### Table 1. Observations of 10 W UMa-type systems

| Hel JD − 2 400 000 | Phase | V₁ | ΔV₁ | V₂ | ΔV₂ |
|---------------------|-------|----|-----|----|-----|
| **GZ And (DDO)**    |       |    |     |    |     |
| 50329.8571          | 0.7752 | −136.2 | −8.1 | 236.8 | −12.2 |
| 50329.8680          | 0.8109 | −116.5 | 3.8  | 229.3 | −4.6  |
| 50329.8800          | 0.8503 | −98.9  | 5.9  | 212.5 | 8.8   |
| 50329.8907          | 0.8854 | −88.4  | −2.9 | 168.1 | 1.8   |
| 50329.9017          | 0.9214 | −58.9  | 2.5  | 156.5<sup>b</sup> | 37.0 |
| 50330.5995          | 0.8978 | −74.5  | 3.2  | 162.4 | 11.4  |
| 50330.5864          | 0.0515 | 42.1<sup>a</sup> | 0.8  | −153.8<sup>b</sup> | −73.6<sup>b</sup> |
| 50330.5863          | 0.0906 | 70.5   | 0.6  | −179.4<sup>b</sup> | −43.6<sup>b</sup> |
| 50330.5804          | 0.1302 | 99.4   | 4.7  | −197.0 | −13.0 |
| 50363.8842          | 0.3370 | 118.0  | 7.2  | −199.3 | 16.0 |
| 50363.8929          | 0.3655 | 93.5   | −3.5 | −196.5 | −8.0 |
| 50398.6186          | 0.2178 | 137.0  | 9.9  | −235.7 | 11.3 |
| 50398.6287          | 0.2509 | 134.1  | 4.4  | −279.1 | −27.0 |
| 50398.7193          | 0.5480 | ⋯     | ⋯   | ⋯    | ⋯    |
| 50398.7310          | 0.5863 | −80.4<sup>a</sup> | −13.5 | 135.3<sup>a</sup> | 5.2 |
| 50398.7437          | 0.6280 | −96.2  | −2.8 | 165.0 | −16.6 |
| 50398.7700          | 0.7142 | −119.8 | 6.6  | 244.7 | −1.1  |
| 50398.7816          | 0.7522 | −132.1 | −2.4 | 245.1 | −7.0  |
| 50407.8025          | 0.3283 | 108.5  | −5.8 | −234.1 | −11.9 |
| 50415.6562          | 0.0776 | 50.9<sup>a</sup> | −9.8 | −152.9<sup>b</sup> | −34.9<sup>b</sup> |
| 50415.6671          | 0.1133 | 76.0   | −8.7 | −187.0 | −22.3 |
| 50415.6797          | 0.1546 | 112.6  | 5.5  | −218.0 | −9.8  |
| 50415.6905          | 0.1900 | 124.2  | 3.6  | −221.4 | 13.0  |
| 50415.7024          | 0.2290 | 123.4  | −5.2 | −245.9 | 4.0   |
| 50438.7185          | 0.6900 | −118.6 | 2.0  | 229.8 | −4.6  |
| 50438.7292          | 0.7251 | −123.5 | 4.6  | 235.0 | −14.0 |
| 50438.7418          | 0.7664 | −124.0 | 5.0  | 253.9 | 3.1   |
| **V417 Aql (DDO)**  |       |     |     |    |     |
| 50321.6014          | 0.1040 | 39.6  | −5.2 | −208.2<sup>a</sup> | −31.0 |
| 50321.6135          | 0.1366 | 63.3  | 4.1  | −231.5 | −14.3 |
| 50321.6280          | 0.1758 | 66.2  | −6.2 | −261.7 | −7.9  |
| 50321.6389          | 0.2052 | 72.0  | −7.0 | −263.7 | 8.2   |
| 50321.6526          | 0.2422 | 80.7  | −2.0 | −285.3 | −3.2  |
| 50321.6639          | 0.2727 | 90.4  | 8.6  | −276.3 | 3.4   |
| 50321.6768          | 0.3076 | 86.4  | 9.9  | −269.1 | −4.0  |
| 50321.6880          | 0.3378 | 66.1  | −2.3 | −231.8 | 10.8  |
| 50321.7031          | 0.3786 | 57.2  | 4.4  | −206.9 | −7.4  |
| 50321.7149          | 0.4105 | 45.2  | 7.7  | −156.9 | 0.4   |
| 50323.6309          | 0.5845 | −65.2 | −1.9 | 139.2<sup>a</sup> | 17.6 |
| 50323.6421          | 0.6147 | −89.6 | −11.4 | 177.2 | 14.4 |
| 50323.6559          | 0.6520 | −97.9 | −4.5 | 194.7 | −10.1 |
| 50323.6666          | 0.6809 | −101.6 | 0.6  | 230.9 | 1.8   |
| 50323.6790          | 0.7144 | −102.1 | 6.7  | 231.1 | −16.2 |
| 50329.6019          | 0.7088 | −98.8 | 9.2  | 240.0 | −5.1  |
| 50329.6128          | 0.7382 | −108.2 | 2.8  | 243.2 | −10.1 |
| 50329.6267          | 0.7757 | −111.3 | −1.3 | 240.2 | −10.3 |
| 50329.6378          | 0.8057 | −103.0 | 2.3  | 241.7 | 3.9   |
| 50329.6522          | 0.8446 | −98.5 | −3.9 | 205.7 | −2.3  |
| 50329.6629          | 0.8735 | −73.2 | 10.3 | 189.8 | 12.5  |
| 50329.6753          | 0.9070 | −73.2 | −5.5 | 149.9<sup>a</sup> | 16.1 |

<sup>a</sup> Relative to the visual minimum.
<sup>b</sup> Absolute magnitude.
| Hel JD – 2 400 000 | Phase | $V_1$ | $\Delta V_1$ | $V_2$ | $\Delta V_2$ |
|-------------------|-------|-------|-------------|-------|-------------|
| **LS Del (DAO)**  |       |       |             |       |             |
| 48153.7319        | 0.5334| •     | •           | •     | •           |
| 48153.7495        | 0.5817| •     | •           | •     | •           |
| 48153.7608        | 0.6128| −70.3*| 0.5         | 94.0* | −0.3        |
| 48153.7722        | 0.6442| −76.5 | 3.7         | 123.5 | 4.0         |
| 48153.7803        | 0.6664| −80.3 | 5.3         | 130.4 | −3.5        |
| 48153.7908        | 0.6953| −88.8 | 2.1         | 146.7 | −1.3        |
| 48153.7984        | 0.7162| −94.8 | −1.4        | 139.5 | −15.2       |
| 48153.8136        | 0.7580| −84.6 | 10.3        | 149.2 | −9.4        |
| 48153.8216        | 0.7799| −88.2 | 5.5         | 169.5 | 13.9        |
| 48153.8427        | 0.8379| −93.4 | −8.7        | 141.8 | 10.4        |
| 48153.6610        | 0.8355| −87.0 | −1.8        | 140.7 | 7.8         |
| 48153.6741        | 0.8715| −79.2 | −3.4        | 117.6 | 10.0        |
| 48153.6825        | 0.8946| −80.1 | −11.7       | 73.3  | −14.5       |
| 48153.6886        | 0.9113| −69.1 | −123.6      | 14.0  | 8.7         |
| 48155.6610        | 0.8355| −69.1 | −123.6      | 14.0  | 8.7         |
| 48155.6741        | 0.8715| −79.2 | −3.4        | 117.6 | 10.0        |
| 48155.6825        | 0.8946| −80.1 | −11.7       | 73.3  | −14.5       |
| 48155.6886        | 0.9113| −69.1 | −123.6      | 14.0  | 8.7         |
| 48155.7028        | 0.9336| •     | •           | •     | •           |
| 48155.7105        | 0.9715| •     | •           | •     | •           |
| 48155.7164        | 0.9876| •     | •           | •     | •           |
| 48155.7240        | 0.0086| •     | •           | •     | •           |
| 48155.7300        | 0.0251| •     | •           | •     | •           |
| 48155.7398        | 0.0521| •     | •           | •     | •           |
| 48155.7420        | 0.0581| •     | •           | •     | •           |
| 48155.7518        | 0.0850| 3.2*  | −6.0        | −123.6*| −3.6        |
| 48155.7580        | 0.1021| 11.8* | −3.6        | −145.1*| −8.7        |
| 48155.7567        | 0.1233| 16.7  | −5.7        | −157.1 | −2.0        |
| 48155.7712        | 0.1384| 17.5  | −9.3        | −184.3 | −17.3       |
| 48155.7760        | 0.1516| 19.0  | −11.3       | −179.3 | −2.9        |
| 48155.7832        | 0.1713| 33.6  | −1.3        | −187.2 | 1.3         |
| 48155.7900        | 0.1900| 46.8  | 8.5         | −193.1 | 4.6         |
| 48155.7989        | 0.2145| 43.0  | 1.6         | −203.6 | 2.5         |
| 48155.8050        | 0.2313| 45.9  | 3.3         | −195.4 | 14.0        |
| 48155.8126        | 0.2522| 40.5  | −2.6        | −223.0 | −12.4       |
| 48155.8203        | 0.2733| 52.7  | 10.3        | −197.0 | 11.7        |
| 48155.8263        | 0.2898| 35.2  | −5.8        | −207.4 | −2.5        |
| 48155.8354        | 0.3148| 33.9  | −3.6        | −195.7 | 0.1         |
| 48155.8416        | 0.3319| 39.9  | 5.7         | −193.6 | −6.8        |
| 48155.8510        | 0.3577| 23.6  | −4.3        | −171.1 | −1.1        |
| 48155.8572        | 0.3747| 42.9  | 19.9        | −146.6 | 10.2        |
| 48155.8649        | 0.3959| 23.7  | 7.6         | −123.1 | 15.3        |
| 48155.8716        | 0.4143| •     | •           | •     | •           |
| 48155.8807        | 0.4393| •     | •           | •     | •           |
| 48155.8877        | 0.4586| •     | •           | •     | •           |

| **EF Dra (DDO)**  |       |       |             |       |             |
| 48764.6756        | 0.0994| −75.2 | −4.4        | 164.0 | 27.2        |
| 48764.6901        | 0.1336| −86.0 | −7.3        | 162.9 | −22.7       |
| 48764.7063        | 0.1718| −91.8 | −6.4        | 216.1 | −11.6       |
| 48764.7205        | 0.2053| −83.0 | 6.2         | 274.2 | 22.3        |
| 48764.7385        | 0.2477| −85.8 | 5.4         | 252.5 | −11.4       |
| 48764.7528        | 0.2814| −79.3 | 10.9        | 254.3 | −3.6        |
| 48764.7694        | 0.3206| −74.3 | 12.1        | 238.1 | 3.8         |
| 48764.7835        | 0.3598| −75.9 | 5.2         | 206.4 | 5.4         |
Table 1. (continued)

| Hel JD − 2 400 000 | Phase | \( V_1 \) | \( \Delta V_1 \) | \( V_2 \) | \( \Delta V_2 \) |
|-------------------|-------|---------|-----------|---------|-----------|
| 48788.6431        | 0.6243| −3.7    | 4.1       | −302.9  | −45.1     |
| 48788.6577        | 0.6587| 1.2     | 2.3       | −287.9  | 11.5      |
| 48788.6748        | 0.6990| −7.6    | −11.8     | −311.9  | 20.9      |
| 48788.6894        | 0.7334| 13.9    | 7.5       | −366.5  | −19.8     |
| 48788.7064        | 0.7736| −3.3    | −9.4      | −313.9  | 31.1      |
| 48788.7208        | 0.8075| 7.2     | 3.7       | −318.0  | 10.6      |
| 48788.7390        | 0.8504| −2.8    | −0.1      | −297.9  | −8.5      |
| 48788.7535        | 0.8846| 3.3     | 13.1      | −285.0  | −39.8     |
|                   |       |         |           |         |           |
| V829 Her (DDO)    |       |         |           |         |           |
| 48415.6430        | 0.5188| ...     | ...       | ...     | ...       |
| 48415.6642        | 0.5780| ...     | ...       | ...     | ...       |
| 48415.6839        | 0.6330| −78.8   | 0.3       | 144.4   | −3.1      |
| 48415.7024        | 0.6846| −106.3  | −11.6     | 172.1   | −13.4     |
| 48415.7202        | 0.7343| −99.0   | 2.6       | 202.3   | −0.2      |
| 48415.7372        | 0.7818| −97.4   | 2.9       | 205.7   | 6.5       |
| 48415.7545        | 0.8301| −81.3   | 9.8       | 183.0   | 6.3       |
| 48415.7941        | 0.9407| ...     | ...       | ...     | ...       |
| 48415.8107        | 0.9870| ...     | ...       | ...     | ...       |
| 48415.8269        | 0.0322| ...     | ...       | ...     | ...       |
| 48416.6938        | 0.4527| ...     | ...       | ...     | ...       |
| 48416.7110        | 0.5008| ...     | ...       | ...     | ...       |
| 48416.7282        | 0.5442| ...     | ...       | ...     | ...       |
| 48416.7461        | 0.5988| −69.2   | −4.2      | 109.0   | −3.8      |
| 48416.7626        | 0.6448| −89.9   | −6.5      | 145.4   | −12.5     |
| 48416.7791        | 0.6909| −94.9   | 1.1       | 193.5   | 4.7       |
| 48416.7960        | 0.7381| −103.1  | −1.3      | 208.9   | 5.9       |
| 48417.6141        | 0.0223| ...     | ...       | ...     | ...       |
| 48417.6350        | 0.0807| ...     | ...       | ...     | ...       |
| 48417.6558        | 0.1388| 55.5    | 1.1       | −180.4  | −0.9      |
| 48417.6766        | 0.1968| 76.8    | 6.5       | −210.5  | 7.9       |
| 48764.8378        | 0.5143| ...     | ...       | ...     | ...       |
| 48764.8523        | 0.5548| ...     | ...       | ...     | ...       |
| 48764.8666        | 0.5947| ...     | ...       | ...     | ...       |
| 48788.7822        | 0.3700| 54.9    | 3.7       | −188.6  | −17.0     |
| 48788.7939        | 0.4027| 36.7    | −0.7      | −143.7  | −5.7      |
| 50489.9281        | 0.1819| 64.0    | −3.2      | −213.5  | −2.7      |
| 50489.9389        | 0.2120| 68.6    | −4.1      | −225.5  | −1.2      |
| 50489.9515        | 0.2472| 68.3    | −6.9      | −227.6  | 2.8       |
| 50489.9622        | 0.2771| 74.2    | 0.3       | −222.1  | 5.2       |
| FG Hya (DDO)      |       |         |           |         |           |
| 50398.9056        | 0.4075| ...     | ...       | ...     | ...       |
| 50398.9167        | 0.4414| ...     | ...       | ...     | ...       |
| 50398.9287        | 0.4780| ...     | ...       | ...     | ...       |
| 50398.9396        | 0.5112| ...     | ...       | ...     | ...       |
| 50398.9526        | 0.5509| ...     | ...       | ...     | ...       |
| 50414.7690        | 0.7964| 25.2    | −3.6      | −295.5  | 19.0      |
| 50414.7798        | 0.8293| 29.5    | 3.6       | −293.5  | −4.6      |
| 50414.7928        | 0.8690| 31.9    | 11.2      | −236.9  | 5.3       |
| 50414.8037        | 0.9022| 16.7    | 1.6       | −170.2\(^a\) | 21.4\(^b\) |
| 50438.8378        | 0.2144| −36.5   | 4.3       | 317.6   | 8.9       |
| 50438.8486        | 0.2474| −41.5   | 0.2       | 301.7   | −14.9     |
| 50438.8622        | 0.2889| −41.4   | −0.8      | 316.8   | 9.7       |
### Table 1. (continued)

| Hel JD – 2 400 000 | Phase | $V_1$ | $\Delta V_1$ | $V_2$ | $\Delta V_2$ |
|--------------------|-------|-------|--------------|-------|--------------|
| 50438.8731         | 0.3221 | -40.7 | -2.6         | 281.5 | -2.6         |
| 50438.8855         | 0.3599 | -36.4 | -3.0         | 256.4 | 13.6         |
| 50438.8954         | 0.3901 | -25.8 | 2.8          | 212.0 | 12.4         |
| 50469.6340         | 0.1534 | -40.8 | -5.5         | 270.8 | 11.7         |
| 50469.6447         | 0.1860 | -36.0 | 2.8          | 295.5 | 4.5          |
| 50469.6582         | 0.2272 | -55.1 | -13.8        | 314.6 | 1.2          |
| 50469.6691         | 0.2605 | -45.4 | -3.8         | 306.3 | -9.7         |
| 50469.6813         | 0.2977 | -41.9 | -1.8         | 295.9 | -6.4         |
| 50469.6920         | 0.3303 | -33.2 | 4.0          | 276.1 | -0.4         |
| 50469.7989         | 0.6564 | 29.0  | 4.7          | -274.7| -0.8         |
| 50469.8097         | 0.6894 | 32.7  | 5.0          | -304.4| 0.6          |
| 50469.8215         | 0.7254 | 27.5  | -2.4         | -312.0| 12.2         |
| 50469.8323         | 0.7583 | 15.7  | -14.6        | -325.2| 2.4          |
| 50469.8450         | 0.7970 | 28.3  | -0.4         | -318.5| -4.4         |
| 50469.8558         | 0.8300 | 14.7  | -11.2        | -294.6| -6.4         |
| 50477.7347         | 0.8633 | 12.1  | -9.5         | -255.9| -6.1         |
| 50477.7451         | 0.8950 | 16.0  | -0.4         | -199.6| 3.6          |
| 50483.6474         | 0.8991 | 16.1  | 0.5          | -177.1| 19.6         |

**AP Leo (DAO)**

|        |       |       |       |       |       |
|--------|-------|-------|-------|-------|-------|
| 48310.7545 | 0.2330 | -102  | 1     | 224   | -12   |
| 48310.7701 | 0.2692 | -103  | 0     | 220   | -16   |
| 48310.7925 | 0.3213 | -98   | -2    | 210   | -2    |
| 48311.7786 | 0.6126 | 30    | 4     | -205  | -8    |
| 48311.7976 | 0.6568 | 53    | 13    | -266  | -21   |
| 48311.8116 | 0.6893 | 37    | -10   | -248  | 21    |
| 48311.8304 | 0.7330 | 63    | 10    | -287  | 0     |
| 48311.8439 | 0.7644 | 49    | -4    | -290  | -2    |
| 48311.8572 | 0.7953 | 48    | -2    | -251  | 26    |
| 48311.8705 | 0.8262 | 38    | -6    | -263  | -4    |
| 48311.8839 | 0.8573 | 46    | 10    | -244  | -13   |
| 48311.8975 | 0.8889 | 41    | 16    | -186  | 8     |
| 48312.5827 | 0.1085 | -60   | 14    | 143   | 2     |
| 48312.8664 | 0.1403 | -94   | -8    | 160   | -18   |
| 48312.8810 | 0.1742 | -96   | -1    | 207   | -1    |
| 48312.8953 | 0.2074 | -92   | 10    | 216   | -12   |
| 48312.9106 | 0.2430 | -98   | 5     | 235   | -2    |
| 48312.9262 | 0.2792 | -90   | 12    | 242   | 8     |
| 48312.9427 | 0.3176 | -93   | 3     | 203   | -11   |
| 48312.9607 | 0.3595 | -94   | -8    | 175   | -3    |
| 48312.9792 | 0.4054 | ...   | ...   | ...   | ...   |

**UV Lyn (DAO)**

|        |       |       |       |       |       |
|--------|-------|-------|-------|-------|-------|
| 48254.7929 | 0.6929 | -80.8 | 0.5   | 213.0 | -7.2  |
| 48254.8101 | 0.7343 | -83.4 | 3.0   | 237.1 | 3.0   |
| 48254.8261 | 0.7729 | -95.2 | -9.2  | 237.5 | 4.7   |
| 48254.8530 | 0.8377 | -65.8 | 8.3   | 195.5 | -4.9  |
| 48254.8691 | 0.8765 | -58.8 | 2.2   | 175.5 | 10.7  |
| 48254.9526 | 0.0777 | ...   | ...   | ...   | ...   |
| 48254.9699 | 0.1194 | 61.0  | 2.4   | -155.6| 5.3   |
| 48254.9846 | 0.1548 | 67.9  | -3.2  | -206.0| -11.0 |
| 48255.0010 | 0.1943 | 84.1  | 3.2   | -226.8| -5.2  |
| 48255.0278 | 0.2589 | 94.6  | 8.6   | -248.2| -12.6 |
| 48255.0446 | 0.2994 | 77.8  | -4.2  | -211.5| 13.2  |
| Hel JD − 2 400 000 | Phase | \(V_1\) | \(\Delta V_1\) | \(V_2\) | \(\Delta V_2\) |
|-------------------|-------|---------|-------------|---------|-------------|
| 48255.0607        | 0.3382| 67.4    | −5.8       | −204.7  | −4.0        |
| 48255.0770        | 0.3775| 55.6    | −4.3       | −161.6  | 2.8         |
| 48260.7996        | 0.1675| 76.0    | 1.2        | −204.9  | 0.0         |
| 48260.8124        | 0.1984| 84.9    | 3.3        | −221.1  | 2.5         |
| 48260.8234        | 0.2249| 75.7    | −9.4       | −299.1  | 3.9         |
| 48260.8366        | 0.2567| 80.2    | −5.9       | −237.8  | −2.1        |
| 48260.8672        | 0.3304| 66.0    | −9.4       | −205.8  | 0.7         |
| 48260.8798        | 0.3608| 64.5    | −1.6       | −172.5  | 8.7         |
| 48260.8929        | 0.3923| …       | …          | …       | …           |
| 48260.9855        | 0.6155| −67.6   | −9.9       | 165.3   | 0.4         |
| 48260.9987        | 0.6473| −82.2   | −12.8      | 196.0   | 8.2         |
| 48261.0091        | 0.6724| −82.9   | −6.2       | 195.9   | −11.8       |
| 48261.0211        | 0.7013| −78.2   | 4.6        | 217.8   | −6.5        |
| 48261.0314        | 0.7261| −70.0   | 15.9       | 224.1   | −8.5        |
| 48261.0438        | 0.7560| −87.4   | −0.6       | 253.9   | 18.8        |
| 48261.0538        | 0.7801| −95.8   | −10.5      | 233.6   | −2.5        |
| 48261.0651        | 0.8073| −76.5   | 4.8        | 210.5   | −9.7        |
| 48261.0814        | 0.8466| −73.2   | −1.8       | 214.9   | 21.7        |
| 48261.0939        | 0.8767| −53.8   | 7.1        | 199.2   | 4.7         |
| 48261.1014        | 0.8948| …       | …          | …       | …           |

**BB Peg (DDO)**

| Hel JD − 2 400 000 | Phase | \(V_1\) | \(\Delta V_1\) | \(V_2\) | \(\Delta V_2\) |
|-------------------|-------|---------|-------------|---------|-------------|
| 50321.7422        | 0.3230| 54.1    | −4.1       | −263.6  | 7.6         |
| 50321.7546        | 0.3573| 49.1    | 2.1        | −241.7  | −1.7        |
| 50321.8049        | 0.4964| …       | …          | …       | …           |
| 50321.8190        | 0.5354| …       | …          | …       | …           |
| 50321.8356        | 0.5813| −70.0\(^a\) | 6.4       | 140.2\(^a\) | 37.0       |
| 50321.8503        | 0.6220| −94.2   | 2.1        | 175.9   | 17.4        |
| 50321.8675        | 0.6696| −110.8  | 3.1        | 206.5   | −1.0        |
| 50324.6104        | 0.2571| 65.2    | −3.0       | −302.5  | −3.7        |
| 50324.6216        | 0.2880| 65.4    | −0.1       | −278.4  | 13.0        |
| 50324.6336        | 0.3212| 53.2    | −5.5       | −270.3  | 2.2         |
| 50324.6445        | 0.3514| 55.2    | 6.0        | −251.9  | −5.8        |
| 50324.6569        | 0.3857| 40.3    | 5.3        | −209.0  | −2.3        |
| 50324.6678        | 0.4158| 30.1\(^a\) | 10.0      | −183.7\(^a\) | −18.5       |
| 50324.7196        | 0.5591| …       | …          | …       | …           |
| 50324.7346        | 0.6006| −103.0  | −16.7      | 127.9   | −2.9        |
| 50324.7785        | 0.7221| −123.4  | 1.2        | 223.4   | −13.7       |
| 50324.7868        | 0.7450| −136.6  | −10.6      | 236.0   | −5.2        |
| 50324.7974        | 0.7743| −114.2  | 10.7       | 226.3   | −11.8       |
| 50324.8074        | 0.8020| −119.4  | 1.5        | 238.1   | 11.1        |
| 50324.8203        | 0.8377| −120.0  | −8.3       | 198.7   | −2.6        |
| 50324.8313        | 0.8681| −92.0   | 8.5        | 177.8   | 7.6         |
| 50324.8445        | 0.9046| −98.6\(^a\) | −14.9      | 147.4\(^a\) | 23.9       |
| 50330.6851        | 0.0611| …       | …          | …       | …           |
| 50330.6964        | 0.0924| 30.1\(^a\) | 5.7       | −197.0\(^a\) | −19.9       |
| 50330.7140        | 0.1411| 47.7    | 1.3        | −245.7  | −7.5        |
| 50330.7274        | 0.1781| 56.6    | −1.9       | −270.9  | 1.1         |
| 50330.7418        | 0.2180| 62.3    | −4.0       | −288.2  | 5.4         |
| 50330.7529        | 0.2487| 64.3    | −4.0       | −291.0  | 8.1         |

\(^a\) Values obtained from the author’s analysis.
| AQ Psc (DDO) |  |  |  |  |  |  |
|--------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 50312.7508   | 0.4320          | ...             | ...             | ...             | ...             | ...             | ...             |
| 50312.7636   | 0.4589          | ...             | ...             | ...             | ...             | ...             | ...             |
| 50312.7780   | 0.4892          | ...             | ...             | ...             | ...             | ...             | ...             |
| 50312.7889   | 0.5121          | ...             | ...             | ...             | ...             | ...             | ...             |
| 50312.8039   | 0.5436          | ...             | ...             | ...             | ...             | ...             | ...             |
| 50312.8145   | 0.5659          | ...             | ...             | ...             | ...             | ...             | ...             |
| 50312.8294   | 0.5972          | 23.8            | 2.5             | −171.2<sup>a</sup> | −7.3     | ...             | ...             |
| 50312.8394   | 0.6183          | 27.0            | −0.4            | −202.8           | −11.8   | ...             | ...             |
| 50312.8506   | 0.6418          | 38.6            | 5.2             | −215.7           | 2.0     | ...             | ...             |
| 50312.8565   | 0.6542          | 38.8            | 2.6             | −225.0           | 4.9     | ...             | ...             |
| 50321.8836   | 0.6344          | 32.3            | 0.7             | −216.1           | −6.3   | ...             | ...             |
| 50321.8945   | 0.6574          | 37.3            | 0.5             | −228.2           | 4.6     | ...             | ...             |
| 50321.9063   | 0.6822          | 43.2            | 1.9             | −249.5           | 3.1     | ...             | ...             |
| 50324.8788   | 0.9321          | ...             | ...             | ...             | ...     | ...             | ...             |
| 50324.8898   | 0.9552          | ...             | ...             | ...             | ...     | ...             | ...             |
| 50324.9028   | 0.9826          | ...             | ...             | ...             | ...     | ...             | ...             |
| 50329.6924   | 0.631           | ...             | ...             | ...             | ...     | ...             | ...             |
| 50329.7019   | 0.0731          | ...             | ...             | ...             | ...     | ...             | ...             |
| 50329.7239   | 0.1193          | −53.6           | −0.1            | 173.8            | 7.3     | ...             | ...             |
| 50329.7357   | 0.1441          | −60.3           | −0.6            | 189.2            | −5.0   | ...             | ...             |
| 50329.7484   | 0.1708          | −64.1           | 1.1             | 206.3            | −12.2   | ...             | ...             |
| 50329.7593   | 0.1937          | −68.3           | 0.5             | 220.2            | −13.9   | ...             | ...             |
| 50329.7726   | 0.2217          | −72.2           | −0.7            | 227.2            | −19.0   | ...             | ...             |
| 50329.7833   | 0.2442          | −70.7           | 1.7             | 236.2            | −14.0   | ...             | ...             |
| 50329.7958   | 0.2705          | −70.8           | 1.2             | 247.2            | −1.0    | ...             | ...             |
| 50329.8065   | 0.2930          | −70.0           | 0.3             | 244.8            | 4.0     | ...             | ...             |
| 50329.8200   | 0.3214          | −68.1           | −1.5            | 226.1            | 1.7     | ...             | ...             |
| 50329.8309   | 0.3443          | −59.9           | 2.4             | 214.7            | 9.2     | ...             | ...             |
| 50329.8432   | 0.3701          | −55.9           | 0.4             | 202.4            | 23.5    | ...             | ...             |
| 50363.7596   | 0.6822          | 39.5            | −1.8            | −250.3           | 2.3     | ...             | ...             |
| 50363.7702   | 0.7045          | 42.1            | −2.1            | −267.9           | −2.4    | ...             | ...             |
| 50363.7818   | 0.7289          | 42.5            | −3.6            | −267.1           | 6.8     | ...             | ...             |
| 50363.7927   | 0.7518          | 46.9            | 0.3             | −281.8           | −5.6    | ...             | ...             |
| 50363.8053   | 0.7783          | 44.6            | −1.1            | −268.3           | 3.7     | ...             | ...             |
| 50363.8162   | 0.8012          | 46.7            | 3.1             | −264.6           | −1.9    | ...             | ...             |
| 50363.8298   | 0.8298          | 41.1            | 1.8             | −266.3           | −22.5   | ...             | ...             |
| 50363.8473   | 0.8666          | 28.5            | −2.9            | −217.8           | −9.1    | ...             | ...             |

<sup>a</sup>Half weight given in the orbital solution.
<sup>b</sup>Not used in the orbital solution due to strong influence of the proximity effects and large deviations from circular model.
<sup>c</sup>Radial velocities of AP Leo were measured with the accuracy of 1 km/s.
Table 2. Spectroscopic orbital elements of 10 W UMa systems

| Name      | Type | $\gamma$ | $K_1$ | $K_2$ | $\epsilon_1$ | $\epsilon_2$ | $T_0 - 2400000$ | $a_1 \sin i$ | $m_1 \sin^3 i$ | $q = m_2/m_1$ |
|-----------|------|----------|-------|-------|--------------|--------------|-----------------|--------------|----------------|---------------|
| GZ And    | W    | 0.0(12)  | 129.7(13) | ±5.9 | 50398.5521(08) | 0.782(08) | 1.164(31) | 0.514(08) |
|           |      |          | 252.1(28) | ±12.3 | 0.3050067 | 1.519(17) | 0.599(13) |
| V417 Aql  | W    | -14.2(14) | 97.0(16) | ±6.5 | 50321.5629(10) | 0.710(12) | 1.376(36) | 0.362(07) |
|           |      |          | 268.2(27) | ±11.1 | 0.37031142 | 1.962(20) | 0.498(15) |
| LS Del    | W    | -25.9(14) | 69.0(16) | ±6.2 | 48154.9932(08) | 0.496(12) | 0.449(11) | 0.375(10) |
| EF Dra    | A    | -42.2(35) | 48.9(43) | ±7.9 | 48788.3784(18) | 0.410(36) | 1.699(91) | 0.160(14) |
| V829 Her  | W    | -13.4(10) | 88.6(15) | ±5.2 | 48417.6061(09) | 0.627(11) | 0.754(19) | 0.408(08) |
| FG Hya    | A    | -5.7(12) | 36.0(13) | ±6.4 | 0.3581502 | 1.535(15) | 0.308(09) |
| AP Leo    | A    | -25.1(21) | 78.2(23) | ±8.9 | 0.327835 | 2.088(12) | 0.157(07) |
| BB Peg    | W    | -28.9(14) | 97.2(15) | ±7.2 | 50324.5174(09) | 0.694(11) | 1.369(33) | 0.360(06) |
| AQ Psc    | A    | -12.9(04) | 59.5(04) | ±2.0 | 50333.4720(09) | 0.559(04) | 1.355(27) | 0.226(02) |
| BB Peg    | W    | 270.2(25) | ±11.5 | 0.361501 | 1.930(18) | 0.493(13) |
| AQ Psc    | A    | 263.3(19) | ±10.2 | 0.4756056 | 2.474(19) | 0.307(05) |

Notes to Table 2.

The standard errors of the circular solutions are expressed in units of last decimal places quoted; they are given in parentheses after each value. For example, the first entry 0.0(12) should be interpreted as 0.0 ± 1.2. The average radial velocities $\gamma$, the velocity amplitudes $K_i$ and the standard unit-weight errors of the solutions are expressed in $km s^{-1}$. The derived quantities of the orbit dimensions $a_i$ and component masses $m_i$ are in the solar radius and solar mass units $R_{\odot}$ and $M_{\odot}$. 
Radial Velocity Studies of Close Binary Stars. I

Wenxian Lu and Slavek M. Rucinski
e-mail: lu@astro.utoronto.ca, rucinski@astro.utoronto.ca

David Dunlap Observatory, University of Toronto
P.O.Box 360, Richmond Hill, Ontario L4C 4Y6, Canada

June 30, 2021

ABSTRACT

Radial velocity data are presented for 10 W UMa-type systems: GZ And, V417 Aql, LS Del, EF Dra, V829 Her, FG Hya, AP Leo, UV Lyn, BB Peg, AQ Psc, together with preliminary, circular-orbit determinations of spectroscopic elements, with the main goal of obtaining mean radial velocities and mass-ratios for these systems. This is the first part of a series which will contain radial velocity data for Northern-hemisphere, short-period eclipsing binaries, accessible to medium-resolution spectroscopic studies with 1.8-meter class telescopes.

Subject headings: stars: close binaries - stars: eclipsing binaries – stars: variable stars

1. INTRODUCTION

Contact binary stars consisting of solar type components (also called W UMa-type binary stars) are very common: According to the new, unbiased statistics, a by-product of the OGLE microlensing project, their apparent frequency of occurrence among main sequence stars of spectral types F to K (intrinsic colors $0.4 < V - I_C < 1.4$) is about $1/130 - 1/100$, which leads to the spatial frequency at the level $1/60 - 1/80$ (Rucinski 1998). Most of them have orbital periods within $0.25 < P < 0.7$ days. They apparently do not exist below the orbital period of 0.22 days and they are rare at orbital periods longer than 0.7 days and spectral types earlier than about F0 to F2. The kinematic data for contact systems in the solar neighborhood (Guinan & Bradstreet 1988) and the spatial distribution in the Baade's Window direction (Rucinski 1997a, 1997b = R97a, R97b), suggest an Old Disk population of interacting binaries formed primarily during the Turn-Off-Point stage of evolution. This stage is conductive to rapid synchronization and formation of contact systems from close, but detached binaries when component stars expand and are able to interact to the point of mutual contact.

While survey data such as from the OGLE project can give statistical information on the relative numbers of stars in various stages of evolution and on duration of the pre- and in-contact stages, only detailed studies of individual systems in the solar neighborhood can yield absolute
parameters of the systems and can help in establishing correct kinematic properties of this contact binary population. Also, precise data for individual bright contact systems should lead to improvements in the luminosity calibration and in their use as distance indicators (R97a, R97b). These aspects formed the main rationale of a program started by the current paper of the series.

The Hipparcos astrometric satellite provided the first set of reliable parallaxes and proper motions for a sample of contact binaries: Parallaxes giving error in absolute magnitude $\epsilon M_V < 0.5$ became available for 40 systems (Rucinski & Duerbeck 1997), with half that number having errors $\epsilon M_V < 0.25$. Most of these systems have high-quality proper-motion determinations with errors at the level of $1 - 10$ milli-arcsec per year. The proper motions data can be combined with mean systemic radial velocities $\gamma$ to provide spatial velocities of these stars. However, many systems with excellent parallax and tangential-velocity data from Hipparcos lack correspondingly accurate radial velocity data. The present paper describes observations of 10 systems collected over the recent years at the Dominion Astrophysical Observatory and at the David Dunlap Observatory (DDO), together with results of a new program which was initiated at the DDO to determine primarily the mean radial velocities $\gamma$. It is hoped that the next papers of this series will be more homogeneous in that they will contain the DDO results only; they will describe typically ten systems per paper.

Determinations of $\gamma$ velocities cannot be usually separated from determinations of the velocity amplitudes, $K_1$ and $K_2$. Thus, the important product of this program are also the spectroscopic mass-ratios, $q = K_2/K_1$, as well as individual masses of the components. For determinations of stellar masses, orbital inclination angles are needed, but these can only come from light curve solutions. In turn, light curve solutions gain in quality when spectroscopic values of $q$ are used. Although we did recognize that combined spectroscopic – photometric solutions would provide the most consistent approach, we decided not to perform full solutions of our program binaries through combination of the new velocity data with the light curves from the literature. The main reason for this decision was that light curves were simply not available for many of our systems or that in some cases they did exist, but were of disputable quality. Thus, the goal of these observations was simply to provide radial velocity data and the simplest possible circular solutions giving $\gamma$, $q$, $K_1$ and $K_2$. The selection of the objects was based on their brightness, visibility from the northern hemisphere and availability of astrometric data from the Hipparcos satellite. It is hoped that this program will lead eventually spectroscopic data for all short period and contact binaries accessible to 2-meter class Northern-hemisphere telescopes equipped with spectrographs providing spectral resolutions of the order of 10,000 – 15,000.

2. OBSERVATIONS AND DATA REDUCTIONS

Observations were collected at the Dominion Astrophysical Observatory (DAO), Victoria, B.C. for 3 stars (LS Del, AP Leo, UV Lyn) and at the David Dunlap Observatory (DDO) near Toronto for the remaining 7 stars. At DAO, the 1.8-meter telescope and the “21121” spectrograph
giving dispersion of 15 Å/mm were used. The CCD detectors, central wavelengths and spectral windows were not the same so that they are described below in discussions of individual systems. Typically, about 240 Å were covered at 0.23 to 0.25 Å/pixel at 4160 or 5020 Å. At DDO, the 1.9-meter telescope and the Cassegrain spectrograph illuminating a CCD at a dispersion of 10.8 Å/mm corresponding to about 0.2 Å/pixel or about 12 km/s/pixel was used for almost all observations (see also the descriptions for individual systems below). All the spectra for stars observed at DDO were centered at 5185 Å giving the spectrum coverage of 210 Å.

The velocity determinations of binary component stars were done using cross-correlation of spectra with standard stars (program VCROSS, Hill 1982) or broadening-function (BF) algorithms (Rucinski 1992), which also use spectra of sharp-line standard stars. The former method was used for the systems observed at DAO, while the latter method was used for the systems observed at DDO. In both cases, the radial velocities of stars were determined by fitting Gaussians to the peaks. Tests showed that systematic differences between VCROSS and BF results were well below the level of formal errors so that it was decided to disregard this minor inconsistency in the methodology.

Spectra of different stars were used as sharp-line templates for cross-correlation and broadening-function determinations. They were, for systems observed at the DAO: HD 32963 (G2V) for LS Del, HD 126053 (G1V) for AP Leo, UV Lyn (HD 22484 (F8V) and HD 32963 (G2V)); at the DDO, HD 22484 (F8V) was used for AQ Psc, V417 Aql, BB Peg, GZ And, and FG Hya, whereas HD 102870 (F9V) was used for EF Dra and HD 187691 (F8V) was used for V829 Her.

The spectra of the program stars were reduced with IRAF\(^1\). The standard procedures were employed, which consisting of de-biasing, cosmic-ray removal, flat-fielding, extraction of one-dimensional spectra, wavelength calibration, and rectification. The radial velocity orbits were solved using programs RVORBIT by Graham Hill (1986, private communication) and SBCM by Chris Morbey (1975). For each system, circular solutions of the form: \( V(t) = \gamma + K_i \sin(\phi) \), with \( \phi \) being the phase, were made separately for each component and then for the whole system. No significant differences in \( \gamma \) velocities for separate solutions were noted in any of the ten systems. Normally, unit weights were given to individual observations with exceptions of those indicating blending at eclipses. The initial epoch \( T_0 \) was included among unknowns in all cases due to lack of recent photometric eclipse timings or possibilities of period changes. The values of \( T_0 \) which we give correspond to moments of the deeper eclipses for each of the systems.

Standard stars were observed on each observing night of program stars. These observations were used to check zero points in velocity. For DAO and early DDO observations, zero points were accurate to 1.2 km/sec on average, while for the 1996-1997 DDO observations, the accuracy

\(^1\)IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
(limited by the spectrograph flexure) was slightly lower and equaled 1.6 km/sec.

From a series of over 60 observations of IAU standard stars, it was found that the velocity of the template-star HD 22484, which was used for the radial velocity determinations of the DDO observations, had the measured value by 1.8 km/sec more negative than the IAU value. The effect may have been caused by a nightly instability of the Cassegrain spectrograph. Thus, the derived radial velocities for five systems, AQ Psc, V417 Aql, BB Peg, GZ And, and FG Hya, should be increased by 1.8 km/sec, leading to a corresponding increase in the derived γ velocity for each of these systems. This value of 1.8 km/s may be taken as an estimate of the external error of our observations.

The observations are listed in Table 1 listing the heliocentric Julian Day of the exposure, the adopted phase and the two radial velocity determinations, together with the deviations from the circular solution. The stars are arranged in this table in the variable-star name order, that is by the alphabetic order of constellations. The next section discusses individual systems. For each system, we first describe the observations and then summarize briefly how they relate to the previous existing data. For some quantities we quote determination uncertainties; they are given in parentheses, following the actual numbers. This convention is used in Table 2 which summarizes the results of the paper. Figures 1 – 3 show individual observations for the program stars together with the respective sinusoidal fits.

3. RESULTS FOR INDIVIDUAL SYSTEMS

3.1. GZ And

The spectroscopic orbit presented here, and based on the DDO observations has been determined for the first time.

A total of 27 spectra were obtained in the period of September – December 1996. The exposure times were 15 minutes corresponding to about 0.034 of the orbital period. This time resolution is a somewhat lower than for the other systems due to the shortness of the period. The orbital period of 0.3050067 day has been adopted after Liu et al. (1987).

The system was discovered as a W UMa-type binary by Walker (1973), as a brightest component (A) of a visual multiple system ADS 1693. whose properties were studied later by Walker (1991, 1996). He claimed that, additionally, the W UMa binary belongs to a close triple system with the period of about 5.3 years for the wide pair. Indeed, on the basis of the photometric properties it appears that all visual components of ADS 1693, except star D, are probably physical members of the multiple system. However, we have been unable to detect the third component in our spectroscopic observations of GZ And (ADS 1963 A). Both Walker (1991, 1996) and Liu et al. (1987) signaled that they made photometric solutions, but their results are not available yet, so that this W-type system still awaits a combined photometric – radial velocity
investigation.

3.2. V417 Aql

The spectroscopic orbit presented here has been determined for the first time. The system was observed at DDO in August – September 1996. A total of 22 spectra were obtained, all of them at phases around the orbital quadratures. The exposure times were 15 minutes long, corresponding to a phase resolution of 0.028. A period of 0.37031142 was adopted in the spectroscopic orbit solution, following Faulkner (1986).

V417 Aql was discovered by Hoffmeister (1935). There were few investigations of this system other than those devoted to timing of eclipse minima. Recently, Samec et al. (1997) obtained high-precision photometric light curves and made solutions of geometric elements. Their mass ratio of $q = 0.3684$ is almost the same as our spectroscopic value of 0.362. By combining the photometric solution of Samec et al. with our radial velocity solution, the following absolute parameters can be derived: $a = 2.68 \, R_\odot$, side radii $R_1 = 1.29 \, R_\odot$, and $R_2 = 0.80 \, R_\odot$, and masses $M_1 = 1.40 \, M_\odot$, $M_2 = 0.50 \, M_\odot$. The degree of contact is 19%. This W-type system is very similar to BB Peg which we discuss below.

3.3. LS Del

The spectroscopic orbit for this system is presented here for the first time. The star was observed at DAO with the “21121” spectrograph and the RCA2 CCD detector at the dispersion of 15 Å/mm, or the scale 0.25 Å/pixel. The binary was observed only on two nights, September 19 and 21, 1990. The spectra were centered at 4160 Å with a coverage of 250 Å. 42 observations were obtained, of which 29 were at orbital quadratures, and 13 were at conjunctions. The conjunctions were observed unintentionally, purely because of the inaccurately known period. Typical exposure time was 8 minutes corresponding to 0.015 in orbital phases. A single spectrum at low dispersion taken in the blue region showed that the spectral type of the star is G0V, not G5 as given in Bond (1976). LS Del is a W-type W UMa system.

LS Del system was discovered spectroscopically as a close binary by Bond (1976). Since then, the system has been analyzed several times. Derman (1991) gave a period of 0.3638384, which was used in our solutions of radial velocities for orbital elements. An attempt at a solution of the light curve (Wang et al. 1986), using the mass-ratio from the present RV data, by means of Wilson-Devinney method (Wilson 1979) led to the inclination $i = 48.5$ degrees, almost identical temperatures of components ($T_2$ higher than $T_1$ by 40 degrees, implying a W-type system) and a shallow contact, $f = 7\%$. The absolute dimensions obtained were: $a = 2.44 \, R_\odot$, $M_1 = 1.07 \, M_\odot$ and $M_2 = 0.40 \, M_\odot$. Another photometric analysis of the system was carried out by Weaver (1990), who obtained a similar inclination of $i \simeq 45$ degree and also a weak contact; he suggested
that light variations are probably due to ellipsoidal deformation of components instead of eclipses; the mass-ratio was not given.

3.4. EF Dra

Two sets of spectra were obtained at DDO at two different dispersions, 10.8 Å/mm and 30 Å/mm. Of the total of 43 spectra, only the 16 higher dispersion spectra (obtained in May – June 1992) were used for the radial-velocity determinations, which led to our first-time spectroscopic orbital orbit. The exposures were 20 minutes long, corresponding to 0.033 in orbital phases. The spectra indicated that the system is a triple one (Lu 1993). This circumstance resulted in such a heavy blending of the low dispersion spectra at 30 Å/mm that no reliable radial velocities could be measured; these spectra were not used in our orbital determinations. The third component is probably a physical companion, since its radial velocity of −38 km/sec is very close to the systemic velocity of −42 km/sec of the eclipsing pair.

The system EF Dra was discovered as an X-ray source by the Einstein Observatory Extended Medium Sensitivity Survey (Gioia et al. 1987). Fleming et al. (1989) suggested it to be a W UMa-type variable. Robb & Scarfe (1989) obtained the first light curves and confirmed the suggestion of Fleming et al., giving the orbital period of 0.42400 day. Later, Plewa et al. (1991) refined the period on the basis of their photometric observation. This period was used in our orbital solution. The photometric mass-ratio derived by Plewa et al., \( q \approx 0.125 \) is different from our spectroscopic result probably because they did not take the third light into account. Our analysis shows that EF Dra is an A-type W UMa system with the more massive primary component eclipsed at the deeper minimum.

3.5. V829 Her

The spectroscopic orbit of V829 Her has been determined for the first time. 30 spectra were obtained at DDO, consisting of 26 observations during the first run in June 1991 and May – June 1992 and 4 observations during the second run on February 10, 1997. Of the spectra obtained during the first run, 13 (one half of the total) were secured around the orbital conjunctions due to an inaccurately known period at the time of the observations. The four spectra of the second run were all around the first orbital quadrature. The exposure times were about 15 minutes long corresponding to about 0.03 in orbital phases.

V829 Her was discovered serendipitously as an X-ray source during the Einstein Observatory Extended Medium Sensitivity Survey (Gioia et al. 1987). It was suspected of being a W UMa system by Fleming et al. (1989). Soon thereafter, Robb (1989) obtained photometric observations of the system and confirmed the W UMa variability type. He found a period of 0.35813 which was only approximate due to the short time span. Later, he obtained a time of light minimum
of 2448505.7163 (Robb 1992, private communication) which were combined with two times of minima by Agerer & Hubscher (1995) to derive an ephemeris: Hel Min(pri) = 2447680.8910(11) + 0.3581502(4) E. For this star, as for all our spectroscopic orbit solutions, the photometric values of periods were adopted and our radial velocities were used only to determine the zero-epochs of the spectroscopic orbital solutions.

By combining the observed and synthesized light curves (Robb R.M. 1992, private communication) and BF fits, in the same way as in Rucinski et al. (1993), we derived the following geometrical and absolute parameters for this W-type W UMa system: \(i = 57(2)\) degree, \(f = 15(9)\%\), \(X = 0.030(6)\), \(a = 2.697(13)R_\odot\), \(R_1 = 1.266(6)R_\odot\), \(R_2 = 0.849(4)R_\odot\), \(M_1 = 1.458(21)M_\odot\), \(M_2 = 0.596(10)M_\odot\), and \(q = 0.409(5)\).

### 3.6. FG Hya

The spectroscopic orbit presented here has been determined for the first time with the modern instrumentation, although five prism spectra at a dispersion of 75 Å/mm at H\(\gamma\) were used by Smith (1963), from which he derived a primary semi-amplitude of 92 km/sec, questioned as too large by Mauder (1972).

The current spectroscopic orbit has been based on data obtained at DDO in November 1996 – February 1997. 30 spectra were secured with exposure times of 15 minutes corresponding to 0.032 in orbital phases. The orbital solution assumed the period of 0.327835 following Yang et al. (1991).

After discovery of its light variation by Hoffmeister (1934), FG Hya was the subject of many investigators. Three sets of photometric solutions exist in the literature: Mochnacki & Doughty (1972), Twigg (1979) and Yang et al. (1991). All these investigations found small mass-ratios: 0.145, 0.142, 0.128, none, however, was as small as our spectroscopic value of 0.112. We admit that for such extreme values the spectroscopic mass-ratio may be difficult to determine accurately and that photometric determinations utilizing eclipse contacts may give superior results. All three photometric solutions arrived at a very deep over-contact; the largest being 90% by Yang et al. (1991).

This A-type system deserves further investigation. Assuming the preliminary value of \(i = 87.6\) degree following Yang et al. (1991), simply because their mass ratio was the closest to ours from among several photometric determinations, we derive \(a = 2.32R_\odot\), \(M_1 = 1.41M_\odot\) and \(M_2 = 0.16M_\odot\). These numbers are obviously approximate as the photometric solution was not for the same mass-ratio; for the same reason, we have not evaluated the radii. The point worth noticing is the very low mass of the secondary component.
3.7. AP Leo

The spectroscopic orbit described here has been determined for the first time. The template-spectrum star for the CCF determinations was HD 126053 (G1V).

A total of 21 spectra, all around at quadratures, were obtained on three consecutive nights, February 23, 24, and 25, 1991 at DAO with the 1.8-m telescope and “21121” spectrograph with the RCA2 CCD detector at a dispersion of 15 Å/mm, or 0.23 Å/pixel. All the spectra were centered at 5020 Å with a coverage of 240 Å. The exposure times were 15 – 20 minutes, corresponding to a phase resolution about 0.024 – 0.032. The period of 0.4303546 day by Zhang et al. (1992) was used in the spectroscopic orbit solution. A spectrum taken in blue showed that the spectral type of the system is F7-8V.

Mauder (1967) obtained the first geometrical-elements solution, based on photometric data. He derived a mass-ratio of 0.31 and inclination of 77 degree. A modern photometric solution was carried out by Zhang et al. (1992) who found a mass-ratio of 0.301, which is almost identical to our spectroscopic value. We note that a similar excellent agreement exists for BB Peg which was also analyzed photometrically by this group. However, their photometric solution of AP Leo leads to a hotter, less-massive secondary being eclipsed at the deeper minimum, a configuration which is normally called the W-type subtype of the W UMa systems, whereas our radial velocity curves show that the primary minimum is a transit, i.e. it is the more massive star which is hotter and eclipsed at the deeper minima, suggesting an A-type W UMa system. This discrepancy should be clarified. There is a chance that the photometric solution of Zhang et al. was affected by incorrect placement of spots (parenthetically, we note that the spot locations were unbelievably accurately determined in this solution). Nevertheless, the inclination of 79.9 deg and fractional radii of $r_1 = 0.502$ and $r_2 = 0.284$ (side values) derived by Zhang et al. could be used with some confidence to derive the absolute dimensions: $a = 2.95 R_\odot$, $M_1 = 1.43 M_\odot$, $M_2 = 0.42 M_\odot$, $R_1 = 1.48 R_\odot$, $R_2 = 0.84 R_\odot$. We note that we were not able to detect any spectroscopic signatures of a third body in the system whose existence was suggested by Zhang et al.

3.8. UV Lyn

The spectroscopic orbit of UV Lyn has been determined by us for the first time. The system was observed on two nights, December 29, 1990 and January 4, 1991 at DAO with the 1.8-m telescope and the “21121” spectrograph. Unfortunately, the data were obtained with two CCD detectors on each of the two nights. On the first night, RCA2 (1024 pixels) was used with a coverage of 240 Å, while on the second night, FORD (512 pixels) was used with a coverage of 160 Å. The dispersion was 0.23 Å/pixel for the former detector and 0.31 Å/pixel for the latter. All the spectra were centered at 5020 Å. Two different template stars were used during each night, HD22484 (F8V) and HD32963 (G2V). A total of 31 spectra were accumulated with the exposure times ranging between 15 and 20 minutes, with the corresponding phase resolution of 0.025 to
RV were first measured using V CROSS and then re-measured using BF’s. The velocities given in Table 1 are those obtained by the BF method. The spectroscopic elements were derived by adopting the period of 0.41498088 days from Markworth and Michaels (1982).

The variability of UV Lyn was discovered by Kippenhahn (Geyer et al. 1955). There are three sets of photoelectric observations in the literature, with the most recent one by Zhang et al. (1995) who published complete light curves and listed two times of minima. Earlier photometric data sets were obtained by Bossen (1973) and by Markworth and Michaels (1982); both groups attempted photometric solutions, but derived photometric mass-ratios very different from those presented here so that other parameters of these solutions are obviously highly questionable.

An attempt was made to produce a combined solution of geometrical elements of UV Lyn, based on the light curve by Bossen (1973) and the BF’s obtained here. The light curve by Bossen was used, since the Markworth and Michaels light curves were very perturbed.

The approach consisted of fitting the theoretical BF’s computed with the light-curve/line-profile synthesis program WUMA5 (a very brief information in Hill & Rucinski 1993 and in a short series of papers cited below) to the observed BF’s, using the spectroscopic mass ratio $q$ derived here as the initial value. A similar approach was used in the three papers of a short series: Rucinski 1992, Lu & Rucinski 1993, Rucinski et al. 1993). The mass-ratio changed from the spectroscopic value insignificantly to $q = 0.371(8)$, with the remaining parameters: $i = 67(2)$ deg, $f = 20\%$, $X = 0.018(4)$. The absolute parameters are: $a = 2.914(17) \, R_\odot$, $M_1 = 1.412(31)M_\odot$, $M_2 = 0.523(15)M_\odot$, $R_1 = 1.403(8)R_\odot$, $R_2 = 0.905(5)R_\odot$.

### 3.9. BB Peg

The present spectroscopic-orbit determination is the second one, after the solution by Hrivnak (1990). Our observations were obtained at DDO in August–September 1996. 28 spectra were obtained with exposure times of 15 minutes corresponding to 0.029 in orbital phases. The orbital period in our solution was fixed at the value of 0.361501 determined by Leung et al. (1985).

The system was discovered by Hoffmeister (1931) and since then has been the topic of several investigations. The only spectroscopic orbit solution of Hrivnak (1990) was based on radial velocity data obtained from spectral cross-correlations. His mass-ratio, $q = 0.34 \pm 0.02$, is in a good agreement with ours, which was derived from the BF’s. The mass-ratio derived from CCF method is not too significantly different from the one from BF method, but the cross-correlation method carries a potential of underestimating the amplitude of the more massive star, which would lead to a smaller value of $q$. The most consistent approach in the derivation of physical parameters is a combined solution of photometric and spectroscopic data, as in the case of AH Vir (Lu and

---

2The light curve was made available by the librarian P.D. Hingley at the Royal Astronomical Society, London, UK.
Rucinski 1993) and also in the case of UV Lyn (this paper), which in both cases confirmed the BF result. As we understand Dr. Hrivnak plans to obtain a combined photometric and spectroscopic solution on the basis of his CCF determination of $q$. This will provide an external check on our solutions as the two datasets are both of good quality but also entirely independent of each other.

Several photometric solutions of light curves are available, among them by Cerruit-sola et al. (1981). They derived a mass-ratio 2.49 or, following our convention, $q = 0.40$, which is significantly different from ours. Moreover, they found a rather deep contact configuration of 37%, which is uncommon for W-type W UMa stars. Leung et al. (1985) solved their light curves of BB Peg and derived a mass-ratio of 0.356, which is almost identical to our spectroscopic $q$. They also found a more likely fill-out factor of 12%. Using their geometrical parameters (inclination and fractional radii), the following absolute dimension of this W-type system have been derived: $a = 2.63 R_\odot$, side radii $R_1 = 1.26 R_\odot$ and $R_2 = 0.76 R_\odot$, $M_1 = 1.38 M_\odot$, $M_2 = 0.50 M_\odot$.

3.10. AQ Psc

The spectroscopic orbit of this system is presented for the first time. It was observed at DDO, in August – October 1996. Due to the inaccurately known period, from among our 37 spectra, 11 were secured around conjunctions rather than quadratures. The exposure times were 15 minutes long, corresponding to about 0.022 in orbital phases.

This system has not been investigated extensively before. Pastori (1985) discovered it to be a W UMa variable and gave a period of 0.47564 day. Since then a few more times of minima were available (Muyesseroglu et al. 1996, Demircan, O., 1997, private communication). With these limited material available, we derived a new ephemeris: Hel Min (pri) = 2449283.3292(16) + 0.4756056(4), of which only the period was used in the spectroscopic orbit solution. Although the period was not precisely determined, it should be accurate enough for our spectroscopic solution since the time span of our observations was relatively short. With our well-determined spectroscopic orbit, this A-type system deserves a new photometric investigation.

4. Summary

The paper presented the first installment of radial velocity determinations for ten bright, close-binary systems lacking adequate radial velocity data. The new results have been obtained using the modern techniques of template-matching (cross-correlation and broadening-function) on the basis of observations collected with the 1.8-meter class telescopes at the Dominion Astrophysical Observatory and David Dunlap Observatory. Preliminary, circular-orbit spectroscopic orbit solutions have been obtained for all ten systems with the immediate goal of extracting the “gamma” velocities and mass-ratios. The former will be used for a re-discussion of the kinematics of the contact systems while the latter can serve as an important departure point in combined,
precise photometric/spectroscopic synthesis solutions of individual systems.

The authors would like to thank the directors of Dominion Astrophysical Observatory and of David Dunlap Observatory for generous allocation of observing time.

REFERENCES

Agerer, F., & Hubscher, J. 1995, IBVS, 4222
Bond, H.E. 1976, IBVS, 1214
Bossen, H. 1973, A&AS, 82, 57
Cerruit-Sola, M., Milano, L., & Scaltriti, F. 1981, A&A, 101, 273
Derman, E., Derircan, O., & Selam, S. 1991, A&AS, 90, 301
Faulkner, D.R. 1986, PASP, 98, 690
Fleming, T.A., Gioia, I.M., & Maccacaro, T. 1989, AJ, 98, 692
Geyer, E., Kippenhahn, R., & Strohmeier, W. 1955, Kleine Veroeffentl. Remeis-Sternw. Bamberg, Nr.11
Gioia, I.M., Maccacaro, T., & Wolter, A. 1987, in IAU Symp. 124, Observational Cosmology, eds. A. Hewitt, G. Burbidge, & Li-Zhi Fang (Reidel:Dordrecht), p. 593
Guinan, E.F., & Bradstreet, D.H. 1988, in Formation and Evolution of Low Mass Stars, eds. A. K. Dupree & M. T. Lago (Kluwer, Dordrecht), p. 345
Hill, G. 1982, Publ. Dom. Astrophys. Obs., 16, 59
Hill, G., & Rucinski, S.M. in “Light Curve Modeling of Eclipsing Binary Stars”, ed. E.F. Milone, Springer-Verlag, p.135
Hoffmeister, C. 1931, Astron. Nachr., 242, 133
Hoffmeister, C. 1934, Astron. Nachr., 253, 199
Hoffmeister, C. 1935, Astron. Nachr., 255, 403
Hrivnak, B.J. 1990, BAAS, 22, 129
Leung, K.C., Zhai, D.S., & Zhang, R.X. 1985, AJ, 90, 515
Liu, X.F., Yang,J., & Tan, H.S. 1987, IBVS 3080
Lu, W.X., 1993, IBVS 3947
Lu, W.X., Rucinski, S.M., 1993, AJ, 106, 361.
Markworth, N.L., & Michaels, E.J. 1982, PASP, 94, 350
Mauder, H. 1967, Veroff. Remeis-Sternw. Bamberg, 7, 61
Mauder, H. 1972, A&A, 17, 1
Muyesserroglu, Z., Gurol, B., & Selam, S.O. 1996, IBVS 4380
Mochnacki, S.W., & Doughty, N.A. 1972, MNRAS, 156, 243
Morbey, C. 1975, PASP, 87, 689
Pastori, L. 1985, IBVS 2756
Plewa, T., Haber, G., Wlodarczyk, K.J., & Krzesinski, J. 1991, AcA, 41, 291
Robb, R.M. 1989, IBVS 3346
Robb, R.M., & Scarfe, C.D. 1989, IBVS 3370
Rucinski, S.M. 1992, AJ, 104, 1968
Rucinski, S.M. 1997a, AJ, 113, 407 (R97a)
Rucinski, S.M. 1997b, AJ, 113, 1112 (R97b)
Rucinski, S.M., & Duerbeck, H.W. 1997, PASP, 109, 1340
Rucinski, S.M., Lu, W.X., & Shi, J. 1993, AJ, 106, 646
Saneec, R.G., Pauley, B.R., & Gaaigan, R.J. 1997, AJ, 113, 401
Smith, H.J. 1963, AJ, 68, 30
Twigg, T.W. 1979, MNRAS, 189, 907
Walker, R.L. 1973, IBVS, 855
Walker, R.L. 1991, BAAS, 22, 881
Walker, R.L. 1996, BAAS, 28, 921
Wang R.Y., Lu, W.X., & Fan Q.Y. 1986, IBVS, 2982
Weaver F.J. 1990, BAAS, 22, 1296
Wilson R.E., 1979, ApJ, 234, 1054
Yang, Y.L., Liu, Q.Y., Zhang, Y.L., Wang, B., & Lu, L. 1991, Acta Astron. Sinica, 32, 326
Zhang J.T., Zhang, R.X., & Zhai, D.S., 1992, Chin. Astron. Astrophys., 16 ,407
Zhang, X.B., Zhang R.X., Zhai D.S., & Fang M.J., 1995, IBVS, 4240

This preprint was prepared with the AAS LaTeX macros v4.0.
Captions to figures:

Fig. 1.— Radial velocities of the first four systems, GZ And, V417 Aql, LS Del, EF Dra, are plotted in individual panels versus orbital phases. The thin lines give the respective circular-orbit (sine-curve) fits to the radial velocities. Open symbols indicate observations given half-weights in the solutions while marks at the lower show phases of available observations which were not used in the solutions because of the blending of lines. EF Dra is the only A-type system among the four systems shown here; all other systems are of the W-type with slightly hotter less-massive components.

Fig. 2.— Radial velocities of the systems V829 Her, FG Hya, AP Leo and UV Lyn, in the same format as in Figure 1. Among the four systems, FG Hya and AP Leo belong A-type.

Fig. 3.— Radial velocities of the systems BB peg and AQ Psc, in the same format as in Figures 1 and 2. AQ Psc is an A-type system.
