GRB accretion disks and jets

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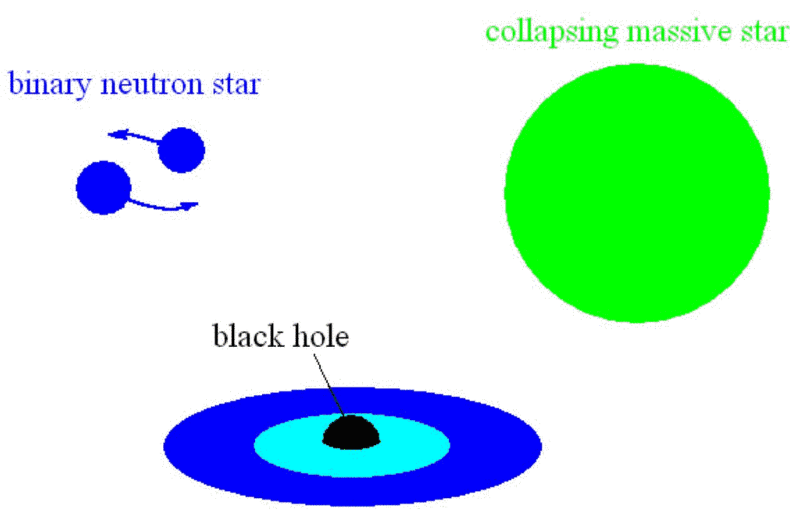
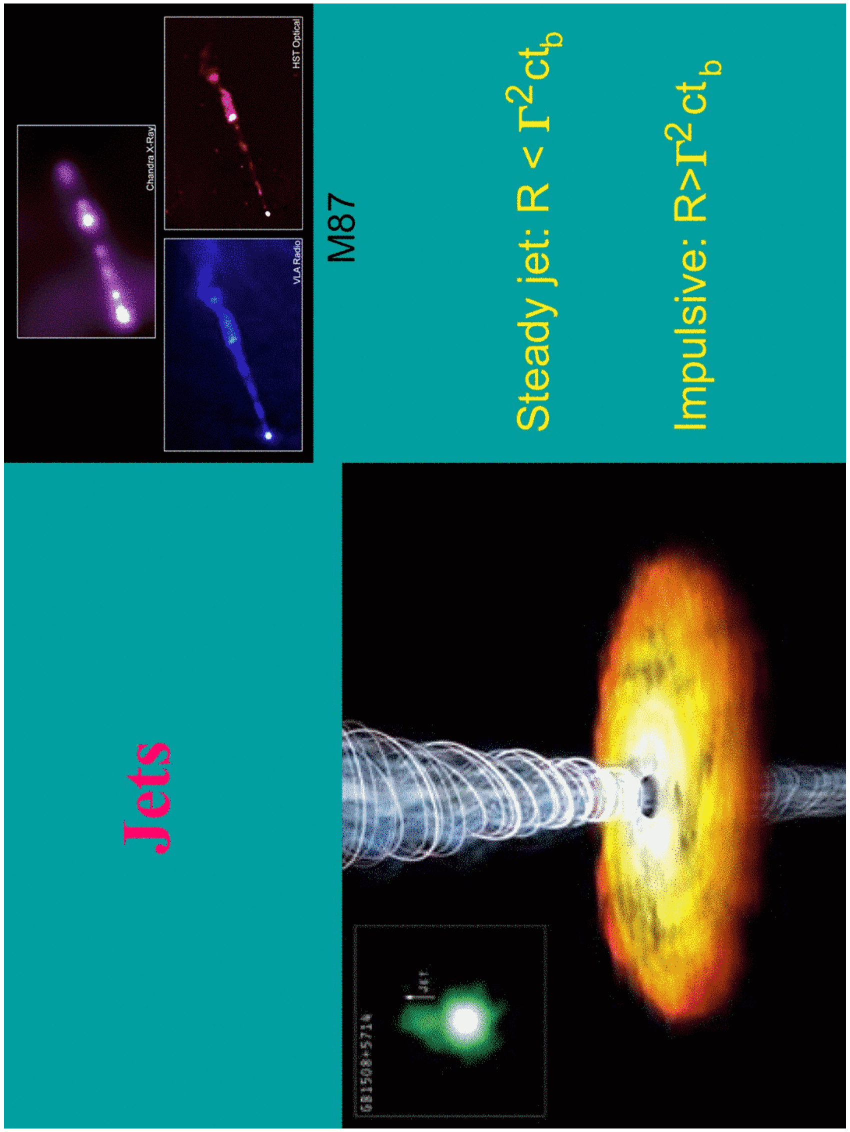
Central Engine

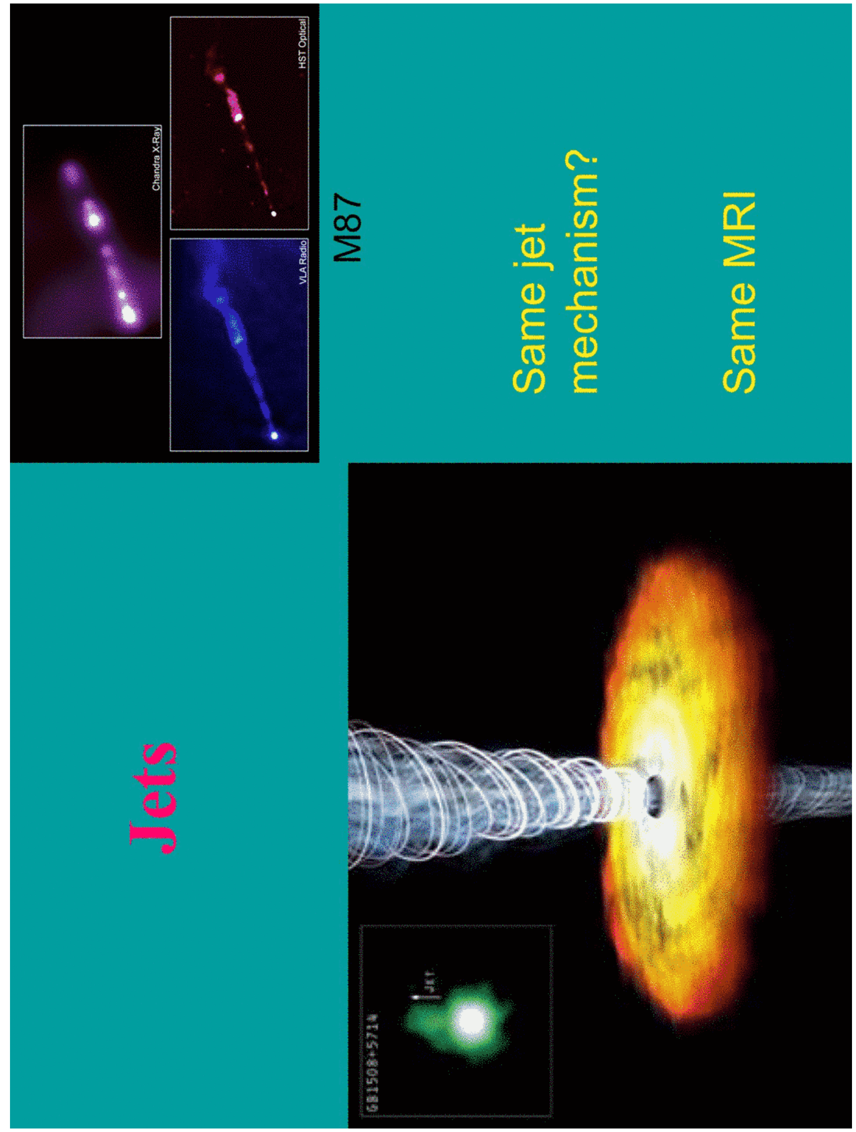
Mass ~ $M_{\odot}$ (energy reservoir ~ 10^{54} erg)

ms variability => size < 10^{7} cm — compact object

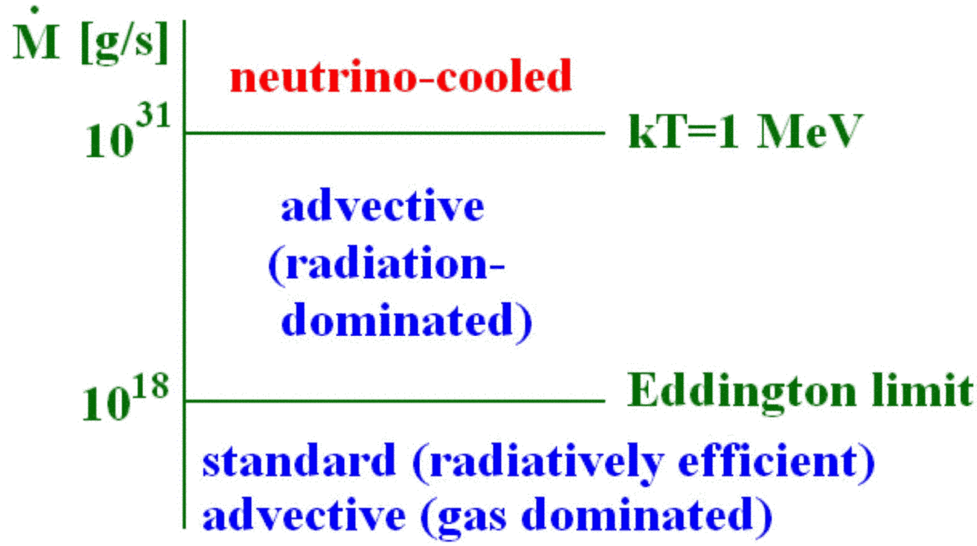
Progenitors




Jets
GB1508+5714
JET
Chandra X-Ray
HST Optical
VLA Radio
M87
Steady jet: $R < \Gamma^2 ct_b$
Impulsive: $R > \Gamma^2 ct_b$


Jets
GB1508+5714
JET
Chandra X-Ray
HST Optical
VLA Radio
M87
Same jet mechanism?
Same MRI

Accretion Disks



Physical conditions in the central engine

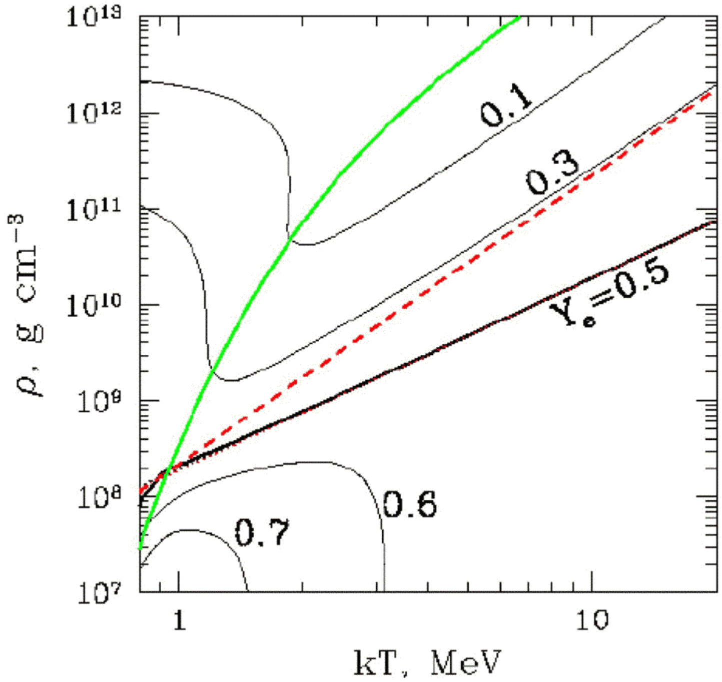
* Black body
  kT > MeV => $e^{\pm}$ population

* $\rho > 10^{10}$ g/cm^3 => electron degeneracy
  $E_{Fermi} \sim 10$ MeV — mild degeneracy

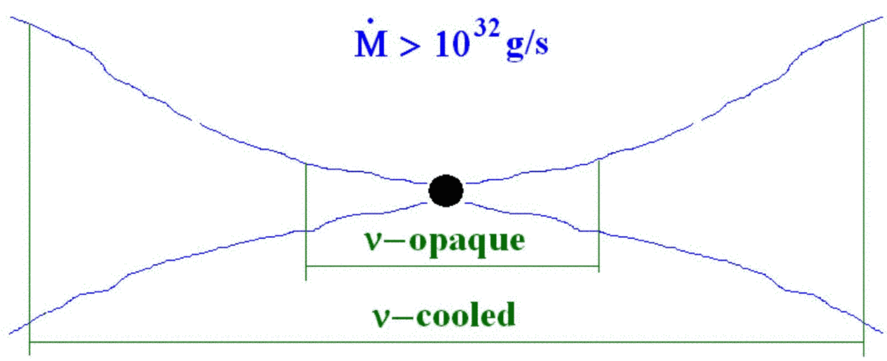
* Neutrino cooling: $e^- + p \longrightarrow n + \nu$
  $e^+ + n \longrightarrow p + \bar{\nu}$
  Equilibrium n/p ratio

Complete equilibrium is achieved in the accretion disk:
thermodynamic + nuclear + β–equilibrium

$$Y_e = \frac{\text{protons}}{\text{protons + neutrons}}$$



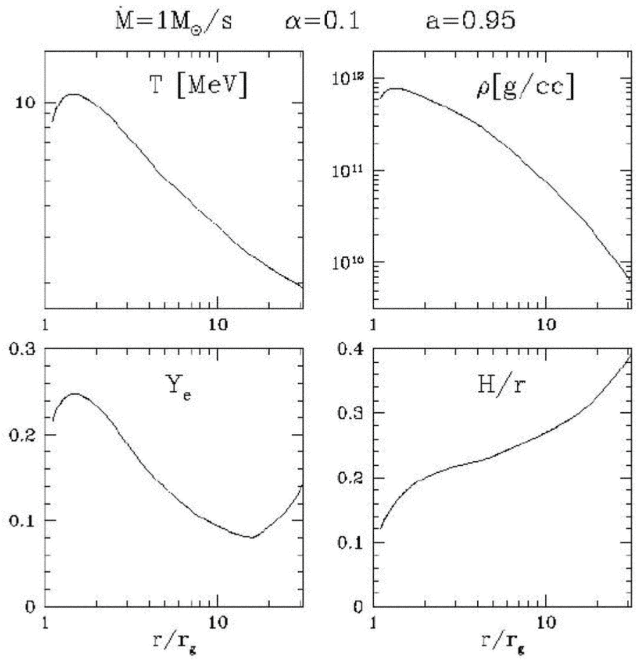
Beloborodov (2003)



Self-consistent disk model must include feedback of low Ye (degeneracy) on the cooling rate:

Cooling → low T → degeneracy → low positron density → reduced cooling rate → higher T

Regulation toward mild degeneracy



Disk model

- Vertically-averaged
- Neutrino transport (escape probability)
- Full microphysics
- Advection of lepton number and heat included
- Fully relativistic (Kerr geometry)

W. Chen, A. Beloborodov

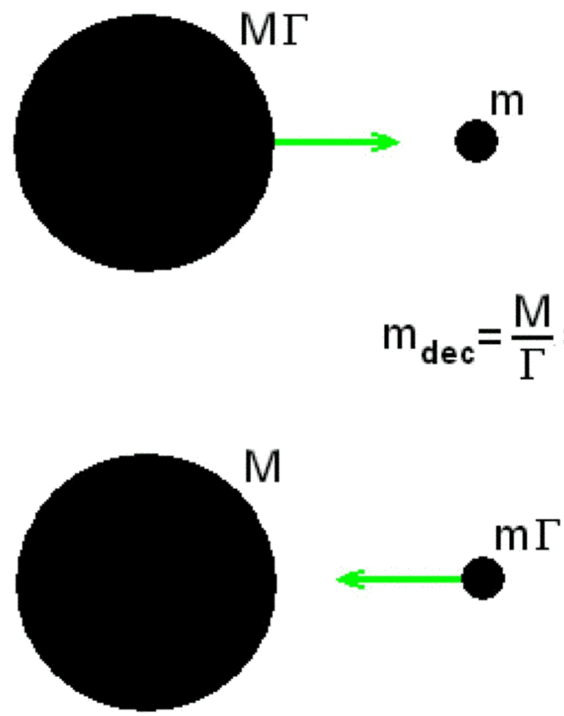
Neutron-loaded jets

1. Expansion as a single fluid. Adiabatic cooling.

2. n-p decoupling and reheating (Rossi, Beloborodov, Rees 2005)
   Multi-GeV neutrino emission (Derishev, Kocharovsky, Kocharovsky 1999; Bahcall & Meszaros 2000)

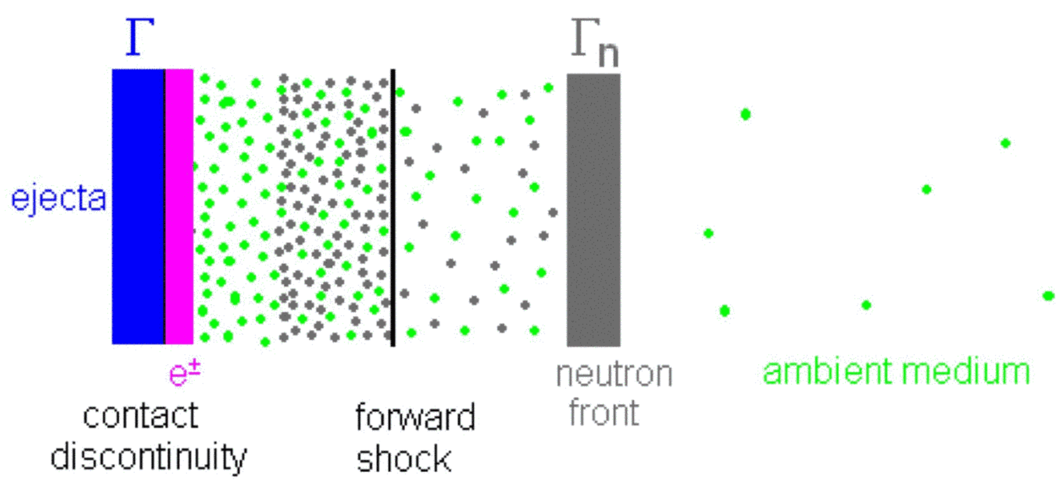
3. Neutron-fed blast wave (Beloborodov 2003)

MHD scenario (Vlahakis, Konigl, Peng 2003)



$$m_{dec} = \frac{M}{\Gamma} = \frac{E}{c^2\Gamma^2}$$

GRB blast wave at the deceleration stage

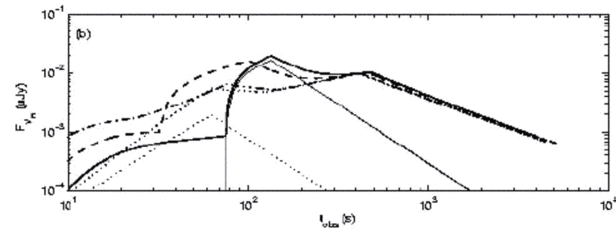


$R_\beta \sim \tau_\beta \Gamma_n c \sim 10^{16} (\Gamma_n/300)$ cm $\quad R_{trail} \sim 10 R_\beta$

Impact of neutrons on the afterglow light curve

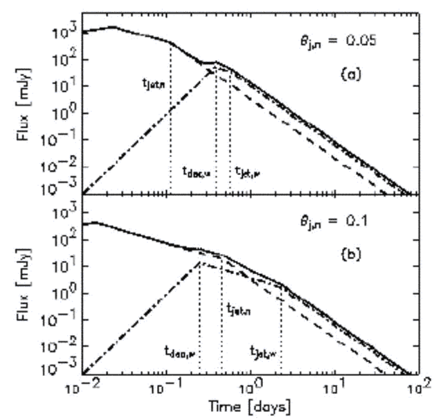
--- Fast and strongly collimated neutron component :

(Fan, Wei, Zhang 2004)



--- Slow and wide neutron component in the MHD jet model:

(Peng, Konigl, Granot 2004)



Summary: GRB disks

- Neutrino-cooled at Mdot > 0.01 Msun/s
- Neutrino-opaque at Mdot > 0.1 Msun/s
- Equilibrium Ye is achieved: Ye ~ 0.1 for Mdot=0.1 Msun/s
Ye ~ 0.2 for Mdot=1 Msun/s

  => neutron-rich material

- Self-consistent disk model is obtained (Ye + cooling rate + hydro)
- **Inviscid mini-disks in GRBs?** (size < 30 GM/c^2)

- Neutron-loaded jet links accretion physics with observed explosion:

  -- after initial stage of adiabatic cooling neutrons reheat the jet

  -- later survived neutrons leak out of the ejecta and change the blast wave mechanism