# Could Gliese 22 Bb be detected by direct imaging?

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## Introduction

We present the latest results [2] about the long-term stability of a very-low mass object orbiting the B component in the hierarchical triple red dwarf system, Gl 22 AB, where component A is itself a binary. They show that the two most likely full three-dimensional solutions obtained for the orbit of Bb are both stable on the 10 Myr timescale.
In addition, an improved arrangement of the system masses have been obtained. Moreover, concerning the planetary or stellar nature of the Bb object and taking into account its mass, we provide a statistical estimation of the probability of each alternative.
This object could be the first example ever discovered of a "speckle-astrometric" binary [5, 6]. This has allowed us to obtain a full set of orbital elements that are accurate enough to calculate reliable ephemerides ($\theta$, $\rho$) for the Ba–Bb orbit. On the basis of these results, prospects for the direct detection of the Bb object using stellar coronagraphs with adaptive optics on ground-based telescopes during the very best observation window (2017-2018) are also discussed. Our aim is to encourage observational astronomers to try to detect this object by direct imaging as well.

## 1. Description of the multiple system

### 1.1 *Orbital parameters of the stellar system*

The hierarchical triple stellar system Gl 22 is located at 10 pc distance. It consists of three M dwarfs: Aa (0.377±0.030 $M_\odot$), Ab (0.138±0.007 $M_\odot$), and B (0.177±0.014 $M_\odot$). The two calculated orbits, Aa-Ab and A-B, are co-revolving and practically co-planar. The elements that define both orbits are shown in Table 1.

**Table 1:** Orbital elements for the Aa-Ab pair and the A-B pair

| ORBITAL ELEMENTS | Aa-Ab PAIR (see [4]) | A-B PAIR (see [6]) |
|---|---|---|
| P (yr) | $15.64 \pm 0.20$ | $223.3^{+7.2}_{-9.8}$ |
| T | $2000.76 \pm 0.20$ | $1859.4^{+5.3}_{-2.4}$ |
| e | $0.174 \pm 0.003$ | $0.293^{+0.044}_{-0.025}$ |
| a ($''$) | $0.511 \pm 0.005$ | $3.322^{+0.040}_{-0.060}$ |
| i (°) | $44.6 \pm 1.5$ | $47.3^{+0.5}_{-0.3}$ |
| $\Omega$ (°) | $175.1 \pm 1.0$ | $174.9^{+2.7}_{-1.3}$ |
| $\omega$ (°) | $106.8 \pm 5.0$ | $146.3^{+2.0}_{-3.8}$ |

### 1.2 *An astrometric detection?*

When we calculated the A-B orbit, we detected a weak sinusoidal pattern in the apparent motion of component B that may be attributed to either a very unusual distribution of observational residuals or

perhaps to an unseen fourth body in the system [5, 6]. In the latter case, component B would consist of two bodies: the main one, star Ba, and a very low-mass object, Bb, that is about 15 times the mass of Jupiter ($M_J$). This could be the first astrometric detection of a planet-like mass object.
In a previous article [1], a set of preliminary elements of the fourth body was determined. At first, the orbit was considered to be circular. Nevertheless, a more detailed study of the observed sinusoidal trajectory showed that orbits with an eccentricity of up to 0.08 are possible because the residuals obtained are similar. Therefore, we consider the cases of minimum and maximum eccentricity: the circular solution (CS) and the elliptic solution (ES) with an eccentricity of 0.08. The elements that define each of these orbits are shown in Table 2. In both cases, the orbit of Bb around Ba is practically co-planar with the Aa-Ab and A-B orbits.

**Table 2:** Proposed sets of orbital elements for the Ba-Bb orbit

| ORBITAL ELEMENTS | CIRCULAR SOLUTION (see [1]) | ELLIPTIC SOLUTION (see [2]) |
|---|---|---|
| P (yr) | $15 \pm 2$ | $15.0 \pm 0.5$ |
| T | $2010 \pm 2$ | $2010.0 \pm 0.5$ |
| e | 0 (assumed) | $0.08 \pm 0.05$ |
| a ($''$) | $0.348 \pm 0.010$ | $0.348 \pm 0.010$ |
| i ($^\circ$) | $46 \pm 5$ | $47.0 \pm 5.0$ |
| $\Omega$ ($^\circ$) | $175 \pm 5$ | $175.0 \pm 5.0$ |
| $\omega$ ($^\circ$) | 0 (assumed) | $347.0 \pm 5.0$ |

## 2. Dynamical analysis

### 2.1 *Orbital stability*

With the objective of investigating the further evolution of the system including the Bb object, we have integrated the hierarchical (nearly-Keplerian) four-body system for the two considered orbital solutions by means of an implicit Runge-Kutta integrator with a variable-step size [2]. Integrations show that all orbital elements undergo relatively small periodical variations except for the arguments of periastra and the times of periastron passages that advance secularly.

### 2.2 *Apsidal motion*

The apsidal behavior of Gl 22 AB has been analysed by monitoring the aforementioned orbital elements over 10 Myr for each pair of adjacent orbits (see [2] for a more detailed analysis). In the case of the Aa-Ab and the A-B orbits, the numerical results clearly show circulation in both the circular solution as well as in the elliptic one.
On the contrary, when we examine the case of the A-B and Ba-Bb orbits, no conclusion is obvious since the trajectory does not show a regular pattern. As regards the circular solution, it seems that the system is in an antialigned configuration but very close to the separatrix between antialigned libration and circulation; in fact, the distance from the origin is very small (see left part in Figure 1). This complex configuration probably arises because of the circularity of the Ba-Bb orbit whose most noticeable consequence is that the orientation of the major axis is not well defined so it can undergo very large changes. In contrast to this, a minor tendency to circulation appears as slightly preferable in the case of the elliptic solution (see the right part in Figure 1).

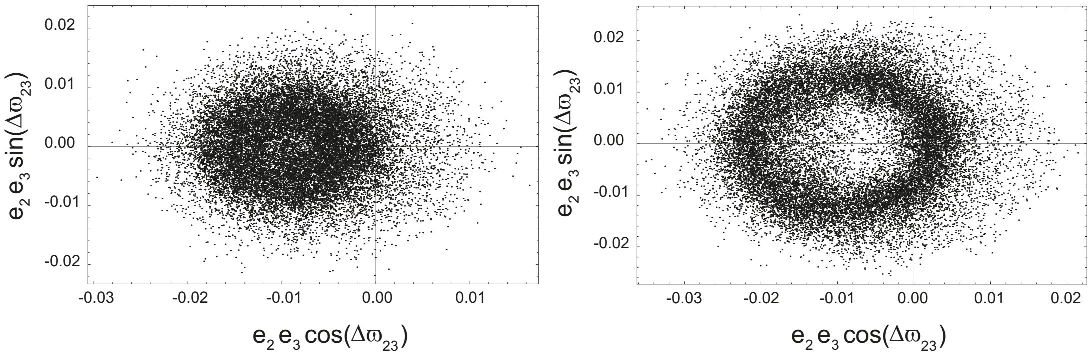


**Figure 1:** Apsidal motion (for the A-B and the Ba-Bb orbits) defined by points that represent the system at 15 yr intervals during 10 Myr for the circular solution (left) and the elliptic solution (right)

## 3. Physical nature: a brown dwarf or a giant planet?

Despite the fact that there are no universally accepted criteria to distinguish giant planets from brown dwarfs, the most widely accepted criterion is that which estimates the mass to fuse deuterium ($12.9 \pm 1.5$ $M_J$ according to [7]) as the threshold for transition from planets to brown dwarfs. That is known as the deuterium-burning mass limit criterion. Another criterion establishes such a delineation according to the object's origin and formation; around 13 $M_J$, there are bodies with stellar and planetary characteristics. In the system studied here, the mass of the Bb companion varies according to the chosen orbital solution: $16.0 \pm 5.6$ $M_J$ (CS) or $15.4 \pm 2.8$ $M_J$ (ES). Assuming a normal distribution for these uncertainties and considering their corresponding probability density functions, we can statistically estimate in each case the probability of the companion mass being below or above the deuterium-burning limit (see Table 3).

**Table 3:** Probability of planetary or stellar nature for the Bb companion according to the deuterium-burning mass limit criterion depending on metallicity

| | | Probability (%) | | |
|---|---|---|---|---|
| Solution | Nature | Low metallicity | Mean metallicity | High metallicity |
| Circular | Planet | 39 | 29 | 20 |
| | Brown dwarf | 61 | 71 | 80 |
| Elliptic | Planet | 36 | 19 | 8 |
| | Brown dwarf | 64 | 81 | 92 |

## 4. Direct imaging

### 4.1 *Prospects for the direct detection*

Several extrasolar planets have been detected by direct imaging since the first successful direct detection in 2004 of a planetary mass companion orbiting a brown dwarf. However, the direct imaging of extrasolar planets and, ultimately, their spectroscopic study around normal stars (not brown dwarfs) remains a difficult task even when using outstanding instrumentation. Nevertheless, in the last few years a very promising technique that combines a stellar coronagraph with adaptive optics on ground-based telescopes has enabled observers to find new planets around nearby stars. For example, the Gemini Planet Imager (GPI), a coronagraphic instrument designed to detect companions by imaging, is capable of perceiving the flux of faint companions near a much brighter host star with detectable contrast ratios of $10^7$.

## 4.2 *The next best observation window*

The small distance to the host star ($3.41 \pm 0.10$ AU) is certainly a drawback in the Gl 22 Bb case. On the contrary, the moderate brightness of the M3V star and the relatively large size of the companion could provide an opportunity to directly detect the latter by means of techniques such as the above-mentioned. Taking into account both orbital solutions given in this paper, we have calculated angular separations and position angles of the Bb object with respect to the Ba stellar component for the coming years up to the completion of an orbital period. The next best observation window will take place between 2016 and 2020 (see Table 4) with separations above $0.''3$ for both solutions (see Figure 2). The maximum value will be $0.''35$ in the middle of 2017 for the circular solution and $0.''38$ at the beginning of 2018 for the elliptic one. Nevertheless, due to the small eccentricity, minimum separation will never be below $0.''24$ which will occur in the middle of 2013 for the circular solution and at the end of 2013 for the elliptic one. We must note that, because of the lack of radial velocities, we cannot determine which is the ascending node and, consequently, in what parts of the observation window the Bb object will be in quarter phase or greater (the most propitious case for a positive detection).

**Table 4:** Ephemerides for both solutions of the Ba-Bb orbit during the next observation window

| Epoch | Circular solution | | Elliptic solution | |
|---|---|---|---|---|
| | $\theta$ (°) | $\rho$ ($''$) | $\theta$ (°) | $\rho$ ($''$) |
| 2016 | 328.2 | 0.315 | 321.6 | 0.320 |
| 2017 | 346.6 | 0.344 | 338.7 | 0.359 |
| 2018 | 3.4 | 0.344 | 353.1 | 0.375 |
| 2019 | 21.8 | 0.315 | 7.5 | 0.362 |
| 2020 | 45.3 | 0.272 | 24.3 | 0.322 |

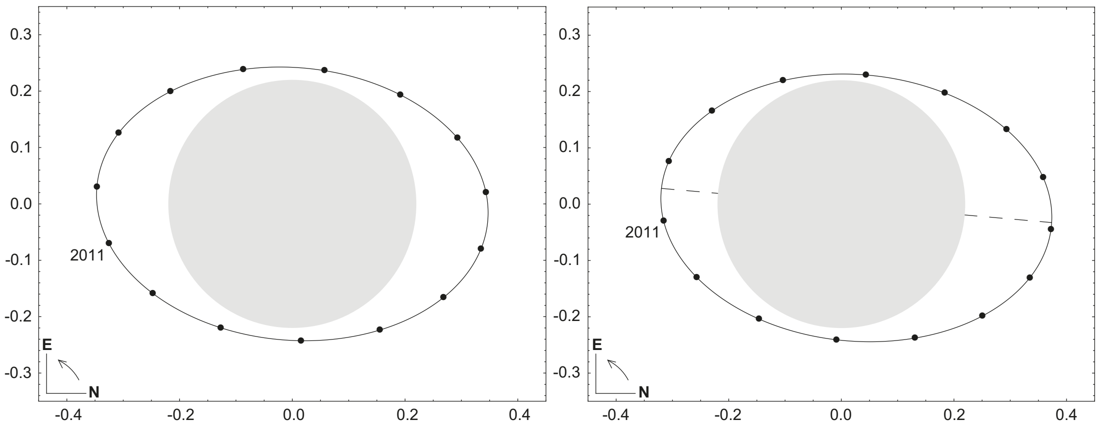


**Figure 2:** Apparent orbit (left: circular solution; right: elliptic solution) for the Gl 22 Bb (scale is in arcseconds). Positions at the beginning of each year during one orbital period from 2011 onward are indicated by black points. The dashed line is the line of nodes. As an example, we have drawn a gray disk which shows the radius ($0.''22$) of the occulting disk of the GPI coronagraph

## Conclusion

According to previous works concerning the utility of astrometry as a precursor to direct detection [3], this astrometric orbit of Gl 22 Bb permits the planning and scheduling of a sequence of imaging observations in order to directly detect this very low-mass object. The completion of this goal would allow us to independently calculate the semimajor axis, eccentricity, and orbital inclination. It could be crucial to specify the planet's true mass and, therefore, to unambiguously determine its stellar or planetary nature. In addition, it would provide the possibility of determining the colors and spectra of Gl 22 Bb. Possibly, in a few years, new coronagraphic instruments combined with adaptive optics could take advantage of the observation window expected from 2016 to 2020 and achieve this goal.

**References**


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