Basic ingredients for the biggest blasts in the cosmos

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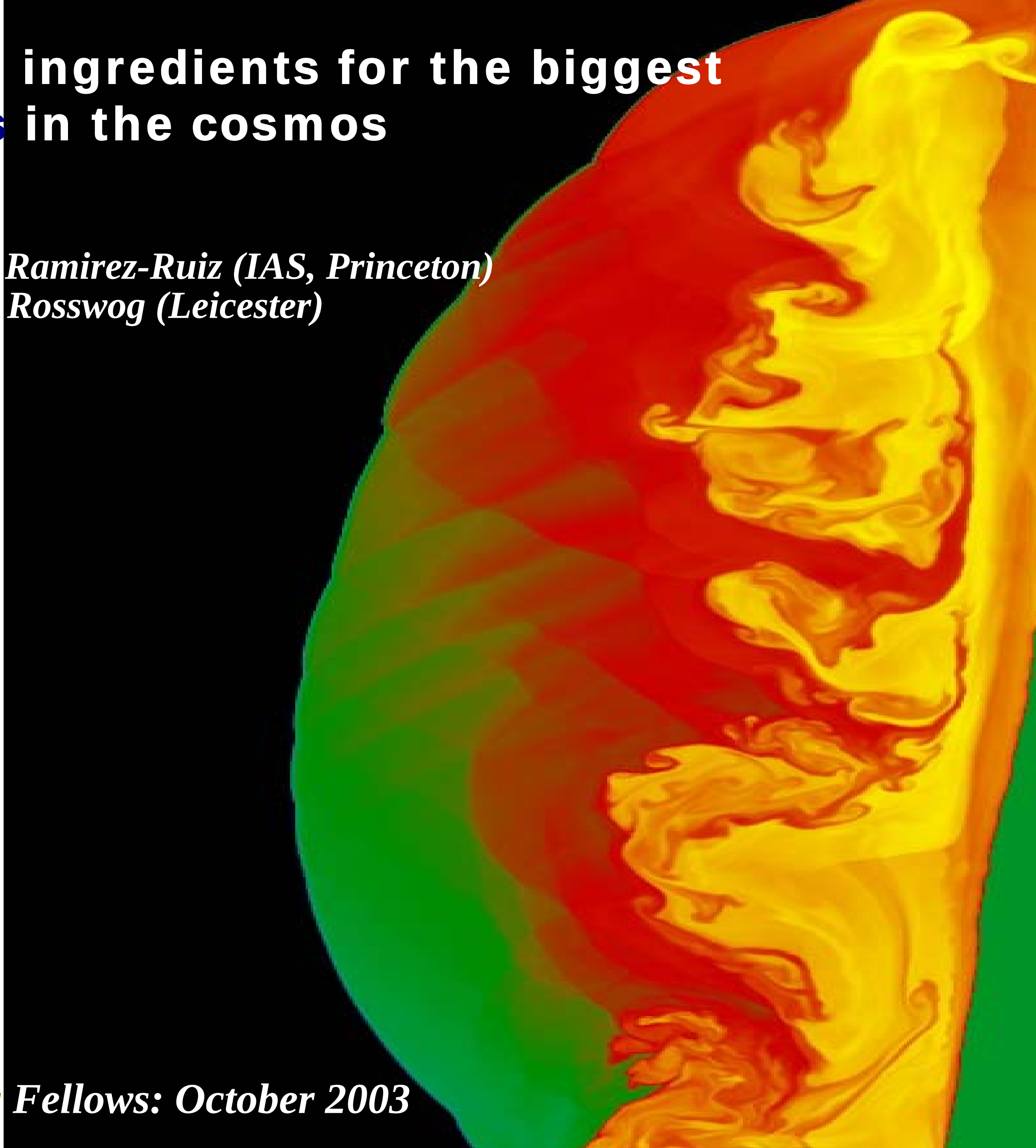
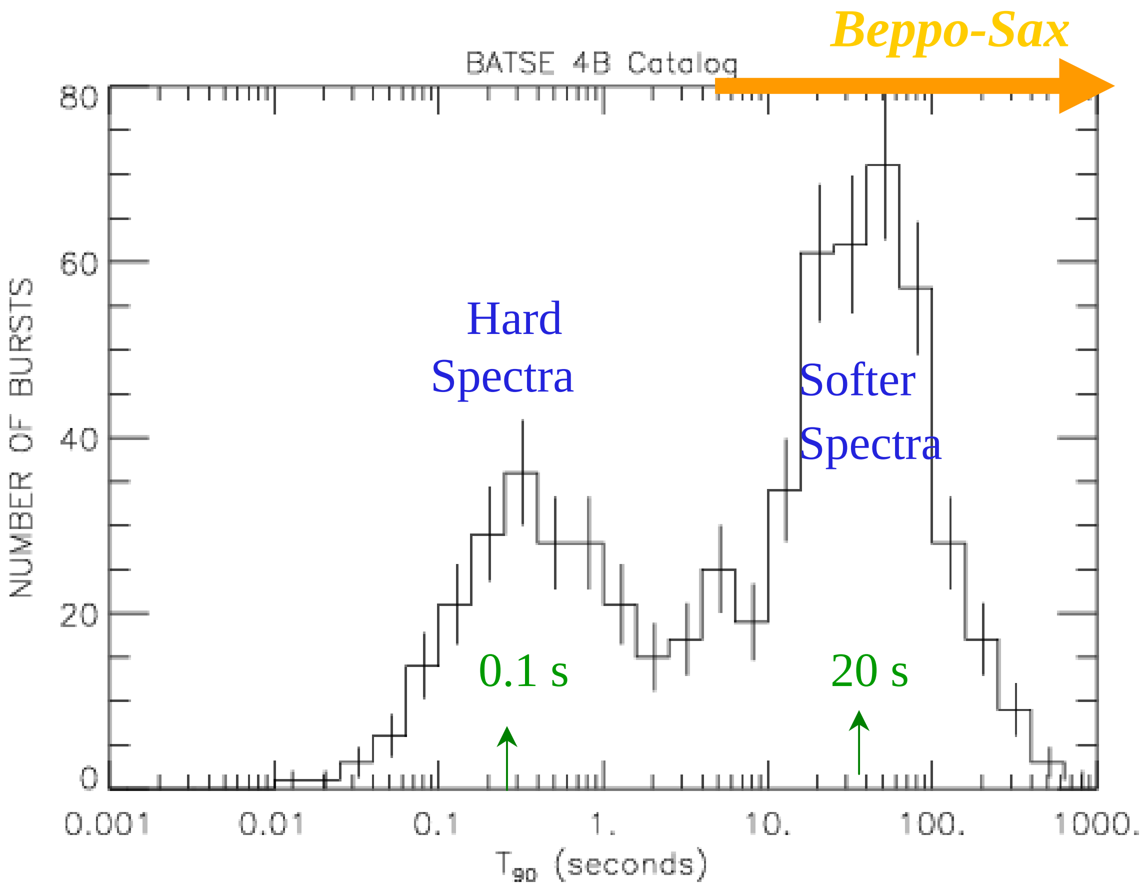


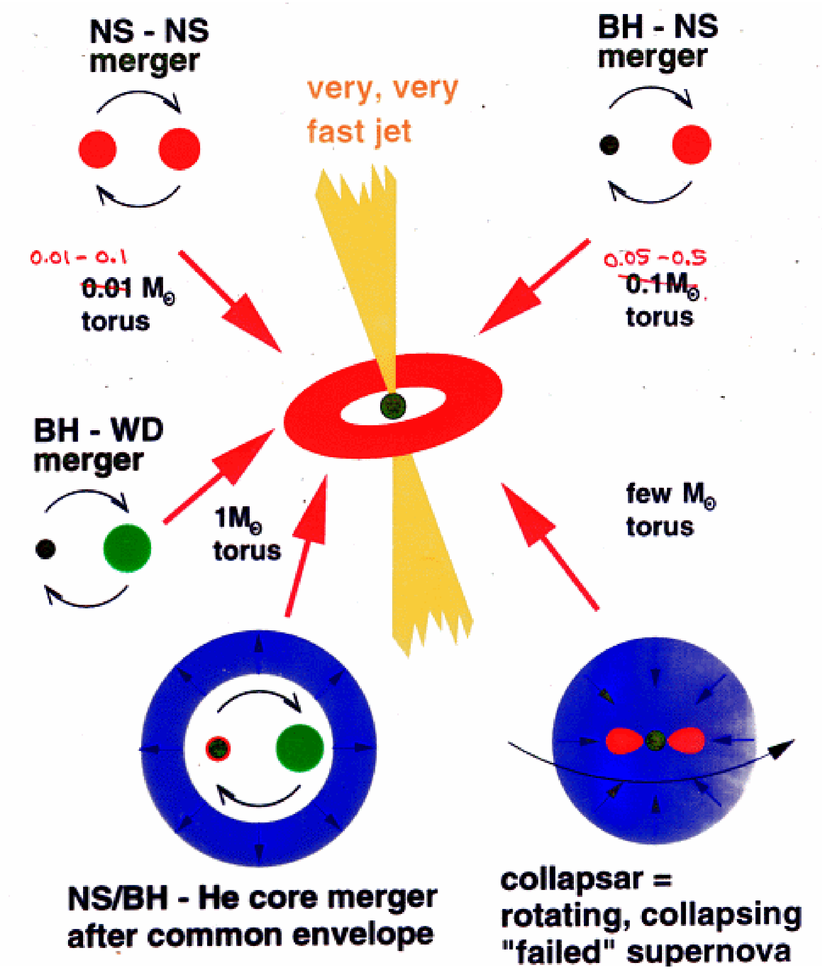
Chandra Fellows: October 2003

Are there distinctive subclasses of γ–ray bursts?



- Diverse. Possibly more than one model
  - Short hard bursts ($\tau \sim 0.1$ s)
  - Long complex bursts ($\tau \sim 20$ s)

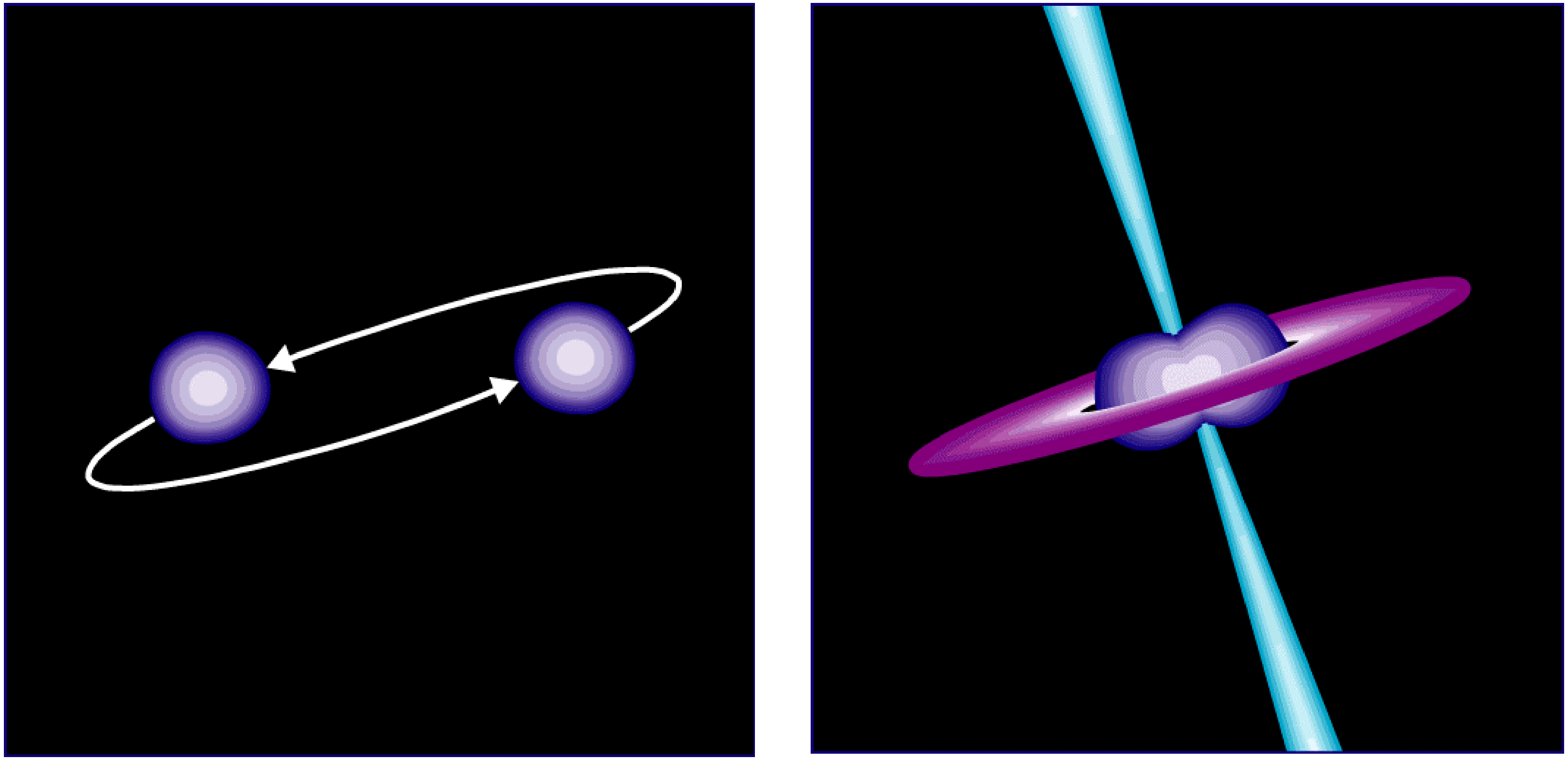
What is the trigger?



The duration of the burst is determined by the viscous timescale of the accreting gas

The duration of the burst is given by the fall-back time of the gas.

Merging Neutron Stars



Scenarios resulting from binary disruption

[Note: $\tau_{dyn} \approx 10^{-3}$ sec]

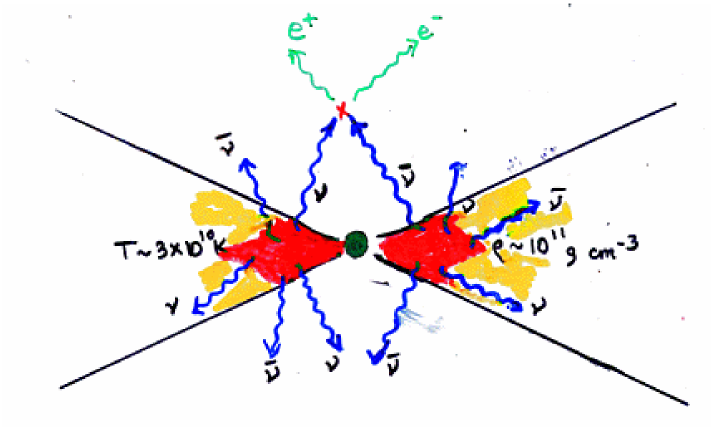
Stage 1

Rapid evolution driven by bar-mode instabilities, gravitational waves, etc.

Stage 2

Slower evolution of surviving axisymmetric torus (mass M_t).
There are two options:

B-field unimportant



$\sim 0.2\ M_t c^2\ \ \varepsilon$

efficiency of

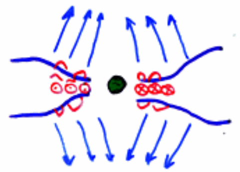
$\nu + \bar{\nu} \longrightarrow e^+ + e^-$

Mochkovitch et al. 1993; Ruffert et al. 1997; Popham et al. 1999

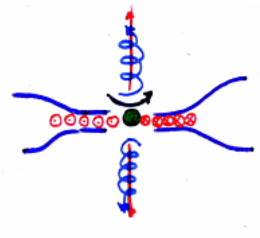
B-field important

B **amplifies to B_{max}**

Relativistic magnetized wind $\propto B_{max}^2$



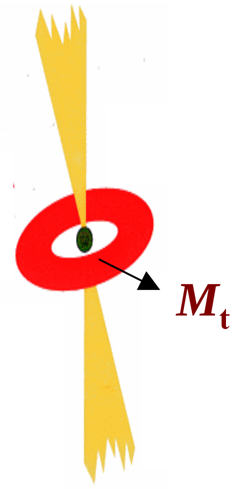
$\sim 0.2\ M_t c^2$



$\sim 0.1\ M_{bh} c^2$

Narayan et al 1992; Usov 1992; Thompson & Duncan 1993; Meszaros & Rees 1997; Katz 1997

Questions

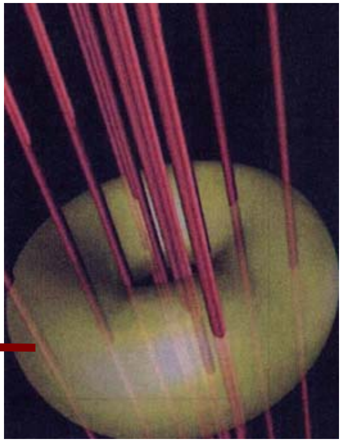


- **What is the maximum mass of the remnant torus which is immune to very violent instabilities?**

Lee & Ramirez-Ruiz (2002)

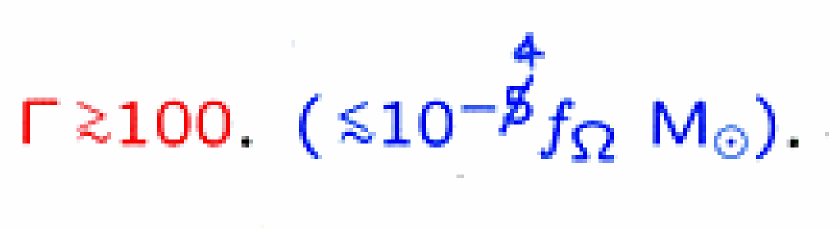
- **What is B_{max}? (10^{14}-10^{15} G required)**

Note: it only takes a residual torus of 10^{-3} $M_\odot$ to confine a field of 10^{15} G.

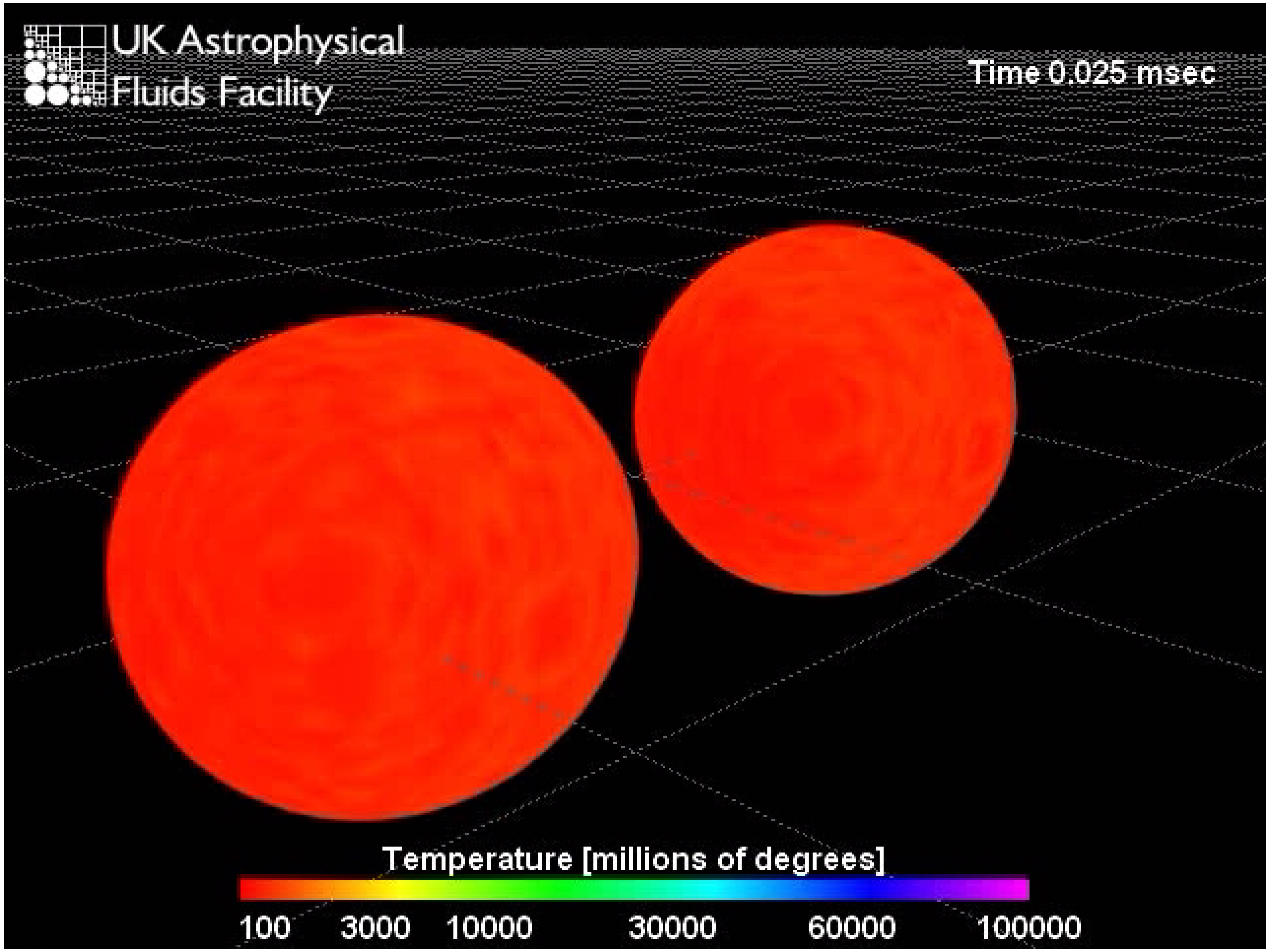


$$B \sim 10^{15} G \sim 1\%\ B_V$$

- **How much entrainment occurs?**



$$\Gamma \gtrsim 100.\ (\lesssim 10^{-\overset{4}{\cancel{5}}} f_\Omega\ M_\odot).$$



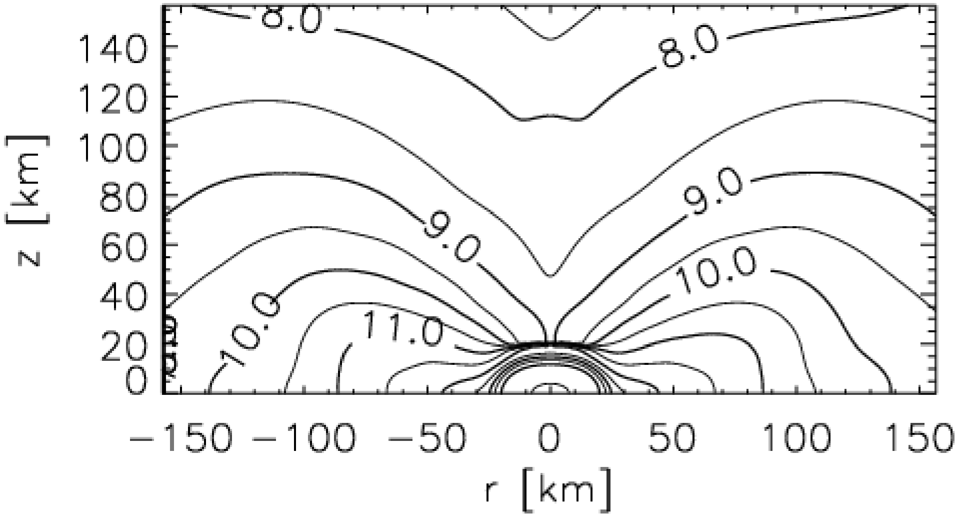
Rosswog (2003)

- **Calculations of the last inspiral stages and the final coalescence. The equations of hydrodynamics are solved using SPH method.**

- **A realistic equation of state for hot, dense nuclear matter (*Shen et al. 1998*) smoothly extended to the low density regime (stiffer than *Lattimer-Swesty*).**

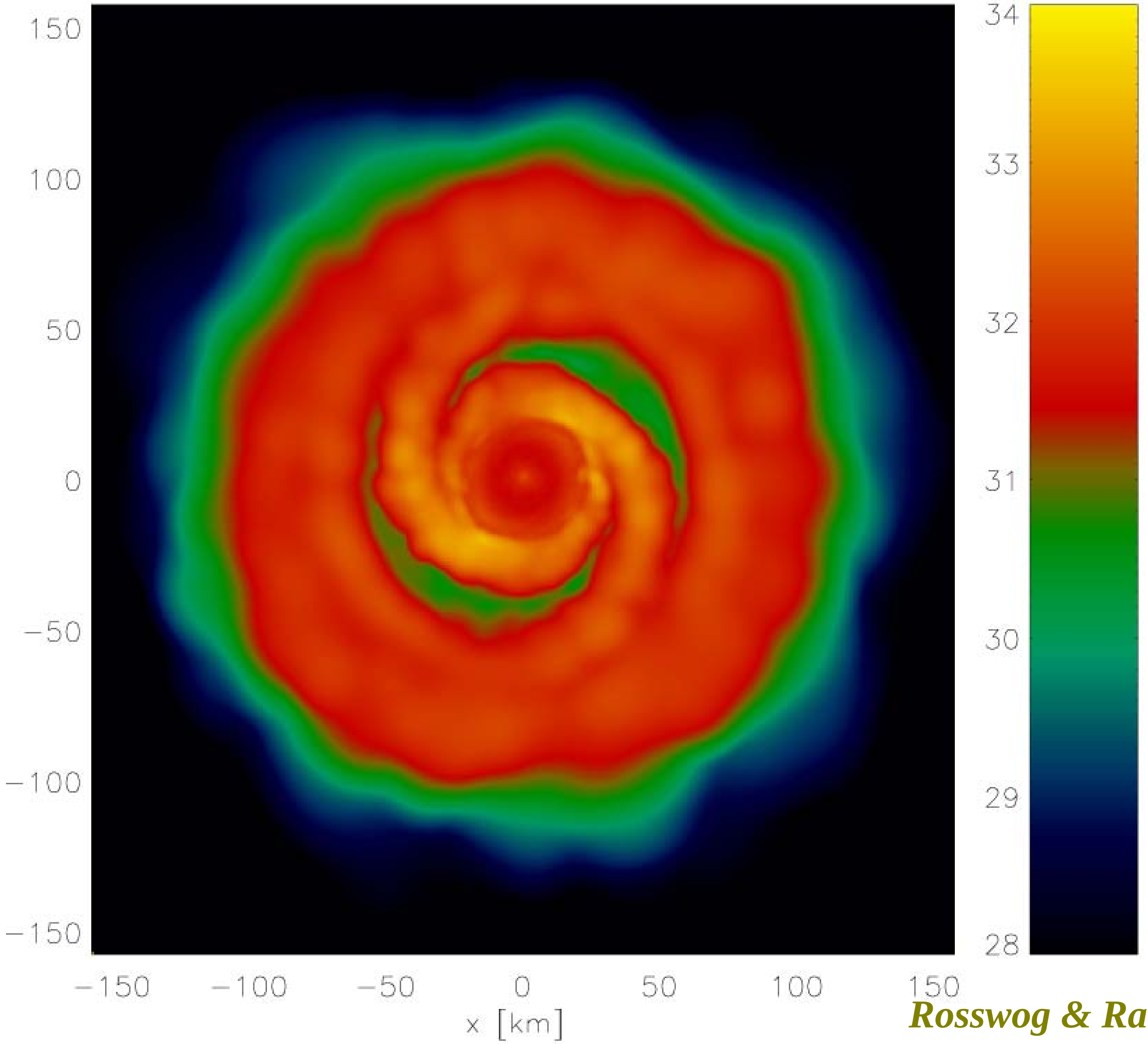
Remnant Properties

	central object	**debris**
masses	$\sim 2.5\ \mathrm{M}_\odot$	$\sim 0.2\ \mathrm{M}_\odot$
densities	$\sim 3 \cdot 10^{14}\ \mathrm{gcm}^{-3}$	$\sim 10^{12}\ \mathrm{gcm}^{-3}$
temperatures	$\sim 15\ \mathrm{MeV}$	$\sim 3\ \mathrm{MeV}$



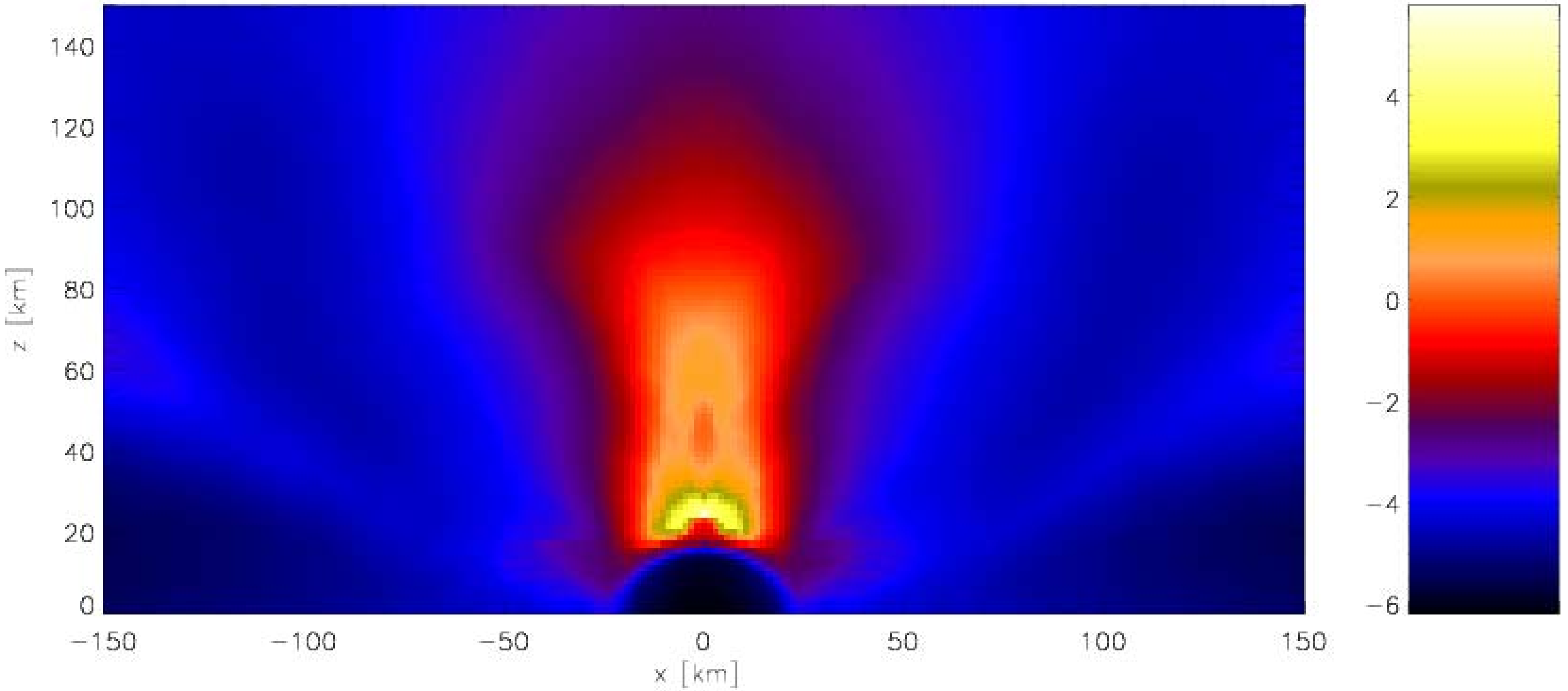
$$\nu + \bar{\nu} \longrightarrow e^+ + e^-$$

- •3D, high resolution calculations (~ 10^6 SPH particles)
- •Temperatures of several **MeV** and densities ~ 10^{12} **g cm** $^{-3}$ → ν are emitted copiously



Rosswog & Ramirez-Ruiz (2003)

$$\eta \sim \frac{\text{energy deposited}}{\text{baryon rest mass}}$$

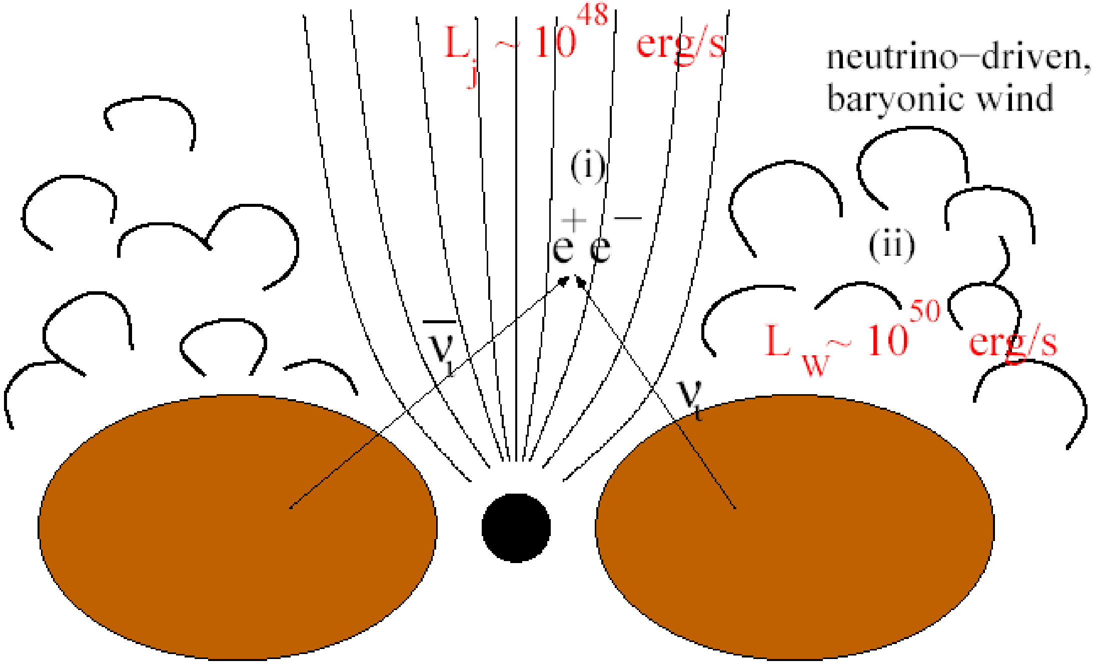


- **Shown are the values of log η in the x-z plane above the merged remnant**

$$L_{\eta \geq 1} \approx 10^{48} \text{ erg s}^{-1}$$

Hydrodynamic collimation

- **The outflow that derives from the debris will have enough pressure to collimate the relativistic fireball that it surrounds** *(Levinson & Eichler 2000; Rosswog & Ramirez-Ruiz 2003)*



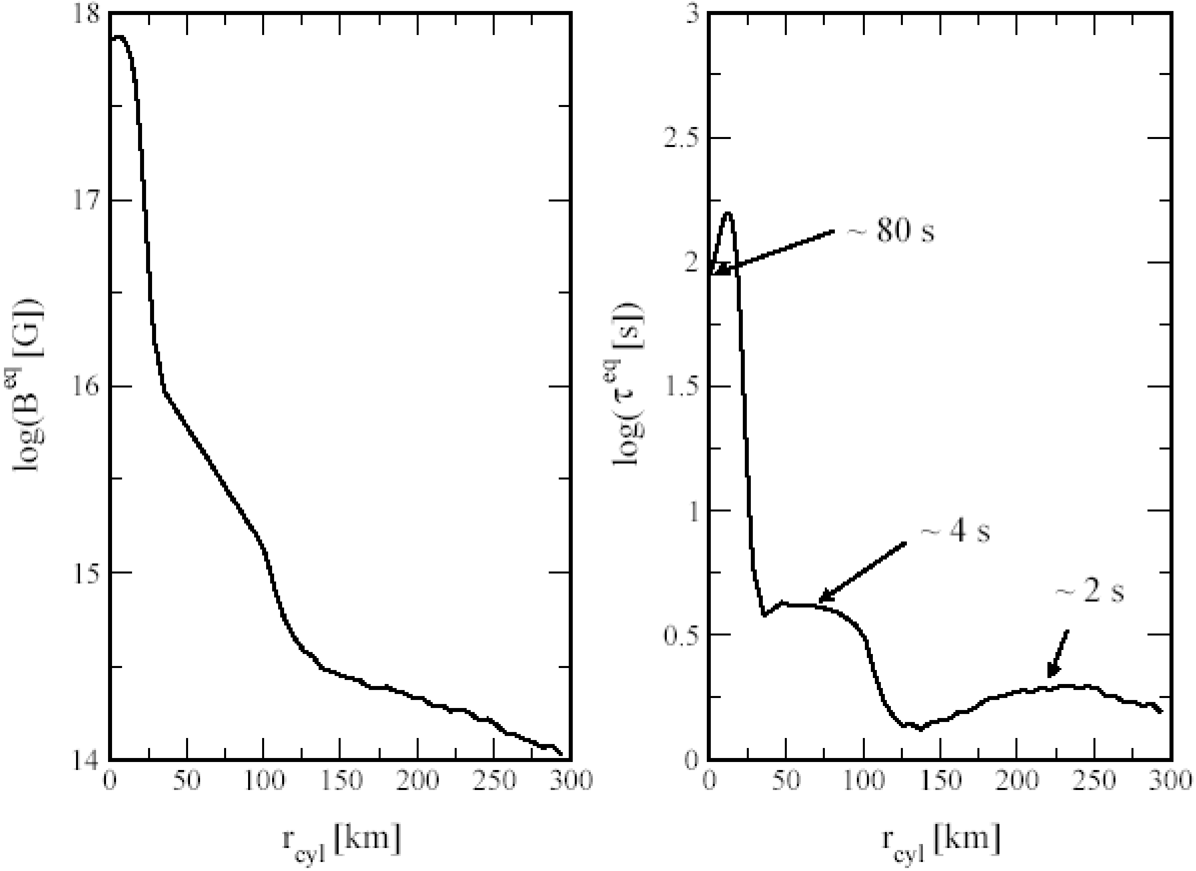
$$f \approx \Delta\Omega/2\pi \approx (\pi^2/2)(L_j/L_w)^2$$
$$\approx 10^{-3}$$

$$L_\Omega \approx f^{-1} L_j \approx 10^{48} f^{-1}\ \mathrm{erg\ s^{-1}}$$
$$\approx 10^{51}\ \mathrm{erg\ s^{-1}}$$

→ **satisfy the apparent isotropic energy of short bursts at $z \approx 1$** *(Panaitescu et al. 2001)*

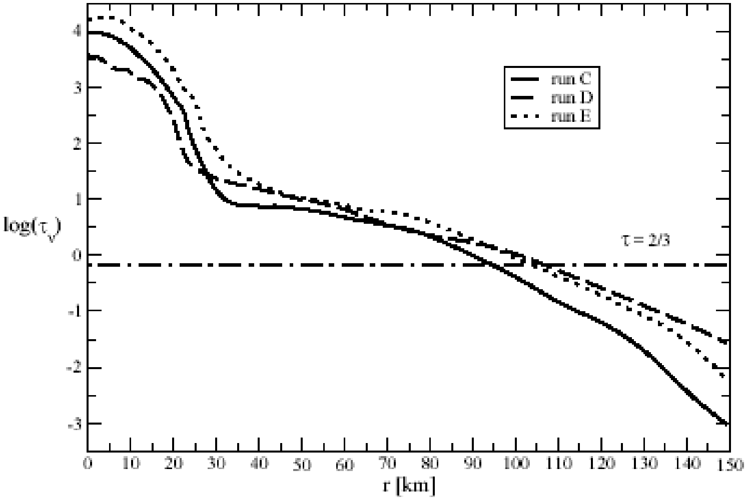
MHD Extraction

- Equipartition field strengths: $P_{mag}=P_{gas}$

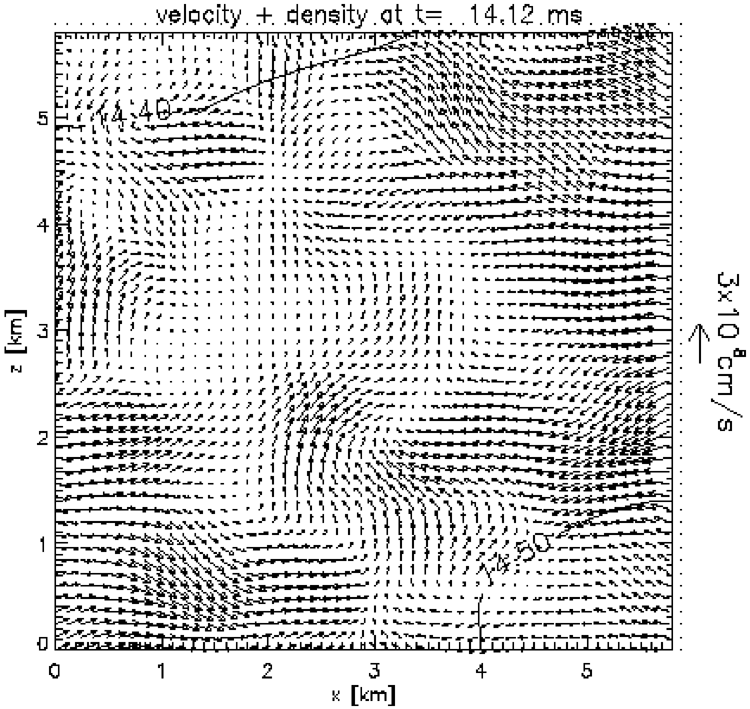


- Timescale for "winding-up" of the field lines via differential rotation.

Convective motion, dynamos & super-pulsars



- **The neutrino emission establishes a negative entropy and lepton number gradient → vigorous convection!**
- **Newly born protoneutron star** *(Epstein 1979; Burrows & Lattimer 1988)*



- **Velocity field on the interior of the central object → convective shells**

$$l_{\text{conv}} \sim 1\ \text{km}$$

$$v_{\text{conv}} \sim 10^{8}\ \text{cm s}^{-1}$$

Convective motion, dynamos & super-pulsars

- If we assume neutrinos to be the dominant source of viscosity, the related viscous damping time scale for the convective motion is:

$$\tau_c \sim l_c^2/\upsilon_\upsilon \sim 60\ \mathrm{sec} \approx 10^5 \tau_{\mathrm{dyn}}$$

- An effective large scale helical dynamo can be supported for $R_0 \leq 1$:

(Duncan & Thompson 1992; 1993)

$$R_0 \approx \tau_{\mathrm{rot}} / \tau_{\mathrm{conv}} \sim 0.3$$

- Such a convective dynamo amplifies seed magnetic fields exponentially:

(Nordlund et al. 1992)

$$\tau_{\mathrm{eq}} \sim \tau\ \mathrm{In}\ (B_{\mathrm{eq}}/B_0) \sim 40\ \mathrm{ms}$$

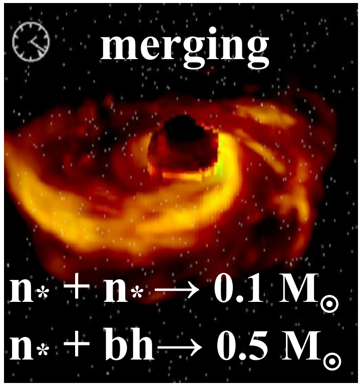
- Using typical numbers we estimated the magnetic dipole luminosity to be:

$$\mathrm{L}_{\mathrm{md}} \sim 10^{53}\ \mathrm{erg\ s}^{-1}$$

and the spin down timescale:

$$\tau_{\mathrm{sd}} \sim 0.3\ \mathrm{s}$$

Summary



$n_* + n_* \longrightarrow 0.1\ M_\odot$

$n_* + bh \longrightarrow 0.5\ M_\odot$

low entropy disk

high entropy disk ($T \geq 5$MeV)

dynamically unstable
very short bursts
≤ few ms

low α
~0.1s

moderate α
≤ 0.1s

short bursts

MHD

$\nu + \bar{\nu} \longrightarrow e^+ + e^-$

B_{max}?

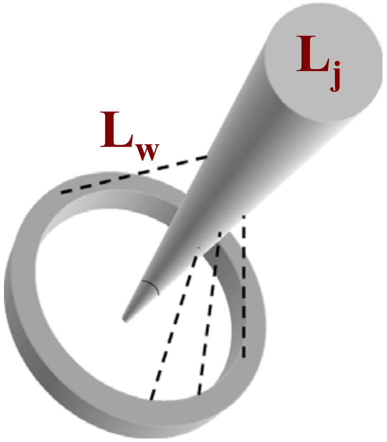
nothing

MHD

$\nu + \bar{\nu} \longrightarrow e^+ + e^-$

10^{53} - 10^{54} erg
no beaming

10^{48} - 10^{49} erg
1% beaming



no convective dynamo
magneto-rotational instability?