# The Star-Planet Climate Connection: Energy Budgets for Terrestrial Extrasolar Planets

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**Exostar Redux**

August 26, 2020

# Our KITP stay
# April-May 2019

Broken foot excluded...

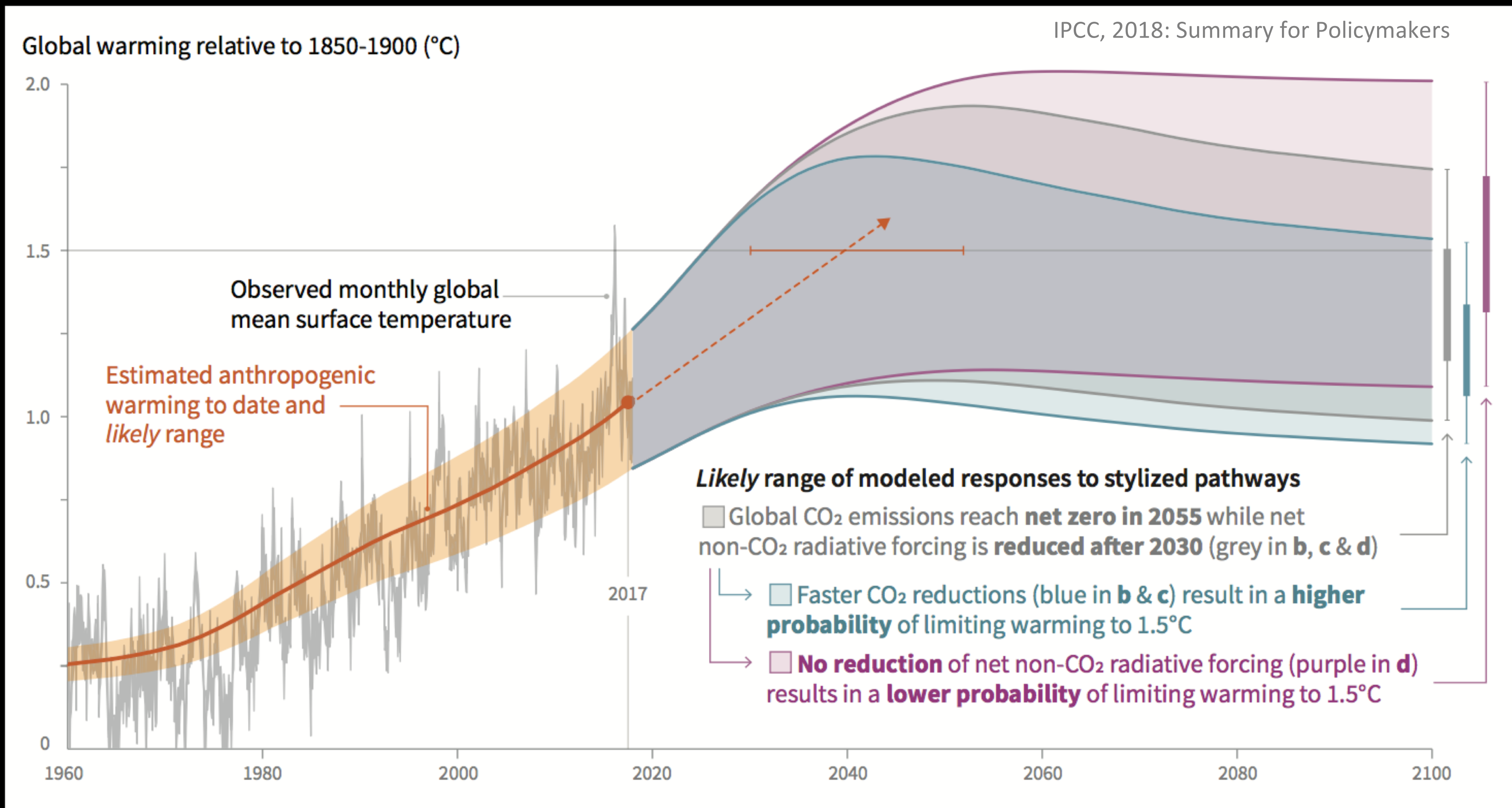

WE'RE LIVING
IN A WHOLE NEW UNIVERSE NOW...

# Global Climate Model (GCM)

## CCSM4 (Gent et al. 2011)

Koshland Science Museum

# PREDICTING FUTURE CLIMATE ON EARTH



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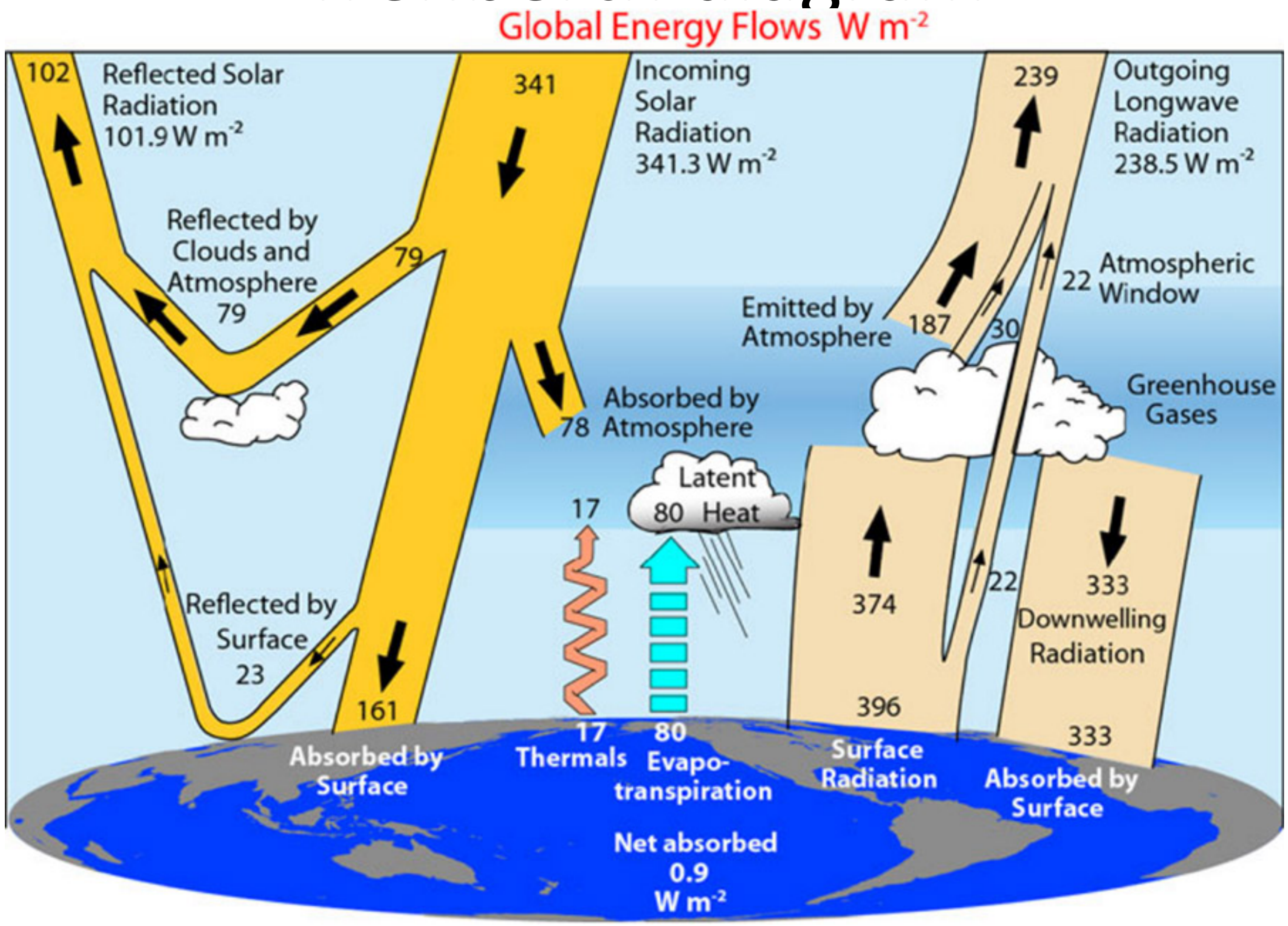
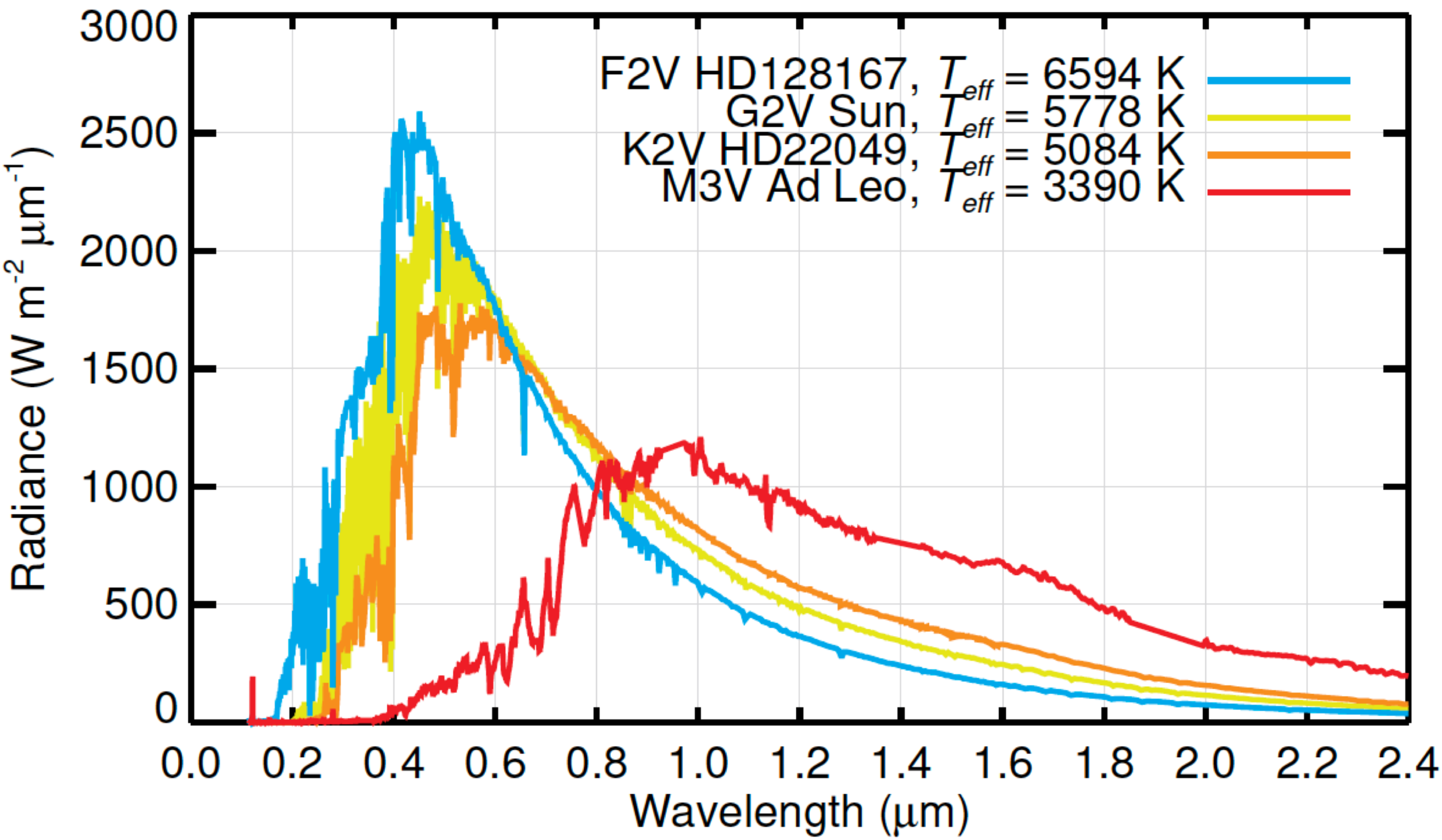
Star-planet Climate Connection

# Trenberth diagram



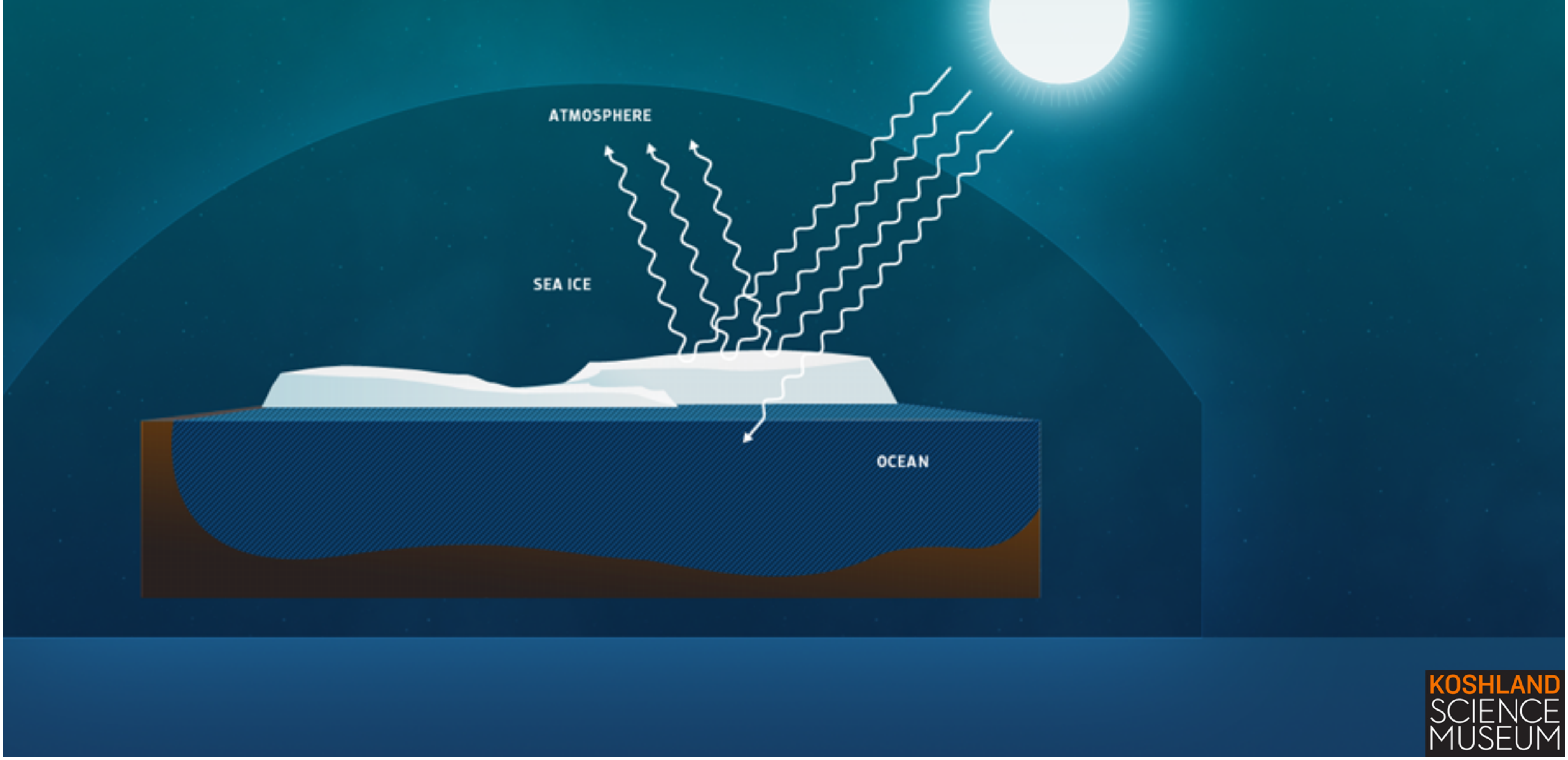

Credit: Kevin Trenberth, John Fasullo and Jeff Kiehl


Starlight

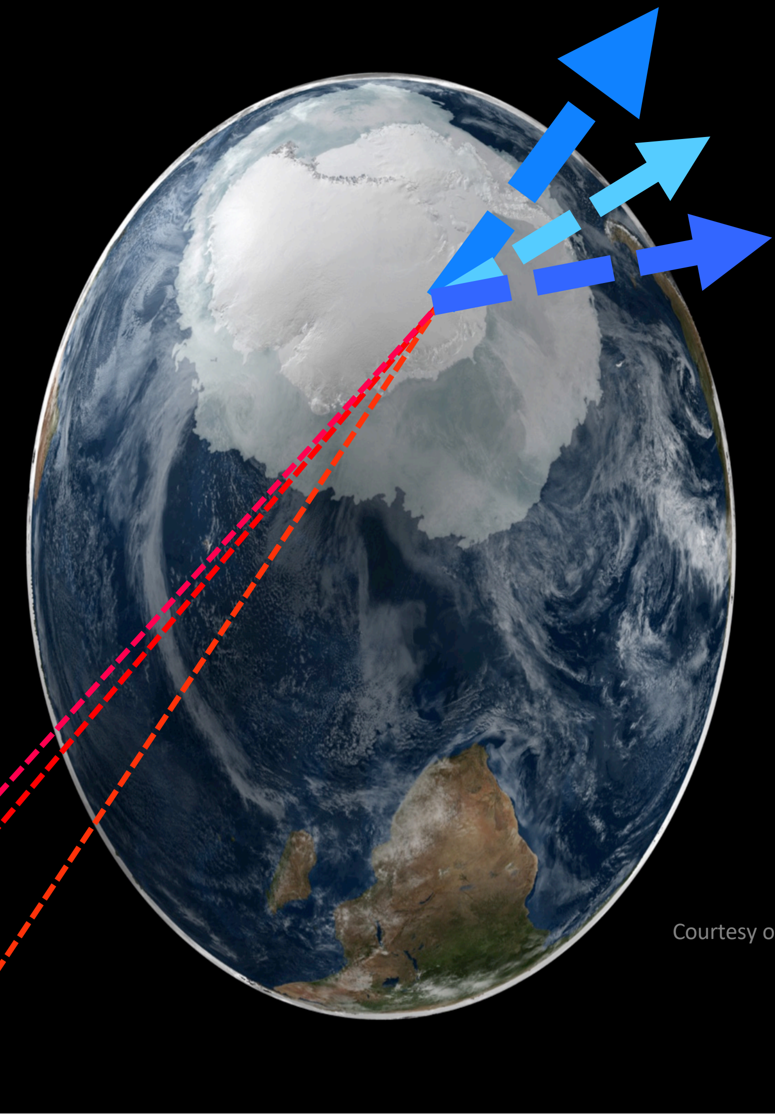



Credit: Based on Wolf, Shields et al. 2017a

# Ice-albedo Feedback




KOSHLAND SCIENCE MUSEUM

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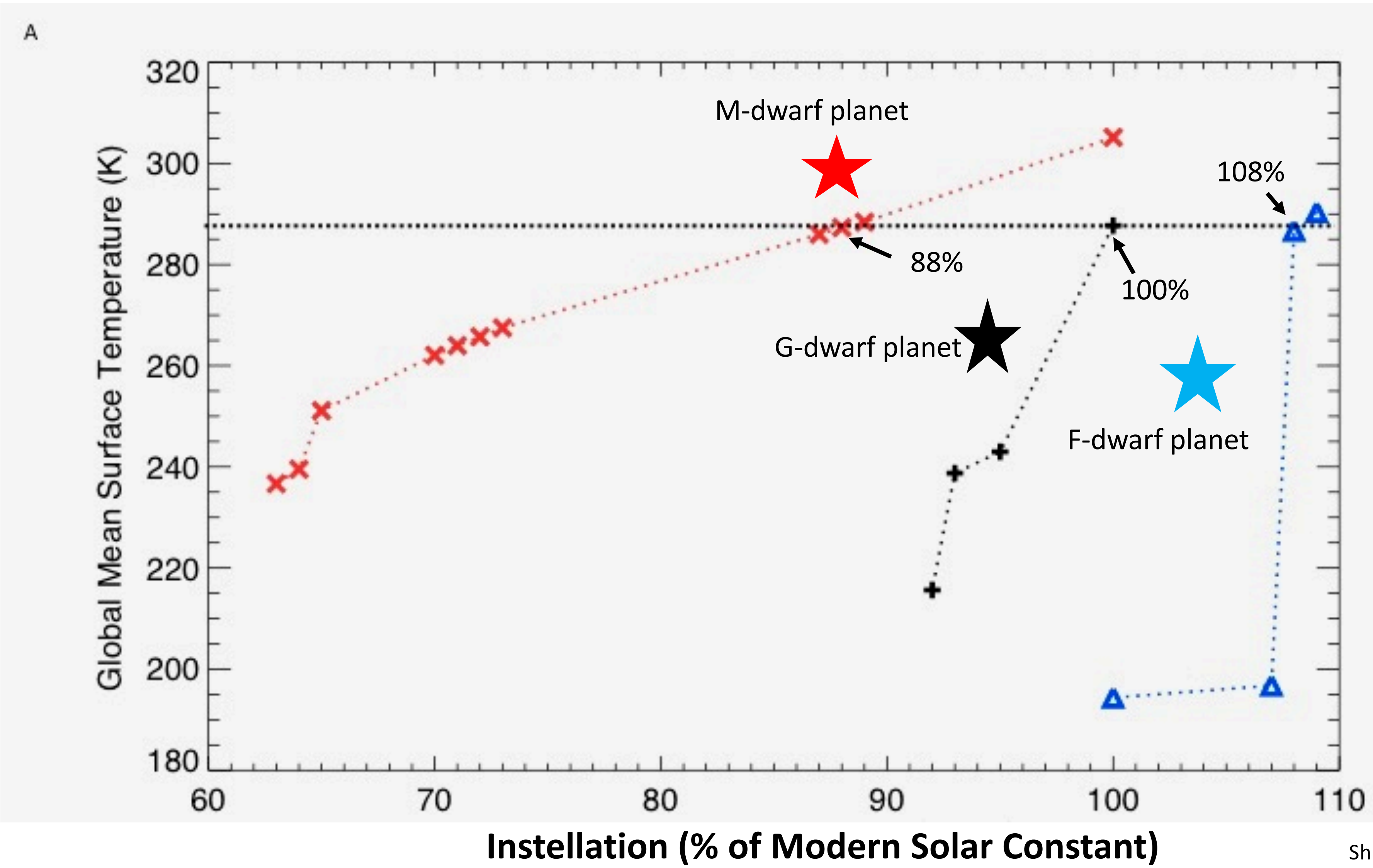
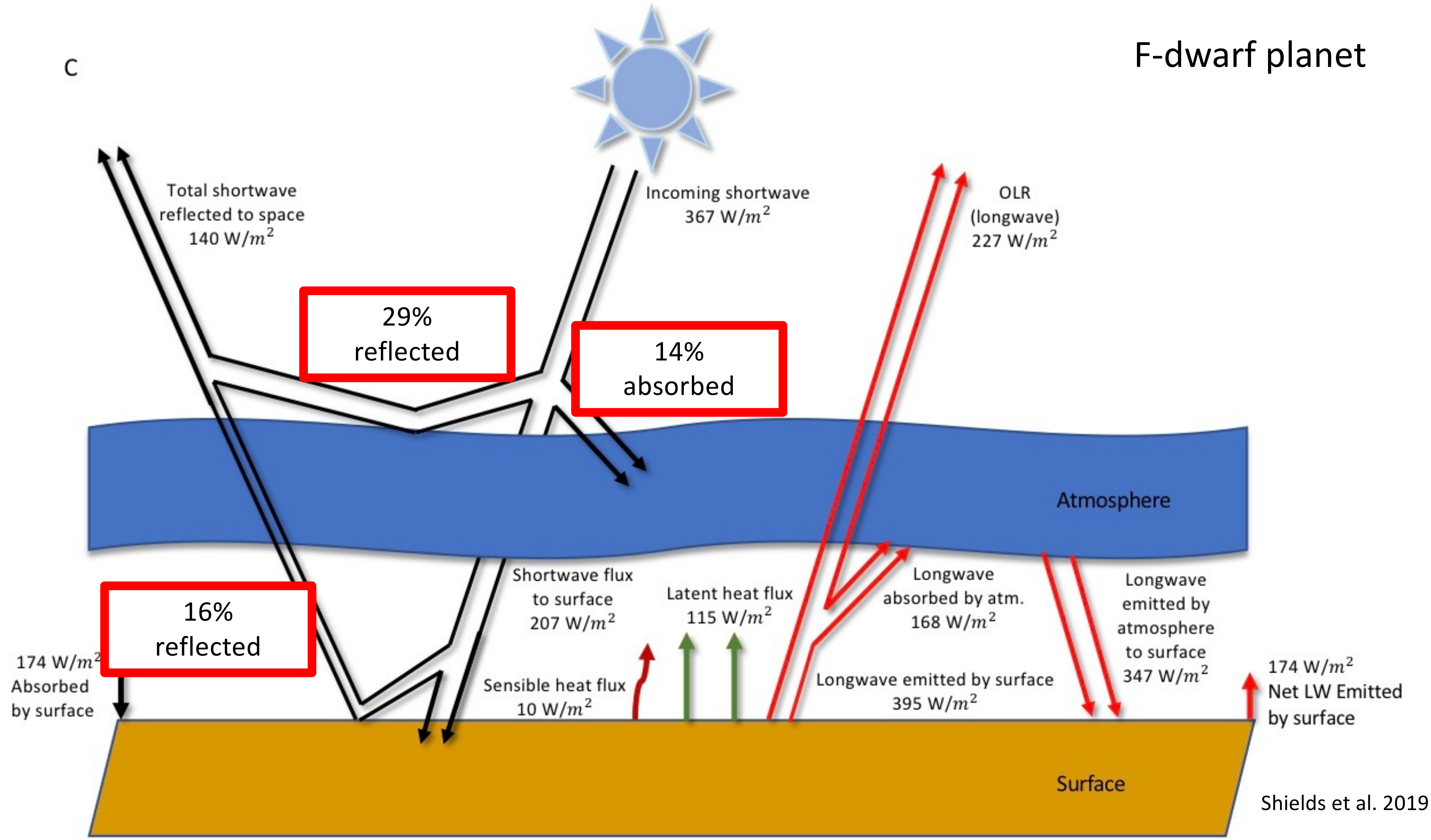
Star-planet Climate Connection

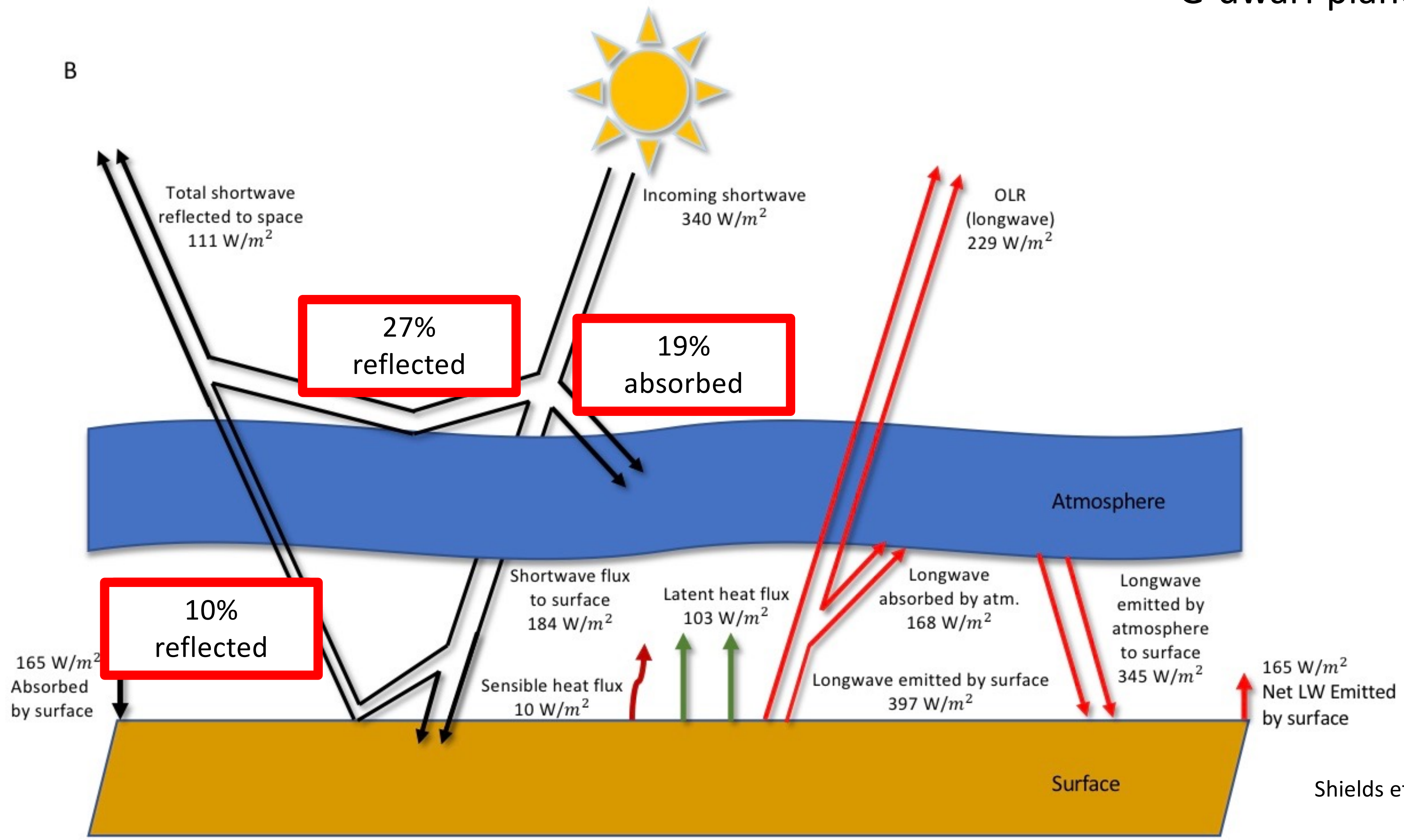



Shields et al. 2019

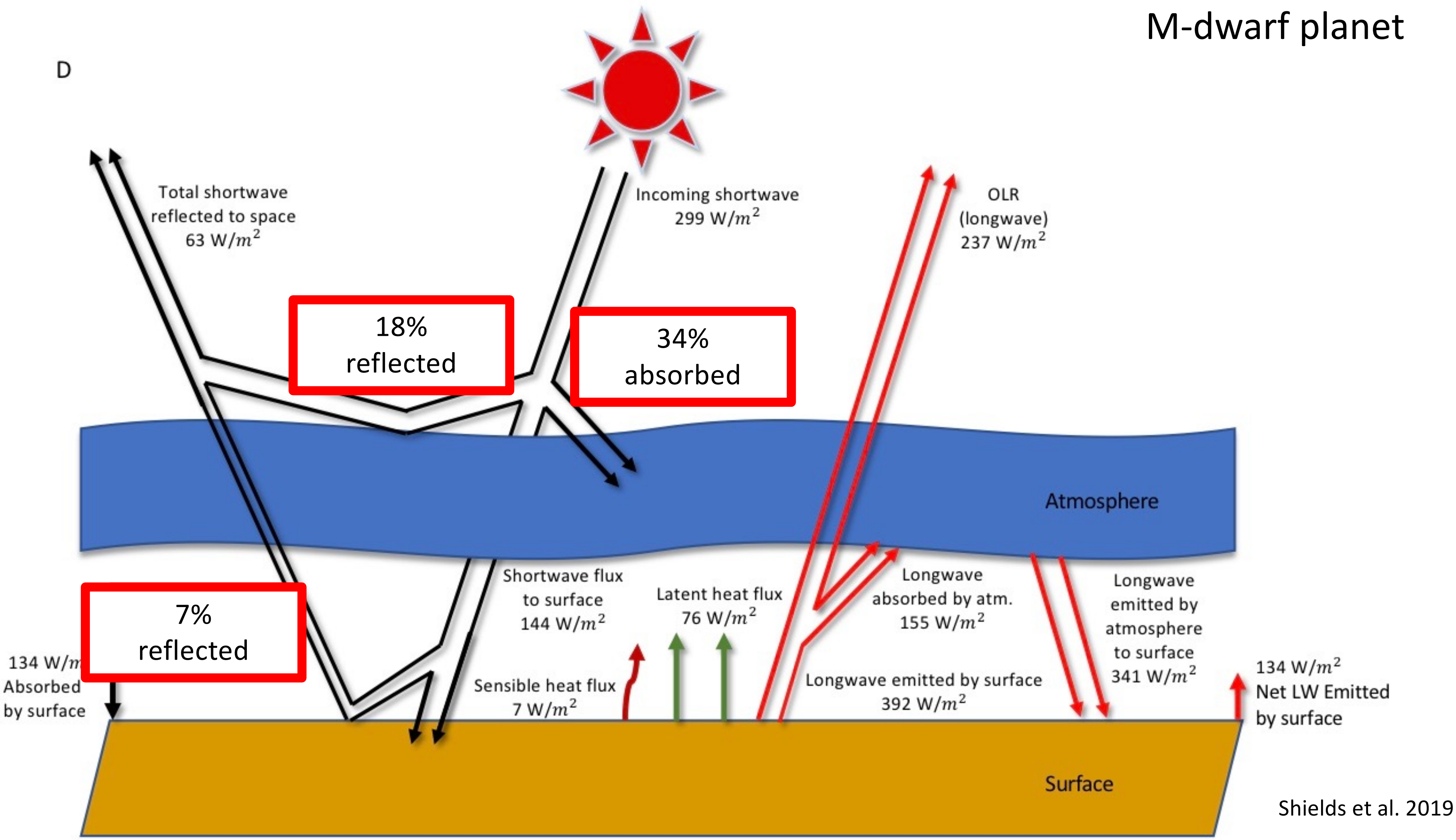


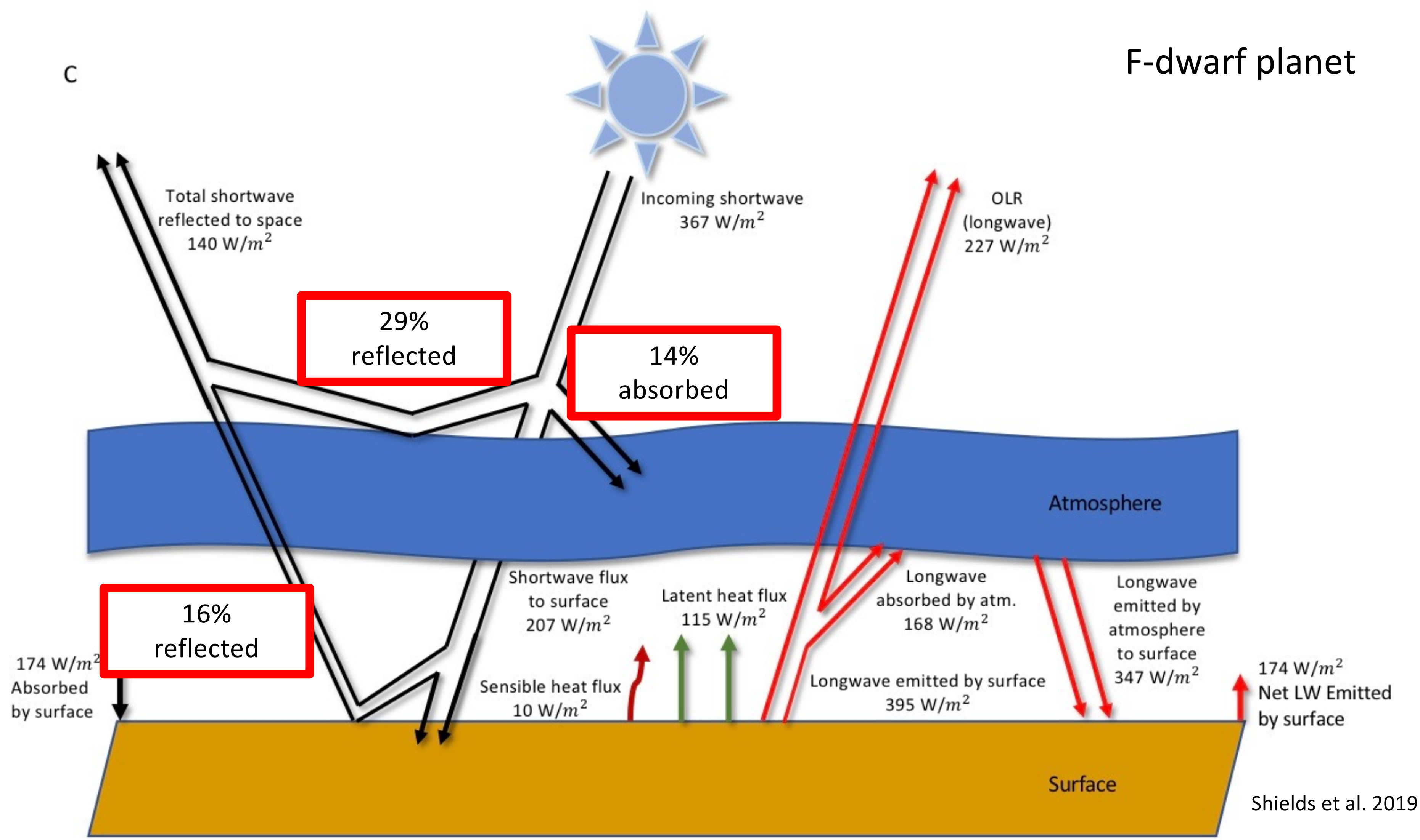
C
F-dwarf planet
Total shortwave reflected to space 140 W/$m^2$
Incoming shortwave 367 W/$m^2$
OLR (longwave) 227 W/$m^2$
29% reflected
14% absorbed
Atmosphere
16% reflected
174 W/$m^2$ Absorbed by surface
Shortwave flux to surface 207 W/$m^2$
Latent heat flux 115 W/$m^2$
Longwave absorbed by atm. 168 W/$m^2$
Longwave emitted by atmosphere to surface 347 W/$m^2$
Sensible heat flux 10 W/$m^2$
Longwave emitted by surface 395 W/$m^2$
174 W/$m^2$ Net LW Emitted by surface
Surface
Shields et al. 2019

G-dwarf planet




Shields et al. 2019


M-dwarf planet
D
Total shortwave reflected to space 63 W/$m^2$
Incoming shortwave 299 W/$m^2$
OLR (longwave) 237 W/$m^2$
18% reflected
34% absorbed
Atmosphere
7% reflected
134 W/m
Absorbed by surface
Shortwave flux to surface 144 W/$m^2$
Latent heat flux 76 W/$m^2$
Longwave absorbed by atm. 155 W/$m^2$
Longwave emitted by atmosphere to surface 341 W/$m^2$
Sensible heat flux 7 W/$m^2$
Longwave emitted by surface 392 W/$m^2$
134 W/$m^2$ Net LW Emitted by surface
Surface
Shields et al. 2019


C
F-dwarf planet
Total shortwave reflected to space 140 W/$m^2$
Incoming shortwave 367 W/$m^2$
OLR (longwave) 227 W/$m^2$
29% reflected
14% absorbed
Atmosphere
16% reflected
174 W/$m^2$ Absorbed by surface
Shortwave flux to surface 207 W/$m^2$
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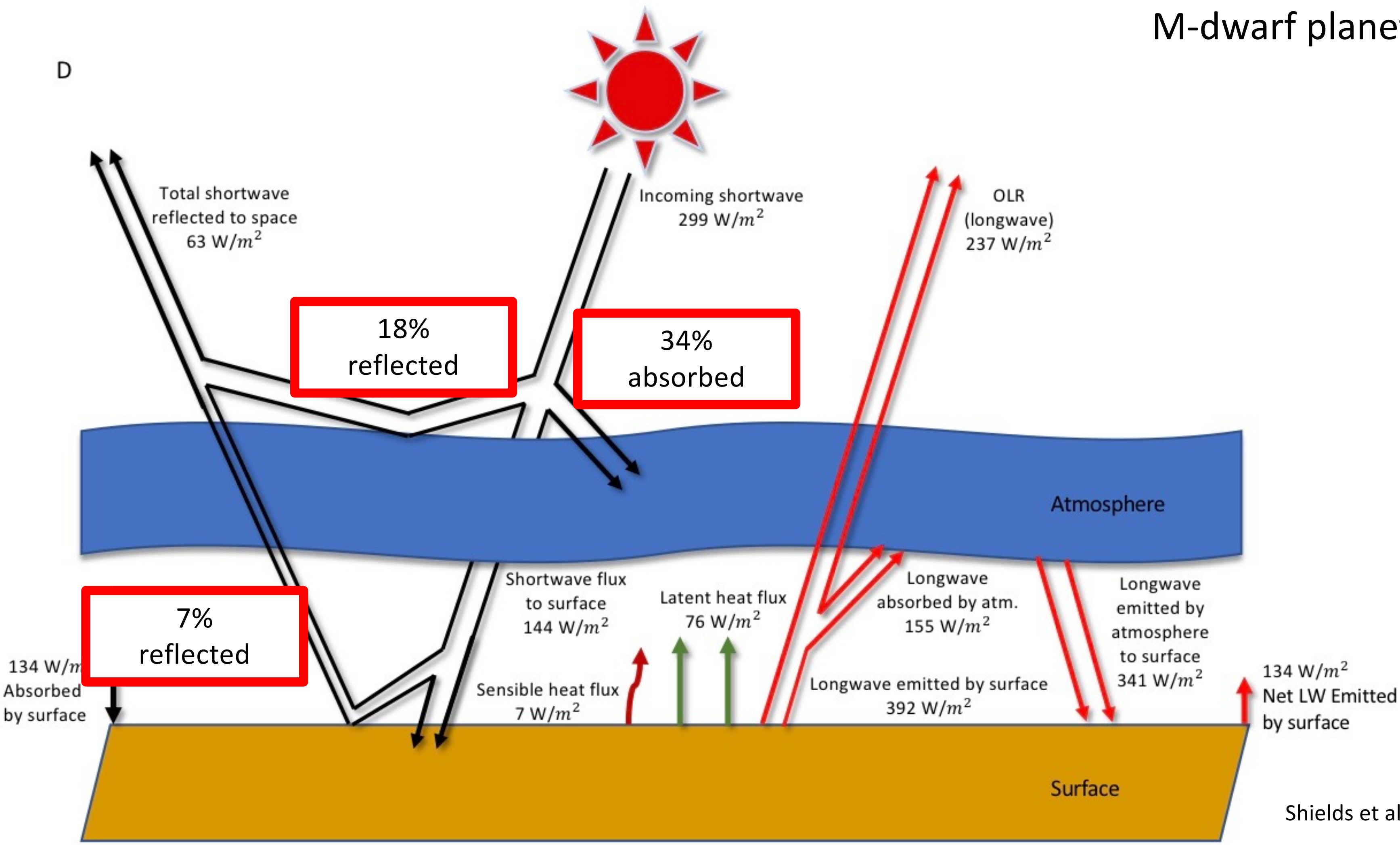
Longwave emitted by atmosphere to surface 347 W/$m^2$
Sensible heat flux 10 W/$m^2$
Longwave emitted by surface 395 W/$m^2$
174 W/$m^2$ Net LW Emitted by surface
Surface
Shields et al. 2019

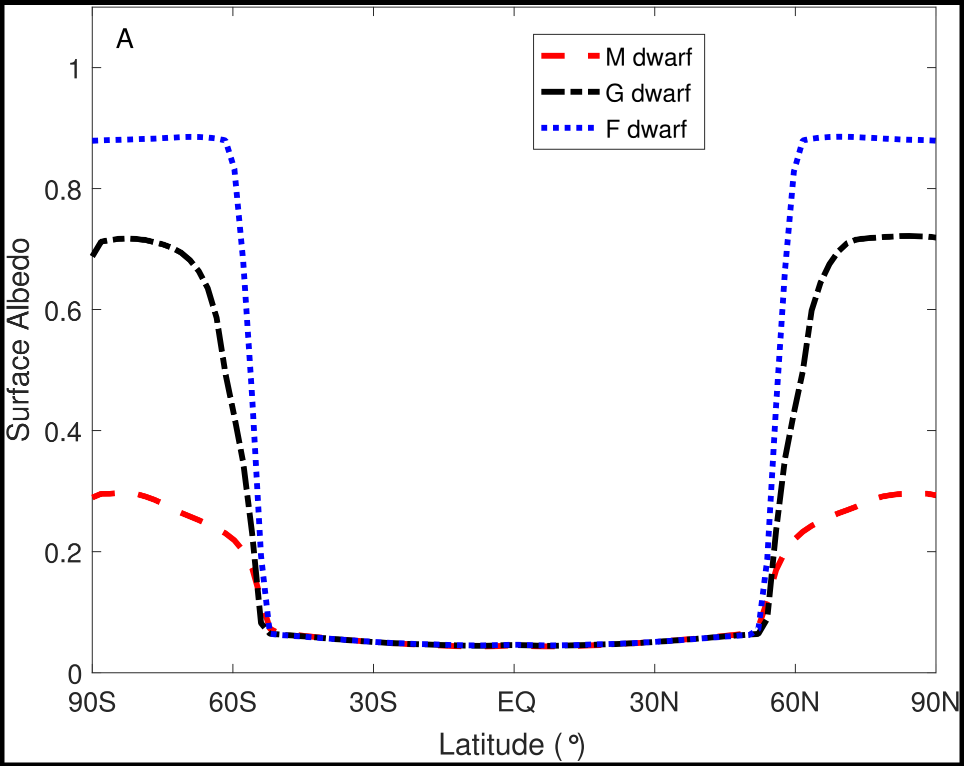
D

# M-dwarf planet

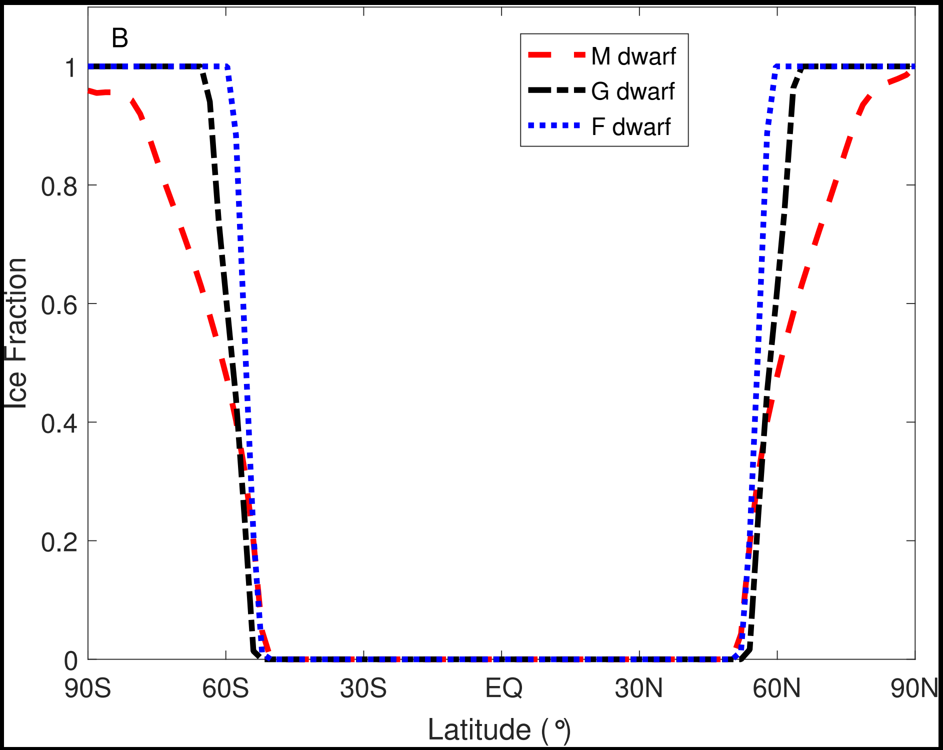



Shields et al. 2019

## Surface Albedo

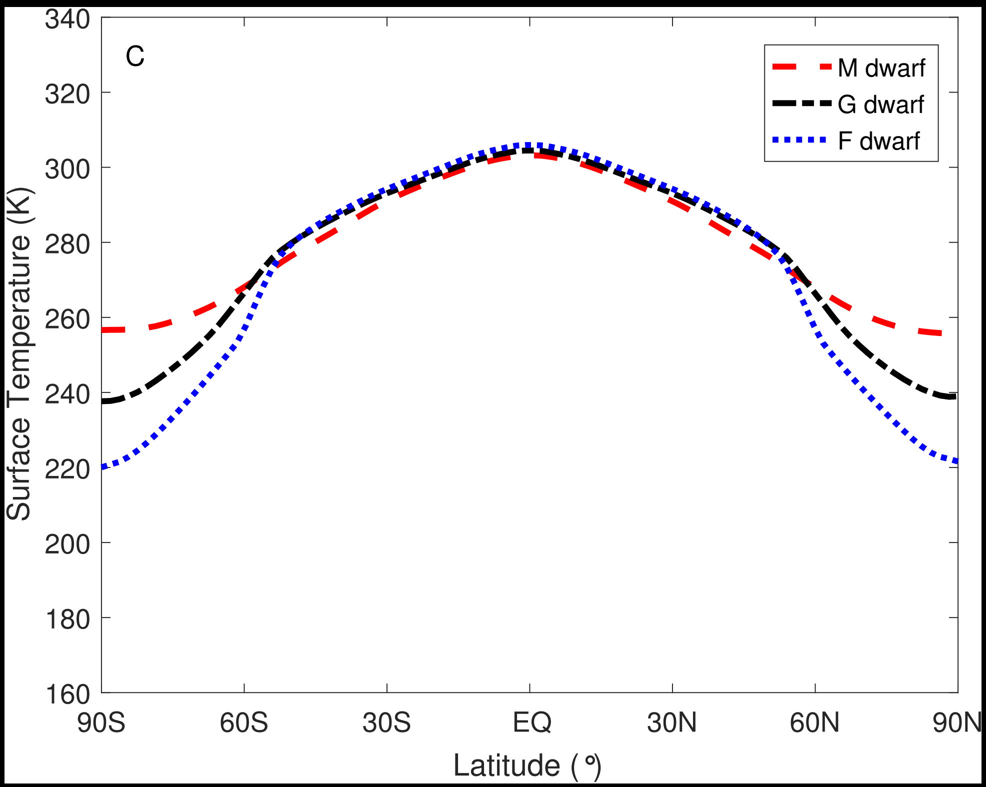



## Ice Fraction

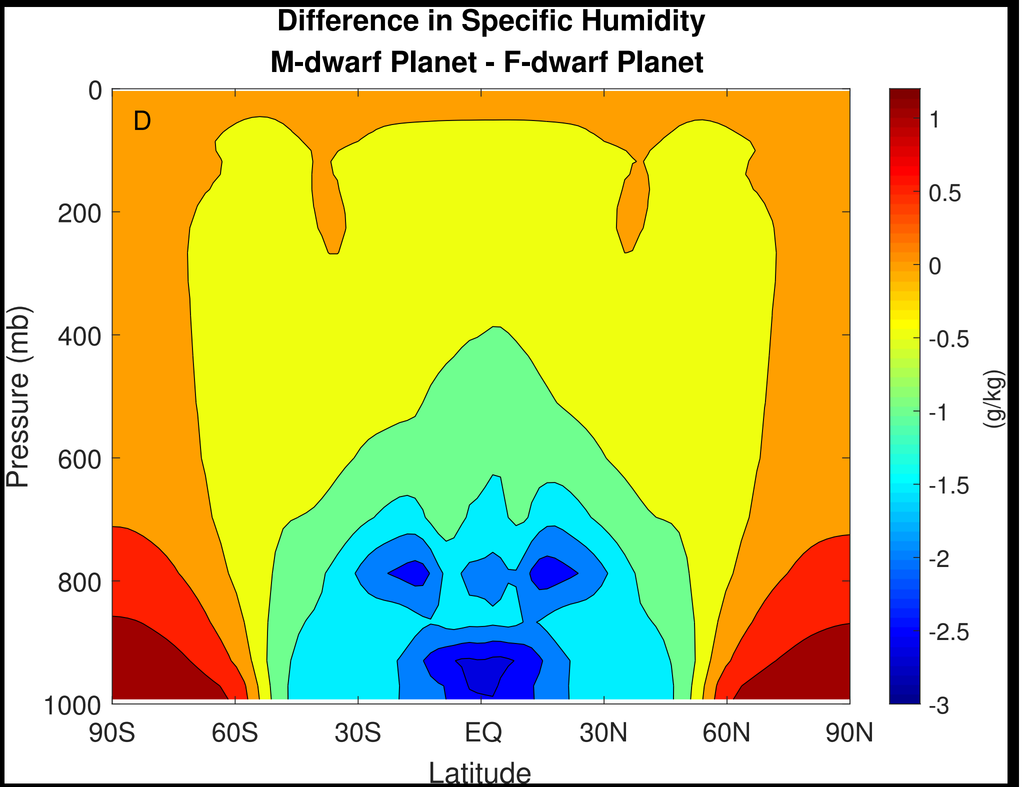



Shields et al. 2019

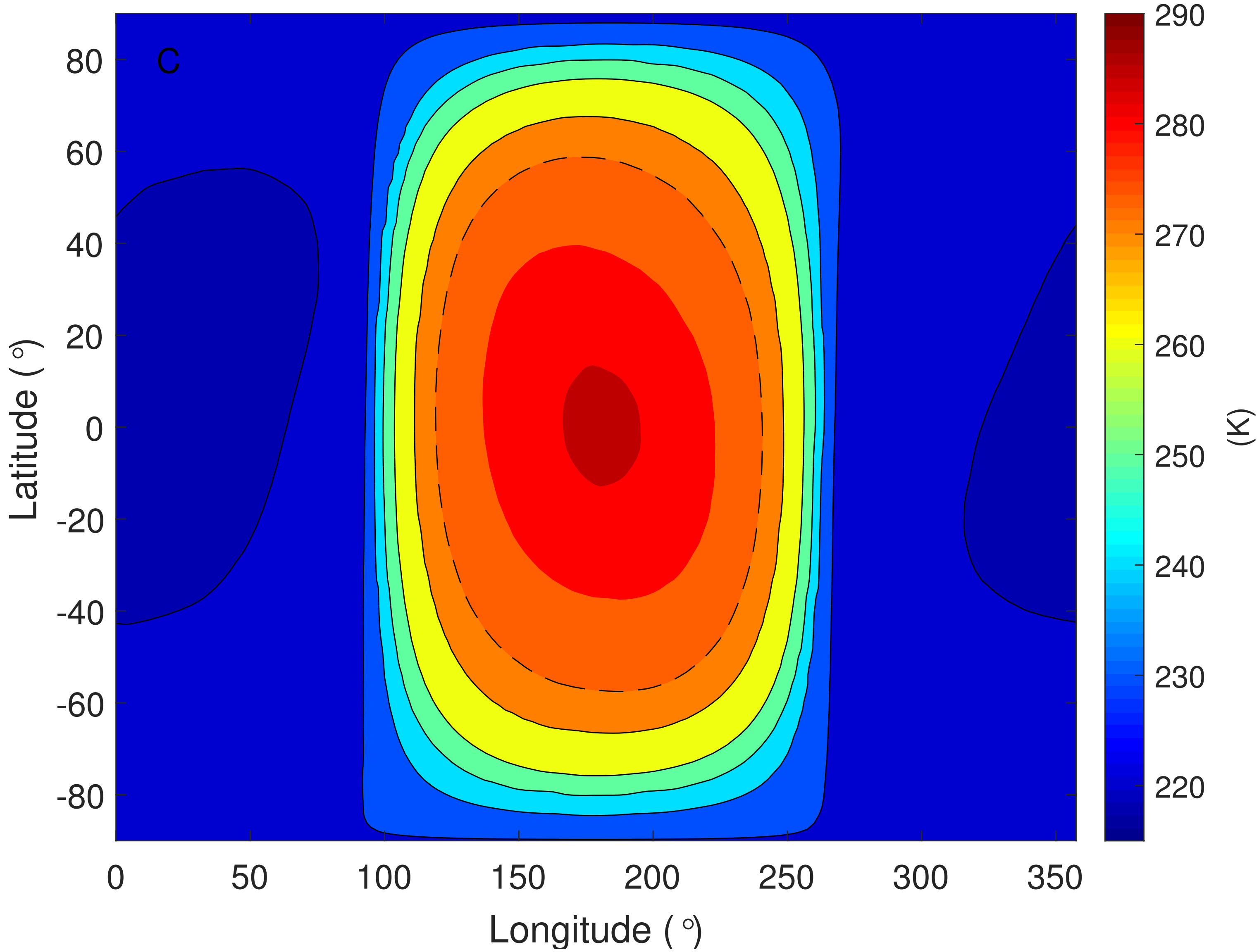
# Surface Temperature



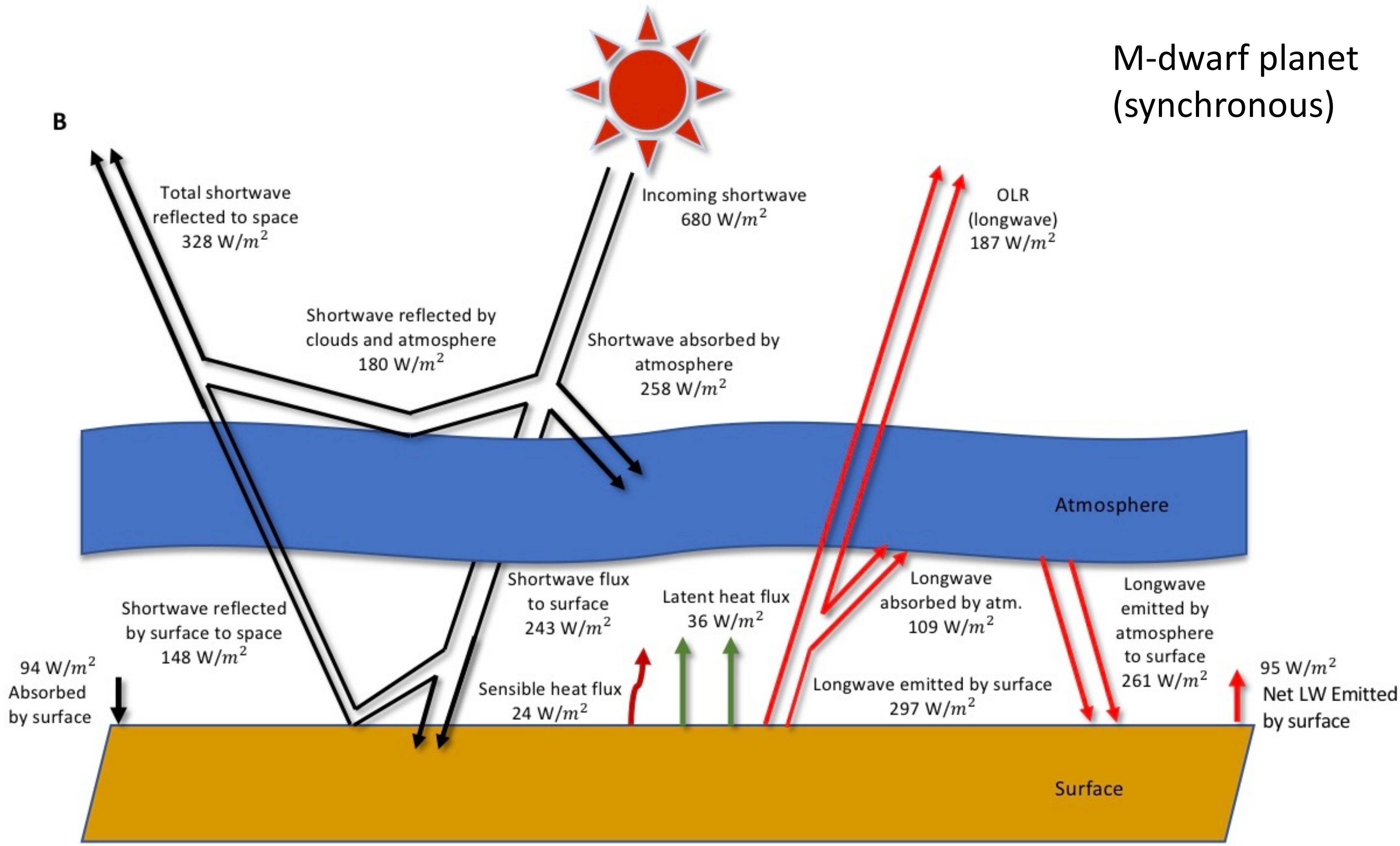

# Difference in Specific Humidity




Shields et al. 2019



C
80
60
40
20
0
-20
-40
-60
-80
Latitude ( °)
0
50
100
150
200
250
300
350
Longitude ( °)
290
280
270
260
250
240
230
220
(K)


M-dwarf planet
(synchronous)
B
Total shortwave reflected to space 328 W/$m^2$
Incoming shortwave 680 W/$m^2$
OLR (longwave) 187 W/$m^2$
Shortwave reflected by clouds and atmosphere 180 W/$m^2$
Shortwave absorbed by atmosphere 258 W/$m^2$
Atmosphere
Shortwave flux to surface 243 W/$m^2$
Latent heat flux 36 W/$m^2$
Longwave absorbed by atm. 109 W/$m^2$
Longwave emitted by atmosphere to surface 261 W/$m^2$
Shortwave reflected by surface to space 148 W/$m^2$
94 W/$m^2$ Absorbed by surface
Sensible heat flux 24 W/$m^2$
Longwave emitted by surface 297 W/$m^2$
95 W/$m^2$ Net LW Emitted by surface
Surface

THE ASTROPHYSICAL JOURNAL LETTERS

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# Energy Budgets for Terrestrial Extrasolar Planets

Aomawa L. Shields[1], Cecilia M. Bitz[2], and Igor Palubski[1]

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The Astrophysical Journal Letters, Volume 884, Number 1

Article PDF   Article ePub

Figures   Tables   References

+ Article information

## Abstract

The pathways through which incoming energy is distributed between the surface and atmosphere have been analyzed for the Earth. However, the effect of the spectral energy

# Take –away points

- Host star SED heavily influences the energy budget of an orbiting planet.
- An M-dwarf planet requires less instellation than a G-dwarf planet to exhibit similar climate, while an F-dwarf planet requires more
- Water ice, atmospheric gases causes this difference
- Synchronously rotating M-dwarf planets have lower min/max dayside surface temperatures compared to global mean on rapidly rotating M-dwarf planets

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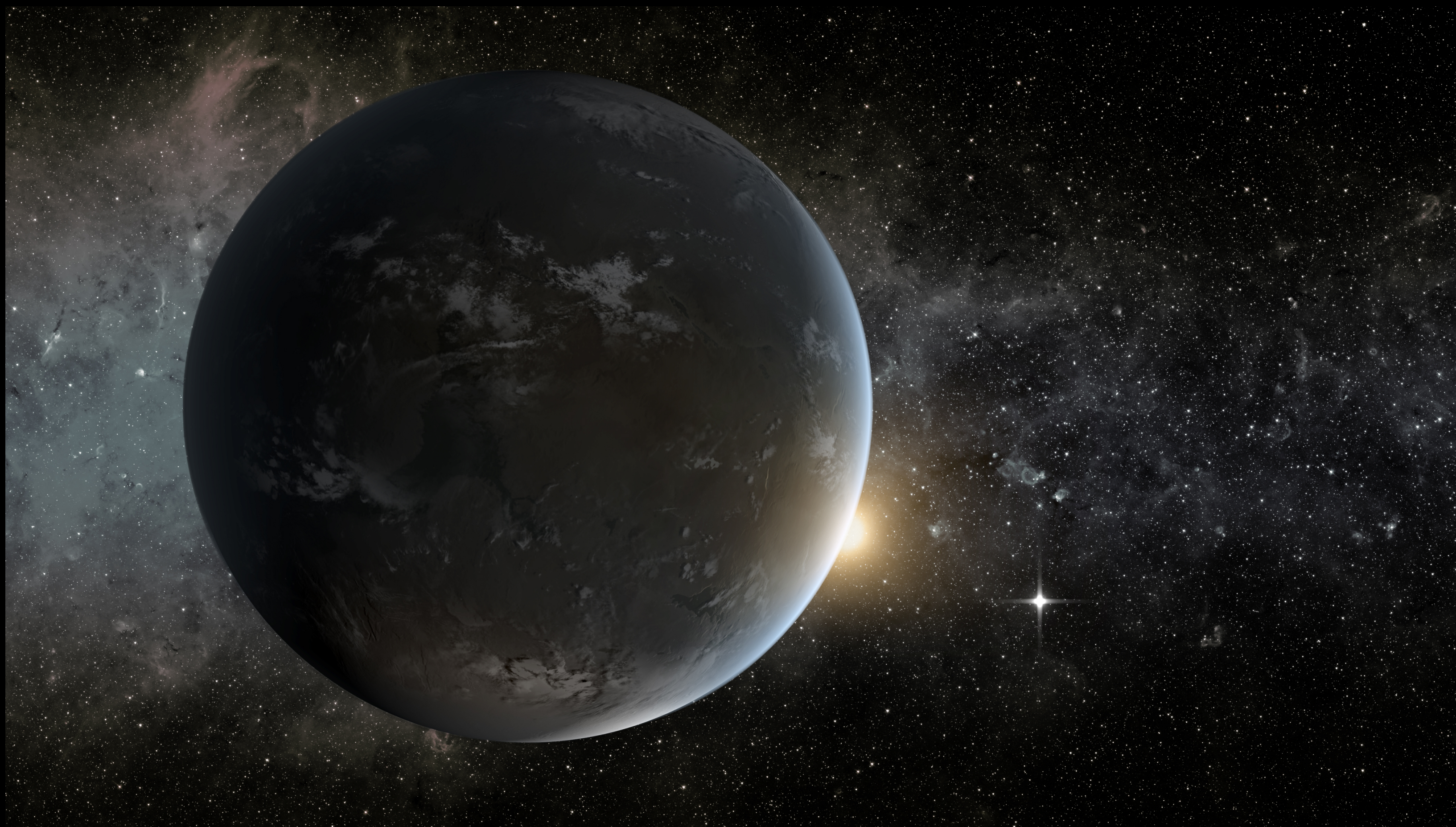
- Collaborators – Cecilia Bitz, Igor Palubski
- Kevin Trenberth, John Fasullo and Jeff Kiehl

# Thank you!



NASA Ames/JPL-Caltech/Tim Pyle

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- Host star SED heavily influences the energy budget of an orbiting planet.
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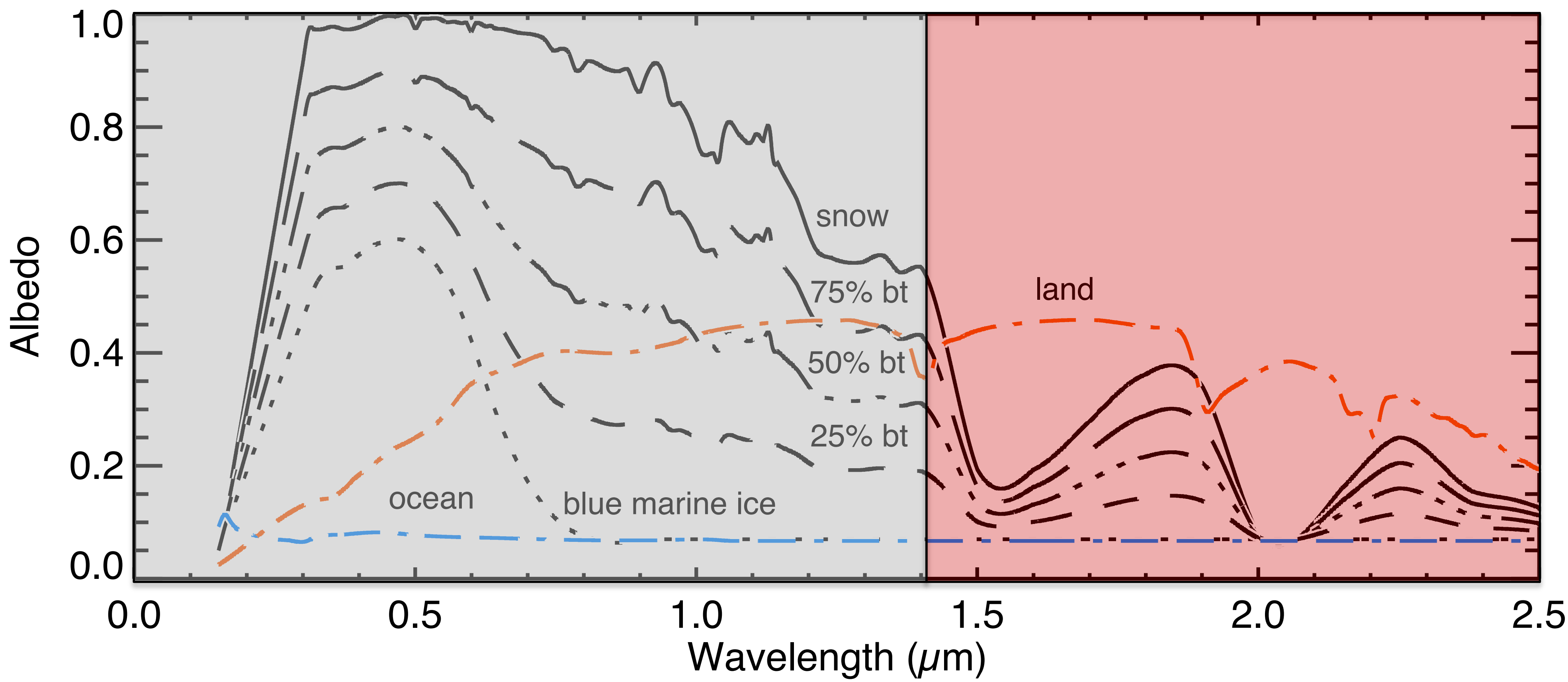
# Rising Stargirls

# Land planets orbiting M-dwarf stars

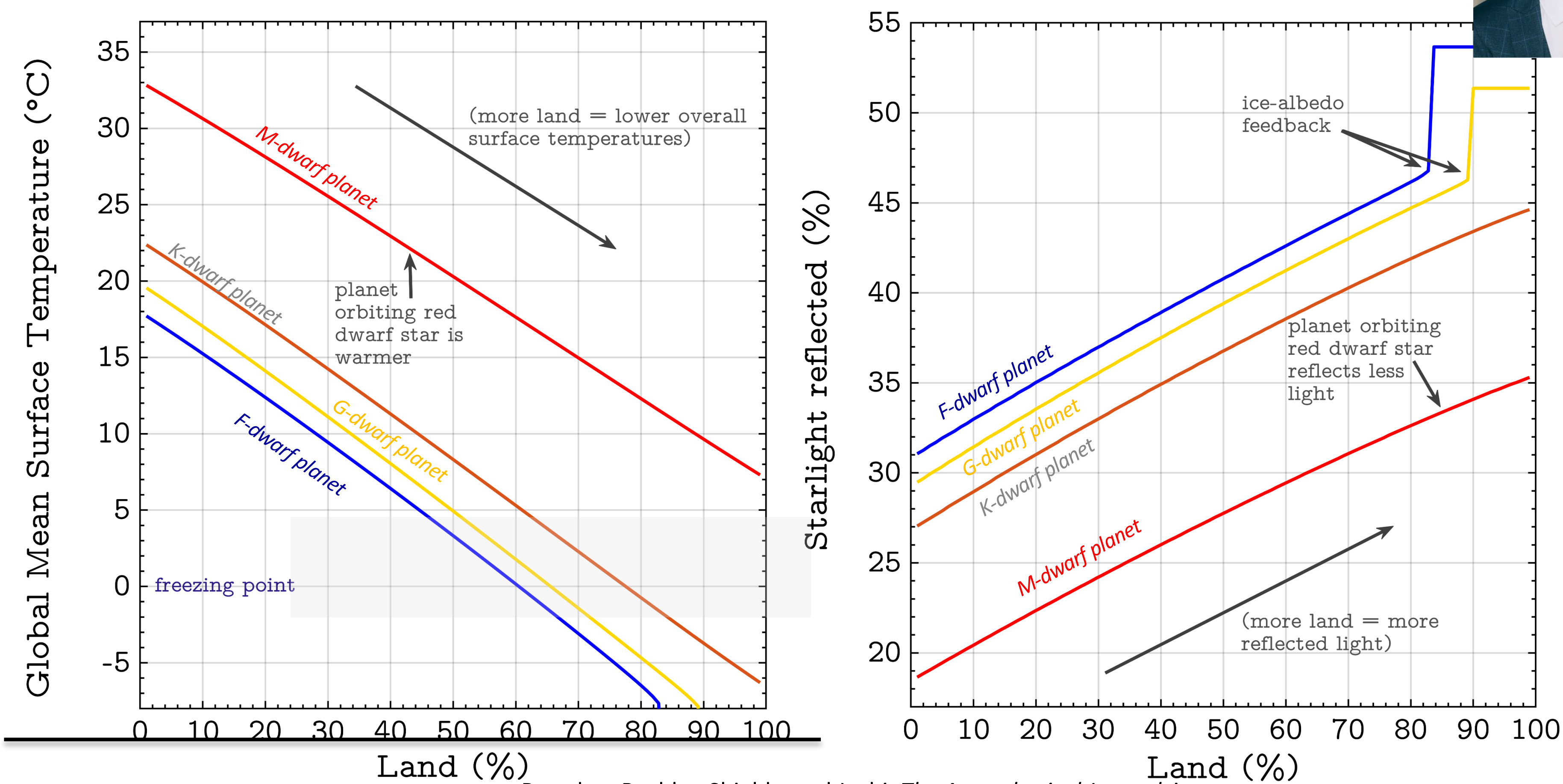


Conservation of momentum → $$\frac{d\vec{v}}{dt} = -\frac{1}{\rho}\vec{\nabla}p - \vec{g} + \vec{F}_{fric} - 2\vec{\Omega} \times \vec{v}$$

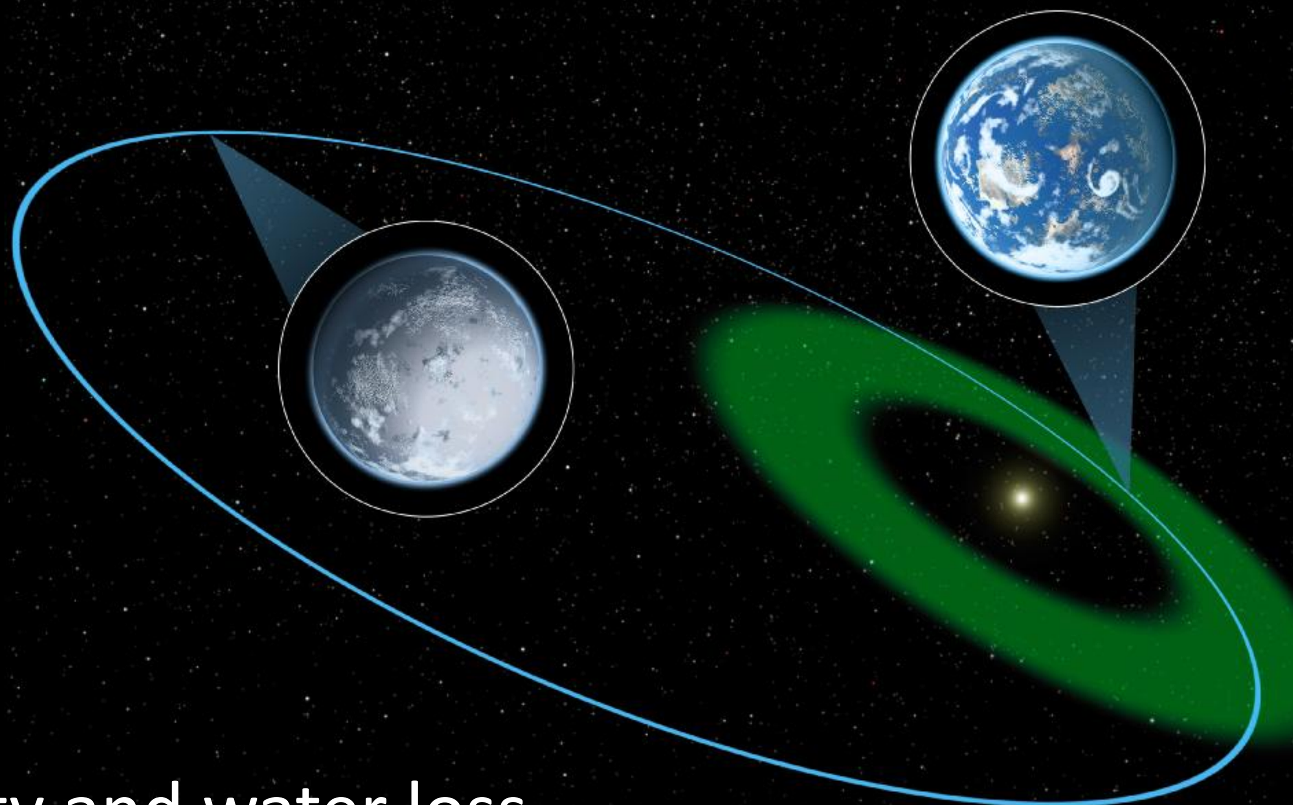
Mass continuity → $$\frac{\partial \rho}{\partial t} = -\vec{\nabla} \cdot (\rho \vec{v})$$

Conservation of energy (1st law of thermo) → $$Q = C_p \frac{dT}{dt} - \frac{1}{\rho}\frac{dp}{dt}$$

Equation of state for the atmosphere → $$p = \rho R T$$

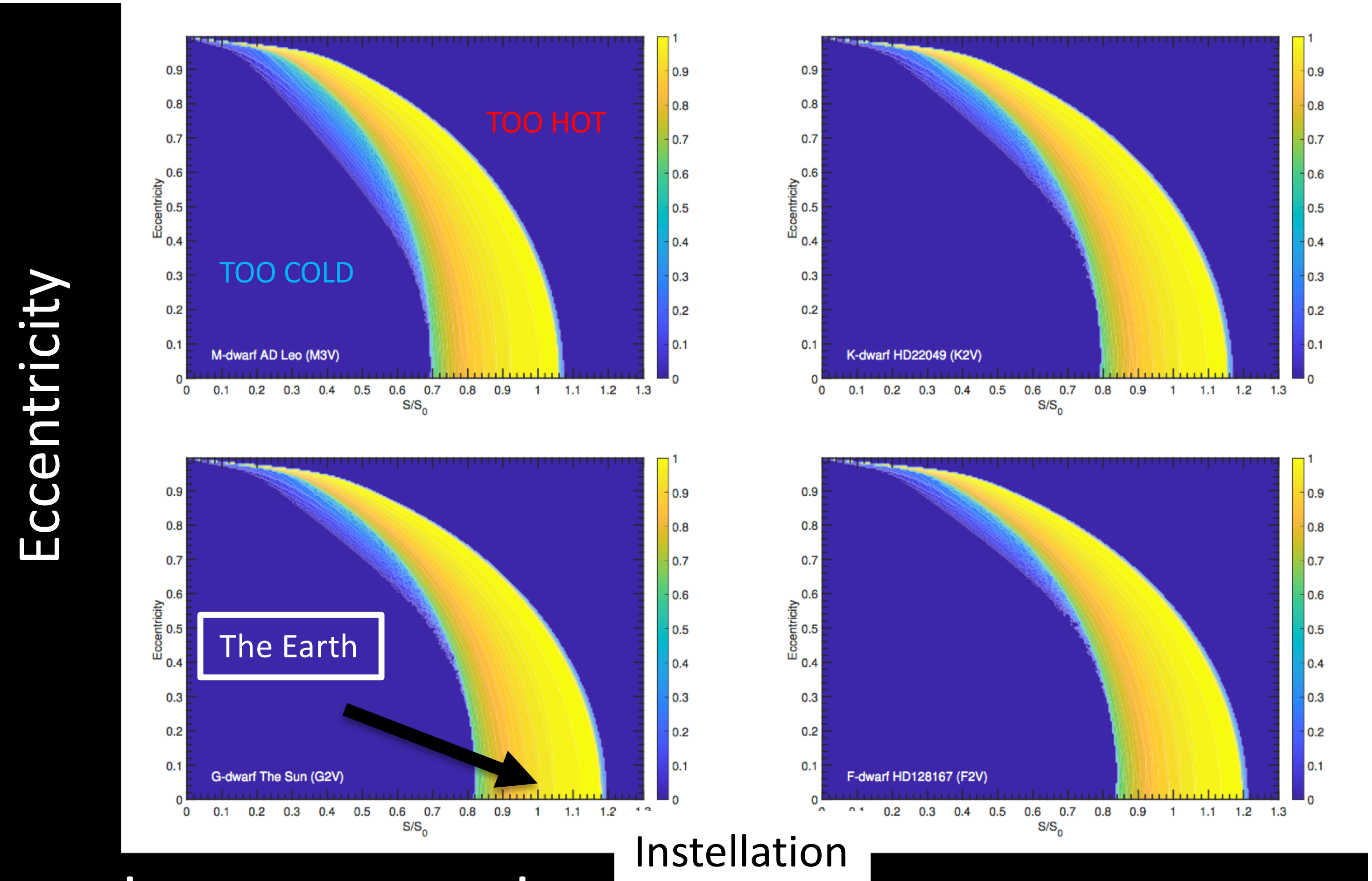



Based on Rushby, Shields, and Joshi, *The Astrophysical Journal*, in press



# Temporal habitability and water loss on eccentric planets

Recipe for a Habitable World




# Planets orbiting cooler stars are thawed for larger fractions of the year

Palubski, Shields, and Deitrick, *The Astrophysical Journal*, in review