Diameter determinations from VINCI using global calibration solutions

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Note that this is an electronic version of a poster, even though it looks like a slide show. I simply prepared my work in this manner and posted the following 14 pages (printed in black & white) up as a “poster.” Thus you need not read the pages in order; in fact some of the illustrations for one page are to be found on a totally different page! Also note that the separate list of diameter solutions presented on that poster has been now moved to a website (but please read this poster in order to understand the origin of the numbers obtained) at:

http://www.strw.leidenuniv.nl/~nevec/VINCI/meisner/

Abstract

VINCI is the test and commissioning instrument of the VLT interferometer (VLTI). It operates in the K band (2.0 - 2.4 microns) using delay-scanning. Optical fibers serve as spatial filters, beam combiner, and photometric pick- offs. Although intended as a test and commissioning instrument, VINCI has produced many scientifically useful results during its 4 years of operation resulting in well over a dozen papers in refereed journals.

Visibilities from VINCI raw data are obtained using coherent integration. These raw visibilities are interpreted using a global solution algorithm which simultaneously solves for calibration (transfer function) fluctuations and stellar diameters. Using this system, 15500 successful visibilities have been processed on 296 objects, including science objects and calibrators. Half of these objects were successfully observed at least 15 times and on at least 5 separate nights, providing a fruitful database for cross-calibration.

The standard approach to calibration based on observations of "calibrator" stars having assumed diameters, is challenged 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."

The results thereby obtained consist mainly of uniform disk diameters, but additionally the algorithm detects specific departures from that model. In about 20 cases, we detect a "zero- baseline power" significantly smaller than unity, probably due to circumstellar emission. Diameter variations of several pulsating stars were also observed. Visibilities beyond the first null were obtained for several objects, thus directly constraining the magnitude of limb-darkening in these cases. Among the uniform disk diameters obtained, about one third had formal errors of better than 1%.

Steps in processing

- VINCI data files are indexed and organized into 16991 “observations.” Auxilliary information in the files is used to check for self-consistency, with some bookkeeping errors repaired, and some observations flagged as “unreliable” so that their results can be discounted.
- Each observation is processed using the “quasi-coherent” method (see below) to obtain a spectrum of correlated flux, which has been normalized relative to the photometry measured during the interferometric exposure. We obtain 15437 successful results.
- Each spectrum is processed to remove second order dispersion, a substantial effect when a large (> 50m) delay-line offset causes one beam to pass through much more air than the other. (Note that first-order dispersion and OPD jitter are removed by the processing method)

- The real part of the corrected spectrum is summed over optical frequency to obtain an estimate of the peak value of the envelope (complex magnitude) of the fringe in delay-space, which we identify as the raw (uncalibrated) visibility.
- An intricate algorithm analyzes the set of raw visibilities obtained in conjunction with the projected baselines and other auxilliary information. A simultaneous solution is sought for the diameters of 276 stars, and a calibration (transfer function) applying to each of 842 nights (or parts of nights). No *a priori* diameters of "calibrator" stars are used. Each star may be used as a "calibrator" unless there is a reason to believe that its visibility curve does not follow that of a uniform disk of some diameter.
- In addition to uniform disk diameters, some stars are flagged as having a "proper calibration" (or "zero-baseline power") significantly less than unity, often due to circumstellar emission. In some cases a systematic variation of diameter over epochs or unusual visibility functions are observed and reported to the astronomer for further examination.

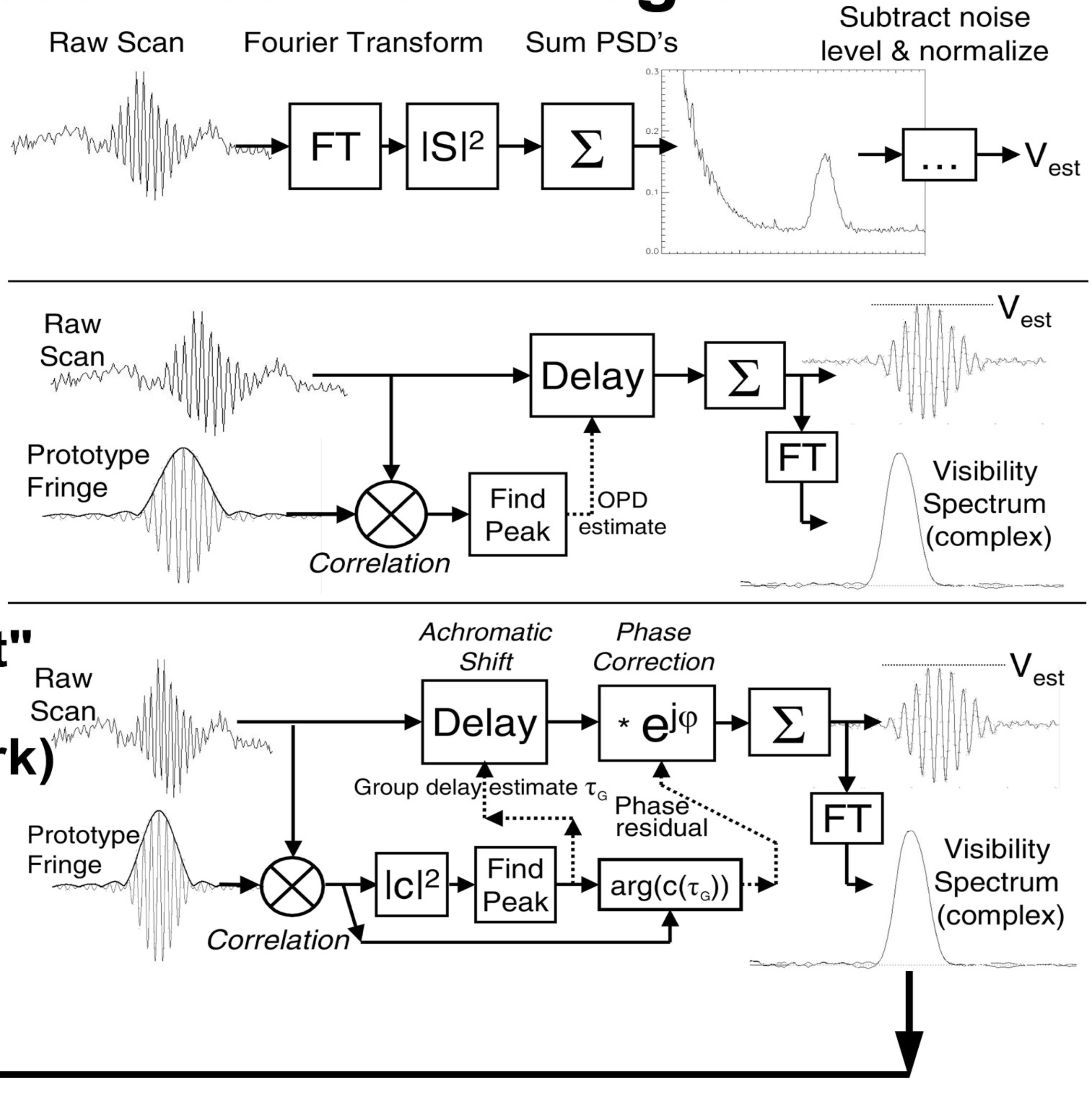
Estimation of correlated spectra from delay-scanned interferograms

3 Methods:

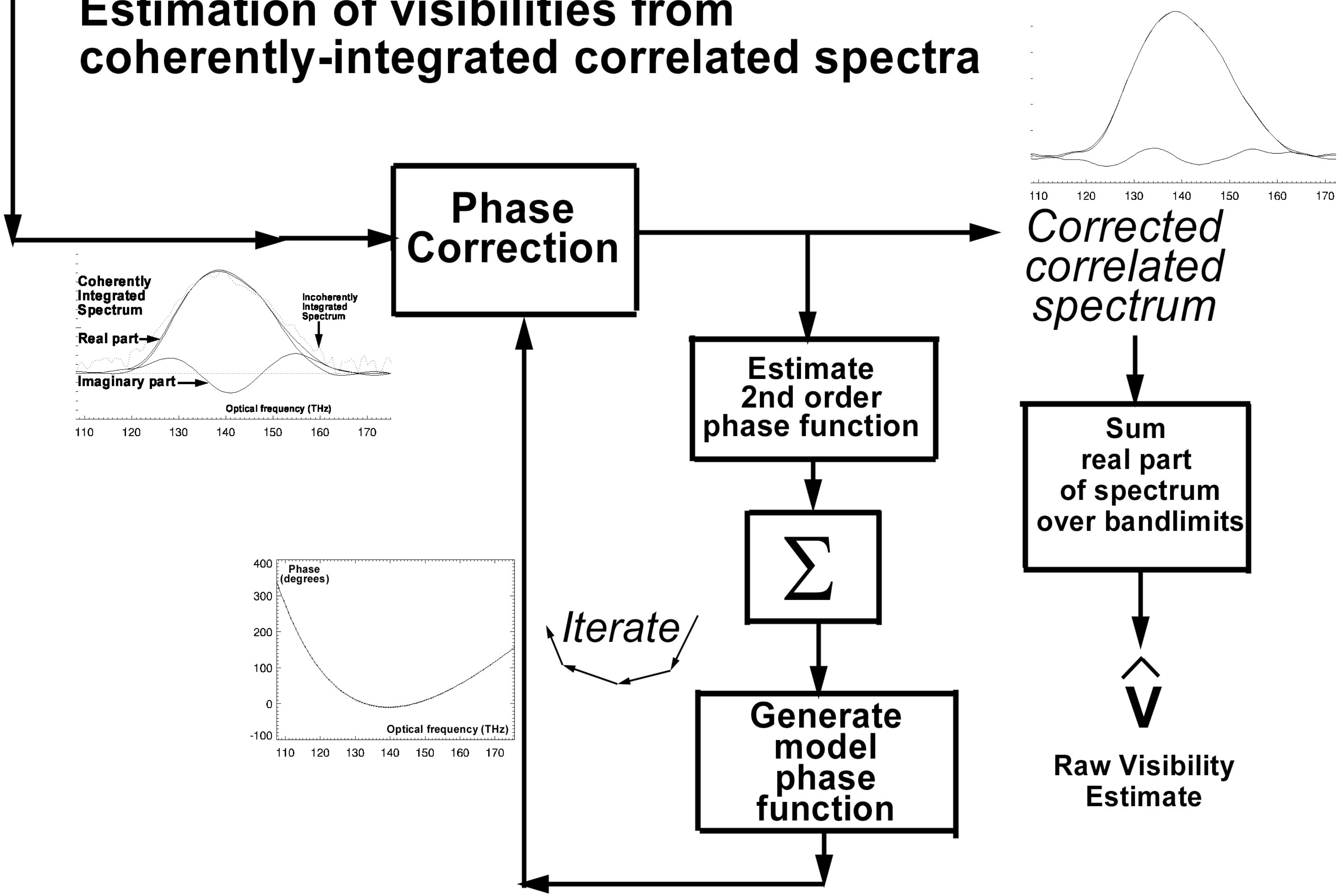
Incoherent Integration

Coherent Integration

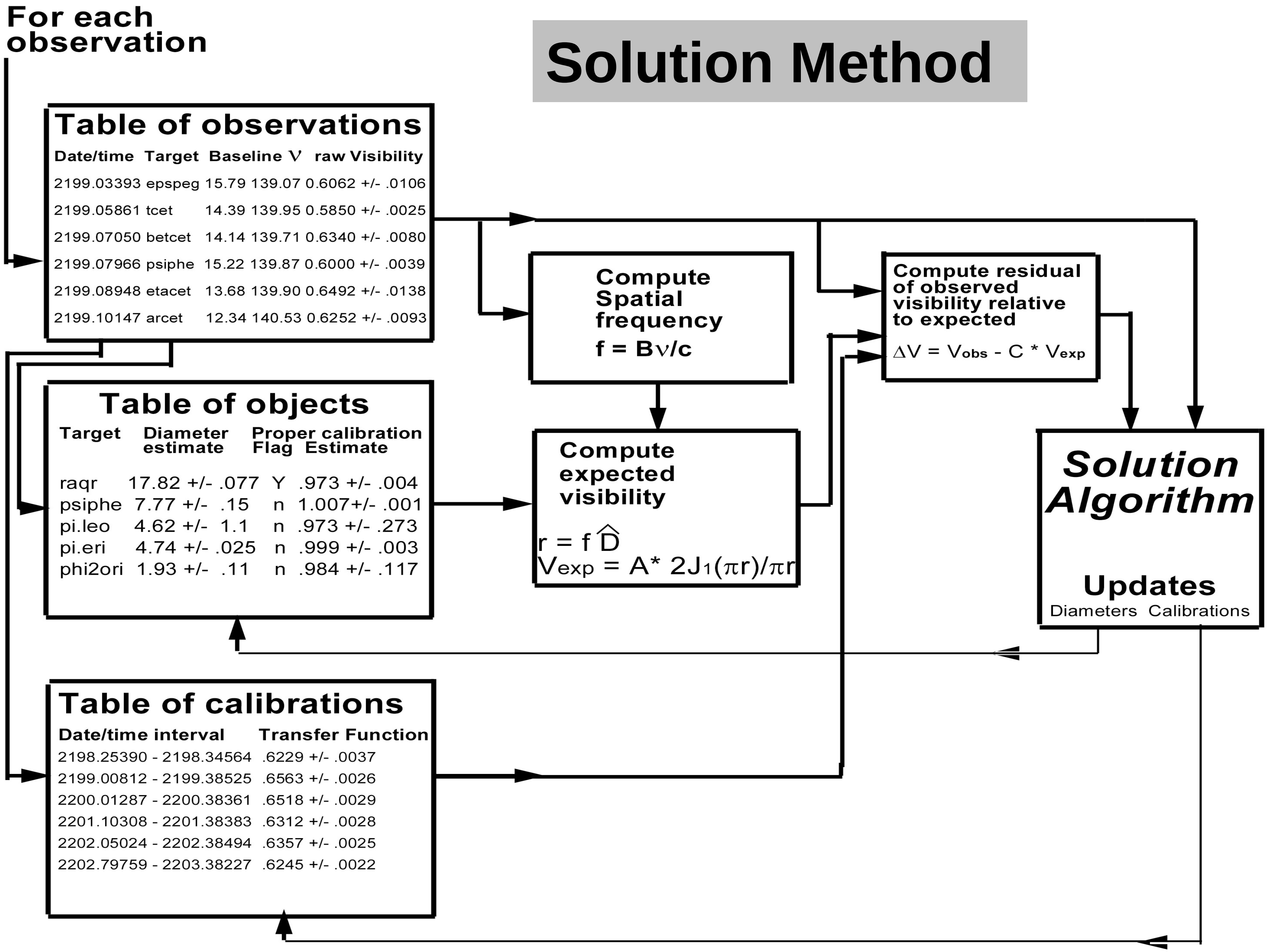
"Quasi-Coherent" Integration (used in this work)

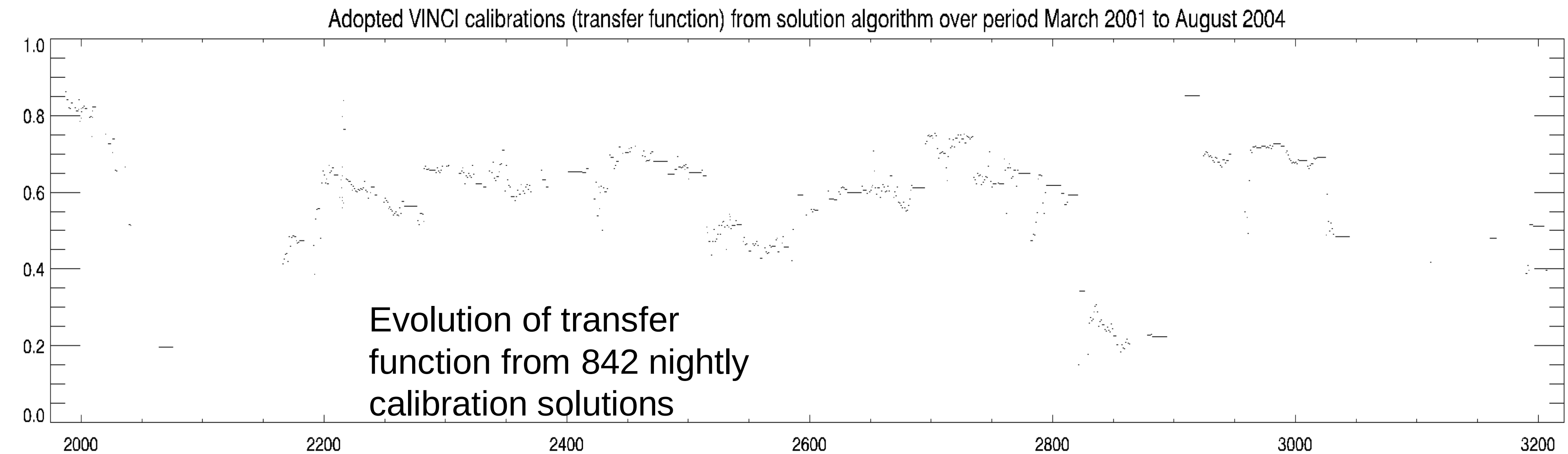


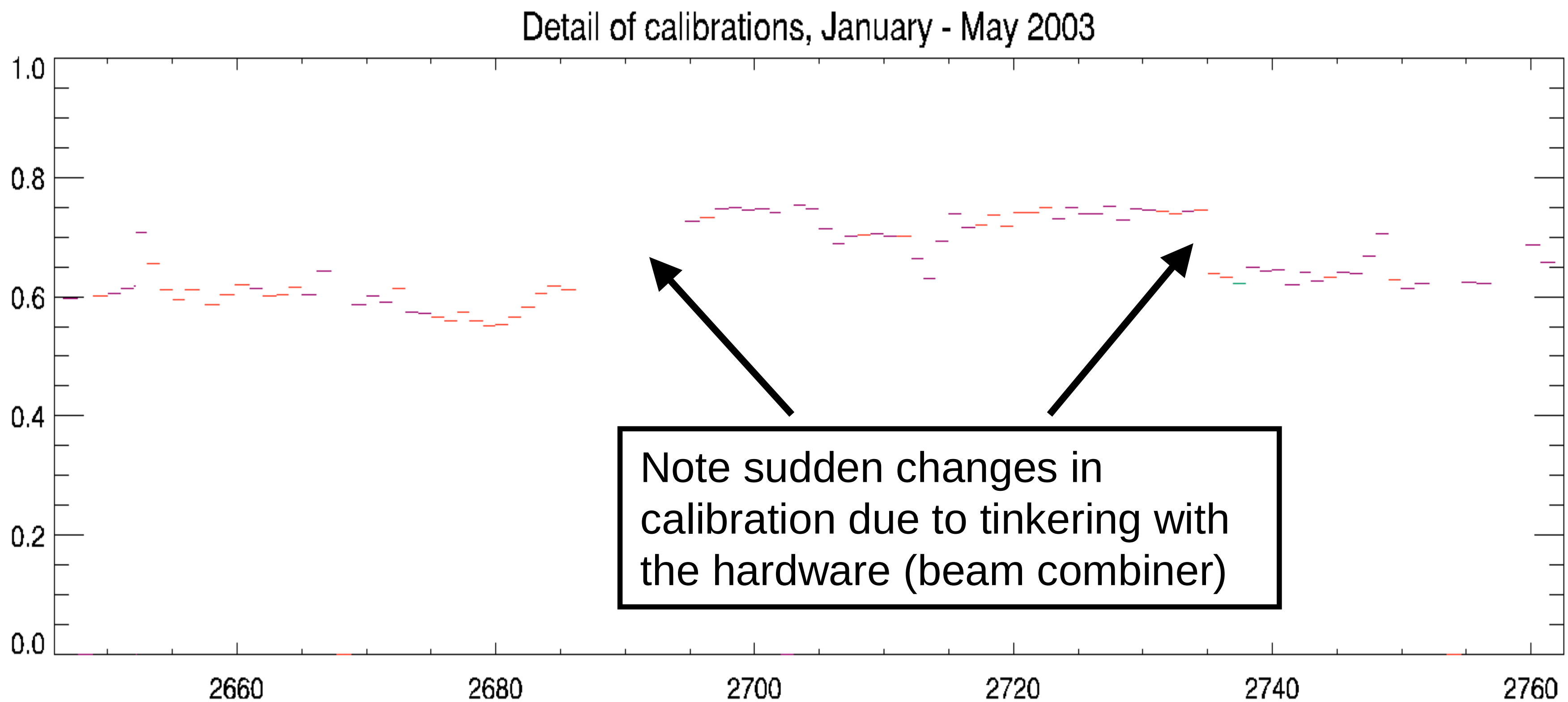
Estimation of visibilities from coherently-integrated correlated spectra



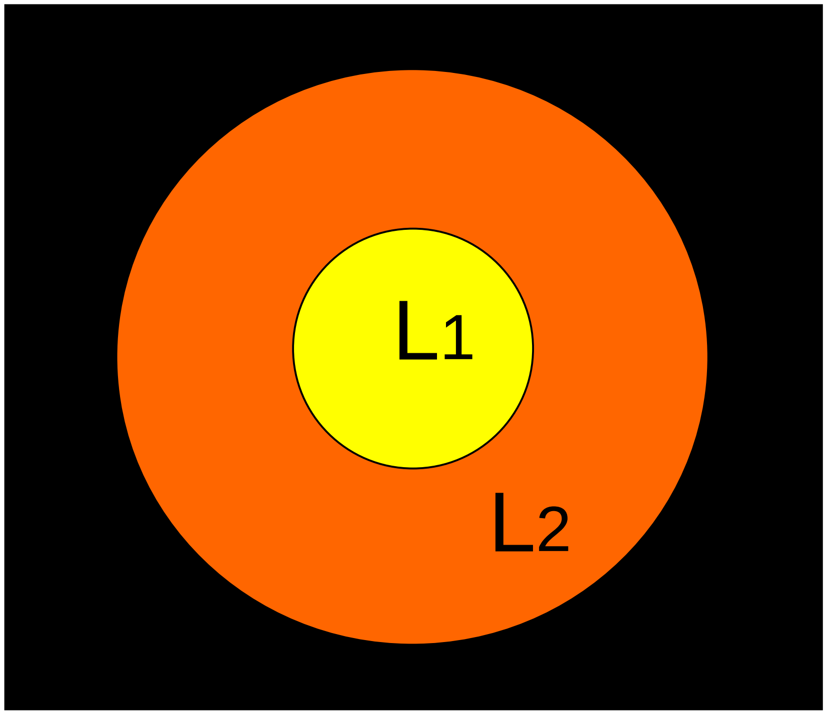
Solution Method




Adopted VINCI calibrations (transfer function) from solution algorithm over period March 2001 to August 2004
1.0
0.8
0.6
0.4
0.2
0.0
2000
2200
2400
2600
2800
3000
3200
Evolution of transfer function from 842 nightly calibration solutions


Detail of calibrations, January - May 2003
1.0
0.8
0.6
0.4
0.2
0.0
2660
2680
2700
2720
2740
2760
Note sudden changes in calibration due to tinkering with the hardware (beam combiner)

Proper calibration or "Zero-baseline power" <1 due to circumstellar emission



Star	A	L_2 / L_1
rr aql	.859 +/- .011	.16
r scl	.958 +/- .007	.04
r lep	.840 +/- .013	.19
r aqr	.962 +/- .001	.04
omi cet	.576 +/- .010	.74

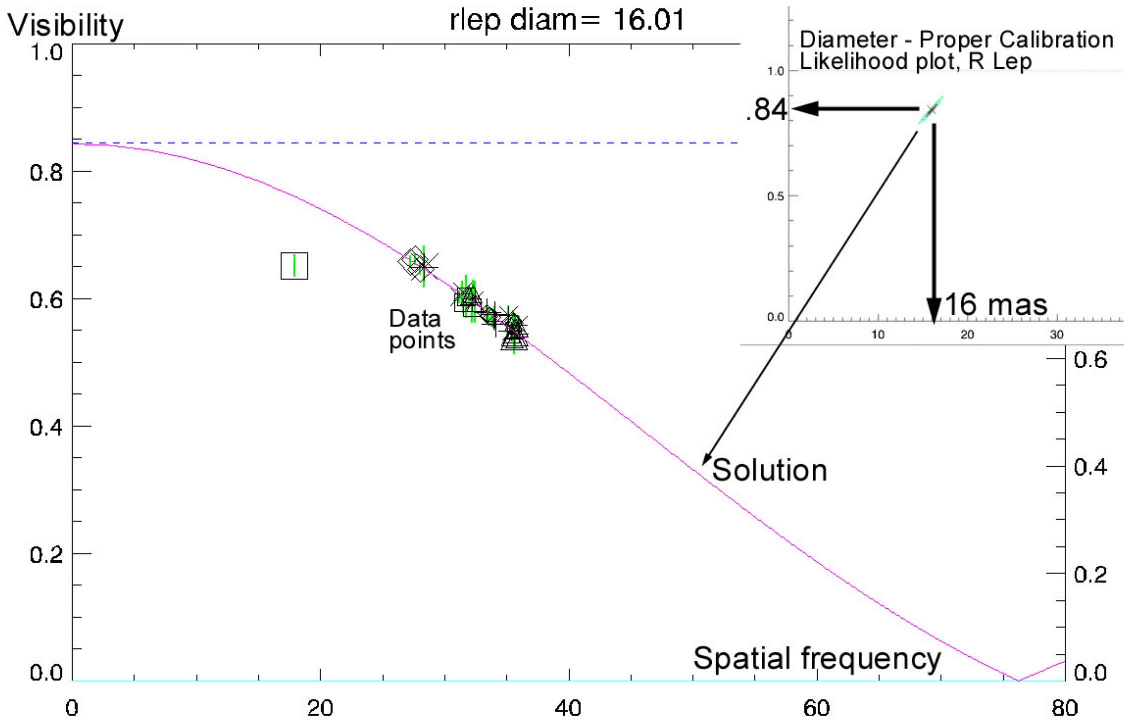
L_1 = Light from photosphere

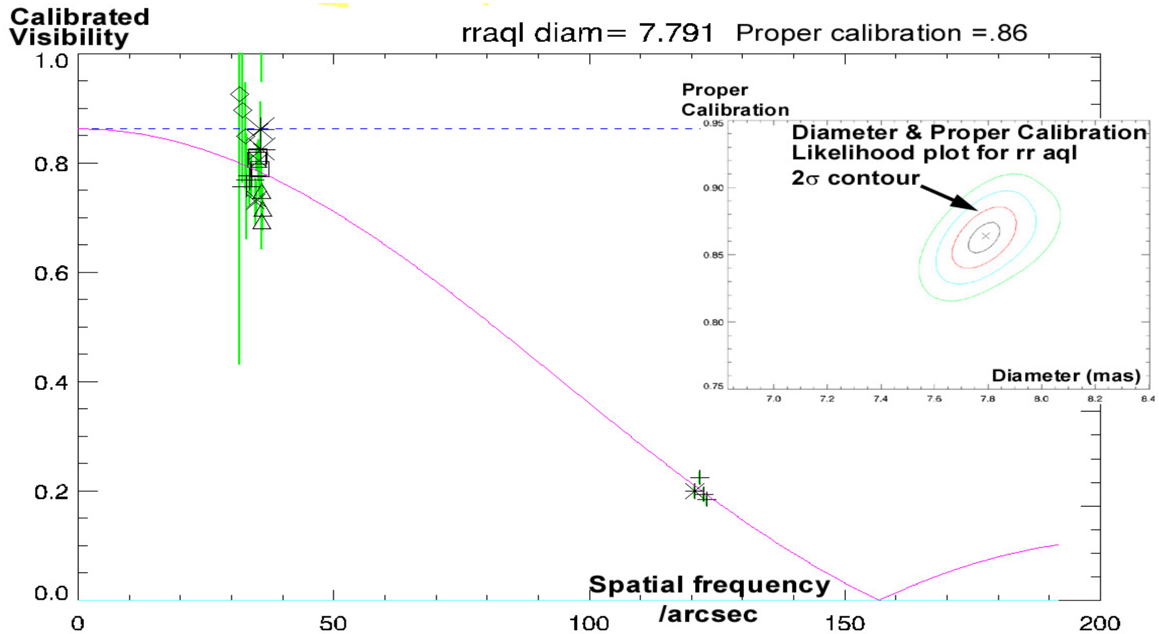
L_2 = Circumstellar emission

At medium to large spatial frequencies, the visibility of the star is reduced by the *proper calibration* **A** where

$$\mathbf{A} = L_1/(L_1+L_2)$$

This is always solved for, and flagged when significantly less than unity. We find significant proper calibrations in the case of 5 Mira's, probably due to H_2O and CO molecular emission near the edges of the K band. Averaged over the passband of VINCI, we have tabulated the circumstellar emission L_2 relative to the photospheric emission L_1.



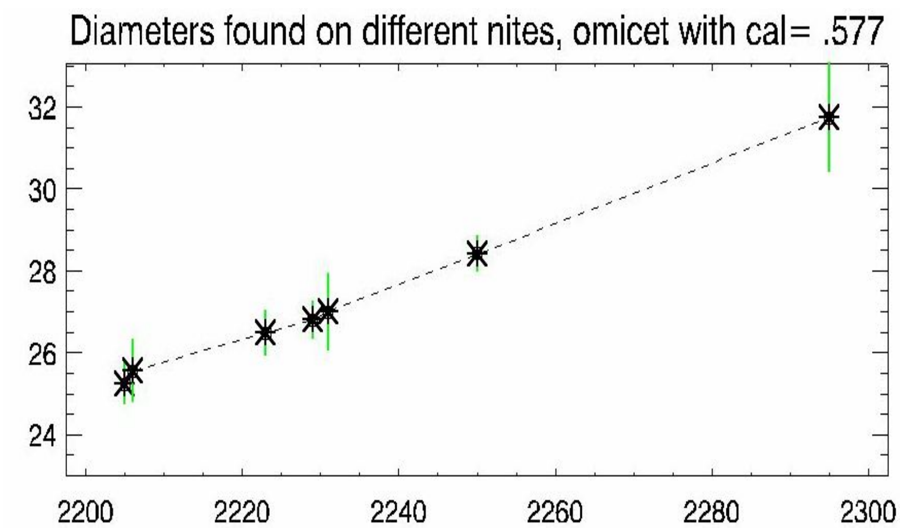


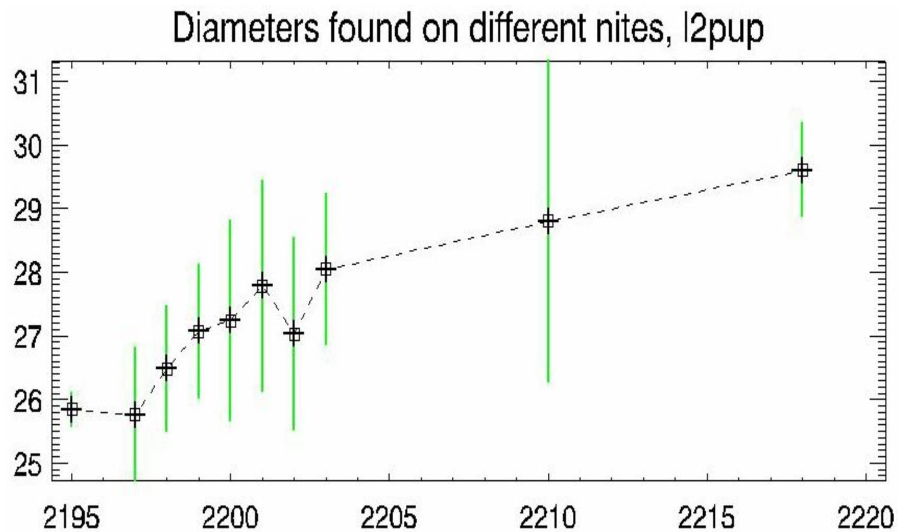
Here are two details of two proper calibration solutions < 1. Such a determination requires sufficient baseline coverage in order to fit both parameters: diameter and proper calibration. Many targets were only observed around one baseline, and their diameter estimates are contingent on the assumption that **A**=1.

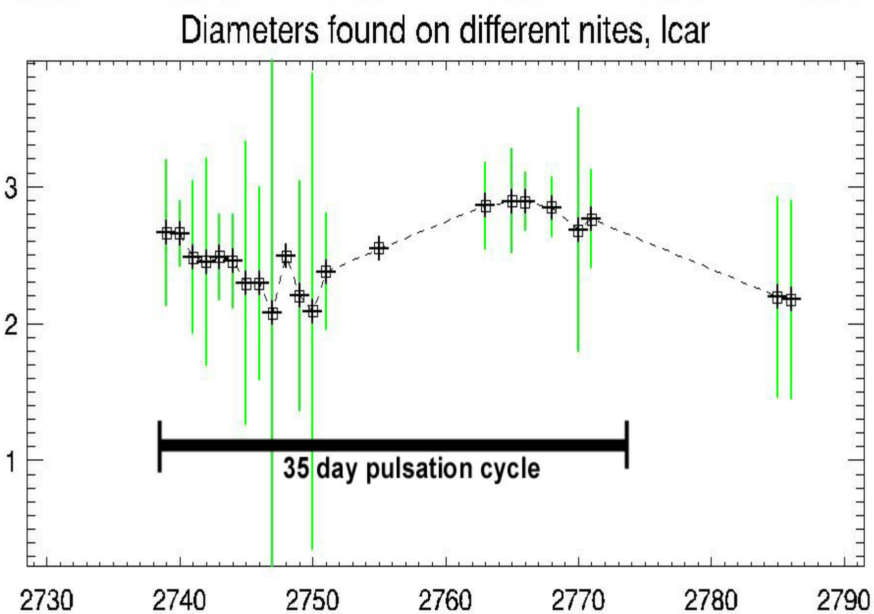
It is also possible for other effects to mimick a proper calibration (or visa-versa). For instance, with one physical baseline, projected baseline and position angle are coupled, and a dependency can easily be misinterpreted.

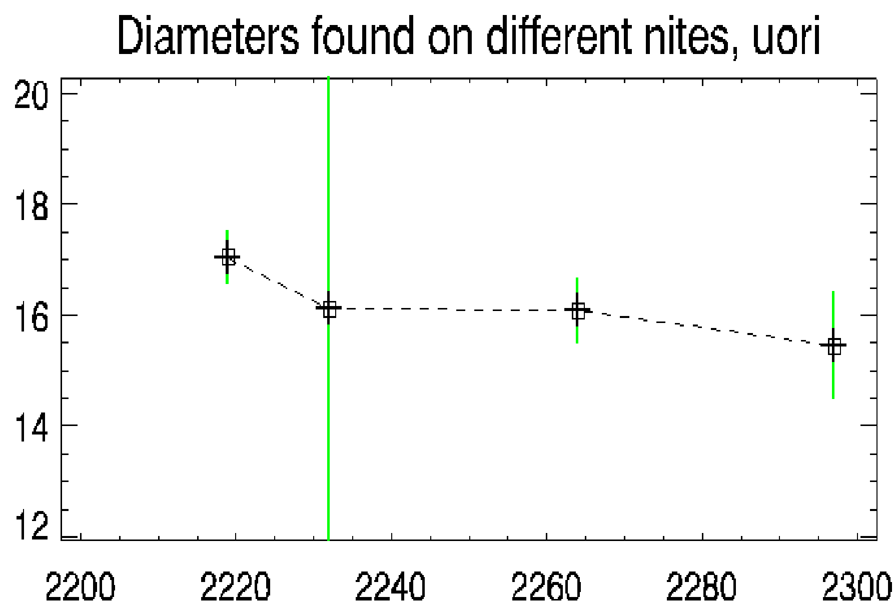
Observing diameter variations over time.

(x-axis is Julian Day – 2450000)







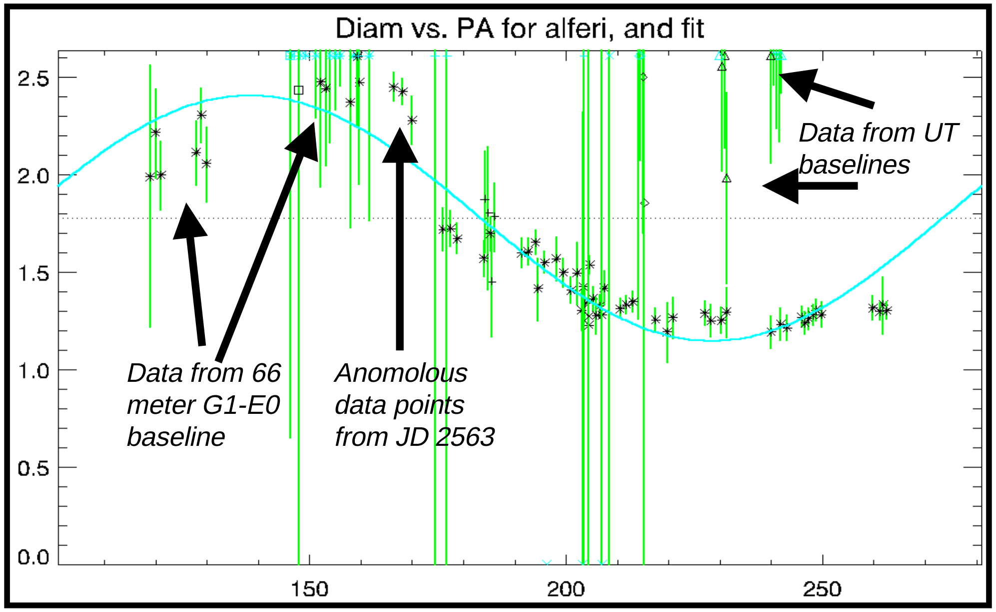


From the original poster

Observation of an elliptical star:

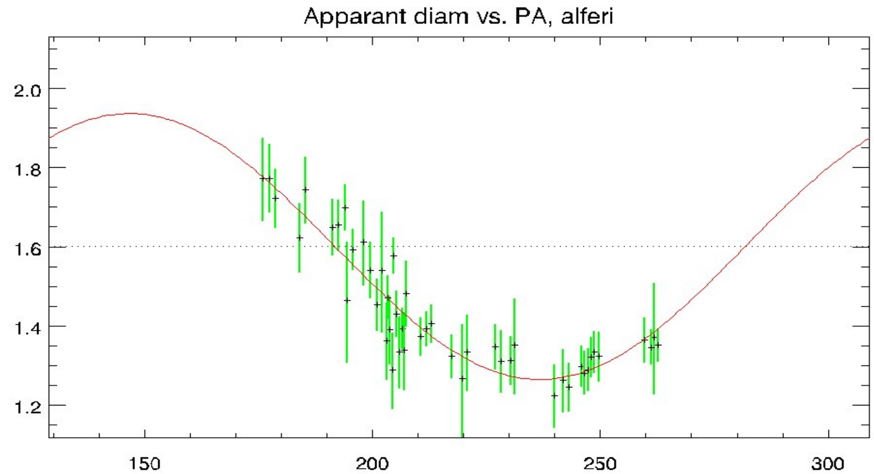
Apparent diameter (from inverting UD visibility function) goes as sin(2*PA) from the minor axis to the major axis. Here is the solution I obtained for alf eri:

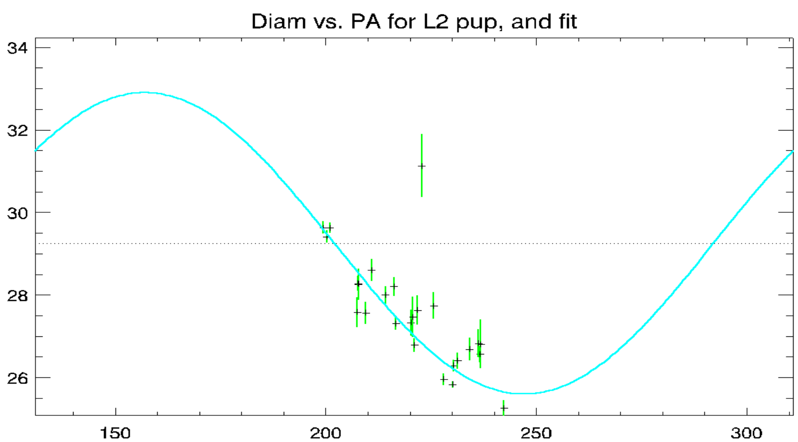
2A=2.417 mas   2B=1.148 mas



Postscript, electronic version:

The original poster contained the solution shown on the left which was a (weighted) least-squares fit to the data points shown. It was generated by the algorithm using all of the available data without editing (the intended procedure!). However the χ^2 was poor (3.7*DF) and the fit is obviously unacceptable. The solution was reworked by removing from consideration data from baselines shorter than the 141 meter M0-B3 baseline which supplied the most precise diameter points. Also the 3 “precise”, but anomolous data points from one night, JD 2563, were removed. The result is a more satisfying fit shown below, with χ^2 =15.8 with 44 DF (implying that the raw error level had been somewhat overestimated). The solution paraameters are: 2A=1.937 mas   2B=1.265 mas, major axis at PA=146.7°. However we do not yet claim this as a trustworthy result due to the somewhat subjective criteria for removal of certain datapoints.

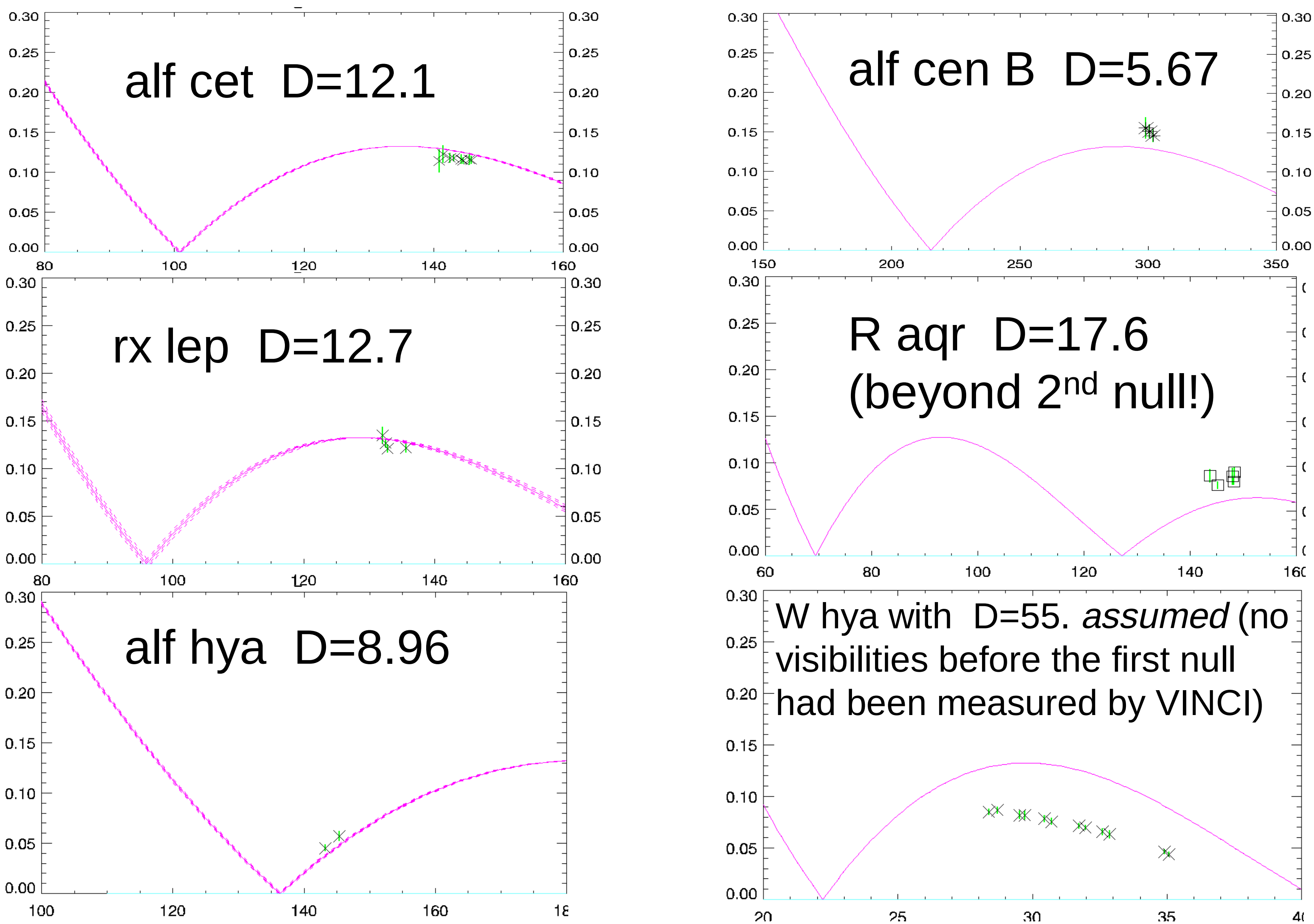




Likewise, here is a solution for the observed non-circularity of L2 pup. However in this case the position angle coverage is insufficient, and the solution is poorly constrained. There are many sine waves that could reasonably fit these data! However we believe we have detected an actual ellipticity, and the solution shown is close to a lower limit on the magnitude of that ellipticity, even though the axis of the ellipse isn’t well constrained.

Visibilities found beyond the first null

(visibility curves shown correspond to the uniform disk model, no limb-darkening)



Uniform Disk Diameter Solutions: A few caveats:

- These are not the final results! They are the raw output of the algorithm at its current stage of development.
- A good number of the stars cannot be described by a single “diameter” (for instance, pulsating stars observed at a limited number of epochs, elliptical stars observed at a limited range of position angles, and stars with an undetected proper calibration) and the numbers reported are invalid. A few invalid results have been spotted and marked with an ‘I’. But there are many more.
- Many of the solutions smaller than 2 mas must be considered unresolved. The non-zero diameter printed is simply a maximum-likelihood solution, but a diameter of zero is not excluded with any degree of confidence. In these cases a ‘U’ has been supplied to indicate “unresolved.”
- The errors reported here are often too optimistic. That is because the algorithm currently does not take into account the correlation of calibration errors from observations conducted on the same night, which prevents reduction of these errors by averaging. A newer version of the algorithm will deal with this problem properly.

The list that was presented at the conference is not included directly in this document, but has been posted on the NEVEC website. That will allow improved solutions of these diameters to later be posted as they are obtained. Find it at:

http://www.strw.leidenuniv.nl/~nevec/VINCI/meisner/