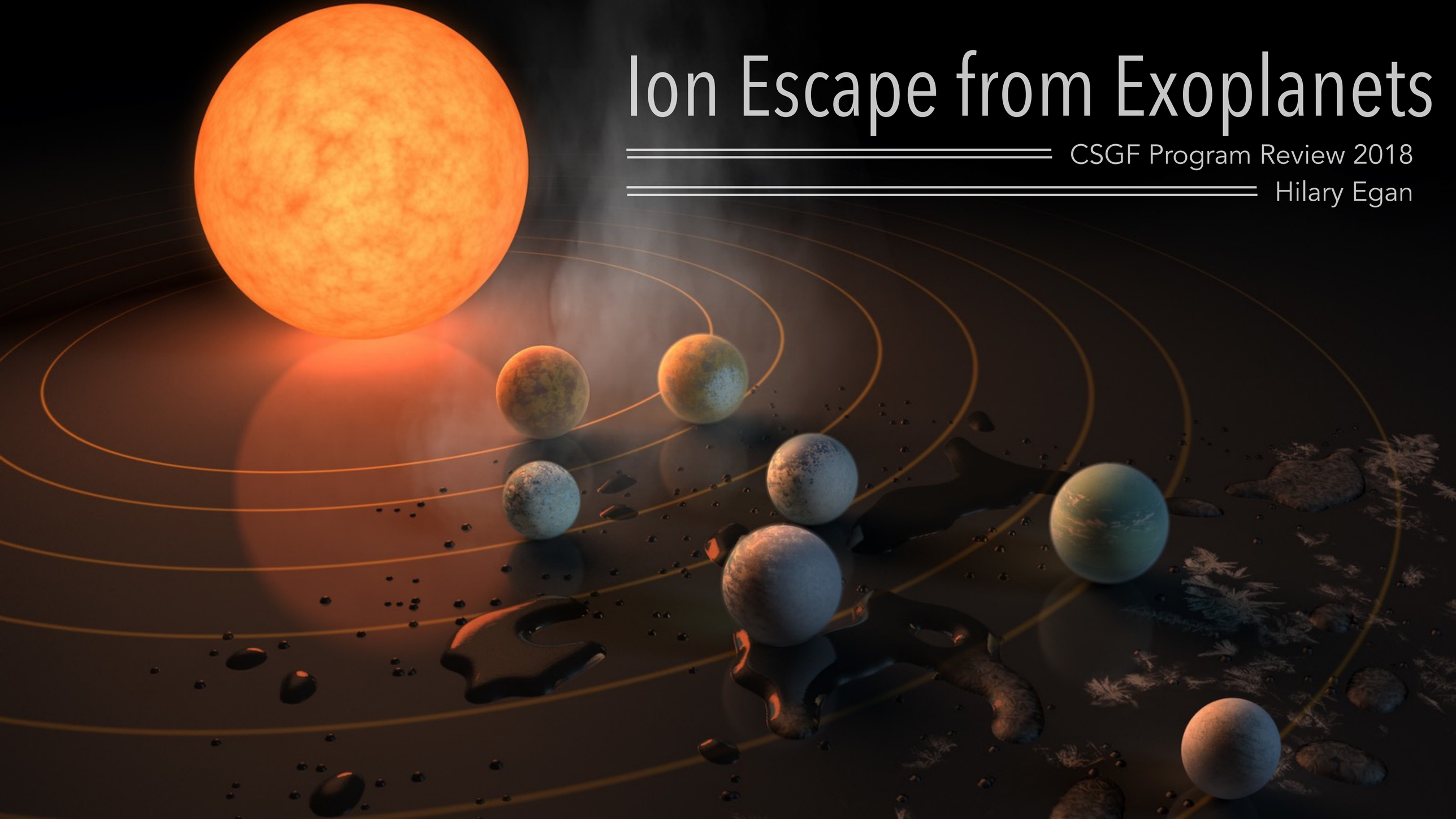


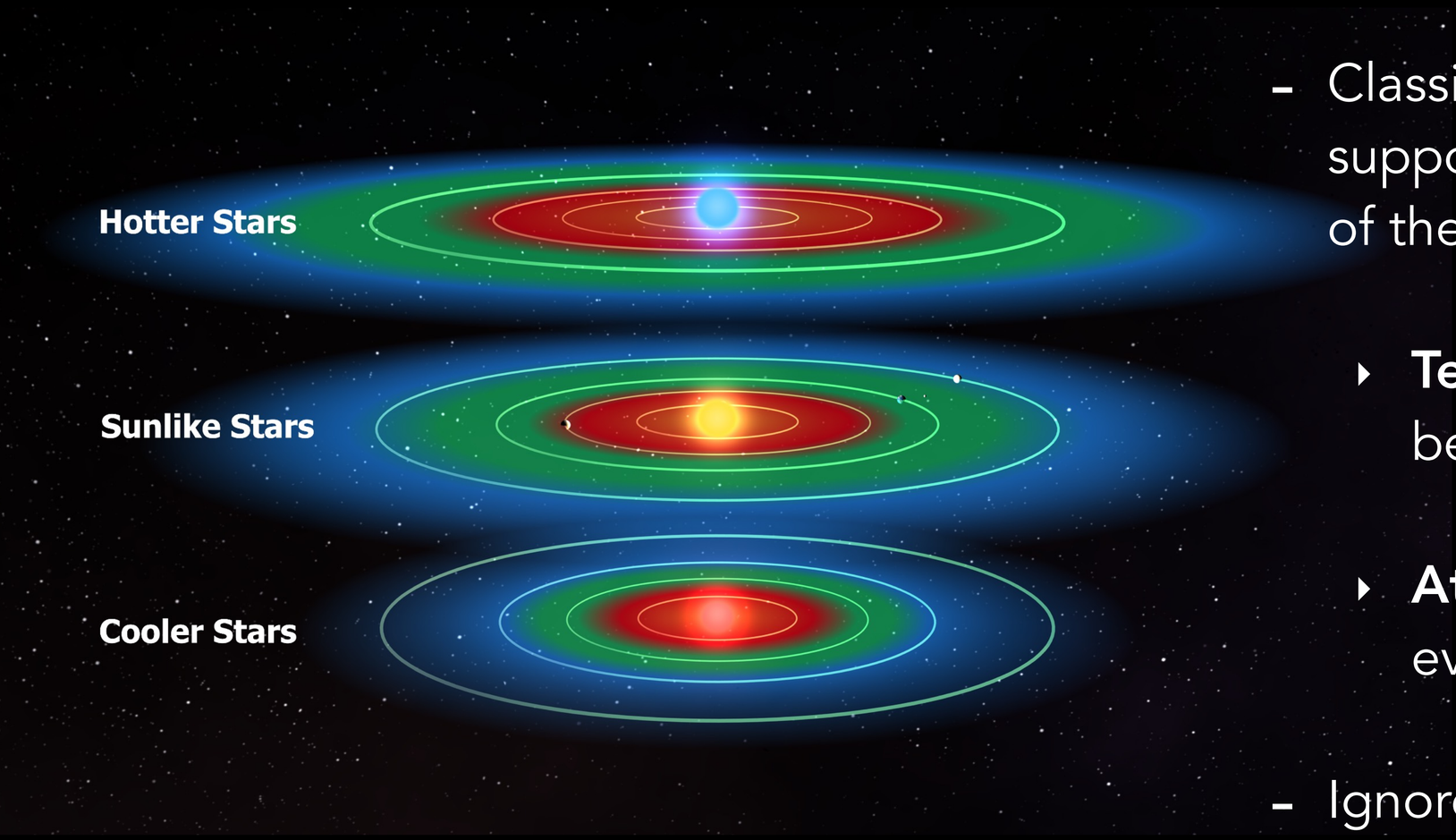
Ion Escape from Exoplanets

CSGF Program Review 2018

Hilary Egan

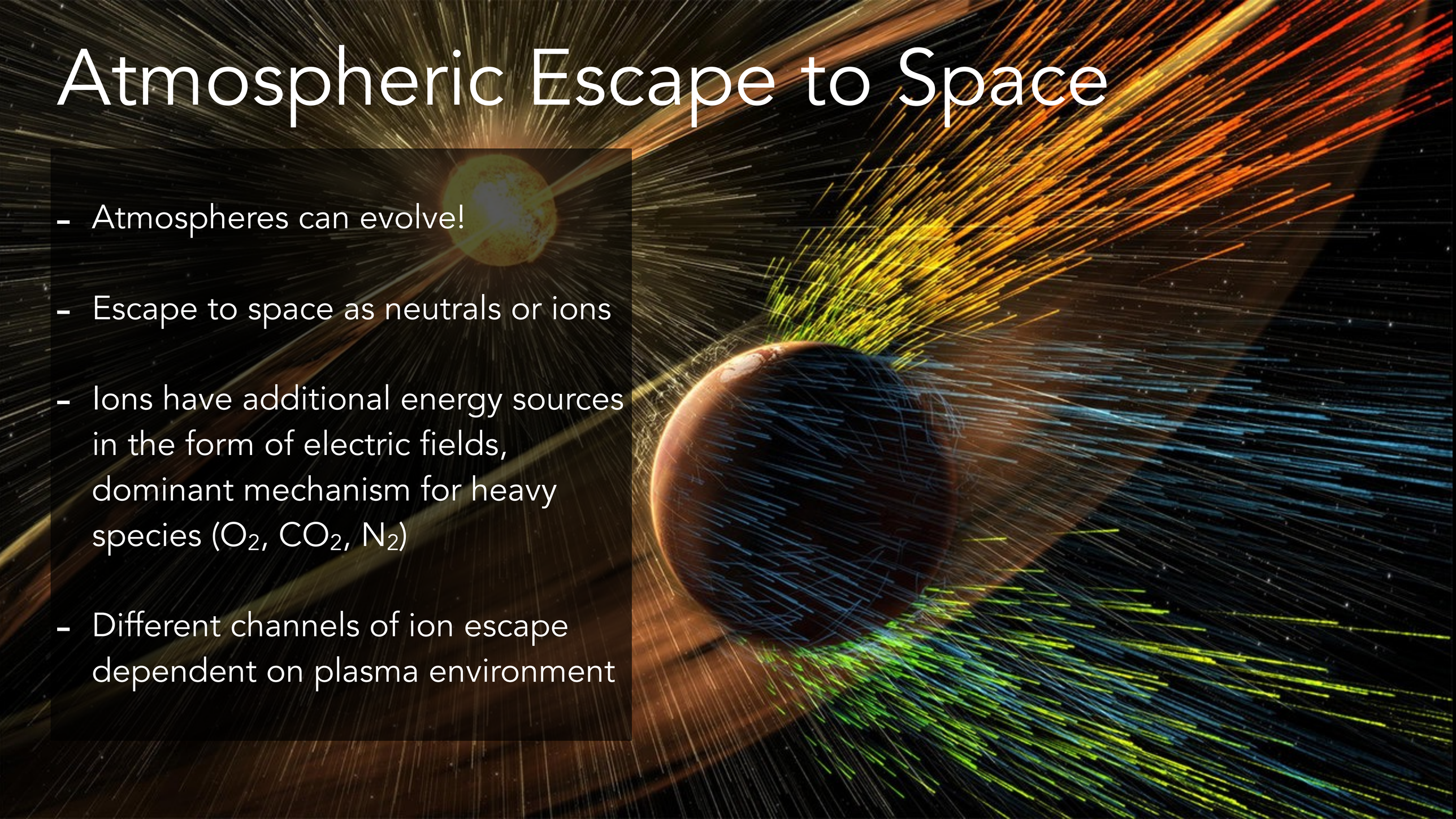
New telescopes like Kepler and TESS have made it possible to discover many strange and exciting new planets

What is habitability?



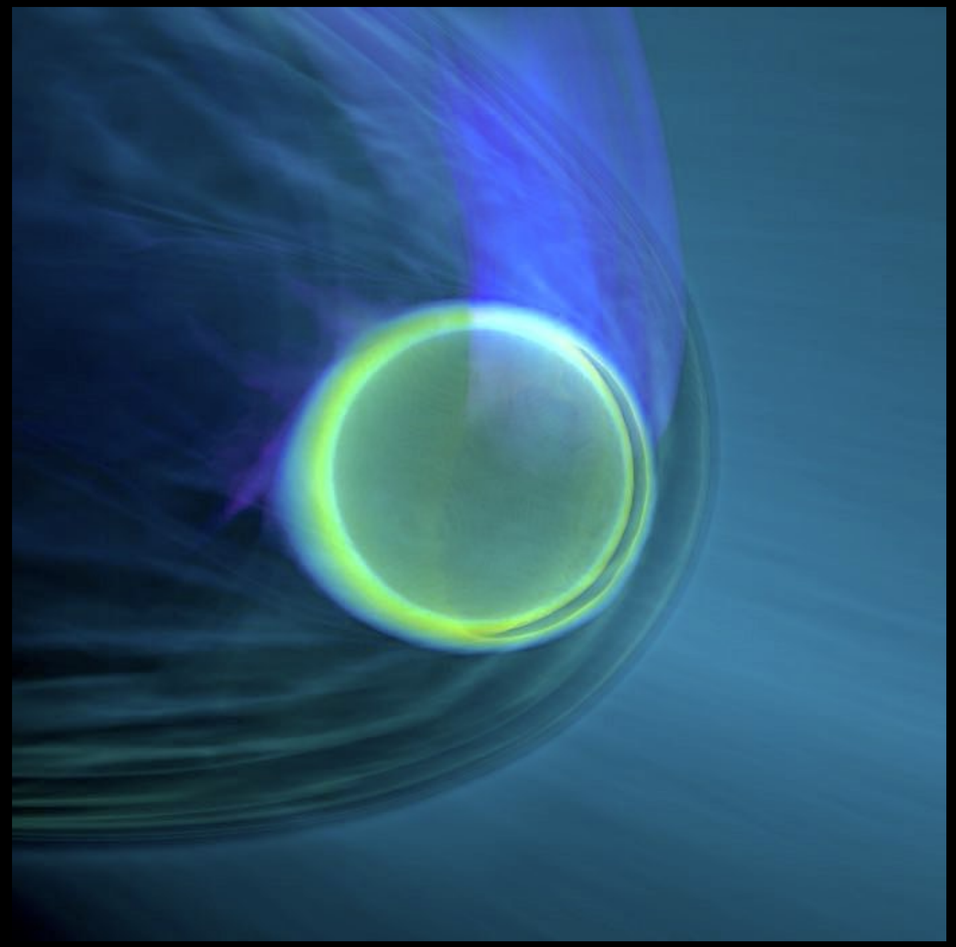
- Classical definition: capable of supporting liquid water on the surface of the planet
  - **Temperature** above freezing but below boiling point
  - **Atmosphere** to prevent evaporation
- Ignores surface irradiation, other less observable forms of life,

Atmospheric Escape to Space



- Atmospheres can evolve!
- Escape to space as neutrals or ions
- Ions have additional energy sources in the form of electric fields, dominant mechanism for heavy species (O_2, CO_2, N_2)
- Different channels of ion escape dependent on plasma environment

Modeling Ion escape



- Inflow side of box set by stellar wind
- Obstacle boundary set by planetary ionosphere
- Box size set by magnetosphere shock size
- Model choices
    - **MHD**: Ions and electrons both treated as fluids
    - **Hybrid**: Ions treated as macroparticles, electrons as charge neutralizing fluid

Models Validated via In Situ Spacecraft Measurements

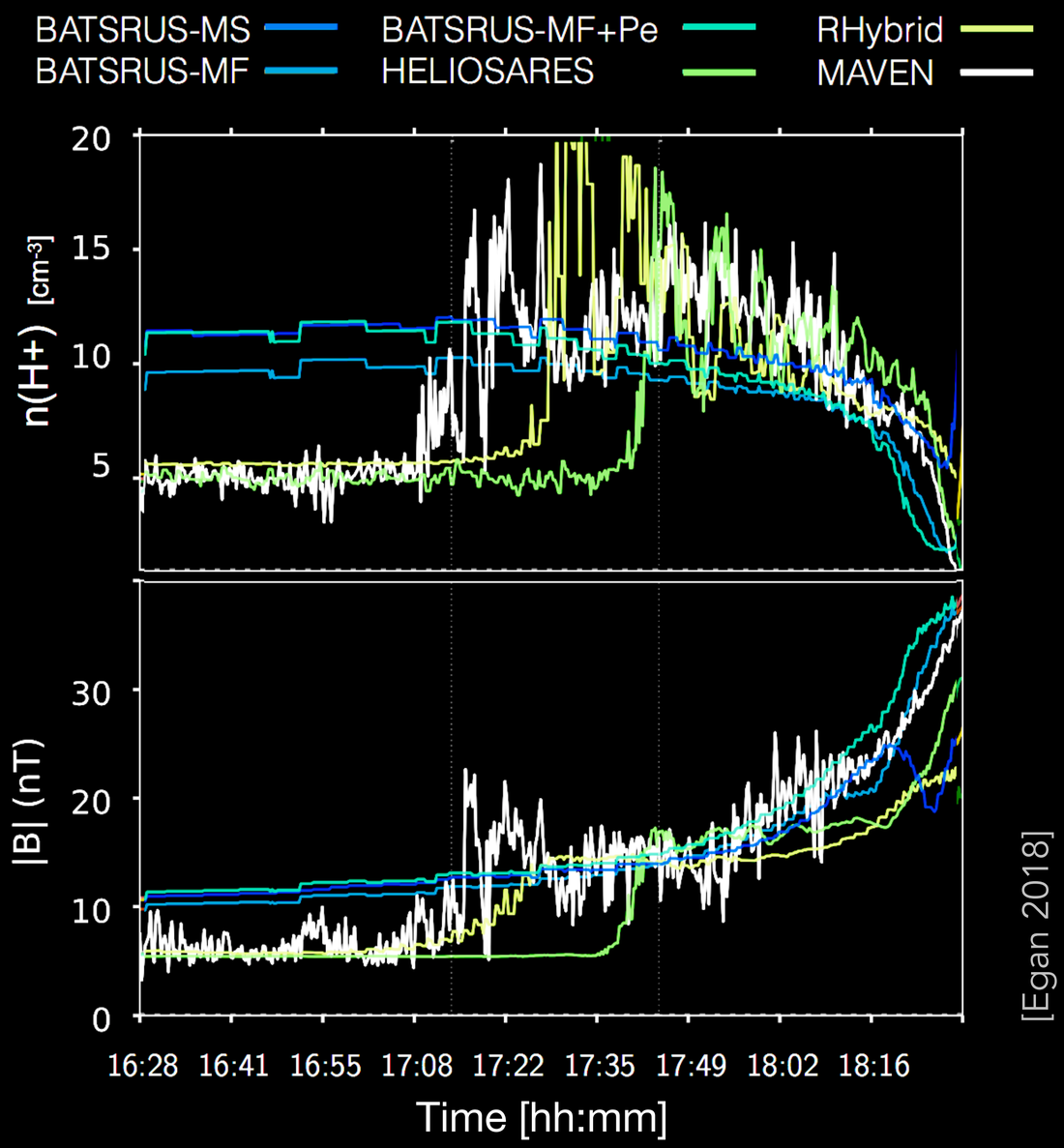
- Validation process

  1. Measure upstream solar wind & different places in interaction region

  2. Simulate planet with the same solar wind input

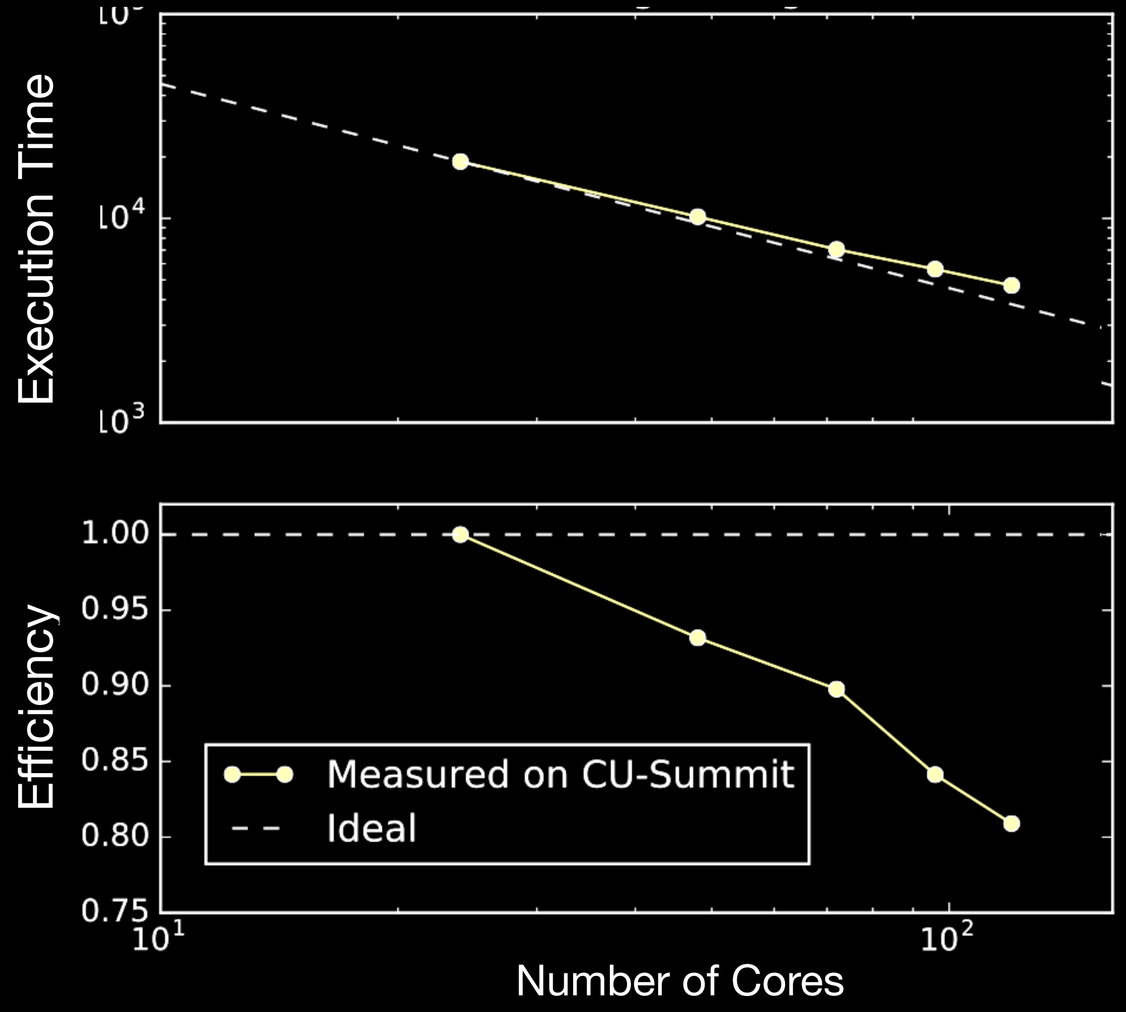
  3. Compare data and models

- No one model is perfect, pick your tool wisely



[Egan 2018]

RHybrid Code



- Problem Features
  - Highly coupled problem across many scale sizes
  - Hundreds of particles per grid cell, not constrained by initial location
- Adaptive load balancing via Zoltan library [Sandia]
- 2nd order Buneman scheme for propagation

Applying Solar System Plasma Models to Exoplanets

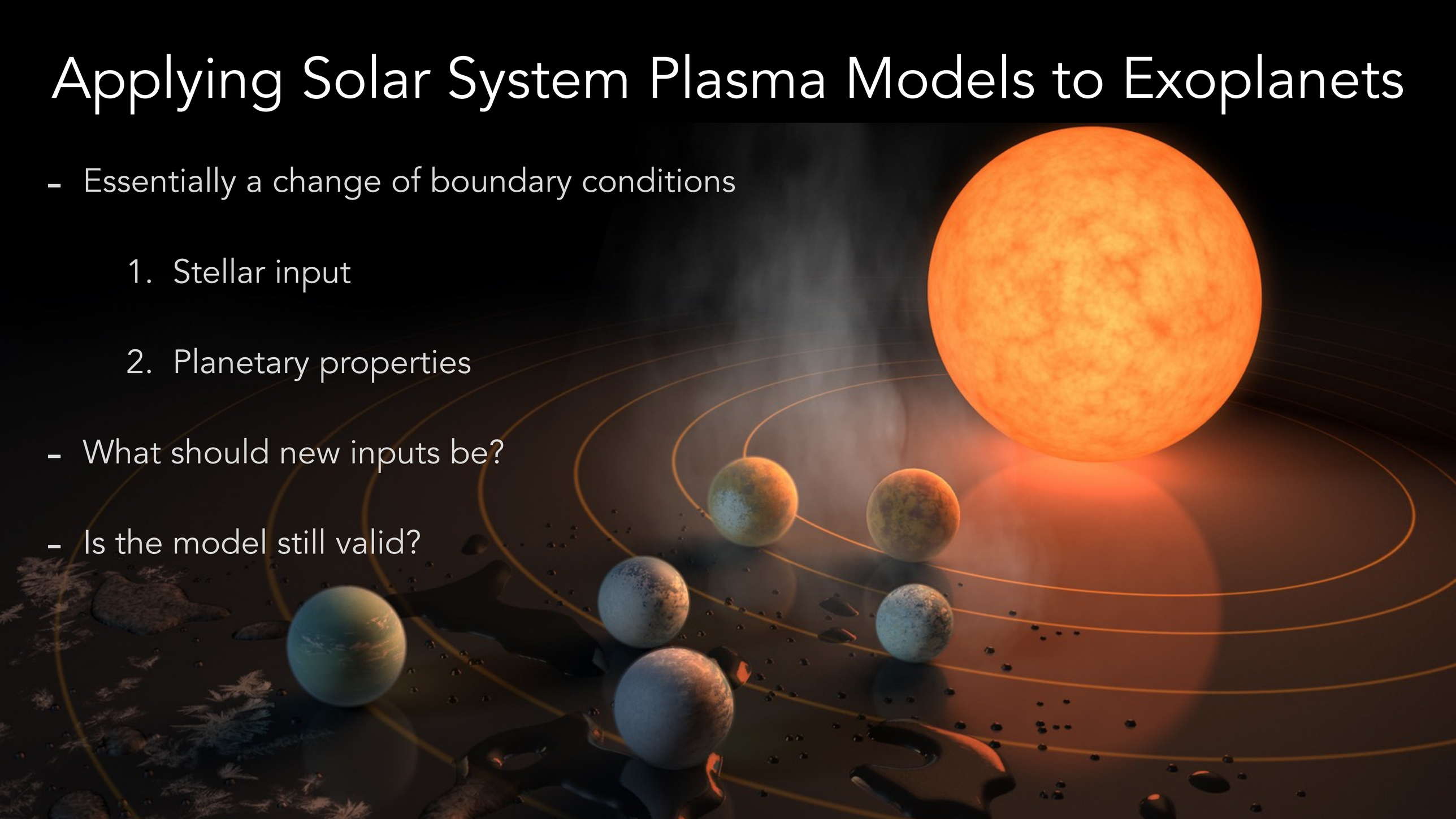
- Essentially a change of boundary conditions

    1. Stellar input

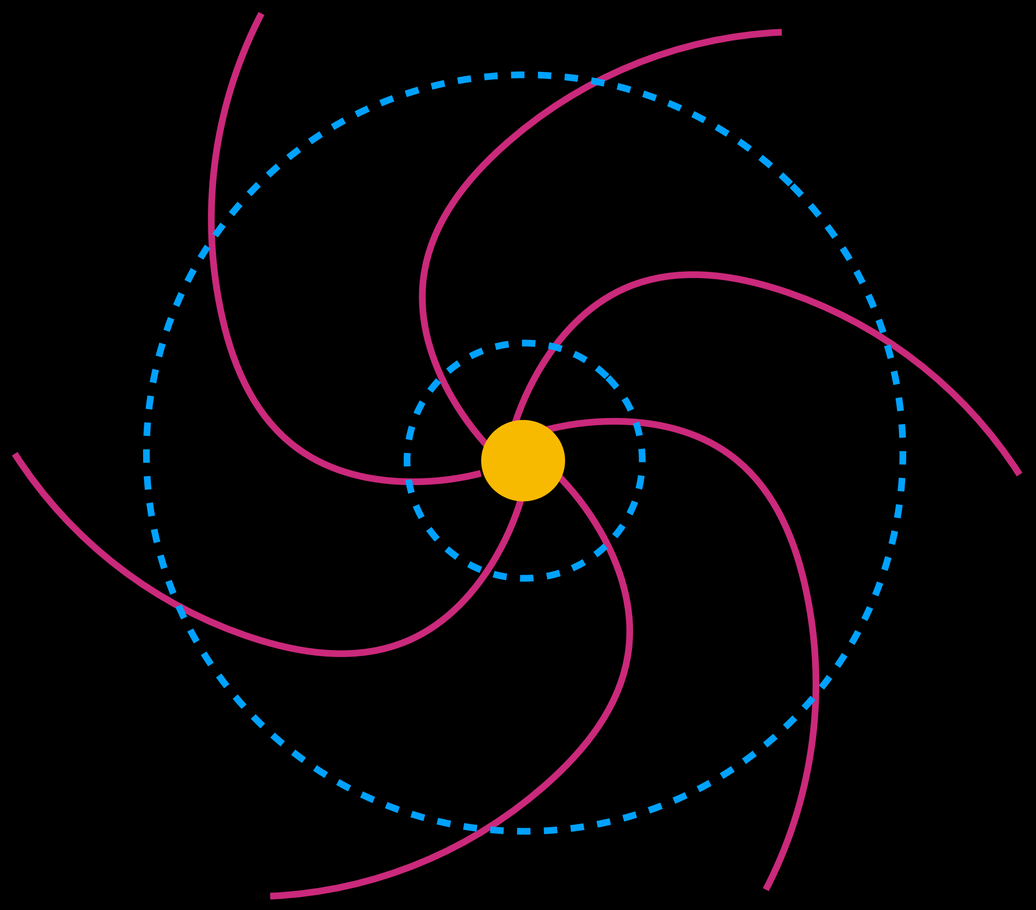
    2. Planetary properties

- What should new inputs be?

- Is the model still valid?



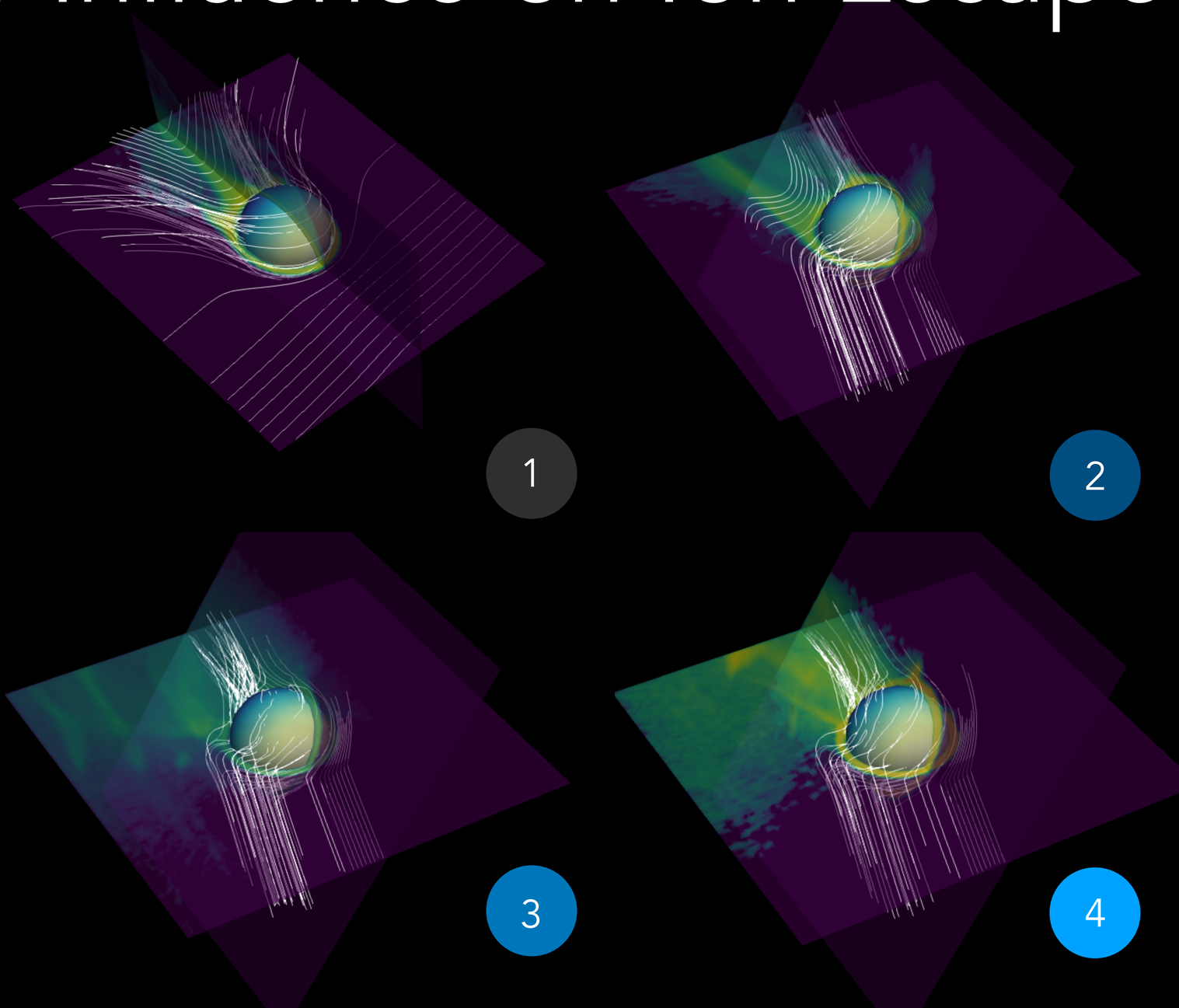
M-Dwarf Stellar Influence



- M-Dwarf stars are a great targets for finding habitable planets
- Stellar environment is challenging because habitable zone is closer
  - More intense solar wind
  - Higher Extreme UV energy input
  - More variable, space weather
  - Radially oriented stellar magnetic field

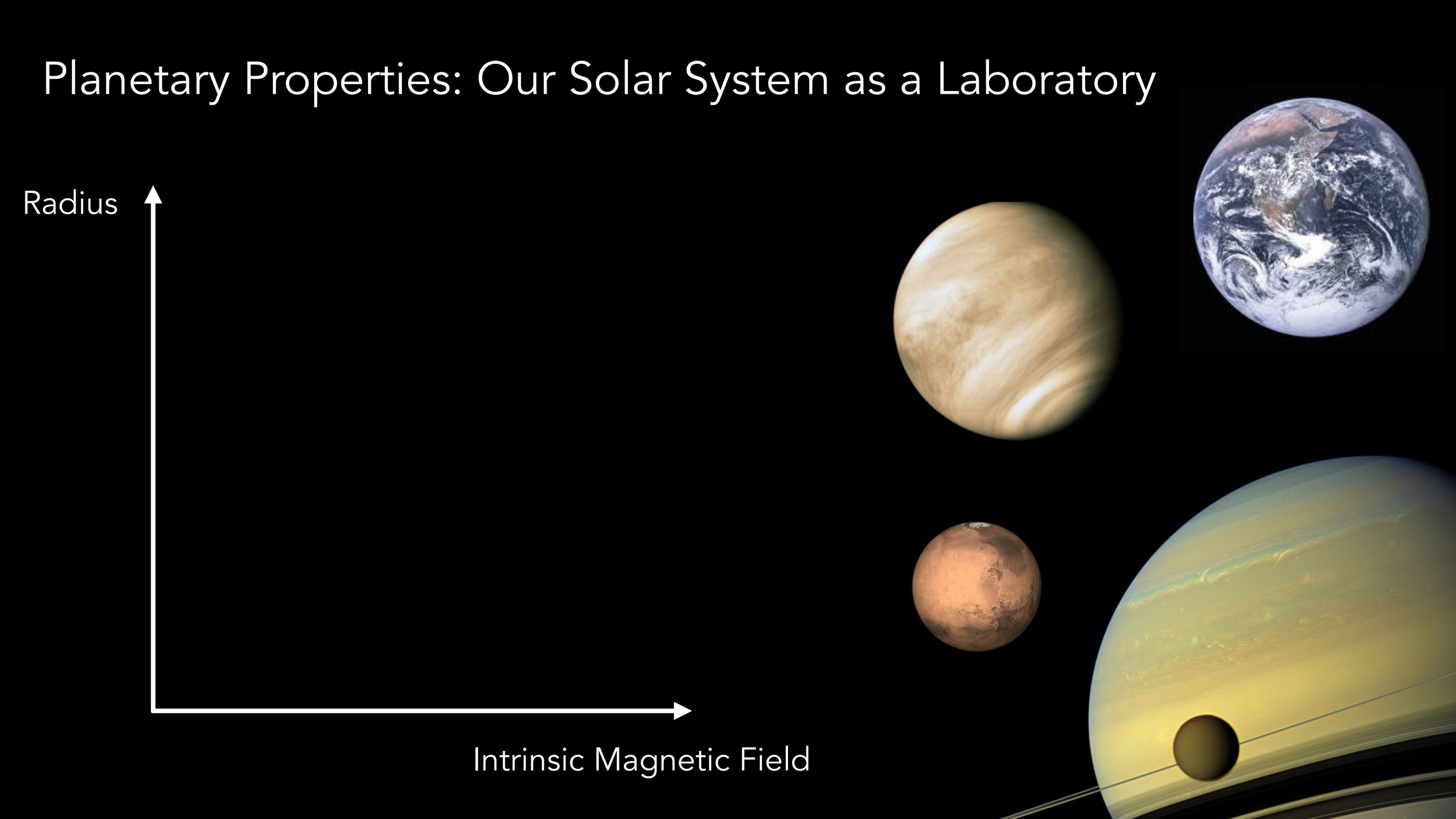
M-Dwarf Stellar Influence on Ion Escape

- 4 simulations, each changing one stellar influence parameter at a time
- Both ion loss rates and morphology change with stellar input
- Processes that are spatially distinct in the solar system are not necessarily distinct in exoplanets; rigorous definitions are important



[Egan 2018, submitted]

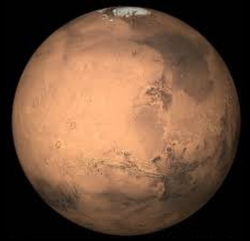
Planetary Properties: Our Solar System as a Laboratory

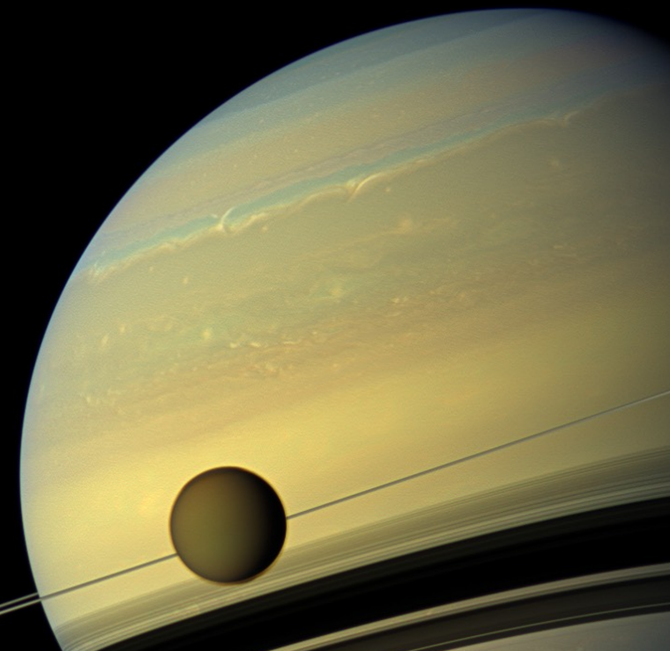


Planetary Properties: Our Solar System as a Laboratory

Radius

Earth





Intrinsic Magnetic Field

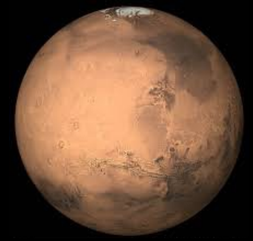
Planetary Properties: Our Solar System as a Laboratory

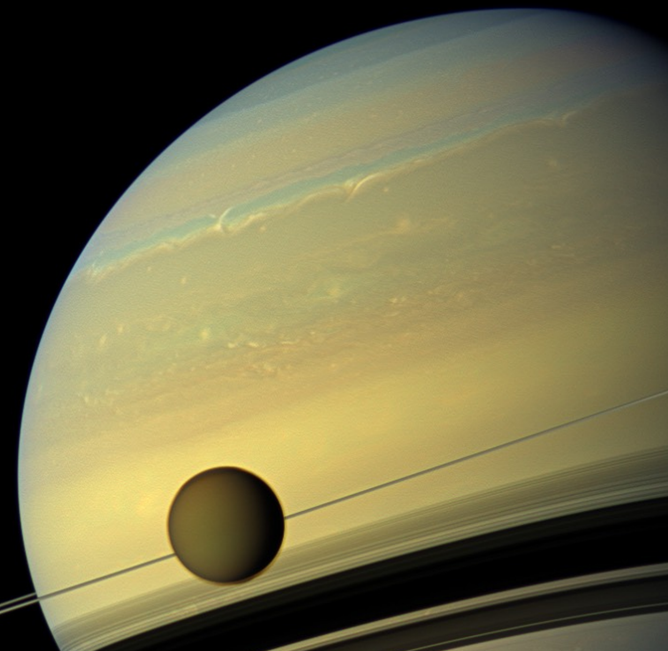
Radius

Venus

Earth

Intrinsic Magnetic Field





Planetary Properties: Our Solar System as a Laboratory

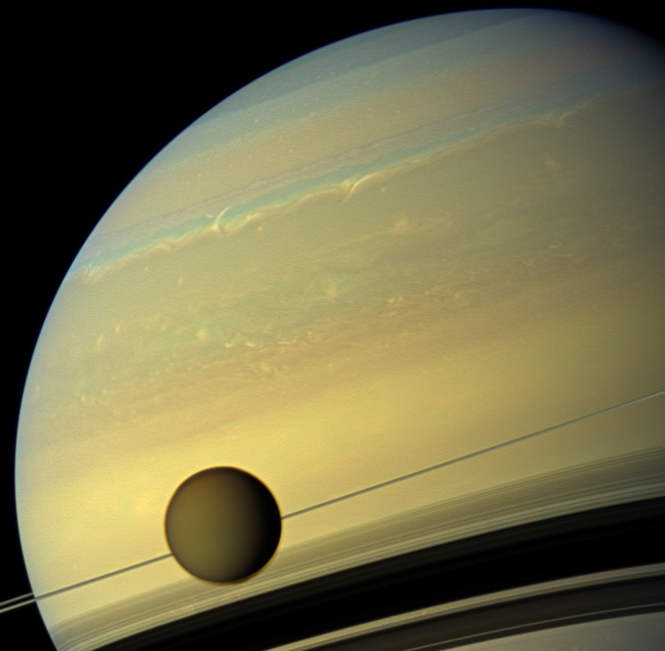
Radius

Venus

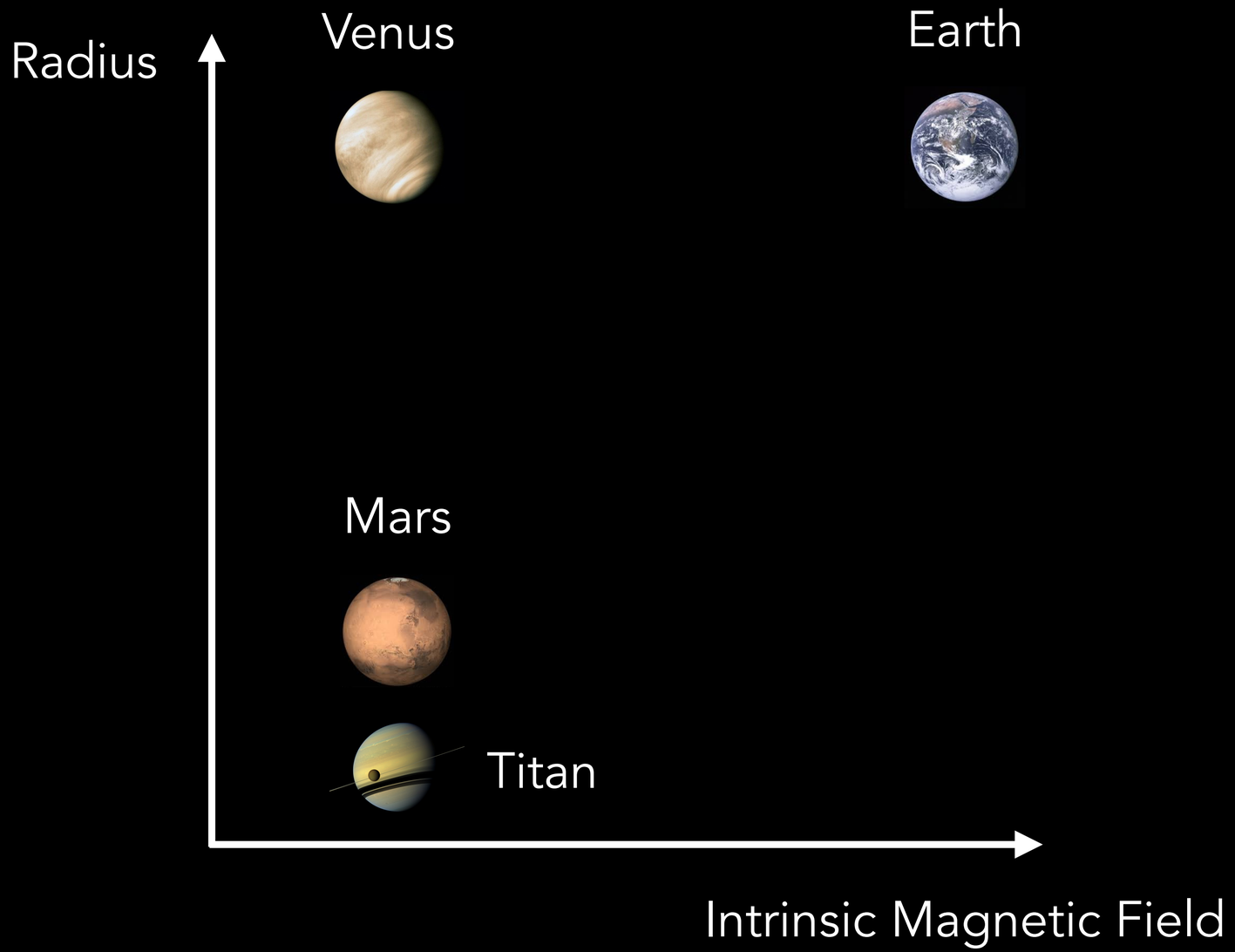
Earth

Mars

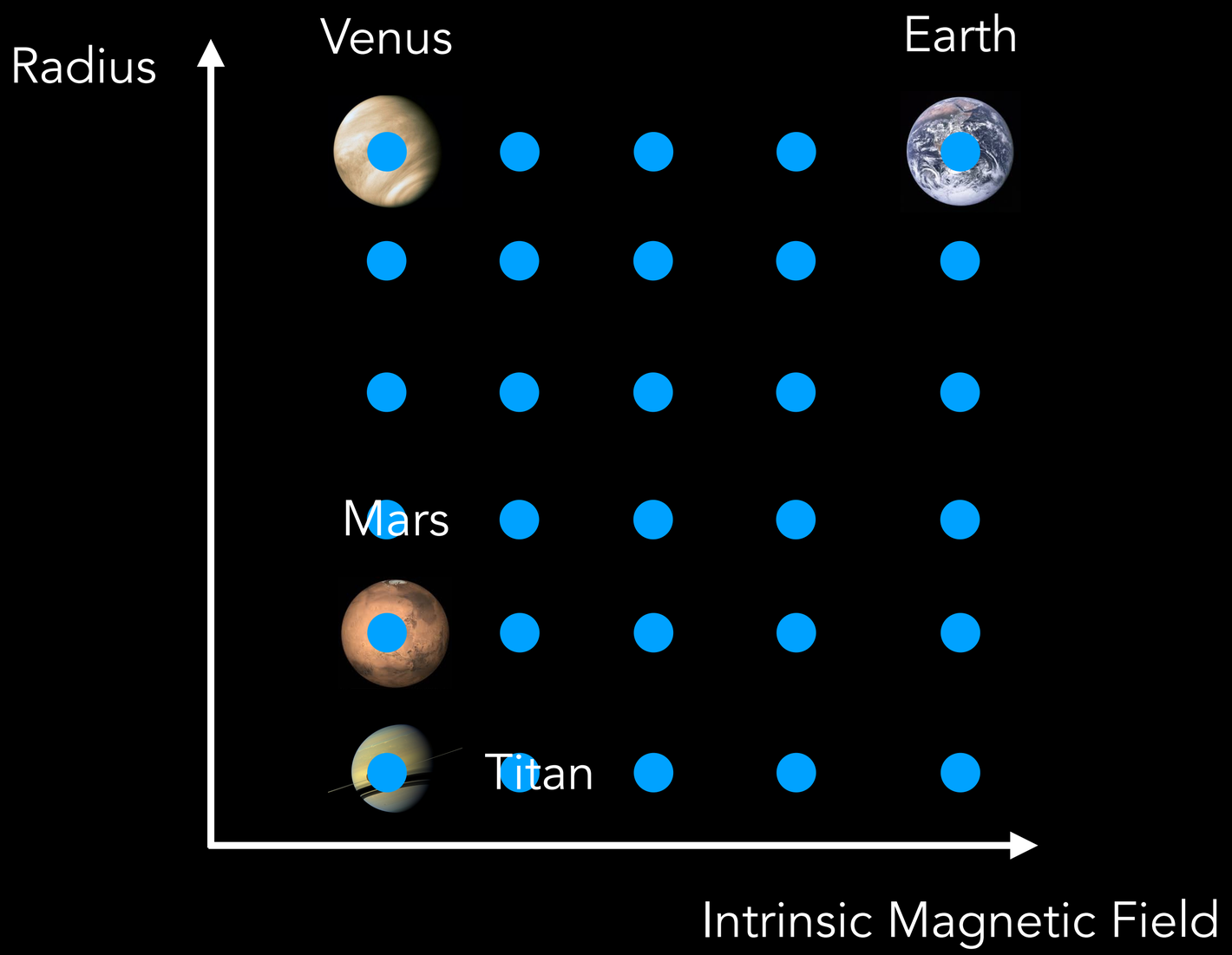
Intrinsic Magnetic Field



Planetary Properties: Our Solar System as a Laboratory



Planetary Properties: Our Solar System as a Laboratory



- Analyzing relationship between planetary properties and atmospheric escape
- Use easy observables (eg. radius) to help select targets for expensive follow up observations
- Using our solar system as constraining data points

Summary

- Exoplanet science beyond discovery is just beginning
- Atmospheric evolution has key implications for habitability
- Solar system observations can be used to validate plasma models, which are then applied to exoplanets
- Both extreme stellar wind and planetary properties influence ion escape

Boulder

DOE CSGF

MAVEN

Mars Atmosphere and Volatile Evolution Mission