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ORIGINS OF SHORT BURSTS

① MOST FAVOURED MODEL:
NS + NS OR NS + BH Coalescence
(BASICALLY THE SAME MODEL as a HYPERNOVA, though without ENVELOPE
(Paczynski 1985 & later: Piran 1989 etc.)

PROBLEMS:- in SOME SHORT BURSTS: late (~ 100 sec) spikes: hard to explain.
- WHY HARDER SPECTRA?

② ALTERNATIVE MODEL:
ACCRETION-INDUCED COLLAPSE OF RAPIDLY ROTATING WHITE DWARF
- USOV (1992, Nature 357, 452)
- Yi & Blackman (1998, Ap.J. Lett.)

Critique: - Fryer, Benz, Herant, Colgate, 1999, Ap.J. 516, 892)
BUT: STILL INTERESTING
(in fact it is: Gunn-OSTRIKER (1970) Ap.J. idea: "DO PULSARS MAKE SUPERNOVAE?")

E.P.J. v.d. Heuvel - 2 Febr. 2006 - GRB

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BASIC IDEA (USOV, 1992)

- MAKE A NS SPINNING with $P \simeq 1$ ms AND A LARGE $B_{dipole} \simeq 10^{15}$ G

$$E_{kin} = \frac{1}{2} I \Omega^2 = 5.10^{52} \left(\frac{\Omega}{10^4 s^{-1}}\right)^2 \text{ergs}$$

$I_{ns} \simeq 10^{45}$ g.cm² ; $P \simeq 0.6$ ms

$$L_{md} = 2.2 \times 10^{51} \left(\frac{B}{3.10^{15} G}\right)^2 \left(\frac{\Omega}{10^4 s^{-1}}\right)^4 \frac{\text{ergs}}{\text{s}}$$

magn. dipole Radiation

$$\Rightarrow \tau_{sd} = \frac{E_{kin}}{L_{md}} \simeq 20 \text{ seconds}$$
("Long" GRB)

[1970 Gunn-Ostriker: $B \simeq 5.10^{12}$ G $\Rightarrow \tau_{sd} \simeq$ 1 month (like a SN)]

- To make a SHORT GRB:
2nd ingredient: GW-emission

If $\Omega > \Omega_{crit}$ ($\simeq 10^4 s^{-1}$): Rapidly Rotating NS unstable to NON-AXIALLY SYMM-PULSATIONS (Chandra 1969).

$\Rightarrow$ Large GW-flux $\Rightarrow$ Rapid Spindown (e.g.: Bildsten refs.)

$$L_{GW} = \frac{32}{5} \frac{G \varepsilon^2 I^2 \Omega^6}{c^5} = 1.8 \times 10^{55} \varepsilon^2 \left(\frac{I}{10^{45}}\right)^2 \left(\frac{\Omega}{10^4 s^{-1}}\right)^6 \frac{\text{ergs}}{\text{s}}$$

If $\varepsilon \gtrsim 0.03 \Rightarrow L_{GW} \gtrsim 1.8 \times 10^{52}$ erg/s $\Rightarrow$ $\boxed{\tau_{sd} < 2 \text{ sec}}$

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IN ALL THESE CASES:

- γ-RAY EMISSION DUE TO THE BEAMED (enormously energetic) RELATIVISTIC e^{+-} pulsar wind in B-FIELD OR E-field

e.g.: (curvature rad. $\gamma \Rightarrow e^{+-} \Rightarrow \gamma \rightarrow e^+ - e^-$)

Yi & Blackman (1998):

- If $\Omega > \Omega_{crit} > \Omega_B \Rightarrow \tau_{sd\,GW} \leq 2$ sec

- If $\Omega_{crit} > \Omega > \Omega_B \Rightarrow \tau_{sd\,m.d.} \simeq 10-100^s$

(Ω_B is "critical" freq. for dynamo-generation of large B-field $\simeq 1$ ms (Duncan & Thompson 1995)

Q: ARE $\Omega \simeq 10^4\ s^{-1}$ & $B \simeq 10^{15}G$ reasonable?

$$P_{rot_{ns}} = P_{rot_{wd}} \left(\frac{R_{ns}}{R_{wd}}\right)^2 \simeq 10^{-6} P_{rot\,wd}$$

Observ.: "Polar" CVs: $P_{rot} = 30 - 1200^s \Rightarrow P_{ns} \lesssim 1$ ms easily - possible

B-fields "Polars" up to $\simeq 10^7 G$

If: Flux conservation $\Rightarrow B_{ns}$ up to $\sim 10^{13} G$

BUT: Dynamo action in ν-convective (diff.) Rotating Proto-NS: can generate B_{dipole} up to $> 10^{15} G$, and B_{toroid} to $\gtrsim 3.10^{17} G$

(Duncan & Thompson 1995)

(Flowers & Ruderman 1977)

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compon. of

USOV (1992): E-field // B:

$$E_{\parallel}^{max} \simeq 2\cdot10^{14}\left(\frac{B_s}{3\cdot10^{15}G}\right)\left(\frac{\Omega}{10^4\ s^{-1}}\right)^{5/2} \text{ e.s.u.}$$

This can be $> E_{crit} = \frac{m^2c^3}{e\hbar} = 4.41\times10^{13}$ e.s.u.

$\Downarrow$

Vacuum breaks down $\Rightarrow$ direct creation of $(e^+ + e^-)$ pairs

So: $E \rightarrow (e^+ + e^-) + E$

In addition: "normal" pulsar pair creation:

$$\gamma_{curv\,rad} + B \rightarrow (e^+ + e^-) + B$$

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WHICH OBJECTS CAN MAKE AIC ?

FAVOURED: ▬ ACCRETING O-Ne-Mg WDs
⇓
go to e-capture collapse
(Nomoto c.s. 1979; Miyaji, Nomoto et al. 1980)

Needed Accr. rate $\gtrsim 10^{-7} M_\odot/yr$

▬ Massive CO-WDs at high accr. Rates may also do it.

POSSIBLE PROGEN. SYSTEMS:

Super-soft X-ray source
Form. Rate? $\approx 10^{-3} - 10^{-4}$/yr/gal
but: mostly CO; O-NeMg rare

DOUBLE WDS:

- CO + CO merger $\Rightarrow \dot{M}_{CO} \gtrsim 10^{-7} M_\odot/yr$

or

[He  + CO]

Saio & Nomoto (1985, 2004): ApJ.
C burns gently towards center $\Rightarrow$ O-Ne-Mg-wd ($\sim 10^3$ yr)
⇓
collapse ⇒ NS

Rate? May be as high as 10^{-3}/yr/galaxy.

- CO + O-Ne-Mg
- O-Ne-Mg + O-Ne-Mg

} much Rarer

ALL will probably Rotate fast enough & B can be generated from a seed-field by α-dynamo.

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CRITIQUE (Fryer et al. 1999):

Their CO-WD AIC ⇒ $0.1 M_\odot$ ejected (due to ν heating which revived the shockfr. → explosion)

As a result: much ang. mom. ejected
⇓
slow spin

+ FOR GRB: BARYON-Load $\lesssim 10^{-5} M_\odot$ needed
⇓
required beaming factor $\lesssim 10^{-4}$

with GRB-rate of 10^{-7}/yr/galaxy
⇓
requires AIC rate 10^{-3}/yr/gal.

much too large to fit observed element-abundance distrib. in galaxy.

BUT: Suppose ν-heating is not cause of Supernova-ejection ⇒ { perhaps very little mass ejected in AIC

∴ It still seems an attractive alternative:

① - Energetics & timescales are in the right range for GRBs

Requirement: Very little mass ejection in AIC

② The sketched mechanisms producing $\approx 10^{51-52}$ ergs in short time must occur in Nature