# ANNIVERSARIES AND ANTICIPATIONS: CHARA AT AGE 20 AND BEYOND

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## Abstract

This talk presents an informal history of speckle interferometry at the Center for High Angular Resolution Astronomy (CHARA) at Georgia State University.

## 1. Introduction

First, I would like to extend thanks on behalf of all the astronomers at Georgia State University (GSU) to the AAVSO staff and to your Local Organizing Committee for inviting us to this meeting. Your hospitality towards us and our spouses has been most appreciated. This is my first AAVSO meeting, and from what I have seen you have a wonderfully vital organization. If you can continue to attract bright young people such as we have seen here this weekend you have a marvelous future ahead of you as well.

I hope you all are enjoying springtime in Georgia! I'd like to think I can claim just a little bit of the credit for your meeting being here in Atlanta during our prettiest time of year. Janet Mattei attended a small IAU conference we organized in April 1992 at Callaway Gardens, about an hour's drive south of here. We scheduled our meeting to coincide with Callaway's Azalea Festival, and arranged session times so that everyone had plenty of time to walk or bike amidst acres of blooming azaleas and dogwoods. Whether that event led to your meeting here or not, we're glad you were able to come.

I'd like to take a quick poll of the audience to see how many of you are spouses and others not into astronomy but just dragged by ... er ... I mean accompanying an AAVSO member. You might like to know that the scientific term for you is "normal person"! For the sake of all you normal people (one of whom I married and who is here with me) I will try to stick to English as much as possible and not lapse too much into astronomy jargon.

You will note the word "anniversary" in the title of my talk. I thought this seemed appropriate, as the AAVSO is celebrating its 85th anniversary this year. My thoughts of anniversaries actually started a few months ago, however, when several of us from GSU attended a workshop in Berkeley, California, held in honor of a gentleman named Charles Townes for his 80th birthday. For those who don't recognize the name, Dr. Townes received the Nobel prize for the invention of the maser and the co-invention of the laser. He has worked for several years in astronomy in the field of interferometry, especially in the infrared. Let me give you a very loose definition of interferometry. In most of astronomy we deal with light as particles—photons which expose a grain of emulsion on a photograph or are counted in a photometer. Interferometry is the study of light as waves, which add together or cancel each other out as they interact with each other. I should note for those of you who live locally that Dr. Townes will be in Atlanta May 1 and 2 as part of our University Center lecture series. He is still amazingly sharp and active—the last time one of my colleagues saw Dr. Townes at his interferometry project he was lying under an optical bench calling for a wrench!

As a further excuse for reminiscing I noted that this past year saw not only the 20th anniversary of our own research effort in the field of speckle interferometry, but also the 25th anniversary of the invention of speckle, the 75th anniversary of a famous interferometry experiment at the Mount Wilson 100-inch telescope, and the 100th anniversary of the first astronomical observations using Michelson interferometry!

## 2. Speckle interferometry

Now, before I explain just what speckle interferometry is, let me pose a true/false question:

TRUE or FALSE: When it comes to telescopes, bigger is always better!

When it comes to the ability of a telescope to gather light, the answer is pretty clear. The bigger the light "bucket," the more photons you can collect and the fainter the object you can see, the better your photometry is, and the more impressive the view you're trying to show off to a friend!

When it come to resolving power—that is, the ability to see detail (for example, trying to see a double star as two stars rather than one merged image or see surface detail on a planet)—the answer isn't as clear cut, however. Optics theory says it is—double the diameter of your telescope and you double your resolving power (in other words, you can separate a pair of stars with half the separation of before). As you know, however, there is another factor to take into account—the atmosphere. While very useful for such things as flying kites, blowing up balloons, breathing, and such, when it comes to astronomy the atmosphere can be a real bother—blurring our view such that the very largest telescopes can't see any finer detail than can the telescope purchased by a beginning amateur. In many cases, especially with older telescopes, one could argue that larger telescopes had worse resolution, due to their enormous domes and locally-induced seeing.

I'm not going to go into the physics of the atmosphere in great detail here, but in general most of the effect of the atmosphere is caused by a single layer or at most a few layers, located about a kilometer in altitude. This layer is made up of many columns of relatively still air or "convective cells"—rather like the structure you may see in a large pot of water on the stove when it's at a gentle rolling boil. The size of these convective cells defines the quality of the "seeing." Typical cells are on the order of 10 cm across, corresponding to about 1 arcsec seeing. Better sites have larger cells—up to perhaps 20 cm or more across, yielding seeing of 0.5 arcsec or better. Unless your telescope aperture is smaller than this cell size its resolution limit is defined by the atmosphere.

These cells don't just sit in one spot, of course, but are blown across your field of view by the wind and also change with time. A large telescope may be viewing through dozens or hundreds of these cells at any instant, each cell acting like a small lens, bending the light coming through it in different directions, shifting it in phase, etc. The result is that light through these lenses interferes with each other, and this constructive and destructive interference creates small light and dark patches on your detector—be it eyeball, photographic film, or CCD. These light patches are what we call speckles (see Figure 1), and it's the moving about of these speckles that we see as "twinkling".

Each of these little speckles may contain within it the detail—the theoretical resolving power—of the full telescope diameter. For a 4-meter telescope (such as the one used to obtain Figure 2), that limiting resolution is about 0.030", or 30 milliarcseconds. You are in effect seeing hundreds of tiny detailed images all overlapping and moving about, and which within a fraction of a second all blur together and lose that detail. In 1970 a French astronomer named Antoine Labeyrie realized that if he could take many fast snapshots "freezing" the atmosphere and somehow add up all these speckles, then he could recover all this lost detail (a caveat here: this only works for rather simple images, such as binary stars or stellar disks). Labeyrie figured out a way to do this, and

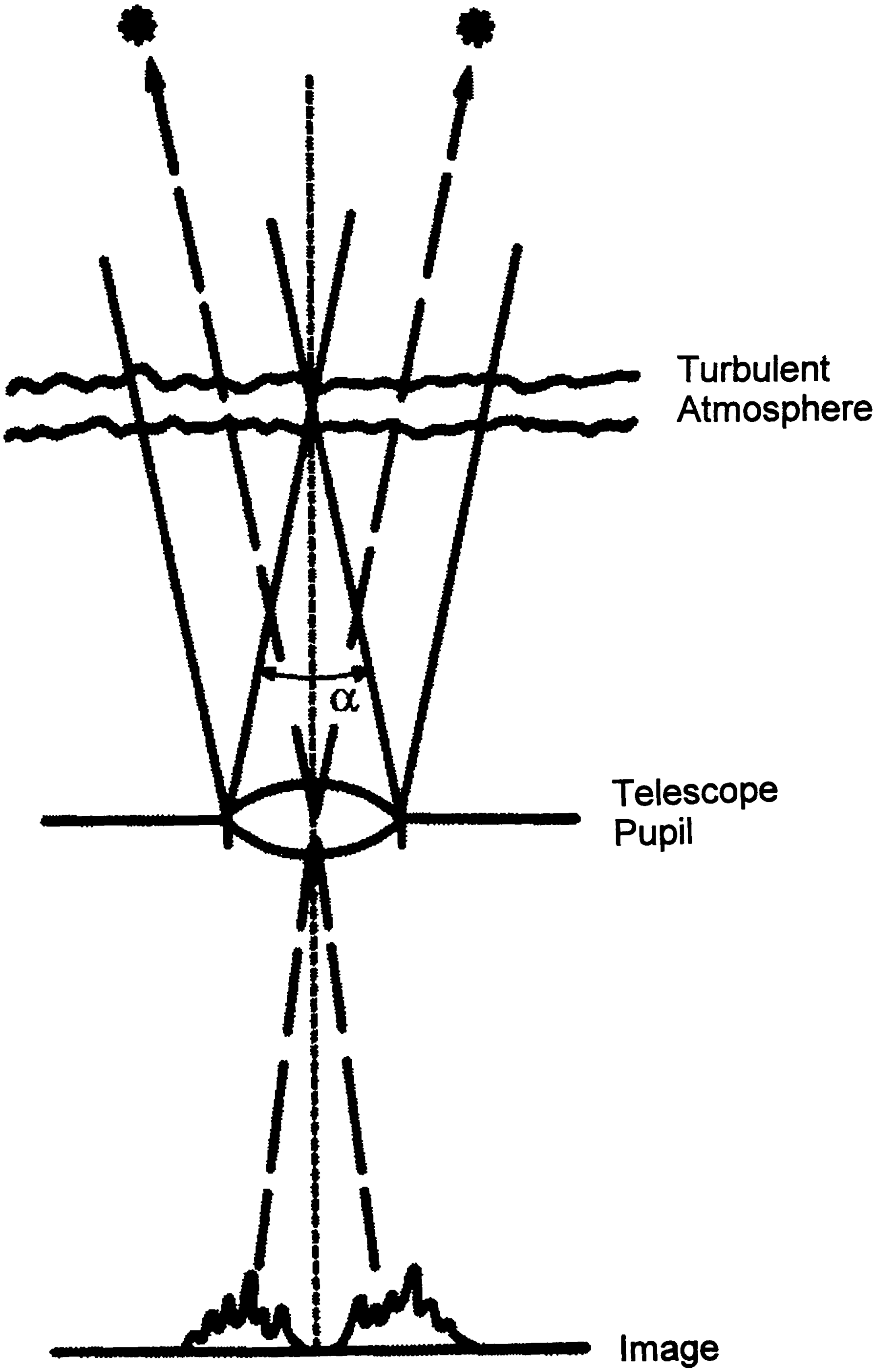

Figure 1. The formation of speckles.

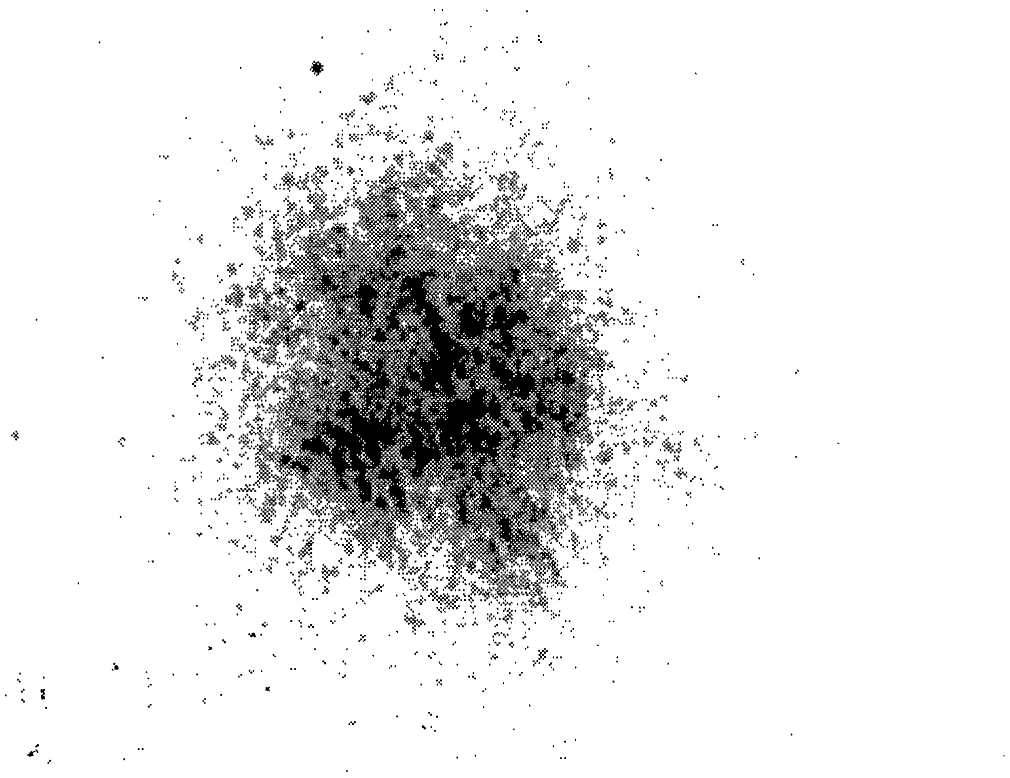

Figure 2. Short-exposure (1/30 sec) snapshot of the 0.1-arcsecond binary 51 Tau. The entire photo is about 1.5 arcseconds across, and was taken using a 4-meter telescope.

thus was born the field of speckle interferometry.

## 3. The birth of CHARA

Let's jump ahead a few years. CHARA was born in 1975 when Hal McAlister, then a postdoc at Kitt Peak National Observatory, started a project using a newly-built speckle camera to observe known binary stars and to try to find new ones. The equipment was a quite large and bulky collection of optics—lenses to magnify the image, filters, prisms to compensate for atmospheric dispersion—coupled to an image intensifier and a 35-mm camera and usually bolted to the Cassegrain focus of the Kitt Peak 4-meter telescope.

Since the speckle camera wasn't operated remotely, the observer (usually Hal) would ride around all night in a cage behind the primary mirror, sitting on a cushion which of course he'd have to move as the telescope slewed around the sky. After centering each star he'd take 50 to 100 snapshots with the camera on 35-mm film—using as you can imagine several hundred-foot rolls of film during an observing run! After developing, these photographic data were reduced by doing an optical Fourier transform (and here I lapse into jargon a bit). A laser was shone through each frame in turn onto another piece of film mounted several feet away, building up an interference pattern which could then by analyzed. In order to do this, Hal first needed to make positive prints of these long rolls of negatives. Now, it so happened that only one place had the equipment to do this—Hollywood! He would splice these 100-ft rolls onto movie reels and ship them off to a company in Hollywood for processing. Even back in the late 1970's processing of black and white movie footage wasn't very common; the only other black and white project this company had was making new prints of old "I Love Lucy" reruns!

Hal came to Georgia State in 1977 and of course continued his speckle work. I'll skip most of the observing stories (such as the time Hal's first graduate student Elaine Hendry rode around in the Cass cage observing in dress and high heels, after her luggage was lost somewhere between Atlanta and Tucson!). We built our own speckle camera in 1982, this time using a modern CCD detector and video tape rather than film, and all our data are now processed in the computer rather than in the darkroom. Since then we've had the fun of observing at telescopes in Chile, California, and Hawaii, as well as at Lowell Observatory and Kitt Peak in Arizona. A little bragging—we're responsible for about 75% of all the speckle measurements ever published. To date we've made nearly 45,000 observations of over 8,000 stars, and have discovered over 300 new binary systems as well.

The aim of most of our research has been to measure accurately orbits of close binary stars in order to determine masses. For example, using a combination of speckle data with spectroscopic data from diverse sources, such as the IUE satellite, we were able to discover that the bright O star 15 Mon (also known as S Mon) was a binary and to make a preliminary estimate of the stars' masses. We are obtaining other data from the Hubble Space Telescope in order to improve our mass estimates.

We have even used speckle in a search for planets around nearby binary stars. The

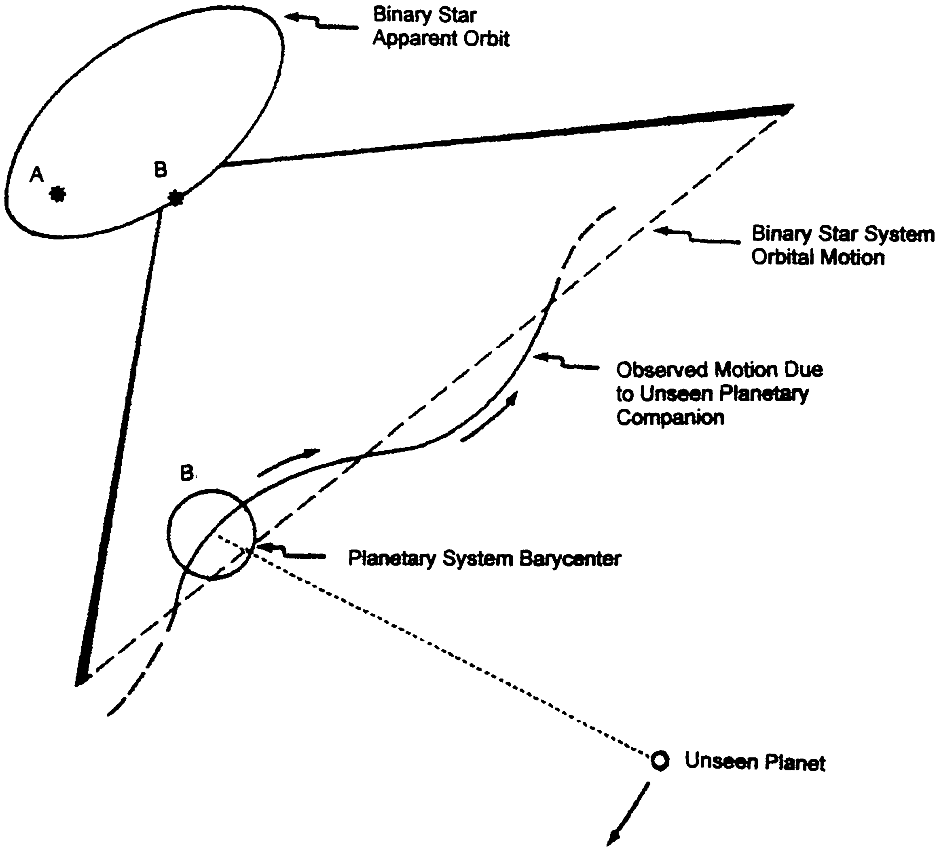

Figure 3. Perturbation to a binary star orbit due to the presence of a planet around one component.

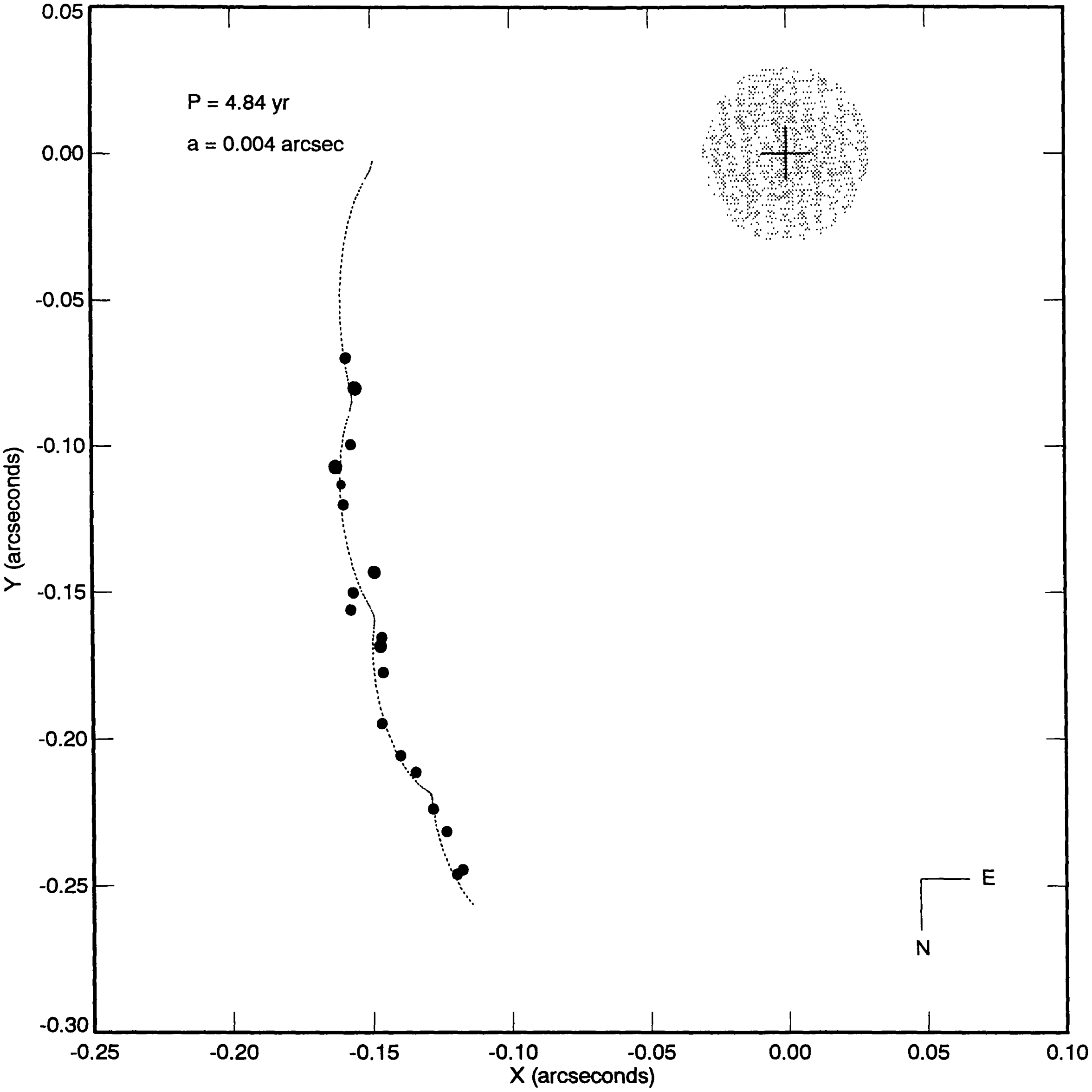

Figure 4. A portion of the orbit of HR 266 = ADS 784, showing a perturbation due to an unseen astrometric companion. The large plus sign indicates the position of the primary star of the known double. The grey circle indicates the 0.03" limit of resolution of a 4-meter telescope.

principle is straightforward—if one component of a binary has a planet orbiting it, then the binary star orbit won't be a smooth ellipse but will have a small oscillation added to it, as shown in Figure 3. It's a very long-term project, and so far we haven't found evidence of another planet, but we did discover a stellar companion to the known binary system HR 266 = ADS 784 through a small oscillation of about 4 milliarcseconds' amplitude (Figure 4).

Speckle interferometry is of course limited by the size of the telescope mirror, and there are many close systems which cannot be resolved even by a 10-meter telescope. In the early 1980's we began to think about the next generation of interferometry. The first step was to start a real research center—and of course, as you know, the most important part of any such effort is to come up with a good acronym! We had numerous compliments on our ability to come up with the name CHARA and then invent words which fit it so well, but in truth Hal McAlister came up with the name "Center for High Angular Resolution Astronomy" and only found out later that CHARA has an astronomical connotation, as well. Chara is the name of one of the two hunting dogs which comprise the constellation Canes Venatici—in fact it's the "southern dawg," which might have been even more appropriate if we worked at the University of Georgia rather than Georgia State! Chara also means "dear to the heart of its master," which we thought seemed rather appropriate.

## 4. The future of CHARA

We began work on designing a multiple telescope array—the optical equivalent of the more familiar arrays of radio telescopes—with the idea of making it larger (i.e., telescopes more widely separated) than other existing or planned optical arrays to give higher resolution, and also to have larger individual telescopes to be able to see fainter objects. After years of designing and redesigning, fundraising, engineering reviews, site selections, architectural studies, environmental impact studies, and the like, the CHARA Array is now about to become a reality, with formal groundbreaking scheduled for this summer! [Note: Ground was indeed broken on July 13th, 1996.] The array will consist of five 1-meter telescopes, spaced along three 200-meter arms in roughly a "Y"-shape. Before I show an artist's conceptions of the Array, however, let me give you a quick "cosmic zoom" to give you a feel for the level of resolution we're talking about.

Figure 5a shows the relative orbits of two visual binaries. In each case, the ellipse shows the motion of the secondary star, while the primary is fixed at the center of the plus sign. Individual measurements are shown as well. The shaded circle represents a typical stellar seeing disk size of 1 arcsecond. The observations of κ Peg are near the limit of the best visual observers' ability to resolve the two stars—a remarkable feat indeed! An historical note: ξ UMa was discovered by William Herschel in 1780; the 60-year period orbit calculated for this system in 1828 was the first ever for a binary star and showed that binary stars were physically associated rather than just being chance optical alignments.

In Figure 5b I have blown up the image by a factor of 10. The shaded circle is now the 0.03-arcsecond resolution limit of a 4-meter telescope. The binary κ Peg is now a very easy speckle pair, and the 50 milliarcsec (0.050") pair α Aur, or Capella, is also clearly resolved.

I've blown up the image by another factor of 5 in Figure 5c and have plotted data and orbits determined by the Mark III interferometer. The Mark III was an array of small siderostats, separated by up to 32 meters, which operated in the late 1980's and early 1990's on Mount Wilson, California. Now closed, it was the only such instrument to observe binary stars in any significant number. Its stated resolution limit was about 3 milliarcseconds, although it looks like it could observe a little closer than that. Capella is now a very easy system; β Aur was the closest system for which they determined an

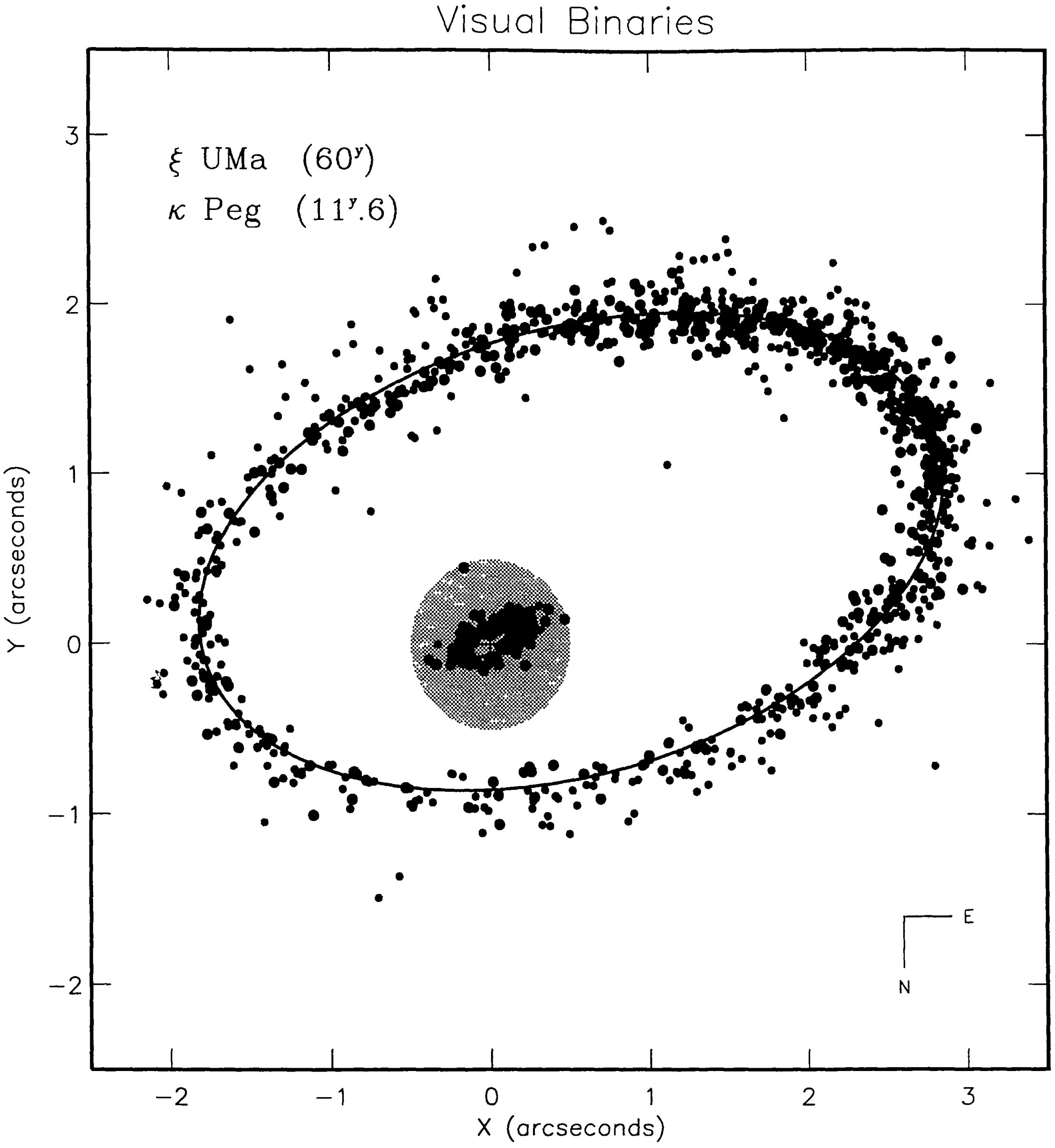

Figure 5a. "Cosmic zoom" showing increasing resolution being made possible by new telescopes and equipment: visual (micrometer) measures. See text for explanation.

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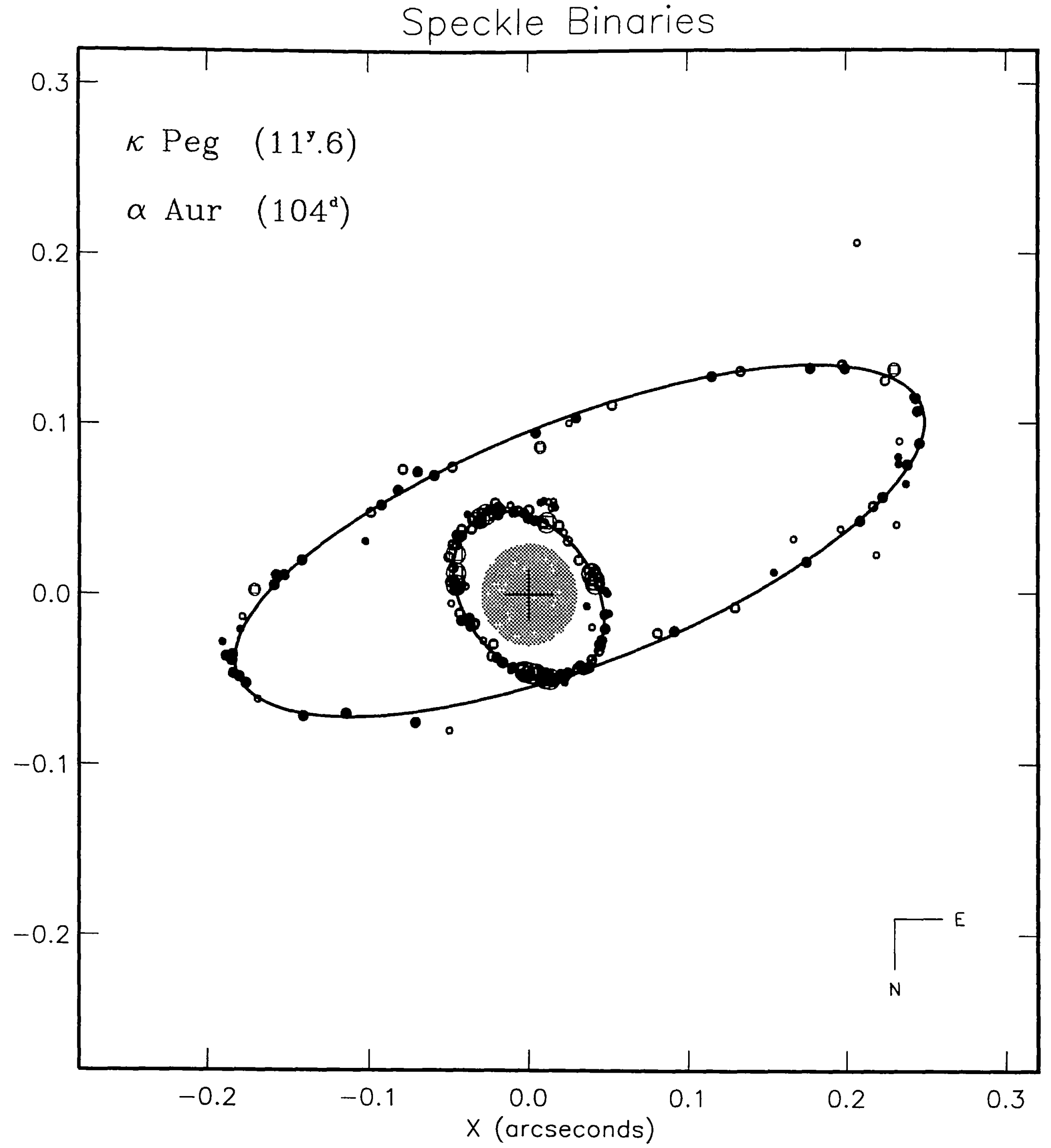

Figure 5b. “Cosmic zoom” showing increasing resolution being made possible by new telescopes and equipment: speckle interferometry. See text for explanation.

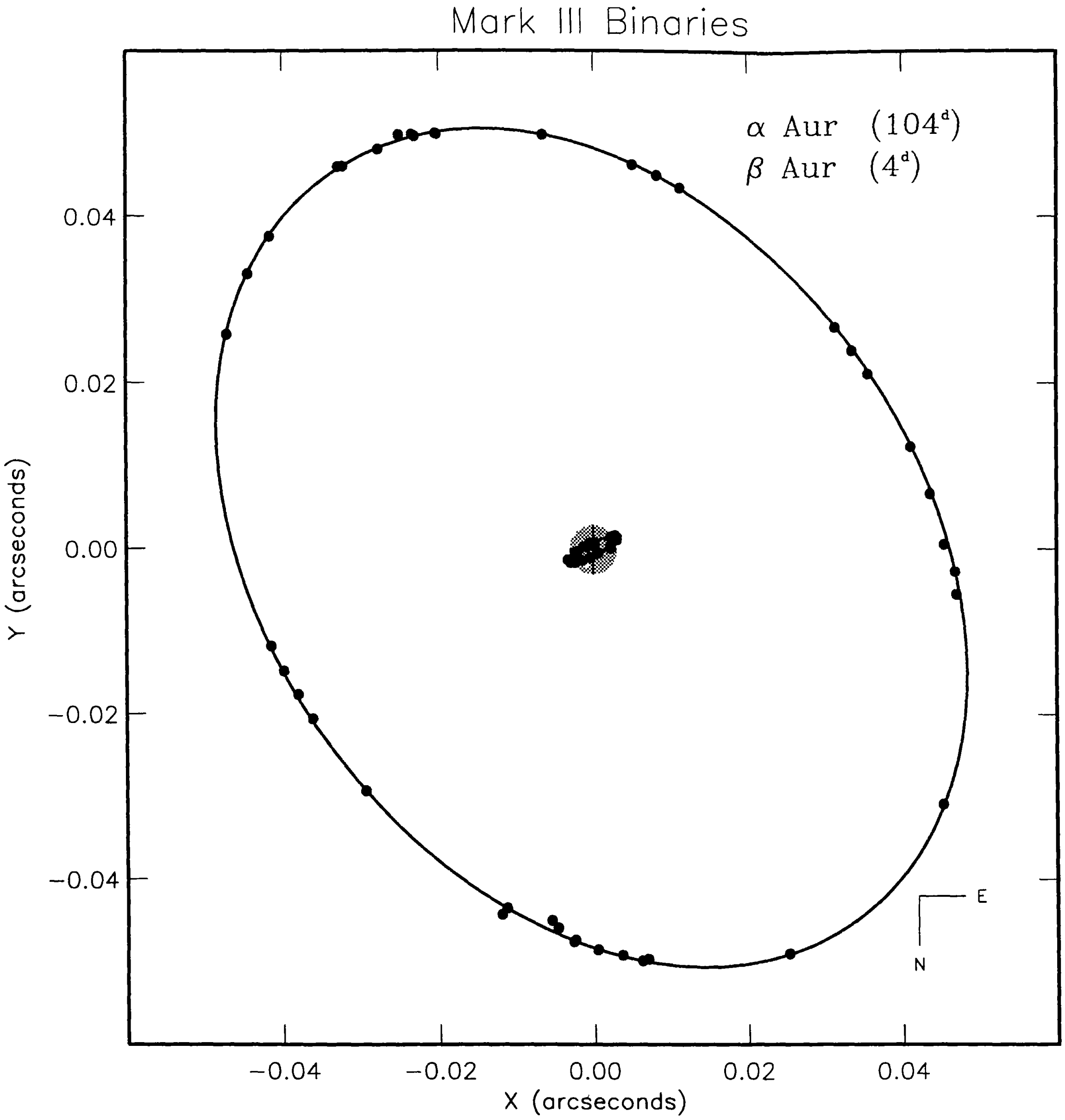

Figure 5c. "Cosmic zoom" showing increasing resolution being made possible by new telescopes and equipment: interferometry using the Mark III. See text for explanation.

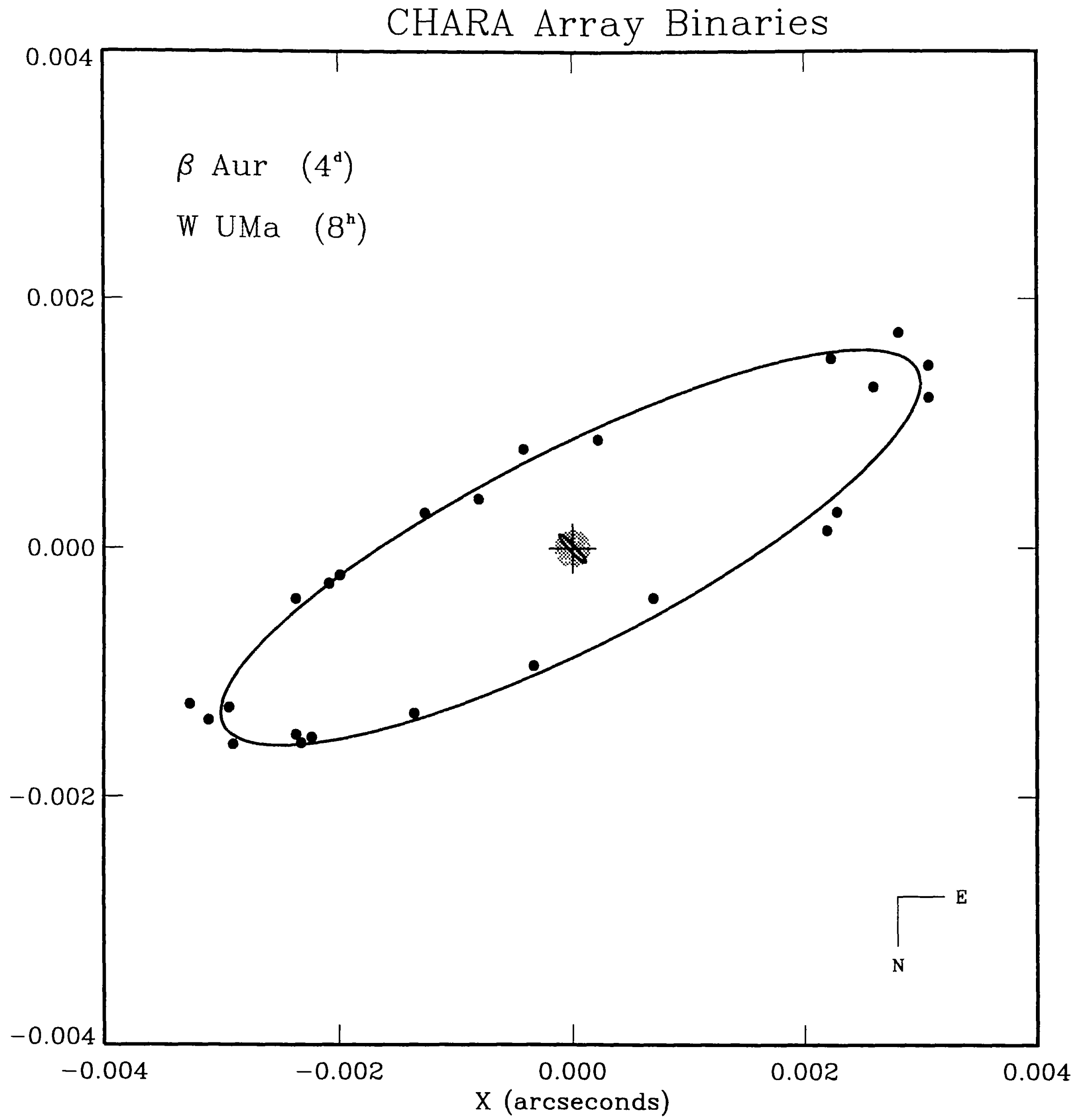

Figure 5d. "Cosmic zoom" showing increasing resolution being made possible by new telescopes and equipment: interferometry using the CHARA Array. See text for explanation.

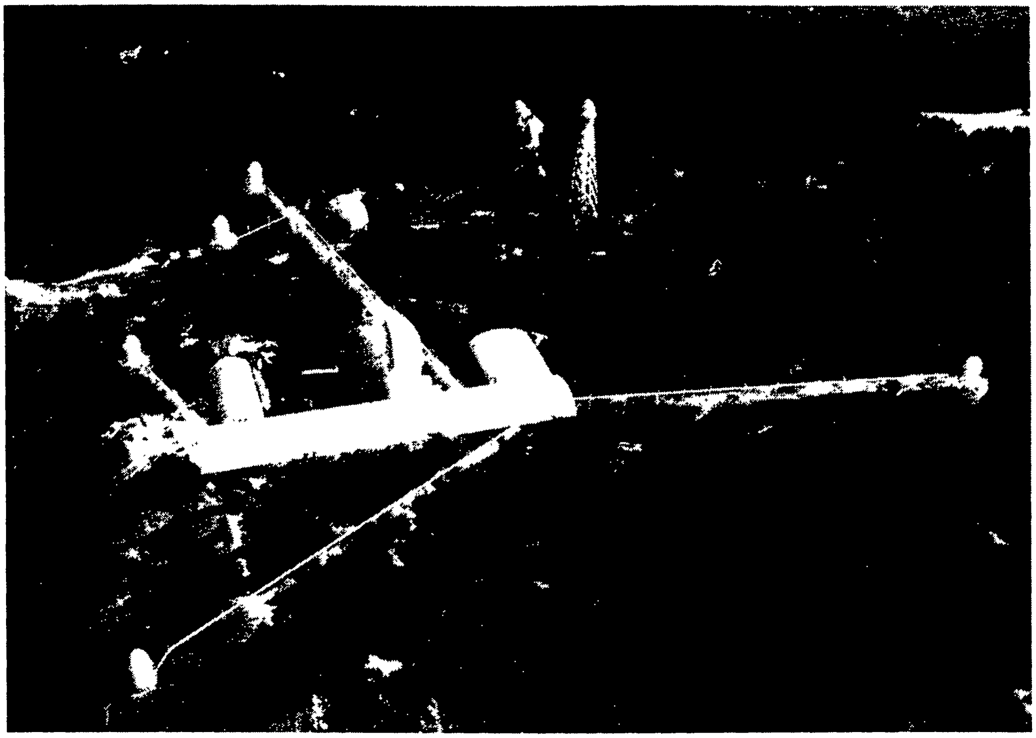

Figure 6. The CHARA Array.

orbit.

Finally, in Figure 5d I have blown up the image by yet another factor of 15 to illustrate the separation regime of the CHARA Array. The resolution limit is now 150 microarcseconds, or 0.000150". β Aur is now an easy system, and we should be able to resolve systems as close as the 8-hour binary W UMa, whose predicted orbit is shown. For comparison with the first plot, on this scale the familiar 1" seeing disk is now 750 times its original size!

The CHARA Array will also be located on Mount Wilson, very close to the historic 100-inch telescope used by Hubble to discover the expansion of the Universe (in fact, we take up much of the parking lot for the 100-inch). Shown here in Figure 6 is a computer-generated "image" of the array, superimposed on a photo of Mount Wilson. The large dome at the center of the photo houses the 100-inch, with the dome housing the 60-inch and the 150-foot solar tower behind. (Our eventual goal is to expand the Array beyond the five telescopes currently funded, hence the nine Array telescopes shown in this image.)

Light from each of the telescopes will be brought through evacuated pipes to a central facility, where it first will enter a set of "optical trombones" in the long building at the center of the photo. The reason for these optical trombones it quite simple: unless a star is exactly overhead, a given wavefront of light from the star will not reach all telescopes simultaneously. The trombones will compensate for these differences (which of course are constantly changing as the earth rotates) to make sure that the light always travels exactly the same distance from the star through each telescope and finally to the detector.

Path lengths must be exact to within a fraction of a micron, so these trombones will consist of mirrors moving along precision rails in a very well-insulated room—actually a building within a building. People won't even be allowed inside this room while we're working, since the air disturbance from their body heat alone would be enough to ruin the observing for several hours. One of our colleagues worked as a graduate student on a similar array in Australia, which he says was sensitive enough to detect kangaroos hopping around outside the facility!

At present, masses accurate to 5% or better are known for maybe 50 stars. Perhaps a similar number, mostly giants, have had their diameters measured. If all goes as planned, in a few years the Array will give us the ability to resolve the vast majority of spectroscopic binaries, and to determine accurate masses for stars of nearly all spectral types. We will also be able to measure diameters of thousands of stars, again of nearly all types. But what about the question you've all been thinking—what will the Array mean for variable star work? In a word, it will revolutionize your field! For example, we will be able to image Mira, Cepheid, RR Lyrae, and other pulsating variables, and measure their changing angular size as they pulsate. We can then combine this information with radial velocities to determine their distances directly and thus recalibrate the whole cosmic distance ladder. We will eventually be able to image starspots on peculiar A stars, RS CVn's, and BY Dra systems. We will even be able to study interacting binary systems through direct imaging. Most of you are more expert in the field of variable star astronomy than I, so I will let you imagine the other areas in which the Array can have an impact in your field!

## 5. Conclusion

I have only touched lightly on our work in speckle interferometry and the CHARA Array project. If you want to find out more about our center or our other research efforts (including a catalogue of all interferometric binary star measurements, as well as over 50 technical reports on the Array), I invite you Web surfers to check out our Web site, at URL http://www.chara.gsu.edu.

Thanks once again for inviting us to your party!