Proper motions of isolated neutron stars measured with Chandra

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ROSAT discovered radio-quiet INS
or
X-ray Dim INS
or
“The Magnificent Seven”

Blackbody-like X-ray spectra with kT ~ 40-100 eV (+ broad absorption lines), low NH (~ 10^{20} cm^{-2}), slow rotators (~10 sec), no (?) radio, no γ-ray emission

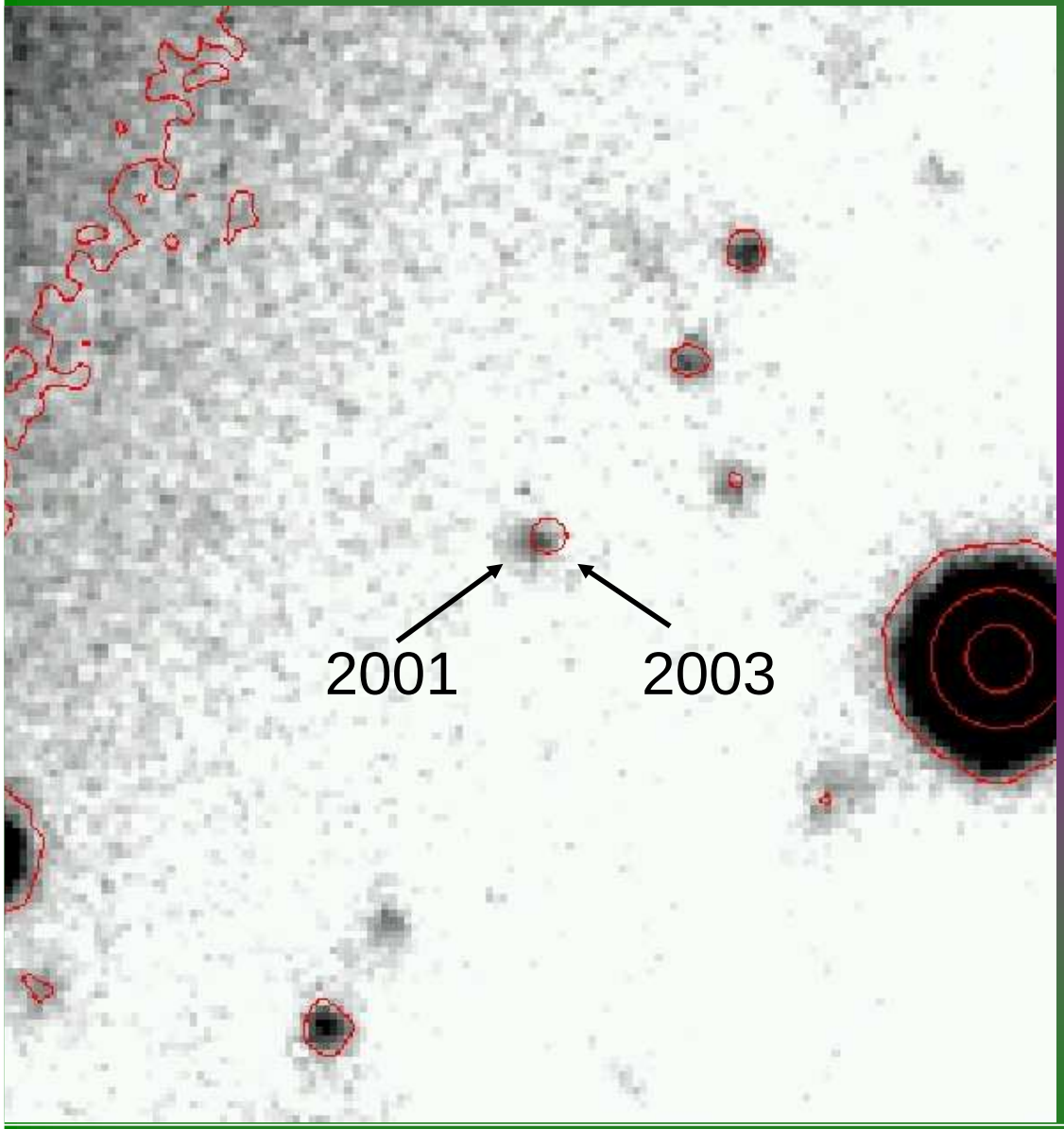
Evolutionary status and link to other groups of INS debated

Only 7 known

Why do we want to measure proper motions ?

- A high proper motion (typically > 30 mas/yr) is a criterion for the optical identification of a neutron star (colours can be misleading)
- Tests accretion from ISM as an X-ray powering mechanism (Lbol ~ V^{-3})
- For young objects, gives information on birth place and age
- Provides clues on birth kick velocities
- Feasible at optical wavelength with HST and VLTs and in X-rays with Chandra

Proper motions in the optical



Proper motion of
RX J0720.4-3125:

$\mu = 97$ +/- 12 mas/yr

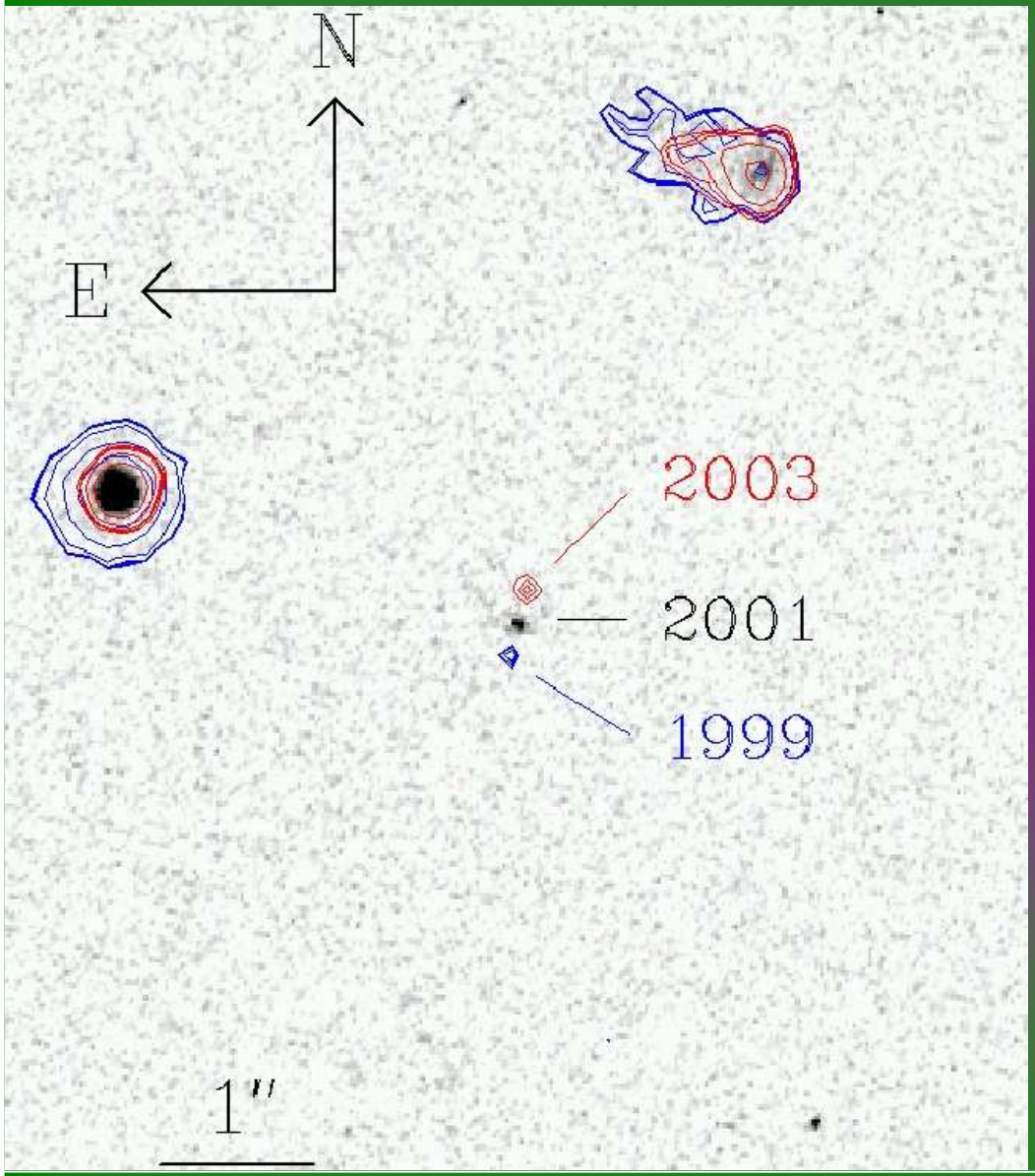
$V_T \sim 46$ (d/100pc) km/s

B = 26.7

ESO-VLT + FORS1
2x8h exposures

Motch et al. (2003)

Proper motions in the optical



Proper motion of RX J1605.3+3249:

$\mu = 144$ +/- 13 mas/yr

$V_T \sim 68$ (d/100pc) km/s

B = 27.2

Subaru (1999, 2003) + HST (2001)

Motch et al. (2005) (see Roberto Mignani talk)

Measuring proper motions with Chandra

Why Chandra ? : several XDINs lack an optical counterpart or have too faint ones to be observed repeatedly.

Targets : RX J0806.4-4123 (ACIS-I) and RX0420.0-5022 (ACIS-S)

Method : use the background of extragalactic (or remote galactic) sources to define an accurate relative astrometric reference frame. Central CCDs only : 16.9' x 16.9' (ACIS-I), 16.9' x 8.3' (ACIS-S)

Observations : two 20ks observations in 2002 and 2005, same period of the year, instrument and roll-angle.

- Typically ~20 background X-ray sources common to the two epochs
- Reference frames matched using a ML method allowing translation and rotation around the aim point of the equatorial coordinates
- Tested celldetect, wavedetect, various detection thresholds and energy bands

Simulations

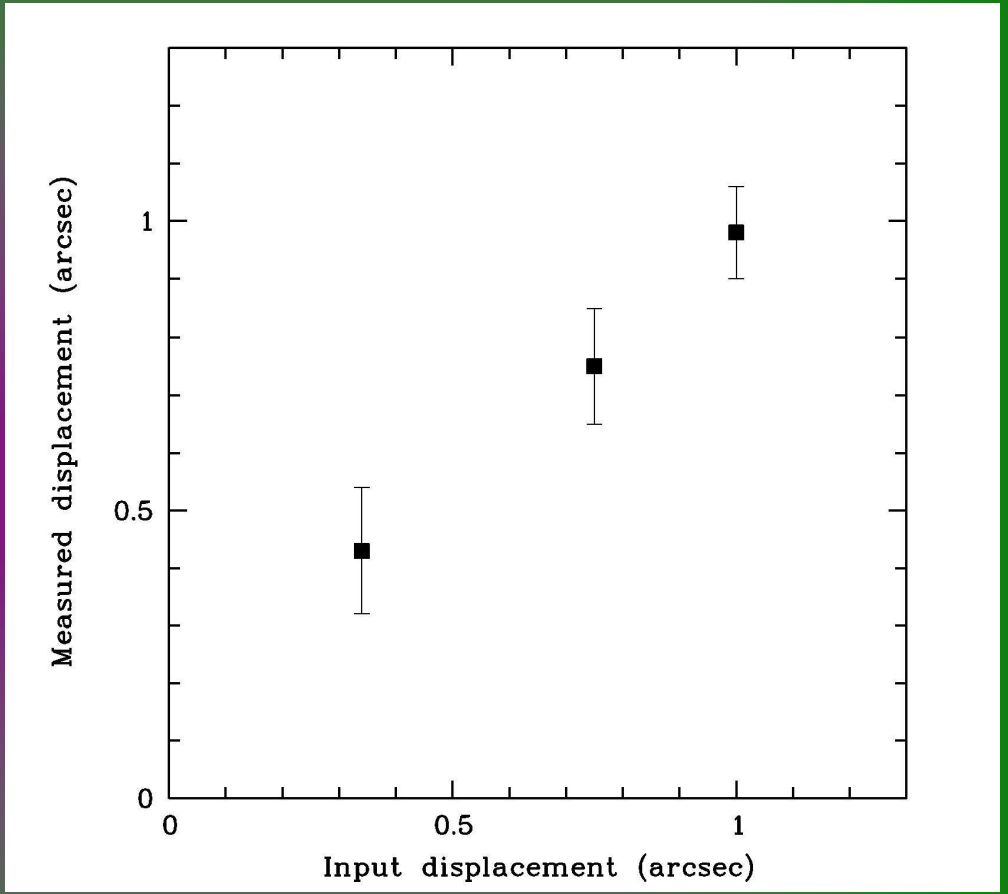
- Chandra ray-tracer MARX 4.2.1
- Simulate the 26 X-ray sources common to the 2002 and 2005 ACIS-I images (same total intensity and position as the real ones, but new photon distributions on the detector pixels)
- Realistic random background extracted from calibration data
- Aim point moved by 1/4, 1/2 and 2/3 of pixel (0.5 arcsec)
- Neutron star position moved by 0.34, 0.75 and 1.0 arcsec

Results of the simulations for ACIS-I

Shift recovered with an accuracy of ~ 0.11 arcsec (1 σ)

Errors dominated by the accuracy with which the frames of astrometric reference sources can be matched

Part of the scatter seems systematic and depends on the fractional pixel offset



Results for RX J0806.4-4123 and RX J0420.0-5022

Best positions are obtained with wavedetect in the 0.5-5.0 keV band

Frame matching errors are of ~0.11 “ (ACIS-I) consistent with simulations, and ~ 0.22 “ (ACIS-S)

NO significant proper motion observed:

RX J0806.4-4123: shift < 0.15 “ (0.10” on average)

=> μ < 73 mas/yr (2 σ)

RX J0420.0-5022: shift < 0.40 “ (0.30” on average)

=> μ < 150 mas/yr (2 σ)

Proper motions of ROSAT discovered INS

RX J1856.5-3758 [1]	μ = 333 +/- 1 mas/yr
RX J0720.4-3125	μ = 97 +/- 12 mas/yr
RX J1605.3+3249	μ = 144 +/- 13 mas/yr
RX J0806.4-4123	μ < 73 mas/yr
RX J0420.0-5022	μ <150 mas/yr

Relatively high velocities =>

XDINSs are likely not old neutron stars re-heated by accretion from the ISM but rather young cooling objects.

1) Neuhäuser 2001, Walter 2001

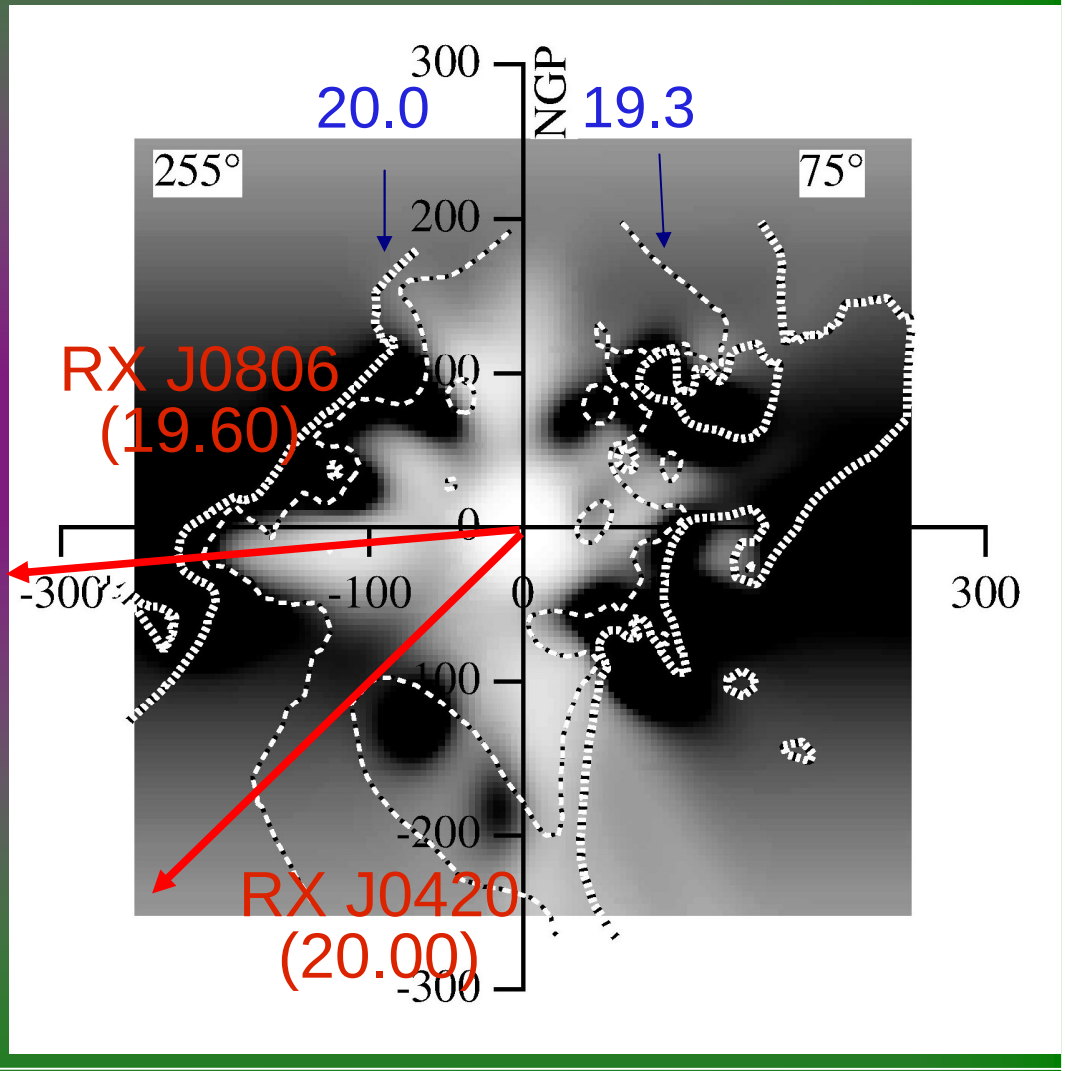
Using the absorption wall marking the edge of the "Local Bubble" to constrain distances

3-D maps derived from NaI absorption toward ~ 1000 nearby stars (Lallement et al. 2003)

(see Bettina Posselt talk)

RX J0806: d < 200 pc

RX J0420: No constraint

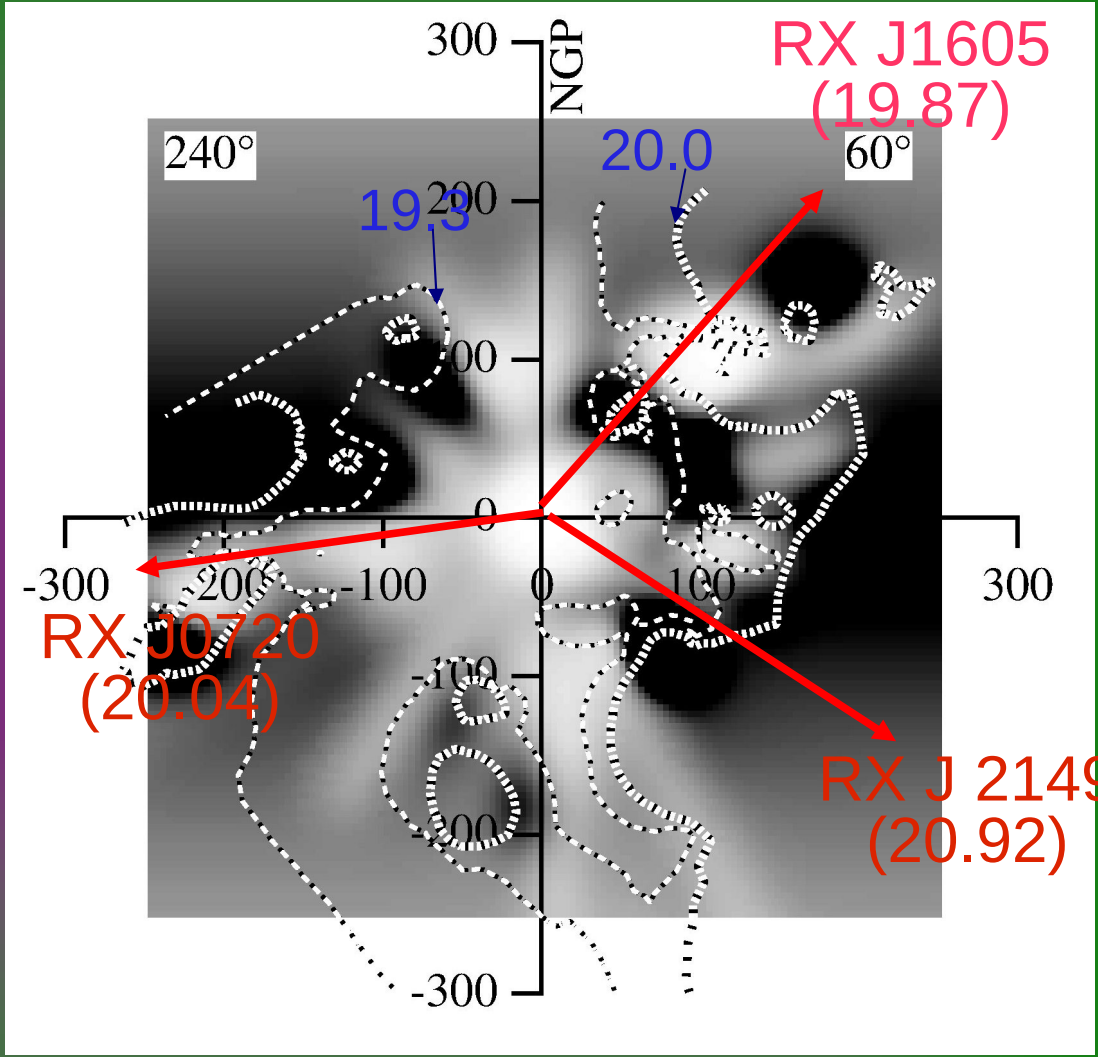


RX J1605: d < 200 pc ?

RX J2149: No constraint

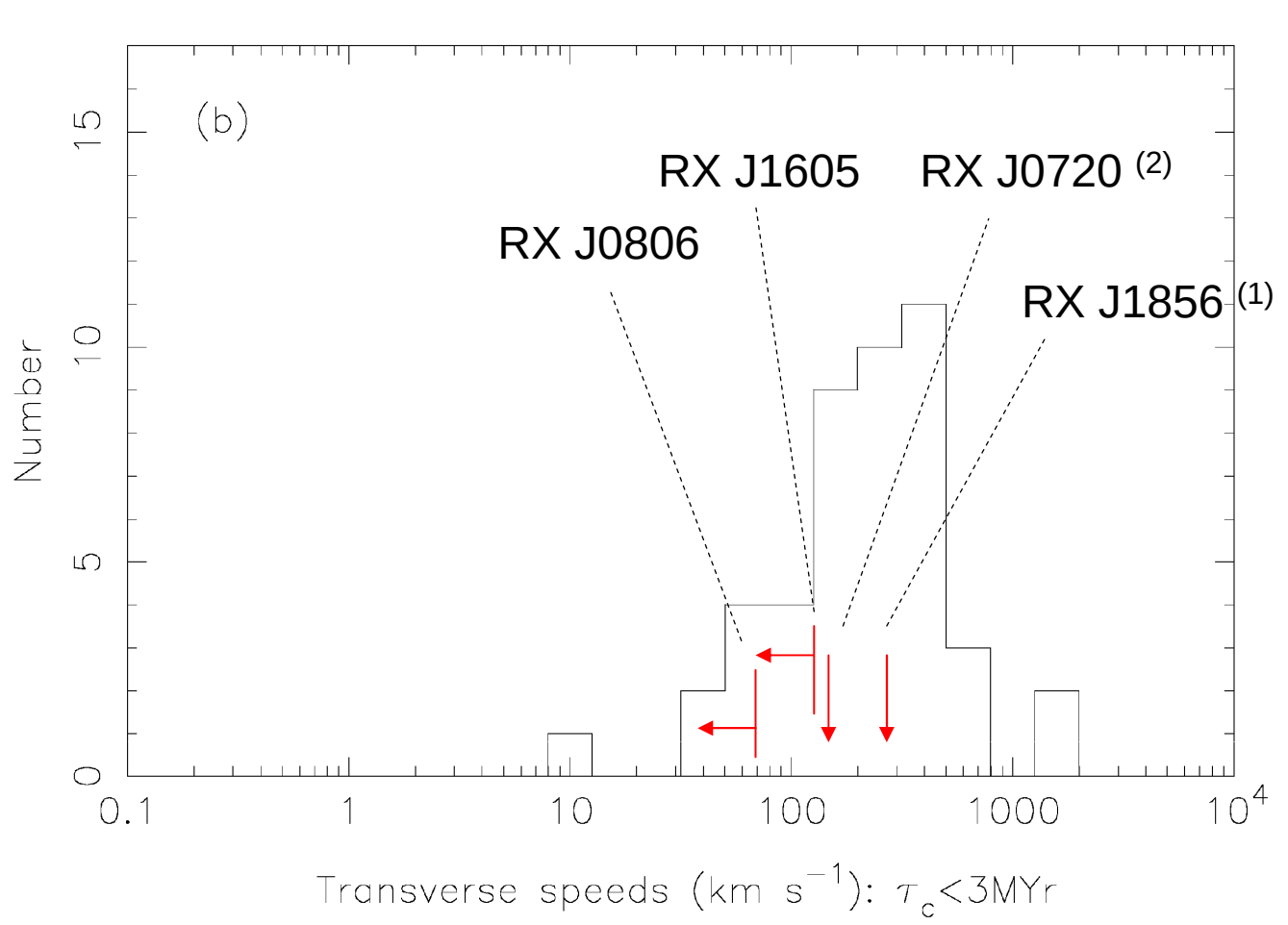
RX J0720: No constraint
(source located in the Canis Major Cavity)

The EUVE database (Welsh et al. 1999) confirms the absorption pattern, albeit with a lower angular resolution.



Transverse velocities of young pulsars (Hobbs et al. 2005)

Are XDINSs moving more slowly than young radio pulsars ?



1) RX J1856 *d* ~ 180 pc, HST parallax, (Kaplan 2004)
2) RX J0720 *d* ~ 300 pc (Kaplan et al. 2002) and now 250pc (MvK, HST)

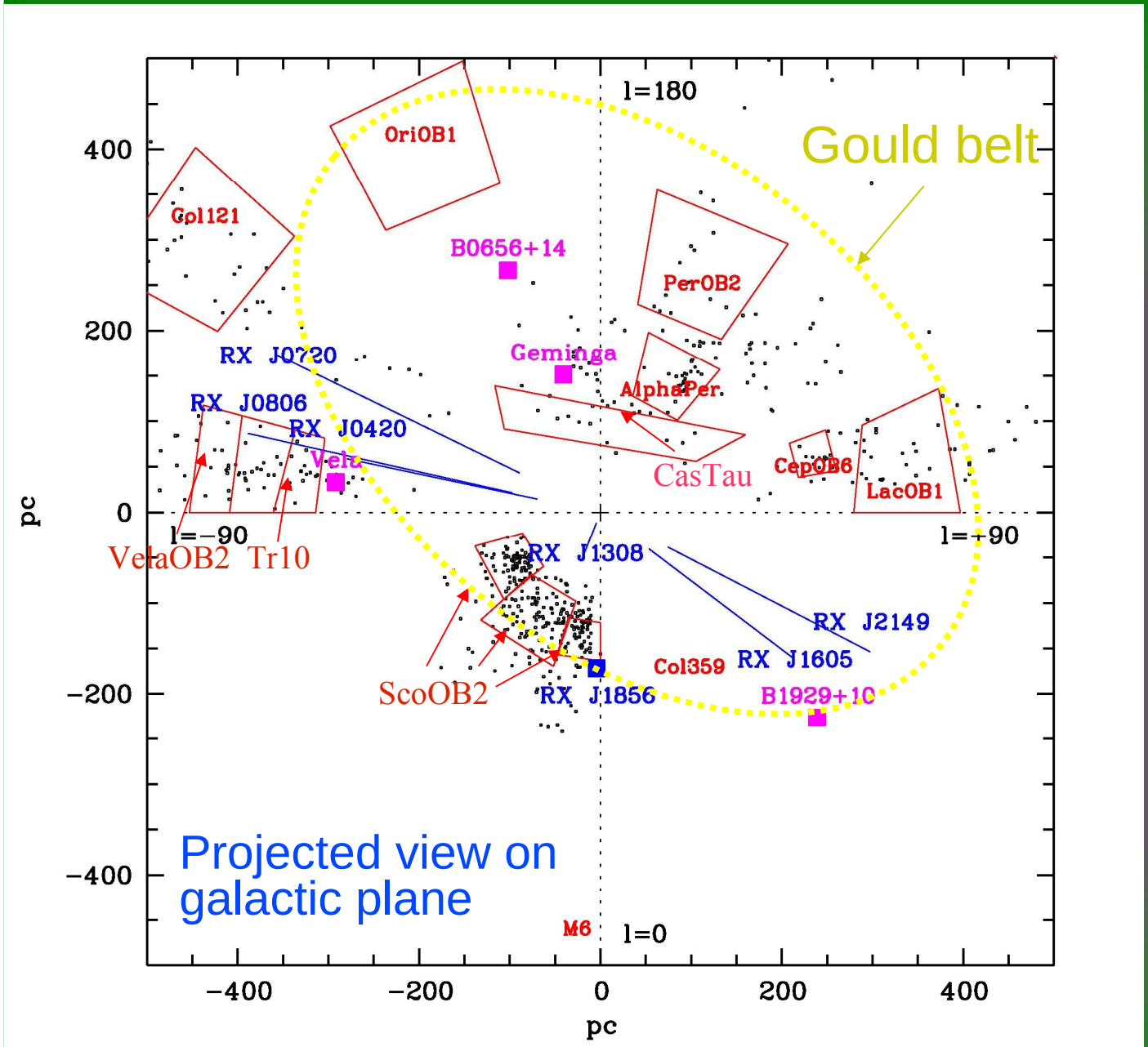
Birth places

Possible XDINS birth places:

RX J1856.5-3758: Upper Sco OB2 (~10^6 yr ?)
RX J0720.4-3125: Tr10 (~6 10^5 yr)
or Lower Sco OB2 (3 10^6 yr)
RX J1605.3+3249: Upper Sco OB2 (~ 10^6 yr)

The 3 brightest of the “Magnificent Seven” seem to have a local origin (Sco OB2 is at ~ 140 pc)

Nearby INS and local stellar structures



Blue lines are possible INS positions assuming d = 100 - 400 pc

OB member locations after de Zeeuw et al. 1999

All XDINSs are located in a half sky centred on Sco OB2

Conclusions

- The “Magnificent Seven” seem a locally born population dominated by the nearby Sco OB2 – Vela OB2 associations. They are probably still close to their birth place.
- Open issues:
  - What is the true distance of these INSs ?
  - Why don’t we detect fainter XDINs born in more remote parts of the Galactic Plane and Gould Belt (e.g. Orion) ?
  - Is the velocity distribution of XDINs really different from that of young pulsars ?
  - What is the numerical importance of this population ?