Growth of a Susy Bubble in Dense Matter

(Physics at the high density frontier)

Susy 2005

Durham, July 2005

- It is not clear whether the standard model has within it an adequate energy release mechanism to explain supernovae and gamma ray bursts.
- Does susy have a role to play here?
- The matter densities prevailing in white dwarf and neutron stars are millions of times greater than obtainable in bulk matter on earth.

L Clavelli, U Alabama

Characteristics of Gamma Ray Bursts

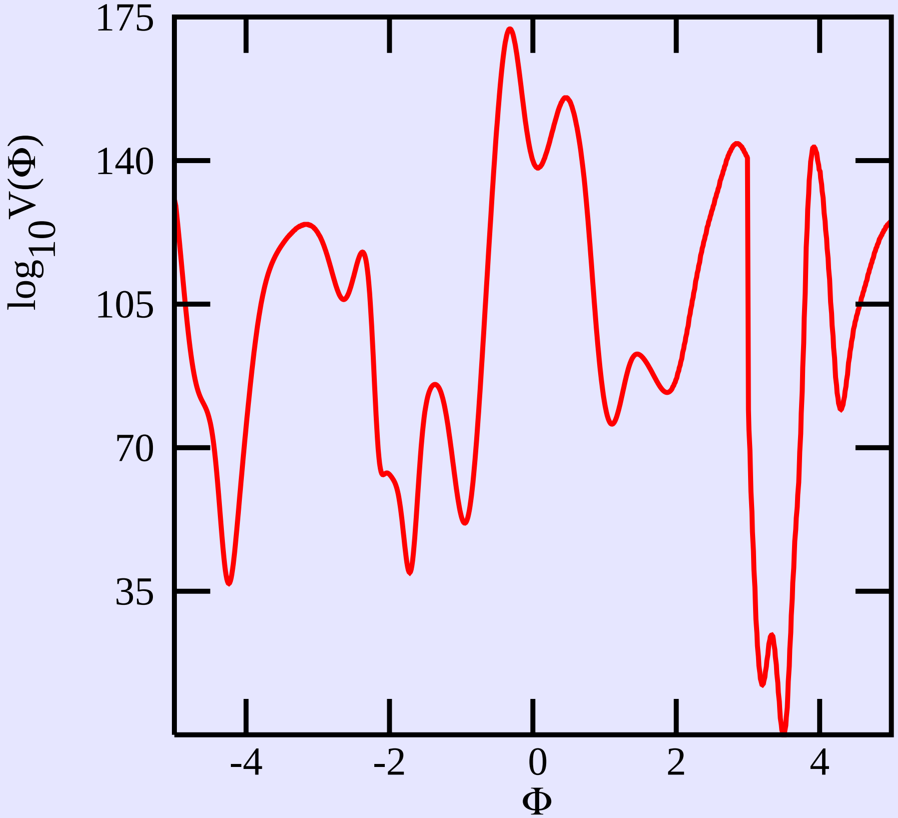
- dominent photon energies:
  ≈ 100 KeV to 1 MeV

- total energy in burst: $\approx 5 \cdot 10^{50}$ ergs
  assuming 5° jet opening angle
  (earth rest energy $= 6 \cdot 10^{48}$ ergs)
  (sun rest energy $= 2 \cdot 10^{54}$ ergs)

- total duration:
  $0.02s < \tau < 2s$ (short duration bursts)
  $2s < \tau < 300s$ (long duration bursts)

- burst rate:
  $\frac{dN}{dt} \approx 5 \cdot 10^{-7} yr^{-1} gal^{-1}$
  (but much less in our galactic neighborhood)

String Landscape

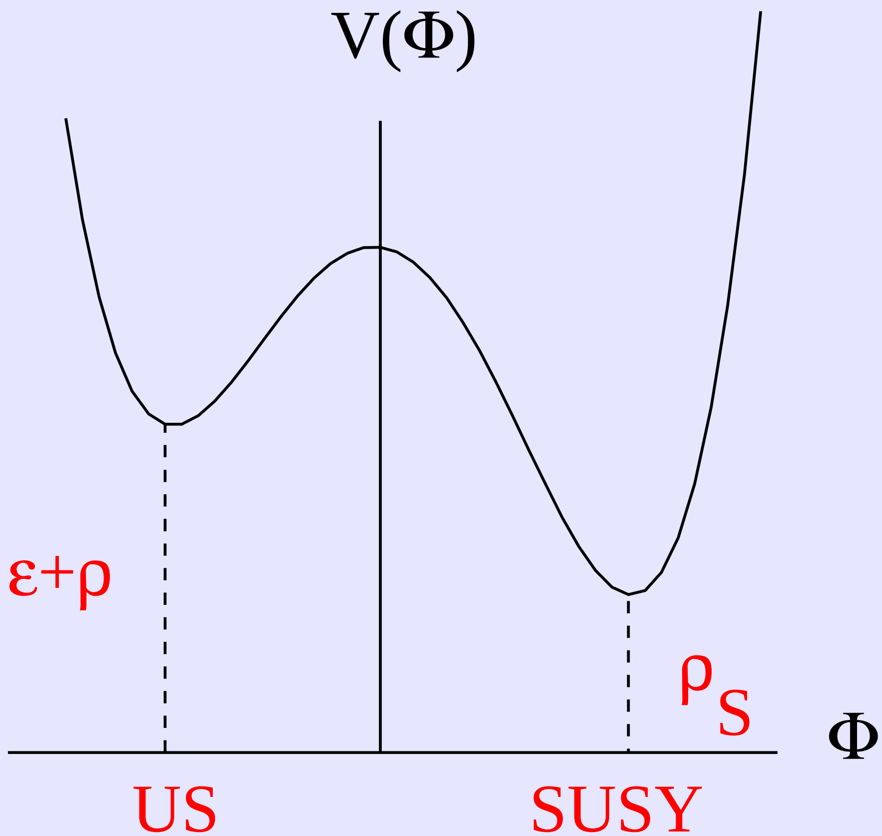


vacuum energy density: $\epsilon = 3560$ **MeV/m**$^3 = (0.0023$ **eV**$)^4$

Planck density: $M_{Pl}^4 = 10^{127}$ **MeV/m**$^3 = (1.66 \cdot 10^{28}$ **eV**$)^4$

Effective potential

in dense media



We live in a broken susy phase with positive vacuum energy while the basic string theories predict an exact susy ground state with vanishing vacuum energy

Gamma Rays from a Susy Star

In our broken susy world, the Pauli principle functions as an enormous energy storage mechanism.

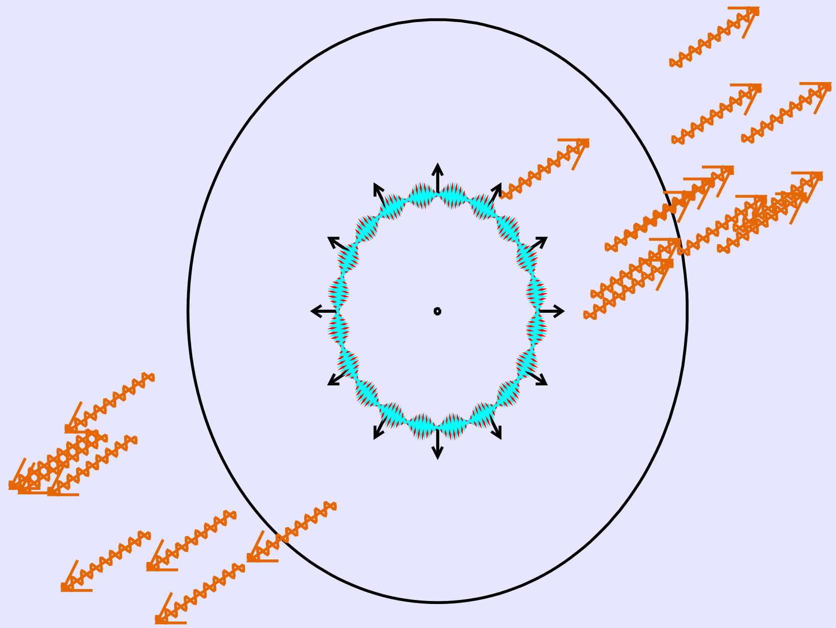
A phase transition to exact susy would allow the recapture of this energy.

Proposed Model for Gamma Ray Bursts

LC+G. Karatheodoris, hep-ph/0403227

LC + I. Perevalova, Phys Rev D, March 05

1. A compact star with a high level of fermion degeneracy (white dwarf or neutron star)
   makes a phase transition to a state of exact Supersymmetry.
2. Electron pairs undergo quasi elastic scattering to selectron pairs via photino exchange. $ee \longrightarrow \tilde{e}\tilde{e}$
3. Uninhibited by the Pauli principle, the selectrons fall into the ground state emitting photons which can penetrate into the broken-SUSY world.
4. Jet structure is aided by stimulated emission of sfermions and gammas.
5. With no further support from electron degeneracy, the star collapses below the Schwarzschild radius and becomes a black hole.



a resonant cavity of susy particles
slowly growing to engulf the star
emitting gamma rays which are light in both phases

broken susy phase with positive vacuum energy density: $\epsilon = 3560 MeV/m^3$

effective potential for susy bubble in vacuo: $V(vac) = -4\pi(r^3\epsilon/3 - r^2 S)$

$$R_c(vac) = \frac{3S}{\epsilon}$$

$$transition\ prob: \qquad \frac{d^2P}{dt d^3r} = Ae^{-B(vac)}$$

Exact Susy: the physics of the future

$$B(vac) = \frac{\pi^2}{6} R_c^4 \epsilon = \frac{27\pi^2 S^4}{2\epsilon^3}$$

$$R_c(vac) > R_{galaxy} \approx 4.7 \cdot 10^{20} \text{ m}$$

$$S > 5.6 \cdot 10^{23} MeV/m^2 = 2 \cdot 10^{-23} M_\circ R_E^{-2} = (0.28 MeV)^3$$

in dense matter (plausibly): $\epsilon \rightarrow \epsilon + \rho - \rho_S = \epsilon + \Delta\rho$

$$B = \frac{27\pi^2 S^4}{2(\epsilon + \Delta\rho)^3}$$

$$p_F = \left(\frac{3\pi^2 N}{V}\right)^{1/3}$$

$$N/V = \frac{\rho}{2M_N}$$

$$< E > -m = m\left(-1 + {}_2F_1(-1/2, 3/2; 5/2; -p_F^2/m^2)\right)$$

limit of zero electron mass: $< E >= \frac{3p_F}{4}$

$$\Delta\rho = \frac{3p_F N}{4V} = \frac{1}{4\pi^2}\left(\frac{3\pi^2\rho}{2M_N}\right)^{4/3}$$

transition probability : $\frac{d^2P}{dtd^3r} = Ae^{-B}$

$$B = \left(\frac{\tilde{\rho}}{\rho}\right)^4$$

$$\tilde{\rho} = \left(\frac{8}{3\pi^6}\right)^{1/4} SM_N$$

The longevity of the universe implies

$$\tilde{\rho} > 0.140 M_{\circ} R_E^{-3} = (1.5 MeV)^4$$

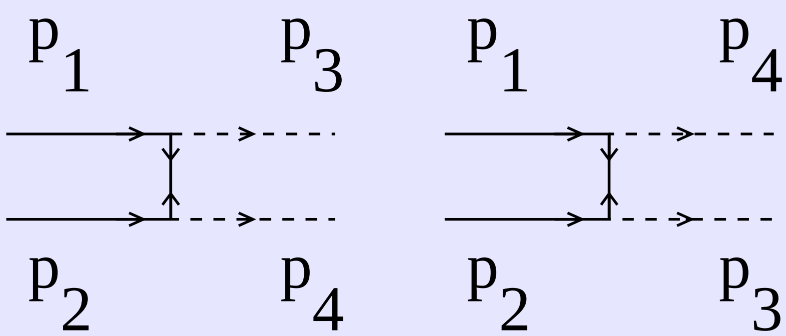
not far from the average density of the prototype white dwarf:

$$\rho_{WD} = \frac{3}{4\pi} M_{\circ} R_E^{-3}$$

transition rate: $\frac{1}{N}\frac{dN}{dt} = AVe^{-(\tilde{\rho}/\rho)^4}$

	M	V	ρ	$Ve^{-(\tilde{\rho}/\rho)^4}$
Cluster core	10^{14}	$4 \cdot 10^{44}$	$2.5 \cdot 10^{-31}$	$e^{-10^{119}}$
Sun	1	$4 \cdot 10^{6}$	$2.5 \cdot 10^{-7}$	$e^{-10^{23}}$
Earth	10^{-6}	4	$2.5 \cdot 10^{-7}$	$e^{-10^{23}}$
White Dwarf	1	4	$.25$	3.7
Neutron Star	1	$0.8 \cdot 10^{-9}$	$1.2 \cdot 10^{9}$	$0.8 \cdot 10^{-9}$
U^{238} Nucleus	$2 \cdot 10^{-55}$	$0.8 \cdot 10^{-63}$	$2.5 \cdot 10^{8}$	$0.8 \cdot 10^{-63}$

Masses, volumes, mean densities, and relative transition rates for $\tilde{\rho} = 0.14$



(a) (b)

$$e^- e^- \longrightarrow \tilde{e}^- \tilde{e}^-$$

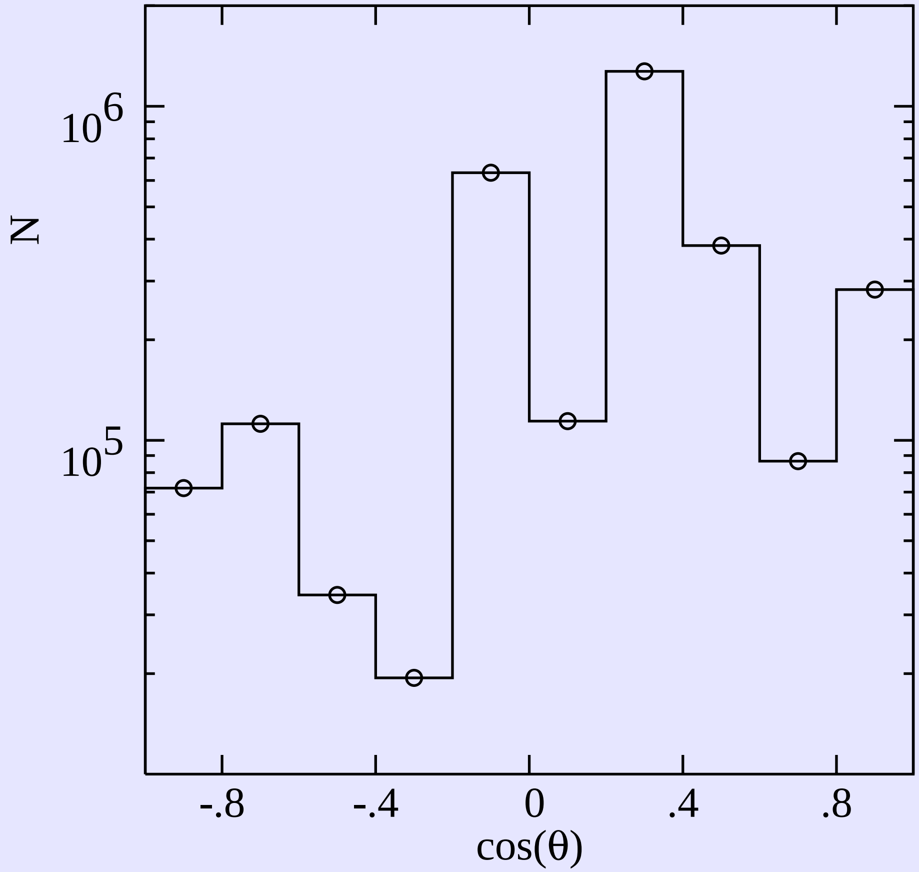
electron to selectron pair conversion via photino exchange

LC and I. Perevalova, Phys Rev D, March 05

also for quarks: $qq \longrightarrow \tilde{q}\tilde{q}$ and nucleons: $NN \longrightarrow \tilde{N}\tilde{N}$

Four types of susy nucleons :

$N_0 = qqq \quad , \quad N_1 = qq\tilde{q} \quad , \quad N_2 = q\tilde{q}\tilde{q} \quad , \quad N_3 = \tilde{q}\tilde{q}\tilde{q}$



$$e^- e^- \longrightarrow \tilde{e}^- \tilde{e}^-$$

angular distribution of final state selectrons after 2 million events including effect of Bose enhancement

$$\mathrm{l}ocal\ Fermi\ momentum: \qquad p_F(r) = \left(\frac{3\pi^2\rho(r)}{2m_N}\right)^{1/3}$$

The momentum distribution in the electron sea is no longer simply quadratic

$$\frac{dN}{dp} = \frac{4p^2}{\pi}\int_0^R r^2 dr\theta(p_F(r) - p)$$

$$p_{max} = p_F(0) = \left(\frac{3\pi^2\rho(0)}{2M_N}\right)^{1/3}$$

n	M ($M_\circ$)	R (R_E)	ρ_0 ($\frac{M_\circ}{R_E^3}$)	$\overline{\rho}$ ($\frac{M_\circ}{R_E^3}$)	$\overline{E}$ (MeV)	E_{tot} (ergs)
1	0.271	1.9518	0.056	0.009	0.013	$3.5 \cdot 10^{48}$
2	0.512	1.4499	0.297	0.040	0.034	$1.7 \cdot 10^{49}$
3	0.811	1.0505	1.572	0.167	0.078	$6.1 \cdot 10^{49}$
4	1.072	0.7376	8.321	0.637	0.158	$1.7 \cdot 10^{50}$
5	1.242	0.5002	44.053	2.366	0.291	$3.5 \cdot 10^{50}$
6	1.330	0.3269	233.238	9.077	0.510	$6.6 \cdot 10^{50}$
7	1.369	0.2062	1234.875	37.212	0.877	$1.2 \cdot 10^{51}$

physical effects influencing the burst duration:

1. **The bubble growth time.**

2. **The light crossing time.**

3. **The free collapse time.**

4. **Radiation pressure.**

bubble growth time assumed to be governed approximately by the speed of sound in dense matter.

$$v_s(r) = \sqrt{\frac{3P}{\rho}}$$

In a gravitationally bound medium of constant density $v_s(r) = \sqrt{\frac{2}{3}\gamma\pi G_N \rho (R^2 - r^2)}$

γ is the ratio of specific heats ($5/3$ for a monatomic gas), and R is the stellar surface radius at which the pressure vanishes.

bubble growth time for constant density: $\tau = \int_0^R dr/v_s(r) = \frac{\pi R}{2 v_s(0)}$

$$\frac{1}{N}\frac{dN}{dt} = 4\pi A \int_0^R r^2 dr e^{-(\frac{\tilde{\rho}}{\rho(r)})^4}$$

classical free collapse time after relief of Pauli blocking:

$$\tau_c = \frac{\pi}{2}\left(\frac{8\pi G_N \rho}{3}\right)^{-1/2} \approx 1.5s\left(\frac{\rho}{\rho_{WD}}\right)^{-1/2}$$

near Schwarzschild radius, GR effects dilate collapse time as seen by a distant observer:

$$\text{Schwarzschild radius :} \qquad r^* = \frac{2G_N M}{c^2}$$

$$r - r^* = (r_0 - r^*)e^{-(t-t_0)c/r^*}$$

$$E = E_{em}\frac{e^{-(t-t_0)c/2r^*}}{\sqrt{(1 + e^{-(t-t_0)c/r^*})}}$$

$$\frac{dN}{dt} = N(M)4\pi A \int_0^R r^2 dr e^{-(\tilde{\rho}/\rho(r))^4}$$

$$\text{bubble } growth\ time: \qquad \tau_0 = \int_0^R dr/v_s(r)$$

$\overline{\tau}$ = bubble growth time assuming constant (average) density

τ_c = classical free collapse time

n	M ($M_\circ$)	R (R_E)	τ_0 (s)	$\overline{\tau}$ (s)	τ_c (s)	E_{tot} (ergs)	$\frac{1}{A}\frac{dN}{dt}$ $\tilde{\rho} = 0.14$	$\tilde{\rho} = 0.7$	$\tilde{\rho} = 3.5$
1	.271	1.92	1.42	12.3	7.82	$3.5 \cdot 10^{48}$	10^{-11}	0	0
2	.512	1.44	0.69	5.80	3.70	$1.7 \cdot 10^{49}$	$\underline{18}$	10^{-7}	$4 \cdot 10^{-44}$
3	.811	1.05	0.35	2.86	1.82	$6.1 \cdot 10^{49}$	0.78	12	$7.9 \cdot 10^{-8}$
4	1.07	.737	0.18	1.47	0.93	$1.7 \cdot 10^{50}$	0.46	$\underline{20}$	31
5	1.24	.500	.095	0.76	0.49	$3.5 \cdot 10^{50}$	0.19	11	$\underline{44}$
6	1.33	.327	.049	0.39	0.25	$6.6 \cdot 10^{50}$	0.062	4.4	24
7	1.37	.206	0.024	0.19	0.12	$1.2 \cdot 10^{51}$	0.017	1.4	9.2

summary

The susy star model of gamma ray bursts provides a new framework in which to discuss violent astrophysical events

conceptual advantages:
1.) Connection to vacuum decay and string landscape
2.) Adequate explosive energy release
3.) jet seeding mechanism through Bose enhancement
4.) possible solution to the baryon loading problem

zeroth order quantitative predictions:
1.) roughly correct mean photon energy
2.) roughly correct total energy release
3.) roughly correct burst duration

taking density inhomogeneity into account, the averge photon energy from a susy phase transition is several times greater than that assuming constant density.

still to be understood:
1.) spikey behavior of bursts
2.) relation to supernovae
3.) bi-modal duration distribution
4.) identifiable bursts seem to be clumped at red-shift $z \approx 1$