Photometric microlensing observed by Gaia

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Gravitational Lensing

- A massive object is passing in front of the source → source image is deformed
- Regimes: strong and weak – cosmological scales, microlensing – in our Galaxy and Local Group
Gravitational Microlensing

- Theoretical lightcurve → Paczynski curve (Paczynski 1986, 1996)
- Model parameters for single lens: impact parameter $u_0$, time of maximum $t_0$ and timescale of event $t_E$ (Einstein time)
Why Gaia is important for microlensing?

- Astrometric microlensing
- Gaia’s main goal is astrometry!!
- Possibility of detecting astrometric centroid shift on a massive scale for stars with $G < 16$ mag
- Possible way to detect single black holes!
Microlensing observed by Gaia

- Gaia Science Alerts: almost 4000 since 2015, 30+ microlensing candidates
- Most microlensing candidates occur in Bulge (a lot of sources → highest chance for a microlensing event to occur)
- To model an event properly – follow-up is needed; one point/30 days is not enough!!!
Gaia16aua 'Auala'

- Single source – single lens
- First confirmed microlensing event
- Towards Galactic Bulge
- Event observed by Gaia and OGLE
- Spectrum: 14\textsuperscript{th} Jul 2016 (SALT)

<table>
<thead>
<tr>
<th>( t_0 )</th>
<th>( t_E )</th>
<th>( u_0 )</th>
<th>( I_{0,\text{OGLE}} )</th>
<th>( f_{b1} )</th>
<th>( I_{\text{Gaia}} )</th>
<th>( f_{b2} )</th>
<th>( \chi^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>7548.34</td>
<td>110.92</td>
<td>0.140</td>
<td>20.15</td>
<td>0.32</td>
<td>19.01</td>
<td>0.21</td>
<td>201.07</td>
</tr>
</tbody>
</table>
Gaia16aye ‘Ayers Rock’

- Event with double lenses and single source
- Towards Northern Galactic Disk
- Follow-up obtained with OPTICON and many other collaborators; 24,000+ points!
- Multiple spectra obtained for various amplification factors

Model by Przemek Mróz
Gaia17aqu ‘Aqua’

- Single lens – single source event
- Towards Southern Disk
- Observed from the ground by OGLE
- Spectra: 28\textsuperscript{th} Mar and 4\textsuperscript{th} Apr (SALT)

<table>
<thead>
<tr>
<th>$t_0$</th>
<th>$t_E$</th>
<th>$u_0$</th>
<th>$I_{0,OGLE}$</th>
<th>$f_{b1}$</th>
<th>$I_{Gaia}$</th>
<th>$f_{b2}$</th>
<th>$\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7879.74</td>
<td>112.06</td>
<td>0.058</td>
<td>18.15</td>
<td>0.41</td>
<td>18.97</td>
<td>0.35</td>
<td>538.74</td>
</tr>
</tbody>
</table>
Gaia17bej ‘Bejeweled’

- Single lens – single source event
- Towards Galactic Bulge
- Follow-up observations obtained by SMART1.3m
- Spectrum: 5th May 2017
Gaia17bts ‘Bangtang Boys’

- Single lens – single source
- Towards Northern Disk
- Follow-up by OPTICON+others
- Spectra: 29\textsuperscript{th} Jul 2017 (Palomar)
  17\textsuperscript{th} Sept 2017 (Keck)
- Best model: with parallax

\begin{tabular}{|c|c|c|c|c|c|c|c|c|c|}
\hline
\(t_0\) & \(t_E\) & \(u_0\) & \(\pi_{EN}\) & \(\pi_{EE}\) & \(l_{0,\text{Gaia}}\) & \(f_{b1}\) & \(l_{0,\text{APASSr}}\) & \(f_{b2}\) & \(t_{0,\text{par}}\) & \(\chi^2\) \\
\hline
7951.45 & 45.97 & 0.226 & 0.26 & -1.01 & 17.95 & 0.71 & 17.94 & 0.75 & 7948.94 & 900.87 \\
\hline
\end{tabular}
Gaia17cad ‘Caddis Fly’

- Single lens – single source event
- Variable source!!! (visible in OGLE)
- Towards Galactic Bulge
- Ground-based observations by OGLE
- Spectrum: 7\textsuperscript{th} Sept 2017
Gaia17ctl ‘Catalonia’

- Towards Galactic Bulge
- Detected when Bulge started to set
- Gaia17ctl: spectrum on X-SHOOTER
- No ground-based follow-up (yet)
Gaia17ddi and Gaia17ddp

- New events! (alert on 02.12.2017)
- Towards Northern Disk
- Close to frequently sampled fields

![Graphs showing detection and alert data for Gaia17ddi and Gaia17ddp]
Missed Events

- AlertPipe missed at least four microlensing events by now
- Three: discovered by ASAS-SN (ASASSN-16oe, ASASSN-V J044558.57+081444.6, ASASSN-V J182456.34-305816.7)
- One: by amateurs (Kojima event, TCP J05074264+2447555)
Summary

- Many microlensing candidates detected
- AlertPipe seems to miss events (or reports them lately)
- Gaia may find single BH via microlensing thanks to it’s astrometry
- We need follow-up!!! Please help if you can :)