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APPLICATION FOR OBSERVING TIME PERIOD: **75A**

To be submitted only to: proposal@eso.org
Important Notice:

1. Title Category: **C–4**

Trigonometric Parallaxes for Member Stars of the Young Nearby TW Hya Association

2. Abstract

We propose to continue our parallax program for member stars of the young nearby TW Hya association. Only very few of the nineteen well established member stars of this association have measured parallaxes from Hipparcos. Because of its proximity, the TW Hya association is a very important reference case for many studies related to star and planet formation, and knowledge of the accurate distances will be beneficial to most of them (e.g., for calculating the mass of a substellar companion discovered by direct imaging). Furthermore, measuring the distances of TW Hya member stars will help to resolve the 3-dimensional structure of the association, and allow to place the stars in the Hertzsprung-Russell Diagram and thereby obtain independent and more accurate individual ages than is possible with the lithium criterion used so far. We already have (the time for) four epochs, and the two more epochs we ask for here would allow us to derive the parallaxes.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky Trans.	Obs.Mode
A	75	SUSI2	2n=2H1+2H1	may	g	$\leq 1.2''$	CLR	v

4.

Number of nights/hours	Telescope(s)	Amount of time
a) already awarded to this project:	NTT	4n (072.C-0320, 074.C-0356)
b) still required to complete this project:		

5. Special remarks. (e.g., indicate here if this is a ToO proposal applying for RRM)

6. Principal Investigator: S. Reffert (née Frink) (Sterrewacht Leiden, NL, sabine@strw.leidenuniv.nl)

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7. Is this proposal linked to a PhD thesis preparation? State role of PhD student in this project

8. Description of the proposed programme

A) Scientific Rationale: Distances are a very fundamental property of stars, at least for us observers from Earth. Yet distances are among the most difficult quantities to measure, since they are not directly observable. In order to get a measure for the distance, one either has to wait for the Earth to revolve around the Sun and use the parallactic effect, which is only possible if the object is close enough and thus the effect large, or otherwise assume that one knows the absolute luminosity of a certain type of object and derive its distance from the apparent magnitude.

Ground-based parallax programs for the nearby stars have a long tradition. Before the advent of the Hipparcos satellite, which determined parallaxes for almost 120 000 stars at the milliarcsecond level, all measured trigonometric parallaxes were compiled in the Yale Parallax Catalog, the latest edition of which contains parallaxes for about 8000 stars. Since Hipparcos, ground-based parallax programs concentrate on faint nearby stars, which are generally not included in the Hipparcos Catalog, but have large parallaxes measurable from the ground.

Examples are the extensive USNO parallax program (Monet et al. 1992, AJ 103, 638) for faint stars in the optical, as well as the recent USNO infrared parallax program for L- and T-Dwarfs (Vrba et al. 2002, AAS 201, 3305). Smaller programs included the ESO 2.2m parallax study of very low-mass stars by Tinney (1996, MNRAS 281, 644), and ongoing parallax surveys at CTIO (Ianna et al. 2001, AAS 198, 4710) and Torino (Smart et al. 2003, A&A 404, 317). A review of ground-based parallax programs at moderately sized telescopes is provided by Dahn (1998, IAU Symp. 189, p.19).

The astrometric precision achievable from the ground has dramatically improved with the advent of CCD technology as compared to photographic plates, in particular due to the availability of bigger sized telescopes at astronomical sites with very good seeing conditions, larger format CCD's (to cover a wide field for potential reference stars), and with smaller pixels and thus a favorable pixel scale. For example, the astrometric accuracy that one can achieve with the classical method, i.e. relative astrometry in a field with reference stars, using the parameters of a pixel scale of 85 mas/pixel and a field of view of $5.5'$, as applicable for SUSI2, centroiding accurate to about 1/100 pixel, and of the order of 100 short exposures in a row, which further reduce the centroiding error, one could *in principle* achieve an astrometric accuracy on the order of $100\,\mu$as.

It has actually been shown that it is possible to achieve this high astrometric accuracy. Pravdo & Shaklan (1996, ApJ 465, 264) conducted a feasibility study at the Palomar 5m Telescope to assess the potential of precise astrometry for planet searches. Their results are very encouraging; indeed they found that they could achieve an astrometric precision of about $100\,\mu$as over periods of hours in a $124''$ field of view and with a pixel scale of 61 mas/pixel, not too different from the SUSI2 specifications. They also showed that atmospheric noise is the dominating factor in the error budget, whereas photometric noise as well as positional uncertainties due to CCD imperfections or optical aberration are sufficiently small to not severely affect the final astrometric accuracy. **Here we propose to measure precise trigonometric parallaxes for ten confirmed member stars of the TW Hya association** (see Webb et al. 1999, ApJ 512, L63, Sterzik et al. 1999, A&A 346, L41, Zuckerman et al. 2991, ApJ 549, L233, Song et al. 2003, ApJ 599, 342).

The aim of this study is twofold. TW Hya is one of the nearest associations of young stars, and as such is a focus of many studies related to star as well as planet formation. The knowledge of the distances of the studied stars would be very beneficial to most of these studies. In particular, age estimates are, due to lack of more accurate methods, based mainly on the lithium criterion, which has been shown to depend on spectral type as well as rotational properties and is not very accurate. Measuring the distances of the TW Hya member stars would enable us to accurately place these stars in the Hertzsprung-Russell Diagram and derive ages from isochrone fitting, a major improvement over the current way of deriving ages. Because it is so close, young and well-studied for all kinds of companions (e.g., the Brown Dwarf companion to TWA 5, Neuhäuser et al. 2000, A&A 360, L39, is the youngest Brown Dwarf known), TW Hya is the best region to test evolutionary tracks. Furthermore, accurate individual distances would also facilitate the characterization of the association in terms of kinematics and 3-dimensional structure. **Parallaxes for stars in the TW Hya association, at a distance of about 50 pc, are of the order of 20 mas, which should be easily detectable.** Hipparcos measured parallaxes for only five out of 19 member stars of the TW Hya association. Kinematic distances have been derived for a larger number of stars in the TW Hya region by Makarov & Fabricius (2001, A&A 368, 866) as well as Frink (2001, ASP Conf. Ser. 244, 16). However, these kinematic studies have to assume that all member stars share the same space velocity, and Makarov & Fabricius also assumed an additional expansion of the association in order to reconcile the observed radial velocities. Again, direct measurements of trigonometric parallaxes are much to be preferred over derived distances based on model assumptions.

Besides the obvious scientific merit of measuring trigonometric parallaxes for many of the TW Hya member stars, this study could also serve as a feasibility study to assess the astrometric potential of the NTT/SUSI2 instrument in general. As outlined above, it should in principle be possible to measure astrometric positions to an accuracy of a few hundred μas. If we can demonstrate that it is possible to reach this level with the NTT and SUSI2, a long-term project to measure the astrometric signatures of Brown Dwarf and giant planetary companions, which are of the order of 1–3 mas, could follow. This would provide unambiguous companion masses for those objects, for which usually only the lower mass limit $m_2 \cdot \sin i$ is available from radial velocity studies.

8. Description of the proposed programme (continued)

B) Immediate Objective: For the success of the present observing program, it is not necessary to reach sub-milliarcsecond astrometric accuracy. The expected distances for most of the stars are of the order of 50 pc, which would yield an astrometric signature of $2 \cdot \pi = 40$ mas. An accuracy of 1 mas would already provide distances accurate to better than 10%, although we expect to achieve a somewhat better precision. We have included some stars with known Hipparcos parallaxes in our targetlist, in order to be able to verify our measurements. In the $5.5' \times 5.5'$ field of SUSI2, there are plenty of reference stars available for all our targets, typically about 50 stars brighter than 16 mag in R. Furthermore, when doing the first epoch observations, we also got photometry in each field in the B and V filters which should allow to characterize the otherwise anonymous reference stars somewhat better and help to establish the appropriate correction from relative to absolute parallaxes. Since we have included three stars with known Hipparcos parallaxes in our program, we will be able to check how good the correction from relative to absolute parallaxes is in those fields. For the first four epoch observations, we have placed the target star at exactly the same pixel, close to the central gap of the two CCD's. Provided that we are able to use both CCD's for astrometry, this ensures that the target star is encircled by reference stars on all sides. We need at least six epochs spread out over 1.5 years to disentangle the effects of proper motion and parallax. The first four epochs were all taken in a similar season, from Jan to Mar, with an epoch difference of 1 year. This allows one to constrain the proper motion. It would be very helpful if the last two epochs requested here would take place in a different season to constrain the parallax ellipse (Fig. 1). Together with the constraint in season due to the visibility of the objects, that means that both epoch observations have to be performed in late May or June. **This is a tight scheduling constraint, but very important to the success of the project.** We did not include all TW Hya member stars in our parallax program. Some of the stars are in close visual double systems, with separations between 0.6 and 1.4" (TWA 2, 3 and 4). This might prevent the calculation of accurate positions because of perturbing light from the companion. Furthermore, we focused on the stars which offer the highest prospects for accurate astrometric measurements. **The stars on our target list are not affected by close companions, and they are all surrounded by many reference stars.** The largest error contribution to the astrometric error budget will be caused by the atmosphere. There are two errors associated with the atmosphere: turbulence, which will cause the image centers to shift around more or less randomly, and differential chromatic refraction (DCR), which will cause systematic displacements of all stars dependent on their colors. Fortunately, the random atmospheric noise, which is of the order of 1 mas for a single exposure, reduces with $\sqrt{n}$, where n is the number of exposures. Taking 16 short exposures, distributed over two consecutive nights, will thus reduce the error contribution from atmospheric turbulence to well beyond 1 mas. In order to keep differential chromatic refraction effects small, we use a narrow band filter (OIII/Cont). Individual refractive constants will then be calculated, taking air temperature and atmospheric pressure into account. With this strategy, Pravdo & Shaklan (1996, ApJ 465, 264) have shown that it is possible to calibrate DCR effects at levels well beyond 1 mas. Other error sources are photon noise and geometric distortions of the CCD and optics. However, it is very likely that these will be much smaller than any residual DCR effects; imperfect DCR corrections will very likely be the major limitation in achieving even better astrometric accuracies (see e.g. Monet et al. 1992, AJ 103, 638).

C) Telescope Justification: SUSI2 at the NTT is quite ideal for our proposed study since it has no internal optics, so that field distortions are kept to an absolute minimum. The pixel size of 85 mas/pixel is also quite favorable, while the field of view is still large enough to contain many stars that can serve as a reference for relative astrometry. Furthermore, the first four epochs were already acquired at that telescope, a strong reason to stay with this choice.

D) Observing Mode Justification (visitor or service): We request visitor mode, since we have scheduling constraints (the same stars on two consecutive nights) that cannot easily be accommodated in service mode.

E) Strategy for Data Reduction and Analysis: The first step in the data reduction after bias subtraction and flatfielding is centroiding, for which no special algorithm is needed; a standard 2-dim Gaussian is probably sufficient. As stated already, the most crucial part in the data reduction will be the accurate calibration of DCR, and special care will be given to this task in order to ensure that we extract the most precise astrometric solution possible for the given data; we will follow the procedure outlined in Pravdo & Shaklan (1996). The only remaining step then is the fit of the plate scale model. Again, a standard linear model should be sufficient, but higher order terms will be included to test whether this will improve the fit significantly. After measurement of the star positions relative to each other, the residuals will be carefully checked for a correlation with zenith angle, which would indicate a systematic error due to imperfect DCR corrections. Thus, iteratively this might allow for an improvement of the whole calibration process, until everything is self-consistent. A slight complication during the data reduction may arise from the gap between the two CCD's; therefore we will calibrate both fields separately. The gap is reportedly very stable, so it might be possible to use both fields after careful checking for any trends. Once all six epoch observations are available, the standard five parameter astrometric model (positions, proper motions, parallax) can be fitted to the offsets of the target star relative to the reference star frames in each field.

8. Attachments (Figures)

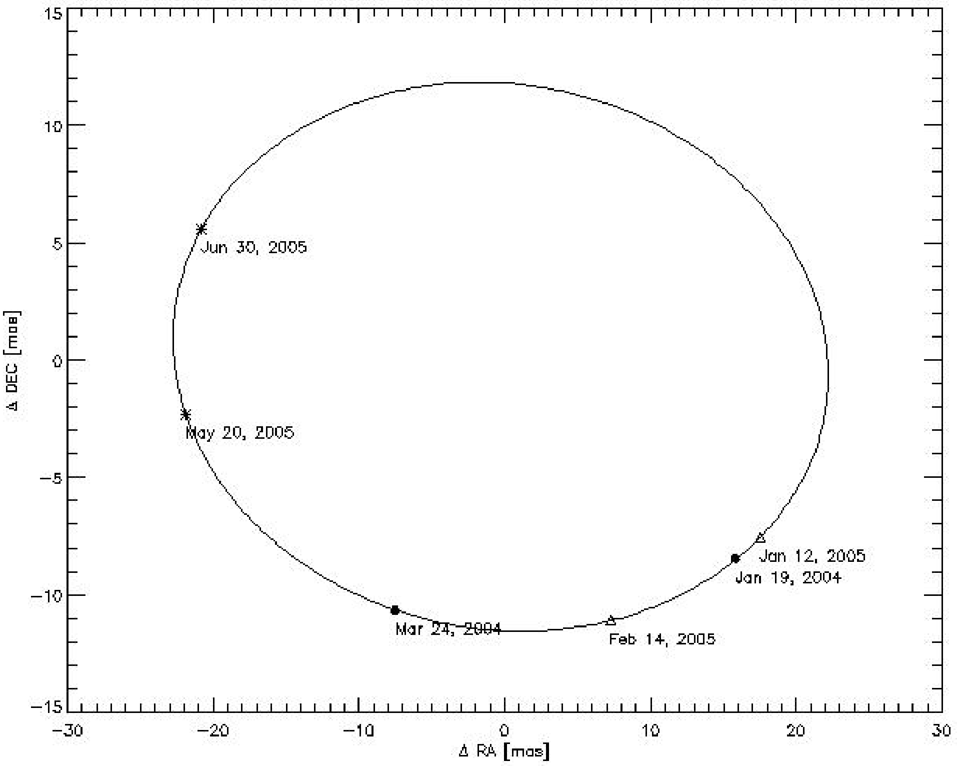

Fig.1 - Expected offsets to the mean position of a typical TW Hya star with a parallax of 20 mas. Only the parallax ellipse is shown; proper motion is ignored. The filled dots (on dates Jan 19, 2004 and Mar 24, 2004) denote the dates of our first and second epoch observations, while the triangles denote the dates where we have been granted observing time for the third and fourth epochs (Jan 12, 2005 and Feb 14, 2005). In order to measure the full parallax ellipse, it would be advantageous to have two more measurements roughly in the indicated time interval between May 20 and Jun 30. Later than June, the objects are not visible any more.

9. Justification of requested observing time and lunar phase

Lunar Phase Justification: We have no stringent constraints on lunar phase; however, full moon should be avoided because an uneven illumination of the CCD by the full moon might introduce additional astrometric errors.

Time Justification: (including seeing overhead) We have ten targets, which span about 3 hours in right ascension. We need about an hour for each target in total for one epoch (including overhead), consisting of about 16 short exposures in the narrow-band filter. In order to correct for atmospheric effects and in order to keep the hour angles small, it is best to distribute those 16 exposures over two consecutive nights, i.e. two times 8 exposures that will be averaged. In order to get one observation for each of our targets, we thus need 10 hours or two half nights.
In order to get a second epoch observation for all our targets, we need a second sub-run of two half-nights, for a total of 2 nights in the current semester.

Calibration Request: Standard Calibration

10. Report on the use of ESO facilities during the last 2 years

We were already awarded four times two half nights for this same program, which have taken place in January and March 2004 (072.C-0320), or will come up in January and February 2005, respectively (074.C-0356). These observations form the first four epochs. Data reduction is underway. The full scientific results however will only be available after we have at least six epochs of observations, as with any other parallax program.
Furthermore, we were awarded service mode observations with the CES spectrograph on the 3.6m telescope, in order to probe for bisector variations for a number of K giant planet candidates: 4 hours in Oct 2003, 4 hours in Feb 2004 (072.D-0319), and 8 more hours in September 2004 (073.D-0300), of which 4 hours were lost due to bad weather. The variations that we are looking for occur on timescales of 1–2 years, so we do not have a sufficient time baseline yet to obtain meaningful scientific results, but the first spectra have been extracted from the data.

11. Applicant's publications related to the subject of this application during the last 2 years

Frink, S., 2001, ASP Conference Series 244, 16: Kinematic Distances to TW Hya Member Stars via the Convergent Point Method

Frink, S., Mitchell, D.S., Quirrenbach, A., Fischer, D.A., Marcy, G.W., Butler, R.P., 2002, ApJ, 576, 478: Discovery of a Substellar Companion to the K2 III Giant ι Draconis

Guenther, E.W., Wuchterl, G.: 2003, A&A 401, 677: Companions of old brown dwarfs, and very low mass stars

Guenther, E.W., Neuhäuser, R., Huélamo, N., Brandner, W., Alves, J., 2001, A&A 365, 514: Infrared spectrum and proper motion of the brown dwarf companion of HR 7329 in Tucanae

Neuhäuser, R., et al., 2000, A&A 354, L9: On the possibility of ground-based direct imaging detection of extrasolar planets: The case of TWA-7

Neuhäuser, R., Guenther, E.W., Petr, M.G., Brandner, W., Huélamo, N., Alves, J., 2000, A&A 360, L39: Spectrum and proper motion of a brown dwarf companion of the T Tauri star CoD$-33°$7795

Neuhäuser, R., Brandner, W., Alves, J., Joergens, V., Comerón, F., 2002, A&A 384, 999: HST, VLT, and NTT imaging search for wide companions to bona-fide and candidate brown dwarfs in the Cha I dark cloud

Neuhäuser, R., Guenther, E.W., Mugrauer, M., Ott, T., Eckart, A., 2002, A&A 395, 877: Infrared imaging and spectroscopy of companion candidates near the young stars HD 199143 and HD 358623 in Capricornius

Torres, G. Guenther, E. W., Marschall, L. A., Neuhäuser, R., Latham, D.W., Stefanik, R.P., 2003, AJ 125, 825: Radial Velocity Survey of Members and Candidate Members of the TW Hydrae Association

12. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT(hrs)	Mag.	Diam.	Additional info	Reference star
A	TWA 6	10 18 29	−31 50 02	2.0	12.			
A	TWA 7	10 42 30	−33 40 17	2.0	11.			
A	TWA 1	11 01 52	−34 42 17	2.0	11.1			
A	TWA 14	11 13 27	−45 23 43	2.0	12.			
A	TWA 12	11 21 06	−38 45 16	2.0	13.6			
A	TWA 9	11 48 24	−37 28 49	2.0	11.1		sep=6”	
A	TWA 15	12 34 21	−48 15 15	2.0	12.		sep=3.7”	
A	TWA 10	12 35 04	−41 36 39	2.0	12.			
A	TWA 17	13 20 45	−46 11 38	2.0	12.			
A	TWA 18	13 21 37	−44 21 53	2.0	12.			

Target Notes: The listed TWA member stars are the ones for which we already have first and second epoch observations. The listed time on target, 2 hours for each star, is the total time required for 2 epochs. One epoch splits into two times half an hour on consecutive nights.

12b. ESO Archive - Are the data requested by this proposal in the ESO Archive (http://archive.eso.org)? If yes, explain why the need for new data.

13. Scheduling requirements

1. Run Splitting

Run	splitting
A	2H1,30w,2H1

3. Unsuitable period(s) of time

Run	from	to	reason
A	01-apr-05	19-may-05	dates too close to previous observations
A	01-jul-05	30-sep-05	objects not visible

14. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
75	SUSI2	A	Imaging-filters	883