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"FLARE STARS IN THE ORION NEBULA REGION" BY HARO & CHAVIRA (1969). OVERVIEW FROM TONANZINTLA PLATES TO THE X-RAY SPACE MISSIONS

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RESUMEN

Se resumen los principales resultados del artículo "Flare stars in the Orion Nebula Region" de G. Haro y E. Chavira, 1969, BOTT, 5, 32, 59. Se describe el impacto que tal investigación ha tenido en los estudios de las estrellas ráfaga, presentando resultados de datos recientes en la región de la nebulosa de Orión. Se mencionan también algunas prospectivas futuras de tal dirección de investigación.

ABSTRACT

The main results of the paper "Flare stars in the Orion Nebula Region" by G. Haro and E. Chavira, 1969, BOTT, 5, 32, 59 are revisited. The impact of such investigation on the research of flare stars is described, presenting results of recent data in the Orion Nebula region. Some future prospects of such line of research are also mentioned.

Key Words: circumstellar matter — ISM: clouds — open clusters and associations: individual (M42) — stars: flare — stars: pre-main sequence — X-rays: stars

1. INTRODUCTION

In this contribution the main results of the Haro & Chavira (1969) paper *Flare stars in the Orion Nebula Region* are reviewed. Since the investigation of flare stars at Tonanzintla was the effort of more than two decades, other papers by Haro and collaborators are also quoted. A re-examination clearly shows that the observational material and the conclusions in those papers contain already many of the basic concepts of recent research on magnetically active solar-type stars, in particular of low-mass ($M < 2.5\ M_\odot$) pre-main sequence (PMS) stars or T Tauri stars. Therefore, throughout this contribution several of the concluding remarks from the Haro et al. papers are incorporated in italics, while their relevance on recent research on flares in PMS stars is commented using data from ground-based optical, infrared, and space X-ray observations in Orion and in other star forming regions (SFRs).

2. SEARCHING FOR FLARE STARS WITH THE TONANTZINTLA SCHMIDT CAMERA

The observational strategies and techniques are very well described in the Haro (1968) and Haro & Chavira (1969) papers. Thus, only some relevant points are recalled here. Each photographic plate at the Tonantzintla Schmidt camera covers a corrected field of view of $\sim$4 × 4 square degrees. To search for flare stars, Haro and collaborators performed multiple exposures in each plate as follows: normally five-to-six consecutive U-band exposures of 15 minutes each were done; the different exposures were shifted in right ascension by about 10 arcsec, with less than one second of delay between each exposure. Thus, a complete observation in a single plate lasted between 75 to 90 minutes. With this technique, many flare stars were discovered by Haro (1964) and called *flash stars* to distinguish them from the UV-Ceti type stars.

The search continued for about two decades revealing more than 320 flare stars in about 16 square degrees around the Orion Nebula. The spatial distribution of these objects, over-plotted on the DSS2 IR image, is shown in Figure 1. The latter is similar to the Plate 3 presented in Haro (1968), but here the whole sample of 321 flare stars reported as "Haro Parsamian RAfaga" (HPRA) stars in the *Simbad* catalog is shown and the approximate areas corresponding to the Ori OB1c and Ori OB1d sub-groups, as reported in Figure 6 by Bally (2008), are indicated. The contrast effect due to the strong nebular emission and/or high extinction in the densest regions prevented the detection of flare stars in M42. Thus, the number of stars showing flares was observed to decrease drastically towards the Trapezium. However, the recent *Chandra* Orion Ultra Deep Project (COUP, Feigelson et al. 2005, and references therein), a nearly continuous 13-day X-ray observa-

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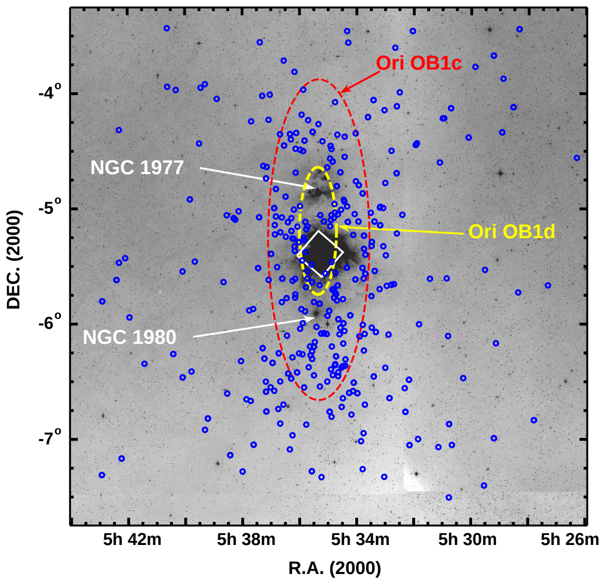

Fig. 1. Spatial distribution of the flare stars (small open circles) around the ONC, overplotted on the DSS2 IR image. The approximate areas occupied by the Ori OB1c and Ori OB1d sub-groups are represented by the dashed elipses. The white square in the center shows the area covered by the COUP X-ray observations.

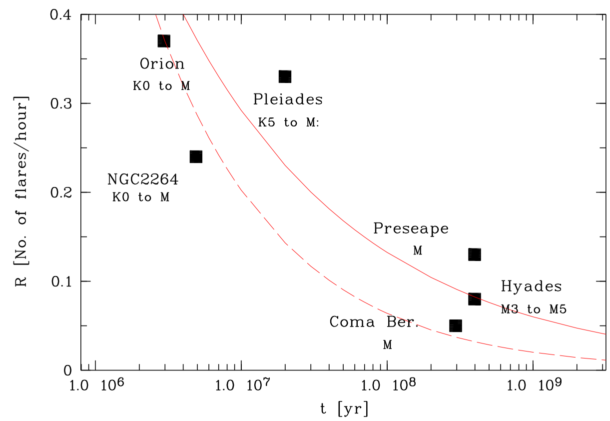

Fig. 2. Rate of flares versus age for the regions and clusters investigated with the Tonantzintla Schmidt telescope. The figure summarises the main results reported in Table 9 of the Haro (1968) review paper. The aggregates and corresponding spectral-type range of the flare stars are indicated. The continuous line represents the power-law fit with index $\alpha \approx -0.4$ to all the data, while the dashed one represents the Skumanich law, $\alpha = -0.5$, normalized to the flare rate and age of Orion.

tion of M42 (see location in Figure 1), detected many X-ray flares in the Trapezium region.

As concluded in the Haro (1968) and Haro & Chavira (1969) papers, the spatial distribution of flare stars follows the one observed for T Tauri and Orion variables in the region, with a clear concentration of objects towards the Orion Nebula Cluster (ONC); a similar spatial distribution of flare stars was observed in other clusters and aggregates (Haro 1968): *it seems evident that most flare stars belong to stellar clusters and have a nonrandom spatial distribution which follows the general pattern of the young* ($< 10^9$ *years) galactic aggregates.*

It is remarkable that the flare stars tend to concentrate in the areas of the Ori OB1c and Ori OB1d sub-groups, approximately following the south-north distribution of the NGC 1980, Orion Nebula and NGC 1977 clusters.

3. PROPERTIES OF FLARE STARS IN ORION

This subsection summarizes the properties of the flare stars in Orion as presented in the Haro & Chavira (1969) paper, as well as in the Haro (1968) review paper. The properties refer to: type and rate of flares, spectral types, emission line spectrum, incidence and nature of the flares and energetics. Comparisons with the results of previous investigations at Tonantzintla of flares stars in open clusters (e.g. Pleiades, Coma Berenices, Praesepe, Hyades) are also included.

3.1. *Type of flares*

The light curve of flare stars is characterized by a sudden, unpredictable rise to a maximum, followed by a slower, but still rapid, decline. A complete flare event may last from a few minutes to a few hours. Haro & Chavira distinguished basically two types of flares in their sample, namely the *pure fast flares*, characterized by a remarkably rapid and conspicuous increase of flux in the light curve, and the *slow flare-ups*, in which the rise from quiescence to maximum lasts more than 45 minutes. Only 7 of the 254 flares detected in the Haro & Chavira (1969) sample showed the slow flare-up features, while at least 70% corresponded to the typical pure fast flares. Haro & Chavira (1969) concluded that about 25% of the flare stars in Orion could be recognized as irregular variables of the classical T Tauri or RW Aurigae type. Examples are the well known T Tauri stars YY Ori, NS Ori, and SU Ori.

3.2. *Rate of flares and the Skumanich law*

The results in Table 9 by Haro (1968) on the rate of flares in clusters and aggregates, provide insight on the decay of stellar magnetic activity with age. Since flares are generated by explosive magnetic reconnection in the atmosphere of active stars, their rate, in homogeneous groups of stars, can be used as a diagnostic for the average level of stellar magnetic activity. Figure 2 shows the flare rate, R, as a function of age, t, of the clusters and aggregates investigated in Tonantzintla. Despite the low number statistics, a power-law fit, $R \propto t^{\alpha}$, yields $\alpha \approx -0.4$. This power-law index recalls the observation by Skumanich (1972) on the decay of the Ca II emission which varies as the inverse square root of the age. Although the Skumanich law (dashed line in Figure 2) formally predicts a faster decay of the flare rate than observed by Haro (1968) for the Pleiades, Hyades and Preseape, the result that stellar magnetic activity decays with age was already implicit in the Tonantzitla 1960's data. Note, however, that a Skumanich-type law fits fairly well the data for Orion, NGC 2264 and Coma Berenices.

3.3. *Spectral type*

The *spectral types of the flare stars in the Orion Nebula region go from G up to early M's. The great majority have a K-type spectrum.* The comparison of the spectral types of flare stars in aggregates of different age led Haro & Chavira (1969) and Haro (1968) to conclude that a relationship between age and spectral type range exists for flare stars, in the sense that the younger the aggregate, the earlier the hot end of spectral type range. They concluded: *independently of the original differences in total mass or coeval or not coeval star generations, the last vestiges for the flare objects would be represented by dMe stars*; thus, flares in stars earlier than M-type are not expected in old associations (Figure 2).

It is known at present that the spectral types of low-mass PMS stars range from late G down to late M. The detection of flares in "early-type" (G-type) only for very young stars could be due to the energy released by flares and contrast reasons. Very powerful flares occurring in young and very active stars can be detected also against a strong quiescent photospheric emission. On the other hand, the fact that the flare stars in Orion revealed by Haro & Chavira (1969) were not cooler than early M was mainly due to the sensitivity limit of the Tonantzintla Schmidt plates. X-ray observations with the *XMM-Newton* and *Chandra* satellites have shown that very low-mass stars and even sub-stellar objects may flare-up (Rutledge et al. 2000; Stelzer 2004; Stelzer et al. 2006, and references therein).

3.4. *Emission line spectrum*

The objective-prism observations with the Tonanzintla Schmidt camera led to the discovery of a large number of Hα emission line objects in Orion (Haro 1953) that were then associated in many cases with flare stars. The emission line spectrum of many flare stars was observed to be indistinguishable from that of T Tauri stars, but the discovery of "pure-flash" objects, lacking the typical strong emission lines of classical T Tauri stars (c.f. Figure 3), led Haro (1964) to predict a wider family of low-mass PMS stars. This will be further discussed in § 4.

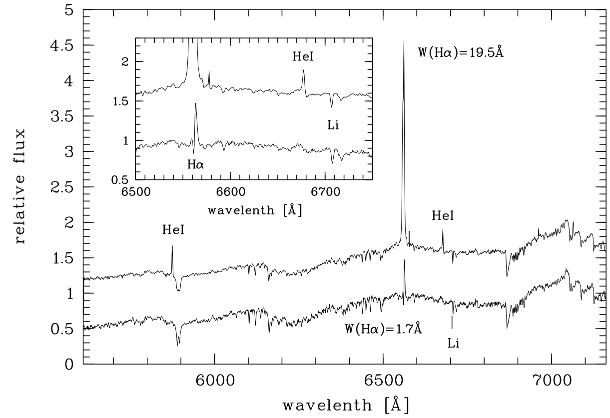

Fig. 3. Example of the Hα emission line variability of IRASF 13052-7653NW, a M0.5 T Tauri star (Alcalá et al. 2008; Spezzi et al. 2008) in the Chamaeleon II star forming region. For clarity the spectra were normalized to the flux at 6540 Å. The spectrum in flare state was vertically shifted. The inset shows a detail in the 6500–6750 Å range, in which the Li I λ6707.8 Å absorption line (W_{Li} = 540m Å) is clearly seen. Adapted from Alcalá et al. (2010, in preparation).

Variability of the emission line spectrum, very similar to the one observed in T Tauri stars, was also detected by Haro & Chavira (1969) in several of the flare stars in Orion: *Although some flare stars have shown the Hα emission only once in our plate collection –an event corresponding probably to a flare-up– there are others that permanently show this bright line even if its relative intensity varies.* The latter type of variations led to the idea of a very rapid succession of flickering events (see § 3.5).

All low-mass PMS stars are spectroscopic variables to some degree, many of them exhibiting the same kind of line variability observed by Haro & Chavira (1969). Figure 3 shows an example in which the strength of the Hα emission line increases by about one order of magnitude; the He I λ5876.7Å and λ6678.7Å lines are clearly seen in emission when the Hα equivalenth width is about 20Å. However, the many strong emission lines, typical of classical T Tauri stars are not present. The

He I λ5876.7 line is the $4^3D \rightarrow 3^3P$ transition, and the He I λ6678.7 line is its singlet $4^1D \rightarrow 3^1P$ analogue. The observed ratio of the intensities of these two emission lines in the spectrum of this star is 3:1, which corresponds to the ratio for a dense gas in thermodynamic equilibrium. Therefore, the spectroscopic variability shown in Figure 3 is most likely due to a flare-up event, similar to that observed by Haro & Chavira (1969) in the flare stars in Orion. This conclusion is reinforced by the observation of a huge intensification in the He I λ 5876 line, that changes from absorption to emission during the strongest flares in RS CVn systems (e.g. García-Alvarez et al. 2003; Frasca et al. 2008). This is usually accompanied by a strong change in the Hα line profile which, in addition to the strong intensity enhancement, displays wide emission wings indicative of vigorous mass motions. Both these effects are clearly visible in Figure 3.

3.5. *Incidence of flares*

From Haro & Chavira (1969): *photoelectric observations of extreme T Tauri stars may perhaps reveal the very rapid succession of flickering events in a matter of seconds or milliseconds – the integrated overall of which should appear as a "permanent" flare phenomenon.*

Later studies by Montmerle et al. (1983) explored the possibility that the X-ray activity of young solar-type stars in the Rho-Ophiuchi dark cloud were dominated by strong stellar flares. This investigation, using the EINSTEIN X-ray satellite, revealed an energy distribution of the young stars similar to the one derived for solar X-ray flares, i.e. a power-law distribution.

The pioneer Tonantzintla observations of flare stars already contain some clues on the above issues: from Table 3 of the Haro & Chavira (1969) paper, an exponential decrease of the number of stars that show flare-ups is apparent. Figure 4 shows the plot of the number of stars, N_*, versus their flare incidence, F, as resulted from that table. 203 (80%) of the flare stars were observed to flare-up just once, while only 1 star was observed to exhibit four or more flares.

Despite the very low number statistics on the incidence of flares, an attempt to a power-law fit $N_* \propto F^{-\alpha}$ yields $\alpha \sim 3.0$. This result can be compared with the incidence of X-ray flares of low-mass PMS stars as revealed during the COUP observations in the Orion nebula, reported by Caramazza et al. (2007) in the histogram shown in their Figure 3. The asterisks overplotted on Figure 4 represent the results of the X-ray observations, when normalizing

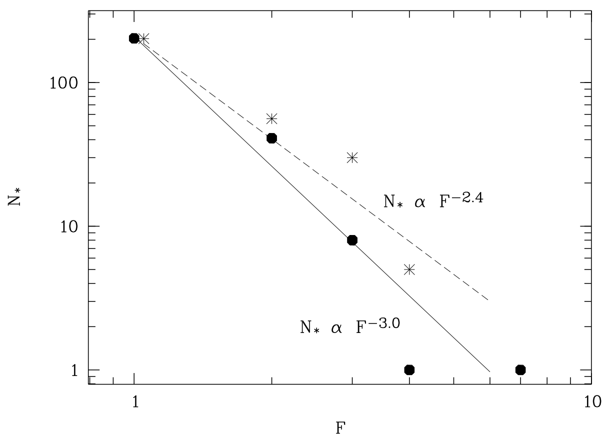

Fig. 4. Number of stars as a function of their flare incidence. The black dots represent the data from Table 3 by Haro & Chavira (1969), while the asterisks represent the results for X-ray flares derived by normalizing the histogram in Figure 3 by Caramazza et al. (2007) to the 203 flare-ups by Haro & Chavira (1969). The continuous line represents the best linear fit to the Haro & Chavira (1969) data, while the dashed one shows the best fit to the COUP X-ray data.

the first bin of the Caramazza et al. (2007) histogram to the 203 stars in the Haro & Chavira (1969) sample that flared-up only once. As can be seen, the incidence of flares observed in the UV by Haro & Chavira (1969) resembles the one in X-rays by Caramazza et al. (2007), though slightly steeper. The fit to the X-ray data yields $\alpha_X \sim 2.4$. The lower exponent for the X-ray flares could be indicative of an easier flare detection at X-ray energies due to the contrast between outburst and quiescent flux and to the instrument sensitivity. These results may be eventually explained in terms of the random nature of flares (c.f. Wolk et al. 2005; Caramazza et al. 2007, and references therein) and the flickering events pointed out in the Haro & Chavira (1969) paper, but the exponent recalls the power-law index derived for the flare energy distribution of solar-type PMS stars. The most energetic –i.e., largest-amplitude– flares are less numerous than the least energetic ones.

Therefore, under the assumption that all the stars represent a single type of flaring object seen at different activity states, and that the objects with more flare-ups are those with the highest level of magnetic activity, i.e. those undergoing the most energetic flares, and vice versa, one can conclude that the power law behavior of the Tonanzintla data may be interpreted in terms of the flare energy distribution of the type $dN/dE \propto E^{-\alpha}$. The latter has become an important tool for the study of flare energetics in low-mass PMS stars (e.g. Albacete Colombo et al. 2007; Caramazza et al. 2007, and references therein).

3.6. *Flare detection versus wavelength*

The investigations of flares carried out by Haro and collaborators were not only performed in the U-band, but also at longer wavelengths. However, despite the intensive search, not a single flare was detected in the I-band plates, even in flare stars of the T Tauri or RW Aurigae type: *This particular type of flare stars show noticeable variations during their "normal" irregular changes in the UBVRI light, yet not a single flare-up has been detected in the near infrared.* However, Haro (1964) was aware of the sensitivity problem in the I-band[2]: *In the near infrared (8400 Å) the flash variation is beyond the range of sensitivity of our photographic method, even in those cases where the amplitude in the ultraviolet is of the order of 4 to 6 magnitudes.*

The reason why the Haro et al.'s surveys did not detect the flare-ups in the I-band is just because the flare amplitude at those wavelengths is rather low. Technology allows now the investigation of flares in the near-IR. Flare-ups have been detected in the I-band in some of the Haro et al. flare stars in Orion. Frasca et al. (2009) report an intensive monitoring of stars in a $\sim 10' \times 10'$ field south of the Orion Nebula Cluster, using the REM (Rapid Eye Mount) telescope[3]. As an example, Figure 5 shows the light curve of V498 Ori. This object corresponds to the flare star #58 in Table 1A of the Haro (1968) paper. With the achieved photometric accuracy ($\sigma_I \approx 0.02$ mag, see error bar in the upper panel of Figure 5) the detection of the flare-up, with an amplitude $\Delta I \approx 0.30$ mag, was possible. The flare is barely revealed in the J-band and not detected in the H-band.

Another example of I-band flare is shown in Figure 6. Despite the flare amplitude of $\Delta I \approx 0.80$ mag, the simultaneous J curve does not show any clear variation. Being rather faint ($V \approx 17$ mag), this object falls below the sensitivity limits of the Haro et al. surveys. These examples show the difficulty of detecting flares in the infrared with the 1960's photographic plate technology, confirming the Haro (1964) conclusions. Measuring flares at different wavelengths allows to determine more accurate flare parameters (c.f. Hawley et al. 1995), as well as their energetics (c.f. § 3.8).

[2]Conventionally I-band was near-IR in the 1960's.

[3]REM is a 60 cm robotic telescope at ESO-La Silla, in Chile, that allows simultaneous photometry in the optical (V, R, I) and near-IR (J, H, K) bands.

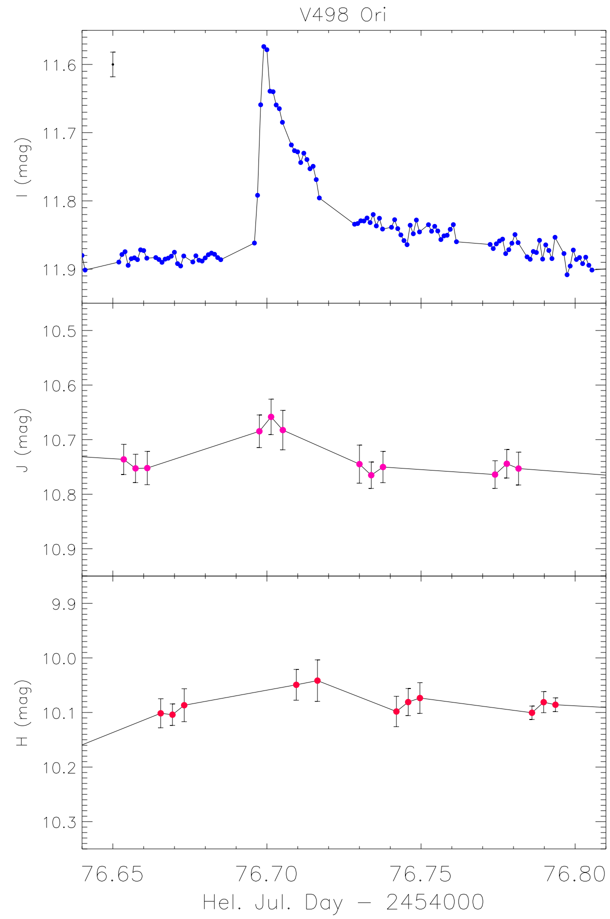

Fig. 5. Flare event of V498 Ori observed on December 7th, 2006 at 4:41 UT in the I band (upper panel). The simultaneous J and H light curves are also displayed in the two bottom panels. Adapted from Frasca et al. (2009).

3.7. *Flare strength versus magnitude*

Another interesting result of the Haro & Chavira (1969) paper is that *in general, the brightest flare stars during minima tend to show outburst of smaller apparent magnitudes than the fainter ones.* This has been reproduced in Figure 7, where the aforementioned trend is clearly seen. The trend is not evident for U between 15 and 17 mag, where the flare amplitude is approximately constant at about $\Delta U \approx 1.0$ mag, but with a rather large dispersion $\sigma_{\Delta U} \approx 0.6$ mag. For $U > 17$ mag the flare amplitude increases more or less linearly with U. The latter is basically a bias very likely due to the contrast between the flare luminosity and the quiescent U-band flux emitted by the star. However, the larger incidence of fast rotators, magnetically more active, among the faintest low-mass stars (e.g. Herbst et al.

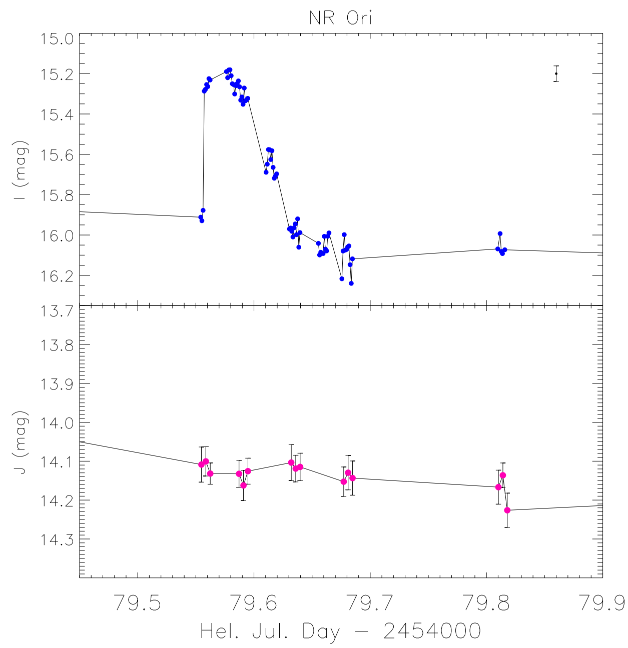

Fig. 6. Flare event of NR Ori observed on December 10th, 2006 at 3:30 UT in the I band (upper panel). The simultaneous J curve is shown in the bottom panel. Adapted from Frasca et al. (2009).

2002) may also play a role. On the other hand, recent X-ray observations of sources in the Taurus molecular clouds (Stelzer et al. 2007), indicate that relatively small X-ray events are more easily detected in bright stars, while events that are small in absolute terms are more easily detected in faint stars.

3.8. *Energetics of flares*

From the Haro (1968) paper: *in the intrinsically brightest flare stars found –for instance, in the Orion Nebula– the outburst of energy in the optical-wavelength region for a flare of about 1 mag will be at least* 10^5 *to* 10^6 *greater than in most conspicuous solar flares.* A rough estimate of the energy release can be derived from the flare amplitude and the magnitudes at minimum. The luminosity, $L_{\rm f}$, of a flare event of amplitude ΔU can be derived from:

$$L_{\rm f} = 4\pi d^2 \cdot F_U^0 \cdot W_U \cdot 10^{-0.4U_0}(10^{+0.4\Delta U} - 1), \quad (1)$$

where d is the distance, F_U^0 is the flux of a zero magnitude star in the U-band, W_U is the band-width, and $U_0 = U_{\rm min} - A_U$ is the extinction corrected U-band magnitude at minimum. For a typical flare star with $U_{\rm min} \approx 18$ mag and $\Delta U \approx 2$ mag (c.f. Figure 7), assuming $d = 460$ pc, $W_U \approx 630$ Å[4], an average extinction $A_V = 1.5$ mag (i.e., $A_U = 1.33 \cdot A_V = 2$ mag) and $F_U^0 = 4.2 \cdot 10^{-9}$ erg s^{-1} cm^{-2} Å^{-1} (Bessel 1979), equation 1 yields ΔL $\approx 1.5 \cdot 10^{32}$ erg s^{-1}. This means that the average 40 min flare events of the Tonantzintla stars typically released $\sim 4 \cdot 10^{35}$ erg. Likewise, the energy release of the Tonantzintla flare stars then ranges from about 10^{32} to 10^{36} erg. For comparison, the median energy release for the X-ray flares in the COUP sample in Orion is $10^{35.5}$ erg (Wolk et al. 2005). From similar arguments, the energy release in the I-band of the flares shown in Figures 5 and 6 is $\sim 2.7 \cdot 10^{35}$ erg and $\sim 6.4 \cdot 10^{34}$ erg for V498 Ori and NR Ori, respectively (Frasca et al. 2009).

[4]Band-width resulting by combining the 103aO photographic plates and the Corning 9863 filter (Lamla 1982)

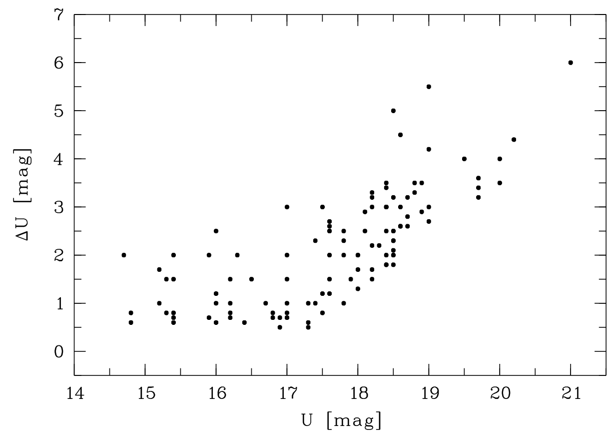

Fig. 7. Flare amplitude ΔU as a function of apparent magnitude U at minimum. The dots represent the data from Table 2 by Haro & Chavira (1969).

4. EVOLUTIONARY STATUS

The observational boundaries between PMS and flare stars are not evident in SFRs. The properties outlined above suggested a PMS nature for the vast majority of the flare stars in Orion. Thus, some of the most interesting conclusions by Haro & Chavira (1969) regard the evolutionary status of the flare stars: *It seems unavoidable to conclude that in the Orion Nebula aggregate there are flare stars that represent very different stages of evolution and, therefore, quite different ages or generations in any case, the flare stars in Orion cannot be significantly older (*$\approx 5 \cdot 10^7$ *years) than the flare stars in the Pleiades. The very young flare stars found in Orion (*$\approx 5 \cdot 10^5$ *years) are certainly absent from the Pleiades.* This led Haro an collaborators to conclude that star formation in Orion might have not been coeval. Later it was proposed that the Orion cloud complex witnessed several episodes of triggered star formation (Elmegreen 1992, and references therein). An age spread of the flare stars studied by Haro & Chavira (1969) is somehow expected because the area covered in their surveys is rather large (c.f. § 2). However, later studies focused on the ONC (Hillenbrand 1997) demonstrated that an age spread indeed exists, even in the "smaller" area of the ONC. Such studies, however, caution against the triggered star formation scenario. Subsequent detailed investigations of the age distribution of ONC members concluded that the star formation began at a relatively low level some 10^7 years ago, more recently undergoing a steep acceleration (Palla & Stahler 2000).

Two remarkable conclusions from the Haro & Chavira (1969) investigations, that had important implications for subsequent studies of low-mass PMS stars, regard the the existence of a wider family of T Tauri stars and of under-luminous objects.

4.1. *A wider family of T Tauri stars*

The spectra shown in Figure 3 illustrate another remarkable observation contained in the Haro (1964) paper, later confirmed by X-ray space missions: *we discovered the first "pure" flash type stars in the Orion Nebula; by "pure" we mean stars that show the flash phenomenon, but cannot be normally classified as T Tauri stars because they lack during minima the appropriate spectroscopic features. We were thus led to contemplate the possibility that the flash stars may be members of the wider T Tauri family; they may represent –we speculated– by-products or a later stage of the T Tauri stars in their evolution toward the main sequence.*

Studies with the EINSTEIN X-ray satellite in SFRs, established the existence of a new class of T Tauri stars, the so called *naked* T Tauri stars (Walter et al. 1988, and references therein), now better known as weak-lined T Tauri stars (wTTS) because they lack the conspicuous excess emission features typical of the Classical T Tauri stars (cTTS); yet, many wTTS appear to be as young as cTTS. Subsequent X-ray surveys with the *ROSAT*, *XMM* and *Chandra* satellites, and optical follow-up work revealed hundreds of candidates to wTTS in and around SRFs (Alcalá et al. 1996; Wichmann et al. 1996; Krautter et al. 1994, and references therein); most were confirmed as legitimate wTTS in high-resolution spectroscopic studies (Covino et al. 1997; Wichmann et al. 1999; Alcalá et al. 2000), and several were found to exhibit strong flare activity in X-rays (e.g. Preibisch, Neuhäuser, & Alcalá 1995; Caramazza et al. 2007, and references therein).

While in the early 1960's the presence of circumstellar matter in low-mass PMS stars was still debated, now it is well established that the lack of strong excess emission in wTTS is due to the absence of an optically thick accretion disk, which is typical of cTTS. Other investigations used the slope of the Spectral Energy Distribution (SED) in the mid-IR to classify young stellar (YSOs) objects in several IR classes (see § 5.1 in Evans et al. 2009, for a review), with cTTS and wTTS being normally classified as Class II and Class III IR-sources, respectively.

Recent studies have used the samples of wTTS to investigate disk evolution in solar-type stars (e.g. Padgett et al. 2006), but whatever the classification, the existence of low-mass PMS stars with ages of ~ 1 Myr and with very little or no circumstellar material, provides constraints on the timescales for the dissipation of circumstellar disks and the formation of planets. Observations with the Spitzer satellite have uncovered indeed a variety of YSO-disk systems at different evolutionary stages (Evans et al. 2009). For instance, some YSOs possess a SED with a deficit of flux in the near-IR, but a rise of emission at mid-IR and longer wavelengths. These YSOs are interpreted in terms of truncated disks, the truncation being attributed to several mechanisms, including photoevaporation and formation of planets (see Merín et al. 2010, and references therein).

4.2. *Under-luminous flare stars*

Although many of the flare stars lie above the main-sequence in the V vs. B-V diagram, there are some that lie very near or even below it. This intriguing result from the Haro & Chavira (1969) paper was not easily explained with the knowledge of the epoch, as the presence of circumstellar matter in PMS stars was still at the level of speculation; from Haro & Chavira (1969): *The infrared excess observed in T Tauri stars and related objects, including some flare stars, have led several authors to speculate about a possible thick circumstellar dust cloud which absorbs the visual radiation and reradiates in the infrared the energy produced by the parent stars.* The possibility of a circumstellar protoplanetary cloud, that absorbs the stellar radiation making the YSOs under-luminous, was proposed by Poveda (1967; see Rodríguez 2011). Hence, Haro & Chavira (1969) close their paper with the following suggestion: *In general, a comparative photoelectric photometry in the UBVRIJHKLM bands for T Tauri like objects lying above as well as below the main-sequence in the V vs. B-V diagram is quite desirable.*

Multi-wavelength photometry has been indeed essential not only to address the problem of under-luminous YSOs, but more importantly to investigate their surrounding matter. The determination of complete SEDs, as well as their modelling as circumstellar disks, allowed to establish that cTTS are systems with an optically thick accretion disk. Such models predict that the SEDs will vary according to disk mass and inclination relative to the line of sight (Dullemond et al. 2001; Robitaille et al. 2006, and references therein). Edge-on YSOs are preferentially detected only because of the scattered light, even at mid-IR wavelengths (c.f. Sonnhalter et al. 1995). Some examples of YSOs with edge-on disks, investigated with the Hubble space telescope, are reported in Padgett et al. (1999). Therefore, the under-luminous flare stars detected by Haro & Chavira (1969) in Orion most likely correspond to edge-on YSOs.

In conclusion, the Haro (1964) intuition on the existence of a wider family of T Tauri stars and the discovery of under-luminous YSOs were far-reaching results.

5. FUTURE PROSPECTS

Many aspects of flares still deserve further investigation. A few are briefly mentioned here that regard YSOs.

Multi-wavelength observations Continuous simultaneous observations, from X-rays to the IR, allow the investigation of the early impulsive flare phase and to probe whether accretion drives flare activity. For instance, optical data simultaneous to the COUP X-ray observations showed that accretion plays a secondary role for the bulk X-ray emission from PMS stars in the ONC (Feigelson et al. 2007). Also, multi-wavelength data may constrain better the flare physical parameters, like plasma temperature, emission measure and geometry (c.f. Hawley et al. 1995). The next generation of wide-field imagers at ESO like the VLT Survey Telescope (VST)[5] in the optical, and the Visible and Infrared Survey Telescope for Astronomy (VISTA)[6] in the near-IR, are suitable facilities to continuously monitore SFRs in a fairly efficient way, simultaneously to deep X-ray imaging and spectroscopy from the next generation of high-sensitivity space telescopes.

Onset of flares Observationally, it is not clear at present at which protostellar phase the magnetic activity begins. Strong flare activity has been reported to be common in Class I proto-stars (Feigelson et al. 2007), but not evident in the earlier Class 0 evolutionary phase (Preibisch 2004). However, recent work based on Spitzer data (Evans et al. 2009) demonstrate that distinguishing Class 0 from Class I YSOs may be ambiguous without very well sampled SEDs in the sub-millimeter regime. Bolometric temperature is probably a better discriminator than the SED slope in those early phases (Evans et al. 2009). Thus, an accurate characterization of the embedded protostars, concomitant with deep X-ray observations that can penetrate dense protostellar cores, are of crucial importance for establishing the onset of flare activity in YSOs. The Atacama Large Millimeter Array (ALMA) project will be a key facility for high-resolution studies of statistically significant samples of embedded sources.

Impact on proto-planetary disks The impact of YSO flaring on proto-planetary disks is crucial for disk evolution and planet formation (c.f. Feigelson et al. 2007). Theoretical models predict that stellar X-rays and EUV photons may ionize elements like neon in the disk "atmosphere" of YSOs. Spitzer spectroscopy has indeed detected [NeII] emission at 12.8 μm (Pascucci et al. 2007). However, it is not clear whether the line emission forms in the disk "atmosphere", in the YSOs outflows or in both. Ongoing high-resolution spectroscopic programs with VISIR at the ESO-VLT will shed light on the origin of the [NeII] emission. This will provide insight on the impact of energetic photons, possibly coming from flare activity, on protoplanetary disks. Comparison of observations with models of X-ray irradiated disks (e.g. Flaccomio et al. 2009) may constrain the disk/envelope parameters in models of YSOs at different evolutionary stages.

Improvements on MHD models of convective stars and the coupling with disks are obviously necessary to understand reconnection in star-disk magnetic fields.

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[5]Commissioning foreseen in 2010.
[6]In operation since winter 2009.

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