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Letter to the Editor

First spectroscopically confirmed discovery of an extragalactic T Tauri star*

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Abstract. We report the first spectroscopic discovery of an extragalactic bona-fide T Tauri star. The object, LTS J054427-692659, is a low-mass, late-type star located within the LMC dark cloud Hodge II 139. It shows Hα emission with an equivalent width of 78 Å, in line with galactic T Tauri stars, but in excess of any main-sequence dwarf star. The only known plausible interpretation of LTS J054427-692659 is a LMC T Tauri star.

Key words. stars: pre-main sequence – stars: late-type – Magellanic Clouds

1. Introduction

Both from observation (Lilly et al. 1996; Madau et al. 1996, 1998) as well as theory (Dwek 1998; Baugh 1998) it appears that star formation is peaked at an early phase of galactic evolution, and declines thereafter. It is therefore of considerable interest to study the formation of solar-type, low-mass stars in an environment matching these earlier phases better than the present-day Galaxy. The LMC, with its vigorous star forming activity and its significantly lower metallicity, represents an excellent laboratory for the study of star formation under conditions which have likely prevailed in our Galaxy during earlier phases of its evolution.

For this reason, we have started a program to study low-mass star formation in the LMC. In our program we are investigating the LMC dark cloud Hodge II 139 (Hodge 1988), located at $05^{\rm h}44^{\rm m}06^{\rm s}$, $-69°25'25''$ (2000.0). Hodge (1988) estimates the cloud size to about 115×48 pc, with a Lynds opacity class (Lynds 1962) of 3. Hodge II 139 is part of a lane of dark clouds that extends from 30 Dor towards the south-east of the LMC (see Fig. 5 in Hodge 1988). This lane apparently is also visible in radio continuum maps by Haynes et al. (1991), but we could not identify Hodge II 139 with any particular emission feature on their maps.

Hodge II 139 is probably associated with CO-37, a molecular cloud (No. 37 in their Table 1) in the CO survey of Cohen et al. (1988). The diameter of CO-37 is given as 234 pc, the CO mass as $6.3 \times 10^6\,M_\odot$, and the virial mass as $13.2 \times 10^6\,M_\odot$. There is also a 6 cm source (MC 86 from the survey of McGee et al. 1972) associated with the CO-37 molecular cloud. However, MC 86 is located at $05^{\rm h}44^{\rm m}04^{\rm s}$, $-69°18.1'$ (1950.0), and thus probably unrelated to Hodge II 139.

All these data suggest that Hodge II 139 is a site with recent ongoing star formation and thus a good place to start searching for extragalactic T Tauri stars.

2. Observations

We have obtained deep JHK images of Hodge II 139 on two nights from Oct. 28–29, 1998 with SOFI at the NTT. A total of 73 exposures in J (40 s each), 72 in H (51 s), and 96 in $K_{\rm s}$ (60 s) were collected. The images were flatfielded, sky-subtracted, registered, and combined using standard tasks from the IRAF data reduction package. The field size of the combined images is $4'55'' \times 4'55''$. Source detection on the resulting JHK images was done using the SExtractor package (Bertin & Arnouts 1996), with a mexhat 3.0 9×9 filter and parameters of *detect_minarea* = 1, *detect_thresh* = 2, and *analysis_thresh* = 2 (for other parameters the defaults were kept). Only sources detected in all three bands were accepted.

Weather conditions during the observations were somewhat unstable, and thus photometric calibration was performed using the Two Micron All Sky Survey (2MASS) second incremental data release. There were 147 matches of 2MASS objects with our source list, and the resulting standard deviations are 0.15 mag (J), 0.18 mag (H),

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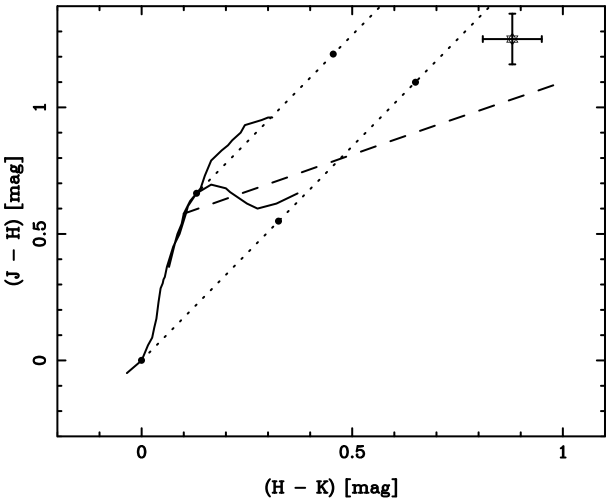

Fig. 1. Location of LTS J054427-692659 in the $H-K$, $J-H$ colour-colour diagram. Also plotted are the intrinsic colours for main sequence (lower curve) and giant (upper curve) stars (Bessel & Brett 1988), the reddening strip (dotted lines, with marks at distances of 5 mag in A_V), and the dereddened locus of Taurus-Auriga CTTS (dashed line) as determined by Meyer et al. (1987).

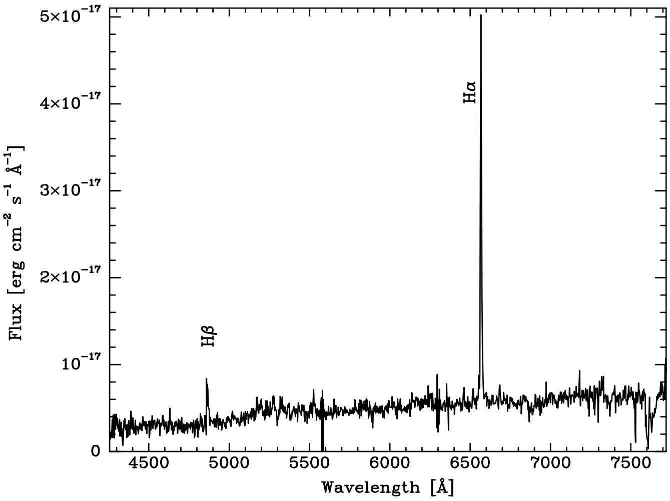

Fig. 2. FORS MOS spectrum of LTS J054427-692659, sky subtracted, wavelength and flux calibrated.

and 0.28 mag (K), which are partly due to the photometric uncertainty of the 2MASS sources.

We then constructed an infrared $J-H$, $H-K$ colour-colour diagram to find candidates for spectroscopic follow-up observations. As shown by Lada & Adams (1992), T Tauri stars with infrared excess can be discriminated from reddened main-sequence stars, because the reddening vector is quite different from the colour shift due to the thermal emission from circumstellar dust. In Fig. 1 we show the location of LTS J054427-692659 in the $(H-K)$, $(J-H)$ colour-colour diagram. Clearly its location makes it a good candidate for spectroscopic follow-up studies.

Candidates in the T Tauri region of the diagram were picked by eye. We selected objects outside and right to the reddening strip in the $J-H$, $H-K$ colour-colour diagram and subjected them to spectroscopic follow-up observations using FORS1 at KUYEN in MOS (multi-object spectroscopy) mode. This mode allows to observe up to 19 objects using a slit unit with individually configurable slitlets. Usage of this observing mode requires precise astrometric positions that were obtained by computing a plate solution for our J image using data from the USNO-A2 catalogue.

Our first FORS observation in Dec. 1999 failed because of technical problems, but in Dec. 2000–Jan. 2001, we could observe one single MOS setting within Hodge II 139 with four exposures of 3090 s each, totalling 12 360 s. The four individual exposures were taken on Dec. 19, 2000, Dec. 20, 2000, Dec. 31, 2000, and Jan. 1, 2001. We used grism 300 V with filter GG435, which provides a resolution of $R = 500$ with a wavelength range of 4200 Å to 7600 Å for a slitlet in the field centre. The actual wavelength range for individual spectra depends on the position of their slitlet on the detector, with a lower cutoff at 4200 Å due to the order separation filter (the spectrum of LTS J054427-692659 extends to 7720 Å).

Using standard tasks from IRAF, we combined the four exposures, eliminated cosmic ray hits, flatfielded the resulting frame, extracted the spectra along with suitable background regions, and performed sky subtraction and wavelength calibration. Flux calibration was performed using two exposures of the spectrophotometric standard star GD 108 taken on Dec. 19 and Dec. 20, 2000, immediately after the corresponding MOS frames.

3. Results

In Fig. 2 we show the spectrum of LTS J054427-692659 (where we have chosen the acronym LTS for "**L**MC **T** Tauri **S**tar"), located at $5^{\mathrm{h}}44^{\mathrm{m}}27.47^{\mathrm{m}}, -69°26'59.2''$ (2000.0).

The star shows strong Hα emission (equivalent width $EW = 78$ Å), along with emission in the Hβ line ($EW = 12$ Å), superimposed on a late-type stellar continuum. These equivalent widths are about an order of magnitude larger than observed in late-type main-sequence dwarfs, but often encountered in T Tauri stars. Radial velocities measured from the two emission lines are $207 \pm 31\,\mathrm{km\,s^{-1}}$ (Hα) and $301 \pm 106\,\mathrm{km\,s^{-1}}$ (Hβ), consistent with an LMC membership.

From the flux calibrated spectra, we estimate the optical brightness of LTS J054427-692659 to $m_B = 23.5, m_V = 22.5, m_R = 21.7$, using $\lambda_0 = 4400$ Å, $I_0 = 6.6 \times 10^{-9}\,\mathrm{erg\,cm^{-2}\,s^{-1}\,Å^{-1}}$ for the B band, $\lambda_0 = 5500$ Å, $I_0 = 3.6 \times 10^{-9}\,\mathrm{erg\,cm^{-2}\,s^{-1}\,Å^{-1}}$ for the V band and $\lambda_0 = 6400$ Å, $I_0 = 2.3 \times 10^{-9}\,\mathrm{erg\,cm^{-2}\,s^{-1}\,Å^{-1}}$ for the R band. Because the B and R passband are covered only partially by our spectrum, we can only use a monochromatic approximation, but for V we can alternatively convolve the spectrum with the filter response. This results in a

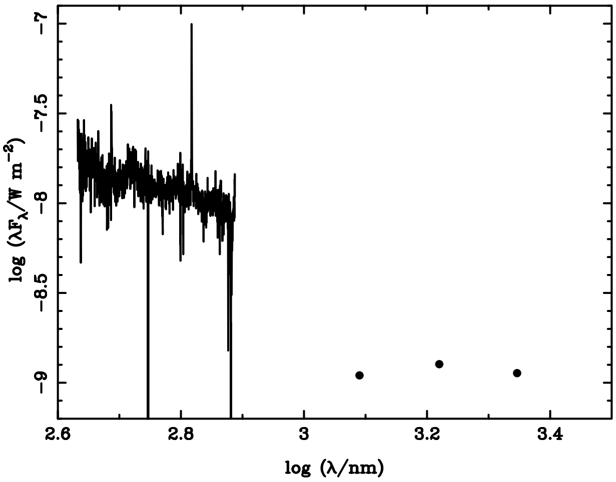

Fig. 3. Spectral energy distribution of LTS J054427-692659 from 0.42 to 2.2 μm, corrected for an extinction of $A_V = 3.3$. From J to K (the three photometric data points), the spectral energy distribution is almost flat, indicating an IR excess superimposed on the steep tail of the stellar continuum.

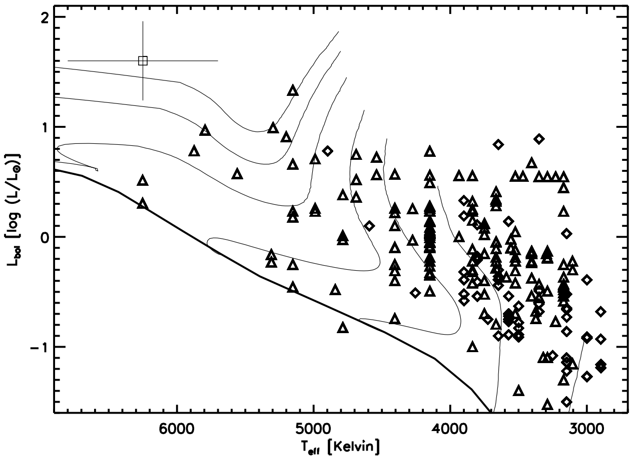

Fig. 4. HR diagram showing the position of LTS J054427-692659 with error bars. Also shown are evolutionary tracks for 2.5, 2.0, 1.5, 1.0, 0.7, 0.4, and 0.1 $M_\odot$ (from top to bottom). In addition, TTS from the Taurus-Auriga association (diamonds) and Lupus association (triangles) are shown for comparison. (Data for Lupus TTS from Hughes et al. 1994, for Taurus-Auriga TTS from the compilation in Neuhäuser et al. 1995.)

magnitude of $m_V = 22.3$, in satisfactory agreement with the value obtained by the monochromatic approximation.

The JHK magnitudes of the star are 20.73 ± 0.09 mag (J), 19.45 ± 0.04 mag (H), and 18.57 ± 0.06 mag (K). The resulting $J - H$, $H - K$ colours (1.27 mag and 0.88 mag respectively) place the star outside and to the right of the reddening strip, but at higher $J - H$ than typical for the bulk of Taurus-Auriga classical T Tauri stars (CTTS), which cluster around $J - H \approx 0.7$ mag (Lada & Adams 1992).

If we deredden LTS J054427-692659 to the reddening-free locus of classical T Tauri stars as determined by Meyer et al. (1997), we obtain an extinction of $A_V \approx 3.3$. This corresponds to $A_J \approx 0.93$, $A_H \approx 0.58$, and $A_K \approx 0.37$ (Rieke & Lebofsky 1985).

Adopting a distance modulus of μ_0 (LMC) = 18.50 mag, the absolute dereddened JHK magnitudes of LTS J054427-692659 are 1.3 mag (J), 0.4 mag (H), and −0.3 mag (K). This places the star in between the galactic CTTS binary GW Ori, which at $K = -1.25$ (for a Hipparcos parallax of 3.25 mas) and a primary mass of 2.5 $M_\odot$ (Mathieu et al. 1991) is one of the brightest and most massive galactic CTTS known, and the Taurus-Auriga T Tauri stars with mean JHK magnitudes of 3.5 mag, 2.5 mag, and 1.9 mag, respectively (Rydgren & Vrba 1983).

The spectral energy distribution of LTS J054427-692659, corrected for an extinction of $A_V = 3.3$, is displayed in Fig. 3. There is clearly an infrared excess, although the star emits much more flux in the optical than in the near-IR.

We have tried to classify the stellar spectrum by dereddening it for $A_V = 3.3$ and comparing the dereddened spectrum with templates from the stellar spectra library by Jacoby et al. (1984). From this, we conclude that the star probably has an F-G spectral type. Figure 4 shows the location of LTS J054427-692659 in the HR diagram. The star apparently has a mass of about 2–3 $M_\odot$, at the upper end of the CTTS range. The fact that our first detection is a rather bright object is certainly due to our detection bias towards more luminous stars, but we expect that fainter objects will be detected as one goes deeper.

4. Conclusions

There is strong evidence that LTS J054427-692659 is a classical T Tauri star with a F-G spectral type, located in the Hodge II 139 dark cloud in the LMC. Since the star has only a weak near-IR excess, we conclude that the major fraction of its extinction of $A_V = 3.3$ is not caused by circumstellar material, but rather by the surrounding dark cloud. This means that the star is not foreground to the dark cloud, but located within it.

Based on HST photometry with wideband filters in the optical range as well as a narrowband Hα filter, Panagia et al. (2000) have argued the detection of a population of low-mass pre-main-sequence (PMS) stars in the region around SN 1987A. So far, our own data are not sufficient to quantify the reliability of photometric selection. According to the discussion presented by Panagia et al. (2000) as well as our present experience, photometry is well suited to search for good T Tauri candidates, but it is not possible to unequivocally identify a PMS star on the basis of photometry alone. For an unambiguous identification and a quantitative study spectroscopic evidence is indispensable. With our VLT data this has been accomplished for the first time.

The discovery of LTS J054427-692659 shows that the Hodge II 139 dark cloud is actively forming low-mass stars. The goal of our project is to find an LMC counterpart of the well-known galactic T Tauri associations, and to determine its properties in comparison with galactic ones. The discovery of LTS J054427-692659 is an important first step towards this goal.

Lamers et al. (1999) have reported the serendipitous discovery of seven luminous irregular variables in the LMC, and suggest that these are Herbig Ae/Be (HAeBe) stars, i.e. massive PMS stars. However, their stars are about a factor 10 more luminous than the upper limit for Galactic HAeBe stars. They speculate that this is due to a shorter accretion timescale or to the smaller dust-to-gas ratio in the LMC. With our work, we are able to extend the observed PMS mass range of the LMC to much lower masses, into the range of solar-like stars. With more data, it will be interesting to see whether a similar phenomenon can be observed in this lower mass range.

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This work has made use of the USNO-A2.0 catalog.

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