Dark Energy impacts on Radio Bursts from Superconducting Cosmic Strings

Batool Imtiaz*, Rui Shii*, Yi-Fu Cai†

Department of Astronomy, University of Science and Technology of China,
Hefei, Anhui 230026, China
CAS Key Laboratory for Researches in Galaxies and Cosmology, Department of Astronomy,
University of Science and Technology of China,
Hefei, Anhui 230026, China
**E-mail: batool24@mail.ustc.edu.cn, ustcwysr@mail.ustc.edu.cn*
†*E-mail: yifucai@ustc.edu.cn*
§*xuelq@mail.ustc.edu.cn*
www.ustc.edu.cn

Superconducting cosmic strings are supposed to emit transient events appearing in radio frequency band. We examine the impact of dark energy on three different structures of superconducting cosmic strings. With the consideration of observational scenario, we investigate event burst rate formalism in terms of redshift "z"by taking string parameter "$G\mu$ "and current parameter "I". We will take these parameters to be free. We fit theoretical data, obtained as a normalised event rate, with normalised observed data, and constrain the $G\mu$ and I be $(10^{22}, 10^{26})$GeV and $(10^{-4}, 10^{2})$ respectively.

1. introduction

It is important to study and investigate cosmic strings as they are one of the important topological defects. They provide tremendous insight into the nature of fundamental interactions. If the strings are superconducting, they emit radiations in radio band. this work is basically the extension of work done by [1]and [2] As our universe has been entered into dark energy era, it is challenging to probe the radiation mechanism. This is an on-going project.We share incomplete results but in near future we will bring complete results.

2. Characteristics of SCSs

For more details about this work we will refer reader an article on arXiv very soon. We are begin with the superconducting string model: [3]

$$S = \int d^2\eta\big\{ -\mu\sqrt{-\gamma} + \frac{1}{2}\sqrt{-\gamma}\gamma^{\alpha\beta}\phi_{,\alpha}\phi_{,\beta} - A_\mu e^{\mu}_{,\alpha}J^{\alpha}\big\} - \frac{1}{16\pi}\int d^4x\sqrt{-g}F^{\mu}\nu F_{\mu}\nu \tag{1}$$

Here, $\gamma_{\alpha\beta}$ be the worldsheet induced metric for the string with $(\alpha, \beta) = 0$ or 1 and string tension is μ. In the action above, first term is Nambo-Goto action; second term is worlsheet current; third term is about electromagnetic gauge coupling and fourth term shows the dynamics of electromagnetic field. Also, if one can consider a string to be one dimensional object, it, of course, sweeps out two dimensional worldsheet in spacetime.

$$e^{\mu} = e^{\mu}(\eta^{\alpha}), \alpha = 0, 1 \tag{2}$$

with η^0 and η^1 be time-like and space-like parameters. The $\gamma_{\mu\nu} = \eta_{\alpha\beta} e^{\alpha}_{\mu} e^{\beta}_{\nu}$ is induced metric with $det(\gamma_{\mu\nu}) = \gamma$.

A trajectory for cosmic string loops is

$$x^{\mu}(t,\sigma) = \frac{1}{2}[x^{\mu}_{-}(\sigma_{-}) + x^{\mu}_{+}(\sigma_{+})] \tag{3}$$

with $\sigma_{\pm} = \sigma \pm t$. The result combined with gauge conditions is as follows:

$$x_{-}(\sigma_{-} + L) = x_{-}, x_{+}(\sigma_{+} + L) = x_{+} \tag{4}$$

3. Radiations from loops of SCS's

The radiation power for any periodic em source is

$$P = \sum_n P_{\omega_n}$$

$$P_{\omega_n} = -\frac{L}{2\pi}\omega_n^2 \int d\Omega j^{*}_{\mu}(\omega_n, k) j^{\mu}(\omega_n, k) \tag{5}$$

Here, $\omega_n = \frac{4\pi n}{L}$ with $n\epsilon N$ is the Fourier mode. The analysis of radiation power from loops of SCS infers that the major contribution is from j^{μ}_{ω}. Therefore, it is noteworthy to identify the solution of four-current j^{μ}_{ω}. The main idea to analyze EM radiations from string loops is to observe emission of radiations from different structures of loops.

4. Event Rate of Burst

The burst event rate can be expressed as:

$$\begin{gathered} d\dot{\mathcal{N}}(L,z) = N^p 4\pi\nu_0(\nu_0 L)^{m-1} k C_L \\ \frac{(r(z))^2}{t_0^2((1+z)^3 L + \Gamma G\mu t_0)^2} dz dL \end{gathered} \tag{6}$$

with

$$r(z) = \frac{1+z}{H_0}\int_0^z \frac{d\xi}{\sqrt{\Omega_m(1+\xi)^3 + \Omega_r(1+\xi)^4 + \Omega_\Lambda}} \tag{7}$$

$$C_L(z) = 1 + (1+z)^{3/4}\sqrt{\frac{t_{eq}}{(1+z)^{3/2}L + \Gamma G\mu t_0}} \tag{8}$$

Till now, we have demonstrated burst event rate in terms of loop length and redshift. In the viewpoint of observable variables, it is quite fascinating to describe event rate in terms of observable variables like energy flux per frequency interval and intrinsic duration of the burst. The energy flux per frequency interval is instrument-sensitive parameter. To constrain the model parameters, first we study how to do variable transformation from (L,z) to (S,Δ) and then event burst rate be defined in the form

of corresponding variables with free parameters $G\mu$ and I. The current parameter I for cosmic string rely on both the loop length L and the energy scale of the phase transition that was supposed to occur in the very early universe. As a result, we are able to modify a pair (G, μ) according to FRB signals.
The observed fast radio bursts are all from extra-galactic sources. Accordingly, the scatterings of these bursts are expected to be contributed by both intergalactic medium(IGM) and interstellar medium(ISM). The time broadening effect due to ISM can be related to the dispersion measures of ISM DM_{ISM} using an empirical function as follows:[4 5 6]

$$DM_{IGM}(z) = \frac{3cH_0\Omega_b f_{IGM}}{8\pi G m_p} \int_0^c \frac{\chi(z')(1+z')dz'}{E(z')} \tag{9}$$

with

$$E(z) = \sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda f(z)} \tag{10}$$

$$f(z) = exp[3\int_0^z \frac{(1+\omega(z'')dz''}{1+z''}] \tag{11}$$

$$\chi(z) = Y_{H\chi_{e},H} + \frac{1}{2}Y_{p\chi_{e},He}(z) \tag{12}$$

with H_0 is the Hubble parameter for today, Ω_b be the baryon mass fraction of the universe and f_{IGM} be the fraction of baryon mass in the intergalactic medium. The hydrogen and helium mass fraction in the intergalactic medium can be represented by Y_H and Y_p and equals $\frac{3}{4}$ and $\frac{1}{4}$. respectively. Likewise, the ionisation fraction of hydrogen and helium are $\chi_{e,H}$ and $\chi_{e,H}$ respectively. As we are taking a regime $z \leq 2.1$ and for this region, both hydrogen and helium ionised completely, so we can take them to be 1.[7 8]

5. FRB Data Fitting

At this stage, we are able to tackle the theoretical predictions of SCSs according to observational data of FRB. In this regard, we can constrained the model parameters very well.We can analyse that there are five parameters in total that can describe FRB data accordingly, which are: $G\mu$, I, ν_0, Δ and S. First we look into constrains set by CMB background anisotropies and the stochastic gravitational wave background
We are required to fit the event burst rate with the normalised observed data, so for each $(G\mu, I)$, we need to express event burst rate in terms of redshift. We also take instrumental threshold into considerations like flux and pulse width and sound-to-noise ratio(SNR).
The observable parameters mingled with SCS model are redshift, the dispersion measure ,pulse width and energy flux. There are 25 observed FRB signals till date[9]

The highest redshift for these observed FRB signals is $z = 2.1$. For numerical analysis, we divide data into different bins. Make the data normalised so that

$$\sum y_{obs} \Delta z_{bin} = 1 \quad (13)$$

with y_{obs} be the normalised event number per redshift. To see the compatibility of theoretical data with the observed ones, we create different values of normalised event burst rate in terms of $(G\mu, I)$ so that

$$\int y_{th} dz = 1 \quad (14)$$

To check the quality of fitting between theoretical and observed normalised data, we use a statistical tool Chi square as

$$\chi^2 = \sum_i^n \frac{(y_{obs} - y_{th})^2}{e_{obs}^2} \quad (15)$$

with n be the number of bins.

References

1. Y. F. Cai, E. Sabancilar, D. A. Steer and T. Vachaspati, Phys. Rev. D **86**, 043521 (2012) doi:10.1103/PhysRevD.86.043521 [arXiv:1205.3170 [astro-ph.CO]].
2. J. Ye, K. Wang and Y. F. Cai, Eur. Phys. J. C **77**, no. 11, 720 (2017) doi:10.1140/epjc/s10052-017-5319-2 [arXiv:1705.10956 [astro-ph.HE]].
3. A. Vilenkin, E.P.S. Shellard, Cosmic strings and other topological defects (Cambridge University Press, Cambridge, 1994).
4. W. Deng and B. Zhang, Astrophys. J. **783**, L35 (2014) doi:10.1088/2041-8205/783/2/L35 [arXiv:1401.0059 [astro-ph.HE]].
5. B. Zhou, X. Li, T. Wang, Y. Z. Fan and D. M. Wei, Phys. Rev. D **89**, no. 10, 107303 (2014) doi:10.1103/PhysRevD.89.107303 [arXiv:1401.2927 [astro-ph.CO]].
6. H. Gao, Z. Li and B. Zhang, Astrophys. J. **788**, 189 (2014) doi:10.1088/0004-637X/788/2/189 [arXiv:1402.2498 [astro-ph.CO]].
7. Masui, K., Lin, H.-H., Sievers, J., et al. 2015, Nature, 528, 523
8. G. D. Becker, J. S. Bolton, M. G. Haehnelt and W. L. W. Sargent, Mon. Not. Roy. Astron. Soc. **410**, 1096 (2011) doi:10.1111/j.1365-2966.2010.17507.x [arXiv:1008.2622 [astro-ph.CO]].
9. E. Petroff *et al.*, Publ. Astron. Soc. Austral. **33**, e045 (2016) doi:10.1017/pasa.2016.35 [arXiv:1601.03547 [astro-ph.HE]].