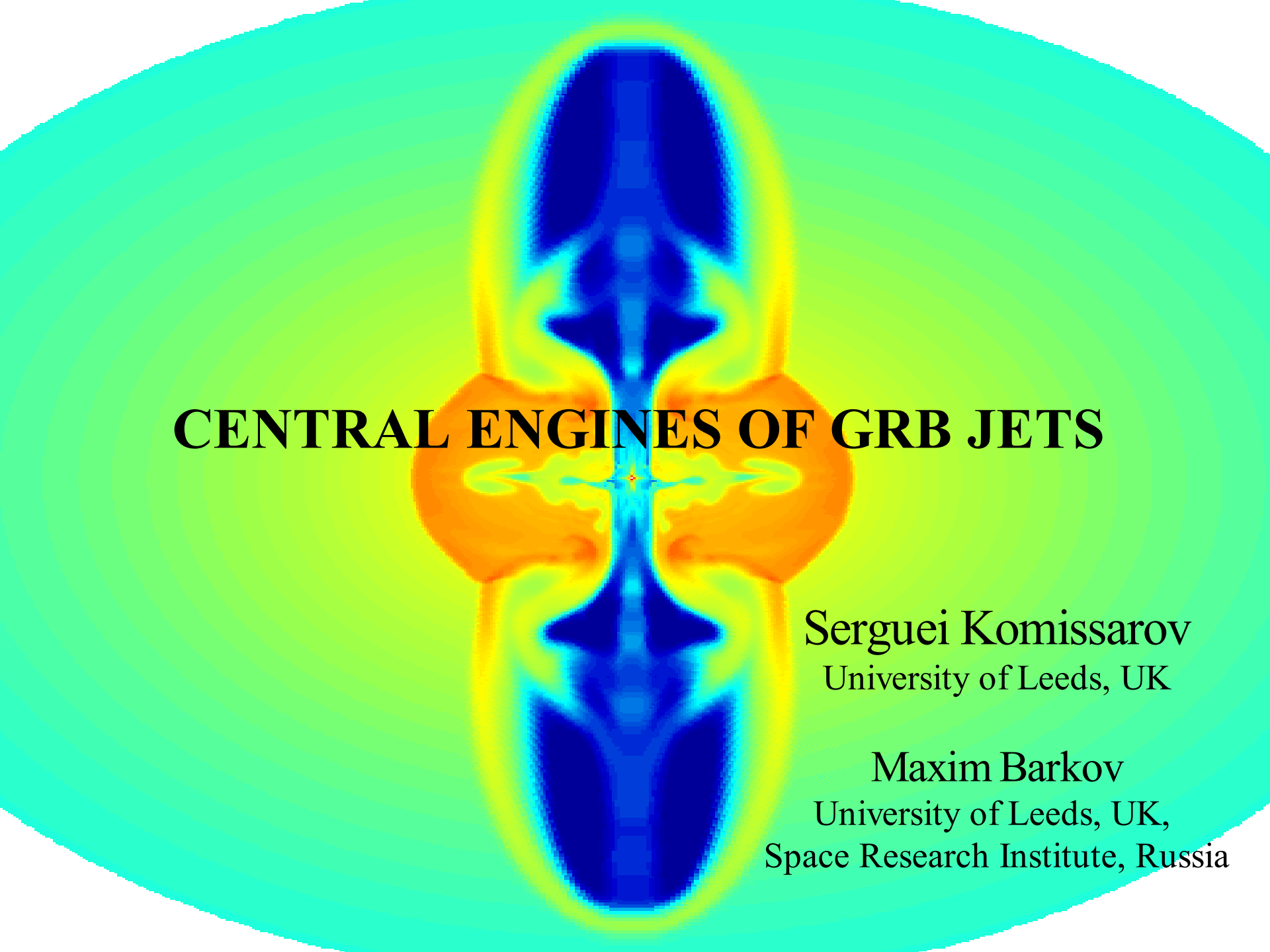


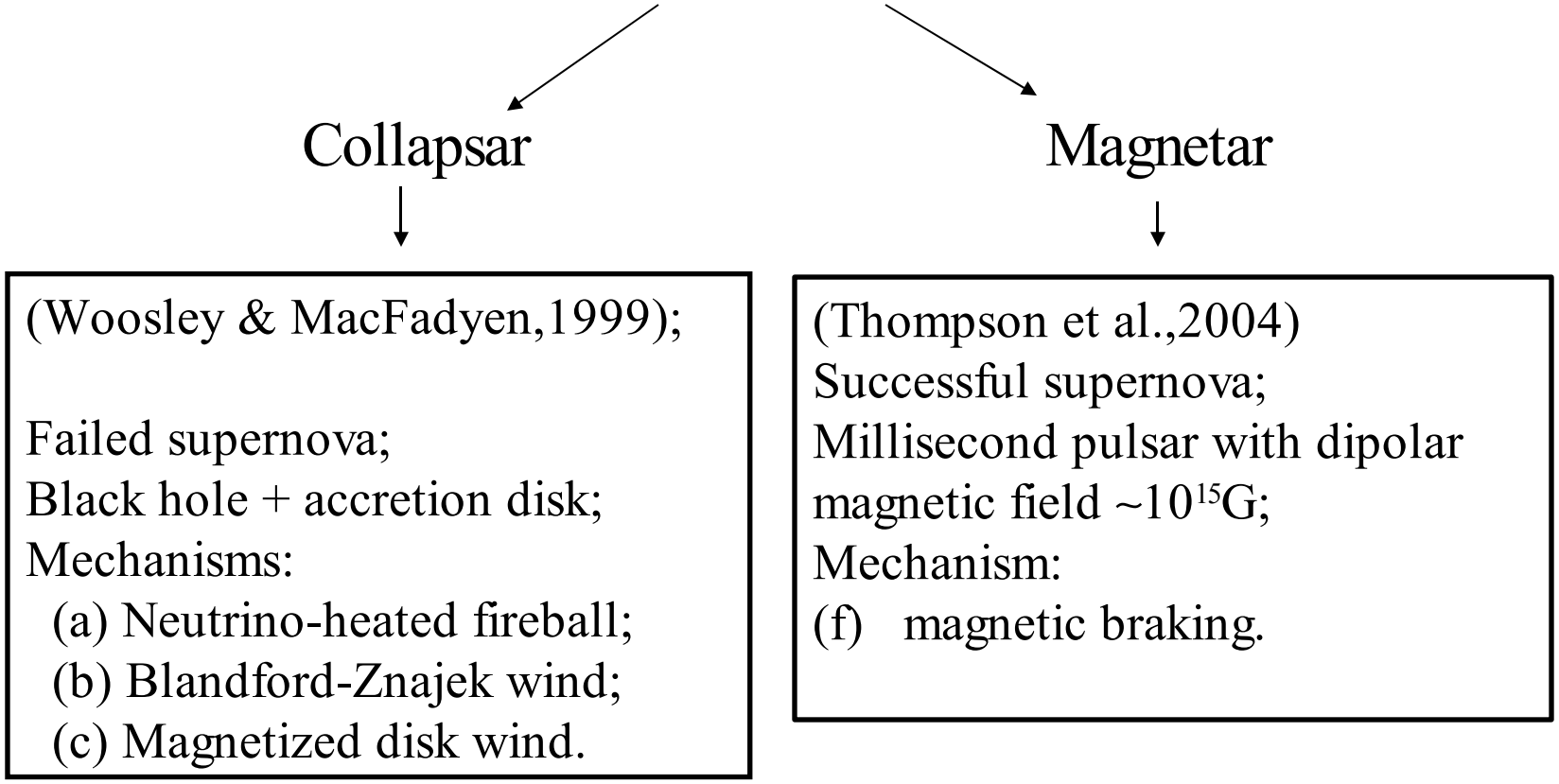
# CENTRAL ENGINES OF GRB JETS

Serguei Komissarov
University of Leeds, UK

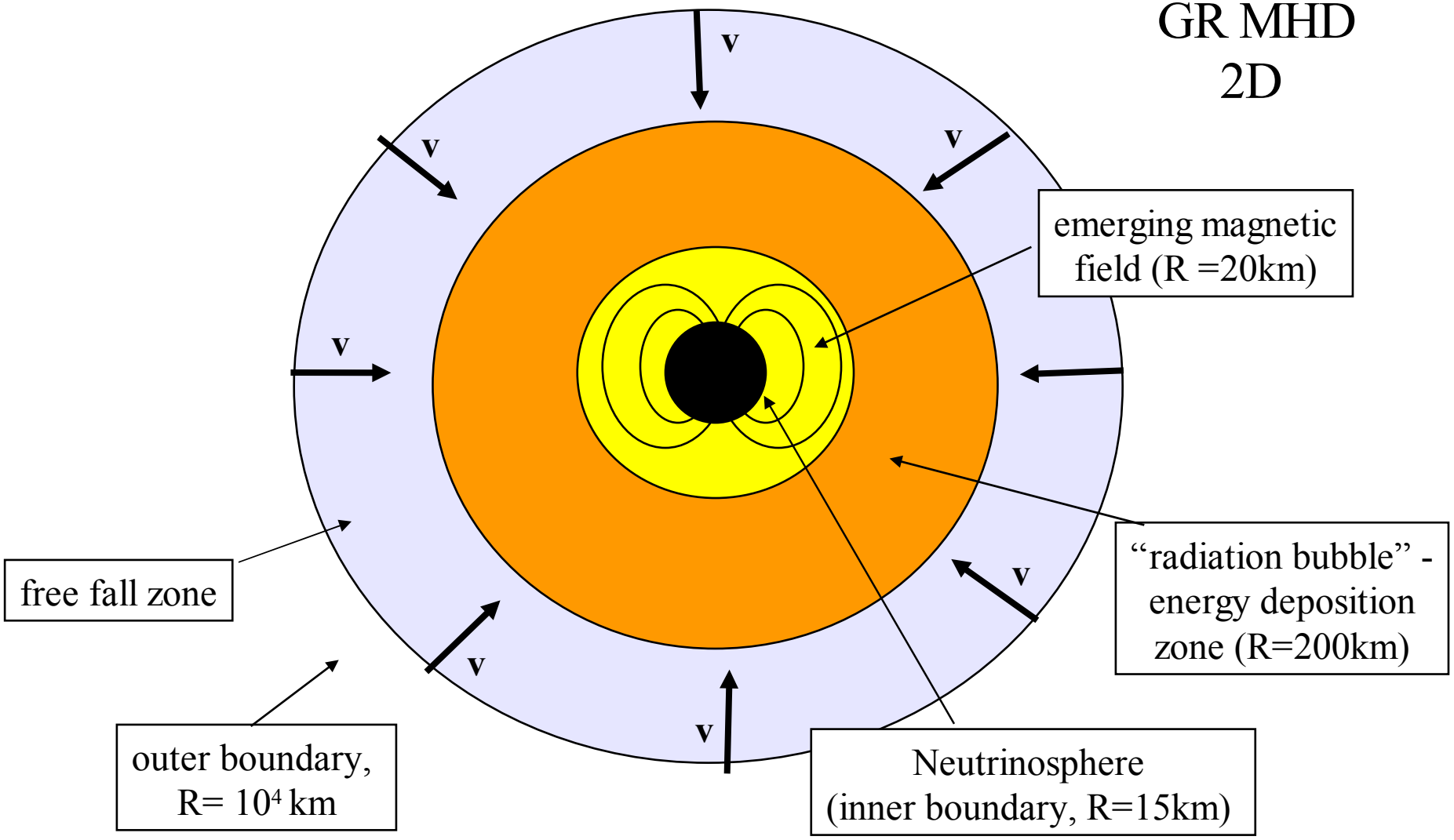
Maxim Barkov
University of Leeds, UK,
Space Research Institute, Russia

# I. Introduction

Origin of long GRB jets



# II. Magnetar simulations setup



# II. Magnetar simulations setup

*Free fall model of collapsing star* (Bethe 1990)

radial velocity: $v^{\hat{r}} = -(2GM/r)^{1/2}$

mass density: $\rho = C \times 10^7 \left(\frac{t}{1\mathrm{s}}\right)^{-1} \left(\frac{r}{100\mathrm{km}}\right)^{-3/2} \mathrm{g\ cm^{-3}}$

accretion rate: $\dot{M} = 0.038\ C \left(\frac{M}{1.4 M_\odot}\right)^{1/2} \left(\frac{t}{1\mathrm{s}}\right)^{-1} M_\odot \mathrm{s}^{-1}$

Bethe gives $C$=1-10; we set $C$=*3* and $t$=1s.

specific angular momentum: $l = 10^{16} \sin\theta$ cm$^2$/s

*Energy of radiation bubble (heat):* $10^{51}$ erg

# II. Magnetar simulations setup

*Inner boundary (R=15km):*

Rotation period: P=2ms; poloidal velocity: $v_p=0$

Mass density: $\rho=3\times10^9 g/cm^3$; gas temperature: T=4 Mev (Thompson et al.,2001);

Neutrino luminosity: $L(R,T)= 6.5\times10^{51}$ erg/s in each flavour;

Neutrino energy: $E_\nu=3.15T=12.6$ Mev in each flavour;

Magnetic field: "squashed" dipole, $B_0=10^{15}$ G;

*Gravity:* gravitational field of magnetar only (Schwarzschild metric); no self-gravity;

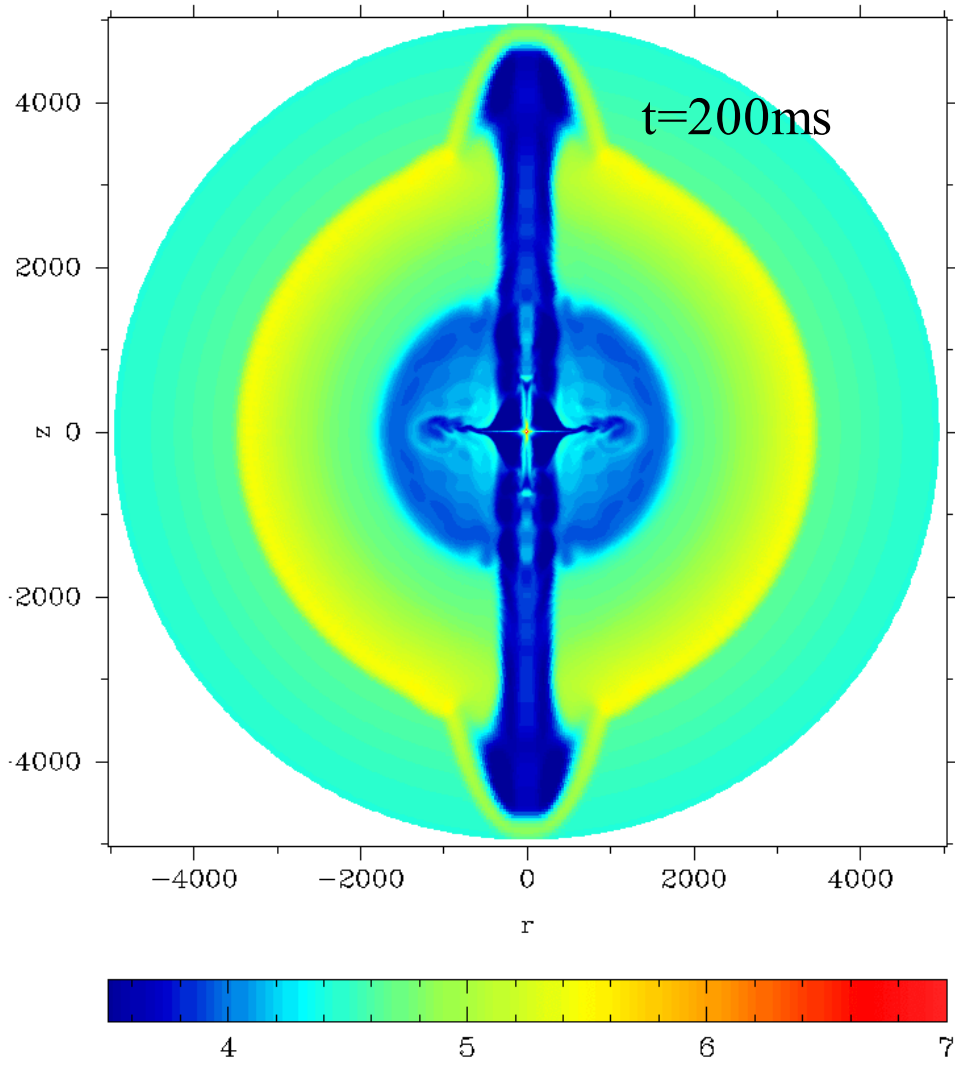
*Microphysics:* neutrino transport – optically thin regime;
neutrino cooling and heating (Thompson et al.,2001);
realistic equation of state, (HELM, Timmes & Swesty, 2000);
dissociation of nuclei (Ardeljan et al., 2005);
no physical resistivity (only numerical);

# III. Magnetar simulations results

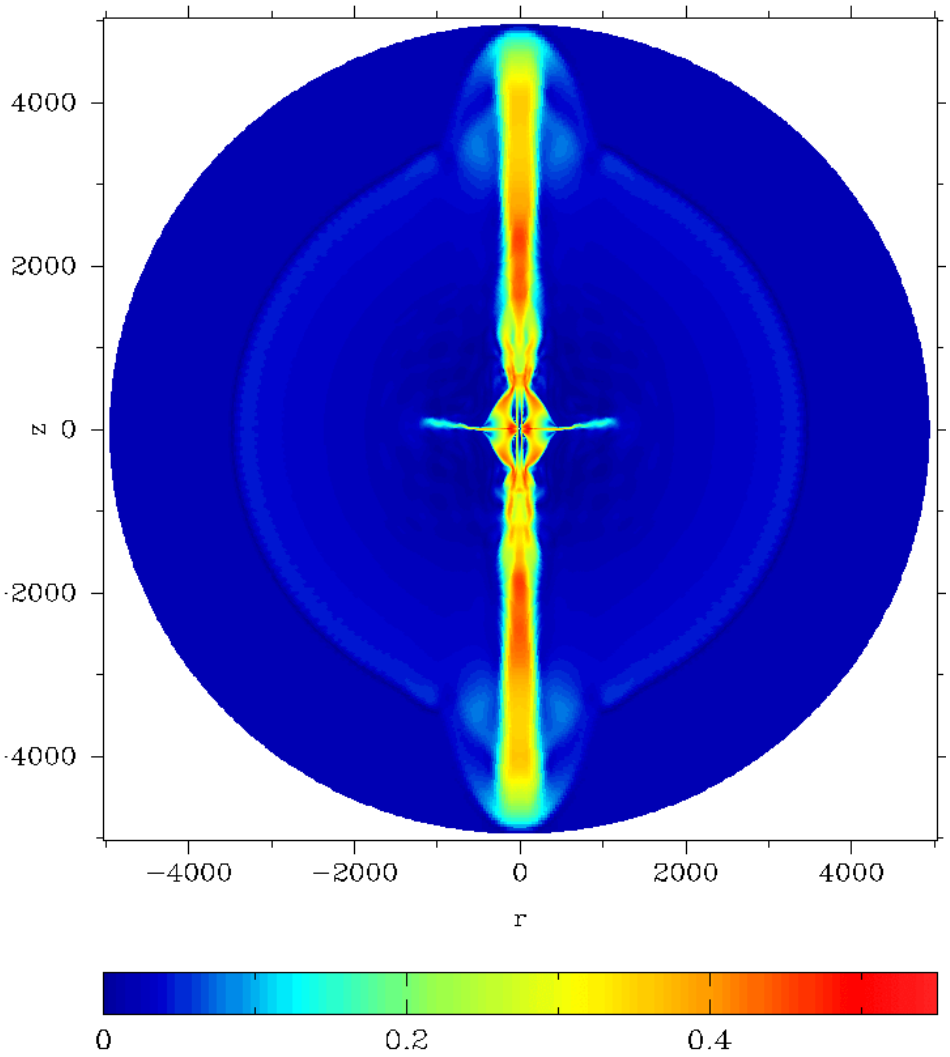
*movie 1: inner region - 1000 km radius;*
*colour image - log(ρ), g/cm³*

*movie 2: inner region - 1000 km radius;*
*lines and colour – poloidal magnetic field lines*

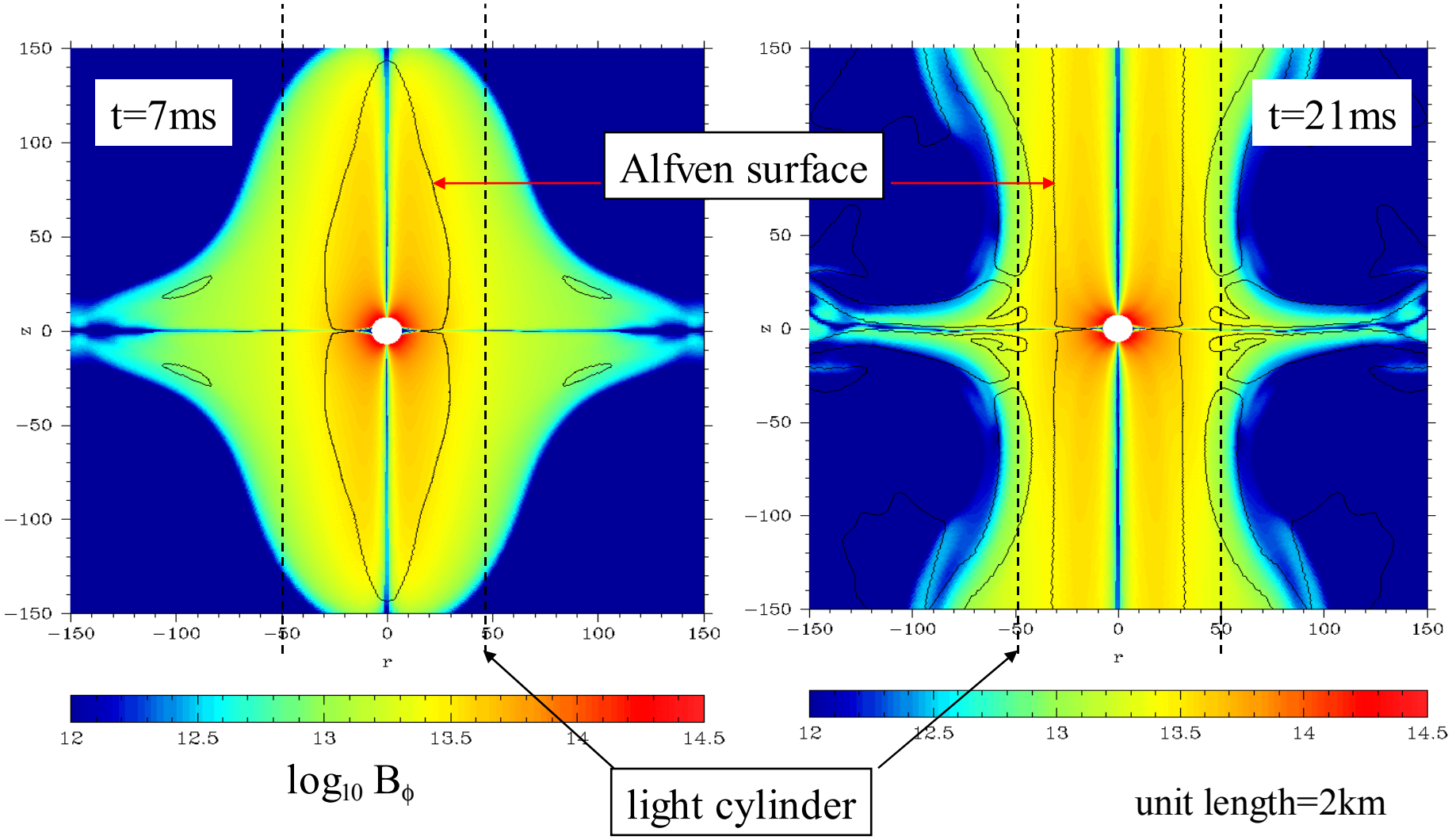
unit length=2km



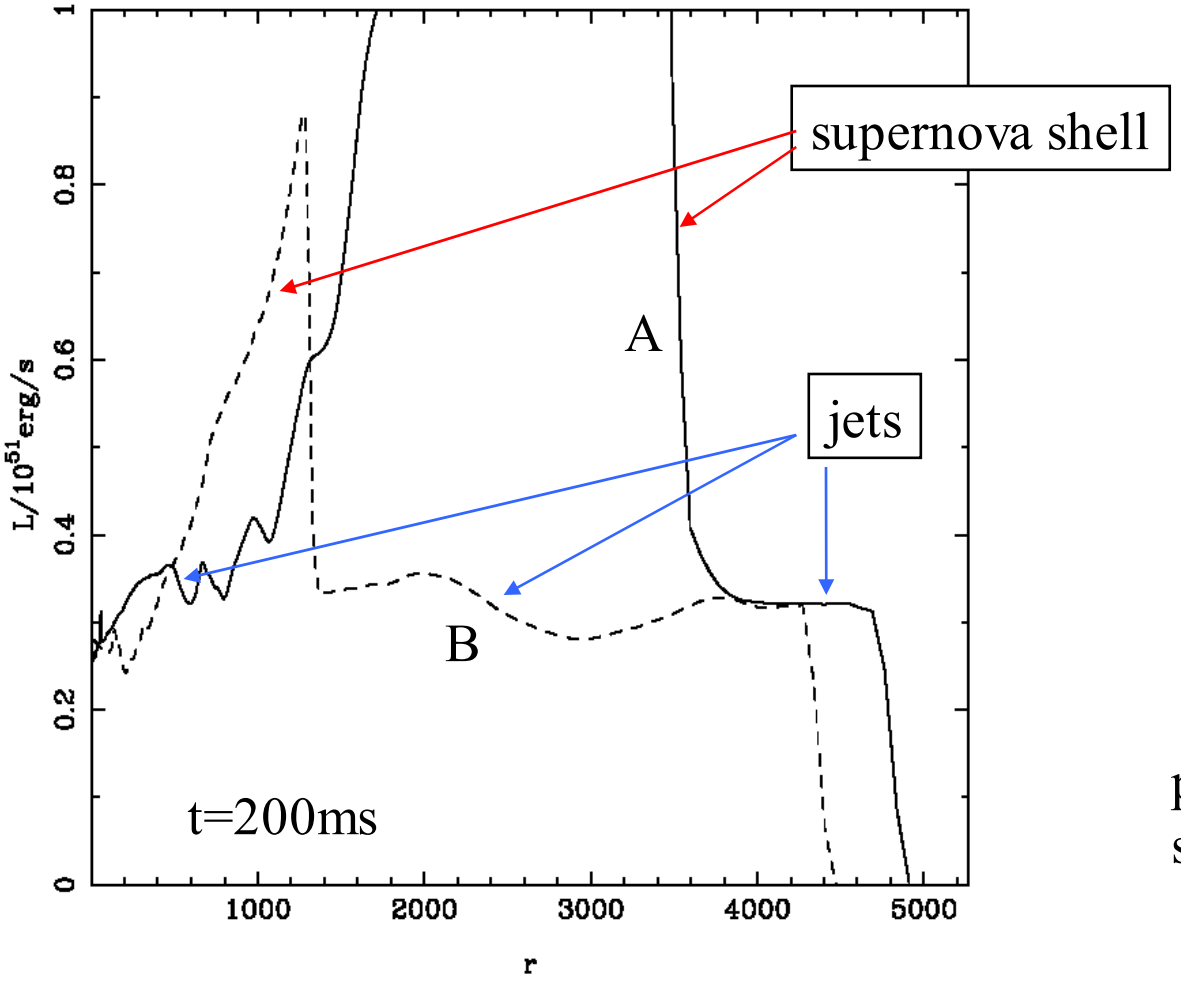

$\log_{10}\rho$ density (g/cm$^3$);




$v_p/c$


t=7ms
t=21ms
Alfven surface
light cylinder
unit length=2km
log10 Bϕ
z
r
150
100
50
0
−50
−100
−150
12
12.5
13
13.5
14
14.5

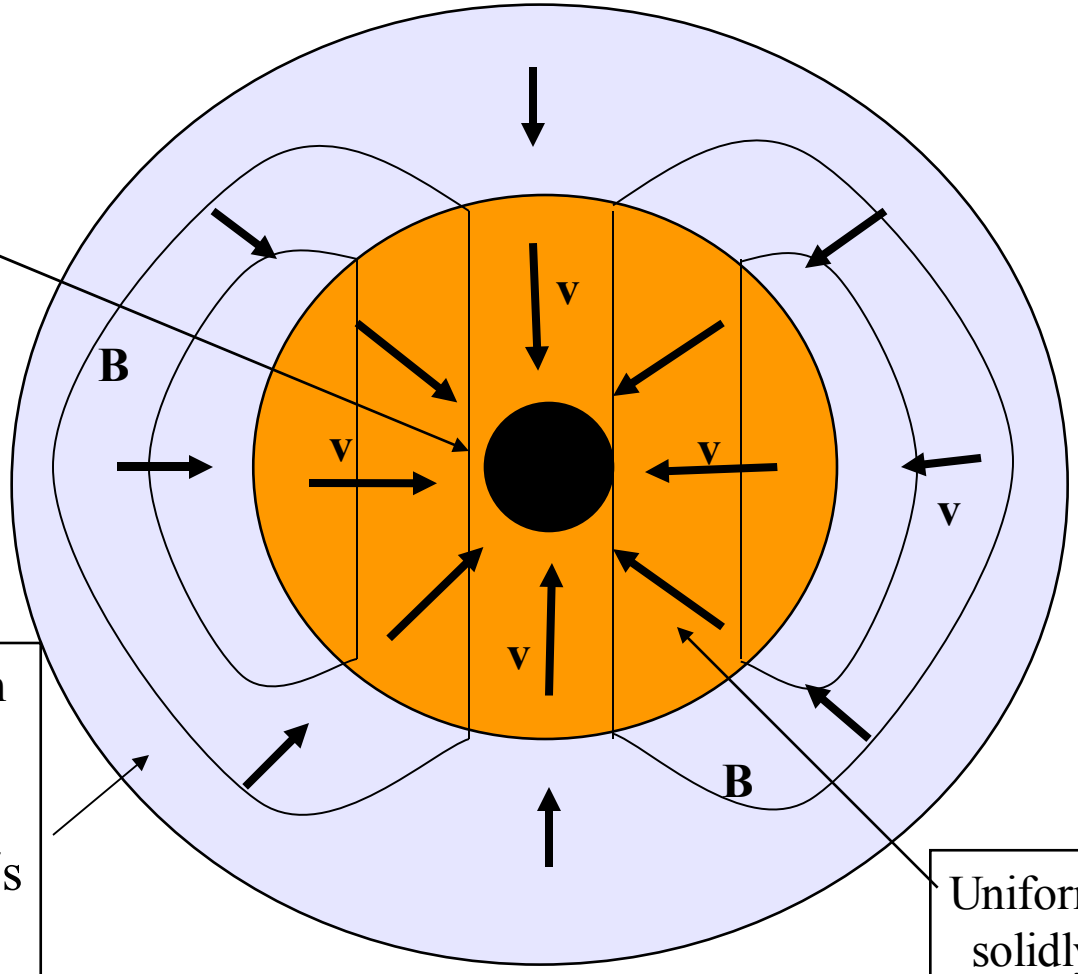
# *Power of jets*




power ~ 3 ×$10^{50}$ erg/s;
spin-down time ~30 s.

# IV. Collapsar simulations setup

GR MHD
2D




black hole
$M=3M_3$
$a=0.9$

free fall zone with specific angular momentum
$l=10^{17}\sin\theta$ cm$^2$/s
and
Bethe's C=9

Uniformly magnetized solidly rotating core
R=3000km
$B_0= 10^9$-$10^{10}$G

No neutrino heating

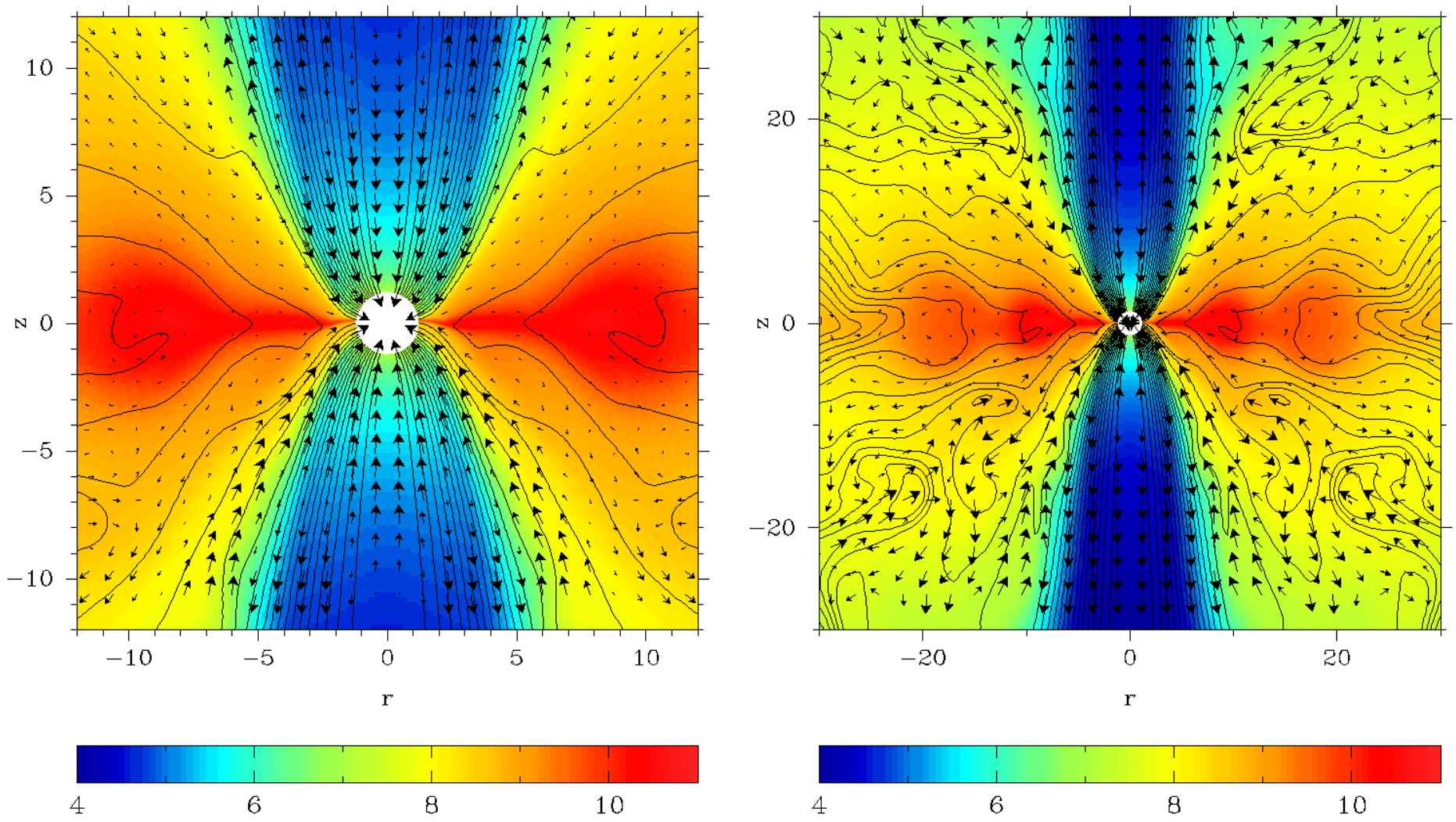
# V. Collapsar simulations results

*movie 1:* $B_0=10^9 G$
*inner region - 800 km radius;*
*colour image - $\log(\rho)$, $g/cm^3$*

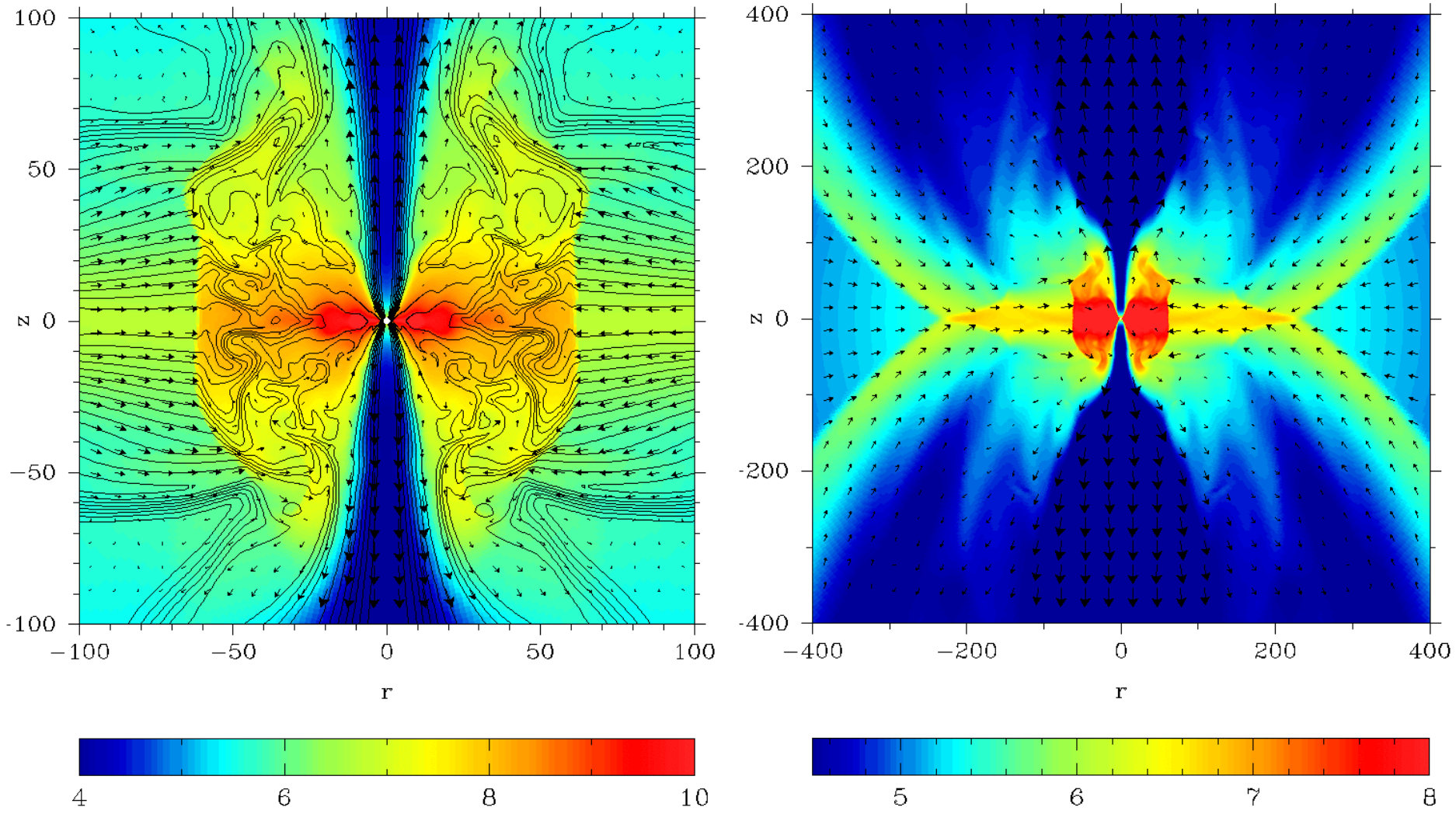
*movie 2:* $B_0=10^{10} G$
*inner region - 800 km radius;*
*colour image - $\log(\rho)$, $g/cm^3$*

*movie 3:* $B_0=10^{10} G$
*inner region - 16000 km radius;*
*colour image - $\log(P/P_m)$,*

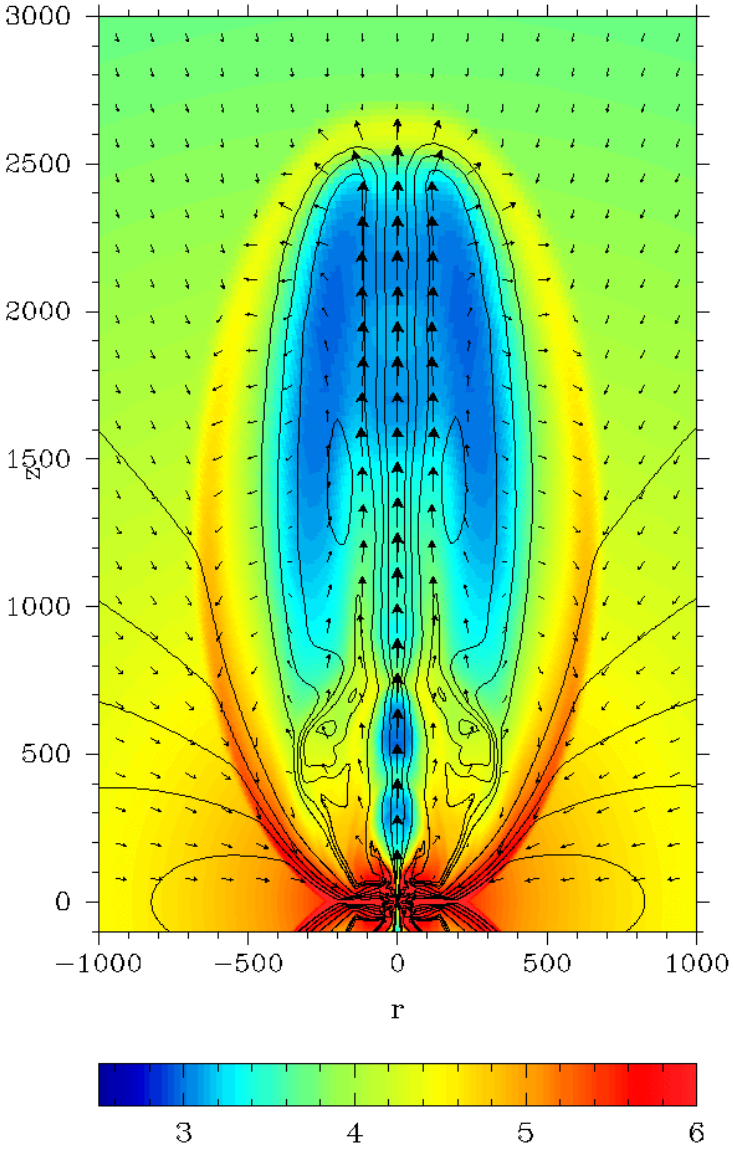
unit length=4km
t=0.4s



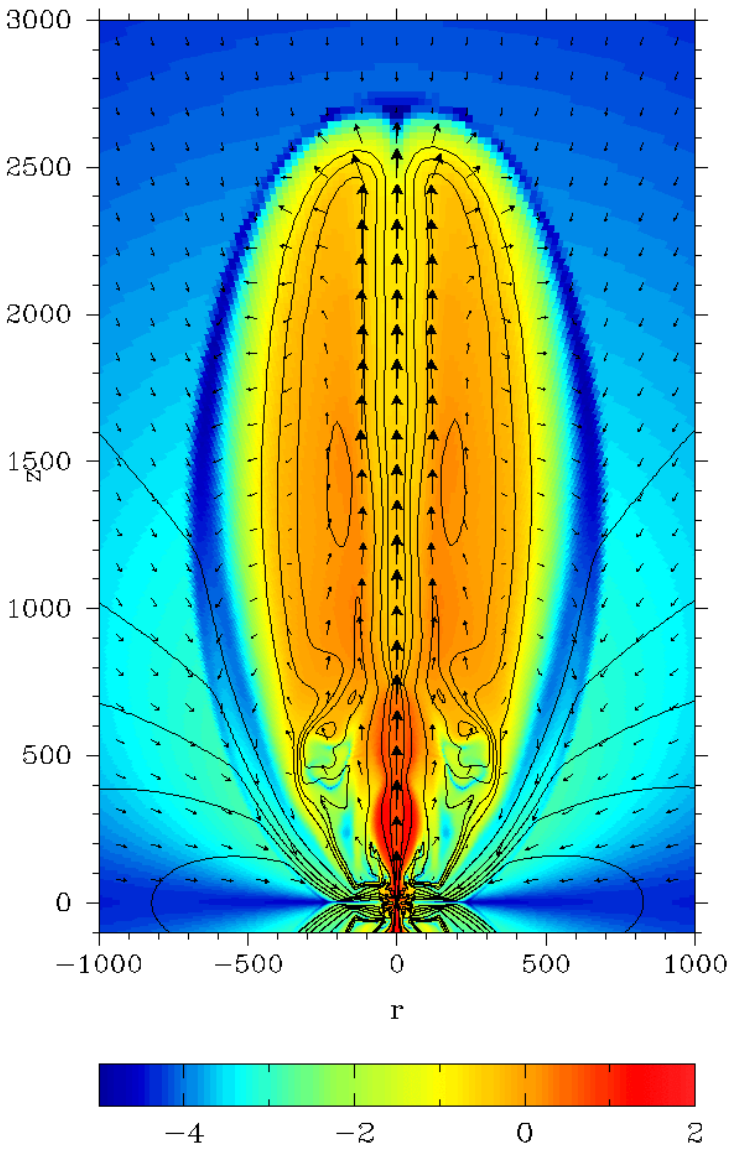

$\log_{10}\rho$ (g/cm$^3$), magnetic field lines, and velocity vectors



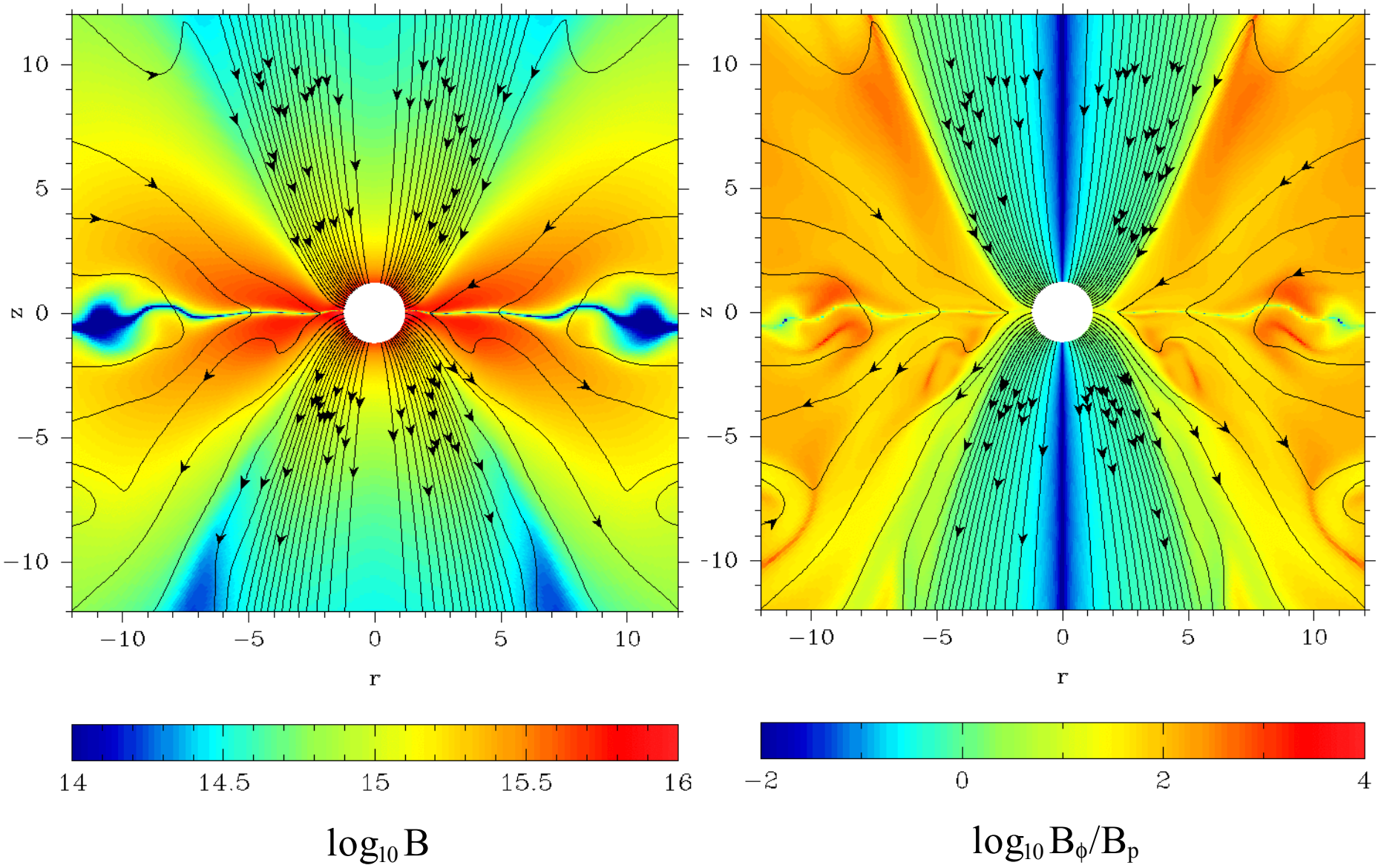

$\log_{10}\rho$ (g/cm$^3$), magnetic field lines, and velocity vectors

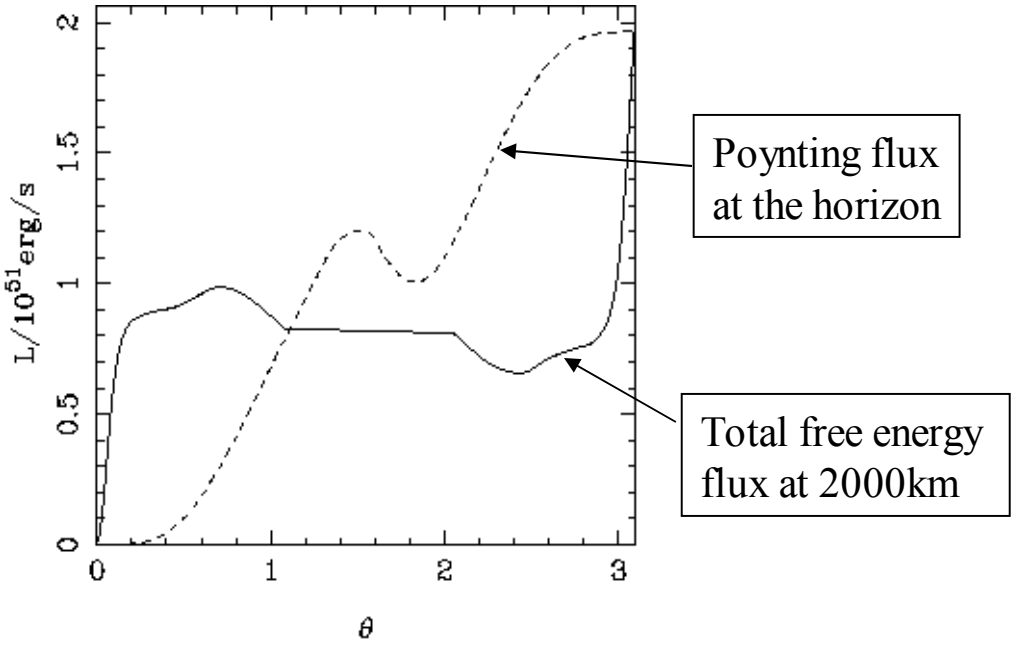


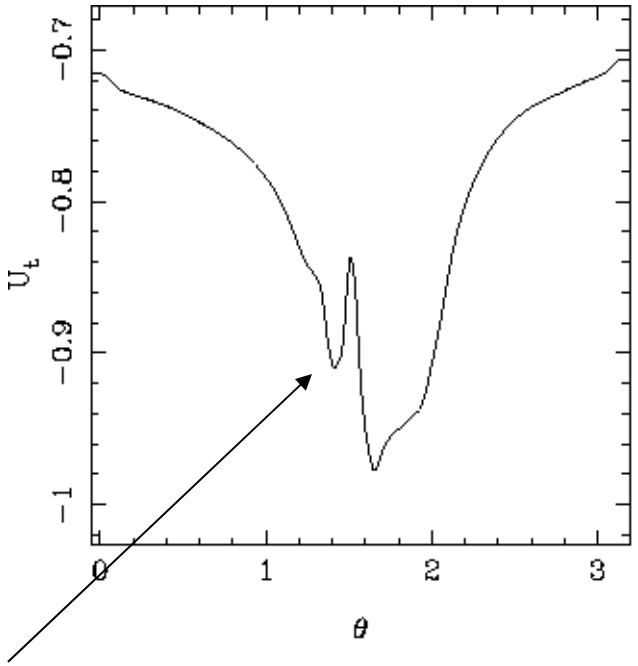

$\log_{10}\rho$




$\log_{10} P_m/P$


10
5
0
−5
−10
z
−10
−5
0
5
10
r
14
14.5
15
15.5
16
log10 B
−2
0
2
4
log10 Bϕ/Bp




$U_t<0$ at the event horizon –
MHD-Penrose does not work

Blandford-Znajek power:

$$L \simeq \frac{B_p^2 \Omega^2 r_+^4}{4c} \simeq 1.3 \times 10^{51} erg/s$$

# VI. Summary

*Magnetar scenario:*

- Magnetars can drive hypernovae and GRB jets;
- The jets can be produced at very early stages of the explosion;
- For P=2ms, R=15km, B=$10^{15}$ G the jet power is ~ 3 ×$10^{50}$ erg/s;

*Collapsar scenario:*

- Relativistic magnetically-driven jets can be produced if the progenitor star has $B_0$ >$10^9$G;
- They are powered by the Blandford-Znajek mechanism;
- For $B_0$=$10^{10}$G, a=0.9, C=9 the jet power is ~ 2 ×$10^{51}$ erg/s; Near the black hole B ~ $10^{16}$G; mainly toroidal in the disk, poloidal~toroidal in the funnel.

*Magnetars*:

*Gamma-Ray-Repeaters and Anomalous X-ray pulsars* -
isolated neutron stars with dipolar(?) magnetic field of $10^{14}$- $10^{15}$ G;

(e.g. Woods & Thompson, 2004 )

Rotational energy:

$$E_{rot} \simeq 2 \times 10^{52} \left(\frac{R}{10km}\right)^2 \left(\frac{P}{1ms}\right)^{-2} erg \quad (M = 1.4 M_{Sun})$$

Standard pulsar wind power (Contopolous et al., 1999):

$$L \simeq 6 \times 10^{49} \left(\frac{B}{10^{15}G}\right)^2 \left(\frac{R}{10km}\right)^6 \left(\frac{P}{1ms}\right)^{-4} erg/s$$

Non-relativistic mass-loaded pulsar wind power (Bucciantini et al.,2006) :

$$L \simeq 4 \times 10^{51} \left(\frac{B}{10^{15}G}\right)^2 \left(\frac{R}{10km}\right)^4 \left(\frac{P}{1ms}\right)^{-5/3} erg/s$$

*Previous numerical studies:*

Bucciantini et al. (2006): Unconfined magnetar winds of variable magnetisation (isentropic eos);

Bucciantini et al. (2007): Applied the Pulsar Wind Nebula model to magnetar-boosted supernova explosion; thin shell approximation (late stages (t >1s);

*We focus on the initial stages of explosion (*t<1s*).*

movie 1

movie 1

movie 1