ASTROPHOTOGRAPHY WITH HIGH ANGULAR AND TEMPORAL RESOLUTION: PRELIMINARY RESULTS FROM THE KAVALUR EXPERIMENTS

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ABSTRACT

Preliminary results in the form of photographs obtained with high angular ($\approx 0.''1$) and temporal ($\approx$ 33 to 6 ms) resolution using the 1-m reflector at the Vainu Bappu Observatory in Kavalur are presented. These results demonstrate the possibility of measuring aberrations introduced by the atmospheric turbulence as well as by the telescope. The faintest star recorded so far in these experiments is the $2^m.99$ companion of α Gem in white light with exposure times of 33 to 6 ms.

INTRODUCTION

TURBULENCE in the earth's atmosphere limits the resolution of all telescopes to a second of arc or so when used in the conventional imaging mode[1]. One can obtain diffraction-limited information by interfering the beams from two[2] or three [3] parts of the mirror or by adding the power spectra of a sequence of short exposure images of the celestial object[4]. The 50 milliarcsecond diffraction-limit of the newly constructed Vainu Bappu telescope at Kavalur, India, is sufficient for resolving interesting objects like asteroids, binary stars, compact bipolar nebulae and even the recent supernova in LMC (after some expansion of the shell). With these ends in mind, we have been experimenting with interferometric techniques at the Kavalur 1-m telescope. We present here the first results in the form of photographs. Apart from imparting considerable excitement from a new mode of astronomical observation, these experiments have shown the possibilities of measuring the aberrations produced by the atmosphere as well as the telescope despite the modest nature of the equipment used. Future experiments incorporating CCD's and image intensifiers will be able to tackle the astrophysical problems cited earlier.

THE APPARATUS USED

The essential requirements for obtaining diffraction limited information are the ability to "freeze" the atmospheric turbulence within its coherence time of a few centiseconds and to resolve the "speckles" which have a typical size of the telescope's Airy disc. We fulfilled the first requirement by using a Bolex-Polliard movie camera (without its lenses) which can record at different speeds ranging from 12 frames/second to 64 frames/second with corresponding exposures of 33 ms to 6 ms respectively. The second requirement was achieved by inserting a Barlow lens (double concave of focal length 12 cm) in the f/13 converging beam at the cassegrain end of the telescope. This lens "slows down" the beam, thereby magnifying the image. Owing to the fine grain size of the 400 ASA ORWO film used for recording the speckles, one could typically accommodate 9 pixels of $10\mu \times 10\mu$ each within one Airy disc of the telescope. The movie camera could be fixed at eight different positions in the beam (figure 1) allowing different magnifications with a maximum of $\approx \times 6.8$ at the extreme distance of 70 cm from the Barlow lens. A paper bellow provided a flexible protection from stray light, to accommodate the different positions of the camera.

RESULTS

Figure 2 shows a 16 ms exposure of α Leo obtained in the blue. The total extent of the image is $\approx$ 1.5 arcsecond. The fine structure seen within this image are the speckles, both dark and bright. Figure 3 shows a sequence of 10 frames of α Gem, each exposed for 33 ms without filters. The $2.^m99$ companion is also registered. Each time frame shows a different speckle pattern implying coherence times $\lesssim 80$ ms for the atmospheric turbulence. We have also recorded a 64 frames/second sequence of this binary but the companion was registered too lightly for reproduction in this article. This sequence also shows considerable change of the speckle pattern from frame to frame implying coherence

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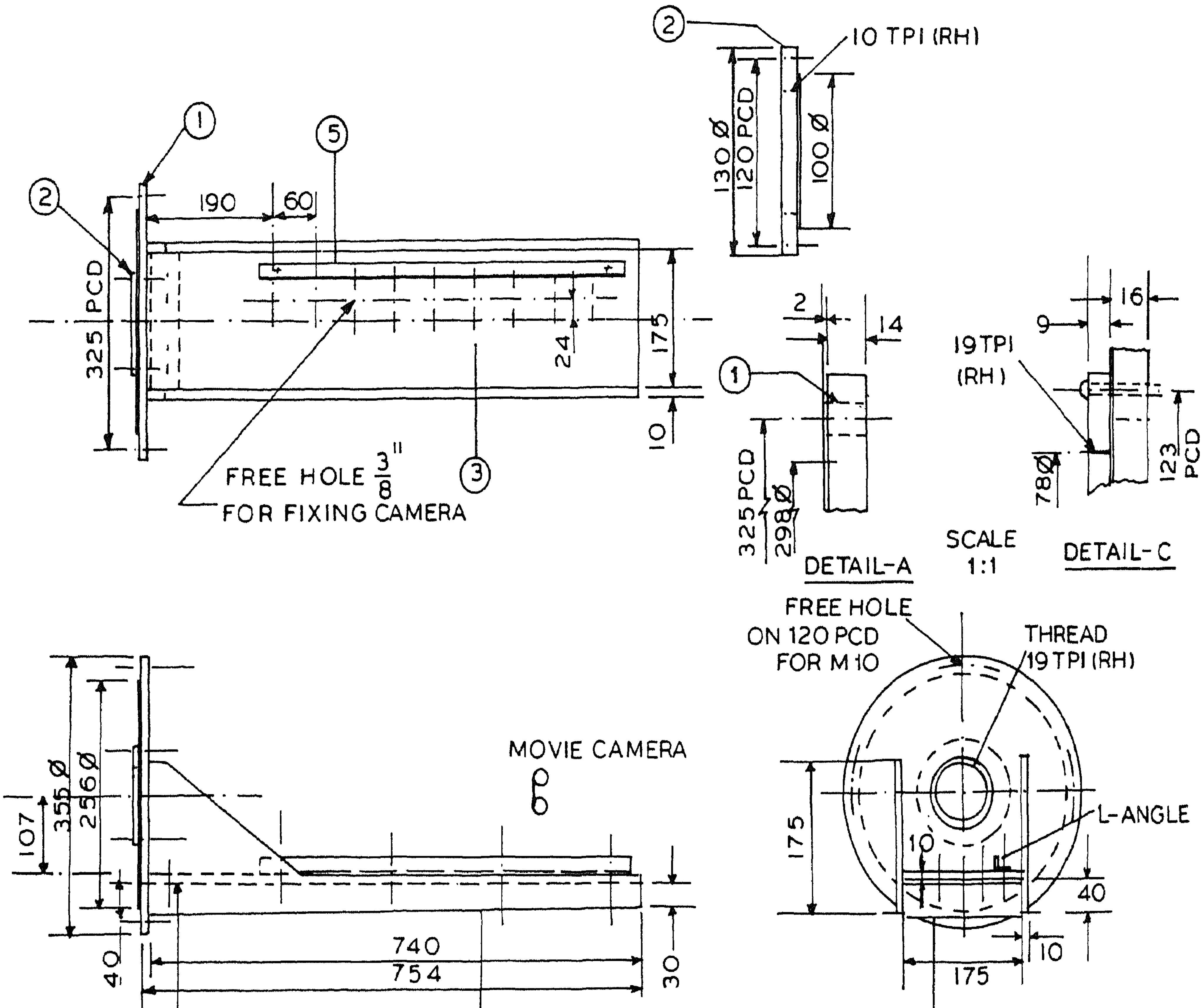
times even < 15 ms. The variation of the speckle pattern in both components of the binary (figure 3) separated by 4 arcseconds appears to be well-correlated indicating isoplanatism better than 4 seconds of arc. The speckle cloud of the fainter companion sometimes stretches right up to the primary star's speckle cloud (frame No. 3 of figure 3) showing the momentary appearance of enhanced power in eddies of sizes $\lesssim 2.5$ cm in the wavefront. The constant separation of the photocentres of the two components in the sequence, rules out differential wavefront tilts within 4 arcseconds which is consistent with isoplanatism $\gtrsim 4$ arcseconds.

To calibrate the image scale, we obtained interference fringes by photographing Sirius through a



NO	DESCRIPTION	MATERIALS	QTY
1	MOUNTING DISC	AL.	1
2	LENS HOLDER	,,	1
3	CAMERA HOLDING ARM	,,	1
4	SUPPORTING PLATE	,,	2
5	CAERA PARALLEL GUIDING ANGLE	,,	1
6	SUPPORTING ANGLE	M S	1

Figure 1. A drawing of the mechanical mount made for holding the Barlow lens-movie camera combination is shown. The aluminium disc 1 fixes the mount to the base plate of the telescope and also contains a threaded holder 2 for the Barlow lens. The camera holding arm 3, is normal to the disc 1. Dimensions are shown in mm. Eight holes are drilled in 3 along a line offset from the dividing line of 3 in order to bring the camera focus in the optical beam of the telescope. A guiding angle 5 is provided to ensure quick alignment of the camera at its different positions. A supporting plate 4 shaped like a fin ensures more rigidity per unit mass of the material. A supporting angle 6 made of iron is fixed to the line joining 3 to the disc 1 to further prevent any flexure.

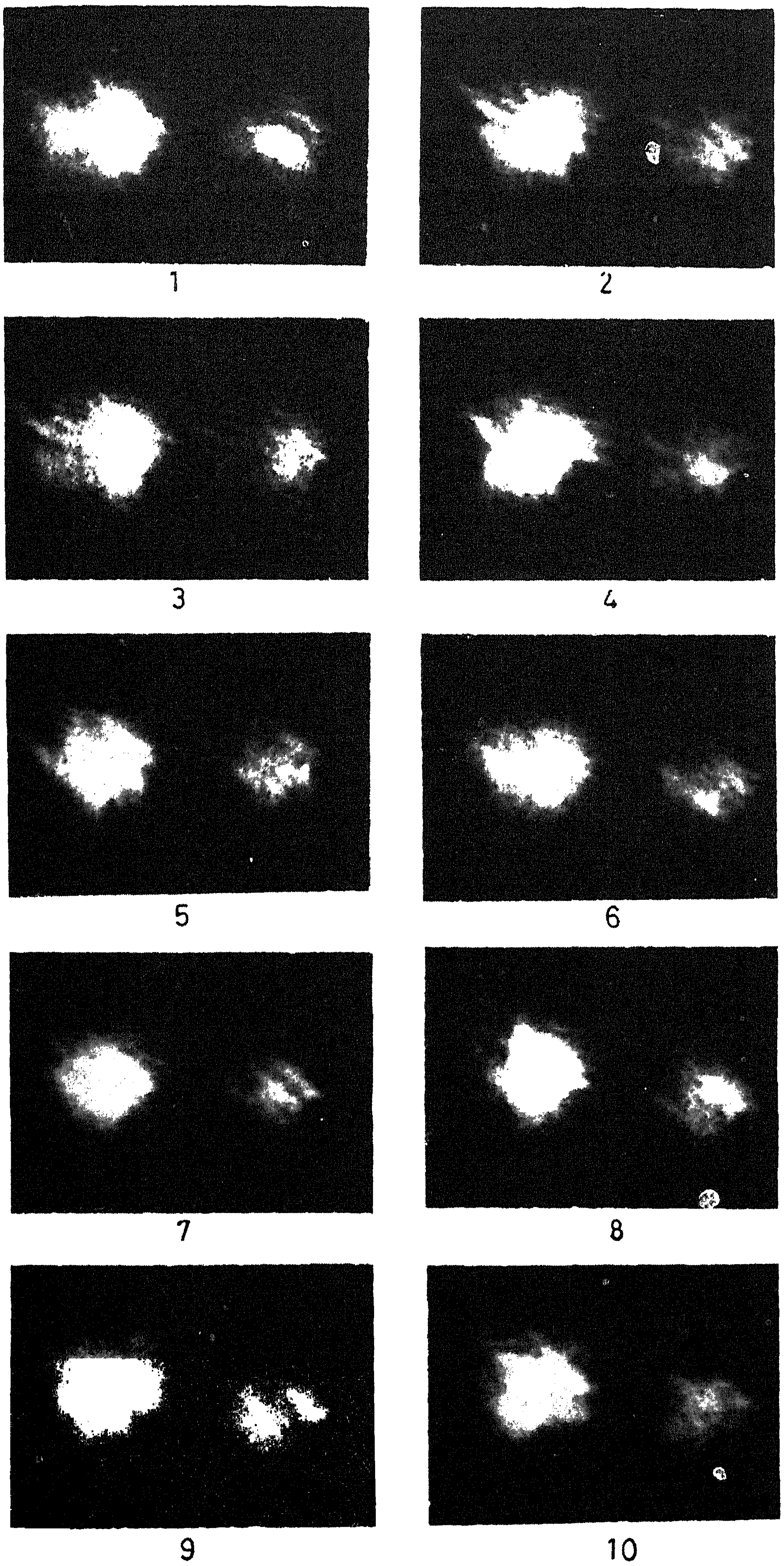


Figure 3. A sequence of 10 consecutive short exposures of αGem showing the $2^{m}.99$ companion 4 arcseconds away. The exposure was 33 ms and the filming rate was 12 frames/second. The frames are numbered in the chronological order.

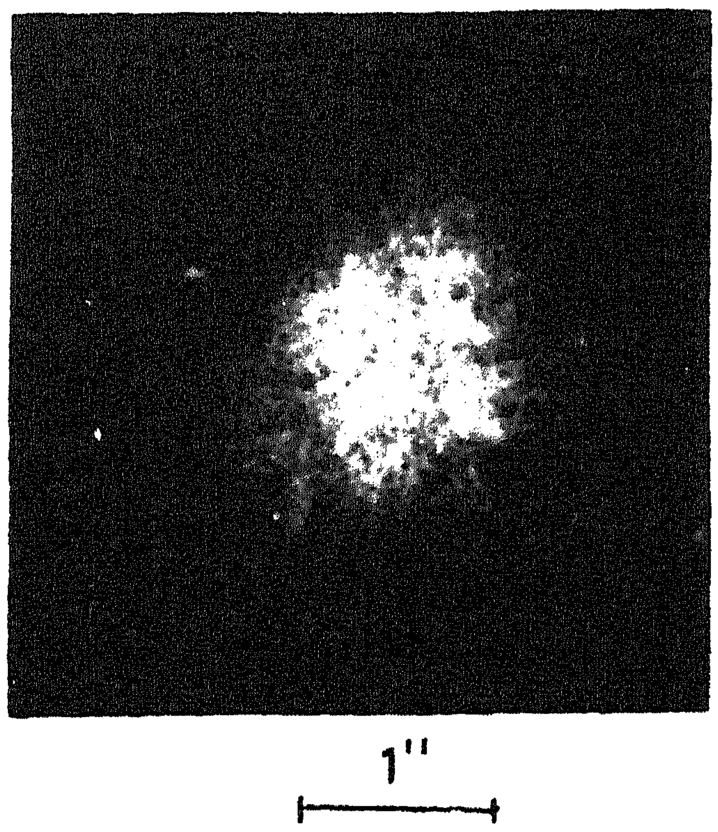


Figure 2. Singie frame of α Leo obtained in the blue. The total extent of the image (speckle cloud) is 1.5. The fine structures seen are the speckles, both dark and bright. Exposure time is 16 ms.

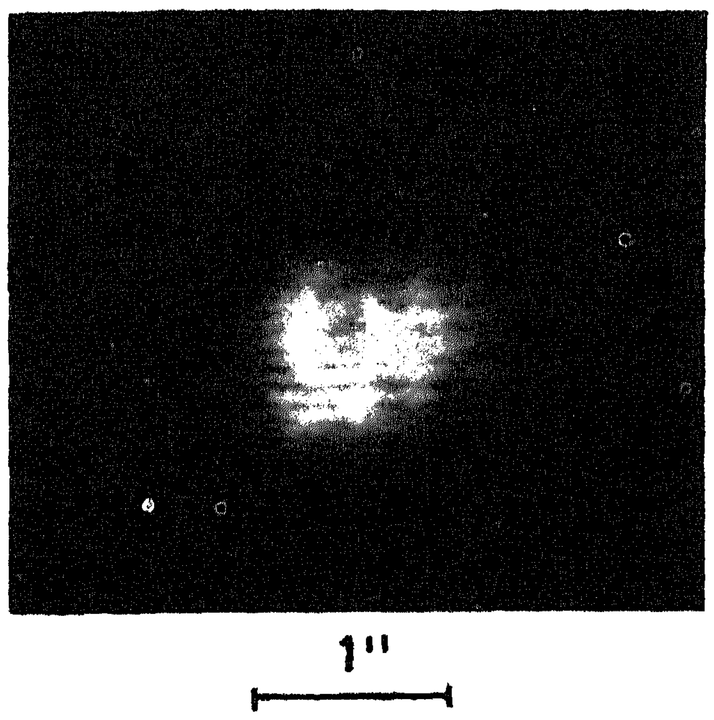


Figure 4. Interference fringes from Sirius produced by fixing a Fizeau mask with 2 holes 10 cm each in diameter and separated by 69.4 cm and recorded with 33 ms exposure.

Fizeau mask fixed in front of the telescope for an exposure time of 33 ms. The mask had two holes, 10 cm in diameter each and separated by $d = 69.4$ cm. Assuming a peak wavelength of 4500 A, the separation of the fringes is $\lambda / d = 0.130$ arcsecond. On the film, these had a linear separation of 0.035 mm thus yielding an image scale of 3.″70/ mm.

A curious modulation of intensity consisting of approximately three bands perpendicular to the fringes can be seen in figure 4. Modulation is present in all frames and could thus result from a time-independent aberration in the optical system with an effective angular size of ⅓ arcseconds. This time-independent pattern can also be discerned in all the speckle frames. Extensive tests ruled out aberration in the Barlow lens-movie camera combination. Thus the source of the aberration must lie in the telescope which is a Ritchey-Chretien system. However more systematic experiments are necessary to pinpoint the cause of the distortion produced by the telescope. Quantitative analysis of the optical transfer function (OTF) of the atmosphere-telescope combination using the specklograms will alone reveal the seriousness of this aberration for retrieval of diffraction-limited information.

DISCUSSION AND CONCLUSIONS

It is clear from the experiments that even modest equipment can be used to understand atmospheric and telescope aberrations. Such equipment would be useful in understanding the OTF's of new sites and new installations. Ability to record $2^m.99$ objects above 3 σ level at 6 ms exposure without filters should also be contrasted with the 1^m limit reported in Dudinov *et al*[5] using the Russian 6-m telescope with 1000 A, bandwidth and 30 ms exposure. Since the number of speckles as well as the total number of photons increase as the square of the telescope's diameter, the number of photons per speckle is independent of the telescope size for comparable "seeing" conditions. Thus, the fainter limit achieved at Kavalur is perhaps indicative of better "seeing" and transparency or a faster effective beam of the apparatus. A proper comparison is only possible for similar S/N. Finally, these experiments allow us to extrapolate to a *13^m limit at the 1-m telescope* with 400 A bandwidth using a 10^4 gain image intensifier (working in photon counting mode) coupled with 50% efficiency via fibre-optics on to a CCD camera. Such a limit is quite useful for a host of astrophysical problems.

ACKNOWLEDGEMENTS

The authors thank Prof J. C. Bhattacharyya for constant encouragement, and Mr. R. Krishnamurthy for help in the photographic reproductions.

28 May 1987; Revised 4 July 1987

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