identification process was optimised to find as many clusters as possible by using all available sources of information, we have now achieved a highly complete cluster selection by just combining the ROSAT All-Sky Survey data and the COSMOS optical data base in a homogeneous way, completely controlled by automated algorithms. Additional information is only used in the final identification but does not influence the selection. This is a very important achievement in this survey work.

The data presented are still not fully complete in redshifts. But with data already obtained in January and September 1998 we can practically complete this data set (to 96%). An extended sample of REFLEX clusters down to a flux limit of $2 \cdot 10^{-12}$ erg s^{-1} cm^{-2} is already prepared and redshifts are available for more than 70% of the objects. This extended set of about 750 galaxy clusters will help very much to tighten the constraints for the power spectrum and extend it to larger scales. It will further enable us to investigate the cluster correlation function – in particular the X-ray luminosity dependence of the clustering amplitude, which is an issue not yet resolved. Finally, a complementary ROSAT Survey cluster identification programme is being conducted in the Northern Sky in a collaboration of the Max-Planck-Institut für Extraterrestrische Physik and J. Huchra, R. Giacconi, P. Rosati and B. McLean which will soon reach a similar depth and provide an all-sky view on the X-ray cluster distribution.

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Timing, Spectroscopy and Multicolour Imaging of the Candidate Optical Counterpart of PSR B1509–58

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1. Introduction

Optical counterparts have now been proposed for nine Isolated Neutron Stars (INSs). For some of them (the Crab and Vela pulsars, PSR B0540–69) the identifications have been confirmed through the detection of optical pulsations (with a tentative detection existing also for PSR B0656+14) or, in the case of Geminga, initially from the proper motion of the proposed counterpart. For the rest of the sample (PSR B1509–58, PSR B1055–52, PSR B1929+10 and PSR B0950+08), the optical identification still relies on the positional coincidence with a field object (see e.g. Caraveo 1998 and Mignani 1998 for a summary). Unfortunately, in most cases the intrinsic faintness of such objects hampers the timing of their optical emission, thus making necessary fast-photometry facilities attached to 4-m-class telescopes.

Among the uncertain cases, the best studied is certainly PSR B1509–58. With a dynamical age close to 1500 yrs, PSR B1509–58 is the youngest INS after the Crab. While its period (*P*=150 ms) is long compared with that of the similarly old Crab pulsar and PSR B0540–69, its spin down rate $\dot{P}$ (~ 1.5 10^{12}s s^{-1}) is the highest in the pulsar family. This made it possible to obtain an accurate measurement of the $\ddot{P}$ and thus of the pulsar braking index (Kaspi et al. 1994). Since PSR B1509–58 lies close to the geometrical centre of the plerionic supernova remnant MSH15–52 (Strom 1994), it may be one of the very few cases of a pulsar/plerion association. However, the ages of the pulsar and of the remnant are significantly different (Gaensler et al. 1998), casting doubts on the association.

PSR B1509-58 was first detected in X-rays by the Einstein Observatory (Seward & Hardnen 1982) and soon after in radio (Manchester, Tuhoy and D'Amico 1982) with a single pulse profile preceding in phase the broad, asymmetric, X-ray peak. Pulsations in the 90–600 keV range have been detected by BATSE (Matz et al. 1994) and OSSE (Ulmer et al. 1993) on board GRO while only an upper limit on the source flux at E $\geq$ 100 MeV was obtained with EGRET (Brazier et al. 1994).

In the optical, a candidate counterpart (V $\sim$ 22), coincident with the pulsar coordinates reported by Taylor, Manchester and Lyne (1993) – TML93 – was proposed by Caraveo et al. (1994a). Were this object indeed the pulsar, at a distance of 4.4 kpc (TML93), its optical emission would certainly be magnetospheric, which is also expected from its young age. However, the corresponding luminosity exceeds by a few orders of magnitude the value expected on the basis of the Pacini Law (Pacini 1971) i.e. $L_{opt} \propto B^4P^{-10}$ (where B is the pulsar magnetic field) which works for the other young pulsars (Pacini & Salvati 1987). A firm confirmation of the optical identification is thus of order. Of course, searching for optical pulsations at the radio period is the default way.

The results of timing of the candidate counterpart were first reported by Caraveo (1998) and soon after confirmed by the independent works of Chakrabarty & Kaspi (1998) and of

Shearer et al (1998). In all cases, no optical pulsations at the radio period were observed, thus leaving the problem of the identification open.

In the next sections we will discuss the results of detailed optical investigations of the PSR B1509–58 candidate counterpart performed by our group with the ESO telescopes. Apart from the fast photometry observations of Caraveo (1998), presented here in detail, the data set consists of both multicolour imaging and spectroscopy.

2. Data Overview

2.1 Timing

Optical timing of the Caraveo et al. counterpart was performed in May 1994 from the ESO 3.6-m telescope (Caraveo et al. 1994b). The telescope was equipped with the ESO fast (0.1 ms time resolution) photometer, a single-channel device with a GaAs photocatode sensitive in the range 3500–9000 Å, mainly used to search for an optical pulsar in SN1987A but also for the timing of PSR B0540–69 (Gouiffes, Finley and Ögelman 1992) and of the Vela Pulsar (Gouiffes 1998). A total of 9 observations, split in two adjacent nights, were performed (see Table 1) with two different filters i.e. a standard R and the *og590* which cuts at wavelengths shorter than 5800 Å. According to the seeing conditions, two different apertures were used with diameters of 7 and 4 arcsec, respectively.

Photon arrival times have been corrected for the Earth rotation and revolution (barycentric correction) using the JPL/DE200 FORTRAN code. The periodicity search was performed applying the standard folding technique. First, the whole procedure was tested using as a reference the ~ 5000-s observation of the slightly fainter (V ~ 22.5) PSR B0540–69 (see Fig.1). The procedure was then applied to the data of PSR B1509–58. Due to the better seeing and atmospheric conditions, we decided to concentrate our analysis on data taken the second night. For each observation, photon counts have been resampled in bins of 4 and 8 ms. The time series have been folded at different trial periods stepping ± 10^{-8} s from the expected period, computed using the ephemeris of Kaspi et al. (1994). For each trial period the corresponding χ^2 has thus been computed but no significant maximum was observed in the χ^2 distribution. The periodicity search was repeated using the whole data set of the second night (≃ 20,000 s) but no significant improvement was achieved. Using as a zero point the observation of a standard star (*V* = 16.125) from an E5 region of a Graham field, we could derive an upper limit *R* ~ 23–23.5 on the pulsed magnitude, which corresponds to a pulsed fraction ≥ 15%, similar to the value given by Chakrabarty & Kaspi (1998).

This means that if the optical candidate of Caraveo et al. is indeed the counterpart of PSR B1509–58, its pulsed fraction must be much smaller than for the Crab and Vela pulsar, which have pulsed fractions ~ 100% and ≥ 50%, respectively.

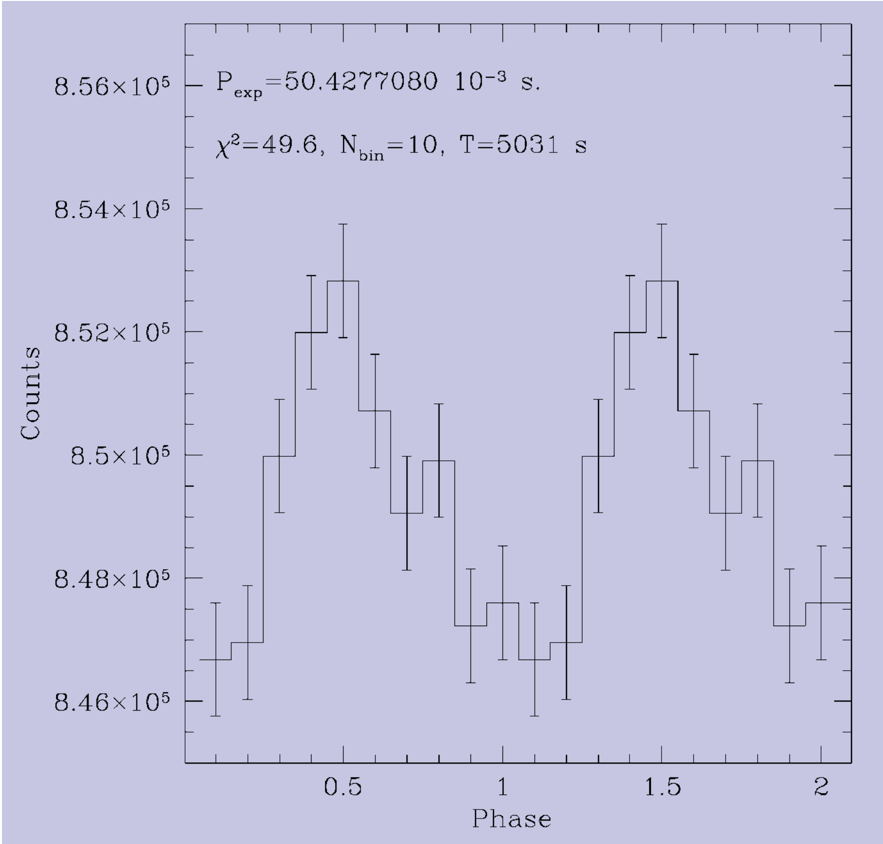

Figure 1: Light curve (≃ 5 ms/bin) of PSR B0540–69 folded over the expected period (P_{exp}) computed by time-propagating at the observing epoch the pulsar's $\dot{P}$ – $\ddot{P}$ according to the ephemeris of Gouiffes, Finley and Ögelman (1992). Two cycles are shown for clarity. A single broad peak is clearly visible in the light curve χ^2 ≃ 50), exactly as expected from previous fast photometry observations. The clear detection of the pulsar shows both the sensibility of the instrument and the correctness of our procedure.

Obs.#	*MJD*	*T (s)*	*r (arcsec)*	*CR (c/s)*	*Filt*	*Obj*
1	49478	1468	4	756	og590	PSR B1509-58
2		2821	4	825	og590	PSR B1509-58
3		462	7	2944	og590	PSR B1509-58
4		6305	7	3269	og590	PSR B1509-58
5		6097	7	1267	R	PSR B1509-58
6	49479	5031	4	1687	free	PSR B0540-69
7		3616	4	305	R	PSR B1509-58
8		2745	4	312	R	PSR B1509-58
9		6809	4	294	R	PSR B1509-58
10		6813	4	316	R	PSR B1509-58
11		4094	4	640	R	Graham std.

Table 1: Journal of fast photometry observations. Columns list the observing sequence, the observing epochs (MJDs), the duration of the single observations (s), the aperture diameter (arcsec), the count rate in the aperture (cts/s), the filter name and the target identifier.

2.2 Spectroscopy and Imaging

To investigate the possibility of a wrong association with a fore/background object, in June 1995 we performed spectroscopy of the object from the NTT. Three 90-minute, medium-resolution (2.3 Å/pixel) spectra were obtained with EMMI-Red (ESO Multi Mode Instrument) in the wavelength range 3800–8400 Å. Unfortunately, the very low S/N made it impossible to perform any spectral analysis of the source, apart from excluding the presence of strong emission/absorption lines.

Multicolour images were also collected from the NTT during different observing runs (see Table 2 for a summary). To complement and improve the first measures in V and R of Caraveo et al. (1994a) we collected longer exposures with SUSI in B, V and the first exposure in I in 1995. A second deep observation in *R* was obtained in 1997. After cosmic-ray rejection, bias subtraction and flat fielding, a zero point was computed for each filter using photometric standards in the Stobie and Landolt fields. These new observations yielded more accurate *V* (22.1 ± 0.1) and *R* (20.8 ± 0.1) magnitudes together with the first measurements in *B* (23.8 ± 0.3) and I (19.8 ± 0.1). In order to assess the colours of the object, an unknown but potentially important amount of interstellar absorption should be considered. X-ray spectral fittings give an $N_H \simeq 8 \times 10^{21}$ cm^{-2} (Becker & Trümper 1997) with an, at least, 50% uncertainty which implies a difference of about one magnitude on the colour indexes. Assuming that the object be at the pulsar distance of 4.4 kpc, it could be thus anything from a G star (for the lowest value of the N_H) to a much highly absorbed O or B star. To search for other possible candidates we have used our deepest exposure of the field (the 1997 one) taken with SUSI under better seeing conditions (~ 0.7 arcsec). The revised radio co-ordinates of PSR B1509–58, reported in Taylor et al. (1995) have been registered on the image using the UK STARLINK software ASTROM (Wallace 1990) and a reference frame given by several USNO stars identified in the SUSI field (2 × 2 arcmin). Adding in quadrature to the pulsar positional error (1.3 arcsec) an average uncertainty of 0.25 arcsec attached to the absolute position of the USNO stars, and the r.m.s. of the plate solution fit (0.42 arcsec) we can estimate a conservative error of 1.4 arcsec on our astrometry. The radio position of the pulsar is thus shown in Figure 2, marked by a yellow cross. As already noted by Caraveo (1998), the revised radio co-ordinates of PSR B1509–58 are slightly different from the old ones reported in TML93, also marked in Figure 2 (in blue). However, the associated errors (± 1 arcsec in both dimensions) leave room for a substantial agreement. The object inside the overlapping error circles is the candidate counterpart of Caraveo et al. (1994a).

As evident from Fig.2, no other source is visible inside the uncertainty regions, down to a lower limit of R ~ 25.

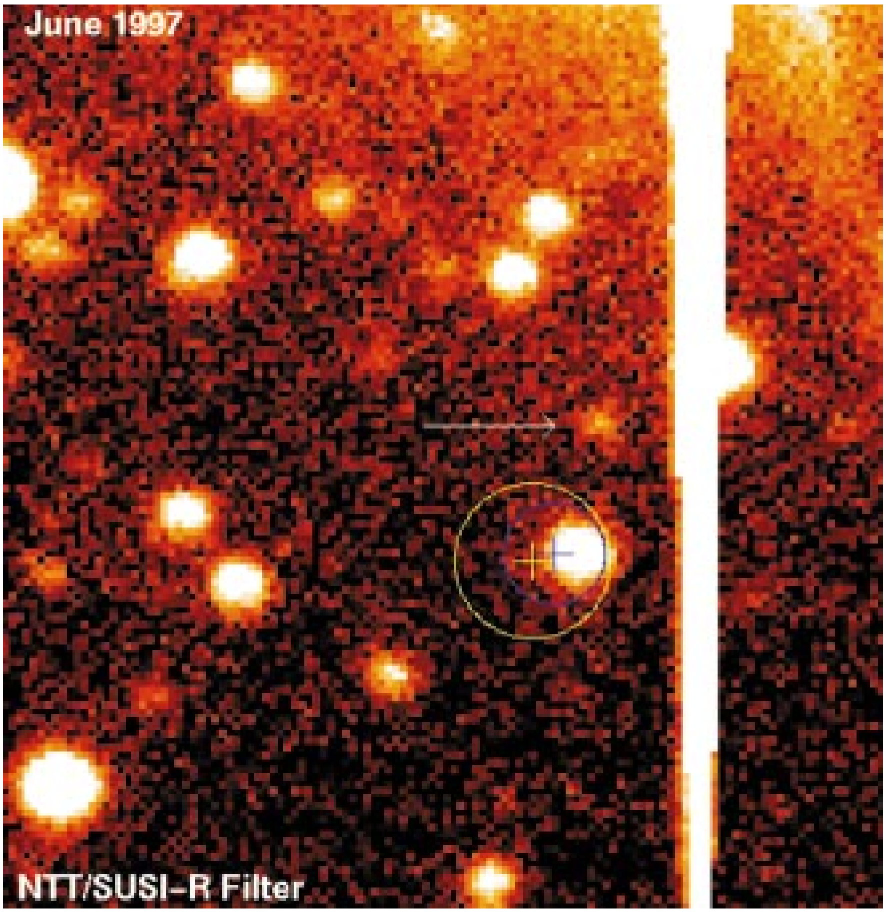

Figure. 2: 16 ×16 arcsec^2 R-band image of the field of PSR B1509–58, taken in June 1997 with the ESO/NTT. The image has been obtained with the SUperb Seeing Imager (SUSI) under sub-arcsec seeing conditions (Q 0.7 arcsec). The exposure time was 45 min. The pixel size of the CCD is 0.13 arcsec. The yellow cross marks the position of PSR B1509–58 computed according to the revised radio coordinates of Taylor et al (1995). The circle (r = 1.4 arcsec) corresponds to the uncertainty region associated to the pulsar position, resulting from the combination of the error on the radio coordinates (r ~ 1.3 arcsec), the average uncertainty on the absolute coordinates of the USNO stars (~ 0.25 arcsec) and the σ of the astrometric fit (~ 0.42 arcsec). The candidate optical counterpart of the pulsar proposed by Caraveo et al. (1994a) is visible inside the error circle. For completeness, the old pulsar position from TML93 (r ≃ 0.9 arcsec) is also shown in blue. The faint object (R ≃ 24) seen about 2 arcsec north of the pulsar position and marked by the arrow is too far to claim any association.

3. Conclusions

No pulsations were detected from the proposed optical counterpart of PSR B1509-58, thus adding more weight to the results obtained by Chakrabarty & Kaspi (1998) and Shearer et al. (1998). Unless invoking a peculiar-emission geometry, the lack of optical pulsations strongly argues against the identification of Caraveo et al. (1994a). Given the high interstellar absorption towards the pulsar, multicolour imaging does not help to constrain the real nature of the object. Spectroscopy, to be performed with the UT1 of the VLT, is thus needed. Were the optical identification of Caraveo et al. be disproved, the real counterpart of PSR B1509-58 is to be searched somewhere in the close surroundings. In this case, it must be fainter than R ~ 25. This is in agreement with the Pacini law (1971) which would predict for PSR B1509-58 a magnitude ~ 27.

Although this values is certainly within reach of the VLT (Mignani et al. 1999), if located a fraction of arcsec from the present candidate, such a faint object would be hardly visible from the ground even under exceptional seeing conditions. The situation would thus be similar to the case of PSR B1055-52, close (≤ 4 arcsec) to a ~ 14.6 magnitudes

Date	Det	Filt.	T	mag
July 93	EMMI-Red EMMI-Red EMMI-Red	V R B	5m 10m 5m	22.0 ± 0.2 20.8 ± 0.3 ⩾ 23
Jan 95	SUSI SUSI SUSI	B V I	20m 25m 5m	23.8 ± 0.3 22.1 ± 0.1 19.8 ± 0.1
Jul 97	SUSI	R	45m	20.8 ± 0.1

Table 2: Summary of the available photometry of the PSR B1509–58 candidate counterpart performed with the NTT from 1993 to 1997. Columns list the observing epochs, the detector used, the filters, the exposure times and the observed (not-dereddened) magnitudes. The July 1993 observations are the ones also reported in Caraveo et al. (1994a).

brighter field star and unresolved by the NTT/SUSI (Mignani et al. 1997). As in that case, high-resolution imaging of the region with the HST would be the only way to pinpoint the pulsar.

Acknowledgements

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The First X-ray Emitting Brown Dwarf

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The increasing number of brown dwarfs discovered in the last few years is rapidly opening the possibilities of studying a wide range of their properties and the ways in which these depend on essential parameters, such as the mass, the age, the rotation, or the environment. One of these properties is the magnetic field, which in principle should be expected to be important in fully convective objects such as brown dwarfs. The chromospheric X-ray emission, widely observed in M-type dwarfs (Neuhäuser 1997), has its origin in this magnetic activity. As such, it offers an observational tool to probe the interior of these objects, the mechanisms for the generation and maintenance of their magnetic fields, and the way in which the magnetic activity is affected by the basic parameters of the object. The detection of X-ray emission from brown dwarfs is thus of great importance to extend our understanding of the properties of stellar magnetic fields to the substellar domain, as well as to ascertain to what extent a small, substellar mass, and the consequent lack of a permanent nuclear energy source, can have an impact in the production and the evolution of a magnetic field.

Until recently, no conclusive evidence for X-ray emission from brown dwarfs had been found, as shown by an extensive search in ROSAT archive observations near the position of known bona-fide and candidate brown dwarfs (Neuhäuser et al. 1999). However, a newly identified member of the Chamaeleon I star form-

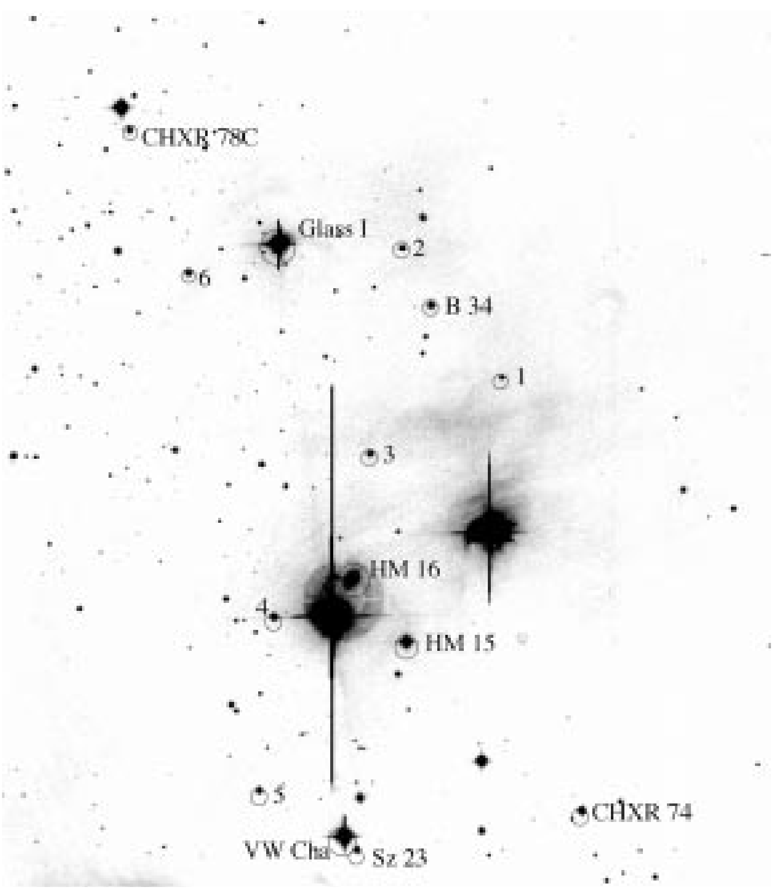

Figure 1: A 13′ ×13′ image of the centre of the Chamaeleon I aggregate in the I band. Labels identify previously known members of the aggregate, and numbers 1 to 6 denote the low-mass members newly found in the Hα survey by Comerón et al. 1999, i.e. Cha Hα 1 to 6. This image was obtained using DFOSC at the 1.5-m Danish telescope on La Silla, and includes the area surveyed in the infrared using IRAC2b at the ESO-MPI 2.2-m telescope. The area covered by the X-ray and ISOCAM observations is considerably larger.