HOW TO LAUNCH MAGNETICALY DRIVEN GRB COLLAPSAR MODEL?

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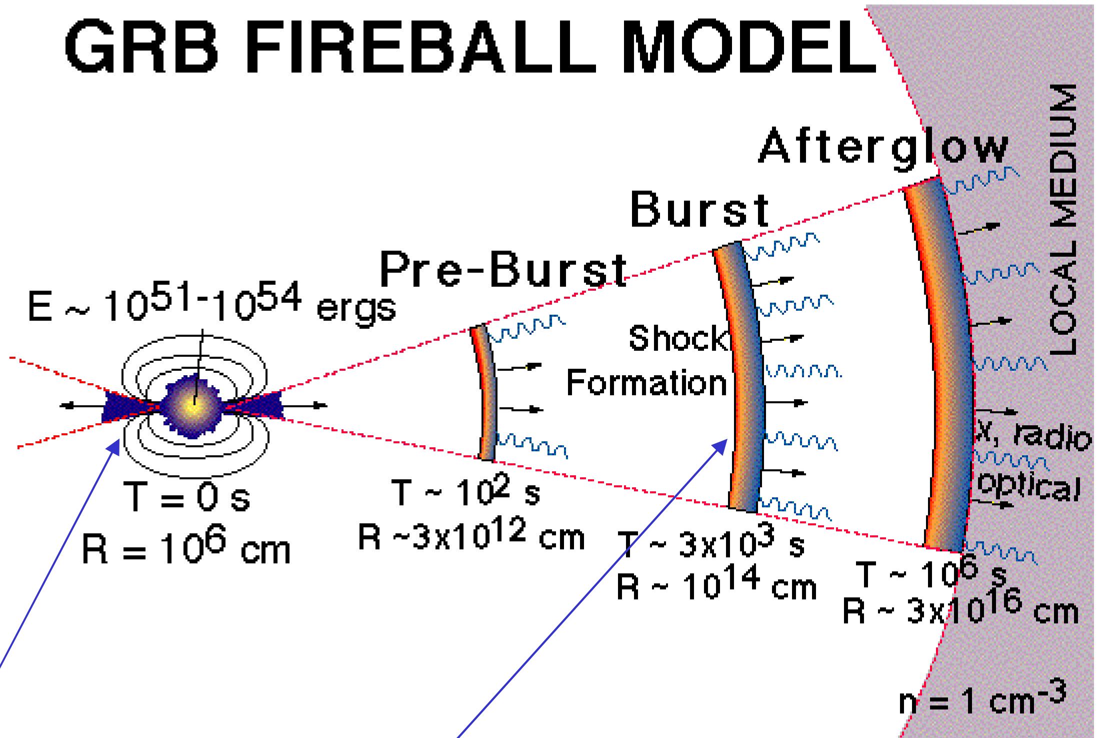
Relativistic jet/pancake model of GRBs and afterglows:



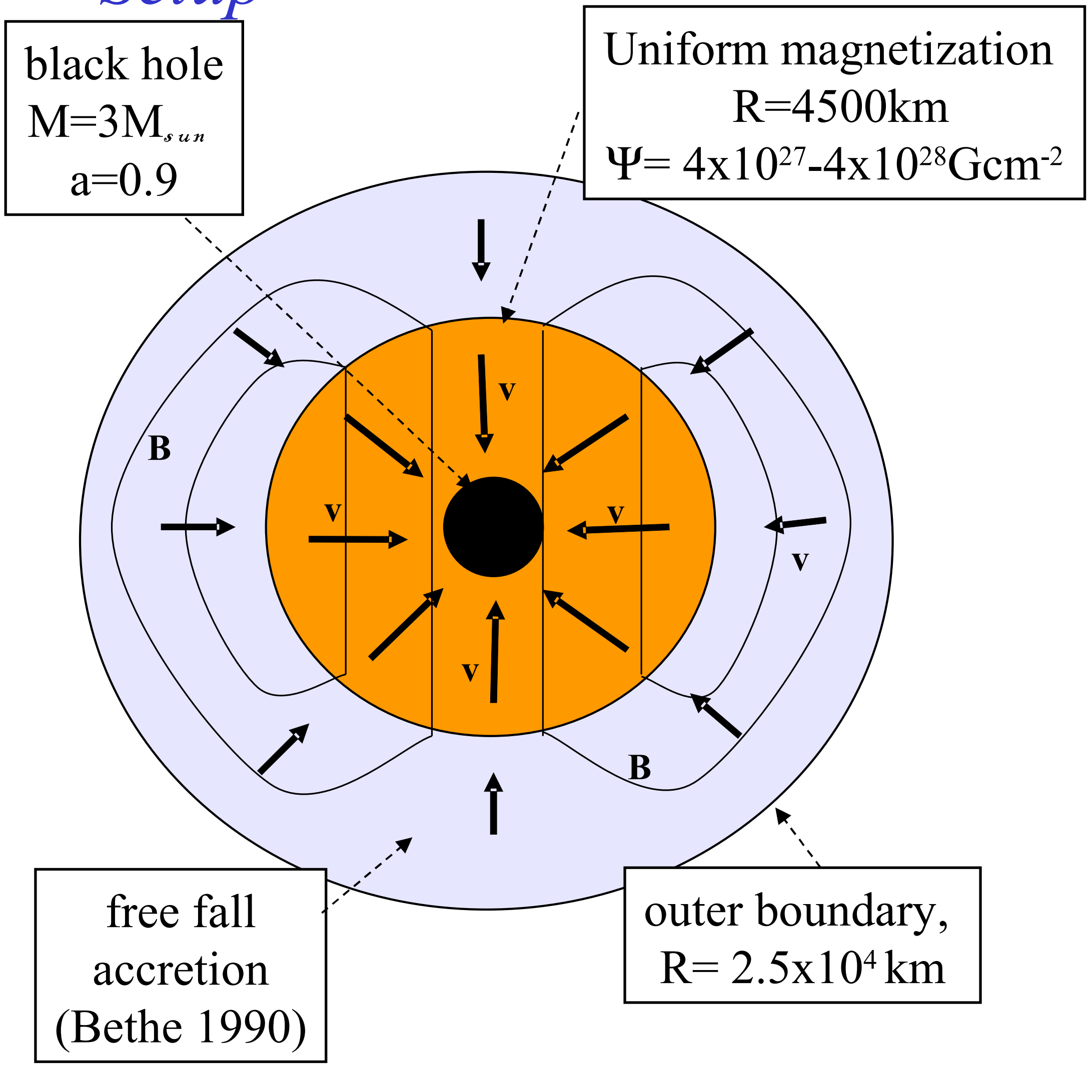
jet at birth
(we are here)

pancake later

I. *Numerical simulations*

Setup

(Barkov & Komissarov 2008a,b)
(Komissarov & Barkov 2009)



Rotation:

$$l = l_0 \sin^3\theta \ \min(r/r_c,1)^2$$

$r_c=6.3\times10^3$km

$l_0 = 10^{17}$ cm^2 s^{-1}

- 2D axisymmetric GRMHD;
- Kerr-Schild metric;
- Realistic EOS;
- Neutrino cooling;
- Starts at 1s from collapse onset. Lasts for < 1s

Free fall model of collapsing star (Bethe, 1990)

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

mass density: $\rho = C_1 \times 10^7 \left(\frac{t}{1s}\right)^{-1} \left(\frac{r}{100km}\right)^{-3/2} \mathrm{g/cm^3}$

accretion rate: $\dot{M} = 0.1 C_1 \left(\frac{t}{1s}\right)^{-1} \left(\frac{M}{10 M_{sun}}\right)^{1/2} M_{sun} s^{-1}$

Gravity: gravitational field of Black Hole only (Kerr metric);
no self-gravity;

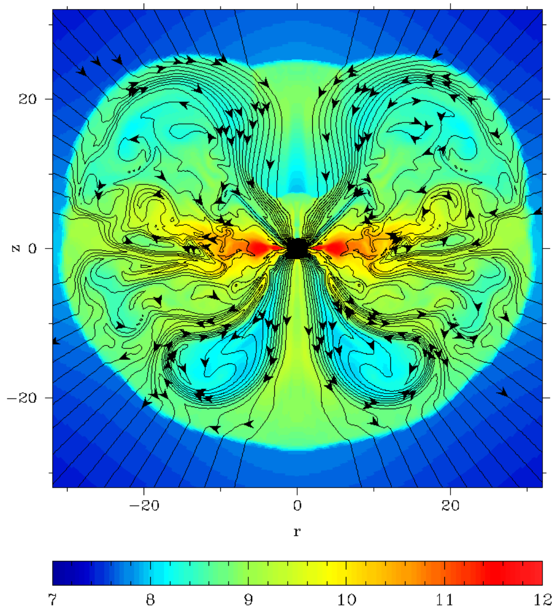
Microphysics: neutrino cooling ;
realistic equation of state, (HELM, Timmes & Swesty, 2000);
dissociation of nuclei (Ardeljan et al., 2005);
Ideal Relativistic MHD - no physical resistivity (only numerical);

Model:A

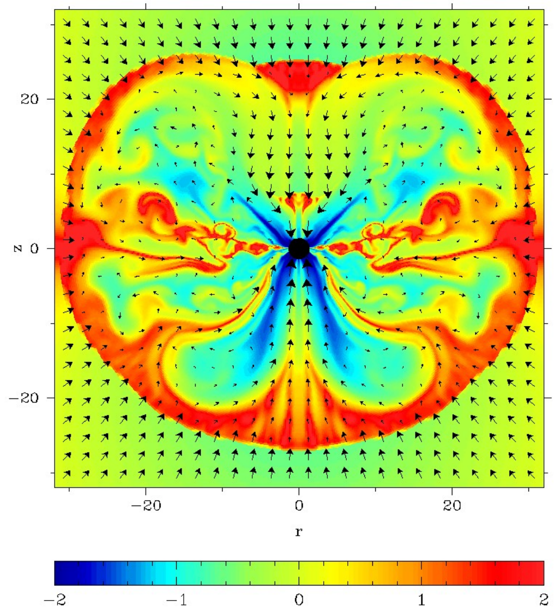
C_1=9; B_p=3x10^{10} G

unit length=4.5km
t=0.24s

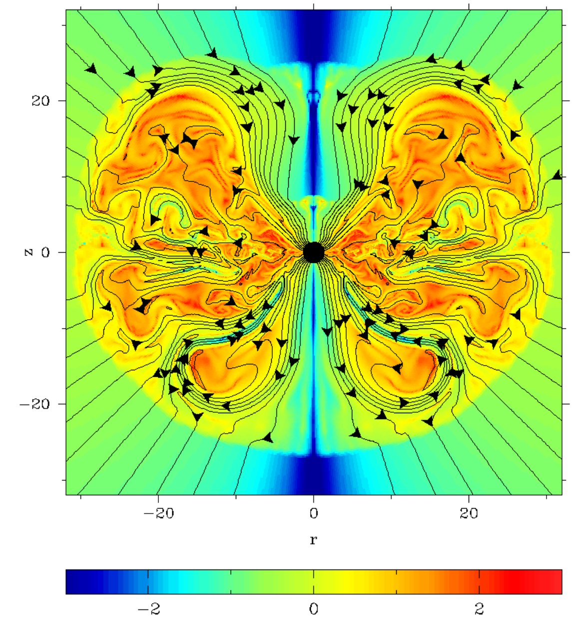
$\log_{10} \rho$ (g/cm^3)



$\log_{10} P/P_m$



$\log_{10} B_\phi/B_p$



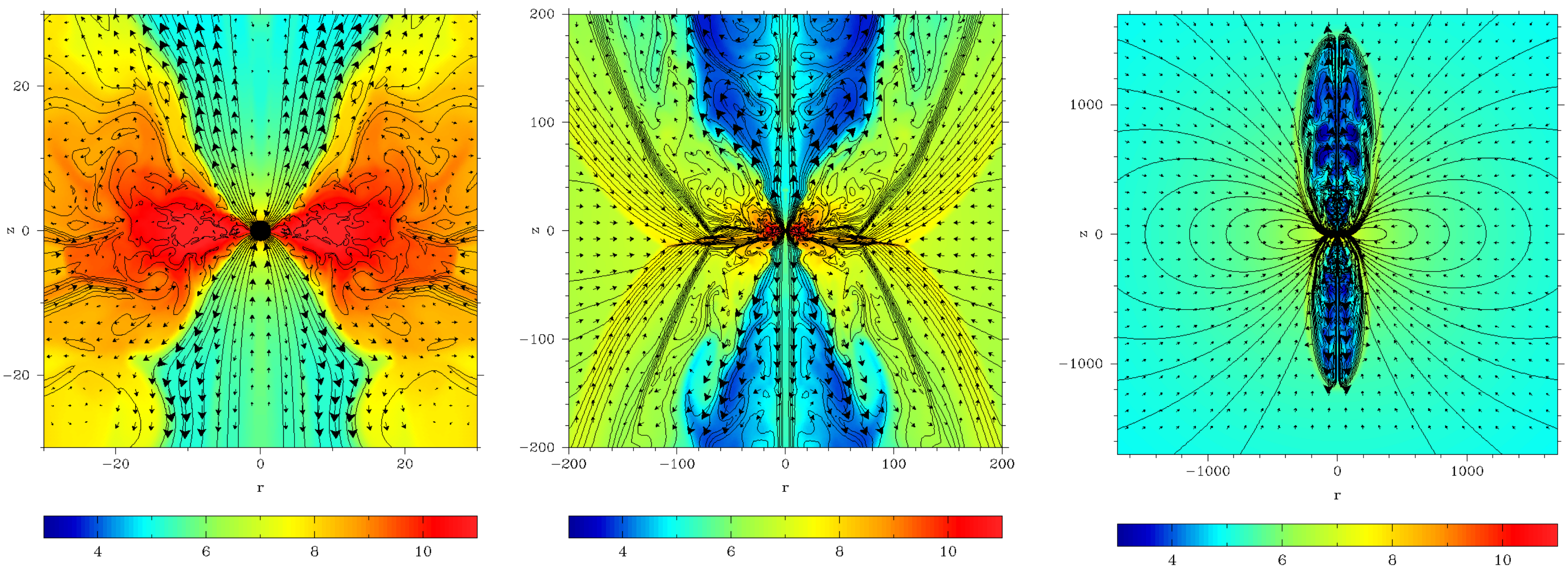
magnetic field lines, and velocity vectors

Model:A

C_1=9; B_p=3x10^{10} G

unit length=4.5km
t=0.31s

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



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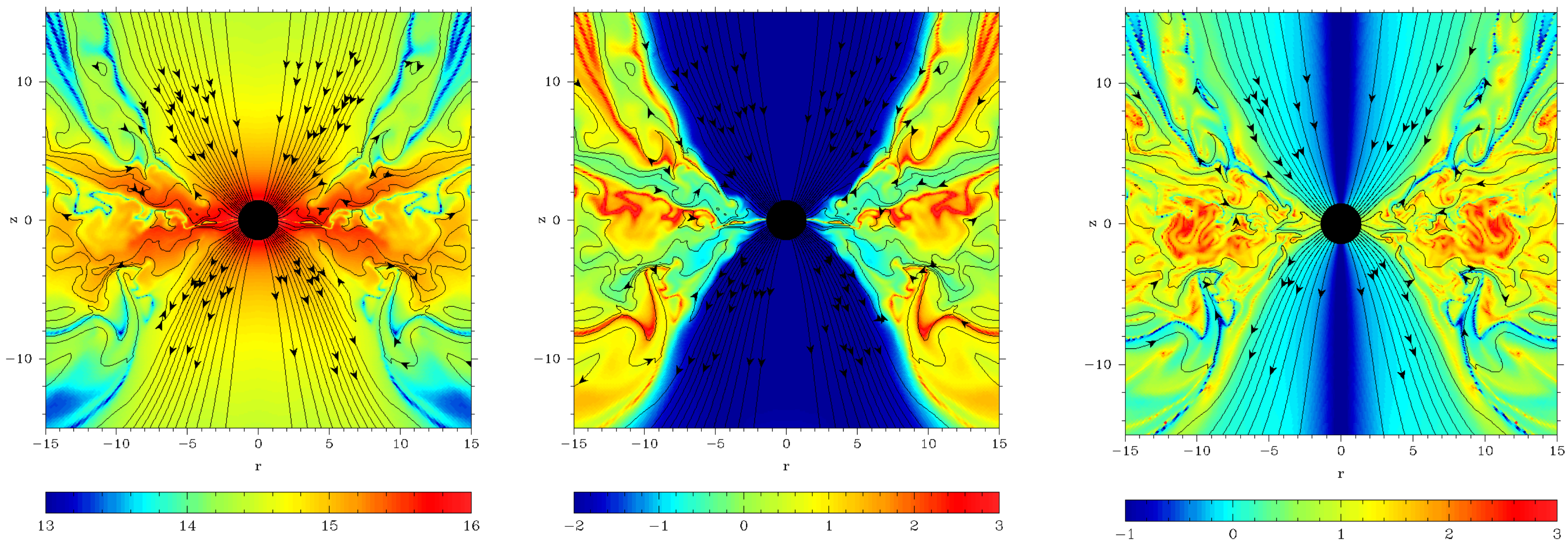
$\log_{10} B$ $\log_{10} P/P_m$ $\log_{10} B_\phi/B_p$



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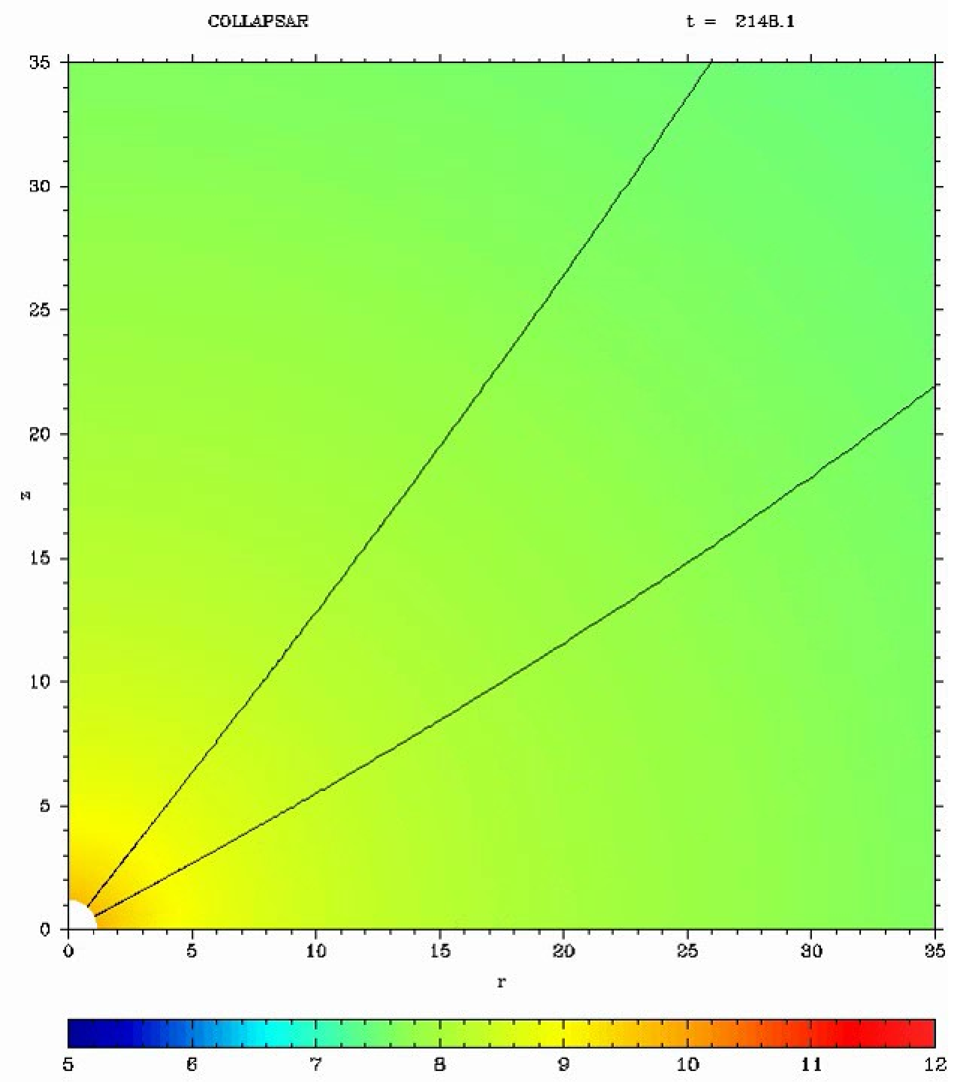
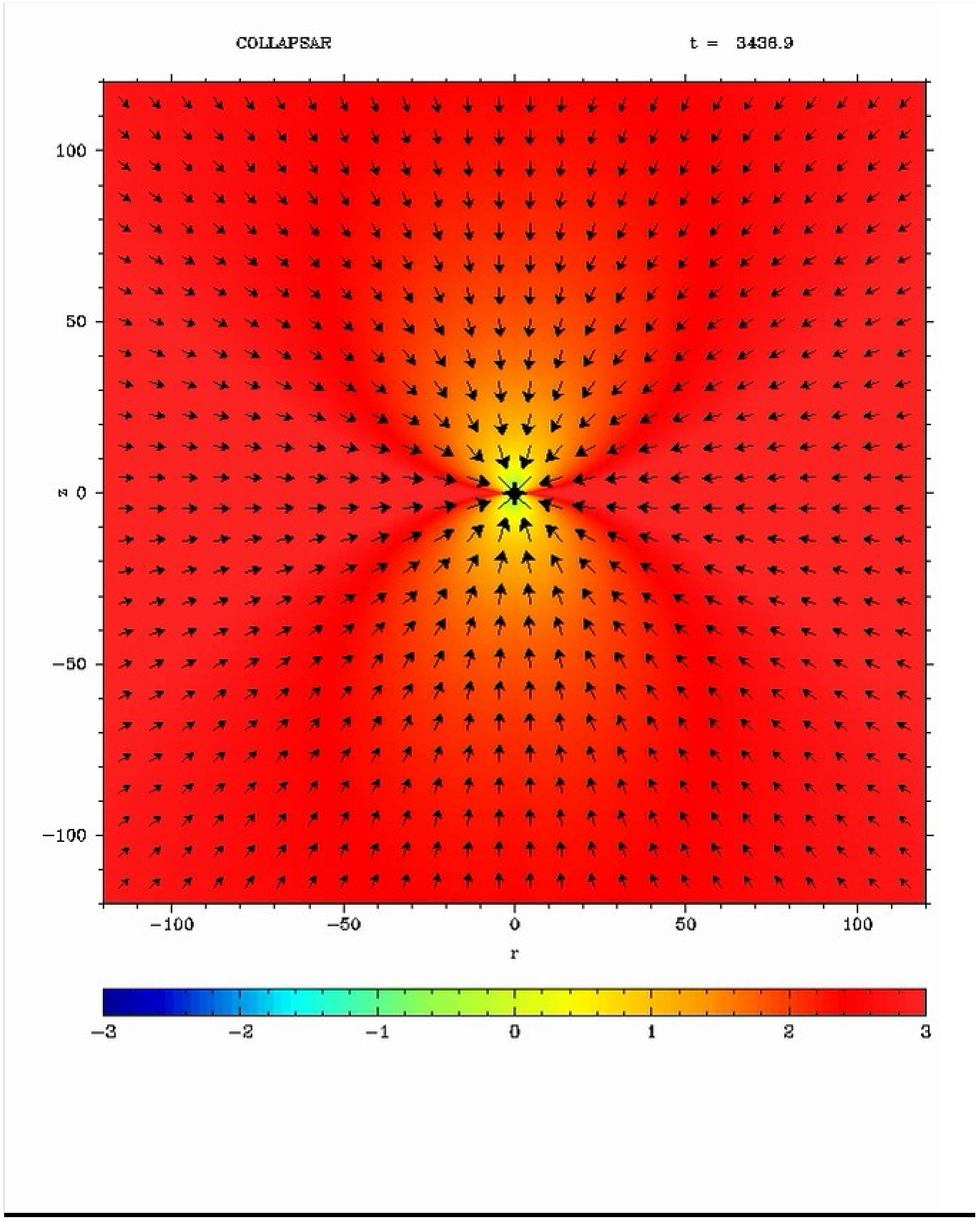


Model:C

$C_1=3; \quad B_p=10^{10}$ G

$\log_{10} P/P_m$

velocity vectors



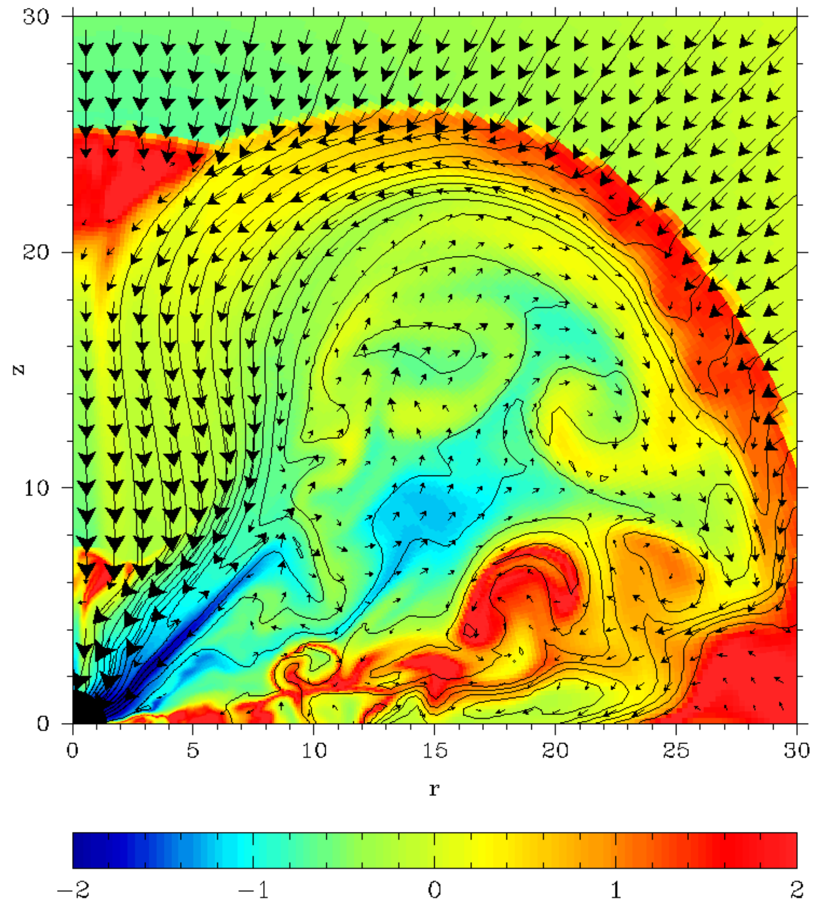
II. Magnetic Unloading

What is the condition for activation of the BZ-mechanism ?

1) MHD waves must be able to escape from the black hole ergosphere to infinity for the BZ-mechanism to operate, otherwise expect accretion.

or $B^2/4\pi\rho c^2 > 1$

2) The torque of magnetic lines from BH should be sufficient to stop accretion

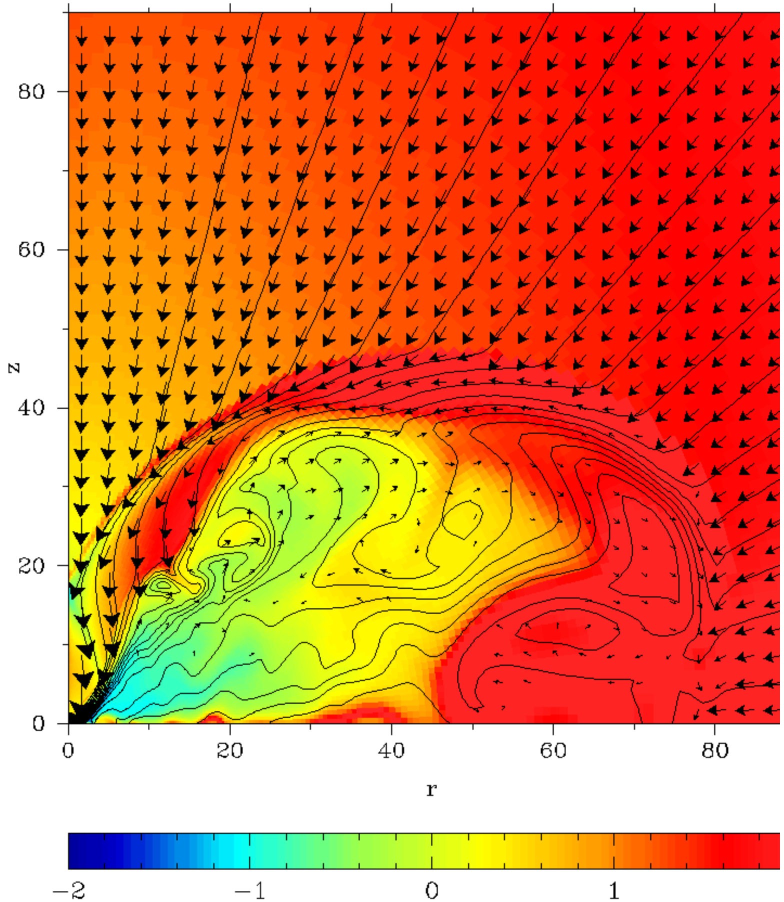


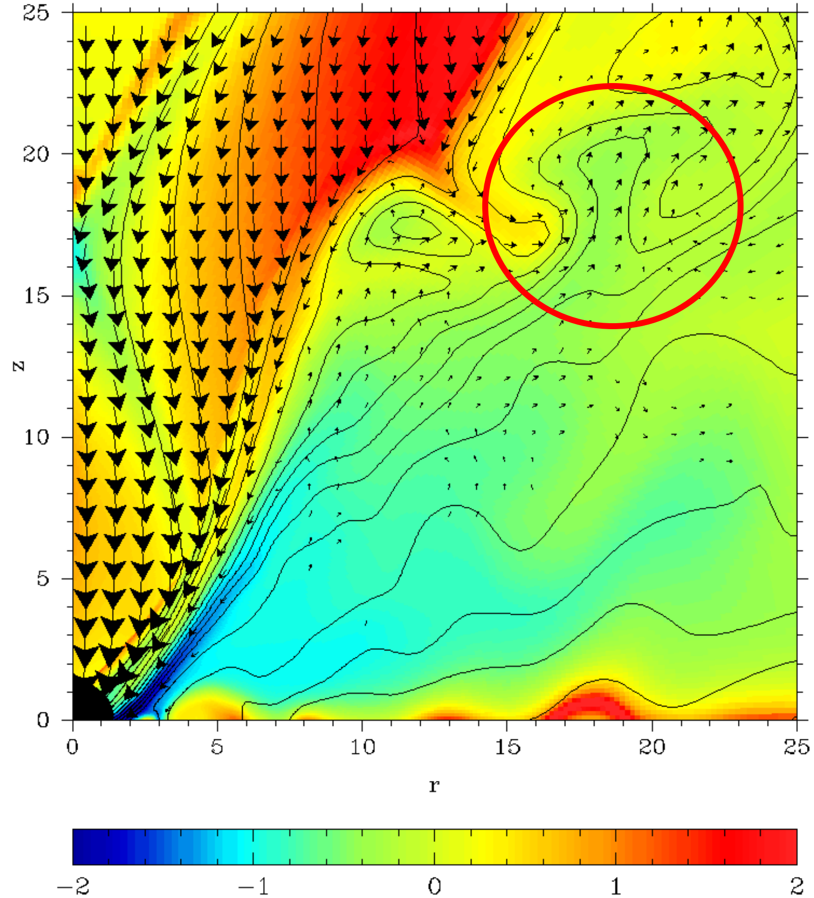
$\Rightarrow$ $\dot{E}_{BZ} / \dot{M}c^2 = \kappa > 1$ (???)

$$\dot{E}_{BZ} = 3.6\times 10^{50} f(a)\Psi_{27}^{2} M_{2}^{-2}$$

$$f(a) = \frac{a^2}{\left(1+\sqrt{1-a^2}\right)^2}$$

(Barkov & Komissarov 2008b)
(Komissarov & Barkov 2009)





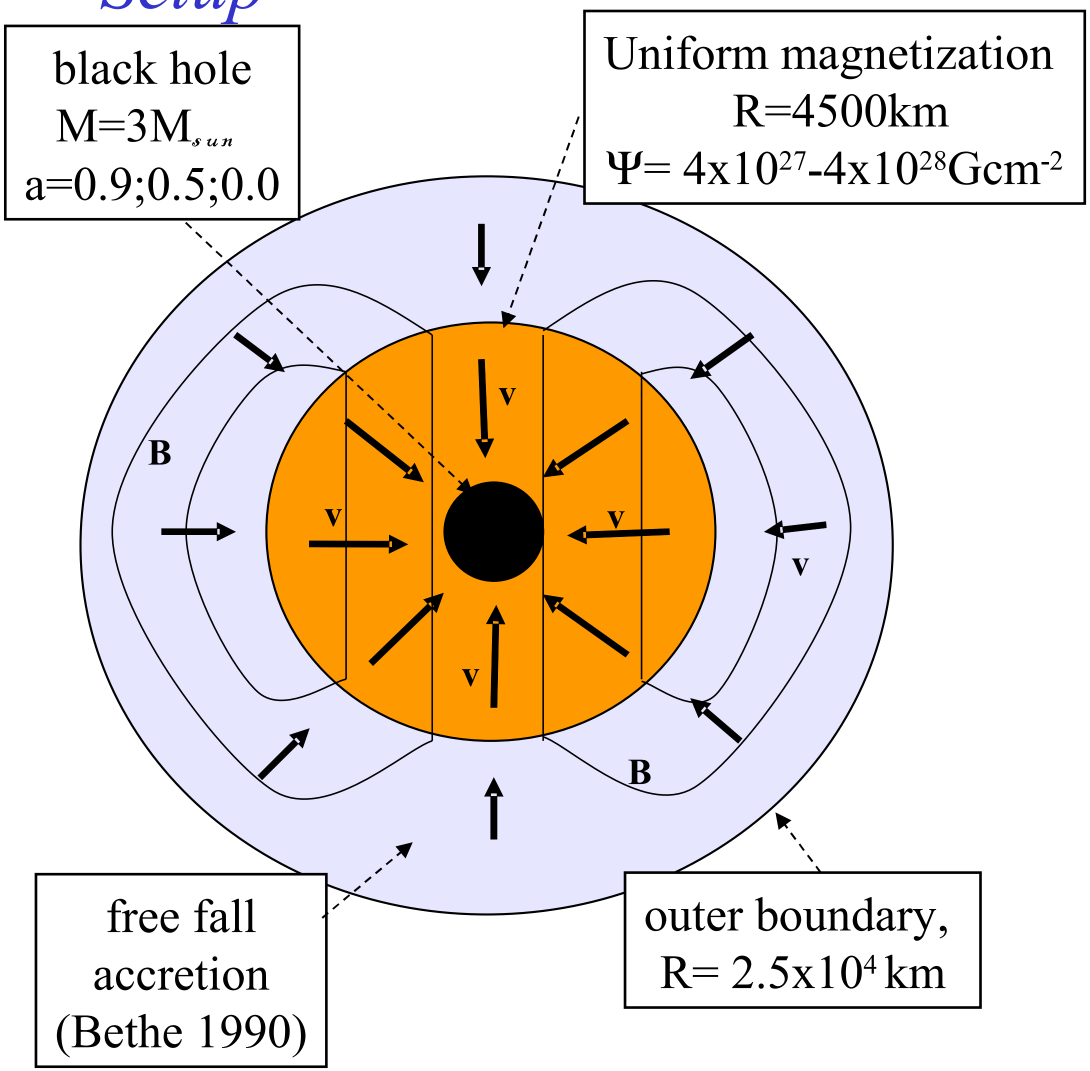
The disk accretion makes easier the explosion conditions. The MF lines shape reduce local accretion rate.

$$\dot{E}_{BZ} / \dot{M}c^2 = \kappa > 1/10$$

III. *Numerical simulations II: Angular Momentum*

Setup

(Barkov & Komissarov 2008a,b)
(Komissarov & Barkov 2009)



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r_c=6.3x10^{3}km

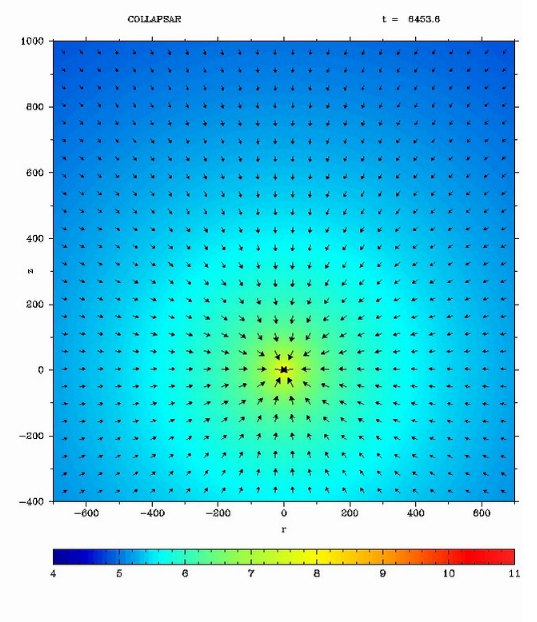
l_0 = 1-3x10^{17} cm^2 s^{-1}

- 2D axisymmetric GRMHD;
- Kerr-Schild metric;
- Realistic EOS;
- Neutrino cooling;
- Starts at 1s from collapse onset. Lasts for < 1s

Preliminary results

C	B_{10}	$l_{max,17}$	a	Explosion	$\Psi_{BH,27}$	$\dot{E}_{BH,51}$	series
3	3	1	0.9	yes	11.0	9	z
3	1	1	0.9	yes	3.2	0.73	z
3	0.3	1	0.9	yes	from 0.78 to 0.66	0.07	z
9	3	1	0.9	yes	8.4	4.8	z
9	1	1	0.9	yes	3.1	0.7?	z
9	0.3	1	0.9	yes?	0.8	0.05?	z
3	3	3	0.9	yes	6.5	2.8	x
3	1	3	0.9	yes	2.1	0.43	x
3	0.3	3	0.9	no	0.5	-	x
9	3	3	0.9	yes	5.5	2.3	x
9	1	3	0.9	no	1.5	-	x
9	0.3	3	0.9	no	0.23	-	x
3	3	1	0.5	yes	11	2.0	p
3	1	1	0.5	no?	3.4	-	p
3	0.3	1	0.5	no	0.4	-	p
9	3	1	0.5	yes	10.5	0.5 one side	p
9	1	1	0.5	no	2.5	-	p
9	0.3	1	0.5	no	0.51	-	p
3	3	1	0.0	yes	12.8	0.2 one side	o
3	1	1	0.0	no	2.7	-	o
3	0.3	1	0.0	no	from 0.85 to 0.47	-	o
9	3	1	0.0				o
9	1	1	0.0				o
9	0.3	1	0.0	no	1.05	-	o

1/50 of case a=0.9

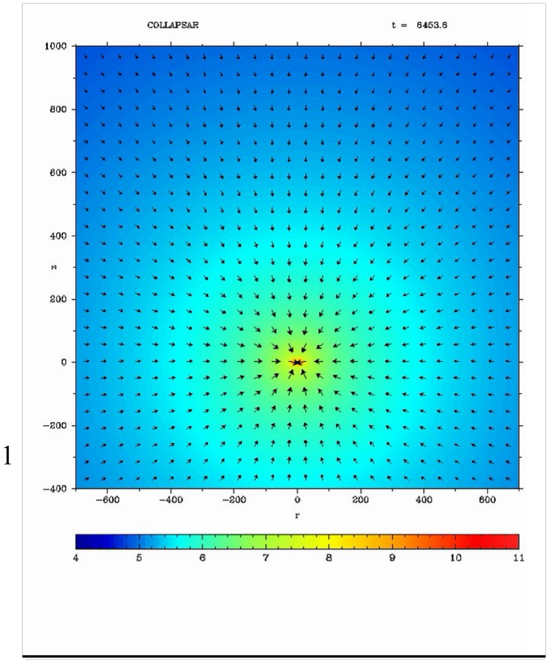


$\dot{M} = 0.15\, M_{SUN}\, s^{-1} \quad (C_1 = 3)$

$B = 3 \times 10^{10}\, G$

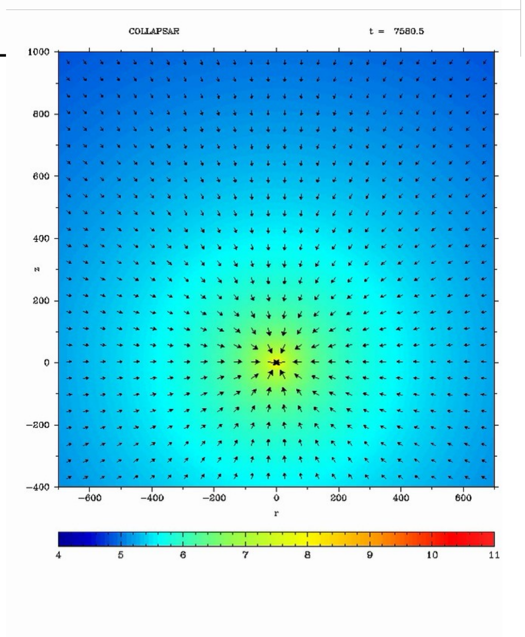
$l_0 = 10^{17}\ cm^2 s^{-1}$

$a = 0.9$



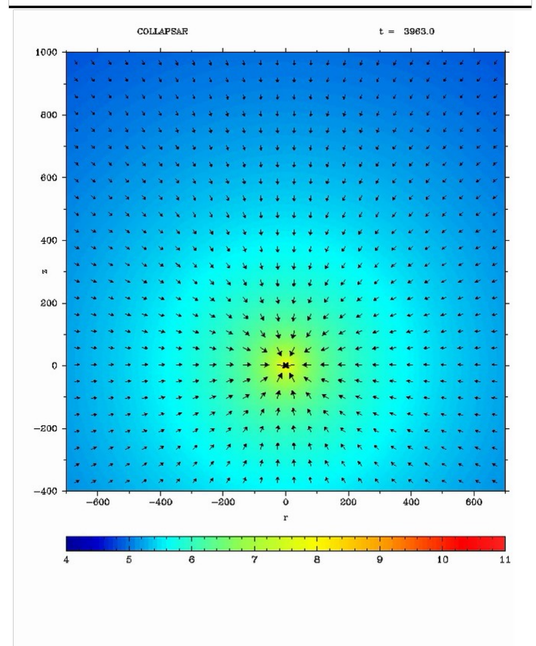
$l_0 = 3 \times 10^{17}\ cm^2 s^{-1}$

$a = 0.9$



$l_0 = 10^{17}\ cm^2 s^{-1}$

$a = 0.5$

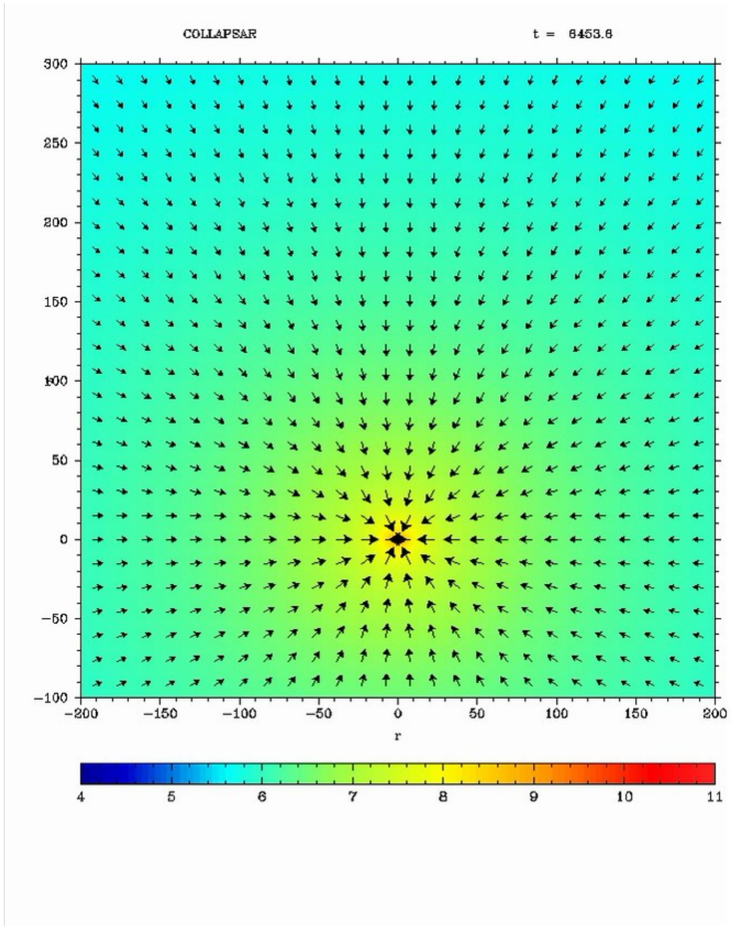


$l_0 = 10^{17}\ cm^2 s^{-1}$

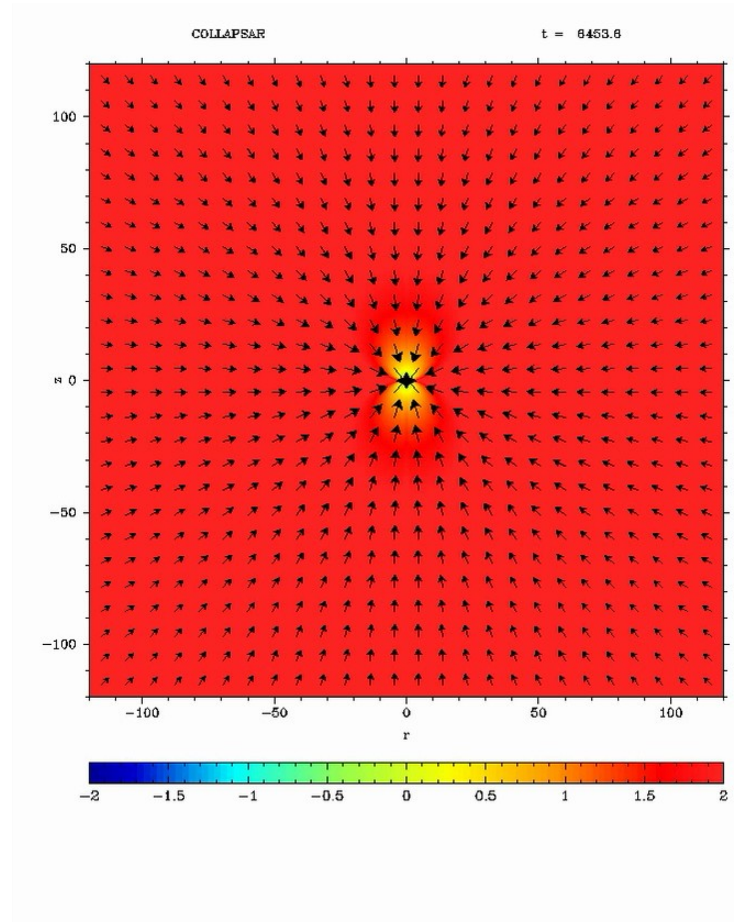
$a = 0.0$

$\dot{M} = 0.15\, M_{SUN}\, s^{-1} \quad (C_1 = 3) \qquad l_0 = 10^{17}\ cm^2\, s^{-1}$

$B = 0.3 \times 10^{10}\, G \qquad a = 0.9$



$\log_{10}(\rho)$



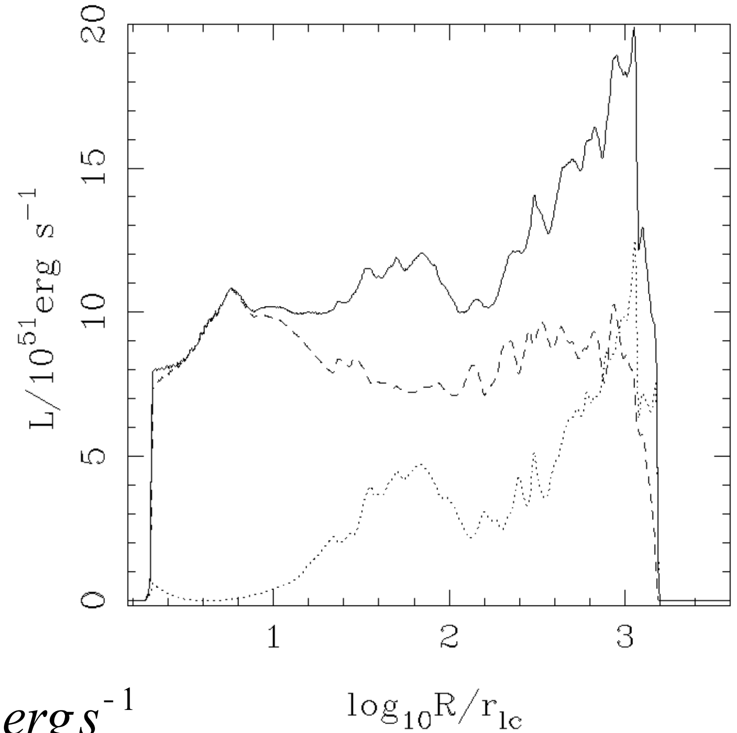
$\log_{10}\left(P_g / P_m \right)$

Jets are powered mainly by the black hole via the Blandford-Znajek mechanism !!

Model: A

- No explosion if a=0;
- Jets originate from the black hole;
- ~90% of total magnetic flux is accumulated by the black hole;
- Energy flux in the ouflow ~ energy flux through the horizon (disk contribution < 10%);
- Theoretical BZ power:

$$\dot{E}_{BZ} = 3.6\times 10^{50} f(a)\Psi_{27}^{2} M_{2}^{-2} = 11\times 10^{51}\ erg\,s^{-1}$$



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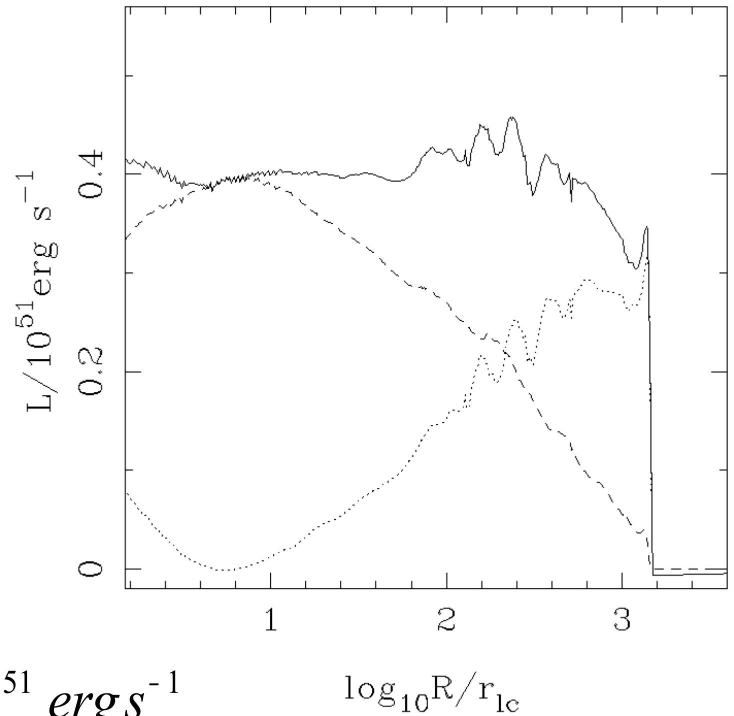
Model: C



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- Jets originate from the black hole;
- ~90% of total magnetic flux is accumulated by the black hole;
- Energy flux in the ouflow ~ energy flux through the horizon (disk contribution < 10%);
- Theoretical BZ power:

$$\dot{E}_{BZ} = 3.6\times 10^{50} f(a) \Psi_{27}^{2} M_{2}^{-2} = 0.48\times 10^{51}\ erg\, s^{-1}$$

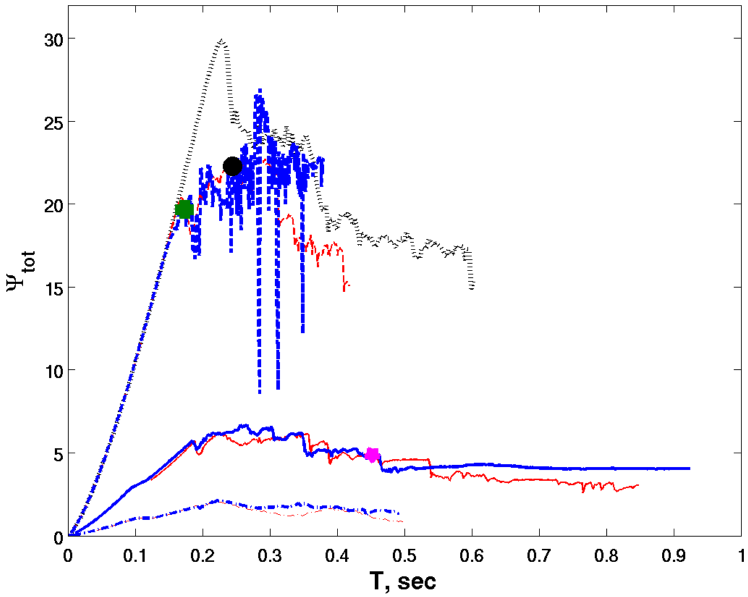
results

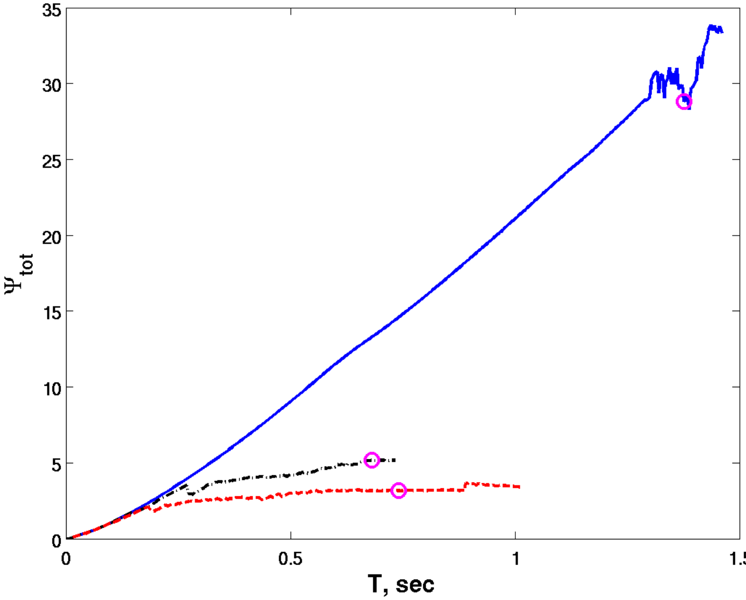
name	B_{10}	C_1	a	Expl	t_e	Ψ_{27}	v_s	$\langle L_{51} \rangle$
A	3	3	0.9	Yes	0.174	11.6	0.49	9.6
B	3	9	0.9	Yes	0.245	13.1	0.40	12.7
C	1	3	0.9	Yes	0.453	2.8	0.10	0.4
D	1	9	0.9	No				
E	0.3	3	0.9	No				
F	0.3	9	0.9	No				
G	3	9	0.0	No				

Magnetic Flux

Models: A,B,C,D,E,F,G

Uniform field models $3x10^9$ G





l	Ψ_{27}	t_{expl}	dM_{BH}/dt	L_{51}	η
l_0	1.9	0.74	0.007	0.22	0.016
$0.6l_0$	3.1	0.68	0.018	0.40	0.012
$0.0l_0$	17	1.37	0.11	16	0.08

$$\eta = \frac{L}{\dot{M}_{BH} c^2}$$

Summary:

- Jets are formed when BH accumulates sufficient magnetic flux.
- Jets power $0.4 \div 13 \times 10^{51} erg\, s^{-1}$
- Total energy of BH $\simeq 8 \times 10^{53}$erg
- Expected burst duration > 1s (?)
- Jet advance speed $V_s \approx 0.1 \div 0.5c$
- Expected jet break out time $\simeq 4$s $(r_* \simeq 2 \times 10^5km)$
- Jet flow speed $\Gamma_j \leq 3$ (method limitation)
- Jets are powered by the Blandford-Znajek mechanism

Good news for the collapsar model of long duration GRBs !