General outline of my talks

1) Gamma Ray Bursts: the observational pillars after two decades of observations

Global observational properties of GRBs in the frequency/ time domain (prompt and afterglow – long and short), their typical energetics, distance scale, spectral properties etc.

2) Theoretical picture: the standard model from its foundation to the latest debates

The standard model, progenitor, energy extraction mechanism, hydrodynamic of the fireball, radiative mechanism. Its developement and the present issues.

3) Gamma Ray Bursts in the cosmological context: present status, issues and perspectives

~118 models in 1993!

Nemiroff, R. J., 1993, Comments on Astrophysics, in press.

Table 1

Model #	Author	Year Pub	Reference	Main Body	2nd Body	Place	Description
1.	Colgate	1968	CJPhys, 46, S476	ST		COS	SN shocks stellar surface in distant galaxy
2.	Colgate	1974	ApJ, 187, 333	ST		COS	Type II SN shock brem, inv Comp scat at stellar surface
3.	Stecker et al.	1973	Nature, 245, PS70	ST		DISK	Stellar superflare from nearby star
4.	Stecker et al.	1973	Nature, 245, PS70	WD		DISK	Superflare from nearby WD
5.	Harwit et al.	1973	ApJ, 186, L37	NS	COM	DISK	Relic comet perturbed to collide with old galactic NS
6.	Lamb et al.	1973	Nature, 246, PS52	WD	ST	DISK	Accretion onto WD from flare in companion
7.	Lamb et al.	1973	Nature, 246, PS52	NS	ST	DISK	Accretion onto NS from flare in companion
8.	Lamb et al.	1973	Nature, 246, PS52	BH	ST	DISK	Accretion onto BH from flare in companion
9.	Zwicky	1974	Ap&SS, 28, 111	NS		HALO	NS chunk contained by external pressure escapes, explodes
10.	Grindlay et al.	1974	ApJ, 187, L93	DG		SOL	Relativistic iron dust grain up-scatters solar radiation
11.	Brecher et al.	1974	ApJ, 187, L97	ST		DISK	Directed stellar flares on nearby stars
12.	Schlovskii	1974	SovAstron, 18, 390	WD	COM	DISK	Comet from system's cloud strikes WD
13.	Schlovskii	1974	SovAstron, 18, 390	NS	COM	DISK	Comet from system's cloud strikes NS
14.	Bisnovatyi- et al.	1975	Ap&SS, 35, 23	ST		COS	Absorption of neutrino emission from SN in stellar envelope
15.	Bisnovatyi- et al.	1975	Ap&SS, 35, 23	ST	SN	COS	Thermal emission when small star heated by SN shock wave
16.	Bisnovatyi- et al.	1975	Ap&SS, 35, 23	NS		COS	Ejected matter from NS explodes
17.	Pacini et al.	1974	Nature, 251, 399	NS		DISK	NS crustal starquake glitch; should time coincide with GRB
18.	Narlikar et al.	1974	Nature, 251, 590	WH		COS	White hole emits spectrum that softens with time
19.	Tsygan	1975	A&A, 44, 21	NS		HALO	NS corequake excites vibrations, changing E & B fields
20.	Chanmugam	1974	ApJ, 193, L75	WD		DISK	Convection inside WD with high B field produces flare
21.	Prilutski et al.	1975	Ap&SS, 34, 395	AGN	ST	COS	Collapse of supermassive body in nucleus of active galaxy
22.	Narlikar et al.	1975	Ap&SS, 35, 321	WH		COS	WH excites synchrotron emission, inverse Compton scattering
23.	Piran et al.	1975	Nature, 256, 112	BH		DISK	Inv Comp scat deep in ergosphere of fast rotating, accreting BH
24.	Fabian et al.	1976	Ap&SS, 42, 77	NS		DISK	NS crustquake shocks NS surface
25.	Chanmugan	1976	Ap&SS, 42, 83	WD		DISK	Magnetic WD suffers MHD instabilities, flares
26.	Mullan	1976	ApJ, 208, 199	WD		DISK	Thermal radiation from flare near magnetic WD
27.	Woosley et al.	1976	Nature, 263, 101	NS		DISK	Carbon detonation from accreted matter onto NS
28.	Lamb et al.	1977	ApJ, 217, 197	NS		DISK	Mag gating of accret disk around NS causes sudden accretion
29.	Piran et al.	1977	ApJ, 214, 268	BH		DISK	Instability in accretion onto rapidly rotating BH
30.	Dasgupta	1979	Ap&SS, 63, 517	DG		SOL	Charged intergal rel dust grain enters sol sys, breaks up
31.	Tsygan	1980	A&A, 87, 224	WD		DISK	WD surface nuclear burst causes chromospheric flares
32.	Tsygan	1980	A&A, 87, 224	NS		DISK	NS surface nuclear burst causes chromospheric flares
33.	Ramaty et al.	1981	Ap&SS, 75, 193	NS		DISK	NS vibrations heat atm to pair produce, annihilate, synch cool
34.	Newman et al.	1980	ApJ, 242, 319	NS	AST	DISK	Asteroid from interstellar medium hits NS
35.	Ramaty et al.	1980	Nature, 287, 122	NS		HALO	NS core quake caused by phase transition, vibrations
36.	Howard et al.	1981	ApJ, 249, 302	NS	AST	DISK	Asteroid hits NS, B-field confines mass, creates high temp
37.	Mitrofanov et al.	1981	Ap&SS, 77, 469	NS		DISK	Helium flash cooled by MHD waves in NS outer layers
38.	Colgate et al.	1981	ApJ, 248, 771	NS	AST	DISK	Asteroid hits NS, tidally disrupts, heated, expelled along B lines
39.	van Buren	1981	ApJ, 249, 297	NS	AST	DISK	Asteroid enters NS B field, dragged to surface collision
40.	Kuznetsov	1982	CosRes, 20, 72	MG		SOL	Magnetic reconnection at heliopause
41.	Katz	1982	ApJ, 260, 371	NS		DISK	NS flares from pair plasma confined in NS magnetosphere
42.	Woosley et al.	1982	ApJ, 258, 716	NS		DISK	Magnetic reconnection after NS surface He flash
43.	Fryxell et al.	1982	ApJ, 258, 733	NS		DISK	He fusion runaway on NS B-pole helium lake
44.	Hameury et al.	1982	A&A, 111, 242	NS		DISK	e- capture triggers H flash triggers He flash on NS surface
45.	Mitrofanov et al.	1982	MNRAS, 200, 1033	NS		DISK	B induced cyclo res in rad absorp giving rel e-s, inv C scat
46.	Fenimore et al.	1982	Nature, 297, 665	NS		DISK	BB X-rays inv Comp scat by hotter overlying plasma
47.	Lipunov et al.	1982	Ap&SS, 85, 459	NS	ISM	DISK	ISM matter accum at NS magnetopause then suddenly accretes
48.	Baan	1982	ApJ, 261, L71	WD		HALO	Nonexplosive collapse of WD into rotating, cooling NS
49.	Ventura et al.	1983	Nature, 301, 491	NS	ST	DISK	NS accretion from low mass binary companion
50.	Bisnovatyi- et al.	1983	Ap&SS, 89, 447	NS		DISK	Neutron rich elements to NS surface with quake, undergo fission
51.	Bisnovatyi- et al.	1984	SovAstron, 28, 62	NS		DISK	Thermonuclear explosion beneath NS surface
52.	Ellison et al.	1983	A&A, 128, 102	NS		HALO	NS corequake + uneven heating yield SGR pulsations
53.	Hameury et al.	1983	A&A, 128, 369	NS		DISK	B field contains matter on NS cap allowing fusion
54.	Bonazzola et al.	1984	A&A, 136, 89	NS		DISK	NS surface nuc explosion causes small scale B reconnection
55.	Michel	1985	ApJ, 290, 721	NS		DISK	Remnant disk ionization instability causes sudden accretion
56.	Liang	1984	ApJ, 283, L21	NS		DISK	Resonant EM absorp during magnetic flare gives hot synch e-s
57.	Liang et al.	1984	Nature, 310, 121	NS		DISK	NS magnetic fields get twisted, recombine, create flare
58.	Mitrofanov	1984	Ap&SS, 105, 245	NS		DISK	NS magnetosphere excited by starquake
59.	Epstein	1985	ApJ, 291, 822	NS		DISK	Accretion instability between NS and disk
60.	Schlovskii et al.	1985	MNRAS, 212, 545	NS		HALO	Old NS in Galactic halo undergoes starquake
61.	Tsygan	1984	Ap&SS, 106, 199	NS		DISK	Weak B field NS spherically accretes, Comptonizes X-rays
62.	Usov	1984	Ap&SS, 107, 191	NS		DISK	NS flares result of magnetic convective-oscillation instability
63.	Hameury et al.	1985	ApJ, 293, 56	NS		DISK	High Landau e-s beamed along B lines in cold atm. of NS
64.	Rappaport et al.	1985	Nature, 314, 242	NS		DISK	NS + low mass stellar companion gives GRB + optical flash
65.	Tremaine et al.	1986	ApJ, 301, 155	NS	COM	DISK	NS tides disrupt comet, debris hits NS next pass
66.	Muslimov et al.	1986	Ap&SS, 120, 27	NS		HALO	Radially oscillating NS
67.	Sturrock	1986	Nature, 321, 47	NS		DISK	Flare in the magnetosphere of NS accelerates e-s along B-field
68.	Paczynski	1986	ApJ, 308, L43	NS		COS	Cosmo GRBs: rel e+/- opt thk plasma outflow indicated
69.	Bisnovatyi- et al.	1986	SovAstron, 30, 582	NS		DISK	Chain fission of superheavy nuclei below NS surface during SN
70.	Alcock et al.	1986	PRL, 57, 2088	SS	SS	DISK	SN ejects strange mat lump craters rotating SS companion
71.	Babul et al.	1987	ApJ, 316, L49	CS		COS	GRB result of energy released from cusp of cosmic string
72.	Livio et al.	1987	Nature, 327, 398	NS	COM	DISK	Oort cloud around NS can explain soft gamma-repeaters
73.	McBreen et al.	1988	Nature, 332, 234	GAL	AGN	COS	G-wave bkgrd makes BL Lac wiggle across galaxy lens caustic
74.	Curtis	1988	ApJ, 327, L81	WD		COS	WD collapses, burns to form new class of stable particles
75.	Melia	1988	ApJ, 335, 965	NS		DISK	Be/X-ray binary sys evolves to NS accretion with recurrence
76.	Ruderman et al.	1988	ApJ, 335, 306	NS		DISK	e+/- cascades by aligned pulsar outer-mag-sphere reignition
77.	Paczynski	1988	ApJ, 335, 525	CS		COS	Energy released from cusp of cosmic string (revised)
78.	Murikami et al.	1988	Nature, 335, 234	NS		DISK	Absorption features suggest separate colder region near NS
79.	Melia	1988	Nature, 336, 658	NS		DISK	NS + accretion disk reflection explains GRB spectra
80.	Blaes et al.	1989	ApJ, 343, 839	NS		DISK	NS seismic waves couple to magnetospheric Alfen waves
81.	Trofimenko et al.	1989	Ap&SS, 152, 105	WH		COS	Kerr-Newman white holes
82.	Sturrock et al.	1989	ApJ, 346, 950	NS		DISK	NS E- field accelerates electrons which then pair cascade
83.	Fenimore et al.	1988	ApJ, 335, L71	NS		DISK	Narrow absorption features indicate small cold area on NS
84.	Rodrigues	1989	AJ, 98, 2280	WD	WD	DISK	Binary member loses part of crust, through L1, hits primary
85.	Pineault et al.	1989	ApJ, 347, 1141	NS	COM	DISK	Fast NS though Oort clouds, fast WD bursts only optical
86.	Melia et al.	1989	ApJ, 346, 378	NS		DISK	Episodic electrostatic accel and Comp scat from rot high-B NSs
87.	Trofimenko	1989	Ap&SS, 159, 301	WH		COS	Different types of white, "grey" holes can emit GRB
88.	Eichler et al.	1989	Nature, 340, 126	NS	NS	COS	NS - NS binary members collide, coalesce
89.	Wang et al.	1989	PRL, 63, 1550	NS		DISK	Cyclo res & Raman scat fits 20, 40 keV dips, magnetized NS
90.	Alexander et al.	1989	ApJ, 344, L1	NS		DISK	QED mag resonant opacity in NS atmosphere
91.	Melia	1990	ApJ, 351, 601	NS		DISK	NS magnetospheric plasma oscillations
92.	Ho et al.	1990	ApJ, 348, L25	NS		DISK	Beaming of radiation necessary from magnetized neutron stars
93.	Mitrofanov et al.	1990	Ap&SS, 165, 137	NS	COM	DISK	Interstellar comets pass through dead pulsar's magnetosphere
94.	Dermer	1990	ApJ, 360, 197	NS		DISK	Compton scattering in strong NS magnetic field
95.	Blaes et al.	1990	ApJ, 363, 612	NS	ISM	DISK	Old NS accretes from ISM, surface goes nuclear
96.	Paczynski	1990	ApJ, 363, 218	NS	NS	COS	NS-NS collision causes v collisions to drive super-Ed wind
97.	Zdziarski et al.	1991	ApJ, 366, 343	RE	MBR	COS	Scattering of microwave background photons by rel e-s
98.	Pineault	1990	Nature, 345, 233	NS	COM	DISK	Young NS drifts through its own Oort cloud
99.	Trofimenko et al.	1991	Ap&SS, 178, 217	WH		HALO	White hole supernova gave simul burst of g-waves from 1987A
100.	Melia et al.	1991	ApJ, 373, 198	NS		DISK	NS B- field undergoes resistive tearing, accelerates plasma
101.	Holcomb et al.	1991	ApJ, 378, 682	NS		DISK	Alfen waves in non-uniform NS atmosphere accelerate particles
102.	Haensel et al.	1991	ApJ, 375, 209	SS	SS	COS	Strange stars emit binding energy in grav. rad. and collide
103.	Blaes et al.	1991	ApJ, 381, 210	NS	ISM	DISK	Slow interstellar accretion onto NS, e- capture starquakes result
104.	Frank et al.	1992	ApJ, 385, L45	NS		DISK	Low mass X-ray binary evolves into GRB sites
105.	Woosley et al.	1992	ApJ, 391, 228	NS		HALO	Accreting WD collapses to NS
106.	Hojman et al.	1993	ApJ, 411, 541	NS		HALO	NS popul at MW halo boundary expected by hydro density jump
107.	Dar et al.	1992	ApJ, 388, 164	WD		COS	WD accretes to form naked NS, GRBs, cosmic rays
108.	Thompson et al.	1993	ApJ, 408, 194	NS		COS	Sudden NS convection with high B drives e- pairs, gammas.
109.	Hanami	1992	ApJ, 389, L71	NS	PLAN	COS	NS - planet magnetospheric interaction unstable
110.	Meszaros et al.	1992	ApJ, 397, 570	NS	NS	COS	NS - NS collision produces anisotropic fireball
111.	Eichler et al.	1992	Science, 257, 937	NS		HALO	High vel halo pulsars accrete after being kicked from disk
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120.	Meszaros et al.	1992	MNRAS, 257, 29P	BH	NS	COS	BH-NS have vs collide to γs in clean fireball
121.	Meszaros et al.	1992	MNRAS, 257, 29P	NS	NS	COS	NS-NS have vs collide to γs in clean fireball
122.	Fatuzzo et al.	1993	ApJ, 407, 680	NS		COS	Alfen waves accel particles which upscatter soft photons
123.	Bisnovatyi-Kogan	1993	A&A Sup, 97, 65	NS		GAL	Absorption by cloud of heavy elements around NS
124.	McBreen et al.	1993	A&A Sup, 97, 81	AGN		COS	Relativistic jets from cocooned AGN
125.	Cline et al.	1992	ApJ, 401, L57	BH		DISK	Primordial BHs evaporating could account for short hard GRBs
126.	Woosley	1993	ApJ, 405, 273	BH		COS	Spinning Wolf-Ray star collapses, failed SN, emitts beamed fireball
127.	Melia et al.	1992	ApJ, 398, L85	NS		COS	Crustal adjustments by extragal radio pulsars
128.	Rees et al.	1992	MNRAS, 258, 41P	NS	ISM	COS	Relativistic fireball reconverted to radiation when hits ISM
129.	Kundt et al.	1993	Ap&SS, 200, 151	NS		GAL	Spasmodic NS accretion causes beamed cooling 'sparks'
130.	Meszaros et al.	1993	ApJ, 405, 278	NS	BH	COS	Compact binary coalesces, fireball hits external medium
131.	Cheng et al.	1993	MNRAS, 262, 1037	NS		GAL	NS glitch reignites magnetosphere of dead pulsar
132.	Melia et al.	1993	ApJ, 408, L9	NS		COS	NS structural readjustments explain both SGRs and GRBs
133.	Piran et al.	1993	ApJ, 403, L67	NS		GAL	Galactic fireball requires rel ejecta, low T, possible but unlikely
134.	Fabian et al.	1993	MNRAS, 263, 49	NS		LMC	NS accretes after ejected from Meg Cloud by companion SN
135.	Fatuzzo et al.	1993	ApJ, 414, L89	NS		COS	Sheared Alfen waves in NS magsphere dissipate focused power

77/118 – Neutron Star(s)

(22 with a second object

NS, Comet/Asteroid, Planet)

88/118 – Glactic or Halo

~118 models in 1993!

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Table 1

77/118 – Neutron Star(s)
(22 with a second object
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Glactic or Halo

1. **Fireball model** with internal and external shocks (> 1992: Paczynsky, Rees, Cavallo, Goodman, Meszaros, Piran … + almost everybody)

2. Fireshell model (Ruffini and collaborators > 2000)

3. Cannonball model (Dar, De Rujula, Dado > 2000)

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46.	Fenimore et al.	1982	Nature, 297, 665	NS		DISK	BB X-rays inv Comp scat by hotter overlying plasma
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115.	Blaes et al.	1992	ApJ, 399, 634	NS		GAL	Old NS accretes from mol cloud, R-T instab at crust
116.	Narayan et al.	1992	ApJ, 395, L83	NS	NS	COS	NS - NS merger gives optically thick fireball
117.	Narayan et al.	1992,	ApJ, 395, L83	BH	NS	COS	BH-NS merger gives optically thick fireball
118.	Brainerd	1992	ApJ, 394, L33	AGN	JET	COS	Synchrotron emission from AGN jets
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132.	Melia et al.	1993	ApJ, 408, L9	NS		COS	NS structural readjustments explain both SGRs and GRBs
133.	Piran et al.	1993	ApJ, 403, L67	NS		GAL	Galactic fireball requires rel ejecta, low T, possible but unlikely
134.	Fabian et al.	1993	MNRAS, 263, 49	NS		LMC	NS accretes after ejected from Meg Cloud by companion SN
135.	Fatuzzo et al.	1993	ApJ, 414, L89	NS		COS	Sheared Alfen waves in NS magsphere dissipate focused power

GRB Part-I (obs): take home list

Prompt emission:

Temporal

1. 2 populations: short/long
2. Highly variable (few ms)
3. Quiescent phases (shut down)

Spectral

4. Featureless, non-thermal spectra (but 5% pure planck)
5. Most photons 300 keV (peak energy)
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Hosts & Progenitors:

1. SF galaxies (irr for long all types for short)
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3. A dozen of long associated with broad lined SN Ibc
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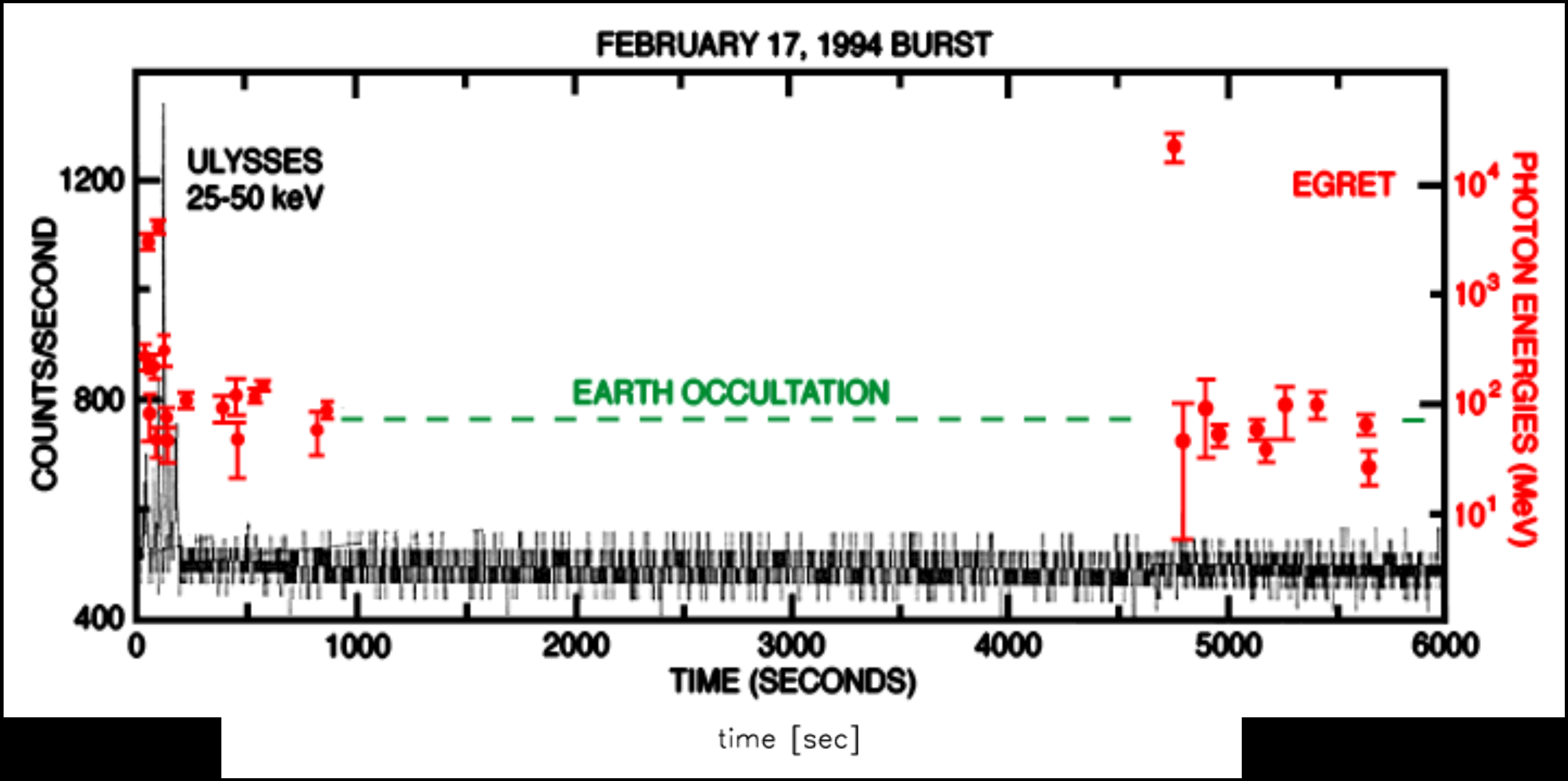
GRBs are relativistic sources

the compactness argument

(e.g. Sari & Piran 1999, Lithwick & Sari, 2001)

→ γ rays with E > 100 MeV, most typically > 0.5 MeV



GRBs are relativistic sources

the compactness argument

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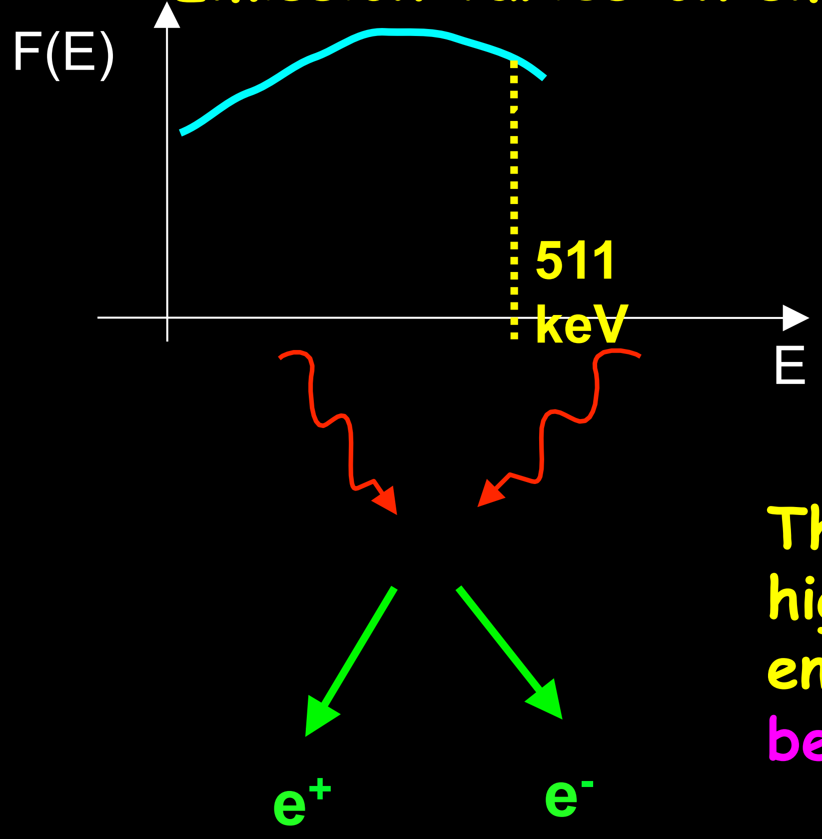
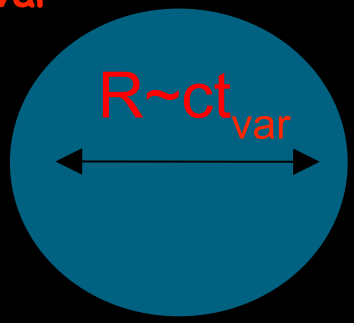
- γ rays with E > 100 MeV, most typically > 0.5 MeV
- Emission varies on small timescales: t_{var} ~ few ms





R~10^7 cm

The probability of γ–γ processes is high in a small region with high energy density i.e. photons would be absorbed within the source.

Compactness argument

$$\tau_{\gamma\gamma} = n_{ph}\sigma_T \Delta R \qquad n_{ph} = \frac{4\pi d^2 F}{\varepsilon \cdot 4\pi R^2 \Delta R}$$

$$\tau_{\gamma\gamma} = f_e \frac{d^2 F \sigma_T}{m_e c^2 \cdot c^2 \delta t^2} \approx 10^{13} f_e d_3^2 F_{-7} \delta t^{-2}{}_{-2}$$

No photon can escape → converted in pairs

Spectrum → dropout at $E>2m_ec^2$

Relativistic corrections

$$\tau_{\gamma\gamma} = n_{ph}\sigma_T \Delta R$$

$$\tau_{\gamma\gamma} = f_e \frac{d^2 F}{\varepsilon \cdot R^2}\sigma_T$$

Including relativistic corrections

$$\varepsilon = \varepsilon' \Gamma$$

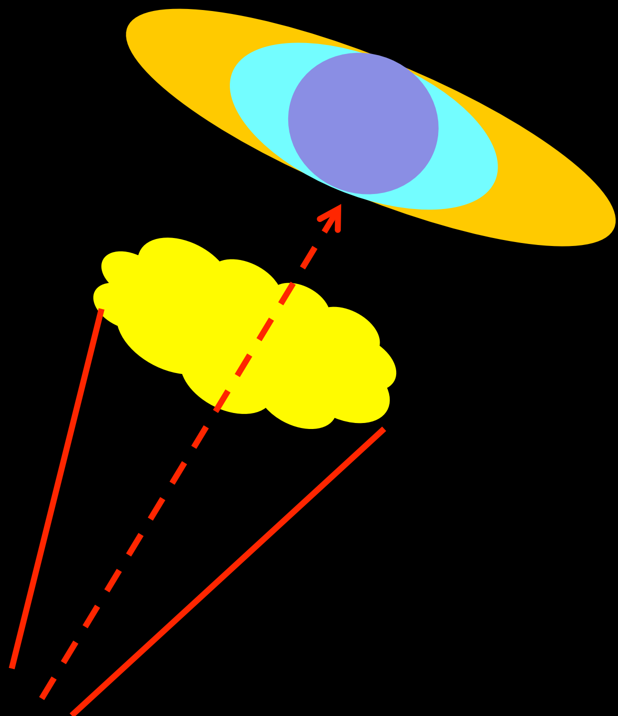
$$R = c\delta t \Gamma^2$$

$$\tau_{\gamma\gamma} = f_e \frac{d^2 F \sigma_T}{m_e c^2 \cdot c^2 \delta t^2 \Gamma^6} \approx 10^{13} f_e d_3^2 F_{-7} \delta t^{-2}{}_{-2} \Gamma^{-6}$$

$$\Gamma \geq 200$$

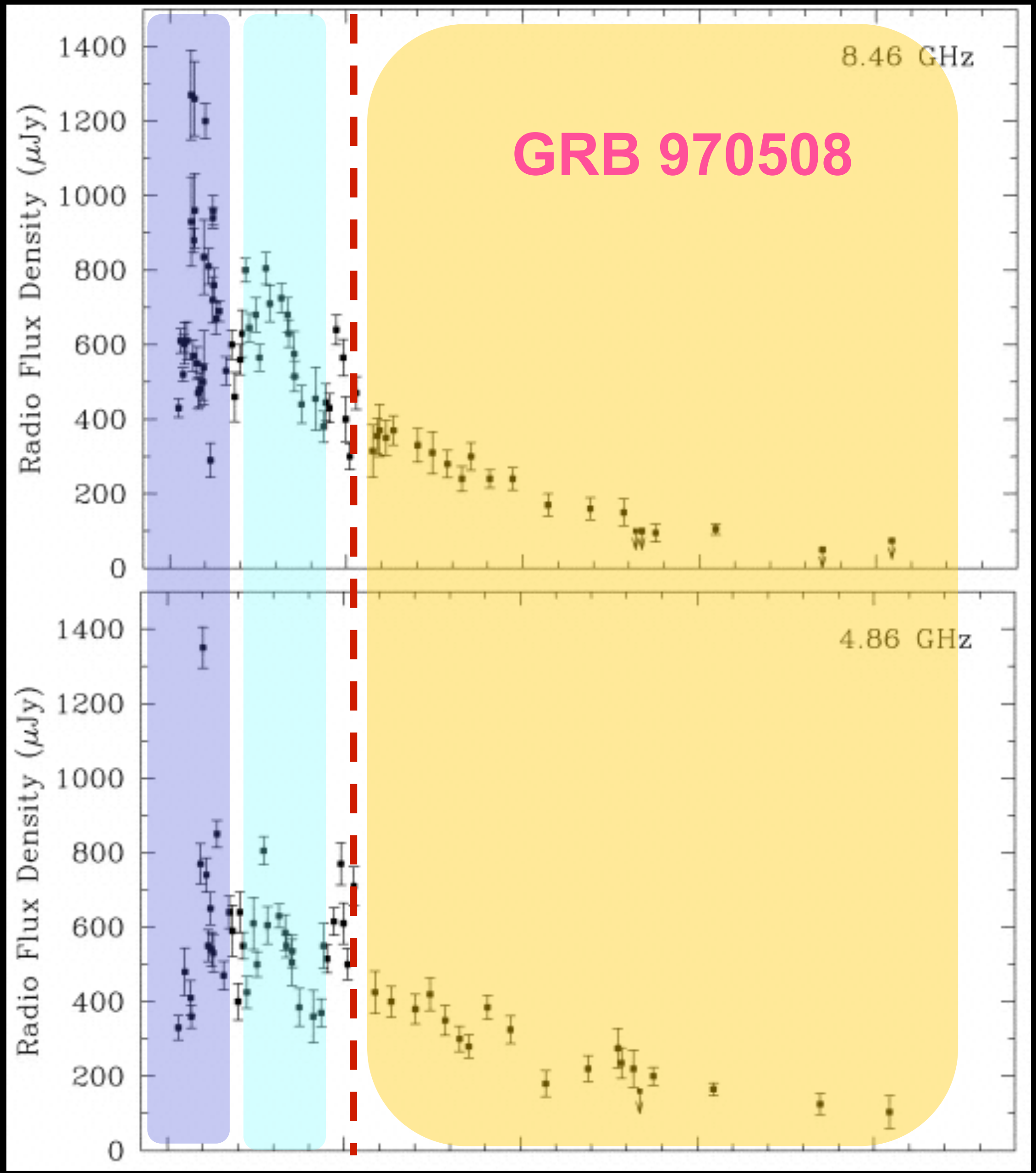
One of the first direct proof of Γ>1

Radio Scinitillation produced by Galactic clouds



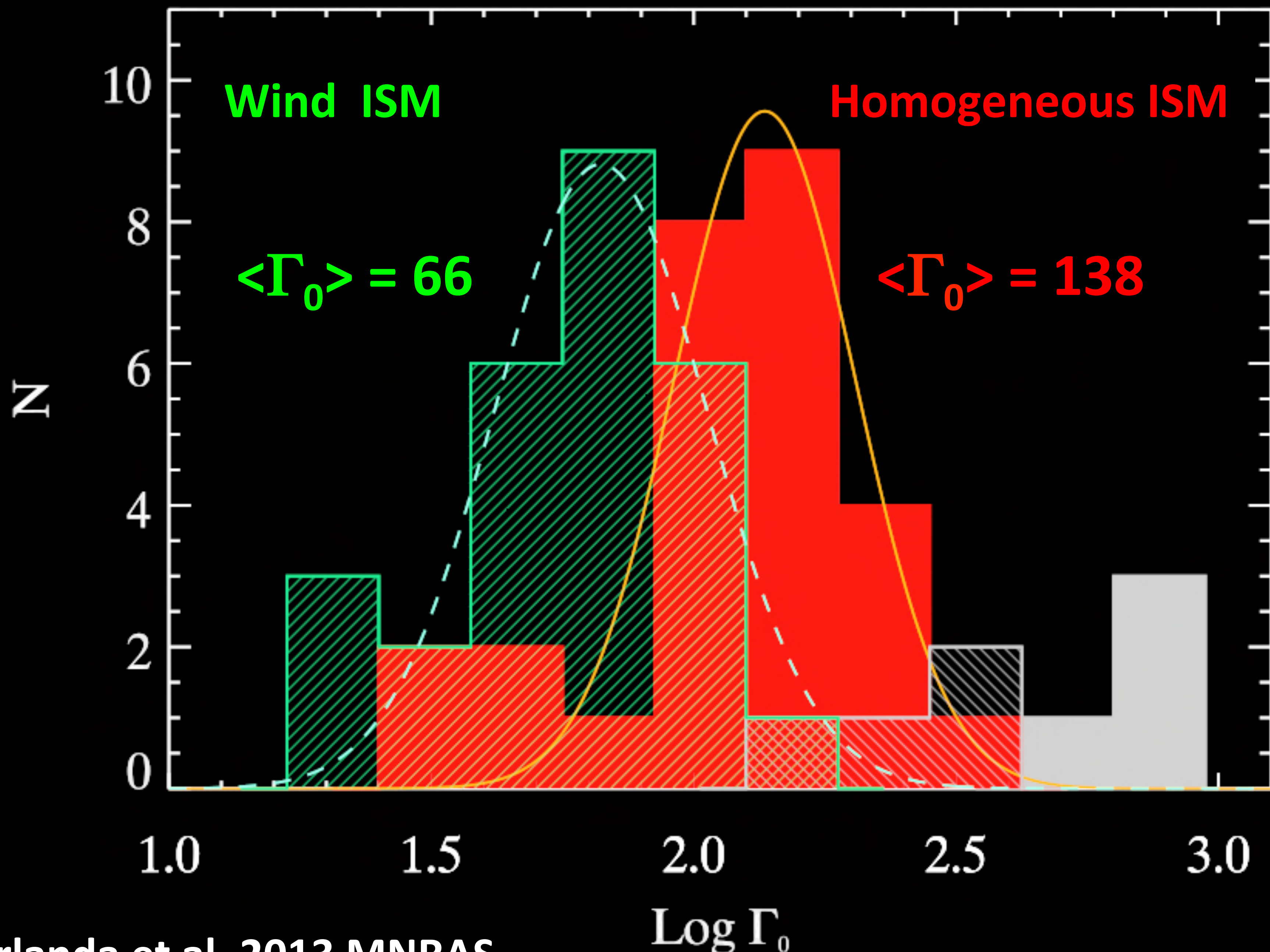
$\Gamma \sim 5\text{–}10$

t* ~ 14 d



Frail et al. 1997

How much relativistic? A lot but <not so much>



Ghirlanda et al. 2013 MNRAS

GRB Part-I: ingredients of fireball model

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2. Relativistic outflows → Γ ~ 100

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Variability + Energetics + Bulk Vel.

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What any GRB model needs

Fireball

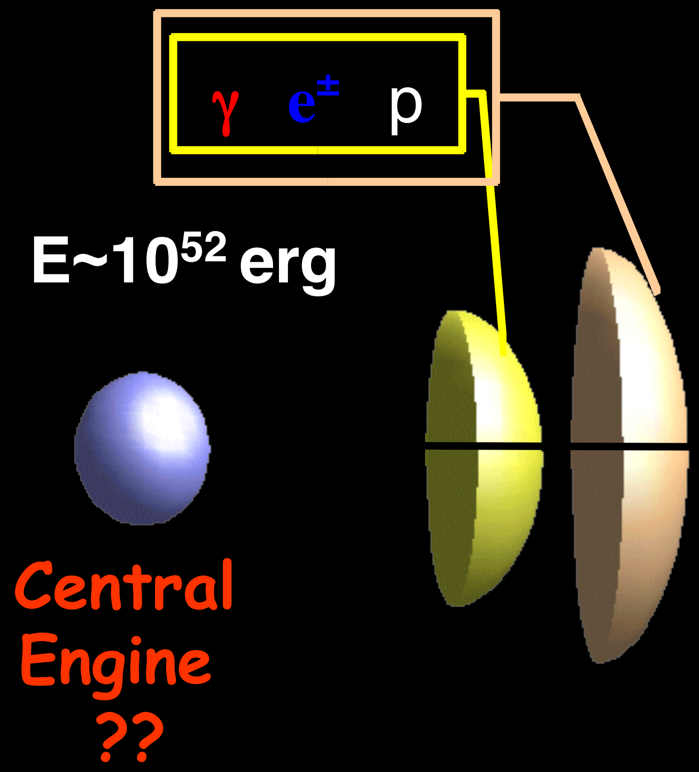
Central engine

Hydrodynamic

Radiation procs

The standard model: Fireball

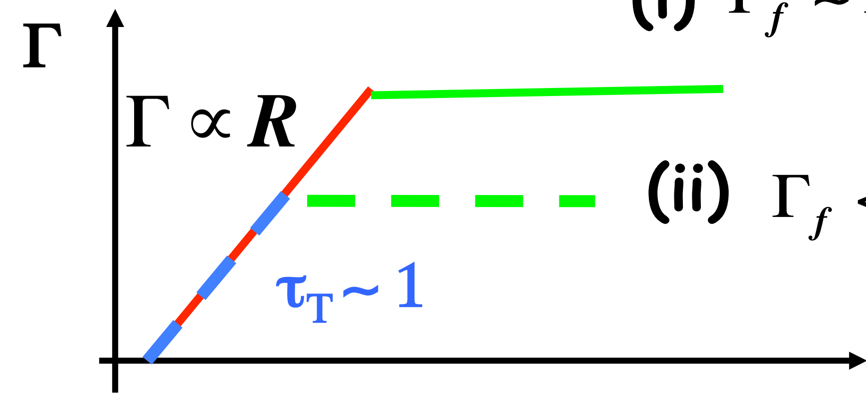
Cavallo & Rees 1986, Goodman 1986, Paczynsky 1990 … + Meszaros & Rees 1997



Shells are optically thick. Internal pressure (due to high energy density) drives the **acceleration** and internal energy is converted into kinetic energy.

Phase I: Internal pressure driven acceleration

Adiabatic free expansion



(i) $\Gamma_f \approx \Gamma_0 = \frac{E_0}{M_b c^2}$

Energy conservation

Momentum conservation

baryon number conservation

$$R^2 \rho \Gamma = const$$

$$R^2 p^{3/4} \Gamma = const$$

$$R^2 (4p + \rho) \Gamma^2 = const$$

p >> ρ →

$$\Gamma \propto R$$

$$\rho \propto R^{-3}$$

$$p \propto R^{-4}$$

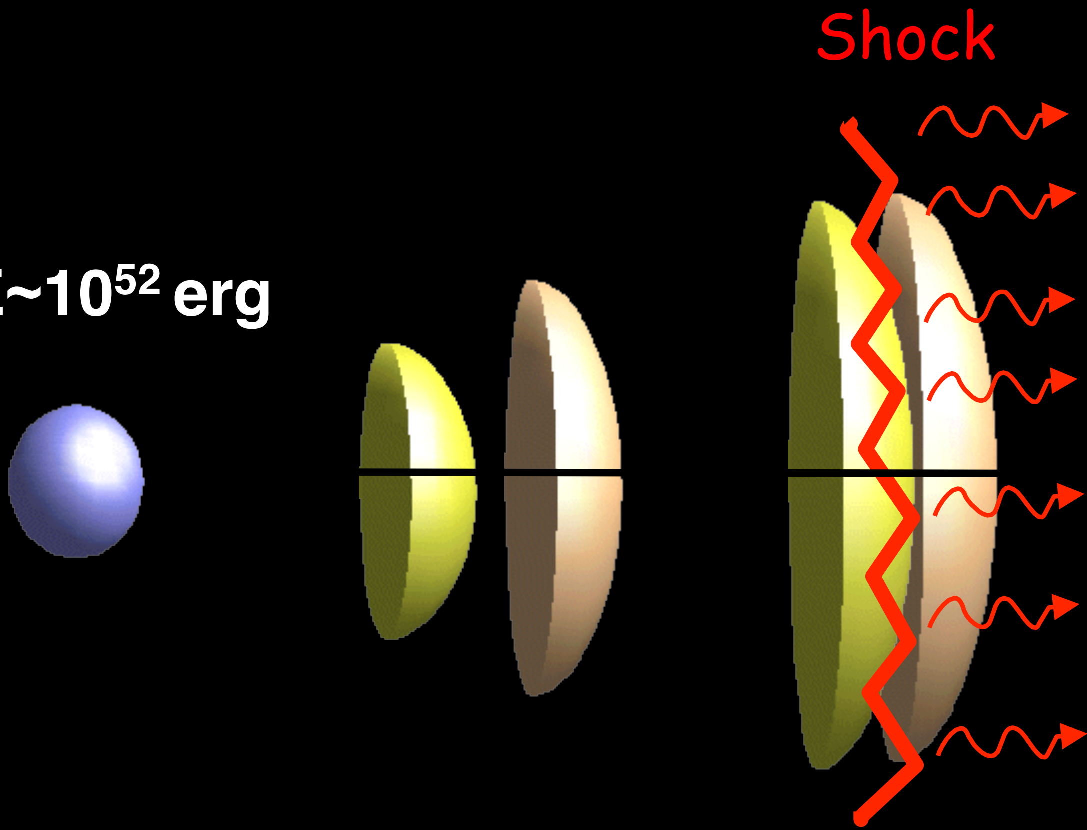
Acceleration ends when:

(i) $\Gamma_f \approx \Gamma_0 = \frac{E_0}{M_b c^2}$

(ii) $\tau_T = n\sigma_T \Delta R = \frac{M_b / m_p}{4\pi \cdot R^2 \cdot \Delta R} \sigma_T \Delta R = \frac{E_0 \sigma_T}{2\pi \cdot \theta^2 R_T^2 m_p c^2 \Gamma N} \approx 1$

The standard model: Fireball + Internal shock

E~10^{52} erg



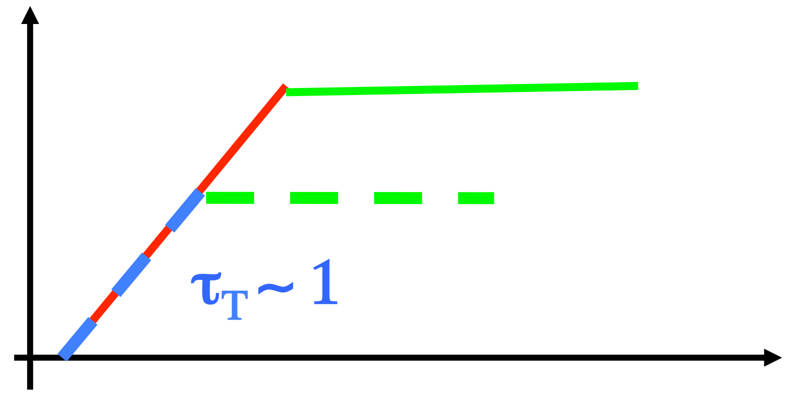
Shock transfers energy to the particles and magnetic field

Prompt emission is synchrotron

Most of the internal energy has been converted into kinetic and the shell coast with constant Γ

Phase I: Internal pressure driven acceleration

$\Gamma \propto R$ $\qquad \Gamma_f \approx \Gamma_0 = \dfrac{E_0}{M_b c^2}$



Since optically thick → BB

$\Gamma \propto R$

$\rho \propto R^{-3}$

$p \propto R^{-4}$

→ $T_{ph} \propto R^{-1}$

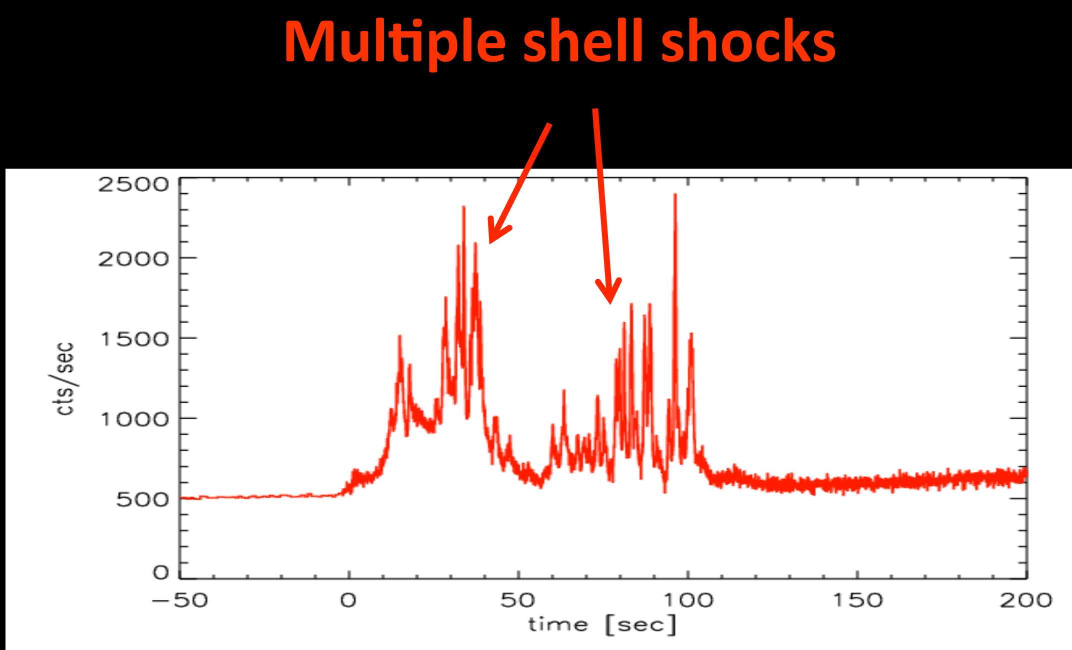
When $\tau_T \sim 1$ a Black body spectrum with $T = T_0$ emerges

Phase II: Coasting phase → Internal shock development

$$t_{IS} = \frac{d}{v_2 - v_1} \qquad t_{IS} = \frac{d}{v_2} \qquad c \cdot t_{IS} = R_{IS} = \frac{d}{\beta_2}$$

$$\beta \approx \frac{1}{2\Gamma^2}$$

$$R_{IS} \approx 2\Gamma^2 c \cdot \delta t = (6 \times 10^{13})\Gamma_2^2 \cdot \delta t_{-1} \quad \text{cm}$$

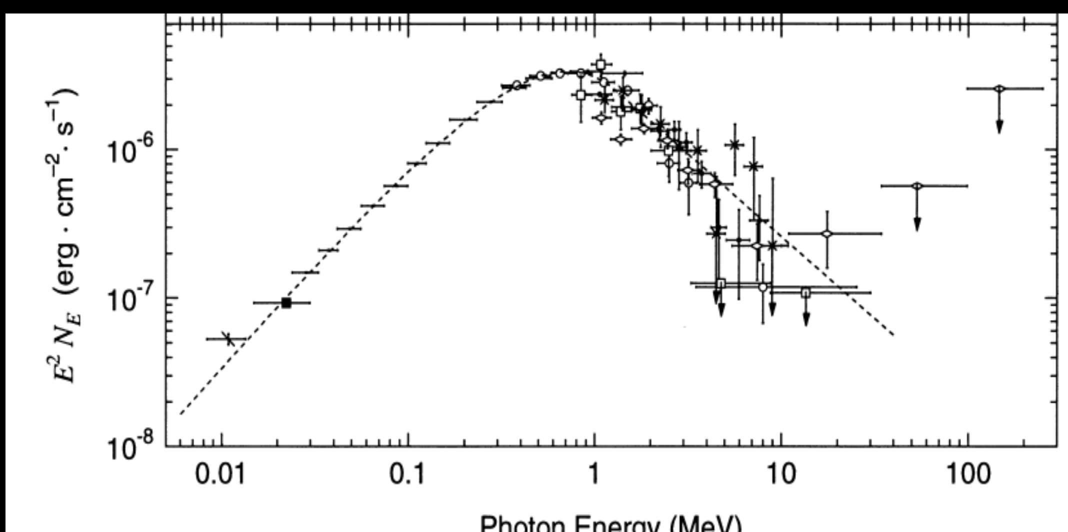


INTERNAL SHOCKS:

Account for variability timescale

The light curve reflects the activity of the central engine

Central engine should be active (and variable) for at least the duration of the observed emission

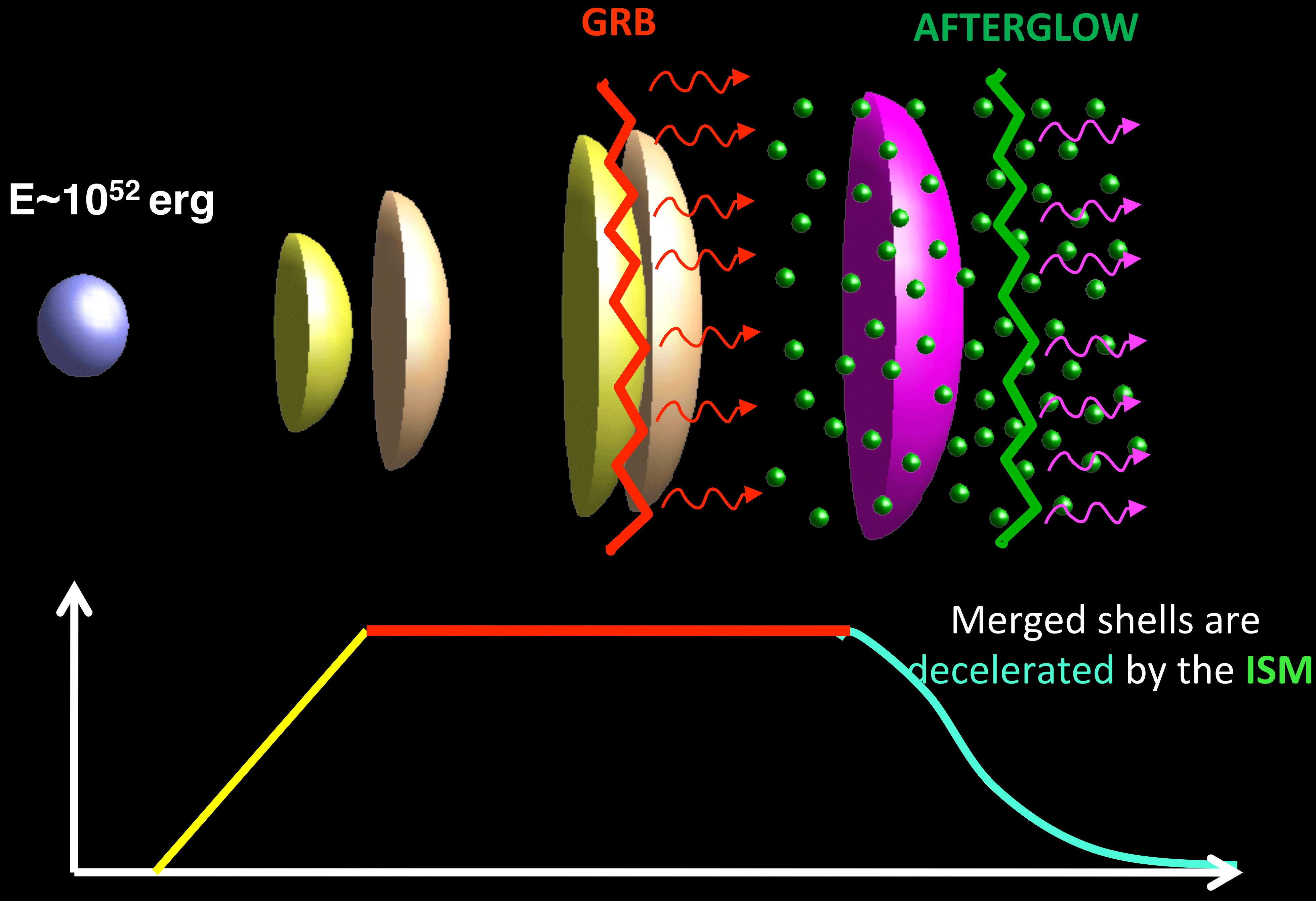


SYNCHROTRON

Accounts for observed prompt spectral shape (non—thermal)

[... but see later]

The standard model: Fireball + Internal + External shock



Phase III: Deceleration → External shock development

Initial Explosion Energy: E_0

Swept-up mass: $M_{sw} = 4\pi m_p n_0 x^3/3$

Baryonic mass mixed into explosion: M_0

Density of surrounding medium = n_0

$\Gamma_0^2 M_{sw} c^2 = E_0 \equiv M_0 c^2 \Rightarrow$

Deceleration radius

$$x_d = \left(\frac{3E_0}{4\pi m_p c^2 n_0 \Gamma_0^{\ 2}}\right)^{1/3} = 2.6\times 10^{16}\left(\frac{E_{52}}{n_0 \Gamma_{300}^2}\right)^{1/3} cm$$

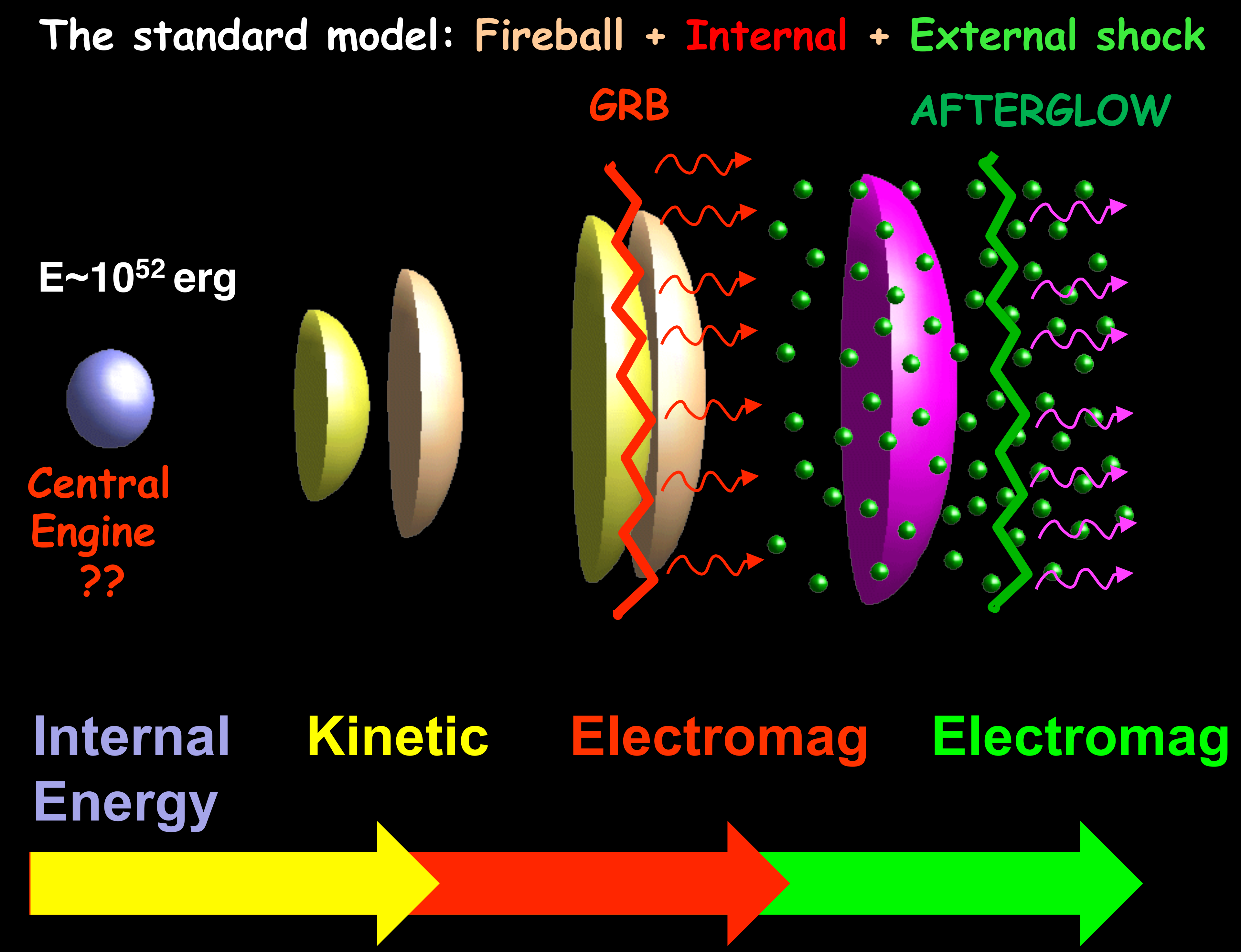
$$\Gamma_{300} \equiv \Gamma_0 / 300$$

Rees and Mészáros (1992)
Mészáros and Rees (1993)

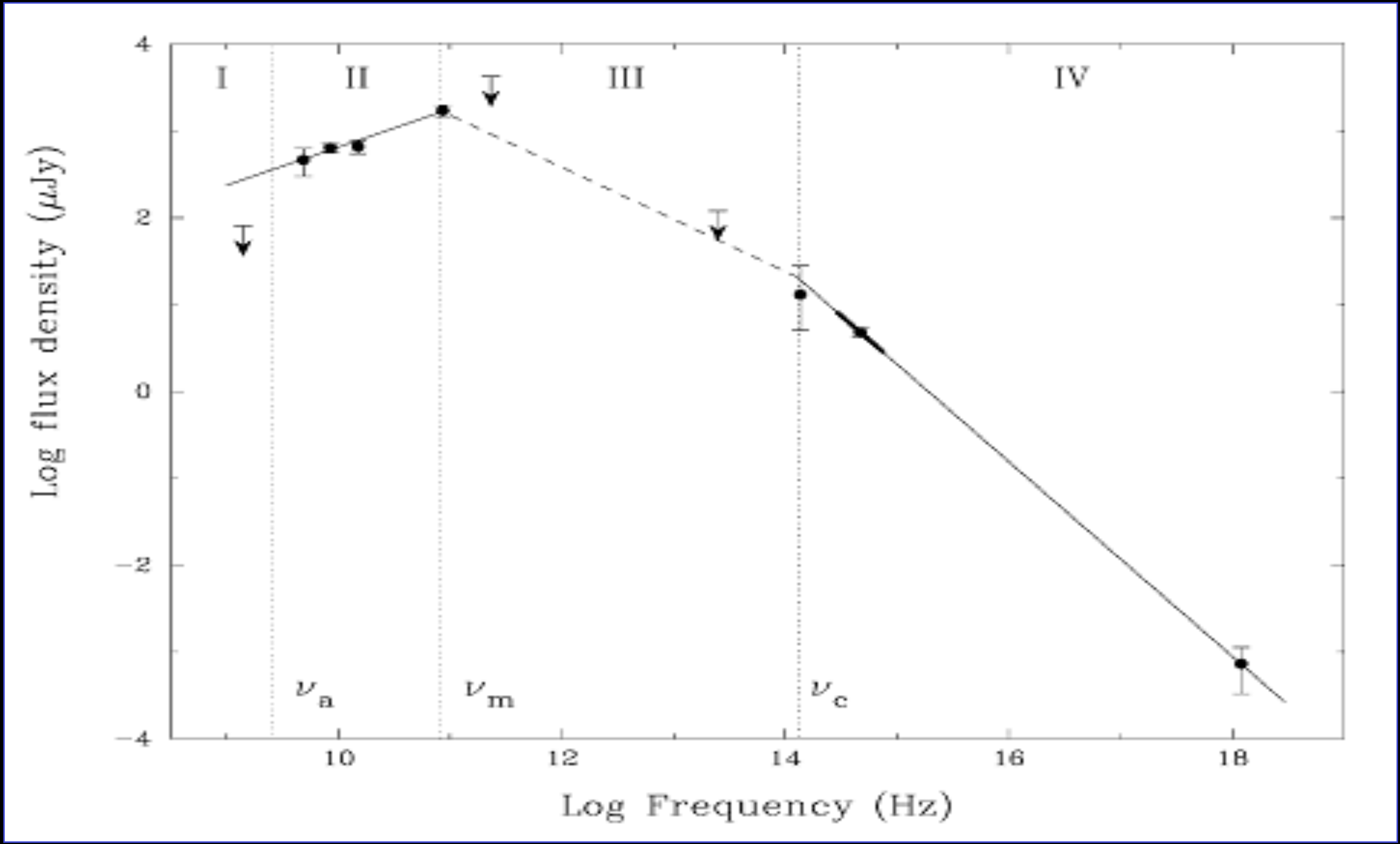
Deceleration time

$$t_d = (1+z)\frac{x_d}{\beta_0 \Gamma_0^2 c} \cong 10(1+z)\left(\frac{E_{52}}{n_0 \Gamma_{300}^8}\right)^{1/3} s$$

(characteristic of mean duration of GRBs)


The standard model: Fireball + Internal + External shock
GRB
AFTERGLOW
E~10^52 erg
Central Engine ??
Internal Energy
Kinetic
Electromag
Electromag

GRB – The Afterglow (spectrum)



Sari & Piran 1998

Synchrotron

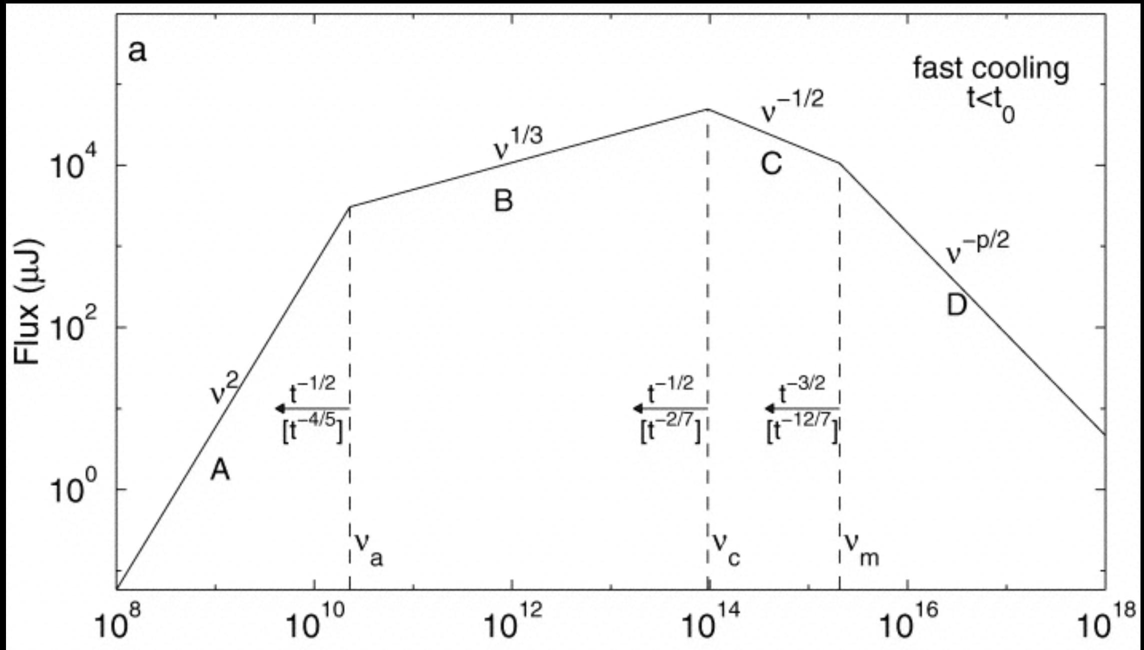
GRBs – 2 phases

$\gamma_m > \gamma_c$:

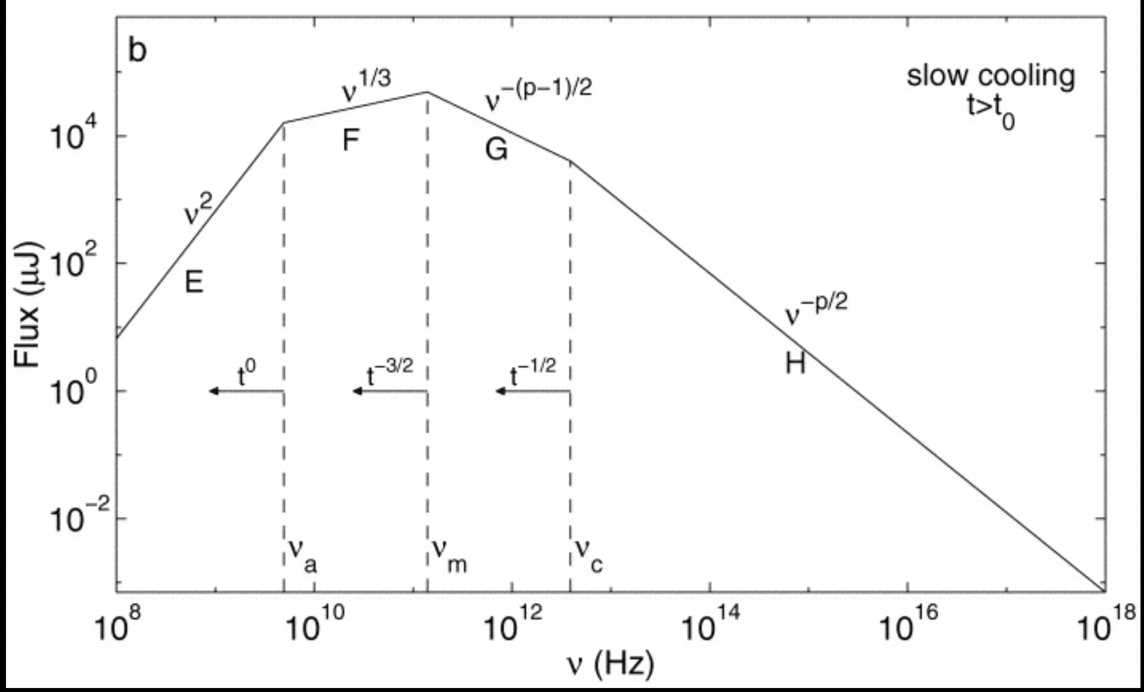
All the electrons cool down to γ_c: fast cooling.

$\gamma_c > \gamma_m$:

Only electrons with $\gamma_e > \gamma_c$ can cool: slow cooling.



Sari, Piran, & Narayan 1998



Parameters regulating the emission

Afterglow model:

Hydrodynamic evolution of the fireball $\Gamma(t) \leftrightarrow R(t)$

Synchrotron emission at the shock

Kinetic energy powering the expansion E_k

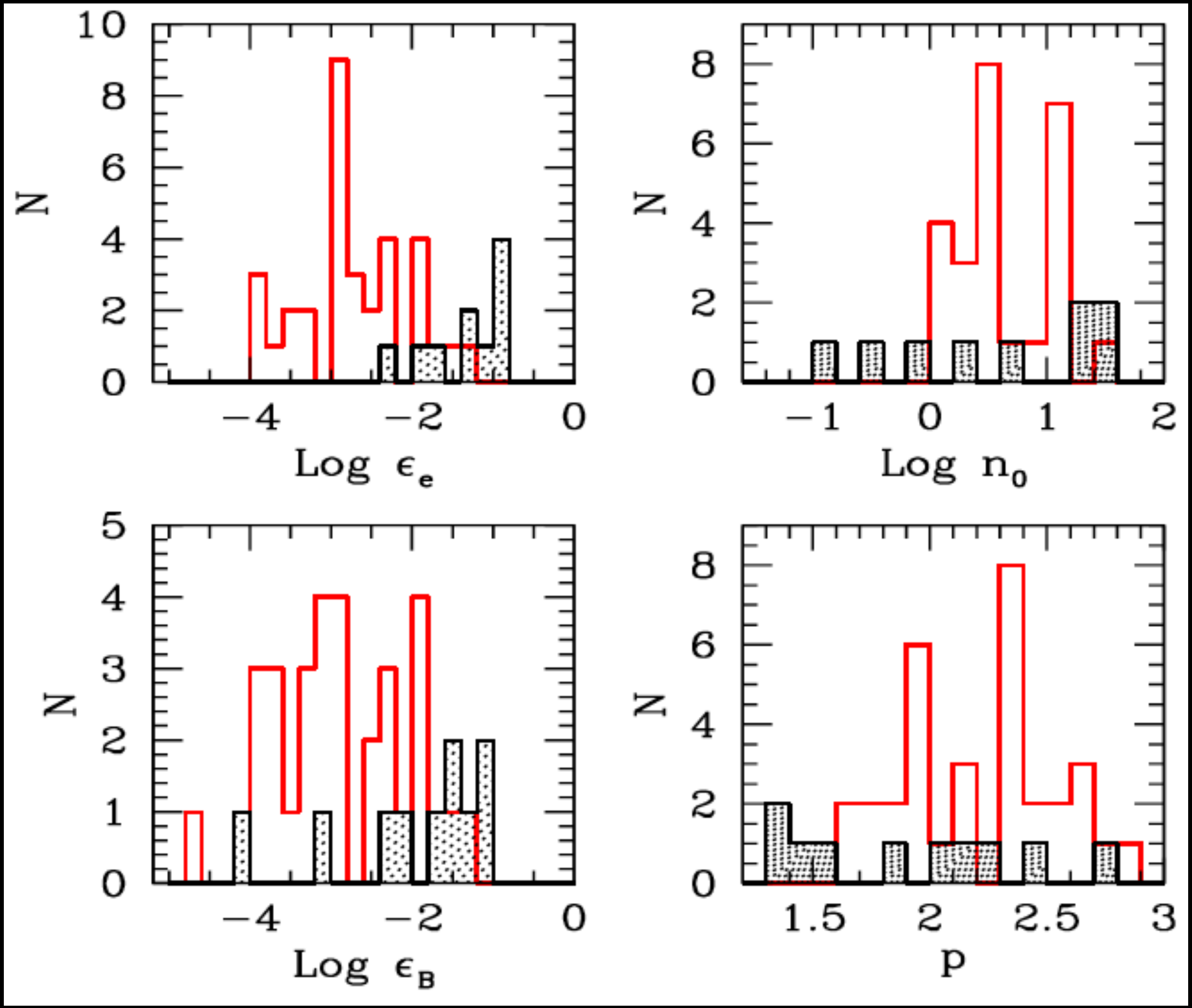
External medium structure $n \propto R^s$

Fraction of shock energy to electrons ϵ_e

Fraction of shock energy to magnetic field ϵ_B

Shock accelerated electrons energy distrib. $N(\gamma) \propto \gamma^p$

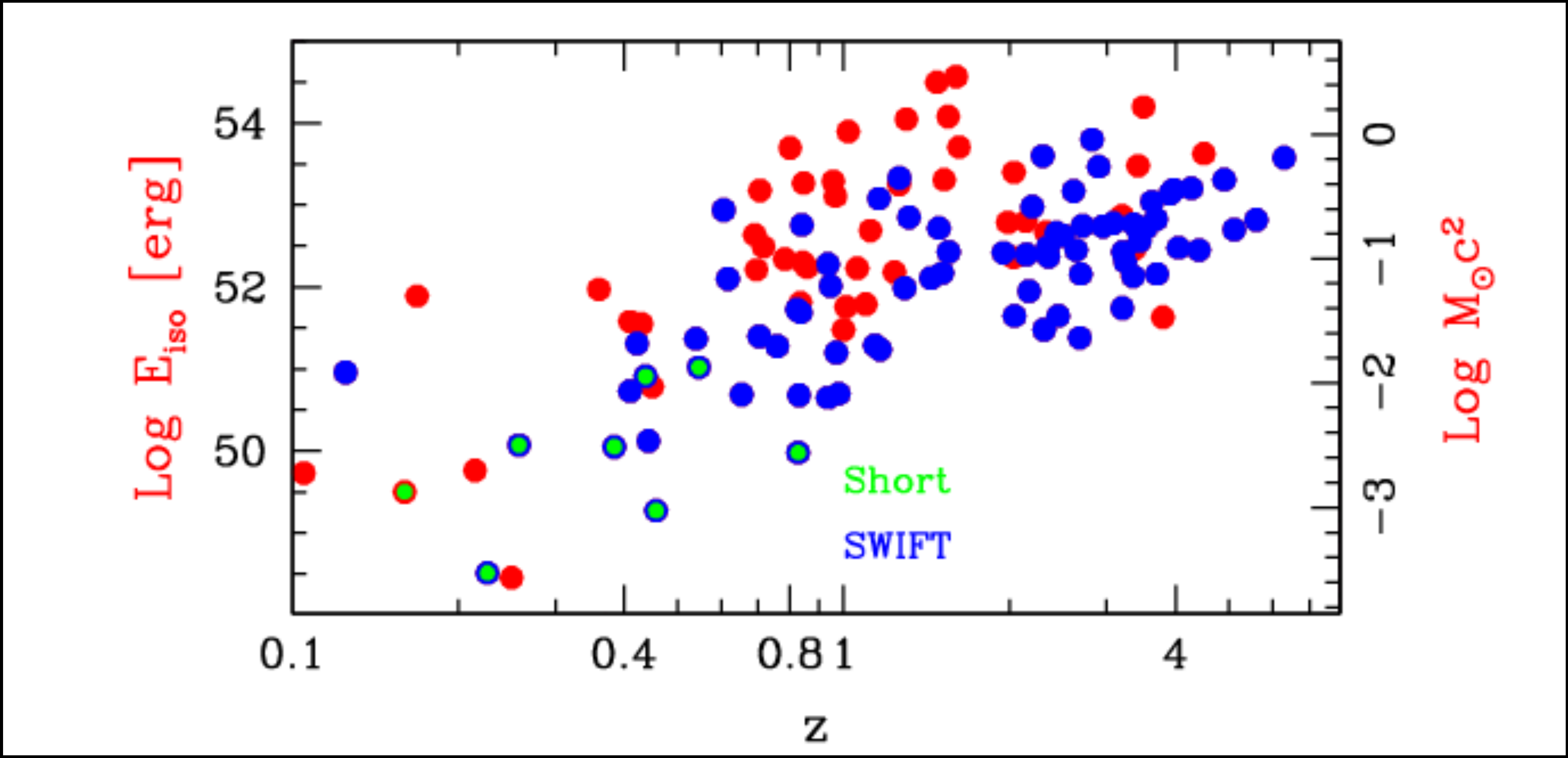
From the modling of the afterglow emission



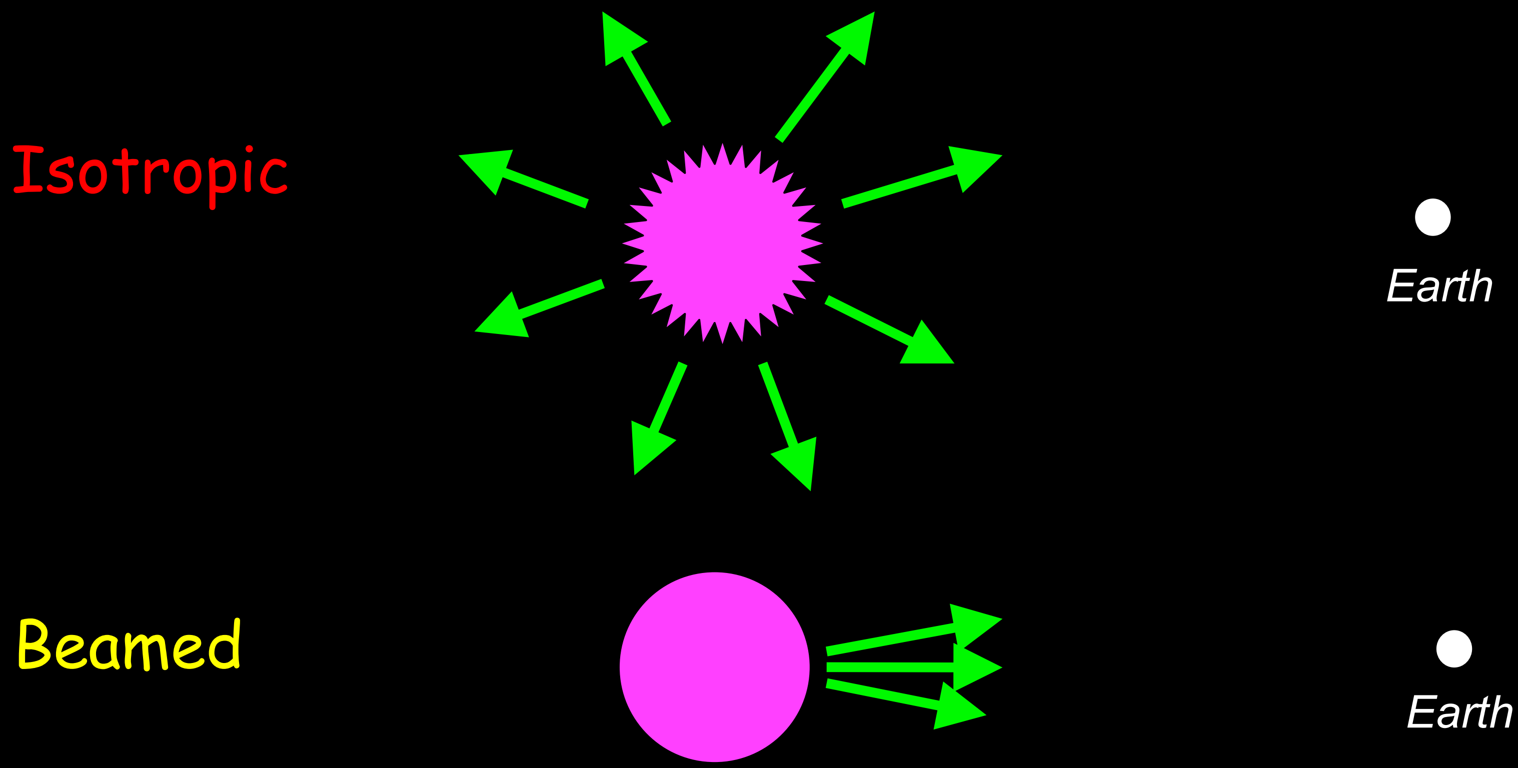
Ghisellini 2008

Energetics

ASSUMING ISOTROPY !!!!



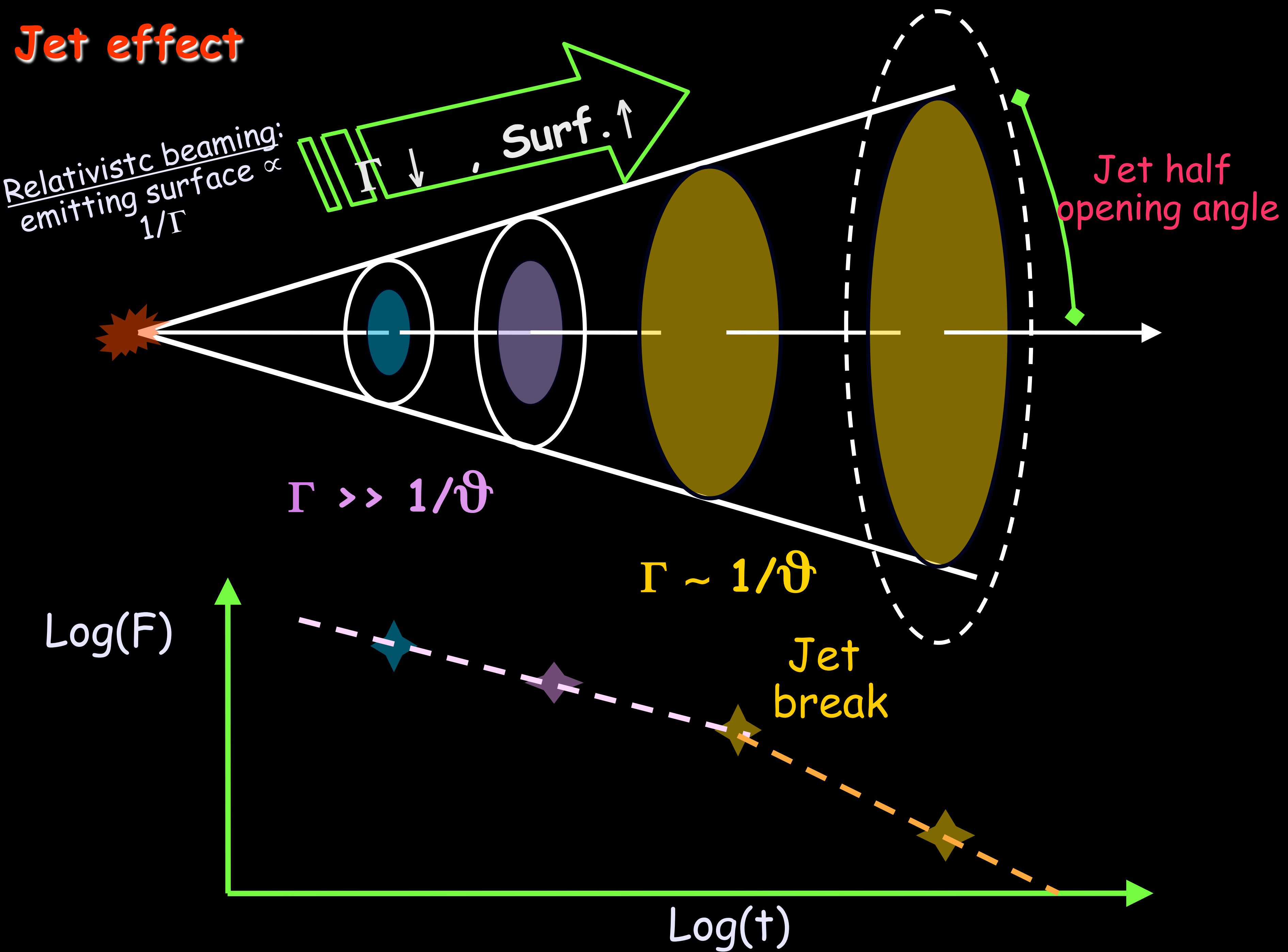
…but is the energy really so huge?



If the energy were beamed to 0.1% ($\theta \sim 5$ deg) of the sky, then the total energy could be 1000 times less

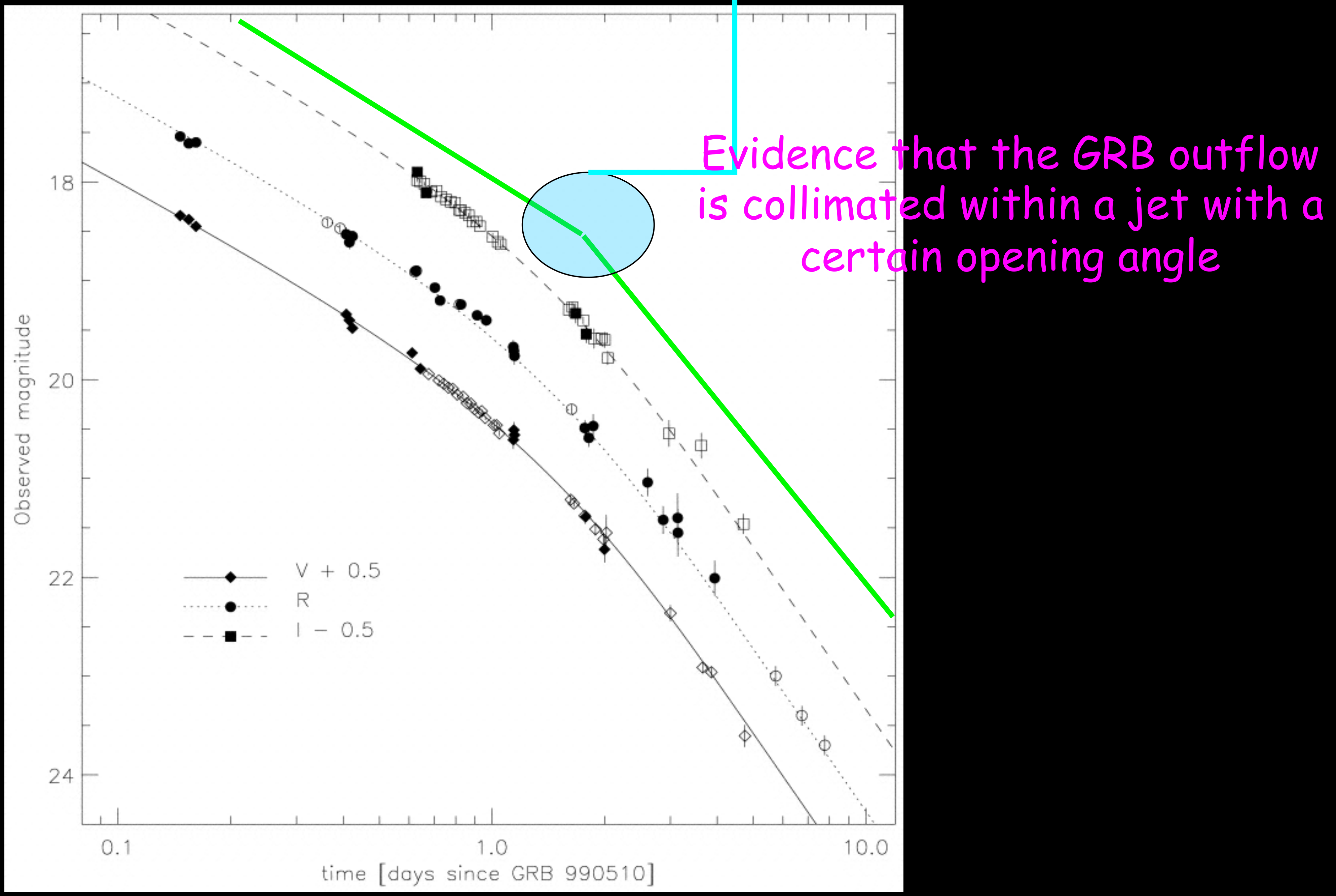
→ Implications for the energy budget
→ Implications for the rate of GRBs

Jet effect

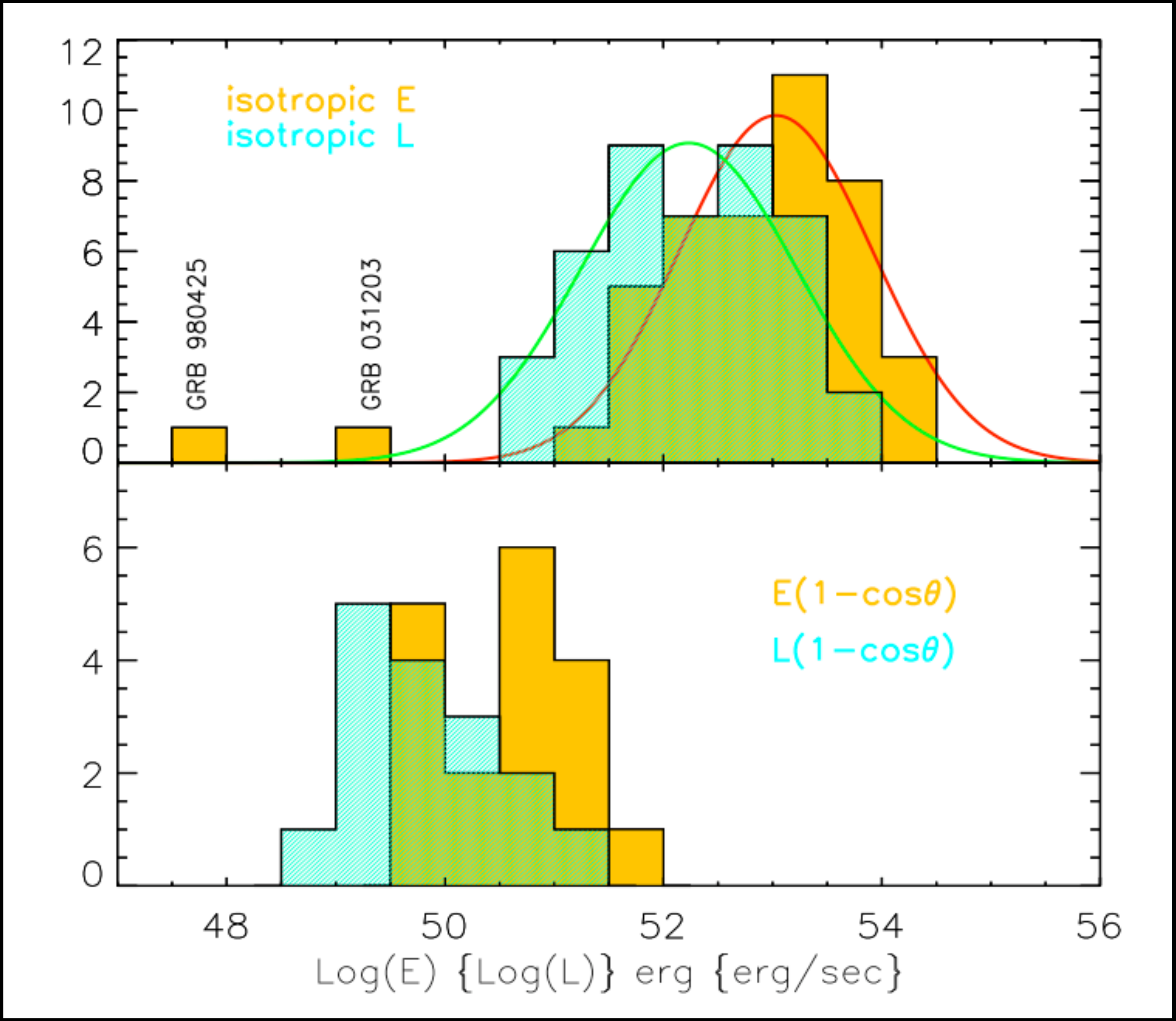


Relativistc beaming:
emitting surface ∝
1/Γ
Γ ↓ , Surf.↑
Jet half
opening angle
Γ >> 1/ϑ
Γ ~ 1/ϑ
Log(F)
Jet
break
Log(t)

Afterglow light curve presents achromatic break

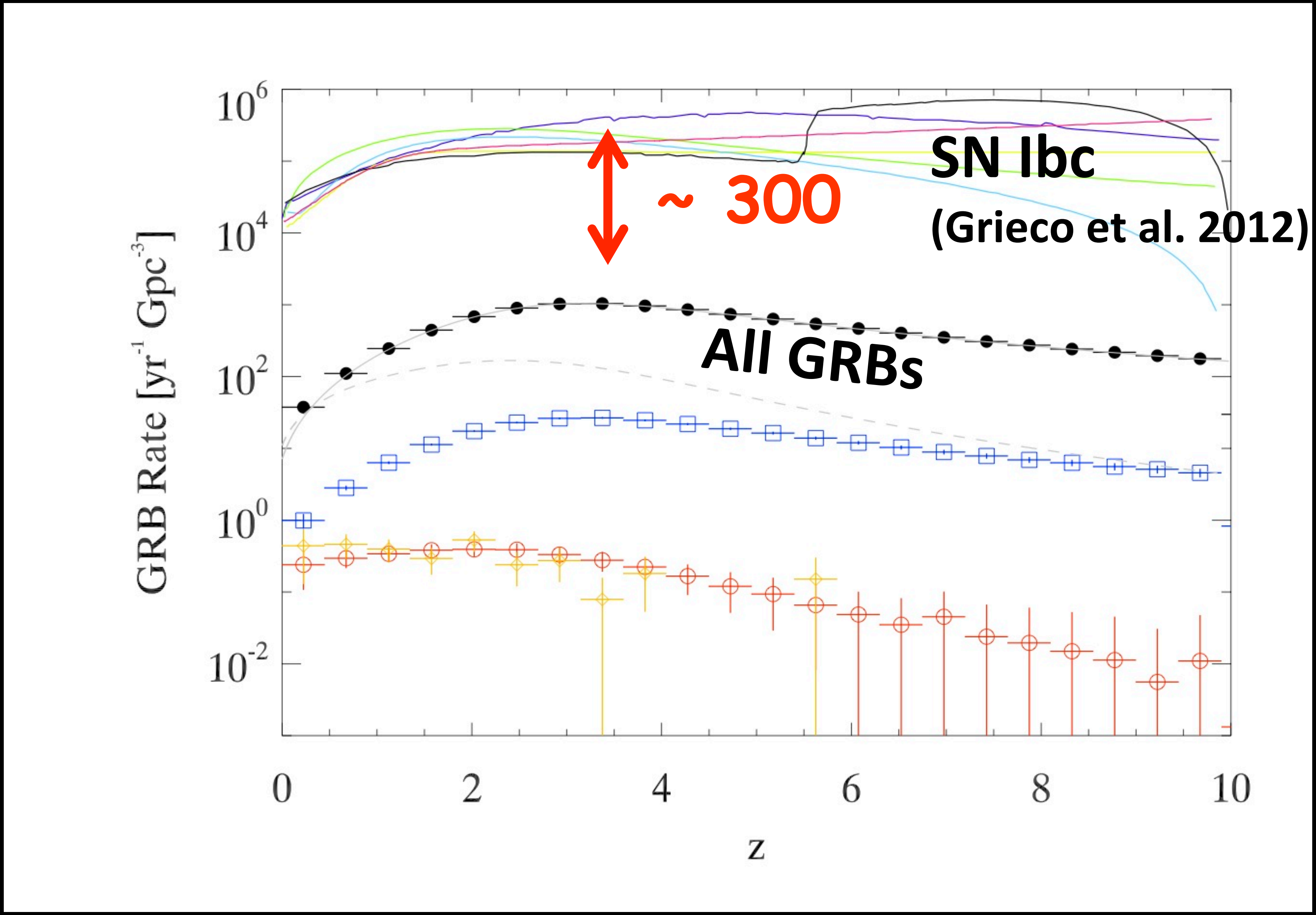


Energy budget



Ghirlanda et al. 2007

GRB Rates



Ghirlanda et al. 2013 – Through a population synthesis code

Parameters regulating the emission

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- **Fraction of shock energy to electrons** ϵ_e
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Jet opening angle θ_{jet}

Viewing angle with respect to the jet axis θ_{view}

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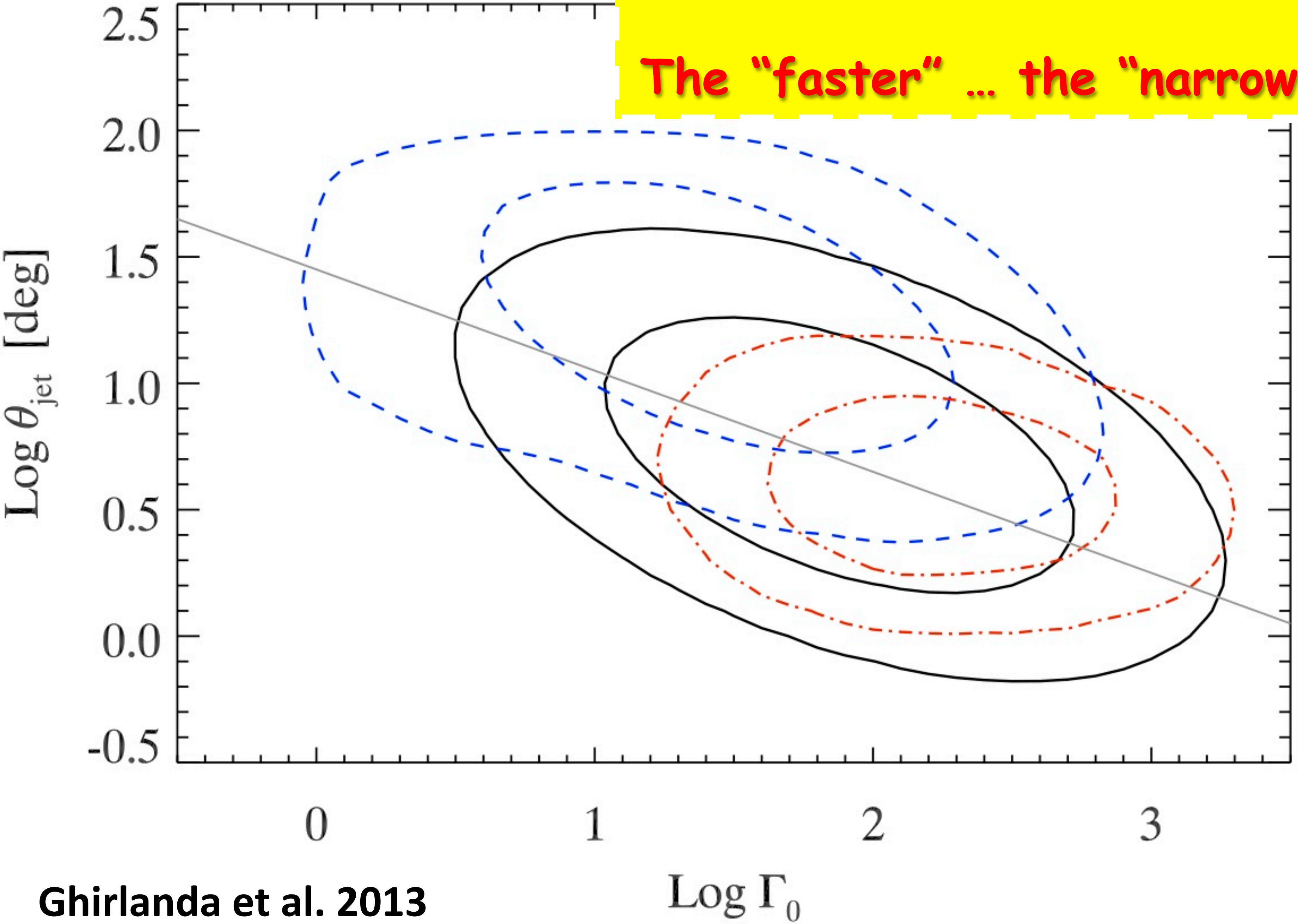
Dynamics and Geometry

Jet opening angle θ_{jet}

Viewing angle with respect to the jet axis θ_{view}

$$\theta_{\mathrm{jet}}^{2} \propto 1/\Gamma_0$$

The “faster” … the “narrower”



Ghirlanda et al. 2013

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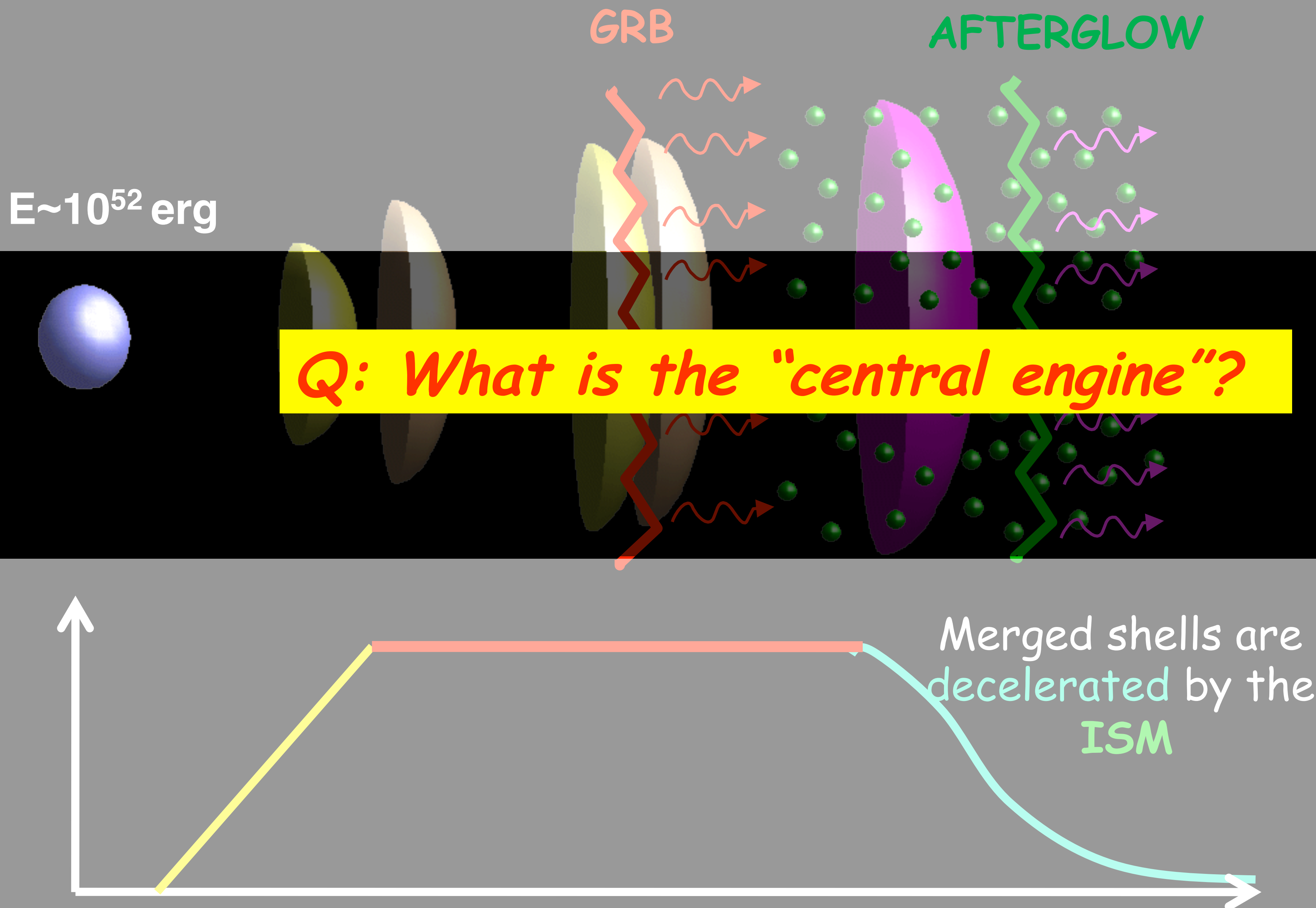

GRB Part-I: ingredients of progenitors

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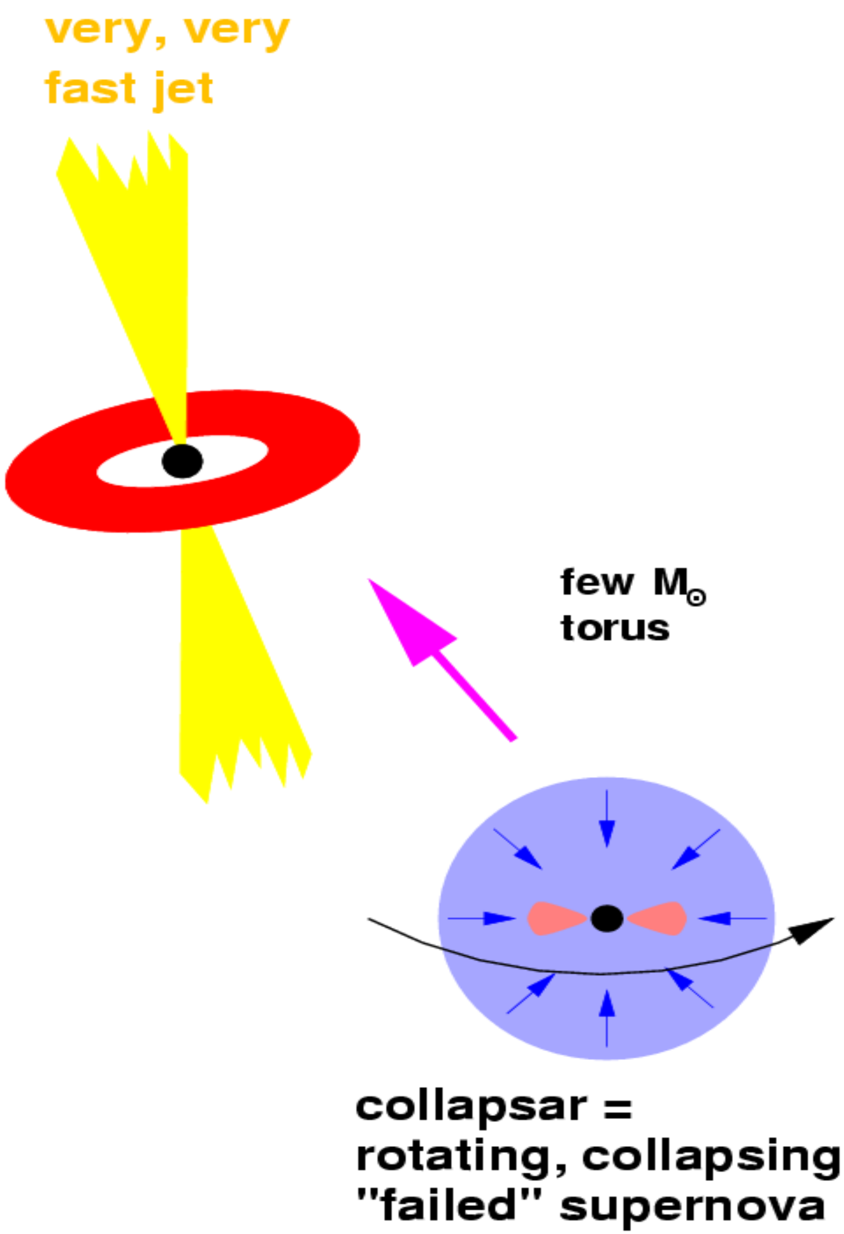
Q: What is the "central engine"?

LONG GRBS

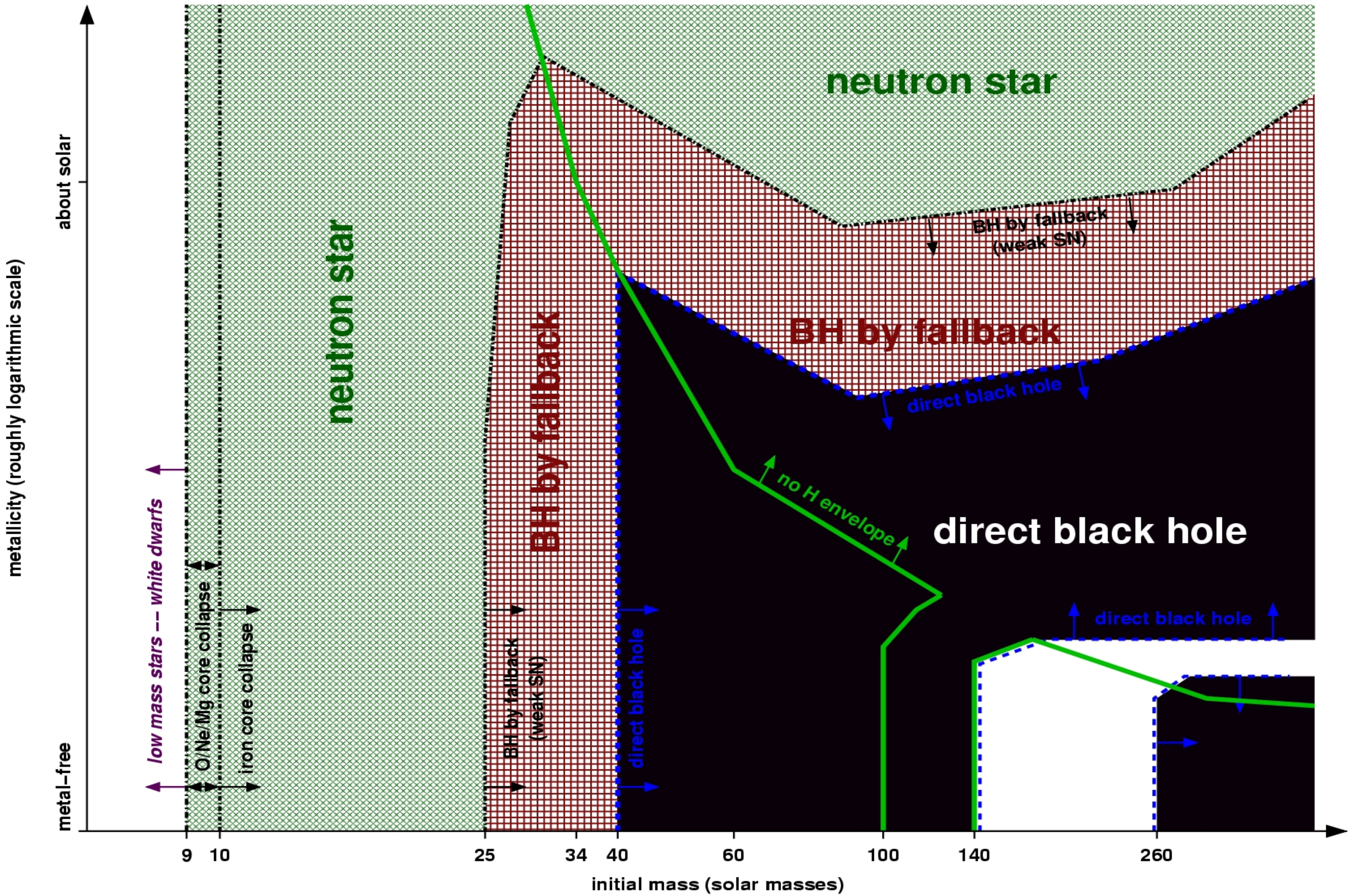
Progenitors Hyperaccreting Black Holes LONG GRBs

Collapsar supported by:

1. SN association
2. Tracing SF in hosts
3. Host properties



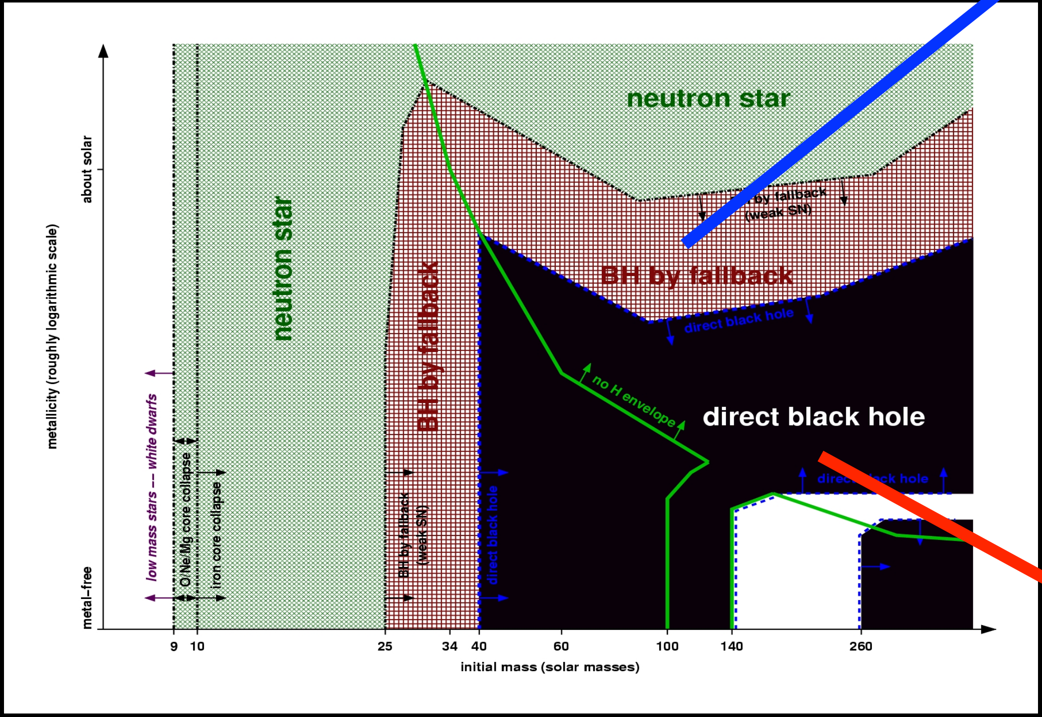
M. Ruffert, H.-Th. Janka, 1998

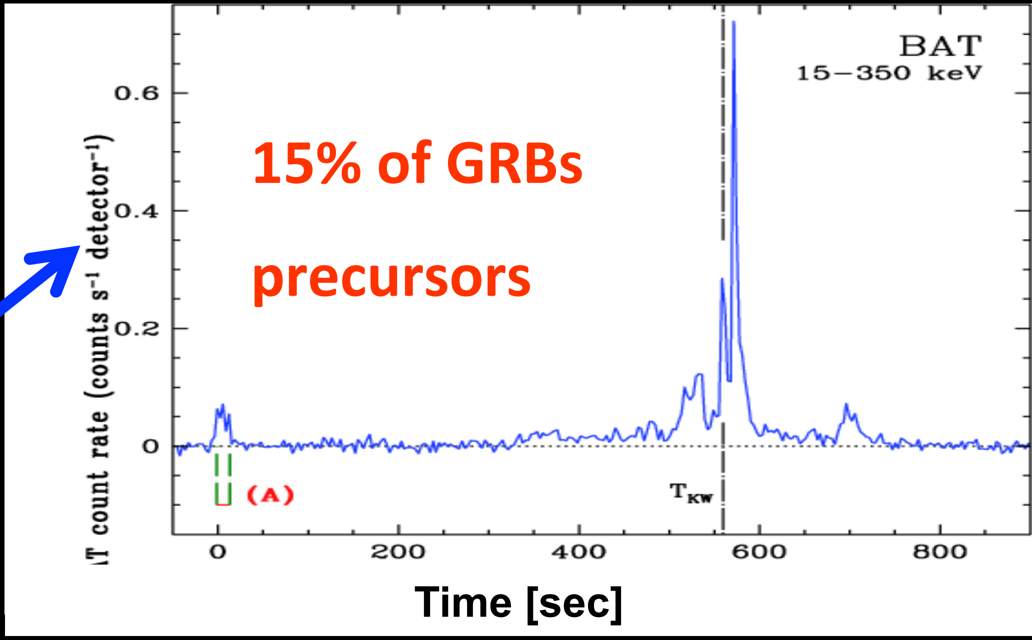


Heger et al. 2003

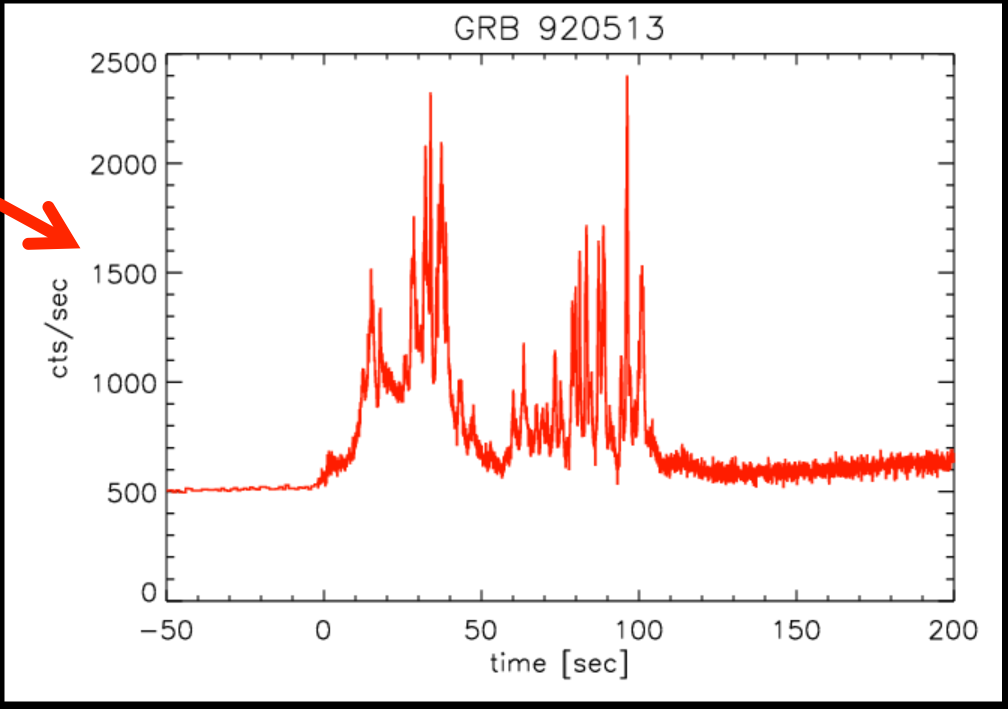
2 step collapse:

NS → BH



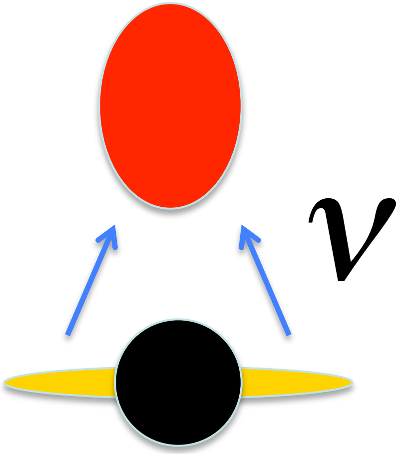


Direct BH



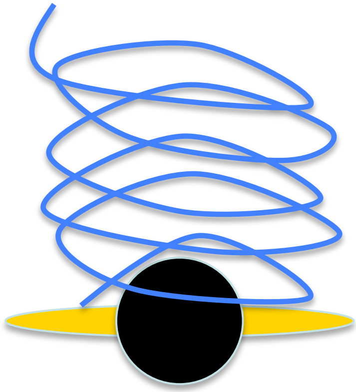
Jet Models

- Baryonic jets
  - Fireball, Thermal pressure
  - Tangled magnetic fields generated locally by instabilities in shock.



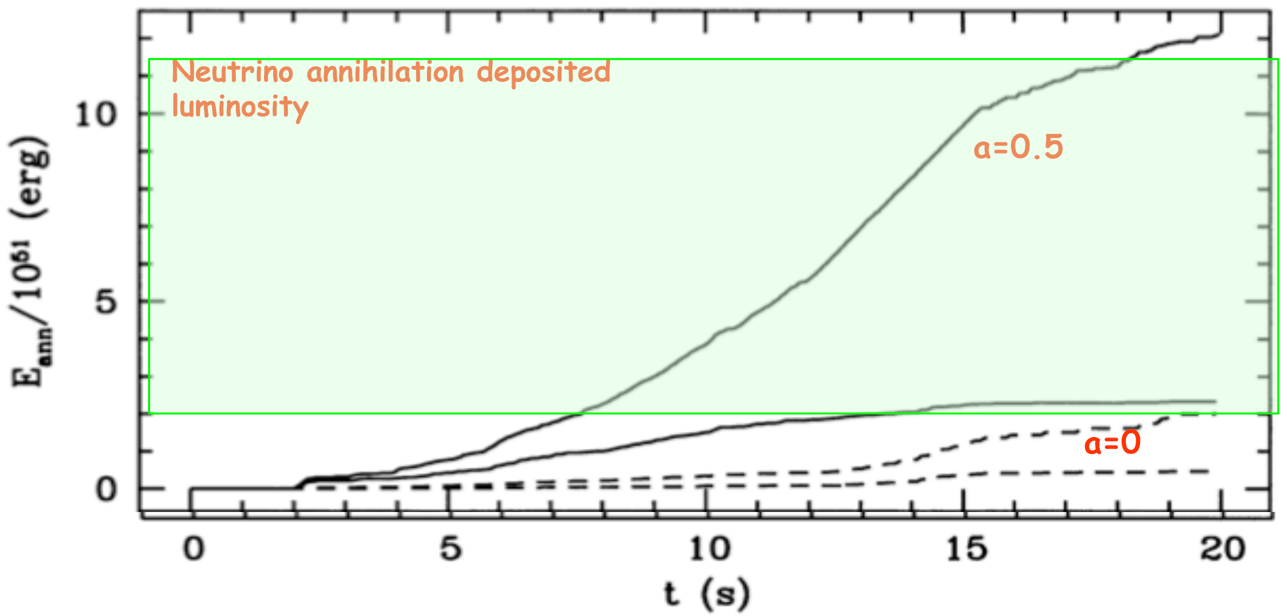
Zhang&Meszaros 2004; Piran 2005
Medvedev&Loeb 1999;Nishikawa et al. 2003; Spitkovsky 2008

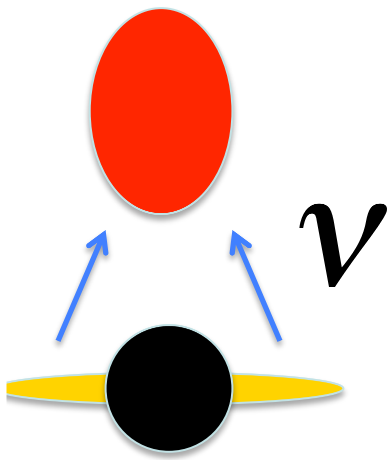
- Magnetized jets
  - Rotating BH system, Magnetic pressure
  - Threaded with globally ordered B-fields



Tchekhovskoy et al. 2008; Mckinney&Blandford 2009; Komissarov et al. 2009
Drekhahn&Spruit2002; Lyutikov 2006; Giannios 2008; Mimica et al. 2009;
Zhang&Yan 2011; Narayan et al. 2011; Granot 2012

Jet Models





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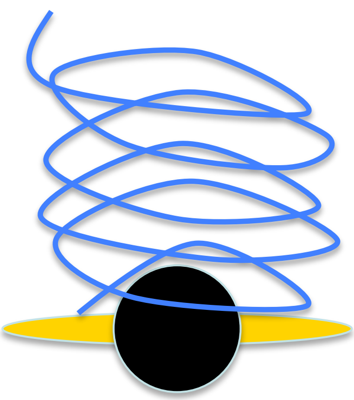


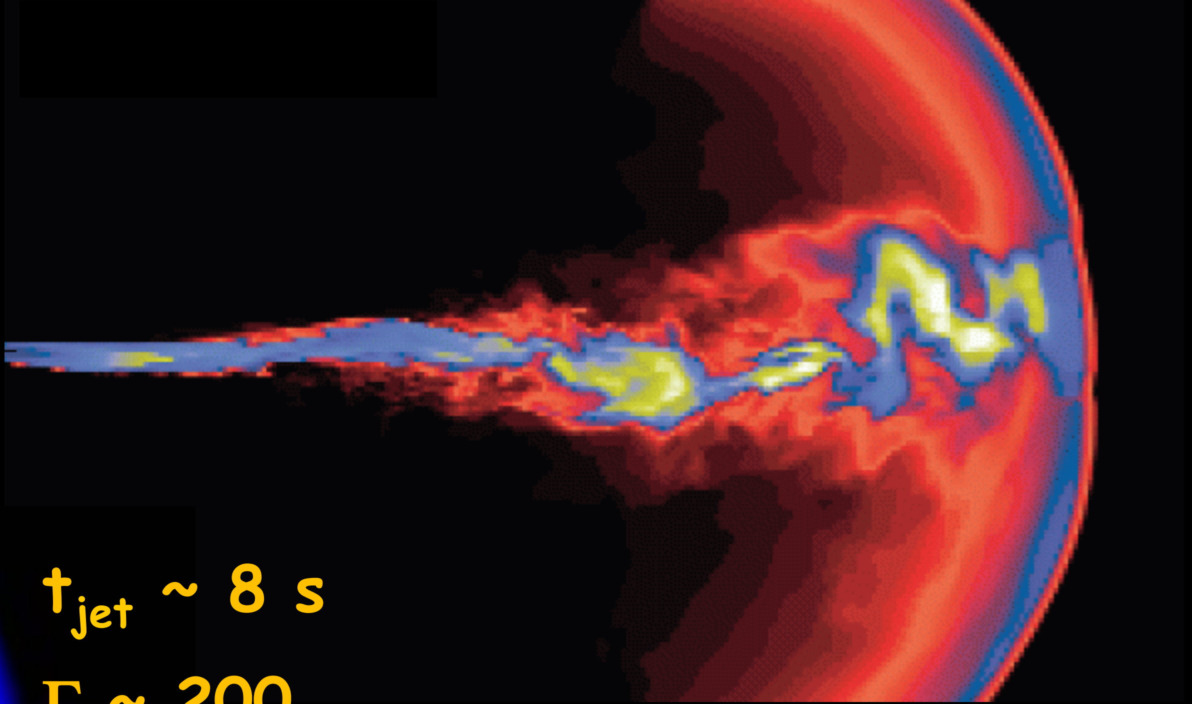
Tchekhovskoy et al. 2008; Mckinney&Blandford 2009; Komissarov et al. 2009
Drekhahn&Spruit2002; Lyutikov 2006; Giannios 2008; Mimica et al. 2009;
Zhang&Yan 2011; Narayan et al. 2011; Granot 2012

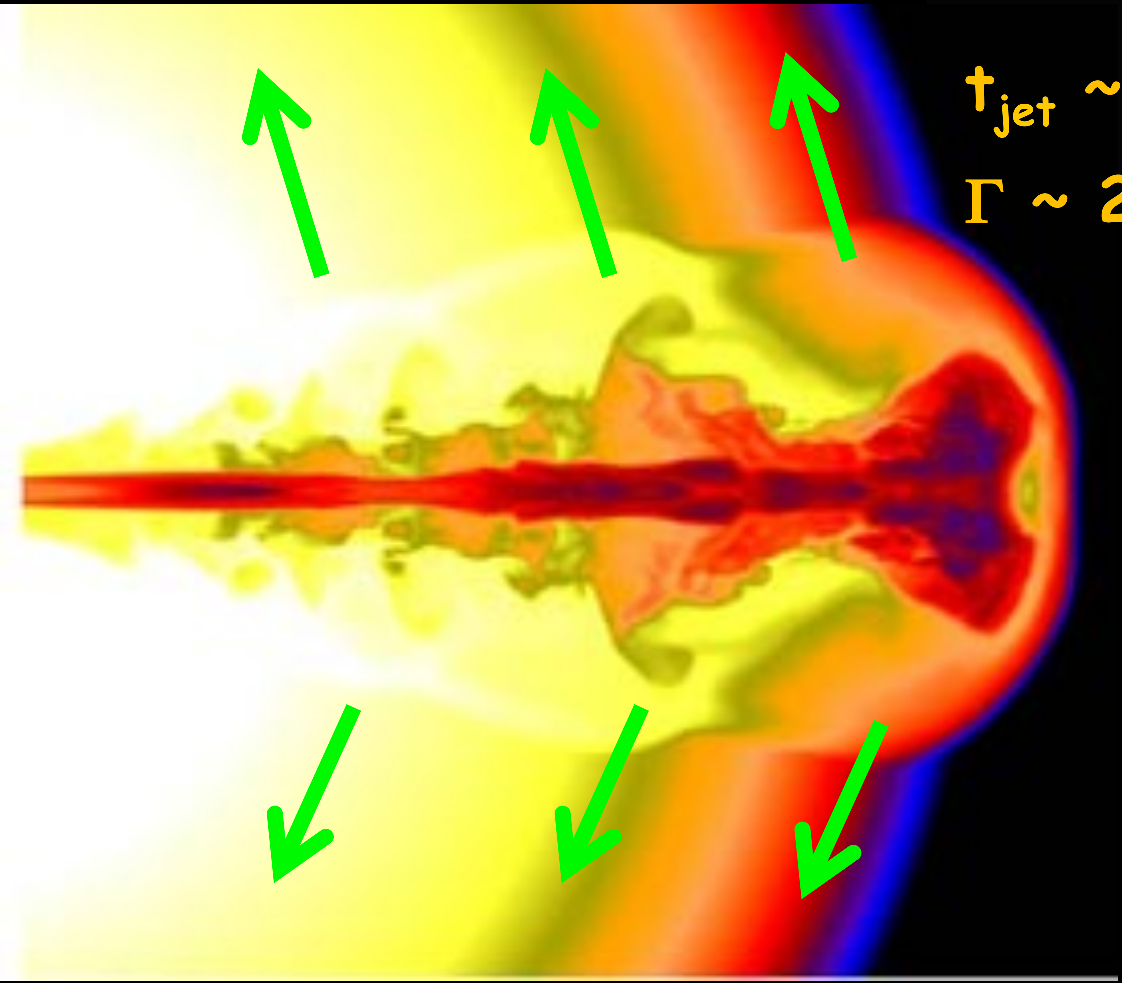
Jet should breakout

E_{jet}=3x10^{50} erg

M^*=15M_{sun}

R^*=9x10^{10} cm





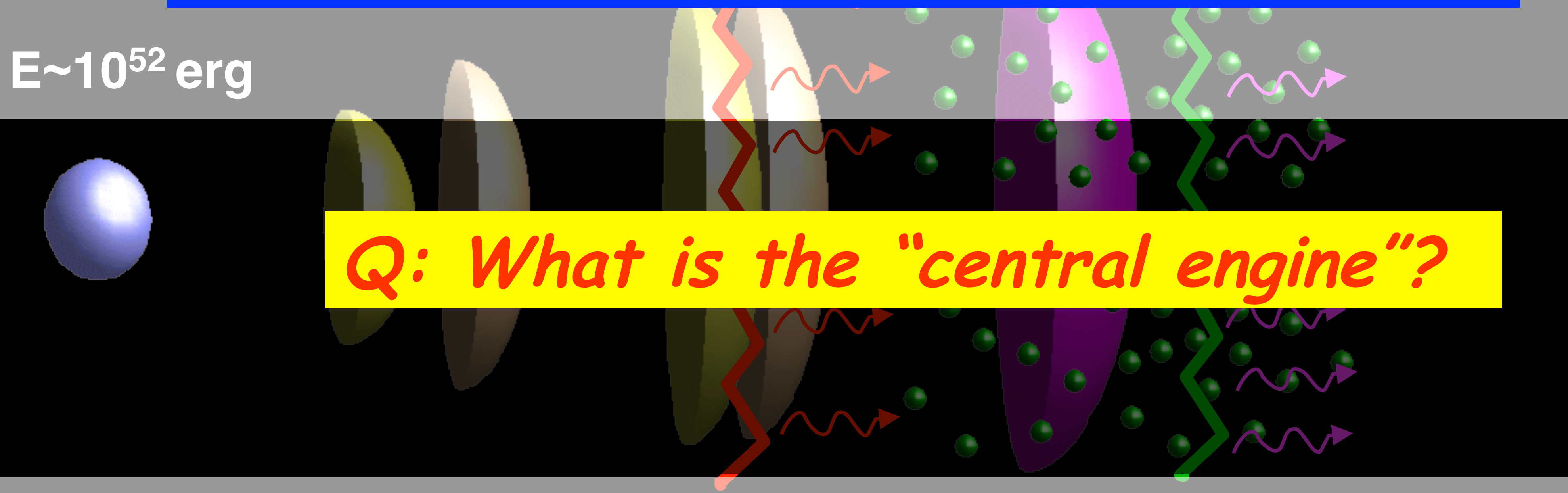
t_{jet} ~ 8 s

Γ ~ 200

In the collapsar model ~10 s from the BH formation are needed for the funnel to be escavated and the jet launched and for it to break out the star.

A fraction of the jet energy goes as extra power in the SN explosion (thus accounting for 10^{52} erg of GRB-SN events)

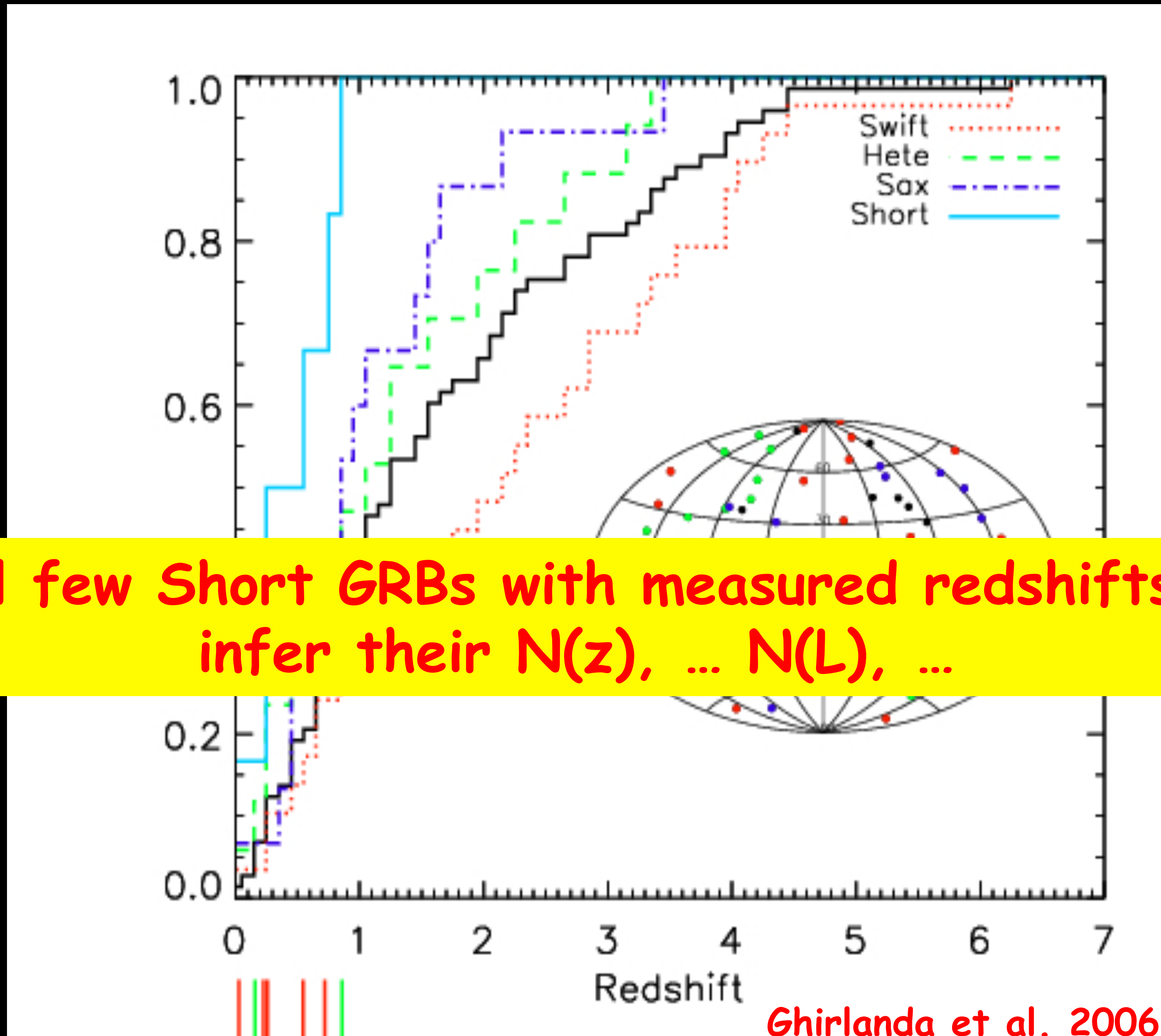
SHORT GRBS



Q: What is the "central engine"?

LONG GRBS

Main differences between short and long GRBs (II)



73 Long

29 Swift

15 Sax

17 Hete

… 12 other

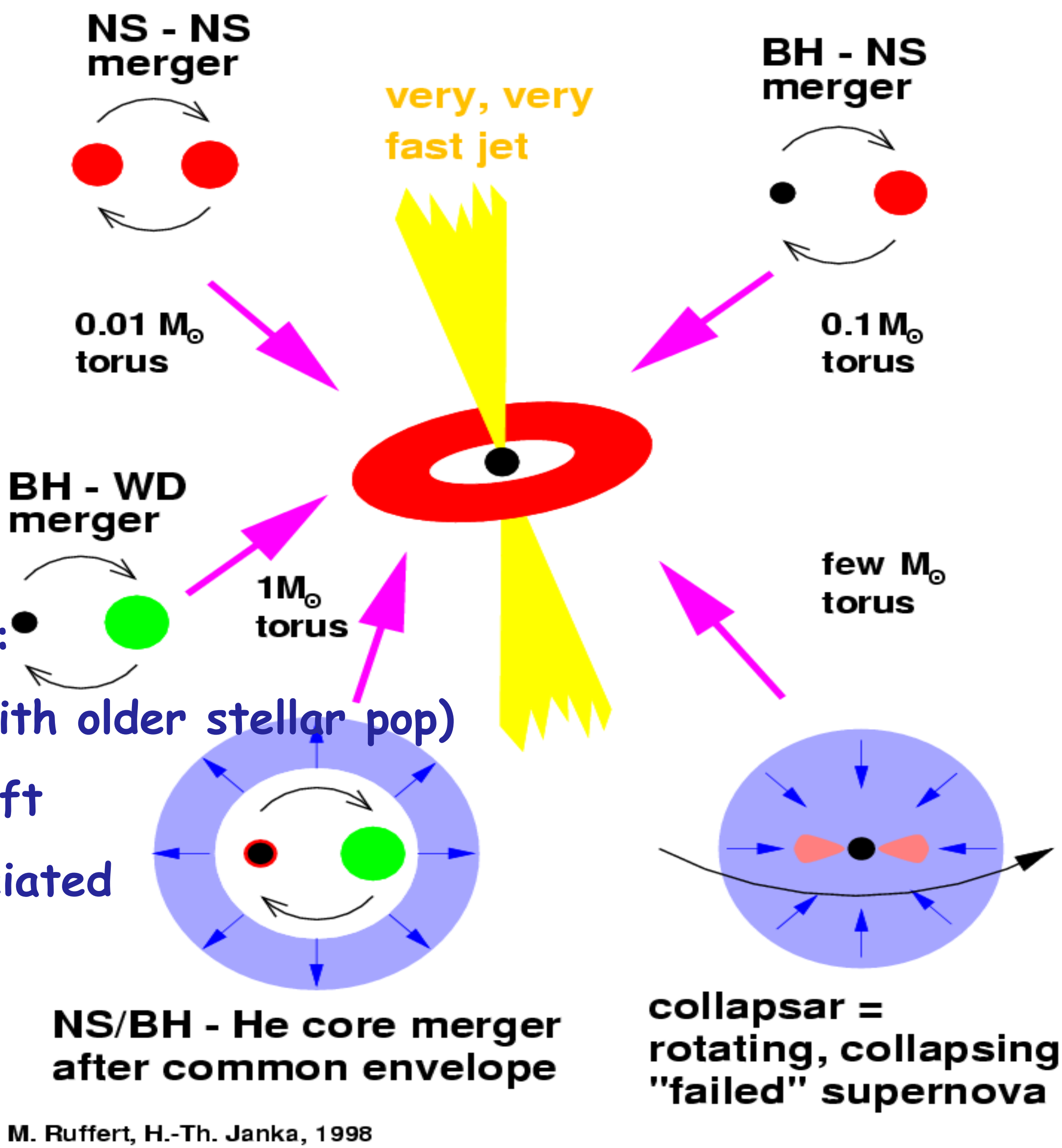
Still few Short GRBs with measured redshifts to infer their N(z), … N(L), …

Short GRB

050925 050709 050509B 050724 051221 050813 040924

Swift 5/7 with redshift

Progenitors Hyperaccreting Black Holes SHORT GRBs



Short
(t < 2 s)

Long
(t > 2 s)

Supported by:

-Hosts (ass with older stellar pop)

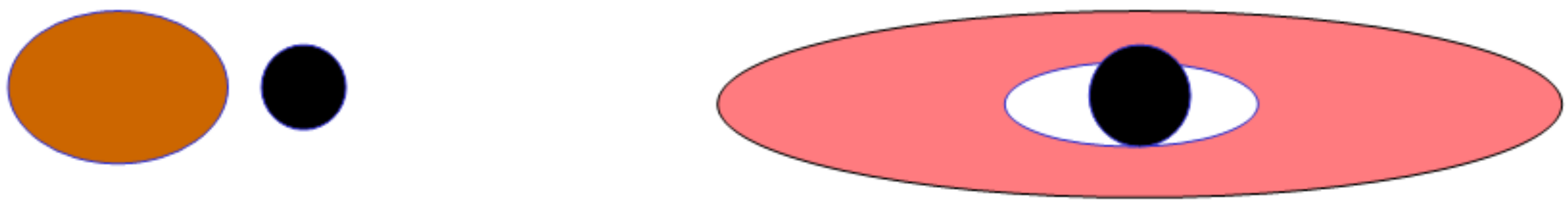
-Lower redshift

-No SN associated

Short GRBs progenitor – Compact object merger

Neutron star + Neutron star
Neutron star + Black hole
White dwarf + Black hole

→ Black hole + compact disk



$M_d \simeq 0.1 - 1 M_\odot$

$R_d \simeq 10 - 100 R_g$

→

Burst duration: 0.1s – 1.0s

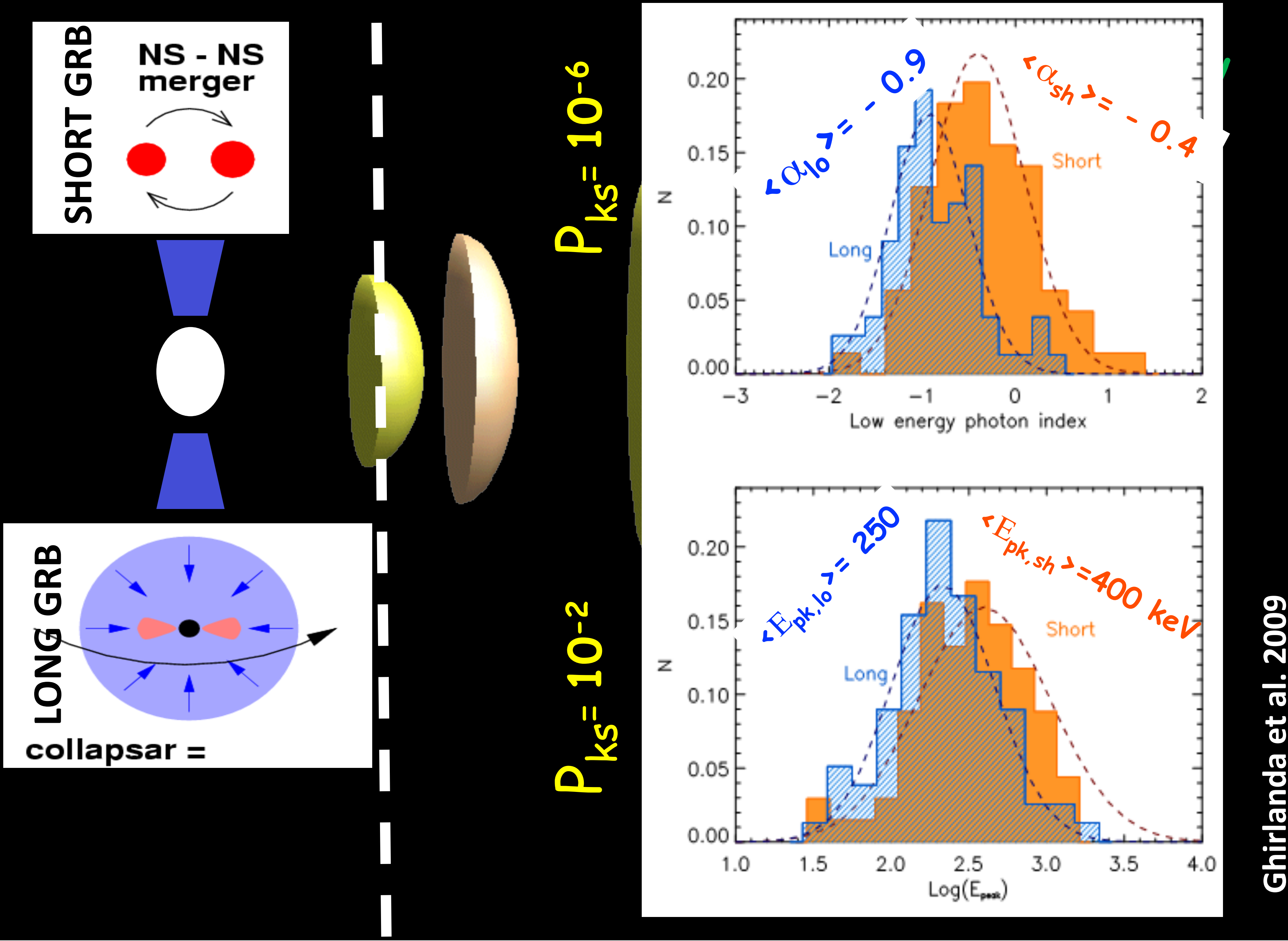
Released binding energy:

$E_d \leq 8 \times 10^{52} \div 8 \times 10^{53}$erg

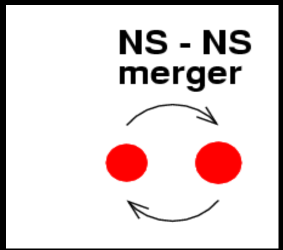
$$E_d < 0.42 M_d c^2 \simeq 8 \times 10^{53} \left(\frac{M_d}{M_\odot}\right) \text{erg}$$

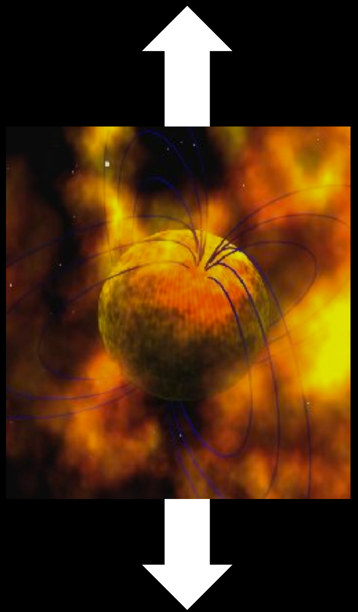
$$t_{acc} \simeq 0.1 \left(\frac{\alpha}{0.1}\right)^{-6/5} \left(\frac{M_b}{M_\odot}\right)^{6/5} \left(\frac{R_d}{10 R_g}\right)^{4/5} \text{s}$$

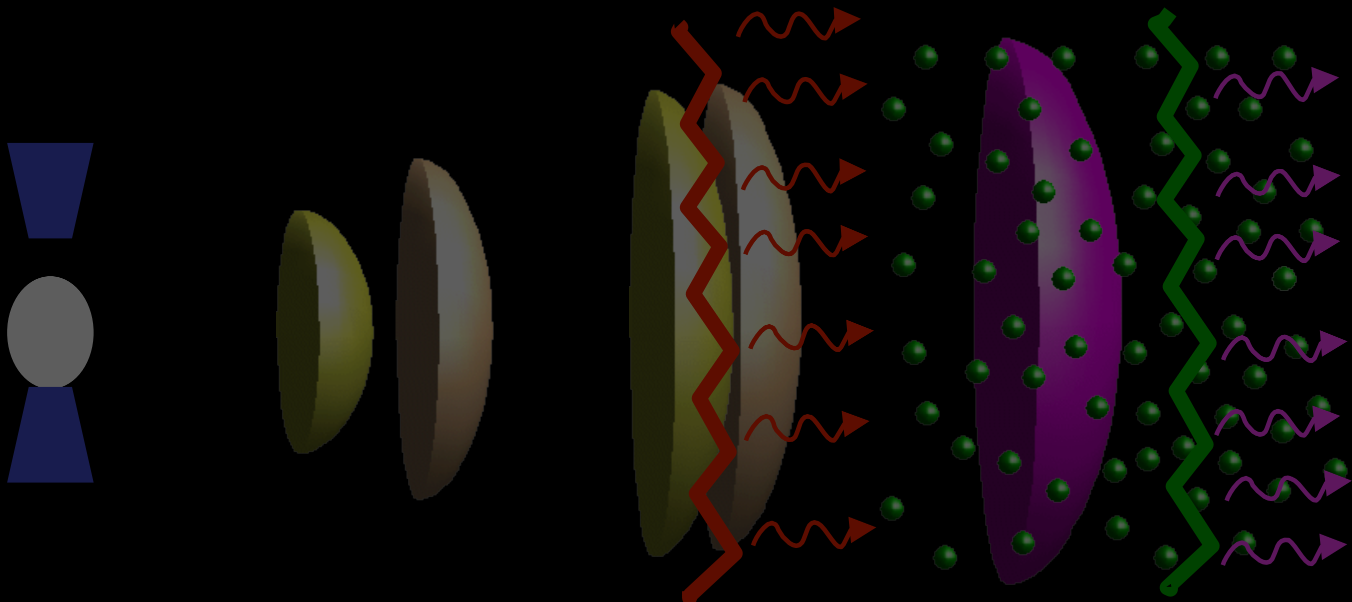
Different progenitor but similar mechanism

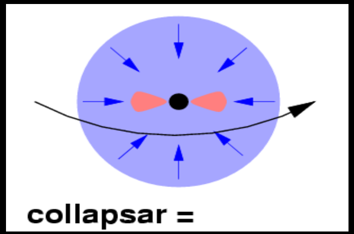


Open questions — **Progenitors**

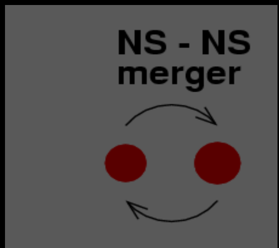


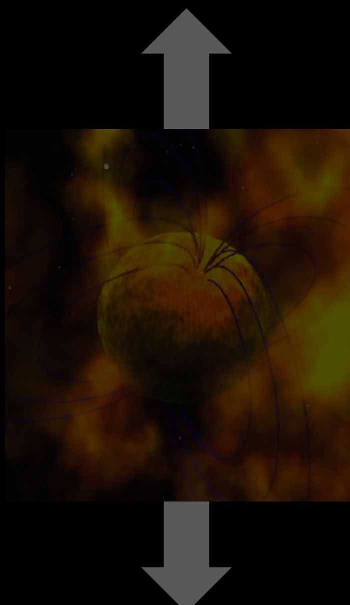


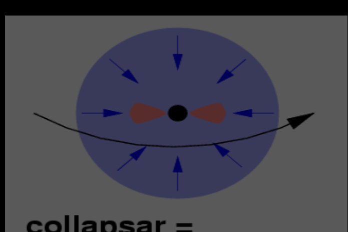


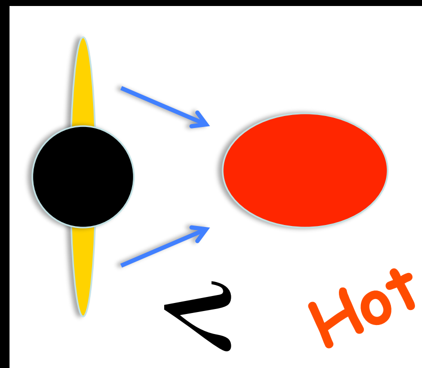


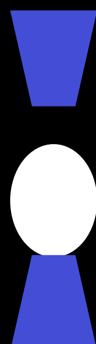
Energy source

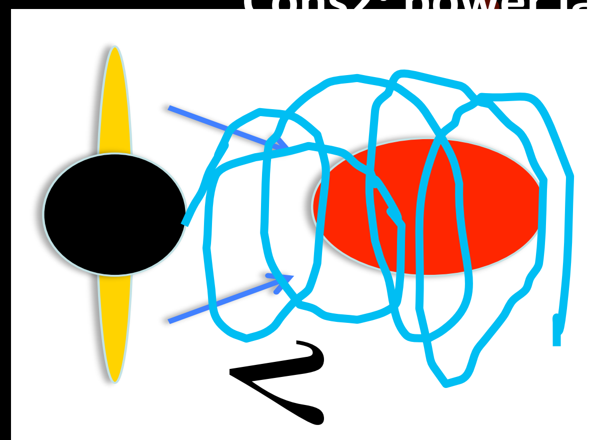


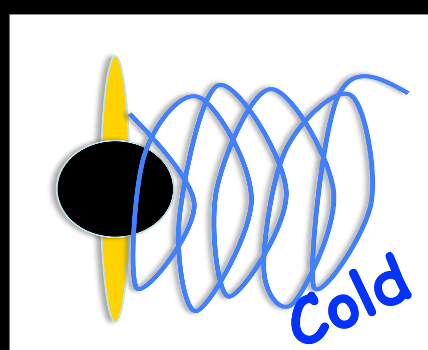


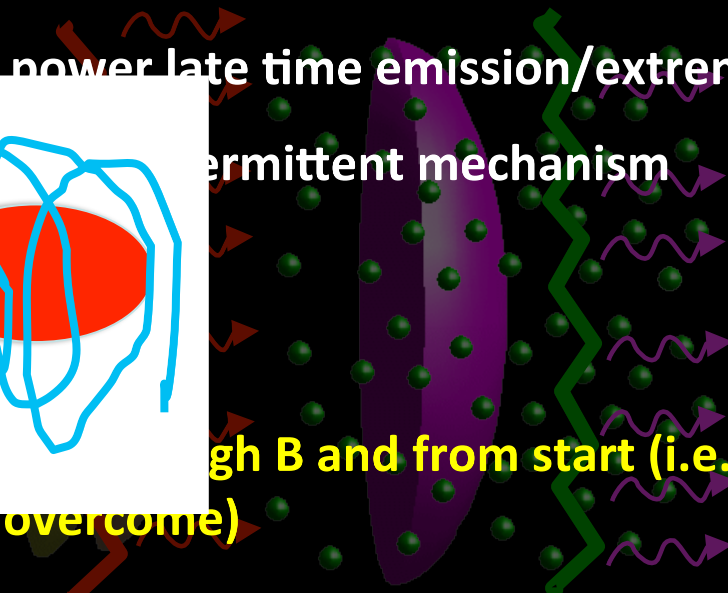












Pro1: natural from disk (known in SN)

Pro2: acceleration by int. P – accounts for BB spectra

Pro3: can drill through the *

Cons1: extreme energetics

Cons2: power late time emission/extremely long GRB

ermittent mechanism

gh B and from start (i.e. B amp at shock overcome)

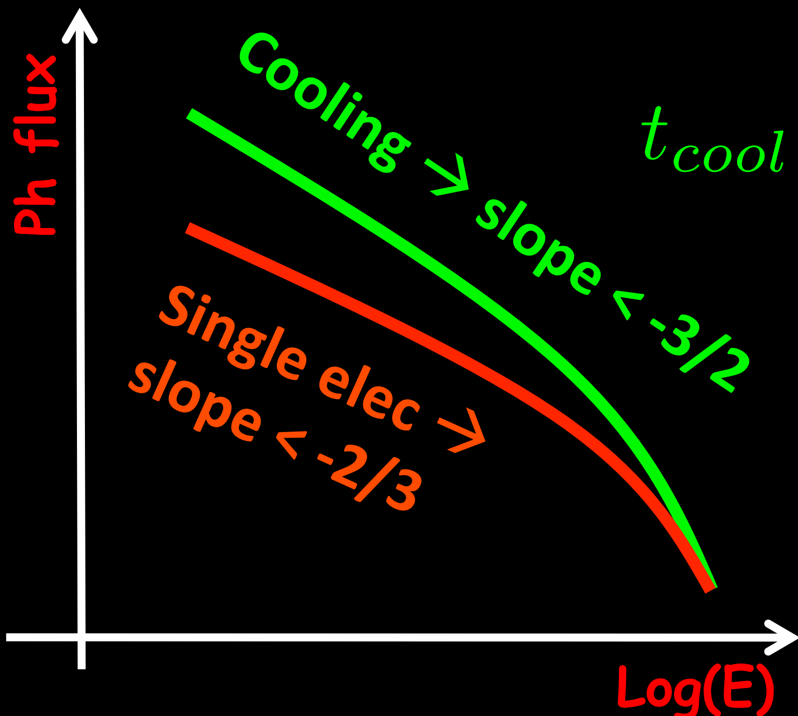
Pro2: naturally explain random prompt (reconnection)

Pro3: high efficiency

Cons1: non thermal emission

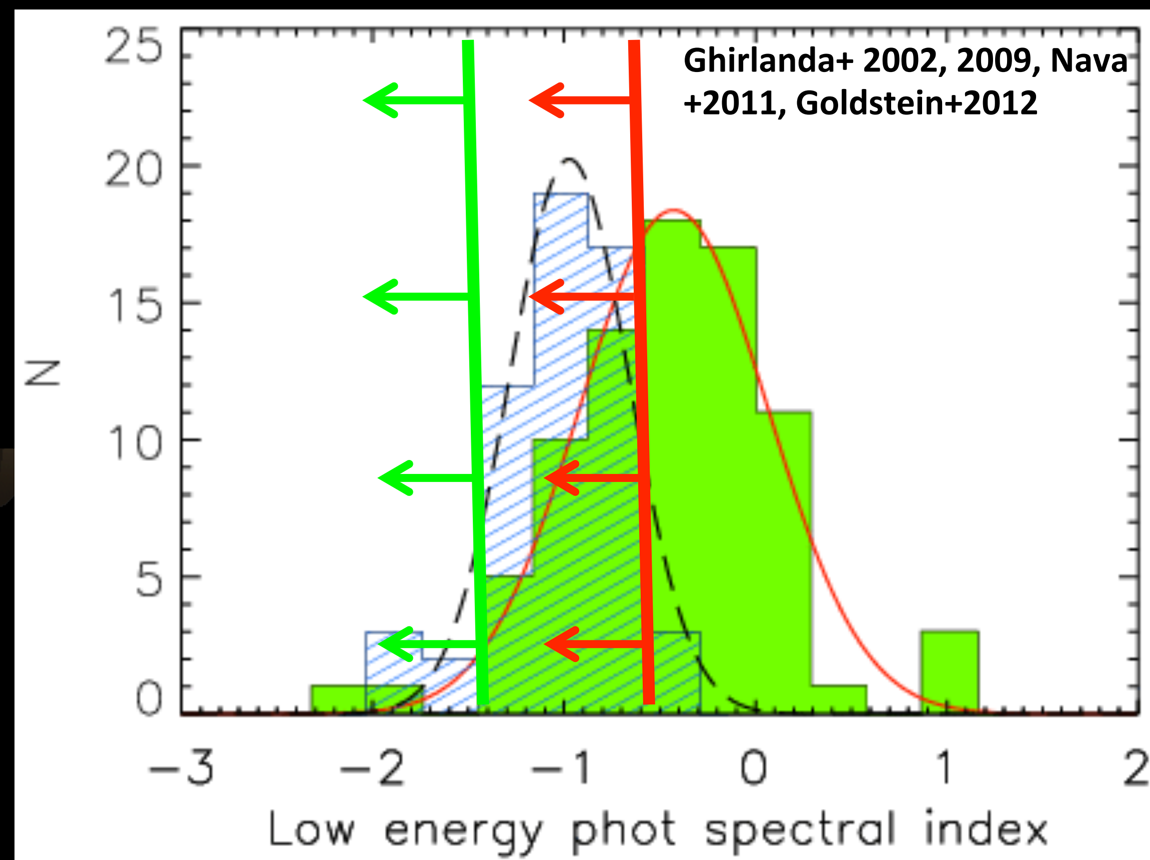
Cons2: need avaquated funnel

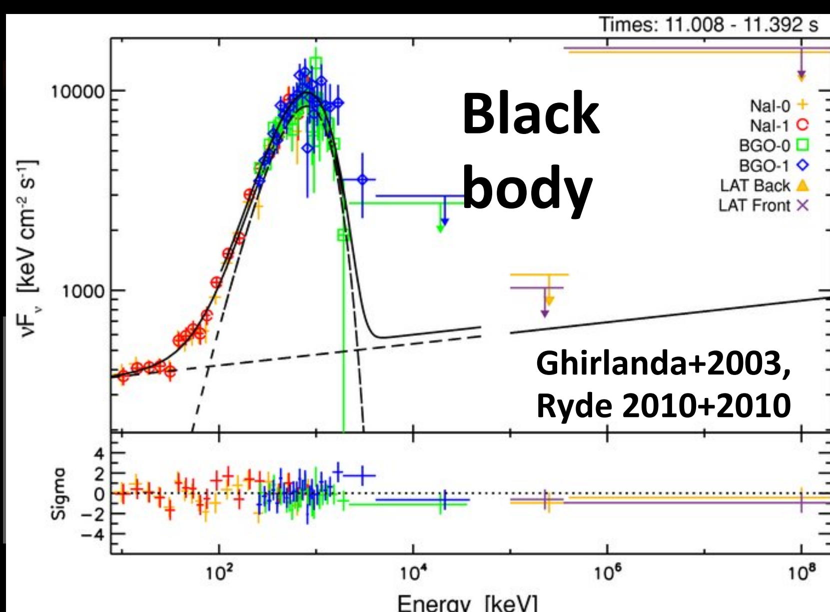
Open questions — Prompt emission mechanism



$$t_{cool} \simeq 10^{-7} \frac{\epsilon_e^3 (\Gamma/100)}{\nu_{MeV}^2} \quad sec$$

Synchrotron has its problems



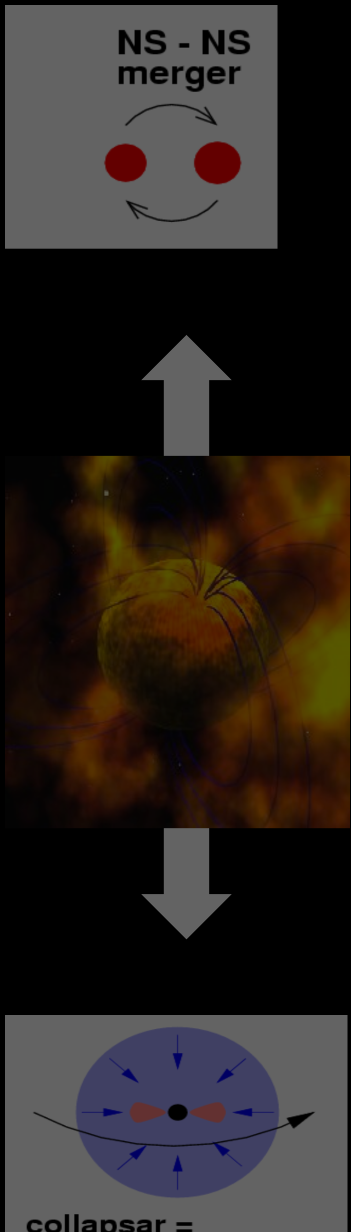


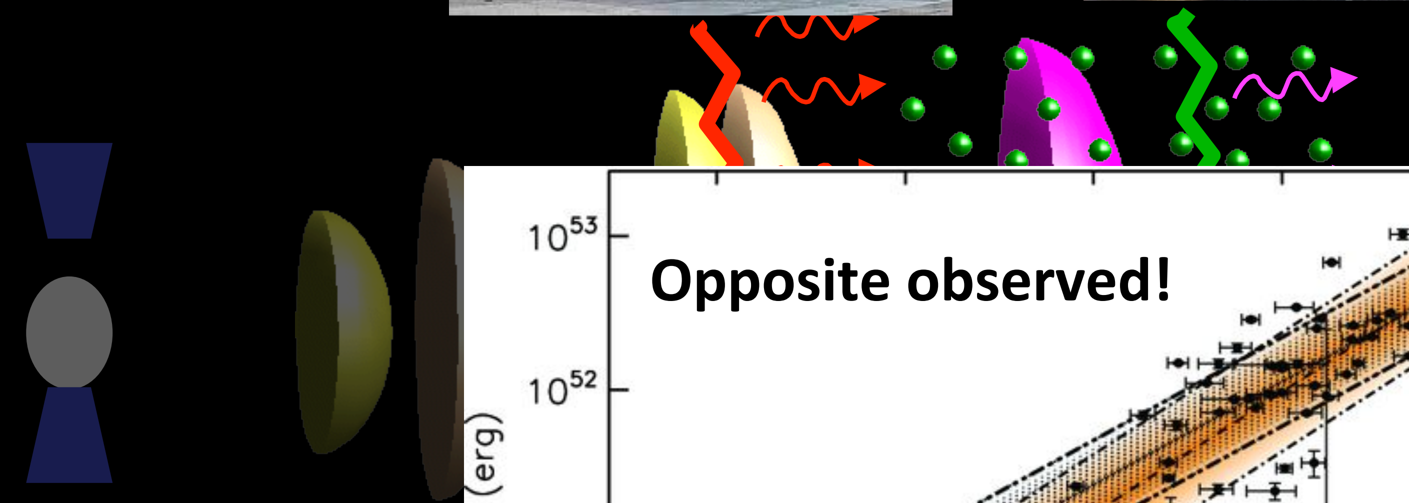
Open questions

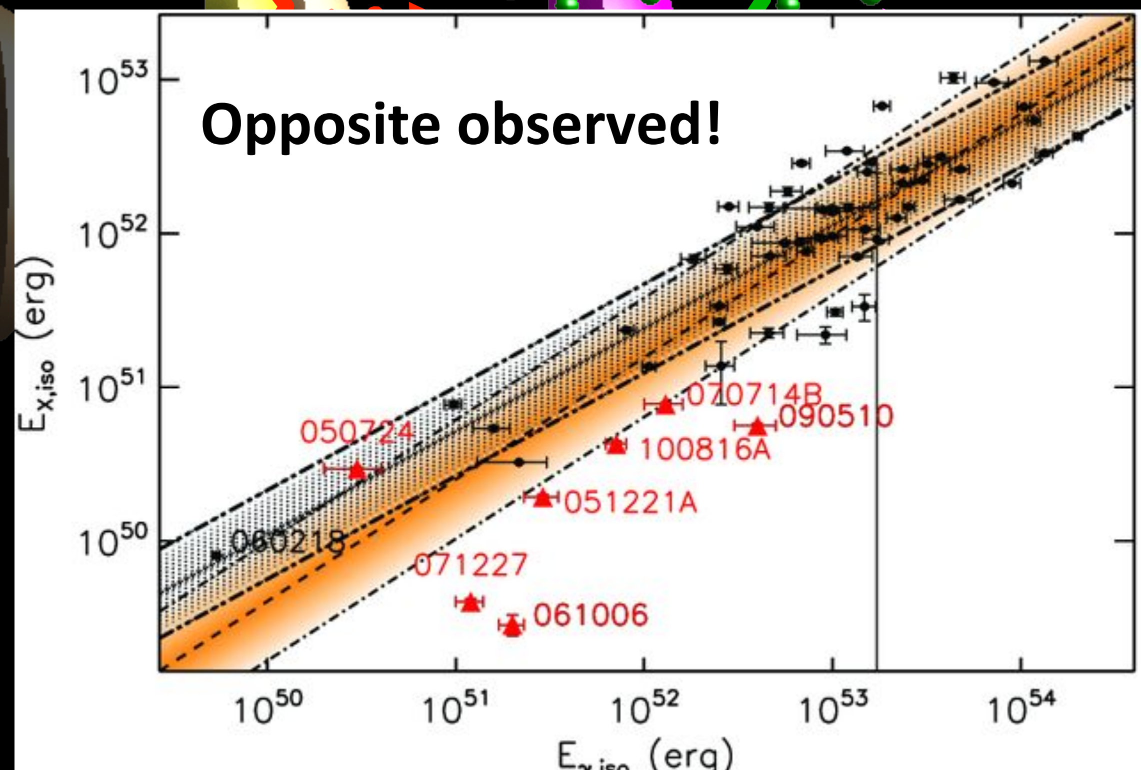
Internal vs external shocks

Efficiency <<

Efficiency >>



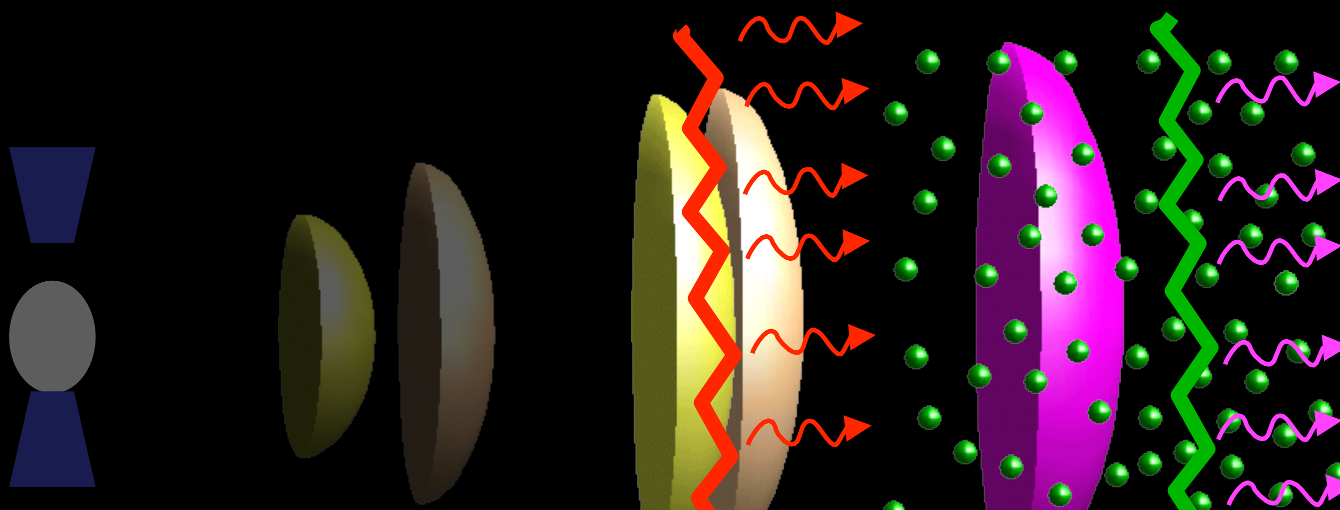


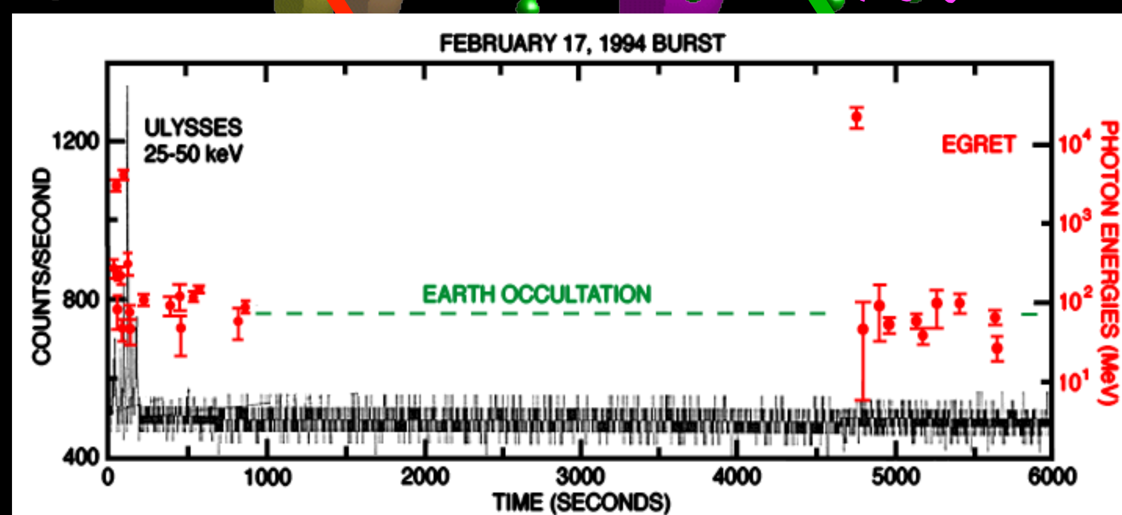


Open questions

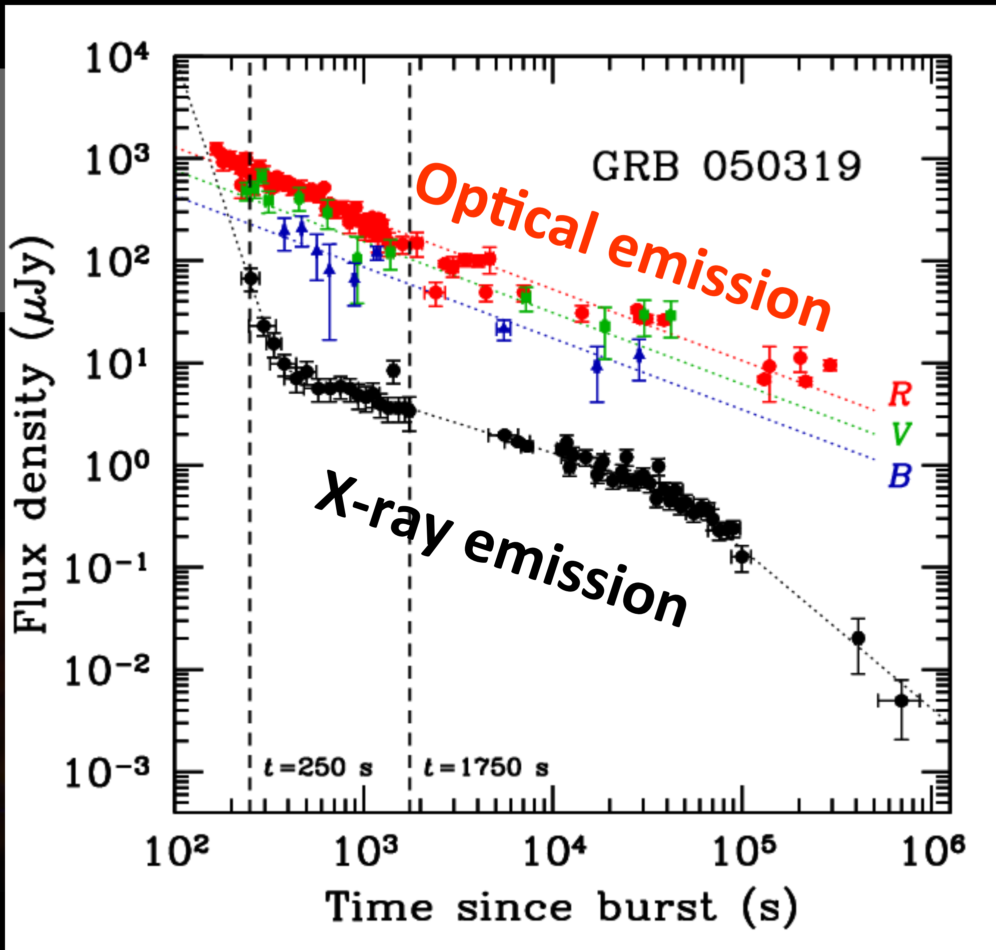
GeV emission

Is GeV (observed by EGRET and Fermi/LAT) emission produced by Internal or External Shocks?





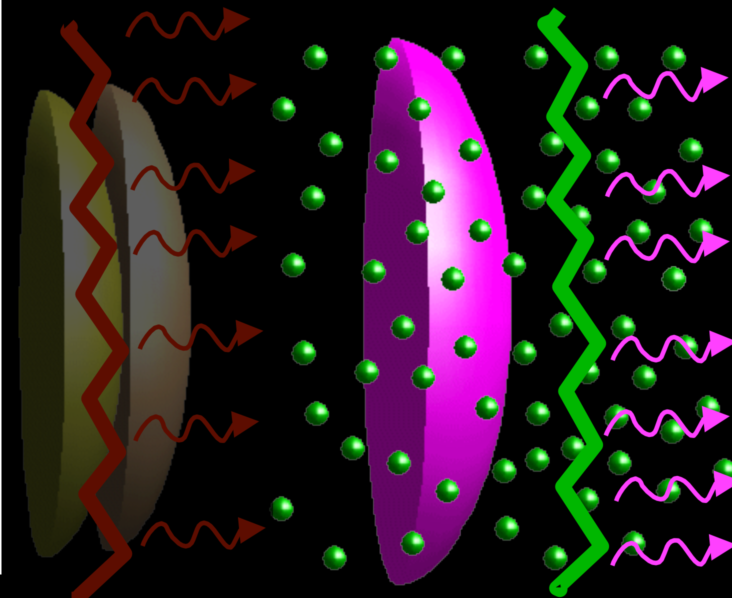
Afterglow & environment



Environment density profile:

(a) constant density (typical approx)

(b) Wind density profile (expect. theoretically)



If Optical and X-ray are afterglow they should be produced:

1. Same elect. Population
2. Same region

Should decay the same way (even if spectral break in between is present)