# MHD simulation of an Uranus type rotating magnetosphere (ST1.9 EGU2020-18905)

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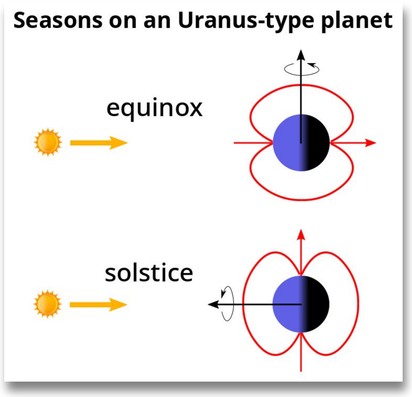
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**Introduction:** The magnetospheric tail of fast rotating planets with a rotation axis oriented at a large angle with respect to their magnetic axis is non-stationary and helically shaped. In the case of Uranus, the tail structure is also subject to substantial seasonal variations as the angle between the solar wind direction and its rotation axis changes by ~90° from solstice to equinox. We show MHD simulations for the equinox and solstice after commenting first the instructive “no wind” case.

**Technical details:** We use the freely available MPI-AMRVAC code to integrate the ideal MHD equations on a 3D spherical grid (see Griton & Pantellini, 2020 for more details). Figures show the asymptotic state of the simulations, once strict time periodicity has been reached within the simul tion domain.




**Set-up:** Not because of technical limitations but in order to ease interpretation we adopt idealized orientations of rotation an dipole axis.

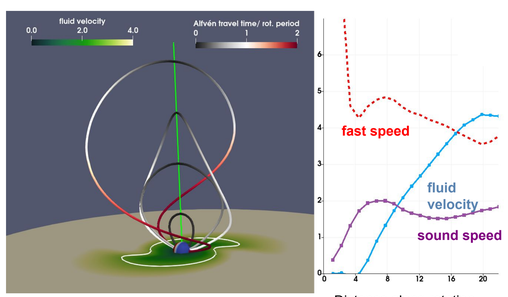
**Key parameter:** the corotation radius

$$Rc = R_0 \left( \frac{v_{A0}}{\Omega R_0} \right)^{1/4}$$

where R0 is the radius of the planet, Ω the rotation frequency and vA0 the Alfvén speed at the magnetic equator (at distance R0 from the dipole center).

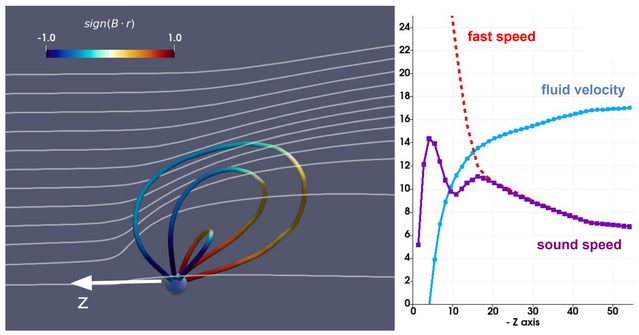
Rotation is significant for Rc < 100 R0 (Uranus Rc ~ 40 R0).

**(A) Case of a rotating dipole in a resting plasma (no wind):** In vacuum, a dipole rotates rigidly out to the light cylinder. On the other hand, plunged in an (ideal) plasma the field lines become massive. Effect of rotation is transmitted along field lines at the Alfvén speed (here Rc=4).

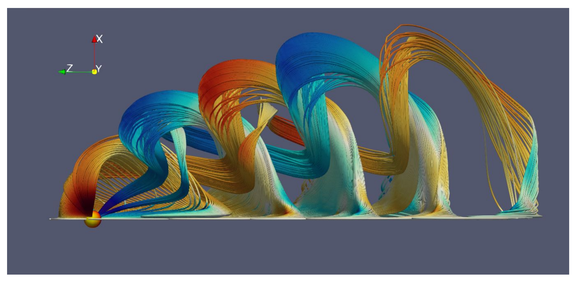



- Field lines are more distorted (with respect to dipole shape) depending on how far an Alfvén wave can travel along the field line during one rotation period.
- Consequence of rotation: plasma is accelerated outwards in all directions, namely along the rotation axis.
- Along rotation axis field lines are always perpendicular to the flow: field lines and plasma are transported at the same speed.
- Acceleration distance is of order Rc=4, which is also the characteristic distance of magnetic field line distortion.
- Asymptotic speed depends on parameters of surrounding plasma and on the location of the outer boundary. In an infinite domain speed is expected to decrease with distance due to “snowplow effect” of the expelled magnetic field pushing the surrounding plasma.
- NB: system is stationary in the rotating frame

**(B) Equinox case with wind:** Adding a supersonic wind (Mach V=20) entering the simulation domain from the left bends the field lines towards downstream as the wind exerts a torque on the expanding dipole field lines (Rc=4).

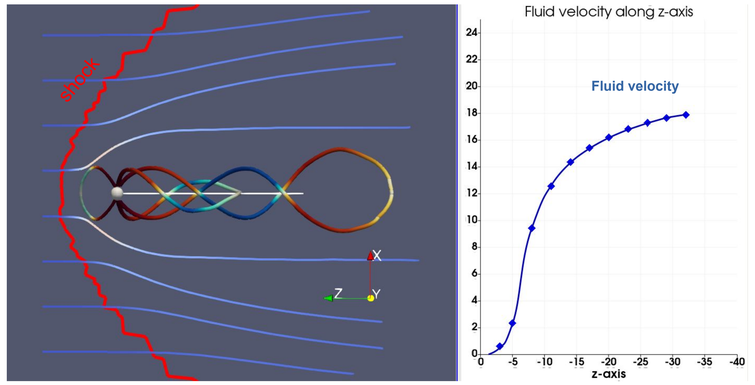



- Again, even measured along the z-axis (rotation axis is x-axis), acceleration distance is of order Rc.
- Fluid velocity approaches wind speed (V=20).
- There is no privileged direction along which field lines and flow velocity are systematically perpendicular to eachother. However, for connected field lines there are always places where this occurs (see below).

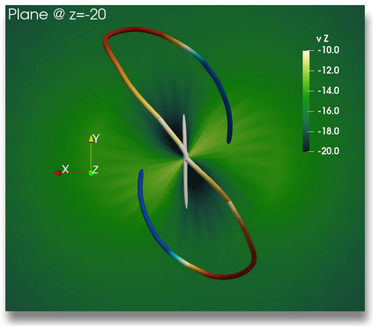



- The above view (from a different simulations) shows the spatial structure of the magnetic tail for the equinox case.
- Filed lines from north and south magnetic poles wind around eachother on with a spatial periodicity asymptotically approaching 2πΩ/V.

**(C) Solstice case with wind:** In this configuration, the rotation axis and the wind speed are aligned. Wind velocity is V=20 and Rc=4. This configuration can be compared to the more slowly rotating “real” Uranus simulations by Toth et al (2004).




- As in the no-wind case (A) and the equinox case (B), the plasma is accelerated over a characteristic distance of order Rc.
- As in the no wind case (A), field lines are perpendicular to the flow velocity on the rotation axis (here the z-axis): field lines and plasma must move at same speed along z-axis.




- Fluid velocity vz in z=-20 plane. Plotted field lines are those of the above figure.
- Fluid velocity vz and field orientation are highly inhomogeneous. Off-axis, Alfvén waves can thus propagate up- and downstream.
- As the field lines crossing the z-axis must move at the speed of the fluid, this must be the case for the whole magnetic structure.

**Conclusion:**

- We argue that the magnetic tail of a rotating planetary magnetosphere moves downstream at the speed of the plasma near the tail axis (contrary to Toth et al 2004 who argue that the speed is the sum of plasma and Alfvén speed).
- The acceleration takes place downstream of the planet over a distance of the order of the corotation distance Rc.

**References:**

- G. Toth et al, JGR Space Physics, 109, A11210, 2004.
- L. Griton & F. Pantellini, A&A, 633, A87, 2020.