Exoplanet Climatology

A Pathway to Accurate Assessments of Planetary Habitability

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ExoSoCal Meeting
September 18-19, 2017

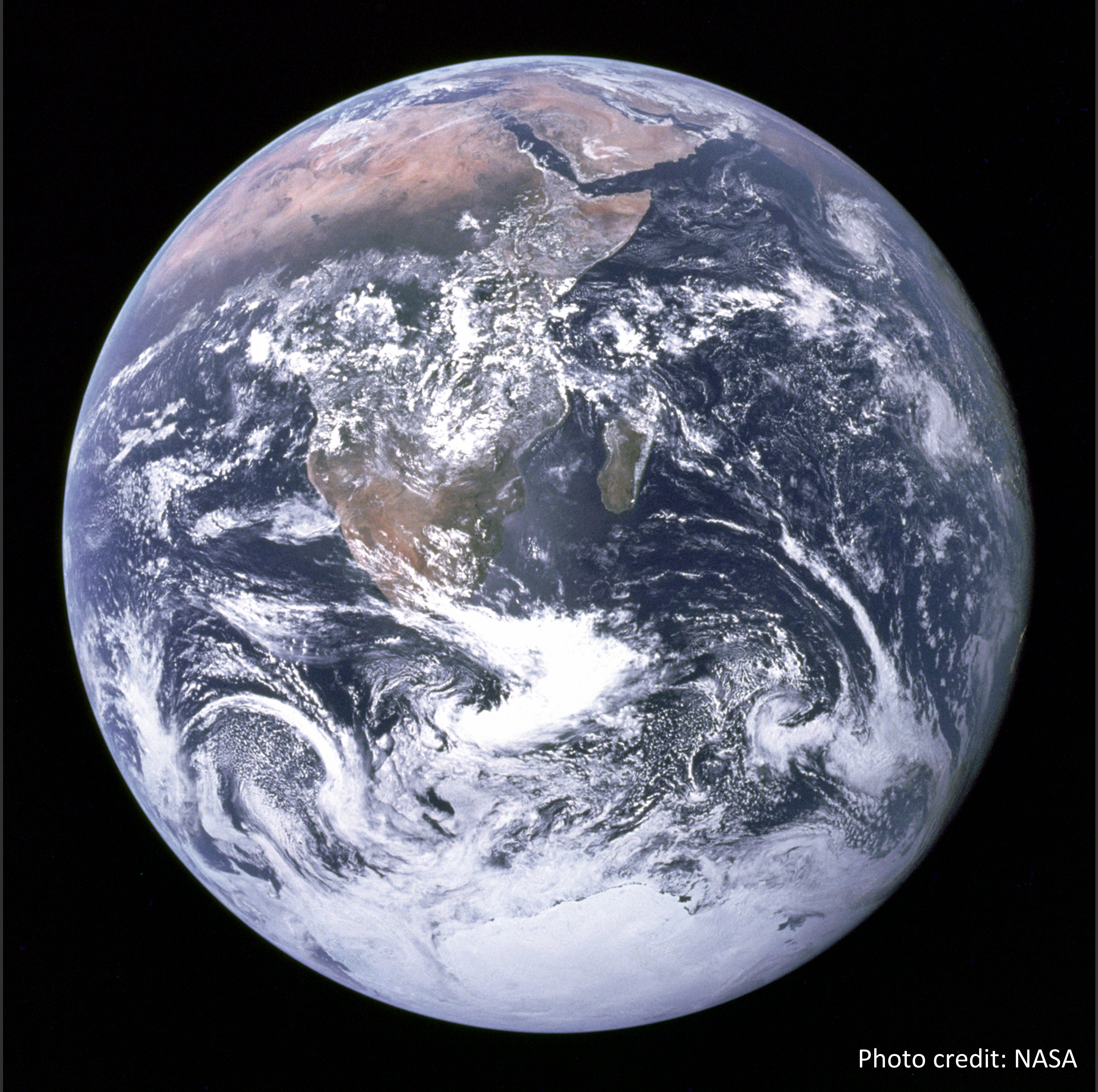
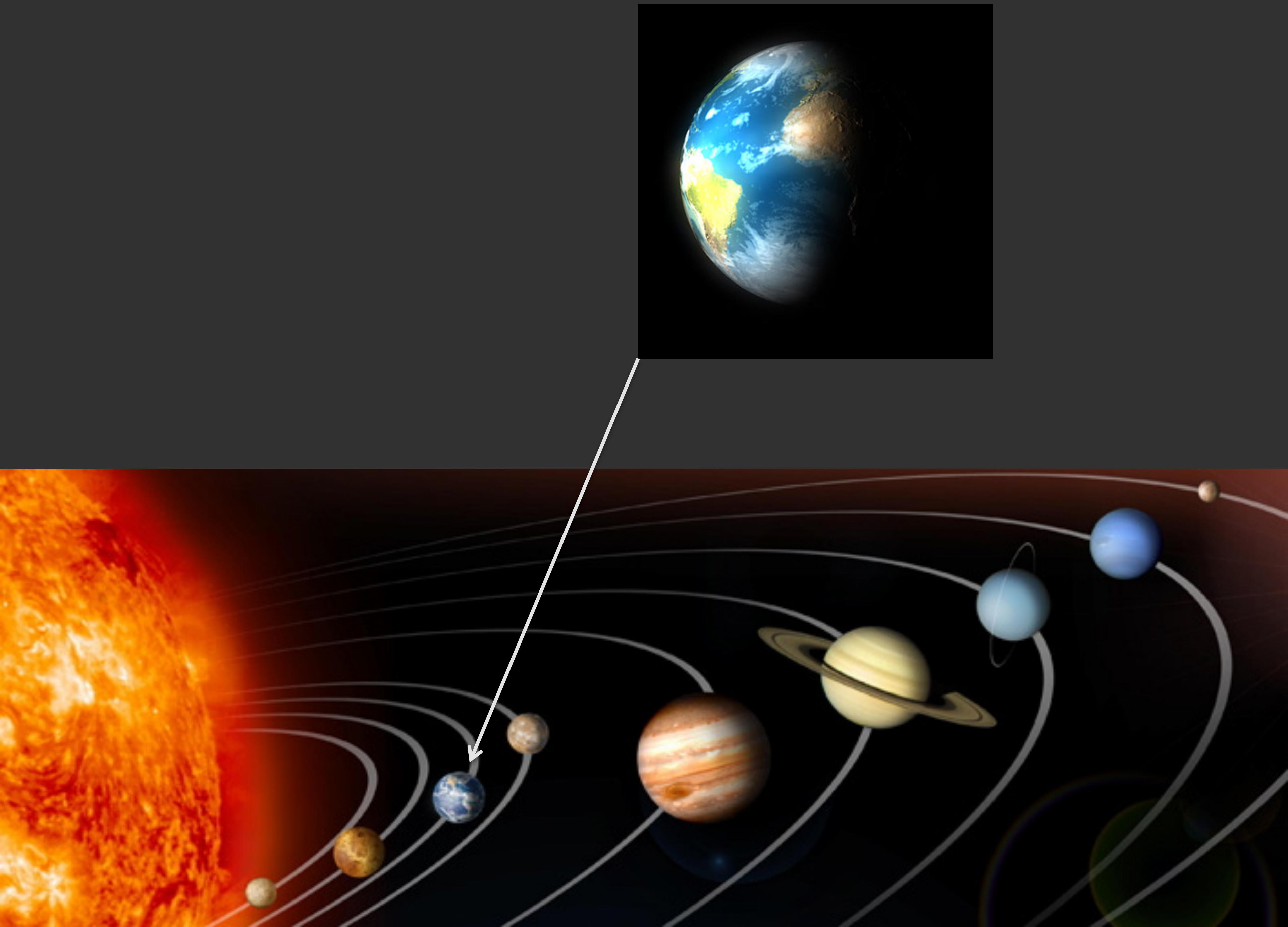
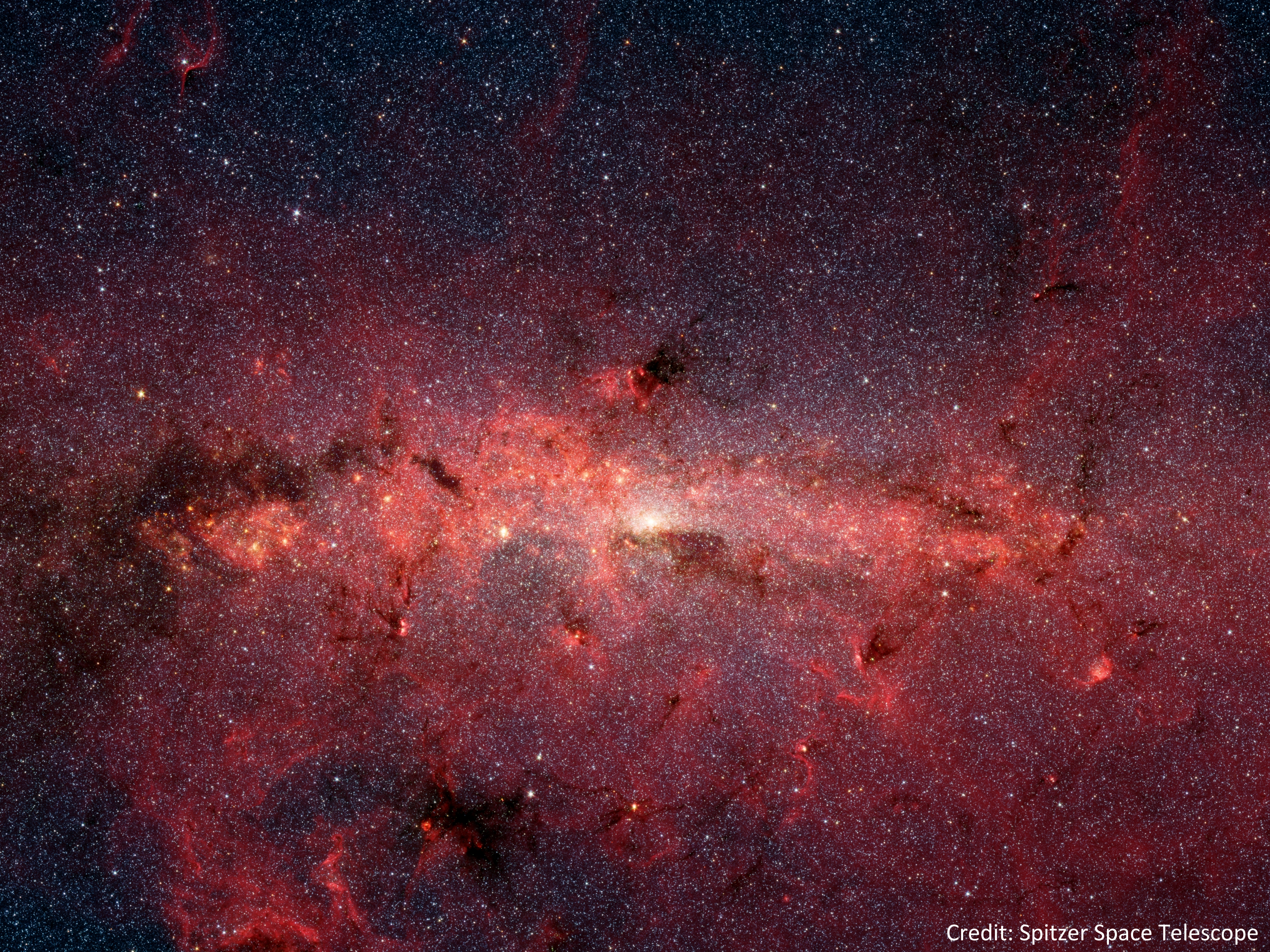


Photo credit: NASA



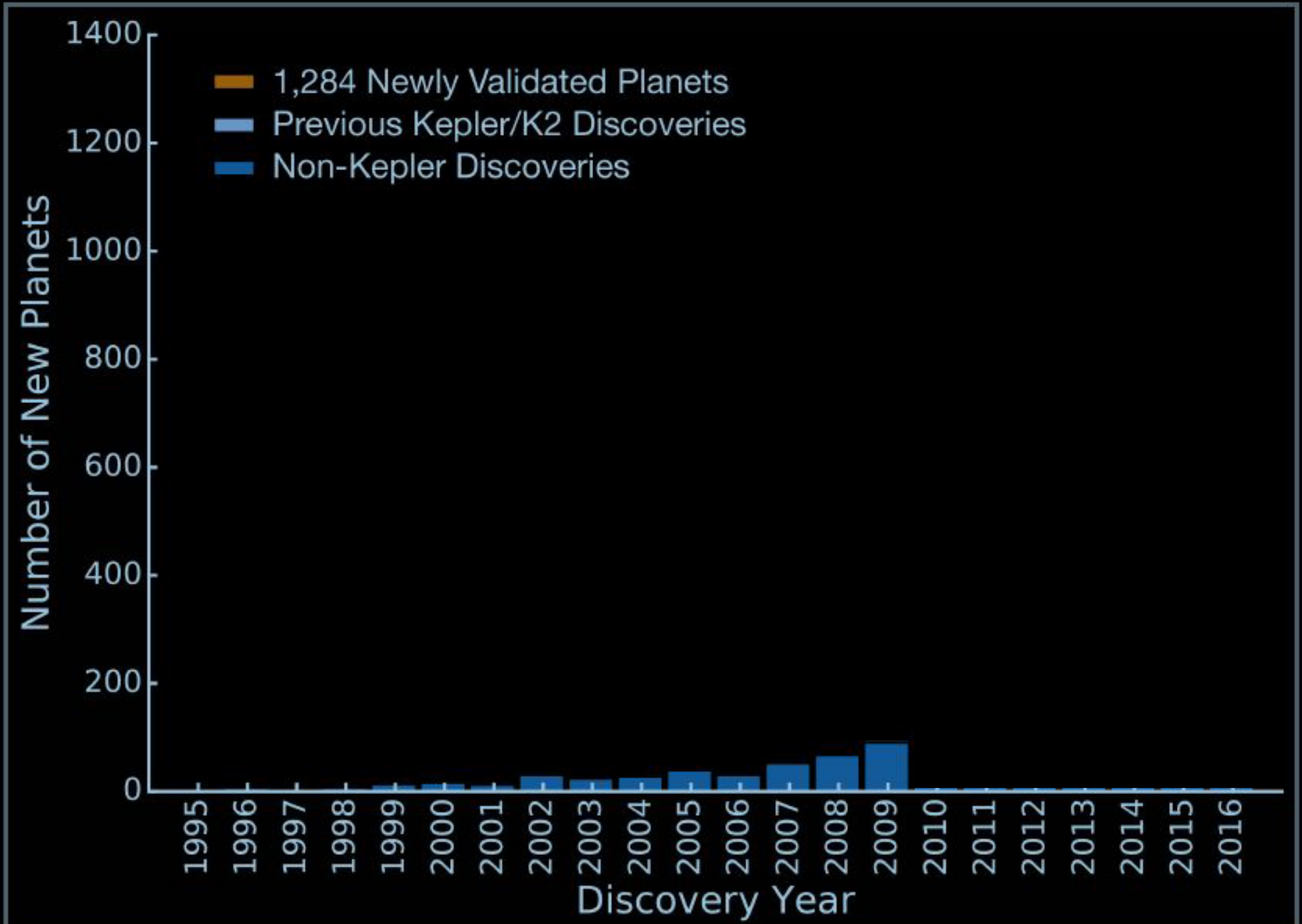


Credit: Spitzer Space Telescope


Credit: NASA, ESA, and S. Beckwith (STScI) and the HUDF Team

Exoplanet Discoveries Through the Years

As of May 10, 2016

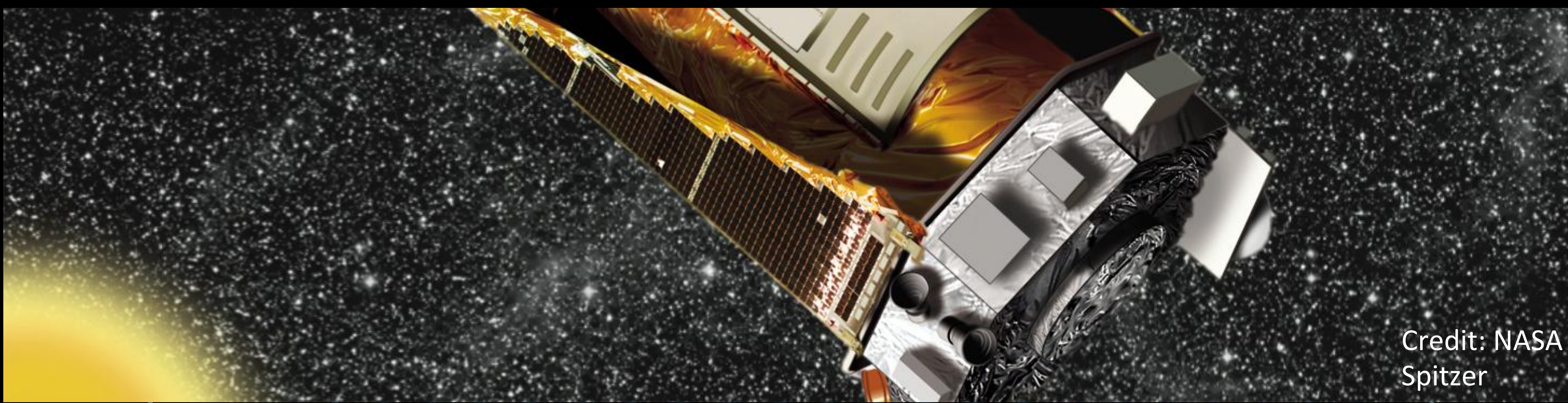


Credits: NASA Ames / W. Stenzel; Princeton University / T. Morton

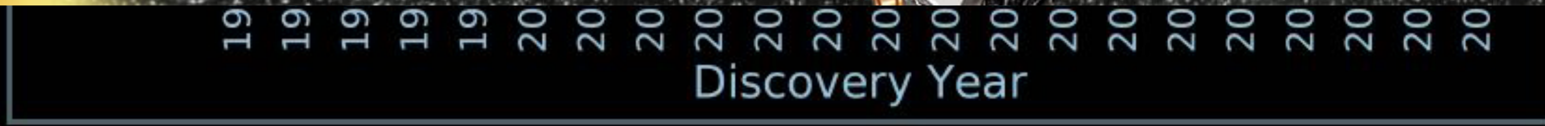
Kepler

3510 confirmed planets

as of 9/15/17, Credit: NASA Exoplanet Archive



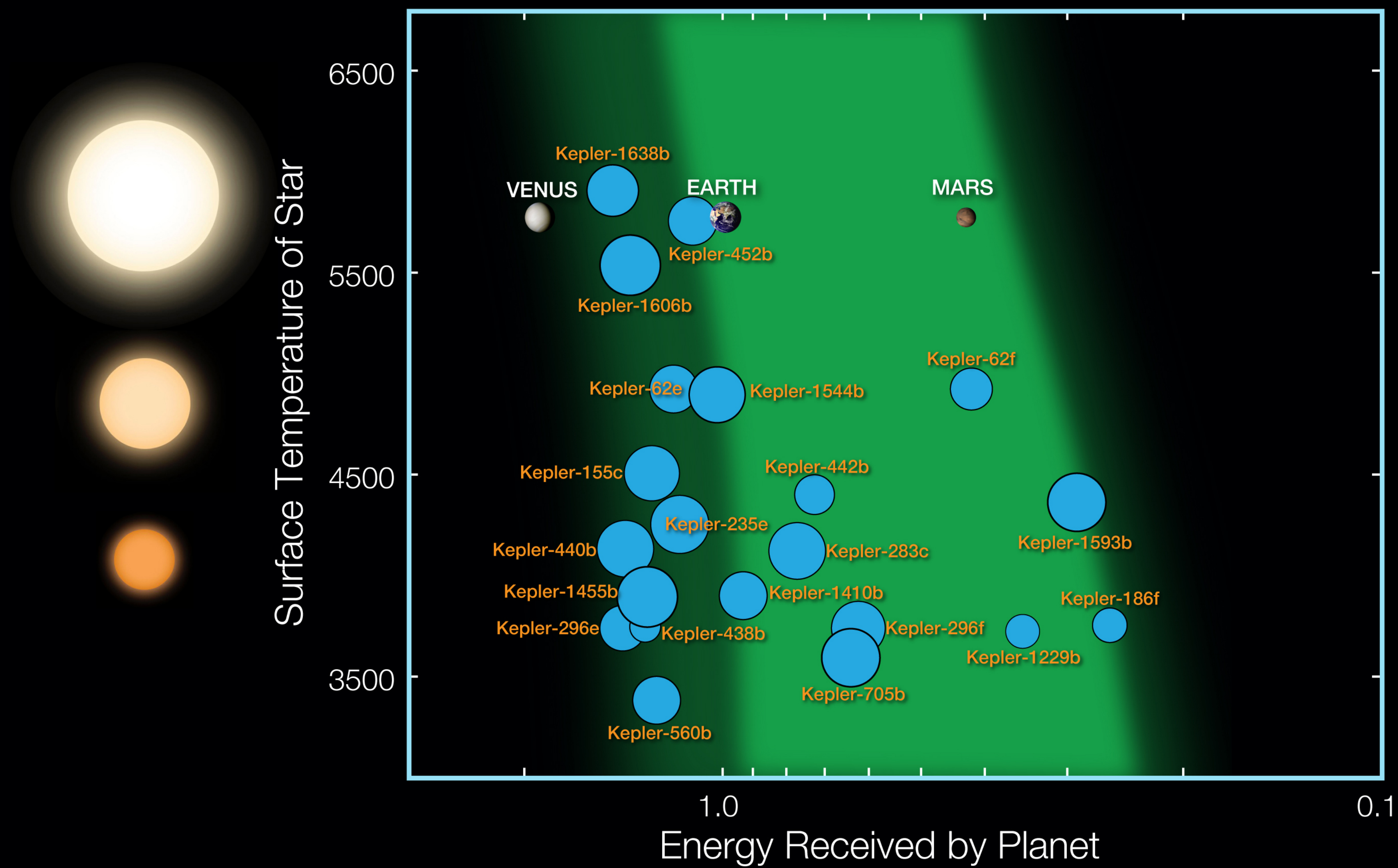
Credit: NASA Spitzer



Credits: NASA Ames / W. Stenzel; Princeton University / T. Morton

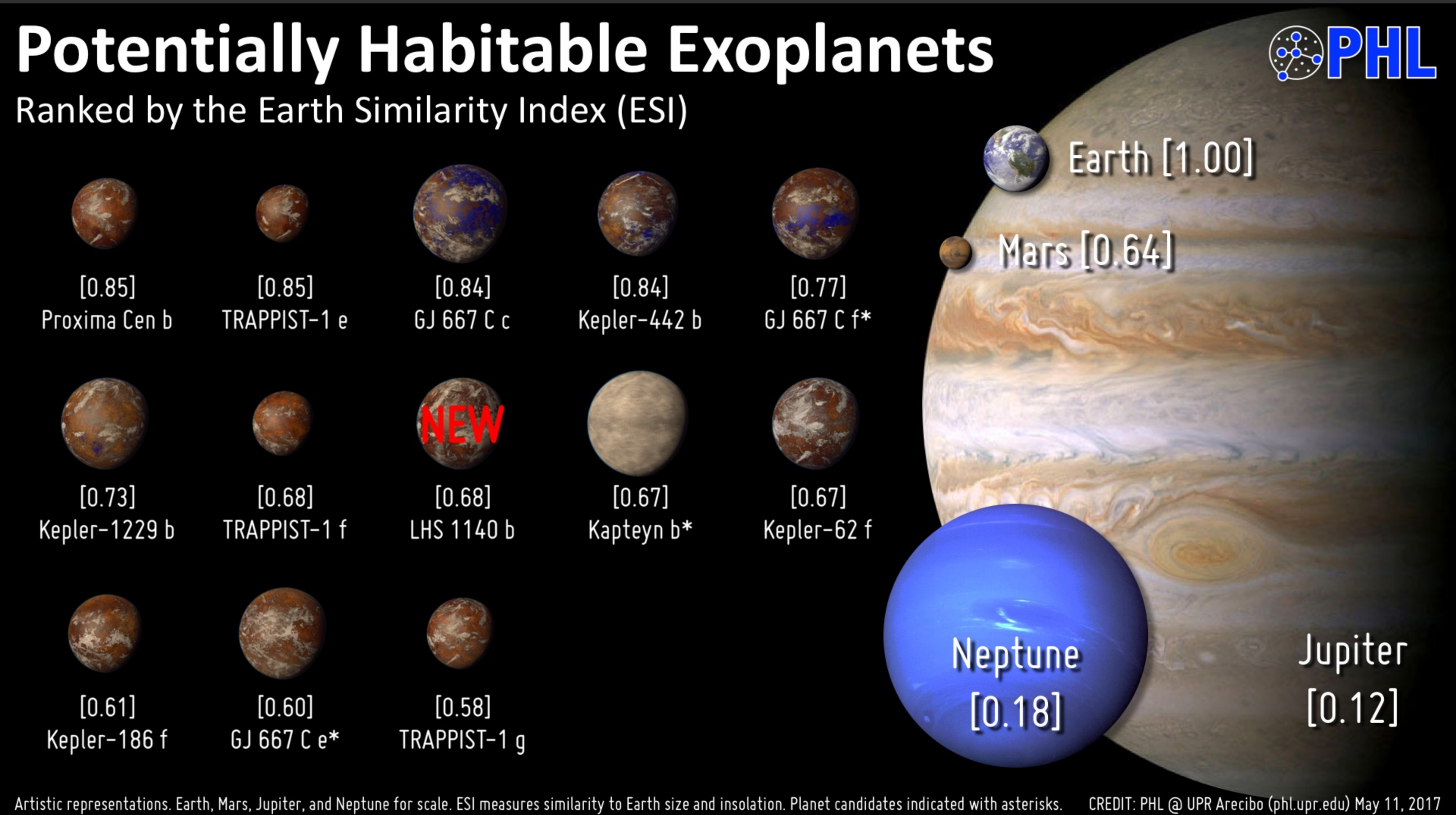
Kepler's Small Habitable Zone Planets

As of May 10, 2016

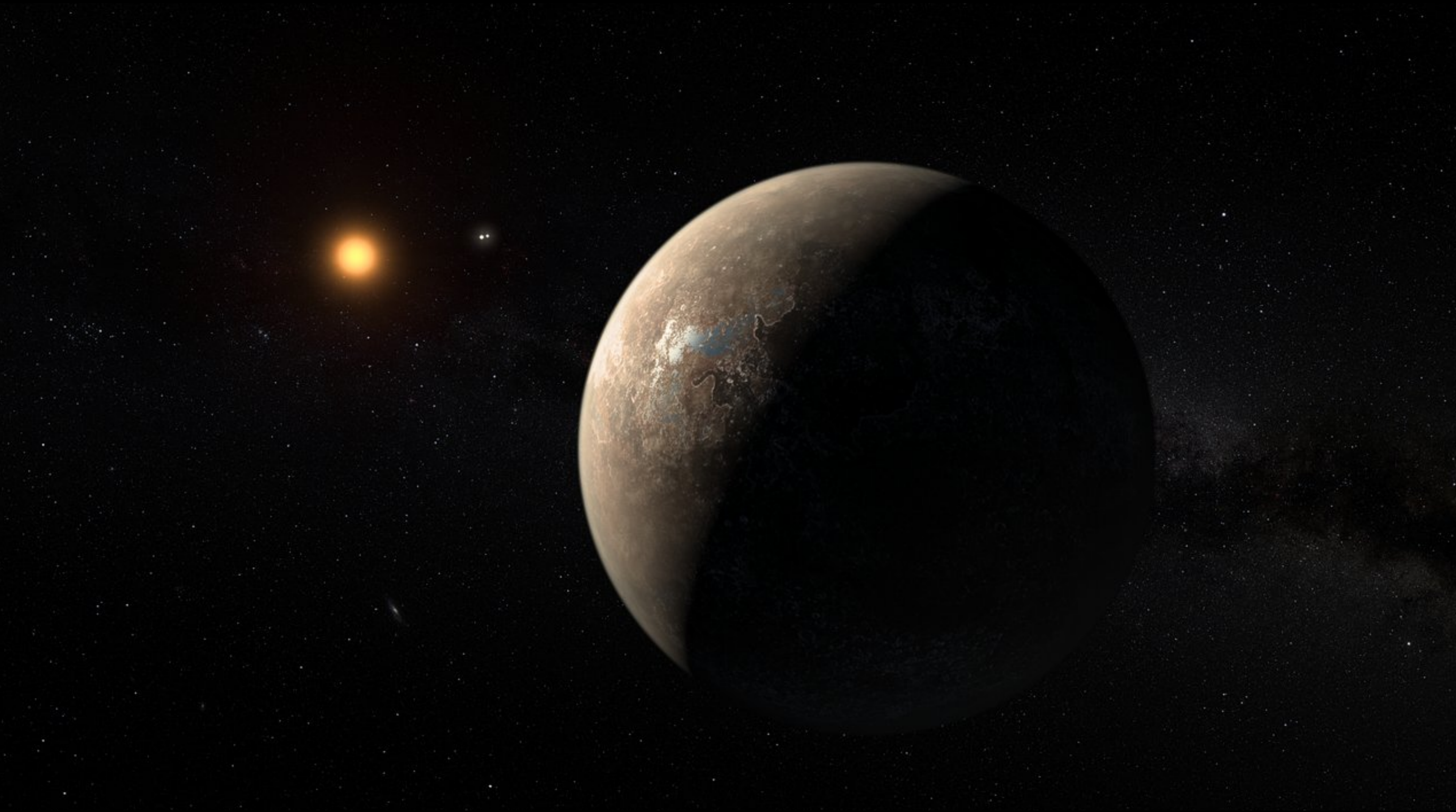


Credits: NASA Ames / N. Batalha and W. Stenzel

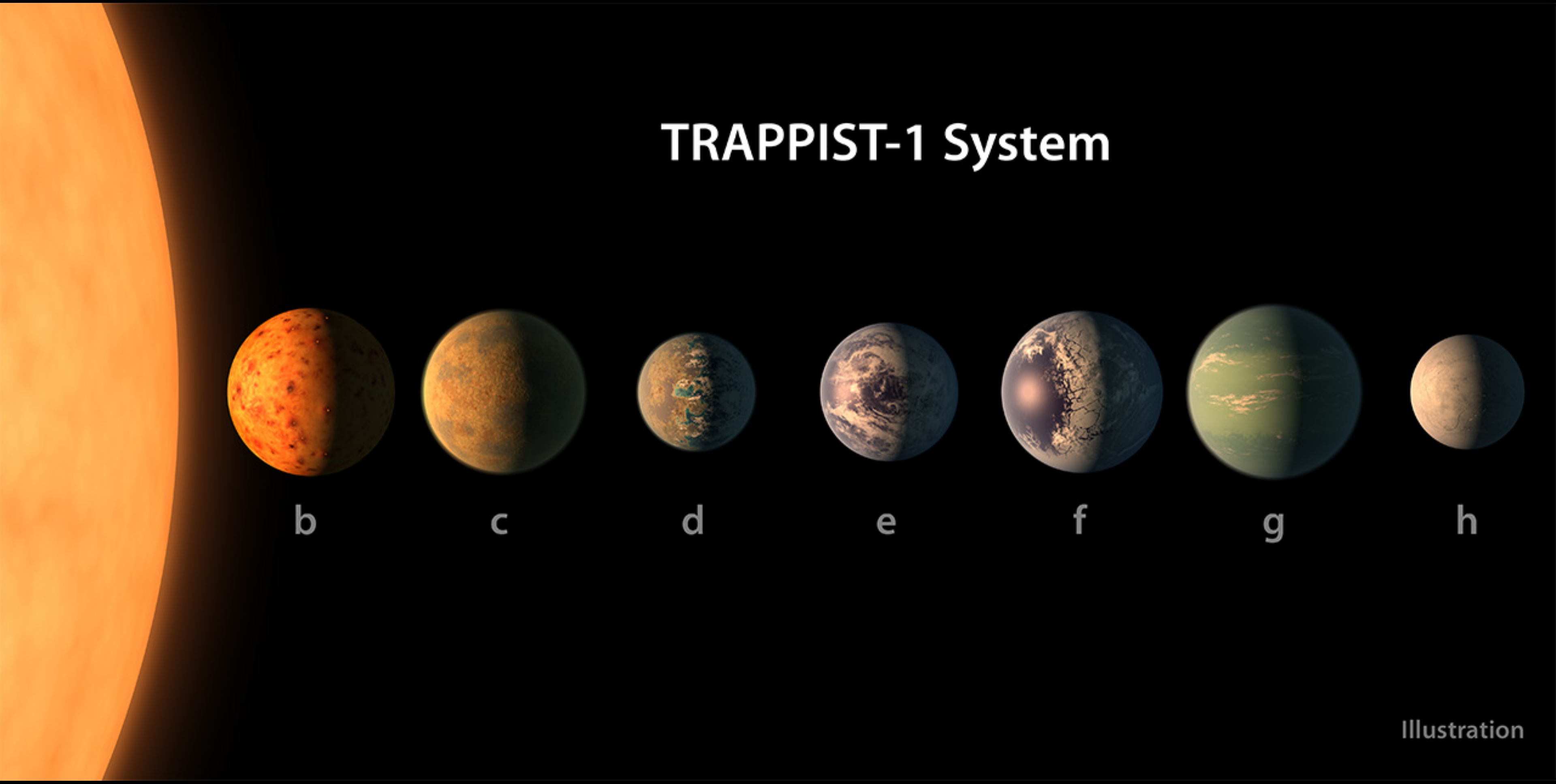
Last updated: Aug. 4, 2017; Editor: Yael Kovo


Potentially Habitable Exoplanets
Ranked by the Earth Similarity Index (ESI)
PHL
Earth [1.00]
Mars [0.64]
[0.85]
Proxima Cen b
[0.85]
TRAPPIST-1 e
[0.84]
GJ 667 C c
[0.84]
Kepler-442 b
[0.77]
GJ 667 C f*
[0.73]
Kepler-1229 b
[0.68]
TRAPPIST-1 f
NEW
[0.68]
LHS 1140 b
[0.67]
Kapteyn b*
[0.67]
Kepler-62 f
[0.61]
Kepler-186 f
[0.60]
GJ 667 C e*
[0.58]
TRAPPIST-1 g
Neptune
[0.18]
Jupiter
[0.12]
Artistic representations. Earth, Mars, Jupiter, and Neptune for scale. ESI measures similarity to Earth size and insolation. Planet candidates indicated with asterisks.
CREDIT: PHL @ UPR Arecibo (phl.upr.edu) May 11, 2017

Proxima Centauri b

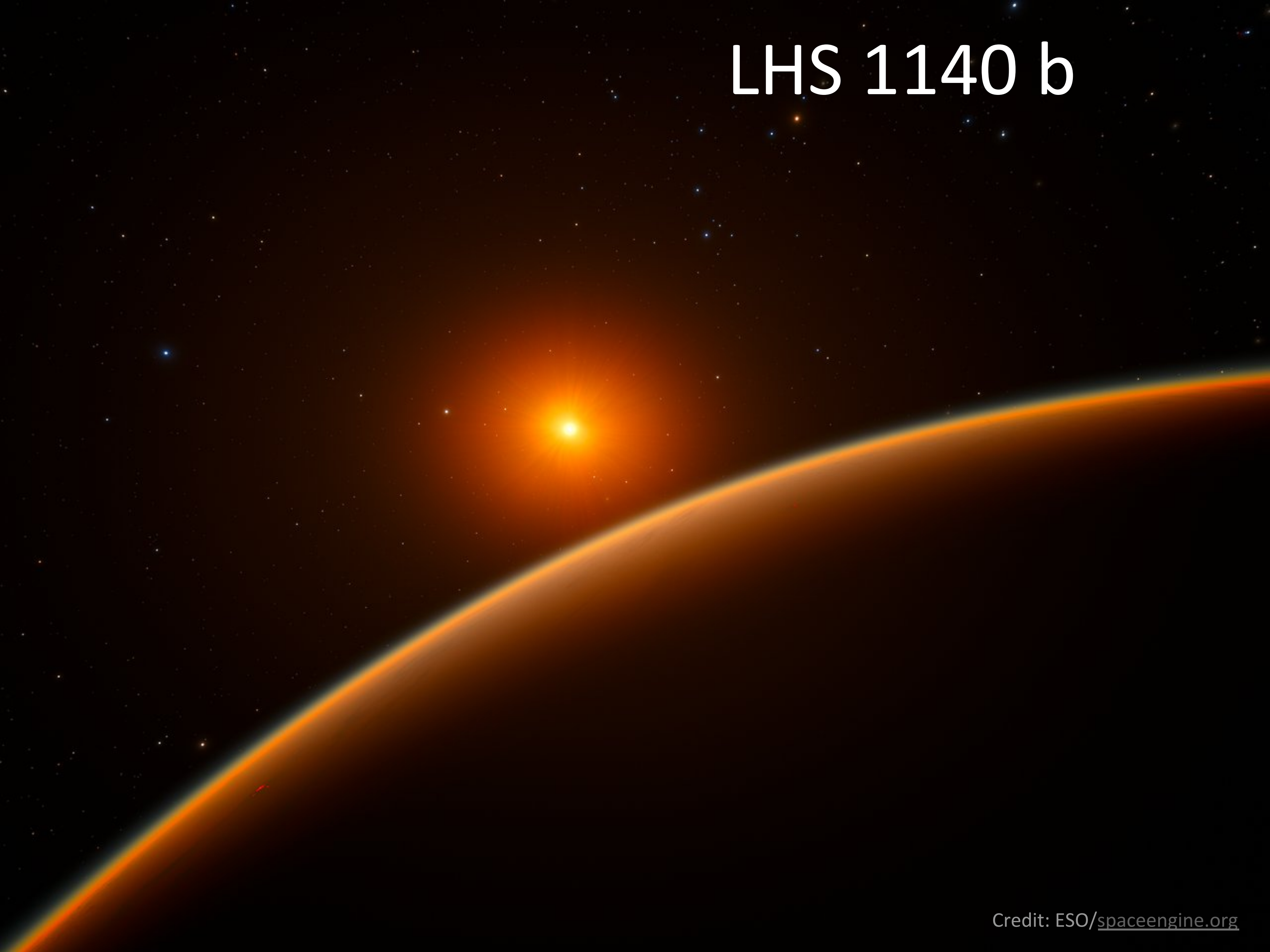


Credit: ESO/M. Kornmesser



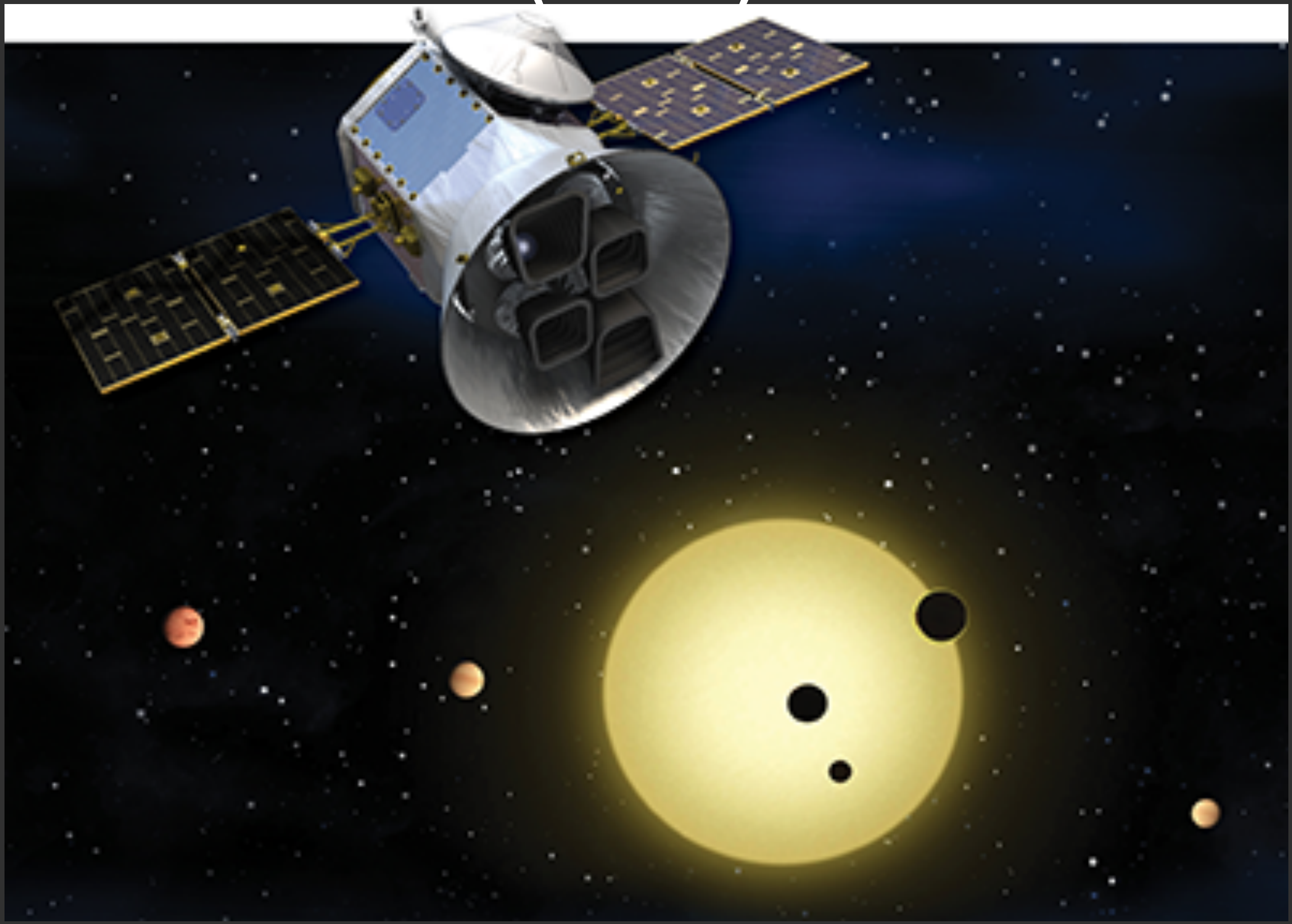
Credit: NASA-JPL/Caltech

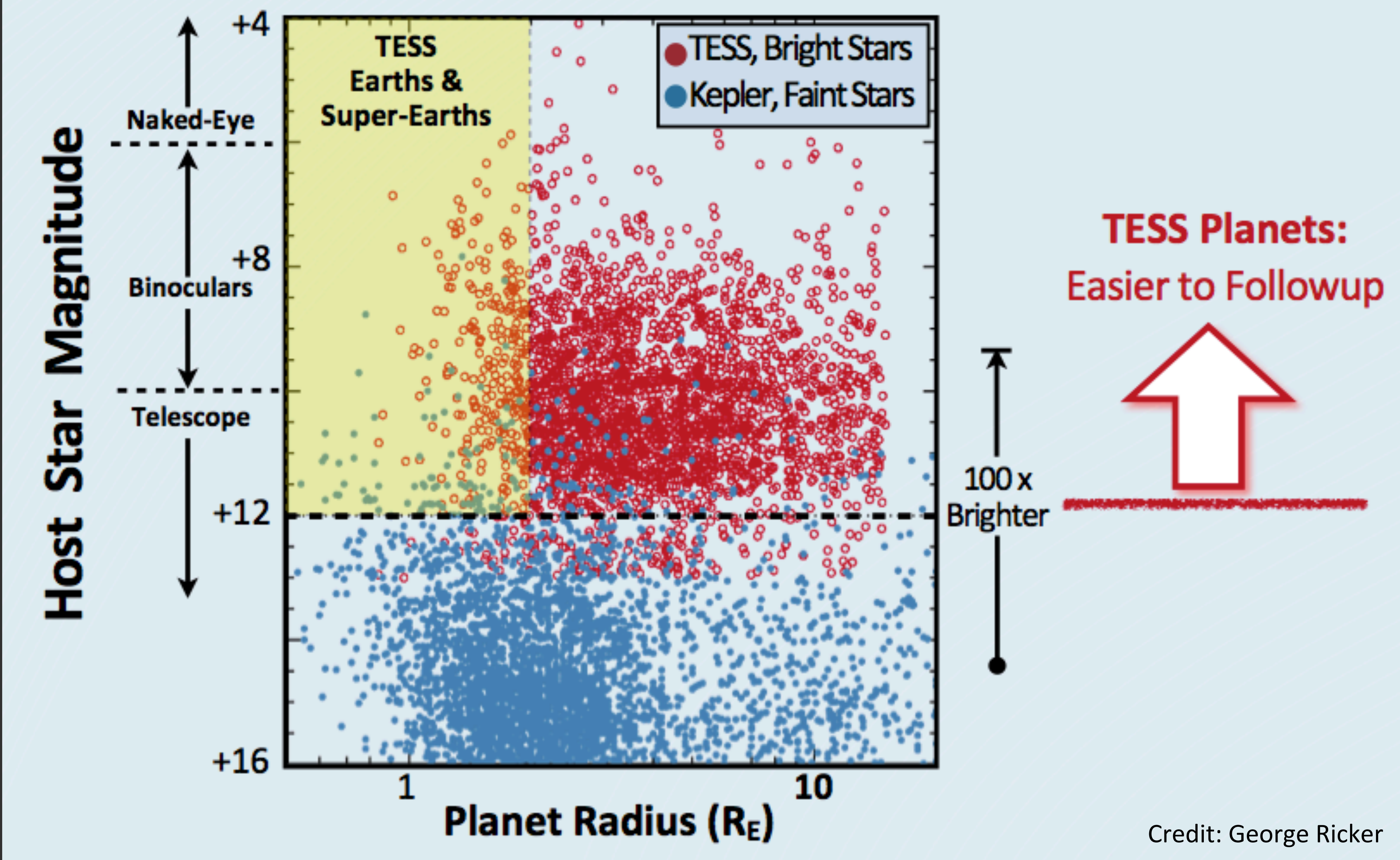
LHS 1140 b



Credit: ESO/spaceengine.org

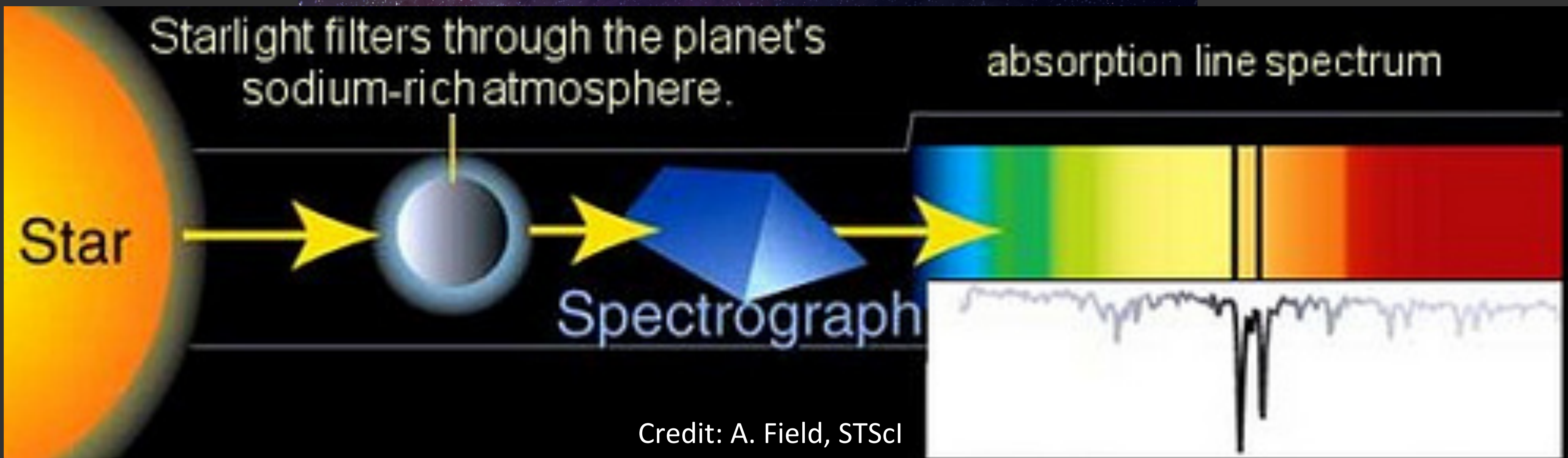
Transiting Exoplanet Survey Satellite (TESS)



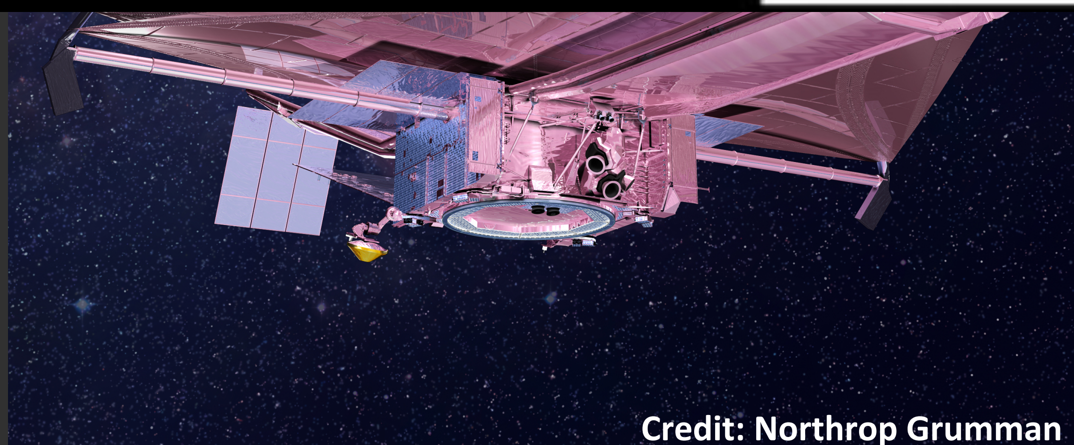


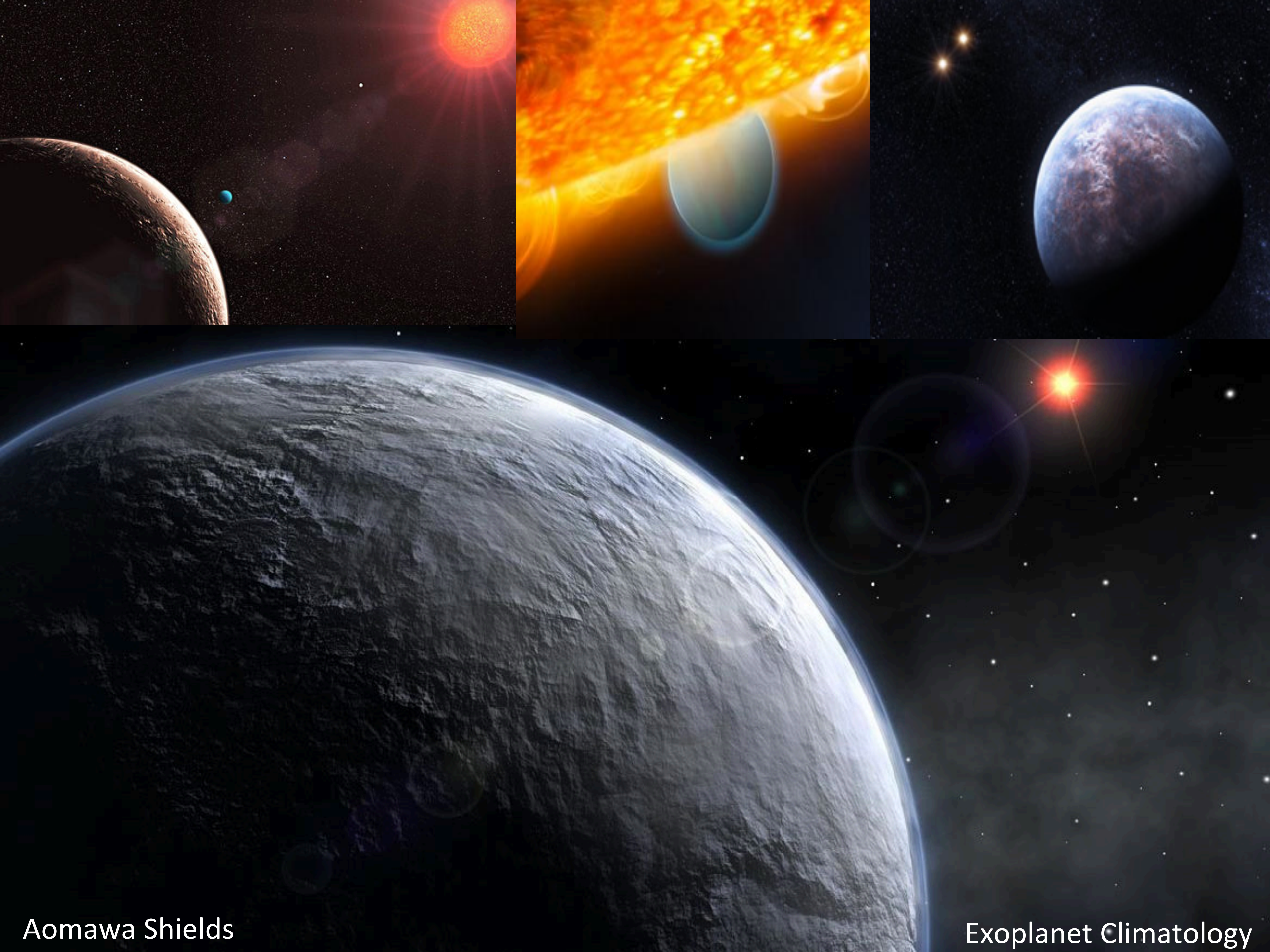
TESS will identify the best and smallest exoplanet targets for characterization of atmospheres

James Webb Space Telescope



Credit: A. Field, STScI


Credit: Northrop Grumman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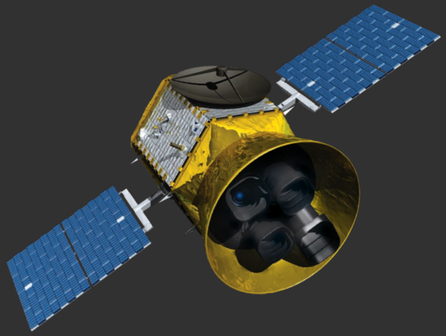
Exoplanet Climatology

New era, new approach

- Observational data AND computer models

NASA



+

Koshland Science Museum

Collaborators

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Tyler Robinson
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Eric Wolf
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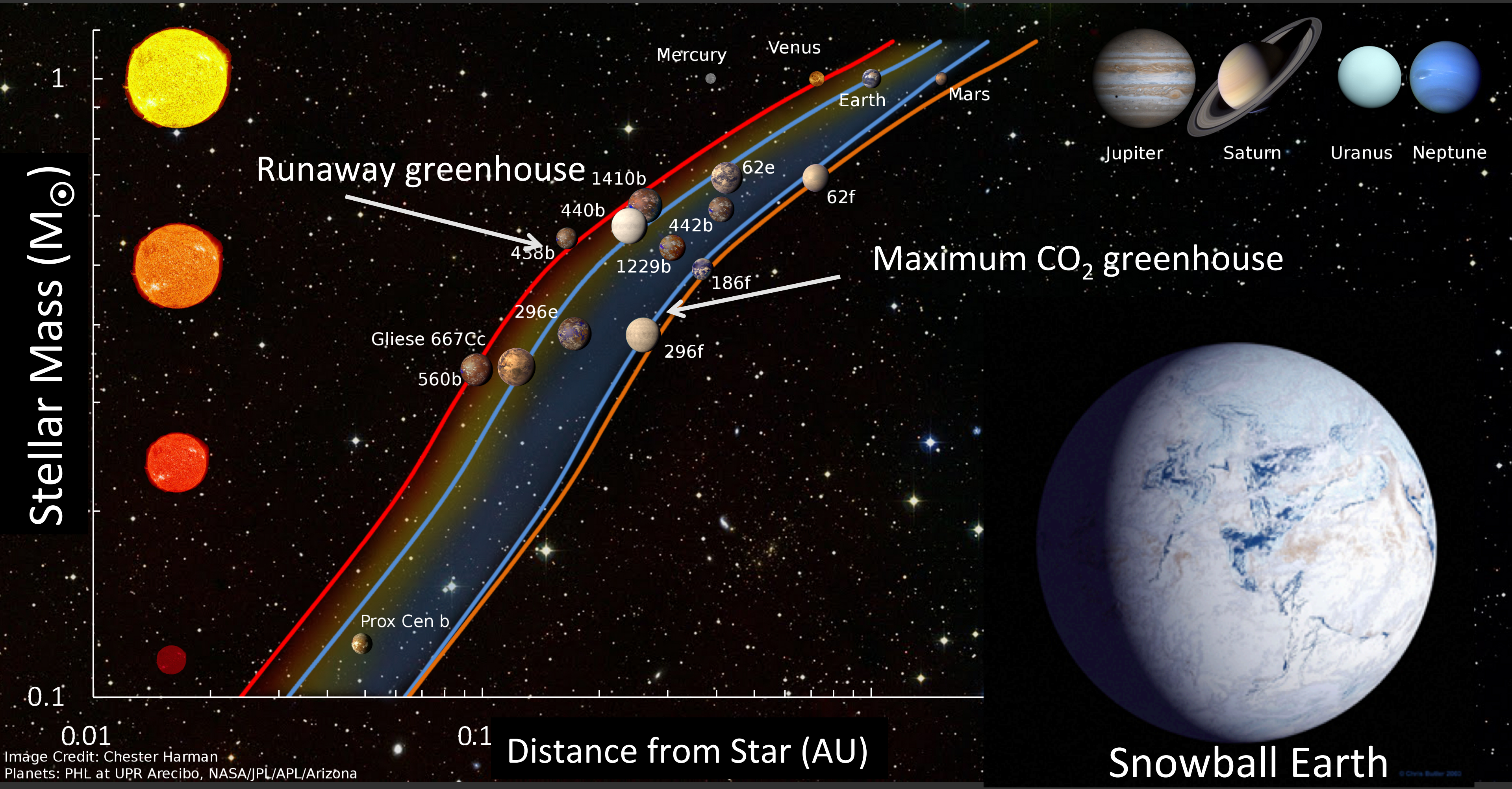
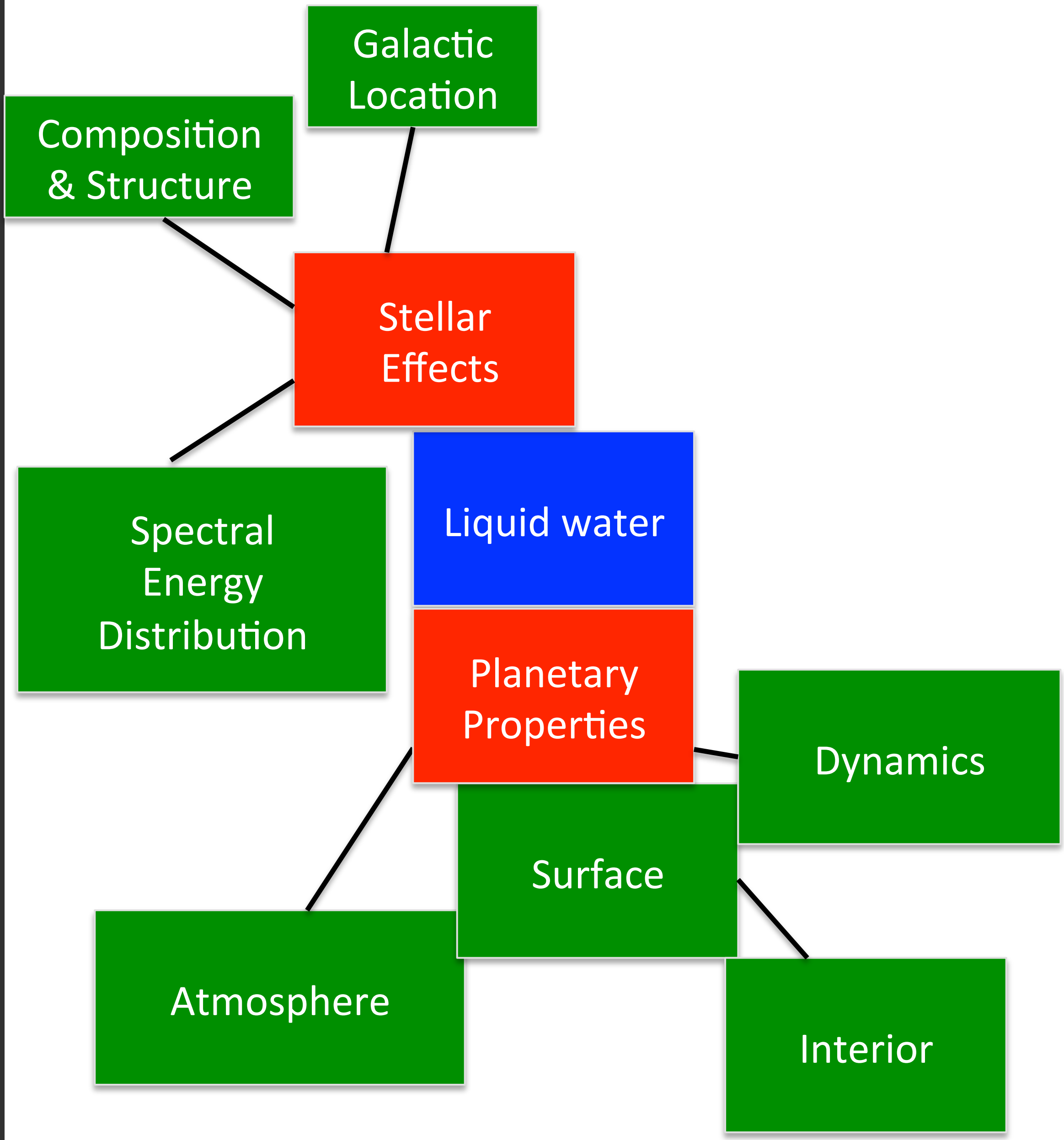
Jacob Haaq-Misra
Brian Toon
Brad Hansen
Matt Walker
Regina Carns

The Habitable Zone



Many factors can affect planetary habitability



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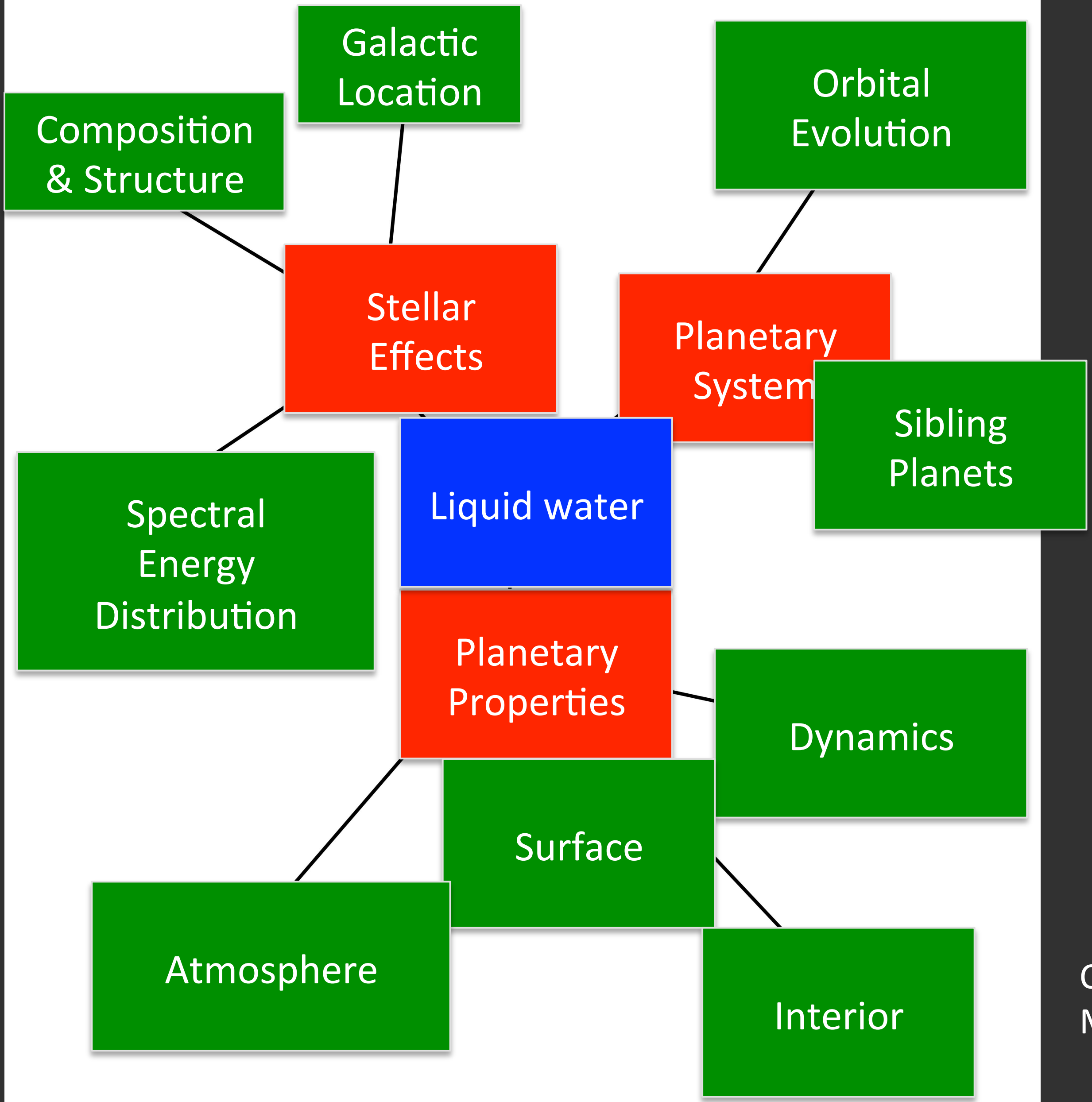
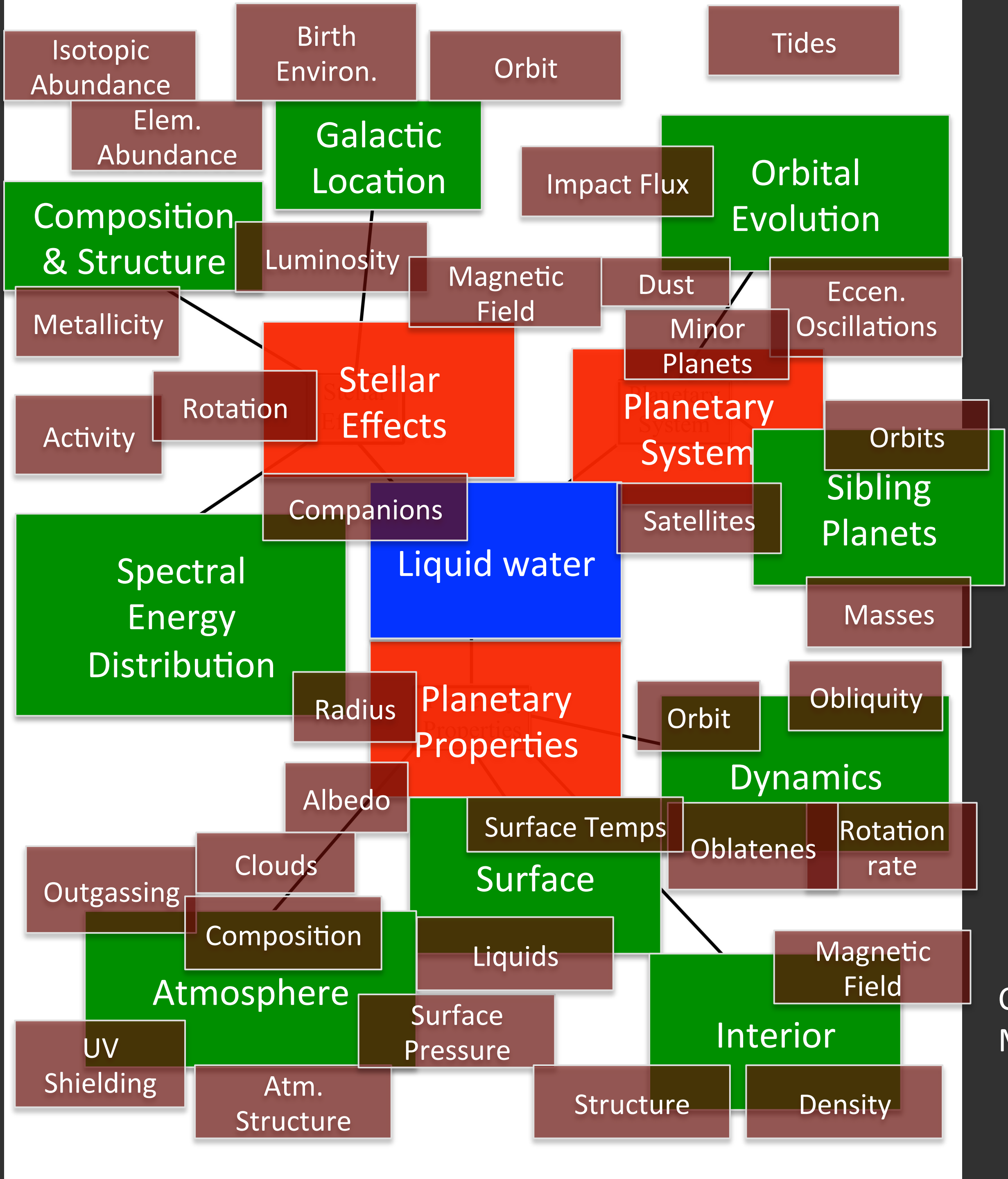


Credit: Victoria Meadows

Aomawa Shields



Credit: Victoria Meadows

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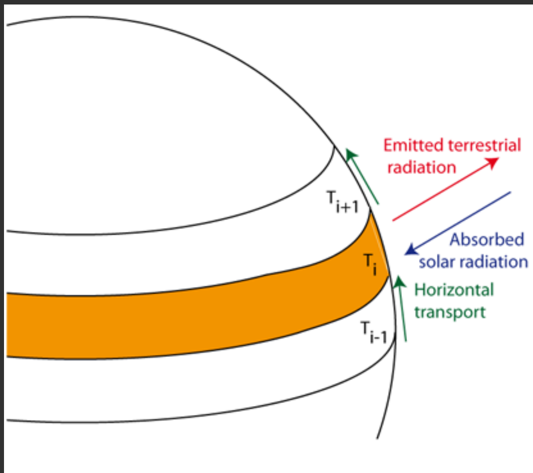
Models

- Spectral Mapping Atmospheric Radiative Transfer model (SMART)
  - 1-D in height
  - Atmospheric gas absorption

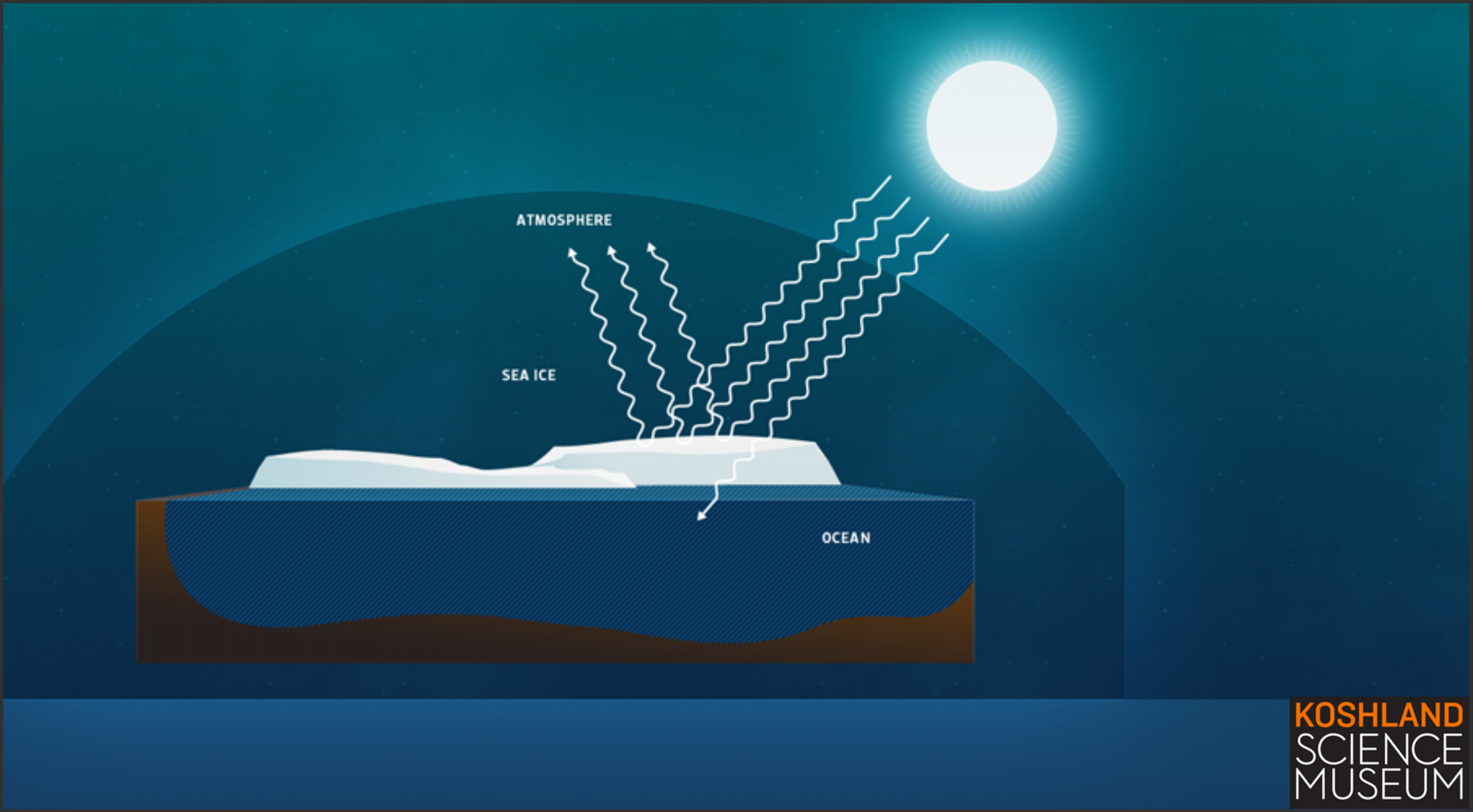


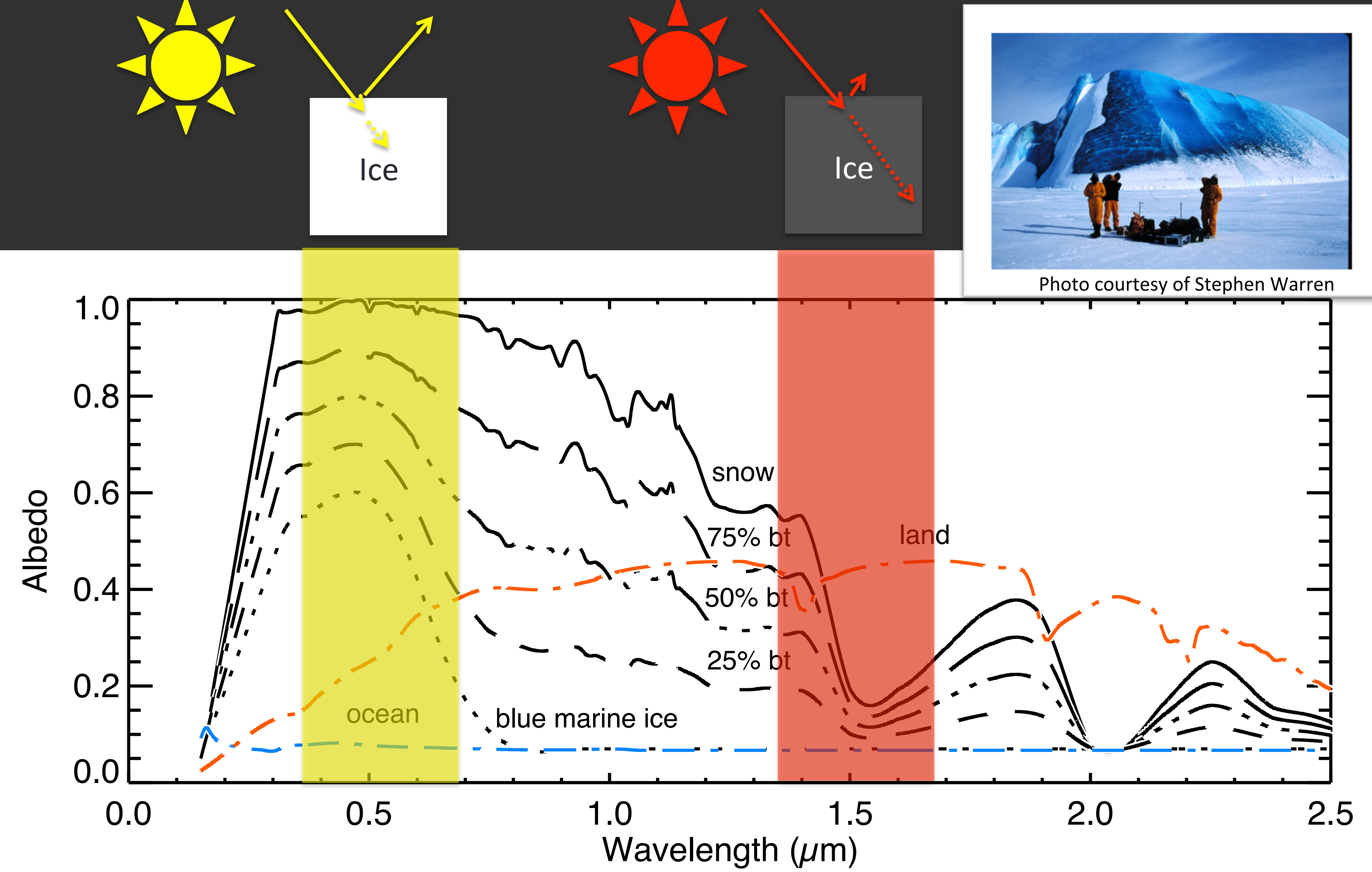
- 1-D seasonal Energy Balance Model (EBM)
  - 1-D in latitude
- 3-D General Circulation Model (GCM)

- *N*-body Models
- Tidal models

Stellar Radiation

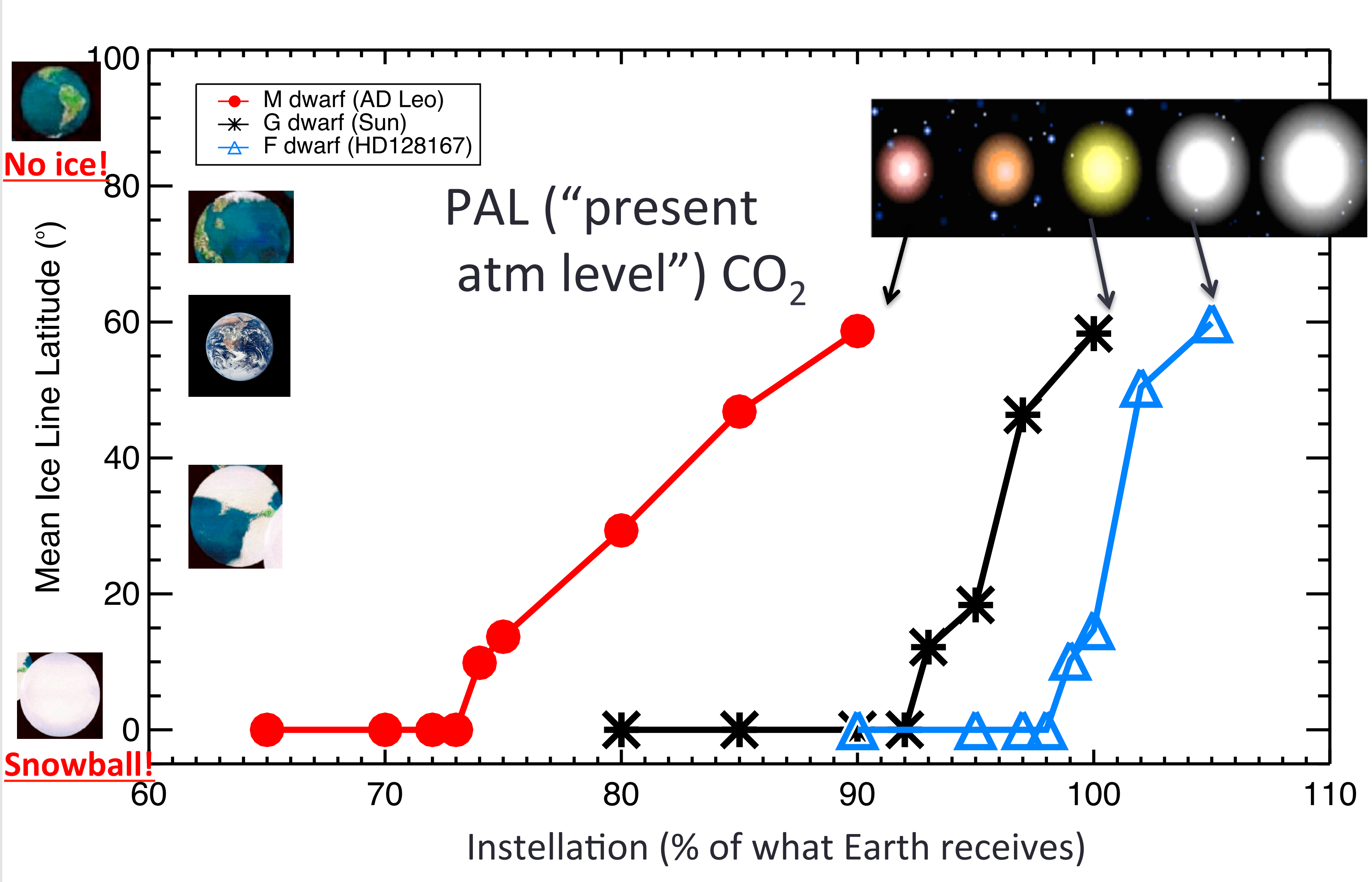
Ice-albedo Feedback





Ice absorbs where M-dwarfs emit strongly

Shields et al. (2013)
Warren et al. (2002)
Grenfell et al. (1994)



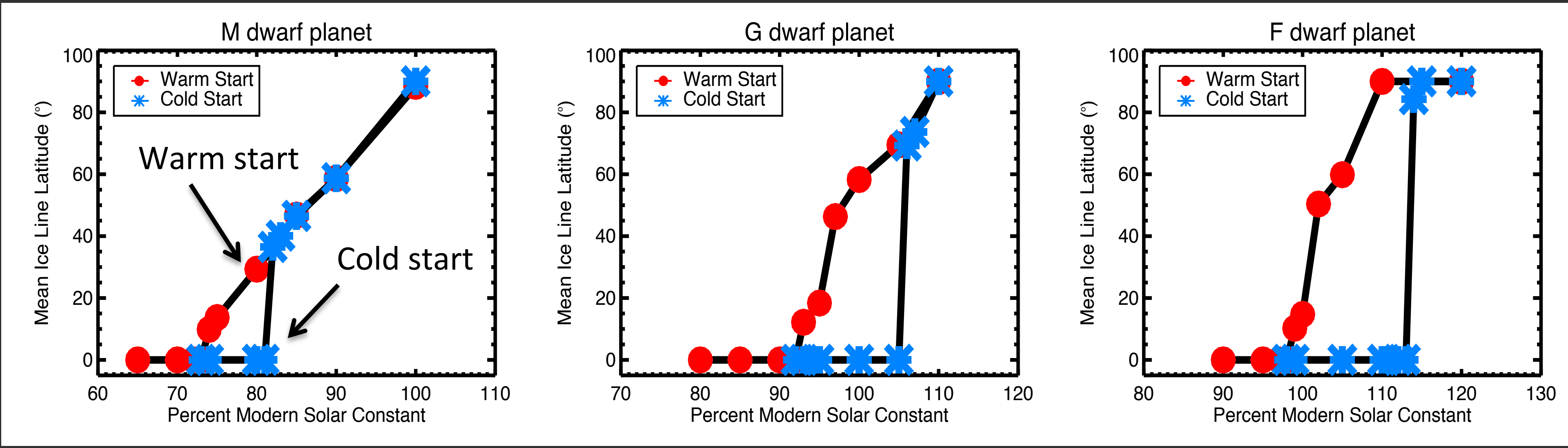
M-dwarf planets less susceptible to snowball

Shields et al. (2013)

F-dwarf planets more susceptible to snowball

Climate Stability

Shields et al. (2014)

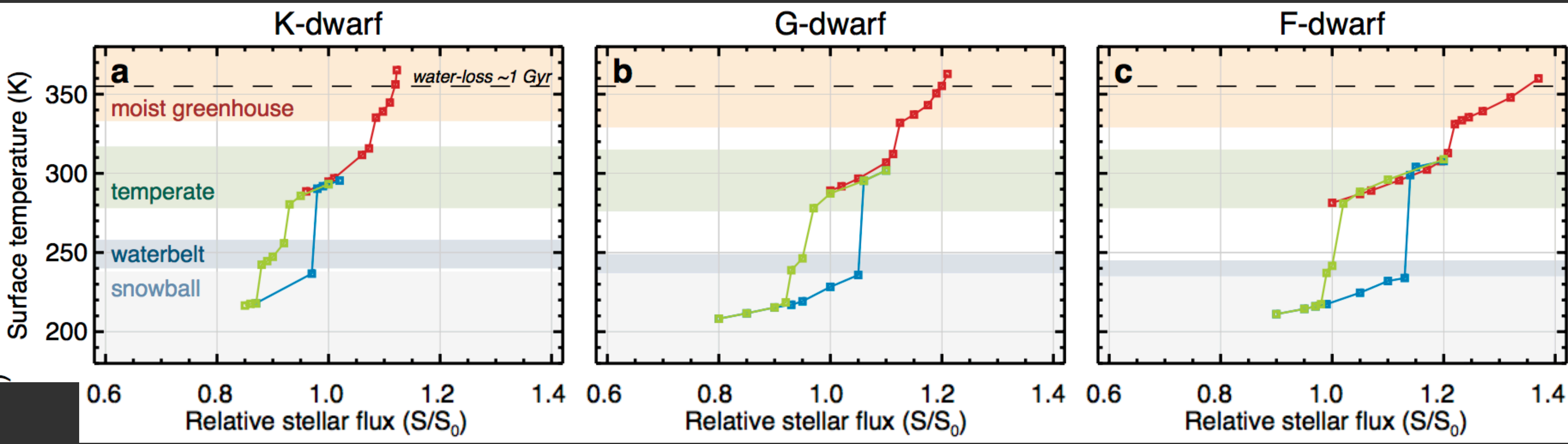


Shorter jump in ice line → Higher jump in ice line

Better for life?

M-dwarf planets have more stable climates

Identifying Multiple Possible Climate Regimes



Wolf, Shields+ 2017

M-dwarf Planet Habitability

Physics Reports

Volume 663, 5 December 2016, Pages 1–38

The habitability of planets orbiting M-dwarf stars

Aomawa L. Shields[a, b, d], Sarah Ballard[c], John Asher Johnson[d]

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http://dx.doi.org/10.1016/j.physrep.2016.10.003

Multiple-planet systems

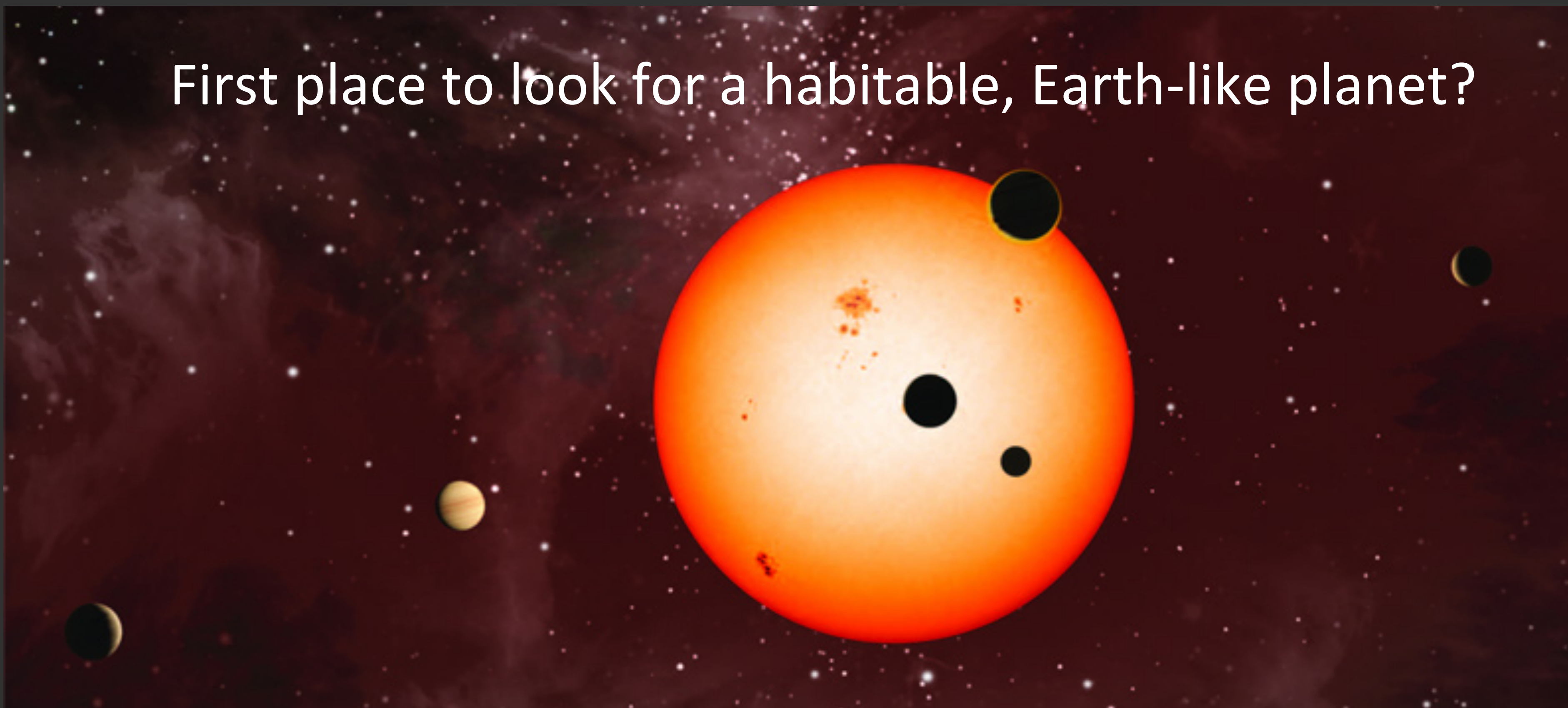
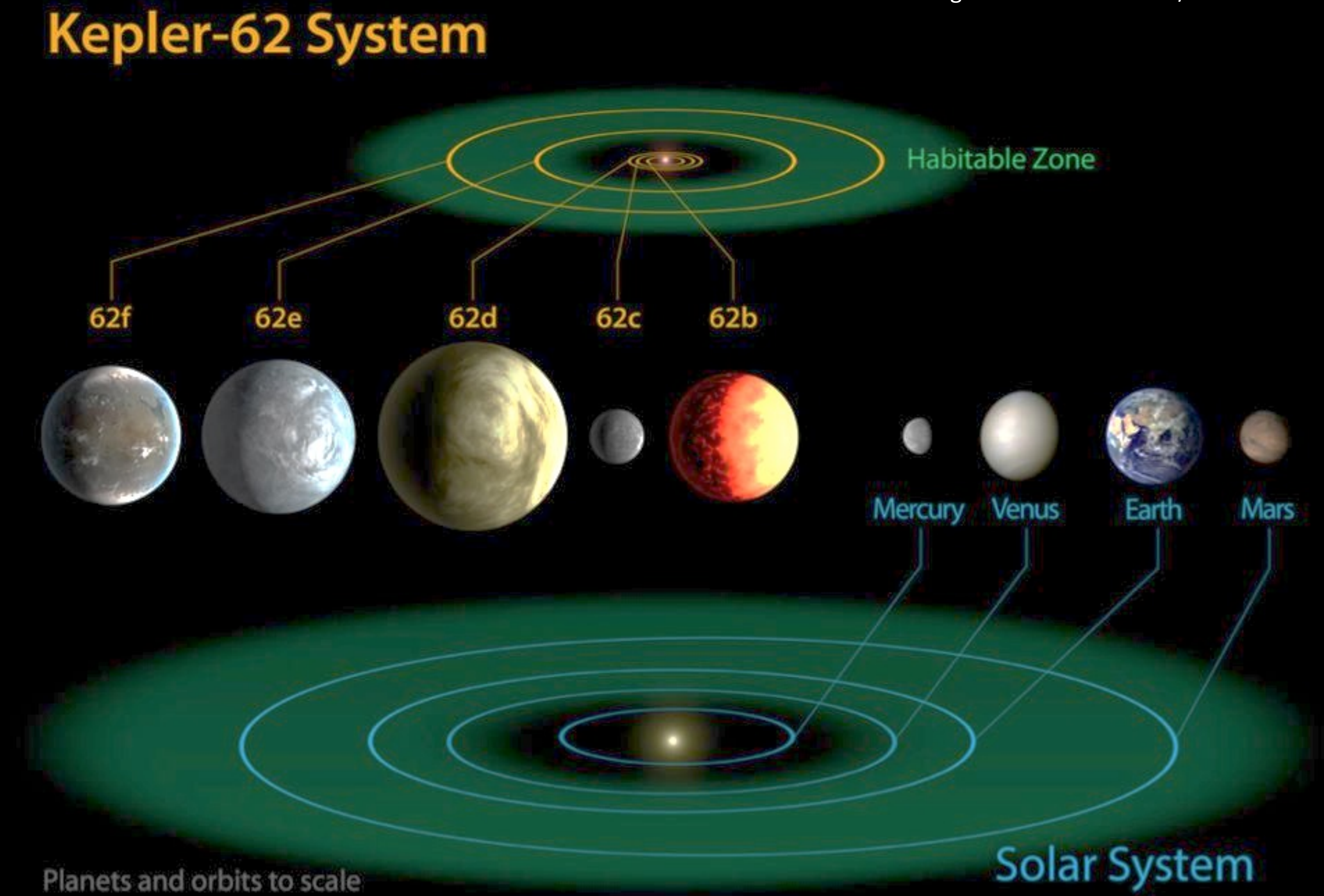


Image credit: NASA Ames/JPL-Caltech



Kepler-62f

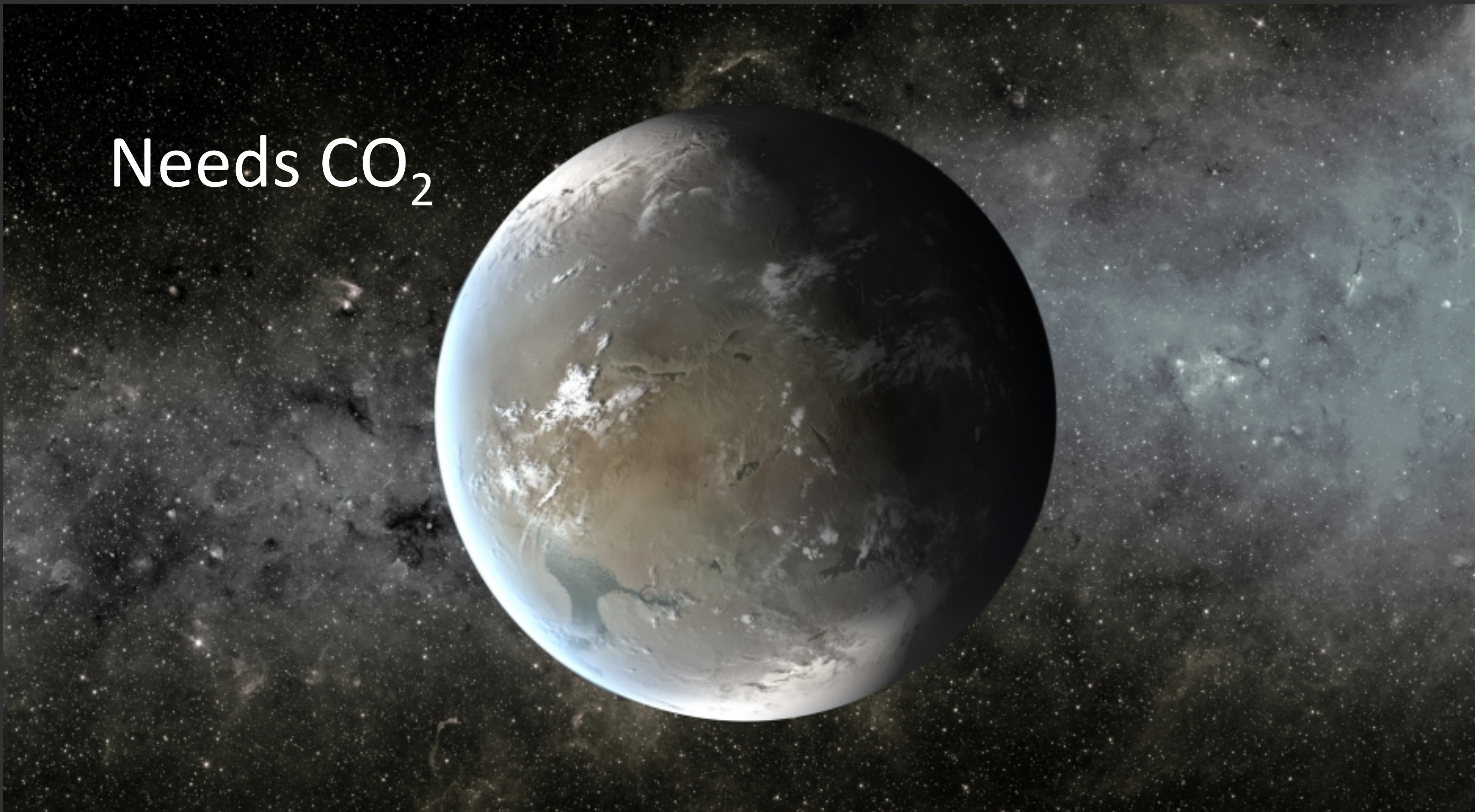
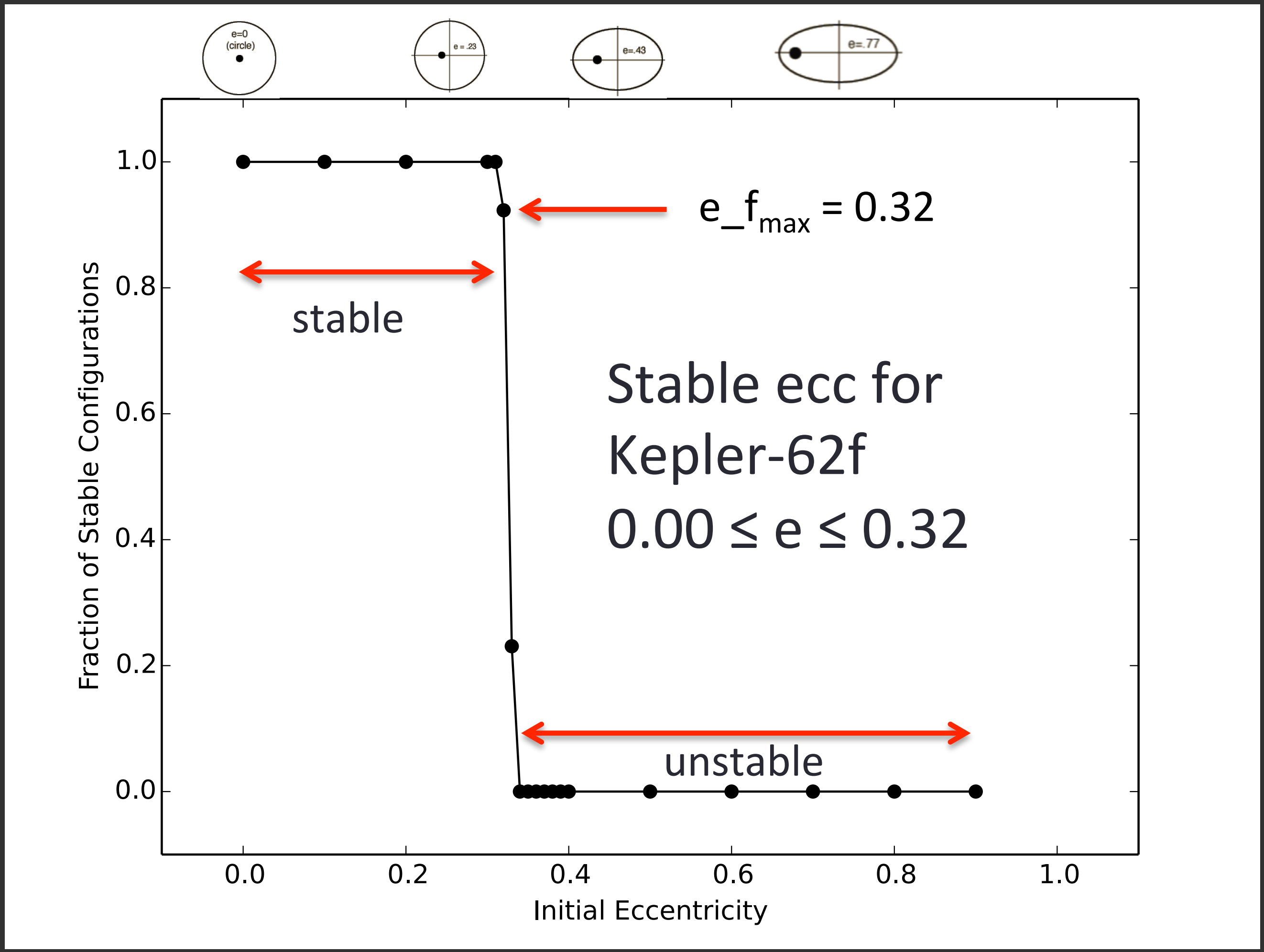


Image credit: NASA Ames/JPL-Caltech

Stable eccentricities



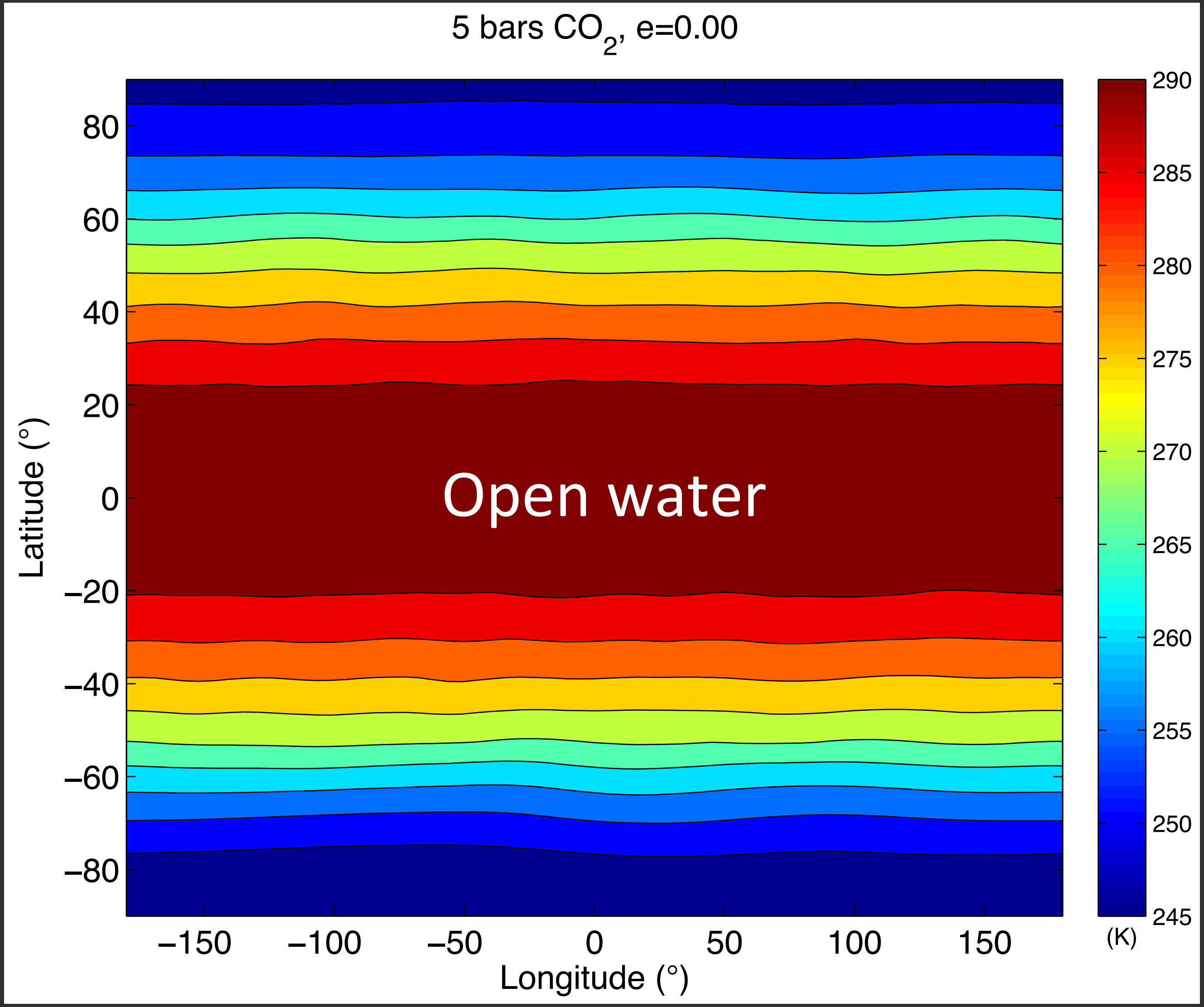
Shields et al. (2016)

Surface Temperature

5 bars CO_2

Obl = 23.5°

Ecc = 0



Global mean surface T ~ 282 K

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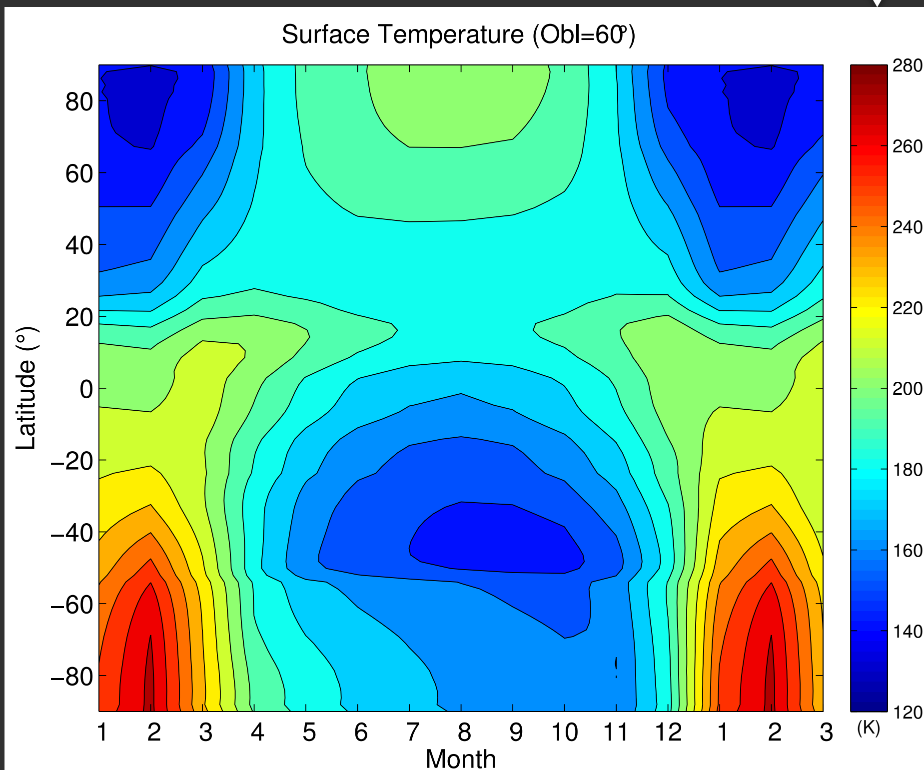
Shields et al. (2016)

Surface Temperature

Obliquity = 60°

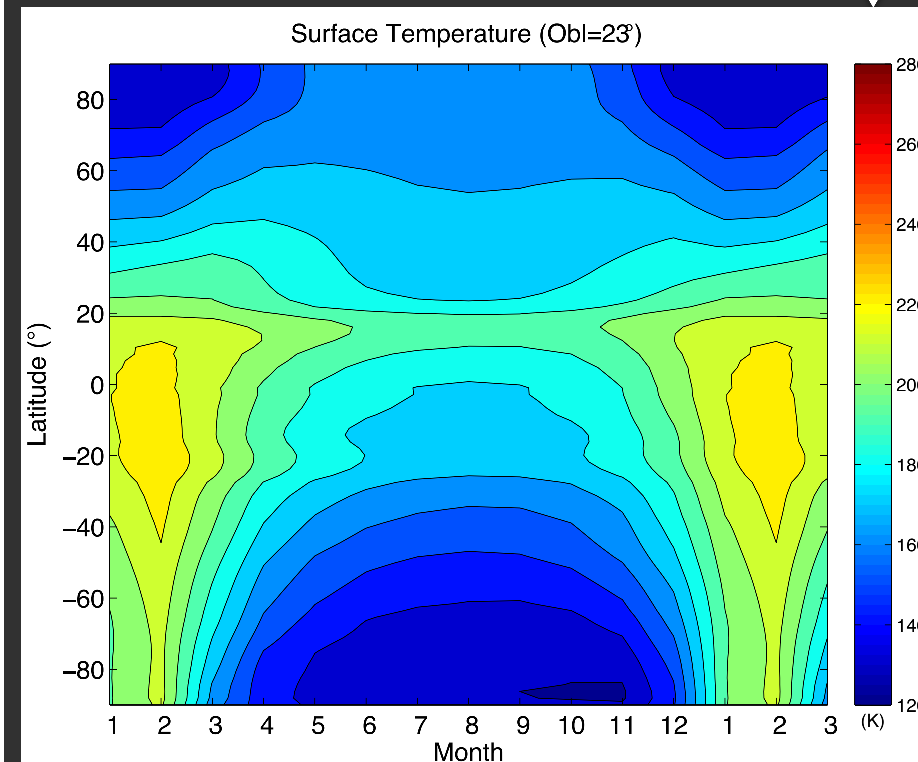
freezing point



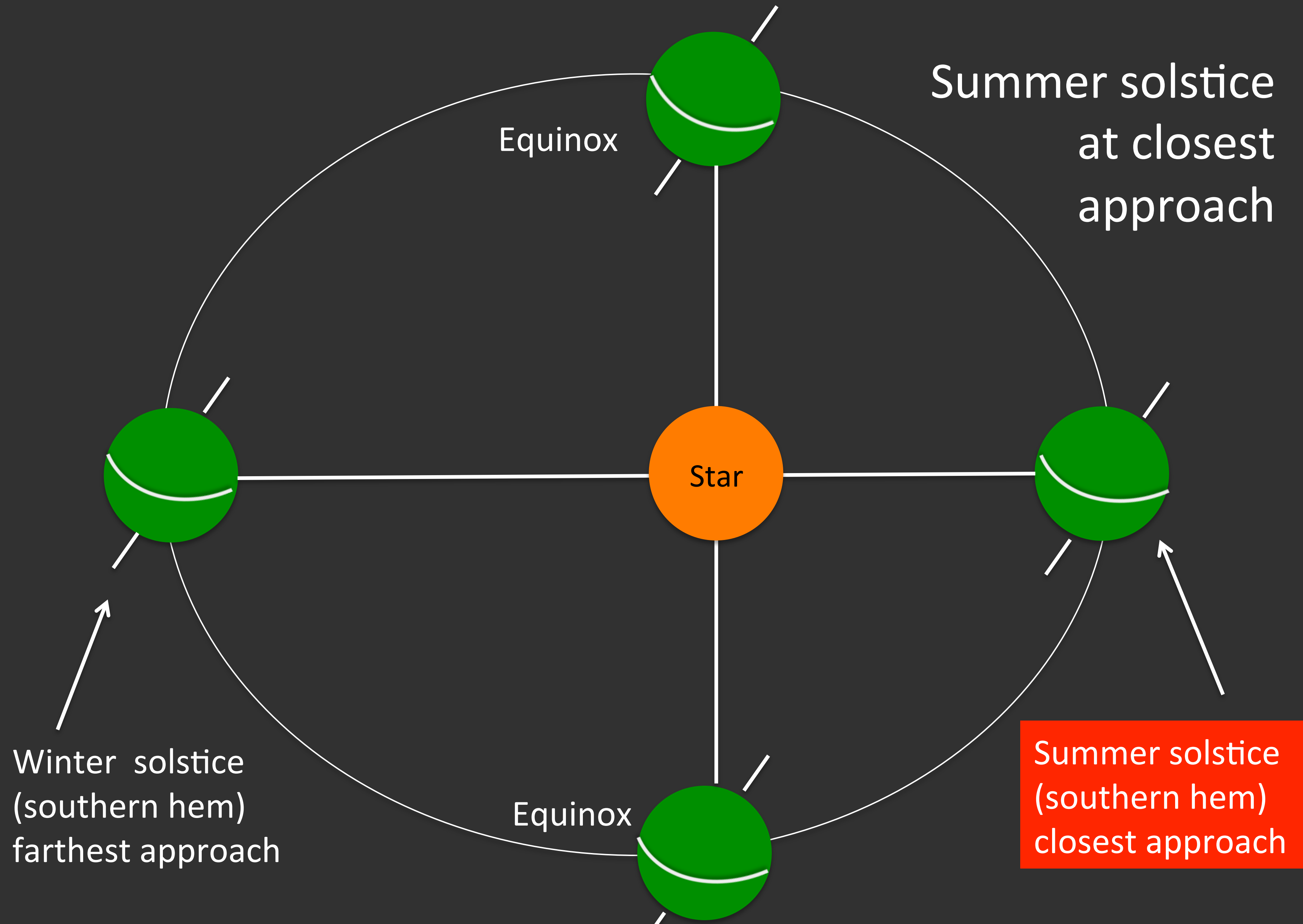
Southern hemisphere summer

Obliquity = 23°

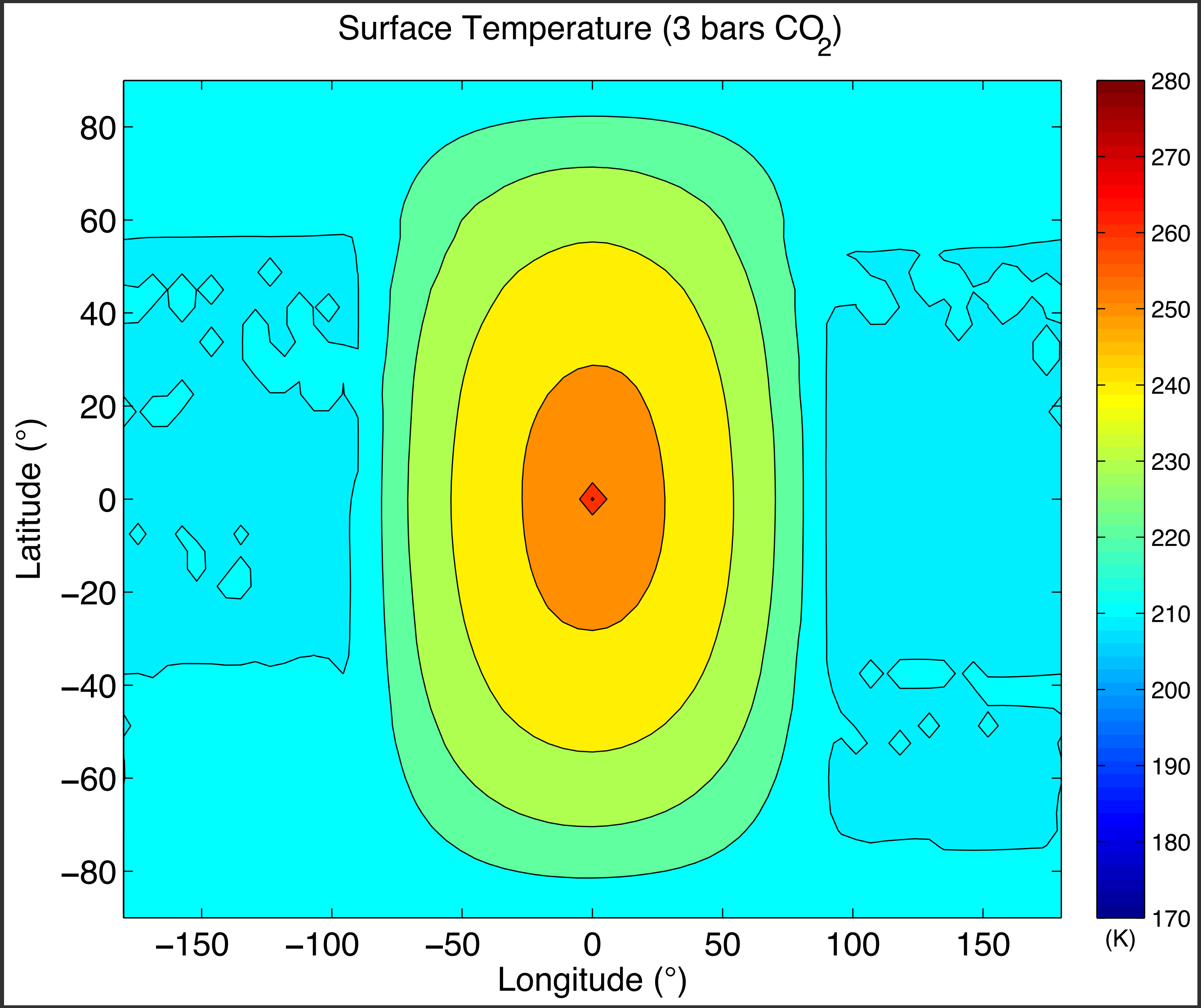
freezing point



Shields et al. (2016)


Summer solstice
at closest
approach
Equinox
Star
Winter solstice
(southern hem)
farthest approach
Equinox
Summer solstice
(southern hem)
closest approach

Surface Temperature 3 bar CO_2



Shields et al. (2016)

Next 5 years at UCI

- Radiative Effects on climate of alternate surface types on exoplanets – **(NEW!)** NASA Habitable Worlds awarded program 16-HW16_2-0003)

- Detailed habitability assessments of newly discovered planets

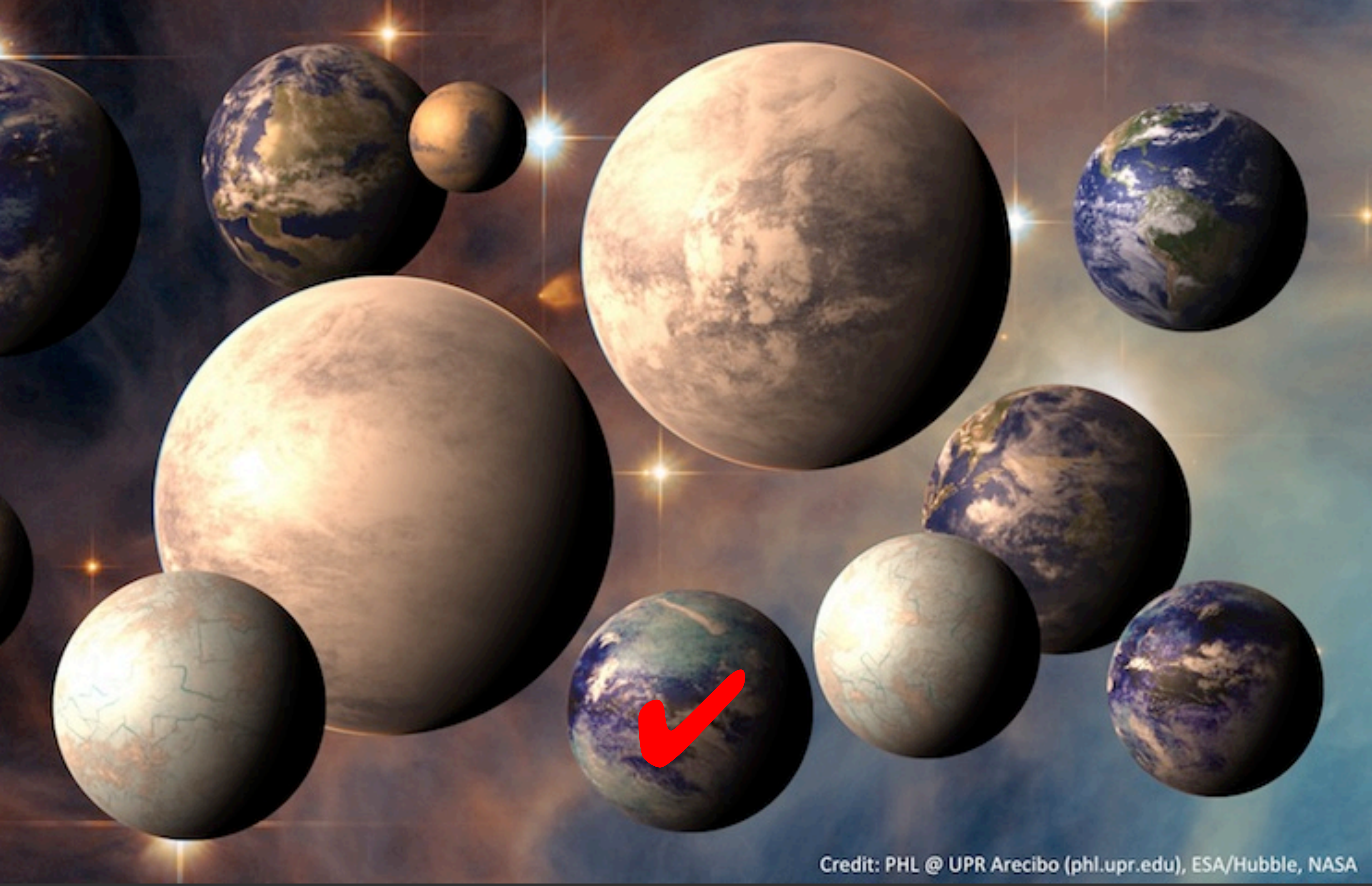
- Lots of opportunities for graduate student involvement

More Exoplanet Research Coming to UCI

Paul Robertson

Hiring a postdoc!

- Start date: Summer/Fall 2018
- Desired background:
  - Climate modeling experience
  - Glaciology, land surface geology and/or atmospheric dynamics
  - Interdisciplinary education and communication
- Application deadline: December 2017



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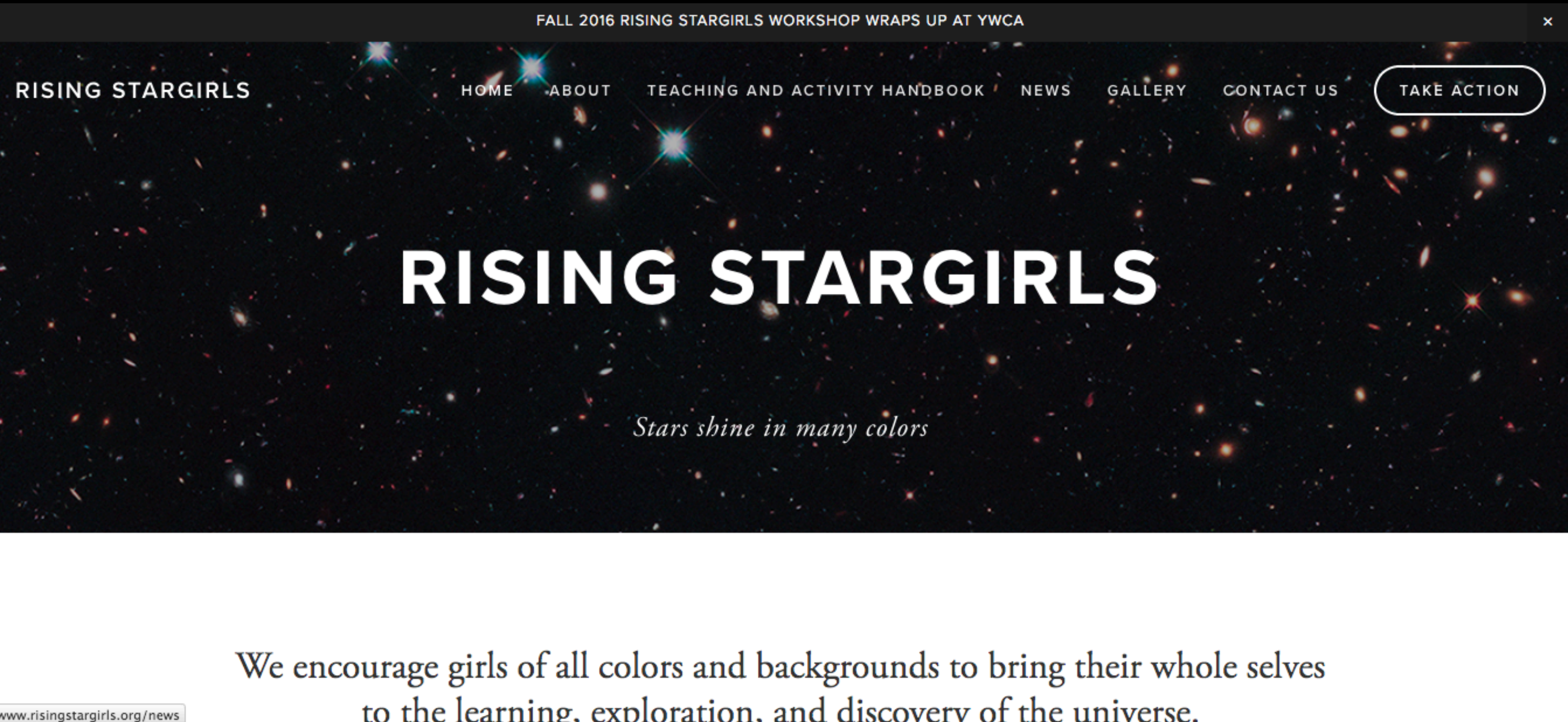
Exoplanet Climatology

Rising Stargirls



www.risingstargirls.org

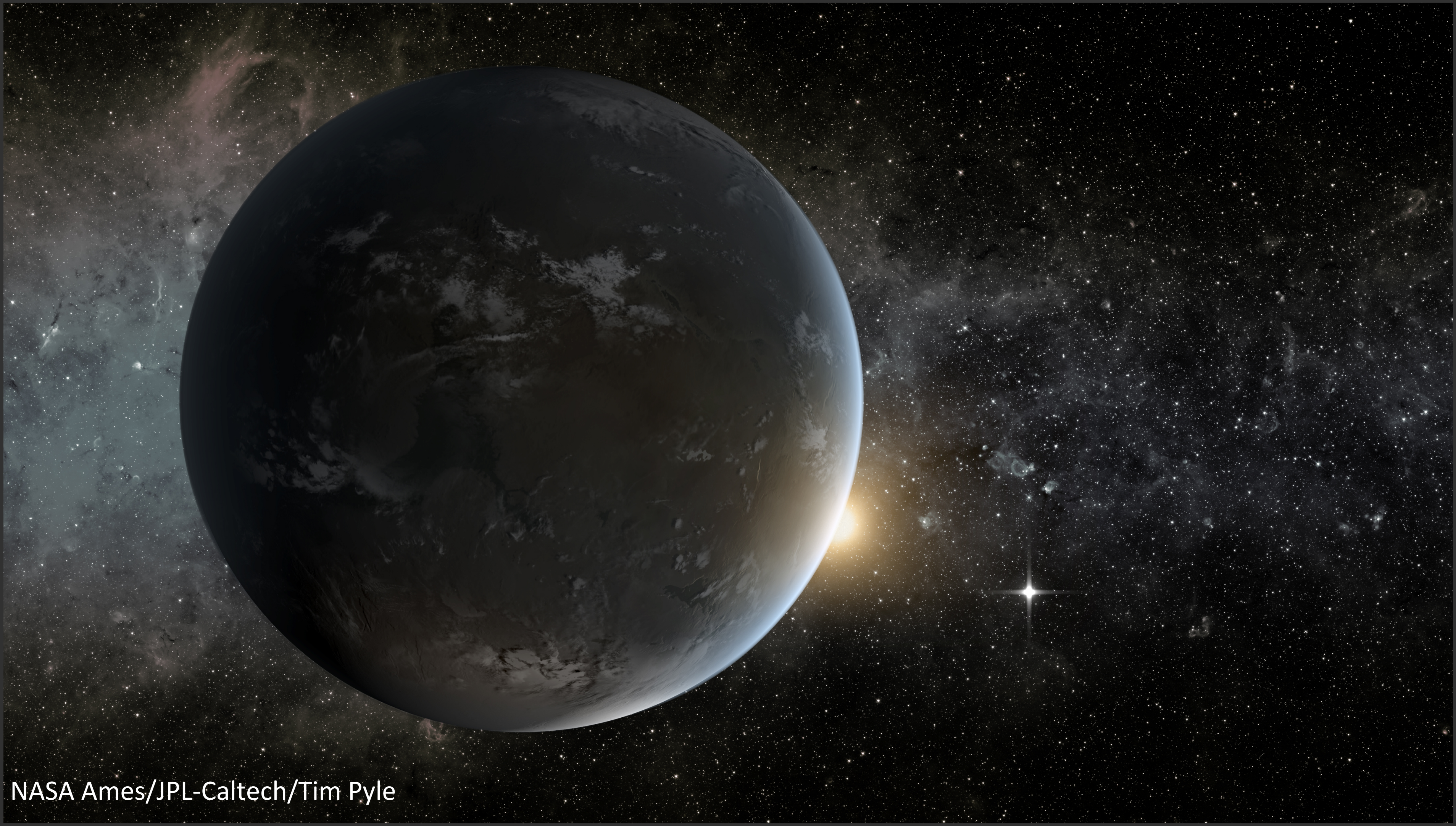
Summary

- Obs. Data + Theoretical Models = Accurate habitability assesments
  - M-dwarf planets exhibit more stable climates
  - Kepler-62f could be habitable
  - Deepening understanding of more complex climatic processes
  - Target prioritization for future mission follow-up

Acknowledgments

- NASA Habitable Worlds Program
- National Science Foundation
- UC President's Postdoctoral Fellowship Program
- Virtual Planetary Laboratory (VPL)
- NASA Astrobiology Institute (NAI)
- Collaborators

Thank you!


NASA Ames/JPL-Caltech/Tim Pyle

Email: shields@uci.edu
Twitter: @aomawa

Aomawa Shields

Summary

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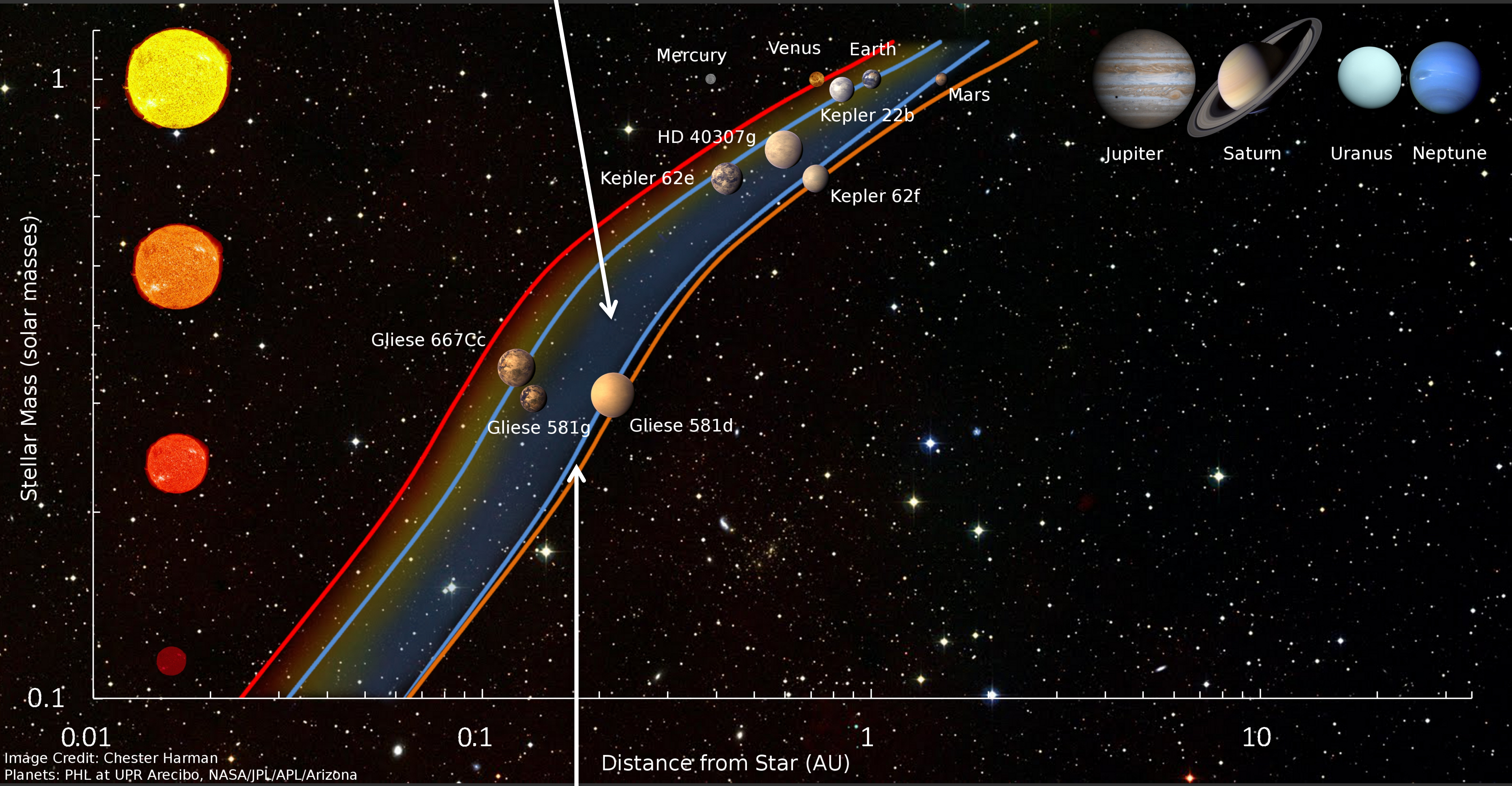
Ice albedo effect matters (middle range of Habitable Zone)



Outer edge?

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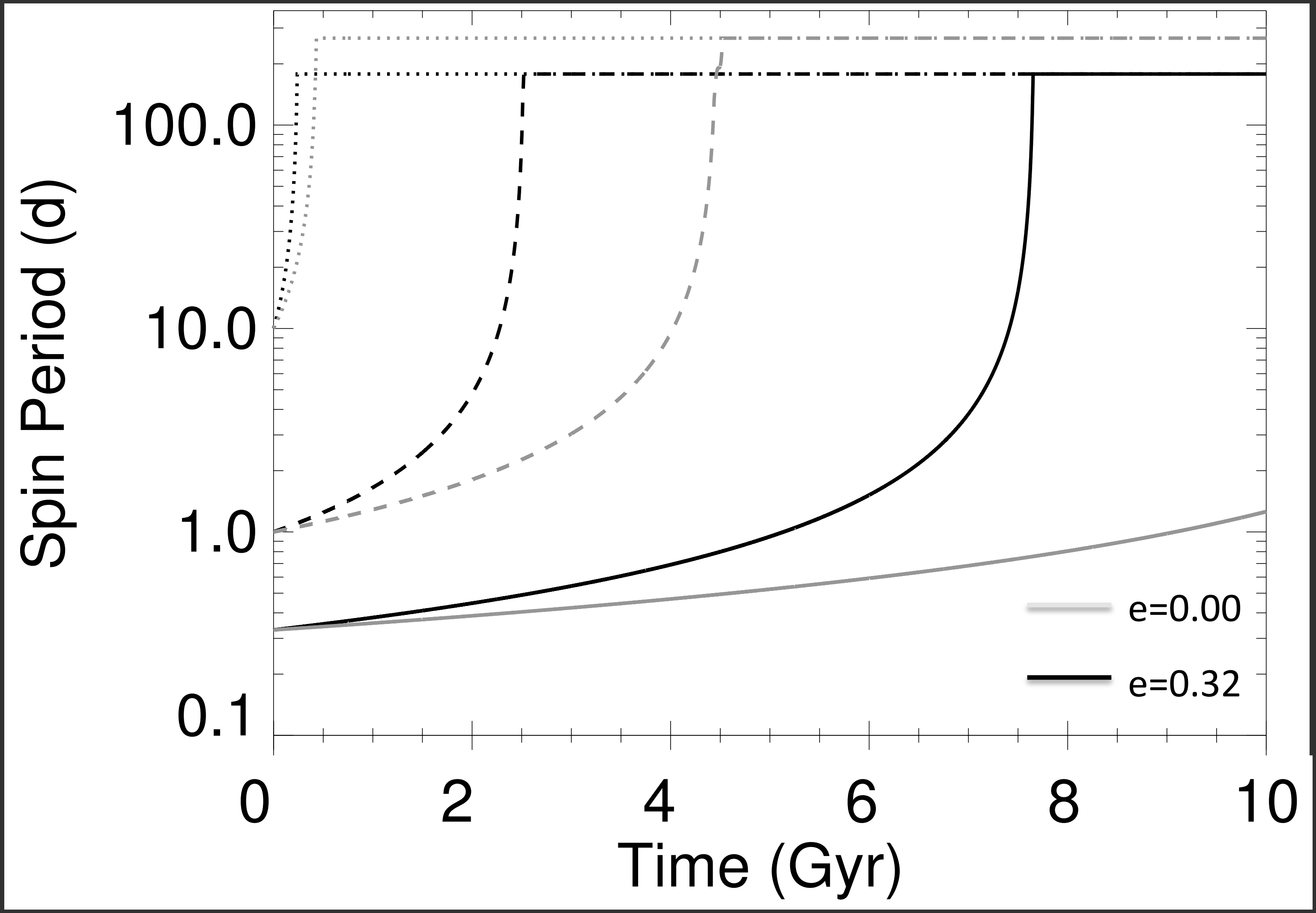
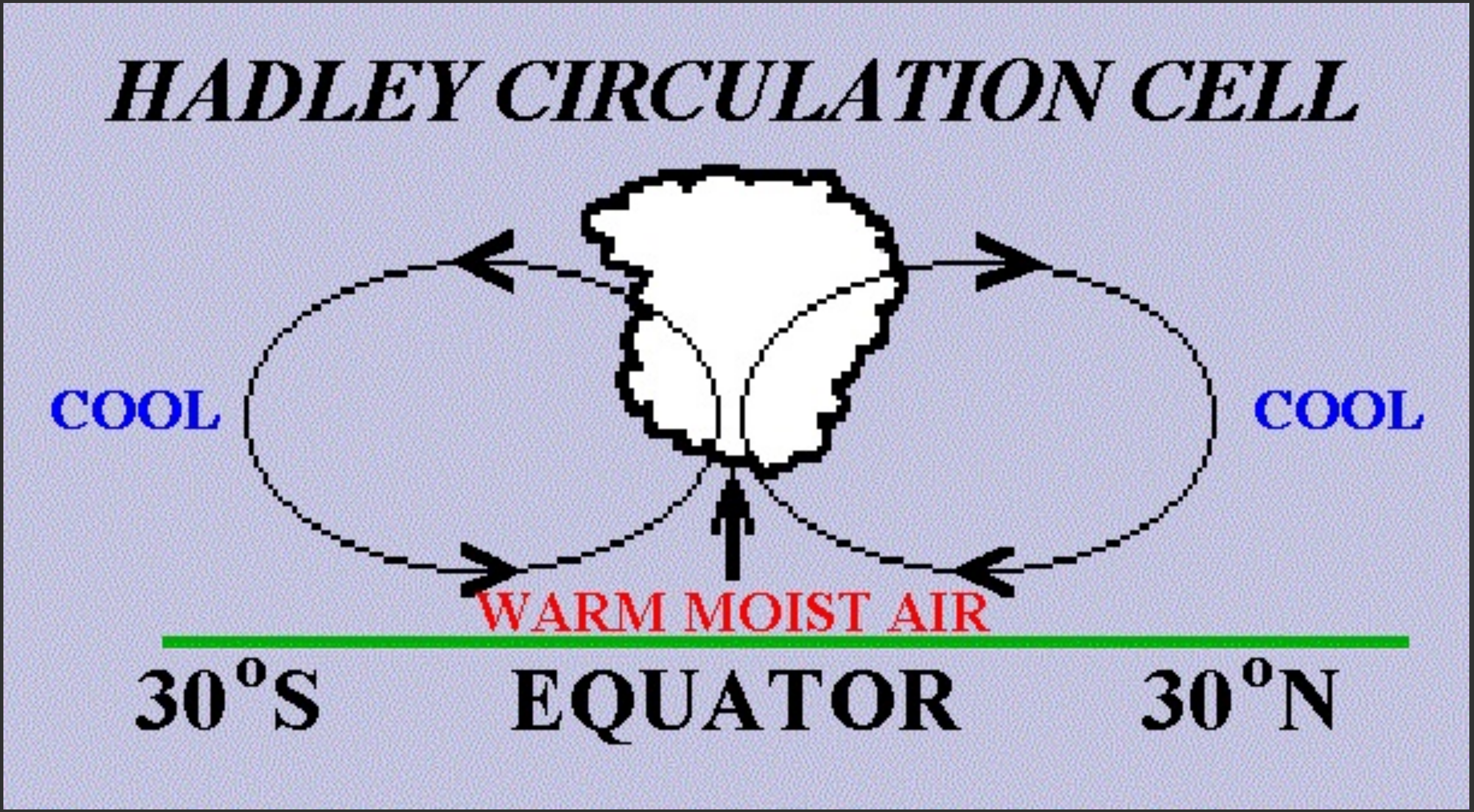
Synchronous rotation is possible



Shields et al. (2016)

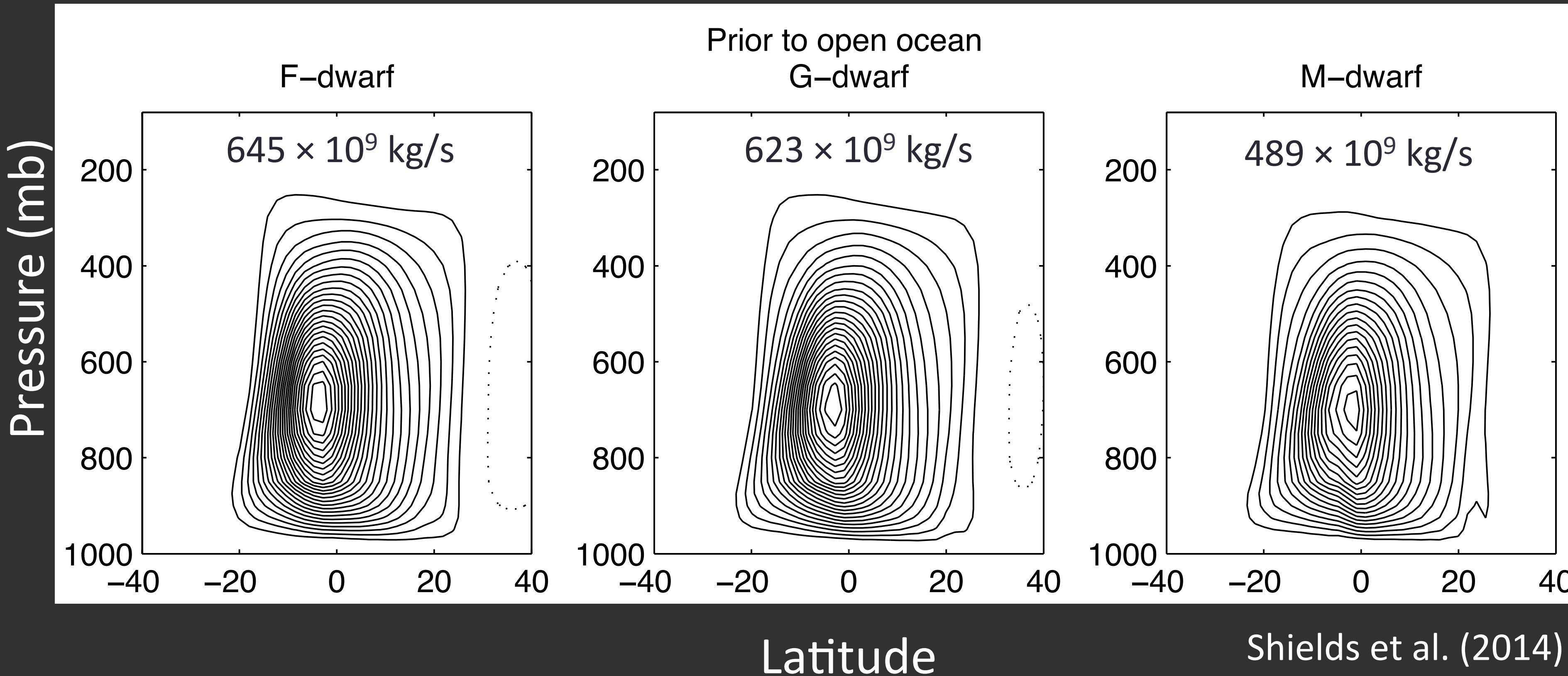
Hadley Circulation



http://sparce.evac.ou.edu/q_and_a/air_circulation.htm, SPaRCE

Transports heat from equator to higher latitudes

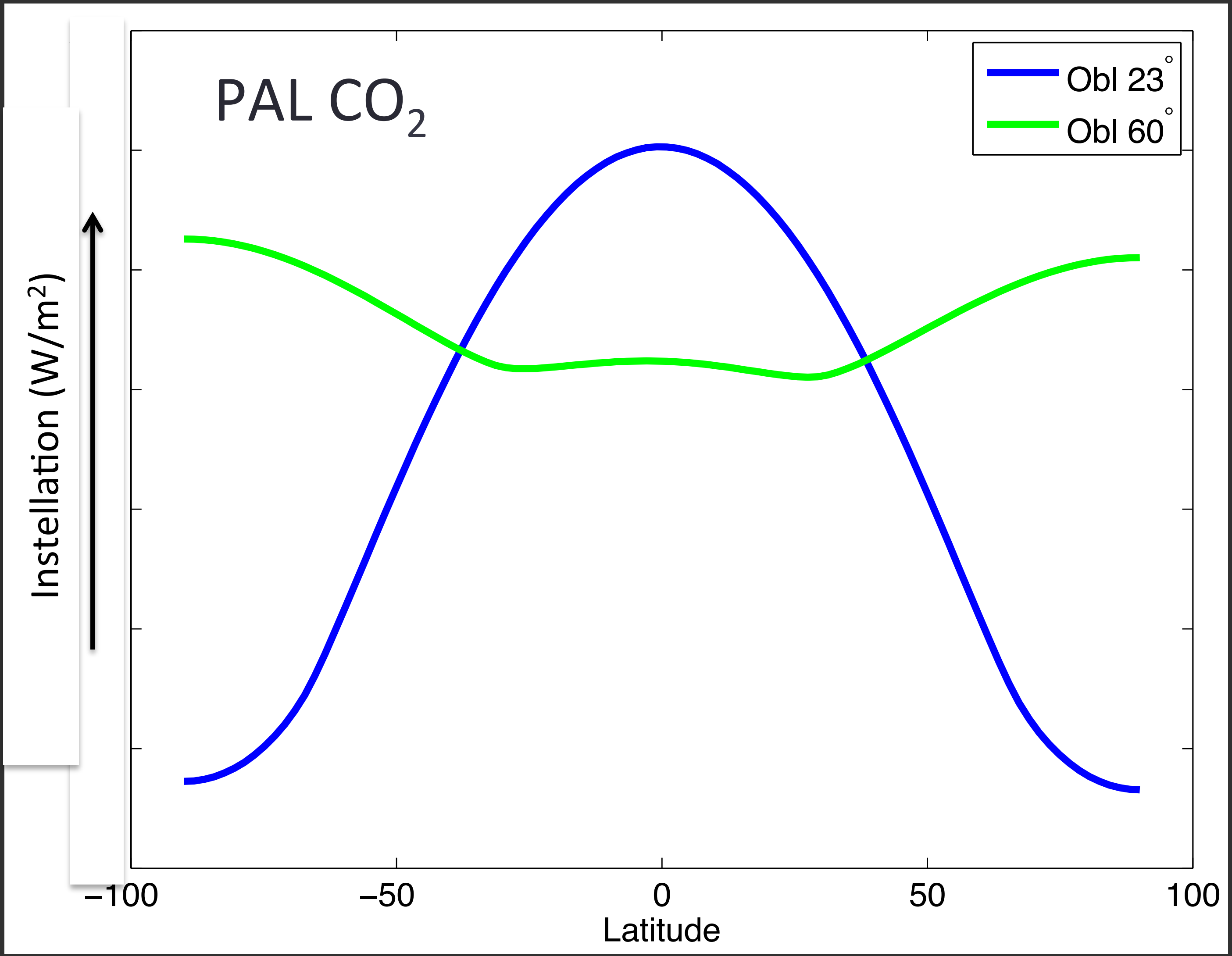
Hadley circulation on deglaciating planets Northern hemisphere winter



Shields et al. (2014)

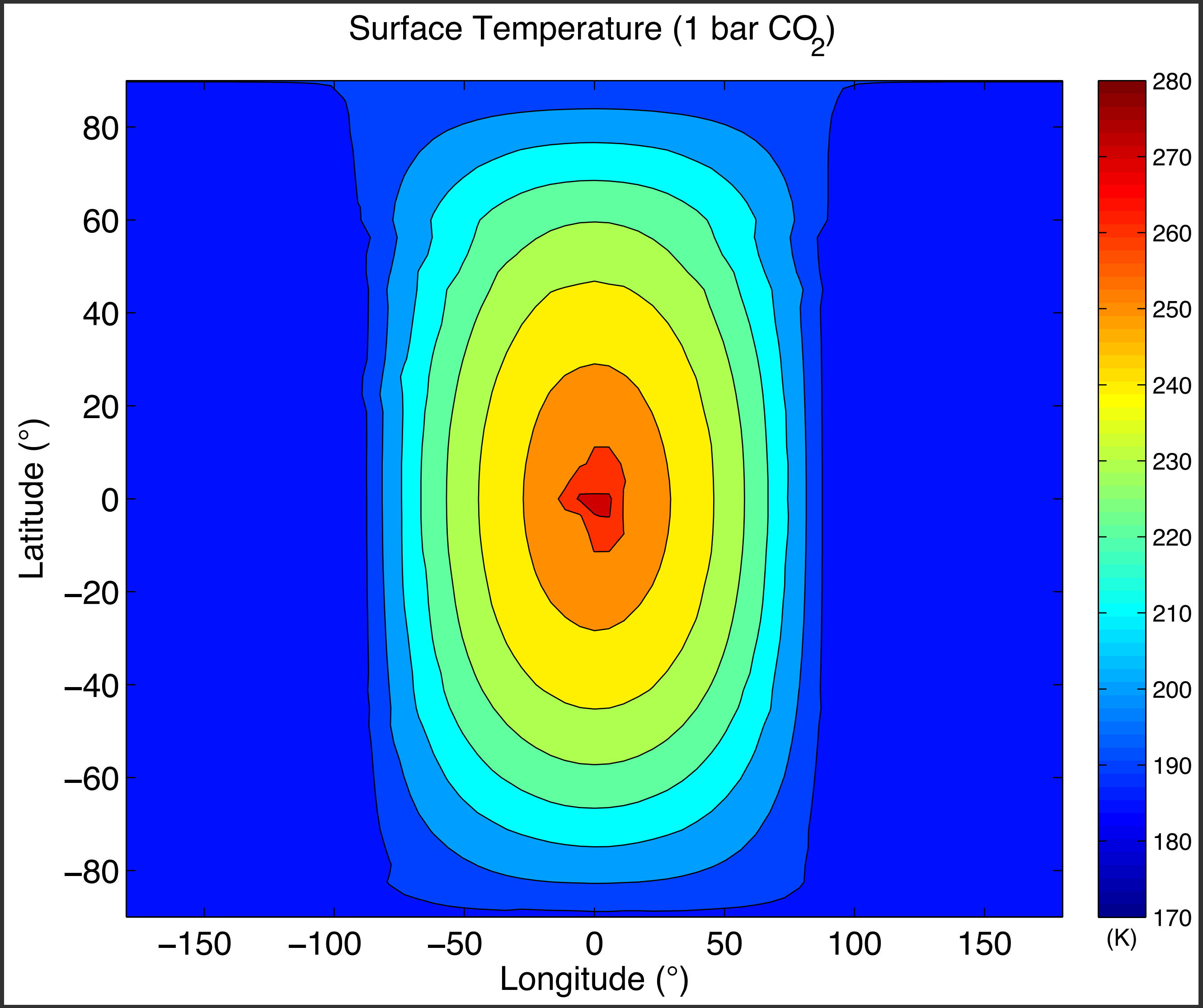
Weaker Hadley circulation helps M-dwarf planet thaw more easily

Insolation



Shields et al. (2016)

Surface Temperature 1 bar CO_2



Shields et al. (2016)

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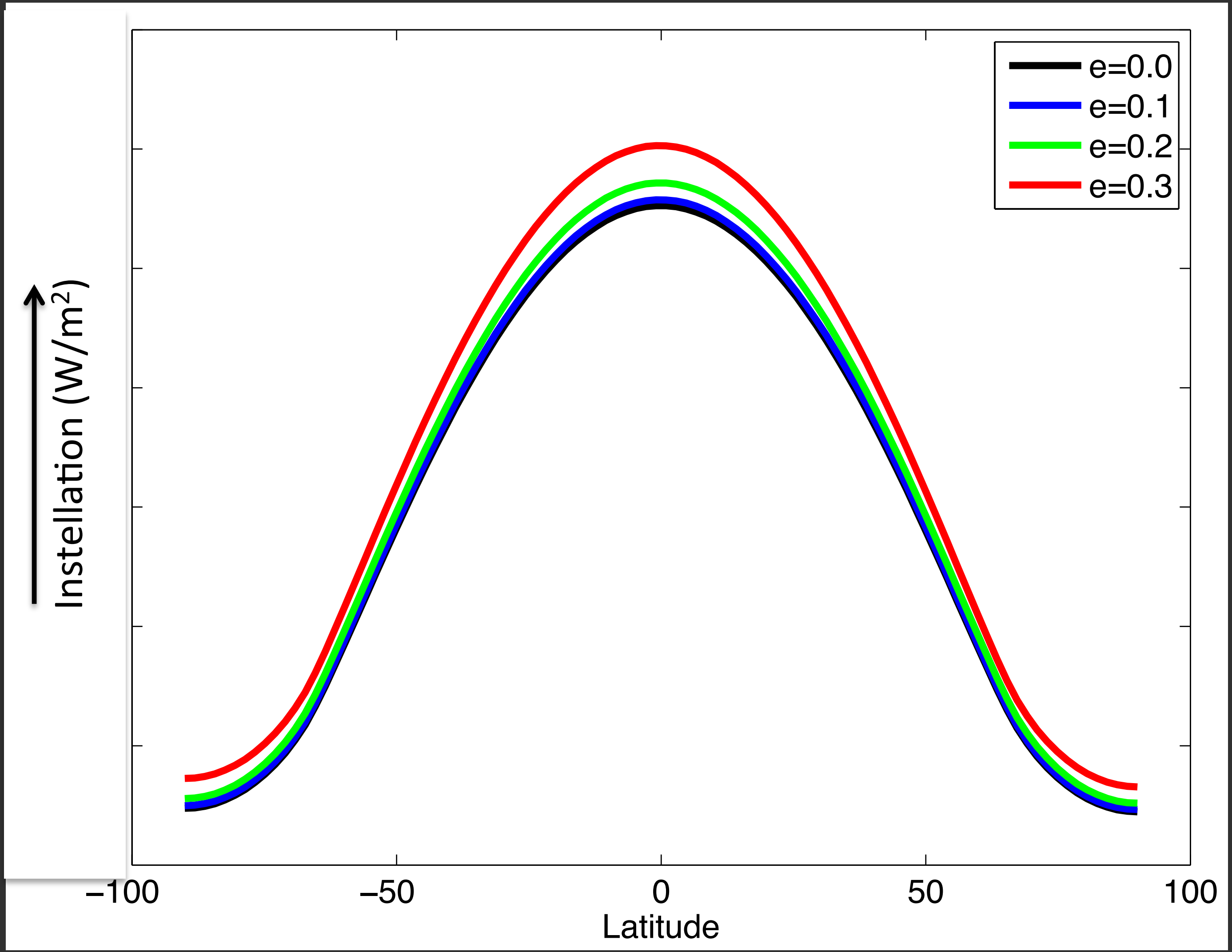

Shields et al. (2016)

Higher eccentricity = More (ann. avg.) stellar insolation ("instellation")

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