National Aeronautics and Space Administration

The Heliophysics Big Year

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NASA Heliophysics Education Activation Team

NASA's Big Questions

1. **What causes the Sun to vary?**
2. **How do the Earth and the heliosphere respond?**
3. **What are the impacts on humanity?**

These Big Questions form the basis for the

Framework for Heliophysics Education

https://science.nasa.gov/learn/heat/big-ideas/

The Framework for Heliophysics Education

What are the impacts of the Sun on humanity?

1.1 The Sun is really big and its gravity influences all objects in the solar system. (PS2, ESS1)

1.2 The Sun is active and can impact technology on Earth via space weather. (PS1, PS2, PS4, ESS2, ESS3)

1.3 The Sun's energy drives Earth's climate, but the climate is in a delicate balance and is changing due to human activity. (PS1, PS2, PS3, LS4, ESS2, ESS3)

How do the Earth, the solar system, and heliosphere respond to changes on the Sun?

2.1 Life on Earth has evolved with complex diversity because of our location near the Sun. It is just right! (PS3, PS4, LS1, LS2, ESS2)

2.2 The Sun defines the space around it, which is different from interstellar space. (PS2, ESS1, ESS2)

2.3 The Sun is the primary source of light in our solar system.(PS1, PS2, PS3,PS4, ESS1)

What Causes the Sun to Vary?

3.1 The Sun is made of churning plasma, causing the surface to be made of complex, tangled magnetic fields. (PS1, PS2, ESS1, ESS2)

3.2 Energy from the Sun is created in the core and travels outward through the Sun and into the heliosphere. (PS1, PS3, PS4, ESS1, ESS2, ESS3)

3.3 Our Sun, like all stars, has a life cycle. (PS1, LS1, ESS1)

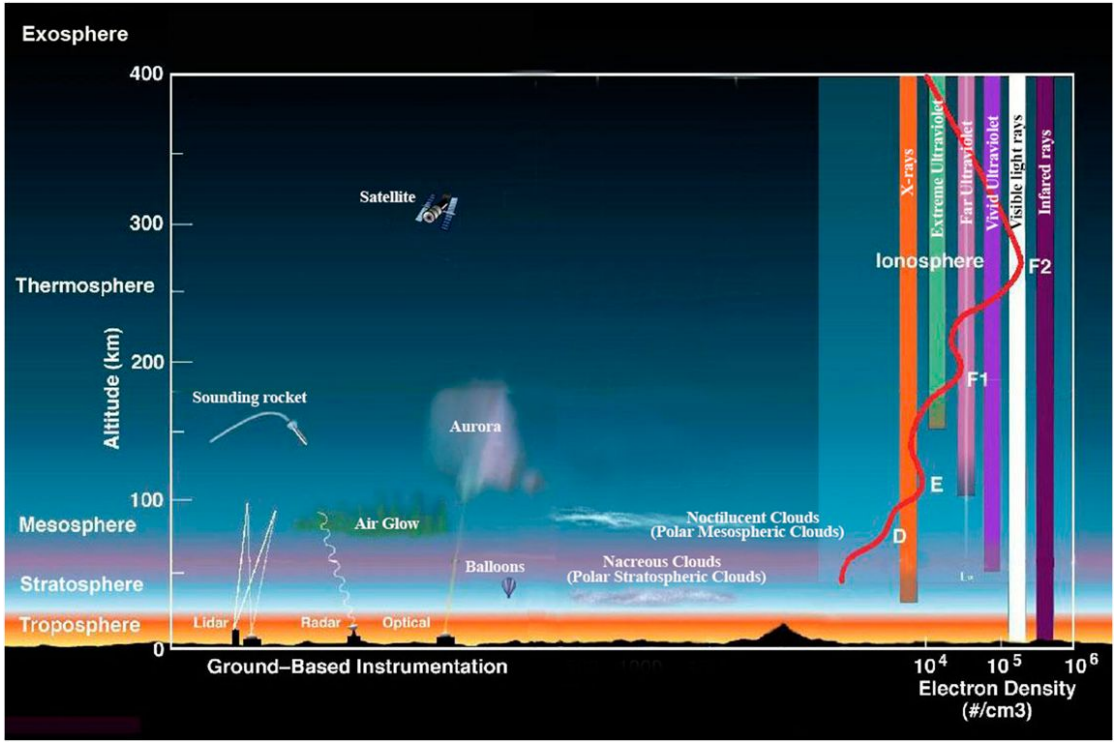
Investigating solar winds and atmosphere loss

The thickness of our atmosphere can be traversed if you:

- Bicycled from Baltimore to Washington DC (38 miles)
- Drove from San Francisco to Sacramento (92 miles)

Anatomy of our atmosphere

Our atmospheric layers



Credit: NASA/Goddard. https://www.nccs.nasa.gov/news-events/nccs-highlights/global-ozone-profile

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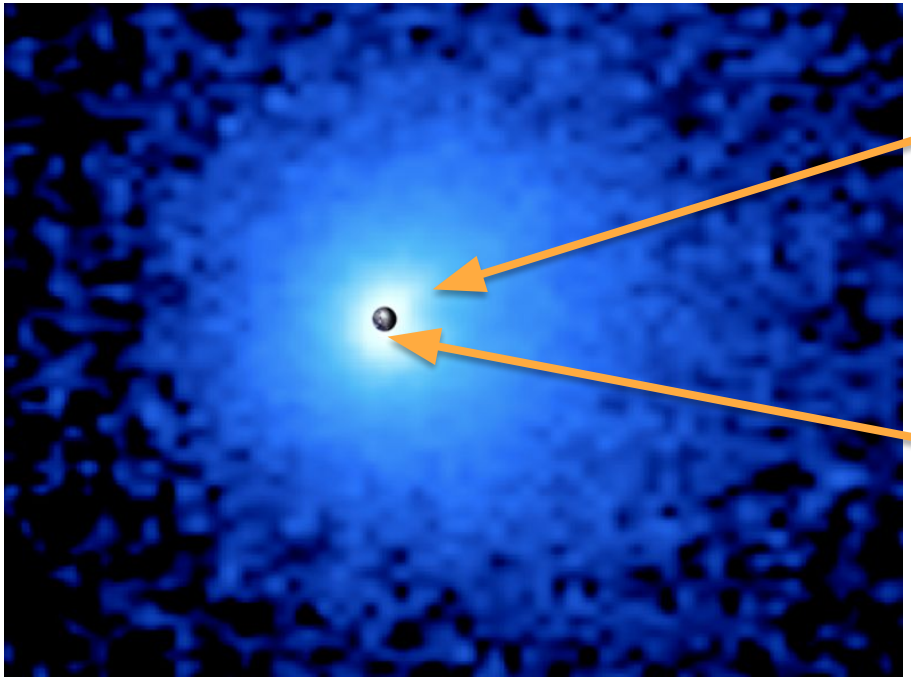
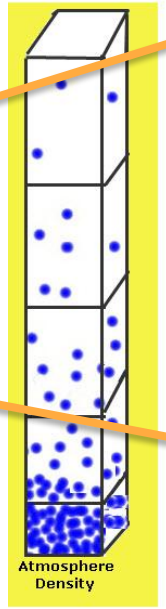
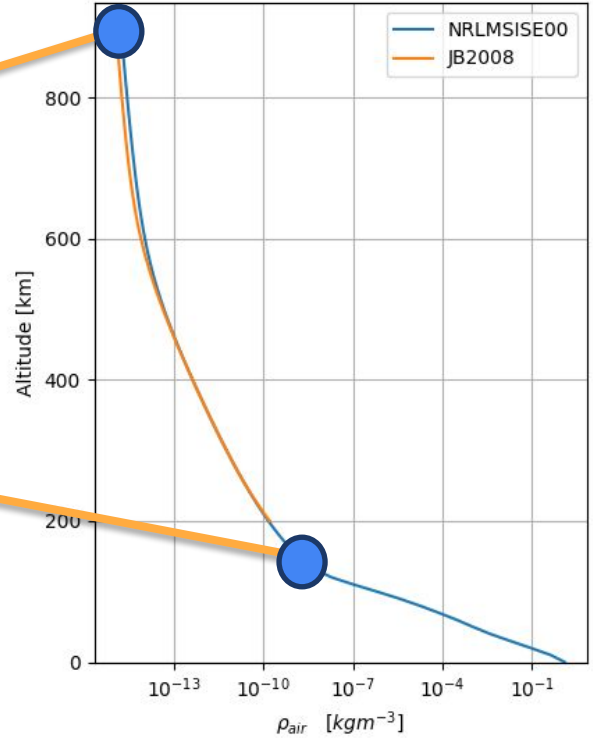
Extent of our atmosphere







Geocorona: Credit: PROCYON/ Rikkyo University

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When bad things happen to good planets

Atmosphere loss:

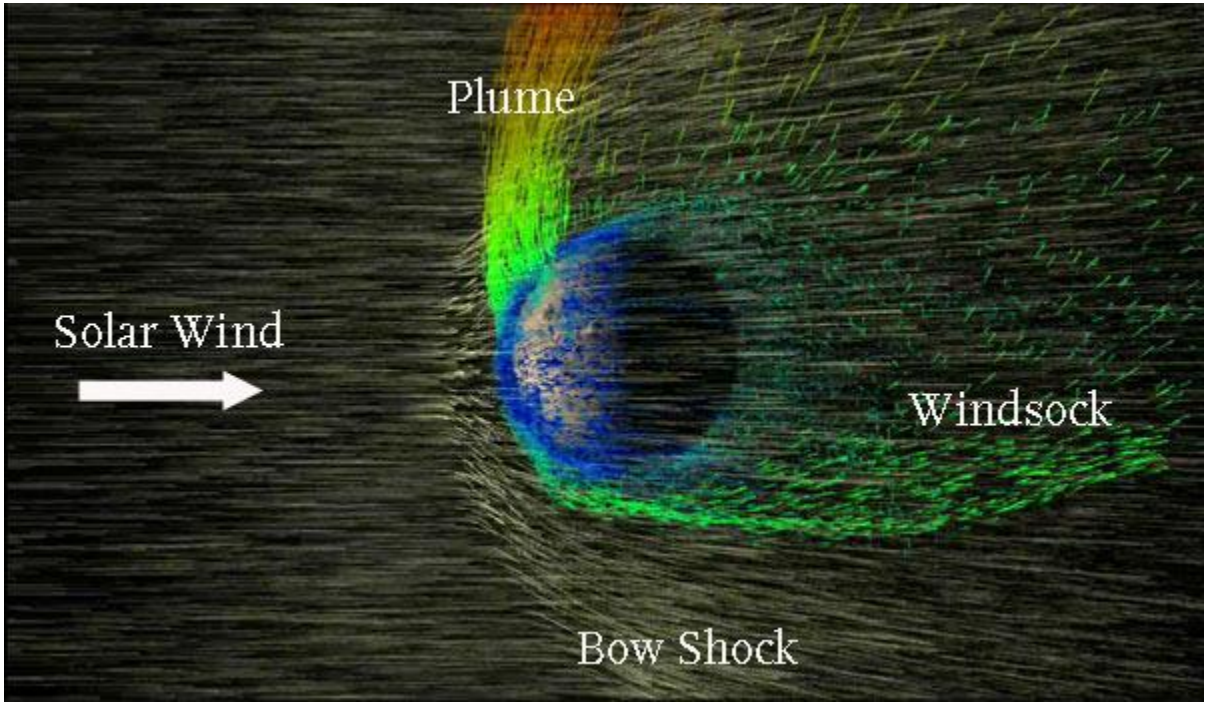
- **Photodissociation**
- **X-ray heating**
- **Jeans Mechanism**
- **Solar Wind**

Current mass: **5,000 trillion tons**

Current Earth loss rate:

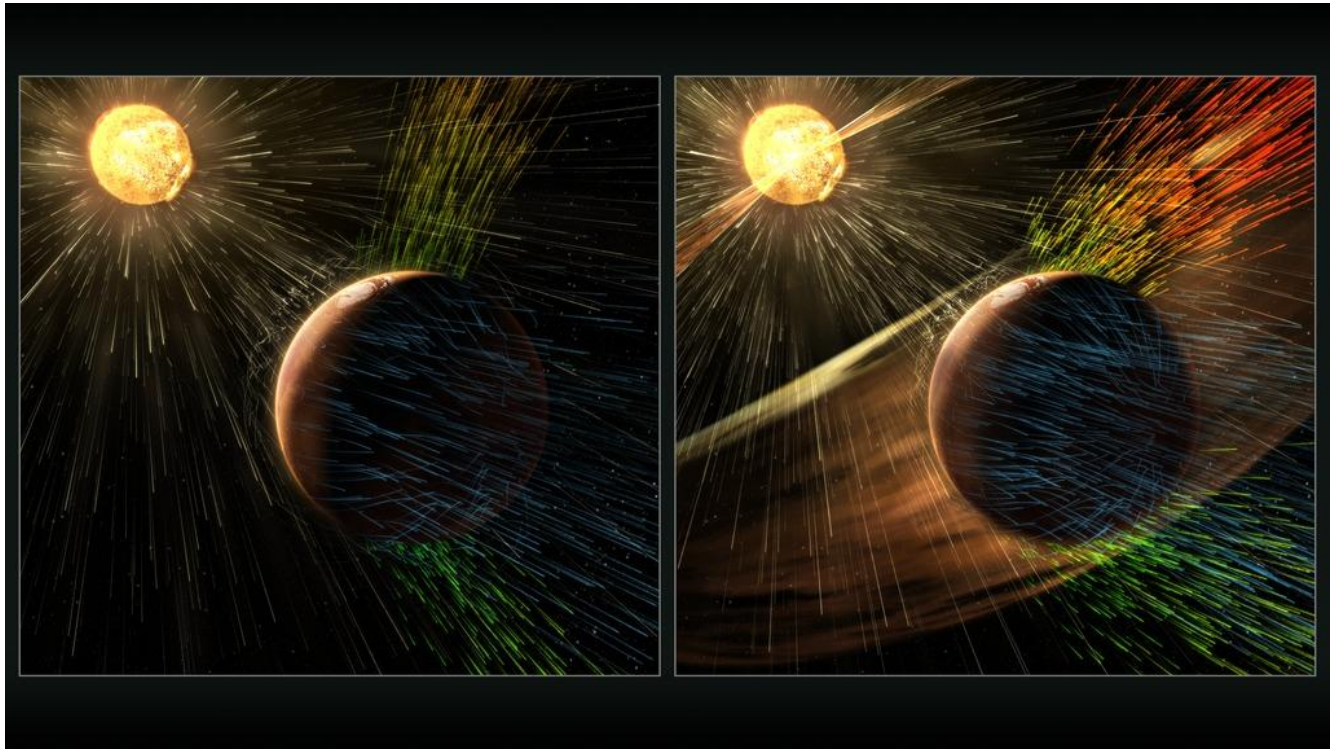
- 95,000 tons/yr hydrogen
- 1,500 tons/yr helium
- 100 tons/yr oxygen

When bad things happen to good planets



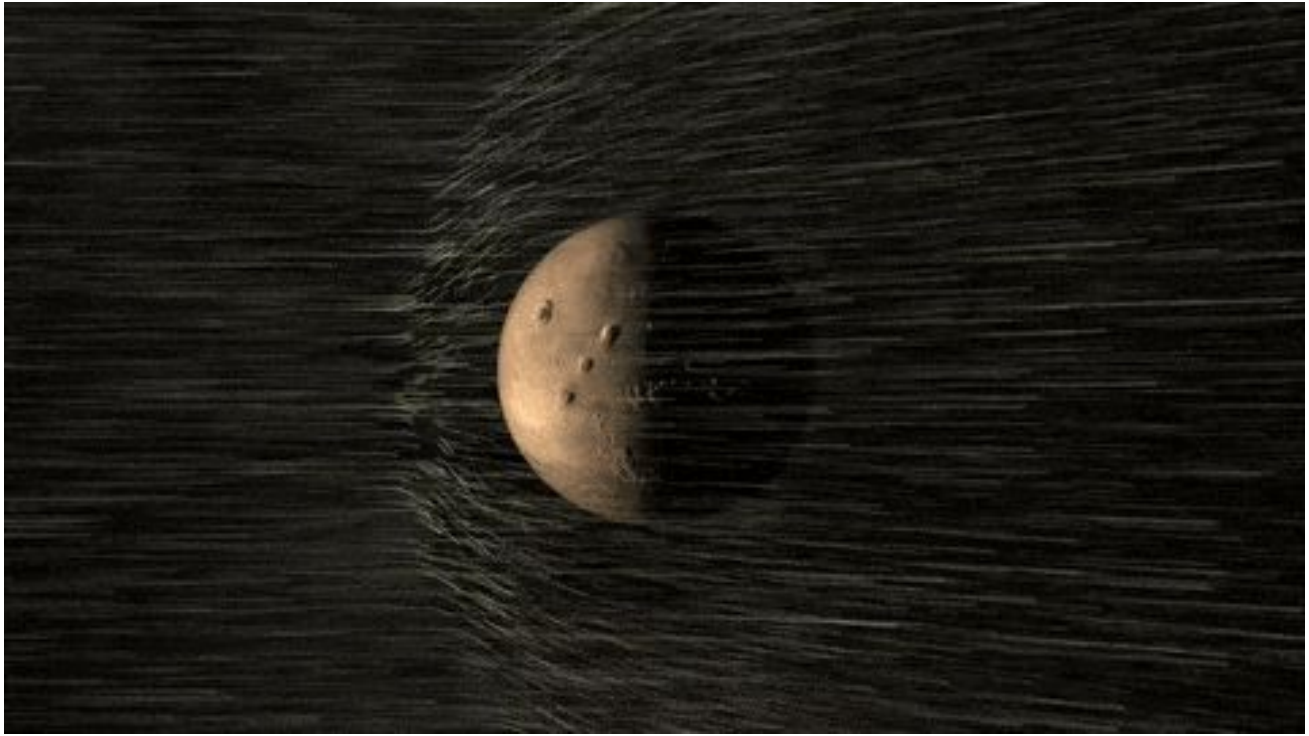
Credit: NASA / Greg Shirah, labels by S&T

When bad things happen to good planets



Credit: NASA/MAVEN https://www.youtube.com/watch?v=8Uwt9HxOH74

Atmospheric stripping - Mars



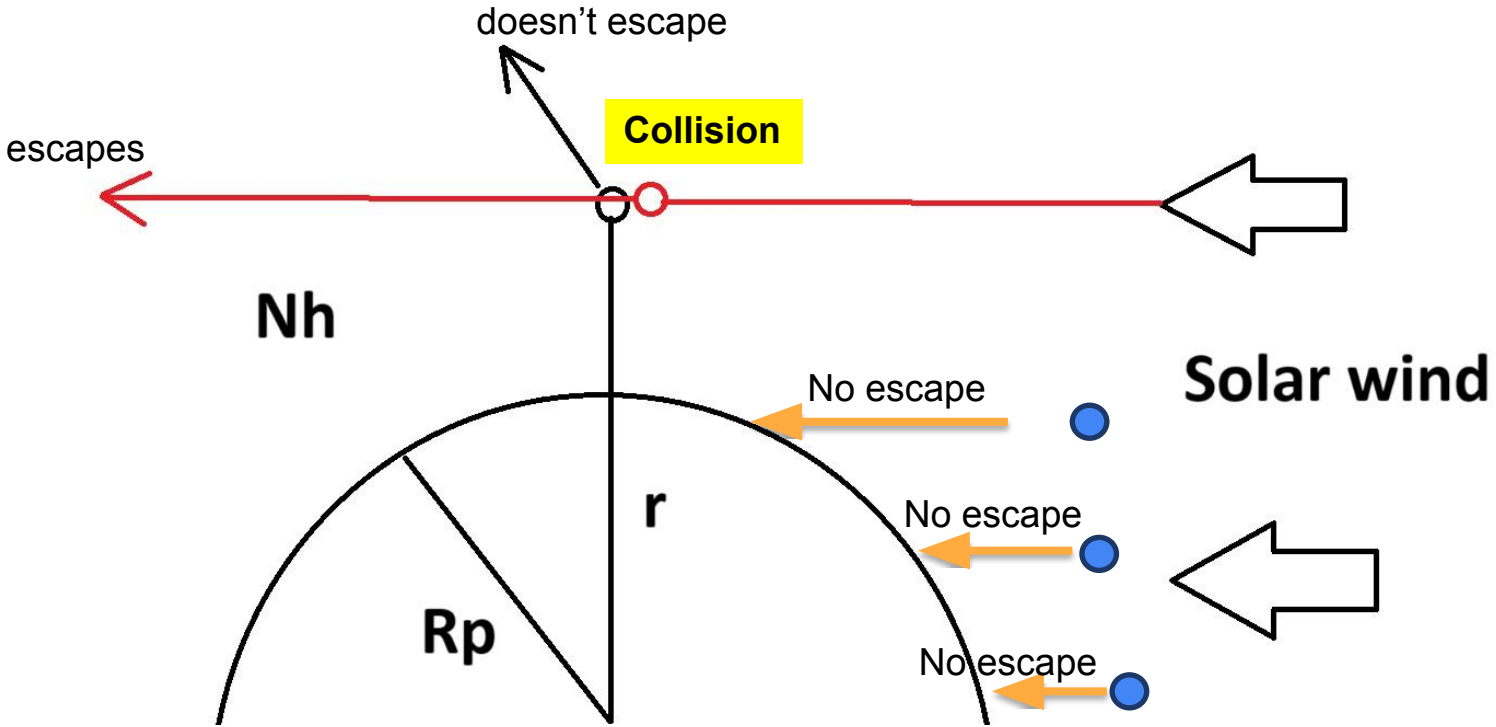
Credit: NASA/MAVEN https://www.youtube.com/watch?v=8Uwt9HxOH74

Solar wind ablation and spallation modeling

Can we model atmosphere escape by solar wind collisions?

- ✔ Solar wind is mostly protons
- ✔ Atmosphere is mostly hydrogen of uniform density
- ✔ Every solar proton collision removes exactly one hydrogen atom

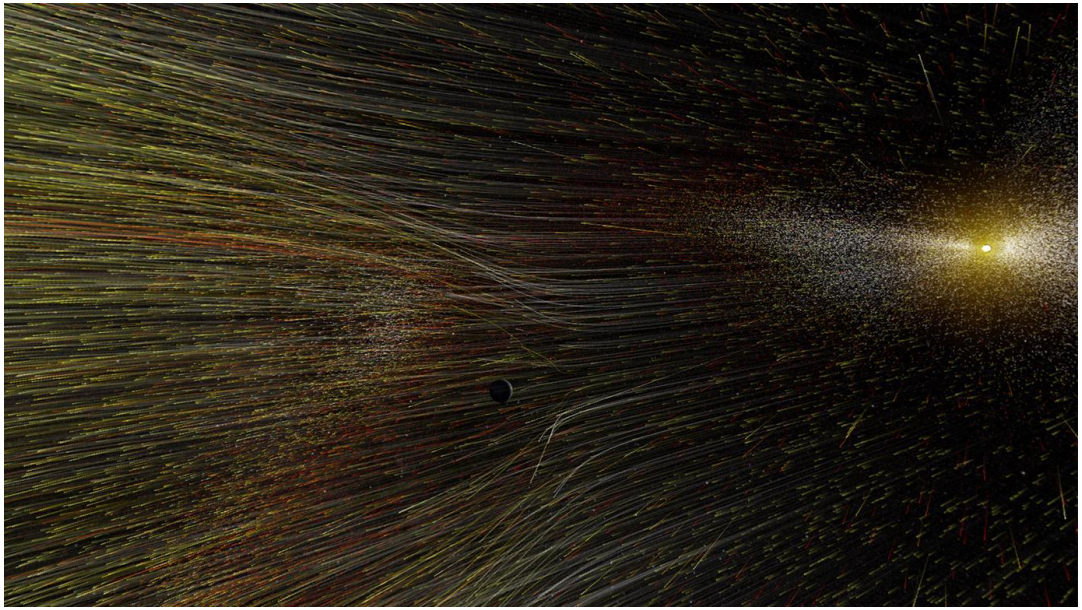
Solar wind ablation and spallation modeling



Solar wind ablation and spallation modeling

Solar wind flow

Sznajder (2023)
2.7×10^8 protons/cm^2/sec
(SOHO,WIND,ACE)



Artist rendering of solar wind: Credit NASA

https://www.sciencedirect.com/science/article/abs/pii/S0273117723000947

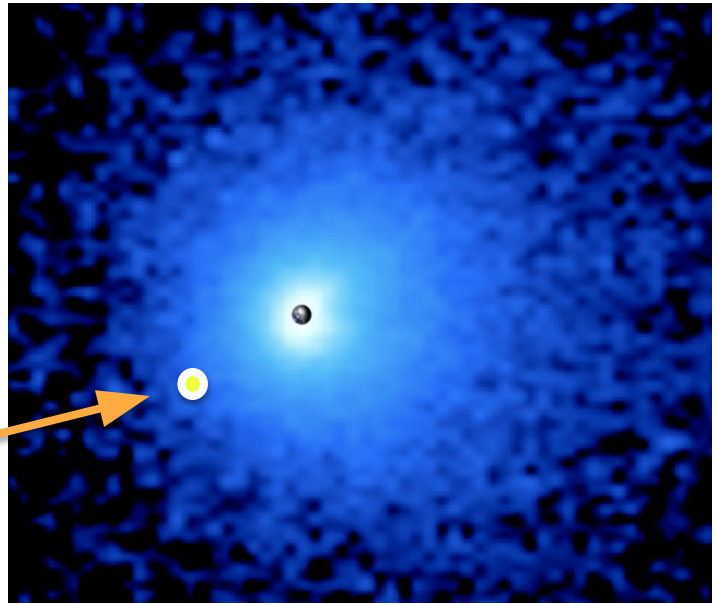
Solar wind ablation and spallation modeling

Geocorona density

Gomez et al (2021)

IBEX spacecraft detects

10 cm^{-3} at 10 Re



Credit: PROCYON/Rikkyo University)

https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2021GL093695

Solar wind ablation and spallation modeling

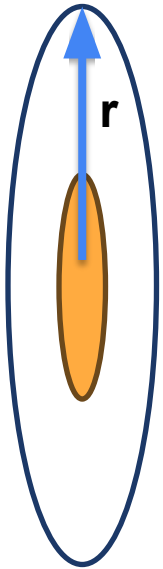
Geometric factors

Radius of Earth **1 Re = 6,378 km**

Outer limit to geocorona: **20 Re** **or** **0.4 lunar distance**

Solar wind ablation and spallation modeling

How many atmospheric collisions per second?



Area = $\pi r^2 - \pi R^2$ where R = 6,378 km

r = 20Re = 1.3×10^5 km = 1.3×10^{10} cm

Area = 5.3×10^{20} cm^2

Earth area = π (637800000 cm)^2 = 1.3×10^{18} cm^2

Collisions = solar wind flow x Annual Area

= (2.7×10^8 protons/cm^2/sec) x (5.3×10^{20} cm^2 – 1.3×10^{18} cm^2)

= **1.4×10^{29} collisions/sec**

Solar wind ablation and spallation modeling

How much mass is ejected every year?

Collisions = 1.4×10^{29} per second

Each collisions ejects **one** hydrogen atom (proton); mass = 1.7×10^{-27} kg

Mass loss = 1.4×10^{29} protons/sec x 1.7×10^{-27} kg/proton
= 240 kg/sec of hydrogen.

Mass loss per year = 240 kg/sec x 3.1×10^{7} sec/yr
= **7.6 million tons of hydrogen/year**

But the measured number is 95,000 tons/year so our model is off by 80x

Solar wind ablation and spallation modeling

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Solar wind ablation and spallation modeling

Professional modeling with all known factors and math used:

Model building is an iterative process.

This is the first ‘loop’

Scientists call it a ‘toy’ model or a ‘back of the envelope’ calculation

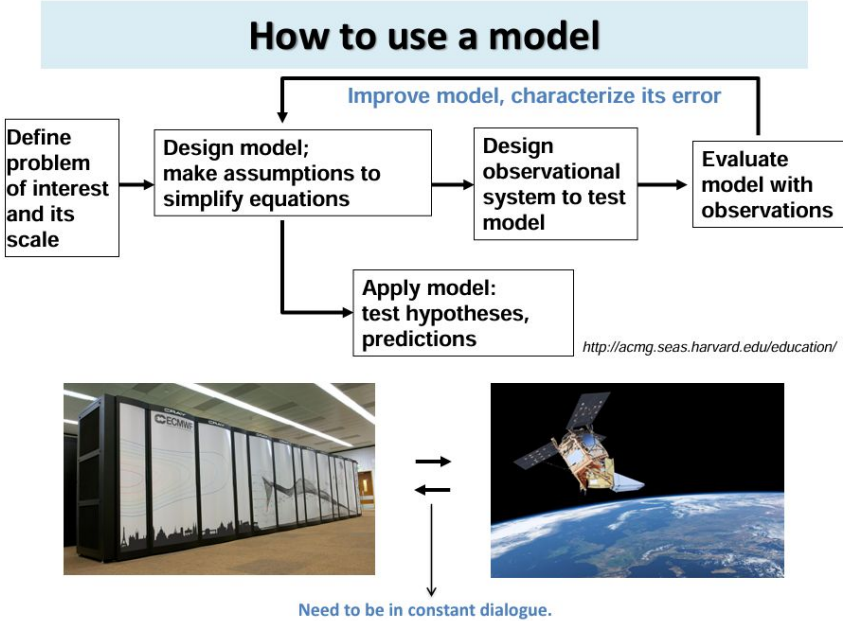

Diagram from: https://atmosphere.copernicus.eu/sites/default/files/custom-uploads/3rd-joint-training/ACT2021_AVoulgarakis.pdf

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When bad things happen to good planets

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That’s what we just created

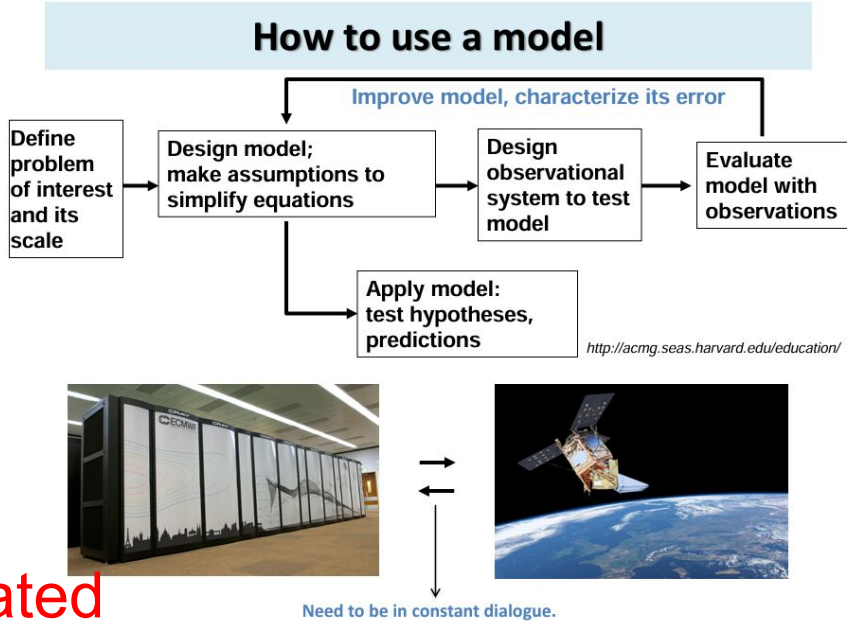

Diagram from: https://atmosphere.copernicus.eu/sites/default/files/custom-uploads/3rd-joint-training/ACT2021_AVoulgarakis.pdf

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Solar wind ablation and spallation modeling

Check your assumptions- Why were we off by 80x?

First of all our Toy Model wasn't all that bad

Instead of being off by only 80x,

we could just as easily have been off by 1,000 or 1,000,000 !!!!!!!!!

Solar wind ablation and spallation modeling

Check your assumptions- Why were we off by 80x?

- ✔ Solar wind is mostly protons – this is measured – Probably not a problem

- ✔ Atmosphere is mostly hydrogen of uniform density
  - Atmosphere contains oxygen and nitrogen ions - Treat each species separately
  - Density falls exponentially with distance - Warning: Calculus needed
  - Density varies with solar wind x-ray heating – Even more calculus

- ✔ Every solar proton collision removed one hydrogen atom. Collision process is complex.
  - More than one ion can be ejected – Stochastic modeling
  - Ejection only happens if ion speed higher than escape speed – Calculus

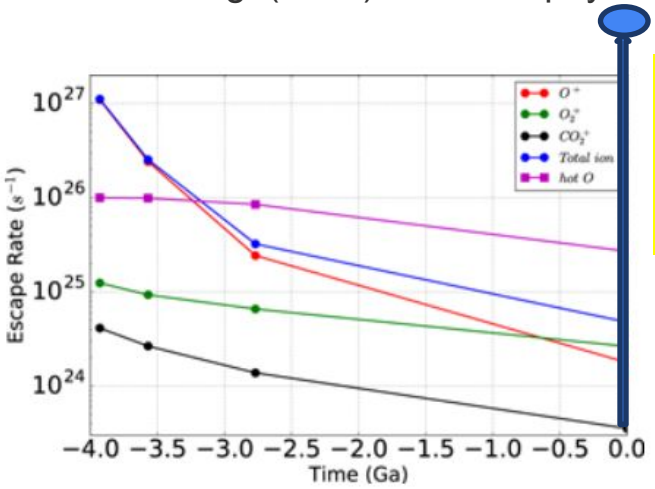
- ✔ Solar wind spallation not the only ejection mechanism – Examine and model all others

Solar wind ablation and spallation modeling

Professional modeling with all known factors and math used:

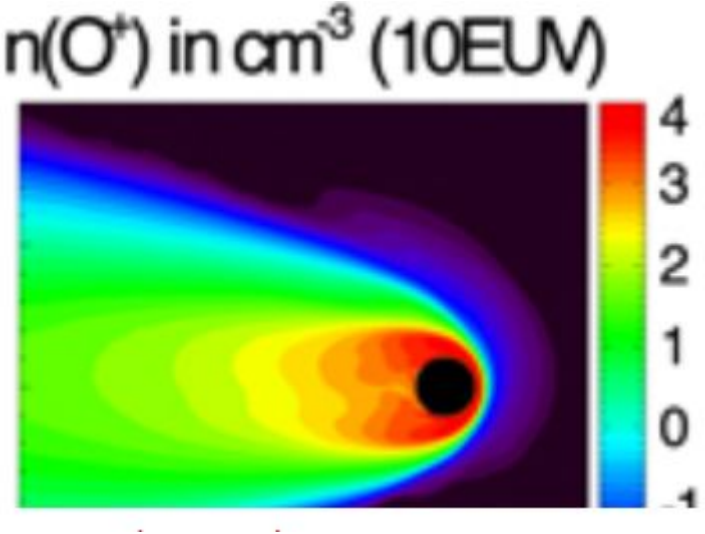
Modeling Martian Atmospheric Losses over Time: Implications for Exoplanetary Climate Evolution and Habitability

Chuanfei Dong (2018) The Astrophysical Journal v. 859, L14.



Our estimate For EARTH

1.4×10^{29}/sec



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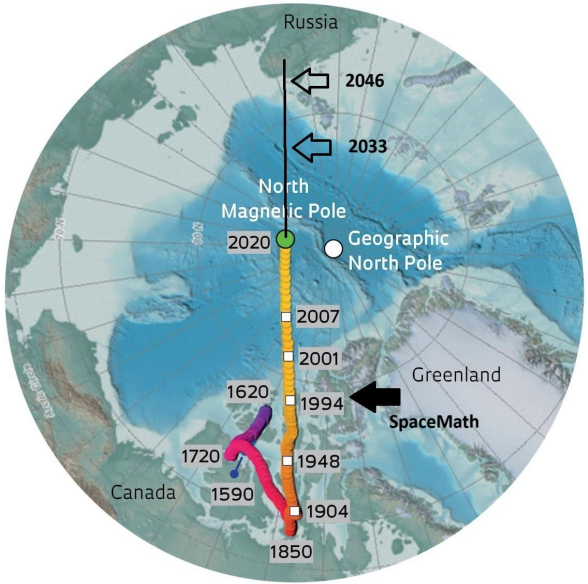
Next Time : April

Where is the Magnetic North Pole now?



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