1. Introduction.

After 30 yrs, the discovery of an Isolated Neutron Stars (INS) at optical wavelengths is no longer a surprise. Up to now, nine INSs have been associated to an optical counterpart (see Table 1 for an observational overview). Young INSs are relatively bright and identified through the detection of optical pulsations. For older INSs, the much fainter optical luminosity prevents in most cases the source timing and the identification just relies on the positional coincidence with a field object as well as on its peculiar colors. However, for some of the closer ($d \leq 500$ pc) INSs other, independent, pieces of evidence can be obtained, e.g., by comparing the angular displacement of the optical counterpart, if any, with the proper motion of the radio pulsar (Mignani, Caraveo & Bignami, 1997a - MCB97a). Our understanding of the optical properties of INSs is limited by their intrinsic faintness. Indeed, only for the Crab, accurate, medium-resolution, optical spectroscopy is available (Nasuti et al, 1996). For few more cases (PSR0540-69, Vela, PSR1509-58, PSR0656+14 and Geminga), which are too faint to be within the spectroscopic capabilities of the present generation of ground/space-based instruments, the spectral information just relies on multicolour photometry (Nasuti et al, 1997; Mignani et al, 1998; Pavlov et al, 1997; Bignami et al, 1996). For the rest of the database (PSR0950+08, PSR1929+10 and PSR1055-52), only one-or two-band detections are available (Pavlov et al 1996; MCB97b).

2. Young INSs.

Young ($\tau \sim 10^{3-4}$ yrs) INSs, hereafter YINSs, are relatively bright with an optical luminosity $L_{\text{opt}} \sim 10^{33}\text{erg/s}$ i.e. $\sim 10^{-5}$ of their spin-down power $\dot{E}$. Apart from PSR1509-58 (Mignani et al, 1998), they are all detected as optical pulsars. The optical emission of YINSs is powered by energetic electron interactions in the
Table 1. Summary of the existing database for all the optically identified INSs, sorted according to their spin-down age $\tau$. Column 3 lists the identification evidence obtained either from optical pulsations (P) or proper motion of the optical counterpart (PM). The numbers correspond to the accuracy of the positional coincide in arcsec. Successful or unsuccessful (-) timing and spectroscopy, both from the ground (G) and from the HST (S), is listed in Columns 4,5. Multicolor photometry (in italics for HST) is given in columns 6-10.

| Name        | Log$\tau$ | ID   | Tim | Spec | $I$  | $R$  | $V$  | $B$  | $U$  |
|-------------|-----------|------|-----|------|------|------|------|------|------|
| Crab       | 3.1       | P$^1$| G,S | G    | 15.63| 16.21| 16.65| 17.16| 16.69|
| 0540-69    | 3.2       | P$^2$| G,S | G,S  | 21.5 | 21.8 | 22.5 | 22.7 | 22.05|
| 1509-58    | 3.2       | 0.35$^3$| G(-) | G(-) | 19.8 | 20.8 | 22.1 | 23.8 |
| Vela       | 4.1       | P$^4$| G   |      | 23.9 | 23.6 | 23.9 | 23.8 |
| 0656+14    | 5.0       | P$^5$| G   |      | 23.8 | 24.5 | 25   | 24.8 | 24.1 |
| GEMINGA    | 5.5       | PM$^6$| G   |      | $\geq$26.4 | 25.5 | 25.5 | 25.7 | 24.9 |
| 1055-52    | 5.7       | 0.1$^7$| G   |      |      |      |      |      | 24.9 |
| 1929+10    | 6.5       | 0.39$^8$|      |      |      |      |      |      | $\geq$26.2 | 25.7 |
| 0950+08    | 7.2       | 1.83$^8$|      |      |      |      |      |      |      | 27.1 |

1Cocke et al, 1969; 2Shearer et al, 1994; 3Caraveo et al, 1994; 4Wallace et al, 1977; 5Shearer et al, 1997; 6Bignami et al 1993; 7MCB97b; 8Pavlov et al, 1996

magnetosphere and is characterized by flat, synchrotron-like spectra (Nasuti et al, 1997). This must be the case also for PSR1509-58, although any precise modelling is hampered by the heavy interstellar absorption (Mignani et al, 1998).

3. Middle-Aged INSs.

Middle-Aged INSs ($\tau \sim 10^5$ yrs) - MINSs-, are much fainter ($L_{opt} \sim 10^{27-28}$ erg/s) and optical pulsations have been observed only recently for PSR0656+14 and Geminga (Sheear et al, 1997a,b). Describing the optical luminosity of MINSs in terms of a single model is not straightforward since different emission processes may become important (MCB97c). For example, the optical magnetospheric emission might have faded enough to make it detectable the thermal emission from the cooling neutron star surface at a temperature in the $10^5 - 10^6$ K range (see e.g. Nomoto & Tsuruta, 1987), in agreement with X-ray observations (e.g. Becker & Trümper, 1997). Indeed, recent multicolor photometry of Geminga (MCB98) clearly suggests thermal radiation from the neutron star surface as the most likely origin of its underlying optical emission. At the same time, a wide emission
feature @ ∼ 6,000Å, which can be attributed to cyclotron emission from light ions in the neutron star’s atmosphere, appears superimposed on the Rayleigh-Jeans continuum of the soft X-ray planckian. However, for PSR0656+14, indeed the youngest of the three, multicolor photometry (Pavlov et al, 1997) show a different spectral behaviour with the optical flux consistent with a steep power law plus an additional hot blackbody component. For PSR1055-52, the HST/FOC point (MCB97b) falls close to the RJ extrapolation of the ROSAT thermal spectrum, but certainly more data are required to investigate the optical emission processes.

4. Old INSs.

Very little is known on the optical emission of the even fainter \( L_{\text{opt}} \sim 10^{26}\text{erg/s} \) Old \( (\tau \geq 10^6 \text{ yrs}) \) INSs (OINs). For both PSR1929+10 and PSR0950+08, the measured magnitudes (Pavlov et al, 1996) are clearly unconsistent with the optical extrapolation of the polar caps/magnetospheric soft X-ray spectra. Again, the optical flux could be due to thermal emission from a cooler neutron star surface.

5. Conclusions.

As inferred from Fig.1, a decay of the optical luminosity of INSs is evident. Still to be established are the effective rate of such a decay and whether it is followed by a turnover in the optical emission mechanisms. For YINSs, the optical output is certainly magnetospheric. However, as originally proposed by Pacini (1971), optical magnetospheric emission is expected to fade away rapidly. Indeed, the slightly older Vela is underluminous \( L_{\text{opt}} \sim 10^{28}\text{erg/s} \), with only \( \sim 10^{-9} \) of its spin down power emitted in the optical. This fading could thus give way to the fainter thermal emission from the cooling neutron star’s surface. Indeed, the optical emission of MINs appears to be either purely thermal or the combination of thermal/non-thermal components. Thermal emission could finally take over the non-thermal one in the case of the OINSs. Of course, any evolutionary picture is far from being settled. More observations, to be performed with the next generation of ground/space based telescopes, are required both to obtain new identifications and to gather additional spectral information.

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Fig. 1. Optical luminosities of INSs vs their spin-down age. Apart from Geminga, the values have been computed for the nominal radio distances. YINSs (open triangles), MINS (full triangles) and OINSs (filled squares) are marked. Vela is marked by an asterisk. Present upper limits are also included.

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