High-precision photometry by telescope defocussing. II. The transiting planetary system WASP-4 (Appendix)

John Southworth\textsuperscript{1}, T. C. Hinse\textsuperscript{2,3}, M. J. Burgdorf\textsuperscript{4}, M. Dominik\textsuperscript{5,*}, A. Hornstrup\textsuperscript{6}, U. G. Jørgensen\textsuperscript{2}, C. Liebig\textsuperscript{7}, D. Ricci\textsuperscript{8}, C. C. Thöne\textsuperscript{9,10}, T. Anguita\textsuperscript{7}, V. Bozza\textsuperscript{11,12}, S. Calchi Novati\textsuperscript{11,12}, K. Harpsøe\textsuperscript{2}, L. Mancini\textsuperscript{11,12}, G. Masi\textsuperscript{13}, M. Mathiasen\textsuperscript{2}, S. Rahvar\textsuperscript{14}, G. Scarpetta\textsuperscript{11,12}, C. Snodgrass\textsuperscript{15}, J. Surdej\textsuperscript{8}, M. Zub\textsuperscript{7}

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\textsuperscript{8}Institut d’Astrophysique et de Géophysique, Université de Liège, 4000 Liège, Belgium
\textsuperscript{9}Dark Cosmology Centre, Niels Bohr Institute, University of Copenhagen, Juliane Maries Vej 30, Copenhagen Ø, 2100, Denmark
\textsuperscript{10}INAF, Osservatorio Astronomico di Brera, 23807 Merate, Italy
\textsuperscript{11}Dipartimento di Fisica “E. R. Caianiello”, Università di Salerno, Baronissi, Italy
\textsuperscript{12}INAF, Osservatorio Astronomico di Brera, 23807 Merate, Italy
\textsuperscript{13}Bellatrix Observatory, Centre for Backyard Astrophysics, Ceccano (FR), Italy
\textsuperscript{14}Department of Physics, Sharif University of Technology, Tehran, Iran
\textsuperscript{15}European Southern Observatory, Casilla 19001, Santiago 19, Chile

30 June 2009

APPENDIX A: RESULTS OF THE LIGHT CURVE ANALYSES

The tables in this section contain the full results of modelling light curve of WASP-4 from Wilson et al. (2008), Gillon et al. (2009), Winn et al. (2009) and from this work.

REFERENCES


This paper has been typeset from a \TeX/\LaTeX{} file prepared by the author.
Table A1. Parameters of the JKTEBOP best fits of the Euler $R$-band light curve of WASP-4 (Wilson et al. 2008), using different approaches to LD. For each part of the table the upper quantities are fitted parameters and the lower quantities are derived parameters. $T_0$ is given as HJD — 2454000.0. The light curve contains 213 datapoints.

<table>
<thead>
<tr>
<th>Linear LD law</th>
<th>Quadratic LD law</th>
<th>Square-root LD law</th>
<th>Logarithmic LD law</th>
<th>Cubic LD law</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_A + \eta$</td>
<td>$r_A + \eta$</td>
<td>$r_A + \eta$</td>
<td>$r_A + \eta$</td>
<td>$r_A + \eta$</td>
</tr>
<tr>
<td>$k$</td>
<td>$k$</td>
<td>$k$</td>
<td>$k$</td>
<td>$k$</td>
</tr>
<tr>
<td>$i$ (deg.)</td>
<td>$i$</td>
<td>$i$</td>
<td>$i$</td>
<td>$i$</td>
</tr>
<tr>
<td>$u_A$</td>
<td>$u_A$</td>
<td>$u_A$</td>
<td>$u_A$</td>
<td>$u_A$</td>
</tr>
<tr>
<td>$v_A$</td>
<td>$v_A$</td>
<td>$v_A$</td>
<td>$v_A$</td>
<td>$v_A$</td>
</tr>
<tr>
<td>$T_0$</td>
<td>$T_0$</td>
<td>$T_0$</td>
<td>$T_0$</td>
<td>$T_0$</td>
</tr>
</tbody>
</table>

Fitting for the linear LD coefficient and fixing the nonlinear LD coefficient

| $r_A + \eta$  | $r_A + \eta$     | $r_A + \eta$       | $r_A + \eta$       | $r_A + \eta$ |
| $k$           | $k$              | $k$                | $k$                | $k$          |
| $i$ (deg.)    | $i$              | $i$                | $i$                | $i$          |
| $u_A$         | $u_A$            | $u_A$              | $u_A$              | $u_A$        |
| $v_A$         | $v_A$            | $v_A$              | $v_A$              | $v_A$        |
| $T_0$         | $T_0$            | $T_0$              | $T_0$              | $T_0$        |

Fitting for the linear LD coefficient and perturbing the nonlinear LD coefficient

| $r_A + \eta$  | $r_A + \eta$     | $r_A + \eta$       | $r_A + \eta$       | $r_A + \eta$ |
| $k$           | $k$              | $k$                | $k$                | $k$          |
| $i$ (deg.)    | $i$              | $i$                | $i$                | $i$          |
| $u_A$         | $u_A$            | $u_A$              | $u_A$              | $u_A$        |
| $v_A$         | $v_A$            | $v_A$              | $v_A$              | $v_A$        |
| $T_0$         | $T_0$            | $T_0$              | $T_0$              | $T_0$        |

Fitting for both LD coefficients

| $r_A + \eta$  | $r_A + \eta$     | $r_A + \eta$       | $r_A + \eta$       | $r_A + \eta$ |
| $k$           | $k$              | $k$                | $k$                | $k$          |
| $i$ (deg.)    | $i$              | $i$                | $i$                | $i$          |
| $u_A$         | $u_A$            | $u_A$              | $u_A$              | $u_A$        |
| $v_A$         | $v_A$            | $v_A$              | $v_A$              | $v_A$        |
| $T_0$         | $T_0$            | $T_0$              | $T_0$              | $T_0$        |
Table A2. Parameters of the JKTEBOP best fits of the $z$-band VLT light curve of WASP-4 (Gillon et al. 2009), using different approaches to LD. For each part of the table the upper quantities are fitted parameters and the lower quantities are derived parameters. $T_0$ is given as HJD − 2454000.0. The light curves contain 244 datapoints.

<table>
<thead>
<tr>
<th>Linear LD law</th>
<th>Quadratic LD law</th>
<th>Square-root LD law</th>
<th>Logarithmic LD law</th>
<th>Cubic LD law</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All LD coefficients fixed</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$r_A + r_b$</td>
<td>0.2085±0.0017</td>
<td>0.2099±0.0015</td>
<td>0.2094±0.0016</td>
<td>0.2094±0.0015</td>
</tr>
<tr>
<td>$k$</td>
<td>0.15167±0.0023</td>
<td>0.15304±0.0025</td>
<td>0.15313±0.0026</td>
<td>0.15308±0.0025</td>
</tr>
<tr>
<td>$i$ (deg.)</td>
<td>89.91±0.05</td>
<td>88.56±0.47</td>
<td>88.61±0.51</td>
<td>88.64±0.53</td>
</tr>
<tr>
<td>$u_A$</td>
<td>0.50 fixed</td>
<td>0.25 fixed</td>
<td>0.10 fixed</td>
<td>0.59 fixed</td>
</tr>
<tr>
<td>$v_A$</td>
<td>0.51 fixed</td>
<td>0.54 fixed</td>
<td>0.26 fixed</td>
<td>0.10 fixed</td>
</tr>
<tr>
<td>$T_0$</td>
<td>396.695401±0.000037</td>
<td>396.695394±0.000035</td>
<td>396.695394±0.000036</td>
<td>396.695393±0.000036</td>
</tr>
</tbody>
</table>

| **Fitting for the linear LD coefficient and fixing the nonlinear LD coefficient** |
| $r_A + r_b$ | 0.2086±0.0017 | 0.2086±0.0017 | 0.2099±0.0015 | 0.2094±0.0015 | 0.2090±0.0016 |
| $k$ | 0.15442±0.0049 | 0.15244±0.0044 | 0.15351±0.0042 | 0.15300±0.0042 | 0.15378±0.0043 |
| $i$ (deg.) | 89.42±0.48 | 88.33±0.63 | 88.66±0.95 | 88.25±0.68 |
| $u_A$ | 0.392±0.010 | 0.270±0.013 | 0.086±0.011 | 0.590±0.012 | 0.375±0.012 |
| $v_A$ | 0.31 fixed | 0.54 fixed | 0.26 fixed | 0.10 fixed |
| $T_0$ | 396.695394±0.000034 | 396.695393±0.000035 | 396.695393±0.000038 | 396.695393±0.000034 | 396.695393±0.000035 |

| **Fitting for the linear LD coefficient and perturbing the nonlinear LD coefficient** |
| $r_A + r_b$ | 0.2086±0.0017 | 0.2086±0.0017 | 0.2099±0.0015 | 0.2094±0.0015 | 0.2090±0.0016 |
| $k$ | 0.15244±0.0055 | 0.15351±0.0045 | 0.15300±0.0042 | 0.15300±0.0042 | 0.15378±0.0043 |
| $i$ (deg.) | 89.42±0.71 | 88.33±0.65 | 88.66±1.02 | 88.25±0.68 |
| $u_A$ | 0.270±0.029 | 0.086±0.038 | 0.590±0.031 | 0.375±0.016 |
| $v_A$ | 0.54 perturbed | 0.54 perturbed | 0.26 perturbed | 0.10 perturbed |
| $T_0$ | 396.695393±0.000037 | 396.695393±0.000037 | 396.695393±0.000038 | 396.695393±0.000034 | 396.695393±0.000037 |

| **Fitting for both LD coefficients** |
| $r_A + r_b$ | 0.2100±0.0017 | 0.2101±0.0016 | 0.2101±0.0016 | 0.2101±0.0017 | 0.2101±0.0017 |
| $k$ | 0.15412±0.0067 | 0.15412±0.0080 | 0.15414±0.0078 | 0.15414±0.0076 | 0.15417±0.0087 |
| $i$ (deg.) | 88.12±0.31 | 88.09±0.76 | 88.11±0.69 | 88.08±0.48 |
| $u_A$ | 0.371±0.039 | 0.290±0.250 | 0.433±0.097 | 0.385±0.023 |
| $v_A$ | 0.050±0.00034 | 0.179±0.042 | 0.059±0.123 | 0.039±0.115 |
| $T_0$ | 396.695393±0.000034 | 396.695393±0.000033 | 396.695393±0.000033 | 396.695393±0.000034 | 396.695393±0.000036 |

| $r_A$ | 0.1817±0.0014 | 0.1820±0.0013 | 0.1820±0.0013 | 0.1816±0.0014 | 0.1819±0.0014 |
| $r_b$ | 0.02804±0.00032 | 0.02805±0.00031 | 0.02800±0.00031 | 0.02800±0.00032 | 0.02800±0.00033 |
| $\sigma$ (mmag) | 0.6042 | 0.6044 | 0.6044 | 0.6044 |
| $X_{\text{red}}$ | 1.6586 | 1.6596 | 1.6592 | 1.6595 |
Table A3. Parameters of the JKTEBOP best fits of the Magellan z-band telescope light curve of WASP-4 (Winn et al. 2009), using different approaches to LD. For each part of the table the upper quantities are fitted parameters and the lower quantities are derived parameters. T$_0$ is given as HDJ – 2454000.0. The light curves contain 713 datapoints.

<table>
<thead>
<tr>
<th>Linear LD law</th>
<th>Quadratic LD law</th>
<th>Square-root LD law</th>
<th>Logarithmic LD law</th>
<th>Cubic LD law</th>
</tr>
</thead>
<tbody>
<tr>
<td>All LD coefficients fixed</td>
<td>All LD coefficients fixed</td>
<td>All LD coefficients fixed</td>
<td>All LD coefficients fixed</td>
<td>All LD coefficients fixed</td>
</tr>
<tr>
<td>$r_A + r_h$</td>
<td>0.2103 + 0.0014</td>
<td>0.2126 + 0.0014</td>
<td>0.2123 + 0.0015</td>
<td>0.212 + 0.0014</td>
</tr>
<tr>
<td>$k$</td>
<td>0.1529 + 0.0028</td>
<td>0.15405 + 0.0026</td>
<td>0.15428 + 0.0025</td>
<td>0.15419 + 0.0026</td>
</tr>
<tr>
<td>$i$ (deg.)</td>
<td>89.63 + 0.79</td>
<td>88.26 + 0.37</td>
<td>88.25 + 0.40</td>
<td>88.24 + 0.37</td>
</tr>
<tr>
<td>$a_A$</td>
<td>0.50 fixed</td>
<td>0.25 fixed</td>
<td>0.10 fixed</td>
<td>0.59 fixed</td>
</tr>
<tr>
<td>$v_A$</td>
<td>0.31 fixed</td>
<td>0.54 fixed</td>
<td>0.26 fixed</td>
<td>0.10 fixed</td>
</tr>
<tr>
<td>$T_0$</td>
<td>697.797573 ± 0.000032</td>
<td>697.797565 ± 0.000034</td>
<td>697.797567 ± 0.000032</td>
<td>697.797566 ± 0.000033</td>
</tr>
<tr>
<td>Fitting for the linear LD coefficient and fixing the nonlinear LD coefficient</td>
<td>Fitting for the linear LD coefficient and fixing the nonlinear LD coefficient</td>
<td>Fitting for the linear LD coefficient and fixing the nonlinear LD coefficient</td>
<td>Fitting for the linear LD coefficient and fixing the nonlinear LD coefficient</td>
<td>Fitting for the linear LD coefficient and fixing the nonlinear LD coefficient</td>
</tr>
<tr>
<td>$r_A + r_h$</td>
<td>0.2123 + 0.0016</td>
<td>0.2122 + 0.0016</td>
<td>0.2123 + 0.0016</td>
<td>0.2119 + 0.0016</td>
</tr>
<tr>
<td>$k$</td>
<td>0.15506 + 0.0044</td>
<td>0.15356 + 0.0044</td>
<td>0.15424 + 0.0044</td>
<td>0.15386 + 0.0044</td>
</tr>
<tr>
<td>$i$ (deg.)</td>
<td>88.00 ± 0.44</td>
<td>88.98 ± 0.44</td>
<td>88.27 ± 0.44</td>
<td>88.51 ± 0.44</td>
</tr>
<tr>
<td>$a_A$</td>
<td>0.412 ± 0.12</td>
<td>0.276 ± 0.14</td>
<td>0.102 ± 0.13</td>
<td>0.601 ± 0.13</td>
</tr>
<tr>
<td>$v_A$</td>
<td>0.31 fixed</td>
<td>0.54 fixed</td>
<td>0.26 fixed</td>
<td>0.10 fixed</td>
</tr>
<tr>
<td>$T_0$</td>
<td>697.797565 ± 0.000032</td>
<td>697.797565 ± 0.000032</td>
<td>697.797567 ± 0.000032</td>
<td>697.797567 ± 0.000033</td>
</tr>
<tr>
<td>Fitting for the linear LD coefficient and perturbing the nonlinear LD coefficient</td>
<td>Fitting for the linear LD coefficient and perturbing the nonlinear LD coefficient</td>
<td>Fitting for the linear LD coefficient and perturbing the nonlinear LD coefficient</td>
<td>Fitting for the linear LD coefficient and perturbing the nonlinear LD coefficient</td>
<td>Fitting for the linear LD coefficient and perturbing the nonlinear LD coefficient</td>
</tr>
<tr>
<td>$r_A + r_h$</td>
<td>0.1838 ± 0.0012</td>
<td>0.1831 ± 0.0013</td>
<td>0.1838 ± 0.0013</td>
<td>0.1836 ± 0.0013</td>
</tr>
<tr>
<td>$r_b$</td>
<td>0.02849 ± 0.0025</td>
<td>0.02808 ± 0.0027</td>
<td>0.02836 ± 0.0027</td>
<td>0.02824 ± 0.0027</td>
</tr>
<tr>
<td>$\sigma$ (mmag)</td>
<td>0.639</td>
<td>0.6014</td>
<td>0.6099</td>
<td>0.6018</td>
</tr>
<tr>
<td>$\chi^2_{red}$</td>
<td>0.7014</td>
<td>0.6961</td>
<td>0.6954</td>
<td>0.6943</td>
</tr>
<tr>
<td>Fitting for both LD coefficients</td>
<td>Fitting for both LD coefficients</td>
<td>Fitting for both LD coefficients</td>
<td>Fitting for both LD coefficients</td>
<td>Fitting for both LD coefficients</td>
</tr>
<tr>
<td>$r_A + r_h$</td>
<td>0.2112 ± 0.0016</td>
<td>0.2122 ± 0.0016</td>
<td>0.2122 ± 0.0016</td>
<td>0.2119 ± 0.0016</td>
</tr>
<tr>
<td>$k$</td>
<td>0.15336 + 0.0049</td>
<td>0.15536 + 0.0049</td>
<td>0.15424 + 0.0049</td>
<td>0.15386 + 0.0049</td>
</tr>
<tr>
<td>$i$ (deg.)</td>
<td>88.98 ± 0.91</td>
<td>88.27 ± 0.91</td>
<td>88.51 ± 0.91</td>
<td>88.18 ± 0.91</td>
</tr>
<tr>
<td>$a_A$</td>
<td>0.276 ± 0.029</td>
<td>0.102 ± 0.029</td>
<td>0.601 ± 0.029</td>
<td>0.391 ± 0.029</td>
</tr>
<tr>
<td>$v_A$</td>
<td>0.31 perturbed</td>
<td>0.54 perturbed</td>
<td>0.26 perturbed</td>
<td>0.10 perturbed</td>
</tr>
<tr>
<td>$T_0$</td>
<td>697.797565 ± 0.000033</td>
<td>697.797565 ± 0.000033</td>
<td>697.797567 ± 0.000033</td>
<td>697.797567 ± 0.000033</td>
</tr>
</tbody>
</table>

\[\chi^2_{red} = \frac{\sum (y - \hat{y})^2}{n-p} \]

\[n = 713, \quad p = 5\]
Table A4. Parameters of the JKT photoprobe best fits of the Danish telescope $R$-band light curve of WASP-4 (this work), using different approaches to LD. For each part of the table the upper quantities are fitted parameters and the lower quantities are derived parameters. $T_0$ is given as $\text{HJD} - 2454000.0$. The light curves contain 452 datapoints.

<table>
<thead>
<tr>
<th>Linear LD law</th>
<th>Quadratic LD law</th>
<th>Square-root LD law</th>
<th>Logarithmic LD law</th>
<th>Cubic LD law</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_A + r_b$</td>
<td>$0.2097^{+0.0018}_{-0.0016}$</td>
<td>$2.097^{+0.0020}_{-0.0016}$</td>
<td>$2.099^{+0.0021}_{-0.0017}$</td>
<td>$2.092^{+0.0020}_{-0.0017}$</td>
</tr>
<tr>
<td>$k$</td>
<td>$0.1534^{+0.0045}_{-0.0029}$</td>
<td>$0.1534^{+0.0045}_{-0.0023}$</td>
<td>$0.1532^{+0.0040}_{-0.0025}$</td>
<td>$0.1531^{+0.0041}_{-0.0026}$</td>
</tr>
<tr>
<td>$i$ (deg.)</td>
<td>$89.86^{+1.04}_{-0.98}$</td>
<td>$89.86^{+1.04}_{-0.98}$</td>
<td>$89.97^{+1.04}_{-0.98}$</td>
<td>$89.97^{+1.04}_{-0.98}$</td>
</tr>
<tr>
<td>$u_A$</td>
<td>$0.60$ fixed</td>
<td>$0.40$ fixed</td>
<td>$0.25$ fixed</td>
<td>$0.70$ fixed</td>
</tr>
<tr>
<td>$v_A$</td>
<td>$0.25$ fixed</td>
<td>$0.50$ fixed</td>
<td>$0.23$ fixed</td>
<td>$0.50$ fixed</td>
</tr>
<tr>
<td>$T_0$</td>
<td>$365.916894_4^{+0.000047}_{-0.000048}$</td>
<td>$365.916893_4^{+0.000047}_{-0.000048}$</td>
<td>$365.916894_4^{+0.000047}_{-0.000048}$</td>
<td>$365.916894_4^{+0.000043}_{-0.000046}$</td>
</tr>
</tbody>
</table>

Fitting for the linear LD coefficient and fixing the nonlinear LD coefficient

| $r_A + r_b$   | $0.2085^{+0.0019}_{-0.0015}$ | $2.099^{+0.0020}_{-0.0016}$ | $2.099^{+0.0020}_{-0.0017}$ | $2.088^{+0.0019}_{-0.0017}$ |
| $k$           | $0.1547^{+0.0046}_{-0.0031}$ | $0.1534^{+0.0045}_{-0.0031}$ | $0.1536^{+0.0045}_{-0.0031}$ | $0.1540^{+0.0048}_{-0.0038}$ |
| $i$ (deg.)    | $89.30^{+0.76}_{-0.81}$ | $89.60^{+0.72}_{-0.72}$ | $89.50^{+0.72}_{-0.72}$ | $90.00^{+0.76}_{-0.81}$ |
| $u_A$         | $0.501^{+0.013}_{-0.013}$ | $0.401^{+0.017}_{-0.017}$ | $0.220^{+0.017}_{-0.018}$ | $0.675^{+0.014}_{-0.015}$ |
| $v_A$         | $0.25$ fixed | $0.50$ fixed | $0.23$ fixed | $0.10$ fixed |
| $T_0$         | $365.916894_4^{+0.000039}_{-0.000047}$ | $365.916893_4^{+0.000045}_{-0.000044}$ | $365.916894_4^{+0.000044}_{-0.000046}$ | $365.916894_4^{+0.000047}_{-0.000043}$ |

Fitting for the linear LD coefficient and perturbing the nonlinear LD coefficient

| $r_A + r_b$   | $0.1806^{+0.0015}_{-0.0013}$ | $0.1819^{+0.0016}_{-0.0016}$ | $0.1814^{+0.0016}_{-0.0016}$ | $0.1809^{+0.0015}_{-0.0016}$ |
| $k$           | $0.0279^{+0.0003}_{-0.0003}$ | $0.0279^{+0.0004}_{-0.0004}$ | $0.0279^{+0.0004}_{-0.0004}$ | $0.0279^{+0.0004}_{-0.0004}$ |
| $i$ (deg.)    | $89.50^{+0.76}_{-0.76}$ | $89.60^{+0.76}_{-0.76}$ | $89.50^{+0.76}_{-0.76}$ | $90.00^{+0.76}_{-0.76}$ |
| $u_A$         | $0.401^{+0.013}_{-0.013}$ | $0.401^{+0.017}_{-0.017}$ | $0.220^{+0.017}_{-0.018}$ | $0.675^{+0.014}_{-0.015}$ |
| $v_A$         | $0.25$ perturbed | $0.50$ perturbed | $0.23$ perturbed | $0.10$ perturbed |
| $T_0$         | $365.916894_4^{+0.000045}_{-0.000046}$ | $365.916894_4^{+0.000046}_{-0.000046}$ | $365.916894_4^{+0.000046}_{-0.000046}$ | $365.916894_4^{+0.000045}_{-0.000045}$ |

Fitting for both LD coefficients

| $r_A + r_b$   | $0.2088^{+0.0023}_{-0.0019}$ | $0.2093^{+0.0019}_{-0.0016}$ | $0.2094^{+0.0020}_{-0.0017}$ | $0.2093^{+0.0022}_{-0.0017}$ |
| $k$           | $0.1542^{+0.0053}_{-0.0031}$ | $0.1549^{+0.0047}_{-0.0031}$ | $0.1542^{+0.0047}_{-0.0031}$ | $0.1542^{+0.0053}_{-0.0031}$ |
| $i$ (deg.)    | $90.00^{+1.34}_{-1.34}$ | $89.59^{+1.13}_{-1.13}$ | $89.59^{+1.13}_{-1.13}$ | $89.36^{+1.19}_{-1.19}$ |
| $u_A$         | $0.476^{+0.042}_{-0.042}$ | $0.276^{+0.058}_{-0.058}$ | $0.276^{+0.058}_{-0.058}$ | $0.493^{+0.069}_{-0.069}$ |
| $v_A$         | $0.881^{+0.015}_{-0.015}$ | $0.412^{+0.029}_{-0.029}$ | $0.114^{+0.014}_{-0.014}$ | $0.983^{+0.018}_{-0.018}$ |
| $T_0$         | $365.916885_5^{+0.000052}_{-0.000047}$ | $365.916885_5^{+0.000052}_{-0.000047}$ | $365.916885_5^{+0.000052}_{-0.000047}$ | $365.916884_5^{+0.000053}_{-0.000048}$ |

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