No bow shock around the young Earth?

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Abstract: We couple stellar wind and magnetosphere simulations to study the evolution of the Earth's magnetosphere during the Sun's main sequence. To do this we vary the Sun's rotation rate from 0.8 to 50 $\Omega_{\odot}$, as we know stars spin down with time. We find that the young Earth's magnetosphere was much smaller than it is today, changing with $\Omega^{-0.27}$ for young ages and $\Omega^{-2.04}$ for old ages. We also find that the extreme young fast system could have had no bow shock present around the Earth, for a relatively short amount of time.

Introduction

As a star spins down on the main sequence, its wind properties are affected

This in turn changes the properties of the stellar wind, which determine the structure of planetary magnetospheres.

In this work we study the change in Earth's magnetosphere in time, using MHD stellar wind and magnetosphere models.

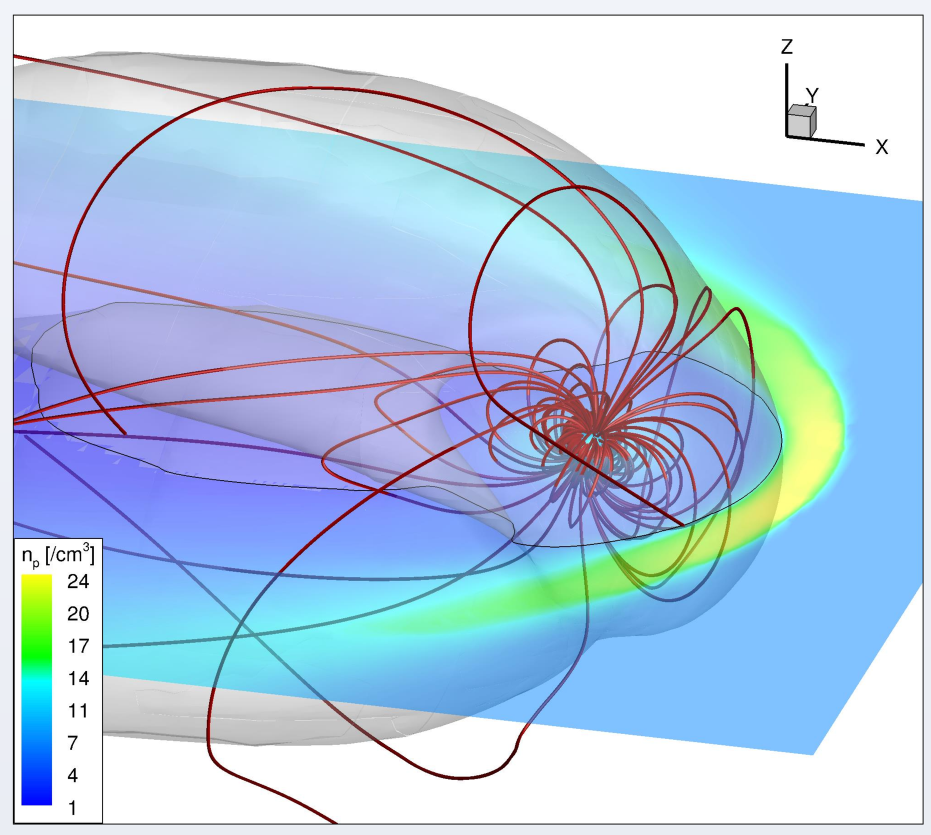

Figure 1: A 3D image of one of our magnetosphere models. The slice shows the density contour in the x-y planet. The surface marks the region inside which magnetic pressure dominates - the magnetosphere. The red lines illustrate magnetic field lines connected to the planet.

The Solar Wind in Time at 1 au

Using 1.5D MHD models, we simulate the solar wind out to 1 au for a range of stellar rotation rates from 0.8 to 50 $\Omega_{\odot}$.

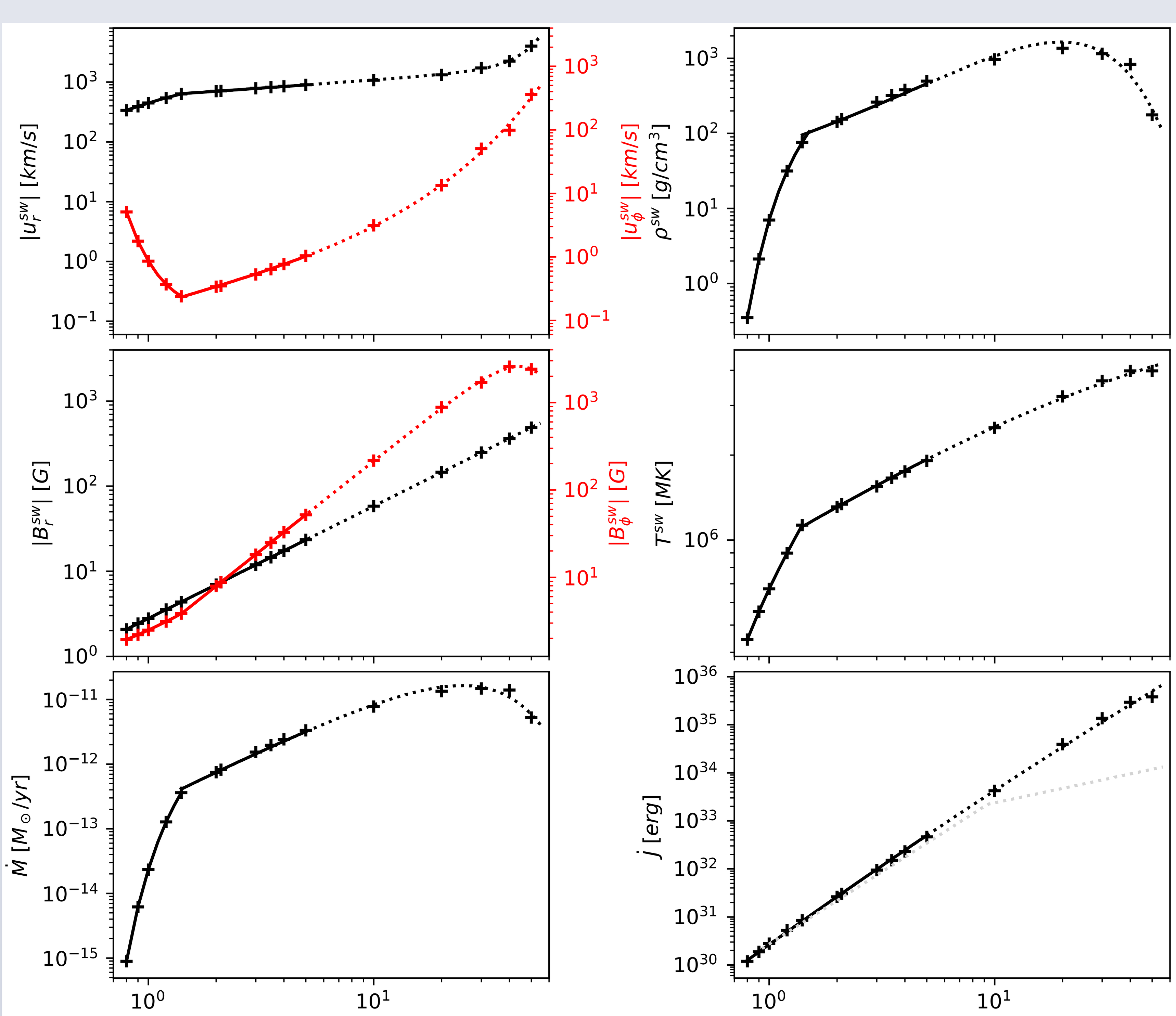

Figure 2: The results of our stellar wind models at 1 au vs stellar rotation. Black represents radial components while red represents the azimuthal components. The dotted line marks values which are only possible in the case that the Sun was a fast rotator in the past.

These winds are injected into our magnetosphere simulations as an outer boundary.

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Earth's Magnetosphere in Time

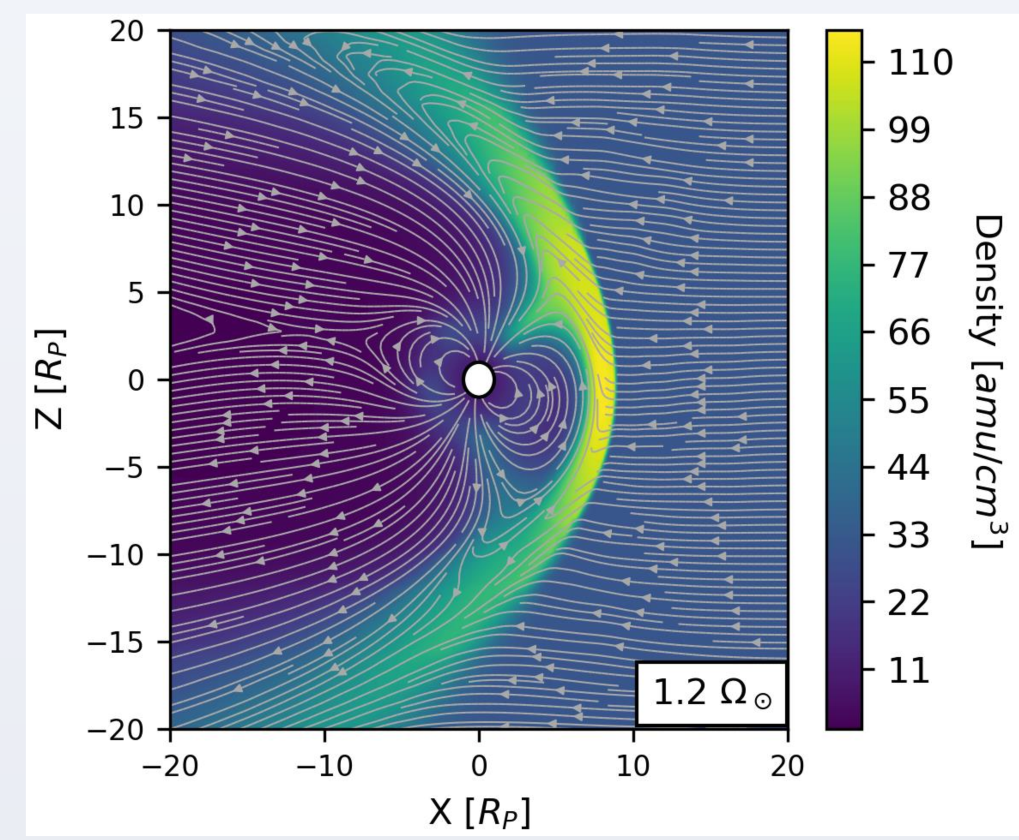
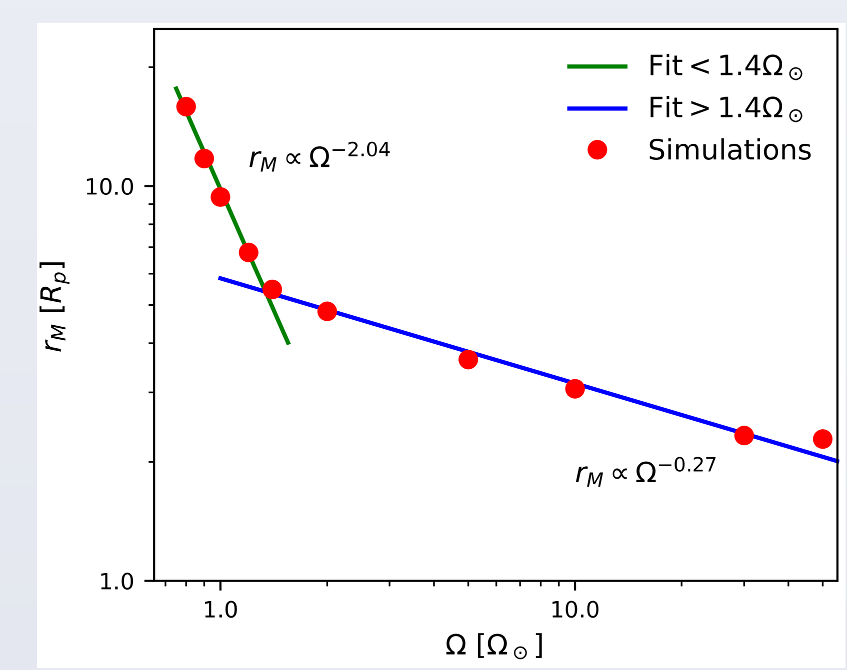


Figure 3: An example of one of our models at 1.2$\Omega_{\odot}$. The contour marks the density, while the stream tracers mark the magnetic field lines in the system. The X axis points towards the star, and the Z points out of the orbital plane.

Figure 4: The variation of magnetopause standoff distance with stellar rotation. The break we see in this relation comes about from the definition of base temperature in our wind model (O' Fionnagáin & Vidotto 2018)



We can see that the young Earth's magnetosphere was substantially smaller than it is today.

Young Earth: no bow shock?

We examined the extreme fast scenarios of Earth's evolution. These would only have occurred if the Sun was a fast rotator and would have had a very short lifetime in comparison to the remainder of Earth's evolution.

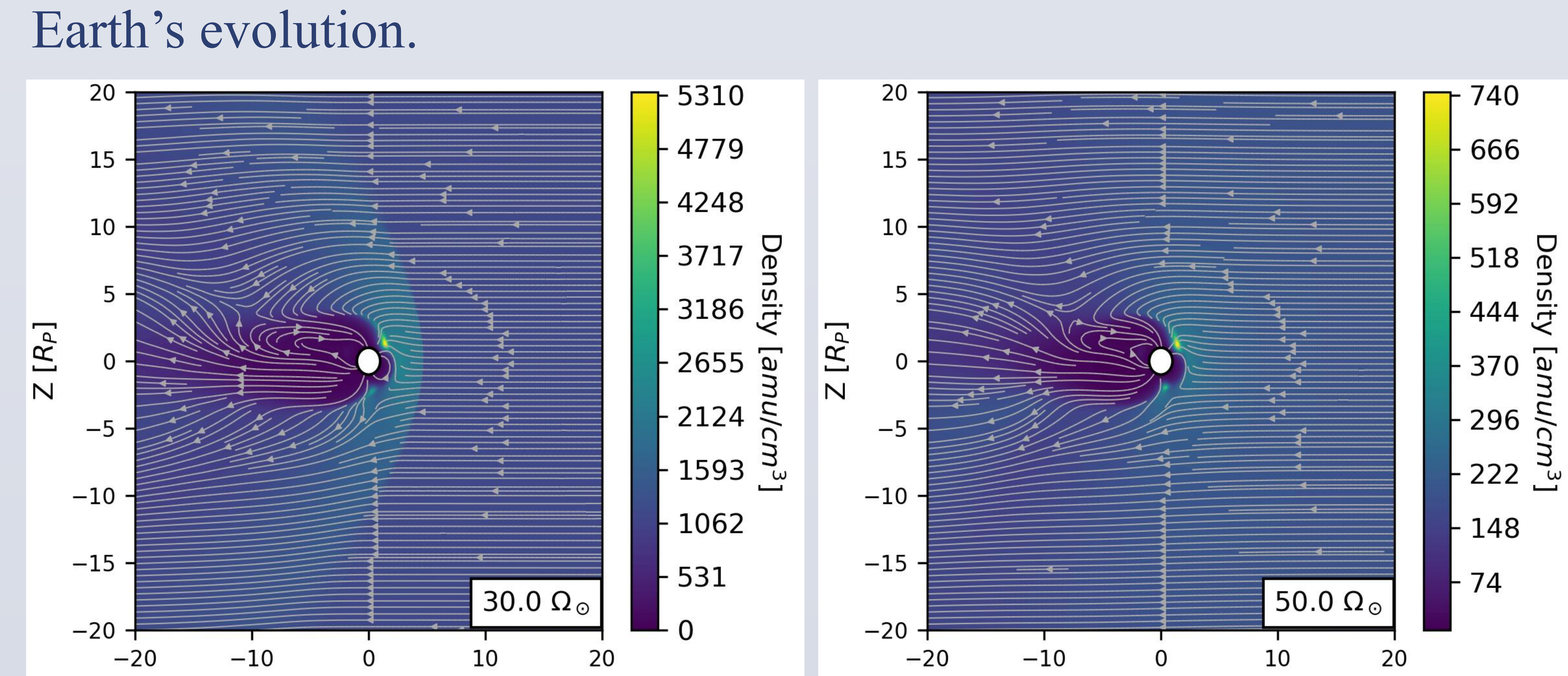


Figure 5: Earth's magnetosphere at 30 and 50 $\Omega_{\odot}$. Our models tell us that there would have been no bow shock present around the Earth at very young ages (right panel), which would be followed by a weak bow shock (left panel) before a strong shock develops at rotation rates lower than 10 $\Omega_{\odot}$.

Conclusions

- We couple stellar wind and magnetosphere simulations to study the evolution of Earth's magnetosphere.
- Earth's magnetopause standoff distance varies with the stellar rotation rate as $\Omega^{-0.27}$ for young ages and $\Omega^{-2.04}$ for old ages.
- It is possible that the young Earth was not surrounded by a bow shock, though the lifetime of this shockless state would have been relatively short (100 Myr).