Collapsar Simulations:

From Engine to Relativistic Outflow, and 56Ni Production

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§ Numerical Simulation of a collapsar by a General Relativistic Magneto-Hydrodynamic (GRMHD) code

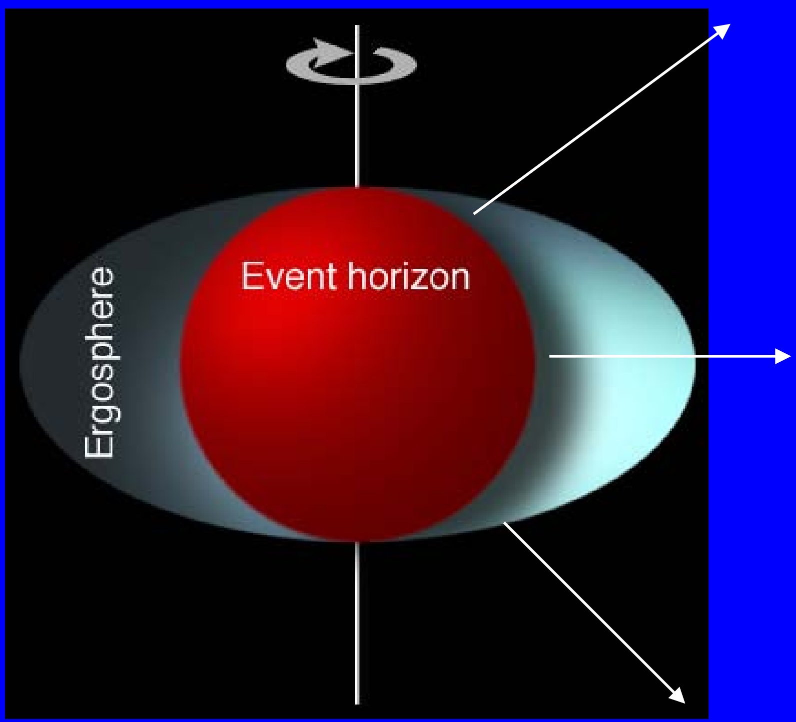
S.N. (2009) ApJ
S.N. (2010) PASJ, submitted.
See also Tanabe and S.N. PRD (2008)

What is Blandford-Znajek Process?

Blandford and Znajek 1977

Tanabe and S.N. PRD 2008

Energy extraction from a rotating BH: General Relativistic Effect



**In principle,
Rotation Energy of a BH can be Extracted when particles with negative Energy are absorbed into the BH.**

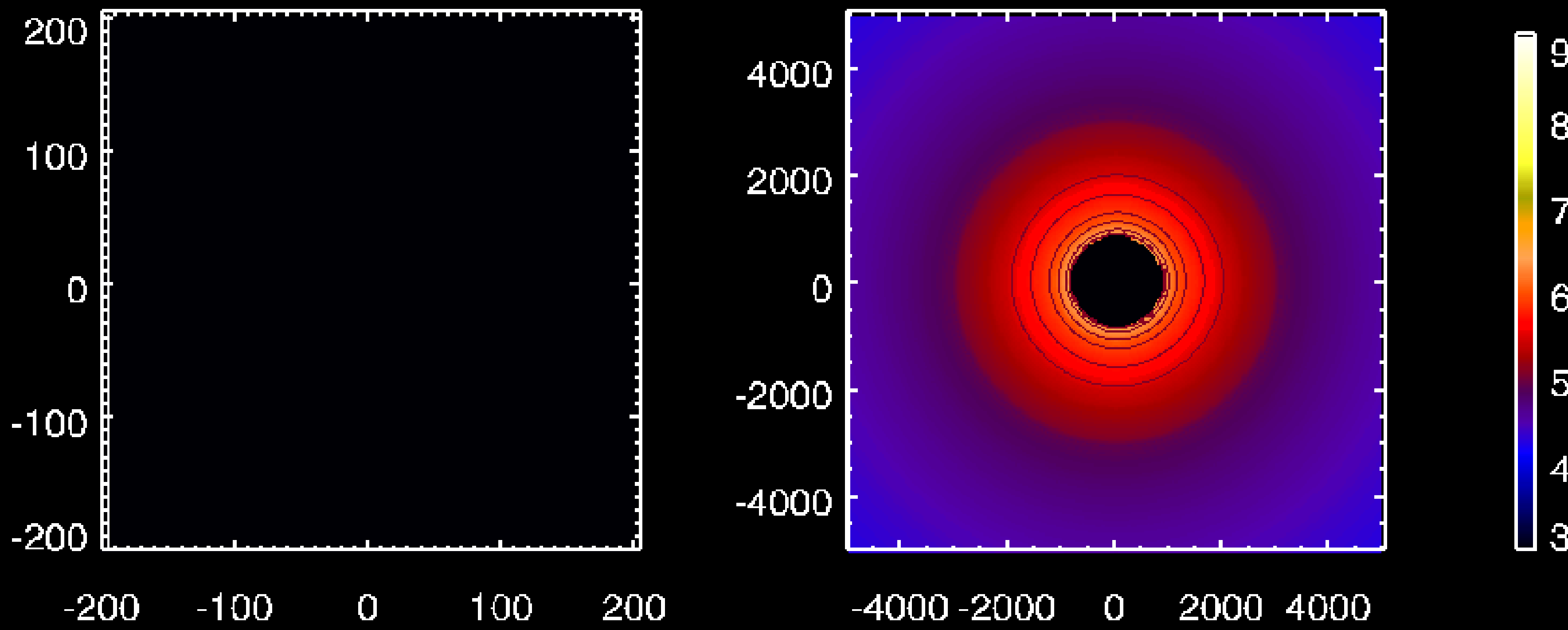
Analytical solution (mono-pole solution) was introduced by BZ. Nowadays, this effect can be seen Numerically with a GRMHD code.

Initial Condition

- １２TJ：Rotating star with１２Msolar, z=0.01, Mass of Fe core=1.82Msolar (Woosley and Heger 2006).
- M_{BH}=2Msolar, a=0.5.
- $\Gamma=4/3$
- $A_\phi \propto \max(\rho/\rho_{\rm max} - 0.2, 0) \sin^4 \theta$
- $p_{\rm gas}/p_{\rm mag} = 10^2$

Simulation of a Collapsar

S.N. 2009 ApJ.



R<200

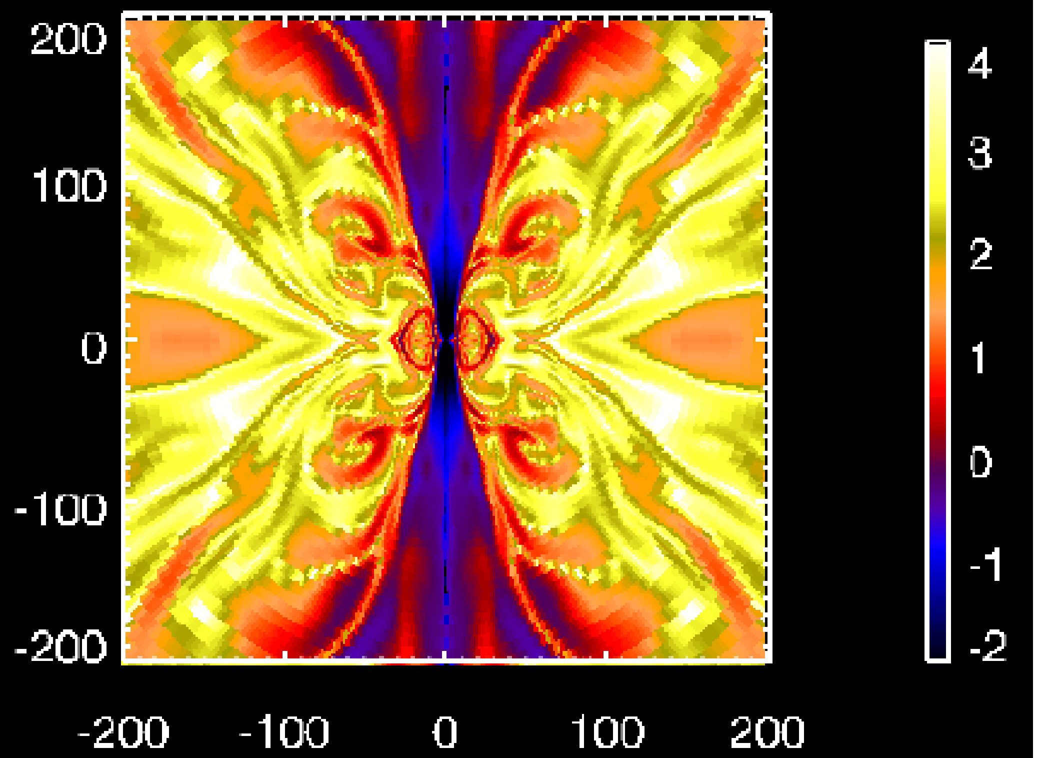
R<5000

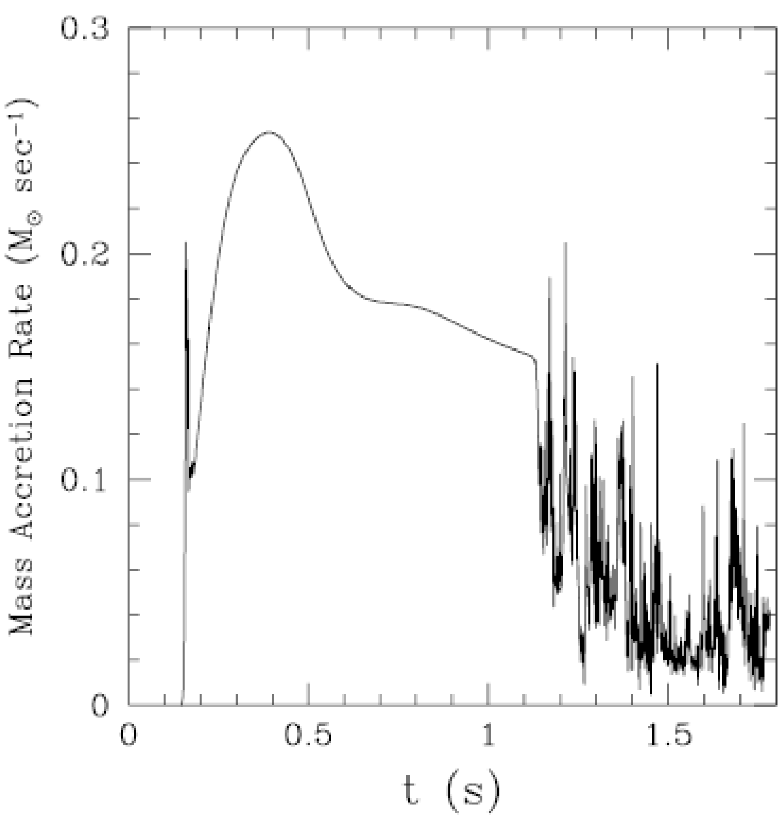
Density contour in logarithmic scale (g/cc)

Final time corresponds to 1.77sec. R=200 corresponds to 600km.

Poynting Flux Dominated Jet with Rapid Time Variability

R=200 corresponds to 600km

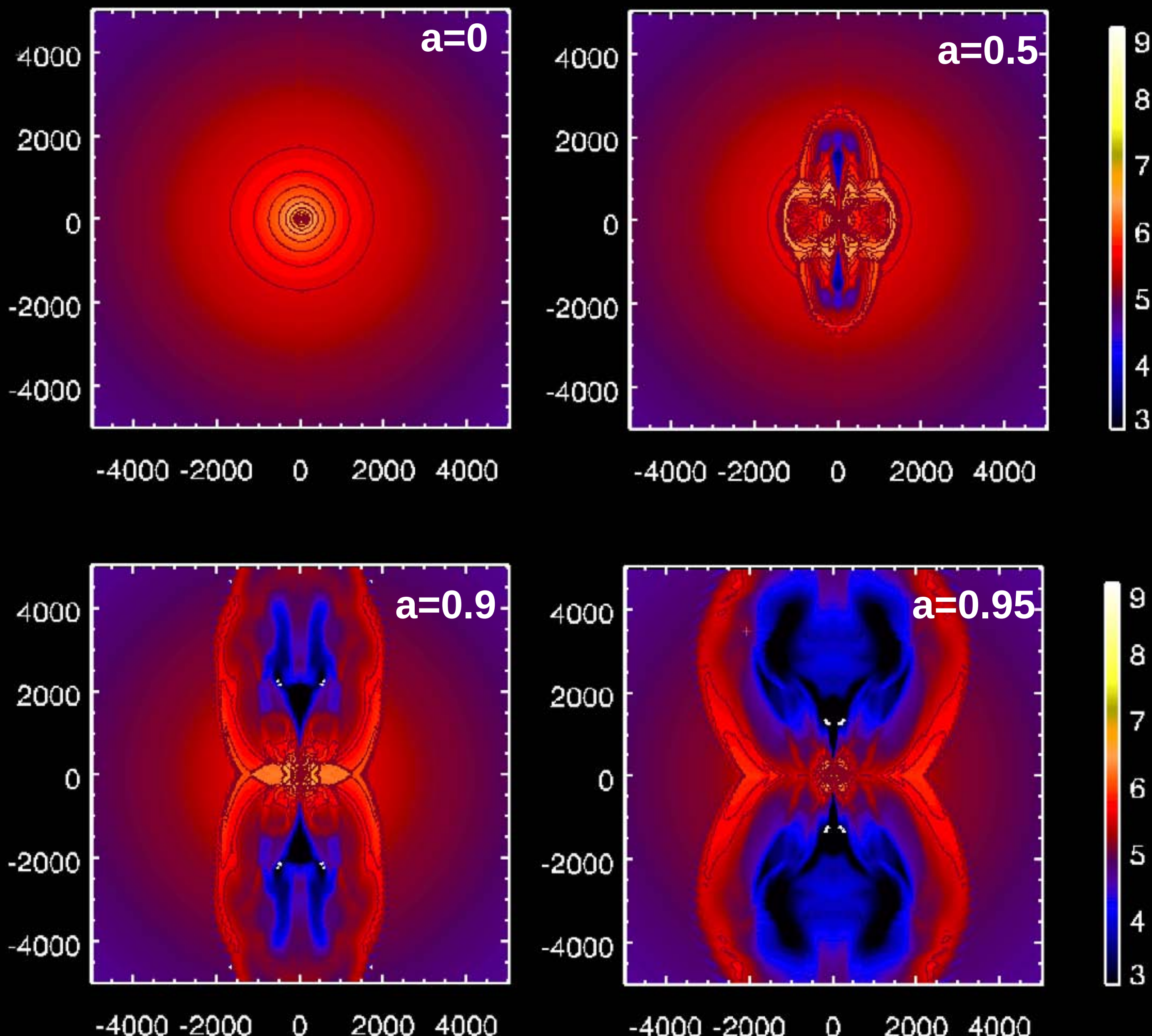




Plasma beta (Pgas/Pmag)
At t=1.77sec.
Poynting Flux-Domindated Jet
EM Energy also dominates rest mass energy in the jet.

Time evolution of the mass accretion Rate at the horizon. It shows a rapid Time variability after the formation Of the jet. Related with the GRB's time Variability?

Dependence of Dynamics on Rotating Black Hole



S.N. (2010)

Density Structure
at T=1.6sec.

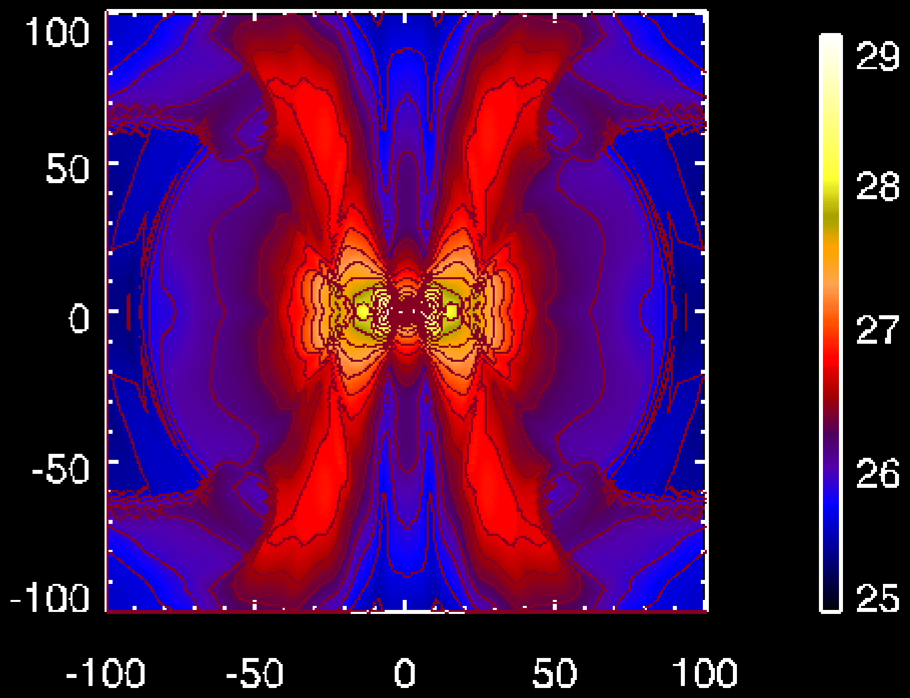
Not the Time
Sequence, but
For Different Models
With different Kerr
parameters.

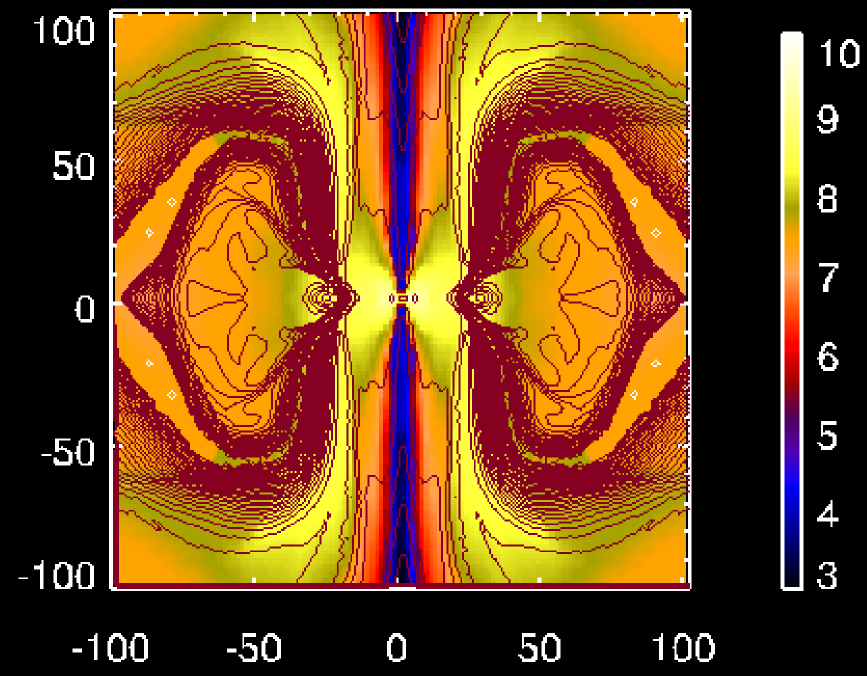
Wall-Like Structure

A Wall-like Structure can be seen.
Collimation of the Jet is determined
By the Wall?

Kerr Parameter, a=0.95

R=100 corresponds to 300km.

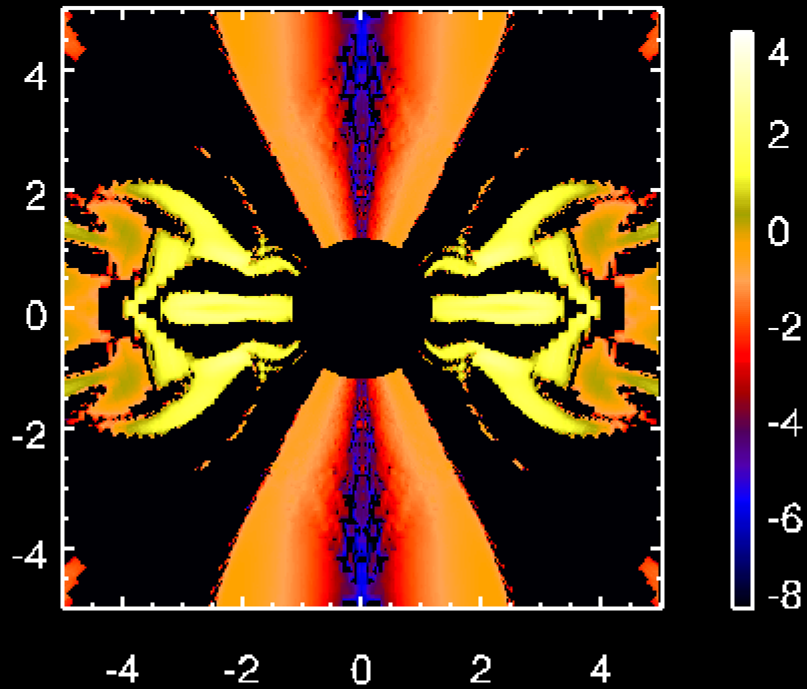




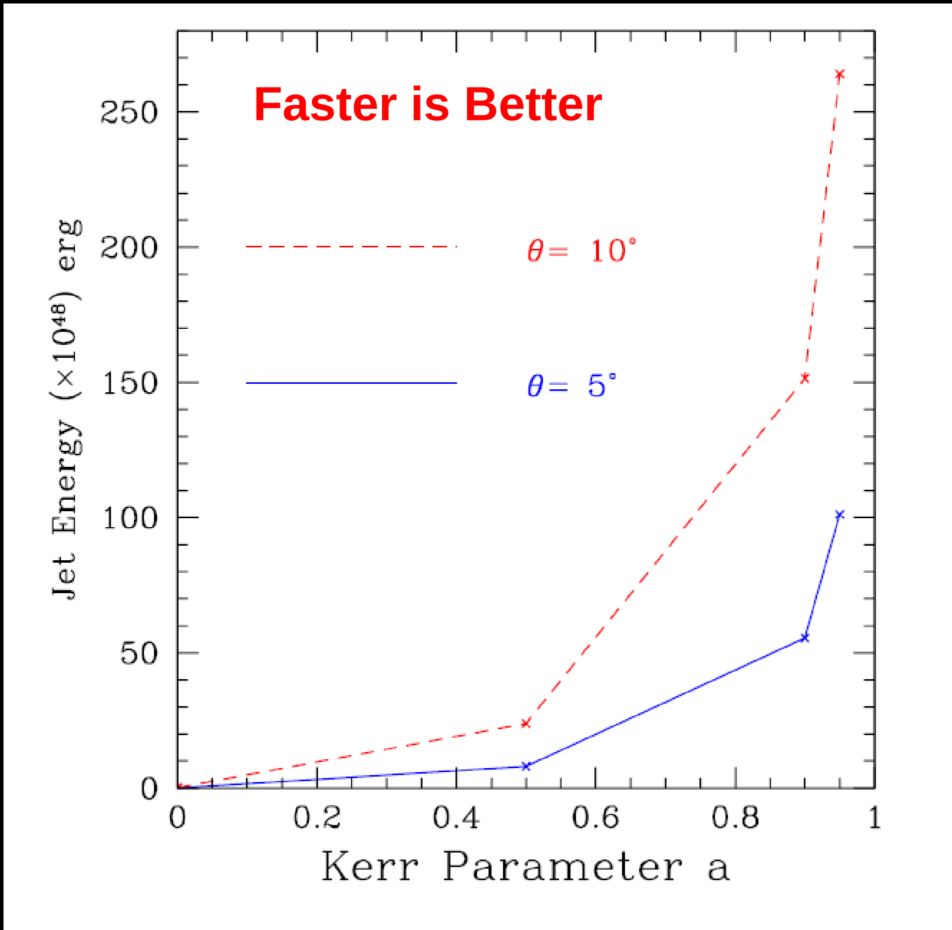
Contours of Total Pressure
(Thermal + Magnetic) in cgs units.

Density contour with Poloidal B-Field lines

Blandford-Znajek Flux and Jet Energy



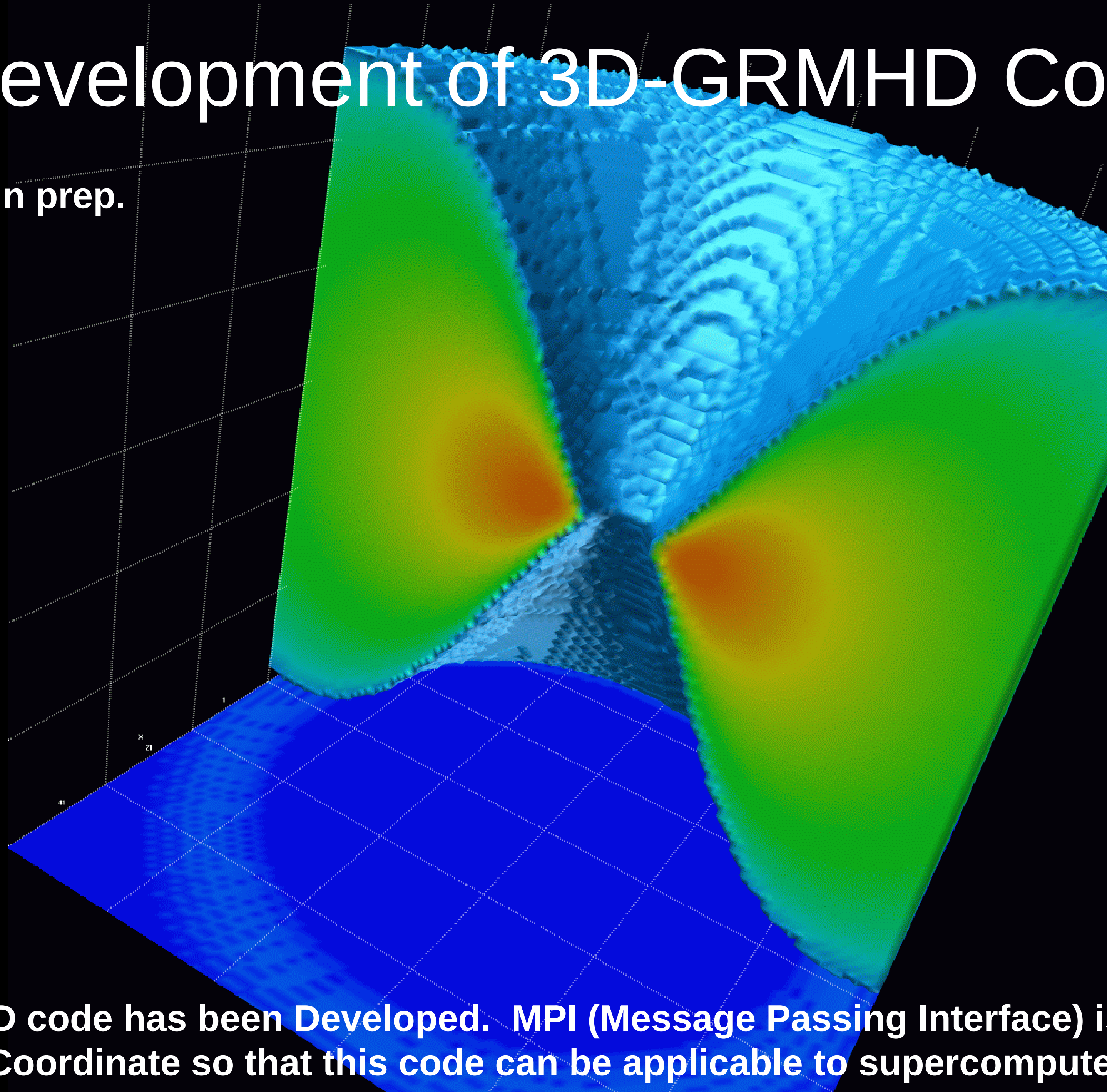
BZ (outgoing poynting)-Flux
In unit of 10^50 erg/s/Sr at
T=160000 (1.5760sec).
Kerr Parameter, a=0.95.
Time variability is also triggered by the BH?



Jet Energy at t=1.5750 sec for a=0, 0.5, 0.9, 0.95

Development of 3D-GRMHD Code

S.N. 10, in prep.



3D GRMHD code has been Developed. MPI (Message Passing Interface) is used for every Coordinate so that this code can be applicable to supercomputers .

§ Jet Propagation and Thermal Emission From the Photo-sphere of the Jet (Pure Hydro Case)

Mizuta, S.N., Aoi (2010), ApJL, submitted.

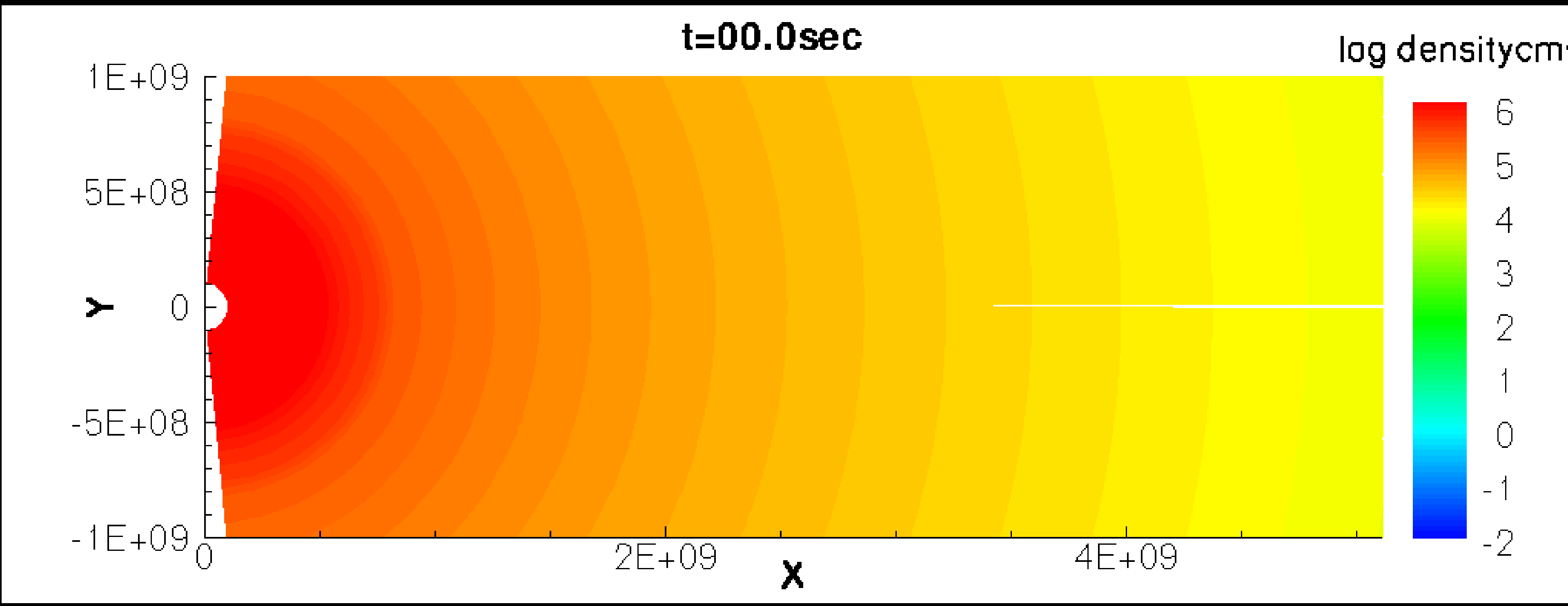
Please see Mizuta's poster (# 2.09) for details.

See also Nagakura's poster (# 10.03).

Related with the talks by Daigne, Zhang, Pe'er, Toma, Beloborodov, Lazzati….

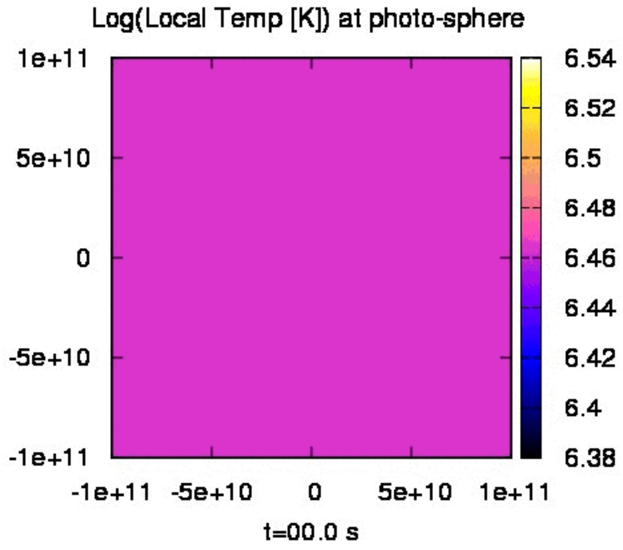
Propagation of Relativistic Jet

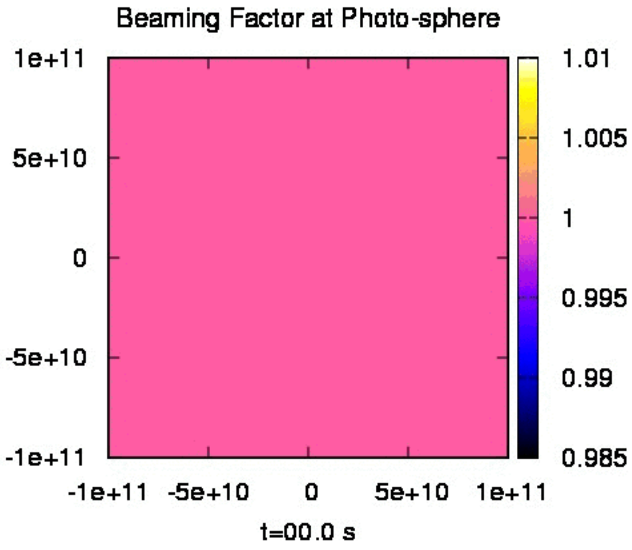
Mizuta, S.N., Aoi 2010



Flow with Bulk Lorentz factor 400 : v/c = 0.99999687 can be followed.

Time evolution of the Photo-sphere and Thermal Emission



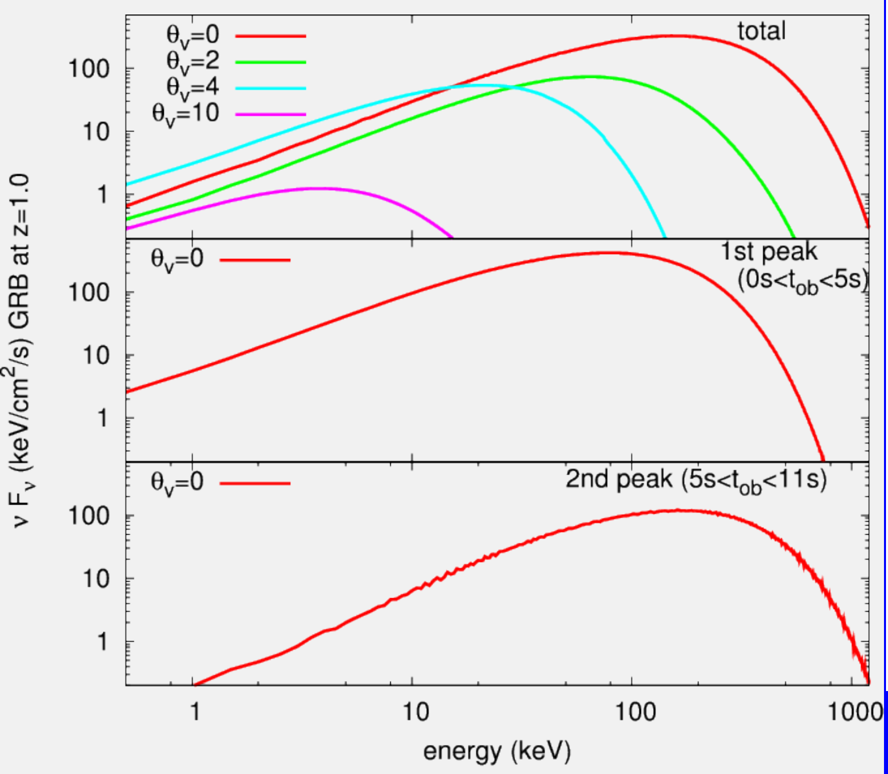


Left: Evolution of the temperature at the photo-sphere viewed from the jet axis.

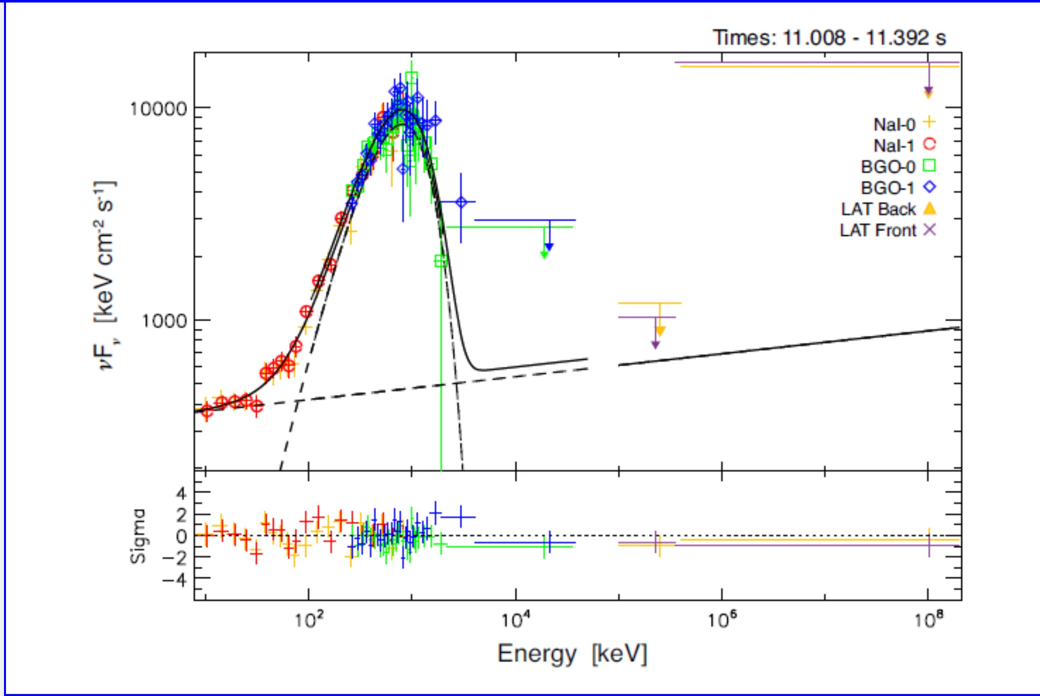
Right: Beaming factor at the photo-sphere.

Superposition of thermal emissions from each area of the photosphere is observed.

Comparison with GRB 090902B



Simulation



observation

- Extra-Component of GRB090902B will be related with our photosphere model.
- Superposition of thermal emission makes the spectrum Power-law like at low-energy side with index (alpha) –(0.5 – 1).

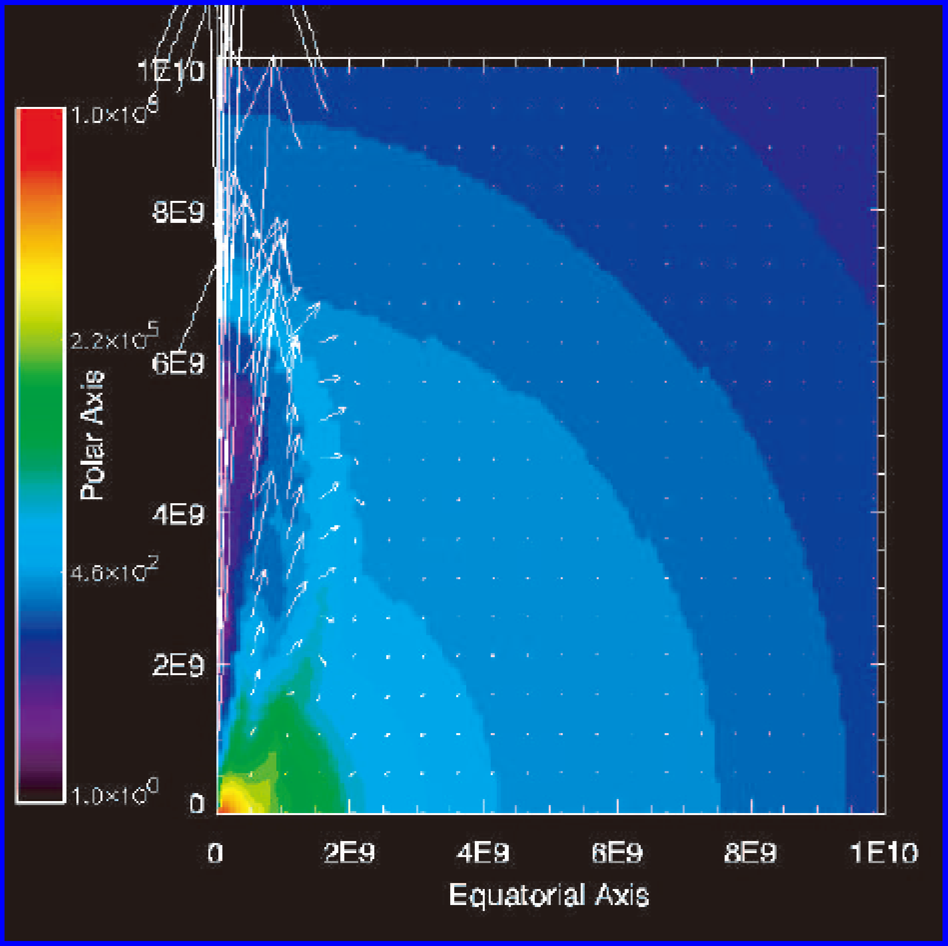
§ Explosive Nucleosynthesis in a Collapsar

S.N. ApJS 2000
S.N. et al. ApJ 2003, 2006

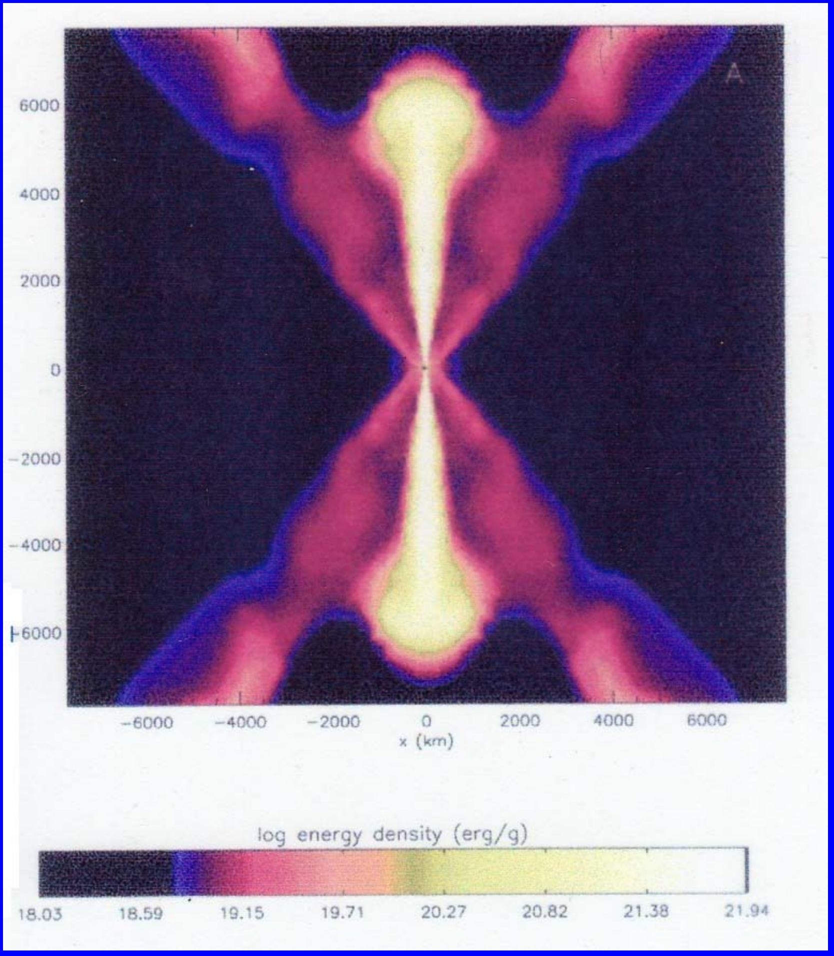
Nishimura, Takiwaki, Kotake, S.N. 2010, In prep.

Luminosity of a supernova is determined by the amount of 56Ni.

Where is 56Ni synthesized in a GRB/Hypernova?



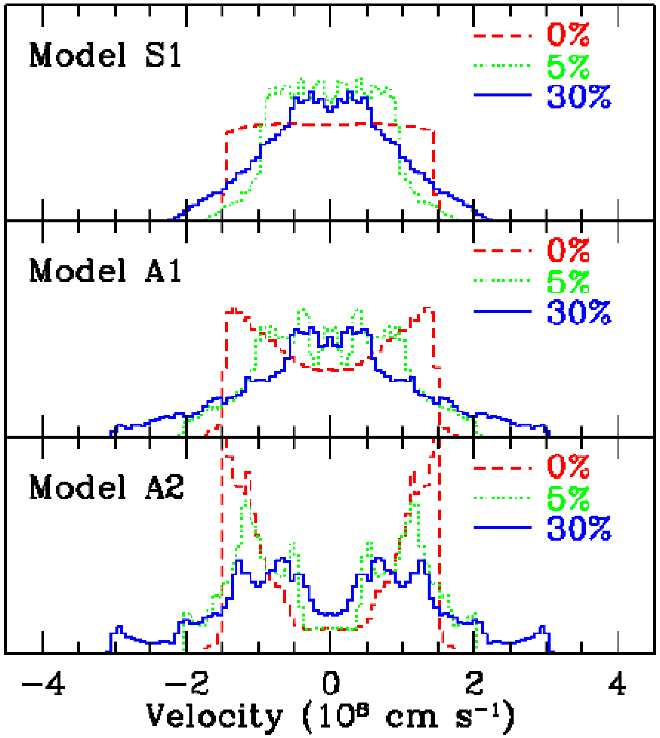
Nucleosynthesis in a GRB jet (S,N. 00, S.N. et al.03, 06)? See also Maeda et al. 02, 05, Tominaga et al. 07.



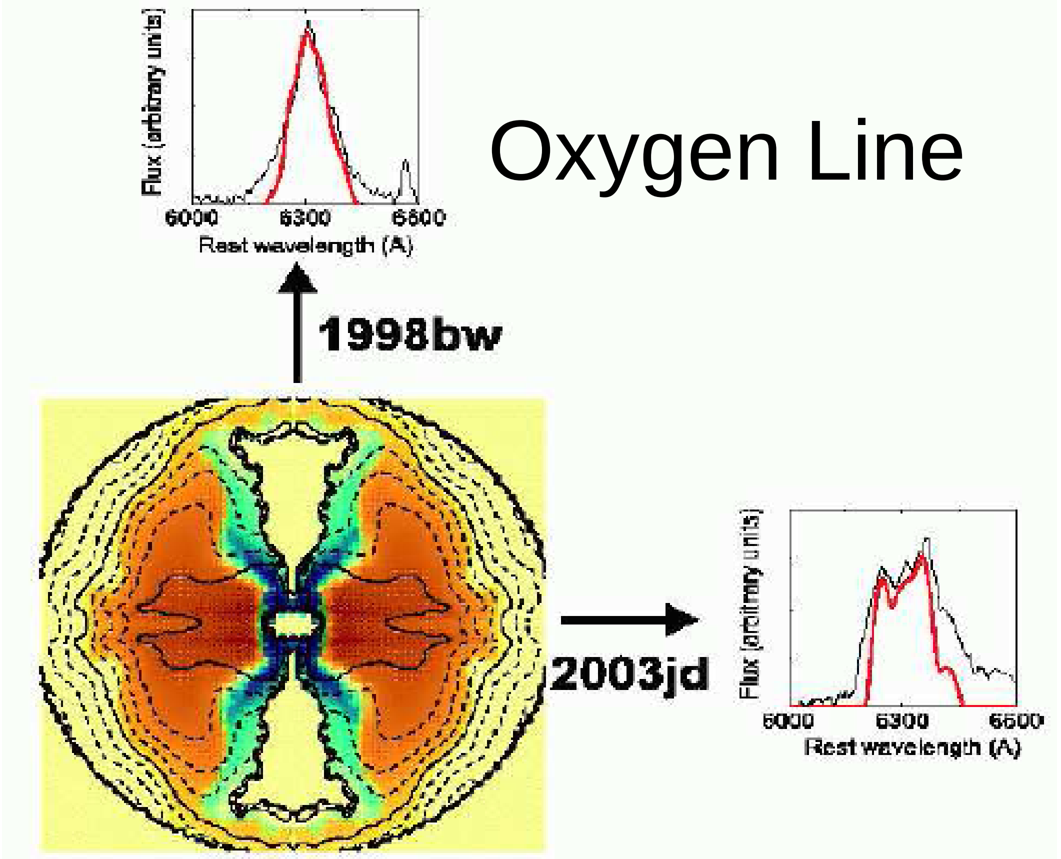
Nucleosynthesis in the accretion Disk? e.g. MacFadyen and Woosly 1999, Popham et al. 1999.

My Prediction in 2000 and Observation in 2005

Velocity Distribution of Iron



Model S1: Spherical Model
Model A1: Vp/Ve = 2:1
Model A2: Vp/Ve = 4:1



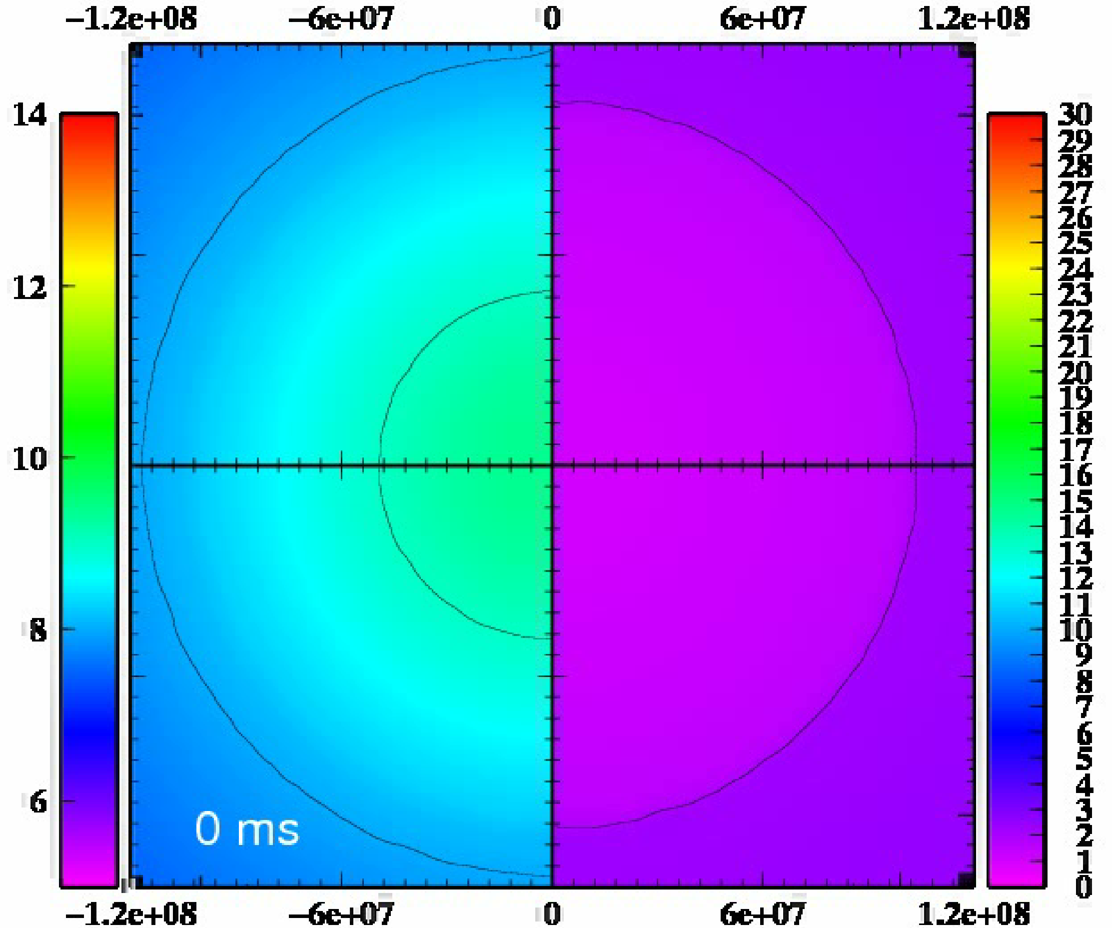
Mazzali et al. 05

S.N. 2000

Nucleosynthesis in the Accretion Disk

Nishimura, Takiwaki, Kotake, S.N. (preliminary)
and possible future collaboration with T. Plewa et al.

Density (Logarismic) g/cc



Entropy Per Baryon

Test Particles (Post-Processing)

- Summary

Summary

- A stronger jet is launched by a more rapidly rotating BH (Faster is Better). Wall-like structure determines the opening angle of the jet?
- Extra-Component of GRB090902B will be related with our photosphere model. Superposition of thermal emission makes the spectrum Power-law like at low-energy side with index (alpha) –(0.5 - 1).
- Explosive Nucleosynthesis in Collapsars: Jet or Accretion Disk (or something else)? This study will shed light on the study of the dynamics of collapsar itself.