The CHARA Array
Year One Science Review

Summary of a Meeting Held at
l'Observatoire de Paris, 7-11 February 2005

Theo ten Brummelaar & Harold A. McAlister, Editors

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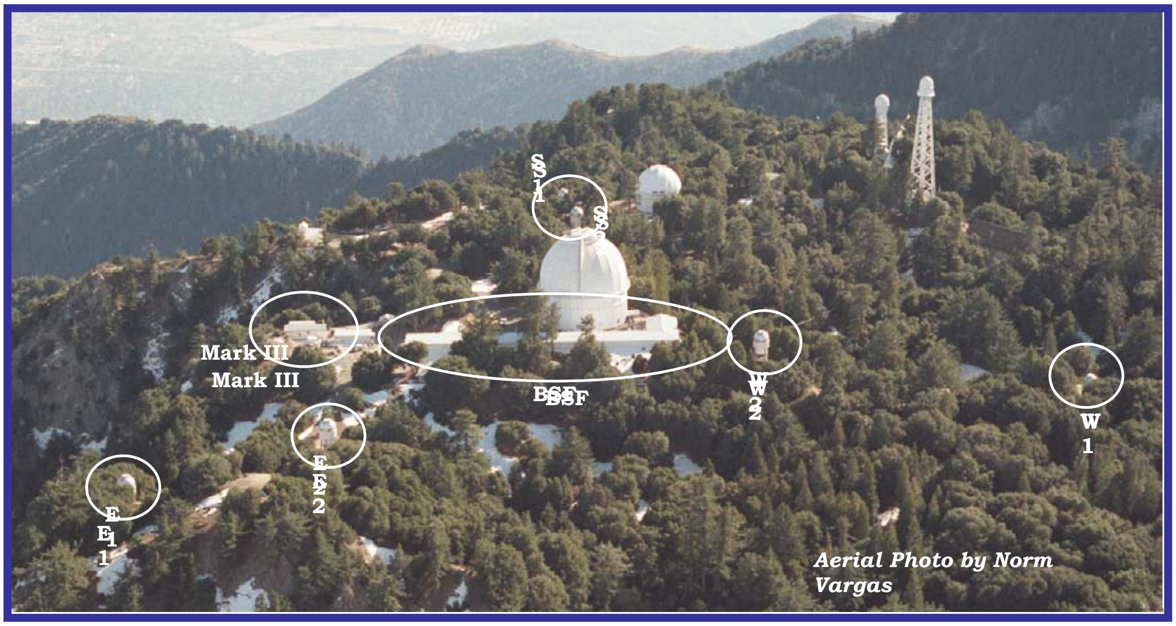
Introduction

Georgia State University's Center for High Angular Resolution Astronomy (CHARA) has constructed a six-telescope optical/IR interferometer on the grounds of the historic Mount Wilson Observatory in California, just north of Los Angeles. The construction of the Array was jointly funded by the National Science Foundation (NSF), Georgia State University (GSU), the W. M. Keck Foundation, and the David and Lucile Packard Foundation, while the operating costs are supplied by Georgia State and the NSF. The CHARA Array achieved first fringes in late 1999 and the sixth telescope was brought online in late 2003. The year of 2004 was the first full year of research at CHARA devoted almost entirely towards scientific observations.



Aerial Photo by Norm Vargas

Figure 1. *An aerial photograph of Mount Wilson showing the main facilities of the CHARA Array. This view is from the north looking south. The large dome in the center houses the Hooker 100 inch telescope and two solar towers can be seen in the upper right. The 60-inch telescope is housed in the smaller dome between these. The components of the CHARA Array are labeled, including all six telescope domes, the central Beam Synthesis Facility (BSF) and the site of the Mark III interferometer, now utilized as CHARA's machine shop.*

These observations included many diverse scientific programs lead by a mixture of CHARA/Georgia State scientists and other members of the CHARA collaboration, including scientists from the LESIA group at l'Observatoire de Paris, the National Optical Astronomy Observatory (NOAO), the University of Michigan (UM), the Sydney University Stellar Interferometer group (SUSI), and the Michelson Science Center (MSC).

During the Glasgow SPIE meeting in mid-2004 it was agreed that we should hold a small workshop, early in 2005, to discuss our progress in 2004 and to make plans for the 2005 observing season. At the invitation of the LESIA/Paris, this meeting was held in early February on the grounds of the l'Observatoire de Paris. All participants felt that this meeting was a great success, and we were all delighted with the progress made, both from a technological and scientific point of view. In this report, we summarize the results presented at the meeting as well as some of the other discussions held.

Participants

The CHARA collaboration consists of a core group of CHARA/Georgia State University scientists and engineers along with a number of people working on related projects: Steve Ridgway from NOAO has been an essential member of the CHARA team from the beginning; the LESIA group led by Vincent du Foresto brought a single-mode fiber-based beam combiner (FLUOR) to the CHARA Array; John Monnier and his group at Michigan, in collaboration with Jean-Phillip Berger, are building the K-band fringe tracking and imaging system for CHARA; the Sydney University Stellar Interferometry group has an MoU with CHARA to allow complementary observations from both hemispheres; while scientists from the Caltech/Michelson Science Center supply expertise and a large software base. We hope that in the long term the CHARA collaboration will continue to expand.

Figure 2. *Workshop participants on the roof of the l'Observatoire de Paris (Photo by Vincent du Foresto - inset)*

Representatives of most members of the collaboration attended the meeting, as well as some interested faculty and a number of graduate students of l'Observatoire de Paris. The participants included: Bill Bagnuolo, Ellyn Baines, Dave Berger, Theo ten Brummelaar, Chris Farrington, Doug Gies, Sandy Land, Hal McAlister, Chad Ogden, Judit Sturmann, Laszlo Sturmann, and Nils Turner *(Georgia State University/CHARA)*; Olivier Absil, Mirel Birlan, Emmanuel di Folco, Vincent du Foresto, Aglae Kellerer, Pierre Kervella, and Antoine Merand *(Observatoire de Paris/LESIA)*; Jason Aufdenberg and Steve Ridgway *(National Optical Astronomy Observatory)*; John Monnier *(University of Michigan)*; David Ciardi and Gerard van Belle *(California Institute of Technology/MSC)*; and Myriam Benisty and Jean-Philippe Berger *(Observatoire de Grenoble)*.

Instrumentation Overview

The first day of the meeting was dedicated to a review of the current status, and near future plans, of the Array hardware. Theo ten Brummelaar gave an overview of the current status of the hardware systems in general. All six telescopes, along with their vacuum tube feed lines, segmented and continuous delay lines, beam reducers, longitudinal dispersion correctors and beam sampling systems are installed and operational.

At present the CHARA Array has a pair of two-beam combiners, an open air Michelson system known as CHARA-Classic and the Fiber-Link Unit for Optical Recombination (FLUOR), a single-mode fiber-based beam combiner. CHARA-Classic provides greater sensitivity and more optical filter options than FLUOR, while the spatial filtering of the FLUOR fibers can provide much more precise measurements of the fringe visibility.

Laszlo Sturmann reported on the progress of the new CCD based tip/tilt detector system. To date, all tip/tilt detection has been done using a pair of photomultiplier-based systems. Since we plan to move towards multi-way beam combination in the near future, a new CCD-based system is now being designed. This will allow simultaneous tracking of all six telescope systems and push the tip/tilt detection sensitivity further into the red. Dr. Sturmann also reported on recent developments in remote alignment systems, including a new telescope coude path alignment jig, flip up LED based fiducials for use within the vacuum system, as well as more surveillance cameras at various locations around the Array.

Figure 3. *One of the six CHARA telescopes shown in its enclosure. The primary, secondary and tertiary mirrors can all be seen inside the main telescope tube. The large wheel on the right is the elevation drive while the azimuth drive is hidden below the floor. The M4 and M5 mirrors are contained inside the black boxes on the right of the telescope. Between these two mirrors is a large area of collimated beam used for acquisition, and will, in the future, allow the installation of an adaptive optics system.*

Nils Turner reported that six weather stations have been installed, one at each telescope, to continuously log temperature, humidity, wind speed and wind direction. Dr. Turner also reported on the first analysis of the seeing logs. These logs are based on r_0 measurements derived from the tip/tilt servos in each telescope. Since they include any telescope motion they have a tendency to underestimate the atmospheric seeing, but now that several years of data have been collected it is possible to look for annual trends in the seeing conditions. As expected, the summer months turn out to have the best seeing, and the most number of clear nights.

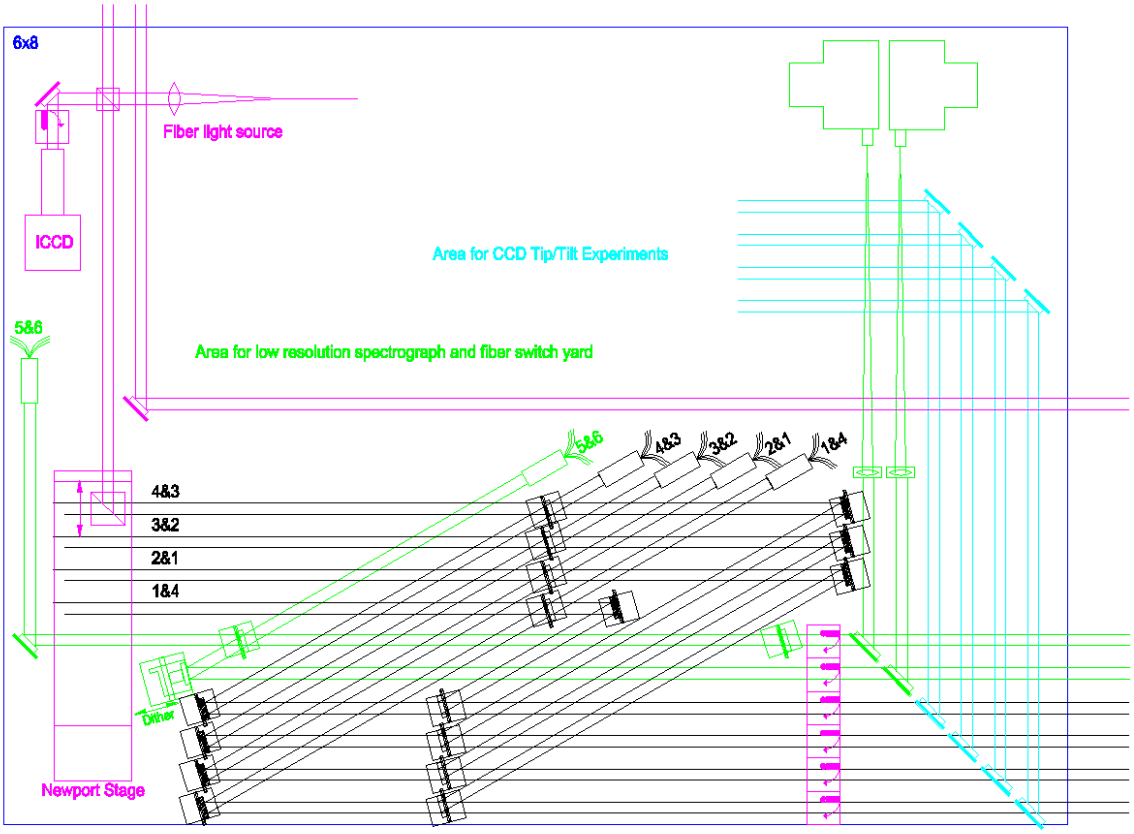


Figure 4. *The layout of the new I- and R-band beam combiner area is shown above. The existing two-way system (green) and alignment optics (pink) remain. The expansion to a four-way system is also shown (black) along with an area for CCD tip/tilt detector experiments (blue). The R/I band low-resolution spectrograph will be fed from fibers at the beam combiner outputs. These fibers can also feed an existing high-resolution spectrograph (not shown).*

Perhaps the most exciting new development planned for 2005 is a phase closure and imaging capability at CHARA along with a new two-way I- and R-band beam combiner. The Michigan Infra-Red Combiner (MIRC), being developed by John Monnier and his group with funding from the National Science Foundation, will allow the combination of up to six beams at once, though it is expected that the initial experiments, planned for late in the summer, will combine three beams. Theo ten Brummelaar and Judit Sturmann reported on the development of an open air "Classic" phase closure beam combiner, and Chad Ogden described the new two-way I- and R-band beam combiner due to come on line this spring.

In order to accommodate these new multi-way beam combiner systems, the existing beam combining laboratory and support electrical and electro-optical systems have been redesigned and rebuilt principally by Judit Sturmann. The new design was motivated by the joint need of allowing the development of the new beam combiner and detection systems while not compromising our existing science capabilities. To this end, the existing two-beam system has been upgraded and consolidated into a smaller area allowing room for expansion, as well as providing test beams for the new tip/tilt detection system. The open-air phase closure system will also be capable of two-beam operation providing redundancy and allowing us to perform measurements on two baselines simultaneously.

Science Review

During 2004, the CHARA Array opened the domes on 229 nights, from which useful data were collect on 154 nights. On the 75 nights where no data was collected, most had very poor weather and a few closures were due to hardware difficulties. The remaining nights were not covered due to lack of sufficient night staff. The principle investigators of the science projects gave a report on the work done during these nights in 2004, and set out some plans for more work in 2005. Each of these topics will be summarized here. Much of this material is yet to be formally published, and we expect much of it to be published in 2005, so these descriptions will be kept to a minimum here. The names listed represent the person giving the talk, and does not reflect the full list of collaborators on each project.

Regulus - *H.A. McAlister and D.R. Gies*

CHARA's analysis of Regulus represents the first refereed paper from the CHARA Array. We expect publication, along with an accompanying paper describing the Array, in the 20 July 2005 issue of The Astrophysical Journal. *The complete author list for the Regulus paper is: H.A. McAlister, T.A. ten Brummelaar, D.R. Gies, W. Huang, W.G. Bagnuolo, Jr., M.A. Shure, J. Sturmann, L. Sturmann, N.H. Turner, S.F. Taylor, D.H. Berger, E.K. Baines, E. Grundstrom, C. Ogden, S.T. Ridgway and G. Van Belle. The abstract of the ApJ paper is reproduced here.*

We report on K-band interferometric observations of the bright, rapidly rotating star Regulus (type B7V) made with the CHARA Array on Mount Wilson, California. Through a combination of interferometric and spectroscopic measurements, we have determined for Regulus the equatorial and polar diameters and temperatures, the rotational velocity and period, the inclination and position angle of the spin axis, and the gravity-darkening coefficient. These first results from the CHARA Array provide the first interferometric measurement of gravity darkening in a rapidly rotating star and represent the first detection of gravity darkening in a star that is not a member of an eclipsing binary system.

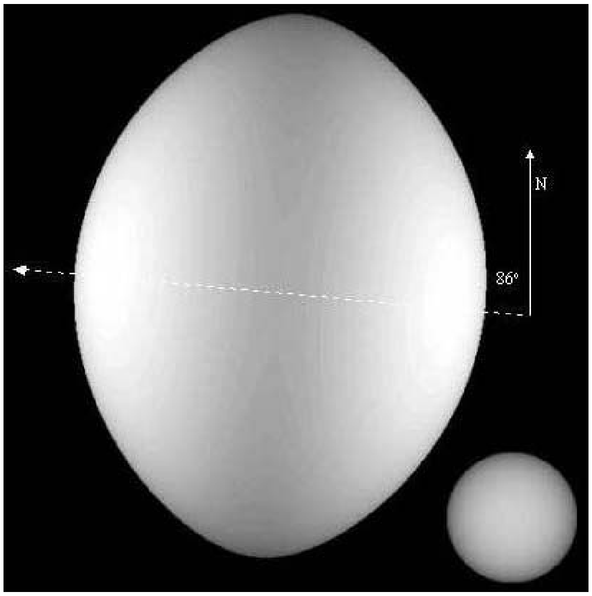


Figure 5. *The CHARA model of the star Regulus (left) along with a similar model for the Sun (right) to the same scale. Regulus is seen almost equator on with its rotational axis tilted 86 degrees from celestial north*

Alderamin – *G. van Belle*

A second rotating star, Alderamin, was observed by CHARA in the summer of 2004. While this star is not as oblate as Regulus, the data quality on these observations was much higher due to far superior seeing. In the best-fit model of Alderamin, the distortion of the stellar photosphere due to the star's rapid rotation makes the object roughly 25% wider at the equator than the poles. Also evident in this model is the temperature gradient from the poles to the equator, with the poles being approximately 8000K, and the lower latitudes dropping to ~7000K. This manifestation of the "von Zeipel" temperature-latitude effect is being directly modeled for the first time, due to the extraordinary breadth and accuracy of the data from the CHARA array. A manuscript describing these results has been submitted to *The Astrophysical Journal.*

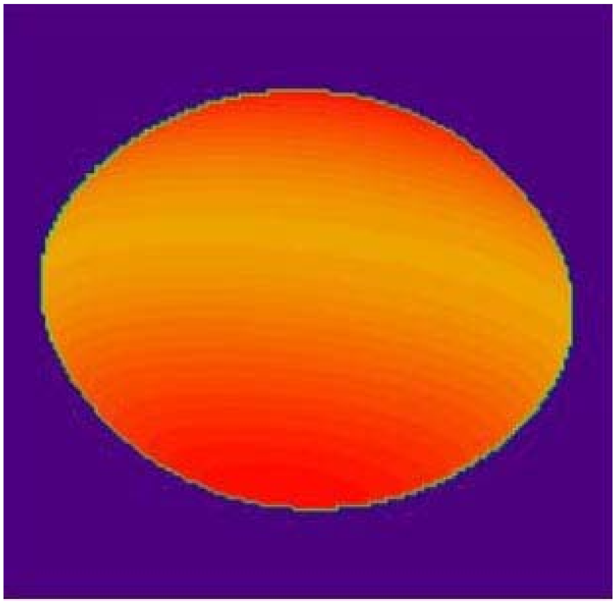


Figure 6. *The CHARA model of the star Alderamin*

Cepheid Variables – *A. Merand*

Pulsating stars have long been a standard candle for astronomers. With the CHARA Array it is now possible to measure angular diameters of nearby stars, including Cepheid variables, with unprecedented precision. Among pulsating stars, classical Cepheids play an important role as standard candles because of the famous Period-Luminosity relation they follow. While calibration of the slope of this relation does not require the direct knowledge of any distances, the zero-point does require independent determinations of distances. There are two important measurements required. First, the projection factor of radial velocity is used not only to account for the spherical projection over the star, but also for the central to limb darkening and the velocity gradient inside the stellar atmosphere. Second, the stellar center to limb darkening of the star is used to derive angular diameters from interferometric observations.

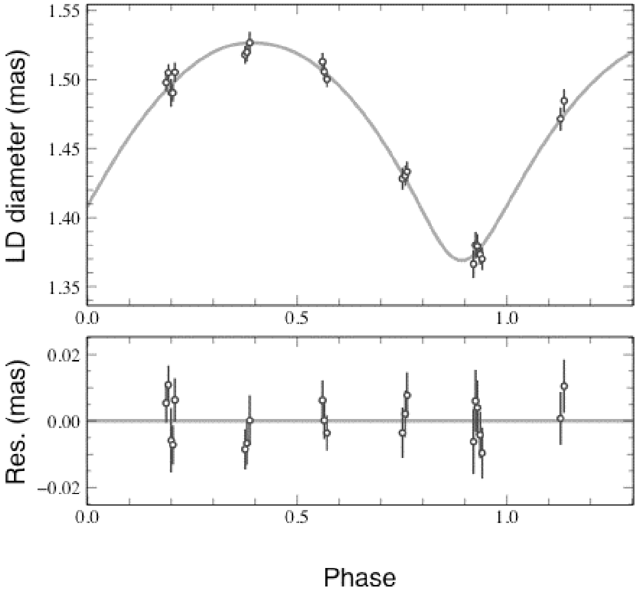


Figure 7. *CHARA/FLUOR observations of* δ *Cep.*

These measurements require long baselines and high precision. The CHARA Array offers the largest baseline available in the world while the FLUOR beam combiner provides the required precision. The projection factor was, for the first time, measured at the CHARA Array on δ Cephei in 2004. The center to limb darkening was measured on the Cepheid Polaris (α UMa) in 2003 and 2004.

These two major results offer a unique perspective on the dynamical processes within the pulsating atmosphere of these stars, allowing us to refine the numerical models. These measurements will also help to measure the distances to these objects more precisely which will allow calibration of the zero point of the Cepheid P-L relation with an unprecedented precision. The results of this work have just been accepted for publication in *Astronomy & Astrophysics*.

Dwarf Star Diameters – *D. Berger*

Stars cooler than our Sun are the oldest and most prevalent class of stars in the Galaxy, and yet they are under-represented in the stellar census due to their small size and low surface brightness. Consequently, accurate measurements of fundamental properties exist for only a handful of stars. We report precise angular diameters for seven low-mass, cool main sequence stars ranging in spectral type from K7 to M3. Combining these data with parallaxes from the NSTARS program, photometry in the visible and near IR, and spectral energy distributions, we calculated the effective temperatures and linear diameters of these stars. These measurements nearly double the existing number of accurate determinations of stellar radii for this type of star and will serve as a calibration for stellar models.

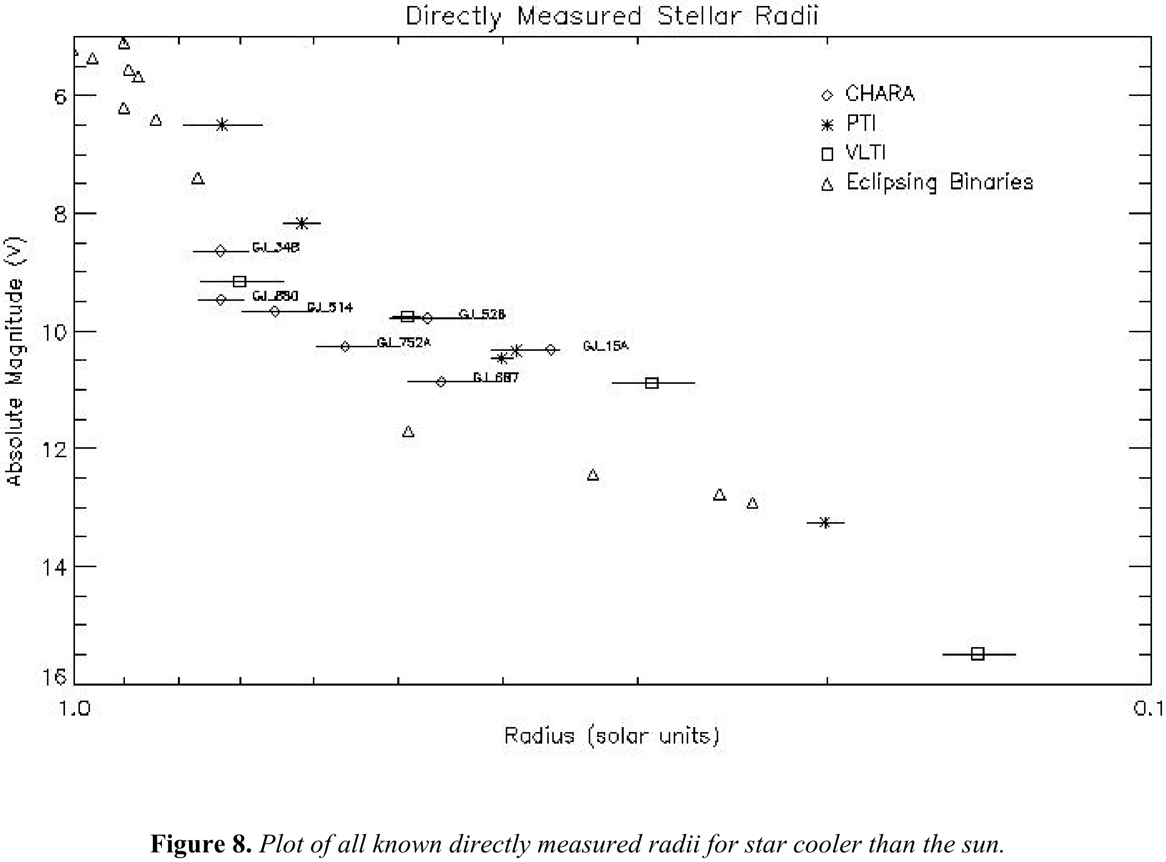


Figure 8. *Plot of all known directly measured radii for star cooler than the sun.*

Limb-Darkening Observations – *J. P. Aufdenberg*

CHARA/FLUOR observations, using the Array's longest baselines, have provided direct (second lobe) limb-darkening measurements of B- and A-type supergiants, and F-stars, for the first time. Extensive observations of Deneb (A2Ia) confirm recent expanding atmosphere model predictions that this star will have a darker limb than expected from hydrostatic model predictions. The second lobe visibility measurements constrain Deneb's mass-loss rate to the range 10^{-7} to 10^{-6} M⊙yr^{-1}, values consistent with spectroscopic and radio continuum diagnostics. In addition, observations obtained in the first null of Deneb's visibility function, at position angles orthogonal to the first and second lobe data sets, suggest the star is not symmetric. Observations of Rigel (B8Ia) in the first and far second lobes are also consistent with expanding atmosphere model predictions and reveal a K-band angular diameter 5% (2σ) larger than expected based on earlier optical observations. This comparison suggests that Rigel's B-band limb darkening is significantly stronger than previously assumed, and this result should further constrain Rigel's wind properties. Observations of Procyon (F5 IV) in the second lobe confirm 1-D and 3-D model atmosphere limb-darkening predictions, although higher precision will be required to differentiate between these two types of models. Observations of δ Scuti variable β Cas (F2 III-IV) in the first and second lobes further tighten constraints on this star's fundamental parameters: radius (to 1.6%), effective temperature (to 1.4%) and luminosity (to 3.5%). These observations also yield an angular diameter 5% (2σ) smaller than expected based on recent optical observations. Possible reasons for this discrepancy are being investigated.

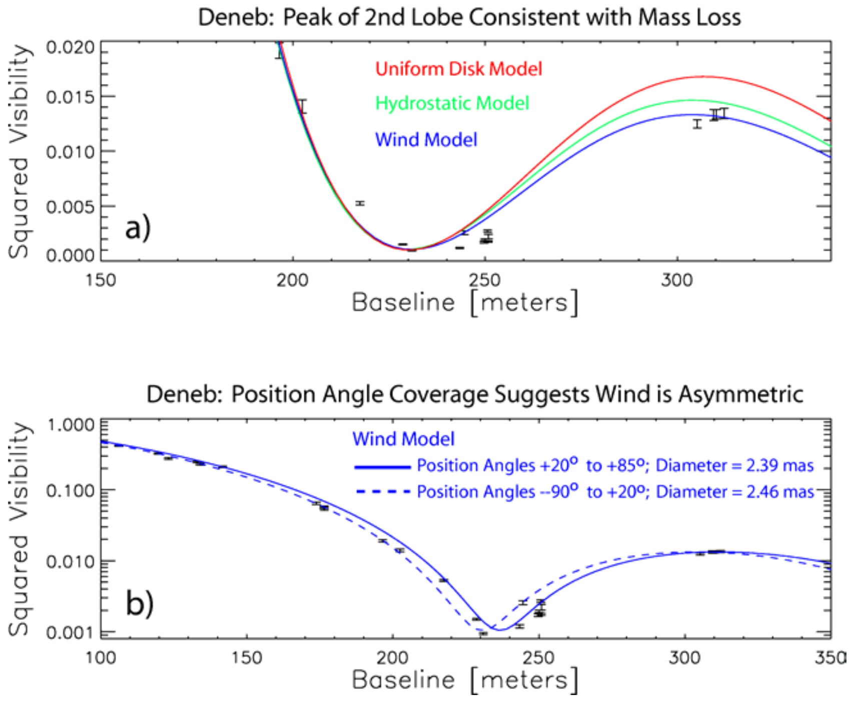


Figure 9. *CHARA/FLUOR 2004 visibility measurements of the A-type supergiant α Cygni. a) Data near the 1st null and 2nd lobe. The peak of the 2nd lobe shows that the star is strongly limb darkened. The limb darkening is stronger than expected for a hydrostatic atmosphere and is consistent with a wind model of mass-loss rate of* 10^{-7} M⊙yr$^{-1.}$ *b) Data between 200 m and 250 m were obtained over a wide range of position angles with baselines S2-W2 and E2-W1. A single angular diameter does not provide a good match to these data. Instead, Deneb's extended atmosphere appears to be asymmetric at a level approximately 3%.*

Diameter of λ Bootis – *D. Ciardi*

We have used the longest baselines of the CHARA array to observe the prototype of the λ Bootis class of stars. λ Boo stars are chemically peculiar A stars, with near-solar abundances of light elements such as C, N, O, & S ([Fe/H] = 0.0) and highly depleted abundances of heavy elements such as Mg, Ca, Fe, Ti, & Sr ([Fe/H] = -2.0). λ Boo stars may be young stars with circumstellar material with the depletions related to gas/dust separations within the disk. Our observations of λ Boo demonstrate that the star has an effective temperature of 10,280 ± 960 K typical of early A-type stars, but a linear radius of only 1.49 ± 0.28 $R_\odot$. The star is 25% smaller than would be expected for an A0 star of solar metallicity ([Fe/H] = -0.0), but the star is also 33% larger than would be expected for an A0 star of extremely low metallicity ([Fe/H] = -2.0).

If λ Bootis is a main sequence star, the interferometric observations of λ Boo indicate that the star appears more akin to the moderately low metallicity models in both size and temperature. The implied metallicity is nearly a full dex in [Fe/H] below the light element metallicity, and is more than a full dex in [Fe/H] above the heavy element metallicity. However, if the star has not yet reached the main sequence and is still contracting towards the low-metallicity ZAMS, then λ Bootis is significantly younger (<10-20 Myr) than previously estimated (100-200 Myr). These results will be presented at the Minneapolis AAS meeting.

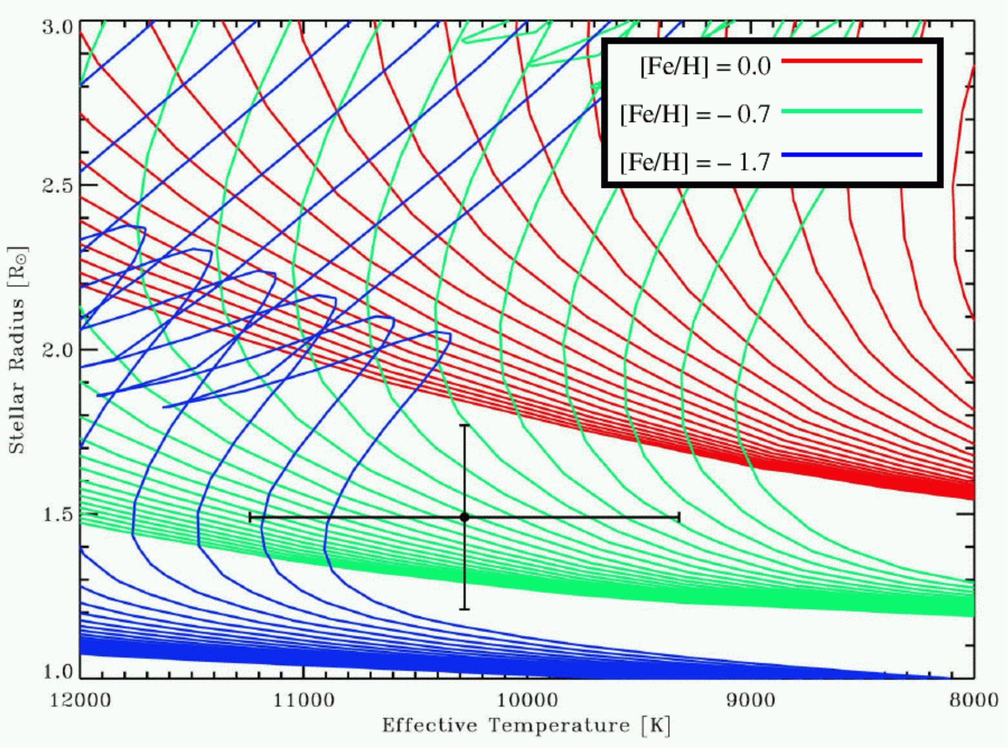


Figure 10. *CHARA observations of λ Boo. This plot shows stellar linear radius vs. effective temperature derived from Girardi et al. 2000. Each set of colored curves represent all stellar masses and all ages (t < 1 Gyr) for three different metallicities: solar (red: [Fe/H] = 0), moderately low (green: [Fe/H] = -0.7), and extremely low (blue: [Fe/H] - 1.7). Any one particular curve represents the positions for a set of stellar masses for a unique pairing of age and metallicity. For a given metallicity, the older stars are represented by larger radii for a given temperature. The position of λ Bootis, as measured by the CHARA Array, is represented by the black dot and uncertainties ranges.*

Be Stars – *D. Gies*

Be stars are rapidly rotating massive stars surrounded by out flowing disks that are many times larger than the star itself. The disks produce hydrogen emission lines and an infrared excess, and recent disk models suggest that the disks should contribute significantly to the total K-band flux. We obtained the first long baseline K-band observations with the CHARA Array of two well known Be stars, ϕ Persei and ζ Tauri. These initial observations demonstrate that the disks do indeed contribute about half the flux in the K-band. The disks in both cases are fully resolved, and the disks are as large or larger in the K-band than found in studies of their H-alpha emissions. New observations are being planned that will map the angular distribution of the disk flux in the sky and that will measure the rotational distortion of the Be star itself.

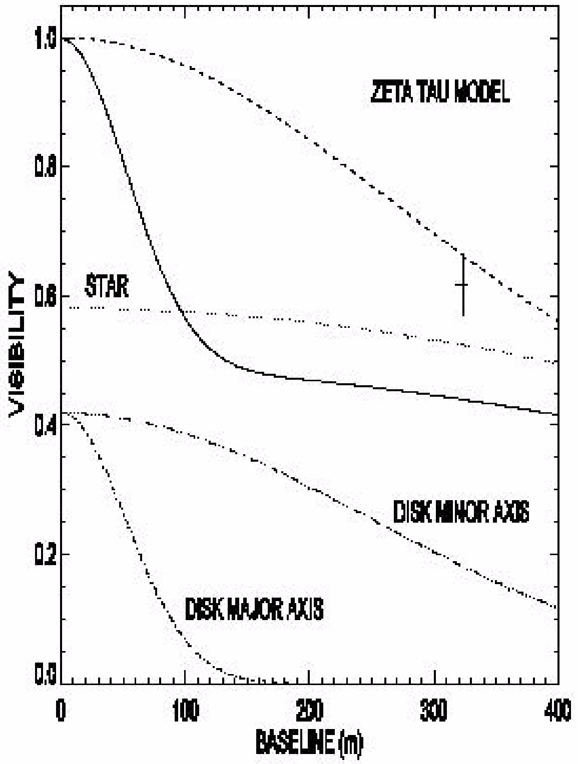


Figure 11. *Model of visibilities for a Be star. The star itself is close to unresolved, while the disk size will depend on the orientation of the baseline.*

Preliminary Analysis of the Triple System η Orionis Aab,c - *H.A. McAlister*

Located in the Orion OB1 association, η Orionis is a classical hierarchical quintuple system consisting of four early B-type stars with a distant A5 V companion. This analysis involves the Aab and Aab,c systems, the latter, having an orbital period of 9.2 years and a typical angular separation of 50 mas, was first resolved by the author using speckle interferometry in the late 1970's. The inner Aab system is a spectroscopic/eclipsing binary with a period of 8 days and a predicted orbital semi-major axis of 0.8+/-0.2 mas. The Aa component is of spectral type B1 V while the Ab star is a β Cephei variable of type B3 V. Based upon the spectral types and estimated angular diameters, we expect to find magnitude differences within the "speckle binary" and the spectroscopic/eclipsing pair of 0.43 and 0.79 magnitudes, respectively, in the K-band infrared.

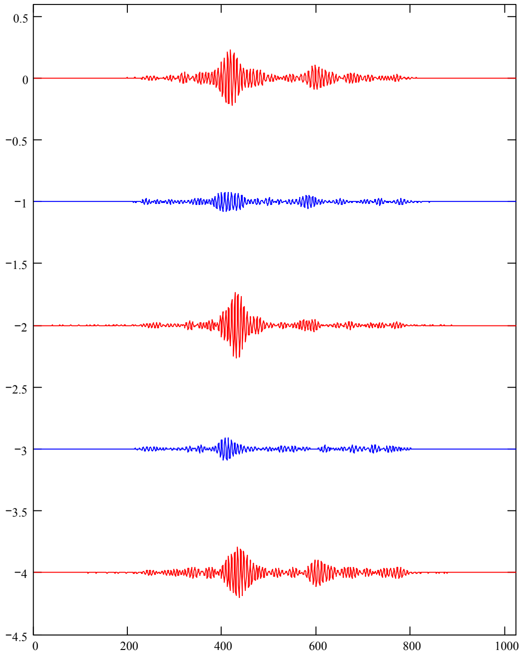


Figure 12. *A sequence of fringe scans shows double fringe packets arising from the Aab (left) and Ac components of* η *Orionis Aab,c.*

In the context of the CHARA Array, the Aab,c system is a "wide" binary, presenting separated fringe packets in each fringe scan. Several examples of separated fringes are shown in Figure 12. The Ac component is believed to be single and thus serves as a visibility calibrator for the Aab pair. In this application, the relative amplitudes for the separated fringe packets must be corrected for the magnitude difference. Observations were obtained on nine nights during late 2004 with the E1/W1 and E1/S1 baselines of the CHARA Array. The E1/S1 observations are of poor quality. The calibrated visibilities were analyzed with a grid search program that can step through any set ranges of the seven visual orbital elements. In this preliminary analysis, The elements P, T, e, i and the longitude of periastron (set as the time of minimum light since e = 0) were taken as known, and a grid involving the semi-major axis and the nodal longitude was searched for a minimum in the variance of the residuals. Values were found consistent with the estimate for the semi-major axis and, as shown in Figure 13, indicate that the orbit is far from being coplanar with the speckle system.

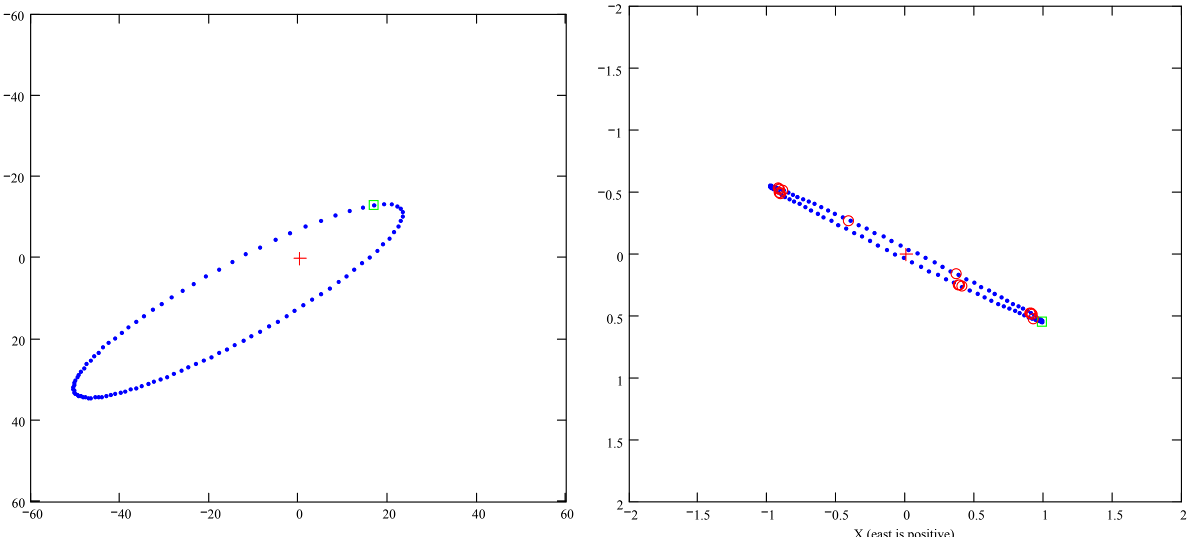


Figure 13. The orbit of the η Ori Aab,c system derived from speckle observations is shown at left. The orbit of the Aab system as deduced from new CHARA observations is shown at right. Note that there is a factor of 30 difference in scale between the two orbit plots.

CHARA Array Observations of Algol - *H.A. McAlister*

This famous star is a hierarchical triple system in which the inner 2.86-day spectroscopic/eclipsing pair AB (the Demon) is accompanied by a C component, thought to be of spectral type F0 V and detected by spectroscopy, astrometry and speckle interferometry. The AB system consists of a B8 V primary and a K2 IV secondary that fills it Roche lobe.

The AB,C system presents separated fringe packets at the longest baselines of the CHARA Array permitting the C packet to serve as a visibility calibrator for the AB packet. Only a handful of triple systems (including η Orionis) permit this wonderful circumstance in which a calibrator is provided nearly simultaneously and immediately adjacent to the target star. The finite time of the fringe scan does introduce sufficient delay between the two fringe packets so as to permit redistribution of the atmosphere, so one cannot expect perfect correlation between packets. Still, it is to be expected that this situation is far superior to the classical interferometric calibration procedure in which the calibrator and target are separated by minutes in time and degrees on the sky.

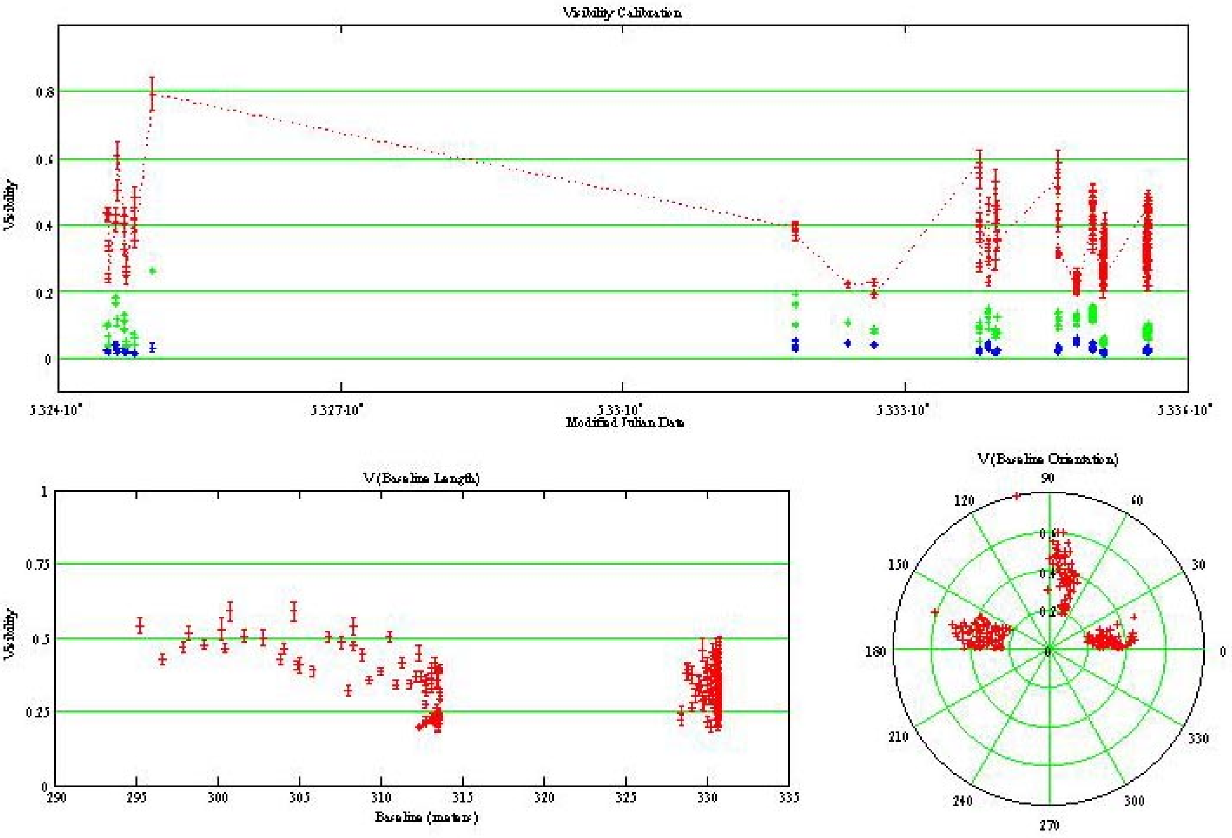


Figure 14. Calibrated visibilities are shown for CHARA observations of Algol AB as a function of epoch (above), and baseline (lower left) along with their distribution in position angle (lower right). These observations clearly show that the object is not a point source or resolved disk, however an attempt to derive an orbit from them has thus far failed. It is likely that Algol AB is presenting a more complicated structure than that due to simple duplicity.

A significant data set was accumulated with the E1/S1 and E1/W1 baselines during the second half of 2004. The calibration process incorporated intensity ratio calculations based upon spectral types and known or estimated diameters. The resulting visibilities show considerable variation when plotted as a function of baseline, and it is clear that they represent more than just a simple diameter dependency. Nevertheless, attempts to perform grid searches among orbital elements fail to converge to any minima. Thus, while it is obvious that the Array has resolved something in the system beyond stellar photospheres, it is likely that the AB system cannot be modeled as a simple binary star. For example, emission from mass exchange may be contaminating the observations. The current data set seems adequate for interpretation by more complex modeling. Although we have no positive result at present, it is clear that the CHARA Array has resolved the close, interacting binary system Algol AB.

P Cygni Emission Shell – *T.A. ten Brummelaar*

P Cygni is a bright luminous blue variable whose well-studied wind serves as the prototype for objects of its type. Indeed, the "P Cygni type profile" exhibited by its emission line spectrum has been adopted to describe partially absorbed emission lines across a broad range of astrophysical environments. Despite this textbook status, many properties of the wind are not well constrained by present observations including the exact form of the density profile and the extent of departures from spherical symmetry. These have important bearing on the underlying physics governing such winds, and in particular, on wind expulsion and acceleration processes.

In August of 2004 we observed P Cygni using the CHARA Array on three large baselines and in two narrow-band filters, one centered on the Hydrogen Bracket-γ emission line and the other in the neighboring continuum band pass used as a reference. The same measurements were performed on a nearby star δ Cygni as a check. An example dataset from a single night is shown in Figure 15. While the seeing conditions were poor, a clear signal was seen and the emission line was found to be spatially resolved. This will allow us to place a lower limit on the size of the shell in this line and, when published in the near future, will be the first reported observations resolving the infrared emission line shells that arise in the circumstellar environment due to the well-known P Cygni wind.

During 2005 we will be exploring “spatio-spectral interferometry”, a combination of high spatial resolution interferometry and Fourier transform spectroscopy to further investigate this star. The techniques developed will also then be applicable to other stars with extended shells, such as Be stars.

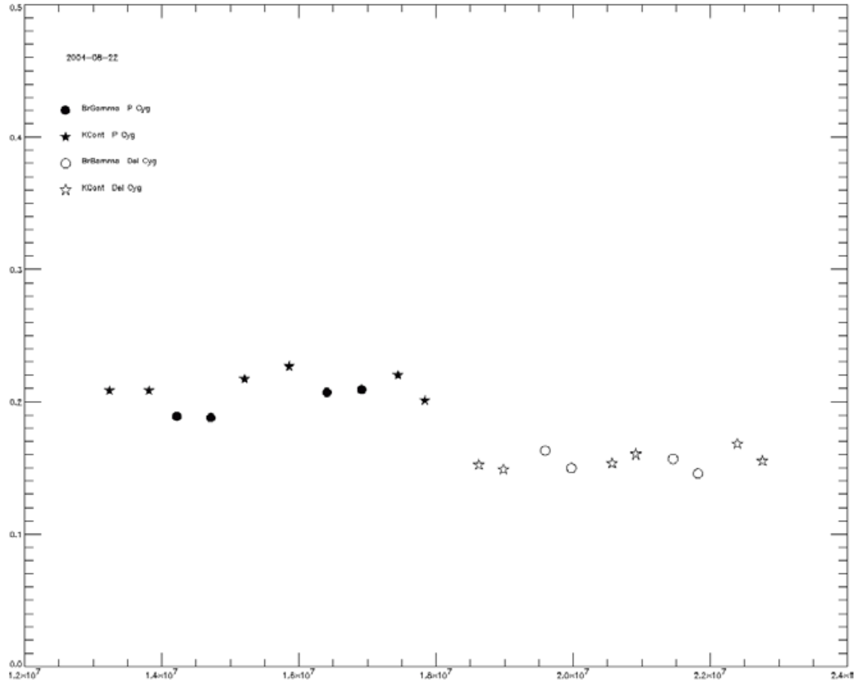


Figure 15. *Visibility data from a night of relatively stable conditions. The reference star, δ Cygni (open symbols), has a somewhat larger apparent diameter than P Cygni (filled symbols) resulting in lower visibilities. However, when comparing the observations in the Brackett-γ filter with the K-continuum, P Cygni shows a clear visibility decrement in the line, while δ Cygni (with no emission-line feature) exhibits no change.*

Wide Binary Astrometry – *W.G. Bagnuolo, Jr.*

The mass of a star is its most fundamental property. Tens of thousands of speckle measurements by CHARA and other groups have resulted in hundreds of binary orbits to obtain masses. We can obtain an improvement of 1-2 orders of magnitude in astrometric accuracy with the CHARA Array over previous methods using speckle interferometry (i.e 15-100 micro-arcsec compared to 1-2 milli-arcsec). This accuracy would improve the determination of the masses to better than 1%, allowing a critical confrontation with theory; for example, the aging of main sequence A-stars, or the evolution of G-giants.

For the CHARA Array, a "wide" binary is one in which the central fringe envelopes of the two stars do not overlap, which occurs for separations of a few tens of milli-arcseconds and greater. The overlapping of the secondary star's fringe packet with the side lobes of the primary's provides a convenient phase reference and produces an apparent oscillation in measured separations of the packets. Results from fits to this oscillation indicate that a precision of about 15 micro-arcsec can be obtained in an hour. Absolute accuracy is currently limited by the accuracy of the effective wavelength to less than 0.1%.

Orbits already reasonably well known can be improved by these high-precision results via a number of techniques. The uncertainties in the seven parameters of the current orbit are used to create a large number of points in the orbit plane. The points in agreement with the new interferometric data are identified. The average parameter values are calculated for these selected points, and the revised orbit, in this case for the 12 Persei system, is shown by a dashed line in Figure 16. The semi-major axis has increased to 54.01 mas vs 53.38 from the original orbit, an increase of 1.2% implying a mass increase of 3.5%. Data from several other nights is consistent with this result. Finally, the technique is useful for several related projects.

First, for triple systems the movement of the photocenter of the hard binary could be measured, giving some indication of this orbit. Second, wide binaries could provide a measurement of τ_0, the effective atmospheric coherence time. We do this by using the correlation coefficient of the two packets' intensities. A star with a rapidly changing projected baseline would be ideal for this test, such as Algol on 14 Dec 2004. Third, another component of the system could be detected. A Jupiter-mass planet could cause a shift of 100 micro-arcsec in a 100 mas binary orbit, which should be easily detectable.

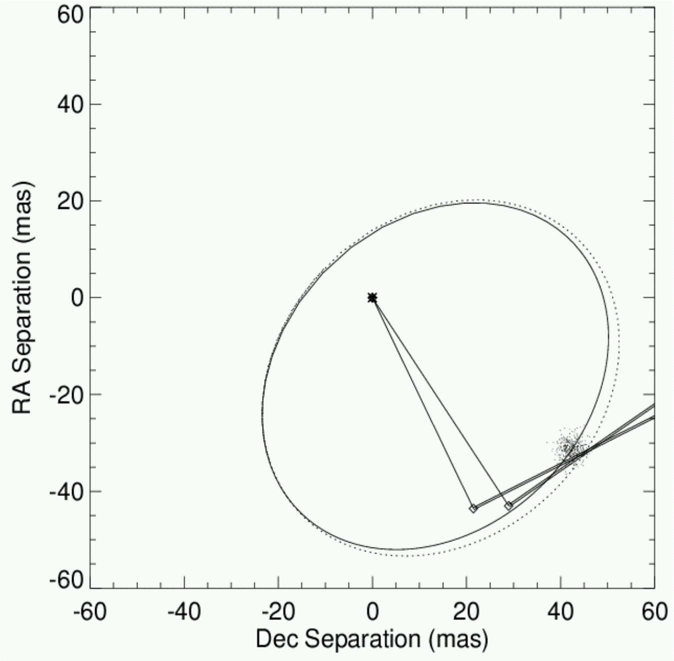


Figure 16. *Improved orbit calculate for the star 12 Persei.*

Interferometry in the Higher Lobes – *S.T. Ridgway*

The many scientific results from optical interferometry have resulted almost entirely from measurements of stars in the first visibility lobe. It is well known that, to first approximation, all stars are "alike" in the first lobe, and measurements of the stellar angular diameters exploit this fact. However, as FLUOR measurements achieve high precision, and pass beyond the first visibility null into the higher lobes, it is increasingly found that stars are typically more complex than suggested by simple, circular limb-darkened disks. This often impacts our understanding of even bright, prototypical, and well-studied objects. For example, it is now known that α Ori has a very extended atmosphere, with an upper, inhomogeneous molecular layer at high altitude. Procyon has a multi-component atmosphere (due to convection) whose signature appears in the amplitude of the second visibility lobe. The rotational darkening (von Zeipel effect) can now be determined, directly constraining the internal energy transport mechanisms. α Bootis has a small visibility distortion best explained by a nearly equal-mass, but younger and fainter, companion. CHARA work still in progress shows that numerous sources, heretofore assumed circularly symmetric, show irregularities in visibility most likely explained by non-circularity of the high atmosphere or of mass loss.

Higher lobe measurements have great diagnostic power. At CHARA, Ridgway, Aufdenberg and Merand are exploring the capability of the instrument for precision measurements at these very low visibilities. At present, the impact of systematic effects is under study, with plans to extend the measurements to higher spectral resolution in the next observing season.

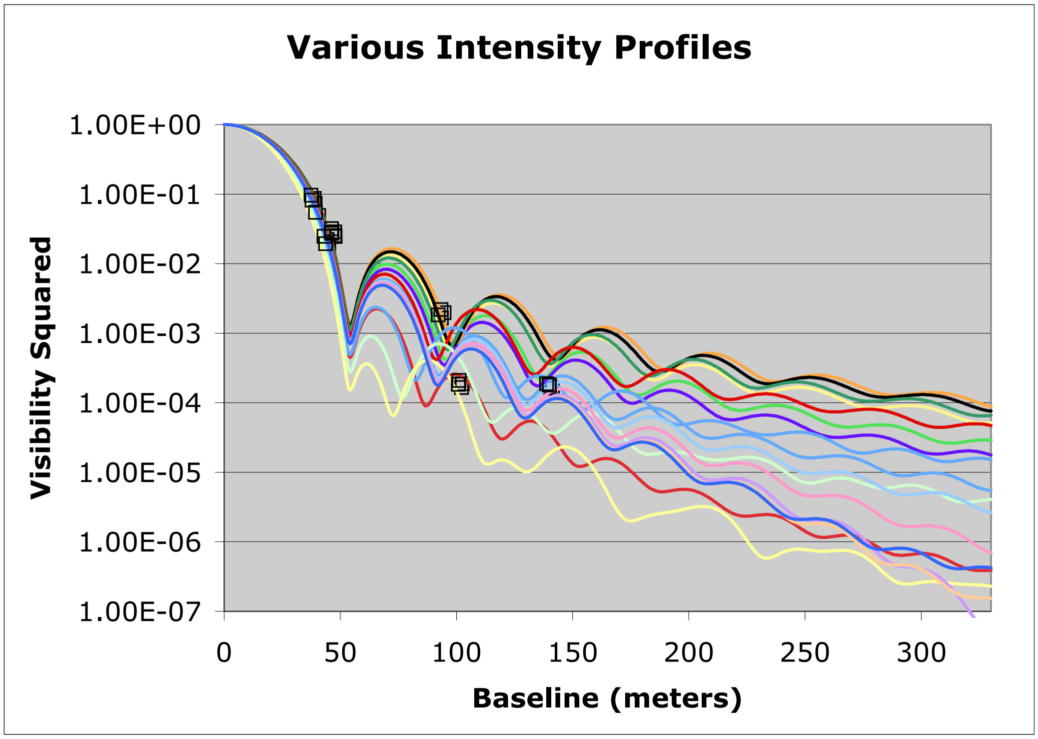


Figure 17. *An example of some CHARA/FLUOR data points measured along with numerous models for intensity profiles. The plot demonstrates the excellent repeatability of high-lobe measurements along with visibility curves for a range of intensity profiles.*

Integrated Optics Beam Combination - *J.-P. Berger*

For the past nine years, LAOG has carried out a significant research and development effort in order to develop integrated optics beam combiners devoted to aperture synthesis imaging in the near IR. Much of the effort thus far has consisted of designing and testing new building-block functions suitable for broadband signals. IOTA 3-way on-sky validations have confirmed the intrinsic quality of IO-based instruments. We are now equipped with all the optical benches necessary to characterize our next generation beam combiners, including a full 8-beam interferometer simulator.

All this effort has been funded in the context of the Vitruv project: a 4 to 8 beam spectro-imager devoted to aperture synthesis at the VLTI. This project is in competition at the European level to be the second-generation VLTI imaging instrument (realistically planned for 2010).

The collaboration with CHARA and the University of Michigan's MIRC instrument fits remarkably well into this project. The CHARA Array is the only fully equipped 6-beam interferometer almost ready for imaging. In addition, MIRC, CHARA's own imaging instrument, has been designed from the start to permit the switch between the fiber combiner and a potential IO beam combiner. Two beam combiner designs have been selected for MIRC and VITRUV. Both CHARA and LAOG should benefit from this collaboration. We hope to provide CHARA with an efficient and high-quality beam combiner. In return, an on-sky demonstration of IO combiner imaging plus the participation in the development of an instrument (MIRC) with close similarities with VITRUV would be an invaluable experience for LAOG in the current competitive context.

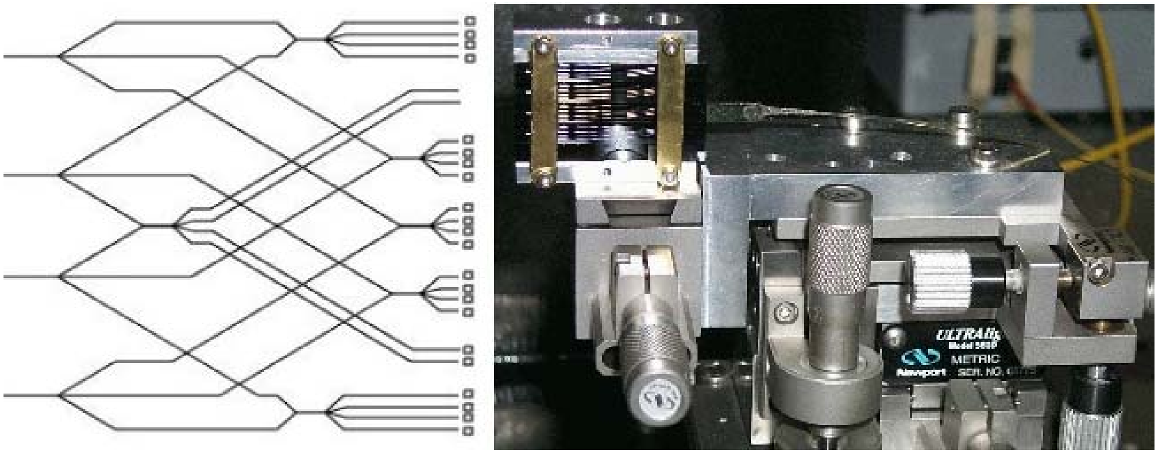


Figure 18. *Left: A schematic is shown of the optical circuit of a 4-way beam combiner that allows pair wise simultaneous ABCD-like combination. The first such chip will be tested during the summer of 2005. If successful, this combiner would be well suited for the CHARA MIRC instrument. Right: The IOTA 3-way beam combiner is shown. The future 4- or 6-way beam combiner should be incorporated into a very similar silica on silicon chip.*

Other Science Programs in Progress

A number of other projects that could soon lead to publications were mentioned, but not presented in detail. These included:

1. Diameters of the Hyades giants.
2. Orbit of the spectroscopic binary star β Aur.
3. Diameters of early spectral type main sequence stars.
4. An extra-solar planet survey to check for close binary companions.

Closing Discussion

Several other discussions took place, including talks on policy of authorship lists and acknowledgements, MIRC installation requirements, calibration, reduction software, future collaborations, future funding, and a number of hardware and software issues. A long discussion was held on how we should go about allocating observing time in 2005. It was agreed that the PI based portion of observing in 2004, while perhaps not the most of efficient use of time, was a great success. It was also agreed that the instrument and mountain staff are not ready yet to undertake schedule based observing. Having the PI on the mountain during the observations has many advantages, not least of which is relieving the workload of our single night assistant. We therefore decided to continue in the PI based model in 2005, and a call for proposals, due 15 March 2005, from the members of the CHARA collaboration was sent out, covering the period of April through August 2005. A second call will go out in June for the remainder of the observing year.

The meeting was adjourned with great enthusiasm for making this an annual tradition, and it is anticipated that the CHARA collaboration will gather in Atlanta in early 2006.