use a well-defined expression for magnetic helicity because they are periodic. Do you have a periodic system? Magnetic helicity is not well defined. One way around that is to use a sophisticated invariant called field-line helicity. I wonder if you had considered that?

Dr. Hosking. I know about this idea. I don't know exactly how one would construct a theory like the one in my thesis using field-line helicity, but it would be interesting to look into how that would work. Your question, I think, drives at the issue that magnetic helicity is only well-defined if one restricts attention to a closed volume; otherwise, it depends on the choice of gauge. In our case, the volume is not closed, but we find that rapid decay of correlations in space, which we do have, also allows one to prove that the theory is gauge invariant.

Professor Priest. Well, I have lots of other technical questions.

The President. I think you should meet up afterwards. Thank you very much indeed. [Applause.]

Just a couple of things. At the railway station this morning I noticed that the Moon and Venus were in a very nice conjunction which is supposed to be even better tomorrow morning. John Zarnecki has alerted me to the fact that the aphelion of Comet Halley should occur at 1 am on Saturday morning, in other words, in about nine hours' time. He has checked previous perihelia and aphelia which have occurred since we were founded in 1820 and he reckons this is the closest occurrence of any aphelia or perihelia to any RAS meeting. Halley is about 35 AU away and is starting to come back in. It should be visible again in 2061. I give notice that the next A&G Highlights meeting will be on Friday, January 12th, 2024. I remind you of the drinks reception to be held in the RAS Council Room and I also have great pleasure in wishing you a very happy Christmas and a productive New Year.

MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2024 January 12 at $16^{h}\ 00^{m}$
in the Geological Society Lecture Theatre, Burlington House

Mike Edmunds, *President*
in the Chair

President. Good afternoon. Welcome. This is a hybrid meeting. Questions can be asked at the end of the lecture but as you will be muted please use the chat facility. Your questions will be read out by the Assistant Editor of *Monthly Notices*, Dr. Pamela Rowden. A list I don't mind is the list of awards. In the New Year's Honours list the following Fellows of the Society received honours: Professor Emma Bunce (former President) is awarded an OBE, Professor Mike Cruise (former President and current Treasurer) an OBE, Dr. Maggie Aderin-Pocock a DBE, and finally a CBE has been awarded to Professor Philip Diamond, Head of *SKA* at Manchester. Very well done to all [applause].

I am now going to announce the RAS Awards for 2024. This is the 200th anniversary of the first award of the Gold Medal, which in 1824 went to

Charles Babbage and Johann Encke. Honorary Fellowships are presented to Professor Ganesan Srinivasan(A), Raman Research Institute, Bangalore, and Dr. Nicola Fox (G), NASA's Science Mission Directorate. The James Dungey Lectureship goes to Dr. Gabrielle Provan, University of Leicester. The Harold Jeffreys Lectureship goes to Dr. Jessica Irving, University of Bristol, and the George Darwin Lectureship to Professor Chiaki Kobayashi, University of Hertfordshire. The Group Achievement Award (A) goes to the *JWST–MIRI* Team, and the Winton Award (G) is given to Dr. Andy W. Smith, Northumbria University. The Winton Award (A) goes to Dr. Chris Lovell, University of Hertfordshire, the Fowler Award (G) to Dr. Christopher Smith, Huddersfield New College (Sixth Form), whilst the Fowler Award (A) goes to Dr. Leah Morabito, Durham University. The Service Award (G) is given to Professor Ian McCrea, Rutherford Appleton Laboratory. The Service Award (A) goes to Professor Ian Robson. The RAS Higher Education Award is given to Dr. David Cornwell, University of Aberdeen, and the RAS Secondary Education Award to Arabi Karteepan, Croydon High School. The RAS Primary Education Award is given to Teresa McGrory, St Joseph's Catholic Primary School, and the Annie Maunder Medal to the AMT Mobile Planetarium Team, University of Namibia. The Jackson-Gwilt Medal (A) is awarded jointly to Dr. Keith Bannister, CSIRO, and Professor Ryan Shannon, Swinburne University of Technology. The Price Medal (G) is awarded to Professor Christopher Davies, University of Leeds. The Chapman Medal goes to Professor Valery Nakariakov, University of Warwick. The Eddington Medal goes to Professor Pedro Ferreira, University of Oxford. The Herschel Medal (A) is awarded to Professor Emerita Roberta Humphreys, Minnesota Institute for Astrophysics. Finally, the Gold Medal (G) goes to Professor John-Michael Kendall, University of Oxford, and the Gold Medal (A) is awarded to Professor Gilles Chabrier, École Normale Supérieure de Lyon, CNRS and University of Exeter. Many congratulations to the award winners. The medals will be awarded at NAM during the summer and we will be hearing lectures from some of them during the coming year.

The first talk today will be given by Dr. Matina Gkioulidou who is a space physicist at Johns Hopkins Applied Physics Laboratory. The talk is about different space-plasma regimes from the magnetosphere to the heliosphere's interaction with the local interstellar field. She is project scientist of NASA's *Interstellar Mapping and Acceleration Probe* (*IMAP*). She is also the lead on *IMAP*'s ultra-energetic neutral-atom camera. She has been a member of NASA's 'Living with a star' programme-analysis group and Geospace Environmental Model Steering Committee and NASA's Heliophysics Advisory Committee. We very much look forward to her talk on 'The *Interstellar Mapping and Acceleration Probe* Mission: Exploring our solar neighbourhood'.

Dr. Matina Gkioulidou. The heliosphere — our home in the Galaxy — is the region of space surrounding our Solar System and dominated by the Sun's presence. It is formed by the million-mile-per-hour solar wind, which blows outward from the Sun to all directions in space, inflating a bubble in the local interstellar medium. The heliosphere provides a shield against the harsh radiation present in the Galaxy, thereby creating and maintaining a habitable Solar System. Understanding the physics of this boundary and its dynamic changes over time can help us comprehend how our Solar System can support life as we know it.

NASA's *IMAP* mission (https://imap.princeton.edu/) will be launched in 2025 on a two-stage Falcon-9 rocket from Kennedy Space Centre and reach its final orbit at L1 using on-board propulsion. With a suite of ten instruments and an international team of 25 institutions, *IMAP* simultaneously investigates two of the most important problems in space physics today: the acceleration of particles expelled from the Sun to high energies, and how the interaction of these high-energy particles with the local interstellar medium shapes our heliosphere.

Four of the instruments on *IMAP*, namely *SWAPI*, *SWE*, *CoDICE*, and *HIT* are taking *in-situ* measurements of energetic particles that are expelled from the Sun's atmosphere, including solar-wind ions and electrons, as well as suprathermal and pickup-ion populations. The *MAG* instrument measures the vector magnetic field to the spacecraft, a crucial measurement to understand particle acceleration within solar-wind structures. *IMAP*'s *I-ALiRT* architecture provides near real-time observations of solar wind, energetic particles, and magnetic fields at L1, measurements necessary for space-weather prediction.

When the energetic charged particles from the Sun reach the outer heliosphere, they charge-exchange with interstellar neutrals and transform into energetic neutral atoms (ENAs). ENAs retain information of the original charged particles, but losing their charge allows them to travel through space unbounded by the Sun's magnetic field, and eventually reach *IMAP*. Three of the instruments on *IMAP*, namely *IMAP-Lo*, *IMAP-Hi*, and *IMAP-Ultra*, covering energies from 10 eV to 300 keV, capture those ENAs, creating all-sky maps of the interaction of our heliosphere, our own habitable astrosphere, with the local interstellar medium.

IMAP also samples interstellar particles, from neutral atoms, to interstellar dust. *IMAP-Lo* derives interstellar neutral O, H, and He flow speed to better than 5% accuracy, fundamental for understanding the kinetic properties of the local interstellar flow, and thus establishing how the interstellar flow interacts with and influences the global heliospheric structure. The *IMAP-Lo* deuterium/hydrogen ratio provides input on stellar evolution, and its contribution to the local matter inventory. The *IDEX* instrument provides the first accurate, *in-situ* measurements of the flux, size distribution, and composition of interstellar dust grains flowing through our Solar System. Dust can interact with everything (electromagnetic radiation, cosmic rays, gas, *etc.*) and it provides a surface for chemical reactions, therefore, it carries information about remote processes through space and time. *IDEX*'s much higher observation rate than previous dust-particle instrumentation (100 particles per year) provides an unparalleled opportunity to sample directly and thereby discover the chemical makeup of solid matter in our galactic environment with unmatched resolution. Finally, the *GLOWS* instrument, measuring UV Lyman-alpha radiation, maps the heliospheric backscatter glow, providing complementary ionization and radiation-pressure measurements, as well as solar-wind measurements, needed to interpret the directly sampled interstellar hydrogen.

In summary, *IMAP* is a ground-breaking mission that uses state-of-the-art instrumentation to create a comprehensive map of the Sun's environment, including high-energy particles and magnetic fields in interplanetary and interstellar space.

The President. Thank you very much, indeed; and the launch date is when?

Dr. Gkioulidou. April 29 to May, 2025.

The President. Any questions in the room, first of all? You are talking about the composition of interstellar dust. Does it actually measure composition or just size and density?

Dr. Gkioulidou. Because you can have mass resolution, you can get all different dust particles.

The President. But you can do the main composition of the particles?

Dr. Gkioulidou. Yes, the composition and the size.

Professor Richard Ellis. Would you be able to get any information on the interstellar magnetic field, like its fine structure?

Dr. Gkioulidou. We will not have a direct measurement of that; however, with ENA imaging and knowing what kind of particles we have and how this structure is at the interstellar boundary, we can infer what the magnetic field can look like. When I said that, the modellers got riled up and they went back to the drawing board; they had to figure out that the magnetic field must be draping round the heliosphere in order to get that structure at 90 degrees perpendicular to the magnetic field. We can make inferences but not direct measurements.

The President. Thank you very much [applause].

Our next contribution is associated with the other specialist meeting here today. 'Simulation-based inference on the Kilo Degree Survey' and Kiyam Lin is giving the talk. He is a final-year PhD student at University College London and works on the task of statistical inference powered by machine learning applied to the large-scale structure of the Universe. Kiyam has so far greatly enjoyed his PhD at UCL since the machine power of computation in general has brought to life tackling problems that are simply too hard with pen and paper. Prior to his PhD, Kiyam had spent several years working in industry after graduating from Imperial College London with an MSci in physics. During those years Kiyam dabbled extensively in both data science and animation work and is bemused by the fact that the nature of work between industry and academia is often very different, even if, in both instances, one is working on analysing data. You come back from industry; we normally send people out, so we are very interested to hear your contribution.

Mr. Kiyam Lin. Cosmic shear is the process by which the images of galaxies are minutely sheared by the gravity from the (mostly dark) matter between the source galaxies and us, the observers. Whilst this phenomenon has proven to be an excellent probe of large-scale structure in the Universe, the statistical analysis of this data has historically involved many statistical simplifications. These simplifications, however, will need to be discarded if we wish to leverage the power of the data that is beginning to stream in from new cosmological probes such as the recently launched *Euclid* space telescope.

The goal of this statistical analysis is often to infer the cosmological parameters of our Universe; for example, one such parameter would be the density of dark matter. There are, however, growing new avenues of doing this statistical inference that requires far fewer simplifications. One such avenue is to learn directly from realistic simulations that propagate all of the physics from the early Universe and its quantum fluctuations to the present-day observations of the night sky with the effects of observing conditions.

This methodology is often called simulation-based inference. In essence, by running lots of these realistic forward simulations, one always has a chance of happening to simulate a Universe realization that is similar to the one we observe today. As one can imagine, however, doing so in such a simplistic manner would result in a huge amount of computational waste as the vast majority of parameter combinations would produce results that are nothing like what we observe today.

Similarly, there isn't often just one optimal parameter value, but rather we want to find the range of possible parameter values, *i.e.*, the probability distribution of parameter values. As such, thanks to the reality that physics often creates smooth probability distributions, we can make use of machine learning to learn the probability distribution from a relatively sparse smattering of simulation runs that span the parameter-value ranges of interest.

In lieu, we can now perform parameter inference whilst keeping as much of the effects of the real physics in there as possible, minimizing the statistical simplifications required to perform successful inference, and gain tight fits on parameters. All of this is to prepare for the new exquisite data we expect to gain from the upcoming stage-IV cosmology surveys such as the *Euclid* space telescope and the Legacy Survey of Space and Time at the *Rubin Observatory*, to name but two.

The President. Thank you very much — statistics clearly put for once! Questions?

Dr. Robert Massey. It's probably really unfair, but you have probably seen the story today about giant arcs and structures. It may not be closely connected to your research but do you have a view on that?

Mr. Lin. I've been here the whole day. I've not seen the news. I'll check it out.

Dr. Quentin Stanley. Is this fit dependent very much on the model or are you able to extrapolate from it that you cannot get a good fit and therefore the physical model needs to be modified?

Mr. Lin. That is a really good point. We have to calculate our observations from data and that relies on the model and also we are always modelling to do the simulation. Anyway, it would be very weird not to be able to model one part without the other part, and so you'll always get a good fit given what you have; however, we can then do something called model comparison where you can find out what kind of physical model fits the data better. Because things are relatively self-consistent, if you think back how to observe the data and you measure them with the model you'll also be able to model a simulation to do this.

The President. I'm put in mind of a criticism Fred Hoyle once voiced. "A fit with no parameters is best, you might learn *something* from a fit with one parameter, if it's two parameters you could fit anything". Thank you very much indeed [applause].

Now we move to a popular event — the George Darwin Lecture. We're delighted to have Dr. Dominic Bowman of Newcastle University today. Dominic completed his PhD in astronomy in 2016 at the University of Central Lancashire under the supervision of Professor Donald Kurtz. He was the recipient of the Springer Thesis Prize for outstanding PhD research. In 2017 he began a postdoctoral research position at KU Leuven, Belgium, and in 2020 he was awarded a Competitive FWO Research Fellowship in massive-star asteroseismology. In 2023 September Dominic began a readership faculty position at Newcastle University and currently holds a prestigious Royal Society University Research Fellowship and ERC/UKRI Frontier Research Grant: SYMPHONY. Dominic has been invited many times as a speaker at international conferences and has won prestigious prizes for his research excellence including the KU Leuven Council Research Award in 2020, the Henri Vanderlinden Prize of the Royal Flemish Academy of Belgium for Science and the Arts in 2022, and the George Darwin Lecture today. In addition to being an outstanding researcher Dominic is passionate about teaching at the BSc/MSc/PhD level and engages regularly in advocacy and mentoring activities for all ages and backgrounds. It's a real pleasure to invite you to give this year's George Darwin Lecture entitled 'Asteroseismology unlocks the hidden physics of stellar interiors'.

Dr. Dominic Bowman. Twinkle, twinkle, little star, how I wonder what you are? More and more these days, I find myself drawing parallels between encouraging curiosity in infants and my research career as an astronomer and academic. It turns out that this particular nursery rhyme must have stuck with me since it is quite an apt summary of my research field known as asteroseismology. Stars appear to twinkle in the night sky because of the Earth's atmosphere. However, in reality almost all stars in the Universe are variable stars, changing their surface brightness periodically because of waves excited deep within their interiors. In my asteroseismology research, I focus on massive stars, which are stars born with masses larger than eight times the mass of the Sun. Massive stars are important metal factories in the Universe, providing chemical feedback to their environments through their winds and explosive deaths as supernovae. Moreover, they are the progenitors of neutron stars and black holes, which can merge to produce important sources of gravitational waves for testing General Relativity.

Massive stars commonly pulsate in two main types of pulsation that are largely grouped into what we call sound waves and buoyancy waves, with the restoring forces being pressure and gravity, respectively. Mathematically, we describe the geometry of pulsation modes using spherical harmonics with three quantum numbers to define the radial order, the angular degree, and the azimuthal order of a particular pulsation-mode frequency. The observational data-driven goal of asteroseismology is thus to assemble long-duration and high-precision light-curve data sets of pulsating stars, calculate the amplitude spectrum of pulsation-mode frequencies and assign them unique spherical-harmonic-mode identification through pattern recognition, and ultimately to compare the frequency to theoretical model predictions. In so doing, we are able to constrain the stars' interior physical conditions with high precision. In recent years, we have experienced a space revolution in asteroseismology, heralded primarily by the ESA *CoRoT*, and NASA *Kepler* and *TESS* space missions, which have assembled light-curves of tens of thousands of pulsating stars. Thus, asteroseismology of many different types of stars within the Hertzsprung–Russell diagram has become possible on a grand scale only in the last two decades.

An important result from ensemble asteroseismology of pulsating stars spanning different evolutionary stages is the measurement of their interior-rotation profiles. In particular, the amount of measured differential rotation, which can be approximately defined as the ratio of the near-core and near-surface rotation rates, is observed to be smaller than expected from theoretical models of stellar evolution. Many pulsating dwarf stars seem to have quasi-rigid radial rotation profiles, with red giants exhibiting somewhat larger ratios, but still much smaller than stellar-evolution-model predictions. This means that a strong angular-momentum-transport mechanism must be operating across different stages of stellar evolution. Leading explanations for this missing mechanism are magnetic fields and the pulsations themselves, which are both efficient transport mechanisms for angular momentum and not necessarily mutually exclusive. A novel result within massive-star asteroseismology is the recent study of HD 192575 published in *Nature Astronomy* by my now-graduated PhD student, Dr. Siemen Burssens. Through our analysis we demonstrated how asteroseismology provides a clear differential rotation profile for HD 192575, and through comparison to stellar-evolution models we extracted an accurate measurement of the star's mass and age to better than 15% relative precision. This is the first time that various sources of observational and theoretical uncertainties were incorporated throughout the analysis, making these results particularly robust and accurate compared to the few other examples in the scientific literature to date.

A common question at astronomy conferences is: what about magnetic fields? Magneto-asteroseismology is becoming an emerging field to help in this regard. Through a combination of asteroseismic modelling, surface magnetic-field measurements from spectropolarimetry, and sophisticated magnetohydrodynamical simulations, magneto-asteroseismology yields the strength and geometry of magnetic fields that are buried deep within the interiors of massive stars. Particularly exciting is the prospect of being able to diagnose the presence of a magnetic field generated within a rotating convective core in a massive star. This framework been applied for the first time to the pulsating magnetic star HD 43317, which has a near-core magnetic-field strength of about 500 kilogauss, and thus acts as a valuable proof-of-concept study for future work.

In recent years a particular focus within my research has been the search for and interpretation of stochastically excited pulsations in massive stars. Such damped pulsations can be excited by turbulence at the boundary of convective cores in massive stars, which then propagate to a star's photosphere and become detectable as chaotic flux perturbations. Such a scenario is distinct from the periodic pulsations excited by a heat-engine mechanism in the outer envelope typically modelled in asteroseismology and producing delta-function-like peaks in the amplitude spectrum of a star's light-curve. On the other hand, stochastically excited pulsations from turbulent core convection produce a broad excess of power in the amplitude spectrum of a star's light-curve with periods of order weeks to minutes. Needing a description for this new phenomenon, we termed it stochastic low-frequency (SLF) variability and have since discovered it to be widespread across a large range of masses and ages. Through developing new numerical methods and techniques to characterize the signatures of SLF variability in time-series observations, I have also demonstrated how SLF variability can be used to infer the mass and age of a massive star, and in turn helped to bring about the emergence of blue-supergiant asteroseismology. In the years to come, my on-going ERC/UKRI SYMPHONY (StudYing Massive star PHysics Of blue supergiaNts with asteroseismologY) project at Newcastle University will build on this work and tackle the remaining uncertainties in our understanding of massive-star evolution using asteroseismology. Thankfully, massive stars clearly twinkle with there being much interesting work for us to do.

Finally, I would like to thank all those who have supported me over the years, especially my mentors, Professor Donald Kurtz and Professor Conny Aerts, and the Royal Astronomical Society's awards committee for the distinct privilege of being awarded the 2023 George Darwin Lecture.

The President. Thank you for what we all agree was a superb lecture. Questions from the floor?

Reverend Garth Barber. What is your view about what is happening to Betelgeuse?

Dr. Bowman. Betelgeuse is the subject of an on-going debate in that we are not sure what evolutionary phase it is in. Is it or isn't it in the core-helium-burning stage? There was a remarkable drop in its brightness and I was actually a visiting astronomer at ESO's La Silla observatory in Chile at the time. I was almost bribed to point the *FEROS* spectrograph at Betelgeuse which would almost certainly have burned the CCDs. It has dropped in brightness by a substantial fraction. There are two ideas. One, which has come out as consensus, is that red supergiants create a lot of dust in the interstellar environment and this gets in the way between us and the star and some of the photosphere will be obscured. I think this explanation has a lot of merit but can be challenging since it requires ultra-precise interferometry such as with *ALMA* to test it. The other theory is that the pulsation and the convection have a non-linear interaction such that the convection can be suppressed by the pulsations and *vice versa* and that will give rise to a cooler star. That is difficult to model and to test, which is why people have been putting effort into testing the dust hypothesis, which I think has been proven to have been fairly well accepted now.

Dr. Gkioulidou. A very impressive talk. I am going to ask you about magnetic fields. I think you said with asteroseismology you can give us the upper limit of the strength of the magnetic field. I think I missed why is it that the more massive stars have weaker magnetic fields.

Dr. Bowman. There is a big diversity in the strength of magnetic fields in massive stars. Typically they are about 1 kilogauss, which is much stronger than the Sun, for instance, but 10% of the massive stars have this strong type of detectable magnetic field. Why this is only 10% of massive stars can be potentially explained by the formation process and/or binary-star evolution. If you take two stars and merge them together you can make a magnetic field. But within that population of magnetic massive stars it can be anything from a few hundred gauss to a few dozen kilogauss which is a large range. I wouldn't say that magnetic fields were weaker, rather there is an unexplored diversity in the field strengths of massive stars and their mechanisms to create them.

Professor Kathy Whaler. I am a geophysicist and not used to oscillations to study the Earth so the question may be a little silly. You showed one example where the peak of $m = +2$ was missing, so you have four out of the five. How do you know it was +2 and not –2?

Dr. Bowman. This is a technicality that I tried to skip over but you have definitely picked up on it so thank you for the question. It is not uncommon for frequencies within a multiplet to have different amplitudes. This depends on the inclination of the star and there can also be a rotation-related boosting factor as well. It can be the case that for rapidly rotating stars the prograde modes have a higher amplitude than the retrograde modes, for example. For this particular star at the time of our original study we thought that there is a fifth frequency which is hiding in the noise. That study was based on one year of *TESS* data and the *TESS* mission is still going. In a follow-up study we have tried to find that little peak and it is actually there. At the time I would say that we were perhaps actually hedging our bets, but the S/N was quite low — it was there but just at a very low amplitude.

Professor Whaler. I could identify something that was equally noisy. My other question was what about the Väisälä frequency? Do you probe this as a function of depth throughout the star? How do the values compare to the rotational frequencies of stars?

Dr. Bowman. I should say that for the stars we are looking at, we're actually in the so-called gravito-inertial regime where the frequencies of gravity-mode oscillations are comparable to the star's rotation frequency. For rapidly rotating stars, the methodology I have described here and the mathematics of spherical harmonics only applies to perfect spheres, so when we solve this forward-modelling problem we have to use the Laplace tidal equation, for example, instead of applying brute-force spherical harmonics, so there is a bit of uncertainty based on what rotation regime you are in. Normally we would derive the rotation frequency independently first and then undertake forward asteroseismic modelling to infer the Brunt-Väisälä frequency profile, then go back just to check that it is consistent with the rotation frequency.

The President. Anything online? In the room?

Professor Ellis. I learned a lot. For those of us working on galaxies, the main-sequence (MS) lifetime of a massive star is really important. Even a small extension of the MS lifetime of the most massive stars would change fundamentals such as if galaxies re-ionize the Universe. What is the extension that is possible by this mixing and rotation to the classical ages of the most massive stars. Is it 10% or 20%?

Dr. Bowman. The scary answer is that for some stars it is a factor of two. But this is probably not the case for all stars. I didn't really mention it but the overshooting value is really just a proxy to make the convective core a little bigger so that the star will live longer. The value for this particular star (HD 192575) is pretty representative for most single stars in this mass regime and that will correspond to an increase in MS lifetime of about 20–30%. There are extremes: for some stars this value is zero, so your MS standard prescription is fine, but if this values gets to a factor of two larger then we are reaching 100% uncertainty on the age of a star. That is something we should fix, right?

Professor Ellis. Absolutely!

Mr. Horace Regnart. Thank you for a brilliant presentation of brilliant research. May I add a strictly non-critical comment. A geophysicist friend described to me how the rotation of the Earth caused the water flowing approximately north-south in the River Mississippi to be slightly higher on one side than on the other side and that the Coriolis effect is actually a pseudo-force.

Dr. Bowman. I agree with that. I think the Panama Canal has the same phenomenon.

Professor Peter Coles. You talked a lot about the amplitude of the different modes or oscillations. Is it possible to get any information about the phases of these modes, particularly if they are coupled together for instance?

Dr. Bowman. This is what I did my PhD thesis on, using observations of the so-called δ Scuti variables. The fundamental data of linear asteroseismology is just the pulsation frequencies. In the non-linear asteroseismic interpretation which we are developing you include the amplitude and phase information. For a stochastically-excited mechanism we would expect a random distribution of phases. For a coherent oscillator like a δ Scuti variable, or a double-mode Cepheid, for instance, it is not realistic, in my opinion, to say that the fundamental mode has no knowledge of the first overtone mode. They will interact and can be revealed through an amplitude-modulation mechanism such as the Blazhko effect but also the phase differences of those modes and when they come into resonance and when they go out of resonance. I would say that for some stars we have done quite a lot of work on that, but for the massive stars that I talked about today there has been effectively very little done on non-linear mode interactions. That would be a very interesting thing to push our models to explain.

Professor Coles. Can one actually measure these phase correlations?

Dr. Bowman. Yes. The phases come from the light-curve and in comparison to models you can see how this relates to other astrophysical phenomena; if you are in phase or out of phase with convection, for example.

The President. Thank you very much indeed, again. [Applause.] I heard something being said in the front during the lecture: "Thank God we live near a boring yellow star" [laughter]. May I remind you that there is a drinks reception in the RAS Council Room immediately following this meeting and I give notice that the next Monthly A&G Highlights meeting of the Society will be on Friday, 9th February.