Observing Cosmic Strings through their Lensing Properties

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Abstract

Superconducting cosmic strings may carry lightlike current pulses after they have passed through a region where a magnetic field was present. If one such string happened to be between us and a distant star, it would produce a double image of this star. The passage of a lightlike current pulse would make this double image move with time, and should therefore provide a means to observe an unambiguous string signature which is discussed here. Details on the material contained in this article may be found in Garriga & Peter, 1994.

Cosmic strings (Kibble 1976, 1980) are linear topological defects suspected to have been formed during a phase transition occurring in the early Universe. They appear as the Universe undergoes a symmetry breaking phase transition of the form \( G \rightarrow H \), with \( G \) and \( H \) the initial and final symmetry groups associated with the invariances of the Grand Unified Theory (GUT) under consideration. After this phase transition, the topology of the vacuum is that of the quotient group \( G/H \), and it may happen that this topology is nontrivial. In particular, if the vacuum manifold is not simply connected (i.e., \( \pi_1(G/H) \neq \{0\} \)), then cosmic strings are formed according to the Kibble mechanism and fill the Universe with a network whose properties and cosmological consequences (in particular its imprint in the microwave background) are discussed in the article by Paul Shellard in these proceedings. It should be mentioned at this stage that the expected energy per unit string length \( U \) say, scales like the square of the energy scale of symmetry breaking, which means roughly \( 10^{17} \) tons per centimeter, so that the relevant dimensionless gravitational parameter \( GU \) with \( G \) the Newton's constant, is expected of order \( 10^{-6} \). If this is to give the correct order of magnitude for light deflection [as it is indeed (Vilenkin 1987, Peter 1994)], this implies effects on the 2" scale, which is observable with present technology. Since strings are the most serious contender to the "standard" inflationary scenario, their direct observation (or lack thereof) could provide invaluable information on the mechanisms by which large scale structures in the Universe were formed.

A point which deserves further emphasis about cosmic strings is their ability
to carry persistent (superconducting) currents (Witten 1985), and in particular electromagneto-magnetic currents. This possible coupling with electromagnetism is in fact very important when gravitational light deflection effects are studied because the electromagnetic field surrounding a cosmic extends very far from it: the cylindrical symmetry of a string implies a very slow decrease of the energy density (far from the string’s core) associated with the Maxwell fields, and its coupling to gravity yields effects that are enhanced by distance. Essentially, setting $r_o$, the string radius (in practice, the Compton wavelength of the GUT scale), and $R$ a typical distance characteristic of observable light deflection (which can be an astrophysical distance, if not cosmological), one finds (Helliwell & Konkowski 1986, Moss & Poletti 1987, Babul et al. 1988, Amsterdamski & Laguna-Castillo 1988, Linet 1989, Peter & Puy 1993) that the electromagnetic “correction” to light deflection is given by $e^2 \ln R/r_o$, with $e^2 \simeq 1/137$ the usual electromagnetic coupling constant. But since $R/r_o$ can be as large as $\sim 10^{10}$ (which, incidentally, is the reason why strings in these conditions are usually treated as zero-thickness Dirac delta distributions), the $e^2$ term gets balanced by the distance effect, so that eventually, both the initial effect and its correction appear to be of similar orders of magnitude.

Let us now calculate the gravitational field surrounding a cosmic string carrying a lightlike current, treating the source as an infinitely thin distribution. One easy way to do so is by the limiting procedure (Aichelburgh & Sexl 1971, Dray & t’Hooft 1985, Loustò & Sanchez 1989, Jackiw et al. 1992) of boosting the metric of the spacelike current case (Witten 1962, Peter & Puy 1993) to the speed of light in the direction parallel to the string (alternatively, one could also boost the timelike current metric, both procedures being equivalent).

In the case of spacelike current, for a static cylindrically symmetric configuration with the string lying along the $z$-axis, the metric outside the core of the string is (Witten 1962)

$$ds^2 = g(-dt^2 + dr^2) + r^2 f \gamma^2 d\theta^2 + \frac{dz^2}{f}. \quad (1)$$

Here, $f = [c_1(r/r_o)^m + c_2(r/r_o)^{-m}]^2$ and $g = (r/r_o)^{2m^2} f$. The various parameters $c_1$, $c_2$, $m$ and $\gamma$ should be determined, in principle, in terms of the microphysical parameters characterizing the vortex by matching the exterior metric (1) with the solution of Einstein’s equations inside the core of the string (i.e., for $r < r_o$). For weak fields, one can arrive at the relations

$$m^2 = 4GI^2 + O(G^2),$$
$$c_1 = \frac{1}{2} [1 + \frac{G^{1/2}}{I}(U - T - I^2)] + O(G^{3/2}),$$
$$c_2 = \frac{1}{2} [1 - \frac{G^{1/2}}{I}(U - T - I^2)] + O(G^{3/2}),$$
$$\gamma = 1 - 4G(U + \frac{1}{2}I^2) + O(G^2). \quad (2)$$