Nuclear Magics
at Explosive Magnetization

NN 2015

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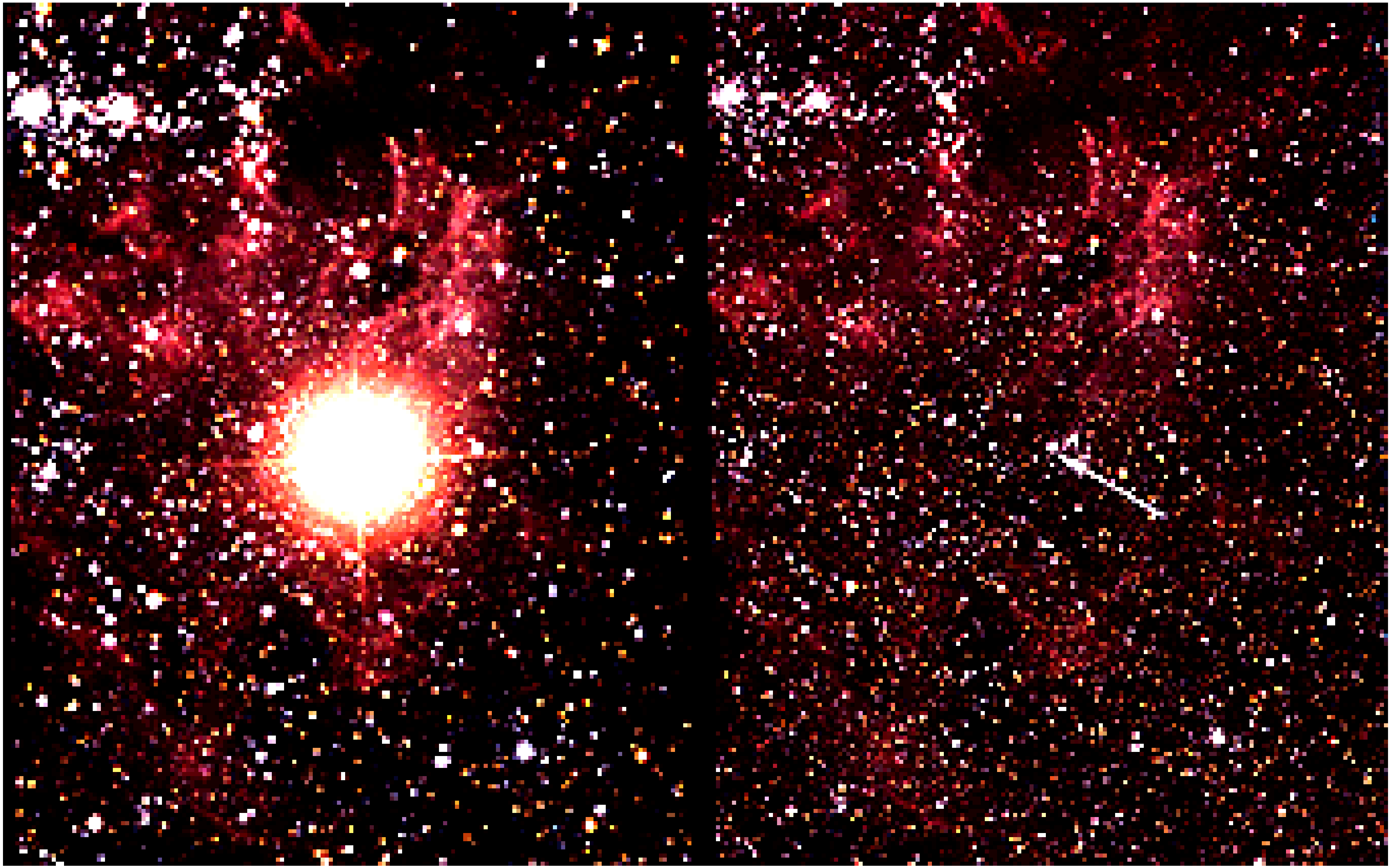
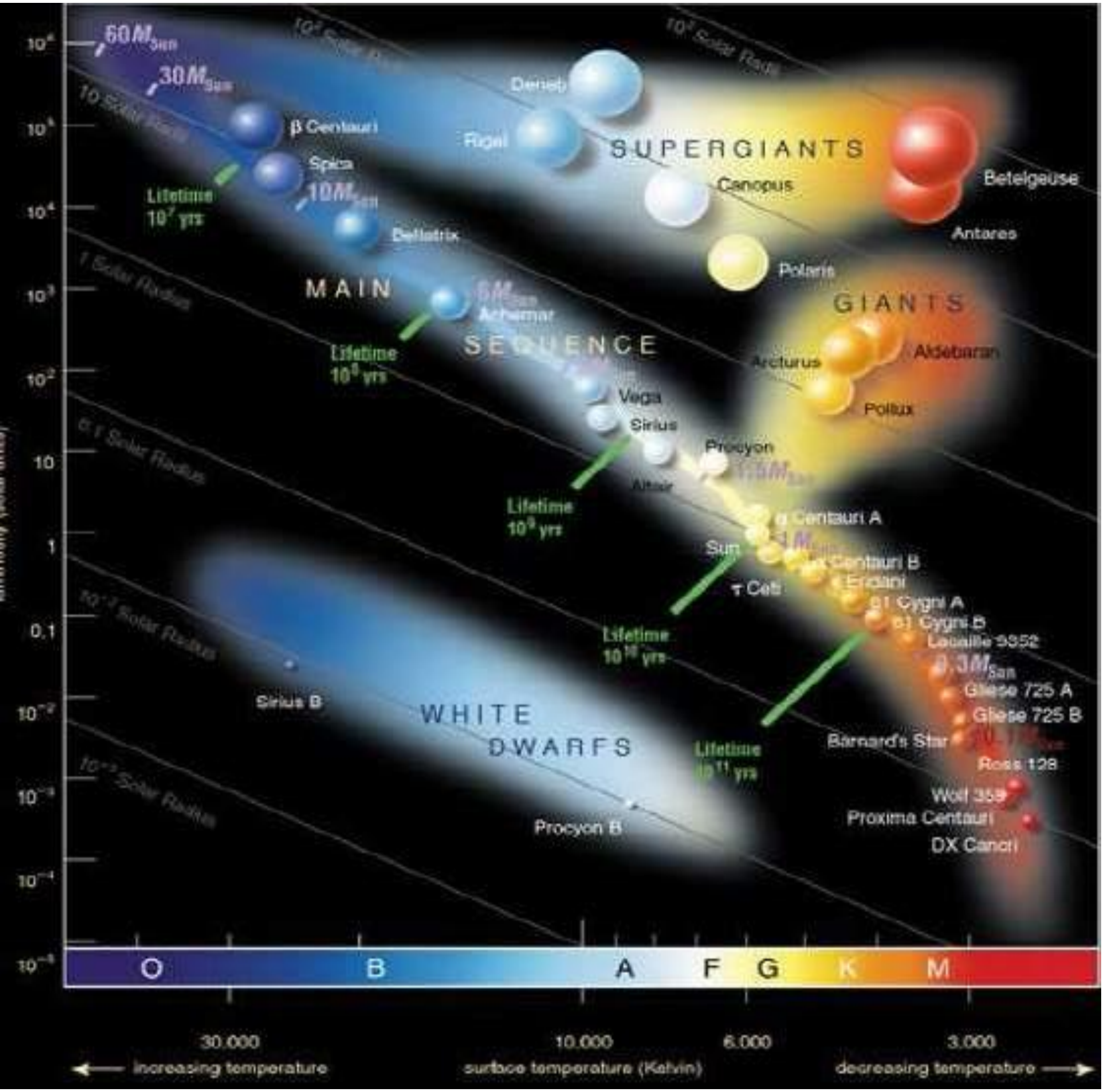
Before and after pictures of SN1987a



Hertzsprung- Russell (H-R) diagram



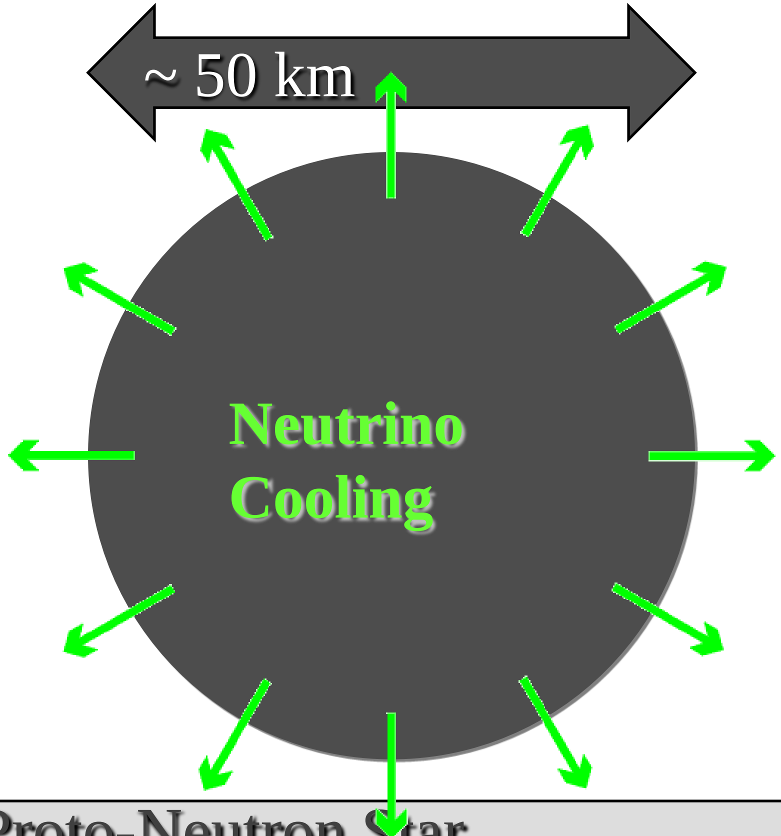
Stefan-Boltzmann
Law for flux

luminosity L
of a star with
radius R **&**
surface temperature T

L~(Surface)T^4~R^{2}T^4

Stellar Collapse and Supernova Explosion

Newborn Neutron Star



Proto-Neutron Star

$\rho \approx \rho_{nuc} = 3 \times 10^{14}\ \mathrm{g\ cm^{-3}}$

$T \approx 1\ \mathrm{MeV}$

Gravitational binding energy

$E_b \approx 10^{53,5}\ \mathrm{erg} \approx 20\%\ M_{SUN}\, c^2$

This is distributed as

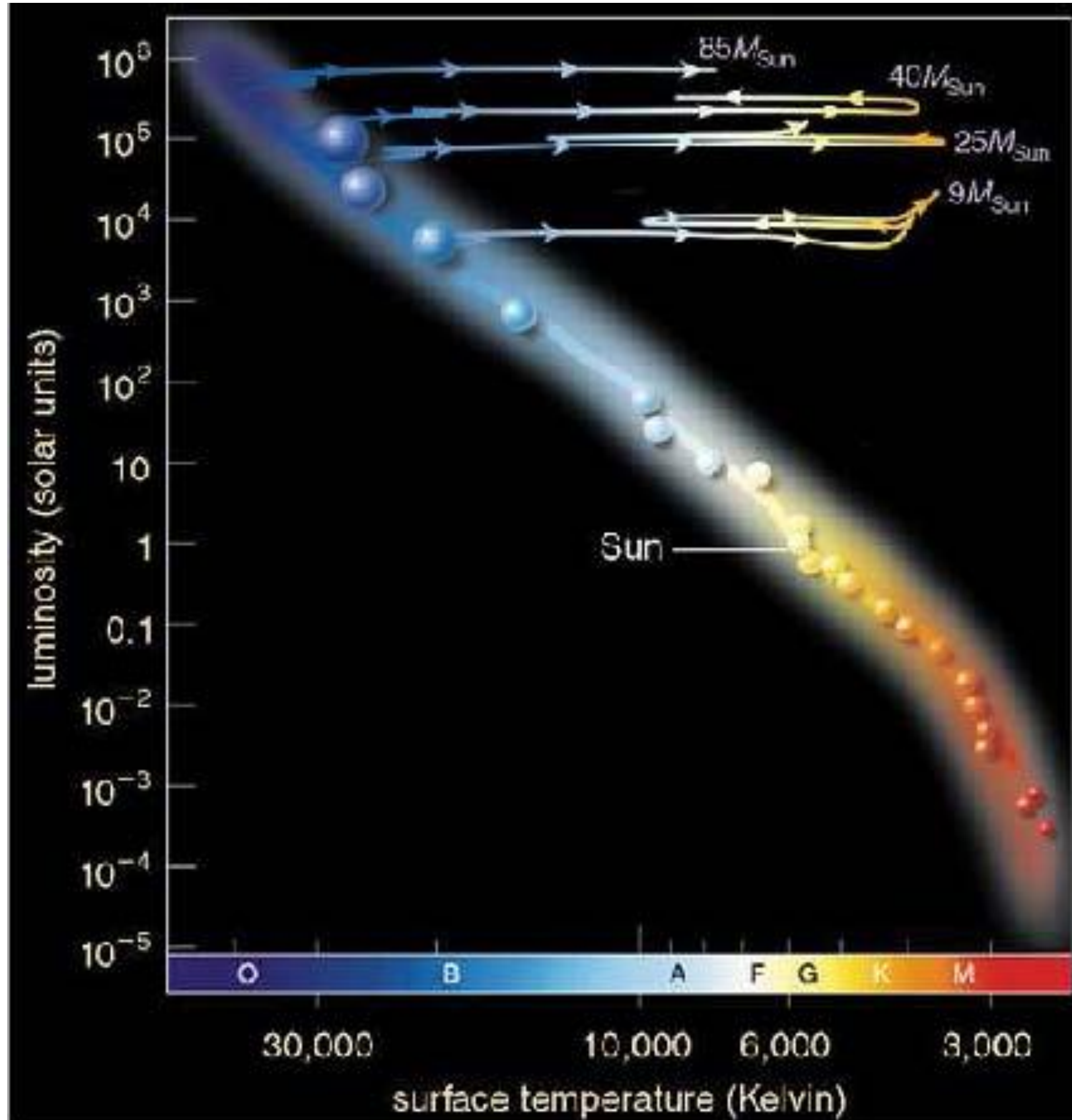
99% Neutrinos

1% Kinetic energy of explosion
(1% of this into cosmic rays)

0.01% Photons, outshine host galaxy

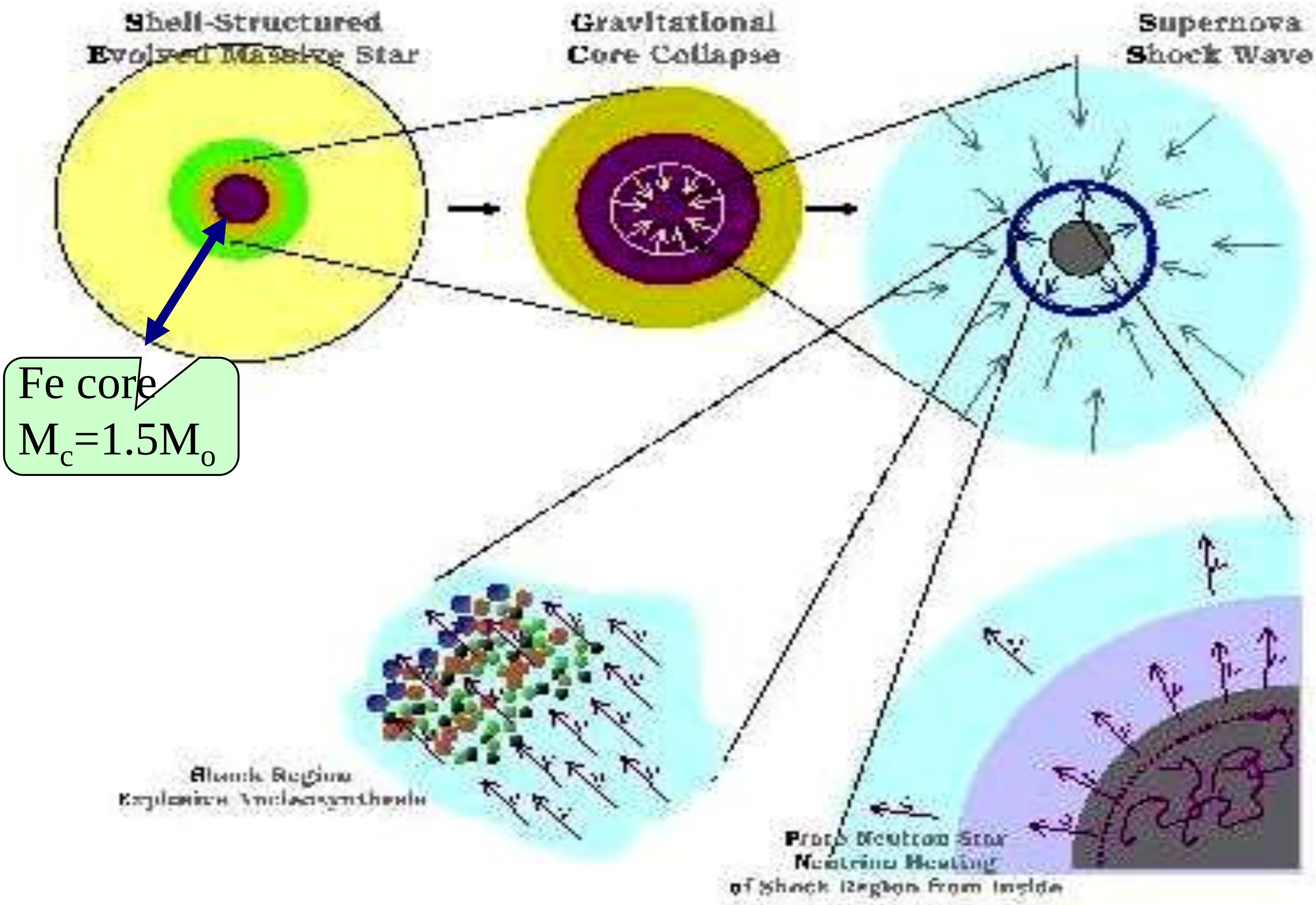
Core-collapse supernova

high-mass($M>8M_o$)star
***Evolution* on HR diagram**

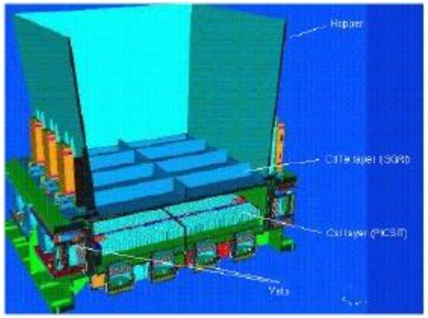


explosive
nucleosynthesis
origin of
Heavy Nuclides

Explosive nucleosynthesis

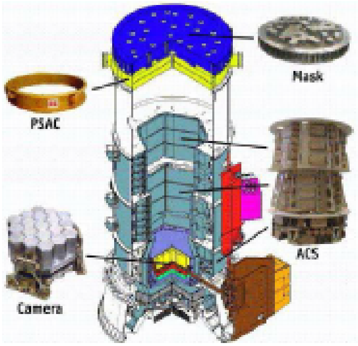


INTEGRAL
VIRGO.UA



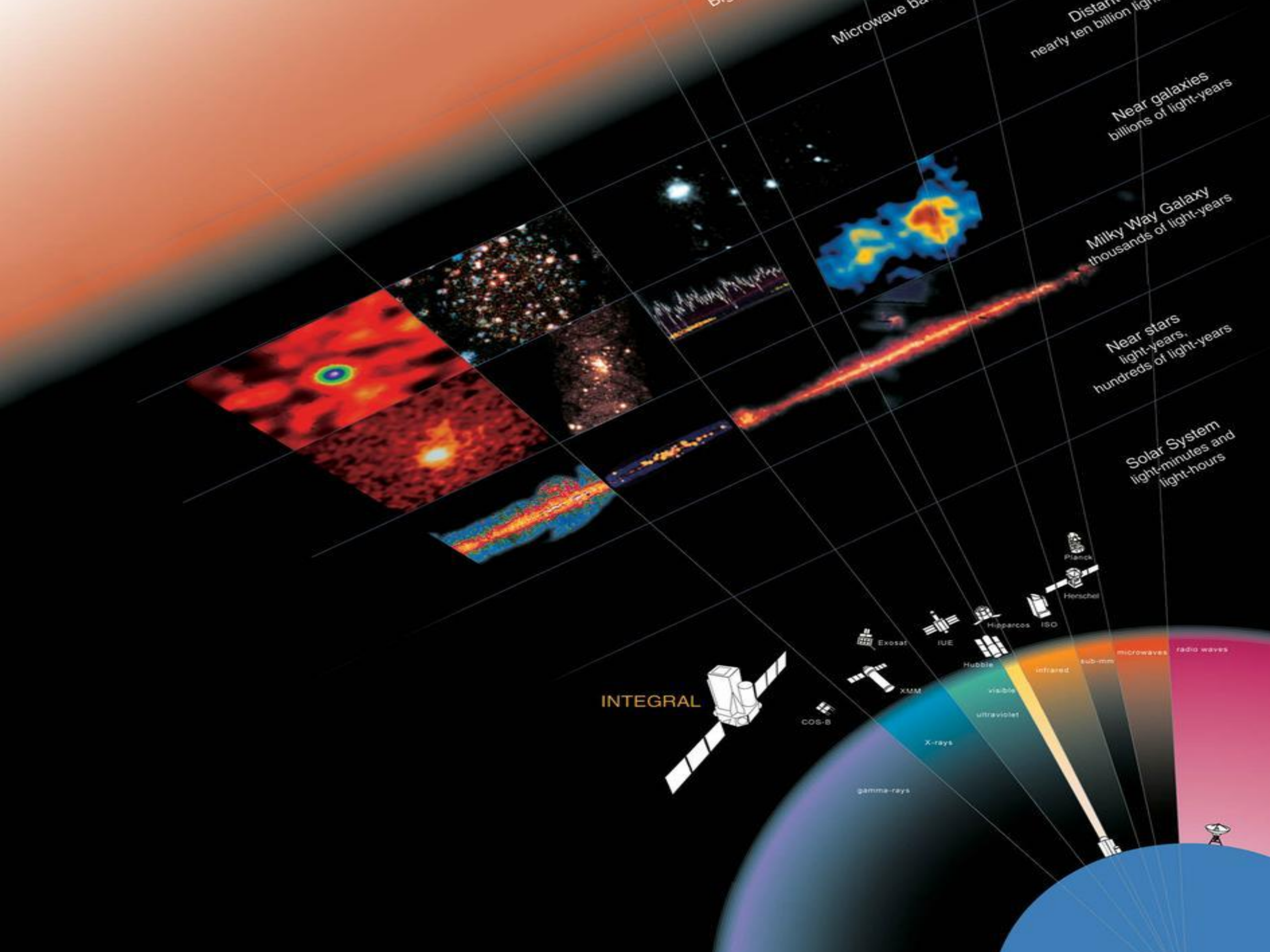
IBIS/ISGRI

Energy range	20 keV – 1 MeV
Energy resolution (FWHM)	7% at 100 keV
Detector area	960 cm2 at 50 keV

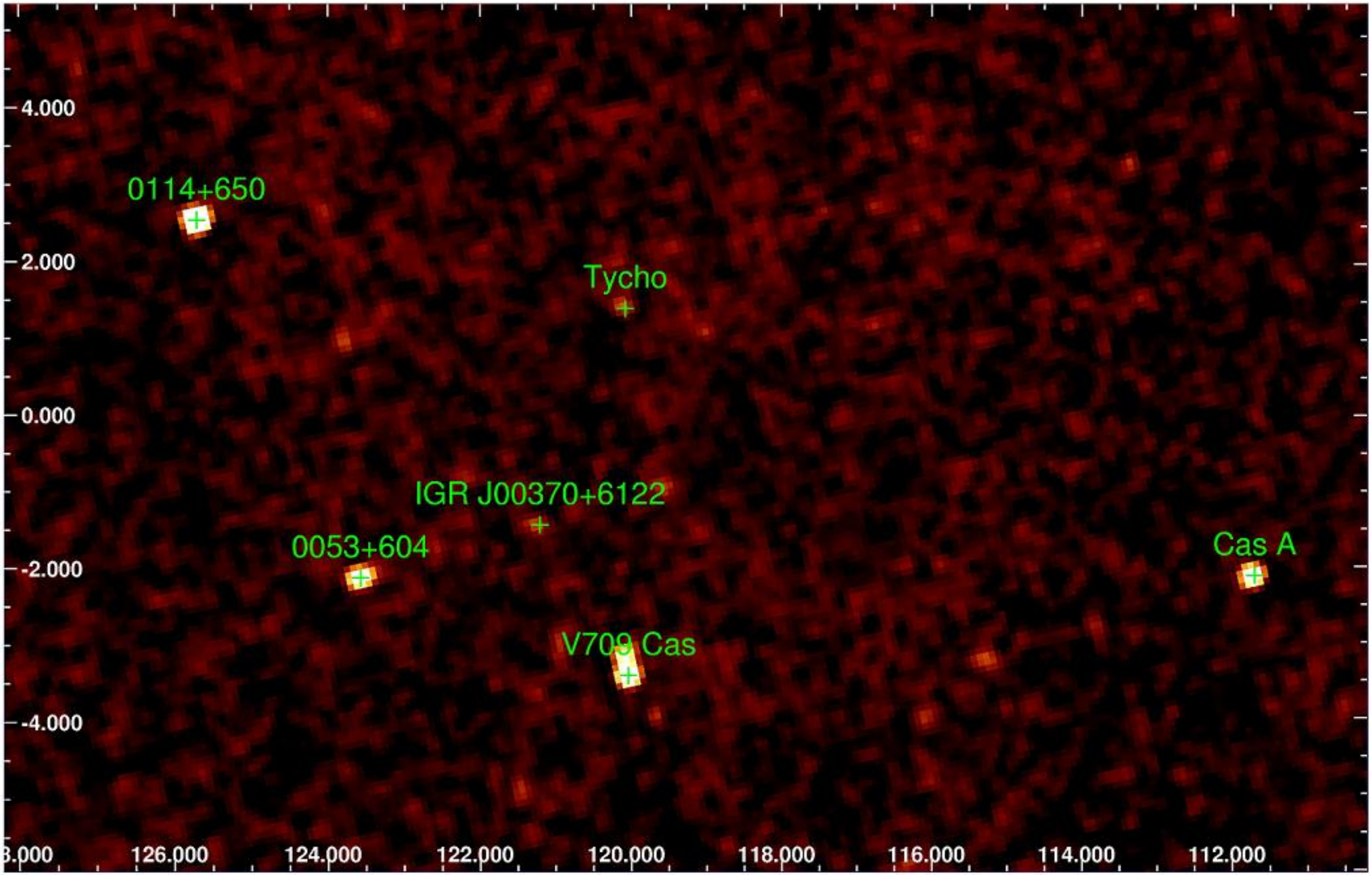


SPI

Energy range	20 keV – 8 MeV
Energy resolution (FWHM)	2.35 keV at 1.33 MeV
Detector area	~ 500 cm^2


Near galaxies
billions of light-years
Milky Way Galaxy
thousands of light-years
Near stars
light-years,
hundreds of light-years
Solar System
light-minutes and
light-hours
Planck
Herschel
Hipparcos
ISO
Exosat
IUE
Hubble
XMM
INTEGRAL
COS-B
radio waves
microwaves
sub-mm
infrared
visible
ultraviolet
X-rays
gamma-rays

CAS A(3.4+0.3-0.1)kpc, TYCHO(2.2+/-0.3)kpc



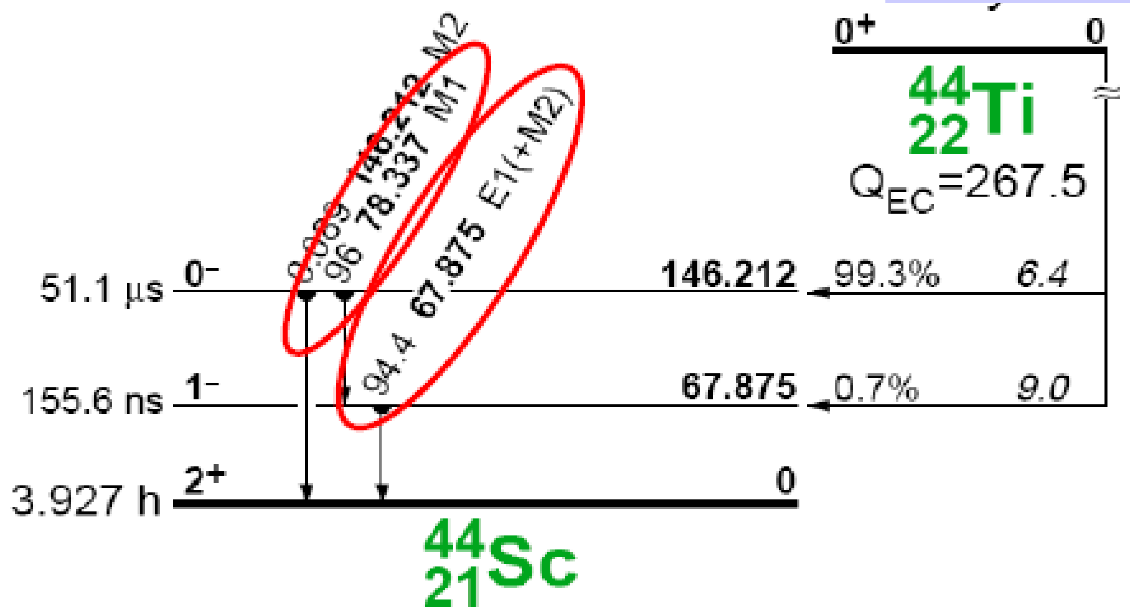
Investigated Supernovas

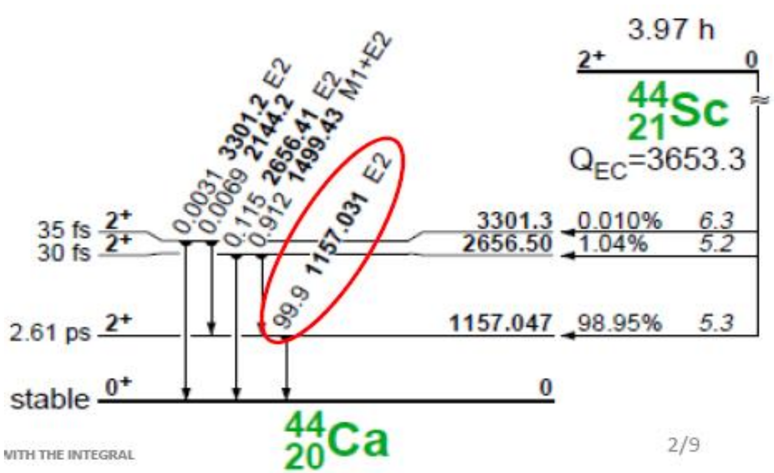
Name	Coordinate	Age
SN 1987A	**-** 279.7 -31.9,	**28 y**
Cas A	**-** 111.7 -2.1,	**330 y**
TYCHO	**-** 120.1 +1.4,	**440 y**
Vela Junior	**-** 266.3 -1.2	**?**

The scheme of the ^{44}Ti decay

Earth environment

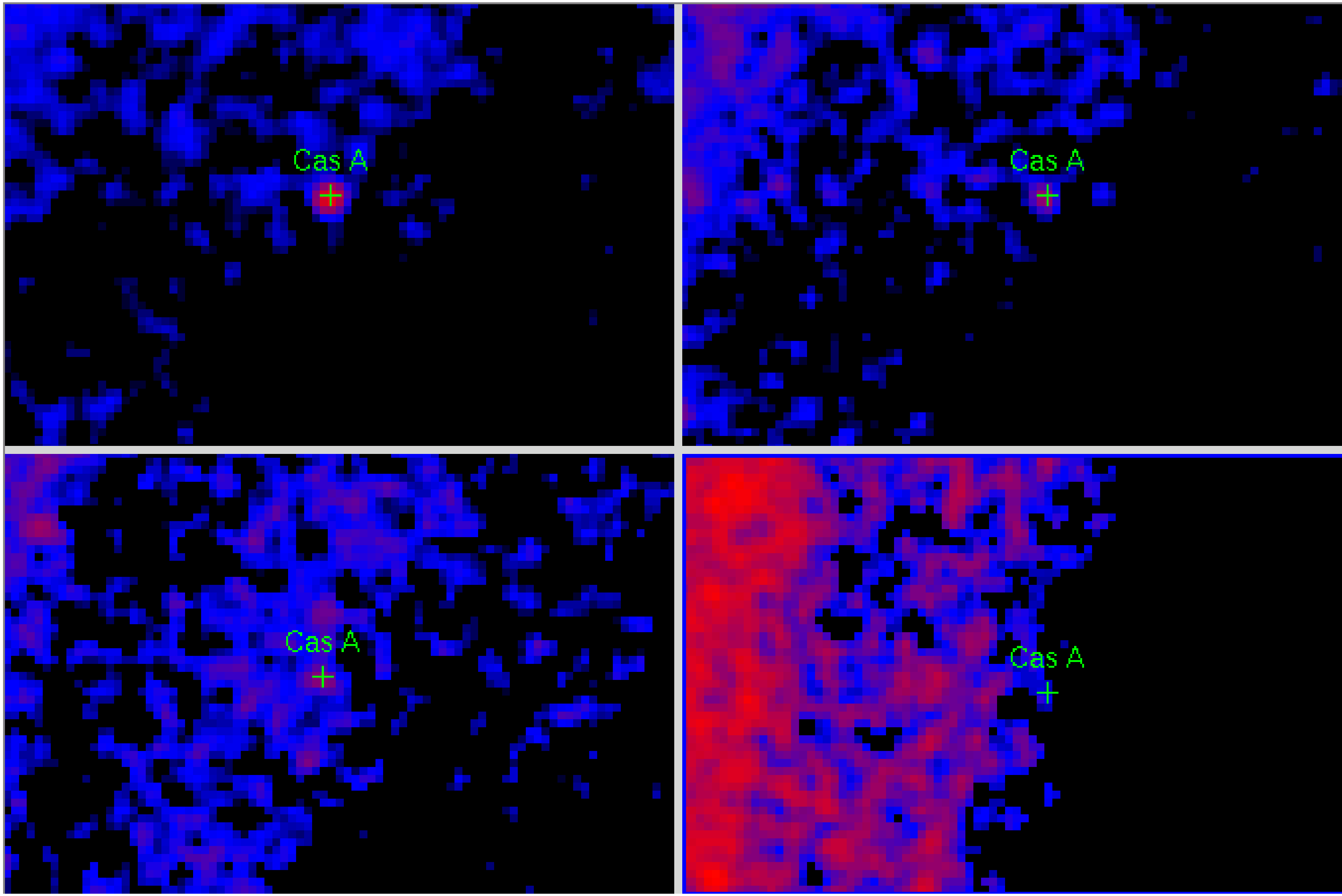
59 y

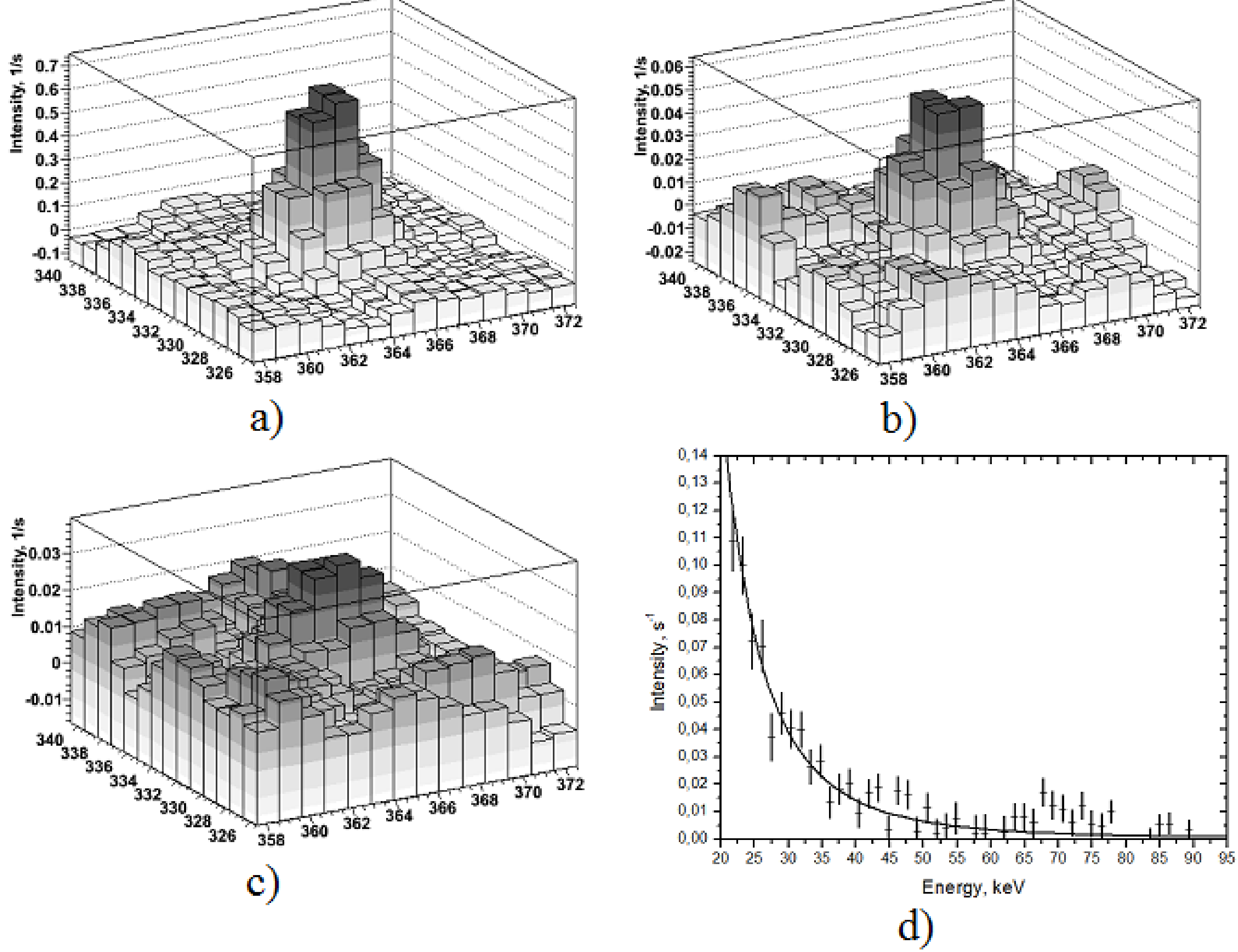




Cassiopeia A (3.4+0.3-0.1)kpc

Energy range (keV): **20-62-72-82-100**



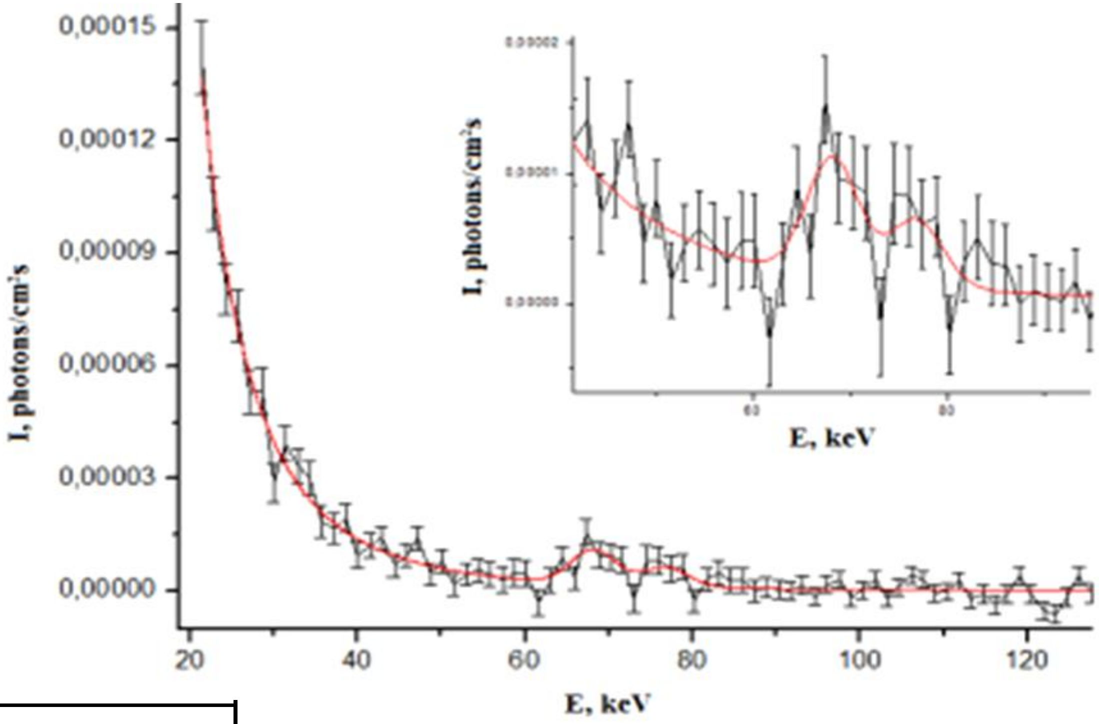


F The direction (i.e.. pixel number) dependence of the registered gamma-ray flux at different energy ranges: **20–62 keV - a, 62–72 keV - b, 72–82 keV – c**; for the angle region containing the Cassiopeia A SN remnant. The right bottom panel (d) represents the spectrum from the Cassiopeia A in the energy range 20–95 keV, the solid line shows the fit with the power law energy *E* dependence, .

Background estimate + Lines

$K \cdot E^a$

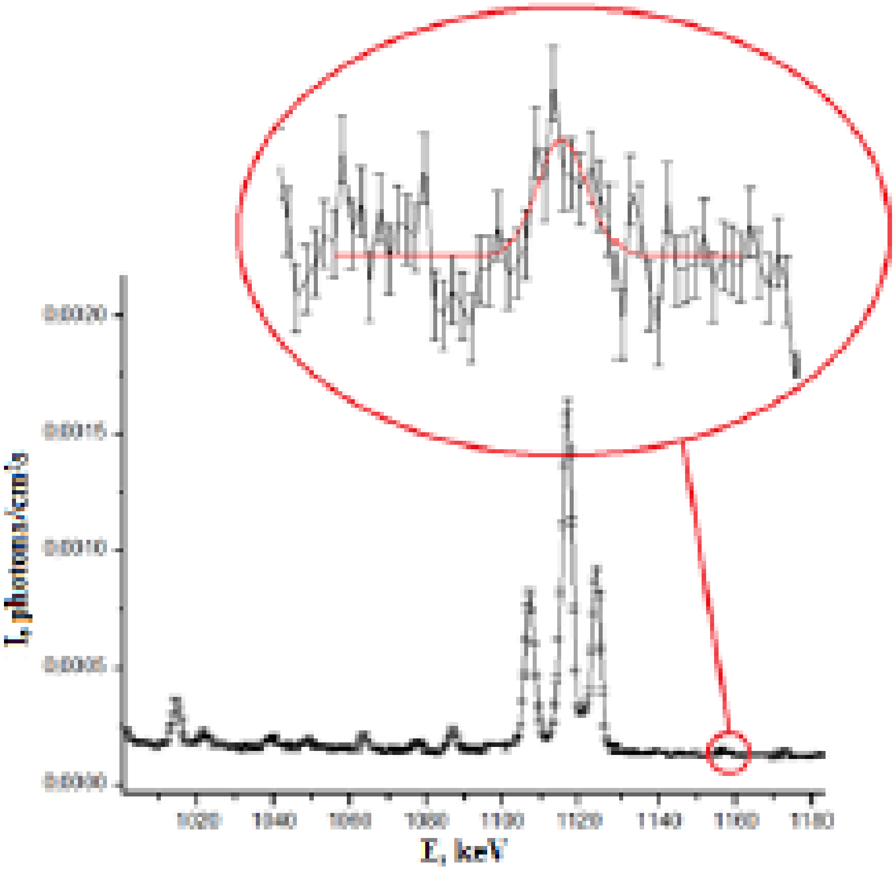
a=-3.64 +/- 0.09



E, keV	I ± ΔI, photons/(cm²s)
67.9	$(6.0 \pm 1.0)\cdot 10^{-5}$
78.3	$(4.0 \pm 1.0)\cdot 10^{-5}$

T= 1.5Ms

SPI detector data



Fit results

$$E = 1157.20 \pm 0.26\ keV$$

$$FWHM = 3.1 \pm 0.7\ keV$$

Flux=(5.1+/-1.0) 10^{-5}ph/cm^2 s

T=1.5 Ms

mass of ^{44}Ti synthesized at Cassiopeia A explosion [VNK et al *'Nucleus2004'; PhAN (2009)*]

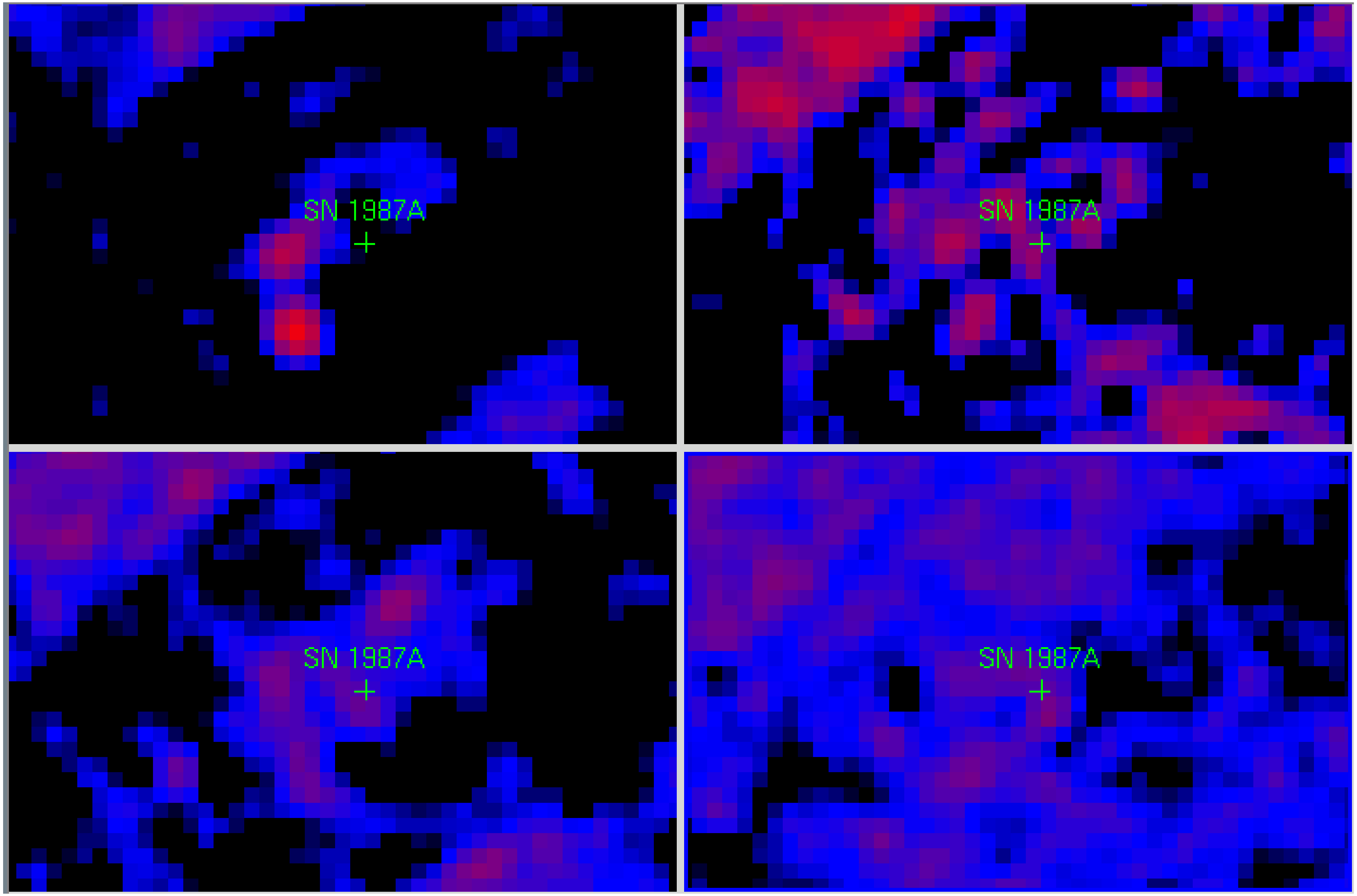
$$m = \frac{4\pi R^2 \cdot T_{1/2} \cdot M \cdot I}{\ln 2 \cdot N_a \cdot p} \cdot 2^{-\frac{t}{T_{1/2}}}$$

R–distance to the object,$T_{1/2}$–the element half-life, N_a–theAvogadro constant,M–mola rmass,I–γ-quanta flux,p-quantum yield, t–remnant age.

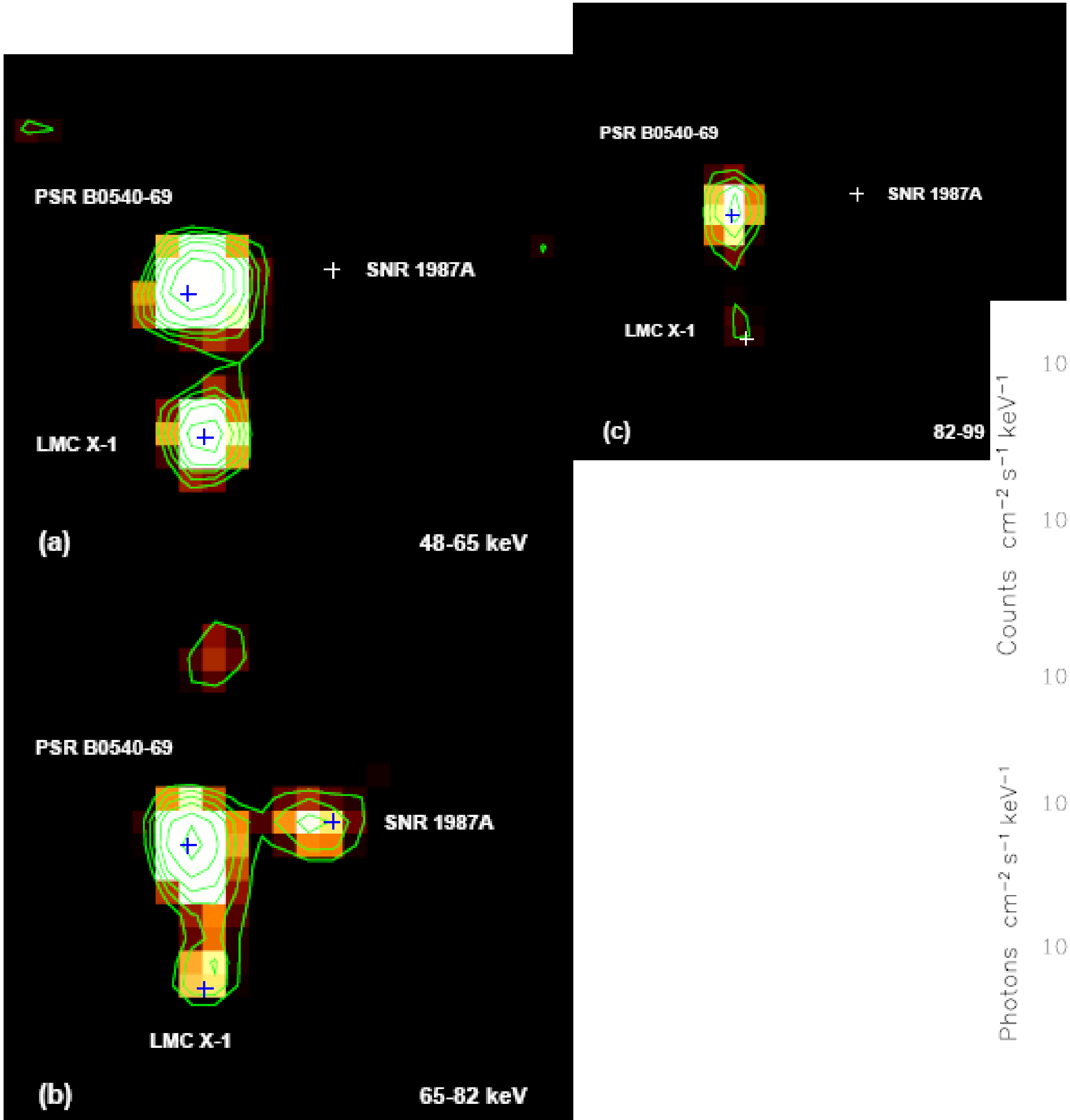
E, keV	$I \pm \Delta I$, 10^{-5} photons/cm^{2}s	$m \pm \Delta m$, 10^{-4} $M_\odot$
67.9 keV	6.0 ± 1.0	4.0 ± 0.7
78.3 keV	4.0 ± 1.0	2.6 ± 0.7
1157.1 keV	5.1 ± 1.1	3.3 ± 0.7

SN1987 A (50kpc)

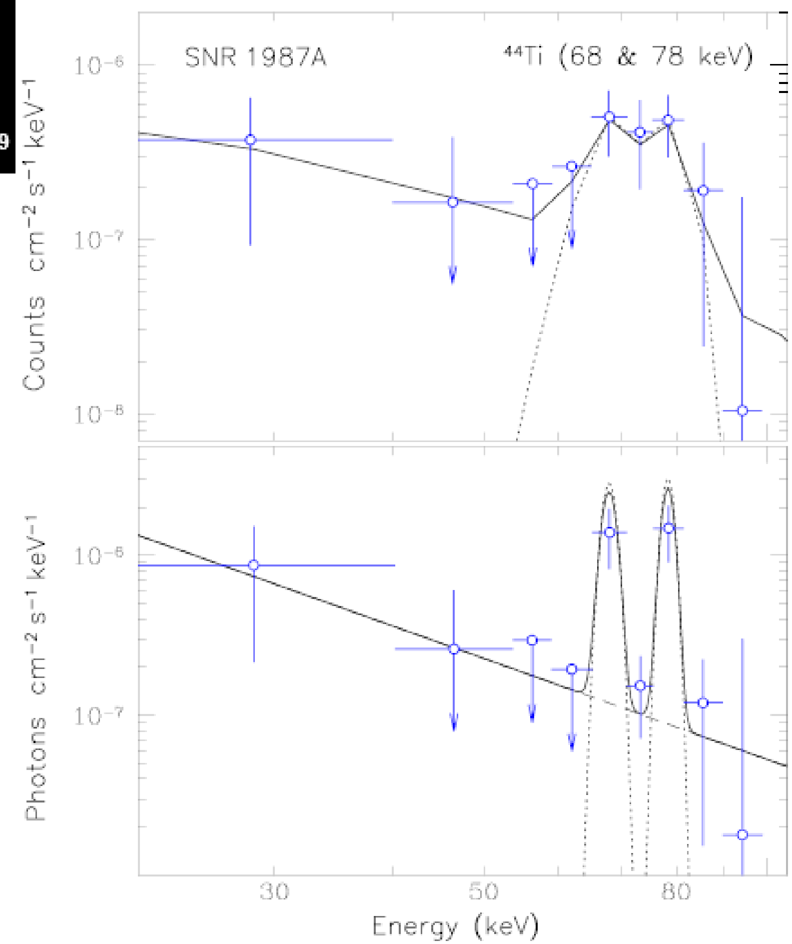
Energy range (keV): **20-62-72-82-100**



S.A.Grebenev et al *Nature*, *490*, *373-375 (2012)*.



$$(3.1 \pm 0.8) \times 10^{-4} \quad M_{\odot}$$



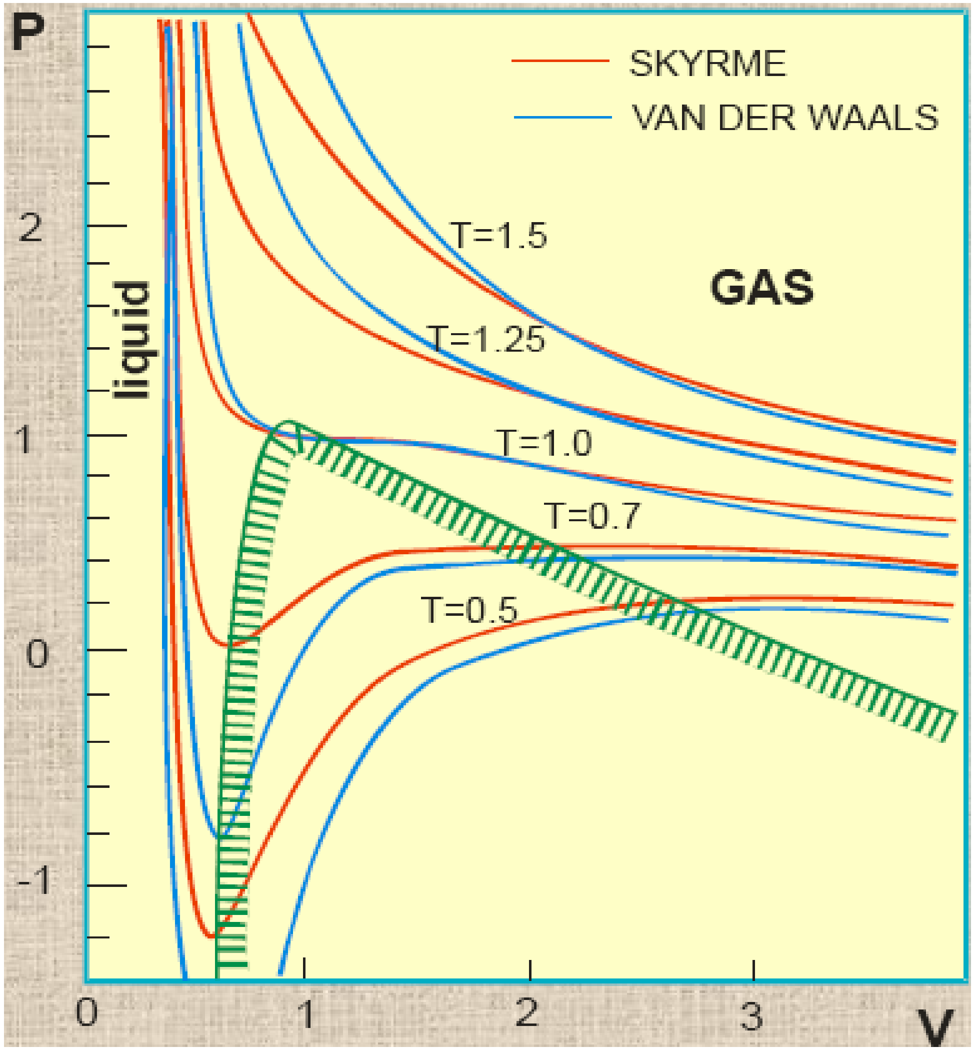
THEORY

$$(0.02 - 2.5) \times 10^{-4} \quad M_{\odot}$$

Thielemann, F.-K., Hashimoto, M. & Nomoto, K. Explosive nucleosynthesis in SN1987A. II. Composition, radioactivities, and the neutron star mass. *Astrophys. J.* ***349, 222–240 (1990)***

Woosley, S.E., & Hoffman, R. D. 57Co and 44Ti production in SN1987A. *Astrophys. J.*, ***368, L31-L34*** (1991).

State Equation (SE): Nuclear Matter *vs* Regular Liquid *(Noble Gas)*



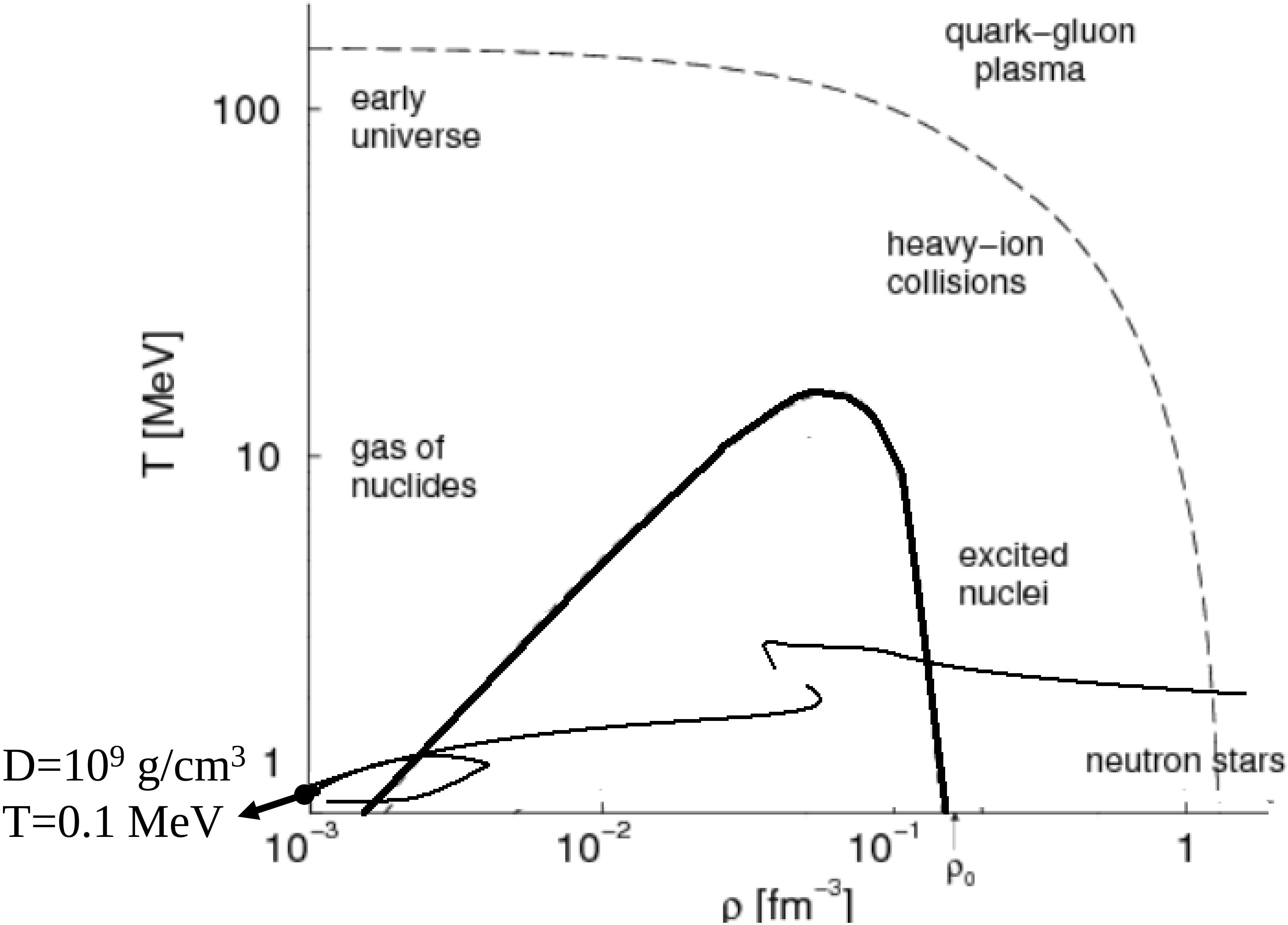
Van der Waals SE *(1875)*
& Nuclear Matter SE (1983)(relative units: ***V/Vc; p/pc ; T/Tc)***

Instability region

$$\partial p / \partial V \big|_T > 0$$

H. Jaqaman *et al*., Phys. Rev. C 27 (1983)2782

Symmetric nuclear matter: Phase diagram

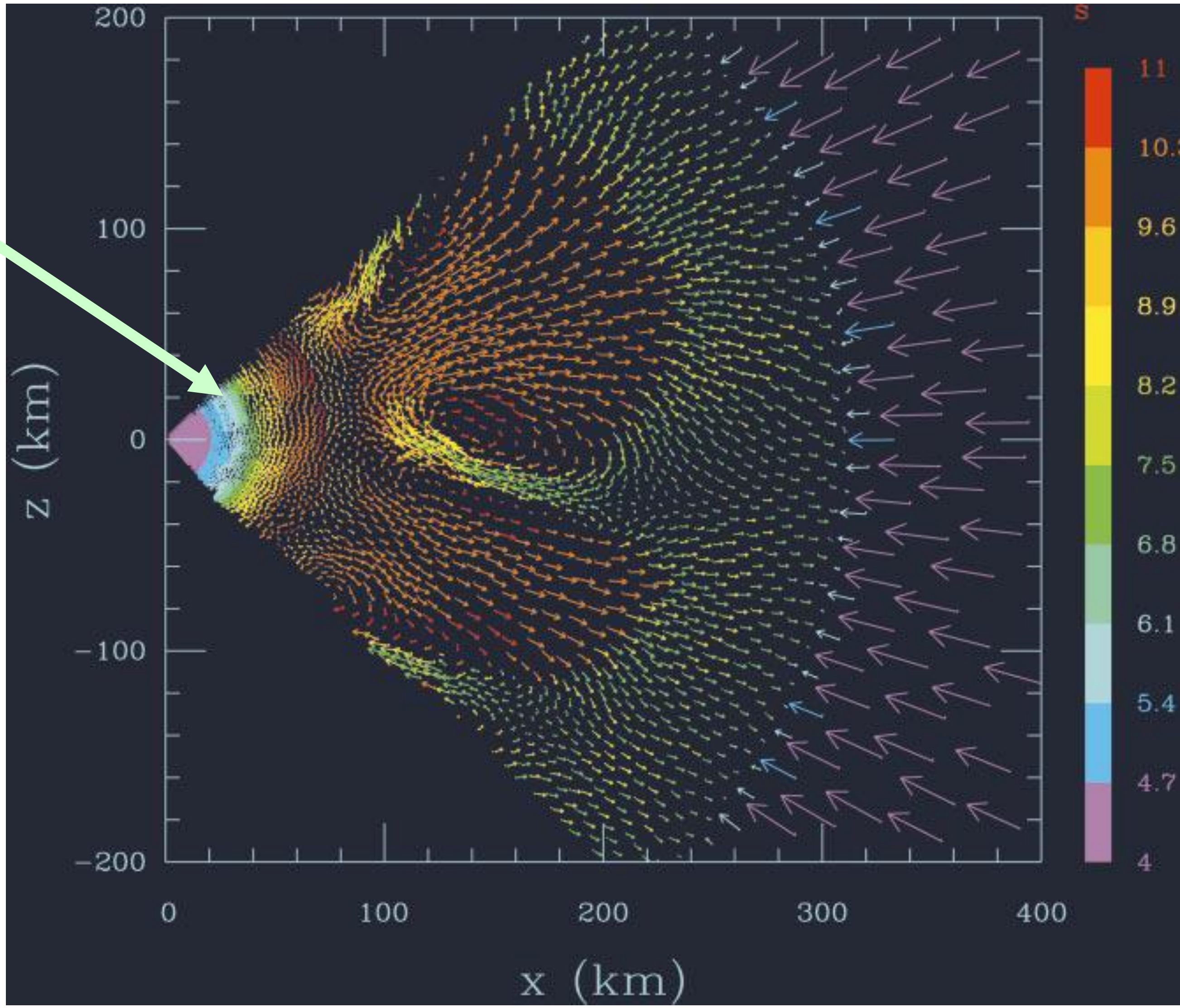


explosion proceeds through convection processes

ν-sphere

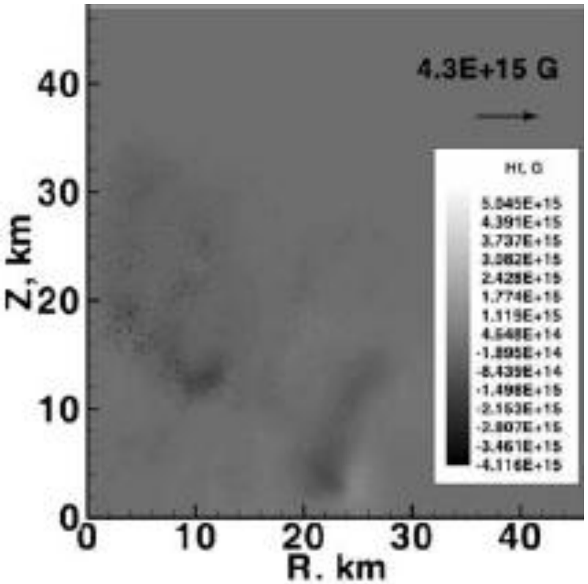
magneto-rotational instabilities & dynamo-action → amplifying

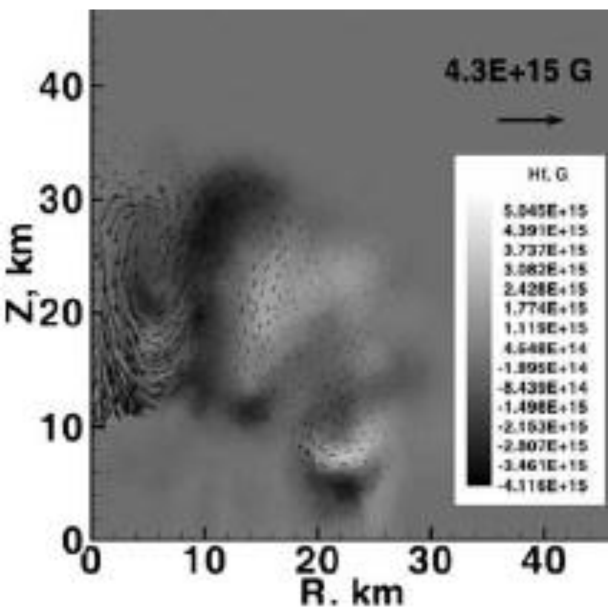
Magnetic fields up to strengths hundred *tera-tesla*

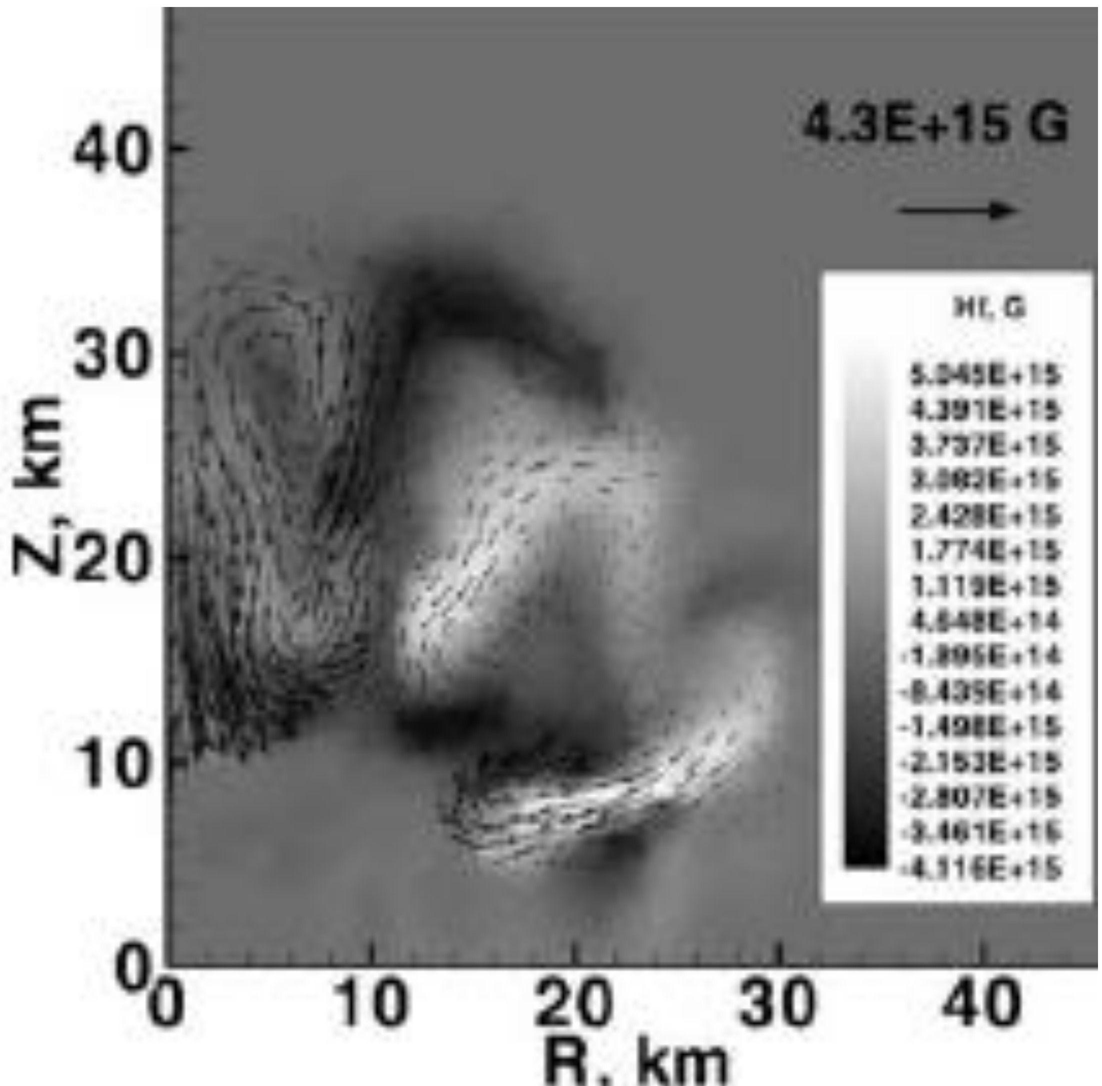


The magnetic field evaluation

(S.G.Moiseenko, G.S.Bisnovatyj-Kogan, N.V.Ardeljan, MNRAS 370 (2006) 501)







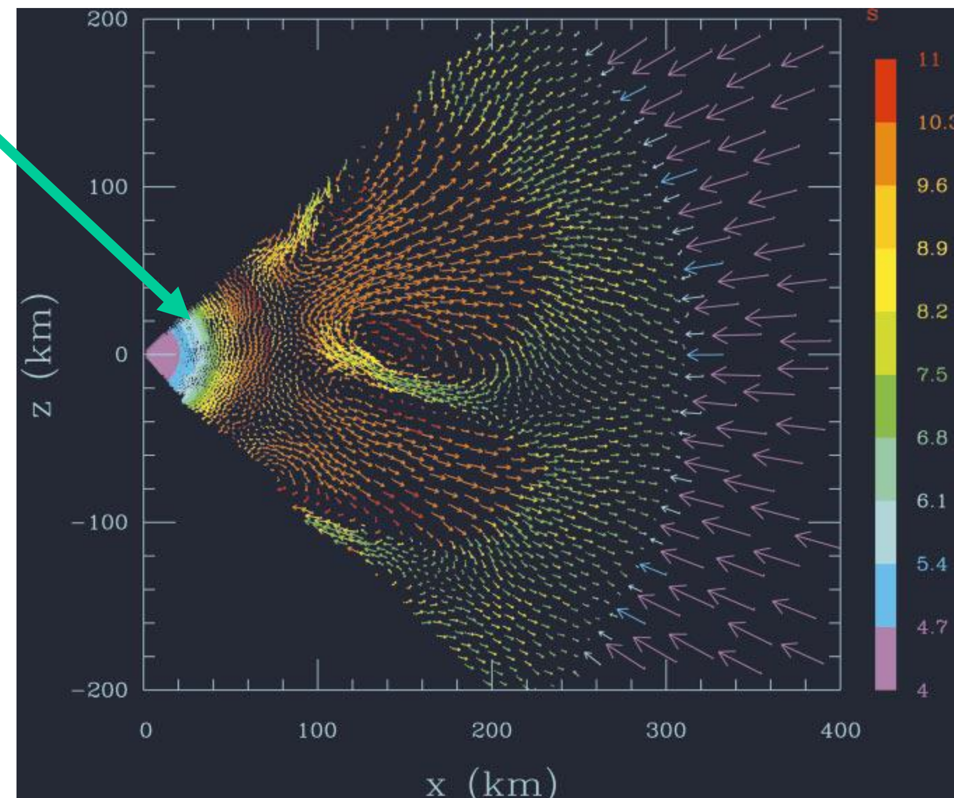
Magnetic field estimates

predominant energy component of shock wave E_S originates from the magnetic pressure

$$\langle B_\nu^2 \rangle R_\nu^2 \Delta R \sim 2 E_S \quad \sim 10^{51,5} \text{ ergs}$$

R_ν~ 40Km; 👎R~ 1Km

$B_\nu \sim 10^1 - 10^2$ TeraTesla



$$B(R) \sim B_\nu \quad R_\nu / R$$

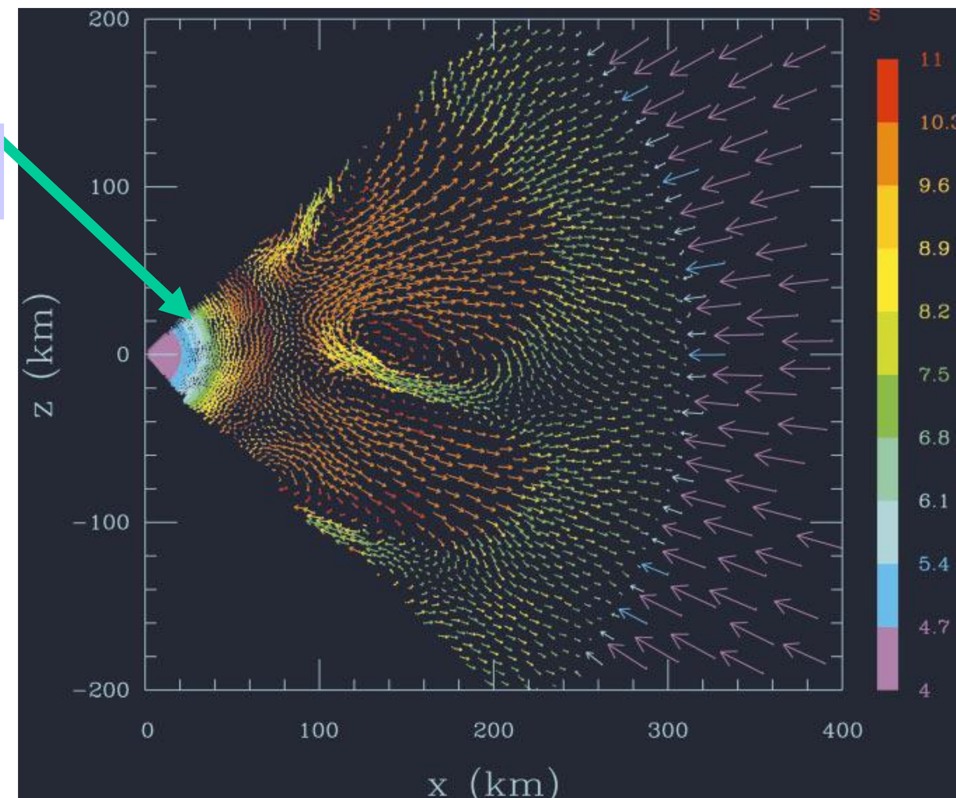
Magnetic field estimates

Magnetic and gravitational forces

$$dB_{\nu}^{2}/dR \sim 8\square\, GM\; n(R)/R^{2}$$

$$4\square R^{2}\, n(R) = dM/dR$$

$B \sim 10^{1.5}$ TeraTesla $(M/M_o)(10km/R)^2$

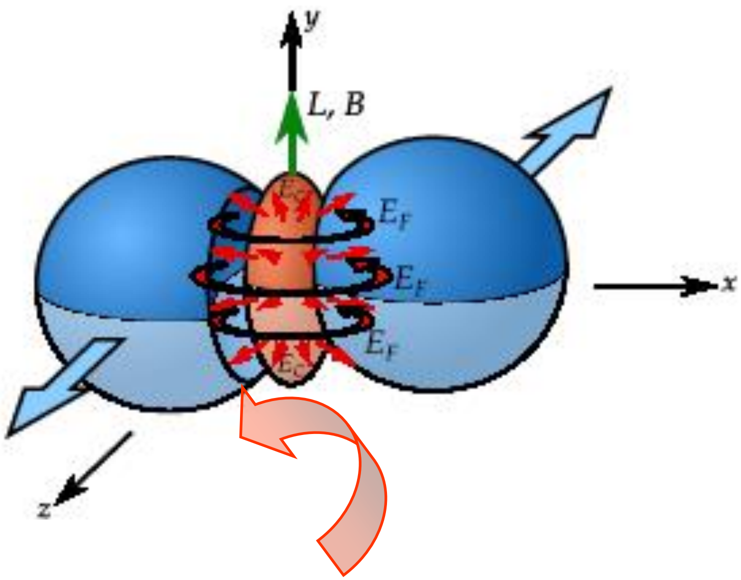


$R_{\nu} \sim 40$Km; 👎$R \sim 1$Km

$B_{\nu} \sim 10^1 - 10^2$ TeraTesla

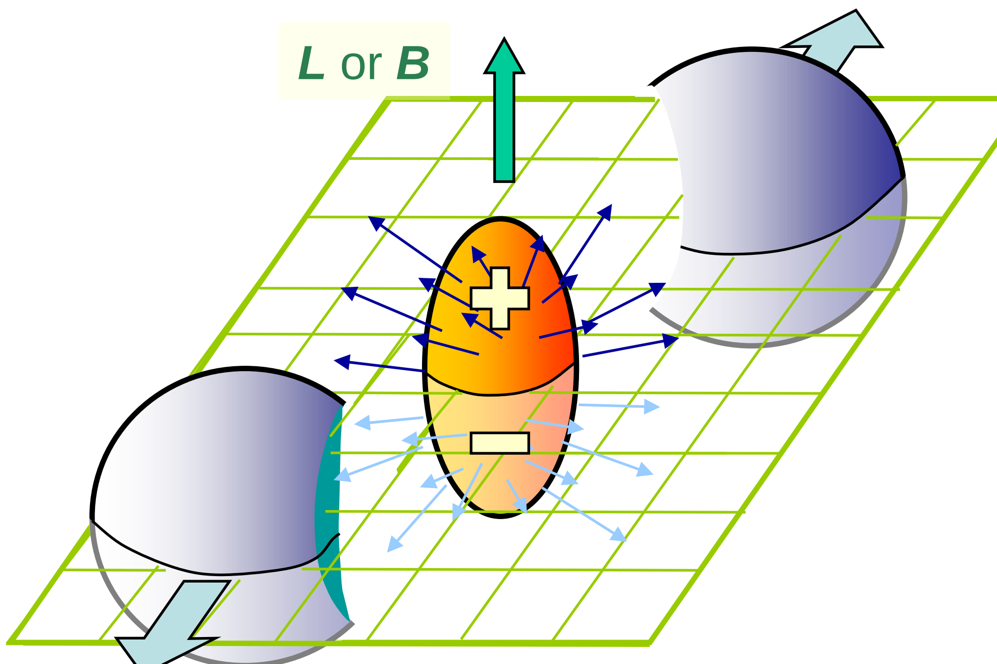
Magnetic fields in HIC

Magnetic field is induced through the axial anomaly



$B \sim 10^{1.5}$ TeraTesla $(E/E_o)^{1/2}$

Non-zero angular momentum
(or equivalently magnetic field)
in heavy-ion collisions



NUCLEAR STATISTICAL EQUILIBRIUM
in Ultra-Strong Magnetic Fields

Entropy *S* extremum →

Nuclear composition at temperature *T*

Binding Energy ***B***

spin-magnetic part in partition function

$$\omega_L = \mu_N H$$

Nuclear Shell Effects at *Ultra-Strong Magnetic Fields*

V.N.K. //PRL 2002. V.88, 221101 // J.Nucl.Sci.Technol. V.1 Sup.2. P.550 // J.Nucl.Radiochem.Sci. 2002. V.3. P.205 // PRC 2004 V.69, 038801/ЯФ. 2012

$$N = \int_{-\infty}^{\varepsilon_F} d\varepsilon \, \rho(\varepsilon)$$

Nucleons

Binding Energy

$$B = \int_{-\infty}^{\varepsilon_F} d\varepsilon \, \varepsilon \rho(\varepsilon) = B_{\mathrm{LDM}} + B^{\mathrm{sh}}$$

Level density

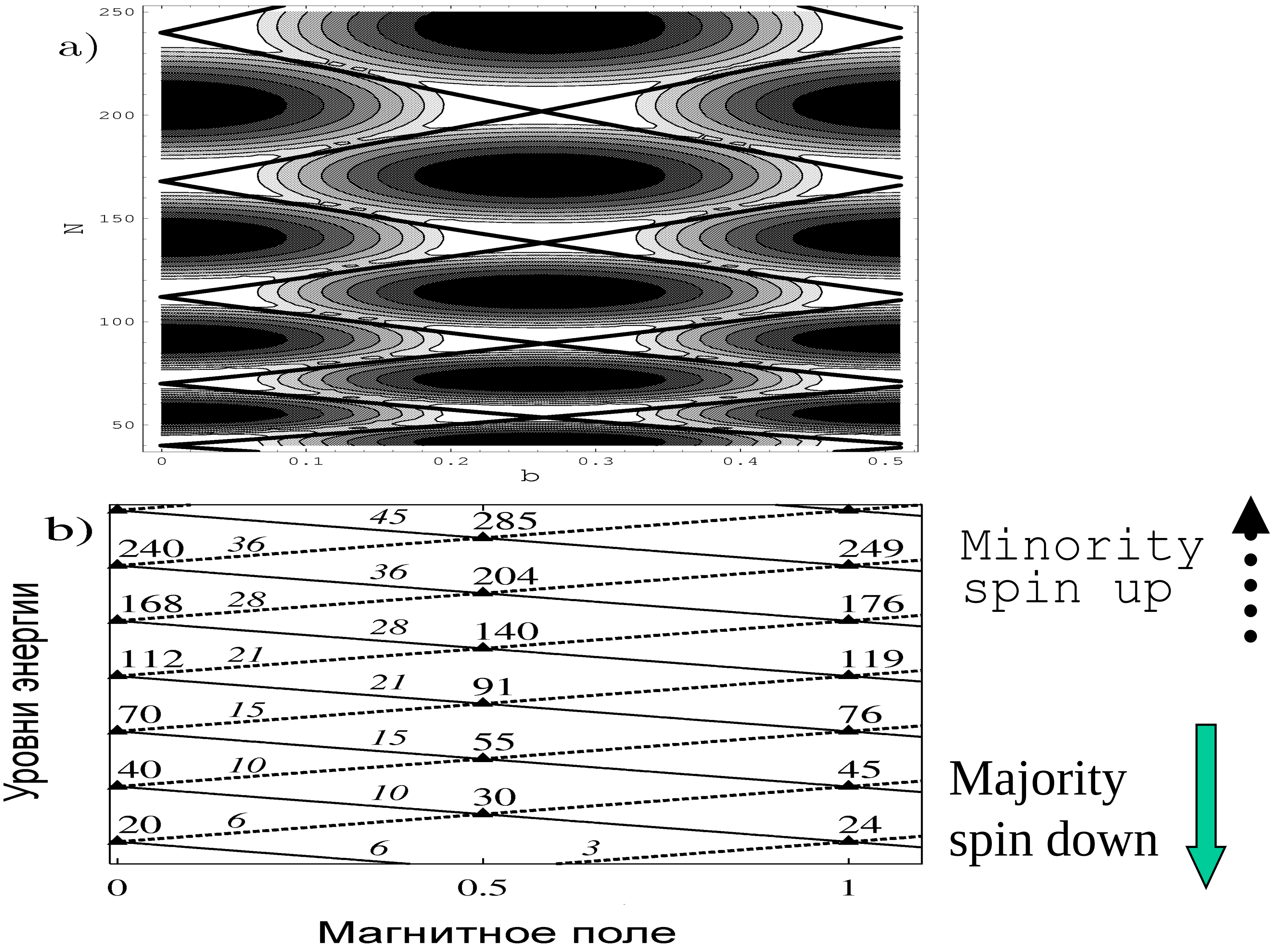
$$\rho = \sum_n \delta(\varepsilon - \varepsilon_n) = \rho_{\mathrm{sm}} + \rho^{\mathrm{sh}}$$

With Single particle levels ε_n ***filled up to the Fermi energy*** ε_F

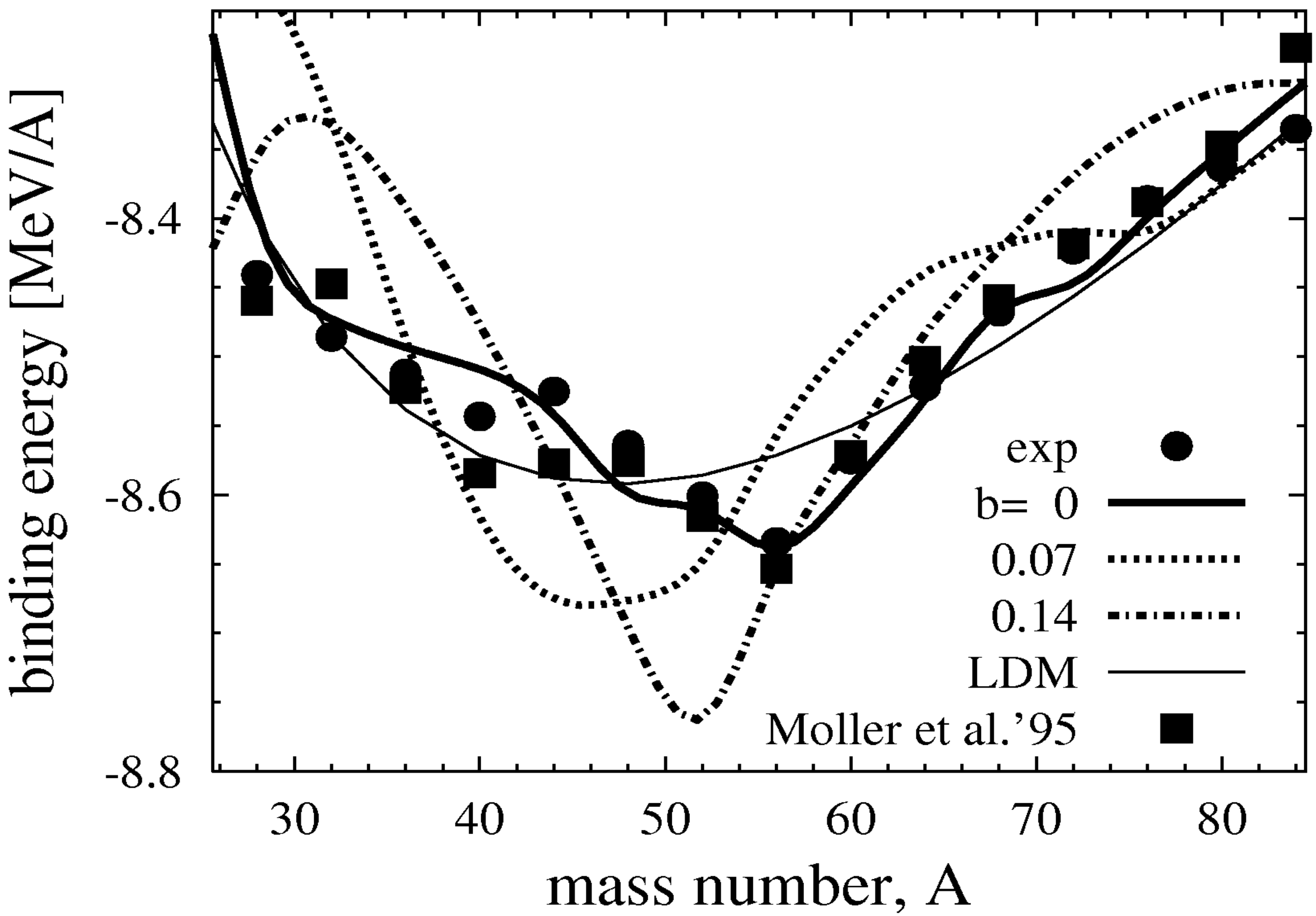
the **Hartree** self-consistent mean field approach in magnetic field : h

- Single particle Hamiltonian
- **$H = H_{MF}$ + (so)*(*ls*) +** ***(Magnetic terms)***
- Pauli–spin (*S*) → **- M (h*S*)**
- Landau–orbital (*l*) → **- M (h*l*) :protons**

Neutrons

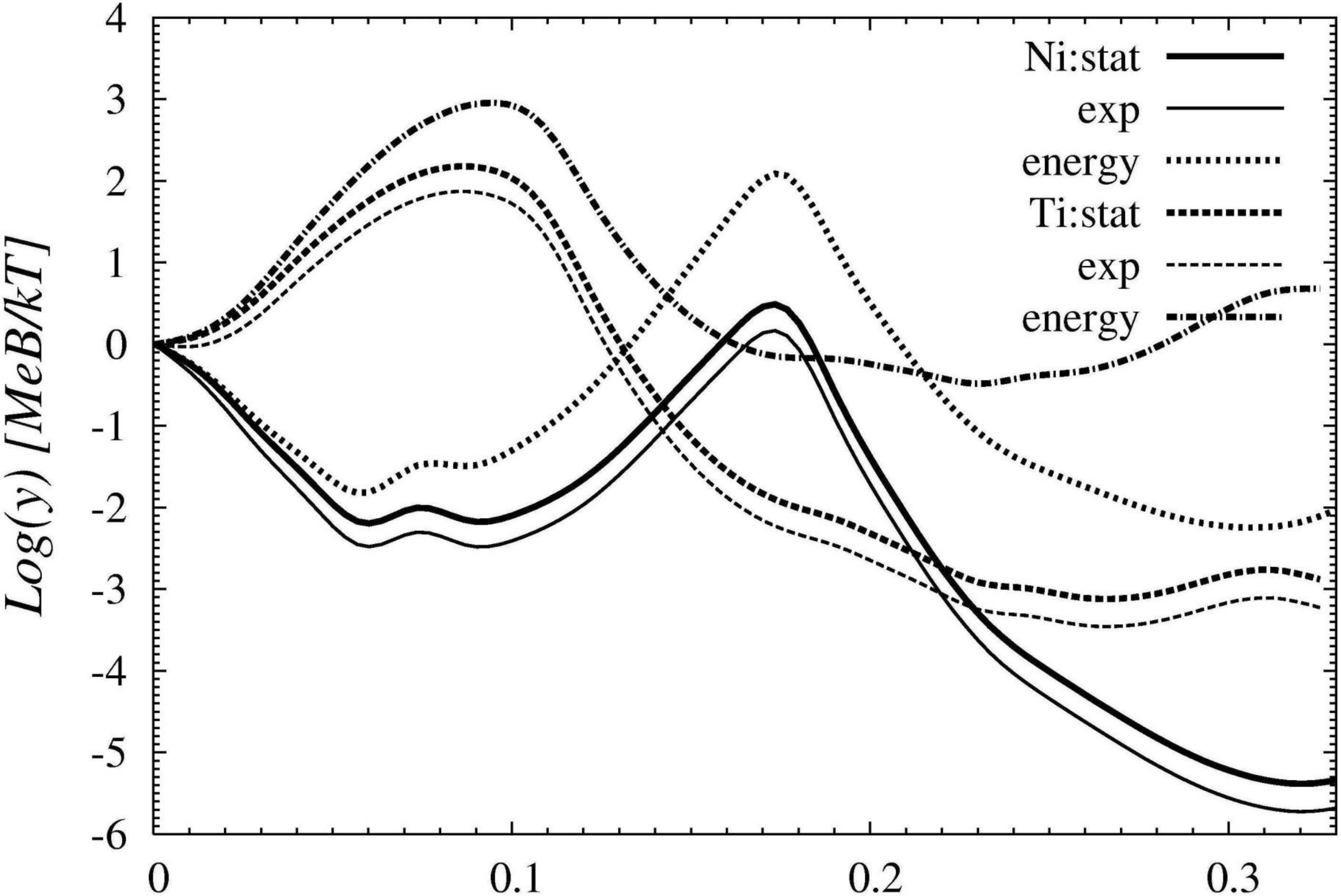

a)
250
200
150
100
50
N
0
0.1
0.2
0.3
0.4
0.5
b
b)
Уровни энергии
45
285
240
36
249
36
204
168
28
176
28
140
112
21
119
21
91
70
15
76
15
55
40
10
45
10
30
20
6
24
6
3
0
0.5
1
Магнитное поле
Minority
spin up
Majority
spin down

Binding energy of even-even symmetric nuclei *at magnetic fields h*



relative yield $y=Y(H)/Y(0)$

^{56}Ni(solid) i ^{44}Ti(dashed line)



Магнитное поле, *h*

SUMMARY

- We analyze the synthesis and decay of ^{n} nuclides in SNRs
- Obtained the spectra and flux for the specific lines of decay products

SUMMARY

- Magnetism of Atomic Nuclei
  Thermodynamic formalism
- Magnetic field effect on Nuclear Shell Structure
  Phase-shift in shell oscillations of Nuclear Masses
- Pauli type Paramagnetic Response
- Landau-type Orbital Magnetism
- Magnetic fields of Tera-Tesla shift
  Nuclear Magics of Iron region towards
  Smaller Masses approaching Ti-44
- Enhancement in Yield at nucleosynthesis