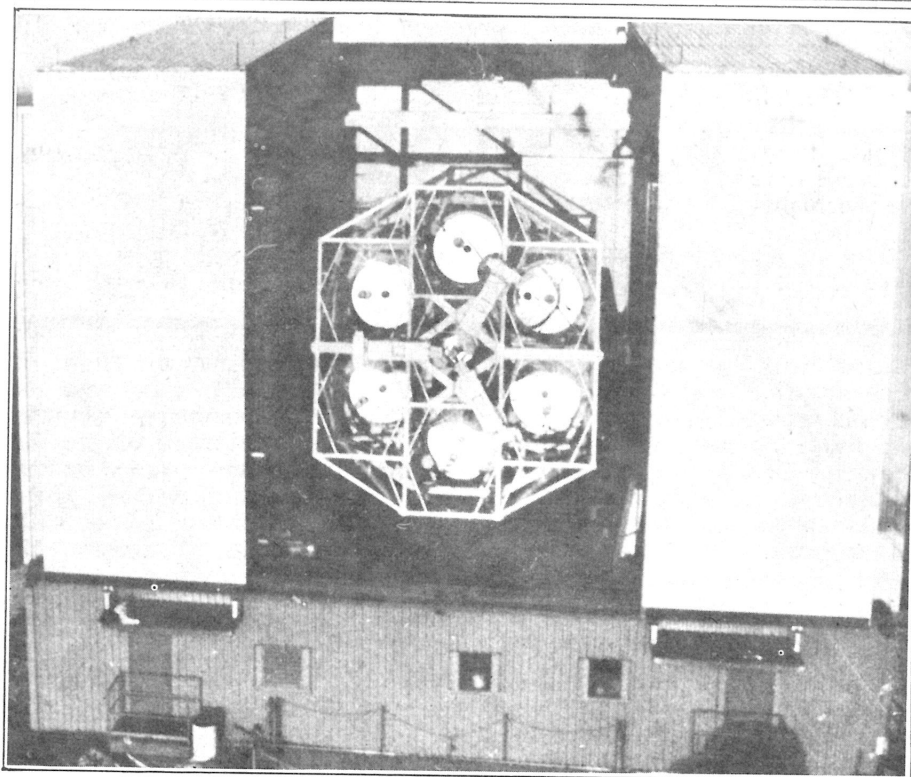
The 100-inch telescope at Mt Wilson that came up in the second decade of this century gave astronomers their true perspective about the extragalactic world. (One inch is approximately equal to 2.5 cm.) Galaxies exist outside our own Milky Way, they are receding from it in a systematic manner, they have star systems of their own — these revelations led in the 1920s to the scientific basis for cosmology. Till then, cosmology, dealing with the origin and structure of the Universe, was only a matter of philosophical speculations. What the 100-inch did for astronomy after World War I, the 200-inch did after World War II. Pioneered by George Ellery Hale, this telescope has continued to play a leading role in extragalactic astronomy. It has shown the way to several telescopes in the 4-metre class that have



The pioneering 100-inch telescope at Mt Wilson heralded the new era of modern cosmology



The 200-inch Hale telescope at Mt Palomar



The MMT has six mirrors in a hexagonal structure

since then come up in different parts of the world.

But what next? Optical astronomers have two ways to go and they are taking them both. One way leads to larger new-technology telescopes in the 8-m to 16-m class. They need not be (and indeed are not) single large dishes. Rather they may be made of several small mirrors combined. The first instrument of this kind is the MMT, the multi-mirror telescope completed in 1979 in Arizona. It has six small mirrors whose combined effect is equal to that of a single mirror of 4.5-metre diameter.

The second way points to space and a telescope of 94-inch size is to be launched by NASA and ESA in this decade. It will have ten times better resolution and it can observe fifty times fainter objects compared to its land-based counterparts — thanks to its location above the atmosphere.

But none of these instruments should be judged purely in terms of their size. Over the years the detection techniques have improved and electronic and solid state devices have more or less replaced the photographic plate or the human observer. A computer with a TV screen can provide much more detailed information about the image of the astronomical source.

"Image processing", as this technique is called, makes use of the rapidly improving hard- and soft-ware coming from the computer industry. Its use extends not only to optical astronomy but to other astronomies as well.

Of these other astronomies radio astronomy is the oldest. Although first conceived in the 1930s by Karl Jansky, it came into its own after World War II. It not only provides further corroborative evidence for objects observed by optical astronomy, but also reveals facts that cannot be "seen" by optical telescopes at all.

For example, when the electron in a hydrogen atom spontaneously changes its spin direction, it emits a wave of 21-cm wavelength. It is known that neutral hydrogen is the most abundant component of the Universe. By observing at the 21-cm radio wavelength the astronomer has been able to learn considerable facts about the structure of our galaxy and also other galaxies.

It is this facility that may bring us important information about the early history of the Universe. In an expanding Universe the wavelength of radiation steadily increases. So radiation coming from the remote corners of the Universe, that left galaxies in the process of formation, would have increased four-fold to five-fold in wavelength. Thus radiation of 21-cm wavelength may lengthen to nearly 1 metre now. This is the logic behind setting up the Giant Metre-Wave Radio Telescope (GMRT) at Narayangaon near Pune. When completed in ten years' time the GMRT will be the largest facility of its kind in the world and it is expected to provide important clues to the unanswered question: "How did galaxies come into existence?"

While radio astronomy was the first

newcomer to the observational field, an entirely new dimension was opened out with the advent of space astronomy. I recall that when the sputnik was launched and space technology became a reality in 1957, several leading astronomers expressed scepticism as to its benefits for astronomy. While they were correct in expecting that the bulk of space budget would go for military purposes, what little has come by the astronomer's way has paid far greater dividends than expected.

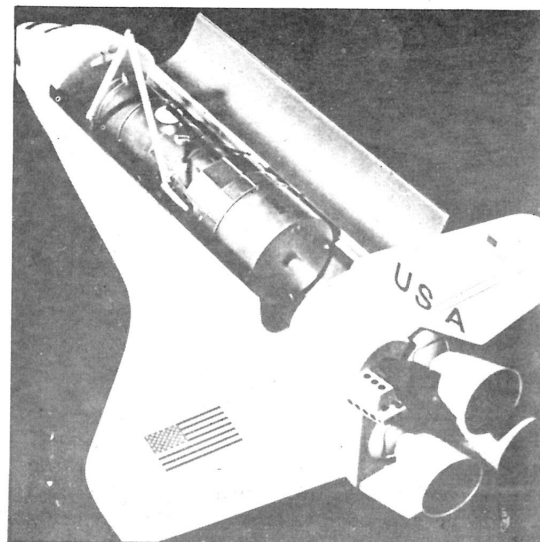
Today we have X-ray, infrared, ultraviolet and gamma-ray astronomies carrying satellite-based instruments detecting these forms of radiation. These would normally have been inaccessible to the astronomer if he were entirely ground based. Starting from the small satellite detectors of the 1960s and 1970s space astronomy holds out the possibilities of advanced facilities on much larger scales by the turn of the century.

It is expected that computer-based image processing will become increasingly more sophisticated in conveying to the ground-based astronomer the fine details of the structure of celestial objects as revealed by these invisible forms of radiation.

Astrophysical insights

What insights will these advanced instruments provide? None, if they are not matched by advances on the theoretical fronts. Of course, it does not happen in any fundamental science that theory and observation are always in phase. In astronomy and astrophysics there are areas in which observations are leading while there are others in which theory is ahead.

Take, for example, quasars. Do we really know what makes quasars shine? Are we even sure of their distances from us? Six to seven decades



The space telescope seen inside the space shuttle from where it will be launched in space

Dark matter

SEVERAL ALTERNATIVES are suggested for dark matter. The fact that it is unseen suggests that it is made of black holes. Or, it could be made of starlike objects which are of such low masses that they are not able to shine by triggering nuclear reactions in their cores. Such objects are often called "jupiters" in analogy to the planet.

Both these alternatives have their own difficulties. Other suggestions include a sea of massive neutrinos. That is, if it is established that neutrinos have a small but non-zero mass (some experiments indicate this possibility while others don't), then they could provide an inert background that is noticed only through its gravitational effects.

More esoteric suggestions come from proponents of supersymmetry. This theory of particle physics requires a host of new particles to exist, corresponding to known ones. Examples are photinos, gravitinos, sneutrinos, selectrons, etc., corresponding to photons, gravitons, neutrinos and electrons. It is too early to assess the impact of these alternatives on the dark matter problem.

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its strong gravitational pull a black hole pulls matter in from the surroundings. How to convert this energy of motion to the observed radiant energy coming from the quasar? Various scenarios have been proposed, all of them demanding extraordinarily high efficiency.

Although more than three thousand quasars have been detected and hundreds closely scrutinized there is as yet no direct method of determining the distance of the quasar. If we accept that the redshift of a quasar comes entirely from the expansion of the Universe then the law, first discovered by Hubble in 1929, puts them very far away. But are we sure that quasar redshifts obey Hubble's law? Most astronomers think so but a few doubters remain. Can future observational programmes settle this question one way or the other?

Even the most advanced part of astrophysics, that dealing with the structure and evolution of stars, brings fresh problems, one of them right at our doorstep. The Sun, the star nearest to us and one which we can and do study so much more easily, presents us with a challenge. The thermonuclear reactions, which generate energy for the Sun to radiate away, also produce a lot of neutrinos. Neutrinos are

particles that are extremely light (are they truly massless? this question also remains to be settled). They interact with matter very weakly and so are hard to detect. The solar neutrinos therefore come out from the deep interior of the Sun essentially unmolested. Can they be spotted as some of them come our way?

The problem is not easy, and a reliable detector set up deep underground in the Homestake mines by R Davis does not seem to detect as many solar neutrinos as theoretically expected. This outstanding puzzle has challenged both the theoreticians and the observers for the last fifteen years.

From the Sun let us now turn to the remote corners of the Universe.

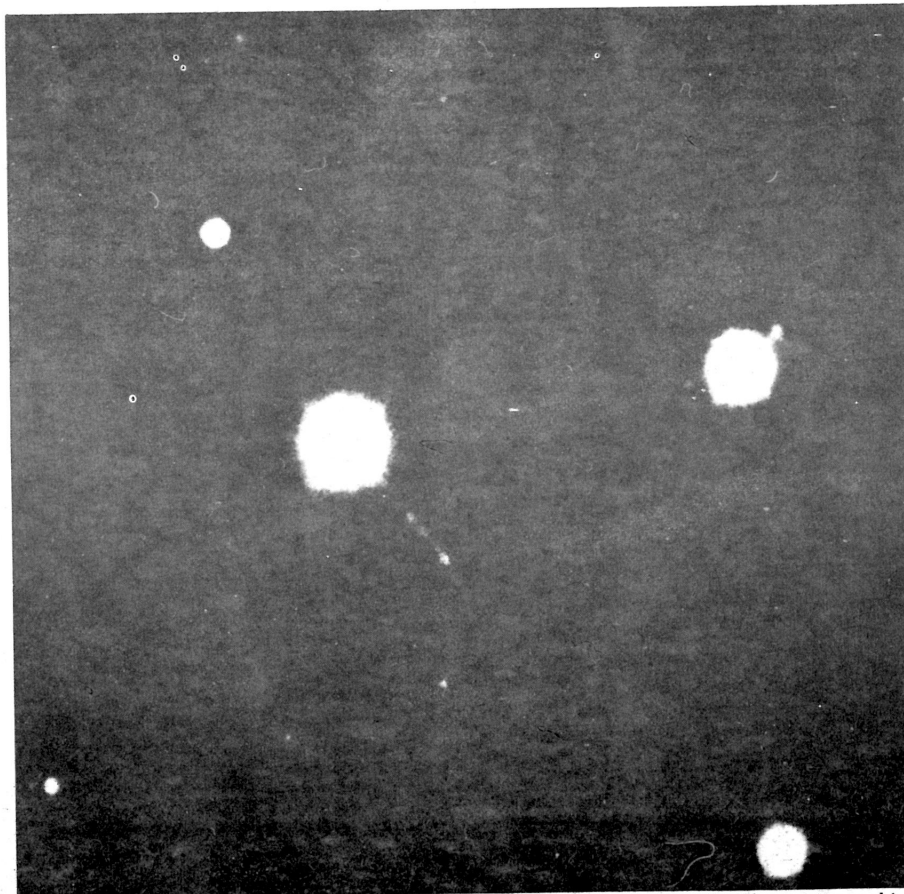
Over the last decade, probes of the large-scale structure of the Universe have revealed big structural inhomogeneities in the form of superclusters of galaxies and voids. A typical supercluster may contain thousands of galaxies distributed over a region of dimensions hundreds of millions of light years. The supercluster is the highest so far in the observed hierarchy of structures:

stars → galaxies → groups → clusters → superclusters.

The nonuniformity of matter distribution is also apparent through the exis-

ago the same questions were being asked about stars. By the 1920s astronomers had realized that their estimates of stellar distances, based largely on the nineteenth century astronomy, were grossly in error. The presence of interstellar dust makes objects look fainter than they actually are — in some cases totally obliterating them and producing voids. It was only after realizing the role of the dust that it was possible to arrive at a true shape of the Milky Way and to discover that we are not at its centre. In the 1920s the Cambridge astrophysicist Eddington was trying to convince the atomic physicists that his models of stars indicated that their source of energy lay in nuclear fusion. The atomic physicists were sceptical and it took them well over a decade to appreciate and accept Eddington's viewpoint.

Unfortunately quasars are a different cup of tea. Their extraordinary brightness and compact volume rule out nuclear energy as a source. As Fred Hoyle and William Fowler first proposed in 1963, soon after the discovery of the first two quasars 3C 273 and 3C 48, the quasar's energy source is most likely gravitational in origin. A version of this idea that is popular today requires a massive black hole to be the mysterious compact source. By



The first quasar (3C 273) to be identified is seen at the centre of the photograph. The energy machine generating its enormous power still remains a mystery

National Optical Astronomy Observatories, USA

tence of apparent voids in certain parts of the sky. The voids appear to extend in depth.

How did this hierarchy of structures get established? Which came first? Did matter accumulate on supercluster scales before condensing into galaxies, clusters, etc? Or did galaxies form first and get together into larger and larger structures though gravitational interactions?

These questions are of course bound up with the unsolved problem of how structure in any form emerges in the expanding Universe. A look at the microwave background radiation, first discovered at 7 cm wavelength by Penzias and Wilson in 1965 (and examined minutely subsequently at several wavelengths), shows that it has a highly homogeneous distribution with the black body spectrum. The simplest interpretation of this radiation is that it is a relic of a very early epoch when the Universe was very hot and homogeneous. So the question is:

how did structure evolve out of a very homogeneous Universe?

Astrophysicists expect that clues to this question are to be found in the so-called dark matter in the Universe. "Dark matter" is the name given to that component of the Universe which cannot be detected directly by any form of electromagnetic radiation. How then do we know that it exists? By its gravitational influence on luminous matter! Thus orbits of stars or gas particles in galaxies and of galaxies moving in a cluster can give us an indication of the amount of dark matter present. Estimates, not quite reliable at present, put the dark matter component at around ten times (or even more) compared to the visible component by mass. Evidently the dark component has an important role in the process of structure formation.

Exactly how the dark matter influenced this process in the past depends on what was its nature. And it is here that we run into a veritable jungle of

theories. This wealth of theories reflects two facts: the paucity of observational checks and the range of scenarios offered by particle theorists for the origin and evolution of matter in the early Universe.

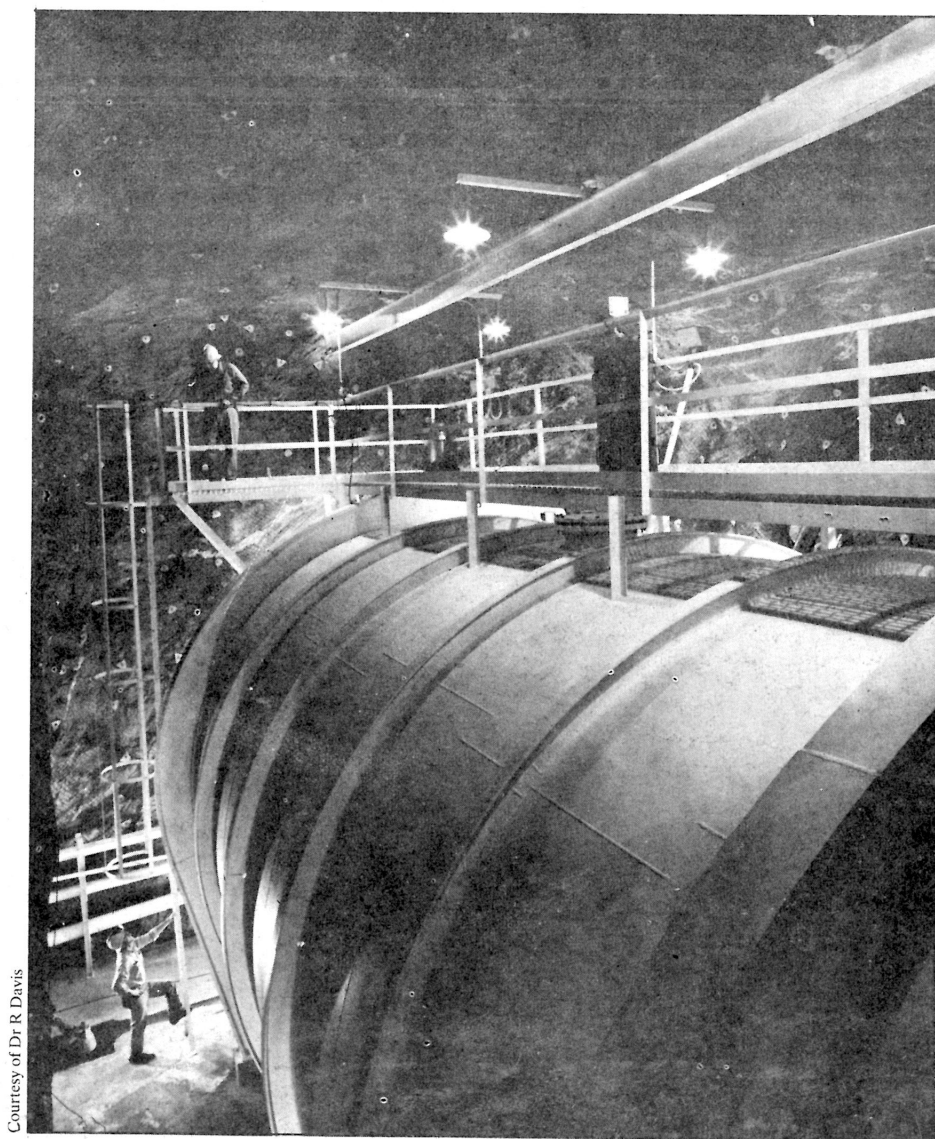
This brings me to my last topic of discussion. If we accept the big bang scenario, then the closer we go to the big bang event the more energetic we find the particles that made up its overall composition. What were these particles? How did they interact at their ultra high energies? Did some of them decay into stabler new particles while others combined together? How did we arrive at our presently observed view of the Universe with bulk of its matter seen in the form of protons, neutrons and electrons?

Particle physicists are excited by these studies because they offer them a unique opportunity of seeing how their attempts to unify basic interactions in physics fared at the ultra-high-energy epoch. Dark matter is one obvious relic of that epoch. Can we determine its nature from our unification theories? Can we link these ideas to the proportion of matter to antimatter in the Universe? If all the galaxies we see in the Universe are made of matter, how did the Universe acquire this matter dominated composition?

Challenges of the unknown

The above questions span our ignorance in the frontier areas of astronomy and astrophysics. There are many more problems which I have not referred to because of lack of space. More importantly there may be even more exciting problems that we are not yet aware of! For, half the fun in fundamental physics comes from the unexpected. Neither the pulsars and the quasars nor the expanding Universe were expected discoveries. I am always sceptical of claims such as "All the important discoveries have now been made" or "The end of physics is close at hand". Such statements have been made before and proved to be wrong. I very much hope that apart from the challenges mentioned here fresh ones will appear in due course!

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Courtesy of Dr R Davis

An underground detector for solar neutrinos