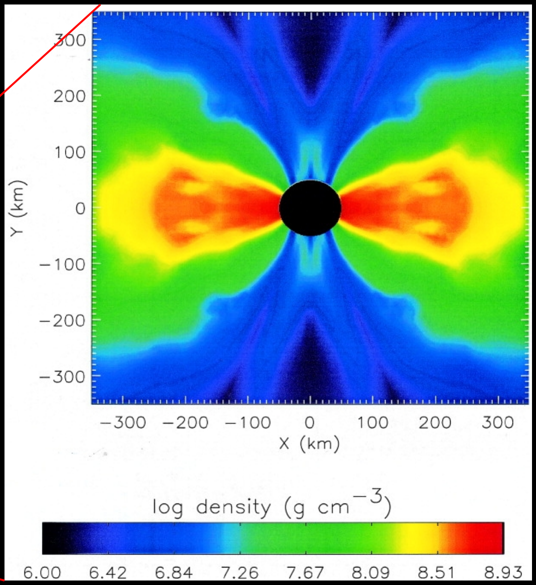
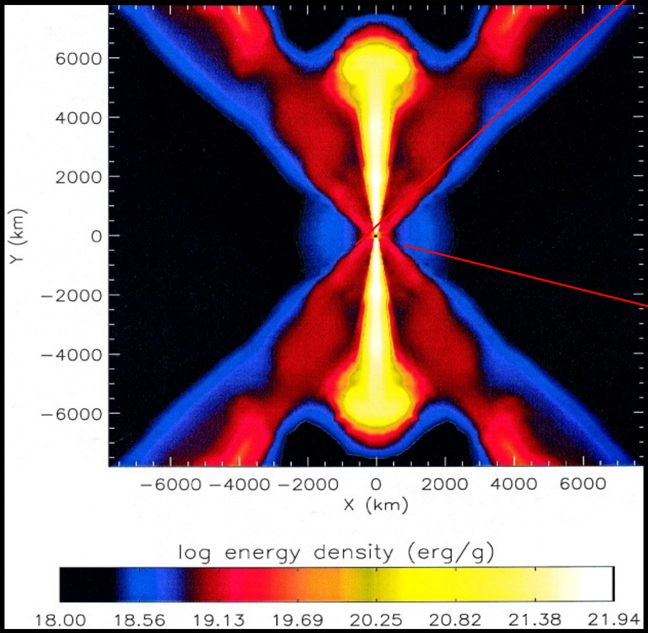
Accretion in the collapsar. How long can be a long GRB?

Agnieszka Janiuk

Copernicus Astronomical Center, Warsaw

Collapsar in the engine of long GRBs





The thick torus may form during the collapse of a massive, rotating star. This torus is likely to be connected with a jet production and gamma ray burst.

Simulations done by MacFadyen & Woosley (1999)

Mechanisms of energy transfer from torus to jet:

1. neutrinos

2. BH rotation

Conditions for torus existence

The rotation must prevent the envelope material from the radial infall onto BH.

Specific angular momentum

$l_{spec} > l_{crit} = 2\, R_S\, c$

Schwarzschild radius

$2GM_{BH}/c^2$

BUT: BH is growing fast (accretion rate of 0.01-1 Msun/s) =>

the GRB is emitted only until $l > l_{crit}$ is satisfied.

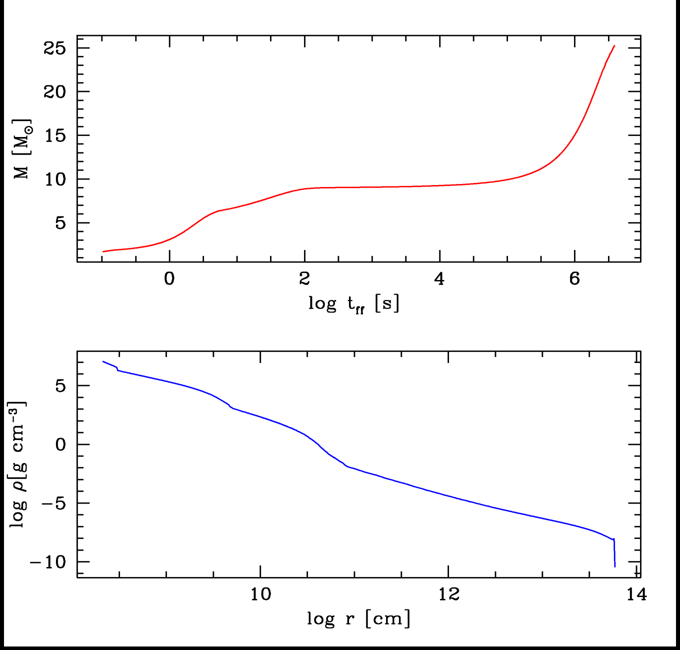
For a rotating BH:

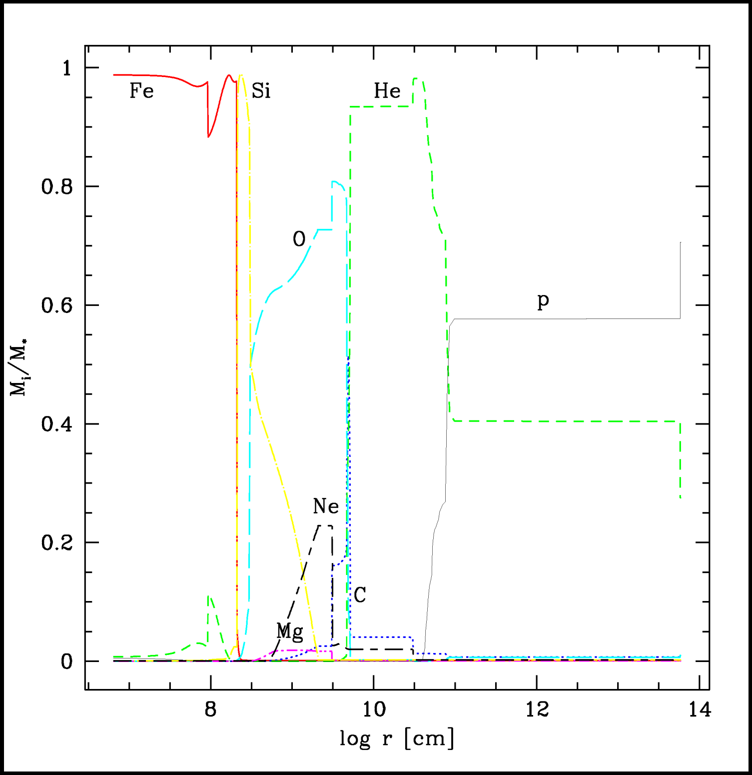
$$l_{crit} = 2GM_{BH}/c\,(2-A+2(1-A)^{1/2})^{1/2}$$

How long can be a GRB?

Pre-SN model: iron core + envelope

Density and mass distribution in the pre-supernova star





Chemical composition

(data from Woosley & Weaver 1995)

How the pre-collapse star rotates?

The distribution of specific angular momentum in the pre-SN star unknown.

Some assumptions:

Polar angle dependence (differential rotation)

Radius dependence (rigid rotation, with a possible cut-off on l_{spec})

Constant ratio of centrifugal to gravitational forces

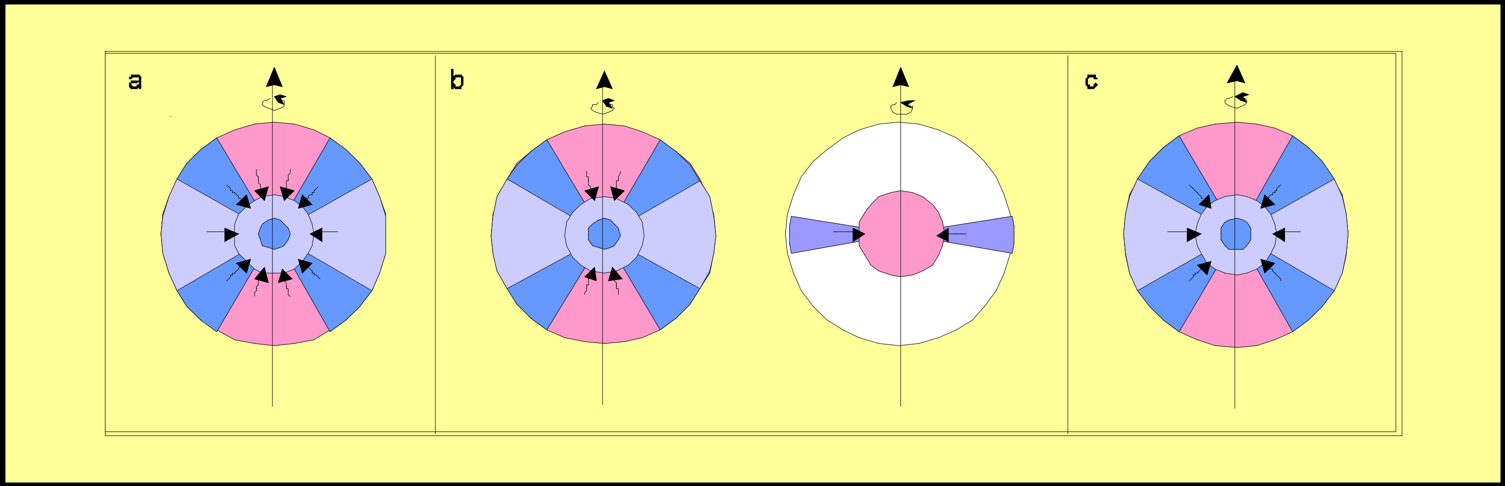
$$l_{spec} = l_0 (1-\cos\theta)$$

$$l_{spec} = l_0 (r/r_{in})\sin^2\theta$$

The black hole grows due to accretion

The time evolution of the collapsar => iterative procedure

1. BH mass = iron core mass
2. Envelope schells accrete
3. Check for conditions given by the changing BH mass and spin

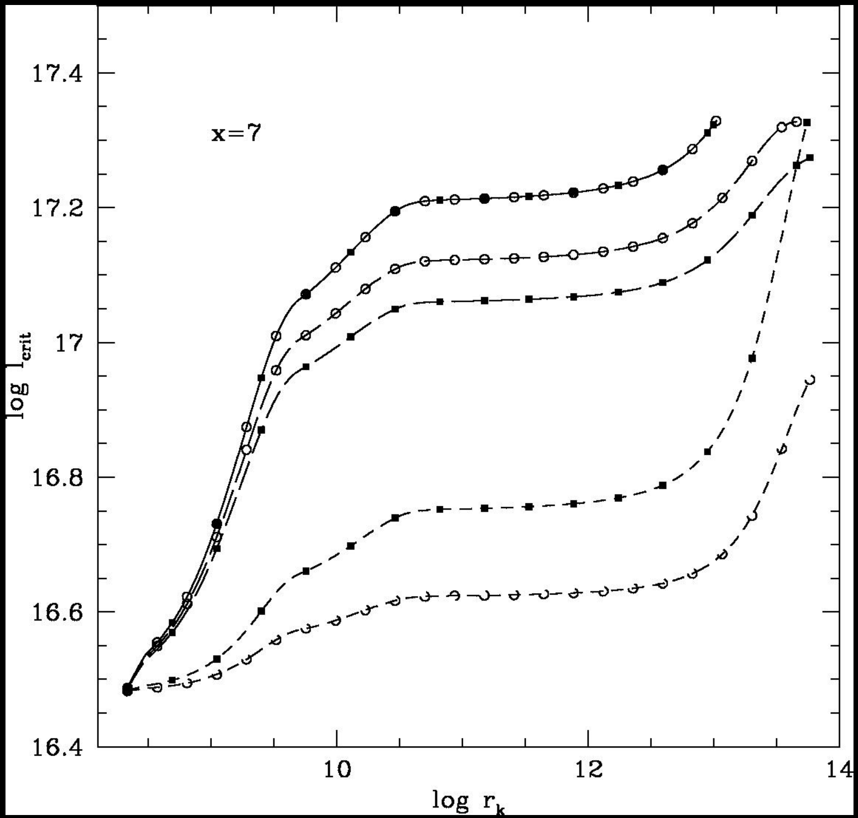


Various possible accretion scenarios

Critical angular momentum during the collapse

Large l_{crit} => less material in the envelope can form torus

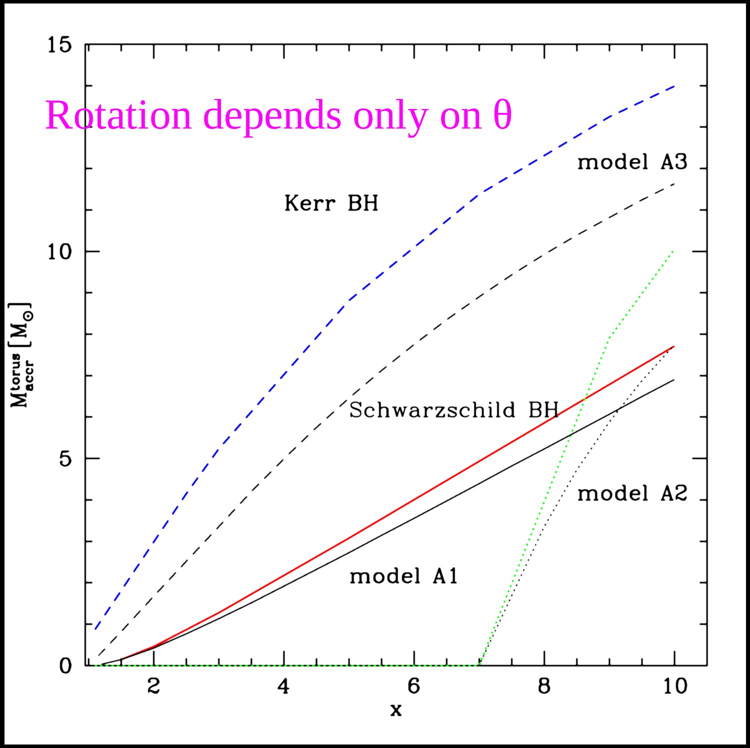
No torus => GRB is finished (the jet is accretion powered)

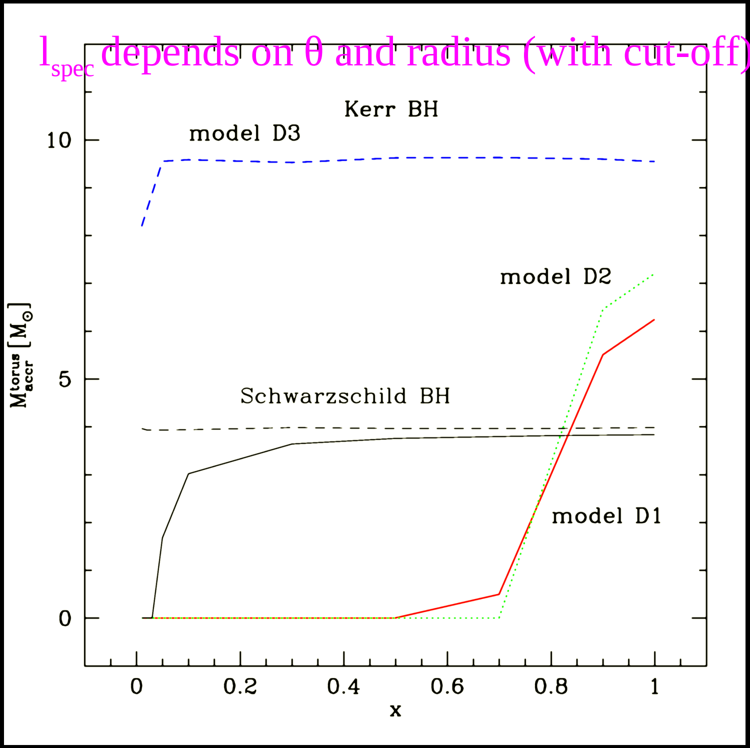


Schwarzschild BH case (Janiuk & Proga, 2008, ApJ, 675, 519)

How long is a GRB?

Constant accretion rate => GRB duration proportional to mass accreted through torus

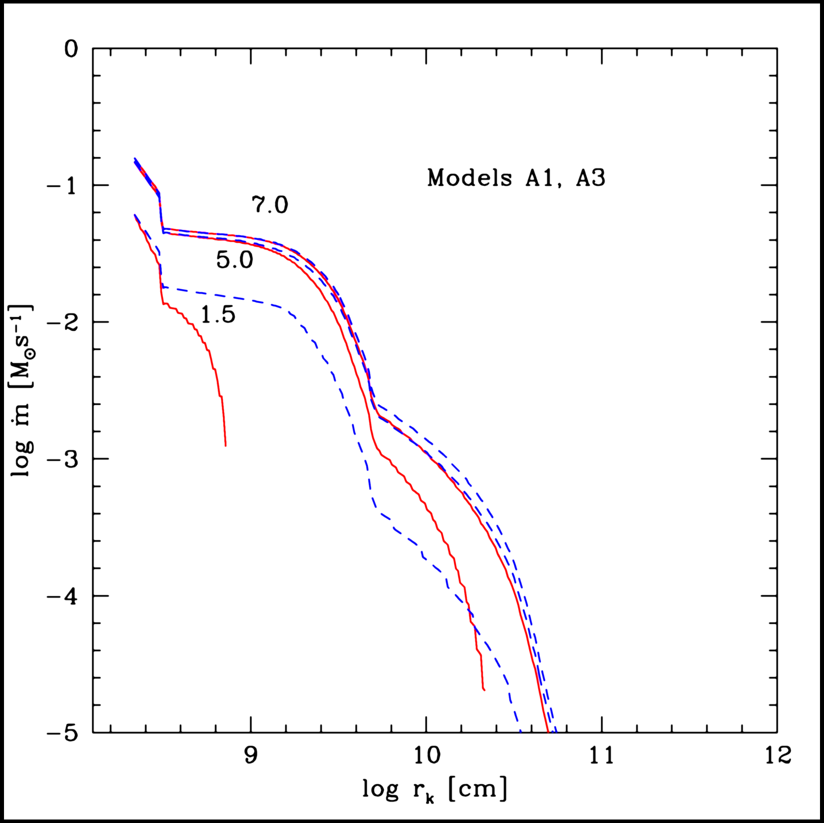


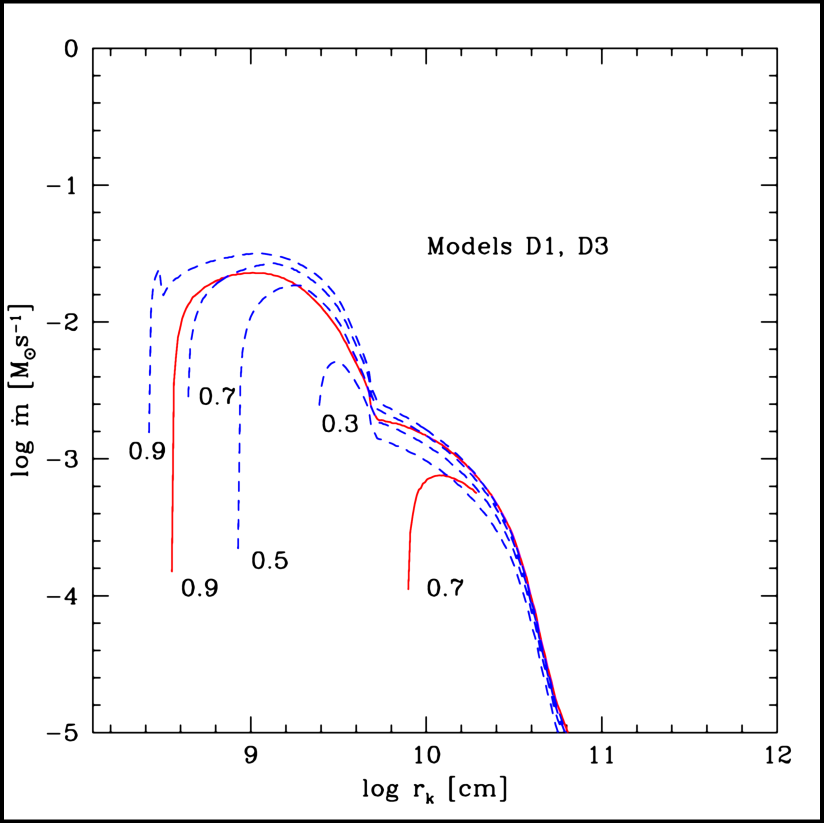


Accreted mass as a function of initial normalization of l_{spec} and for various models of rotation.

Kerr BH case: Janiuk, Moderski & Proga, 2008, ApJ, submitted

Accretion rate is not constant

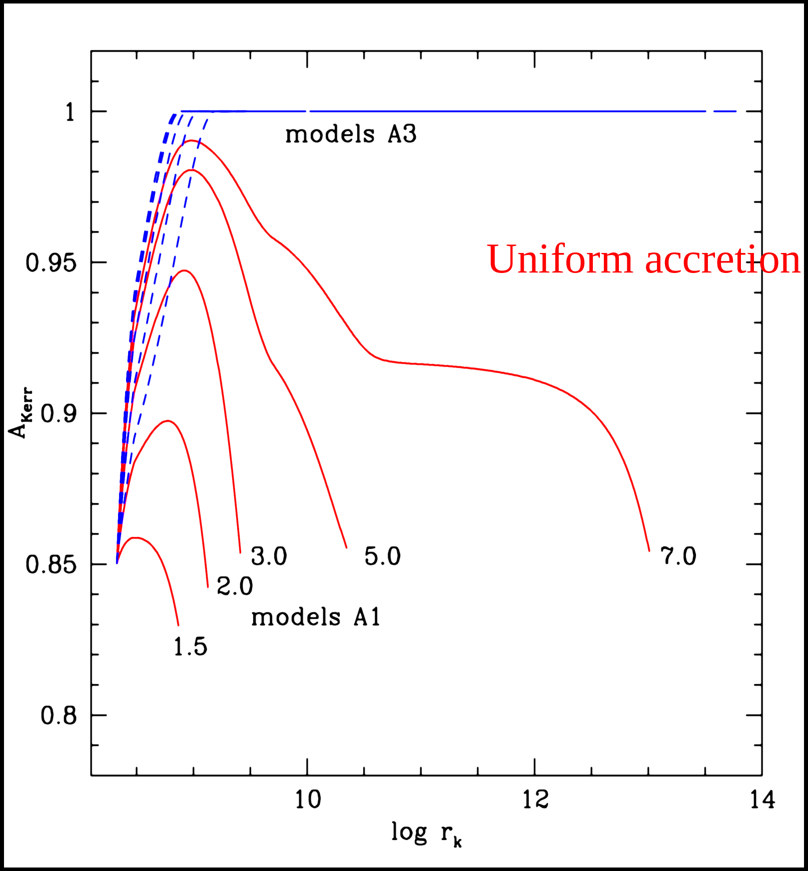


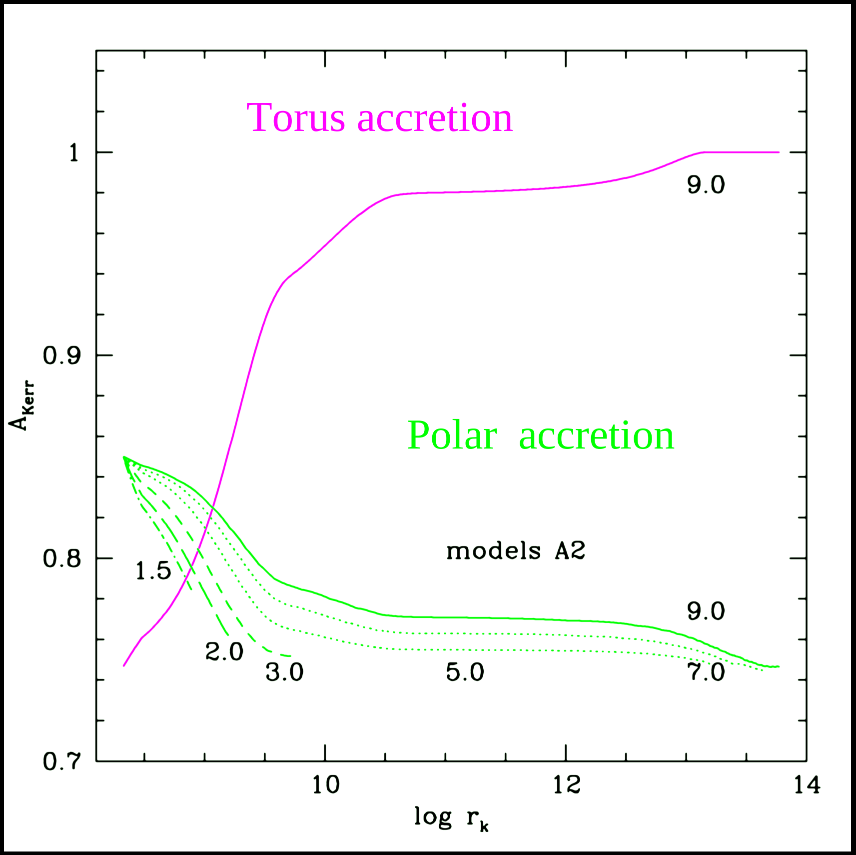


Neutrino annihilation inefficient when accretion rate < 0.01 M_{sun}/s => GRB finishes

(e.g. Popham et al. 1999; Di Matteo et al. 2002; Janiuk et al. 2004; 2007)

Evolution of the BH spin

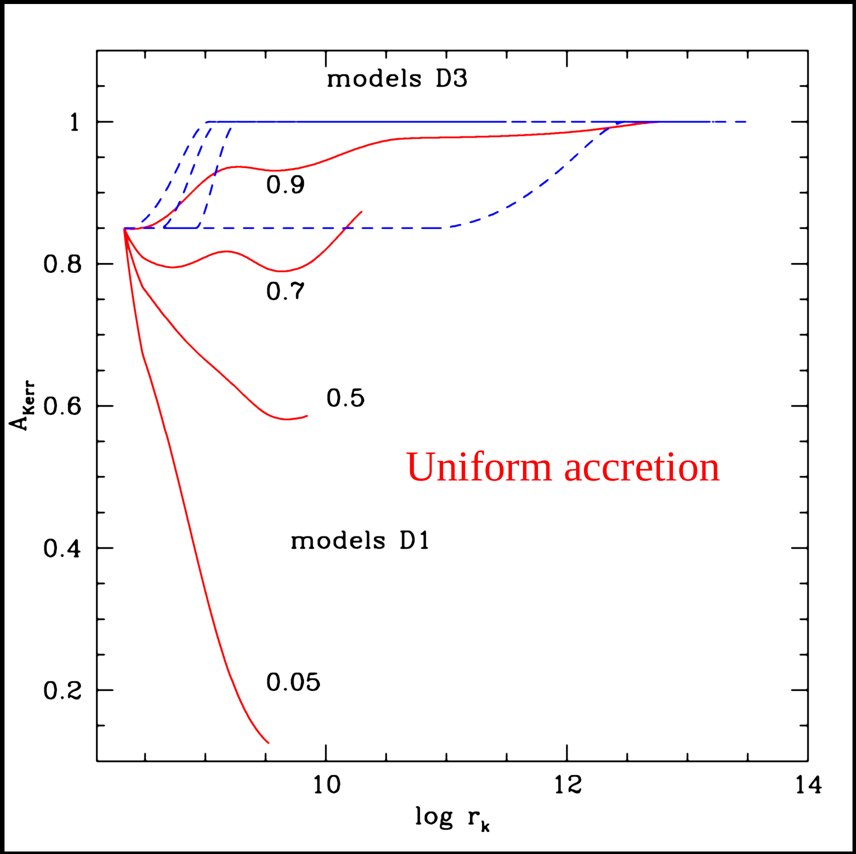


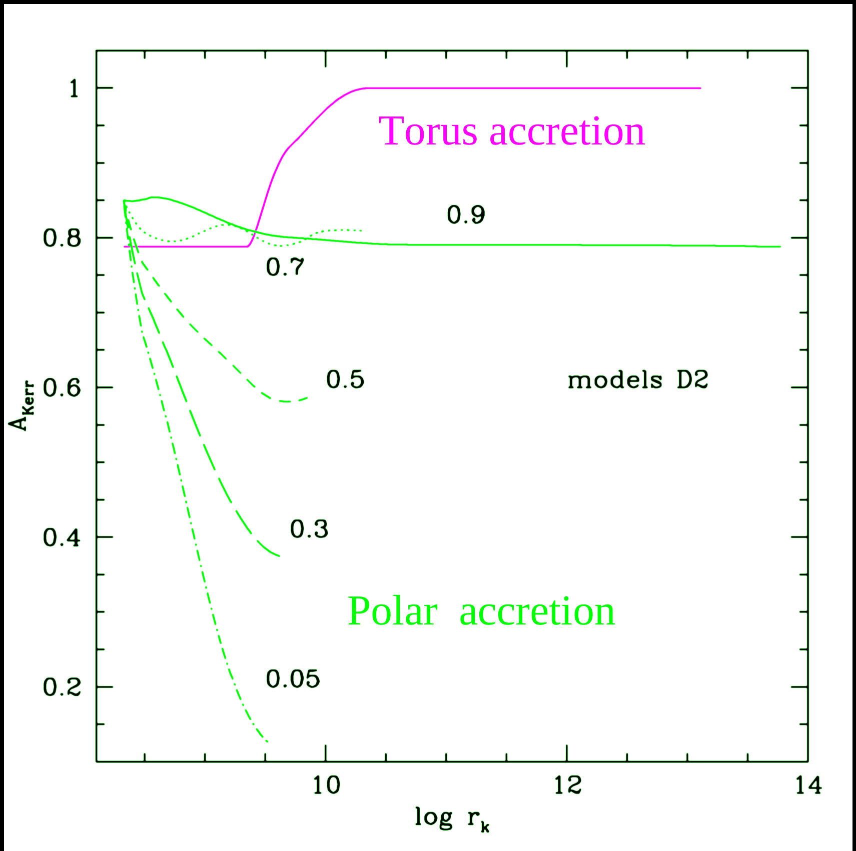


Differential rotation models

B-Z mechanism inefficient when A < 0.9 (Blandfor-Znajek 1977; McKinney 2005)

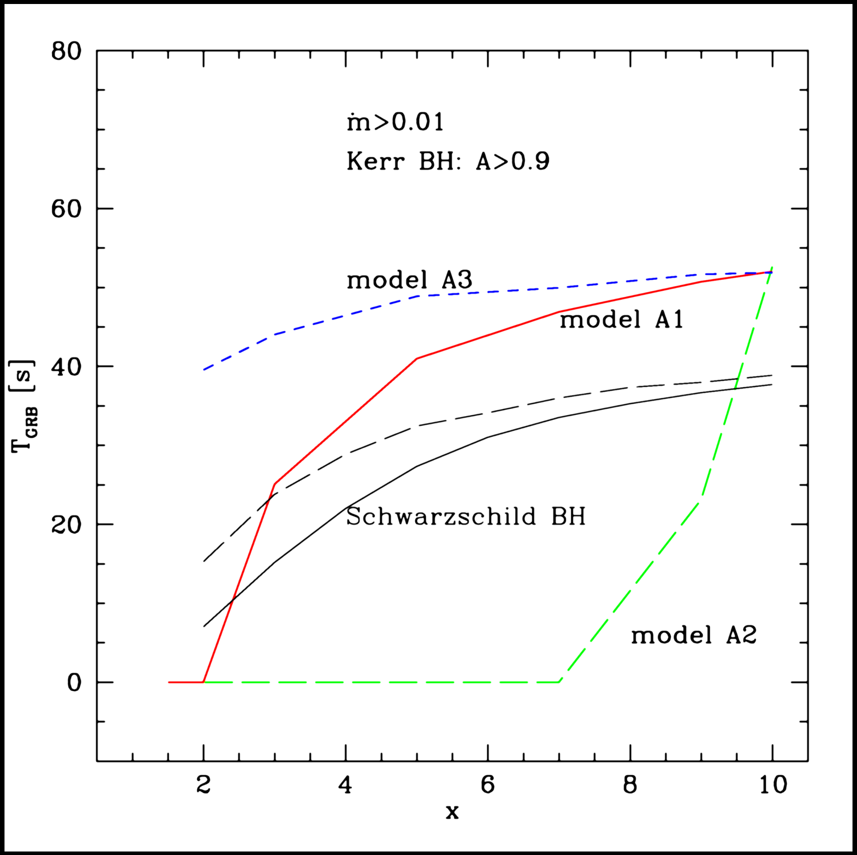
… BH may even spin down completely

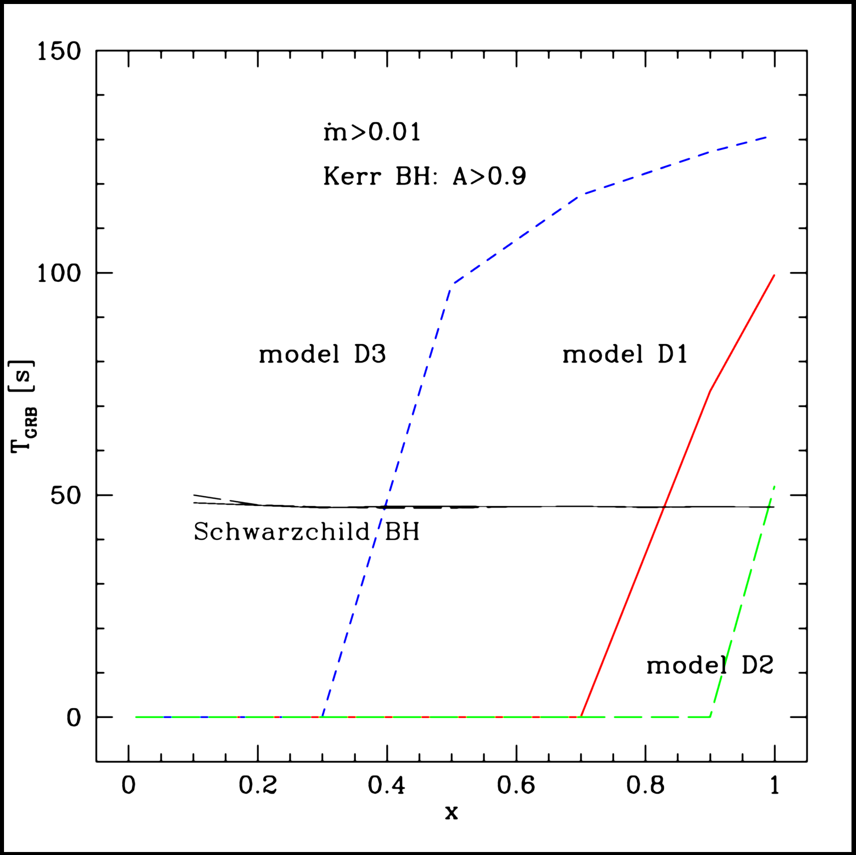




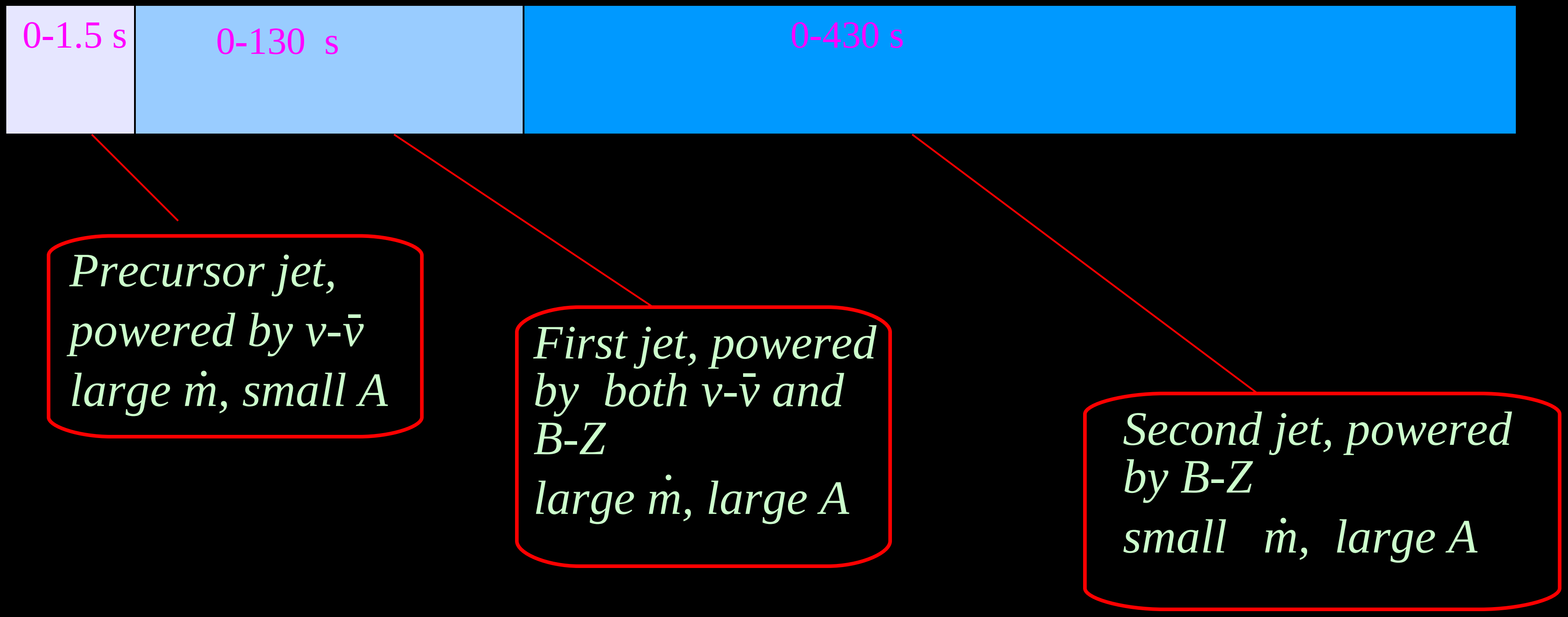
Rotation models with centrifugal-gravity balance

GRB: large accretion rate *and* spinning BH





Three kinds of jets in the collapsar



Summary

GRB long durations may provide constraints for the rotation law in the pre-SN star.

Realistic rotation laws result in mass accreted through the torus less than 4-15 M_{sun}.

The minimum accretion rate limit for the *neutrino-powered jets*, in the Schwarzschild black hole models, results in GRB durations up to 40-100 s.

The minimum *accretion rate and BH spin* limit, for jets powered by both neutrinos and B-Z mechanism, results in GRB durations up to 50-130 s.

In the Kerr black hole models, we find the solutions corresponding to three kinds of jets: precursor jet, early jet and late jet, powered by different mechanisms. Possibly, the opening angle of these jets is changing, which would have strong observational consequences.