Heliophysics and Exoplanet Research

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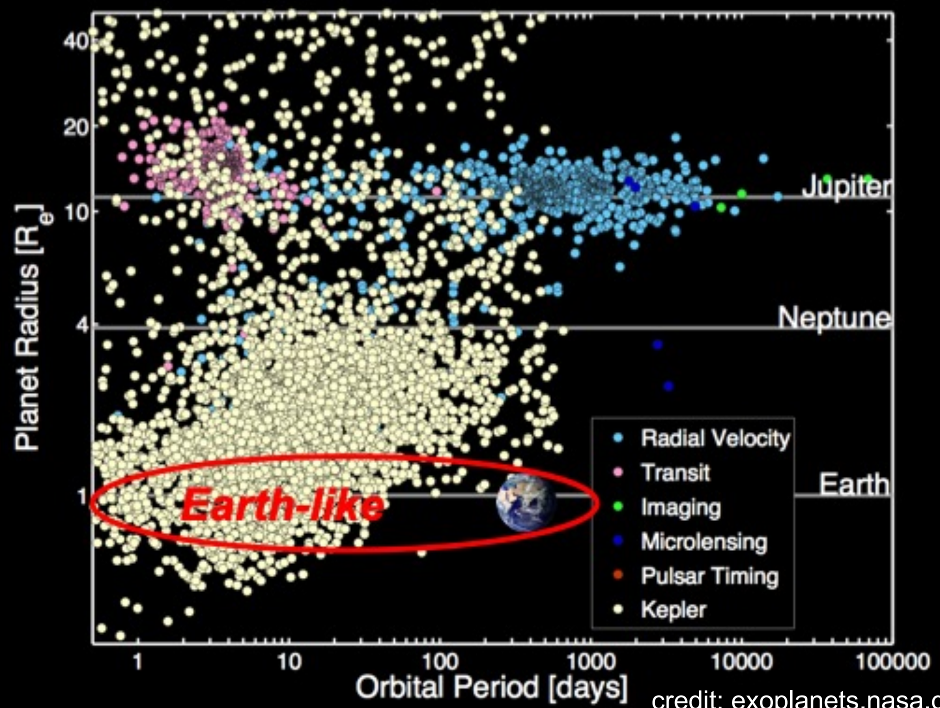
Outline

- The extreme space weather conditions encountered by exoplanets
- The extreme energy inputs to the atmosphere from the star
    - Particles Radiation – Stellar Energetic Particles (SEPs)
    - Stellar Winds
    - Photon Radiation – EUV and XUV stellar flux
- Show examples of how data constrained helio models contribute to exoplanetary problems

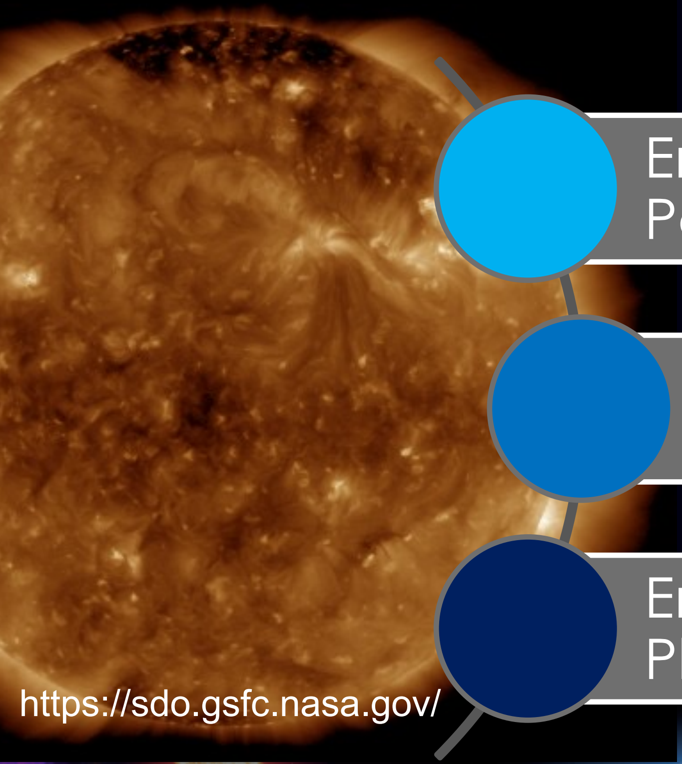
Explosion of Detection/Characterization of Exoplanets



credit: exoplanets.nasa.gov

Implication: Close-in **exoplanets** experience extreme space weather conditions

Enhanced Energy Inputs at Close-in Exoplanets



https://sdo.gsfc.nasa.gov/

- Enhanced Stellar Energetic Particles
- Enhanced Stellar Wind
- Enhanced Stellar EUV/XUV Photon Flux

Enhanced Energy Inputs at Close-in Exoplanets

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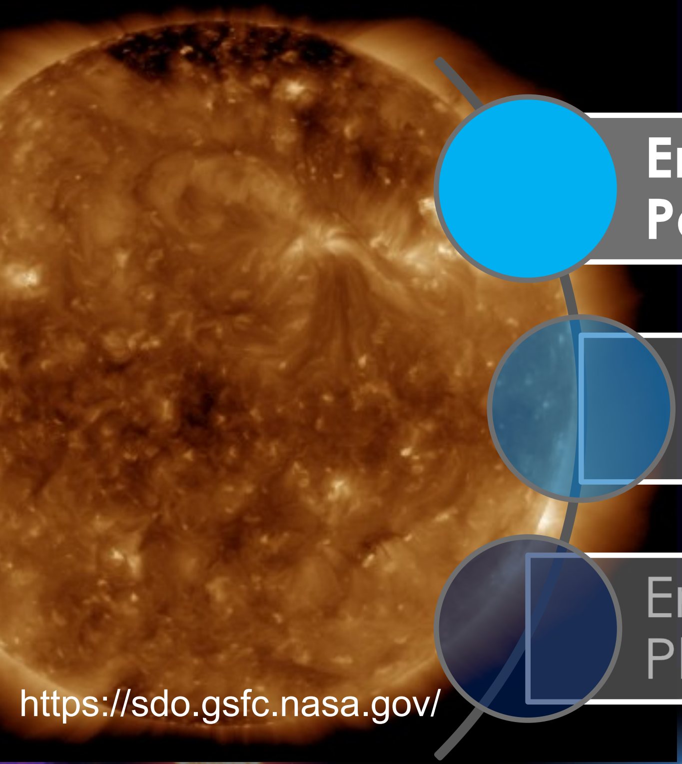

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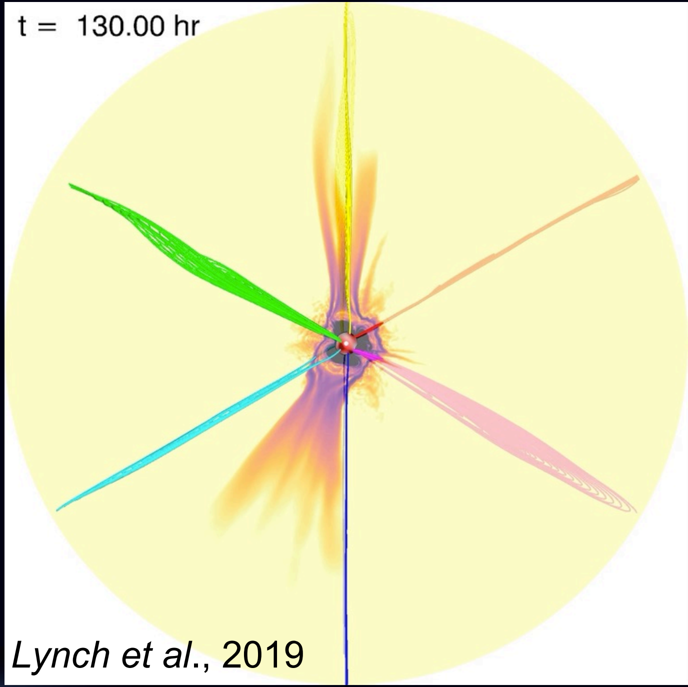
Strong CMEs Driving Strong SEPs and Flares

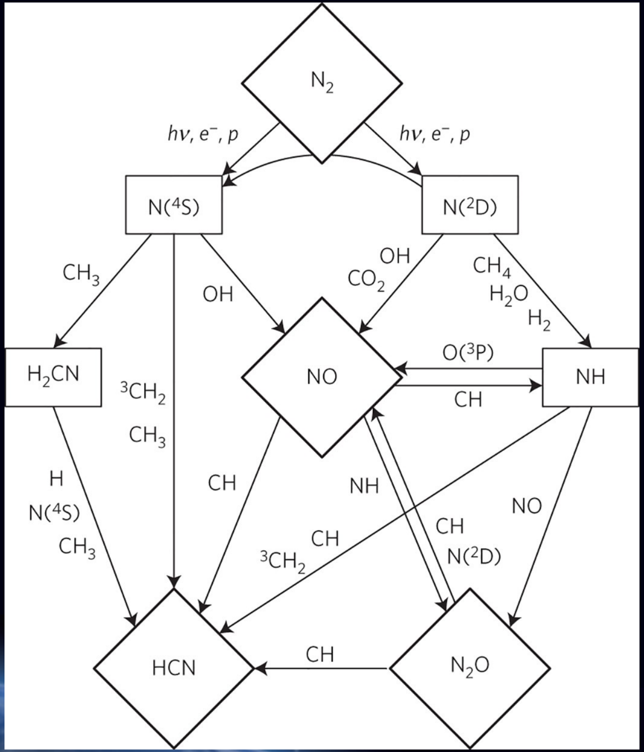
- Example: κ^1 cet is a young solar type star that is an analog for our young sun.
- This star is very magnetically active with observed superflares
- MHD simulations with ARMS code by *Lynch et al.*, 2019 are used to simulate magnetic eruptions from the star.
- Estimated flare energy and accelerated particles are on par with strongest space weather events.



Lynch et al., 2019

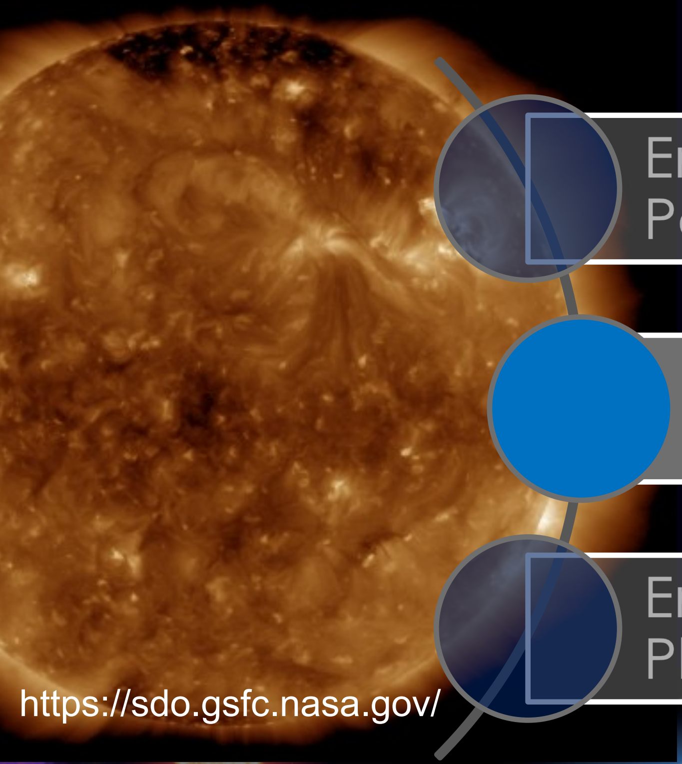
Large SEP Fluxes Impact Planetary Atmospheres

- Large SEP fluxes accelerated by super CMEs and flares impact the atmosphere.
- One example: Dissociates N2 molecules and drives chemical chain.
- Affects greenhouse gas production.
- Affects HCN production which is a key ingredient for biochemistry.



Airapetian et al., 2016

Enhanced Energy Inputs at Close-in Exoplanets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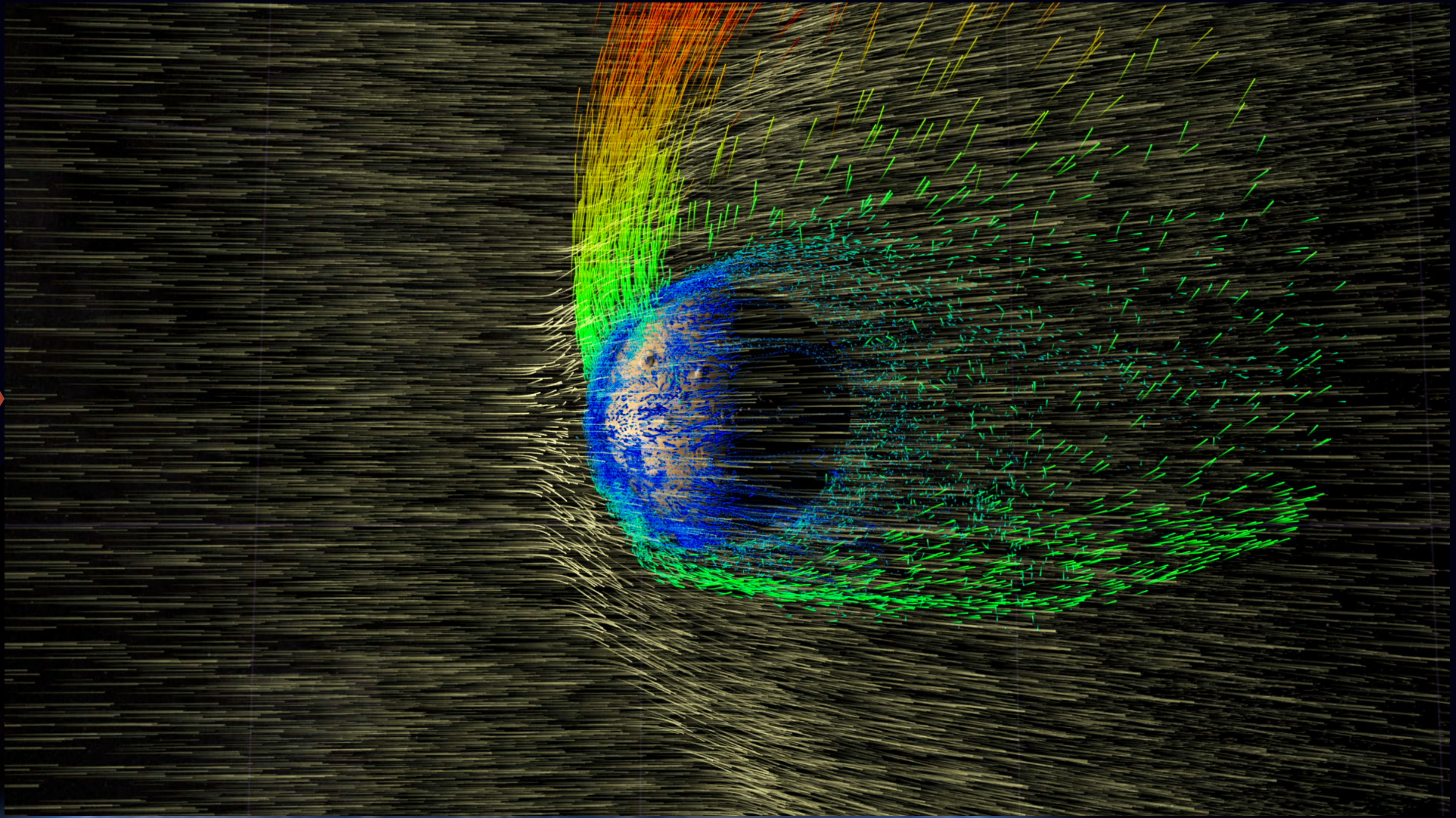
- Enhanced Stellar Energetic Particles
- **Enhanced Stellar Wind**
- Enhanced Stellar EUV/XUV Photon Flux

Planetary Magnetic Field

Shield or Sail?

- Does a magnetic field help or hinder a planet's ability to hold onto an atmosphere?
- How does this change over time?
- Is this different for different classes of planets?

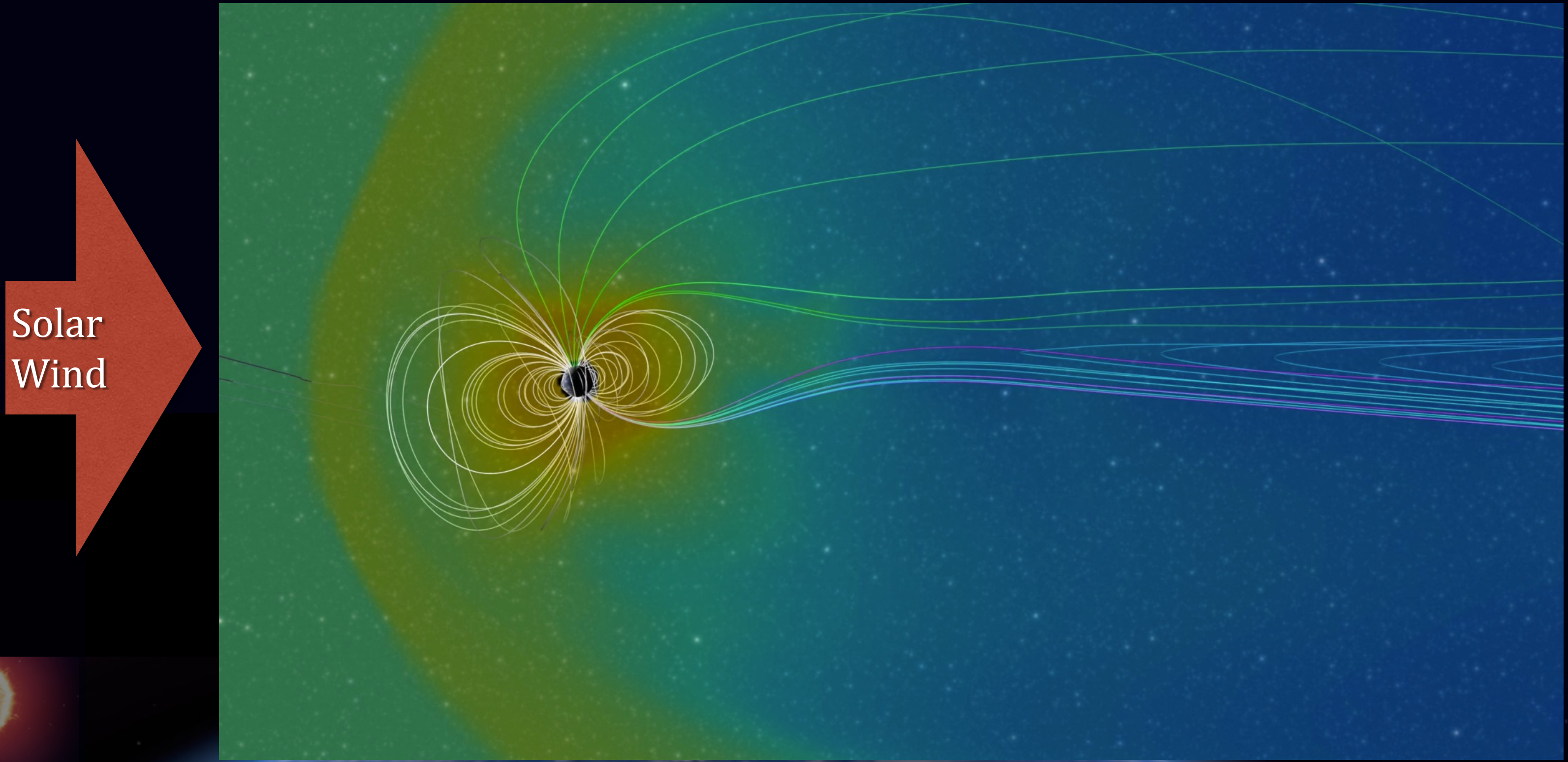
No Internal Planetary B-Field



Solar Wind

Credit: NASA SVS

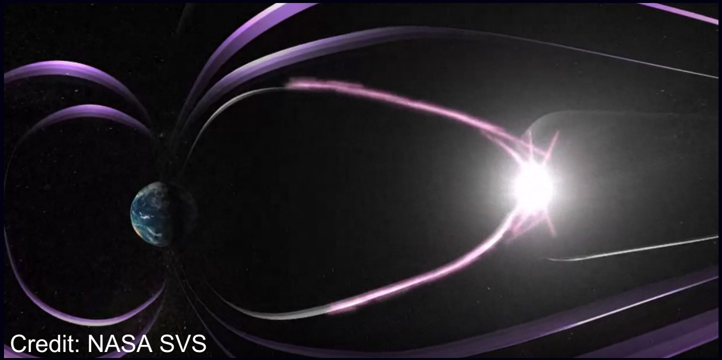
With Internal Planetary B-Field

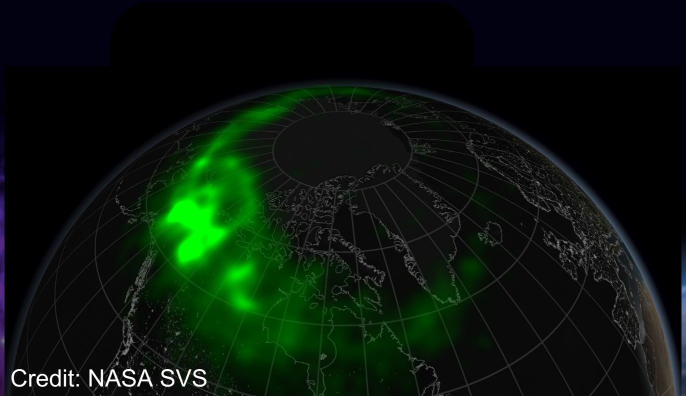


Credit: NASA SVS

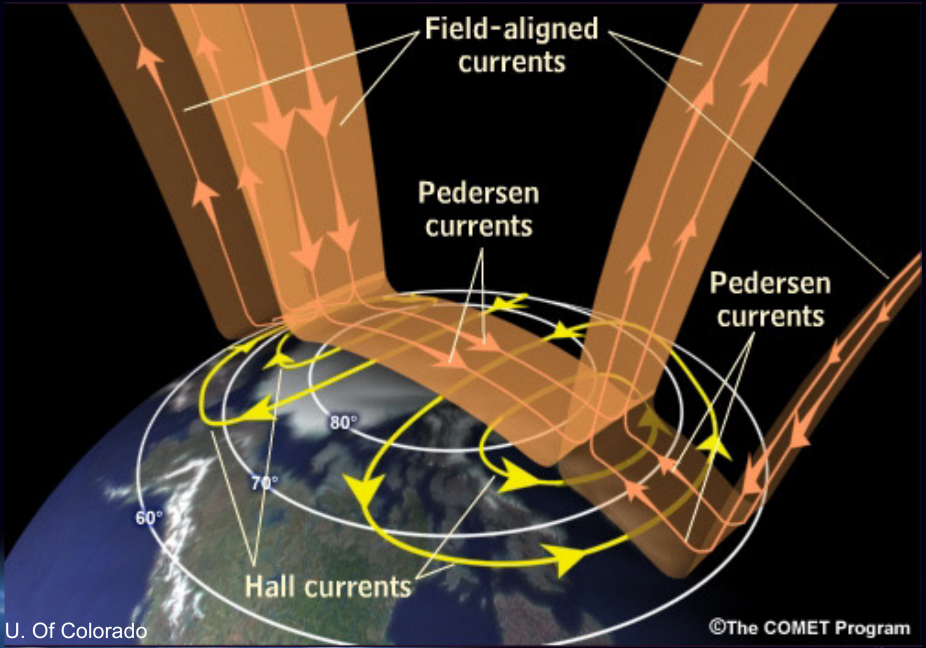
Transmitting Energy Input to the Atmosphere

Particle Precipitation and Aurora


Credit: NASA SVS


Credit: NASA SVS

Electromagnetic Energy Input



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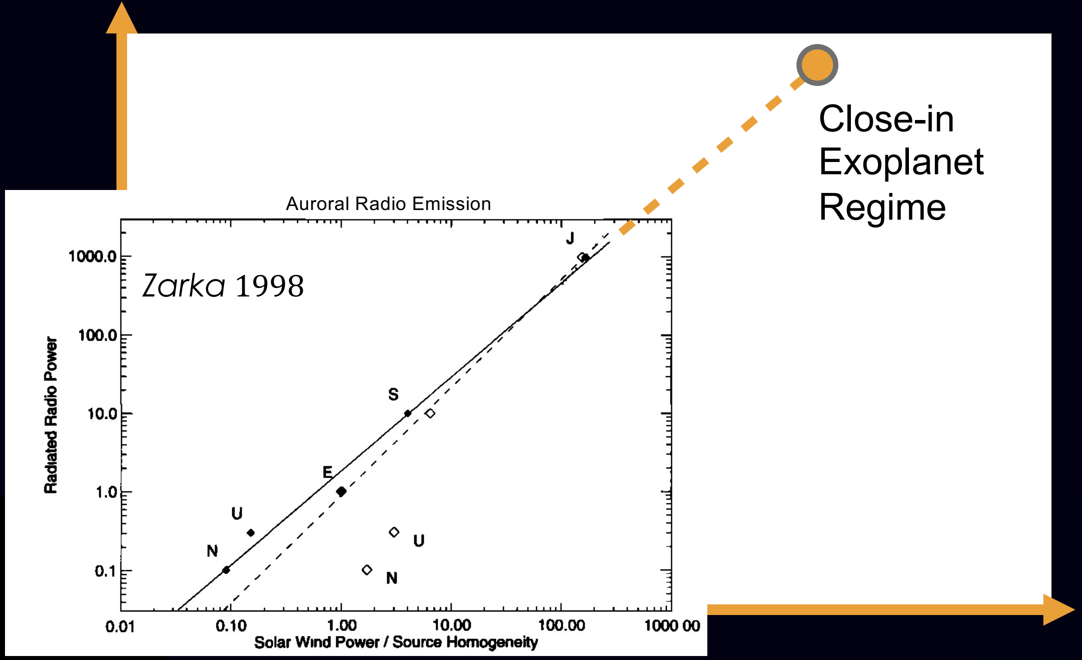
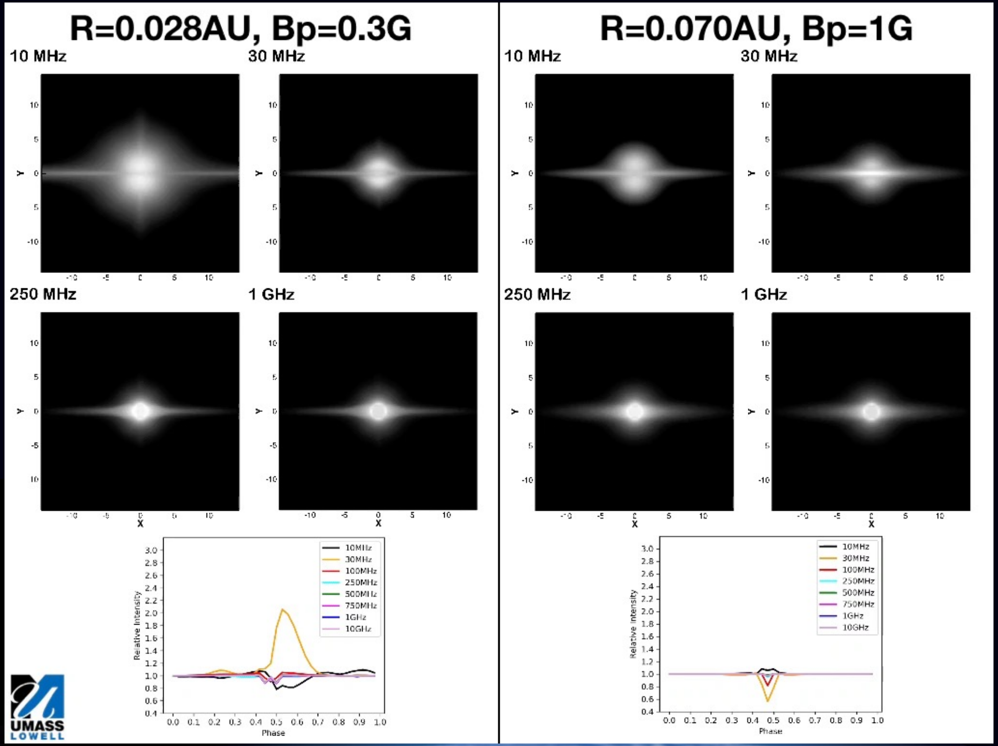
Consequence of Enhanced Particle Precipitation: Exoplanet B Field Detection?



- "Radiometric Bodes Law"
- Heliophysics models of Aurora can help us understand this scaling.

Another Approach to Detecting Magnetic Fields of Exoplanets

Modulation of Coronal Radio Emission

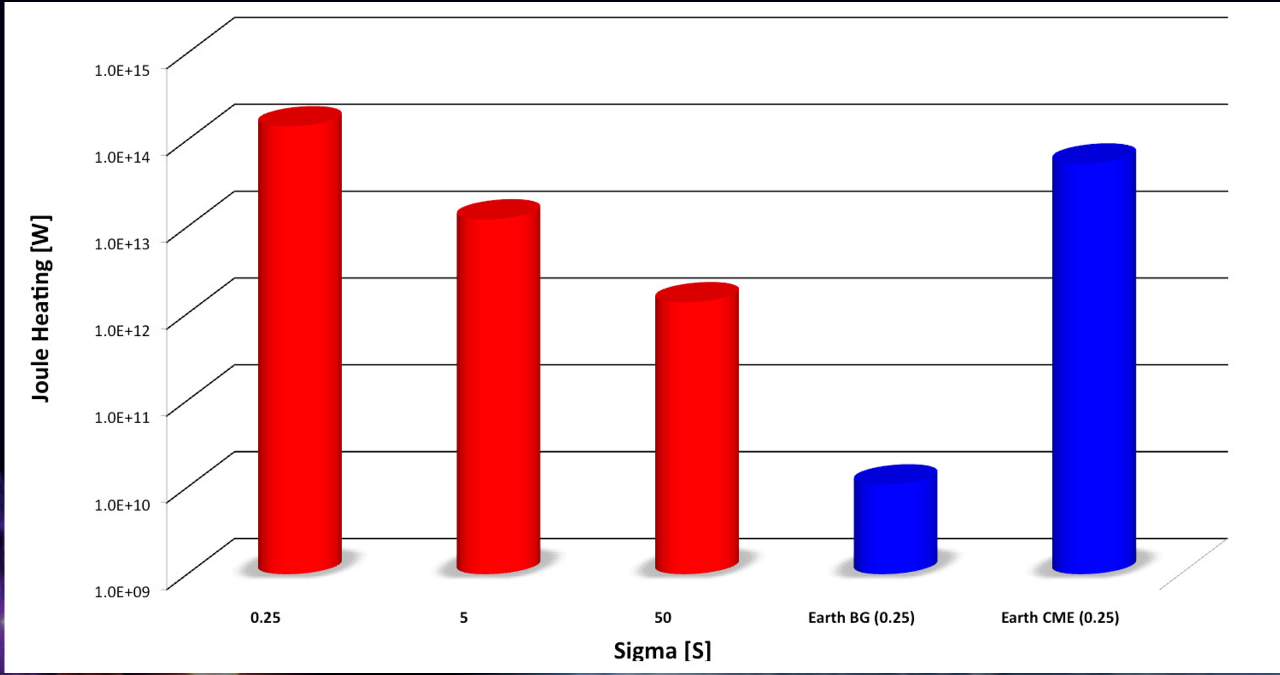


Cohen et al., 2018

- Another Approach: Modulation of Coronal Radio Emission
- Relies on Heliophysics models of stellar corona and planetary magnetic field interaction

Consequence of Electromagnetic Interaction

Stronger Stellar Wind = More Joule Heating

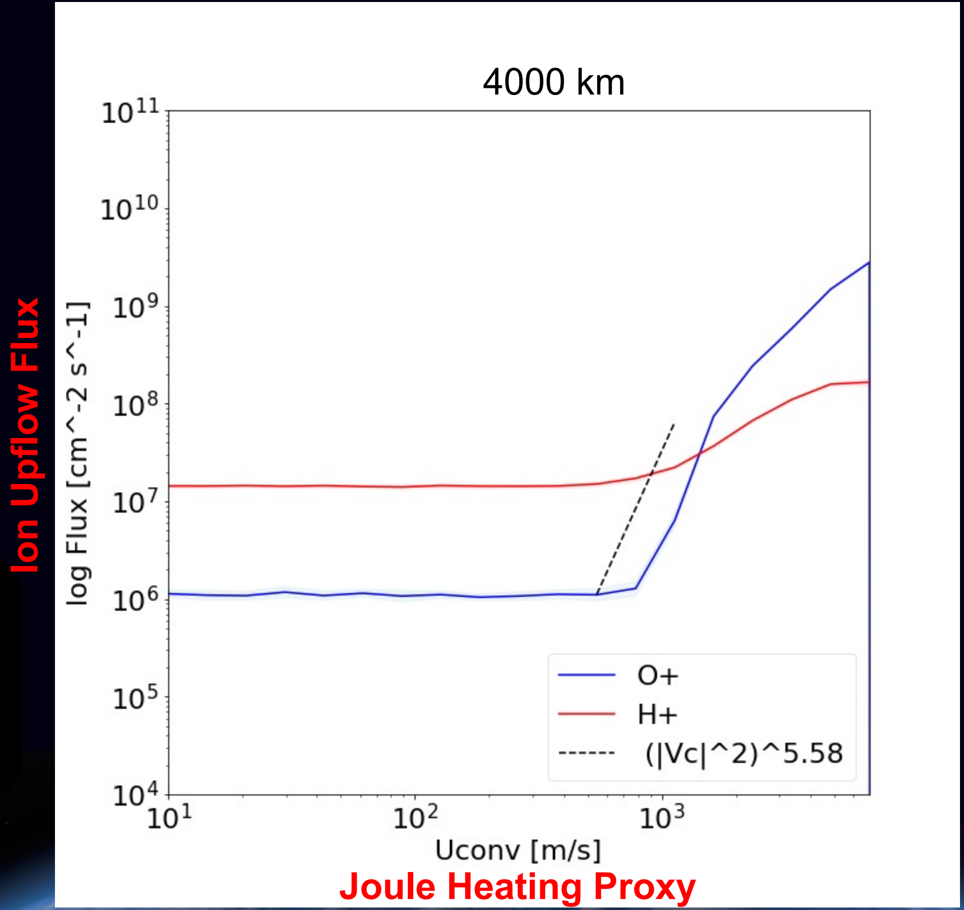


Joule Heating can be quite large for a close-in exoplanet

Result depends strongly on conductance

Cohen, Drake, Glocer et al. , 2016

More Joule Heating Can Given More Ion Escape



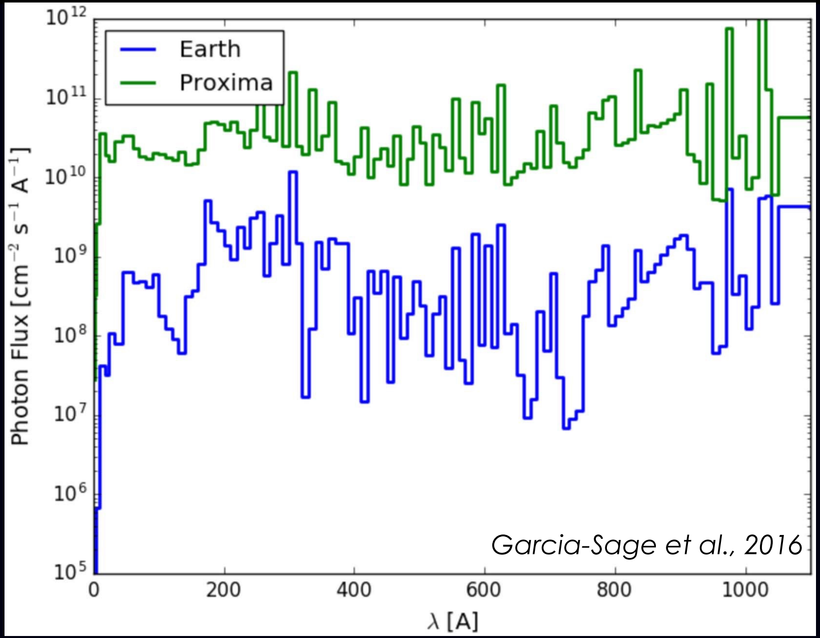
Enhanced Energy Inputs at Close-in Exoplanets

- Enhanced Stellar Energetic Particles
- Enhanced Stellar Wind
- **Enhanced Stellar EUV/XUV Photon Flux**

https://sdo.gsfc.nasa.gov/

EUV/XUV Radiation Environment Is Very Intense

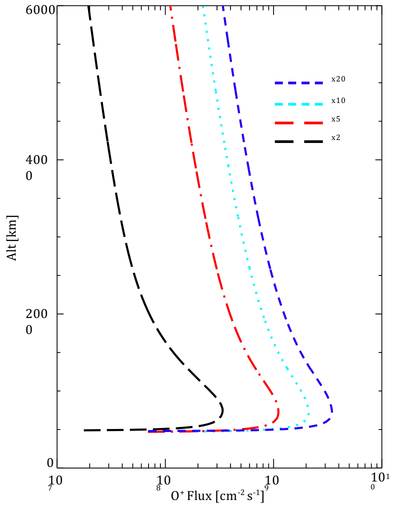
Enhanced EUV at Proxima b



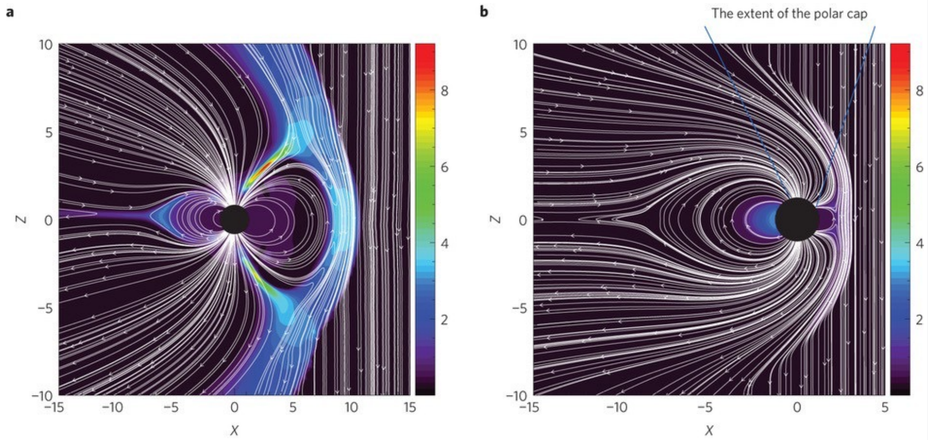
- Many close-in exoplanets are around actively flaring stars and experience extreme UV input

Ionospheric Outflow With Enhanced EUV/XUV Input

Scaling Outflow with XUV



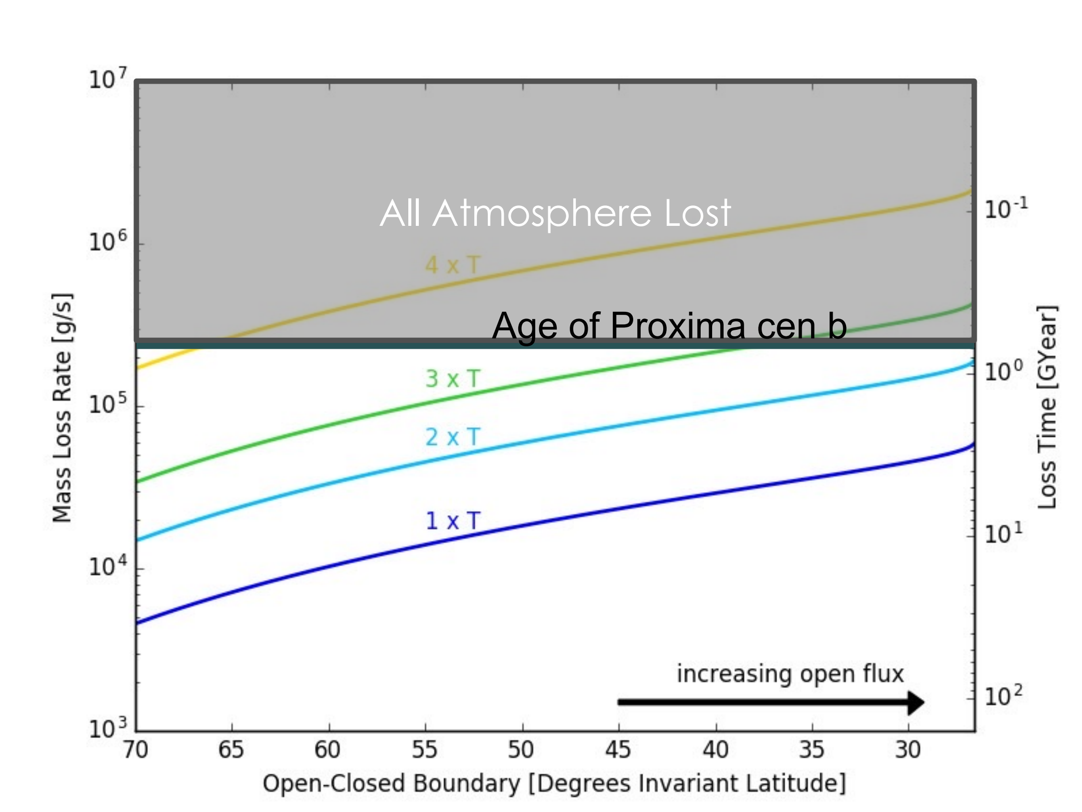
Polar Cap Size



Airapetian VS, Glocer A, Khazanov GV, Loyd RO, France K, Sojka J, Danchi WC, Liemohn MW. How hospitable are space weather affected habitable zones? The role of ion escape. Ap.J Letters. 2017

- Mass loss scales roughly linearly with enhanced EUV/XUV input.
  - $\dot{M}$(in g/s) ~ 1.6×10^4 F_{XEUV} (in erg/cm^2/s)
- Enhanced stellar wind means larger polar cap for escape.
- Integrated mass loss over polar cap ~400 kg/s
- Note: No wave heating, Joule heating, or precipitation considered here.

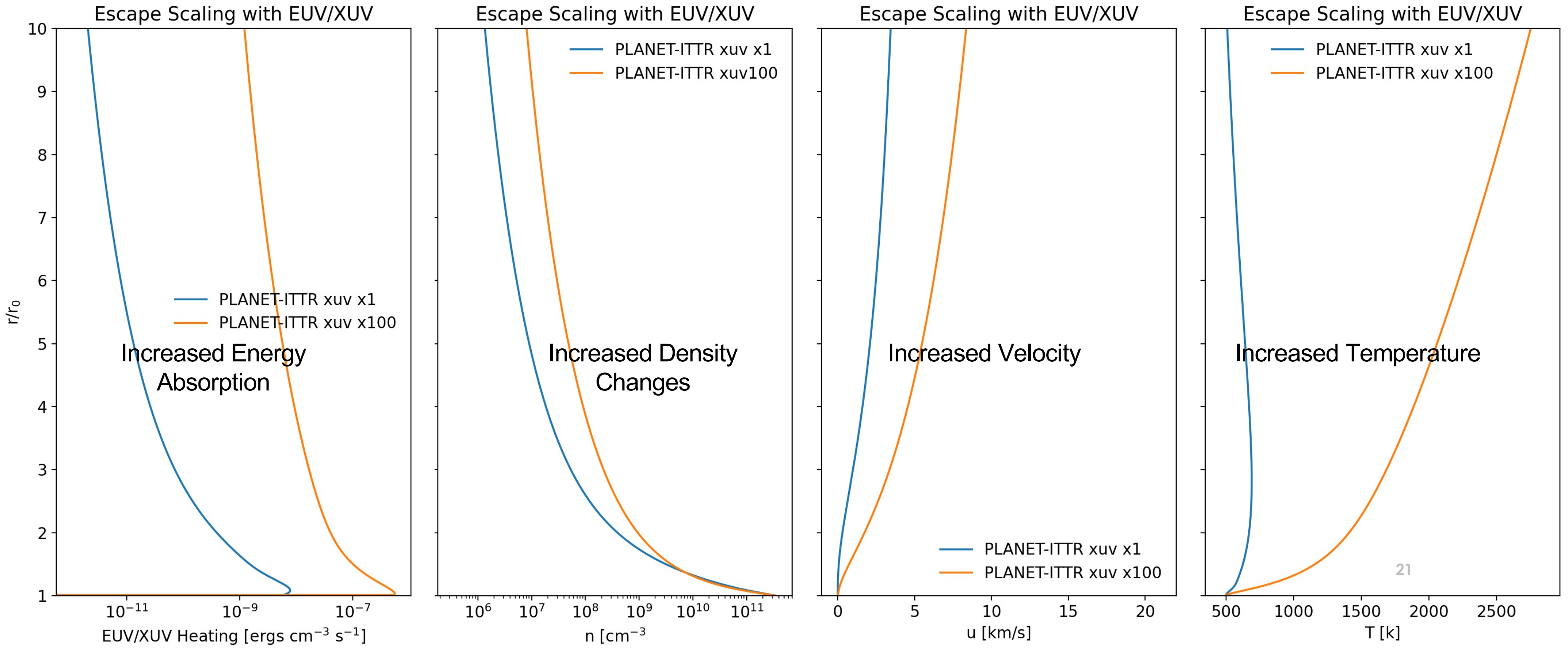
Enhanced EUV Input Dramatically Increases Ion Escape



Garcia-Sage et al., ApJ Letters, 2017

Polar cap area increases

More EUV Input Yields More Hydrodynamic Escape



Summary

- Exoplanets experience extreme space weather conditions
- Elevated Energy inputs include:
    - Stronger SEPs
    - Stronger stellar winds
    - Stronger EUV/XUV input
- Extreme space weather then has consequences for the atmosphere and potential exoplanet observations.
- Heliophysics models have been developed for the relatively data rich environment of our solar system can contribute here!

Thank you!