Seminar departmana za fiziku, Prirodno-matematički fakultet
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Ubrzanje čestica na udarnim talasima i njihov uticaj na hidrodinamičku i radio-evoluciju ostataka supernovih

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1. Kosmički zraci

2. Ostaci supernovih i $\Sigma-D$ relacija

3. Metod

4. Preliminarni rezultati

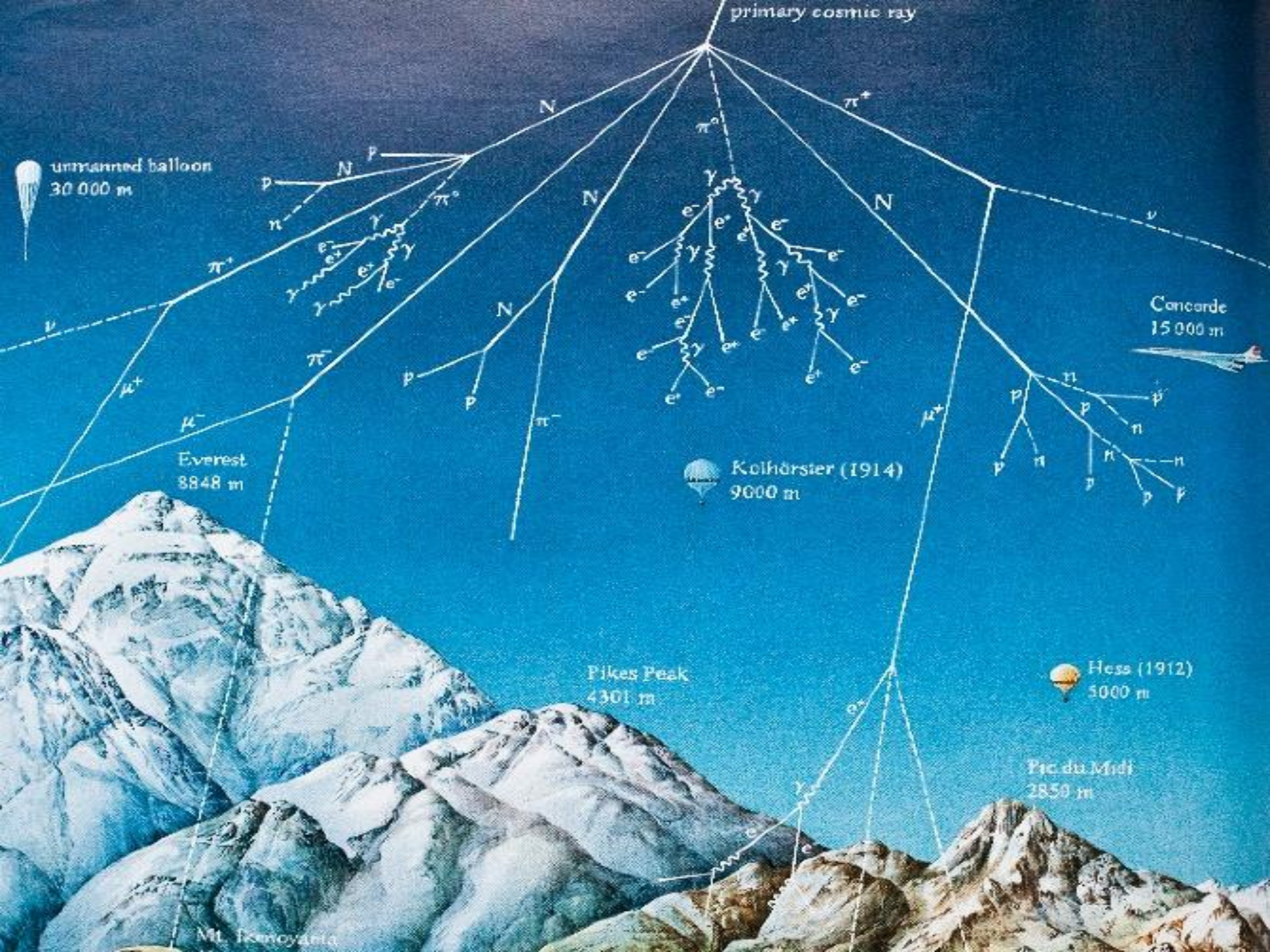
    4.1. Blasi-jev model

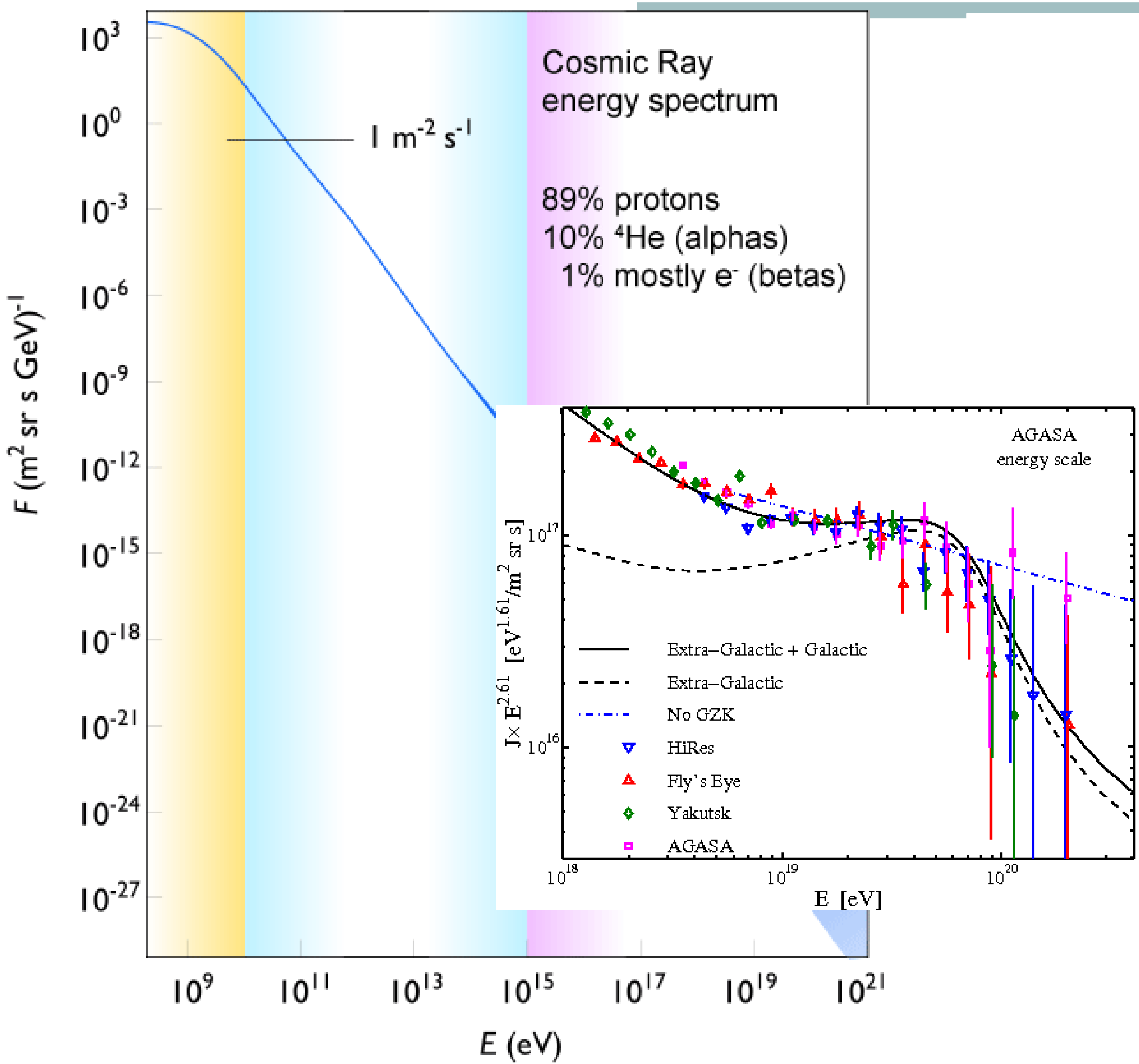
    4.2. Drugi radovi

5. Pitanja i diskusija

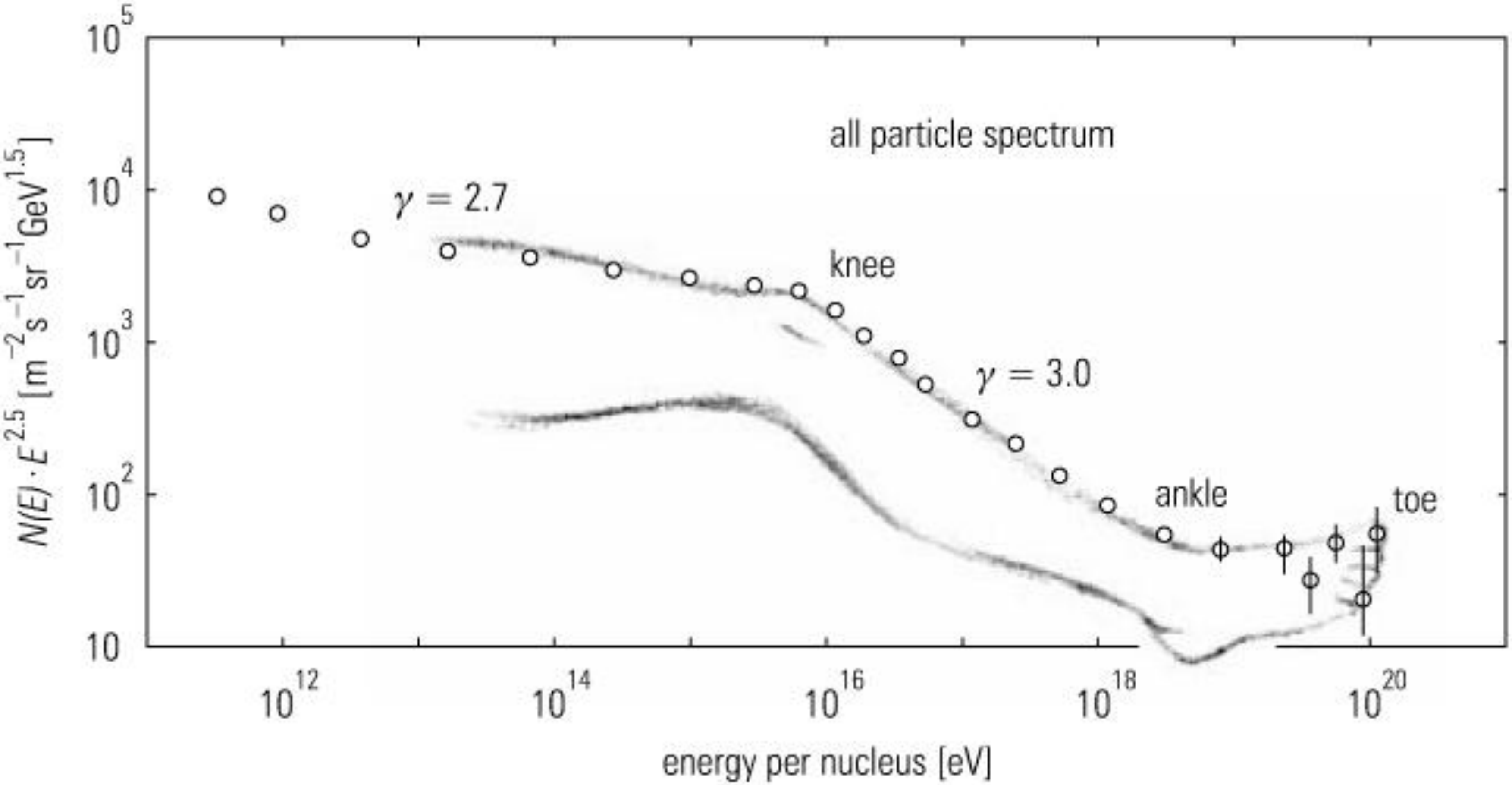
1. Kosmički zraci

Viktor Fransis Hes (1883-1964)

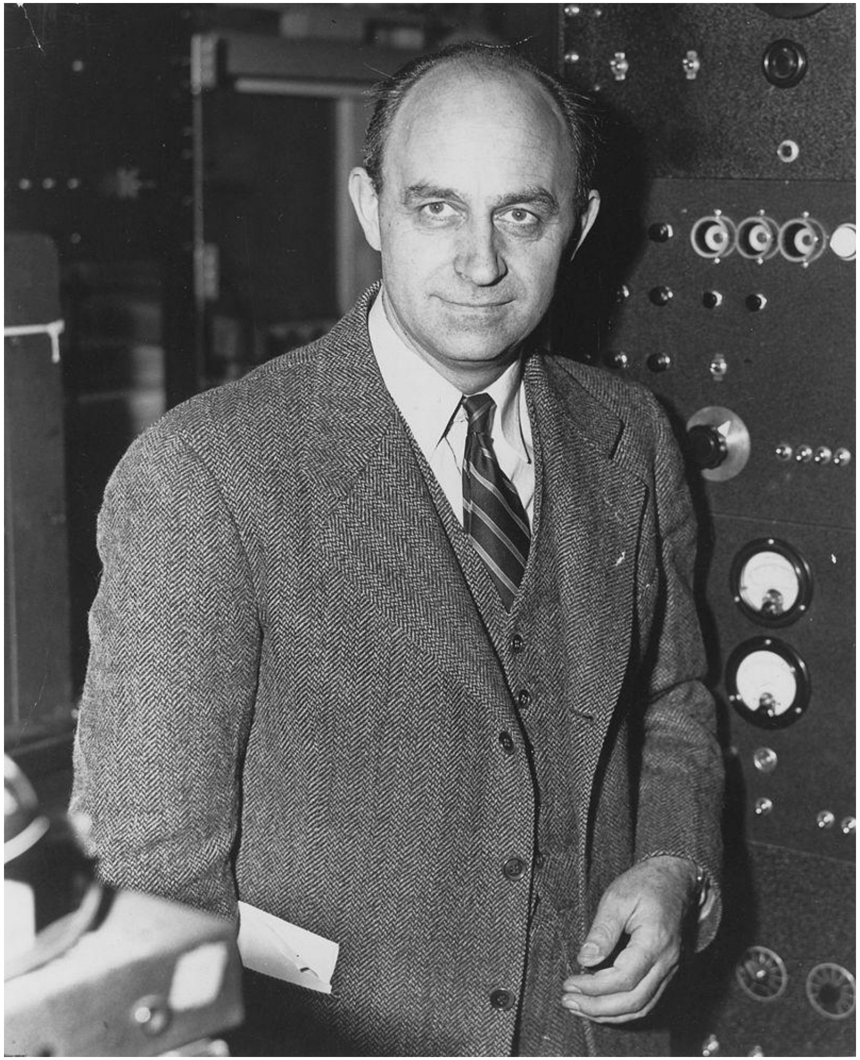

primary cosmic ray
unmanned balloon
30 000 m
Concorde
15 000 m
Everest
8848 m
Kolhörster (1914)
9000 m
Pikes Peak
4301 m
Hess (1912)
5000 m
Pic du Midi
2850 m



Cosmic Ray energy spectrum
89% protons
10% ⁴He (alphas)
1% mostly e⁻ (betas)
1 m⁻² s⁻¹
F (m² sr s GeV)⁻¹
E (eV)
AGASA energy scale
Extra–Galactic + Galactic
Extra–Galactic
No GZK
HiRes
Fly's Eye
Yakutsk
AGASA
J× E^2.61 [eV^1.61/m² sr s]
E [eV]



all particle spectrum
$\gamma = 2.7$
knee
$\gamma = 3.0$
ankle
toe
10^5
10^4
10^3
10^2
10
10^{12}
10^{14}
10^{16}
10^{18}
10^{20}
energy per nucleus [eV]
$N(E) \cdot E^{2.5}$ [$m^{-2}s^{-1}sr^{-1}GeV^{1.5}$]



Enriko Fermi (1901-1954)

PHYSICAL REVIEW VOLUME 75, NUMBER 8 APRIL 15, 1949

On the Origin of the Cosmic Radiation

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(Received January 3, 1949)

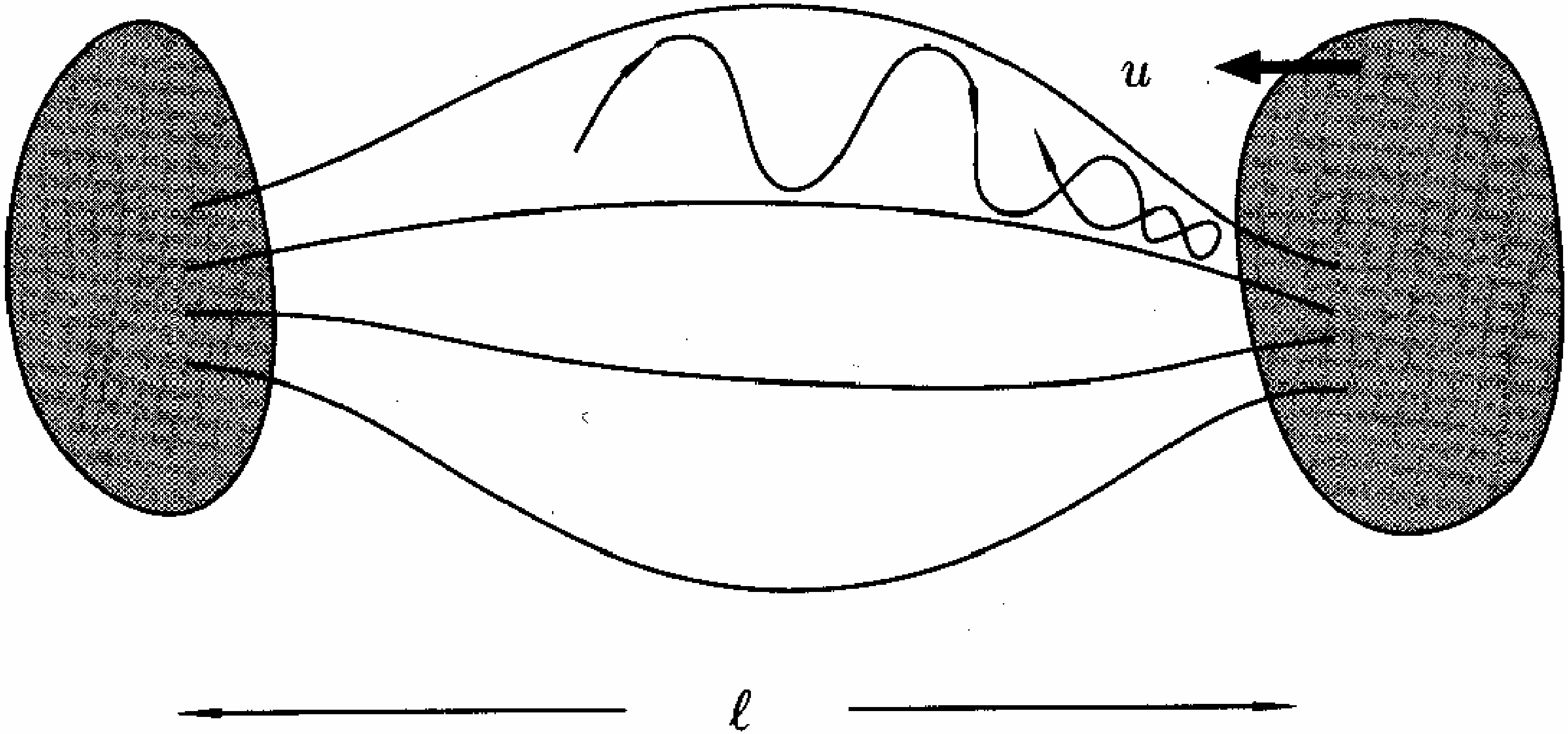
A theory of the origin of cosmic radiation is proposed according to which cosmic rays are originated and accelerated primarily in the interstellar space of the galaxy by collisions against moving magnetic fields. One of the features of the theory is that it yields naturally an inverse power law for the spectral distribution of the cosmic rays. The chief difficulty is that it fails to explain in a straightforward way the heavy nuclei observed in the primary radiation.

I. INTRODUCTION

IN recent discussions on the origin of the cosmic radiation E. Teller[1] has advocated the view that cosmic rays are of solar origin and are kept relatively near the sun by the action of magnetic fields. These views are amplified by Alfvén, Richtmyer, and Teller.[2] The argument against the conventional view that cosmic radiation may extend at least to all the galactic space is the very large amount of energy that should be present in form of cosmic radiation if it were to extend to such a huge space. Indeed, if this were the case, the mechanism of acceleration of the cosmic radiation should be extremely efficient.

where H is the intensity of the magnetic field and ρ is the density of the interstellar matter.

One finds according to the present theory that a particle that is projected into the interstellar medium with energy above a certain injection threshold gains energy by collisions against the moving irregularities of the interstellar magnetic field. The rate of gain is very slow but appears capable of building up the energy to the maximum values observed. Indeed one finds quite naturally an inverse power law for the energy spectrum of the protons. The experimentally observed exponent of this law appears to be well within the range of the possibilities.



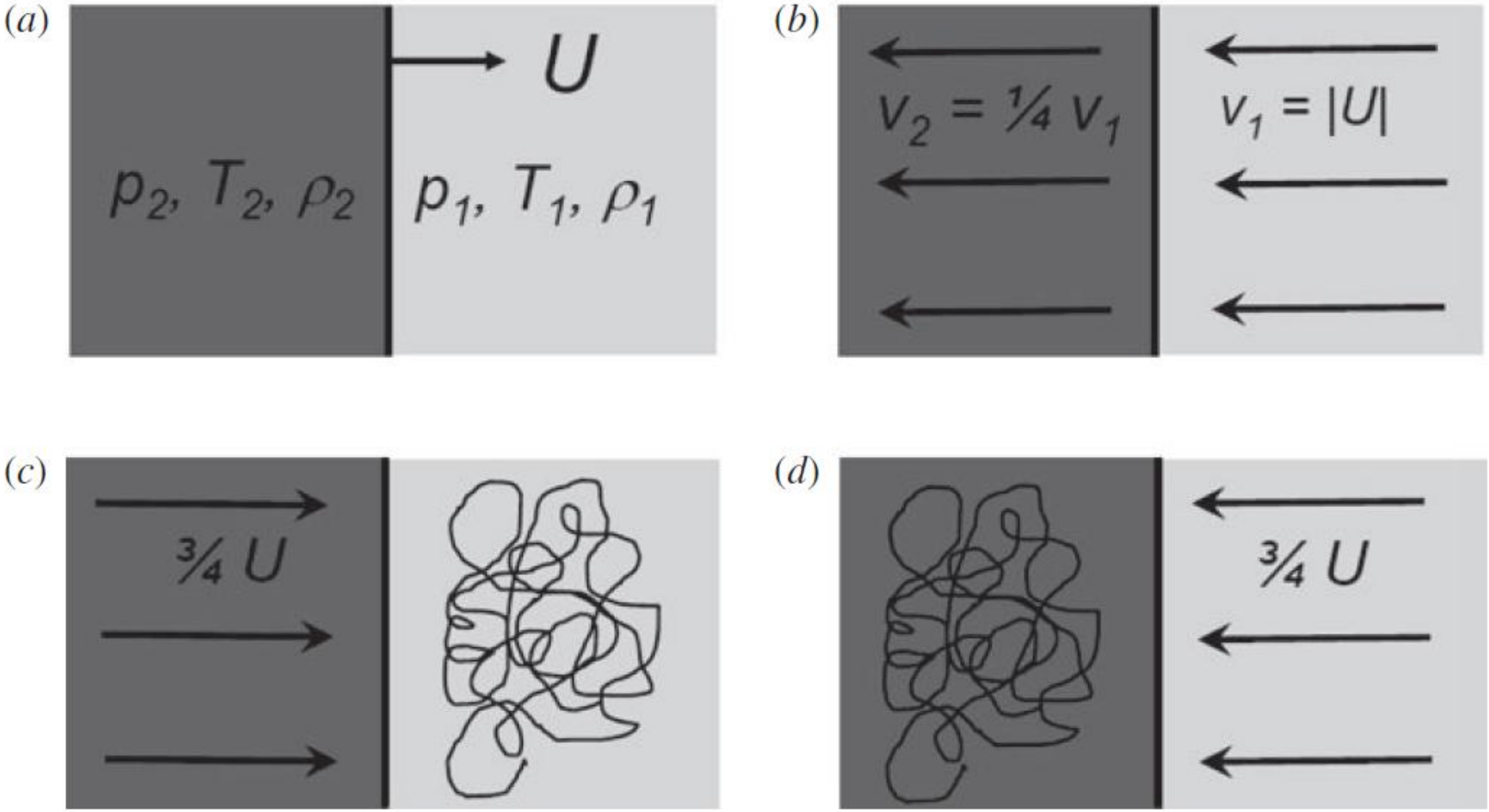
$$\Delta W / W = -2\left(\mathbf{v} \cdot \mathbf{V}\right)/c^2 \sim \frac{V^2}{c^2}$$

Bell (1978a, 1978b)

Difuzno ubrzanje na udarnim talasima (DSA)

$$\frac{\Delta E}{E} \approx \frac{4}{3}\frac{v_0 - v_2}{c} = \frac{4}{3}\left(\frac{\chi - 1}{\chi}\right)\frac{V_s}{c}$$

$$n(E)\,dE \propto E^{-q}\,dE, \quad q = \frac{\chi + 2}{\chi - 1}$$

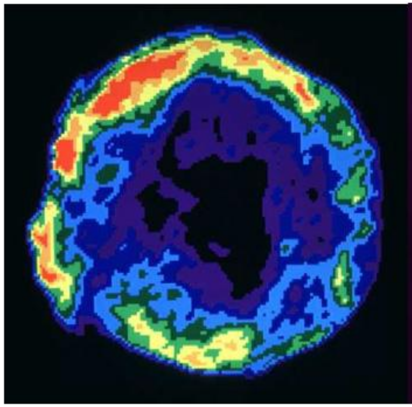
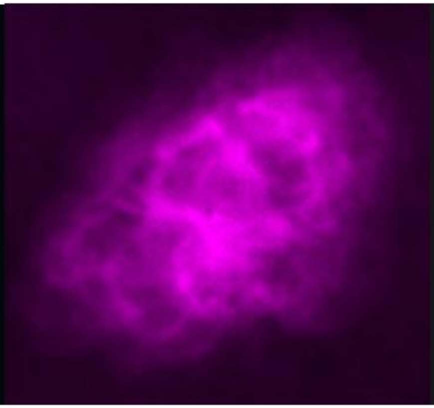
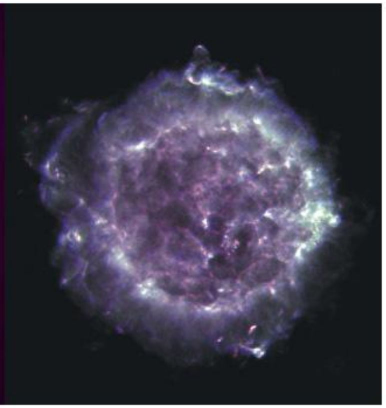


Longair (2011)

2. Ostaci supernovih i Σ−D relacija

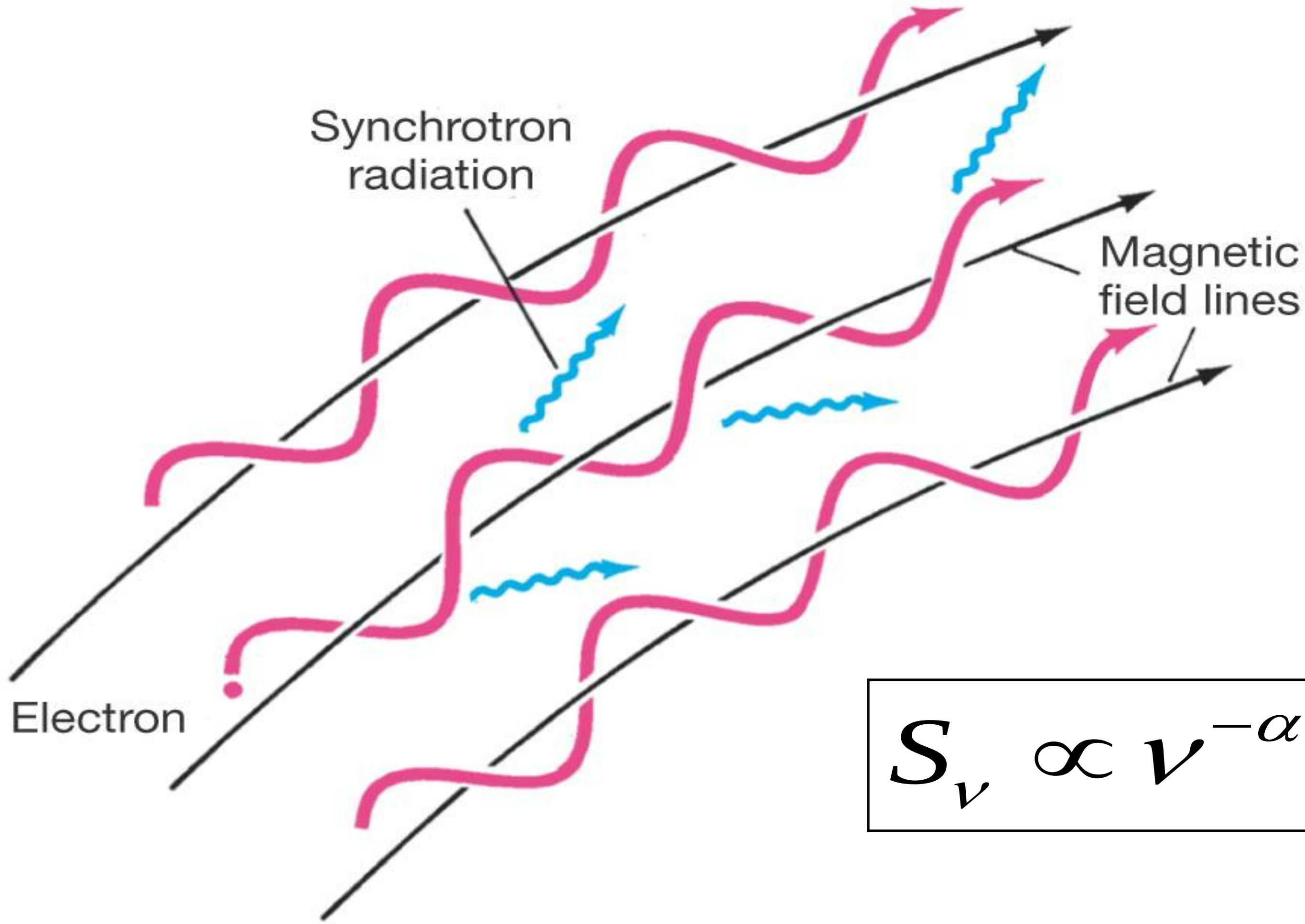
Supernova – visokoenergetska zvezdana eksplozija

$$E \approx 10^{51} erg \qquad \upsilon \approx 20000 \text{ km/s}$$

Tiho (Tycho) *Krab (Crab)* *Kasiopeja A (Cassiopeia A)*

- jaka sinhrotronska emisija
- netermalni spektar opisan zakonom:



$$\boxed{S_{\nu} \propto \nu^{-\alpha}}$$

Površinski sjaj radio izvora:

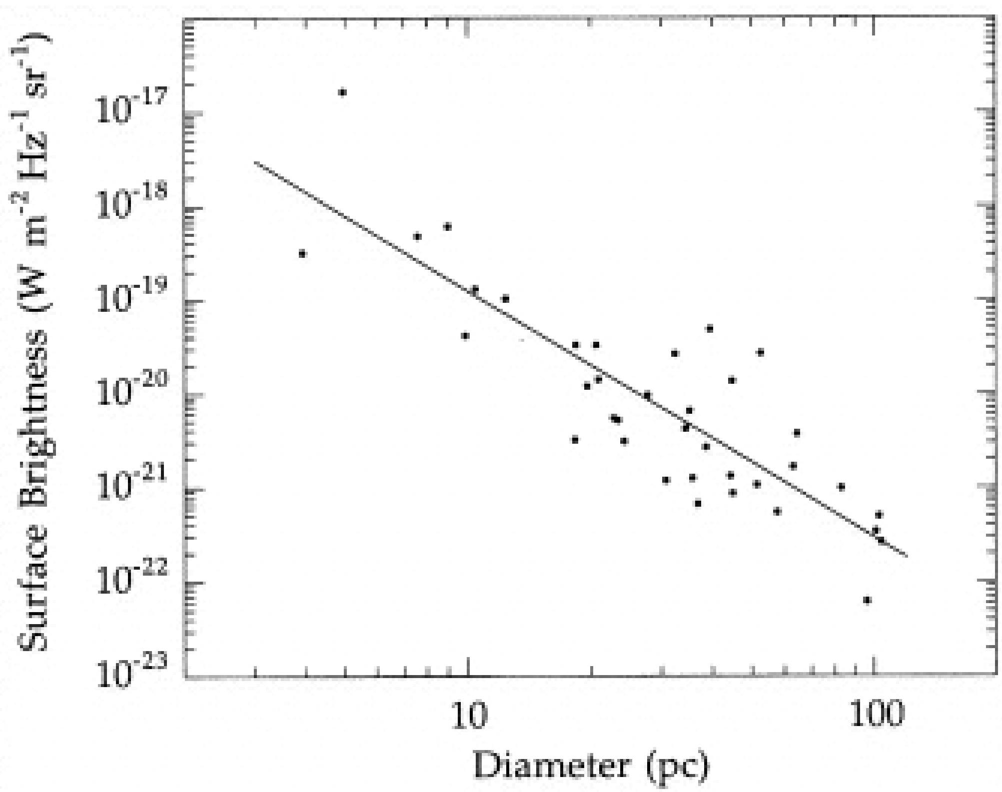
$$\Sigma_\nu = 1.505 \cdot 10^{-19} \frac{S_\nu}{\theta^2} \ \mathrm{Wm^{-2}Hz^{-1}sr^{-1}}$$

- gustina fluksa u Janskima $\left(1\,\mathrm{Jy} = 10^{-26}\,\mathrm{Wm^{-2}Hz^{-1}}\right)$
- uglovni dijametar u lučnim minutima

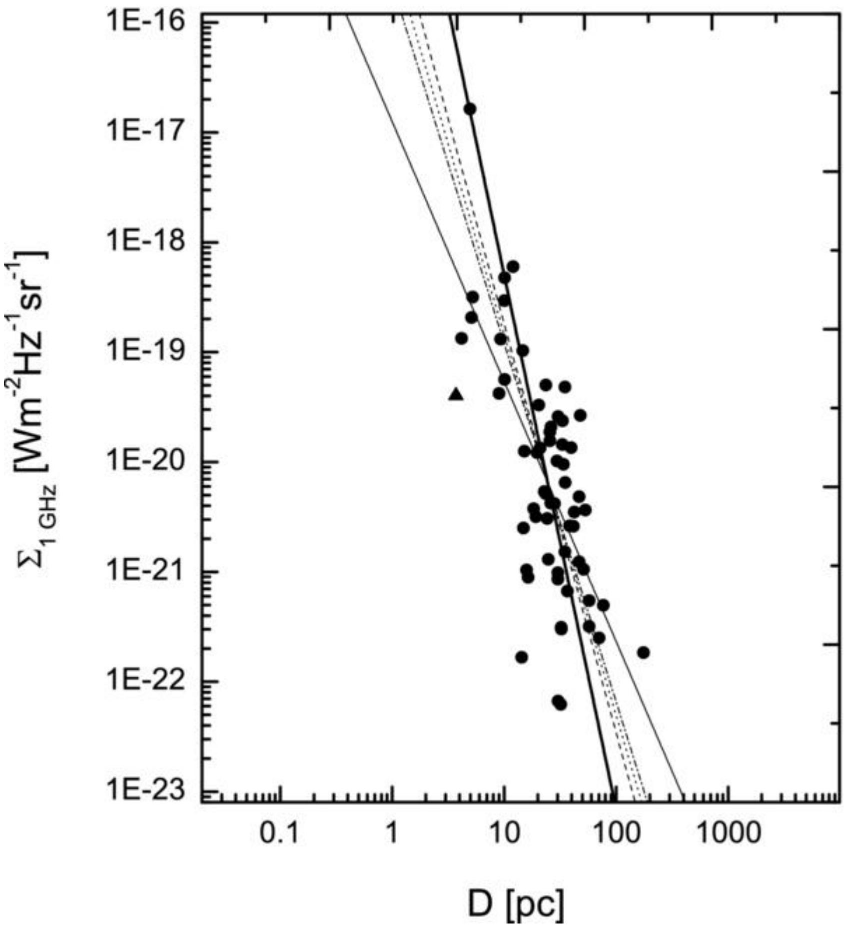
$$\boxed{\Sigma_\nu(D) = AD^{-\beta}}$$

Evolucija ostataka supernovih

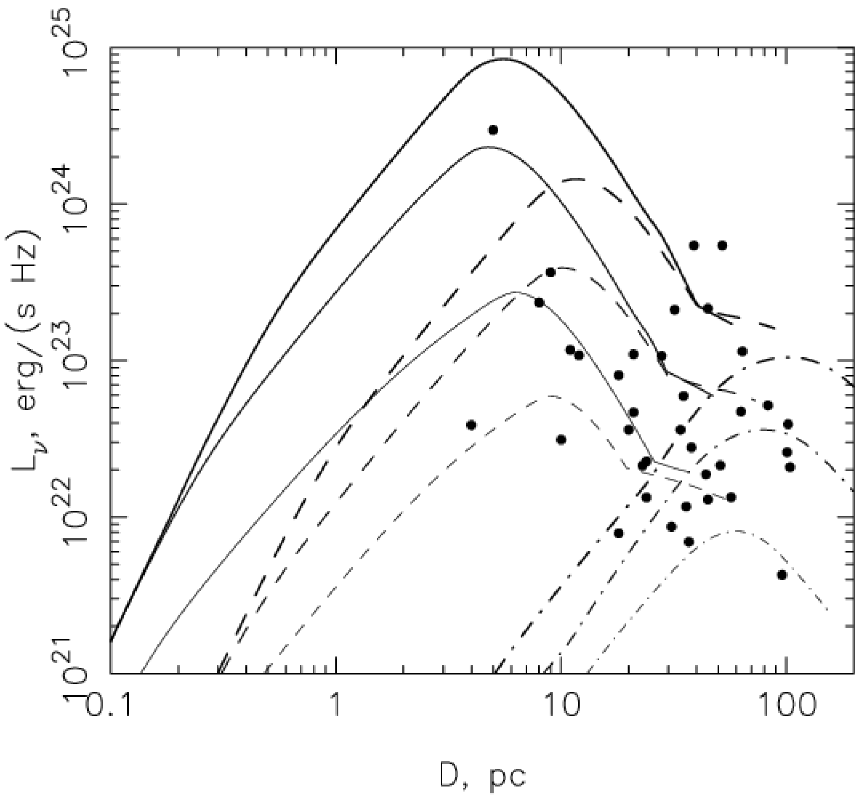
Određivanje daljina do ostataka



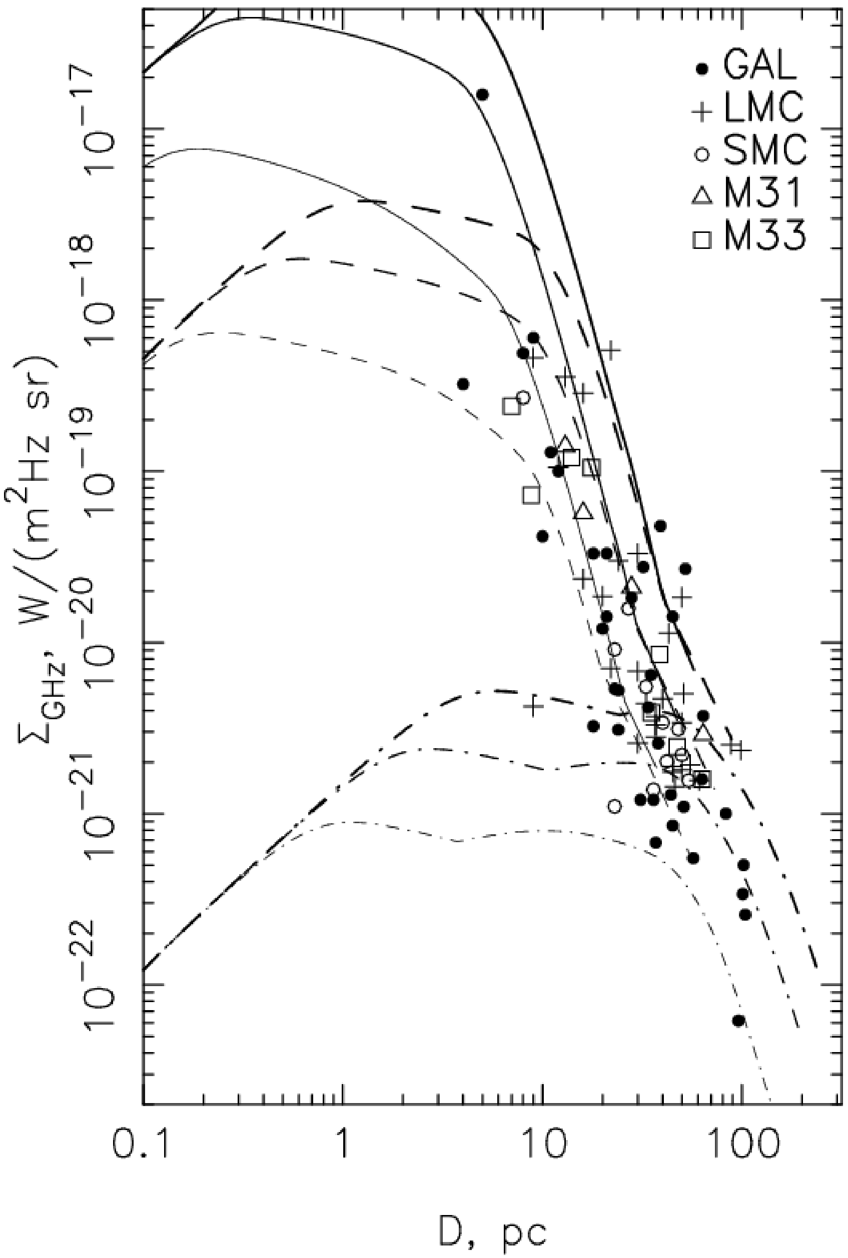
Case & Bhattacharya (1998)



Pavlović, Urošević, Vukotić, Arbutina & Goker (2013); Pavlović, Dobardžić, Vukotić & Urošević (2014)



Berezhko & Volk (2004)



3. Metod

Berezhko & Volk (2004) **vs.** Mi (2016?)

Uprošćena dinamika udarnog talasa, semi-analitički modeli?

PLUTO MHD kod

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}) = 0,$$

$$\frac{\partial \rho \boldsymbol{u}}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}\boldsymbol{u} - \boldsymbol{B}\boldsymbol{B}) + \nabla P_* = 0,$$

$$\frac{\partial \rho E}{\partial t} + \nabla \cdot [\boldsymbol{u}(\rho E + P_*) - \boldsymbol{B}(\boldsymbol{u} \cdot \boldsymbol{B})] = 0,$$

$$\frac{\partial \boldsymbol{B}}{\partial t} + \nabla \cdot (\boldsymbol{u}\boldsymbol{B} - \boldsymbol{B}\boldsymbol{u}) = 0,$$

$$P = (\gamma - 1)\rho\epsilon$$

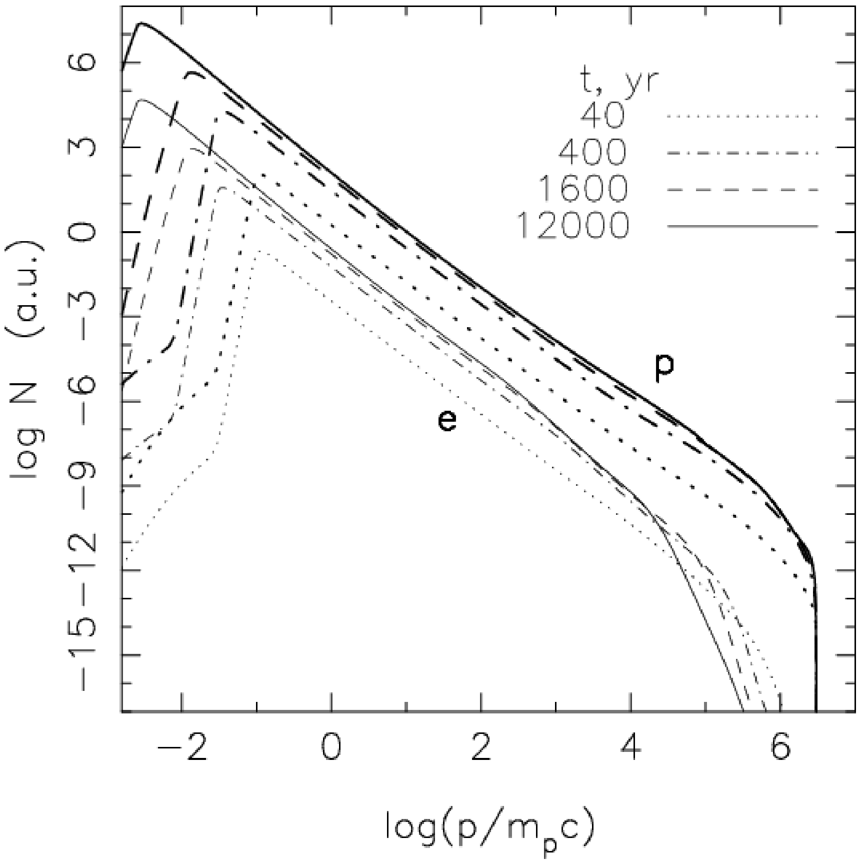
$$P_* = P + \frac{B^2}{2}, \qquad E = \epsilon + \frac{1}{2}|\boldsymbol{u}|^2 + \frac{1}{2}\frac{|\boldsymbol{B}|^2}{\rho},$$

$$f_e(p) = K_{ep} f_p(p)$$

$$K_{ep} = 10^{-2}$$

$$\eta = \frac{4}{3\pi^{1/2}}(R_{sub} - 1)\xi^3 e^{-\xi^2}$$

$$(p_{inj} = \xi p_{th,2})$$

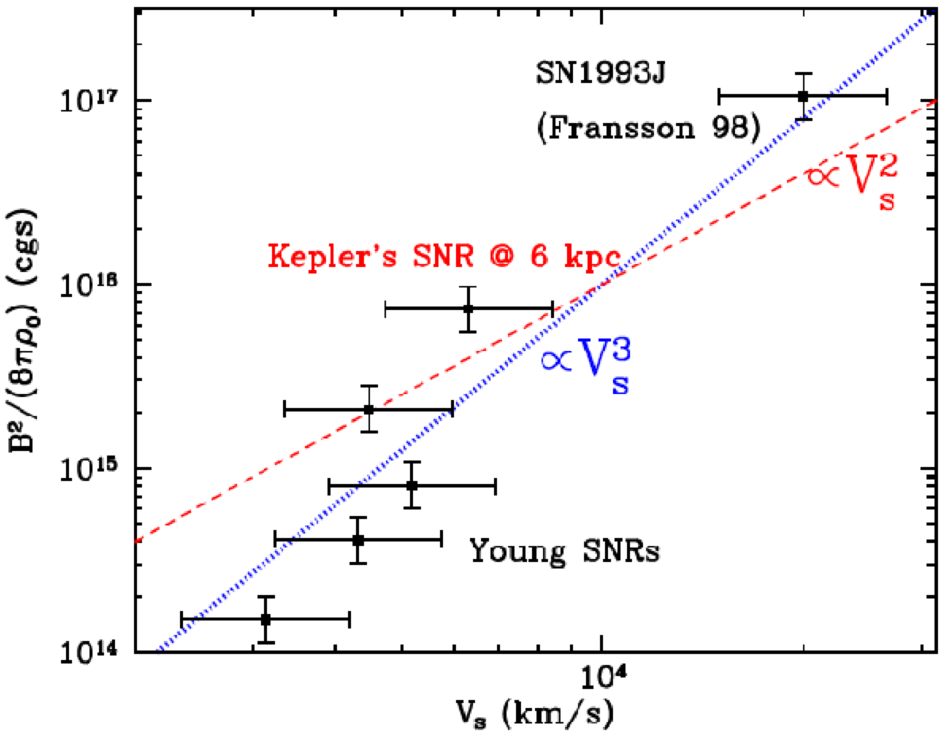


Blasi, Gabici & Vannoni (2005) ; Ellison (1981); Ellison, Jones & Eichler (1981); Ellison & Eichler (1984); Gieseler, Jones & Kang (2000)

$$B_{\mathrm{d}}^2/(8\pi) \approx 10^{-2}\rho_0 V_s^2$$

$$B^2/(8\pi) \propto \rho_0 V_s^3$$

Bell (2004); Vink (2012)



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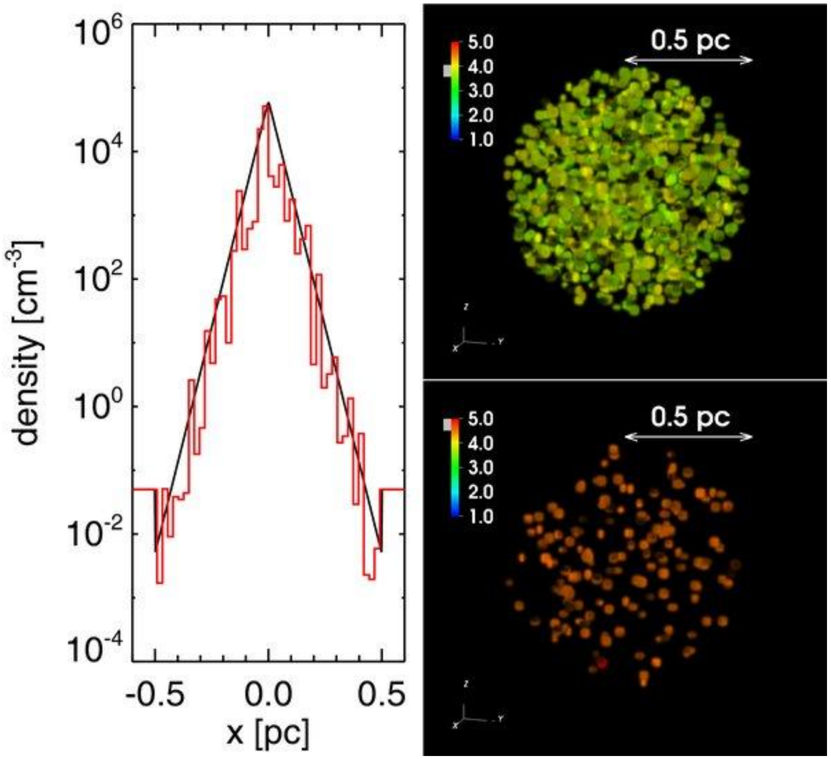
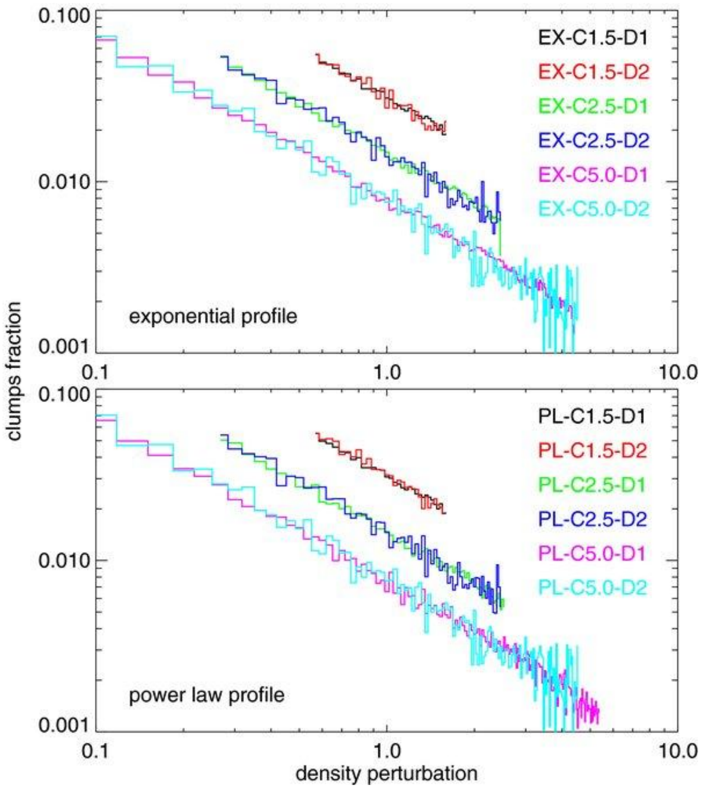
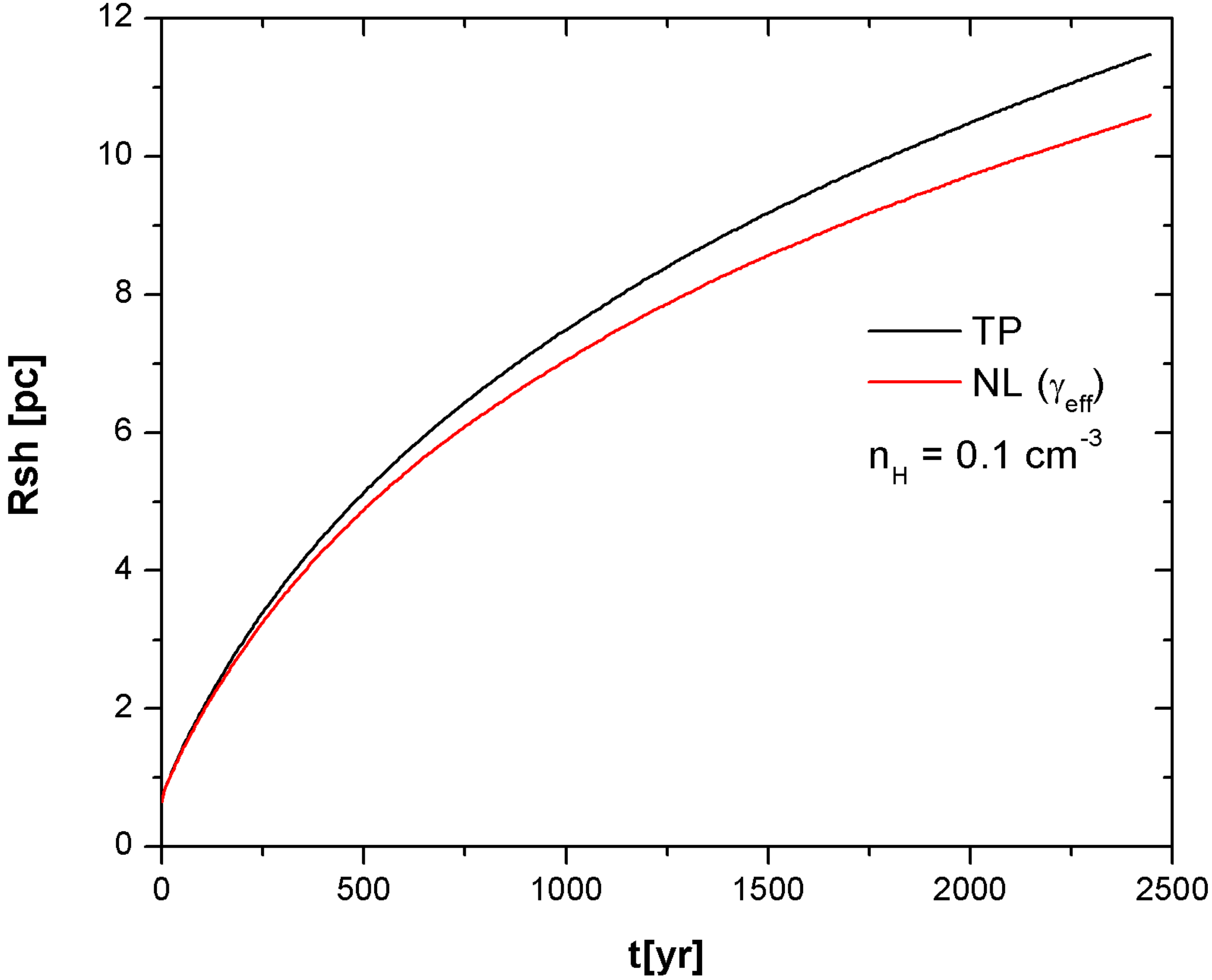
Ejecta clumping

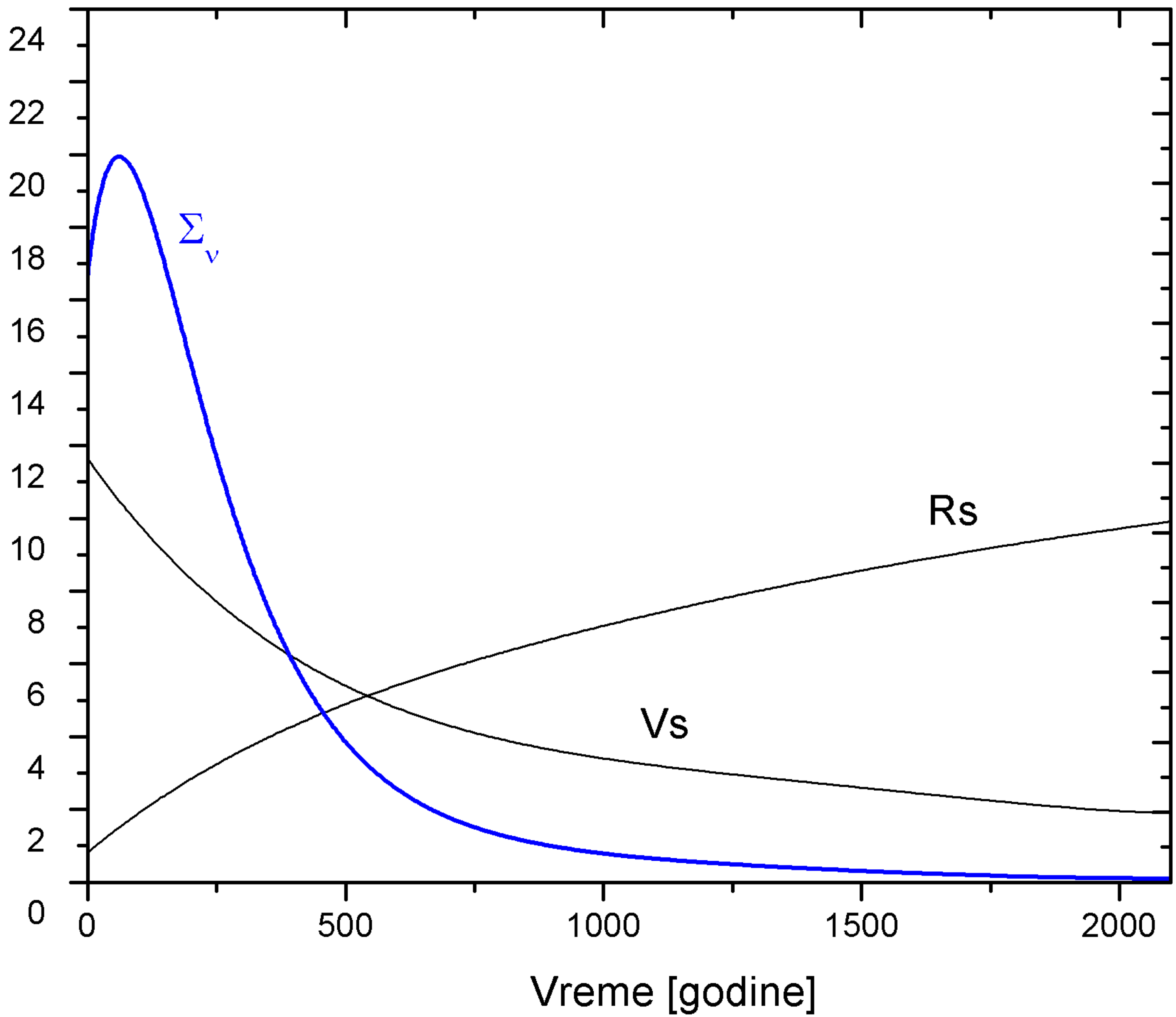




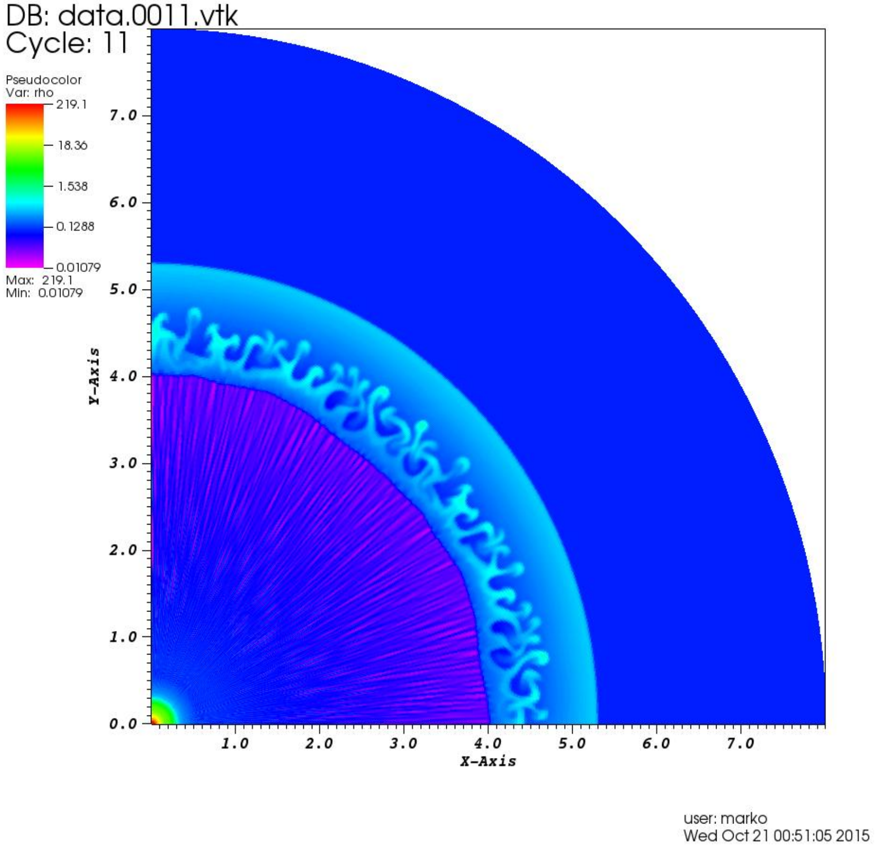
Orlando et al. (2012)

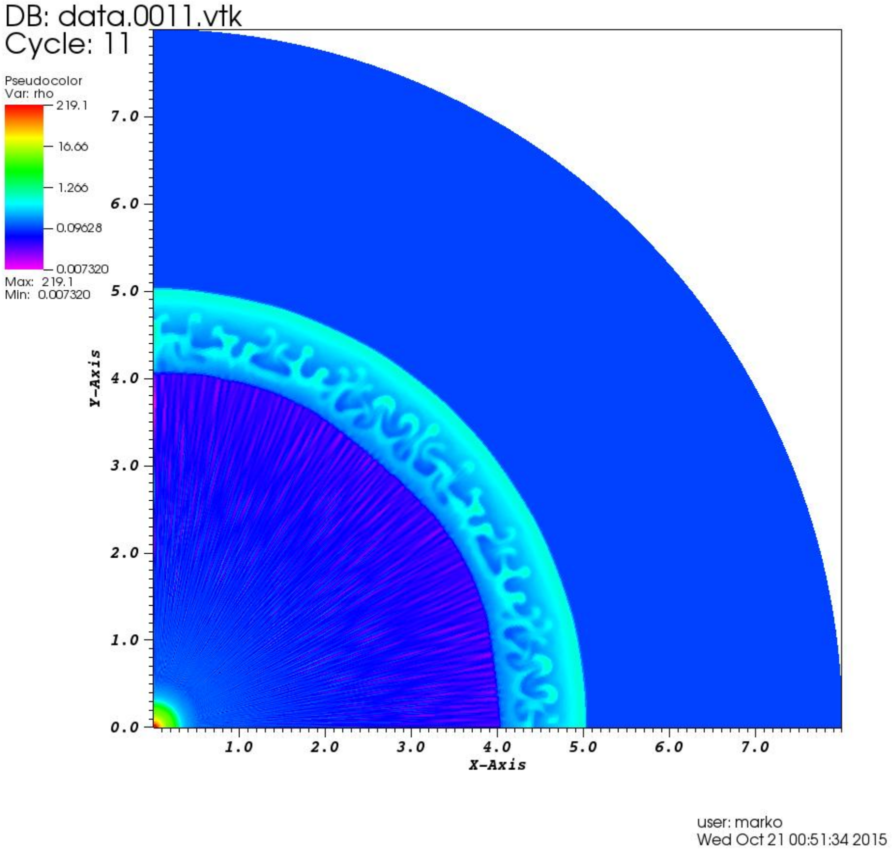
4. Preliminarni rezultati



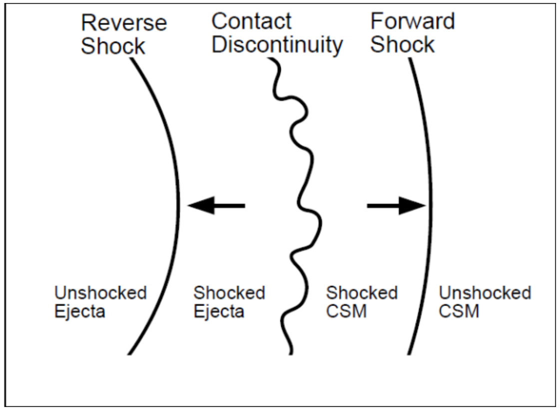


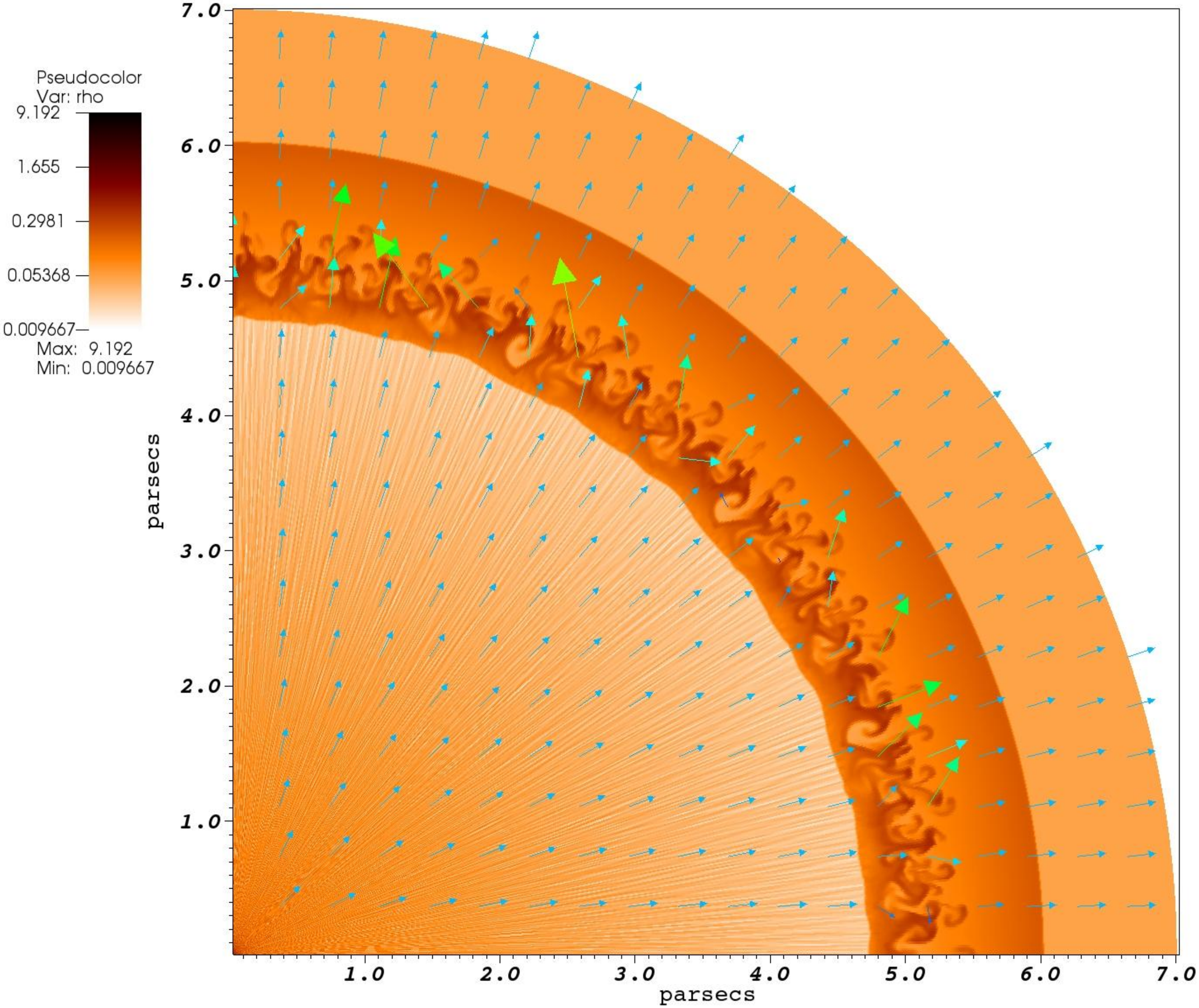
24
22
20
18
16
14
12
10
8
6
4
2
0
0
500
1000
1500
2000
Vreme [godine]
Σ ν
Rs
Vs



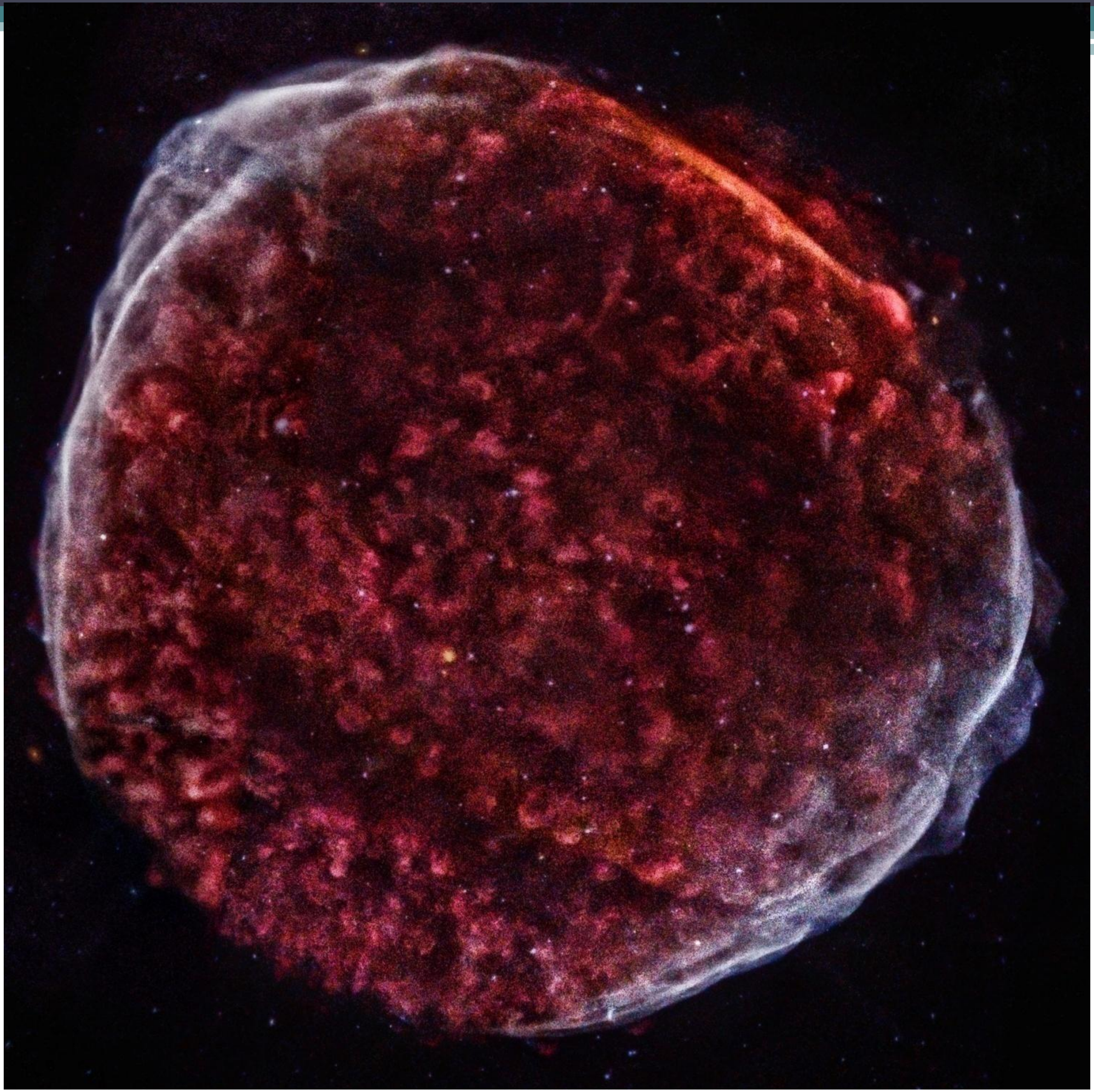


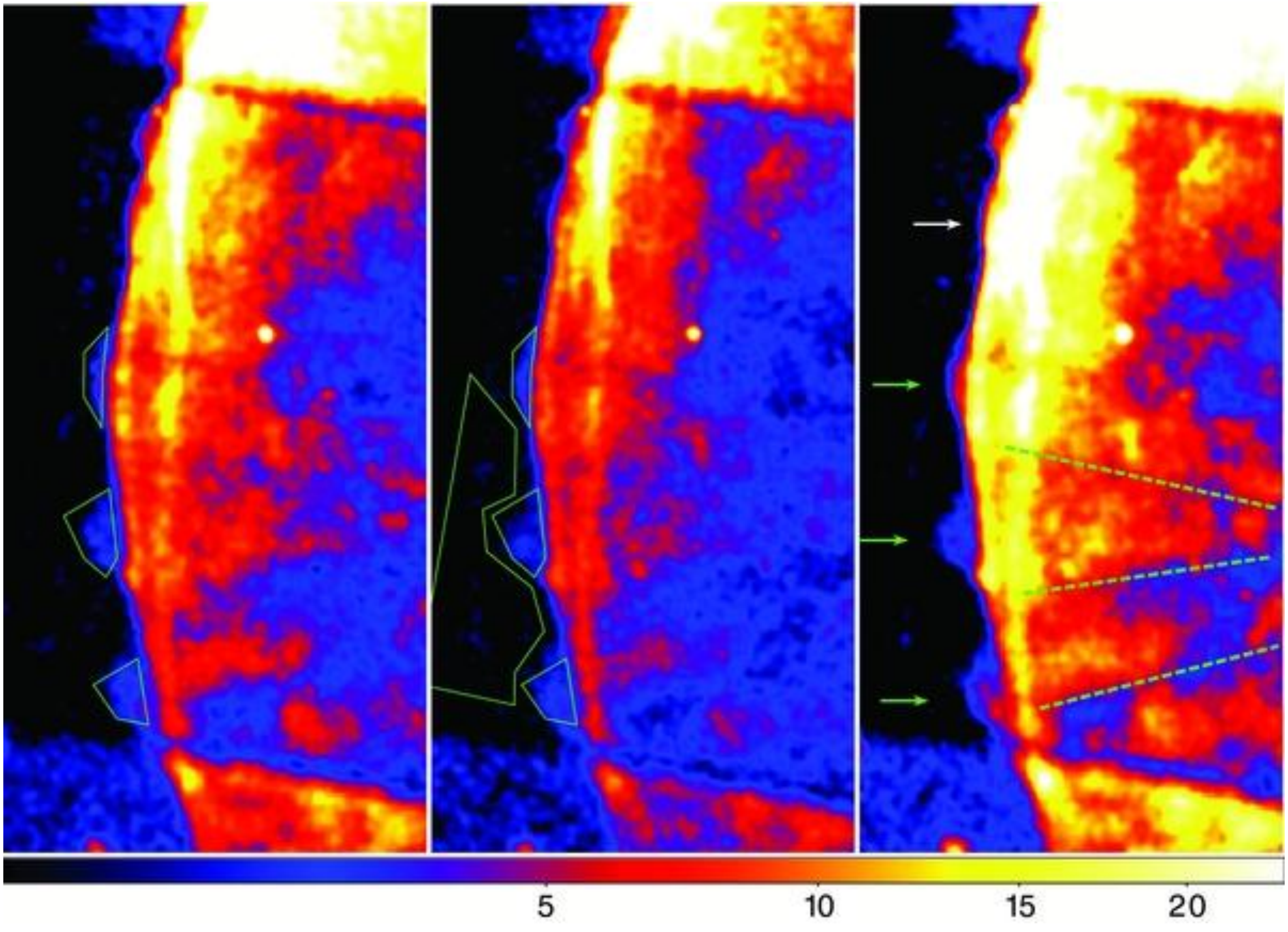
$$\gamma_{\rm eff} = \frac{M_{\rm S}^2(r_{\rm tot}+1) - 2r_{\rm tot}}{M_{\rm S}^2(r_{\rm tot}-1)}$$





Pseudocolor
Var: rho
9.192
1.655
0.2981
0.05368
0.009667
Max: 9.192
Min: 0.009667
7.0
6.0
5.0
4.0
3.0
2.0
1.0
parsecs
1.0
2.0
3.0
4.0
5.0
6.0
7.0
parsecs

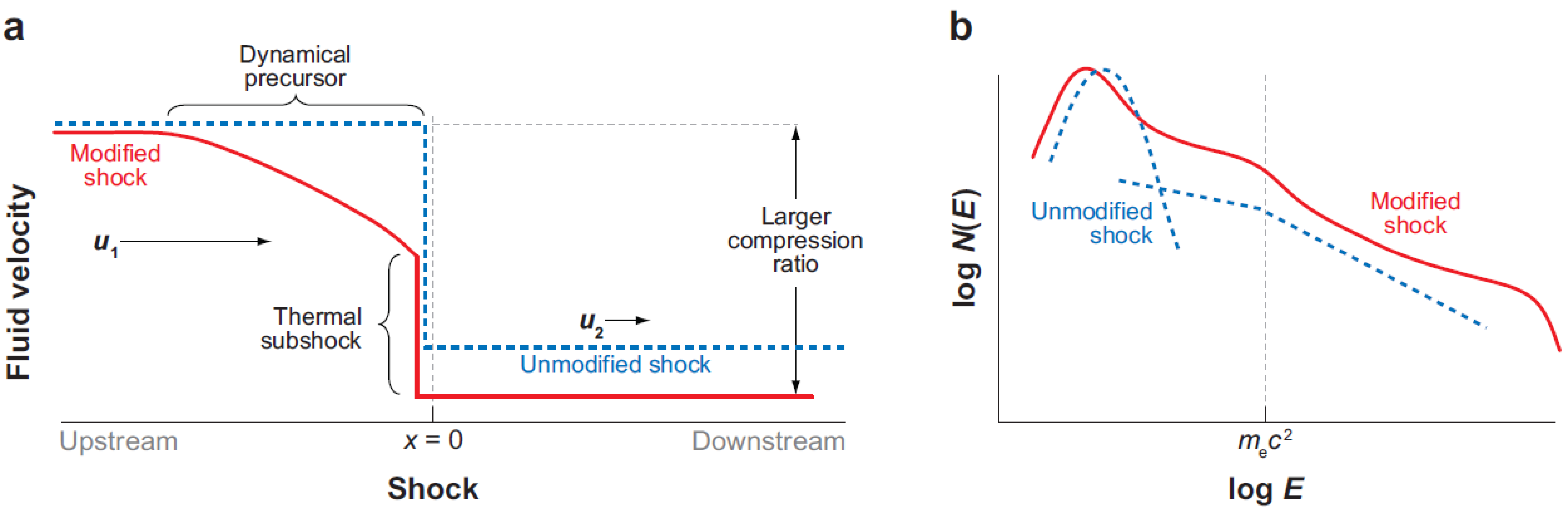




Rakowski et al. (2011)

4.1. Blasi-jev model

Blasi (2002, 2004); Blasi, Gabici & Vannoni (2005); Amato & Blasi (2006)



$$\frac{\partial}{\partial x}\left[D\frac{\partial}{\partial x}f(x,p)\right]-u\frac{\partial f(x,p)}{\partial x}+\frac{1}{3}\frac{\mathrm{d}u}{\mathrm{d}x}\,p\,\frac{\partial f(x,p)}{\partial p}$$
$$+Q(x,p)=0,$$

$$f(x,p) = f_0(p)\exp\left[-\frac{q(p)}{3}\int_x^0 \mathrm{d}x'\,\frac{u(x')}{D(x',p)}\right]$$

$$q(p) = -\mathrm{d}\ln f_0/\mathrm{d}\ln p$$

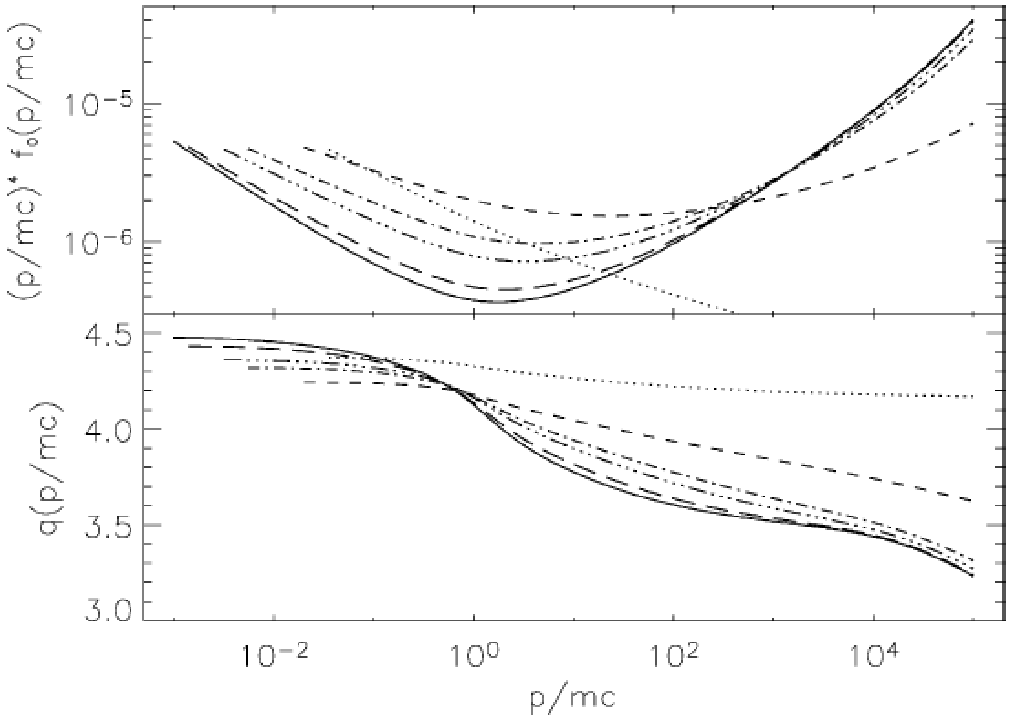
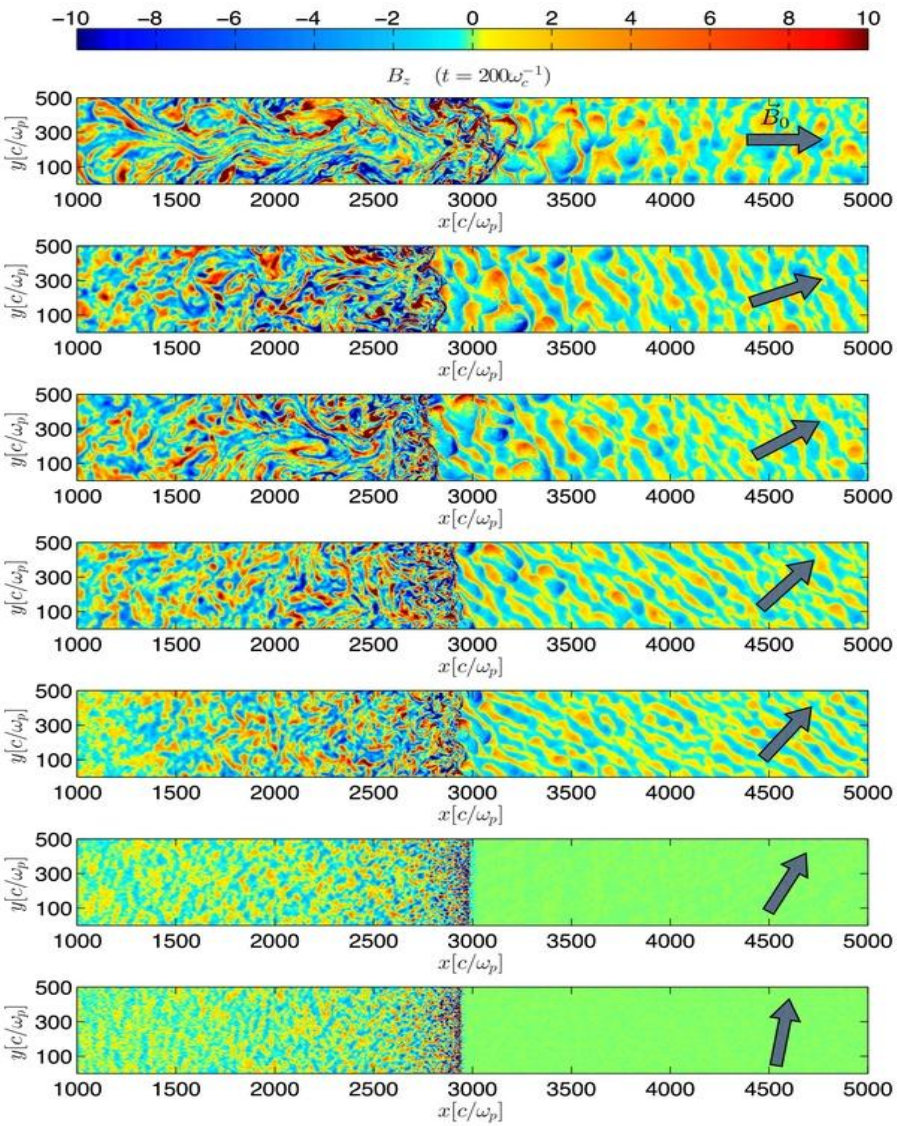


Figure 1. Upper panel: spectra of accelerated particles at the location of the shock for $M_0 = 4$ (dotted line), 10 (short-dashed line), 50 (dash–dotted line), 100 (triple-dot–dashed line), 300 (long-dashed line) and 500 (solid line). Lower panel: momentum-dependent slope for the same values of Mach numbers. In both panels we used $\xi = 3.5$ and $p_{\max} = 10^5 mc$.

4.2. Drugi radovi

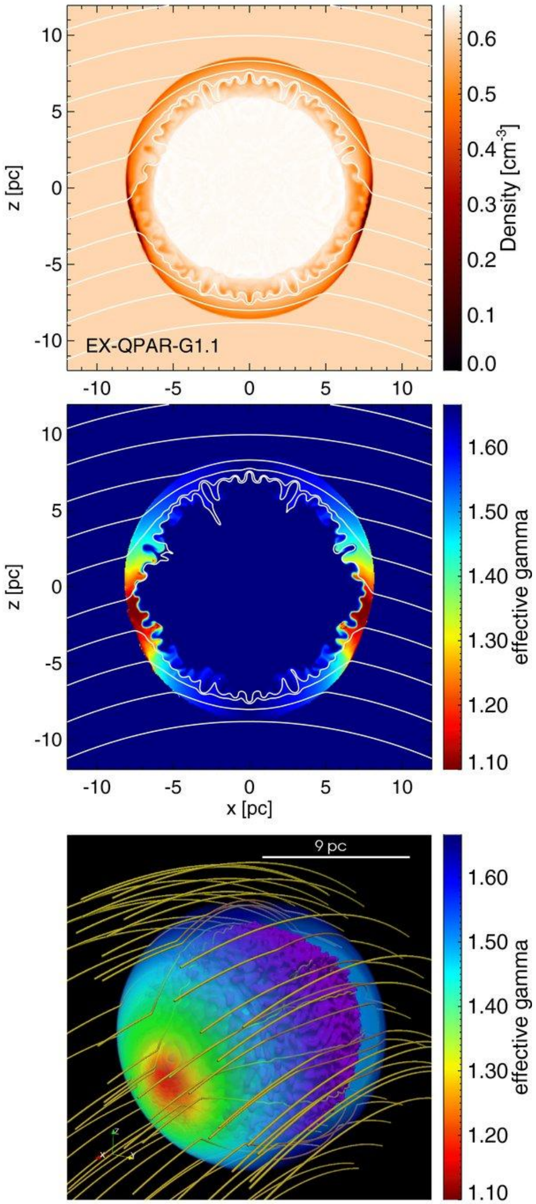


units of the ion skin depth c/ω_p

$$\omega_p = \sqrt{4\pi n e^2/m}$$

$$\approx 10^{-13}\,\mathrm{pc}$$

Caprioly & Spitkovsky (2014)



$$\gamma_{\rm eff} = \gamma - (\gamma - \gamma_{\rm min}) \times f_\varsigma(\Theta_{\rm o})$$

$$f_\varsigma(\Theta_{\rm o}) = \cos^2 \Theta_{\rm s}$$

$$f_\varsigma(\Theta_{\rm o}) = \sin^2 \Theta_{\rm s}$$

$$f_\varsigma(\Theta_{\rm o}) = 1$$

Orlando et al. (2012)

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HVALA LIJEPA
NA PAŽNJI !

5. Pitanja i diskusija