Daemon Decay and Cosmic Inflation

Emil M. Prodanov

Dublin Institute of Technology

Emil M. Prodanov, *Daemon Decay and Inflation*, Physics Letters **B** 681, 214-219 (2009) arXiv:0910.1769 [hep-th]

Emil M. Prodanov, Rossen I. Ivanov, and V.G. Gueorguiev, *Equation of State for a van der Waals Universe during Reissner-Nordström Expansion*, JHEP 0806:060 (2008) arXiv:0806.0076 [hep-th]

Emil M. Prodanov, Rossen I. Ivanov, and V.G. Gueorguiev, *Reissner-Nordström Expansion*, Astroparticle Physics **27**,150-154 (2007) hep-th/0703005

DAEMONS – Dark Electric Matter Objects (*Drobyshevsky et al., Ioffe Physical-Technical Institute, Russian Academy of Sciences*)

Mon. Not. R. astr. Soc. (1971) **152,** 75–78.

GRAVITATIONALLY COLLAPSED OBJECTS OF VERY LOW MASS

Stephen Hawking

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SUMMARY

It is suggested that there may be a large number of gravitationally collapsed objects of mass 10^{-5} g upwards which were formed as a result of fluctuations in the early Universe. They could carry an electric charge of up to ± 30 electron units. Such objects would produce distinctive tracks in bubble chambers and could form atoms with orbiting electrons or protons. A mass of 10^{17} g of such objects could have accumulated at the centre of a star like the Sun.

Hawking's arguments:

Since gravitational collapse is essentially a classical process, it is probable that black holes could not form with radii less than the Plank length $(Ghc^{-3})^{1/2} \sim 10^{-33}$ cm, the length at which quantum fluctuations of the metric are expected to be of order unity. A Schwarzschild radius of this length would correspond to a mass of about 10^{-5} g. For lengths larger than 10^{-33} cm it should be good approximation to ignore quantum gravitational effects and treat the metric classically. One might therefore expect collapsed objects to exist with masses from 10^{-5} g upwards.

It might be thought that a collapsed object could not form unless its Schwarzschild radius were greater than the Compton wavelength h/cm of one of the elementary particles which went to form it. This would imply a minimum mass for a collapsed object of about 10^{14} g. However, this does not seem a valid argument since the Compton wavelengths of the photon and other zero rest-mass particles are infinite, yet a sufficient concentration of electromagnetic radiation can cause gravitational collapse. The relevant wavelength to compare with the Schwarzschild radius is not the wavelength at rest but hc/E where E is the typical energy of a particle. This will be much greater than mc^2 as the particles will be ultra-relativistic.

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Charged Dark Matter

A. De Rújula*, S.L. Glashow† and Uri Sarid†

*) *Theory Division, CERN, CH-1211 Genève 23, Switzerland*

†) *Lyman Laboratory of Physics, Harvard University, Cambridge, MA 02138*

We propose that dark matter is made of CHAMPs, charged massive particles that survive annihilation in the early Universe. We constrain champs to be matter-antimatter symmetric, to provide critical mass density, and to constitute the non-baryonic halo of galaxies such as ours. We show that the window of allowed champ mass extends from 20 to 1000 TeV. Champs of charge +1 should now appear as super-heavy isotopes of Hydrogen. While some of their antiparticles could bind to ^{4}He nuclei somewhat after primordial nucleosynthesis (also to appear today in the disguise of super-heavy Hydrogen), we argue that negative champs overwhelmingly bind to protons to pose as super-heavy stable neutrons. *En route* to detectors, these bound champs suffer nuclear reactions that change their ultimate appearance. By the time they come to rest, negative champs have recombined with larger nuclei to form various super-heavy isotopes. We discuss how and where to search for relic champs.

To have avoided detection, champs must be very massive. Under earthly conditions, charged champs would be — or would be bound to — atomic nuclei, depending on whether their charge is positive or negative. With one exception, champs disguise themselves as preposterously heavy isotopes of known chemical elements. Negative champs bound to protons, however, correspond to the missing zeroth entry in the Periodic Table.

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Cosmological Production of Superheavy Magnetic Monopoles

John P. Preskill
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02138
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Grand unified models of elementary particle interactions contain stable superheavy magnetic monopoles. The density of such monopoles in the early universe is estimated to be unacceptably large. Cosmological monopole production may be suppressed if the phase transition at the grand unification mass scale is strongly first order.

Tracing the evolution of such objects, a mechanism accounting for the cosmic inflation is proposed.

The inflation is followed by a period of reheating phases and has a graceful exit into a mechanism of expansion of a radiation-dominated Universe.

The inflation mechanism is based on the accumulative effects of Coulomb repulsion at very short range, initially completely "cocooned" by purely general-relativistic Reissner–Nordström gravitational effects of naked singularities and subsequently unleashed by quantum tunneling.

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Naked singularities, event horizons, and charged particles

Jeffrey M. Cohen
Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania 19174

Ronald Gautreau
Department of Physics, New Jersey Institute of Technology, Newark, New Jersey 07102
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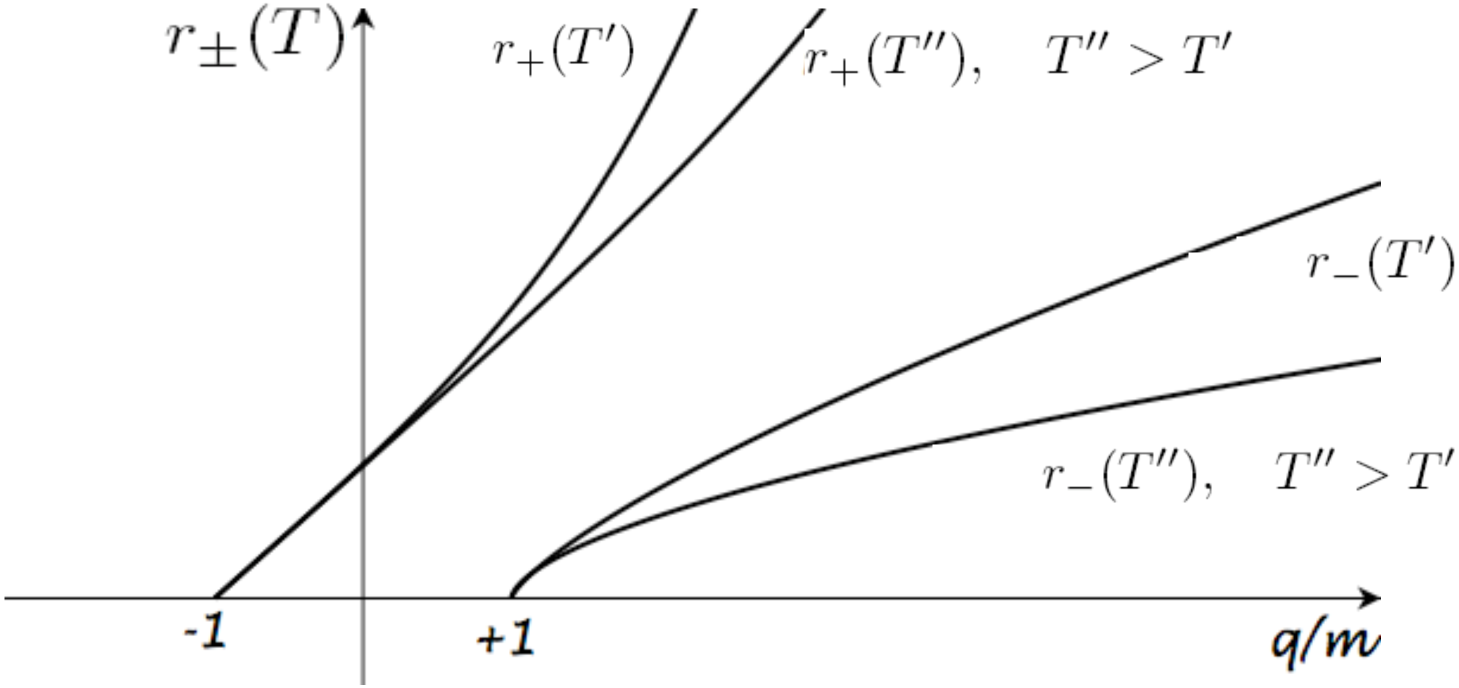
The motion of charged test particles in a Reissner-Nordström field is investigated. It is shown that naked singularities can be destroyed by shooting in suitably charged test particles to produce an event horizon around the source where none previously existed. It is also shown that existing event horizons cannot be destroyed by bombardment with charged test particles. In this manner existing naked singularities can be destroyed but not created while event horizons can be created but not destroyed. Furthermore, a simple explanation is given for radial test-particle oscillations—a phenomenon with no Newtonian analog.



The Kerr–Newman metric in Boyer–Lindquist coordinates and geometrized units is given by:

$$\begin{aligned} ds^2 &= -\frac{\Delta}{\rho^2}(dt - a\sin^2\theta\, d\phi)^2 + \frac{\sin^2\theta}{\rho^2}\left[a\, dt - (r^2 + a^2)d\phi\right]^2 \\ &\quad + \frac{\rho^2}{\Delta}dr^2 + \rho^2 d\theta^2 \end{aligned}$$

where:

$$\begin{aligned} \Delta &= r^2 - 2Mr + a^2 + Q^2 \\ \rho^2 &= r^2 + a^2\cos^2\theta \end{aligned}$$

The motion of a particle of mass m and charge q in gravitational and electromagnetic fields is governed by the Lagrangian:

$$L = \frac{1}{2}\, g_{ij} \frac{dx^i}{d\lambda} \frac{dx^j}{d\lambda} - \frac{q}{m} A_i \frac{dx^i}{d\lambda}$$

Where λ – proper time τ per unit mass m: $\lambda = \tau / m$, and A – the vector electromagnetic potential, determined by the charge Q and specific angular momentum a of the centre:

$$A_i dx^i = -\frac{Qr}{\rho^2}(dt - a \sin^2\theta \, d\phi)$$

The equations of motion for the particle are:

$$\rho^2 \frac{dt}{d\lambda} = -a^2 E \sin^2\theta + aJ + \frac{r^2+a^2}{\Delta}\left[E(r^2+a^2) - Ja - qQr\right]$$

$$\rho^2 \frac{dr}{d\lambda} = \pm\sqrt{\left[E(r^2+a^2) - Ja - qQr\right]^2 - \Delta\left[m^2 r^2 + (J-aE)^2 + K\right]}$$

$$\rho^2 \frac{d\theta}{d\lambda} = \pm\sqrt{K - \cos^2\theta\left[a^2(m^2-E^2) + \frac{1}{\sin^2\theta}J^2\right]}$$

$$\rho^2 \frac{d\phi}{d\lambda} = -aE + \frac{J}{\sin^2\theta} + \frac{a}{\Delta}\left[E(r^2+a^2) - Ja - qQr\right]$$

where:

$E = (1/m)\partial L/\partial\dot{t}$ – conserved energy of the particle

$J = (1/m)\partial L/\partial\dot{\phi}$ – conserved projection of the particle's angular momentum on the axis of the centre's rotation

K is another conserved quantity given by:

$$K = p_\theta^2 + \cos^2\theta\left[a^2(m^2 - E^2) + \frac{1}{\sin^2\theta}J^2\right]$$

with $p_\theta = (1/m)\partial L/\partial\dot{\theta}$ – the θ-component of the particle's four-momentum.

We consider the radial motion of a particle in Reissner–Nordström geometry with $|Q| > M$:

$$\dot{\theta} = 0 = \dot{\phi}$$

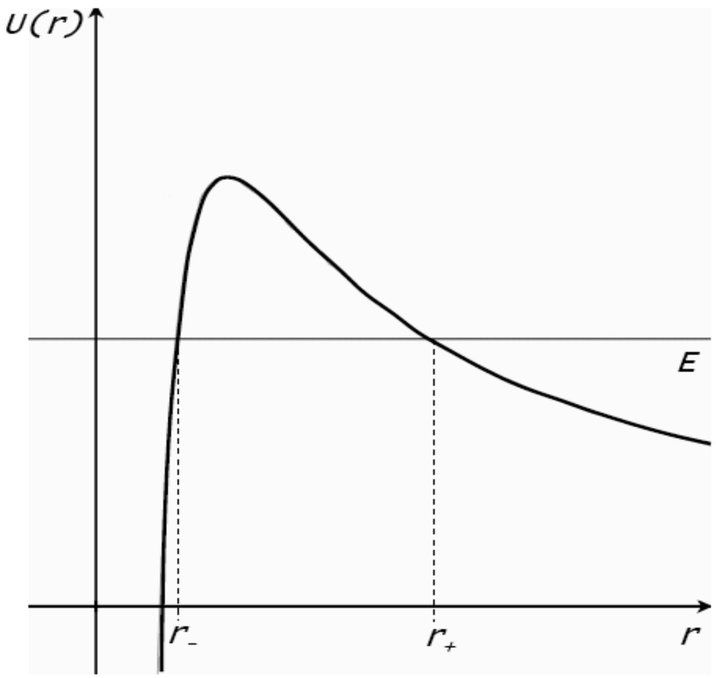
$$a = 0$$

The radial motion of an ultra-relativistic test particle of m and charge q in Reissner–Nordström geometry can be modeled by an effective one-dimensional motion of a particle in non-relativistic mechanics with the following equation of motion:

$$\frac{\dot{r}^2}{2} + U(r) = \frac{\epsilon^2 - 1}{2}$$

where $E = (\epsilon^2 - 1)/2$ is the specific energy of the effective one-dimensional motion, $\epsilon = kT/m + 1$ is the specific energy of the three-dimensional relativistic motion and the effective non-relativistic one-dimensional potential per unit mass is:

$$U(r) = \frac{1}{2}\left(1 - \frac{q^2}{m^2}\right)\frac{Q^2}{r^2} - \left(1 - \frac{q}{m}\frac{Q}{M}\epsilon\right)\frac{M}{r}$$



Motion is possible only if $\dot{r}^2$ – non-negative.

Thus the radial coordinate of the test particle must necessarily be outside the region $(r_-\,,\,r_+)$ where the turning radii are given by:

$$r_\pm = \frac{M}{\epsilon^2 - 1}\left[\epsilon\,\frac{q}{m}\,\frac{Q}{M} - 1 \pm \sqrt{\left(\epsilon\,\frac{q}{m}\,\frac{Q}{M} - 1\right)^2 - (1-\epsilon^2)\left(1 - \frac{q^2}{m^2}\right)\frac{Q^2}{M^2}}\,\right]$$

Trapped particles tunnel quantum-mechanically through the classically forbidden region between the two turning radii r_- and r_+

Schrödinger equation in the effective potential:

$$\frac{d^2\psi}{dr^2} + \left(\frac{A}{r^2} - \frac{B}{r}\right)\psi = -\frac{2mE}{\hbar^2}\psi(r)$$

where: $A = -mQ^2(1 - q^2/m^2)/\hbar^2 = \text{const} > 0$

$$B = -2mM[1 - (qQ\epsilon)/(mM)]/\hbar^2 > 0$$

Potential $-1/r^2$ in quantum mechanics is pathological – no bound states ($E < 0$) and no well-defined vacuum. We are interested in the continuum of scattering states ($E > 0$) only.

Following the analogy with the Gamow theory of alpha-decay, the Wentzel–Kramers–Brillouin (WKB) approximated wave function is:

$$\psi(r) \simeq \frac{D}{\sqrt{|p(r)|}}\, e^{\pm \frac{i}{\hbar} \int\limits_{r_-}^{r_+} |p(r)| dr}$$

where: $D = \mathrm{const}$ and $|p(r)| = \sqrt{2m[U(r) - E]}$

The amplitude of the transmitted wave, relative to the amplitude of the incident wave, is diminished by the factor $e^{2\gamma}$, where:

$$\gamma = \frac{1}{\hbar} \int\limits_{r_-}^{r_+} |p(r)| dr$$

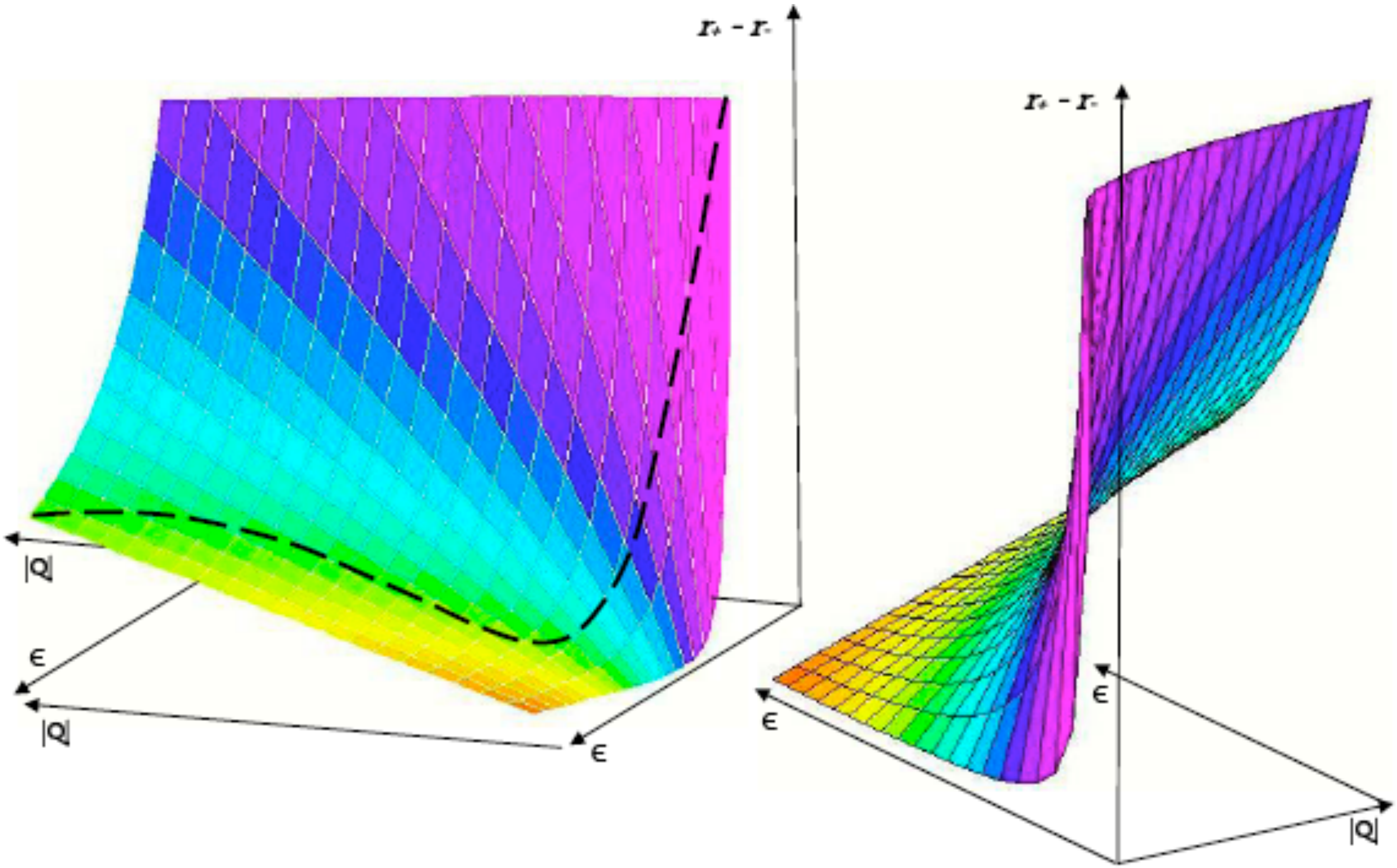
Upon integration:

$$\gamma = \frac{\pi}{\hbar}\sqrt{2mE}\left(\frac{r_- + r_+}{2} - \sqrt{r_- r_+}\right)$$

$$= -\frac{\pi}{\hbar}\sqrt{m}\,|Q|\sqrt{\frac{q^2}{m^2} - 1} + \frac{\pi}{\hbar}\sqrt{m}\,M\,\frac{\epsilon\,\frac{q}{m}\,\frac{Q}{M} - 1}{\sqrt{\epsilon^2 - 1}}$$

The tunneling probability P is proportional to the Gamow factor $e^{-2\gamma}$.

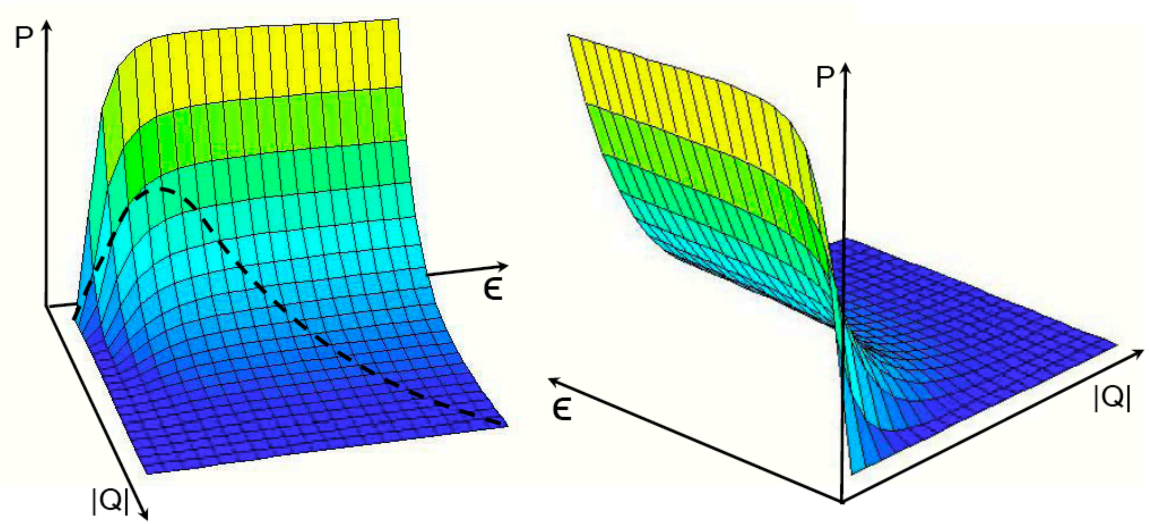
With the drop of the temperature (when ϵ starts falling from ∞ to 1) the inner turning radius $r_-(T)$ tends to a finite value, while the outer turning radius $r_+(T)$ tends to ∞. The width of the forbidden classical region, $\delta = r_+ - r_-$, also tends to ∞ in the limit $\epsilon \longrightarrow 1$.



As a function of $|Q|$ and ϵ , the width $\delta = r_+ - r_-$ of the classically forbidden region initially drops with the drop of the temperature and then rapidly increases to infinity.

In the very early Universe, at extremely high temperatures (regime $\epsilon \gg 1$), the two turning radii are approximated by $r_{\pm} = (qQ \pm m|Q|)/(kT)$ and γ is not temperature-sensitive:

$$\gamma|_{\epsilon\gg 1} = -\frac{\pi}{\hbar}\sqrt{m}\,|Q|\sqrt{\frac{q^2}{m^2}-1} + \frac{\pi}{\hbar}\frac{qQ}{\sqrt{m}} \sim -\frac{\pi}{\hbar}m^{3/2}|Q|/|q|$$



As a function of $|Q|$ and ϵ , the tunneling probability P initially increases rapidly and consequently falls off to zero.

The tunneling rate in alpha-decay is given by the Gamow factor multiplied by $v/2r$, where v is the particle's speed and r is the radius of the nucleus.

For an ejectile to be recaptured, it has to oscillate between two daemons charged identically. The rate of recapture is proportional to r_-/r_+ and diminishes very rapidly (as fast as the barrier widens). We neglect the process of recapture.

Over dimensionless time dt, the charge of the daemon will decrease by the amount $d|Q|$ which is proportional to $-Pdt$. Thus, in the very early Universe, $|Q(t)| \sim \ln\ (C - t)$ and $P(t) \sim 1/(C - t)$, where $C = \text{const}$.

In alpha-decay, the daughter nucleus recoils after the emission. The ejectile's kinetic energy E prior to the emission, is diminished by the recoil energy after the emission:

$$E_R = (m/M)E + 2(1 - m^2/M^2)E^2/M$$

where m and M are the masses of the ejectile and the daughter daemon, respectively.

If E_0 is the total kinetic energy of all particles inside the daemon, the k^{th} ejectile will have energy

$$E(t) = E_0 m/M - E_0/[(m/M)(m/M - k(t) + 1)]$$

where $k(t)$ is the number of particles emitted after dimensionless time t.

The charge inside a daemon decreases in time from its initial value Q_0 as $Q(t) = Q_0 - k(t)\, q$.

Thus $k(t) = Q_0/q - (1/q)\ln(C-t) \simeq M/m - (1/q)\ln(C-t)$

where $C = \text{const}$.

The energy of the outer fraction is therefore:

$$E(t) \simeq E_0(m/M)\{1 - 1/[1 + (1/q)\ln(C-t)]\}$$

The temperature drops at least as the square root of E

The outer turning radius r_+ (which is inversely proportional to the temperature) has an accelerated increase with time.

The scale factor of the Univrse, *a(t)* (which is proportional to the outer turning radius r_+) has an accelerated increase with time and <u>positive second derivative</u>. Thus we have power law <u>inflation</u>.

The <u>*graceful exit*</u> of the inflation occurs when the width of the barrier,

$$r_+ - r_- = 2m|Q|/(kT)$$

grows large enough so that quantum tunneling is naturally switched off.

This happens before daemons become fully depleted – when the temperature T drops sufficiently low and the second term in γ takes over:

$$\gamma = -\frac{\pi}{\hbar}\sqrt{m}\,|Q|\,\sqrt{\frac{q^2}{m^2}-1} + \frac{\pi}{\hbar}\sqrt{m}\,M\,\frac{\epsilon\,\frac{q}{m}\,\frac{Q}{M}-1}{\sqrt{\epsilon^2-1}}$$

As the probability for tunneling is brought down very rapidly towards 0 and particles are no longer ejected by the daemons, the medium outside the daemons is no longer cooled by the tunneling process.

Without quantum tunneling, the charges of the daemons remain practically constant.

However, the temperature of the outside fraction of the Universe continues to drop after the rapid accelerated expansion, as a different expansion mechanism (Reissner–Nordström expansion mechanism) has naturally taken over.

With constant charges of the daemons, the Universe continues to cool: $T \simeq t^{-1/2}$ and expand: $a \simeq t^{1/2}$

This is the start of the radiation-dominated epoch and also the beginning of a supercooling phase.

At the end of the inflation, the daemons are still much hotter than the outside fraction of the Universe.

A daemon will now cool not through quantum tunneling, but through interaction with the particles of oppositely charged daemons, which, in turn interact with the particles outside the original daemon. In view of the low densities, this does not happen as fast as the Universe expands. Eventually, the temperature of the daemons and the temperature of the "free" fraction of the Universe will equalize and, in result, the Universe will have reheated, but not enough to reignite the inflation.

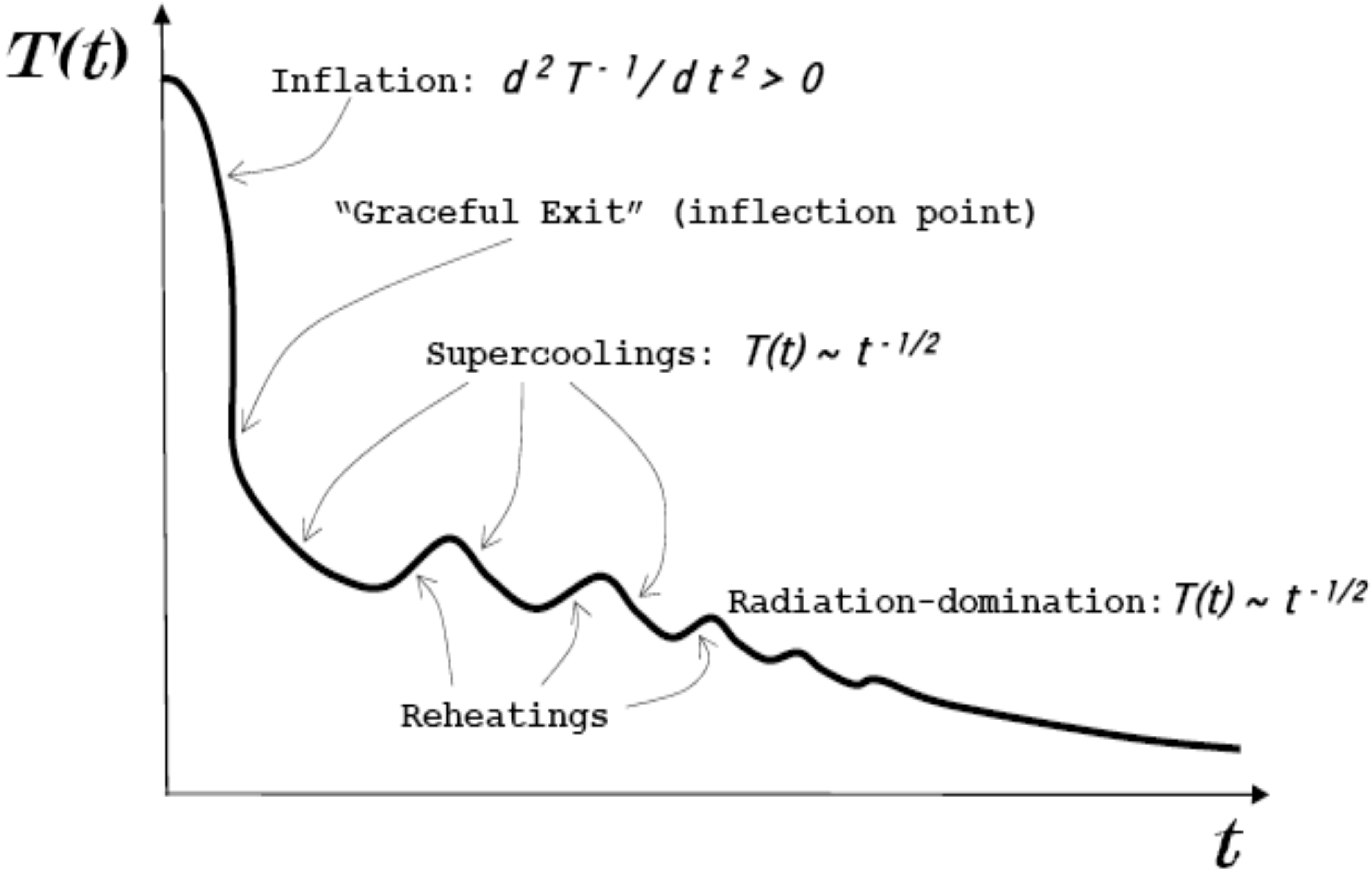
During the reheating, the scale factor $a(t)$ of the Universe does not decrease as there is no mechanism to draw particles, blown away by the growth of the daemons' outer radii, back towards the daemons.

The Universe then enters another supercooling phase followed by another reheating. This process is repeated until daemons cool down to the temperature of the surrounding fraction and cannot re-ignite futher reheatings.

After this, the temperature drop will simply follow

$$T \simeq t^{-1/2}$$

and the expansion will be at the rate of $\sqrt{t}$



T(t)
Inflation: d 2 T - 1 / d t 2 > 0
"Graceful Exit" (inflection point)
Supercoolings: T(t) ~ t - 1/2
Radiation-domination: T(t) ~ t - 1/2
Reheatings
t