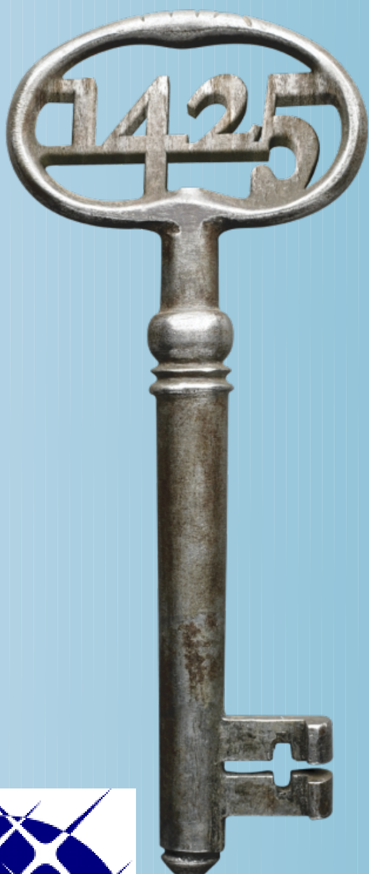
KU LEUVEN

Deciphering spectral features of extra-solar planets




# Mapping 3D climates in the habitable zone of M dwarfs

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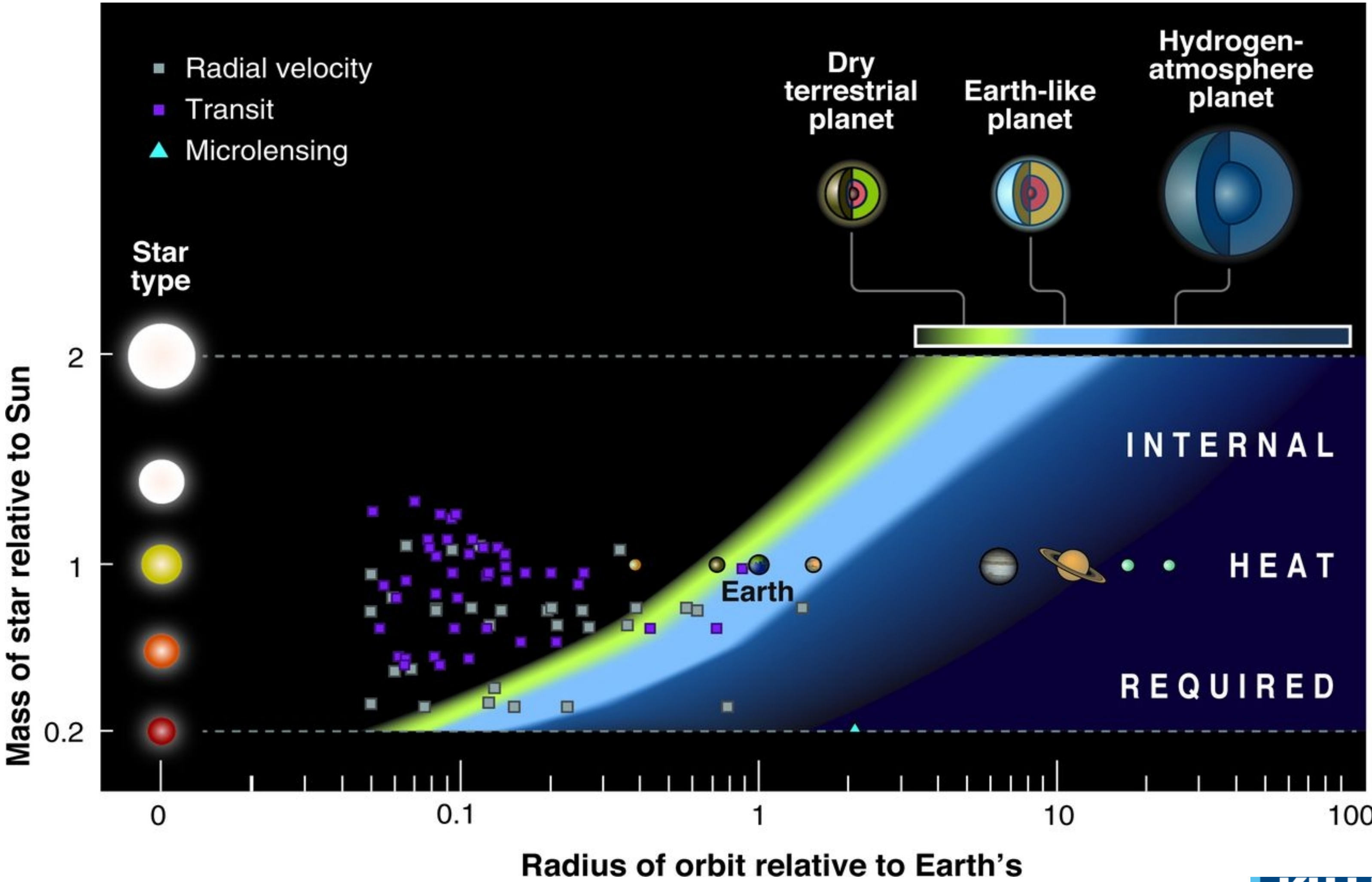
**(1) Centre for mathematical Plasma-Astrophysics**
**(2) Institute of Astronomy**

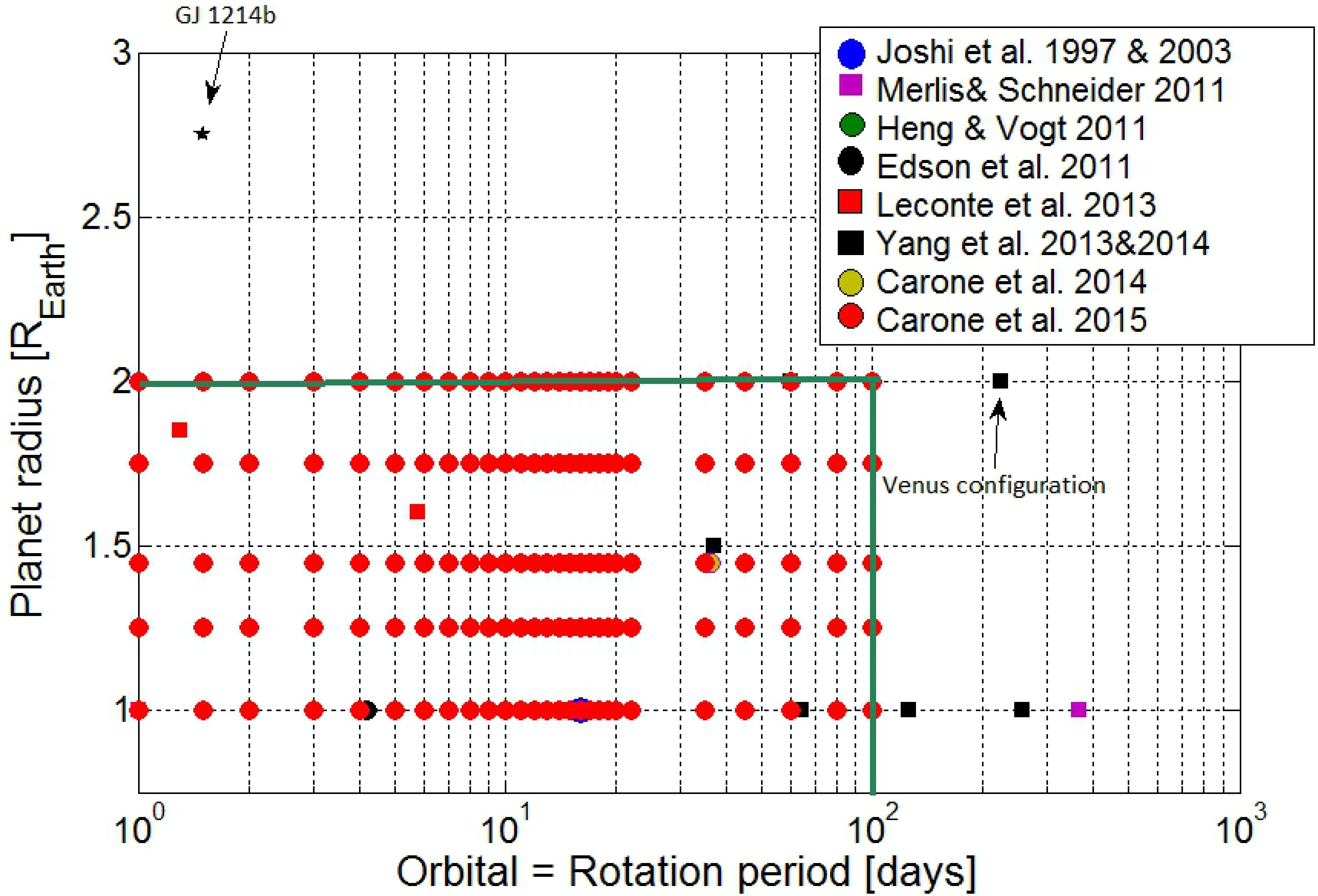
# The inner edge of the HZ – When is hot too hot?

Seager 2013, Science

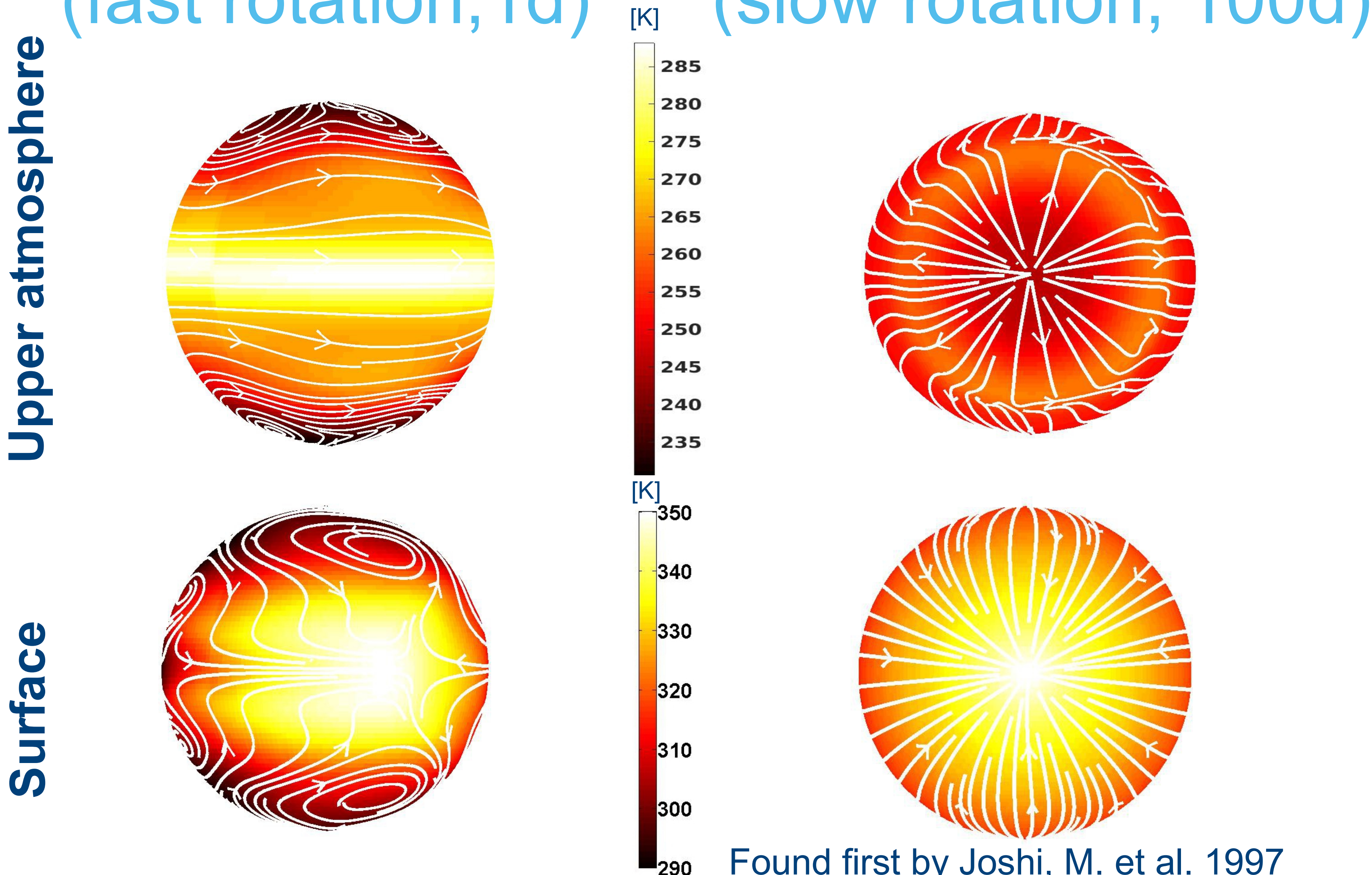



Light blue: Kasting et al. 1993, Kopparapu et al. 2013
Yellow: Zsom et al. 2013

# 165 full 3D climate simulations

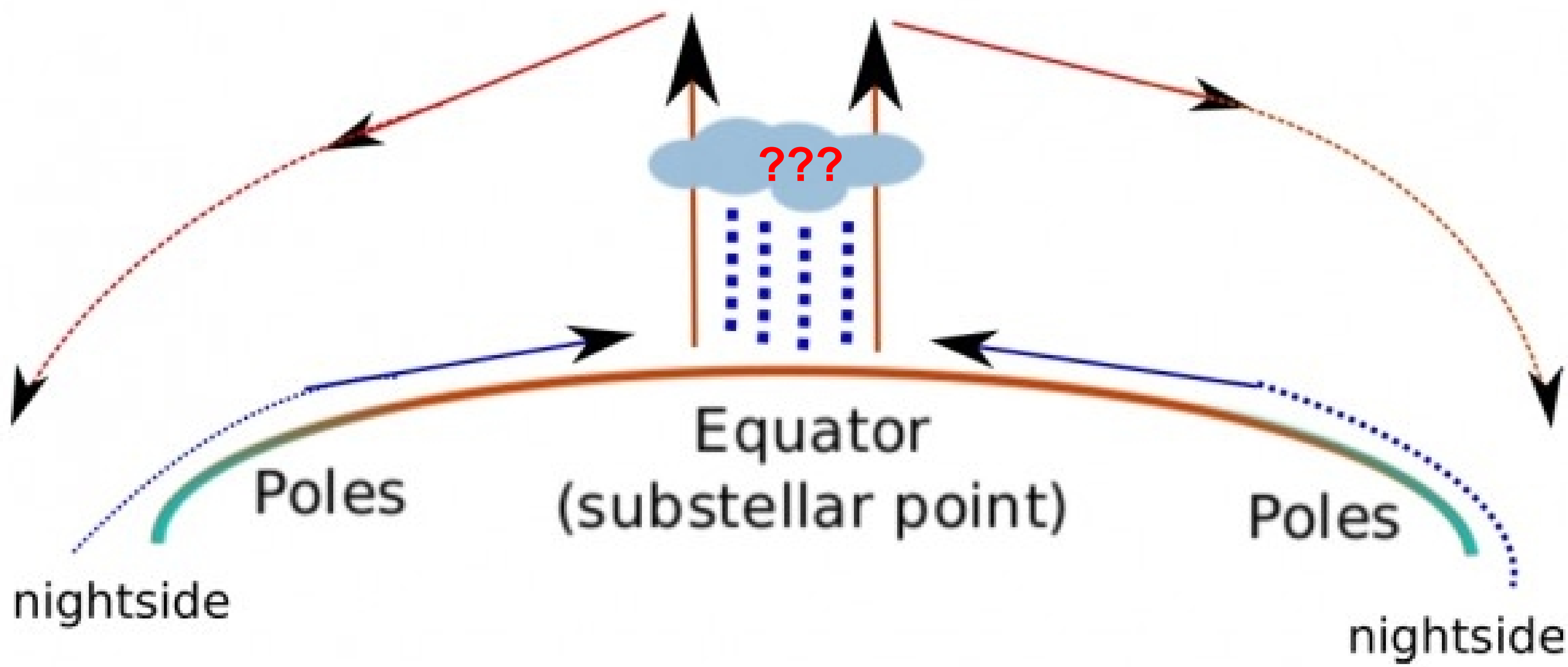


# Rossby wave jets vs Direct circulation
# (fast rotation,1d) (slow rotation, 100d)



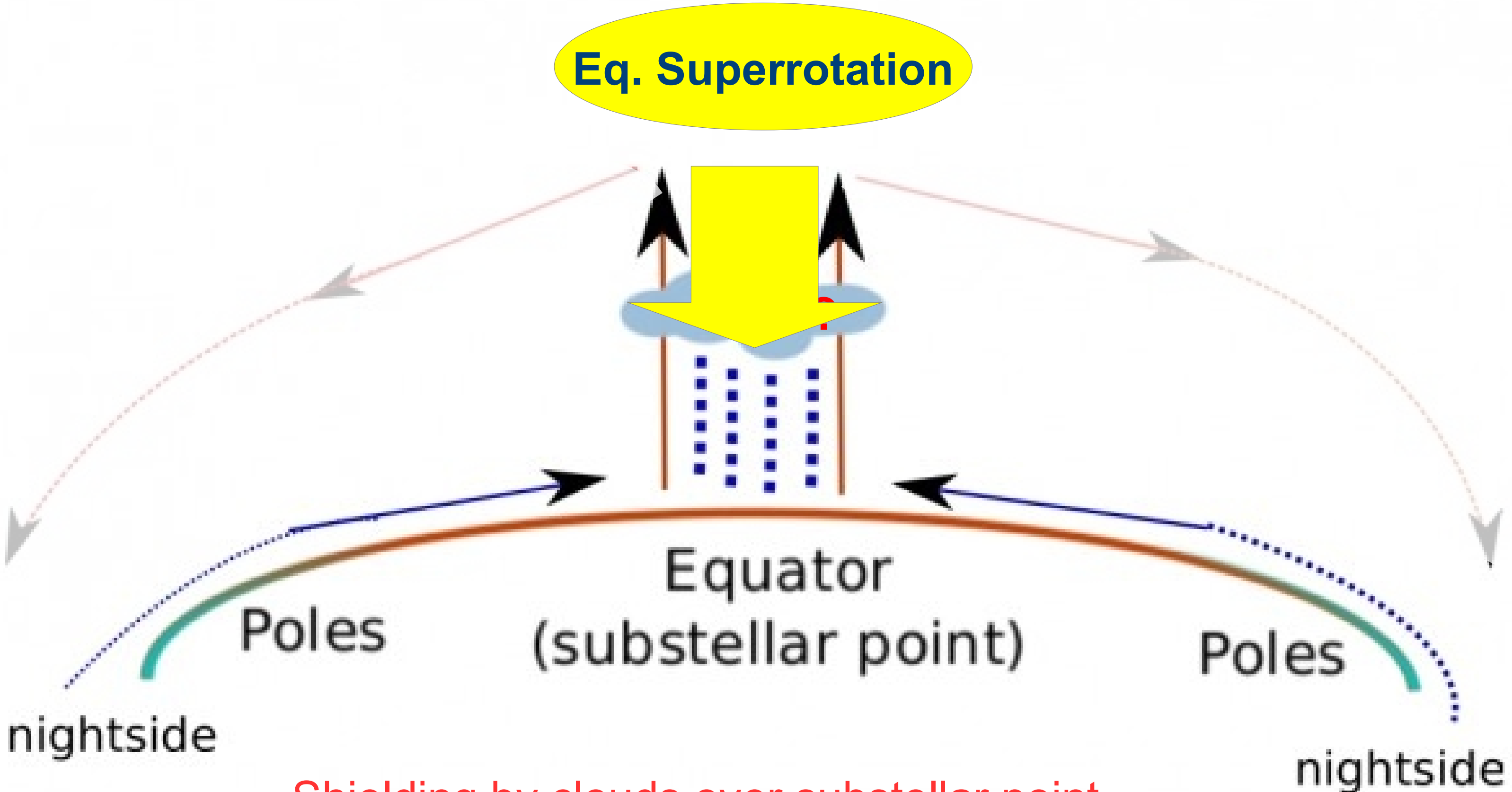

Found first by Joshi, M. et al. 1997

# Substellar point surface cooling via direct circulation



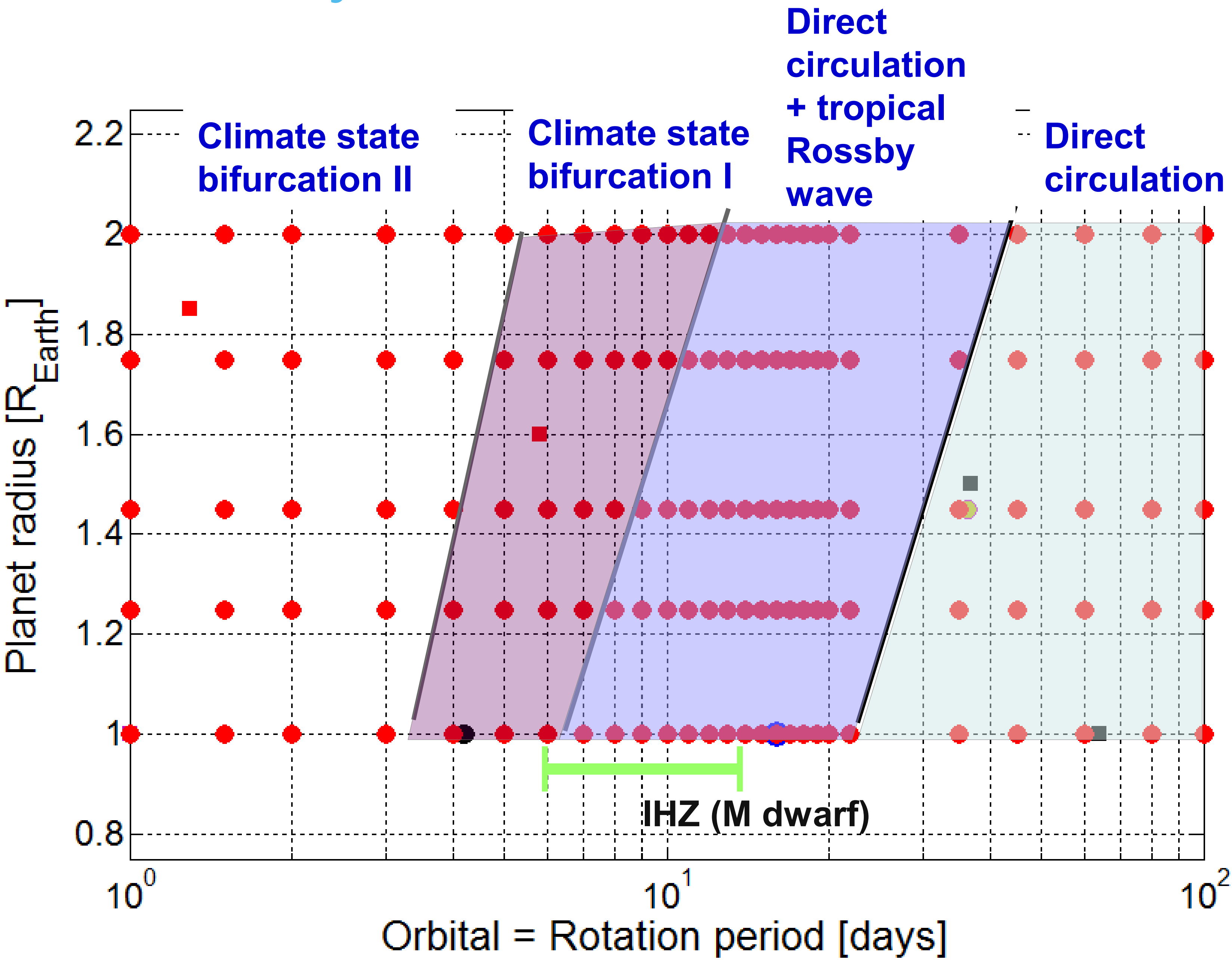

Shielding by clouds over substellar point
Yang, Y. et al. 2014, 2013

# Direct circulation disrupted by strong equatorial superrotation (Climatel)

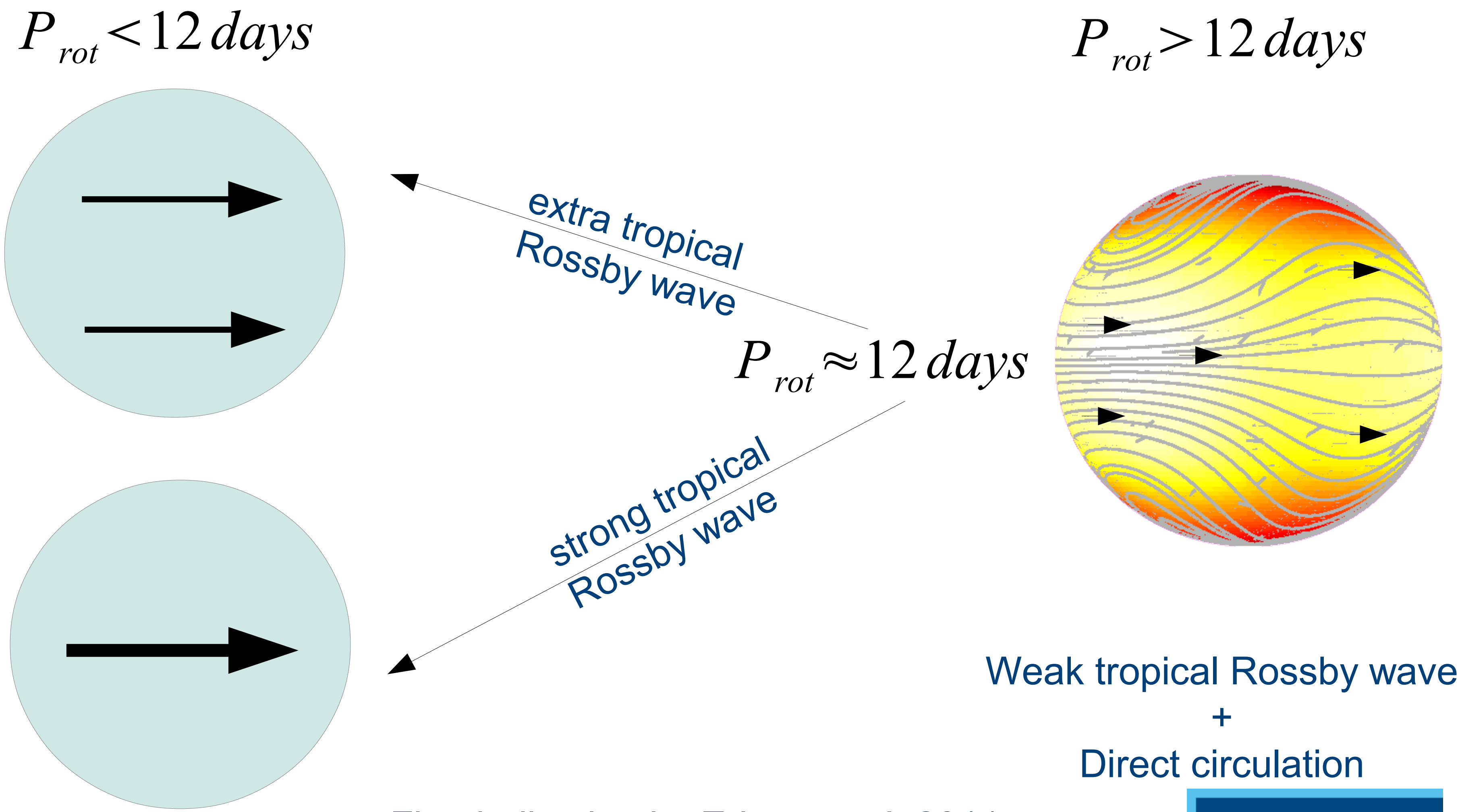



Shielding by clouds over substellar point
Yang, Y. et al. 2014, 2013
also suppressed

# Climate dynamic state maps

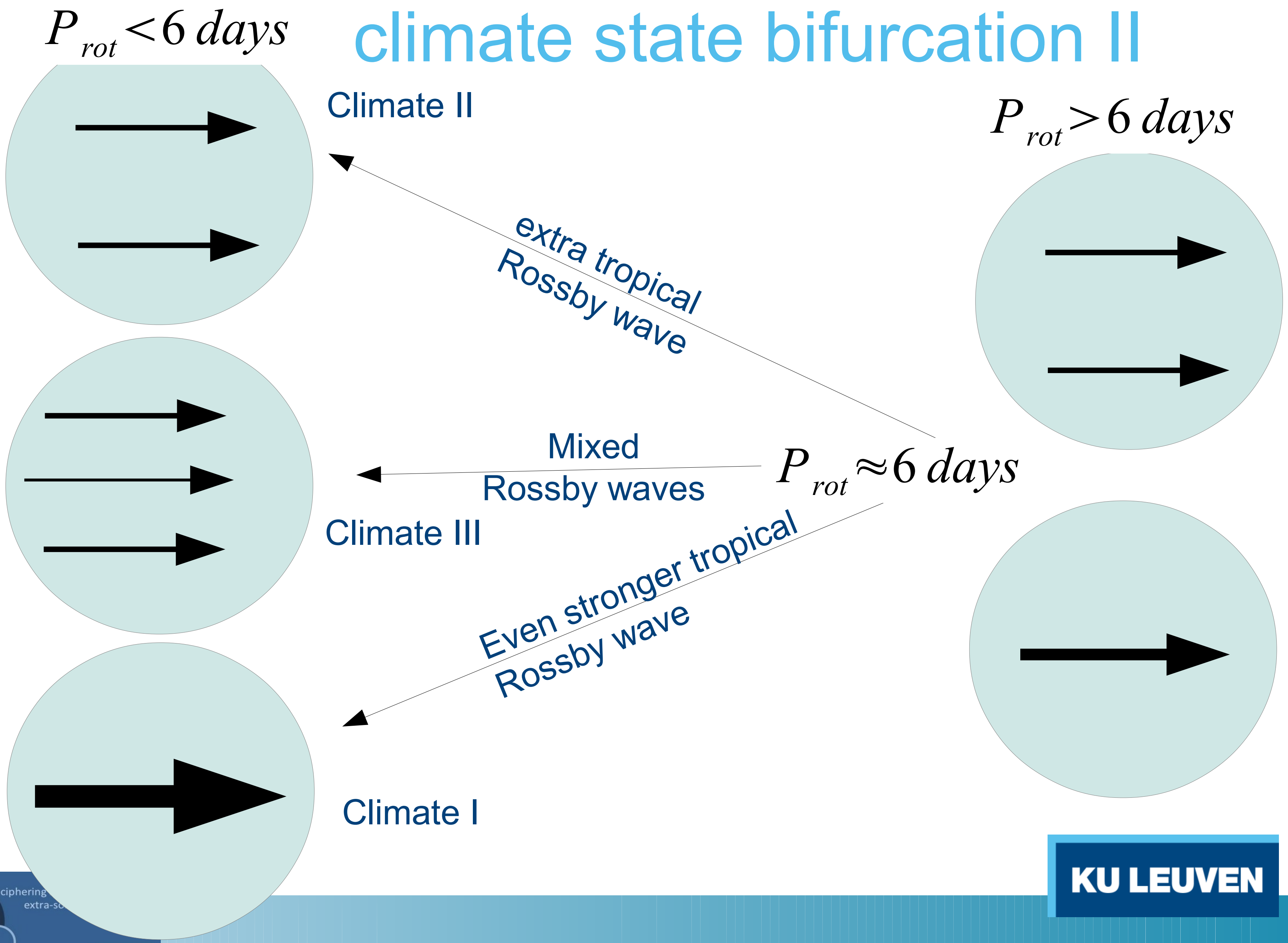


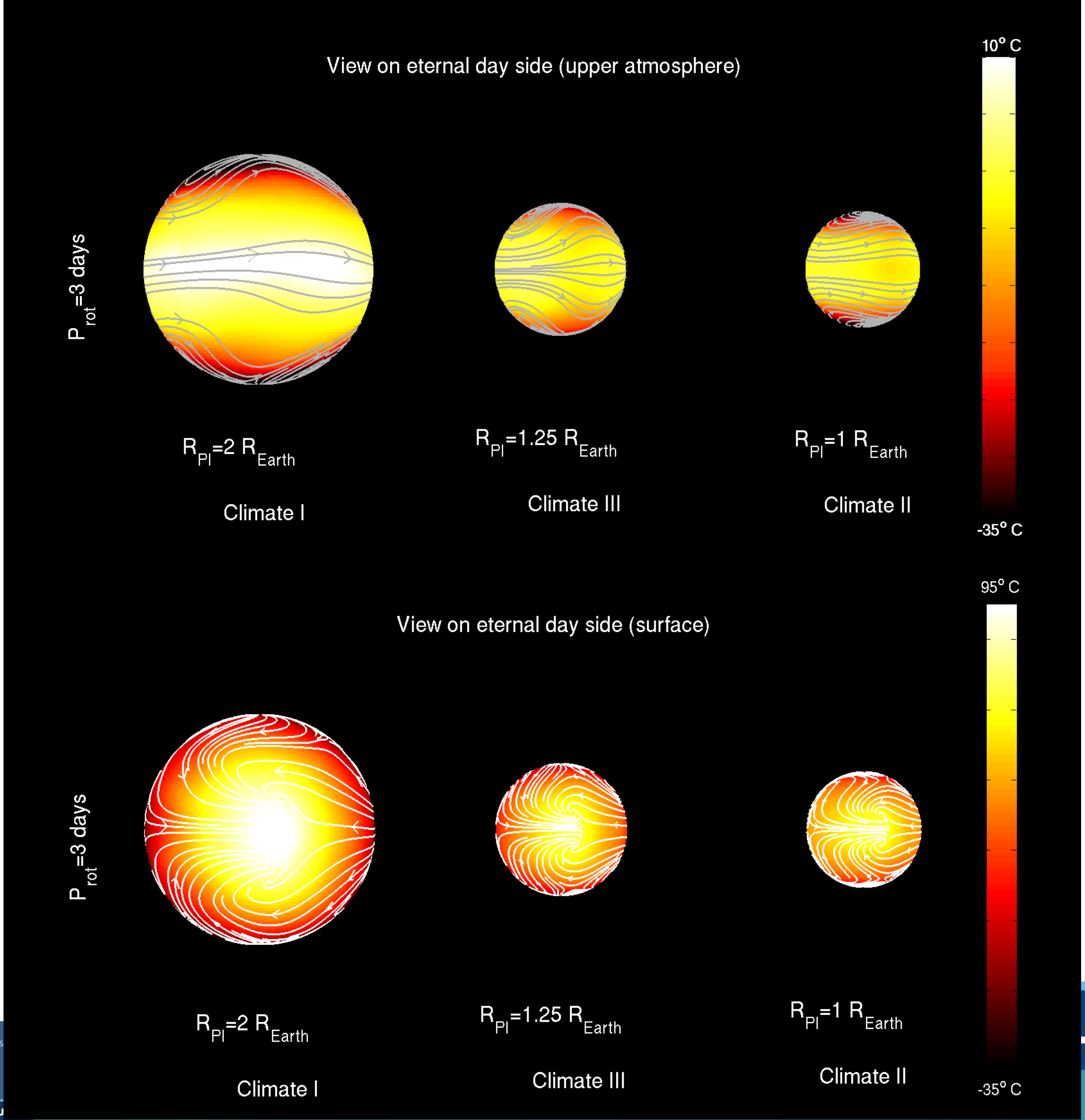
# Rossby wave driven climate state bifurcation I

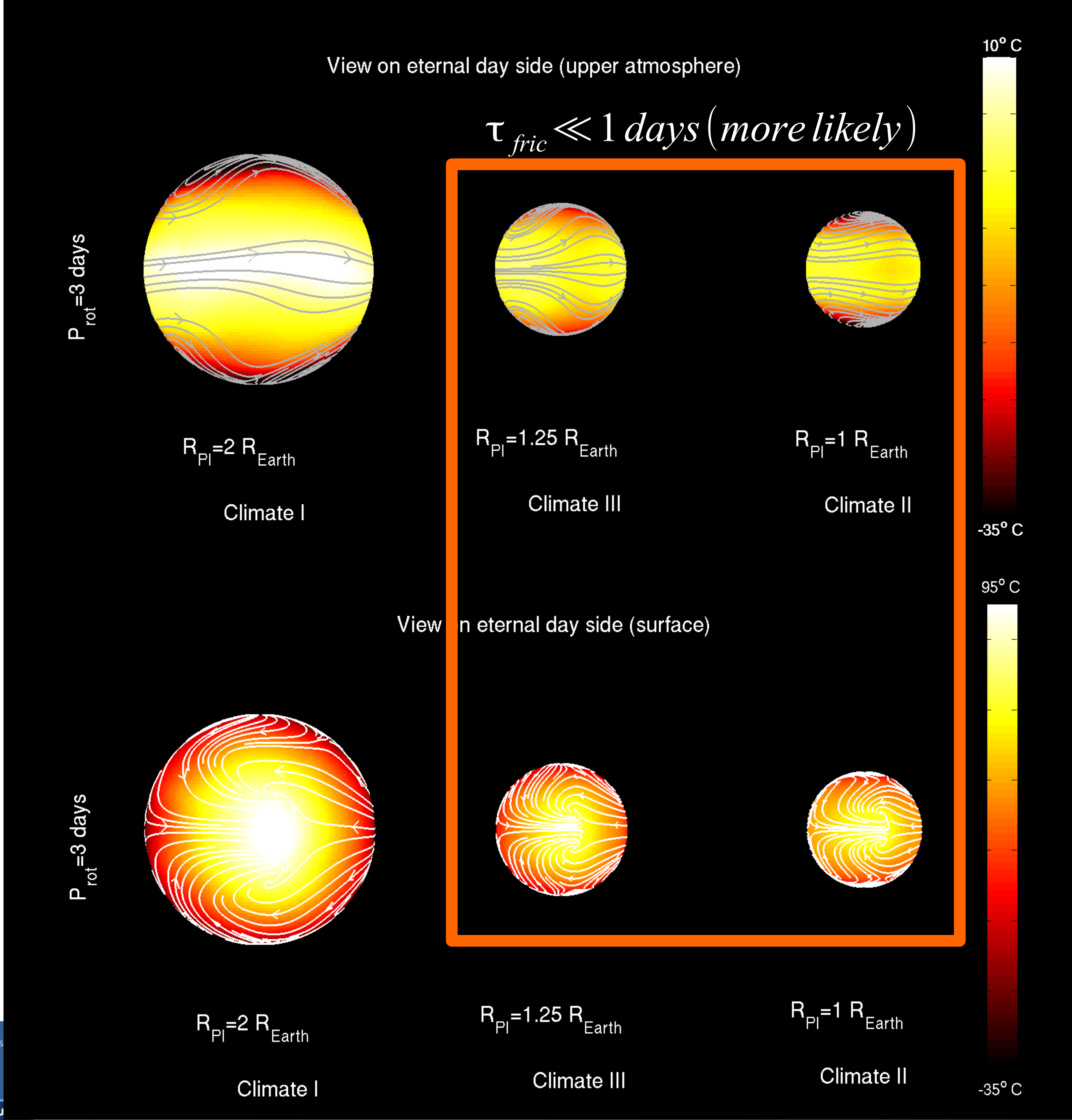



First indication by Edson et al. 2011

# Rossby wave driven climate state bifurcation II




View on eternal day side (upper atmosphere)
10° C
-35° C
$P_{rot}$=3 days
$R_{Pl}$=2 $R_{Earth}$
Climate I
$R_{Pl}$=1.25 $R_{Earth}$
Climate III
$R_{Pl}$=1 $R_{Earth}$
Climate II
View on eternal day side (surface)
95° C
-35° C
$P_{rot}$=3 days
$R_{Pl}$=2 $R_{Earth}$
Climate I
$R_{Pl}$=1.25 $R_{Earth}$
Climate III
$R_{Pl}$=1 $R_{Earth}$
Climate II



View on eternal day side (upper atmosphere)
$\tau_{fric} \ll 1\, days\, (more\ likely)$
10° C
-35° C
$P_{rot}$=3 days
$R_{Pl}=2\ R_{Earth}$
Climate I
$R_{Pl}=1.25\ R_{Earth}$
Climate III
$R_{Pl}=1\ R_{Earth}$
Climate II
View on eternal day side (surface)
95° C
-35° C
$P_{rot}$=3 days
$R_{Pl}=2\ R_{Earth}$
Climate I
$R_{Pl}=1.25\ R_{Earth}$
Climate III
$R_{Pl}=1\ R_{Earth}$
Climate II

# Conclusions

- Climate states of tidally locked planets at IHZ of M stars can be dominated by Rossby waves
- Short rotation periods: <12 days
  - 2 Climate states possible:
    - Equatorial Superrotation
    - High latitudes westerly jets
- Ultra short rotation period < 6 days
  - 3 Climate states possible
    - Two as above
    - + mixed states
- Eq. superrotation 'kills' direct circulation cells and thus efficient cooling of dayside
- Efficient surface friction =>High latitude jets state favored