Constraining the Depth of the Winds on Uranus and Neptune via Ohmic Dissipation

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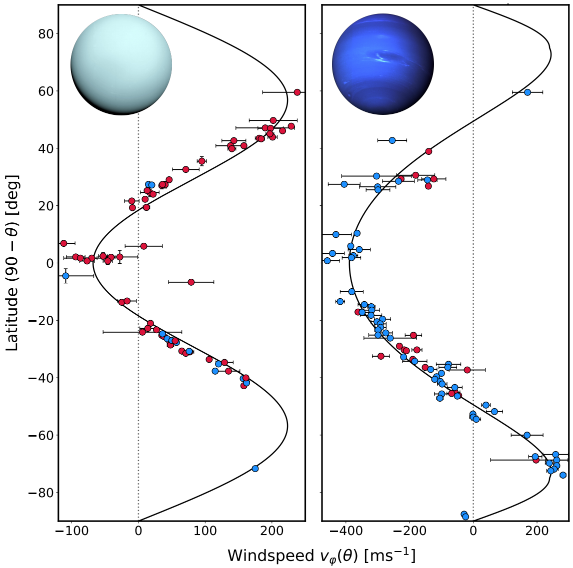
Equatorially symmetric and **strong** surface winds.



Non-axisymmetric and **multipolar** magnetic fields.

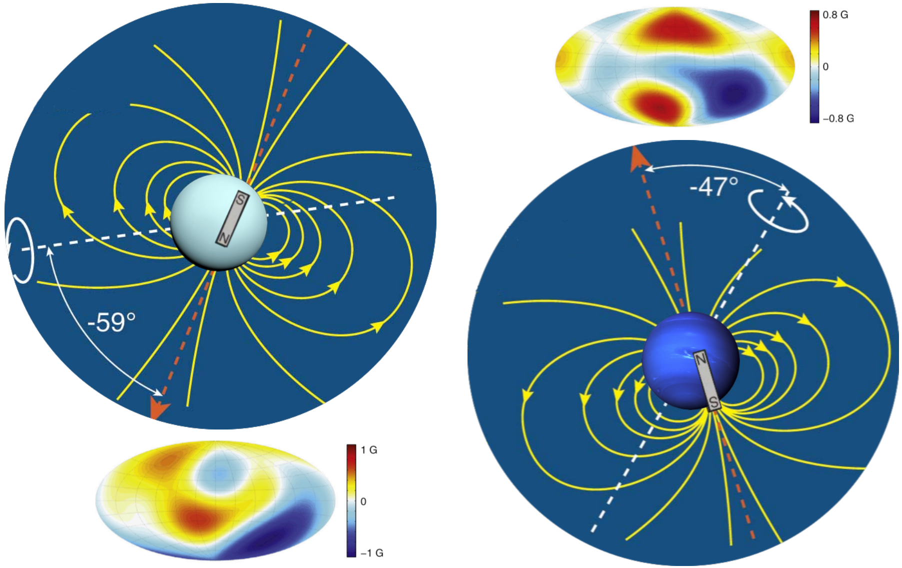
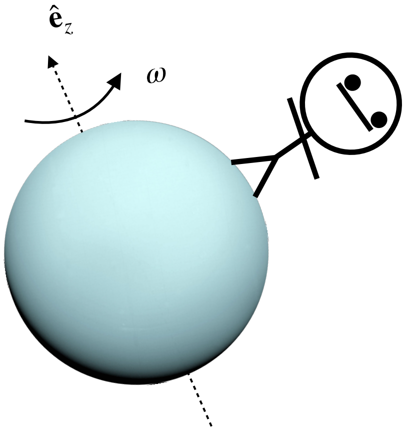


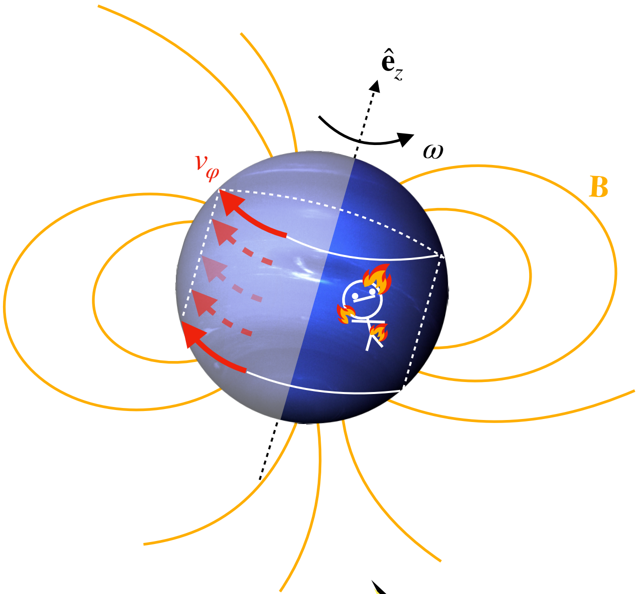
Image Credits:
- Cao & Stevenson 2017
- https://plasma.pics/magnetic-field-alignments/

Fast planetary rotation imposes geostrophic flow.

→ *weak variation of wind velocities along the z-direction*



Winds penetrate inside the planets along cylinders parallel to the rotation axis.



Winds interact with **the magnetic field** and induce **a current!**

Currents lead to **Ohmic dissipation!**

Current density: $$\mathbf{j} = \sigma(\mathbf{E} + \mathbf{U} \times \mathbf{B})$$

Total built-up **Ohmic dissipation**: $$P_{\mathrm{tot}} = \int_V \frac{\mathbf{j}^2}{\sigma} dV$$

How do you estimate the conductivity?

How much dissipation is too much?

Estimating electrical conductivity

- Assume a mixture of **hydrogen**, **helium** and heavier elements.
- Represent heavy elements with **water**.
- The mixture starts to conduct **ionically** with depth.

Does not actually have +1 charge!

Detailed description in:
doi:10.1093/mnras/staa2461

Relevant species: $\beta \in \{H_2O, HO^-, O^{2-}, H_2, H^+\}$
under conditions of interest

Ionic conductivity

via the fluctutation-dissipation theorem
assuming the charges are time-independent

Fraction of H in β

Number density of H

Diffusion coeffecient of β

Charge of β

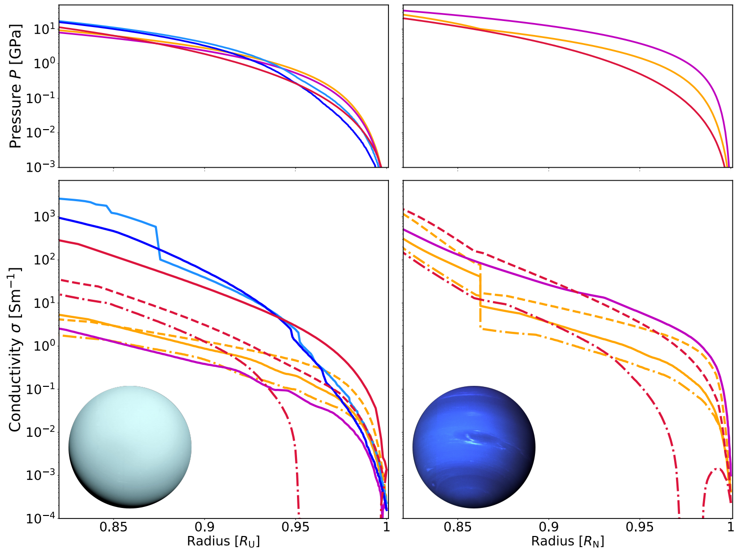
$$\sigma_{\text{ion}} = \sum_{\beta} q_{\beta}^{2} \frac{\xi_{\text{H},\beta}\, n_{\text{H}}}{k_{\text{B}}T} D_{\beta} + \sum_{\beta} q_{\beta}^{2} \frac{\xi_{\text{O},\beta}\, n_{\text{O}}}{k_{\text{B}}T} D_{\beta}$$

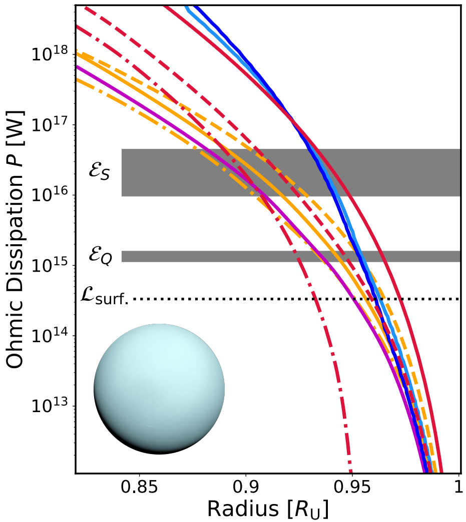
Summed for hydrogen

Summed for oxygen

Ionic conductivity

of various structure models in literature
calculated with our prescription





Energy flux budget: assuming adiabatic cooling balances dissipative heating at each layer

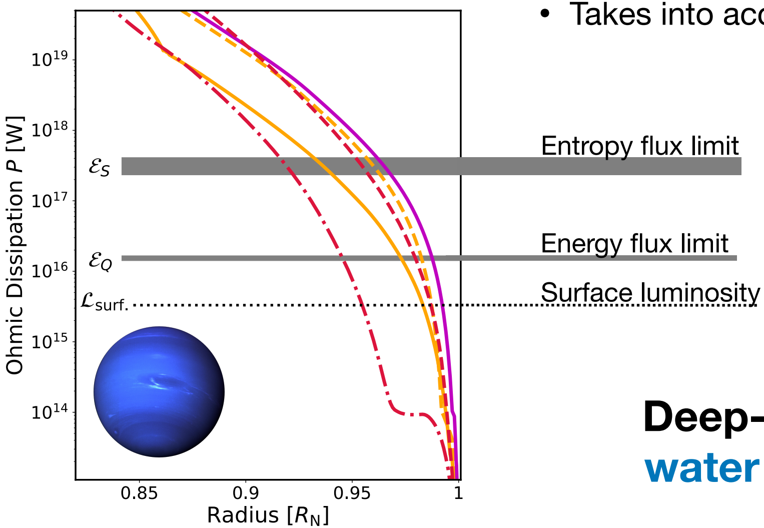
$$P_{\rm tot} \lesssim \mathcal{E}_Q = \int_{r_i}^{R} \frac{Q_A}{-T/(\partial T/\partial r)} r^2 dr$$

- Takes into account the dissipative heating throughout the interior.
- Assumes advection Q_A is the major contributor to the heat flux.

Entropy flux budget:

$$P_{\rm tot} \lesssim \mathcal{E}_S = \frac{T(r)}{T_0} L_{\rm surf.}$$

- Takes into account the entropy generation throughout the interior.



The limits are violated above **0.90 $R_{\rm U,N}$.**

Deep-seated winds are unlikely if water is present in outer regions!