# GRBs and their contribution to the stochastic background radiation in gravitational waves

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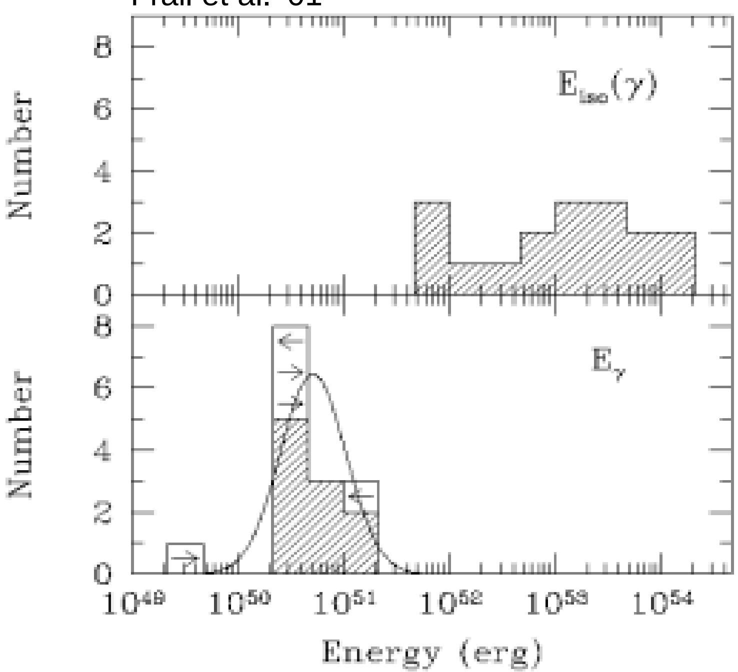
*GRB-durations and energies* | *GRB-SNe association*

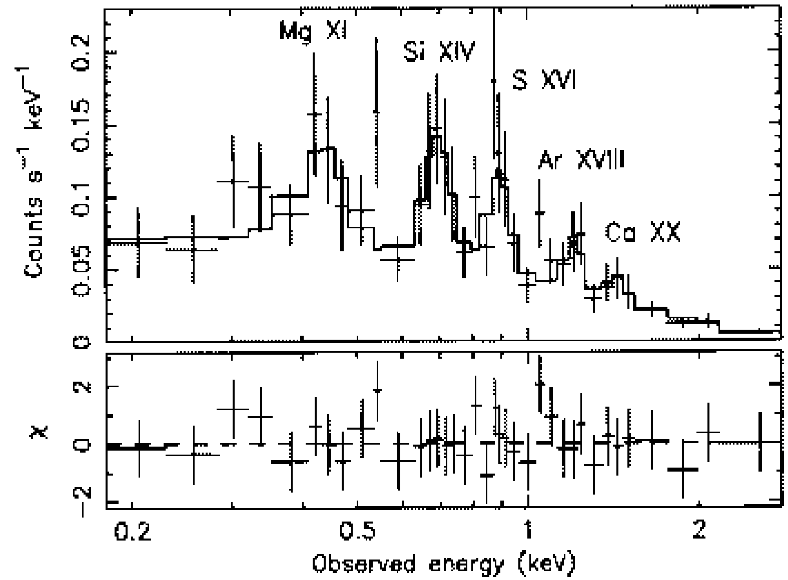
Kouvelioutou et al. '93

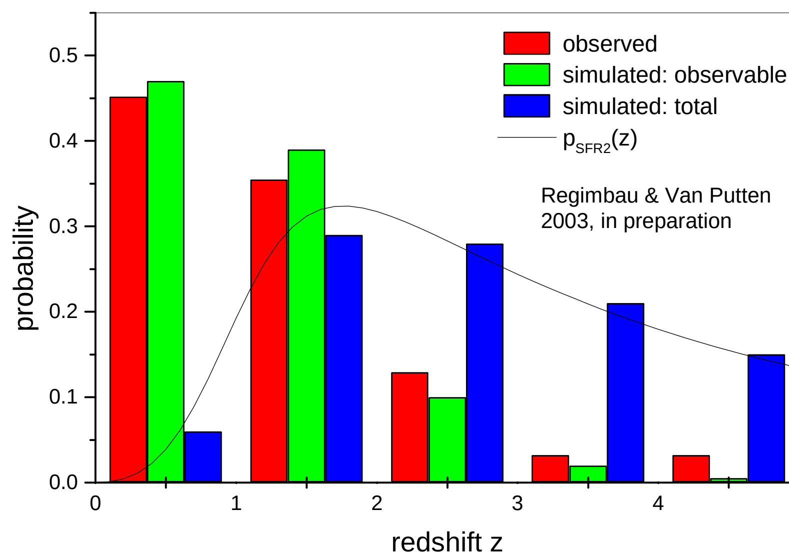
Van Putten '02

Frail et al. '01

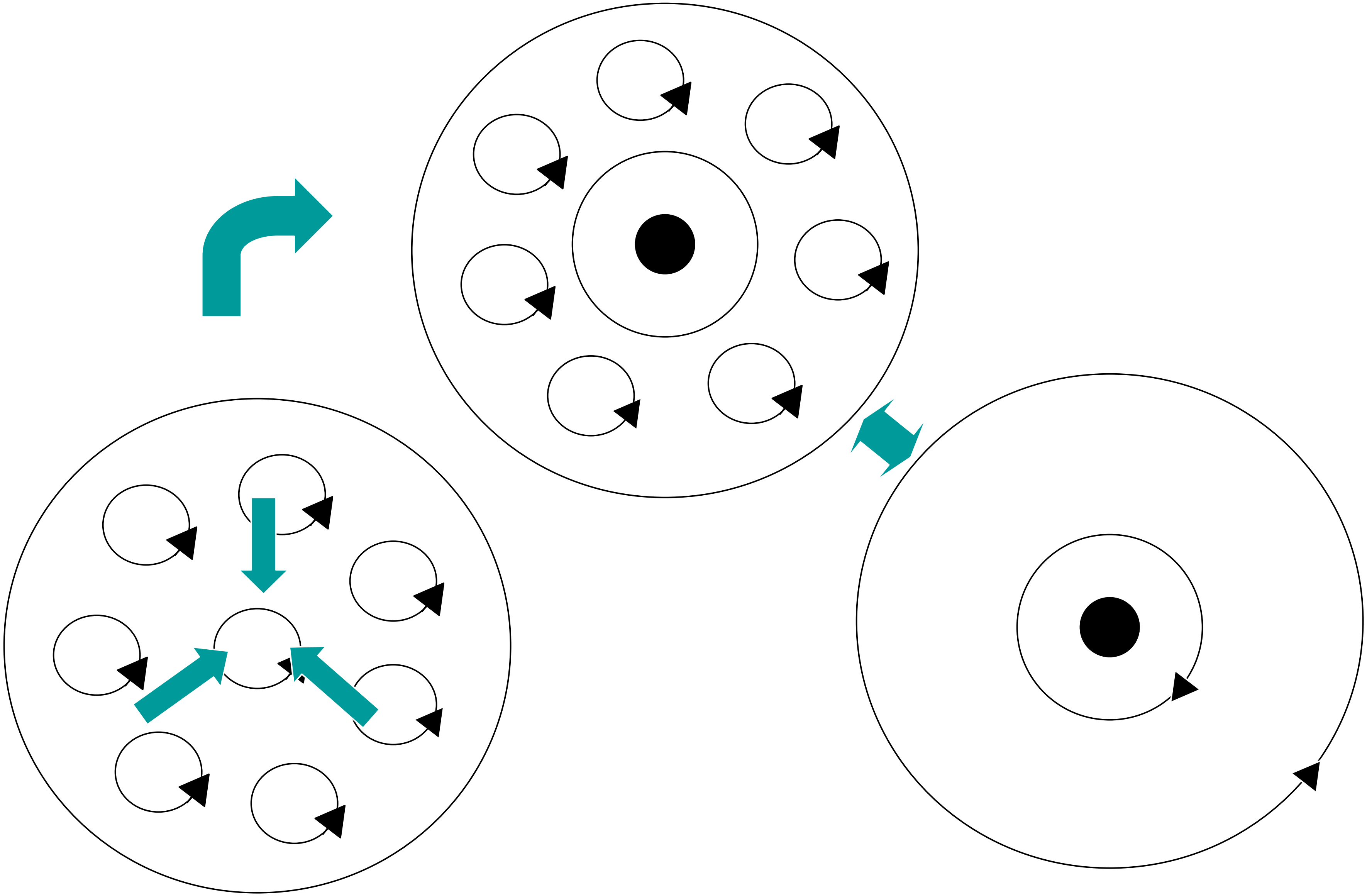



GRB 011211 (z=2.41) Reeves et al. '02



# Formation of counter-oriented current rings in core-collapse



Van Putten & Levinson, ApJ, 2003

# Topology of flux-surfaces of a uniformly magnetized torus

(vacuum case)

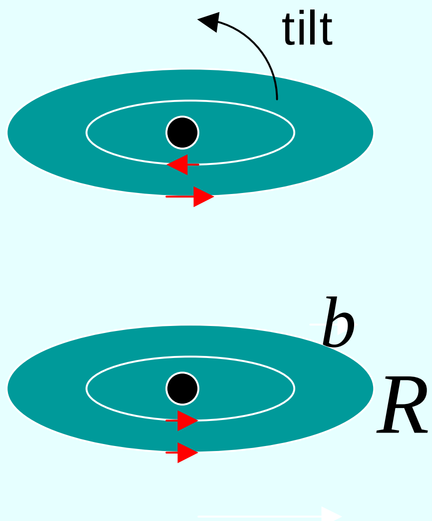
separatrix

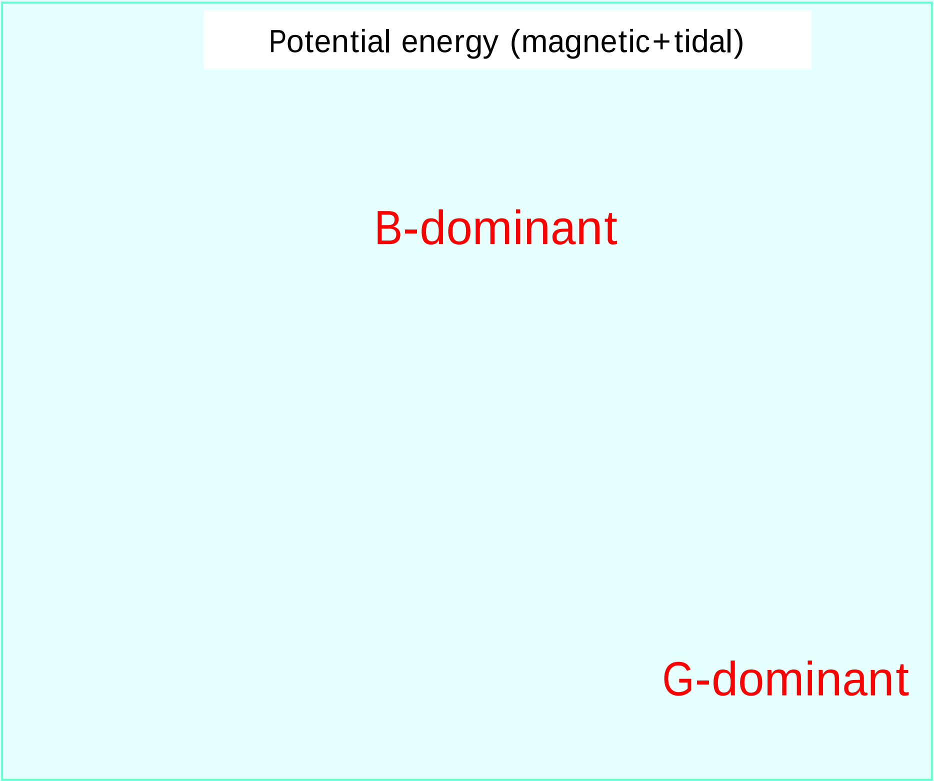
Van Putten & Levinson, ApJ 2003

# Magnetic stability

$$U_{\uparrow\downarrow} = \mu B > 0$$

$$U_{\uparrow\uparrow} = -\mu B < 0$$



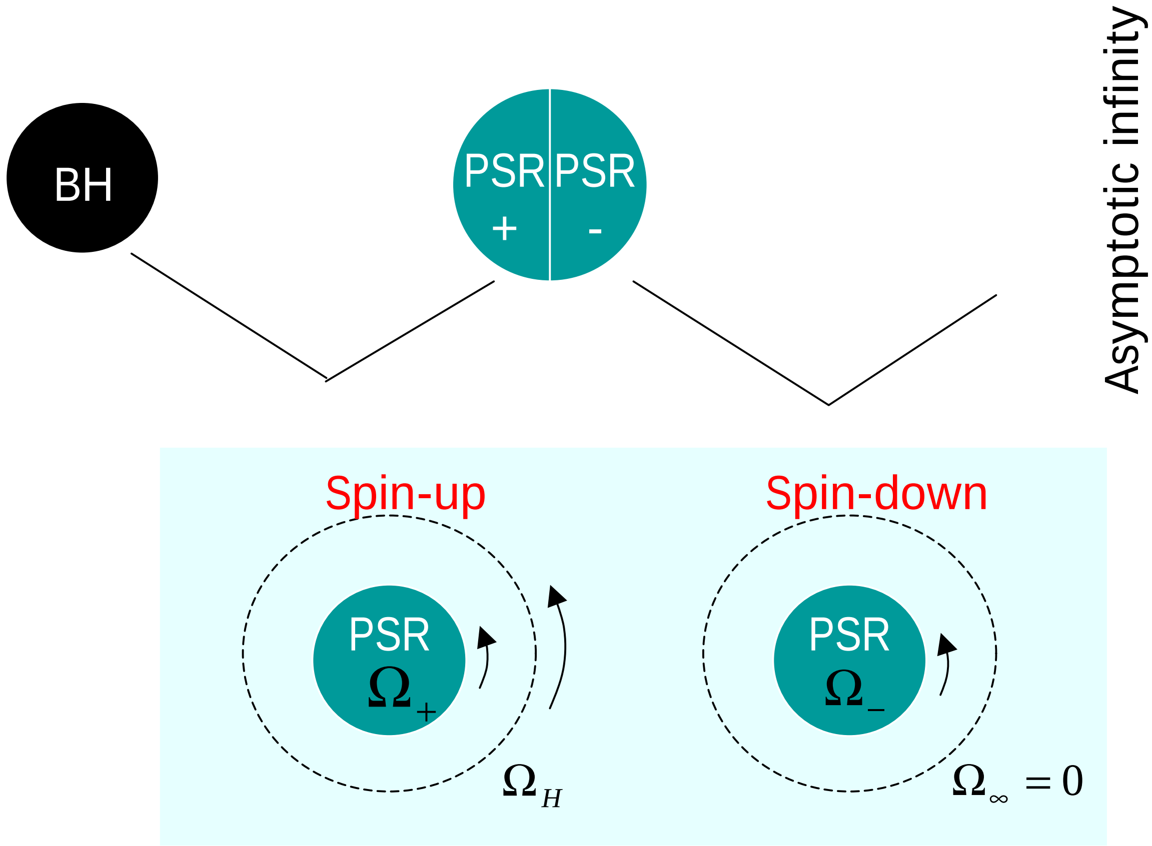




Van Putten-Levinson stability criterion:

$$E_B / E_k < 1/12 \text{ tilt } [1/15 \text{ buckling}]$$

Van Putten & Levinson, ApJ 2003

# Topological Equivalence to Pulsars




Black hole luminosity from horizon Maxwell stresses:

Perturbative limit: Ruffini & Wilson (PRD 1975)
Non-perturbative: Blandford & Znajek (MNRAS 1977)
*but*: causality unresolved (Punsly & Coroniti ApJ 1989)
Causality by topological equivalence to PSRs: van Putten (Science 1999):

(a) *Most* of the black hole luminosity is incident onto the inner face of the torus
(b) *Most* of the black hole-spin energy is dissipated in the horizon

# *Long durations*

$$T_s = \frac{E_{rot}}{T_H \dot{S}} \geq 40\,\mathrm{s}\left(\frac{\mu}{0.03}\right)^{-1}\left(\frac{R}{6M_S}\right)^{4}\left(\frac{M}{7M_S}\right), \quad \mu = M_T / M_H$$

Large parameter

$$\gamma_0 = T_{90} / P = 4\times 10^4 (\eta / 0.1)^{-8/3} (\mu / 0.03)^{-1}$$

in

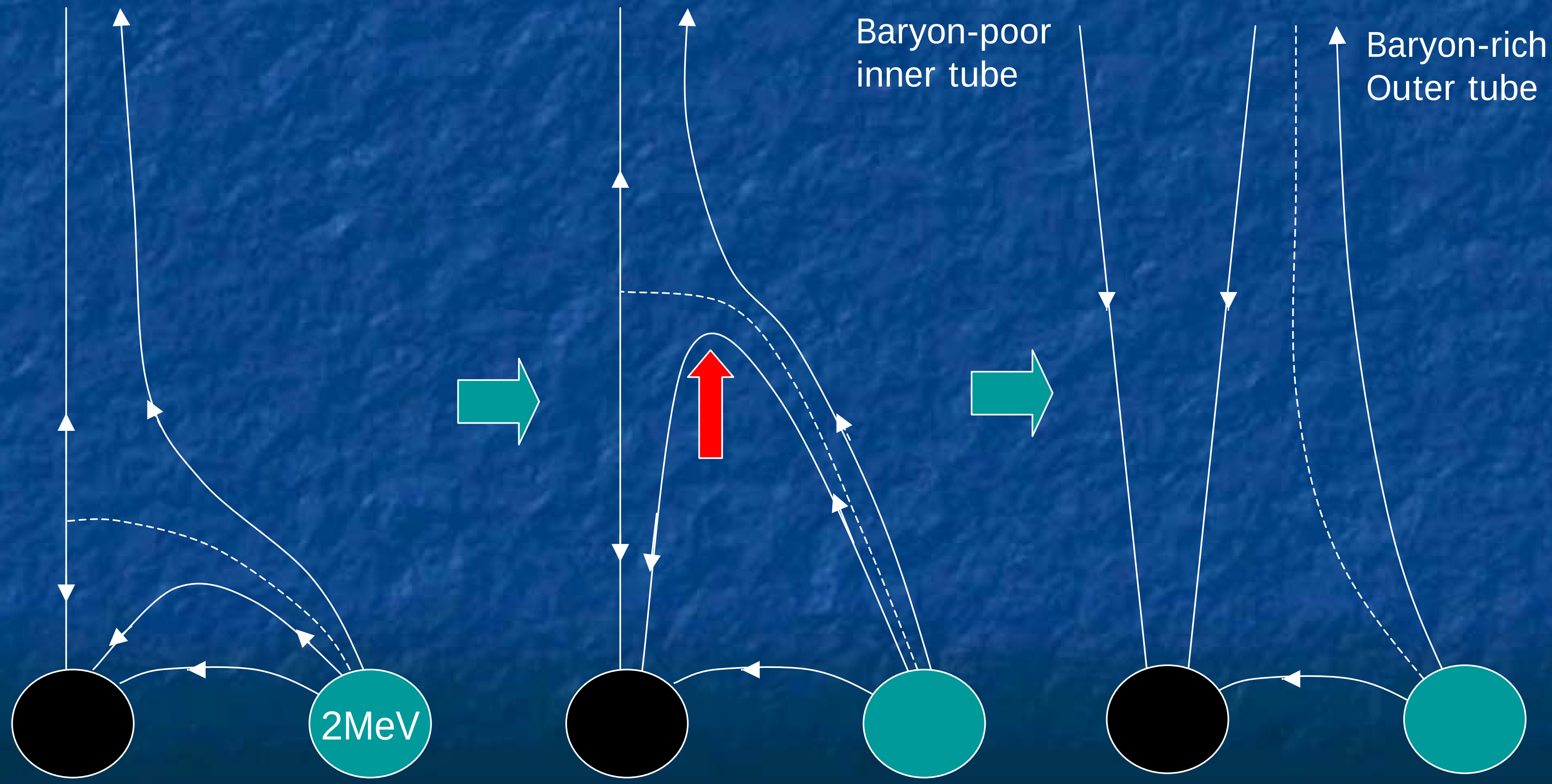
$$\eta = \Omega_T / \Omega_H \approx 0.1$$

$$\mu = M_T / M_H \approx 0.03$$

*Observed* : $\gamma_0 = \text{few} \times 10^4$

Van Putten & Levinson ApJ 2003

# Creation of open magnetic flux-tubes



# Energy in baryon-poor outflows

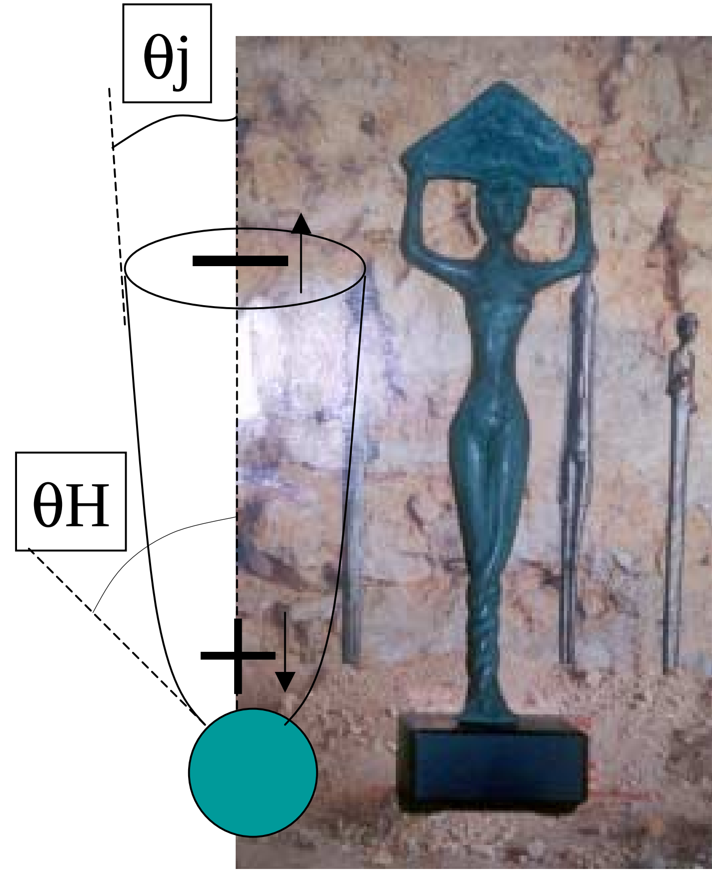
Outflow along rotation axis

$$E_j = T_{90}\Omega_H^2 A_\varphi^2$$

$$A_\varphi = BM_H^2\theta_H^2$$

Poloidal curvature of flux-surfaces

$$\theta_H \cong 10^\circ (6M_H / R)$$




Van Putten ApJ 2003

Van Putten & Levinson APJ 2003

# Small GRB-energies

Small parameter

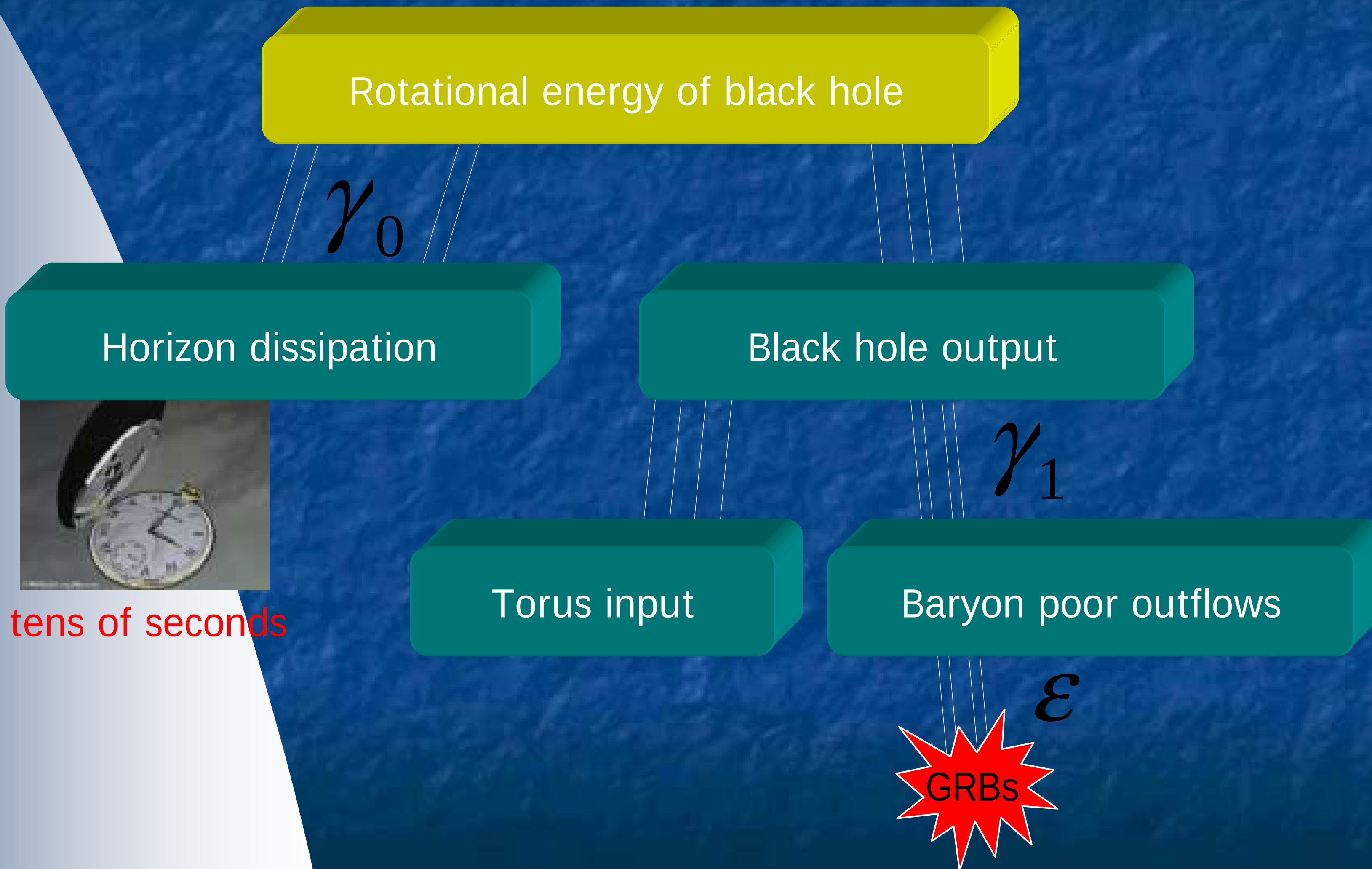
$$\gamma_1 = \frac{E_j}{E_{rot}} \cong 2\times10^{-4}\left(\eta/0.1\right)^{8/3}$$

$$Observed:\ \gamma_1 = \frac{E_\gamma \varepsilon^{-1}}{E_{rot}} = 5\times10^{-4}(\varepsilon/0.16)^{-1}$$

Van Putten ApJ 2003

Van Putten & Levinson APJ 2003

# T90 and GRB-energies



# Stability diagram of multipole mass-moments

$$\Omega(r) = \Omega_a \left(\frac{a}{r}\right)^q \quad \left(q \in [3/2, 2]\right)$$

$$q_c = \sqrt{3} \text{ as } b/a \sim 0$$

Papaloizou - Pringle (1984)

Goldreich et al. (1986)

*U*

*S*

Slenderness ->

Van Putten, 2002

# Gravitational Radiation in suspended accretion

Balance in angular momentum and energy transport for a torus around a black hole with a quadrupole mass moment

$$\tau_+ = \tau_- + \tau_{rad}$$

$$\Omega_+ \tau_+ = \Omega_- \tau_- + \Omega \tau_{rad} + P$$

with the constitutive ansatz for dissipation

$$P \approx A_r^2 (\Omega_+ - \Omega_-)^2$$

by turbulent MHD stresses, into thermal emissions and MeV-neutrino emissions

Van Putten, 2001

# Energy emissions from the torus

Asymptotic results for small slenderness

$$\gamma_2 = \frac{E_{gw}}{E_{rot}} \sim \eta \quad \gamma_3 = \frac{E_w}{E_{rot}} \sim \eta^2 \quad \gamma_4 = \frac{E_{diss}}{E_{rot}} \sim \delta\eta$$

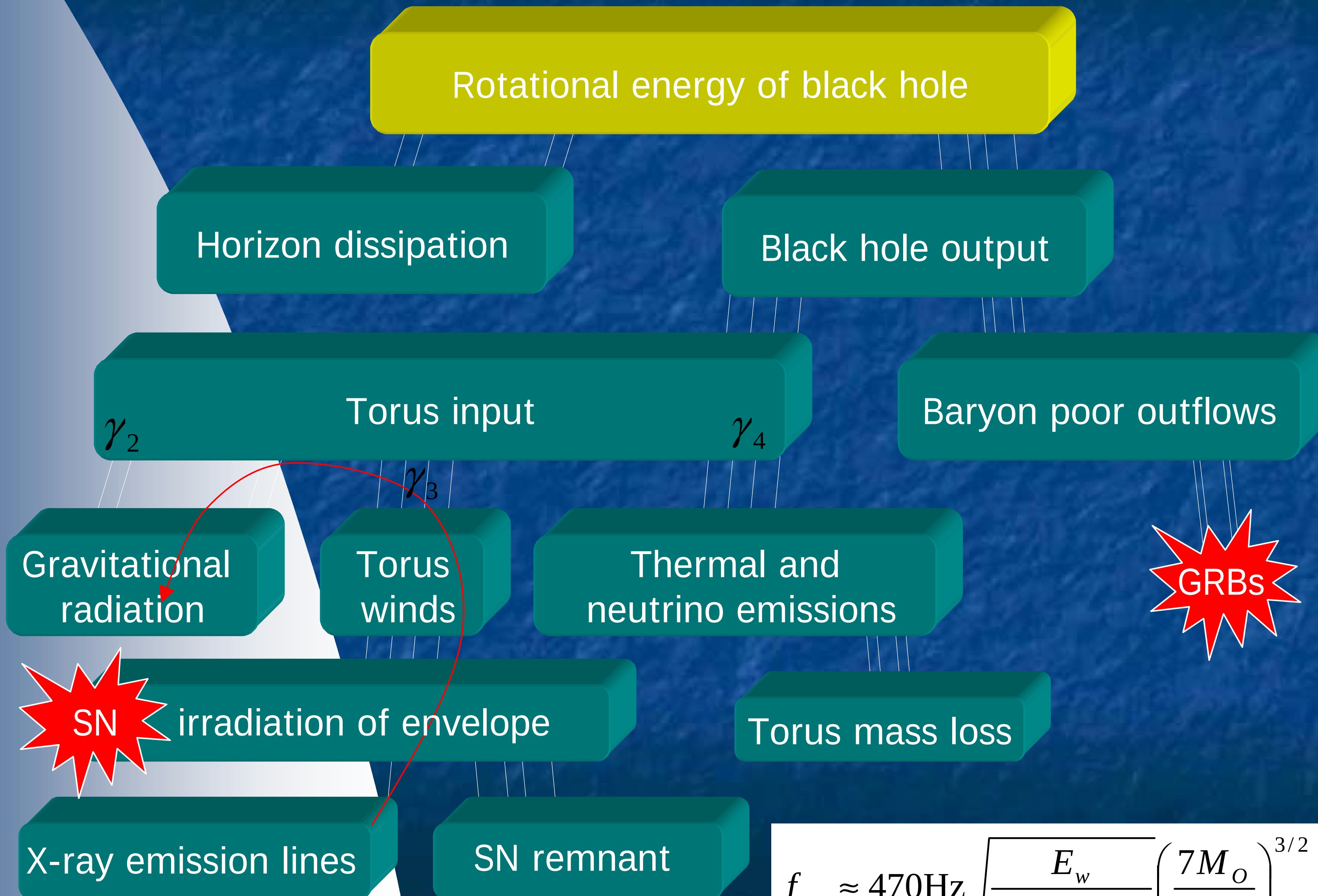
In practical terms…

$$E_{GW} = 4\times 10^{53}\ \mathrm{erg}\left(\frac{M_H}{7M_S}\right)$$

$$= 200\%\, M_T \times \left(\frac{M_T}{0.1M_S}\right)$$

Gravitational radiation by catalytic conversion of spin-energy

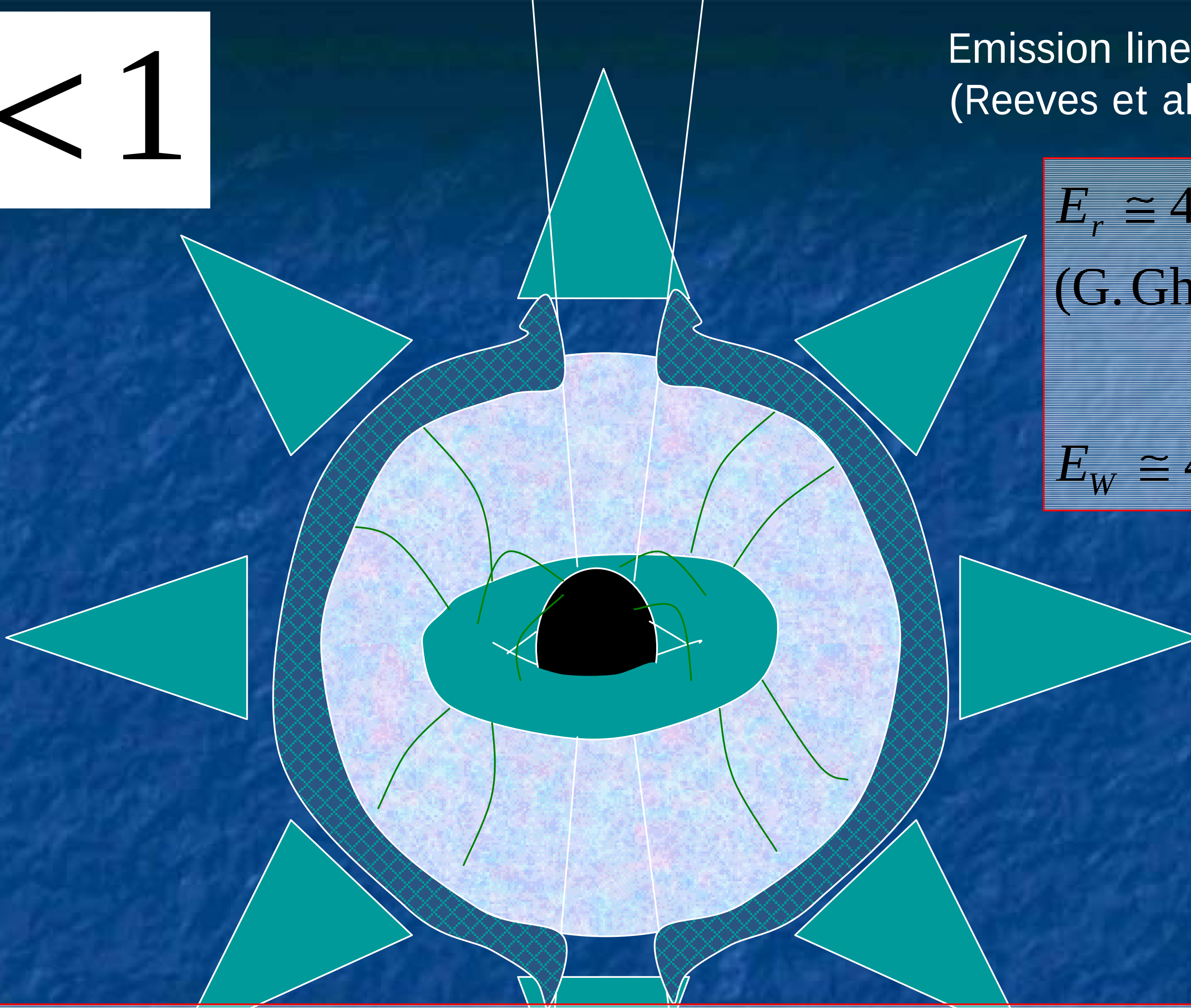
# Calorimetry




$$f_{gw} \approx 470\text{Hz}\sqrt{\frac{E_w}{4\times10^{52}\,\text{erg}}}\left(\frac{7M_O}{M}\right)^{3/2} \quad (m=2)$$

$$\tau < 1$$

Emission lines in GRB 011211
(Reeves et al., 2002)



$$E_r \simeq 4\times10^{52}\ \mathrm{erg}$$

(G. Ghisillini, 2002)

$$\Downarrow$$

$$E_W \simeq 4\times10^{52}\ \mathrm{erg}$$

$$f_{GW} \simeq 470\mathrm{Hz}\left(\frac{7M_S}{M}\right)^{3/2} = 180\text{-}1200\mathrm{Hz}\ (M = 4-14M_S)$$

Van Putten, ApJ, 2003

# Observational opportunities in astronomy

- Calorimetry on SNRs of GRB-remnants: constrain wind energies and frequency in gws
- Morphology of GRB-remants: black hole in a binary with optical companion surrounded by SNR

RX J050736-6847.8

Chu, Kim, Points et al., ApJ, 2000

# Stochastic background radiation

$$f_{gw}(7M_S) = 470\text{Hz} \ \ \text{(line)}$$
$$f_{gw}(7M_S) = 1000\text{Hz} \ \ \text{(dashed)}$$
$$M_H = 4-14M_S \ \ \text{(upper)}$$
$$M_H = 5-8M_S \ \ \text{(lower)}$$

Coward, van Putten & Burman (2002)
Van Putten (2003), in preparation

$$\Omega_B(f) \cong 9\times 10^{-9}\left(\frac{E_{gw}(7M_S)}{4\times 10^{53}\text{erg}}\right)\left(\frac{f_{gw}(7M_S)}{470\text{Hz}}\right)^{-1} f_{\Omega_B}(x)/\| f_{\Omega_B}\|$$

$$f_{\Omega_B}(x) = x^{-2}\int_{7M_S/M_2x}^{7M_S/M_1x} y^{-3}D(y)dy, \quad x = f/f_{gw}(7M_S), \quad M_H = [M_1, M_2]$$

Van Putten (2003), in preparation

# Observational opportunities for LIGO

- Radiation from GRB-SNe, point sources:

$$\frac{S}{N}=8\times\left(\frac{S_h^{1/2}(500\mathrm{Hz})}{4\times10^{-24}}\right)^{-1}\left(\frac{E_{gw}(7M_S)}{4\times10^{53}\mathrm{erg}}\right)^{1/2}\left(\frac{470\mathrm{Hz}}{f_{gw}(7M_S)}\right)^{2}\left(\frac{M_H}{7M_S}\right)^{5/2}\left(\frac{140\mathrm{Mpc}}{d_L}\right)$$

$$\left\langle\frac{S}{N}\right\rangle=\begin{cases}18 & \text{averaged over } M_H=4-14\times M_S\\ 7 & \text{averaged over } M_H=5-8\times M_S\end{cases}$$

- Associated with SNe, test t0[gw-burst]=t0[SN]

- Radiation from GRB-SNe, stochastic background radiation:

$$\frac{S}{N}=\begin{cases}10 & (M_H=4-14M_S)\\ 2 & (M_H=5-8M_S)\end{cases}\times\left(\frac{S_h^{1/2}(500\mathrm{Hz})}{4\times10^{-24}}\right)^{-2}\left(\frac{E_0}{4\times10^{53}\mathrm{erg}}\right)\left(\frac{470\mathrm{Hz}}{f_{gw}(7M_S)}\right)^{11/2}\left(\frac{T}{\mathrm{year}}\right)^{1/2}$$

Van Putten (2003), in preparation

# A line-detection algorithm

$$h_i(t) = \varepsilon h_s(t) + \sigma n_i(t) \quad (i = 1, 2)$$

$$h_s(t) = a \sin(\omega t + \phi) + b \sin(1.5\omega t)$$

$$\rho(\lambda) = \int_0^T h_1(t) h_2(\lambda t) dt$$

$$\Sigma(\lambda) = M\left(\frac{< \rho^2(\lambda) >^{1/2}}{\sigma^2} - 1\right) = \frac{NM}{2}\left(\frac{\varepsilon}{\sigma}\right)^4 \times \begin{cases} 2 & (\lambda = 1) \\ 1/4 & (\lambda = 3/2) \end{cases}$$

Van Putten & van Putten, in prep

# Conclusions

- *Model:* GRB-SNe from rotating black holes in dimensionless gamma parameters as a function of normalized angular velocity eta, slenderness delta and mass mu of the surrounding torus
- Long durations (large gamma0~1e4) stem from lifetime black hole-spin, subject to the Van Putten-Levinson stability criterion for the torus.
- GRB-energies (small gamma1~1e-3) derive from a BPJ produced by the black hole, regulated by poloidal curvature in torus magnetosphere
- Gravitational radiation during the GRB-SNe event of energies of a few times 0.1MSolar (gamma2~0.1) at an expected nominal frequency around 470Hz
- Expect spectral closure density of about 1e-8 @100-300Hz

Observational opportunities for HF in Advanced LIGO with 3 detectors

GRB remnants: black hole-binaries in SNRs
Gravitational radiation in GRB-SNe (1/yr within D=100Mpc)
LIGO GRB-sensitivity range *presently*: 1Mpc@500Hz
Multiple lines in stochastic background radiation (1 yr obs LIGO-II)