YOUNG CLOSE-BY NEUTRON STARS: THE GOULD BELT vs. THE GALACTIC DISC

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Abstract

We present new population synthesis calculations of close young neutron stars. In comparison with our previous investigation we use a different neutron star mass spectrum and different initial spatial and velocity distributions. The results confirm that most of ROSAT dim radioquiet isolated neutron stars had their origin in the Gould Belt. Several tens of young neutron stars can be identified in future in ROSAT data at low galactic latitudes and some of them also can be EGRET unidentified sources.

astro-ph/0304141 (A&A accepted), astro-ph/0305599 (Ap&SS submitted)

Table 1: Local ($r < 1$ kpc) population of young (age < 4.25 Myrs) isolated neutron stars

Object name	Period, s	Count rate, ROSAT cts/s	$\dot{P}$ /10^{-15}	Distance, kpc	Age^a, Myrs	Ref.
RX J185635-3754	—	3.64	—	0.117^d	~ 0.5	[1,2]
RX J0720.4-3125	8.37	1.69	~ 30 – 60	—	—	[1,3]
1RXS J130848.6+212708 (RBS1223)	5.15	0.29	$< 10^4$?	—	—	[1.4]
RX J1605.3+3249 (RBS1556)	—	0.88	—	—	—	[1]
RX J0806.4-4123	11.37	0.38	—	—	—	[1,5]
RX J0420.0-5022	3.45	0.11	—	—	—	[1]
1RXS J214303.7+065419 (RBS1774)	—	0.18	—	—	—	[6]
PSR 0633+17 (Geminga)	0.237	0.54^c	10.97	0.16^d	0.34	[7]
RX J1836.2+5925 (3EG J1835+5918)	—	0.015	—	—	—	[8]
PSR 0833-45 (Vela)	0.089	3.4^c	124.88	0.294^d	0.01	[6,9,10]
PSR 0656+14	0.385	1.92^c	55.01	0.28^d	0.11	[6,10]
PSR 1055-52	0.197	0.35^c	5.83	~ 1^b	0.54	[6,10]
PSR J0056+4756	0.472	—	3.57	0.998^e	2.1	[10]
PSR J0454+5543	0.341	—	2.37	0.793^e	2.3	[10]
PSR J1918+1541	0.371	—	2.54	0.684^e	2.3	[10]
PSR J2048-1616	1.962	—	10.96	0.639^e	2.8	[10]
PSR J1848-1952	4.308	—	23.31	0.956^e	2.9	[10]
PSR J0837+0610	1.274	—	6.8	0.722^e	3.0	[10]
PSR J1932+1059 → sl?	0.227	—	1.16	0.169^e	3.1	[10]
PSR J1908+0734	0.212	—	0.82	0.584^e	4.1	[10]

[a]) Ages for pulsars are estimated as $P/(2\dot{P})$,
for RX J1856 estimate of an age comes from kinematical considerations.

[b]) Distance to J1057-52 is uncertain (~ 0.9-1.5 kpc)

[c]) Total count rate (black body + non-thermal)

[d]) Distances determined through parallactic measurements

[e]) Distances determined with dispersion measure

(1) Treves et al. (2000)
(2) Kaplan et al. (2002a)
(3) Zane et al. (2002)
(4) Hambaryan et al. (2001)
(5) Haberl, Zavlin (2002)
(6) Zampieri et al. (2001)
(7) Becker, Trümper (1997)
(8) Mirabal, Halpern (2001)
(9) Pavlov et al. (2001)
(10) ATNF Pulsar Catalogue
(http://wwwatnf.atnf.csiro.au/research/pulsar/catalogue/)

THE MAGNIFICENT SEVEN

Object name	Period, s	CR^a, cts/s	$\dot{P}$ /10^{-15}	Dist., kpc	Age, Myrs
RX J1856.5-3754	—	3.64	—	0.117	~ 0.5
RX J0720.4-3125	8.37	1.69	$\sim 30 - 60$	—	—
RX J1308.6+2127	10.3	0.29	$< 10^4$?	—	—
RX J1605.3+3249	—	0.88	—	—	—
RX J0806.4-4123	11.37	0.38	—	—	—
RX J0420.0-5022	3.45	0.11	—	—	—
RX J2143.7+0654	—	0.18	—	—	—

Close and Recent SNs
& The Gould Belt

① Local ISM

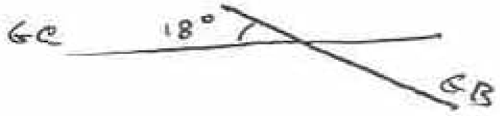
Local Bubble, Loop I, ...

> 3 ÷ 6 SNs in the last few million yrs
(Cox, Smith 2001,
Maíz-Apellániz 2001)

② The Gould Belt

Benjamin Gould
(1874, 1879)

Age ~ 30 Myrs
B2 ÷ B5 stars
SN rate ~ 30/Myr



N (< B4) ≃ 430
(see Pöppel 1997)

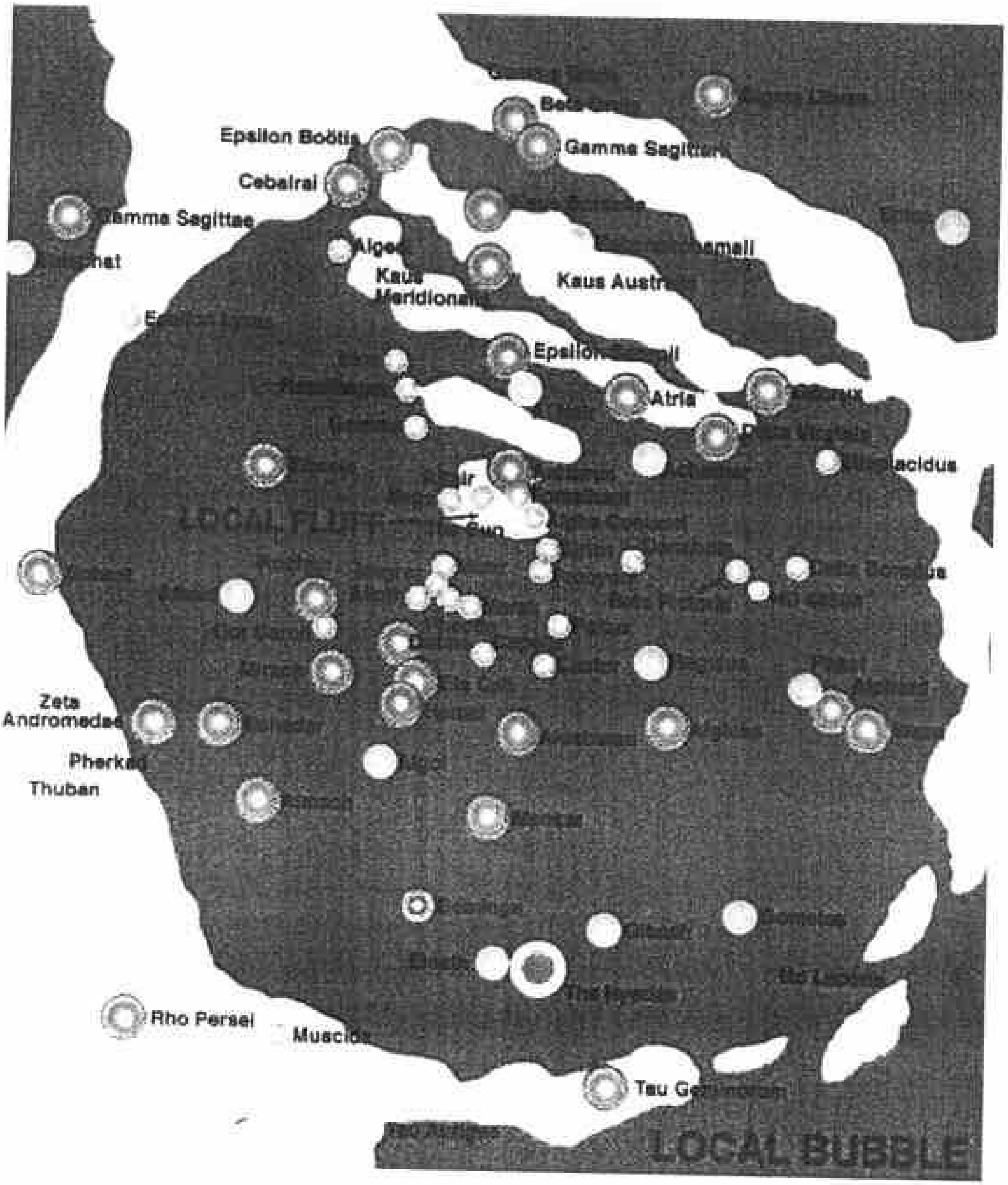
③ Cosmic Rays

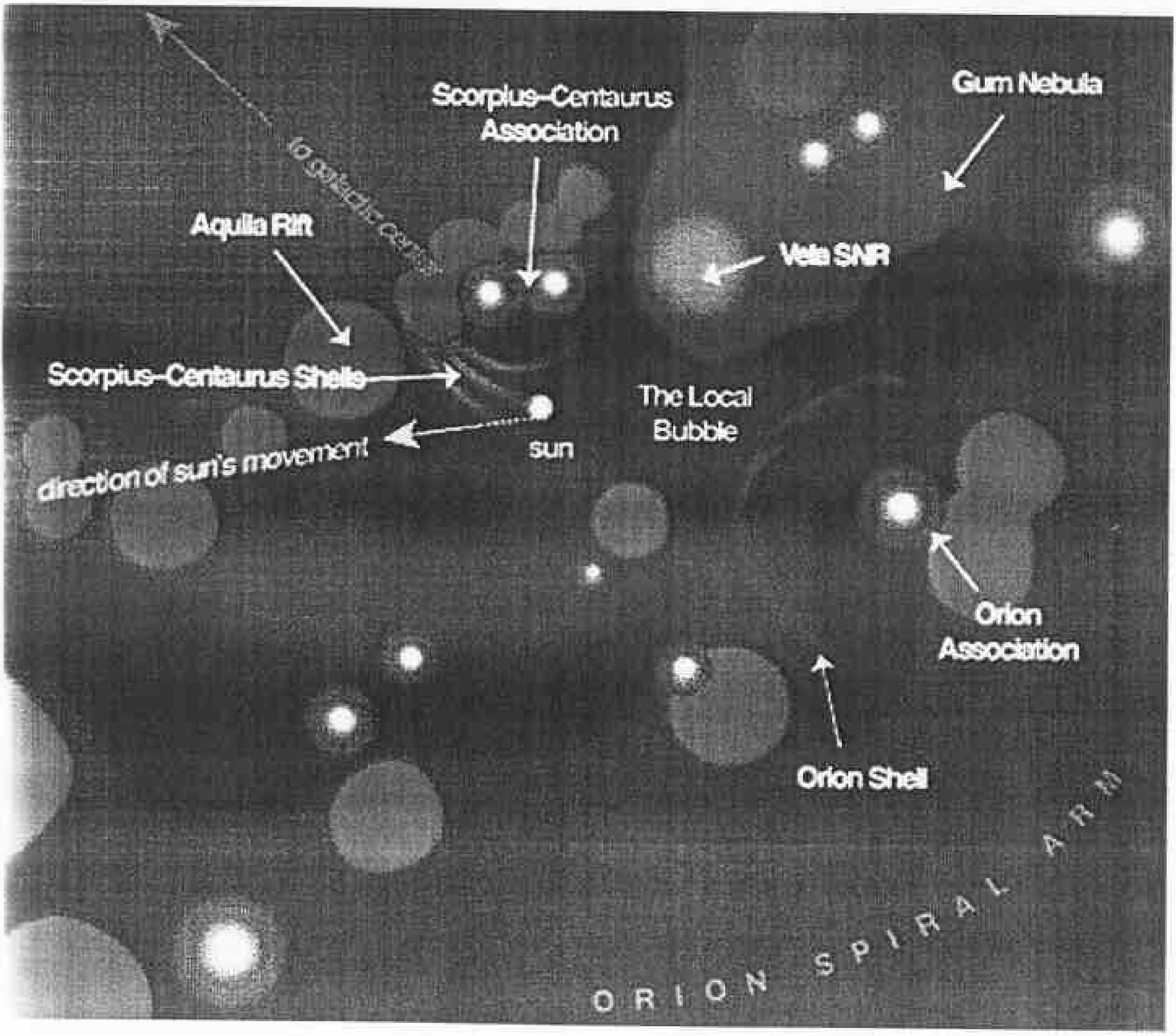
(Stozhkov 2001, Erlykin, Wolfendale 2003)

④ Geophys. Data

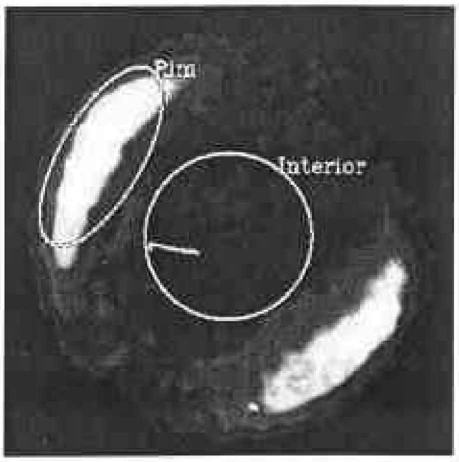
(Kocharov et al. ; Benitez et al. [0201018])

THE LOCAL BUBBLE




to galactic center
Scorpius–Centaurus Association
Gum Nebula
Aquila Rift
Vela SNR
Scorpius–Centaurus Shells
The Local Bubble
sun
direction of sun's movement
Orion Association
Orion Shell
ORION SPIRAL ARM

Connections between recent close SN and Cosmic Rays



ASCA image of SN1006. CANGAROO observed TeV photons from it

Cosmic rays are believed to be related to SNRs.

CR flux is dependent not only on average SN rate in the Galaxy in general, but on SN rate in our more or less close neighbourhood.

- Changes of CR flux during passages through spiral arms (Shaviv 2002)
- Anisotropy from the direction of the Cygnus region (Hayashida et al. 1999)
- Single source model (Erlykin, Wolfendale 1997)

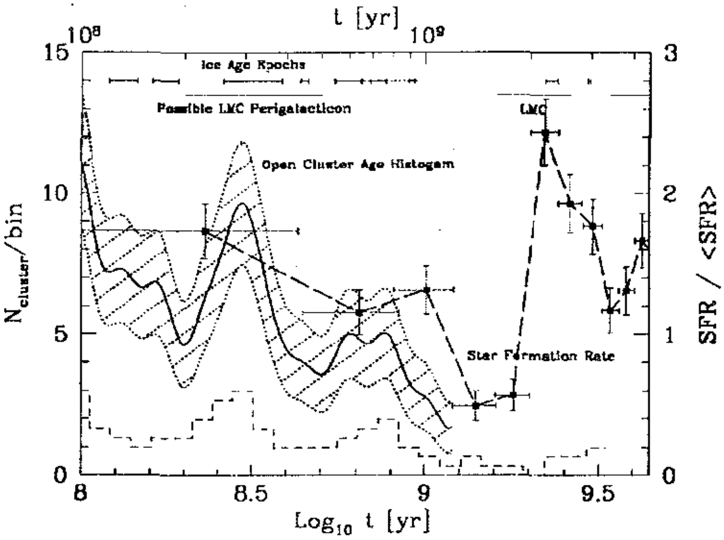
Also as it was recently calculated by Bednarek & Bartosik (astro-ph/0405310) pulsars can make a significant contribution to CR.
(We note, that some assumptions of these authors are questionable)

So it is very important to study recent SN in the Solar proximity.

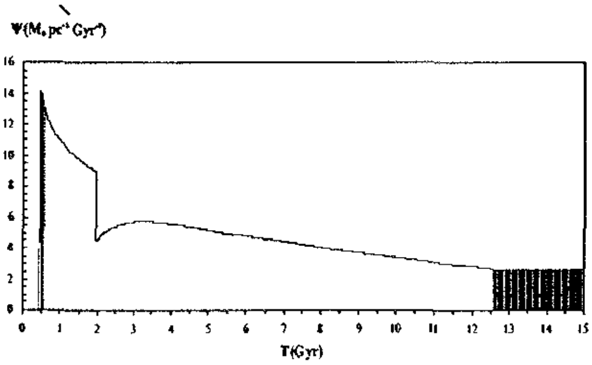
One of the way to do it is to study close-by young compact objects:
neutron stars and black holes.

Crab Nebula. Contours show high-energy data

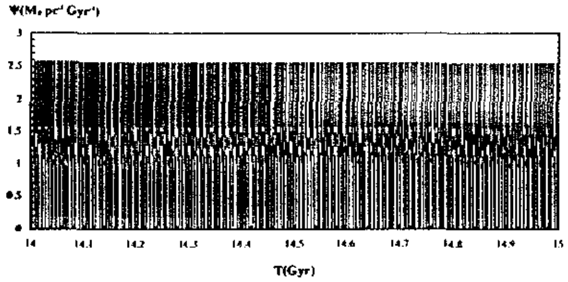
Variations of SF rate in the Solar vicinity on large time scale



From Nir Shaviv (astro-ph/0209252).



From Vanbeveren, De Donder (astro-ph/0309104).

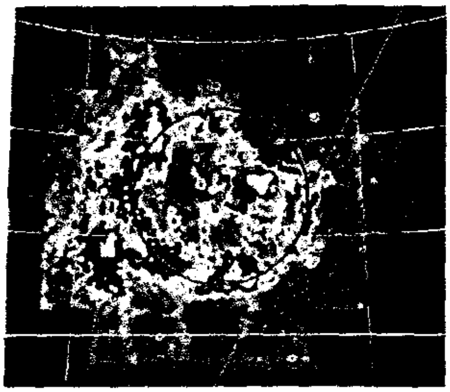


From Vanbeveren, De Donder (astro-ph/0309104, see also New Astronomy Reviews 2004).

Single Source Model (Erlykin, Wolfendale)

authors proposed in 1997 that the knee in the CR spectrum is connected with a single e, probably a SNR. The estimated distance is 230-350 pc, age — 84-100 kyr.

and Thorsett et al. (2003) discussed a possibility, that PSR 0656+14 and the Monogem can be a genetically related pair which forms the Single Source.



Monogem Ring. X-ray Image by ROSAT.

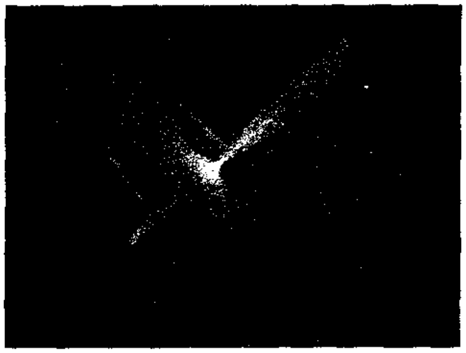
Other close-by sources

— too young.

ninga — too old.

Magnificent Seven:
- robably too old
- ong periods
- hermal spectrum

Choked jets, neutrino and chirality (crazy idea)

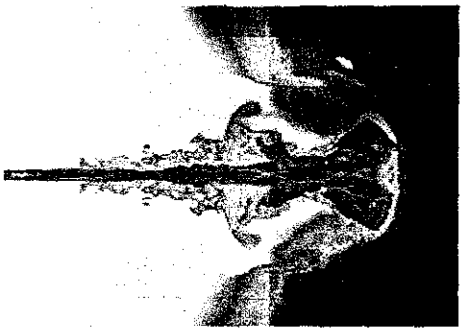


MIRROR SYMMETRY BREAKING IN THE BIOORGANIC WORLD

Tsarev (1999) suggested that mirror symmetry breaking can be connected with
he neutrino flux from close-by supernova
(see reviews in Avetisov, Goldanskii 1996; Chernavskii 2000 Physics Uspekhi **www.ufn.ru**).

However a SN itself is not that *friendly* for bioorganics......

Meszaros and Waxman (astro-ph/0103275) suggested a conception of choked jets:
"choked jets will produce .... a burst of neutrinos with energies in excess of 5 TeV"
(see also MacFadyen, Woosley and Heger astro-ph/9910034).



It is possible to suggest that such "choked jet" from "failed SN" are *guilty* in the mirror symmetry breaking in the Earth bioorganic world.

THE GOULD BELT

Benjamin Gould (1874, 1879)
(see detailed description in Pöppel (1997)
Fund. Cosm. Phys. 18, 1)

$N(<B4) \approx 430$
Age $\approx$ 30 Myrs
SN Rate $\approx$ 30/Myr (see Grenier 2000)

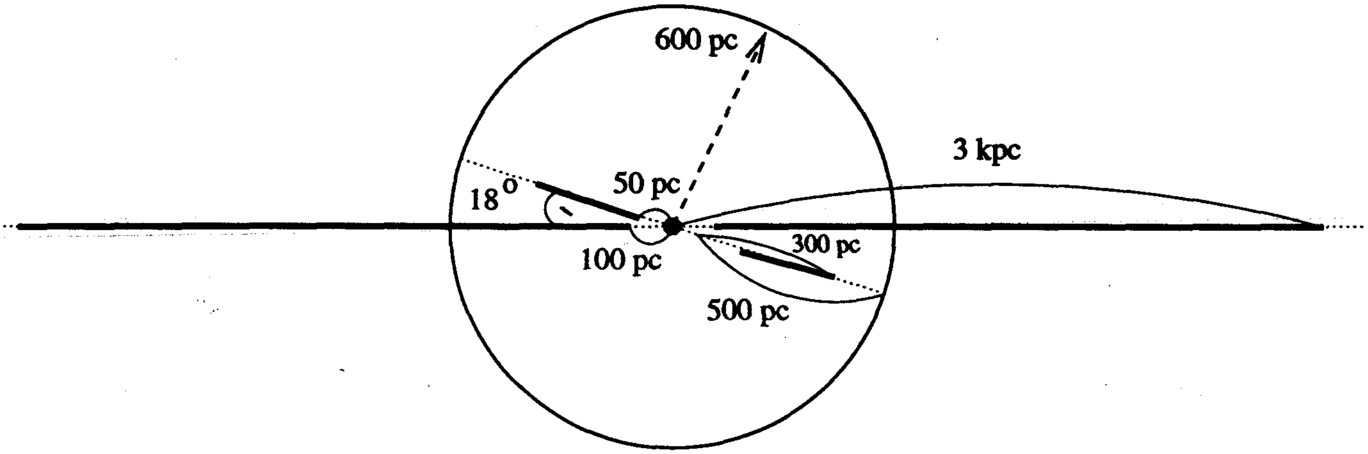
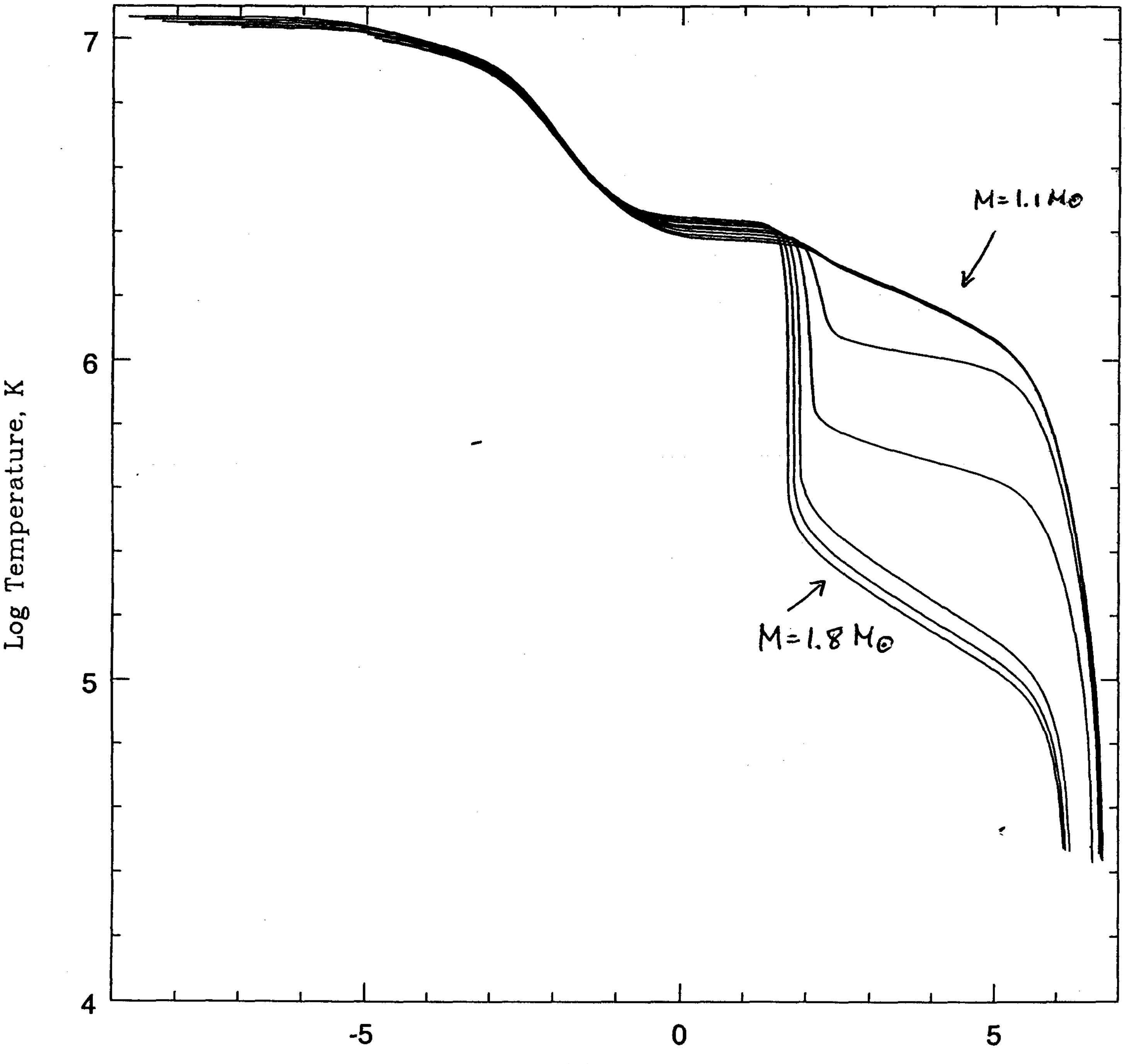
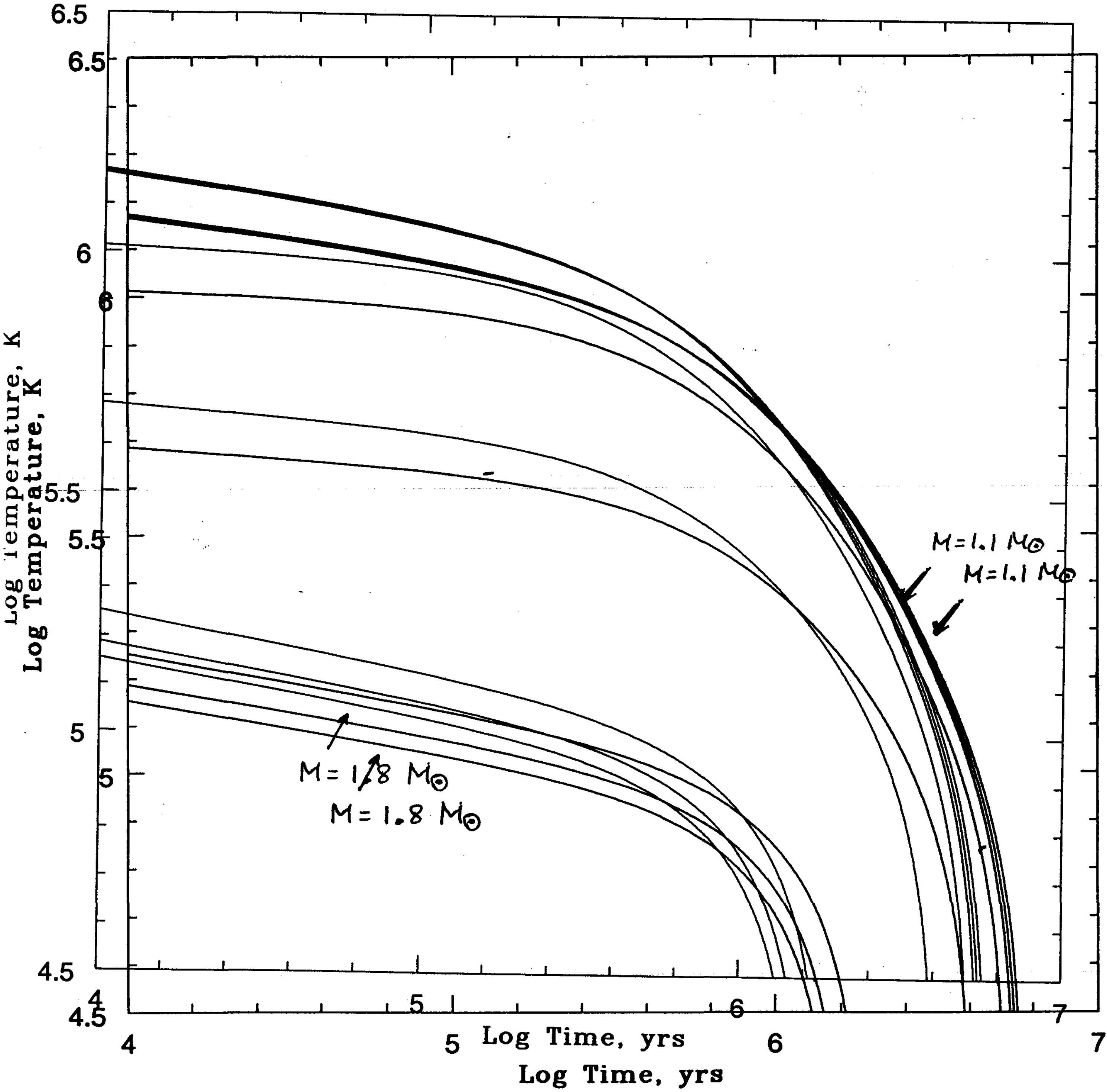


Figure 1: A sketch of the initial spatial distribution. It is a projection to the plane perpendicular to the galactic one. Stars are born in the Gould Belt, which is inclined to the galactic plane by 18 degrees, and in the galactic disc. Star producing regions are shown with thick lines.



Kaminker et al. (2001)
Yakovlev et al. (1999)



Kaminker et al. (2001)

Kaminker et al. (2001)

Yakovlev et al. (1999)

Yakovlev et al. (1999)

How do we estimate mass spectrum ("details")

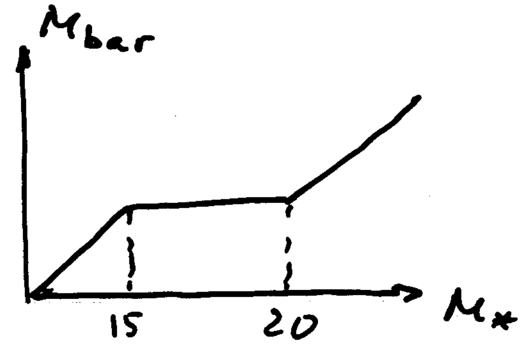
- Hipparcos' stars with $p < 0.''002$ up to B2

- Spect. class vs. mass

B2 : 8.5 - 11.5 (352)
B1 : 11.5 - 15 (124)
B0 : 15 - 18 (61)
O9 : 18 - 20 (25)
O8 : 20 - 25 (8)

- Woosley et al.

M_*	M_{NS} (grav)
8.5	1.051
11.5	1.221
15	1.416
18	---
20	---
25	1.766



$$M_{bar} - M_{grav} = 0.075\, M_{grav}^2$$

(Timmes et al 1996)

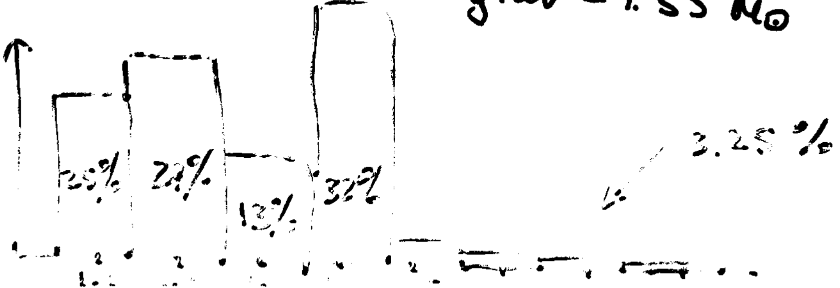
- $M \to$ Age $\to \ldots$

$$\lg T = 9.9 - 3.8 \lg M + \lg^2 M$$

- all stars $\leq 11\, M_\odot \Rightarrow M_{grav} = 1.27\, M_\odot$ (Timmes et al.)

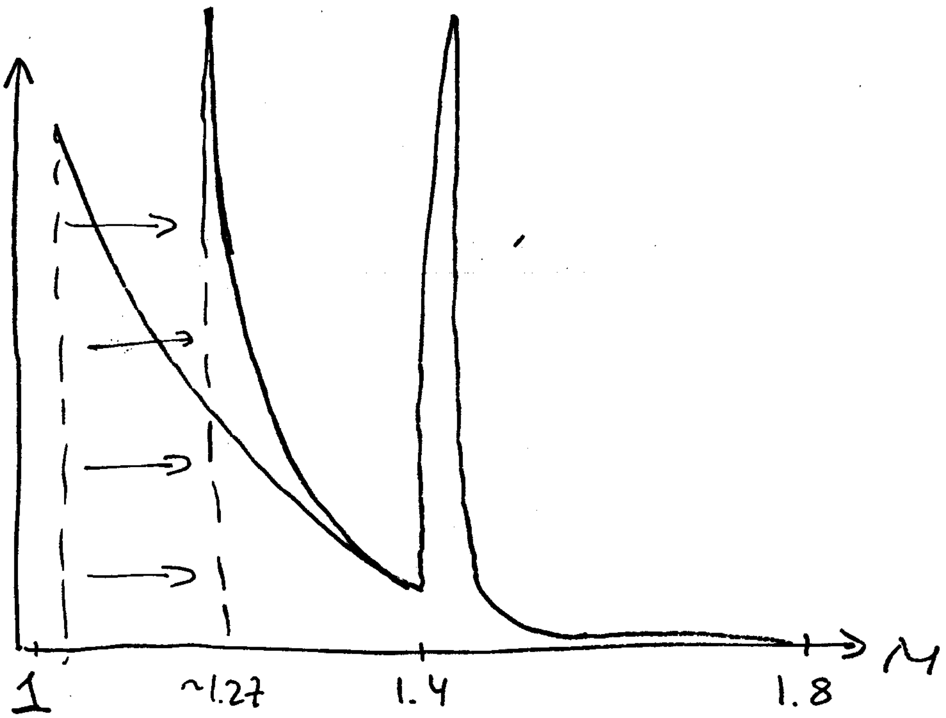
(Not crustal for us)

$M_{cr} = 13.85\, M_\odot \to M_{grav} = 1.35\, M_\odot$



Mass spectrum

- We use calculations by Woosley et al. (see also Timmes et al.) to estimate compact objects' masses from known progenitor masses
- We use HIPPARCOS data on close massive stars, which can produce NSs in their future evolution (570 stars)
- $M_{min} \approx 1.05\, M_\odot$, $M_{max} \approx 1.76\, M_\odot$
- The Gould Belt increases the number of low-mass ($M < 1.35\, M_\odot$) NSs by a factor of 4-5 in comparison with Salpeter IMF



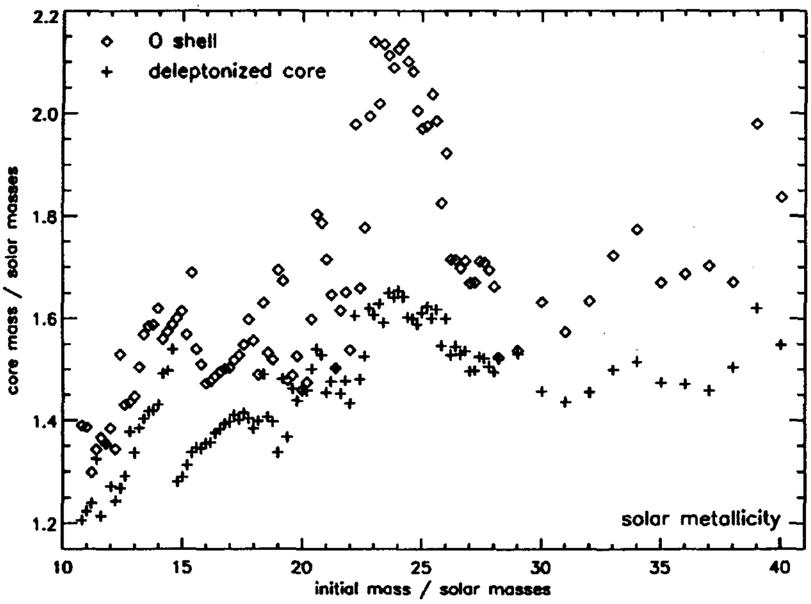


FIG. 17. The mass of the final iron cores and location of the oxygen-burning shells in a large number of presupernova stars of solar metallicity (Heger, Woosley, Rauscher, and Hoffman, 2002). The baryonic mass of the neutron star remnant might lie between these two masses.

rotation (and possibly magnetic fields) are overwhelmingly important or quite unimportant in the explosion.

F. Effect of metallicity on the presupernova model

The principal effects of low metallicity on the presupernova structure come about because of the diminished mass loss. For solar metallicity, the helium core at death reaches a maximum of $\sim 12 M_\odot$, corresponding to an initial main-sequence mass of $35 M_\odot$ (Fig. 16). This does not preclude the existence of more massive Wolf-Rayet stars at an earlier stage in their evolution, but for higher-mass main-sequence stars of solar metallicity, the presupernova mass decreases rapidly above $35 M_\odot$ because of efficient mass loss from Wolf-Rayet stars [Eq. (15)]. This saturation of the core mass manifests itself in a variety of ways directly relevant to the explosion mechanism. Since the helium-core mass of the presupernova star ceases to grow, the iron-core mass and especially the location of the oxygen-burning shell quit increasing at around $30 M_\odot$ (Fig. 17). The binding energy of all matter outside the iron core also ceases to increase and even decreases a little. This suggests that the final products of extremely massive solar metallicity stars ($30 M_\odot$ to $> 100 M_\odot$) may be no more difficult to explode than their lower-mass counterparts. We believe that such stars have their counterparts in nature as type-Ib/Ic supernovae and (if $M_{\rm preSN} \gtrsim 4 M_\odot$) subluminous type-Ib supernovae.

Presupernova stars of lower metallicity have significantly different characteristics, at least at high mass. Because of the metallicity dependence of mass loss (Sec. II.G), the mass of the lightest single star to lose its hydrogen envelope increases with declining metallicity and, along with it, the mass of its helium core at death.

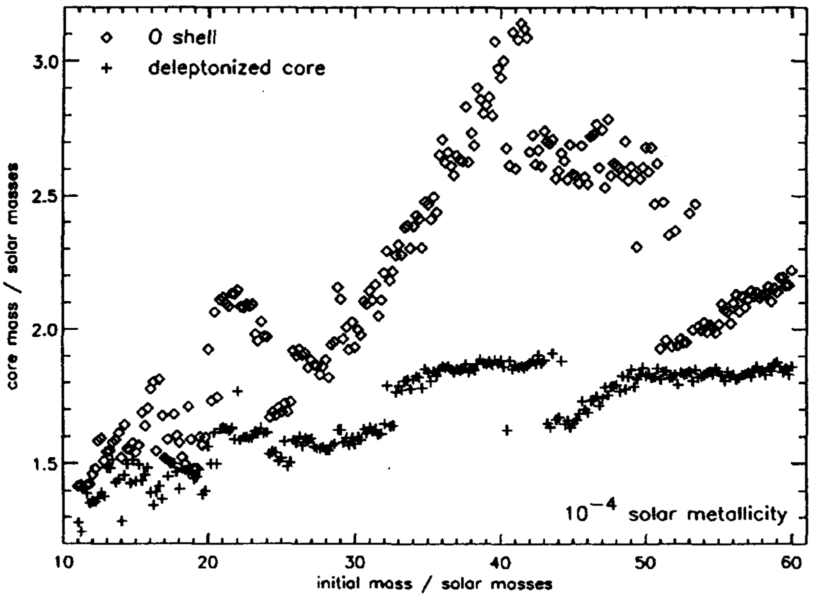


FIG. 18. The mass of the final iron cores and location of the oxygen-burning shells in a large number of presupernova stars of 10^{-4} solar metallicity (Heger, Woosley, Rauscher, and Hoffman, 2002).

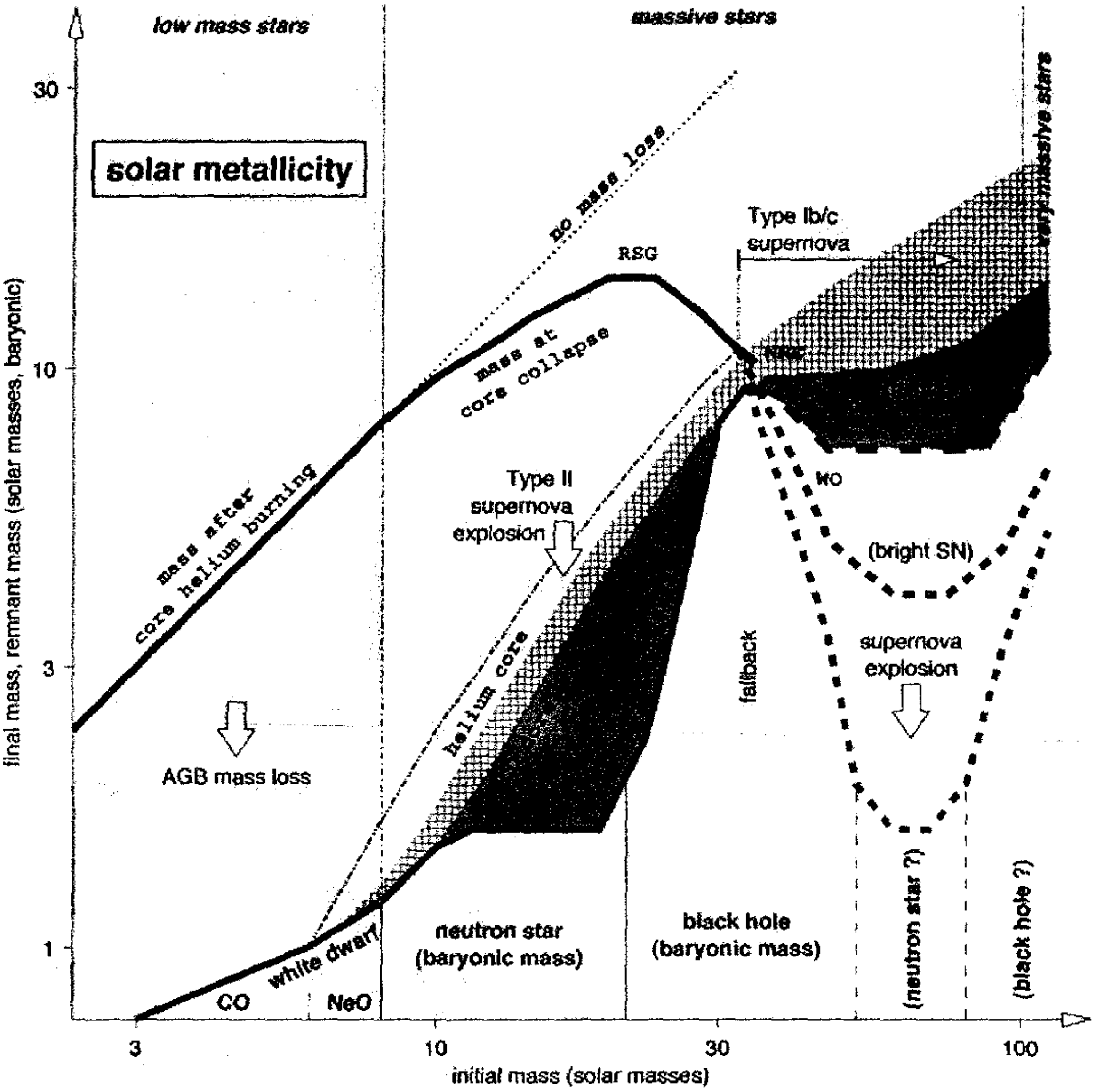
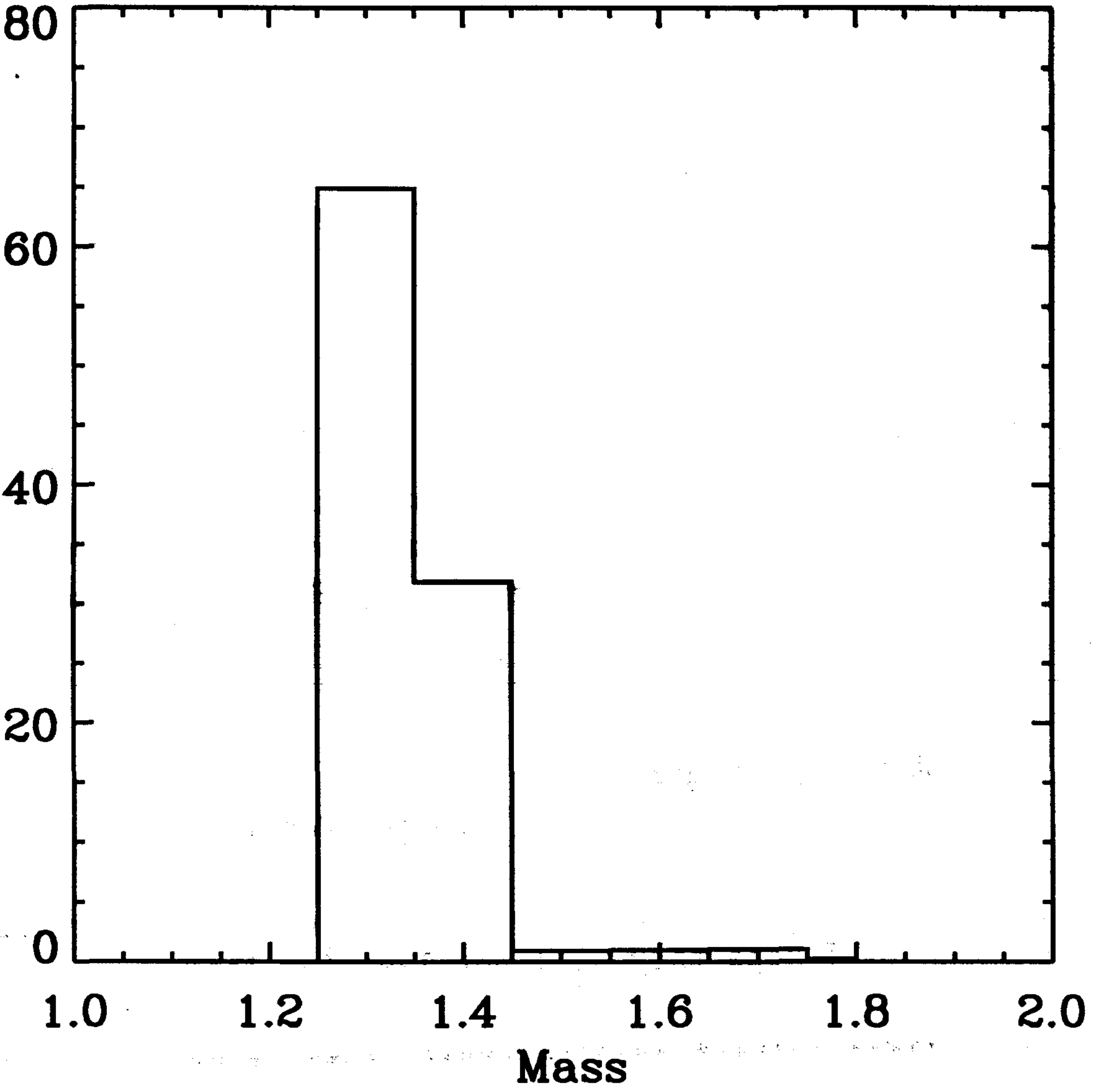


FIG. 16. Initial-final mass function of nonrotating stars of solar composition, similar to Fig. 12. Mass loss reduces the mass of the envelope (blue curve) until, for a mass above $\sim 33 M_{\odot}$ the helium core is uncovered before the star reaches core collapse. At this point the star becomes a Wolf-Rayet star and the strong Wolf-Rayet mass loss sets in. We give two scenarios for the uncertain strength of the Wolf-Rayet-mass-loss rate: The short-dashed red and blue lines are for a high mass-loss rate. Here a "window" of initial masses may exist around $50 M_{\odot}$, where neutron stars are still formed (bound by higher- and lower-mass stars that make black holes). For a low Wolf-Rayet mass-loss rate (long-dashed red and blue lines) the final mass at core collapse is higher and the "neutron star window" may not exist. Then only black boles are formed above $\sim 21 M_{\odot}$. "RSG," "WE," "WC," and "WO" indicate the type of the last mass-loss phase and also the (spectral) type of the star when it explodes. The heavy-element production (green and green cross hatched) is given only for the low-mass-loss case [Color].

ing helium core and an essentially stationary red giant envelope would halt the rotation of the former in far less than a helium-burning lifetime. The iron cores of massive stars, for them, collapsed without rotation, and pulsars acquired whatever spin they have from asymmetries in the explosion mechanism. The magnetic torque is proportional to the product of the radial component of the field B_r and the poloidal component B_{ϕ}. The latter can become quite large owing to differential winding, but will still reach a maximum given by instabilities and reconnection. The radial field, on the other hand, is given almost entirely by instabilities. Spruit and Phinney took $B_r \sim B_{\phi}$.

More recent work by Spruit (1999, 2002), which uses a physical model to estimate B_r, suggests an important but diminished role for magnetic torques. Using Spruit's new prescription, Heger, Woosley, and Spruit (2002) find angular momenta in their presupernova models corresponding to pulsar rotation rates that, though rapid (~ 10 ms), are well below breakup. Clearly this is an area of rapid development and current great uncertainty. Unfortunately it is difficult to say today whether

NS MASS SPECTRUM



Mass distribution for young close-by NSs. Stars were distributed in eight bins from 1.1 to 1.8 solar masses. The vertical axis shows percentage in each bin. To derive this spectrum we use *Hipparcos* data and calculations of Timmes et al. (1996) and Woosley et al. (2002).

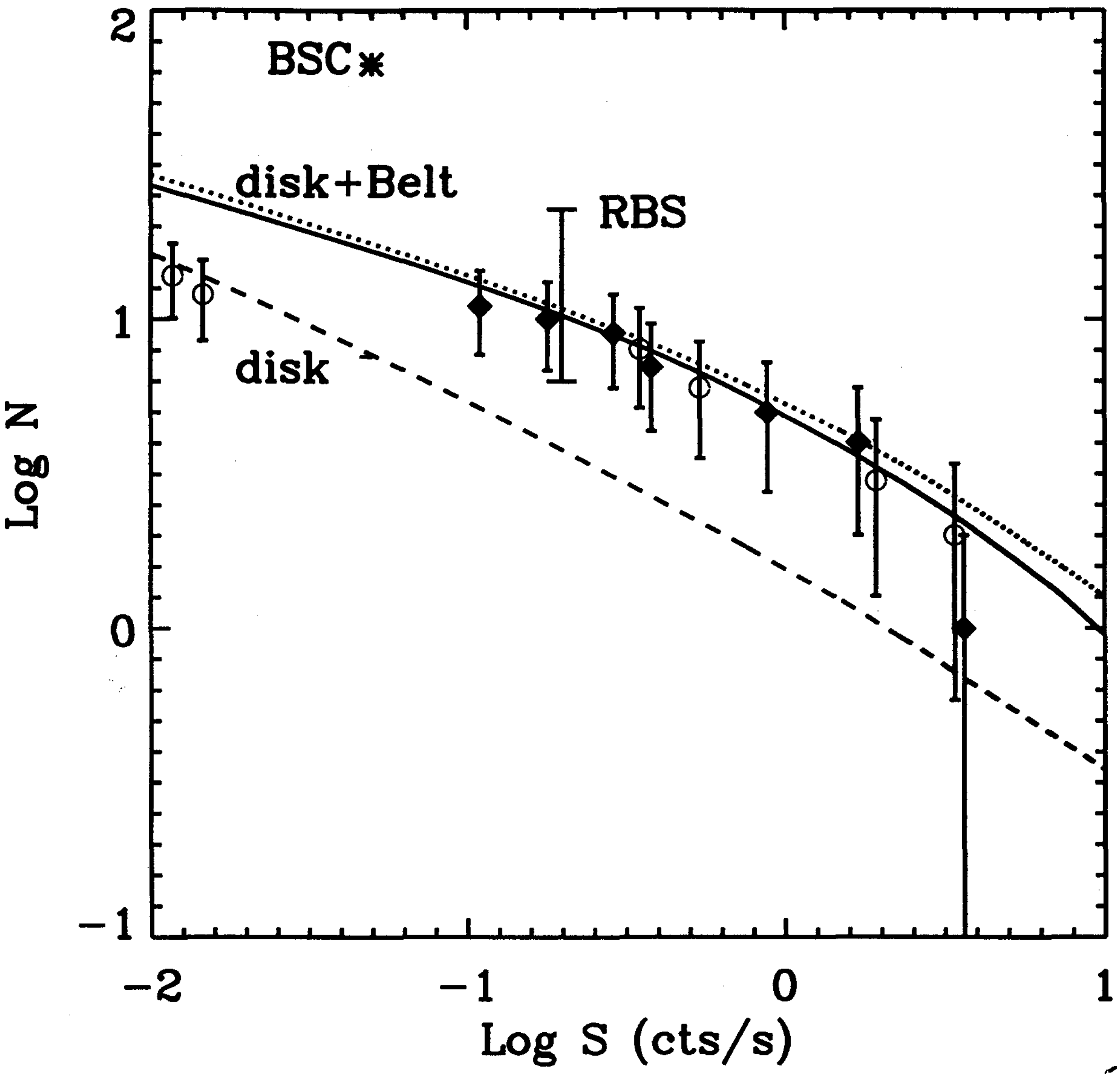


Figure 3: A "new" model (solid line: $R_{Belt} = 300$ pc, new mass spectrum, an "atmospheric effect", new kick velocity distribution) in comparison with older results (dotted line — disc+Belt, dashed line — only disc).

SKY MAP FOR CLOSE COOLING NSs

Projected distribution of cooling INSs in the sky in galactic coordinates. Only sources with count rate > 0.05 cts s^{-1} are accounted for. The plot shows contours of constant INS number density per square degree. Darker areas close to the Belt or/and to the galactic plane correspond to ~ 0.001 sources/square degree. The total number of sources is ~ 17.

Only about 12% of sources with ROSAT count rate > 0.01 cts s^{-1} are found at $|b| > 40°$. About 20% of sources lie outside the belt ±30° from the galactic plane, while ~ 50% are expected to be within ±12° from the plane of the Galaxy.

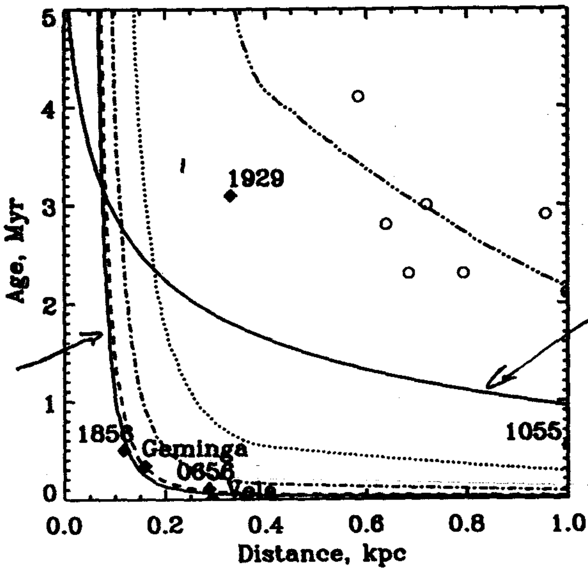
Age-Distance diargam

To illustrate properties of close-by young NSs we introduce
Age – Distance diagram

Detected thermal X-ray emission

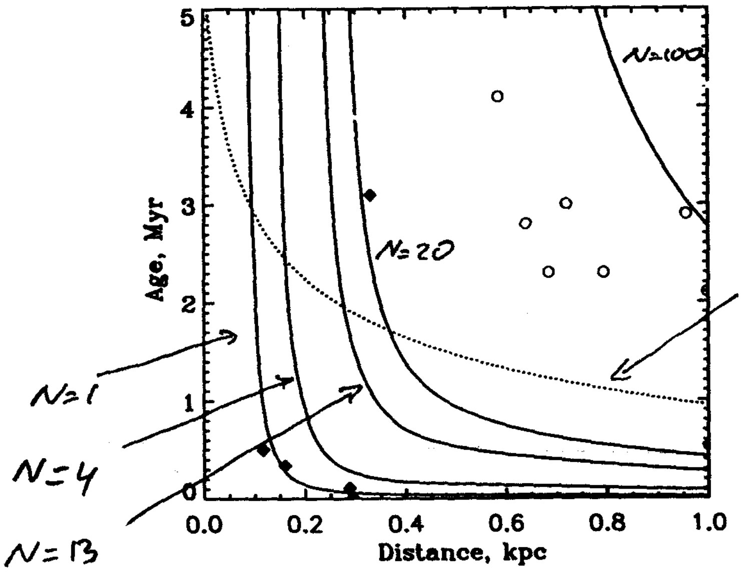
Undetected thermal X-ray emission

+ there are objects with undetermined age (or/and distance)



visibility line $M \le 1.35 M_\odot$ (Yakovlev, Kaminker et al.)

$f_{unabs} = 10^{-12}$ erg/cm²/s



visibility line

Conclusions

- We live in a special region of the Galaxy.
  It is enriched by young compact objects ($R < 1$ kpc, Age<30 Myrs).
  The SN rate is also enhanced.
- Some of young isolated NSs from the Gould Belt are observed as dim X-ray sources.
- There are also young isolated BHs in the solar vicinity.
  The approximate positions of some of them can be estimated using massive runaway stars.