has also been detected by sedimentation equilibrium studies[48,50]. and by small-angle X-ray scattering[51,52].

The negative cooperativity of NAD binding could be the result of a change in packing of parts of the protein chain, especially of the residues in the S-loop. In holo-GPDH this segment of 20 residues is devoid of secondary structure and most of its main chain is inaccessible to solvent. Expansion of the molecule in apo-GPDH opens this region and might make the S-loop more flexible. The following chemical evidence supports this. If muscle apo-GPDH is acylated, and then incubated at pH 8.5, the acyl group is transferred specifically from cysteine 149 to N^ε of lysine 183 (refs. 26, 27). (Residue 183 is arginine in the bacterial enzyme, but the position of the arginine side chain is the same as that of the lysine 183 in lobster GPDH.) In holo-GPDH this transfer does not happen because the N^ε is 10 Å from the sulphydryl of cysteine 149. The occurrence of the reaction in apo-GPDH only, is indicative of the greater flexibility of the S-loop.

The S-loop has many of the properties expected of a structure which transmits a structural change from one subunit to another in a cooperative system. It interacts with two adjacent subunits (including a direct coenzyme contact), it is shielded from solvent at least in holo-GPDH and lacks strong secondary and tertiary interactions. In addition, there is evidence that its structure in the apoenzyme is quite different from that in the holoenzyme.

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letters to nature

A better way of searching for black-hole explosions?

BLACK holes of $\lesssim 10^{15}$ g evaporate in $\sim 10^{10}$ yr, and eventually annihiliate into a burst of energetic photons and particles[1]. To test this theoretical prediction would be extraordinarily significant for quantum and gravitational physics. There could be $\sim 10^{23}$ 'miniholes' within our Galaxy[2–4]; on the other hand, there may not be any at all. But even if they exist in profusion, how best could we detect black-hole explosions? Attention has been focused on the problem of directly detecting the γ rays, but the prospects seem bleak[3]. The possibility that the particles ejected in the explosion may generate conspicuous effects has hitherto been overlooked. I argue here that collective interaction of electrons and positrons with an ambient interstellar magnetic field can (on some specific assumptions) generate radio bursts powerful enough to be detected from anywhere in our Galaxy, or even beyond. This opens up a more promising perspective on the search.

A conducting sphere, expanding into a uniform magnetic field, will develop surface currents which prevent the field from penetrating it. If the shell expands relativistically, with constant Lorentz factor $\gamma \gg 1$, out to a radius $r_{\max}$, then the work done against the field is

$$\sim \gamma^2 \times (\text{energy of swept-up field}) \tag{1}$$

(Note the factor γ^2, which occurs just as it would if the sphere were reflecting electromagnetic radiation.) A distant observer would see the part of the shell moving at angles $\lesssim \gamma^{-1}$ to the line of sight blue-shifted by $\sim \gamma$; he sees a surface current on this part of the shell increasing $\propto t^2$ for a time $\sim r_{\max}/c\gamma^2$. The energy (1) therefore appears as an electromagnetic pulse with characteristic wavelength

$$\lambda \simeq r_{\max}/\gamma^2 \tag{2}$$

We now investigate how this classical electromagnetic phenomenon might apply to the type of 'fireball' resulting from an exploding black hole.

Suppose that, when the mass of an evaporating minihole has fallen to M_{crit} g, it vomits forth its remaining energy in an essentially instantaneous burst of $\sim 10^{21}\ M_{crit}$ erg. In the Hagedorn theory, $M_{crit} \simeq 10^{14}$ g; but on other theories of elementary particles it would be lower. Very near the hole, the energy would be distributed between a variety of exotic species; but we assume that these quickly decay, and that, by the time the ejecta have expanded to macroscopic radii, a substantial fraction (say $\sim 50\%$) of the energy is in a 'fireball' of electron–positron pairs[15]. From the theoretical relation between temperature and mass, we expect this fireball to expand with $\gamma_f = (M_{crit}/2\times10^{16}\ \mathrm{g})^{-1}$.

For illustrative purposes, we consider fireballs with energy $\varepsilon_f \simeq 10^{37}\ \gamma_f^{-1}$ erg in electron–positron pairs. The number of pairs is then $N_f \simeq 10^{43}\ \gamma_f^{-2}$.

We must then address these questions:

(i) How large a radius can the fireball attain before the energy in the swept-up field decelerates it?

(ii) To what extent is it a good enough conductor to sweep up the field?

(iii) Would the fireball be braked by sweeping up external plasma as well as magnetic flux?

Suppose that the uniform external magnetic field is $B \simeq 5\times10^{-6}\ b$ G (where b would be ~ 1 for a typical interstellar field with energy density $\sim 10^{-12}$ erg cm^{-3}). If the fireball behaved as a perfect conductor, it would be significantly braked when it had swept up a magnetic field energy of $\sim \varepsilon_f/\gamma^2_f$. Thus we have, on energetic grounds, an upper limit to r of

$$r_{en} \simeq (10^{16}/\gamma_f)b^{-2/3}\ \mathrm{cm} \qquad (3)$$

Quite apart from this limit, the fireball cannot behave like a perfect conductor and expel the magnetic field (without being decelerated) unless the charge density is sufficient to carry the currents. This requires a surface density $\sim 10^3\gamma_f\ b$ charges per cm^2. The conductivity condition thus breaks down at a radius r_{cond} where $N_f/2\pi r^2$ falls to this value. One finds

$$r_{cond} \simeq (4\times10^{19}/\gamma_f^{3/2})b^{-1/2}\ \mathrm{cm} \qquad (4)$$

The appropriate value of r_{max} to use in (1) and (2) is the smaller of r_{en} and r_{cond}. For $\gamma_f < 10^7$, r_{cond} exceeds r_{en} (that is, the conductivity is good at all relevant times); so a fraction ~ 1 of the total fireball energy then emerges as electromagnetic waves of characteristic wavelength $\lambda \simeq r_{en}/\gamma_f^2$. This means that, for $\gamma_f \simeq 10^5$, $\sim 10^{32}$ erg emerges at $\lambda \gtrsim 10\,b^{-\frac{2}{3}}$ cm; and for $\gamma_f \simeq 10^7$, $\sim 10^{30}$ erg emerges at $\sim 10^4\ b^{-\frac{2}{3}}$ Å.

Such a radio burst would be readily detectable anywhere in our Galaxy, or even beyond[6,7], and the optical flash from a $\gamma_f \simeq 10^7$ fireball could be detected $\gtrsim 1$ kpc away (J. V. Jelley *et al.*, to be published). We must, however, check the validity of our assumption (question (iii) above) that the fireball is not braked by external plasma before attaining a radius r_{en}. External particles can be swept up, yielding a relativistic blast wave, only if the gyroradius of a particle with Lorentz factor γ_f in a field γ_f B is $< r/\gamma_f$. This requires

$$r \gtrsim 4\times10^8\ b^{-1}\ \gamma_f \qquad (5)$$

In the cases $\gamma_f \simeq 10^5$ and 10^7 cited above, r_{max} $(= r_{en})$ does not satisfy (5) for $b \lesssim 1$, so we are justified in assuming that the fireball transfers its momentum to the field rather than the ambient particles. (Arguments analogous to those used in deriving (4) and (5) show that the weak steady efflux preceding the final explosion cannot create a field-free heliosphere-type cavity around a minihole. This vindicates our assumption that the fireball impacts directly on to a typical ambient magnetic field).

In the 'extreme Hagedorn' case ($\gamma_f \simeq 300$), where the earlier argument would have yielded a strong ultra-low-frequency pulse that in any case would not propagate freely, (5) is fulfilled, so we would expect a relativistic blast wave with a swept-up shell. There is then no chance of getting efficient coherent radiation, the energy going instead into random relativistic particle motions. The field strength in the shell would be $\sim 5\times10^{-3}\ b$ G, and relativistic electrons with $\gamma_f \simeq 300$ would lose only 10^{-10} of their kinetic energy while the shell expanded. If a Hagedorn-type explosion occurred on a timescale Δt sudden enough to cause a coherent radio pulse, then most of the pairs would in any case have annihilated into photons. (The expansion timescale, in the comoving frame, when the fireball temperature falls to ~ 0.5 MeV is $\propto \gamma_f^{-2}(\Delta t)^{1/2}$, and our assumption that there is no time for annihilation to occur is self-consistent for $\gamma_f \gtrsim 10^5$.)

It is thus the case $\gamma_f \gg 10^3$ which—even though it entails a lower ε_f—offers the greatest promise of radio (or optical) detection. The pulse-production mechanism requires that the final outburst be 'instantaneous' in the sense that its timescale is $\lesssim \lambda/c$. This requirement is perhaps not met by quark theories, unless a lot of extra species occur above some energy $\gtrsim 100$ GeV. Because of this sensitivity to the uncertain particle physics, the absence of frequent strong radio pulses reaching the Earth cannot be used to improve the present upper limits on the number of miniholes in the Galaxy[2–4]. On the other hand, linearly polarised radio-frequency pulses (rather than γ-ray pulses) may well be much the most conspicuous manifestations of black-hole explosions, because radio techniques are exceedingly sensitive[6,7]. To dramatise the potential advantage, the γ rays from a fireball with $\gamma_f \simeq 10^5$ would only be registered by a detector of effective area 100 cm^2 if the event occurred within 10^{-2} pc; but even a crude non-directional antenna would detect the corresponding radio pulse at distances $\sim 10^4$ pc. And an Arecibo-type telescope could detect such pulses—each triggered by a single entity of subnuclear size—from as far away as the Andromeda galaxy!

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Is Cas A illuminated by a binary system?

I REPORT here indications that the supernova remnant Cas A (and probably many others) contains a neutron star at its centre, in close orbit around a 'normal' star. The indications are of three types: of evolutionary, statistical and indirect character, arguing that the high observed magnetic field strengths and the steepening synchrotron spectrum cannot be explained by stochastic processes.

Supernova explosions are commonly believed to derive their energy from the collapse of the (degenerate) core of a formerly massive late star. The conversion of gravitational energy into the kinetic energy of radial motion could be achieved through a magnetic spring[1–3] rather than a combination of neutrino[4] and thermal pressures. The mass of the collapsing core is expected to be near the Chandrasekhar mass ($\approx 1.4 M_\odot$), because this is the minimum mass for gravitational instability according to stellar evolution theory, and because all the overlying material is ejected by the action of the magnetic spring. The core thus turns into a stable neutron star. Mass determinations[5] of neutron stars in binary systems confirm this picture, which might apply to supernovae of all types (I, II, ...), their differences being due to the density of the surrounding medium which controls the mass in the envelope.