like I was ploughing a lonely furrow. However, the various measurements we had been able to make – the neutrino, muon, proton, pion and neutron spectra – together made it possible for us to estimate the primary spectrum of cosmic rays at the top of the atmosphere. This was a very elegant calculation, rather like a calorimeter experiment, and it led me to wonder where these cosmic rays came from. That is what drew me into astronomy, in my forties, with no previous interest in astronomy other than general "natural history" awareness of the skies. I started a big programme looking at where cosmic rays came from and what they did on the way. This led me eventually into gamma-ray astronomy.

Absurd results

Coming into astrophysics, I was able to look at results from different fields and draw conclusions. I worked out from the accepted estimates of gas levels in different parts of the galaxy what cosmic-ray intensity would be expected – and got absurd results: cosmic-ray intensities higher in the outer galaxy than in the inner regions. In fact the levels of molecular gas in the inner galaxy had been overestimated by three times. This made us very popular with radio astronomers, among others! We were rather less popular with people who thought that the Earth's history of mass extinctions was a result of the solar system moving up and down relative to the galactic plane, disturbing the Oort cloud and sending in more comets. We showed that the molecular clouds were not big enough to have such an effect, and that the proposed movements were not enough to make any difference.

Once I started to work on the infrared and examined the heating of dust in the universe, I really got hooked. I got many of my colleagues to move into astronomy and that I think is probably my biggest contribution to the subject – not what I did myself. I managed to get the vice-chancellor here at Durham to come to the RAS Club and he was turned on by the subject. Together we got people to move to Durham. We established cosmology here. One of my staff was working on fundamental quantum theory and getting nowhere. I told him: "Form a cosmology group. You're a mathematician really, you think about airy-fairy things: cosmology's for you! Do that and I'll find you a senior demonstrator." He said OK and we appointed Richard Ellis, later a distinguished astrophysicist and good friend.

We had John Major, who had worked at CERN on bubble chamber photos. I said: "We're too small a place to be doing research at CERN where we're lost among 300 authors on a paper. Found a group where we've got a chance of making a mark." This led on to active optics and the success we've had there. We needed a statistician and I recruited Tom Shanks, who had done the MSc at IC and came here for the PhD, and then there was George Efstathiou and others from Cambridge. I'm not really a devious fellow, but I am willing take a chance. Once I learned that they were good, I made them an offer. I told them that if they accepted my offer, then I'd take them, whatever class of degree they achieved. Martin Rees, who was also after these very promising young researchers, went ballistic, but I wanted them for Durham.

"I got many of my colleagues to move into astronomy ... probably my biggest contribution to the subject."

As time went on, we shut down the experimental particle physics work here, but the theoretical particle work went from strength to strength. We boosted the numbers, too. I convinced the VC that we needed a chair of astronomy, and it was funded partly by a university anniversary appeal and partly by SERC (the Science and Engineering Research Council) for five years. Astronomy was certainly a boost to numbers; once we added astronomy to physics, our intake went up. We never changed the name of the department to "Physics and Astronomy", as so many places did, because I didn't think names matter. Physics includes the applied work that is so vital for industry, and astronomy is pure as the driven snow, with the strengths and weaknesses that implies. I certainly pushed the astronomy, but think we kept a good balance in the department.

The future

I think the art in research is in knowing where to stop; when the cream is off, do something else. I do like to keep an open mind, and there are a few areas that I worry about. It looks as though contemporary models of the origin of the universe are too good to be true, for example. They fit too well. I have a problem with the cosmic microwave background from WMAP and the extent of the contribution from our galaxy. I think it would be weird if we could see evidence of the really early universe without worrying about what's in between. I see interesting correlations between features in the halo of the galaxy and cosmic-ray physics that are not accepted by most scientists. They are taking the map of the sky and correcting for effects of cosmic-ray synchrotron radiation, but the people doing that are often not specialists in that field. One man's noise is another man's signal.

It wouldn't surprise me if there were surprises. There are exciting things coming up in other areas, too. Terry Sloan and I are looking at the links between cosmic rays and global warming. I was surprised that *A&G* published Svensmark's work on cosmic rays and clouds. It's a stimulating idea, but it stands or falls on the evidence, and the evidence isn't there.

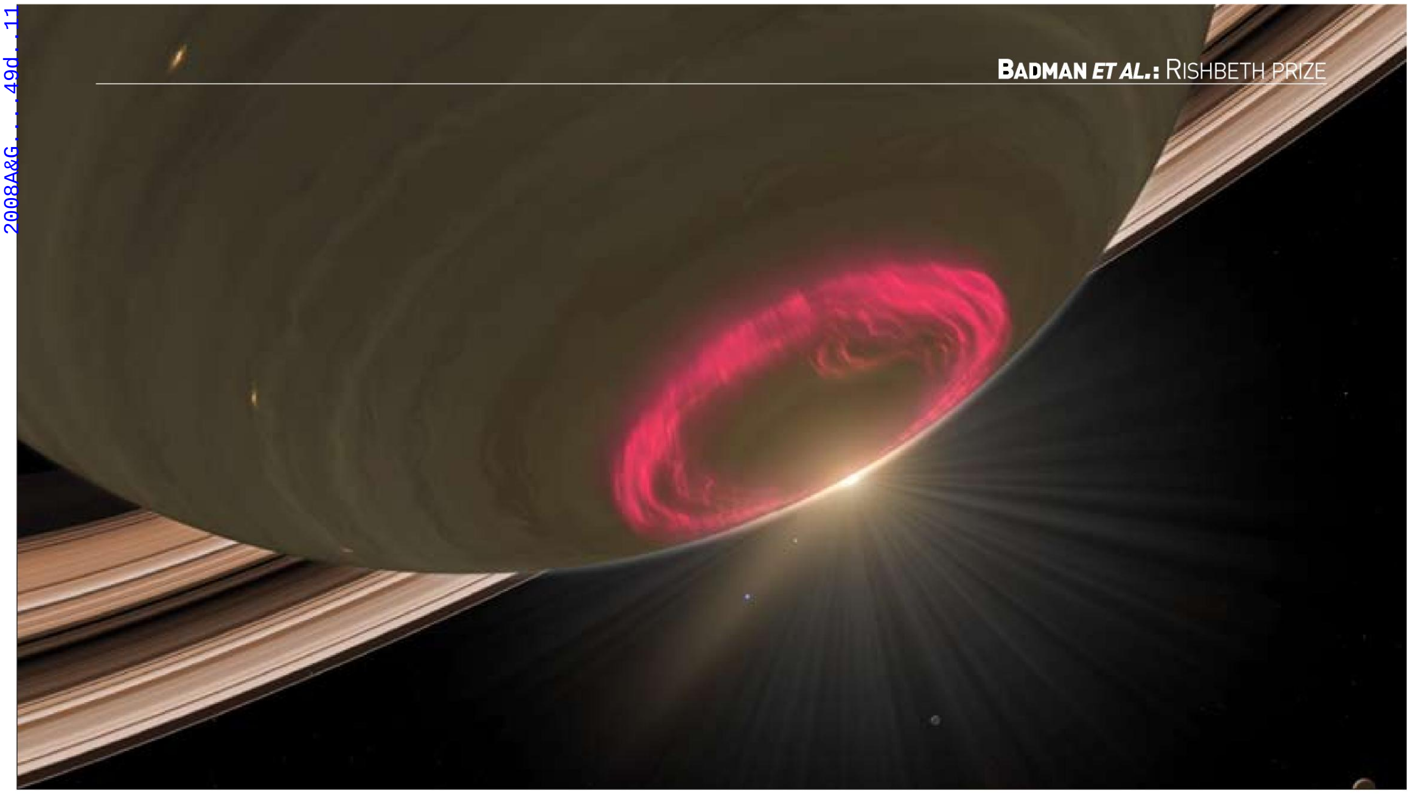
"It looks like contemporary models of the origin of the universe are too good to be true ... they fit too well."

I was surprised to become President of the RAS. I had never thought of it and when Mike Seaton rang and asked me if I would be interested, I said yes. An even bigger surprise was my appointment as 14th Astronomer Royal [1991–95]. A letter came from the Prime Minister, John Major, suggesting that my name be put forward to the Queen. It was a great honour, especially as I had not been at Oxford or Cambridge. It was particularly useful being Astronomer Royal in dealing with government and other bodies – and not just for astronomy. I used to rant and rave about ineptitudes in all sorts of areas, and particularly in the area of funds for science. I felt I was doing something for the community and on a certain level I felt I owed it to people.

John Harrison

Part of my career I'm very proud of is the work I've done over John Harrison. I came across him in Dava Sobel's book *Longitude* and thought: "That's interesting, I wonder how Harrison is honoured in Britain?" The answer was "not at all", so I set about changing it. I'm a member of the Worshipful Company of Clockmakers and I had them institute a medal, the Harrison Medal, which was not a trivial task. Dava Sobel was awarded the second such Medal and when we were chatting I wondered about a memorial for John Harrison in Westminster Abbey. She said "we tried and failed" and I realized that this was a cause for me. I got the historical good and great on-side, the Dean of Westminster Abbey agreed, and we had exhibitions and published a little book, and raised the £30 000 we needed. I think the memorial is in a good position – next to the grave of Livingstone and that shared by Tompion and Graham.

I certainly never dreamt about this sort of success early in my career. I did what I could and enjoyed myself in research. The pleasure of research for me lies in finding something new. There are good questions there that I could answer, and get other people involved in the questions. It certainly was not money that motivated me. Academic freedom is still there, although people often seem too timid to take the route I did. I found that, in universities, vice-chancellors will take action if pressed hard enough by people with fire in their bellies. When we were short of money for astronomy, I'd go and see politicians and argue the toss with financiers and committees. I used to enjoy it. Some of our leaders at the moment seem a bit timid. ●



Saturn's radio clock

The joint winner of the Rishbeth Prize at the NAM in Belfast this year was "How do solar wind compressions affect the pulsing and intensity of Saturn kilometric radiation?" by Sarah V Badman with Stan W H Cowley, Laurent Lamy, Baptiste Cecconi and Philippe Zarka. Sarah Badman writes.

ABSTRACT

Saturn emits bursts of radio waves from its polar regions as it rotates. This study examines how the solar wind affects the intensity and periodicity of the radio bursts. The results not only show how Saturn's magnetosphere interacts with the solar wind, but they also provide a framework for understanding radio emissions from extrasolar planets and pulsars.

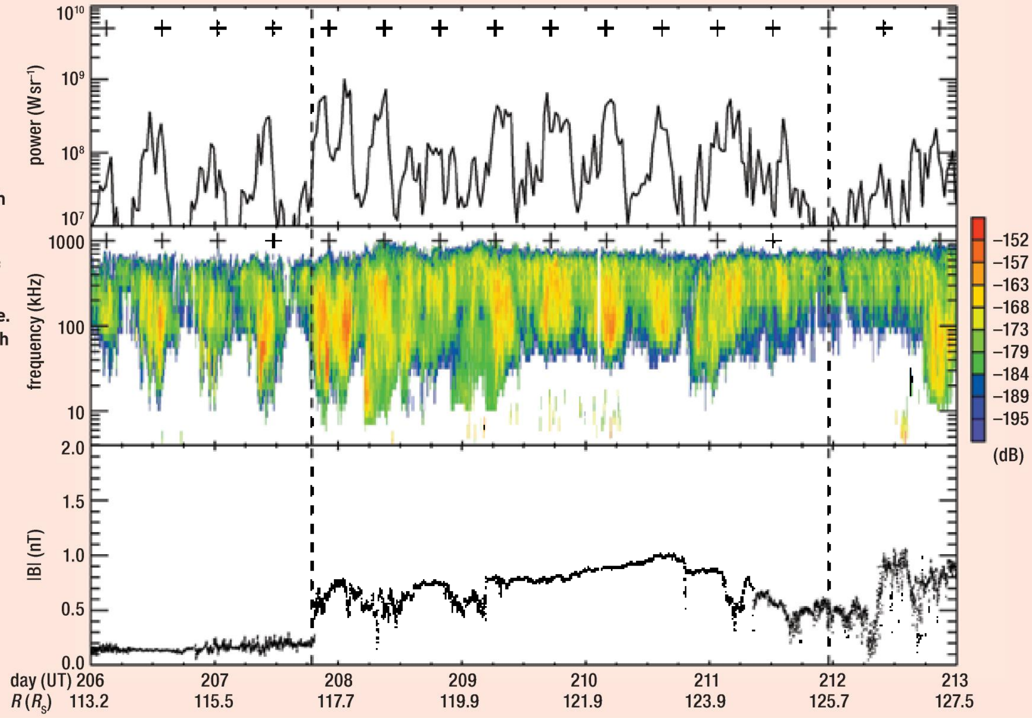
Auroral radiowave emissions have been detected from six of the magnetized planets in our solar system and provide a useful method of remotely sensing the planetary environments. Saturn's radio emissions, known as Saturn kilometric radiation (SKR), were first detected by the Voyager spacecraft as they flew by Saturn in 1980 (Kaiser *et al.* 1980). SKR is believed to be generated by wave–particle interactions on magnetic field lines mapping into the planet's polar auroral regions and its emission peaks in the frequency range 100–300 kHz. Voyager measurements showed that the intensity of the radio bursts was modulated at a period of 10 h 39 m 24 s which, in the absence of any fixed surface features, scientists used as the first determination of Saturn's rotation rate (Desch and Kaiser 1981).

Since then the story has become far more complicated: more recent measurements by the Ulysses and Cassini spacecraft have shown that the SKR period has changed significantly since the Voyager measurements, which cannot be explained by a change in the rotation rate of Saturn itself because of the planet's large inertia. The SKR period also exhibits fluctuations on timescales of a few days and it seems likely that there may be factors other than the planet's rotation that influence the emission of SKR (Zarka *et al.* 2007).

A planet pulsar?

The region that contains and is controlled by a planet's magnetic field is called its magnetosphere. The magnetosphere acts as a bubble protecting the planet from the high-speed solar wind plasma flowing past it. The solar wind also carries with it the Sun's magnetic field, forming the interplanetary magnetic field (IMF). The pressure of the solar wind flowing past the planet is positively correlated with the intensity of the emitted SKR bursts (Desch 1982). The solar wind has important effects on planetary environments, including the exchange of plasma and momentum, establishment of current systems, and changes in the configuration of the planet's magnetic field. Planetary missions such as Cassini suffer the disadvantage of having no nearby upstream solar wind monitor, such as the ACE spacecraft which is in the solar wind upstream of the Earth. If the SKR response to different solar wind conditions can be accurately characterized, then the SKR could be used as a solar wind monitor even while Cassini is deep inside Saturn's magnetosphere.

Understanding potential solar wind control of SKR emissions will help isolate those features controlled by the planet's rotation. In addition, it is well known that the solar wind conditions strongly affect the brightness and morphology of Saturn's ultraviolet auroral emissions (Crary *et al.* 2005) as illustrated in figure 1. Because SKR is also produced by auroral electrons, it seems likely that the solar wind will affect the radiowave emissions too. Further study of the solar wind effects on auroral emissions at different wavelengths will improve understanding of the auroral plasma properties, and the dynamics and currents that drive the aurora. Understanding SKR behaviour has broader applications too,



2: SKR and IMF data from days 206–212, 2004. (Top): The emitted power of the SKR integrated over 100–300 kHz. The crosses mark the expected times of the SKR peaks from Kurth *et al.* (2007). (Middle): SKR electric field power as a function of frequency and time, with crosses, as above. (Bottom): IMF strength in nT (time in days) and spacecraft range from Saturn in units of Saturn radii (R_S = 60 268 km). The solar wind propagation delay is estimated at 0.1 h, assuming radial propagation and a constant solar wind speed of 500 km s^{-1}. The vertical dashed lines mark features described in the text.

for example in aiding the discovery and study of extrasolar planets and pulsars. Predictions can be made about the detection of emissions from extrasolar bodies by comparing with observations made in our own solar system. In addition, when emissions are detected from a pulsar they can be interpreted based on our understanding of planetary and interplanetary (or stellar and interstellar) interactions. In this study we have therefore examined the effects on both the intensity and the pulsing of SKR of compression regions in the solar wind as they impinge on Saturn's magnetosphere.

Features of the SKR

Since Cassini approached Saturn, many more features of SKR behaviour have been observed. For example, as well as the detection of intense SKR bursts following compressions of Saturn's magnetosphere by high-pressure solar wind, a "missed" SKR pulse was also identified (Bunce *et al.* 2005, Jackman *et al.* 2005). This was when virtually no SKR was detected at a time when its intensity should have been at a maximum. These case studies were obtained from isolated solar wind compressions in January and July 2004, but a more general picture of SKR behaviour has been gained by carrying out a survey of all compression regions in the solar wind encountered by Cassini. In each identified case the following features were examined: the timing and intensity of the SKR burst immediately following the arrival of the compression, the pulsing of any intensified emissions, any drop-out in emissions at the expected times, and the relative timing and intensity of the SKR bursts before and after the compression.

The Cassini data used in this study are from late 2003 (day 344) until Cassini encountered Saturn's magnetosphere on day 179 of 2004, and then days 195–298 of 2004 when Cassini had left Saturn's magnetosphere and moved back into the solar wind. Over this time, during the declining phase of the solar cycle, the solar wind generally exhibited a two-sector structure of a few days of high field and density compression regions, surrounded by longer low-field rarefaction regions. The SKR data were measured by the Cassini Radio and Plasma Wave Science (RPWS) instrument over the same time intervals. Fifteen compression events were identified when there was good data coverage during this time. One of the purposes of this study is to determine whether solar wind compressions disrupt or shift the pulsing of the SKR peaks, therefore the expected times of the pulses based on their long-term behaviour must be known for comparison with those observed. These times are found from an expression derived by Kurth *et al.* (2007) for the variation of the SKR phase relative to a fixed period (T_0 = 0.4497 d) by fitting a third-order polynomial to Cassini measurements of the timing of the SKR peaks over the interval from 1 January 2004 to 28 August 2006. This expression was then solved to give a set of times when the peak SKR emissions were expected to occur, for comparison with the observations.

An example interval is shown in figures 2 and 3, which we now describe to highlight some of the common features observed during this study. This was a 14-day interval beginning on day 206 (24 July) of 2004. To examine the variation in intensity of the SKR emissions, the data are presented in two formats. The centre panel shows the electric field power spectrogram measured by RPWS over the frequency range 4 kHz – 2 MHz, incorporating the peak frequency range of 100–300 kHz. The total emitted power integrated over this peak frequency range, and normalized to a distance of 1 AU is plotted in the top panel of the figure. Both these formats clearly reveal the pulsed nature of the SKR emissions. The crosses in the upper part of both of these panels show the expected timings of the SKR peaks from the Kurth *et al.* (2007) algorithm. The bottom panel shows the IMF magnitude |B| in nanoTeslas, which was used as a proxy for the solar wind dynamic pressure in the absence of the pressure data. The time axis is labelled at intervals of days, with Cassini's radial distance from Saturn also labelled in units of Saturn radii (here 1 R_S = 60 268 km). The time taken for the solar wind to propagate from the spacecraft to the planet, assuming purely radial motion and using a nominal solar wind speed of 500 km s^{-1}, is given at the top of the figure. The IMF data plotted in the bottom panel is lagged by the radial propagation delay (<0.1 h in this case) to indicate how they may correspond to the detected SKR emissions.

Squashing the magnetosphere

The start of a solar wind compression region is evident in the IMF data in figure 2 as a sharp