Analysis of the Spitzer 24μm Light Curve of the Eclipsing M-dwarf Binary GU Boötis

Kaspar von Braun[1], Gerard T. van Belle[1], David R. Ciardi[1], D. W. Hoard[2], Stefanie Wachter[2]

[1]Michelson Science Center, Caltech; [2]Spitzer Science Center, Caltech

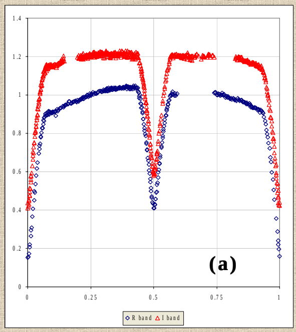
Abstract: We present a carefully controlled set of Spitzer 24 μm MIPS time series observations of the M-dwarf eclipsing binary star GU Boötis. These observations produced the first Spitzer variable star light curve and serve to characterize the MIPS-24 observing techniques of the spacecraft, precisely establishing the photometric repeatability of this instrument at the tens of μJy level. The data aim to substantiate the previously reported and upcoming observations of extrasolar planet transits at similar flux levels. A further science return is the long wavelength (and thus limb darkening-independent) characterization of such a low-mass object's light curve, allowing for improved characterization of the components' linear radii and other aspects of their surface morphologies.

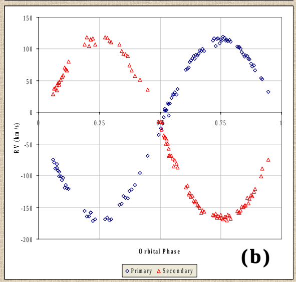
What is GU Boötis?

- GU Boötis is a nearby, low-mass eclipsing binary system, consisting of two M-dwarfs (López-Morales & Ribas 2005).
- The nearly equal mass binary system was only recently discovered in 2005.

Why is GU Boötis important?

- Very few (<10 pairs) double-lined, detached eclipsing low-mass (M< 1$M_\odot$) binaries are known.
- Eclipsing binaries can be used to ascertain fundamental stellar properties such as mass, linear radius, and effective temperature.
- Over 70% of the stars in the Milky Way are low-mass objects with M< 1 $M_\odot$.
- There is still considerable uncertainty over the mass-radius relation for low-mass stars.





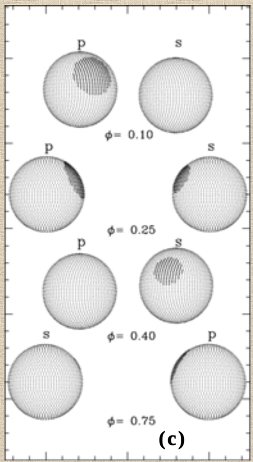


Fig. 1 a, b, c: *R*-band and *I*-band differential photometry curves (**a**), radial velocity curves (**b**), and visualization of star spot geometry (**c**) from López-Morales & Ribas (2005).

Table 1: GU Boo System Parameters

Parameter	Value
Orbital Period (*days*) [a]	0.488728 ± 0.000002
Orbital Eccentricity[a]	0.0
Component radii (solar units) [a]	0.623 / 0.620
Component masses (solar units) [a]	0.610 / 0.599
Secondary Eclipse duration (*sec*)	5665
Combined 24 μm flux (μJy)	502 ± 30
Secondary eclipse minimum 24 μm flux (μJy)	253 ± 80

[a] From López-Morales & Ribas (2005)

Observations / Data Reduction

- A total of ~2,500 epochs (10s exp time) of 24 μm MIPS data were obtained in 9 AORs over 3 observing campaigns.
- Two secondary eclipse events were recorded in MIPS campaign 29 (20-21 Feb 2006), a third was observed during MIPS campaign 30 (1 Apr 2006) to test MIPS repeatability from event to event, over the short- and long-term.
- 24 μm observations were selected as being minimally affected by limb darkening and/or spots for M-dwarfs.
- BCD frames were mosaiced together in sets of 17.
- The Spitzer *mopex/apex* package was utilized to extract the point-source aperture photometry.

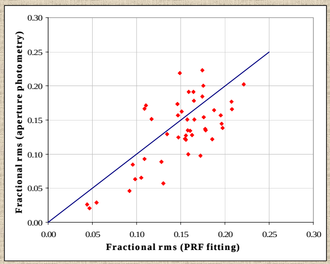


Figure 2: Comparison between aperture photometry vs point-response-function fitting for calculation of stellar flux values. Plotted are fractional rms values of all stellar light curves over the entire data set. The blue line is representative of where these values are the same. We find that using aperture photometry decreases the scatter in the photometry when compared to PRF fitting.

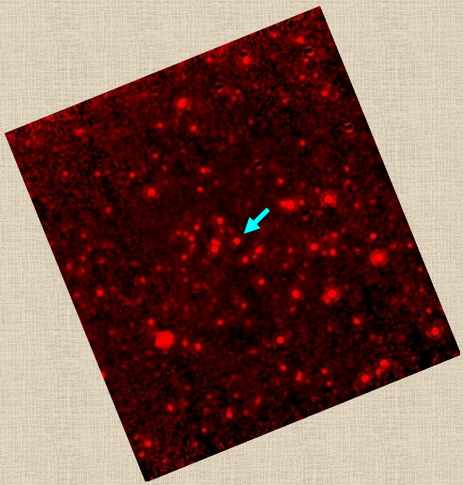


Figure 3: A mosaic of 272 MIPS-24 images from Spitzer. At the center of this mosaic is GU Boötis (marked by arrow). North is up and east is left. The size of the image is about 5 arcmin on the side. Note the Airy Rings around the brighter stars in this diffraction limited image. There are about 45 objects in the field with good photometry coverage.

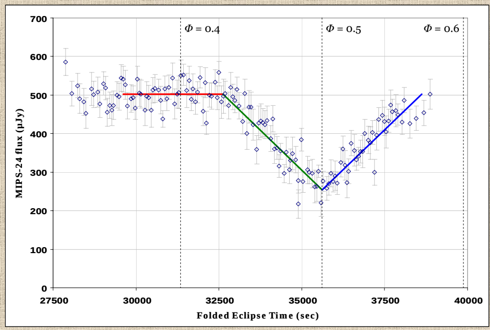


Figure 5: Folded 24 micron light curve for all 3 observed secondary eclipses of GU Boötis. Constant flux level prior to the eclipse is 502±31 μJy; minimum flux level is 253±80 μJy during the eclipse, consistent with a nearly total eclipse of a secondary star with equal surface brightness. Phase angles shown for comparison with **Fig. 1**.

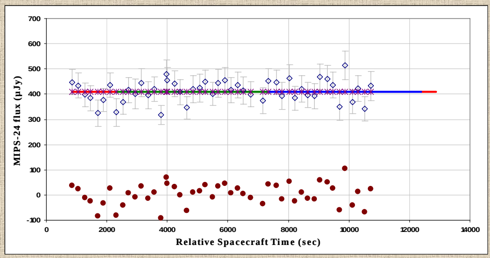


Figure 6: Light curve for arbitrary non-variable star (observing campaign #1). Colors of fit-line segments correspond to the ones in **Figs. 4 & 5**. Diamonds represent actual data, brown dots residuals about the fit. Flux levels are 409±34 μJy (campaign #29.1); 415±34 μJy (campaign #29.2); 430±33 μJy (campaign #30).

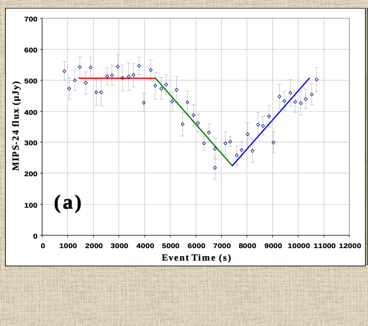
Conclusions (thus far)

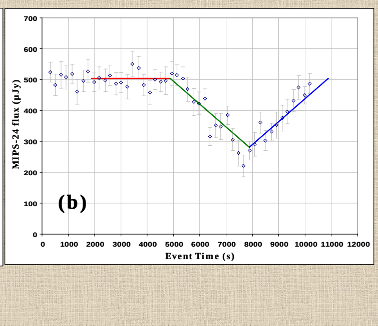
- Spitzer's photometric repeatability from campaign to campaign is statistically consistent with intra-campaign levels (**Fig. 4**).
- At 500 μJy (max. GU Boo flux level), the rms is 30μJy (**Fig. 5**).
- For comparison, the 24 μm flux decrement during the secondary eclipse for HD 209458 is 55 μJy (stellar flux ~ 22,000 μJy).
- We find that the data rms produced by *apex* aperture photometry is smaller than the one produced by point-response function fitting (**Fig. 2**).
- We find that photometry quality is independent of whether we use calibration images obtained at Spitzer's 4 cardinal dither positions or combined from all data in one AOR (272 images).
- 24 μm light curve for GU Boötis appears to be uncontaminated by surface morphology compared to optical counterparts (**Fig. 1**).

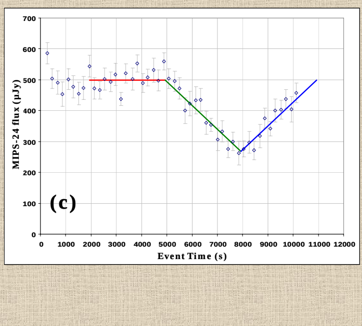
References

- Berger et al. 2006, ApJ, 644, 475
- Deming et al. 2005, Nature, 434, 740
- López-Morales & Ribas 2005, ApJ, 631, 1120
- Torres et al. 2006, ApJ, 640, 1018

Figure 4 a, b, c: Individual observed secondary eclipse events for of GU Boötis. Constant flux level for (**a,b,c**) are 506±30, 504±31, 498±30 μJy; ingress egress slopes are 0.094±0.028, 0.074±0.034, 0.077±0.032 μJy/sec; minimum flux during maximum eclipse is 224±72, 282±87, 268±83 μJy. Reduced χ2 for each fit is 1.98, 0.91, 1.62, respectively.







Contact: Kaspar von Braun:
626.395.1970
kaspar@caltech.edu