203. Gaia's third exoplanet, Gaia22dkvLb

I have estimated that Gaia will eventually discover tens of thousands of exoplanets based on the astrometric motion of the system's photocentre (Perryman et al., 2014). Admittedly, these estimates are sensitive to the quality of the final astrometric calibrations, and the presence of other massive planets within each system.

Pending the enlarged data sets, improved calibration, and binary system (including sub-stellar mass) processing in the next data releases DR4 (2025) and DR5 (around 2030), only two Gaia exoplanets (from Gaia's transit photometry) so far appear in NASA's Exoplanet Archive: Gaia–1 b and Gaia–2 b (Panahi et al., 2022).

Of nearly 6000 exoplanets discovered globally to date, some 200 have been detected by gravitational microlensing. A new such discovery was added to the NASA archive on 2024–08-07: Gaia22dkvLb. This was discovered as a Gaia 'science alert', and it has a number of interesting features that I will expand on here.

I have covered various aspects of gravitational microlensing relevant to Gaia in some earlier essays: focussing on *astrometric* microlensing (11); on microlensing with Gaia more generally (84); candidate black holes from astrometric microlensing (101); and the discovery of new microlensing systems from follow-up of Gaia's 'science alerts' processing system (36 and 202).

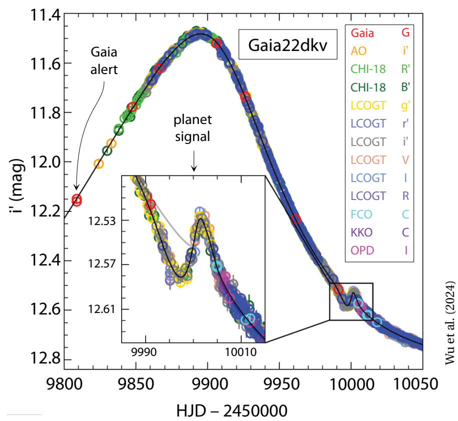
Microlensing relies on the chance (and very rare) alignment of a background source, an intervening lens, and the observer. If the foreground lens is itself of complex structure (whether a cluster of galaxies, or a binary system, or a star orbited by one or more planets), then the background source may show a more complex lensed light curve resulting from the time-varying magnification as the alignment changes.

This has led to discovery of more than 200 microlensing exoplanets. All but 3 have been by the ground-based surveys MOA (Sako et al., 2008), OGLE (Udalski, 2009) and, most recently KMT (Kim et al., 2016). It is the rarity of alignment that has motivated these surveys to focus on the Galactic bulge, where alignment probabilities benefit from much higher stellar surface densities.

Gaia's latest planet was discovered through the Gaia Science Alerts, part of the Gaia Data Processing and Analysis Consortium (DPAC), which processes the real-time photometric data from the scanning satellite, and flags unexpected magnitude increases, allowing rapid follow-up by ground-based photometry (Hodgkin et al., 2021, and essay 202). For microlensing candidates, the goal is to initiate a rapid and dense sampling of the rising light curve (while the lensing event is still ongoing), with the aim of detecting light-curve perturbations signalling the existence of an orbiting planet.

This specific event announcement (all include the Gaia light curve and low-resolution B_P/R_P spectra at each epoch) was released on 2022–08–16 at 22:40:56. It drew attention to a bright, Galactic plane source with historic magnitude $G = 13.18 \pm 0.02$, as it brightened by 0.6 mag to an 'alert magnitude' of $G = 12.53$ mag.

The subsequent observations and analysis are reported by Wu et al. (2024). The figure below shows their follow-up photometry, from several telescopes [including Auckland (AO), El Sauce Chile (CHI–18), and Las Cumbres (LCOGT)], and in various filters, here transformed to the photometric band i'. The dense sampling over the subsequent 250 days, the photometric accuracy, and the perturbation on the falling light curve around days 9990–10010 (HJD–2,450,000), are all very striking.



THE OBJECT DESIGNATION, Gaia22dkvLb, denotes the Gaia science alert identifier, Gaia22dkv (itself following the convention GaiaYYaaa, with YY denoting the event year, and a 3-letter encoding of the event sequence in that year), with the suffices Lc adhering to the microlensing exoplanet nomenclature in denoting the planet b associated with the lensing object L.

I SHOULD EMPHASISE that the analysis of most microlensing events is not straightforward. For example, for a single lens event, the Einstein time scale, derived from the event duration, is a degenerate combination of the lens mass, $M_{\rm L}$, and lens distance, $D_{\rm L}$ (or, for a source at finite distance, the 'microlens parallax' defined as the (scaled) relative parallax between lens and source, denoted $\varpi_{\rm E}$ or $\pi_{\rm E}$), and the lens–source relative transverse velocity. Indeed, the clear asymmetry in the main light curve is due to the Earth's orbital motion.

Measurements of $\varpi_{\rm E}$ can be made by exploiting this non-linear (orbital) motion of the Earth around the Sun (an 'orbital microlens parallax'), or in favourable cases by making simultaneous observations of the microlensing light curve over an extended measurement baseline on Earth (a 'terrestrial microlens parallax'), or by observing the same event from Earth and a satellite (a 'satellite–microlens parallax'). The latter has been achieved with both Earth–Spitzer observations, and even Spitzer–Kepler K2 observations (see, e.g., Zang et al., 2020), but this is not applicable to the Gaia observations due to its low photometric sampling rate.

There are other complications. If the lens is unseen, its mass and distance can be determined only in particularly favourable circumstances. If the lens is visible, solutions depend on the degree of light blending between lens and source, and the possible contribution of another (non-lensing) object along the line of sight. Finite source size effects can also be evident.

ACCOUNTING FOR THESE and other complexities, Wu et al. (2024) concluded that the lens is a $M_{\rm L} = 1.15^{+0.16}_{-0.08} M_\odot$ star at a distance $D_{\rm L} = 1.27^{+0.43}_{-0.25}$ kpc, orbited by a planet of mass $M_{\rm p} = 0.59^{+0.15}_{-0.05} M_{\rm J}$ with a projected orbital separation $a = 1.41^{+0.76}_{-0.36}$ au, and an orbital period $P = 2.96 \pm 0.20$ yr.

The host star and planet masses are typical of exoplanet systems, including microlensing discoveries, but there are other properties that make it more unusual.

AS I NOTED ABOVE, ground-based microlensing surveys have focussed on the direction of the Galactic bulge to provide enhanced lens and source densities, and so improve alignment (and therefore event occurrence) probabilities. Accordingly, all but one of the previous microlensing planets lie in the direction of the Galactic bulge.

The only other non-bulge microlens planet, TCP J0507+244Lb, was found as an alert from ASAS–SN (Nucita et al., 2018; Fukui et al., 2019). It is of order Neptune mass, $M_{\rm p} = 19 \pm 3 M_\oplus$, orbiting a $0.495 \pm 0.063 M_\odot$ star, at a distance of 429 ± 21 pc (Zang et al., 2020). Interestingly, both Gaia22dkv and TCP J0507+244 reached $V < 12$ mag at peak. All-sky rates for such bright events are very low, with only ~0.1 events yr^{-1} (Han, 2008).

SEVERAL PROPERTIES make Gaia22dkv noteworthy. The first is that, like TCP J0507+244, it lies in a non-bulge direction, although still in the Galactic plane.

Second, the planet's semi-major axis places it within the snow-line, where water may be in liquid form. In common with TCP J0507+244, but nonetheless a rarity amongst microlensed planets, it therefore contributes to an improved understanding of the mass–radius distribution of these systems.

Third is the exceptional quiescent brightness of the lens star, $V \sim 14$ mag. If this represents (as they infer) the magnitude of the star (and not some blended image), it is the brightest microlensing host star to date.

The combination of such a bright host, high planet mass, and relatively small orbit separation, makes it the most promising microlensing planet for (the first!) radial velocity follow-up. Such observations would definitively establish the planet's orbital period and eccentricity, and would allow the search for other co-orbiting planets.

FINALLY, and pending release of Gaia's epoch astrometry, Wu et al. (2024) simulated the host's astrometric motion, based on their system parameters and the known epochs of the Gaia measurements (shown below). They conclude that the *astrometric* effects of the microlens event should be measurable once the Gaia epoch astrometry is made available (black curve). This will constrain the microlens parallax, $\varpi_{\rm E}$, break the current ($u_0 + / -$) model degeneracy (which I have not detailed), and directly yield the lens mass and distance.