1. Semester report №3

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Ph.D. Thesis title: Searching for signs of new physics beyond the standard model

Introduction: I am a second-year international student at ELTE-Doctoral School of Physics from the 2020/2021 Autumn semester. In first semester, because of some difference between the Mongolian and Hungarian educational systems, I had to catch up on more advanced topics first and did not start my research work. However, 2^{nd} semester I started my research work which is based on cosmological aspect of Super-weak U(1) extension of Standard Model. In particular, I am interested in late-time accelerated expansion of the universe.

I am a member of ELTE – Particle Phenomenology Group, which has 7 members and supervised by professor Zoltán Trócsányi. Currently, there are many ongoing research topics, such as Cosmological constraints on the U(1) extension of Standard Model, Neutrino mass model, and Vacuum stability. My current research interest is a connection between cosmology, inflation, and particle physics

Research work carried out in the current semester: My current research work mostly concerns with the cosmological aspect of Super-weak U(1) extension of Standard Model (SWSM). The SWSM has many phenomenological applications such as: inflation, neutrino mass and late-time accelerated expansion of the universe. As the SWSM has two scalar fields, it might be responsible for inflation and late-time accelerated expansion of the universe. In order to study late-time accelerated expansion of the universe in the SWSM, I am studying the dynamical system analysis (DSA) approach. The dynamical system analysis is based on developing autonomous system equations from given Lagrangian density and studying critical points of that system. In other words, DSA treats the Friedmann equations as autonomous system equations and studies its critical points. To study the stability of the critical points of the system, the DSA uses different methods. One standard method is to use the linear stability theory, which is based on slight perturbations of the critical points. However, the linear stability theory fails to analyze the stability of the critical points when the eigenvalue of the Jacobian of the system has vanishing real part. In this case, the center manifold theory or the Lyapunov function method is used.

In the 3^{rd} semester, I continued my analysis with only one scalar field case and cross-checked my result with [1]. It is important that the form of the potential of the scalar field can be either exponential or power-law. Last semester, I found 4 critical points when the potential has a form of exponential. The complete set of critical points is shown in Table 1. I was missing the critical point B compared to [1]. The origin of the missing critical point was the coinciding equation of the state of the scalar field and that of the matter content.

Point	Stability
O	Saddle
A_+	Unstable if $\lambda^2 < 6$, saddle if $\lambda^2 > 6$.
A_-	Unstable if $\lambda^2 > -6$, saddle if $\lambda^2 < -6$.
B	Stable node if $3(\omega+1) < \lambda^2 < \frac{24(\omega+1)^2}{9\omega+7}$, stable spiral if $\lambda^2 \geq \frac{24(\omega+1)^2}{9\omega+7}$
C	Stable if $\lambda^2 < 3(1+\omega)$, saddle if $3(1+\omega) > \lambda^2 > 6$.

Table 1:The critical points of the system when the potential has exponential form.

Models based on a canonical scalar field for explaining the late time cosmic accelerations, are collectively denoted with the name *quintessence* and different models are distinguished by the form of their potential. Another common case of the *quintessence* model is where potential has power-law form. The critical points of this model are presented in Table 2, while the corresponding eigenvalues are given in Table 3.

Point	x	y	z	ω_{eff}	Existence
O_z	0	0	always	ω	always
$A_\pm$	$\pm$ 1	0	0	1	always
B_x	always	0	1	$\omega + x^2(1-\omega)$	always
C	0	± 1	0	-1	always

Table 2: The critical points of the system with power-law potential.

Point	Eigenvalues
O_z	$\{\ 0\ ,\ -\frac{3}{2}(\omega \pm 1)(z-1)\ \}$
$A_\pm$	$\{0, 3, 3-3\omega\}$
B_x	$\{\ 0,\ -\frac{3}{2}x,\ \sqrt{6}(\Gamma-1)x\ \}$
C	$\{$ -3, 0 , $-3(1+\omega)\ \}$

Table 3: Eigenvalues of the critical points of the system with power-law potential.

When the potential has power-law form, the linear stability theory fails to analyze the stability of the critical points of the system since Jacobian of the system has vanishing real part. To analyze the stability of the critical points of the system with power-law potential, I used center manifold theory. The method of center manifold theory reduces the dimensionality of the dynamical system, and the stability of this reduced system can then be investigated. The stability properties of the reduced system determine the stability of the critical points of the full system. In the result, the critical point C is stable or unstable depending on the inverse power-law or direct power-law potential. The inverse power-law potential can produce late time accelerated expansion for the universe while direct power-law potential cannot. Unfortunately, this is not the case with the SWSM where we have Higgs like direct power-law potential with quadratic and quartic terms. Next, I am planning to extend my analysis to direct power-law potential with quadratic and quartic terms, first with only one scalar field then consider the case of 2 scalar fields [2]. The case of 2 scalar fields I will consider two different scenarios, 1st without, 2nd with mixing of the scalar fields.

Studies in current semester:

1. **FIZ/02/083E** Quantum Chromodynamics

References

[1] Sebastian Bahamonde, Christian G. Boehmer, Sante Carloni, Edmund J. Copeland, Wei Fang, Nicola Tamanini. *Dynamical systems applied to cosmology: dark energy and modified gravity.* Physics Reports Vol. 775-777 (2018) 1-122.

[2] Jiro Matsumoto, Sergey V. Sushkov. *Cosmology with nonminimal kinetic coupling and a Higgs-like potential.* JCAP 1511, no. 11, 047 (2015).