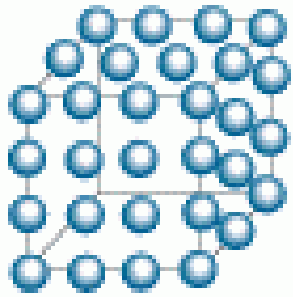


States of matter under extreme conditions⁺

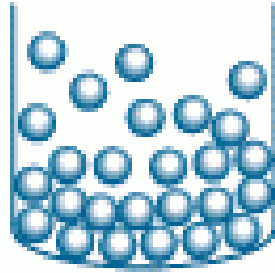
S. V. G. Menon
Bhabha Atomic Research Centre

⁺ Lecture given at IIT-Indore on 07-04-2011

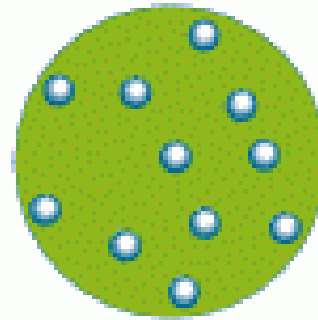
Four states of matter



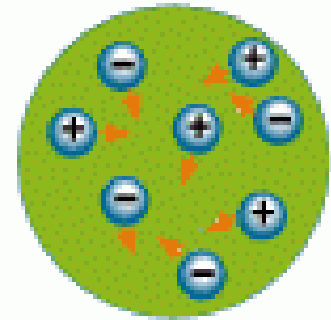
Solid



Liquid



Gas

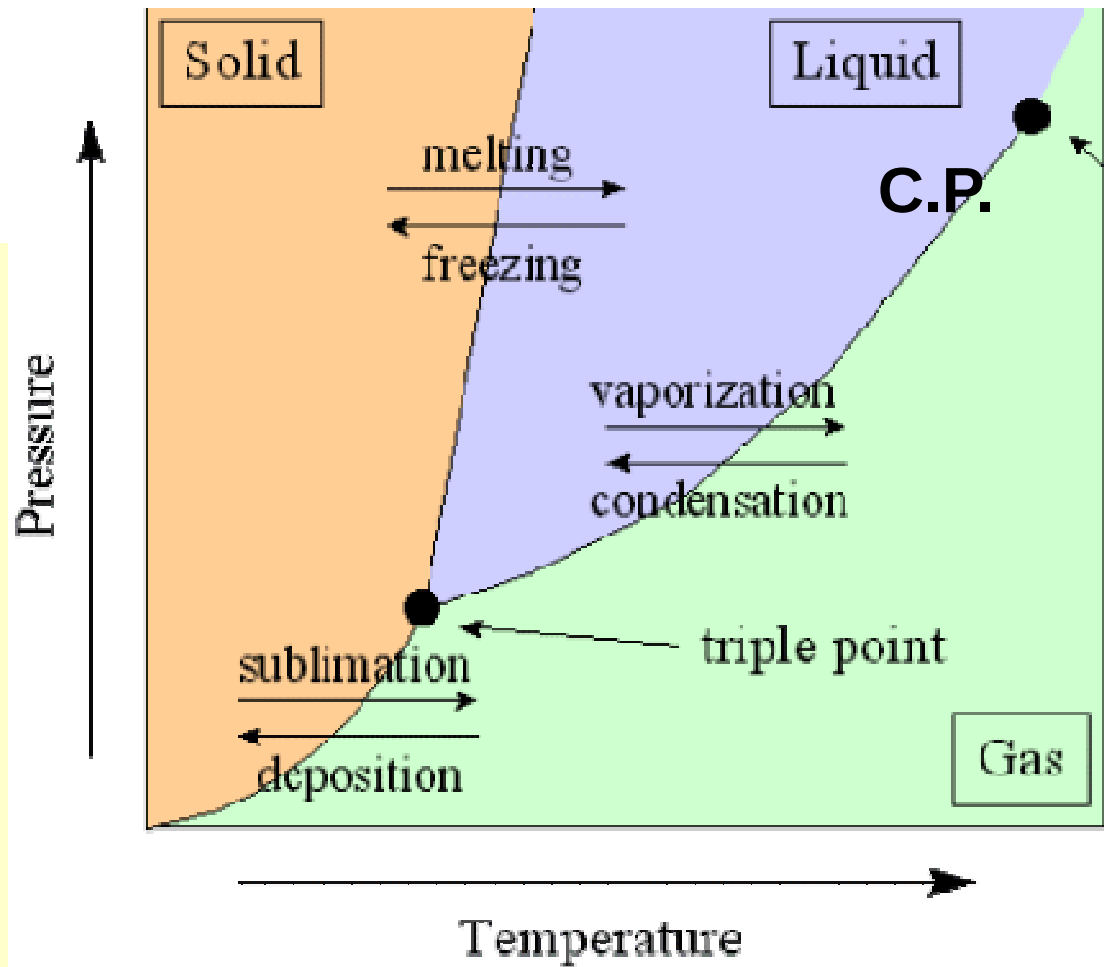


Plasma

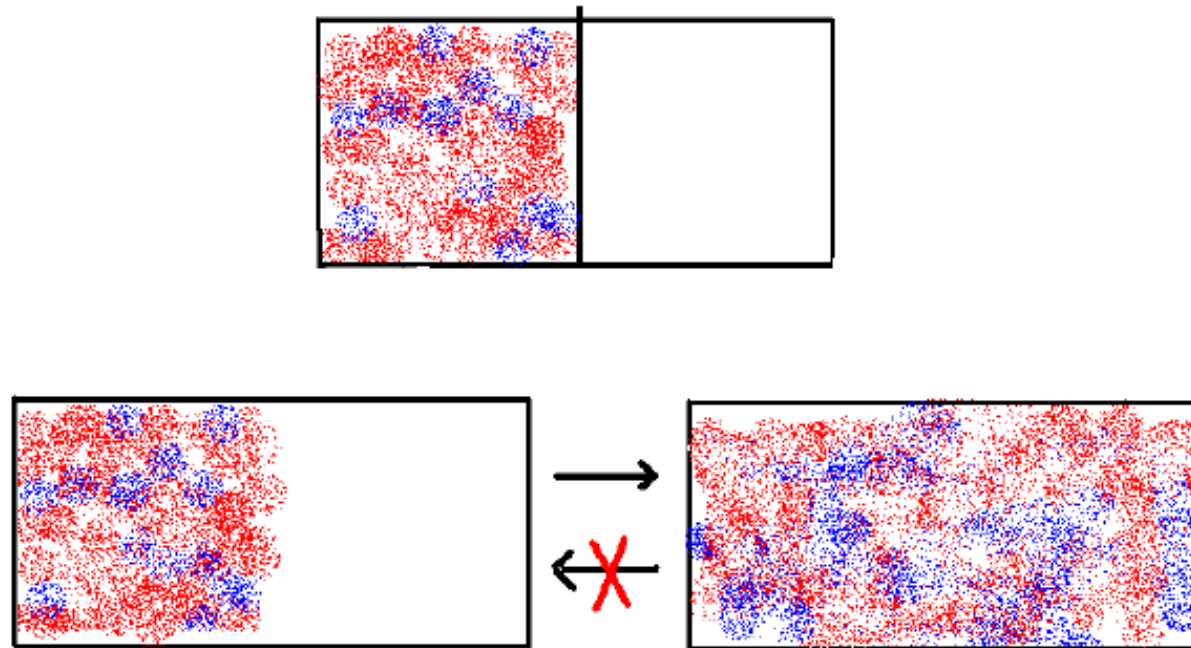
Phase transitions in matter

Competition between
Energy
&
Entropy
determines
phase stability

Typical phase diagram

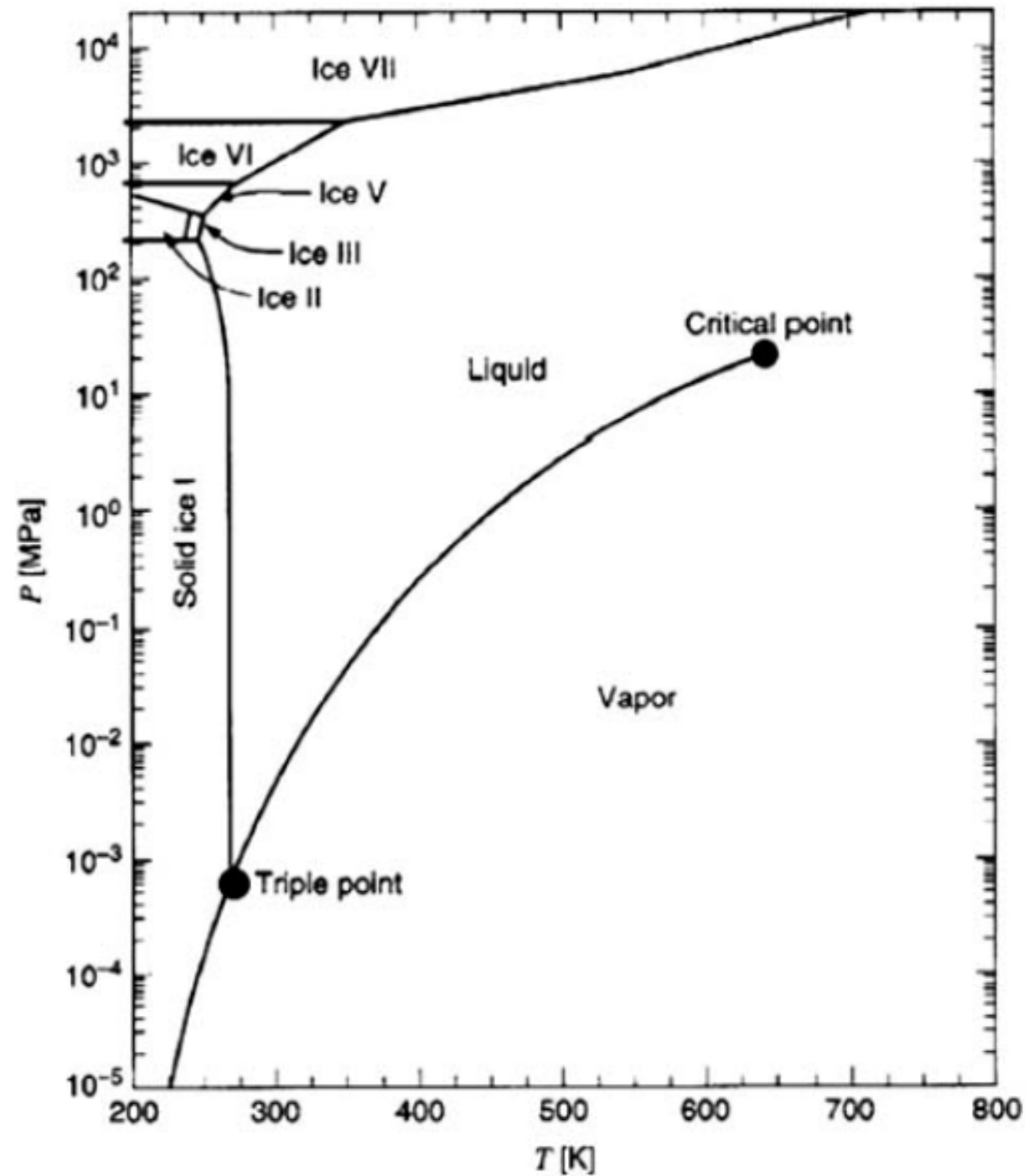


What is entropy



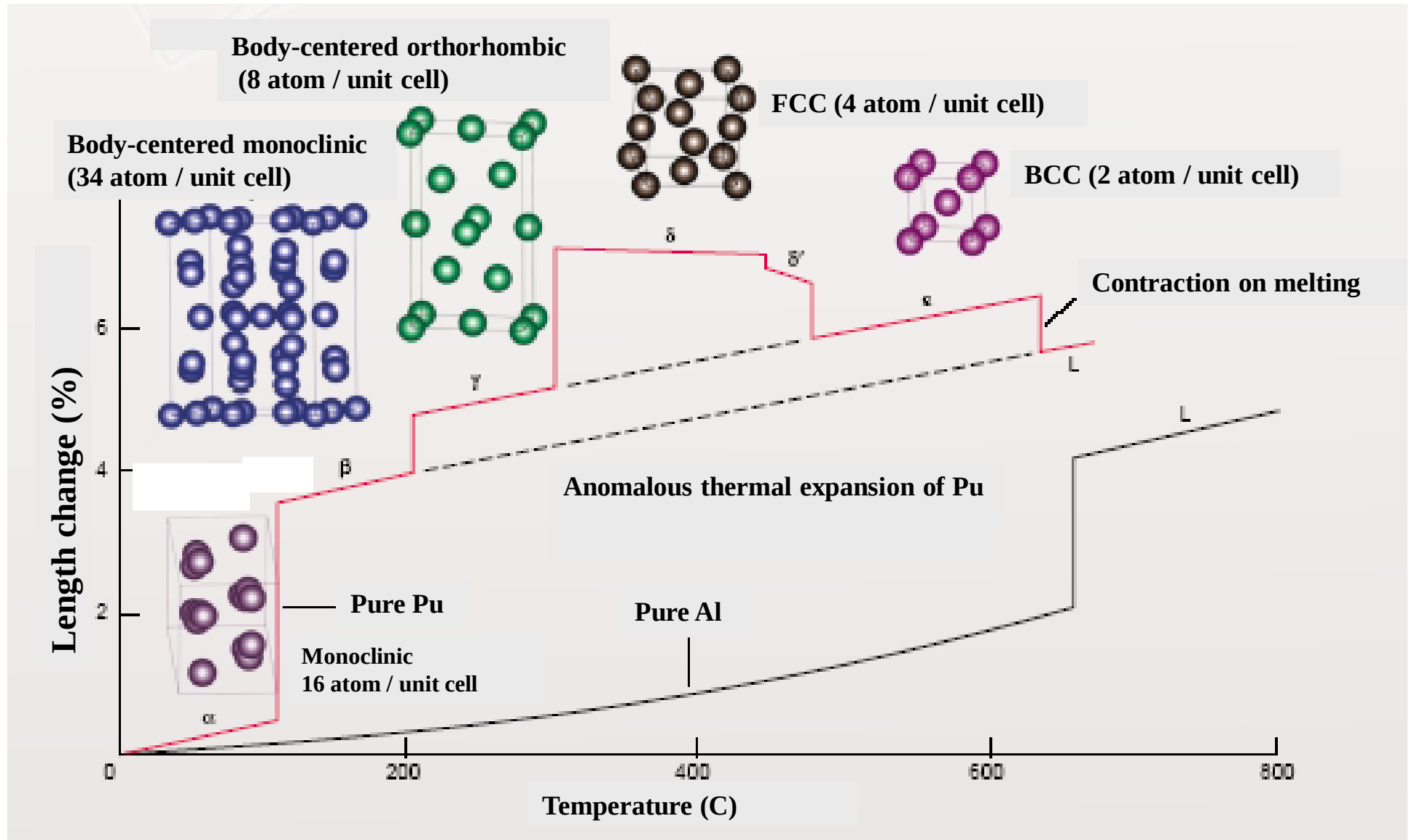
The probability of going from left to right is overwhelming, but that of going in the other way is practically zero

Phase diagram of water

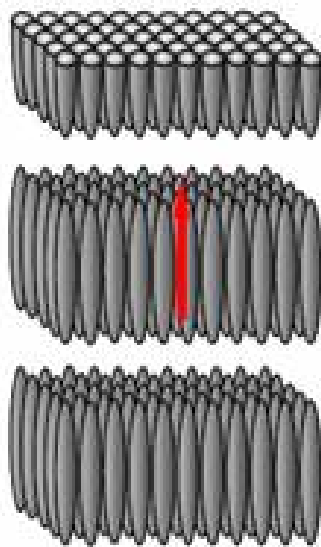


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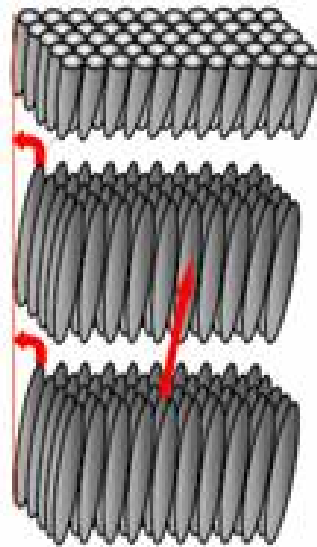
Six distinct phases of plutonium



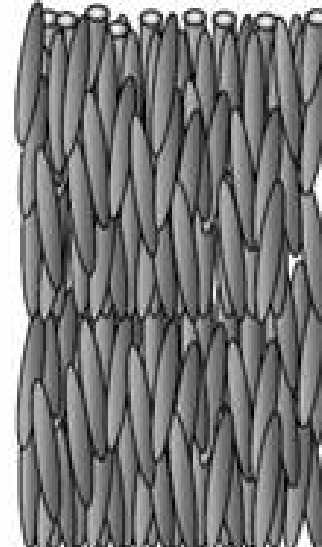
Ordering in liquid crystals



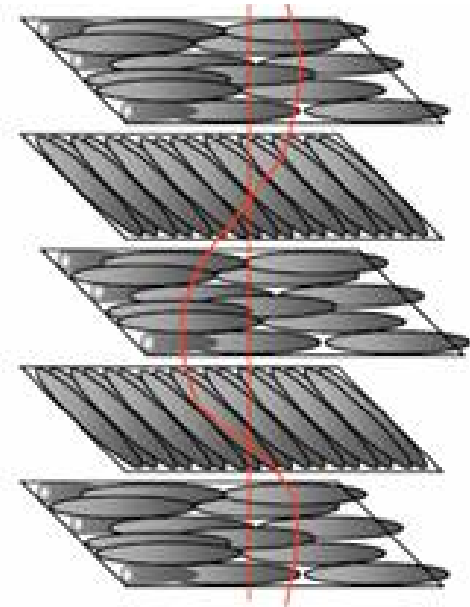
Smectic A (a)



Smectic C (b)



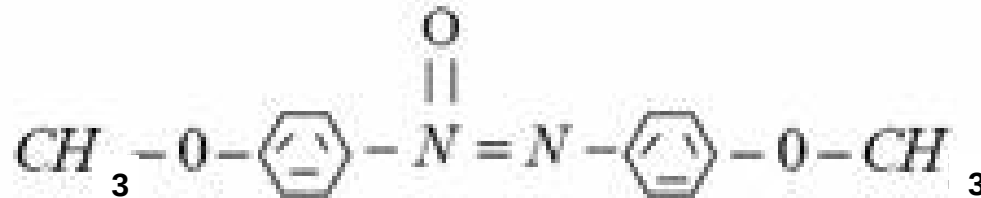
Nematic (c)



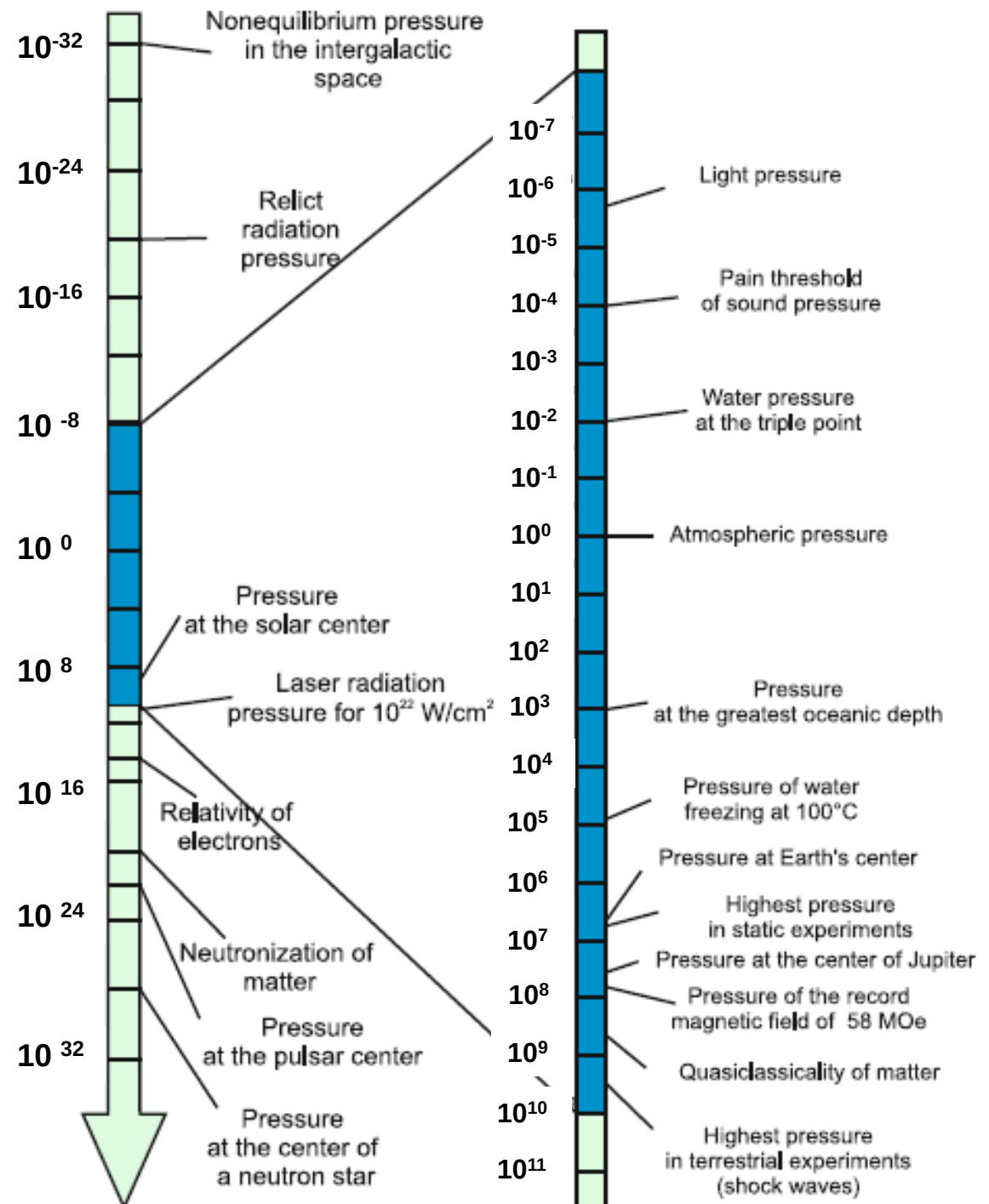
Cholesteric (d)

Entropy

- Translation
- Orientation

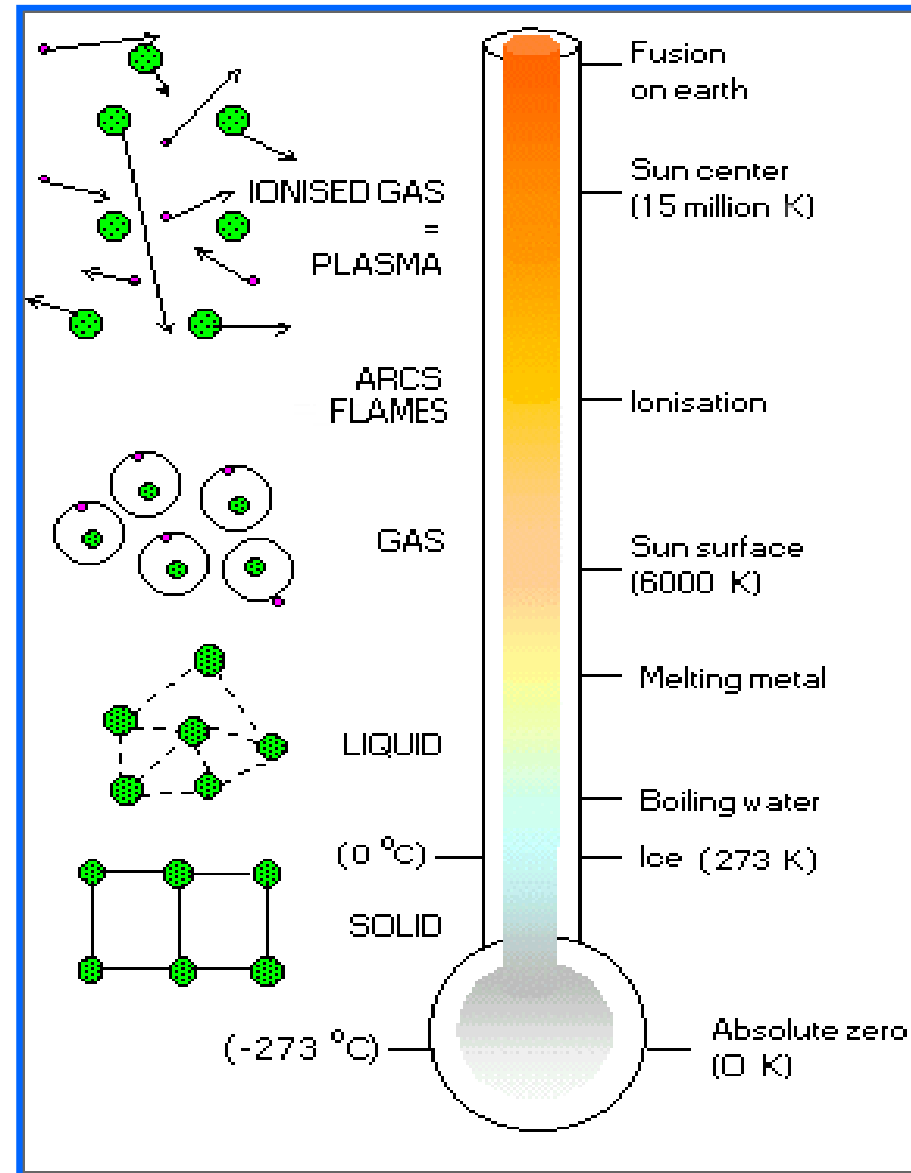


Pressure scale

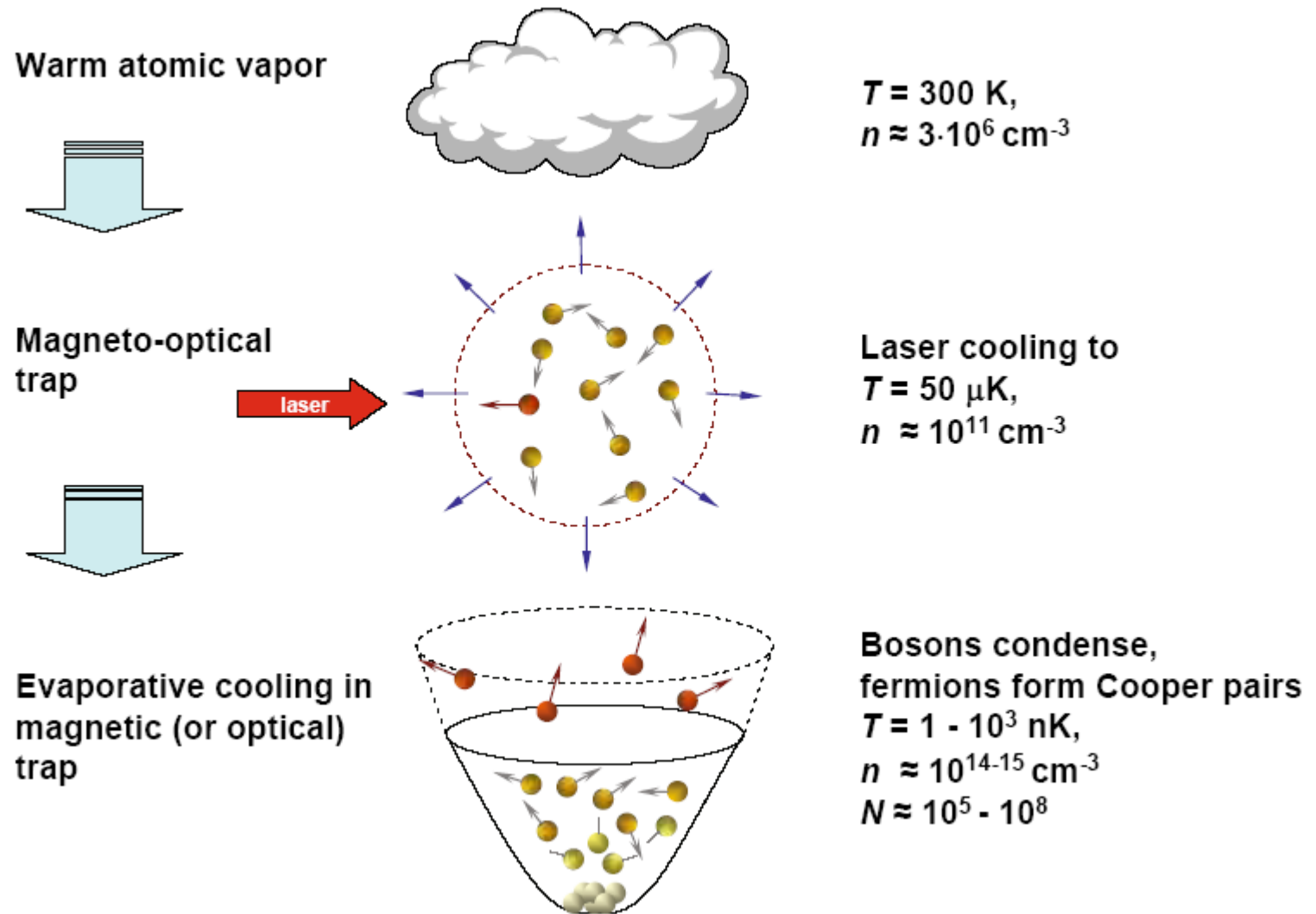


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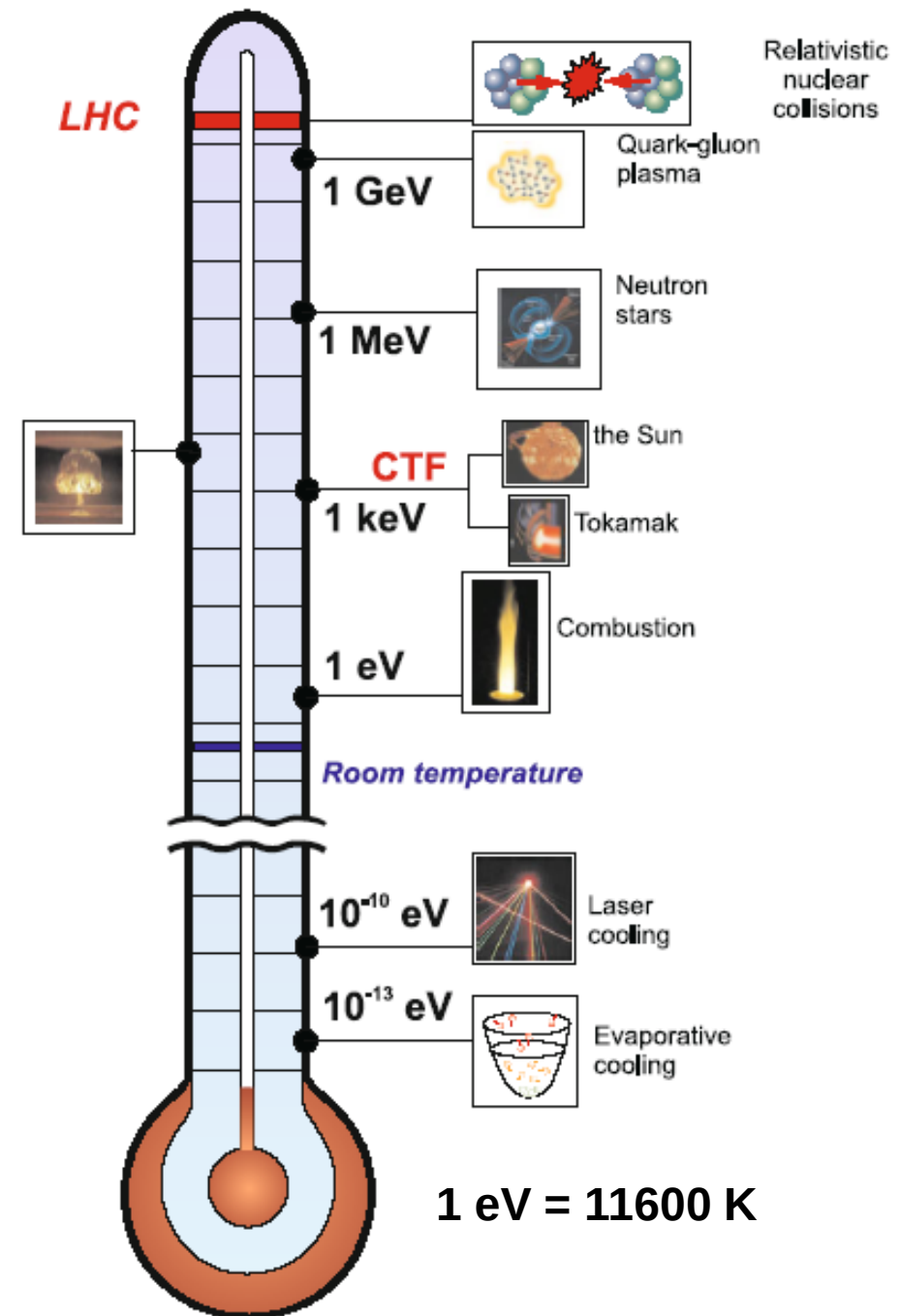
Temperature scale



Extreme low temperatures



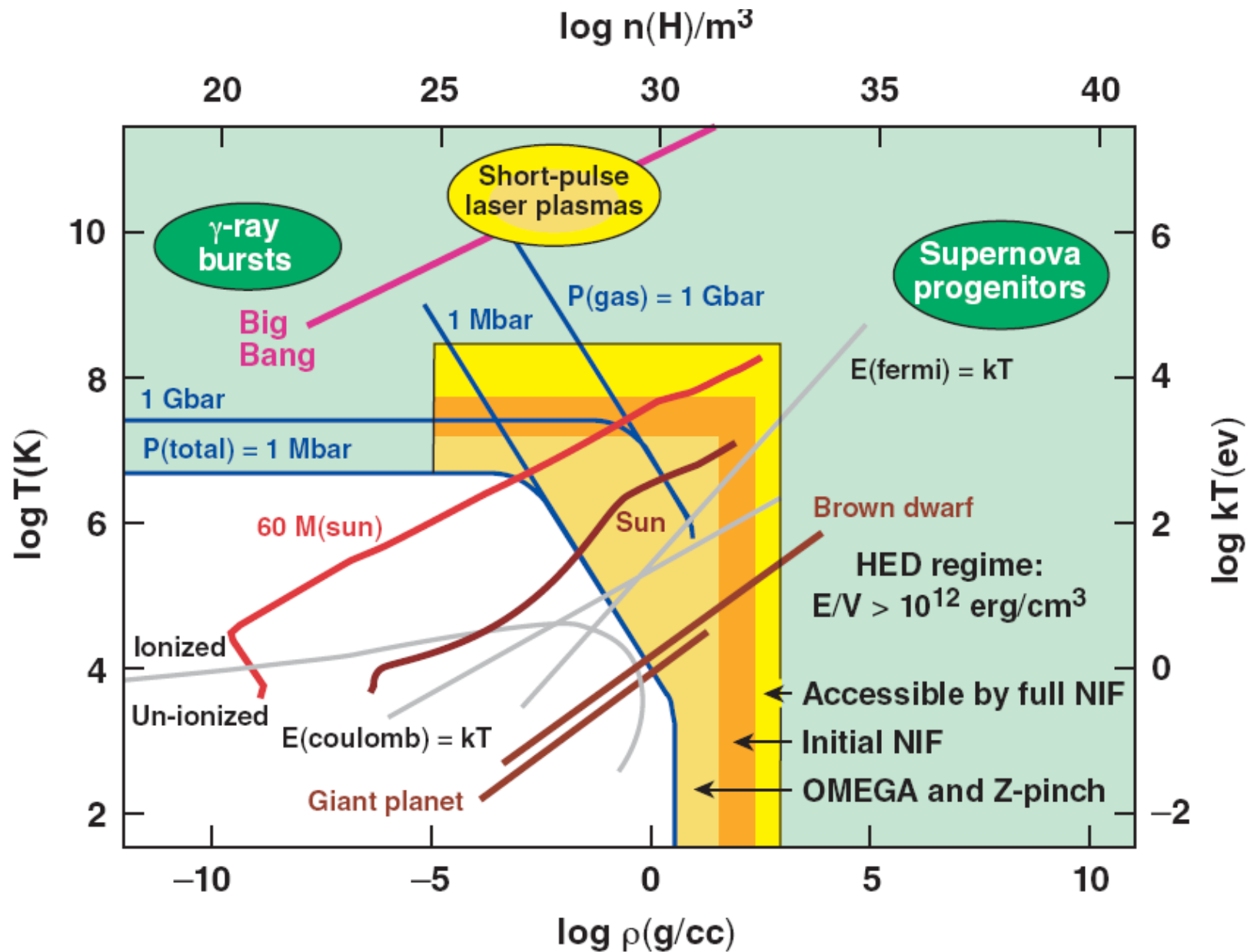
Attainable temperatures in nature



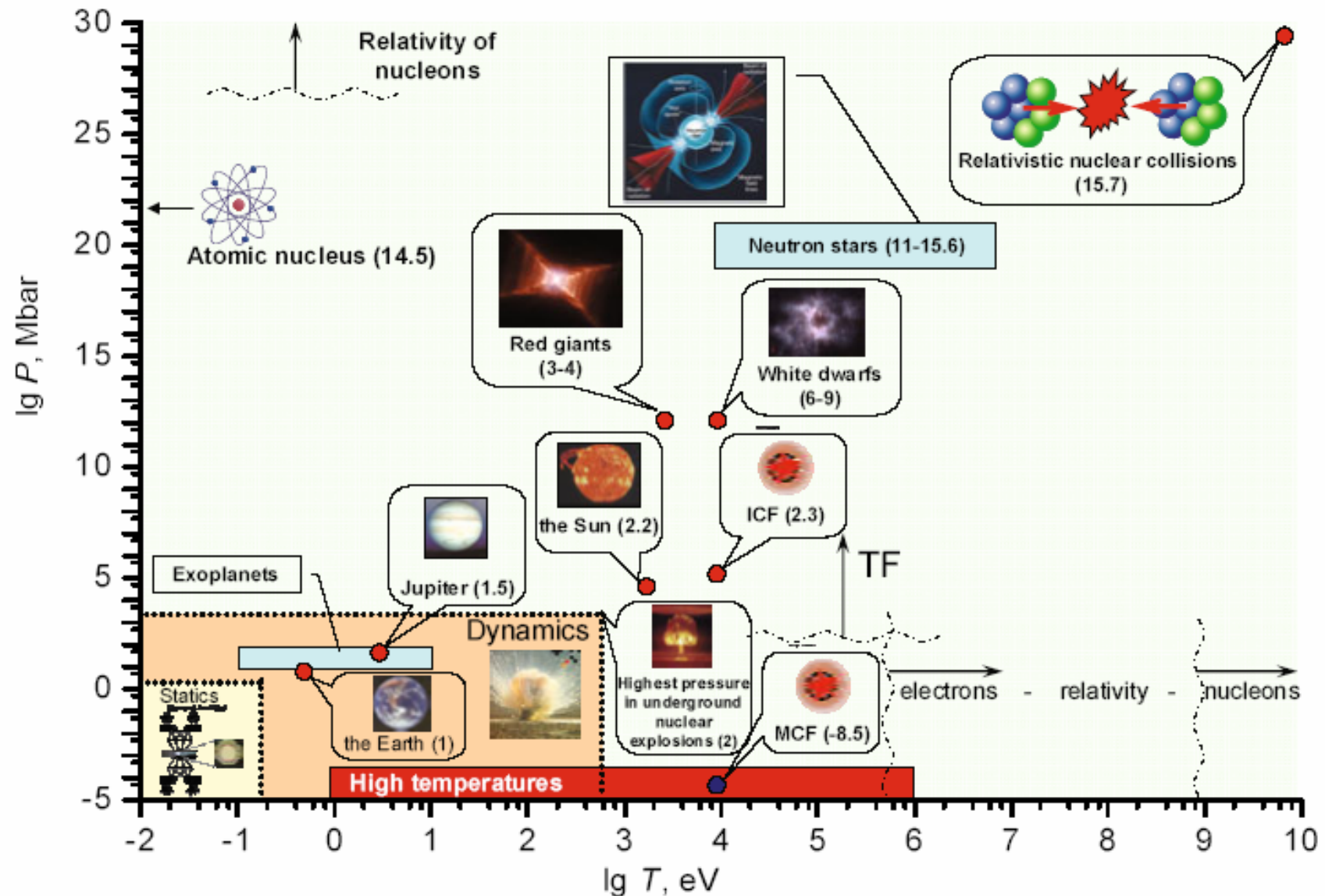
Parameters at extreme conditions

Object	T [K]	ρ [g/cc]	P [bar]
Intergalactic gas	$10^{-7} - 10^{-8}$	$10^{-30} - 10^{-3}$	$10^{-17} - 10^{-7}$
Earth centre	5×10^3	10 – 20	3.6×10^6
Jupiter centre	$(1.5-3) \times 10^4$	5 - 30	$(3-6) \times 10^7$
Diamond anvils	4×10^3	5-20	5×10^6
Shock waves	10^7	13-15	5×10^9
MCF (Fusion)	10^8	3×10^{-9}	50
ICF (Fusion)	10^8	150-200	1×10^{11}
Sun	1.5×10^7	150	10^{11}
Red giant	$(2-3) \times 10^7$	$10^3 - 10^4$	5×10^{12}
White dwarf	10^6	$10^6 - 10^9$	$10^{16} - 10^{22}$
Nuclear collision (Au)	$10^7 - 10^{14}$	10^{15}	10^{30}
Neutron stars Black holes	$10^8 - 10^{11}$	$10^{14} - 10^{16}$	$10^{25} - 10^{27}$
Early universe	10^{32}	10^{94}	10^{106}

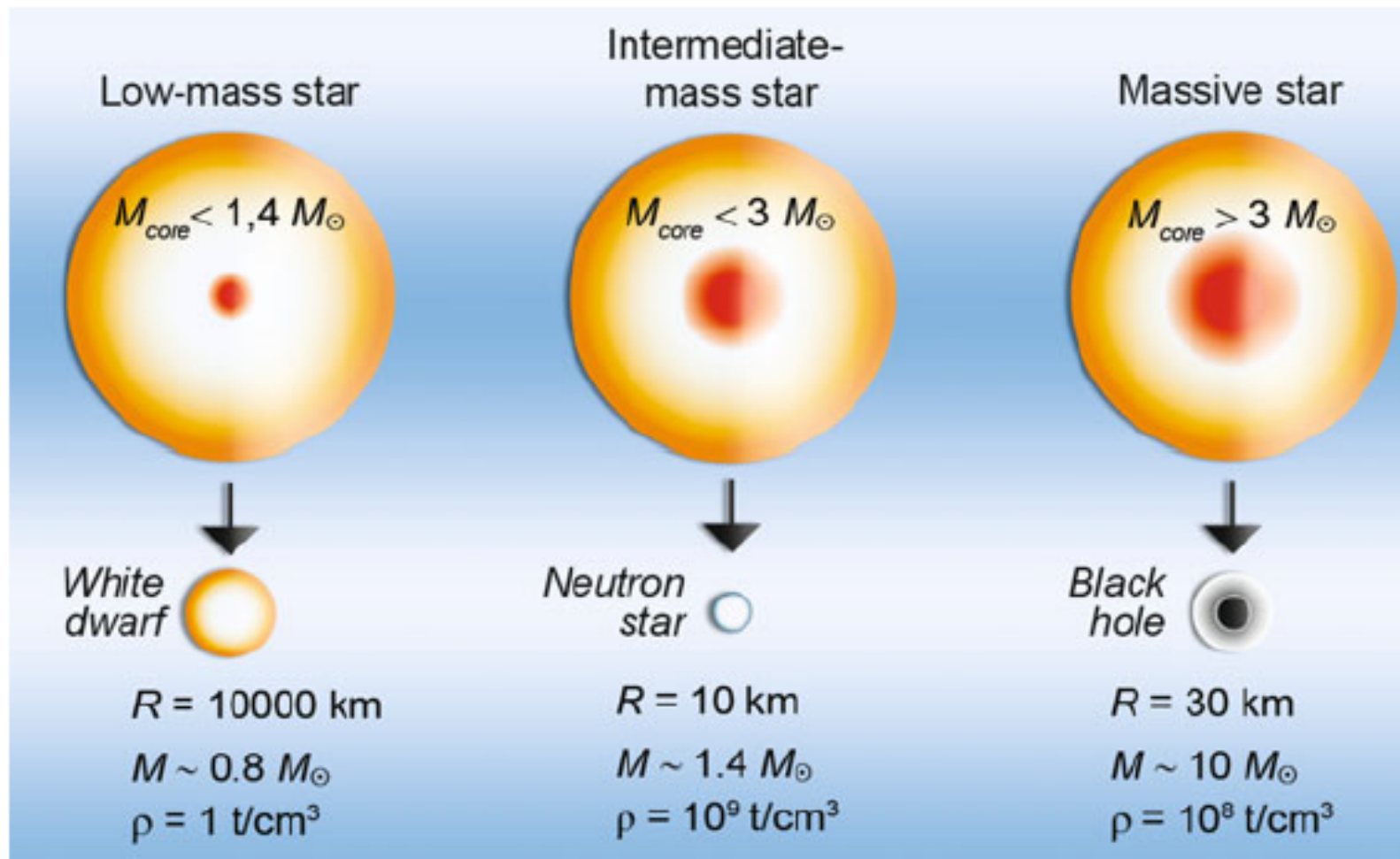
Matter phase diagram



Matter at extreme conditions



Neutron stars, Black holes

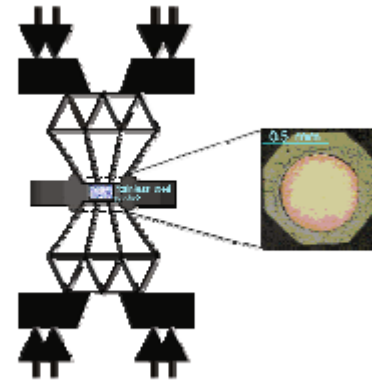
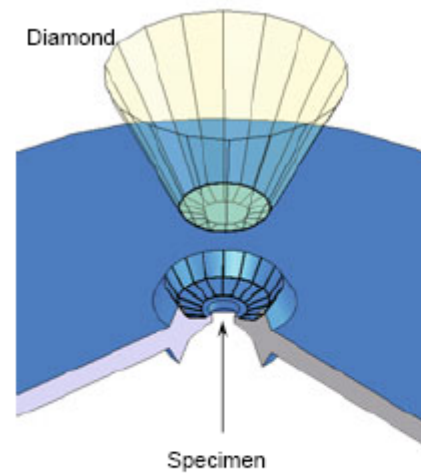
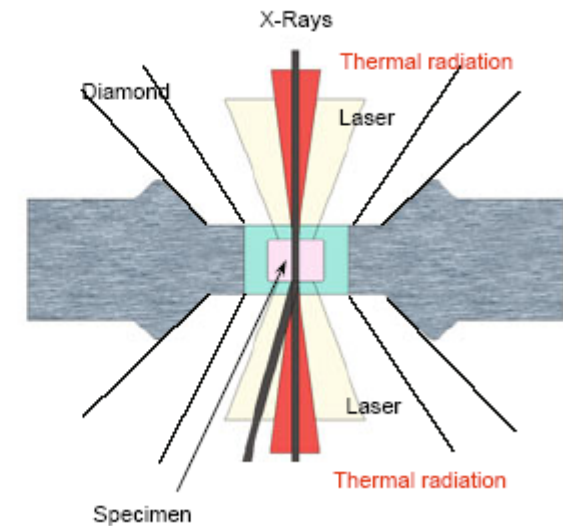


Laboratory experiments



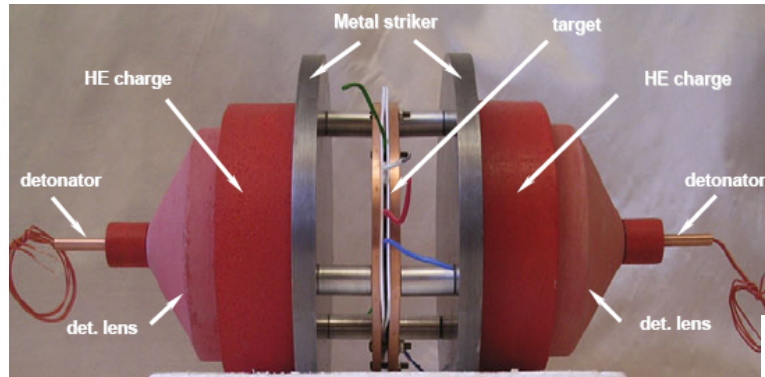
Maximum pressure ≤ 3 Mbar

Compression scheme



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Dynamic experiments



EXPLOSIVE LOADING, GUNS

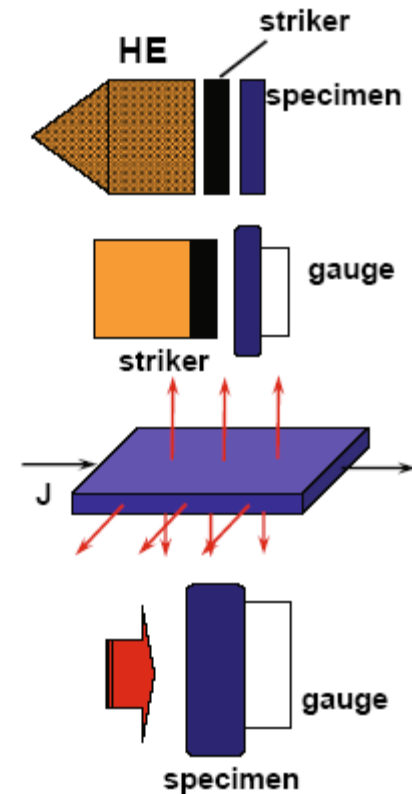
plane-wave lens
explosion-driven flyer plates
cumulation
propellant guns
light gas guns
rail guns

ELECTRIC

cylinders }
foils } + cover

RADIATION

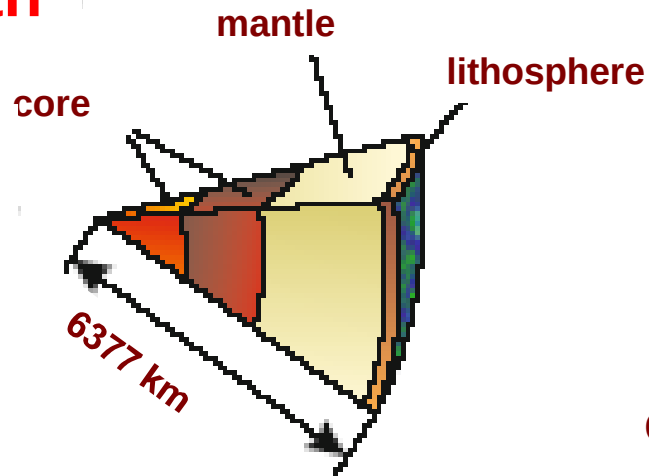
ion, laser beams
electron beams
nuclear explosions
soft X-rays



Planetary interiors

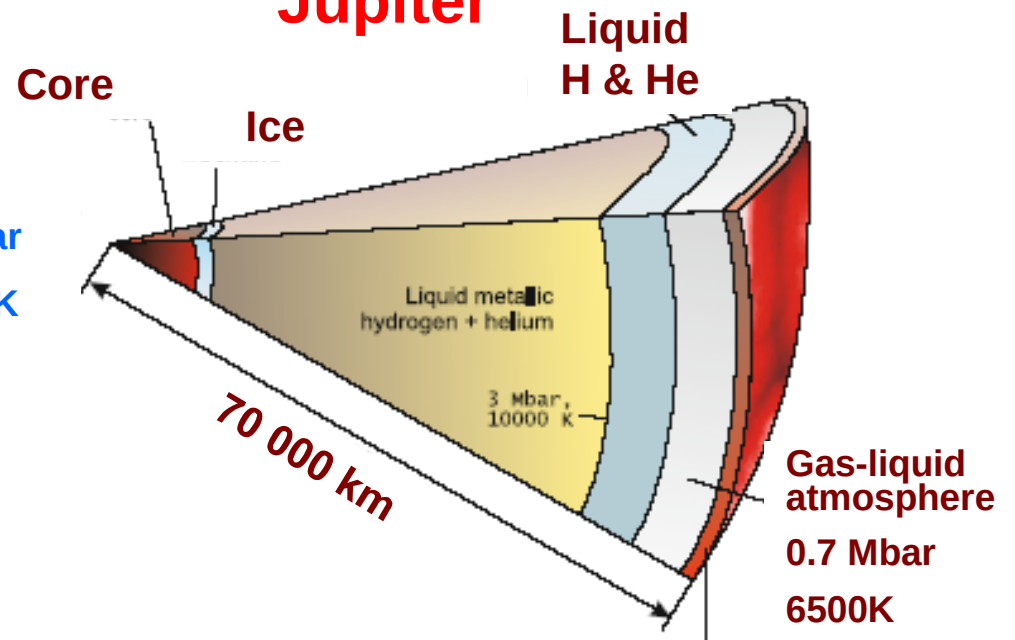
The Earth

At centre
 $P=4 \text{ Mbar}$
 $T=6000\text{K}$
 $\rho=13\text{g/cc}$

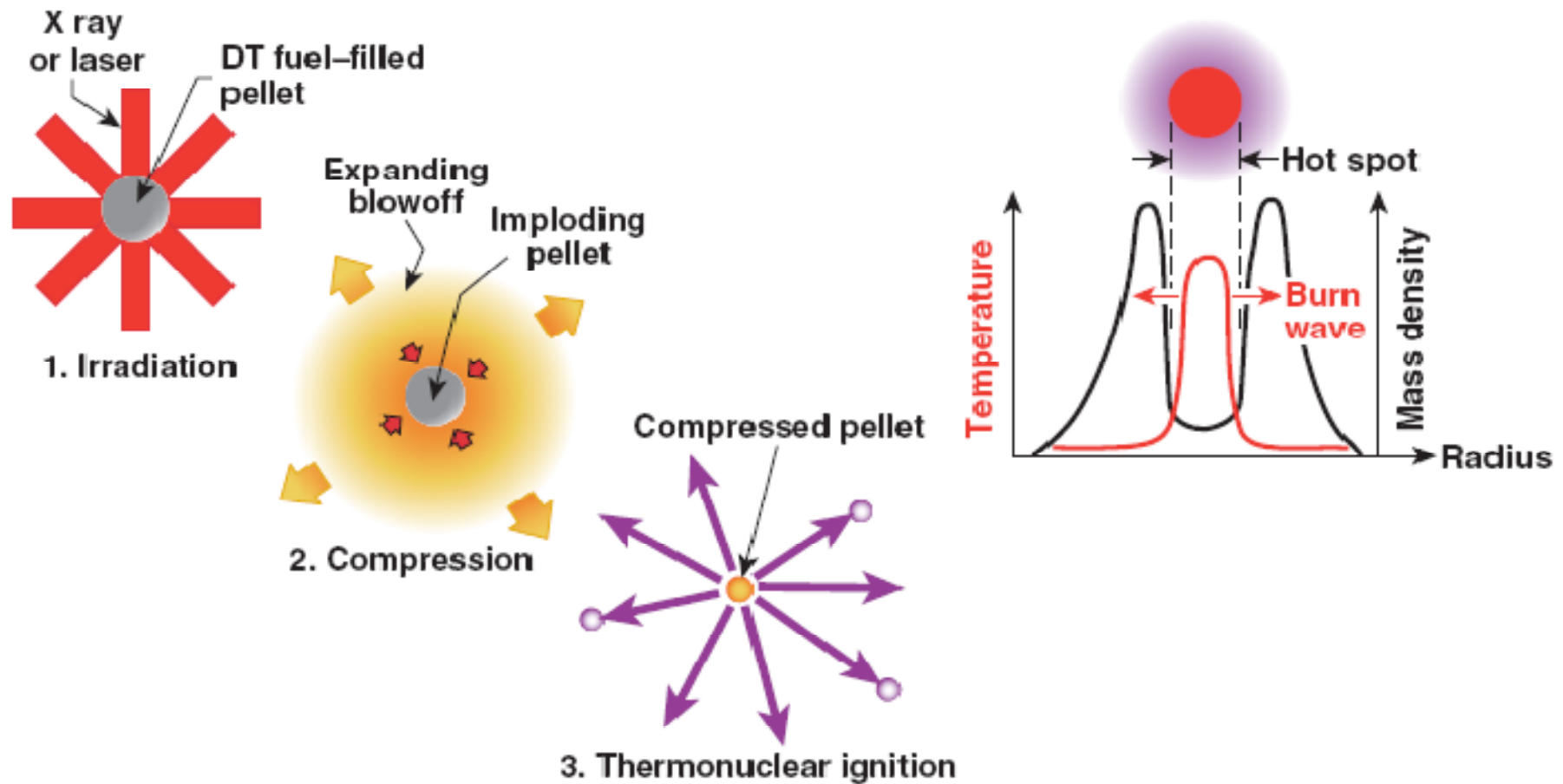


Jupiter

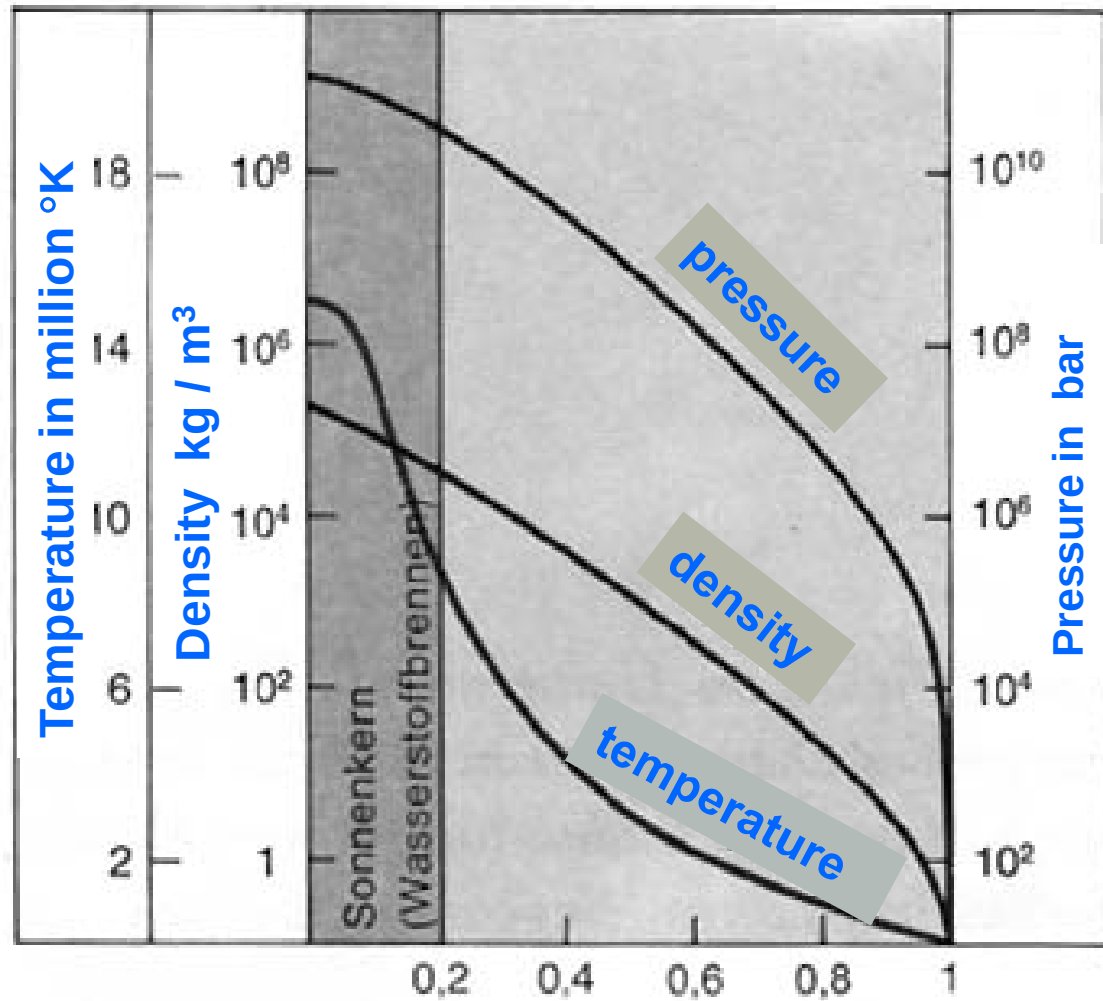
$P=70 \text{ Mbar}$
 $T=20\,000\text{K}$
 $\rho=23\text{g/cc}$



Extreme pressures are generated in fusion

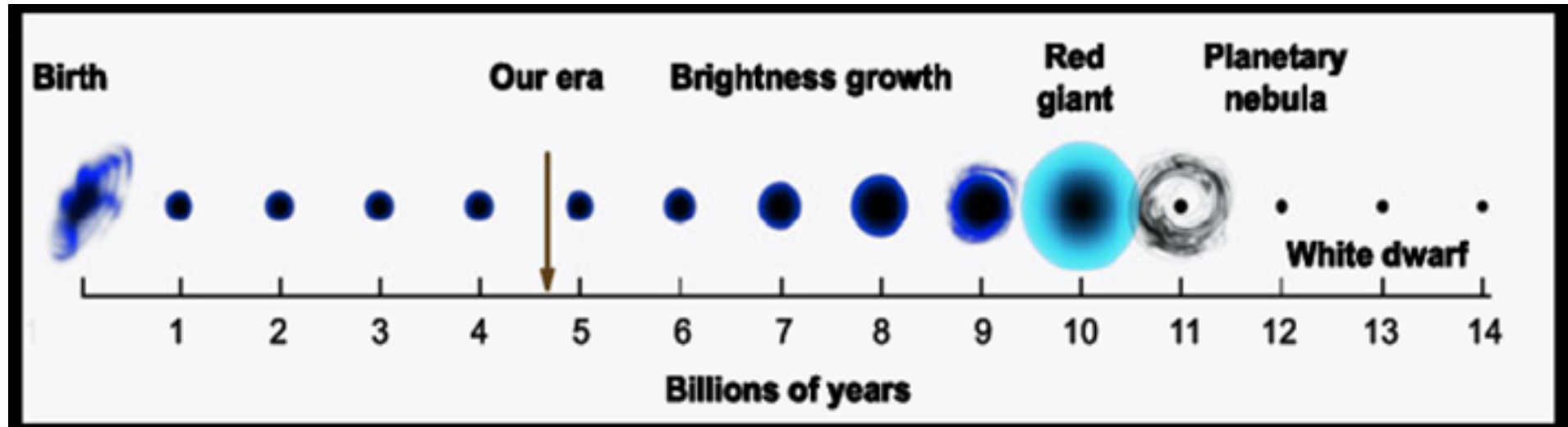


Temperature in Sun



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Solar evolution



Star Life time $\sim 10 \text{ billion years} \times (M^* / M)^3$

Extreme States of Matter (Springer 2011)

Vladimir E. Fortov

Russian Academy of Sciences

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Thank You

07/04/2011