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LETTER TO THE EDITOR

Ongoing astrometric microlensing events of two nearby stars

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ABSTRACT

Context. Astrometric microlensing is an excellent tool to determine the mass of stellar objects. By measuring the astrometric shift of a background source star in combination with precise predictions of its unlensed position and of the lens position, gravitational lensing allows to one determine the mass of the lensing star with a precision of 1%, independently of any prior knowledge.

Aims. Making use of the recently published *Gaia* Data Release 2 (*Gaia* DR2) we predict astrometric microlensing events by foreground stars of high proper motion passing by a background star in the coming years.

Methods. We compile a list of approximately 148 000 high-proper-motion stars within *Gaia* DR2 with $\mu_{\rm tot} > 150\,{\rm mas\,yr^{-1}}$. We then search for background stars close to their paths and calculate the dates and separations of the closest approaches. Using color and absolute magnitude, we determine approximate masses of the lenses. Finally, we calculate the expected astrometric shifts and magnifications of the predicted events.

Results. We detect two ongoing microlensing events by the high-proper-motion stars Luyten 143-23 and Ross 322 and predict closest separations of (108.5 ± 1.4) mas in July 2018 and (125.3 ± 3.4) mas in August 2018, respectively. The respective expected astrometric shifts are (1.74 ± 0.12) mas and (0.76 ± 0.06) mas. Furthermore, Luyten 143-23 will pass by another star in March 2021 with a closest separation of (280.1 ± 1.1) mas, which results in an expected shift of (0.69 ± 0.05) mas.

Key words. astrometry – proper motions – catalogs – gravitational lensing: micro

1. Introduction

Gravitational lensing is a powerful tool to probe our universe on very different mass and distance scales, from exoplanets in the Milky Way to multiply imaged quasars and giant arcs at cosmological distance scales. When a foreground star ("lens") passes a background star ("source"), two effects can be observed due to gravitational lensing: A magnification of the source (photometric microlensing), and a shift of the source position (astrometric microlensing). Whereas more than 10 000 photometric microlensing events have been observed – including a few dozen extrasolar planet detections (e.g. Udalski et al. 2015), astrometric microlensing was detected for the first time only recently (Kains et al. 2017). Due to its dependence on mass, astrometric microlensing is one of the few possibilities to "weigh" stellar objects with a precision of about one percent (Paczynski 1995).

For photometric microlensing, the impact parameter between lens and source needs to be of the order of the angular Einstein radius or smaller ($\Delta\theta \lesssim 1\,\theta_{\rm E}$) for measurable effects. Astrometric microlensing can be detected at much larger angular separations between lens and source (i.e., $\Delta\theta \gg 1\,\theta_{\rm E}$). Furthermore, it is possible to *predict* astrometric microlensing events from precise proper motions and positions of lens and source (Paczynski 1995). For the prediction of astrometric events, in particular faint nearby stars with high proper motions are of interest. High proper motions are preferred because the covered area within a given time is larger, and therefore microlensing events are more likely. Furthermore, a high proper motion leads to a significant positional shift on a shorter timescale. Nearby stars are preferred, because their Einstein radius is larger and therefore the expected shift is also larger. Furthermore, faint lenses are favourable, since the measurement of the source position is less contaminated by the lens. Astrometric microlensing events have already been predicted by, for example, Proft et al. (2011), Sahu et al. (2014) and McGill et al. (2018). The second data release of *Gaia* (*Gaia* DR2, Gaia Collaboration 2018) now provides a highly improved data set for such studies. Not only are the proper motions of the lenses provided by *Gaia* DR2, but also precise parallaxes which are needed to calculate the mass of the lens afterwards, as well as the proper motion of the source. These large improvements in data quality and quantity lead to much more precise predictions. In addition, the excellent resolution and accuracy of *Gaia* provides the opportunity to actually measure the predicted shifts of the background sources. The events during the *Gaia* Mission are therefore of particularly high scientific interest.

This letter is structured as follows: in Sect. 2 we explain the basics of our method, in Sect. 3 we present the predicted microlensing events of two nearby stars, and in Sect. 4 we summarise our results and present conclusions.

2. Method

We use a method similar to that of Proft et al. (2011) in order to search for new astrometric microlensing events. Here we briefly delineate the main steps of our method; the complete method will be detailed in an upcoming paper (Klüter et al. in prep.).

We start with a list of high-proper-motion stars ($\mu_{\rm tot} > 150\,{\rm mas\,yr^{-1}}$) from *Gaia* DR2 and apply the following quality cuts, using parallax (ϖ), proper motion (μ) and two *Gaia* specific columns, to eliminate possibly erroneous data: $\varpi > 8\sigma_\varpi$, $\varpi/\mu_{\rm tot} < 0.3$ yr and `phot_g_n_obs`^{2} $\cdot$ `phot_g_mean_flux_over_error` $> 10^6$.

Approximately 148 000 stars fulfill these criteria. For those potential lenses, we search for background stars in a rectangular box defined by the J2015.5 positions and the positions in 50 yr, with a box width of ($\pm 7''$) perpendicular to the direction of the proper motion. In the following, the combination of a high-proper-motion foreground lens and a background source is called "candidate". The source parameters are labelled with the prefix "Sou_". To avoid binary stars in our candidate list, we exclude common proper motion pairs. Using the *Gaia* DR2 positions, proper motions, and parallaxes, we then determine the minimum separation between source and lens, and the epoch of closest approach for roughly 68 000 candidates.

In order to obtain a realistic value for the expected astrometric shifts of our candidates, we estimate an approximate mass for the lens in the following way. We sort the potential lenses into the three classes; white dwarfs (WD), main sequence (MS) stars, and red giants (RG), by using the following cuts:

$$\begin{aligned} &\text{WD:} \quad G_{\rm BP,\,abs} \geq 4 \cdot (G - G_{\rm RP})^2 + 4.5 \cdot (G - G_{\rm RP}) + 6 \\ &\text{RG:} \quad G_{\rm BP,\,abs} \leq -3 \cdot (G - G_{\rm RP})^2 + 8 \cdot (G - G_{\rm RP}) - 1.3, \end{aligned} \tag{1}$$

where $G_{\rm BP,\,abs}$ is the absolute $G_{\rm BP}$ magnitude. For white dwarfs and red giants, we use approximate masses of $(0.65 \pm 0.15)\,M_\odot$ and $(1.0 \pm 0.5)\,M_\odot$, respectively. For MS stars we use the following relation with absolute G magnitude ($G_{\rm abs}$), determined from a list of temperatures and stellar radii for different stellar types (Pecaut & Mamajek 2013), the translation between *Gaia* and Johnson filters (Jordi et al. 2010), and mass-luminosity relations (Salaris & Cassisi 2005):

$$\begin{aligned} &(G_{\rm abs} < 8.85): \\ &\log\left(\frac{M}{M_\odot}\right) = 0.00786\, G_{\rm abs}^2 - 0.290\, G_{\rm abs} + 1.18 \\ &(8.85 < G_{\rm abs} < 15): \\ &\log\left(\frac{M}{M_\odot}\right) = -0.301\, G_{\rm abs} + 1.89 \\ &(15 < G_{\rm abs}): \\ &M = 0.07 M_\odot, \end{aligned} \tag{2}$$

The first two relations are due to different slopes in the mass-luminosity relations, and the third one is for brown dwarfs. For MS stars, we consider an error of 10%. We also use these equations when *Gaia* DR2 does not provide colour information for the lens, that is, we assume those stars are MS stars. As the next step, we calculate the angular Einstein radii from the masses and the *Gaia* DR2 parallaxes:

$$\theta_{\rm E} = 2.854\,{\rm mas} \sqrt{\frac{M}{M_\odot} \cdot \frac{\varpi - {\rm Sou\_}\varpi}{1\,{\rm mas}}}. \tag{3}$$

Finally, we determine the expected shift of the centre of light of the two images (Paczyński 1998),

$$\delta\theta_{\rm c} = \frac{u}{u^2 + 2} \cdot \theta_{\rm E}, \tag{4}$$

where u is the unlensed angular separation between lens and source in units of $\theta_{\rm E}$. We note that for large separations ($u > 5$), Eq. (4) is also a good approximation for the shift of the brighter image only. For small separations, luminous-lens effects have to be taken into account, that is, a factor of $A/(A + f_{\rm LS})$ has to be added, where A is the magnification of the event, and $f_{\rm LS}$ is the flux ratio between lens and source.

Table 1. Important *Gaia* DR2 parameters for the lenses.

	Luyten 143-23	Ross 322
ID	5254061535097566848	314922605759778048
RA	161.085375416°	16.956492031°
Dec	−61.202862014°	34.210553416°
$\sigma_{\rm RA}$	0.10 mas	0.05 mas
$\sigma_{\rm Dec}$	0.13 mas	0.04 mas
$\mu_{\rm RA}$	−346.43 mas yr^{-1}	1373.67 mas yr^{-1}
$\mu_{\rm Dec}$	1610.34 mas yr^{-1}	−480.33 mas yr^{-1}
$\sigma_{\mu_{\rm RA}}$	0.17 mas yr^{-1}	0.09 mas yr^{-1}
$\sigma_{\mu_{\rm Dec}}$	0.25 mas yr^{-1}	0.08 mas yr^{-1}
ϖ	206.82 mas	42.51 mas
σ_ϖ	0.08 mas	0.05 mas
G	11.9 mag	12.4 mag
$G_{\rm RP}$	10.9 mag	11.3 mag
$G_{\rm BP}$	14.2 mag	13.6 mag

Notes. Listed are source ID (ID), J2015.5 position (RA, Dec), proper motion (μ), parallax (ϖ), and magnitude (G, $G_{\rm RP}$, $G_{\rm BP}$) for the lens stars. Further information for the lens stars can be extracted from *Gaia* DR2 using the Source ID.

3. Astrometric microlensing event

We found and report here two currently ongoing astrometric microlensing events by the high-proper-motion stars Luyten 143-23 and Ross 322. The expected maximum shifts are (1.74 ± 0.12) mas and (0.76 ± 0.06) mas, respectively.

3.1. Luyten 143-23

Luyten 143-23 is an M dwarf (M4V) with a parallax of 206.8 mas and an absolute proper motion of 1647.2 mas yr^{-1}. Its apparent G magnitude is 11.9 mag (see Table 1 for more details). By using our $G_{\rm abs}$ – Mass relation (Eq. (2)) we determine an approximate mass of 0.12 $M_\odot$. We found that it currently passes a $G = 18.5$ mag star with a closest approach on July 7, 2018 and a smallest separation of 108.53 mas. Position, proper motion, parallax and magnitudes for the background source star are given in the top part of Table 2, information on the closest approach can be found in the bottom part of Table 2. The top panel of Fig. 1 shows a 2MASS (Skrutskie et al. 2006) image of Luyten 143-23; the interesting background star is marked with a green circle. The motion of the background star within 5 yr and the positional uncertainties are smaller than the centered dot. The predicted path of Luyten 143-23 is shown as a thick blue/thin red line, where the red parts indicate the times at which Luyten 143-23 is not observable. The blue triangle indicates its J2015.5 position listed by *Gaia* DR2. We note that the observability is only a rough estimate, since it depends on the location of the observatory and the capability of the instruments.

Due to the large Einstein radius of $\theta_{\rm E} = 14.0$ mas caused by the small distance of Luyten 143-23, a maximum shift of (1.74 ± 0.12) mas is expected. The unlensed motion of the background star as well as the predicted path due to lensing are shown in the top panel of Fig. 2. Finally, the absolute shift as a function

Table 2. Important parameters for the astrometric microlensing events reported here.

	Luyten 143-23 (2018)	Luyten 143-23 (2021)	Ross 322 (2018)
Sou_ID	5254061535052907008	5254061535097574016	314922601464808064
Sou_RA	161.08462829°	161.08436459°	16.95791867°
Sou_Dec	−61.20147495°	−61.20032468°	+34.21100433°
Sou_σ_{RA}	0.16 mas	0.06 mas	0.27 mas
Sou_σ_{Dec}	0.16 mas	0.06 mas	0.38 mas
Sou_μ_{RA}	−4.85 mas yr^{-1}	−5.20 mas yr^{-1}	−1.12 mas yr^{-1}
Sou_μ_{Dec}	2.82 mas yr^{-1}	2.17 mas yr^{-1}	0.83 mas yr^{-1}
Sou_$\sigma_{\mu_{\mathrm{RA}}}$	0.38 mas yr^{-1}	0.13 mas yr^{-1}	0.60 mas yr^{-1}
Sou_$\sigma_{\mu_{\mathrm{Dec}}}$	0.33 mas yr^{-1}	0.12 mas yr^{-1}	0.62 mas yr^{-1}
Sou_ϖ	0.09 mas	0.07 mas	−0.05 mas
Sou_σ_{ϖ}	0.19 mas	0.07 mas	0.44 mas
Sou_G	18.5 mag	17.0 mag	18.6 mag
Sou_G_{RP}	16.9 mag	15.9 mag	17.6 mag
Sou_G_{BP}	19.1 mag	18.0 mag	18.6 mag
θ_{E}	14.0 mas	14.0 mas	9.8 mas
$\sigma\theta_{\mathrm{E}}$	0.7 mas	0.7 mas	0.5 mas
T_{min} (TCB)	J2018.51236 yr	J2021.18674 yr	J2018.5995 yr
σT_{min}	0.00051 yr	0.00063 yr	0.0022 yr
D_{min}	108.5 mas	280.1 mas	125.3 mas
σD_{min}	1.4 mas	1.1 mas	3.4 mas
$\Delta\theta_{\mathrm{max}}$	1.74 mas	0.69 mas	0.76 mas
$\sigma\Delta\theta_{\mathrm{max}}$	0.12 mas	0.05 mas	0.06 mas

Notes. The table lists source ID (Sou_ID), J2015.5 position (Sou_RA, Sou_Dec), proper motion (Sou_μ) parallax(Sou_ϖ), and G magnitude (Sou_G, Sou_G_{RP}, Sou_G_{BP}) for the background stars. Furthermore, the angular Einstein radii (θ_{E}), epoch and distance of closest approach ($T_{\mathrm{min}}, D_{\mathrm{min}}$), and the maximum expected shifts ($\Delta\theta_{\mathrm{max}}$) are shown. Further information for the background stars can be extracted from *Gaia* DR2 using the Source ID.

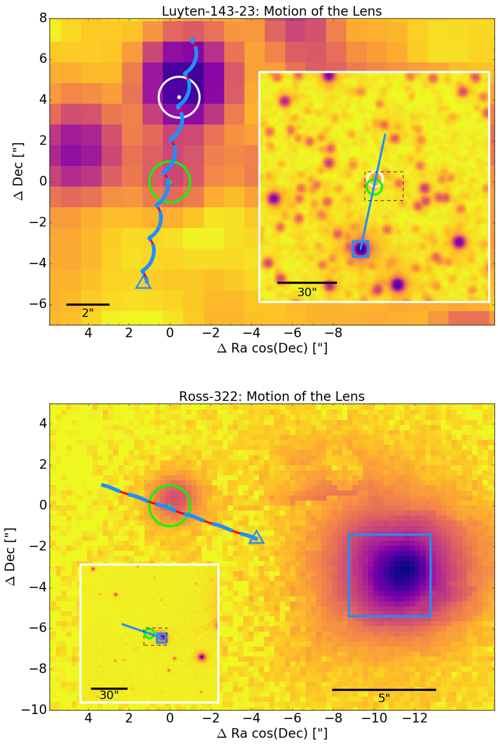

Fig. 1. *Top panel*: 2MASS image with the two background stars that Luyten 143-23 passes by in July 2018 (green circle) and in March 2021 (white circle), respectively. *Bottom panel*: Pan-STARRS image with the background star which Ross 322 passes by in August 2018 (green circle). The exact positions of the background sources are indicated with small dots at the centres of the circles. Their motions and the uncertainties are smaller than the size of the dots. The triangles indicate the J2015.5 positions of the lens stars measured by *Gaia*. The predicted motions are shown as thick blue/thin red curves, where the thin red parts indicate the epochs at which the stars cannot be observed. In both panels, the original positions (at earlier epochs) of the lens stars in the 2MASS and PanSTARRS images are indicated as squares. Larger views of the sky areas are displayed in the insets. The blue lines in the insets show the motion of the lens stars until 2035.

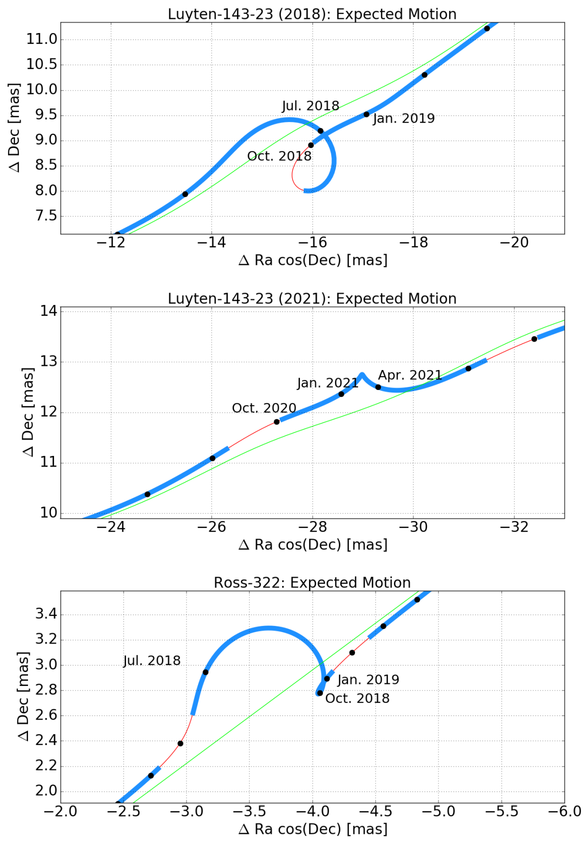

Fig. 2. Predicted motions of the background stars for the events by Luyten 143-23 in 2018 (*top*), in 2021 (*middle*), and by Ross 322 in 2018 (*bottom*). The origin of the coordinate system is the background star's J2015.5 position. The thin green lines show the unaffected motions of the background stars, the expected paths are shown as thick blue/thin red lines (red parts indicate the epochs at which the star is not observable). $\delta\theta_{\mathrm{c}}$ is the difference between both lines at the same epoch. The black dots indicate equal time intervals of 3 months.

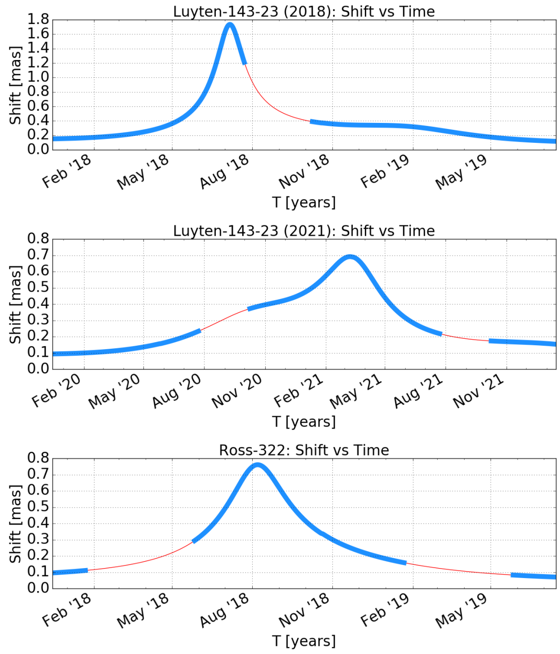

Fig. 3. Expected shifts as a function of time for events by Luyten 143-23 in 2018 (*top*), in 2021 (*middle*), and by Ross 322 in 2018 (*bottom*). The thin red parts indicate the epochs at which the star is not observable.

of time is displayed in the top panel of Fig. 3. Due to the high proper motion of Luyten 143-23, we expect a rapid change of the astrometric shift between June and September 2018 (1.3 mas in 3 months). Unfortunately, Luyten 143-23 is not observable in August/September 2018 from the ground or by *Gaia*.

We found a further close encounter of Luyten 143-23 with a $G = 17.0$ mag star to occur in 2021. The smallest separation of (280.1 ± 1.1) mas is reached on March 9, 2021; we expect a maximum shift of (0.69 ± 0.05) mas. This background star is marked with a white circle in Fig. 1. The expected motion and the astrometric shift are shown in the middle panels of Figs. 2 and 3.

3.2. Ross 322

Ross 322 is an M dwarf (M2V) with a parallax of 42.5 mas. Its absolute proper motion is 1455.2 mas yr^{-1} (Table 1). We determine an approximate mass of 0.28 $M_{\odot}$. Ross 322 currently passes by a $G = 18.6$ mag star with a closest approach on August 8, 2018, with a separation of (125.3 ± 3.4) mas. Since the Einstein radius of Ross 322 is smaller than that of Luyten 143-23, the expected shift is only (0.76 ± 0.06) mas. However, this should still be measurable with sufficient accuracy. The important parameters are also displayed in Table 2 and the same plots as for Luyten 143-23 are given in the bottom panels of Figs. 1–3, superposed on a Pan-STARRS image (Chambers & Pan-STARRS Team 2018).

4. Summary and conclusions

We report two ongoing astrometric microlensing events by the two nearby stars Luyten 143-23 and Ross 322. They reach their closest approaches in July 2018 and August 2018, respectively. Thanks to the precise data of *Gaia* DR2, we were able to predict the separations between foreground and background stars as a function of time with an accuracy of a few percent and the time of the closest approach with an accuracy of a few hours. Because of the large Einstein radii (14.0 mas; 9.8 mas), we expect a measurable effect even though the minimum separation is above 100 mas. Luyten 143-23 will pass a further star in March 2021 with a closest separation of 280.1 mas and an expected shift of 0.69 mas. For these separations, it is also possible to resolve both stars with high-resolution instruments such as GRAVITY (Gravity Collaboration 2017), although the background source is approximately five magnitudes fainter (K band) than the lens. Further, the high proper motions of the lenses lead to a fast change of the astrometric shifts. Therefore, both events are ideal for monitoring with high-accuracy astrometric instruments like *Gaia*, GRAVITY, Keck, or LBT. Due to the precise prediction, observations of both events offer the possibility to determine the masses of the two nearby high-proper-motion stars Luyten 143-23 and Ross 322 with a precision of a few percent. An initiative to acquire observations with GRAVITY and at the Keck Telescope during the two ongoing events has been launched by the authors.

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