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

Implication: Close-in *exoplanets* experience extreme space weather conditions
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/
Enhanced Energy Inputs at Close-in Exoplanets

Enhanced Stellar Energetic Particles

Enhanced Stellar Wind

Enhanced Stellar EUV/XUV Photon Flux

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Strong CMEs Driving Strong SEPs and Flares

- Example: $\kappa^1$ 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 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.
Enhanced Energy Inputs at Close-in Exoplanets

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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

Credit: NASA SVS
With Internal Planetary B-Field

Credit: NASA SVS
Transmitting Energy Input to the Atmosphere

Particle Precipitation and Aurora

Credit: NASA SVS

Electromagnetic Energy Input

Field-aligned currents
Pedersen currents
Hall currents

Credit: The COMET Program

Ohmic to XUV energy dissipation

Ionospheric current system

U. Of Colorado

Cohen et al., 2017
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

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

Cohen et al., 2018
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

log Flux \( [cm^{-2} s^{-1}] \)

- Blue line: \( O^+ \)
- Red line: \( H^+ \)
- Dashed line: \( \langle |V_c| \rangle^2 \)^{5.58}

Uconv \([m/s]\)

Joule Heating Proxy
Enhanced Energy Inputs at Close-in Exoplanets

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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

Garcia-Sage et al., 2016
Ionospheric Outflow With Enhanced EUV/XUV Input

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

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. ApJ Letters. 2017
Enhanced EUV Input Dramatically Increases Ion Escape

Polar cap area increases

All Atmosphere Lost

Age of Proxima cen b

More EUV Input Yields More Hydrodynamic Escape

Increased Energy Absorption

Increased Density Changes

Increased Velocity

Increased Temperature
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!