TSIMF

清华三亚国际数学论坛

Tsinghua Sanya International Mathematics Forum

(清华三亚国际数学论坛)

Many-body Entanglement and Topological Quantum Phenomena Workshop

December 13-17, 2016

No.100 Tsinghua Rd., Tianya District, Sanya, Hainan.

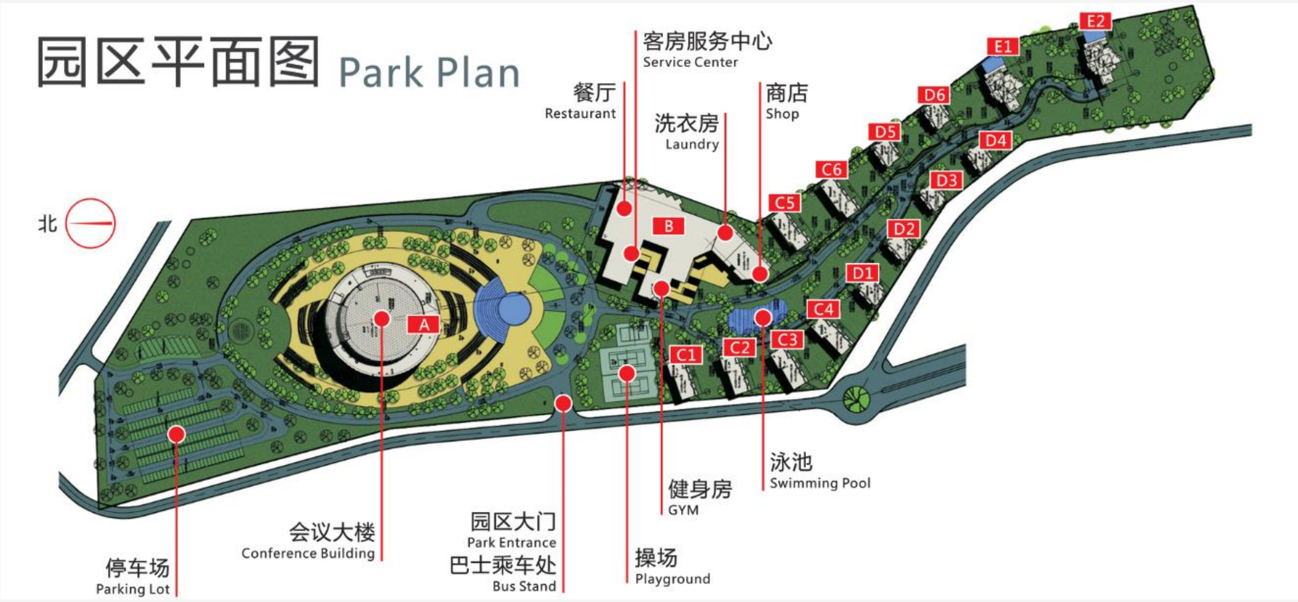
(海南省三亚市天涯区清华路100号)

Welcome to TSIMF

The facilities of TSIMF are built on a 23-acre land surrounded by pristine environment at Phoenix Hill of Phoenix Township. The total square footage of all the facilities is over 29,000 square meter that includes state-of-the-art conference facilities (over 10,000 square meter) to hold many international workshops simultaneously, two libraries, a guest house (over 10,000 square meter) and the associated catering facilities, a large swimming pool, gym and sports court and other recreational facilities.

Mathematical Sciences Center (MSC) of Tsinghua University, assisted by TSIMF's International Advisory Committee and Scientific Committee, will take charge of the academic and administrative operation of TSIMF. The mission of TSIMF is to become a base for scientific innovations, and for nurturing of innovative human resource; through the interaction between leading mathematicians and core research groups in pure mathematics, applied mathematics, statistics, theoretical physics, applied physics, theoretical biology and other relating disciplines, TSIMF will provide a platform for exploring new directions, developing new methods, nurturing mathematical talents, and working to raise the level of mathematical research in China.

About Facilities



Registration

Conference booklets, room keys and name badges for all participants will be distributed at the Registry. Please take good care of your name badge. It is also your meal card and entrance ticket for all events.

Guest Room

Conference Center can receive about 378 people having both single and double rooms, and 42 family rooms.

All the rooms are equipped with: free Wi-Fi, TV, air conditioning and other utilities.

Family rooms are also equipped with kitchen and refrigerator.

Library

Opening Hours: 08:00am-22:00pm

TSIMF library is available during the conference and can be accessed by using your room card. There is no need to sign out books but we ask that you kindly return any borrowed books to the book cart in library before your departure.

Restaurant

All the meals are provided in the Chinese Restaurant (Building B1) according to the time schedule.

Breakfast	07:30-08:30
Lunch	12:00-13:30
Dinner	17:30-19:00

Laundry

Opening Hours: 24 hours

The self-service laundry room is located in the Building 1 (B1), next to the shop.

Convenience Store

The convenience store is located in Building 1 (B1), next to the laundry. The store sells snacks, beer, soft drinks, notepads, bathing suits and various etc.

Gym

The gym is located in the Building 1 (B1), opposite to the reception hall. The gym provides various fitness equipment, as well as pool tables, tennis tables and etc.

Playground

Playground is located on the east of the central gate. There you can play basketball, tennis and badminton. Meanwhile, you can borrow table tennis, basketball, tennis balls and badminton at the reception desk.

Swimming Pool

Please note that there are no lifeguards. We will not be responsible for any accidents or injuries. In case of any injury or any other emergency, please call the reception hall at +86-898-38882828.

Shuttle Service:

We have shuttle bus to take participants to the airport for your departure service. Please feel free to contact Ms. Li Ye (叶莉) if you have any questions about transportation arrangement. Her cell phone number is (0086)139-7679-8300. We would provide transportation at the Haipo Square （海坡广场） of Howard Johnson for the participants who will stay outside TSIMF.

Contact Information of Administration Staffs

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The Schedule for Many-body Entanglement and Strongly Correlated Phenomena at TSIMF, Dec 13-17, 2016

Time&Date	Tue (Dec 13)	Wed (Dec 14)	Thu (Dec 15)	Fri (Dec 16)	Sat (Dec 17)
7:30-8:30	*Breakfast*				
8:50-9:00	*Opening*				Departure
	Chair: Bei Zeng	*Chair: Xie Chen*	*Chair: Zheng Liu*	*Chair: Lih King Lim*	
9:00-9:50	Canli Song	Frank Verstraete	Beni Yoshida	Janet Hung	
9:50-10:20	*Group Photo & Tea Break*	*Tea Break*			
10:20-11:10	Tao Xiang	Norbert Schuch	Zhen-Sheng Yuan	Muxin Han	
11:10-12:00	Sung-Sik Lee	Ling Wang	Kiwan Kim	Xinhua Peng	
12:00-13:30	*Lunch*				
	Chair: Hong Yao	*Chair: Zhong Wang*	**Free Discussion 13:30-17:00**	*Chair: Hui Zhai*	
14:00-14:50	Cenke Xu	Pinyan Lu		Zhengcheng Gu	Departure
14:50-15:40	Yizhuang You	Fernando Brandao		Maissam Barkeshli	
15:40-16:10	*Tea Break*			*Tea Break*	
16:10-17:00	Yidun Wan	Tim Hsieh		Liang Kong	
18:00-19:30	***Banquet 18:00-20:00***	*Dinner*			

Titles and Abstracts

1. **Canli Song**. Tsinghua University, China

Title: Topological Superconductivity and Majorana Zero Modes on β-Bi2Pd Thin Films

Abstract: The search for Majorana fermions in solid state system is one of paramount research targets in physics today. Majorana fermions are an exotic class of fermions (which are their own antiparticles) and predicted to exist in topological superconductors. By growing β-Bi2Pd epitaxial films on SrTiO3 substrates with state-of-the-art molecular beam epitaxy, we here demonstrate a topologically nontrivial superconductivity on β-Bi2Pd thin films. Majorana zero modes, supported by such a superconducting state, are identified by directly probing quasiparticle density of states within the vortex cores under magnetic field with a cryogenic scanning tunneling microscope. The superconductivity and Majorana zero modes (MZMs) exhibit resistance to intrinsic point and linear defects, characteristic of a time-reversal-invariant topological superconductor. Our discovery of the topological superconductivity and MZMs in single material of β-Bi2Pd thin films represents one of the major advances in topological quantum physics.

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[1] Y. F. Lv, W. L. Wang, Y. M. Zhang, H. Ding, W. Li, L. L. Wang, K. He, C. L. Song, X. C. Ma, Q. K. Xue, arXiv:1607.07551 (2016)

2. **Tao Xiang**. Institute of Physics, CAS, China

Title: Gapless spin-liquid ground state in the S=1/2 kagome antiferromagnet

Abstract: Frustrated quantum magnetism has moved to the forefront of physics research, posing fundamental questions concerning quantum disordered states, entanglement, topology and the nature of the quantum wavefunction. The defining problem in the field is one of the simplest, the ground state of the nearest neighbor S = 1/2 antiferromagnetic Heisenberg model on the kagome lattice, but has defied all theoretical and numerical methods employed to date. We apply the formalism of tensor-network states, specifically the method of projected entangled simplex states, whose combination of a correct accounting for multipartite entanglement and infinite system size provides qualitatively new insight. By studying the ground-state energy, the staggered magnetization we find at all finite tensor bond dimensions and the effects of a second-neighbour coupling, we demonstrate that the ground state is a gapless spin liquid. We discuss the comparison with other numerical studies and the physical interpretation of the gapless ground state.

1) Z. Y. Xie, J. Chen, J. F. Yu, X. Kong, B. Normand, T. Xiang, *Renormalization of quantum many-body systems by the projected entangled simplex states*, Phys Rev X 4, 011025 (2014).

2) H. J. Liao, Z. Y. Xie, J. Chen, X. J. Han, H. D. Xie, B. Normand, T. Xiang, *Heisenberg antiferromagnet on the Husimi lattice*, Phys Rev B 93, 075154 (2016).

3) H. J. Liao, Z. Y. Xie, J. Chen, Z. Y. Liu, H. D. Xie, R. Z. Huang, B. Normand, T. Xiang, *Gapless spin-liquid ground state in the S=1/2 kagome antiferromagnet*, arXiv:1610.04727

3. **Sung-Sik Lee**. McMaster University, Canada

Title: Low energy field theories for non-Fermi liquids

Abstract: Non-Fermi liquids are exotic metallic states which do not support well defined quasiparticles. Due to strong quantum fluctuations and the presence of extensive gapless modes near the Fermi surface, it has been difficult to understand universal low energy properties of non-Fermi liquids reliably. In this talk, we will discuss recent progress made on field theories for non-Fermi liquids. A systematic expansion based on a dimensional regularization scheme which tunes the number of co-dimensions of Fermi surface provides important insight into strongly interacting non-Fermi liquids. This allows us find the non-perturbative solution for the strange metal realized at the antiferromagnetic quantum critical point in 2+1 dimensions and predict the exact critical exponents.

4. **Cenke Xu**. University of California, Santa Barbara (UCSB), USA

Title: Stable Self-Dual Interacting conformal field theories in 2+1d

Abstract: Recently the condensed matter and string theory communities both proposed several unexpected dualities between seemingly different (2+1)d field theories, including a fermionic version of the particle-vortex duality. Assuming these dualities are correct, we identify a series of (2+1)d self-dual stable interacting CFTs, which are fundamentally different from any well-known Wilson-Fisher critical points. Properties of these CFTs can be calculated analytically in a controlled expansion, and also simulated numerically. Comparison between the analytical and numerical calculations can provide quantitative evidence for the original fermionic particle-vortex duality.

5. **Yizhuang You**. Harvard University, USA

Title: Bilayer Graphene as a platform for Bosonic Symmetry Protected Topological States

Abstract: Bosonic symmetry protected topological (BSPT) states, i.e. bosonic analogue of topological insulators, have attracted enormous theoretical interests and efforts in the last few years. Although the BSPT states have been successfully classified with various approaches, there has been no successful experimental realization of BSPT states yet in two and higher dimensions. In this paper, we propose that the two dimensional BSPT state with U(1) × U(1) symmetry can be realized in a bilayer graphene under a tilted magnetic field, where the two U(1) symmetries stand for the total spin Sz and total charge conservation respectively. The Coulomb interaction plays a central role in this proposal: 1. it gaps out all the fermions at the boundary of the system, hence the remaining symmetry protected gapless boundary states only have bosonic charge and spin degrees of freedom; 2. based on the conclusion above, we propose that the bulk quantum phase transition between the BSPT and trivial phase, which can be driven by a competition between the out-of-plane magnetic field and electric field, under strong interaction can become a "bosonic phase transition", i.e. only bosonic modes close their gap at the transition. This transition is fundamentally different from all the well-known topological-trivial transition in the free fermion topological insulators. The latter statement is supported by recent determinant quantum Monte carlo simulation on a similar sign-problem-free model on a bilayer honeycomb lattice.

6. **Yidun Wan**. Fudan University, China

Title: Classification of Gapped Boundaries of Topological Phases of Mater

Abstract: In this talk I would tour you through the classification of gapped domain walls of topological orders via anyon condensation.

7. **Frank Verstraete**. University of Vienna, Austria

Title: Shadows of anyons

Abstract: This talk will describe how tensor networks yield a natural framework for describing ground and excited states of topologically ordered systems. In particular, we will discuss how matrix product operator algebras give a representation for modular tensor fusion categories.

8. **Norbert Schuch**, Max-Plank-Institute of Quantum Optics, Germany

Title:Studying topological quantum phenomena using Tensor Networks

Abstract: Tensor networks form a framework for the local modelling of stronglycorrelated systems based on their entanglement structure. In my talk, Iwill show how tensor networks can be used to investigate systems withtopological order. In particular, I will discuss how tensor networks allowto characterize topological spin liquids, and their application in the study of topological phase transitions and their relation tosymmetry-protected phases at the boundary.

9. **Ling Wang**. Beijing Computational Science Research Center (CSRS), China

Title: Phase diagram of the frustrated J1-J2 Antiferromagnetic Heisenberg model on square lattice

Abstract: The ground state phase diagram of the spin-1/2 J1-J2 antiferromagnetic Heisenberg model on square lattice has been debated for decades. We studied this model using tensor network states (TNS) and reduced density matrix renormalization group (DMRG) methods, and determined the phase diagram in good accuracy. By comparing the quantum critical scaling behavior with the well studied J-Q model, we conclude that the quantum phase transition between the Neel order and the valence bond solid order is captured by the deconfined quantum criticality scenario.

10. **Pinyan Lu**. Shanghai University of Finance and Economics, China

Title: Uniqueness, Spatial Mixing, and Approximation for 2-Spin Systems

Abstract: In this talk, we will discuss the relation between uniqueness, spatial mixing, and approximate computation of partition function for two-state spin systems. For anti-ferromagnetic 2-spin systems, a beautiful connection is established, namely that the following three notions align perfectly: the uniqueness in infinite regular trees, the decay of correlations (also known as spatial mixing), and the approximability of the partition function. The uniqueness condition implies spatial mixing, and an FPTAS for the partition function exists based on spatial mixing. On the other hand, non-uniqueness implies some long range correlation, based on which NP-hardness reductions are built. For ferromagnetic

2-spin system, these connections are much less clear. A partial implication is discovered.

The talk is mainly based on the following two papers.

https://arxiv.org/abs/1111.7064

https://arxiv.org/abs/1511.00493

11. **Fernando Brandao**. California Institute of Technology (Caltech), USA

Title: Boundary States and Entanglement Spectrum from Strong Subadditivity

Abstract: In this talk I will consider quantum states satisfying an area law for entanglement. I will show that both the boundary state and the entanglement spectrum admit a local description whenever there is no topological order. The proof is based on strong subadditivity of the von Neumann entropy. For topological systems, in turn, I'll show that the topological entanglement entropy quantifies exactly how many extra bits are needed in order to have a local description for the boundary state.

The talk is based on joint work with Kohtaro Kato (University of Tokyo)

12. **Tim Hsieh**. University of California, Santa Barbara (UCSB), USA

Title: Topological Bootstrap: Fractionalization from Kondo

Abstract: I will present a route toward realizing fractionalized topological phases of matter (i.e. with intrinsic topological order) by literally building on un-fractionalized phases. Our approach employs a Kondo lattice model in which a gapped electronic system of non-interacting fermions is coupled to non-interacting local moments via the exchange interaction. Using general entanglement-based arguments and explicit lattice models, we show that in this way gapped spin liquids can be induced in the spin system. We demonstrate the power of this topological bootstrap concept with two examples: (1) a chiral spin liquid induced by a Chern insulator and (2) a Z2 spin liquid induced by a superconductor. In particular, in the latter example, the toric code is realized as an exactly solvable example of topological bootstrap. Our approach can be generalized to all lattices, higher dimensions, and non-abelian topological orders.

13. **Beni Yoshida**. Perimeter Institute for Theoretical Physics, Canada

Title: Chaos and complexity by design

Abstract: We study the relationship between quantum chaos and pseudorandomness by developing probes of unitary design. A natural probe of randomness is the "frame potential," which is minimized by unitary k-designs and measures the 2-norm distance between the Haar random unitary ensemble and another ensemble. A natural probe of quantum chaos is out-of-time-order (OTO) four-point correlation functions. We show that the norm squared of a generalization of out-of-time-order 2k-point correlators is proportional to the kth frame potential, providing a quantitative connection between chaos and pseudorandomness. Additionally, we prove that these 2k-point correlators for Pauli operators completely determine the k-fold channel of an ensemble of unitary operators. Finally, we use a counting argument to obtain a lower bound on the quantum circuit complexity in terms of the frame potential. This provides a direct link between chaos, complexity, and randomness.

This is a joint work with Dan Roberts.

14. **Zhen-Sheng Yuan**. University of Science and Technology of China, China

Title: Spin Ring-exchange Interactions and Anyonic Fractional Statistics in Optical Lattices

Abstract: Ring exchange is an elementary interaction for modeling unconventional topological matters which hold promise for efficient quantum information processing. We report the observation of four-body ring-exchange interactions and the topological properties of anyonic excitations within an ultracold atom system. A minimum toric code Hamiltonian, in which the ring exchange is the dominant term, was implemented in disconnected four-spin plaquette arrays formed by two orthogonal superlattices. The ring-exchange interactions were resolved from the dynamical evolutions of the spin orders in each plaquette, matching well with the predicted energy gaps between two anyonic excitations of the spin system. A braiding operation was applied to the spins in the plaquettes and an induced phase 1.00(3) π in the four-spin state was observed, confirming 1/2-anynoic statistics. This work

represents an essential step towards studying topological matters with ultracold atoms and will contribute to the development of topological quantum computing.

15.**Kiwan Kim**. Tsinghua University, China

Title: Multi-party entanglement of phonons and application to molecular spectroscopy.

Abstract: In this talk, I introduce the ion trap system and report the multi-party entangled state of phonons experimentally created in our trapped ion system and discuss the application for the test of quantum supremacy and molecular simulation.

Multi-party entangled state, in particular, NOON state has brought great interests because it allows the precision measurement to the ultimate limit as the number of particles increases. However, experimental preparation of the NOON state with sufficiently high number of particles N remains as a challenge. We develop a deterministic method to generate the NOON state of arbitrary phonon numbers and experimentally create the states up to N = 9 phonons in two radial modes of a single trapped 171Yb+ ion. We clearly observe the fidelity of the NOON state over classical limit by measuring the contrast of the characteristic phase oscillations and the populations through the phonon projective measurement of two motional modes. We also observe the Heisenberg scaling of phase sensitivity in the NOON states through quantum Fisher information [1].

The phonons and manipulation technology of phonons in trapped ion can be used for the demonstration of quantum supremacy by performing boson sampling beyond the classical limit [2]. The boson sampling is to obtain the final distribution of a number of indistinguishable bosons that pass through intertwined some number of modes. The problem is related to compute the permanent of the matrix and it has been proved that it is classically intractable even approximately unless the established hierarchy of computational complexity is collapsed. Recently many serious experimental efforts have been invested and growing experimental demonstrations have been reported mainly in photonic systems. On the other hand, phonons in the trapped ion system do not have the detection efficiency problem and the generation problem of single quanta and it is believed to have an advantage of scaling the number of bosons beyond the classical limit of the computation [3]. We discuss how to realize such boson sampling with phonons. Moreover, the bosom sampling device with some modifications can be applied to perform a simulation of molecular transitions [4]. We present an experimental evidence that such simulation can be performed in the trapped ion system.

[1] Junhua Zhang, et al., Experimental Preparation of High NOON States for Phonons, arXiv:1611.08700

[2] S. Aaronson and A. Arkhipov, The Computational Complexity of Linear Optics, Proc. ACM Symposium on Theory of Computing, 333 (2011).

[3] C. Shen, et al., Scalable Implementation of Boson Sampling with Trapped Ions, Phys. Rev. Lett. 112, 050504 (2014).

[4] J Huh, et al., Boson Sampling for Molecular Vibronic Spectra, Nature Photon. 9, 615 (2015).

16.**Janet Hung**. Fudan University, China

Title: Exploring the tensor network and AdS correspondence

Abstract: We will describe recent progress in understanding the tensor network as an emergent bulk via perfect tensors. We will see how small deviations lead to computations of correlation functions that invoke structures strongly reminiscent of Witten diagrams in the AdS/CFT correspondence. We also describe structures analogous of the BTZ black hole can be constructed based on the tensor network.

17.**Muxin Han**. Florida Atlantic University, USA

Title: Loop Quantum Gravity, Exact Holographic Mapping, and Holographic Entanglement Entropy

Abstract: The relation between Loop Quantum Gravity (LQG) and tensor network is explored from the perspectives of bulk-boundary duality and holographic entanglement entropy. We find that the LQG spin-network states in a space with boundary is an exact holographic mapping, which is a realization of AdS/CFT correspondence. The tensor network, understood as the boundary CFT ground state, is the output of the exact holographic mapping emerging from a coarse graining procedure of spin-networks. Furthermore, when a region A is specified on the boundary, we show that the boundary entanglement entropy S(A) of the emergent tensor network satisfies the Ryu-Takayanagi formula in the semiclassical regime, i.e. S(A) is proportional to the minimal area of the bulk surface attached to the boundary of A.

18.**Xinhua Peng**. University of Science and Technology of China, China

Title: Towards exotic many-body physics on nuclear magnetic resonance quantum simulator

Abstract: Topological phases are exotic states of matter which are beyond the usual symmetry description. These phases have some interesting properties, such as robust ground state degeneracy that depends on the surface topology, quasiparticle fractional statistics, topological entanglement entropy, and so on. Topological phase not only plays a significant role in the basic scientific research of condensed matter physics, but also provides a natural medium for fault-tolerant quantum computation. Quantum simulations thus offer the possibility to investigate strongly correlated systems exhibiting topological orders and other complex quantum systems that are challenging for simulations on classical computers. Nuclear magnetic resonance is a good test platform for the physical implementation of quantum simulator due to its sophisticated control and precise measurement in multi-qubitexperiments. Here Using a kind of nuclear magnetic resonance simulator, we experimentally performed quantum simulations of some topological spin models and observed interesting physical phenomena, including the adiabatic transition in the Wen-plaquette model between two different Z2 topological orders and the measurement of the modular S, T matrices in Kitaevtoriccode model to identify the Z2 topological order. The technique is scalable to much larger-spin systems where theory becomes intractable. These experiments demonstrate the feasibility of small quantum simulators for strongly correlated quantum systems and provide an experimental tool for further studies of complex quantum systems.

19.**Zhengcheng Gu**. The Chinese University of Hong Kong, China

TBA

20.**Maissam Barkeshli**. University of Maryland, USA

Title: Time reversal and reflection symmetry in 2+1 dimensional SETs

Abstract: There has been immense progress recently in the understanding of interacting topological phases of matter in the presence of symmetry. I will discuss new developments for the case of time-reversal / reflection SETs. This includes a systematic construction of a wide class of time-reversal / reflection SETs in terms of a topological path integral defined on general space-time manifolds. I will further derive a simple formula for computing topological path integrals on non-orientable space-times, which provides a way to distinguish different time-reversal / reflection SETs. I then use these developments to develop an understanding of anomalies associated with time-reversal / reflection SETs.

21.**Liang Kong**. University of New Hampshire, USA

Title: Topological orders and factorization homology

Abstract: It is known that the topological excitations in a topological order can be described by (braided) tensor categories or higher categories. I will explain that this description is a local description that makes sense only on an open disk. In other words, the categorical data are local observables in long wave length limit. In order to obtain global observables, we need integrate local observables on a closed manifold.

This natural process of integration is called factorization homology. I will explain the idea via toric code models and Levin-Wen models. As an application, I will show how to use it to compute the ground state degeneracy of closed surfaces decorated by an anomaly-free topological orders and anomaly-free defects.