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# Dark Matter in Astroparticle and Particle Physics

Dark 2007

Editors

Hans Volker Klapdor-Kleingrothaus

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## REISSNER–NORDSTRÖM EXPANSION

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We propose a classical mechanism for the cosmic expansion during the radiation-dominated era, assuming the Universe as a two-component gas. The first component is the ultra-relativistic “standard” fraction described by an equation of state of an ideal quantum gas of massless particles. The second component consist of superheavy charged particles and their interaction with the “standard” fraction drives the expansion. This interaction is described by the Reissner–Nordström metric purely geometrically — the superheavy charged particles are modeled as zero-dimensional naked singularities which exhibit gravitational repulsion. The radius of a repulsive sphere, surrounding a naked singularity of charge  $Q$ , is inversely proportional to the energy of an incoming particle or the temperature. The expansion mechanism is based on the “growing” of the repulsive spheres of the superheavy particles with the drop of the temperature — this drives apart all neutral particles and particles of specific charge  $q/m$  such that  $\text{sign}(Q)q/m \geq -1$ . The Reissner–Nordström expansion mechanism naturally ends at Recombination. We model the Universe during the Reissner–Nordström expansion as a van der Waals gas and determine the equation of state.

In 1971, Hawking<sup>1</sup> suggested that there may be a very large number of gravitationally collapsed charged objects of very low masses, formed as a result of fluctuations in the early Universe. A mass of  $10^{14}$  kg of these objects could be accumulated at the centre of a star like the Sun. Hawking treats these objects classically and his arguments for doing so are as follows:<sup>1</sup> gravitational collapse is a *classical* process and microscopic black holes can form when their Schwarzschild radius is greater than the Planck

length  $(Gh/c^3)^{-1/2} \sim 10^{-35}$  m (at Planck lengths quantum gravitational effects do not permit purely classical treatment). This allows the existence of collapsed objects of masses from  $10^{-8}$  kg and above and charges up to  $\pm 30$  electron units.<sup>1</sup> Additionally, a sufficient concentration of electromagnetic radiation causes a gravitational collapse — even though the Schwarzschild radius of the formed black hole is smaller than the photon's Compton wavelength which is infinite. Therefore, when elementary particles collapse to form a black hole, it is not the *rest* Compton wavelength  $hc/mc^2$  that is to be considered — one should instead consider the *modified* Compton wavelength  $hc/E$ , where  $E \sim kT \gg mc^2$  is the typical energy of an ultra-relativistic particle that went to form the black hole.<sup>1</sup> Microscopic black holes with Schwarzschild radius greater than the modified Compton wavelength  $hc/E$ , can form classically and independently on competing quantum processes. Hawking suggests that these charged collapsed object may have velocities in the range 50 – 10000 km/s and would behave in many respects like ordinary atomic nuclei.<sup>1</sup> When these objects travel through matter, they induce ionization and excitation and would produce bubble chamber tracks similar to those of atomic nuclei with the same charge. The charged collapsed objects survive annihilation and, at low velocities (less than few thousand km/s), they may form electronic or protonic atoms:<sup>1</sup> the positively charged collapsed objects would capture electrons and thus mimic super-heavy isotopes of known chemical elements, while negatively charged collapsed objects would capture protons and disguise themselves as the missing zeroth entry in the Mendeleev table. Such ultra-heavy charged massive particles (CHAMPS) were also studied by de Rujula, Glashow and Sarid<sup>2</sup> and considered as dark matter candidates. Dark Electric Matter Objects (DAEMONS) of masses just above  $10^{-8}$  kg and charges of around  $\pm 10$  electron units have been studied in the Ioffe Institute and positive results in their detection have been reported<sup>3</sup> — observations of scintillations in ZnS(Ag) which are excited by electrons and nucleons ejected as the relic elementary Planckian daemon captures a nucleus of Zn (or S). The DAMA (DARK MATter) collaboration also report positive results<sup>4</sup> in the detection of such particles using 100 kg of highly radiopure NaI(Tl) detector.

These superheavy charged particles can serve as driving force for the expansion of the Universe during the radiation-dominated epoch in a classical particle-scale model, which we recently proposed.<sup>5</sup> Along with this type of particles, within our model, magnetic monopoles can also play the same role for the expansion of the Universe: it has been suggested<sup>6</sup> that ultra-heavy

magnetic monopoles were created so copiously in the early Universe that they outweighed everything else in the Universe by a factor of  $10^{12}$ .

The classical mechanism of the cosmic expansion relies on the assumption that the Universe is a two-component gas. One of the fractions is that of ultra-relativistic “standard” particles of typical mass  $m$  and charge  $q$  with equation of state of an ideal quantum gas of massless particles. The other component consists of the superheavy charged particles of masses  $M$  (of around  $10^{-8}$  kg and above) and charges  $Q$  (of around  $\pm 10$  electron charges and above) — exactly as those described earlier.

For an elementary particle such as the electron, the charge-to-mass ratio is  $q/m \sim 10^{21}$  (in geometrized units  $c = 1 = G$ ), while for the superheavy charged particles,  $M \lesssim Q$ . In view of this, the general-relativistic treatment of elementary particles or charged collapsed objects of very low masses also necessitates consideration from Reissner–Nordström (or Kerr–Newman) viewpoint — for as long as their charge-to-mass ratio remains above unity. We also treat the superheavy charged particles classically (in line with Hawking’s arguments outlined earlier). That is, the superheavy charged particles are modelled as Reissner–Nordström naked singularities and the expansion mechanism is based on their gravito-electric repulsion. Instead of the Schwarzschild radius, the *characteristic length* that is to be considered now and compared to the *modified* Compton length,<sup>1</sup> will be the radius of the van der Waals-like impenetrable sphere that surrounds a naked singularity (see Cohen *et al.*<sup>7</sup> for a very thorough analysis of the radial motion of test particles in a Reissner–Nordström field). As shown in Prodanov *et al.*,<sup>5</sup> for temperatures below  $10^{31}$  K, the radius of the impenetrable sphere of a superheavy charged particle of mass  $10^{-8}$  kg and charge  $\pm 10$  electron units is greater than the *modified* Compton wavelength of the superheavy charged particle itself. The “standard” particles of the expanding Universe are therefore too far from the superheavy charged particles for quantum interactions to occur between the two fractions.

Consider a “standard” particle of specific charge  $q/m$ , and a superheavy charged particle of charge  $Q$ , such that  $\text{sign}(Q)q/m \geq -1$ , with the “standard” particle approaching the superheavy charged particle from infinity. The pseudo-Newtonian potential of the field of the naked singularity is given by<sup>5</sup>  $U(r) = -(mM)/r + (qQ)/r + [(m/2)(-M^2 + Q^2)]/r^2$  and the field is characterized by three regions.<sup>5,7</sup> The region between  $r = 0$  and  $r = r_0(T)$  is *impenetrable* due to the condition for reality of the kinetic energy of the incoming test particle. The turning radius  $r_0(T)$  is given by<sup>5,7</sup>  $r_0(T) = Q(q + m)/(kT)$  for very high temperatures. This can

be thought of as the radius of an “impenetrable” sphere, surrounding the naked singularity, that grows with the drop of the temperature: the higher the energy (or the temperature), the deeper an incoming particle will penetrate into the gravitationally repulsive field of the naked singularity. The region between the turning radius  $r_0(T)$  and the critical radius  $r_c \geq r_0(T)$  is *repulsive*. At this critical radius, repulsion and attraction interchange:<sup>5</sup>  $r_c = M(Q^2/M^2 - 1)/[1 - (qQ)/(mM)]$  and the region above  $r_c$  is *attractive*. As the temperature drops, the superheavy charged particles “grow” (incoming particles have lower and lower energies and turn back farther and farther from the naked singularity). When the temperature gets sufficiently low, the radius  $r_0(T)$  of the impenetrable sphere of a superheavy charged particle grows to  $r_c$  (but not beyond  $r_c$ , as in the region  $r > r_c$  the incoming probe is attracted and cannot turn back). This means that incoming particles have such low energies that they turn back immediately after they encounter the gravitational repulsion. Incoming particles of charge  $q$  such that  $qQ > Mm$  do not even experience attraction — the repulsive region for such particles extends to infinity (the gravitational attraction will not be sufficiently strong to overcome the electrical repulsion) and for them  $r_0(T)$  has no upper limit. The interaction between the two fractions of the Universe results<sup>5</sup> in power law expansion with scale factor  $a(\tau) \sim \sqrt{\tau}$ , corresponding to the expansion during the radiation-dominated era.

In our picture, the Universe has local Reissner–Nordström geometry, but globally, the geometry is that of Robertson–Walker. Namely, we confine our attention to the local spherical neighbourhood of a single naked singularity and consider the Universe as multiple copies (fluid) of such neighbourhoods. It is plausible to assume that these naked singularities are densely packed spheres that fill the entire Universe. Thus, the volume  $V$  of the Universe, at any moment during the Reissner–Nordström expansion, would be of the order of the number  $N$  of these particles, times the “volume” of the repulsive sphere of a superheavy charged particle:  $V \sim Nr_0^3(T)$ . Therefore, the number density of the superheavy charged particles is of the order of  $r_0^{-3}(T)$ . At Recombination, the free ions and electrons combine to form neutral atoms ( $q = 0$ ) and this naturally ends the Reissner–Nordström expansion mechanism — a neutral “normal” particle will now be too far from an “usual” particle to feel the gravitational repulsion (the density of the Universe will be sufficiently low).

The standard treatment of a Robertson–Walker Universe uses the isotropicity and the homogeneity for modeling the energy-momentum sources as a perfect fluid. This applies for matter known observationally

to be very smoothly distributed. On smaller scales, such as stars or even galaxies, this is a poor description. In our picture we model the Universe as a van der Waals gas and we use small scale density and pressure variables. Such modeling is possible in the light of the deep analogies between the physical picture behind the Reissner–Nordström expansion and the classical van der Waals molecular model: atoms are surrounded by imaginary hard spheres and the molecular interaction is strongly repulsive in close proximity, mildly attractive at intermediate range, and negligible at longer distances. The laws of ideal gas must then be corrected to accommodate for such interaction: the pressure should increase due to the additional repulsion and the available volume should decrease as atoms are no longer entities with zero own volumes. Therefore, at Recombination, the radius  $r_0(T)$  of a superheavy charged particle will be of the order of  $R_c = N^{-1/3}t_{recomb}$ . We request that, once  $r_0(T)$  becomes equal to  $R_c$ , i.e. when the charged particles recombine, then the potential of the interaction between a naked singularity and a particle of charge  $q$ , such that  $qQ > mM$ , becomes zero. For particles of charge  $q$ , such that  $\text{sign}(Q)q/m \geq -1$  and also  $qQ \leq mM$ , the potential of the interaction becomes negligible earlier: when  $r_0(T)$  reaches  $r_c$ .

With  $N$  superheavy particles, the effective space left for the motion of the “standard” fraction consisting of  $n$  particles, is reduced by a factor of  $N$  times the volume of the repulsive sphere of a superheavy particle. Then the “van der Waals” equation  $p + (N^2\alpha)/V^2 = nkT[1 + (N\beta)/V]/V$  has:  $\alpha = 2\pi \int_{r_0(T)}^R U(r) r^2 dr = \pi m(M^2 - Q^2)[R - r_0(T)] + \pi mM[1 - (qm)/(QM)][R^2 - r_0^2(T)]$  and  $\beta = 2\pi \int_0^{r_0(T)} r^2 dr = 2\pi r_0^3(T)/3$ . Here  $R = r_c$  if  $\text{sign}(Q)q/m \geq -1$  and also  $qQ \leq mM$ , or  $R = R_c$  if  $qQ > mM$ . The equation of state is  $p = \eta\rho^{4/3} - \alpha/\beta^2$ , where  $\eta = \text{const}$ . The second term depends on the temperature via  $\alpha$  and  $\beta$  and becomes irrelevant towards the end, as  $\alpha \rightarrow 0$  when  $r_0(T) \rightarrow R$ .

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