Poster # 18.02  (Revised title)

Short-Term Changes in the Eclipse Timings and Light-Curve Shapes of W UMa Binaries

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with 
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Overall Purpose of the Program

The overall purpose of our program is to look for subtle short-term changes in the eclipse timings and light-curve shapes of short-period W Ursa Majoris binaries

**Eclipse timing changes could be due to**
* Angular momentum loss
* The Applegate effect
* Third body light-time effect
* Micro-episodes of mass flow

**Light curve shape changes could be due to**
* Starspots or other photometric surface phenomena
* Flares (only in U—and not until a future observing season)

Of course any changes in either eclipse timings or light curve shapes could also be due to observational errors
Research Approach

Concentrate on a few short-period binaries
* Select binaries at or near the 0.22 day “limit”
* Favor binaries with RV curves and known orbital parameters
* Obtain complete light curves (one orbit or more) nearly every night
* Observe same systems all season long for several seasons

Observational strategy
* Observe binaries simultaneously from two observatories
* Minimize photometric errors via ensemble photometry
* Transform all data to standard magnitude system
* Start with a trial pilot season of observations and analysis
* Follow with three full “industrial-strength” seasons

Complimentary analytic approaches
* Statistical—seasonal parameters and trends
* Nonparametric modeling—curve shape changes
* Parametric modeling—Wilson Devinney (with Dirk Terrell)
## Pilot Season Observations

<table>
<thead>
<tr>
<th>Binary</th>
<th>DRO</th>
<th>Orion</th>
<th>Total</th>
<th>Period</th>
<th>V_J Max</th>
<th>Delta Mag</th>
</tr>
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<tbody>
<tr>
<td>V523 Cas</td>
<td>27</td>
<td>7</td>
<td>34</td>
<td>0.234</td>
<td>10.6</td>
<td>0.83</td>
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<tr>
<td>RW Com</td>
<td>18</td>
<td>8</td>
<td>26</td>
<td>0.237</td>
<td>11.0</td>
<td>0.70</td>
</tr>
<tr>
<td>V400 Lyr</td>
<td>7</td>
<td>10</td>
<td>17</td>
<td>0.253</td>
<td>12.7</td>
<td>0.65</td>
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<tr>
<td>TZ Boo</td>
<td>18</td>
<td>13</td>
<td>31</td>
<td>0.297</td>
<td>10.4</td>
<td>0.59</td>
</tr>
<tr>
<td>V1191 Cyg</td>
<td>22</td>
<td>39</td>
<td>61</td>
<td>0.313</td>
<td>10.8</td>
<td>0.33</td>
</tr>
<tr>
<td>GM Dra</td>
<td>14</td>
<td>3</td>
<td>17</td>
<td>0.339</td>
<td>8.8</td>
<td>0.27</td>
</tr>
</tbody>
</table>
Sample Light Curves

V523 Cas
RW Com
V400 Lyr

TZ Boo
V1191 Cyg
GM Dra
Statistical Analysis

Times of minima (and other parameters)
* Kwee van Woerden, Fourier, and Hertzsprung
* Actual (external) errors (precision) based on simultaneous observations
* Other parameters—secondary minima, maxima, delta magnitudes, etc.

Seasonal ephemeris and O-C analysis
* Period (and epoch) derived solely from our seasonal observations
* Error of mean for seasonally-derived period less than one second
* Seasonal ephemeris used in seasonal O-C analysis

Photometric Precision
* Precision of classical variable minus single comparison photometry
* Precision of ensemble photometry (multiple comparisons)
* Relationship between times of minima and photometric precision

Analysis of variance (ANOV)
* Partition of variances between observatories, orbital cycles, nights, etc.

Nonparametric Light Curve Modeling

**Nonparametric light curve models**
* Make no physical assumptions / compliment parametric models
* Tsesevich\(^2\) introduced concept of standard light curve for sparse data
* We extended Tsesevich concept to a season of dense-data light curves

**Model formulations**
* Models are magnitude as a function of phase (they can be piecewise)
* Points transformed to a function via smoothing spline or Fourier low pass
* Models formulated for every individual night (each observatory)
* Seasonal master model formulated from best nights (each observatory)

**Quantitative differential analysis between models**
* Compare single night models with seasonal standard model, or compare models from individual nights two at a time
* Use comparisons to evaluate quantitative changes in light curves with respect to magnitudes, colors, and asymmetries
* Converted phase shifts for best fits to whole-curve times of minima
  
Parametric Light Curve Modeling

Parametric light curve models
* Models provide physical representation / necessarily make assumptions
* Parametric models yield astrophysical interpretation at the cost of some fit to data if the underlying model is inadequate
* Wilson-Devinney model analysis (Dirk Terrell)

Model formulations
* Initial modeling develops a single set of orbital parameters for the season
* Using these, develop a model for each night with variations in time of minima, and in starspot numbers, lat/longs, diameters, and temperatures

Quantitative differential analysis between models
* Compare models from individual nights—two at a time
* Use comparisons to evaluate quantitative changes in light curves with respect to magnitudes, colors, and asymmetries
* Also use models to interpret variations as changes in starspots
* Converted phase shifts for best fits to whole-curve times of minima
Parametric / Nonparametric Model Comparison

Roles of each model type
* Nonparametric models are the empirical standards / reality checks
* Parametric models provide astrophysical interpretation

Comparing the two tells us
* How well the parametric models fit the empirical data
* What variation remains unexplained

This will suggest
* How complete our parametric models are in explaining reality
* And therefore whether they are in need of further explanatory parameters
Program Future Plans

Complete pilot season analysis
* Ensemble photometry reduction procedure
* Statistical analysis
* Nonparametric model analysis
* Parametric model analysis (Terrell)

Report pilot season results to the community
* IAU Commission 42 conference in Syros, Greece, 27-30 June, 2005
* Close Binaries in the 21st Century: New Opportunities and Challenges

Further out
* Select binaries for second season / some the same, some new
* Observe in V & I (sequentially) instead of R only
* Eventually add two new larger telescopes (one for each observatory)
* Equip these new systems with simultaneous UVI photometers
  (using dichroic beamsplitters and three CCD cameras)