

From Stellar Spin to Planetary Atmospheres

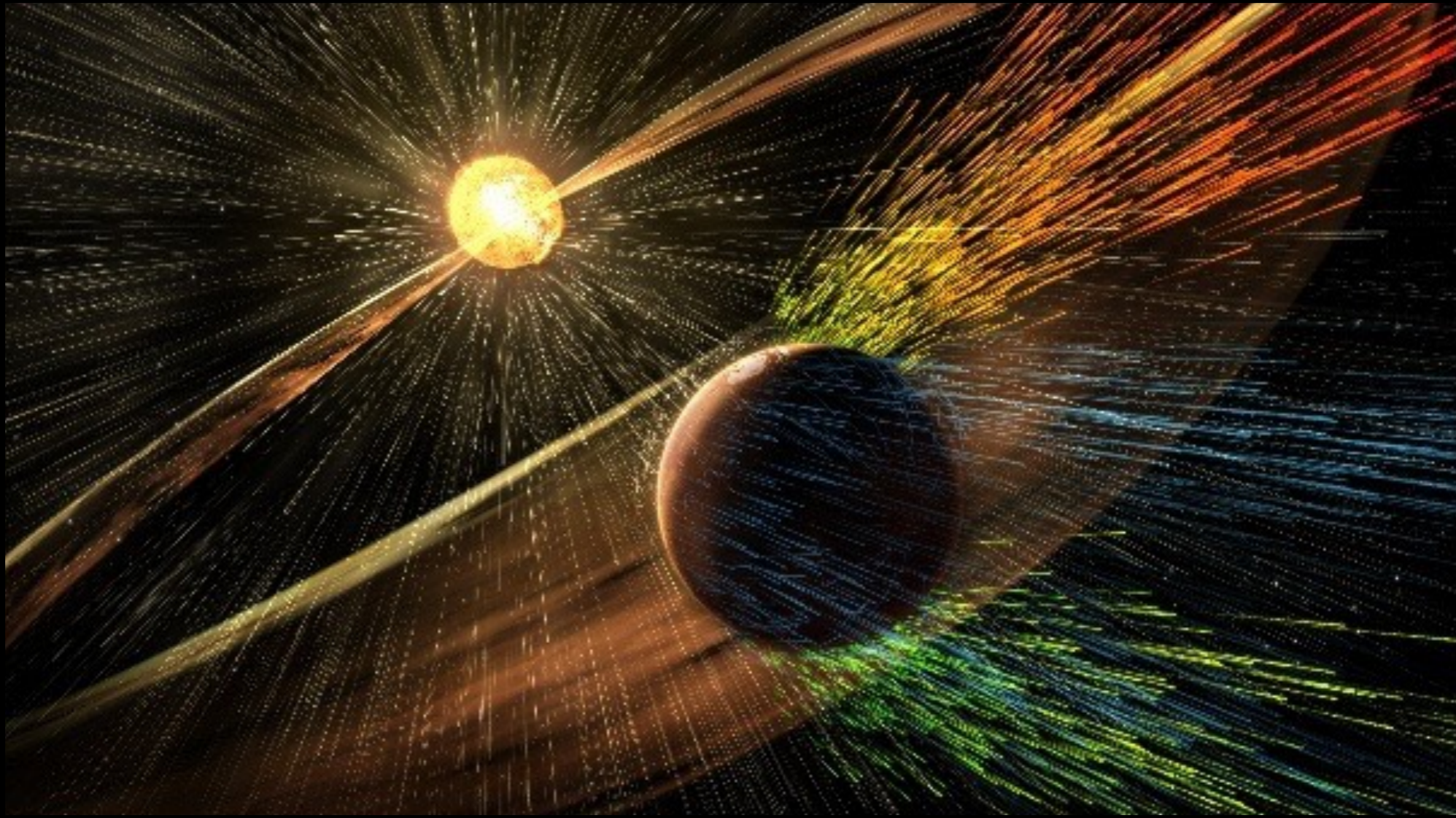
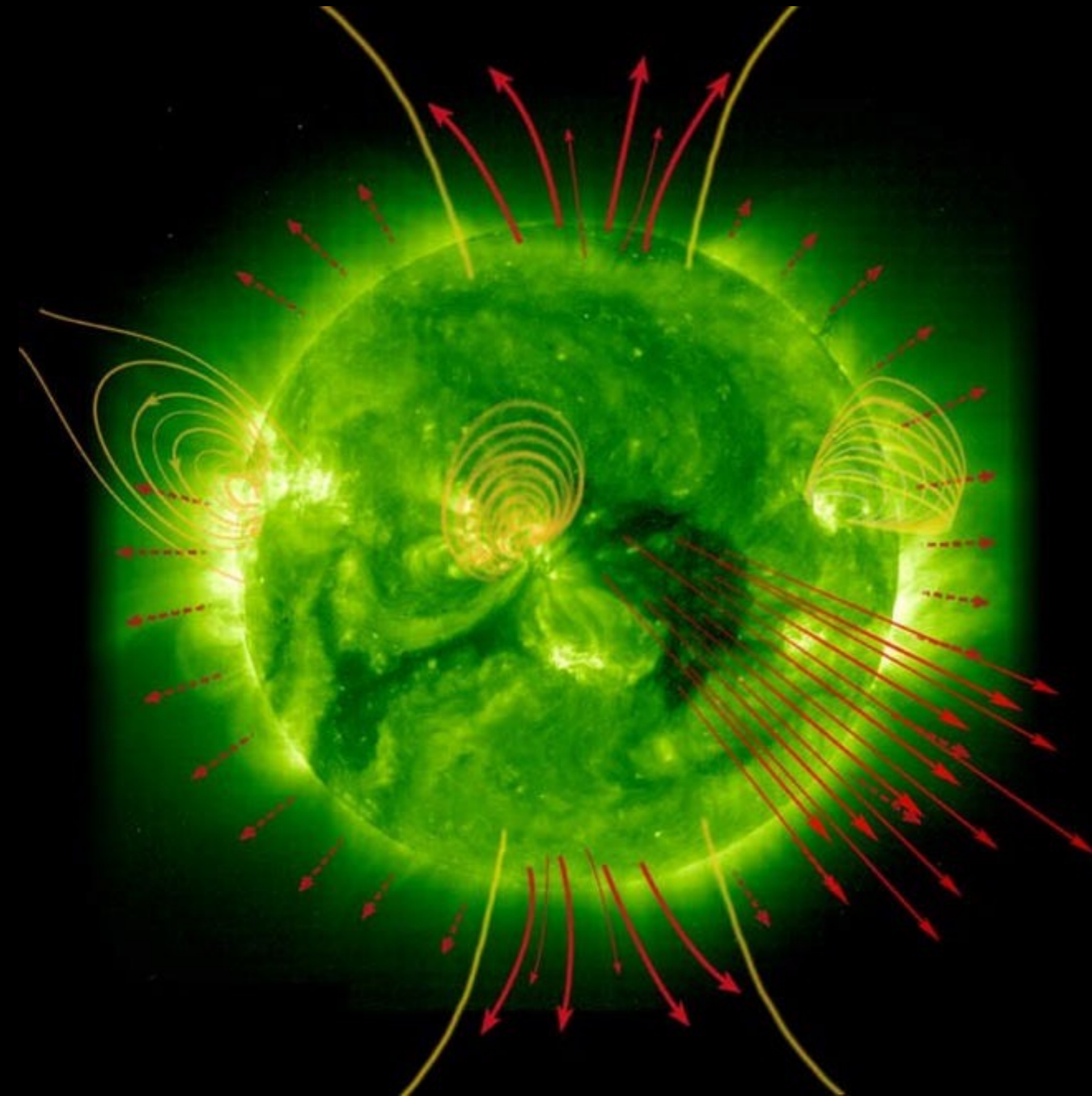


Image: D. Aguilar, CfA

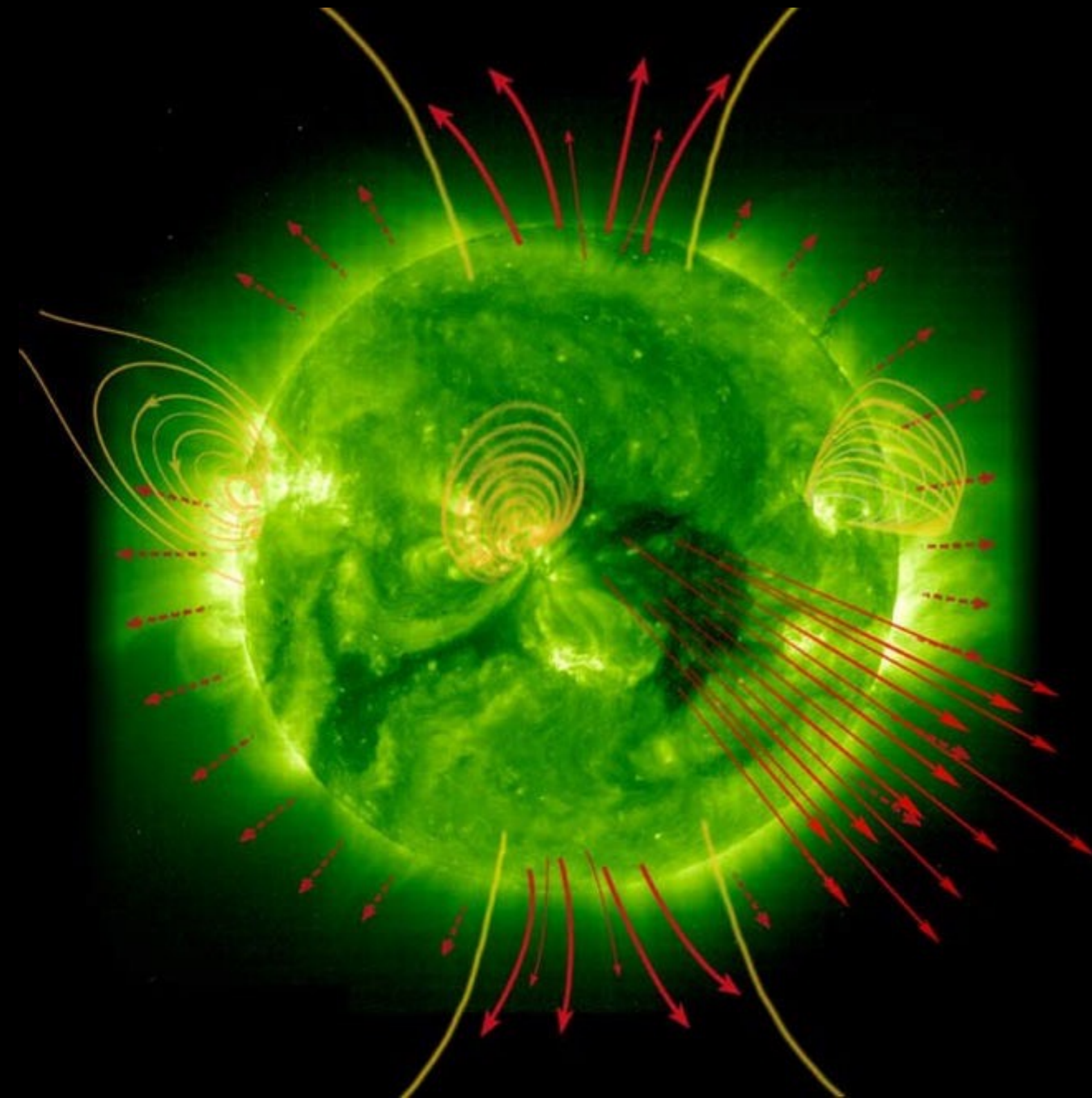
Cecilia Garraffo
IACS Harvard University

with J. J. Drake, O. Cohen, J. D. Alvarado-Gomez, and S. P. Moschou

Stellar Activity - Rotation



Stellar Activity - Rotation

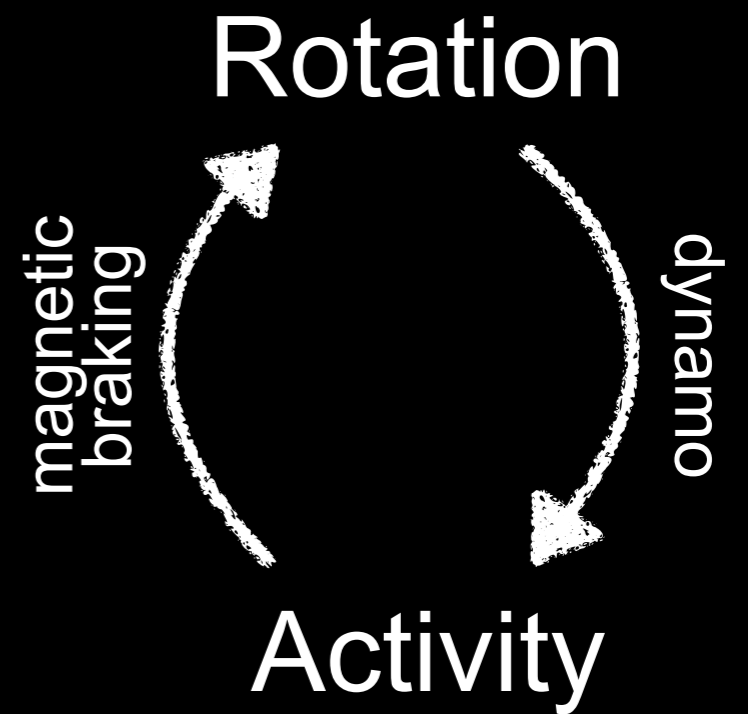
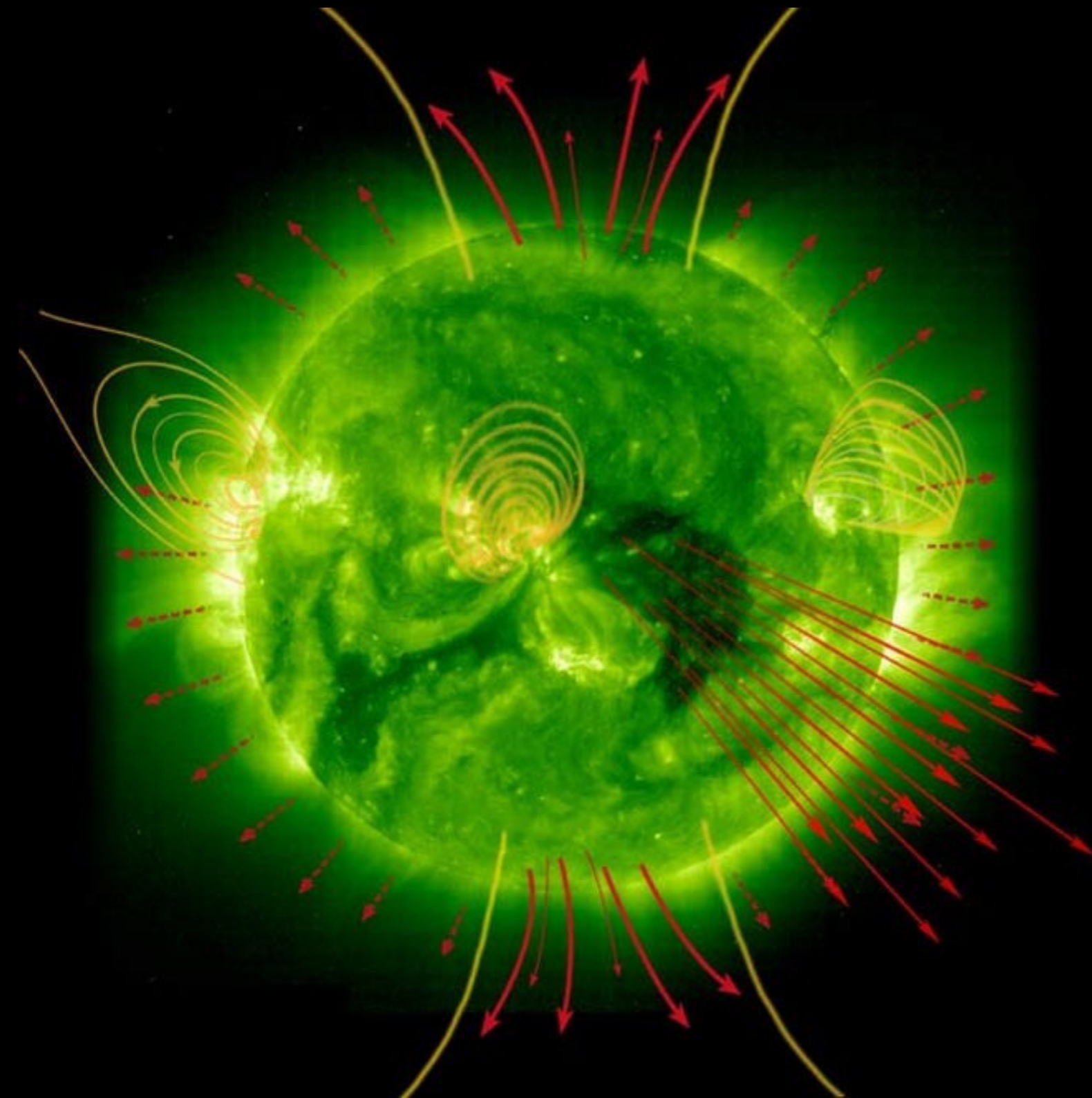


Rotation

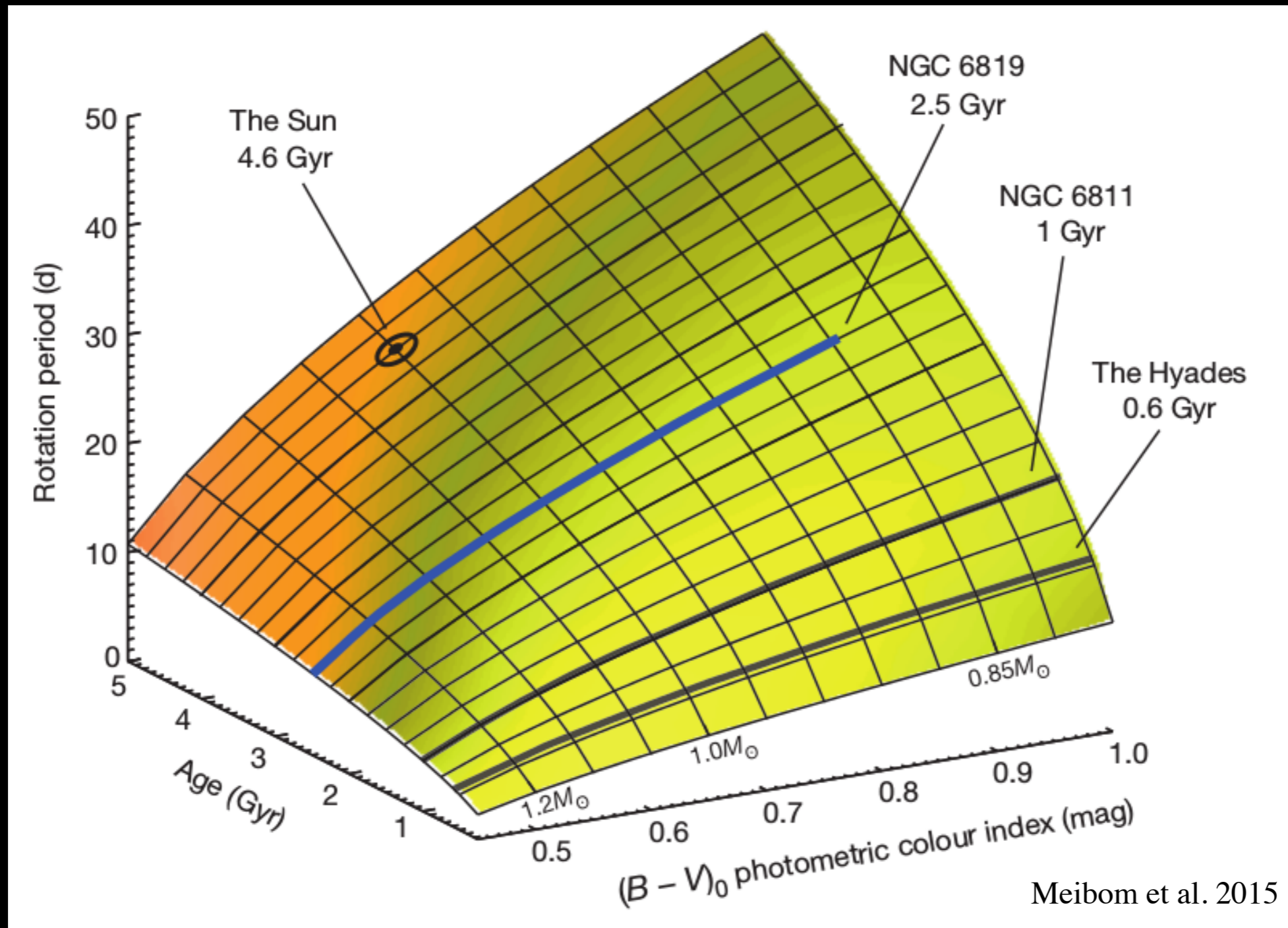
dynamo

Activity

Stellar Activity - Rotation

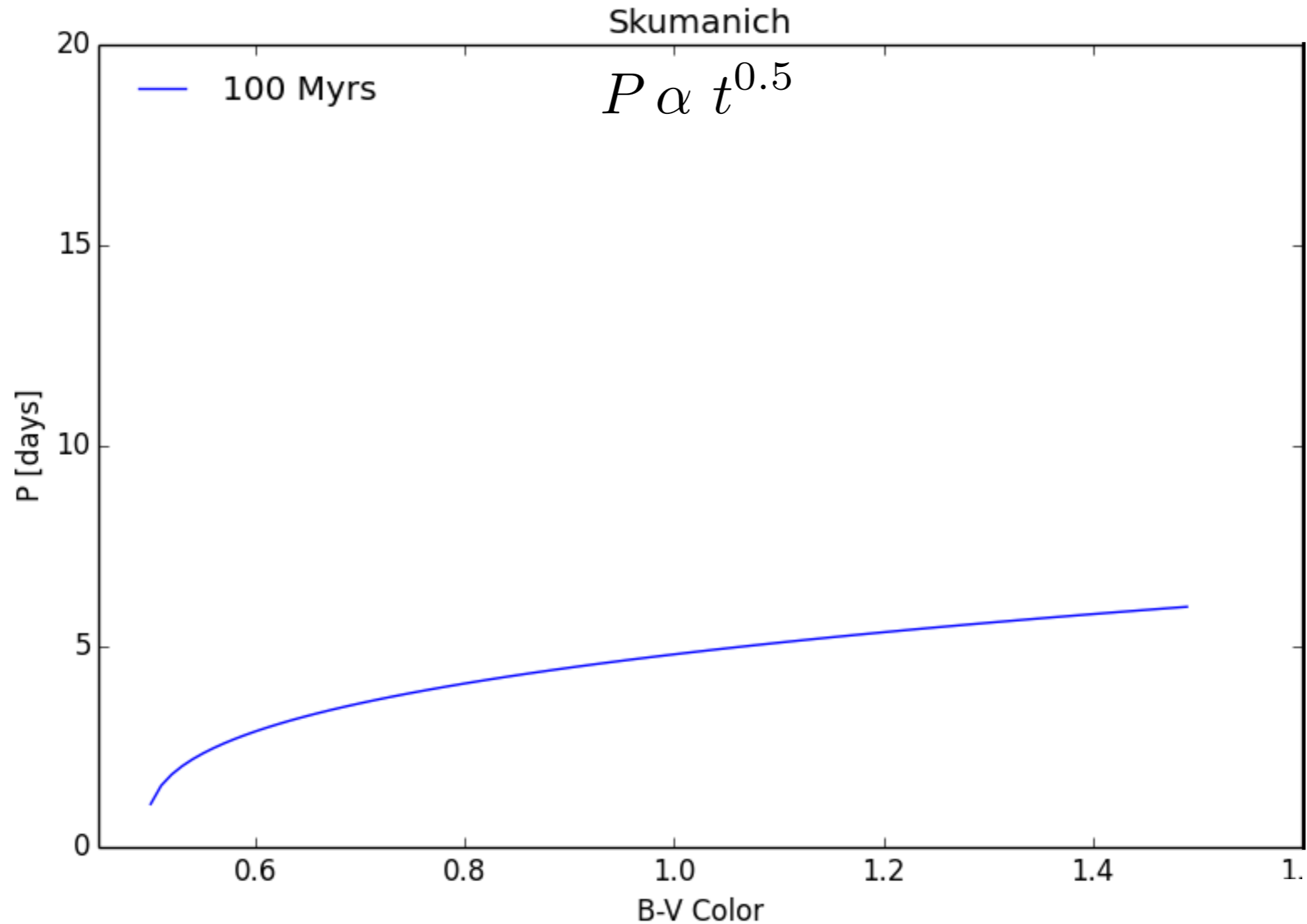


Stellar Activity - Rotation



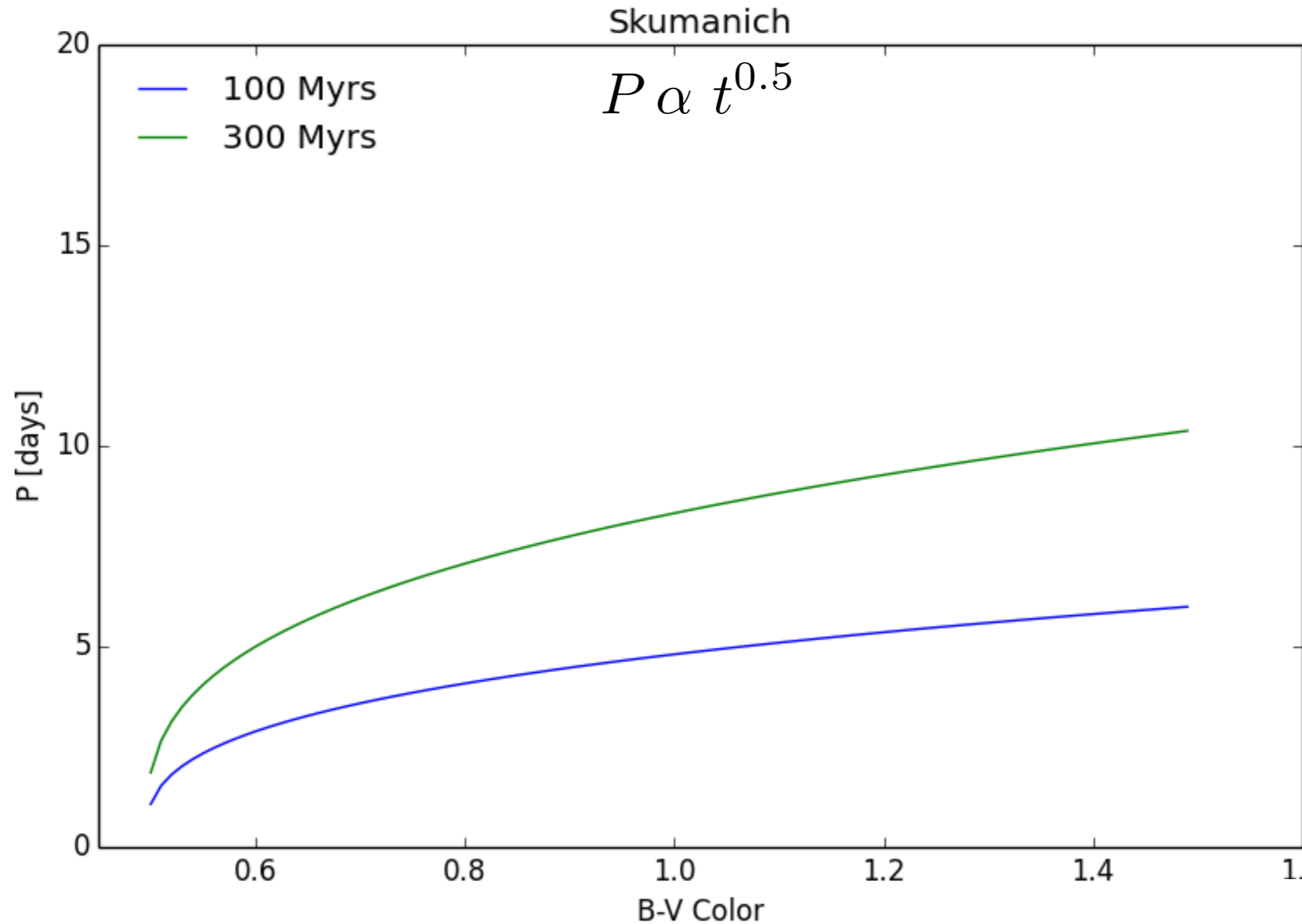
Gyrochronology

Stellar Activity - Rotation



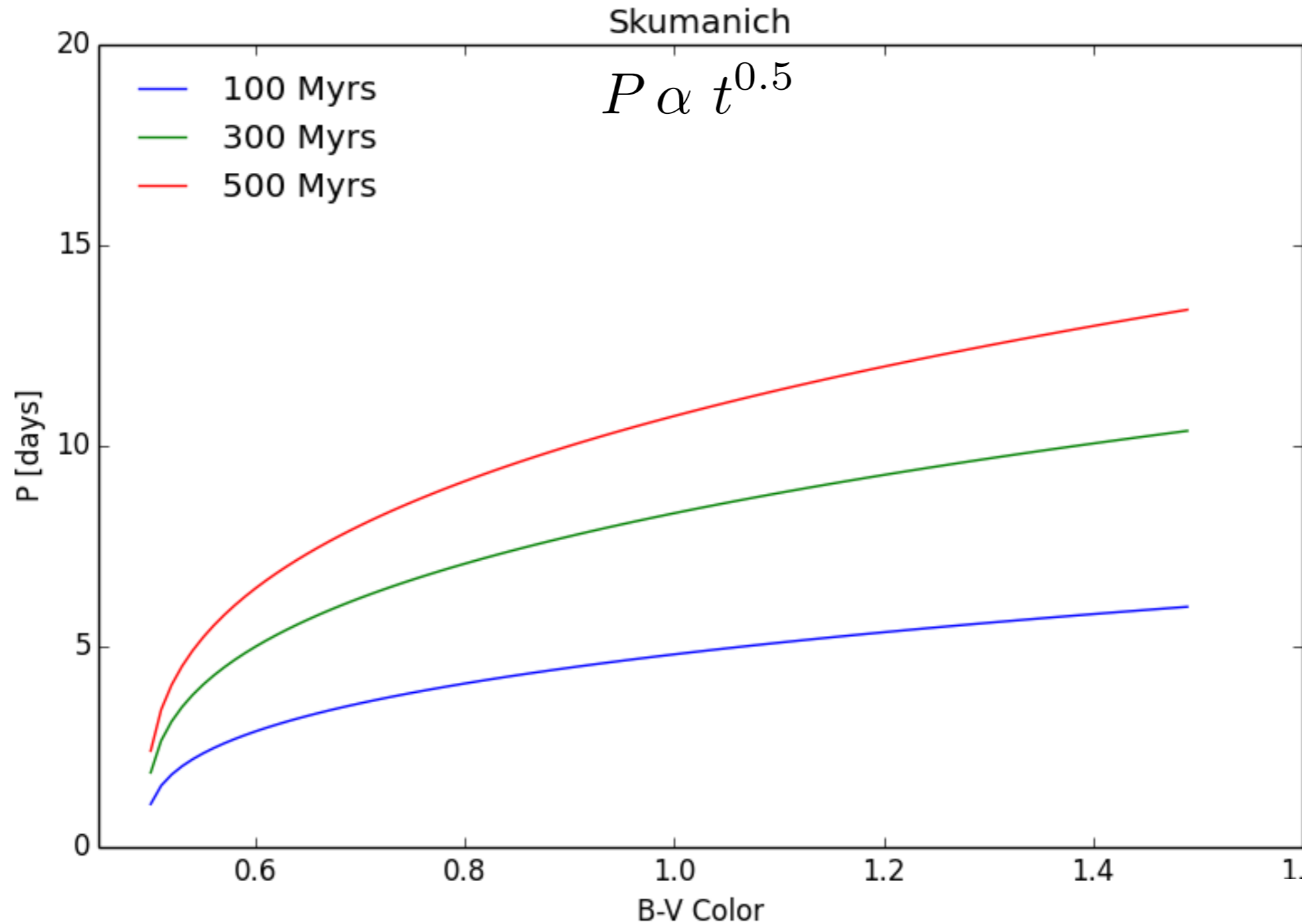
Gyrochronology

Stellar Activity - Rotation



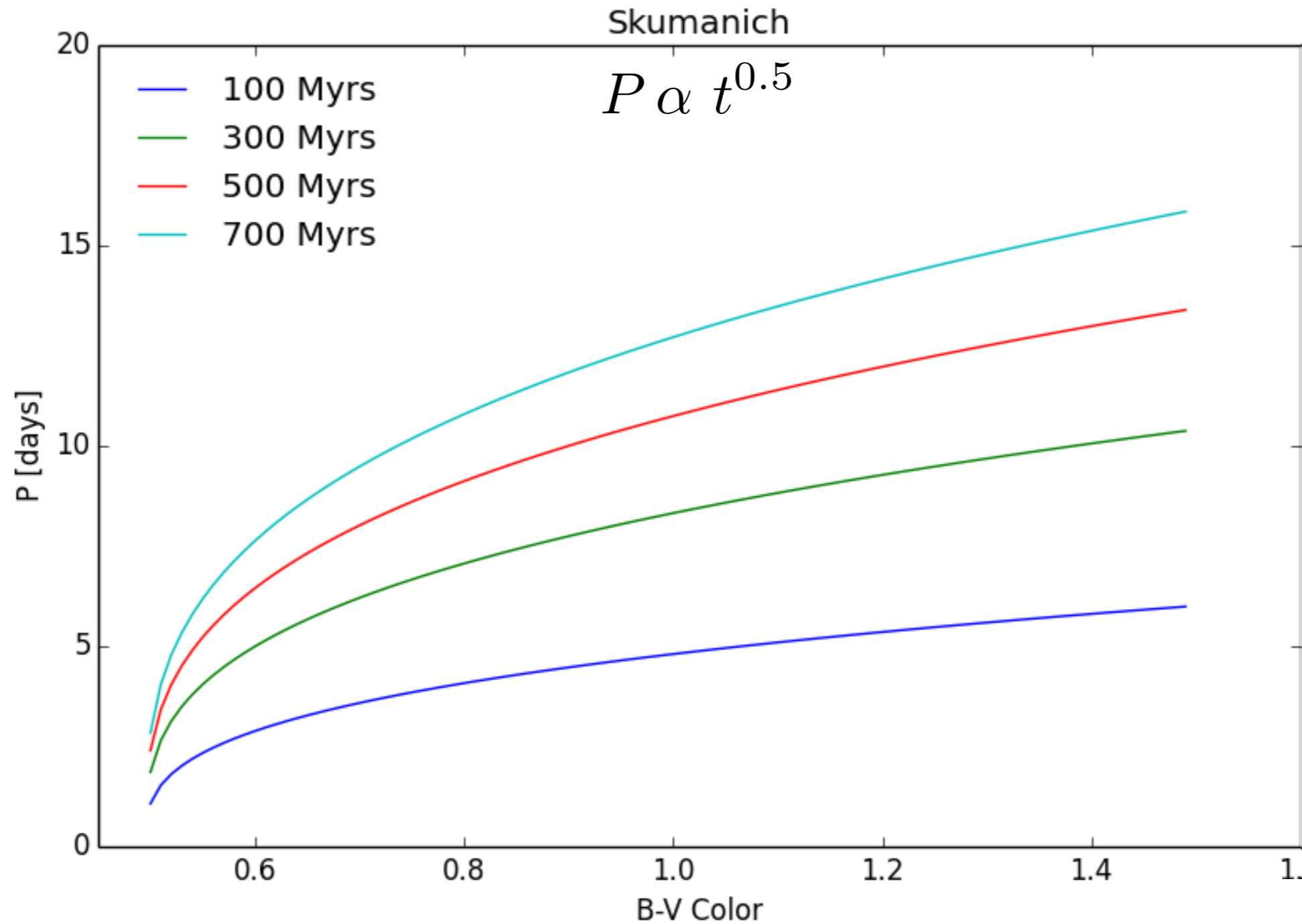
Gyrochronology

Stellar Activity - Rotation



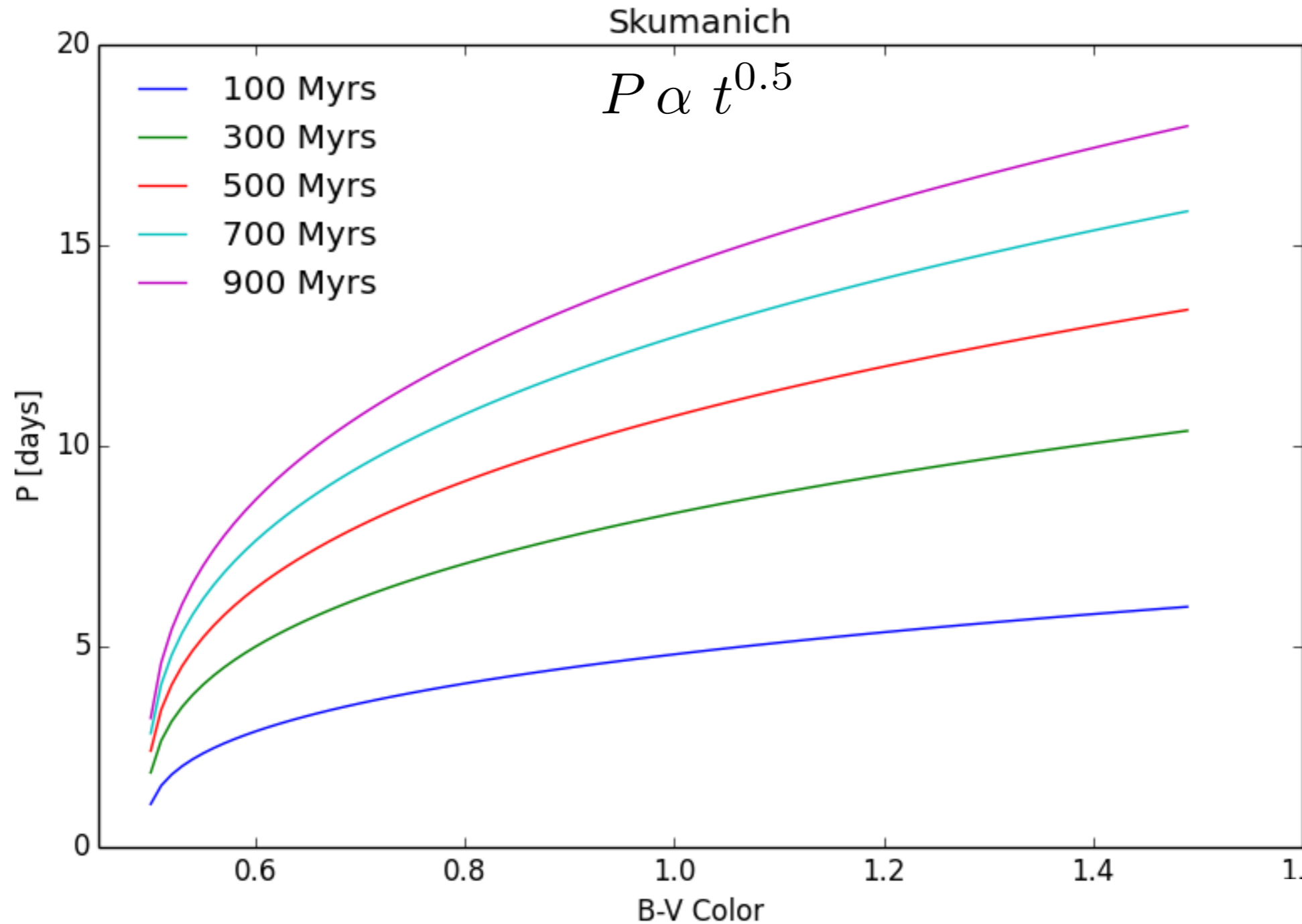
Gyrochronology

Stellar Activity - Rotation



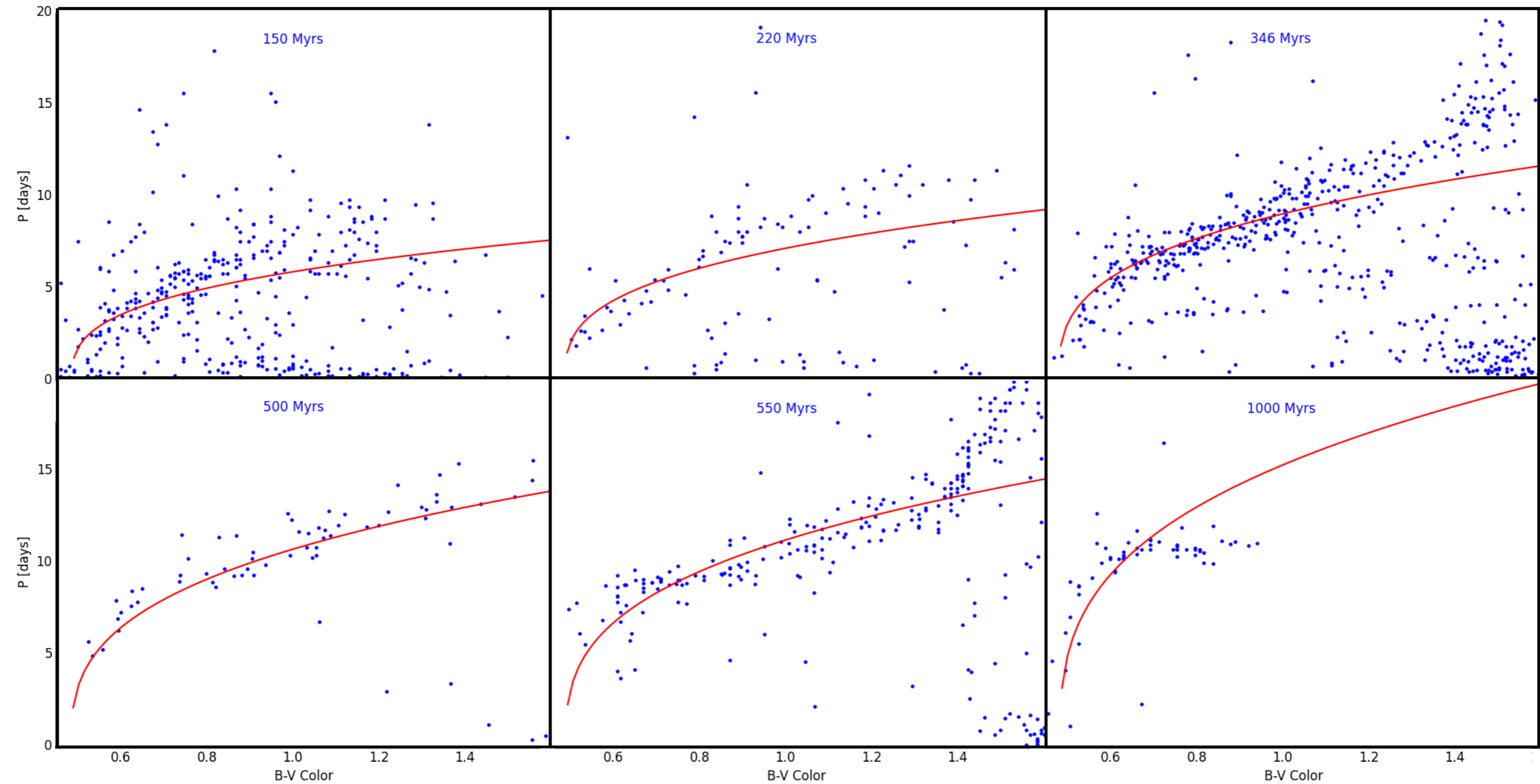
Gyrochronology

Stellar Activity - Rotation



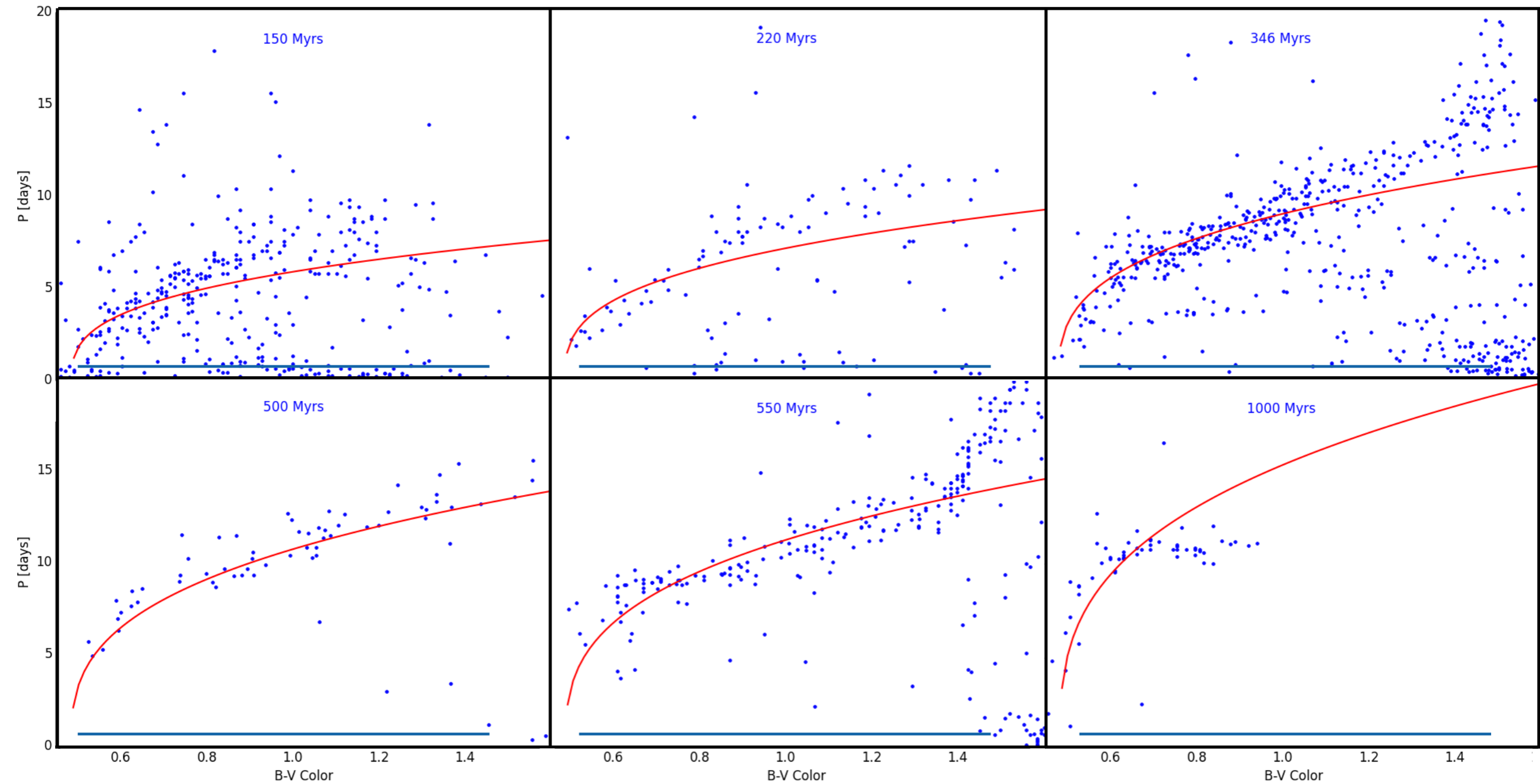
Gyrochronology

Stellar Activity - Rotation



Open Clusters Observations

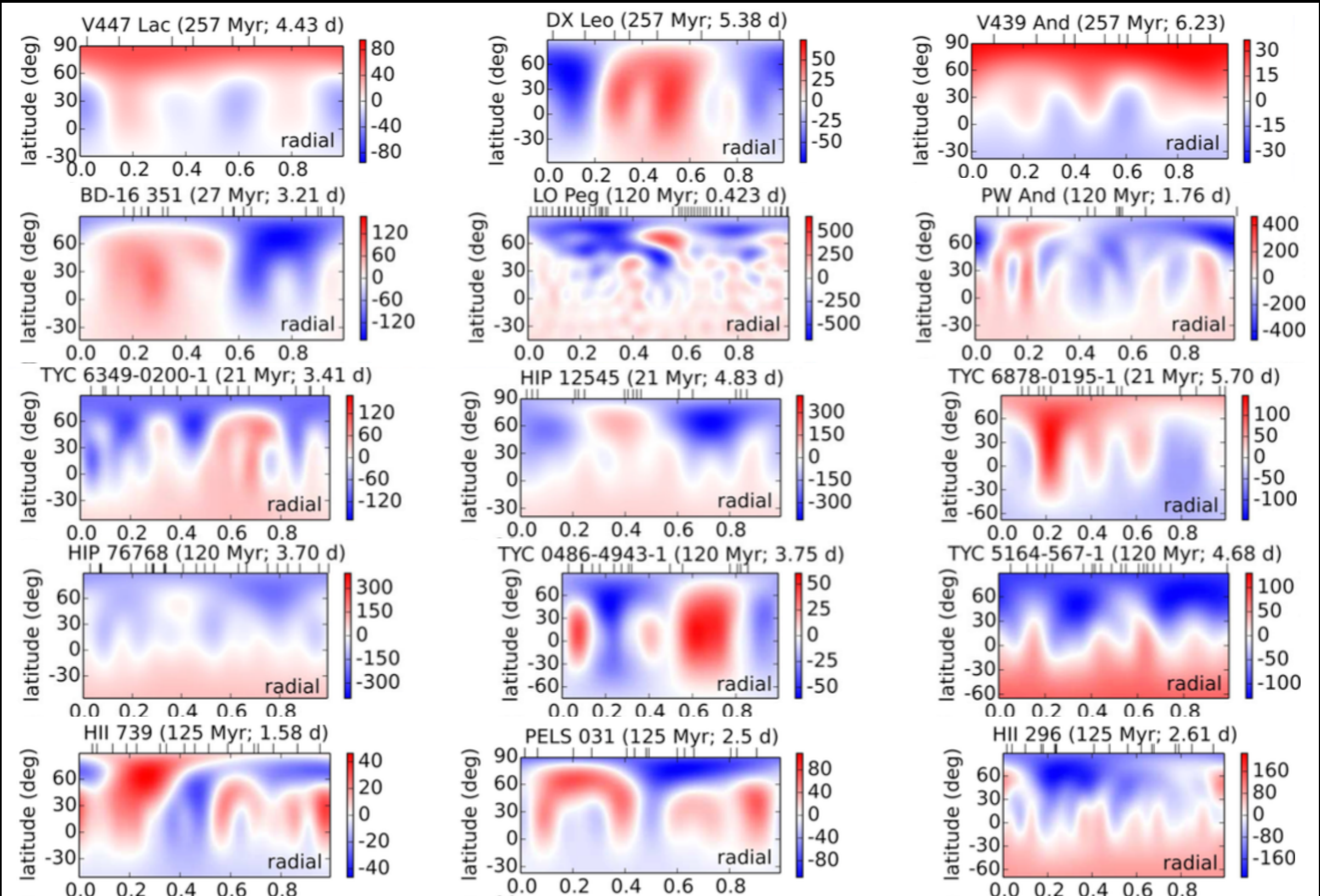
Stellar Activity - Rotation



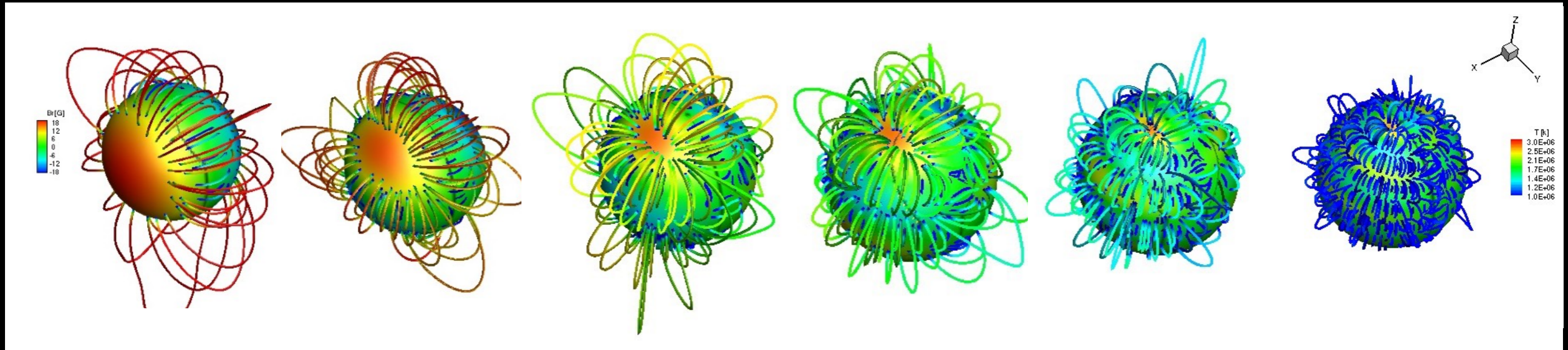
Open Clusters Observations

Magnetic Activity Observations

Folsom et al. 2016

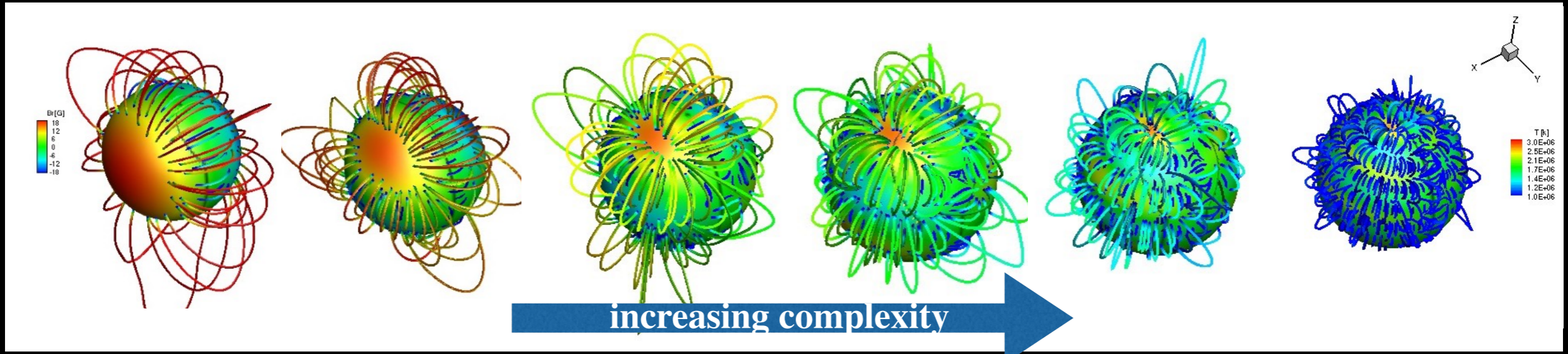


Magnetic Complexity



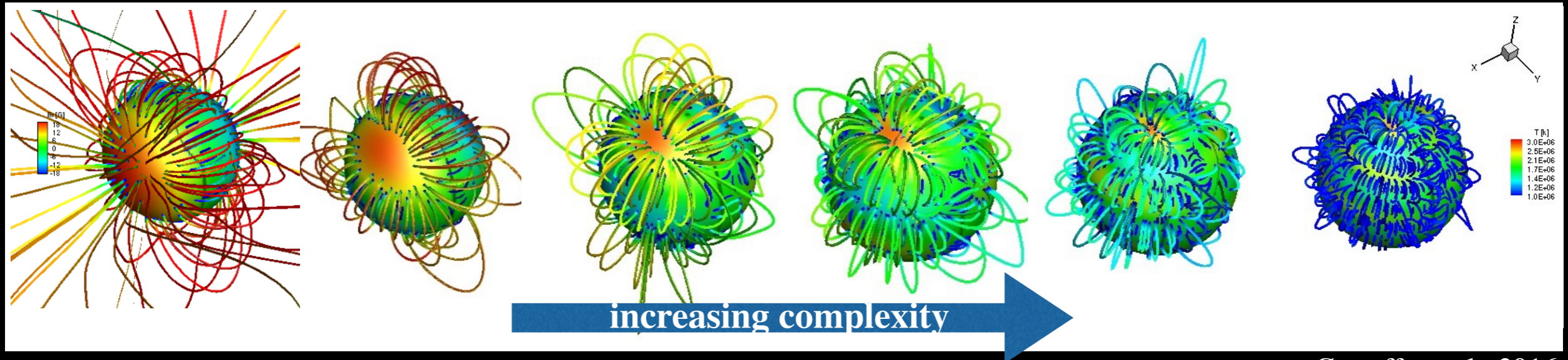
Garraffo et al., 2016

Magnetic Complexity



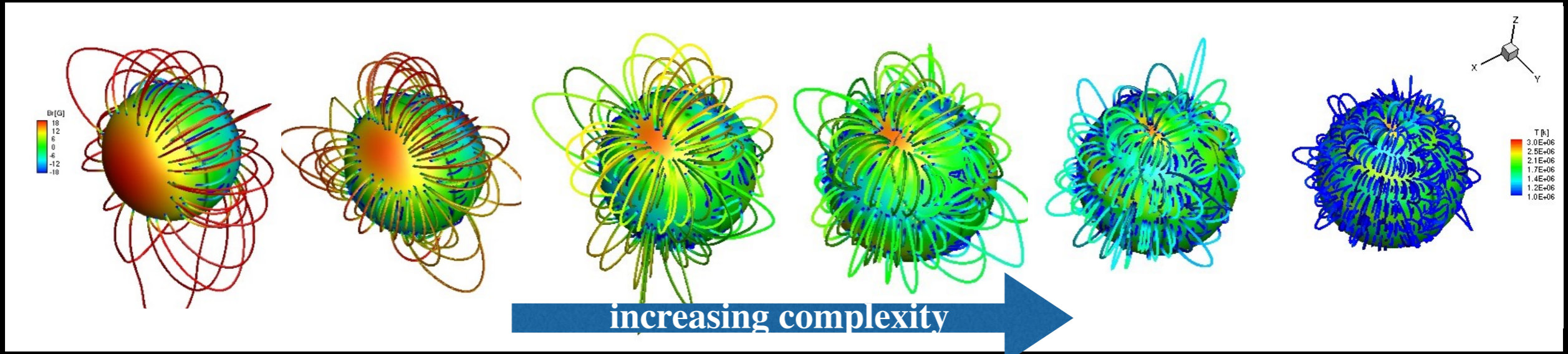
Garraffo et al., 2016

Magnetic Complexity



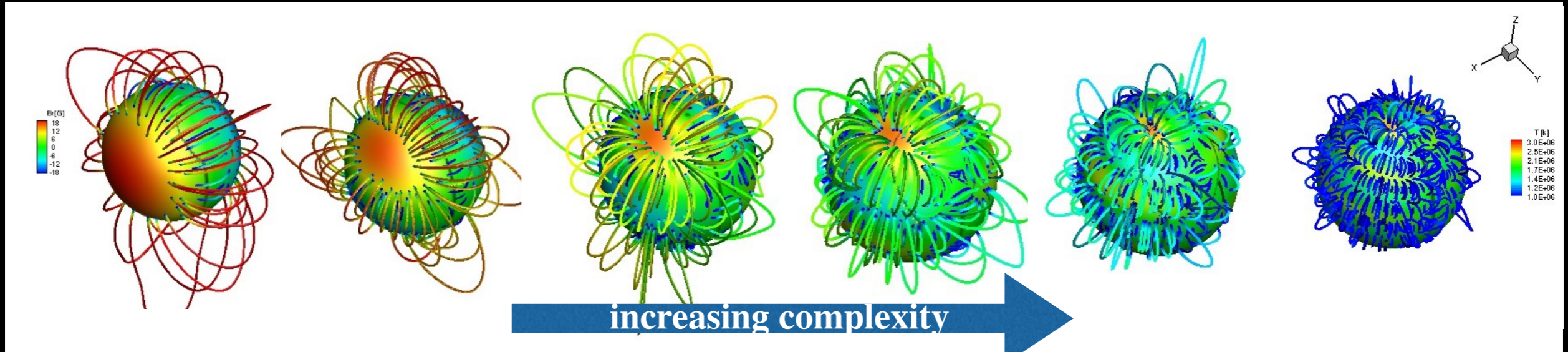
Garraffo et al., 2016

Magnetic Complexity



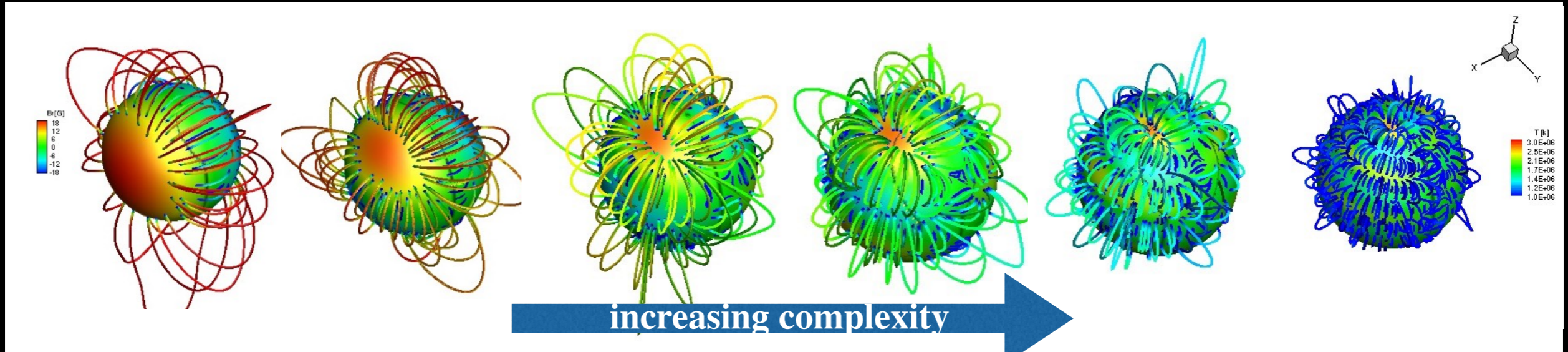
Garraffo et al., 2016

A Complete Spin-down Model

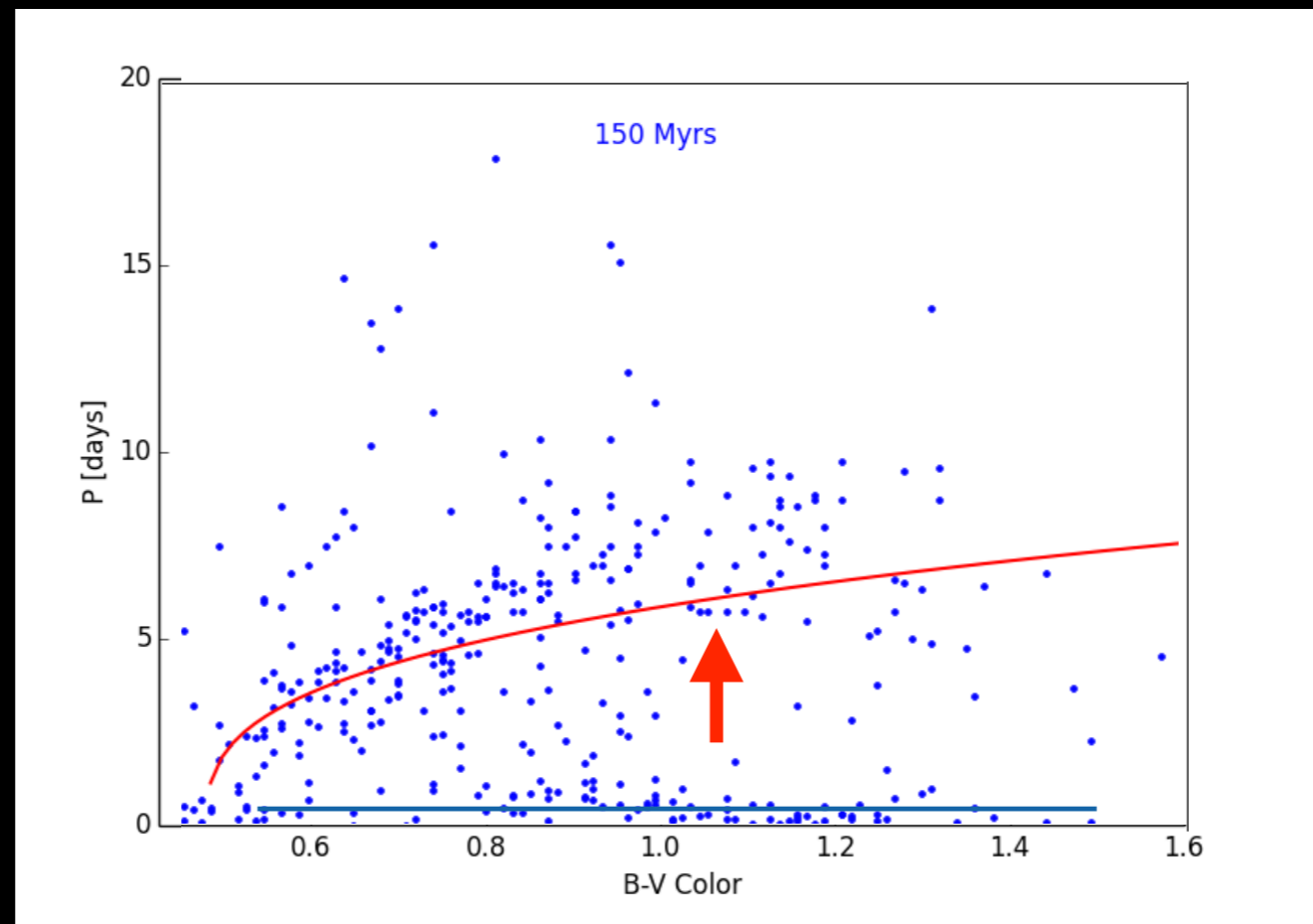


Garraffo et al., 2016

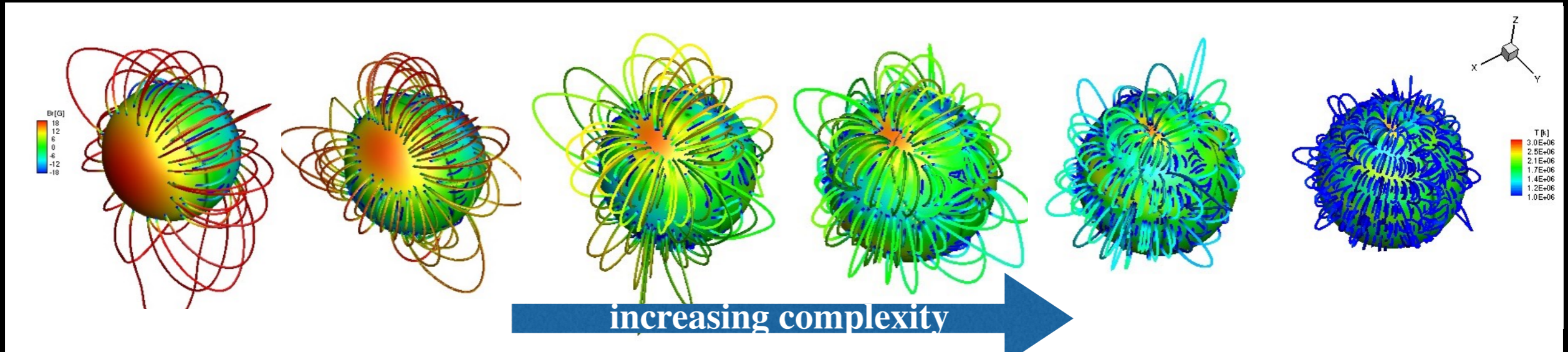
A Complete Spin-down Model



Garraffo et al., 2016

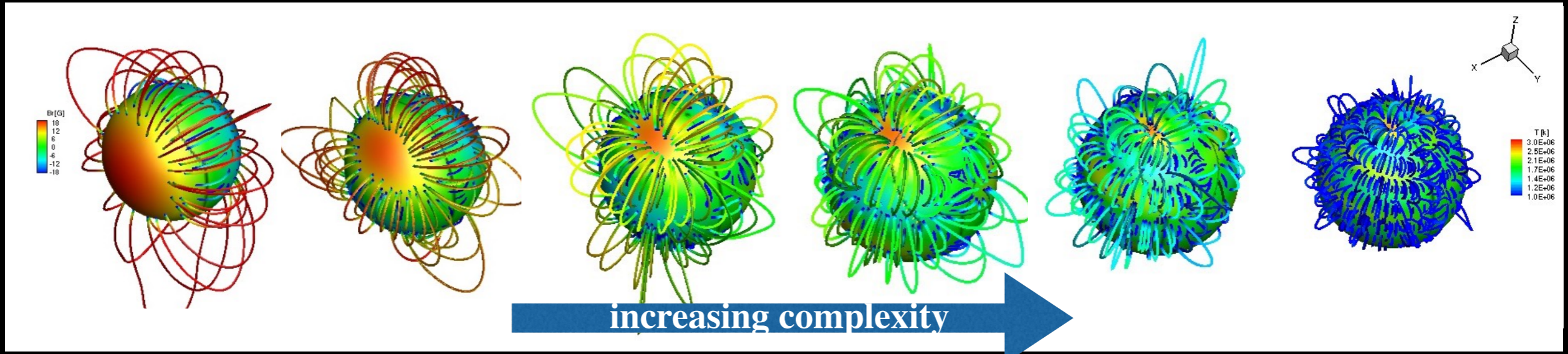


A Complete Spin-down Model



Garraffo et al., 2016

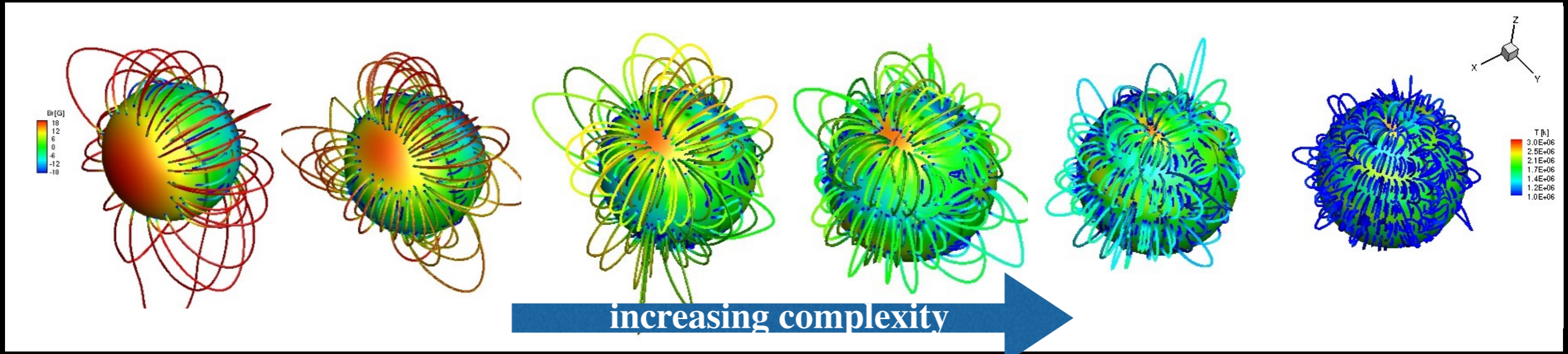
A Complete Spin-down Model



Garraffo et al., 2016

$$\dot{J} = \dot{J}_{Dip} Q_J(n)$$

A Complete Spin-down Model



Garraffo et al., 2016

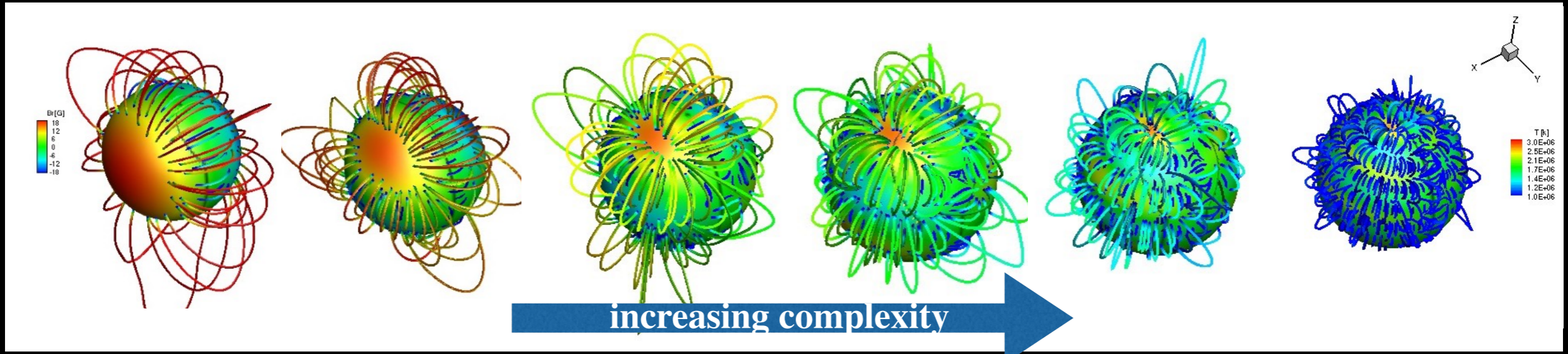
$$\dot{J} = \dot{J}_{Dip} Q_J(n)$$



Skumanich

$$\dot{J}_{Dip} = c \Omega^3 \tau$$

A Complete Spin-down Model

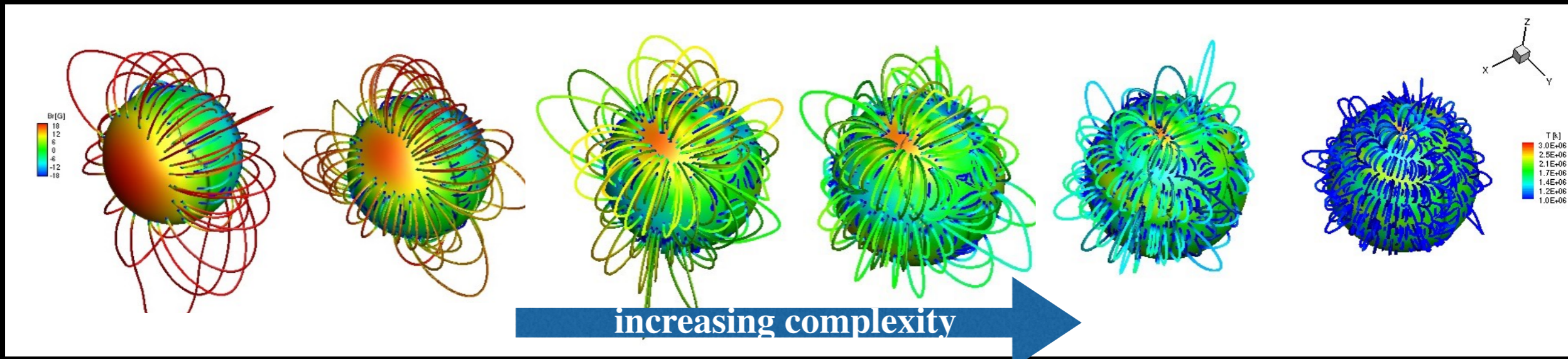


Garraffo et al., 2016

$$\dot{J} = \dot{J}_{Dip} Q_J(n), \quad Q_J(n) = 4.05 e^{-1.4n}$$

$$\begin{array}{c} \uparrow \text{Skumanich} \\ \dot{J}_{Dip} = c \Omega^3 \tau \end{array}$$

A Complete Spin-down Model

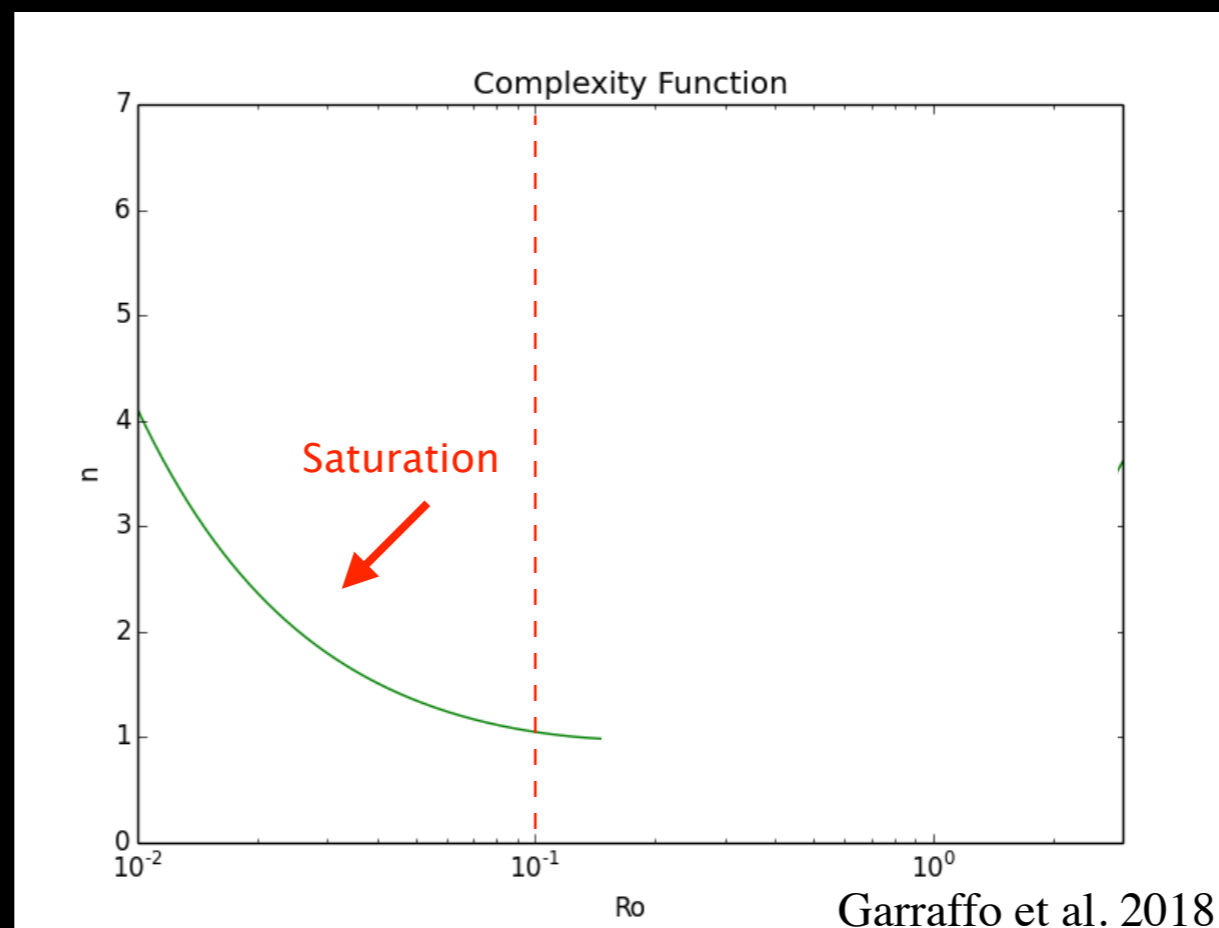


Garraffo et al., 2016

$$\dot{J} = \dot{J}_{Dip} Q_J(n), \quad Q_J(n) = 4.05 e^{-1.4n} \rightarrow n = a/Ro + 1$$

↑ Skumanich

$$\dot{J}_{Dip} = c \Omega^3 \tau$$

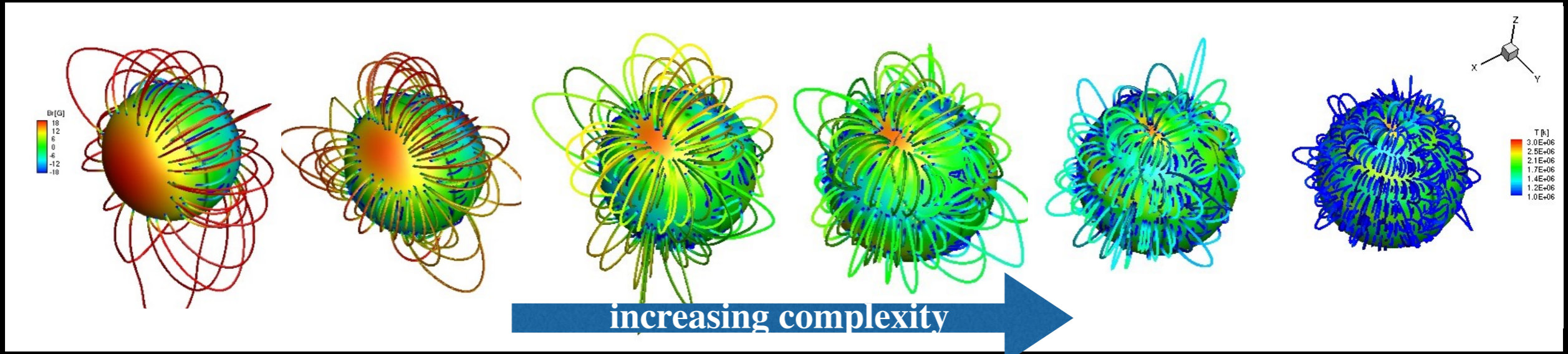


Garraffo et al. 2018

↑

$$Ro = P_{rot} / \tau$$

A Complete Spin-down Model

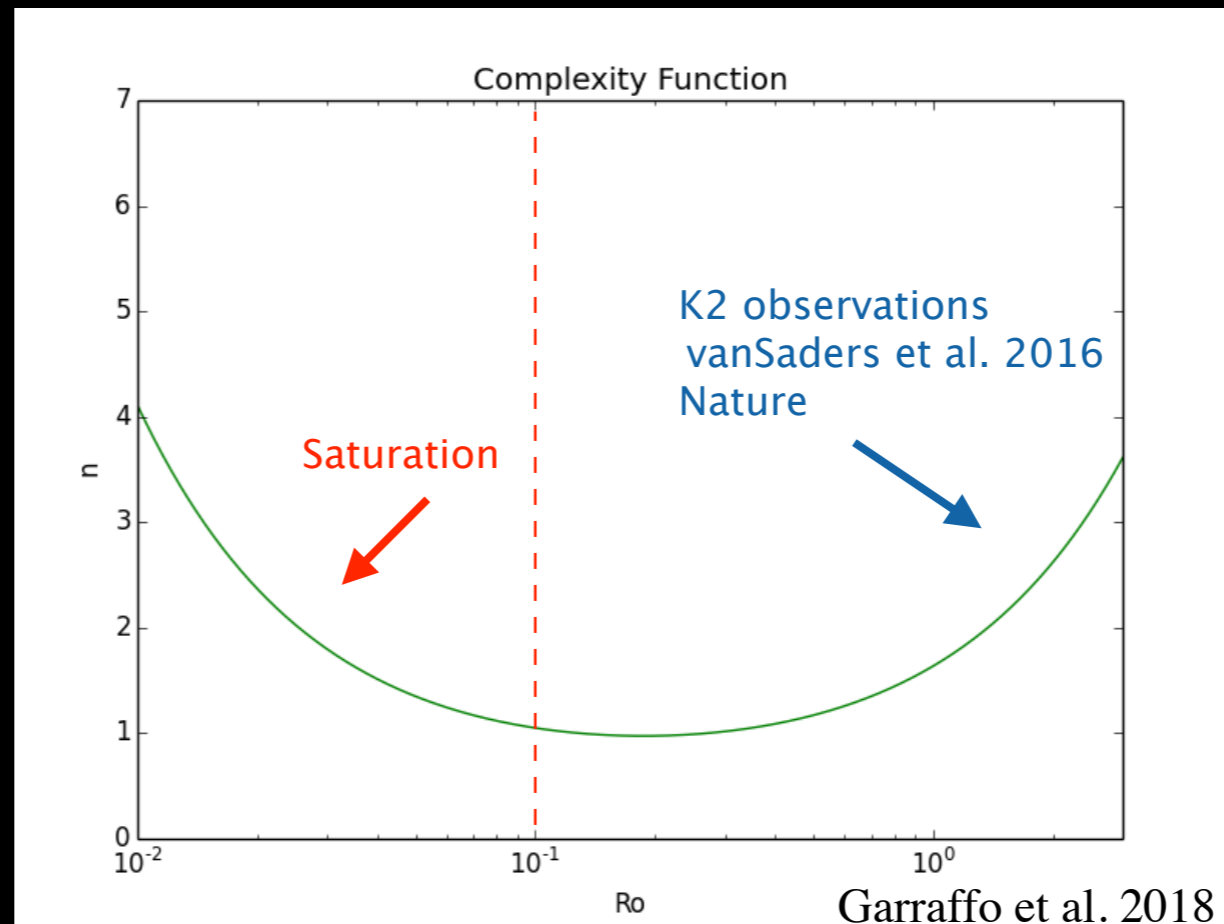


Garraffo et al., 2016

$$\dot{J} = \dot{J}_{Dip} Q_J(n), \quad Q_J(n) = 4.05 e^{-1.4n} \rightarrow n = a/Ro + 2Ro + 1$$

↑ Skumanich

$$\dot{J}_{Dip} = c \Omega^3 \tau$$

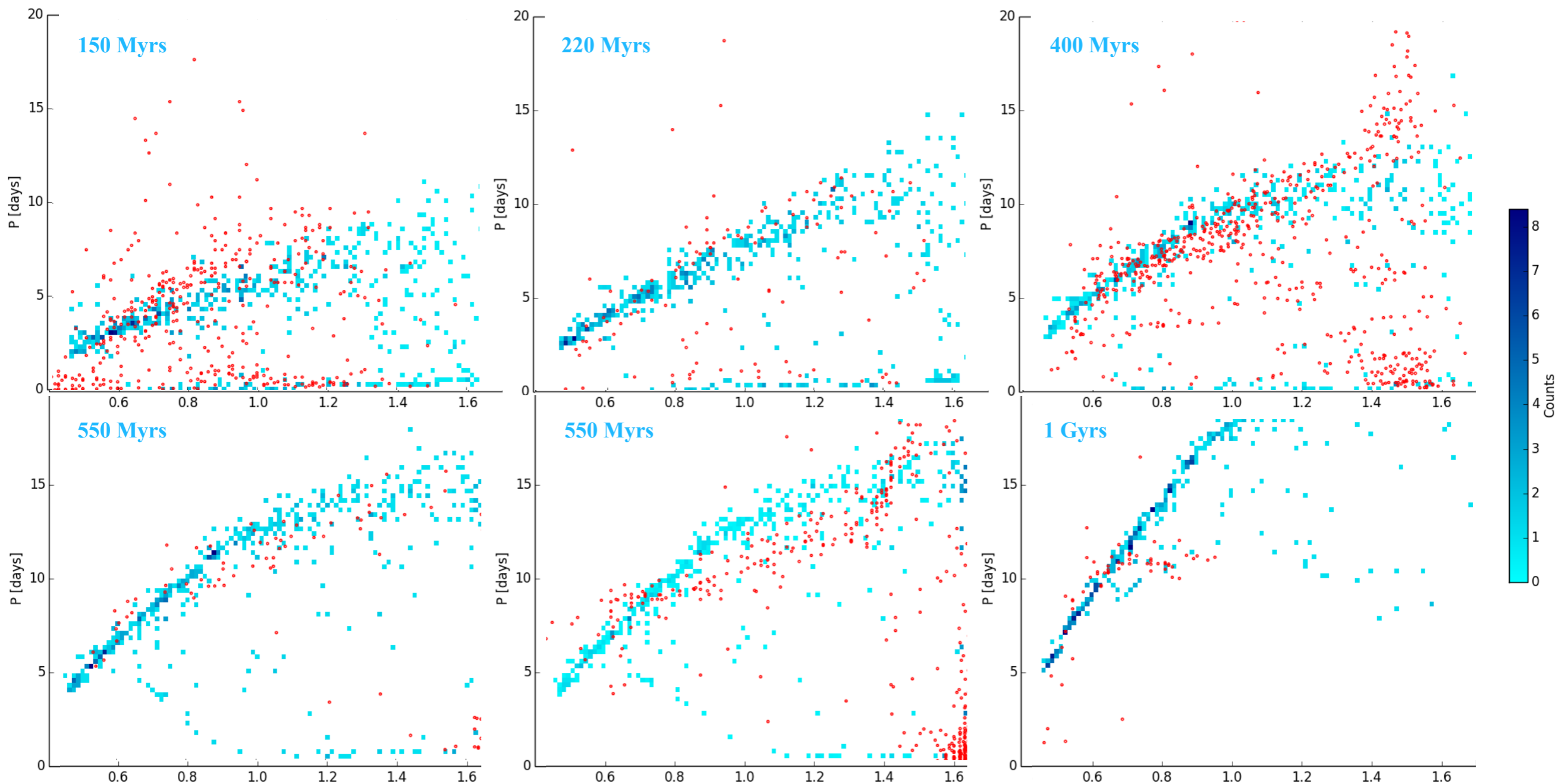


↑

$$Ro = P_{rot}/\tau$$

A Complete Spin-down Model

$$\dot{J} = \dot{J}_{Dip} Q_J(n), \quad Q_J(n) = 4.05 e^{-1.4n} \longrightarrow n = 0.02/Ro + 2Ro + 1$$

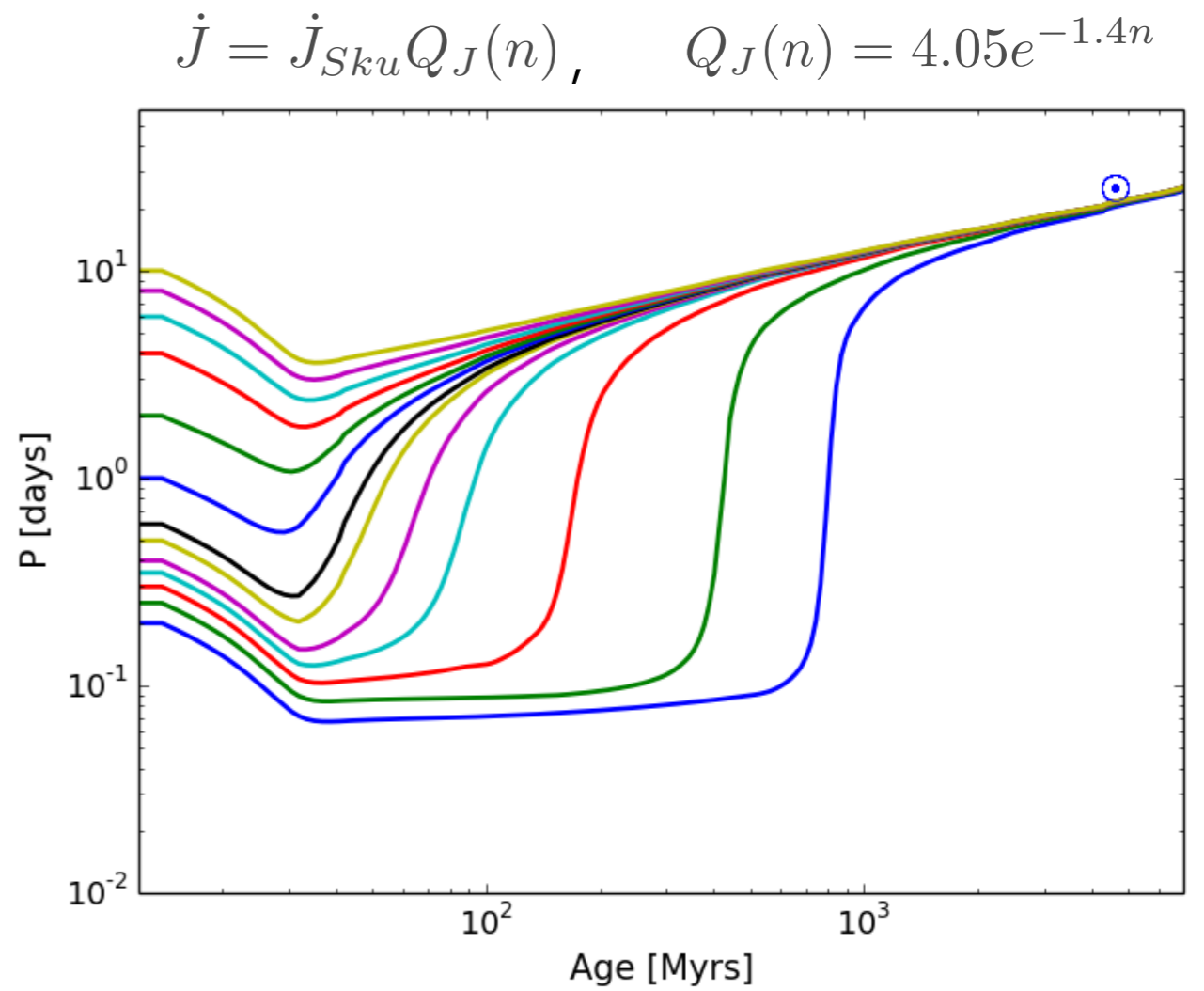
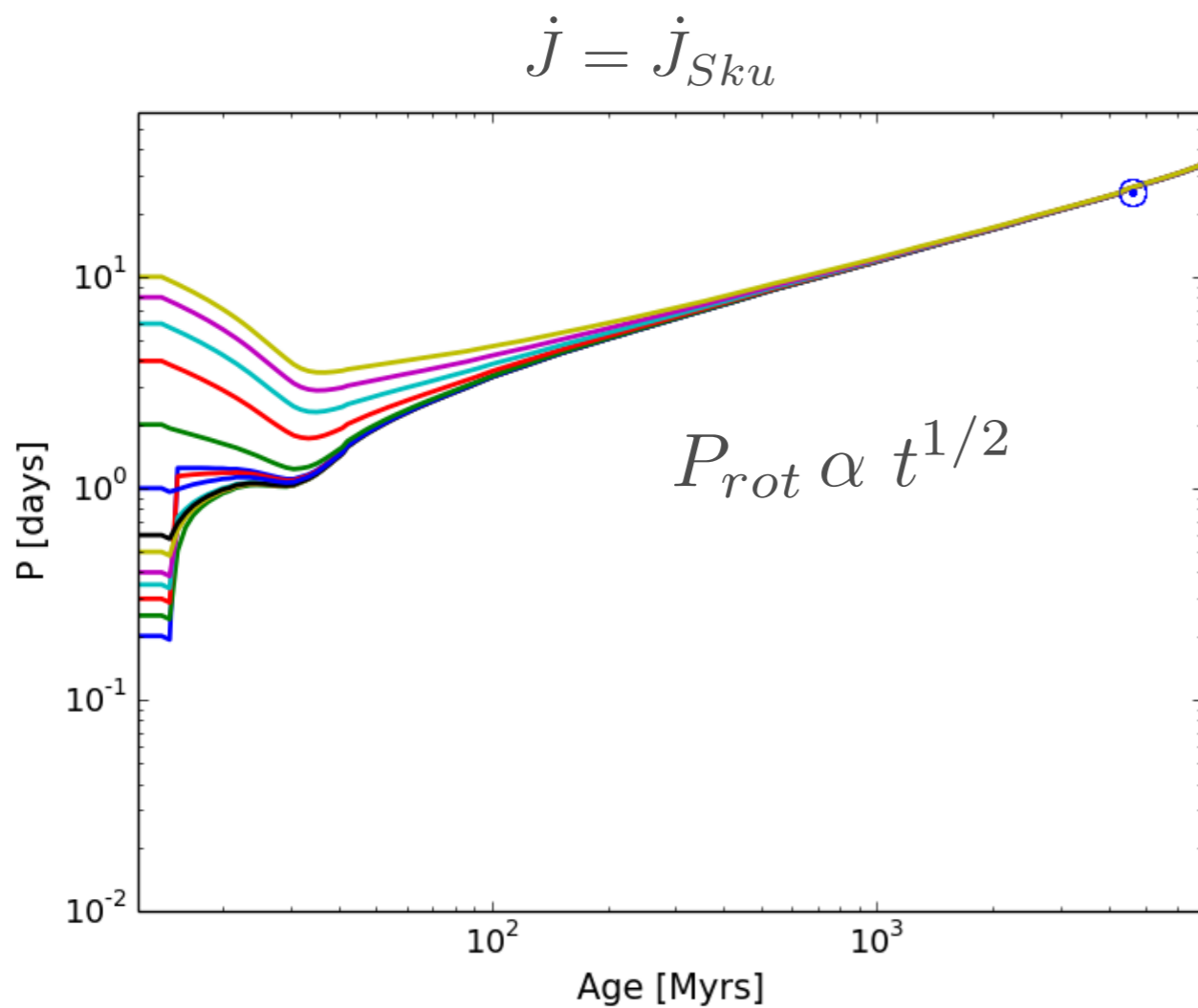


Garraffo et al. 2018

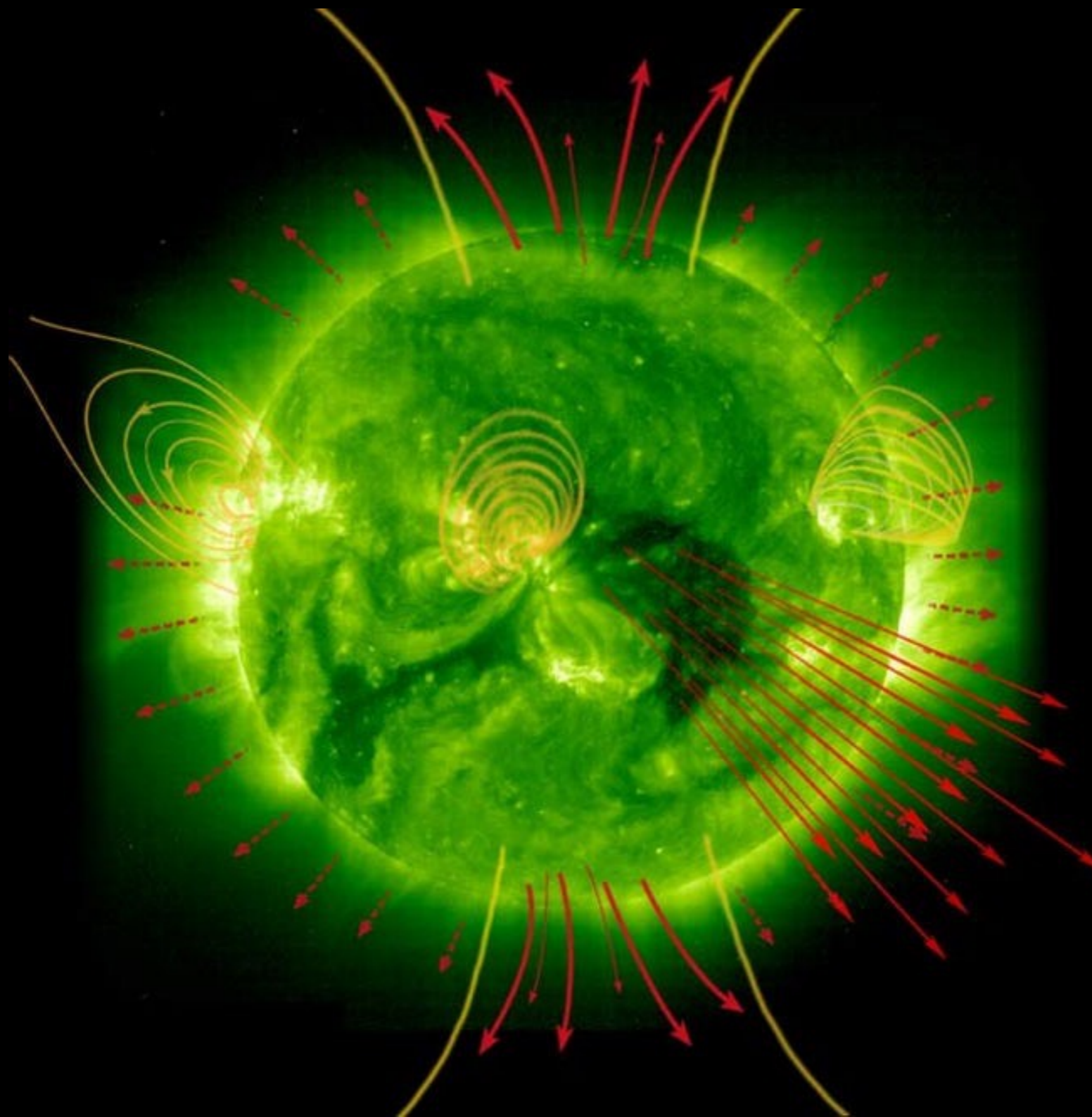
A Complete Spin-down Model

Just Skumanich

Including Complexity

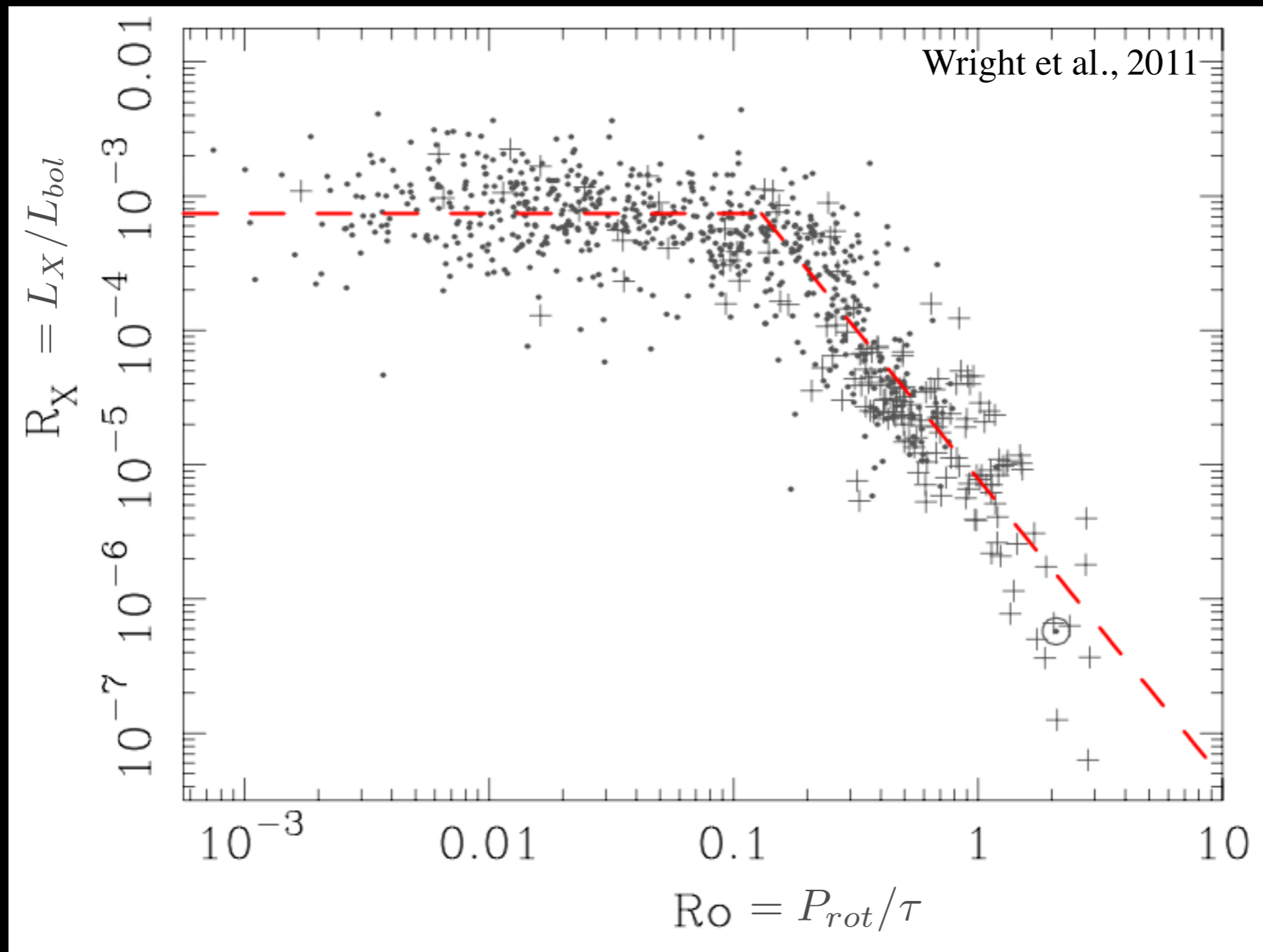


Stellar Activity-Rotation



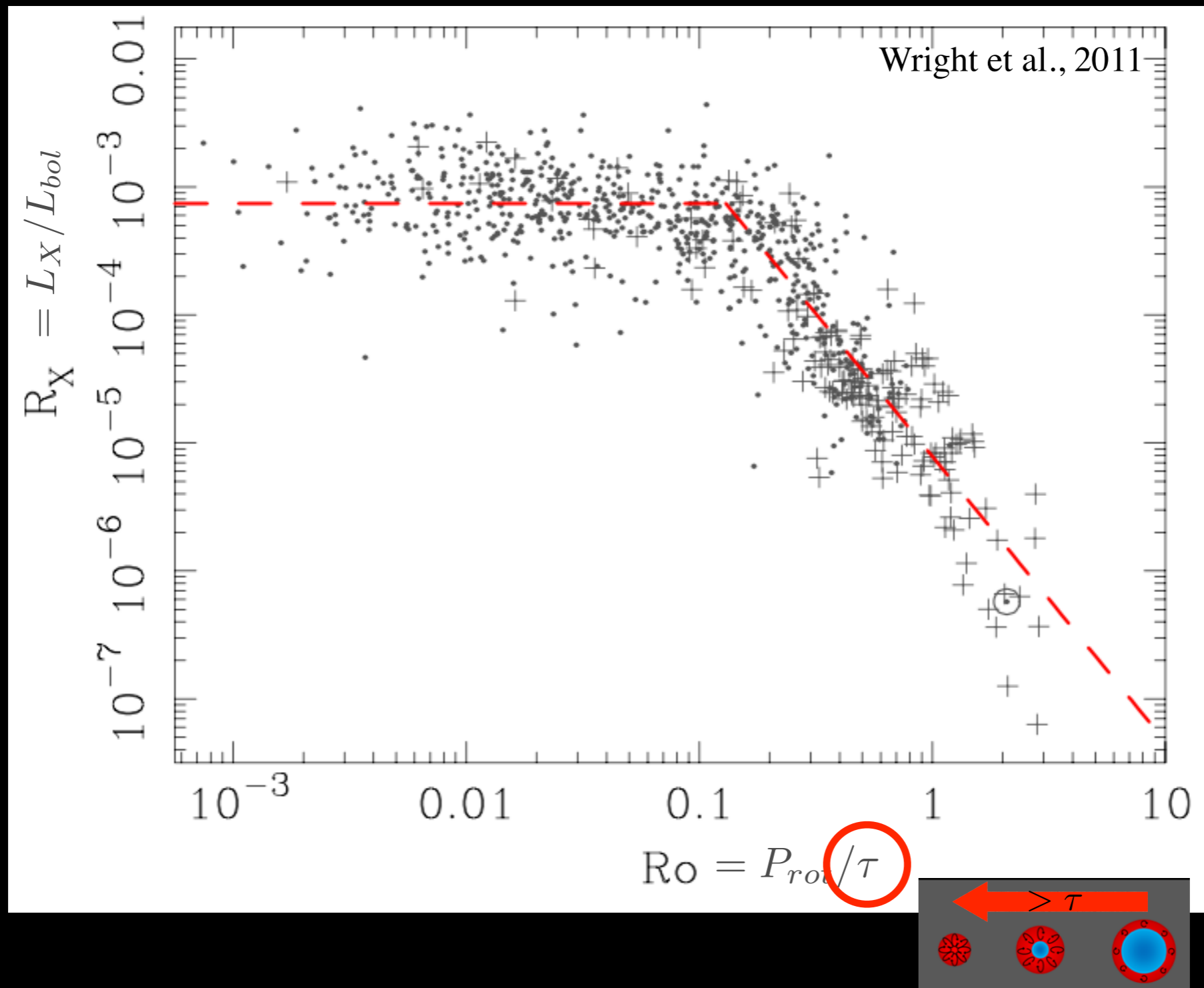
Stellar Activity-Rotation

X-ray to bolometric luminosity ratio



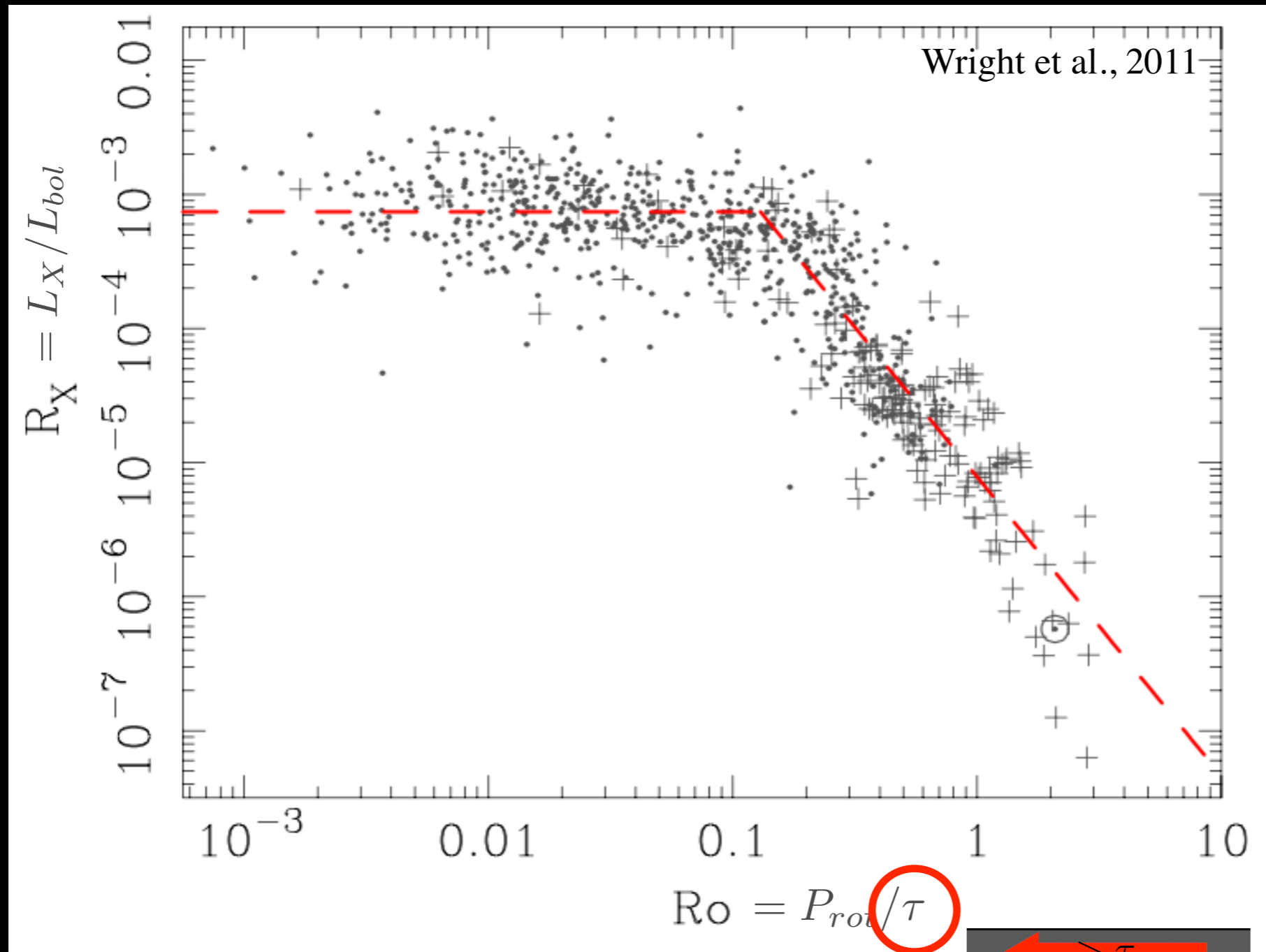
Stellar Activity-Rotation



X-ray to bolometric luminosity ratio



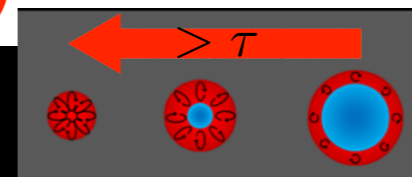
Stellar Activity-Rotation

X-ray to bolometric luminosity ratio



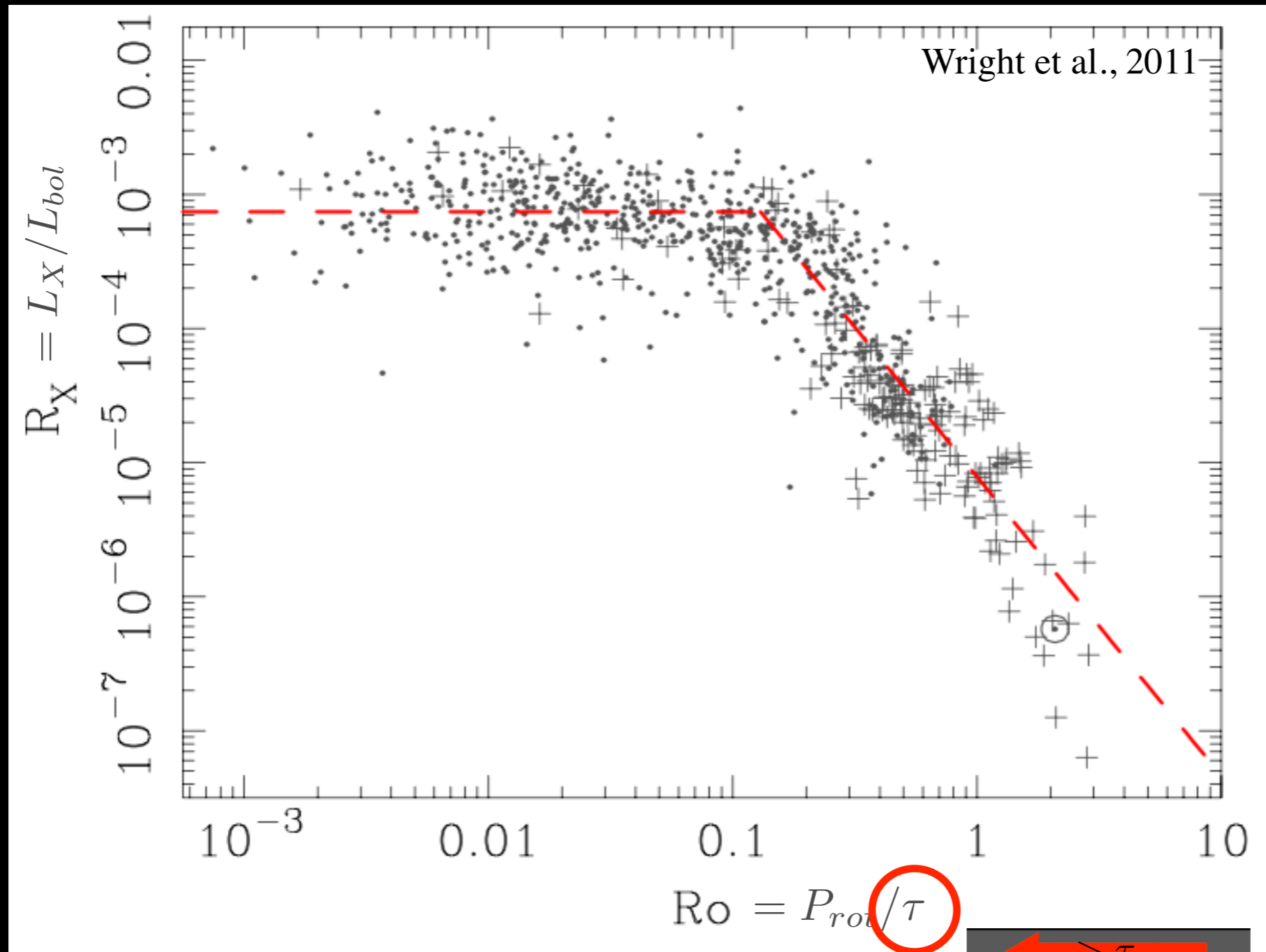
 

$$P_{rot} = P_{rot}$$

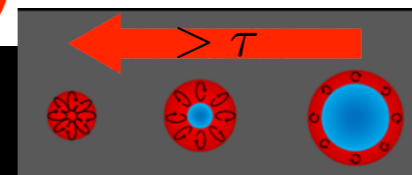


Stellar Activity-Rotation

X-ray to bolometric luminosity ratio

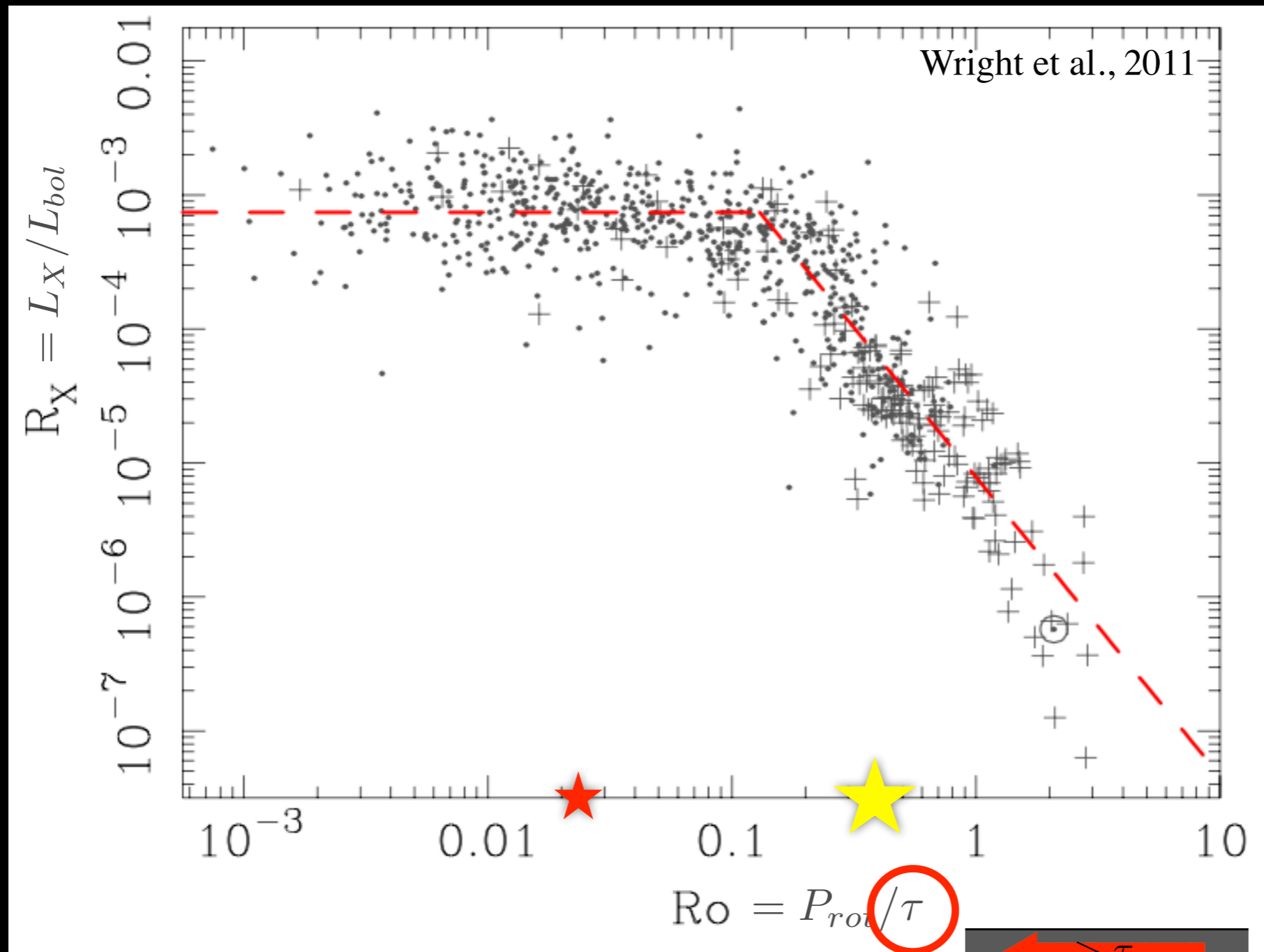


★ ★
 $P_{rot} = P_{rot}$
 $\tau > \tau$

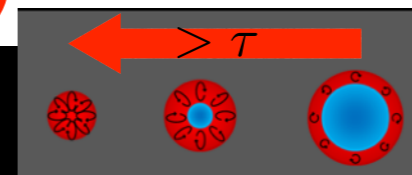


Stellar Activity-Rotation

X-ray to bolometric luminosity ratio

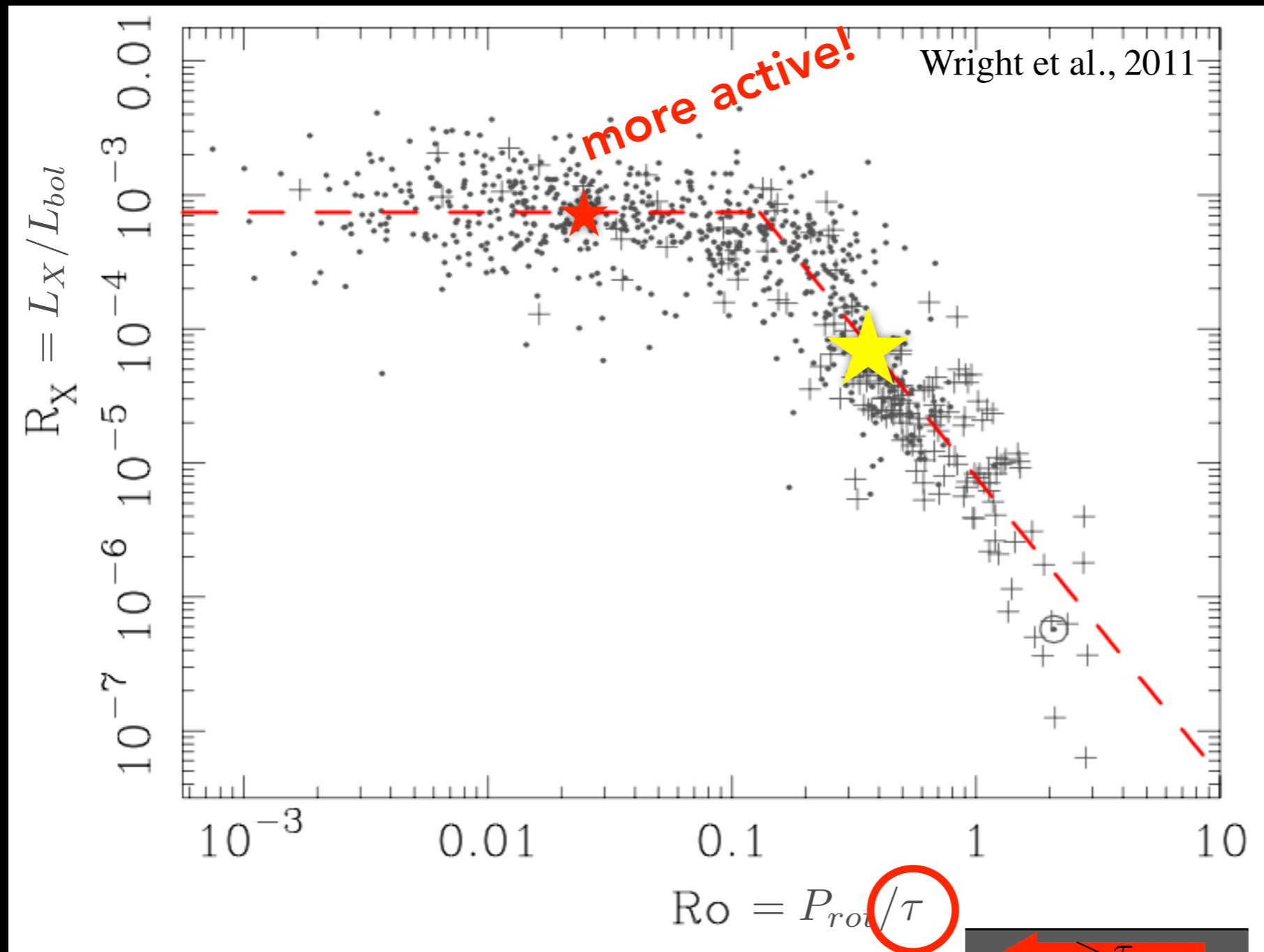


★ ★
 $P_{rot} = P_{rot}$
 $\tau > \tau$
 $R_0 < R_0$

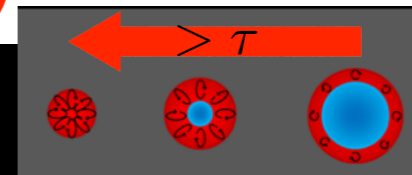


Stellar Activity-Rotation

X-ray to bolometric luminosity ratio

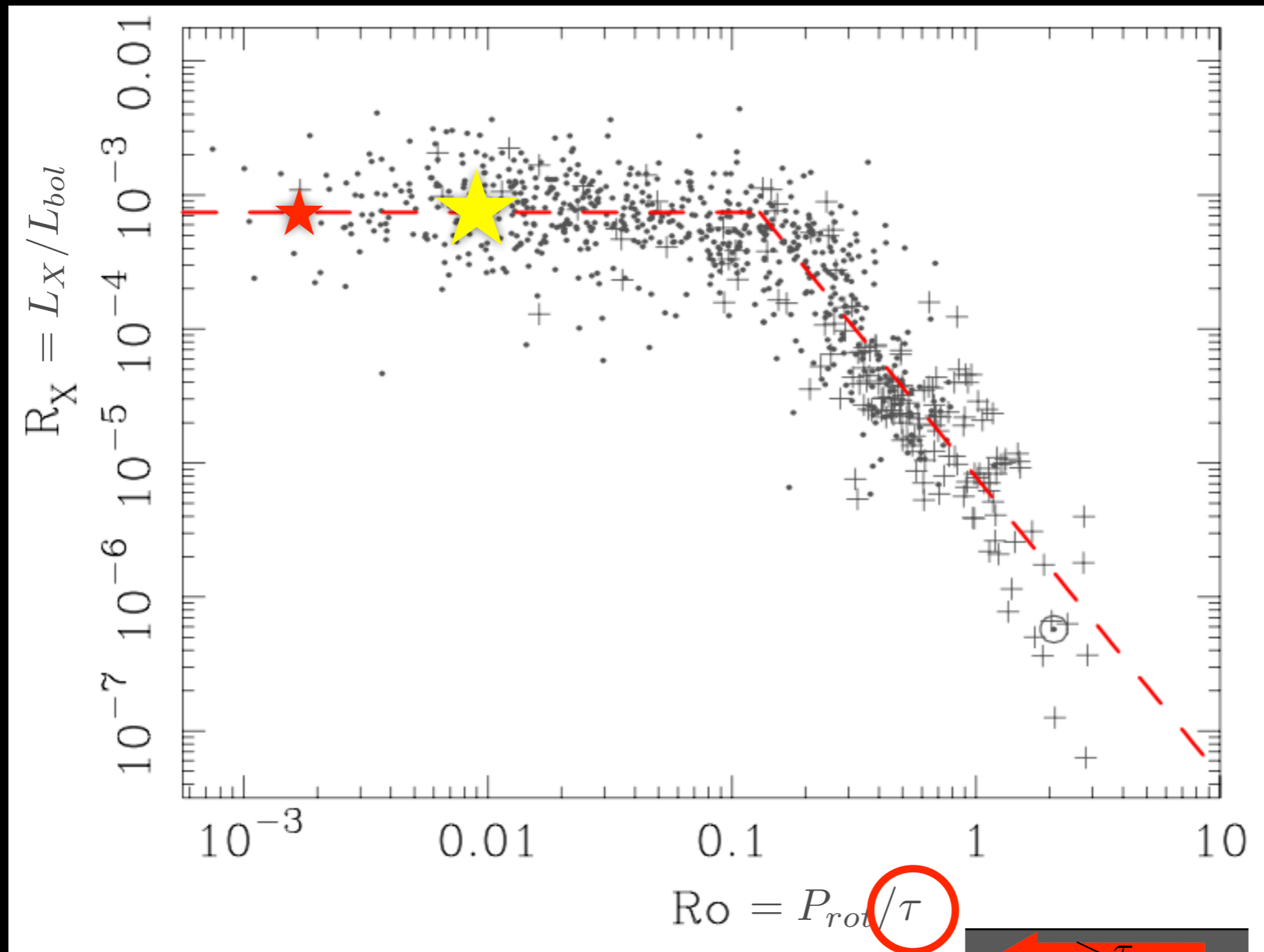


★ ★
 $P_{rot} = P_{rot}$
 $\tau > \tau$
 $R_0 < R_0$

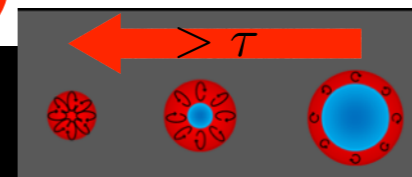


Stellar Activity-Rotation

X-ray to bolometric luminosity ratio

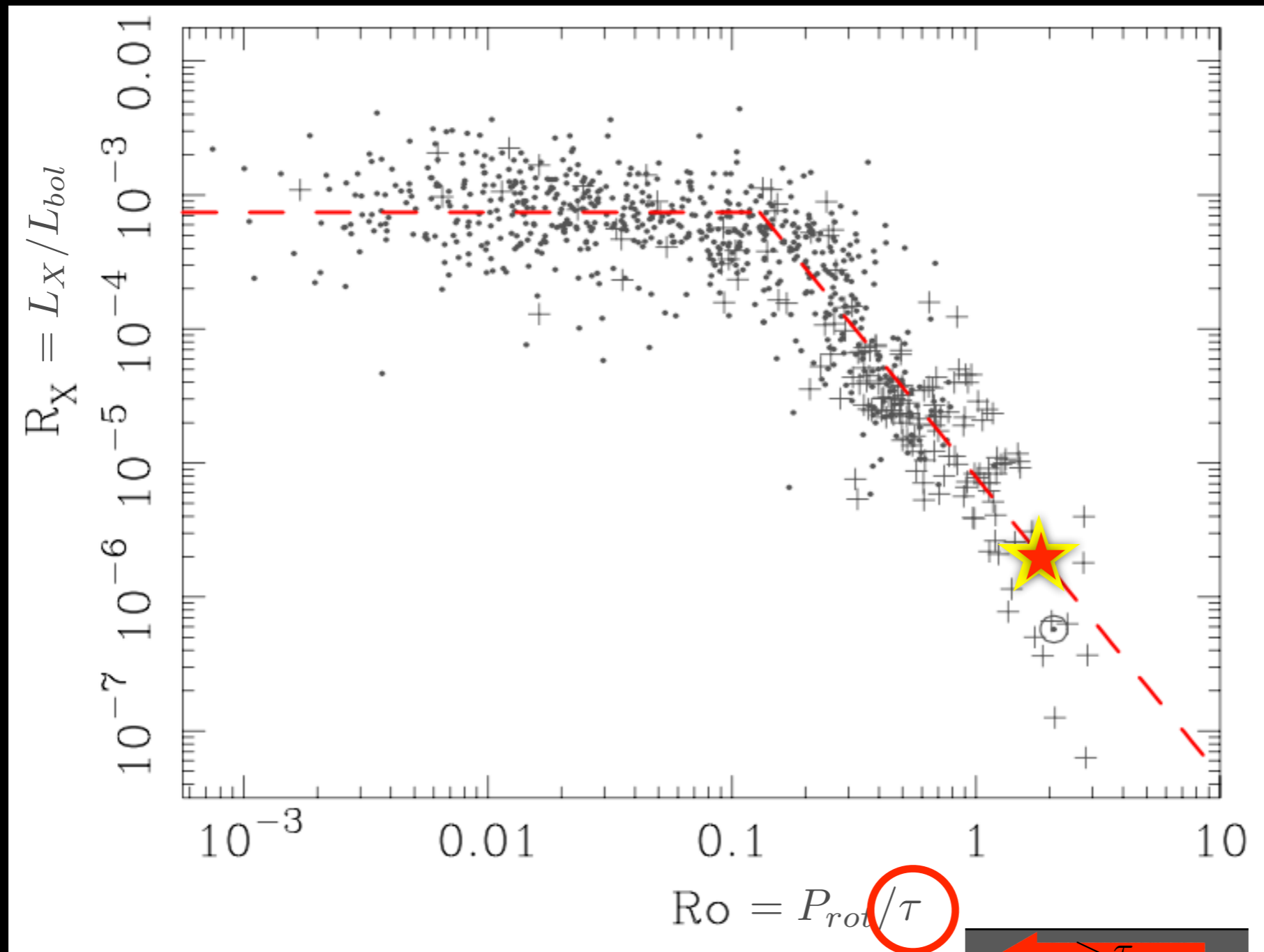


★ ★
 $P_{rot} = P_{rot}$
 $\tau > \tau$
 $R_0 < R_0$

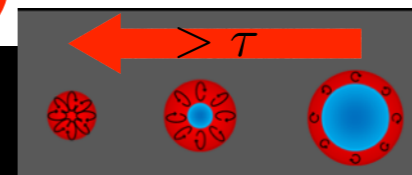


Stellar Activity-Rotation

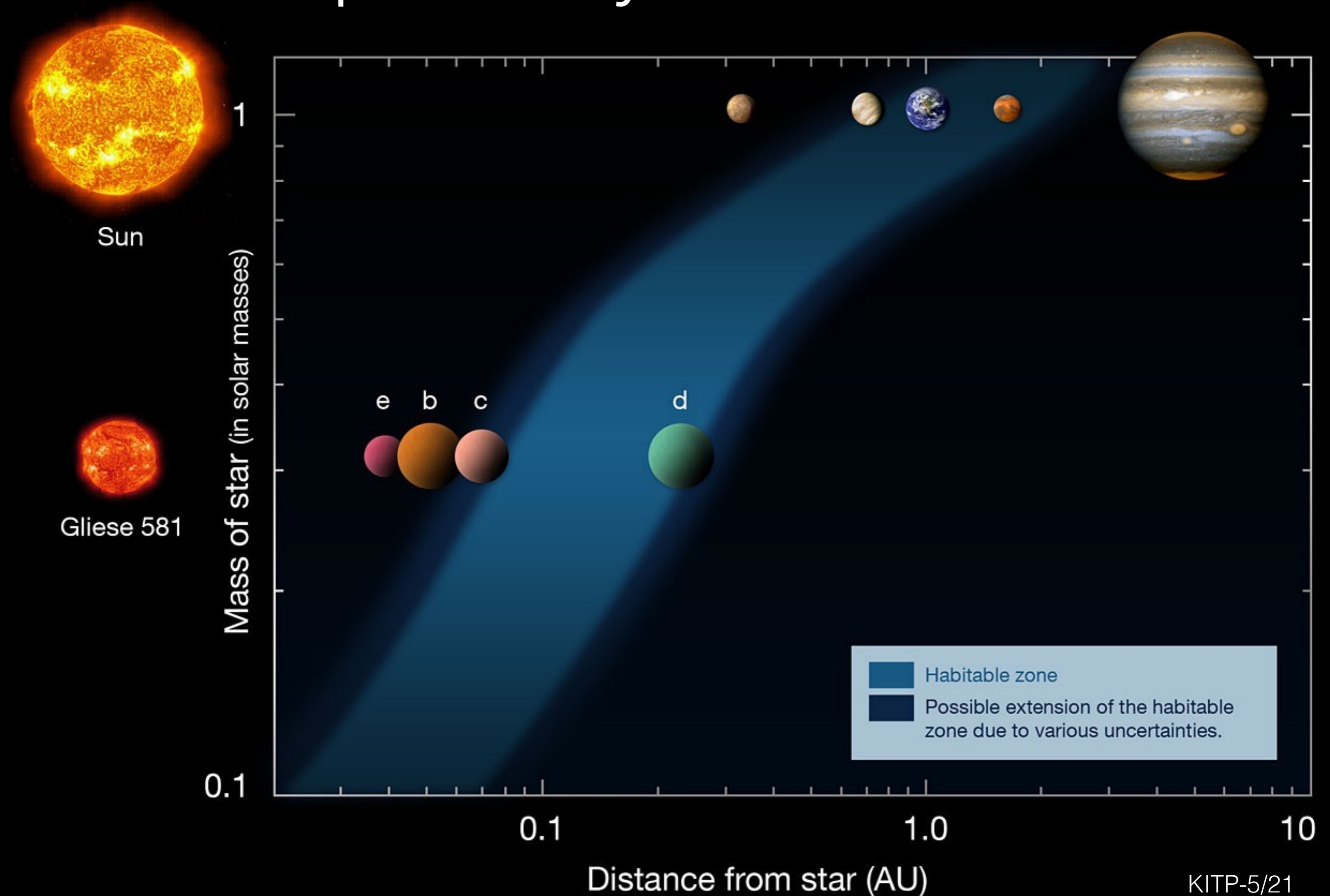
X-ray to bolometric luminosity ratio



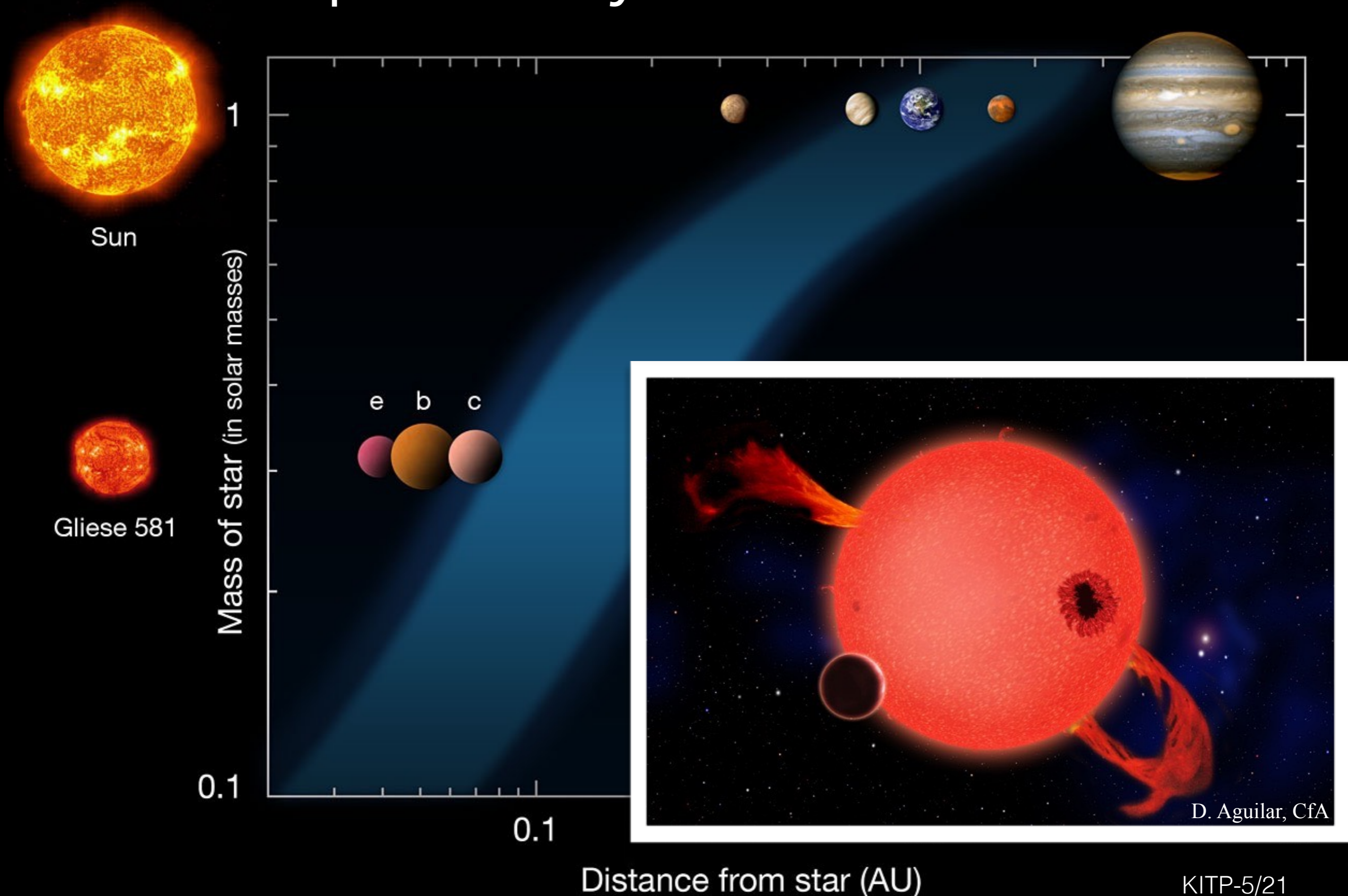
★ ★
 $P_{rot} = P_{rot}$
 $\tau > \tau$
 $R_0 < R_0$



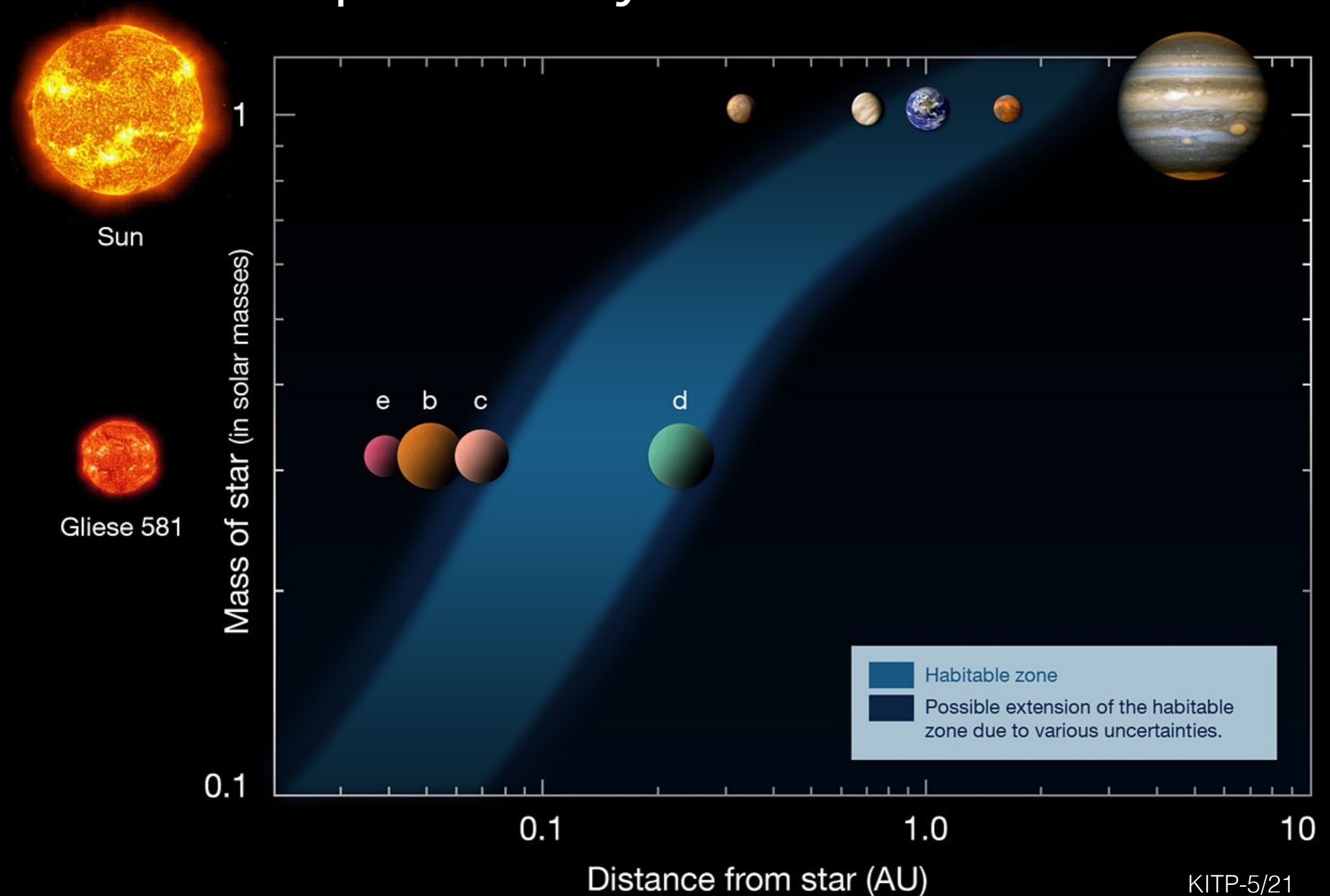
Exoplanetary Environments



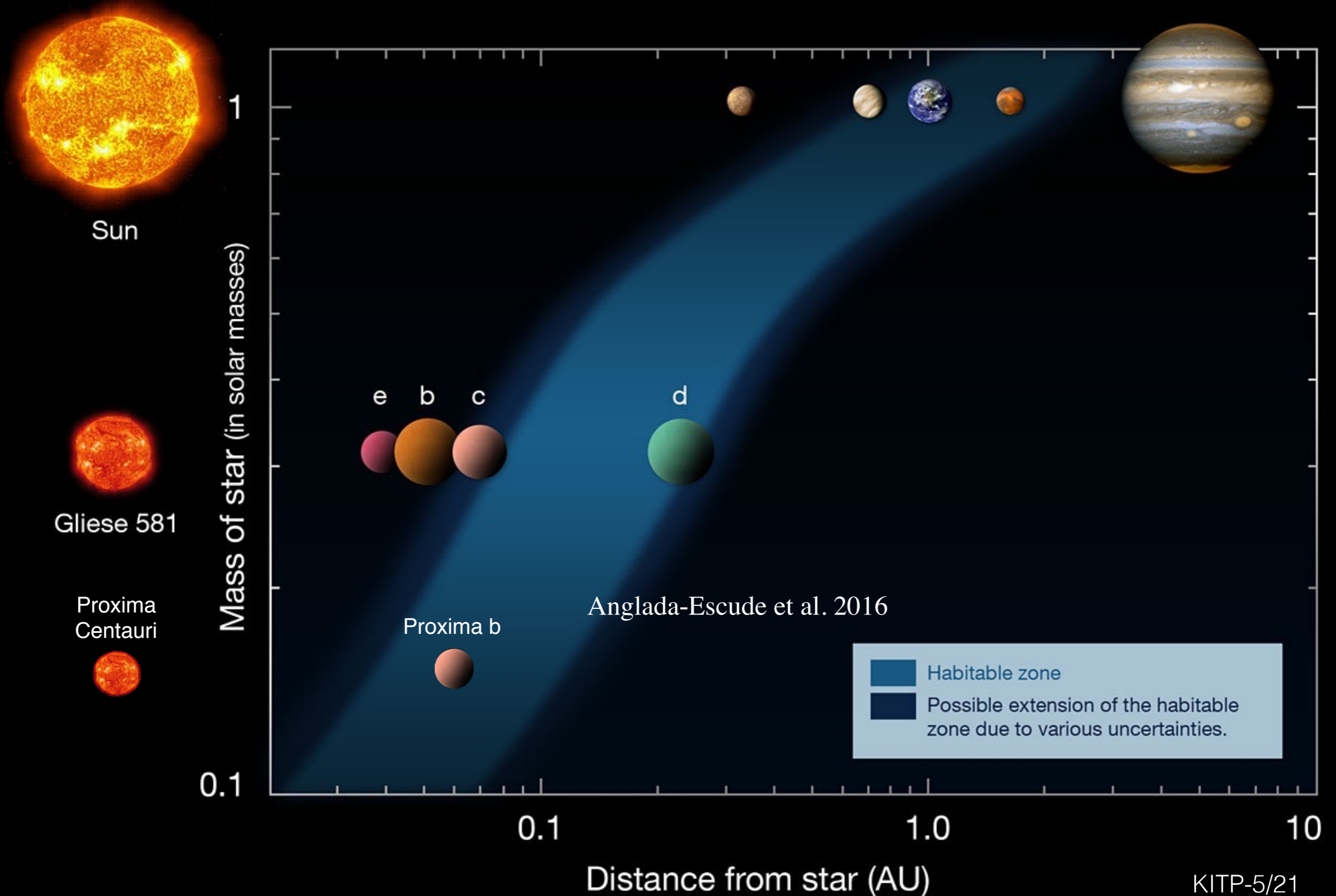
Exoplanetary Environments



Exoplanetary Environments



Exoplanetary Environments



Exoplanetary Environments

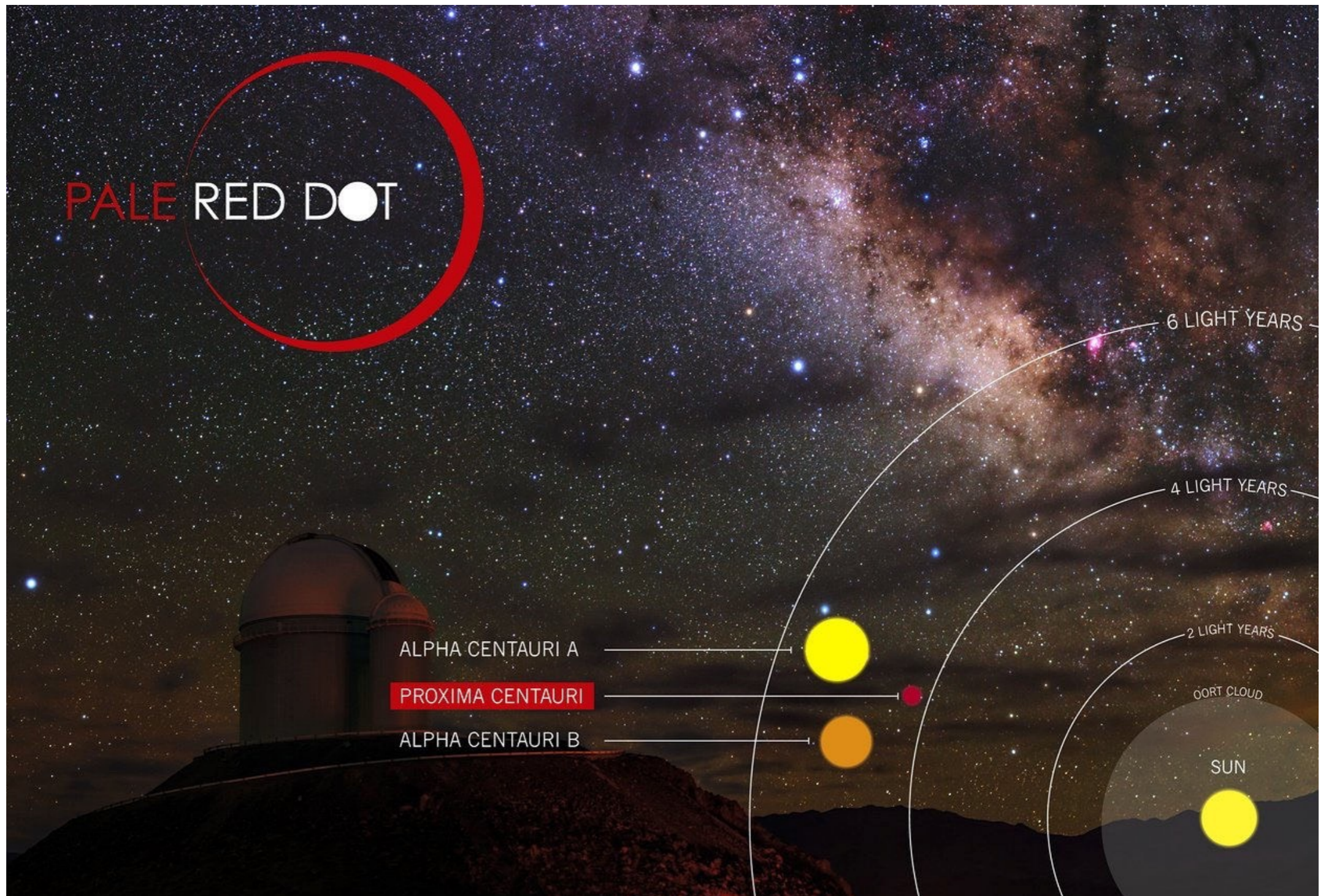
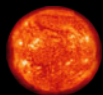


Sun



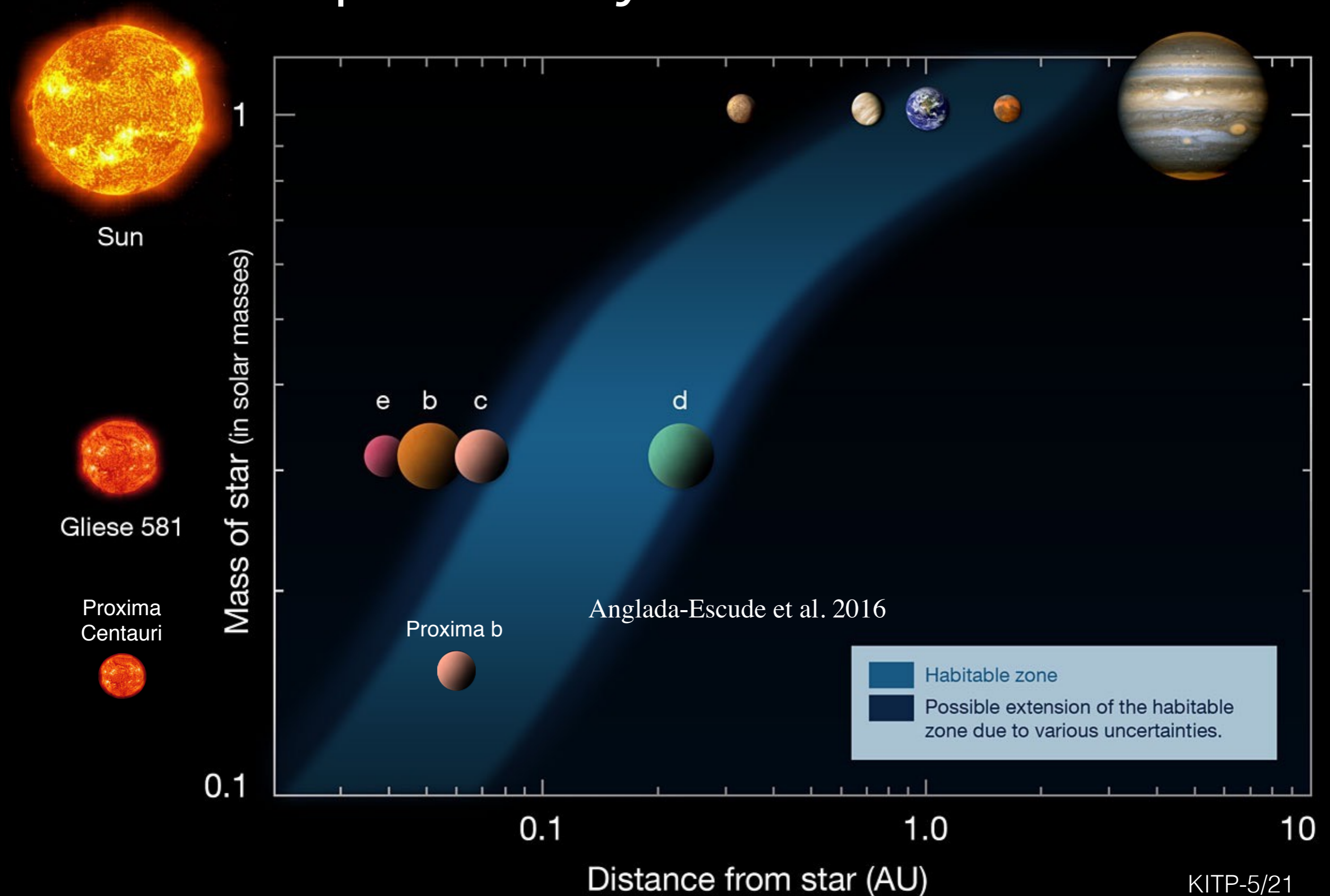
Gliese 581

Proxima Centauri

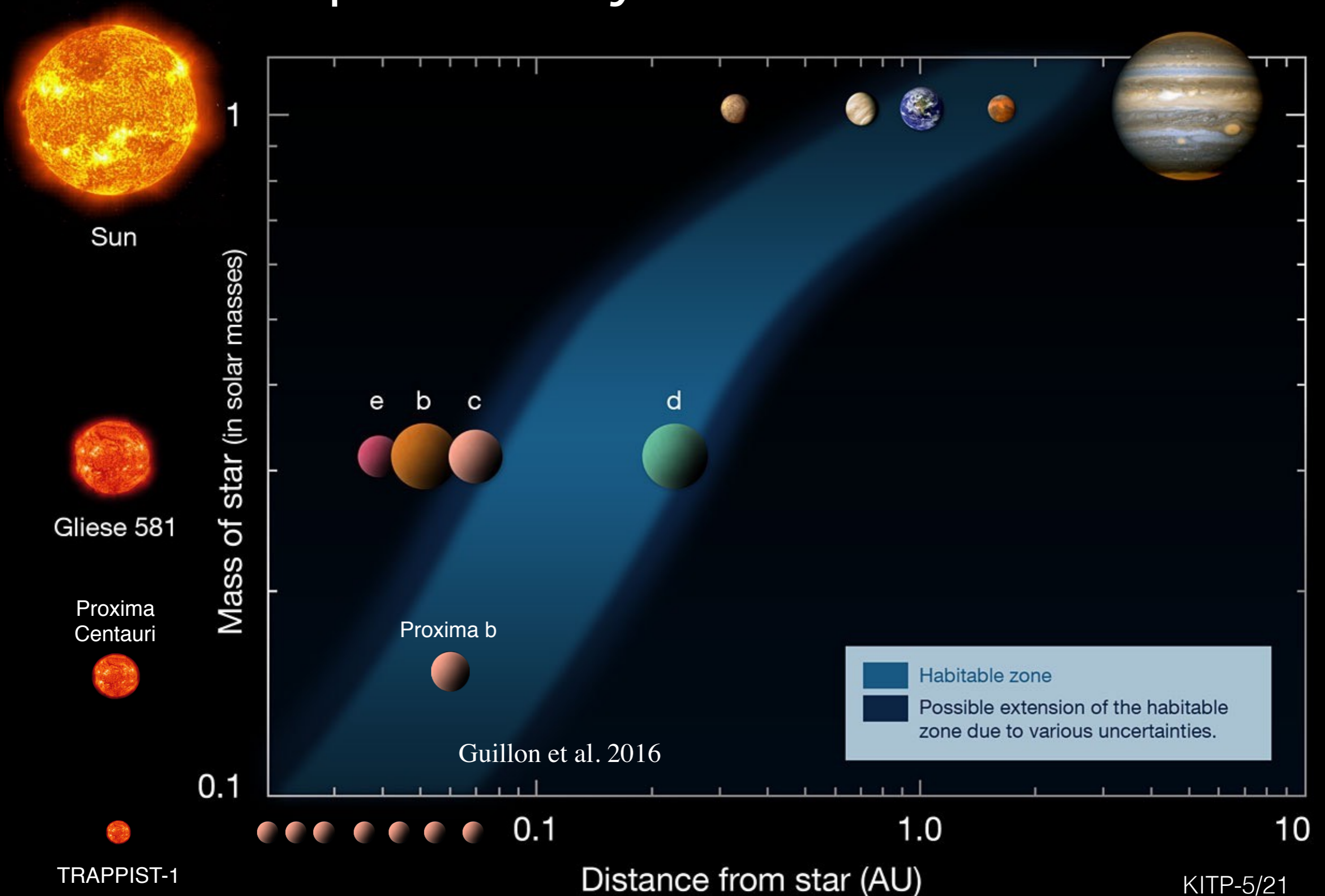


Distance from star (AU)

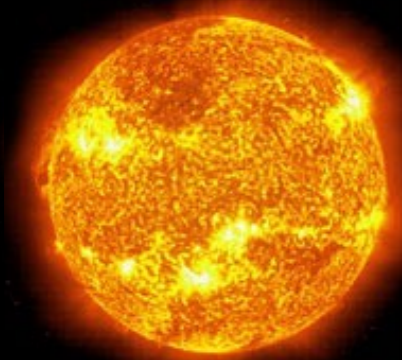
Exoplanetary Environments



Exoplanetary Environments



Exoplanetary Environments

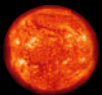


Sun

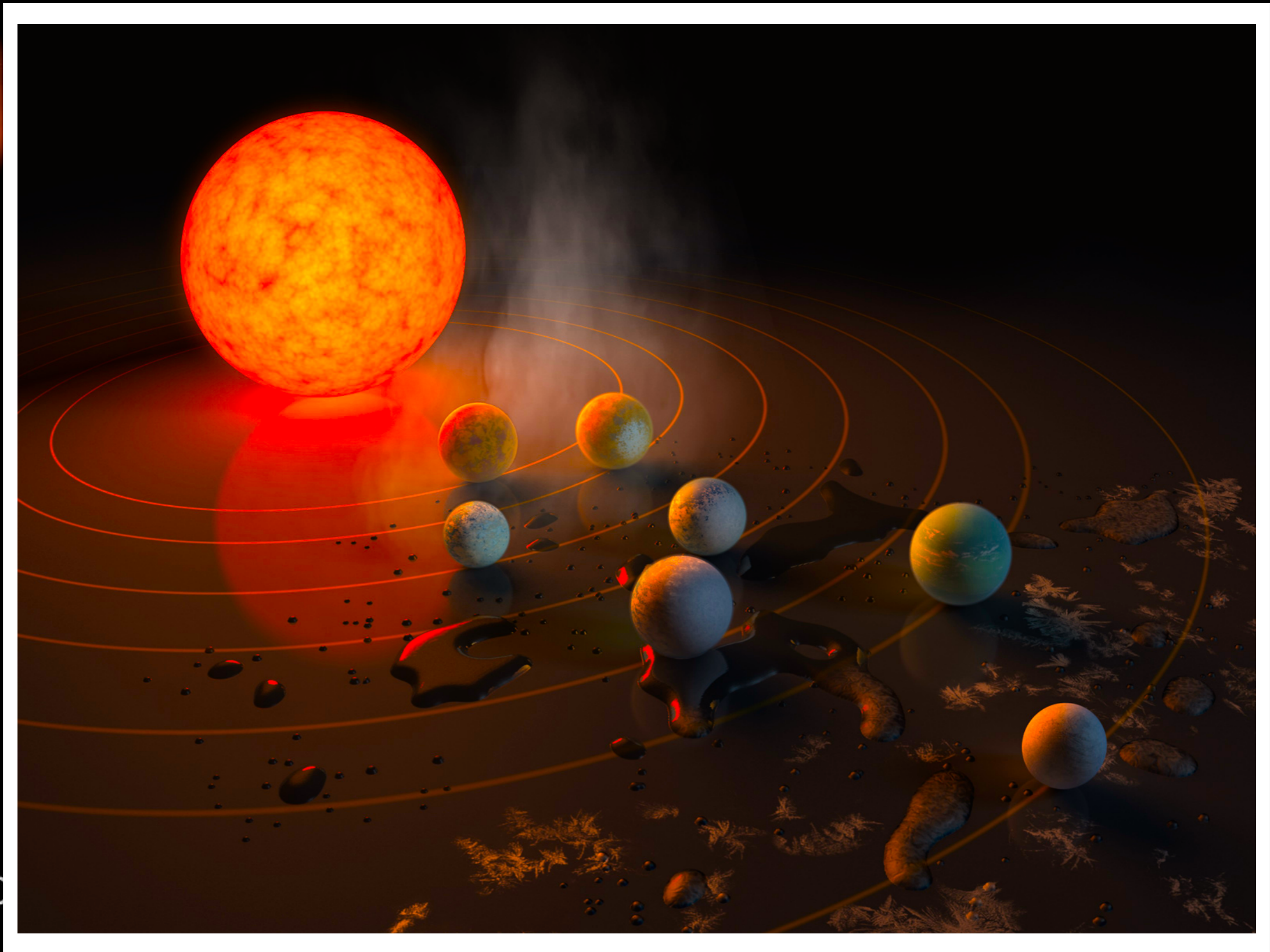


Gliese 581

Proxima Centauri

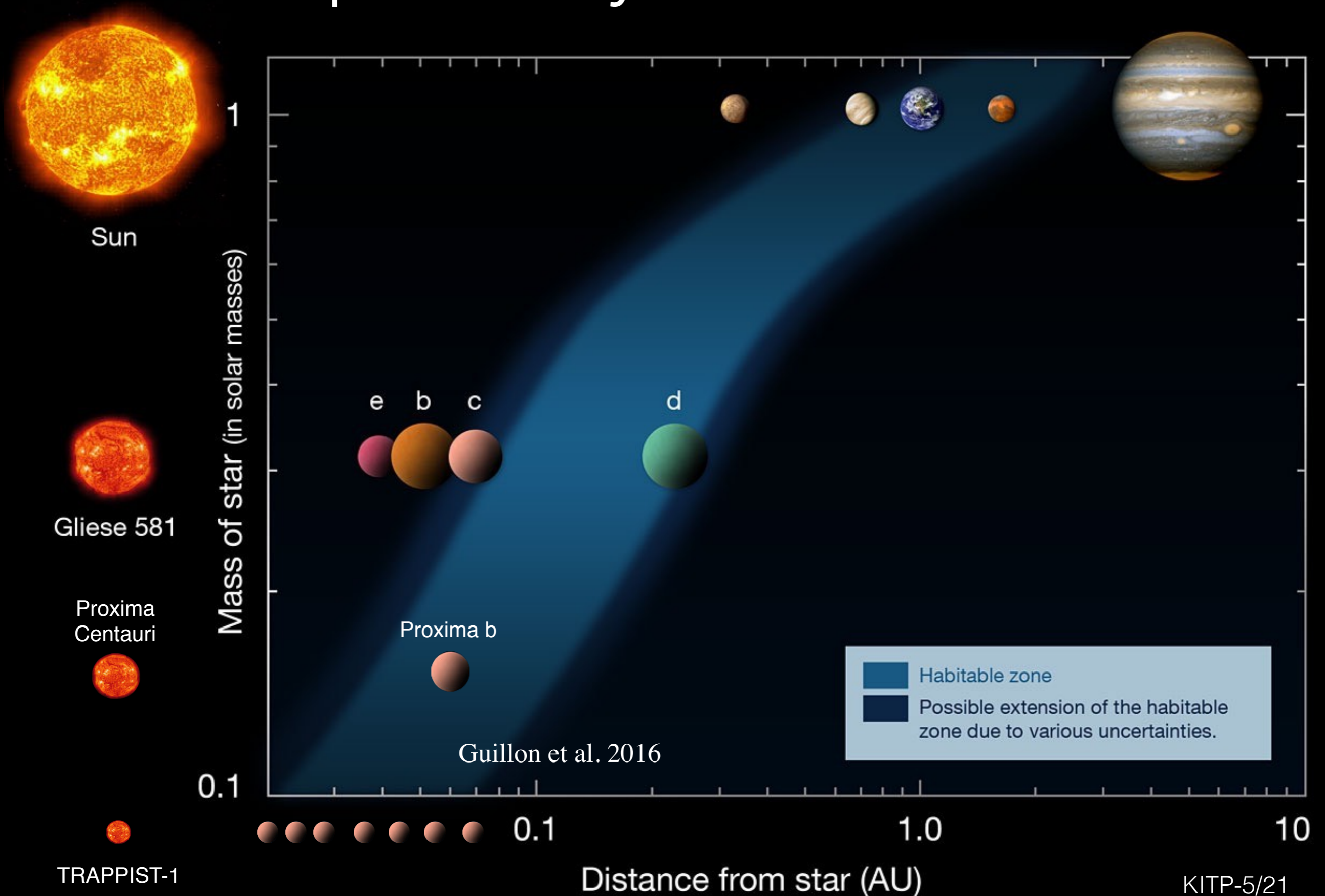


TRAPPIST-1

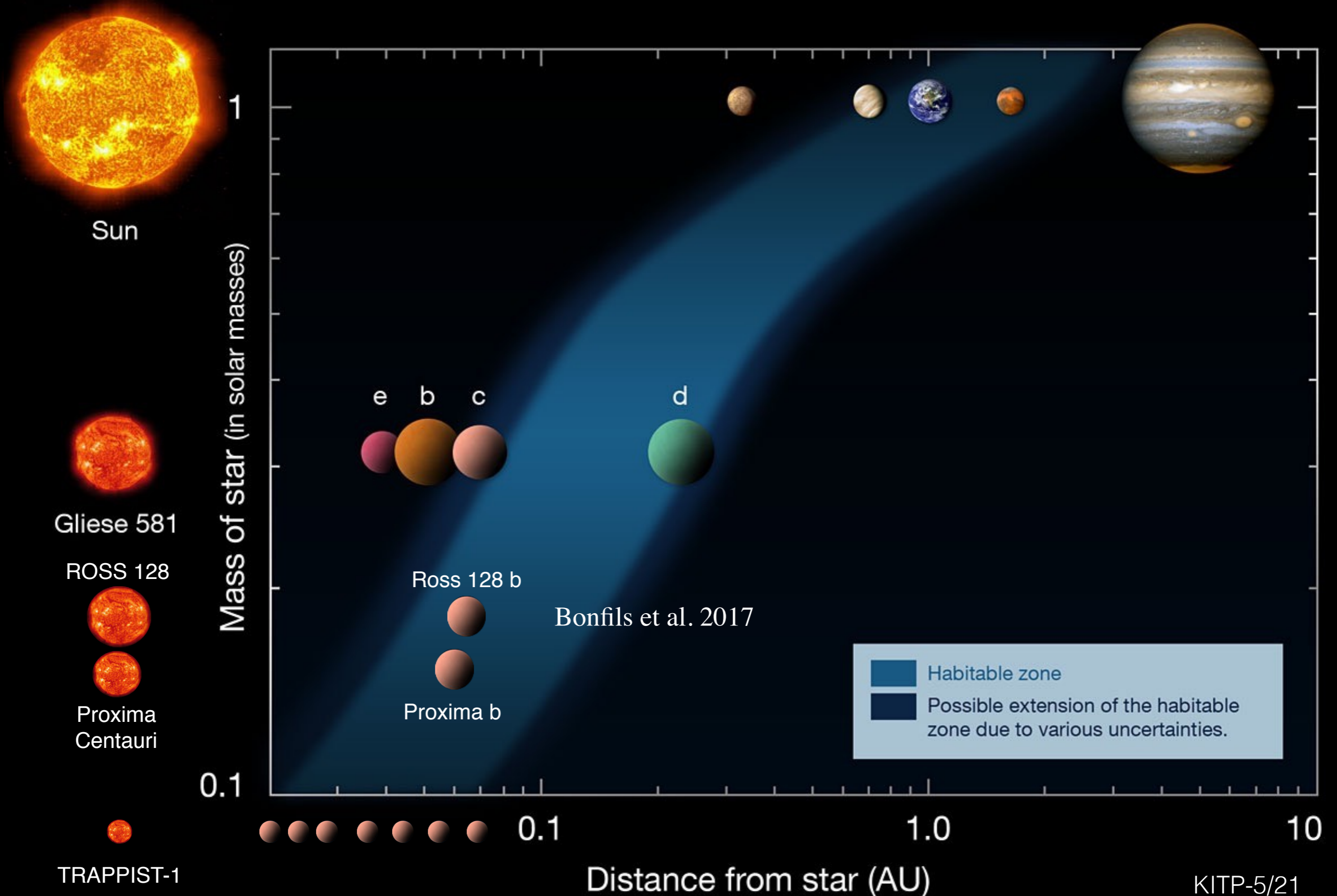


Distance from star (AU)

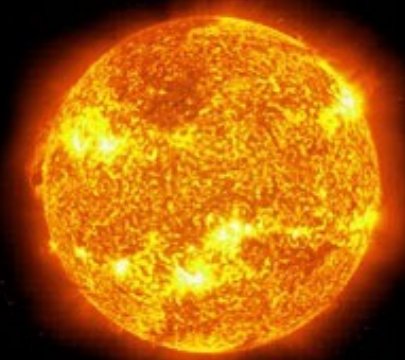
Exoplanetary Environments



Exoplanetary Environments



Exoplanetary Environments

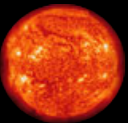


Sun



Gliese 581

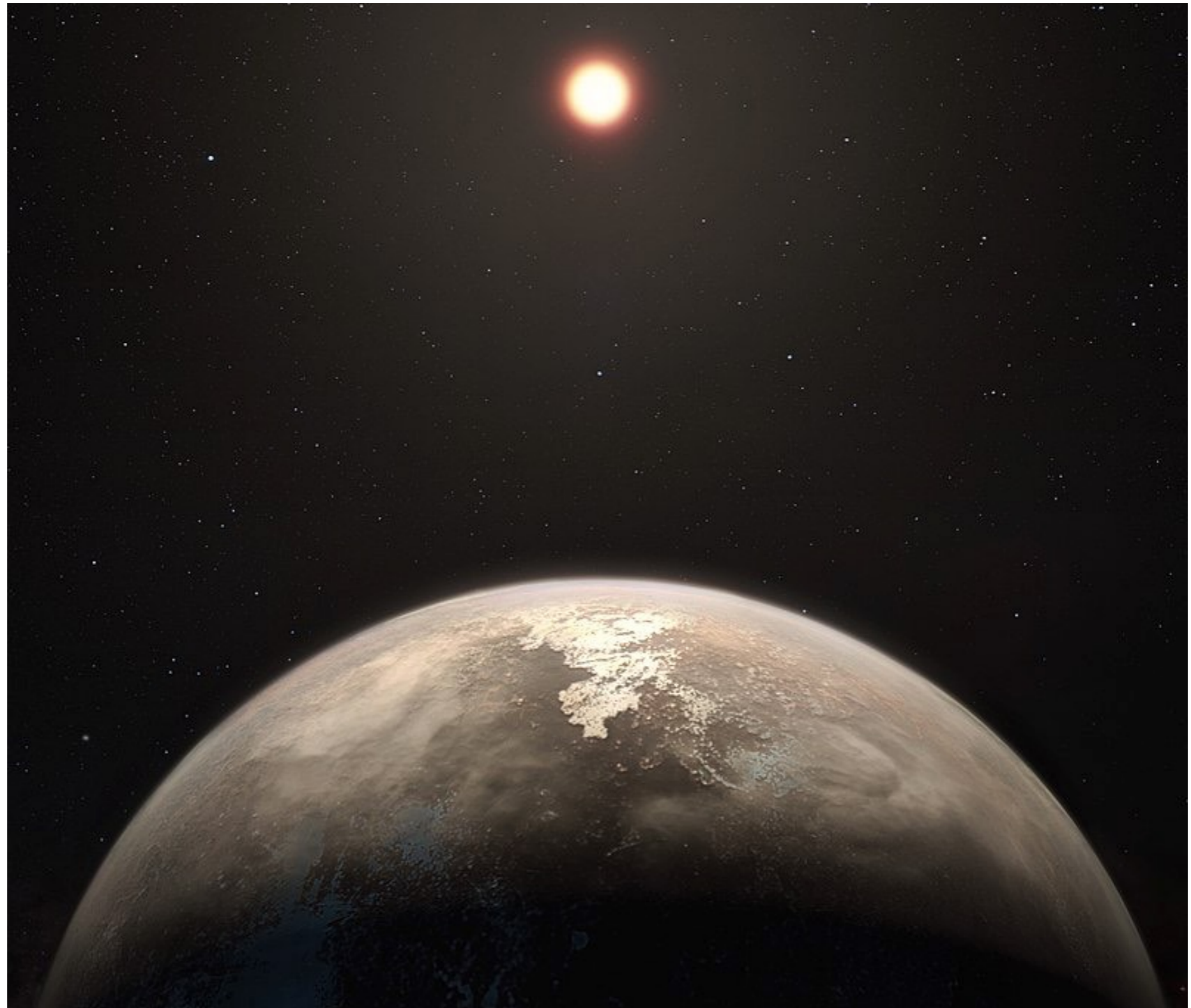
ROSS 128



Proxima Centauri

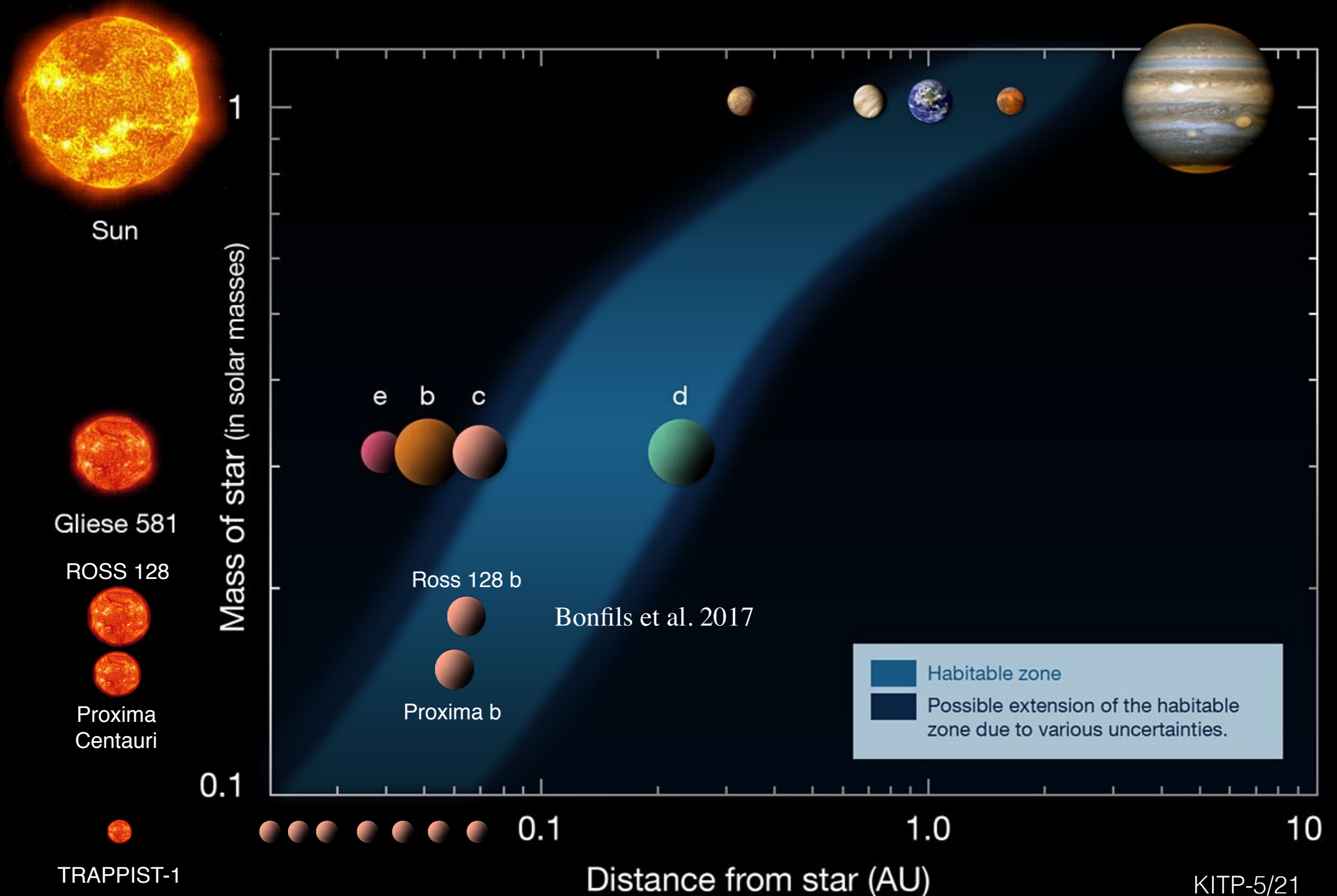


TRAPPIST-1

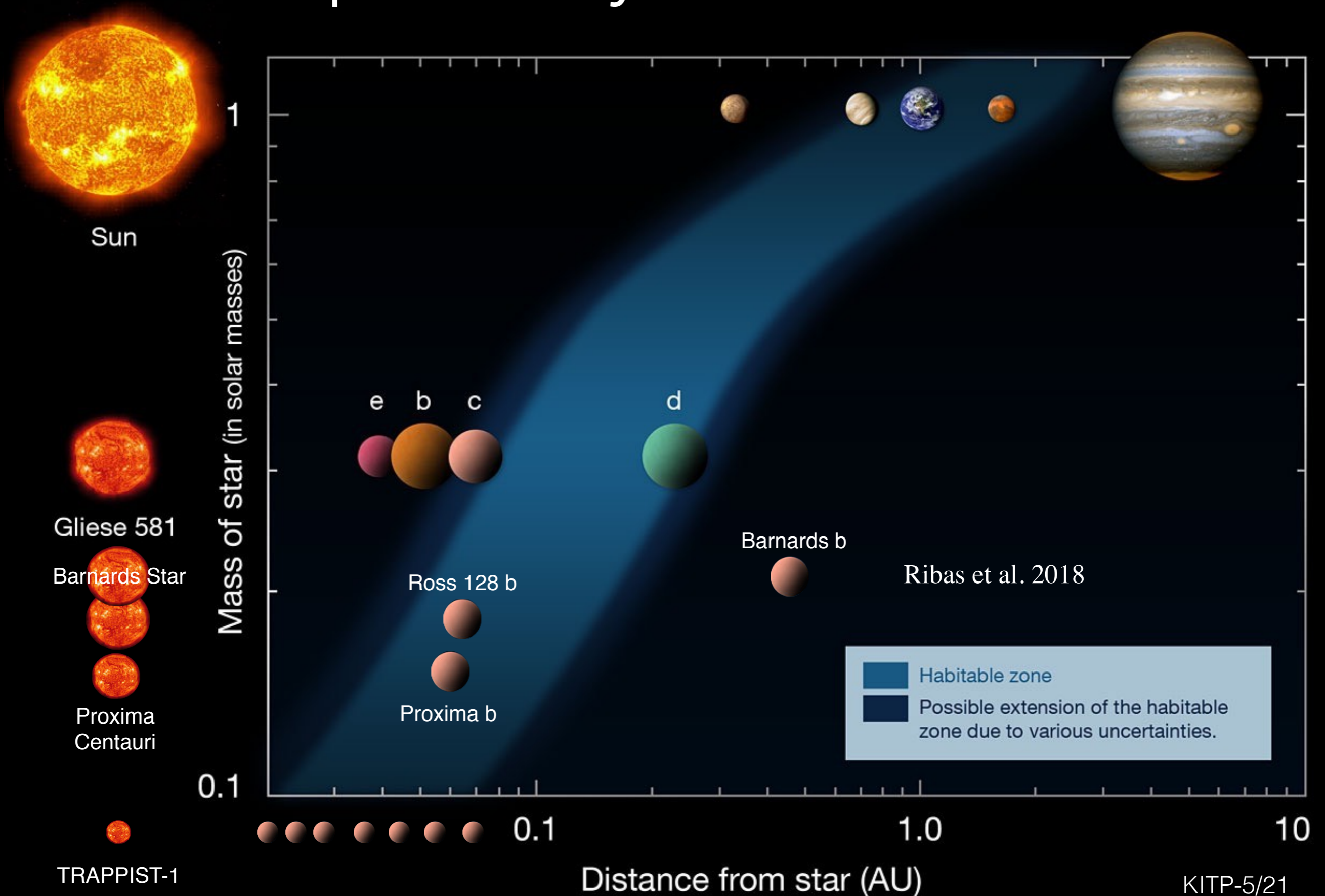


Distance from star (AU)

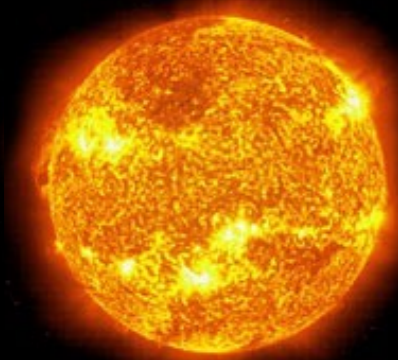
Exoplanetary Environments



Exoplanetary Environments



Exoplanetary Environments



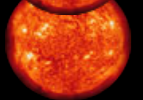
Sun



Gliese 581



Barnards Star



Proxima Centauri

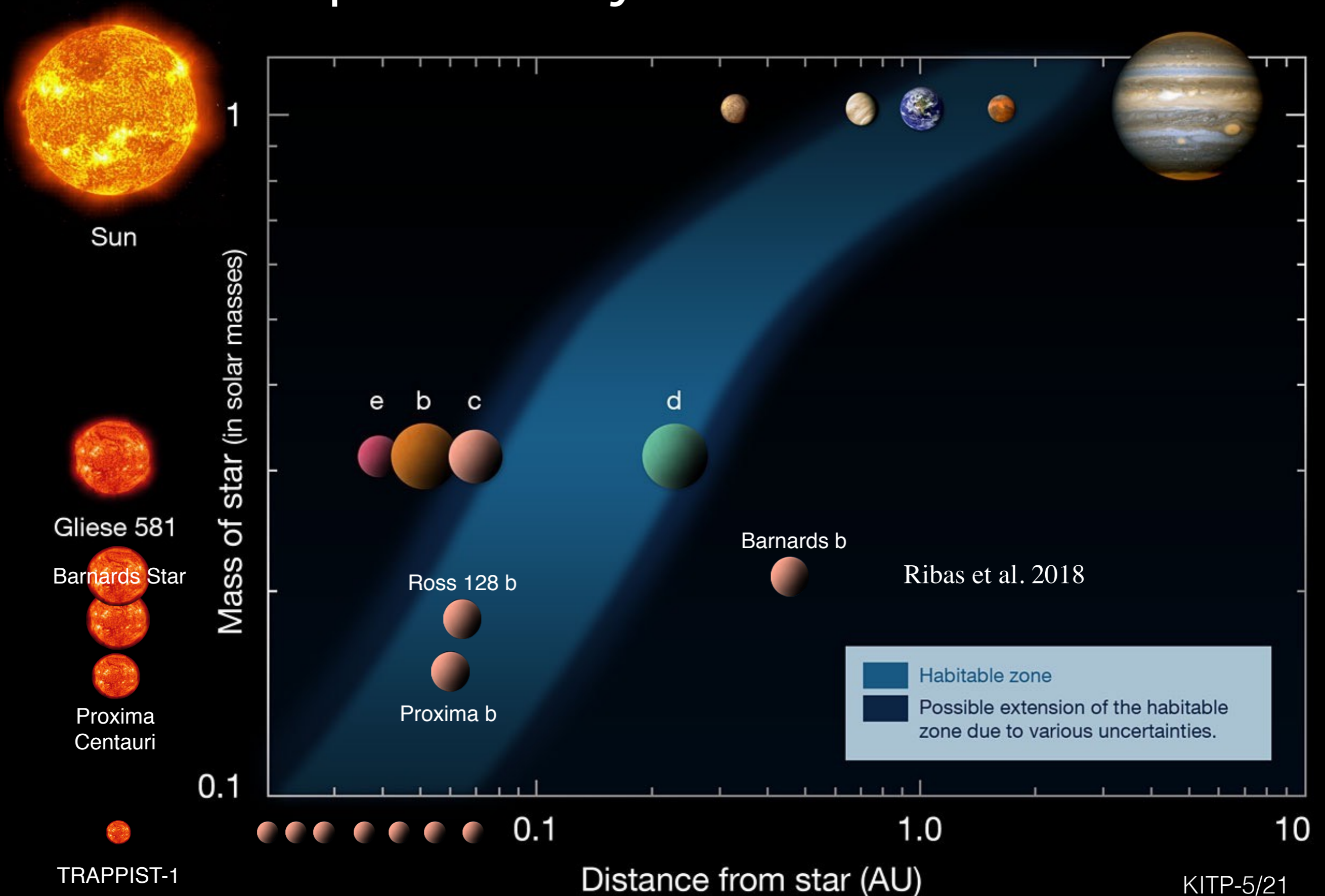


TRAPPIST-1



Distance from star (AU)

Exoplanetary Environments



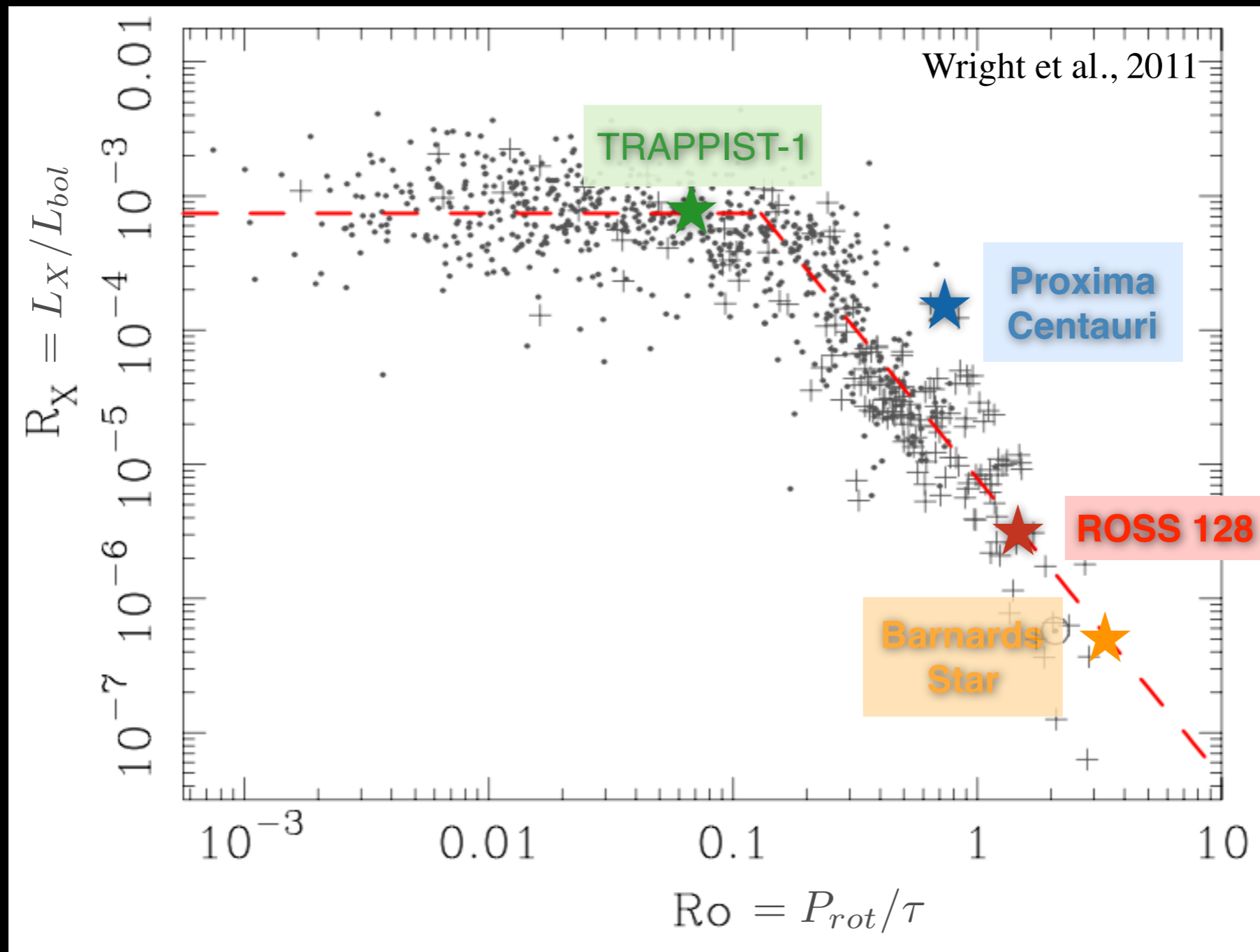
Exoplanetary Environments

Exoplanetary Environments



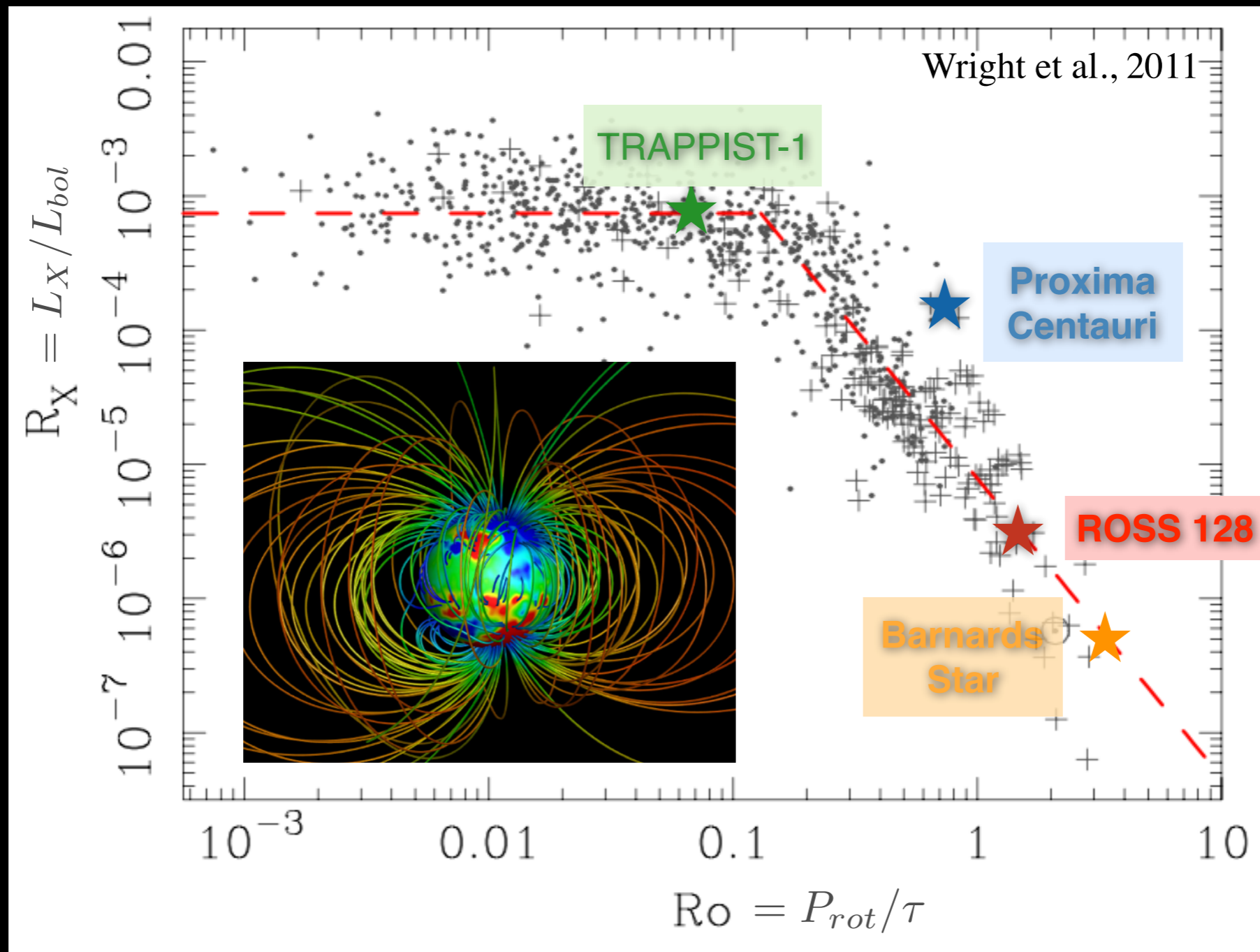
Stellar Activity-Rotation

X-ray to bolometric luminosity ratio



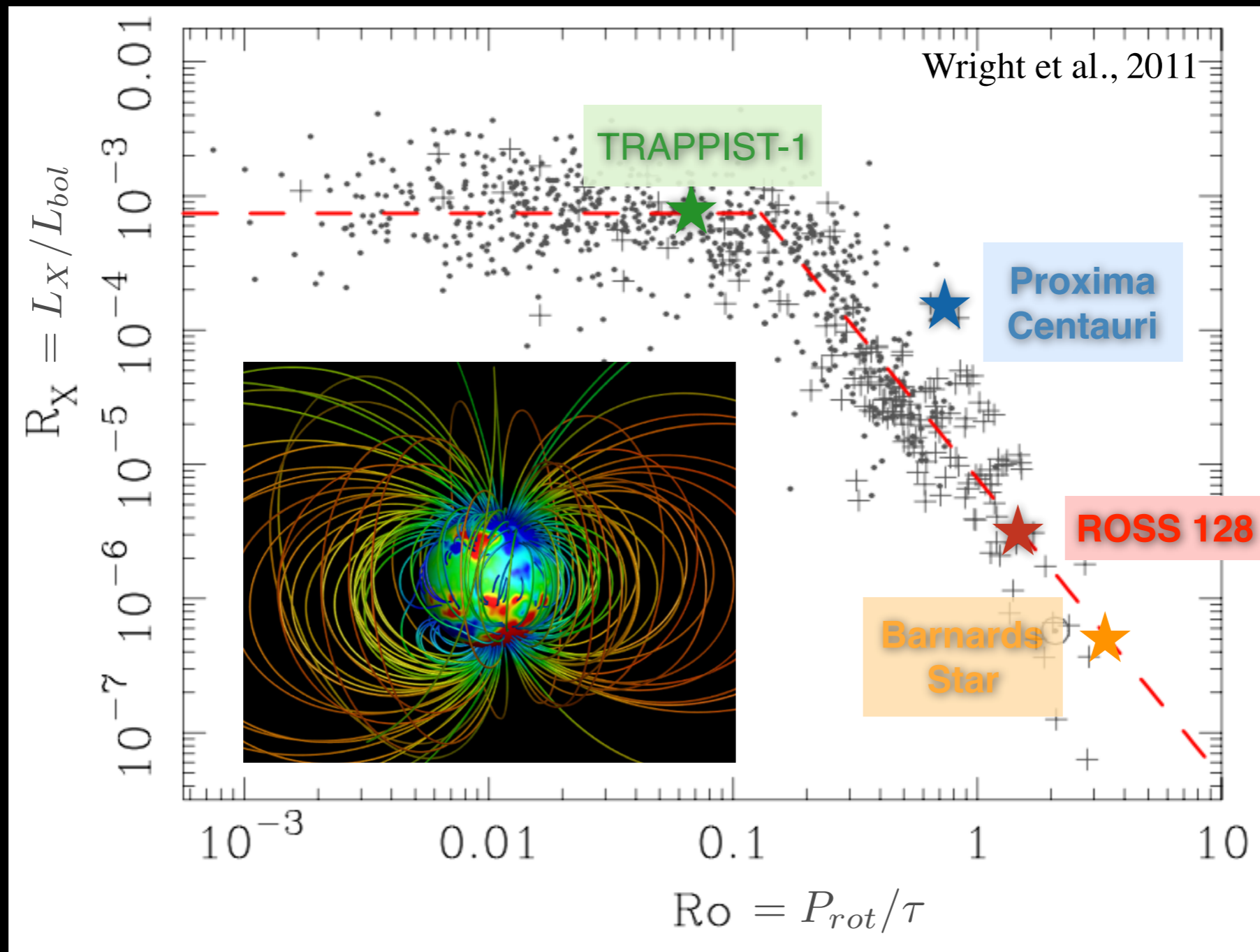
Stellar Activity-Rotation

BATS-R-US (U. of Michigan) 3D MHD code



Stellar Activity-Rotation

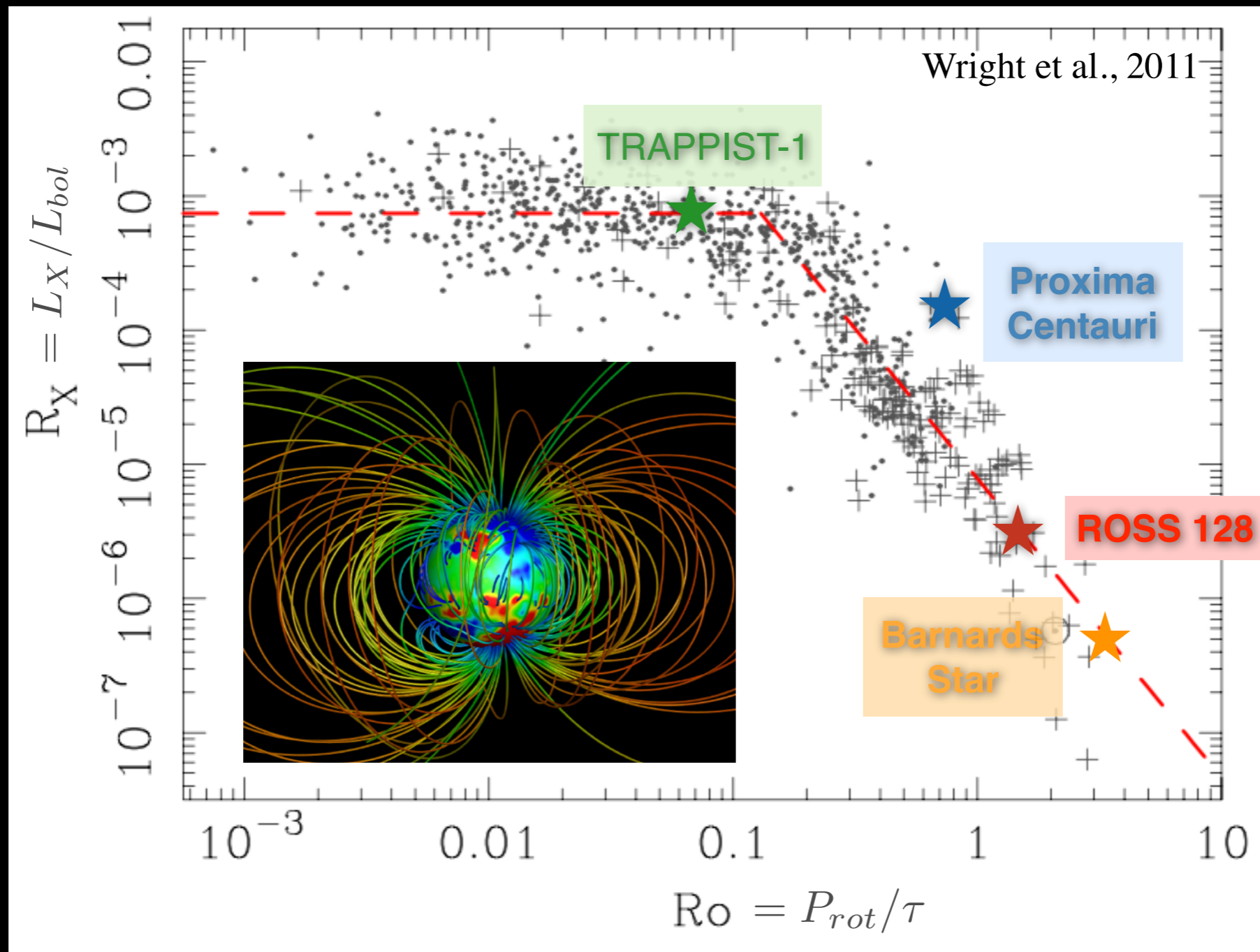
BATS-R-US (U. of Michigan) 3D MHD code



magnetic map

Stellar Activity-Rotation

BATS-R-US (U. of Michigan) 3D MHD code

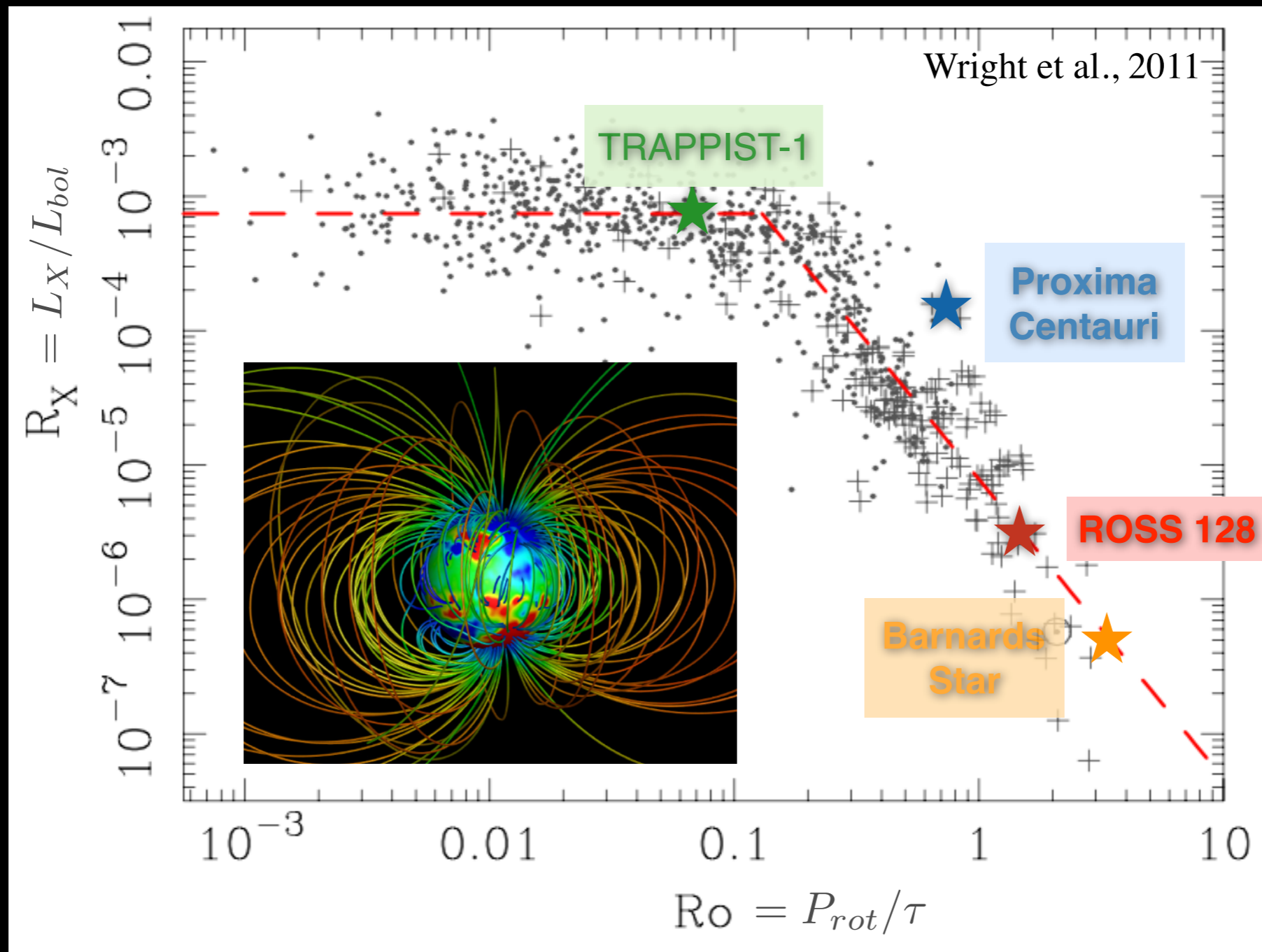


magnetic map → 3D corona solution

Stellar Activity-Rotation

BATS-R-US (U. of Michigan) 3D MHD code

B Field
Zeeman
Splitting
X-rays

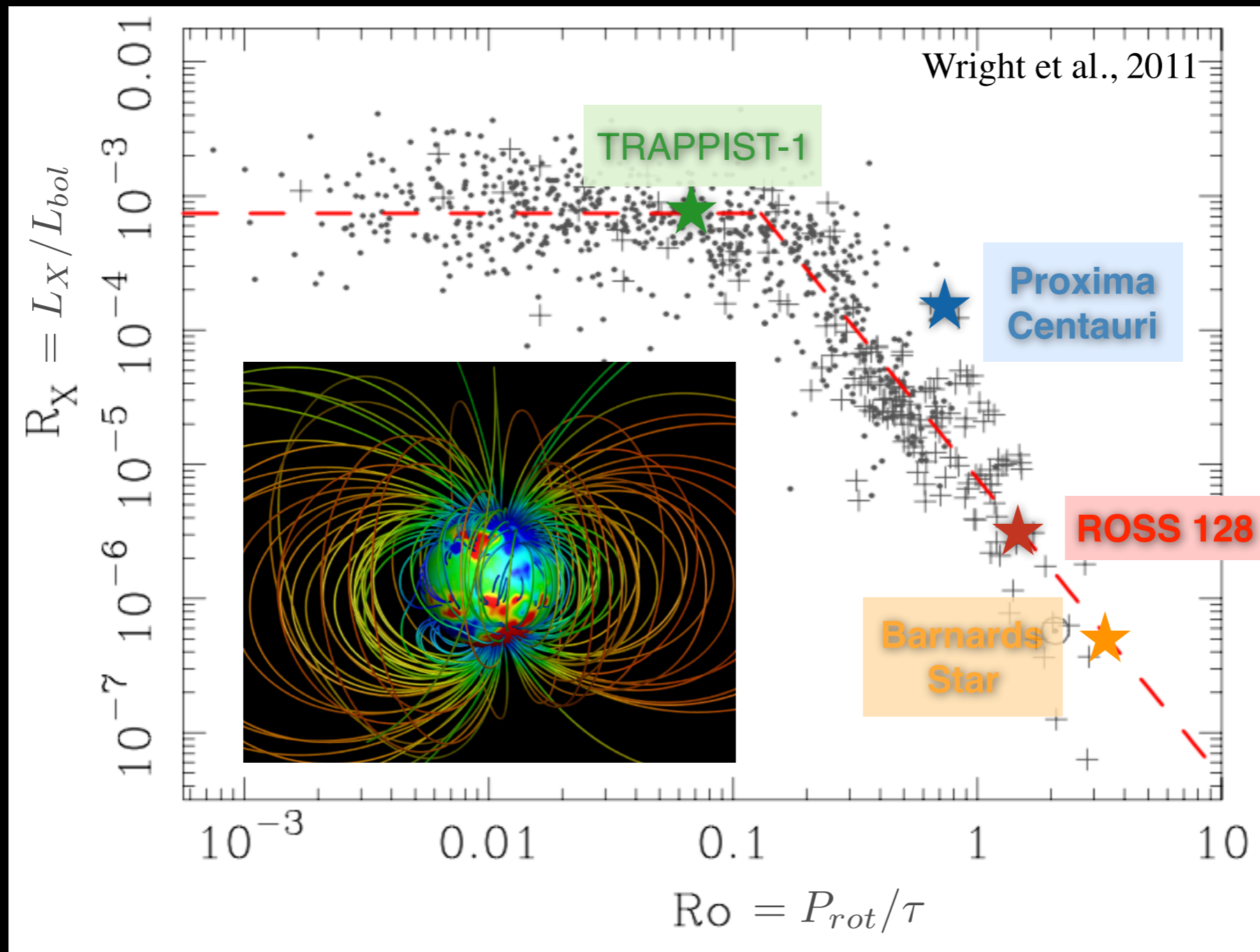


magnetic map → 3D corona solution

Stellar Activity-Rotation

BATS-R-US (U. of Michigan) 3D MHD code

B Field
Zeeman
Splitting
X-rays



Geometry
ZDI

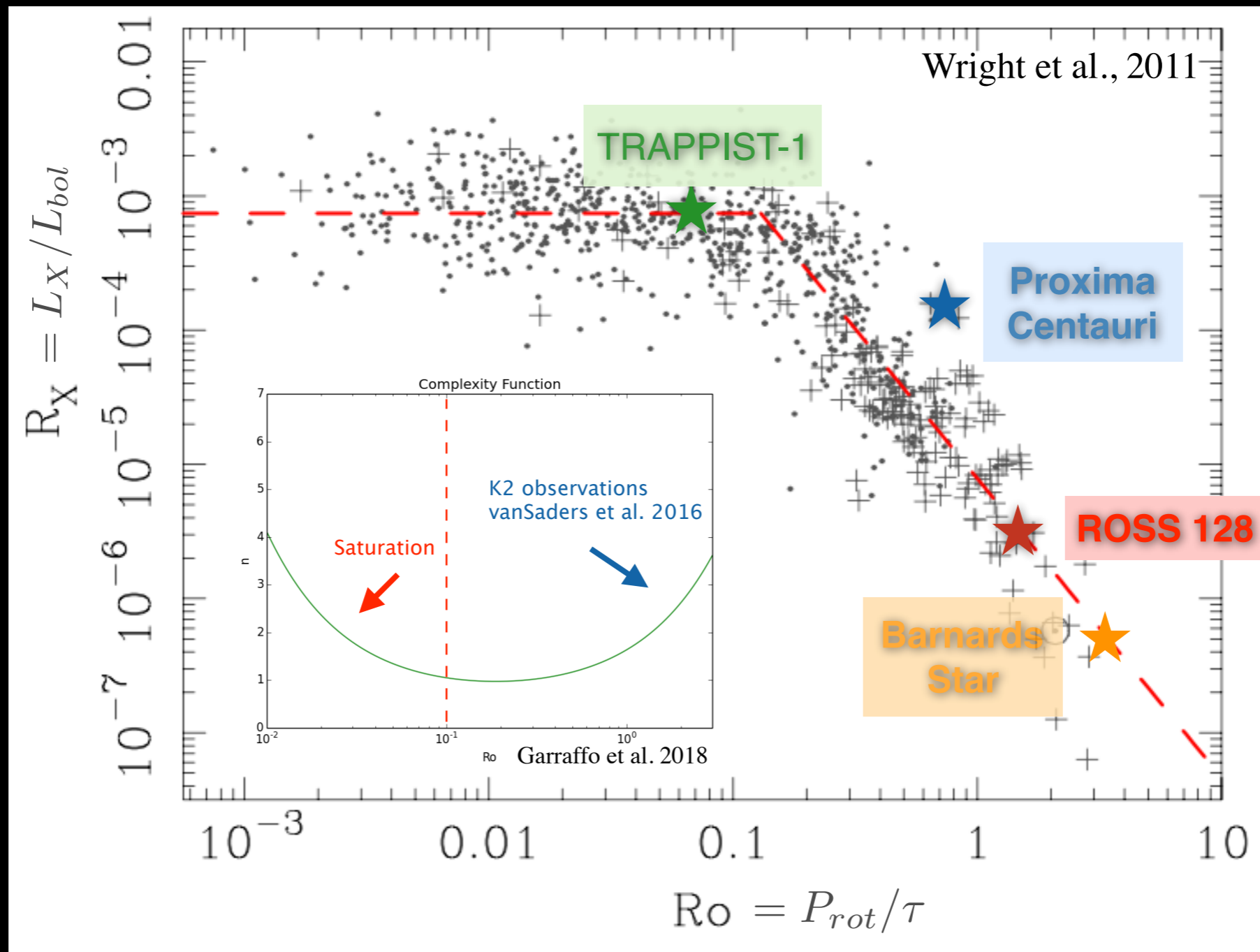
magnetic map → 3D corona solution

Stellar Activity-Rotation

BATS-R-US (U. of Michigan) 3D MHD code

B Field
Zeeman Splitting
X-rays

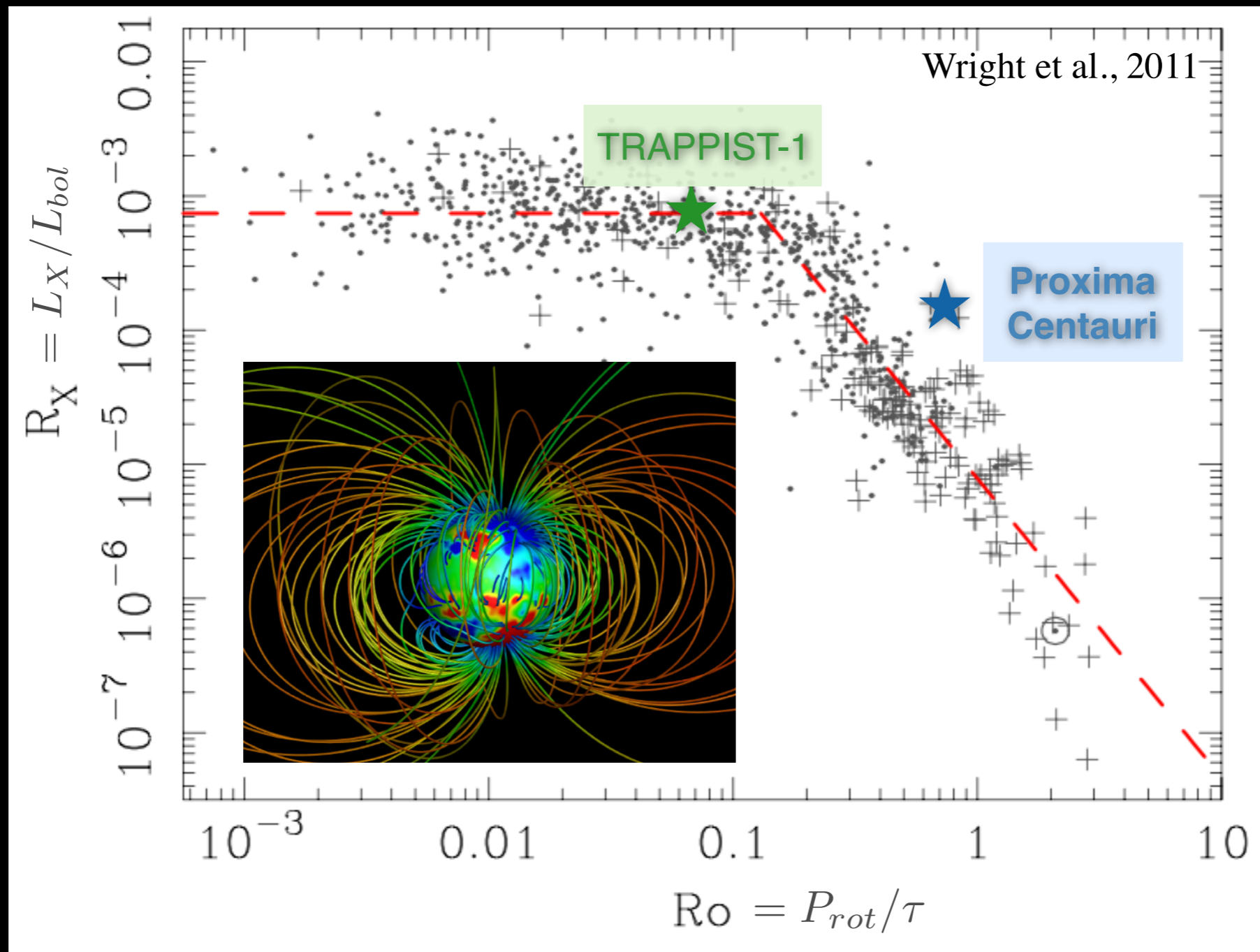
Geometry
ZDI



magnetic map \longrightarrow 3D corona solution

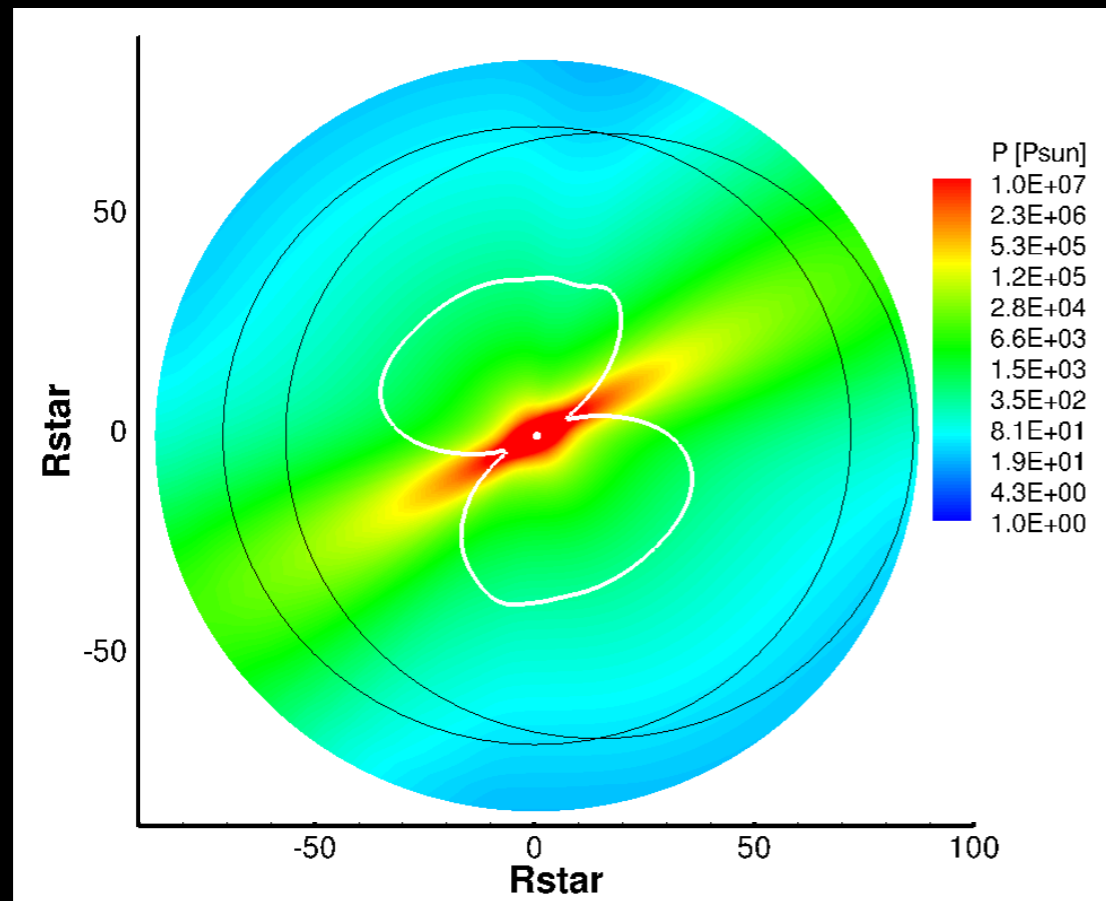
Stellar Activity-Rotation

BATS-R-US (U. of Michigan) 3D MHD code

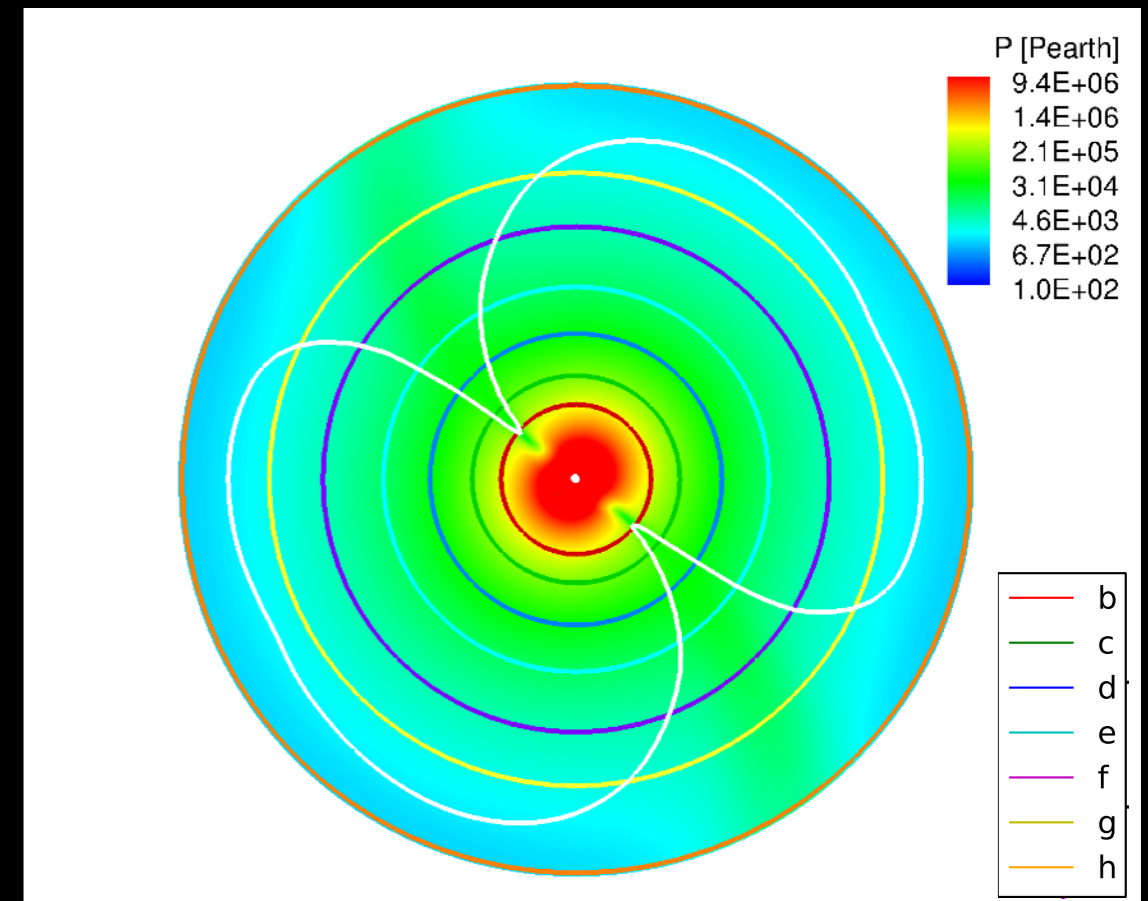


Exoplanetary Environments

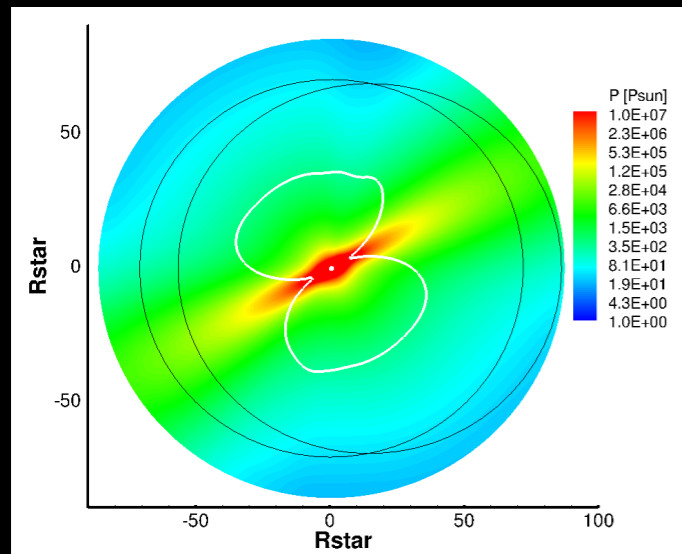
Proxima b



TRAPPIST-1

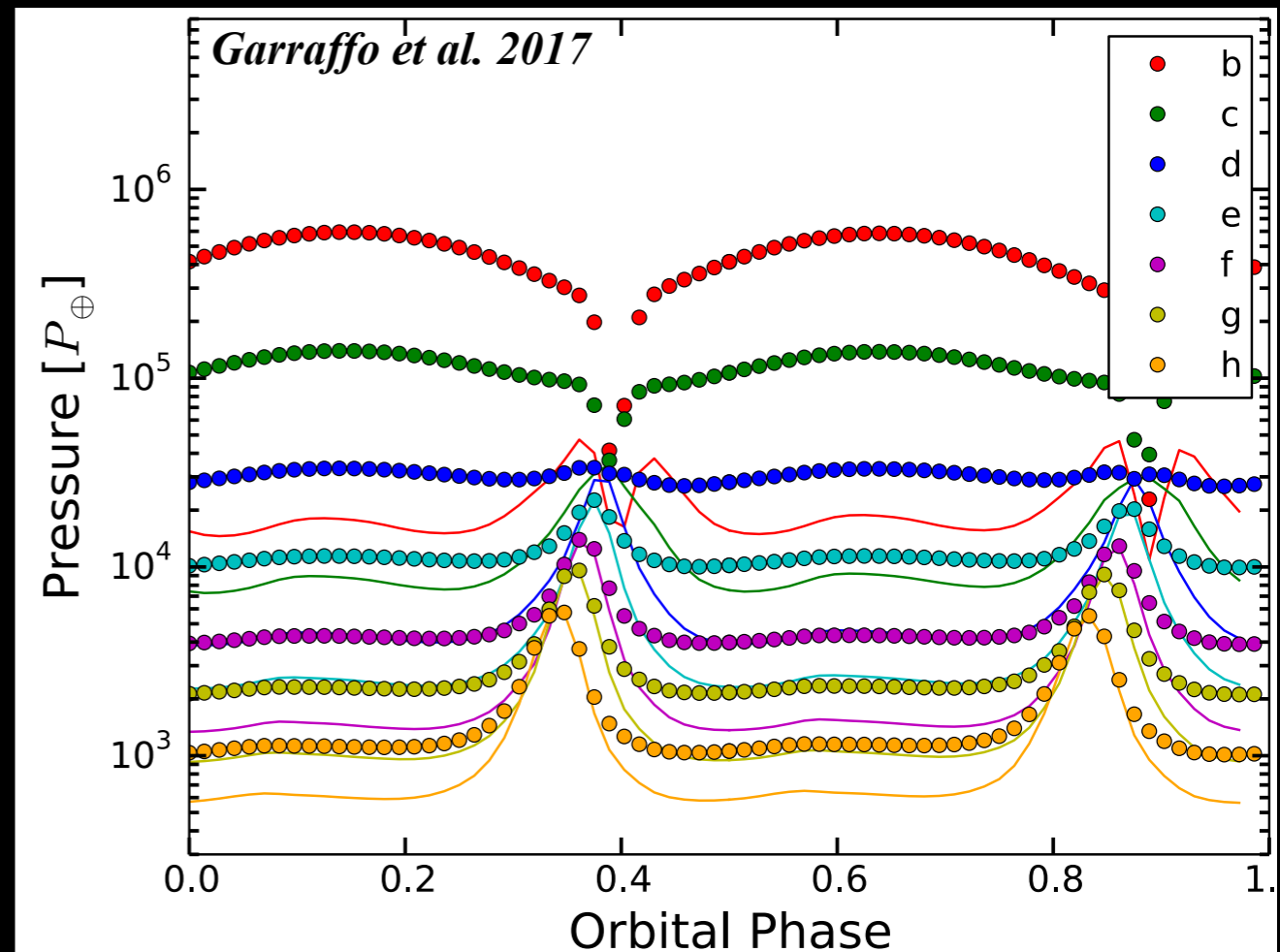
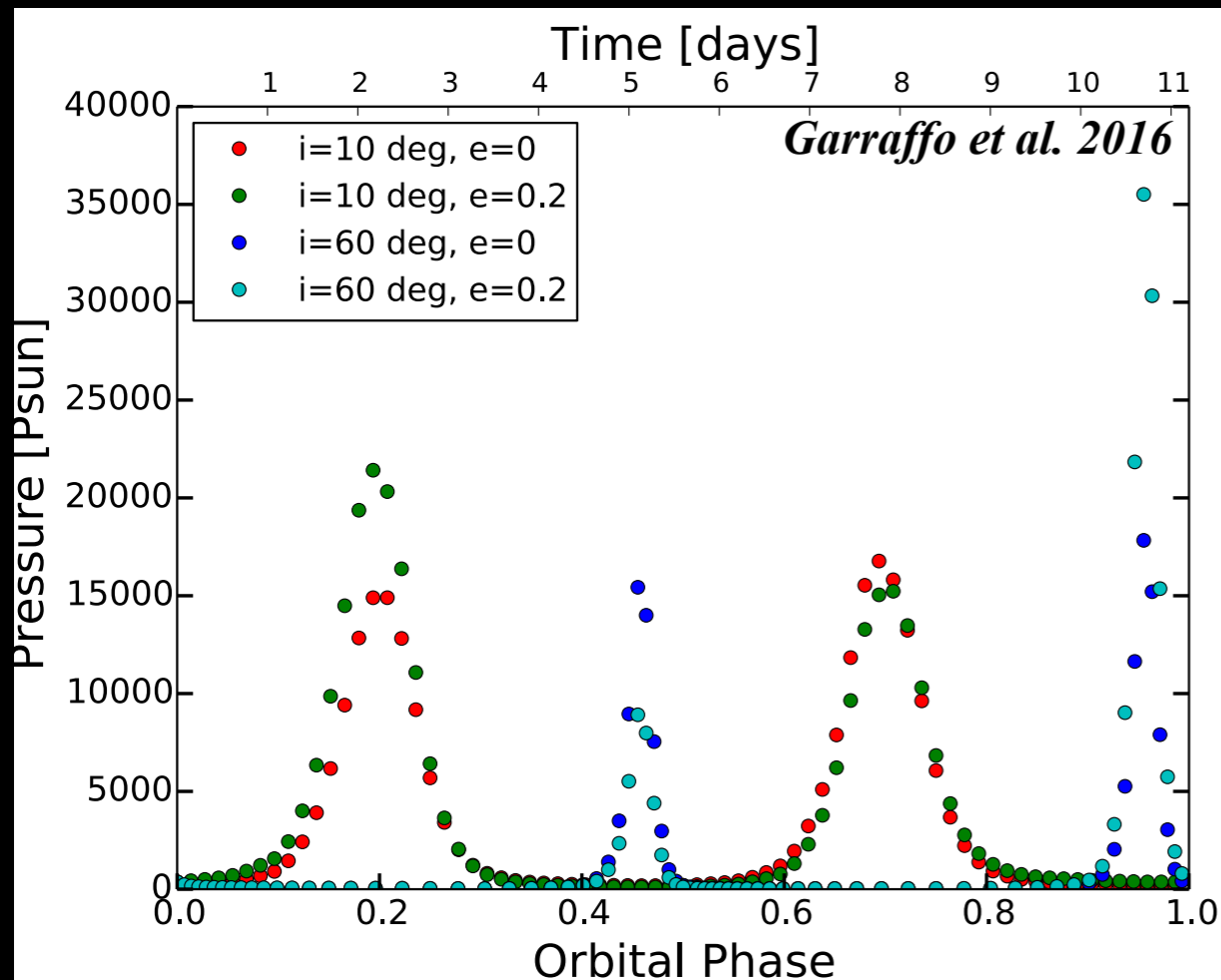
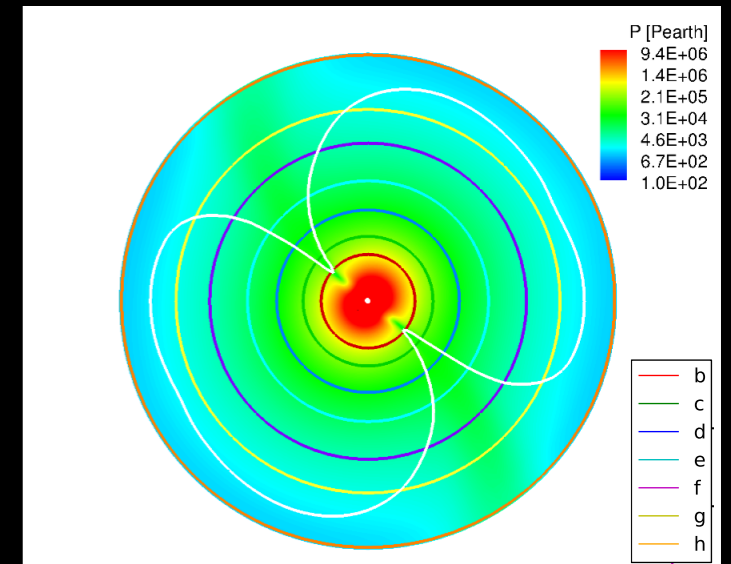


Exoplanetary Environments



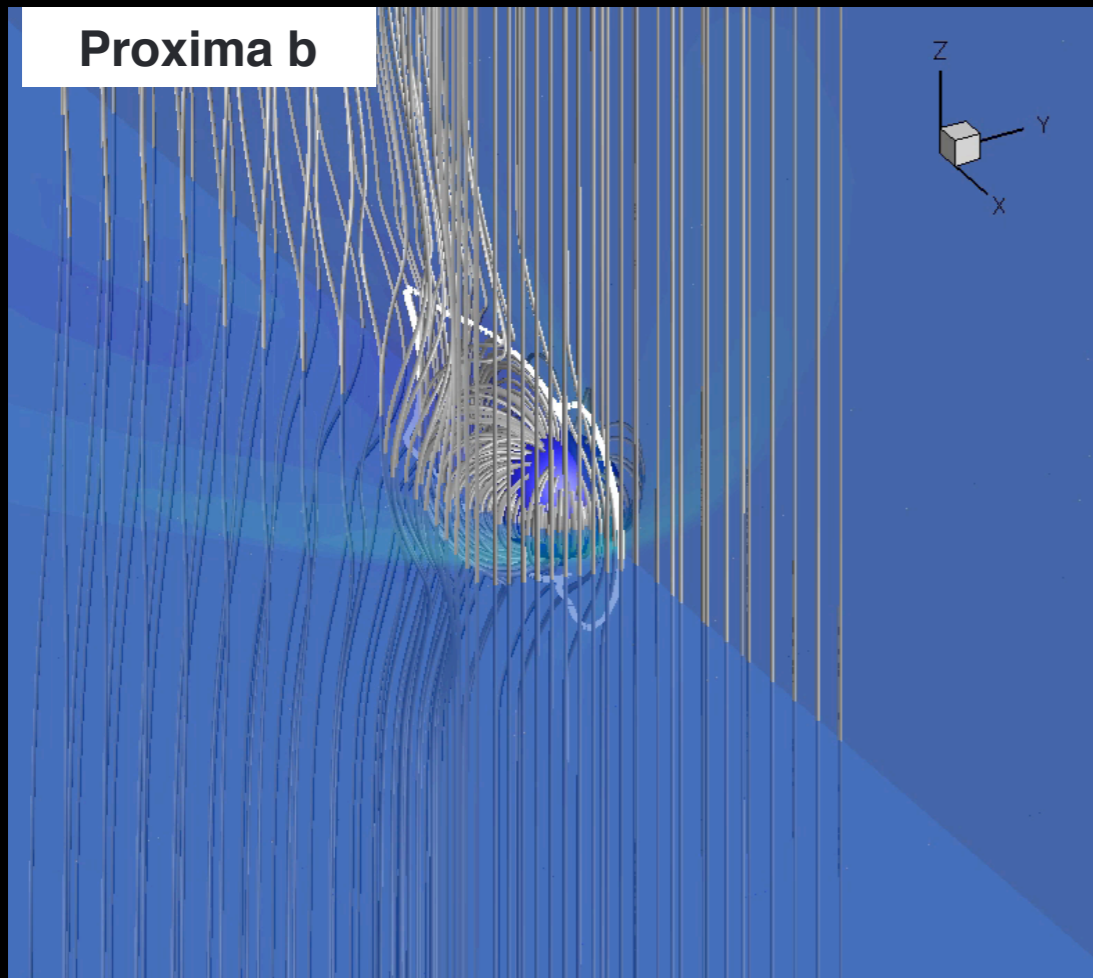
Proxima b

TRAPPIST-1

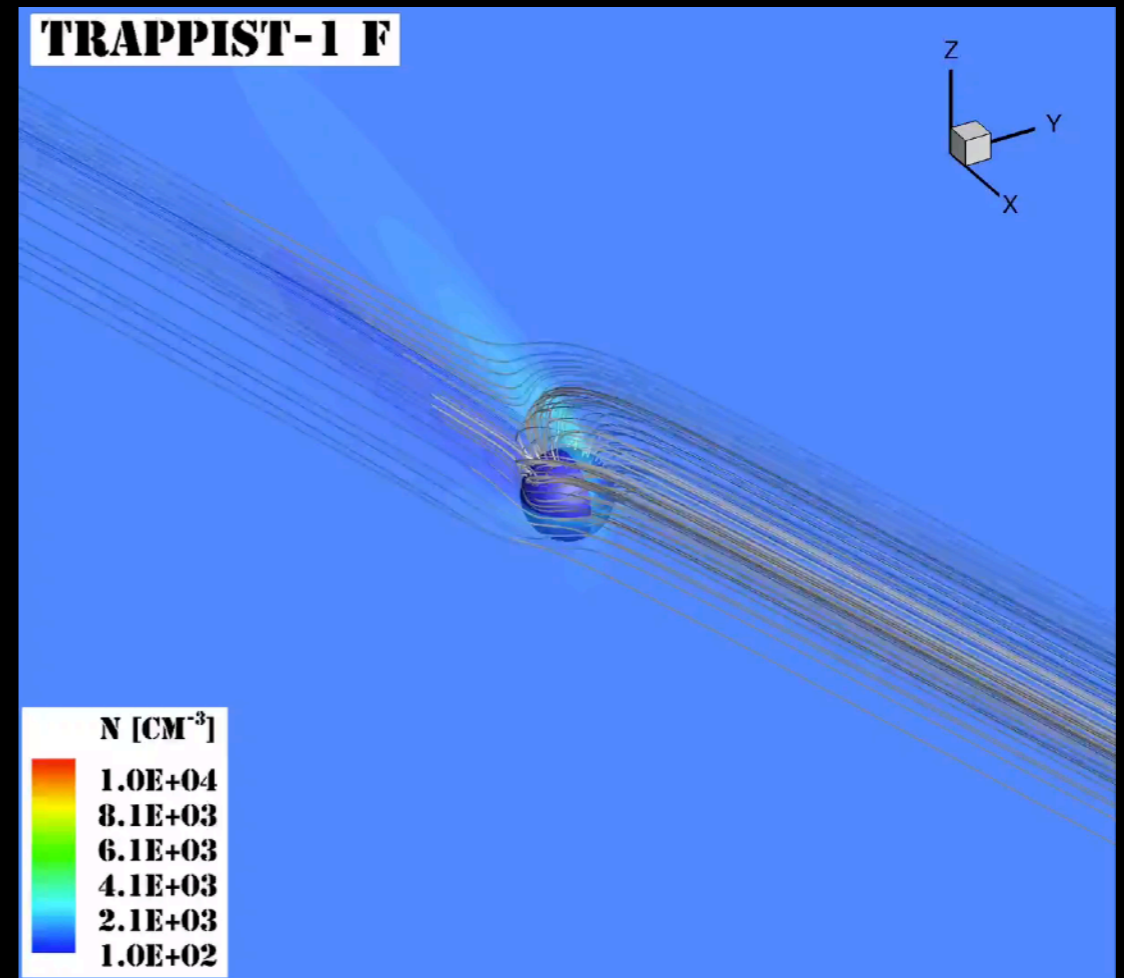


Exoplanetary Environments

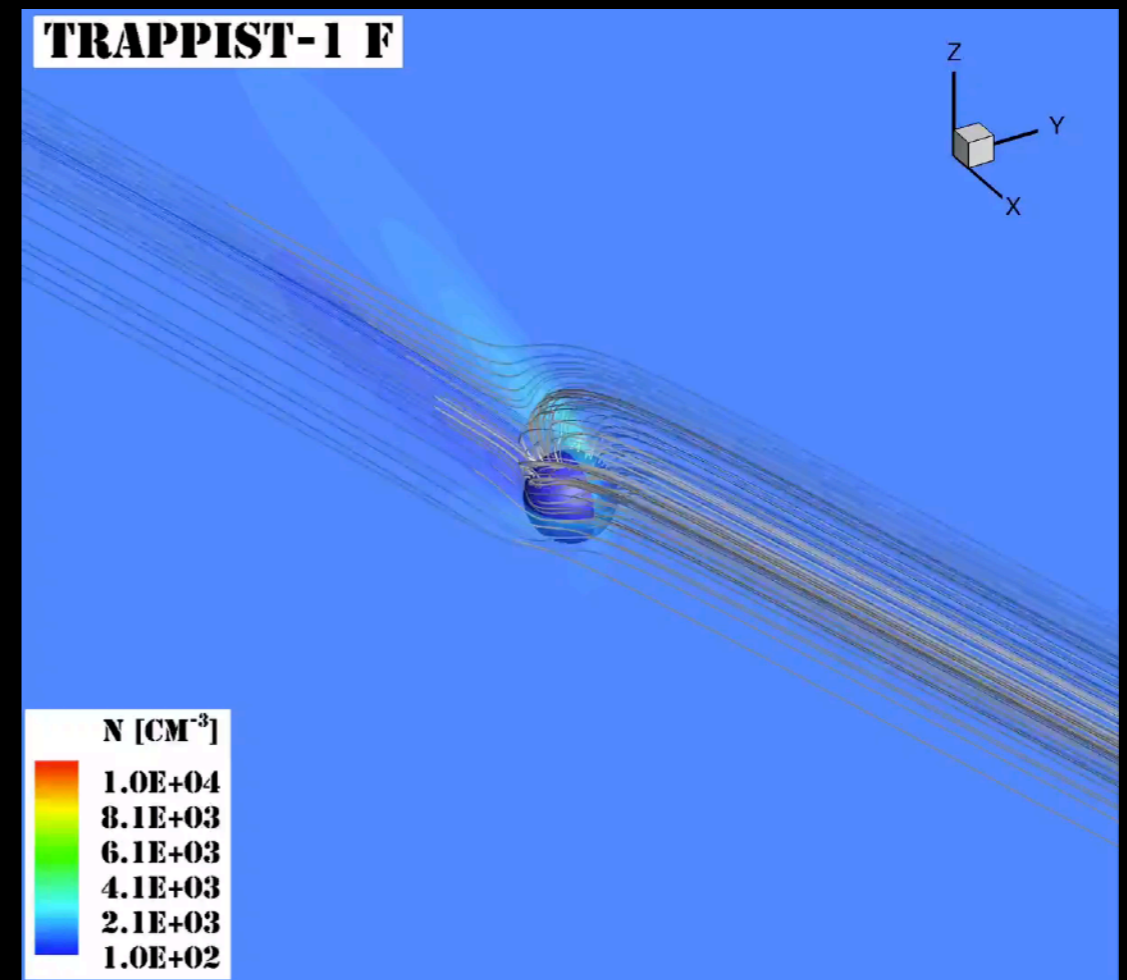
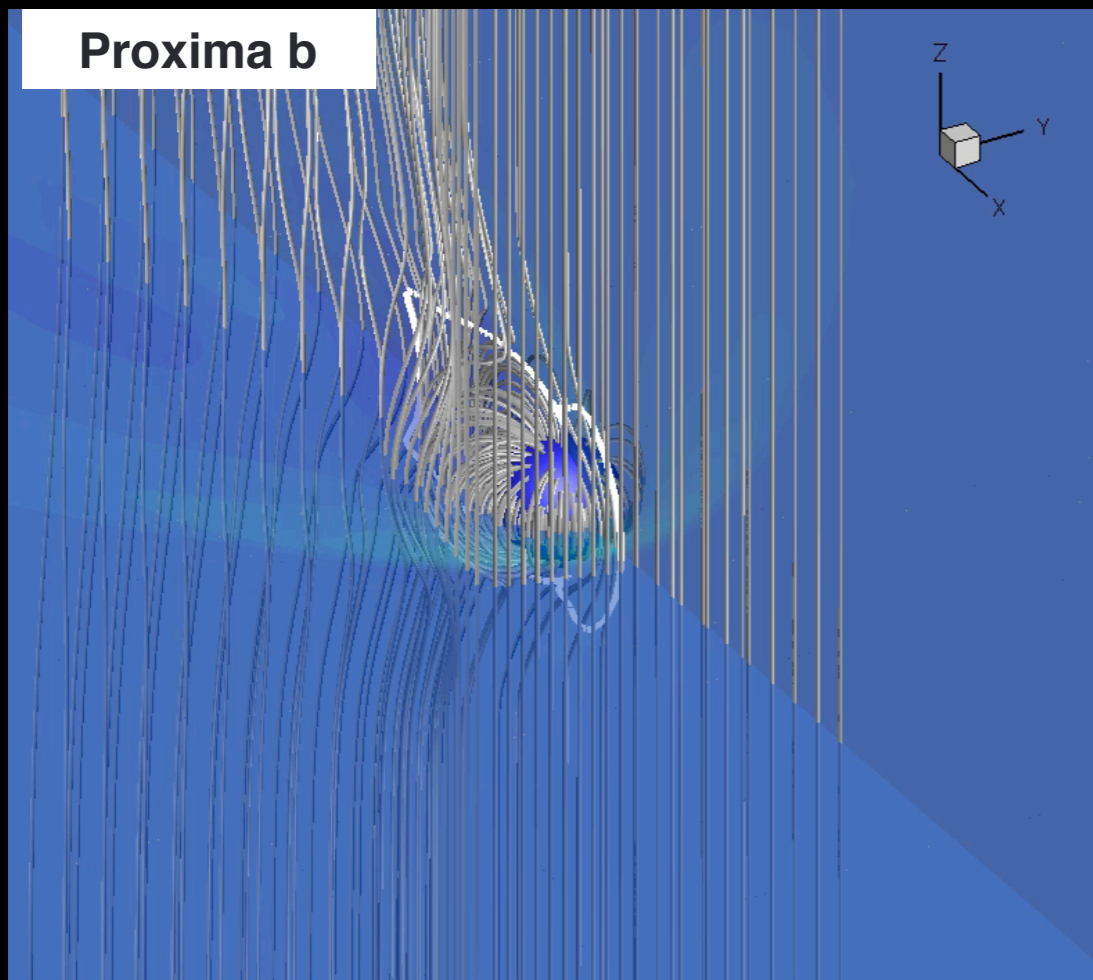
Proxima b



TRAPPIST-1 F

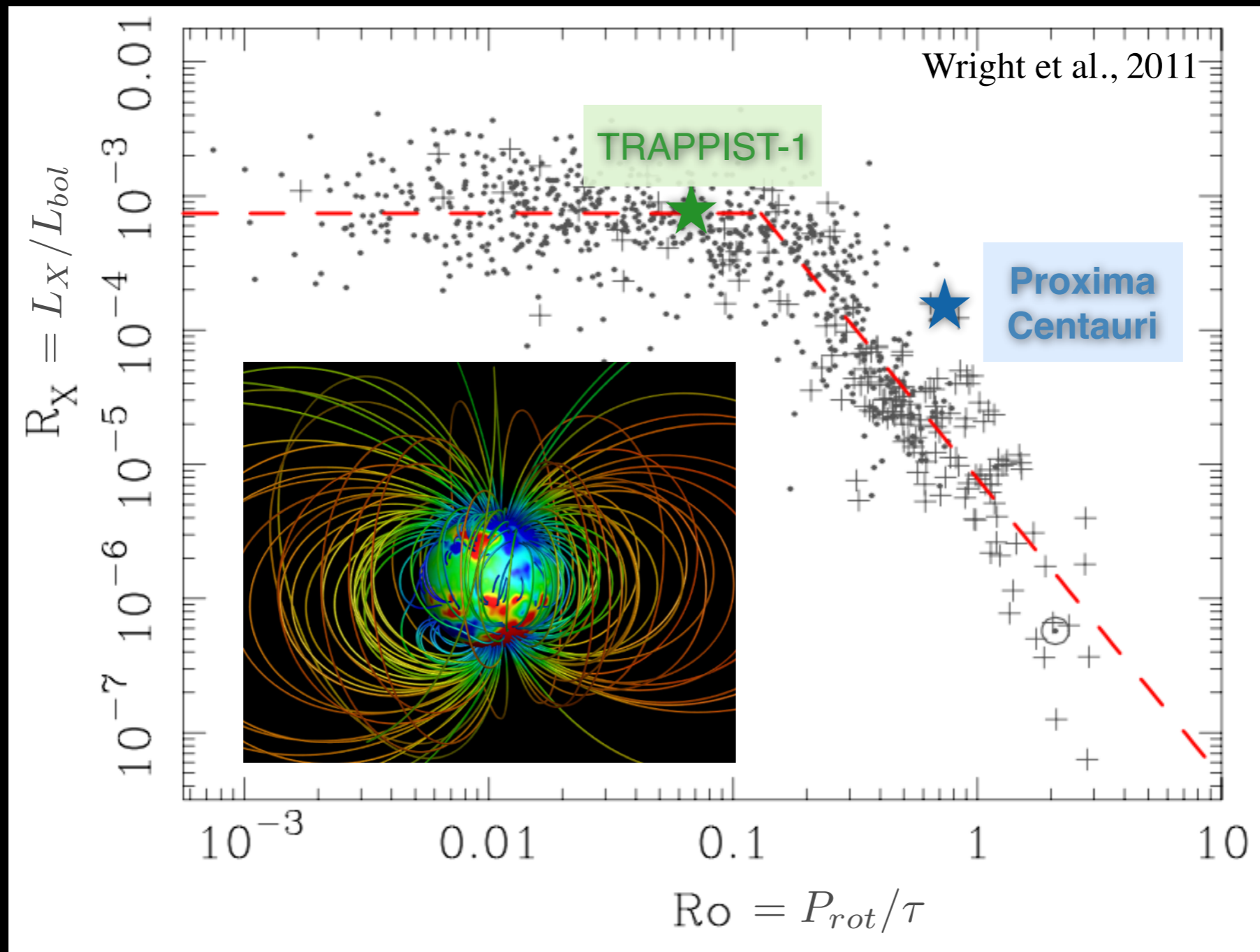


Exoplanetary Environments



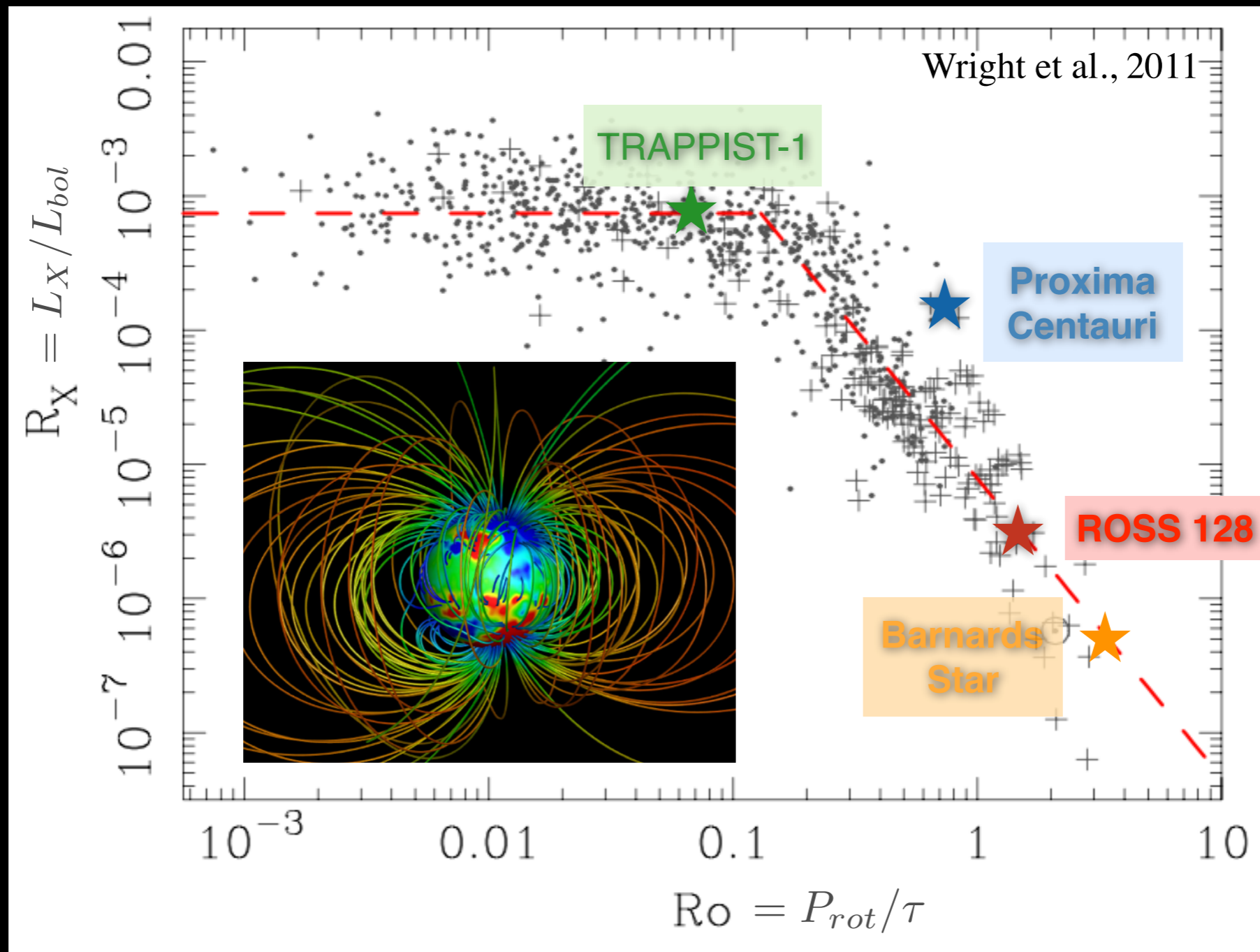
Stellar Activity-Rotation

BATS-R-US (U. of Michigan) 3D MHD code

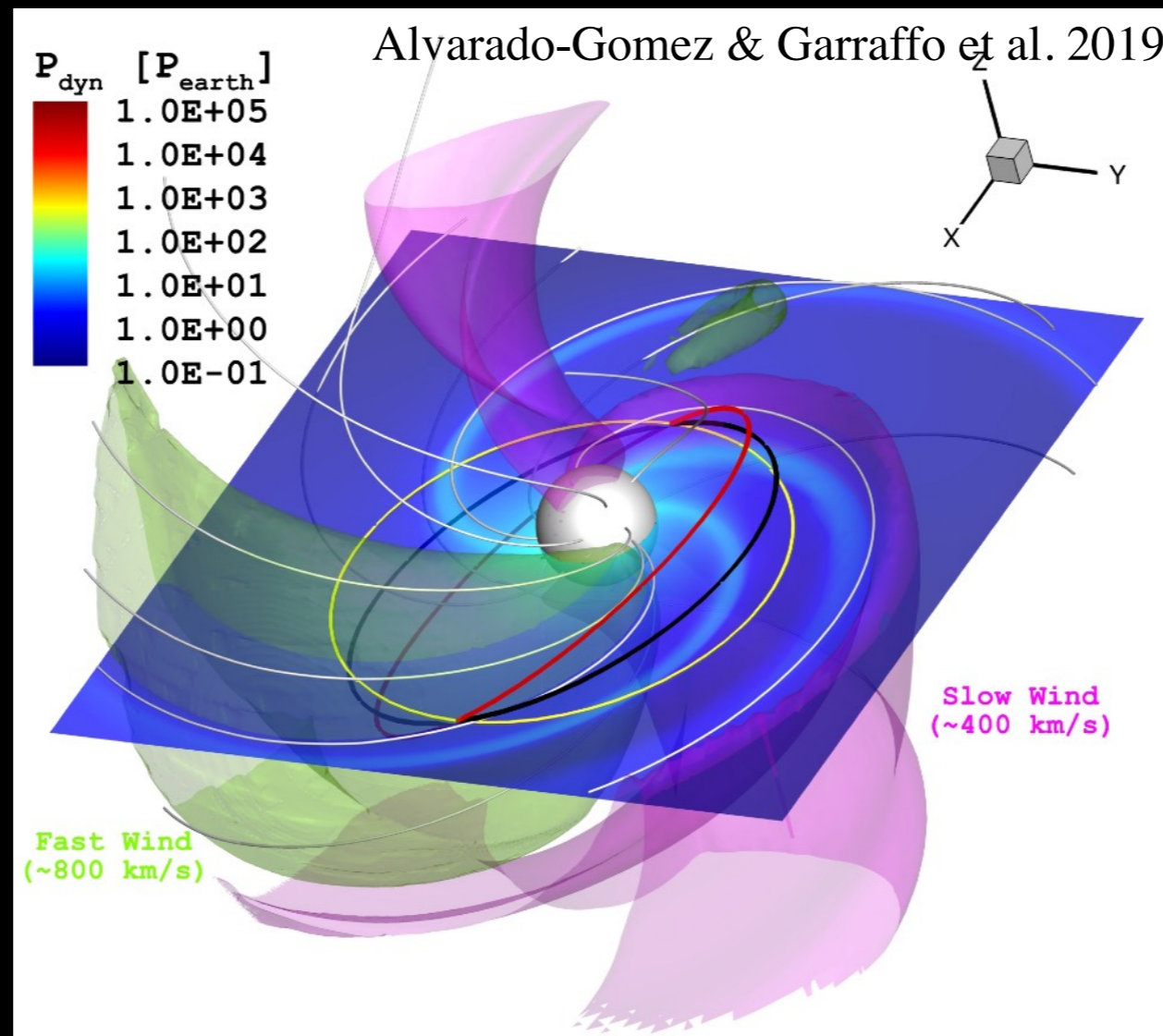
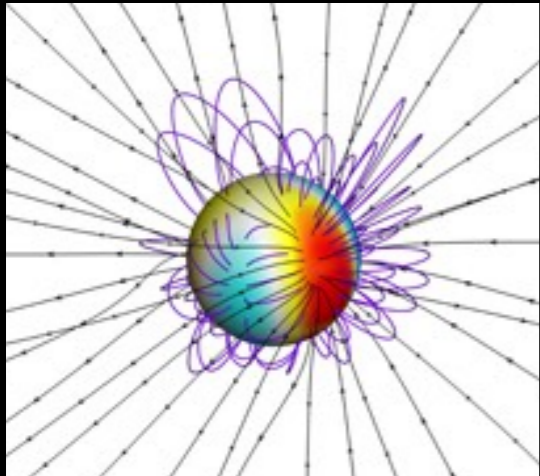


Stellar Activity-Rotation

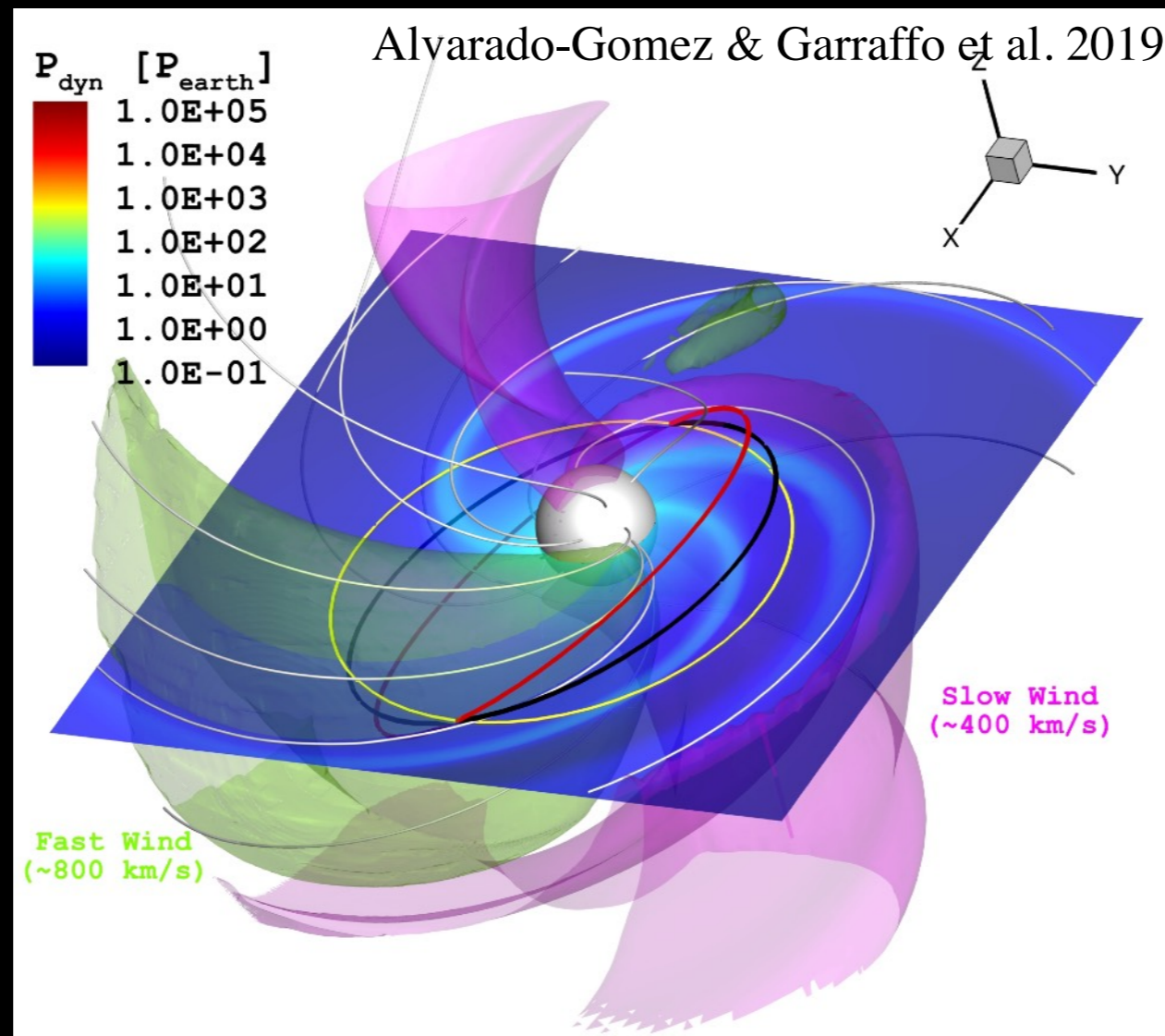
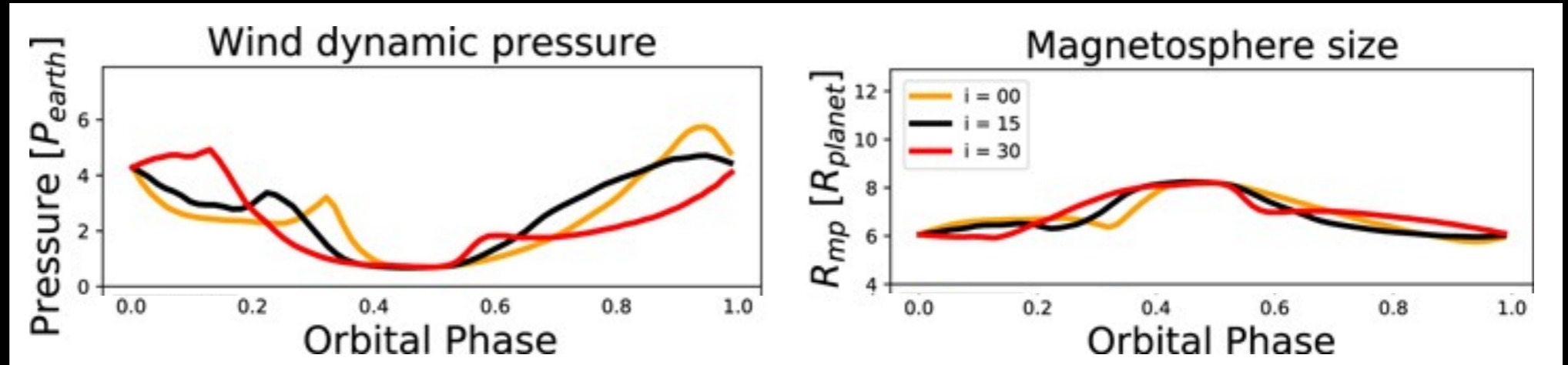
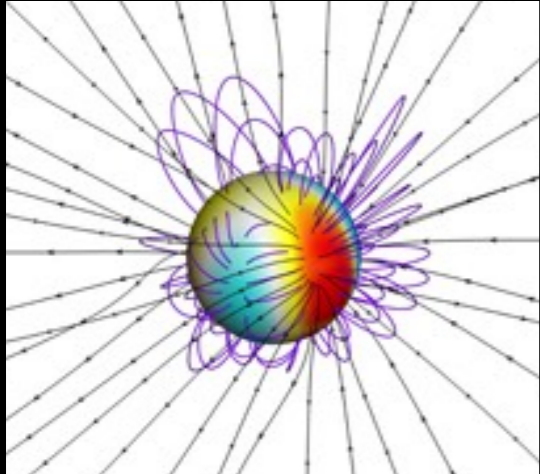
BATS-R-US (U. of Michigan) 3D MHD code



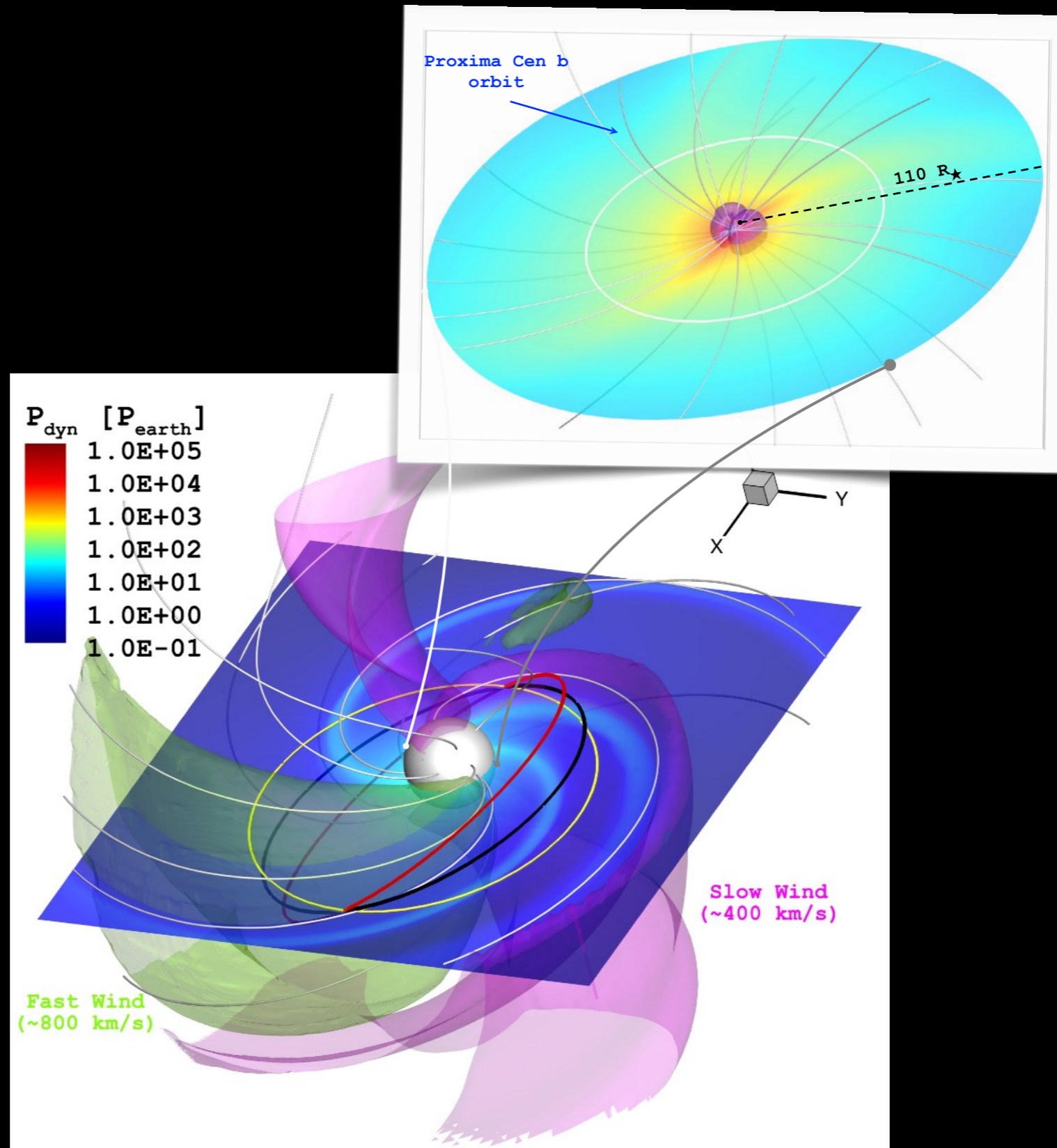
Exoplanetary Environments



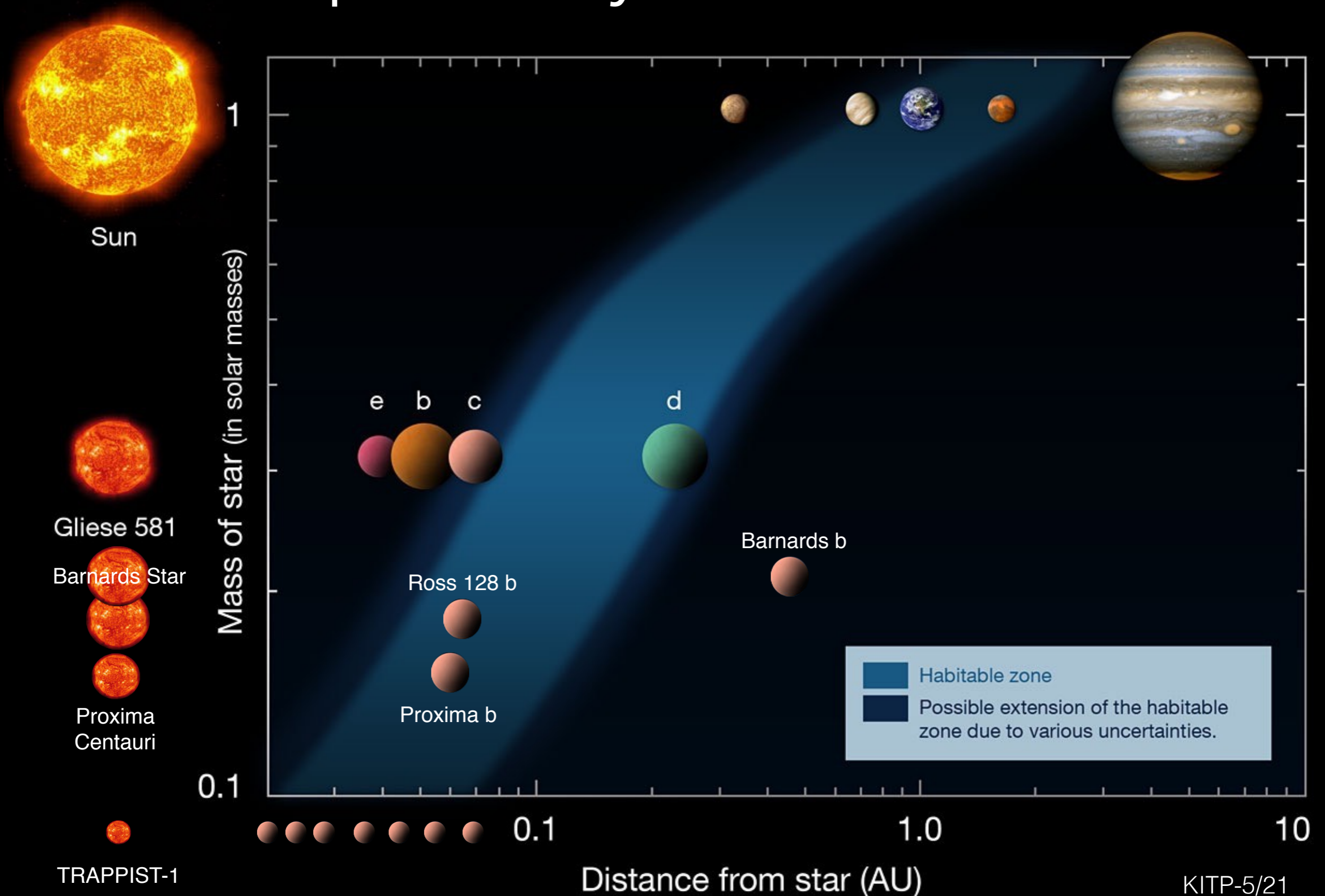
Exoplanetary Environments



Exoplanetary Environments



Exoplanetary Environments



Exoplanetary Environments



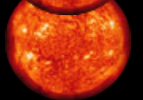
Sun



Gliese 581



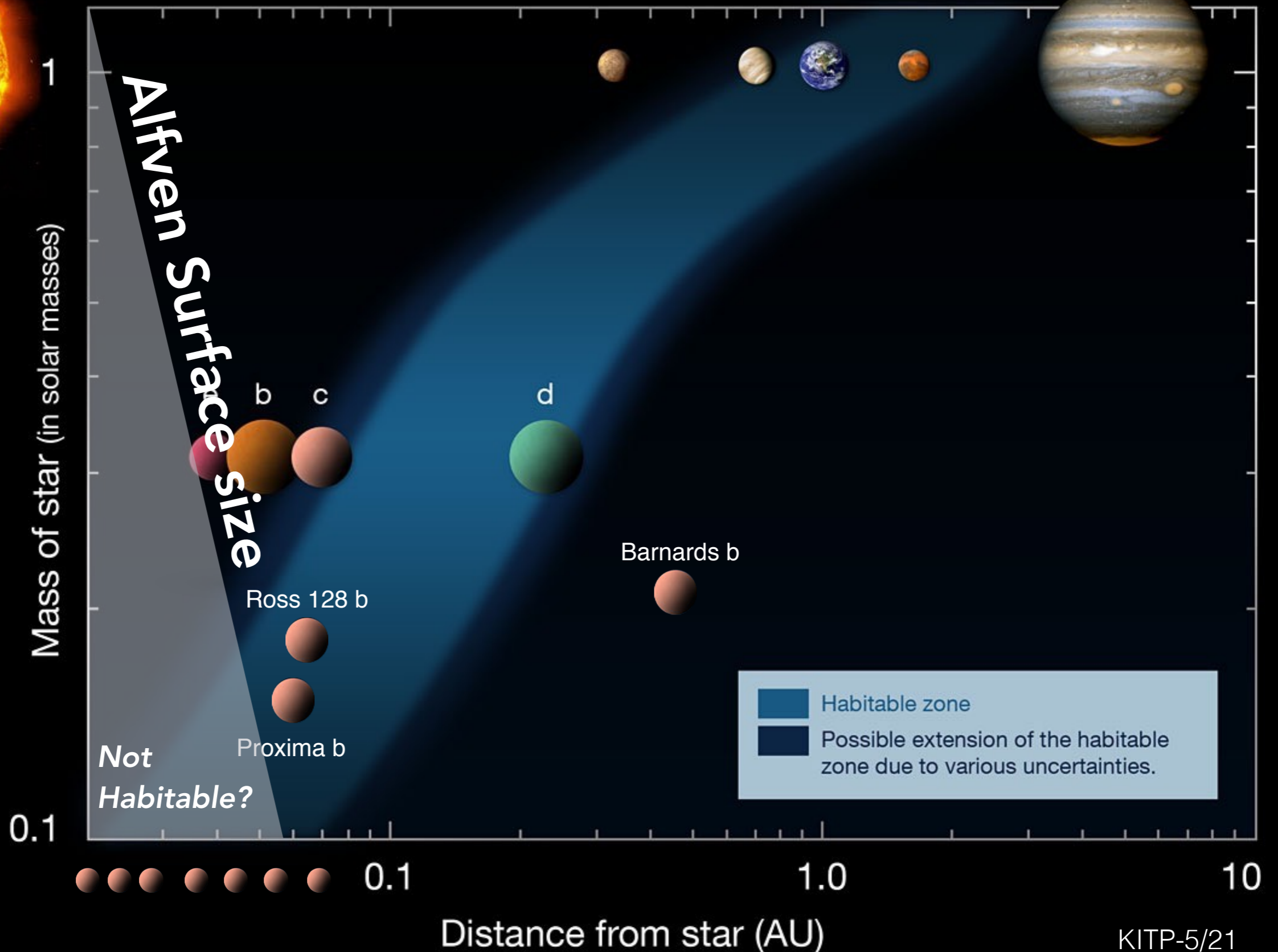
Barnards Star



Proxima Centauri



TRAPPIST-1



Exoplanetary Environments



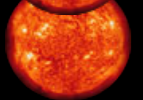
Sun



Gliese 581



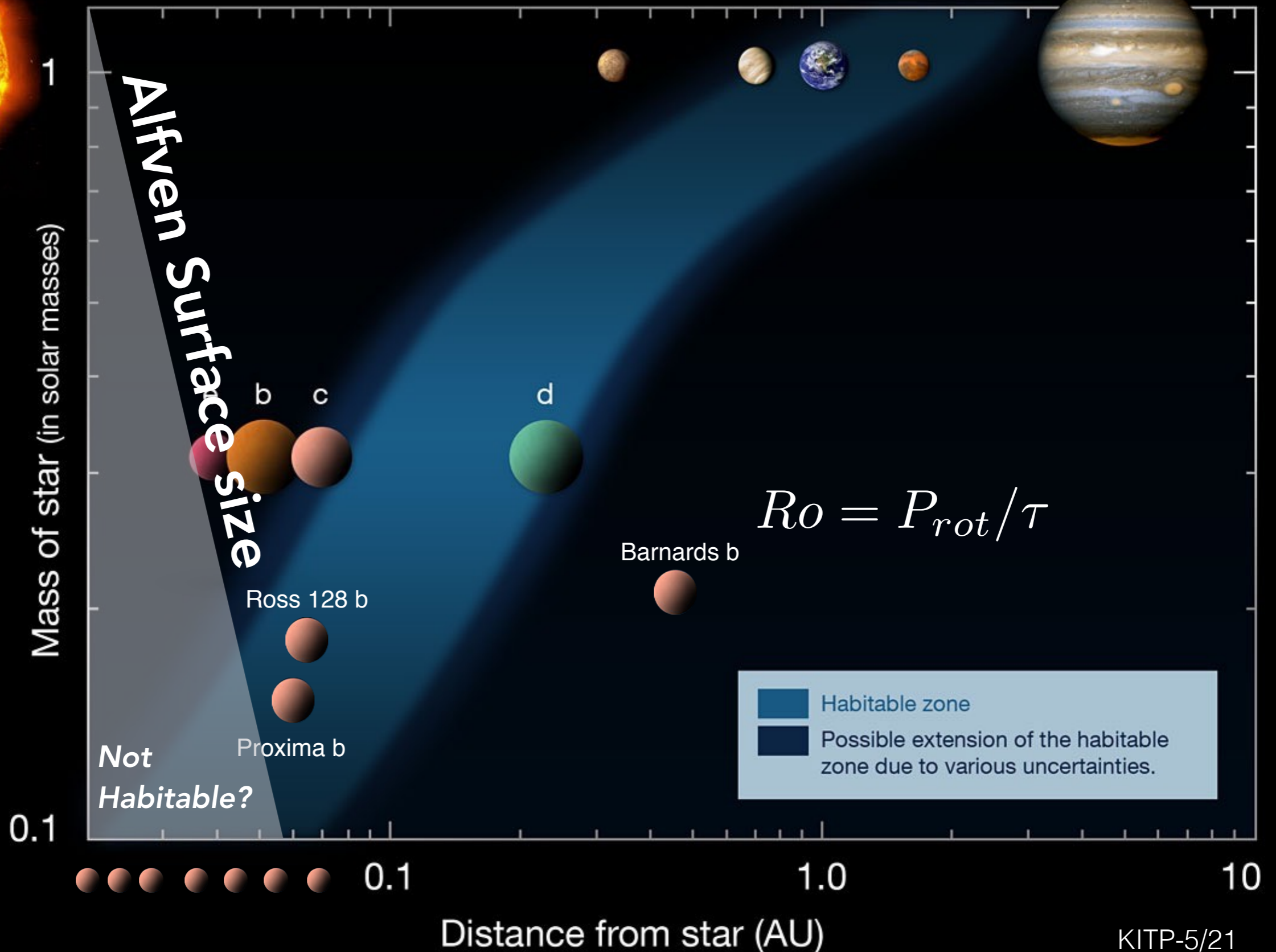
Barnard's Star



Proxima Centauri

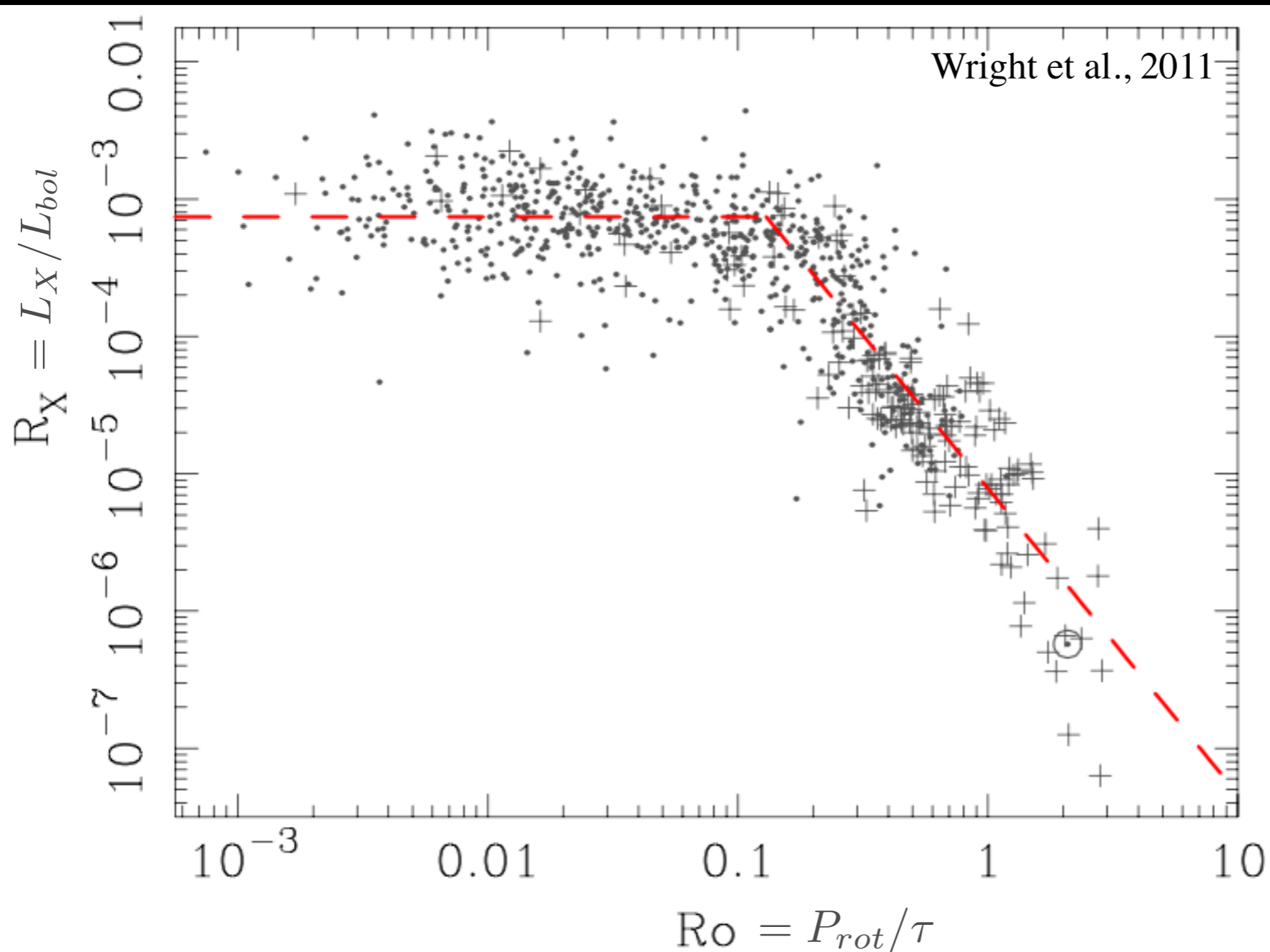


TRAPPIST-1



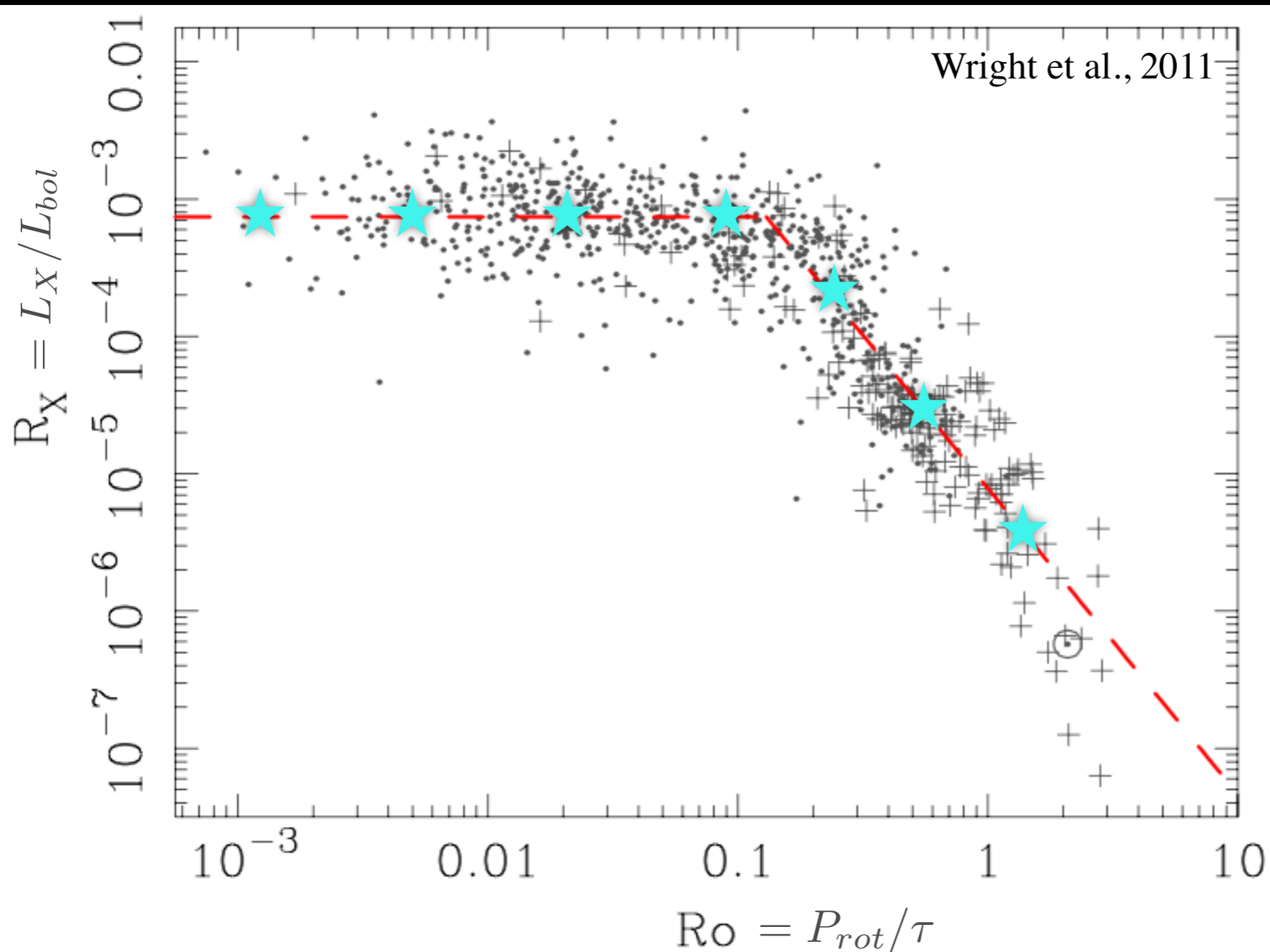
Next Steps

A General Framework



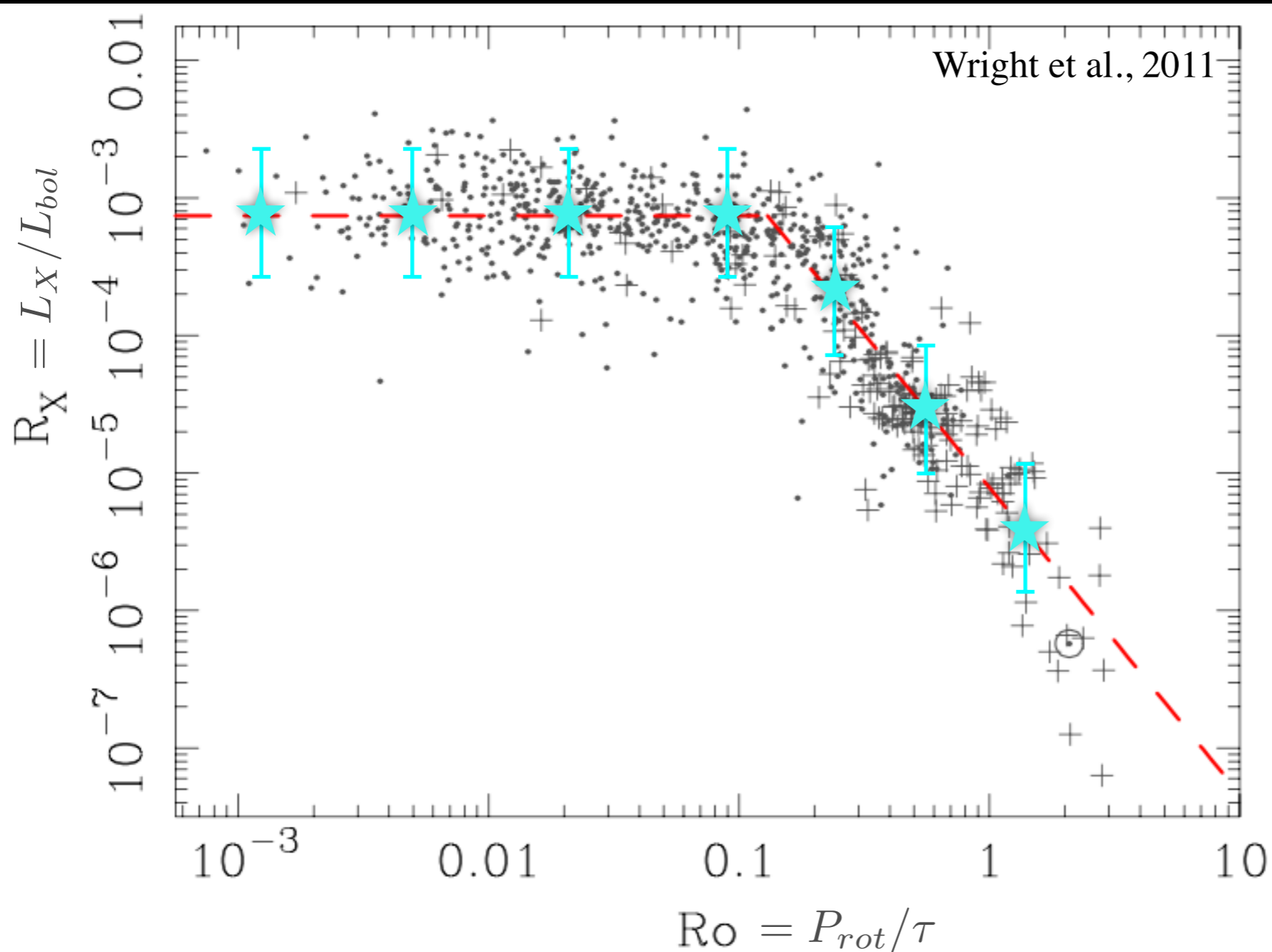
Next Steps

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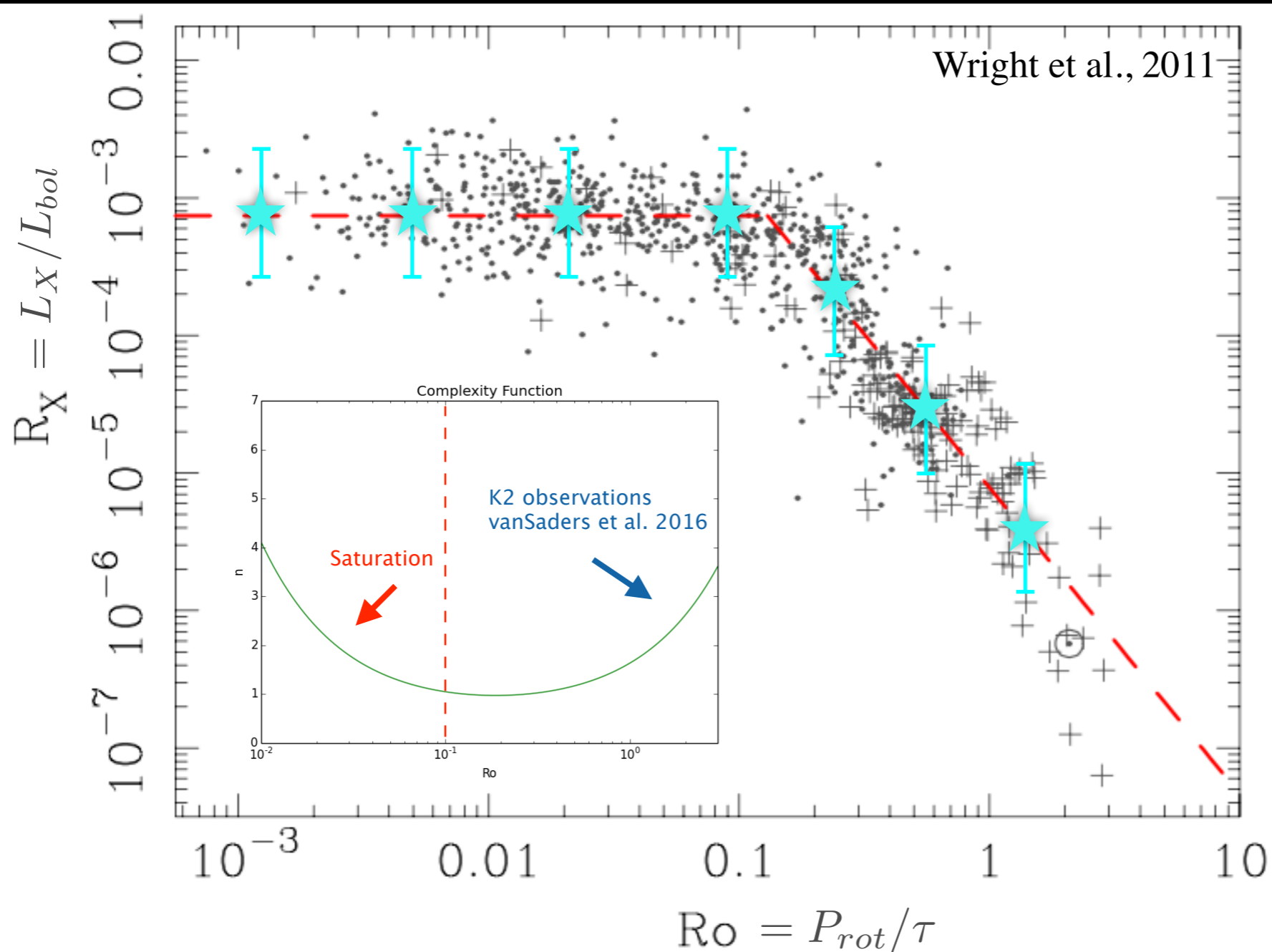
Next Steps

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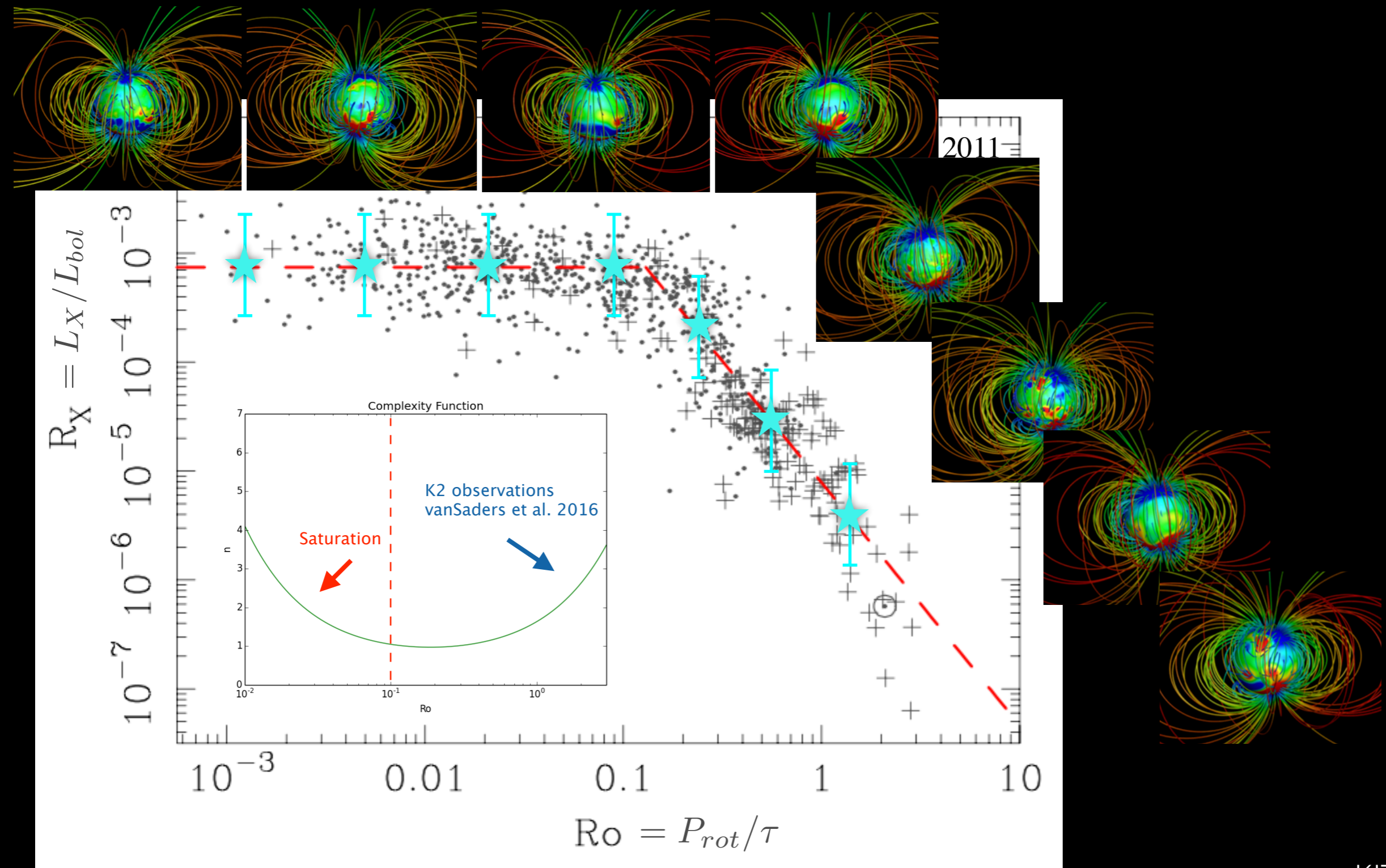
Next Steps

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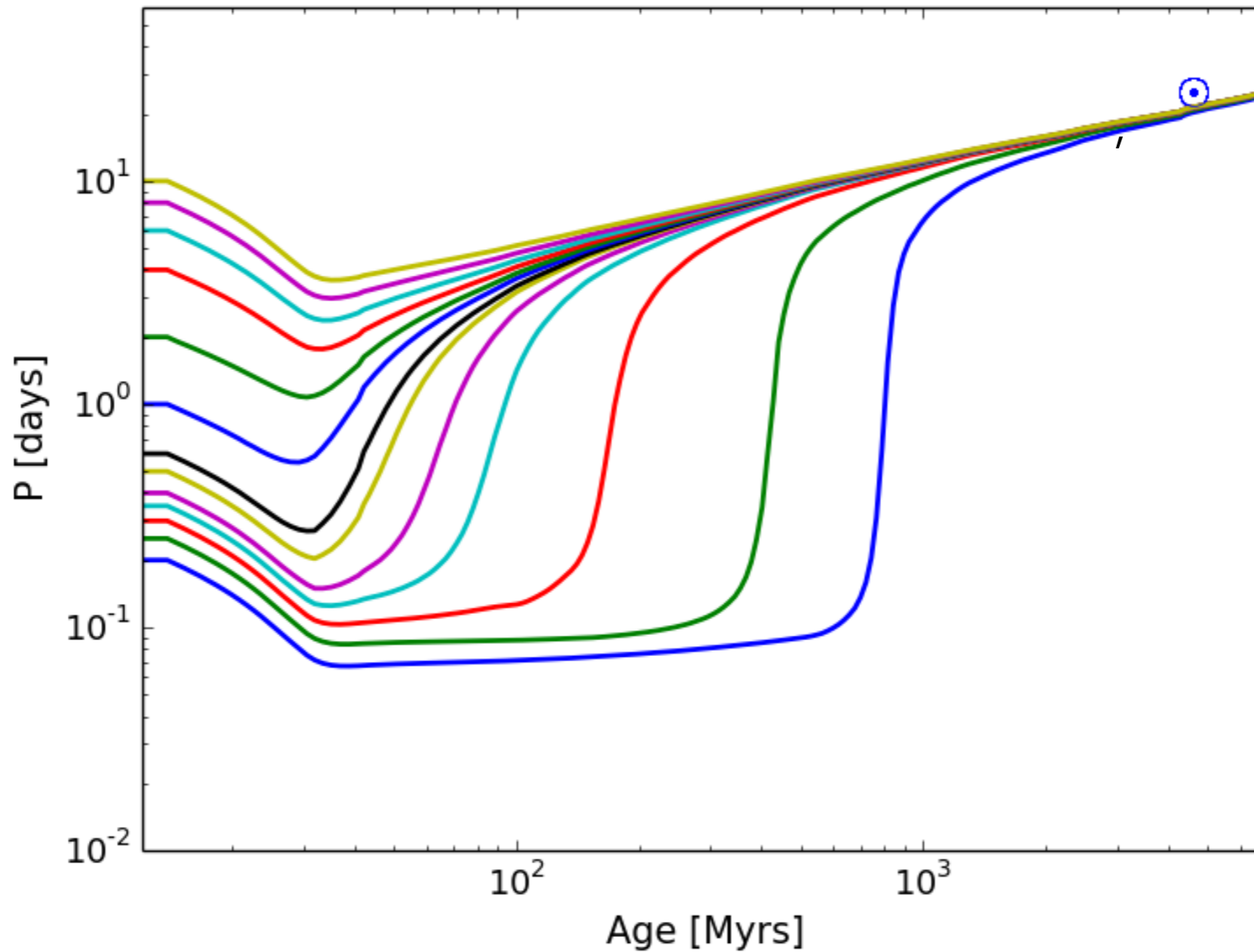
Next Steps

A General Framework



Next Steps

Initial Conditions Matter?

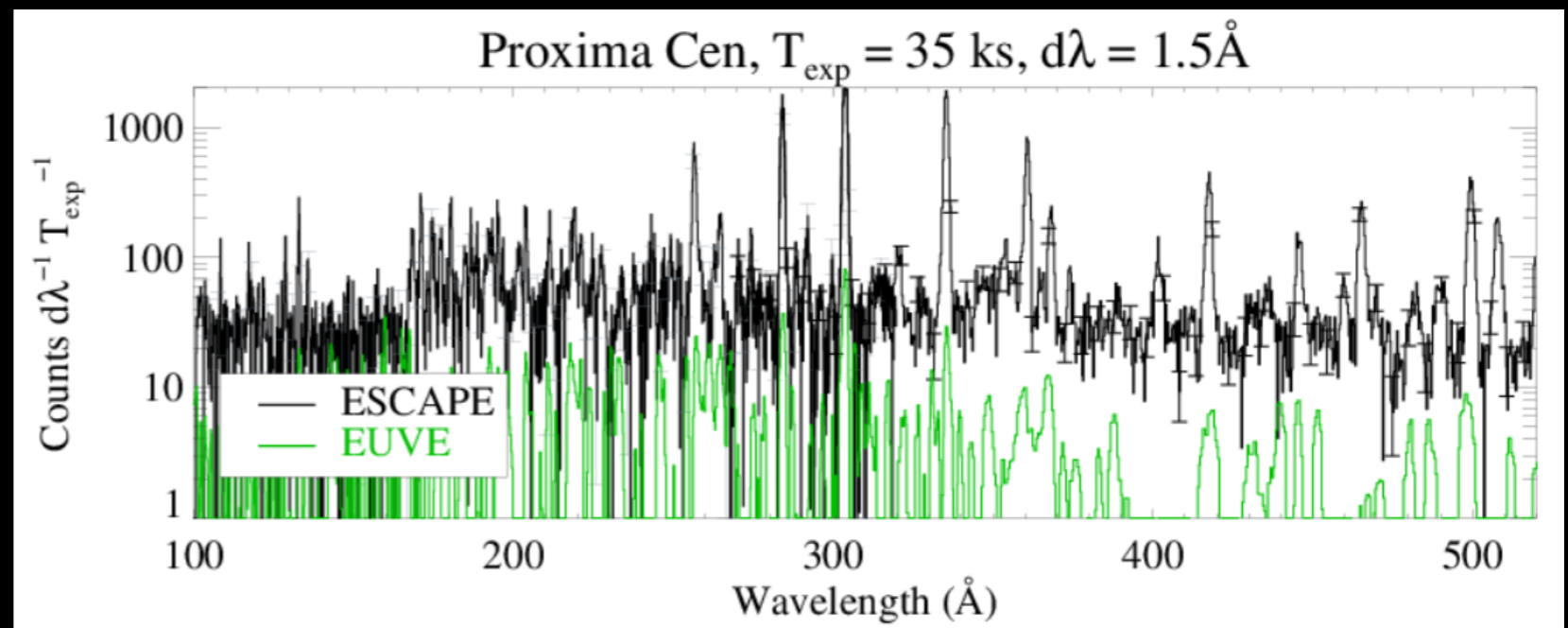
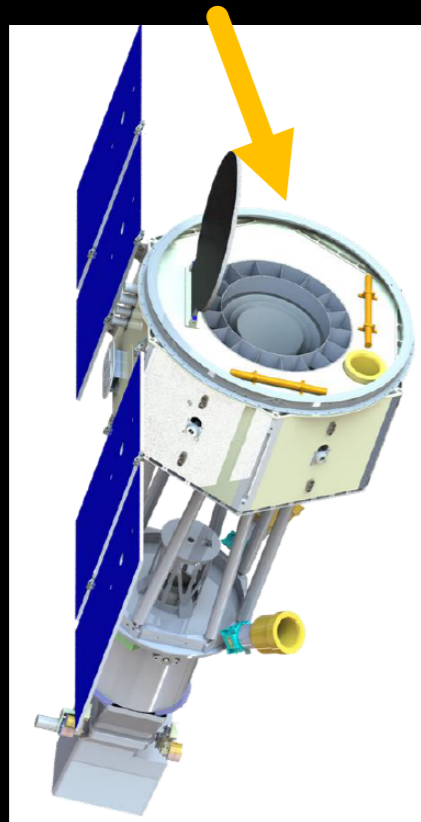


The ESCAPE Small Explorer Concept

(EUV Stellar Characterization for Atmospheric Physics and Evolution)

PI Kevin France, PS Jeremy J Drake

Grazing incidence
telescope + EUV/FUV
spectrograph



70 – 1700 \AA
spectroscopy of 200
nearby stars, 100 x
sensitivity of EUVE.



Summary

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- Close in planets around active stars (M dwarfs) are at risk of atmospheric stripping and evaporation
- Orbital distance is the dominant factor in space weather conditions
- Activity history is important
- We need a general framework

Thank you!