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Letter to the Editor

# A brown dwarf companion to the intermediate-mass star HR 6037*

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**ABSTRACT**

*Context.* The frequency of brown dwarf and planetary-mass companions around intermediate-mass stars is still unknown. Imaging and radial velocity surveys have revealed a small number of substellar companions to these stars.
*Aims.* In the course of an imaging survey we detected a visual companion to the intermediate-mass star HR 6037. We here confirm it as a co-moving substellar object.
*Methods.* We present two epoch observations of HR 6037, an A6-type star with a companion candidate at 6.″67 and position angle of 294 degrees. We also analyze near-infrared spectroscopy of the companion.
*Results.* Two epoch observations of HR 6037 have allowed us to confirm HR 6037 B as a co-moving companion. Its $J$ and $H$ band spectra suggest that the object has a spectral type of M9, with a surface gravity that is intermediate between a 10 Myr dwarf and a field dwarf of the same spectral type. The comparison of its $K_s$-band photometry with evolutionary tracks allows us to derive a mass, effective temperature, and surface gravity of $62 \pm 20$ $M_{\rm Jup}$, $T_{\rm eff} = 2330 \pm 200$ K, and $\log g = 5.1 \pm 0.2$, respectively. The low binary mass ratio, $q \sim 0.03$, and its long orbital period, ~5000 yr, make HR 6037 a rare and uncommon binary system.

**Key words.** binaries: general – brown dwarfs – stars: individual: HR 6037

## 1. Introduction

The frequency of brown dwarfs (BDs) and planetary-mass companions around intermediate-mass main sequence (MS) stars is uncertain. Brown dwarfs can be formed by several mechanisms (e.g. Padoan & Nordlund 2004; Stamatellos & Whitworth 2009), but the expected substellar fractions for B–F type primaries are uncertain. For giant planets that were formed in the disks of young stars, some works predict a higher frequency around AB-type stars than in solar-type stars (e.g. Kennedy & Kenyon 2008). However, Kornet et al. (2006) arrive at an opposite result when they conclude that the percentage of stars with giant planets decreases with increasing stellar masses from 0.5 to 4 $M_\odot$.

To shed light on this issue, different observational programs have been focused on deriving the frequency of BDs and planetary-mass objects around intermediate-mass stars. As a result, planetary mass companions have recently been detected around three A-type stars through adaptive optics (AO) assisted observations (Marois et al. 2008; Kalas et al. 2008; Lagrange et al. 2010). Radial velocity (RV) studies, which are sensitive to short-period companions, have also reported the presence of substellar objects around several A–F type MS stars (Galland et al. 2005, 2006; Guenther et al. 2009), with minimum masses ($M \sin i$) in the planetary mass regime, which means that they could also be BDs. Transit programs have also detected planetary mass companions around several F-type stars (e.g. Bakos et al. 2007; Johns-Krull et al. 2008; Joshi et al. 2009; Hellier et al. 2009), and one around an A5 star (Christian et al. 2006; Cameron et al. 2010).

Direct imaging surveys have allowed to study the fraction of wide substellar companions around intermediate-mass stars for BDs. As an example, Kouwenhoven et al. (2005, 2007) studied the late-B and A-type star population from the Sco OB2 association. Although sensitive to substellar companions, they reported the detection of only two BDs companion candidates. They concluded that the dearth of BD companions to intermediate-mass stars is consistent with the extrapolation of the stellar companion mass distribution into the BD regime (assuming they formed like stars). Recently, Ehrenreich et al. (2010) conducted an AO survey to detect substellar companions in wide orbits around a volume-limited sample of 38 A- and F-type field stars previously observed with RV techniques. They did not report any new BD companion. Indeed, up to now there is only one BD companion to an intermediate-mass star, HR 7329 B, that is confirmed by direct imaging and near-IR spectroscopy (Lowrance et al. 2000; Guenther et al. 2001). Radial velocity studies have also detected BD companions to A–F type MS stars

* Based on observations collected at the Paranal Observatory under programs 272.D-5068(A), 77.D-0147(A), and 285.C-5008(A).

**Table 1.** Physical properties of HR 6037 A&B derived here.

| Name | Sp. type | $T_{\rm eff}$ [K] | log $g_s$ [cm/s$^2$] | Mass [$M_\odot$] | [Fe/H] |
|---|---|---|---|---|---|
| HR 6037A | A6 | 8120 ± 100 | 4.2 ± 0.1 | 1.8 ± 0.2 | 0.00 ± 0.05 |
| HR 6037B | M9 | 2330 ± 200 | 5.1 ± 0.2 | 0.06 ± 0.02 | – |

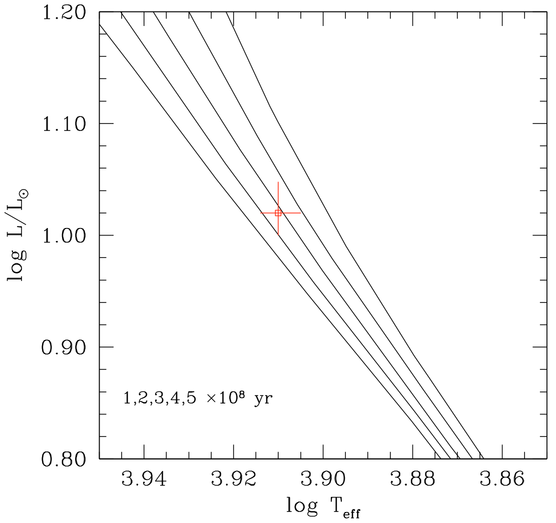


**Fig. 1.** HR Diagram with the location of HR 6037. We have overplotted the Marigo et al. (2008) isochrones for five different ages between 100 Myr and 500 Myr (from the left to the right). We estimate an age of ~300 ± 100 Myr for the primary.

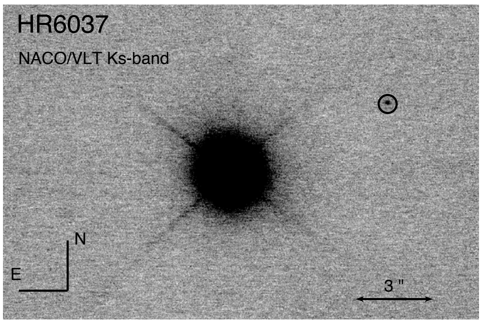


**Fig. 2.** NACO/VLT image of HR 6037. The co-moving companion is encircled.

(Galland et al. 2006; Hartmann et al. 2010), and transit observations have reported a BD around an F-type star, CoRoT-3 b (Deleuil et al. 2008).

Thus it is that despite the efforts, the occurrence of planetary-mass objects and BDs around intermediate-mass stars is still unknown and deserves additional observations.

In 2004, we started a project aimed at deriving the binary fraction and properties among a large volume-limited sample of intermediate-mass stars in the field (hereafter, Multi-NETS Project, Ivanov et al. 2006). Thanks to the use of deep AO near-infrared (near-IR) imaging with Naos-Conica (NACO, Lenzen et al. 2003) at the Very Large Telescope (VLT), we have been able to extend our study to substellar companions that are important to understand the formation of low mass ratio binaries. In the course of our survey, we detected a faint, visual companion to the star HR 6037. In this letter, we report the discovery and the co-moving confirmation of the companion to HR 6037 based on NACO astrometric observations obtained at two different epochs. We also present ISAAC near-IR spectroscopic data that confirms together with the near-IR photometry that this companion is likely to be a new and rare substellar companion to the intermediate-mass star HR 6037.

## 2. HR 6037 stellar properties

The source HR 6037 is a main-sequence A-type star classified as "variable" by Samus et al. (2009), although its type of variability is uncertain. Its proper motion and parallax, according to Hipparcos (Perryman et al. 1997), are $\mu_\alpha = -44.74 \pm 0.56$ and $\mu_\delta = -84.65 \pm 0.43$ mas/yr, and $18.13 \pm 0.69$ mas, respectively. The latter value translates into a distance of 55 ± 2 pc.

We derived the physical properties of HR 6037 by analyzing high-resolution ($R = 80\,000$) optical archival spectroscopy obtained with the UVES instrument at the VLT (Program ID 266.D-5655(A)). The spectrum was obtained integrating a total of 70 s, and was centered at 5800 Å.

The primary is an A6V, as derived from spectral synthesis using SYNTHE (Kurucz 1993). Our analysis also yields [Fe/H] = 0.00 ± 0.05, namely solar metallicity, and provides values for the effective temperature and surface gravity (see Table 1). Using the Hipparcos parallax we derive $M_V = 2.24$, or $\log(\frac{L}{L_\odot}) = 1.02^{0.038}_{0.02}$, assuming no extinction. Stromgren $H_\beta$ = 2.884 and $b - y = 0.069$ photometry (Hauck & Mermilliod 1998) confirms HR 6037 A as an A6 dwarf whose temperature and gravity agree with the values derived from the UVES spectrum. We plotted the object on a Hertzsrpung-Russel diagram (see Fig. 1) and compared it with the Padova evolutionary tracks for solar metallicity (Marigo et al. 2008). We used the isochrones from 100 to 500 Myr, which is a typical age range for a star of this spectral type. We estimate an age of 300 ± 100 Myr and a mass of 1.8 ± 0.2 $M_\odot$.

Finally, we note that the object was included in a RV survey to look for very close BDs and planetary-mass companions, showing no significant RV variation (Lagrange et al. 2009).

## 3. Observations and data reduction

### 3.1. NACO deep imaging

The source HR 6037 was observed in service mode with NACO, the adaptive optics facility at the VLT on 2004-06-30 and 2006-06-09. We used the visible wavefront sensor with the primary as a reference star. We observed in the $K$s-band filter with the S27 objective (field of view of 27″ × 27″) in "autojitter mode", dithering within a box of 12″ width. The total on-source exposure time was ~13 min. The average coherence time and optical seeing were 1.5 ms and 1.″0, and 1.2 ms and 1.″7, during the first and second epoch, respectively.

The data were reduced with *Eclipse* (Devillard 1997) and following the standard procedure: dark subtraction, flat-field division, sky subtraction, alignment, and stacking. The final image from 2006 is displayed in Fig. 2. Apart from the bright primary, we detect a visual companion at a projected separation of ~6.″66 and position angle of ~294 degrees.

In order to measure precise separations and position angles, we derived the plate scale and orientation of the detector, CONICA, using archival observations of the astrometric calibrator IDS 21506-5133 (van Dessel & Sinachopoulos 1993) obtained on 2004-06-19 and 2006-08-26. The values for the two campaigns are 27.01 ± 0.05 mas/pix and 27.02 ± 0.05 mas/pix respectively for the plate scale, and 0.0 ± 0.2 deg and −0.1 ± 0.2 deg for the True North orientation.

### 3.2. ISAAC near-infrared spectroscopy

Near-IR spectra of the HR 6037 B were obtained in service mode with ISAAC/VLT (Moorwood et al. 1998) on 2010-06-06/07 in the $J$ and $H$ atmospheric windows, and on 2010-06-11/12 in the $K$ window, in the "classical" nodding-along-the-slit observing strategy. We used the low-resolution mode and the 0.6″ wide slit, delivering a spectral resolution of $R \sim 800$. We collected six exposures for $J$ and $H$, and twelve for $K$, but one $J$ spectrum was discarded because of a low signal. The total integration times were 1115, 2232, and 4464 s, for $J$, $H$, and $K$ respectively. The seeing was better than 1″ during both nights. The sky was clear on 2010-06-06/07, and thin clouds were present on 2010-06-11/12. B-type telluric standards were observed back-to-back with the science targets with the same instrument setup. One of them showed a strong Bracket $\gamma$ emission line, which was fitted with a Gaussian and subtracted from the spectrum before applying the telluric correction.

The data were reduced with IRAF[1] and following the standard steps: flat field division, sky emission removal by subtracting images from corresponding nodding pairs, and extraction and combination of the individual spectra into the final spectrum. The wavelength calibration was performed using arcs. The telluric absorption was removed by dividing the target spectra by the telluric standards, and by multiplying them with the corresponding spectra from the library of Pickles (1998). Some of the spectra from this library are featureless models, which means that artificial emission lines remained in the final product. To remove them, we went back to the telluric spectra and subtracted Gaussian fits to their intrinsic stellar features – mainly hydrogen recombination lines. This together with the Bracket $\gamma$ emission mentioned above implies some uncertainty in the spectral regions around the strong hydrogen lines.

## 4. Results

### 4.1. HR 6037 B, a co-moving companion

Figure 3 shows the difference in right ascension (RA) and declination (Dec) of HR 6037 and its companion candidate as measured in 2004 and 2006. We also overplotted the expected difference in RA and Dec of a background object taking into account the proper motion and parallax of the primary. It is evident that the companion shows RA and Dec differences consistent with a co-moving object. Indeed, the difference in the separation and the position angle between the two epochs are consistent with a bound companion within the errors (see Table 2).

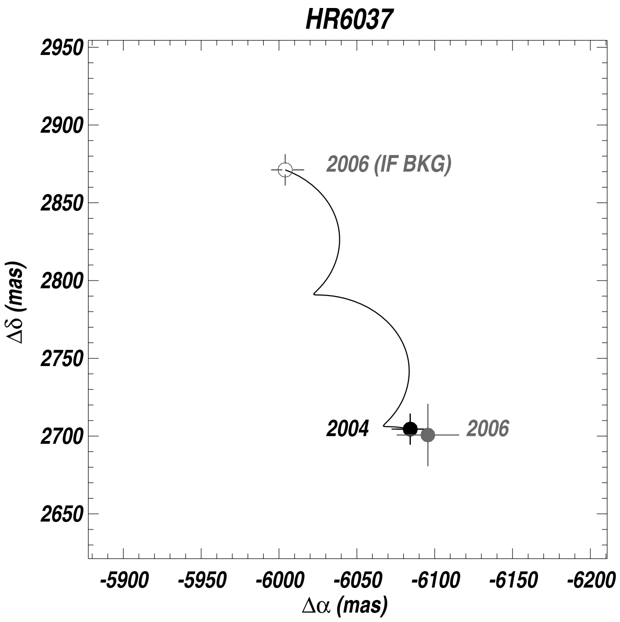


**Fig. 3.** Analysis of the two NACO/VLT epochs of HR 6037. The axes show the difference in right ascension and declination of the binary members in the two epochs. The solid black and grey circles represent the position of the companion candidate in 2004 and 2006, respectively. The open grey circle represents the expected position of HR 6037 B if it were a background object. The data is consistent with HR 6037 B being a co-moving companion.

**Table 2.** Binary parameters for the two epoch observations.

| Date | Separation (arcsec) | PA (deg) | $\Delta K_s$ (mag) |
|---|---|---|---|
| 2004-06-30 | 6.66 ± 0.01 | 293.96 ± 0.1 | 8.2 ± 0.1 |
| 2006-06-09 | 6.67 ± 0.03 | 293.98 ± 0.2 | 8.7 ± 0.2 |

### 4.2. Spectral characterization of HR 6037 B

The ISAAC $JHK$ spectra of HR 6037 B were first compared to libraries of template spectra of field dwarfs (Cushing et al. 2005; Rayner et al. 2009) and moderately young dwarfs from Upper Scorpius, TW Hydrae and $\beta$ Pictoris associations (Allers et al. 2009; Rice et al. 2010). The $K$-band spectrum of HR 6037 B is much bluer than all M and early-L type dwarfs. This is probably owing to a problem of flux loss during the observation. Therefore, only the $J$ and $H$-band spectra were considered for the spectral classification based on the continuum comparison with libraries of field and young dwarfs. The best matches are displayed in Fig. 4. The $J$ and $H$ continuum of HR 6037 B is well reproduced by the spectrum of the young M8.5 dwarf 2M1207 A from the TW Hydrae association (8 Myr) and the M9V field dwarf (Rayner et al. 2009), consequently we estimate an M9 ± 1 spectral type.

Careful identification of the lines over the $JHK$ spectral range shows the presence of broad molecular absorptions of $H_20$ (longward 1.33 and 1.6 $\mu$m), FeH (at 1.194, 1.222, 1.239, 1.583-1.591 and 1.625 $\mu$m) as well as CO overtones longward 2.29 $\mu$m all typical of late-M dwarfs. There is also the possible presence of VO absorptions from 1.17 to 1.20 $\mu$m. In the $J$-band, the atomic line doublets of Na I and K I at 1.138, 1.169, 1.177, 1.243, 1.253 $\mu$m are well detected. We also detect the K I atomic line at 1.517 $\mu$m. Their strengths are intermediate between spectra of 10 Myr-old dwarfs, and those of field dwarfs with identical spectral types (see Fig. 4). This finding corroborates the age estimate of HR 6037 A and B of a few tens to hundreds Myr (if both components are coeval).

### 4.3. HR 6037 B physical properties

The difference in $K_s$ magnitude between HR 6037 A&B in the NACO images was derived with standard packages for aperture photometry within IRAF, and provided in Table 2. Because the 2MASS $K_s$ value of the primary is $5.66 \pm 0.02$ (Cutri et al. 2003), we estimate an average $K_s$ = 14.1 ± 0.3 mag for the secondary,

[1] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA) under cooperative agreement with the National Science Foundation.

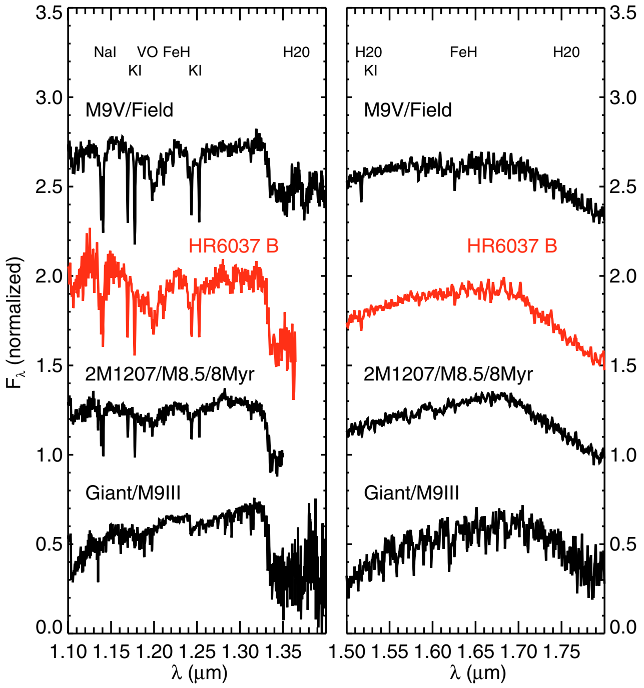


**Fig. 4.** Comparison of the $J$ and $H$ band ISAAC spectra of HR 6037 B companion (red) to the template spectra of the young 8 Myr-old dwarf 2M1207 A (M8.5) and the field dwarf (M9V). The spectrum of the very late type giant (IO Virginis) is also reported for comparison. All spectra have been normalized to 1.23 $\mu$m and 1.65 $\mu$m and offsetted.

which translates into $M_{K_s} = 10.4 \pm 0.3$ mag for a distance of $55 \pm 2$ pc. We have compared this value with the DUSTY evolutionary tracks by Baraffe et al. (2002), assuming the age derived from the UVES spectrum of the primary. According to the DUSTY evolutionary tracks, a $300 \pm 100$ Myr object with $M_{K_s}$ of $10.4 \pm 0.3$ mag corresponds to a $62 \pm 20$ $M_{\rm Jup}$ BD with $T_{\rm eff} = 2330 \pm 200$ K, and $\log g = 5.1 \pm 0.2$.

### 4.4. HR 6037 A&B: main properties of the binary system

The mass ratio of HR 6037 A&B is $q = 0.034$. This mass ratio is uncommon for binaries with intermediate-mass stars as primaries. The projected separation of the binary components for a distance of 55 pc is ~366 AU. Using Kepler's third law, we derive an orbital period of ~5000 yr. Even if imaging surveys are sensitive to these long period, low binary mass ratio systems, they are uncommon (e.g. Kouwenhoven et al. 2007; Ehrenreich et al. 2010). Hence, we can conclude that HR 6037 A&B is an extremely rare binary system.

## 5. Conclusions

We report the detection of a BD companion to the 300 Myr old star HR 6037. Our main results can be summarized as follows:

1. HR 6037 is a binary system with a separation of 6.″66 and a position angle of $293.9 \pm 0.1$ degrees. Two epoch observations confirm that HR 6037 B is a co-moving companion.
2. Near-IR spectroscopy reveals a spectral type of M9 ± 1 for HR 6037 B by comparison of the $J$ and $H$ band continuum to templates. The strength of the gravity-sensitive features is consistent with a dwarf intermediate between a low-gravity young dwarf and high-gravity field dwarf of similar spectral type. This result is consistent with the age derived for the primary, 300 Myr, i.e. both objects appear to be coeval.
3. Evolutionary tracks predict a mass of $62 \pm 20$ $M_{\rm Jup}$, an effective temperature of $T_{\rm eff} = 2330 \pm 200$ K, and a surface gravity of $\log g = 5.1 \pm 0.2$.

To our knowledge, HR 6037 B is the second BD companion confirmed to be bound to an intermediate-mass star by two epoch observations and spectroscopy. Its low binary mass ratio and long orbital period make it a rare and uncommon binary system.

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## References

Allers, K. N., Liu, M. C., Shkolnik, E., et al. 2009, ApJ, 697, 824
Bakos, G. Á., Kovács, G., Torres, G., et al. 2007, ApJ, 670, 826
Baraffe, I., Chabrier, G., Allard, F., & Hauschildt, P. H. 2002, A&A, 382, 563
Cameron, A. C., Guenther, E., Smalley, B., et al. 2010, MNRAS, 407, 507
Christian, D. J., Pollacco, D. L., Skillen, I., et al. 2006, MNRAS, 372, 1117
Cushing, M. C., Rayner, J. T., & Vacca, W. D. 2005, ApJ, 623, 1115
Cutri, R. M., Skrutskie, M. F., van Dyk, S., et al. 2003, VizieR Online Data Catalog, 2246, 0
Deleuil, M., Deeg, H. J., Alonso, R., et al. 2008, A&A, 491, 889
Devillard, N. 1997, The Messenger, 87, 19
Ehrenreich, D., Lagrange, A., Montagnier, G., et al. 2010, A&A, in press, [arXiv:1007.0002]
Galland, F., Lagrange, A., Udry, S., et al. 2005, A&A, 444, L21
Galland, F., Lagrange, A., Udry, S., et al. 2006, A&A, 452, 709
Guenther, E. W., Neuhäuser, R., Huélamo, N., Brandner, W., & Alves, J. 2001, A&A, 365, 514
Guenther, E. W., Hartmann, M., Esposito, M., et al. 2009, A&A, 507, 1659
Hartmann, M., Guenther, E. W., & Hatzes, A. P. 2010, ApJ, 717, 348
Hauck, B., & Mermilliod, M. 1998, A&AS, 129, 431
Hellier, C., Anderson, D. R., Cameron, A. C., et al. 2009, Nature, 460, 1098
Ivanov, V. D., Chauvin, G., Foellmi, C., et al. 2006, Ap&SS, 304, 247
Johns-Krull, C. M., McCullough, P. R., Burke, C. J., et al. 2008, ApJ, 677, 657
Joshi, Y. C., Pollacco, D., Cameron, A. C., et al. 2009, MNRAS, 392, 1532
Kalas, P., Graham, J. R., Chiang, E., et al. 2008, Science, 322, 1345
Kennedy, G. M., & Kenyon, S. J. 2008, ApJ, 682, 1264
Kornet, K., Wolf, S., & Różyczka, M. 2006, A&A, 458, 661
Kouwenhoven, M. B. N., Brown, A. G. A., Zinnecker, H., Kaper, L., & Portegies Zwart, S. F. 2005, A&A, 430, 137
Kouwenhoven, M. B. N., Brown, A. G. A., Portegies Zwart, S. F., & Kaper, L. 2007, A&A, 474, 77
Kurucz, R. 1993, SYNTHE Spectrum Synthesis Programs and Line Data. Kurucz CD-ROM No. 18. Cambridge, Mass.: Smithsonian Astrophysical Observatory, 18
Lagrange, A., Desort, M., Galland, F., Udry, S., & Mayor, M. 2009, A&A, 495, 335
Lagrange, A., Bonnefoy, M., Chauvin, G., et al. 2010, Science, 329, 57
Lenzen, R., Hartung, M., Brandner, W., et al. 2003, in SPIE Conf. 4841, ed. M. Iye, & A. F. M. Moorwood, 944
Lowrance, P. J., Schneider, G., Kirkpatrick, J. D., et al. 2000, ApJ, 541, 390
Marigo, P., Girardi, L., Bressan, A., et al. 2008, A&A, 482, 883
Marois, C., Macintosh, B., Barman, T., et al. 2008, Science, 322, 1348
Moorwood, A., Cuby, J., Biereichel, P., et al. 1998, The Messenger, 94, 7
Padoan, P., & Nordlund, Å. 2004, ApJ, 617, 559
Perryman, M. A. C., Lindegren, L., Kovalevsky, J., et al. 1997, A&A, 323, L49
Pickles, A. J. 1998, PASP, 110, 863
Rayner, J. T., Cushing, M. C., & Vacca, W. D. 2009, ApJS, 185, 289
Rice, E. L., Faherty, J. K., & Cruz, K. L. 2010, ApJ, 715, L165
Samus, N. N., Durlevich, O. V., et al. 2009, VizieR Online Data Catalog, 1, 2025
Stamatellos, D., & Whitworth, A. P. 2009, MNRAS, 392, 413
van Dessel, E., & Sinachopoulos, D. 1993, A&AS, 100, 517