The orbit of the Mercury-Manganese binary 41 Eridani

Christian A. Hummel[a], Markus Schöller[a], Gilles Duvert[b], Jean-Baptiste Le Bouquin[b], and Swetlana Hubrig[c]

[a]European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching, Germany
[b]UJF-Grenoble 1/CNRS-INSU, Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), UMR 5274, Grenoble, F-38041, France
[c]Leibniz-Institut für Astrophysik Potsdam (AIP), An der Sternwarte 16, 14482 Potsdam, Germany

ABSTRACT

The mercury-manganese (HgMn) stars are a class of peculiar main-sequence late-type B stars. Their members show a wide variety of abundance anomalies with both depletions (e.g., He) and enhancements (Hg, Mn) and tend to be slow rotators relative to their normal analogs. More than two thirds of the HgMn stars are known to belong to spectroscopic binaries with a preference of orbital periods ranging from 3 to 20 days.[1]

Interferometric orbits were already measured for the HgMn binaries ϕ Herculis,[2] χ Lupi,[3] and α Andromedae.[4] Here we report on a program to study the binarity of HgMn stars with the PIONIER near-infrared interferometer at the VLTI on Cerro Paranal, Chile. Among 40 stars, companions were found for 11 of them, and the data allowed the determination of the orbital elements of 41 Eridani, with a period of just 5 days and a semi-major axis of under 2 mas.

Keywords: stars:binaries:close, stars:chemically peculiar, techniques:high angular resolution

1. INTRODUCTION

The abundance anomalies found in the atmospheres of chemically peculiar stars are thought to be caused by gravitational settling or radiatively driven diffusion in a stable environment. These stars are typically of spectral types B and A, i.e. they do not have a convective outer region. The high occurrence of spectroscopic binaries among the HgMn stars[1] could be related to the phenomenon, or just reflect the higher multiplicity rate of early type stars[5,6] compared to late type stars as a consequence of the formation of massive stars. Optical interferometry in the visual and near infrared bands is a technique complementary to Doppler spectroscopy for the study of these stars and allows determination of fundamendal stellar properties including flux ratios, multiplicity rates, and surface imaging.[7,8]

2. OBSERVATIONS AND DATA REDUCTION

Observations were carried out with the PIONIER[9] beam-combiner attached to the VLTI.[10] In 2012 and 2013, fringes were recorded in dispersed (GRISM) mode and resulted in measurements of the (squared) visiblity amplitude and closure phase in three narrow-band channels centered at 1.60μm, 1.69μm, and 1.77μm. In 2014, the grism was not used and the fringes were recorded in a broad band channel approximately 0.245μm wide (FREE mode). The 2014 data were reduced with the `pndrs` pipeline,[9] while the older data, reduced and calibrated, were retrieved from the OiDB[*] data base hosted at the Jean-Marie Mariotti Center (JMMC) in Grenoble, France. A good knowledge of the spectral band passes for the FREE mode is essential in order to avoid systematic errors. Model visibilities have to be integrated over the band pass before comparison with the observed visibilities. The pipeline uses scans of the fringes obtained with an internal lamp to compute the fringe amplitude power-spectral-density distribution (PSD) of which an example is shown in Fig. 1. The internal lamp spectrum is very red and would introduce a (small) bias in the band pass. However, if measured on sky, the stronger fringe motion blurs the PSD.

Further author information: (Send correspondence to C.A.H.)
C.A.H.: E-mail: chummel@eso.org, Telephone: (49) 89 3200 6151
[*]http://oidb.jmmc.fr/index.html

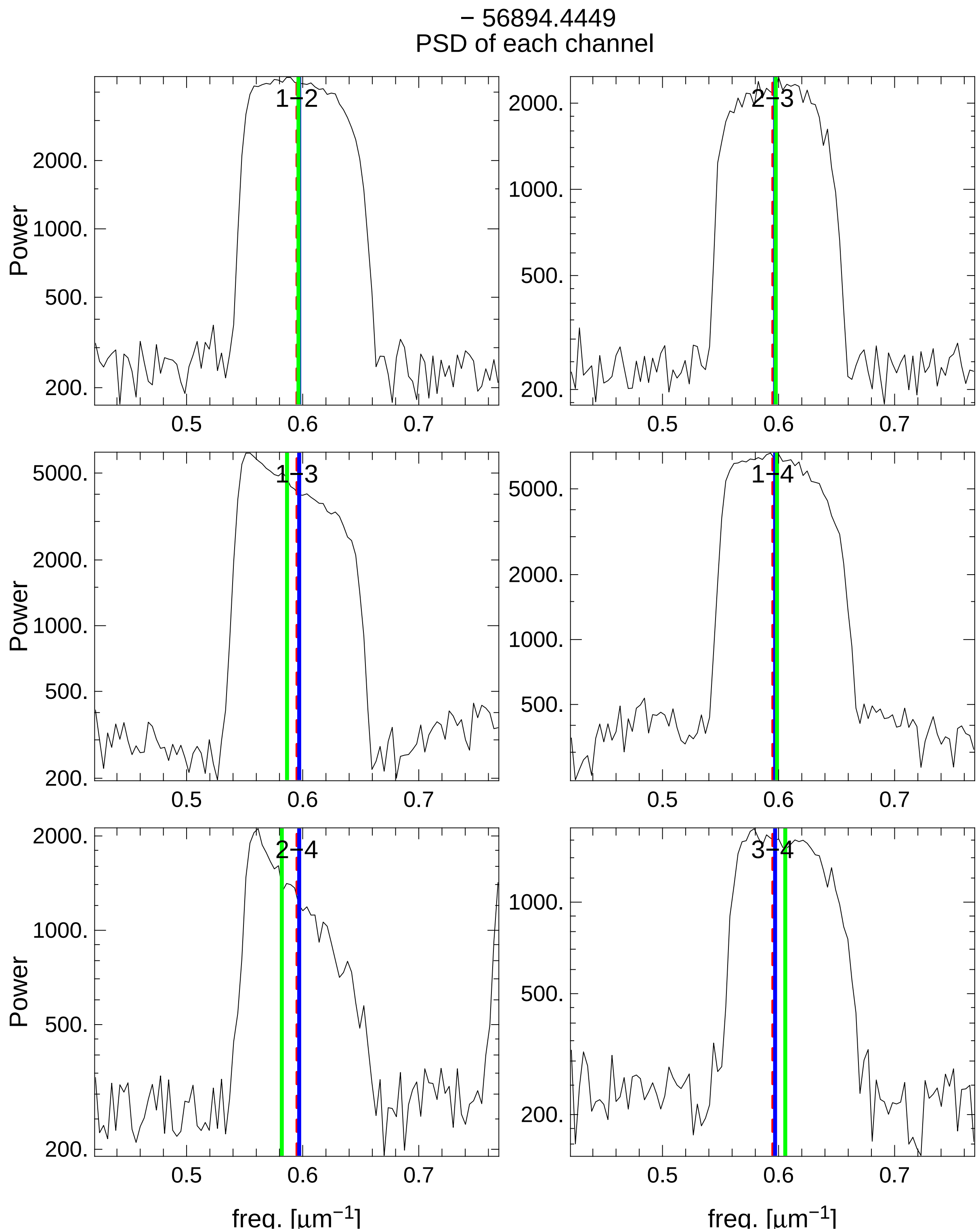

Figure 1. Band passes for the 6 baselines recorded in the FREE mode.

3. CALIBRATION AND ANALYSIS

Calibrators were selected with the SearchCal[†] tool. Inspection of the transfer function (i.e., the visibility measured on the calibrators corrected for their finite angular diameters) led to the exclusion of just a few calibrator stars due to inconsistent results. (Bad calibrator stars can be reported to JMMC[‡]).

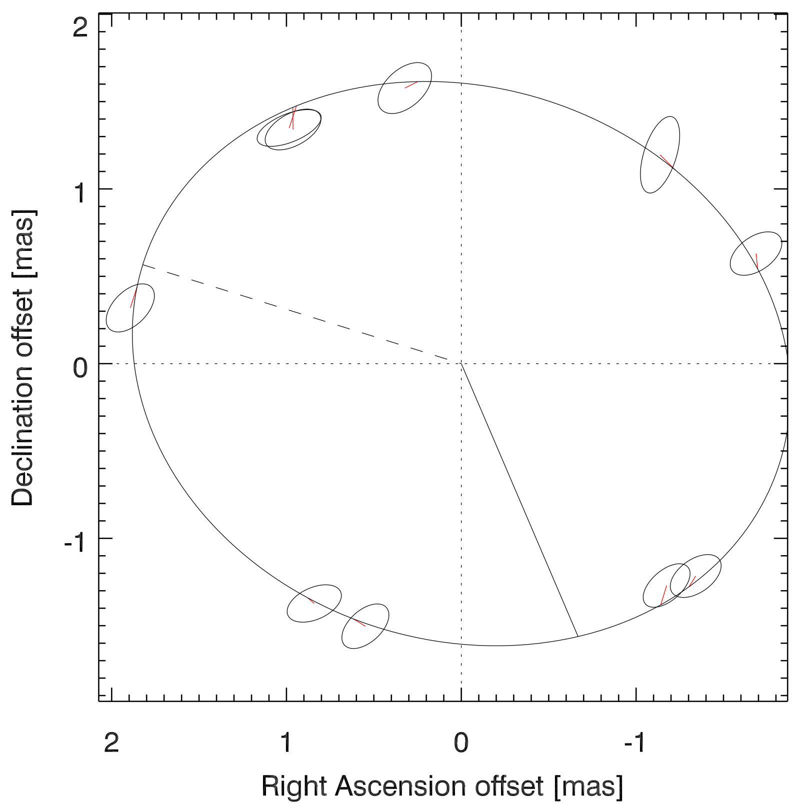

Figure 2. The apparent orbit of 41 Eridani. The solid line indicates the periastron, while the dashed line indicates the ascending node. The 2014 results correspond to the two superposed error ellipses in the upper left quadrant of the orbit. The short (red) lines connect the measurements with the orbital model values. The two measurements at PA $\approx 30^\circ$ were taken (almost) exactly one orbital period apart, and appear slightly offset from the orbit possibly due to an imperfect band pass correction since they were obtained with the FREE mode of PIONIER.

The orbital modeling was performed with OYSTER[§]. Initial nightly companion positions were obtained using CANDID[11] An initial orbit was fit to the astrometry, and then directly to the visibility data taking into account orbital motion. We adopted a circular orbit[12] and fit the elements listed in Table 1 directly to the visibility data.

Stellar masses and the orbital parallax were fit to published radial velocity data[12,13] and are also given in Table 1. The parallax is in good agreement with the Hipparcos value.

[†]http://www.jmmc.fr/searchcal_page.htm

[‡]http://apps.jmmc.fr/badcal/

[§]http://www.eso.org/~chummel/oyster

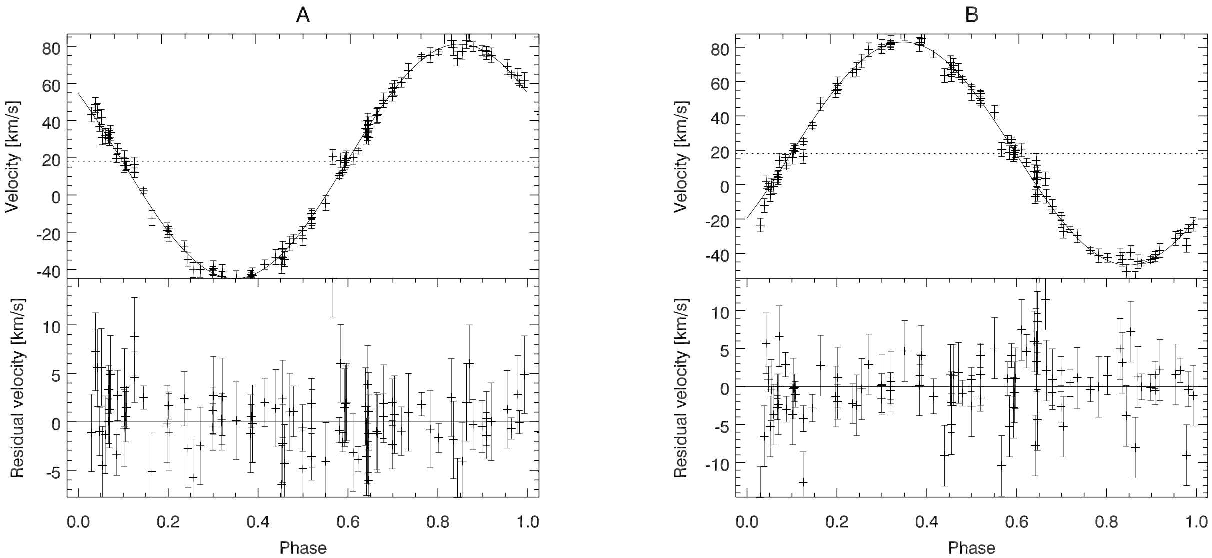

Figure 3. Radial velocity data for components A and B[12,13] with solid lines showing the orbital model. The lower panels show the fit residuals.

4. DISCUSSION

To obtain estimates for the diameters of the stars, we adopt, as the two components of 41 Eri appear nearly identical, the same spectral type of B9V for both of them. We used the `sedFit`[15] tool to retrieve photometric data from the Simbad data base and to fit stellar template spectra. Thus we derived the effective temperature and angular diameter for the components, which are listed in Table 1. The effective temperatures derived from spectroscopy[16] ($T_{\mathrm{eff,A}} = 12750$K and $T_{\mathrm{eff,B}} = 12250$K, uncertainty of 200 K) are quite a bit higher, but still consistent within the 2σ of the photometric uncertainty of 800 K. The diameters translate into stellar radii of $2.31 \pm 0.36 R_\odot$.

Table 1. Preliminary orbital elements and component parameters for 41 Eridani. The Hipparcos parallax is 18.33 ± 0.15 mas.[14]

a/mas	1.908 ± 0.002
$i/^\circ$	146.1 ± 0.1
$\Omega/^\circ$ (J2000.0)	72.7 ± 0.2
T (JD)	2454407.22 (fixed)
e	0 (fixed)
$\omega/^\circ$	54.7 ± 0.2
P/days	5.0103250 ± 0.0000008
$M_{\mathrm{A}}/M_\odot$	3.13 ± 0.06
$M_{\mathrm{B}}/M_\odot$	3.05 ± 0.06
ΔH	0.053 ± 0.006
$D_{\mathrm{A},B}$/mas	0.39 ± 0.06
T_{eff}/K	10700 ± 800
$\pi_{orb.}$/mas	18.14 ± 0.16

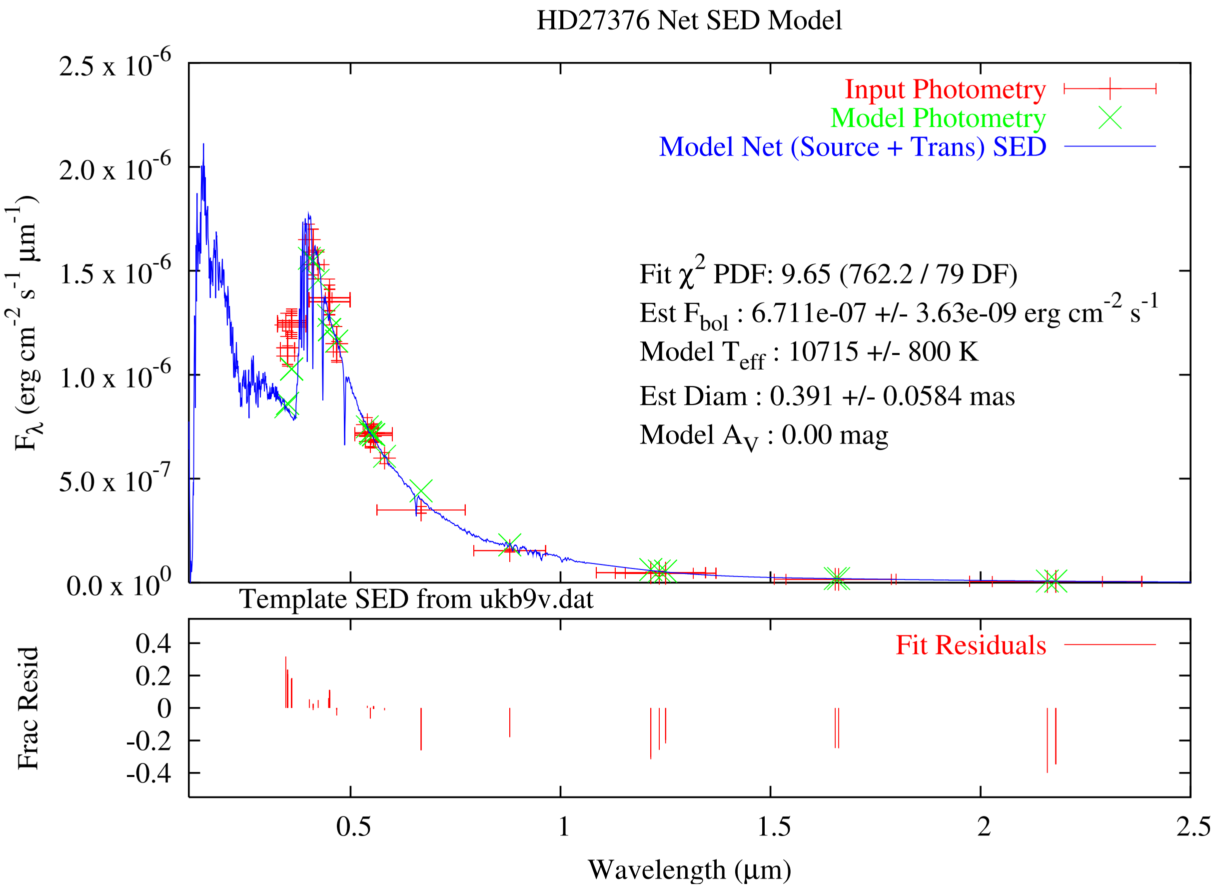

Figure 4. Fit to Simbad photometry with `sedFit`. The lower panel shows the fit residuals as fractions of the total flux.

We are currently conducting a survey with PIONIER to study the multiplicity of HgMn stars. Of the 40 stars observed by the end of 2015, 11 showed a companion at separations between 1 mas and 10 mas.

ACKNOWLEDGMENTS

We thank Gerard van Belle for providing an installation of `sedFit`.

REFERENCES

[1] Hubrig, S. and Mathys, G., "Some remarks on the origin of the abundance anomalies in HgMn stars.," *Comments on Astrophysics* **18**, 167–179 (1995).

[2] Zavala, R. T., Adelman, S. J., Hummel, C. A., Gulliver, A. F., Caliskan, H., Armstrong, J. T., Hutter, D. J., Johnston, K. J., and Pauls, T. A., "The Mercury-Manganese Binary Star ϕ Herculis: Detection and Properties of the Secondary and Revision of the Elemental Abundances of the Primary," ApJ **655**, 1046–1057 (Feb. 2007).

[3] Le Bouquin, J.-B., Beust, H., Duvert, G., Berger, J. P., Ménard, F., and Zins, G., "Masses and age of the chemically peculiar double-lined binary χ Lupi," A&A **551**, A121 (Mar. 2013).

[4] Pan, X., Shao, M., Colavita, M. M., Armstrong, J. T., Mozurkewich, D., Vivekanand, M., Denison, C. S., Simon, R. S., and Johnston, K. J., "Determination of the visual orbit of the spectroscopic binary Alpha Andromedae with submilliarcsecond precision," ApJ **384**, 624–633 (Jan. 1992).

[5] Sana, H., Le Bouquin, J.-B., Lacour, S., Berger, J.-P., Duvert, G., Gauchet, L., Norris, B., Olofsson, J., Pickel, D., Zins, G., Absil, O., de Koter, A., Kratter, K., Schnurr, O., and Zinnecker, H., "Southern Massive Stars at High Angular Resolution: Observational Campaign and Companion Detection," ApJS **215**, 15 (Nov. 2014).

[6] Schöller, M., Correia, S., Hubrig, S., and Ageorges, N., "Multiplicity of late-type B stars with HgMn peculiarity," A&A **522**, A85 (Nov. 2010).

[7] Shulyak, D., Paladini, C., Causi, G. L., Perraut, K., and Kochukhov, O., "Interferometry of chemically peculiar stars: theoretical predictions versus modern observing facilities," MNRAS **443**, 1629–1642 (Sept. 2014).

[8] Wittkowski, M., Schöller, M., Hubrig, S., Posselt, B., and von der Lühe, O., "Measuring starspots on magnetically active stars with the VLTI," *Astronomische Nachrichten* **323**, 241–250 (July 2002).

[9] Le Bouquin, J.-B., Berger, J.-P., Lazareff, B., Zins, G., Haguenauer, P., Jocou, L., Kern, P., Millan-Gabet, R., Traub, W., Absil, O., Augereau, J.-C., Benisty, M., Blind, N., Bonfils, X., Bourget, P., Delboulbe, A., Feautrier, P., Germain, M., Gitton, P., Gillier, D., Kiekebusch, M., Kluska, J., Knudstrup, J., Labeye, P., Lizon, J.-L., Monin, J.-L., Magnard, Y., Malbet, F., Maurel, D., Ménard, F., Micallef, M., Michaud, L., Montagnier, G., Morel, S., Moulin, T., Perraut, K., Popovic, D., Rabou, P., Rochat, S., Rojas, C., Roussel, F., Roux, A., Stadler, E., Stefl, S., Tatulli, E., and Ventura, N., "PIONIER: a 4-telescope visitor instrument at VLTI," A&A **535**, A67 (Nov. 2011).

[10] Schöller, M., "The Very Large Telescope Interferometer: Current facility and prospects," New A Rev. **51**, 628–638 (Oct. 2007).

[11] Gallenne, A., Mérand, A., Kervella, P., Monnier, J. D., Schaefer, G. H., Baron, F., Breitfelder, J., Le Bouquin, J. B., Roettenbacher, R. M., Gieren, W., Pietrzyński, G., McAlister, H., ten Brummelaar, T., Sturmann, J., Sturmann, L., Turner, N., Ridgway, S., and Kraus, S., "Robust high-contrast companion detection from interferometric observations. The CANDID algorithm and an application to six binary Cepheids," A&A **579**, A68 (July 2015).

[12] Hubrig, S., González, J. F., Ilyin, I., Korhonen, H., Schöller, M., Savanov, I., Arlt, R., Castelli, F., Lo Curto, G., Briquet, M., and Dall, T. H., "Magnetic fields of HgMn stars," A&A **547**, A90 (Nov. 2012).

[13] Paddock, G. F., "The spectroscopic binary, 41 nu4 Eridani, A.G.C. 4821.," *Lick Observatory Bulletin* **8**, 168–179 (1915).

[14] van Leeuwen, F., "Validation of the new Hipparcos reduction," A&A **474**, 653–664 (Nov. 2007).

[15] Boden, A. F., "Calibrating optical/IR interferometry visibility data," New A Rev. **51**, 617–622 (Oct. 2007).

[16] Dolk, L., Wahlgren, G. M., and Hubrig, S., "On the elemental abundance and isotopic mixture of mercury in HgMn stars," A&A **402**, 299–313 (Apr. 2003).