Termalno zračenje ostataka supernovih u radio-području

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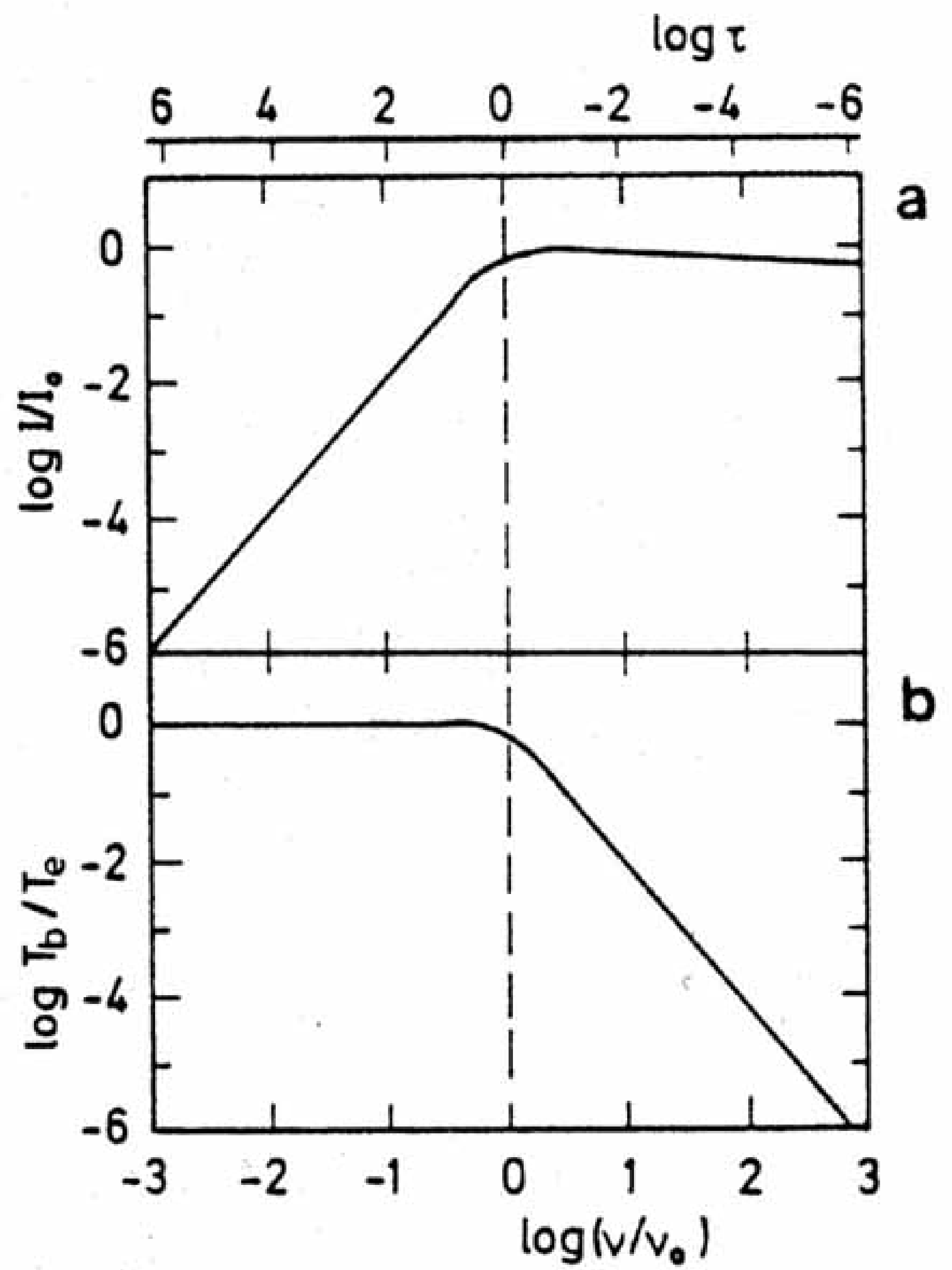
- Synchrotron emissivity $\varepsilon_\nu \propto K H^{1+\alpha} \nu^{-\alpha}$, where *K* is taken from $N(E) = KE^{1+2\alpha}$, *H* is the magnetic field and the spectral index α is taken from $S_\nu \propto \nu^{-\alpha}$.

- Thermal bremsstrahlung

$\varepsilon_\nu \propto N^2 T^{-1/2}$,

where N is particle concentration and T is temperature



log τ
6
4
2
0
-2
-4
-6
a
b
log I/I₀
log Tb / Te
0
-2
-4
-6
-3
-2
-1
0
1
2
3
log(ν/ν₀)

- There are two rare types of SNRs with possible strong thermal emission

  (Urošević and Pannuti 2005)

- the first type – the relatively young SNRs in the adiabatic phase of evolution that evolve in the dense molecular cloud (MC)
  - $D \approx 20$ pc, $\Sigma_{1GHz} \sim 10^{-20}$ (SI)
  - for $N \approx 300\ cm^{-3}$ and $T \sim 10^6$ K $\Rightarrow$

$$\varepsilon_{1GHz,\ therm.} \approx \varepsilon_{1GHz,\ synch.}$$

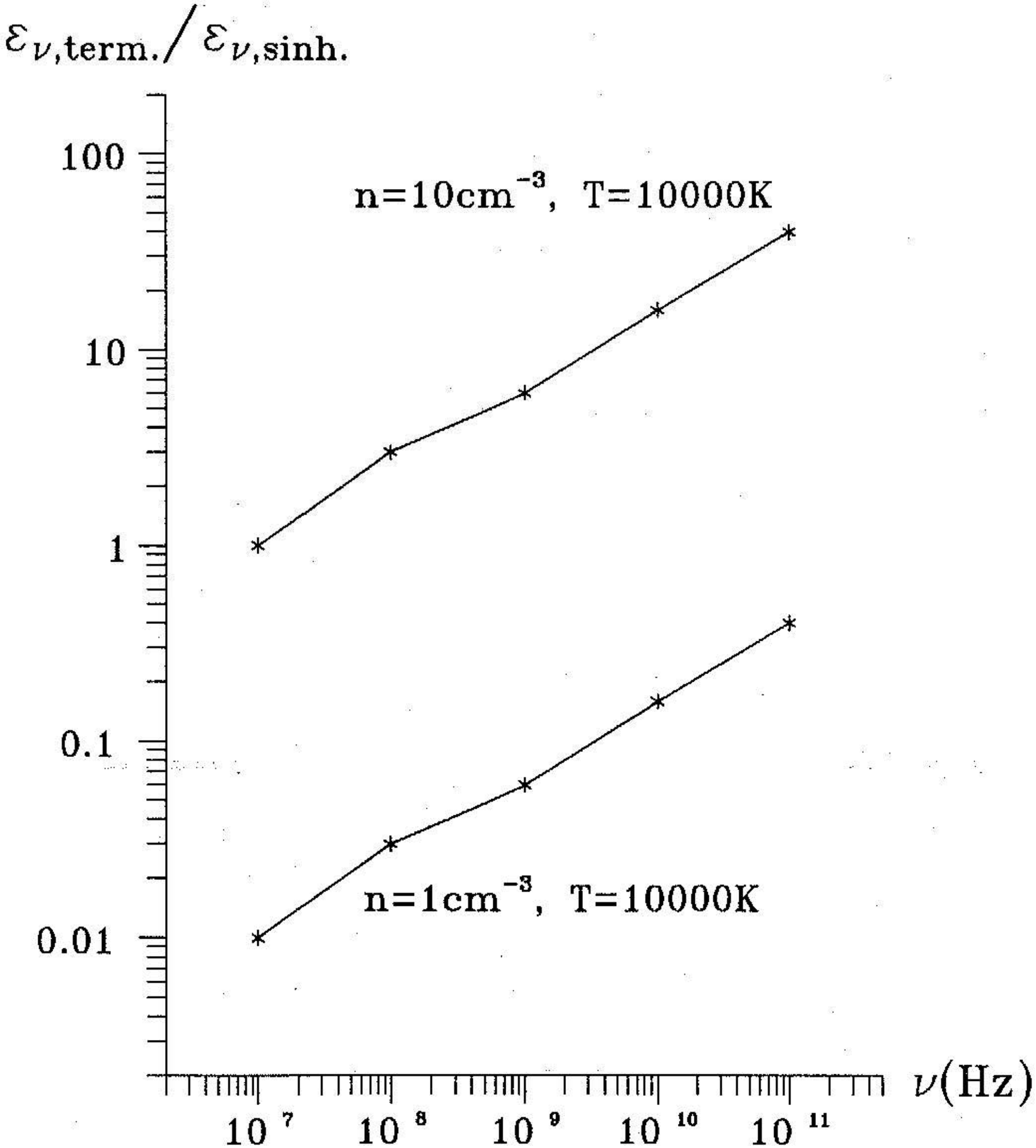
- there are four observed relatively young SNRs with identified thermal absorption or emission evolved in MCs with N = 100 – 1000 cm^{-3}
- γ Cygni, Cygnus Loop, HB21 and 3C391 (Zhang et al. 1997, Leahy and Roger 1998, Zhang et al. 2002, Brogan et al. 2005)

- the second type – the extremely evolved SNRs in the late adiabatic phase expanded in denser warm medium

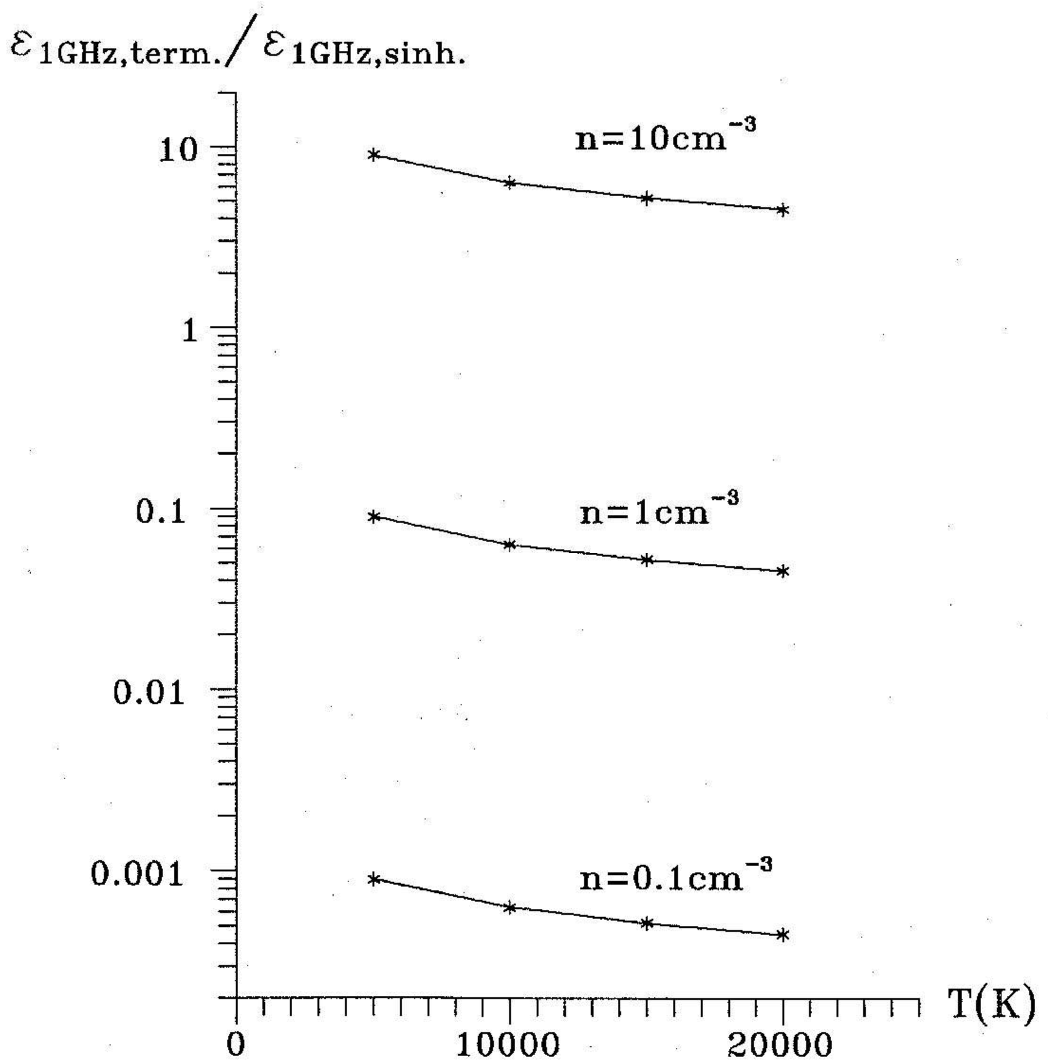
– D ≈ 200 pc, $\Sigma_{1GHz} \sim 10^{-22}$ (SI)

– for N ≈ 1 - 10 cm^{-3} and T ~ 10^4 K

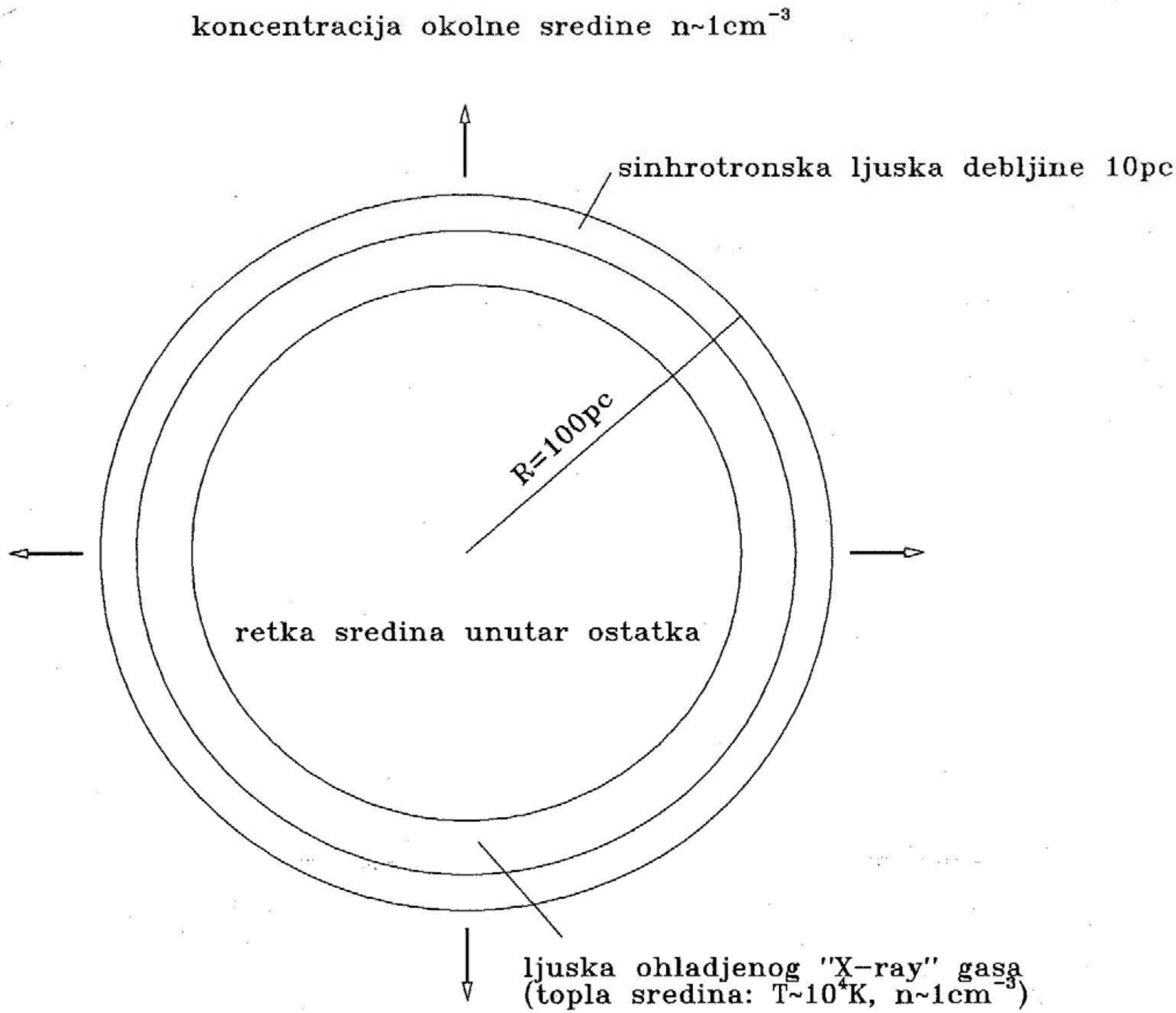
$\Rightarrow \varepsilon_{1GHz,\ therm.} \approx (0.1 - 10)\ \varepsilon_{1GHz,\ synch.}$



$\varepsilon_{\nu,term.}/\varepsilon_{\nu,sinh.}$
100
10
1
0.1
0.01
$n=10cm^{-3}$, T=10000K
$n=1cm^{-3}$, T=10000K
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
ν(Hz)

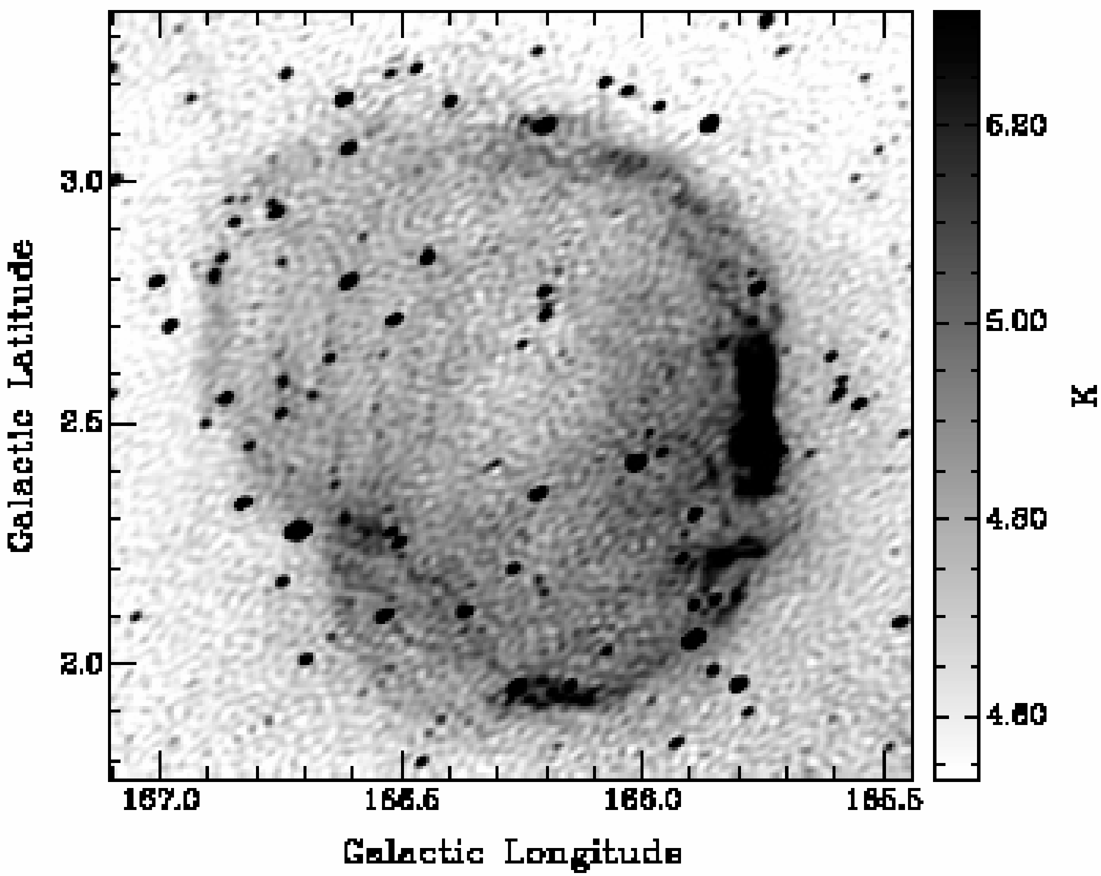


$\varepsilon_{1GHz,term.} / \varepsilon_{1GHz,sinh.}$
10
1
0.1
0.01
0.001
n=10cm^{-3}
n=1cm^{-3}
n=0.1cm^{-3}
0
10000
20000
T(K)

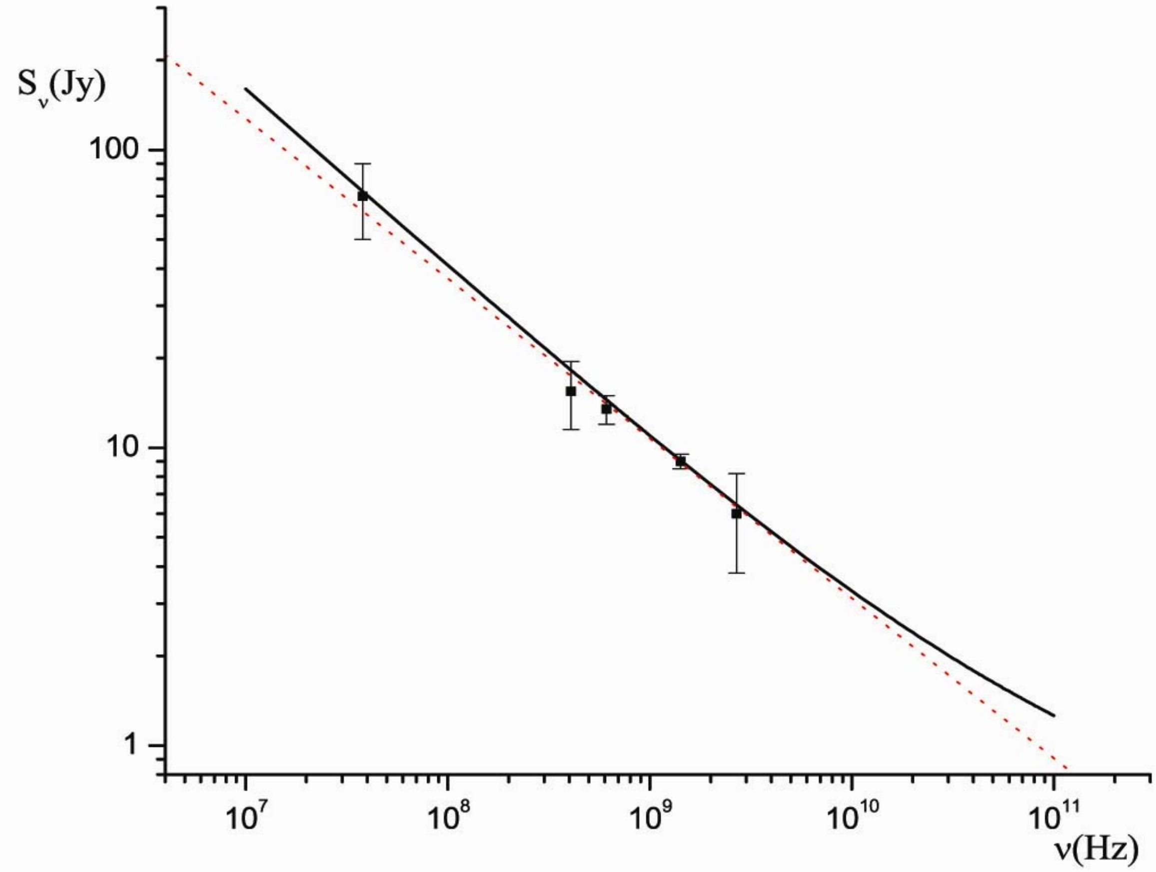

koncentracija okolne sredine $n \sim 1cm^{-3}$
sinhrotronska ljuska debljine 10pc
R=100pc
retka sredina unutar ostatka
ljuska ohladjenog "X-ray" gasa
(topla sredina: $T \sim 10^4 K$, $n \sim 1cm^{-3}$)

- there is one observed extremely evolved SNR in the adiabatic phase with identified thermal absorption, HB9 (Leahy et al. 1998)
- also we propose observations of the one good candidate SNR with possibly strong thermal flux - OA184

OA 184, 1420 MHz; Leahy and Tian 2005

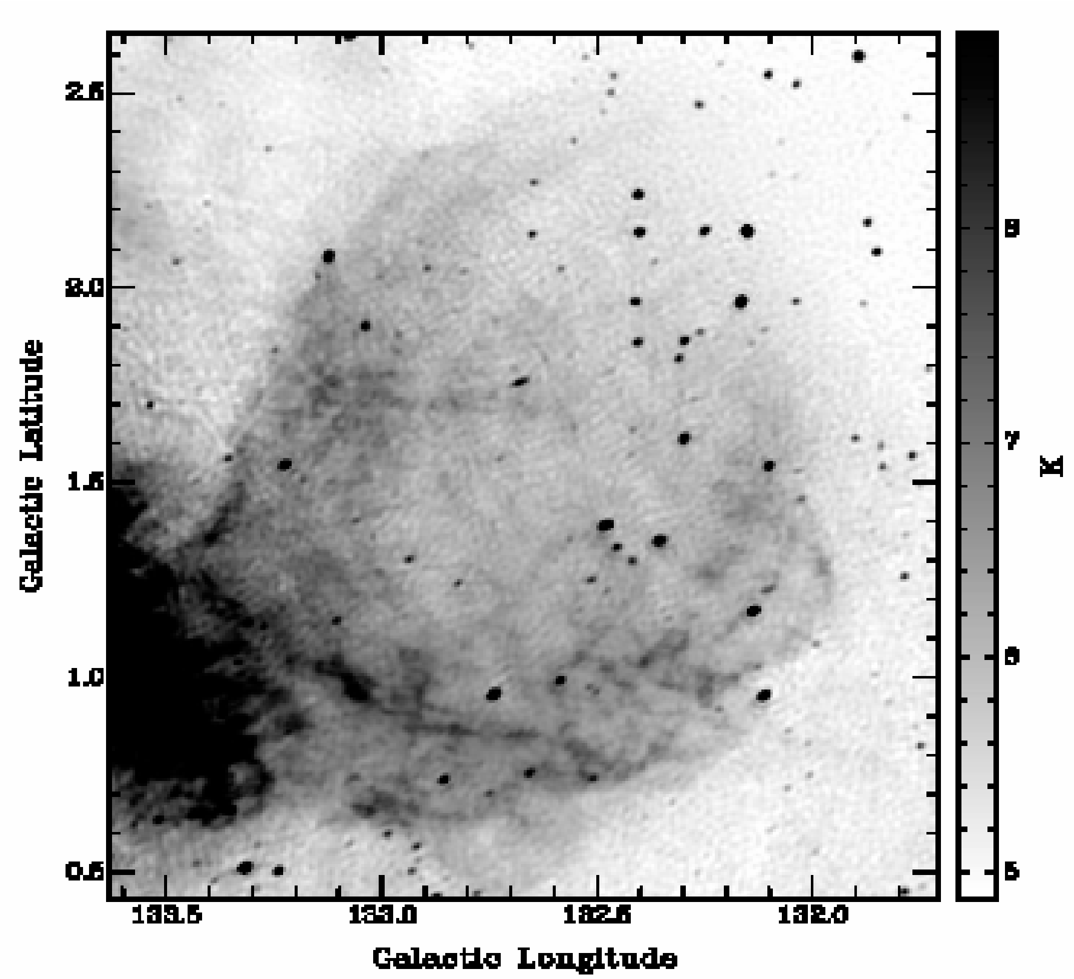


OA 184, bremss.=10%synch.
Urošević and Pannuti 2005

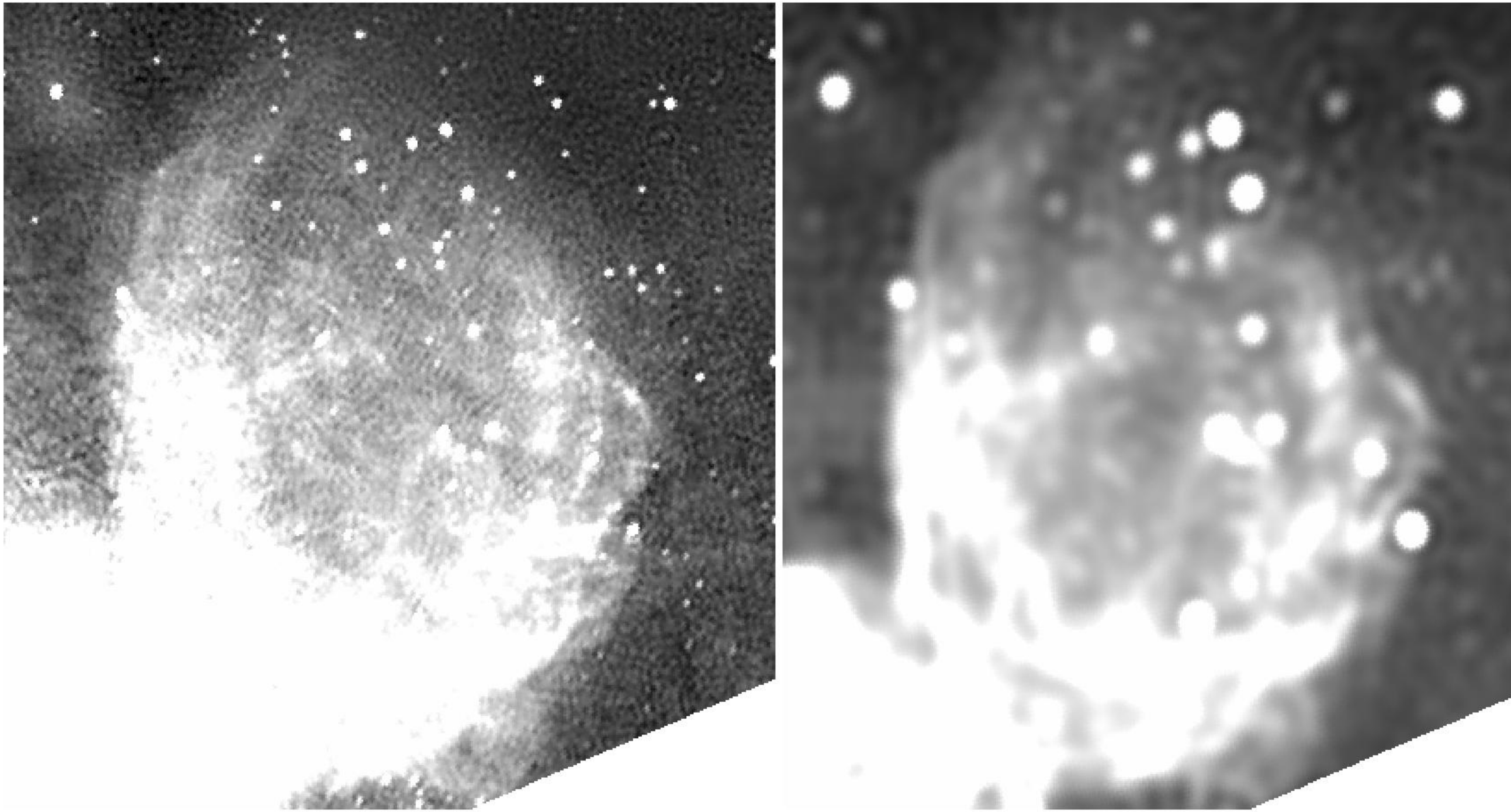


HB3

HB3, 1420 MHz,
Tian and Leahy 2005



HB3 – 1420 MHz and 408 MHz



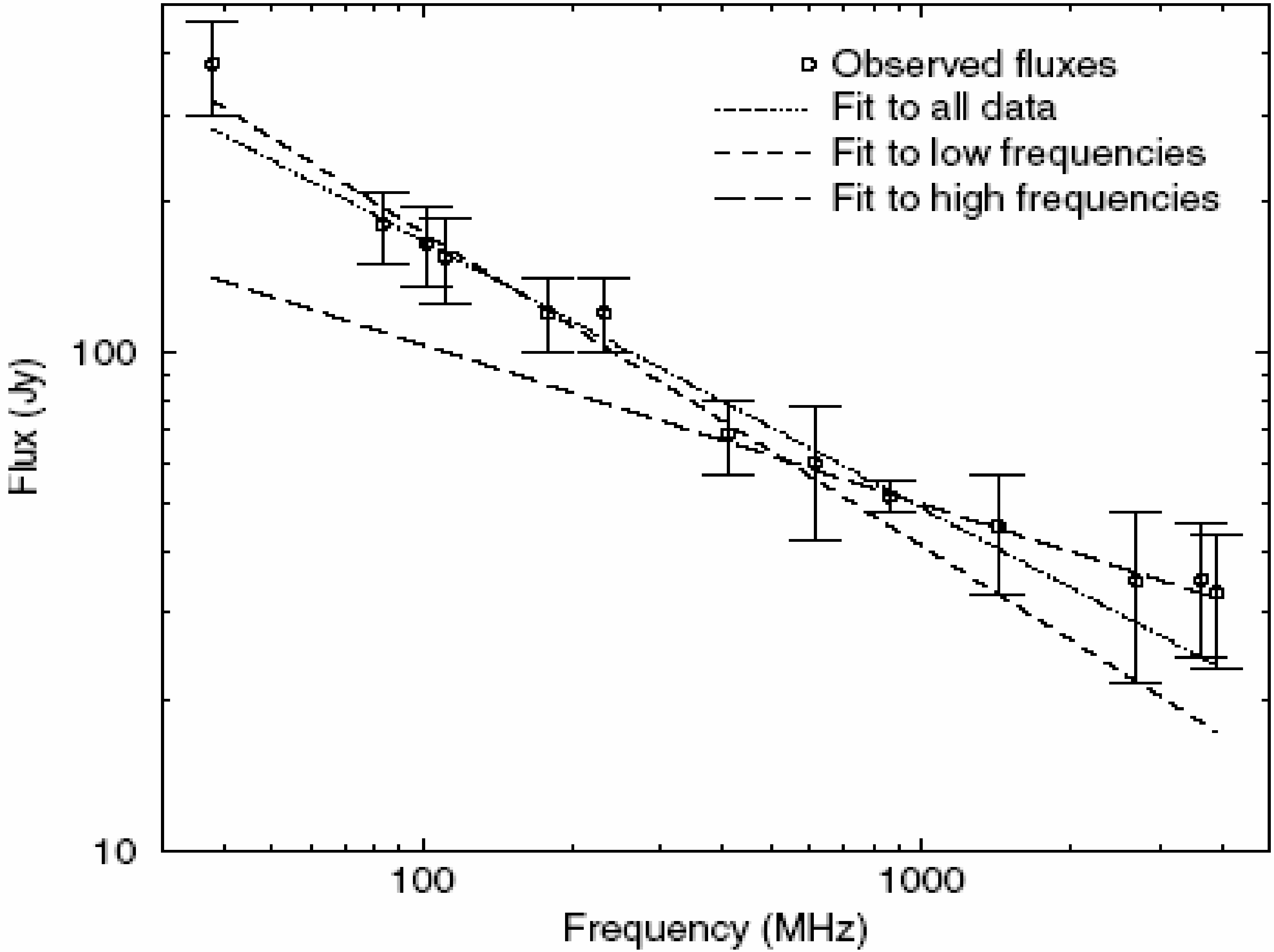
HB3 – observational data

- S_{1GHz} = 50 Jy
- D = 70 pc (for distance of 2 kpc)
- Shell thickness = 0.05 D

↓↓↓

- Emissivity $\varepsilon_{1GHz} = 1.67 \times 10^{-37}$ (ergs sec^{-1} cm^{-3} Hz^{-1})

HB3 spectrum (Tian and Leahy 2005)

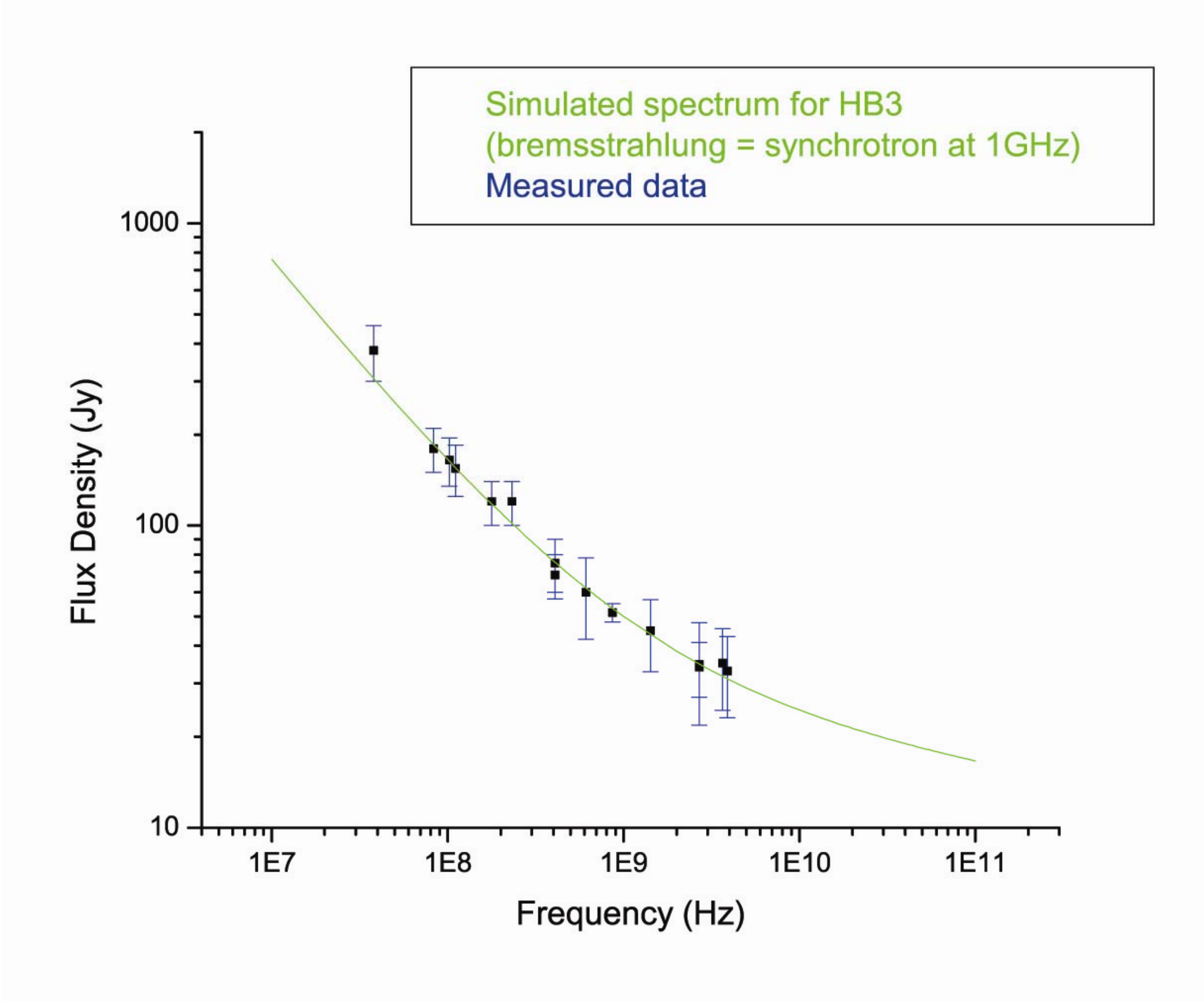


HB3 – artificial spectrum

- Assumption:
  thermal bremsstrahlung (α=0.1) =
  synchrotron (α=0.73) = $\frac{1}{2}\varepsilon_{1GHz}$

- 200 points (10^7 – 10^{11} Hz)

- "pure" synchrotron spectrum α=0.73 (38 – 178 MHz)



Simulated spectrum for HB3
(bremsstrahlung = synchrotron at 1GHz)
Measured data
Flux Density (Jy)
1000
100
10
1E7
1E8
1E9
1E10
1E11
Frequency (Hz)

HB3 - density of environment

We recall ε_ν(cgs)= $7 \times 10^{-38}\, N^2\, T^{-1/2}$

if we suppose $10^4 < T < 10^6$ K

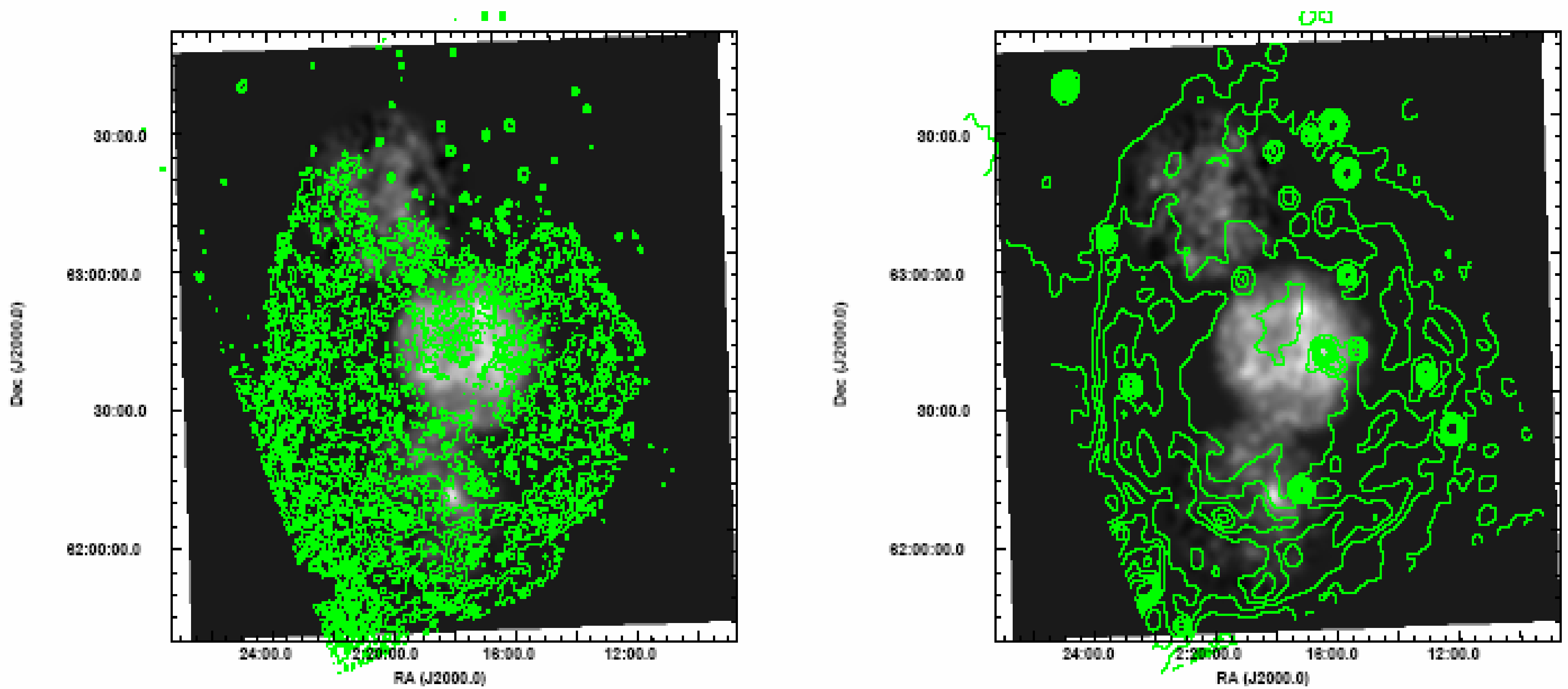
↓↓↓

$10 < n_e < 35\ \mathrm{cm}^{-3}$

HB3 – X ray observations

- ASCA – Advanced Satellite for Cosmology and Astrophysics
- GIS observations – Gas Imaging Spectrometers (gas scintillation proportional counters)
- 0.6 – 12 keV
- HEASARC – High Energy Astrophysics Science Archive Research Center

Fig. 1.— *ASCA* GIS images of HB3 with radio contours overlaid for emission at 1420 MHz (left) and 408 MHz (right). In units of brightness temperature, the contour levels in the left image are 6, 6.5, 7, 7.5, 8, 8.5, 9, 9.5 and 10 K while the contour levels in the right image are 50, 60, 70, 80, 90, 100, 110, 120, 130, 140 and 150 K. The X-ray emission has been smoothed with a Gaussian of 1 arcminute: the intensity range of this emission is from 0 to 1.4×10^{-3} — cts sec^{-1} arcmin^{-2}.



HB3 – density from X observations

- Independent estimate of density from X rays
- $EM_x=(const/d^2)n_e n_H V$

$$\downarrow\downarrow\downarrow$$

$$n_e \approx 5\ cm^{-3}$$

CONCLUSIONS

- curved spectrum of HB3 can be explained by including the thermal bremsstrahlung
- the density of SNR environment can be determined using thermal component
- the similar values for environmental density are obtained from radio and X-ray observations of HB3 (definitely, this SNR evolves in denser environment)
- density in SNR interior is lower compared to density in the rim