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Letter to the Editor

New T Tauri stars in the vicinity of TW Hydrae ⋆

Michael F. Sterzik[1], **Juan M. Alcalá**[2,3], **Elvira Covino**[2], **and Monika G. Petr**[1]

[1] European Southern Observatory, Casilla 190001, Santiago 19, Chile
[2] Osservatorio Astronomico de Capodimonte, Via Moiariello 16, I-80131 Napoli, Italy
[3] Instituto Nacional de Astrofísica, Optica y Electrónica, A.P. 51 y 216 C.P. 72000, Puebla, México

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Abstract. We report the discovery of four weak-line T Tauri star candidates in the vicinity of the TW Hydrae association, the closest known region of recent star formation. Three stars are probably association members. They exhibit high Lithium abundances, M spectral types, and a high level of chromospheric and coronal activity. Two of them form a binary system. They also share a consistent radial velocity with previously known members of the association. A fourth candidate T Tauri star is of earlier spectral type, has a weaker Lithium absorption feature, and a different radial velocity, and is probably located in the background of the association. Our findings support the idea that the isolated T Tauri stars in that region belong to a physical association around TW Hydrae.

Key words: stars: flare – stars: pre-main sequence – X-rays: stars

1. Introduction

The classification of TW Hydrae as a classical T Tauri star (cTTS) by Rucinski & Krautter (1983) has challenged the conventional picture of star formation, because *(i)* TW Hydrae is located far from any dark cloud or concentration of molecular material and *(ii)* appears to be far from other pre-main sequence (PMS) stars. Dubbed as *isolated TTS* the origin of TW Hya remained puzzling, even after de la Reza et al. (1989) and Gregorio-Hetem et al. (1992) identified four other T Tauri systems in the same region of the sky on the basis of the IRAS point source catalog. However their physical association remained unclear until recently, when results of the *HIPPARCOS* and the *ROSAT* mission shed new light on their nature.

HIPPARCOS distances towards HD 98800 and TW Hya of $\approx$ 50–60 pc each confirmed earlier speculations that the "isolated" T Tauri stars around TW Hya are actually the closest PMS stars known with ages between $\approx$ 10–20 Myrs based on evolutionary tracks in the HR diagram (Wichmann et al. 1998). Selection within the *HIPPARCOS* catalog in a search area of about 10 degrees around TW Hya also revealed the existence of one additional PMS star, namely CoD-36°7429 (Jensen et al. 1998). More evidence for the physical association of PMS stars around TW Hya came from X-ray observations with the *ROSAT* satellite. Strong X-ray emission from all postulated PMS stars around TW Hya was detected, similar to those TTS found in other star forming regions (Kastner et al. 1997). However a detailled analysis of *ROSAT* pointed observations around TW Hya and CoD-29°8887, another association member, did not find evidence for more TTS within 1 degree radius around each target position. The relative looseness around TW Hya is plausible in terms of member proximity to Earth and older ages, which could imply larger mean nearest-neighbourhood distances (Hoff et al. 1998). For even larger scales, TTS candidates can be selected from the *ROSAT All-Sky Survey* (RASS) (see e.g. Sterzik et al. 1995). And indeed, seven new TTS and one brown dwarf candidate could be discovered in extended areas around the previously postulated TW Hya association members, based on a search within a sample of X-ray bright RASS sources (Webb et al. 1999).

The relevance of this group of TTS in the vicinity of the sun is manifold. Their origin, and star formation scenarios can be studied without obscuration. The exceptional proximity of this group allows study of their immediate circumstellar environment with high spatial resolution. And their evolutionary status at the end of the TTS phase will help to understand circumstellar disk dispersal, and possible planetary system formation.

In this *Letter* we report additional TTS in the general direction of TW Hya. Our original candidate sample is based on RASS sources, but considers fainter X-ray sources than Webb et al. (1999). We describe our X-ray selection and detection procedure, together with the X-ray properties of the new TTS. The identification as TTS is based on high resolution echelle spectroscopy which enables measurement of Lithium abundances and radial velocities. Furthermore, we performed adaptive optics near-infrared imaging to search for close companions. We interpret our findings in terms of mounting evidence for the physical association of this group of young stars.

Send offprint requests to: Michael Sterzik (msterzik@eso.org)

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Table 1. X-ray properties of the new wTTS candidates.

RXJ	RA(2000)	DEC(2000)	$\mathcal{L}$	Count rate (cts/ksec)	HR1	HR2	$F_x \cdot 10^{12}$ (ergs cm^{-2} sec^{-1})
1109.7−3907	11:09:40.2	−39:06:49	75	119(19)	0.20(0.16)	0.02(0.21)	1.1
1121.1−3845	11:21:05.6	−38:45:16	12	90(37)	0.17(0.46)	0.13(0.69)	0.8
1121.3−3447	11:21:17.3	−34:46:46	444	480(35)	−0.09(0.07)	0.00(0.11)	3.8

2. Observations

2.1. X-ray properties

The X-ray data were obtained from the ROSAT all-sky survey in $6° \times 6°$ fields centered on each one of the known TTS TW Hya, CoD−29°8887 and Hen(3)-600. The three fields slightly overlap to cover the region between the three T Tauri stars. The reduction of the X-ray data was performed following the pipelines of the Extended Scientific Analysis System (EXSAS) as described in Alcalá et al. (1995). Some 50 X-ray sources were detected. The three T Tauri stars TW Hya, CoD−29°8887 and Hen(3)-600, were all detected with a high confidence level. In order to search for candidate TTS of the X-ray sources detected, intermediate resolution spectroscopic observations were carried out using the Boller & Chivens spectrograph attached to the ESO 1.5m telescope at La Silla, Chile. Only four stars out of the 71 investigated showed Lithium absorption, late spectral type and/or Hα emission, and hence, could be classified as new wTTS candidates. The rest of the X-ray sources can be identified with unrelated active stars. The X-ray properties of the wTTS candidates are listed in Table 1, as well as their maximum likelihood of detection $\mathcal{L}$, hardness ratios (HR1 and HR2), and X-ray fluxes, derived using an energy conversion factor of $(5.3 \cdot HR1 + 8.31) 10^{-12}$ ergs cm^{-2} cnts^{-1} (Schmitt et al. 1995). The optical counterpart of RXJ1121.3−3447 turned out to be a visual binary (see below). Spectra of both components could be obtained.

2.2. High resolution spectroscopy

High resolution spectroscopic observations of the four wTTS candidates were performed using the Cassegrain Echelle Spectrograph (CASPEC) attached to the ESO 3.6m telescope in February 1998. The spectral range of the CASPEC spectra is from 5350 to 7720 Å and their nominal resolving power, resulting from the measurements of the FWHM of several well isolated lines in the ThAr comparison spectrum, is $\lambda/\Delta\lambda \approx$ 22,000.

The CASPEC spectra in the Sodium and in the Hα – Li ranges are shown in Fig. 1. With the same instrumental set-up we have also observed TW Hya, and display its spectrum as comparison. The spectral types assigned from the mid-resolution spectra and the lithium equivalent widths as well as radial and projected rotational velocities are also indicated in the lower panel. The latter three quantities were derived from the CASPEC spectra using the procedures described by Covino et al. (1997).

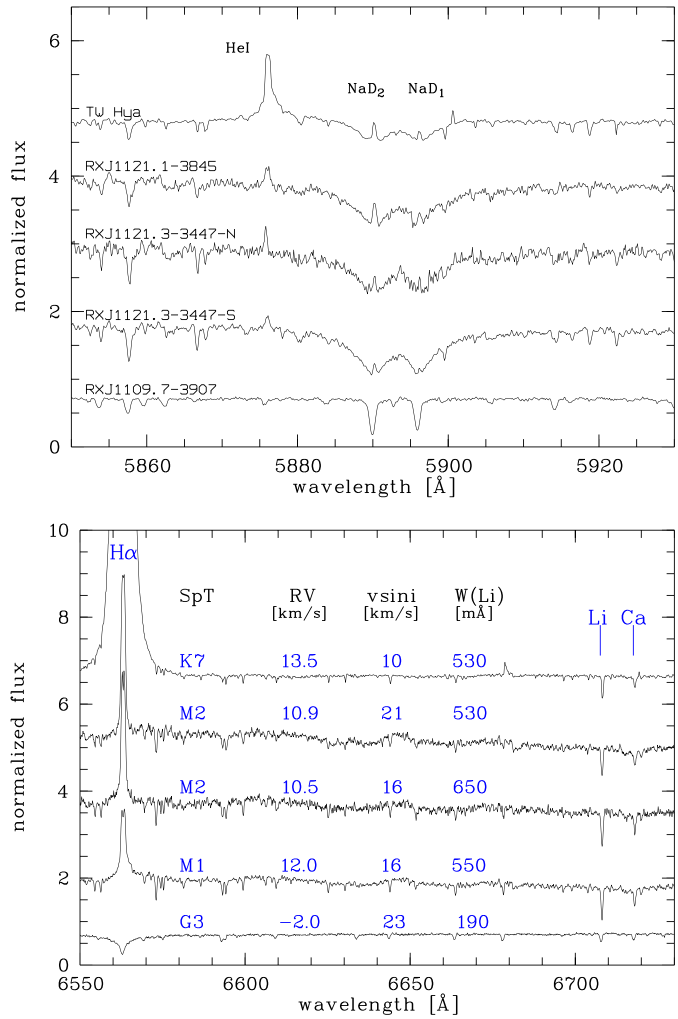

Fig. 1. High resolution spectra of the four new wTTS candidates (and TW Hydra itself as comparison) in the Sodium (upper panel) and the Hα – Lithium range (lower panel). The spectra of the lower panel are plotted in the same order as those in the upper panel in which the RXJ names are indicated.

Note that the intensity of the lithium absorption line is stronger than that of the Calcium line in the four stars. Except for the G3 type star, the other three show a typical chromospheric Hα emission. The M type stars show evidence of He I (λ5876 Å) in emission, as well as of the reversal emission in the Na I D lines, which are characteristics of an active chromosphere, similar to those identified in TW Hya itself.

An estimate of the effective temperature of these stars has been performed using the calibrations between the Na I D lines equivalent width and $\log T_{\rm eff}$ for the G type star (Tripicchio et al. 1997) and the K I (λ7699Å) line equivalent width versus $\log T_{\rm eff}$ for the M stars (Tripicchio et al. 1999).

In Table 2, the spectral types and the quantities derived from the high-resolution spectra are summarised. The spectral types and the derived effective temperatures are consistent, within the errors, when using the calibration between spectral types and effective temperatures (de Jager & Nieuwenhuijzen 1987). Lithium abundances in the $\log(H) = 12$ scale were derived for the four wTTS candidates and TW Hya from the W(Li) and $T_{\rm eff}$ values using the non-LTE curves of growth given by Pavlenko & Magazzù (1996), conservatively assuming $\log g = 4.5$.

2.3. Adaptive optics imaging

In order to study the stellar environment of the new wTTS candidates on spatial scales down to ~ 8 AU ($0\farcs16$ at 50 pc distance) we have performed adaptive optics imaging using ADONIS at the ESO 3.6 m telescope on 8. and 9. Jan. 1999. We used a K_s-filter (2.16μm) to search for close companions to the new TTS, where in case of a positive detection we performed additional $J(1.25\mu$m) and $H(1.65\mu$m) band imaging.

The companion to RXJ1121.3−3447 was easily detected on our near-infrared images. It is not a really close system, but separated by $5\farcs13(\pm0\farcs01)$, having a measured brightness difference of $\Delta K_s = 0.13 \pm 0.04$, $\Delta H = 0.03 \pm 0.09$, and $\Delta J = 0.02 \pm 0.08$. The position angle determined from the images is $\mathrm{P.A.} = 327.1 \pm 0.1$ degree. No companions were detected for the other two targets. For RXJ1109.7−3907 we estimate that potential companions separated from the primary by $1\farcs0$ or more have to be fainter than $\Delta K_s \geq 5.8$, while at separations of $0\farcs5$ and $0\farcs2$ potential companions must be fainter than $\Delta K_s \geq 2.0$, or $\Delta K_s \geq 1.5$ respectively, to be undetected in our images. Due to the faintness of star RXJ1121.1−3845 in the optical, wavefront sensing was difficult, i.e. only very low order adaptive optics corrections could be applied, and thus the sensitivity to close companions is worse than for the other objects. Essentially, companions to RXJ1121.1−3845 separated by less than $0\farcs3$ remain undetected. At a separation of $1\farcs0$ ($0\farcs5$) our detection limit is $\Delta K_s = 2.8$ (1.0).

3. Discussion and conclusions

Two of our three X-ray sources that have new wTTS candidates as optical counterparts are contained in the RASS Bright Source Catalogue (W. Voges et al. 1996), but they escaped the selection criterion of Webb et al. (1999). Their measured X-ray fluxes are typical for TW Hya association members (see Kastner et al. 1997).

The derived Lithium abundances for the three late type stars are comparable, or even higher than those found for similar types in young open clusters, like the 30 Myr old IC2602 (Randich et al. 1997). On the other hand they appear somewhat lower than those derived for TTS in regions of ongoing star forma-

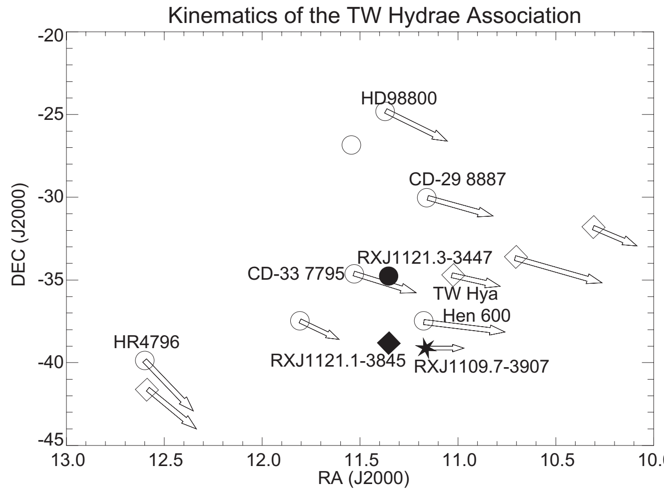

Fig. 2. Spatial distribution of all candidate members of the TW Hydrae association. An explanation of the symbols is given in the text.

tion. We do not attempt an absolute age determination based on rather uncertain Lithium depletion models, but stress that our "Lithium age" of 10−30 Myrs is fully consistent with the age determination of other TW Hya association members based on pre-main sequence evolutionary tracks (Webb et al. 1999). Also kinematics supports their membership in the TW Hya association: they have, within the errors, consistent radial velocities with TW Hya. From the Lithium abundance and radial velocities we conclude that the three M type stars are low-mass PMS stars and members of the TW Hya association.

The membership of RXJ1109.7−3907 is less clear: it has a considerable amount of Lithium, and therefore resembles wTTS properties. But Lithium depletion is much slower for a G3 type star as compared to M dwarfs. Its Lithium strength is just at the upper envelope, characteristic for Pleiades stars (Soderblom et al. 1993), and hence, only an upper limit of about 100Myrs for its age can be estimated. A lower limit on its distance is about 80−100pc, derived from placing the star on the zero-age main sequence. This is probably too far away to be associated with TW Hya. Also the radial velocity of this star is not consistent with that of the other stars (in case this object is not an unresolved spectroscopic binary corrupting the radial velocity). RXJ1109.7−3907 (PPM288568) has a proper motion of $PM_{\rm RA} = -52.4$ mas yr^{-1} and $PM_{\rm DEC} = 0.0$ mas yr^{-1}. These values are only marginally consistent with those of the other TW Hya members: the mean values derived for the members indicated by Webb et al. (1999) are $\langle PM_{\rm RA}\rangle = -80.9 \pm 22.0$ mas yr^{-1} and $\langle PM_{\rm DEC}\rangle = -26.4 \pm 14.1$ mas yr^{-1} respectively. In summary we conclude that RXJ1109.7−3907 is probably a young (30−100Myrs old) field star located *in the background* of the TW Hya association. It resembles spectroscopic properties typical for very young, coronally and chromospherically active field stars (see e.g. Favata et al. 1993, Jeffries 1995, Sterzik & Schmitt 1997).

The spatial distribution together with all available proper motion data are shown in Fig. 2: Likely TW Hya association members are indicated either with diamonds (single stars) or

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Table 2. Optical properties of the new wTTS candidates and, for comparison, of TW Hya.

RXJ	V (GSC)	SpT	$T_{\rm eff}$ (±200 K)	W(Hα) [Å]	W(Li) [mÅ]	RV [km/s]	vsini [km/s]	log$N(Li)$
1109.7−3907	9.8	G3	5800	1.8	190(10)	-2.0(1.1)	23(2.0)	3.21
1121.1−3845	13.6	M2	3600	−4.5	530(15)	10.9(1.1)	21(2.0)	1.98
1121.3−3447N		M2	3600	−4.0	650(20)	10.5(1.2)	16(1.5)	2.25
1121.3−3447S	11.5	M1	3800	−2.8	550(10)	12.0(1.2)	16(1.5)	2.25
TW Hya	12.1	K7	4150	−150.0	530(10)	13.5(1.5)	10(1.0)	2.68

with circles (binary and multiple systems). The length of the arrows corresponds to known proper motion vectors extrapolated over 200000 yrs (see Webb et al. 1999). Open symbols indicate those candidates already known, filled symbols mark our new identifications. RXJ1109.7−3907, an unlikely association member, has a different symbol. Our new candidate members double the number of TTS systems in the area roughly delimited between $11^h < \alpha < 11^h30^m$ and $-40° < \delta < -35°$, which could give the impression that the former cluster centre might have been located in this area. But due to the spatial selection bias, and the limited size of the fields investigated we cannot infer the true, large scale, spatial distribution of potential TTS potentially contained within the fainter RASS source sample.

Finally we note the presence of a highly significant excess of young stars around TW Hya over predictions from standard galactic models: the expectation on the number density of the X-ray emitting stellar population above the RASS completeness limit (0.03 cnts/sec) is about 0.5 X-ray sources/deg^2 at the galactic latitude of TW Hya (see Guillout et al. 1996). They have shown that the highest fraction (about 40%) of these X-ray sources are low-mass stars younger than 150Myrs. *Assuming* a constant star formation rate over the last 150Myrs we expect in total about 2 RASS sources with ages less than 15Myrs within a 100 deg^2 area. Contrarily, the observations reveal a much higher density: the 37.5 deg^2 field defined above already contains 8 or 9 stars in 6 stellar systems with ages younger than a few 10Myrs!

In summary, there is compelling evidence that the TTS found around TW Hya are not unassociated, young, field stars, but rather generic members of a group that formed recently.

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