DYNAMICAL MODELS OF ASYMPTOTIC-GIANT-BRANCH STARS

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Abstract. The dynamical behaviour of the envelopes of four 0.9 $\mathfrak{M}_\odot$ asymptotic-giant-branch stars of composition $(X, Z) = (0.68, 0.02)$ and luminosity $\log L/L_\odot = 3.41$, 3.60, 3.85 and 4.14 has been studied. At $\log L/L_\odot = 3.41$, the envelope pulsates in the first-overtone mode and exhibits properties similar to those of the Mira variables. The more luminous models were all found to pulsate in the fundamental mode while simultaneously undergoing violent envelope relaxation oscillations. A significant amount of mass loss occurred from the model with luminosity $\log L/L_\odot = 3.60$. It is suggested that a redgiant star undergoing envelope relaxation oscillations would be recognised as a symbiotic star. In the two most luminous models, a distinct outward-moving shell containing almost all the hydrogen-rich material in the star is formed. A suggestion is made that a further increase in luminosity would completely eject this shell to form a planetary nebula.

DISCUSSION

Iben: I have a number of questions. The first one: Are these models complete? That is, do you construct an asymptotic branch star including the core or do you just pick the surface temperature and go down and stop at some distance from the center?

Wood: I got a complete evolutionary model, got the luminosity-core mass relation (there's a very well defined luminosity/core mass relation) and if you integrate inward, you find that at about a third of a solar radius, there is a big discontinuity in pressure. So there's a very well defined core, so all you really need from the stellar interior calculation is the luminosity/core mass relation and then you can apply the boundary condition where the pressure goes up very sharply and I chose my core masses to agree with the luminosity/core mass relation for asymptotic giant branch stars.

Iben: So evolutionary calculations *do* put the stars to the red of the first giant branch by a considerable amount.

Wood: Rood's Z was 0.01, mine was 0.02, I think that's the reason for the difference.

Iben: Number 2, what's the driving mechanism, H_2?

Wood: No, if you look at the driving mechanism, the driving occurs right at the top of the hydrogen ionization zone so it's linked in with hydrogen mainly and possibly convection.

Iben: Can you comment on stars of intermediate mass in this phase?

Wood: I've done other calculations at 1.2 $M_\odot$ and 1.5 $M_\odot$ and the effect of this is, you're not changing the luminosity/core mass relation, that's pretty independent of anything for these stars. What you're doing is putting all that mass into the envelope and the effect of that is to move the top of the hydrogen ionization zone closer to the surface in mass, and that means that the driving which occurs at the top of the ionisation zone is closer to the surface. That tends to favour first overtone pulsation or overtone pulsation for higher modes, so the effect is that if you increase the total mass you raise the luminosity at which the transition to fundamental pulsation occurs. And, as you saw, fundamental pulsation always seems to be associated with some violent behaviour, like mass loss.

Iben: Why is it that convection doesn't damp out the pulsation? Is there some point where convection, although it occurs, carries so little flux that it has no influence on the driving mechanism?

Wood: All the models I've done have convective envelopes.

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Cox: But what fraction of the flux is being carried by convection?

Wood: Just about all of it.

Iben: Then how can you have a driving mechanism?

Wood: It all happens at the very surface of the ionisation zone and I think it may be something to do with matter passing in and out of this convection zone which starts at the hydrogen ionisation zone. It's a very sharp discontinuity at the beginning of convection.

Kemp: How do you include mass loss in the hydrodynamic model? Doesn't that produce a mathematical problem since the mass inside the envelope is not conserved?

Wood: I haven't. When things get too far away, you've exceeded the escape velocity. I just stop my calculations when things blow up. But there's no artificial mass loss put in, it just comes out of the dynamics.

Kemp: Is the part of the envelope that exceeded the escape velocity conserved in the calculation?

Wood: Yes, because you're considering the envelope as a whole and the matter that's escaped is still in the envelope. It's passed escape velocity but you've still got it in the dynamic calculation.

Schatzman: For such an extended envelope you are likely to have convective velocities which are highly supersonic, which means that the turbulence being supersonic, you have always conversion of the kinetic energy into heat and this complicates the picture a little bit for the convective zone. Have you taken that into account?

Wood: I had a look at the convective velocities and they didn't exceed the velocity of sound. I think because the specific heat is so high in hydrogen and helium ionisation zones you don't need a very large velocity in order to carry the required flux. If you go to hotter stars it does get supersonic.

Schatzman: That is very close to the surface but you have a zone which is convective over one half of the star or more than that.

Wood: Convection carries less of the flux at these deep levels.