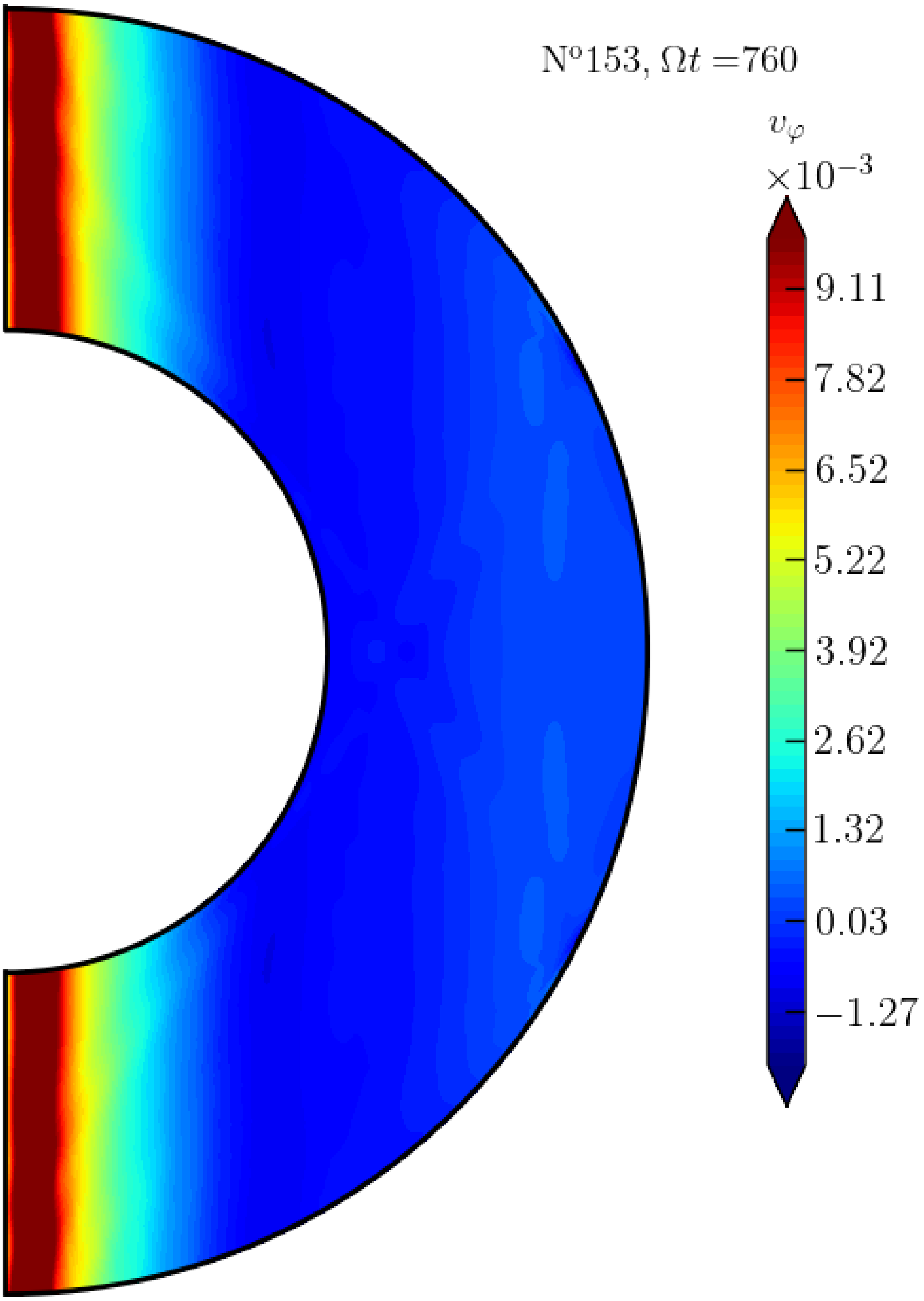
EPSC Abstracts
Vol. 15, EPSC2021-813, 2021
https://doi.org/10.5194/epsc2021-813
Europlanet Science Congress 2021

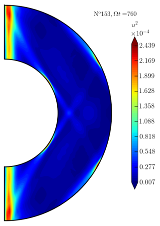
Non-linear effects on tides in the convective envelope of low-mass stars and giant gaseous planets

Aurélie Astoul and Adrian Barker
Department of Applied Mathematics, School of Mathematics, University of Leeds, Leeds, LS2 9JT, UK

In close two-body astrophysical systems, like Hot-Jupiter systems, tidal interactions often drive the dynamical evolution of the system on secular timescales, modifying body spins and the orbit of the planet (e.g. Mathis 2019). Most stars around which planets have been discovered are cool stars and feature a convective envelope which is magnetised, as shown by ground-based Zeeman broadening/Doppler imaging techniques and 3D (magneto-)hydrodynamical simulations. Moreover, strong surface magnetic fields have also recently been inferred through star-planet interaction in Hot-Jupiter giant gaseous planets (e.g. Cauley et al. 2019). Due to the tidal potential of the companion (star or planet), tidal flows are generated in the convective layers and dissipated through friction mechanisms, like viscous or Ohmic turbulent damping (e.g. Duguid et al. 2020, Astoul et al. 2019). This tidal dissipation leads to the redistribution and exchange of angular momentum in the convective shell and with the companion, respectively. In the most compact systems, non-linear effects are likely to have a significant impact on the tidal dissipation and change the zonal flows triggering differential rotation, as shown in the hydrodynamical study of Favier et al. (2014).

In this context, we also investigate how the addition of non-linearities affect the tidal flow properties, the energy and angular momentum balances, thanks to 3D (magneto-)hydrodynamic non-linear simulations of an adiabatic and incompressible convective shell. In our neutrally-stratified model, the action of convective eddies on tides is simply taken into account through an effective viscosity. Moreover, we have chosen a body forcing where the equilibrium tide (the quasi-hydrostatic tidal flow component) acts as an effective force to excite tidal waves, while using stress-free boundary conditions. As a result, our perturbed flow is decomposed into a non-wave like part (the equilibrium tide) plus (magneto-)inertial waves. In that respect, our model differs from the above mentioned study which is using an incoming radial flow at the surface to excite inertial waves. In particular, within our more realistic set-up, we are able to identify and assess the importance of the different types of non-linearities (wave/wave, non wave-like/non wave-like, or mixed), and thus discuss unphysical contributions leading to non expected angular momentum evolution for some simulations observed in Favier et al. (2014). By removing these contributions, we also demonstrate that differential rotation can develop in the shell (left figure, azimuthal velocity in a meridional cut) due to the anisotropic deposition of angular momentum in hydrodynamical simulations (right figure, kinetic energy in a meridional cut), which would not be the case in magneto-hydrodynamic simulations according to our early results. Moreover, we show new results for the amplitude of the energy stored in these zonal flows, as well as angular momentum evolution. In particular, we find that non-linearities tends to smooth the frequency dependence of tidal dissipation by lowering it compared to linear predictions (as in Jouve & Ogilvie 2014 using a Cartesian box). As the dissipation of tidal waves in convective envelopes is a major part of total tidal dissipation for close low-mass stars and giant gaseous planets, the inclusion of non-linear effects in its estimation can deeply modify the tidal efficiency (the tidal quality factor) and the associated tidal migration/spins timescales.




N°153, Ωt =760
u^2
$\times 10^{-4}$
2.439
2.169
1.899
1.628
1.358
1.088
0.818
0.548
0.277
0.007