his for many years, through my association with the University of Sussex, and I have learned a lot from conversations with him and by reading some of his outstanding books, notably *Theories of Everything*, which I enjoyed during the summer holidays and which I warmly recommend all of you to read if you have not already done so.

Professor Barrow referred in his lecture to the classic quip by the late Professor Herbert Dingle who remarked (in connection with the 'Perfect Cosmological Principle') that one should call a spade a spade and not a Perfect Agricultural Principle, and he evidently had himself taken this advice to heart in his lecture when he used arguments related to what is sometimes called the 'Strong Anthropic Principle' without explicitly using that expression. In other words, he decided to call a spade a spade and not a Strong Agricultural Principle. (The 'Dilute-Wormhole Approximation' sounds as though it could be yet another agricultural principle!) In the course of his lecture he showed us with great clarity and elegance how the search for grand universal principles, neglecting the inevitable selection effects associated with our mere existence, could well lead to little more than a can of wormholes.

I accordingly ask you to join with me in thanking Professor Barrow for an extremely clear, informative, enjoyable and stimulating lecture! [Applause.]

The President. The meeting is now adjourned until Friday, November 13.

MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 1992 November 13 at $16^{h}00^{m}$
in the Scientific Societies' Lecture Theatre, Savile Row

M. J. Rees, *President*
in the Chair

Secretaries: K. Whaler
D. A. Williams

The President. My first duty today is to record, with sadness, the death of Professor Jan Oort, at the age of 92. This is not the time to record all his contributions, over many decades, to our subject. He was a Gold Medallist of the Society, and he was an Associate for more than 50 years. I ask you all to stand for a few moments in his memory.

We now move on to the scientific programme. We have four talks this afternoon. The first is from Dr. Perry Williams of ROE, who is going to talk about 'Wolf-Rayet Wind Collisions'.

Dr. P. M. Williams. Mass transfer from one component of a binary system to another is well known to provide a rich variety of phenomena, but today let's consider what happens when both stars have mass-losing winds, and neither accretes matter. The stars having the strongest stellar winds are the Wolf-Rayet (WR) stars, carrying about 5×10^{-5} solar masses a year at about 3000 km s^{-1}. Many of these stars are in binary systems with OB stars, which themselves have stellar winds of about the same speed but which are less dense by at least an order of magnitude. The winds collide at the contact discontinuity, close to where the wind momenta balance. Because the mass-loss rate of the OB component is so much lower than that of the WR star, the contact discontinuity has a form like a cone close to the OB star, with its apex pointing towards the WR star. This low-density cone moves through the dense WR stellar wind with the orbiting OB star. The effects of this can be mapped spectroscopically through selective line eclipses, but today I would like to concentrate on three other effects resulting from the standing shocks formed in the wind on either side of the contact discontinuity.

First, as predicted some years ago, the heating of the wind in the shocks to 10^7–10^8 K provides a source of X-radiation, and binary Wolf-Rayet systems are brighter X-ray sources than single stars; the extent to which this is observed depends on the opacity of the wind in our direction. Secondly, many of these sources contain strong non-thermal radio sources. Synchrotron radiation originating where the winds collide is affected by free-free absorption through the wind in our direction, often being extinguished altogether. Most remarkable of all is that these systems can produce clouds of dust. The presence of small amounts of dust, say 10^{-8} solar masses, in the radiation field of a hot star is easily detected by its re-radiation in the infrared of the UV and visual stellar radiation it absorbs. The prototype, which shows all these effects, is the system HD 193793 or WR 140, whose dust formation in 1977 I described to the RAS in 1978. This system formed dust again in 1985, and was subsequently shown to be a binary of period almost eight years in a highly eccentric orbit. Subsequent observations show that the infrared radiation rises sharply by a factor of about ten in three months and then declines over a period of years, the decline being slower at longer wavelengths (because it is caused by the dust cooling). The radio flux rises to a maximum around phase 0·8 and then falls sharply. Observation of the spectral-energy distribution over eight decades of frequency — from 6-keV X-rays to 21 cm — shows that the ultraviolet, visible, and millimetre fluxes apparently do not vary. The infrared spectrum changes from the stellar-wind power-law to one intermediate between that and synchrotron radiation. This occurs as the circumstellar extinction to the non-thermal source varies as the stars move in their orbit; the extinction is at a minimum when the OB star, and low-density cone, cross our sightline. The variation in the X-ray extinction around 1–2 keV as the circumstellar extinction along our sightline varied in 1984/85 allowed a measure of the CNO abundances in the wind. New observations of the most recent radio maximum, from Westerbork, particularly at 21 cm, allow tight mapping of the low-extinction cone in the wind because of the high free-free opacity at this wavelength.

It is timely to return to these stars now for three reasons. First, there has been a lot of theoretical work recently, partly stimulated by the remarkable variations of WR 140, on high-energy processes in colliding stellar winds, by Usov, Stevens, and their associates. They have examined the geometry of the interaction region and shock fronts and shown that the shocks can accelerate the electrons sufficiently to produce the observed levels of radiation. Hydrodynamical calculations show the presence of instabilities in the interaction region which may lead to the clumping probably necessary for the dust formation in such inhospitable circumstances.

Secondly, more colliding-wind WR + OB binaries have been discovered from infrared observations of their episodic dust formation, showing that WR 140 is not a freak. Generally, these systems are not the well-known spectroscopically studied WR + OB binaries, but systems which vary on timescales of years. Among them is WR 48a, which formed a dust cloud in 1979 and whose infrared radiation has been fading ever since; and WR 137, which rose to a maximum in

1984. The most recent example is WR 125, described in the October 1st *Monthly Notices*. It is very like WR 140 in its infrared and radio variation. At radio maximum, observation at three wavelengths allowed independent solutions for the circumstellar extinction to the embedded source and the intrinsic spectral index. The latter turned out to be −0·5 in frequency space, as expected for synchrotron radiation.

Two new observations help to resolve problems with this system. An optical spectrum obtained in the violet with the *INT* shows the presence of hydrogen and He II absorption lines attributable to the OB companion to the Wolf-Rayet star, which had been inferred only indirectly from the blue spectra. Two spectra observed in the 8–13 micron region with *UKIRT* showed no evidence for the 11·52-micron resonance expected from graphite dust, supporting the view that the dust is amorphous carbon.

The third reason for discussing these objects now is that the prototype, WR 140, is approaching another maximum of activity in 1993 March. There is an international campaign to observe it at as many frequencies as possible. The radio maximum caused by the transit of the low-density cone and mapped by the 21-cm flux has already occurred. To measure the intrinsic high-energy maximum expected at periastron passage, we will search for gamma radiation, which is not expected to suffer circumstellar extinction, with *Compton* in 1993. Infrared observations will help us model the rate of dust formation in 1993, and the subsequent cooling. Of central importance will be observations of radial velocities, to strengthen the orbital elements: the eccentricity, longitude of periastron, and 21-cm light-curve will constrain the cone shape. The interaction region will also be mapped using selective line eclipses from *IUE* spectra. You are very welcome to join us!

The President. Are there any questions?

Dr. C. D. Scarfe. I take it that you don't know at present at which bit of the orbit the abrupt change takes place?

Dr. Williams. The abrupt change in the dust formation is very clearly tied to the periastron passage, and the radio must be tied roughly to where the 'hollow' occurs.

Dr. D. A. Williams. The amorphous-carbon model of dust would suggest that this dust might emit strongly in the extended red emission, at about 6000 Å. Would it be possible to detect that?

Dr. Williams. It should be. We are attempting to get photometric observations. So far what little work has been done in the optical has not shown any changes. The effect is, of course, much smaller than in the infrared, and it requires careful observations.

The President. Thank you very much. Our second speaker on the listed programme is unfortunately unable to come. We are grateful, therefore, that instead we have Mr. Duncan McNeill from Geonics in Toronto, who will be talking about 'Applications of Electromagnetic Methods to Environmental Geophysics'.

Mr. D. McNeill. The electrical conductivity of soils is dependent on the electrical conductivity of the included soil water, among other factors, which is in turn dependent on the concentration of ions in the soil water. Typical industrial contaminants (with the exception of hydrocarbons) increase the ion concentration and thus the electrical conductivity of the soil; such contamination can often be detected by mapping the soil conductivity. Because soil conductivity is also affected by other parameters (porosity, clay content, *etc.*), a significant part of the survey interpretation procedure lies in determining the shape of any conductivity anomalies (and often their dependence on depth), to ensure that an actual contaminant plume has been detected, and not simply a local change in soil constituents or structure.

Recently developed inductive electromagnetic instruments (operating in either the frequency or time domain), exploring to shallow depths, are ideally suited for industrial-contaminant mapping since they do not require galvanic contact with the earth (no electrodes), and thus terrain conductivity can be measured more quickly than with conventional DC-resistivity techniques. Most importantly, large areas can now be measured in great detail, permitting accurate determination of the size, shape, and depth extent of a suspected plume. An additional advantage of electromagnetic techniques is that they are also sensitive detectors of buried metal, which is often associated with contaminant sites.

Many examples of the use of inductive electromagnetic techniques to map subsurface contaminants may be given. These include, in addition to mapping the nature and extent of hitherto unknown industrial-disposal areas, mapping brine leaking from petrochemical-production facilities and potash-mine tailings sites; mapping acid mine drainage generated in reclaimed surface coal mines; locating buried concrete storage tanks; mapping dry-land soil salinity, and finally, mapping (underwater) the enhanced conductivity of lake-bottom sediments resulting from absorption of effluent from local sewage-disposal pipes.

It must be kept in mind that the electrical conductivity of the soil is also dependent on parameters other than industrial contamination; the objective of an electromagnetic-conductivity survey is to indicate to the environmental hydrologist where to locate monitoring wells most effectively to investigate whether the geophysical anomaly is, in fact, a contaminant plume.

The President. Thank you very much for a talk so comprehensible to those of us who normally look up, and who may not even have our feet on the ground!

Mr. McNeill. I have to confess, I did my Master's degree in radio astronomy. [Laughter.]

The President. Would you like to answer some questions, perhaps from any radio astronomers in the audience?

Professor R. J. Tayler. Given that there is so much waste that has to be disposed of, do your techniques tell people where they ought to put their waste so as to minimize the damage to the environment?

Mr. McNeill. They are used in assessing sites that are going to be used for landfill later on. ('Landfill site' is a euphemism for 'garbage pit'.) It's a good idea to survey the area first. You then have a database against which to compare subsequent surveys, to learn what's actually going on. They can also detect faulting, so that they do let you determine whether sites are poorly suited to contaminant storage.

Professor R. E. Hills. What frequency do you use?

Mr. McNeill. We use low audio frequencies, in order to stay in the low-induction-number approximation.

Professor Hills. Do you scan in frequency?

Mr. McNeill. No. Within that approximation, changing the frequency makes no difference. To get changes in depth, we have to make parametric changes; that is, we'd have to change the inter-coil spacing or its coupling. If you're familiar with the concept of skin depth, the inter-coil spacing is always much smaller than the skin depth.

The President. To what extent can you scale this up to get to greater depths?

Mr. McNeill. Unfortunately, with these simple instruments, not very much. We do, however, make other measurements which go to much greater depths.

The President. Thank you very much. Our next speaker is Professor Bernie Burke from MIT, who is spending this year on sabbatical leave at Jodrell Bank. It is a very great pleasure to welcome Professor Burke, who is a former President of the American Astronomical Society and who has been the chairman of a recent NASA study on techniques for looking for planets around other stars. This afternoon he is going to tell us about this work.

[Professor Burke had not provided a summary of his talk at the time of going to press. He described the work of the NASA Science Working Group on Exoplanetary Systems between the years 1985 and 1992, culminating in the recent publication of its report *Towards Other Planetary Systems (TOPS)*. The expectation of detecting a planetary system about a star, an 'exoplanet', is derived from the observation that approximately one star in three appears to be single, and that T-Tauri stars commonly have associated dusty discs 10 to 100 AU in radius. The three phases of the *TOPS* programme were described as being: reconnaissance (using ground-based test-beds to search for several examples of exoplanetary systems, extending the studies of circumstellar material, and the provision of resources for theoretical work to proceed); survey (using a moderate-mission space facility, establishing the prevalence and variety of planetary systems, and continuing theoretical work); and intensive study (direct imaging using an advanced observatory facility). Professor Burke then outlined the methods of detecting exoplanetary systems by methods indirect (inferred from the motions of the star) and direct (from the observation of preplanetary and circumstellar discs in the infrared and optical regions), and the instrumental limitations.]

The President. We have time for quite a few questions after this talk, so who would like to start?

Dr. Scarfe. I think that the doppler-detection people did start to keep an eye on each other at a conference at the Center for Astrophysics in July.

Professor Burke. I was supposed to go to that conference and I'm sorry I didn't make it, but I hope it was a good opportunity for them to start talking to each other.

Dr. Scarfe. I should have said, I wish I'd attended it too! Some of the people who did attend have been looking at these things for a decade or more now. If there are Jupiter-sized planets they probably have Jupiter-sized periods, and they are hard to detect that way.

Professor Burke. I want to see the first publications.

Dr. Scarfe. I think there's one in *PASP*, by Campbell and Walker.

Professor Burke. That was in the *Bulletin* of the AAS. It promised great things, but nothing more was heard of it. They may have published something in *PASP*, but I don't know of it.

The President. You didn't say anything about planets around pulsars. Is that because you think they are irrelevant to the main problem of proto-solar systems?

Professor Burke. Well, when you make a report like this, you want to make sure to the greatest possible extent that anything you have in it is not going to be disproved the next week. I think that at present it seems to be teaching us a very interesting lesson. Since it appears that planet-like things do occur around pulsars, it suggests that nature likes to conglomerate things into planets. I think that's a lesson of hope.

Professor M. J. Disney. Is the instrumentation that you want for this so specialized that it can be used for nothing else, or are these instruments things that we'll need anyway in the next century to do all sorts of astronomy, so that everybody will be behind this?

Professor Burke. Well, I think that the answer is an unequivocal 'yes'. In fact, it goes the other way round: the work that is being done today on ground-based interferometers is sure to lead to interesting science that can be done from the Earth's surface now, and builds towards these more ambitious projects of tomorrow.

Professor Tayler. Did your group talk at all with the 'Search for Extraterrestrial Intelligence' group, and is there anything in common between you?

Professor Burke. We have a reference. [Laughter.] I don't mean to be derogatory. We refer to SETI in the preface. The probability of finding some extraterrestrial intelligence is given by the Drake equation: the probability of planets being formed, times the probability of a planet being suitable for life, times the probability of such planets developing intelligent life, times the probability of that life reaching the technological stage, times the probability of that society being willing to communicate. SETI starts from the right-hand end of this equation. What I have been describing is a programme that starts from the other end. This does not say that the SETI programme is bad at all. I was on their advisory committee, and I'm delighted that they have a programme.

Professor D. Lynden-Bell. Which end would you bet on getting there first? [Laughter.]

Professor Burke. We could take a vote in this audience!

The President. Did I detect a slight embarrassment when you were asked about SETI? Did you feel that it may taint this whole programme with being slightly 'flaky'?

Professor Burke. No, not at all. With a glass of something in my hand I'll explain later.

The President. Are there any more questions? If not, thank you very much, and we wish you the best of luck with selling this to NASA. We now move on to the last talk, and this is again on a planetary topic. We're used to the idea of celestial objects being named after characters from Greek mythology. It now seems that newer objects can be named, perhaps less in accord with IAU precedents, after seedy characters from cold-war mythology. The title of this talk is 'An Evaluation of Smiley', by Professor Iwan Williams.

Professor I. P. Williams. An object discovered by Drs. David Jewitt and Jane Luu at the University of Hawaii 88-inch telescope on 1992 August 30 caused considerable excitement in the British national press; according to some of these press reports, at least, this object is called Smiley, and may well be the tenth planet for which many astronomers have been searching for a long time! Let me take some of these statements in turn. Smiley was, of course, the master spy in John le Carré's books. Smiley is also minor planet 1613, named after a European astronomer. The name of the object discovered by Jewitt and Luu is 1992 QB1, and nothing else at present. At discovery, 1992 QB1 was at magnitude 23, and two images were obtained roughly two hours apart. In that time, the object moved through about 2 arc seconds. This is consistent with the motion of a body moving on a near-circular orbit at about 40 AU. From its known magnitude and estimated distance we can deduce that it is a body about 120 km in radius. It is therefore five times smaller than asteroid number 1, Ceres, and it was deemed to be a minor planet rather than a 'proper' planet when it was discovered at exactly the position where a planet was expected. 1992 QB1 is thus not a tenth planet, long-searched-for or otherwise.

1992 QB1 is not the first small body to be found beyond the main belt of minor planets. That distinction belongs to 2060 Chiron, orbiting between Saturn and Uranus. A second, very similar object was found in 1991: 1991 DA. In 1992, Minor Planet 5145, Pholus, was discovered. Its semi-major axis is a little larger than that of Uranus, but moves out to beyond Neptune. The question is whether 1992 QB1 is a fourth member of this group of distant asteroids, or whether it is the first of something different. We are not as yet in a position to give a definitive answer to that question, for the answer depends on whether 1992 QB1 is moving on a near-circular orbit at about 40 AU, or whether it has been observed near aphelion in an elongated orbit, with the perihelion possibly close to Saturn's orbit. This we will not know until many more observations are available, covering a much longer time span. If the circular orbit proves to be correct, then it is probable that 1992 QB1 could be the first object belonging to the Kuiper Belt, the very inner part of the Oort cloud of comets, out of which new comets are perturbed.

It is thus a case of mostly 'nots': 1992 QB1 is not Smiley; it is not a tenth planet; but nevertheless, it may also be not uninteresting.

The President. Thank you very much. I invite questions.

Dr. R. C. Smith. There seems to be the tacit assumption in what you were saying that the distance you observe for it at the moment is the furthest distance from the Sun. Is there any reason to believe that?

Professor Williams. No. What you have at present is basically two observations separated by six arc minutes, or whatever the distance was, and that is all. People got excited because back-of-the-envelope calculations produced this velocity of 4·7 km s^{-1}, which fitted a circular orbit at roughly the distance one desires. So they said "Yippee, we have possibly found the first Kuiper-Belt object". Those among us who have studied orbits in their undergraduate days will know that there are at least five free parameters needed to determine an orbit, and therefore with only two measurements you are slightly stuck. One option is to make guesses, and the circular-orbit guess is the first one to make. If one believes that one is getting nearer to the perihelion identification of it as well, then you have three points. If you then assume the inclination to be zero you are then trying to fit only four free parameters with three points, and you are in with a chance. It would then make sense to have this thing roughly at aphelion. You don't have to. The data aren't there, and really it does need more observation.

Mr. D. Francke. May I pass on the suggestion from a composer colleague of mine, Dr. Anthony Milner, that Smiley be re-christened Cerberus, who was the dog who guarded Pluto's infernal regions. He had 50 heads and a ferocious bark.

Professor Williams. I should add, incidentally, that Smiley hasn't been designated anything yet. With only two identifications it's not even been given a proper asteroid number. It's just got 1992 QB1, which is the identification. So the name Smiley is only a press-type 'hype' in some sense.

The President. You said this object wasn't particularly likely to belong to the Kuiper Belt. Would you like to comment on other ways of finding Kuiper-Belt objects; for instance, looking with small telescopes for occultations of stars?

Professor Williams. If you find one serendipitously that way, that's fine. I doubt that many people would volunteer to spend their nights looking at stars and hoping to see an occultation. I don't think you'd get time from panels for allocation of telescope time to do it, either. I think that you have to do what they are doing now, which is to take CCD images of the outer Solar System and just hope to find something eventually. It will come within a few years, I hope.

The President. So eventually you'll get to a stage where an upper limit might cheer you up, just as it would cheer up Bernie Burke if he finds no Jupiters.

Professor Williams. Yes, an upper limit would cheer one up, but we're talking about finding 26th-magnitude objects. It's not that difficult if you have a dedicated telescope and CCD imager.

The Rev. G. Barber. How far away from the ecliptic is it?

Professor Williams. It's quite close at present, but the two observations available are not sufficient to say how highly inclined the orbit is.

Professor Tayler. Have you any idea who was responsible for the highly misleading publicity which led to all our telephones ringing with school teachers wanting to know about the tenth planet?

Professor Williams. I don't know who was responsible for the actual publicity. I do know who was responsible for the discovery: Dave Jewitt, who as some of you may know was an undergraduate student at University College London. He is one of the Brits who emigrated to Hawaii as a result of Government policy. [Laughter].

Dr. J. Darius. If the 100-km radius turns out to be correct, is that consistent with the upper end of a speculative size distribution in the Kuiper Belt?

Professor Williams. The 100 km comes from a guess at an albedo together with a brightness and a distance. It's very consistent with the size of Chiron, and presumably, by the same token, very consistent with Pholus and 1991 DA. So I think that is the sort of upper limit I would guess at for the size of what I'd regard as inert comets.

Dr. Darius. Do you think Chiron is a displaced Kuiper-Belt object?

Professor Williams. I think at the end of the day that they all must be, in the sense that the lifetimes within the Solar System of all these comets are considerably less than the age of the Solar System. Therefore they must come from some form of cold storage, whether you call it the Kuiper Belt, or the inner Oort Cloud, or indeed the interplanetary material which some people like to make a claim on.

Dr. D. W. Hughes. Just a brief comment. As Dave Jewitt discovered it, he still has nine years and ten months to think up another name. If he can't manage it in that time, it then goes to an IAU committee who can call it what they like.

Professor Williams. They can call it 'Not Smiley'.

Professor Sir William McCrea. I'd like, if I may, to ask the last two speakers: if they are looking for strange planets, why don't they look in the envelopes of galaxies like our own, if there is a lot of dark matter there. One suggestion is that it's all made of planets.

Professor Williams. Certainly the suggestion has been made that our 'missing matter' is cold dark matter in the form of planets. A much more efficient way of hiding it is, I think, in cometary nuclei, which are even harder to discover.

Professor Burke. I think there is a definite answer that can be given to that. I know of two groups who are pursuing that line. The group at Berkeley, for example, have a very ambitious and highly professional effort to look for these planets.

The President. Are they using the gravitational-lensing method?

Professor Burke. Yes, looking for Jupiter-sized planets in the Galactic halo. Incidentally, you'll find a page given over to the signature of a planet orbiting a star in our report *Towards Other Planetary Systems*. You'd see a stellar gravitational-lensing event followed by a planetary-lensing event.

The President. If there are no more questions, thank you very much. That concludes the session, and we now adjourn until 1992 December 11.