TALKS

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A personal view of the scientific career of Wojtek Dziembowski (perceived by an admirer from abroad)

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Abstract. I present a personal view of Wojtek Dziembowski's scientific career, derived mainly from my direct interactions with Wojtek. Necessarily this presentation is biased towards the earlier days, partly because we interacted more then, and partly because the presentation after mine is by a local admirer who has been much more involved than I with Wojtek's later work.

Keywords. instabilities, Sun: abundances, Sun: evolution, Sun: helioseismology, Sun: interior, Sun: magnetic fields, Sun: oscillations, Sun: rotation, stars: binaries, stars: chemically peculiar, stars: interiors, stars: oscillations (including pulsations), stars: rotation, stars: giants, stars: variables: Cepheids, stars: variables: δ Scuti, stars: white dwarfs

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1. Introduction

Wojtek Dziembowski has many friends; it could hardly be otherwise of such a kind and gentle person. It is demonstrated at this conference by the large gathering who have come to wish him well. Indeed, it is always a great pleasure to be in Wojtek's company. He is amusing – see the twinkle in his eye – and he is very knowledgeable of many subjects: art, literature, music, philosophy, politics; and, of course, he is a superb scientist, whose achievements we are here to celebrate. Wojtek always thinks deeply about all that he studies, taking much more into consideration than is often evident from his published work. That becomes apparent as one witnesses his questions and responses at conferences, as I am sure that we all shall experience this week.

It is a great pleasure and honour to have been invited to whet your anticipation with a personal view of a small sample of his opera, and to try to convey some of the gratitude that I and many others owe to his teaching and his friendship. In so doing, I shall be able to refer explicitly to but a few of Wojtek's 250 or so publications.

2. The pulsations of B stars

I first met Wojtek in 1967 at Columbia University, New York. He had just arrived as a postdoctoral research associate to work with Norm Baker on theoretical aspects of pulsating stars. I was also working with Norm, in my spare time, on the role played by convection in the excitation and damping of the pulsations of RR Lyrae stars, Cepheids and Miras, so it was inevitable that we should soon meet. At that time Wojtek was interested mainly in hotter stuff than I, and he continued to be so for long after, as I shall allude later when describing his teaching in Aci Trezza. In particular, he was trying to understand how β Cephei pulsations are driven. I recall his having a great deal of trouble (as did I, but for a different reason), and he didn't publish on the subject until long afterwards (and I likewise). We had each chosen difficult problems that took a long time to resolve, and in those days, fortunately, one was not pressured as one is today to publish come what may. Wojtek was concerned also with other stars, on which he did publish soon afterwards, such as planetary nebulae (1977a), low-mass stars (with Maciek Kozłowski, 1974), giants (1977b) and also White Dwarfs (1977c, also with Ryszard Sienkiewicz, 1977), having been attracted to the last, one might surmise, by their initials.

Notwithstanding his early inability to obtain pulsationally overstable models, Wojtek did publish, with Marcin Kubiak in 1981, the outcome of an investigation of the efficacy of the κ mechanism in exciting low-degree nonradial oscillations in β Cephei stellar models. Their procedure was to compute linearized oscillations, nonadiabatic in only the outer layers and forced by an artificially imposed inner boundary condition to be neutrally stable, a technique that Wojtek had learned from Norm, who earlier had investigated RR Lyrae instability that way with Rudi Kippenhahn. The work expended by the motion of the inner boundary determines the stability of the star, whose actual sources of driving and damping, because they are all weak, can be estimated from the neutrally stable 'eigenfunctions'. The procedure affords a substantial improvement on the quasi-adiabatic approximation, which Wojtek (1971) had used previously. Even though Wojtek and Marcin were unable to find overstability in their models, they nonetheless concluded that it is the κ mechanism operating in the He II ionization zone that is likely to be the cause of the oscillations in the actual stars, suggesting that future, appropriately higher, calculated opacities would do the trick for theory. Subsequently, in response to helioseismologists' pressure arising from a different matter, Carlos Iglesias and Forrest Rogers at Livermore provided by moonlight what was required – revised opacity having a local hump at a temperature of about 2×10^5 K – which enabled Paweł Moskalik and Wojtek (1992) to solve that principal β Cephei problem, obtaining an instability strip that was more-or-less in agreement with observation. Wojtek had waited a quarter of a century for that result. I'm sure that it made him very happy.

The flood gates were now opened to admit an outpouring of further fruitful investigation. First, an extension of the new results, in collaboration with Alosha Pamyatnykh (1993) and also Paweł (1993) to a wider range of models, including SPB stars. Then asteroseismology of β Cephei stars with Mike Jerzykiewicz (1998, 1999) and Alosha (2008), and also the slow g-mode oscillations of rotating B stars, joining Jagoda Daszyńska-Daszkiewicz (2007) for assessing their visibility. Work of this genre has been applied to other kinds of star, such as δ Scuti, but I shall leave discussion of such matters to Alosha in the next presentation.

3. The excitation and damping of solar gravity modes

In 1972 I proposed with Fisher Dilke that a low-order low-degree g mode in the Sun has at times been excited by the ϵ mechanism, and that it grew to such an amplitude as to have triggered a nonlinear direct mode in a manner analogous to a similar triggering of direct overturning motion in thermohaline convection. The outcome would have been an episodic redistribution of heat and the chemical products of the nuclear reactions in the core, which would have caused the solar neutrino flux temporarily to have declined. The Sun's luminosity would have declined too, with important consequences for the terrestrial climate. The proposal attracted considerable attention from climatologists, and also from two giants in astrophysics: Martin Schwarzschild and Paul Ledoux, Martin partly because it overturned an important assumption in solar-evolution theory, Paul because of his interest in the intrinsic dynamics. However, a decade later, a new young giant emerging in the field demonstrated that the idea is very likely to be wrong. That giant was Wojtek.

A digression on the ϵ mechanism is not out of place here. The programme of Geophysical Fluid Dynamics held annually at the Woods Hole Oceanographic Institution, Massachussetts, USA, is housed in an old wooden 'cottage' in which the participants work. 'Geophysical', in this context, is interpreted quite broadly, often encompassing the astrophysical and even what one might call the syllastrophysical. Each morning and afternoon the participants assemble for coffee or tea, and, of course, scientific intercourse. The water for the beverages was boiled on an electric stove in a somewhat battered aluminium pan which had been overheated too many times and had consequently developed a rounded bottom. The pan could rock on the flat hotplate, and, if the quantity of water it contained were right for a surface gravity mode to resonate with the rocking, an oscillation would be sustained. With each rock, alternate sides of the bottom of the pan would receive a thermal impulse as it momentarily came into contact with the hotplate, thereby driving the motion. Here was the ϵ mechanism visibly operating on a human scale. Then, once the water was boiling, turbulent viscosity quenched the oscillation. If it could happen in the pan, then surely it could happen even more easily in a star, thought I, because in a star the diffusion coefficients (appropriately scaled to Reynolds and Rayleigh numbers) are much smaller, and the dissipation correspondingly lesser. I was wrong. In 1982 Wojtek published a paper in *Acta Astronomica* in which he demonstrated that grave low-degree g modes in a main-sequence star are likely to couple to resonating high-degree daughter pairs who drain energy from their parent so efficiently that the parent cannot grow to a respectable stature. There was a follow-up discussion the following year applying the result explicitly to the Sun. I illustrate in Fig. 1 part of the analysis, extracted, perhaps a little unfairly, from the first paper; it is typical of Wojtek's early style. After reading it for the first time I was left wondering how it could be that the lower the damping rates γ_2 and γ_3 of the daughters, the lower the limiting amplitude Q_1 of the parent. Surely greater amplitude limitation requires the daughters to dissipate energy faster. The explanation, of course, is clearly evident from a more careful reading of Wojtek's lucid mathematics, which speaks louder than words, as Fig. 1 illustrates. I have to confess, however, that it took a second reading for me to realize that. One further conclusion that I can therefore draw, from generalizing this anecdote, is that no paper by Wojtek should be read only once. I should perhaps point out also that in his later years (e.g. 2012a,b) Wojtek has become rather more expansive.

4. Wojtek's longest collaborations

In 1981, following a meeting at the Crimean Astrophysical Observatory on stellar and solar oscillations, I stopped off in Warsaw on the way home – my first visit to Poland – to work with Wojtek, starting one of the longest, yet, I am quite sure, the most unsuccessful of his collaborations. On my arrival I was immediately told that there was hardly any food in Warsaw; the canteen at the Copernicus Center, where I was housed, was permanently closed for lack of food. However, I hasten to add that that does not explain the paucity of our overt scientific achievements; in fact, it might even have mitigated our apparent failure, for it probably induced us to spend more time working. Wojtek was well prepared for averting famine: he had purchased 250 g of butter for me before leaving the Soviet Union, and then each day in Warsaw he gave me a hunk of dry bread, a hard-boiled egg and an apple or pear to stave of hunger until evening. I was worried that I was depriving him and his family of essential sustenance, but of course, as is characteristic of Wojtek, he denied it vehemently. (It is only on occasions such as that that one cannot trust

4. Parametric resonance instability

This effect, also called a "decay instability", consists of an instability of a linearly driven mode ($\gamma_1 > 0$) to growth of two modes that have frequencies σ_2 and σ_3 such that $\sigma_1 \approx \sigma_2 + \sigma_3$ and which are linearly damped

The equations governing the initial growth of modes 2 and 3 may be obtained from Eq. (2 26) for $k = 2$ (say) and the complex conjugate of this equation for $k = 3$. Setting $Q_k = S_k \exp(i\Delta\sigma\tau/2)$ to get rid of the explicit time-dependence, we obtain

$$\frac{\mathrm{d}S_2}{\mathrm{d}\tau} = \gamma_2 S_2 + i\frac{H}{2\sigma_2 I_2} Q_1 S_3^*, \tag{4.1}$$

$$\frac{\mathrm{d}S_3^*}{\mathrm{d}\tau} = \gamma_3 S_3^* - i\frac{H}{2\sigma_3 I_3} Q_1^* S_2. \tag{4.2}$$

We assume here that Q_1 is constant which is justified in the initial phase of the development of the instability if γ_1 is sufficiently small.

Assuming now $S_k \sim \exp(\nu\tau)$ we get a characteristic equation that yields

$$\nu = \frac{1}{2}[\gamma_2 + \gamma_3 \pm \sqrt{(\gamma_3 - \gamma_2 + i\Delta\sigma)^2 + \nu_{pr}^2 |Q_1|^2}, \tag{4.3}$$

where

$$\nu_{pr} = \frac{H}{\sqrt{I_2 I_3 \sigma_2 \sigma_3}}, \tag{4.4}$$

which is equivalent to Vandakurov's (1981) Eq. 7. The instability takes place ($Re(\nu) > 0$) if

$$|Q_1|^2 > \frac{1}{\nu_{pr}^2}\left\{\Delta\sigma^2\left[1 - \frac{(\gamma_2 - \gamma_3)^2}{(\gamma_2 + \gamma_3)^2}\right] + 4\gamma_2\gamma_3\right\}. \tag{4.5}$$

It is interesting to notice that except in the case $\gamma_2 = \gamma_3$ the criterion in the limit $\gamma_{2,3} \to 0$ differs from the strictly adiabatic one that is obtained from (4.3) setting there $\gamma_2 = \gamma_3 = 0$. This paradox is easily resolved by the realization that the instability occuring at γ_2 or γ_3 passing through zero is a vibrational, not a dynamical, instability. It remains important, however, that with grossly unequal damping rates the dissipation may promote instability.

Substituting Eqs. (3.21) and (3.23) in Eq. (4.4), we get

$$\nu_{pr} = Z_{123}\left\langle \frac{C}{A}[(H_1 - H_3' - H_3)\cos(\psi_2 - \psi_3) + \varkappa_{g,2}(H_2 - H_3)\sin(\psi_2 - \psi_3)]\right\rangle_g$$

$$\text{where} \quad \langle\ \rangle_g = \frac{1}{\psi_2}\int \mathrm{d}\psi_2 \tag{4.6}$$

It is easy to see that the expected minimum frequency mismatch, $\Delta\sigma$, decreases like l_2^{-2} with increasing l_2.

On the other hand, γ_2 increases with increasing l_2. If the quasiadiabatic approximation is valid there is a simple estimate of γ_2 (see *e.g.* Dziembowski 1971).

$$\gamma_2 = \frac{A_2}{\sigma_2^2 \tau_{th}} \sim l_2^2,$$

where

$$\tau_{th} = 18\frac{GM^2}{RL}(4\pi G\langle\varrho\rangle)^{-1/2}\left\langle \frac{L_r}{L}\nabla\nabla_{ad}\left(1 - \frac{\nabla_{ad}}{\nabla}\right)\left(\frac{R}{r}\right)^5 \frac{\langle\varrho\rangle}{\varrho}\right\rangle^{-1} \tag{4.8}$$

is the thermal time-scale of the g-mode propagation zone in our time-units. This quantity is of the order of $10^{10} - 10^{12}$ in the interior of main sequence stars.

The final amplitude of mode 1 may be written in the form

$$|Q_1| = \frac{2}{\nu_{pr}}\sqrt{(1 + q^2)\gamma_2\gamma_3}.$$

Figure 1. Part of Wojtek's (1982) lucid derivation of the expected amplitude of a low-order solar g mode (with permission from *Acta Astronomica*).

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Wojtek to tell the truth.) In the evenings I went into town to seek an open restaurant. I was finding the Polish language totally inscrutable, but it didn't matter: I wanted to eat, a restaurant would be open only if it had food to serve, and Wojtek assured me that no restaurant would have more than one dish, so I would encounter no difficulty with communication; all I needed to do was to smile and nod. It worked well. Only on my last day, when I chose a grander-looking establishment in celebration of a most stimulating visit, did I nearly fail, for the waitress tried to engage me in conversation. I could make neither head nor tail of what she was trying to tell me, and eventually she gave up and disappeared, apparently back into the kitchen. Was I going to be fed? Should I stay, or should I leave? I waited. And I was rewarded: after quite a while the waitress returned, armed with pictures of a chicken and a pig. Wojtek was wrong! I had a choice. Subsequent visits to Poland have been more salubrious, not least this wonderful stay in Wrocław.

Weekends in Warsaw were very enjoyable. Many of the members of the Copernicus Center would go to the Observatory, just outside the city. There we foraged and subsequently feasted on wild mushrooms, and had much discussion over and after dinner on a wide variety of subjects, except politics: that subject was reserved for walks in the forest.

But I digress. The intellectual outcome of this first visit to Warsaw was the start of a collaboration to seek an approximate second-order differential equation to describe nonradial adiabatic stellar oscillations that takes some account of the perturbation to the gravitational potential, at least at high order. The purpose was for using it as a basis for obtaining simple formulae that could be applied straightforwardly to diagnosing aspects of the structure of the underlying star from its oscillation eigenfrequencies. We found a relatively simple equation, which we named the first post-Cowling approximation. Then we embarked on improving it. We didn't complete our task, and a year or two later Wojtek made his first visit to Cambridge, where, I believe, we almost achieved the second post-Cowling approximation. Later I made a second visit to Warsaw, well after the lifting of Martial Law; Wojtek was so happy with the new freedom that he insisted on exchanging currency with me in public in the middle of the main square in the old town. But the scientific adventure was not as successful as we had hoped, because what we thought was a brilliant final manoeuvre subsequently became irretrievably lost (actually stolen), and neither of us have been able to recover the derivation since. Wojtek then said that he washed his hands of the matter, for it was so easy to compute frequencies numerically. I held on to the surviving remnants, and, with Wojtek's permission, even published the formula of the first approximation in some lecture notes for a Les Houches summer school. I doubt that anyone has noticed it because it is unobtrusively buried in the text. I still think that it would be useful for this first result to see the light of day, and I intend to make that happen. Therefore, after 32 years, I continue to consider this dormant collaboration not to have died, despite our failure to have published. Incidentally, when Wojtek made another visit to Cambridge we wisely decided to work on something else: the pulsations of red-giant stars such as α UMa, in collaboration with Günter Houdek and Ryszard Sienkiewicz (2001).

Not all of Wojtek's long collaborations have been so fraught. On the contrary, a still-ongoing and highly successful collaboration began with Phil Goode when Wojtek was visiting Henry Hill in Tucson, helping him organize one of the most memorable conferences in helioseismology. Wojtek and Phil have worked much together since, mainly on some of the more interesting aspects of helioseismology, often away from the main stream. Their first paper, published in 1983, concerned imposing seismologically inferred limits to the strength of the magnetic field in the core of the Sun. Since that time, they have contributed significantly to almost every facet of the subject, publishing to date some 50 papers, some of which I shall mention later.

Wojtek has also collaborated very fruitfully with Alosha Pamyatnykh; I leave discussion of that work to Alosha's presentation. His collaboration with Jagoda Daszyńska-Daszkiewicz is notable because, like his association with Luis Balona, it has drawn him closer to the techniques of observation. Strictly speaking, I should not have included it in a discussion of the longest collaborations, for it has taken place only during the current millennium; however, we all hope that it will continue for many years to come.

5. Scientific leadership

In 1983 Wojtek gave an extensive introductory talk at a conference in Catania on the combined effect of rotation and a magnetic field on degeneracy lifting of stellar acoustic oscillations, work that was in progress with Phil Goode. Application to the Sun was principally in mind. The necessarily aspherical perturbations were regarded as being globally, if not locally, small, so perturbation theory about the oscillations of a spherically symmetrical star could be employed. The speaker who followed was stunned; the talk he had intended to give appeared to address the identical subject, and suddenly he found himself in front of the audience wondering what there was left to say. Pointing out to the audience the embarrassing situation in which he found himself, he stalled for time by asking Wojtek if he could borrow one of his transparencies ('overhead' projection of transparencies was the technology of the day), a diagram illustrating the manner in which the eigenfrequencies are split, in the hope that Wojtek would not be too hasty. Since Wojtek had established his main point in his usual mathematical fashion – recall Fig. 1 – the second speaker offered to explain it in physical terms, which is why he had asked for that particular transparency. But to his bewilderment, when the transparency had been placed on the projector plate, and he had inspected it more carefully than he had had time to do during Wojtek's presentation, it was apparent that Wojtek's conclusion was very different from his own: Wojtek's frequency splitting had the opposite sign, and the magnitude was 40 times greater! What was the second speaker to do now? Evidently the truth had to be established. So he chose the usual scientific procedure: democracy. He called for a vote from the audience. Wojtek won by precisely 2:1. Wojtek was delighted, not for having won, but for witnessing a procedure which resonated with his political ideals. Nevertheless, there remained the task of finding the root of the discrepancy. It turned out to be a matter of principle, rather than of algebra; and it was resolved some weeks afterwards, in time for the two published versions of the presentations (1984) to be made consistent. The event was just one of many which demonstrates the faith the scientific community has in Wojtek's work.

One afternoon during a gap between lectures, some of the participants of the Catania conference climbed Mount Etna – it was not forbidden in those days – some of us intent on peering into the throat. We didn't see much other than the thick choking sulphurous smoke. I recall my feet nearly burning despite my thick-soled shoes, and later Wojtek and I being taken into a small hut and being plied with strong brandy to help recover from the fumes. I recall also remarking that I didn't know that such brandy was made in Sicily, and being told that what I was drinking could not be found in any shop. Somewhat revived, and certainly undeterred, Wojtek and I then decided to venture with our colleagues even closer to the action. Not presuming to emulate Empedocles, we descended into an ostensibly dormant fumarole, although by now the adventurous wing of the party had dwindled to just us two. Later, as we emerged, choking yet elated, it was Wojtek, of course, who was leading.

Most of the conferees were housed in a hotel in Catania. The invited lecturers, however, were honoured with a luxurious resort in a nearby village, Aci Trezza, overlooking the

Cyclops. Each day, after the formal activities, we were driven to the resort and left for an hour to swim and relax. Then, those other participants who were not yet too exhausted to continue talking science were driven to meet us by the pool. I noticed that most of us each had accumulated similar small groups of enthusiastic, mainly male, young people. But Wojtek's was different: he was surrounded by a bevy of beautiful ladies. Evidently, Wojtek is no ordinary scientific leader.

There was another interesting occurrence concerning Wojtek at this conference. On the traditional free Wednesday afternoon there was an outing to Syracusa. Just before we boarded the coaches that were to take us, six police arrived on motorcycles. They watched us from afar. Lucio Paternò, the organizer of the conference, went over to ask them why they had come, but they would not say. They escorted us to Syracusa, some riding ahead, others behind, and some to the side when there was no oncoming traffic. We thought, somewhat arrogantly, that they had come to protect us from possible Mafia intervention. It later transpired that we were quite wrong: they had been there to protect the Sicilian people from us, for they had heard that somewhere on board was a delegate from an Eastern-Bloc country.

It turned out that the police escort actually became beneficial to us. On the way home we encountered a serious traffic jam – several kilometres of stationary traffic on a narrow road. The reason was a road-widening operation, causing the traffic to wait while a gap in an outcrop of rock through which the road passed was enlarged with dynamite. One of the police rode ahead. When he returned, we were then escorted on the wrong side of the road past the waiting vehicles and the scene of the road work, where explosions had been halted temporarily, affording us, thanks evidently to Wojtek, a timely arrival home.

6. Rapidly oscillating Ap stars

The analysis reported at the Catania meeting can also be applied to the rapid oscillations of Ap stars. As in the paper that follows in the proceedings of that meeting, the point of view is that of an Earthbound observer, as is the case also of a companion paper with Phil Goode in 1985, resolving the oscillations into normal modes as seen from an inertial frame. The stars generally have two antipodal spots, produced, we believe, by a large-scale, predominantly dipolar, magnetic field. The magnetic axis, and that of the spots, is usually inclined from the axis of rotation. The oscillations also appear to be mainly dipolar, with their axes of symmetry more-or-less aligned with the spots. This is a natural consequence of degeneracy lifting if the spot-induced asphericity of the star dominates over that due to rotation. Wojtek subsequently went into some detail with the problem, mainly with Phil Goode (1996) and with Lionel Bigot (2002, 2003) and other collaborators (2000). With Lionel (2002), he also noted the possibility that the effect on the oscillations of the second-order, centrifugally induced asphericity could, in some circumstances, exceed that of both the first-order Coriolis force and, more pertinently, the asphericity due to the spots, and then the strong connexion between the oscillations and the spots is broken. But always the discussion was just about normal modes.

There are circumstances in which some may consider it to be prudent to describe the oscillations as (precessing) standing waves, superpositions of suitable pairs of modes propagating in opposite senses around the star. The two descriptions, are, of course, equivalent. Yet, as witness to Wojtek's well deserved influence even on scientists outside our field, there have been times when referees of putative journal articles inadequately familiar with wave dynamics, yet conversant with some of what has been written at least in some of Wojtek's abstracts, have failed to recognize the equivalence, and have recommended rejection on the mistaken ground that Wojtek has proved otherwise, so confident are they in their incomplete interpretation of Wojtek's words. That is surely another measure of the extent to which confidence in Wojtek has spread.

7. Rotation of the Sun and other stars

Wojtek was amongst the first to analyse rotational splitting data from the Sun and obtain a (nonuniformly weighted, spherically averaged) estimate of the angular velocity almost to the energy-generating core (Duvall *et al.* 1984; see also Brown *et al.* 1989). Subsequently, with Phil Goode and Ken Libbrecht (1989), he obtained one of the two-dimensional views, describing the (near) discontinuity across the tachocline in terms of the continuity of the (uniformly weighted) spherical average of the angular-momentum density (1993), which had earlier been discussed as a consequence of a putative local latitudinally uniform stress-strain relation. Wojtek pursued further the rotational perturbation to (mainly acoustic) stellar oscillations from a theoretical point of view (with Sasha Kosovichev 1987a,b, Maciek Kozłowski 1987, Phil Goode 1992, and Fatma Soufi and Marie-Jo Goupil 1998), taking higher-order terms into account. As I have mentioned already, there are circumstances in which the centrifugal force can dominate over the inertial (Coriolis) effects, a result which is pertinent particularly to work on roAp stars.

Rotational effects on the oscillations of γ Doradus and SPB stars have also attracted Wojtek's attention, hardly surprising in view of his early love in New York. Here, gravity modes are the centre of interest, and they can have frequencies comparable with or less than the angular velocity of the star. That adds richness to the investigation, for it is no longer the case that rotation imparts only a small perturbation to the dynamics. The oscillation problem is no longer straightforwardly nearly separable in radial and angular coordinates, and more extensive argument is called for. Together with Alosha and Jagoda, Wojtek (2007, 2009, 2010) adopted what geophysicists call the traditional approximation, which ignores the contribution of the horizontal component of the angular velocity of the star to the Coriolis force acting on the pulsations, restoring the differential system to one that admits separable solutions, and thereby making the problem much more tractable.

8. WET

Although Wojtek is primarily a theorist, he has been involved directly with observation (e.g. Breger *et al.* 1995; Handler *et al.* 1997). I am not sure what precisely was Wojtek's role.

9. Structural helioseismology

Wojtek seized on helioseismology very soon after its power had been established. I have already mentioned his visit to Tucson with Henry Hill, and his consequent meeting with Phil Goode, resulting in a long and fruitful collaboration. Most of that joint work concerned the Sun. And that spawned other investigations in collaboration with Alosha Pamyatnykh and with Ryszard Sienkiewicz (1990, 1992). From these investigations emerged one of the early seismic solar models (1990, 1994, 1995), an early estimate of the protosolar helium abundance (1991, 1998), and the realization (1999) that, subject to the usual assumptions of solar evolution theory, a helium-abundance estimate (Kosovichev *et al.* 1992, Richard *et al.* 1998) appeared to be consistent with a main-sequence age that itself is more-or-less consistent with the ages of the oldest meteorites (Dziembowski *et al.* 1999). There were also examinations of solar models (Richard *et al.* 1996,

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degl'Innocenti *et al.* 1997), the solar core (1996), the theoretical neutrino luminosity (1996, 2000), a seismic radius (Schou *et al.* 1997) and the opacity. Moreover, Wojtek published a suite of papers with Phil Goode (1991, 2002, 2004, 2005) on the seismic response to magnetic activity, and diagnosis of the solar cycle, sometimes in collaboration with Jesper Schou (2001), and also Steve Tomczyk (1997) and Sasha Kosovichev (2000). The work was not undertaken in isolation; there were others elsewhere with similar pursuits. Wojtek's contributions certainly added credence to the other work, and invariably stimulated further thought.

10. Nonlinear matters

The matters to which I refer all concern interactions between distinct modes of stellar oscillation. They have pervaded Wojtek's entire career. I discussed at some length the nonlinear suppression of grave solar g modes by their daughters, but that work is but a tiny fraction of Wojtek's contribution to the subject. My emphasis was chosen because it related directly to my own interests, and my presentation here is supposed to illustrate my personal exposure to Wojtek's work. But most of Wojtek's nonlinear studies (some with Małgosia Królikowska 1985) arose from his attempts to understand δ Scuti pulsations, and the effect of rotation (with Sasha Kosovichev, 1987, 1988), not to mention amplitude limitation of double-mode Cepheids (with Géza Kovács 1984 and with Radek Smolec 2009), and amplitude modulation in RR Lyrae stars (with Rafał Nowakowski 2001, 2003, and with Tomek Mizerski 2004) and the Blazhko effect. Indeed, I would dare suggest that Wojtek regards that work as his most important; and I'm sure that there are many others who think likewise. However, I shall not dwell on these matters here because Alosha, who has been much closer than I to Wojtek when these studies were being carried out, will address them more authoritatively in the following presentation.

11. Giants and supergiants

Much of Wojtek's attention in this arena (e.g. 1977, 2001b, 2012a, also Van Hoolst *et al.* 1998) has been devoted to addressing issues concerning mixed modes: frequency pulling, as it is sometimes called, to describe how the frequency of a mixed mode – g-mode-like near the centre and p-mode-like in the outer envelope – is an appropriately weighted average of the frequencies of a putative pure g mode and a corresponding pure p mode that are considered to be isolated from one another by the evanescent zone that separates their corresponding cavities. The work on a theoretical model of α UMa, which I mentioned earlier, is such an example. Understanding this subject is crucial to the asteroseismology of these stars, for which it is necessary to identify the modes responsible for the oscillation frequencies observed. It is a burgeoning issue for those trying to analyse the enormous number of data newly acquired from the *Kepler* space mission, a mission with which Wojtek is involved directly. Moreover, in my opinion, the pertinent theoretical issues are yet inadequately understood. The (linear) "interactions", as some call them, between the acoustic and gravity components of a mixed mode of oscillation lead to oscillation spectra with complicated nonuniformities which demand to be sorted out. That can be a difficult, tedious task, which many would shun. Wojtek, despite his penchant for the clean mathematical argument, has had considerable experience with similar issues related to δ Scuti pulsations, and, by virtue of his extremely strong theoretical background, has been an invaluable contributor to that endeavour, and will be so in this case too if he decides to put his mind to it. Life is limited, however, and one cannot do everything. So it is possible that Wojtek will decide to devote his energies elsewhere.

12. An astrophysical miscellany

Wojtek is concerned not just with theory, but also with the interpretation of astronomical observations. It is that, I believe, that has led him to study so many different phenomena. He has contributed, albeit not as thoroughly as the other subjects that I have mentioned, to the stability of accreting white dwarfs (Sienkiewicz & Dziembowski 1977), to explaining the acoustic flux of Sirius B as the outcome of resonant interactions between short-period acoustic modes and travelling waves (Dziembowski & Gesicki 1983), to the study, with Paul Bradley, of PG1159 stars, and to the theory of tidal friction in close binary systems (1967), to name but a few. He has been brought much closer to observation by collaborating particularly with Luis Balona and Jagoda Daszyńska-Daszkiewicz, and he has also joined much larger groups to explain observations of red giants (Soszyński *et al.* 2011a,b). His very latest publication to date (2012b) concerns the puzzling periods of first-overtone Cepheids: they are typically 0.6 of the fundamental period, yet it seems to be difficult to explain the driving mechanism in models that can reproduce that period ratio. Wojtek's is an excellent discussion of the pertinent unresolved issues, setting up the groundwork and paving the way for future research, on which I am sure Wojtek is ready to embark.

13. Postscript

Wojtek seems to have covered almost the entire arena of stellar pulsation. The possible pulsations of pulsars is a notable exception; they rotate and harbour large-scale magnetic fields, just as do roAp stars, which is right up Wojtek's street, although the physical conditions are very different. Moreover, Wojtek has paid only scant attention to the driving of very red variables, such as Miras. That is because in these stars convection is so important, and that is an area of fluid dynamics that Wojtek has chosen to avoid. He has made many studies of the nonlinear interactions between distinct modes of oscillation, but, so far as I am aware, he has not paid dynamical attention to the nonlinear interaction of a mode with itself. These matters he has kindly left to others, like me, who can therefore feel that they are not living completely in the shadow of the giant. However, this giant is always very happy to discuss the issues with whomever so wishes, and his insight is always very illuminating.

Recently, Wojtek told my wife, Rosanne, how wonderful it is to become old. I'm not sure that he really explained why, although, being not very much younger than he, I no doubt appreciate some of the reasons. One thing that it implies is that we have been able to know each other for a long while: 46 years, to be precise. I have truly valued that time, not just the time we have spent in each other's company, but also time apart with the knowledge that Wojtek is a true friend for whom I have enormous respect. Wojtek is a source of energy and inspiration to us all, much of which has been made possible by the continual encouragement and support from his dear wife Anna.

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