The Nature of Variability in Early L Dwarfs

J. E. Gizis[1]

[1] *University of Delaware. Dep. of Physics and Astronomy, Newark, Delaware 19716, USA*

Abstract. The M/L transition features the onset of dust formation, a change on character in magnetic activity, and the hydrogen-burning limit. I report on Kepler and Spitzer observations of a nearby L1 dwarf. Starspots, clouds, and aurorae have all been proposed as causes of variability in early L dwarfs. The photometry favors an inhomogeneous cloud model.

1. Motivation

The M/L transition features dramatic changes in the atmospheric properties of stars and brown dwarfs. Condensate clouds form but are difficult to model. Measuring weather though photometric variability is a key way of probing the atmosphere (Gelino et al. 2002; Heinze et al. 2013). At the same time, indicators of magnetic activity show a major transition at this spectral type. However, ground-based observations of faint M/L dwarfs can be challenging (Bailer-Jones & Mundt 1999).

Gizis et al. (2011) discovered an L1 dwarf (WISEP J190648.47+401106.8) at 16.4 pc in the original Kepler (Koch et al. 2010) field of view. Gizis et al. (2013) previously reported 1.2 years of Kepler data, showing evidence of a stable spot, an 8.9 hour rotation period, frequent white light flares, quiescent radio emission, and variable H alpha. Here we present the full Kepler dataset and supporting Spitzer and Kitt Peak 2.1m observations. The full work will be reported in Gizis et al. (2014, ApJ, in prep.)

2. Observations

Our Kepler observations consist of 30-minute cadence photometry of W1906+40 for nearly two years, Quarters 10-17. We find that PSF fitting (Figure 1) using the PyKE package (Still & Barclay 2012) improves on the aperture photometry. The data are consistent with a single period (0.370178 days) and phasing. Quarters 13 and 17 are discarded due to an instrumental (bad pixel) problem. A 2-dimensional histogram of the combined light curve is shown in Figure 2 and all data points in Figure 3.

W1906+40 was also observed with the Spitzer Space Telescope (Fazio et al. 2004) for 20 hours in October 2013. Although this is months after the Kepler failure, the IRAC1 (3.6 micron) data

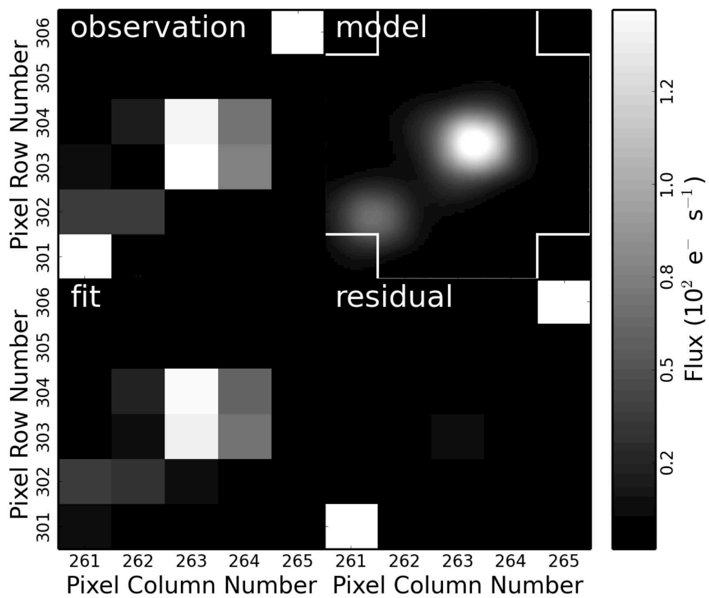

Figure .1: PSF modeling of W1906+40. We find that the PSF photometry is more optimal (less scatter) than simple aperture photometry.

matches the predicted phasing. There are no variations detected at IRAC2 (4.5 micron); i.e., the feature which is brighter or darker at 0.8 micron and 3.6 microns is the same brightness at 4.5 microns.

3. Discussion

The 4.5 micron (CO) feature forms high in the atmosphere above the expected position of the clouds. Figure 5 shows a Burrows et al. (2006) E-class cloud model predicting that the Kepler and IRAC1 bands form deeper(higher pressure) in the atmosphere. Alternatively, we can consider aurorae as in late M dwarfs (Heinze et al. 2013; Harding et al. 2013). Using Kitt Peak, we detected i, z variabilty but rule out large g, r ; this rejects hot (> 2800K) temperatures for the spot. We also found that the Balmer emission is not in phase with the Kepler/Spitzer light curve and is not a significant fraction of the Kepler energy budget. We therefore favor an inhomogeneous cloud model

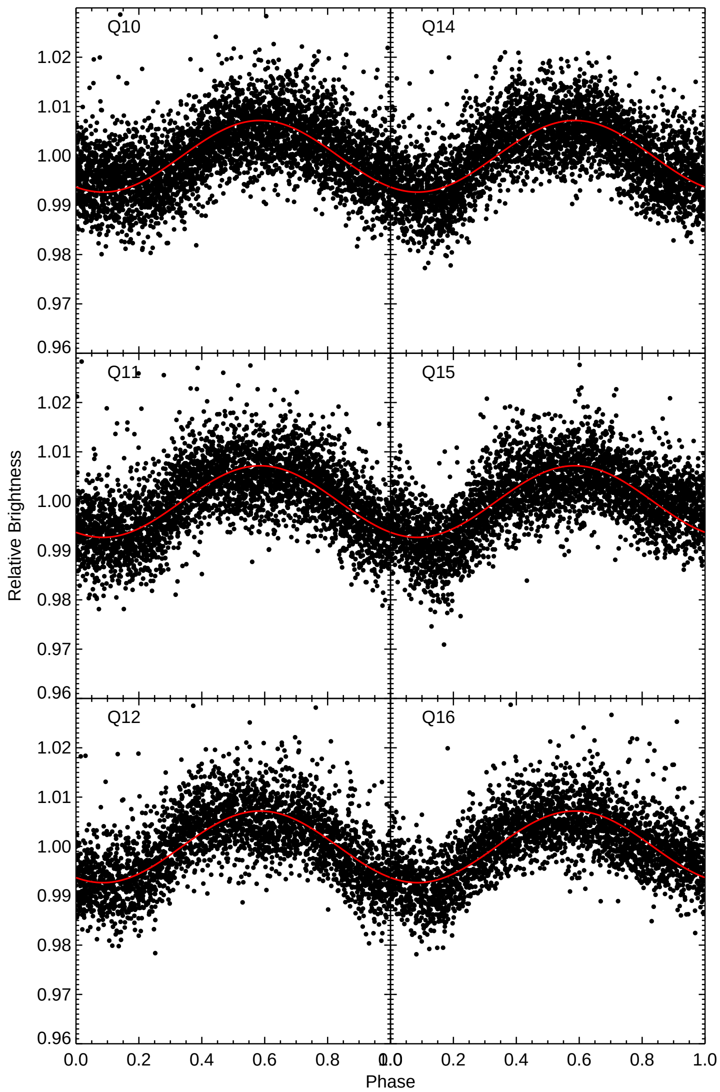

Figure .2: Each quarter of Kepler data phased to a single period. The spacecraft is rotated quarterly so that every 4th quarter is on the same pixels; Quarters 13 and 17 are affected by bad pixels.

as in Heinze et al. (2013)'s L3 dwarf. Magnetic fields (i.e., starspots) may be important for the stability of the feature.

Acknowledgements. This paper includes data collected by the Kepler mission. Funding for the Kepler mission is provided by the NASA Science Mission directorate. The material is based upon work supported by NASA under award No. NNX13AC18G. This work is based in part on observations made with the Spitzer Space Telescope, which is operated by the Jet Propulsion Laboratory, California Institute of Technology under a contract with NASA. Support for this work was pro-

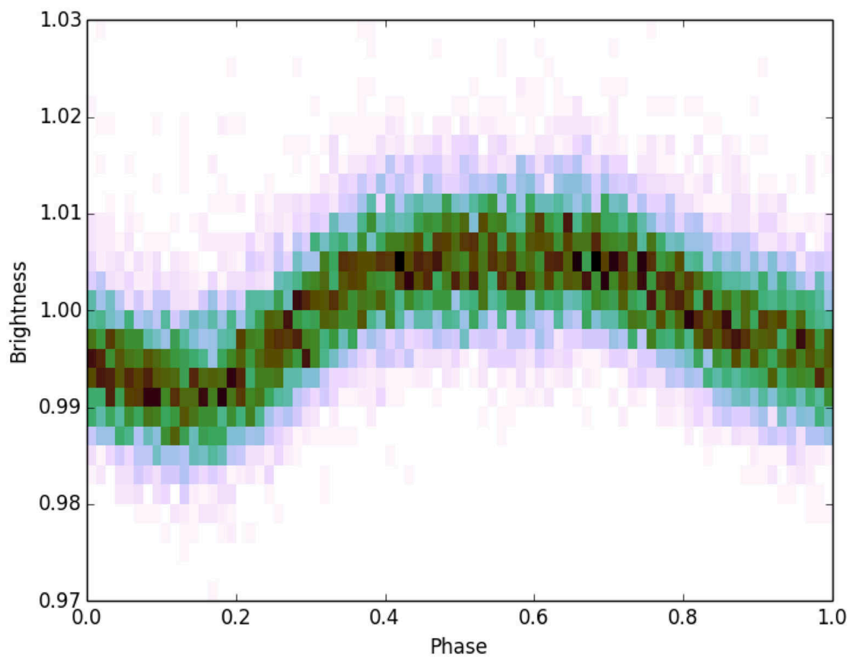

Figure .3: Kepler photometry (Quarters 10-12, 14-16) phased to a single period. Note the consistency of the data, demonstrating that the surface spot lasts for years.

vided by NASA through an award issued by JPL/Caltech. JEG was a Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA) under cooperative agreement with the National Science Foundation.

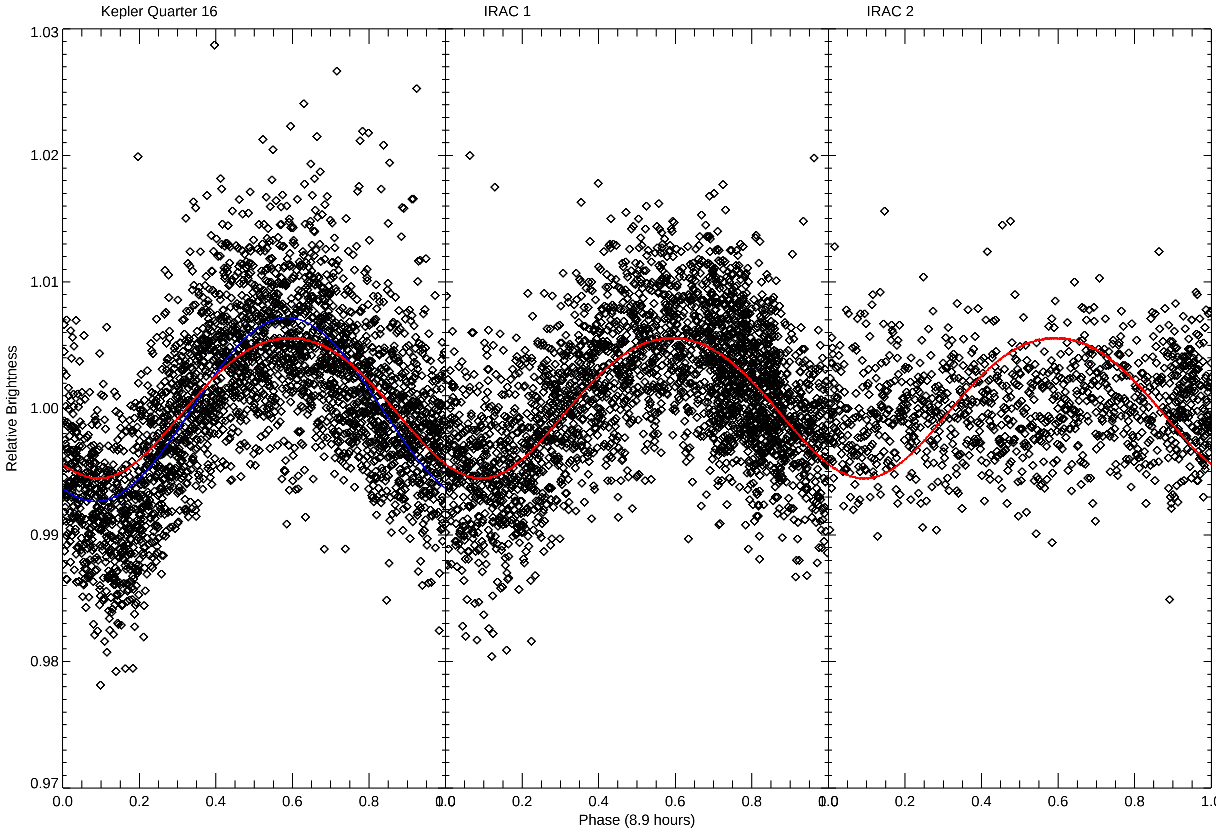

Figure .4: The Spitzer data compared to Quarter 16 of the Kepler data. Note the consistency of the phase at Kepler and 3.6 microns an the lack of variability at 4.5 microns.

References

Bailer-Jones, C. A. L., & Mundt, R. 1999, A&A, 348, 800

Burrows, A., Sudarsky, D., & Hubeny, I. 2006, ApJ, 640, 1063

Fazio, G. G., Hora, J. L., Allen, L. E., et al. 2004, ApJS, 154, 10

Gelino, C., & Marley, M. 2000, in Astronomical Society of the Pacific Conference Series, Vol. 212, From Giant Planets to Cool Stars, ed. C. A. Griffith & M. S. Marley, 322

Gelino, C. R., Marley, M. S., Holtzman, J. A., Ackerman, A. S., & Lodders, K. 2002, ApJ, 577, 433

Gizis, J. E., Burgasser, A. J., Berger, E., et al. 2013, ApJ, 779, 172

Gizis, J. E., Troup, N. W., & Burgasser, A. J. 2011, ApJ, 736, L34

Harding, L. K., Hallinan, G., Boyle, R. P., et al. 2013, ApJ, 779, 101

Heinze, A. N., Metchev, S., Apai, D., et al. 2013, ApJ, 767, 173

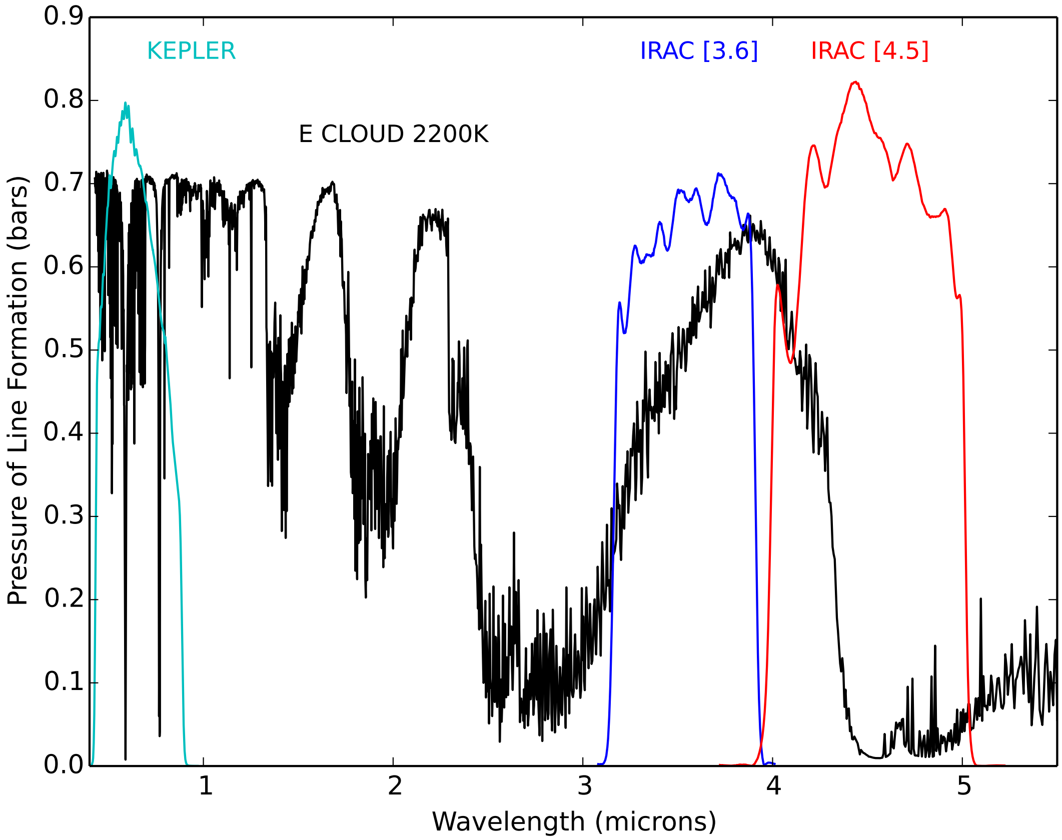

Figure .5: The pressure (depth) of line formation ($\tau = 2/3$) in an L1 dwarf model Burrows et al. (2006).

Koch, D. G., Borucki, W. J., Basri, G., et al. 2010,ApJ, 713, L79

Still, M., & Barclay, T. 2012, PyKE: Reduction and analysis of Kepler Simple Aperture Photometry data, ascl:1208.004, Astrophysics Source Code Library

Mark Giampapa chaired the Tuesday morning sessions.