

# Beyond Light: Why Thy Star's Corpuscular Space Weather is Key for Understanding Exoplanets

R. O. Parke Loyd

Evgenya Shkolnik, Joseph Lazio, Gregg Hallinan, Laura Neves Ribeiro do Amaral, Ivey Davis, Alison Farrish, James Green, Julián Alvarado-Gómez, Dave Brain, Bin Chen, Christina Cohen, Shannon Curry, **Karin Dissauer**, Arika Egan, Nat Gopalswamy, Guillaume Gronoff, Shadia Habbal, Renyu Hu, **Meng Jin**, Heather Knutson, **James Mason**, Ruth Murray-Clay, Kosuke Namekata, Rachel Osten, Antígona Segura, Astrid Veronig, Aline Vidotto, Maurice Wilson, Yu Xu

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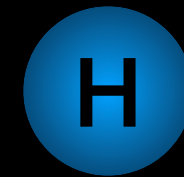
**we're finding some bare rocks**

Illustration

Credit: NASA/JPL-Caltech/R. Hurt (IPAC)



# what's a “corpuscule?”



this is a corpuscule

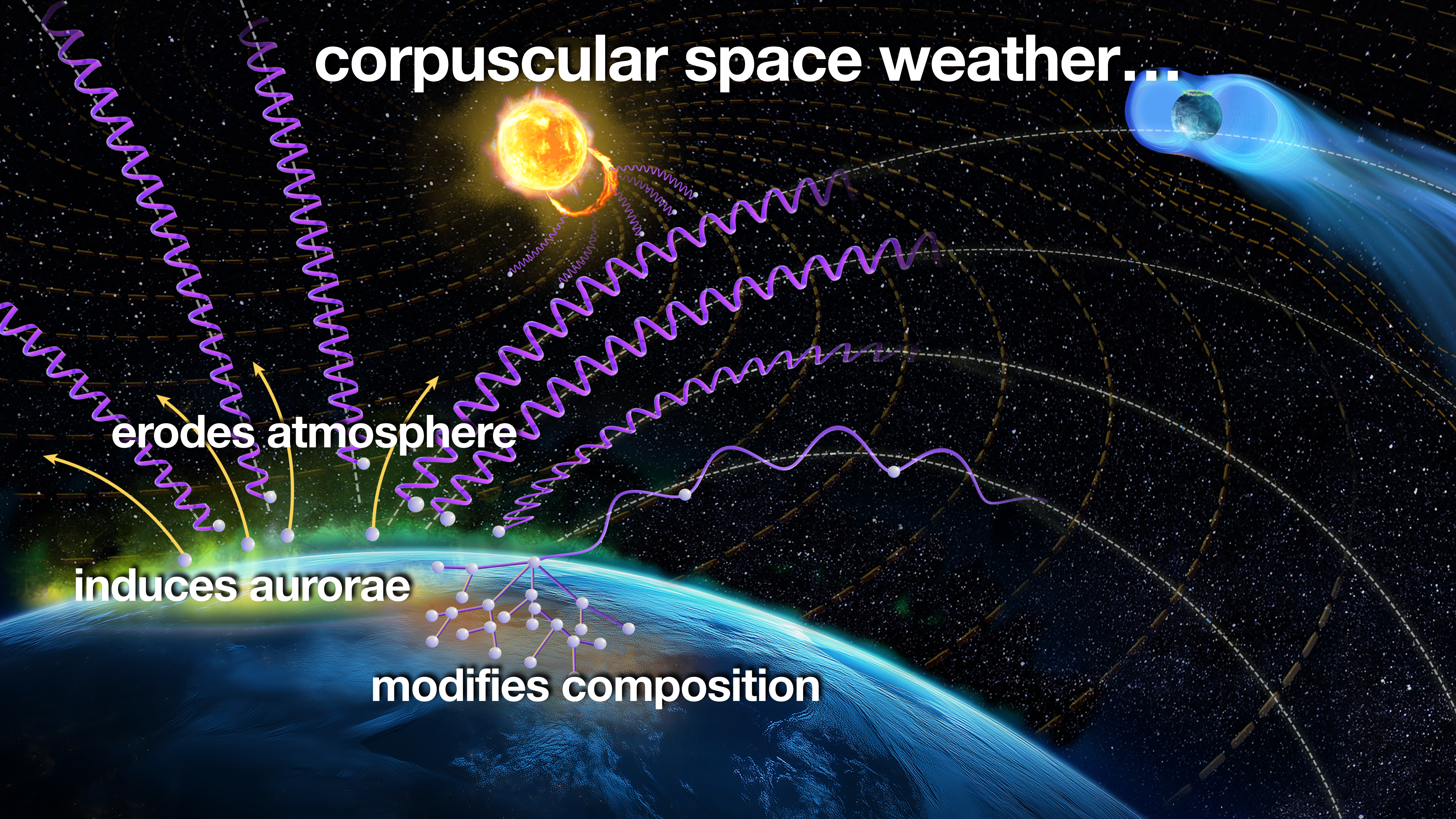


**and this is an example of corpuscular space weather  
a “corpuscular mass ejection” (CME)**





# corpuscular space weather...



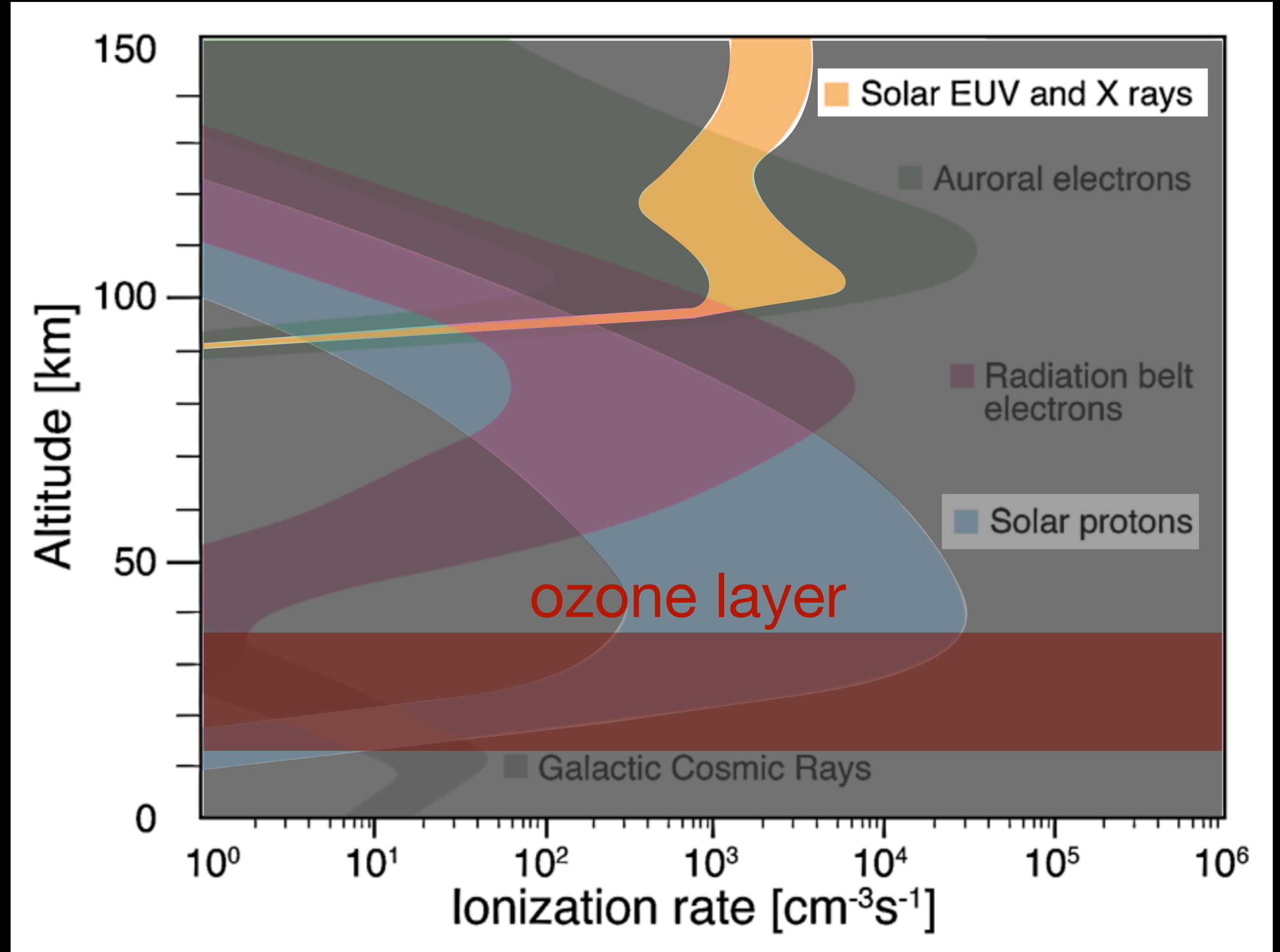
erodes atmosphere

induces aurorae

modifies composition



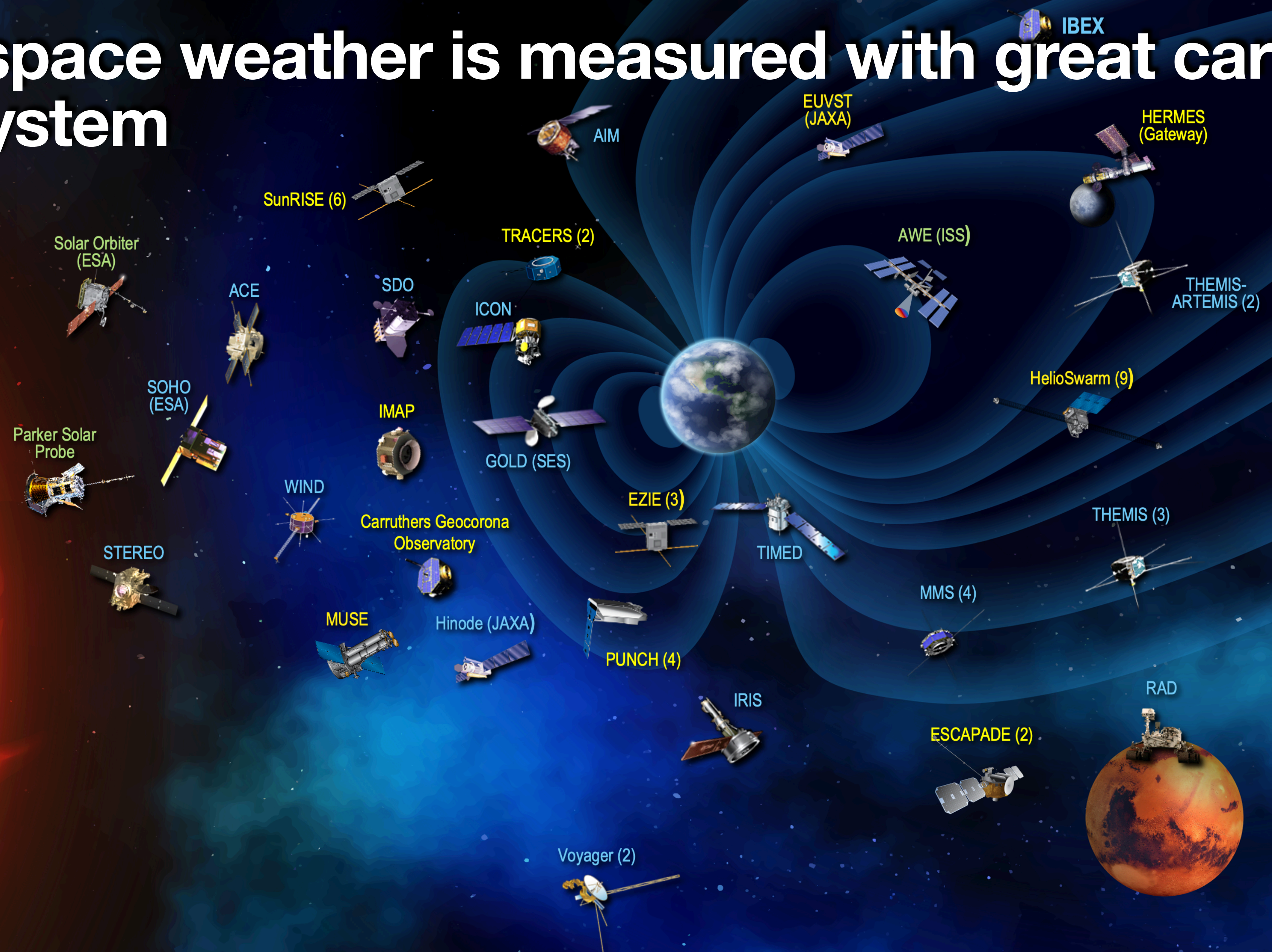
corpuscles dive  
deeper than  
photons



Mironova et al. 2015

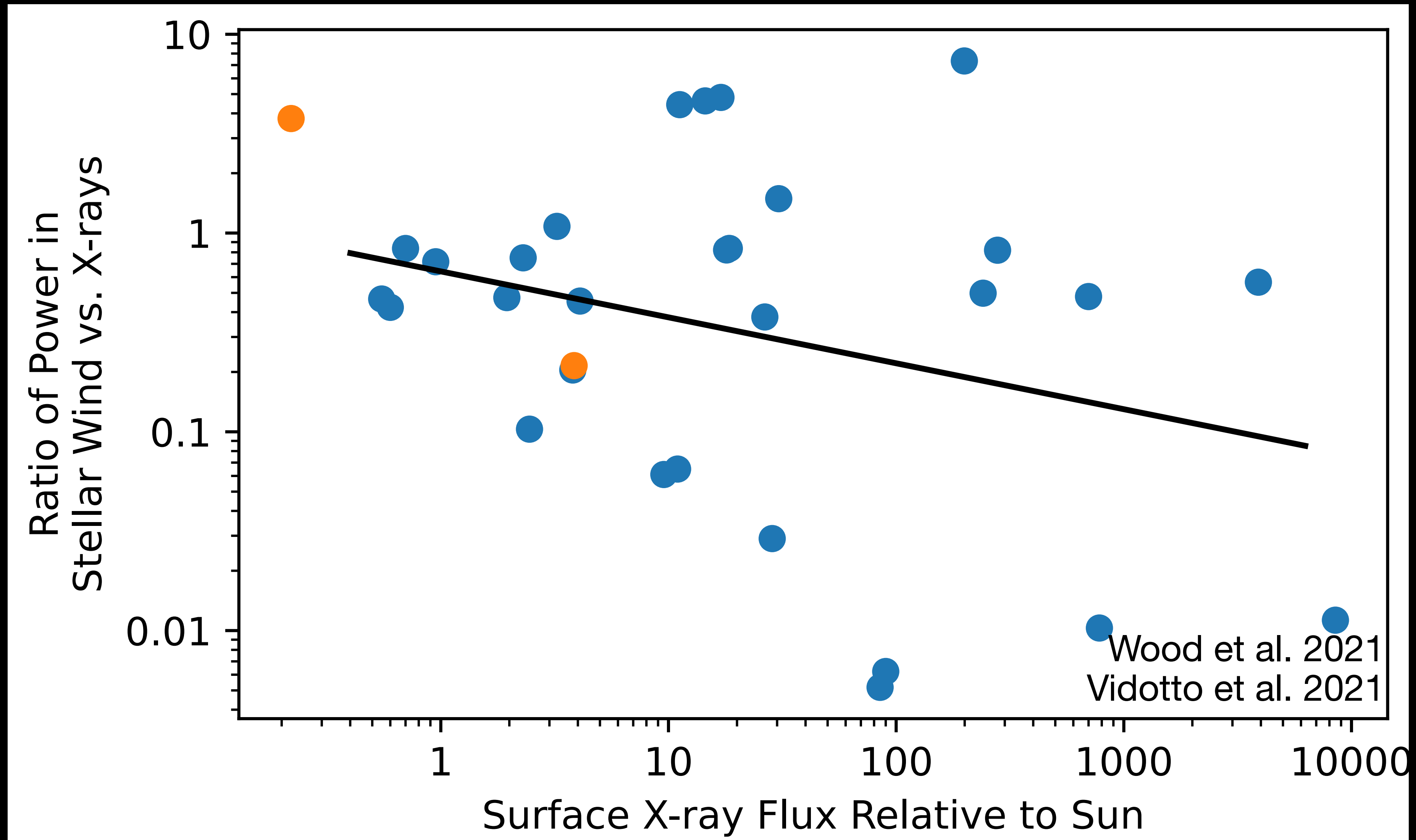


# corpuscular space weather is measured with great care in the solar system



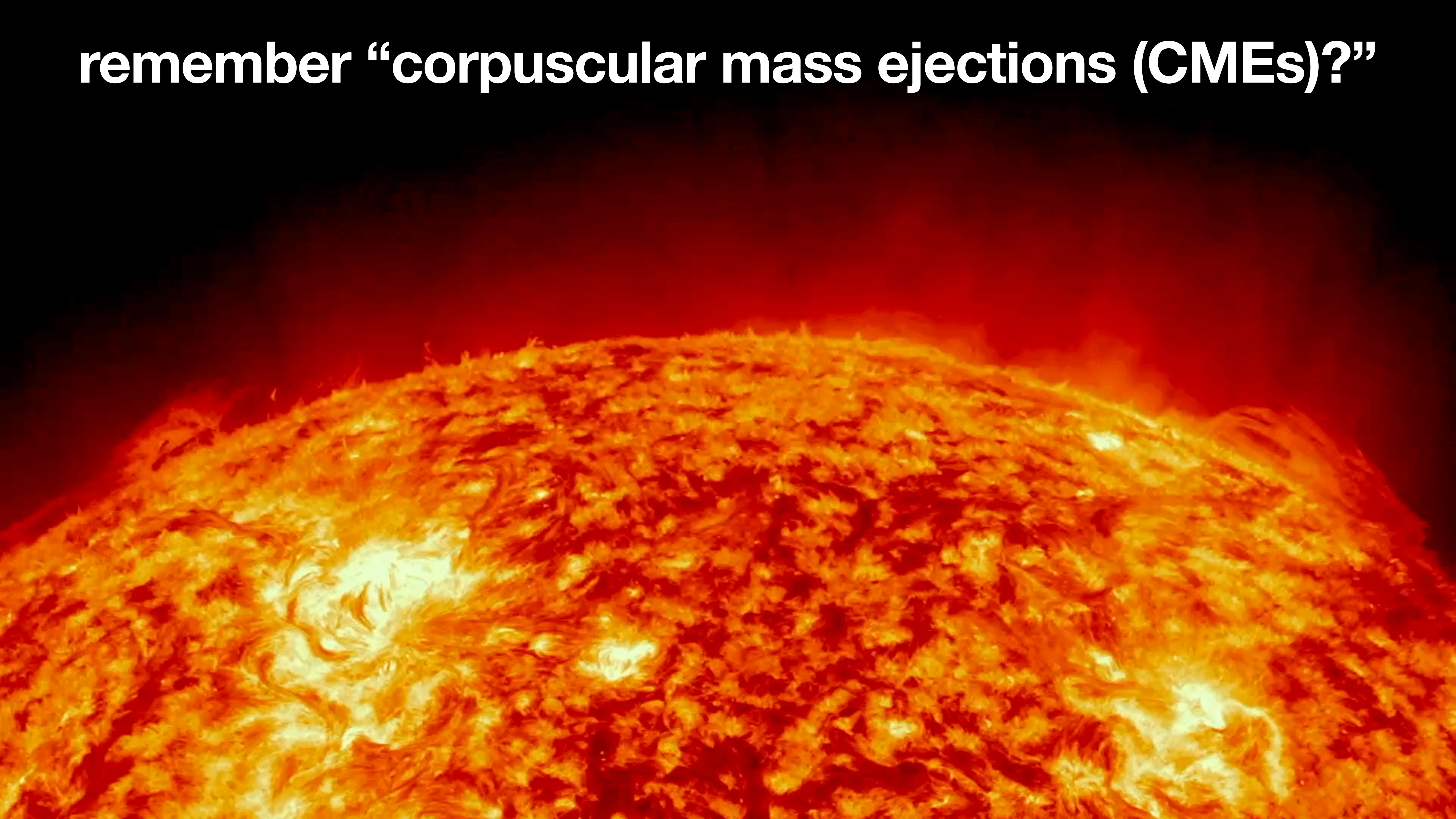


# There are some constraints on stellar winds





**remember “corpuscular mass ejections (CMEs)?”**





# corpuscles are camera shy

Widely-accepted, definitive detections of corpuscular mass ejections:

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- 1.



# The Keck Institute Corpuscular Workshop



*Not shown:* Heather Knutson, Rachel Osten

Search “Keck Institute particles” for more info.



**there are many promising approaches to characterizing stellar corpuscular space weather — it is only a matter of effort and resources**

## **Winds**

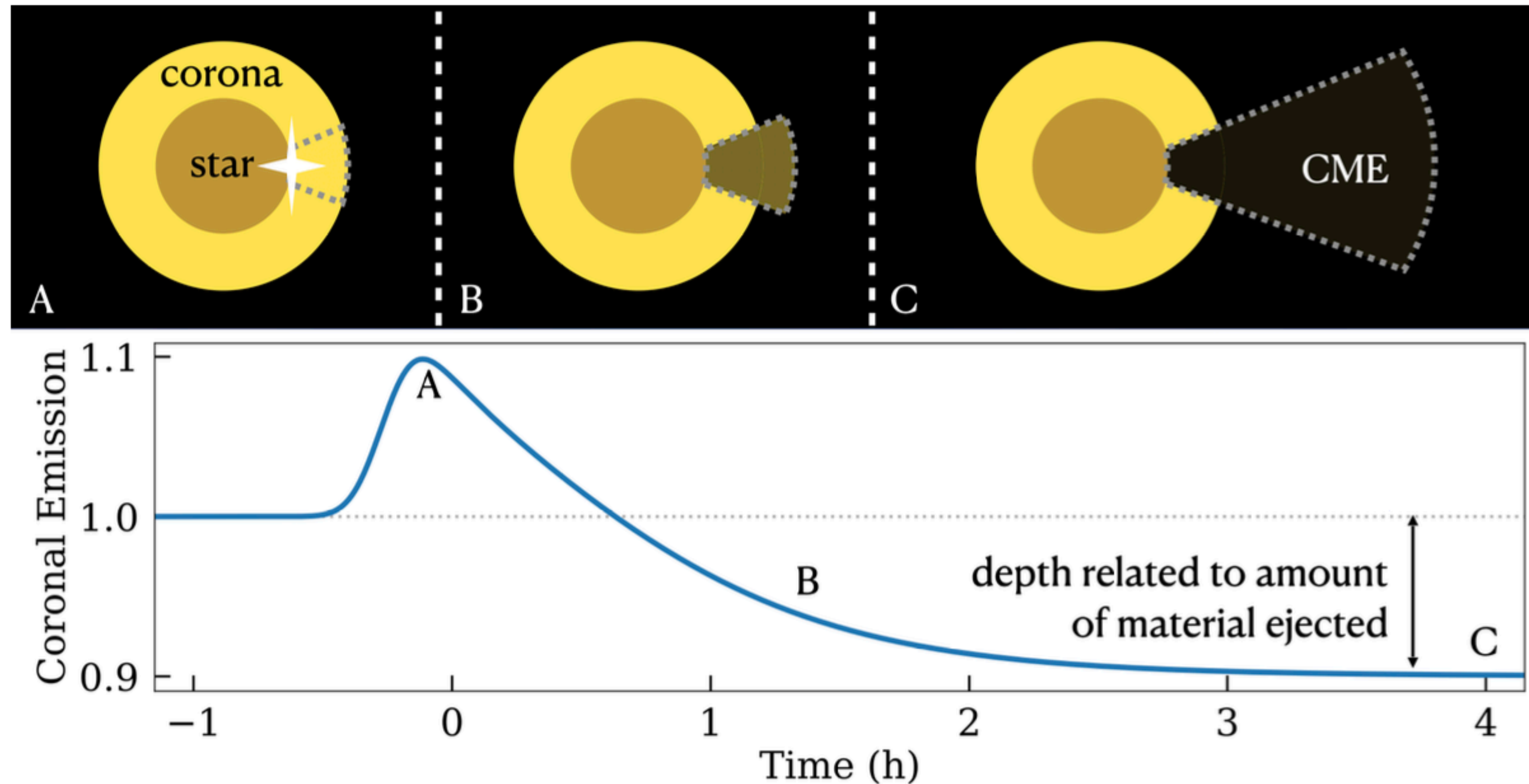
1. Ly $\alpha$  absorption from wind-ISM (interstellar medium) collisional wall
2. Direct imaging of emission from wind-ISM interaction
3. Charge exchange X-ray emission
4. Exoplanet outflow-wind interactions producing Doppler-shifted transits
5. Radio free-free emission
6. Coronagraphic imaging
7. Presence of zodiacal dust?
8. In-situ measurements (e.g., Breakthrough Starshot)?

## **CMEs**

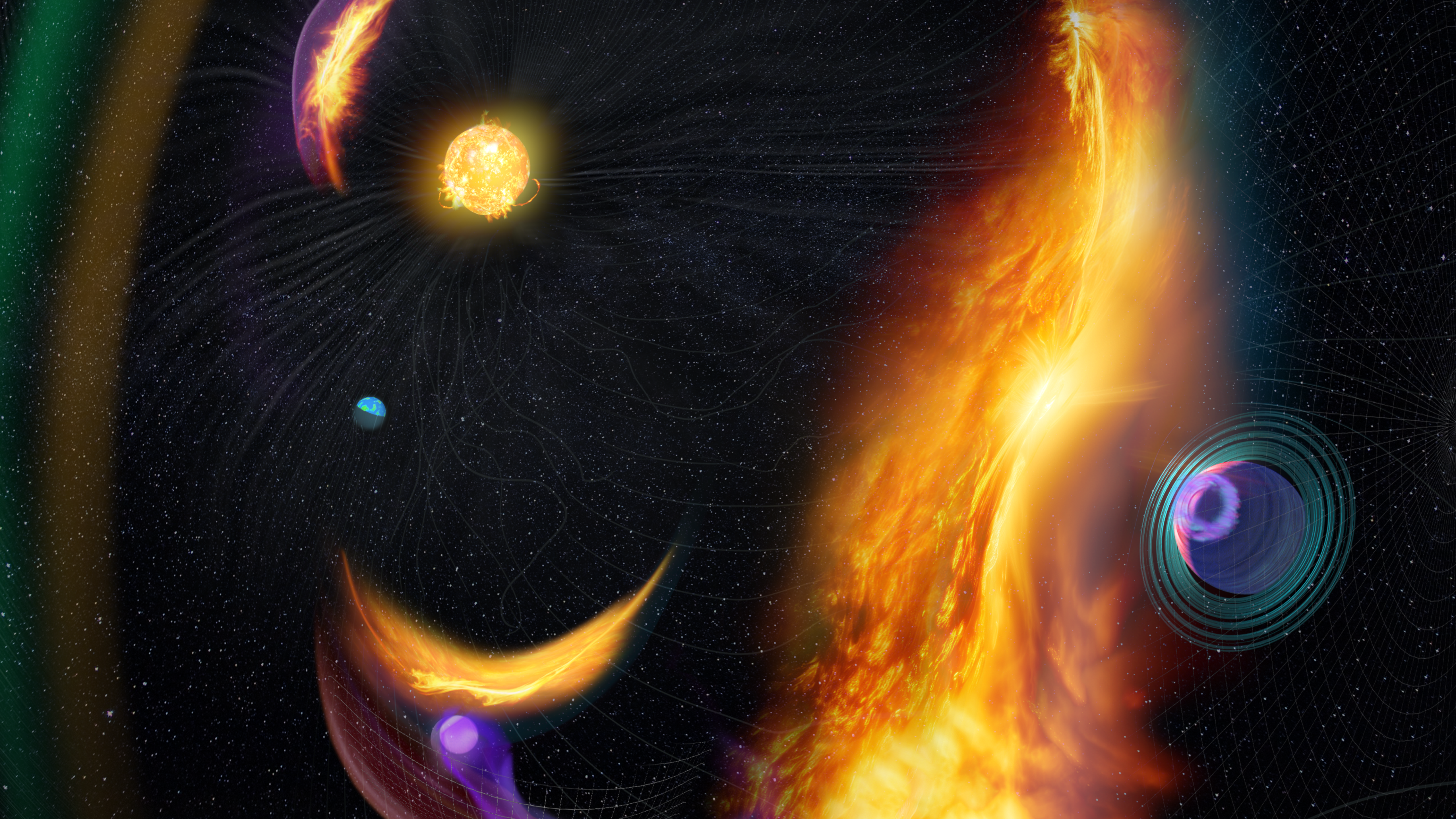
1. Doppler shifted emission/absorption from prominence eruptions
2. Coronal dimming due to mass loss
3. Coronal dimming due to ejected absorbing material
4. Type II radio burst
5. Moving type IV radio burst
6. Nonthermal radio emission from CME plasma
7. Planetary aurorae
8. Switching on/off magnetic star-planet interactions
9. Variability in exoplanet outflows
10. Perturbations of stellar disks
11. Coronagraphic imaging
12. Thermal radio emission?



# Coronal dimming may be a scalable way to survey stellar CMEs









# Backup



# Stellar Wind Observational Techniques

- Ly $\alpha$  absorption from wind-ISM (interstellar medium) collisional wall
- Direct imaging of emission from wind-ISM interaction
  - Charge exchange X-ray emission
- Exoplanet outflow-wind interactions producing Doppler-shifted transits
- Radio free-free emission
- Coronagraphic imaging
- Presence of zodiacal dust?
- In-situ measurements (e.g., Breakthrough Starshot)?



# Coronal Mass Ejection Observational Techniques

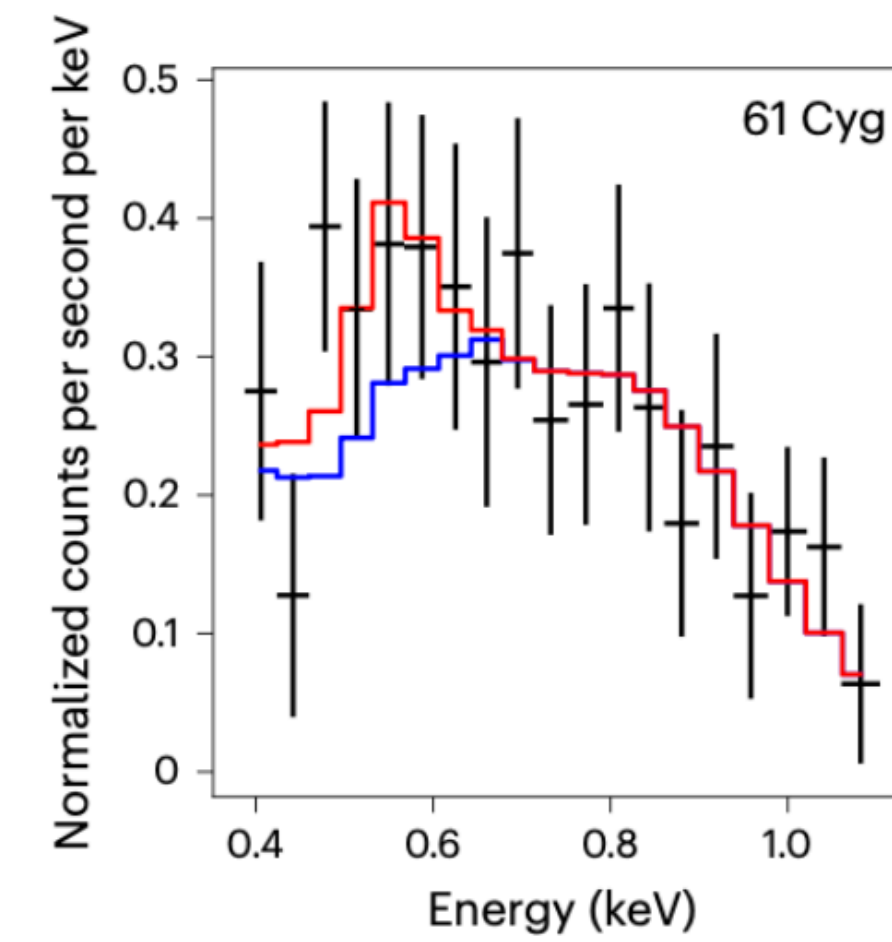
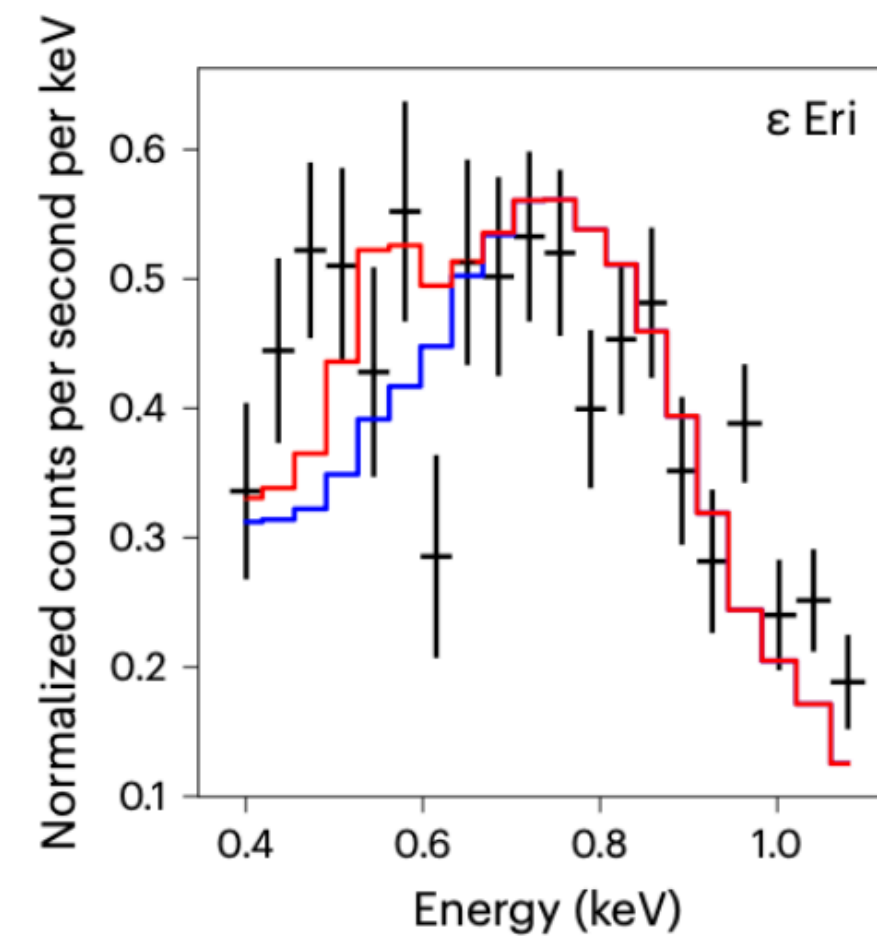
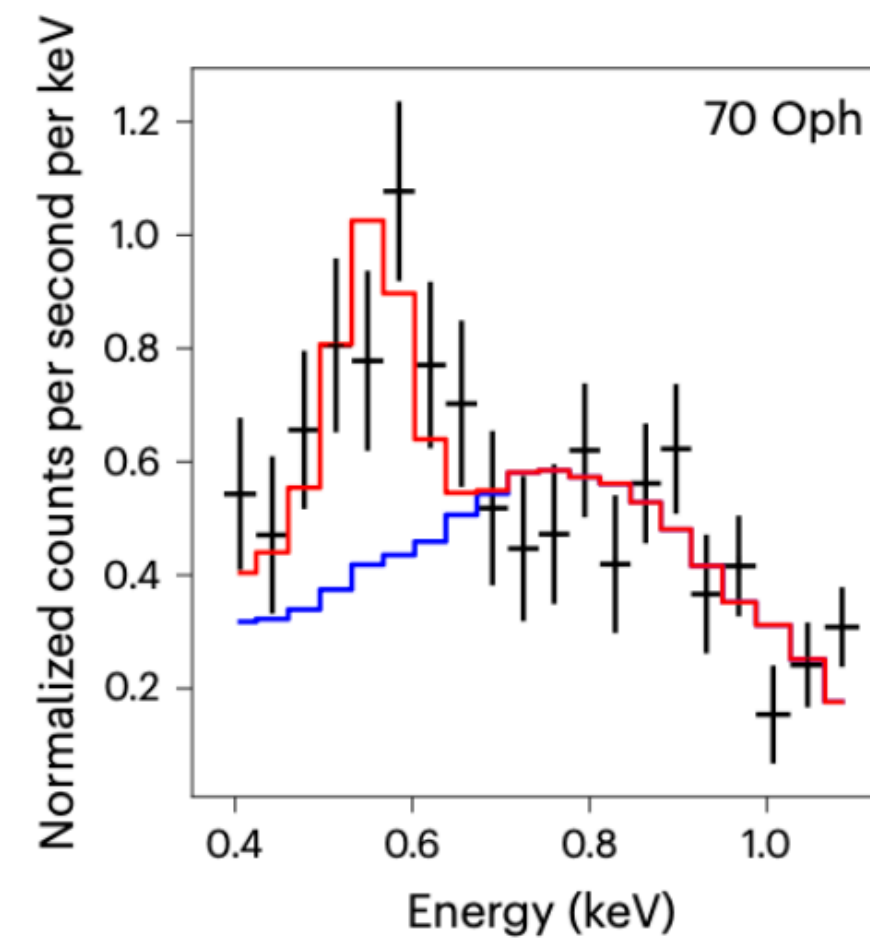
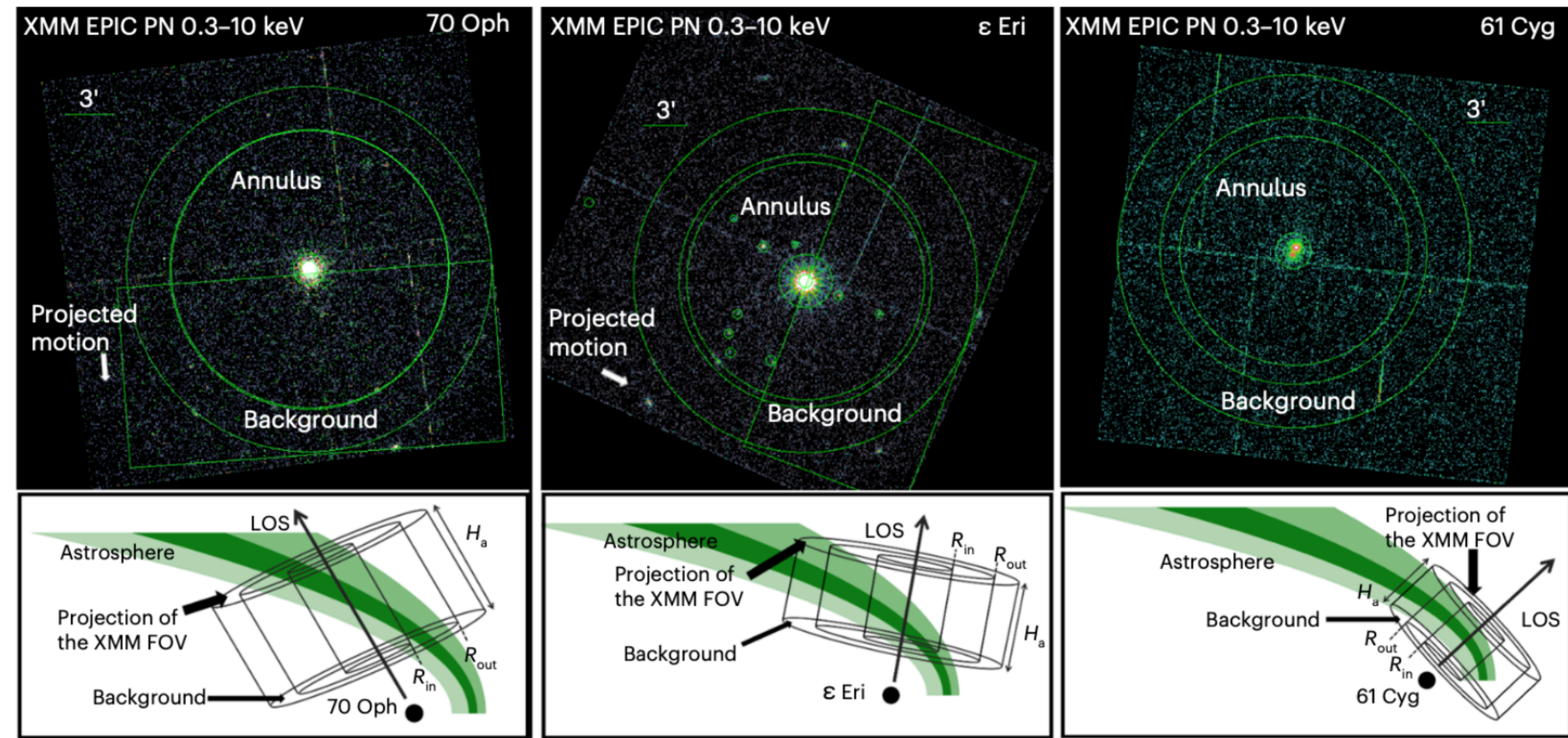
- Doppler shifted emission/absorption from prominence eruptions
- Coronal dimming due to mass loss
- Coronal dimming due to ejected absorbing material
- Frequency drifting radio emission
  - from moving shock (Type II)
  - from moving trapped electrons (Type IV)
- Nonthermal radio emission from CME plasma
- Planetary aurorae
- Switching on/off magnetic star-planet interactions
- Variability in exoplanet outflows
- Perturbations of stellar disks
- Coronagraphic imaging
- Thermal radio emission?



# Stellar Energetic Particle Events Observational Techniques

- Frequency drifting radio emission from beamed particles (Type II)
- Hard X-ray emission?
- Gamma ray emission?
- Planetary aurorae

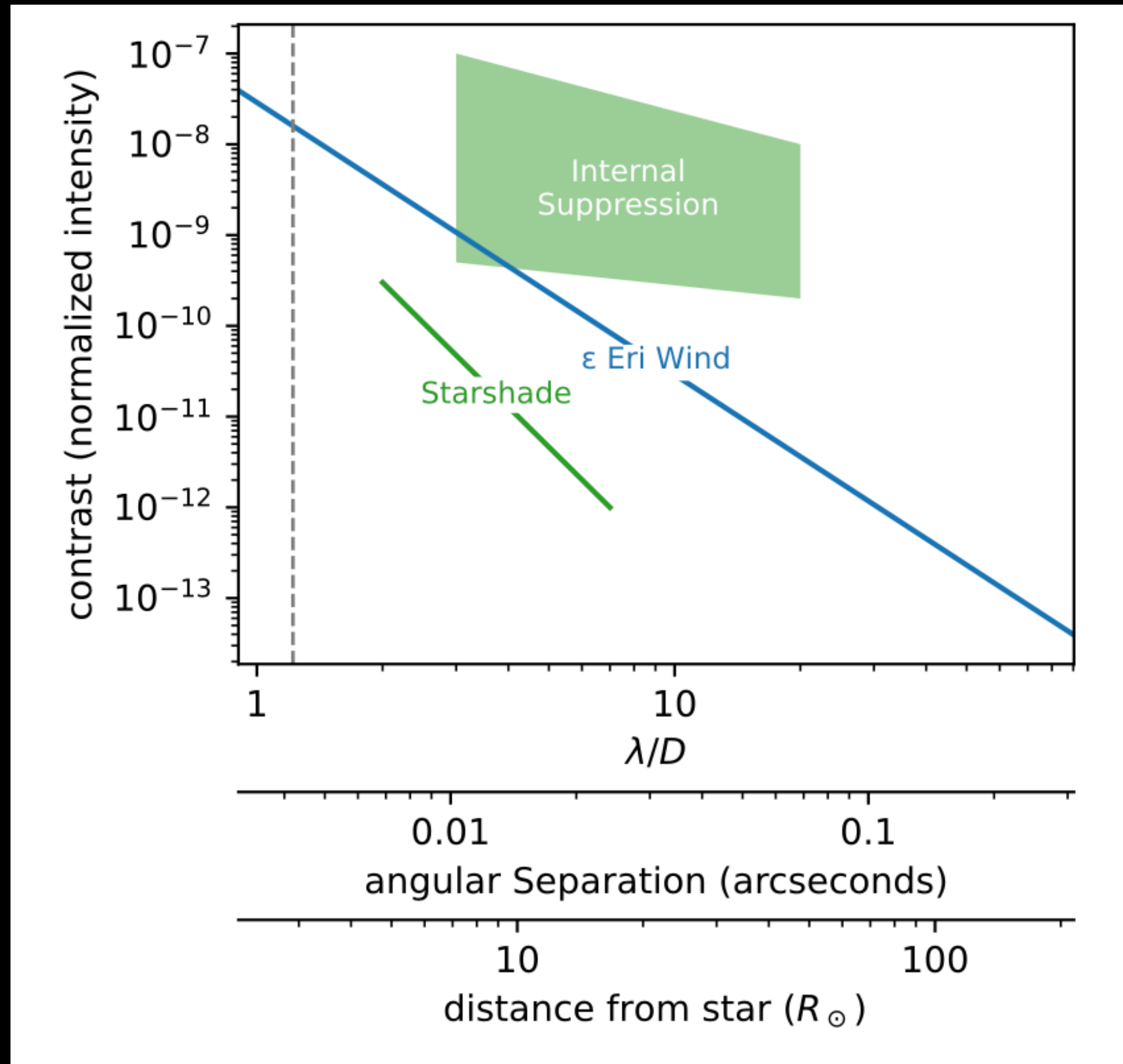




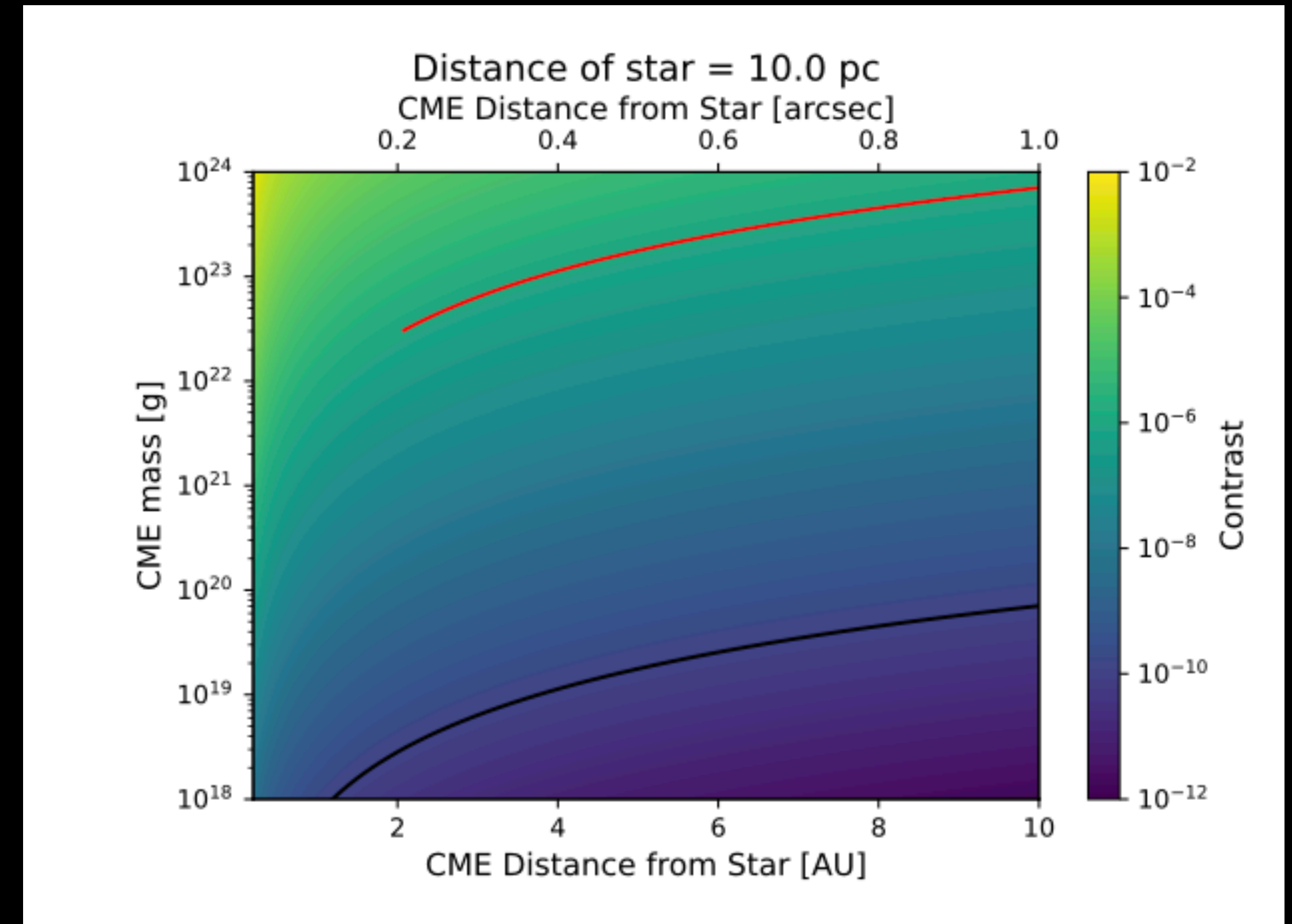


# Coronagraphic imaging might not be as impossible as previously thought

## Winds



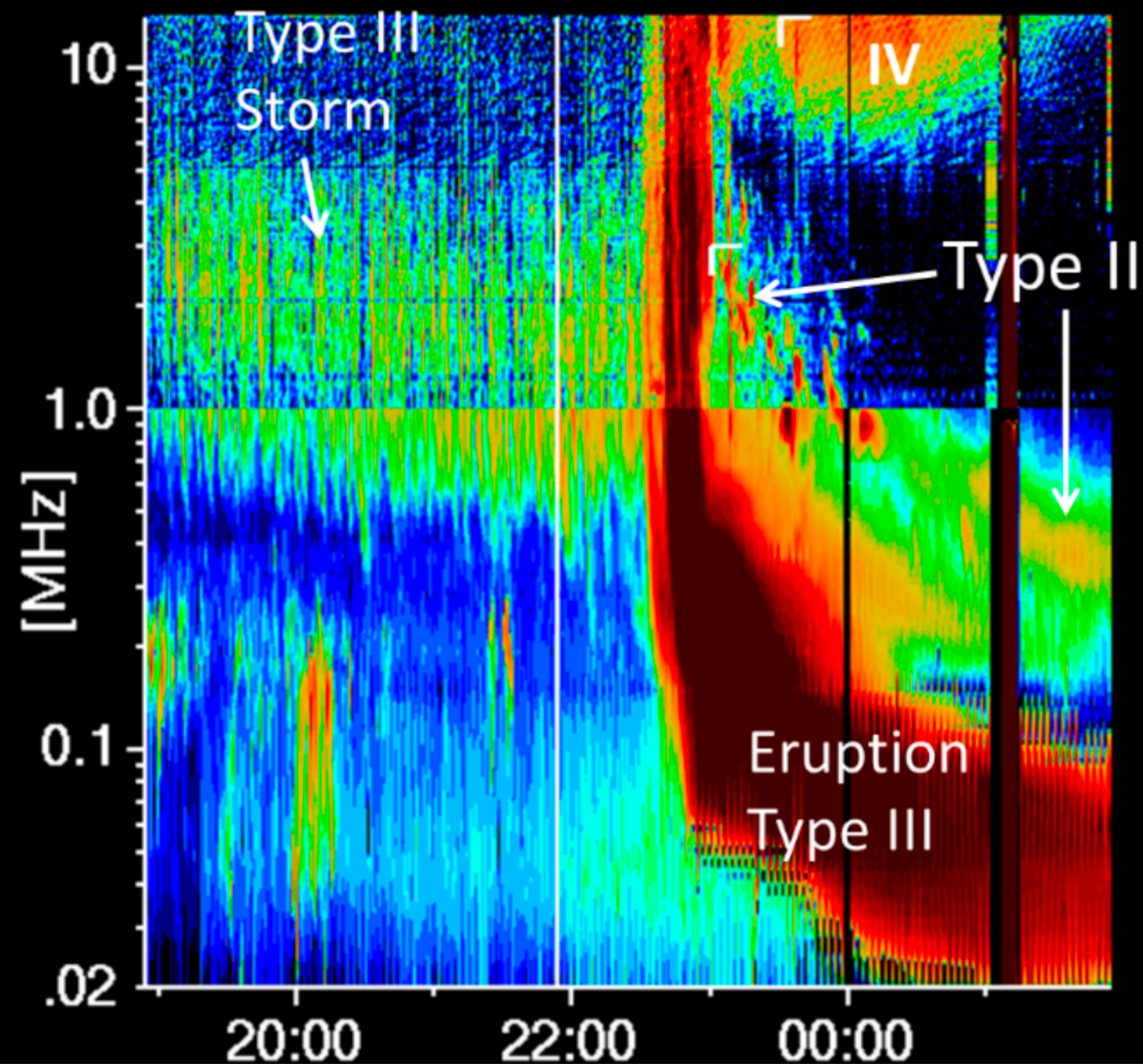
## CMEs



Analysis and figures by **Ivey Davis** & R. O. Parke Loyd



WIND/WAVES: 2005/01/15 21:54





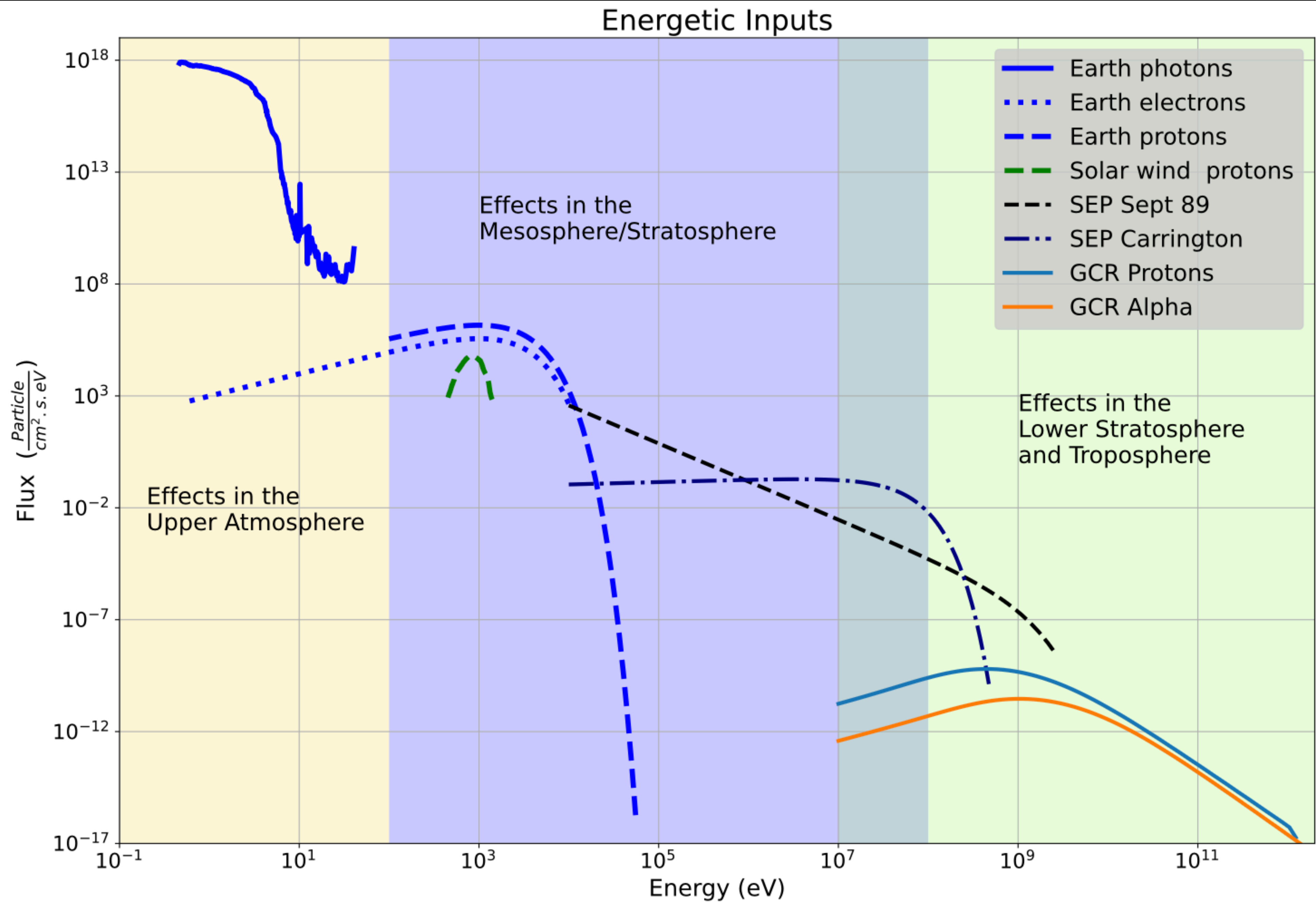


Figure by Guillaume Gronoff



