# Weather on Other Worlds. V. The Three Most Rapidly Rotating Ultra-Cool Dwarfs

Submitted to the Astronomical Journal

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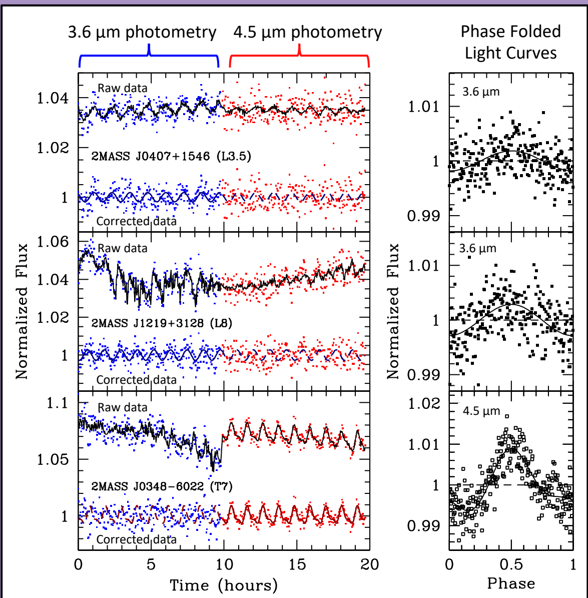
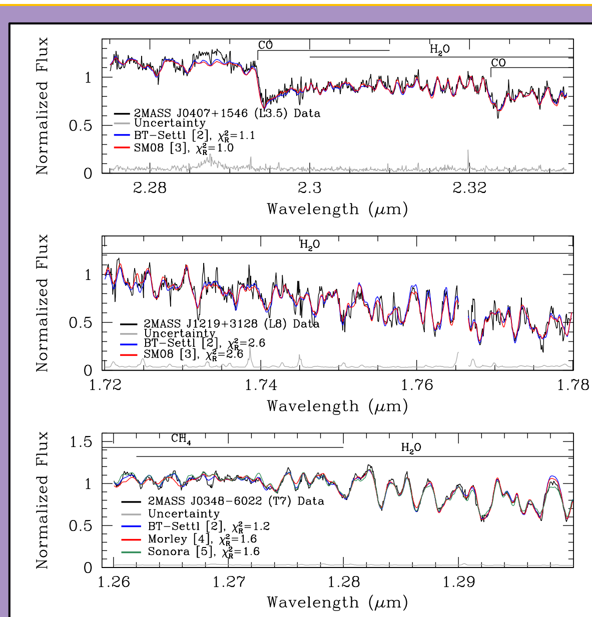
**Abstract**

We present the discovery of rapid photometric variability in three ultra-cool dwarfs from long-duration monitoring with the *Spitzer Space Telescope*. **The T7, L3.5, and L8 dwarfs have the shortest photometric periods known to date: $1.080^{+0.004}_{-0.005}$h , $1.14^{+0.03}_{-0.01}$ h, and $1.23^{+0.01}_{-0.01}$ h, respectively.** We confirm the rapid rotation through moderate-resolution infrared spectroscopy that reveals projected rotational velocities between 79 and 104 km s$^{-1}$. We compare the near-infrared spectra to photospheric models to determine the objects' fundamental parameters and radial velocities. We find that the equatorial rotational velocities for all three objects are ≳100 km s$^{-1}$. The three L and T dwarfs reported here are the most rapidly spinning and likely the most oblate field ultra-cool dwarfs known to date. Correspondingly, all three are excellent candidates for seeking auroral radio emission and net optical/infrared polarization. As of this writing, 78 L-, T-, and Y-dwarf rotation periods have now been measured. **The clustering of the shortest rotation periods near 1 h suggests that brown dwarfs are unlikely to spin much faster.**




**Left:** *Spitzer* light curves. The data have been corrected for the pixel phase effect [1] and offset by a constant for clarity. Fits to the raw data are shown in black, and Fourier models for the corrected data are shown in blue for 3.6 μm and red for 4.5 μm.

**Right:** Sample near-infrared spectra. We fit photospheric models [2; 3; 4; 5] to constrain physical parameters (see table below). We consider a Bayesian likelihood analysis to find the family of best fitting models.




**Possibility for Auroral Emissions**

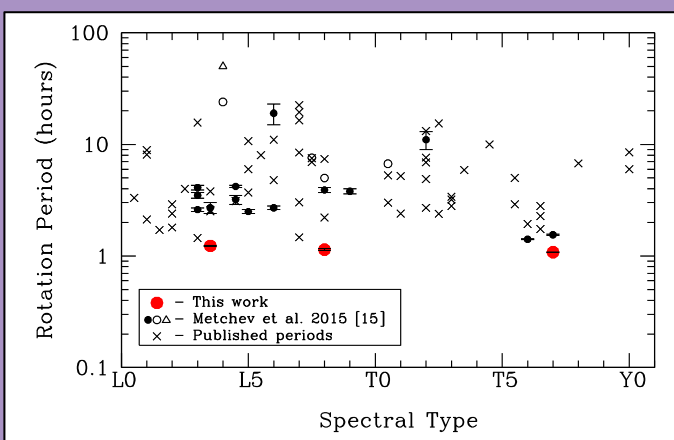
The L3.5 dwarf 2MASS J0407+1546 is known to be chromospherically active based on strong (60 Å equivalent width) Hα emission [6]. Its rapid rotation and Hα emission may indicate the presence of an aurora as rapid rotation is key to powering auroral emissions via the electron synchrotron maser instability [7]. Brown dwarf Hα, radio luminosities, and radio aurorae are correlated [8; 9; 10]. It is possible that all three of our rapidly rotating brown dwarfs have strong dipole fields that power auroral emission [8]. In particular, the near equator-on view of the T7 dwarf 2MASS J0348–6022 makes it an excellent candidate for seeking pulses of circularly polarized electron synchrotron maser emission.

**The Most Oblate Field Ultra-Cool Dwarfs Known**

The Darwin-Radau relationship (e.g., [11]) connects the oblateness (fractional difference between polar and equatorial radii), mass, radius, rotation, and moment of inertia for objects with smoothly varying interiors. Our fast rotators have oblatenesses between 0.05 and 0.08. For comparison, Saturn, the most oblate planet in the Solar System, has an oblateness of 0.1. Because of their significant oblateness, the three rapid rotators are potentially good targets for searches for polarized thermal emission (e.g.,[12], [13],[14]).

**Below:** Physical parameters determined from *Spitzer* photometry, near-infrared spectroscopy, and interpolation of evolutionary models [2].

| Parameter | 2MASS J0348-6022 | 2MASS J1219+3128 | 2MASS J0407+1546 |
|---|---|---|---|
| Spectral Type | T7 | L8 | L3.5 |
| $P_{\rm rot}$ (hr) | $1.080^{+0.004}_{-0.005}$ | $1.14^{+0.03}_{-0.01}$ | $1.23^{+0.01}_{-0.01}$ |
| $v \sin i$ (km s$^{-1}$) | $103.5 \pm 7.4$ | $79.0 \pm 3.4$ | $82.6 \pm 0.2$ |
| $v_{\rm equatorial}$ (km s$^{-1}$) | $105^{+18}_{-12}$ | $107^{+29}_{-15}$ | $99^{+24}_{-8}$ |
| Mass ($M_\odot$) | $0.041^{+0.021}_{-0.017}$ | $0.047^{+0.022}_{-0.025}$ | $0.064^{+0.009}_{-0.027}$ |
| Age (Gyr) | $3.5^{+11.5}_{-2.9}$ | $0.9^{+12.8}_{-0.8}$ | $0.8^{+11.2}_{-0.65}$ |
| Inclination (°) | $81^{+9}_{-27}$ | $47^{+9}_{-17}$ | $57^{+7}_{-21}$ |
| Oblateness | 0.08 | 0.08 | 0.05 |




**Above:** The three rapid rotators delineate a lower boundary to the envelope of all 78 L-, T-, and Y-dwarf rotation periods measured to date. This limit holds over a broad range of spectral types, for objects that presumably have different ages. **Hence,~1 h may be close to a physical lower limit to the period of field-aged Jupiter-sized brown dwarfs.**

**References (hyperlinked)**

[1] Reach et al. 2005
[2] Allard et al. 2012
[3] Saumon & Marley 2008
[4] Morley et al. 2012
[5] Marley et al. 2018
[6] Reid et al. 2008
[7] Kao et al. 2018
[8] Kao et al. 2016
[9] Pineda et al. 2017
[10] Richey-Yowell et al. 2020
[11] Barnes & Fortney 2003
[12] Marley & Sengupta 2011
[13] de Kok et al. 2011
[14] Stolker et al. 2017
[15] Metchev et al. 2015

Thanks for reading!