Understanding Magnetars with Conventional Physics

David Eichler

My collaborators

Yuri Lyubarsky

Chris Thompson

Peter Woods

Michael Gedalin

Andrew Cheng (back in 1986-88)

How can we tell what magnetars are made of?

How can we tell what magnetars are made of?

Try thermal echos as a diagnostic (Eichler and Cheng 1989).

Short-term afterglow (hours): Settling of uplifted matter

Medium-term afterglow (weeks): Cooling of outer crust

Long-term afterglow (years): Cooling of inner crust

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THERMAL AFTERGLOW FROM TRANSIENT ENERGY RELEASE IN NEUTRON STARS

D. EICHLER
University of Maryland, College Park, Maryland; and Ben-Gurion University, Beer Sheva, Israel
AND
A. F. CHENG
The Johns Hopkins University, Applied Physics Laboratory
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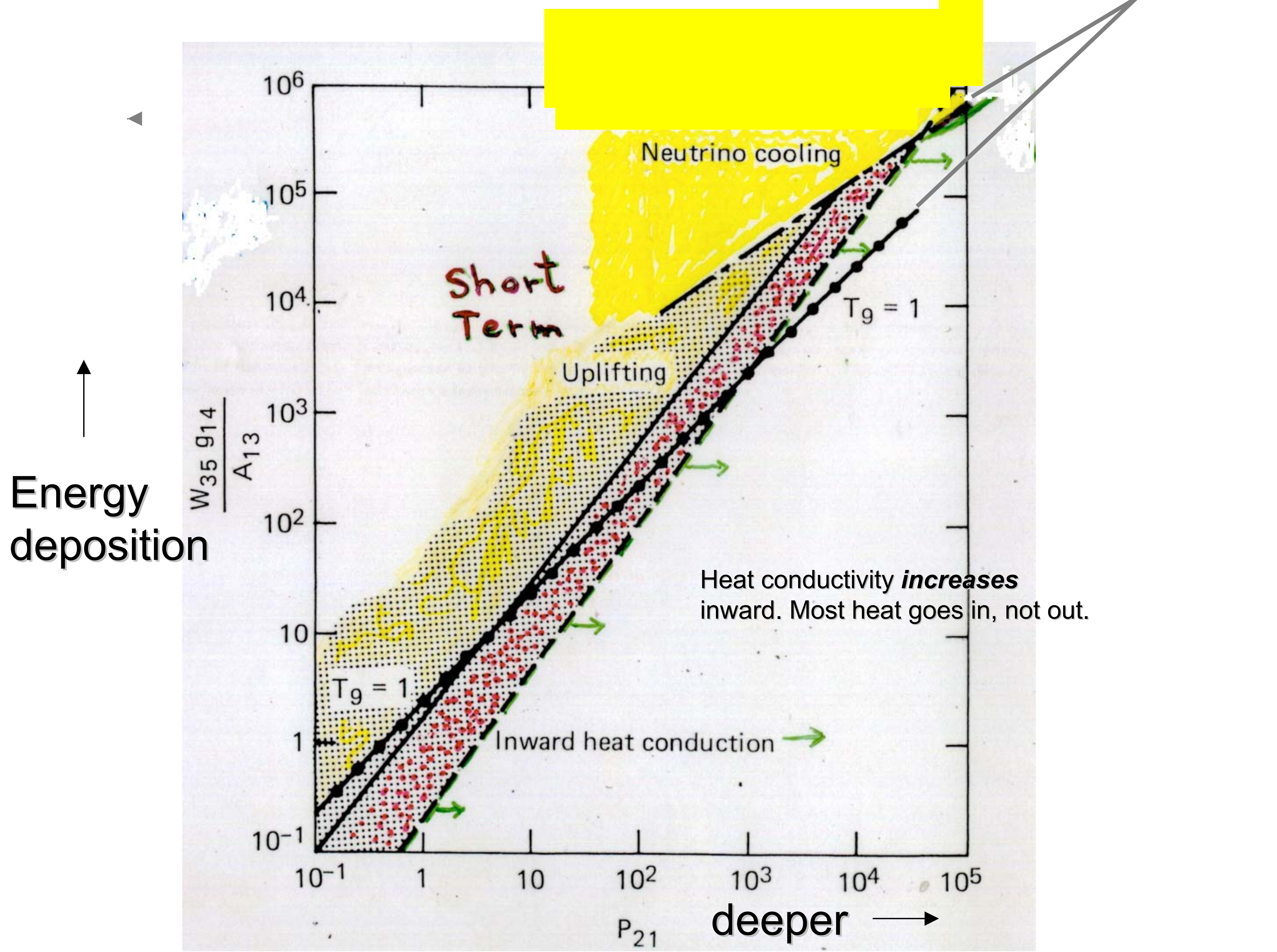
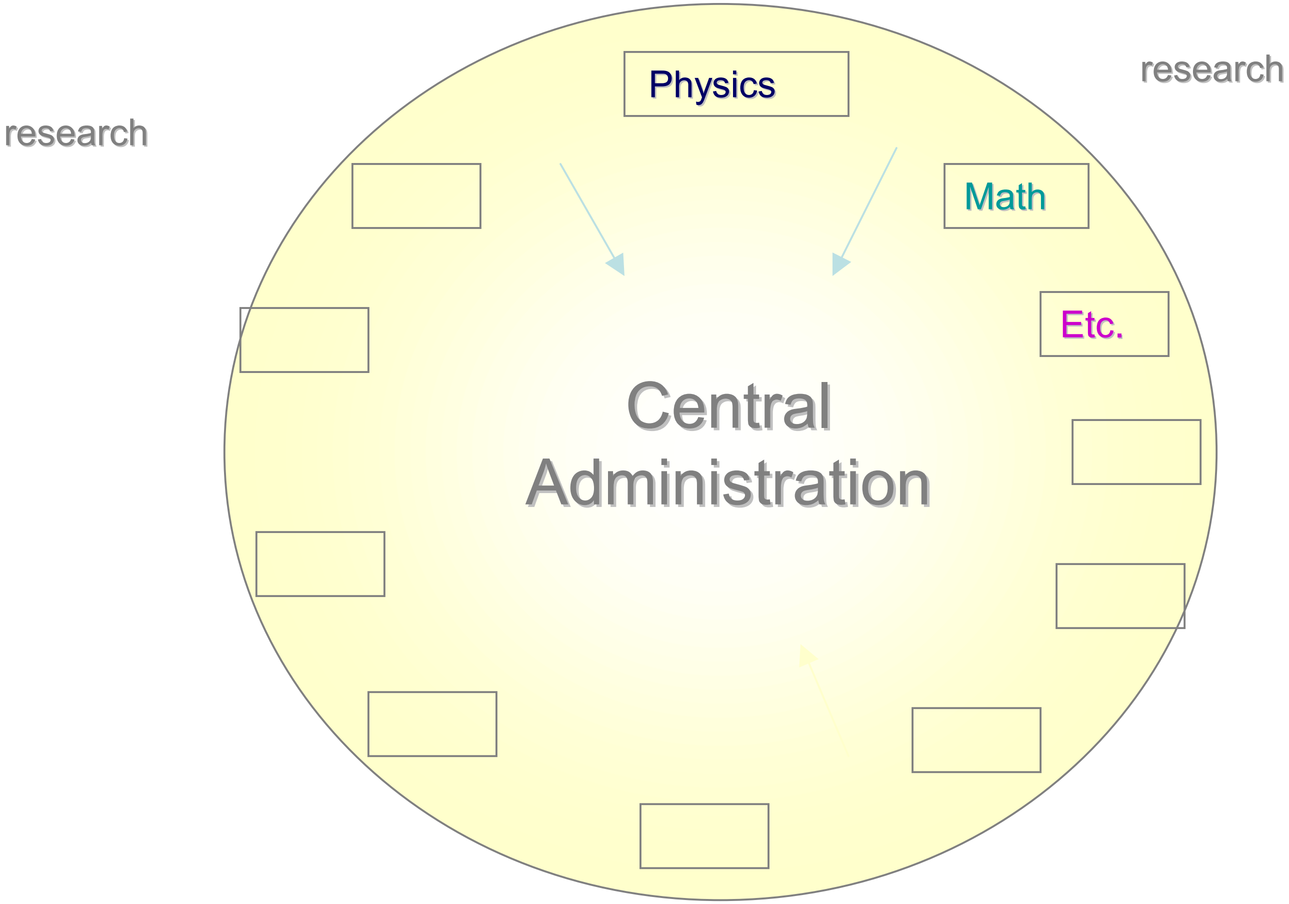
ABSTRACT

We consider thermal afterglow from transient energy releases in neutron stars, such as may result from glitches or gamma-ray bursts. If observable, thermal afterglow may provide important information on the nature of these events and on neutron star structure. For standard neutron star models, the energy released is either reradiated within a short time of at most hours for energy release near the surface, or most of the energy is stored in the deep interior and then reradiated over thousands of years. Intermediate time scales of order months are possible for afterglow, but only when the prompt afterglow accounts for a very small fraction of the total energy release, and enormous energy releases $\sim 10^{42}$ ergs are required to make the afterglow last much longer than a few hours. An observational program to detect afterglow will need to accommodate short time scales.

Subject headings: radiation mechanisms — stars: interiors — stars: neutron


Neutrino cooling
Short Term
Uplifting
T_9 = 1
T_9 = 1
Inward heat conduction
$\frac{W_{35}\, g_{14}}{A_{13}}$
P_{21}
Energy deposition
deeper
Heat conductivity ***increases*** inward. Most heat goes in, not out.

The Storage Problem



The change in the magnetic field geometry of 1900+14

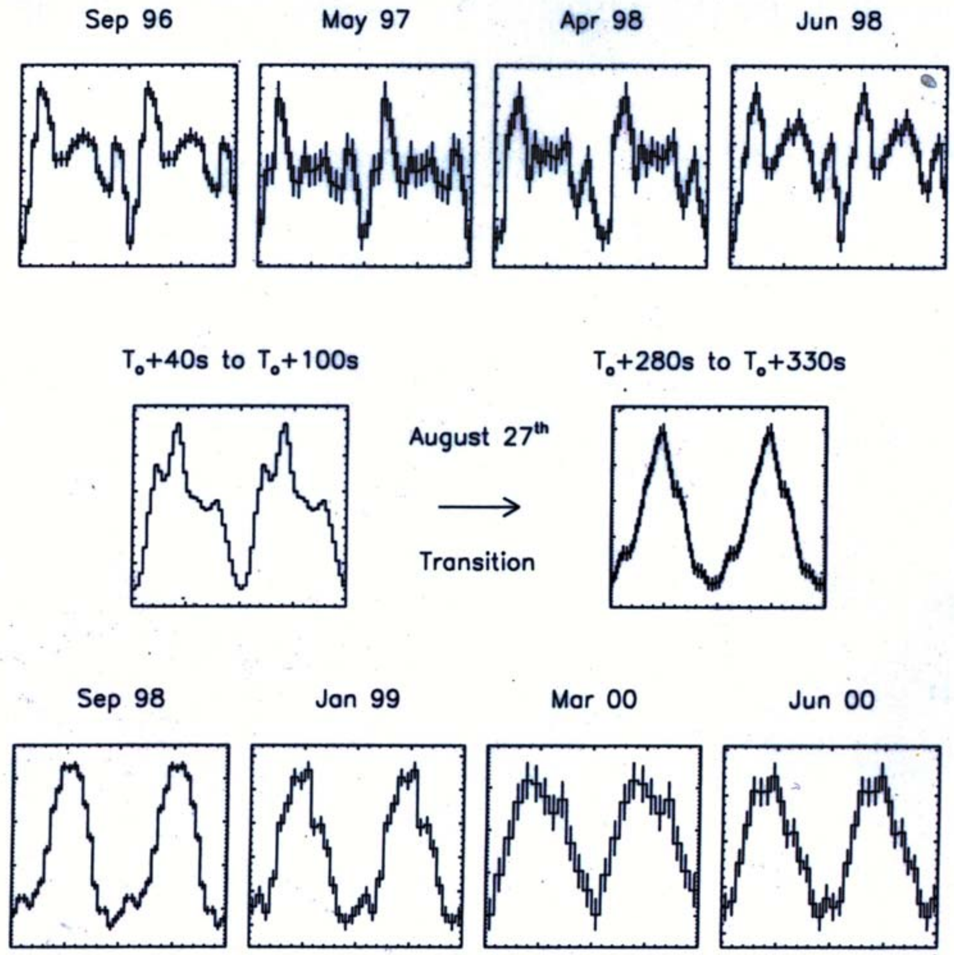
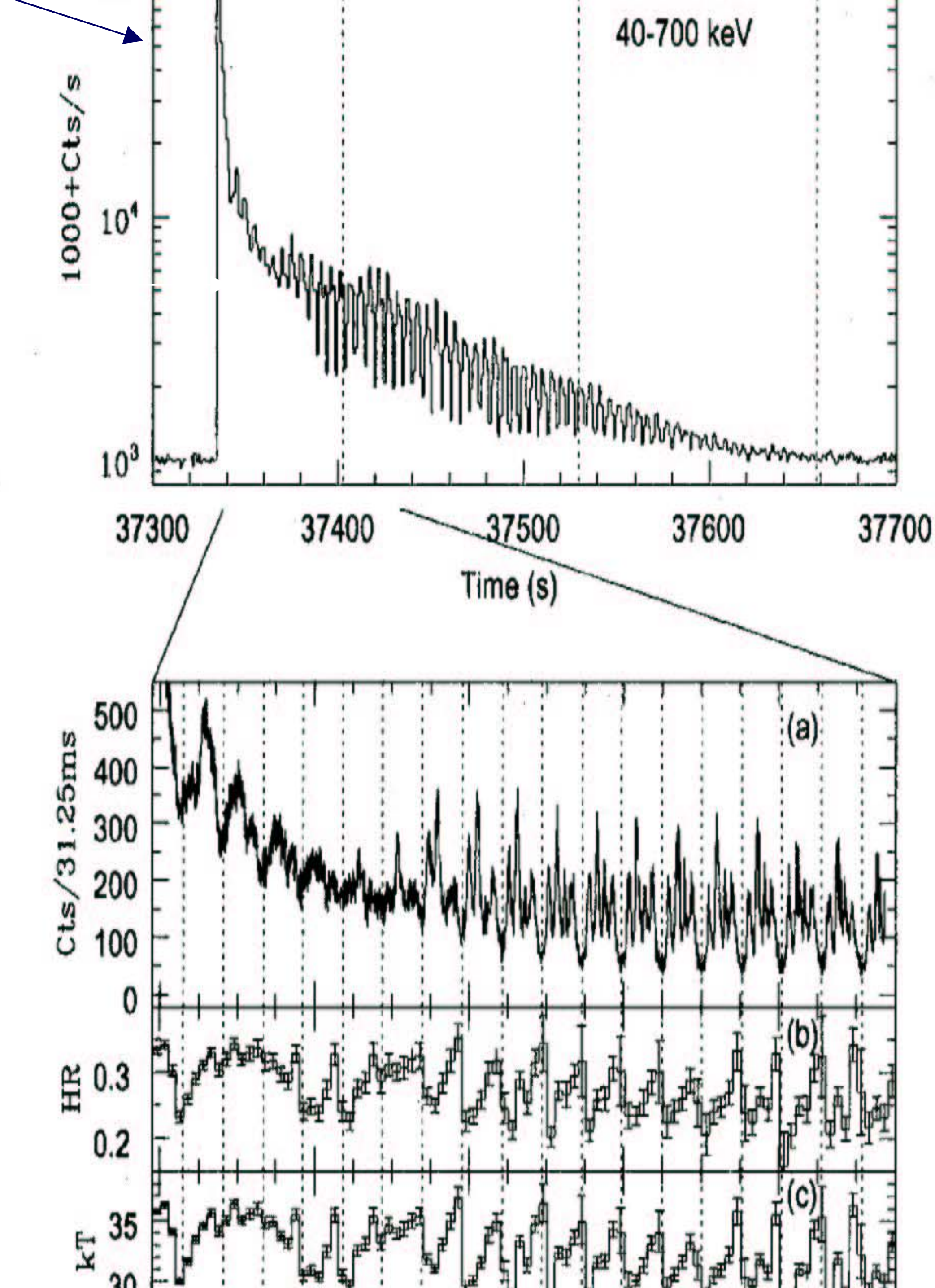


Fig. 3.— Evolution of the pulse profile of SGR 1900+14 over the last 3.8 years. All panels display two pulse cycles and the vertical axes are count rates with arbitrary units. The two middle panels were selected from Ulysses data (25–150 keV) of the August 27th flare. Times over which the Ulysses data were folded are given relative to the onset of the flare (T_o). See text for further details. The top and bottom rows are integrated over the energy range 2–10 keV. From top-to-bottom, left-to-right, the data were recorded with the RXTE, BeppoSAX, ASCA, RXTE, RXTE, RXTE, BeppoSAX, and RXTE.

Periodic Emission:
trapped pair plasma



The medium term afterglow of 1900+14

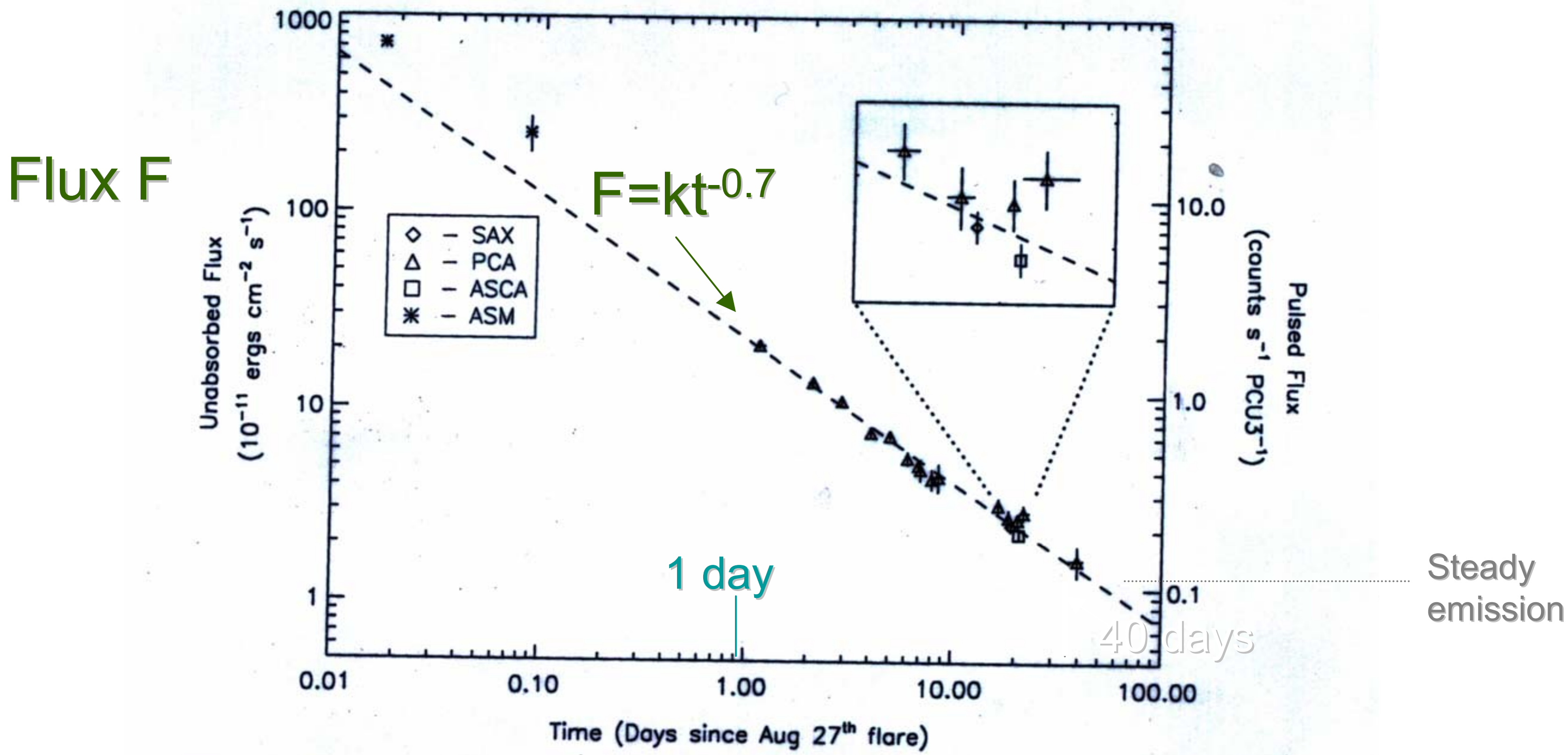


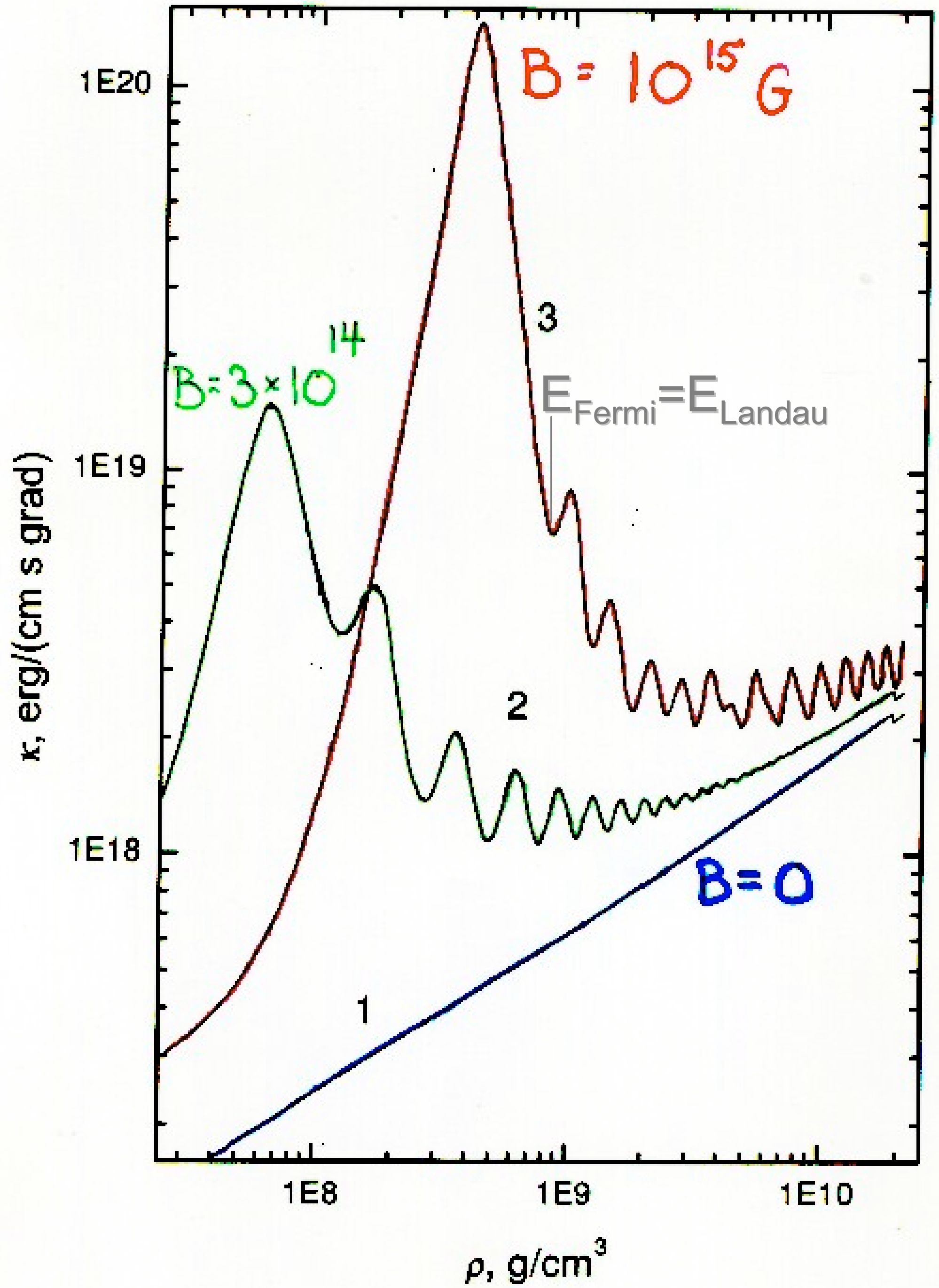
Fig. 2.— Log-log plot of SGR 1900+14 flux versus time following the August 27th flare. The reference time is the beginning of the flare as observed in soft γ-rays. The dotted line is a fit to

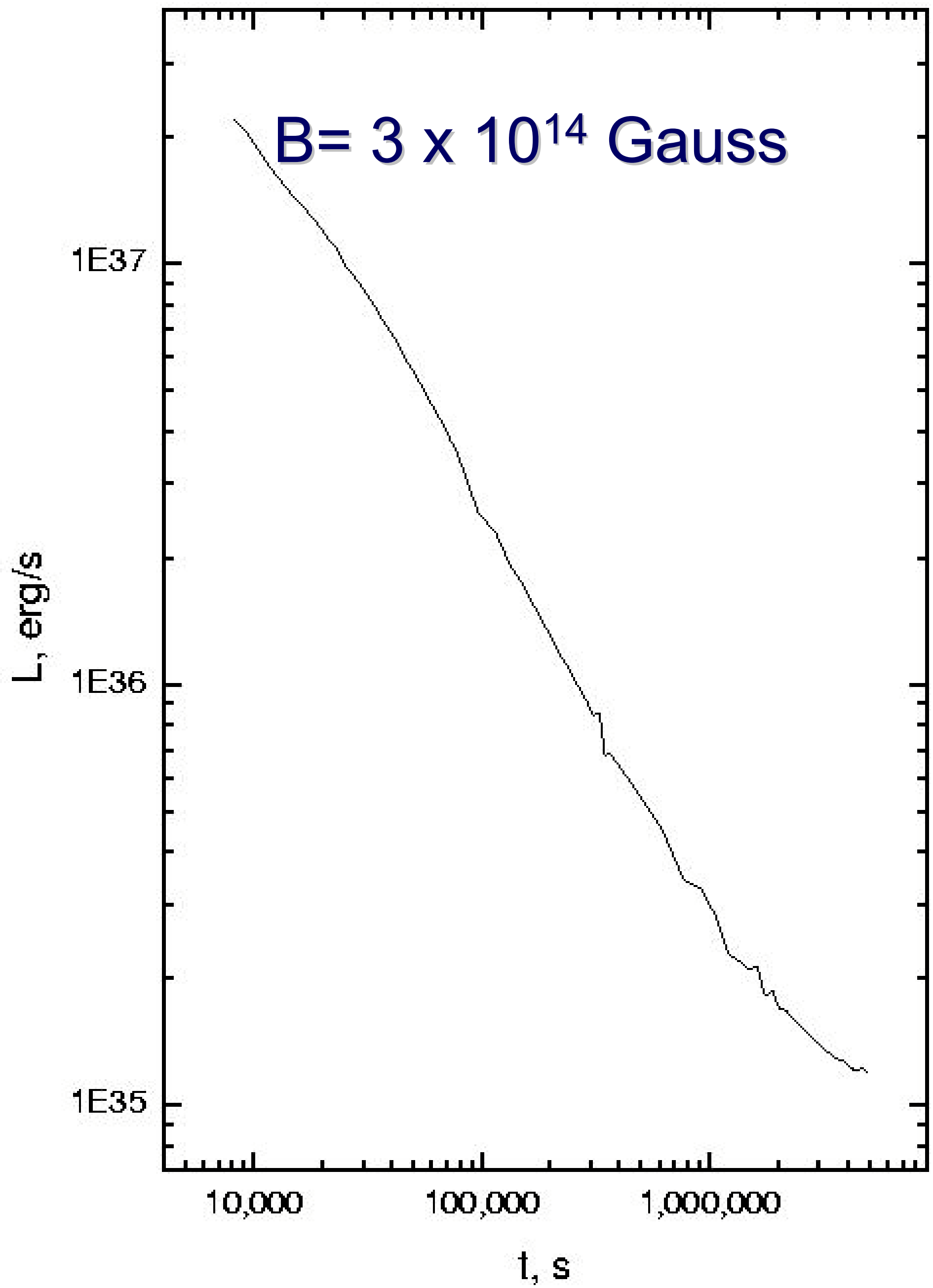
The predicted medium term afterglow

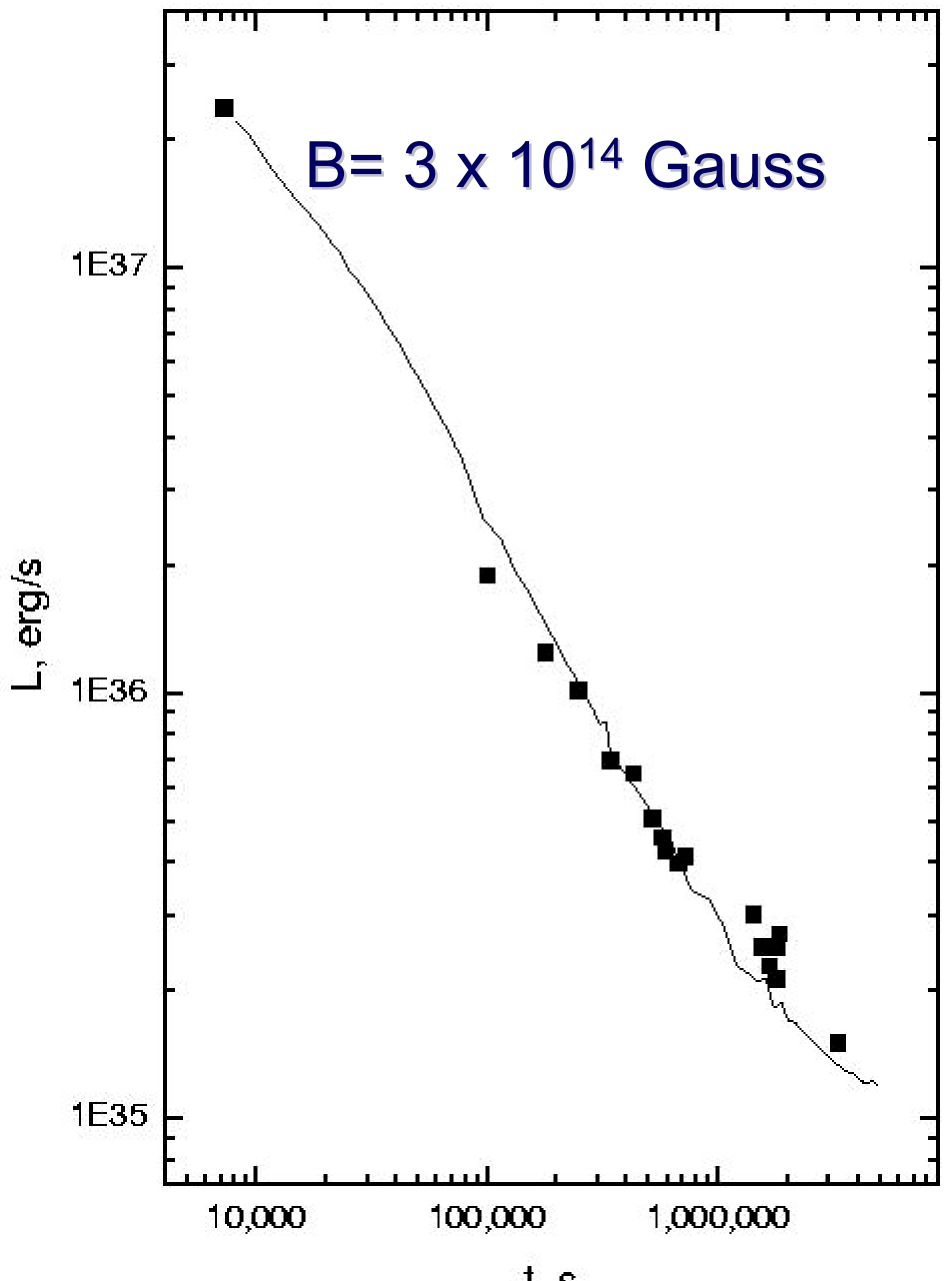
Lyubarsky, Eichler, and Thompson (2002), especially Lyubarsky

Assume central temperature corresponding to steady emission, 7 x 10^8 K, uniform energy deposition corresponding to observed burst energy

Conductivity




B= 3 x 10^14 Gauss
1E37
1E36
1E35
L, erg/s
10,000
100,000
1,000,000
t, s



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L, erg/s
10,000
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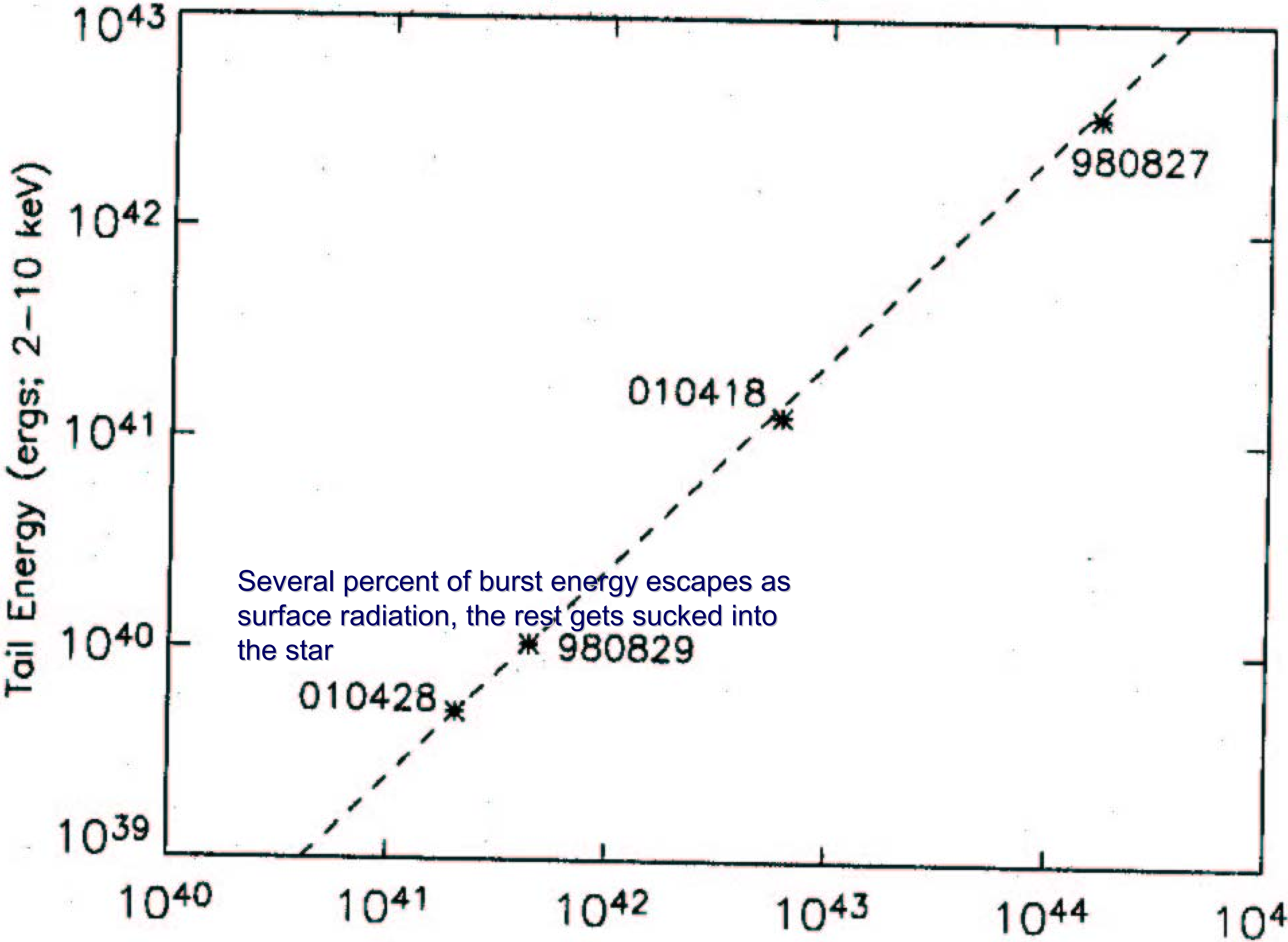
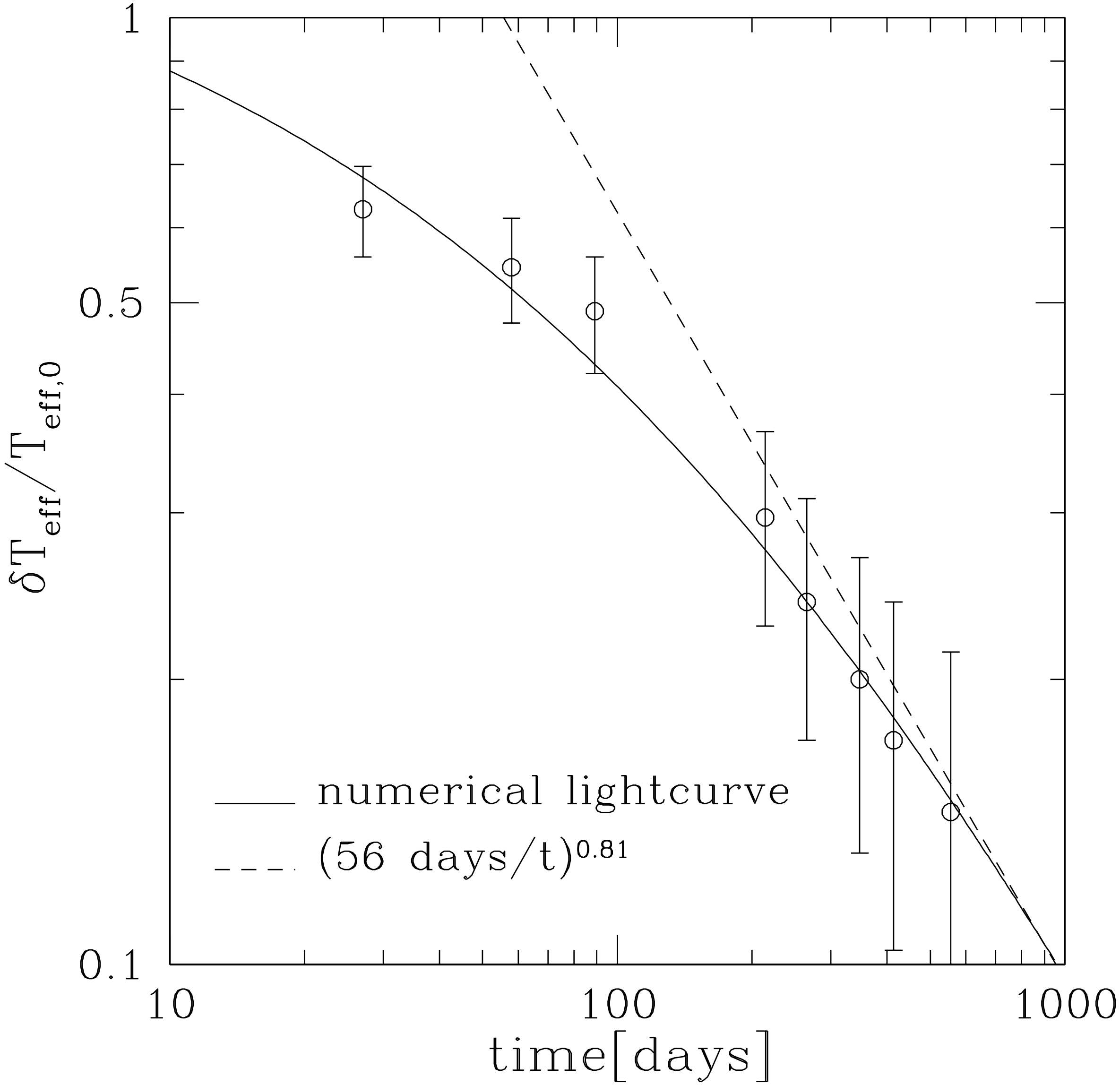

Tail Energy (ergs; 2–10 keV)
10^43
10^42
10^41
10^40
10^39
10^40
10^41
10^42
10^43
10^44
10^4
980827
010418
980829
010428
Several percent of burst energy escapes as surface radiation, the rest gets sucked into the star

White dwarf cooling after dwarf nova

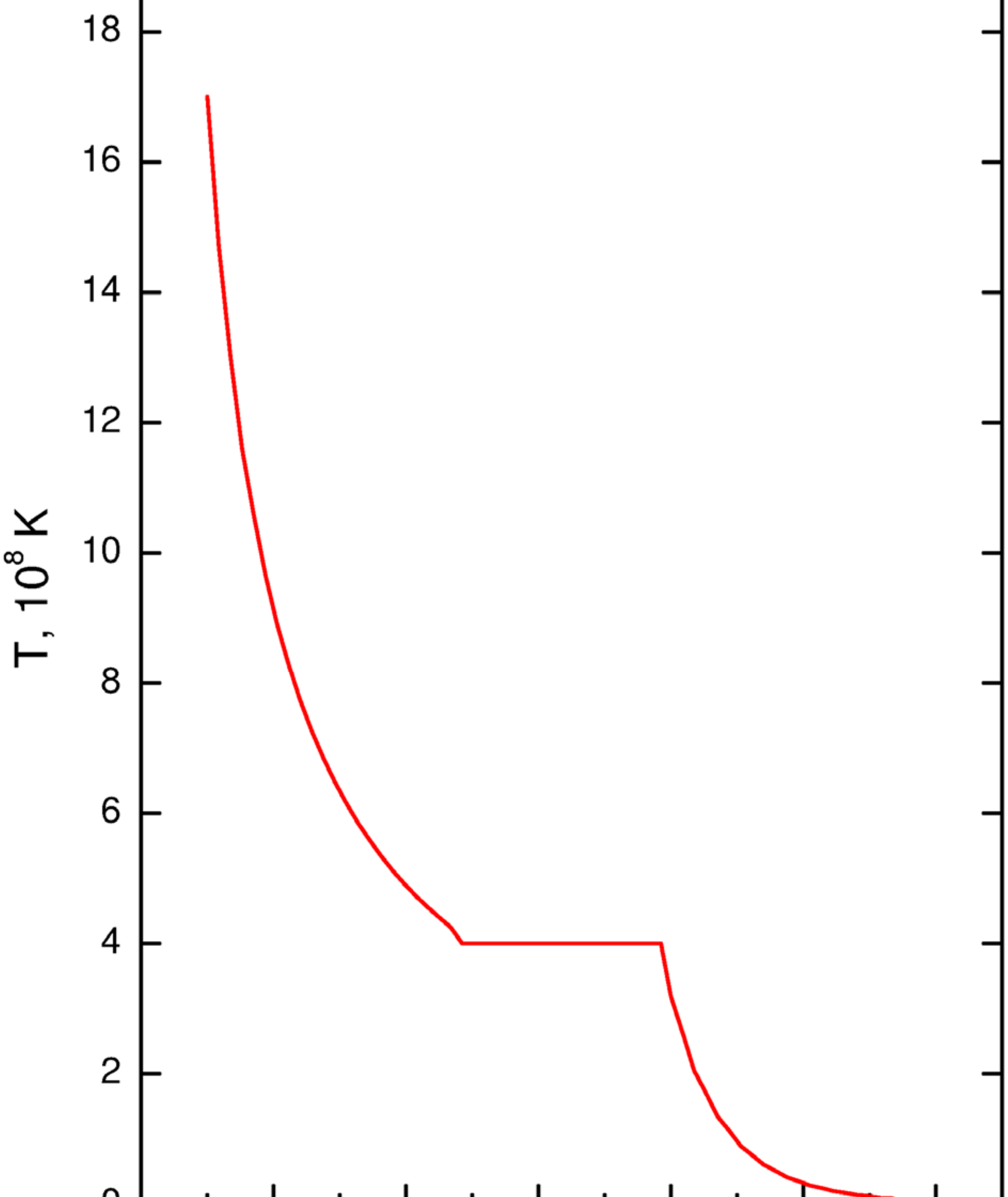
Arras, Bildsten ……



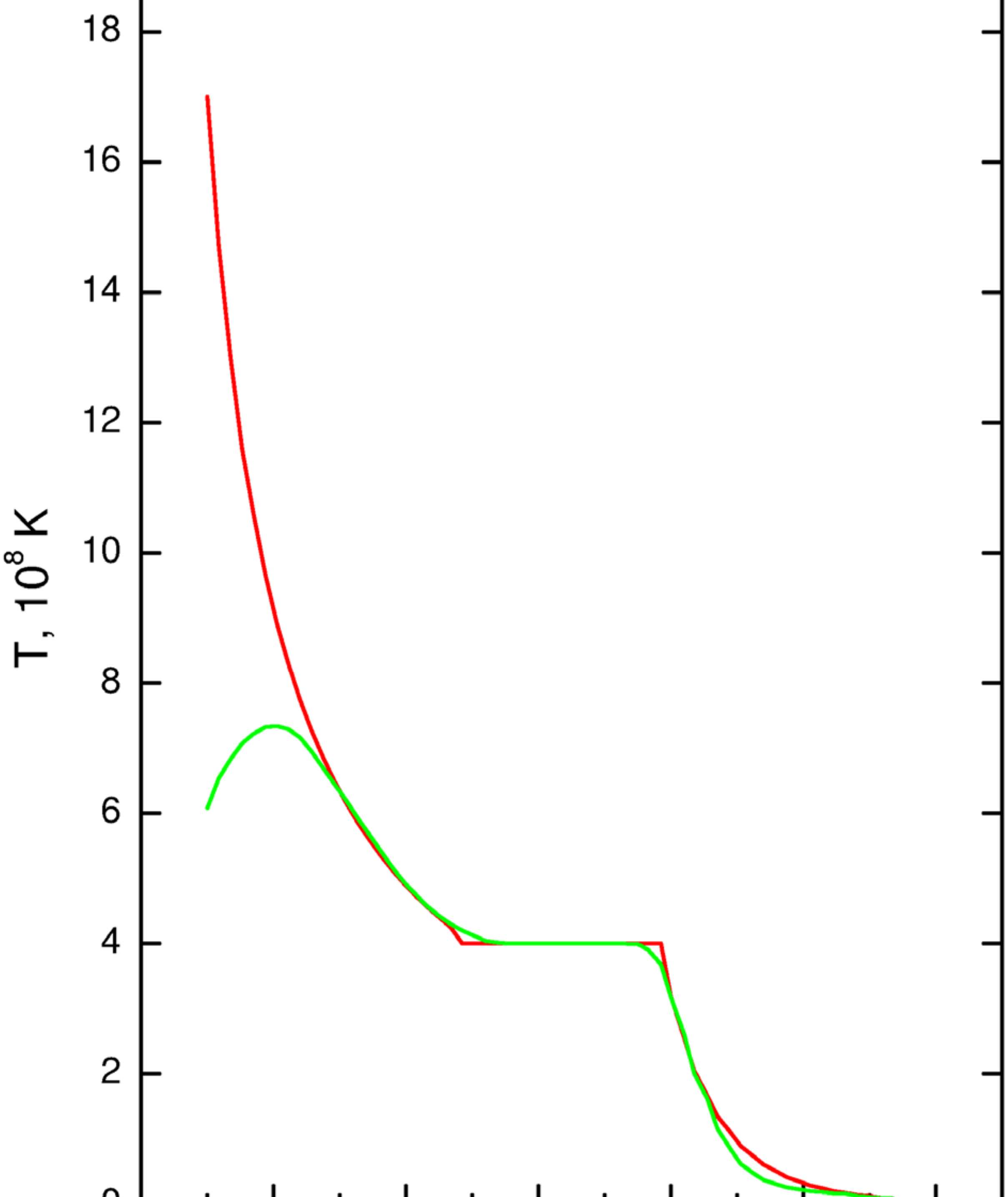
The really long term afterglow of 1627-41

Kouveliotou, Lyubarsky, Eichler, …..(2003)

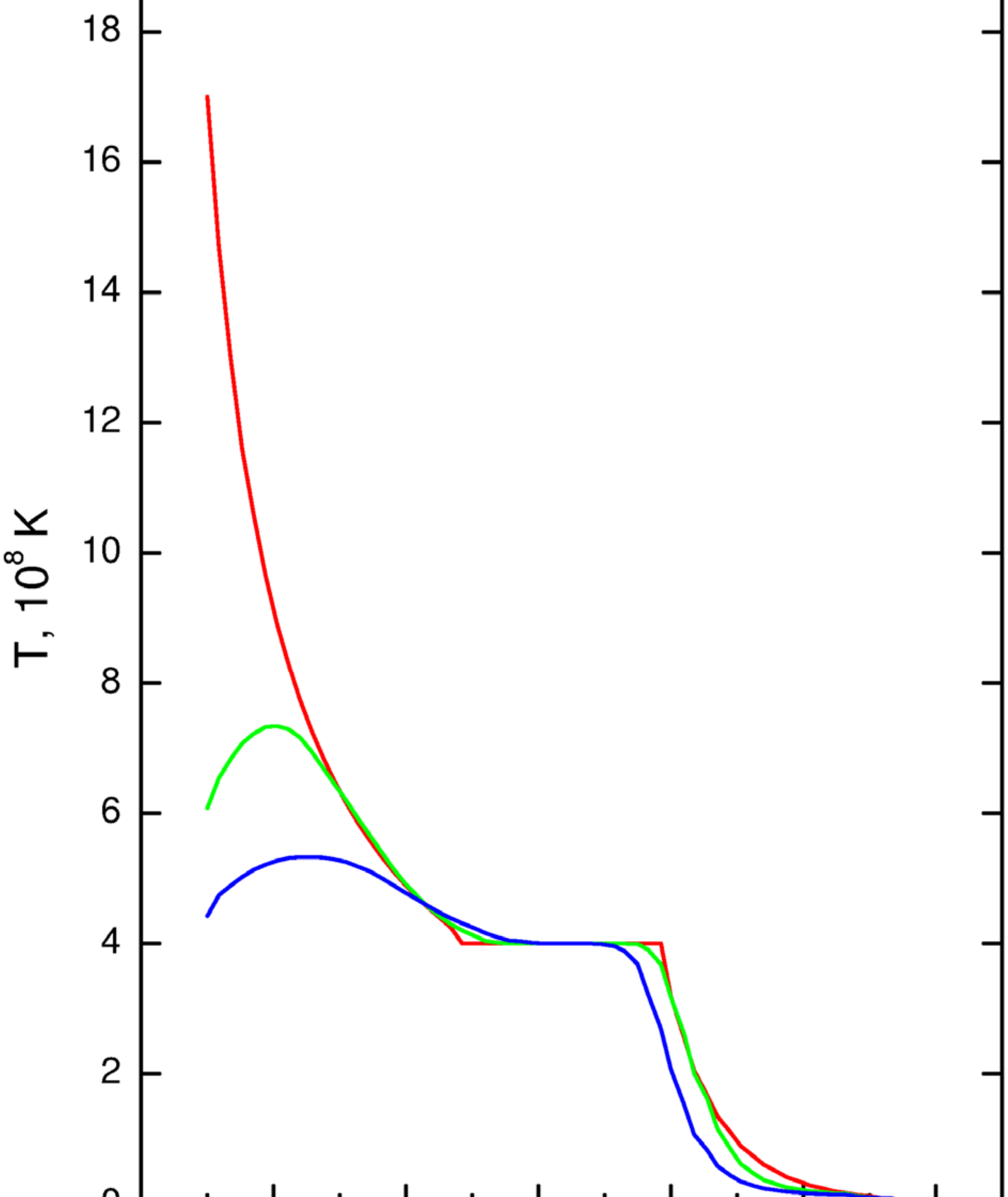
Assume deep heating of crust, but not core



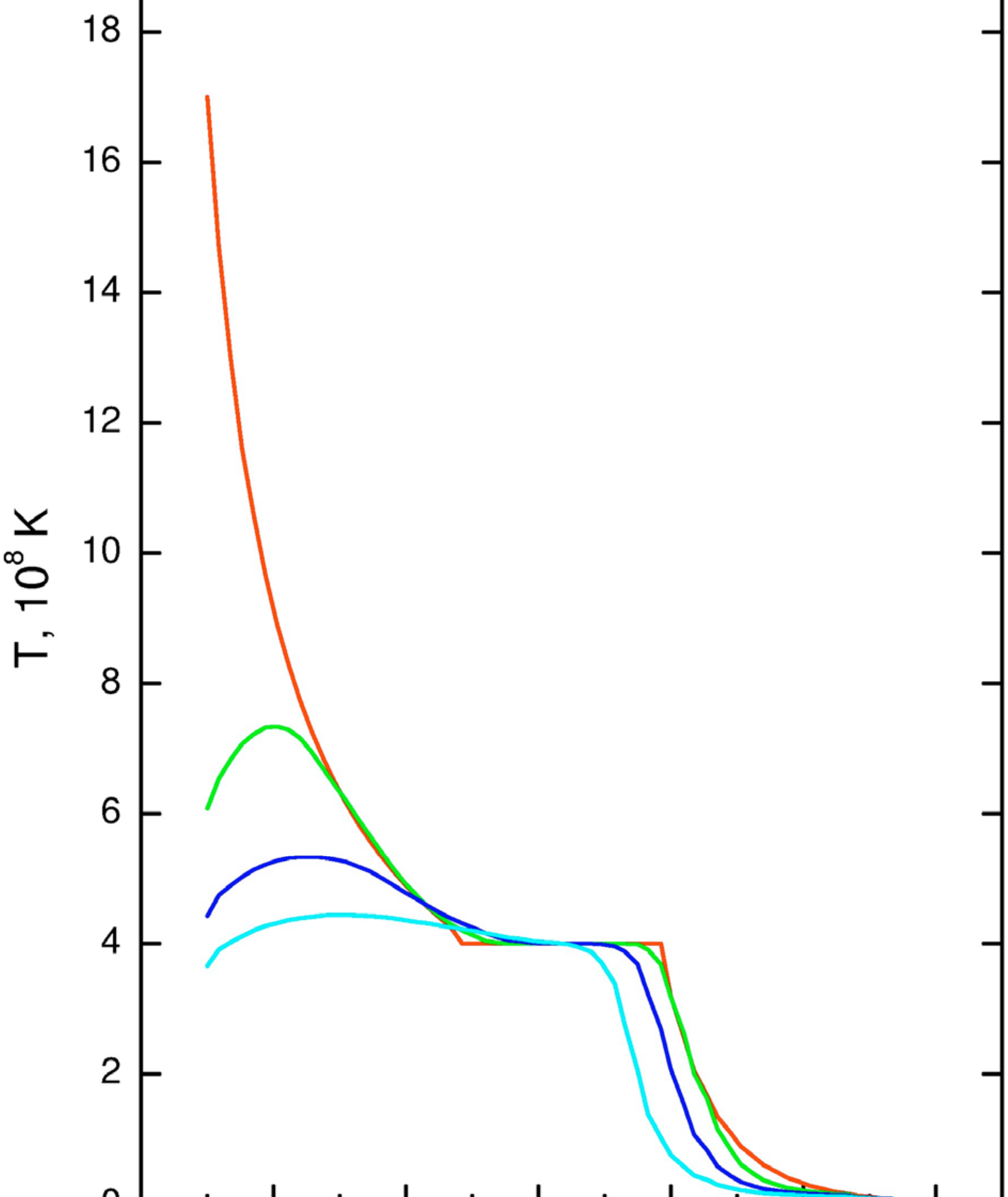
18
16
14
12
10
8
6
4
2
T, 10^8 K



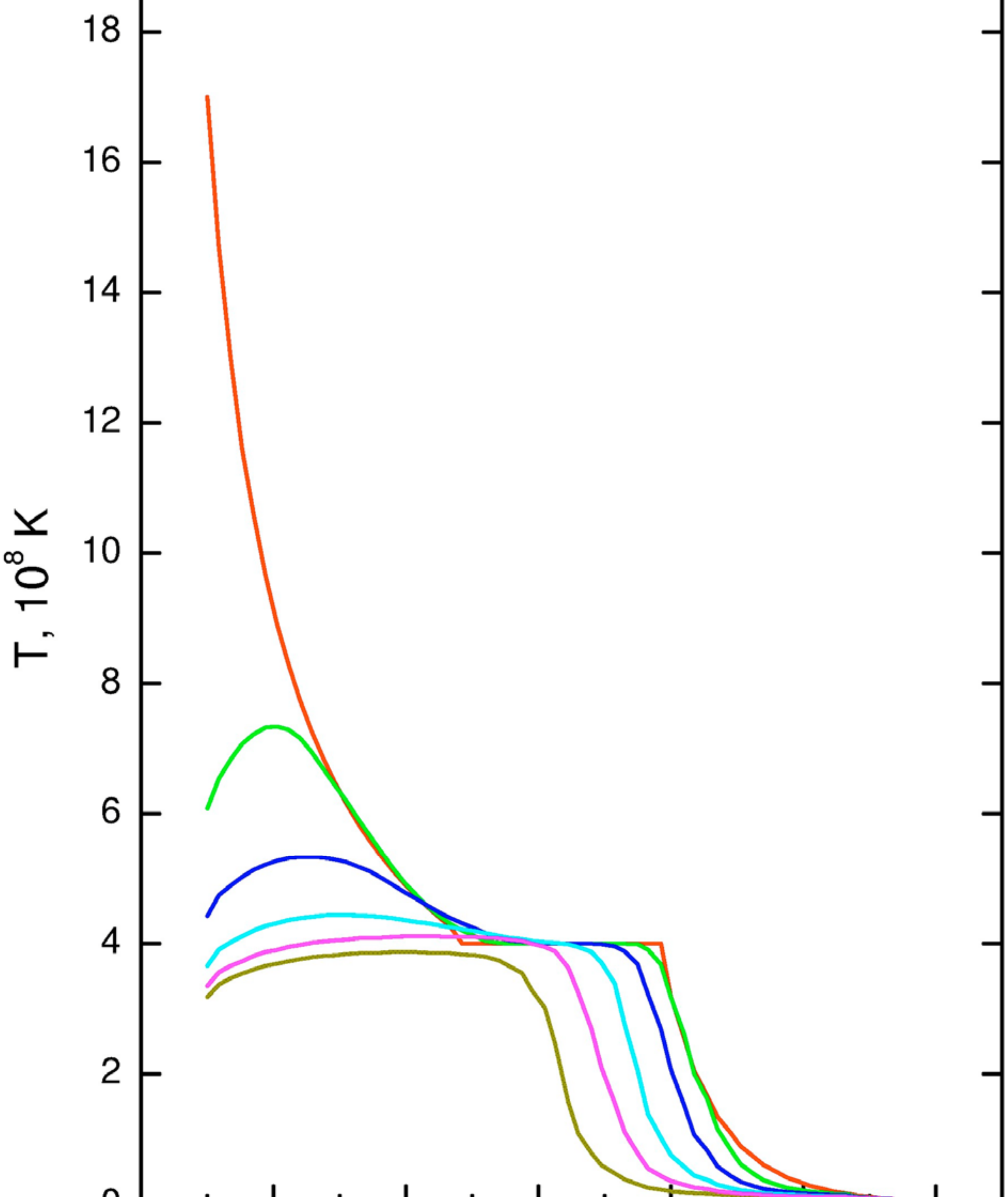
T, 10^8 K
18
16
14
12
10
8
6
4
2
0



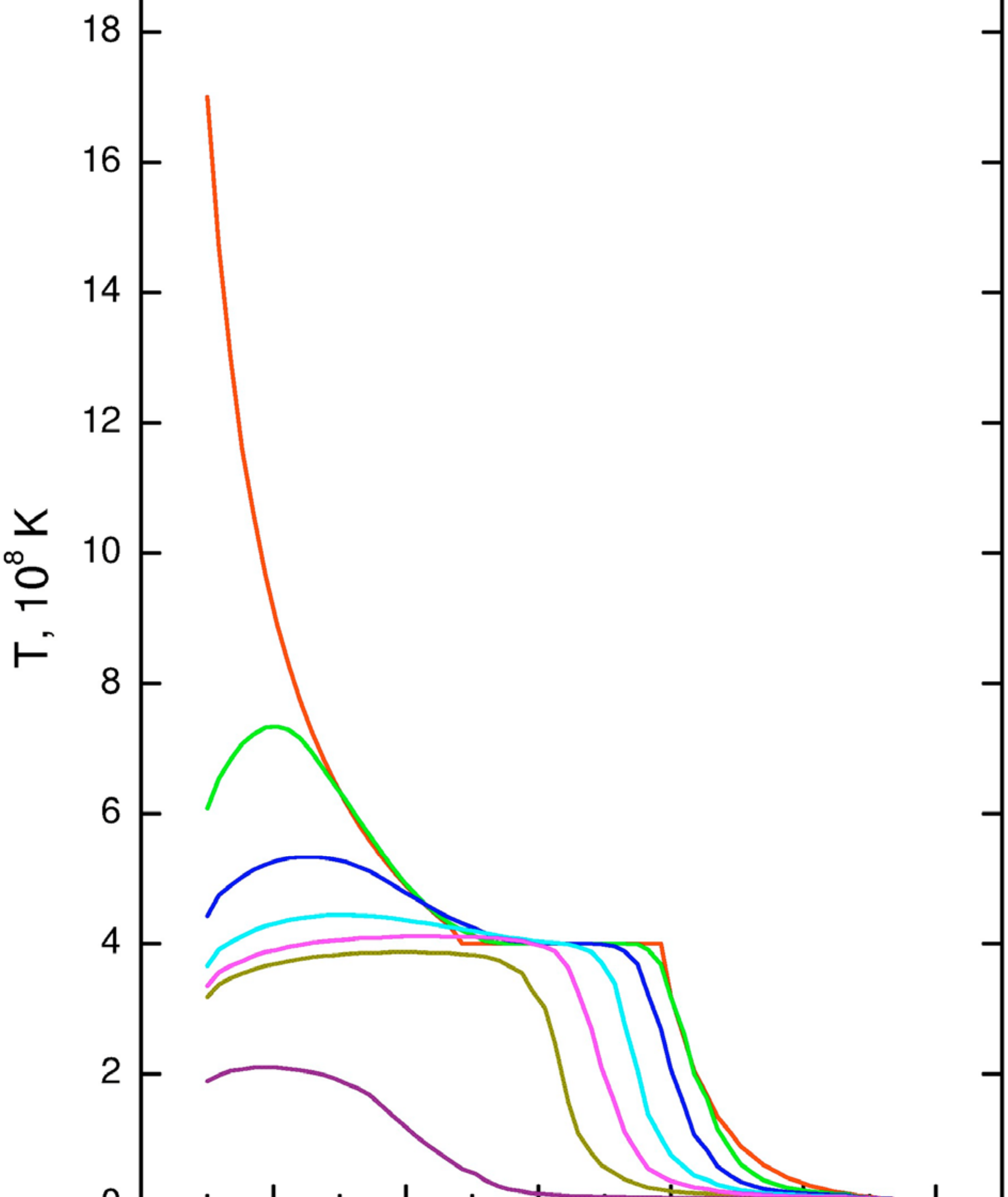
T, 10^8 K
18
16
14
12
10
8
6
4
2

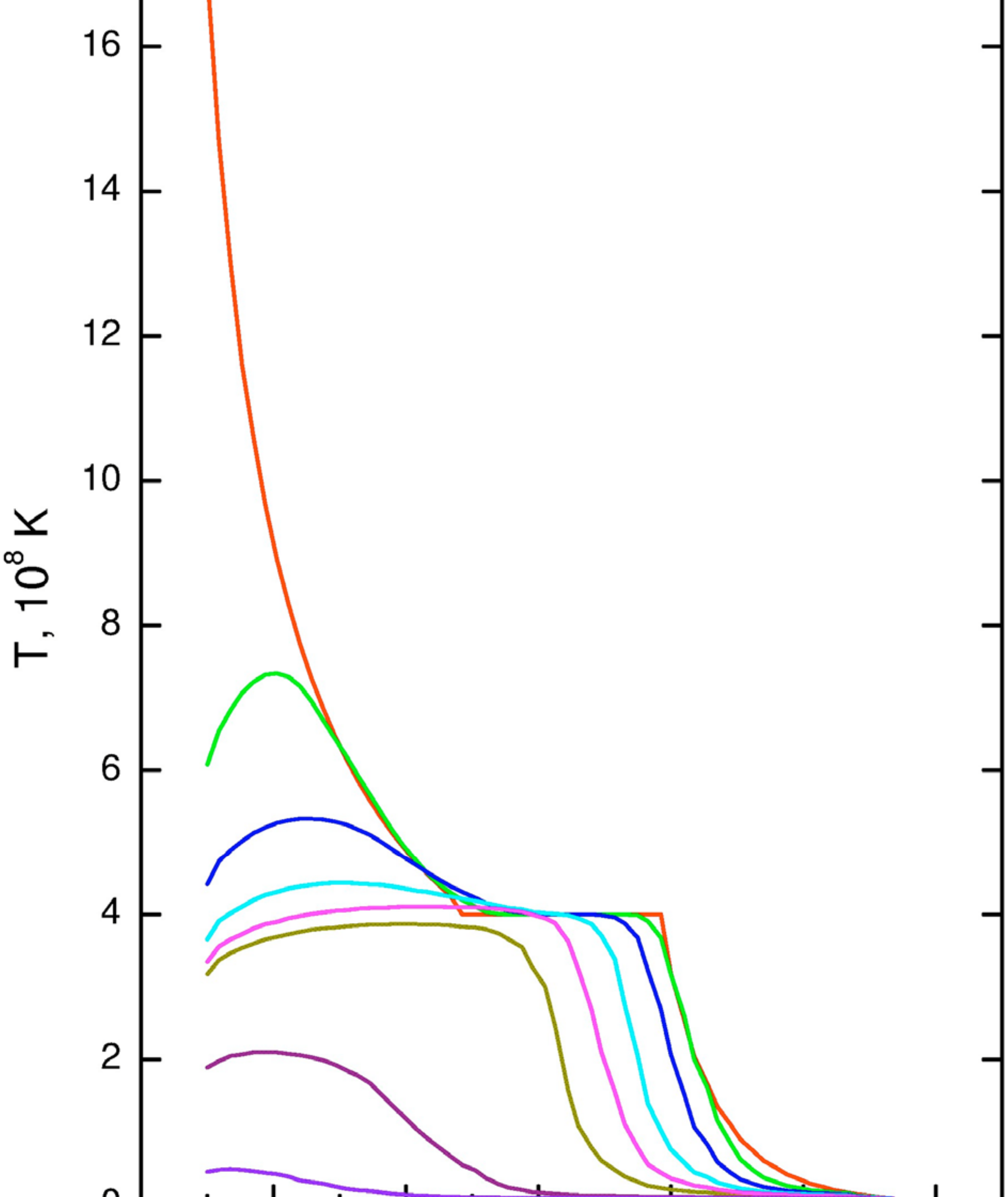


T, 10^8 K
18
16
14
12
10
8
6
4
2

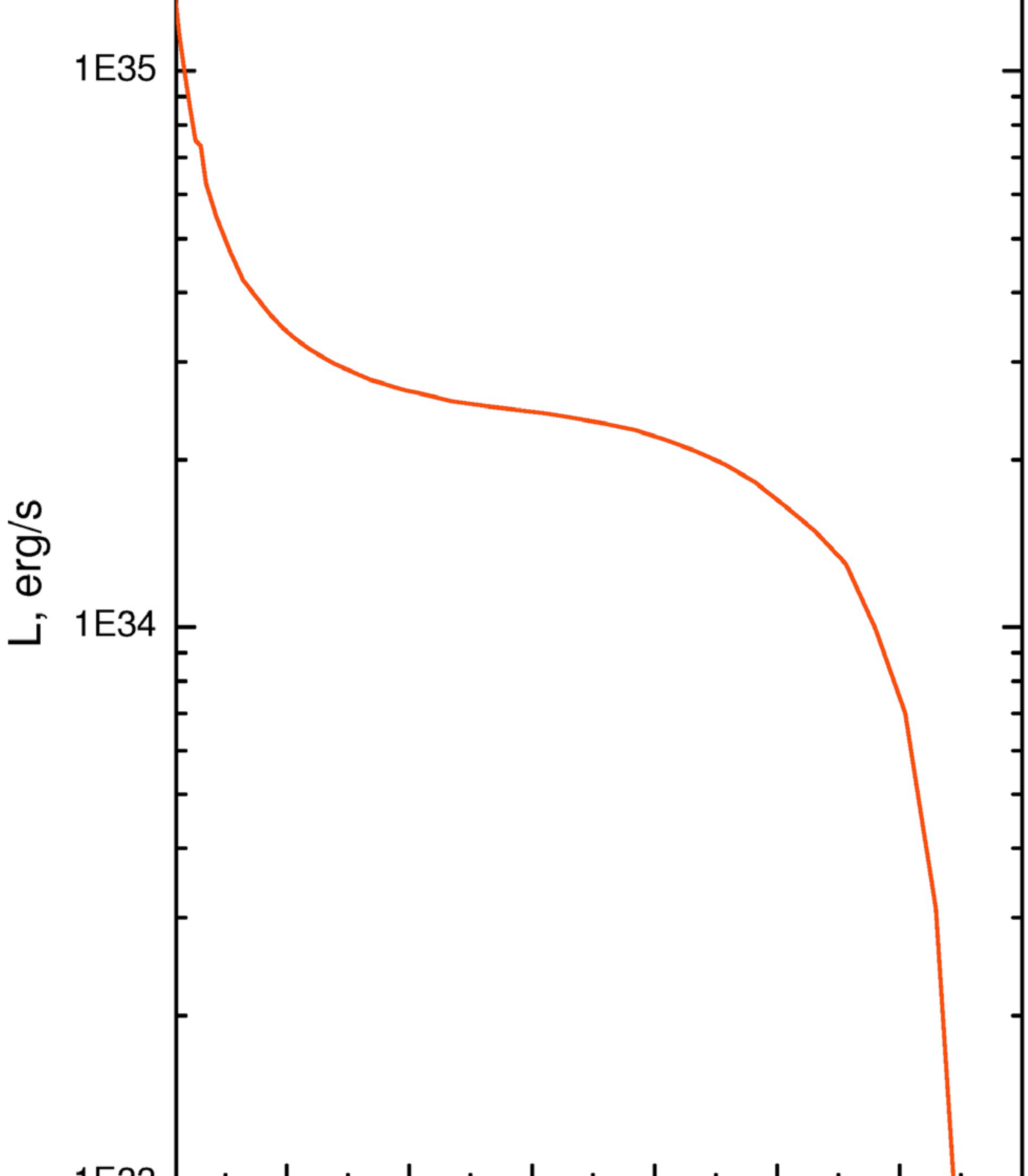


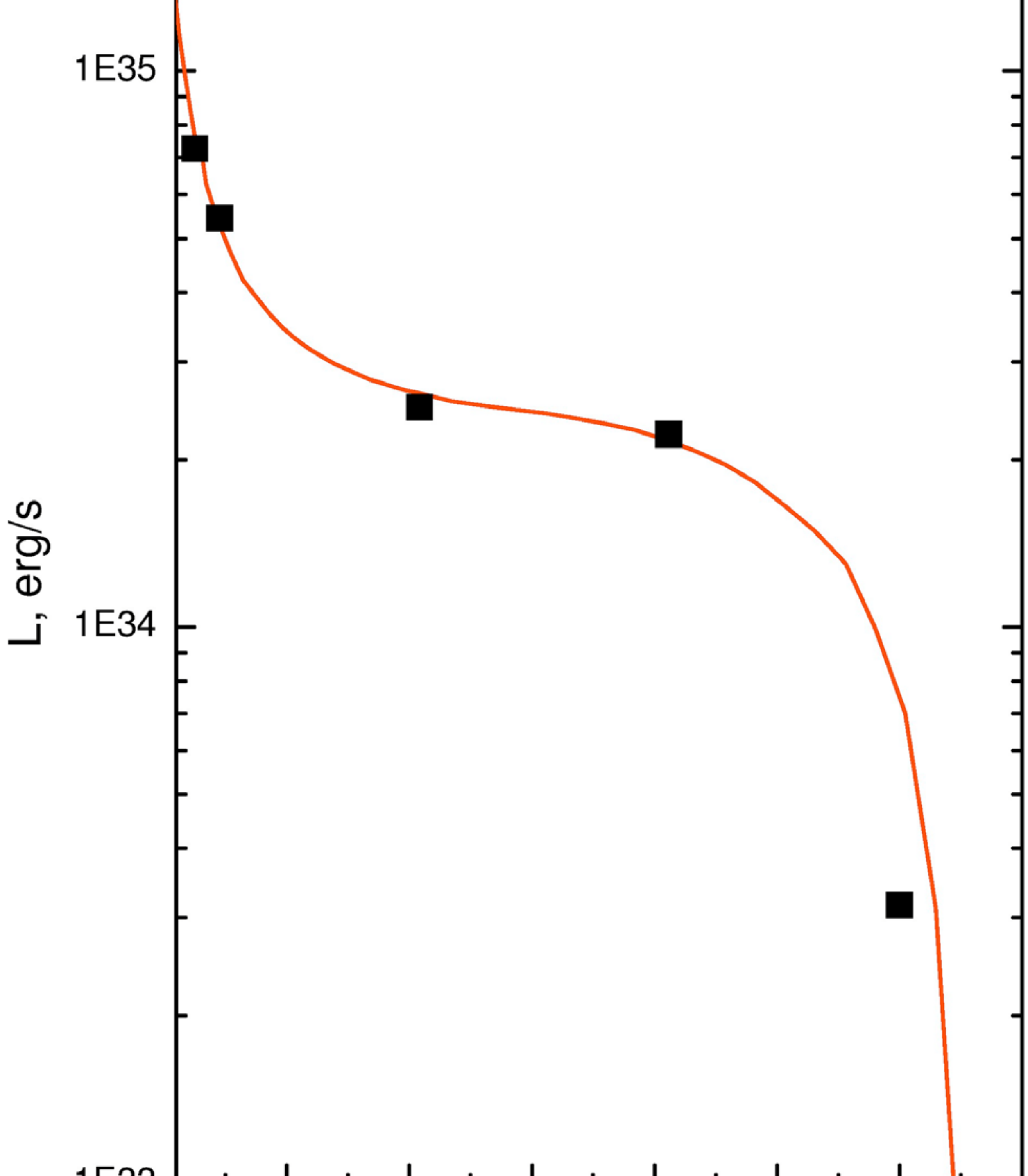
T, 10^8 K
18
16
14
12
10
8
6
4
2
0


T, 10^8 K
18
16
14
12
10
8
6
4
2

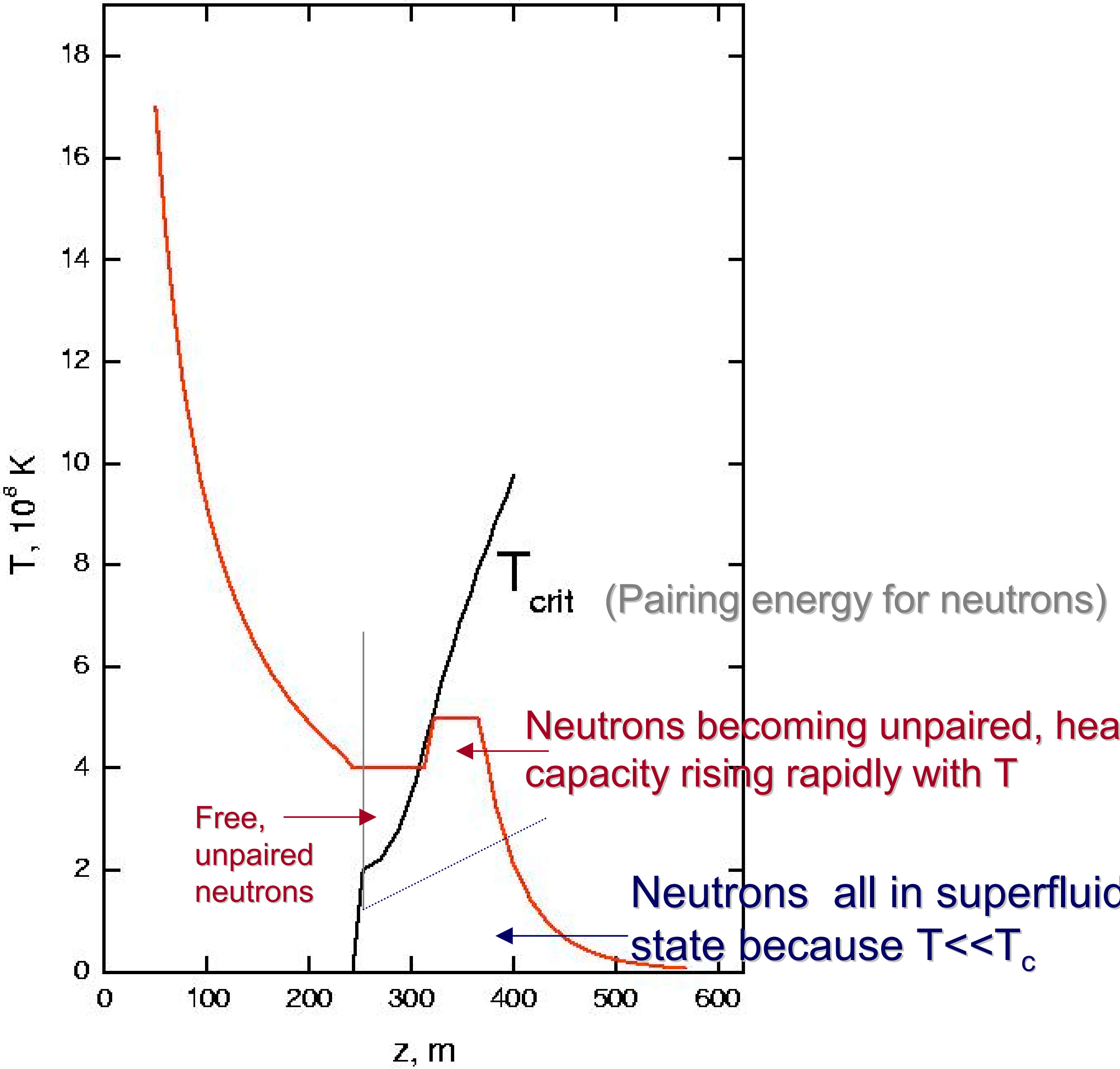


T, 10^8 K
16
14
12
10
8
6
4
2
0

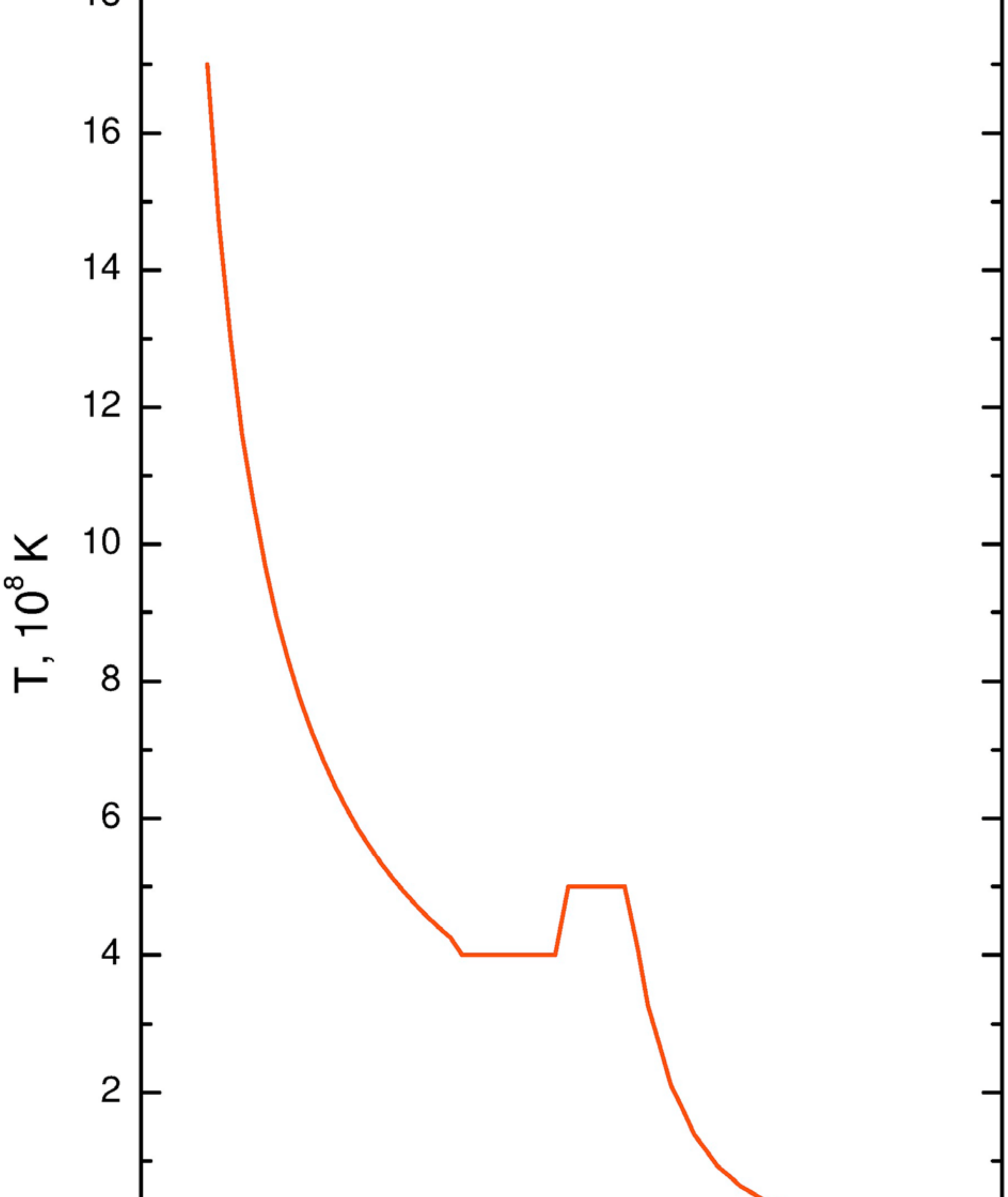

L, erg/s
1E35
1E34

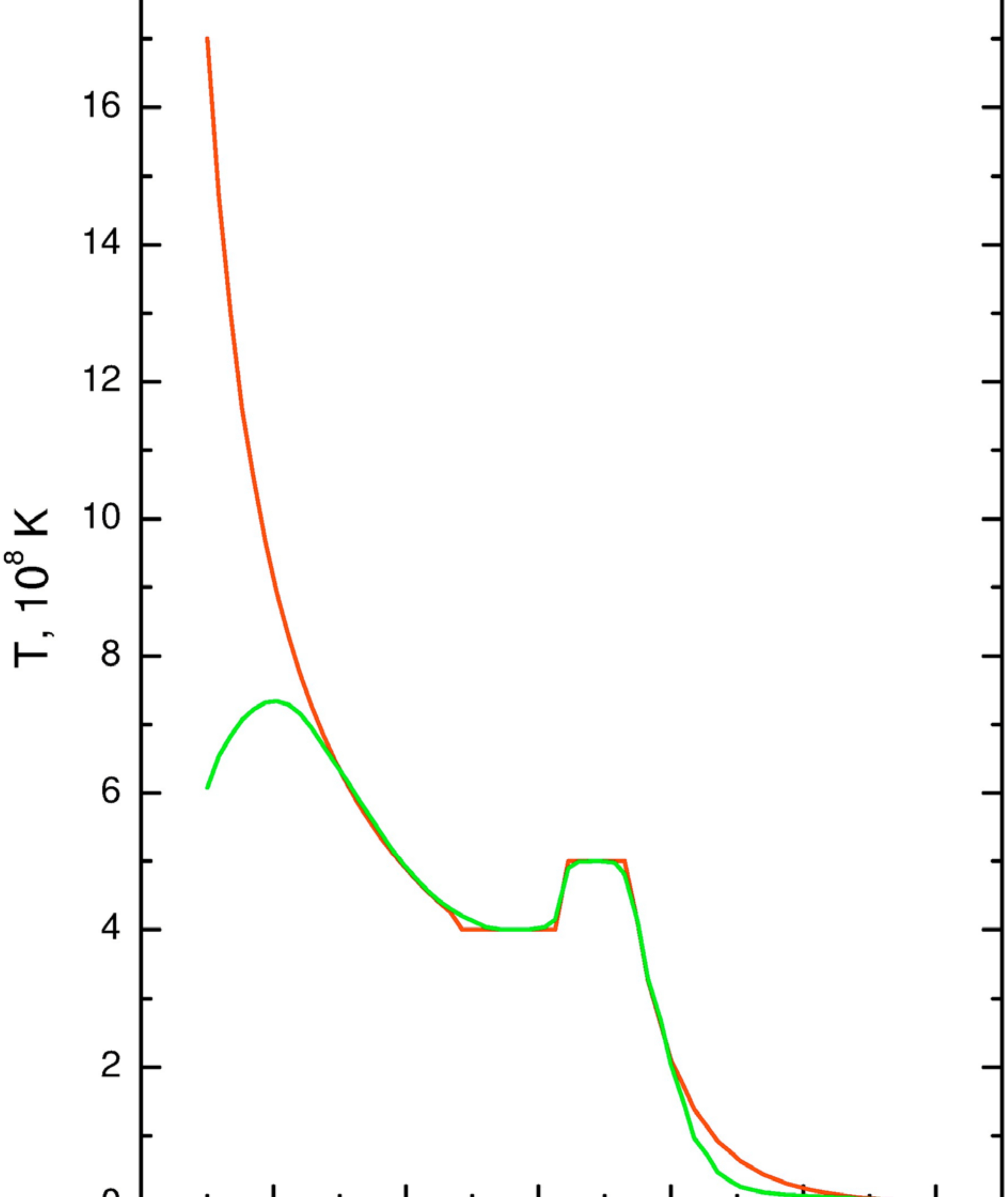


1E35
1E34
L, erg/s

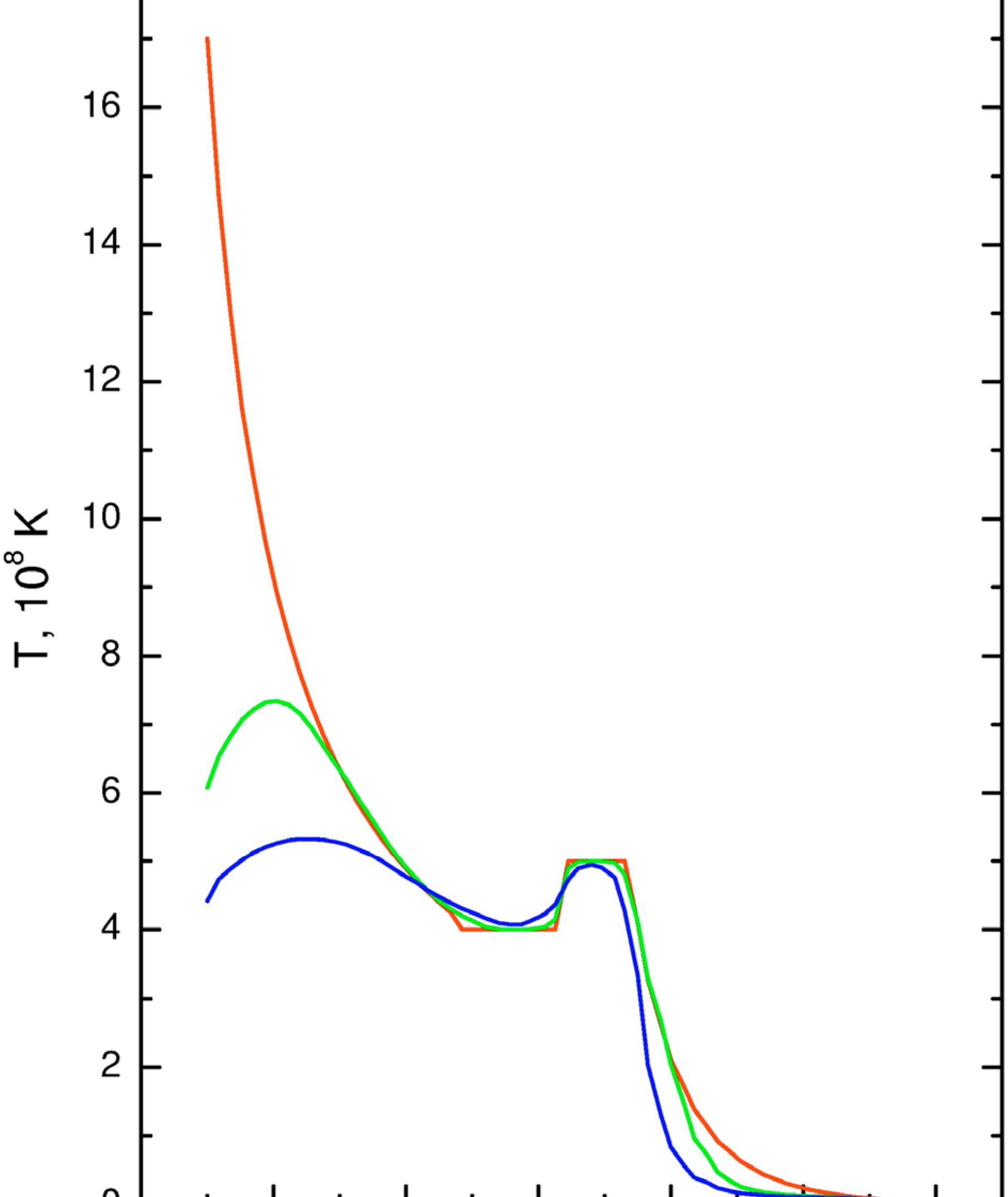


T, 10^8 K
18
16
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
z, m
T_{crit}
(Pairing energy for neutrons)
Neutrons becoming unpaired, heat capacity rising rapidly with T
Free, unpaired neutrons
Neutrons all in superfluid state because $T<<T_c$

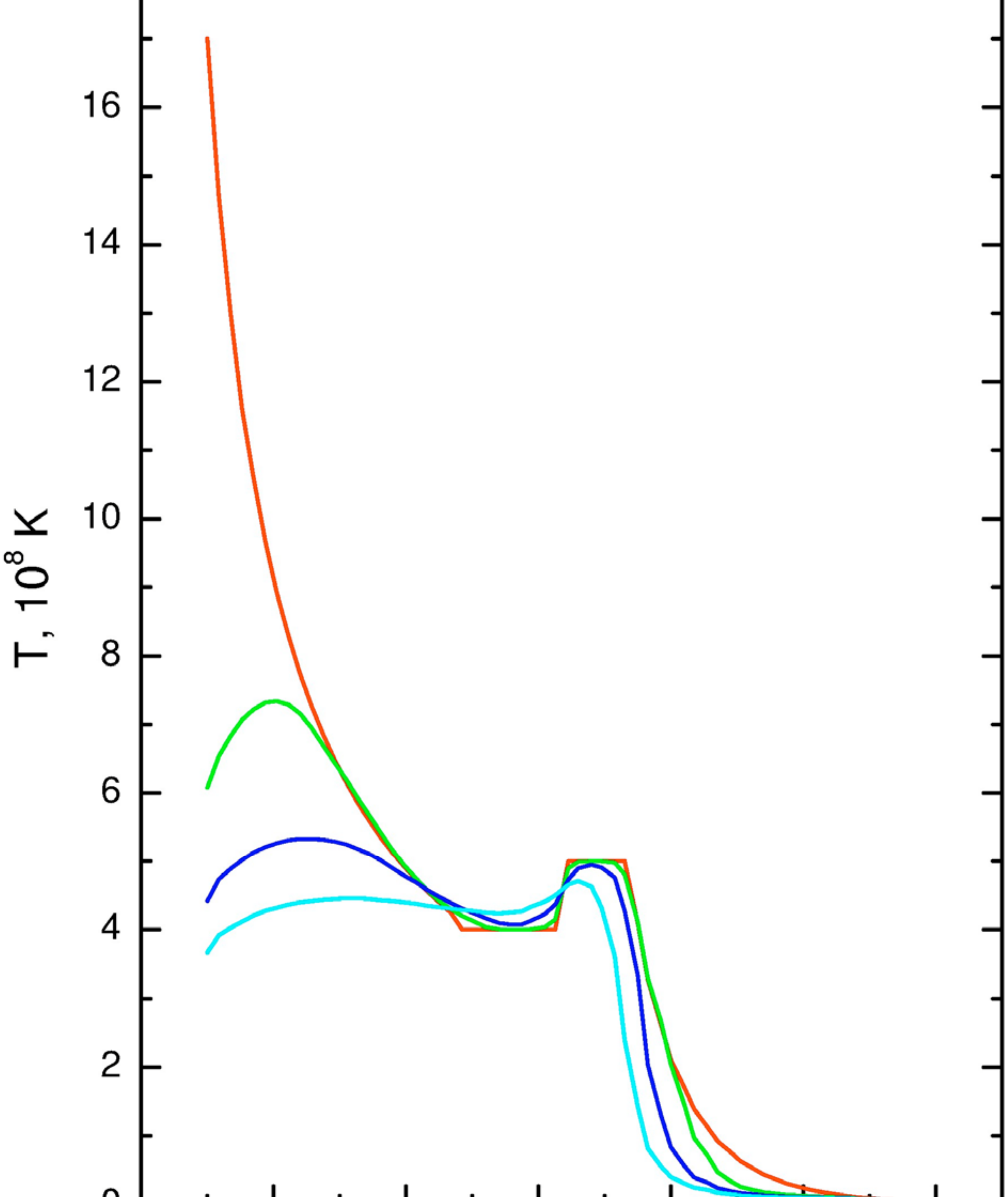

T, 10^8 K
16
14
12
10
8
6
4
2



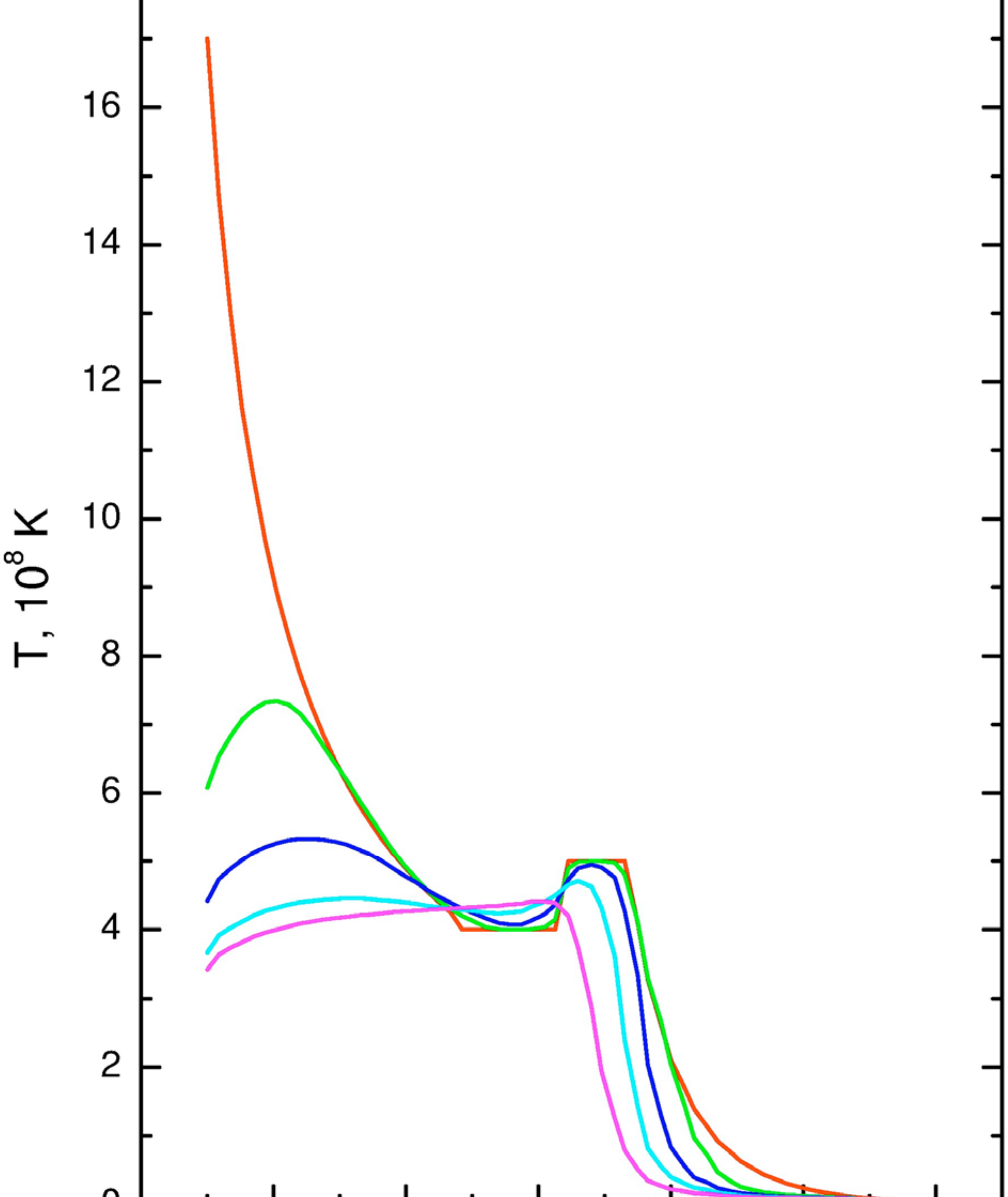
T, 10^8 K
16
14
12
10
8
6
4
2



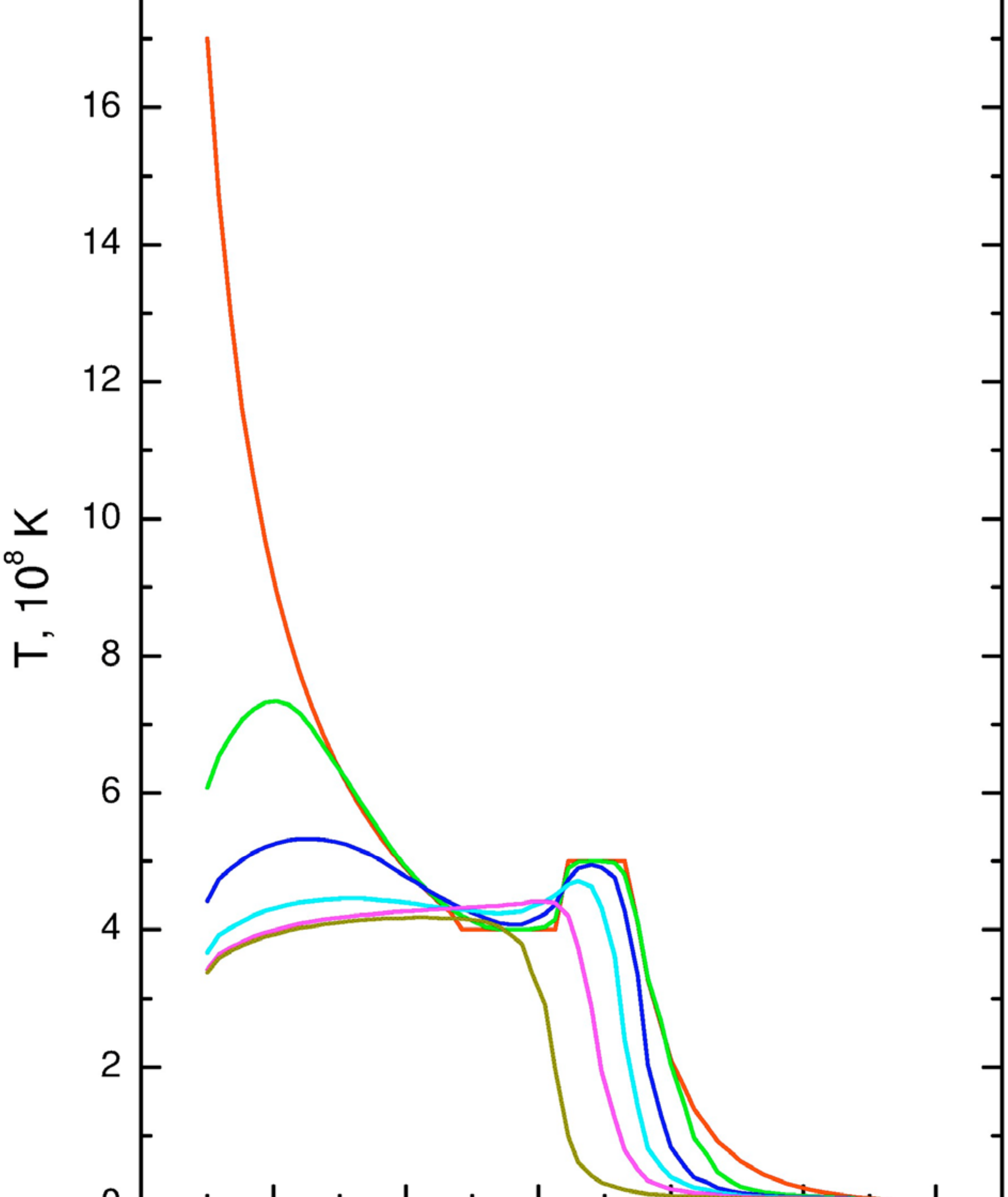
T, 10^8 K
16
14
12
10
8
6
4
2



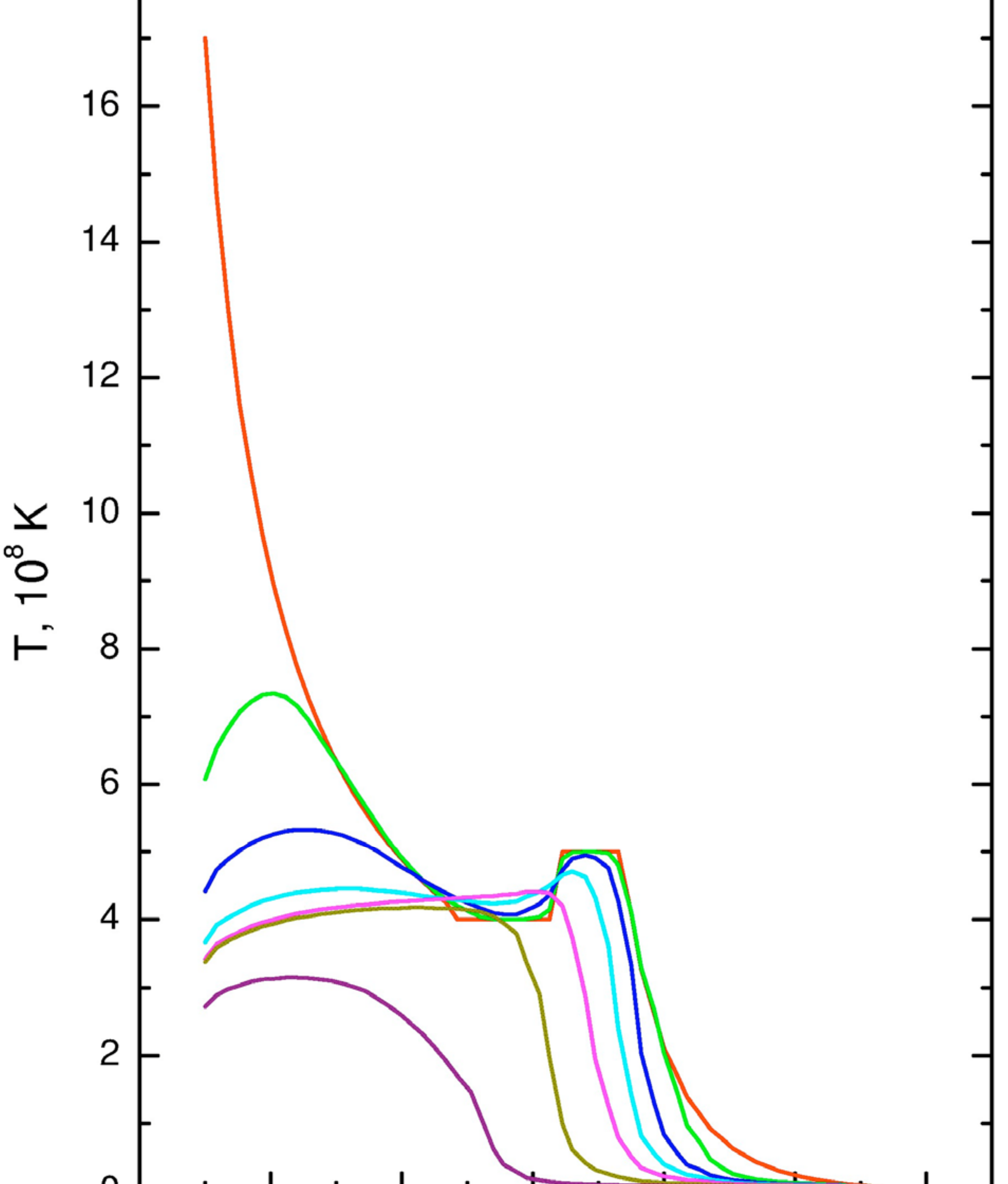
T, 10^8 K
16
14
12
10
8
6
4
2



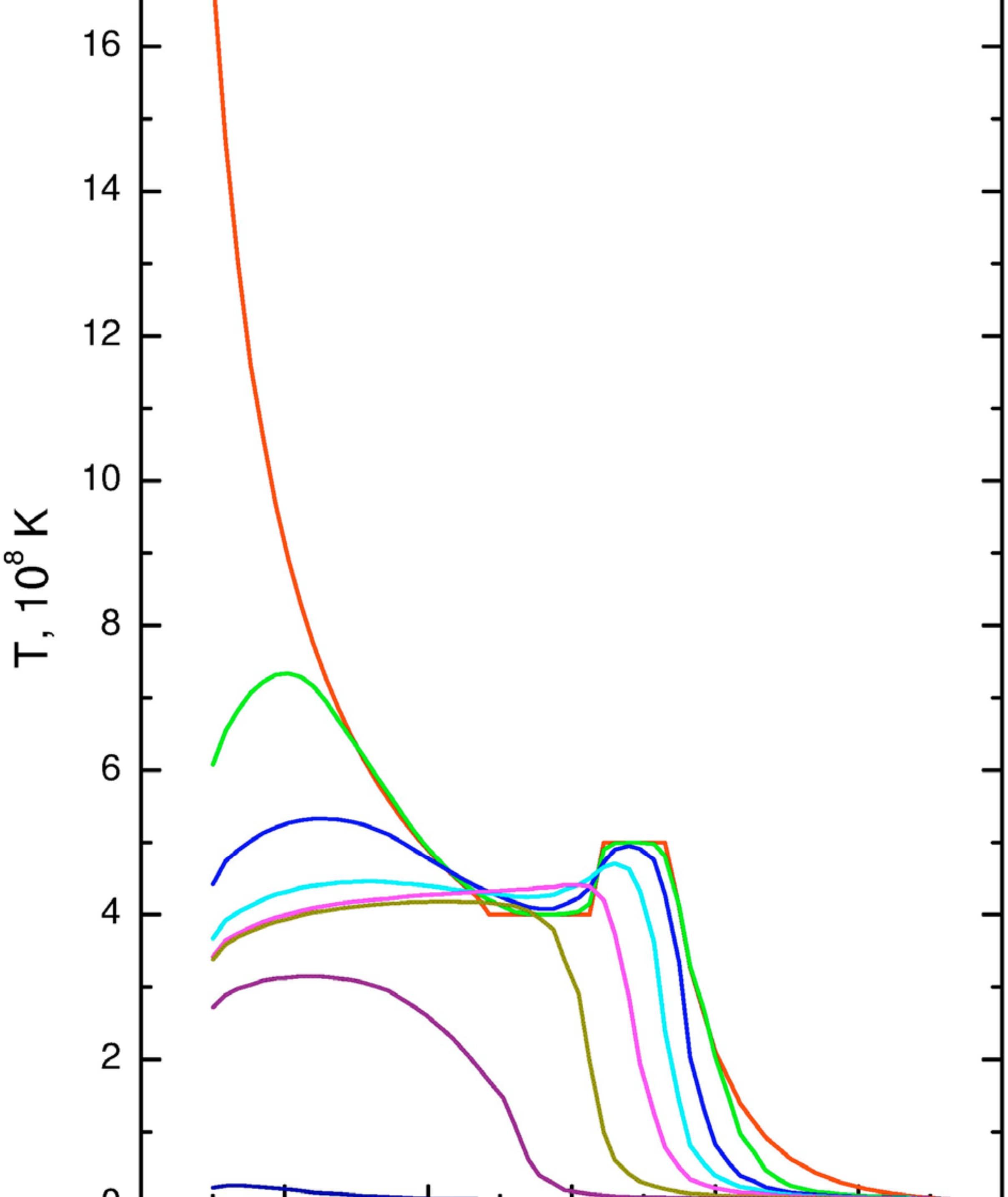
T, 10^8 K
16
14
12
10
8
6
4
2



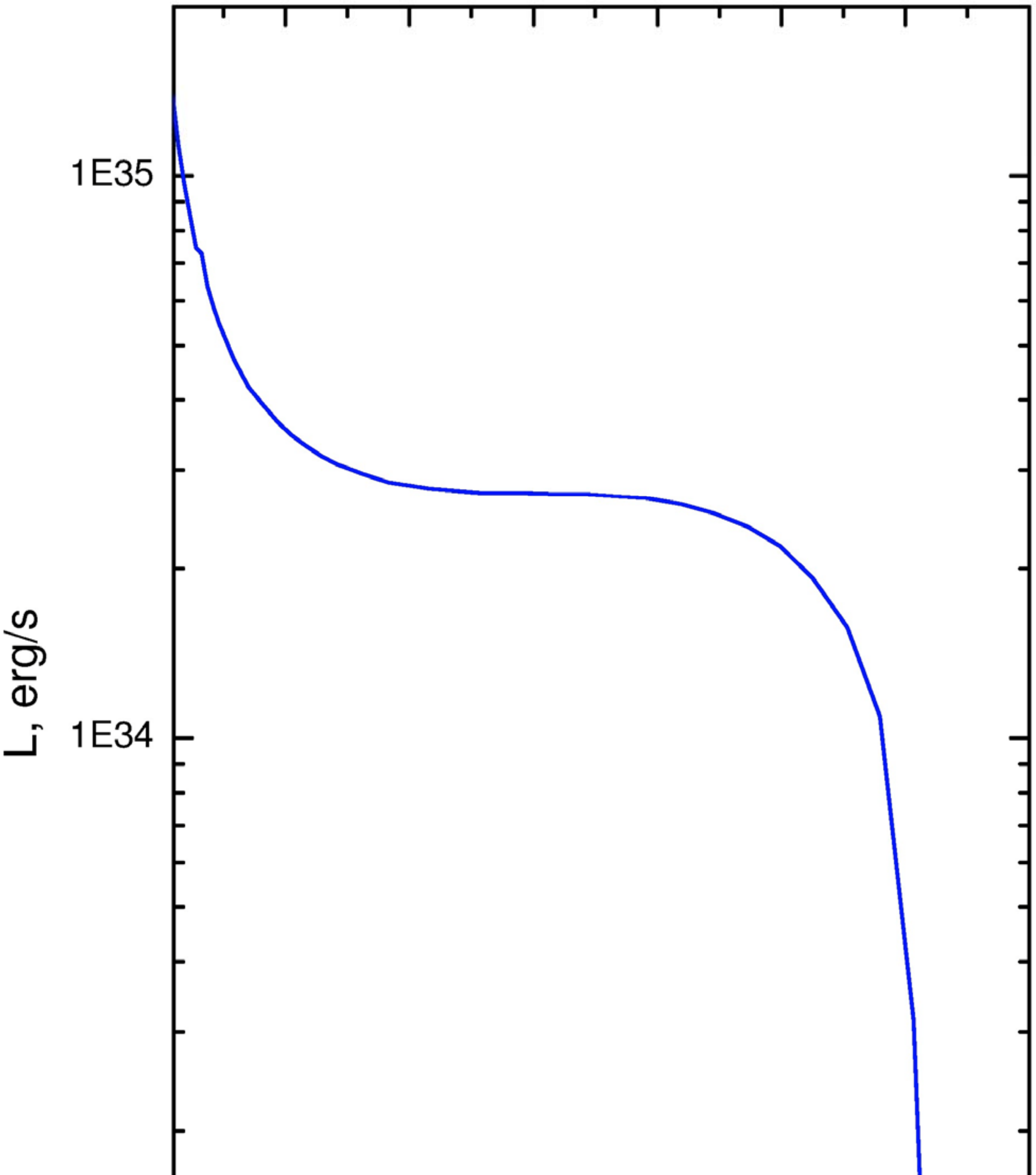
T, 10^8 K
16
14
12
10
8
6
4
2



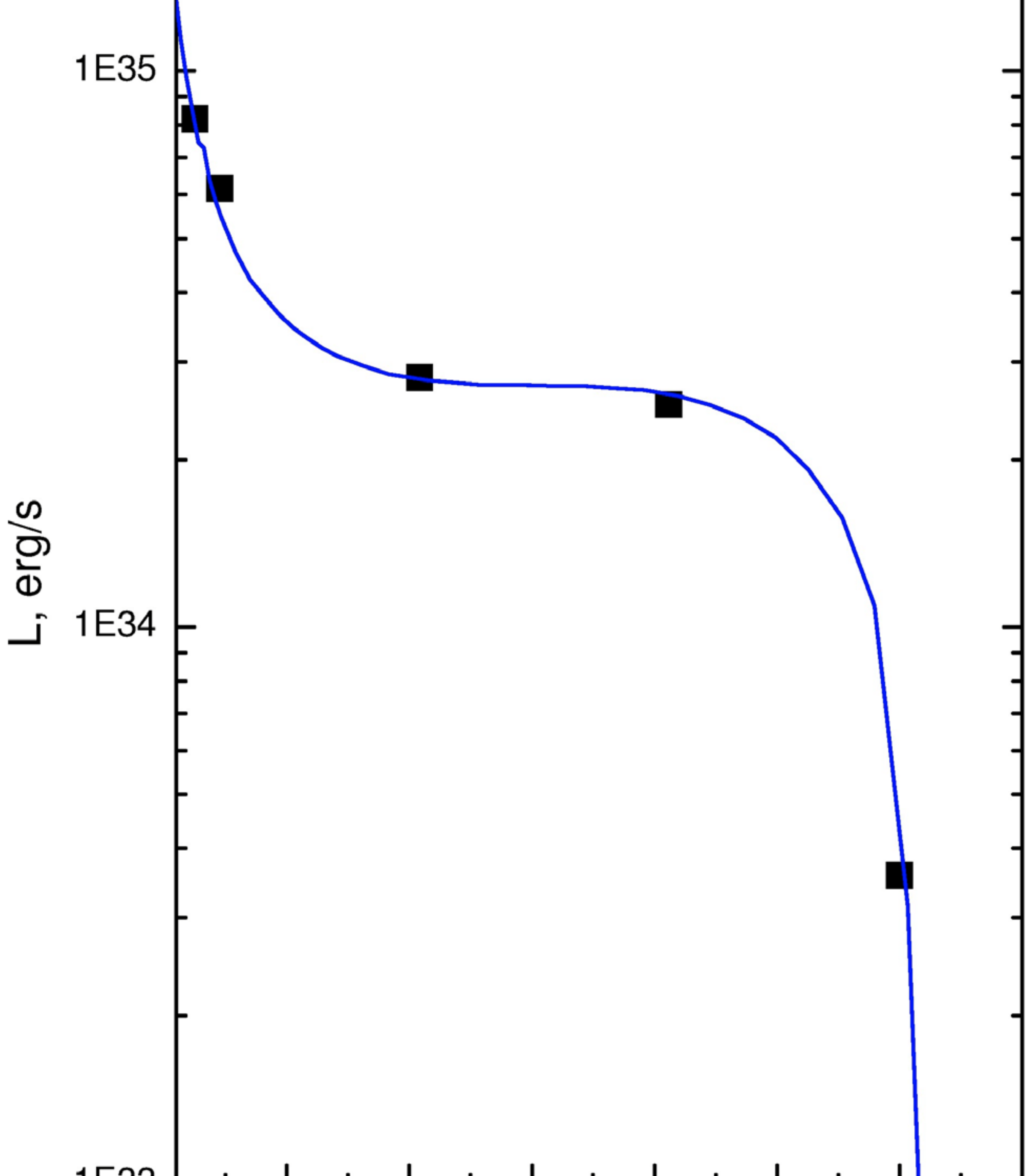
T, 10^8 K
16
14
12
10
8
6
4
2



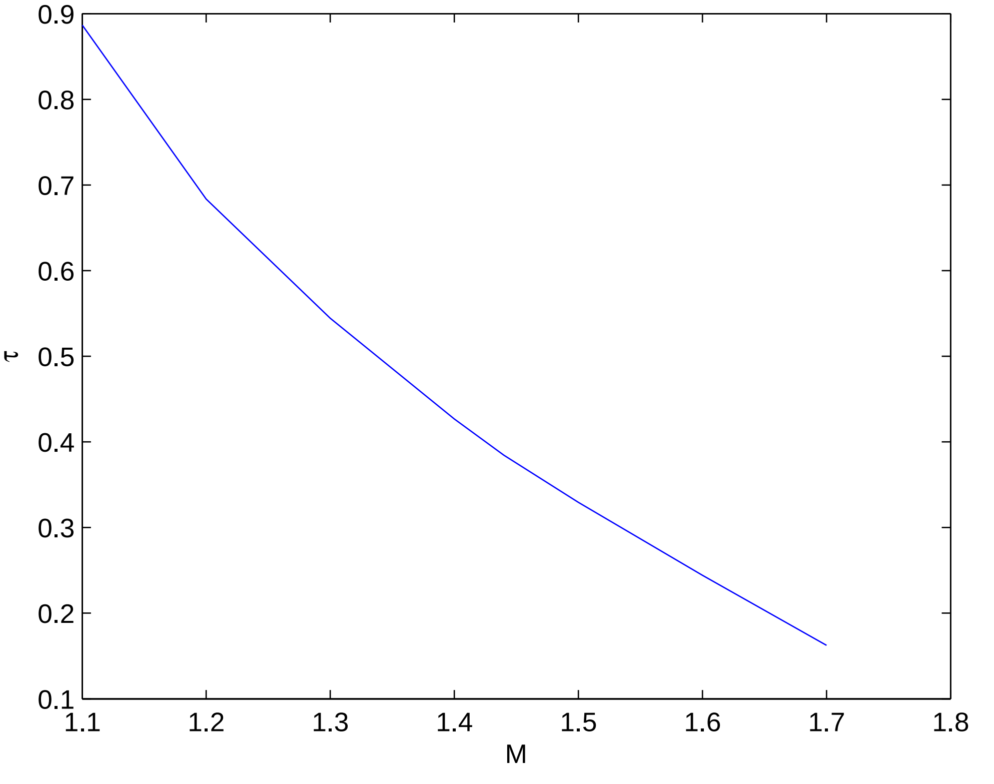
T, 10^8 K
16
14
12
10
8
6
4
2
0



1E35
1E34
L, erg/s



1E35
1E34
L, erg/s



0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
τ
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
M

Perhaps the “persistent” emission from some magnetars is, in fact, long-term afterglow from heating of the inner crust.

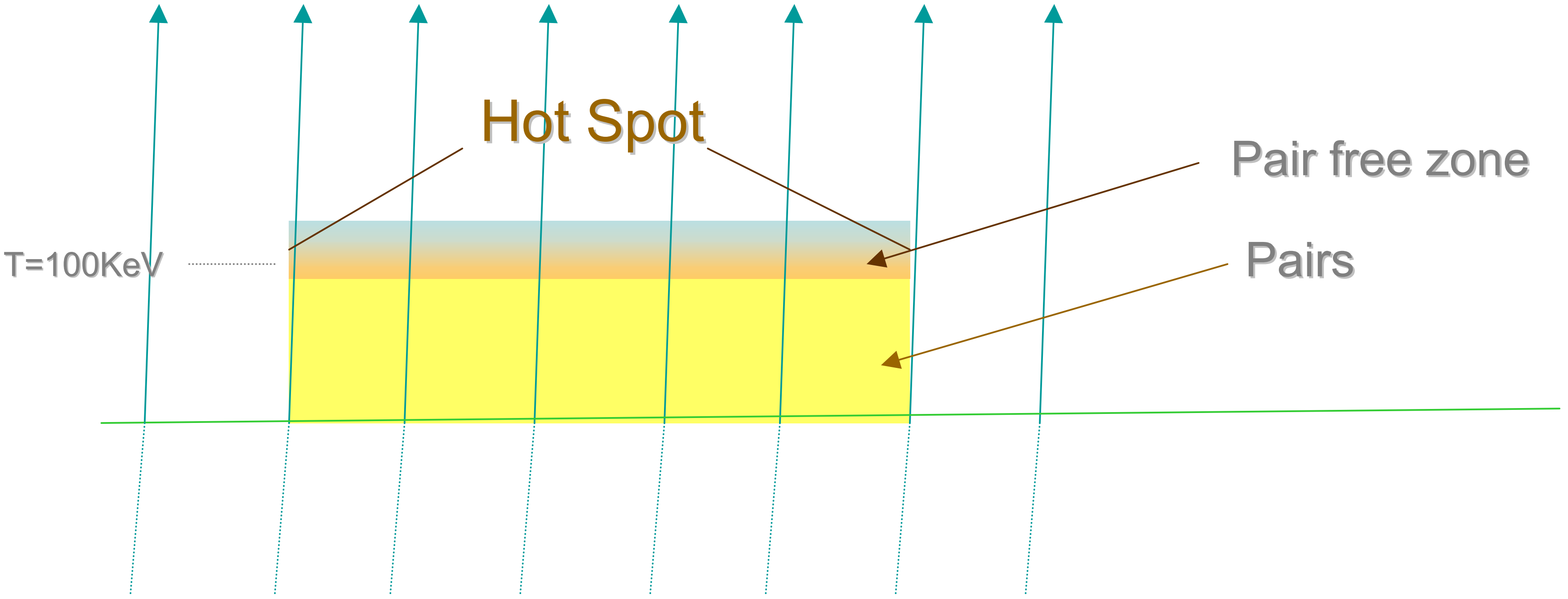
In this case, we may see their steady x-ray emission decline over a time scale of 5 – 10 years.

The short term afterglow of 1900+14

Thompson, Woods, Eichler and Lyubarsky 2003

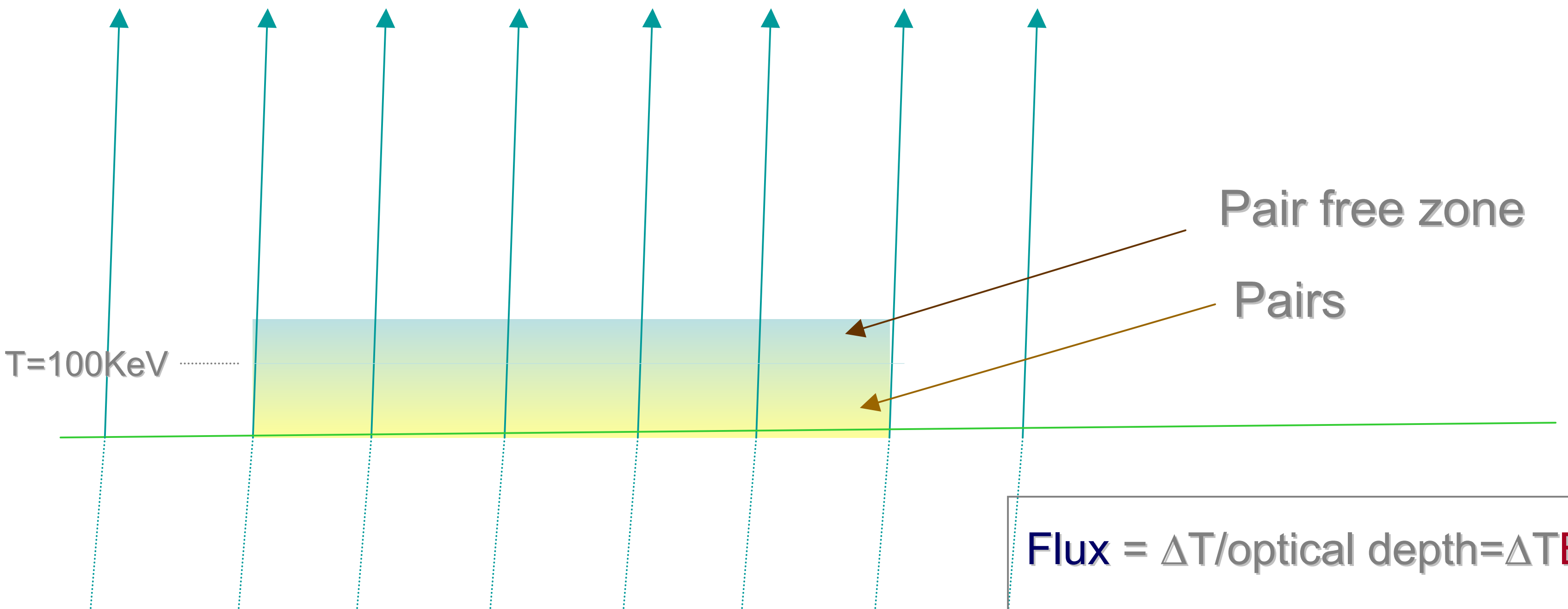
Assume outer layer is heated by energy flux from above surface during initial flare, uplifted by pair pressure

Short Term Afterglow



Short Term Afterglow

(some time later)



Flux = ΔT/optical depth=ΔTB/Σ

dΣ/dt = Flux/h

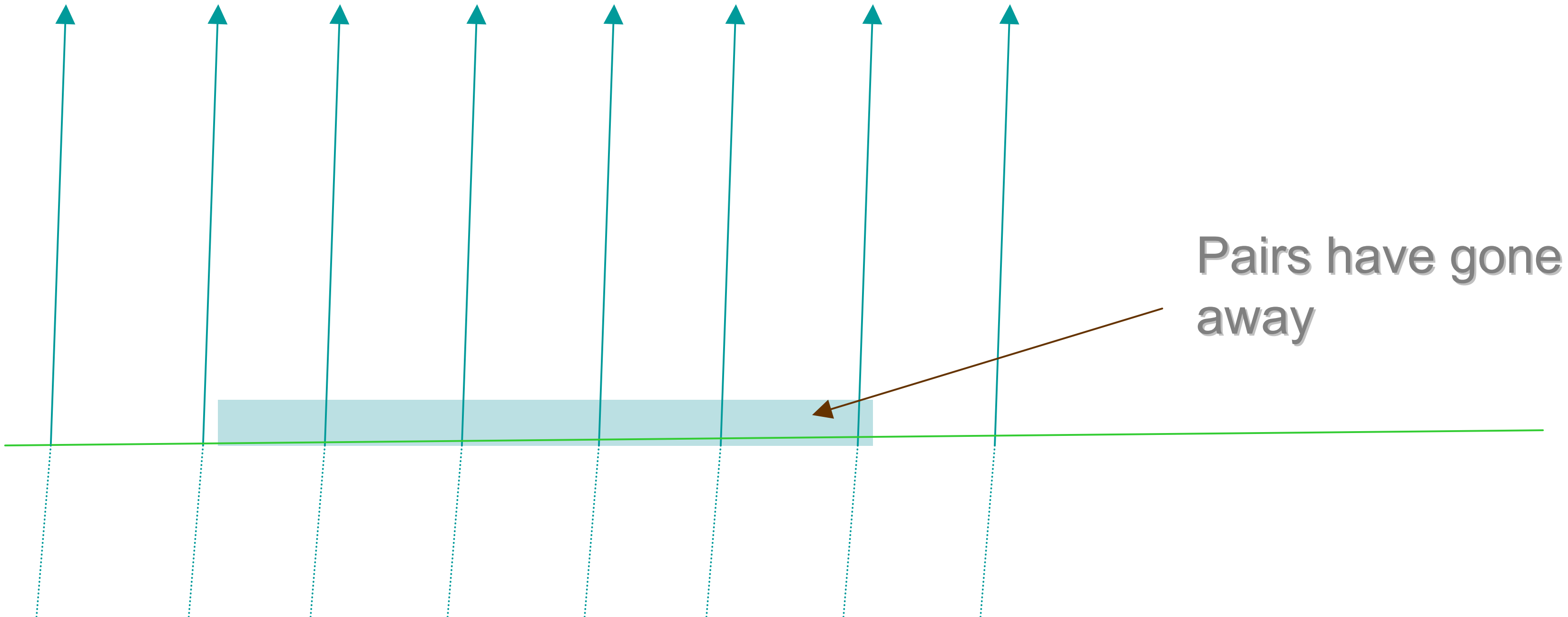
Flux = kBt$^{-1/2}$

Rate of cooling measures magnetic field

ΔT constant, specific enthalpy h constant

Short Term Afterglow

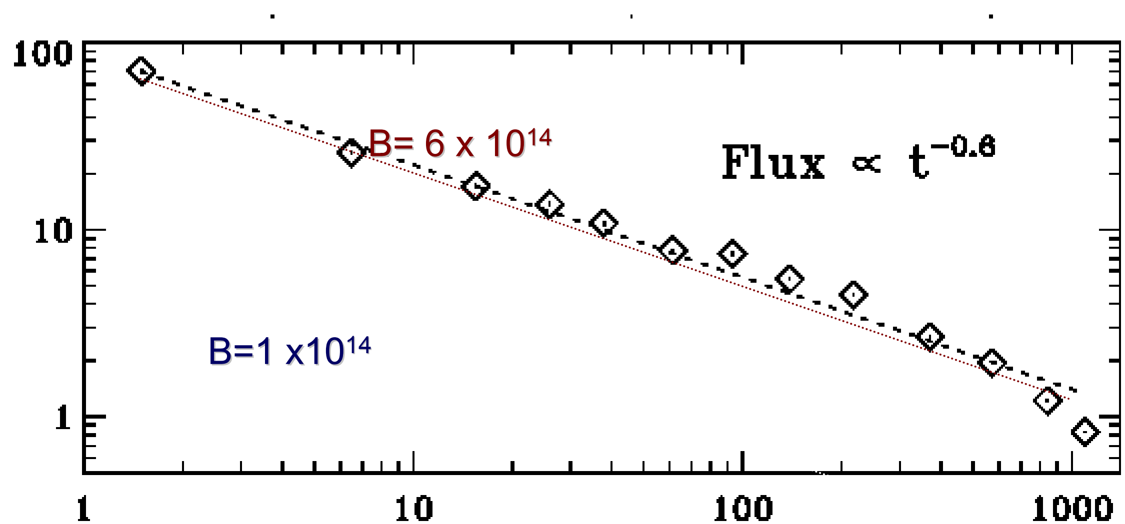
(still later)



Rate of cooling measures magnetic field

Find B= 10^{15} Gauss (Thompson, Woods, Lyubarsky and DE 2003)

Ibrahim et al 2001



Column density is at least about 10^{10} g in normal material

Magnetars as Optical Lasers

Dereddened flux > 2×10^{-13} erg/cm^{2}s

D=5 to 10 Kpc

Lopt >5 x 10^{32} erg/s

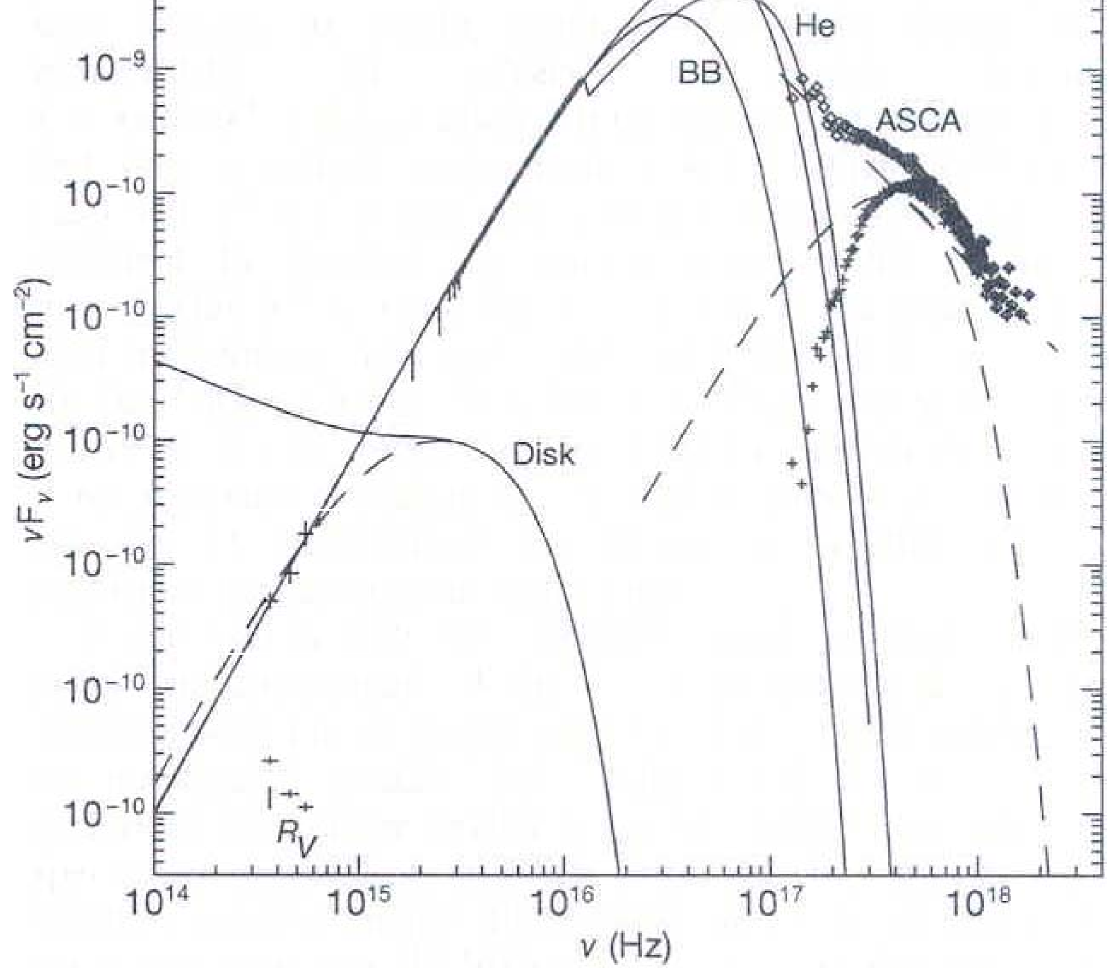
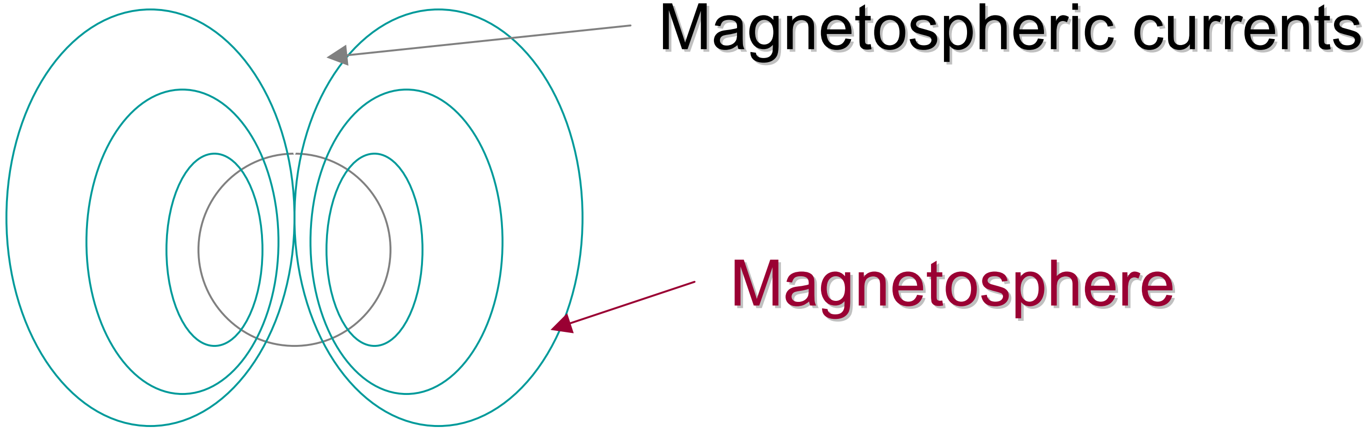


Figure 3 Energy distribution for 4U0142+61. At low frequencies (10^{14}–10^{15} Hz), the points marked V, R and I indicate the observed V-, R-, and I-band fluxes. The vertical error bars reflect the uncertainties, while the horizontal ones indicate the filter bandwidths. The set of points above the measurements indicate dereddened fluxes for $A_V = 5.4$, as inferred from the X-ray column density[10,11]. The errors include a 3% uncertainty in the reddening correction[9]. At high frequencies (10^{17}–10^{18} Hz), the crosses show the incident X-ray spectrum as inferred from ASCA measurements[10]. The diamonds show the spectrum after correction for interstellar absorption, and the two thick dashed curves show the two components used in the fit[10]: a power law of the form $F_\nu = 102(h\nu/1\,\mathrm{keV})^{-2.67}$ μJy and a black body with $T = 4.4 \times 10^6$ K and

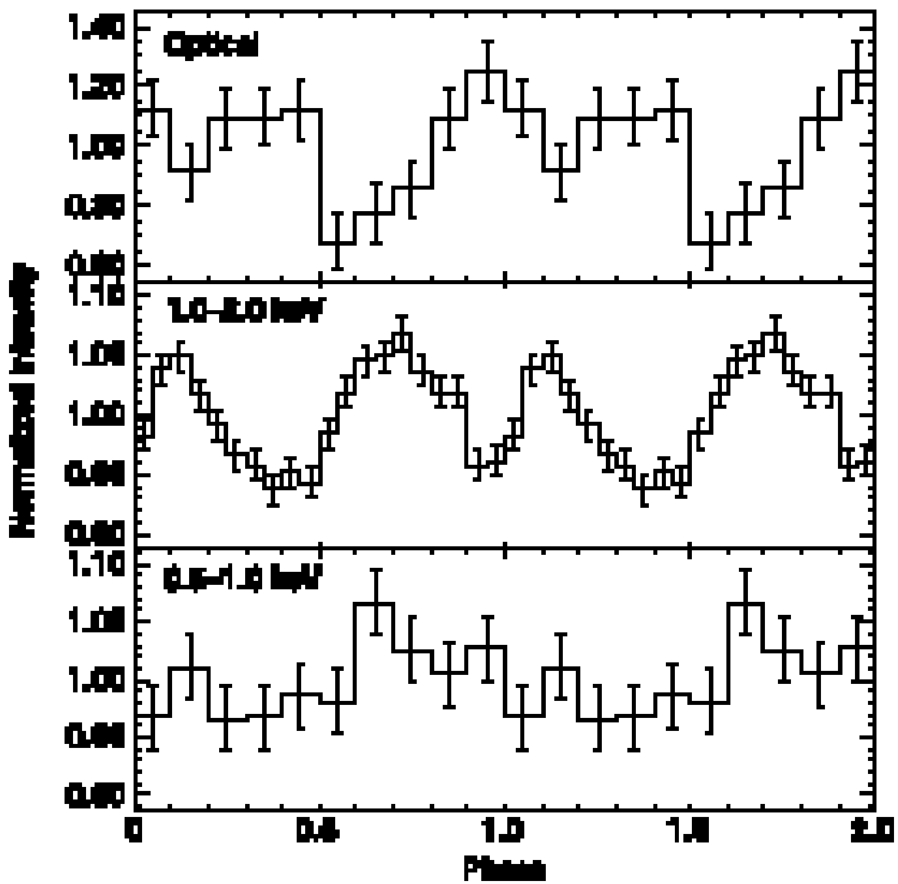
Magnetars as Optical Lasers



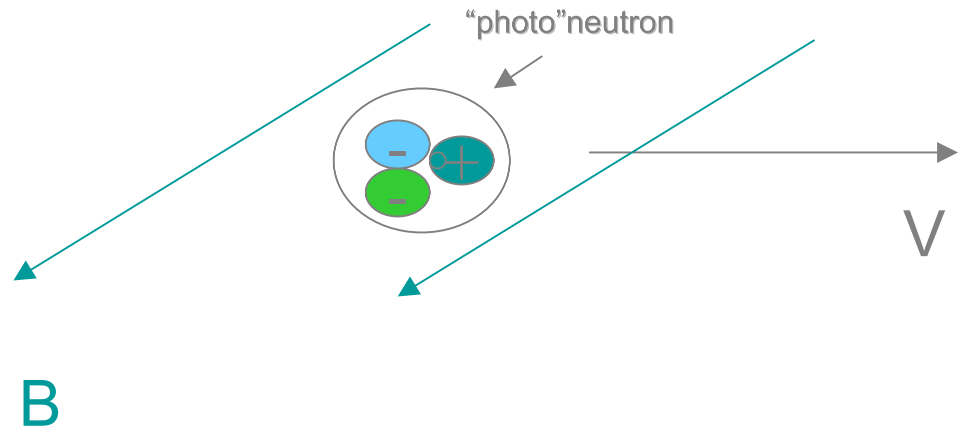
Say the currents are relativistic pairs. Lorentz factor about 10^3. Density about 10^{17} charges/cm^3.

Plasma frequency as seen in the lab frame 10^{14-15} hz. Two stream instability (Gedalin, Gruman and Melrose, 2002) makes coherent optical or IR emission.

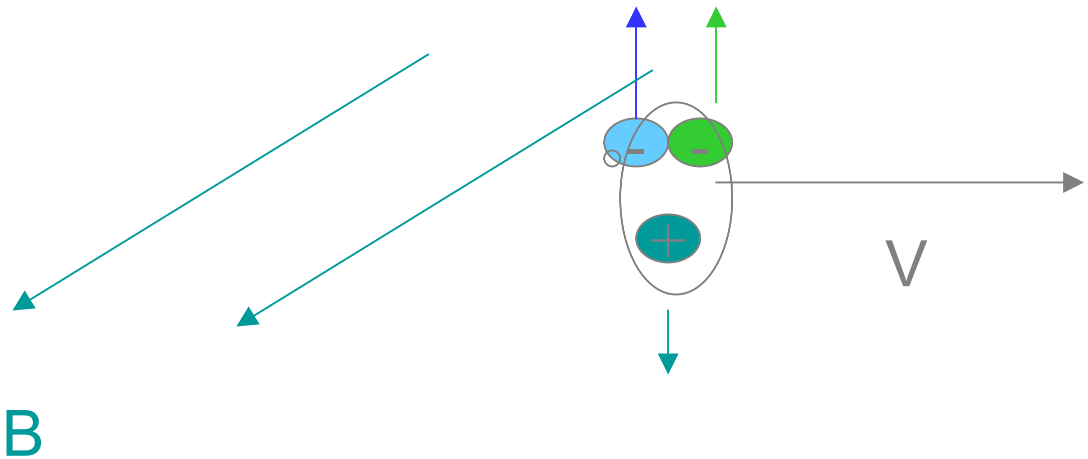
Optical Pulses from 4U0412 (Kern and Martin, Nature May 31 2002)

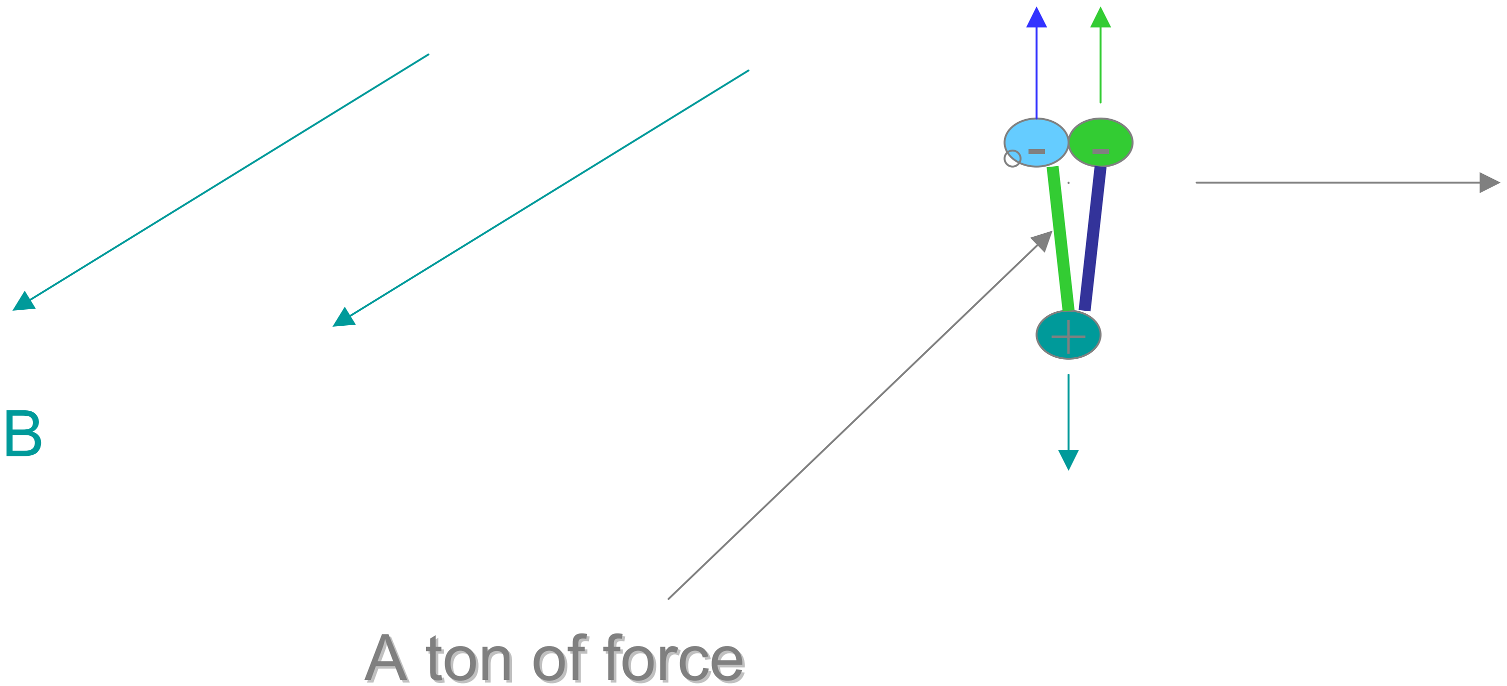


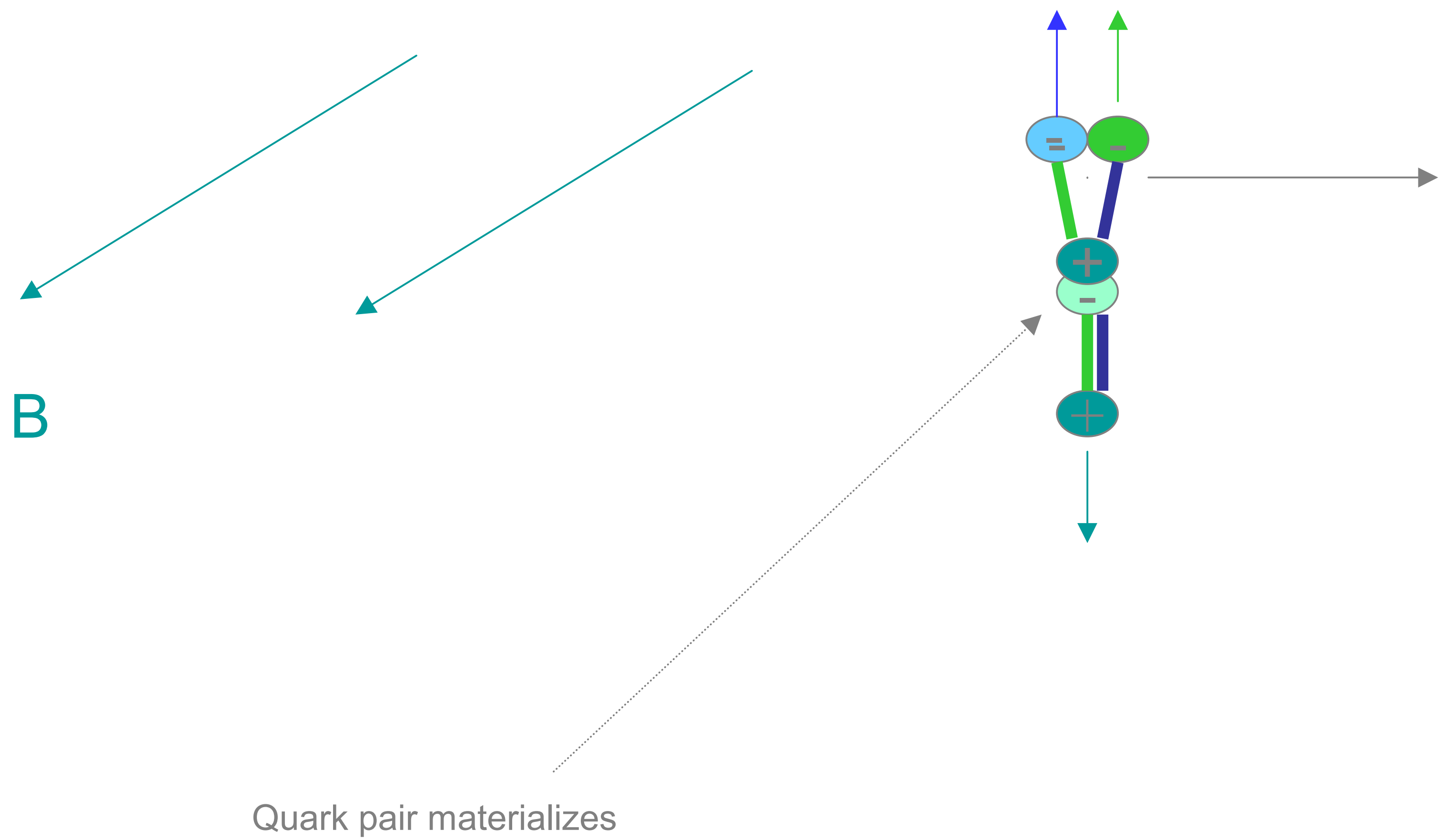
Tearing Nucleons Apart

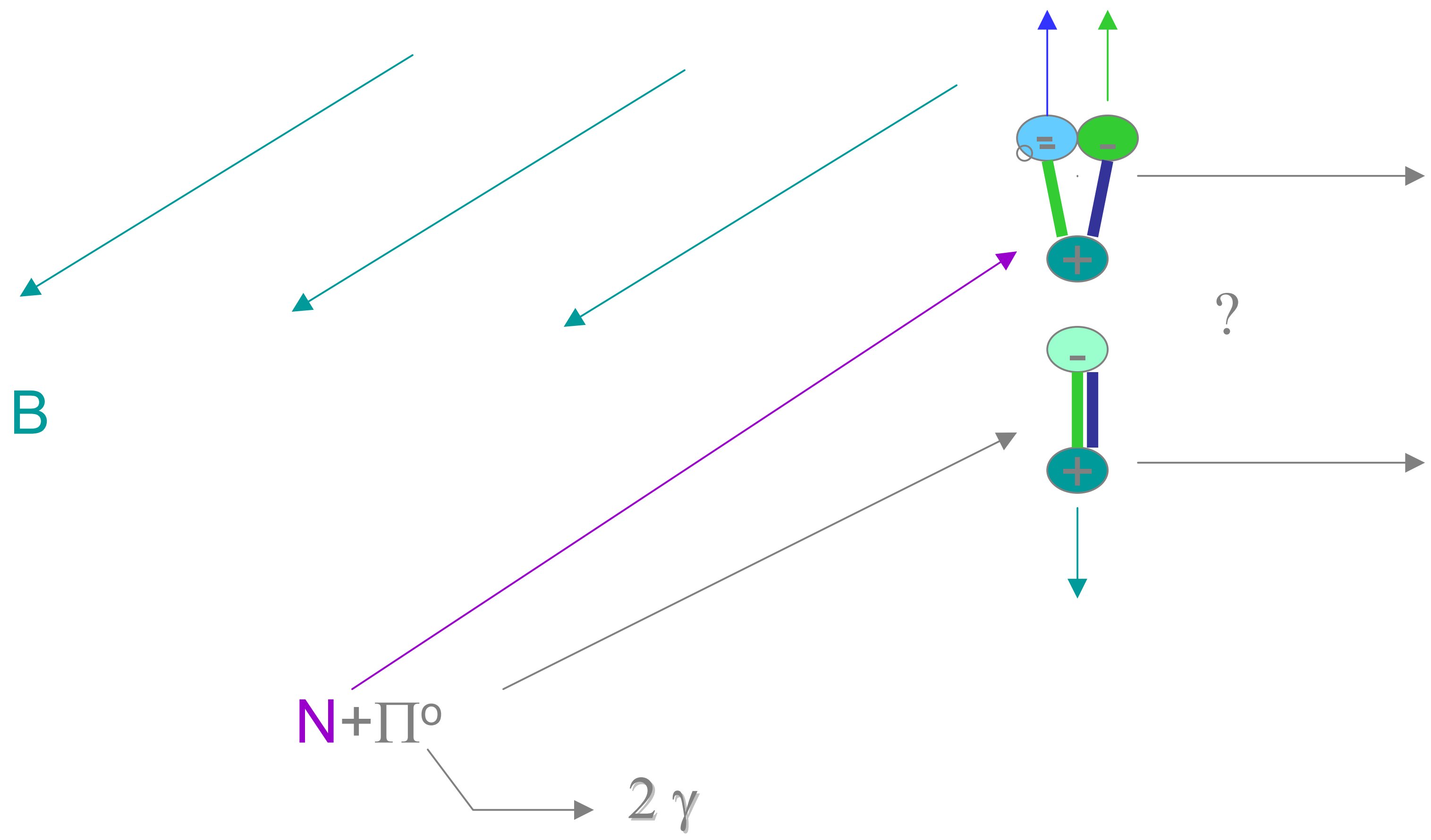


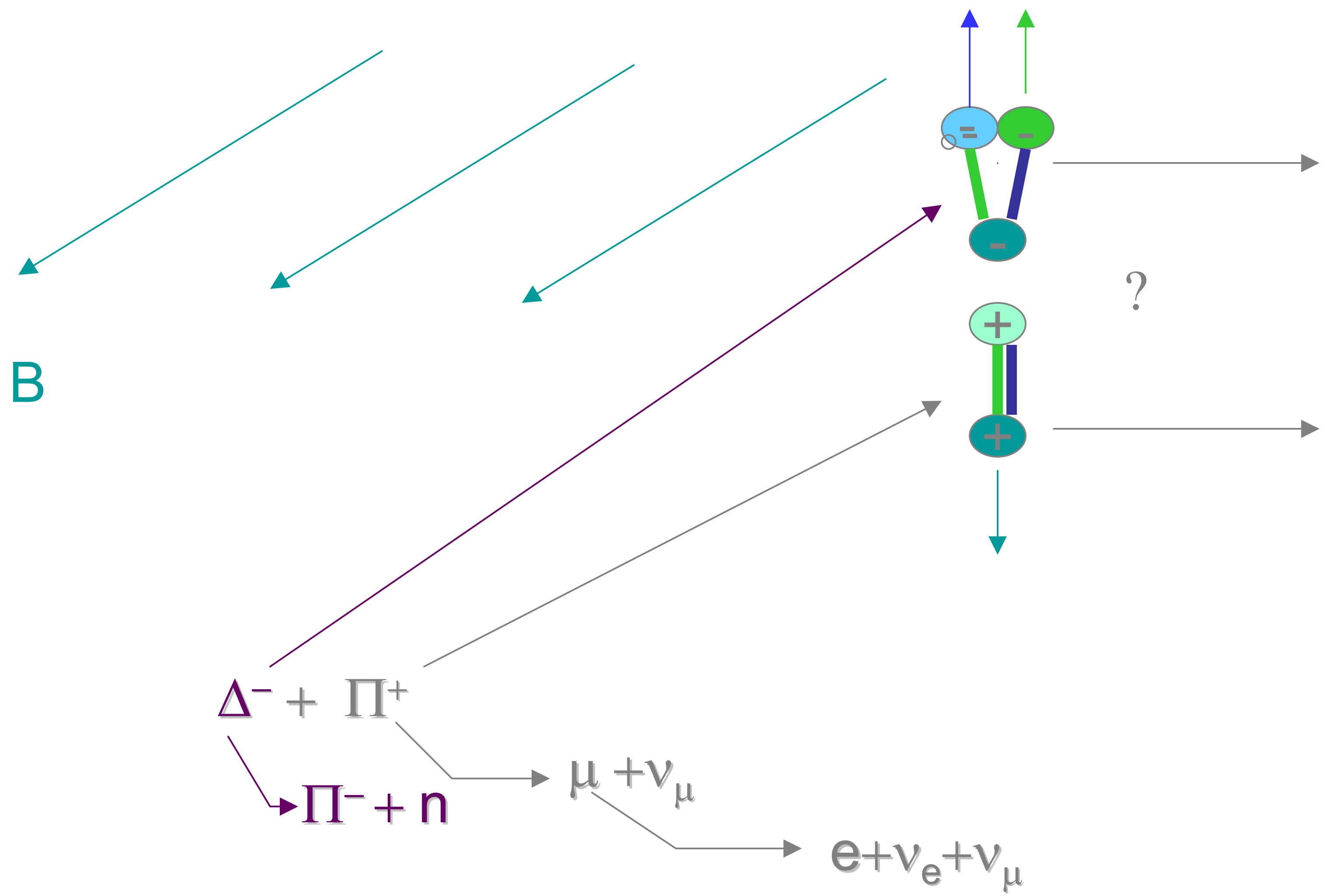
“photo”neutron
V
B


V
B


B
A ton of force

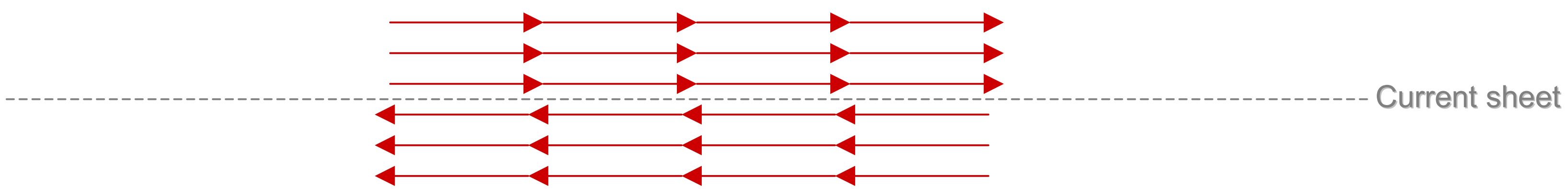

B
Quark pair materializes

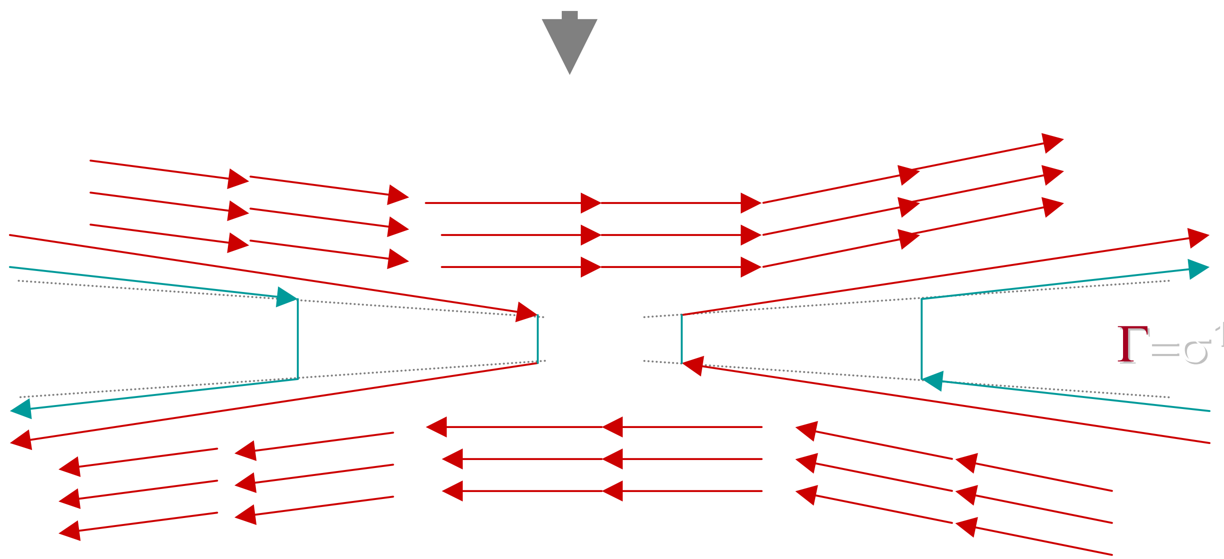

B
?
N+Πo
2 γ



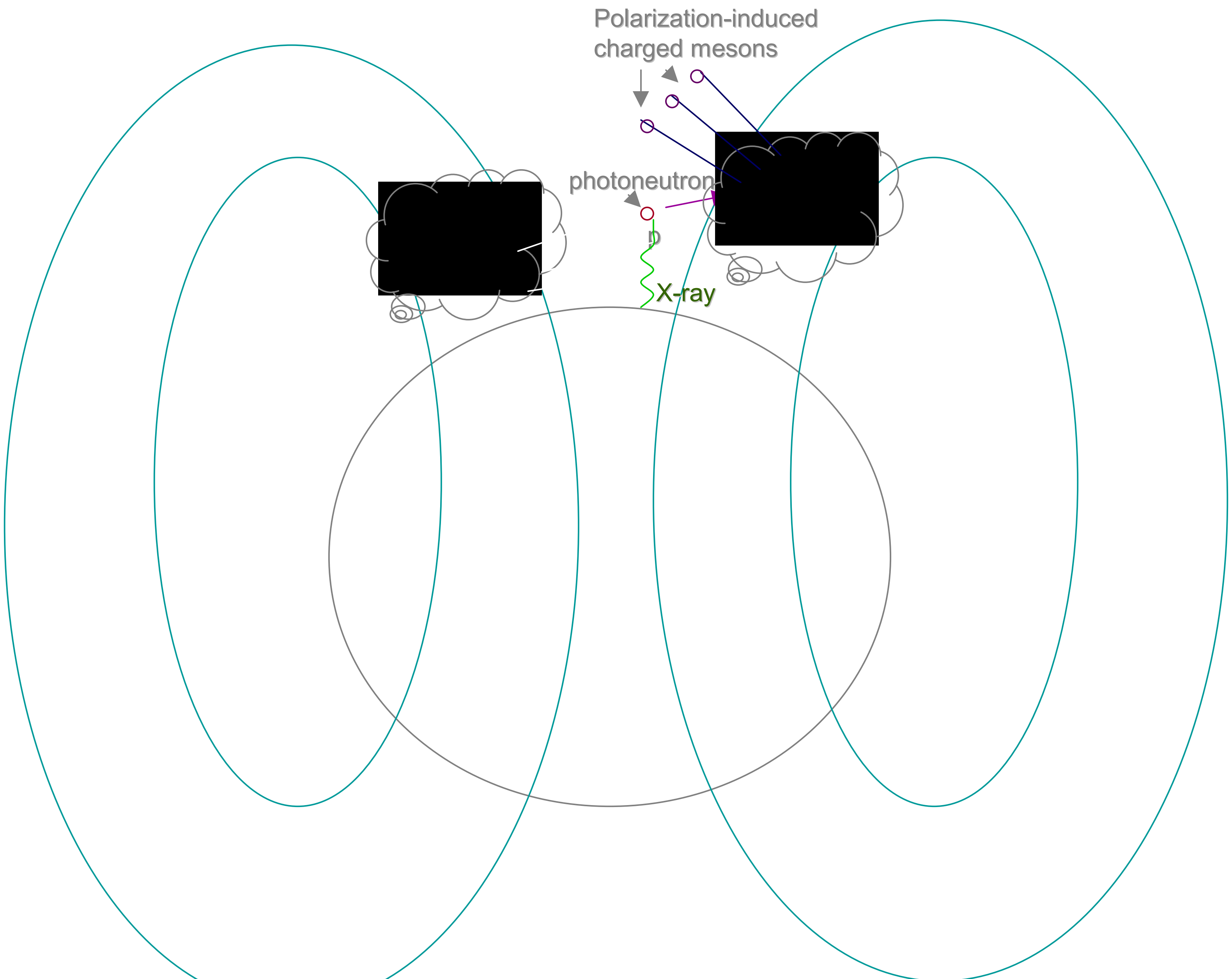
B
?
Δ⁻ + Π⁺
Π⁻ + n
μ + ν_μ
e+ν_e+ν_μ

Relativistic Petschek reconnection





σ can be 10^{12} to 10^{14} for a magnetar, so Γ can exceed 10^5



Polarization-induced charged mesons
photoneutron
p
X-ray

Other indications of baryons in NS peripheries:

GRB X-ray afterglow – nearly always present

Afterglow from 27 December event: Baryons seem to have been ejected at about 0.6c (Gelfand et al 2005)

Conclusions

We may actually understand some of the crazy physics of magnetars.

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Magnetar crusts are consistent with ordinary matter. No ice nine scenario implied (yet). More research needed.

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Magnetar crusts are consistent with ordinary matter. No ice nine scenario implied (yet).

Short term afterglow confirms $B = 6 \times 10^{14}$ Gauss

Magnetars may be free electron optical lasers. Many predictions (wavefront coherence, photon statistics, polarization…) can be tested.

Magnetars offer

New quantum electrodynamics

new condensed matter physics,

new nuclear physics,

maybe new laser physics,

and lots of new astrophysics.