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Anti-diffusive transport of angular momentum and super-rotation in planetary atmospheres

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Observations show that most known planetary atmospheres tend to rotate faster on average than their underlying planet[1,2]; a phenomenon that may have some analogous features in common with the intrinsic rotation of fusion plasmas[3]. In practice this may be manifest as a global and/or localised excess of angular momentum compared with the corresponding value obtained in co-rotation with the bulk of the planet. This can be measured[1] by dimensionless ratios of total angular momentum S or local maxima s of specific angular momentum to their equivalent in solid body rotation with the underlying planet.

Excesses of angular momentum are typically quite small for rapidly rotating planets such as the Earth (around a few per cent) but can be very large (O(10)) for slow rotators such as Venus or Titan (e.g. see Figure 1). Such a phenomenon cannot be consistent with down-gradient diffusive transport of angular momentum and depends on strongly counter-gradient, anti-diffusive transport due to nonlinear wave-zonal flow interactions.

We review a range of possible mechanisms for atmospheric super-rotation and present some recent work[4] which attempts to develop scaling arguments to account for some aspects of this phenomenon.

Predictions from theoretical scaling arguments are compared with numerical model simulations of idealised atmospheric circulations with widely differing planetary rotation rates. Results of these simulations indicate that atmospheric super-rotation for an Earth-like planet is consistent with an angular momentum conserving, quasi-axisymmetric scaling[5] for fast rotating planets but with a strongly diffusive angular momentum scaling[6] with slow rotation (see Fig. 1b). The latter scaling appears to work well for the atmospheres of Titan and Venus, though is difficult to capture in numerical simulations.

References

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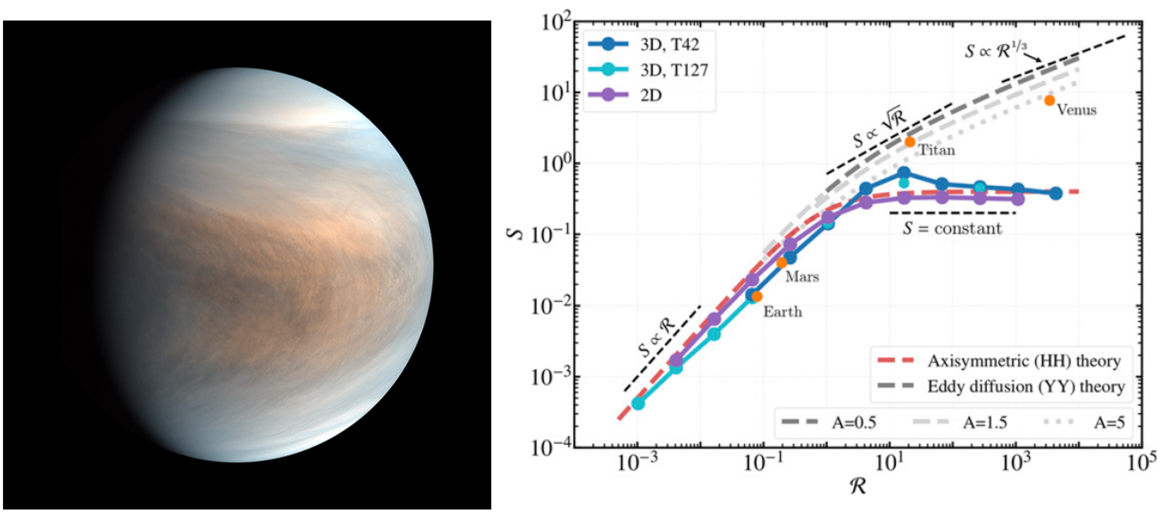

(a) (b)

Figure 1: (a) False colour image of Venus using images at wavelengths of 283 and 365 nm, taken by the UltraViolet Imager (UVI) on the Akatsuki spacecraft (Credit: JAXA/ISAS/Akatsuki Project Team); (b) Variation of the dimensionless measure of global atmospheric super-rotation S with thermal Rossby number $\mathcal{R} = R_d \Delta T_{eq}/(\Omega a)^2$ for numerical simulations of atmospheric circulation (2D axisymmetric – blue curve; 3D - purple curve), observations (orange dots) and theoretical curves (dashed lines), from [4].