Atmospheric Circulation of Habitable Exoplanets Orbiting Low-Mass Stars

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The discoveries of Proxima Centauri b around our closest stellar neighbor [1] and the seven planets of the TRAPPIST-1 system [2] indicate that M-dwarfs can harbor terrestrial planets within their liquid water habitable zones [3, 4, 5, 6], which makes them likely targets for upcoming surveys.

We use the Community Atmosphere Model (CAM) to investigate the atmospheric dynamics of terrestrial planets in synchronous rotation within the habitable zone of low-mass stars. We show that the temperature contrast between the day and night hemispheres decreases with an increase in incident stellar flux, with little dependence upon stellar spectral type and no dependence upon rotation rate. This trend is opposite that seen on gas giants, where the same forcing shows a *decrease* in the day-night temperature contrast instead.

We define three dynamical regimes in terms of the equatorial Rossby deformation radius and the Rhines length [7]. The slow rotation regime is characterized by the deformation radius exceeding planetary radius, which should occur for planets around stars with effective temperatures of 3700 K to 4500 K. The rapid rotation regime is defined by a deformation radius being less than planetary radius, which occurs for planets orbiting stars with effective temperatures of less than 3000 K. In between these two limits is the Rhines rotation regime with planetary-scale turbulent flow, which occurs for planets around stars with effective temperatures of 3000 K to 3300 K. The dynamical state can be inferred from astronomical observations of orbital period, spectral type of the host star, and the day-night temperature contrast. These dynamical regimes all respond differently to increases in stellar forcing, which also suggests different responses of these atmospheres to the main sequence brightening of their host star. The next generation of space telescope missions, such as the Origins Space Telescope, may be able to use thermal phase curves to identify the atmospheric circumation regime.

References: [1] Anglada-Escudé et al. (2017) *Nature* 536, 437. [2] Gillon et al. (2017) *Nature* 542, 456. [3] Kasting et al. (1993) *Icarus* 101, 108. [4] Kopparapu et al. (2013) *ApJ* 765, 131. [5] Yang et al. (2013) *ApJ* 771, L45. [6] Yang et al. (2014) *ApJ* 787, L2. [7] Haqq-Misra et al. (2018), *ApJ*. 852, 67.