Origin of the Radio-Quiet X-ray emitting Isolated Neutron Stars

Christian Motch
CNRS/ULP
Strasbourg Observatory, France

In Collaboration with F. Haberl, A.Schwope, V.E. Zavlin

ROSAT discovered radio-quiet INS

Low N_H ($\sim 10^{20}$ cm^{-2}), no associated SNR, no radio, no γ-ray, blackbody-like emission with kT ~ 40-100 eV, slow rotators (~10 sec)

Faint optical counterparts (V ~ 26-28)

Absence of strong non-thermal component (e.g. magnetospheric power law emission) allows easier comparison with neutron star model atmospheres.

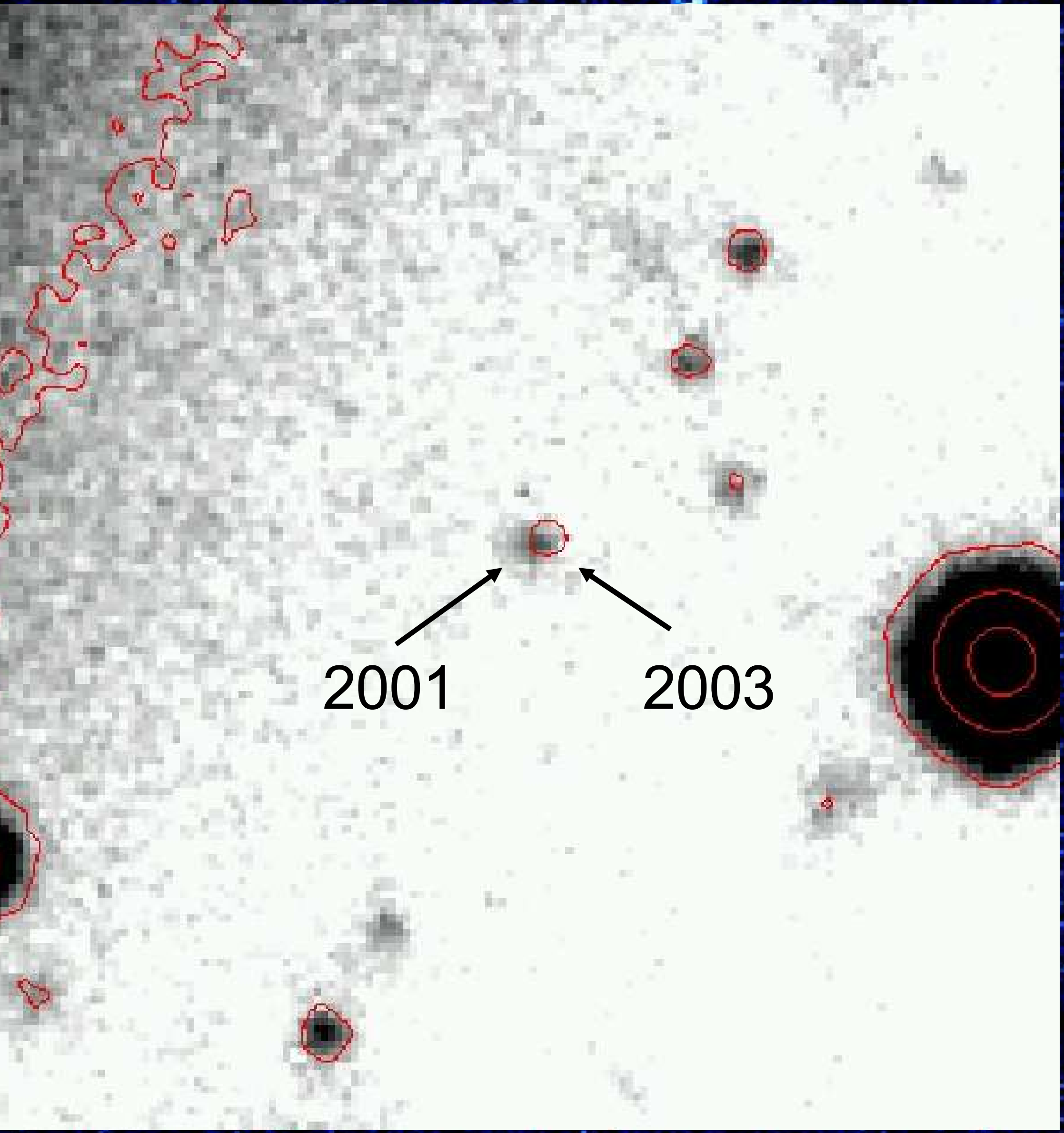
Properties of ROSAT discovered Isolated Neutron Stars

Source	PSPC cts/s	P (s)	dP/dt (s s^{-1})	kT (eV)	B or V mag
RX J0420.0-5022	0.11	3.453	<9 10^{-12}	45	26.6?
RX J0720.4-3125	1.69	8.391	6.98 10^{-14}	85	26.7
RX J0806.4-4123	0.38	11.371	<2 10^{-12}	96	>23
RX J1308.6+2127	0.29	10.313	<1 10^{-12}	90	28.0
RX J1605.3+3249	0.88	-	-	95	27.2
RX J1856.5-3754	3.64	-	-	60	25.8
RX J2143.0+0654	0.18	9.437	-	101	>23

Proper motions

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

Proper motions



Proper motion of RX J0720.4-3125:

μ= 97 +/- 12 mas/yr

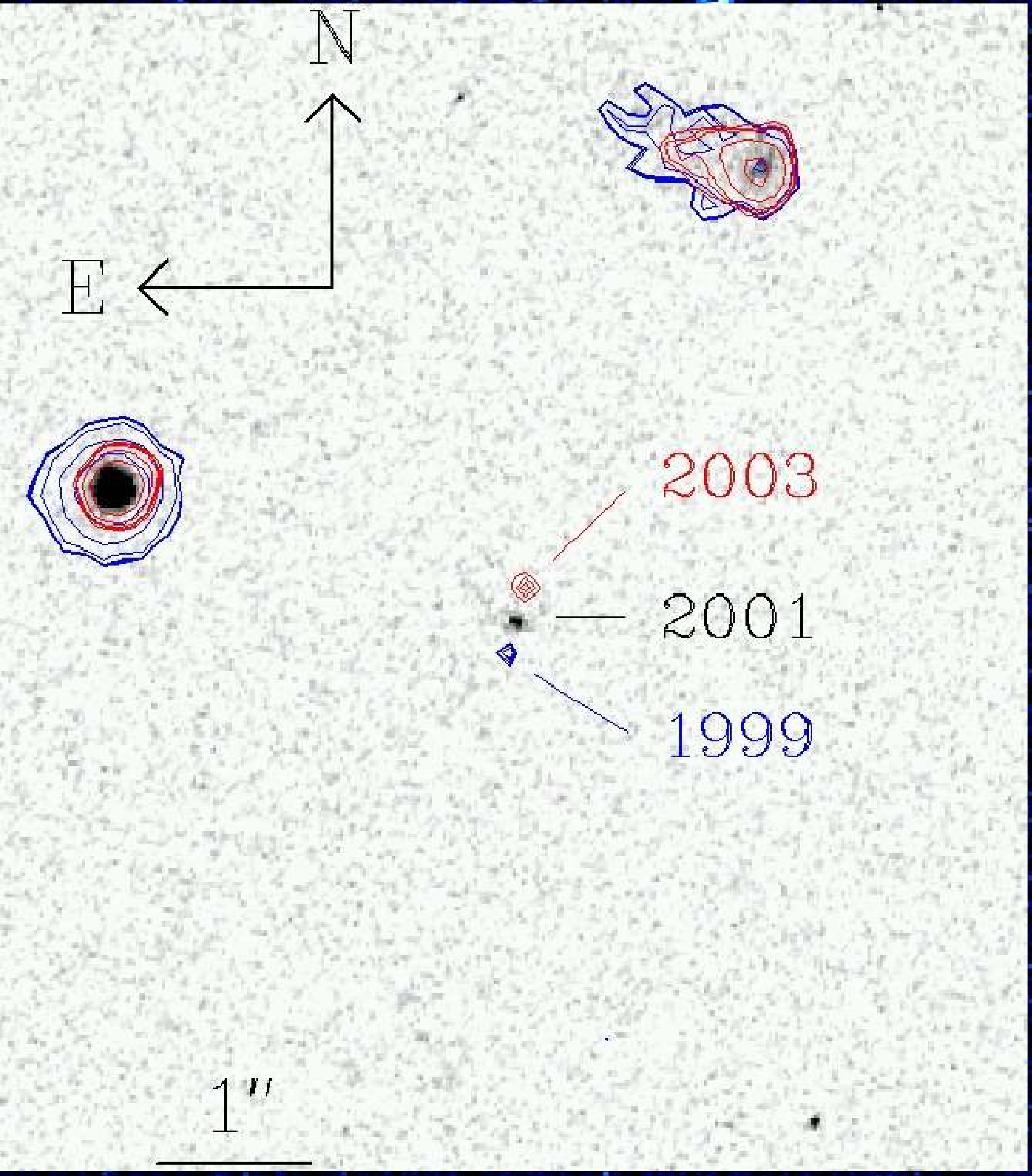
Vt ~ 50 (d/100pc) km/s

B = 26.7

ESO-VLT + FORS1
2x8h exposures

Motch et al. (2003)

Proper motions



Proper motion of RX J1605.3+3249:

μ= 144 +/- 13 mas/yr

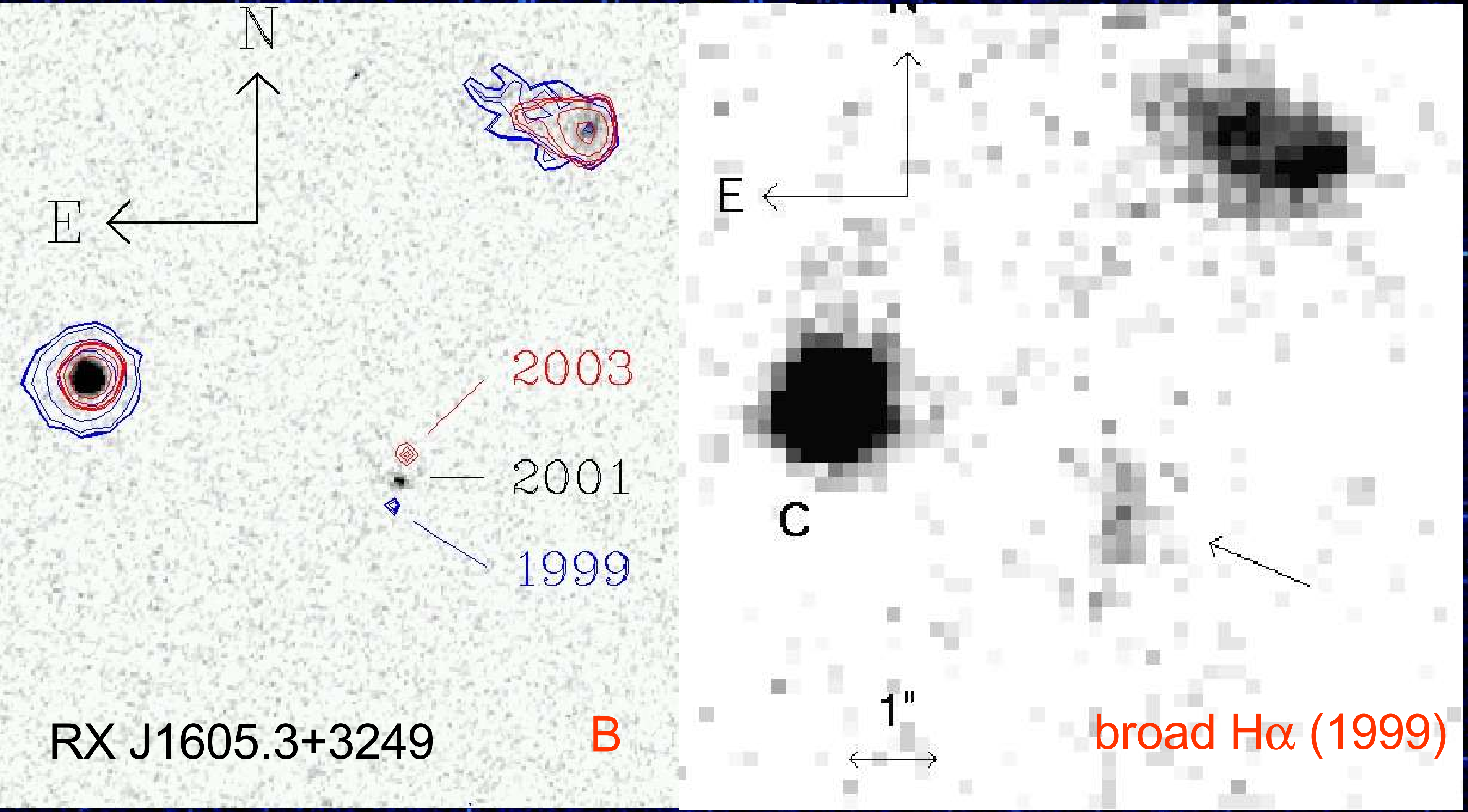
Vt ~ 70 (d/100pc) km/s

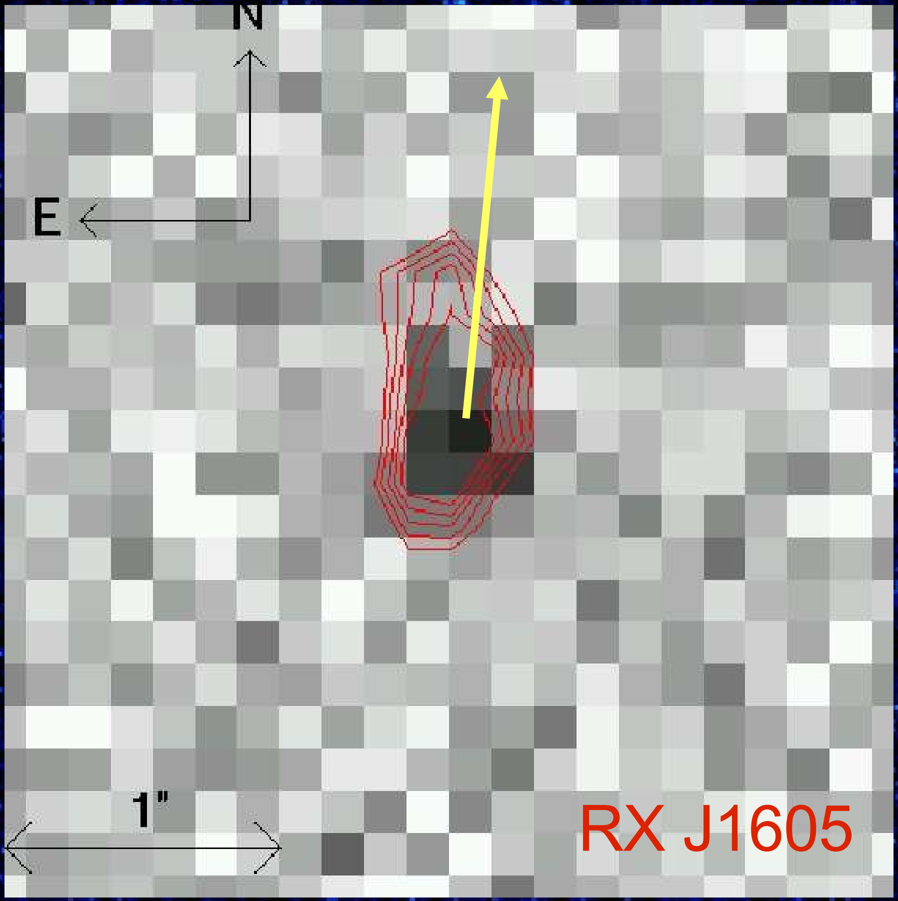
B = 27.2

Subaru (1999, 2003) + HST (2001)

Motch et al. (2004)

A faint nebula around RX J1605.3+3249 ?





Nebula aligned within 5 deg with the apparent trajectory of the neutron star

Emission almost centred on RX J1605

Geometry incompatible with a bow shock or a X-ray ionized nebula

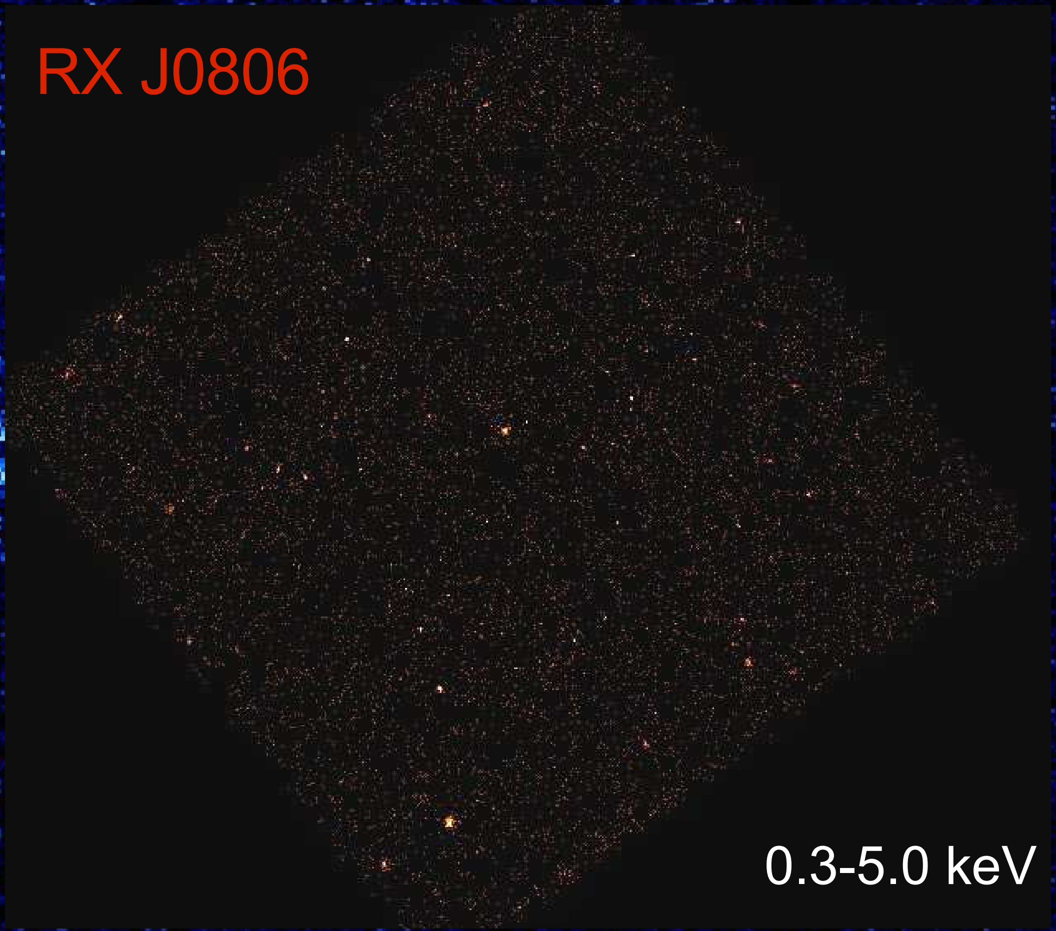
requires observational confirmation

Measuring proper motions with Chandra

Use the background of extragalactic sources to detect or constrain the proper motion

So far applied to RX J0806: two 20ks observations in 2002 and 2005.

20 background X-ray sources common to the two observations



$\mu < 140$ mas/yr (95% confidence level)

Proper motions

Proper motions are measured so far for 4 ROSAT discovered INS:

RX J1856.5-3758:	μ = 333 +/- 1 mas/yr	Vt ~ 220 km/s
RX J0720.4-3125:	μ = 97 +/- 12 mas/yr	Vt ~ 50 (d/100pc) km/s
RX J1605.3+3249:	μ = 144 +/- 13 mas/yr	Vt ~ 70 (d/100pc) km/s
RX J0806.4-4123:	μ < 140 mas/yr	Vt < 70 (d/100pc) km/s

Relatively high velocities -> ROSAT INS are not old neutron stars re-heated by accretion from the ISM.

ROSAT INS are young cooling objects. The lack of radio emission could be due to high magnetic field or to a radio beam not sweeping the earth.

Absence of accurate distance estimates (apart for RX J1856) and lack of radial velocity measurements do not allow birth places to be determined without ambiguity. However, the location of an OB association on some backwards trajectories is a strong hint since most (> 75%) OB stars are located in associations.

Birth places

Possible birth places of ROSAT discovered neutron stars (assuming a cooling time of ~10^6yr):

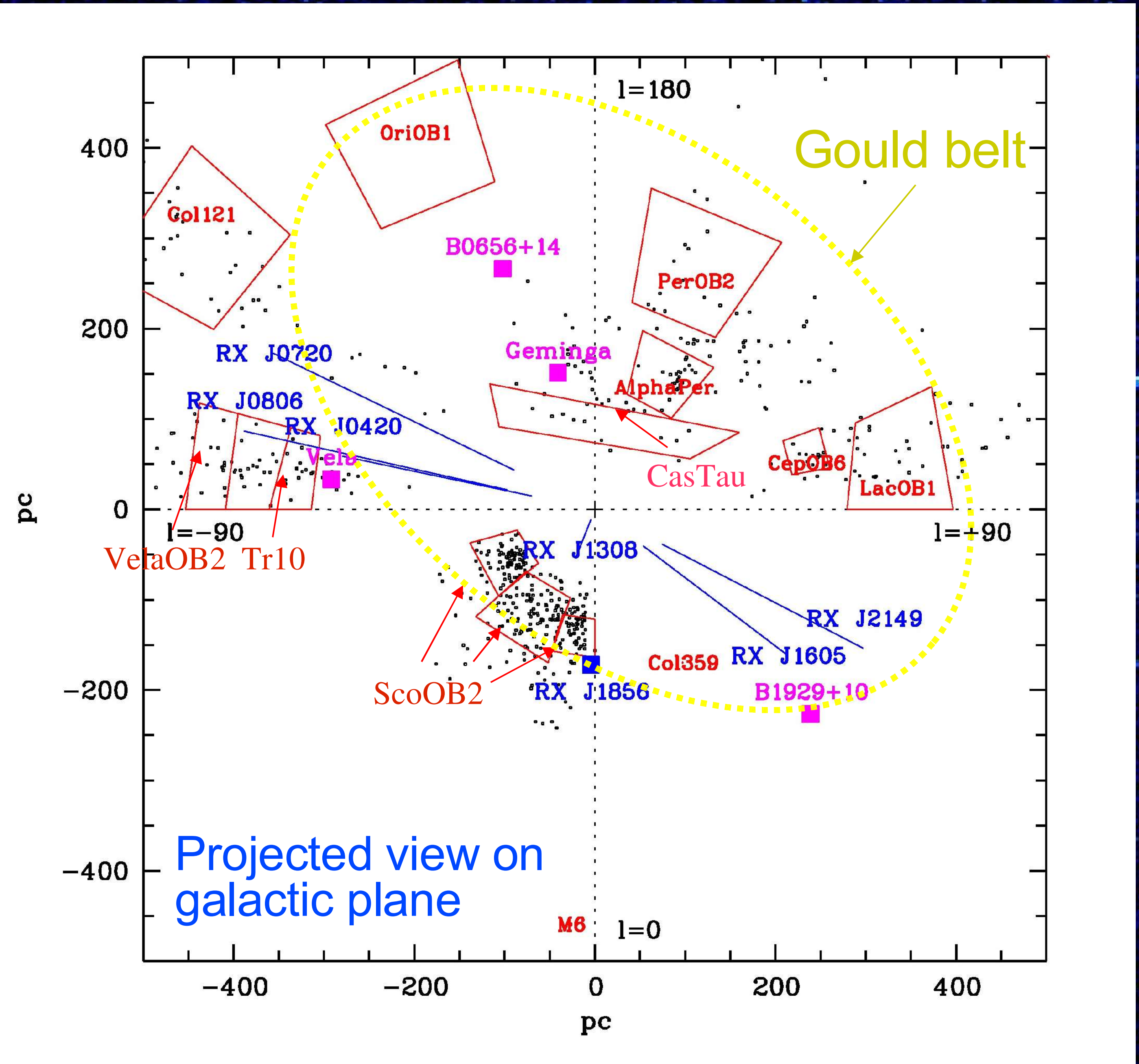
RX J1856.5-3758:	Upper Sco OB2
RX J0720.4-3125:	Lower Sco OB2, Vela OB2 or Tr10
RX J1605.3+3249:	Upper Sco OB2

The brightest ROSAT INS are thus a locally produced population

Tentative birth place for other nearby INS:

Geminga:	Orion OB1 or Cas Tau
PSR B0656+14:	Orion OB1
PSR J1932+1059:	Sco OB2

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 ROSAT discovered INS are located in a half sky centred on Sco OB2

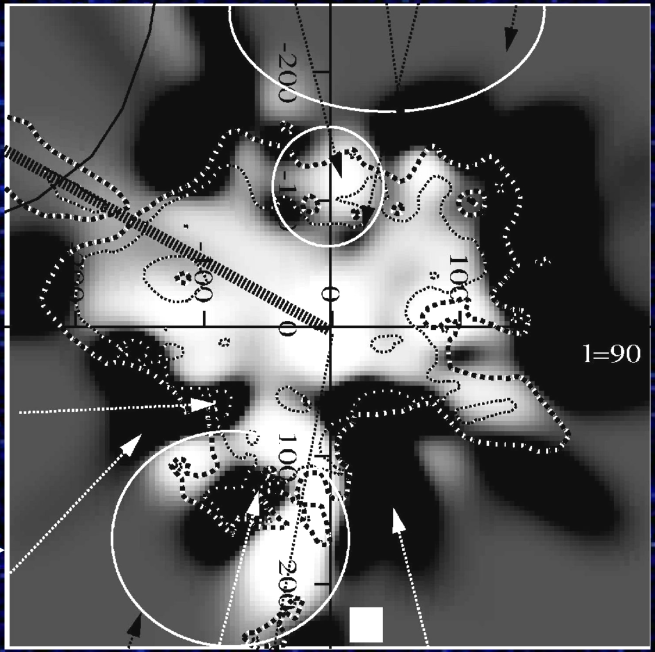
Possible explanations for this asymmetry:

- Chance coincidence ?
- ROSAT all–sky survey has no such sensitivity feature. (optical search complete down to 0.2 ROSAT PSPC cnt/s)
- Interstellar absorption is unlikely to explain the effect either

- Bias in optical searches ? Optical identification in the large ROSAT error circles is difficult at low galactic latitude.

- Evidence for a ROSAT INS production dominated by the closest part of the Gould Belt (Sco OB2, Vela OB2, Tr10) ?

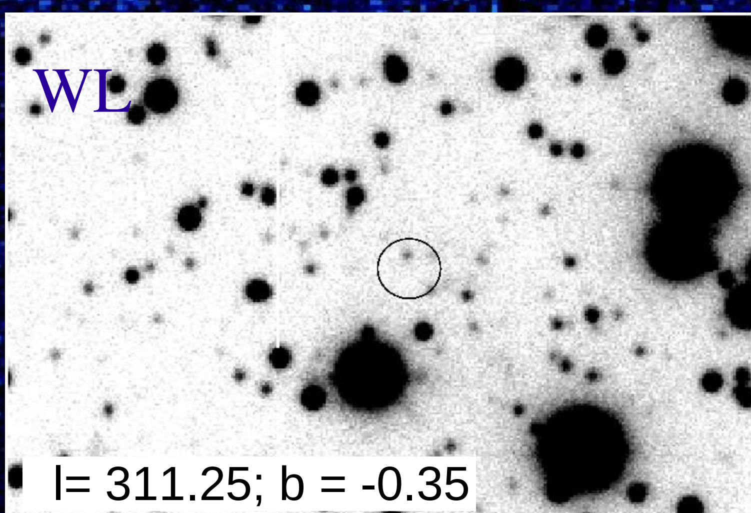
3-D NaI absorption map (Lallement et al. 2003)

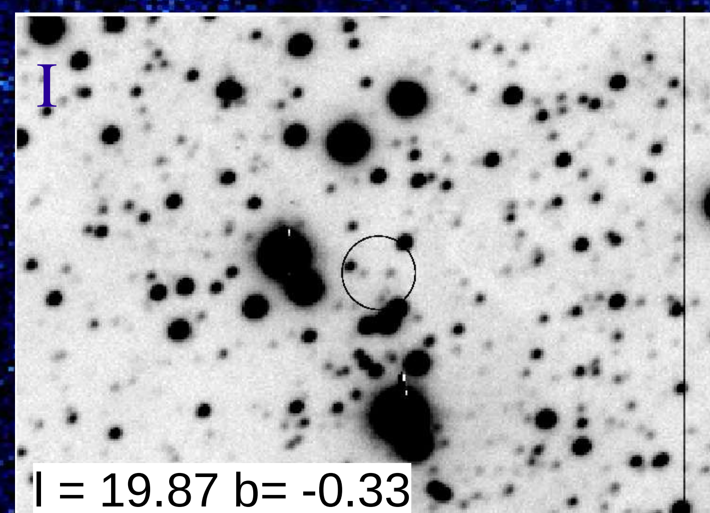


But why don't we detect cooling INS born in Orion and other more remote parts of the Gould Belt ?

New INS candidates from the XMM-Newton Survey Science Center survey of the Galactic Plane

- Two soft sources found at low b in the 1XMM catalogue (10 deg^2) and in the XGPS, (3 deg^2 ;Hands et al. 2004)
- About 100 times fainter than ROSAT INS
- Optical imaging and spectroscopy at ESO 3.6m and ESO-VLT reveal no likely candidate (e.g. Me star, AM Her CV) R_{lim} = 23 & 25
- Current fx/fopt > 200-400 could still allow an extreme polar system.
- Black-body like spectra with kT=120 +/- 20 eV; $N_H \sim 5\ 10^{21}\ cm^{-2}$
- Close (~ 5° / ~ 200 pc) to rich OB associations (Cen OB1 and Ser OB1&2)
- Properties consistent with those of ROSAT INSs moved at the distance of these OB associations (~ 2-2.5 kpc) and undergoing similar absorption.





Conclusions

- ROSAT INS are probably a locally born population dominated by the nearby Sco OB2 – Vela OB2 associations.
- Relative proximity to potential birth places and tangential velocities suggest a slow or medium velocity population (a neutron star with v = 300 km/s moves by 300 pc in a cooling time of 10^6 yr)
- This strengthens the idea that the local density of radio-quiet and cooling INS may be as large or even larger than that of the radio-pulsar population.
- Searches for new X-ray bright and radio quiet INS should target surroundings of remote OB associations.