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ASTRONOMY AND ASTROPHYSICS

The TIRGO infrared spectrometer (1–5 μm)

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Abstract. In October 1988 the new infrared spectrometer was installed at the TIRGO telescope, becoming part of the infrared instrumentation normally available to visiting astronomers, who share the observing time on the basis of approved proposals.

The TIRGO infrared spectrometer is designed to acquire spectra in the 1–5 μm bands, with a resolving power from 400 to 2200 according to the band and the grating order. It is equipped with a cooled grating in Littrow arrangement, cold collimating and reimaging optics, and a linear array of seven InSb detectors. The detected photocurrent is accumulated on an array of seven charge integrating preamplifiers, which give a readout noise of about 550 e^- at 16 s of integration time; at the TIRGO telescope (1.5 m diameter) a sensitivity of 10^{-17} W m^{-2} at S/N ratio equal to 1 is achieved with 600 s of total integration time. The spectrometer is remotely controlled by a PDP 11/34 computer: the interface with the user is by means of the control console, which can be used to send commands and to start the measurements. The state of the measurement can be monitored on a second console, where the updated spectrum is displayed at selected time intervals in the course of data acquisition.

The first scientific use of the TIRGO infrared spectrometer has included a survey of hydrogen emission lines in a sample of T Tauri stars and several IR observations of active galactic nuclei: some typical spectra are presented to show the scientific potentiality of the instrument.

Key words: instruments – infrared radiation – spectroscopy

1. Introduction

The TIRGO infrared spectrometer is a cryogenically cooled grating spectrograph for use in near infrared bands (1–5 μm) with a resolving power in the range of 400–2200, depending on the band and the grating order. It has been designed to be used at the focal plane adapter of the $F/20$ Cassegrain focus of the 1.5 m TIRGO telescope, with a 10.″6 × 10.″6 slit. The same instrument can be used as a mapping photometer, with an equivalent aperture on the sky of 10.″6 × 10.″6 × 7 or, alternatively, 5.″3 × 10.″6 × 7, at the same plate scale.

In Sect. 2 we describe the main features of the design: in particular, the optical, mechanical and cryogenic designs are reviewed in relation to the general requirements of the instrument. The detectors and associated cold electronics are briefly presented, and the control electronics and software are described, along with the operating modes. In Sect. 3 we report the performance achieved in laboratory tests and the results obtained during the preliminary observing runs; in particular, we show the H I emission lines at 2.16 μm (Br γ) and at 1.28 μm (Pa β) in a sample of T Tauri stars and a 2.10–2.19 μm spectrum of NGC 7027. Finally, in Sect. 4 some future developments are discussed.

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2. System design

2.1. Optical design

The general characteristics of the TIRGO spectrometer are summarized in Table 1. The optical arrangement of the spectrometer is fairly classic: it is sketched in Fig. 1. The focal plane adapter of the telescope holds a dichroic mirror (1) which splits the $F/20$ beam into two components: the optical component enters the TV camera which is used for centering and guiding, and the infrared component is deviated onto the entrance window of the spectrometer (2). After the window, the beam passes through the order sorting filter (3) and subsequently crosses the slit (4), placed on the focal plane of the telescope. The beam is collimated by an inverted Cassegrain: the primary (5) is a parabolic mirror with a central hole and the secondary (6) is a hyperbolic mirror of 24 mm diameter. A flat mirror (7) deflects the parallel beam (70 mm diameter) towards the grating (8), operated in Littrow arrangement. The dispersed beam is deflected by a plane mirror (9), which is the first element of an $F/2.5$ Pfund camera, the second element of the camera being a parabolic mirror (10) which images the beam onto the seven detectors (11). The rear face of the grating is a plane mirror; when the grating is rotated by 180° with respect to the zeroth order direction, the spectrometer becomes a seven-pixel imaging photometer; two interchangeable stop diaphragms give different apertures of about 11″ × 82″ or 5″ × 82″, with a spectral band defined by the filter (3), and a plate scale of 53″ mm^{-1} at the TIRGO telescope. The optical components are cooled to 80 K through thermal contract with a liquid nitrogen bath at atmospheric pressure, as described in the next paragraph. The mounting of the optical elements is designed to take account of the dimensional changes generated by temperature differences; at the same time, the optical design features a relatively large tolerance in the positioning of the optical components, rendering unimportant the small misalignments generated by the cooling process.

Table 1. TIRGO infrared spectrometer: general characteristics

Wavelength range	1–5 μm
Resolving power (slit 10″.6 × 10″.6, pixel size 0.2 × 0.2 mm)	400–2200
Detector	7 pixel array with cold integrating charge preamplifiers
Readout noise (at 16 s integration time)	550 e^-
Peak efficiency (counted electrons/incident photons)	15%
Cryogenic system	Liquid nitrogen for optics and solid nitrogen (pressure 0.1 mbar) for detectors

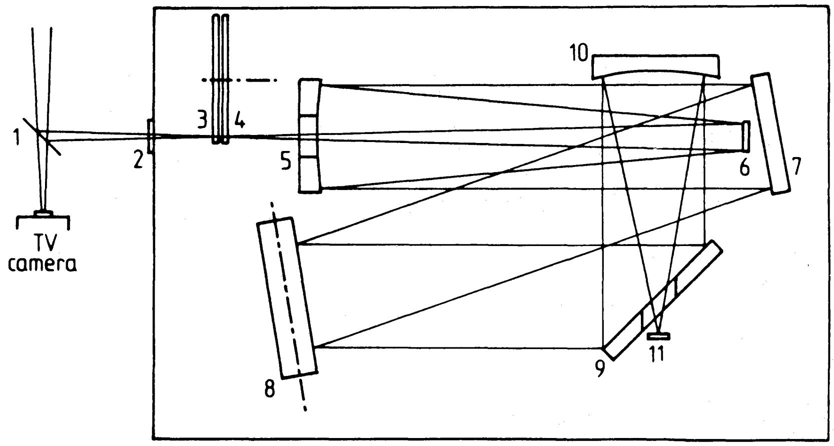

Fig. 1. Optical diagram of the TIRGO spectrometer. (1) Dichroic mirror, (2) entrance window, (3) filter wheel, (4) slit wheel, (5) primary mirror of the collimator, (6) secondary mirror of the collimator, (7) flat mirror, (8) grating, (9) flat mirror, (10) parabolic mirror (reimaging camera), (11) array detector

2.2. Mechanical and cryogenic design

The optical design of the TIRGO spectrometer, with its large collimated beam and the strong demands for rigidity of the optical bench, is not easily accomodated in a commercially available cryostat, so an original design has had to be developed. As we can see in Fig. 2, the heart of the cryostat is the toroidal liquid nitrogen vessel (a), which has a rectangular cross section and contains about 4 litres of cryogen (Gennari, 1988). The liquid nitrogen vessel provides mechanical support and cooling for two optical benches, which are located on the opposite faces of the vessel itself, and for the radiation shield (b). The central aperture of the toroid allows for the collimated beam to pass from one optical bench to the other. The entire cold structure is supported by six low thermal conductivity stands, which are fixed to the inner surface of the external vacuum shield (c). The optical bench supporting the detectors also carries a solid nitrogen vessel; three fiberglass rods thermally decouple the vessel itself from the optical bench, and provide mechanical support. The working pressure at the surface of the solid nitrogen is about 0.1 mbar, giving an equilibrium temperature close to 40 K. A copper strap joins the InSb detectors (11), supported by another fiberglass stand, to the solid nitrogen reservoir. Due to the electrical (and thermal) connection with the warmer electronics, the steady state temperature of the InSb detectors lies at about 42 K. The external vacuum shield is rigidly linked to the focal plane adaptor of the telescope via an interface flange, allowing a fine alignment with the telescope's optical axis. Externally the spectrometer has the form of a compact cylinder with a base of about 40 cm in diameter and a length of about 60 cm. The grating motor is mounted externally and the coupling is assured by a ferrofluidic feed-through and a stainless steel bellow. The filter and slit wheels (3–4) are driven by two stepper motors which operate inside the dewar at liquid nitrogen temperature; these motors are suitably modified to operate reliably at cryogenic temperature. Besides the 10″.6 × 10″.6 slit, the slit wheel carries two further apertures for spectroscopic use whose equivalent angular dimensions are 10″.6 × 5″.3 and 10″.6 × 3″.5 at the TIRGO telescope.

The optical and mechanical components of the spectrometer have a high thermal capacity; considering also the poor thermal conductivity of the glass of the grating and mirrors, it is apparent that the cooling and the heating of the instrument are critical operations. The standard procedure for cooling infrared instrumentation of this class starts with the evacuation of the internal air; the heat transfer between the warmer parts of the instrument and the cryogenic bath is then determined by the conduction through the supports of the optical components (or through suitable metallic straps) and by the radiative exchange. Using this procedure, the time needed to cool the grating of the TIRGO spectrometer down to liquid nitrogen temperature would be about a week. In order to obtain a shorter cooling time, a different technique has been developed (Gennari, 1988): after the evacuation of the air, the TIRGO spectrometer is filled with gaseous nitrogen. This gas allows a very efficient heat exchange into the dewar by means of two mechanisms: the first one is the thermal conduction, and the second, and most important, results from the large convective flow, which is generated by the differences of temperature into the dewar. The gaseous nitrogen is evacuated only when a sufficiently low temperature is reached: with this procedure the cooling time is about five hours. The warming

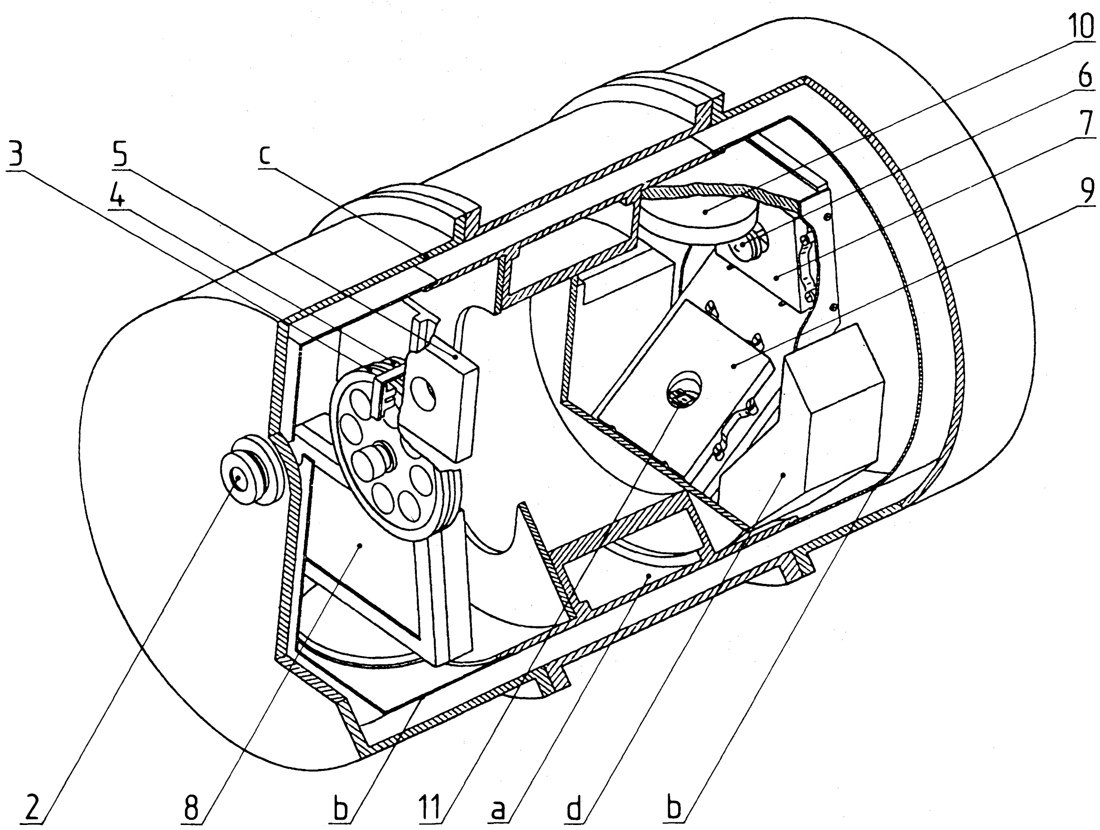

Fig. 2. Internal view of the TIRGO spectrometer. (a) Liquid nitrogen vessel, (b) radiation shield, (c) external vacuum shield, (d) solid nitrogen vessel, (2) entrance window, (3) filter wheel, (4) slit wheel, (5) primary mirror of the collimator, (6) secondary mirror of the collimator, (7) flat mirror, (8) grating, (9) flat mirror, (10) parabolic mirror (reimaging camera), (11) array detector

process is even faster: using the gaseous nitrogen to fill the dewar and powering a set of electrical heaters, which are in contact with the vessels of liquid and solid nitrogen, the instrument can be heated from operating to room temperature in less than three hours.

The internal vacuum is assured by a small quantity of active charcoal, in thermal contact with the solid nitrogen. In normal operation at the TIRGO Observatory (3100 m), the supply of liquid nitrogen lasts more than 24 hours; the solid nitrogen reservoir needs refilling once a week.

2.3. *Detectors and data acquisition electronics*

The TIRGO IR spectrometer is equipped with a 7-element InSb array detector made by Cincinnati Electronics Corporation. Each detector has a square active area of 0.2×0.2 mm and the center to center distance between two adjacent elements (pixels) is 0.224 mm. The read-out scheme of the array is somewhat unusual, because the detected photocurrent is not stored inside a potential well built into a hybrid multiplexer. Instead, the storage element is a discrete capacitor which is also the feedback element of a charge integrating preamplifier. This approach permits a tight control of the voltage bias of the detectors; in normal operation, the value of bias voltage is kept constant, at a value very close to zero volts. With this technique low dark current, good linearity and a low $1/f$ noise figure in the region below 0.1 Hz are easily obtained. The seven charge integrating preamplifiers, made of discrete components, are contained into the dewar, in good thermal contact with the liquid nitrogen reservoir. A detailed description of the electrical diagram of the preamplifier, along with a report of laboratory tests, has been published elsewhere (Hartill et al. 1985); here we will describe the general structure of the data acquisition system. The output voltage ramps of the seven charge integrators are routed to the external electronics through vacuum-tight connectors. A set of seven sample-and-hold amplifiers samples the ramps at the starting point, after the reset of the integrators, and at the ending point, after the selected integration time has elapsed. A multiplexer scans the outputs of the sample-and-hold amplifiers after each sampling, and the seven pairs of analog signals are converted by a 16-bit analog-to-digital converter. The conversion that takes place at the end of the ramps is followed by the reset of the integrators, then another integration cycle begins. The seven pairs of digital words are transmitted to the on-line computer (PDP 11/34) by means of a buffer memory, to avoid any possible problems resulting from asynchronous communication between the data converter and the computer, particularly when the integration time is short. The control software takes the difference of the two digital words that represent the final and initial levels of the single ramp, so that a correlated double sampling is operated on the signal. The proper timing of the charge integrating preamplifiers and of the data conversion system requires a set of logic signals having variable length and precise time relation. This task is handled by a sequence controller, in which a recirculating memory is suitably programmed by the on-line computer before the starts of measurements (Baffa and Sozzi, 1988). Another interface circuit makes possible the control of the three stepper motors (filters, diaphragms and grating) by means of the same computer (Biliotti, 1987).

2.4. Operating modes and control software

The TIRGO infrared spectrometer is controlled via two consoles of the PDP 11/34 computer. The first console displays the main parameters of the spectrometer and the status of the current measurement; in addition, it allows the user to type commands on the associate keyboard. The second console is a graphics device where the crude results of the measurements are shown: at fixed time intervals the updated spectrum is displayed (usually in the form of a hystogram), along with the standard deviation for each pixel.

The TIRGO infrared spectrometer can be operated in three different modes: the observing mode, the centering mode and the calibration mode. In the observing mode astronomical spectra are acquired, displayed and stored on disk files. The grating position can be held fixed, with the central pixel at a selected wavelength; alternatively, the grating can be automatically moved to cover a range of wavelengths. The user enters absolute wavelength values via the console, and the control software translates them into the corresponding grating positions by means of a calibration function which is obtained and stored in calibration mode. When spectra cover a range of wavelengths, the grating can be moved in such a way that a specified number of pixels overlap in two contiguous sections of the spectrum. If the required spectrum is centered on a specified wavelength, it is possible to move the grating at intervals which are a fraction of the pixel size to get a better sampling of the spectral feature.

When in observing mode, the measurement can be performed in DC mode, in chopped mode (with the secondary mirror of the telescope alternatively presenting the source and the sky to the instrument), or in beam-switching mode (with nodding of the telescope and chopping secondary). The selection of parameters for a complete measurement begins with the selection of suitable integration time and gain settings, in order to account for the band, the selected order, the brightness of the source, and so on. In DC mode the control software acquires the result of the single elementary integration and computes the mean value and the standard deviation of a number of such integrations, as decided by the user. This group of integrations is called a measurement cycle: it is possible to instruct the control software to perform the desired number (from 1 to 45) of such cycles to obtain the programmed total integration time on the source. Only the mean and the standard deviation of each measurement cycle are stored by the software.

In chopped mode, the measurement cycle is composed of a chosen number of chopper cycles, each of which consists of one elementary integration on the object and one elementary integration on the sky. Again, the software stores only the mean and the standard deviations of each measurement cycle and the user can decide how many cycles are needed to obtain a complete measurement.

In beam-switching mode, the measurement cycle corresponds to a selected number of chopper cycles in each beam position. The software stores in a file the separate results for each beam position and the result of each complete cycle of beam-switching. The total number of beam-switching measurement cycles defines the total integration time on the object. Whatever the mode, the file of a complete measurement contains both the final spectrum and the results of the individual measurement cycles, in addition to the instrument settings, the object identification and coordinates, airmass, universal time and a comment entered by the user. The output format of the measurement file conforms to the FITS format, allowing a standard interface to data reduction packages for astronomical use, such as MIDAS. A simple preliminary reduction of spectra is possible when the computer is not performing measurements: by typing simple commands, the rough spectrum can be divided by a standard source spectrum and the result displayed on the graphics console.

The centering mode is used to locate the entrance slit of the spectrometer on the TV monitor and to focus the telescope. In this mode the intensity of the signal on each pixel is displayed at the end of a cycle, along with the corresponding standard deviation; a graphic presentation with a bar graph is also possible. This mode excludes the storage of data and can be used to center the astronomical sources when they present a continuum – or a line – which is sufficiently bright.

The calibration mode allows the recording of spectra of the spectral line lamps to obtain the wavelength calibration curve, which is a function of wavelength versus the position of the grating in steps from a reference point. This mode is not normally used by astronomers, because the wavelength calibration is sufficiently stable; the checking of wavelength calibration is a task periodically performed by the technical staff of TIRGO.

At present, the use of the TIRGO spectrometer as a mapping photometer has not yet been put into effect, because the control software is still under development.

3. Performance

3.1. Tests

Table 2 summarizes the main parameters of optical and mechanical quality when the spectrometer is attached to the focal plane adapter of the TIRGO telescope. The values quoted under the entries optical quality, grating positioning, and flexure suggest that, under normal observing conditions, the total rms error is of the order of 50 μm: that is, a quarter of a pixel. We can conclude that the optical quality and the total mechanical error do not limit the resolving power of the spectrometer.

Apart from an initial problem with small leaks at the O-ring seals, the cryogenic system has performed quite satisfactorily since the preliminary tests. In the functioning of the electronics, the spectrometer was at first plagued by an excessive sensitivity to electrical interferences: after suitable modifications, the incidence of spikes has been reduced to about a single event per hour, which is not far from the expected arrival rate of cosmic rays.

In the following, we sill discuss the noise performance of the spectrometer both in terms of absolute units (electrons per second) and in terms of normalized counts of the A/D converter. At low gain, one A/D count is equivalent to 250 e^-; at high gain, one A/D count is about 23 e^-. The spectra which the software writes to files and presents on the graphics console are converted to normalized counts, which are the counts that would be obtained at low gain in one second of elementary integration time: i.e., in units of 250 $e^- s^{-1}$.

Table 2. TIRGO infrared spectrometer: optical parameters

Input beam	$F/20$
Grating	Ruled area: 102 × 128 mm, Littrow mounting (300 lines mm^{-1}, blaze angle 36°52′)
Collimator	Inverted cassegrain ($f = 1400$ mm)
Camera	Pfund, $F/2.5$
Detector size	200 × 200 μm (224 μm pitch)
Plate scale (as a mapping photometer)	53″ mm^{-1}
Optical quality	40 μm (image size at 80% of energy)
Grating positioning	20 μm rms
Flexure	30 μm (from 0° to 60° zenith angle)

Table 3. Resolving power and sensitivities

λ_0 (μm)	Order	Resolv. power	Efficiency (%)	Limiting magnitude[a]	Sensitivity[a] (10^{-18} Wm^{-2})	(10^{-14} Wm^{-2} μm^{-1})
1.25	2	660	0.8	10.8	300	16.0
	3	1120	5.8	12.5	33	3.0
1.65	1	420	2.6	10.2	67	1.7
	2	940	11.0	12.8	16	0.9
2.20	1	570	10.0	12.7	12	0.3
	2	1460	8.0	11.4	16	1.1
3.80	1	1150	3.0	8.0	106	3.2
4.60	1	1900	2.0	6.5	140	5.7

[a] Magnitudes and sensitivities in J, H, K bands are at S/N = 1 and are based on an estimate of the total noise of about 25 e^- in 600 s of integration time (elementary integration time 16 s), with the 1.5 m TIRGO telescope. In L and M bands the limiting noise is the background fluctuation; the quoted sensitivities are for S/N = 1

In J, H, and K bands the limiting noise is the read-out noise of the integrating preamplifier: the typical integration time on weak sources is 16 s with the gain set high. No sign of $1/f$ noise is observed in this condition, and the read-out noise is about 550 e^-. With 600 s of total integration time, noise scales down appreciably to give about 24 e^-, or 0.1 normalized counts. The thermal infrared bands, longward of 3.0 μm, are limited by the shot noise of the background; the typical time of an elementary integration is much shorter, of the order of 1 s or less.

Table 3 shows a summary of the sensitivity obtained with the spectrometer mounted at the TIRGO telescope (1.5 m diameter). The quoted resolving powers correspond to a representative wavelength in each band, when different grating orders are selected. Efficiencies were measured in October 1988 by means of standard stars; chopping mode in J, H, and K bands and beam-switching mode in L and M bands were used. The quoted efficiencies include the efficiency of the optics and grating and the detector quantum efficiency, but also include the telescope losses and the atmospheric transmission. Taking into account the effects of the external factors, the peak efficiency of the spectrometer alone can be estimated to be about 15%. Limiting magnitudes and sensitivities are based on a total integration time of 600 s and a detection level of 1 σ; as already mentioned, in J, H, and K bands the noise level is about 24 e^-, while in L and M bands the noise in 600 s is about 150–200 e^-.

The level of broadband straylight impinging upon the detectors is relatively large in comparison with the magnitude of the sky background in non-thermal infrared bands. To be precise, the internal straylight gives a mean of about 15 normalized counts, while the sky background gives only 10 counts at 2.3 μm. This might lead to two different problems: a noise excess due to the statistical fluctuations of the internal background, and difficulties in DC mode measurements, caused by long term instability of the internal background itself. In practice, both these problems are negligible: the statistical fluctuations of the internal background are small compared to the read-out noise, and the drift of the pixel response pattern, when the array detector is exposed only to the internal straylight, is typically much smaller than the total noise. On the other hand, spectra are normally acquired in the chopped mode and it is interesting to see to which extent the internal background is eliminated by means of this technique. Figure 3 shows the results obtained in chopped mode after 72 min of total integration time, when the entrance window is fully covered with the cold shutter, so that the detector array is observing the residual straylight. The mean of the seven pixel is −0.022 counts and the mean standard deviation – taken over the seven pixel – is

0.030, in total agreement with the expected total noise and with no trace of long term drifts.

3.2. First scientific results

Since autumn 1988, the TIRGO IR spectrometer has been used to collect data for several observation programs. Among them we mention a survey of hydrogen emission lines in Seyfert and starburst galaxies and the measurement of H I line strengths in a sample of T Tauri stars. Here we present some of the recorded spectra, without comment as to their astrophysical significance, in order to give an impression of the capabilities of the instrument; a full discussion will be given in a set of papers currently in preparation.

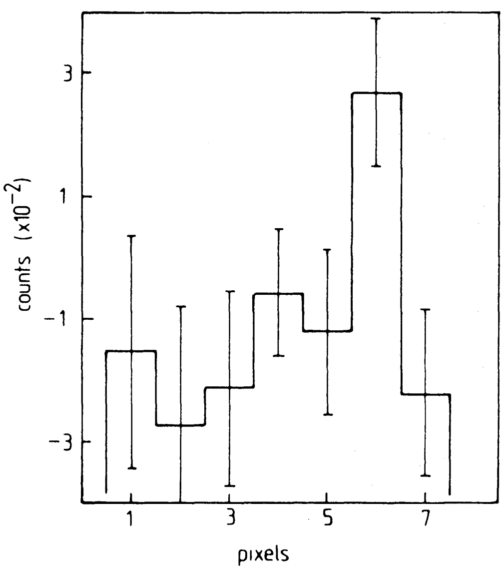

Fig. 3. The internal straylight as seen in chopping mode. The mean level on the seven pixels is -0.022 normalized counts, with a total standard deviation of 0.030 counts

Figure 4 shows the spectrum of the planetary nebula NGC 7027 in the spectral region between 2.10 and 2.19 μm, with a resolving power of about 1500 (grating at order two). The measurement was made in chopped mode, with an elementary integration time of 16 s and two complete chopper cycles per measurement cycle. The spectrum was scanned with ten grating positions and no pixels overlapping, with a total acquisition time of about 12 min. The spectrum (left) is dominated by the emission line of atomic hydrogen at 2.165 μm (Bracket γ), but three other lines are also well detected: the emission line of molecular hydrogen, corresponding to the transition $S(1)$ 1–O at 2.121 μm, the emission line of neutral helium 3^3S–4^3P at 2.113 μm, and the emission line of ionized helium He II 7–10 at 2.189 μm (Treffers et al., 1975). The spectrum of Fig. 4 is very crude: the original data have been processed only to take into account the pixel-to-pixel response (the corrections are smaller than about 7%). A comparison with the spectrum of a standard star showed that no large telluric absorption features are present. In particular, Fig. 4 (right) presents the spectrum of NGC 7027 with an expanded vertical scale; it can be noticed that the single segments of the spectrum are well connected. The two dotted lines are the $\mp 1\ \sigma$ levels around the mean value of the continuum, as determined by the statistics of the measurement.

H I emission lines of selected T Tauri stars are the objects of an observation program in which the stellar winds of young objects are studied to verify the theories of star formation processes. Figures 5 and 6 report four examples of such lines, measured in the two T Tauri stars DL Tau and SU Aur, respectively. The two spectra of SU Aur were recorded in chopper mode, with 16 s of elementary integration time and 10 min of total integration time; to record the spectra of DL Tau, the beam-switching mode was activated, using the same time of integration. The grating position was centered alternately on the two wavelengths of interest: Bracket γ at $\lambda = 2.165\ \mu$m and Paschen β at $\lambda = 1.282\ \mu$m. For the K band, the grating at order two gave a resolving power of about 1540; for the spectrum in J band, the grating at order three was used for a resolving power of 1200. The flux calibration was performed by comparison to K stars with a brightness not too different from that of the two T Tauri stars. In

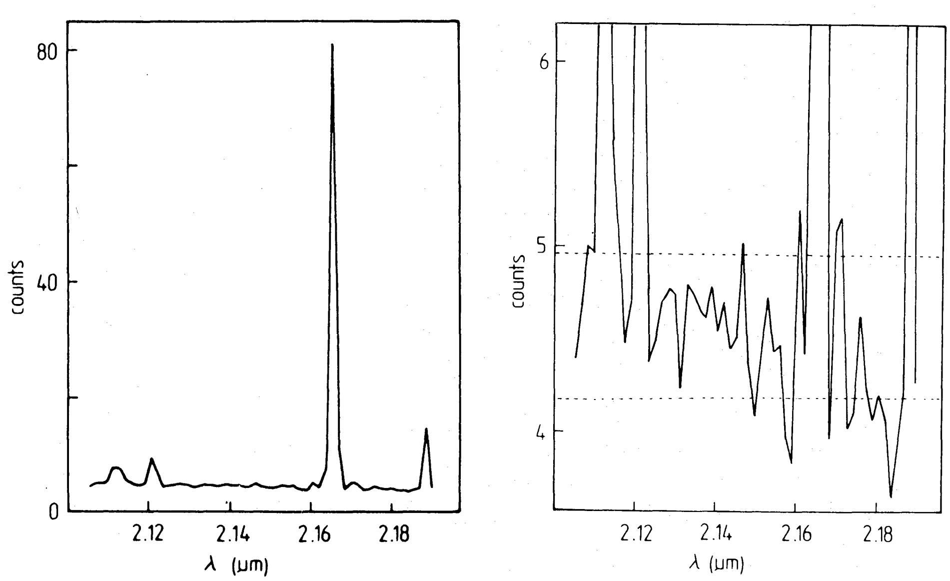

Fig. 4. The spectrum of NGC 7027 between 2.10 and 2.19 μm (left); the resolving power is 1500. The emission line of H I at 2.165 μm (Brackett γ) is dominant; H_2 at 2.121 μm, He I at 2.113 μm, He II at 2.189 μm are well detected. The enlarged spectrum (right) shows the details of the continuum, along with the $\mp 1\sigma$ levels (dotted lines)

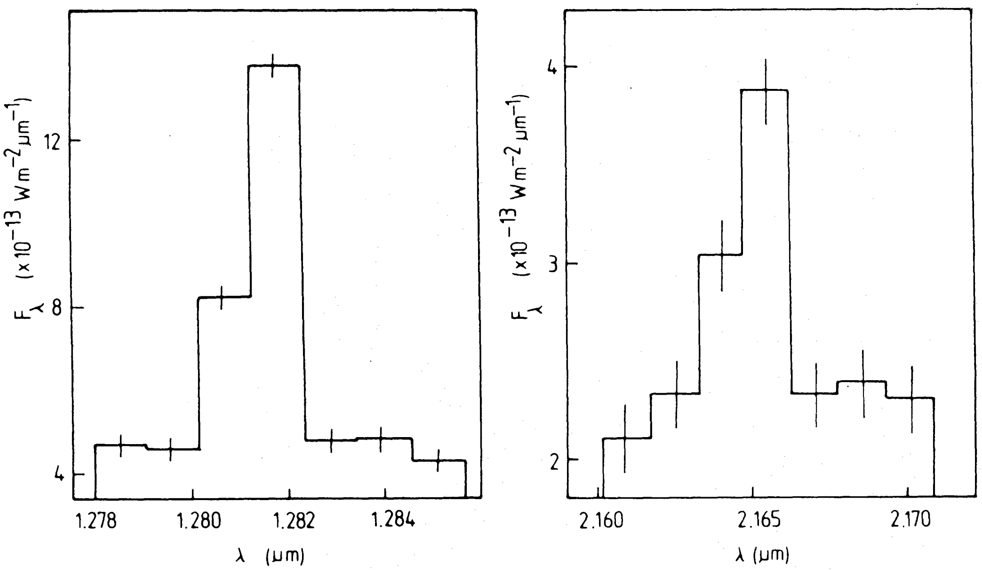

Fig. 5. The spectra of DL Tau around Paschen β, at $\lambda = 1.282\,\mu$m, (left) and Brackett γ, at $\lambda = 2.165$ (right). The total integration time is 600 s in beam-switching mode, with the grating at order two. Error bars represent $\mp 3\sigma$ errors (see text)

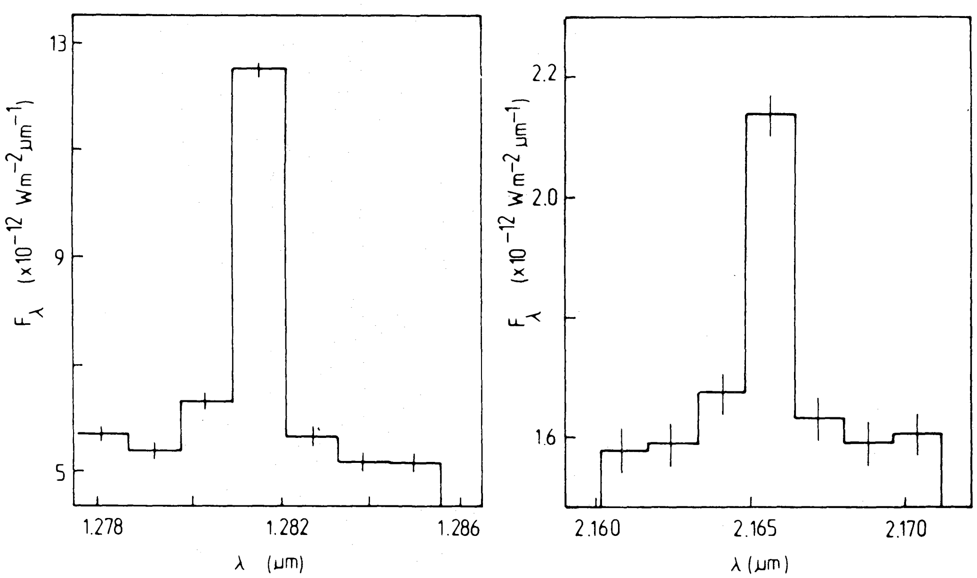

Fig. 6. The spectra of SU Aur around Paschen β, at $\lambda = 1.282\,\mu$m (left) and Brackett γ, at $\lambda = 2.165$ (right). The total integration time is 600 s in chopping mode (grating at order two). Error bars in Fig. 6b represent $\mp 3\sigma$ errors (see text)

this case, the scope of the measurement was to find the relative strength of the lines; indeed, the scintillation and the variation of the atmospheric transparency did not allow a good absolute photometry. An examination of the intermediate spectra, as recorded every each measurement cycle, shows that the continuum level and the line flux fluctuate accordingly, so their ratio tends to be constant. An estimate of errors in the final spectrum based on the absolute photometric error would be pessimistic. The adopted criterium is to consider the final spectrum and the distribution of values of the pixels which record the continuum flux. The quoted errors are in good agreement with the sensitivity of Table 3; we can conclude that the TIRGO spectrometer can be usefully employed to obtain useful data, in spite of the quality of the night.

4. Future developments and conclusion

The read-out noise is the limiting factor to the sensitivity of the TIRGO spectrometer in *J*, *H*, and *K* bands, as discussed in Sect. 3. That is to say that the theoretical read-out noise of the charge integrating preamplifier is lower than the actual read-out noise measured on the spectrometer. The difference is not negligible, being a factor 2 or 3 (for a complete discussion, see Hartill et al., 1986). The excess of noise is apparently due to the stages that follow the input; the elimination of this noise is an important task that we are planning to address in the near future. Another area where more work is needed in reducing the level of the internal straylight: the internal baffling suffers from leaks, and its thorough revision will help to screen out the sources of the infrared radiation present into the dewar.

After the reimaging camera, the optical design of the TIRGO spectrometer provides a corrected field of 3.5 mm diameter; allowing some vignetting, the useful field is even larger, more than 4 mm. On the other hand, as noted in Sect. 3, pixels of 60 μm size would be ideal to fully match the potential resolution of the TIRGO spectrometer. The present version of the instrument could obtain outstanding advantages by the new developments of infrared technology in the field of two dimensional array detectors. At present, bidimensional arrays with 128×128 pixels of 60 μm size are appearing; they have quite good performances with respect to the two parameters which are fundamental for spectroscopy, i.e. the dark current and the read-out noise. One of these device could be used as a detector for the TIRGO spectrometer, giving higher resolution and a wider coverage of a spectral region with a single grating position. Moreover, with a suitable slit, a portion of the array could be used to record the sky spectrum while the rest of the array registers the source spectrum, so that chopping becomes unnecessary.

With the commissioning of the IR spectrometer, the TIRGO telescope has been equipped with a very useful tool for astrophysical research in the field of IR spectroscopy. In the course of tests and in normal use, the TIRGO infrared spectrometer has shown itself to be stable and easy to operate. Its sensitivity is very good in comparison to other similar instruments, when the collecting area of the telescope is considered. We think that exciting new observation programs have been put within reach of the users of the TIRGO telescope.

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