THE INTERMEDIATE-AGE OPEN CLUSTERS NGC 6940 AND IC 4651 AS SEEN THROUGH THE X-RAY WINDOW

GIANPIERO TAGLIAFERRI[1], TOMASO BELLONI[2]
[1] *Osservatorio Astronomico di Brera, Via Bianchi 46, I–22055 Merate, Italy (gtagliafmerate.mi.astro.it)*
[2] *Astronomical Institute "Anton Pannekoek", University of Amsterdam, Kruislaan 403, 1098 SJ Amsterdam, The Netherlands*

ABSTRACT. The ROSAT data on NGC 6940 and IC 4651 confirm that binary stars are still very active coronal sources at an age of $\geq$ 1 Gyr, and that good spatial resolution images in the X-ray band are a powerful instrument to investigate their evolution in clusters of different age. However, it is clear that an optical follow-up is necessary in order to better establish the physical nature both for the detected members of the clusters and for the objects still to be identified.

1. Introduction

A ROSAT PSPC (see Trümper 1983) observations of the old open clusters M 67 (~5 Gyr) led to the detection of a number of sources (Belloni et al. 1993). Indication of chromospheric activity has been found from most of the optical candidates (Pasquini & Belloni 1994). Similar results were obtained in a PSPC pointing of NGC 752 (~2 Gyr) (Belloni & Verbunt 1996).

In view of these results, we observed with the PSPC detector the two intermediate age open clusters NGC 6940 and IC 4651, in the framework of a project to cover the X-ray observational gap between old and young clusters.

2. NGC 6940

NGC 6940 in an intermediate age (~1 Gyr) open cluster at a distance of $\sim$ 900 pc, with an angular size of $27' - 40'$ (Trumpler 1930; Vasilevskis & Rach 1957) and a moderate E(B-V) = 0.05–0.30. NGC 6940 was observed with the PSPC at the end of 1993, for a net observation time of 7365 s. In the inner $20'$ of the PSPC FOV we detected 17 sources (Belloni & Tagliaferri 1997).

To identify the optical counterpart of the detected X-ray sources, we used the Palomar red plates from the Digitized Sky Survey and the catalogs of stars in the field of NGC 6940 by Vasilevskis & Rach (1957) and by Larsson-Leander (1960), who performed deep photometric studies of the region of sky around the cluster. We identified four of our X-ray sources with cluster members (Belloni & Tagliaferri 1997) and three of them are among the six binaries studied by Mermilliod & Mayor (1989) and with periods

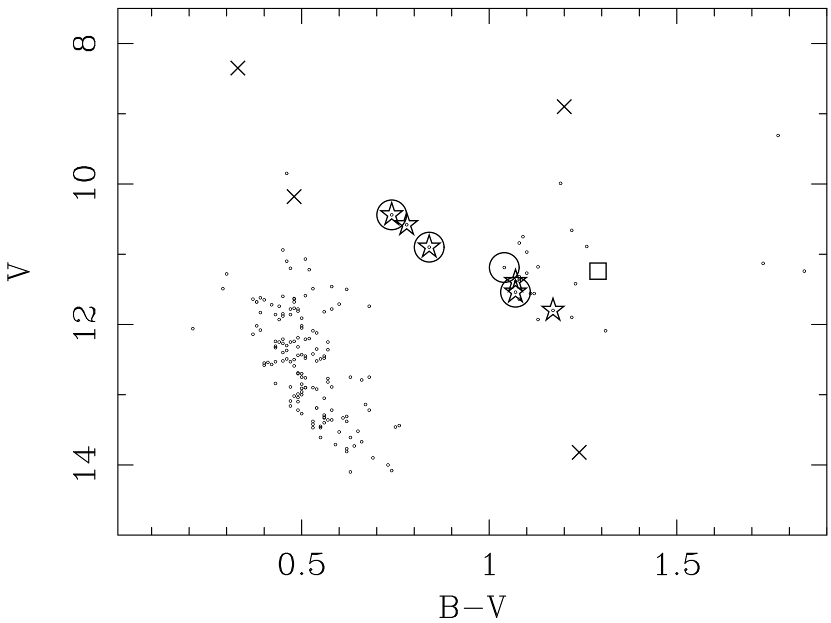

Fig. 1. Color-magnitude diagram for NGC 6940 (data from Larsson-Leander 1960, membership from Sanders 1972). Stars indicate binary systems, circles are X-ray detections with a member counterpart, crosses are X-ray detections with a non-member counterpart. The square is a star that we suspect to be also a cluster member (see text).

ranging between $\sim$ 54 and $\sim$ 3600 days. The fourth X-ray source identified as a member of the cluster is also a giant studied by Mermilliod & Mayor, who quote a probability of 87% against binarity. The six binaries detected by Mermilliod & Mayor and the four X-ray sources identified with cluster members (three are coincident) are all red giants, with the position of the three more luminous binaries shifted toward bluer colors, within the Hertzsprung gap (see Fig. 1).This is probably due to a composite type: a red giant primary and an A- or F-type main sequence secondary, with mass ratio larger than 0.8 (Mermilliod & Mayor 1989).

We also identify another source with a star classified as G8 III by Larsson-Leander (1960). It is not considered member of the cluster on the basis of proper-motion measurements (Vasilevskis & Rach 1957, Sanders 1972). However, we derive a distance of $\sim$ 900 pc, a value very similar to the distance of the cluster. Thus, it could be somehow associated with it (e.g. it could be a run a way member). This is shown also in Fig. 1, where this star (square symbol) lies in the region of the giant stars belonging to the cluster.

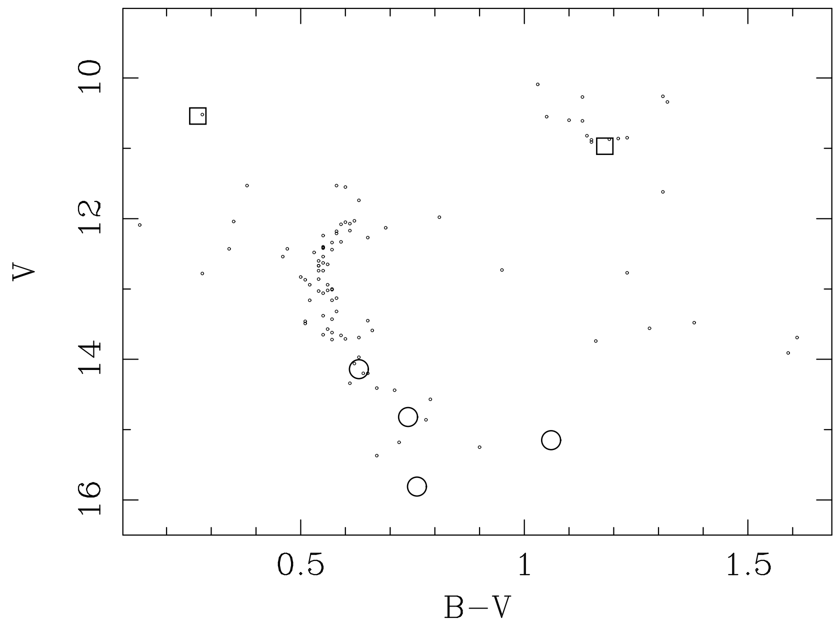

Fig. 2. Color-magnitude diagram for IC 4651. Squares are X-ray detections with a member counterpart, circles are X-ray detections for which we have both V and B–V, but no membership information. From this figure they all seem to belong to the cluster.

3. IC 4651

IC 4651 is an intermediate age ($\sim$ 2 Gyr) open cluster at a distance of $\sim$ 700 pc. It has an angular size of $\sim 15'$ and a low reddening of E(B-V) = 0.15 (Eggen 1971). IC 4651 was observed with ROSAT in September 1993 for a net observation time of 15213 s. In the inner $20'$ of the PSPC FOV we detected 25 sources.

Eight of these sources are identified with catalog stars. Of these, two are members of the cluster; a single line spectroscopic binary and a binary blue straggler. In Fig. 2 we plot the color–magnitude diagram for IC 4651 (data from Anthony–Twarog et al. 1988), together with six X-ray detections for which we could find both V and B–V values in the literature. From this figure it appears that, although we lack the membership information also the other four stars seem to belong to the cluster.

4. Discussion

As in the case of M 67 (Belloni et al. 1993) and NGC 752 (Belloni & Verbunt 1996), in NGC 6940 and IC 4651 we find that the majority of the detected members are binary systems, with X-ray luminosity values typically found in the RS CVn type of binaries, confirming that 1 Gyr old binary stars can still be extremely active coronal sources.

Two of the X-ray detected binaries in NGC 6940 are short period binaries, but one is not. Its detection as an X-ray source is puzzling. The same is true for the fourth X-ray source of the cluster that is not a known binary, and for the other X-ray source that that we identified with a giant star that we suspect to be also a member of the cluster. If both sources are single giants, it is not at all clear why they show such a strong X-ray emission. However, since one them is not classified as a cluster member, it was not included in the sample studied by Mermilliod & Mayor, leaving for this star the binary possibility open. A detailed optical investigation is needed in order to establish the nature of the X-ray emission of these stars.

All the identified members are red giants, or blue stragglers, in agreement with the presence of a saturation level. This has been found for different samples of active stars, e.g. for a sample of X-ray selected stars (Fleming et al. 1989), for a sample of flaring stars (Pallavicini et al. 1990) and for various young open clusters (Stauffer et al. 1994, Randich et al. 1995, 1996a). This means that the maximum X-ray luminosity possible for each star scales with the star's surface. In this scenario, the presence of a detection threshold could make all main–sequence stars unobservable, while bright giants are still detectable. Actually, for the nearer cluster IC 4651, there is the possibility that some of the stars detected by ROSAT could be main–sequence stars belonging to the cluster (see. Fig. 2).

References

Anthony–Twarog B.J., Mukherjee K., Caldwell N., Twarog B.A.: 1988, *Astron. J.* **95**, 1453.

Belloni T., Verbunt F., Schmitt J.H.M.M.: 1993, *Astron. Astrophys.* **269**, 175.

Belloni T., Tagliaferri G.: 1997, *Astron. Astrophys.* **in**, press.

Belloni T., Verbunt F.: 1996, *Astron. Astrophys.* **305**, 806.

Eggen O.J.: 1971, *Astrophys. J.* **166**, 87.

Fleming T.A., Gioia I.M., Maccacaro T.: 1989, *Astron. J.* **98**, 692.

Larsson-Leander G.: 1960, Stockholm Obs. Ann., 20, n.9

Mermilliod J.-C., Mayor M.: 1989, *Astron. Astrophys.* **219**, 125.

Pallavicini R., Tagliaferri G., Stella S.: 1990, *Astron. Astrophys.* **228**, 403.

Pasquini L., Belloni T.: 1994, in *Cool Stars, Stellar Systems, and the Sun*, J.-P. Caillault (ed.), ASP Conference Series, 64, 122.

Randich S., Schmitt J.H.M.M., Prosser C.F., Stauffer J.R., 1995, *Astron. Astrophys.* **300**, 134.

Randich S., Schmitt J.H.M.M., Prosser C.F., Stauffer J.R., 1996a, *Astron. Astrophys.* **305**, 785

Stauffer J.R., Caillault J.-P., Gagné M., Prosser C.F., Hartmann L.W.: 1994, *Astrophys. J. Suppl.* **91**, 625.

Trümper J.: 1983, *Adv. Space Res.* **2**, no.4, 241.

Trumpler R.J.: 1930, Lick Obs. Bull., **18**, 562.

Vasilevskis S., Rach R.A.: 1957, *Astron. J.* **62**, 175.

Vilhu O.: 1987, in *Cool Stars, Stellar Systems, and the Sun*, Eds. J.L. Linsky & R.E. Stencel, Lect. Notes in Phys., p. 291, Springer-Verlag Berlin