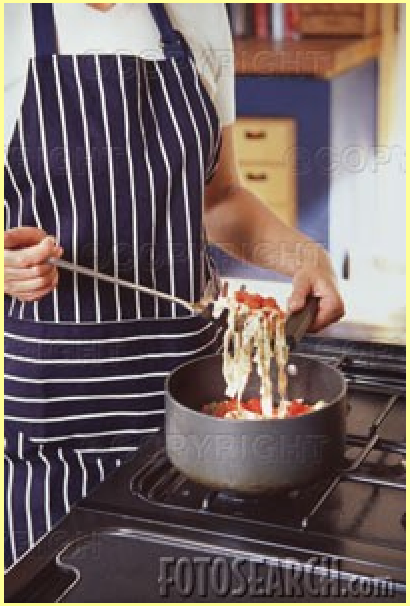
GRBs from Population III stars

T. Bulik(CAMK, OAUW)
K. Belczyński (NMSU),
Ch. Fryer, A. Heger(LANL)

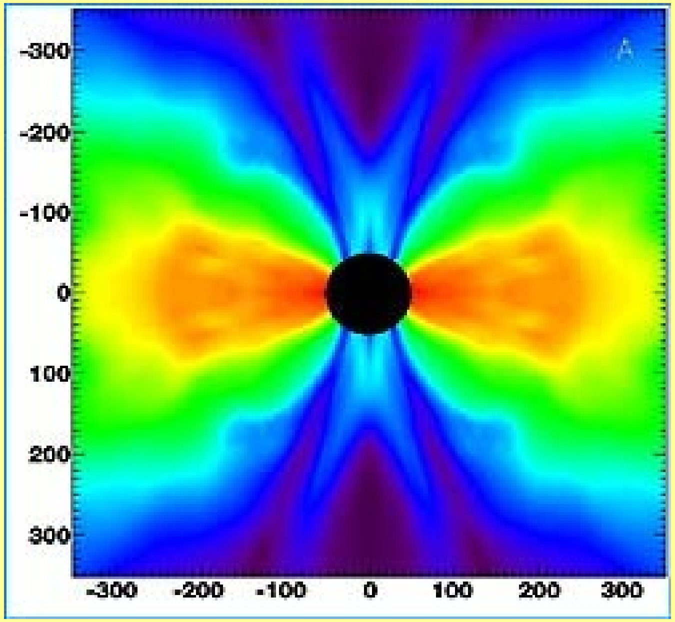
Collapsars as GRB progenitors

- Observational evidence
- The collapsar recipee:
  - massive naked He stars,
  - quick rotation
  - BH and an accretion torus



- Single stars? Not really...
- Quick rotation: binary evolution helps

Quick rotation



- Formation of Kerr BH
- Formation of accretion torus
- Specific angular momentum in GR units:

$$
\begin{array}{ll}
0.42 < \tilde{j}_{7\mathrm{in}} < 2.8 & \text{MacFadyen \& Woosley (1999) (A)} \\
1 < \tilde{j}_{7\mathrm{in}} < 10 & \text{this work (B)} \\
\tilde{j}_{7\mathrm{in}} > \sqrt{6} & \text{Podsiadlowski et al. (2004) (C)}
\end{array}
$$

Why Population III?

- GRBs may be associated with low metalicity
- First stars
- Relevance for cosmology
- Phenomenological redshift estimates and high redshift bursts

Population III stellar evolution

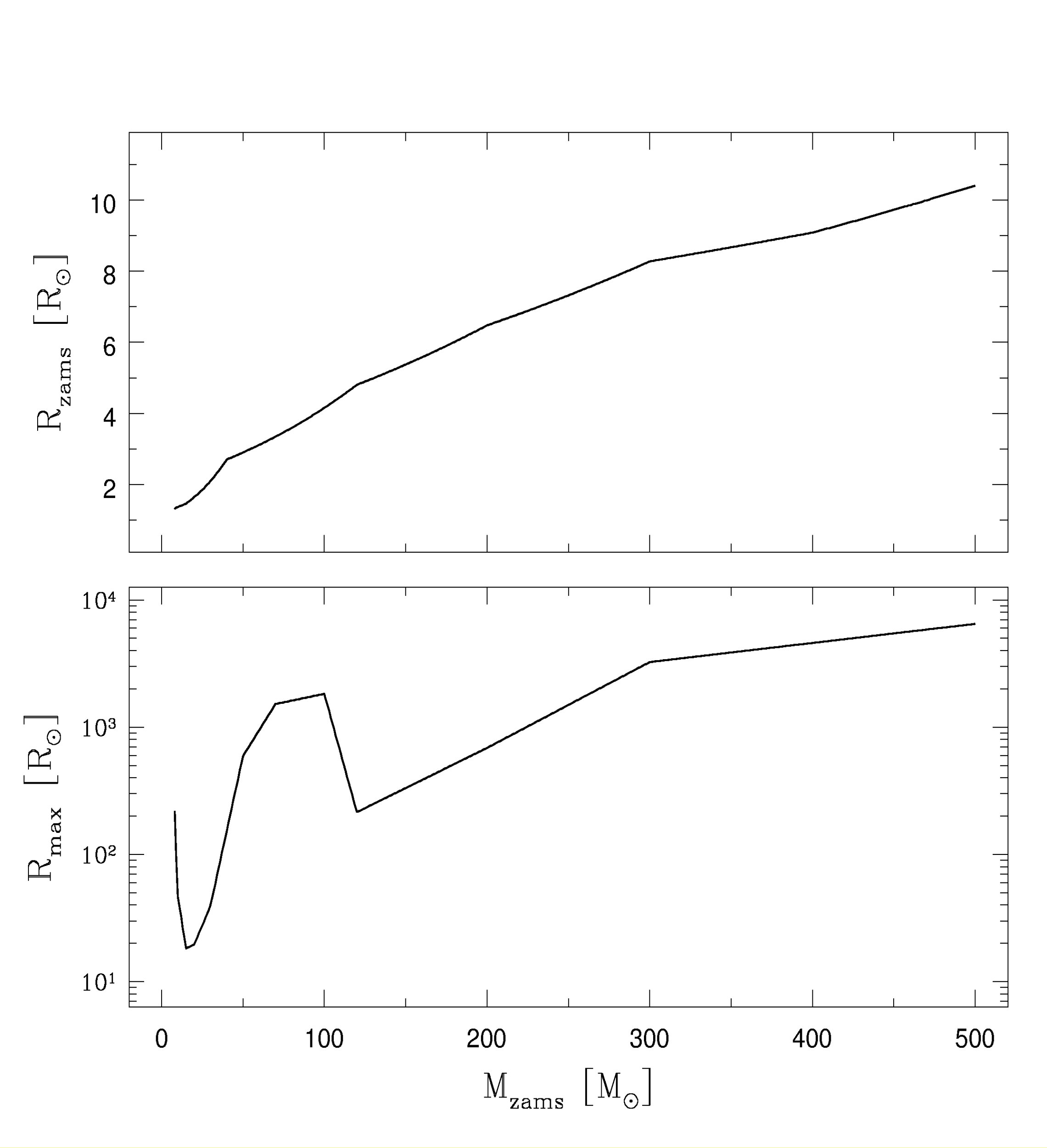
- Stellar masses up to 500-1000 M_{sun}
- No mass loss during evolution
- Pair instability SNe
- Disruption between 140-260 M_{sun}
- Effective BH production
- How to strip H envelopes? Binaries!
- How to spin them up?

The plan

- Numerical models of stars
- Binary evolution
- Initial parameters
- Population synthesis of Pop III stars
- Finally – calculation of SWIFT detection rate

Stellar models

- Radii
- Structure – core , envelope
- Moments of inertia
- Final masses of BHs
- Parametrization of evolution with analytical formulae



Population synthesis models

- Initial parameters: masses, mass ratios, orbital separations
- Binary evolution, mass transfers
- Spin evolution
- Tidal locking
- Core envelope coupling – spin up, spin down

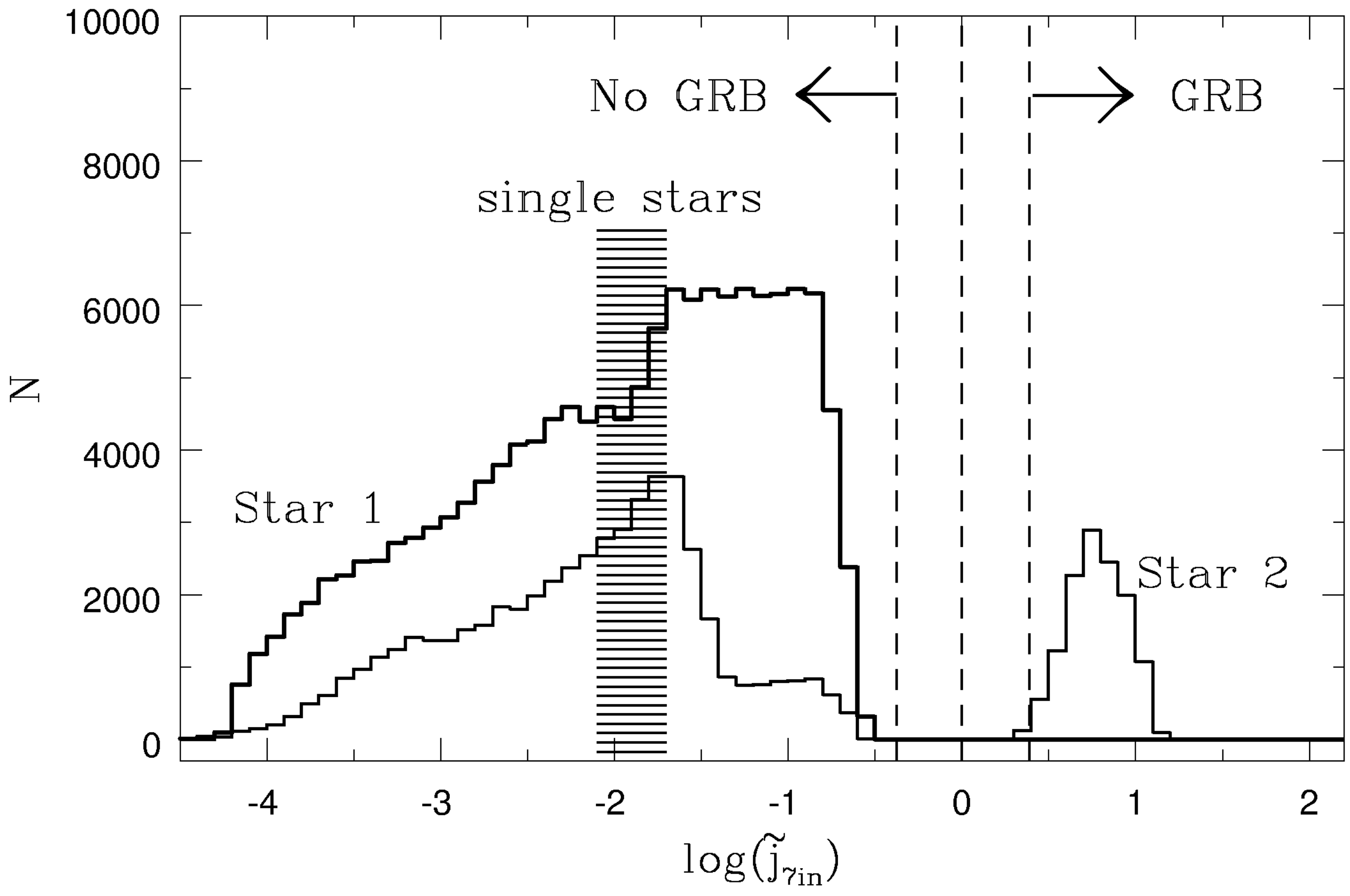
Spin evolution

- Initial spins:
- Separation of core and envelope
- Tidal interaction in close binaries
- Core – envelope coupling
- Final spin depends on the binary separation

Leading ccenarios leading to naked He core formation

- MT1 GRB1 CE2 GRB2
- CE1 GRB1 MT2 GRB2
- MT1 GRB1
- Other

Naked He core spin



Specific angular momentum of the core

GRB production efficiency

Table 1. GRB Formation Channels and Efficiencies[a]

Channel	Evolutionary Sequence[b]	η_1	η_2	η_3	η_4
grb01	MT1 GRB1 CE2 GRB2	0.0733	0.0002	0.0058	0.0063
grb02	CE1 GRB1 MT1 GRB2	0.0121	0	0	0
grb03	MT1 GRB1	0.0110	0	0	0
grb04	All others	0.0077	0	0	0
Total	All channels	0.1041	0.0002	0.0058	0.0063

[a]Formation efficiencies in case of no angular momentum constraints (η_1); MacFadyen & Woosley 1999 (η_2); this work (η_3); Podsiadlowski et al. 2004 (η_4).

[b]Notation explained in § 3.1.

Detection rate

- Assume constant star formation between z=10 and z=30
- Luminosity function form observed bursts
- Beaming as in nearby bursts
- Moderate binary fraction

$$R_{SWIFT} = \frac{\eta_{mass}\eta_{beam}\eta_S\eta_i}{M_{av,bin}} \int \Phi(L)dL \int_0^{z_{max}(L)} \frac{SFR(z)}{1+z}\frac{dV}{dz}dz$$

SWIFT detection rate

$$R_{SWIFT} = 3\text{yr}^{-1}\eta_i \left(\frac{\eta_{mass}}{0.15}\right)\left(\frac{\eta_{beam}}{0.02}\right)\left(\frac{\eta_S}{0.1}\right)\left(\frac{S}{S_0}\right)\left(\frac{36M_\odot}{M_{av}}\right)\left(\frac{F(z_{start}) - F(z_{stop})}{3.93}\right)$$

Fraction of mass in binaries

Beaming

SWIFT detection effciency

Star formation rate

Average stellar mass

Star formation rate history convolved with the luminosity function

$$R_{SWIFT} = 0.1 - 0.01\text{yr}^{-1}$$

A number of models considered: the same conclusion

Table 2. GRB Formation Efficiencies: Parameter Study[a]

Model	η_1	η_2	η_3	η_4	Description[b]
Mod01	0.1041	0.0002	0.0058	0.0063	standard
Mod02	0.1103	0	0	0	no tides
Mod03	0.0837	0.0001	0.0034	0.0037	kicks
Mod04	0.2602	0.0008	0.0147	0.0146	$M_{\rm zams,1} \geq 30$ M$_\odot$
Mod05	0.1041	0.0002	0.0058	0.0064	tides on envelope only
Mod06	0.1042	0.0002	0.0058	0.0064	$X_{\rm cou1} = 0.01$
Mod07	0.1039	0.0002	0.0058	0.0063	$X_{\rm cou1} = 1$
Mod08	0.1041	0.0242	0.0111	0.0067	$X_{\rm cou2} = 1$
Mod09	0.1041	0.0053	0.0006	0	$X_{\rm cou2} = 0.01$
Mod10	0.0831	0.0002	0.0037	0.0037	$\alpha_{\rm ce} \times \lambda = 0.3$
Mod11	0.1295	0.0001	0.0082	0.0104	$\alpha_{\rm ce} \times \lambda = 3$
Mod12	0.0471	0.0001	0.0020	0.0022	alternative IMF
Mod13	0.1030	0.0002	0.0056	0.0062	Pop I rotation
Mod14	0.1051	0.0002	0.0062	0.0068	RLOF spinup
Range	.04–.26	0–.02	0–.01	0–.01	all models

[a]Formation efficiencies in case of no angular momentum constraints (η_1); MacFadyen & Woosley 1999 (η_2); this work (η_3); Podsiadlowski et al. 2004 (η_4).

Summary

- Formation of naked He cores is easy for Population III binaries
- Spinning up the core is difficult
- Expected rate of Population III collapsars too low to warrant detection by SWIFT
- If detected:
  - all stars high mass
  - exotic scenarios\

Summary continued

- High metallicicity seems to prevent GRBs
- Too low metallicity is not good either...
- An era of GRBs?

Details are in: astro-ph/0610014