Annual Technical Report on ONR Grant N00014-96-1-0737

for the Support of Infrared Spatial Interferometry

Introduction

The grant N00014-96-1-0737 began March 1, 1996. Its purpose is to explore high precision astrometry in the 10 micron wavelength region by interferometric techniques. This involves study and measurement of atmospheric properties as well as development and testing of advanced interferometric equipment. The work is being carried out with the help of two 65 inch telescopes, stationed at the Mount Wilson Observatory, which can be separated by various baselines, and by HeNe laser interferometers which measure pathlength distance fluctuations near the ground.

Recent Technical Improvements

A number of improvements have been made in our interferometer during the past year which have enhanced our ability to measure and track the phase of stellar interference fringes.

An improved detector has been installed in one of the telescopes, bringing its quantum efficiency from about 0.25 to about 0.40, only slightly poorer than the efficiency of our very best detector, which is in the second telescope.

New tracking cameras sensitive to 2 micron infrared radiation have been installed on the telescopes and programmed to automatically track stars. This is particularly useful for infrared stars. But in addition, tracking at 2 microns wavelength rather than in the visible region more accurately follows the atmospheric light path for 10 micron radiation than does tracking at visible wavelengths. This is particularly important for angles which are not near the zenith.

First-order adaptive optics have been installed in the form of fast tip-tilt guiding for each telescope by means of a small mirror near their focal points. The mechanical and electrical components have been installed, but the servo guiding system remains to be programmed. This system should improve the precision of telescope guiding, particularly when atmospheric fluctuations are rapid.

These important upgrades of the equipment, along with other changes such as computer reprogramming, have occupied much of our efforts so that not a large number of measurements were made during the nine months since this grant was begun. However, we have hopes and there is good promise that the changes will pay off in much improved measurements related to "seeing" and astrometry during the coming observing season.

While data obtained recently is somewhat limited in amount, it reflects substantial improvement. We have made fringe phase measurements which do indeed show excellent results, partly because of the improvements mentioned. Our signal to noise ratio is now sufficiently high under some conditions that very rapid and accurate fringe phase measurements can be made. Figures 1 - 3 illustrate such improved results.

Illustrations of Present Measurements and Equipment Performance

Figure 1a shows the fringe phase variations for α Orionis during a 6-minute period with a 4 m baseline. Although this is a short baseline, the data quality is such that high precision in stellar position can be achieved. Fig. 1a shows the fringe phase variations during a 6-minute observation. Figure 1b is a histogram which represents the distribution of phase variations between adjacent 1 second averages during the observations, showing that such changes are a small fraction of a complete cycle, or of 360°. Fig. 1c also represents variations in phase between adjacent measurements, but with measurements made much more rapidly, every 1/10 sec. This shows that for times even as short as 1/10 sec, the signal to noise ratio is high enough to clearly and accurately follow and measure the phase change.

At 10 micron wavelengths, the typical time for appreciable atmospheric changes of path-length is about 1/2 sec, whereas at optical wavelengths this time is much shorter, about 1/60 sec. The modest increase in phase fluctuations seen in Fig. 1c from 1 sec to 1/10 sec is thus in part due to noise. However, the noise is sufficiently small that the phase can be adequately tracked in some cases on a time scale still smaller than 1/10 sec, as shown in Fig. 2.

Figure 2 is a plot of fluctuations between successive measurements as a function of the time elapsed for the bright IR star IRC+10216. It can be seen that the phase was properly measured for times as short as 1/50 sec. For the point shown in Fig. 2 at 1/500 sec, the phase fluctuation is much higher than at 1/50 sec, because noise has become dominant for that short time, which is the shortest time between successive recorded signals in our system. Figure 2 also gives information on the spectrum of fluctuations, which increase from times of about 1/10 sec up to several seconds, and then decrease somewhat. This seems to be a frequent characteristic of our measured atmospheric fluctuations.

A power spectrum of the data used in Fig. 1 is shown in Fig. 3. Here the fluctuations for very fast variations can be seen to decrease proportional to $\nu^{-2.61}$ which is quite close the $\nu^{-2.667}$ predicted by standard theory (Kolmogorov approximation). However, at lower frequency it is proportional to $\nu^{-0.63}$, very different from the value $\nu^{-1.667}$ predicted by a simple Kolmogorov approximation. This again indicates the importance of good quantitative measurement to the understanding of such fluctuations.

An assessment of the phase and angular precision for α Orionis can easily be made from Fig. 1. For 1 sec averaging, shown in Fig. 1b, the RMS fluctuation between adjacent points is approximately 0.025 cycles, i.e., the relative change in path-lengths to the two telescopes is $\frac{\lambda}{40}$, where the wavelength λ is 11 microns. Each measurements must hence give a phase precision of

$\frac{360°}{40 \times \sqrt{2}}$, which for a 4 m baseline corresponds to an angular precision as good as 14 milliarcsec (mas). This data was taken, however, during a time of excellent seeing. Such precision of measurement in 1 second means that a precision of 1 mas would be achievable in only about 3 minutes of measurement and averaging if the average atmospheric positional distortion were that small. Under good seeing conditions, such atmospheric effects clearly will be the primary limitation. They need more evaluation, and we hope to do that.

Plans for the Coming Year

Although we are still somewhat occupied with the upgrading of our equipment and methods, we hope and expect to obtain reasonably extensive measurements of atmospheric characteristics during the coming year and astrometry on the relative positions of stars. The latter will be oriented both towards science on stars with SiO and H_2O masers and on tests of astrometric precision in the 10 micron atmospheric window. Present indications, after improvements noted above, appear quite promising.

Figure Captions

Figure 1

(1a) A plot of fringe phase for α Orionis as a function of time in units of 2π, or one wavelength relative pathlength change.

(1b) Histogram of the differences between two succeeding fringe phase measurements each made over a time of 1 second.

(1c) Histogram of the difference between two succeeding fringe phase measurements, each made over a time of 1/10 second.

Figure 2 A plot of RMS phase differences for IRC+10216 between two successive averages as a function of the averaging time or time interval. The ordinate in phase is cycles, or units of 2π. Only for time intervals below 0.02 sec does noise becomes dominant rather than real phase fluctuations.

Figure 3 The power spectrum of fringe phase fluctuations for α Ori. The straight lines show the approximate power law dependence on frequency. They agree well with the Kolmogorov approximation at high frequencies but not at low frequencies.

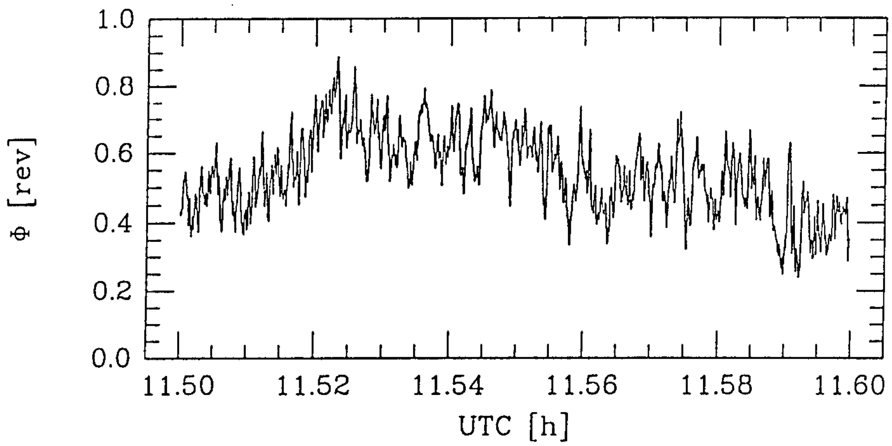


Fig. 1a

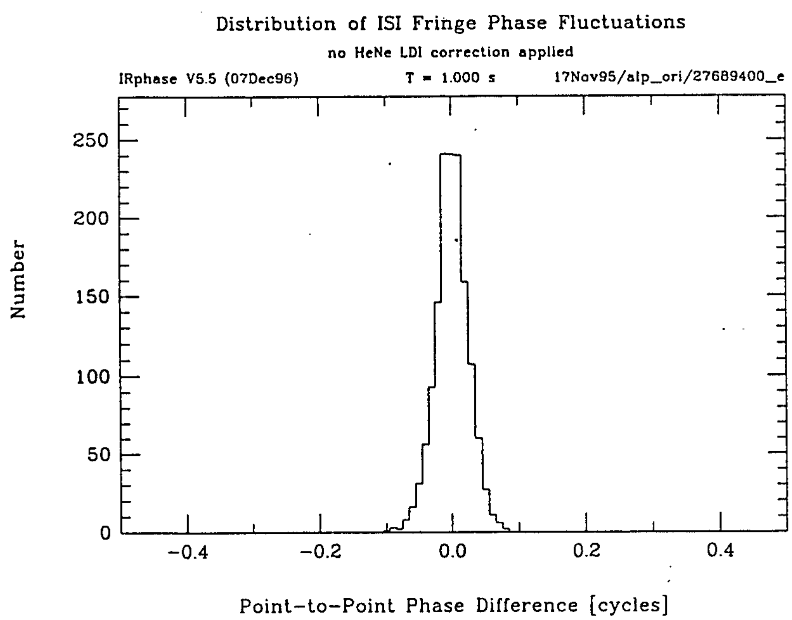


Fig. 1b

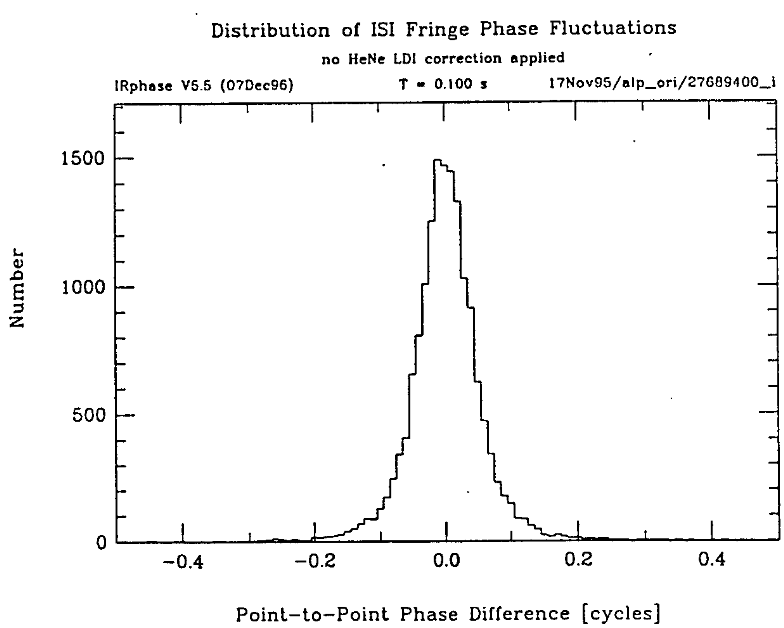


Fig. 1c

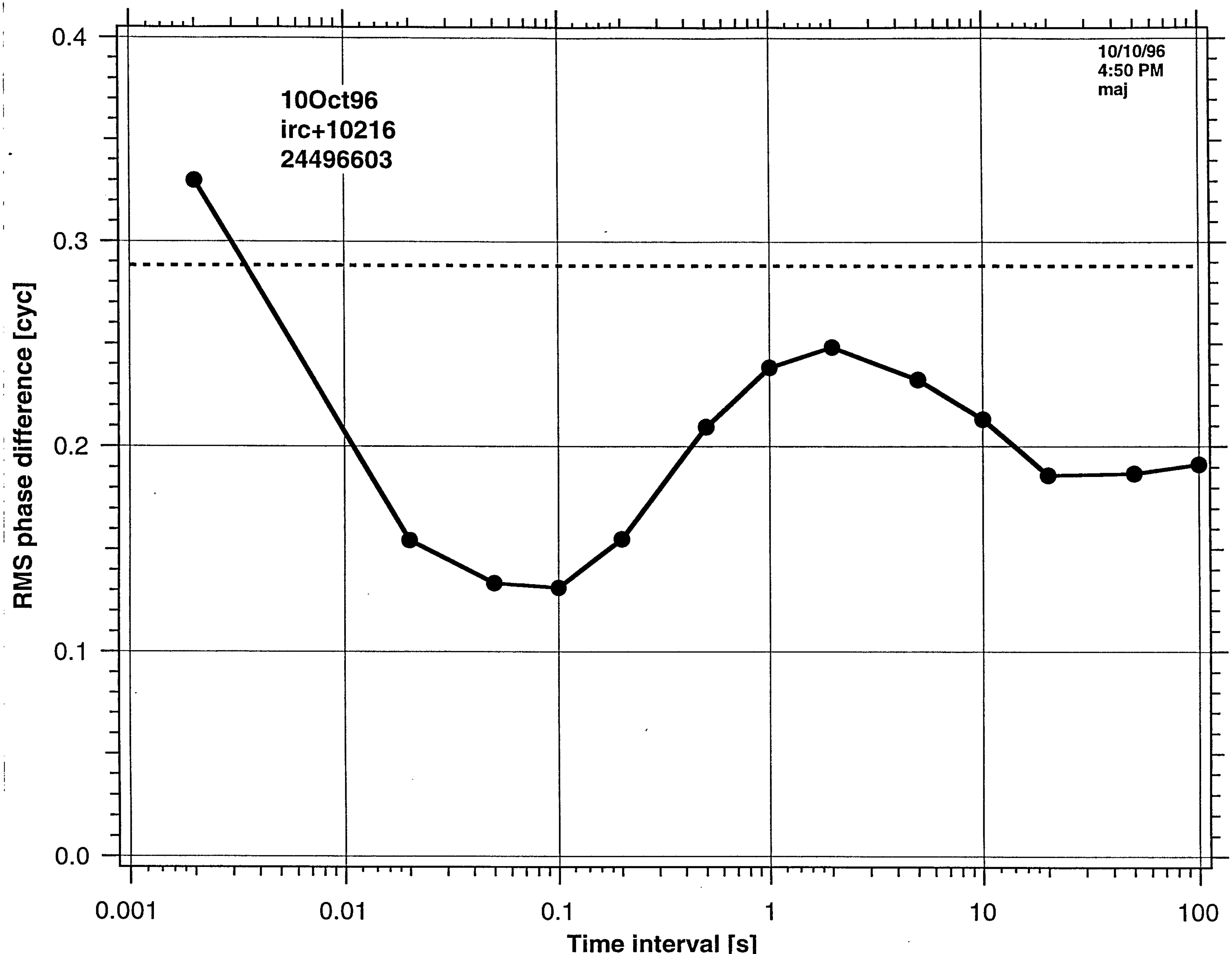
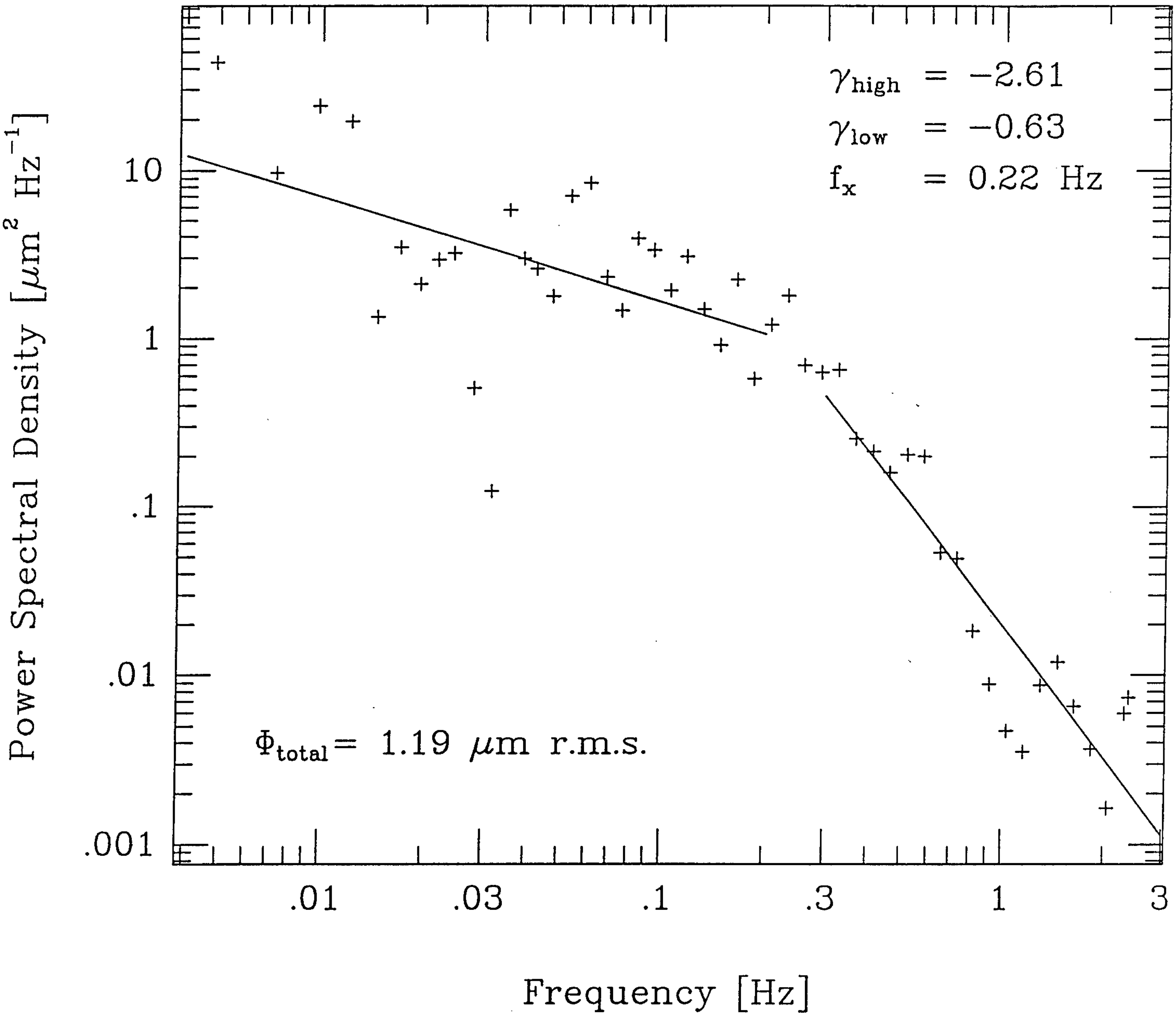

10Oct96
irc+10216
24496603
10/10/96
4:50 PM
maj
RMS phase difference [cyc]
0.4
0.3
0.2
0.1
0.0
0.001
0.01
0.1
1
10
100
Time interval [s]

Fig. 2



Power Spectral Density [μm² Hz⁻¹]
Frequency [Hz]
γhigh = −2.61
γlow = −0.63
fx = 0.22 Hz
Φtotal = 1.19 μm r.m.s.
10
1
.1
.01
.001
.01
.03
.1
.3
1
3

Fig. 3

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A number of upgrades of the 10 micron interferometer have been made during the first nine months of this grant, and a limited number of measurements. Upgrades include new IR tracking cameras, tip-tilt corrections, a new detector, and system programming. The system performance now shows that, with favorable atmospheres, good fringe phase measurements can be made in times as short as 1/10 sec, yielding a precision of 14 milliarc sec in a one second measurement.

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