Flare stars in the TW Hydrae association: The HIP 57269 system

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Received date will be inserted by the editor; accepted date will be inserted by the editor

Abstract. We discuss a new member candidate of the TW Hydrae association (TWA) among the stars of the Gershberg et al. (1999) flare star catalog. TWA is one of the closest known associations of young stars at about 60 pc. Three supposedly young flare stars are located in the same region of the sky as TWA. One of them (HIP 57269) shows strong Lithium absorption with spectral type K1/K2V and a high level of chromospheric and coronal activity. It is located at a distance of 48.7 ± 6.3 pc in common with the five TWA members observed with Hipparcos (46.7 to 103.9 pc). HIP 57268 A has a wide companion C which also shows Lithium absorption at 6707 Å and which has common proper motion with HIP 57269, as well as a close companion resolved visually by Tycho. HIP 57269 A&C lie above the main sequence and are clearly pre-main-sequence stars. The other two flare stars in the TWA sky region do not show Lithium at all and are, hence, unrelated.

Key words: stars: flare, late-type, binary, pre-main sequence

1. Introduction: Flare stars in TW Hydrae

The Gershberg et al. (1999) catalog of UV-Cet type flare star (FSs) provides a sample of chromospheric and coronal active stars located in the entire sky. The existence of luminous young FSs, also in young T associations, indicates a possible connection between the UV Cet-type and T Tauri stars. All late-type stars go through a flare stage during their early evolution. Hence, FSs may well be weak-line or post-TTS or young zero-age main-sequence stars. The flare rates decline from young pre-main sequence TTS to somewhat older FSs, but flares on FSs attract more attention because they do not show other peculiarities (for a study see Guenther & Ball 1999 and Stelzer et al. 2000).

We placed the stars of the Gershberg catalog in an H-R diagram using their Hipparcos parallaxes and compared their position to theoretical tracks and isochrones. In the H-R diagram the stars appear close to the main sequence or above it. Because of the activity and the position in the H-R diagram, many of them are likely to be young. To confirm this we take spectra to resolve the Lithium I line at 6707 Å and compare the line-depth relative to the continuum to zero-age main-sequence stars of the same spectral type and to TTSs. Here, we concentrate on flare stars which may be related to the TW Hydrae association (TWA). Spectra of all other observed FSs will be published later.

The star TW Hya was first thought to be an isolated TTS. Only later similar stars and member candidates were found by accident and by systematic searches among infrared and X-ray sources (Hoff et al. 1997, Kastner et al. 1997, Jensen et al. 1998, Sterzik et al. 1999, Webb et al. 1999, Zuckerman et al. 2001). More kinematic member candidates can be found in Makarov & Fabricius (2001), Torres et al. (2000), and Tachihara et al. (2003). TWA was found to be a loose group without nearby cloud material. Today there are 19 known and confirmed member systems of the association, called TWA 1-19 (Webb et al. 1999, Zuckerman et al. 2001). These stars have common radial velocity and proper motion and comparable Lithium abundance. Yet, some discussions are ongoing, e.g. if TWA-19 is a member of the Scorpio-Centaurus association (Mamajek et al. 2002). Makarov (2003) has also some restrictions to TWA-9.

Hipparcos has observed five confirmed member stars of the association. This leads to a mean distance of 62.2 ± 7.8 pc with a range of 46.7 ± 7.2 pc to 103.9 ± 17.5 pc. The newly proposed member candidate would be the sixth member with a Hipparcos parallax.
Table 1. Basic data of the flare stars located in the TWA sky region

| name           | plx      | V        | SpT.  | T_eff | \(\mu_\alpha\) | \(\mu_\delta\) | v sin i | RV   |
|----------------|----------|----------|-------|-------|---------------|---------------|---------|------|
| Flare stars located in the TWA-region |
| HIP 57269      | 20.55±2.38 | 9.34±1  | K1/K2V  | 4990±100 | -137.21±1.90 | -47.71±1.37 | 20'     | 16'' | 19.0±3.14  |
| HIP 56244      | 95.46±2.59 | 11.54    | M3.5e  | 3420±100 | -715.75±1.38 | 170.75±1.38 |         |      | 6.06         |
| GJ 3780        | 62.5±14.3 | 12.94    | M3.5   | 3420±100 | -5565         | -2495         |         |      | -0.36         |
| TWA range      | 9.62 to 21.43 | 8 to 14  | A0 to M9 | -122.2 to -30.0 | -38.0 to +16.3 | 5 to 58         | 5.73 to 14.0 |

1: Hipparcos catalog 2: Gershberg et al. (1999) 3: Hawley et al. (1997) 4: SIMBAD 5: Bakos et al. (2002) 6: Gliese & Jahreiss (1995): Catalog of nearby stars (CNS4) 7: Pallavicini et al. (1992) 8: Anders et al. (1991) 9: Cutispoto (1998) 10: Torres et al. (2003) 11: Fabricius & Makarov (2000) 12: Adapted from Kenyon & Hartmann (1995) 13: this work, measured from two DFOSC spectra

2. Spectroscopy in the optical regime

The optical spectroscopy was performed using the Danish 1.54 m telescope at La Silla, ESO equipped with the focal reducer instrument DFOSC (Danish Faint Object Spectrograph and Camera) in short slit échelle mode. The spectral resolution in the red wavelength range is about 5000 (\(\lambda/\Delta \lambda\)). This resolution is sufficient to distinguish Lithium I at 6707 Å from Calcium at 6718 Å, but not from the nearby much weaker Iron lines at 6706 Å. The total wavelength range covered is from 5850 Å to 8500 Å, i.e. including Hα.

Data reduction was performed using the échelle package of IRAF. We have subtracted the mean bias created with dedicated bias images and a flat-field correction was applied, using a mean dome-flat. We note that the flat-field lamp does not have a Lithium I line at 6707 Å. In each spectra we subtracted the sky by extracting 10-13 pixel to the left and right of the stellar spectrum.

The sample of stars were taken from Gershberg et al. (1999) and listed in Table 1 namely the stars located in the region of \(\alpha = 10\) h to 13 h and \(\delta = -24^\circ\) 30’’ to -50’. Fig. 1 shows how the sky appears to the left and right of the stellar spectrum.

![Fig. 1](image-url) A section of the spectrum of HIP 57269 A&B showing Lithium at 6708 Å and Calcium at 6718 Å and HIP 66244 and GJ 3780 without Lithium.

![Fig. 2](image-url) Proper motion of the known confirmed TWA members and the flare stars discussed in this paper: HIP 57269, GJ 3780 and HIP 56244. Proper motions were taken from Torres et al. (2003) for the TWA members and the Song et al. (2002) member candidates, for the flare stars from the Hipparcos catalog or from the Simbad database. The labels song-1 correspond to TYC 7760-0835-1, song-2 to TYC 8238-1462-1, and song-3 to TYC-8234-2856-1.

| \(W_\lambda\)(Li) | \(W_\lambda\)(Ca) | log N(Li) | v sin i | rad. vel. | ref. |
|------------------|-----------------|-----------|--------|-----------|------|
| [mÅ]             | [mÅ]            |          | [km/s] | [km/s]    |      |
| 196±5            | 200±3           | 2.7      | 20     | P         |
| 205              | 2.5             | 23       | 15.9   | A         |
| 196              | 20              |          |        | S         |
| 200±20           | 270±20          | 2.5      | 19.0±3 | K         |
| P: Pallavicini et al. (1992), R: Randich et al. (1993), A: Anders et al. (1991), S: Song et al. (2002), K: this paper |

The two stars HIP 56244 and GJ 3780 do not show Lithium (see Fig 1). HIP 56244 is classified as a flare star by Pettersen (1991) and GJ 3780 by Eggen (1987) Their properly classified HIP 57269 as a BY Dra type variable. HIP 57269 A,
Fig. 3. The Lithium EW versus temperature of the confirmed TWA member stars (open boxes) and HIP 57269 A and its companion C (filled box). The three member candidates from Song et al. (2002) are also shown (big dots) with temperatures adopted from Mamajek et al. (2002) for two stars and for one estimated from Kenyon & Hartmann (1995). Underlayed are TTSs in Taurus (crosses and arrows (upper limits)) and Pleiades stars (open dots) for reference. Figure adapted for the TTS and Pleiades stars from Neuhäuser (1997). The temperatures for the TWA members and member candidates were derived from published spectral types using the Kenyon & Hartmann (1995) temperature scale. Lithium iso-abundance lines are taken from Pavlenko & Magazzù (1996).

A star with spectral type K1/K2V, shows Lithium absorption (see Fig. 1). The spectral type was published by Cutispoto (1998) and references therein after a thorough study and was confirmed by our DFOSC spectrum. The equivalent width (EW) of the 6707 Å line is 0.20 ± 0.01 Å while Calcium at 6718 Å has 0.27 ± 0.01 Å. This is very similar to the Lithium EW of TWA-19 with spectral type G3-5, with 0.19 Å EW (Webb et al. 1999, Sterzik et al. 1999 and Zuckerman et al. 2001), see Fig. 3. This Lithium EW and spectral type leads to a Lithium abundance of $\log(N(\text{Li})) = 2.5$ for HIP 57269 following Pavlenko & Magazzù (1996) for dwarfs. This $W_\lambda(Li)$ is near the upper envelope of $W_\lambda(Li)$ of the Pleiades at the spectral type early K and similar as in G- and early K-type TTS in Taurus (see Fig. 3).

Anders et al. (1991) have also analyzed high resolution spectra of this star deriving high Lithium abundances. They also take into account the proper motion, the space motion and a distance of 42 pc, they conclude that the star is a Pleiades super cluster member. We note that before 1997, when Pallavicini et al. (1992), Randich et al. (1993), and Anders et al. (1991) studied this star, TWA was not yet recognized as a young cluster and the proper motion of the Pleiades super cluster is quite similar to the proper motion of TWA.

3. Kinematics and multiplicity

The proper motion of HIP 57269 (−137.21 ± 1.0 mas/yr, −47.71 ± 1.37 mas/yr) could be consistent with the proper motion (see Fig. 4) of the other stars in TWA, so that Makarov & Fabricius (2001) list it as a kinematic member candidate. The radial velocity measured by us of 19.0 ± 3.0 km/s and the space motion leads to a space velocity of $U = 18.5$ km/s, $V = −28.4$ km/s and $W = −15.2$ km/s which is quite different from the average space velocity of TWA ($U = 10.8$ km/s, $V = −11.9$ km/s and $W = −18.6$ km/s).
The three flare stars and HIP 57269 C (big asterix) together with the confirmed members of TWA (TWA-1 - 19) plotted in an H-R diagram using distances from Tab. 1. The luminosity for HIP 57269 A was computed using Tycho $V_T$- and $B_T$-magnitudes for the component A only. The V-magnitude for component C was taken from SIMBAD. For a comparison are overlayed the theoretical tracks and isochrones of Baraffe et al. (1998). It can be seen that both HIP 57269 A & C lie above the main sequence and on the same isochrone taking into account the errors in photometry and conversion to temperature from their spectral type. The temperature for all stars in the diagram were derived using Kenyon & Hartmann (1995). The photometry was taken from various sources (the references can be found in Torres et al. 2003) and the distance to the individual objects was taken from Hipparcos or from Frink (2001) when possible, for the other stars we use a mean distance of 61.5 pc. GJ 3780 and HIP 56244 are unrelated foreground stars. TW A-9 B and TW A-15 A&B are also located on the lower right below the main-sequence, most certainly because the assumed mean distance of 61.5 pc to TWA may be different to the true distance of these stars.

\[ V = 17.7 \text{ km/s}, W = -5.6 \text{ km/s}, \text{Torres et al.} (2002) \] and it is more consistent with the star being a Pleiades super cluster member (Chereul et al. 1999).

HIP 57269 (component A: $V=9.34$ mag) is a common proper motion triple star with the secondary (component B) being a $V=10.48$ mag companion at a position angle of 306° and 0.430” separation (Fabricius & Makarov 2000) and the third star (component C) with $V=13.5$ mag at a position angle of 349° and 9.6” separation (Hipparcos catalog) (see also Fig. 5). The component C also shows Lithium absorption at 6707 Å (Fig. 6). Multiplicity is typical for young stars.

**4. H-R diagram**

We use the Tycho $V_T$- and $B_T$-magnitudes for component A (Fabricius & Makarov 2000) only to convert to luminosity, and to place it into the H-R diagram at a temperature of 4990 ± 100 K at a spectral type of K1/2V. In the H-R diagram (Fig. 4) HIP 57269 A lies above the main sequence, with an age of 40 ± 10 Myrs and a mass of 0.88 ± 0.05 $M_\odot$ compared to tracks and isochrones of Baraffe et al. (1998). This age is comparable to the age of TWA-19A.

We also include the wide companion HIP 57269 C in the diagram. Assuming that the star is at the same distance as the component A, the star has an age of 50 ± 10 Myrs, consistent with A and a mass of 0.75 ± 0.05 $M_\odot$. This star is clearly
younger than the TWA-9A and it lies on the same isochrone as TWA-7 and TWA-18.

Song et al. (2002) argue that HIP 57269 not a member of TWA because the Li EW is more consistent with a 30 Myrs star rather than a 10 Myrs, and that it lies on the main sequence on a specific set of the Siess et al. (2000) models.

Fabricius & Makarov (2000) give Tycho $B_7$ and $V_7$ for the components HIP 57269 A & B separately. Transforming those to a Johnson V-magnitude and calculating the absolute magnitude, HIP 57269 A appears above the main-sequence on the 30 Myrs isochrone using the Siess et al. (2000) model shown in the paper of Song et al. (2002). Given the error-bars, the star may be consistent with an age of 10 Myrs in the Siess et al. (2000) tracks.

5. X-ray emission

The region of TW Hydrae was observed during the ROSAT all-sky survey (RASS) using the Position-Sensitive Proportional Counter (PSPC) in scanning mode. A total of 127 sec have been taken, making it possible to detect HIP 57269 clearly with a maximum likelihood (ML) of 268.7. The source has a count-rate of $0.75 \pm 0.08$ cts/sec. The count-rate range for single or unresolved TWA members is $0.11 \pm 0.06$ cts/sec to $0.66 \pm 0.12$ cts/sec (Stelzer & Neuhäuser 2000). The triple HIP 57269 appears to be the X-ray brightest TW A member (candidate), not surprising, because it is an unresolved multiple in the RASS, it has a relatively close distance, it shows flare activity (as flare star), and it has one of the earliest spectral types in TWA. A high level of X-ray activity is a strong youth signature.

The PSPC provides some spectral information, allowing to calculate hardness ratios:

$$HR1 = \frac{cr_{H1} + cr_{H2} - cr_S}{cr_{H1} + cr_{H2} + cr_S}$$

$$HR2 = \frac{cr_{H2} - cr_{H1}}{cr_{H1} + cr_{H2}}$$

where $cr_{S}, cr_{H1}, cr_{H2}$ denote the count-rates in the three ROSAT-PSPC energy bands soft (0.1 - 0.4 keV), hard 1 (0.4 - 0.9 keV) and hard 2 (0.9 - 2.1 keV) respectively. See Tab. for the ROSAT data. These hardness ratios for HIP 57269 are typical for TWA (HR1: -0.31 to 0.58 and HR2: -0.29 to 0.53, Stelzer & Neuhäuser 2000)

The RASS observations of field rs932622 do not show flare activity for HIP 57269. Follow-up XMM spectroscopy and variability monitoring as well as high angular resolution X-ray imaging by Chandra would be interesting.

| name          | RASS ML | HR1    | HR2    |
|---------------|---------|--------|--------|
| HIP 57269     | 0.75 ± 0.08 | 268.7  | -0.27 ± 0.10 | 0.04 ± 0.18 |
| HIP 56244     | 0.79 ± 0.06 | 600.0  | -0.35 ± 0.07 | 0.27 ± 0.27 |
| GJ 3780       | 0.15 ± 0.32 | 71.6   | -0.28 ± 0.16 | 0.05 ± 0.27 |

Fig. 5. HIP 57269 A with companion C and a few more companion candidates labeled cc 1 to cc 4 detected in our SofI H-band image; superimposed are the slit orientation for follow-up spectroscopy with SofI in the same run and ISAAC later on. Slit widths are not to scale.

6. Near-infrared imaging of HIP 57269

We imaged HIP 57269 in the H-band with the Son of Isaac (SofI)\(^1\) at the 3.5 m New Technology Telescope (NTT) of the European Southern Observatory (ESO) on La Silla, Chile, on 2001 Dec 8 from 08:38 h to 08:58 h UT with 500 times 1.2 s integrations. The SofI detector is an Hawaii HgCdTe 1024 x 1024 array with 18.5 $\mu$m pixel size. We used the small SofI field with its best pixel scale for better angular resolution and determined the pixel scale by comparing the separations between several stars on other images taken in the same night with 2MASS images of the same fields to be $0.150 \pm 0.002''$ per pixel. Darks, flats, and standards were observed in the same nights with the same set-up and data reduction was done with eclipse\(^2\) version 3.8, a C-based software library. While eclipse is made for VLT data reduction, like e.g. the Infrared Imaging And Array Camera (ISAAC), and not guaranteed to work for SofI data, it also does work for SofI imaging data reduction (dark, flat, shift+add); after all, SofI is the Son of Isaac. See Fig. for the final co-added image of HIP 57269 and its surroundings. The FWHM in the final image is 0.9''.

The bright object 8.5'' SE of HIP 57269 AB is the known wide companion HIP 57269 C. We label the additional companion candidates cc 1 to cc 4 (cc for companion candidate) considering only those candidates within (somewhat arbitrary) 1000 AU, i.e. 16.6''. The faint HST standard stars S361-D and S754-C (Persson et al. 1998) were used to obtain the H-band magnitudes of HIP 57269 AB and C as well as its companion candidates, see Tab.\(^4\) (±0.2 mag). Whether the companion candidates are truly bound companions to HIP

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1\) see www.ls.eso.org/lasilla/Telescopes/NEWNTT/
2\) see www.eso.org/projects/aot/eclipse/
57269 can be decided on the bases of spectroscopy and/or proper motion follow-up observations. 2MASS data of this field are not yet available.

Table 4. HIP 57269 and companion candidates

| Name           | Separation ["] | H      | Spec type |
|----------------|-----------------|--------|-----------|
| HIP 57269 A    | primary         | 7.1*   | K1/2V     |
| HIP 57269 C    | Δα = 5.11, Δδ = -6.74 | SE     | 9.6       | K4-6       |
| HIP 57269/cc 1 | Δα = 7.18, Δδ = 12.48 | NE     | 10.7      | K5-7       |
| HIP 57269/cc 2 | Δα = -0.43, Δδ = 6.74 | NW     | 12.8      | G-M        |
| HIP 57269/cc 3 | Δα = -10.22, Δδ = -4.65 | NW     | 15.3      | mid-K      |
| HIP 57269/cc 4 | Δα = 10.15, Δδ = -8.68 | SE     | 15.2      | ?          |

*: Combined H-band magnitude of A & B

7. Spectroscopic follow-up of companion candidates

To verify or reject the companion candidates as real companions or unrelated background objects, we have taken follow-up spectra, both in the optical and in the infrared (for cc 1 through cc 3).

Optical spectra have been obtained with DFOSC at the 1.54 m Danish telescope located at ESO La Silla on 2002 January 24th for both HIP 57269 C and HIP 57269/cc 1 to determine their spectral type and to check for Lithium absorption, a youth indicator, which should be present, if the objects were real companions, i.e. as young as the primary. Figure 6 shows part of the spectrum taken with DFOSC at La Silla of HIP 57269 C and cc 1. Lithium is detected in the HIP 57269 C.

Infrared spectra have been obtained with SofI in the night 9 Dec 2001 between 08:35 h and 08:56 h UT. We took 40 spectra with 30 sec exposure each through a 1" slit with a red grism including both the H- and K-band (1.53 to 2.52 µm) with a resolution of R ≃ 1000. Data reduction was done in the usual way using IRAF: Dark subtraction, normalization, flat fielding, sky subtraction, wavelength calibration, and co-adding the spectra. The spectra were not flux-calibrated. The final K-band spectra of HIP 57269 A, C, and cc 2 are shown in Fig. 7. HIP 57269 A is known to be a K1/K2-type dwarf star (see Fig. 6), and the spectral type of HIP 57269 C was just determined to be K5 ± 1 by us (Fig. 6).

Our IR spectra are consistent with those spectral types, we can see the typical Na, Mg, and Ca lines as well as weak CO molecular bands, but no Br γ lines which would be typical for earlier types. Unfortunately, the spectrum of cc 2 is very noisy, so that it is hard to determine the spectral type. Na and Br γ are very weak or not present at all, CO bands are also weak, so that it is a dwarf star between early-G and late-M. It is definitely not an L- or T-type object. If cc 2 would be a real companion, given the magnitude difference between primary and cc 2, the object should be below the sub-stellar limit with an early-L spectral type (at the same age and distance as the primary), which we can exclude from our spectrum. Hence, cc 2 is a background object.

Then, we took H-band spectra of cc 1 and 3 with the Infrared Spectrograph and Array Camera (ISAAC, 1024 by 1024 ESO-Hawaii chip) at the ESO 8.2 m telescope Antu, Unit Telescope No. 1 (UT1) of the Very Large Telescope (VLT) on Cerro Paranal on 19 March 2001 between 07:20 h and 08:16 h UT in service mode, 28 spectra with 60 sec each through a 1" slit. The slit was aligned such that both cc 1 and cc 3 were on the slit, but that the bright primary HIP 57269 A was outside of the slit. In the acquisition image and during the spectroscopy, the seeing was around 0.4" to 0.5". Darks, flats, arcs, and spectrophotometric standards were taken in the same night. Data reduction was done in the standard way: dark subtraction, normalization, flat fielding, sky subtraction,
Fig. 8. Spectra taken with ISAAC at the VLT in March 19th 2001. For the alignment of the slit see Fig. 5. We show a spectrum of TWA-5 A (M1) for comparison and we determine the spectral type of cc 1 to K6 and of cc 3 to mid-K.

wavelength calibration, and co-adding the spectra. Both objects are clearly detected in the final co-added spectrum, see Fig. 8.

The companion candidate HIP 57269/cc 1 was shown to be K5-7 in Fig. 4 above, using the optical DFOSC spectrum. This is consistent with the IR spectrum, where we can see the typical Mg and Si lines and the CO bands; and the peak emission is more in the blue than in, e.g., the young M1 dwarf TWA-5 A shown as comparison (taken from Neuhäuser et al. 2000), so that HIP 57269/cc 1 is a bit hotter than TWA-5 A. Because HIP 57269/cc 1 does not show Lithium absorption (in its optical spectrum, Fig. 4), it is not a companion. HIP 57269/cc 3 is very similar to HIP 57269/cc 1, with the Mg and Si being slightly weaker, i.e. of spectral type mid-K. Given the spectral type (mid-K) and its faintness in the IR, HIP 57269/cc 3 cannot be a companion to HIP 57269 A; as a true companion, it would be a low-mass brown dwarf with spectral type L (similar for cc 4, for which we did not obtain spectra, yet). Hence, HIP 57269/cc 3 is an unrelated background K star. HP 57269 is a hierarchical triple with a close pair A & B and a wide companion C.

8. Summary

Is HIP 57269 a member of TWA? The distance (48.49±6.54 pc), the location in the sky and the spectral type, the position in the H-R diagram, the $v\sin i$ and X-ray emission are very similar to the other confirmed TWA-members. It is a visual binary with a known radial velocity companion, in total a triple system, which is typical for young stars. But the space motion, as well as the Lithium absorption suggest that it is more likely a young star belonging to the Pleiades super cluster. It is clearly a pre-main sequence star. The other companion candidates cc 1 - cc 4 are likely not members of the HIP 57269 system nor of TWA.

Acknowledgements. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France. R.N. wishes to acknowledge financial support from the Bundesministerium für Bildung und Forschung through the Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR) under grant number 50 OR 0003. We would like to thank the ESO User Support Group for assistance, the ISAAC team for the VLT service mode observations and also the NTT team with O. Hainaut, L. Vanci, and M. Billeres for support during the SofI observations.

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Acknowledgements. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France. R.N. wishes to acknowledge financial support from the Bundesministerium für Bildung und Forschung through the Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR) under grant number 50 OR 0003. We would like to thank the ESO User Support Group for assistance, the ISAAC team for the VLT service mode observations and also the NTT team with O. Hainaut, L. Vanci, and M. Billeres for support during the SofI observations.