Heavy Ion Escape from Terrestrial Exoplanets

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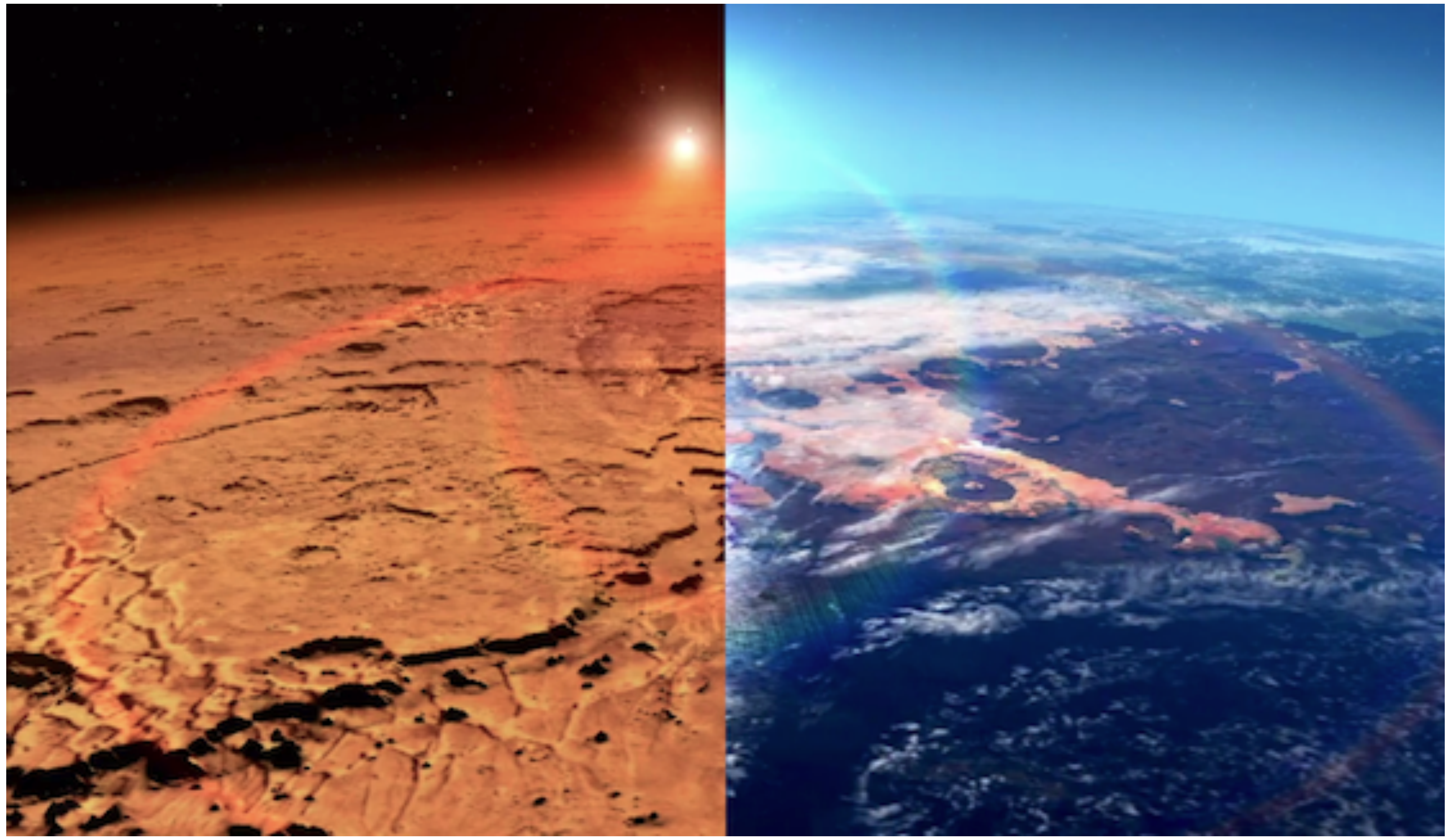
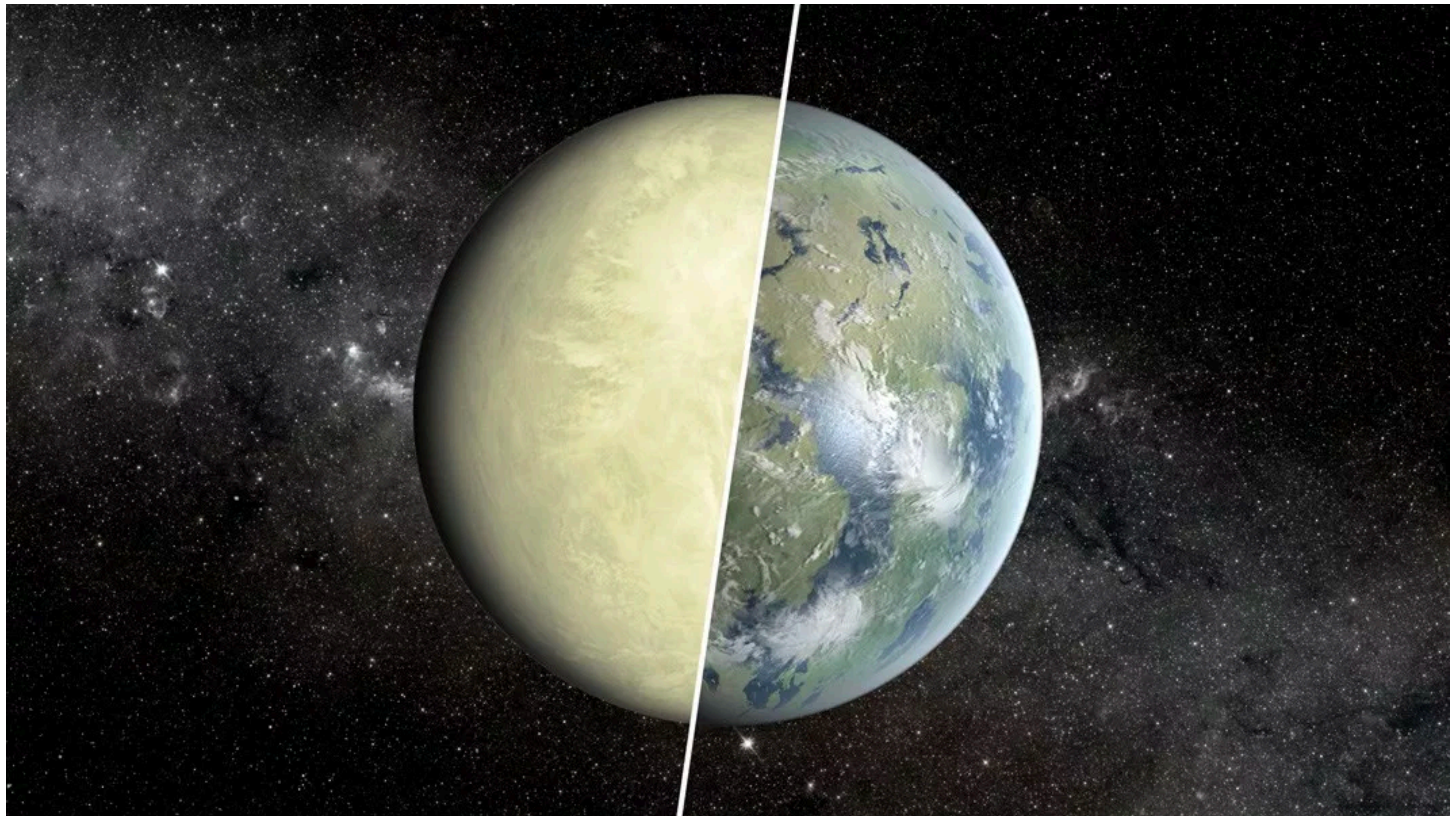
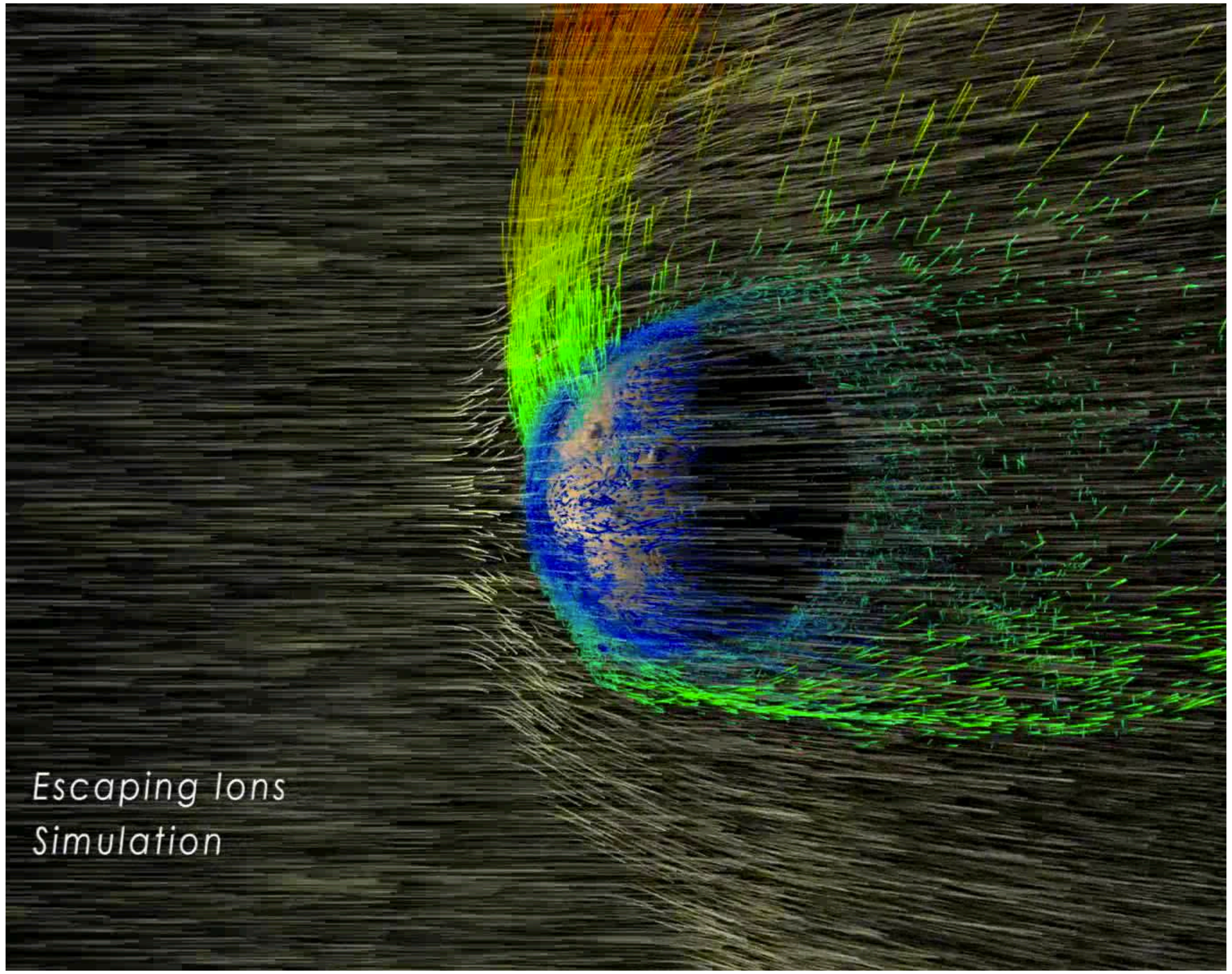
Solar System as a Laboratory





Mars and Venus may have been habitable in the past, but have undergone significant **atmospheric evolution** over billions of years much of it through **loss to space**

Heavy Species (O, O_2, CO_2, …) are commonly lost as Ions



[NASA's Scientific Visualization Studio and the MAVEN Science Team]

- Light species (H) may escape via thermal motion but **heavier species need additionally energy sources** such as electric fields to reach escape velocity

- Ion escape is observed occurring at all terrestrial solar system planets today

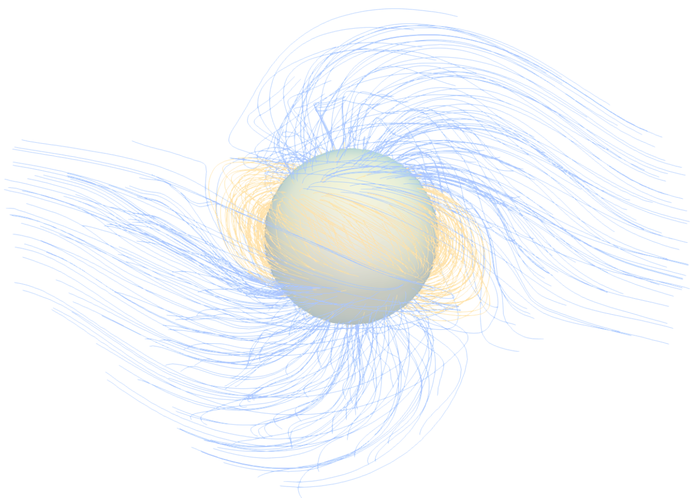
My Work Applying Planetary Models to Exoplanets

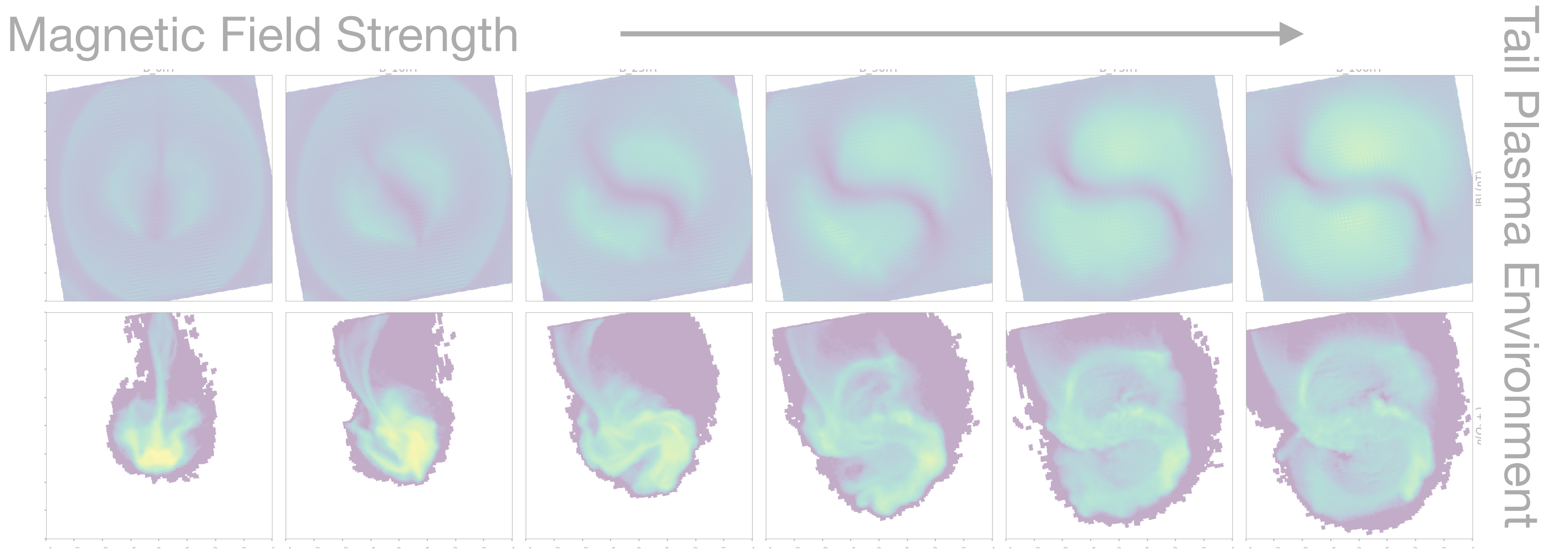
Weak Magnetic Fields & Ion Escape

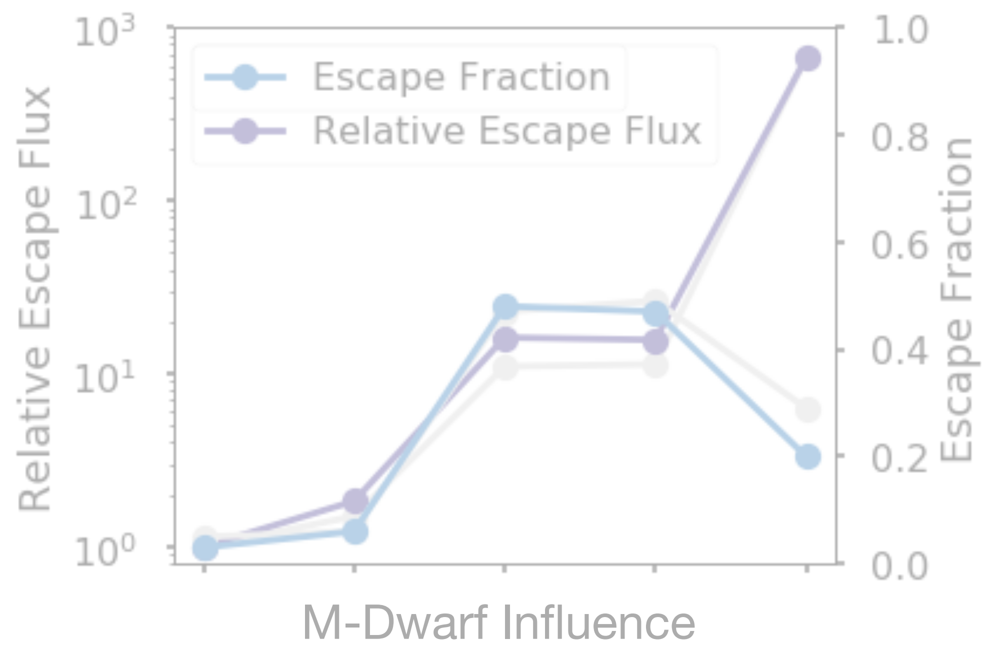
- Topology of weak intrinsic fields
- Plasma environment for weak dipoles and ion morphology
- **Influence of global planetary magnetic fields on ion escape**

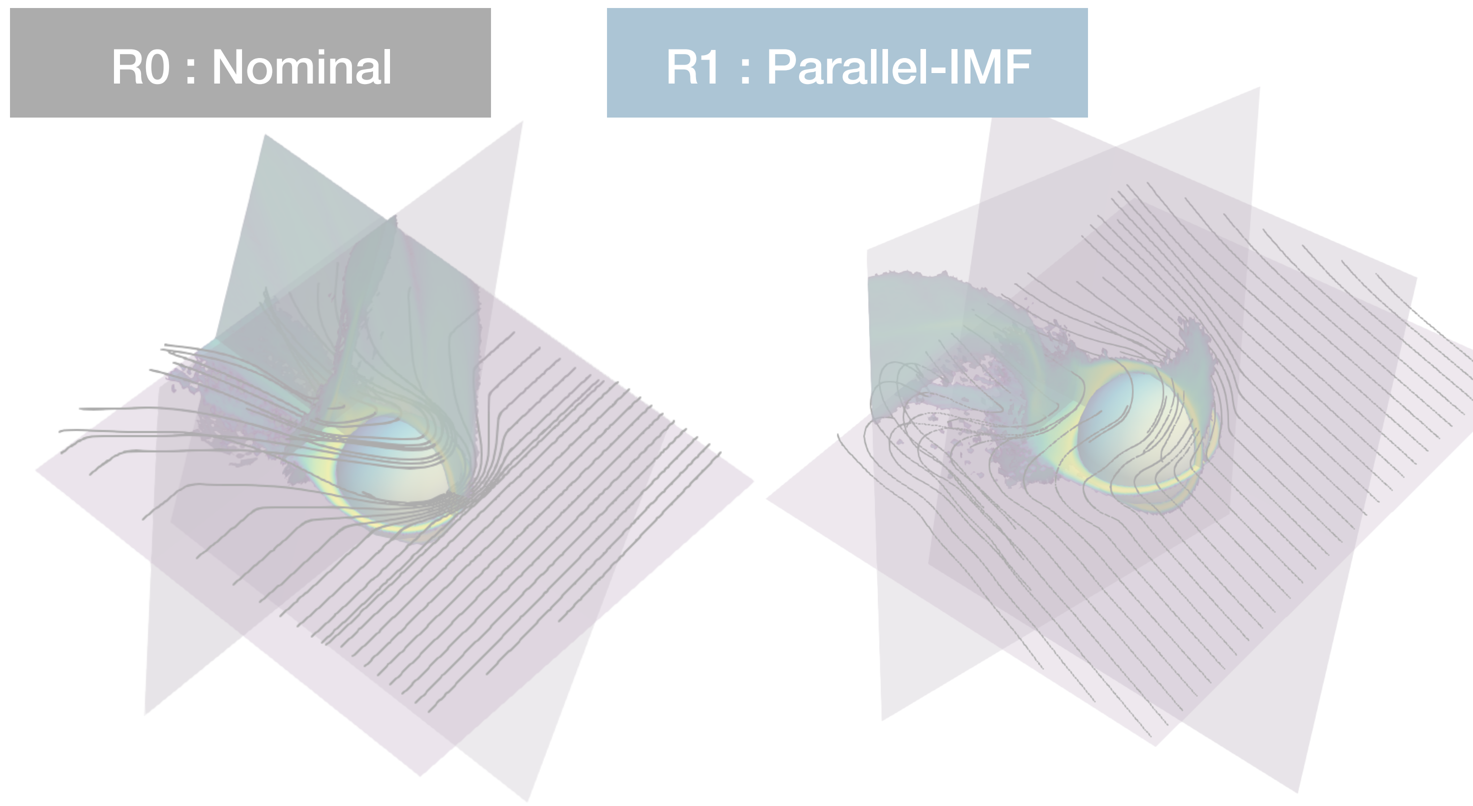
Ion Escape from Planets around M-Dwarfs

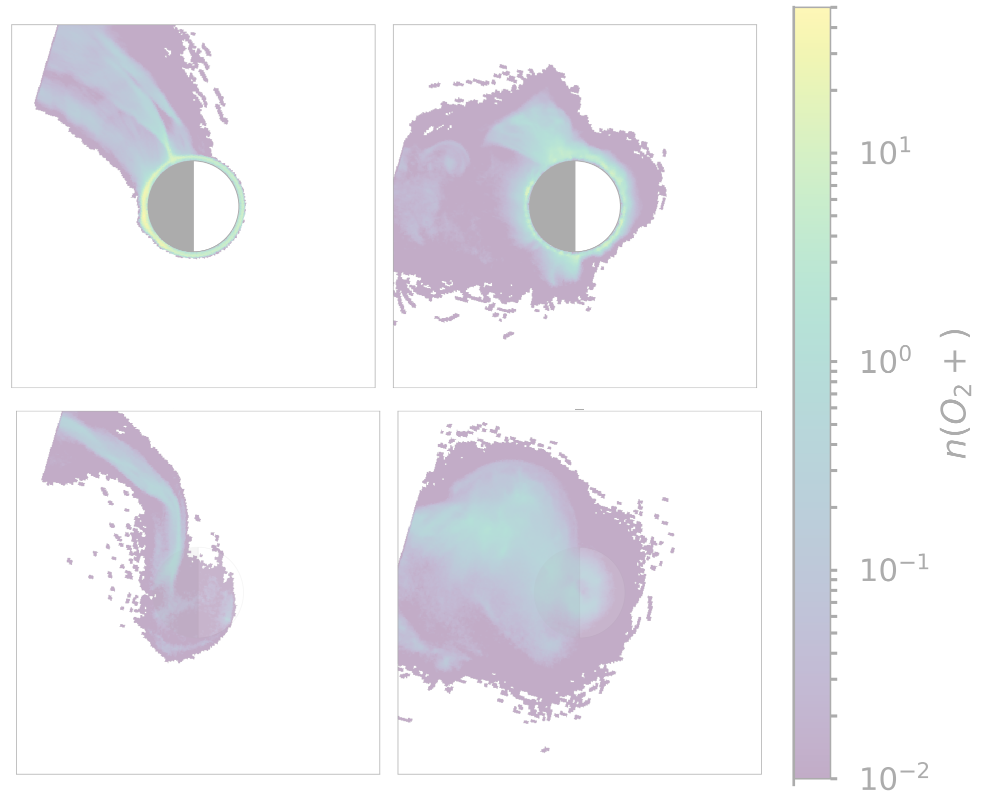
- Stellar properties relevant for escape (**stellar magnetic field**, stellar wind pressure, EUV flux) and influence on escape processes
- Stellar driving of loss asymmetries, with atmospheric implications
- Coupling of stellar properties and escape rates

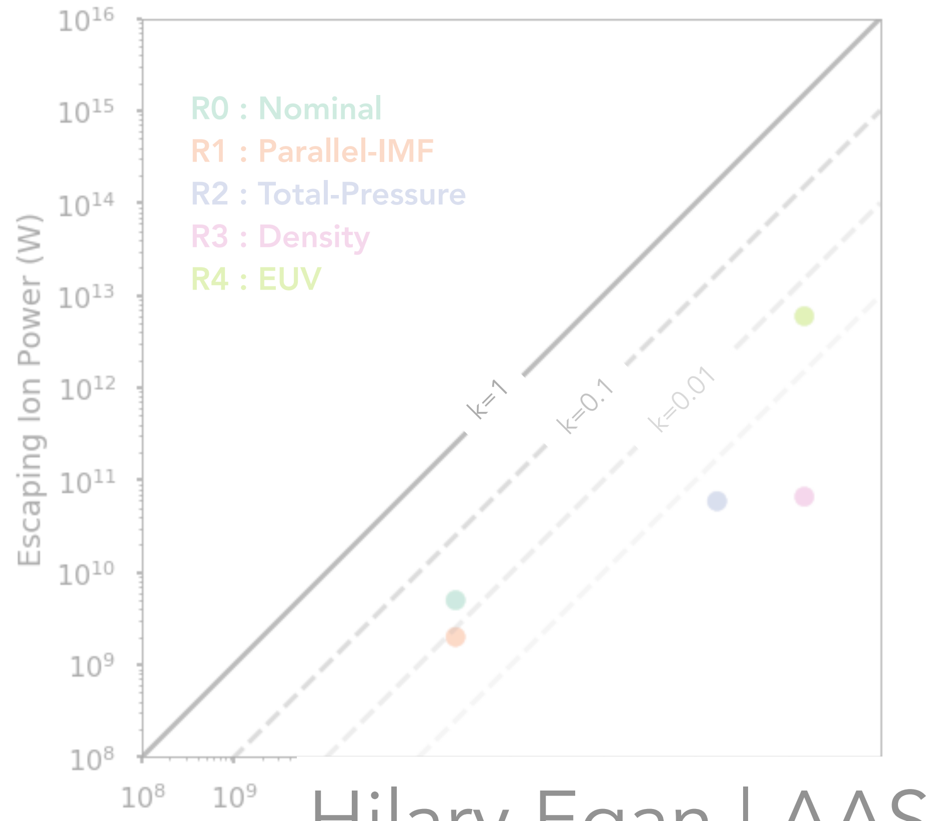












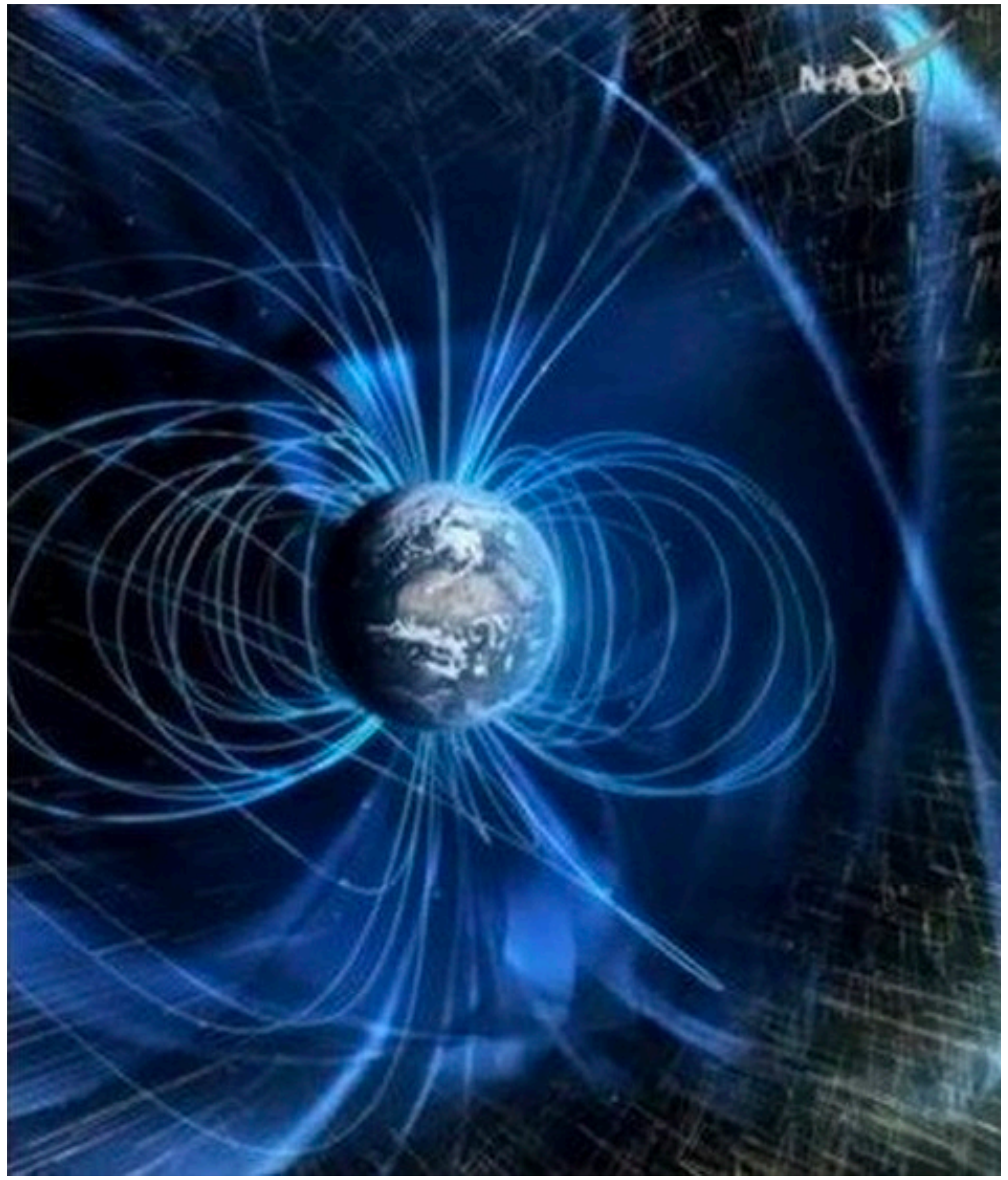
Why Consider Weakly Magnetized Planets?

- Terrestrial around M-dwarfs planets are likely to be unmagnetized or weakly magnetized

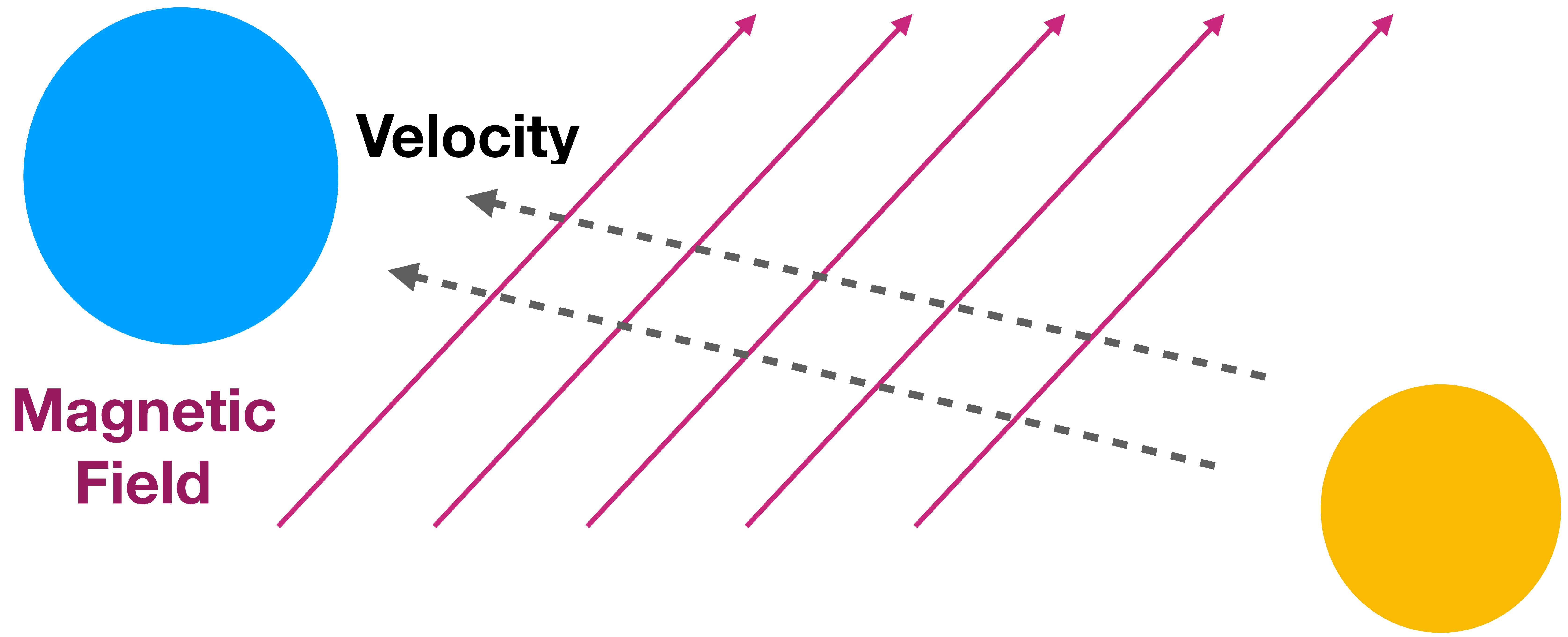
- Even a weakly magnetic field can change the overall morphology of the system

- Ion escape is incredibly dependent on magnetic fields

- **Prevailing wisdom says magnetic fields act as a shield for atmospheric erosion**



“Quick” Ion Escape Paradigm Overview



Unmagnetized Planets

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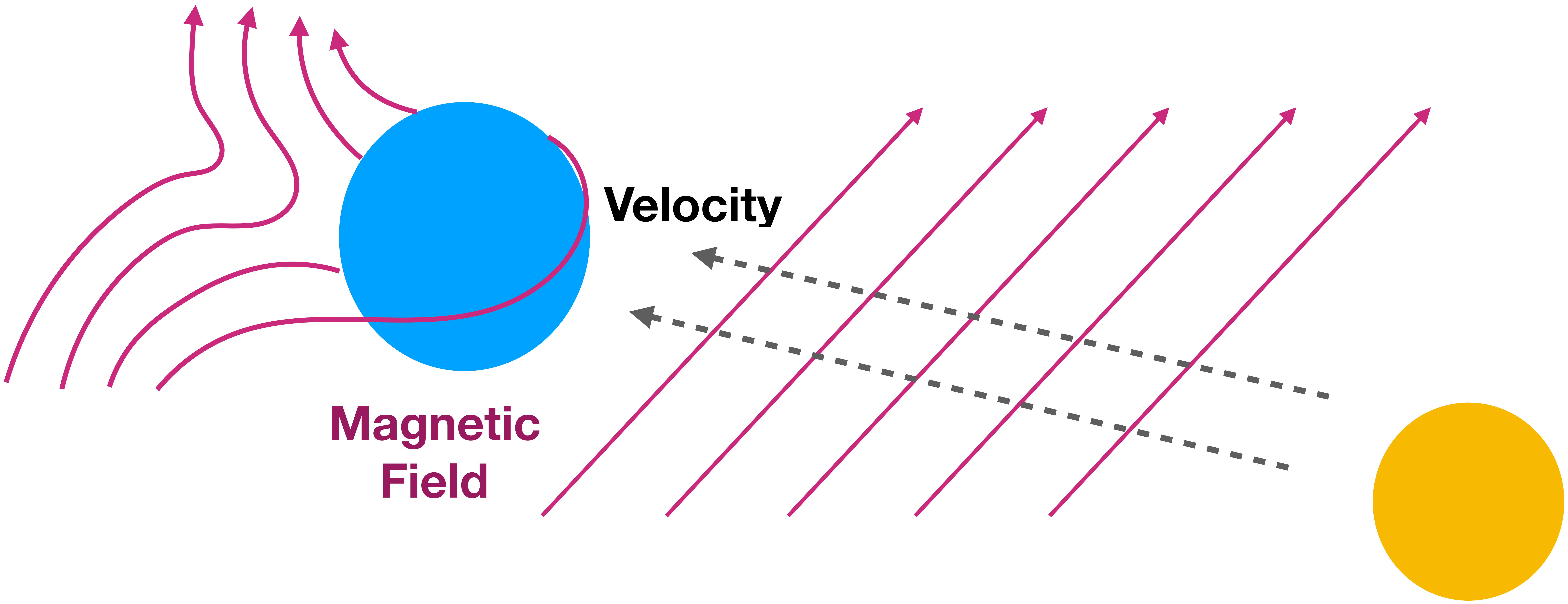

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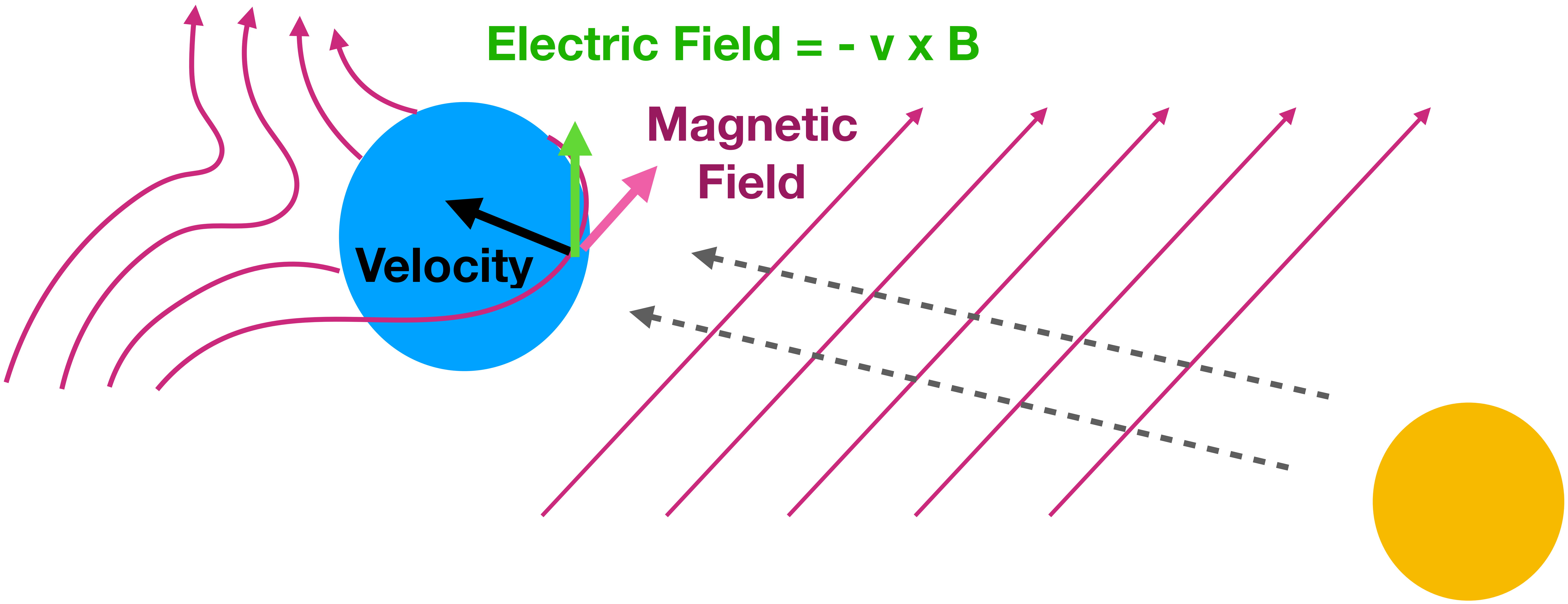

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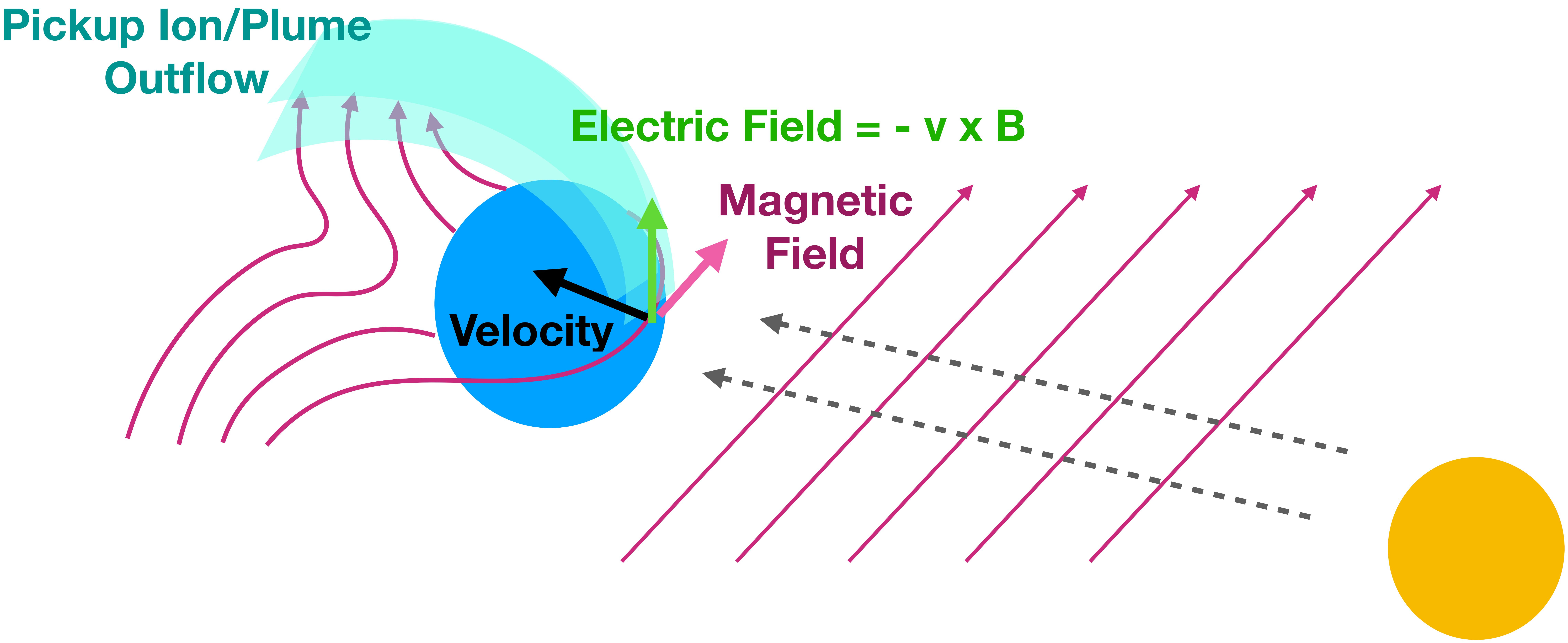

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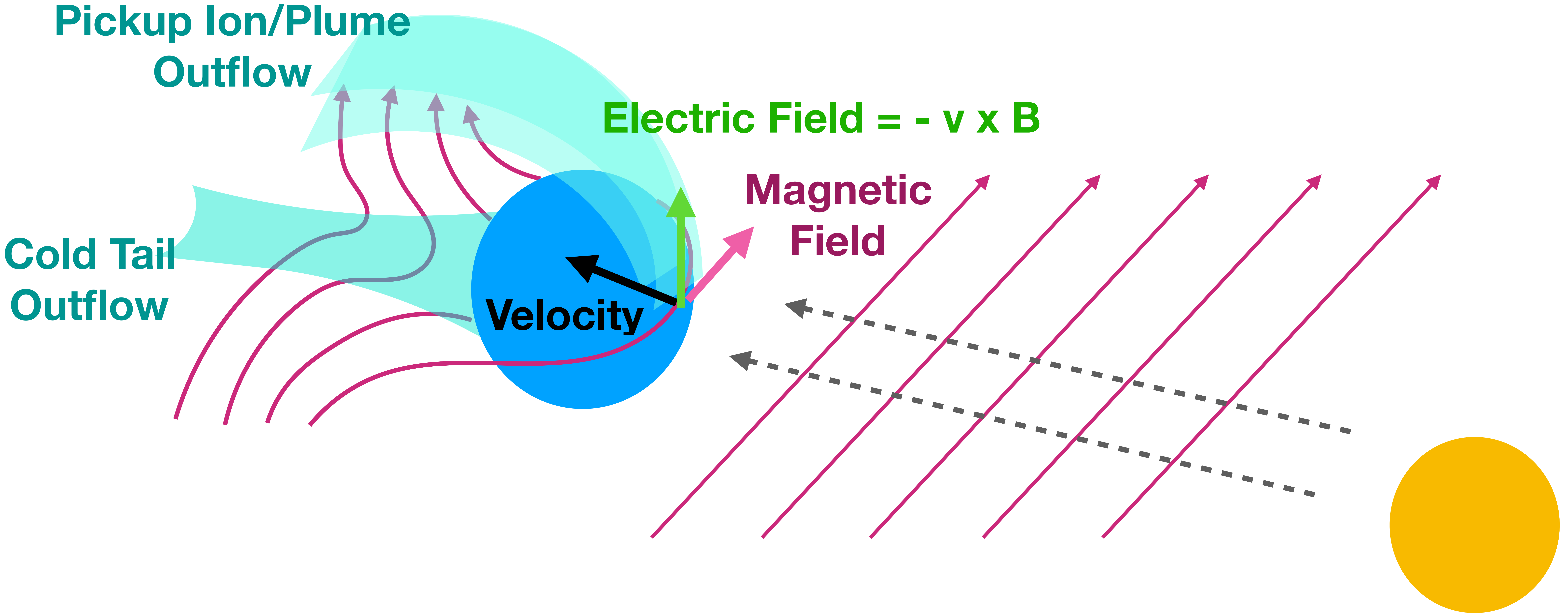

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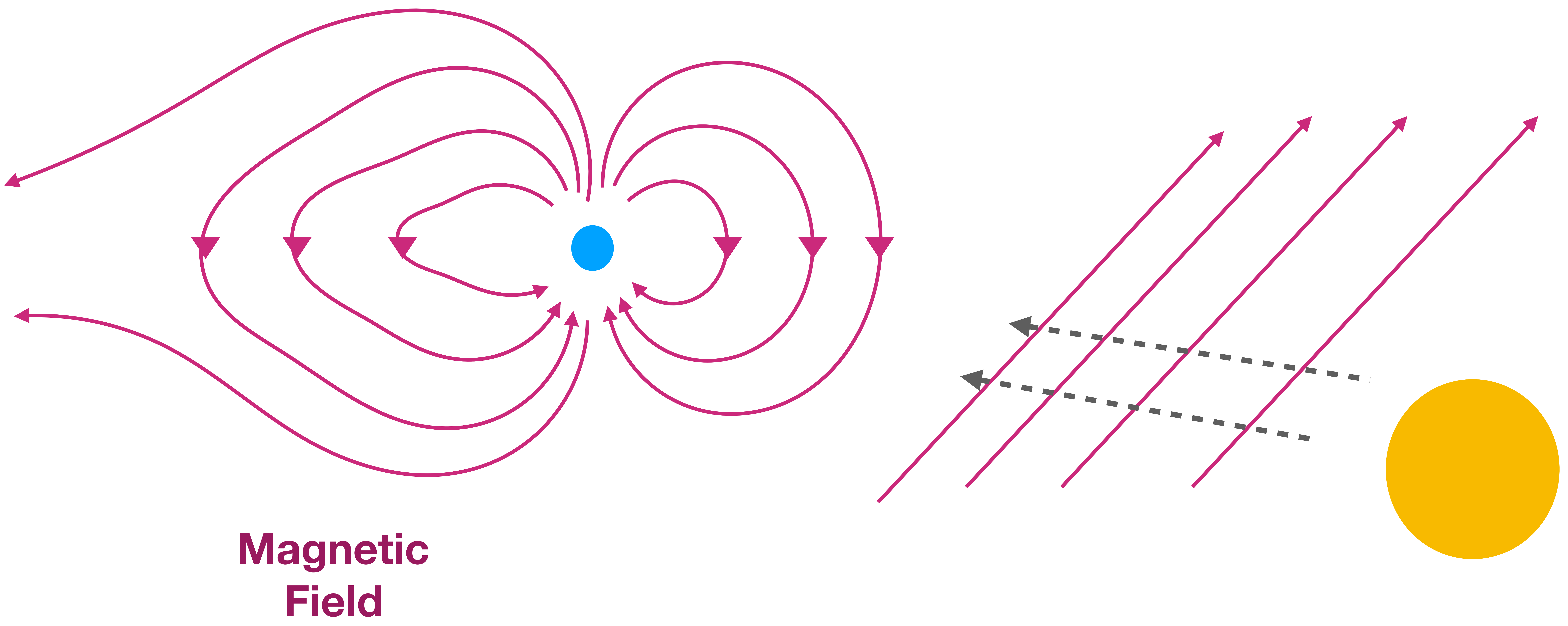

Magnetized Planets

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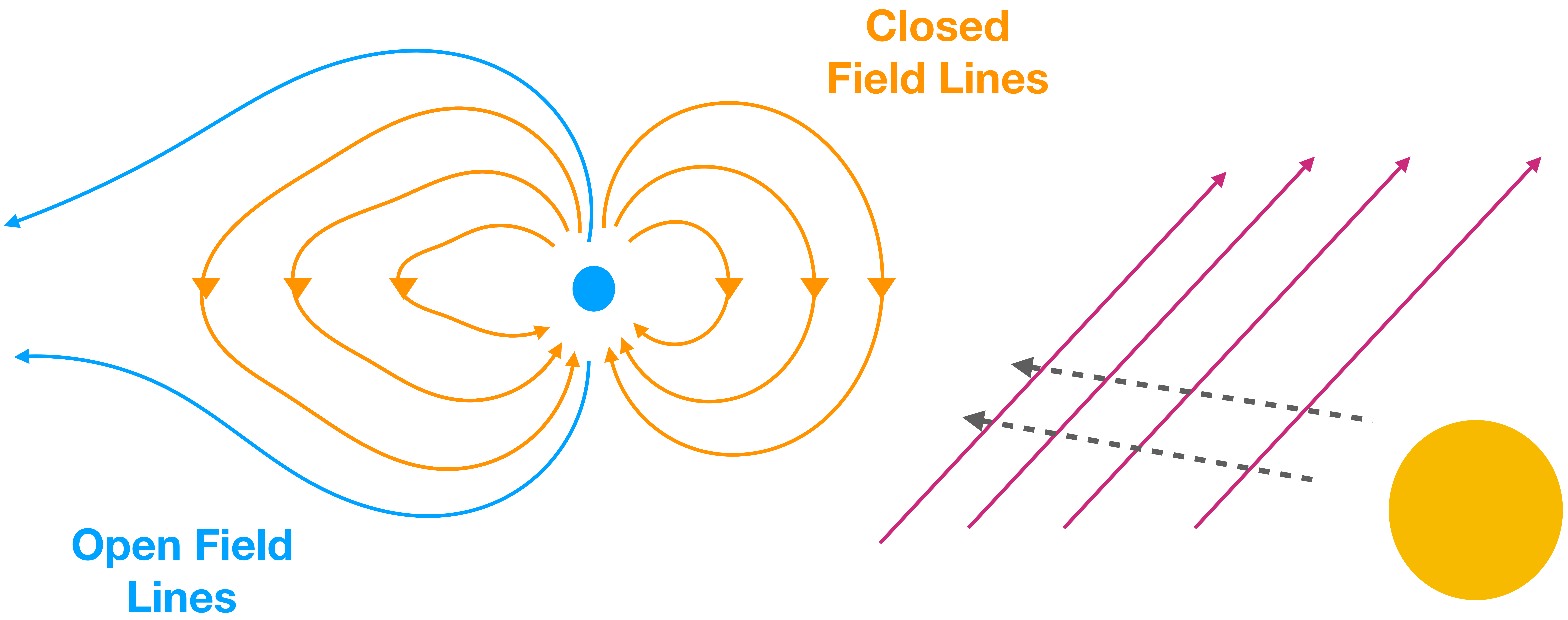

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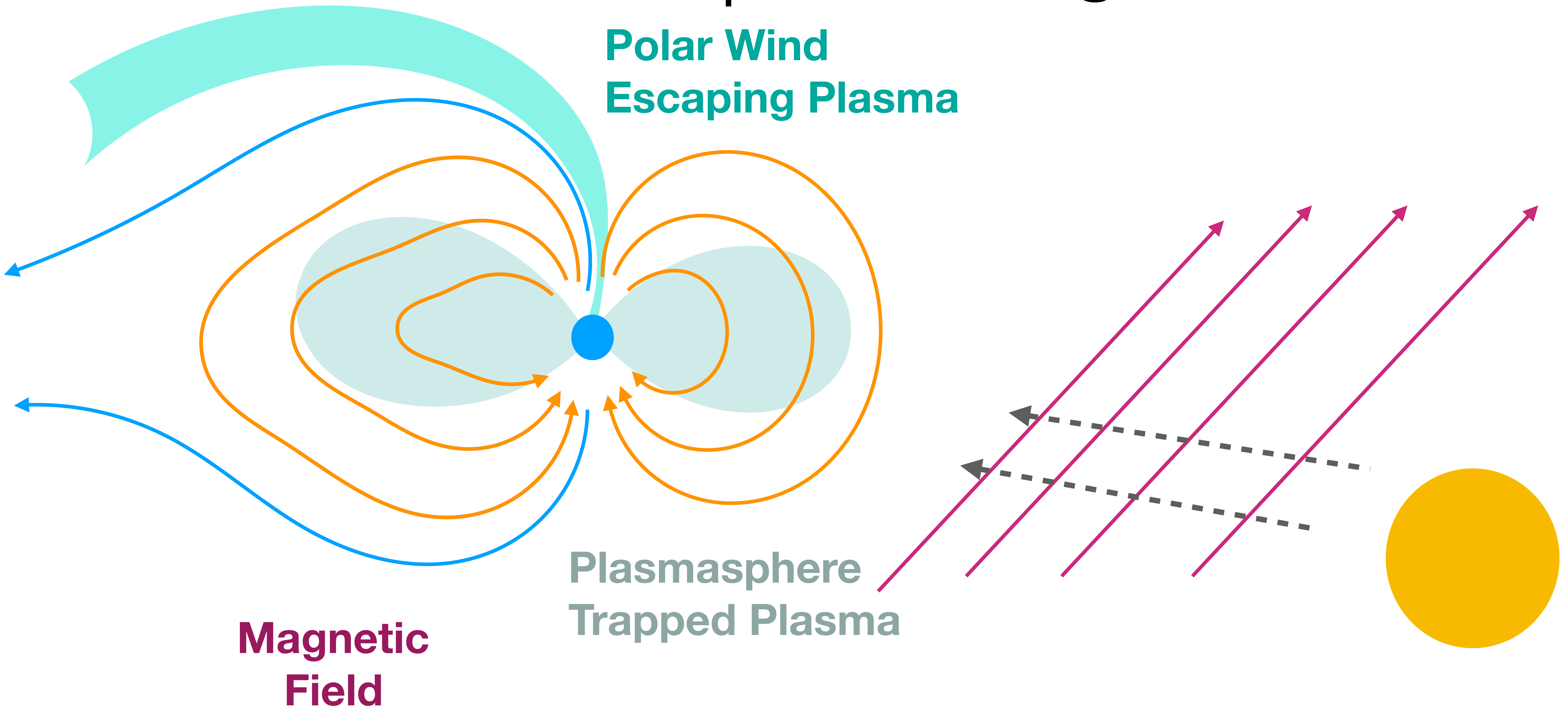

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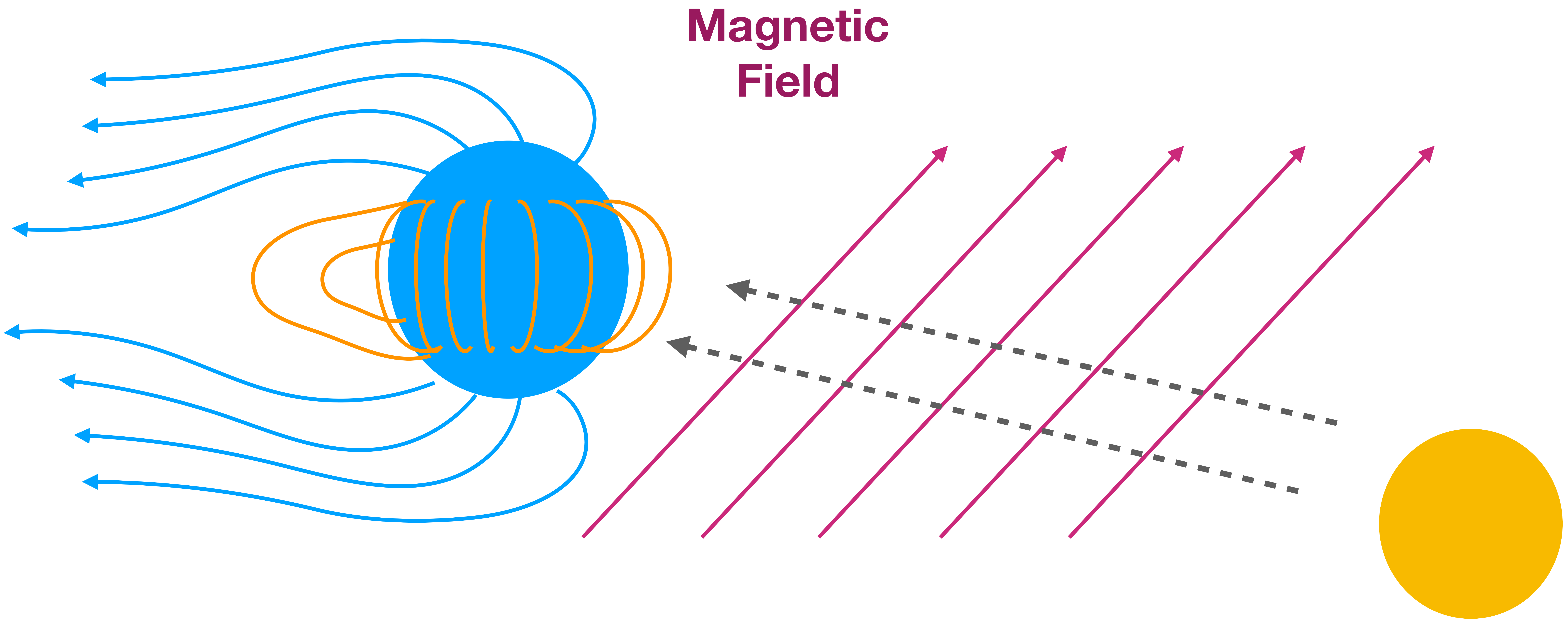


Weakly Magnetized Planets

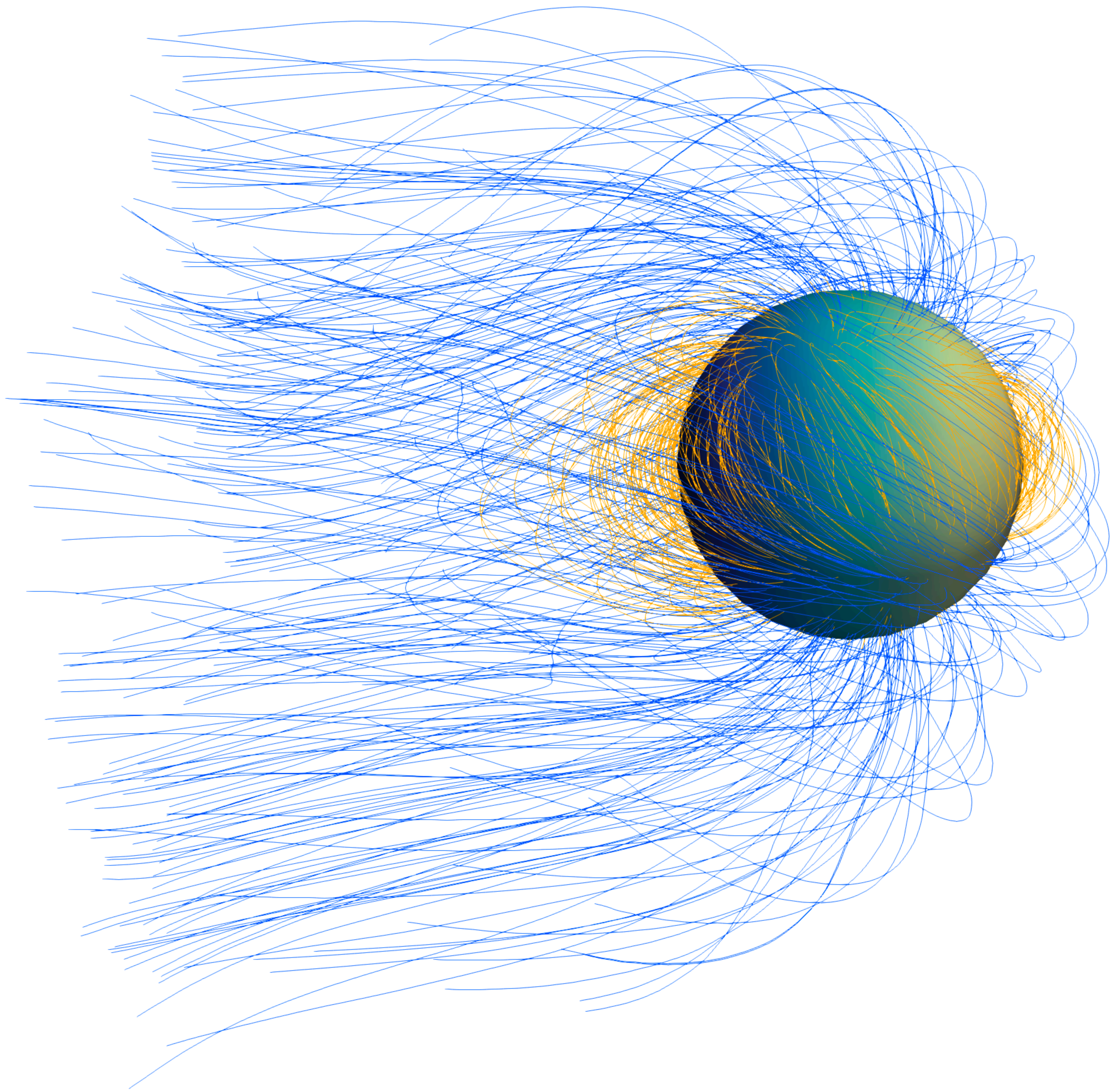
Hybrid Modeling of Weakly Magnetized Planets

- Hybrid model treats ions as macroparticles evolved under the Lorentz equation, electrons as a fluid

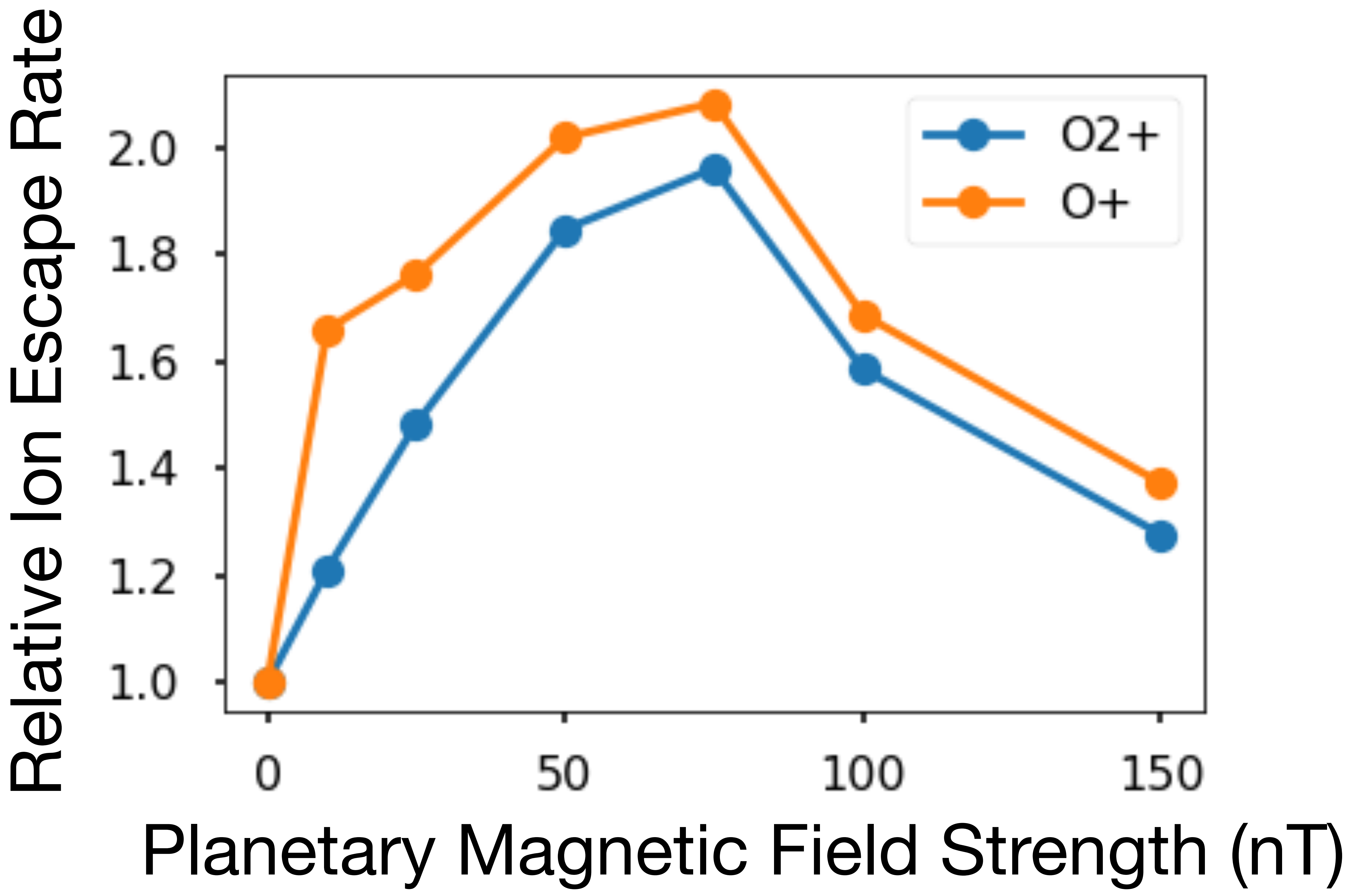
- Validated by observations at Mars, Venus

- Ionospheric production implementation via Chapman profiles *(not self-consistent)*

- Magnetic fields of 0-150 nT



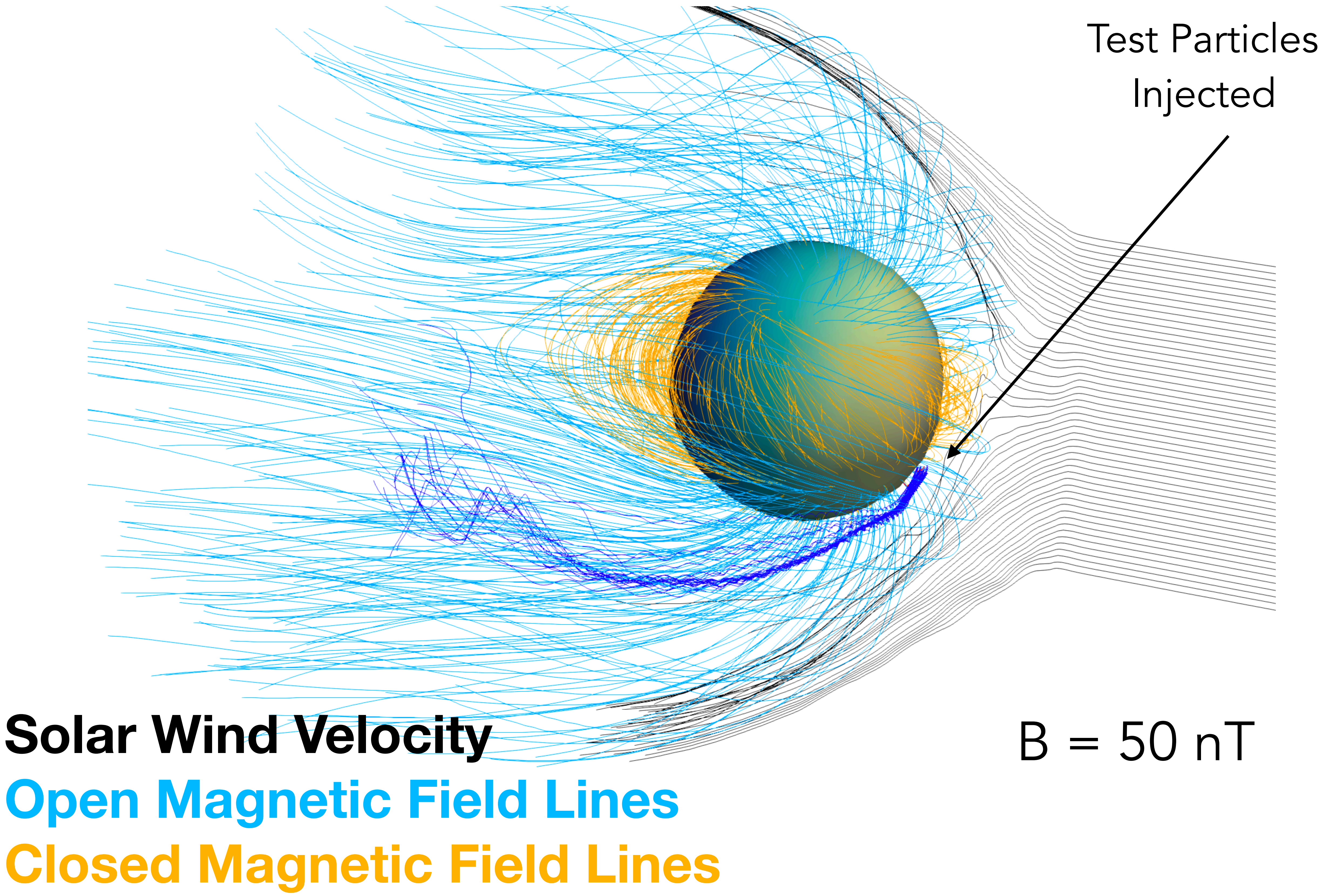
Magnetic Fields Drive Escape Before Inhibiting

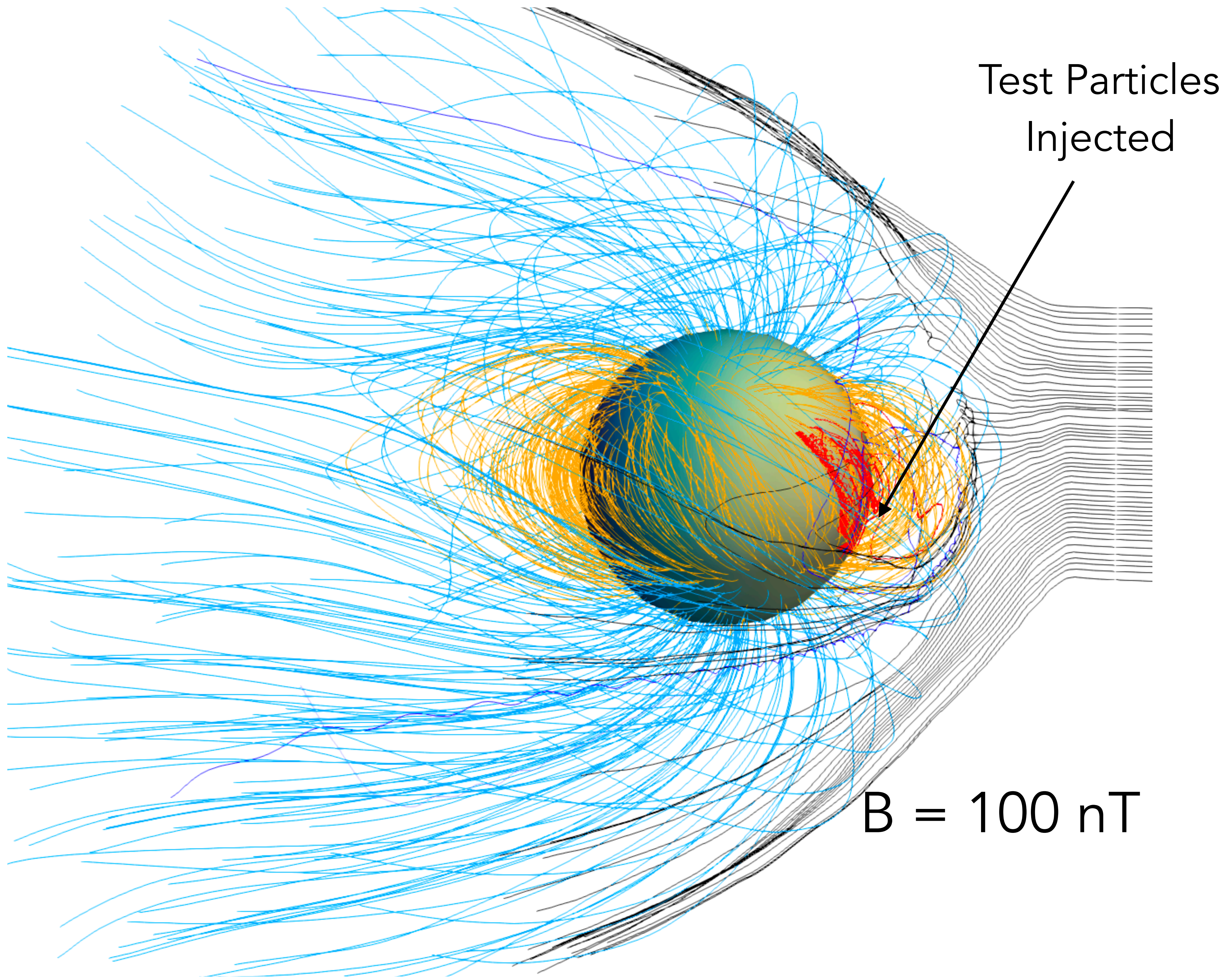


- Peak escape rate for B_P ~ 75 nT with both species

- Factor of 2 difference between strongest and weakest escape

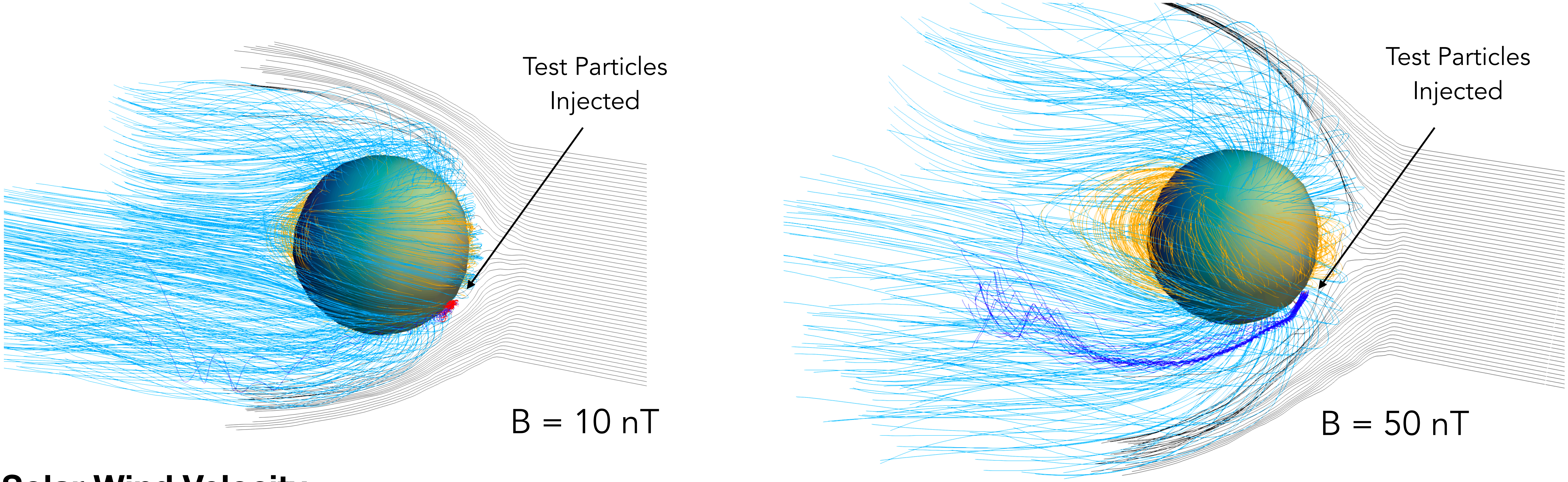
Escape *Decreases* Due to Plasmasphere Trapping





As a larger area of the planet becomes wrapped in stronger, closed magnetic field lines, it becomes more difficult for ions to escape the plasmasphere

Escape *Increases* Due To Shielding of Southern Hemisphere



Solar Wind Velocity
Open Magnetic Field Lines
Closed Magnetic Field Lines

Particles travel along open field lines farther from the planet before being exposed to tailward oriented v x B forces, because of magnetic field standoff

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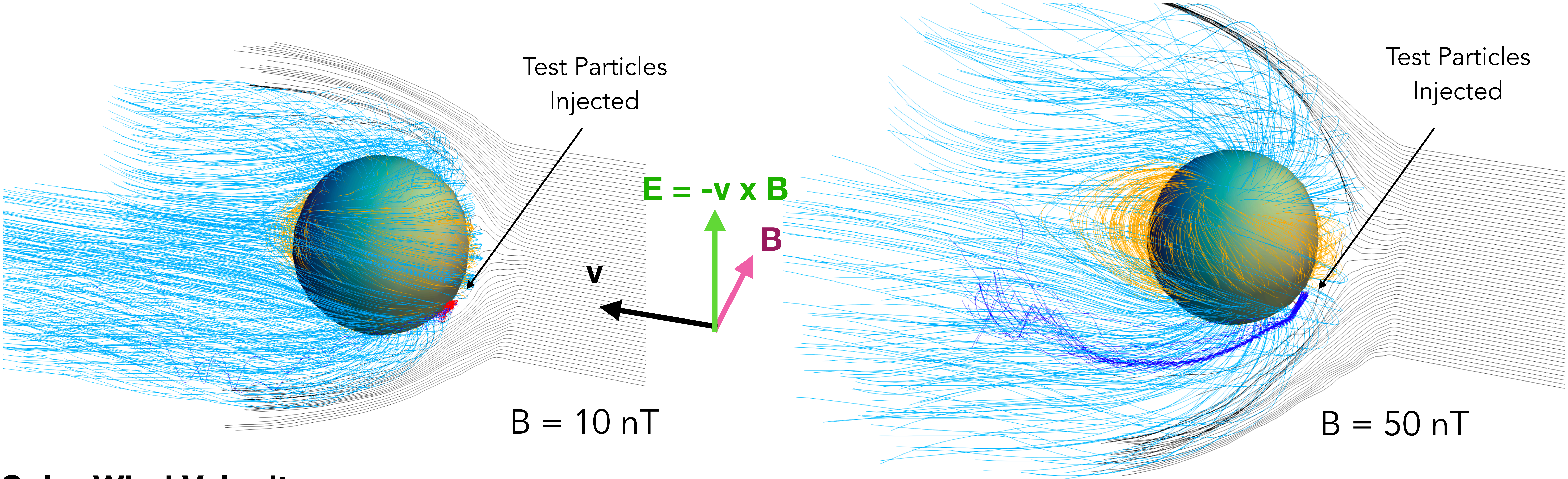

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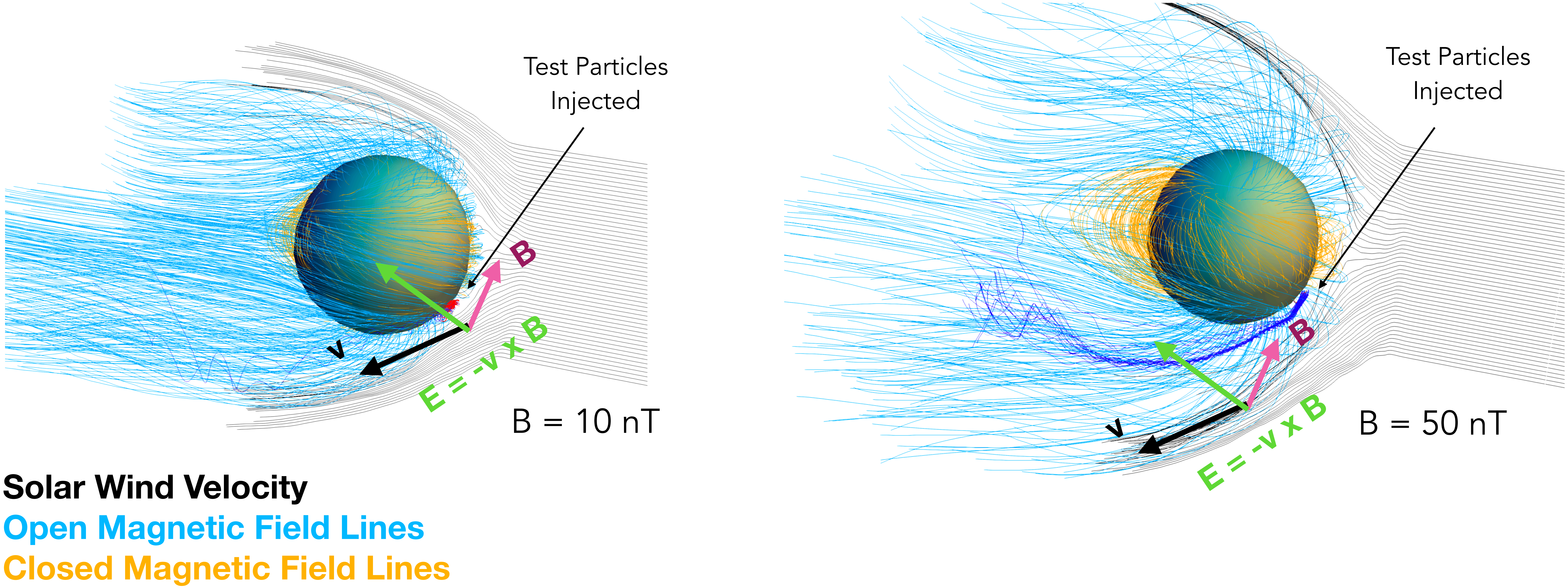

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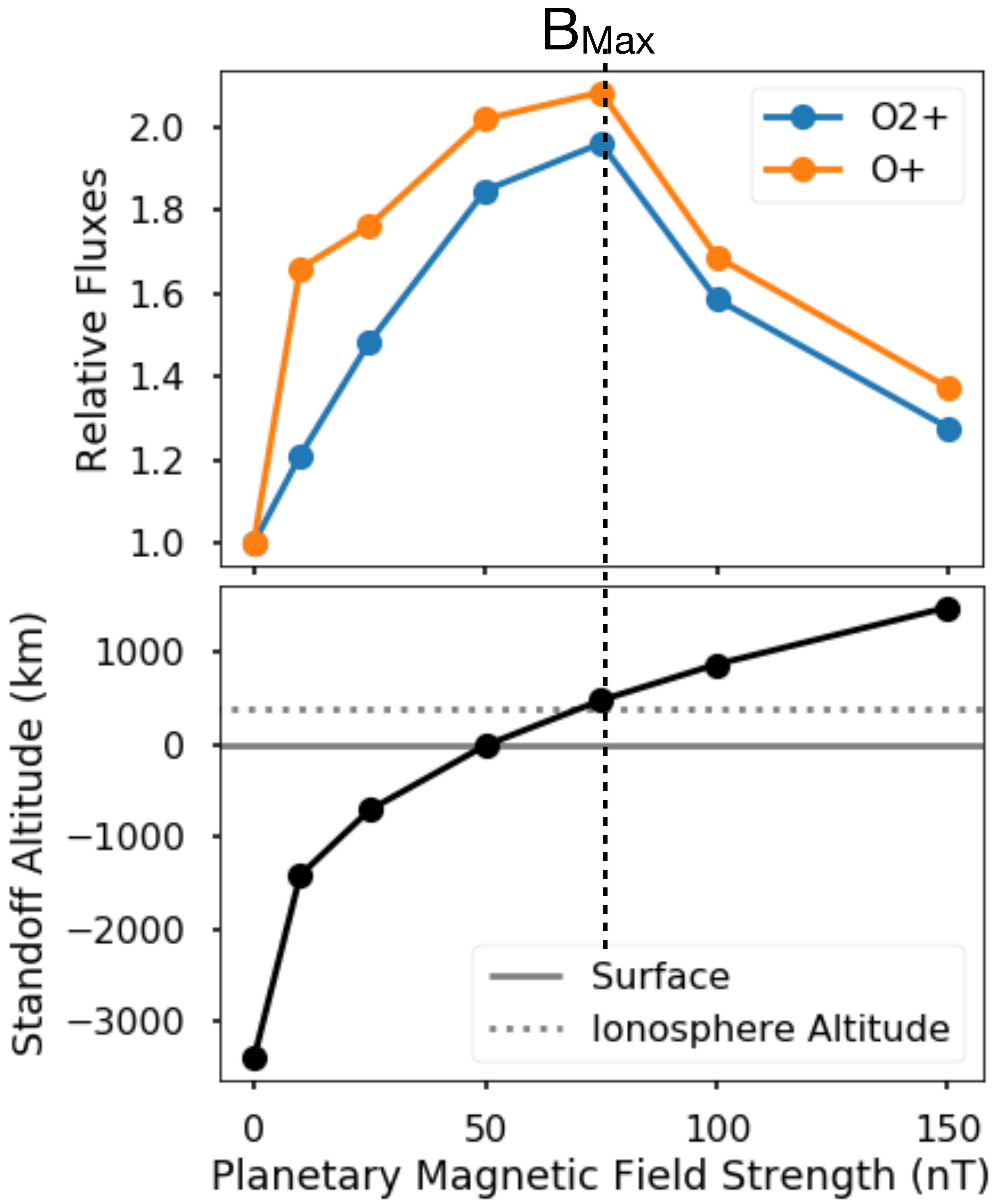
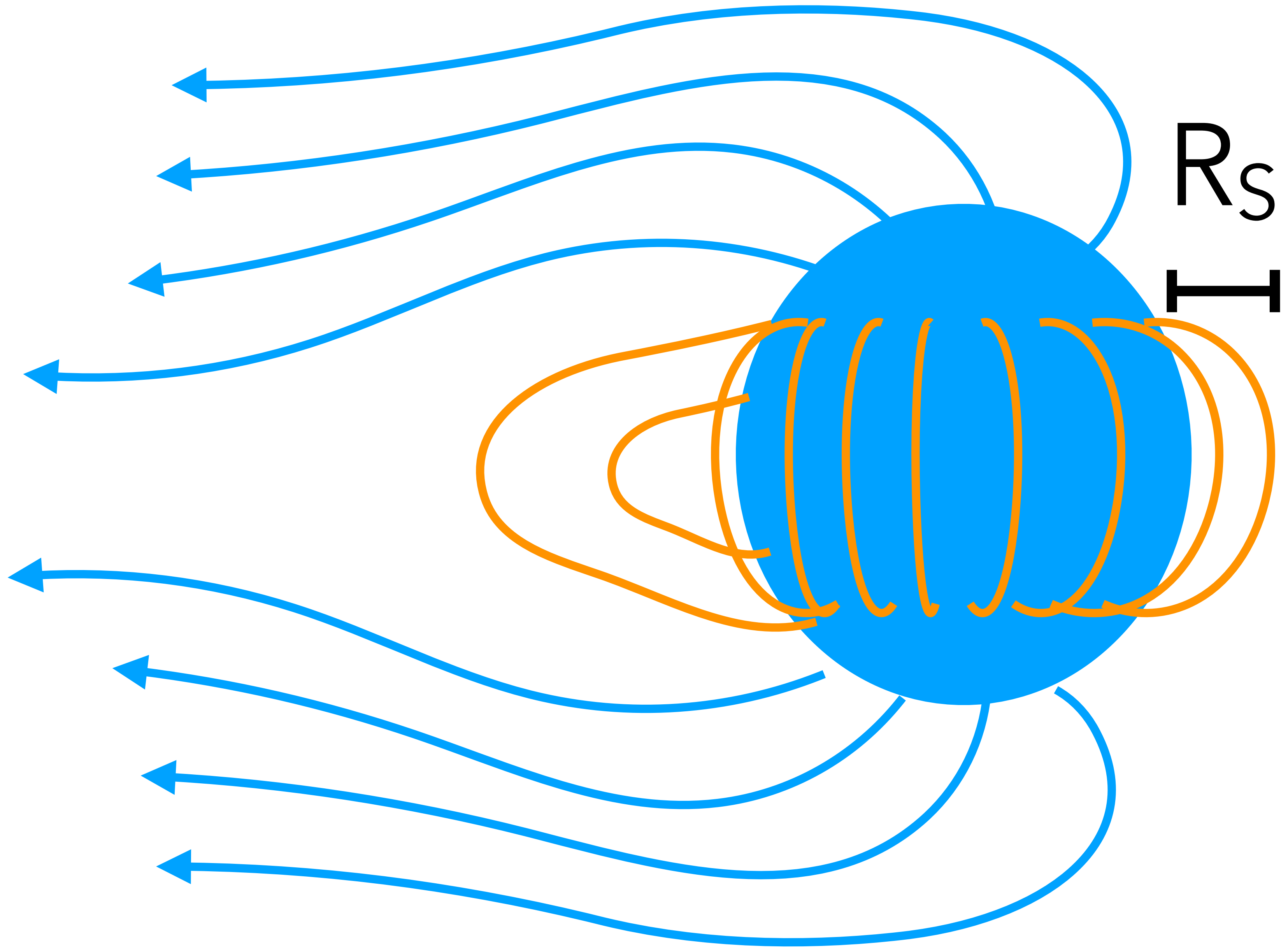
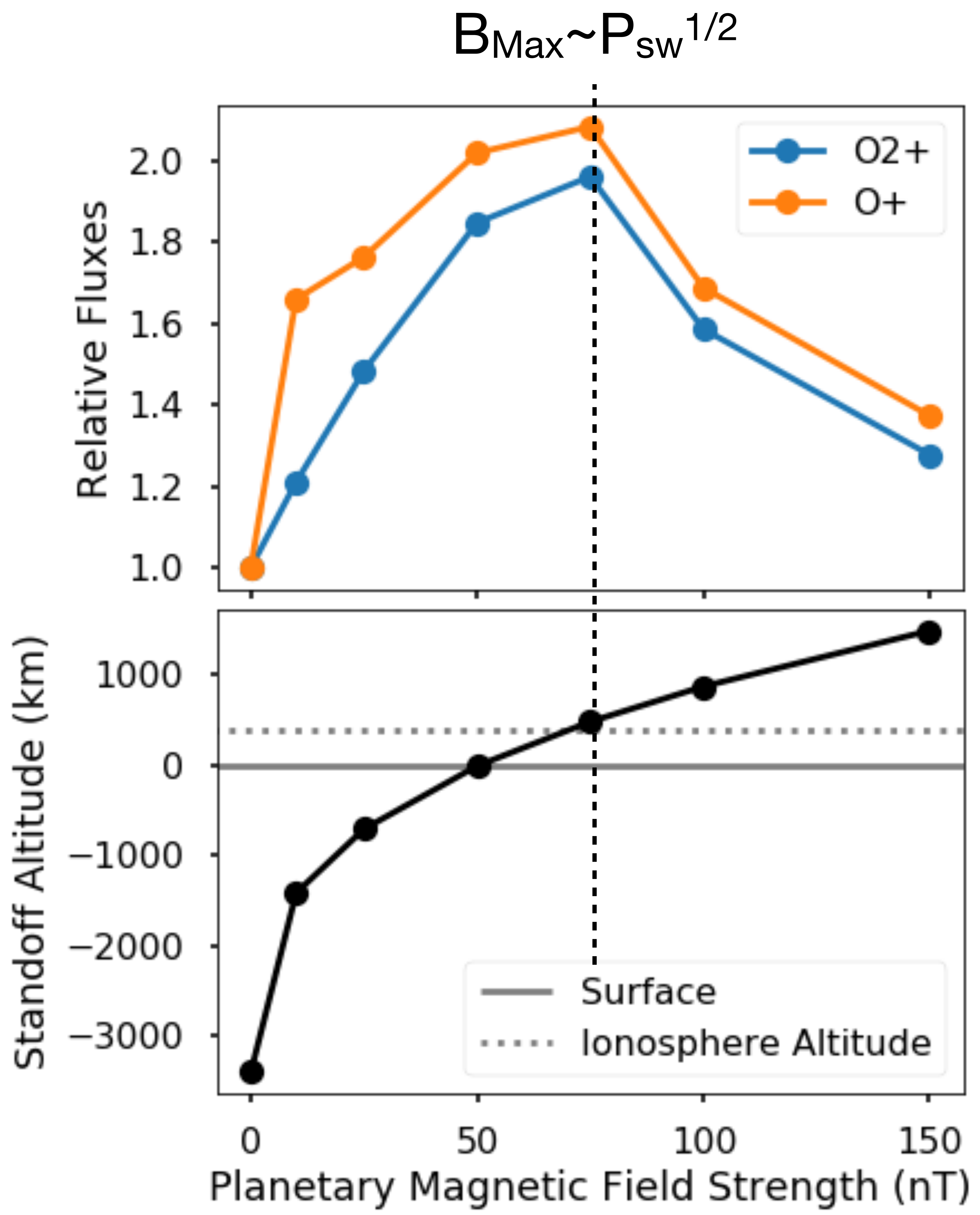
Magnetic Stand-off Distance Controls Peak Escape B-Field



- Both increase and decrease are dependent on the **magnetic stand off distance** (R_S) in comparison to the altitude of the planetary ions



Peak Escape Magnetic Field Depends on Solar Wind Pressure



- For a dipole:

$$R_s = R_p \left(\frac{P_{B_0}}{P_{sw}} \right)^{1/6} \rightarrow B_{Max} \sim P_{SW}^{1/2}$$

- **This will not scale indefinitely**, very strong fields change escape scale lengths and introduce new physics (e.g. polar wind)

M-Dwarf Habitable Zone Likely Has More Radial Magnetic Field

- Everything so far has been under assumptions of present day solar conditions

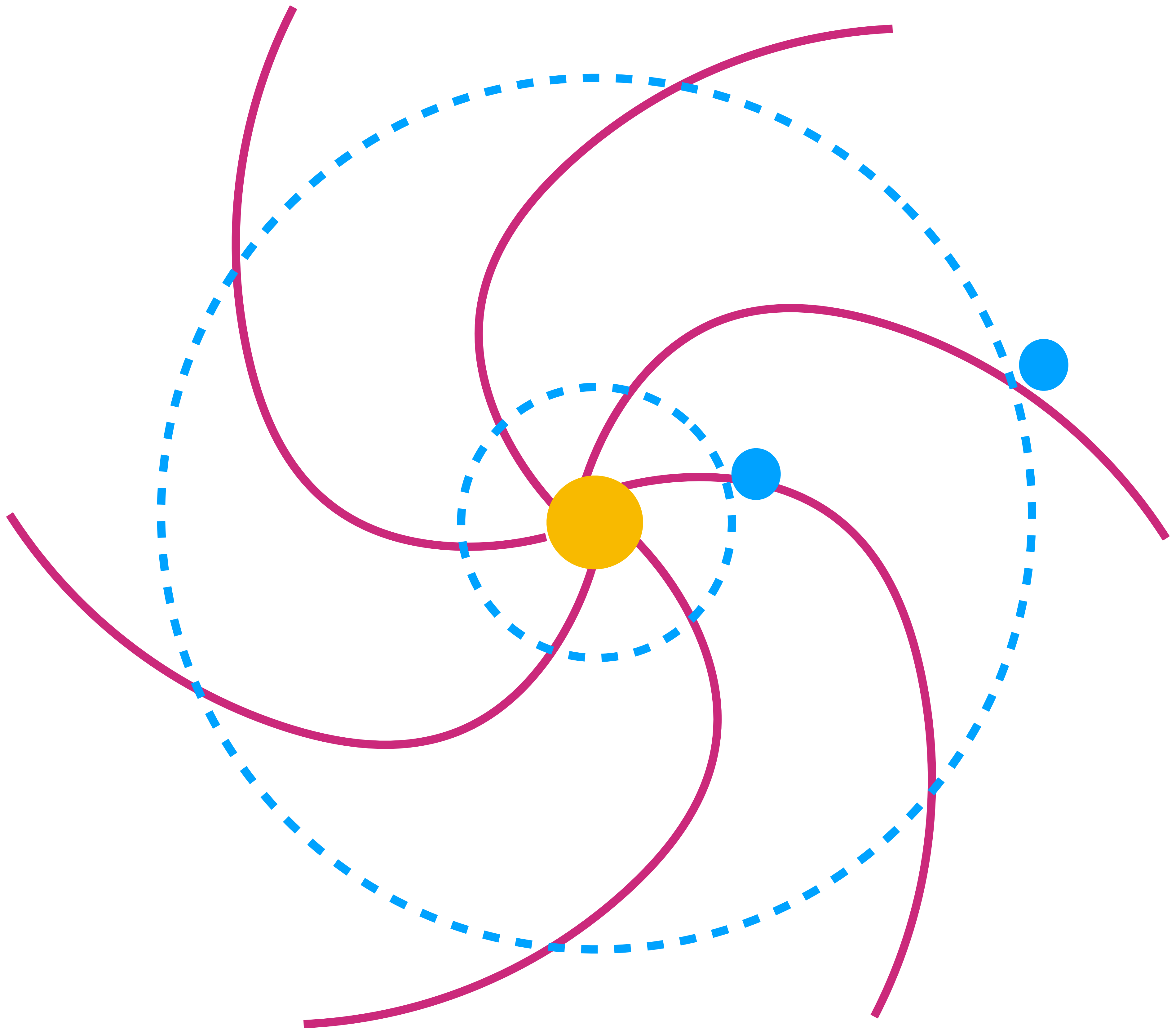
- Stellar environment around M-Dwarfs challenging because habitable zone is closer

    - More intense solar wind

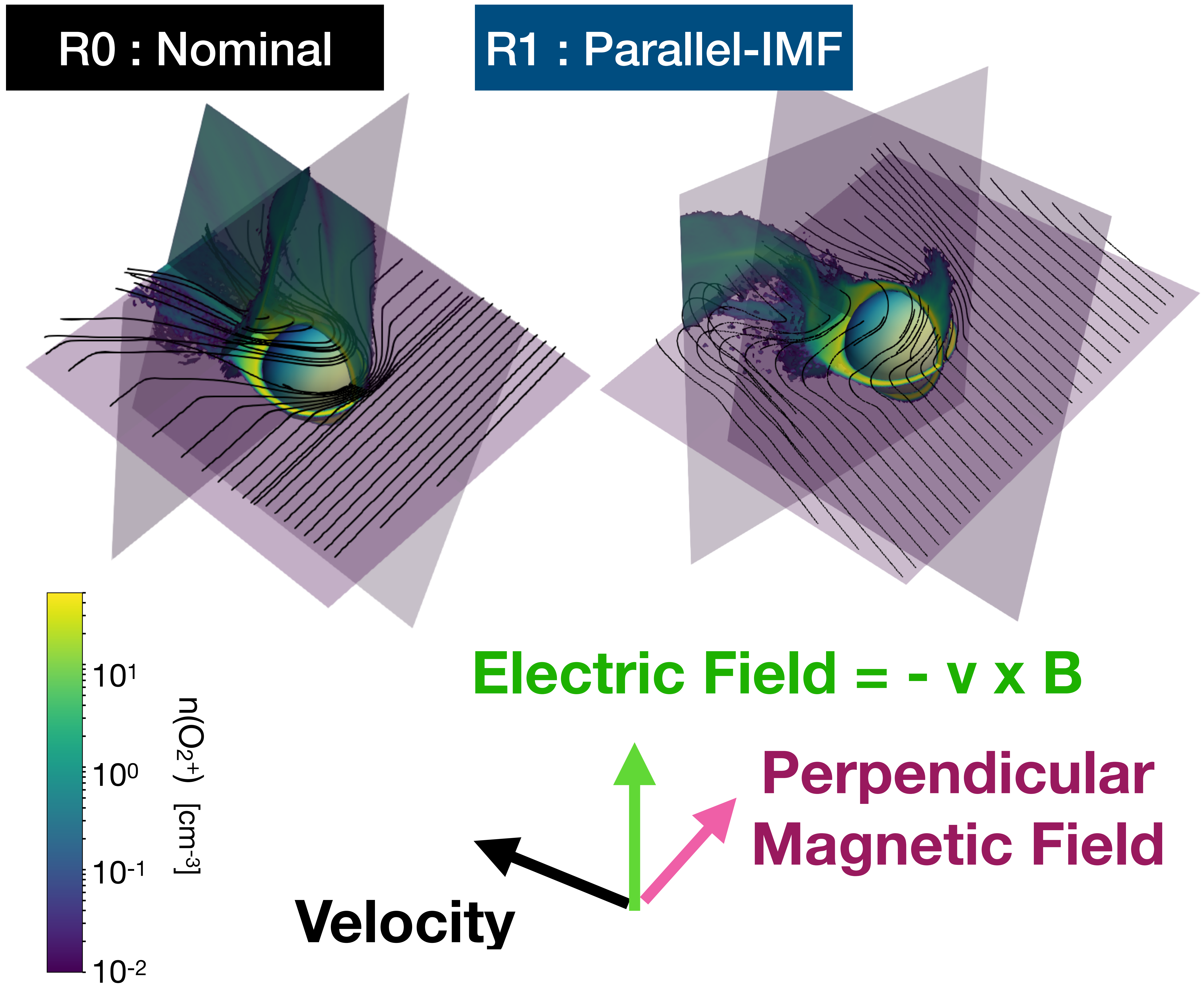
    - Higher EUV input

    - More variable, space weather

    - Radially oriented stellar magnetic field



IMF Orientation Drives Asymmetric Ion Outflow



- Radial magnetic field case introduces asymmetry
- Plume ions are accelerated from side due to unstable shock
- May introduce/enhance compositional atmospheric asymmetry, especially for tidally locked planets

Conclusions

- **Ion escape is important for habitability!** Can change both atmospheric composition and overall mass

- Planetary magnetic fields can enhance ion escape before inhibiting it, reflecting a balance between increased ion pickup and plasmasphere trapping

- The planetary plasma environment around M-Dwarfs can vary in a variety of ways, making systematic studies important

Come talk to me during coffee about…

Magnetic Fields & Ion Escape

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