Infrared Imaging and Speckle Observations with a TV Camera

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Introduction

The lack of suitable two-dimensional detectors has been a major problem for infrared imaging in astronomy, and most results so far have been obtained by scanning the object with a single detector (e. g., Terrile and Westphal, *Icarus,* **30,** 730, 1977). The relative merit of both techniques was thoroughly investigated by Hall *(Applied Optics,* **10,** 838, 1971) who concluded that, below about 2.5 μm, camera tubes should be preferred to scanners. Besides, sufficiently long times required by the scanning technique are not always available for some astronomical applications. These considerations led us to acquire a standard television camera equipped with an infrared vidicon tube N156 manufactured by Hamamatsu Co. (Japan). This tube has a PbS-PbO target whose sensitivity extends to about 2.4 μm (Fig. 1) although it has its maximum in the visible at about 0.57 μm. For such a target, theoretical considerations led to a quantum efficiency of the order of 3×10^{-3} at 1.6 μm and at room temperature. Our first objective was to image the thermal emission of the solar F-corona during the 1976 solar eclipse in Australia. Bad weather prevented the observation but we realized the potentiality of television imaging in the range 1-2.4 μm for other astronomical applications. This wavelength interval is interesting because it gives some access to the thermal emission of dust grains. Mapping the intensity as well as the polarization of infrared sources therefore offers a powerful means of studying their dust component. As examples, let us mention circumstellar envelopes, in particular those of carbon stars, such as IRC 10216, where considerable departure from spherical symmetry has already been observed (McCarthy et al., *Astrophysical Journal,* **235,** L27, 1980), and compact H II regions (e.g., W3). Of even greater interest is the possibility of performing speckle observations in the interval 1-2.4 μm, thanks to the short-exposure (20 msec) capability of television cameras. This technique should allow the determination of angular diameter and limb darkening of sufficiently bright stars. Two applications are worth mentioning:

(i) supergiant stars (e.g., α Ori, o Cet, α Tau) whose diameters have already been shown to vary with wavelength (Bonneau and Labeyrie, *Astrophys. J.,* **181,** L1, 1973); Welter and Worden, *Astrophys. J.,* **242,** 673, 1980);

(ii) accreting young stars, such as the BN object and W3IRS5, which have been studied in a single radial direction by Chelli, Léna and Sibille *(Nature,* **278,** 143, 1979); as pointed out by these authors, their "specklographic" method does not allow them to answer the crucial question of the flattening in the accretion shell and its possible rotation.

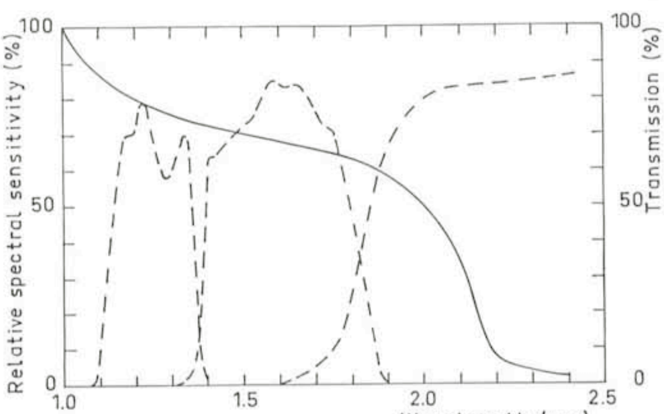

Fig. 1: *The relative spectral sensitivity of the N156 tube arbitrarily normalized at 1 μm (solid line) and the transmission curves of the filters (broken line).*

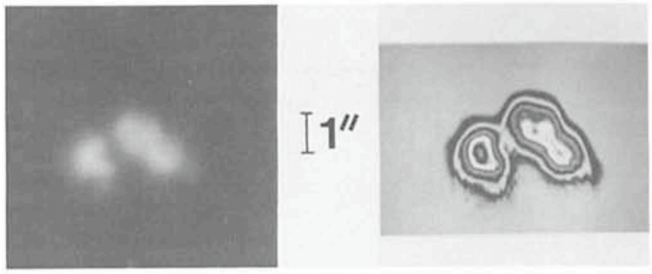

Fig. 2: *The image of α Ori at 2 μm obtained with the 193 cm telescope of Observatoire de Haute-Provence and its isophotes.*

We started our observations with the 1 m telescope at Pic-du-Midi Observatory *(Astronomy and Astrophysics,* **77,** 257, 1979) and showed how the smearing function improves with increasing wavelength. The "instantaneous" image structure (speckles) of α Ori was visualized in three infrared passbands as defined in Fig. 1. As expected, very few speckles were formed compared to similar experiments in the visible, since the telescope has a smaller aperture in the infrared. Furthermore, their temporal evolution was much slower than in the visible and could be followed on the monitor, although this could be due to the lag of the TV tube. Solar observations were also performed at 1.6 μm using the horizontal coelostat and included direct imagery of sunspots and simultaneous spectrography of the photosphere and sunspot umbra showing the Zeeman splitting of the Fe I line at 1.5648 μm, indicating the possibility of detecting very small-scale photospheric concentrated magnetic fields.

Stellar observations were pursued with a larger telescope, the 193 cm of Observatoire de Haute-Provence, unfortunately under poor weather conditions. Fig. 2 shows an instantaneous image of α Ori at 2 μm secured at the f/15 Cassegrain focus together with its isophote map obtained with the video-processing system of the Institut d'Astrophysique du CNRS, Paris (Coupiac and Koutchmy, *Journal of Optics,* **10,** 338, 1979). The smallest structures have a size of 0.35 arcsec, in good agreement with the resolving power of the 193 cm telescope at 2 μm.

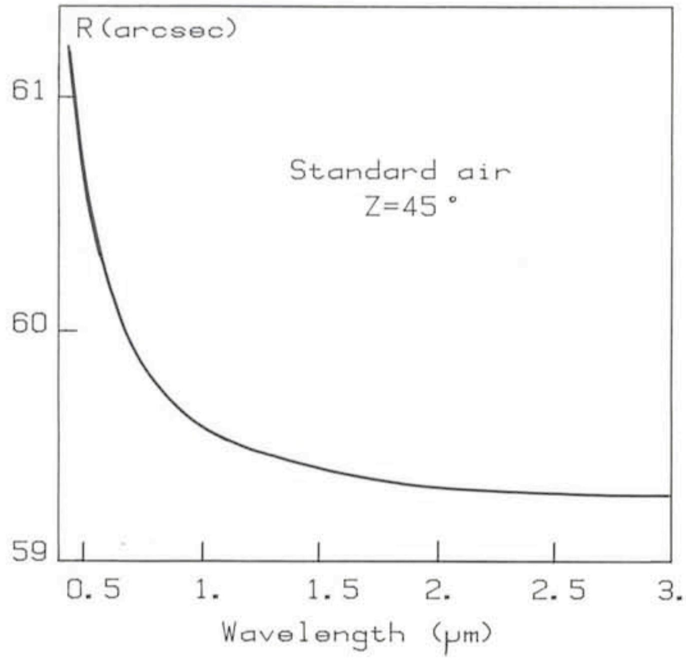

Fig. 3: *Angular deviation of light rays as a function of wavelength calculated for a standard dry atmosphere at 760 mm Hg for a zenith distance of Z = 45°.*

Note that the individual speckles are practically not lengthened by the differential atmospheric refraction, although the passband is rather large. This is because this differential effect is less severe in the infrared than in the visible. This is illustrated in Fig. 3 where we show the atmospheric dispersion as a function of wavelength (deviation angle of the light rays) calculated for a standard dry air at a pressure of 760 mm Hg and for a zenithal distance Z = 45°. This curce indicates a differential atmospheric dispersion of 3×10^{-2} arcsec between 1.55 and 1.8 μm. Finally, we observed more speckles than with the 1 m telescope, a sound physical result which supports the validity of our observation.

Observations at the 3.6 m Telescope

For our observations with the ESO 3.6 m telescope, we prepared a new camera completed by a video-disk and a magnetoscope. The video-disk acts as an analog memory which stores the video image which results from an integration of the target signal, a capability useful for direct imagery: in this conventional mode, the electron beam readout is cut and the target operates very much like a photographic plate. At the end of the exposure time – some 5 to 10 sec at room temperature – the readout is initiated and the video signal (one image, that is two interlaced frames) is recorded by the video-disk. Unfortunately, this video-disk was damaged during the transport and could not operate properly at the telescope, in spite of very dedicated efforts by the ESO electronic staff. Another disappointment came from the weather on La Silla which restricted our observations to episodic intervals during one night when sufficiently large holes formed in the clouds.

Direct imagery at 1.6 μm was attempted with a focal reducer working at f/1. With integration times of the order of 1 sec, Jupiter VYCMa and the η Carinae nebula were easily detected and "briefly" (for 40 msec) visualized on a TV monitor following real-time readout (no storage was possible as explained above). For the speckle observations, the focal reducer was removed and a new optical system was set up to expand the telescope focal length by a factor two (57.3 m). This moderate magnification was justified by our aim of first studying the properties of speckled images in the infrared with considerations of the signal-to-noise ratio, leaving the astrophysical aspects – which are probably even beyond the reach of a 3.6 m telescope – to a second step. Fig. 4 shows a speckled image of α Sco at 1.6 μm together with its isophote map obtained likewise that of Fig. 2. This photograph corresponds to a single frame and the size of the pixel amounts to 31 μm equivalent to 0.113 arcsec. The smallest structures have a typical size of 0.23 arcsec, in good agreement with the diameter of the Airy disk for a 3.6 m telescope at 1.6 μm. The fact that the structure of this image closely resembles that obtained at the 193 cm telescope – the number of speckles being approximately similar – remains a puzzle to us. It may be that we are reaching some limitation of the television tube. In this respect, we emphasize that all the above observations have been carried out at ambient temperature. Laboratory tests have shown that cooling the tube does have a positive effect by reducing both the lag and the thermal noise of the target; the second advantage is of particular interest for direct imagery as it allows far longer integration times. These tests are now being pursued to quantitatively assess the improved performances. We hope to come up with a better instrument and to resume our observing programme in this new and exciting field.

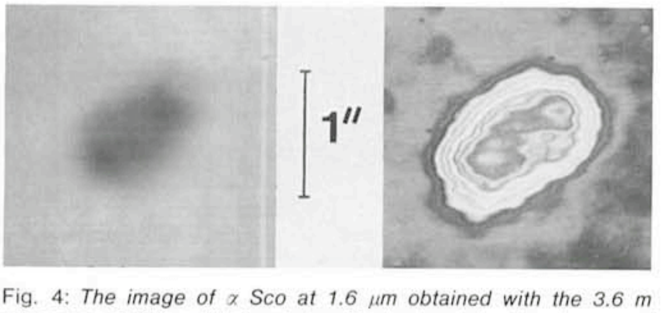

Fig. 4: *The image of α Sco at 1.6 μm obtained with the 3.6 m telescope of ESO and its isophotes. The horizontal pattern is caused by the TV raster.*

The European Space Agency (ESA) is organizing an

International Symposium on X-ray Astronomy

The symposium will take place on 22–26 June 1981 in Amsterdam. About 150 participants are expected. The deadline for applications and abstracts is 1 April 1981. The conference fee is f 150.–. For further information please contact Dr. R.D. Andresen, Space Science Department, ESTEC, Postbus 299, Noordwijk, The Netherlands.