From Interacting Binaries to Exoplanets: Essential Modeling Tools
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Panel Discussion III

Panel: F. Allard, A. Batten, E. Budding, E. Devinney, P. Eggleton, A. Hatzes, I. Hubeny, W. Kley, H. Lammer, A. Linnell, V. Trimble, and R. E. Wilson

Discussion

I. Hubeny: Does anyone from the panel have a theme question to start with today?

V. Trimble: It's another one-liner: From an active galaxy meeting many years ago when people talked about spiral structure. I was reminded by Dr. Rucinski's talk of Lodewijk Woltjer's remark: "The larger our ignorance, the stronger the magnetic field."

A. Batten: The last two talks this afternoon (by Wilhelm Kley and Adam Burrows) left my mind reeling! Some years ago, I read (in translation) Kant's *Allgemeine Naturgeschicle mit Theorie des Himmels*, the book in which he presented both the idea of "island universes" and his theory of the origin of the Solar System. The latter is purely qualitative and the tone of Kant's presentation is disturbingly similar to that of the many crank letters all of us receive. I thought to myself that the only thing lacking was a statement that the author did not have the mathematical ability to work out the details himself but offered those ideas to those who could do so. Sure enough, just a page or two later Kant made such a remark! Then, of course, Laplace came along and took up the challenge, but even his treatment of the problem proved inadequate. Wilhelm Kley has shown us that the mathematics required goes far beyond the techniques available to Laplace. If someone had told me when I was a graduate student, more than half a century ago, that I would live to see not only the detection of planets around other stars but also the probing of the constitution of those planets' atmospheres, I would have supposed that he or she was joking. If he or she convinced me that the prediction was serious, I would have dismissed him or her as a crank, but Adam Burrows has shown us the evidence. The only conclusion I can draw is that we should never say to ourselves that any kind of observation will be "impossible."

V. Trimble: Possibly everybody else has already heard this, but NASA announced a fourth moon of Pluto today. If you have four moons, you're a planet; I'm sorry.

A. Linnell: This conference shows the result of deliberate planning by the organizers to bridge two different but related areas. A number of us from the U.S. can remember the wrenching discussion within the AAS over the issue of initiating parallel sessions at meetings. There is the hazard of increasing compartmentalization. We need to fight against the sort of thing that happened in physics, where people in one sub-field simply don't understand things that are going on in other sub-fields. So, I believe the meeting organizers deserve thanks from all of us for the way they have planned this meeting.

I. Hubeny: That was exactly the point we realized, and in fact was one of main reasons for organizing this conference. For instance, only a few astronomers knew about the Rossiter-McLaughlin effect beyond the group of binary star astronomers, and now it is a common term.

I. Hubeny: Any more comments?

D. J. Hillier: We have the planets in the Solar System. How well do we do modeling them, especially if we limit our knowledge base to what we might infer for them (now and in the next decade) if they existed around an external star?

A. Burrows: We assumed equilibrium methane abundances at super-solar levels for the giant planets. We didn't really put much into that study, and that paper was published in 2000. For the other planets, the compositions are clearly non-equilibrium (e.g., the Earth's atmosphere), we need to know what that is in advance. But, if you're given the composition, then it's not too hard to simulate the atmosphere. That's been done for Mars very simply, and for the Earth, in particular. People have been focusing a lot on the Earth, for a variety of obvious reasons. So, there have been some benchmarks like that. There are some subtleties for Jupiter at 8 microns. We see methane in emission, so you do see some weak inversions in the upper atmosphere and we need to be able to reproduce that. There is some heating in the upper atmosphere of Jupiter that's not completely explained.

There's a nice summary on the atmospheres of Jupiter and Saturn that was done by Tristan Guillot and Didier Saumon. There are also many other workers who have focused on Jupiter and Saturn. And what they do is to use the best equations of state and a variety of equations of state, just to explore the range, to try to include the rotation that's observed on the surface and assume rotation on cylinders. And they try to fit the gravitational moments that are measured by fly-bys, etc. So, they see the J_2, J_4, J_6 moments of inertia. There are some ambiguities with J_6, but they want to be able to figure out the atmospheric structure and be able to infer for Saturn that there's a definite presence of a core of about 15 Earth masses. For Jupiter it's a little ambiguous. For both planets, the structures are consistent with super-solar abundances, consistent with the measurements of the atmospheres. There's a depletion in helium in Saturn, which is quite significant in the upper atmosphere, and that's consistent with theories that were developed for the miscibility of helium and hydrogen and the settling of helium. The evolution of Jupiter was examined to see whether it has the radius and the temperature that we measure now after 4.6 billion years. And that works. For Saturn, it doesn't work unless you include the helium drop rates. If you include the amount of helium rain-out that is inferred from the atmosphere (the depletion in the atmosphere of Saturn, which is only about 18% by mass instead of 25% by mass of helium), and if you include the gravitational energy contribution that would heat up Saturn and keep it hotter longer, then instead of being the current temperature it is now of 95 K at 2.5 Gyr, it's the current temperature of 95 K at 4.5 Gyr with the emissibility of that heat source. So, there has been some attempt to use those objects as benchmarks or as launching pads to adventure beyond the Solar System. It's not perfect. We know far too much about the Solar System not to be humble. Exoplanets are easier in that sense. There have been these campaigns, and they're pretty good.

E. Budding: I would like to ask Dr. Burrows to explain something about the term 'disequilibrium chemistry' that was mentioned once or twice during his talk. The physics alone seemed complex.

A. Burrows: Welcome to my world. For brown dwarfs, there are some good spectral indications that the carbon and nitrogen chemistry is out of equilibrium. The equilibrium is modeled by comparing in a simple way the timescale for the chemical equilibration of

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methane and CO, and the timescale for the upwelling by convection of those same materials. In brown dwarfs, it turns out in many circumstances that the upwelling timescale is shorter than the chemical equilibration timescale, which is a very stiff function of temperature; you get the low temperatures too quickly and it punches out the CO abundance. You see a superfluidity of CO and a deficit of methane. You see the same thing with ammonia in the nitrogen chemistry. It can be reproduced quite nicely. You see this for brown dwarfs and more importantly you see this in Jupiter; this an old story for Jupiter. So, that's the way it's handled. People also try to include photolysis, particularly when they're talking about winds from HD209458b. We measured winds coming off these planets. We have scandium, magnesium, atomic hydrogen, all sorts of indications of species that are coming off at reasonable speeds with interesting mass losses. You have to do that sort of thing on equilibrium. Those models are starting to be developed for photolysis. I would be one of the last people to say that we really have a handle on all of this. It's going to be at least as complicated as any of the non-LTE stuff we've heard about. We're just starting; these are the early-days; we're trying to do the simple things first.

V. Trimble: This is probably a question to France. Do we need magnetic fields for anything with exoplanets?

F. Allard: Nice question. Well, like Adam has been saying and as I have been saying, we need more precise cloud models before we need magnetic fields. But the answer is "Yes."

A. Burrows: I would like to follow-up on that comment. There is an issue of what determines the speeds of super-rotational flows in the planets of the Solar System, or jet streams. If you look at Jupiter, you can watch them moving around in the belts, but we don't know what determines those speeds. You heat from one side and you cool from the other side, and so you have an engine, but that would accelerate the flow. You need to have some dissipation. For Jupiter, a number of years ago, it was suggested that magnetic fields in Jupiter would give you magnetic torques, and there could be ohmic dissipation as well. This was work done by Liu and Schneider, in particular, and Dave Stevenson. Recently, people have used those ideas, not for Jupiter but for exoplanets, to try to determine what is limiting the speeds of these winds, which we don't understand that well, but we know some process has to happen. Also, perhaps this type of magnetic dissipation, joule heating, might contribute to the puffing up of some of these planets. That was suggested by Batygin and Stevenson recently, with an interesting set of ideas that were very poorly developed; it needs a lot more work. But in both Jupiter and in the large exoplanets, magnetic fields are starting to be invoked in some recent work by Kristen Menou and collaborators. We're also doing some work with it. Magnetic fields may be much more important much earlier than we hoped.

R. Wilson: When I first heard about people discovering sodium and potassium in these planets, I thought maybe it was a misprint because they're so reactive. Maybe they can exist because it's very hot there, but potassium is not really light, so I don't know how they get up that high where you can see them. So, are there conditions in which we could observe sodium and potassium in Solar System planets?

A. Burrows: We do see sodium and potassium prominent in the Earth's atmosphere that's coming from dust coming in, and they are used in AO systems to produce artificial stars. But that's not something you can calculate *ab initio*. It's just there, it's just one of those things you have to measure.

R. Wilson: These elements have some very nice strong spectral lines, but I imagine that concentrations are actually very very low. It's just because the conditions are good for finding them that we are able to see them at all.

A. Burrows: I'll just call your attention, and I know France would as well, to the fact that brown dwarf spectra are dominated by sodium and potassium; the two lines dominate from 0.4 microns to 1 micron. The wings are so broad, whatever their shapes, they cover the entire region. There are other features there, but the two lines determine the entire slope of the spectrum. We measure this for many, many objects. It's just the chemistry. They're hot enough that they haven't condensed out into sulfides or chlorides into which they would otherwise condense. The Solar System objects are just too cold.

I. Hubeny: I remember you made the point that brown dwarfs cannot be brown, because if you do the color synthesizer it absorbs all the red part of the spectrum, so they will be at best magenta or magenta-brown instead.

C. Chambliss: If you toss even a single salt crystal into a fire you will get the characteristic Na D lines. So their resonance lines are exceedingly easy to excite, and it takes only moderate temperatures of approximately 800 K or 1500 F. But, 800 K will do a very nice job of producing the D lines. The potassium lines aren't quite as obvious, because their resonances are over in the near-infrared; or at least deep red. But the sodium is bright yellow. Well, I use streetlights for that too, and those are easy to turn on, although astronomers don't always like them.

A. Burrows: To answer Bob's question: We use solar luminosities with the potassium in the atmosphere. These large strengths can easily explain what we see, within a factor of two – the saturated lines.

N. Bochkarev: When we talk about astrobiology, mainly original life in the universe, it is important to know how the evolution of the planetary system depends on the chemical composition of matter. Are there minimal abundances of heavy elements for the origin of planetary systems?

P. Eggleton: I just wonder sometimes how comfortable we are with the fact that the general public is probably led to expect us to find life on other planets. Are there many people here who expect to find life on other planets, and are they looking forward to it? My personal answers would be 'No' and 'No.'

V. Trimble: There is of course a considerable literature on this: from science fiction, from theology, from ordinary people who worry a lot. The chance of finding anybody we could talk to without needing 10^6 years for the messages to go back and forth is quite small. If you happen to like stromatolites, that is pond scum, there may well be pond scum or something equivalent fairly close. Would I like other intelligent life? Yes. Do I know they would be friendly? No, but I think it's worth finding out. Consider the cultures that were destroyed when Europe reached Australia, sub-Saharan Africa, Native America; if it hadn't happened just then with those people it would have happened not much later with other people. So, if it's out there, we will find it, or it will find us. Sir Martin Ryle was terribly worried that we had sent a message to a globular cluster from

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which the round trip travel time is 10^5 years or something. There is no use in being afraid of it. One has to think about the chances and what kind of communication could take place. For some people, silver rockets land in their yards and take them for rides, but these people generally have other problems as well.

P. Eggleton: I can't help thinking that the public is going to be rather disappointed with our progress if we don't find intelligent life. I wonder whether the public has been led to believe that it is rather likely we will find such things. I am personally very worried about it. I do wonder whether you get into the taxi and say "take me to the astronomy tower" and they'll say "oh yes you must be looking for life on other planets."

V. Trimble: If we disappoint long enough they'll stop sending money. But at the moment, at least in the US, there is still a considerable, well not enthusiasm but, willingness at least in Congress to continue funding unmanned (unpersoned) missions to Mars. There have been several near misses with Mars rocks that had interesting structures and some of those interesting structures may have been alive. That's one bit of astrophysics and astronomy research that Congress and the public still seem to be willing to support even though all they've got is at best rocks with old stromatolites.

A. Batten: I find myself halfway between the skeptics and the enthusiasts. I recently wrote a book in which I quoted W. R. Inge, an Anglican clergyman who was Dean of St. Paul's Cathedral in London during the early part of the twentieth century. In the year that I was born, he wrote: "There is, I think, something derogatory to the Deity in supposing that he made this vast universe for so paltry an end as the production of ourselves and our friends."

V. Trimble: There was also a very famous cartoon in the United States which maybe half of you would be old enough to remember, if you are Americans. It showed a couple of animals in a swamp looking up the sky and saying: "Either we're the most intelligent creatures in the Universe or we are not. And it's pretty sobering either way."

P. Niarchos: I would like to ask how many of the panel believe in extraterrestrial intelligence?

A. Batten: I believe that once per galaxy is a reasonable guess for the frequency of the emergence of intelligent life. The Drake equation does not help us very much, since we do not know very much more about the quantities on the right-hand side than that none of them is zero, but we do know that the left-hand side is at least one. Even if intelligent life occurs only once in a hundred galaxies, the cosmos could be teeming with life, but it would be difficult in that case to envisage the various communities making contact with each other. However, I will not say that contact would be impossible!

R. Wilson: My feeling would be that, at a given moment, the chance of finding a technical civilization that we could communicate with is pretty close to zero for our Galaxy. If you would integrate over a billion years, there could be several other civilizations.

E. Budding: I think the issue of extraterrestrial intelligence depends on the definition of life, about which it is difficult to be categorical. Regarding 'intelligence,' this can perhaps be related basically to the operation of a feedback mechanism dealing with information about the environment surrounding an organism. This could operate at a very low level in a wide variety of feasible situations, but that probably does not concern the type of thing Panos has in mind. From the empirical point of view, however, I would think that the most practical steps that could be taken at the present time relate to those studies of 'disequilibrium chemistry' discussed by Dr. Burrows.

I. Hubeny: Actually, when the Terrestrial Planet Finder (TPF) mission was still alive there were a number of conferences asking that question, and it relates to the previous point about the expectations of the public. For example, the detection of life would be considered as the simultaneous detection of ozone and methane in the atmosphere in the spectrum of an exoplanet. Those two gases cannot really exist in large concentration to be able to produce spectral features. Ozone is a proxy for oxygen. That would be a detection and a big discovery, but it would be a sort of non-equilibrium chemistry, because this additional oxygen would have been created by life of any sort. Of course, that life could mean bacteria on the level which inhabited the Earth during the first 2.5 billion years. That would've been a big discovery, but the public would certainly be disappointed.

F. Allard: Long before we have spectra of extraterrestrial Earths at 1 AU, perhaps polarization would be the way to see something on another planet. One life characteristic is monochirality.

K. Bjorkman: A couple of years ago, there was actually a very interesting and speculative poster at the AAS in which Wolstencroft actually had done some calculations of the polarization that would be produced by various types of plant life on Earth-like exoplanets. It was quite entertaining, and I chatted with him a little bit and he said: "Well, I figured I might as well go ahead and do some calculations and we'll see what we might be able to see."

A. Hatzes: I think life is very easy to form, but intelligent life? As an infamous Secretary of Defense once said: "There are so many unknown unknowns." You have the wonderful Drake equation, and there are a lot of factors that probably should go in there that we don't know about. We need plate tectonics. We need something colliding with the Earth and produce the Moon to stabilize its inclination axis. You need a Jupiter outside to clean out the inner debris, so you don't have as many impacts. There are a lot of things we don't know that we don't know. The question is what happens when you put in all these probabilities? I think the probability is one in a hundred billion! That's why I say it's one per galaxy.

V. Trimble: It can be considerably less than 1 per galaxy, if you agree with panspermia.

N. Bochkarev: This week was launched a radioastronomy mission, which can measure other condensations with very high angular resolution. There are some predictions of measurements of protoplanetary disks and protoplanets. It's an actual problem now.

V. Trimble: I think that's more important news than we perhaps felt as Dr. Bochkarev said this the first time. At least three groups: US, Japan, Russia have been talking about doing radio interferometry with the baseline larger than the diameter of the Earth. This is a step toward that. I think it's very important and I'm ashamed that we haven't heard about it as quickly as we've heard about the fourth moon of Pluto.

I. Hubeny: That's all for today. Thanks for your participation in this discussion.