Studies of Neutron Stars at Optical/IR Wavelengths

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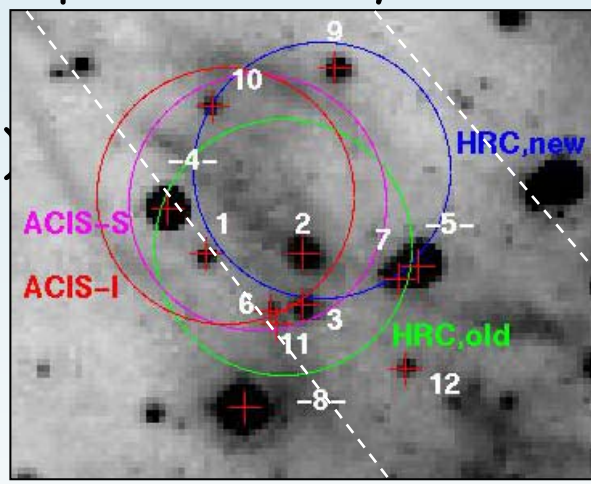
Talk Layout

- *Optical Observations of Radio Pulsars*
- *Optical Observations of CCOs*
- *Optical/IR Observations of XDINSs*
- *IR Observations of High-B Radio Pulsars*

The 16 ms pulsar PSR J0537-6910

- 16ms PSR in the LMC (N157B), age=5,000 yrs, dE/dt ~1.6 10^{38} ergs s^{-1}
- Still undetected in radio. First optical observations performed by Mignani et al. (2000).



Mignani et al. (2005)

- Deep HST/ACS observations (Mignani et al. 2005) unveiled two "best candidates" (#2,#9) based on the SED, plus one (#11) based on V-I>-0.5
- Follow-up timing observations performed on March 2004 (5x5000s) with the HST/STIS NUV-MAMA (2" slit/PRISM)
- Only candidate #5 detected with (dereddened) Log F_ν = -27.49 (2300-3000 Å). No pulsations.
- Upper limit (Log F_ν = -28.97) seem to rule out the two "best candidates" #2 and #9 but not candidate #11 (Kargaltzev et al.)
- Elusive optical counterpart still unidentified. PSR J0537-6910 appears to be significantly under luminous in the optical wrt the Crab and PSR B0540-69

Optical Polarimetry of Pulsars

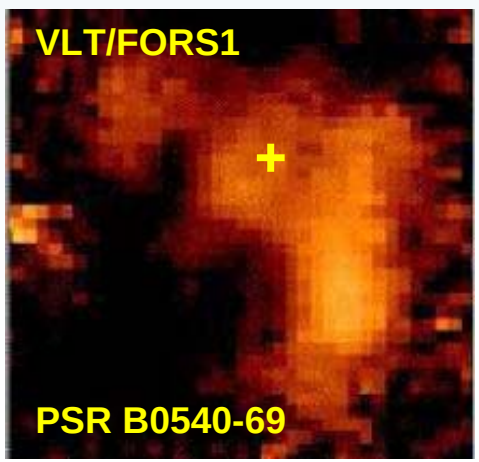
- First optical polarization measures for the Crab (Wampler et al. 1969), then for PSR B0656+14 (Kern et al. 2003)
- Crab: ~ 1%(MP/IP), ~20%(Bridge),~40% (OP)
- *PSR B0656+14: ~100% (IP)*

Phase-resolved

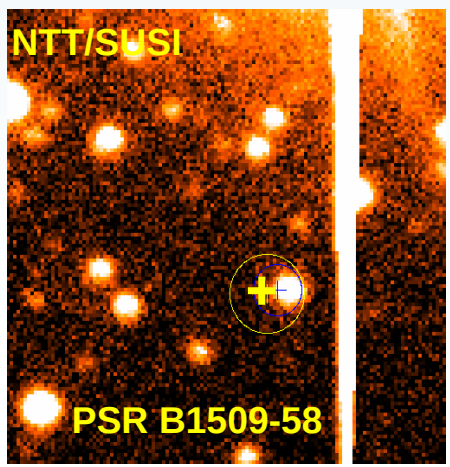
MP=Main Pulse; IP=Inter Pulse; OP=Off Pulse

- Recent polarization measures with the VLT (Wagner and Seifert 2000)
- *PSR B0540-69: ~ 5% ?? ← polluted by SNR !!*
- *PSR B1509-58: ~10% ?? ← polluted by nearby star !!*
- Vela: ~8 %±0.8% ← *errors underestimated !!*

Phase-averaged



Caraveo et al. (2000)



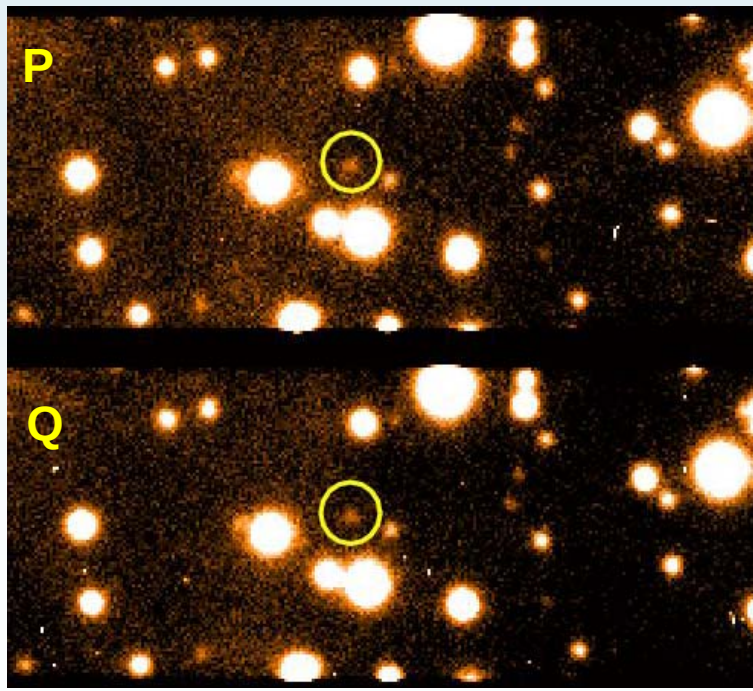
Mignani et al. (1998)

Polarimetry Observations of Vela

- Observations of Vela performed on April 1999 during the FORS1 Science Verification (airmass≈ 1.4-1.9, seeing 0.7")
- 4x1000s R-band exposures (angles 0°,22.5°, 45°,67.5°)

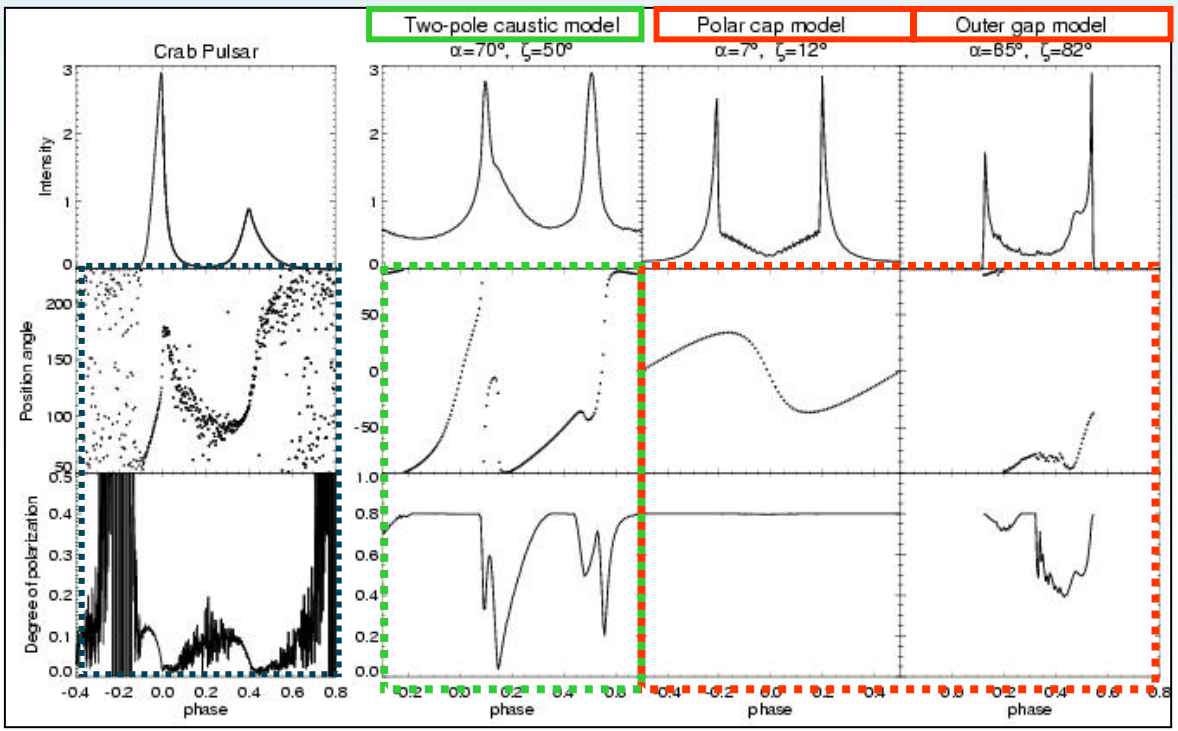
- Measured Polarization: 8.5% ± 2.5%, consistent with the one of Wagner and Seifert (2000) but with a more realistic error assessment (Mignani et al. in prep.)
- No systematic effects, polarization is statistically null on a number of field stars

- Large-scale polarization map shows no evidence for an optical PWN associated with the Vela pulsar, not seen also in continuum images (Mignani et al. 2003).

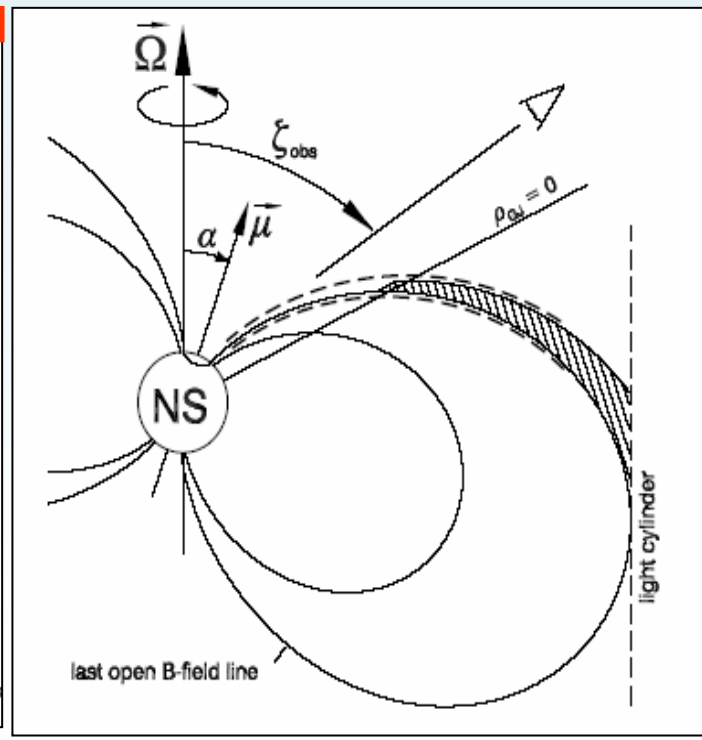


Inputs to Magnetosphere Models

- Polar cap and outer gap models can not reproduce the Crab optical polarization BUT the Two-Pole Caustic (TPC) model does.
- Vela polarization is compatible with the predictions of the TPC model for a dipole inclination of 70°and 30°<ξ<60° (J. Dyks, private comm.)



Kanbach et al. (2003)



Dyks and Rudak (2003)

Future Goals

- *TPC, as well as polar cap/outer gap, model comparisons need to be fed by more observations*

- *Obtain polarization measures of all the 6 youngest (brightest) pulsars*

- *Observations of **PSR B0540-69** approved with ACS@HST (Cycle 15) to measure the pulsar polarization and the SNR polarization map (plus features)*

- *Observations of **PSR B0656+14** and **Geminga** just requested at FORS1@VLT.Older pulsars (measures not polluted by SNRs) → polarization evolution*

The Proper Motion of RXJ 1605.3+3249

- Optical counterpart detected with the HST/STIS (Kaplan et al. 2003)
- HST fluxes consistent with a RJ≈ x10 above the RJ tail of the X-ray BB

- Identification confirmed by proper motion measure with Subaru (Motch et al. 2005): $\mu_\alpha \cos(\delta) = -24.7 \pm 16.3$ mas yr^{-1} ; $\mu_\delta = 142.4 \pm 15.4$ mas yr^{-1} (PA=350° ± 6°)
- For an age of 10^5 -10^6 yrs, probable birth place in the Sco OB2 OB association (Motch et al. 2005)

- Very compact (0.4" x 1.1") Ha nebula tentatively detected

- Subaru B and R fluxes fitted with a power-law with α ~ 1.5 (!)

Observations

- Observations performed with ACS@HST* on Feb 6th 2005 as a part of a programme aimed at measuring the parallax
- 4x1200s exposures performed with the ACS/WFC (50 mas/px) - F606W filter (λ=5907 Å, $\Delta\lambda$=2342Å)

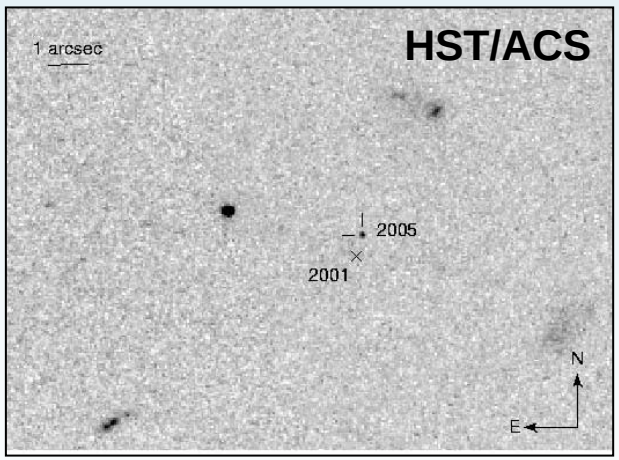
- Original STIS@HSTobservations performed on July 21st 2001 (Kaplan et al. 2003)
- 4x675 s exposures performed with the STIS/50CCD (50 mas/px) – unfiltered

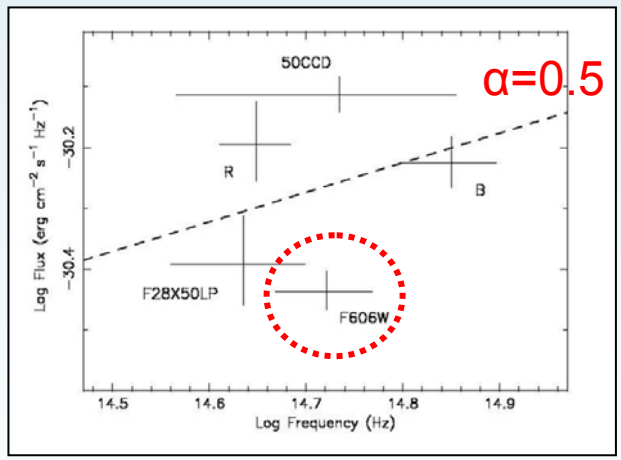
- Data retrieved from the HST archive, processed and calibrated
- Usual astrometric procedures for (i) geometric distorsions correction, (ii) frame registration, (iii) relative astrometry

*Originally proposed for the STIS/CCD, the configuration was replaced due to the STIS failure of 03 Aug. 2004

Results

- $\mu_\alpha \cos(\delta)$ = -43.7 ± 1.7 mas yr^{-1} μ_δ = 148.7 ± 2.6 mas yr^{-1} (PA=344° ± 1°)
- Result consistent (≈ 1 σ) with the one of Motch et al. (2005), although a factor 4 more accurate (Zane et al. 2006)

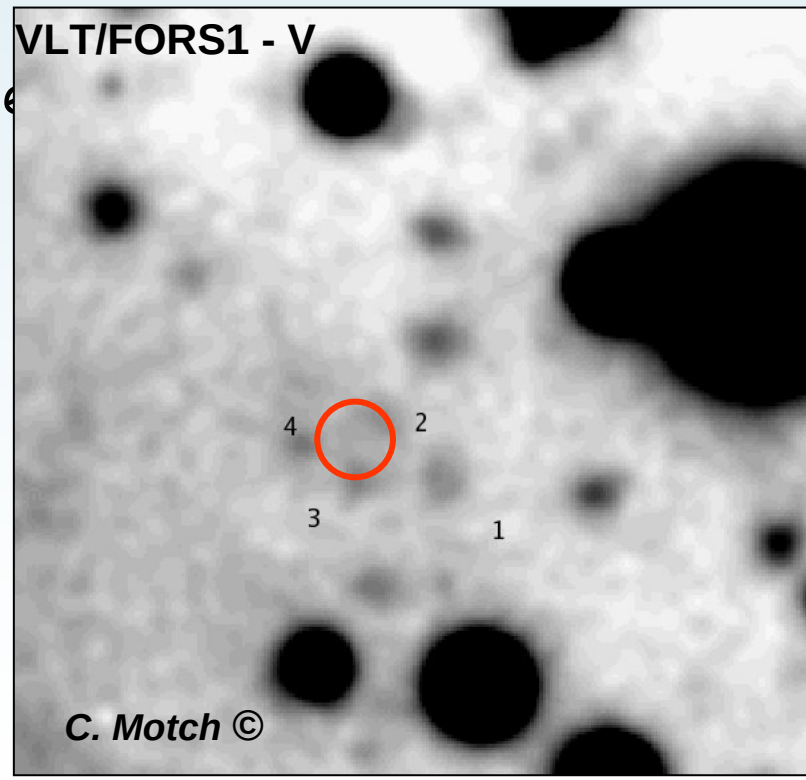




- Spectral energy distribution is unclear. A tentative fit to all points with a single (or with a composite) spectral model does not yield statistically acceptable results.
- Problems with X-calibrations?
- *Coherent photometry measures very much needed to characterize the source SED*

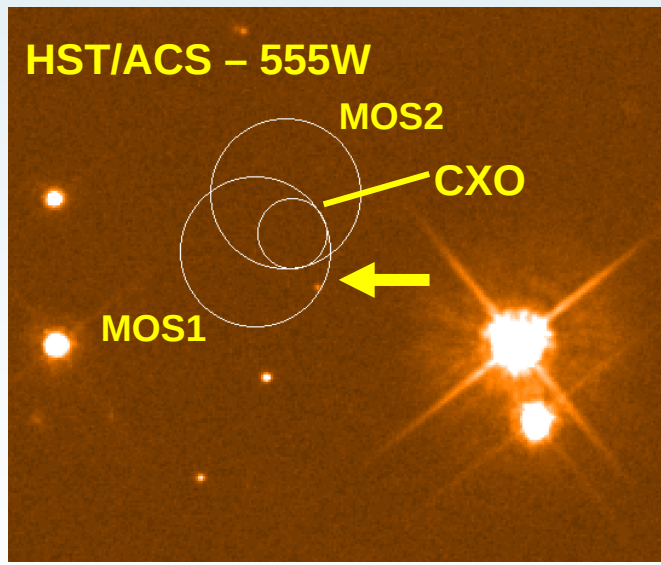
1 RXS J214303.7+065419 (a.k.a. RBS 1774)

- Last XDINS added to the family (Zampieri et al. 2001)
- No optical counterpart yet.
- B (4hrs),V (4 hrs) bands observations approved for the VLT
- Only ≈ 1 hrs actually performed on september last year (V band).
- Bad observing conditions (seeing > 1.5")
- Four objects detected within/close to the 3" XMM error circle (see also Poster A7 by Komarova et al. - 6m SAO)
- No other object down to V≈25.5
- Association with RBS1774 unlikely:
  i) x10 brighter than expected
  ii) B-V>0.5 from comparison with Komarova et al. photometry → red also seen in IR obs (see later)



The CCO in G296.5+10.0 – 1E 1207- 5209

- HST/ACS U,V,I (PI Sanwal) + VLT/ISAAC J,H,Ks (PI Zavlin) obs
- Candidate counterpart V=26.8, I=23.4, J=21.7, H=21.2, K=20.7 (Moody, Pavlov and Sanwal 2005), likely a low mass star (M dwarf) → BINARY
- Undetected (V>27.3, R>27.1) in VLT/FORS1 images (De Luca et al. 2004)
- Variable object ?

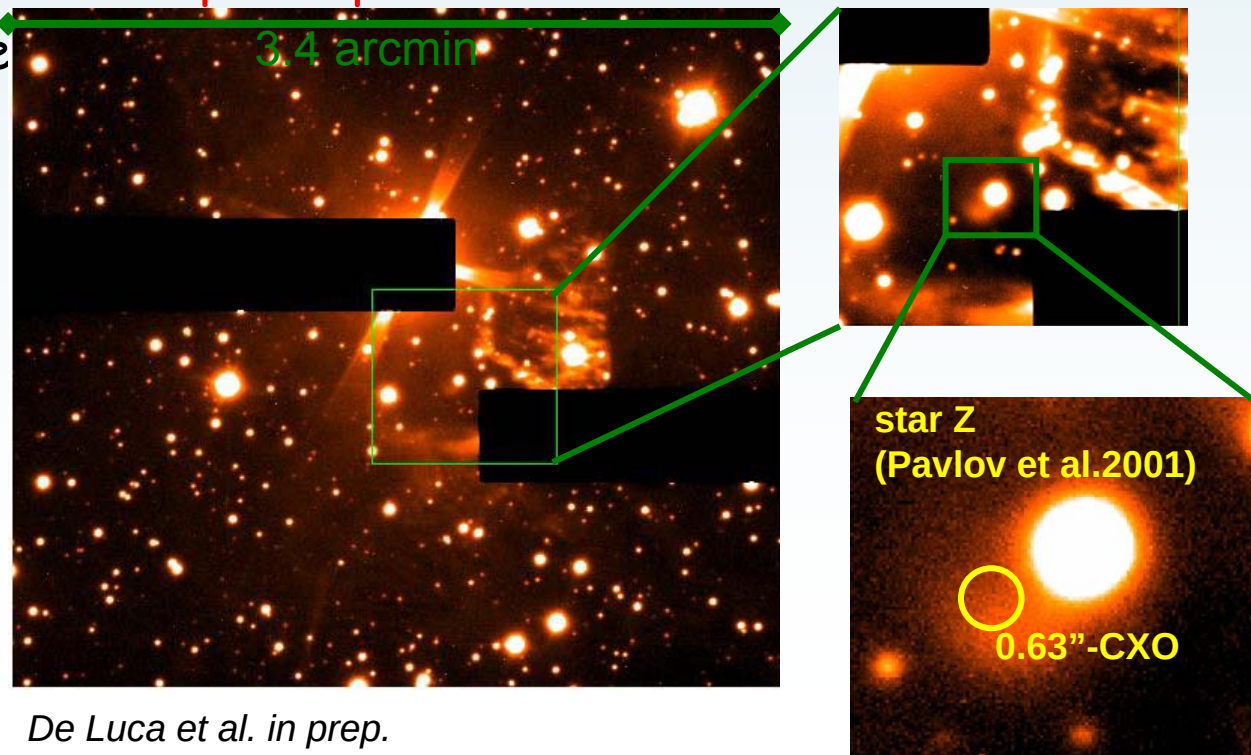


- Re-analysis of the HST/ACS astrometry
- Candidate out of the computed CXO position (0.7″) but at the edge of the XMM/MOS1 position (1.55″)
- Real counterpart ?

- *HST/ACS programme approved to measure the counterpart proper motion wrt the center of the SNR (PI De Luca)*

The CCO in Vela Jr – RX J0852.0- 4622

- First observations by Pellizzoni et al. (2002) with the ESO/2.2m → B>23, R>22. ESO/2.2m + UKST Hα observations unveiled an emission blob intepreted as a bow-shock seen face-on (Pellizzoni et al. 2002)
- 20 260s R-band exposures with FORS1 (airmass≈ 1.3, seeing 0.9"-1.0") in HR mode (0.1"/px). Masking of a very bright field star ≈ 40" away
- No point-like source detected at the CXO position down to R ~ 26 (De Luca et al. 2006) but a compact optical nebula
- Coincident with the one seen in Hα by Pellizzoni et al. (2002)
- Counterpart of the putative bow-shock
- Multi-band obs needed to study the spectrum

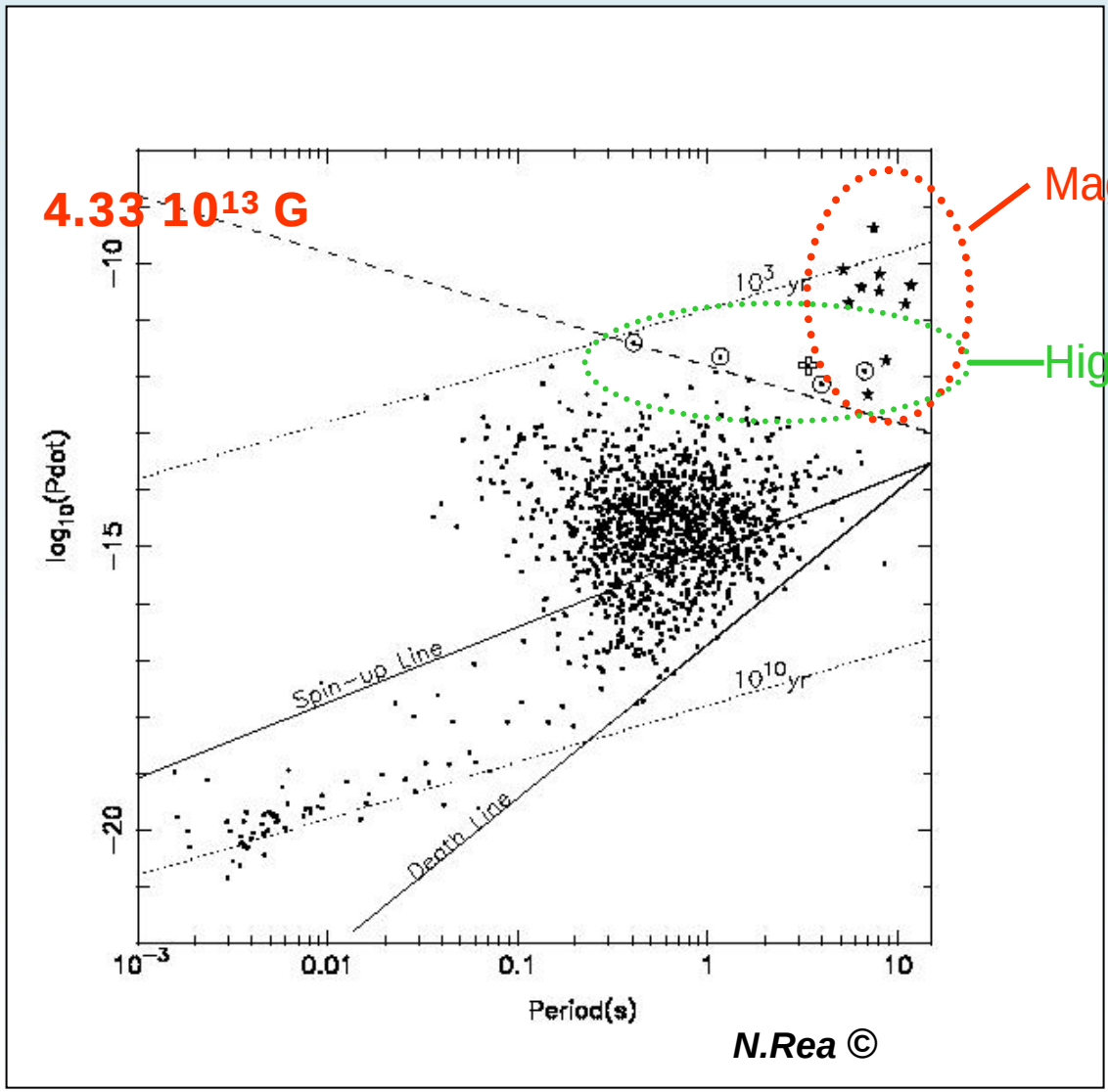


De Luca et al. in prep.

IR Observations of High-B radio Pulsars

- A few (~40) apparently ordinary radio pulsars identified with B>10^{13} G
- **5** with B>4.33 10^{13} G, i.e., the critical quantum field value above which radio emission should be suppressed
- These High-B radio pulsars should NOT be radio pulsars at all !

NAME	P (s)	dP/dt (10^{-11} s s^{-1})	dE/dt (10^{34} ergs s^{-1})	B (10^{14} G)	Age (kyrs)
PSR J1119-6127	0.4	0.41	250	0.41	1.7
PSR J1734-3333	1.17	0.22	5.6	0.52	8.1
PSR J1814-1744	3.97	0.074	0.047	0.55	84.8
PSR J1847-0130	6.70	0.127	0.017	0.93	83.3
PSR J1718-3718	3.3	0.15	0.16	0.74	34


4.33 10^13 G
Magnetars
High-B PSRs
10^3 yr
Spin-up Line
10^10 yr
Death Line
log10(Pdot)
−10
−15
−20
10^−3
0.01
0.1
1
10
Period(s)
N.Rea ©

Magnetars?

- **HBPSRs are Magnetars by definition but not by reputation**
  - HBPSR do not show SGR-like behavior.
  - Only two HBPSRs have been detected in X-rays (plus upper limits on other three), with $L_X \sim 10^{32\text{-}33}$ ergs/s i.e. lower wrt Magnetars

- **Are these high-magnetic field PSRs dormant SGRs?**
  - Maybe. The timescales for SGRs burst activity can be long

- **Are HBPSRs low X-ray luminosity Magnetars?**
  - X-ray luminosity related to the magnetic field

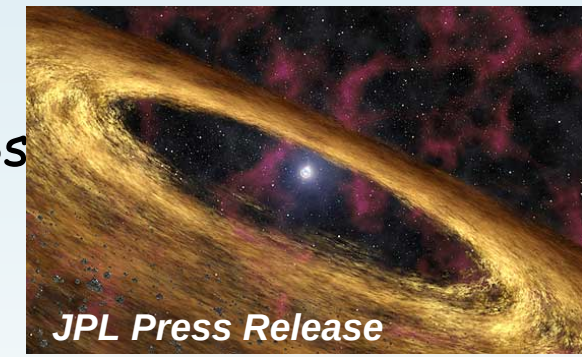
- **Do Magnetars manifest in different ways? And Why?**
  - As, e.g., AXPs wrt SGRs

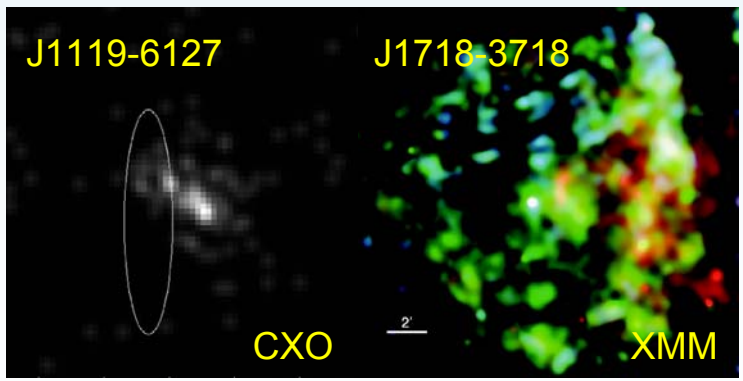
- **Do Magnetars evolve in the same way?**
  - Different evolutions could explain different phenomenologies

Or What else?

- **Are HBPSRs indeed such?**
  - Spin down torques from a fossil disk could pollute timing-derived B

- A disk could be detectable through deep IR observations
- The existence of disks (passive or not) around NSs is supported by the recent Spitzer observations of the AXP 4U0142+61 (Wang et al. 2006)

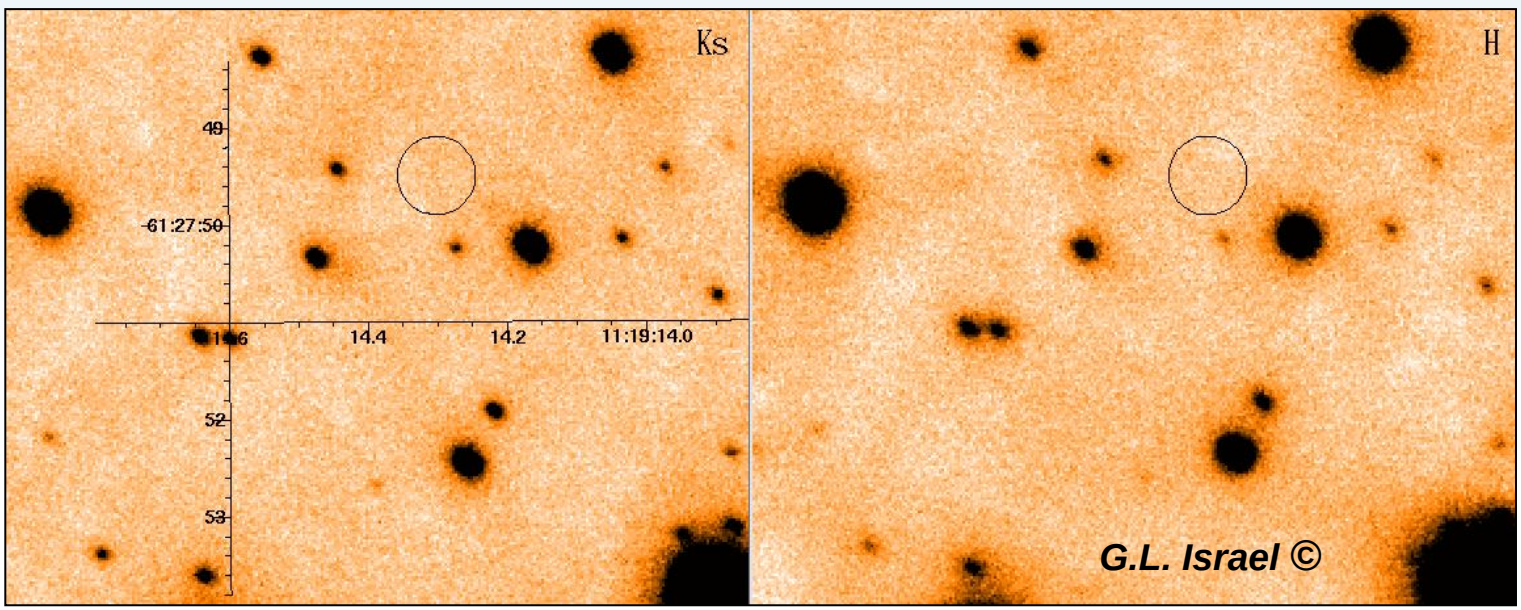


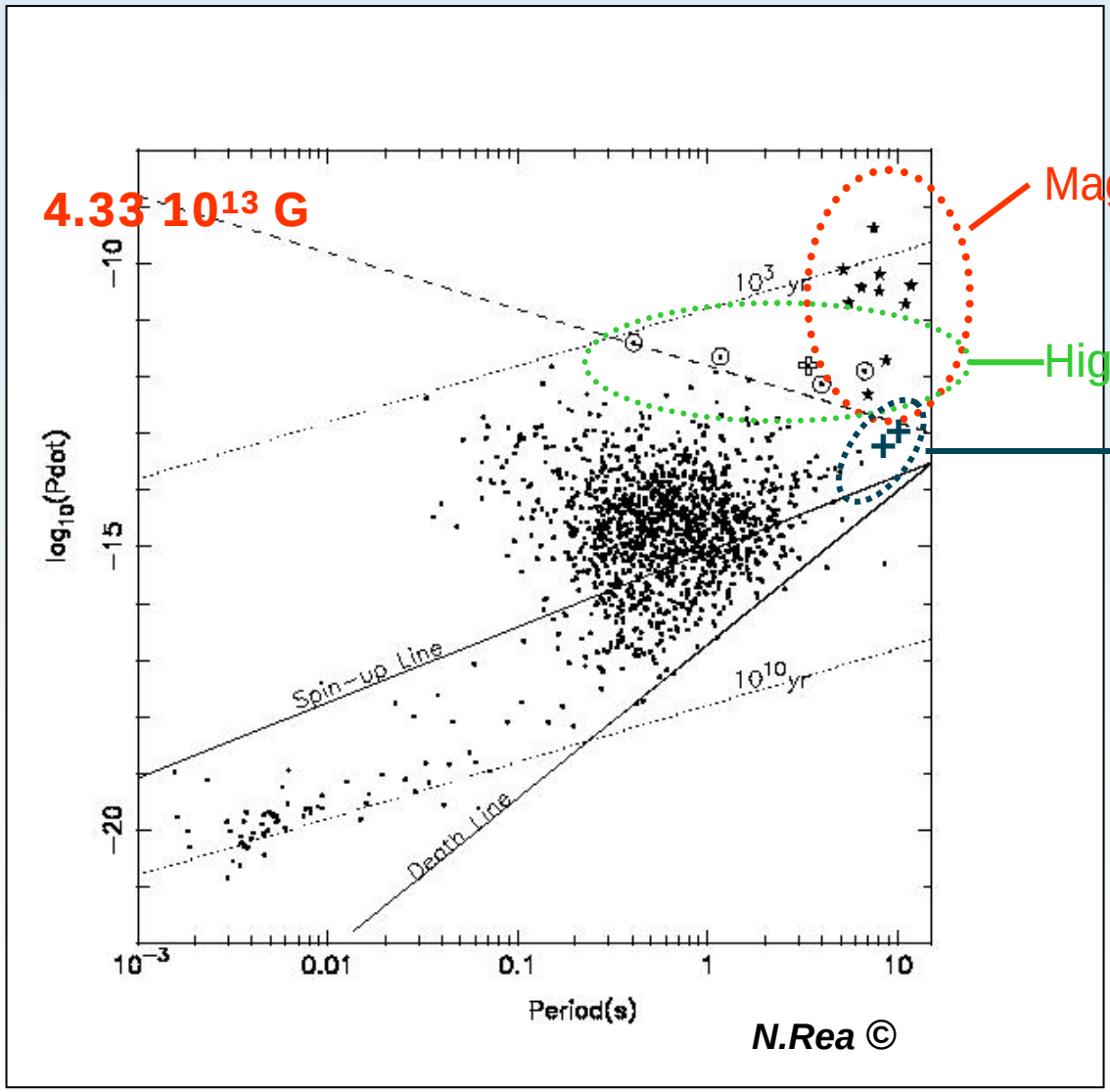


- Two pulsars are the best candidates (so far), both detected in X-rays by CXO and/or XMM (Gonzalez et al. 2005; Kaspi et al. 2005)
- The predicted IR luminosity of a disk $L_{IR} \approx 10^{-2} L_X$ (Perna , Hernquist, Narayan 2000)

IR Observations of PSR J1119-6127

- Adaptive Optics observations performed with NACO@VLT in Service Mode at the end of Feb 2006.
- 2 hrs integrations in J, H, K_s – 0.6" seeing
- Data delivered end of March and promptly reduced with different pipelines/recipes. And ….
- No emission at the pulsar position down to J ~24, H ~ 23 and K_s ~ 22
- Disk extending down to $R_{in} \approx R_{mag}$ seems not ruled out (Perna et al. in prep)




4.33 10^13 G
Magnetars
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10^3 yr
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Spin-up Line
Death Line
log10(Pdot)
Period(s)
−10
−15
−20
10^−3
0.01
0.1
1
10
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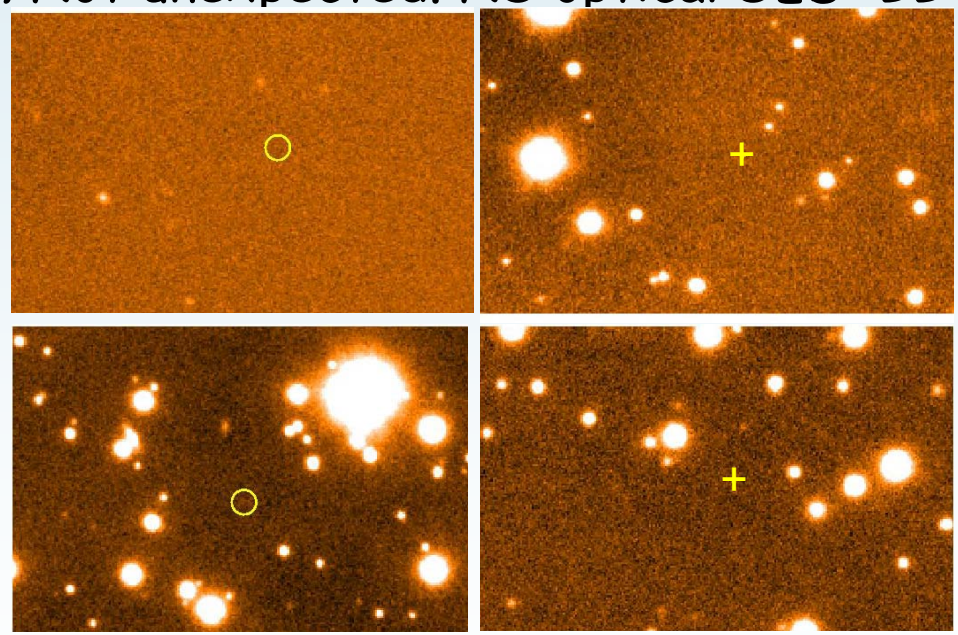
IR Observations of XDINSs

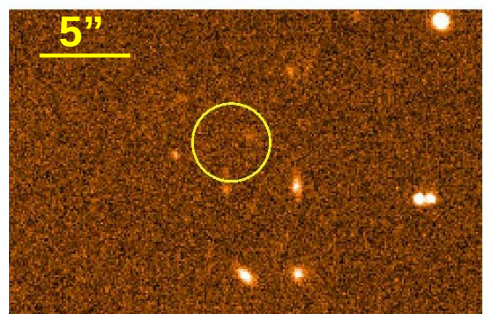
- VLT/ISAAC observations btw May 2003-Dec 2004, (PI Neuhäuser)
- ≈ 4000-6000 s integration time (per target), H band only
- Data retrieved from the VLT archive and re-analyzed
- No candidate IR counterpart. Not unexpected. NS optical SED≈BB → quick decline in the IR

- RX J0420-5022 → H > 21.9 ± 0.15
- RX J0720-3125 → H > 22.1 ± 0.1
- RX J0806-4122 → H > 22.4 ± 0.1
- RX J1856-3754 → H > 21.6 ± 0.2
- RX J2143+0654 → H > 21.7 ± 0.2

- IR upper limits are not deep enough to set tight constraints on the presence of a disk extending down to $R_{in} < R_{LC}$



Lo Curto et al. In prep.



Summary and Conclusions

- By re-analyzing VLT data we have obtained an updated measure of the Vela optical polarization, so far the only one available after the Crab's.
- HST observations of PSR J0537-6910 have ruled out previously proposed candidates. The pulsar stands out to be underluminous in the optical wrt other young pulsars
- With HST, we have obtained an updated proper motion measure of the XDINS RXJ 1605.3+3249
- A reanalysis of HST astrometry of the 1E 1207-5209 CCO candidate counterpart reopened the ID issue
- Deep VLT observations of the Vela Jr CCO have provided evidence for a compact optical nebula, the first associated with a CCO.
- VLT IR observations of the high-B PSR J1119-6127 and of five XDINSs have been used to constrain the presence of fossil disks