Diameter determinations from VINCI using global calibration solutions

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Summary. Although primarily built for testing and alignment purposes, the K band instrument VINCI at the VLTI has produced numerous scientific results on individual targets. The present work consists of a global analysis of the entire VINCI data archive. A visibility estimator using coherent integration has successfully obtained some 15500 raw visibilities on 293 objects. Those results are interpreted using a global solution algorithm which simultaneously solves for calibration (transfer function) fluctuations and for stellar diameters. Stars which do not follow the standard uniform disk visibility curve are automatically or manually flagged and are avoided in the solutions for nightly calibrations.

The standard approach to calibration based on observations of "calibrator" stars having assumed diameters, is rejected in the present work. No *a priori* diameters are input to the algorithm, which relies on baseline diversity to simultaneously solve both for diameters of stars having well-behaved characteristics, and a quasi-static transfer function subject to various hardware fluctuations. The success of this approach depends on a diversified schedule of observing the same target on different nights in conjunction with a mixture of other targets, so that all visibilities can be "cross-calibrated."

This is practical in the case of the VINCI data set where half of the 666 observing nights produced at least 22 successful visibilities on a median of 7 different targets. Half of the 293 objects were successfully observed at least 18 times and on at least 6 separate nights, with observations over a median baseline range of 4.8:1. Uniform disk diameters are a by-product of the cross-calibration procedure which uses this database to solve for an evolving transfer function on a nightly basis.

1 Solving for calibrations and fitting of visibilities

In Fig. 1 we see the solution for the transfer function over a period of 9 months. Also shown is a set of 94 visibility points for observations of β *gru* which is fit as a uniform disk of diameter 26.25 mas. The fitting procedure employs a cost function appropriate for gaussian distributed errors among 95% of the data

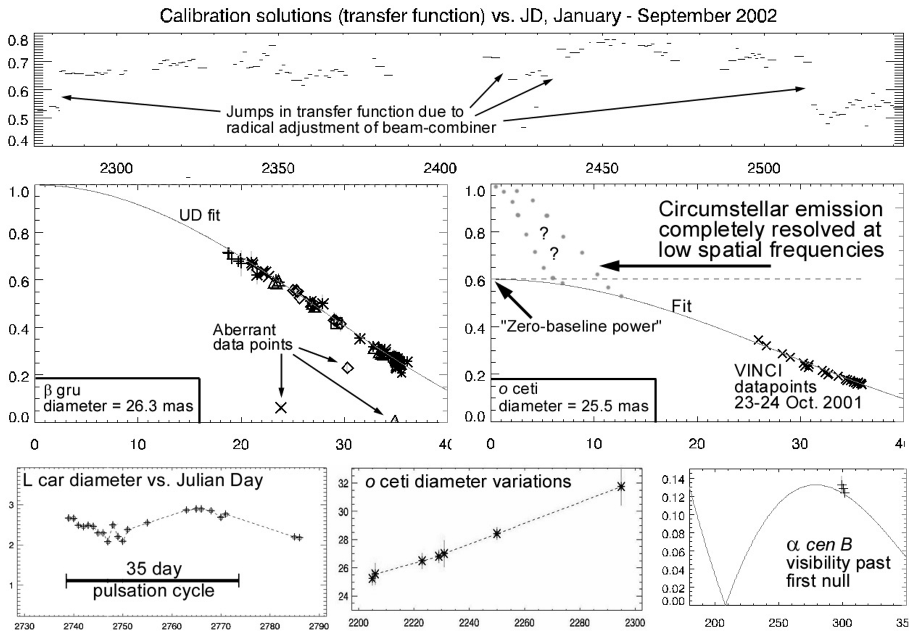

Fig. 1. Top: Solutions for VINCI transfer function over 9 months. **Center left:** Calibrated visibility vs. spatial frequency (cycles/ arcsec) for a typical star. **Center right:** Visibility model for a star with circumstellar emission, fit using a "zero-baseline power" of .6. **Bottom:** Diameter solution for each night for $L\,car$ and $o\,ceti$ (taking its reduced zero-baseline power into account). **Bottom right:** Three visibility points for $\alpha\,cenB$ past first null with UD fit for D=5.87 mas.

points, and up to 5% "bad" datapoints whose possible large deviations from the fit will thus not degrade that fit; in this example 3 aberrant visibility points can be seen which have effectively been ignored in the diameter determination. The raw results of these diameter solutions are posted on the web at:
`http://www.strw.leidenuniv.nl/~nevec/VINCI/meisner/`

Improvements in the diameter determinations over, typically, 50 iterations of the algorithm, result in increasingly precise determinations of the evolving transfer function, and thus more precise calibrated visibilities. We have examined the statistics of the residuals of these calibrated visibilities in fitting uniform disk functions as in Fig. 1. If we take, for each object, the median of the magnitude of residuals divided by their visibilities, then taking the median over all objects observed at least 10 times, we can obtain a relative error as low as 1.1%, reflecting both the inherent precision of VINCI, and the success of this approach to fitting these data.

In several cases (apparent) diameter variations over time are detected. Solving for a nightly diameter, we have plotted this variation in Fig. 1 for $L\,car$, a cepheid, and the long period variable $o\,ceti$. Also, in at least two cases, a convincing variation of apparent diameter with position angle, contradicting circular symmetry, is detected.

2 Reduced zero-baseline power

In a number of interesting cases a portion of the "stellar" emission comes not from the surface of the star, but from elsewhere in the telescopes' field-of-view. If that emission, whose luminosity is L_2, is overresolved at the baselines at which the star is observed, then the measured visibility will be reduced by the factor $L_1/(L_1 + L_2)$ where L_1 is the luminosity due to the photospheric emission itself. This (over-)simplified model may well approximate Mira's and other stars with extended molecular atmospheres.

By extrapolating the observed visibility curve to zero spatial frequency, we can often detect a "zero-baseline power" significantly reduced from unity. This is illustrated in Fig. 1 for observations of $o\,ceti$ at one epoch; the visibility must approach unity at zero spatial frequency, but at medium spatial frequencies we consider the circumstellar emission to be completely resolved, which reduces the star's visibility by the above cited factor. The algorithm attempts to measure this quantity routinely, from which we have obtained a number of apparent detections. Thus we obtain an estimate of the relative circumstellar emission, L_2/L_1 for the following stars: $\alpha\,ori$ .065, $o\,cet$ .53, $R\,aqr$ .04 (with up to .18 resolved using the longer baseline), $R\,leo$ 1.1, $R\,lep$ .19, $R\,scl$ .04, $RR\,aql$ .16, and $24\,psa$ .015. These results were all reported with rms error bars of 15% to 25%, and in several cases anomalies in the visibility fits and/or pulsation of the star call the numerical accuracy of the results further into question. We believe that these are actual detections of circumstellar emission, while a number of other statistically significant results obtained remain questionable at best.

3 Observations past the first visibility null

13 stars were observed at baselines beyond the first visibility null. Among these, 5 had visibility points consistent with a uniform disk visibility curve, and whose visibility offset from that curve is within .01 ($\alpha\,cma$) or .005 ($\alpha\,cenB$, $2\,cen$, $\alpha\,hya$, $\lambda\,vel$). These data for $\alpha\,cenB$ are shown in Fig. 1. Three stars, $\psi\,phe$, $W\,hya$ and $\alpha\,ceti$, had visibilities clearly lower than the uniform disk curve indicating limb-darkening; additionally $RX\,lep$ and $\sigma\,lib$ had formally significant visibility reductions of less than .01 which we treat cautiously. The interpretation of visibilities of $R\,aqr$ obtained beyond the first null were complicated by the lack of a simple diameter solution for this star, while the visibilities of $\alpha\,sco$ and $\alpha\,ori$ past the first null were anomalous.