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Synchrotron and Inverse Compton radiation of the superconducting cosmic strings

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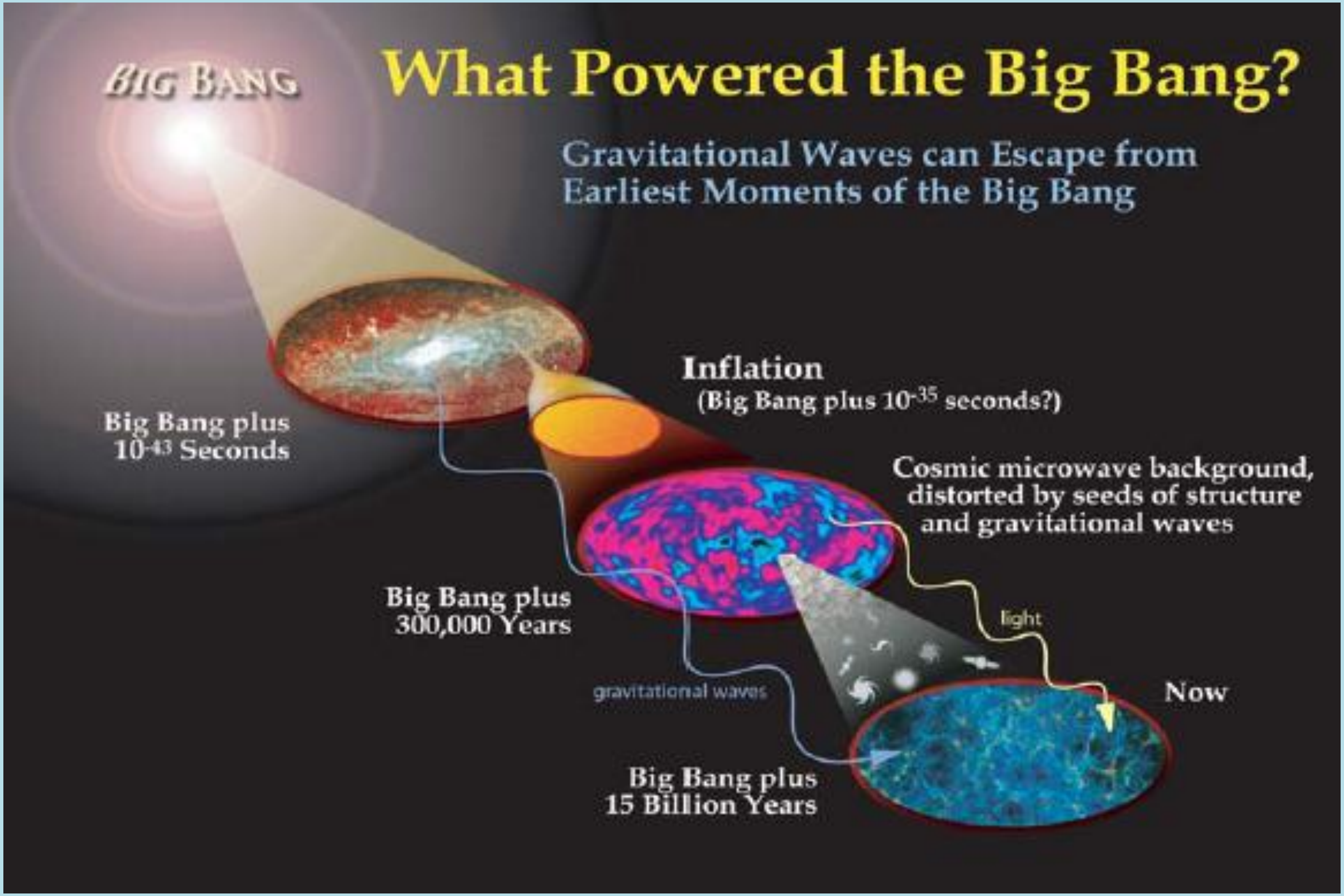
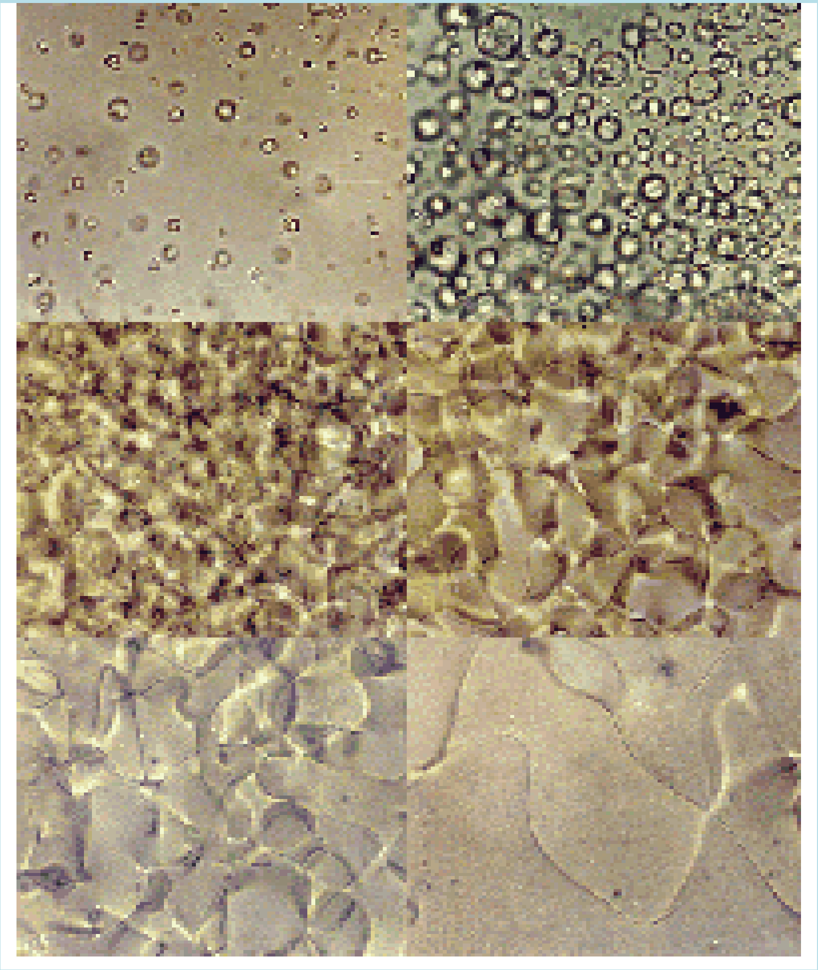
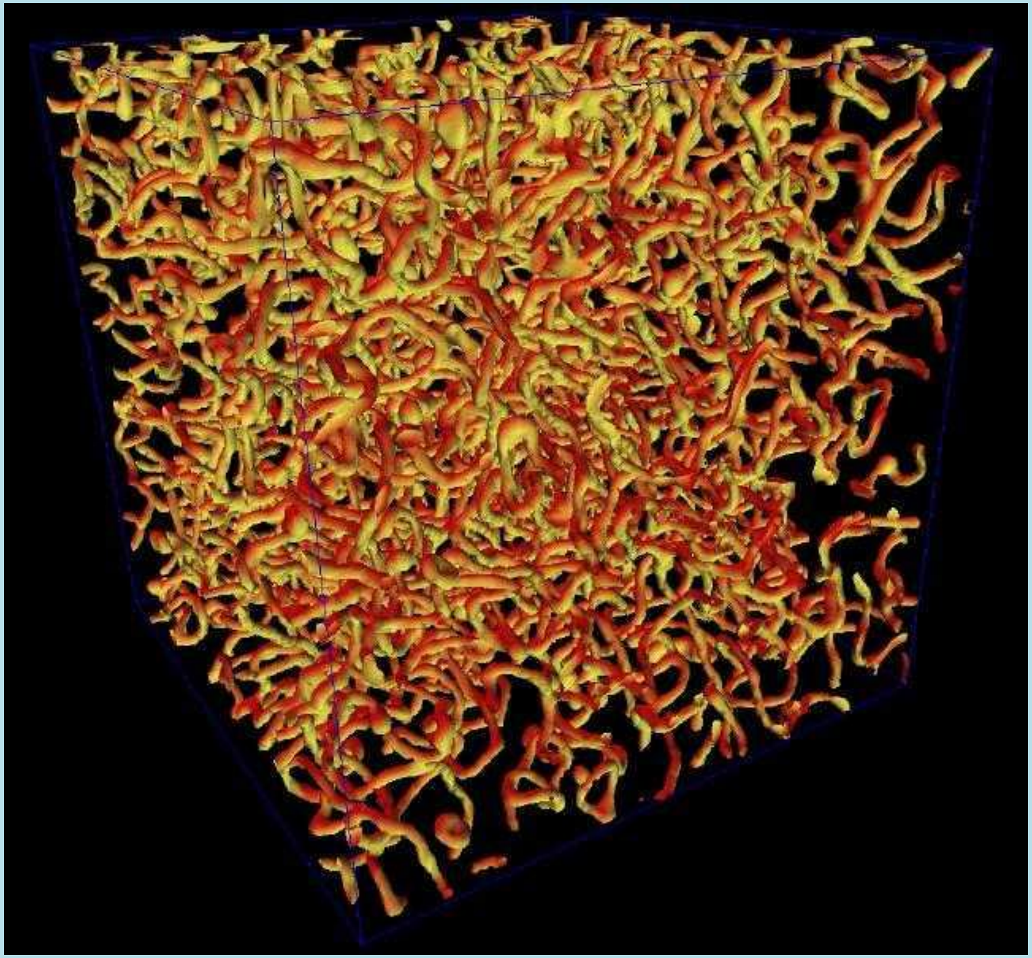
Cosmic strings – is a result of phase transitions in the early Universe



Formation of the cosmological defect can be modeled in a laboratory, when we observe phase transitions between the phases with different optical properties in a liquid crystal

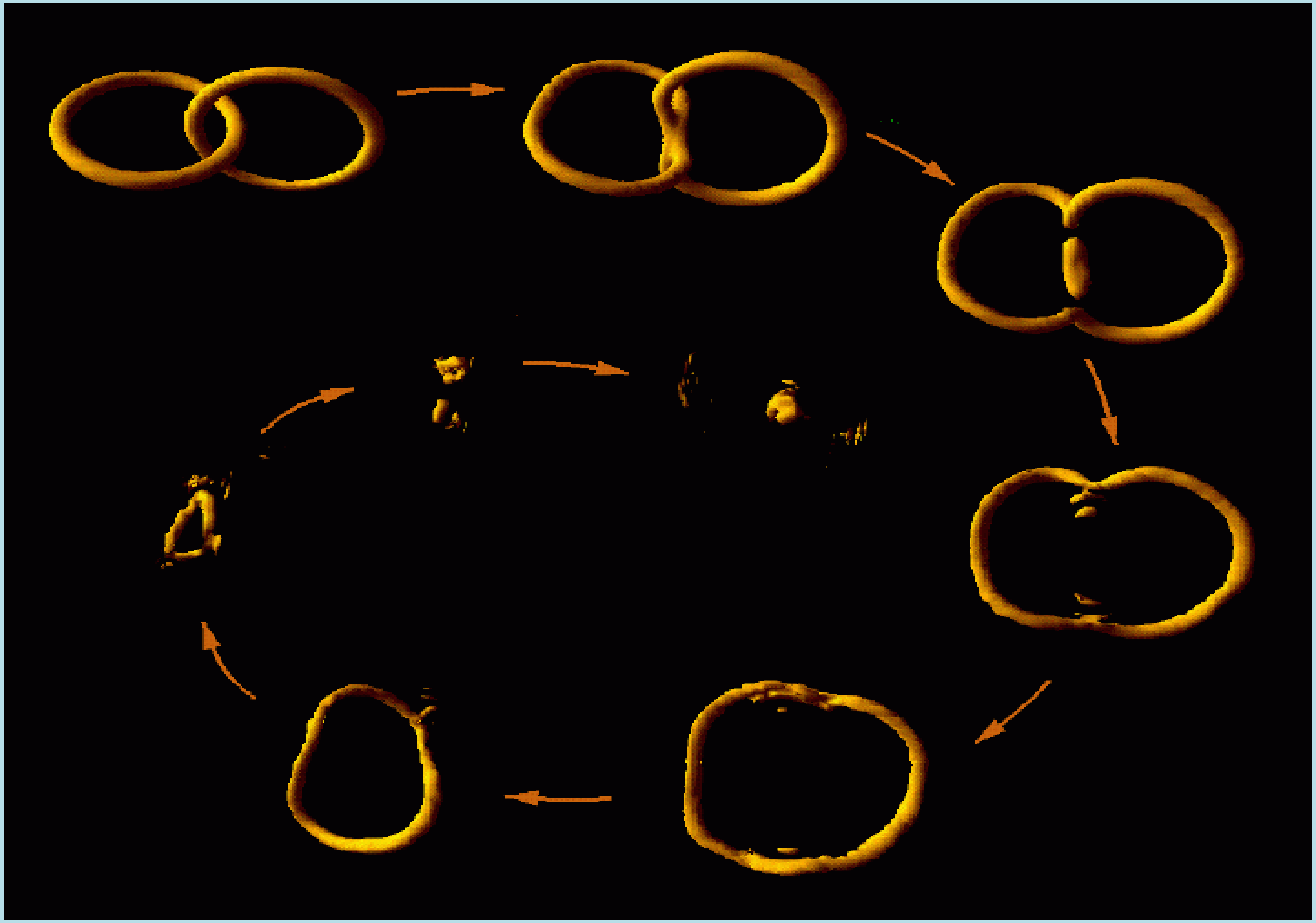


Water – Ice Transition

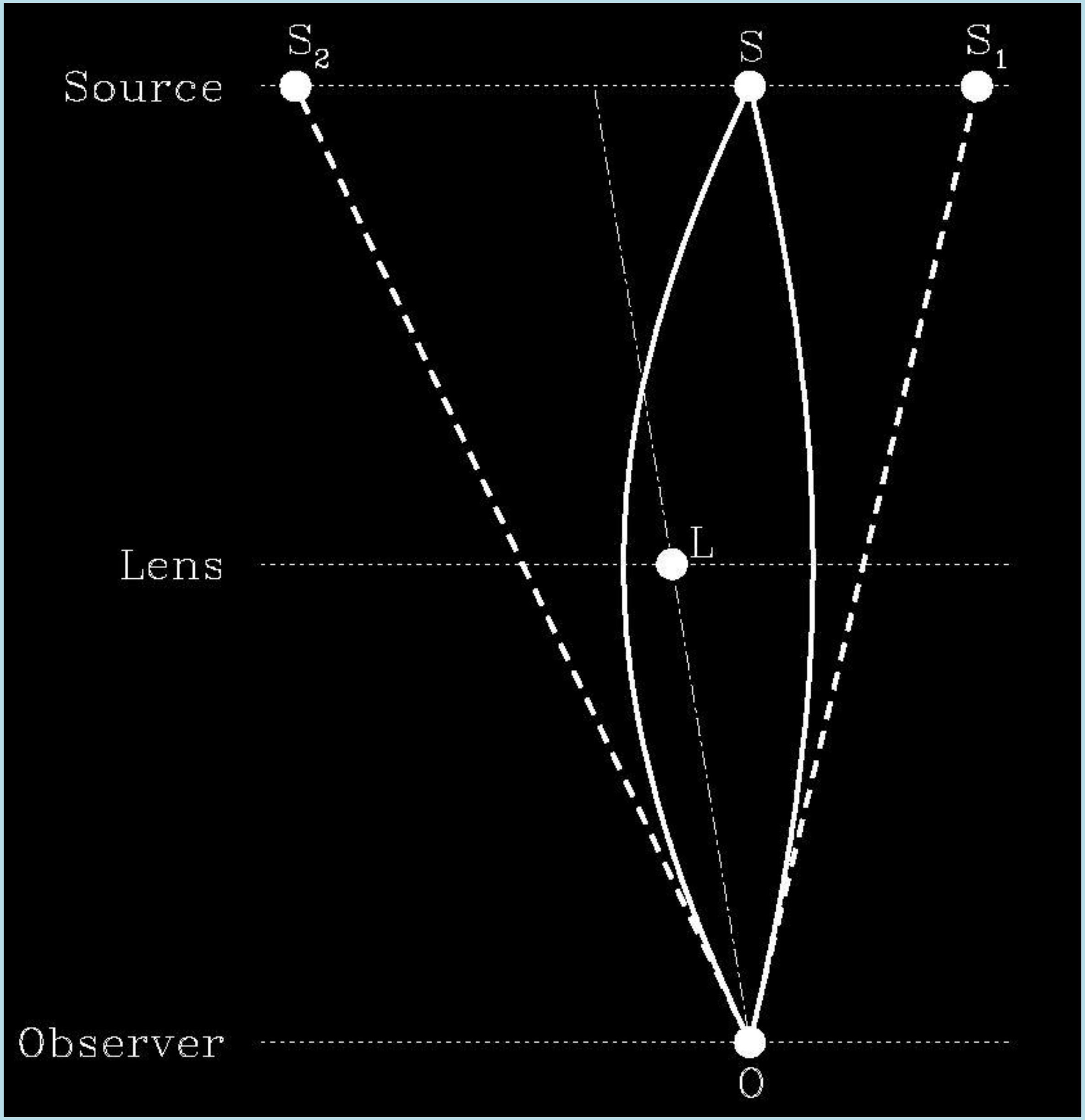


Evolution of cosmic strings:

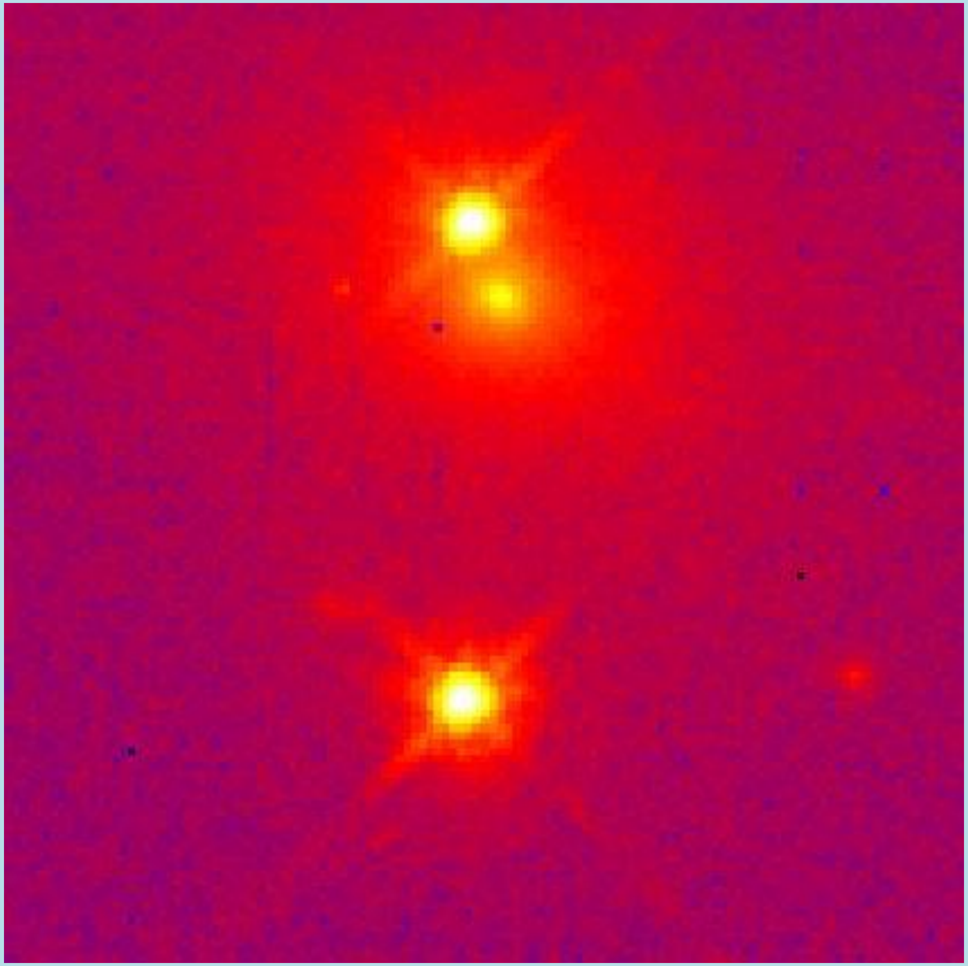
they can cross each other, band and as a result disappear



Gravitational lensing on cosmic string



First gravitational lens Q0957+561 A,B



In 2004, the model of synchronous fluctuations of a brightness was proposed as an action of gravitational field of the cosmic string. (R.Schild, I.S. Masnyak, and B.I. Hnatyk, [arXiv: astro-ph/0406434])

Radiation of the cosmic strings

The energy loss rate by a string due to the gravitational emission is determined by the parameter α:

$$\alpha = \frac{\Gamma G\mu}{c^2}$$

, where $\Gamma \approx 50$ – dimensionless parameter, μ - tension of string.

The typical length of string is determined by the relation:

$$l = \alpha c t$$

, where $t = 13{,}6 \cdot 10^9$ years.

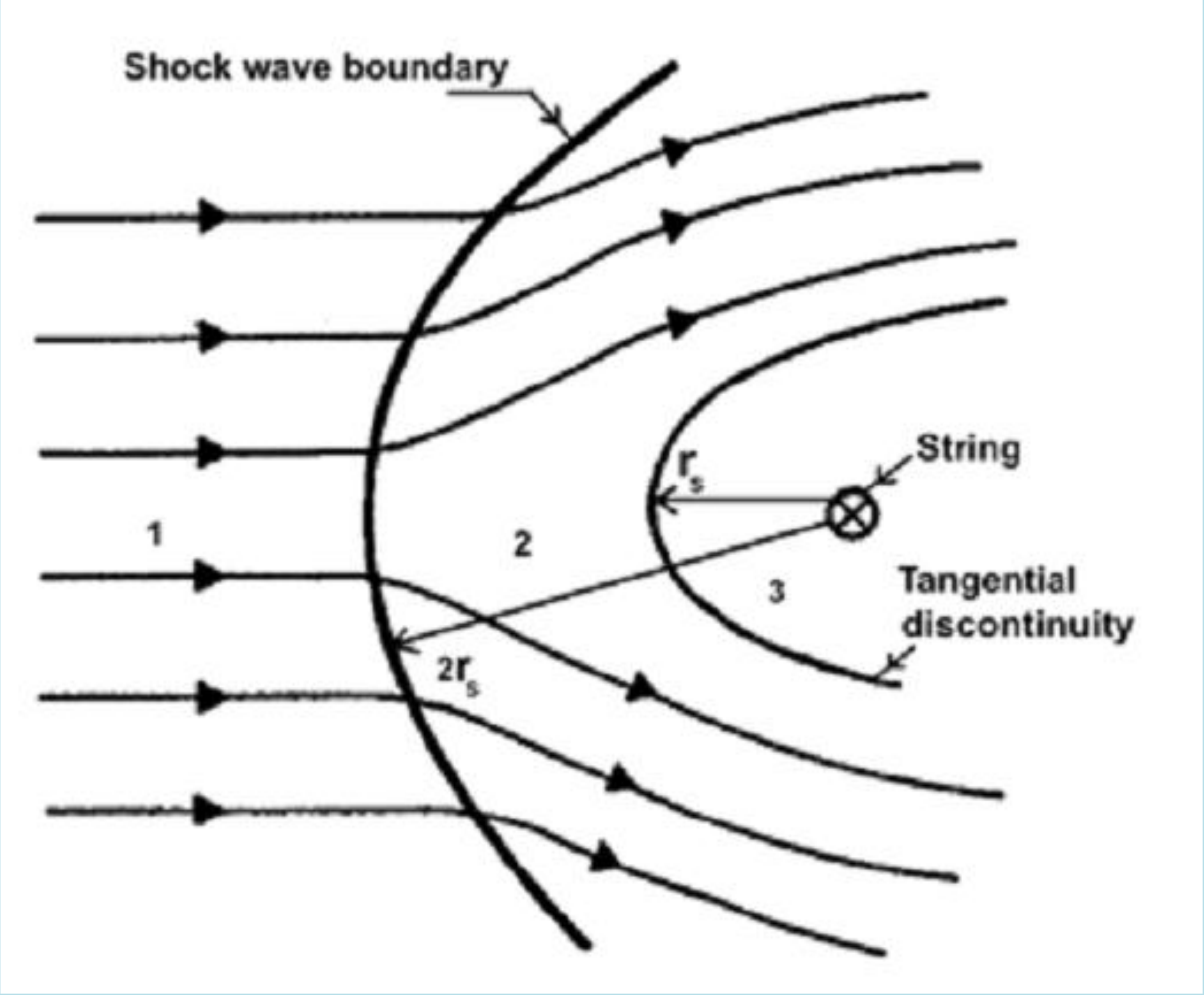
For a given α, the average distance, on which the loops can be located is:

$$d_s = \alpha^{1/3} c t$$

Characteristics of strings with different parameter α

α	Parameters of strings	
	l, pc	d_s , pc
$5 \cdot 10^{-6}$	$2{,}1 \cdot 10^{4}$	$7{,}2 \cdot 10^{7}$
10^{-6}	$4{,}2 \cdot 10^{3}$	$4{,}2 \cdot 10^{7}$
10^{-8}	42	$9{,}1 \cdot 10^{6}$
10^{-11}	0,042	$9{,}1 \cdot 10^{5}$

Schematic diagram of a flow of the cosmic plasma near a superconducting cosmic string. The trajectories of particles of the plasma are marked by lines with arrows.



An electric current which is generated in the cosmic string has the mean amplitude:

$$i = k_i q_e^2 B_{\rm IGM} l/\hbar$$

A current generates the proper magnetic field near the string:

$$B_{\rm mag}(r) = 2i/cr$$

A radius of the shock-wave can be calculated from:

$$r_s = \frac{k_i q_e^2 B_{\rm IGM} l}{2\hbar c^2 \gamma_{\rm sh} \sqrt{\pi n_1 m_p}}$$

Synchrotron radiation of the superconducting cosmic strings

- Spectral emissive ability from one electron per unit of volume is described by the formula:

$$J(\nu, E_e) = \frac{\sqrt{2}e^3 B}{m_e c^2} x \int\limits_x^{\infty} K_{\frac{5}{3}}(\eta) d\eta = \frac{\sqrt{2}e^3 B}{m_e c^2} C x^{\frac{1}{3}} e^{-x}$$

, where C ≈ 1,85

In this formula: $x = \frac{\nu}{\nu_c} = \frac{2\nu}{3{\gamma_e}^2 \nu_g} = \frac{4\pi m_e c \nu}{3eB{\gamma_e}^2} = b\frac{\nu}{{\gamma_e}^2}$, де $b = \frac{4\pi m_e c}{3eB}$

and we used approximation, which was proposed by Aharonian (World Scientific Publishing Co. Pte. Ltd., 2004)

- Spectral emissive ability from electrons which are distributed with power law $N(E_e) = K{E_e}^{-p}$ is:

$$j(\nu) = \int\limits_{E_e} J(\nu, E_e) N(E_e) dE = CK\frac{\sqrt{2}e^3 B}{m_e c^2} \int\limits_{E_{e,min}}^{E_{e,max}} x^{\frac{1}{3}} e^{-x} {E_e}^{-p} dE_e$$

Synchrotron radiation of the superconducting cosmic strings

- Let us use more appropriate energetic distribution of electrons:

$$N(E_e) = K E_e^{-p_e} e^{-\frac{E_e}{E_{e,max}}}$$

- In this case spectral emissive ability from electrons will be :

$$j(\nu) = C K' \frac{\sqrt{2} e^3 B b^{\frac{1}{3}}}{(m_e c^2)^2} \int_{\gamma_{e,min}}^{\gamma_{e,max}} \left(\frac{\nu}{\gamma_e^2} \right)^{\frac{1}{3}} e^{-b \frac{\nu}{\gamma_e^2}} \gamma_e^{-p_e} e^{-\frac{\gamma_e}{\gamma_{e,max}}} d\gamma_e$$

Spectral flux from the loop of the cosmic string

- Finally, when we know spectral emissivity j(ν) we can calculate spectral flux F_ν:

$$F_\nu = \frac{V_{em} j(\nu)}{4\pi {d_s}^2},$$

where d_s – is an average distance from terrestrial observer to a string, V_{em} – is a volume of the emission region.

- The volume of the emission region V_{em} can be written as:

$$V_{em} = \frac{3}{2}\pi {r_s}^2 l,$$

where r_s – is a radius of the shock-wave around the superconducting cosmic string, l – is a length of string loop.

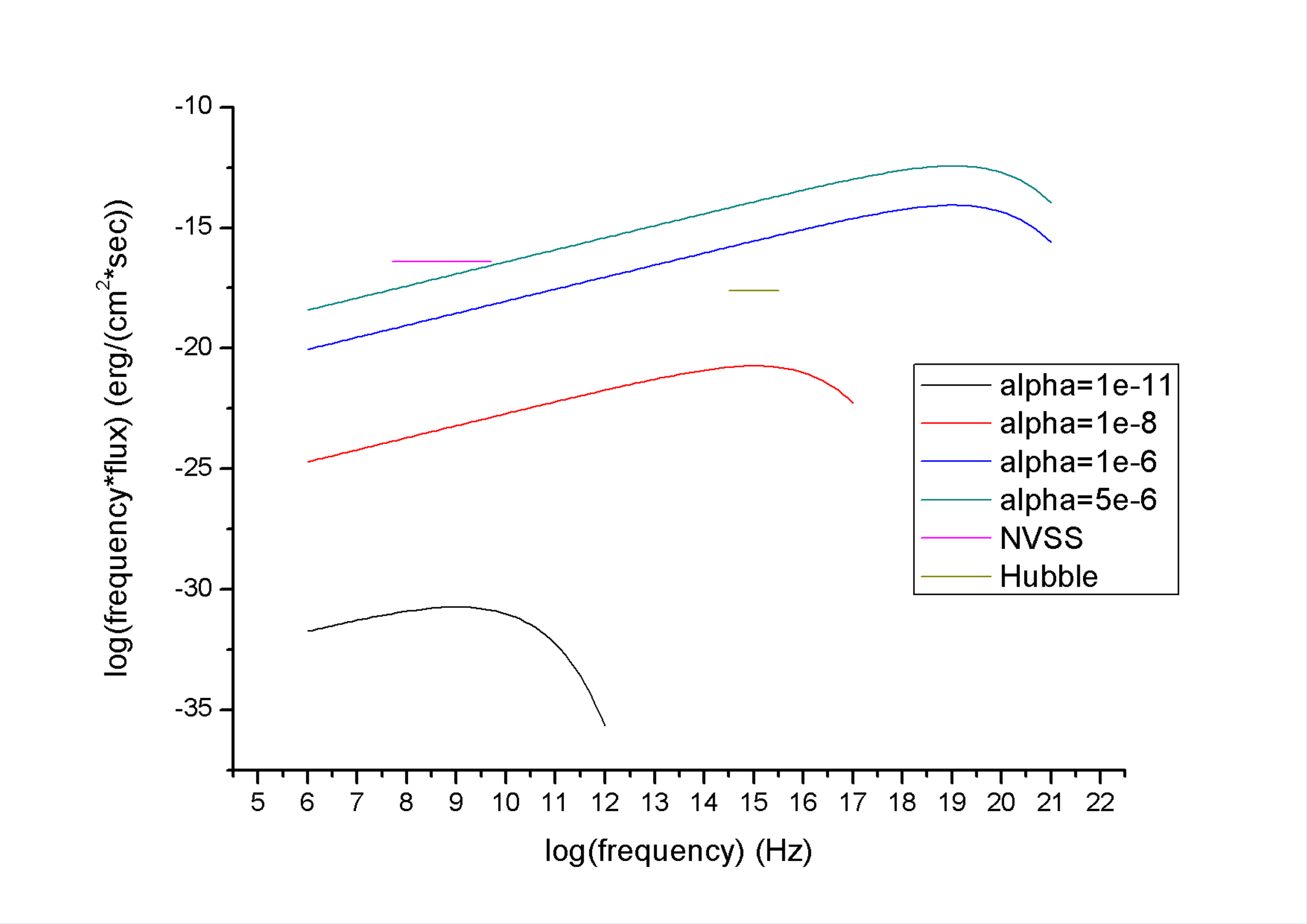


Fig. 1: Expected spectral flux of synchrotron radiation from a loop of a cosmic string in the intergalactic medium at the average distance from the observer for strings with different tenses ($B=10^{-7}$ Гс, $n=10^{-7}$ $см^{-3}$, $\gamma_{sh}=2$, $\epsilon_e=0{,}1$, $\epsilon_B=0{,}1$).

Inverse Compton radiation on the cosmic microwave background photons

- The spectral distribution of the volume emissivity of isotropically distributed electrons due to IC process is :

$$P(E_\gamma) = cE_\gamma \int d\gamma N(\gamma) \int d\epsilon n_{ph}(\epsilon) \sigma_{KN}(E_\gamma, \epsilon; \gamma),$$

where

$$\sigma_{KN}(E_\gamma, \epsilon; \gamma) = \frac{3\sigma_T}{4\epsilon\gamma^2} G(q, \eta)$$

$$G(q, \eta) = 2q \ln \eta + (1 + 2q)(1 - q) + 2\eta q(1 - q),$$

$$q = \frac{E_\gamma}{\Gamma(\gamma m_e c^2 - E_\gamma)}, \quad \Gamma = \frac{4\epsilon\gamma}{m_e c^2}, \quad \eta = \frac{\epsilon E_\gamma}{(m_e c^2)^2}.$$

- In some astrophysical environments, the initial photon energy field may be represented by the isotropic black-body radiation:

$$n_{ph}(\epsilon) = \frac{1}{\pi^2 \hbar^3 c^3} \frac{\epsilon^2}{\exp(\epsilon/\epsilon_c) - 1}$$

- Let us re-write the spectral emissivity in the form :

$$P(E_\gamma) = \int d\gamma N(\gamma) p(\gamma, E_\gamma),$$

where the spectral emissivity of IC radiation power of a ”single” electron with Lorenz factor γ is :

$$p(\gamma, E_\gamma) = \frac{3\sigma_T {m_e}^2 c^2 \epsilon_c}{4\pi^2 \hbar^3} \gamma^{-2} I(\eta_c, \eta_0) = \frac{2e^4 \epsilon_c}{\pi \hbar^3 c^2} \gamma^{-2} I(\eta_c, \eta_0)$$

- Function I ($\eta_c(E_\gamma)$, $\eta_0(\gamma, E_\gamma)$) can be expressed as:

$$I(\eta_c, \eta_0) = \int \frac{(\eta/\eta_c) G(\eta_0/\eta, \eta)}{\exp(\eta/\eta_c) - 1} d\eta,$$

$$\text{при} \quad \eta_c = \frac{\epsilon_c E_\gamma}{(m_e c^2)^2}, \quad \eta_0 = q\eta = \frac{E_\gamma^2}{4\gamma m_e c^2 (\gamma m_e c^2 - E_\gamma)}.$$

- Let us use the approximation for integral I(η_c; η_0) (Petruk, [arXiv: astro-ph/0807.1969v2]):

$$I(\eta_c, \eta_0) \approx \frac{\pi^2}{6} \eta_c \left(\exp\left[-\frac{5}{4} \left(\frac{\eta_0}{\eta_c} \right)^{1/2} \right] + 2\eta_0 \exp\left[-\frac{5}{7} \left(\frac{\eta_0}{\eta_c} \right)^{0.7} \right] \right) \exp\left[-\frac{2\eta_0}{3\eta_c} \right]$$

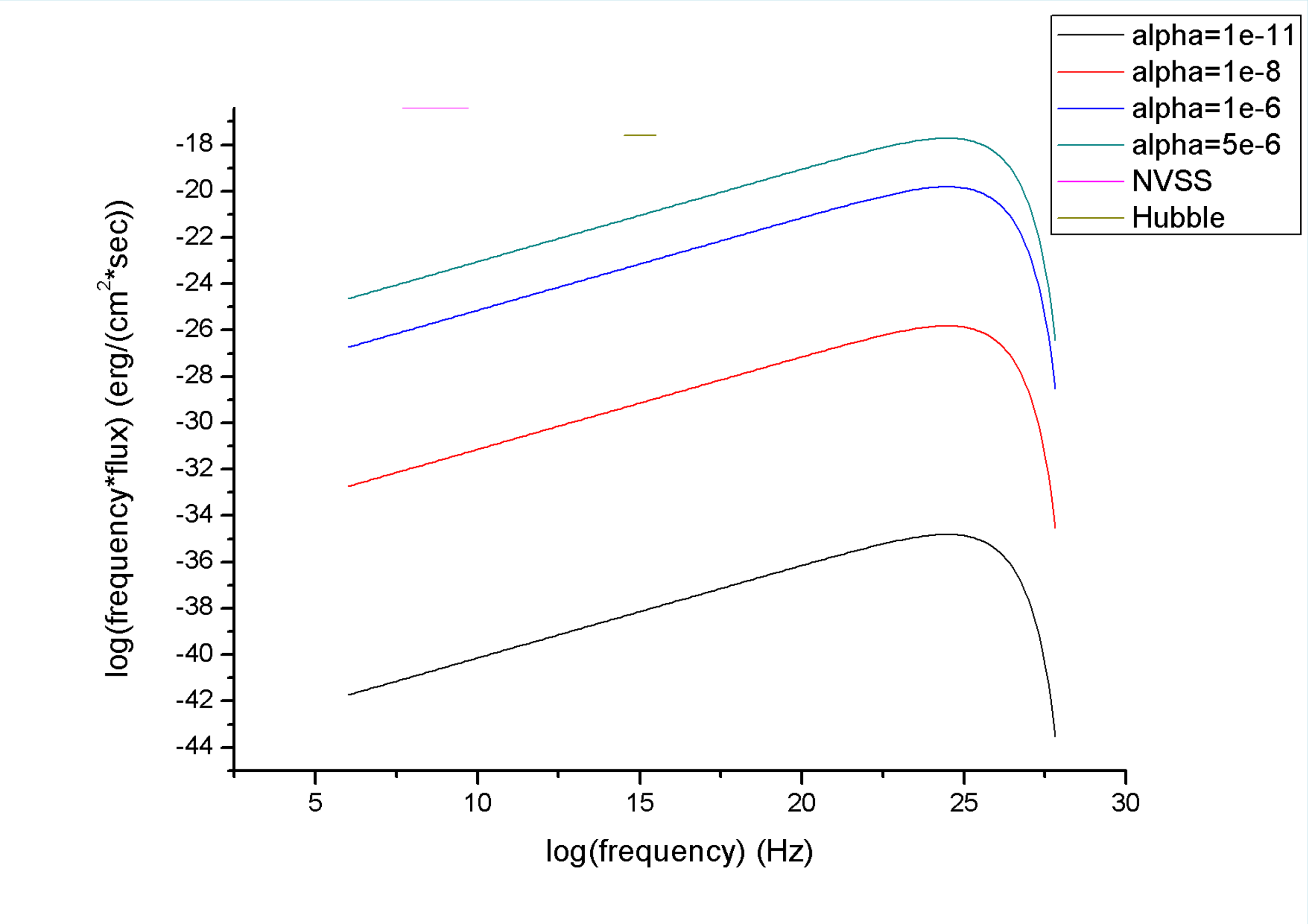


Fig. 2: Expected spectral flux of Inverse Compton radiation from a loop of a cosmic string in the intergalactic medium at the average distance from the observer for strings with different tenses ($B=10^{-7}$ Гс, $n=10^{-7}$ см$^{-3}$, $\gamma_{sh}=2$, $\epsilon_e=0{,}1$, $\epsilon_B=0{,}1$).

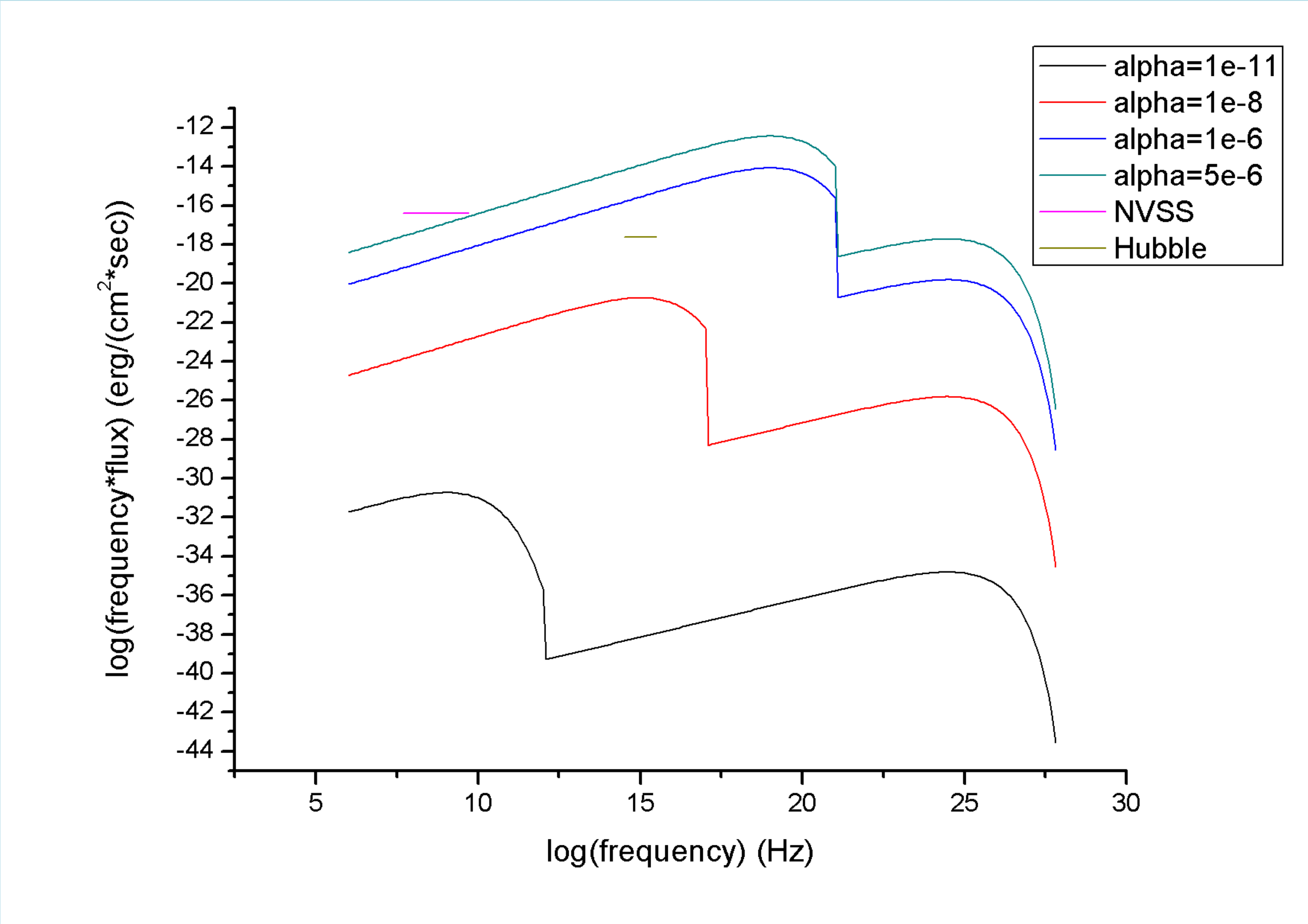


Fig. 3: Expected spectral flux of synchrotron and Inverse Compton radiation from a loop of a cosmic string in the intergalactic medium at the average distance from the observer for strings with different tenses ($B=10^{-7}$ Гс, $n=10^{-7}$ см$^{-3}$, $\gamma_{sh}=2$, $\epsilon_e=0{,}1$, $\epsilon_B=0{,}1$).

Conclusions

- The model of motion and interaction of the superconducting cosmic string with the ambient intergalactic plasma was considered.
- Fluxes of synchrotron and Inverse Compton radiation from the superconducting cosmic strings in the intergalactic medium with more realistic spectra of the relativistic electrons were calculated.
- Possibility of fluxes detection by existing facilities were estimated.