Convection in Astrophysics
Proceedings IAU Symposium No. 239, 2006
F. Kupka, I. W. Roxburgh & K. L. Chan, eds.

doi:10.1017/S1743921307000452

Round table discussion of session C: convection in planets and brown dwarfs

Kwing L. Chan

Department of Mathematics, The Hong Kong University of Science and Technology
email: maklchan@ust.hk

The following is an edited excerpt of the DVD recording of Session C's Round Table Discussion. Due to the tight publication schedule, participants have not been given much time to review its contents in detail. There may be unclear and inaccurate spots, but it should give an illustrative description of the dynamics of the interesting discussions.

Panelists: U.R. Christensen, G. Glatzmaier, A. Ingersoll, S. Mohanty, G. Wuchterl

Chair: K.L. Chan

Chan: I have a list of questions that came up in my mind during the presentations. It might serve as a guide for what are to be discussed in this round table discussion session.
1. What is common between the planets, the sun, and the brown dwarfs?
2. How perfect or imperfect are the current models of global flows?
3. What about the interaction of local and global models? How may the two interact, or help each other?
4. The brown dwarfs' convection zones host a wide range of parameters. Does it sound like that brown dwarfs are good laboratories for studying convection?
5. Is rotation treated in collapse? How would rotation change during evolution?

Wuchterl: The angular momentum issue is a good question for stars, but for giant planets it might be a second order effect. If you calculate the relative specific angular momentum in the Keplerian disk and have it put in Jupiter, you don't have an angular momentum problem. Jupiter rotates within a factor of 2 or 3 of what you would find.

Piskunov: There are other effects of rotation, in particular differential rotation, which is connected to dynamo, convection, and so on. We can, to some extent, measure differential rotation in other stars and the sun, and we see a wide range of differential rotation patterns. Do you have any idea why the patterns of differential rotation can be so different? And how is it affected by general rotation of stars?

Glatzmaier: Is this a question about different differential rotation in different stars? or planets?

Chan: Presumably they are related?

Glatzmaier: I don't think we have a good understanding. We don't even have a good understanding of the differential rotation in the sun, or the dynamo of the sun. Not until we understand that well, can we understand why different stars have different differential rotation patterns.

Ingersoll: Uranus and Neptune have retrograde differential rotation at the equator, and Jupiter and Saturn have prograde equatorial jets. And the winds on Neptune are greater than they are on Jupiter. We don't understand that.

Piskunov: So I guess, if I understand the current situation correctly, since we don't understand that we don't take it into account. We ignore rotation in the models.

Glatzmaier: I think it depends on what models and what questions you are asking. If you are concerned about the formation of giant planets, or stars, it may be a secondary effect. But if you are concerned about matured planets and stars, then their differential rotation and flows, and magnetic field generation are fundamental. Rotation is very, very critical.

Roxburgh: I still want to come back to this (collapse models). I don't think that rotation is a secondary effect. To understand the behavior of the convection in forming brown dwarfs, and the extent to which convection penetrates and affects the surrounding region may be crucial to the evolution.

Wuchterl: It might be. But it turns out that giant planets form in a way that is inverse to the process of a main-sequence star becoming a giant with mass loss. In the inner part, where a proto giant planet is very compact, you can hope that convection behaves like in stars, and the outer part is more envelope-like with convection playing, I think, a minor role.

Roxburgh: Are you telling me you can understand convection in the center of stars?

Glatzmaier: Let me add something to that. My former student, Martha Evonuk did some simulations with a three-dimensional numerical code that included the interior fully convective, and she was trying to answer the question of what type of flow would you get at the center, and how does that depend on rotation. With very low rotation or with no rotation, the most unstable mode is flow right through the center. The dipolar flow is the easiest way of getting heat out of the center. But when you have significant rotation, it's a completely different flow profile and I would agree that the evolution would be affected by the flow profile. It also pertains to pre-supernova. What happens is if you have very low rotation rate, you'll have hot regions not in the center, but off-center because of the dipolar flow, and this will trigger supernovae very differently than if they're in the center.

Chan: I have a question about scaling laws. Apparently, at least it seems to me, that essentially all the models of differential rotation are idealistic and non-realistic. You need to jack up viscosity, and diffusivity, and flux, and things like that. Along that line, then would you say that some kind of study that can give some scaling would help for extrapolation to the true regime? Would you say that is something necessary?

Glatzmaier: This is a very logical thing to do. We cannot get into the correct parameter regimes. So you do what you can. And what we do, and what everybody does, is to use much larger viscosity and thermal diffusivity. With computational resources limited, you can't do anything else. So you do what you can, and then hopefully try to extrapolate into a regime that is more realistic. The only hesitation I have is that I don't think you can extrapolate from a very simple, laminar solution to a regime that is very, very

https://doi.org/10.1017/S1743921307000452 Published online by Cambridge University Press

turbulent. So you need to do your simulations so that they're at least weakly turbulent. I assume most of your (Christensen's) simulations were at least weakly turbulent.

Christensen: Well, they are at the verge of becoming turbulent. If they are already far enough into the turbulent regime, certainly, that's a major issue. So far the scaling looks pretty good, and it looks as if actually the viscosity is unimportant even for the kind of models we are able to run today. This looks fairly encouraging, and that's clearly the way to go - try to push the simulation parameters, to make them more turbulent, to see if the scaling laws are confirmed.

Glatzmaier: Yes, in the next 5 to 10 years when computer resources increase, then we should be able to keep checking, to push further into the turbulent regime.

Canuto: Can I go back to this business of rotation for a second? Let me differentiate between rigid rotation and differential rotation, and rigid rotation and mixing. Do the speakers agree that with numerical simulation, and physical intuition, that rigid rotation is a hindrance to mixing? Experiments showed that the Rayleigh numbers at which convection would set in are much higher if you have rotation. As far as mixing is concerned, (rigid) rotation is not a help at all; that's number one. The second statement about rigid rotation is that it is more important for stably stratified flows than unstably stratified flows. As far as differential rotation is concerned, yesterday I was impressed with Andy Ingersoll who showed that his Reynolds stresses, at least in Jupiter if I remember correctly, have opposite sign to what we usually have in shear flows.

Ingersoll: In the 40s and 50s Victor Starr invented the concept of negative viscosity, and that's the same thing that I was talking about. You should regard it as a fairly ubiquitous phenomenon. If you have eddies that have their own energy source, they are going to give some of that energy up to the shear flow. It is the opposite of when eddies are parasitic and living at the expenses of the shear flow. So if you have convection, you are going to have eddies that have their own energy source, and they'll give that energy to zonal jets.

Christensen: I may have a remark for your (Canuto's) first question or remark – rotation basically is a hindrance for convection and for mixing. To mention that the critical Rayleigh number for the onset of convection increases strongly in a rotating system certainly is true. But once convection has started, it is supercritical; then as you increase the driving, convection becomes very vigorous and very efficient rather soon. One example is the Nusselt number, which is somehow related to the efficiency of mixing, once you get above 5 or 10 times supercritical, the Nusselt number rises extremely rapidly with the Rayleigh number. So, once you overcome this rotational constraint, mixing becomes very efficient.

Roxburgh: It's delayed in stars by an insignificant amount.

Chan: I have a question for the brown dwarf people. Have people observed differential rotation type of behavior in brown dwarfs?

Mohanty: If you are looking at objects in the field, you see activities really fall off in the L type stars. The magnetic field is not coupling to the neutral atmosphere. You find out about the rotation rate by simply looking at spectral line broadening. On the other

https://doi.org/10.1017/S1743921307000452 Published online by Cambridge University Press

hand, in the young objects, you can also have activity as well, as they are hotter at the same mass. But you certainly don't see any sign of differential rotation.

Roxburgh: Is the rotation large or small?

Mohanty: It's rather large. They seem to have much longer spin down time scale. For example, in some of these field objects, they have rotation rates of about 80 km/s, extremely fast.

Wuchterl: I want to say something about formation models which discriminate between stars and brown dwarfs. Stars start a factor two larger than they are now. Brown dwarfs have huge factors; they really shrink substantially, and so they spin up.

Glatzmaier: I've a follow up question. If brown dwarfs did have differential rotation, and I can't imaging why they won't, what would you see? How do you know? You say you are not observing it. Is that a problem of observation?

Mohanty: I don't mean to say that it doesn't exist. I mean that we just haven't detected it, and I think that's more of an observational issue. It's not like that it doesn't exist.

Helling: I think there are observations of variability that nobody knows the reason for it. Something they know is it's not just activity because these stars are not very active. The variations are so small scale that they are thought to be associated with dust clouds.

Piskunov: Typically, the cheapest way of detecting the differential rotation is through detecting the period changes. If transient surface structures affect the colors of a star and persist for at least one rotation, one sees periodic variations of colors or light. If those structures change their latitudes the differential rotation will result in changing period. This is how one normally detects differential rotation in stars.

Chan: Time's up for the discussion. Thank you.

https://doi.org/10.1017/S1743921307000452 Published online by Cambridge University Press